Astrobiology Survey™

An Introductory Course on Astrobiology

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All images by the author unless otherwise attributed

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Table of Contents

Dedication

- To my parents - who encouraged my interests as a child…
- To my wife - who encourages these interests as an adult…
- To my sons - I hope this guides you towards your future…

Inspirations

- Jacques Yves Cousteau
- Star Trek TOS and TAS
- 2001 A Space Odyssey's vision of the future, especially the Space Clipper Orion

User's Manual

- Stop! Before reading any further make sure you have the latest version of this course, which can be downloaded at http://www.astrobiologysurvey.org
- The initial version of this course was published in 2012
- An updated version of this course is published each January
- If you wish to print this course for viewing on paper, print it as "Handouts" with 6 slides per page to save on paper

"Excellence is never an accident. It is always the result of high intention, sincere effort, and intelligent execution; it represents the wise choice of many alternatives - choice, not chance, determines your destiny."

- Aristotle

Topic 1

Introduction

Song

Giant steps are what you take
Walking on the moon
I hope my legs don't break
Walking on the moon
We could walk forever
Walking on the moon
We could live together
Walking on, walking on the moon

Walking back from your house
Walking on the moon
Walking back from your house
Walking on the moon
Feet they hardly touch the ground
Walking on the moon
My feet don't hardly make no sound
Walking on, walking on the moon

- The Police, Walking On The Moon

Thematic Quote
Our Philosophy

"We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win."

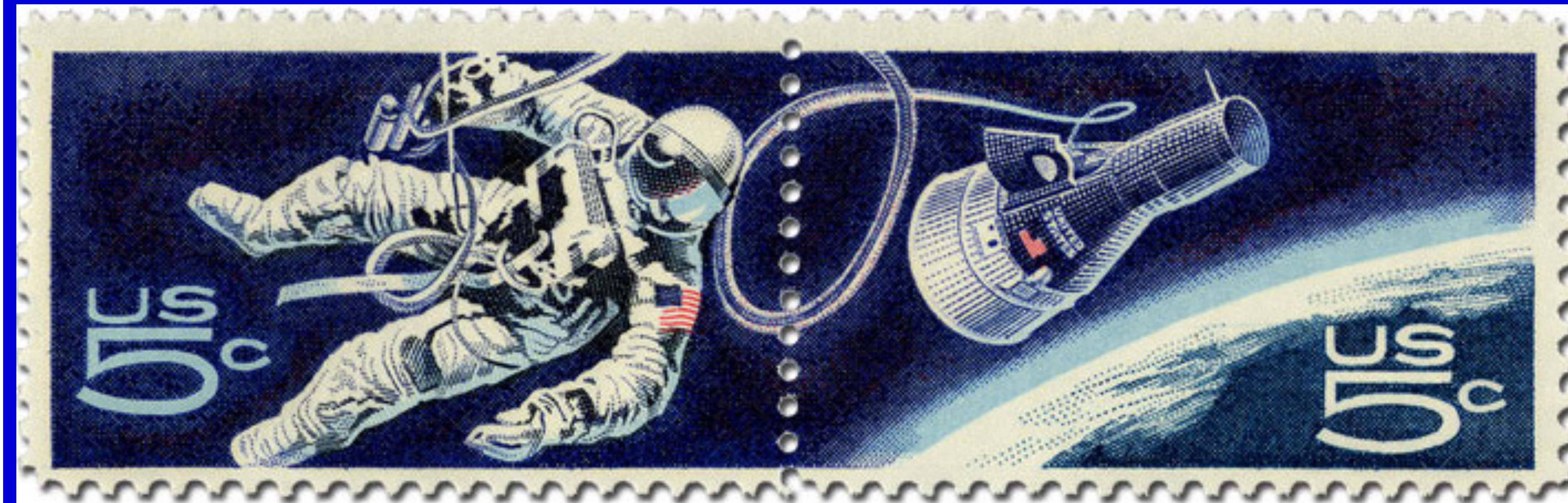
- President John F. Kennedy

Thematic Quote

"In the beginning, when all was fire, there were no stars or planets, no atoms or molecules... and no life. Eons passed, and life appeared on at least one small planet orbiting an average star in a spiral galaxy called the Milky Way. On that planet, one species, endowed with the capacity to think and speak, began to wonder: Did it happen only here? Perhaps not. Terrestrial life is embedded in a cosmic web, and it seems reasonable to speculate that life is cosmically commonplace. The challenge facing science is to move from speculation to fact... by learning how life and intelligence originated on Earth, and by searching the universe for signs of life elsewhere."

- Life Beyond Earth, Timothy Ferris, 1999

The Painting



Space Twins
- Paul Calle
(U.S. Postal Service)

Artifact

- Name
- Year
- Story

The Question

- Astrobiology's three primary questions
  - Where do we come from? (What is the history of life?)
  - Are we alone?
  - Where are we going? (What is the future of life?)

- Astrobiology is the study of the origins, evolution, distribution, and future of life in the universe. Astrobiologists address three fundamental questions:
    - How does life begin and evolve?
    - Does life exist elsewhere in the Universe?
    - What is the future of life on Earth and beyond?

- NASA Astrobiology Institute (NAI)

Some Framing Questions

"Intellectually the quest to know how we - and living things in general - fit into the universe is all part of the same nested series of questions:

- How does matter turn into living cells?
- Is this unlikely or inevitable?
- What is required of a planet to support this and the subsequent transitions to differentiated cells, multicellular life, cognition, curiosity, and technology?
- What planetary transitions accompanied, enabled, or were caused by these biological leaps?
- Should these have occurred on other types of planets that we know or suspect exist, and how would we recognize them?"

- David Grinspoon, Advancing the SETI Quest, Sky and Telescope, July 2018

The Origin of Astrobiology

- At time of Sputnik's launch in 1957, Joshua Lederberg realized that if humans were about to travel into space, they could spread terrestrial organisms to other planets + bring alien organisms back to Earth
  - Man was set to destroy indigenous life-forms across solar system or ourselves - a "cosmic catastrophe"
  - "I was the only biologist at the time who seemed to take the idea of extraterrestrial exploration seriously." - Joshua Lederberg
  - Lederberg coined the term "exobiology" - the study of life beyond Earth - and placed biology on NASA's agenda
- Exobiology influenced how space exploration was conducted
  - Protocols developed for sterilization of spacecraft + for quarantines to restrict what spacecraft might bring back
- Exobiology began to evolve into a broader subject, co-opting everything, and by 1990's was re-branded as "astrobiology" which is merger of astronomy + biology to pursue quest to understand life as cosmic phenomenon

- Caleb Scharf, How the Cold War Created Astrobiology, Nautilus, Feb. 6, 2014

What is Astrobiology?

"Astrobiology, the study of life as a planetary phenomenon, aims to understand the fundamental nature of life on Earth and the possibility of life elsewhere."

- Astrobiology Primer 2006

"Astrobiology is the study of the origins, evolution, distribution and future of life in the universe. It requires fundamental concepts of life and habitable environments that will help us to recognize biospheres that might be quite different from our own."

- NASA

Astrobiology = exobiology = xenobiology

What is Astrobiology?

"Astrobiology is the science of the consideration of life in the universe, with the goal of trying to understand where else there might be life or how widely distributed life might be...Our data is the history of life on Earth and the requirements of life on Earth and what we know about the environments on other planets and trying to map that in and trying to understand the possibilities for life in those environments."

- David Grinspoon, Curator of Astrobiology at The Denver Museum of Nature and Science

What is Astrobiology?

- A branch of science concerned with the study of the origin and evolution of life on Earth and the possible variety of life elsewhere.
- The study of life in the universe.
- The study of life in a cosmic context

Why Study Astrobiology?

"Astrobiology has a compelling driving force: the search for life beyond Earth offered the chance to answer the question of humanity's place in the universe, to place Homo sapiens in a cosmic context just as Darwin had placed them in a terrestrial context."

- Steven J. Dick, NASA and the Search for Life in the Universe, Endeavour, June 2006

Why Study Astrobiology?

"The intellectual scope of astrobiology is breathtaking,

From understanding how our planet went from lifeless to living,

To understanding how life has adapted to Earth's harshest environments,

To exploring other worlds with the most advanced technologies to search for signs of life"

\- Carl Pilcher, Director of the NASA Astrobiology Institute

Why Study Astrobiology?

- Astrobiology puts universe in context of biology by focusing on 3 questions:
  - Where do we come from? (What is the history of life?)
  - Are we alone?
  - Where are we going? (What is the future of life?)

Why Study Astrobiology?

- To take our place in the continuum of scientific revolutions
  - Copernicus - 1473-1543 - De Revolutionibus Orbium Coelestium (Our Place in the Solar System)
    - Recognized physical world is governed by laws ~ Taught us our place in the solar system
  - Galileo - 1564-1642 - First use of telescope in astronomy
    - Endorsed Copernicus ~ Recognized there are other Earth-like bodies
  - Darwin - 1809-1882 - The Origin of Species
    - Recognized biological world is governed by laws ~ Found evidence for change and mechanism for change ~ Taught us our place amongst life on Earth
  - Astrobiology (Exobiology) - 1959
    - Will teach us our place in the universe ~ Are we unique?

Who Studies Astrobiology?

- Multidisciplinary field
- Therefore it is appealing to learners at all levels
  - From K-12 to Ph.D.

Why is Astrobiology Important?

"If we ever discover that genesis has occurred independently twice in our solar system, no matter where we find it, then that means that the spell has been broken, the existence theorem has been proven, and we could infer from that that life is not a bug but a feature of the universe in which we live, and has occurred a staggering number of times throughout the 13.7 billion-year history of the universe. And that would be a huge scientific result. I don't think there'd be any question about it. It probably wouldn't be the socially cataclysmic event that the discovery of intelligent life would be. But scientifically it would be a radically phenomenal event."

- Carolyn Porco, planetary scientist

Why is Astrobiology Important?

- Teaches us the fragility of life
  - Earthrise from Apollo 8
  - Pale Blue Dot from Voyager 1
  - Influence of impact events on extinction / evolution

Why is Astrobiology Important?

- For the first time in mankind's history, we are about to find answers to astrobiology's three primary questions:
  - Where do we come from? (What is the history of life?)
  - Are we alone?
  - Where are we going? (What is the future of life?)

Goal of This Course

- Equip you with an intellectual toolkit for the multi-disciplinary study of astrobiology that will allow you to:
  - Understand astrobiology from the micro to the macro levels - from the single cell to the universe
  - Undertake meaningful discussion and debate as astrobiology's three primary questions begin to be answered
  - Embark upon a course of lifelong learning regarding astrobiology and its role in society
- - or - Provide an introduction to astrobiology, interest you in the further study of astrobiology, point you to tools to aid your further study of astrobiology
- As a survey course, it is designed to encourage broad horizontal thinking across the discipline of astrobiology rather than vertical (silo) thinking

"Our 15 hour mission: to seek out new life and new civilizations, to boldly go where you have never gone before."

Themes

What we are going to discuss / What we have discussed
Everything is deeply intertwingled

- Introduction
  - Astrobiology is the study of the origins, evolution, distribution and future of life in universe
  - Astrobiology's three primary questions
    - Where do we come from / What is the history of life? and Are we alone? and Where are we going / What is the future of life?
- In the Beginning (Life, the Universe and Everything)
  - Size of universe - large
  - History of / timeline of universe and Earth - long ~ Universe is 13.7 billion years old + Earth is 4.5 billion years old
- Sensors
  - New instruments change our view and understanding of universe

Themes

What we are going to discuss / What we have discussed
Everything is deeply intertwingled

- What is Life?
  - Astrochemistry - interstellar medium filled with chemical building blocks of life - they are ubiquitous in universe
  - How do you define life / what is life
    - NASA definition - Life is a self-sustained chemical system capable of undergoing Darwinian evolution
  - What is needed for life - where all these exist and persist is where you look for life
    - Chemical building blocks, liquid solvent (water best), energy (chemosynthesis or photosynthesis)
  - How does life begin / Origin of life
    - Astrochemistry becomes astrobiology somehow (RNA world or protein first)
  - Extremophiles help us explore limits of life to appreciate what is possible
    - Extremophiles show life extremely tenacious + can survive in extraordinary conditions
  - Timeline for development of simple life = short on Earth
  - Timeline for evolution of intelligent life = long on Earth
  - Astrobiology is evolutionary biology writ large
- Life in our Solar System
  - Extremophiles and where does life exist on Earth - subsurface, deep oceans, oceans, land, atmosphere
  - Tour of habitable planets + moons of our solar system searching for life - Mars, Europa, Titan, Enceladus
  - Planetary protection

Themes

What we are going to discuss / What we have discussed
Everything is deeply intertwingled

- Life in the Universe
  - Exoplanets - cosmos is filled with exoplanets ~ all solar systems are different
  - Habitable zone - initially defined by distance from star / liquid water, now widened by tidal heating from gravity
  - Simple life probably common, intelligent life probably rare (Rare Earth Hypothesis)
  - Is evolution predictable / what would life look like on other planets?
- Impact Events (The Good, the Bad, and the Ugly)
  - Panspermia / Alh 84001 / Are we Martians?
  - Impact events: frequency / results - Tunguska sized event from 50 meter asteroid every few hundred years
  - Asteroid defense - detection + deflection
- Search for Extraterrestrial Intelligence (SETI)
  - Techniques for searching ~ What to say ~ Should we speak at all?
  - Drake equation
- Crewed + Uncrewed Spaceflight
  - Crewed SETI (or SET) - history of crewed spaceflight organized by planet
  - Uncrewed SETI (or SET) - history of uncrewed spaceflight organized by planet

Themes

What we are going to discuss / What we have discussed
Everything is deeply intertwingled

- Future Astrobiology Missions
  - Exploring for life in solar system
    - Future crewed missions to asteroids / Phobos / Mars
    - Future uncrewed missions to Mars, Europa, Titan, Enceladus
  - Backing up life to space
    - Space settlements and Terraforming Mars with synthetic biology / Mars settlements
  - Exploring for life in universe
    - Starships
- The Arts
  - Art provides a vision for us to strive towards, identifies problems that need to be overcome to achieve the vision, and creates and tests possible solutions to those problems
- The Divine
  - How to reconcile latest scientific discoveries with your religious beliefs
- Contact + Conclusion
  - How will we make contact

Cosmic Evolution

(Upper left) The formation of stars, the production of heavy elements, and the formation of planetary systems, including our own. (Left) Prebiotic molecules, RNA, and DNA are formed within the first billion years on primitive Earth. (Center) The origin and evolution of life leads to increasing complexity, culminating with intelligence, technology, and astronomers (upper right) contemplating the universe.

- The image was created by David DesMarais, Thomas Scattergood, and Linda Jahnke at NASA Ames Research Center in 1986 and reissued in 1997. From NASA

Learning Objectives of This Course / Astrobiology Frequently Asked Questions (FAQs)

- Where do we come from? (What is the history of life?)
- Are we alone?
- Where are we going? (What is the future of life?)

Case Study Summary - Mission

- Goal
- Center of Gravity (Strategy)
- Equipment
- Training
- Leadership
- Morale
- Tactics
- Intangibles
- Mistakes
- Outcome

Computing Case Study Summary - Saturn Launch Vehicle Digital Computer (LVDC)

- Goal
  - Autopilot Saturn V rocket from launch into Earth orbit insertion and then perform a trans-lunar injection burn
- Center of Gravity (Strategy)
  - Provide digital guidance system for launch vehicle, updating itself 25 times per second
- Technology / Equipment
  - Located in Instrument Unit in S-IVB stage of Saturn I + Saturn V rockets
  - Used semiconductors for logic + magnetic cores for memory
  - Operated 1 million times slower than 2012-era microprocessor
  - Computing power of Saturn V rocket was equivalent to a (very) dumb mobile phone
- Training ~ Leadership ~ Morale
- Tactics
  - Used triple-redundant logic + voting system for 99.6% reliability
- Intangibles ~ Mistakes
  - Computing support for lunar missions provided on the ground by Real-Time Computer Complex at NASA's Manned Spacecraft Center + consisted of a primary + backup mainframe computer, at first IBM 7094-11 + then IBM System/360 Model 75J computers which were augmented with extra memory in the form of IBM 2361 Core Storage Units which contained half a megabyte of RAM
- Outcome
  - Worked every time
  - This computer got us to the Moon ~ The computers we have today should take us far beyond…

  - IBM Archives

Personal Case Study - Name

- Role
- Story

Astrobiology Analog Case Study - Name

- Location
- Story

Drake Equation

$$N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

- N = The number of communicative civilizations
- R* = The rate of formation of suitable stars (stars such as our Sun)
- fp = The fraction of those stars with planets. (Current evidence indicates that planetary systems may be common for stars like the Sun.)
- ne = The number of Earth-like worlds per planetary system
- fl = The fraction of those Earth-like planets where life actually develops
- fi = The fraction of life sites where intelligence develops
- fc = The fraction of communicative planets (those on which electromagnetic communications technology develops)
- L = The "lifetime" of communicating civilizations

Class Simulation

- Topic aspects

Poem

Questions for Further Discussion

- See Learning Objectives / Astrobiology Frequently Asked Questions for this course in Topic 1

Reading Assignments

- Astrobiology Primer 2.0 (2016) Chapter 1
  - https://doi.org/10.1089/ast.2015.1460
- TED Talks for this Topic
  - http://www.astrobiologysurvey.org/ToLearnMore.html

Recommended Reading to Learn More

- Non-fiction
  - Carl Sagan - Cosmos
- Fiction
- Movies
- Simulations

Conclusion

No Boundaries

"You don't think of it as Texas or the US, you really think of it as Earth."

- Anonymous Apollo astronaut

"(It) makes you realize just what you have. The Earth there is a grand oasis in the big vastness of space."

- Jim Lovell, astronaut Apollo 8 and 13

The Home Planet by Kevin W. Kelley

"The first day or so we all pointed to our countries. The third or fourth day we were pointing to our continents. By the fifth day we were aware of only one Earth"

- Sultan Bin Salman al-Saud, Saudi Arabian astronaut

"We went to the moon as technicians; we returned as humanitarians"

- Edgar Mitchell, astronaut Apollo 14

" . . . I understood that we are all sailing in the same boat"

- Vladimir Kovalyonok, Russian astronaut

Summary - Why We Explore

"I submit that one of the most important roles of government is to inspire and motivate its citizens, and particularly its young citizens - to love, to learn, to strive to participate in and contribute to societal progress. By that measure, NASA will without doubt rank in the top tier of government enterprises."

The goal is far more than just going faster and higher and further. Our goal - indeed our responsibility - is to develop new options for future generations: options in expanding human knowledge, exploration, human settlements and resource development, outside in the universe around us.

Our highest and most important hope is that the human race will improve its intelligence, its character, and its wisdom, so that we'll be able to properly evaluate and choose among those options, and the many others we will encounter in the years ahead."

- Neil Armstrong, astronaut Apollo 11

Conclusion - Perspective - Pale Blue Dot

"We succeeded in taking that picture [from deep space], and, if you look at it, you see a dot. That's here. That's home. That's us. On it, everyone you ever heard of, every human being who ever lived, lived out their lives. The aggregate of all our joys and sufferings, thousands of confident religions, ideologies and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilizations, every king and peasant, every young couple in love, every hopeful child, every mother and father, every inventor and explorer, every teacher of morals, every corrupt politician, every superstar, every supreme leader, every saint and sinner in the history of our species, lived there on a mote of dust, suspended in a sunbeam."

- Carl Sagan, planetary scientist

Conclusion - Pale Blue Dot

"The earth is a very small stage in a vast cosmic arena. Think of the rivers of blood spilled by all those generals and emperors so that in glory and in triumph they could become the momentary masters of a fraction of a dot. Think of the endless cruelties visited by the inhabitants of one corner of the dot on scarcely distinguishable inhabitants of some other corner of the dot. How frequent their misunderstandings, how eager they are to kill one another, how fervent their hatreds. Our posturings, our imagined self-importance, the delusion that we have some privileged position in the universe, are challenged by this point of pale light."

- Carl Sagan, planetary scientist

From NASA

Conclusion - Pale Blue Dot

"Our planet is a lonely speck in the great enveloping cosmic dark. In our obscurity -- in all this vastness -- there is no hint that help will come from elsewhere to save us from ourselves. It is up to us. It's been said that astronomy is a humbling, and I might add, a character-building experience. To my mind, there is perhaps no better demonstration of the folly of human conceits than this distant image of our tiny world. To me, it underscores our responsibility to deal more kindly and compassionately with one another and to preserve and cherish that pale blue dot, the only home we've ever known."

- Carl Sagan, planetary scientist

From NASA

Conclusion

"We protect what we love"

- Jacques Yves Cousteau, marine biologist

Let's End On An Optimistic Note…

"Mankind's future lies in exploring the abundance of space rather than fighting over the limited resources of Earth."

- Michael P. D'Alessandro, M.D.

Topic 2

In the Beginning
(Life, the Universe, and Everything)

Song

There's antimony, arsenic, aluminum, selenium,
And hydrogen and oxygen and nitrogen and rhenium,
And nickel, neodymium, neptunium, germanium,
And iron, americium, ruthenium, uranium,
Europium, zirconium, lutetium, vanadium,
And lanthanum and osmium and astatine and radium,
And gold and protactinium and indium and gallium,
<gasp>
And iodine and thorium and thulium and thallium.

There's yttrium, ytterbium, actinium, rubidium,
And boron, gadolinium, niobium, iridium,
And strontium and silicon and silver and samarium,
And bismuth, bromine, lithium, beryllium, and barium.

…

These are the only ones of which the news has come to Harvard,
And there may be many others, but they haven't been discovered.
- Tom Lehrer, The Elements

Thematic Quote

"In the beginning, God created the heaven and the earth; and the earth was without form and void, and darkness was upon the face of the deep; and the spirit of God moved upon the face of the waters.

And God said, "Let there be light," and there was light.

And God saw the light, that it was good…"

- Book of Genesis

Thematic Quote

Bill Anders

"We are now approaching lunar sunrise and, for all the people back on Earth, the crew of Apollo 8 has a message that we would like to send to you.

In the beginning God created the heavens and the earth.

And the earth was without form, and void; and darkness was upon the face of the deep.

And the Spirit of God moved upon the face of the waters. And God said, Let there be light: and there was light.

And God saw the light, that it was good: and God divided the light from the darkness.

Jim Lovell

"And God called the light Day, and the darkness he called Night. And the evening and the morning were the first day.

And God said, Let there be a firmament in the midst of the waters, and let it divide the waters from the waters.

And God made the firmament, and divided the waters which were under the firmament from the waters which were above the firmament: and it was so.

And God called the firmament Heaven. And the evening and the morning were the second day.

Frank Borman

"And God said, Let the waters under the heavens be gathered together unto one place, and let the dry land appear: and it was so.

And God called the dry land Earth; and the gathering together of the waters called He Seas: and God saw that it was good.

And from the crew of Apollo 8, we close with good night, good luck, a Merry Christmas - and God bless all of you, all of you on the good Earth." - Crew of Apollo 8 in lunar orbit, December 24, 1968

Thematic Quote

"Space is big. Really big. You just won't believe how vastly hugely mind-bogglingly big it is. I mean, you may think it's a long way down the road to the chemist, but that's just peanuts to space."

- The Hitchhiker's Guide to the Galaxy

Thematic Quote

"We're made of star-stuff"

- Carl Sagan, planetary scientist

"Pre-imagining is the imagining of things that are to be"

- Leonardo da Vinci

The Painting

Earthrise

- William Anders, Apollo 8

(NASA)

Artifact

- Name
  - Pahoehoe lava
- Year
  - March 2003
- Story
  - Hawaii Volcanoes National Park
  - Ranger-guided hike to where volcano is erupting March 2003

    "What thinking person wouldn't be deeply impressed when, for the first time, he sees, hears, smells and feels molten rock oozing from the bowels of the Earth?

    The sight was a restless lake of lava, churning and roiling in a half-mile-wide crater. The sound was the hiss of noxious gases leaking off the top of the cauldron's brew. The smell was that of sulfurous fumes wafting up from the lake. And the feel was that of seeing heat rising from the 2000-degree liquid, and the vibrations of the ground, which shook and quivered from the sloshing of that primordial soup in its crater container.

    Aware that I was literally witnessing part of Earth's creation I was humbled and in awe…"

    - Wendell Duffield, US Geological Service

The Question

What came after the Big Bang?

Nota Bene: Terminology!

- Ga = billions of years ago
- Ma = millions of years ago

Putting it All in Perspective

- In order to understand "where we come from", we must understand the evolutionary history of life,
- In order to understand that, we must understand the physical history of the Earth,
- In order to understand that, we must understand Earth's history in the solar system,
- In order to understand that, we must understand the solar system's history in the Milky Way galaxy,
- In order to understand that, we must understand the Milky Way's history in the universe,
- In order to understand that, we must understand the Big Bang

\- Seth Shostak, The Big Bang, Our Universe and All That Jazz, Lecture in Stanford Astrobiology Course, April 28, 2008

Timeline of the Universe

- 0 seconds - Universe, tinier than a speck of dust begins - is billions of times hotter than sun
- First fraction of second - Entire universe expands dramatically
- First second - Universe cools to below 10 billion degrees C and neutrons, protons and electrons begin to form
- First 3 minutes - Universe keeps cooling, protons and neutrons and electrons begin to stick together and first atoms begin to form
- 300,000 years - Universe expands enough for light to flow freely across space and universe can be seen for first time
- 1-3 million years - He and H atoms clump together into clouds of gas that will become stars
- 100 million years - First stars begin to shine, inside stars bigger atoms begin to form, every time star dies and explodes, more atoms form and are spread out
- 9 billion years - Our solar system is formed
- 10 billion years - First life appears in Earth's oceans
- 13.75 billion years - Today

- Karen C. Fox and Nancy Davis, Older Than the Stars

Composition of the Universe

- Number of stars in a galaxy is 100 billion
- Number of galaxies in the universe is 100 billion
- So number of stars visible in the universe is 10E22 = number of grains of sand on all beaches of America
- Probably number of planets in universe is 10E23 = number of grains of sand on all the beaches of Earth

- Seth Shostak, The Big Bang, Our Universe and All That Jazz, Lecture in Stanford Astrobiology Course, April 28, 2008

Composition of the Universe
Known Unknowns

- 96% Invisible to us
  - 23% Dark matter (pulls on stars + galaxies)
  - 73% Dark energy (speeds up expansion of universe)
- 4% Visible to us
  - This 4% consists of atoms
  - Half of this has been seen with telescopes
- So after 350 years of science we've only been studying 2% of universe

The Dark Side

- The more distant a galaxy is from the Earth, the faster it is moving away from the Earth
  - After the rapid but short burst of expansion at the beginning of the universe (inflation), expansion of space had slowed down but then sered speeding up again
  - So not only was universe getting bigger, it was getting bigger, faster
  - Cause was dark energy
- Recipe for universe
  - 68.3% dark energy, 26.8% dark matter, 4.6% familiar matter, 0.3% neutrinos
  - So 95% of universe has yet to be discovered
- Ultimate fate of the universe will be dictated by dark energy
  - 1. Universe expands calmly for ever
  - 2. Expansion of universe speeds up as effects of dark energy overwhelm everything else = "Big Rip"
  - 3. Matter wins out over dark energy with its gravity slowing + reversing expansion, drawing everything back together into a "Big Crunch"

- To The Dark Side, The Economist, Aug. 22, 2015

Scale Model of Our Solar System

- If you shrink Earth to size of a grain of sand, and Sun to the size of a dime
  - Earth is more than 2 arms lengths from the Sun
- If you shrink our sun to a grain of sand
  - Nearest stars are 6 miles away
  - So galaxies are mainly empty space

Scale Model of Our Solar System

- Sun is grain of sand
- Earth is microscopic grain orbiting around it at one inch
- Orbit of Mars is in palm of your hand
- Whole solar system within reach of your arms
- Nearest star is 4 miles away

Difference Between Star and a Planet

- Star generates its own energy from nuclear reactions in its center by fusion
- Planets are cold, dense and don't generate their own energy from nuclear reactions and are therefore faint

Where Do Stars and Planets Come From?

- Within gas clouds composed primarily of H and He, stars form by gravity from gas and dust
- 80% of young stars have protoplanetary disks from which planets form, dust and gas congeals into planets
- Planets grow larger from collisions amongst planetismals (planetismals are kilometer sized comets and asteroids)
- Asteroids and comets bring water to planets (= Heavy bombardment period in first 100 million years of solar system)

How Does Solar System Form

- 4.6 Ga, vast cloud of dust + gas collapses on itself, pressure increases, temperature at center rises to millions of degrees
- Then energy from early Sun blasts away some of this cloud, lighting up young solar system
- The spinning cloud of dust becomes bigger and bigger particles through collisions + as they get bigger and their gravity increases their temperature rises + they become spheres of rock with hot molten cores = protoplanets
- Proto-Earth, 4.5Ga - surface is solid + cool, atmosphere thick with CO2 and sulfuric acid from volcanic activity
  - Protoplanet size of Mars slams Earth, melts surface, creates larger planet and forms Moon

- Finding Life Beyond Earth, PBS Nova, Oct. 19, 2011

How Does Solar System Form

- Giant impacts play role in producing water on Earth's surface - impacts heat crust enough to release water trapped beneath surface as steam which condenses and falls as rain, covering surface with seas + oceans
- Several million years after forming, Earth has 2 of 3 ingredients needed for life: water + energy from Sun - but what about organic molecules?
- Comets can be a source of organic materials needed for life on Earth
- Comets got to Earth during late heavy bombardment, which is caused by Jupiter + Saturn tugging on each other which altered orbits of Uranus + Neptune + sent them towards Kupier Belt, blasting comets out of their orbits
    - All planets were hit

- Finding Life Beyond Earth, PBS Nova, Oct. 19, 2011

A Star is Born

- Solar systems form from collapse of giant molecular clouds (solar nebulae)
  - Collapse of cloud can originate very slowly in self-gravitational attraction or triggered by shock waves from nova + supernova travelling through interstellar medium
- Extent of primordial cloud matters
  - Very low-mass cloud forms brown dwarf which is not quite a star that glows from heat of formation from gravitational collapse but never gets hot enough to initiate H fusion. Planets can orbit brown dwarfs
  - Low-mass cloud forms red dwarf star with tiny habitable zone
  - High-mass cloud forms star that burns fast + hot with lifetime in millions rather than billions of years so unlikely to form life on its planets

- Edward Lerner, Alien Worlds: Not in Kansas Any More, Analog, Oct. 2013

Life Cycle of a Low Mass Star (Our Sun)

- Diffuse interstellar medium dust cloud ->
- Dense molecular cloud (nebula) ->
- Gravitational collapse of gas, dust, H ->
- Low mass star is born ->
- Cloud breaks up and planetismals form->
- Planets / comets / asteroids ->
- Red giant ->
- Planetary nebula
- Cycle begins again

- [N.B. High Mass stars eventually go supernova]

Generations of Stars

- As stars are born out of gas and dust in the galaxies they convert H -> He -> C - > etc
- As star dies it spews out its content
- First generation stars were born of pure H and eventually made He + C
- Second generation stars built of heavy element (metal) enriched
- Third generation stars even more heavy element enriched (our Sun)
- So it took us ~ 12 billion years for stars to make elements needed for life

History of Life on Earth

- 5.0 Ga - Solar system forms
  - 50 million years later was lunar forming impact
  - Rogue planet 1/2 diameter of Earth + located between Earth + Mars collided with proto Earth
  - Dust and debris were thrown off which within 10,000 years coalesced into Moon
  - Due to tidal friction, moon has been receding ever since at ~ 4 cm / year
- 4.6-4.0 Ga - Heavy Bombardment period, Earth's surface being sterilized
  - We know this by looking at cratering on Moon
- 3.8 Ga - Oldest fossil evidence of life
  - Probably took 200 million years for life to emerge on Earth after it cooled down
- Could life have arisen before then - if so, could it have survived Late Heavy Bombardment?
  - Maybe - there is evidence of water on Earth before Late Heavy Bombardment

Cosmic Calendar

- January 1 at midnight - Big Bang
- September 9 - Our solar system appears
- September 30 - Life on Earth begins
- December 25 - First dinosaurs appear on Earth
- December 28 - First flowers appear on Earth
- December 30 - First primates appear on Earth
- December 31 at 10:00 pm - First humans appear on Earth
- December 31 at 11:59 pm - All human history from this point forward is recorded

- Carl Sagan

History of the Earth in a Single Day

- Midnight - 4.5 Ga - Earth is born
- 00:08 am - Earth is raging furnace from bombardment + internal radioactive decay
- 00:16 am - Iron Catastrophe over, Moon forms
- 00:50 am - Oceans exist
- 3:30 am - Asteroid + comet bombardment that started just after midnight begins to slow down
- 4:00 am - 3.8 Ga - Life begins with first single-celled organisms
- 5:00 am - 3.5 Ga - Asteroid + comet bombardment ceases, life can move out of its hiding places underground + undersea and onto surface where photosynthesis begins
- 1:00 pm - Oxidation of iron completed
- 9:00 pm - Oxygen from cyanobacteria finally raise level of oxygen in atmosphere to 21%
- 9:06 pm - 0.6 Ga - First multi-celled life
- 10:50 pm - First dinosaurs
- 11:40 pm - First primates
- 11:59:30 pm - First humans
- In the last 10% of Earth's history there has been life on the surface you could see with your naked eye
- Microbes ruled the planet for > 3 billion years, 2/3rds of its history

- Origins, PBS Nova, Sept. 28+29 2004

Highway Through Time

- Earth's evolutionary history is a 5 kilometer stretch where each kilometer = 1 billion years
- 4.5 billion years ago - Earth's formation
- 3.75 billion years ago - Earliest identified fossilized life forms = stromatolites, are single-celled organisms
- 1.7 billion years ago - Oxygen revolution = O2 abundant in Earth's atmosphere
- 600 million years ago - first multi-celled organisms (85% of Earth's present age)
- Evolution of Earth is long periods of stasis punctuated by sudden bursts of innovation
- 0.54 billion / 500 million years ago - Cambrian explosion is a burst of innovation
- 0.2 billion / 225 million years ago - Mammals develop
- 4 million years ago - We walk upright
- Whole human story lies in last 500,000 years or half meter
- 40,000 years ago - Humans become big game hunters
- 20,000 years ago - Humans learn to plant crops
- 6,000 years ago - Humans develop writing
- 5,000 years ago / last few mm - All recorded history lies here
- 400 years ago - Modern science develops - need microscope to see it

- Life Beyond Earth, Timothy Ferris, 1999

Tour Through Time on Earth

- Precambrian Era begins 4.5 Ga (Accounts for 90% of Earth's history)
  - Early Earth atmosphere = C02, N, H20 vapor => greenhouse effect
  - Meteorites bombard planet 4.5-4.0 Ga, volcanoes lava created land, volcanic steam condenses into water forming oceans
  - Organic compounds formed in hydrothermal vents or were delivered by meteorites
  - Life begins at 3.8-3.5 Ga = prokaryotes (simple cells)
  - Some prokaryotes develop photosynthesis using chlorophylls to catch light (6CO2 + 6H2O => C6H12O6[Sugar] + 6O2) - Over 2 billion years photosynthesis oxidized iron + created our O2 atmosphere + ozone layer which blocks Sun's harmful radiation + protects life
  - 2.5 Ga eukaryotes (cells with nucleus + organelles) develop => development of sexual reproduction => variation
  - 600 Ma multicellular organisms develop, amount of O2 in atmosphere + oceans reaches current levels

- Evolving Planet, Field Museum, 2006

Tour Through Time on Earth

- Paleozoic Era begins 543 Ma
  - Cambrian Period begins 543 Ma
    - Explosion of life (by factor of 3) in Earth's immense shallow oceans, skeletons appear, vertebrates appear
  - Ordovician Period begins 490 Ma
    - First mass extinction at end of period, probably due to global cooling, at least 70% species wiped out
  - Silurian Period begins 443 Ma
    - Trailblazing plants on Earth, fishes, tetrapods crawl ashore
  - Devonian Period begins 417 Ma
    - Second mass extinction at end of period, may be due to continental drift to over South Pole, up to 70% of marine species may have died out
  - Carboniferous Period begins 354 Ma
    - Great tropical forests
  - Permian Period begins 290 Ma
    - Pangea supercontinent, first reptiles + synapsids (mammal precursors)
    - Third mass extinction at end of period, may be due to global warming from volcanic activity, 90% of marine animals + 80% land animals died out

- Evolving Planet, Field Museum, 2006

Tour Through Time on Earth

- Mesozoic Era begins 248 Ma - age of dinosaurs, age of reptiles, first flowering plants
  - Triassic Period begins 249 Ma
    - Fourth mass extinction at end of period, due to shifting continents leading to volcanic activity causing global warming and sea levels falling, 50% marine animals + 95% plant species went extinct
  - Jurassic Period begins 206 Ma
  - Cretaceous Period begins 144 Ma
    - Fifth mass extinction, due to meteorite hitting Earth, kills > 50% of life on Earth
- Centozoic Era begins 65 Ma
  - Tertiary Period begins 65 Ma
    - Age of mammals supported by grasslands, Hominids develop
  - Quaternary Period begins 1.8 Ma
    - Ice Age, life on Earth begins to look familiar
    - Sixth mass extinction, starts 10,000 years ago, for the first time a single species - humans - is primary cause of mass extinction
    - Average rate of extinction over Earth's history = 1 species every 4 years ~ Today rate of extinction is 30,000 species every year

- Evolving Planet, Field Museum, 2006

Cambrian Explosion

- Earth was a near-desert of life for 4 billion years
  - Bacterial life goes back 3.5 - 3.8 billion years
  - 2 billion years ago bacteria joined by eukaryotes
  - 760 million years ago eukaryotes became multicellular = first animals
  - 632 million years ago in Ediacaran period there were more complex creatures…but none have shells
  - 542 million years ago, animals started developing shells = beginning of Cambrian period
    - When Cambrian explosion occurred, in 20 million years, world's fauna diversified from simple life to a more complex variety
      - No animals lived on land but seas teamed with animals

- The Other Big Bang, The Economist, Aug. 29, 2015

Cambrian Explosion

- Why did it take so long for Cambrian explosion to occur?
  - Something changed in physical environment
    - Rise in oxygen levels which could have allowed for development of bigger animals
    - More calcium in sea, providing material for construction of shells
    - Both could have been facilitated by "Snowball Earth" period of huge ice ages that when glaciers melted, huge areas of rock got weathered + their mineral contents including calcium + nutrients were poured into oceans leading to rise in calcium levels + oxygen levels through increase in photosynthesis…but last of these ice ages ended 635 million years ago

- The Other Big Bang, The Economist, Aug. 29, 2015

Cambrian Explosion

- Why did it take so long for Cambrian explosion to occur?
  - Something changed biologically - rise of diploblasts (endoderm + ectoderm + radial symmetry) and triploblasts (endoderm + ectoderm + mesoderm + bilateral symmetry)
    - Bilateral symmetry encourages animals to have front + rear, allowing them to move purposefully in one direction, leading to accumulation of sense organs + nerves at front of animal = cephalization which encouarges them to evolve brains to interpret + integrate signals from sense organs
    - Bilateral symmetry animals also have linear guts
    - Bilateralism opens activity of active hunting, relying on directed movement + cephalized nervous system -> sudden rise in armored skeletons
  - Or is real mystery Ediacaran, whose animals appeared out of nowhere + then vanished before Cambrian
    - Was there a mass extinction here...and some unidentified Ediacaran triploblasts emerged from obscurity and proliferated

- The Other Big Bang, The Economist, Aug. 29, 2015

History of the Earth

- Huge ancient stars reaching end of lives explode as supernovas that cook up chemicals we know - Fe, C, Au, Ur
- Gravity takes hold, this cloud of stardust collapses into huge rotating disk - solar nebula
- In center of disk, temperature and pressure rise, a star is born
- H and He gas swept to far reaches of disk, closer to sun are dust grains made of heavier elements
- Dust grains collide and because of gravity grow bigger into pebbles, rocks, + eventually planetismals, + eventually the 4 rocky planets (Mercury, Venus, Earth, Mars)
  - No rocks from this time survive on Earth, we look to asteroids for rocks from this time which can provide chemical fingerprint of Earth

- Origins, PBS Nova, Sept. 28+29 2004

History of Earth

- Earth becomes raging furnace from Heavy Bombardment + radioactive decay in its core - outer part of Earth is magma ocean
  - Iron catastrophe occurs with heaviest elements (iron) sinking to center and lightest elements (carbon + water) floating to top
    - Swirling liquid iron core generates electric currents turning Earth into giant magnet with N and S poles
    - This magnetic field protects us from solar wind
    - [Mars had thick atmosphere + surface water, but is much smaller than Earth, so cooled more rapidly, molten iron core hardened, magnetic field / shield disappeared, atmosphere (and life) scoured away by solar wind]
- Earth's atmosphere = CO_2, N, steam
  - No O_2 to breathe, no ozone to block UV radiation

- Origins, PBS Nova, Sept. 28+29, 2004

History of Earth

- Earth hit by planetismal size of Mars, melting outer layers of two objects, they fused together forming larger Earth, debris from collision coalesces to form moon
    - Impact forced Earth's axis to tilt, giving us seasons
    - Moon was 200,000 miles closer, Earth was spinning faster (day = 6 hours), tides were 200 feet high
    - Moon moves away from Earth 1.5" / year, slowing Earth's rotation rate and moderating tides
    - Moon stabilizes Earth, prevents it from wobbling on its axis
- Earth's hot molten surface cools to form crust within 150 million years
- By 200 million years there was primitive ocean on Earth
    - Water comes from volcanic steam that condensed into rain as Earth cooled + massive ice bearing comets in Heavy Bombardment

- Origins, PBS Nova, Sept. 28+29, 2004

History of Life on Earth

- All life made from H, O, C, N
- Meteorites contain amino acids, comets contain organics also
- When amino acids slam into Earth the impact energy helps them form peptides
- Chemistry of life is a fairly probable chemistry
- Life may have started underground or near hydrothermal vents in ocean in order to escape the assault from comets + meteors
- With end of bombardment life reaches Earth's surface, takes advantage of photosynthesis, spreads over Earth's surface
  - Stromatolites probably composed of cyanobacteria, caused oxidation of iron and oxygenation of atmosphere
  - Oxygen creates ozone layer which protects life on Earth

- Origins, PBS Nova, Sept. 28+29, 2004

Magnetospheres

- Magnetosphere can mitigate solar wind's effects by deflecting its stream of charged particles
- Earth has magnetosphere from circulation of electrical currents within its still-molten core
- Mars is smaller than Earth, no longer has a molten core, no longer has a magnetosphere

- Edward Lerner, Alien Worlds: Not in Kansas Any More, Analog, Oct. 2013

Tectonics

- Subsurface molten rock drives plate tectonics
- Essential to long-term survival of life by recycling through the slow motion transfer of material down into subduction zones from whence those materials can return to the surface through volcanic activity

  - Edward Lerner, Alien Worlds: Not in Kansas Any More, Analog, Oct. 2013

Ozone

- Ozone in trace amounts blocks UV light
- Mars is farther from Sun than Earth - yet for lack of ozone layer Martian surface receives more UV radiation than Earth

  - Edward Lerner, Alien Worlds: Not in Kansas Any More, Analog, Oct. 2013

Tides

- Gravitational pull between planet + star or moon + planet are symmetrical
  - As Moon produces tides on Earth, Earth produces tides in Moon - these tides have braked Moon's rotation until it shows only one face to Earth = tidal locking
  - Earth's spin has also been slowed + Moon's orbit is slowly receding from Earth
- Close orbiting planet can become tidally locked to its sun
  - A red dwarf is small / cool / dim with a small habitable zone very close to it, so any planet in that habitable zone will be tidally locked to it

- Edward Lerner, Alien Worlds: Not in Kansas Any More, Analog, Oct. 2013

Nomad Planets

- Nomad planet is planet that wanders through space rather than orbiting a star
- Nomad planet could be icy body, rocky body, or gas giant
- Milky Way galaxy may have 100,000 times more nomad planets than stars
  - Milky Way galaxy has 200-400 billion stars meaning there could be quadrillions of nomad planets
- If nomad planet is big enough to have thick atmosphere, it could trap enough heat from internal radioactive decay + tectonic activity for bacterial life to exist

- Galaxy May Swarm With Nomad Planets, Astrobiology Magazine, Feb. 29, 2012
- Nomads of the Galaxy, Astrobiology Magazine, May 25, 2012

Born Free?

- Rogue planet is a free-floating planet that does not orbit around a star
  - 200 billion in Milky Way galaxy
  - In past felt to have been ejected from existing planetary system
- Now cold clouds in space are felt to have all characteristics necessary to form planets without a parent star
  - Have dense cores that can collapse under own weight + form free-floating planets, largest of these would form brown dwarfs

- Free Floating Planets May Be Born Free, Astrobiology Magazine, Aug. 22, 2013

Our Universe is Set Up For Life - Why?

- God created it, or
- Laws of physics dictate it, or
- Universes are cheap, there are multiple universes, by chance this one got it right

This is the End

- What is the future of the universe
  - Expansion of universe is accelerating - The Big Rip?
  - Something must be acting as antigravity - perhaps Dark Matter
  - In 5.5 billion years our Sun will start running out of fuel, and will swell up to 10-20 times its size
    - It may swallow Earth but for sure the oceans will boil away
  - The sun will then condense to a charcoal briquet in 100 billion years
  - Universe will keep expanding, by 10E100 years the Universe will be so big, so cold, and so diffuse that nothing will happen
    - There will be no energy left in the universe - it will be an infinite amount of nothing

- Seth Shostak, The Big Bang, Our Universe and All That Jazz, Lecture in Stanford Astrobiology Course, April 28, 2008

One More Thing…
The Multiverse

- Is our universe just one of many (billions?) of universes?

- or -

- Is our universe not the center of the multiverse?

Multiverse

- Four types of multiverse
  - Type 1 - Assumes laws of physics are same everywhere
    - Infinite extension of familiar
    - Each universe isolated from others
    - All permitted arrangements of matter might exist somewhere
  - Type 2 - Assumes laws of physics vary from one universe to another
    - Tinkering with physics laws would change nature of reality, so these universes would be very different from each other
    - Each universe within it began with Big Bang
  - Type 3 - Assumes laws of physics are same everywhere
    - Component universes continually separating from each other
    - All possible futures allowed by uncertainties of quantum mechanics actually happen somewhere, that somewhere constitutes new universe
  - Type 4 - Any + all coherent systems of mathematics describe physical reality of some sort
- Why are conditions in observable universe so finely tuned to needs of mankind? If you change some of physics constants slightly the universe can't sustain humans = Fine tuning problem
  - Solved for some by a Creator who made things just right for people to evolve
  - But if universes are commonplace, and rules that govern them vary, then Fine-tuning problem - and need for human-friendly creator - vanishes
  - It is no fluke that at least one universe has right conditions for intelligent life to emerge, since there are zillions of universes that do not
  - Type 2 multiverses offer an answer to Fine-tuning problem

- Multiversal Truths, The Economist, Aug. 15, 2015

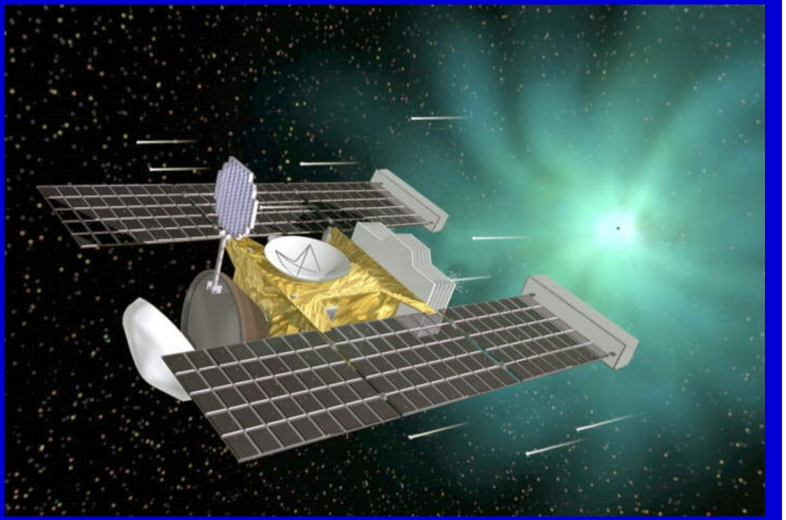
The Fine Tuned Universe

- Fine-tuning = seemingly arbitrary arrangements which are necessary for life
- An example: Fine-structure constant, which says how strong electromagnetic forces are, has value of 1/137
  - A small change in its value either way would affect the abundance of carbon in universe + make universe radically less amenable to life
  - If fine structure constant was 4% higher or smaller, the universe would be rubber / wool / carbon free and without chemical basis for life
- Some take fine-tuning as evidence for role of an intelligence in creation of universe or setting of its laws
- Others see fine-tuning as selection effect: of all universes that could be, only those in which observers are possible get observed
- Multiverse = that which is observed, or will ever be observed, from Earth is but tiniest fraction of all there is, with other universes subject to other rules endlessly beyond ours

- Reflections on the Fine Structure Constant, The Economist, July 13, 2017

Case Study Summary - Stardust

- Goal
  - Collect dust samples from coma of comet Wild 2 + cosmic dust samples and return them to Earth
- Center of Gravity (Strategy)
  - Fly through comet's ice + dust
- Equipment
  - Satellite ~ Collector ~ Return capsule
- Training / Leadership / Morale
- Tactics
  - Use aerogel as collection medium
- Intangibles ~ Mistakes
- Outcome
  - Successful sample return of dust from comet, also identified 7 interstellar dust particles
  - Mission extension, named NExT revisited + reimaged in 2011 comet Tempel 1 which had been visited by Deep Impact in 2005



From NASA

Computing Case Study Summary - Simulation as Tool for Studying Astrobiology

- Goal
  - Situate learning in practice
- Center of Gravity (Strategy)
  - Children + adults learn by doing
- Technology / Equipment
  - Board games modeling space exploration - Liftoff
  - Computer games modeling space exploration - Buzz Aldrin's Race to Space, Kerbal Space Program
  - Board games modeling evolution - Phylo
  - Computer games modeling evolution - EVO, SimEarth, SimLife, Spore
- Training ~ Leadership ~ Morale
- Tactics
  - Make them fun
- Intangibles
  - Just how good are the simulation models?
- Mistakes
- Outcome
  - Ground learning in real-life situations

Personal Case Study - Jud E.

- Role
  - Wrote software used on NASA's Kuiper Airborne Observatory
- Story
  - Physics major
  - Worked for NASA Ames as summer intern, wrote software for experiments on NASA's Kuiper Airborne Observatory and flew on it and watched it work
  - Loved NASA but decided he couldn't afford to work for them so made his career at Chrysler as engineer and becoming a quality guru / blackbelt for them

Astrobiology Analog Case Study - Present At The Creation

- Location
  - Hawaii Volcanoes National Park
- Story
  - Ranger-guided hike to where volcano is erupting March 2003

"What thinking person wouldn't be deeply impressed when, for the first time, he sees, hears, smells and feels molten rock oozing from the bowels of the Earth?

The sight was a restless lake of lava, churning and roiling in a half-mile-wide crater. The sound was the hiss of noxious gases leaking off the top of the cauldron's brew. The smell was that of sulfurous fumes wafting up from the lake. And the feel was that of seeing heat rising from the 2000-degree liquid, and the vibrations of the ground, which shook and quivered from the sloshing of that primordial soup in its crater container.

Aware that I was literally witnessing part of Earth's creation I was humbled and in awe…"

- Wendell Duffield, US Geological Service

Drake Equation

$$N = R^* \times fp \times ne \times fl \times fi \times fc \times L$$

- N = The number of communicative civilizations
- R* = The rate of formation of suitable stars (stars such as our Sun)
- fp = The fraction of those stars with planets. (Current evidence indicates that planetary systems may be common for stars like the Sun.)
- ne = The number of Earth-like worlds per planetary system
- fl = The fraction of those Earth-like planets where life actually develops
- fi = The fraction of life sites where intelligence develops
- fc = The fraction of communicative planets (those on which electromagnetic communications technology develops)
- L = The "lifetime" of communicating civilizations

Class Simulation

- Topic aspects

Poem

These are the people just like you,
who live with the plants and animals, too,
that grow on the planet green and blue
that circles the sun, our daily view,
that was born from the dust, so old and new,
thrown from the blast intense enough
to hurl the atoms so strong and tough
that formed in the star of red-hot stuff
that burst from the gas in a giant puff
that spun from the blocks
that formed from the bits
that were born in the bang
when the world began.

- Karen C. Fox and Nancy Davis, Older Than the Stars

Questions for Further Discussion

- Where does the universe come from?
- What is the timeline of the universe?
- How big is the universe?
- Where do stars come from?
- Where did our star come from?
- Where do solar systems + planets come from?
- What is the timeline of the Earth?
- What is the timeline of intelligent life on Earth?
- How does life on Earth + evolution continually reset itself?
- What is the age of the Universe and Earth?

Reading Assignments

- Astrobiology Primer 2.0 (2016) Chapter 3
  - https://doi.org/10.1089/ast.2015.1460
- TED Talks for this Topic
  - http://www.astrobiologysurvey.org/ToLearnMore.html

Recommended Reading to Learn More

- Non-fiction
  - Kees Boeke - Cosmic View: The Universe in 40 Jumps
- Fiction
- Movies
- Simulations

Conclusion - Perspective

"I think it's healthy for people to understand their wider environment. The world's a lot less troubling when you understand the systems that it's part of, in the huge scope of space and time in which human life exists. People used to ask -- and maybe they still do -- "Doesn't this make you feel insignificant, that everything out there is so big?" But I really think the reverse is true, that one feels much better about the human condition when one understands it in its natural context. That context extends out through the stars and the wider universe. It's all nature, and it's always good for the mind and heart to understand nature and our place in nature."

- Timothy Ferris, science writer

Conclusion

"The Universe is not only queerer than we suppose, but queerer than we can suppose."

- JBS Haldane, biologist

Conclusion

"For such small creatures such as we the vastness is bearable only through love."

- Carl Sagan, planetary scientist

Topic 3

Sensors

Song

I know you've deceived me, now here's a surprise
I know that you have 'cause there's magic in my eyes

I can see for miles and miles and miles and miles and miles
Oh yeah

If you think that I don't know about the little tricks you've played
And never see you when deliberately you put things in my way

Well, here's a poke at you
You're gonna choke on it too
You're gonna lose that smile
Because all the while

I can see for miles and miles…

- Pete Townshend, I Can See For Miles

Thematic Quote

"Measure what is measurable, and make measurable what is not so"

- Galileo Galilei, astronomer

The Painting

Romance of Discovery

- N.C. Wyeth

(National Geographic Society)

Artifact

- Name
  - Galileoscope
- Year
  - 2009 International Year of Astronomy
- Story
  - Inexpensive refractor telescope designed to give a similar viewing experience to what Galileo had - craters of Moon, four of Jupiter's moons

The Question

How have new instruments changed our view of our place in the Universe and our understanding of the Universe over time?

How has the breadth of the electromagnetic spectrum aided our exploration of the Universe?

Our Changing View Of The Universe

BC - Greeks	Mediterranean-centric
AD - Ptolemy/Christian	Geo (Earth) -centric
1530 - Copernican	Helio-centric
1609 - Galileo	Helio-centric
	Discovered solar system of Jupiter within our solar system
1838 - Bessel	Found stars are light years away
	Measured distance to stars using parallax
1900	Milky Way-centric / universe is static (but what about nebulae?)
1925 - Hubble	Galaxy-centric / universe is expanding (universe has multiple galaxies)
	Used Cepheid variables as standard candle to measure distance to nebulae starting with Andromeda nebula
	Realized nebulae are galaxies that are moving away from us
	The farther away they are the faster they are moving away from us
	Run the tape backwards to get to the beginning of the universe
1995	First exoplanet detection
Today	Big Bang 13.7 billion years ago
	Universe was small / hot / dense at beginning + inhomogeneous
	Heisenberg Uncertainty Principle = Universe not completely uniform
	When universe gets big there are clumps of matter that form galaxies with stars, most stars have planets, add in some chemistry and you get life
	And no you are not the center of the universe just because all galaxies are moving away from you - Think of raisins in bread pudding analogy
	Space and time came with Big Bang so there was nothing before it
Future	Multiverse?

- Seth Shostak, The Big Bang, Our Universe and All That Jazz, Lecture in Stanford Astrobiology Course, April 28, 2008

Evolution of the Optical Telescope

Tool	Magnification	Diameter of light gathering part (aperture)	Type of light detected (wavelength)
Eye	1x	0.2-0.3"	Visible
Early scope in 1620's refractor	9x	0.5"	Visible
Herschel's Uranus scope 1781 reflector	227x, 460x, 932x	6.2"	Visible
Herschel's last scope 40' long reflector largest in world		48"	Visible
Dearborn scope 1864 refractor	220x	18.6"	Visible
Mount Wilson 1917 reflector		100"	Visible
Mount Palomar 1949 reflector		200"	Visible
Keck reflector 1990s currently largest land-based scope	Depends	394" across 1 mirror (there are 2 scopes - each is 33' across but together can operate as telescope 280' in diameter = interferometer)	Visible + near IR
Hubble 1990	Depends	94"	Visible, UV, near IR

- Adler Planetarium, Telescopes: Through the Looking Glass

Timeline of the Optical Telescope

1608 - Telescope unveiled by Hans Lippershey

1610 - Galileo's key observations

- Sun has spots (imperfections)
- Jupiter has moons orbiting it
- Moon does not appear smooth - has mountains and craters (imperfections)
- Venus has phases like Moon

1638-1715 - Louis XIV known as Sun King in honor of his Copernican world view

1659 - Christiaan Huygens discovers Titan around Saturn

1718 - Newton develops telescope using mirror rather than lens to gather light to overcome halo problem encountered with lens (chromatic aberration)

Problems with lens (refractors)

- Blurry images (due to spherical aberration)
- Colored halos (chromatic aberration)

Leads to use of mirrors (reflectors)

- Don't have blurring and halos

1781 William Herschel accidentally discovers Uranus

1800's - Golden age of refractor

1893 - Largest refractor was 40" at Yerkes Observatory

1900's - Photographic plates replace eye at end of scope. Photos show things too faint for eyes

Moving from solar system models to galactic models

Starting to take spectra that shows composition of stars + dust clouds

1951 - First excellent model of Milky Way by William Morgan

Today - Telescopes must be remote to avoid light pollution and high to avoid atmosphere

Today - Map of universe shows distribution of galaxies not stars

- Adler Planetarium, Telescopes: Through the Looking Glass

Spectroscopy of Stars

- 1859 - Bunsen + Kirchoff
- Spectral lines can show
  - Composition of stars + gas clouds, their temperatures, densities, presence of magnetic fields and whether they are moving towards or away from earth

Spectroscopy of Planets

- Particular chemicals absorb certain wavelengths of light
  - Carbon dioxide, for example, absorbs specific wavelengths in infrared spectrum, as does water, methane, ozone, etc
- By collecting light from a planet and analyzing its spectrum for missing wavelengths, we can deduce what chemicals are in the atmosphere.
  - Is the first step to detecting life

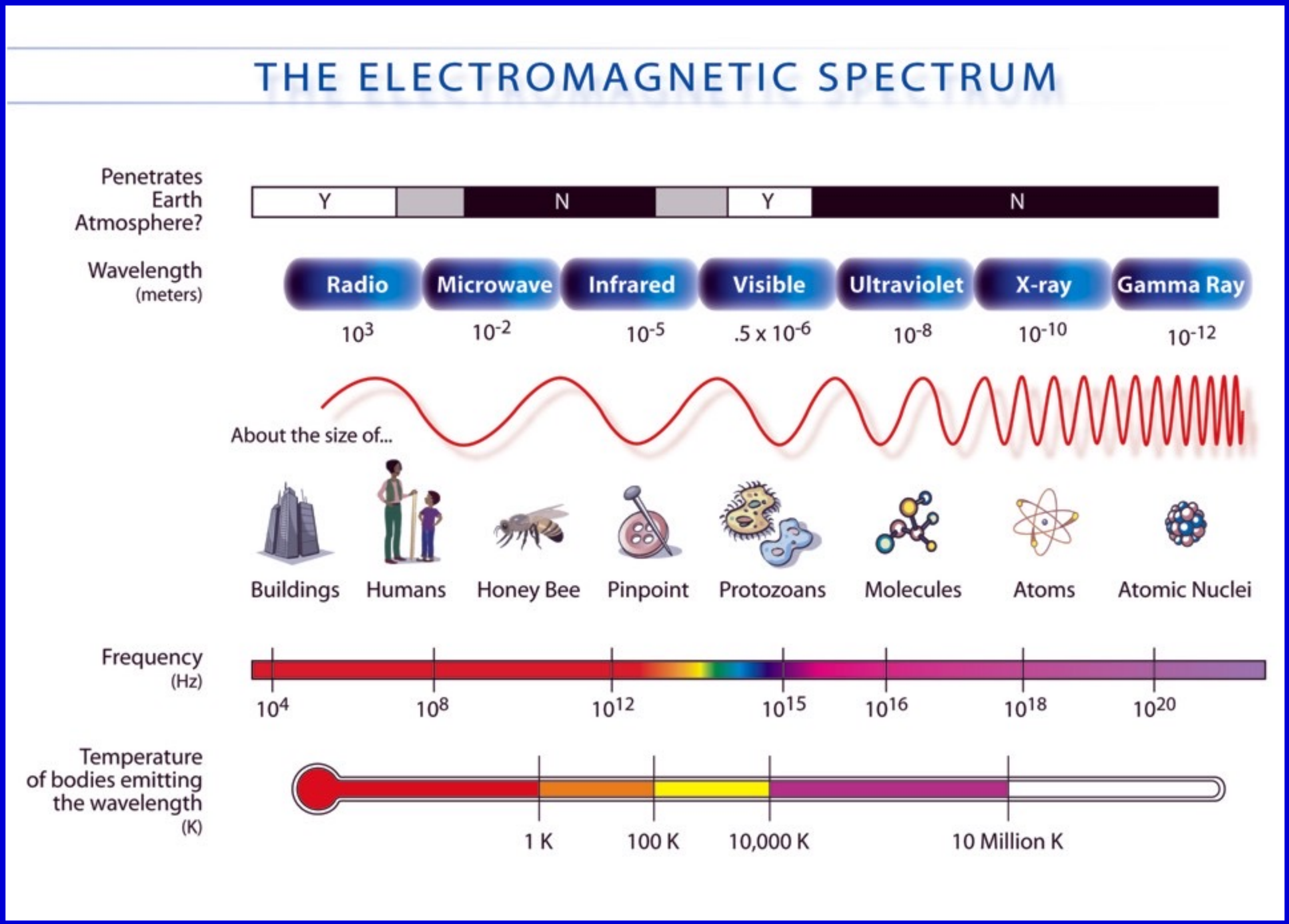
- Finding Life Beyond Earth, PBS Nova, Oct. 19, 2011

Detecting Life From Afar

- "A Physical Basis for Life-Detection Experiments" by James Lovelock
  - First suggestion of how to conduct searches for life from afar
  - Emphasized looking for unstable mixtures of chemicals in planetary atmospheres
- Gases in planet's atmosphere absorb specific parts of starlight, leaving holes (black lines) in its spectrum with pattern of lines revealing planet's atmospheric composition

- Life Story, The Economist, Aug. 8, 2015

Electromagnetic Spectrum



From NASA

- If electromagnetic spectrum stretched from New York to California (3000 miles), visible light would be the thickness of a book (few inches)

Electromagnetic Spectrum

- Visible light
  - Violet has the shortest of all wavelengths
  - Moving to longer and longer wavelengths, we pass from one color to the next, right on up to orange and then red - there ends visible light
- But light continues beyond that, just increase the wavelength - What do you get?
  - Infrared. Can't see infrared, but we feel it, we sense it as heat
- Beyond infrared, we find microwaves and
- Then, the longest of them all, radio waves. Both radio waves and microwaves we use to communicate through earth's atmosphere and through space itself

- Origins, PBS Nova, Sept. 28+29, 2004

Electromagnetic Spectrum

- Full spectrum from low energy / long wavelengths to high energy / short wavelengths
  - Radio waves to microwaves to infrared to visible (ROYGBIV) to ultraviolet to X-rays to gamma rays
- Many astrophysical phenomena reveal themselves only in certain portions of the spectrum

- Neil deGrasse Tyson, Space Chronicles, 2012

Radio Waves

- First radio waves coming from beyond Earth seen in 1931 by Karl Jansky of Bell Labs
  - Saw radio signals coming from center of Milky Way galaxy
- Radio telescope discoveries
  - Quasars (quasi-stellar radio source) - amongst most distant + energetic objects in universe
  - Gas-rich galaxies emit radio waves from their abundant H atoms + thus their gas content can be mapped from their radio waves

- Neil deGrasse Tyson, Space Chronicles, 2012

Radio Waves

- Go through dust and gas clouds - universe is transparent to them
- Low frequency, long wavelength, low energy, least penetrating
- Square Kilometer Array will be biggest radiotelescope in world
- SETI search

Microwaves

- Microwave telescope discoveries
  - Enable us to look into cool dense clouds of interstellar gas that collapse to form stars + planets - heavy elements in these clouds assemble into complex molecules with distinctive microwave signatures
  - 1964 Arno Penzias + Robert Wilson of Bell Labs detected heat left over from Big Bang - cosmic microwave background

    - Neil deGrasse Tyson, Space Chronicles, 2012

Infrared

- Infrared telescope discoveries
  - Probing dense clouds containing stellar nurseries, whose infant stars are covered by excess gas + dust - these clouds absorb most of visible light from their new stars and re-radiate it in infrared

    - Neil deGrasse Tyson, Space Chronicles, 2012

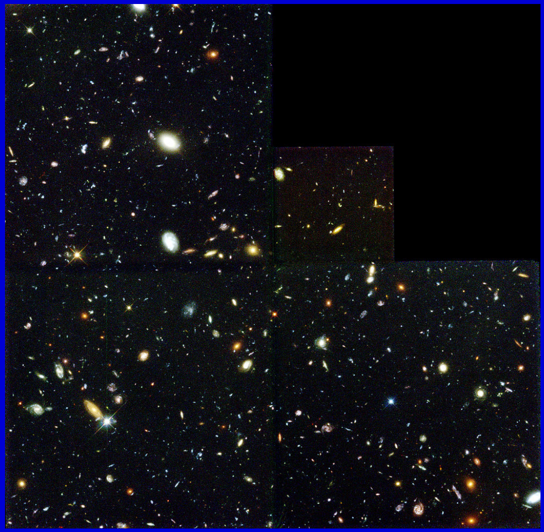
Infrared

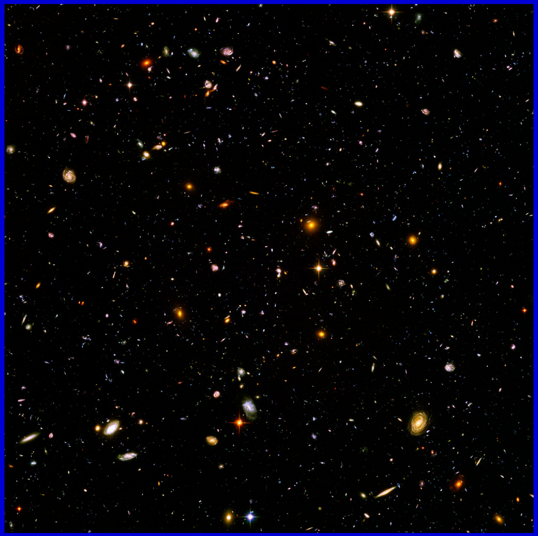
- First step down from visible
  - Near infrared = what operates remote control
  - Far infrared = heat from sun
- Instrument
  - Infrared spectroscopy is key to helping us discover astrochemistry but atmosphere blocks infrared so did observations via Kupier Airborne Observatory which flew above most of the atmosphere

Visible

- As you go to shorter wavelength the light has more energy
- Maximum of our Sun's energy output is in the visible spectrum, thus life on Earth adapted to it

Hubble Deep Field





All From NASA

- Hubble Deep Field (left) - 1995
  - 1,500 galaxies
- Hubble Ultra Deep Field (center) - 2004
  - Thousands of galaxies
- Hubble Extreme Deep Field (right) - 2012
  - Shows 5,500 galaxies formed 13 billion years ago, 450 million years after Big Bang - the farthest + most distant galaxies seen
  - 23 days exposure time (2 million seconds)

Ultraviolet

- Earth's atmosphere ozone layer absorbs most UV light so to study UV light you should be in Earth orbit
- Ultraviolet telescope discoveries
  - Stars that are 4 times hotter than our Sun are big producers of ultraviolet light
  - Ultraviolet light can indicate the presence of black holes as Ultraviolet light (+ X-rays) is the predominant form of energy released by material before it enters into black hole

    - Neil deGrasse Tyson, Space Chronicles, 2012

Ultraviolet

- Ultraviolet a - longer wavelength - can penetrate skin and cause wrinkling and perhaps cancer
- Ultraviolet b - shorter wavelength - causes sunburn and melanoma

X-Rays

- Earth's atmosphere ozone layer absorbs most X-rays so to study them you should be in Earth orbit
- X-ray telescope discoveries
  - X-rays can indicate the presence of black holes as X-rays (+ Ultraviolet) are the predominant form of energy released by material before it enters into black hole

    - Neil deGrasse Tyson, Space Chronicles, 2012

X-Ray

- High frequency - short wavelength - high energy - most penetrating waves
- Chandra X-ray observatory
  - Supernova remnants imaged
  - Black holes imaged
  - Must be in space above atmosphere because Earth's atmosphere protects us from x-rays

Gamma Rays

- Gamma ray telescope discoveries
  - Gamma ray bursts are the signature of distant stellar catastrophes
    - Neil deGrasse Tyson, Space Chronicles, 2012

Gamma Rays

- Small and powerful
- Highest frequency - shortest waves - highest energy - most dangerous
- Don't penetrate Earth's atmosphere so put telescope in space

Gravity Waves

- Predicted by Einstein
- Distortions of space time
- Can we detect them?
- Would need to look back to Big Bang
  - So far we've seen the Cosmic Microwave Background Radiation which looks back to 400,000 years after Big Bang
- Laser Inferometer Gravitational Wave Observatory (LIGO)
  - Detected gravitational waves from the merger of 2 black holes in 2015

NASA's Great Observatories

- Hubble Space Telescope
  - Ultraviolet, visible, near-infrared
- Compton Gamma Ray Observatory
  - Gamma rays
- Chandra X-Ray Observatory
  - X-rays
- Spitzer Space Telescope
  - Infrared

What Telescopes Detect

- Radio
  - Understand what is left after large stars explode such as pulsars + supernova remnants + SETI
- Microwave
  - Molecular gas which forms stars + planets
- Infrared
  - Cosmic gas + dust
- Visible (Optical)
  - Stars, gas clouds, expansion of universe
- Ultraviolet
  - Young hot stars + hot gas between stars
- X-Ray
  - Very hot gas from stars, gas from exploding stars + quasars + galaxy clusters
- Gamma Ray
  - Most energetic objects in universe - like fast moving jets from supermassive black holes + remnants of exploding stars

Summarizing…

Copernican Principle

- We are not special
  - Earth is not center of our solar system
  - Our solar system is not center of Milky Way galaxy
  - Milky Way galaxy is not center of the universe

Anthropic Principle

- The universe is fine-tuned for life

Copernican Principle

"The human race is just a chemical scum on a moderate-sized planet, orbiting around a very average star in the outer suburb of one among a hundred billion galaxies."

- Stephen Hawking, physicist

Connecting the Dots…

- Every new instrument we have built changed our view of our place in universe and our understanding of universe
  - What's next?

Case Study Summary - Hubble Space Telescope

- Goal
  - Take extremely high resolution + clear images of universe
- Center of Gravity (Strategy)
  - Take images above distortion of Earth's atmosphere
- Equipment
  - Take spy satellite technology + point it away from Earth instead of at Earth
  - 2.4 meter mirror with multiple instruments attached to it
- Training ~ Leadership ~ Morale
- Tactics
  - Image in near ultraviolet, visible, near infrared spectra
- Intangibles
  - Designed to be serviced in space, was serviced 5 times
- Mistakes
  - Main mirror ground incorrectly, was subsequently corrected
- Outcome
  - Told us rate of expansion of universe (Hubble constant) + expansion is speeding up
  - …So therefore told us age of universe - 13.7 billion years
  - Told us every large galaxy has super massive black hole in center
  - Told us rate at which universe is forming new stars

Computing Case Study Summary - Adaptive Optics

- Goal
  - Improve performance of optical systems on telescopes by reducing effect of atmospheric distortion caused by temperature changes
- Center of Gravity (Strategy)
  - Use deformable mirrors which change shape thousands of times/second to compensate for atmospheric distortion
- Technology / Equipment
  - Technology was developed for Strategic Defense Initiative + then declassified in 1991
  - Computers drive the mirrors + were fast enough to do so by 1990's
- Training ~ Leadership ~ Morale
- Tactics
  - Can be designed into new telescopes + retrofitted into older telescopes
- Intangibles ~ Mistakes
- Outcome
  - Has expanded + revolutionized the ability of Earth-based telescopes to acquire high resolution images
  - This second life for Earth-based telescopes which can be easily upgraded has lessened the needs for space-based telescopes which cannot be easily upgraded

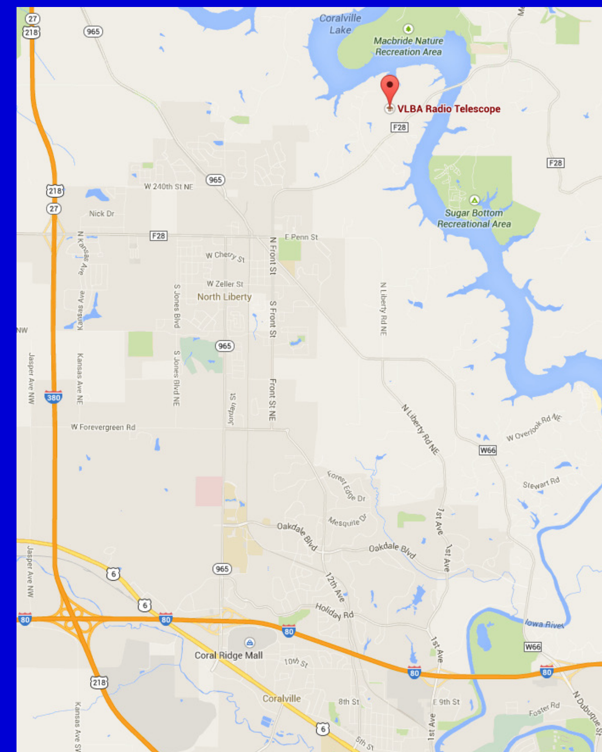
- Joe Palca, For Sharpest Views, Scope the Sky with Quick-Change Mirrors, NPR, June 24, 2013

Personal Case Study - Last Year's Model

- Location
  - Yerkes Observatory, Williams Bay, Wisconsin
- Story
  - Largest refractor telescope in world (40"), built in 1897
  - Built by George Ellery Hale who went on to build next two largest telescopes in world at Mount Wilson (100" reflector in 1917) and Mount Palomar (200" reflector in 1949)

Personal Case Study - Very Long Baseline Array (VLBA)

- Location
  - North Liberty, Iowa
- Story
  - 1 of 10 radio telescopes in VLBA spread over 5,351 miles from Hawaii to Virgin Islands overseen by National Radio Astronomy Observatory
  - When used together provide same angular resolution as telescope 5,351 miles in diameter



From Google Maps (above) and Bing Maps (below)

Astrobiology Analog Case Study - Journey Back In Time

- Location
  - Grand Canyon National Park
- Story
  - As you hike down Bright Angel Trail, each step down carries you ~ 20,000 years into the past
  - The rocks at the bottom of the Grand Canyon are 1.7 billion years old
  - …a journey to the center of the Earth..

Drake Equation

$$N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

- N = The number of communicative civilizations
- R* = The rate of formation of suitable stars (stars such as our Sun)
- fp = The fraction of those stars with planets. (Current evidence indicates that planetary systems may be common for stars like the Sun.)
- ne = The number of Earth-like worlds per planetary system
- fl = The fraction of those Earth-like planets where life actually develops
- fi = The fraction of life sites where intelligence develops
- fc = The fraction of communicative planets (those on which electromagnetic communications technology develops)
- L = The "lifetime" of communicating civilizations

Class Simulation

- Topic aspects

Poem

Slide text

Questions for Further Discussion

- How has utilizing the whole electromagnetic spectrum opened our eyes to the universe?
- Compare and contrast the Copernican principle and the Anthropic principle

Reading Assignments

- Astrobiology Primer 2.0 (2016) Chapter
  - https://doi.org/10.1089/ast.2015.1460
- TED Talks for this Topic
  - http://www.astrobiologysurvey.org/ToLearnMore.html

Recommended Reading to Learn More

- Non-fiction
- Fiction
- Movies
- Simulations

Conclusion

"The real voyage of discovery consists not in seeking new landscapes, but in having new eyes."

- Marcel Proust, novelist

Topic 4

What is Life?

Song

Igor Stravinsky, Rite of Spring

Thematic Quote

"Where the telescope ends, the microscope begins. Which of the two has the grander view?"

- Victor Hugo, Les Miserables

The Painting

Cosmic Evolution

- David DesMarais, Thomas Scattergood, and Linda Jahnke (NASA Ames)

Artifact

- Name
  - Stromatolite
- Year
  - 2012
- Story
  - Seen outside Glacier National Park in a road cut

The Question

Where do we come from?

or

What is the history of life?

Scientific Method

- Phenomena observed but not understood
- Hypothesis formulated to explain observations
- Experiment performed to test hypothesis
- Observe experiment / Data gathering
- Data analysis
  - Hypothesis proven => go to theory formation
  - Hypothesis not proven => go to step 2, modify hypothesis

- Evolving Planet, Field Museum, 2006

Scientific Theory

- Facts = knowledge or information based on real occurrences that have been directly observed. Facts support or refute theories
- Hypothesis = proposed explanation for phenomenon, is first step in formation of theory
- If hypothesis is confirmed through experimental testing, observation + data collection it can become theory
- Scientific theory = explanation of an aspect of natural world that is well substantiated by evidence

- Evolving Planet, Field Museum, 2006

Theory of Evolution

- Evolution is scientific theory that unifies all aspects of biological sciences + provides framework to understand history of life on Earth
- One of most strongly substantiated theories in modern science
- Only scientifically accepted theory that explains diversity of life on Earth + provides explanation for why this diversity has changed throughout history
- Every living organism is connected through single process of evolution

- Evolving Planet, Field Museum, 2006

Theory of Evolution

- Intelligent design + creationism not within realm of science + are best characterized as faith-based belief systems
  - Are not testable scientific theories
  - Offer non-scientific explanations for life's origins + diversity of life forms
- Science and religion are not mutually exclusive

- Evolving Planet, Field Museum, 2006

Basics of Evolution

- Evolution definition = change through time
- Biological evolution is cumulative changes in gene frequency that occur within populations through time…that over time can produce entirely new species
  - Modern understanding begins with Darwin's On the Origin of Species (1859)
- Darwin's definition of evolution = "descent with modification"

  - Evolving Planet, Field Museum, 2006

Biological Evolution

- Populations experience small genetic changes from one generation to next generation
- Over time, through process of natural selection, such small changes can add up to big changes overall, including emergence of new species

  - Evolving Planet, Field Museum, 2006

Natural Selection

- Natural selection is mechanism that passes favorable variations from generation to generation
- Natural selection = survival of fittest = an organism's ability to survive + reproduce
- Basic tenets of Darwin's Theory of Evolution by means of natural selection
  - Variation exists amongst individuals within a species
  - Organisms produce more offspring than environment can support
  - Competition exists between individuals
  - The individuals who best fit their environment are likely to survive, reproduce + pass their traits to next generation
- The survival + passing of genes is natural selection, the driver of evolution

- Evolving Planet, Field Museum, 2006

"He (Darwin) became the first to realize how evolution works by combining the creativity of random mutation with the editing power of natural selection to turn one species into many."

"All organisms are fitted to the environment they occupy. Life is a selection for wherever that organism happens to be."

"Evolution is not just a matter of random chance. It is also a matter of discarding the variations that don't work and keeping the ones that do."

- Timothy Ferris, Life Beyond Earth

Evolution

- Evolution does not always have to lead to increased complexity - it can lead to increased adaptation
- Evolutionary biology covers / in astrobiology we focus on
  - A historical sequence - particular emphasis on microbes
  - Classification of living organisms, preferably by genealogy - in that it helps us to understand biodiversity
  - Understanding how and why evolution has produced such diversity - and how it might relate to evolution elsewhere
  - Understanding biogeography - where can life survive in the universe (think extremophiles)

Evolution

- What astrobiology brings to table is that all evolution acts in a physical environment
- Astrobiology is evolutionary biology on steroids
  - It takes into account environmental processes including planetary + even extraterrestrial processes that could effect evolution
    - Supernovae anyone?
    - So what is evolution? Descent with modification

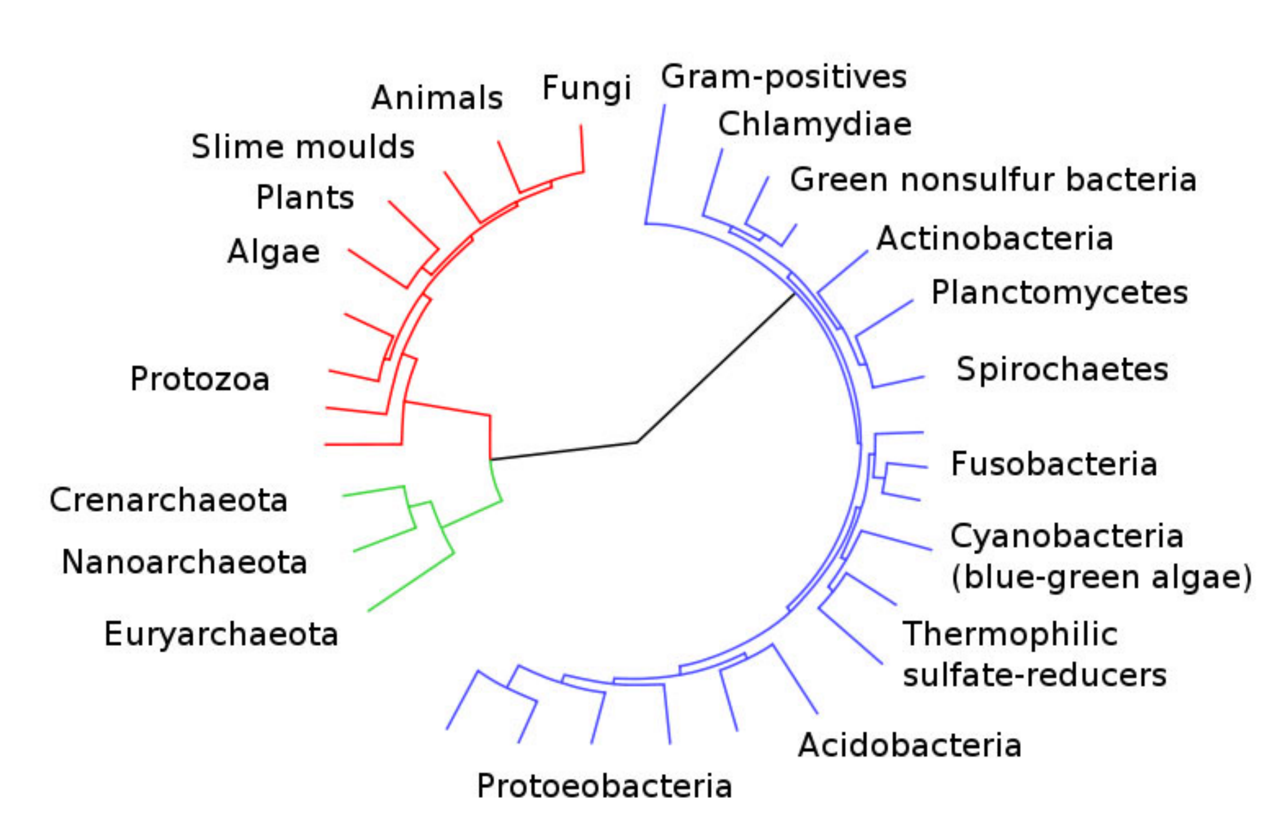
Evolution

- Evolution of life does not occur in a vacuum - evolution occurs in a physical and chemical context which is often changing
  - Sun changed - solar luminosity + UV regime
  - Earth changed - rotation rate slowed down over time
  - Moon changed and the interactions of the Earth and Moon changed
  - Atmosphere changed - had greenhouse gases at origin of life
  - Continents changed
  - Water chemistry changed
  - Temperatures changed

Three Domain System Tree Of Life

- Bacteria
  - Prokaryote
- Archaea
  - Prokaryote
- Eurkarya
  - Eurkaryotes

Current Tree of Life



A highly resolved Tree Of Life, based on completely sequenced genomes [1]. The image was generated using iTOL: Interactive Tree Of Life[2], an online phylogenetic tree viewer and Tree Of Life resource. Eukaryotes are colored red, archaea green and bacteria blue. PNG image traced by hand to produce SVG version.

1. Ciccarelli, FD (2006). "Toward automatic reconstruction of a highly resolved tree of life." (Pubmed). Science 311(5765): 1283-7.

2. Letunic, I (2007). "Interactive Tree Of Life (iTOL): an online tool for phylogenetic tree display and annotation.". Bioinformatics 23(1): 127-8.

Definition of Life

- Operational definition
  - Life is a self-sustained chemical system capable of undergoing Darwinian evolution - NASA

"I know it when I see it"

- United States Supreme Court Justice Potter Stewart to describe his threshold test for obscenity in Jacobellis v. Ohio (1964)

Definitions of Life

- Star Trek definition of life
  - If you can see eyes it is alive - Gene Roddenberry
  - Sentience - Turing Test - if you don't know if you are talking to computer or person it is alive - TNG "The Measure of Man" - is Data alive?
  - For Data, best test is Descartes' "Cogito ergo sum" - TNG "Elementary, Dear Data" and "Ship in a Bottle"
  - Behavior - "Devil in the Dark" - silicon based life form was mother trying to protect young
  - What if they evolve - TNG "Evolution" - Nannites behave in collective manner + evolve
  - There are basic definitions for organic life: must have the ability to assimilate, respirate, reproduce, grow and develop, move, secrete and excrete - TNG "Home Soil"

Definition Of Life

- Life is a system that is capable of Darwinian evolution
  - Has to be able to reproduce
  - Need source of variation
  - Natural selection chooses the variants that function best

- Origins, PBS Nova, Sept. 28+29, 2004

Definitions of Life

- Biochemist's definition - 7 Pillars of Life
  - Program (DNA), improvisation, compartmentalization, energy, regeneration, adaptability, seclusion

  \- Daniel E. Koshland, biochemist
- Physicist's definition
  - "What is Life?" by Erwin Schrodinger
    - Life is a little patch of order in a sea of chaos and everything tends towards chaos
    - Life feeds on negative entropy (organization) / Life fights entropy

What is Required For Life

- Energy
- Place warm enough for chemical reactions to go on

  - National Academy of Sciences Committee

What is Required For Life

- Organic compounds
- Energy source
- Liquid water as solvent
- [Time]

A Key Question

- How do the biogenic compounds (C H O N P S) come together to form organic compounds and how do they ultimately wind up as life?

Why Is Liquid Water Essential For Life?

- Biochemical reactions that sustain life need fluid to operate
  - In liquid, molecules can dissolve + chemical reactions occur
  - Liquid is always in flux, thus conveying vital substances from one place to another
- Why is water best liquid
  - Is best solvent in universe - dissolves almost anything
  - Bends enzymes to facilitate their actions
  - Only chemical compound that occurs naturally on Earth's surface in all three physical states
  - Has extremely large liquid range compared to other liquids + has high heat capacity
    - Temperatures on Earth's surface can undergo extreme variations without water freezing or boiling away, thus oceans serve as moderating influence on world's climate
  - When water freezes it expands and becomes less dense (it floats)

- Origins, PBS Nova, Sept. 28+29, 2004

Focused Case Study: Miller-Urey Experiment 1950's

- One flask filled with gases of Earth's primitive atmosphere, connected to another flask with water representing oceans
  - Primitive atmosphere in flask is methane, ammonia, H gas, water vapor
- Put electrical charge through it to simulate lightning going through early atmosphere
- In few days brown goo developed in reaction vessel which was found to contain amino acids, the building blocks of proteins + cells
  - Amino acids were in about same proportions you would find in a meteorite

- Origins, PBS Nova, Sept. 28+29, 2004

"Life really is a form of chemistry, a particular form in which the chemicals can lead to their own reproduction…Life is something that emerges on a developing planetary surface as part and parcel of the chemistry of that surface."

- Andy Knoll, paleontologist

Most Common Elements in Universe

- 4 most common elements in universe = H, He (inert), C, O
  - 3 most abundant chemically active ingredients in cosmos are top 3 ingredients of life on Earth = 95% of atoms in all known life on Earth
    - Life on other planets will probably have similar mix
- Astronomer's periodic table
  - H is huge, He is big, C N O are small, traces of Ne Mg Fe Si S Ar
  - Universe is primarily H, a remnant of Big Bang
  - [C N O Ne Mg Fe Si S Ar are produced by stellar cycle]

How Does Life Begin

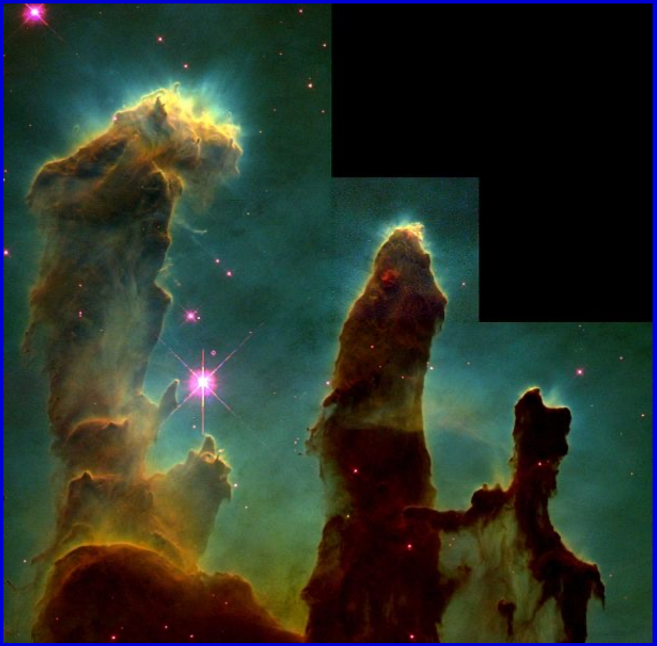
- First forms of life must be able to grow, reproduce, be subject to Darwinian evolution
- Molecule must be simple enough to be made by physical processes on young Earth, but complicated enough that it can reproduce
- Planet must have certain range of environments, certain types of gases in atmosphere, certain types of geological processes at work
- Need C H O N P S (mainly C O H)
  - Atmosphere is C O H and is inorganic
  - How do you go from atmospheric CO2 (or CH4 in early atmosphere) + water vapor + H and make them into building blocks of life?

- Origins, PBS Nova, Sept. 28+29, 2004

Where Do The Building Blocks of Life Come From?

- Infant universe filled with vast clouds of H
- Clouds begin to condense due to gravity, central region grows more dense, star lights up
  - These first stars are H giants and short lived (2-3 million years) and go out with big explosion (hypernovae)
  - And the cycle repeats itself and as it does each generation of stars enriches / concentrates interstellar medium
  - All atoms in universe heavier than H + He are forged by stars - stars are ultimate alchemist
  - So we are all stardust

    - Origins, PBS Nova, Sept. 28+29, 2004



From NASA

From Astrochemistry to Astrobiology

- The ready abiotic synthesis of:
  - Membrane forming molecules + vesicles
  - Complex photoluminescent molecules
  - Racemic amino acids and sugar precursors
  - Quinones
  - Functionalized + heterocyclic aromatics
  - in realistic cosmic ice analogs implies these are widespread throughout the cosmos and available to habitable planets.
- Thus if conditions are right and (BIG AND) biochemistry is extreme chemical complexity, the conclusion the universe is poised for life seems inescapable

From Astrochemistry to Astrobiology

- Ionized polycyclic aromatic hydrocarbons (PAHs), shockingly large interstellar molecules, are widespread and abundant throughout cosmos
- In cold molecular clouds, the birthplace of planets + stars, interstellar molecules freeze into ice particles containing species such as water, methanol, ammonia, CO + PAHs
- In these clouds, especially close to stars and planet forming regions, these ices are processed by UV light + cosmic rays forming far more complex species, many of biogenic interest
- Comets + meteorites seed primordial planets with these compounds, where they take part in the budding chemistry on their young worlds
- Astrochemistry is astrobiology
  - Astrobiology is astrochemistry, is step by step building of chemical complexity to eventually living organisms
- The language of chemistry in the universe is very similar to the language of chemistry of life on Earth and that suggests that if there is life somewhere else, that it may be based on similar chemistry to life on Earth

Minimal compliment of cell functions

- Must catalyze chemical reactions for maintenance and growth = metabolism
- Must be able to pass information between generations
- Must have a boundary
- Must have a mechanism for capturing energy from environment and using it for chemical reactions
- Needs to move nutrients and waste products in and out

Central Dogma of Genetics

- DNA is transcribed into RNA which is translated into protein and this is one directional phenomena and DNA is the master molecule of the cell, RNA is the messenger and protein is the effector
  - Sole purpose of RNA is to carry information from nucleus to ribosomes
- But discovery of reverse transcriptases in RNA viruses that would transcribe RNA back into DNA began to cause this paradigm to be questioned

Life Relies on 2 Biopolymers

- Nucleic acids - carry genetic information - shape is double helix - code for proteins
- Proteins - work horses of cells (especially catalyze chemical reactions) - fold into complex structures - synthesize DNA
  - Proteins also transport material, capture energy, provide scaffolding in cells
- So these 2 biopolymers are closely coupled but which was first - i.e. where do biopolymers come from - was it RNA first or protein first

RNA World

- RNA world = RNA was first genetic + enzymatic polymer, RNA is easier to make than DNA
- RNA world hypothesis pros
  - RNA can act as hereditary material, coding material and can have catalytic - including autocatalytic - activity (can function as an enzyme) + self replicate
  - There are many palindromes in DNA, derived from hairpins in RNA
  - Evolution of cellular life:
    - Prebiotic world->
    - RNA world ->
      - Self replicating RNA
      - Lipoprotein vesicles
    - Early cellular life ->
      - RNA is coding + catalytic molecule
    - Protein coup ->
      - Protein takes over catalysis (protein better than RNA at catalysis)
    - DNA coup
      - DNA takes over coding (double stranded DNA more stable than RNA)
- How to go from prebiotic world to RNA world
  - From chemicals -> vesicle composed of lipids that contains RNA -> protocell that is simple cellular life where proteins take over catalytic + structural functions from RNA -> DNA which is more stable than RNA and takes over from RNA as hereditary material
- RNA world hypothesis cons
  - Building blocks of RNA difficult to synthesize + RNA polymers are fragile
  - How did RNA polymerases emerge?
  - There is no clear pathway from RNA World to world of proteins + RNA
  - RNA molecules are difficult to incorporate into membranes

Who Was First

- RNA world hypothesis - RNA was first
  - RNA played a role in enzymes and information molecules - RNA can replicate itself and catalyze chemical reactions
  - Evolution progressed through standard mechanism of mutations because RNA can replicate
  - Combinatorial explosion prevented by mechanism of autocatalysis
- Proteins came first hypothesis
  - Answers question of where do polymers that make up RNA come from
  - But proteins don't replicate
- Protocell is a proposed intermediate step between an envelope and a cell

The First Cells

- Cells are molecular systems of boundaries + polymers - both structures + their respective functions are required for origin of cellular life
- Self-assembly of boundary structures
  - Amphiphilic molecules assemble spontaneously into bilayer structures that form membranous components
- Directed assembly of polymers
  - Catalyzed growth + replication involving catalytic polymers + genetic polymers that contain sequence information

Who Came First Conclusion

- **Conclusion**
  - It's easy to make protocells in the laboratory, membranous vesicles that contain biopolymers such as enzymes + nucleic acids
  - Reality check: can self-assembly occur in environmental models of pre-biotic conditions?
  - Model to be tested: hydrothermal regions associated with volcanic activity
- **The origin of life was a global experiment in combinatorial chemistry**
  - One milligram of lipid, dispersed as liposomes in a milliliter of water, produces a trillion individual vesicles.
  - If multiple species of peptides and oligonucleotides having random sequences are present, each vesicle will be different from all the rest, representing a massively parallel experiment employing a trillion microscopic mixtures
  - The prebiotic Earth had more than a trillion tons of organic compounds and half a billion years to carry out natural version of combinatorial chemistry

How Did Biology Begin?

- Cells rely on
  - DNA to encode genetic information
  - RNA to carry that information around
  - Proteins made using that information to run chemical reactions they require to live
- RNA can carry out functions of DNA + proteins
  - Like DNA, RNA can store genetic information
  - Like proteins, RNA can catalyze chemical reactions
- Clues in modern cells suggest they are descended from RNA-based life
  - Almost all have ribosome, molecular factory that creates proteins from amino acids, and the part of ribosome that does the assembling is single long strand of RNA
  - Have ribozymes - enzymes made from RNA rather than from proteins
  - But if there was first an RNA world, where did RNA come from?

- Life Story, The Economist, Aug. 8, 2015

How Did Biology Begin?

- Protein world
  - Start with chemistry, see what you can build
  - Miller-Urey experiment - fill flask with water, hydrogen, ammonia, methane (early Earth atmosphere) + add energy in form of electrical sparks (lightning) => several types of amino acids
    - Out of favor as hypothesis of how life began because rate of chemical synthesis is very slow + unclear how synthesized components could come together
  - But life could have started underwater in "white smokers" with pores in their honeycomb acting as primitive cells

- Life Story, The Economist, Aug. 8, 2015

The Origins of Life

- Life requires one or more of: ability to self-replicate, ability to extract energy from environment, a boundary between inside + outside worlds
- Despite 60 years of effort, scientists have not figured out how lifeless molecules gave rising to living matter…usually by attempting to recreate molecules in "clean" way, using tightly controlled + predictable chemical reactions
- But emergence of life did not occur in clean bubble - Miller-Urey experiment left a complex brew behind + meteorites may have delivered huge array of complex organic molecules / building blocks for life to Earth

  "The origin of life was likely a period of exploration and experimentation, where life tried out a huge array of possibilities and eventually converged to one particular form...The idea is not to seek prebiotic synthesis of biomolecules that resemble extant ones, but rather to seek principles of self-organization in complex chemical systems." - Nathaniel Virgo, artificial life researcher

- The origin of life would correspond to an evolutionary transition within a complex / "messy" chemical system, going from growth of loose network to emergence of highly integrated whole

  - Johnny Bontemps, Meta Musings on the Origins of Life, Astrobiology Magazine, Nov. 29, 2016

How Life Began

- The ultimate question - how a mixture of chemicals could have coalesced into something that we would recognize as "alive" is not known either theoretically or from actual evolutionary detective work.
  - Current consensus is that there were several stages including
    - the concentrations of precursors,
    - the origin of membrane-bound vesicles that contained biomolecules,
    - the origin of RNA as both a hereditary as well as catalytic class of molecules,
    - the subsequent departure from the RNA world as proteins took on structural and catalytic functions and DNA became the genetic material of all by some viruses.
    - Indeed, vestiges of the RNA World exist in our cells even today.
- Conclusion
  - Origin of life - bottom line is we don't know
  - We think there was an RNA world first that was taken over by DNA in terms of genetic material and proteins in terms of enzymes + scaffolding

In The Beginning

- Where did life begin on Earth
  - Hydrothermal vents / ocean floor
  - Volcanic hot springs
  - Tidal pools with rising + falling of tides from then-nearby Moon
- How does ordinary chemistry get transformed into life?
- Physics + chemistry of early solar system
  - Life on Earth starts while Earth still being bombarded
  - Was first organism a thermophile that could cope with volcanoes sulphuric geysers + meteorite storms
    - Energy for this organism comes from thermal vents not sun
  - Extremophiles show life does not have to originate in sunny pond
  - Life can originate in dark of ocean depth if it has molten core with heat + energy
    - This expands the habitable zone

What Was First Life On Earth?

- **Extremophiles at high temperatures**

  - Life Beyond Earth, Timothy Ferris, 1999

Where Did Life Begin on Earth?

"But if (and Oh! What a big if!) we could conceive in some warm little pond, with all sorts of ammonia and phosphoric salts, light, heat, electricity etc., present, that a protein compound was chemically formed ready to undergo still more complex changes…"

- Charles Darwin in a letter to Joseph Hooker, 1871

When Did Life Arise on Earth?

- Earth formed 4.6 billion years ago
- In 2016 stromatolites that were 3.7 billion years old were found in rocks in Greenland
- In 2017 signatures of living organisms that were 3.8-4.3 billion years old were found in rocks in Quebec that resemble networks of bacteria that live in hydrothermal vents
  - If true, life started on Earth within a few hundred million years of its formation

\- The Living Was Easy, The Economist, Mar 4, 2017

Theories of How and Where Life Originated

- Theories of how life originated
  - Delivery of organic material from space to Earth and life evolved near surface of ocean using light as source of energy (photosynthesis)
  - Deep in ocean at hydrothermal vents high temperatures which accelerate chemical reactions using chemical source of energy (chemosynthesis)
- Where did life on earth start?
  - Drying lagoons or sandy beaches due to concentration
  - Clay minerals - clay was genetic template
  - Near hydrothermal vents
  - Aerosols in clouds or water droplets
  - Darwin's warm little pond
  - Glacial islands
  - Interstellar space

Where Did Life Originate?

- Warm pond
- Boiling, bubbling mud bath
- Scorching volcanic vent

- Dennis Overbye, It's Alive! It's Alive! Maybe Right Here on Earth, New York Times, July 27, 2011

Where Do Eukaryotes Come From?

- Prokaryotic cells ingested other prokaryotic cells creating organelles within them

Extremophiles Definition

- What is an extremophile?
  - Extremus (Latin) - on the outside
  - Philos (Greek) - love
  - Doesn't necessarily love extremes - but can tolerate extremes
- Extreme because life is based on organic carbon in aqueous solution
  - Carbon is 4th most common element in universe
  - Carbon is capable of forming vast array of compounds from methane -> DNA
  - Carbon and simple compounds with up to 13 atoms have been detected by spectroscopy in interstellar space including amino acids and nucleotide bases
    - This means interstellar space is a C chemistry
- Anything that destroys carbon is an extreme environment - so an extreme environment is one where it is difficult to keep a C based body together
  - Temperature
  - Radiation
  - Pressure
  - Dessication + salinity
  - pH
  - Oxygen tension
  - Chemical extremes
  - Vacuum

Examples of Extremes

- Temperature
  - Solubility of gases in a liquid is temperature dependent, as temperature goes up, solubility goes down
  - Enzymes have optimal temperatures
  - Various biomolecules are temperature sensitive
  - In very cold temperatures cell membranes get stiff
  - In warm temperatures cell membranes leak
- pH = concentration of H ions
  - pH of 1 has most H ions
- Salinity
  - Salt needed for electrical connectivity, proteins to function, enzymatic reactions
    - You need solutes
- Radiation
  - Radiation and biotic evolution
  - Natural selection has 2 stages
    - Generation of heritable variability
    - Selection amongst the variants
  - Radiation is unusual in that it is both a mutagen and a selective agent

Early Earth Was Extreme Environment

- Sun was less luminous but young star can produce more UV and we did not have an ozone shield so life on surface of Earth was zapped
- Impactors produced heat on Earth
- Earliest organisms on Earth likely thermophiles
  - Did life arise in hot areas or were there organisms that were survivors of bombardment period
- CO_2 levels have changed - CO_2 probably kept early Earth warm
- Surface UV flux has changed

Early Earth Was Extreme Environment

- Physical environment of earth
  - When life arose on earth sun was 70% as luminous but had similar UV radiation
  - Radiation from sun must go through atmosphere, but there is no atmosphere until cyanobacteria appear

Early Earth Was Extreme Environment

- 4.5 billion years ago
  - Sun had 70% of its current luminosity
  - Multiple impact events creating lots of heat
  - Lots of internal heat
  - Continents unstable
  - Sun got brighter, impacts decreased, continents stabilized, Earth cooled
    - We ended up with the Earth we know
  - Meteorites account for much of the carbon on Earth today

Extremophiles

- Extremophiles show that life
  - Tolerates heat or cold
  - Thrives in acidic or alkaline environments
  - Takes food from a variety of sources
  - Copes with intense or no solar radiation

Extremophile Conclusion

- Extremophilia is an n-dimensional problem
  - Extremophiles live in an n-dimensional space
  - Organisms can live in a temperature above boiling and below freezing, pH of 0, boiling battery acid
- Conclusion
  - Extremophiles are intimately connected with the fact that we are based on organic carbon in liquid water
  - The story of extremophile research is many stories that have come together in the field of astrobiology
  - The envelope for life is far beyond what we could have imagined - thus the habitats for life have been expanded
  - Some adaptations to life in extreme environments are biochemically simple or convergent, suggesting that it could happen elsewhere

Is Evolution Predictable?

- **If we take the story of evolution and reset the clock to some arbitrary time, how much of the future could be predicted?**
  - Surely the details would be quite different, but could we predict anything?
  - Is there such a thing as a law in evolution?
  - What about some of life's greatest hits, from the eukaryotic cell, to photosynthesis, multicellularity, intelligence and even us?
- **Suggestions**
  - Evolution is a tinkerer that uses what is available and is constrained by physics, chemistry, development and history
  - Evolution makes its way to localized adaptive peaks (fine tuning?)
  - But if we stand back we can see the big mountain (coarse tuning?)
  - How life gets there may be contingent (allowing for developmental + engineering constraints + history) but the selective pressures will be to get there somehow

Convergent vs. Contingent Evolution

- Convergent evolution
  - Similar forms and functions of life will evolve and converge over time in response to similar environmental pressures.
    - Wings in insects, birds, bats
    - Similar shapes of fish and dolphins
- Contingent evolution
  - Every species is the unique product of an unpredictable or chance chain of events
  - If the 'tape of life' is rerun, the evolutionary outcomes or species that will emerge each time will be quite different
  - Championed by Stephen Jay Gould

An Evolutionary Biologist's Speculation on What Intelligent Alien Would Look Like

- The creature will be the product of evolution
- The alien will be a complex confederation of differentiated cells or cell-like structures forming organs that specialize in the different tasks of keeping it alive
- Our new friend's species will likely have sex
- It will be engineered to be efficient in its environment
- It will be a social species

- Steven Peck, Five Wagers on What Intelligent Life Elsewhere in the Universe Will be Like, Analog, Mar. 2015

What would intelligent life from other worlds be like?

How may they look, what are their constraints and what are their likely features?

- **1. They would be land dwellers**

  "In order to have an advanced tool-making species, of course we require a concentrated source of energy, like fire, that can be transported from one place to the other and just used as a tool itself. And I can't think of a way that that can be accomplished on an aquatic planet or an aquatic part of a planet."

- **2. Their head is distinct, big, located up front and they have light to moderate jaws and teeth**

  "All of the major lines of terrestrial animals, big terrestrial animals, that have evolved over and over again for over 400-million years on land have heads and sensory organs concentrated in them, up front ..."

- **3. They communicate through sight and sound**

  "Human beings are highly unusual among all life on earth for being audio visual. We share that with birds and very few other kinds of animals. The vast majority, you could say almost all organisms on earth, plant and animal and micro-organisms, communicate by pheromone, by odour."

- **4. They would be moral**

  "Within groups, selfish individuals beat altruistic individuals. Between group competition groups of altruists eat groups of selfish individuals."

- **5. They won't colonize earth**

  "Never...because it would be a biological train wreck. You know H.G. Wells had it right. You recall that his aliens had no problem taking over Earth but then they fell to the bacteria."

  "The biological systems, possibly right down to the details of the genetic code would be so different in the alien that the incompatibility that they would have microbe for microbe, insect-like creature for insect-like creature, they would probably have to bring some of their supporting fauna and flora with them."

  - Brent Bambury, Edward O. Wilson On What Aliens Will Look Like and Why, CBC, Oc. 23, 2014

What would intelligent life from other worlds be like?
According to E.O. Wilson

- SF writers base intelligent aliens on assumption that process of evolution on planet produces an intelligent life form that because of intelligence proceeds to develop a complex technological civilization
- E.O. Wilson says random walk of evolutionary development + varying conditions of environment generate a species that by chance develops cooperative social structure + then if conditions are right the cooperative social structure pushes development of intelligence
  - Such cooperative social structures are very rare among animal species
  - 400 million years of evolution on Earth have produced 20, most are insects

- John Cramer, The Specifications of Extraterrestrial Intelligence, Analog, May 2015

What would intelligent life from other worlds be like?
According to E.O. Wilson

- Characteristics of intelligent alien that could develop on Earth-like planet of another star
  - Will be land dwellers, not aquatic - require use of fire
  - Will be relatively large animals - small body size means smaller brains
  - Will be biologically audio-visual - most animals rely on smell + pheromes but pheromes are unsuitable for rapid communication + are road block on path to high intelligence
  - Will have large distinct head up front - for quick scanning + action
  - Will have light to moderate jaws + teeth - only broad high energy meat + vegetable diet could sustain large populations needed for later stages in development of intelligence
  - Will have a high social intelligence - functioning in a fast-moving + complex social network requires great deal of social intelligence
  - Will have small number of free locomotory appendages, levered for maximum strength with stiff internal or external skeletons composed of hinged segments + with at least one pair that are terminated by digits with pulpy tips used for sensitive touch + grasping - needed for tool manipulation
  - Will be moral - cooperation in all highly social species based on some degree of altruism + self-sacrifice
  - Intelligent aliens skilled in genetic engineering will not use genetic modification to change their social nature

- John Cramer, The Specifications of Extraterrestrial Intelligence, Analog, May 2015

What would intelligent life from other worlds be like?
According to E.O. Wilson

- Has serious reservations about human settlement of planets of other star systems

  "Any planetary ecology is a vast array of interacting viral, bacterial, plant, and animal life that, after many eons of natural selection and responses to random events, challenges, and catastrophes, has arrived at a stable system. The ecology of an alien world would necessarily be qualitatively different from that of Earth and would be wholly incompatible with our own ecology. The two worlds would necessarily have radically different origins, different molecular machinery, and would differ in fundamental ways, due to the endless paths of evolution that produced the inhabiting life forms."

  - Vast majority of Earth's organisms are unsuitable for human consumption, organisms of alien planets would be even more so
  - Problem of transporting Earth's ecosystem to another planet has no solution + we must resign ourselves to living on planet we currently occupy

  - John Cramer, The Specifications of Extraterrestrial Intelligence, Analog, May 2015

Case Study Summary - Mission

- Goal
- Center of Gravity (Strategy)
- Equipment
- Training
- Leadership
- Morale
- Tactics
- Intangibles
- Mistakes
- Outcome

Computing Case Study Summary - Spore

- Goal
  - Create astrobiology sim / game to explain astrobiology to the masses + interest them in science
- Center of Gravity (Strategy)
  - Massively single player online game - play by yourself + share results on social media
  - Evolve from a single cell organism to conquer the galaxy
- Technology / Equipment
  - Procedural development of content
- Training / Leadership
  - Will Wright, creator of SimCity/Life/Earth/Farm/Ant + The Sims
- Morale
  - Very high - expected to be next big franchise for Electronic Arts (EA)
- Tactics
  - Go through 5 stages / games - Cell, Creature, Tribal, Civilization, Space
- Intangibles / Mistakes
  - Did not stay true to original goal of making a highly regarded Maxis simulator
  - Instead dumbed it down to a game to aim it at casual players to increase sales + thus made an EA game like The Sims ~ Evolution is all wrong
- Outcome
  - By end of development science was almost gone from the game + game stages were not very fun
  - Epic failure in sales ~ Will Wright has not developed a game since

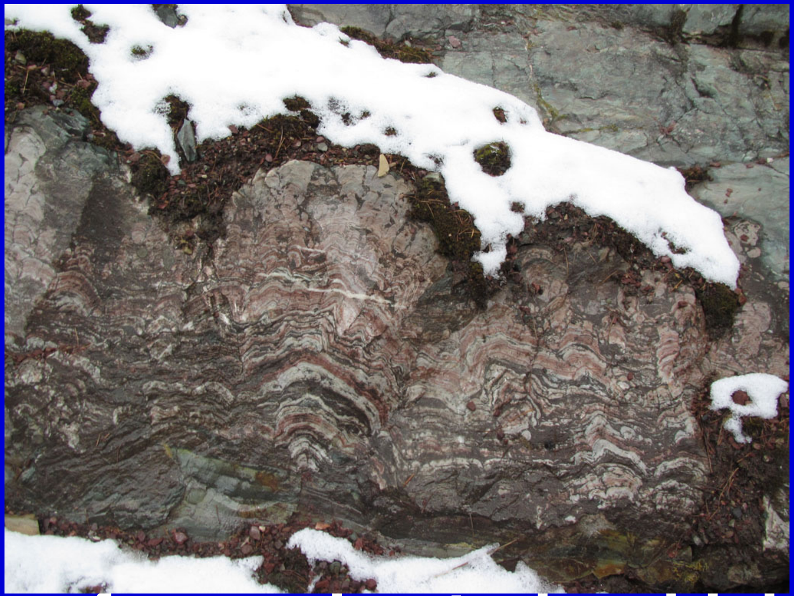
\- Steven Johnson, The Long Zoom, New York Times Magazine, Oct. 8, 2006

\- John Seabrook, Game Master, New Yorker, Nov. 6, 2006

Personal Case Study - Extremophiles

- Location
  - Yellowstone National Park
- Story
  - Extremophiles
  - Participated in Junior Ranger Extremophile Research Program

Astrobiology Analog Case Study - Stromatolites



- Location
  - Glacier National Park
- Story
  - Oldest fossils in world, 3.5 Ga
  - Grow in shallow water
  - Composed of layers of colonies of cyanobacteria which conducted photosynthesis which released oxygen as waste product that oxidized iron in the ocean and built up O2 in atmosphere to its current level of 21%
  - Without cyanobacteria there would be no oxygen and plants, animals, and humans would have never evolved

- Origins, PBS Nova, Sept. 28+29, 2004

Drake Equation

$$N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

- N = The number of communicative civilizations
- R* = The rate of formation of suitable stars (stars such as our Sun)
- fp = The fraction of those stars with planets. (Current evidence indicates that planetary systems may be common for stars like the Sun.)
- ne = The number of Earth-like worlds per planetary system
- fl = The fraction of those Earth-like planets where life actually develops
- fi = The fraction of life sites where intelligence develops
- fc = The fraction of communicative planets (those on which electromagnetic communications technology develops)
- L = The "lifetime" of communicating civilizations

Class Simulation

- Topic aspects

Poem

Slide text

Questions for Further Discussion

- What is the definition of life?
- Did life emerge by chance or necessity?
- What is needed for life to emerge?
- What is the astrochemistry of the universe?
- How does astrochemistry become astrobiology?
- How did first simple cells form?
- How could a mixture of chemicals coalesce into something that we would recognize as alive?
  - What is self-assembly? How do membranes assemble into compartments that capture large molecules? What conditions would be conducive to self-assemble on the early Earth? Can such conditions drive synthetic chemistry leading to biopolymers such as RNA?
- Where did the water come from + where did the organic C come from?
- How does life begin?
- Where does life begin?
- What is the significance of extremophiles to the development of life?
- What is the timeline for the evolution of intelligent life?
- Is evolution predictable based on the physical or biological environment or is it contingent - that is a product of quirks of history?
  - How do we go from Big Bang to life?
  - How does life evolve?
  - What is role of environment?
  - What are results of evolution?
  - Where is life found beyond Earth? (Rare Earth hypothesis…)
- How important is evolution to the history of life?
- Astrobiology is evolutionary biology writ large - True or False?
- What would alien life look like?

Reading Assignments

- **Astrobiology Primer 2.0 (2016) Chapters 2 + 4 + 5**
  - **https://doi.org/10.1089/ast.2015.1460**
- **TED Talks for this Topic**
  - **http://www.astrobiologysurvey.org/ToLearnMore.html**

Recommended Reading to Learn More

- Non-fiction
- Fiction
- Movies
- Simulations

Conclusion

Neil deGrasse Tyson: You cannot ask what something is if you only have one example of it...

You cannot characterize life if, as much as biologists celebrate what they call biodiversity at the end of the day all life has common DNA and common origin, you are dealing with a sample of one....

And when you have a sample of one you don't really have a science do you?

How do you define what life is if you only have one example of it?

Neil deGrasse Tyson: Normally when you have a field of science, there is a data set that people appeal to to conduct their research and last I checked you have no data. There is no life somewhere other than Earth.

David Grinspoon: You could say that. We've been accused of being a science without a subject.

Neil deGrasse Tyson I'm saying you are a science without data.

David Grinspoon: Our data is the history of life on Earth and the requirements of life on Earth and what we know about the environments on other planets and trying to map that in and trying to understand the possibilities for life in those environments.

Neil deGrasse Tyson: So Earth is your proxy for now?

David Grinspoon: It has to be.

Neil deGrasse Tyson: And the moment you get a microbe you are good to go?

David Grinspoon: That can considerably increase the legitimacy of our field once we have some other examples.

- StarTalk Radio, February 10, 2013

Conclusion

"Astrobiology is evolutionary biology writ large"

- Lynn Rothschild, astrobiologist

Conclusion

"It's not the strongest of the species that survives, not the most intelligent, but the one most responsive to change"

- Charles Darwin

Topic 5

Life in our Solar System

Song

Fly me to the moon
Let me play among the stars
Let me see what spring is like
On a-Jupiter and Mars
In other words, hold my hand
In other words, baby, kiss me

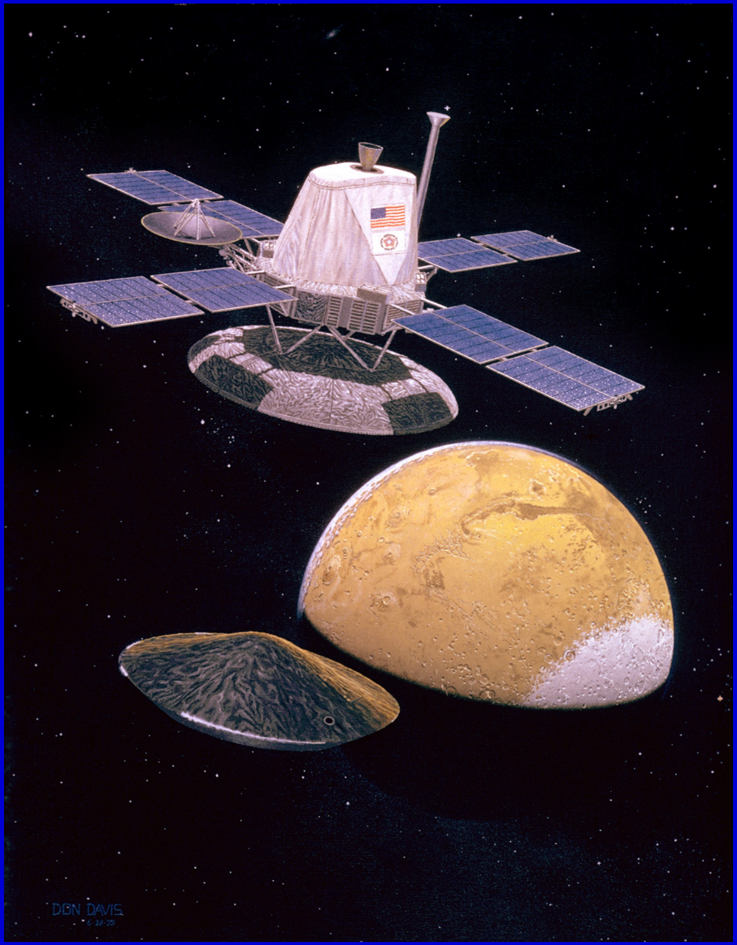
Fill my heart with song
And let me sing for ever more
You are all I long for
All I worship and adore
In other words, please be true
In other words, I love you
- Frank Sinatra, Fly Me To The Moon (In Other Words)

Thematic Quote

"Somewhere, something incredible is waiting to be known"

- Carl Sagan, planetary scientist

The Painting



Viking Orbiter Releases Viking Lander

- Don Davis

(NASA Headquarters)

Artifact

- Name
  - Scale model of the solar system
- Year
  - 2012
- Story
  - Gives a sense of scale from the Sun to the Oort Cloud

The Question

What would it mean if we found life anywhere in our solar system, and if the life was similar to life on Earth and had DNA / RNA / proteins?

What if life found in our solar system was very different from Earth life?

Why Search For Evidence of Life in the Solar System?

- The possibility of a second genesis of life
  - Looking for an alternative type of life
  - If there is alien life in the solar system
    - Would allow us to do comparative biochemistry
  - If life started twice in our solar system it must be common in universe

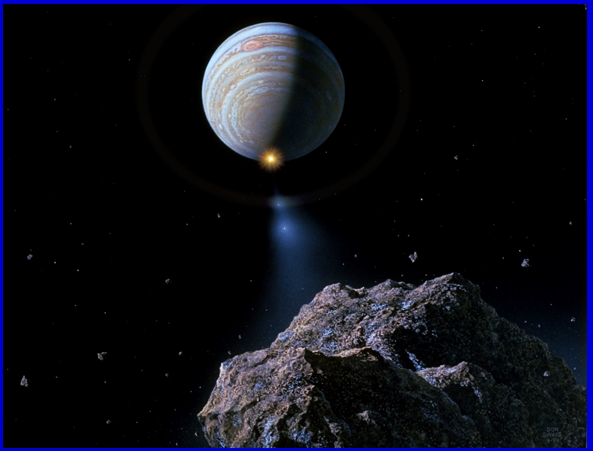
How Do We Look For Life 101

- In our solar system
  - Image planets and moons
    - From Earth + space + flybys + in orbit
  - Study chemical signatures of planets and moons atmospheres
    - From Earth + space + flybys + in orbit
  - Place sensors on planets and moons
    - Venera, Viking, MER, MSL, Galileo, Huygens
- Outside our solar system
  - Detect extrasolar planets and moons
    - From Earth + space
  - Study chemical signatures (biosignatures) of extrasolar planets and moons atmospheres
    - From Earth + space
  - Use sensors to conduct SETI to look for technological artifacts (technosignatures) of civilizations
    - From Earth + space

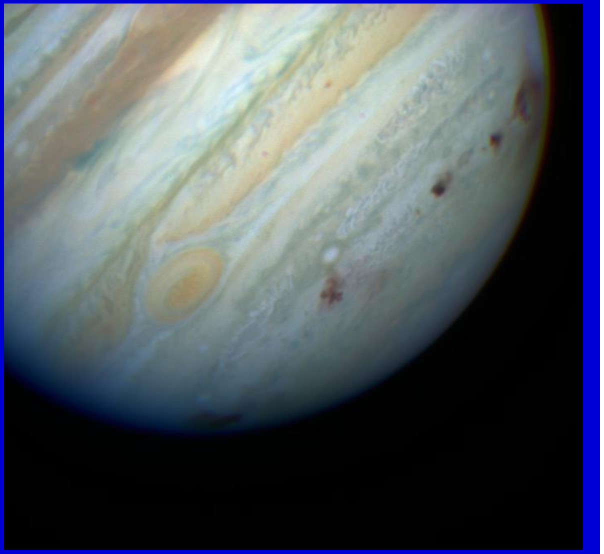
Our Solar System Architecture - Jupiter As Goalkeeper

- Rocky planets, gas giants, ice giants
  - In neat, round orbits
- Presence and position of Jupiter provides particular shelter for Earth
  - Jupiter's enormous gravity protects Earth, gravitationally vacuuming up or throwing off course asteroids + comets, making Earth a more peaceful place than it would otherwise be and therefore allowing evolution to occur on it with fewer interruptions
  - Without Jupiter, these objects would frequently smash into Earth + destroy life as we know it
    - Without Jupiter, impact rate on Earth would be 10,000 times higher than it is
  - Example: Comet Shoemaker-Levy 9 impacting Jupiter in July 1994
    - Previous encounter with Jupiter broke it into chunks
    - In 1994, each chunk slammed into Jupiter at 20,000 km per hour with equivalent energy of Chicxulub impact

- Life Beyond Earth, Timothy Ferris, 1999
- Origins, PBS Nova, Sept. 28+29, 2004
- Neil deGrasse Tyson, Space Chronicles, 2012



From Don Davis / NASA



From NASA

Habitable Zone = Goldilocks Zone

- Definition
  - Where conditions may support life in a solar system
  - Where it is neither too hot nor too cold for liquid water and thus life to exist
- Presumes liquid water is prerequisite for life
- Initially defined to be liquid water heated by sun's energy
  - If planet orbits too close to star, temperature is too high and water vaporizes
  - If planet orbits too far from star, temperature is too cold and water freezes
  - Therefore thought to be limited to between orbits of Venus to Mars where solar energy could drive chemistry of life and water could be in liquid state
- Definition now expanding due to
  - Realization that strong gravitational pull caused by large planets heats cores of their moons allowing for liquid water to exist much farther from the Sun than Mars = gravitational habitable zone
  - Extremophiles allows us to expand our boundaries for the search of life beyond Earth

Expanding the Habitable Zone

- Traditional habitable zone = narrow habitable zone as it describes conditions necessary for life to exist at surface of planet
- The habitat for microbes beneath surface of Earth extends down several kilometers = deep biosphere
- Definition of habitable zone must be widened to describe conditions necessary for life to exist at surface of planet / moon and in its deep biosphere where liquid water can exist due to internal heating
  - For an Earth-like planet orbiting a Sun-like star
    - If you assume liquid water + life can survive 5 km below surface your habitable zone is 3 times wider
    - If you assume liquid water + life can survive 10 km below surface your habitable zone is 14 times wider
- So life may occur much more commonly deep within planets + moons rather than on their surfaces

- Jonathan Ball, More Planets Could Harbour Life, BBC News, Sept 10, 2012
- Adam Withnall, Life Could Exist Much Further From the Sun Than Previously Thought, Scientists Say, The Independent, Jan. 7, 2014

- **Evidence of habitability is not evidence of habitation…**

Shrinking the Habitable Zone

- The likelihood of a habitable zone planet being able to support complex life - life beyond a microbe - is limited due to presence of toxic chemicals such as carbon monoxide or excesses of carbon dioxide
  - Perhaps only 10-20% of habitable zone planets could support complex ecosystems that would be suitable to support complex life

- Marc Kaufman, Exoplanets With Complex Life May be Very rare, Even in Their "Habitable Zones, Many Worlds, June 14, 2019

Why is Life Beyond Earth Difficult?

- Space is a vacuum
- Temperature extremes - hot + cold
- Altered gravity
- Different radiation regime (solar+cosmic) - we're moving past our magnetosphere
- Difference in atmospheric composition
- Nutrient sources (organic C, N)
- Radiation is nasty in space
  - Ozone layer protects us from UV
  - Outside magnetosphere you are subjected to cosmic radiation, solar particle events, solar flares, solar wind, etc
  - All can cause damage to DNA and other molecules

Space Weather

- Earth constantly bathed by low-energy particles from solar wind
- More energetic particles in flares / coronal mass ejections leave sun in narrow directions that sometimes are aimed at Earth, drenching us in deluge of radiation
- Space weather = how solar wind + more explosive events from Sun affect Earth + solar system
- Earth shielded from particulate + electromagnetic radiation by
  - Magnetosphere that deflects charged solar particles away from Earth and by
  - Van Allen belts that trap some particles
  - O, N, water vapor in atmosphere protect us against solar radiation
  - Water vapor absorbs much infrared light
  - Ozone layer prevents UV light from reaching us
  - Atmosphere also opaque to X-rays + gamma rays
- Increased number of high-energy particles associated with solar flares / coronal mass ejections cause Earth's magnetic field to fluctuate (= geomagnetic storm) thus inducing damaging electrical currents in power grids

- H.G. Stratmann, Space Weather: The Latest Forecast, Analog, May 2012, pp. 35-46

The Carrington Event

- Summer 1859 British astronomer Richard Carrington observed white-light flare on Sun, an extremely violent eruption of hot-plasma from Sun
  - Earth's magnetic field affected within minutes
  - 17.5 hours later Earth's magnetic field convulsed for hours with Northern Lights seen as far south as Cuba + Honolulu
  - Telegraph operators saw sparks leap from their equipment, melt wires, start fires
- Geomagnetic storm
  - Sunspots mark locations of strong turbulence on Sun + flares mark strongest outbursts of energy - if flares are aligned in right direction they can send their power in Earth's direction
  - Energy comes in two forms
    - First is electromagnetic - visible light, X-rays, UV light that hit almost instantaneously with first sighting of flare and which ionize gas molecules temporarily altering our magnetosphere
    - Second is coronal mass ejection where ionized gas, containing most of storm's energy causes brilliant auroras + magnetic surges so strong that any long metal object on Earth acts as giant antenna picking up energy from space
- How big was Carrington Event?
  - March 13, 1989 geomagnetic storm produced auroras down to tropics + sent electrical surges through Canada's Hydro-Quebec power grid knocking out power relays leaving 9 million Canadians without power for 1 night
  - Carrington Event was 3 times more powerful
- 3 categories of solar storms
  - Radio-blackout
    - Short lived nuisance, affects AM radio, SW radio, satellite communications, GPS
  - Radiation
    - Earth is shielded, affects astronauts outside of radiation shelters + poorly shielded satellites
  - Geomagnetic
    - Electrical power surges can blow out giant transformers which are so interconnected that hundreds could be destroyed cutting power to millions of people leaving infrastructure in tatters with power out for week / month / year + cost $1-2 trillion

- Richard Lovett, The Day The Sun Exploded, Analog, Nov. 2012 pp. 21-27.

Space Weather

- Sun is producing a constant number of solar storms but consequences of storms are more significant as society becomes increasingly dependent on technologies (satellites, electrical grid) that can be disrupted by major storm
- Space weather warning satellites are old + not dedicated to task
- We have little planning on how to respond to space weather event
- Odds of Carrington-level event are 6-12% in next decade
- Accurate prediction of solar storms - of an hour or a day - could help power operators take steps to reduce chances + severity of electrical blackouts

- Jeff Foust, Storm Preparations, The Space Review, Jan. 7, 2013

3 Major External Radiation Threats to Earth

- Supernovae
  - Large release of energy from star collapsing at end of its fuel-burning lifetime
  - Produce high-energy cosmic rays which would be direct threat to life
  - Every few hundred million years Earth is likely to be within 30 light years needed for extinction-level event
- Solar proton events = Geomagnetic storms
  - Carrington-level event from our Sun would damage infrastructure (electrical power, transformers, satellites) crippling world economy for months at best…could this be extinction-level event for humans?
- Gamma-ray bursts
  - Beamed gamma-ray energy of about 10E45 Joules, few per day pointed at us in Universe, one per few hundred thousand years in Milky Way galaxy, one per millions of years in Milky Way galaxy pointed at us
  - Energy release is mass of Sun converted to energy in few seconds - long bursts from collapse of very large rapidly spinning stars to black holes when they run out of fuel - short bursts from merger of pairs of neutron stars
  - End result would be depletion of Earth's ozone layer and increase of ultraviolet-B light at sea level which could crash food chains
  - Can gamma-ray burst be implicated in mass extinction events on Earth? It is possible

- Adrian Melott, The Earth Dies Screaming: Radiation Threats From Beyond, Analog, March 2012, pp. 25-31

Gamma Ray Bursts (GRBs)

- Most energetic phenomena in universe - emits as much energy in few seconds as star will in its entire life
- Caused by hypernova (sudden collapse of massive star to form black hole) or collision between two neutron stars which are ultra-dense remnants of supernovas (slightly less massive collapsed stars)
- GRB within 10,000 light years of Earth would wreck its biosphere - blast of radiation would instantly kill most living organisms on or near surface both on the surface facing blast and via secondary showers of charged particles and re-emitted gamma rays on side facing away from blast and the GRB would destroy > 90% of Earth's ozone layer for several years letting in intense UV light
- Model suggests Earth has been hit by at least one GRB in last 4.6 billion years.
- Photosynthesis starts 2.3 billion years ago and ozone begins to form after that so any GRB after that would cause mass extinction
- Any extinction that happened before 540 million years ago when animals with shells appeared + fossils became common would be invisible in geological record
- Since then there have been 5 mass extinctions, model suggest 50% chance Earth has been struck by GRB in last 500 million years
- Farther a solar system is to the center of its galaxy, less likely it is to be hit by GRB - our Sun is 24,000 light years from center of Milky Way
- The more metal-rich a galaxy is, the less likely it is to have a GRB - Milky Way is metal rich
- Now only 10% of universe's galaxies host sufficiently few GRBs to give evolution of complex life a fair chance
- The older the universe gets the friendlier it becomes to life
- Before 5 billion years ago GRBs were so frequent life would have struggled to find foothold in universe

- Bolts From the Blue, The Economist, Oct 18, 2014

Gamma Ray Bursts (GRBs)

- In 1973 VELA satellites, designed to detect nuclear weapons tests, detected once per day bursts of gamma radiation that were time-triangulated as originating outside Solar System + coming from all directions
- In 2004 Swift satellite determined GRB sources were extra-galactic in origin + billions of light years away and were huge amounts of energy
- Two GRB production mechanisms
  - Short GRB (< 2 seconds) - originate in merger of compact objects like neutron stars + black holes
  - Long GRB (> 2 seconds) - originate when rapidly rotating high-mass star has core-collapse to black hole in hyper-supernova event
    - Occur four times as often as short GRB + liberate up to an order of magnitude more energy
    - Have largest potential impact on life in Universe
    - Probability of long GRB event is larger when metalicity of galaxy from which it originates is low
- Metalicity provides indication of time after Big Bang at which star was formed, with low metalicity earlier + high metalicity later
  - We live in a high metalicity galaxy

- John Cramer, Galactic Death Stars and Extinction Events, Analog, Jul./Aug. 2015

Gamma Ray Bursts (GRBs)

- When GRB occurs close to life-bearing planet, gamma rays form NO in stratosphere which depletes protective ozone layer for months, thus exposing planetary surface to bombardment by UVB sunlight, intense UVB irradiating surface of ocean destroys surface marine life including plankton thus depriving all other marine life of their main nutrient, results in massive extinction event for marine life on planet + probably also for plants / animals on land
- Probability of having > 1 GRB / billion years is 95% if star is 2,000 parsecs from galactic center, 50% if star is 10,000 parsecs from galactic center (that's us)
- 5 major extinction events during evolution of life on Earth, at least 1 of these likely due to lethal GRB from within Milky Way
- For GRBs > 50,000 parsecs away, there is no danger from gamma radiation, so we don't have to worry about other members of our Local Group of galaxies
- Thus, although most stars in Milky Way are closer to galactic center than our Sun, there is low probability of finding Earth-like life there due to higher frequency of extinction events, thus Earth is in a preferred location in Milky Way galaxy
- Friendly neighborhood for life is where galaxies formed late, are large + diffuse, and have high metalicity - thus life in Universe may have become possible only in past few billion years

- John Cramer, Galactic Death Stars and Extinction Events, Analog, Jul./Aug. 2015

What Do You Need For Life

- Organic compounds
- Solvent (Liquid water)
- Energy

    - Origins, PBS Nova, Sept. 28+29, 2004

Search For Life in Solar System

- Looking for 3 ingredients
  - Life's basic chemical building blocks, made from simple elements found in cloud of gas + dust that gave birth to planets + moons
    - Organic molecules (molecules that contain C the basis of life)
    - Come from molecular clouds outside the solar system
      - Molecular clouds have ice that facilitates organic compound formation
    - Delivered by comets + asteroids billions of years ago
  - Liquid (solvent) like water that allows chemical building blocks to mix + interact
    - Come from molecular clouds outside the solar system
    - Delivered by comets + asteroids billions of years ago
  - Energy source like sun to power chemical reactions that make life possible
    - Energy can also come from volcanoes on geologically active planets which pump water vapor + organics into atmosphere which links geological activity below surface to life above surface
- These three things are found throughout the universe

- Finding Life Beyond Earth, PBS Nova, Oct. 19, 2011

Where Can Life Be In Our Solar System?

- Water and organics come in our solar system from
  - Poles of Mercury have ice
  - Poles of Moon have ice
  - Mars has ice
  - Jupiter and Saturn have organics
  - Jupiter's + Saturn's moons have ice
  - Comets have water and organics
- Water and organics come from outside solar system in molecular clouds
  - Molecular clouds have ice that facilitates organic compound formation

Where Is There Water In Our Solar System?

- Mercury
  - Poles have ice
- Venus
  - May have had water in the past
- Earth
  - Poles of our moon have ice
- Mars
  - From orbit - ancient dry rivers + canyons
  - From surface - sedimentary rocks
  - There was water there in the past, we might find fossilized life
  - Poles have ice
- Jupiter / Europa
  - Cracked ice on top of ocean with 3 times the water that is on Earth
- Saturn / Enceladus
  - Has cryovolcanoes
- Saturn / Titan
  - Oceans of liquid ethane

- The only two bodies in our solar system with liquid on the surface are Earth and Titan

Where Are There Oceans in Our Solar System?

- On Earth
- At Jupiter
  - Europa, Callisto, Ganymede
- At Saturn
  - Enceladus, Titan
- At Neptune
  - Triton
- On Pluto?

Which Planets Are Likely Places For Life?

- Mars, Jupiter / Europa, Saturn / Enceladus, Saturn / Titan

Mercury

- Water
  - Poles have ice
- Atmosphere
- Temperature
  - 425° C on side facing Sun, -143° C on side opposite Sun
- Magnetic fields
- Geologic activity
- Life
  - Ultimate desert world - too hot and too dry for life
  - Life seems unlikely

- Finding Life Beyond Earth, PBS Nova, Oct. 19, 2011

Water Ice on Mercury

- Mercury seems to be unlikely place to find ice given proximity to sun
- Mercury's rotational axis is tilted less than 1 degree so there are pockets at poles that never see sunlight
- Thus there is abundant water ice + other frozen volatile materials in its permanently shadowed polar craters

- New Evidence For Water Ice on Mercury, Astrobiology Magazine, December 2, 2012

Venus

- Water
  - Once flowed on surface, currently surface is dry
- Atmosphere
  - Almost entirely CO_2 with clouds of concentrated sulfuric acid
  - Atmospheric pressure at surface 90 times greater than Earth
  - No oxygen
  - Victim of runaway greenhouse effect due to excess CO_2 trapping solar heat under blanket of its atmosphere
- Temperature
  - 477° C - hottest in solar system due to greenhouse effect - hot enough to melt lead
- Magnetic fields
  - None because although it has metal core, it rotates so slowly (243 Earth days to make 1 rotation) it can't generate a magnetic field
- Geologic activity
  - Thousands of ancient volcanoes
  - 500 million years ago turns itself inside out, resurfacing entire planet, flooding planet with greenhouse gases
  - Volcanically active, has few craters
  - There are tectonics but no plate tectonics - so chemically lively surface

- Life Beyond Earth, Timothy Ferris, 1999
- Finding Life Beyond Earth, PBS Nova, Oct. 19, 2011

Venus

- Life
  - Too hot for life on surface now due to greenhouse effect
  - Early Venus had similar water content to early Earth but they diverged due to runaway greenhouse effect
  - So could there be life on Venus that started in an ocean (or on Mars or Earth) and then adapted to life in clouds as oceans disappeared?
  - Clouds at 31 miles high, have water droplets, temperature of 158° C - may use S as UV shield
  - Could extremophiles be in biozone in clouds?
  - Can you have a complete life cycle in a cloud? - not proven on Earth
- Miscellaneous
  - Roughly same size as Earth
  - 30% closer to Sun
  - Soviet Venera spacecraft landers in 1970's lasted 1 hour
  - So it is Earth's twin that went bad - are there lessons for us?

- Life Beyond Earth, Timothy Ferris, 1999

- Finding Life Beyond Earth, PBS Nova, Oct. 19, 2011

Earth

- Water
- Atmosphere
- Temperature
- Magnetic fields
- Geologic activity
- Life
- Miscellaneous

Earth

- What makes life possible
  - All life composed of organic molecules consisting of C, in compounds including N H O
    - Organic molecules are basic building blocks of every living organism
  - Life needs liquid, like water, in which organic molecules can mix, interact, become more complex
  - Energy source, like sun, to power chemical reactions that drive life

    - Finding Life Beyond Earth, PBS Nova, Oct. 19, 2011

Earth / Aerobiology

- How high can life exist above Earth's surface?

Earth / Aerobioloy

- Troposphere
  - From surface to 7 km at poles to 17 km at equator
  - Contains 80% of atmospheric mass (50% in first 5.6 km)
  - Temperature decreases with altitude - We have air masses - heat + rises - it cools + falls - vertical mixing
  - Viable microbes isolated (Bacteria, Archaea, Eukarya) - Are these transient organisms or can they live there?
- Stratosphere
  - From Troposphere to 50 km
  - Temperature increases with altitude but pressure = 0.001 of sea level
  - Contains ozone layer
  - Viable microbes isolated (mostly spores + fungi) - Are these transient organisms or can they live there?
- Mesosphere
  - From top of stratosphere to 90 km
  - Temperature decreases with increasing altitude (-100 C)
  - Highest altitude from which viable microbes isolated (78 km) - spores + fungi (this is the highest we've been able to sample)
- Thermosphere
  - From 90 km to 600 km
  - Temperature increases with altitude ~ 1,500 C - Due to absorption of solar radiation, but would seem cold due to low density of molecules to transfer heat
  - It is within thermosphere that UV radiation causes some elements to ionize + create ionosphere
  - Not been sampled for microbes but microbes exposed + survived
- Exosphere
  - Uppermost layer of atmosphere
  - Upward traveling object can escape to space if greater than escape velocity (11.2 km/sec)
  - Contains mainly H, He, CO2, O - Not sampled for microbes

Vesta

- Vesta completely melted in past forming layered body with iron core
- Vesta has survived two colossal impacts in last 2 billion years
- Vesta is survivor from earliest days of solar system + resembles small planet more closely than a typical asteroid

- NASA's Dawn Spacecraft Prepares for Trek to Ceres, Astrobiology Magazine, Sept. 2, 2012

Vesta / Ceres

- Process of planetary formation by agglomeration disrupted by Jupiter's gravity resulting in asteroids
- Vesta
  - Big enough to be differentiated - core overlaid by rocky mantle, surface covered with ancient lava, dry as bone
- Ceres
  - Dwarf planet in asteroid belt
  - 1% mass of Earth's Moon - is spherical
  - Big enough to be differentiated - core overlaid by icy mantle, may be 25% water
  - Why is it so different from Vesta? Could it be a Kuiper Belt Object that moved to asteroid belt?

- Harvest Festival, The Economist, Feb. 28, 2015

Mars Is…

- Mars is alive - Percival Lowell in 1894
- Mars is dead - Mariner 4 in 1965
- Mars was alive - Spirit + Opportunity in 2000's
- Mars is alive - ?

- Kenneth Chang, On Mars Rover, Tools to Plumb a Methane Mystery, New York Times, Nov. 22, 2011

Mars Is…

- 1877 - 1888 Giovanni Schiaparelli - Canali (channels) - Mars is alive
- 1894 Percival Lowell - Canals - signs of dying advanced civilization using them to redistribute water from poles - Mars is alive
- 1898 HG Wells - War of the Worlds - Mars is alive and they want to conquer us
- 1965 Mariner 4 - First Mars flyby shows Mars is heavily cratered + utterly desolate - Mars is dead
- 1971 Mariner 9 - First Mars orbiter shows Mons Olympus, Valles Marineris, dry river channels - Mars is fascinating (but still dead)
- 1976 Viking 1+2 - First Mars landers find no trace of life detected (controversial) - Mars is dead
- 1996 ALH-84001 - Microfossils on Martian meteorite (controversial) - Mars is alive
- 1997 Mars Pathfinder + Sojourner Rover - First Mars rover
- 1997 Mars Global Surveyor - First high resolution images of Mars shows Martian history more complex than previously thought with evidence of sustained flowing liquid - Mars is alive
- 2004 Mars Exploration Rovers Spirit and Opportunity - Evidence of standing water - Mars is alive (Warm wet Mars)
- 2012 Mars Science Laboratory Curiosity - ?

- Andrew Chaikin, A Passion For Mars

Mars

- Water
  - Was home to abundant supply of surface water 3.5 billion years ago, lasted brief time
  - Lots of frozen water
- Atmosphere
  - 100 times thinner than Earth
  - Has water vapor and CO_2 but no O_2
- Temperature
  - Very cold
- Magnetic fields
  - Weak
- Geologic activity
  - Has volcanoes but is geologically dead
  - Earth's molten core drives plate tectonics so you get multiple volcanoes as they pass over one hot spot - think Hawaii
  - But Mars does not have plate tectonics and you get one very high volcano (Olympic Mons) over a hot spot
    - Life Beyond Earth, Timothy Ferris, 1999

Mars

- Life
  - Was home to abundant supply of water 3.5 billion years ago that lasted for brief time, then atmosphere thinned out, ozone layer collapsed, surface exposed to sterilizing UV radiation, rivers + streams evaporated or froze into ground
    - Did life start before this?
  - Has frozen water and water in atmosphere but no organics
    - Extant life vs. extinct life
- Miscellaneous
  - Smaller than Earth
  - 1.5 times distance to Sun
  - Radiation 43% that of Earth
  - Lack of atmosphere + magnetic field so planet is not as protected from radiation as Earth is

  \- Life Beyond Earth, Timothy Ferris, 1999

What Went Wrong With Mars?

- Problem with Mars is that it is too small - it is 1/10th the mass of Earth
  - As a result of being too small it does not have plate tectonics which would recycle its atmosphere
  - It has less gravity which means it is harder to hold an atmosphere
  - It has no magnetic field to protect it from solar wind
- All these factors caused it to lose its atmosphere which is 100 times thinner than the Earth's
- When atmosphere thinned out, ozone layer collapsed, surface exposed to sterilizing solar UV radiation, abundant supply of water 3.5 billion years ago in rivers + streams evaporated or froze into ground

Viking Life Detection Experiment On Mars - Con

- Viking lander
  - Assume life is based on organic carbon
  - Experiments
  - 1. Pyrolytic Release Experiment
    - Looks for carbon fixation - turn inorganic carbon into organic carbon - it was negative
  - 2. Labeled release - looking for heterotrophs - looking for release of radioactive carbon
    - No carbon fixation detected
    - No metabolism of organic compounds detected
    - No production or uptake of gases
    - Gas chromatograph / mass spectrometers
      - No organic carbon detected
      - We know this material is always raining down so it is being destroyed
- Official NASA conclusion - no clear evidence of life found

Viking Life Detection Experiment on Mars - Pro

- Gilbert Levin believes his experiment on Vikings 35 years ago, designed to detect life, did indeed detect life
  - Drops of nutrient solution containing radioactive carbon-14 were added to Martian soil
  - Stream of radioactive carbon dioxide was detected rising out of the soil
    - That is what would be expected from micro-organisms eating the food.
  - To rule out the possibility that a nonbiological chemical process was generating the carbon dioxide, other samples were heated to 320 degrees Fahrenheit to sterilize them
    - No radioactive carbon dioxide was seen rising from those when the nutrient drops were added, fitting with the hypothesis that the heat had killed the Martian microbes
    - If a nonbiological process were at play, the radioactive carbon dioxide should have been seen after the sterilization as well
- But other Viking experiments had failed to measure any organic molecules, so Dr. Levin's results - even though they matched exactly what would be expected for life - were like announcing the discovery of a brick house in the absence of bricks
  - Consensus was that the claim was mistaken
- Recent discovery offers a possible explanation for how Dr. Levin could be right after all
  - In 2008, NASA's Phoenix lander found chemicals known as percholorates in the Martian soil
  - Viking's organic molecule detector heated the soil to release organics
    - But heating organic molecules in the presence of perchlorates destroys them, so even if they were there, Viking's experiment may have missed them

- Kenneth Chang, On Mars Rover, Tools to Plumb a Methane Mystery, New York Times, Nov 22, 2011

Viking's Search For Life On Mars

- Labeled release experiment
  - Mixed Martian soil with nutrient containing radioactive carbon
  - Hypothesis: If bacteria present in soil, and it digested nutrient, would emit some of digested molecules as CO_2 containing radioactive carbon
  - Hypothesis proven - CO_2 containing radioactive carbon was released from soil
- Gas Chromatograph Mass Spectrometer (GCMS) experiment
  - Looking for organic carbon, found none
- NASA said life can't exist without organic carbon, declared this trumped results of Labeled release experiment
- But what if GCMS experiment was not sensitive enough to detect organics?
- If Curiosity detects organic carbon today, will that validate the Labeled release experiment?

- Michael Brooks, Curiosity May Prove We've Already Found Life on Mars, New Scientist, August 8, 2012

Why Mars is Inhospitable Place For Life at Surface

- Never had big oxygen atmosphere
- Surface always bathed in strong UV light
- When magnetic field died away 3.9 billion years ago radiation from sun sterilized surface of Mars
- The only subsurface life we see on Earth is microbial rather than evolved forms and on Earth evolved (multicellular) forms appear late in the game

Life On Mars

- Life on Earth needs energy, C and a few other elements, liquid water
- Lacking tectonic recycling of Earth that prevented early buildup of oxygen there, Mars could have become oxygen rich faster than Earth and could have had complex life faster than Earth
- But the lack of plate tectonics on Mars meant its atmosphere got thinner over time, you lose your greenhouse effect and planet cools down and atmospheric pressure is so low that water goes from solid to vapor without forming liquid
  - UV + cosmic radiation come through thin atmosphere + hit surface
- Possible places for life on Mars
  - Polar regions where there may be liquid water from melting ice
  - Underground where geothermal heat from interior keeps water liquid

- Origins, PBS Nova, Sept. 28+29, 2004

Life on Mars

- Viking orbiter
  - Past evidence of flowing liquid water on surface in dry riverbeds and a dense atmosphere
- Phoenix
  - Few inches below ground is water ice
- Mars is ice cube covered with dirt
  - Beneath layer of frozen CO2 at polar ice caps is lot of water ice, if it all melted, it would cover whole planet with ocean 80 feet deep
  - Ice is also beneath desert floor
  - But because atmospheric pressure is 150 times lower than ours, water can't exist as liquid at surface - it goes from solid ice to vapor
- Could life exist in this water ice near surface?
  - Could summer seasonal methane emissions into Mars' atmosphere be due to the presence of microorganisms on Mars…or could it be due to geological activity on Mars

- Finding Life Beyond Earth, PBS Nova, Oct. 19, 2011

Mars

- Mars has < 1% atmospheric density as Earth
  - This is one of reasons Mars is cold - it has no greenhouse effect
  - Mars is very dry
  - There was flowing water on Mars 3.5 billion years ago - we see the channels
  - Early Earth was similar to early Mars 3.5 billion years ago
    - 3.5 billion years ago - lots of volcanic activity, oceans, stromatolites on coasts, hot springs, atmosphere rich in CO_2 + devoid of oxygen
    - When there was liquid water on early Mars there was already life on early Earth
  - There are no rocks on Earth > 3.5 billion years old - they have been destroyed - but the rocks on Mars are preserved
  - Life at surface of Mars today is improbable but there may be liquid water under surface
  - Mars Exploration Rover demonstrated long standing surface water in Mars' past

Mars

- Why look on Mars / Why is it a target for astrobiology?
  - Evidence of water on Mars
  - Mars has C + N in atmosphere
  - Mars good place to look for life from past because it is a cold vacuum
- Why doesn't Mars have life today?
  - It is too small - 10% mass of Earth
    - Has no plate tectonics
    - Low gravity
    - No magnetic field
    - So because of these 3 it lost its atmosphere
- Is Martian life on our tree of life?
  - Earth + Mars may not be biological separated
  - Think of meteorite Alh 84001
- Where can we find a Martian organism (fossils are not enough)
  - Dead organisms preserved in permafrost on Mars
  - Where is there old ice on Mars
  - The bugs in the Martian permafrost will probably be dead
    - You want a corpse with its biomolecular info (DNA) intact

Focused Case Study - Mars Science Laboratory / Curiosity

- Microbially-induced sedimentary structures (MISS) are carpet-like colonies of microbes that trap + rearrange sediments thus forming distinctive features in shallow bodies of water on Earth (lakes / coastal areas) that fossilize over time
- There are morphological similarities between ancient Martian sedimentary rocks in Gillespie Lake outcrop + MISS
- Is this evidence of ancient life on Mars?
  - Would need to return rock samples to Earth to confirm

- Johnny Bontemps, Potential Signs of Ancient Life in Mars Rover Photos, Astrobiology Magazine, Jan. 5, 2015

Focused Case Study - Mars Science Laboratory / Curiosity

- Is an astrobiologist as well as a geologist
- Gale Crater chosen as landing site due to it giving you ability to crawl upward through a layered stratigraphic sequence of rocks
- Will use spectroscopic analysis to see if rocks contain any chemical ingredients for life
- But finding organic molecules is a challenge because there are lots of processes that destroy organic molecules
  - Radiation from space
  - Oxidizing compounds in Martian atmosphere

- Kenneth Chang, On Mars Rover, Tools to Plumb a Methane Mystery, New York Times, Nov. 22, 2011

Focused Case Study - Mars Science Laboratory / Curiosity

- Curiosity achieved its primary objective 4 months after landing on Mars

"We have found a habitable environment that is so benign and supportive of life that if this water had been around and you had been on the planet, you would have been able to drink it."

- John Grotzinger, project scientist, Curiosity

Focused Case Study - Mars Science Laboratory / Curiosity

- Organic molecules definitely found on Mars
- Life on Earth begins 3.8 billion years ago
- At same time on Mars there were same conditions as on Earth - liquid water, warm environment, organic molecules
    - So why couldn't life begin on Mars at same time?

- How NASA Curiosity Instrument Made First Detection of Organic Matter on Mars, Astrobiology Magazine, Dec. 18, 2014

Methane

- Methane important to astrobiologists because it is gas produced by geological or biological activity
  - Detection of methane around a planet implies it is either geologically or biologically active

Focused Case Study - Mars Science Laboratory / Curiosity

- Methane on Mars could be due to geological activity or biological activity
- In 2013 Curiosity found tiny amounts of methane in the atmosphere…
- In 2014 Curiosity found itself in middle of methane plume for 2 months, the rest of the time it found tiny amounts of methane again
- What caused the methane plume?
  - A nearby meteorite strike with freshly delivered organic compounds decaying?

- Curiouser and Curioser, The Economist, Dec. 20, 2014

Plate Tectonics on Mars

- Mars has primitive stage of plate tectonics
- Two plates are seen, depth beneath surface is uncertain
- May be how early Earth looked

- Plate Tectonics on Mars? Astrobiology Magazine, Aug 11, 2012

Steno's Principles of Geology

- Rules for reading the rocks
  - Principle of superposition
    - When sediments are deposited, those deposited first are at bottom so lowest sediments are oldest
  - Principle of original horizontality
    - Sediment is originally laid down flat
  - Principle of original continuity
    - Sediment originally deposited in continuous horizontal sheet until it meets an obstacle or tapers off due to distance from source
- Works for sedimentary rocks, doesn't work for igneous rocks, should not be mixed with tectonics

- Emily Lackdawalla, Steno's Principles and Planetary Geology, Planetary Society Blog, Jan 11, 2012

Flowing Water on Mars

- Since Mars formed, a big chunk of its water has boiled away into space, another chunk has seeped deep into its interior, what little remains on or near surface has frozen solid
- But some water still trickles over surface from time to time
  - Recurrent slope lineae - dark streaks on walls of certain craters that wax + wane with seasons - darkening in summer + fading in winter
    - Surface temperature of Mars rarely rises above pure water's freezing point but chemicals in regolith (magnesium perchlorate, magnesium chlorate, sodium perchlorate) can act as antifreeze + depress freezing point of brine containing them by more than 70 degrees C + thus permit brine to stay liquid
  - Recurrent slope lineae summer darkening caused by brine flow + winter lightening due to brine freezing
  - Recurrent slope lineae are intermittent streams, thus there is liquid brine on Mars
    - Could there be extremophiles there?

- Blue Streaks on a Red Planet, The Economist, Oct. 3, 2015

Jupiter / Io

- Water
- Atmosphere
- Temperature
- Magnetic fields
- Geologic activity
  - Active volcanism
  - Io's orbit around Jupiter is slight ellipse, with every orbit, Io experiences gravitational pushes + pulls from Jupiter which creates friction deep inside moon which heats it up + is source of its volcanic energy + heat
    - Jupiter's gravitational forces flex Io's rocky interior, turning into ocean of magma
  - Powerful tidal force, generated by massive gravitational pull of Jupiter, creates source of energy that is alternate from Sun's energy
    - This expands definition of habitable zone
- Life
  - Probably does not have life as it does not have solvent like water
- Miscellaneous

- Finding Life Beyond Earth, PBS Nova, Oct. 19, 2011

Jupiter / Europa

- Water
  - Surface is ice covered with cracks, looks like sea ice on Earth
  - Underneath is ocean of salt water that could be twice as large as all oceans on Earth
  - Jupiter's gravitational forces flex its rocky core generating tidal heating which melts Europa's ice to produce ocean of liquid water + cracks on its surface
- Atmosphere
- Temperature
  - Jupiter gets 1/25th of Sun's energy that Earth gets so its moons are cold
- Magnetic fields
- Geologic activity
  - Energy from Jupiter's strong gravitational pull causes Europa to flex tidally which gives moon heat in interior and thus a molten core and which allows liquid water to exist and gives it a young active surface = gravitational habitable zone

- Finding Life Beyond Earth, PBS Nova, Oct. 19, 2011

Jupiter / Europa

- Life
  - Has liquid water, energy source, chemical building blocks delivered by asteroids + comets
  - The icy shell may be only 1 km thick
    - There could be continual resurfacing by 2 dominant processes - tectonics + formation of chaotic terrain
      - Each wipes out the surface that was there before
      - Resurfacing is rapid + recent
      - Each involves interaction of an ocean with the surface
      - They produce a variety of potentially habitable niches in crust
  - Analog of Europa's ocean is Lake Vostok in Antarctica which is teeming with life
  - Are there organics on surface - what are the tiger stripes?
  - Could extremophiles be in Europan ice + oceans?
  - May have hydrothermal vents with life
  - So Europa is potential environment for life
- Miscellaneous
  - Opens up idea of habitability
    - Jupiter beyond habitable zone
    - Europa gets liquid water ocean through tidal flexing / tidal heating due to resonance with Io and Ganymede

- Finding Life Beyond Earth, PBS Nova, Oct. 19, 2011

Jupiter / Europa

- Surface processes and features involve ocean linked to surface - this makes ocean and possibly crust habitable
- So the icy crust is highly permeable - ocean is often exposed to surface - has major implications for life
- If there is life on Europa, its biosphere extends to the surface
- Implications for planetary protection
  - Even if not inhabited, Europa is vulnerable to infection or biological contamination
  - NASA needs to take this seriously
- Implications for planetary exploration
  - Current strategy driven by problem of how to drill through thick ice
  - But real problem is how to choose landing sites so as to sample oceanic material at surface
  - Need to rethink Europa exploration strategy

- Rick Greenberg, Unmasking Europa: The Search For Life on Jupiter's Ocean Moon

Jupiter / Europa

- Europa is constantly bombarded by radiation in the form of high energy electrons from Jupiter's magnetosphere + this could destroy life on Europa's surface and at shallow depths
- How deep beneath the crust does organic life need to be on Europa in order to survive?

- Nola Taylor Redd, How Deep Must Life Hide to be Safe on Europa?, Astrobiology Magazine, March 29, 2012

Jupiter / Europa

- Salty water from Europa's subsurface ocean makes its way to the surface
- The ocean and surface of Europa talk to each other

\- Astronomers Open Window to Europa's Ocean, Astrobiology Magazine, Mar. 6, 2013

- Plumes of water vapor 200 km tall are erupting off the surface of Europa
- These plumes may be connected with the subsurface ocean

\- Hubble Sees Evidence of Water Vapor at Jupiter Moon, Astrobiology Magazine, Dec. 12, 2013

- Europa appears to have giant tectonic plates of ice sliding on top of each other and this could be a way to cycle organic compounds from the surface to the ocean

\- Alexandra Witze, Plate Tectonics Found on Europa, Nature, Sept. 7 2014

Jupiter / Europa

- Evidence for a global ocean deep beneath Europa's ice
  - Chaos terrain on surface that indicates sub-surface melting
  - Ridges that may have formed from upwelled material
  - Weak magnetic moment induced in ocean by Jupiter's magnetosphere
  - Reddish-brown stains seen in ice around chaos terrain + ridges suggest material has convectively risen to surface from ocean below
  - Spectroscopic observations have identified possibly salts left over from ocean water that has risen to surface in vicinity of chaos terrain along with iron + sulfur

- Keith Cooper, Icy Worlds and Their Analog Sites, Astrobiology at NASA, Jan. 28, 2016

Saturn / Titan

- Water
  - Only world other than Earth with liquid on surface - super-chilled liquid methane + ethane
  - Hundreds of lakes / oceans of liquid methane and ethane
  - Mountains of frozen water ice that are carved by liquid methane
  - Methane carves river valleys, forms clouds, falls as rain
  - What kind of solvent is liquid methane?
- Atmosphere
  - Thick, clouded, only moon with significantly dense atmosphere rich in methane + nitrogen
- Temperature
  - - 143º C
- Magnetic fields
  - None so is exposed to intense solar winds
- Geologic activity

- Life Beyond Earth, Timothy Ferris, 1999

- Finding Life Beyond Earth, PBS Nova, Oct. 19, 2011

Saturn / Titan

- Life
  - Has organic building blocks of life
  - Has energy sources
  - Could there be life in this liquid at these low, cold temperatures?
  - Could extremophiles be on Titan?
  - Frozen prebiotic sandbox - is this what Earth was like before life arose?
  - Could have life in subsurface water aquifer or non-water life forms in methane / ethane lakes on surface
- Miscellaneous

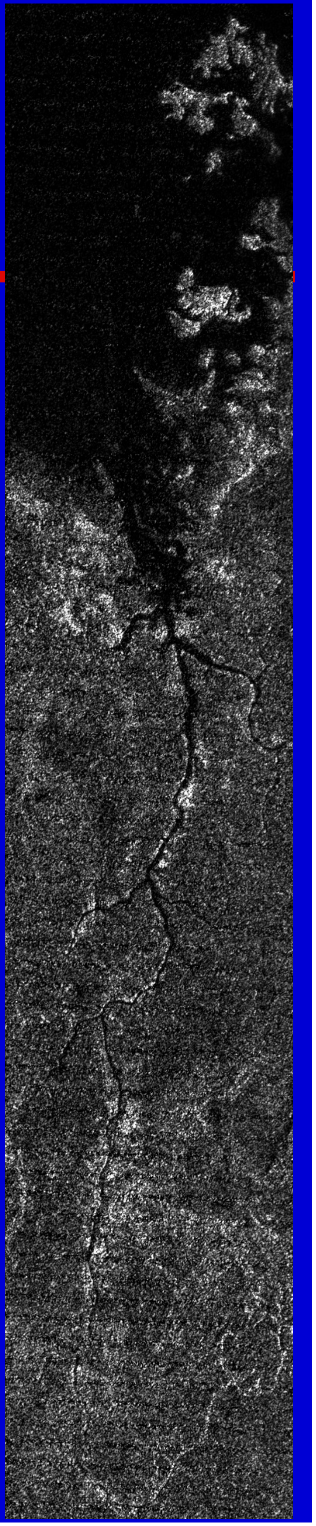
  - Life Beyond Earth, Timothy Ferris, 1999

  - Finding Life Beyond Earth, PBS Nova, Oct. 19, 2011

Saturn / Titan

- Hydrological cycle runs with methane - methane lakes, methane rivers, methane rain
- Structure is icy / rocky core, an ocean of liquid water, an icy crust
  - Radioactive elements in core decay + generate heat that keeps ocean from freezing
  - Tidal heating from Saturn also plays a minor role in keeping ocean from freezing
- River valley has been seen that stretches > 400 km

- Rare Rains on Titan, Astrobiology Magazine, Mar. 27, 2012
- Titan is Icier Than Thought, Astrobiology Magazine, Dec. 7, 2012
- A Mini Nile River on Titan, Astrobiology Magazine, Dec. 15, 2012



From NASA

Saturn / Enceladus

- Water
  - Has highest albedo of any body in solar system because surface is dominated by fresh, clean ice
- Atmosphere
- Temperature
- Magnetic fields
- Geologic activity
  - Has large cracks across South pole that radiate heat and that have vast ice jets traveling at 1,200 miles per hour erupting into space = cryovolcanism
    - Jets help form Saturn's E ring
    - Body of Enceladus is being flexed, that causes internal friction, that leads to heat
    - Caused by friction from gravitational forces as it orbits Saturn which cause it to flex + heat up and melt its interior
    - There is a sea beneath Enceladus' south pole
    - In the jets are chemical building blocks of life
- Life
  - So you have ingredients for habitable zone - chemical building blocks, heat, liquid water
  - Could extremophiles be here?

    - Finding Life Beyond Earth, PBS Nova, Oct. 19, 2011

Saturn / Enceladus

- **Miscellaneous**

  "It has liquid water, organic carbon, nitrogen (in the form of ammonia), and an energy source. There is no other environment in the Solar System (except Earth) where we can make all those claims."

  - Chris McKay, astrobiologist

  "To me, it's like there's a sign on Enceladus that says "Free Samples. Take One." We've just got to fly through the plume and collect the stuff. We don't have to drill; we don't have to dig; we don't have to scurry around looking for it. It's being ejected into space."

  - Chris McKay, astrobiologist

Saturn / Enceladus

- Geysers from cryovolcanoes contain complex organic compounds - propane, ethane, acetylene
  - Supply E-ring of Saturn
- Has liquid water, organic material, source of heat
- Has thin atmosphere of water vapor, CO_2, methane, nitrogen

- Robin McKie, Enceladus: Home of Alien Lifeforms?, The Guardian, Jul. 29, 2012

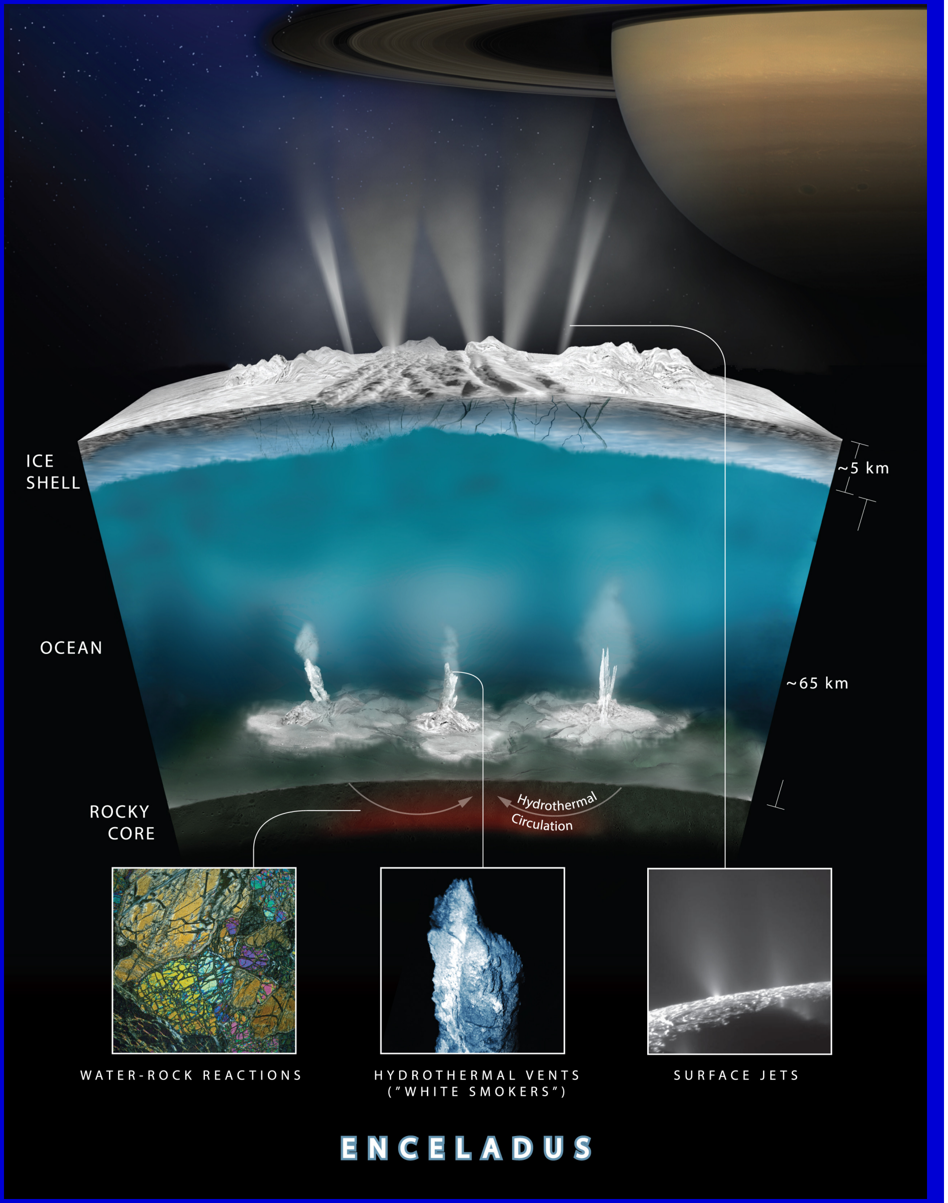
Saturn / Enceladus

- There is a large reservoir of liquid water the size of Lake Superior under the icy crust of Enceladus in its south pole region due to tidal heating
- Enceladus is a differentiated body with a rocky core

- Sheyna Gifford, Out-of-This-World: An Ocean on Enceladus, Astrobiology Magazine, April 3, 2014

Saturn / Enceladus

- Enceladus has everything needed for life
  - Liquid water
  - Complex organic molecules (detected in its plumes by Cassini)
  - Source of energy - molecular H thought to have formed in geochemical reactions in hydrothermal vents on sea floor (detected in its plumes by Cassini)



From NASA

What Cassini Found at Saturn

- Enceladus has everything needed for life
  - Plumes of water vapor shooting into space from south pole in 2005
  - Complicated organic molecules in plumes in 2008
  - Traces of hydrogen in plumes which could serve as an energy source for organisms at hydrothermal vents in (evidence of interactions between heated water + seafloor rocks) in 2017
- Titan
  - Only moon in solar system with thick atmosphere
  - Only body (besides Earth) with liquid on its surface in form of hydrocarbons
  - Hydrological cycle: Hydrocarbons evaporate into atmosphere and then fall as rain, producing geological features found only also on Earth and Mars: streams + rivers carving valleys and laying down deltas before emptying into lakes

- So Long and Thanks For the Postcards, The Economist, Sept 9, 2017

Uranus

- Water
- Atmosphere
- Temperature
- Magnetic fields
- Geologic activity
- Life
- Miscellaneous

- Only close data points come from Voyager for a few hours

Neptune

- Water
- Atmosphere
- Temperature
- Magnetic fields
- Geologic activity
- Life
- Miscellaneous

- Only close data points come from Voyager for a few hours

Neptune / Triton

- Has retrograde orbit around Neptune so most likely Triton is a captured Kuiper Belt object
- Has surface mainly of water ice along with N, methane, CO2
- Likely to have ammonia-rich subsurface ocean due to tidal heating + radiogenic heating

- Amanda Doyle, Does Triton Have a Subsurface Ocean?, Astrobiology Magazine, Dec. 6, 2012

Pluto

- Water
- Atmosphere
  - Blue sky due to size + composition of haze particles (tholins) which form high in atmosphere where UV light breaks apart + ionizes N + CH_4 molecules which recombine into complex macromolecules which get coated with ice frost
- Temperature
- Magnetic fields
- Geologic activity
  - Numerous small regions of water ice
  - Diversity of terrain - craters, mountains, ice fields, icy crust
- Life
- Miscellaneous

- May have liquid ocean beneath icy crust
- New Horizons closest approach was 7,750 miles at speed of 30,000 miles per hour

What New Horizons Found at Pluto in 2015

- Mountain ranges made of water ice, which thanks to a surface temperature of -229C plays the geological role on Pluto that rock does on Earth
- Hazes rising 130 km into the thin atmosphere
- Relative lack of craters, suggesting the surface is regularly renewed through some sort of currently unknown geological activity

- Two Years On, the Kuiper Belt is in Sight, The Economist, Sept. 14, 2017

Kuiper Belt

- Kuiper Belt defined by discovery of first Kuiper Belt Object (KBO) in 1992
  - In retrospect first KBO was Pluto discovered in 1930 and second KBO was Pluto's moon Charon discovered in 1978
- Kuiper Belt is largest structure in our solar system
  - Preserves evidence about early formation of solar system
- There are probably 100,000 KBOs with diameters of 100 km or more + there are billions of smaller objects
  - They are very diverse objects
- What we have learned from Kuiper Belt
  - Our planetary system is much larger than we think
  - The locations + orbital eccentricities + inclinations of planets in our solar system can change over time
  - Our solar system was very good at making small planets which dominate our planetary population - the ultimate number of dwarf planets we will discover in Kuiper Belt may exceed 10,000

- The Kuiper Belt at 20, Astrobiology Magazine, Sept. 1, 2012

Summary - Which Planets Have…

- **Atmosphere**
  - Venus, Earth, Mars (thin), Saturn / Titan, Saturn / Enceladus
- **Water**
  - Mercury (poles), Earth, Mars, Jupiter / Europa, Saturn / Enceladus, Saturn / Titan
- **Magnetic field**
  - Earth, Mars (weak)
- **Plate tectonics**
  - Earth, ?Mars, ?Jupiter / Europa
- **Volcanoes**
  - Venus, Earth, Mars (dead), Jupiter / Europa (cryo), Saturn / Enceladus (cryo), Saturn / Io, Neptune / Triton (cryo)
- **Geysers**
  - Earth, Jupiter / Europa, Saturn / Enceladus, Neptune / Triton

Planetary Protection

- To protect extraterrestrial objects from terrestrial biologic contamination that may interfere with search for extant life, its remnants or its precursors
- To protect the Earth from the possible hazards of an extraterrestrial sample return
  - Should we protect other planets?
  - Do we need to protect Earth?

Planetary Protection

- Why
  - We don't want to screw up data before we look at it
  - We don't want to contaminate the evidence we are looking for
  - We don't want to alter the thing we wish to study
- Policies
  - We want to make sure we are preserving conditions of any target location we want to study so we can do appropriate experiments now and preserve the possibility of doing additional experiments and exploration in future (Don't litter!)
  - If you bring something back you want to protect Earth + biosphere from potential damage from harmful organisms that get brought back (backward contamination)
  - Documented in Treaty on Peaceful Uses of Outer Space signed in 1967
    - Article 9 of treaty deals with this specifically

Planetary Protection

- Sterilization means we remove all life from spacecraft
  - We don't do this
  - We decrease bioload (biological contaminants) on spacecraft
  - We say it is sterile if < 30 spores / 10 square meters

NASA Planetary Protection Categories

Category	Mission Type	Target & Encountered Solar System Bodies
I	Any	Sun, Mercury, Moon
II	Any	All but Mars, Europa, Sun, Mercury, Moon
III	Orbiter, flyby	Mars, Europa
IVA	Lander without life detection	Mars, Europa
IVB	Lander with life detection	Mars, Europa
IVC	Lander in special region	Mars, Europa
VU	Sample return from unrestricted body	Case by case (examples = Genesis + Stardust)
VR	Sample return from restricted body	Mars and by default all until ruled on case by case basis

Categories of Target

1 - Planet with no interest for understanding process of chemical evolution of life

Planet is not protected

Examples - Mercury, Earth's moon

2 - Planet has interest related to possibility of chemical evolution of life but there is only a remote chance spacecraft could jeopardize potential for future exploration

Examples - Titan, Venus

3 - Planet is of significant interest related to the possibility of understanding chemical evolution of life and there is significant chance of contamination

Examples - Europa + Mars for flybys

4 - Lander to planet with Category 3

Examples - Europa + Mars for landers

5 - Sample return to Earth

Restricted - have to be careful

Unrestricted - don't have to be careful

All sample returns so far have been unrestricted

Astrobiology Analogs

- Definition - locations on Earth similar to other planets + moons
- Examples
  - Mars - very dry + cold
    - Atacama desert in Chile - driest desert
    - Dry Valleys of Antarctica - coldest desert
  - Europa
    - Lake Vostok in Antarctica
  - Enceladus
    - Yellowstone / Old Faithful

Case Study Summary - Mars Exploration Rover Spirit 2004-2010

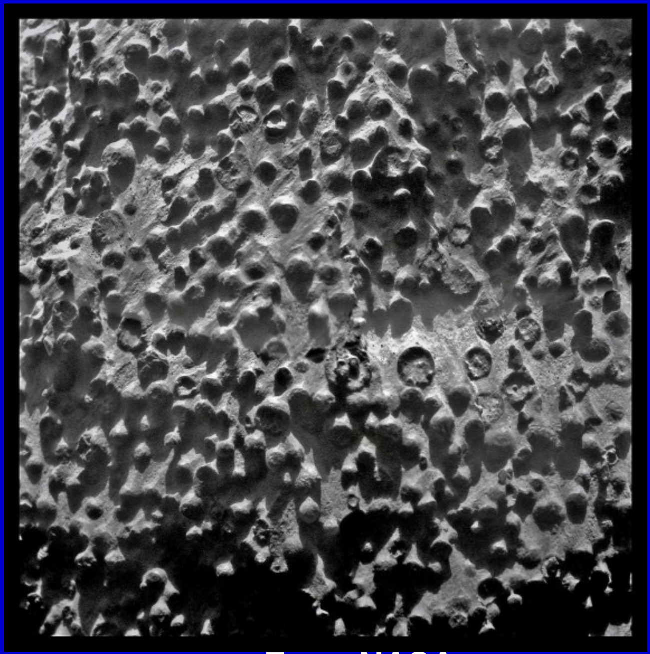
- Goal
- Center of Gravity (Strategy)
  - Follow the water
  - Landing site Gusev Crater
- Equipment
  - 6 wheeled rover size of golf cart, solar panels, functions as field geologist
- Training
- Leadership
  - Steve Squyres
- Morale
  - High
- Tactics
  - Short sprint -> long haul
- Intangibles
  - Designed for 90 days ~ Who would have believed it would have lasted this long (6 years)
- Mistakes
- Outcome

From NASA

Case Study Summary - Mars Exploration Rover Opportunity 2004-18

- Goal
- Center of Gravity (Strategy)
  - Follow the water
  - Meridiani Planum found to be high in hematite from orbit so Opportunity sent there, landing in Eagle Crater
- Equipment
  - 6 wheeled rover size of golf cart, solar panels, functions as field geologist
- Training ~ Leadership
  - Steve Squyres
- Morale
  - High
- Tactics
  - Short sprint -> long haul ~ From Eagle to Victoria to Endeavor Craters
- Intangibles
  - Designed for 90 days ~ Who would have believed it would have lasted this long (14 years+)
- Mistakes
- Outcome
  - Found blueberries (concretion formed in water) at landing site -> found newberries at Endeavor Crater

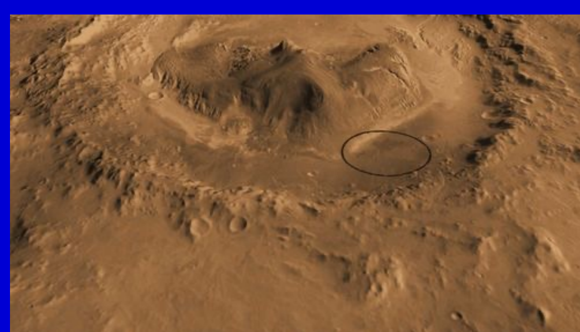
From NASA

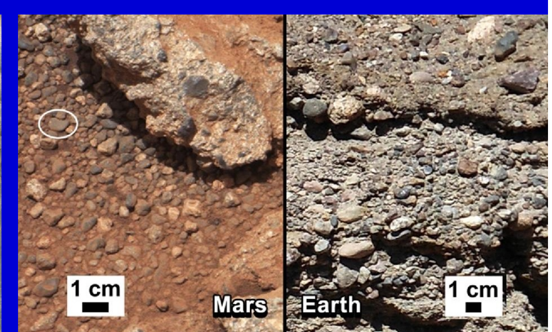


From NASA

Case Study Summary - Mars Science Laboratory (Curiosity)

- Goal
  - Assess habitability of Mars - Were environmental conditions favorable for microbial life on Mars in past
    - 1) Was there liquid water there (yes), 2) Are there the basic elements of life (C H O N P S) and are there reduced forms of carbon, especially organics? - that is what it is looking for
  - Did these habitable conditions persist long enough for life to emerge + establish planetary foothold over hundreds of millions of years?
- Center of Gravity (Strategy)
  - MRO identified Gale Crater, land near Mount Sharp in middle
  - Gale Crater is 3.5-4 billion years old, when Mars was much like early Earth when life evolved with water / denser atmosphere / warmer temperature
  - Study drying out of Mars - as go from bottom to top of Mount Sharp
    - Bottom - very wet - find clay minerals
    - Higher up - wet - find sulfate minerals + clay minerals
    - Even higher up - less wet - find sulfate minerals without clay
    - At top - dry - find no water related minerals
  - Rover will crawl upward through layered stratigraphic sequence of rocks in Gale Crater through millions / billions years of Martian geologic history
- Equipment
  - Mars Reconnaissance Orbiter instruments helped choose Gale Crater
  - 6 wheeled rover size of Mini car, radioisotope power source, field scientist with onboard science lab
- Training
- Leadership
  - John Grotzinger
- Morale
- Tactics
  - Long haul
- Intangibles
  - How long will it last?
- Mistakes
- Outcome
  - At Yellowknife Bay found a fresh water lake bed with clay sediment with neutral pH with traces of C H N O P S and sulfates / sulfides which can serve as energy source so this is habitable site - it has water, basic elements of life, energy



All From NASA

Case Study Summary - LCROSS - October 9, 2009

- Goal
  - Determine if there is water on the Moon
- Center of Gravity (Strategy)
  - Drop a bomb(s) on the Moon, into a crater near the South Pole of the Moon
- Equipment
  - Two-ton spent rocket cylinder + Lunar Crater Observation and Sensing Satellite (LCROSS) which followed 4 minutes behind
- Training ~ Leadership ~ Morale
  - Pete Worden of NASA Ames
- Tactics
  - Lunar Prospector mission in 1998 suggested water ice at Moon's poles
  - Moon has axial tilt of 1.54 degrees so sunlight never reaches depths of darkest craters which can get to be 26 degrees Kelvin which is below freezing point of N + O and in these cold traps water ice behaves as rock
  - Boil volatiles out of soil + blast dust + vapor ½ mile up into sunlight so observers could spectroscopically figure out what vapor contained
- Intangibles ~ Mistakes
  - Impact was promised to be visible to amateur astronomers but it was not
- Outcome
  - Impact blasted crater 25-35 meters wide lofting dust + vapor high enough to be observed
  - Ejected material found to be 5.6% water in form of ice (twice the average moisture found in Sahara Desert), also found H2S, ammonia, methane, ethane, ethanol, mercury, atomic hydrogen (can be used for rocket fuel), CO
  - From each ton of lunar soil you could extract 12 gallons of water
  - So lunar poles could be good place for settlement given presence of water there + near permanent sunlight

- Richard Lovett, Fluffy Impact: What LCROSS Found When It Hit the Moon, Analog, Jul/Aug 2012 pp. 44-48

Case Study Summary - New Horizons

- Goal
  - First close-up study of Pluto, a dwarf planet / largest Kuiper Belt Object
- Center of Gravity (Strategy)
  - Instead of studying the smallest of the main planets, you are studying the largest of the dwarf planets which are hundreds of times more common
- Equipment
  - Developed quickly + at low cost
  - New Horizons spacecraft left Earth at greatest speed ever for departing spacecraft - 36,000 mph
  - Data rate Is 2,000 bits per second due enormous distance + small antenna size…data will take over 15 months to transmit back uncompressed
- Training ~ Leadership ~ Morale
  - Alan Stern - "It's raw exploration…how exciting it is to turn a point of light into a planet before their very eyes."
- Tactics
  - Take advantage of planetary alignment in 2006 to get gravity boost from Jupiter to arrive at Pluto 9.5 years after liftoff
- Intangibles
  - At encounter on July 14, 2015 light from Sun at Pluto will be 1,000 dimmer than it is at Earth
- Mistakes
  - Text
- Outcome
  - Text

- Andrew Chaikin, Pluto at Last, Air & Space Magazine, Mar. 2015

Computing Case Study Summary - Voyager 1 - The World's Longest Continuously Running Computer

- Goal
  - Control + operate the Voyager 1 and 2 interplanetary / interstellar spacecraft
- Center of Gravity (Strategy)
  - Onboard computer linked to Earth and reprogrammable via Deep Space Network
- Technology / Equipment
  - 3 pairs of computers for redundancy built by General Electric with total of 68 kilobytes of memory
  - Master clock runs at 4 MHz but CPU's clock runs at 250 KHz so it performs 8,000 instructions / second
  - [A 2013 smartphone runs at 1.5 GHz with 4 or more processors and performs 14 billion instructions / second]
- Training ~ Leadership ~ Morale
- Tactics
  - Computer Command System - carries out instructions from ground to operate spacecraft + look for problems with spacecraft + respond to them
  - Flight Data System - collect data from + control scientific instruments + format data for storage / transmission
  - Attitude + Articulation Control System - moves scan platform + maneuvers spacecraft
- Intangibles ~ Mistakes
- Outcome
  - Started working in 1977 and still running today

  - Jet Propulsion Laboratory, Voyager FAQ

Personal Case Study - Getting It Wrong

- **Location**
  - **Lowell Observatory**
- **Story**
  - **Right - Pluto is a planet**
  - **Wrong - Pluto is a dwarf planet**
  - **Right - Pluto is very interesting…it is the largest of the dwarf planets which are most common type of planets in our solar system**

Astrobiology Analog Case Study - Extremophiles

- Location
  - Yellowstone National Park
- Story
  - Extremophiles

Astrobiology Analog Case Study - Lake Vostok + 200 Other Subglacial Lakes

- Location
  - Antarctica
- Story
  - Analog for Europa + Enceladus
  - Deep ice crust covering liquid water in subglacial rivers + lakes warmed by sources other than Sun such as heat generated by core of Earth
  - Microbes live everywhere in ice in Antarctica
  - Looking for microbes that have evolved to survive in extreme cold + without light / nutrients
  - Lake Vostok has not felt wind for 20-30 million years
  - Drilling though thick ice to get there
    - Russia drilling through 2 miles of ice at Lake Vostok for 15 years but not using best drilling practices
    - United Kingdom drilling at Lake Ellsworth and using best drilling practices
    - US drilling through 0.5 miles of ice at Whillans Ice Stream and using best drilling practices
  - At Lake Whillans a large wetland ecosystem was discovered of single-cell Archaea that convert ammonium + methane into energy

- Marc Kaufman, Breaking Through the Ice at Lake Vostok, Astrobiology Magazine, Feb. 16, 2012
- Breaking Through the Antarctic Ice, Astrobiology Magazine, Feb. 2, 2013
- Life Under Lake Ice, Astrobiology Magazine, Feb. 13, 2013
- US Expedition Finds Life Under Antarctic Ice, Astrobiology Magazine, Aug 21, 2014

Drake Equation

$$N = R^* \times fp \times ne \times fl \times fi \times fc \times L$$

- N = The number of communicative civilizations
- R* = The rate of formation of suitable stars (stars such as our Sun)
- fp = The fraction of those stars with planets. (Current evidence indicates that planetary systems may be common for stars like the Sun.)
- ne = The number of Earth-like worlds per planetary system
- fl = The fraction of those Earth-like planets where life actually develops
- fi = The fraction of life sites where intelligence develops
- fc = The fraction of communicative planets (those on which electromagnetic communications technology develops)
- L = The "lifetime" of communicating civilizations

Class Simulation

- Topic aspects

Poem

Slide text

Questions for Further Discussion

- Describe a solar system architecture that favors the development of intelligent life
- What is the original definition of habitable zone?
- What is the expanded definition of habitable zone?
- What do you need for life to arise?
- Why are Mars / Europa / Enceladus / Titan considered to be favorable places for life in our solar system?
- How do we protect planets from contamination from Earth?
- Is planetary protection a necessity or a luxury?
- What is the ethical way to treat alien life?
- Will life on other planets (and moons) in our solar system look like life on Earth?
- Which planet or moon would <u>you</u> advocate going to in order to look for life - and why?
- Just because a planet can support life, does that mean it will?

Reading Assignments

- Astrobiology Primer 2.0 (2016) Chapter 6
  - https://doi.org/10.1089/ast.2015.1460
- TED Talks for this Topic
  - http://www.astrobiologysurvey.org/ToLearnMore.html

Recommended Reading to Learn More

- Non-fiction
  - Andrew Chaikin - A Passion For Mars
- Fiction
  - Michael Crichton - The Andromeda Strain
- Movies
  - The Andromeda Strain
- Simulations

Conclusion

- What would it mean if we found life anywhere in our solar system, and if the life was similar to life on Earth and had DNA / RNA / proteins?
  - Could mean panspermia is true…or…
  - Life forms in similar ways no matter where it forms
- What if life found in solar system was very different from Earth life?
  - If we find two independent origins of life in our solar system it would mean that life is everywhere in the universe
- We know how to go evolutionarily from unintelligent to intelligent life
- We don't know how to create life from inanimate matter

Conclusion

"If we ever discover that genesis has occurred independently twice in our solar system, no matter where we find it, then that means that the spell has been broken, the existence theorem has been proven, and we could infer from that that life is not a bug but a feature of the universe in which we live, and has occurred a staggering number of times throughout the 13.7 billion-year history of the universe. And that would be a huge scientific result. I don't think there'd be any question about it. It probably wouldn't be the socially cataclysmic event that the discovery of intelligent life would be. But scientifically it would be a radically phenomenal event."

- Carolyn Porco, planetary scientist

Topic 6

Life in the Universe

Song

Sun turnin' 'round with graceful motion
We're setting off with soft explosion
Bound for a star with fiery oceans
It's so very lonely
You're a 100 light years from home

Freezing red deserts turn to dark
Energy here in every part
It's so very lonely
You're 600 light years from home

It's so very lonely
You're a 1000 light years from home
It's so very lonely
You're a 1000 light years from home

Bell flight 14 you now can land
See you on Aldebaran
Safe on the green desert sand
It's so very lonely
You're 2000 light years from home
It's so very lonely
You're 2000 light years from home

- Mick Jagger and Keith Richards, 2000 Light Years From Home

Thematic Quote

Summary History Of Life On Earth

"So the short history goes like this: life early, but the familiar life that we think of, plants and animals, that is really a relatively recent development on this planet. And intelligent life, people like ourselves, technologically competent humans, that's just a snap in the full history of the planet."

- Andy Knoll, palentologist

Thematic Quote

Summary History Of Life On Earth

"The history of animals that we've recorded from fossils is really only the last 15 percent or so of the recorded history of life on this planet. The deeper history of life and the greater diversity of life on this planet is microorganisms-bacteria, protozoans, algae. One way to put it is that animals might be evolution's icing, but bacteria are really the cake."

- Andy Knoll, paleontologist

The Painting

Pioneer 10 Leaving The Solar System

- Don Davis

(NASA Ames)

Artifact

- Name
  - Petoskey stone
- Year
  - 1970
- Story
  - Stone of my youth
  - Fossilized biomarkers from the past

The Question

Are there other planetary systems and are any of them like our solar system and do any of them contain Earth-like planets?

Exoplanet Definition

- = extrasolar planet = planet outside our solar system

"With regards to living things, it cannot be proven that the seeds from which animals, plants and other things originate are not possible on any particular world-system… There are an infinite number of worlds, some like this world, others unlike it."

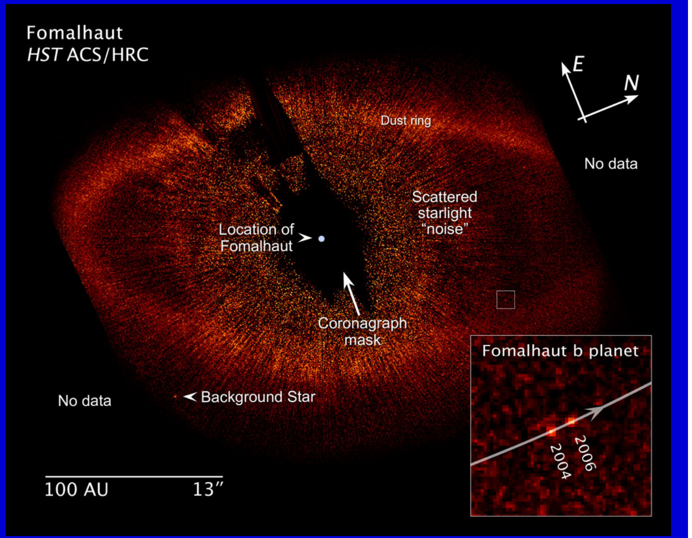
- Epicurus, philosopher, in letter to Herodotus in 300 BC

History of Exoplanet Detection

- ~ 400 BC - Democritus and ~ 300 BC - Epicurus were Greek philosophers who believed in extrasolar planets with life
- 1600 - Giordano Bruno believed in the Copernican theory that the planets circle the Sun and also believed that there are other planets around other stars, some of them with life - he was burned at the stake by the Catholic Church
- ~ 1650 - First attempt to find exoplanets around stars was by Christiaan Huygens who was inspired by Galileo's discovery of Jupiter's moons
- 1995 - First exoplanet detected - star 51 Pegasi - a planet half mass of Jupiter which orbited it every 4 days
- Catalog of exoplanets - PlanetQuest
  - http://planetquest.jpl.nasa.gov/
- Habitable Exoplanets Catalog
  - http://phl.upr.edu/projects/habitable-exoplanets-catalog

Exoplanet Detection Techniques - Direct Detection / Optical

- Difference between a star and a planet
  - Star generates its own energy from nuclear reactions in its center by fusion
  - Planets are cold, dense and don't generate their own energy from nuclear reactions and are therefore faint
- Why can't you easily optically observe planets around stars with the Hubble Space Telescope?
  - Stars are 10 billion times brighter than the planets around them
- First direct detection of exoplanets
  - 4 planets around star HR8799, 130 light years away
  - 1 planet circling Formalhaut, 25 light years away



From NASA

- New Study Brings Exoplanet Back From the Dead, Astrobiology Magazine, Oct. 28, 2012

Exoplanet Detection Techniques - Direct Detection / Optical

- Searching optically for an exoplanet next to a star is like searching for a firefly next to a search light
  - Planet is 1 billion times dimmer than a star

Direct Detection - Gemini Planet Imager

- Built for purpose of direct imaging of exoplanets
- Exposure time reduced from 60 minutes to 1 minute, star can be 1000 times dimmer than before
- Works by Micro-Electro-Mechanical Systems (MEMS) mirrors, diffraction-suppressing coronograph to block light from parent star, integral field spectrograph which allows spectra to be taken over entire field of study
- Can also do atmospheric spectroscopy
- Currently can image Jupiter-sized planets around stars similar to our Sun

- Sheyna Gifford, Starlight Starbright: New Imaging Technique Reveal Planets Near Bright Stars, Astrobiology Magazine, May 28, 2014

Direct Detection

- Taking pictures of exoplanets is hard because of
  - Their distance
    - Interstellar distances reduce apparent gap between planet + host star so it is hard to separate them in photo
    - Separating objects which appear this close together requires very big telescope
  - Their dimness
    - They are massively outshone by their host stars
    - Blocking light that comes directly from star requires coronagraph inserted into telescope's optics which permits any light reflected from planets around star to shine through
- Exoplanets directly imaged so far have been
  - Gigantic orbs (which reflect a lot of light) orbiting at great distances (maximizing angular separation) from dim host stars (minimizing glare)…and many have been young worlds still glowing from heat of their formation
- Good news is that giant telescopes, fitted with coronagraphs, are becoming more common
  - Right now we can photograph gas giants (using Gemini Telescope + Very Large Telescope)
  - Soon we will be able to photograph ice giants + large rocky planets / super-Earths (using Extremely Large Telescope)

- Portraits of Worlds, The Economist, Nov. 26, 2016

Exoplanet Detection - Wobble / Radial Velocity Technique

- Used in 1995 to detect first exoplanet 51 Pegasi
- Planet gives star little gravitational tug as it orbits it, causing star to go back and forth, or wobble, as star + planet circle same center of gravity
  - One can determine a star has a planet, or more than one planet, just by the motion of the star, which should be stationary but wobbles due to the pull on it by planet
- It's hard to detect this motion directly, so use Doppler Effect
  - As star wobbles toward you, wavelengths of light get compacted, and they get shifted toward bluer colors
  - As the star wobbles away from you, wavelengths of light get stretched out, and they get shifted toward redder colors
- Is an indirect method
  - Measures how fast a star is coming towards you and going away from you and this lets you infer the presence of a planet in orbit and what the planet's orbital period is

  \- Origins, PBS Nova, Sept. 28+29, 2004

What Can Be Learned About a Planet from the Wobble Technique

- Even though you can't directly detect the planet, from the star's doppler shift you can calculate the planet's mass and orbital period and temperature

Exoplanet Detection Techniques - Transit

- When planet goes in front of a star it blocks a small amount of the star's light and you measure the temporary dimming of the star's light
  - Earth's would block 84 parts per million of Sun's light - less than 1/100th of a percent
- Is technique Kepler spacecraft uses
- Planet crosses star, blocks out sunlight reducing its apparent brightness
  - Planet size calculated from amount of dimming
  - Star size comes from how long dimming lasts
  - Size of planet's orbit calculated by interval between dips in light
  - Planet temperature calculated from orbital size and temperature of star
  - Star's surface temperature calculated by measuring its brightness / luminosity / wavelengths of light it emits

What Can Be Learned About a Planet From the Transit Method

- You learn size of planet by how much light dims
- If you have radial velocity measurements you get mass of planet relative to mass of star
- Mass and radius of planet gives you density which gives you idea of composition of planet
- You learn period of orbit so you learn how long a year is on planet
- If you can make transit measurement in different wavelengths you can learn more - you can begin to study composition of atmosphere
- If you can measure secondary eclipse when planet goes behind star you see tiny dip in light due to light reflecting off surface of planet - this is measure of how reflective planet is - its albedo - and that can tell you whether it is a terrestrial or gas giant
- If you are looking in infrared wavelength you can learn even more about structure of atmosphere

Exoplanet Detection

- Direct imaging
  - 11 exoplanets seen so far, all big + bright + far away from their stars
- Spectroscopic Doppler technique / Wobble technique
  - Starlight analyzed for evidence star is being tugged ever so slightly back + forth by gravitational pull of its planets
  - Can detect star being pulled from its appointed rounds by only 1 m/s (about human walking speed) which allows for detection of giant planet in big orbit or small planet in close orbit but not Earth at its distance from its star as Earth tugs the Sun at only 1/10 m/s (crawling speed of baby)
  - Close-in planet exerts stronger pull on its star, making it easier to detect with Doppler method
- Transit technique
  - Watch star for slight periodic dip in brightness that occurs when orbiting planet circles in front of it + blocks fraction of its light
  - 10% of planetary systems are oriented edge on so these transits are visible from Earth
  - Dimming can be mimicked by pulsations of variable star or large sunspot moving across star's surface so transit must be seen 3 times before it is confirmed which takes few days or weeks for planet rapidly circling close to star but years for a terrestrial twin farther from its star
  - Best hunting grounds for transits are dwarf stars smaller than our Sun - are plentiful, enjoy long stable careers, supply steady sunlight to a planet in their habitable zone, habitable zones are close to dwarf star so transits occur more quickly
- When Earth-like planet found in habitable zone space telescope will study spectrum of light coming from planet looking for biosignatures such as atmospheric methane / ozone / O2 or for the red edge produced when chlorophyll-containing photosynthetic plants reflect red light

- Timothy Ferris, Worlds Apart, National Geographic, Dec. 2009

Summary of Exoplanet Detection Methods

- **Radial velocity method**
  - Orbiting planet causes its star to wobble slightly, the heavier the planet + the tighter its orbit, the bigger the wobble
  - Wobbling detected from Earth by measuring regular variations in star's speed along line of sight to Earth - its radial velocity - as star moves back + forth its Doppler shift causes slight change in its color which is detected with spectroscopy
  - Used to discover first exoplanet, 51 Pegasi b in 1995
  - Best at finding large planets in tight orbits = hot Jupiters
- **Transit method**
  - Continuously monitor brightness of star to look for periodic dimming caused by planet passing between star + observer with size + frequency of dips allowing size + orbital period of planet to be calculated
  - Only works for stars whose planets are orbiting edge on as seen from observer
  - Kepler uses this method
- **Direct visualization**
  - Use clever tricks to blot out light of star that planets orbit
  - Still hard to do with few examples

- How Do You Find Planets Around Other Stars, The Economist, Jun 12, 2013

Exoplanets 'R Us

- Classic habitability zone = Goldilocks zone = distance from a star where liquid water is present
- Habitability is multi-parameter system that depends on interaction not only of components of planet itself but of planet with its environment including its host star + all its sibling planets in the system
  - Planet's habitability can't be separated from its inhabitants
- How will you know if a planet is habitable? You look for out-of-equilibrium chemistry, looking for O2 or ozone or a reducing gas. For most of Earth's history such a signature wasn't present. So even if planet is inhabited it can be missed with spectroscopy
  - Earth throughout much of its history, even when it was inhabited, was nothing like Earth today - it lacked atmospheric signatures it has today
- Earth-size planet vs. Earth-like planet are different concepts
  - Earth-size planet is the size of Earth but it could be extremely hot (Venus)
  - Earth-like planet is like Earth with oceans, land, trees, etc.
  - Kepler will tell us the fraction of stars with Earth-size planets, we'll have a planet radius + a mass, the planet will be potentially habitable, but it won't tell us if they are Earth-like

- The Great Exoplanet Debate Parts 1-10, Astrobiology Magazine, Mar. 11, 2013 - May 13, 2013

Habitability Index

- Two-tiered classification scheme of exoplanet habitability
  - Earth Similarity Index (ESI) - categorizes planet's Earth-like features + how suitable it is for life based on place in habitable zone
    - Allows worlds to be screened with regard to their similarity to Earth, the only known inhabited planet at this time
    - Based on data available or potentially available for most exoplanets such as mass, radius, and temperature
  - Planetary Habitability Index (PHI) - describes variety of chemical + physical parameters that are conducive to life in more extreme + less Earth-like conditions
    - Based on the presence of a stable substrate, available energy, appropriate chemistry, and the potential for holding a liquid solvent
    - Designed to minimize the biased search for life as we know it and to take into account life that might exist under more exotic conditions
    - PHI requires more detailed knowledge than is available for any exoplanet at this time

- Dirk Schulze-Makuch et. al., A Two-Tiered Approach to Assessing the Habitability of Exoplanets, Astrobiology, Dec. 2011
- Habitable Does Not Mean Earth-Like, Astrobiology Magazine, Nov. 11, 2011
- Robert Lee Hotz, Searching a Billion Planets for Life, Wall Street Journal, May 19-20, 2012

What Would Make an Exoplanet Super-Habitable?

- Tidal heating can make rocky bodies habitable outside normal confines of habitable zone + make worlds within conventional definition of habitable zone uninhabitable
- Planets with same amount of land area as Earth but broken up into smaller continents to minimize vast interior inhospitable deserts
- Planets with shallower waters as they have greater biodiversity
- Planets with masses up to twice Earth's will have plate tectonics for longer periods that helps recycle materials from interior to surface
- Planets with fewer major swings in temperatures could experience few mass extinctions by avoiding ice ages + snowball states
- Worlds slightly warmer than Earth could have larger tropical zones that are more benign for biodiversity
- More oxygen in atmosphere could increase maximum possible body size of organisms
- More massive atmospheres could offer greater shielding from high-energy radiation from space
- K stars (orange dwarfs) that are a bit cooler + smaller than our sun may provide more favorable / less damaging UV environments than yellow dwarfs like our Sun + orange dwarfs have longer lifetimes which would allow worlds to spend more time within their habitable zones thus having more time to develop life + develop biodiversity
- In conclusion, a super-habitable world will orbit an orange dwarf + be slightly older and 2 to 3 times more massive than Earth
  - Nearest orange dwarf to us is Alpha Centauri B, the nearest star to us

- Charles Choi, Super-Habitable World May Exist Near Earth, Astrobiology Magazine, Mar. 14, 2014

The Best Place for Life

- On a super Earth, in the habitable zone of an orange dwarf (K type) star
- An orange dwarf star lasts twice as long (15 billion years) as our sun
    - Evolution can run for twice as long
- A super Earth is several times more massive than Earth
    - Keep their heat longer + remain volcanically active for lifetime of orange dwarf, molten core produces magnetic field which gives it protection from cosmic rays + solar flares
- Super Earth has stronger gravity than Earth
    - Plate tectonics start when planets are Earth-sized and stops when planets are 5 times Earth mass
- When planet is 1 times Earth mass they have deep oceans + large continents, when planet is 2 times Earth mass you get shallow oceans + island archipelagos
    - Shallow oceans + islands are great for biodiversity

- Ben Miller, The Aliens Are Coming!: The Extraordinary Science Behind Our Search For Life in the Universe

Red Dwarfs

- 40% of all red dwarf stars have a super-Earth orbiting in habitable zone
  - Since there are 160 billion red dwarf stars in Milky Way galaxy, there are tens of billions of habitable planets in Milky Way
  - There could be 100 super-Earths in habitable zones of red dwarfs less than 30 light years from Earth
- Red dwarfs are subject to stellar eruptions + flares which could bathe planet in X-ray or UV radiation which could make life less likely there
- Study done with High Accuracy Radial Velocity Planet Searcher (HARPS) instrument which uses the radial-velocity technique to detect exoplanets and which detected first exoplanet

- Jonathan Amos, Super-Earths In The Billions, BBC News, Mar 28, 2012

Habitable Worlds Around Red Dwarfs

- Red dwarf stars are 1/5th as massive as our Sun + up to 50 times dimmer, are 70% of stars in universe so it should be considered if they could host life
- Kepler shows that > 50% of red dwarfs host rocky planets that are ½ to 4 times mass of Earth
- Due to coolness of red dwarfs their habitable zone is closer than Mercury is to our Sun
    - Such a close habitable zone makes planets in it easy to spot with transit technique
- Habitable world may be tidally locked to its red dwarf leading to 3 possible scenarios
    - World resembles eyeball with night side covered in icy / frozen shell and day side having giant ocean of liquid water being warmed by the sun
    - If world is little bit closer to star it would thaw + become water world
    - If world is little bit farther from star it would freeze + become iceball like Europa but with potential for life under crust
- Red dwarf can go from barely to highly active with UV radiation going up 100-10,000 times which could sterilize planet in habitable zone

- Charles Choi, Eyeball Earths, Astrobiology Magazine, Apr. 25, 2013

Habitability of M-class Red Dwarfs

- Red dwarf stars are smaller, cooler, dimmer and much more common than yellow dwarf stars like our Sun - red dwarfs are 75% of stars in Milky Way
    - On average are 1/3rd the size + 1,000 times dimmer than the Sun which makes it easier to directly image
- > 50% of red dwarfs could have habitable exoplanets
- Habitable zone is much closer to red dwarf star than Mercury is to our Sun
    - From the habitable planet its red dwarf sun in the sky would be 1.5 to 3 times bigger than our Sun is to us, will be very red
    - Planet will probably be tidally locked, with enough atmosphere thick clouds would form on sun facing side of planet preventing solar radiation from scorching its surface and help spread heat all around planet as well as also protecting it from solar flares + UV radiation
    - Best place for life may be under water that provides additional protection
    - Habitable planet could be water world that formed further out in solar system + migrated in
    - Because red dwarf radiates so much less visible light than yellow dwarf, plants on such a world may absorb almost all wavelengths of light + reflect back little light thus appearing black to us
- Life on such a planet may be much much older than life on Earth because red dwarfs have extremely long lifetimes

- Bruce Lieberman, Earth-Like Planets Could be Right Next Door, Air and Space Magazine, Jun. 2013

Habitability of M-class Red Dwarfs

- M-dwarf stars, cooler than our sun, have habitable zones close to their stars, making habitable planets transit frequently and thus increasing their chances of discovery
  - M-dwarf stars are extremely active in early years + nearby planet likely to get hit by high energy radiation making it hard for life to take hold
  - Close orbiting planets unlikely to have water because they form inside the snow line
- But if gas giant / mini-Neptune migrated into habitable zone, it could become viable planet for life
  - First it would have to lose its atmosphere
  - When atmosphere is gone, solid core left behind becomes terrestrial planet + secondary atmosphere forms through volcanic outgassing
  - It would have water since it formed beyond snow line + thus would become water world

- Amanda Doyle, Mini-Neptunes Might Host Life Under Right Conditions, Astrobiology Magazine, Jul. 23, 2015

Current Potential Habitable Exoplanets

- Habitable Exoplanet Catalog
  - http://phl.upr.edu/projects/habitable-exoplanets-catalog

How To Detect Life On a Planet Without Going There

- Biosignature = Any measurable phenomenon that indicates the presence of life
- Look spectroscopically - take chemical fingerprints of planets in habitable zones around stars, look for signatures that indicate presence of life
  - Strongest signature is finding elements like methane, nitrogen, and molecular oxygen that are not in equilibrium
  - Indicates there is biological activity contributing to production of these elements
    - Doesn't tell you anything about the kind of life but is a clue
- If it doesn't have this spectral signature it doesn't have any life on surface
- Could always be life below surface that would go completely undetected by that means

- Life Beyond Earth, Timothy Ferris, 1999

How Spectroscopy Works

- A star emits light, a planet reflects light from star + light comes to us
- A star heats the planet, planet emits this heat as infrared light, you capture this infrared light, split it into separate wavelengths + graph it as spectrum to figure out what atmosphere is made of
- If there are chemicals in atmosphere of planet, they absorb part of infrared light, so where there is an absorption feature in spectrum you know what is in planet's atmosphere
- Particular chemicals absorb certain wavelengths of light, so by collecting light from planet + analyzing spectrum for missing wavelengths we can see what chemicals are in atmosphere of planet

- Melissa Salpietra, Detecting Life Beyond Earth, Nova Science Now, Apr. 1, 2009

Spectroscopy

- Signs of life / biomarkers in Earth's atmosphere
  - Photosynthesis causes high oxygen levels + thick ozone layer, microbes emit methane + NO, seaweeds emit chloroethane gas
- Chemicals in planet's atmosphere affect light passing through it, leaving chemical fingerprints in star's spectrum
- So far we can learn about atmospheres of large hot exoplanets but biomarker signals in their atmospheres will be very weak + hard to detect

- Detecting Biomarkers on Faraway Planets, Astrobiology Magazine, Sep 13, 2013

Spectroscopy False Positives and False Negatives

- Initially felt that presence of oxygen in exoplanet atmosphere was strong + certain sign of presence of biology because oxygen is byproduct of much life + it bonds quickly with other molecules and thus would be undetectable unless it was continuously replenished
- But large amounts of oxygen can be produced without biology under a number of extreme conditions (false positive)
- Earth, for as long as 2 billion years, was inhabited by lifeforms that produced little oxygen that would not be detectable (false negative)

- Marc Kaufman, Rocky Close and Potentially Habitable Planets Around a Dwarf Star, Many Worlds, Jul. 20, 2016

Spectroscopy Methods

- For gas giants orbiting close to host stars
  - Compare spectrum of star when planet is transiting across its surface to spectrum when planet is out of transit - comparing spectra lets you see what elements are in planet's atmosphere
  - Can't be used for rocky planets as atmosphere of rocky planet is much thinner than atmosphere of gas giant + rocky planets orbit farther away from stars making this more difficult to do
- For rocky planets
  - Will need coronograph to block out star light
  - James Webb Space Telescope will only work on atmospheres of massive planets

- Amanda Doyle, What Does the Next Generation Telescope Need to Detect Life?, Astrobiology Magazine, Oct. 23, 2014

Spectroscopy - Project 1640

- Project 1640 uses Hale Telescope to take direct spectra of exoplanets that are not transiting by blocking out starlight, picking out faint specks that are planets, + obtaining their atmospheric spectra
- Works though coordinated operation of an advanced adaptive-optics system, coronograph that optically dims star but not other celestial objects in field of view, imaging spectrograph that records 30 images in rainbow of colors simultaneously, wavefront sensor that distinguishes residual starlight sneaking through coronograph + light from planets thus allowing residual starlight to be filtered out

- Astronomers Observe Planets Orbiting Another Star Like Never Before, Astrobiology Magazine, Mar. 15, 2013

In The Glint of An Eye

- How to directly detect oceans on exoplanets
  - Ocean acts as mirror + bright reflection from such a mirror would, if it could be seen, give that ocean's existence away
  - Optimal moment for seeing it is when a planet's parent star is behind the planet - starlight glancing off an ocean on planet's limb produces glint (specular reflection) that same light glancing off dull rocky surface would not
- Worked on LCROSS observing Earth
- It would be possible using Exo-C instrument now on drawing boards to see glints from oceans on planets around nearby stars

\- Searching For Pale Blue Dots, The Economist, Jan. 10, 2015

The Closest Exoplanet

- Earth-sized planet found around Alpha Centauri B 4.3 light years away
- Alpha Centauri A + B are similar to our Sun, Proxima Centauri is red dwarf
- Mass is 1.13 times that of Earth, star is 93% as massive as Sun, orbits its star every 3.2 Earth days, almost certainly tidally locked, not in habitable zone, must be too hot for life
- First planet with mass similar to Earth found around star like Sun
- Where there is one rocky planet, there are likely to be others - perhaps one in the habitable zone?
- Found with HARPS instrument using radial velocity technique, wobble was 0.5 m/s

- Small, Furry Creatures From Alpha Centauri?, The Economist, Oct. 20, 2012

- Jason Palmer, Exoplanet Around Alpha Centauri is Nearest-Ever, BBC News, Oct 17, 2012

- SuperEarth Found Nearby, Astrobiology Magazine, Oct. 19, 2012

The Closest Exoplanet

- Proxima Centauri
  - Red dwarf star
  - Is unstable therefore producing frequent large solar flares
  - Habitable zone close to star
  - Closest star to our Sun - 4.25 light years away
- Proxima b
  - Orbits Proxima Centauri at 0.05 AU with an orbit of 11.2 days
  - Likely tidally locked to Proxima Centauri
  - Average temperature on planet should allow for liquid water in twilight zone between its sun-facing side and non-sun-facing side
  - Atmosphere could be stripped away by Proxima Centauri's large solar flares
  - Could generate a magnetic field that protects its atmosphere
  - So could be habitable but would not be Earth-like

- John Cramer, The Discovery of Planet Proxima B, Analog, Jan/Feb 2017

Pale Red Dot

- Proxima Centauri
  - Closet star to our sun, 4 light years away
    - 266,000 times as far away as distance from Earth to Sun
  - Is red dwarf / M dwarf star
    - Long lived but small + cool ($1/10^{th}$ power) compared to our sun
    - Most common type of star in galaxy
    - Go through early phases where they send out huge solar flares that could sterilize a close-in planet
- Proxima b is a planet that orbits Proxima Centauri
  - Larger than Earth (at least 1.3 times larger)
  - Small enough to be rocky (so may be rocky)
  - Inside habitable zone so could have liquid water
  - Orbits it every 11 days
  - Probably tidally locked which is obstacle to habitability

- Marc Kaufman, Found: Our Nearest Exoplanet Neighbor, Many Worlds, Aug. 24, 2016

- Marc Kaufman, Proxima b Is Surely Not "Earth=Like" But It's a Research Magnet and Just May be Habitable, Many Worlds, Sep. 12, 2016

The Closest Habitable Exoplanet

- Wolf 1061c is one of 3 planets surrounding the red dwarf star Wolf 1061 which is 14 light years away
- Wolf 1061c is in habitable zone of Wolf 1061
- Is a super-Earth with a mass more than 4 times mass of Earth, could have rocky surface, has orbit of 17.9 days around its sun

First Water World

- GJ 1214b is a water world covered by thick steamy atmosphere that is 40 light years from Earth
- Is a super-Earth 2.7 times Earth's diameter, orbiting a red-dwarf star at a distance of 1.3 million miles every 38 hours, with a temperature of 450 degrees F
- Possibly formed further out from its star, then migrated inward, passing through star's habitable zone

- Hubble Reveals a New Type of Planet, Astrobiology Magazine, Feb. 22, 2012

What Do Other Solar Systems Look Like?

- Our solar system inventory
  - Terrestrial (rocky) planets in close to sun
  - Gas giants (Jupiter + Saturn)
  - Ice giants (Neptune + Uranus)
  - Kupier belt objects / dwarf planets
- Other solar systems do not look like ours
  - Inventory of planet types are in different positions from their star
  - Orbits of planets in these solar systems are very diverse from near circular (like Earth) to very elliptical

Typical Solar System

- Our own solar system is not a model that is repeated elsewhere in galaxy
  - Is unlikely product of gas giant formation followed by resonant period of chaotic Late Heavy Bombardment that happened to place Jupiter at 5.2 AU - far enough out to leave inner system relatively unperturbed so Venus, Earth + Mars could form + have stable orbits in inner region
  - More likely scenario is no gas giants form, instead set of outer planets with masses less than Uranus form, largest of which with 10 Earth-masses orbits at 1.5 AU, probably leaving room for only one inner planet which may or may not be Earth-like + support life

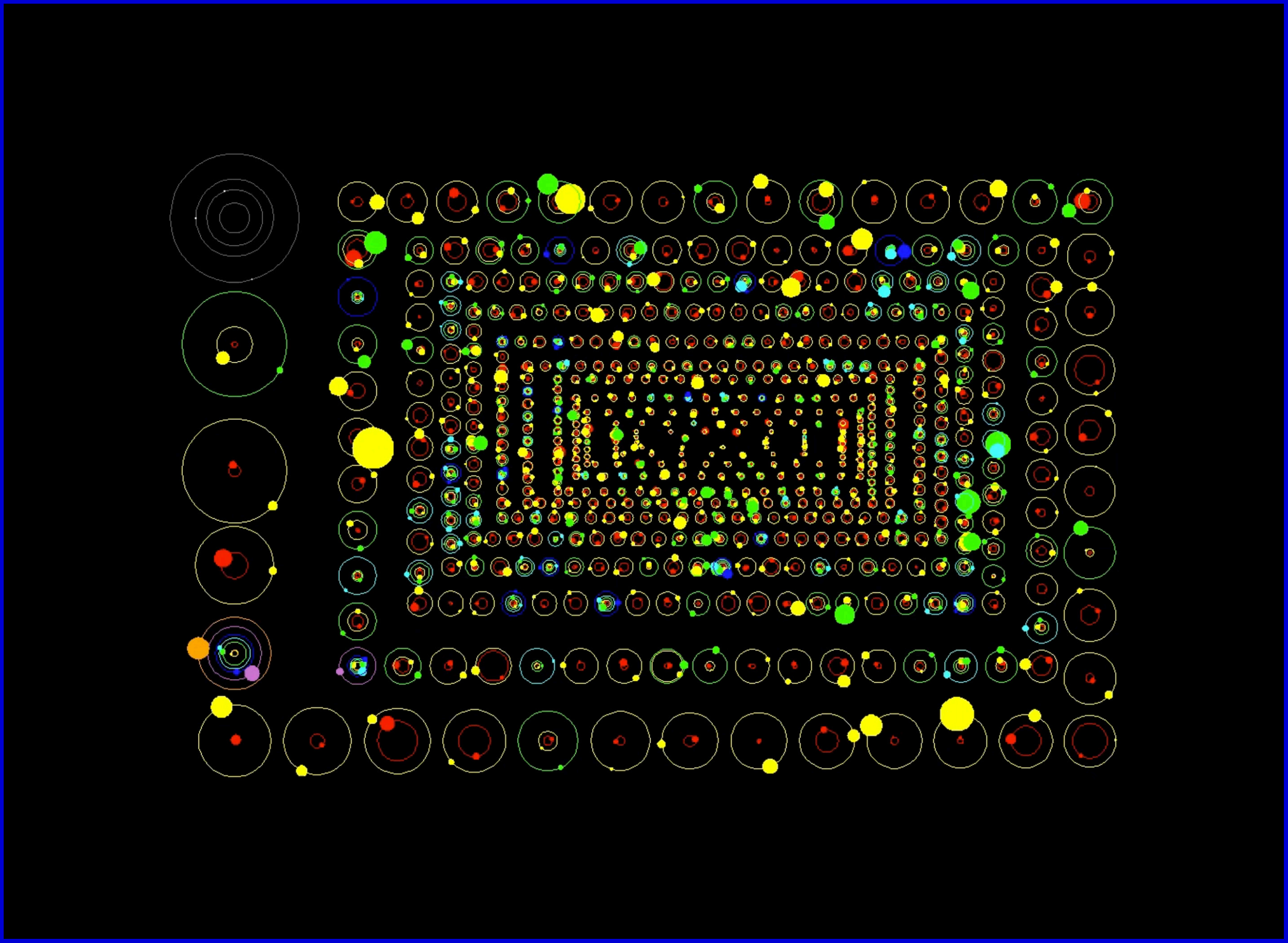
- John Cramer, What is a Typical Solar System? Analog, Dec. 2012

Solar System Models

"We find that the properties of the planets in our solar system are not so significantly special compared to those in exosolar systems to make the solar system extremely rare. The masses and densities are typical, although the lack of a super-Earth-sized planet appears to be somewhat unusual. The orbital locations of our planets seem to be somewhat special but this is most likely due to selection effects and the difficulty in finding planets with a small mass or large orbital period. The mean semi-major axis of observed exoplanets is smaller than the distance of Mercury to the Sun. The relative depletion in mass of the solar system's terrestrial region may be important. The eccentricities are relatively low compared to observed exoplanets, although the observations are biased toward finding high eccentricity planets. The low eccentricity, however, may be expected for multi-planet systems. Thus, the two characteristics of the solar system that we find to be most special are the lack of super-Earths with orbital periods of days to months and the general lack of planets inside of the orbital radius of Mercury."

- Rebeca Martin and Mario Livio, "The Solar System as an Exoplanetary System," The Astrophysical Journal Vol. 810, No. 2 (3 September 2015)

Solar System Models



Model of all the multi-planet systems found by Kepler as of November 2013; our terrestrial planets are shown in grey at the top left for comparison. Credit: NASA/Kepler/Dan Fabricky.

Types of Planets

- Rocky worlds
- Gas giants
- Ice giants
- Lava worlds
- Hot Jupiters - gas giants like Jupiter but orbiting so close to their stars they complete single orbit in days
- Super Earths - several times more massive than Earth but smaller than Uranus + Neptune
- Water worlds

Kepler

- Goal - search for Earth-size planets in habitable zone of stars…these planets will be potentially habitable
- Use transit technique to monitor 100,000 stars like our Sun using photometer attached to 95 megapixel camera
- Need 3 transits to confirm a detection
- Data reveals the planet's
  - Size from brightness change + size of star
  - Orbital period from time between transits
  - Orbital size from mass of star, period, + using Kepler's third law
  - Temperature from planet's orbit + temperature of star
- This data can give the fraction of stars that have planets + distribution of planetary sizes + orbits thus telling us how often planets occur in habitable zones
- For every planet detected there are at least 50 that can't be seen because they are not oriented to make transits possible

- Kepler, NASA's First Mission Capable of Finding Earth-Size Planets, NASA

Kepler Results

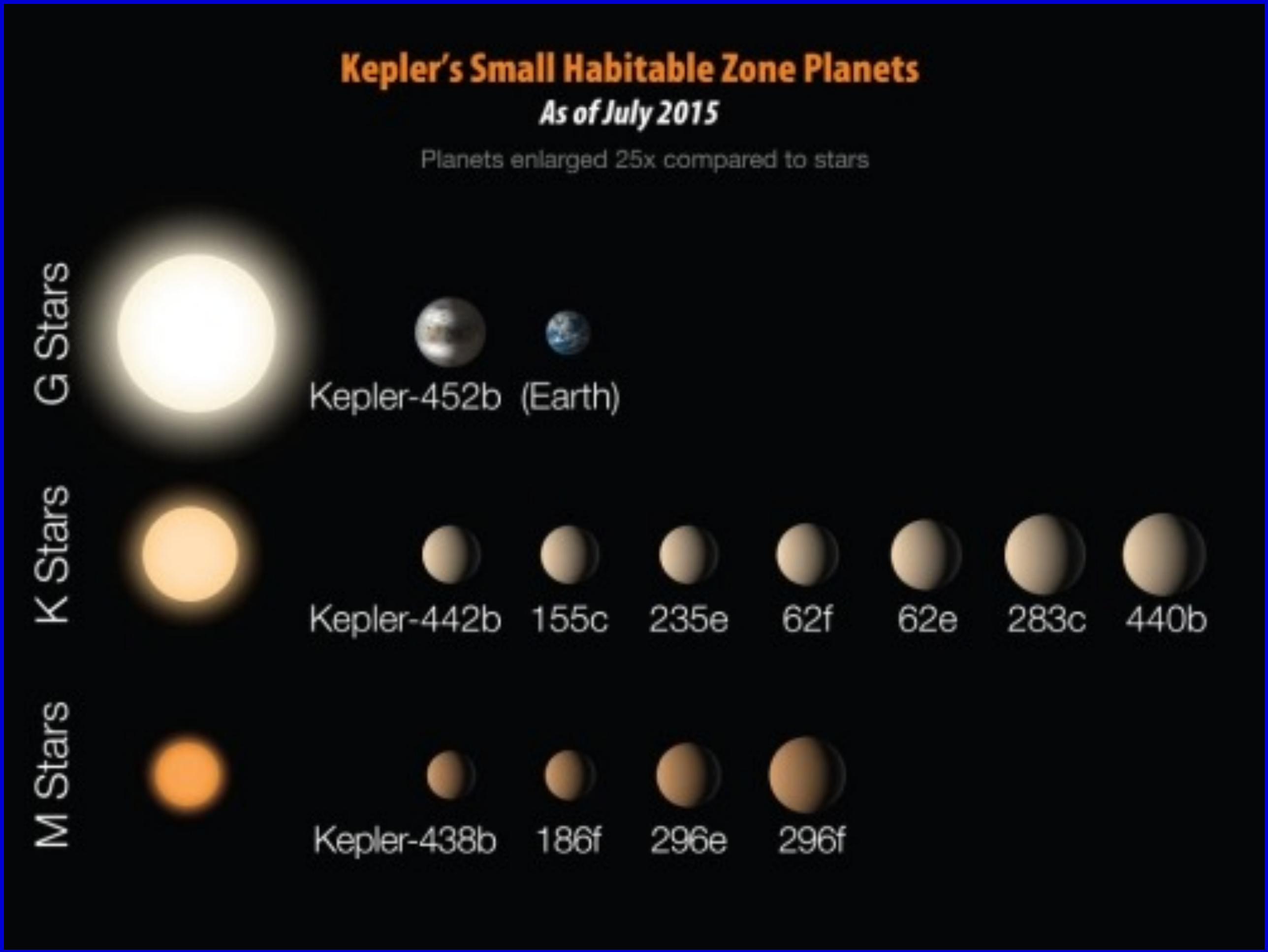
- 20% of Sun-like stars in our galaxy have Earth-sized planets in their habitable zone that are potentially habitable + this result satisfies Kepler's primary mission
  - Closest of these statistically is less than 12 light years from Earth
  - [Remember that 1/5 Sun-like stars = 1/25 of all stars in our galaxy]

- One in Five Stars Has Earth-Sized Planet in Habitable Zone, Astrobiology Magazine, Nov. 4, 2013

Kepler as of May 12, 2015

- We have learned exoplanets are common, most sun-like stars have at least one planet, nature makes planets with unimaginable diversity
- 4,601 candidate exoplanets
- 1,024 confirmed exoplanets
- 8 confirmed small habitable zone exoplanets

- Kepler's Six Years in Science (and Counting): By the Numbers, Astrobiology Magazine, May 14, 2015

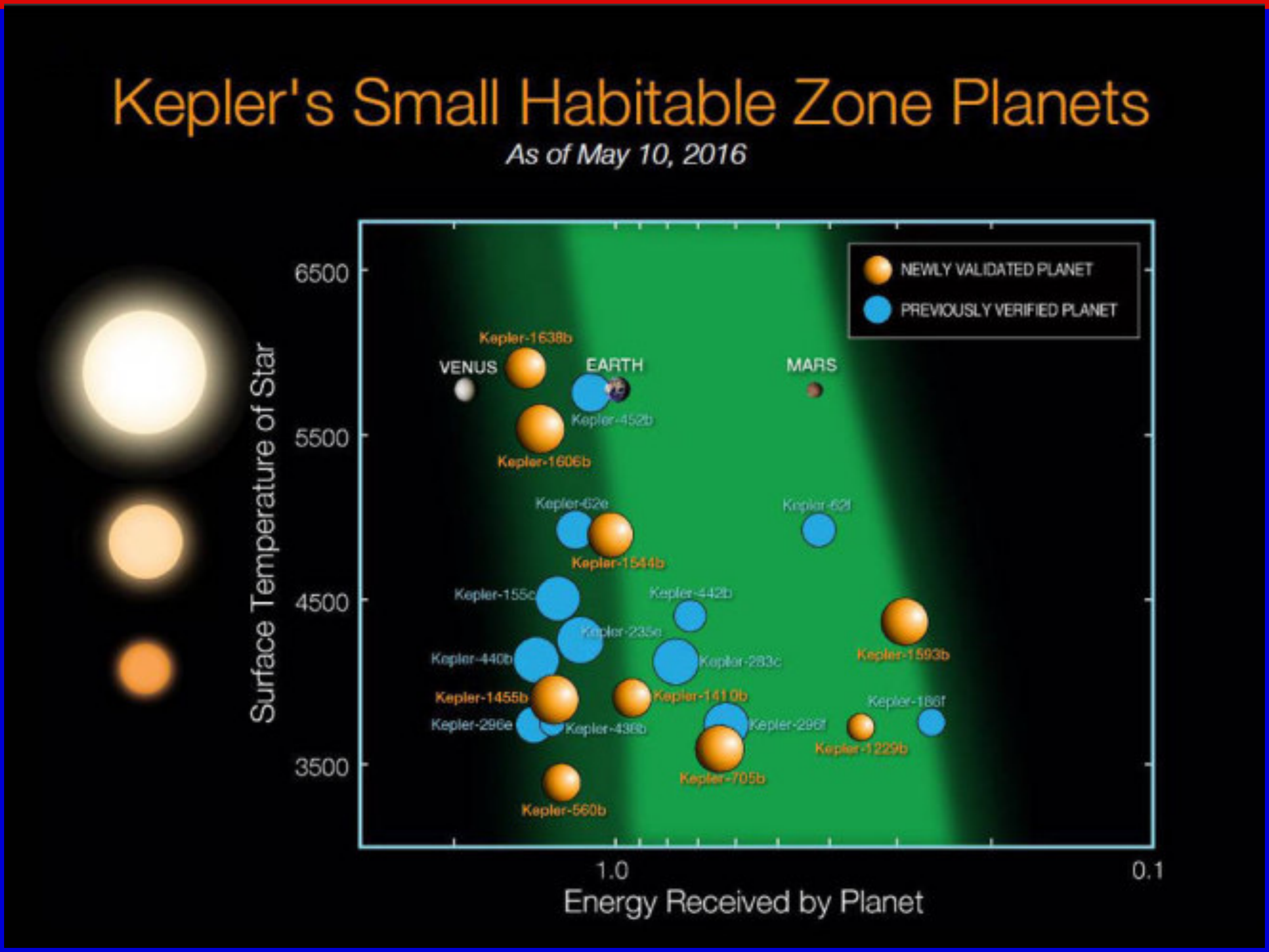


Twelve Exoplanet discoveries from Kepler that are less than twice the size of Earth and reside in the habitable zone of their host star. The sizes of the exoplanets are represented by the size of each sphere. These are arranged by size from left to right, and by the type of star they orbit, from the M stars that are significantly cooler and smaller than the sun, to the K stars that are somewhat cooler and smaller than the sun, to the G stars that include the sun. The sizes of the planets are enlarged by 25X compared to the stars. The Earth is shown for reference. Credits: NASA/JPL-CalTech/R. Hurt

Kepler as of May 10, 2016

- Based on observations + statistics from Kepler, we can expect there are 10 billion relatively small, rocky, and potentially habitable planets in our galaxy, with the closest likely to be 11 light years away
- 2,308 confirmed exoplanets
- 21 confirmed small habitable zone exoplanets
- But exoplanets detected by Kepler are too distant (between 600 - 3,000 light years) for the precise spectroscopic observing follow-up needed to understand their atmospheres + chemical compositions

\- Marc Kaufman, A Flood of Newly Confirmed Exoplanets, Many Worlds, May 10, 2016



Since Kepler launched in 2009, 21 planets less than twice the size of Earth have been discovered in the habitable zones of their stars. The orange spheres represent the nine newly validated planets announcement on May 10, 2016. The blue disks represent the 12 previous known planets. These planets are plotted relative to the temperature of their star and with respect to the amount of energy received from their star in their orbit in Earth units. Credits: NASA Ames/N. Batalha and W. Stenzel

Kepler 2017 Update

- Kepler's final tally of exoplanets
  - 4,034 possible planets - 2,335 have been verified
  - 50 possible planets are Earth-sized + in habitable zone of their stars - more than 30 have been verified
  - 6 confirmed exoplanets are circling within habitable zone of G-dwarf stars like our Sun

- Kepler Has Taught Us That Rocky Exoplanets Are Common, Astrobiology Magazine, Jun. 28, 2017

Kepler

- Kepler-186f - first Earth-size planet orbiting an M-class red dwarf in the habitable zone

- First Earth-Size Planet in the Habitable Zone of Another Star, Astrobiology Magazine, Apr. 4, 2014

Kepler

- Kepler 452b is first near-Earth size planet discovered in habitable zone around sun-like star
  - First planet less than twice size of Earth discovered in habitable zone of G-type star
- Is super-Earth, 60% larger in diameter than Earth, has good chance of being rocky
- Kepler-452 star is 1,400 light years away, is 6 billion years old and is 10% larger / 20% brighter / same temperature as our Sun

\- NASA's Kepler Mission Discovers Bigger, Older Cousin to Earth, Astrobiology Magazine, Jul. 23, 2015

Geoff Marcy on Kepler

- There are 3 main groups of planets
  - Jupiter-like planets that are H + He
  - Water-dominated planets like Uranus + Neptune
  - Rocky planets like Earth, Venus, Mars
- Questions
  - Is there a size at which planets change their nature from water-rich planets like Neptune to rocky planets like Earth?
  - How do you make planets like Earth in universe that has far more water than iron + nickel? Is is possible that Earth is rare in universe?
- Next step
  - Get telescope size of football field to take spectrum of Earth-like planets around nearby stars + look for water, methane, CO2, ozone

- Anil Anathaswarmy, Hunting for the Great Galactic Internet, New Scientist, Apr. 8, 2012

Kepler Results

- Where is boundary between rocky super-Earths + gassy mini-Neptunes
- Around twice diameter of Earth - planets smaller are likely to be rocky with thin or no atmospheres, planets larger are gassy with solid surfaces buried beneath deep blankets of H + He
- Super-Earths with thin atmospheres + low atmospheric pressures could be habitable if they have dry land and are not waterworlds

- Planetology Comes of Age, The Economist, Jan. 11, 2014

Exoplanet Family Tree

- Kepler shows nearly every star has at least one planet larger than Earth and smaller than Neptune
- Majority of these exoplanets come in two types
  - At top end are mini-Neptunes that are mostly gas with cores made of rock + ice
    - Mini-Neptunes are 2-3.5 times diameter of Earth
  - At bottom end are rocky objects with little / no atmosphere = Super Earth
    - Maximum diameter of rocky planets is 1.75 times diameter of Earth
- Jump between rocky planet + mini-Neptune is addition of 1% of planet's mass in form of hydrogen + helium

- Planets Come in Diffent Species, The Economist, Jun. 22, 2017

- New Branch in Family Tree of Exoplanets Discovered, Astrobiology Magazine, Jun. 20, 2017

Example of Successful Detection of Life in Our Universe

- During December 1990 fly-by of Earth by Galileo spacecraft found via spectroscopy evidence of
  - Abundant gaseous oxygen
  - Widely distributed surface pigment with sharp absorption edge in red part of visible spectrum (= evidence of photosynthesis)
  - Atmospheric methane in extreme thermodynamic disequilibrium
- …together these are strongly suggestive of life on Earth
  - "A necessary but not sufficient condition for the presence of life is a marked departure from thermodynamic equilibrium. Once candidate disequilibria are identified, alternative explanations must be eliminated. Life is the hypothesis of last resort…Galileo found such profound departures from equilibrium that the presence of life seems the most probabe cause."
- Also, presence of narrow-band, pulsed, amplitude-modulated radio transmission seems uniquely attributable to intelligence
- These observations are a control experiment for SETI by spacecraft

- Carl Sagan et.al., A Search For Life On Earth From The Galileo Spacecraft, Nature, Oct. 21, 1993

Example of Successful Detection of Habitable Planet in Our Universe

- When viewing Earth from space, how could you tell Earth was habitable - what signatures would you look for?
- LCROSS spacecraft, which had primary mission to look for signature of lunar water, looked briefly at Earth
  - Detected ozone spectroscopically in Earth's atmosphere + liquid water by seeing glint off of Earth's oceans

- Elizabeth Howell, Would Earth Look Like a Habitable Planet From Afar?, Astrobiology Magazine, Jun. 30, 2014

Exomoons

- Moons are just as good a place to look for life as planets are
- Currently being searched for in the Kepler data - Hunt for Exomoons with Kepler (HEK)
- Tidally heated exomoons (Super-Ios) may be visible with James Webb Space Telescope

- A Harvest of New Moons, The Economist, Nov. 10, 2012

Habitability of Exomoons

- Because they orbit a larger planetary body, exomoons have additional set of constraints on habitability compared to exoplanets
  - Exomoons have additional sources of energy that alter their energy budget that can raise their temperature too high
  - Typically stellar illumination is greatest source of energy on a moon - but if moon orbits its host planet closely, the planet's stellar reflection, its thermal emission, eclipses, + tidal heating in moon can be significant
- Habitable edge of exomoon is innermost orbit in which exomoon will not undergo a runaway greenhouse effect
- To be considered habitable, exomoon must meet the criteria for a habitable planet
  - Must have liquid surface water, long-lived substantial atmosphere, magnetic field to protect it from solar radiation or from charged particles created in a Jupiter-like planet's magnetosphere…and to have these qualities a habitable exomoon will have to be more on the size of Earth

- Adam Hadhazy, The Habitable Edge of Exomoons, Astrobiology Magazine, Mar. 4, 2013

- Elizabeth Howell, Exomoons Could Be Abundant Sources of Habitability, Astrobiology Magazine, Oct. 20, 2014

Transiting Exoplanet Survey Satellite (TESS)

- Uses array of telescopes to perform all-sky survey to discover transiting exoplanets - from Earth-size to gas giants - in orbit around hundreds of thousands of nearest + brightest stars
  - Mainly looking at M-class Red Dwarf stars
- Goal is to find terrestrial planets in habitable zones of nearby stars
- Then follow-up handful of these potential Earth-like planets using James Webb Space Telescope to look at their atmospheres for signs of life

- NASA Selects Exoplanet Satellite for Next Explorer-Class Mission, Astrobiology Magazine, Apr. 10, 2013

- Life After Kepler: Upcoming Exoplanet Missions, Astrobiology Magazine, Nov. 9, 2013

Kepler vs. TESS

- Kepler
  - Used transit method
  - Looked at narrow field of view
  - Looked at stars 600-3,000 light years away
  - Taught us that every star system has at least 1 planet around it
- TESS
  - Uses transit method
  - Looks at wide field of view, will end up studying 85% of sky which is area 350 times greater than Kepler
  - Looks at stars less than 300 light years away
  - Provides cueing for ground and space based telescopes to further study these close exoplanets for evidence of habitability / life
  - Hope to find 20,000 exoplanets, with ~ 500 exoplanets less than twice size of Earth and dozens of exoplanets the size of Earth

\- Paul Gilster, TESS: Concluding First Year of Observations, Centauri Dreams, Jul 26 2019

Starshade

- Starshade - blocks light from star, allowing space telescope to avoid star's glare + peer into planets in orbit around it + look for signs of alien life
  - Starshade would be launched in concert with a space telescope, would be 34m in diameter, would be 50,000 km from the telescope
- Needed because Sun-like star is 10 billion times brighter than Earth-sized planet
- Want to identify gases in planet's atmosphere + detect chemicals that suggest presence of life - oxygen one of most promising biosignatures
- When planet passes in front of star, starlight penetrates atmosphere around planet, molecules in atmosphere absorb specific wavelengths of light, depending on what molecules are, so by measuring what wavelengths are absorbed, the gases in atmosphere can be identified
  - James Webb Space Telescope will use this transit technique to conceivably detect biosignatures in planetary atmospheres - but only for planets around M-class Red Dwarfs, not for planets around stars like our Sun
  - The Starshade would let you look for biosignatures in planetary atmospheres for planets around stars like our Sun
- Could first be used with WFIRST telescope

- Marcus Woo, To Find Aliens We Need to Build a Giant Space Parasol, BBC, Nov. 16, 2015

Life in the Universe

- 3 prerequisites for life in our solar system - chemical building blocks, energy, liquids - and these are widespread in our solar system
- Are they widespread in the universe?
  - Hubble Space Telescope lets us see stellar nurseries, inside these nurseries we see solar systems forming, in some of these we see C O H, the three key elements needed to make chemical building blocks of life

- Finding Life Beyond Earth, PBS Nova, Oct. 19, 2011

Is There Life in the Universe?

- Where do habitable planets come from?
  - Within gas clouds composed primarily of H and He, stars form by gravity from gas and dust
  - 80% of young stars have protoplanetary disks from which planets form, dust and gas congeals into planets
  - Planets grow larger from collisions amongst planetismals (planetismals are kilometer sized comets and asteroids)
  - Asteroids and comets bring water to planets (= Heavy bombardment period in first 100 years of solar system)
- Finding Earth-like planets
  - Habitable planets have liquid water and a planet that can have liquid water is said to be in a star's habitable zone
  - Kepler looks at 100,000 stars for transiting Earths
- Extremophiles (think Yellowstone) show that life
  - Tolerates heat or cold
  - Thrives in acidic or alkaline environments
  - Takes food from a variety of sources
  - Copes with intense or no solar radiation
- So liquid water leads to life and primitive life (think single cell) is common in the universe
- Recipe for microbial life
  - Planets ~ Organic molecules ~ Water ~ Energy (stars, tidal, geothermal)
- Primitive life is common in the universe

Rare Earth Hypothesis

- Simple (bacterial) life is very common in universe
- Complex life (multicellular life forms, or animals - let alone intelligent life) is very rare

What do we need to take into account when looking for a planet with life according to Rare Earth Hypothesis?

- 1. Proper distance from the star
  - Distance from Sun helps determine presence of liquid water
  - You need a solvent (water)
- 2. Proper distance from the center of the galaxy
  - Density of stars near the center of the galaxy is so high that the amount of cosmic radiation in that area would prevent the development of life
  - Stay away from supernovae

What do we need to take into account when looking for a planet with life according to Rare Earth Hypothesis? (continued)

- 3. Star of the proper mass
  - A too-massive star would emit too much UV energy, preventing the development of life
  - A star that is too small would require the planet to be closer to it (in order to maintain liquid water)
    - But such a close distance would result in tidal locking
    - In this case one side becomes too hot, the other too cold, and the planet's atmosphere escapes
  - If too large, burn too fast, have too short a lifetime
  - If too small may not have enough energy to power photosynthesis, may be too small to hang on to rocky bodies
- 4. A proper mass
  - A planet that is too small will not be able to maintain any atmosphere
  - A planet that is too massive would attract a larger number of asteroids, increasing the chances of life-destroying cataclysms

What do we need to take into account when looking for a planet with life according to Rare Earth Hypothesis? (continued)

- 5. Oceans
  - Must have liquid water
  - On the other hand, too much water (i.e. a planet with little or no land) will lead to unstable atmosphere, unfit for maintaining life
- 6. A constant energy output from the star
  - If the star's energy output suddenly decreases, all the water on the planet would freeze.
    - This situation is irreversible, since when the star resumes its normal energy output, the planet's white surface will reflect most of this energy, and the ice will never melt
  - Conversely, if star's energy output increases for a short while, all the oceans will evaporate + result would be an irreversible greenhouse effect, disallowing the reformation of the oceans
  - If sun takes year off + you freeze over may not be able to melt ice again
  - If you get greenhouse effect and oceans boil off you may not get them back

What do we need to take into account when looking for a planet with life according to Rare Earth Hypothesis? (continued)

- 7. Successful evolution
  - Even if all of these conditions hold and "simple" life evolves (which probably happens even if some of these conditions aren't met), this still does not imply that the result is animal (multicellular) life
- 8. Avoiding disasters
  - Potential disasters include the supernovae of a nearby star, a massive asteroid impact, drastic changes in climate, etc.

- The above seem reasonable but you also need
  - Jupiter like planet - takes hits for you from comets and meteorites
  - Large nearby moon - stabilizes our obliquity -> stabilizes our climates and seasons
  - Plate tectonics - recycle greenhouse gases

Is Intelligent Life Common?
Rare Earth Hypothesis

- Major argument against there being many intelligent civilizations
  - Need a long period of time without a catastrophic event to evolve from bacterium to intelligence
  - Took 500 million years on Earth (from Cambrian explosion until today)

- Origins, PBS Nova, Sept. 28+29, 2004

"There are maybe 30 million species on the planet today-10 to 30 million. If we look at the fossils, there are hundreds of millions of species in the past. And one time on Earth has intelligence arisen to the point where we can build a radio telescope (which is the definition of intelligence to a radio astronomer). One time out of hundreds of millions of possibilities. That's an astronomically small number of intelligences that have arisen-just one."

- Peter Ward, paleontologist

Is Intelligent Life Common?
Rare Earth Hypothesis

- Galaxies have habitable zones
  - As you get towards center of galaxy (50% of stars), neighborhood gets dangerous…
    - Oort Clouds get bigger + denser => increased bombardment
    - Gamma ray bursts, supernovae, black holes, energetics, sterilization events all increase
  - As you go towards edge of galaxy you run out of heavy elements needed to make habitable planet
- Need temperature stability, low impact rate, Earth System Science to sustain life of planet
- Earth-like planet is moment in time
  - Earth-like planet not only geography but is time - planets start uninhabitable, become habitable if lucky, become uninhabitable again
    - Mars is great example - probably had water + plate tectonics to begin, but this lasted for ~ 100 million years

- Origins, PBS Nova, Sept. 28+29, 2004

Is Intelligent Life Common?
Rare Earth Hypothesis

- What do you need to make intelligent life?
  - Sun that is large enough to give constant source of energy over time, but not so large it burns out quickly
    - This excludes tiny stars, big stars, double stars…as well as center of galaxies…so we are down to 10% of stars in a galaxy
  - Plate tectonics helps Earth maintain constant temperature…and it is probably rare

- Origins, PBS Nova, Sept. 28+29, 2004

Geology is Destiny
Rare Earth Hypothesis - 1

"Earth got lucky early. Fossil evidence suggests that microbial life was already inhabiting the Earth as early as 3.8 billion years ago - only 700 million years after the planet collapsed into existence, and a geological instant after the end of a rain of comets and asteroids that brought just the right amount of precious water in the form of ice from the outer solar system to what would otherwise be a dry planet, astronomers say. "The question of whether the Earth is unique because of its water abundance is perhaps the most interesting one in the arsenal of Rare Earth arguments," said Dr. Kasting, who explained that calculations showed that the planet could have easily had too much or too little water.

The planet has remained comfortable ever since thanks to a geological feedback process, by which weather, oceans and volcanoes act as a thermostat. Known as the carbonate silicate cycle, it regulates the amount of carbon dioxide in the atmosphere, where it acts like a greenhouse - trapping heat and keeping the planet temperate and mostly stable. Rain washes the gas out of the air and under the ocean; volcanoes disgorge it again from the underworld.

Without greenhouse gases and this cycle - which Dr. Brownlee called "this magic thing" - the Earth would have frozen into a snowball back in its early days when the Sun was only 70 percent as bright as it is now. Still, with all this magic, it took four billion years for animal life to appear on the Earth.

The seeds for animal life were sown sometime in the dim past when some bacterium learned to use sunlight to split water molecules and produce oxygen and sugar - photosynthesis, in short. The results began to kick in 2.4 billion years ago when the amount of oxygen in the atmosphere began to rise dramatically.

- Dennis Overbye, Hot on Trail of 'Just Right' Far Off Planet, New York Times, December 2, 2011

Geology is Destiny
Rare Earth Hypothesis - 2

The Great Oxidation Event, as it is called in geology, "was clearly the biggest event in the history of the biosphere," said Dr. Ward from Washington. It culminated in what is known as the Cambrian explosion, about 550 million years ago, when multicellular creatures, that is to say, animals, appeared in sudden splendiferous profusion in the fossil record. We were off to the Darwinian races. Whatever happened to cause this flowering of species helped elevate Earth someplace special, say the Rare Earthers. Paleontologists argue about whether it could have been a spell of bad climate known as Snowball Earth, the breakup of a previous supercontinent, or something else.

In other words, alien planets that have been lucky enough to be habitable in the first place might have to be lucky again. "The big hurdle" for other planets, said Dr. Brownlee, is to have some event or series of events to trigger their own "Cambrian-like" explosions.

Eventually though, Earth's luck will run out. As the Sun ages it will get brighter, astronomers say, increasing the weathering and washing away of carbon dioxide. At the same time, as the interior of the Earth cools, volcanic activity will gradually subside, cutting off the replenishing of the greenhouse gas.

A billion years from now, Dr. Brownlee said, there will not be enough carbon dioxide left to support photosynthesis, that is to say, the oxygen we breathe.

And so much for us.

"Even Earth, wonderful and special as it is, will only have animal life for one billion years," Dr. Brownlee said."

- Dennis Overbye, Hot on Trail of 'Just Right' Far Off Planet, New York Times, December 2, 2011

Rare Earth Hypothesis

- Rare Earth Equation
  - New version Drake Equation with additional factors for
    - Fraction of planets with a large moon
    - Fraction of planetary systems with Jupiter-sized planets
    - Fraction of planets with critically low number of mass extinctions
  - Also assigns very low numbers to
    - How often intelligence would develop
    - Length of time communicating intelligences would last
  - Bottom line - while odds are that intelligent life must exist somewhere, the universe is so large, for all intents + purposes we are alone

    - Finding Life Beyond Earth, PBS Nova, Oct. 19, 2011

    [from - Peter Ward and Donald Brownlee, Rare Earth Why Complex Life is Uncommon in the Universe]

Rare Earth Equation

- **N = N* x ne x fg x fp x fpm x fi x fc x fxl x fm x fj x fme**

- N = the number of Earth-like planets in the Milky Way having complex life forms
- N* = the number of stars in the Milky Way. N* is at least 100 billion, and may be as high as 500 billion, if there are many low visibility stars
- ne = the average number of planets in a star's habitable zone. This zone is fairly narrow, because constrained by the requirement that the average planetary temperature be consistent with water remaining liquid throughout the time required for complex life to evolve. Thus ne = 1 is a likely upper bound
- fg = the fraction of stars in the galactic habitable zone - estimate this factor as 0.1
- fp = the fraction of stars in the Milky Way with planets
- fpm = the fraction of planets that are rocky ("metallic") rather than gaseous
- fi = the fraction of habitable planets where microbial life arises - unlikely to be small
- fc = the fraction of planets where complex life evolves. For 80% of the time since microbial life first appeared on the Earth, there was only bacterial life - this fraction may be very small
- fl = the fraction of the total lifespan of a planet during which complex life is present. Complex life cannot endure indefinitely, because the energy put out by the sort of star that allows complex life to emerge gradually rises, and the central star eventually becomes a red giant, engulfing all planets in the planetary habitable zone. Also, given enough time, a catastrophic extinction of all complex life becomes ever more likely
- fm = the fraction of habitable planets with a large moon. If the giant impact theory of the Moon's origin is correct, this fraction is small
- fj = the fraction of planetary systems with large Jovian planets. This fraction could be large
- fme = the fraction of planets with a sufficiently low number of extinction events - low number of such events the Earth has experienced since the Cambrian explosion may be unusual, in which case this fraction would be small

- Assume N* x ne = 5 x 10E11. The Rare Earth hypothesis can then be viewed as asserting that the product of the other nine Rare Earth equation factors, which are all fractions, is no greater than 10E–10 and could plausibly be as small as 10E–12. In the latter case, N could be as small as 0 or 1

- Note: Rare Earth equation, unlike the Drake equation, does not factor the probability that complex life evolves into intelligent life that discovers technology

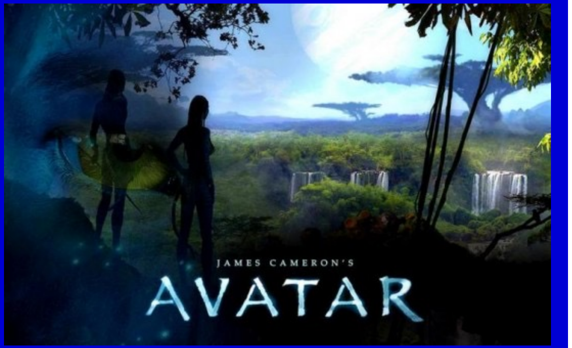
Threats to Intelligent Life

- A short burst (< 2 seconds) of gamma-ray energy hit the Earth in 774 / 775 AD according to tree ring data
- Could be due to collision of two compact stellar remnants - black holes, neutron stars, white dwarfs
- The two merging stars could not have been closer than 3,000 light years to Earth or it would have led to extinction of some life on Earth

- Did an 8th Century Gamma Ray burst Zap Earth?, Astrobiology Magazine, Jan. 1, 2013

Focused Case Study - Pandora

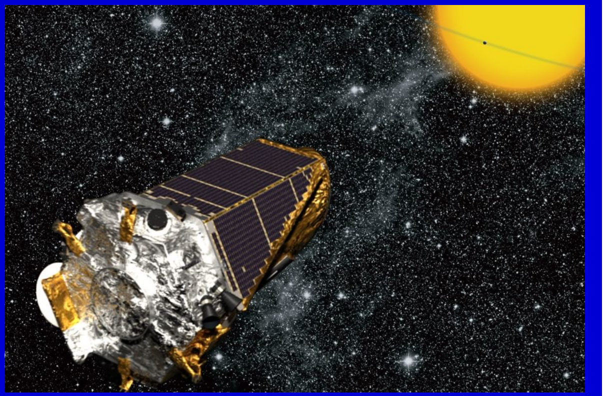
- Location
  - Moon of gas giant planet Polyphemus which orbits star Alpha Centauri A which is 4.4 light years from Earth
  - Alpha Centauri is trinary star system + our Sun's closest stellar neighbor - Alpha Centauri A + B are Sun-like, Proxima Centauri is red dwarf
  - Polyphemus is same distance from Alpha Centauri A as Earth is from our Sun, has 14 moons
  - Pandora is moon of Polyphemus, is size of Earth
- Water
- Atmosphere
  - N-O atmosphere is 20% denser than Earth's due to 5.5% of it being Xe, > 18% CO_2, also contains H_2S
  - Gravity is 80% of Earth's
- Temperature
- Magnetic fields
  - Liquid iron core creates a dipole but its strength is magnified by unobtainium
  - Shields surface from cosmic rays
- Geologic activity
  - Liquid iron core, plastic mantle, semirigid crust
  - Tidal heating from Polyphemus + 2 closest moons to Pandora leads to rapid continental drift which creates intense vulcanism + fractures large continents into small continents thus moderating moon's weather
  - Unobtanium and its superconducting magnetic properties create remarkable geological formations such as Hallelujah Mountains + Stone Arches
- Life
  - Teeming with intelligent + unintelligent life
- Miscellaneous
  - Biosignature was spectroscopic detection of atmosphere containing O in a concentration nearly equal to that of Earth



- Maria Wilhelm + Dirk Mathison, Avatar: A Confidential Report on the Biological and Social History of Pandora

Case Study Summary - Kepler

- Goal
  - To find Earth-size planets in habitable zones
  - Aims to tell us the frequency of Earths - how common are Earth-size planets in Earth-like orbits about Sun-like stars
  - Can detect Earth clones if they exist in habitable zone of Sun-like stars
- Center of Gravity (Strategy)
  - Neighborhood for cosmic census = patch of sky 20 full moons across near Northern Cross in constellations Cygnus + Lyra, containing 4.5 million stars that are hundreds to thousands of light years away
  - Measures brightness of 156,000 of those stars every half hour, looking for dips in light of stars caused by transits
- Equipment
  - Has 1 meter telescope
  - Field of view is 10 degrees x 10 degrees
  - Camera is 95 megapixels
  - Takes a picture of 100,000 stars, every minute, for 4 years
- Training ~ Leadership ~ Morale
- Tactics
- Intangibles
  - Kepler now providing cueing data for SETI's Allen Telescope Array
- Mistakes
- Outcome
  - Lost 2 of 4 reaction wheels by May 2013 so primary mission terminated
  - K2 Mission extension will look for planets around M-class red dwarfs



From NASA

- Dennis Overbye, Gazing Afar for Other Earths, and Other Beings, New York Times, Jan 30, 2011

Case Study Summary - Juno

- Goal
  - Answer the questions - When and where was Jupiter formed? Does it have a rocky core? Is there water deep in its atmosphere?
- Center of Gravity (Strategy)
  - Perform polar orbit of Jupiter
- Equipment
  - Satellite - especially computers - in titanium vault to protect them from Jupiter's radiation
- Training ~ Leadership ~ Morale
  - Scott Bolton
- Tactics
  - Short lifetime due to Jupiter's harsh environment means gather data up front in mission
- Intangibles
  - Sun made almost entirely of H and He
  - Jupiter is first planet formed after Sun, made up largely of H and He but also has C, N, P, some gases
  - If Jupiter has rocky core, it most likely began as small planetesimal + then pulled in + kept massive amounts of gas + dust
  - If Jupiter does not have rocky core, it is most likely failed star collapse that didn't have mass to become star that formed through gravitational collapse that didn't have the mass to become a star
  - Amount of water present will provide clue whether it was formed inside or outside ice line of solar system + whether it has migrated in position in solar system
- Mistakes
  - N/A
- Outcome
  - Results important to exoplanet scientists as well as planetary scientist

- Marc Kaufman, Juno Jupiter and Exo-Jupiters, Many Worlds, Jun. 24 2016

Case Study Summary - James Webb Space Telescope (JWST)

- Goal
  - Identify habitable worlds
- Center of Gravity (Strategy)
  - Detect potential biosignatures in atmosphere of Earth-like planets orbiting nearby stars
- Equipment
  - 6.5 m mirror looking in the long wavelength visible to the mid-infrared
  - Because of its size, will be first chance of studying atmospheres of potentially habitable Earth-like worlds
- Training ~ Leadership ~ Morale
  - Pre-mission modeling of atmospheric fingerprints of potential alien worlds
- Tactics
  - Transiting Exoplanet Survey Satellite (TESS) will find a pool of transiting Earth-sized + super-Earth planets
  - JWST will study these super-Earth's orbiting stars smaller than our Sun (M-class Red Dwarfs)
  - TESS will discover + JWST will characterize (spectroscopically analyze)
  - Look for biosignatures of liquid water + atmospheric gases like O2 that would indicate presence of life
- Intangibles
  - Will require hundreds of hours of observation to study each atmospheric signature so number that can be studied will be small
  - Also will be used to probe mysteries of galaxy formation + dark matter
  - Located at L2, 1 million miles from Earth so can't be serviced, designed for 5 years but may last 10 years
- Mistakes
  - Underestimated complexity of construction
- Outcome
  - Pending

- James Webb and the Search for Life Beyond Earth, Astrobiology Magazine, Jul. 15, 2014
- Alexandra Wolfe, An Astrophysicist in Search of E.T., Wall Street Journal, Aug. 21, 2014
- Johnny Bontemps, Guiding Our Search for Life on Other Earths, Astrobiology Magazine, Feb. 15, 2015

Computing Case Study Summary - No Man's Sky

- Goal
  - Create a vast digital cosmos that humans can explore while finding their own existential purpose
- Center of Gravity (Strategy)
  - Through science of procedural generation, make a program that allows a universe to create itself
- Technology / Equipment
  - For PC and PlayStation 4
- Training ~ Leadership
  - Sean Murray
- Morale
  - Of the 12 developers - great
- Tactics
  - Procedural generation of the universe
  - 600,000 lines of code ~ Provides unified mathematical framework for all phenomena
  - Uses real physics most of the time
  - Entire universe exists at moment of its creation but is only revealed when there is a player present to witness it
- Intangibles

  "What are the chances that we are living in a simulation?" - Elon Musk to Sean Murray
- Mistakes
  - How do you balance gameplay between survival + joy of exploration?
- Outcome
  - 18,446,744,073,709,551,616 unique planets

  "A team of programmers has built a self-generating cosmos, and even they don't know what's hiding in its vast reaches"

  - Roc Morin, Inside the Artificial Universe That Creates Itself, The Atlantic, Feb. 19, 2016

  - Raffi Khatchadourian, World Without End, New Yorker, May 18, 2015

Personal Case Study - Name

- Role
- Story

Astrobiology Analog Case Study - Rare Earth Requirement

- Location
  - Grand Tetons National Park
- Story
  - Great example of plate tectonics

Drake Equation

$$N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

- N = The number of communicative civilizations
- R* = The rate of formation of suitable stars (stars such as our Sun)
- fp = The fraction of those stars with planets. (Current evidence indicates that planetary systems may be common for stars like the Sun.)
- ne = The number of Earth-like worlds per planetary system
- fl = The fraction of those Earth-like planets where life actually develops
- fi = The fraction of life sites where intelligence develops
- fc = The fraction of communicative planets (those on which electromagnetic communications technology develops)
- L = The "lifetime" of communicating civilizations

Class Simulation

- Topic aspects

Poem

Slide text

Questions for Further Discussion

- What is an exoplanet?
- What are the different methods of exoplanet detection and the advantages + disadvantages of each?
- Once you find an exoplanet, how do you look for signs of life on it?
- Is evolution predictable? Is it contingent and / or convergent?
- Will life on other planets (and moons) outside our solar system look like life on Earth?
- According to the Rare Earth Hypothesis, is intelligent life common or uncommon in the universe, and why?
- Are we the biologic center of the universe?
- Do you believe in the Rare Earth Hypothesis? Is life rare in the universe?
- Are we alone? What's our place in this universe? How do we fit in? Are we just run of the mill? Are we totally exceptional? Or are we somewhere in between?
- Where would you search for life - unintelligent + intelligent - in the universe?
- Analyze an exoplanet all of us have been to - Pandora in the movie Avatar

Reading Assignments

- Astrobiology Primer 2.0 (2016) Chapter 7
  - https://doi.org/10.1089/ast.2015.1460
- TED Talks for this Topic
  - http://www.astrobiologysurvey.org/ToLearnMore.html

Recommended Reading to Learn More

- Non-fiction
  - Wayne Douglas Barlowe - Expedition
  - Karl Kofoed - Galactic Geographic Annual 3003
- Fiction
  - Arthur C. Clarke - Rendezvous With Rama
- Movies
  - Avatar
- Simulations

Conclusion

"If you want to look back to what we remember from hundreds of years ago, inevitably it is the great explorers. Christopher Columbus didn't know what he was going to find, and he came across North America. Many of us working in the field of exoplanets believe that thousands of years from now, when people look back at our generation in the early 21st century, they will remember the discovery of other Earths as one of our most significant accomplishments. "

- Sara Seager, astronomer

Topic 7

Impact Events
(The Good, the Bad, and the Ugly)

Song

…And we will all go together when we go.
What a comforting fact that is to know.
Universal bereavement,
An inspiring achievement,
Yes, we all will go together when we go.

We will all go together when we go.
All suffuse with an incandescent glow.
No one will have the endurance
To collect on his insurance,
Lloyd's of London will be loaded when they go.

Oh we will all fry together when we fry.
We'll be french fried potatoes by and by.
There will be no more misery
When the world is our rotisserie,
Yes, we will all fry together when we fry.

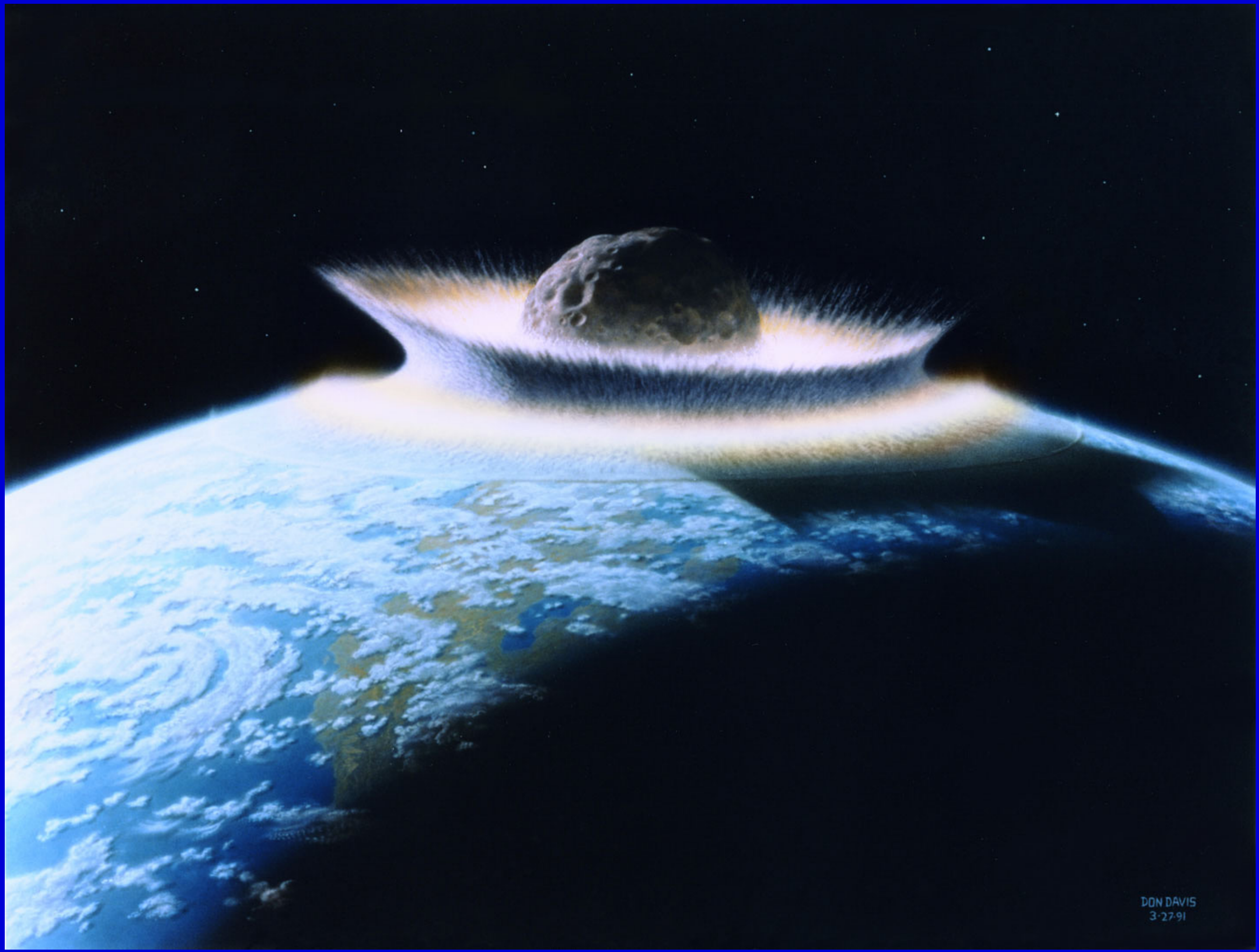
…And we will all bake together when we bake.
There'll be nobody present at the wake.
With complete participation
In that grand incineration,
Nearly three billion hunks of well-done steak.
- Tom Lehrer, We'll All Go Together When We Go

Thematic Quote

"The odds of a space-object strike during your lifetime may be no more than the odds you will die in a plane crash - but with space rocks, it's like the entire human race is riding on the plane."

- Nathan Myhrvold, physicist

The Painting



Big Impact

- Don Davis

(NASA)

Artifact

- Name
  - Meteorite
- Year
- Story

The Question

Do we have the moral and ethical authority to interrupt the process of evolution if we are faced with another K-T (asteroid extinction) event or should we let nature take its course?

- David Morrison, NASA Astrobiology Institute

Panspermia

- Definition - transport of microorganisms between planets and solar systems
- First mentioned by Anaxagoras, a Greek philosopher, in 5^{th} Century BC
- Scientific theory is 100 years old
  - Theory asks can bacterial spores survive in space and be transported by radiation pressure of a star?
- Note this theory may explain where life comes from but it doesn't explain how life begins

Panspermia

- Experiments show bacteria can't survive in space
- But can bacteria that live inside rocks (lithopanspermia) survive a journey through space?
  - Organism must first escape planet it is on via surviving meteorite impact + escape velocity / ejection from planet
    - Experiments suggest yes
  - Organism must survive in space from solar UV radiation, cosmic radiation and vacuum, extreme temperatures, microgravity, long time
    - Experiments show a few centimeters of meteorite can protect spores from solar UV radiation
    - Experiments show galactic cosmic radiation can kill spores so you need 1-2 meters of meteorite shielding to protect them
  - Organism must survive reentry / landing
    - Meteorites keep their cold interior after reentry (i.e. interior of meteorite does not heat up on reentry)

Panspermia

- So in conclusion
  - Original panspermia hypothesis not true - > because bacterial spores are killed by solar UV radiation
  - But lithopanspermia may be true
    - Meteorites of a few cm thick can shield against solar UV radiation
      - But not galactic cosmic radiation - for that you need 2 meters of shielding
        - And these types of large meteorites occurred, especially during heavy bombardment period
  - Therefore planets are not isolated bodies anymore

Panspermia

- Primary question - what is the potential for survival, adaptation, and biological evolution in the atmosphere and beyond (outer space - another planet)?
- First step is to determine if terrestrial life can survive and live away from Earth's surface [survive = not die]
  - In atmosphere? In space? On another planet?
- Why bother with this issue
  - Evolutionary questions
    - Origin of life on Earth and how did early life survive on Earth when we didn't have O2 or ozone layer and environment was more inhospitable?
    - Panspermia, or are we really Martians?
  - What is the extent of the biosphere
    - We know it extends kilometers beneath Earth's surface
    - We do not know how high it extends - if organisms get thrown up into atmosphere can they multiply and thrive or just survive?

What is Panspermia

- Living organisms travel throughout universe and develop wherever and whenever the environment is favorable
  - Criticisms
    - It cannot be experimentally tested
    - It does not answer question of origin of life
    - Life will not survive long exposure to the hostile environment of intergalactic space
      - It is dry and dessicated, you have to have no metabolism, you can't repair yourself -> organism will die
      - You get exposed to radiation, get a lot of it over time
- The transport of life from one planet to another
  - Need to travel from the surface through the atmosphere and into space
- Note that panspermia is not the travel of life from star to star because life will not survive long exposure to hostile environment of intergalactic space

Panspermia

- How to do interplanetary space travel
  - Meteorites (natural) = lithopanspermia
  - Satellites (artificial)
- Microbes (viruses, bacteria, spores) have been flown + exposed to space environment
  - All died instantly except spores
    - Spore = organism shuts down, dehydrates, puts them in capsule
    - Spore is in suspended animation so spore is dessication resistant, UV radiation resistant, hard radiation resistant

Early Bombardment

- Late heavy bombardment occurred 3.9 billion years ago
- Earth not necessarily sterilized during Late Heavy Bombardment
- Mars + Earth exchanged rocks
- Microbes will survive the ejection and landing process
- Lithopanspermia (transfer of microbes between solar system bodies via meteors)

Why is Space Environment Difficult For Life?

- Space is a vacuum
- Temperature - cold
- From sun you get
  - Solar wind - protons, electrons, alpha particles, heavy ions
  - Radiation - UV
  - Solar flares - electrons produce x-ray + radiobursts, protons produce gamma rays
  - Solar particle events - mostly protons, occurs sporadically
  - Cosmic radiation - protons, electrons, alpha particles, heavy ions
- Earth protects life
  - Ozone layer protects us from UV radiation
  - Magnetosphere protects us from hard radiation

Why is Life Beyond the Home Planet on Another Planet Difficult

- Differences in atmospheric pressure + composition
- Altered gravity
- Temperature differences
- Nutrient sources (Organic N + C)
- Different radiation regime (solar + cosmic)

Panspermia

- **Lithopanspermia**
  - **Basic life forms are distributed throughout Universe via meteorite-like planetary fragments cast forth by disruptions such as volcanic eruptions + collisions with other matter**
  - **Eventually, another planetary system's gravity traps these roaming rocks, which can result in a mingling that transfers any living cargo**
- **Weak transfer**
  - **Slow-moving planetary fragment meanders to outer edge of gravitational pull, or weak stability boundary, of planetary system which has only a loose grip on the fragment, meaning it can escape and be propelled into space, drifting until it is pulled in by another planetary system**
- **Weak transfer mechanism provides strongest support yet for lithopanspermia + makes it a viable hypothesis**
  - **Would have allowed large quantities of solid material to be exchanged between planetary systems**
  - **Involves timescales that could allow survival of microorganisms embedded in large boulders**
  - **Could have happened in infancy of our solar system when it was close to other stars with their solar systems**

- The Probability of Panspermia, Astrobiology Magazine, Sept. 28, 2012

Directed Panspermia

- Life is complex + has drive for self-propagation
- As part of life, humanity should safeguard + protect life
- This can be done via directed panspermia, seeding life in our solar system + other solar systems with colonizing cyanobacteria / extremophile microorganisms / eggs of multicellular rotifers to start higher evolution
- Launching / targeting / decelerating / capturing such payloads is technologically feasible with good probability of success
- Such a program can give human existence a cosmic purpose

- Michael Mautner, Seeding the Universe With Life: Securing Our Cosmological Future, Journal of Cosmology, 2010, Vol 5 982-994

Panspermia via Starshot = Terrestrial Biomes in Space

- To send a creature to Alpha Centauri, it would have to travel in suspended animation for 20 years, frozen by chill of space
- Caenorhabditis elegans, a nematode worm, can be frozen for years + within minutes of thawing in drop of warm water begins to squirm, eat, reproduce
  - C. elegans have survived in suspended animation for 33 years, survived space shuttle Columbia's fatal reentry, are composed of fewer than 1,000 cells but can manifest complex behavior + can be trained + remember learned behaviors after suspended animation
- Tardigrades are another possible organism = water bears
  - Tardigrades when frozen + dehydrated can withstand suspended animation for 100 - 1,000 years + are radiation + pressure resistant
- Project Starshot is creating miniature chambers in which frozen worms could travel + be revived with heat from Starshot's plutonium power source

- Life in the Fast Lane, The Economist, Nov. 4, 2017

Panspermia Writ Large - 1

"Tsiolkovsky saw the future of space as a problem of biology rather than as a problem of engineering. He worked out the theory of rockets and saw that rockets would solve the problem of space travel, to get from here to there. Getting from here to there is the problem of engineering that Tsiolkovsky knew how to solve. That is the easy part. The hard part is knowing what to do when you have got there. That is the problem of biology, to find ways to survive and build communities in space, to adapt the structures of living creatures, human and nonhuman, so they can take root in strange environments wherever they happen to be."

...

"Sometime in the next few hundred years, biotechnology will have advanced to the point where we can design and breed entire ecologies of living creatures adapted to survive in remote places away from Earth. I give the name Noah's Ark culture to this style of space operation. A Noah's Ark spacecraft is an object about the size and weight of an ostrich egg, containing living seeds with the genetic instructions for growing millions of species of microbes and plants and animals, including males and females of sexual species, adapted to live together and support one another in an alien environment."

...

- Freeman Dyson, The Green Universe: A Vision, New York Review of Books, Oct. 13, 2016

Panspermia Writ Large - 2

"Suitable places where life could take root are planets and moons, and also the more numerous cold dark objects far from the sun, where air is absent, water is frozen into ice, and gravity is weak. The purpose is no longer to explore space with unmanned or manned missions, but to expand the domain of life from one small planet to the universe. Each Noah's Ark will grow into a living world of creatures, as diverse as the creatures of Earth but different."

...

"The essential new species, enabling Noah's Ark communities to survive in cold places far from the sun, will be warm-blooded plants. A warm-blooded plant is a species with leaves and flowers and roots and shoots in a central structure, kept warm by sunlight or starlight concentrated onto it by mirrors outside. The mirrors are cold, separated from the warm center by a living greenhouse with windows that let the light come in but stop heat radiation from going out. The mirrors are attached to the greenhouse like feathers on a peacock. The mirrors and the greenhouse perform the same functions for a warm-blooded plant that fur and fat perform for a polar bear."

- Freeman Dyson, The Green Universe: A Vision, New York Review of Books, Oct. 13, 2016

Panspermia Writ Large - 3

"Almost all the current discussion of life in the universe assumes that life can exist only on worlds like our Earth, with air and water and strong gravity. This means that life is confined to planets and their moons. The sun and the planets and moons contain most of the mass of our solar system. But for life, surface area is more important than mass. The room available for life is measured by surface area and not by mass. In our solar system and in the universe, the available area is mostly on small objects, on comets and asteroids and dust grains, not on planets and moons.

When life has reached the small objects, it will have achieved mobility. It is easy then for life to hop from one small world to another and spread all over the universe. Life can survive anywhere in the universe where there is starlight as a source of energy and a solid surface with ice and minerals as a source of food. Planets and moons are the worst places for life from the point of view of mobility. Because Earth's gravity is strong, it is almost impossible for life to escape from Earth without our help. Life has been stuck here, waiting for our arrival, for three billion years, immobile in its planetary cage.

When humans begin populating the universe with Noah's Ark seeds, our destiny changes. We are no longer an ordinary group of short-lived individuals struggling to preserve life on a single planet. We are then the midwives who bring life to birth on millions of worlds. We are stewards of life on a grander scale, and our destiny is to be creators of a living universe."

- Freeman Dyson, The Green Universe: A Vision, New York Review of Books, Oct. 13, 2016

Panspermia 'R Us

- Many planets may have limited habitability windows
- Humans should send "Genesis Missions" to planets with limited habitability windows
- Equip probes with tiny cell-synthesizing machines, upon arrival at target planet they create single-celled organisms sealed into dissolvable capsules which would be dropped onto planet
- Organisms synthesized would resemble those on Earth just before Cambrian explosion, most creative evolutionary period in Earth's history
- The probe would allow the planet to skip billions of years of pre-Cambrian evolution + help it move quickly towards a biosphere that could spawn intelligent life
- Send the probes to thousands of local planets, wait a few hundred million years...
- If probe finds a pre-existing biosphere around it planet it would not carry out its mission
- Why do it? ..."it is a question of aesthetics. Life is something beautiful and giving life the possibility to blossom elsewhere in the universe would be wonderful." - Claudius Gros

- Ross Anderson, How to Jump-Start Life Elsewhere in Our Galaxy, The Atlantic, Aug. 25, 2016

Allen Hills 84001 and other Martian Meteorites - An Example of Lithopanspermia?

- 1% of meteorites recovered from Antarctica are from Mars
- Alh 84001, a Martian meteorite discovered in Antarctica, was described in 1996 Science paper
  - A combination of 4 closely associated features in Alh 84001 could best be explained by biogenic hypothesis
    - 1. Carbonates were formed at relatively low temperatures + involved water-formation possibly assisted by microbial action
    - 2. Possible microfossils present
    - 3. PAHs present + associated with carbonates
    - 4. Nanophase magnetite (Fe_3O_4) similar to magnetite produced by magnetotactic bacteria is present embedded in the carbonites

From NASA

Panspermia Summary

- Terrestrial life can survive away from Earth
  - Space environment
  - Simulated Mars environment
- Addresses origin of life + early evolution of life questions - such as what were survival strategies prior to complex DNA repair
- We have just taken the first step in understanding the process of life beyond our planet

The Sky *Is* Falling

- Space strikes on Earth are not rare events
  - 70% strike ocean + do not leave visible crater
  - Others explode above ground + do not leave crater
- Recent strikes
  - 1908 - Tunguska - 30 meter object air burst = several hundred times the explosive force of Hiroshima
  - 536 AD - Gulf of Carpentaria north of Australia - 300 meter object caused global cooling according to Byzantines
  - 2800 BC - 3000 meter object in Indian Ocean near Madagascar - caused 600 foot high tsunami - ?Genesis
  - 12,000 years ago - air burst over Canada lead to global cooling and large mammal + Clovis civilization extinction
- Near-Earth asteroids + comets are more numerous + in more unstable orbits than previously believed
  - Risk dangerous object will strike the Earth? 10% chance per century

- Gregg Easterbrook, The Sky Is Falling, The Atlantic, June 2008

Mass Extinction

- Death and extinction of life
  - 99% of species that have lived are now extinct
  - Extinction is to evolution of life as death is to birth
  - All species become extinct eventually
  - There has to be extinction so new species can evolve
  - Extinction enables progress
- What is role of cosmic impacts in mass extinction?
  - Most recent mass extinction 65 million years ago (K-T extermination) was due to cosmic impact - this has been demonstrated
  - Hypothesis is that this happened more than once
    - That other mass extinctions were due to cosmic impacts

Mass Extinction

- Mass extinction definition - An event in which > 50% of all species on Earth go extinct in a short period of time (1 million years)
- After extinction a whole lot of ecological niches are open
  - There is room for expansion
  - That is why speciation follows mass extinction
  - ...so drop in diversity is followed by rise in diversity
- In past 500 million years there have been 5 mass extinctions - we only know what caused one of these (K-T extinction)
- Largest mass extinction was 200 million years ago at Permian / Triassic boundary
  - 90% of all families / species went extinct
    - If it had been a little worse you would have had to start all over again

Mass Extinction

- Most recent is 65 million years ago - end Cretaceous or Tertiary / Cretaceous boundary (K-T extinction)
  - Evidence
    - Scientists found extra layer of iridium in the rocks
    - Calculated how big a meteorite would have to be to deliver that much iridium - was 15 km in diameter
    - Figured out how big an impact crater it would have to be + how much debris it would throw up
    - Figured Sun would be blocked for ~ 1 year
    - This leads to ecological catastrophe of temperature drops and photosynthesis ceases - most life would die
    - Crater would be 200 km in diameter
  - In addition to extra material in the rock, they found a lot of shocked quartz that you only get in a huge explosion and that keyed them into that it was due to 1 large impact
  - And they also saw a layer of soot equivalent to what you would see if you burned the biomass of Earth

Mass Extinction

- Evidence
  - Extinction
  - Extraterrestrial material
  - Shock quartz from huge explosion
  - Soot from global fire
- This caused extinction of dinosaurs and > 50% of mammals
  - Big animals could not hide from lack of Sun and global firestorm caused by falling debris thrown up by impact
  - Took 20 minutes to kill dinosaurs from blast / firestorm
  - Dinosaurs were doing well up to this point
  - Lack of photosynthesis affected ocean life

Mass Extinction

- Cosmic impact changes evolution
  - Usually survival of fittest in slowly changing static environment
  - But in a changing (post impact) environment there are different criteria for survival of fittest
- What hit the Earth - either comet or asteroid
- Crater is in Mexico / Yucatan - 200 km in diameter
  - Chicxulub - this K-T impactor was 100 million megatons
- Evidence for 4 other mass extinctions is not as good - yet

Firestorms

- Chicxulub impact could have triggered global firestorm that would have burned every twig, bush, tree on Earth leading to extinction of 80% of Earth's species
- Collision would have vaporized huge amounts of rock that were blown high above Earth's atmosphere
- Re-entering ejected material would have heated upper atmosphere to 2,700 degrees F for several hours, thus generating infrared heat pulse that reached Earth's surface killing everything not sheltered underground or underwater

- Ancient Asteroid Caused Global Firestorm, Astrobiology Magazine, Mar. 30, 2013

Impacting Mass Extinction

- Biggest extinction, 252 million years ago at end of Permian period was triggered by impact event, causing extinction of 80% of animal species on Earth, permitting rise of reptiles
  - Impact crater is Araguainha crater in Brazil, 40 km in diameter
  - Crater is small because rock at impact site is oil shale + impact would have released oil + gas from rocks leading to release of huge amount of methane (a greenhouse gas) leading to instant global warming thus killing off much of Earth's animal life
- Extinction 66 million years ago at end of Cretaceous period was triggered by impact event, causing extinction of 70% of animal species on Earth, permitting rise of mammals
  - Impact crater is Chicxulub crater in Mexico, 180 km in diameter

- Small but Deadly, The Economist, Jul. 27, 2013

Impacting Iowa - Close to Home

- Manson Impact Structure
  - 74 million year old impact crater
  - Asteroid was 2 km in diameter, created 35 km wide crater, now buried beneath topsoil
- Decorah Impact Structure
  - 470 million year old impact crater
  - Asteroid was 200 m in diameter, created 5.5 km wide crater, now concealed beneath bedrock + sediments
- [Asteroid that created Meteor Crater was 50 m in diameter, created 1.2 km wide crater]

- Aerial Survey Confirms Ancient Impact, Astrobiology Magazine, Mar. 12, 2013

- Developing Technologies to Save the Earth From Asteroids, Astrobiology Magazine, Mar. 9, 2013

A Recent Significant Near-Miss?

- On August 12+13, 1883 astronomer Jose Bonilla counted 450 objects over 2 ½ hours - each surrounded by mist - pass across face of Sun - not sure what it was
- Now felt to represent fragments of comet that had recently broken up
- Fragments passed between 600 - 8,000 km from Earth, were 50 to 800 meters across
- Each fragment was size of meteorite that hit Tunguska, there were 3275 fragments overall
- If they had collided with Earth, would have had 3,275 Tunguska events in 2 days = extinction event

- Billion-Ton Comet May Have Missed Earth by a Few Hundred Kilometers in 1883, MIT Technology Review, Oct. 17, 2011

Chelyabinsk

- Feb. 15, 2013, 20 m diameter meteorite weighing 10,000 tons exploded few dozen km about Chelyabinsk, Russia with force of 500 KT of TNT
  - 1,000 m asteroid = planet-killer
  - 30 m asteroid = city-killer
- Shock wave from airburst shattered windows injuring > 1,000 people - shock wave effects would have been greater if meteorite had a more vertical entry path
- Not seen beforehand because of small size + orbit coming from direction of Sun
- Asteroids more likely to hit Russia because of its large land mass
- Should occur every 100 years

- The Russian Meterorite, Astrobiology Magazine, Feb. 17, 2013
- Jeff Foust, Piercing Together the Chelyabinsk Event, Space Review, Apr. 15, 2013
- A Close Shave, The Economist, Feb. 23, 2013
- Gautam Naik, Smaller Asteroids Post Bigger Threat, Wall Street Journal, Nov. 6, 2013

To Russia With Love
Chelyabinsk

"A year ago today, the Universe sent a shot across our bow. A house-sized meteor exploded over Russia.

The 15 Feb 2013 Russian meteor, carried 25X the energy of the Hiroshima bomb. Exploding 30km up, it "only" shattered windows.

Had the 15 February 2013 Russian meteor exploded 0.6 km high, as in Hiroshima, no person in Chelyabinsk would have survived.

The Russian meteor injured 1500 people, most running to the window, not remembering that blast waves travel slower than light.

Without a space program that discovers, tracks & deflects killer asteroids, our extinction is assured by one. Have a nice day."

- Neil deGrasse Tyson, astrophysicist, from Twitter, February 15, 2014

Mass Extinction

Event	Energy	Asteroid Diameter	Frequency
K-T extinction	100 million megatons of energy	Diameter 15 km	Happens once every 100 million years
Impact winter		Diameter 1-2 km	Happens every million years
Tunguska event	10 megatons of energy	Diameter < 1 km (Tunguska was 50 m in diameter)	Happens every few centuries
Hiroshima size	10 kilotons of energy		Should happen every year but explodes in atmosphere so don't hit Earth - DSP satellites shows this happens every year

Risks of Impacts on Earth

Once per	Asteroid Diameter (meters)	Impact Energy (megatons of TNT)	Impact Energy (atomic bomb equivalents)
Month	3	0.001	0.05
Year	6	0.01	0.5
Decade	15	0.2	10
Century	30	2	100
Millennium	100	50	2,500
10,000 years	200	1,000	50,000
1 million years	2,000	1 million	50 million
100 million years	10,000	100 million	5 billion

- The Spaceguard Survey: Report of the NASA International Near-Earth Object Detection Workshop

Tunguska meteorite - 60 m meteorite, exploded in midair, incinerated 300 square kilometers and felled thousands of square kilometers of trees around ground zero

Chicxulub meteorite - 10 km meteorite, created 200 km wide crater

- Neil deGrasse Tyson, Space Chronicles, 2012

Tunguska vs. Chelyabinsk

- Tunguska impactor
  - Stony, between 50 and 80 meters in diameter, entered atmosphere at about 15 kilometers per second, producing equivalent of 10 to 30 megaton explosion at between 9.5 and 14.5 kilometers altitude
  - Interval between impacts like Tunguska is not, as has been previously estimated, on timescale of centuries but rather millennia
- Chelyabinsk impactor
  - Likely stony asteroid that broke up about 24 kilometers above ground, producing shock wave like that of 550 kiloton explosion
  - Interval between impacts of Chelyabinsk-class objects is every 10 to 100 years

- Tunguska Special Issue, Icarus, July 2019

Effects of Impacts

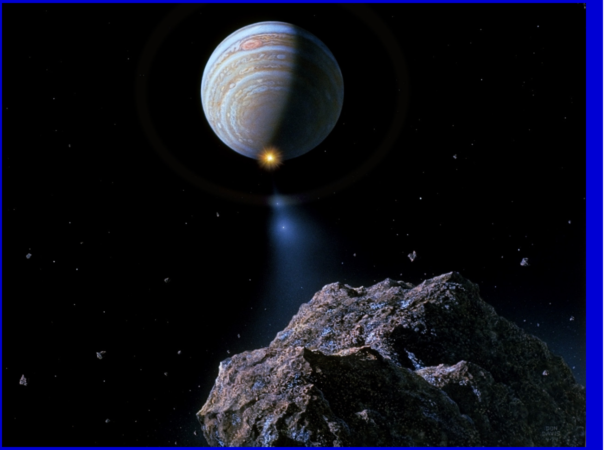
- Most impactors with < 10 megatons of energy explode in atmosphere leaving no crater
  - Few that survive in one piece likely to be iron based
- Blast of 10-100 megatons from iron asteroid will make crater, stony equivalent will disintegrate + produce airburst
  - Iron impactor would destroy large city
- Land impact of 1,000 to 10,000 megatons produces crater
  - Destroy area size of Delaware
  - Oceanic impact of this size produces significant tidal wave
- Blast of 100,000 to 1 million megatons results in global destruction of ozone
  - Oceanic impact generates tidal waves on entire hemisphere
  - Land impact raises enough dust into stratosphere to alter Earth's weather + freeze crops
  - Land impact destroys area size of France
- Blast of 10 million to 100 million megatons results in prolonged climate change + global conflagration
  - Land impact destroys area size of US
- Blast of 100 million to 1 billion megatons, on land or sea, leads to mass extinction on scale of Chicxulub impact, wiping out 75% of Earth's species

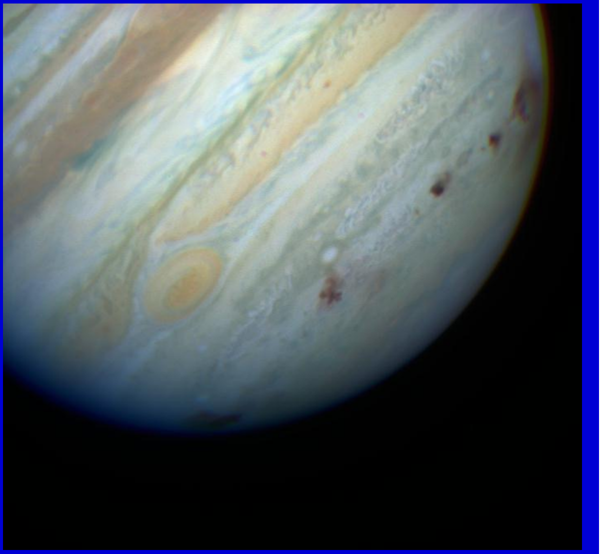
\- T. Gehrels, Hazards Due to Comets and Asteroids

Our Solar System Architecture - Jupiter As Goalkeeper

- Rocky planets, gas giants, ice giants
  - In neat, round orbits
- Presence and position of Jupiter provides particular shelter for Earth
  - Jupiter's enormous gravity protects Earth, gravitationally vacuuming up or throwing off course asteroids + comets, making Earth a more peaceful place than it would otherwise be and therefore allowing evolution to occur on it with fewer interruptions
  - Without Jupiter, these objects would frequently smash into Earth + destroy life as we know it
    - Without Jupiter, impact rate on Earth would be 10,000 times higher than it is
  - Example: Comet Shoemaker-Levy 9 impacting Jupiter in July 1994
    - Previous encounter with Jupiter broke it into chunks
    - In 1994, each chunk slammed into Jupiter at 20,000 km per hour with equivalent energy of Chicxulub impact

- Life Beyond Earth, Timothy Ferris, 1999
- Origins, PBS Nova, Sept. 28+29, 2004
- Neil deGrasse Tyson, Space Chronicles, 2012


From Don Davis / NASA


From NASA

Three Components of Protection of Earth From Near Earth Object (NEO) Impacts

- **Early warning / Detection**
- **Proven deflection capability**
- **International decision-making protocol**

Vermin of the Sky

"With planetary defense, there's a complex interaction of science, psychology, politics, and money - and everything falls into a gap between the disciplines. The science guys say, 'NEOs are not scientifically interesting, and saving the planet is not our job,' and the military guys say, 'We'll blow them up, but we don't have anything to do with telescopes or space missions.' The issue's an orphan."

- Robert Arentz, Ball Aerospace

- Three options to deflect NEOs
  - Small asteroids discovered with plenty of warning could be nudged aside with gravity tractor, a plasma-powered spacecraft that would fly next to asteroid + use its gravity to divert the asteroid
  - For larger or closer NEO use a kinetic impactor, spacecraft loaded with lead or copper to ram NEO
  - For NEOs > 0.5 km in diameter or too close, use nuclear weapon
- NEO Detection data
  - 1998 - Congress directs NASA to find + track 90% of NEOs > 1 km in diameter (which would obliterate France) - by 2011 NASA has found 999 / 1000
  - 2005 - Congress directs NASA to find + track NEOs > 140 m in diameter (which would obliterate Washington DC) - by 2011 NASA has found 6,903 / 25,000

- Tad Friend, Vermin of the Sky, New Yorker, Feb. 28, 2011

How to Prevent Impacts

- Find potentially threatening asteroids + comets
- Track them - get enough data on them to determine their orbits to see if they intersect with Earth
- Characterize them - spin rate, composition, is it one of the 10-20% that are binary pairs?
- Deflect them - passive gravitational tractors, kinetic impactors, Laser Bees, nuclear deflections
- Internationally coordinate + educate - coordinate observations, plan for how countries will work together during a deflection, disaster preparedness for incoming impacts

- Bruce Betts, Planetary Defense Conference: Steps to Prevent Asteroid Impact, Planetary Society Blog, Apr. 13, 2015

Asteroid Detection

Value of Early Warning System

- If threat is spotted too late to intercept or deflect there is option of evacuation
  - In 2008 a small asteroid was detected 20 hours before hitting Earth, it's point of impact was calculated with reasonable accuracy in the Nubian Desert in Sudan and there were no injuries
  - Demonstrates an early-warning system would prove valuable if ground zero was populated region

- Defenders of the Earth, The Economist, Jun. 29, 2013

An Early Warning System

- Asteroid Terrestrial-Impact Last Alert System (ATLAS)
- 8 small telescopes in Hawaii scanning sky twice / night for faint objects moving in space
- Offers 1 week warning for 50 m diameter city killer asteroid + 3 week warning for 150 m diameter county killer asteroid
- Complements Pan-STARRS project that searches for large killer asteroids years, decades, centuries before they impact Earth

- An Asteroid Alert System, Astrobiology Magazine, Feb. 17, 2013

NASA's Center for Near Earth Object Studies

- http://cneos.jpl.nasa.gov/

Our Neighborhood in Space

- Spaceguard Survey of NEOs as of 2008
  - Total discovered ~ 6050 asteroids
  - Total > 1km ~ 768 (out of 940 suspected)
  - Total of 6050 asteroids with non-zero but very low probability of impact within next 100 years ~ 238 asteroids
- As new larger telescopes come on line the discovery of NEOs will increase tremendously

What is Minimum Size of NEO That Can Hurt Us On the Ground / That Atmosphere Will Not Burn Up?

- The answer is 40-45 m in diameter
  - That is the size of 1908 Tunguska impact in Siberia - which burned up in low atmosphere and burned up 200,000 sq km of Siberian forest
- There are suspected to be a million 40-45m in diameter asteroids out there compared to about a thousand > 1 km asteroids
  - So we've got to find, track, and predict the orbits of 1 million objects that could hit us
  - We get hit by one of these objects every 500 years

US Approach to Planetary Defense

- Planetary defense = locating asteroids + comets that have potential for impacting Earth + employing technical means for diverting them from collision course
- 1992 NASA presents to Congress Spaceguard Survey outlining threat posed by NEOs
- 1994 comet Shoemaker-Levy 9 collides with Jupiter, comet breaks into 21 fragments, each up to 2 km in diameter, impacts create debris clouds up to thousands of miles in diameter, releasing more energy than is contained in all nuclear weapons on Earth
- 1995 Spaceguard Foundation established in Europe, Minor Planet Center of Harvard-Smithsonian Center for Astrophysics designated as clearinghouse for all NEO-related observations + data
- 1995-1997 Gene Shoemaker urges Congress to pass NEO detection program
- 1998 NASA announces goal to detect 90% of NEOs > 1 km in diameter within a decade
- 2005 NASA announces goal to detect, catalog, track 90% of NEOs > 140 m in diameter within 15 years
- 2013 UN creates International Asteroid Warning Network, building on Spaceguard Foundation + creates Space Mission Planning and Advisory Group to develop profiles for asteroid deflection missions
- Current US space policy has 3 deficits
  - Lack of interest in identification of mid-sized city-killer + nation killer asteroids of < 140 m in diameter, with 99% of these asteroids remaining unidentified
  - Lack of development of mitigation strategies to respond to threatening asteroid
  - Lack of centralization of US government effort on this issue
- Conclusion: Asteroid impacts are the only significant natural hazard that can be avoided using existing technology

- James Howe, US Space Policy and Planetary Defense, Space Review, Oct. 6, 2014

Latest US Approach to Planetary Defense

- 2016 - Planetary Defense Coordination Office is created at NASA

"The whole priority for the Planetary Defense Coordination Office is to find these (NEO's) as far ahead of time as we can so that we have enough time to be able to deal with them in a reasonable way…We are working with other government agencies to do some of the preliminary thought and planning as to what we might do [if] faced with such a threat."

- Lindley Johnson, NASA planetary defense officer

US Planetary Defense Coordination Office

- Founded in 2015 - Connects efforts of hundred of people around globe concerned with preventing an extinction event
- Manages all NASA programs that detect, track, characterize Near Earth Objects
- Develops missions to move asteroids out of Earth's path + create strategies for dealing with impact if asteroid can't be avoided
- Hub for related US agency programs + international efforts
- If threatening asteroid discovered, gets information from telescope's staff up through NASA and to White House + US government agencies

- Elizabeth Howell, Defenders of the Planet, Air & Space Magazine, Dec. 2017

B612 Foundation

- Founded in 2002
- Original purpose was to invent new ways to deflect NEOs on collision course with Earth, leaving discovery of them to others
- Today, too many of smaller NEOs remain undetected so it has changed its purpose to discovering them
- Will create Sentinel - an asteroid-spotting space telescope
    - Paid for by private donations, engineered by NASA veterans, launched by SpaceX
    - Has 50 cm mirror, will scan in infra-red where dark but warm asteroids should show up bright against cold of deep space
    - Ambition is to record 90% of NEOs > 140 meters in diameter + 50% of NEOs > 50 meters in diameter

- Rock On, The Economist, Jul 7, 2012

Watching For Asteroids

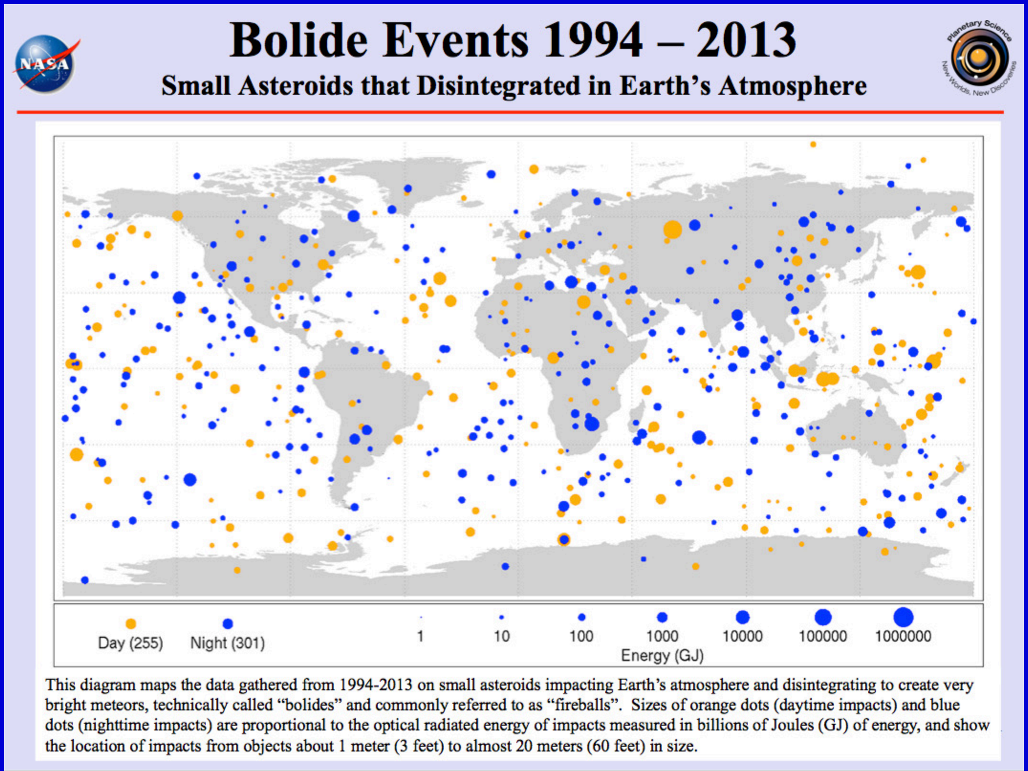
- B612 Foundation raising $400 million to build, launch, operate Sentinel, an infrared space telescope for finding Earth-threatening asteroids

  "We are talking about building the wing of an art museum" - Ed Lu, astronaut
- Sentinel will be in orbit near that of Venus which is most efficient place to find NEOs inside Earth's orbit
  - NEOs > 1,000 m in diameter (impact causes global extinction)
  - There are 14,000 NEOs > 150 m in diameter (impact = 27,000 Hiroshimas) + only 33% have been found + tracked
  - There are 300,000 NEOs > 30 m in diameter (impact = Tunguska-sized = 1,000 Hiroshimas) + only 1% have been found + tracked
- Sentinel's goal is to track 90% of asteroids > 100 m + 50% of asteroids > 30 m

"It's very clear that we can deflect an asteroid. The prerequisite, of course, and we've known this for many years, is adequate early warning...What was clearly happening within NASA was that this was not being picked up and championed." - Rusty Schweickart, astronaut

- Bruce Lieberman, Asteroid Watch, Air & Space Magazine, Jan. 2013

Asteroid Watch



From NASA

- **US satellites with infrared sensors (DSP + SBIRS) have been detecting fireballs generated when asteroids hit Earth's atmosphere + burn up for 20 years**
- **Asteroids measuring > 1 m in diameter enter atmosphere every other week**
- **Most powerful event observed = Chelyabinsk = 440-500 KT of TNT**

- Counting Fireballs as They Hit Earth's Atmosphere, Aviation Week & Space Technology, Nov. 24, 2014

Asteroid Watch

- Comprehensive Nuclear-Test-Ban Treaty Organization maintains world-wide network of infrasound sensors that listen for clandestine atomic bomb explosions
  - From 2000-2013 this system catalogued 26 major explosions on Earth from asteroid strikes
  - Ranged in energy from 1-600 KT of TNT (Hiroshima = 15 KT of TNT)
  - Most disintegrated high in atmosphere, thus causing few problems on ground
  - Many are unseen as they occur over ocean
  - Only 1 event was detected in advance by matter of hours
- Data suggests Earth is hit by multi-megaton city-killer asteroid every 100 years (last was Tunguska in 1908 with 45 m in diameter asteroid that had 10-15 MT of TNT)

- Jonathan Amos, Asteroid Impact Risks Underappreciated, BBC News, Apr. 22, 2014

NEOs Now

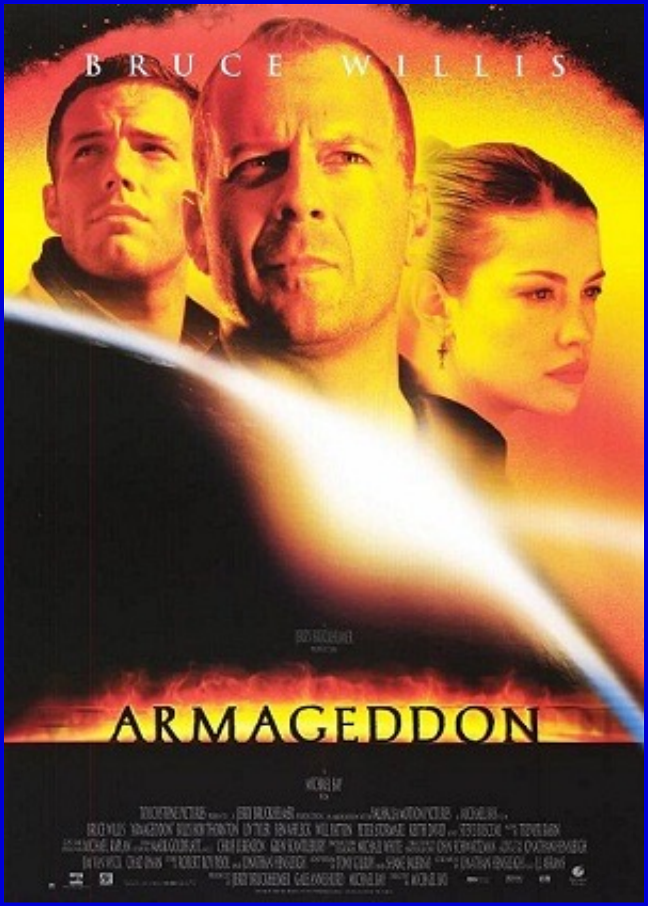
- Near Earth Objects (NEO)
  - 25,000 found by end of 2016
  - Adding 500 / year that are > 140 meters in size
  - 50% > 140 meters in size
  - 74% of Near Earth Objects > 140 meters in size have yet to be found
- Potentially Hazardous Asteroids (PHA)
  - Must pass within 0.05 AAU of Earth, must be > 150 m in size
  - Only a small number of asteroids are classified as PHAs

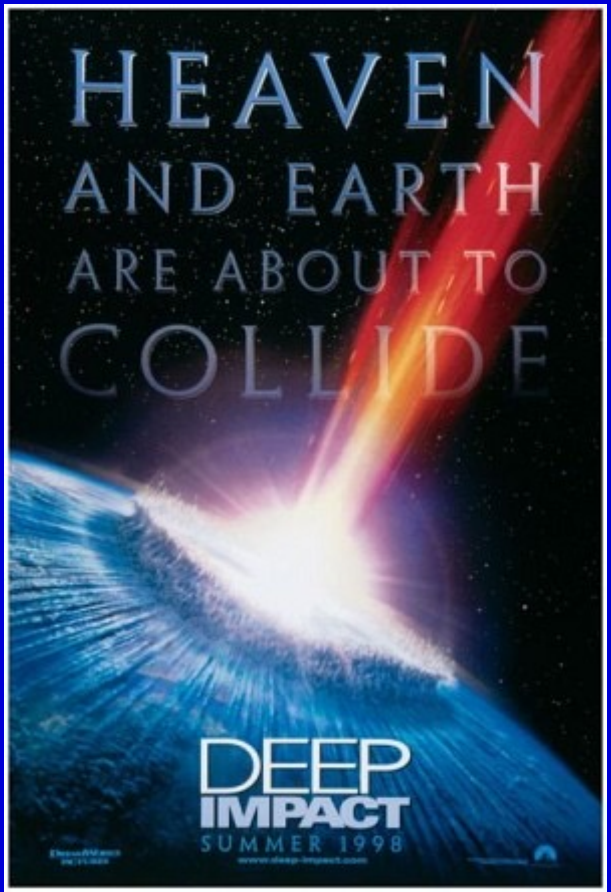
- Marianne Dyson, In Defense of the Planet, Analog, Nov/Dec 2018

Asteroid Deflection

- Blow it up
- Deflect it
- Geopolitical challenges involved

Current Asteroid Defense Capabilities





From Wikimedia Commons

NEOShield

- NEOShield is international project (EU / Russia / US) to assess threat posed by NEOs + look at best solution for dealing with them
- Strongest mitigation candidates
  - Kinetic impactor - like NASA's Deep Impact mission
    - Amount of debris produced in impact affects momentum of NEO + that depends on physical composition of NEO (how porous or dense it is) so you would have to test it first
  - Gravity tractor
    - Spacecraft with ion thrusters positioned alongside NEO, gravitational attraction between the two objects acts as tow-rope to pull NEO off its trajectory…but will spacecraft work for years / decades needed?
  - Blast deflection
    - Detonate nuclear device close to or on surface or under surface of NEO + outcome would depend on physical composition of NEO

- Jonathan Amos, NEOShield To Assess Earth Defense, BBC News, Jan. 20, 2012
- Project NEOShield, Astrobiology Magazine, Feb. 10, 2012

Potential Deflection Capabilities

- Kinetic impact - pushes asteroid via direct impact
  - Nuclear weapons could do it but nobody likes nuclear weapons in space
- Gravity tractor - pulls the asteroid using mutual gravity as a tow rope
  - You can slow the asteroid down or speed it up -- but if something happens while you are doing this you will hit a new area on Earth
  - So when you decide to move an asteroid's impact area off the Earth, you temporarily put at risk someone who was not initially at risk
    - Who should decide this is OK to do? What do you base the decision on? This is an international issue…should the UN decide?

The Nuclear Approach

- How to use one-two nuclear punch to break asteroid into harmless pieces when there isn't sufficient warning to use non-nuclear defenses
  - Satellite carrying nuclear device would be launched into orbit
  - Satellite's trajectory would intercept incoming 50 - 300 m in diameter asteroid
  - Satellite travels up to 30 days to reach asteroid
  - Satellite hits asteroid at speed of 10 kilometers per second, creating large crater in asteroid
  - Just before impact, nuclear device would be released from the back of satellite, creating slight delay in detonation + thus allowing nuclear device to fly into middle of crater
  - Explosion from inside crater would blast asteroid apart
  - Overall effect of an explosion under surface is 20 times larger than an explosion on surface
  - Asteroid chunks would spread into large debris cloud.
  - By time cloud reached Earth, less than 0.1 percent of chunks would enter atmosphere + those should only be 5-meter pieces that won't do much harm

- Developing Technologies to Save the Earth From Asteroids, Astrobiology Magazine, Mar. 9, 2013

Killer Bees

- As material is ablated / vaporized by laser from NEO surface it pushes against it like rocket exhaust + generates thrust + deflects it
  - Used to think you would need megawatt class laser powered by nuclear reactor
  - Instead use many solar-powered kilowatt class lasers, on swarm of small spacecraft flying in formation close to NEO, to ablate its surface + deflect it

- Deflecting Asteroids With Lasers, Astrobiology Magazine, March 28, 2012

- Solar-Powered Laser Spacecraft Could Prevent Apophis Hitting Earth in 2036, Technology Review, Jun. 8, 2012

International Decision Making Protocol

- United Nations

I'm From the UN and I'm Here to Help

- UN General Assembly has approved a set of measures developed by the Association of Space Explorers to protect Earth from the dangers of rogue asteroids
- The UN should oversee these functions
  - Information gathering, analysis, and warning
  - Mission planning and operations
  - Mission authorization and oversight group

- Clara Moskowitz, United Nations to Adopt Asteroid Defense Plan, Scientific American, Oct. 28, 2013

Founder of Astrogeology
Gene Shoemaker

- His study of Barringer (Meteor) Crater on Earth proved it was caused by impact event, not a volcano + that impact events can cause global catastrophes
- Then he started discovering other impact craters on Earth that were partially hidden by erosion
- Then he set his sights on studying perfectly preserved craters in-situ on the Moon but was disqualified from being an Apollo astronaut by underlying medical condition…so he trained Apollo astronauts to be his lunar geologists
- Turned his energy to detecting NEOs
- Led the first real-time observation of a NEO striking a planet - Comet Shoemaker-Levy 9 (SL-9) striking Jupiter in 1994
  - Tunguska was 12 megaton explosion, SL-9 Nucleus G was 6 million megaton explosion
- Raised awareness of NEO threat to Earth
- Ashes carried to Moon with this plaque

"And, when he shall die

Take him and cut him out in little stars

And he will make the face of heaven so fine

That all the world will be in love with night

And pay no worship to the garish sun."

- William Shakespeare, Rome and Juliet

- The Doomsday Asteroid, PBS Nova, Apr. 29, 1997

Case Study Summary - Stop Icarus

- Goal
  - Design a defense against a 1.4 km wide asteroid (1566 Icarus) heading towards Earth which would hit Earth with force of 500,000 megatons ~ You have 15 months to stop it
- Center of Gravity (Strategy)
  - Fast intercept is only option - fly out to Icarus+detonate bomb near surface to change its course
- Equipment
  - Must use Apollo-era technology ~ Use 6 Saturn V rockets, launched at 2 week intervals, each carrying a 100 megaton nuclear warhead, detonating 30 meters from asteroid
  - Assume you can increase Saturn V production + build third launch pad
- Training ~ Leadership ~ Morale
  - 1967 MIT seminar with graduate students lead by professor ~ Believed they could do anything
- Tactics
  - 5 Atlas-Agena rockets with Intercept Monitoring Satellites to tell you what each explosion did
- Intangibles
  - What does asteroid look like? What is asteroid composed of? Will bomb fragment or deflect asteroid?
- Mistakes
  - N/A
- Outcome
  - Improvise under pressure

\- Dwayne Day, Icarus Falling: Apollo Nukes and Asteroid, The Space Review, Jun 17, 2019

Case Study Summary - Deep Impact

- Goal
  - Study interior composition of comet Tempel 1
- Center of Gravity (Strategy)
  - Release an impactor into comet nucleus
- Equipment
  - Impactor of 100 kg with kinetic energy of 4.8 tons of TNT ~ Satellite
- Training ~ Leadership ~ Morale
- Tactics
  - Release impactor in front of satellite, image impact crater with satellite
- Intangibles ~ Mistakes
  - Large + bright dust cloud unexpectedly created by impact obscured satellite's imaging of impact crater
- Outcome
  - Impact crater reimaged in 2011 by Stardust-NExT + found to be 150 m wide x 30 m deep

Computing Case Study Summary - Computer

- Goal
- Center of Gravity (Strategy)
- Technology / Equipment
- Training
- Leadership
- Morale
- Tactics
- Intangibles
- Mistakes
- Outcome

Personal Case Study - Jane B.

- Role
  - Computer scientist
  - Helped oversee installation of hardware + software network used to monitor Comprehensive Nuclear Test Ban Treaty
- Story
  - This network's infrasound system now being used to monitor meteorite impacts on Earth

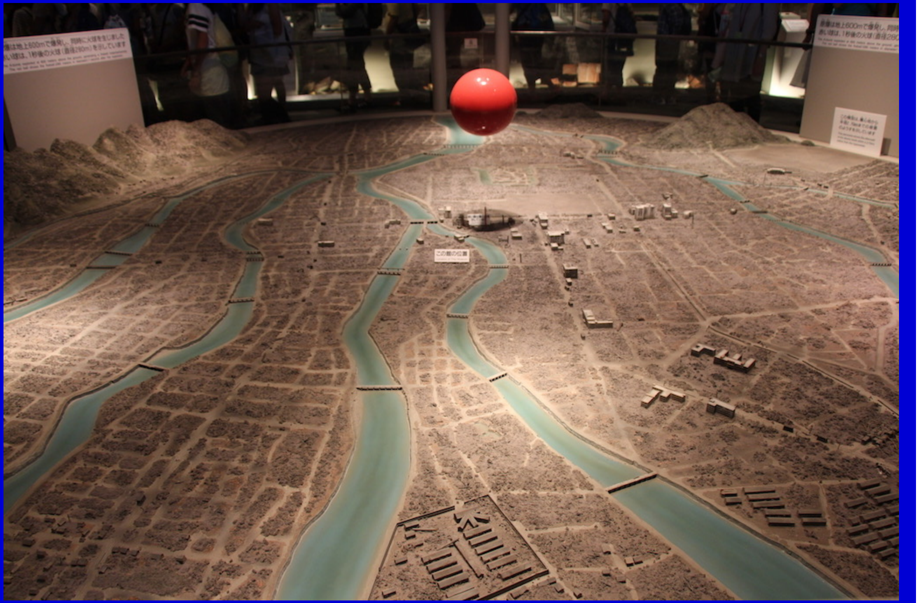
Astrobiology Analog Case Study - A Profound Impact

- Location
  - Meteor Crater
- Story
  - 50,000 years ago
  - Meteor size was 50 m ~ 10 megatons of energy
  - Blasted a hole nearly a mile wide, deep enough to hold 60 story building
  - Force of impact vaporized almost entire meteor, 300,000 tons in size

- Origins, PBS Nova, Sept. 28+29, 2004

Astrobiology Analog Case Study - Hiroshima

- Location
  - Hiroshima, Japan
- Story
  - August 6, 1945
  - What happens when a 15 kiloton nuclear weapon hits a city?
  - Hiroshima serves as a yardstick / unit of measure of the destruction caused by an impact event



Drake Equation

$$N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

- N = The number of communicative civilizations
- R* = The rate of formation of suitable stars (stars such as our Sun)
- fp = The fraction of those stars with planets. (Current evidence indicates that planetary systems may be common for stars like the Sun.)
- ne = The number of Earth-like worlds per planetary system
- fl = The fraction of those Earth-like planets where life actually develops
- fi = The fraction of life sites where intelligence develops
- fc = The fraction of communicative planets (those on which electromagnetic communications technology develops)
- L = The "lifetime" of communicating civilizations

Class Simulation

- **Topic aspects**

Poem

Slide text

Questions for Further Discussion

- Describe panspermia and what are its advantages + disadvantages as a theory?
- Are we (on Earth) really Martians?
- What has been the effect of asteroid impacts on Earth's history?
- What happens when the Earth is hit by an asteroid that is 5 meters in diameter vs. 50 meters in diameter vs. 1,000 meters in diameter vs. 15,000 meters in diameter?
- After reviewing this topic, how well will you sleep at night?
- What steps should mankind take to protect Earth from Near Earth Objects?
- What defense mechanisms would you use to protect Earth from an asteroid?

Reading Assignments

- Astrobiology Primer 2.0 (2016) Chapter
  - https://doi.org/10.1089/ast.2015.1460
- TED Talks for this Topic
  - http://www.astrobiologysurvey.org/ToLearnMore.html

Recommended Reading to Learn More

- Non-fiction
- Fiction
- Movies
  - Armageddon
  - Deep Impact
- Simulations

Conclusion - Facing Future

"It (exploration) is about the expansion of human activity out beyond Earth…this point was very recently noted and endorsed by no less than Stephen Hawking…Hawking joins those…who have long pointed out this basic truth: The history of life on Earth is the history of extinction events, and human expansion into the Solar System is, in the end, fundamentally about the survival of the species."

- Michael Griffin, NASA Administrator in NASA is Not Short Changing Science, AWST, Sept 25, 2006 p. 66

"If man is to survive, for most of human history, the word 'ship' will mean space ship."

- Arthur C. Clarke, author

"Is the surface of Earth really the best place for an expanding technological civilization?

A Space Roadmap: Mine the sky, Defend the Earth, Settle the universe"

- Lee Valentine, Space Studies Institute (www.ssi.org), 2002

Conclusion

"Tree of life has been slashed by crazy cosmic gardener again and again over 4.5 billion years and it always grows back with more variety than was present before the impact. But now we can turn off the crazy cosmic gardener. The marriage of humankind and machines has reached the point where we can now terminate this historic evolutionary process - which is an amazing thing to consider."

- Rusty Schweickart, astronaut Apollo 9

Topic 8

Search for Extraterrestrial Intelligence (SETI)

Song

Just a castaway
An island lost at sea
Another lonely day
With no one here but me
More loneliness
Than any man could bear
Rescue me before I fall into despair

I'll send an SOS to the world
I'll send an SOS to the world
I hope that someone gets my
I hope that someone gets my
I hope that someone gets my
Message in a bottle
Message in a bottle

….

Walked out this morning
Don't believe what I saw
A hundred billion bottles
Washed up on the shore
Seems I'm not alone at being alone
A hundred billion casatways
Looking for a home

I'll send an SOS to the world
I'll send an SOS to the world
I hope that someone gets my
I hope that someone gets my
I hope that someone gets my
Message in a bottle
Message in a bottle
Message in a bottle
Message in a bottle

Sending out an SOS…
- The Police, Message in a Bottle

Thematic Quote

"The probability of success is difficult to estimate, but if we never search, the chance of success is zero."

- Giuseppe Cocconi and Philip Morrison (from first paper written on SETI - "Searching for Interstellar Communications" - Nature, vol. 184, no. 4690, pages 844-846, Sept. 19, 1959)

Thematic Quote

"In this field, the number two is the all-important number. We count one, two, infinity. We're all looking for number two."

- Jill Tarter, astronomer

Thematic Quote

"We'll be saying a big hello to all intelligent life forms everywhere. And to everyone else out there, the secret is to bang the rocks together, guys."

- The Hitchhiker's Guide to the Galaxy

The Painting

The Earth At Night

- Defense Meteorological Satellite Program
- Maps locations of permanent lights on Earth's surface

Artifact

- Name
  - SETI@Home Participation Certificate
- Year
  - 2003 - present
- Story
  - SETI@Home Classic done on an original iMac - 13 workunits completed ~ 651 hours of computer time [from 2001 - 2003]
  - SETI@Home from 2005 - present on current iMac has contributed 1,337,237 Cobblestones of computation

The Question

Are we alone?

SETI Goal

- Goal is to locate evidence of past or present communicative civilizations in universe, particularly in our galaxy

  - Life Beyond Earth, Timothy Ferris, 1999

SETI Definition of Intelligence

- Anyone who can build a radio transmitter

  - Origins, PBS Nova, Sept. 28+29, 2004

Ways To Find Life

- 1. Find it nearby - Mars, Europa, Ganymede, Callisto, Enceladus, Venus, Titan - they all might have water
- 2. Find it in someone's atmosphere by directly visualizing an exoplanet and examining its spectra
  - What fraction of stars have planets - probably all
  - Looking for oxygen - produced by bacteria on Earth
  - Looking for methane - produced by cows + pigs on Earth
- 3. SETI

- Each of the 3 methods will take 20 years to succeed
  - 1+2 are looking for stupid life
  - 3 is looking for intelligent life

- Seth Shostak, astronomer

History of SETI

- 1920's - Tesla and Marconi
- 1960 - Project Ozma at National Radio Observatory in Green Bank, West Virginia - Frank Drake
- History of SETI is that as we develop a technology on Earth, we begin to search for it amongst the stars
  - Radio (Radio SETI)
  - Laser (Optical SETI)
  - DNA sequencing (Genomic SETI)
    - Could aliens have visited ancient Earth and left a message in our DNA?
    - Could searching our DNA for a message be a future form of SETI?

History of SETI

- 1959 - Philip Morrison + Giuseppe Cocconi, Searching for Interstellar Communications, Nature, Sept. 19, 1959

  "The reader may seek to consign these speculations wholly to the domain of science fiction. We submit, rather, that the forgoing line of argument demonstrates that the presence of interstellar signals is entirely consistent with all we now know, and that if signals are present the means of detecting them is now at hand."

  "The probability of success is difficult to estimate, but if we never search, the chance of success is zero."

- 1960 - First SETI at Green Bank Observatory by Frank Drake, listening to Tau Ceti + Epsilon Eridani, for 115 hours over 4 months
- 1971 - Cyclops Report from NASA = SETI's bible - Cyclops, a telescope composed of many smaller antennas that would together have an area of 100 square kilometers (39 square miles), be built in a modular fashion, costing $6-10 billion

  "We now have the technological capability of mounting a search for extraterrestrial intelligent life."

- 2007 - SETI Institute's Allen Telescope Array is an implementation of Cyclops

\- Sarah Scoles, Jill Tarter Believes, Air and Space Magazine, Aug. 2017

History of SETI

- Roman silver mining, which required the Roman's cutting down + burning huge parts of Spain's forests for fuel, was the first time humanity's impact on Earth was noticeable from space
- What sort of beacons would extraterrestrials use?
  - Water hole, between 1,420 mHz and 1,660 mHz, as hydrogen the most abundant chemical element in cosmos emits photons at 1,420 mHz + hydroxyl emits photons at 1,660 mHz and when the two combine you get water, since life requires water, the region between those two frequencies is the water hole where galactic citizens meet in desert of space
- Wow! signal detected in 1977 was right at 1,420 mHz + 30 times stronger than cosmic background noise
- Today, Breakthrough + SETI Institute are conducting broadest ever radio search between 1,000 + 15,1000 mHz

- Jason Davis, Is There Anybody Out There?, Planetary Society Blog, Oct. 25, 2017

How To Do SETI

- 1. Look for UFO's - we can't go there
- 2. Look for artifacts (Dyson Spheres)
- 3. Look for signals
  - Where are they transmitting their signals
    - Long waves
    - Short waves
    - Microwaves
    - IR
    - Optical
  - Radio - starting in 1960 - Frank Drake
  - Optical - use lasers to send signals

How To Do SETI

- You are looking for a narrow band signal from a transmitter
  - Nature (think quasars) makes broadband signals; intelligent life makes narrow band signals
- They are looking for a signal - not a message - because they are looking for evidence of a signal
- Any signal we pick up is most likely from a civilization far ahead of us and therefore you probably won't be able to decode it
- SETI really about searching for another species that has developed symbolic language like we have
  - Without language you can't have a history or science
- SETI's search follows Moore's Law
  - You double your computing power every 18 months that you use to search the data you gather for signals, thus you are doubling the speed of your SETI search every 18 months
  - So by 2030 SETI will have looked at 1 million stars

Where to Aim SETI - Globular Clusters

- Globular clusters
  - Spherical collections of hundreds of thousands of stars, amongst oldest stellar inhabitants of galaxies
  - Are good place to hunt for advanced civilizations
    - Age means life will have had best chance of coming into existence + climbing ladder of complexity to where it can travel from star to star
    - Age means clusters have stopped being disrupted by life-destroying supernovae + gamma-ray bursts
    - Proximity of cluster's stars to one another means interstellar travel is shorter + easier - distance from star to nearest star is 1,000 AU on average, for us on Earth distance is 275,000 AU
      - This also makes communication practical
- Settling a globular cluster would be a lot easier than settling a galaxy

- Cluster Analysis, The Economist, Jan. 9, 2016

Where to Aim SETI

- Propensity for emergence of intelligent life strongly influenced by time available for evolution to proceed undisturbed by sterilizing effect of nearby supernovae
- Times between supernovae events provide windows of opportunity for evolution of intelligence
- Inner galaxy provides greatest number of opportunities for intelligence to arise due to substantially higher number density of habitable planets there, which outweighs effects of higher supernova rate in region
- Inner galaxy reached similar level of evolutionary opportunity available to Earth 2 billion years ago
- Therefore inner galaxy should be prime target region for SETI as any civilizations that have emerged there are potentially much older than ours

- Ian Morrison + Michael Gowanlock, Extending Galactic Habitable Zone Modeling to Include the Emergence of Intelligent Life, Astrobiology, Aug. 2015

Radio SETI

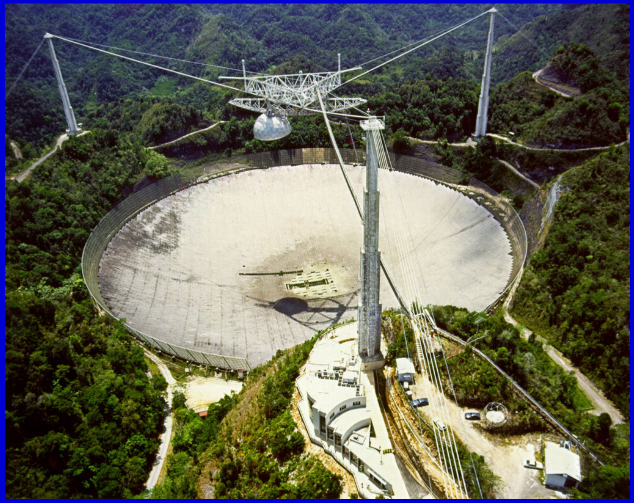
- What radio SETI is looking for
  - Any wavelength longer than microwave
    - This radio frequency spectrum is huge, much wider than visible light spectrum
- At what wavelength is communication most efficient + background noise is at minimum
  - At 1-100 GHz background noise is at minimum and that is where they are looking
- Where to look for SETI signal
  - 1-100 GHz (microwaves) - galaxy is quiet here
    - SETI operates at 1.4-1.7 GHz
  - Hydrogen line is where they look (1420 MHz) because
    - Fundamental radio frequency of most abundant element of the universe - maybe it is where civilizations meet

Water Hole

- Region of radio spectrum bounded by spectral lines of two products of water = H + -OH
  - Exists at 1.42 - 1.665 GHz (1,420 MHz - 1,665 MHz)
  - Relatively quiet region of radio spectrum
  - Wavelengths not significantly absorbed by material between the stars and galaxies
- Because life presumed to require liquid water + water is composed of H + -OH, this region seen as natural window where intelligent water-based life forms would signal their existence

Radio SETI

- To really do SETI needed to have large radio telescopes and sensitive radio receivers
- SETI done for only 20 days / year at Arecibo radio telescope
- Wanted to get own dedicated SETI facility
    - Allen Telescope Array grew out of this run by SETI Institute + UCB Radio Astronomy Department - 42 networked dishes currently



From Wikimedia Commons

Problems With Radio SETI

- SETI looking for narrowband signals but today on Earth we send almost no narrowband signals - we use spread spectrum signals - like in cell phones
  - So need to adapt SETI software to search for spread spectrum frequencies
- Another problem is big radio signals are disappearing as services go digital
- Another problem is sending TV signals via satellites like DirectTV which are very low power
- So Earth will become hard to find
  - L (tl) value in the Drake Equation may be equal to 100 years
- Solar power satellites would have microwave signals of 1 gigawatt to Earth and a few million watts would radiate out to space so they could be detectable

Optical SETI

- There are 3 programs
  - SETI Institute
  - University of California Berkeley
  - Harvard
- They all look for flashes of light from stars

Optical SETI

- Lasers are great way for interstellar civilizations to communicate
  - Using a narrow beam, with light at one frequency, allows for private, low energy communication
- We are already broadcasting to the stars with lasers through the use of lasers in adaptive optics systems hooked up to our optical telescopes

- Anil Ananthaswamy, Hunting for the Great Galactic Internet, New Scientist, Apr. 8, 2012

Optical SETI

- Prior attempts at optical SETI looked for isolated + intense bursts of light
  - Over 10,000 stars scanned over several years without a light detection
- New attempts at optical SETI looking for repetitive + faint bursts of light received over long amount of time

- Charles Choi, Looking For Alien Lasers One Photon at a Time, Astrobiology Magazine, Aug. 12, 2013

Spectral SETI

- Evidence of intelligent life may be seen in planetary atmospheres
- Chlorofluorocarbons (CFCs) are an example - are entirely artificial with no natural way to create them in atmospheres - on Earth were used for hairspray + air conditioners
- Detecting CFCs in atmosphere of exoplanet might be evidence that intelligent alien civilizations were the cause either intentionally through terraforming or unintentionally via industrial pollution
- Atmospheric CFCs could be a technosignature equivalent to radio signals or pulsed lasers

- Charles Choi, Do Aliens Use Hairspray?, Astrobiology Magazine, Nov 22, 2012

Ultimate SETI

- Ultimately use your star as a gravitational lens in your telescope
  - The focal point is several astronomical units from the star
  - Would be the power of 30,000 Areceibos
  - Would let you build an intergalactic Internet
  - You could detect planets and photograph them in detail and detect weak signals

SETI Reborn

- 1960 - Project Ozma
  - 26 meter dish at Green Bank Observatory, 150 hours, observe 2 nearby stars, Tau Ceti + Epsilon Eridani, listen to 1 radio channel at a time
- 2016 - Breakthrough Listen - $10 million / year x 10 years (10 times increase in funding)
  - Use 100 meter dish at Green Bank Observatory, 15% of its observing time, observe nearest 1 million stars + core and disc of Milky Way galaxy + 100 other nearby galaxies, listen to 100 billion radio channels at a time between 1 and 10 GHz
  - Has 50 times sensitivity of previous efforts
  - Use 64 meter dish at Parkes Observatory
  - Use Lick Observatory's Automated Planet Finder optical telescope to search for laser transmissions
    - Laser signals don't disperse as quickly as radio waves, have higher bit rate, have less noise in system because lasers shine at single specific wavelength
    - Laser signals are attenuated by dust + gas in interstellar medium which results in dimming of light - by time you travel 1,000 light years an optical laser loses 90% of its light due to absorption by interstellar medium
    - Way around this is to search for infrared lasers because interstellar medium is mostly transparent to infrared light + radio waves
  - Overall will do as much searching every day as any previous project managed in year
- Why now?
  - Kepler has shown there are lots of habitable planets
  - Relentless rise of signal processing power
  - Unprecedented amount of time is available on radio telescopes

- The Optimistic Gamble, The Economist, Jul. 25, 2015
- Keith Cooper, SETI Reborn: The New Search For Intelligent Life, Astrobiology Magazine, Sep. 10, 2015
- Damond Benningfield, SETI Gets an Upgrade, Air and Space, Jun 2016

Breakthrough Initiatives

- Key questions of Breakthrough Initiatives
  - Is there any life elsewhere?
  - Is there intelligent life elsewhere?
  - Is it possible to send probes and possibly life between the stars?
- Key questions of Breakthrough Listen
  - Is anyone sending us a signal?
  - Is anyone sending anyone else a signal (leakage)
  - Are there any remnants / artifacts of anyone else out there?

SETI - Looking for Technological Artifacts of Other Civilizations

- One way to look for them
  - Use Kepler data to search for presence of Dyson spheres around stars
  - Dyson sphere is megastructure - a shell of solar panels - that orbits a star, captures large proportion of its energy
  - Way for advanced civilizations to power themselves because they will be power hungry
  - Do Dyson spheres cause transits?
- Another way to look for them
  - Dyson sphere will heat up with solar energy and then radiate off it in the infrared, so look for them in infrared

- Ross Anderson, The Best Way to Find Aliens: Look for Their Solar Power Plants, The Atlantic, Oct. 2012
- Searching for Dyson Spheres and Alternate Universes, Astrobiology Magazine, Oct. 10, 2012

SETI - Looking for Technological Artifacts of Other Civilizations

- Assumptions for Radio SETI
  - Advanced civilizations will value communicating with other civilizations enough to justify huge energy expenditures needed
    - "To operate a radio beacon that is on all the time, broadcasting in all directions, strong enough to be picked up from many light years away, you need an enormous amount of energy - something in the range of thousands and thousands of big power plants." - Robert Gray, astronomer
  - Civilizations will communicate via radio waves
  - Civilizations will transmit signals on one of frequencies we monitor
- Assumptions for Dyson Sphere SETI
  - Assumes a lot less than Radio SETI, assumptions come from biology
  - Life uses energy which it reradiates as waste heat. The larger the civilization, the more energy it uses and the more heat it reradiates. Life reproduces which leads to exponentially increasing energy needs which outstrip energy available on a planet + leads civilizations to mine energy from stars via Dyson Spheres
  - Searching for Dyson Spheres allows us to find aliens who are not necessarily interested in talking to us

- Ross Anderson, The Best Way to Find Aliens: Look for Their Solar Power Plants, The Atlantic, Oct. 2012

- Searching for Dyson Spheres and Alternate Universes, Astrobiology Magazine, Oct. 10, 2012

Artifact SETI / Dyson Sphere

- Dyson sphere is hypothesized artificial habitat built around a star by civilization with sufficient technology
  - Intended to capture as much as possible of the power output of the star, and should be a distinctive characteristic of a civilization able to control the resources of a planetary system
  - Dyson sphere would be a cloud of inhabited objects orbiting a star, surrounding the star densely enough to absorb all the starlight, but with the orbits carefully arranged so as to avoid collisions
- Any civilization using a large flow of energy, whether or not it wished to communicate, would be forced by the laws of thermodynamics to get rid of waste heat, which must be radiated into space in the form of infrared radiation
  - Uncommunicative civilizations could therefore be detected as sources of infra-red radiation
- Kardashev Scale = Long-lived civilizations are likely to belong to three types
  - Type I controls the resources of a planet
  - Type II controls the resources of a star
  - Type III controls the resources of a galaxy

  - Our own civilization is not yet type I but will be so within a few hundred years at most
  - Dyson sphere is an example of a type II civilization.
- The spirit of Dyson's idea, look for pyramids rather than radio signals, may ultimately be the paradigm that identifies intelligence beyond our solar system

- Freeman Dyson + Richard Carrigan, Dyson Sphere, Scholarpedia

Artifact SETI / Interstellar Archaeology

"An advanced civilization inhabiting a solar system might break up the planets into very small planetoids or pebbles to form a loose shell that would collect all the light coming from the star. The shell of planetoids would vastly increase the available "habitable" area and absorb all of the visible light. The stellar energy would be reradiated at a much lower temperature. If the visible light was totally absorbed by the planetoids a pure Dyson Sphere signature would be an infrared object with luminosity equivalent to the hidden star and a blackbody distribution with a temperature corresponding to the radius of the planetoid swarm."

"An unambiguous Dyson Sphere signature could be interesting evidence for "interstellar archaeology", signs of intelligent activity elsewhere in the Universe. Unlike most SETI signals generated as beacons, the creation of a Dyson Sphere signature did not require an active strategy on the part of the originating civilization."

"A distinction between SETI searches and systematic searches for objects like Dyson Spheres is that no presumption has to be made concerning the intent or motivation of the originating civilization. In this sense a Dyson Sphere search is more akin to a search for extra solar planets."

- Richard Carrigan, Dyson Spheres and Interstellar Archaeology, Fermilab

Looking For Leakage

- Power beaming
  - Efficiently transfer large amounts of energy between distant locations by electromagnetic radiation such as light or microwaves
- Uses
  - Launch to orbit, orbit raising, interplanetary commerce, interstellar boundary probes, starships, space solar power stations
- Beams would have high power levels, be focused, transient, visible over large interstellar distances
- Not a SETI signal so much as leakage
- Extraterrestrial intelligences could put a message on the power beam

- James Benford + Dominic Benford, Seeing Alien Tech, Analog, May / June 2018

Interstellar Archaeology

- Interstellar archeology = searching for signatures of cosmic-scale archaeological artifacts - is alternative to conventional SETI as it does not require intentional transmission of signal from original civilization
  - Current reach of radio SETI programs = 250 - 1000 light years
- Possible interstellar archaeological signatures
  - Non-natural planetary atmospheric constituents
  - Stellar doping with isotopes of nuclear waste
  - Dyson spheres
  - Signatures of stellar + galactic-scale engineering

- Richard Carrigan, Starry Messages: Searching for Signatures of Interstellar Archaeology, Journal of British Interplanetary Society, 63, 90 (2010)

Evidence of Alien Engineering?

- KIC8462852 - a star 1,500 light years away - is more massive, hotter, five times brighter than our Sun
  - Kepler has observed hundreds of non-periodic, very deep, oddly shaped dips in its light (up to 15-22%)
  - Dips not due to a planet or star - what is blocking star is big - up to half diameter of star
  - Dips not something in telescope or processing, not due to starspots, not due to planetary or cometary collisions due to lack of dust
- Could the dips be due to advanced civilization building a Dyson Sphere?
- SETI Institute observed it for 2 weeks for narrow + broadband signals + found none

- Phil Plait, Did Astronomers Find Evidence of an Alien Civilization? (Probably Not. But Still Cool.), Bad Astronomy, Oct. 14, 2015

- Seth Shostak, Are There Signals Coming From Deep Space?, Huffington Post, Nov. 5, 2015

Alien Archeology

- Cosmic Menagerie Scenario = advanced civilizations, in attempt to observe us in our natural state, are hiding
- Extraterrestrials may have unintentionally left calling cards in the form of discarded garbage - their midden
- Finding alien litter is difficult as it would entail a probe stumbling upon an artifact as remote sensing of trash on galactic scale is beyond our technology
- Wide-field Infrared Survey Explorer (WISE) spacecraft has done a search for Kardashev III civilizations and found none, but found 93 interesting sources so now they are being checked for Kardashev II civilizations
- Aliens could have left a message embedded in the DNA of life on Earth which would be reproduced + passed down
- Sentinel hypothesis - robotic sentinels monitor biologically promising planets in habitable zones for the development of intelligent life
  - If they contained artificial intelligence (Bracewell probe), once intelligent life was detected they could attempt to communicate with it locally

- Michael Carroll, Alien Archeology, Searching For the Fingerprint of Advanced Extraterrestrial Civilizations, Analog, May/June 2017

Why Look?

- We can learn something of value from them
- We would have the assurance we can survive
- We would have the answer to are we alone
- Could spark a new Renaissance

- Michael Carroll, Alien Archeology, Searching For the Fingerprint of Advanced Extraterrestrial Civilizations, Analog, May/June 2017

Kardashev Scale

- Method of measuring civilization's level of technology, based on the amount of energy it utilizes
  - Type I civilization uses all the available energy of its home planet (~ Earth)
  - Type II civilization uses all the available energy of its star (~ Dyson sphere)
  - Type III civilization uses all the available energy of its galaxy
- Puts energy consumption in a cosmic perspective
- Kardashev asked how powerful an extraterrestrial radio signal would have to be in order to be detected by conventional radio astronomy techniques
  - Type II and Type III civilizations would be sending the signals, Type I civilizations would be only receiving the signals

- JN Nielsen, What Kardashev Really Said, Centauri Dreams, Mar. 21, 2014

Entering the Anthropocene

- Kardashev described classification scheme for evolutionary stages of civilizations + categorized worlds by amount of energy their inhabitants could harness + use
  - Is concerned with extracting energy...but using energy causes waste, which affects state of planet
  - Does not take into account how civilization affects its planet as it gathers + uses energy
- New classification scheme for evolutionary stages of civilizations based on non-equilibrium thermodynamics - a planet's energy flow being out of sync, due to life
  - It's not just how much energy you use, but how you use it that matters
  - In order to survive long-term, a civilization must learn to think like a planet - think about sustainability on a planetary scale
- Presence of life on Earth has altered atmosphere + lithosphere

- Earth as a Hybrid Planet: New Classification Schemes Places Anthropocene Era Into Astrobiological Context, Astrobiology Magazine, Sep. 7, 2017

- Climate Change for Aliens, Astrobiology Magazine, Sep. 9, 2017

Classification Scheme for Evolutionary Stages of Civilizations Based on Non-equilibrium Thermodynamics

- Class I: Planets without atmosphere - ability of planet to change + evolve severely limited (Mercury or Earth's moon)
- Class II: Planets with atmospheres but no life forms. Flow of gases + fluids leads to change + evolution in form of climate and weathering. (Venus and Mars)
- Class III: Planets with thin biosphere that might sustain some biological activity, but does not affect planet as whole. No current examples of Class III planets. However, Earth 2.5 billion years ago, before life created the oxygen atmosphere, would have been a Class III world. If early Mars hosted life when it had liquid water on its surface then it too might have been a Class III world. Once life appears, new forms of change, evolution, and innovation become possible.

- Earth as a Hybrid Planet: New Classification Schemes Places Anthropocene Era Into Astrobiological Context, Astrobiology Magazine, Sep. 7, 2017

- Climate Change for Aliens, Astrobiology Magazine, Sep. 9, 2017

Classification Scheme for Evolutionary Stages of Civilizations Based on Non-equilibrium Thermodynamics

- Class IV: Planets with thick biosphere strongly affecting flow of energy and work through rest of the planetary systems. Planets co-evolve with their biospheres as life dominates many of the processes happening between the surface and the upper atmosphere. (Earth today)
- Class V: Planets in which an energy-intensive technological species establishes a sustainable form of cooperation with the biosphere that increases productivity of both. On these planets the civilization enhances the ability of biosphere to innovate + evolve. Earth could reach Class V if it learns to harvest solar energy
- Other ways to get to Class V include greening large deserts by planting trees that absorb carbon + release oxygen, create genetically modified trees that covert Sun's energy into electricity

- Earth as a Hybrid Planet: New Classification Schemes Places Anthropocene Era Into Astrobiological Context, Astrobiology Magazine, Sep. 7, 2017

- Climate Change for Aliens, Astrobiology Magazine, Sep. 9, 2017

Interstellar Message Composition

"What is needed now is a new specialty, anti-cryptography, or the designing of codes as easy as possible to decipher."

- Philip Morrison, physicist

Interstellar Message Composition
Early History

- In 19th century scientists wishing to communicate with Martians suggested digging giant triangle in Siberia, filling it with kerosene and setting it afire
  - Martians would recognize triangle as symbol of Euclidean geometry - a sign of intelligent life on Earth

    - Life Beyond Earth, Timothy Ferris, 1999

Interstellar Message Composition
Our Ever Expanding Inadvertent Radio Bubble

- For last 100 years we've been leaking radio + TV transmissions traveling at speed of light into space, the leading edge of which has passed 1,000 stars

  - Life Beyond Earth, Timothy Ferris, 1999

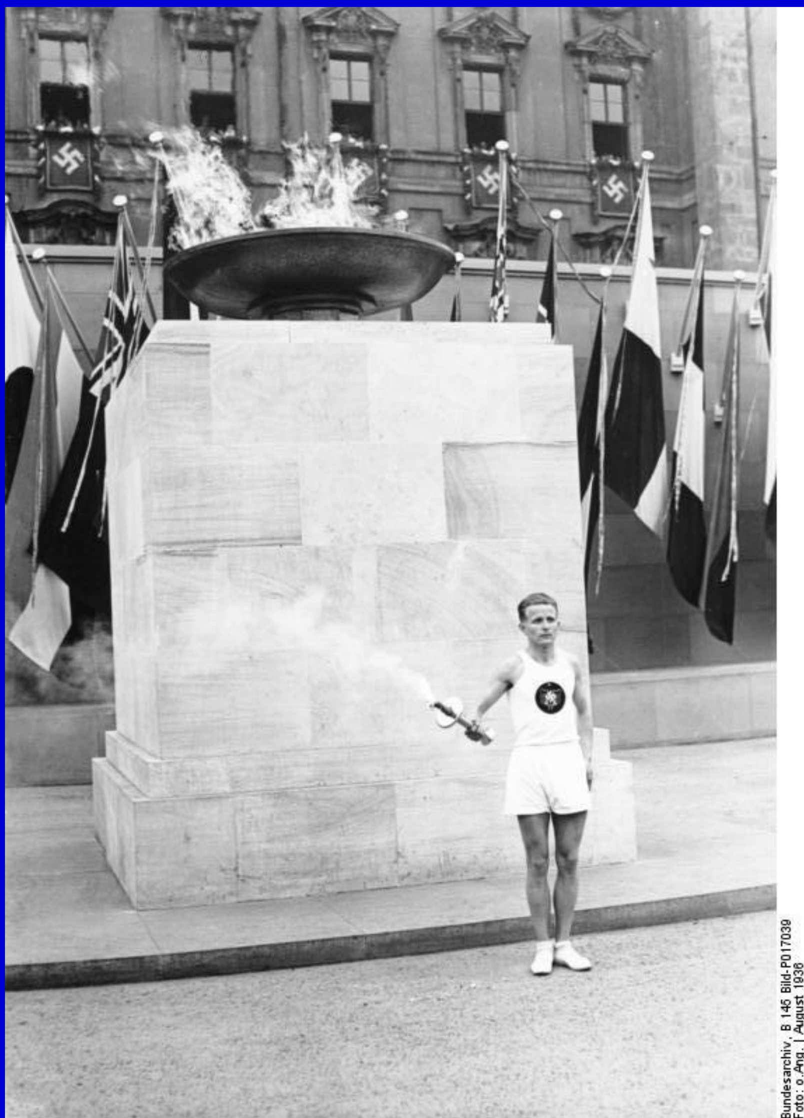
- Expanding edge of our radio bubble
  - 70 light years away
  - Consists of Nazi rallies, I Love Lucy, The Honeymooners

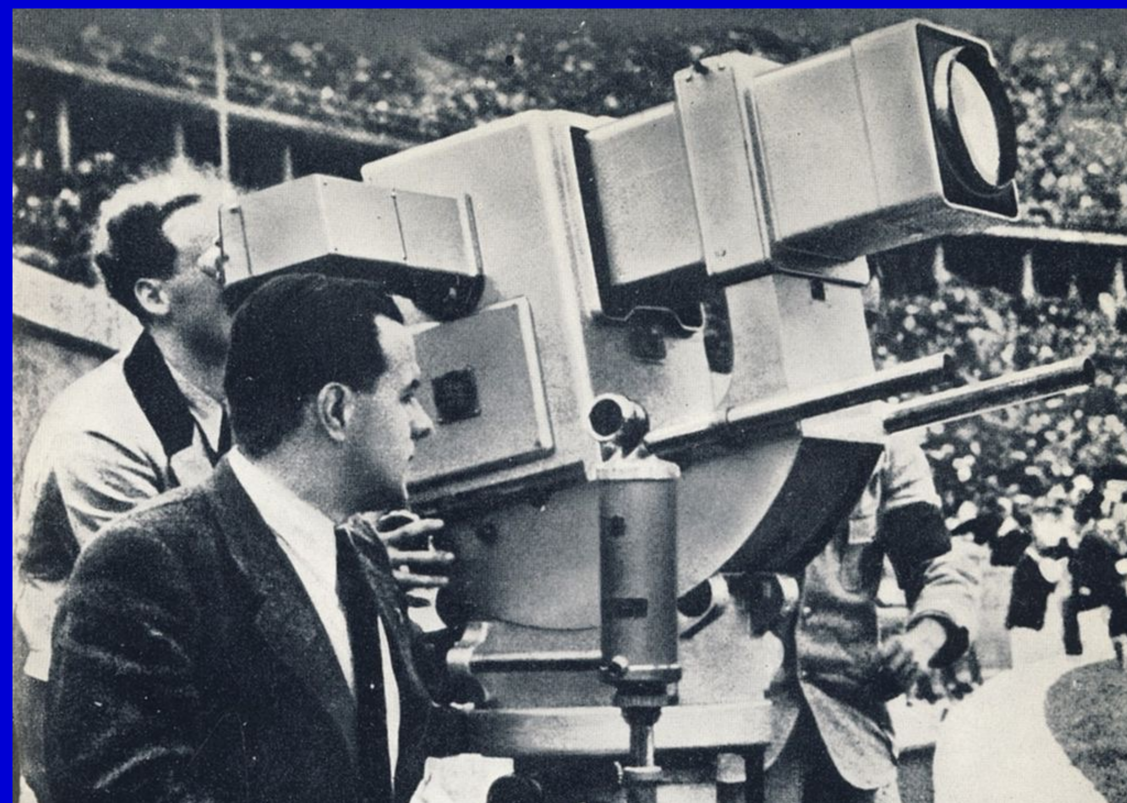
Our Radio Bubble

From Adam Grossman / Nick Risinger

- **Our radio bubble is 200 light years across and is the little blue dot in the center of the black box**

What is near the Edge of Our Radio Bubble?
1936 Olympic Games in Berlin

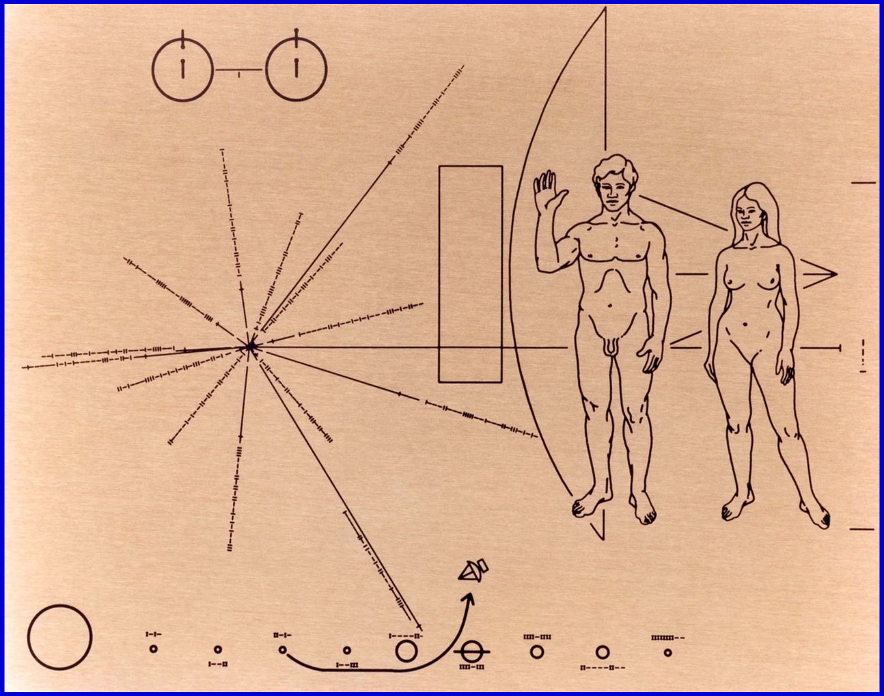




From Wikimedia Commons

Interstellar Message Composition

One way to figure out what a signal should look like …



All From Wikimedia Commons

- …is to design your own signal
  - Pioneer 10 + 11 plaque 1972
  - Arecibo message 1974
  - Voyager I + II records Sounds of Earth in 1977

The Golden Record

- Given 6 months to create
- Are longest-lasting objects crafted by humans
  - Etched in copper, plated with gold, will remain intelligible for > 1 billion years
- Contents
  - Samples of human voices speaking many different languages
  - Whale songs
  - Greetings from UN representatives
  - Wide variety of world music
  - Natural sounds organized chronologically as audio history of Earth + compressed logarithmically so humanity's story would not be limited to short beep at end
  - Photographs
- Dedication: "To the makers of music - all worlds, all times."

- Timothy Ferris, How the Voyager Golden Record Was Made, The New Yorker, Aug. 20, 2017

The Golden Record
A Sonic Description of Earth's History

"The sequence begins with an audio realization of the "music of the spheres," in which the constantly changing orbital velocities of Mercury, Venus, Earth, Mars, and Jupiter are translated into sound, using equations derived by the astronomer Johannes Kepler in the sixteenth century. We then hear the volcanoes, earthquakes, thunderstorms, and bubbling mud of the early Earth. Wind, rain, and surf announce the advent of oceans, followed by living creatures-crickets, frogs, birds, chimpanzees, wolves-and the footsteps, heartbeats, and laughter of early humans. Sounds of fire, speech, tools, and the calls of wild dogs mark important steps in our species' advancement, and Morse code announces the dawn of modern communications. (The message being transmitted is Ad astra per aspera, "To the stars through hard work.") A brief sequence on modes of transportation runs from ships to jet airplanes to the launch of a Saturn V rocket. The final sounds begin with a kiss, then a mother and child, then an EEG recording of (Ann's) brainwaves, and, finally, a pulsar-a rapidly spinning neutron star giving off radio noise-in a tip of the hat to the pulsar map etched into the records' protective cases."

- Timothy Ferris, How the Voyager Golden Record Was Made, The New Yorker, Aug. 20, 2017

Interstellar Message Transmission

"No technology available in the near-term will allow us to deliver powerful signals every minute of the day over a span of multiple epochs… But we might be able to make a beacon that works more efficiently, by targeting only those star systems where life seems most likely, and then pinging them each in turn, repeating the cycle every few months or so. Presumably, if a curious civilization caught one transmission, it would train its telescopes on that exact spot until the next part of the beacon's message arrived. This more sensible approach-a sort of Energy Star specification for SETI-would save enough power to keep the beacon running for millions of years."

- James Benford and Gregory Benford and Dominic Benford, Messaging with Cost Optimized Interstellar Beacons, Astrobiology Vol. 10(5) (June, 2010)

Gregory Benford and James Benford and and Dominic Benford, Searching for Cost Optimized Interstellar Beacons, Astrobiology Vol. 10(5) (June, 2010)

Good Example of Interstellar Message Composition

- Challenge - find a way to present information that is obviously a message, is understandable without much effort, conveys the intended contents for extraterrestrials
- Consider John 3:16 white poster with 8 black letters in stands of major sporting event, where people will look (behind a goal / home plate) in line of sight of TV cameras, quickly read, easily remembered
  - Is link to core Christian message in Bible, delivered easily + cheaply to good fraction of world's population
    - "For God so loved the world that he gave his only Son, that whoever believes in him should not perish but have eternal life."
  - Can reach hundreds of millions of people / year, without permission of stadium owners or sports officials
  - Is loud, brief, cheap, clear - maximizes its audience with message that is
    - In place where it is most likely to be seen
    - Easy to spot
    - Brief - so it is easy to understand + remember
    - Cheap
    - Friendly to bureaucracy - gets permission from well-disposed stadium staff

- Jon Lomberg, We Need a World Cup for SETI, Slate, Dec. 9, 2015

Good Example of Interstellar Message Composition

- Is exactly what a SETI beacon should be
  - Two ways to orient yourself to be seen - time + space
    - Time - radiate powerfully in direction that is looking at recent event like a supernova
    - Space - lay the beacon so it contains the Sun + connects us to galactic center, now it is easy to find anyone who lives on same avenue as you
  - Very bright + very brief beacon = Benford Beacon
  - Use beacon to convey message WE ARE HERE
  - Brief radio beacon can be bright, briefer it is the cheaper it is
  - Senders don't have to be leaders of their race, can be small groups or individuals as long as costs are cheap
- Dwell time is most important consideration - how long SETI project looks in preferred direction
  - Need 3 antenna spread around planet to keep any location in continuous observation, if you detect possible beacon have to remain on it long enough for it to repeat
  - You have to be listening when they are transmitting, so you have to listen constantly

- Jon Lomberg, We Need a World Cup for SETI, Slate, Dec. 9, 2015

Interstellar Message Composition

"Greetings from one of the species that inhabit Earth, a blue planet orbiting an average star. We call ourselves Homo Sapiens, by which we mean that we're capable of mathematics, science, and the technology by which this message is being sent. We're the only such creatures on this world, and so far as we know, the only ones to have lived here throughout its long history. Science has brought a better life for millions of us, but many more of us still live in poverty, tyranny and ignorance. Sometimes we wonder if there's intelligent life on Earth. We've only just glimpsed the vastness of time and space and of our own ignorance. We've learned that we have a lot to learn. And so we're dispatching this message in hopes of learning something about you and about ourselves. We request the favor of a reply."

- Timothy Ferris in Life Beyond Earth

Interstellar Message Composition

- What is best way to make message understandable to minds that may be organized in ways far different from ours?
  - Use math + chemistry to encode our message as they should be universal languages
  - Send a Rosetta Stone equivalent - use pictures as one of the languages
  - Send time capsule composed of images
  - "My personal preference is to send the Internet - send it all because if you send a lot of information then there's some chance that they'll work it out" - Seth Shostak, astronomer
- Beware of anthropocentrism - don't assume way we think or describe things will be same for extraterrestrials

- Seth Shostak, Talking to Aliens, Huffington Post, Nov. 14, 2014

- Seth Shostak, Messaging the Stars, New York Times, Mar. 27, 2015

Interstellar Message Composition

- earthspeaks.seti.org

Who Speaks For Earth?

- Governments / Politicians
- Scientists / Professional organizations
- Everyday people

To Speak or Not to Speak…

Active SETI / Messaging to Extraterrestrial Intelligence (METI)

- **Pro**
  - "Maybe there is some chance that if you wake somebody up you'll get a response" - Seth Shostak, astronomer
  - "We have been telling them willy-nilly that we are here for 70 years now. They are not very interesting messages but the early TV broadcasts, the early radio, the radar from the Second World War - all that has leaked off the Earth…Any society that could come here and ruin our whole day by incinerating the planet already knows we are here." - Seth Shostak
    - Better to try + control message by speaking deliberately to anyone out there than let them form their own conclusions from what they've seen so far
  - "If you're going to conduct SETI experiments where you're trying to look for putative alien broadcasts, it may be very instructive to have to construct a transmitting project" - Seth Shostak

- Pallab Ghosh, Scientist: Try to Contact Aliens, BBC News, Feb. 12, 2015
- Yoo-hoo, We're Over Here!, The Economist, Feb. 21, 2015
- Joel Achenbach, Is There Life Beyond Earth? Do We Even Want to Know?, Washington Post, Feb. 28, 2015
- Jeff Foust, Who Speaks For Earth and Does It Really Matter?, Space Review, Mar. 9, 2015

To Speak or Not to Speak…

Active SETI / Messaging to Extraterrestrial Intelligence (METI)

- Con
  - "It is like shouting in the jungle. You don't know what is out there; you better not do it." - Seth Shostak, astronomer
  - "Historians will tell you that first contact between industrial civilizations and indigenous people does not go well…The arrogance of shouting into the cosmos without any proper risk assessment defies belief. It is a course that would put our grandchildren at risk" - David Brin, author
    - "ETI's reaction to a message from Earth cannot presently be known. We know nothing of ETI's intentions and capabilities, and it is impossible to predict whether ETI will be benign or hostile...Intentionally signaling other civilizations in the Milky Way Galaxy raises concerns from all the people of Earth, about both the message and the consequences of contact. A worldwide scientific, political and humanitarian discussion must occur before any message is sent.…As a newly emerging technological species it is prudent to listen before we shout." - David Brin, Geoff Marcy, Elon Musk + 25 others
  - Unintentional planetary leak is omnidirectional + faint + therefore much harder to detect than intentional narrowly focused signal transmission…so they don't necessarily know we are here already
  - "I think it's a waste of time at the present. It's like somebody trying to send an e-mail to somebody whose e-mail address they don't know, and whose name they don't know." - Frank Drake, astronomer

- Pallab Ghosh, Scientist: Try to Contact Aliens, BBC News, Feb. 12, 2015
- Yoo-hoo, We're Over Here!, The Economist, Feb. 21, 2015
- Joel Achenbach, Is There Life Beyond Earth? Do We Even Want to Know?, Washington Post, Feb. 28, 2015
- Jeff Foust, Who Speaks For Earth and Does It Really Matter?, Space Review, Mar. 9, 2015

METI Con - 1

"The anti-METI movement is predicated on a grim statistical likelihood: If we do ever manage to make contact with another intelligent life-form, then almost by definition, our new pen pals will be far more advanced than we are."

"If you are going to do something that is going to change some of the fundamental observable parameters of our solar system, then how about an environmental-impact statement?" - David Brin, author

"If aliens visit us, the outcome would be much as when Columbus landed in America, which didn't turn out well for the Native Americans." - Stephen Hawking, physicist

"Every single case we know of a more technologically advanced culture contacting a less technologically advanced culture resulted at least in pain." - David Brin, author

- Steven Johnson, Greetings E.T. (Please Don't Murder Us), New York Times Magazine, June 28, 2017

METI Con - 2

"Whether you believe that the aliens are likely to be warriors or Zen masters, if you think that METI has a reasonable chance of making contact with another intelligent organism somewhere in the Milky Way, then you have to accept that this small group of astronomers and science-fiction authors and billionaire patrons debating semi-prime numbers and the ubiquity of visual intelligence may in fact be wrestling with a decision that could prove to be the most transformative one in the history of human civilization."

"Wrestling with the METI question suggests, to me at least, that the one invention human society needs is more conceptual than technological: We need to define a special class of decisions that potentially create extinction-level risk. New technologies (like superintelligent computers) or interventions (like METI) that pose even the slightest risk of causing human extinction would require some novel form of global oversight. And part of that process would entail establishing, as Denning suggests, some measure of risk tolerance on a planetary level. If we don't, then by default the gamblers will always set the agenda, and the rest of us will have to live with the consequences of their wagers."

- Steven Johnson, Greetings E.T. (Please Don't Murder Us), New York Times Magazine, June 28, 2017

METI Con - 3

"Do we want to be the sort of civilization that boards up the windows and pretends that no one is home, for fear of some unknown threat lurking in the dark sky? Or do we want to be a beacon?"

- Steven Johnson, Greetings E.T. (Please Don't Murder Us), New York Times Magazine, June 28, 2017

METI: A Response to Steven Johnson

"METI is not scientific exploration. It is an attempt to provoke a reaction from an alien civilization whose capabilities and intentions are not known to us.

The most likely motivation for alien intervention is not a wish to exploit Earth's territory or resources, but the potential threat posed by a new space-faring civilization - us."

Gregory Benford, astrophysicist and science fiction author

James Benford, radio astronomer

David Brin, astrophysicist and science fiction author

Catharine A. Conley, NASA Planetary Protection Officer

John Gertz, former chairman of the SETI Institute

Peter W. Madlem, former board member of the SETI Institute

Michael Michaud, former diplomat, author

John Rummel, former Director, NASA Planetary Protection Office

Dan Werthimer, radio astronomer

The Three-Body Problem by Cixin Liu

- Trilogy's animating philosophy

  "No civilization should ever announce its presence to the cosmos...Any other civilization that learns of its existence will perceive it as a threat to expand-as all civilizations do, eliminating their competitors until they encounter one with superior technology and are themselves eliminated. This grim cosmic outlook is called "dark-forest theory," because it conceives of every civilization in the universe as a hunter hiding in a moonless woodland, listening for the first rustlings of a rival."

- Liu believes China's experience with the West reinforces this philosophy and that throughout history expansive civilizations have used advanced technologies to bully others, and that China had done this to its neighbors in its past as well
- Liu believes a civilization would only send a beacon as a "death monument" that would announce its impending extinction

- Ross Andersen, What Happens if China Makes First Contact?, The Atlantic, Dec. 2017

Communications Case Study Summary - Cosmic Call

- **Goal**
  - Send radio message of text, drawings, images, songs, videos from ordinary people to nearby stars to show alien finders what life is like on Earth
- **Center of Gravity (Strategy)**
  - Create a primer so message could be understood
  - Choose 9 stars to send message to that are 1) similar to Sun, 2) visible from Evpatoria radio telescope, 3) in galactic plane (we now know 3 of these stars have exoplanets)
- **Technology / Equipment**
  - Use Evpatoria radio telescope in Ukraine with 150,000 watt output so message would be detectable at distance of 50-70 light years
  - Primer sent at 100 bits / second to maximize chance of clear transmission, message sent at 2000 bits / second
- **Training ~ Leadership**
  - Charlie Chafer of Team Encounter led project; astrophysicists Yvan Dutil + Stephane Dumas wrote primer

- Michael Chorost, How a Couple of Guys Built the Most Ambitious Alien Outreach Project Ever, Smithsonian Magazine, Sep. 26, 2016

Communications Case Study Summary - Cosmic Call

- **Morale**
  - **Was crowd funded hobby project, costing $50,000 in direct costs + $50,000 in indirect costs, involved 20 people**
- **Tactics**
  - **Primer contained 370,967 bits contained in 23 pages of glyphs that end with invitation to a conversation**
- **Intangibles**
  - **Aliens will need to be listening during 4 hour period message sweeps past them**
- **Mistakes**
  - **Drawback of such a freelance project is there is no institution to preserve memory of event**
- **Outcome**
  - **4 hour long message broadcast to 4 stars in 1999 + 5 stars in 2003**
  - **The primer had "a complexity and depth that's unparalleled in interstellar messages." - Douglas Vakoch, social scientist at SETI Institute**

- Michael Chorost, How a Couple of Guys Built the Most Ambitious Alien Outreach Project Ever, Smithsonian Magazine, Sep. 26, 2016

A Universal Grammar?

"Noam Chomsky has often said that if a Martian visited Earth, it would think we all speak dialects of the same language, because all terrestrial languages share a common underlying structure."

- Douglas Vakoch, METI

A Universal Grammar?

- Noam Chomsky thought human brain contained a "language organ" that arose during human evolution + that was pre-organized at birth with basic rules of language = universal grammar, which allowed infants to learn whatever language they were exposed to based on limited number of examples
- Due to the contingent nature of evolution, Chomsky initially assumed it would be very difficult for humans to learn the language of an alien whose language organ had arisen during a different set of evolutionary influences
- But convergent evolution may be a universal phenomenon, and Chomsky now feels that the language organ + universal grammar may be another instance of convergent evolution + thus an alien language may follow universal grammar as it is the one best way to make recursive core of language organ

- Paul Patton, Language in the Cosmos I: Is Universal Grammar Really Universal?, Universe Today, Jun 4, 2018

A Universal Grammar?

- Chomsky defined Universal Grammar as "the system of principles, conditions, and rules that are elements or properties of all (6000) human languages not merely by accident, but by biological necessity"
- Essential architecture of an extra-terrestrial grammar must be virtually identical to that of human grammar: having evolved under the same ultimate constraints of the universe: space, time, physics, and math
- Therefore universal grammar is not just one among many theoretical possibilities, it is the system any intelligence will inevitably converge on

- Hey Aliens We Should Talk, Oceanit, July 5, 2018

How to Determine if a Communication is a Language

- Use information theory
- Step 1 - Does it follow Zipf's law? = most common letters in language used exponentially more often than least common ones, same for most common worlds
  - True for all human languages, bottlenose dolphin squeaks, almost true for humpback whale songs
- Step 2 - Does it contain conditional probabilities? = there is a correlational structure to a language
  - True for all human languages, probably true for humpback whale songs
- Challenge - can you equate the complexity of a species communication with the size of its brain so you could predict the intelligence of the species that sent the communication?
  - Related to idea of encephalization quotient

- Brian Resnick, What Humpback Whales Can Teach Us About Alien Languages, Vox, Dec. 6, 2018

METI Via Directed Panspermia

- Rather than transmit information across interstellar distances using radio waves, send solid objects containing information instead
- Objects 1-10 microns in size - size of many bacteria - can be sent across interstellar distances using pressure of a star's light, once they have reached planetary escape velocity
- Bacterium 5 microns in size could store 120 kilobytes of information ~ 10,000 word / 30 page booklet
- Traveling at velocity of 30 kilometers / second (0.0001c) it would take 100,000 years to fly 10 light years
- Could be shielded against cosmic rays + UV rays by half a micron of soot
- The information we should send is how to make ourselves

- Robert Zubrin, Interstellar Communication Using Microbrial Data Storage: Implications for SETI, The Space Review, Jun 19 + Jun 26, 2017

METI Via Directed Panspermia

- Radio SETI researchers record radio waves from space + examine them with algorithms to detect something that seems too organized to be the result of natural phenomenon
- Microbial SETI researcher could use gene sequencing technology to process large numbers of bacterial genomes + look for something that does not seem natural
- Where should we look for bacteria to sequence for microbial SETI?
  - In space, using aerogels on spacecraft, in the vicinity of comets as they outgas during journeys through the inner solar system as it is possible that Oort Cloud objects might collect interstellar bacterial voyagers over time
  - Or you could fly balloons in Earth's upper stratosphere and look for anerobes there...and balloons could be used in the atmospheres of Mars and Venus which have sterile surfaces

- Robert Zubrin, Interstellar Communication Using Microbrial Data Storage: Implications for SETI, The Space Review, Jun 19 + Jun 26, 2017

First Contact Questions

- 1. Need to figure out how to communicate
  - Need to figure out social mores and cultural expectations of alien
- 2. Science - Find out how science came to them - how they discovered what they know about universe
  - Show them periodic table, $E=mc^2$, etc.
- 3. Art - What do you do to stimulate the senses you have to take in the world around you. Think of how we stimulate our 5 senses - art, music, food, touch
  - What do you do in your culture to bring joy and happiness to your lives

- Neil deGrasse Tyson, astrophysicist

Can We Control The Message?

"...we may not have as much control over the messages we do send to extraterrestrial life and that we may, in fact, already be sending a message."

"After thousands of years of cohabitation and scientific work here on Earth, we have yet to communicate with other intelligent species on our own planet the same way we do with one another. This suggests the challenge of communicating with extraterrestrial life may be at least as great as communicating with other species here on Earth and probably much greater. On the other hand, we may be able to communicate and be understood by simply mutually witnessing one another-by seeing all of their actions and allowing them to see us in return."

"And by looking at us, they will receive and understand the only message we can send that can be understood and believed: the sum total of all our actions...This sum total of all our actions may be the message we are already sending to extraterrestrials, a message composed by and reflecting the best and worst of every one of us here on Earth."

- Michael Oman-Reagan, Our Living Message for Extraterrestrial, Sapiens, Apr. 19, 2016

Drake Equation

$$N = R^* \times fp \times ne \times fl \times fi \times fc \times L$$

- N = The number of communicative civilizations
- R* = The rate of formation of suitable stars (stars such as our Sun)
- fp = The fraction of those stars with planets. (Current evidence indicates that planetary systems may be common for stars like the Sun.)
- ne = The number of Earth-like worlds per planetary system
- fl = The fraction of those Earth-like planets where life actually develops
- fi = The fraction of life sites where intelligence develops
- fc = The fraction of communicative planets (those on which electromagnetic communications technology develops)
- L = The "lifetime" of communicating civilizations

- Sarah Scoles + Sue Ann Heatherly, The Drake Equation: 50 Years of Giving Direction to the Scientific Search for Life Beyond Earth, Astronomical Society of the Pacific, Winter 2011

Another Way to Frame the Drake Equation

$$N = R^* \times fp \times ne \times fl \times fi \times fc \times L$$

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- L = The "lifetime" of communicating civilizations

- First three terms have to do with physical science
- Fourth + fifth terms have to do with biological science
- Last two terms have to do with social + behavioral science

- Sarah Scoles + Sue Ann Heatherly, The Drake Equation: 50 Years of Giving Direction to the Scientific Search for Life Beyond Earth, Astronomical Society of the Pacific, Winter 2011

What is the Longevity of a Civilization?

- How long can advanced civilizations last?
  - SETI much less likely to succeed if cultures destroy themselves when they reach certain level of technology such as nuclear weapons, genetic engineering, climate change
- We are in Anthropocene era - human civilization is major agent in planetary change, influencing function of the Earth, straining its natural resources + increasingly polluting its ecosystem
- Will longevity of human civilization be imperiled by or enhanced by our world-changing technologies? Will our technology threaten our survival as species / threaten Earth as a whole - or can we live comfortably with these new powers?
  - What of nature is left to be saved + how will we choose to save it?
  - How can world-altering technologies affect climate change, biological evolution, or prevent future disasters?
- One constant about Earth is that it is system always in flux
  - We need to use technology if we want to live well with 9 billion people on Earth but we must take care with it

- Leslie Mullen, The Longevity of Human Civilizations, Astrobiology Magazine, Oct. 11, 2013

"It (the Drake Equation) is a great way to organize our ignorance."

- Jill Tarter, astronomer

"What makes the Drake Equation so mesmerizing is in part the way it forces the mind to yoke together so many different intellectual disciplines in a single framework. As you move from left to right in the equation, you shift from astrophysics, to the biochemistry of life, to evolutionary theory, to cognitive science, all the way to theories of technological development."

- Steven Johnson, Greetings E.T. (Please Don't Murder Us), New York Times Magazine, June 28, 2017

Drake Equation Calculator

- Do it yourself at
  - http://www.pbs.org/lifebeyondearth/listening/drake.html
  - http://www.bbc.com/future/story/20120821-how-many-alien-worlds-exist

The Drake Equation According to Frank Drake

NT = R* x fp x ne x fl x fi x ft x tl

NT - number of detectable (communicative) civilizations in our galaxy

	1962 estimate	2010 estimate
R* - mean rate at which suitable stars are born (rate of star formation)	1-10/year	10/year
fp - fraction of stars with planetary systems (rate of production of planetary systems)	0.1-0.5	>0.5
ne - number of Earth-like worlds per planetary system (habitable worlds)	1-3	1-3
fl - fraction of those Earths where life develops	0.1-1	Much closer to 1
fi - fraction of these on which intelligence develops (life is rare vs brains evolve bigger)	0.01-1	Leans to 1
ft - fraction of intelligent beings who develop technology (need ability to manipulate tools)	0.1-1	Leans to 1
tl - lifetime of a civilization with ability to communicate in a way you can detect	1000-1,000,000	1000-1,000,000

First 6 factors multiplied together is equal to rate of production of detectable civilizations and is equal to about 1
Last factor is average length of how long a detectable civilization lasts

So he feels N=L (N = longevity of civilizations) and it implies intelligence is common and L is a long time
More exactly NT=tl - his license plate is "NEQLS L"

- Frank Drake, A Life With SETI, Lecture in the Stanford Astrobiology Course, Mar. 9, 2010

The Drake Equation According to Nadia Drake

NT = R* x fp x ne x fl x fi x ft x tl

NT - number of detectable (communicative) civilizations in our galaxy

	2014 estimate
R* - mean rate at which suitable stars are born (rate of star formation)	5-10/year
fp - fraction of stars with planetary systems (rate of production of planetary systems)	~ 1
ne - number of Earth-like worlds per planetary system (habitable worlds)	0.2
fl - fraction of those Earths where life develops	open question
fi - fraction of these on which intelligence develops (life is rare vs brains evolve bigger)	*
ft - fraction of intelligent beings who develop technology (need ability to manipulate tools)	*
tl - lifetime of a civilization with ability to communicate in a way you can detect	*

* = impossible to define until extraterrestrial intelligence detected

Least known caveat of Drake equation is that fl depends on technological capability of civilization doing the searching as this span of time depends not only on noisiness of alien technology but also on sensitivity of technology we're using for searching

- Nadia Drake, How My Dad's Equation Sparked the Search for Extraterrestrial Intelligence, National Geographic News, Jun. 30, 2014

Seth's Estimate Of Solving The Drake Equation

- We'll find a signal in 2 dozen years
- In next 2 dozen years SETI will look at 1 million star systems
  - There are 100 billion stars in our galaxy
  - Virtually every star has planets, probably has more than 1 planet
  - What fraction of planets are suitable for life?
    - Best guess today is 1/100 to 1/1000 planets are suitable for life -> there are 1 billion habitable planets in our galaxy

\- Seth Shostak, Senior Astronomer SETI Institute, ET Is (Probably) Out There -- Get Ready, TEDx Talk, April 2012

Seth's Estimate Updated

"If you look at 10 stars on average, maybe one of them has a planet sort of like Earth. That planet number is definitely uncertain, but it's a substantial fraction."

- Neel Patel, SETI Director Seth Shostak on Our Sudden Openness to the Idea of Alien Life, Inverse, Jan. 8, 2016

Seth's Estimate in 2019

- Frank Drake in 1986 felt that N = length of time civilization is visible = 10,000 years = so 10,000 civilizations detectable in our galaxy at any moment
  - …and in 2019 Seth still agrees with that estimate

- The Curious Cases of Rutherford & Fry, BBC Radio, May 27, 2019

The Seager Equation

N = N* x fq x fhz x fo x fl x fs

N - number of planets with detectable signs of life

N* - number of stars observed
fq - fraction of stars that are quiet
fhz - fraction of stars with rocky planets in the habitable zone
fo - fraction of those planets that can be observed
fl - fraction that have life
fs - fraction on which life produces a detectable signature gas

An estimate of how many alien, breathing biospheres might be detectable with telescopes this decade
Focusing on M-class stars (smaller + less luminous that our Sun), she feels N=2

Use Transiting Exoplanet Survey Satellite (TESS) to find rocky planets transiting small stars
Then use James Webb Space Telescope to observe atmospheres of those planets during transits, looking for biosignature gases (oxygen, water, etc.) produced by life that accumulate in planetary atmospheres to levels that can be detected

- The Drake Equation Revisited: An Interview With Sara Seager, Astrobiology Magazine, Sep. 3, 2013
- Nadia Drake, How My Dad's Equation Sparked the Search for Extraterrestrial Intelligence, National Geographic News, Jun. 30, 2014

Rare Earth Hypothesis

- Rare Earth Equation
  - New version Drake Equation with additional factors for
    - Fraction of planets with a large moon
    - Fraction of planetary systems with Jupiter-sized planets
    - Fraction of planets with critically low number of mass extinctions
  - Also assigns very low numbers to
    - How often intelligence would develop
    - Length of time communicating intelligences would last
  - Bottom line - while odds are that intelligent life must exist somewhere, the universe is so large, for all intents + purposes we are alone

    - Finding Life Beyond Earth, PBS Nova, Oct. 19, 2011

    [from - Peter Ward and Donald Brownlee, Rare Earth Why Complex Life is Uncommon in the Universe]

Rare Earth Equation

- **N = N* x ne x fg x fp x fpm x fi x fc x fxl x fm x fj x fme**

- N = the number of Earth-like planets in the Milky Way having complex life forms
- N* = the number of stars in the Milky Way. N* is at least 100 billion, and may be as high as 500 billion, if there are many low visibility stars
- ne = the average number of planets in a star's habitable zone. This zone is fairly narrow, because constrained by the requirement that the average planetary temperature be consistent with water remaining liquid throughout the time required for complex life to evolve. Thus ne = 1 is a likely upper bound
- fg = the fraction of stars in the galactic habitable zone - estimate this factor as 0.1
- fp = the fraction of stars in the Milky Way with planets
- fpm = the fraction of planets that are rocky ("metallic") rather than gaseous
- fi = the fraction of habitable planets where microbial life arises - unlikely to be small.
- fc = the fraction of planets where complex life evolves. For 80% of the time since microbial life first appeared on the Earth, there was only bacterial life - this fraction may be very small.
- fl = the fraction of the total lifespan of a planet during which complex life is present. Complex life cannot endure indefinitely, because the energy put out by the sort of star that allows complex life to emerge gradually rises, and the central star eventually becomes a red giant, engulfing all planets in the planetary habitable zone. Also, given enough time, a catastrophic extinction of all complex life becomes ever more likely.
- fm = the fraction of habitable planets with a large moon. If the giant impact theory of the Moon's origin is correct, this fraction is small.
- fj = the fraction of planetary systems with large Jovian planets. This fraction could be large.
- fme = the fraction of planets with a sufficiently low number of extinction events - low number of such events the Earth has experienced since the Cambrian explosion may be unusual, in which case this fraction would be small.

- Assume N* x ne = 5 x 10E11. The Rare Earth hypothesis can then be viewed as asserting that the product of the other nine Rare Earth equation factors, which are all fractions, is no greater than 10E–10 and could plausibly be as small as 10E–12. In the latter case, N could be as small as 0 or 1.

- Note: Rare Earth equation, unlike the Drake equation, does not factor the probability that complex life evolves into intelligent life that discovers technology

Is Our Milky Way Galaxy of 200 Billion Stars Teeming With Intelligent Life? - Geoff Marcy's View

- There are 30 billion planetary systems, 50% are older than Earth
- Pessimist says 1 in a million planetary systems have intelligent life
- Therefore there must be thousands of advanced civilizations in the Milky Way Galaxy
- But if this is true where are they?
  - Mars + Moon - No sign of visits to planets or moons in our solar system
  - Earth - is a lovely planet but has no alien settlement
  - 100's of telescopes - No alien spacecraft spotted
  - Night sky - No exotic rocket exhaust gamma-rays
  - No robotic probes orbiting our solar system
  - SETI - no signal detected
- Where is everybody?
  - Hypothesis: Thousands of advanced civilizations in galaxy ~ Migration throughout galaxy easy with robotic spacecraft
  - Observation: No aliens detected and no traces
  - Conclusion: Hypothesis possibly flawed
- Did we overestimate the probability of intelligent life in the Milky Way Galaxy?

Is Our Milky Way Galaxy of 200 Billion Stars Teeming With Intelligent Life? - Geoff Marcy's View

- Earths - a lucky amount of water is needed for intelligent life
  - Earth is 0.03% water, comes from asteroids + comets luckily hitting Earth
  - Possible water content of earths:
    - < 0.01% - Desert
    - > 0.05% - Water world - tough to make technological life
  - Most rocky planets are water worlds or deserts
- Does evolution favor intelligence? If so, species would become smarter with time
  - But 200 million years of dinosaur evolution refutes this
- Maybe it takes too much energy and time to travel between stars
- What is the typical lifetime of a civilization?
  - Maybe civilizations destroy themselves within a few thousand years and therefore don't overlap each other
  - Suppose human's chance of survival = 0.9999 each century
    - Probability of surviving 5 million years = 0.007
- Reasons that technological life may be rare in universe
  - Atoms only rarely arrange themselves into single-cell life
  - Earths with 0.03% water are rare - most are desert or water worlds
  - Intelligence is not favored by evolution
  - Technological civilizations kill themselves within 1 million years
- Bottom line: primitive life in universe is common, but technological life is probably rare

Fermi's Paradox

"Where are they?" - Enrico Fermi, physicist

- Is apparent contradiction between high estimates of probability of the existence of extraterrestrial civilization and our lack of contact with, or evidence for such civilizations
- Argument:
  - Sun is a young star, there are billions of stars in the galaxy that are billions of years older
  - If Earth is typical, some of these stars likely have planets with intelligent life
  - Presumably some of these civilizations will develop interstellar travel, as Earth seems likely to do
  - At any practical pace of interstellar travel, the galaxy can be completely settled in just a few tens of millions of years
  - Observable universe is currently believed to have at least 80 billion galaxies
- So Earth should have already been settled, or at least visited, but no convincing evidence of this exists

Great Filter

- Great Filter is argument that attempts to resolve Fermi Paradox
  - One of the steps from humble planet to interstellar civilization is extremely unlikely (a bottleneck) because either intelligent life is extremely rare or has tendency to go extinct
- Possible bottlenecks
  - Filter behind us
    - Paucity of Earth-like planets or self-replicating molecules
    - Big jump from simple prokaryotic life to more complex eukaryotic life
    - Rare Earth hypothesis - evolution of complex life requires very large number of perfect conditions: Earth must be in habitable zone of Sun, star must be far enough away from galactic center to avoid destructive radiation, gas giants must be big enough to sweep asteroids away from Earth, unusually large moon stabilizes axial tilt that gives us seasons
    - Emergence of symbolic language, tools, intelligence could also require perfect conditions
  - Filter ahead of us
    - Nuclear weaponry
    - Biotechnology
    - Machine superintelligence

- Andrew Snyder-Beattie, Habitable Exoplanets Are Bad News For Humanity, The Conversation, Apr. 24, 2014

Great Silence

- Advanced technological civilization (ATC) only a bit more capable than us could settle a galaxy in few tens of millions of years
  - Self-replicating robotic interstellar probes could do it even faster
- Chasm between logic that evidence of aliens should be all around us and absence of such evidence is Fermi Paradox
- Reason for Fermi Paradox #1 - Intelligence is rare
  - Terrestrial life almost 4 billion years old, but terrestrial multicellular life only 750 million years old, intelligence only few million years old - so road from single celled organism to intelligence may be difficult to travel
  - "If there are 30 million living species, and if the average life expectancy of a species is about 100,000 years, then one can postulate that there have been billions, perhaps as many as 50 billion species since the origin of life. Only one of these achieved the kind of intelligence needed to establish a civilization." - Ernst Mayer, evolutionary biologist

- Edward Lerner, Alien AWOLs: The Great Silence, Analog, Oct. 2014

Great Silence

- Reason for Fermi Paradox #2 - Intelligence is common but…
  - Impatience - We haven't searched long enough
  - Wrong Strategy - Traditional SETI assumes always-on light shining brightly in every direction. They may be periodically sweeping a directional searchlight beam across plane of galaxy. If you were paying the bill, which would you choose?
  - Wrong technology - They're using neutrino beams or gravity waves rather than electromagnetic signals
  - Misdirection - They choose not to be found
  - Impracticality of interstellar travel - It is too expensive
  - Loss of interest in planets - Planets are raw materials to them
  - Transience - They are not interested in communicating or exploring
  - Great Filter - Danger is in our future - nuclear war, ecological collapse, technological runaway, retail self-destruction
  - Big Intervention - Older, wiser ATCs hide to protect themselves as they think Great Silence is caused by an ATC wiping out all the other ATCs so to preempt this they send out probes to detect + destroy other ATCs
  - Galactic low-rent district - We are in depleted / abandoned region of galaxy

- Edward Lerner, Alien AWOLs: The Great Silence, Analog, Oct. 2014

Alan Stern's Answer to Fermi's Paradox

- Buried oceans may be common across the galaxy
  - Found in our solar system at Jupiter moons Callisto + Ganymede + Europa, Saturn's moons Enceladus + Titan, Pluto
- Provide a more stable environment than surface water, giving life more time to evolve intelligence + complexity
- For life in a buried ocean, impacts + solar flares, nearby supernovae, what orbit you are in, whether you have a magnetosphere, whether you have a poisonous atmosphere - none of them matter
- But the shell of ice that protects them likely isolates them + makes them hard to detect
  - Would they even know of other stars in the galaxy?
- Developing crewed spaceflight would be tough as their life-support systems would require a lot of water which is heavy

- Mike Wall, Where Are All the Intelligent Aliens? Maybe They're Trapped in Buried Oceans, Space.com, Oct. 26, 2017

Is Complex Life Common?

- If origin of life is not a rare even, then complex macroscopic life should be common in universe
  - Once life originates, march to increasing complexity of life naturally follows - certain fraction of organisms reach higher levels of complexity given suitable environment + sufficient time
  - For main transitions / key innovations of life on Earth in its history (transition from single-cell to multicellular life, rise of photosynthesis, evolution of macroscopic life), these transitions were invented several times
  - For transition of rise of technological intelligence, this has been invented only once in humans
  - So "Great Filter" can be put at origin of life, or just before ascent of technological intelligence, or in our future
  - Conclusion: not only should we see microbial biosignatures on planets with life, but we should see biosignatures that are generated by complex multicellular organisms such as vegetation's red edge

- Dirk Schulze-Makuch, The Cosmic Zoo: Why Animal-Like Life Should be Common in the Universe, Air and Space, July 2016

Is Earth a Prematurely Inhabited Planet?

- Possible answer to Fermi Paradox is that Earth may be among very early planets with life in universe
- Dominant factor in terms of which planets might become habitable is lifetime of stars
- Stars larger than 3 times Earth's mass burn out before life can evolve, our sun has relatively short lifespan of 11 billion years, and smaller low-mass red dwarf stars can have lifespan of trillions of years…and red dwarf stars are 75% of all stars
- So we are relatively at the beginning of the universe…and life will become increasingly common as eons pass...

- Marc Kaufman, Earth: A Prematurely Inhabited Planet? Many Worlds, Aug. 22, 2016

From the Anthropocene to the Sapiezoic

- Key assumption of Kardashev scale is that civilizations will inevitably increase their energy use in order to fuel continuing expansion into cosmos
  - "The inevitable expansion fallacy" - David Grinspoon
- Doesn't take into account key term (L in Drake's equation) about lifetime of a technological civilization - what if expanding in Kardashev manner is most likely way to end growth of a culture?
  - "…it is reasonable to suppose that truly successful, long-lived species have all discarded the expansion imperative, and replaced it with an ethic of sustainability, of valuing longevity of expansion. If technological intelligence has a true and lasting form, one of its basic properties must be that it moves beyond the exponential expansion phase (characteristic of simple life in a petri dish or on a finite planet) before it hits the top of the S-curve and crashes. For us, achieving this kind of planetary intelligence will require critically examining our inherited biological habits and shedding those that have become liabilities." - David Grinspoon
- Planetary intelligence involves:
  - "…thoughtful control over one's self, escape from the mindless drives to multiply, to expand, to lay waste, kill, and drown in your own waste. Perhaps this is why we will not find what Shklovskii called 'miracles,' the highly visible works of vastly expanded super-advanced civilizations. Because advanced intelligences are not stupid." - David Grinspoon

- Paul Gilster, SETI in the Anthropocene, Centauri Dreams, Nov. 21, 2016

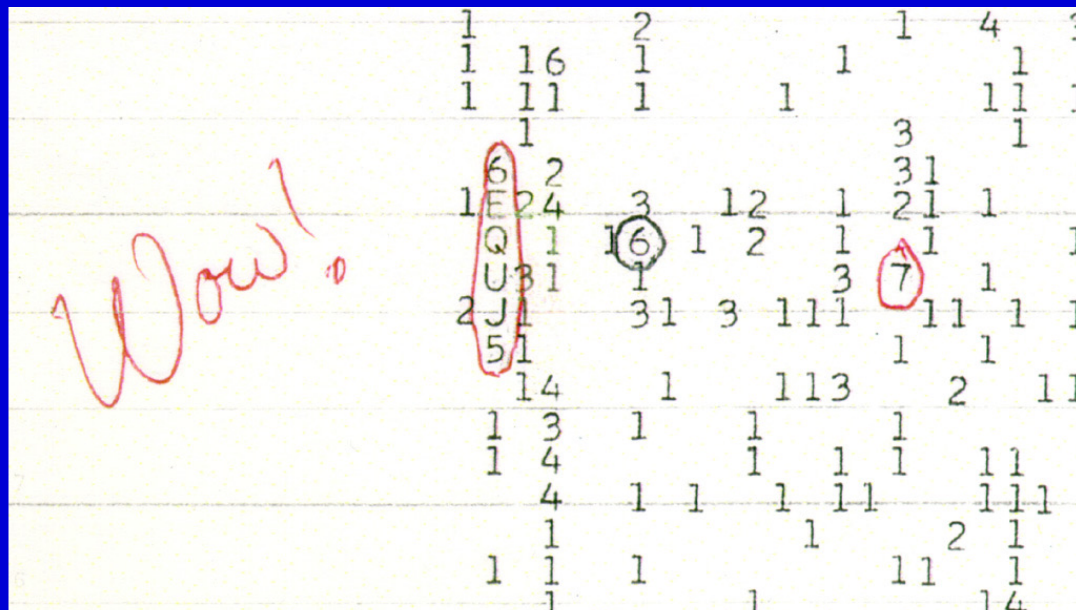
From the Anthropocene to the Sapiezoic

"Kind of technological intelligence that lasts is one that has the ability to overcome its biological need for exponential growth. If this is the case, then we are confronted with the possibility that the more advanced a technological civilization becomes, the less likely we will be to distinguish it from natural phenomena. We may confront a cosmos rife with advanced civilizations whose work is so harmonized with their surroundings as to be invisible."

"The 'Sapiezoic' eon would be the long-lived stage of technological civilization that leads conceivably to immortality. Exponential expansion may simply be an evolutionary dead end, and the likelihood of finding civilizations that are learning this lesson the hard way is vanishingly small. They are simply not in existence long enough for us to see them."

- Paul Gilster, SETI in the Anthropocene, Centauri Dreams, Nov. 21, 2016

SETI Results To Date
Wow! Signal



From Wikimedia Commons

- Strong narrowband radio signal detected by Jerry R. Ehman on August 15, 1977, while working on a SETI project at Big Ear radio telescope
- The signal bore expected hallmarks of potential non-terrestrial and non-Solar System origin
- Lasted for the full 72-second duration that Big Ear observed it, but has not been detected again
- It was at 1420 kHz, the emission frequency of hydrogen which is where SETI searchers would expect to find a signal

  - Ross Anderson, The 'Wow!' Signal: One Man's Search for SETI's Most Tantalizing Trace of Alien Life, The Atlantic, Feb. 2012
  - Amir Alexander, One Man's Quest for SETI's Most Promising Signal, Planetary Society Blog, Jan. 27, 2012

SETI Results To Date
SETI Sampling Analogy

- You are at a beach
- To figure out if there are fish in the ocean, you dip a glass into the water and look inside it - if there are no fish in the glass, there must be no fish in the ocean
  - Not very logical but this type of reasoning plagues SETI
- In 40 years SETI has sampled only ~ 1,000 star systems (1,000 glasses of water)
- Allen Telescope Array will speed up search substantially
  - Looked at ~ 1,000 stars in last decade, in next decade will look at 1 million stars
  - Now tying Moore's Law to the search, letting you run the experiment faster every year, so the chance you may find something keeps getting better each year

- Finding Life Beyond Earth, PBS Nova, Oct. 19, 2011

Speeding Up

"I think the big thing is to be pertinent in not only receivers but also the number of channels a receiver can monitor. It's thousands now, but then it'll be tens of millions and then hundreds of millions. That means that the experiment keeps speeding up."

- Neel Patel, SETI Director Seth Shostak on Our Sudden Openness to the Idea of Alien Life, Inverse, Jan. 8, 2016

SETI Results To Date

"Absence of evidence is not evidence of absence"

- Sir Martin Rees, cosmologist

Smart SETI

- Traditional targeted SETI strategy takes point of view of receivers, not transmitters
  - Background noise minimum in "water hole" region near 1 GHz seemed plausible as did assumption altruistic radiator would beam forth steady targeted microwave signals of narrow bandwidth to make detection easy
- But if you look at SETI from view of those who pay - transmitters
  - You realize broadcasting is expensive
- Motivations for transmitters
  - Kilroy Was Here (graffiti), High Church (convey culture's highest achievements), Funeral Pyre, Ozymandias (sheer pride), Help!, Leakage Radiation, Join Us (religion)
- How to do it
  - Use arrays of antennas to produce large radiation areas (~ square kilometers) that interstellar beacons require, they are also highly reliable + degrade gracefully
  - Beam in pulses to attract attention, its also much cheaper
  - Beam at high powers in broadband emission
  - Most favored spectral region near 10 GHz as it minimizes cost of beacon
  - So cost-efficient beacons will be pulsed, narrowly directed, broadband in 1-10 GHz with cost preference for higher frequencies…so SETI may be looking for wrong kind of signals

- Gregory Benford + James Benford, Smart SETI, Analog, Apr. 2011 pp. 33-39.

Smart SETI

- Where to Look
  - Search in plane of spiral disk, looking inward
- Have we seen beacons?
  - Distant cost-optimized beacons may provide a signal lasting fractions of a second, so receiver gets short burst of pulsed microwaves + doesn't see it again until ~ 1 year later
- Conclusion
  - SETI searches may be looking for wrong thing by seeking narrow-band signals at lower end of cost-optimum frequencies
  - Searches may have found beacons but could not verify them because they did not steadily observe over periods of years
  - Transmission strategy for distant cost-conscious beacon may be rapid scan of galactic plane to cover angular space + such pulses will be infrequent events for receiver + will have different characteristics from what we currently seek
  - Future searches should pay attention to areas along Galactic Disk where SETI searches have seen coherent signals that have not recurred on limited observations we have done so far

- Gregory Benford + James Benford, Smart SETI, Analog, Apr. 2011 pp. 33-39.

The Long Stare

- Project Argus - SETI League's microwave SETI project
  - Deploy + coordinate 5,000 small radio telescopes around word to provide continuous monitoring of sky in real time
  - Is amateur installation that could detect a Benford beacon's transient signal
  - In terms of cost has more in common with amateur radio than Arecibo ~ costs few thousand dollars
- "Wow Signal" could be a Benford beacon

  "Clearly SETI would benefit from a supplementary system that covers the Earth, searching continuously and broadly for pings that are sent by Extraterrestrial civilizations narrowly. That system would be ready to detect and pounce upon any new Wow Signals and automatically net-notify larger telescopes to zoom quickly on the source. Not a competitor with classic SETI, this second layer could serve as an ideal alert-generating system, filling a glaring deficit in the current approach."   - David Brin, author

- Paul Gilster, SETI: Project Argus and the Long Stare, Centauri Dreams, Dec. 14, 2015

Perspectives on SETI

"Archaeology of the future is what it should be called. Archaeology of the past is very interesting because it tells us what we once were. But archaeology of the future is the study of what we're going to become, what we have a chance to become...it's a missing element in our understanding of the universe which tells us what our future is like, and what our place in the universe is. If there's nobody else out there, that's also quite important to know."

- Philip Morrison, physicist

Perspectives on SETI

"The best reason to support SETI research is because it is an investment in our own future. The scientist Phil Morrison said that 'SETI is the archaeology of the future.' Think about it. If we detect a signal, we could learn about THEIR past (because of the time their signal took to reach us) and the possibility of OUR future. Successful detection means that, on average, technologies last for a long time. That's the only way another technological civilization can overlap with us in time and space. Understanding that it is possible to find solutions to our terrestrial problems and to become a very old civilization, because someone else has managed to do just that, is hugely important! Knowing that there can be a future may motivate us to achieve it."

- Jill Tarter, astronomer

Search Completeness and SETI

- Our search completeness to date is so low, akin to having searched a drinking glass's worth of seawater for evidence of fish in all of Earth's oceans - Jill Tarter
- Our search completeness to date is calculated to be the ratio of the volume of a large hot tub or small swimming pool to that of the Earth's oceans

- Wright JT, Kanodia S, Lubar E. How Much SETI Has Been Done? Finding Needles in the n-dimensional Cosmic Haystack, Astronomical Journal, Dec. 2018

Perspectives on SETI

"We're going to do the archaeology of the future. We're going to find out what we're going to become."

- Frank Drake, astronomer

Perspectives on SETI

- China, not the US, has built first world-class radio observatory with SETI as core scientific goal
  - US Congress has spent hundreds of millions of dollars in past searching for phenomena whose existence was in question (black holes, gravitational waves) - so why not fund SETI?
- Chinese civilization has longest continuous tradition of astronomy of any civilization on Earth, over 3,500 years
- China is lone survivor of great Bronze Age civilizations (Babylonians, Mycenaeans, ancient Egyptians)
- China's emperors drew political legitimacy from sky in form of a "mandate from heaven"

"In the technopoetic idiom of the 21st century, nothing would symbolize China's rise like a high-definition shot of a Chinese astronaut setting foot on the red planet. Nothing except, perhaps, first contact."

- Ross Andersen, What Happens if China Makes First Contact?, The Atlantic, Dec. 2017

Lurkers in Our Solar System

- **Bracewell's sentinel hypothesis - advanced alien civilizations could place AI monitoring probes on or near worlds of other evolving species to track their progress**
- **Once a civilization developed technology to find such a probe, the probe could undertake conversation in realtime with civilization and report back to its creators**
- **Promising location to place (and therefore search for) such probes would be co-orbital objects (quasi-satellites) discovered in last decade which approach Earth very closely annually at distances much shorter than anything except the moon**
- **These co-orbital objects should be passively observed by radio / optical / microwave / infrared, actively investigated by radar, contacted by METI, have unmanned probes and manned missions sent to them = full spectrum approach to SETI**
- **Most attractive target is Earth's Constant Companion 2016 HO3 which is smallest, closet, most stable quasi-satellite of Earth - and China is going to send a probe to it**

- James Benford, Looking for Lurkers: Objects Co-orbital with Earth as SETI Observables

What Happens When A Signal Comes In
SETI Post-Detection Protocols
International Academy of Astronautics

- "First, the discoverers should verify that the signal is really extraterrestrial and artificial, not man-made interference or natural, cosmic static.
- Having done so, those who made the discovery are to notify all the other signatories to the document so that they can independently proceed to check it. They should also inform national authorities.
- Next on the list of those notified are all the world's astronomers, so that every available telescope can be used to study the source of the signal.
- And then there's this, verbatim from the protocol; namely that the detection "should be disseminated promptly, openly, and widely through scientific channels and public media…""

  - Seth Shostak, Contact: What Happens if a Signal is Found, Space.com, Aug. 17, 2006
  - Protocols for an ETI Signal Detection, SETI Institute

False First Contacts

- 1938 - War of the Worlds radio broadcast
- 1967 - Discovery of pulsars
- 1977 - Wow! radio signal
- 1996 - Martian meteorite with reported fossilized microbes
- 2015 - Tabby's star - unusual flickering
- 2018 - 'Oumuamua - first interstellar object in our solar system

How Will Humanity React to First Contact?

- History, discovery, analogy are useful frameworks for approaching the problem
- History
  - August 1835 "Moon hoax" - New York Sun newspaper claimed astronomer Sir John Herschel had discovered life on moon, which set off frenzy of great interest
  - Halloween eve 1938 "War of the Worlds" - radio broadcast claimed Martians invading Grovers Mill New Jersey. Newspapers at time said it caused a panic, but recent scholarship refutes this and claim newspapers said this to discredit new medium of radio
  - 1996 NASA announces nanofossils found in Mars rock, took 10 years to determine this was probably not true
- Discovery
  - Discovery is an extended process - something is detected, it can take months or years or decades to interpret what was detected, and even longer to understand it
    - After Galileo detected protuberances around Saturn it took 40 years until Christian Huygens determined they were rings
- Analogy
  - Culture contact - Europeans meeting the Native Americans, Chinese treasure fleets in 15th century, transmission of knowledge from ancient Greeks through Arabs to Latin West in 12th + 13th centuries which leads to Renaissance

- Steven J. Dick, former NASA Chief Historian, Discovering Life in the Universe, interview on C-SPAN American History TV Sep. 15, 2014

Are You Ready to SETI?

- Around midnight August 22, 1924 Mars was closer to Earth than it had been since before the invention of telescope
- The mass media (newspapers) speculated that if Martians were going to communicate with Earth, this would be the night
- In North American, military radio transmitters were silenced + commercial radio stations ended broadcasts early to keep airways open for alien signals
- The most sensitive radio receivers scanned the airways
- Standing by to translate any alien message was William Friedman, chief of the US Army Signal Corps code division, who later cracked the Japanese PURPLE code before Pearl Harbor and later founded the National Security Agency
- Nothing was heard - but at the time it was serious business as people believed intelligent life might exist on Mars

- Terence Dickinson + Adolf Schaller, Extraterrestrials A Field Guide for Earthlings

How Would Extraterrestrial Life Change Our World View?

"If we found microbes, it would have an effect on science, especially biology, by universalizing biology...If we found an independent example on Mars or Europa, we have a chance of forming a universal biology." - Steven Dick

"I've done a book about discovery in astronomy, and it's an extended process...You have to detect something, you have to interpret it, and it takes a long time to understand it. As for extraterrestrial life, the Mars rock showed it could take an extended period of years to understand it." - Steven Dick

- Contact with new cultures can go in vastly different directions
  - Contact gone bad - Hernan Cortes treatment of Aztecs
  - Contact gone good - French fur traders working closely with Native Americans, Chinese treasure fleet in 15th century bring its culture far beyond its borders
- Indirect contact by way of radio communications through the Search for Extraterrestrial Intelligence illustrates challenges of transmitting information across cultures
  - Historical precedence is when Greek knowledge passed West through Arabs in 12th Century.
  - It is possible for ideas to be revived, even from dead cultures

- Elizabeth Howell, How Would the World Change if We Found Extraterrestrial Life?, Astrobiology Magazine, Jan. 29, 2015

Preparing For Alien Life

- How might we prepare for the discovery of life in the Universe?
  - Three ways to find life in space
    - Find it nearby in our solar system
    - Sniff it out of atmosphere of an exoplanet using telescopes to look for gases (methane + O2) that would hint at biosphere
    - Listen for radio signals from the stars
  - Finding life in our solar system, likely microbial, might not have as great an impact as hearing from intelligent civilization far away
  - Short window observation
    - Civilization capable of radio communication would likely have developed artificial intelligence by time we hear from them
    - Going from inventing radios to inventing thinking machines is very short
    - Once you create technology that puts you in touch with cosmos you are only few hundred years away from going from biological life to artificial intelligence - so dominant intelligence in cosmos may be non-biological
  - What if we don't find anyone?
    - If we are alone we should take better care of life on Earth + contemplate our duty of settlement

- Johnny Bontemps, Preparing for Alien Life, Astrobiology Magazine, Nov. 10, 2014

Rio Scale

- Rio Scale Index (RSI) provides a way to quantify the significance of contact with an extraterrestrial intelligence
- RSI = Q x lowercaseDelta
  - RSI is potential effect on human kind of an announcement of the discovery of an extraterrestrial intelligence, ranging from 0 (no hazard for mankind) to 10 (certain collision inducing global catastrophe)
  - Q is estimated level of consequences obtained from sum of class of phenomenon, type of discovery, and distance of phenomenon
  - lowercaseDelta is the discovery's credibility

- Bruno Martini, The Rio Scale: Quantifying the Consequences of an ET Discovery, Astrobiology Magazine, Apr. 4, 2013

Ethics of First Contact

- Learn all you can before risking anything
- If it seems to be alive leave it alone!
- Avoid bringing samples to the home world because I don't want to bet on it being 100 percent incompatible with our ecosystem

  - Les Johnson, Deputy Manager of NASA's Advanced Concepts Office

- Ian O'Neill, The Ethics of Interstellar Alien Encounters, Discovery News, Aug. 22, 2013

How to Approach Aliens

- Because of a century of experience in "intraterrestrial" fieldwork and their commitment to a multicultural approach, anthropologists may be most appropriately-trained scientists to inform protocol for + initiate encounters in first contact situations
- Primary rule in ethnographic field work: Make no assumptions, keep a completely open mind
- Best ethical response in one word it would be "hospitality"
- Don't assume that aliens will speak or write - may use signaling systems that we barely recognize
    - Dolphins seem to have some kind of language but despite 50 years of study we haven't been able to figure it out
- One possible way to communicate with aliens would be to "perform," or act out how humans behave to each other
- Could humans get their collective act together and behave well with another species from space?

- Annalee Newitz, Anthropologists Explain How to Approach Aliens Parked in Earth Orbit, io9, Apr. 22, 2013

Complexity of Markers for Profiling Life in Exobiology (COMPLEX)

- **Historically we define intelligence in other beings based on how much it resembles human intelligence**
  - **This may shortchange these creatures intellectual abilities**
- **The COMPLEX dimensions are**
  - **Encephalization quotient (neural complexity assessment)**
  - **Communication signals (complexity of signal coding)**
  - **Individual complexity (the presence of personalities, essentially)**
  - **Social complexity (whether living as a group or solitarily)**
  - **Interspecies interaction (the character of external relationships)**
  - **Each of these categories was broken down into further, more defined attributes.**
- **The specific assessed examples were dolphins, octopuses, bees, microbes and machines**
  - **Both bees and machines scored highly in the communication signal and social complexity categories**
  - **Dolphins, octopuses and machines all racked up big encephalization (neural complexity) points**
  - **Microbes - easily mistaken by us humans for lacking social abilities - scored relatively high in the interspecies interaction category.**

- Adam Hadhazy, Extraterrestrial Intelligence: The Challenge of Comprehending E.T.'s IQ, Astrobiology Magazine, Jan. 27, 2014

Geopolitical Implications of SETI

- What does it mean for a liberal Western democracy to compete with a totalitarian communist state over who makes first contact with aliens?
- What are the political and geopolitical implications of who makes first contact?
  - Whoever makes the contact will become the leader on what is done with it

- What would a liberal Western democracy (the US) do with a first contact discovery?
  - The US would emphasize the scientific nature of the discovery
  - The US would say we made this discovery for the good of humanity (like at the moon - We Come in Peace For All Mankind)
  - The US would conduct the contact as an open, democratic scientific process
  - The US would conduct an open process to determine what message is sent back

- What would a totalitarian communist state (China) do with a first contact discovery?
  - China would emphasize the propaganda nature of the discovery
  - China would claim the discovery for itself and say we made this discovery to show the superiority of our system and to justify our righteous place as the Middle Kingdom between heaven and Earth
  - China would conduct the contact as a closed scientific process that they control completely
  - China would choose itself what message is sent back

Is Technological Life the Predominant Form of Life in the Galaxy?

Robots will be the "last invention" that humans will ever make. "Let an ultraintelligent machine be defined as a machine that can far surpass all the intellectual activities of any man however clever. Since the design of machines is one of these intellectual activities, an ultraintelligent machine could design even better machines; there would then unquestionably be an 'intelligence explosion,' and the intelligence of man would be left far behind."

- Irving John Good, mathematician, 1965

"Enormous transformative power is being unleashed. These advances open up the possibility to completely redesign the world, for better or worse for the first time, knowledge and ingenuity can be very destructive weapons."

- Bill Joy, co-founder and chief scientist of Sun Microsystems, 2000

"Robots will eventually succeed us: humans clearly face extinction."

- Hans Moravec, director Robotics Institute at Carnegie Mellon University

- Ray Villard, Do Robots Rule the Galaxy? Discovery News, Dec. 1, 2012

Is Technological Life the Predominant Form of Life in the Galaxy?

- If on grand cosmic evolutionary scale, artificial intelligence supersedes its biological builders over a relatively rapid time period, there may be no biological life out there for us to talk to
- Artificially intelligent machines would be immortal + able to survive in wide variety of space environments deadly to us. They would have no need to settle planets and thus the concept of habitable planets would be meaningless
- One way to find them would be to find evidence of their technological activities
- They would have no reason to communicate with such a primitive life form as us

- Ray Villard, Do Robots Rule the Galaxy? Discovery News, Dec. 1, 2012

Should We Be Searching For Machine Life?

"Any society that invents radio, so we can hear them, within a few centuries, they've invented their successors. And I think that's important, because the successors are machines."

...

"We're looking for analogs of ourselves, but I don't know that that's the majority of the intelligence in the universe. I'm willing to bet it's not."

- Seth Shostak, Senior Astronomer for the SETI Institute

- Implications for SETI
  - Super-advanced extraterrestrial machines would not require water or other chemicals to survive, so are not tied to ancestors' home worlds
  - Journeying huge distances would not be a big deal to these machines, provided they could access enough energy and raw materials to keep repairing themselves over time
  - May be good idea to expand SETI to regions of space that would be attractive to digital life-forms - places with lots of available energy like centers of galaxies.

- Mike Wall, Electronic E.T.: Intelligent Aliens Are Likely to be Machines, Space.com, Nov. 14, 2016

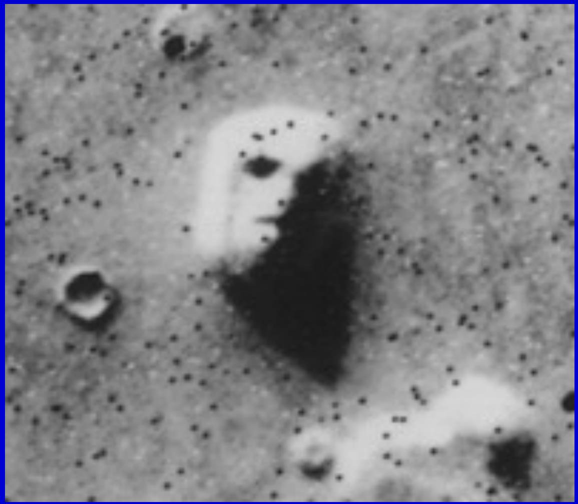
Ancient Astronauts
Have We Already Made Contact?

"Extraordinary claims require extraordinary evidence."

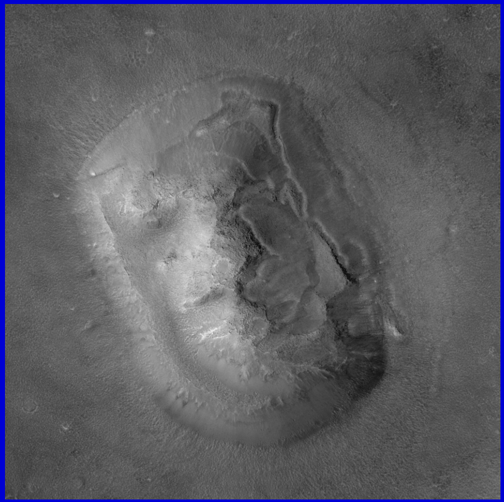
- Carl Sagan, planetary scientist

- Chariots of the Gods? Unsolved Mysteries of the Past by Erich von Daniken
  - Hypothesis - technologies + religions of many ancient civilizations were given to them by ancient astronauts who were welcomed as gods
  - Theories
    - Existence of ancient structures + artifacts that have been found that represent higher technical knowledge than existed at time they were created
    - Interpretation of ancient artwork as showing astronauts, spaceships, extraterrestrials, complex technology
    - Explanation of origins of religions as reactions to contact with alien race
  - Discredited
    - Some of the evidence is pseudoscientific
    - Some of the evidence is fabricated

Man in Mars?



From NASA



"Extraordinary claims require extraordinary evidence."

- Carl Sagan, planetary scientist

- **In 1976 Viking Orbiter photographed region of Mars called Cydonia - some felt they saw a human face on the surface**
- **In 2000 Mars Global Surveyor rephotographed the area at much higher resolution and it was found to be a natural geological formation and not of artificial origin**

- Erica Phillips, Earthlings Look for Signs in New Photos of Mars, Wall Street

UFO's - One Possible Explanation

- In WWII Germans were experimenting with antigravity
  - Zero point energy
  - Disc shaped aircraft
  - Leads to foo fighters?
- Did so in research structure run by SS General Hans Kammler who also had overseen creation of death camps
- After war Operation Paperclip transferred many of these scientists to USA
  - Kammler disappeared. Did he help create the black program structure in US?
  - Did this research continue?
  - Did the CIA encourage the UFO craze as cover story for US continued development of these aircraft?
  - Did the Soviets have a similar program created by the Germans they captured?

- Nick Cook, Into the Black, The Atlantic, Sep. 2002

UFO-Drake Equation

Number of reported sightings x
Fraction of sightings made by credible observers x
Number of those sightings that resist conventional explanation
= Total number of sightings that seem explicable only by extraterrestrial visitation

- Traditional SETI rationale = so many stars; most likely someone else is out there
- Traditional UFO rationale = so many unexplained sightings; most likely some are credible
- Just like with Drake Equation, assumptions made to arrive at number for most factors in UFO-Drake Equation can be wildly far off the mark
- But factors in UFO-Drake Equation can be known with far more certainty that those in Drake Equation
  - CIA has admitted that some UFO sightings were sightings of secret aircraft…so correlating flight histories of secret aircraft to UFO sightings attributable to those flights will yield a UFO-Drake Equation factor that is more reliable than any factor in the Drake Equation
- So it's unfair that SETI people are taken seriously when UFO people are not because they both use identical arguments

- Jeffrey Kooistra, Isaac Was Wrong (Maybe), Analog, Nov. 2003

Oumuamua (Scout) - A/2017 U1

- First object from another solar system to have been spotted visiting our solar system
  - Discovered by Pan-STARRS on Maui
- Rapidly entered solar system, swung past Sun, exited at 44 kilometers / second
- 400 meters long with cylindrical shape
- Covered in organic material but no water
- Could it be an alien spaceship - like Rendezvous with Rama?
  - SETI listened to it for any transmissions but heard none

- Rendezvous with Rama, The Economist, Nov. 4, 2017

What Is A Teaser?

"Unfortunately, I got stuck on the Earth for rather longer than I intended," said Ford. "I came for a week and got stuck for fifteen years."

"But how did you get there in the first place then?

"Easy, I got a lift with a teaser."

"A teaser?"

"Yeah."

"Er, what is..."

"A teaser? Teasers are usually rich kids with nothing to do. They cruise around looking for planets that haven't made interstellar contact and buzz them.

"Buzz them?" Arthur began to feel that Ford was enjoying making life difficult for him.

"Yeah," said Ford, "they buzz them. They find some isolated spot with very few people around, then land right by some poor unsuspecting soul whom no one's ever going to believe and then strut up and down in front of him wearing silly antennas on their head and making beep beep noises. Rather childish really."

- Douglas Adams, Hitchhiker's Guide to the Galaxy

"As Commander (Air) I was rather ruefully resigned to a full programme running the day-to-day air business of the station, with no excitement in the air. I had just two exceptions to liven up my time while I was at Brawdy.

The first was in February 1956, when one evening just as the last aircraft were returning to the airfield we had a phone call from a lady schoolteacher near Fishguard to say that she could see a flying saucer. My scepticism almost made me laugh outright as I listened to her, but I promised that I would ask one of the returning aircraft to have a look.

Jokingly, we told one of our pilots over the radio what had been reported. To our surprise, he said, 'Yes and I can damn' well see it, too'.

Again I was anything but convinced, especially as it was rapidly moving out of his sight. Minutes later one of our air traffic controllers called down to my office to say that he could see it with the naked eye from the control-tower roof. I shot upstairs and saw what did look like a saucer in the air.

I decided it was interesting enough to go and have a look at it, and I leapt off in a (deHavilland) Vampire to see what I could make of it. I climbed to about 40,000 feet but the shape was still above me and moving fairly fast, and in the now half-light of dusk I could not identify it. But I am certain it was not a cosmic research balloon, which was the only tangible thing I thought it might be.

The shape continued to be identified along the entire Bristol Channel coast that evening without any explanation ever coming out. Where once I scoffed -- I now have an open mind."

- Captain Eric (Winkle) Brown, Royal Navy, in Wings On My Sleeve

Pediatric Radiologist as Astrobiological Sleuth

- The documentary film "Sirius" from the Center for the Study of Extraterrestrial Intelligence featured a skeleton found in the Atacama Desert that was said to be extraterrestrial in origin
- Skeleton was 6 inches long, had abnormally shaped head, 10 ribs
- Forensic DNA analysis of skeleton showed it to be human
- The skeleton's x-rays + CT scans were examined by Dr. Ralph Lachman who runs the International Skeletal Dysplasia Registry
  - Is size of 22 week fetus but with high levels of calcification in the legs suggesting it was a child 5-8 years old
  - Is it a fetus that underwent natural mummification in desert or is it a dwarf?

- Cara Reichard, Professor Debunks Theories of Skeleton's Alien Origins, Stanford Daily, May 20, 2013

Future of SETI

- "The new primary questions for SETI and the institute to probe are:
  - How abundant is intelligent life in the universe?
  - How does it communicate?
  - How can we detect intelligent life?"

  - Nathalie Cabrol, director of SETI Institute's Carl Sagan Center for Research

- Marc Kaufman, SETI Reconsidered and Broadened, Many Worlds, Aug. 11, 2016

Future of SETI

- Primary goal: Understand how intelligent life interacts with its environment and communicates
- This will be explored through three main questions:
  - How abundant and diverse is intelligent life in the Universe?
  - How does intelligent life communicate?
  - How can we detect intelligent life?

- Nathalie Cabrol, Alien Mindscapes - A Perspective on the Search for Extraterrestrial Intelligence, Astrobiology 16(9) 2016

Case Study Summary - Allen Telescope Array

- Goal
  - Locate evidence of past or present communicative civilizations in universe
- Center of Gravity (Strategy)
  - Search for a signal on a dedicated full-time basis
- Equipment
  - Was to be 350 antennas, each 20 feet in diameter
  - Only 42 antennas currently built due to lack of funding
- Training ~ Leadership ~ Morale
- Tactics
  - Designed to map entire sky in one night with 350 antennas
  - Now being cued by Kepler data to search Kepler-discovered habitable planet candidates for signals

  "We're not just pointing at stars. We're pointing where you have shown us there are planets, and perhaps technologists." - Jill Tarter, astronomer
- Intangibles
  - Will it be another example of a new telescope redefining our view of ourselves in the universe?
- Mistakes
- Outcome
  - Pending

- Dennis Overbye, Search For Aliens is on Again, But Next Quest is Finding Money, New York Times, Jan. 29, 2012

Case Study Summary - 2001: A Space Odyssey

- Goal
  - Make first contact with extraterrestrial life
- Center of Gravity (Strategy)
  - Follow direction of warning signal emitted by sentinel TMA-1 monolith to Jupiter to find aliens
- Equipment
  - Discovery ship, HAL-9000 computer, human crew of engineers + first contact scientists
- Training
  - First contact scientists trained + kept separate in hibernation during voyage from engineers
- Leadership
  - United States Astronautics Agency / Heywood Floyd
- Morale
  - High
- Tactics
  - Once in Jupiter orbit, wake up scientists and brief engineers on true nature of the mission
- Intangibles ~ Mistakes
  - U.S. keeps the news of signal detection secret from Soviets and the world
  - Engineers in charge of Discovery have no idea what the real mission is
  - HAL 9000 computer murders most of crew in order to keep mission secret from them
- Outcome
  - First contact made by untrained crew member who stumbles through it - what is the outcome?

- Frederick Ordway III, 2001: A Space Odyssey in Retrospect

Computing Case Study Summary - SETI@Home - SETI + Citizen Science

- Goal
  - Detect a signal from an extraterrestrial civilization
- Center of Gravity (Strategy)
  - Acquire data from Arecibo radio telescope
- Technology / Equipment
  - Personal computers using their spare capacity are networked together
- Training ~ Leadership ~ Morale
  - Started in 1999, has attracted > 6 million users
- Tactics
  - Personal computers using their spare capacity process data acquired by SETI's radio telescopes, looking for signals
- Intangibles
  - Disadvantage is that processing is not done real-time, data is months old when it is processed so when signal is found it is an old signal that can't be acted upon
- Mistakes
- Outcome
  - Is a virtual supercomputer

- The Wow Factor, The Economist, Mar. 10, 2012
- John Markoff, In Search for Alien Life, Researchers Enlist Human Minds, New York Times, Mar. 20, 2012
- Alex Lux, Little Green Men, @CHM, Oct. 19, 2012

Computing Case Study Summary - SETI

- Goal
  - Find radio signal from extraterrestrial civilization
- Center of Gravity (Strategy)
  - Allen Telescope Array to gather data ~ Computers to process data
- Technology / Equipment
  - Allen Telescope Array of 42 antennas will speed up search substantially
    - Looked at ~ 1,000 stars in last decade, in next decade will look at 1 million stars
  - Computers following Moore's Law
    - You double your computing power every 18 months that you use to search the data you gather for signals, thus you are doubling the speed of your SETI search every 18 months
- Training ~ Leadership ~ Morale
- Tactics
- Intangibles ~ Mistakes
- Outcome
  - SETI's search follows Moore's Law
    - By tying Moore's Law to the search, lets you run the experiment faster every year, so the chance you may find something keeps getting better each year
  - Quantity has a quality all its own
  - Sufficient quantitative change can be qualitative change

Computing Case Study Summary - SETILive - SETI + Citizen Science

- Goal
  - Detect a signal from an extraterrestrial civilization
- Center of Gravity (Strategy)
  - Acquire data from Allen Telescope array radio telescope targeted at Kepler detected exoplanets
- Technology / Equipment
  - Uses pattern recognition capabilities of human's brains
- Training ~ Leadership ~ Morale
  - Started in 2012, has attracted 100,000 users over 2 years
- Tactics
  - Humans look at waterfall plots of data trying to detect true signal amidst noise from stars or humans in real-time
  - You have 90 seconds to find signal, if signal is found, telescope is retargeted within 3 minutes to look again for signal
- Intangibles
  - Human analysis of data is form of machine learning for the system to fine-tine its signal-finding algorithms
- Mistakes
- Outcome
  - Ran for 2 years until it ran out of funds

- The Wow Factor, The Economist, Mar. 10, 2012

- John Markoff, In Search for Alien Life, Researchers Enlist Human Minds, New York Times, Mar. 20, 2012

- Alex Lux, Little Green Men, @CHM, Oct. 19, 2012

Computing Case Study Summary - HAL 9000 (Heuristically programmed ALgorithmic computer)

- Goal
  - Create in 1966 a vision of what computing would be like in 2001
- Center of Gravity (Strategy)
  - Interview IBM's best and brightest (Ernest Bevilacqua, Gil Fox, Bob D'Arcona) for basic programming structure for HAL + Prof. Irving John Good (an associate of Alan Turning) for his predictions on sentient computers
- Technology / Equipment
  - Relies on heuristic algorithm design
  - Executes 2 trillion computations / second ~ Has quintillion megabytes of optical memory
  - HAL could see, listen, speak, reason, play chess, plan, express emotions
  - Has reasoning, knowledge, planning, learning, communication, perception, ability to manipulate objects
- Training
  - HAL was taught by an instructor, Dr. Chandra
- Leadership
  - HAL believes mission's success is up to it

    - Arthur C. Clarke, 2001 A Space Odyssey
    - Adam Johnson, 2001: The Lost Science
    - Frederick Ordway III, 2001: A Space Odyssey - Vision Versus Reality at 30

Computing Case Study Summary - HAL 9000 (Heuristically programmed ALgorithmic computer)

- Morale
  - The HAL 9000 series has never made an error
- Tactics
  - HAL is responsible for overseeing the operation of the spaceship Discovery
  - Sentience of HAL based on 4 philosophical questions + their relevance to mission: What am I doing? What should I be doing? How am I doing? How should I be doing?
- Intangibles
  - HAL gets paranoid, begins to make errors, crew decides to turn it off
- Mistakes
  - HAL tries to murder the crew to contain true nature of mission
- Outcome
  - Crew lobotomizes HAL ~ Crew achieves mission success without HAL

    - Arthur C. Clarke, 2001 A Space Odyssey
    - Adam Johnson, 2001: The Lost Science
    - Frederick Ordway III, 2001: A Space Odyssey - Vision Versus Reality at 30

Staff Ride - War of the Worlds by HG Wells 1898 - 1

- **Prelude - Politics - Strategy**

  "Yet across the gulf of space, minds that are to our minds as ours are to those of the beasts that perish, intellects vast and cool and unsympathetic, regarded this Earth with envious eyes, and slowly and surely drew their plans against us."

  - Martians - running out of resources, have trashed their planet, need new home, were done in by climate change ~ Want to terraform Earth to make it habitable via red weed + drink human blood for nutrition
  - British - at height of empire + have crushed many "primitive" empires in recent past, now tables are turned ~ Want to keep their empire
- **Approach of armies to battlefield - Why was battle fought here**
  - Martian strategy is to decapitate British Empire by seizing its capital - London, so they land in Woking and advance on London
- **Leaders**
  - Martians are just basically brains without digestive systems or ethics ~ British are humans
- **Logistics**
  - Martians - bring everything they need and have assemblers that build their equipment ~ British - logistics are overrun and overwhelmed
- **Weapons - Direct and indirect**
  - Martians - are encased in tripod exoskeleton / mecha and use Heat-Ray (laser) and Black Smoke (chemical weapons) ~ British - gunpowder (rifles + cannons)
- **Order of Battle**
  - A few Martians against the whole British army
- **Organization - Units and formations**
  - Individual Martians versus the regimental squares of the British
- **Command, control, communications, intelligence**
  - British C3I hampered by Martian attacks on their communications infrastructure
- **Tactics**
  - Martians - zap and gas humans ~ British are on the opposite side of asymmetric warfare for once as their conventional weapons don't work against Martians so British turn to improvised explosive devices (IEDs)

- Francis Spufford, Following the Martian Invasion, BBC Radio 4, 2017

Staff Ride - War of the Worlds by HG Wells 1898 - 2

- Weather
  - N/A
- Terrain
  - N/A
- Operational
  - Martians stage a Blitzkrieg (think France 1940), waging a total war against the British, in particular attacking infrastructure such as transportation (railways), communications (telegraph lines) and armaments (ammunition dumps) + routing civilians out of their homes
- Chronologic narrative of battle taking note of friction and fog
  - In 80 hours the Martians conquer British Empire but in end are defeated by asymmetric weapon in the form of inadvertent biological warfare by the British

  "…slain, after all man's devices had failed, by the humblest things that God, in his wisdom, has put upon this Earth"
- Decisions - What good and bad ones were made
  - Martians don't take precautions against bacteria ~ British don't realize the only way to defeat the Martians is to attack them after they land and before their emerge from their capsules
- OODA loop - Who is inside the other's
  - Martians are inside the British
- Who thought they won, who really won
  - Martians won all the battles but the British won the war
- What effect did it all have - Aftermath of battle
  - Reflects British interest in rise + fall of empires ~ Is way of looking at what British did to natives through native's eyes
  - Depicts an imperial power as a victim of imperial aggression
  - Was first popular first contact story which went on to influence many others

  "And before we judge them [the Martians] too harshly, we must remember what ruthless and utter destruction our own species has wrought, not only upon animals, such as the vanished Bison and the Dodo, but upon its own inferior races. The Tasmanians, in spite of their human likeness, were entirely swept out of existence in a war of extermination waged by European immigrants, in the space of fifty years. Are we such apostles of mercy as to complain if the Martians warred in the same spirit?"

- Francis Spufford, Following the Martian Invasion, BBC Radio 4, 2017

Personal Case Study - Cahokia

- Location
  - Cahokia Mounds State Park
- Story
  - From 800-1300 AD
  - Was capital of Mississippian people
  - 20-40,000 inhabitants
  - Largest city in North America until Philadelphia in ~ 1800
  - Had an observatory
  - Demonstrates primeval need to try and understand who and what is out there

Personal Case Study - SETI Institute

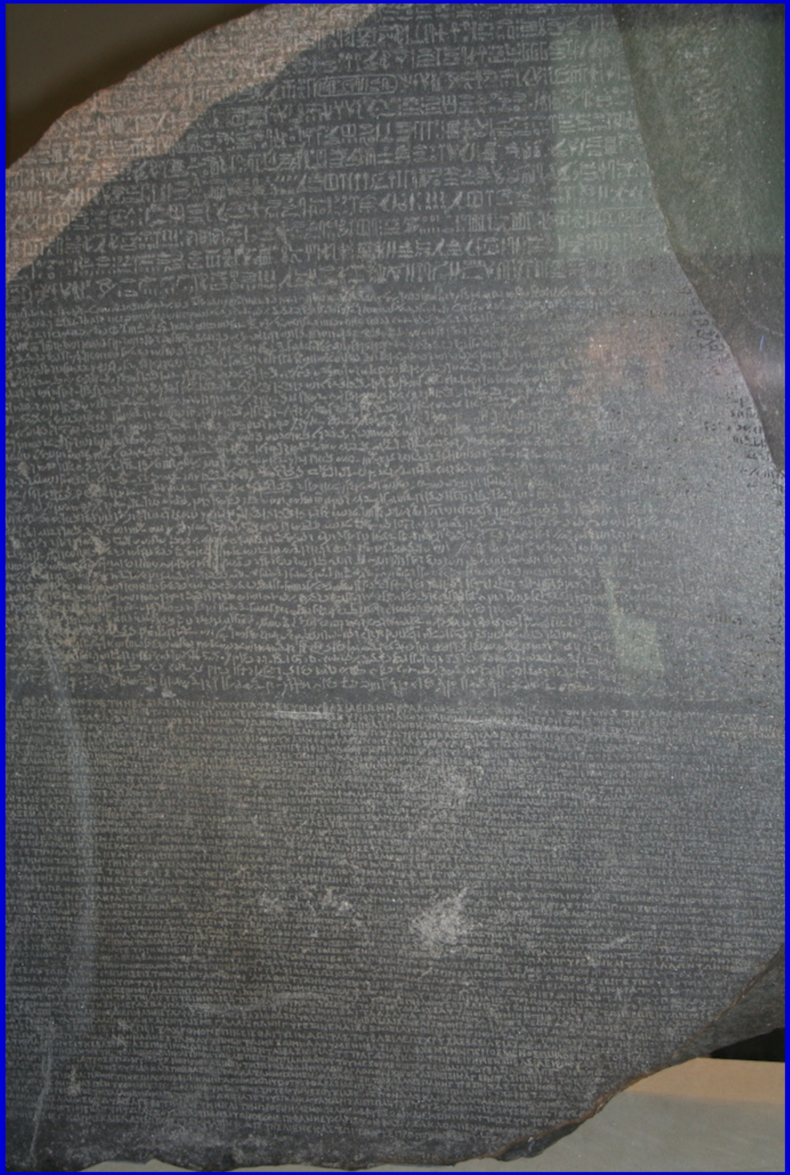
- Location
  - SETI Institute
- Story
  - Virtual laboratory - scientist's offices no longer need to be with their instruments thanks to Internet
  - No matter the time of the day, Seth Shostak is in his office working away

Astrobiology Analog Case Study - Attempting Contact

- **Location**
  - **Great Barrier Reef, Heron Island**
- **Story**
  - **Snorkeling amongst so many diverse species and trying to make a connection**

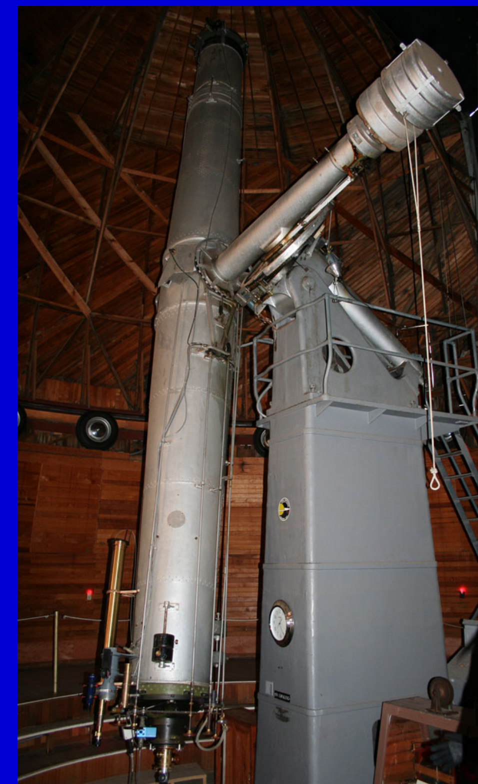
Astrobiology Analog Case Study - Rosetta Stone

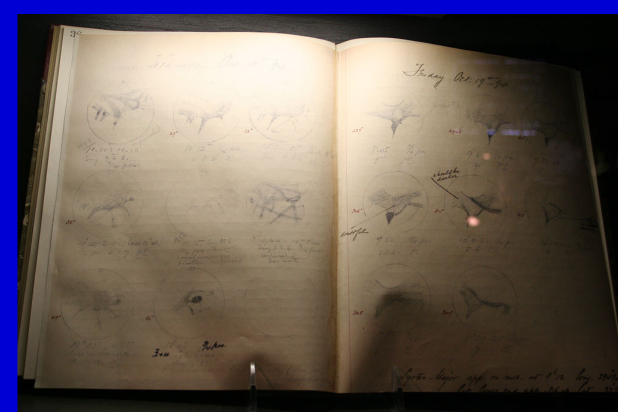
- Location
  - British Museum, London
- Story
  - Example of using science, logic and luck to decipher a message



Personal Case Study - Getting It Wrong

- Location
  - Lowell Observatory
- Story
  - Wrong - canals on Mars
    - A false positive SETI experiment
  - Right - Mars is very interesting…there was water on it…there may have been life on it





Class Simulation

- Topic aspects

Poem

'Is there anybody there?' said the Traveller,
  Knocking on the moonlit door;
And his horse in the silence champed the grasses
  Of the forest's ferny floor:
And a bird flew up out of the turret,
  Above the Traveller's head:
And he smote upon the door again a second time;
  ‘Is there anybody there?' he said.
But no one descended to the Traveller;
  No head from the leaf-fringed sill
Leaned over and looked into his grey eyes,
  Where he stood perplexed and still.
But only a host of phantom listeners
  That dwelt in the lone house then
Stood listening in the quiet of the moonlight
  To that voice from the world of men:
Stood thronging the faint moonbeams on the dark stair,
  That goes down to the empty hall,
Hearkening in an air stirred and shaken
  By the lonely Traveller's call.

- The Listeners, Walter de La Mare

Questions for Further Discussion

- What is <u>your</u> definition of intelligent life?
- What is more interesting to you: The discovery of simple life around a star nearby Earth - or - Intelligent life in another galaxy?
- What will intelligent life most likely <u>not</u> look like?
- Is it a good idea or a crazy idea to search for intelligent life?
- What is your solution to the Drake Equation - N=?
- Are we alone in the universe - pick a side and give an evidence-based approach to proving it
- Will the intelligent life we encounter be biological or robotic intelligent machines?
- What are the advantages and disadvantages of the various techniques for performing SETI?
- Describe what interstellar message you would send from Earth to introduce yourself to alien races?
- If you could send a message to an extraterrestrial somewhere across the galaxy, what would you say?
- Should we be sending interstellar messages out or should we be hiding from extraterrestrial intelligences?
- Should we practice "safe SETI"? / How do you practice "safe SETI"?
- How would the discovery of life beyond Earth affect you personally?
- How would the discovery of life beyond Earth affect mankind?
- What are the societal implications of discovering life beyond Earth?
- What would be the impact of discovering life elsewhere?
- What evidence exists that Earth has already been visited or contacted by aliens?

Questions for Further Discussion - First Contact

- See Topic 13 Conclusion

Reading Assignments

- Astrobiology Primer 2.0 (2016) Chapter 8
  - https://doi.org/10.1089/ast.2015.1460
- TED Talks for this Topic
  - http://www.astrobiologysurvey.org/ToLearnMore.html

Recommended Reading to Learn More

- Non-fiction
- Fiction
  - Carl Sagan - Contact
  - Arthur C. Clarke - Rendezvous With Rama
- Movies
  - Close Encounters of the Third Kind
  - Contact
- Simulations
  - The Dig

Bottom Line on SETI

"It's a question that people were asking a thousand years ago, but there was nothing they could do about it. We can do something about it. We can actually mount an experiment that looks good on paper. How crazy would it be not to at least try?"

- Seth Shostak, astronomer

"People seem somewhat surprised that I would do this for a living. To me, that in itself is surprising. Because it seems like kind of a privilege to try and answer a question that you know, every generation has asked. It's very exciting to be able to do that."

- Seth Shostak, astronomer

What Would Be the Impact of the Discovery of Life Elsewhere?

"Scientifically, the discovery of extraterrestrial life would be the greatest discovery of all time. Its impact on other fields of human thought are, in my estimation, literally incalculable."

- Timothy Ferris, science writer

Conclusion

"The fact that we have not yet found the slightest evidence for life - much less intelligence - beyond this Earth, does not surprise or disappoint me in the least. Our technology must still be laughably primitive, we may be like jungle savages listening for the throbbing of tom-toms while the ether around them carries more words per second than they could utter in a lifetime."

- Arthur C. Clarke, author

"Sometimes I think we're alone. Sometimes I think we're not. In either case, the prospect is staggering."

- Arthur C. Clarke, author

Conclusion

"I've always felt that extraterrestrial contact will be the greatest source of uncertainty for humanity's future."

- Cixin Liu, Chinese science fiction writer (The Three-Body Problem)

Conclusion

"When SETI succeeds, it will give us access to the entire knowledgebase of other civilizations, most of which will be much older than ours, so they will be wiser, they will know far more of science and technology than we do, and from this will come tremendous benefits to all of humanity, far more than you could achieve by spending the money that was required in any other way. So its a long shot, it will take a long time, but in the end the cost will be justified like no other thing that has ever been done."

- Frank Drake, astronomer

Final Thought - Paradigm Shift

From SETI -> Search for Technosignatures

"We need to be very careful about our language...SETI is not the search for extraterrestrial intelligence. We can't define intelligence, and we sure as hell don't know how to detect it remotely. [SETI]...is searching for evidence of someone else's technology. We use technology as a proxy for intelligence...[The acronym] 'SETI' has been problematic in history, and we should just drop [it] and just continue to talk about a search for technosignatures."

- Jill Tarter, astronomer

Topic 9

Crewed and Uncrewed Spaceflight

Song

Gather round while I sing you of Wernher von Braun,
A man whose allegiance
Is ruled by expedience.
Call him a Nazi, he won't even frown.
"Ha, Nazi Schmazi," says Wernher von Braun.

Don't say that he's hypocritical,
Say rather that he's apolitical.

"Once the rockets are up, who cares where they come down?
That's not my department," says Wernher von Braun.

Some have harsh words for this man of renown,
But some think our attitude
Should be one of gratitude,
Like the widows and cripples in old London town
Who owe their large pensions to Wernher von Braun.

You too may be a big hero,
Once you've learned to count backwards to zero.
"In German oder English I know how to count down,
Und I'm learning Chinese," says Wernher von Braun.
- Tom Lehrer, Wernher von Braun

Thematic Quote

"Real progress is not a leap in the dark, but a succession of logical steps"

- Robert Goddard, rocket scientist

"It is difficult to say what is impossible, for the dream of yesterday is the hope of today and the reality of tomorrow."

- Robert Goddard, rocket scientist

Thematic Quote

"No bucks, no Buck Rodgers."

- The Right Stuff (movie)

The Painting

In the Beginning

- Alan Bean

(Private collection)

Artifact

- Name
  - Spacecraft models
- Year
  - 1960's -> present
- Story
  - Tangible representations of what has been done

The Question

What is the best way to explore our solar system and the universe for life - with crewed or uncrewed spacecraft?

Crewed and Uncrewed Spaceflight Search For Extraterrestrial Intelligence So Far

Prehistory - Exploration Visionaries Ancient Greeks ~ 4th Century BC

"What a waste of space it would be if there was nothing else except humans on planet Earth."

- Anonymous 4th Century BC Greek philosopher

["The Universe is a pretty big place. If it's just us, seems like an awful waste of space."

- Carl Sagan, planetary scientist]

Prehistory - Exploration Visionaries - Chinese ~ 1400s

- Invented gunpowder
- Invented rocketry
  - Chinese Emperor taking a voyage on a rocket propelled throne

Prehistory - Rocketry in War

- Shock is not the hallmark of Chinese way of war - battle is fought at a distance
  - Bow is weapon of choice
    - The decisive moment / tipping point is mental - not physical
    - Two armies stand still on battlefield firing arrows + rockets at each other until one side panics + runs

"Rockets Red Glare, The Bombs Bursting in Air…"

  - = British Congreve rockets
  - Stolen technology from Mysore in India

Rocket's Red Glare

- Rockets used to bombard Fort McHenry in War of 1812
- Developed by William Congreve, evolved the rocket from a firework into a reliable weapon intended to destroy Napoleon's fleet
  - Increased their size, increased their range, made a variety of warheads - especially incendiary ones, stabilized them in flight by addition of 15 foot wooden pole / guide stick
- Rockets used against Fort McHenry were 3.5 inches in diameter with incendiary warhead and weighed 32 pounds but were not effective as ship firing them could not get close enough due to fort's effective defensive gun fire
- Were a terror weapon, were also used to help burn down the White House
- Their use influenced other countries to establish rocket troops + establishments

- Frank Winter, The Rockets That Inspired Francis Scott Key, Air & Space Magazine, Sep. 2014

Prehistory - Exploration Visionaries - Jules Verne - 1865

- A Voyage From the Earth to the Moon
  - Novel by Jules Verne, Film by George Melies

Prehistory - Exploration Visionaries - Konstantin Tsiolkovsky ~ 1903

- Same year Wright Brothers achieved first powered, heavier than air flight
  - Tsiolkovsky calculated speed necessary to reach escape velocity and achieve orbit of Earth
  - Proposed liquid fueled multistage rockets as way to achieve escape velocity
  - Designed spacecraft with steering thrusters, space stations with air locks, space suits
  - Rocket equation that tells you how much fuel you need for journey through space
- Died in 1935, saw none of it achieved

Rocket Equation

$$\Delta v = v_e \ln \frac{m_0}{m_1}$$

From Wikimedia Commons

- m0 - initial total mass, including propellant,
- m1 - final total mass,
- ve - effective exhaust velocity,
- delta-v - maximum change of velocity of the vehicle (with no external forces acting)

- Describes the motion of vehicles that follow the basic principle of a rocket: a device that can apply acceleration to itself (a thrust) by expelling part of its mass with high speed and move due to the conservation of momentum. The equation relates the delta-v (the maximum change of speed of the rocket if no other external forces act) with the effective exhaust velocity and the initial and final mass of a rocket (or other reaction engine)

Prehistory - Exploration Visionaries - Robert Goddard ~ 1920's

- First successful liquid fuel rocket
- Ignored in his time by scientific + academic communities

Prehistory - Exploration Visionaries - The Germans ~ 1930's + 1940's

- Oberth and his club
- Co-opted by the German military
- Peeneumunde
- V-2
- Plans for intercontinental ballistic missile, man in space, antipodal Sangar space plane
- Wernher von Braun
  - Surrenders to side with most money

  "I aim for the stars but sometimes I hit London"
  - V-2 evolves into Redstone and Saturn rockets for US

Prehistory - Exploration Visionaries - Man Will Conquer Space Soon! - Collier's 1952-1954

- Das Marsprojekt (novel) written in 1948 but unpublished
  - Das Mars Projekt (scientific appendix to novel) published in 1952
- 1951 - "Space Travel Symposium" at Hayden Planetarium
- Collier's magazine
  - In 1952-1954 published articles "Man Will Conquer Space Soon!" which was Wernher von Braun's blueprint for spaceflight
- Became 3 books
  - Across the Space Frontier (1952)
  - Conquest of the Moon (1953)
  - The Exploration of Mars (1956)
- Became Disneyland TV programs in 1955-1957
  - Man in Space
  - Man and the Moon
  - Mars and Beyond

- Albert Jackson, The Collier's Series Backstory, AIAA Houston Section Horizons, Jul / Aug. 2012
- Albert Jackson, The Conquest of Space, AIAA Houston Section Horizons, Mar. / Apr. 2012

Prehistory - Exploration Visionaries - International Geophysical Year July 1957 - December 1958

- Wernher von Braun's team at Redstone Arsenal was aware of prestige that would be given to first country to orbit a satellite
- Was all ready to launch US satellite in 1956 / 1957
- Was stopped by White House who wanted U.S. Navy team - Project Vanguard - to go first rather than the Germans at the Redstone Arsenal

History Begins

"Scientists are men who dream about doing things. Engineers do them"

- Harry Crampton at Langley in Space by James Michener p. 222

"Basic research is what I am doing when I don't know what I am doing"

- Wernher von Braun, rocket scientist

"God is in the details"

- Mies van der Rohe, architect

The First Satellites - Sputnik + Explorer I

- October 4, 1957 - Sputnik 1 (USSR) ~ 184 pounds
  - Is proof of concept that Soviet Intercontinental ballistic missile works
- November 3, 1957 - Sputnik 2 (USSR) ~ 1,120 pounds + Laika the dog
- June 31, 1958 - Explorer 1 (US) ~ 31 pounds
- Soviet firsts
  - Satellite, animal, man, woman, multiperson crew, spacewalk, space station, photograph far side of Moon, land on Venus, etc.
- NACA -> NASA as a civilian space program in the US to counter Soviet military space program

"I will not go to bed by the light of a Red Moon."

- U.S. Vice President Lyndon Baines Johnson

Soviet Firsts in Space

- 1957 - Artificial satellite - Sputnik
- 1957 - Animal in space - Laika
- 1959 - Spaceship to land on another celestial body - Luna
- 1961 - Human being in space - Yuri Gagarin
- 1963 - Woman in space - Valentina Tereshkova
- 1970 - Lander on another planet (Venus) - Venera
- Lander on Mars
- Crew in space - Voskhod-1
- Spacewalk - Leonov - Voskhod-2
- Pictures from the far side of the moon
- Space station

- Doug Millard, Cosmonauts: Birth of the Space Age

First Humans in Space

- Soviet
  - Vostok - Yuri Gagarin + Valentina Tereshkova
  - Vokshod - Leonov walk in space, 3 man crew, co-orbital flights
- US
  - Rocket planes X-1 to X-15
  - Mercury suborbital - Shepard + Grissom
  - Mercury orbital - Glenn
  - Kennedy

    "I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth." - President John F. Kennedy

    Man. Moon. Return. Decade.

Soviet Race to the Moon

- Almost orbit the Moon in Zond spacecraft with humans just before US Apollo 8 does it
- Almost successfully execute uncrewed sample return from Moon with Luna 15 just before Apollo 11
- Can't get N1 rocket for crewed lunar landing to work so crewed lunar landing abandoned
- Ends with successful uncrewed rover and sample return after Apollo 11

US Race to the Moon

- Mercuy
  - Demonstrates you can remain alive in vacuum of space
- Gemini
  - Demonstrates you can maneuver and work in space
- Apollo
  - Demonstrates you can land on and return from the Moon
  - Apollo is the high water mark of the United States
  - Ends because we won the race, don't want to loose a crew
  - Earthrise is iconic picture, launches Earth Day and the environmental movement
  - Ends with realization we must study Earth next

What's It Like to Walk on the Moon?

"No sooner have you tested the surface with your feet to find your sense of balance in one-sixth g [gravity] than you're already trying to keep up with the schedule Houston is drumming into your earphones, and you're moving around and getting sore from the friction of the joint rings and the gloves on the goddamned space suit, and you haven't really slept in five days, and your back hurts, and on top of that you're constipated."

- Tom Wolfe, Post-Orbital Remorse Part IV: The Last Great Galactic Flash, Rolling Stone, Mar. 1, 1973

What We Learned From the Space Race

- …we had to go all the way to the Moon
- To realize how precious the Earth was…

Soviet Space Stations

- Salyut
- Mir

US Space Station + Space Shuttle

- Space station
  - Skylab
    - Devoted to science in space
- Space shuttle
  - Most important shuttle missions - Hubble Space Telescope launch and repairs

The Potential of the Space Shuttle

"To me there was a touch of Rip Van Winkle about it all. After 54 ½ hours in earth orbit an airplane - not a capsule or a command module but an airplane, a ship with wings - descends above the high desert of California. It glides toward a landing at Edwards Air Force Base. As in the old days, the mirages of Rogers Dry Lake envelop it like a hallucination. The ship makes a perfect touchdown and rolls to a stop. At last the commander emerges. He is 50 years old. He has grown old and farsighted waiting for this flight. He had to wear glasses to read the instrument panel. He opens his mouth, and out comes a drawl that takes me back 25 years, at least, to the cowboy days of Chuck Yeager.

Not to press John Young into the role of Rip Van Winkle, but his flight with his 43-year old copilot, Robert Crippen, in the space shuttle Columbia resumes a story that was broken off a quarter of a century ago. It returns the American space program to where it started - which was not Cape Canaveral but the throwback landscape of Edwards Air Force Base, a terrain that evolution left behind, a desert decorated with the arthritic limbs of Joshua trees and memories of Chuck Yeager, Scott Crossfield, Joe Walker, Iven Kinchloe, and other pioneers of manned rocket flight."

- Tom Wolfe, Columbia's Landing Closes a Circle, National Geographic, Oct. 1981

Case Study Summary - International Space Station

- Goal
  - Permanent human presence in space
- Center of Gravity (Strategy)
  - Permanent space station
- Equipment
  - Length of football field, interior volume of 6 bedroom house
  - Half Russian, half US (includes modules from Canada / Japan / Europe)
  - Most sophisticated water-recycling system ~ Food mainly vacuum-packed / canned
- Training
  - Thorough
- Leadership
  - Excellent
- Morale
  - Has rhythm of living on a ship
  - Paying attention to morale is important - 6 months is long time to be in space with responsibility to maintain station + body but without family, friends, fresh food, sunshine, rain, gravity, bathing / laundry
  - Singular experience of space is flying inside the station / being liberated from gravity

- Charles Fishman, 5,200 Days in Space, The Atlantic, Jan/Feb 2015

Case Study Summary - International Space Station

- Tactics
  - Medically get space sickness for few days, stuffy head due to fluid redistribution, farsighted
  - Zero-G is harmful - lose bone mass, lose muscle mass + strength, lose blood volume, lose aerobic fitness / anaerobic fitness / stamina - so must exercise 2 ½ hours / day x 6 days / week
  - Day to day life in space is more thrilling + dangerous and choreographed + mundane than one would think
  - Costs $350,000 / hour to operate = $8 million / day = operating cost of US Navy aircraft carrier battlegroup
  - Astronauts don't fly station - Houston + Moscow do - Takes 1,000 people to support each astronaut in orbit
  - Takes 50 ground personnel to build the daily work schedule - Each day's planning begins 18 months out - astronauts merely highly skilled technicians
  - Praise inflation to ground personnel is a problem
  - Getting into spacesuit + out the hatch takes 4 hours + is 400 step checklist

- Charles Fishman, 5,200 Days in Space, The Atlantic, Jan/Feb 2015

Case Study Summary - International Space Station

- **Intangibles**
  - **Station was to have 7 functions - research lab, manufacturing facility, observatory, space transportation hub, satellite-repair facility, spacecraft-assembly facility, staging base for crewed missions to solar system**
  - **30 years later is only a research lab with 40% of its research capacity unused**
  - **2/3rds of work done by each astronaut each day is to maintain station, handle logistics, stay healthy**
- **Mistakes**
  - **Life in space is harder than NASA imagined**
- **Outcome**
  - **US is a permanently spacefaring nation - To date 216 men + women have lived on it**
  - **Engineering marvel that goes in a circle without yielding any noteworthy breakthroughs**
  - **Most important purpose may be to teach us how to make life in space more practical + less dangerous - astronauts currently have no autonomy but going to Mars would require autonomy due to communications lag**
  - **So give astronauts on station more autonomy - figure out what autonomy for astronauts would look like + how the ground can support it and how it will shape the design of future spacecraft**

- Charles Fishman, 5,200 Days in Space, The Atlantic, Jan/Feb 2015

Focused Case Study - Space Race

- Three historic rationales for macro engineering projects
  - Warfare, monument to power, make a pile of money
    - Neil de Grasse Tyson
- Motivation for Project Apollo was partly warfare (defeat Soviet Union) and partly monument to power

Focused Case Study - Space Race

- **John F. Kennedy Moon Speech in Rice Stadium Sept. 12, 1962**
  - "The exploration of space will go ahead, whether we join in it or not, and it is one of the great adventures of all time, and no nation which expects to be the leader of other nations can expect to stay behind in the race for space."
  - "...this generation does not intend to founder in the backwash of the coming age of space. We mean to be a part of it--we mean to lead it. For the eyes of the world now look into space, to the moon and to the planets beyond, and we have vowed that we shall not see it governed by a hostile flag of conquest, but by a banner of freedom and peace."
  - "Yet the vows of this Nation can only be fulfilled if we in this Nation are first, and, therefore, we intend to be first. In short, our leadership in science and in industry, our hopes for peace and security, our obligations to ourselves as well as others, all require us to make this effort, to solve these mysteries, to solve them for the good of all men, and to become the world's leading space-faring nation."
  - "...only if the United States occupies a position of pre-eminence can we help decide whether this new ocean will be a sea of peace or a new terrifying theater of war."

Focused Case Study - Space Race - Phase 1 - Sneak Attack

- Provides arena for non-military competition / decompression between superpowers
- Germans
  - First true rocket scientists - had the vision
- Soviets
  - Bypass strategic bombers ~ Build big boosters for ICBMs
  - Don't trust their Germans
- US
  - Believes in strategic bombers ~ Builds smaller boosters
  - Doesn't want to give credit to our Germans
- Early results for USSR
  - Sputnik, Gagarin - invincible
- Early results for US
  - Total panic - don't want to live under a red moon
  - Shift from crewed space planes (X-15) to capsules (Mercury)

Focused Case Study - Space Race - Phase 2 - Race to the Moon

- US
  - Kennedy reluctantly picks long term goal of moon
    - "Not because they are easy but because they are hard"
  - Manhattan-like project
    - Turn our Germans loose
    - Turn our aerospace industry loose
    - Well organized and managed open process overcame adversity of Apollo 1 and made it
      - First humans to moon 1968, first landing on moon 1969, first science on moon 1971
    - Spinoffs - microelectronics / computer revolution
  - (Quietly performing planetary exploration)

Focused Case Study - Space Race - Phase 2 - Race to the Moon

- US
  - Apollo really was an incredible achievement given state of technology
    - Computational capability of Saturn V stack in 1969 = 1 cell phone in 2004
  - Canceled due to lack of public support, lack of funds, Nixon's desire to not want to lose a crew

Focused Case Study - Space Race - Phase 2 - Race to the Moon

- USSR
  - What do we do next?
    - OK, the moon then
  - Tremendously destructive competition between design bureaus - political machinations
    - Closed process
    - Pursuing space station at same time
    - But almost sent first human around the moon in 1968 in Zond just before Apollo 8
      - Soviet launch window to moon opened 2 weeks before US window in December 1968 but Politburo unwilling to take risk due to unreliable Zond hardware
    - First uncrewed rover on moon
    - First uncrewed sample return from moon
      - Luna 15 crashes on moon July 13, 1969 trying to beat Apollo 11 astronauts back to earth with first moon rock samples
  - (Quietly performing planetary exploration)

Focused Case Study - Space Race - Phase 3 - Going in Circles

- US
  - Plan
    - Skylab short term space station, then…
    - Shuttle + long term space station
  - Reality
    - Skylab, then Shuttle
    - Purposeless long term space station way later
    - Ends with loss of Columbia while doing Larry Light bulb science experiments
  - (Quietly dominates planetary + galaxy exploration - Pioneer - Viking - Voyager - Hubble)
  - Computationally ascendant

Focused Case Study - Space Race - Phase 3 - Going in Circles

- USSR
  - Dominates space station
  - Clones shuttle (Buran) which is uncrewed!
  - Abandons planetary exploration
  - Computationally bankrupt / bereft

Focused Case Study - Space Race - Phase 4

- US
  - Back to Apollo? - To the moon via Ares?
  - Marginalized in crewed spaceflight
  - Continued triumphs of planetary + galaxy exploration
    - Galileo, Cassini, Pathfinder, Mars Rover, Hubble
- Russia
  - No plan
  - Same old hardware - Soyuz uber alles
  - Partners with US on space station
    - Strange bedfellows

Focused Case Study - Space Race - Phase 4

- Commercial
  - Cater to masses - space tourism
    - Spaceship One is way forward
  - Lives are expendable
    - Cancels zero risk mentality
- China
  - Starts crewed space program based on obsolete USSR hardware
    - Wants space station and to go to moon
    - Those who forget lessons of history…
  - Could it start new space race?

Focused Case Study - Space Race

- It cost the U.S. ~ $25 billion to go to the moon in 1960's dollars. That would be $185 billion in 2019 dollars

  - Douglas Brinkley

Focused Case Study - Space Race

- "The entire lunar effort (with robotic missions and Gemini included) [cost $28 billion in original dollars and] would cost $288 billion in today's [2019] dollars. If the US prioritized the project financially the same way it did in the 1960s, the nation would have to spend $702 billion to occupy the equivalent share of GDP."

- Casey Dreier, A New Accounting For Apollo: How Much Did It Really Cost? The Space Review, June 17, 2019

"Space has stalled. And to get it going again, I'm afraid we need a war. War has always been good for humankind. Obviously, it's not so great when you're on the battlefield with a big leak in your torso and an arrow in your eye, but, truth be told, battlefields have very little to do with the eventual outcome of the conflict. That's rarely decided by the soldiers and the generals. It's decided by the tools they're given...

When Russia launched Sputnik 50 years ago, it was nothing more than a small radio, but the beeps it transmitted, when translated, told the listening world: "This is Russia and we'd like you all to know that our German scientists are a hell of a lot better than America's German scientists..."

The space race became what really ought to have been known as "the ego war". And it was brilliant. Because unlike in other wars, casualties were restricted to just 22 astronauts and 70 ground personnel, and the benefits to the rest of us were immense...

- Jeremy Clarkson, Why I Am a Space Nut, The Times, Oct 7, 2007

The cold war and the space race that resulted were fantastic. It was the greatest lurch forward since Victorian England decided that it could use coal to get itself an empire...

And then the Russians decided to give up, so now it's all gone wrong...

That's why I'm delighted to see Russian bombers back in NATO airspace and radioactive poison all over the restaurant tables in London. And it's why I'm delighted to note that Russia, buoyed by its new wealth and power, has announced plans to build a moon base for missions to Mars.

It means we can go back to the good old days. It means we can go to the stars."

- Jeremy Clarkson, Why I Am a Space Nut, The Times, Oct 7, 2007

One Small Step?

"We were a competitor in perhaps the greatest peacetime competition of all time: the space race - USA versus USSR. Like a war, it was expensive. Like a war, each side wanted intelligence on what the other side was doing. And I'll not assert that the space race was a diversion which prevented a war. Nevertheless, it was a diversion. It was intense. It did allow both sides to take the high road with the objectives of science and learning and exploration.

Eventually, it provided a mechanism for engendering cooperation between adversaries and then since, among others. It was an exceptional national investment for each side."

- Neil Armstrong

What The Space Program Is Really All About

"Here on Earth we live on a planet that is in orbit around the Sun. The Sun itself is a star that is on fire and will someday burn up, leaving our solar system uninhabitable. Therefore we must build a bridge to the stars, because as far as we know, we are the only sentient creatures in the entire universe. When do we start building that bridge to the stars? We begin as soon as we are able, and this is that time. We must not fail in this obligation we have to keep alive the only meaningful life we know of."

- Wernher von Braun

Why not send robots?

"There is no computerized explorer in the world with more than a tiny fraction of the power of a chemical analog computer known as the human brain, which is easily reproduced by unskilled labor."

- Wernher von Braun

- Tom Wolfe, One Giant Leap to Nowhere, New York Times July 19, 2009

The Secret of Success

"If you want to be successful, you must early to bed, early to rise, work like hell and advertise"

- Wernher von Braun, rocket scientist

"To do something well is so worthwhile that to die trying to do it better cannot be foolhardy. It would be a waste of life to do nothing with one's ability, for life is measured in achievements, not in years alone."

- Bruce McLaren, racing driver

The Test Pilot's Mantra

"There is no liberty except the liberty of someone making his way towards something"

- Antoine de Saint-Exupery, pilot

The Lonely Sky

"She carries me at Mach .8 silently through the lonely sky in a long glide path down, and the only life and sound in the world now is mine and the noise of my breath and the wind outside at the edge of the canopy. It is a dream. A soft, floating kind of dream, at the bottom of which is a terror, but I make no move to rouse myself. The terror seems unreal."

- William Bridgeman and Jacqueline Hazard in The Lonely Sky p. 227

What Rocket Flight is Like - 1

"Eighty thousand feet. It is intensely bright outside; the contrast of the dark shadows of the cockpit is extreme and strange. It is so dark lower in the cockpit that I cannot read the instruments sunk low on the panel. The dials on top, in the light, are vividly apparent. There seems to be no reflection; it is all black or white, apparent or nonapparent. No half-tones. It is a pure, immaculate world here.

She levels off silently. I roll to the right and there it is. Out of the tiny window slits there is the earth, wiped clean of civilization, a vast relief map with papier-mache mountains and mirrored lakes and seas. The desert is not the same desert I have seen for two years; it is a pale brown hole bordered by dwarf mountains that run into other dwarf mountain chains that plait into other chains down to the Gulf of California and the Republic of Mexico. The coastline is sharply drawn with little vacant bays and inlets, a lacy edge to the big brown pieces of earth that dissolve into grays and the glimmer of lake puddles cupped in mountaintops and back to brown, gray and finally the enormous black-blue of the Pacific. A globe-world in a planetarium, the earth curves to the south."

- William Bridgeman and Jacqueline Hazard in The Lonely Sky p. 304-305

What Rocket Flight is Like - 2

"It is as if I am the only living thing connected to this totally strange, uninhabited planet 15 miles below me. The plane that carries me and I are one and alone.

There is a world down there and it must be revisited. There is the turn back to the place where the field is a pinpoint on the globe under me. The only way back from the springboard I am on has to be from memory, automatic. This, now, is the payoff for my preflight conditioning, for the drills, for the memorizing of steps back. Without this conditioning I am sure at this moment that I would not be able to return quickly enough from the euphoric state that holds me.

Following the steps mechanically, I am able to enter the turn. I am on my descent and slowly I return to what I knew before. Again I hear myself laboring for oxygen inside the helmet, and the world under me comes gradually into focus as something identifiable with life. At 15,000 it is comfortingly familiar. I take the face-plate out of the helmet and breathe air again, deeply, and I am back, fully returned to time and dimension and the brief span that is allowed to me."

- William Bridgeman and Jacqueline Hazard in The Lonely Sky p. 304-305

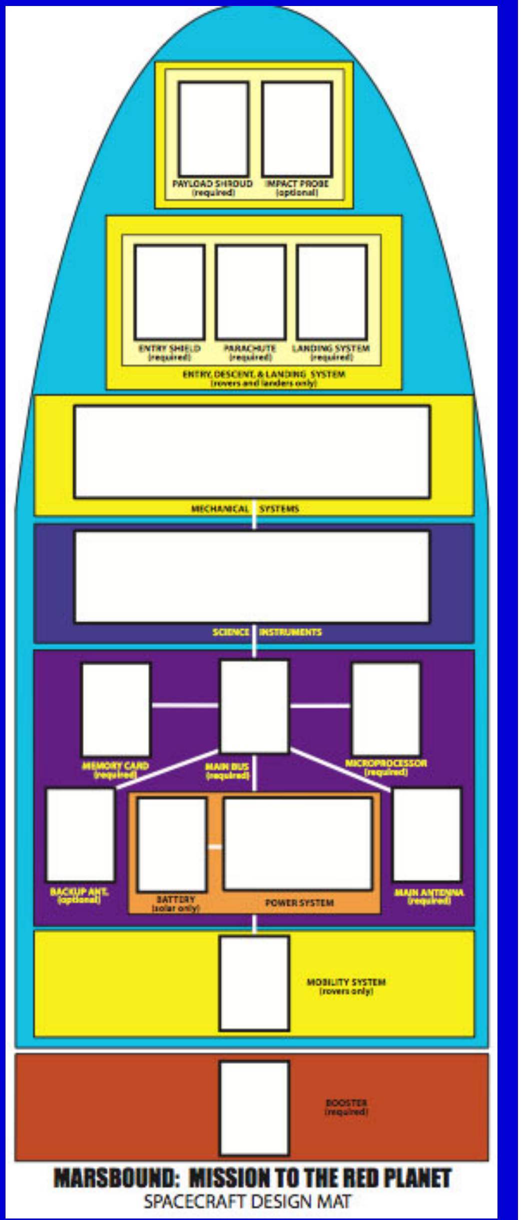
How to Design an Uncrewed Spacecraft / Mission

- Orbiter's instruments provide cueing on where to send landers
- Landers make discoveries, giving orbiters new things to look for
- Repeat as funded

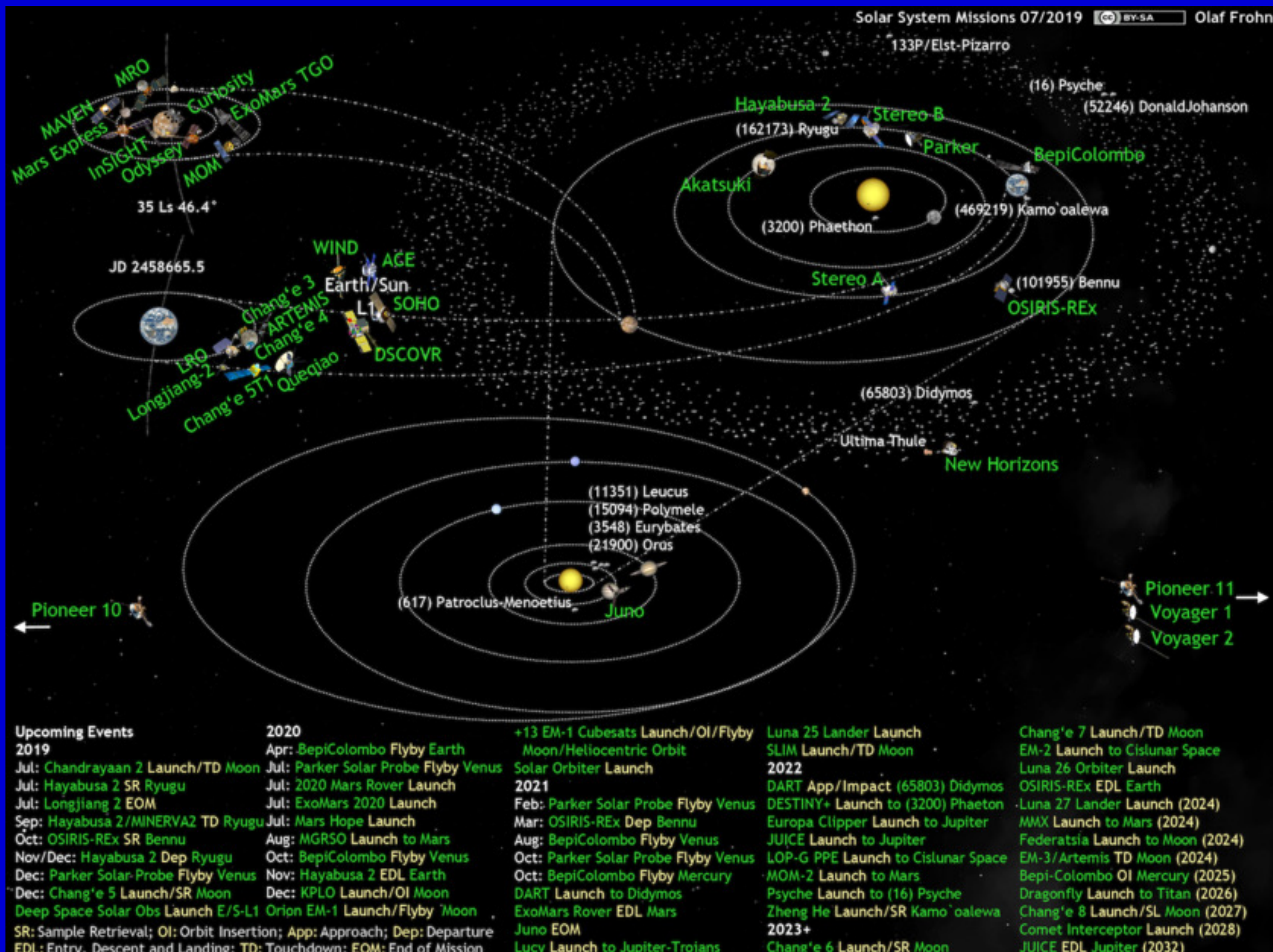
How to Design an Uncrewed Spacecraft / Mission

- Start with science goals and budget
- Mission design is series of tradeoffs
  - Orbiter or probe or lander (rover?)
  - Booster - payload capability + reliability
  - Power generation - fuel cells vs. solar panels vs. radioisotope thermoelectric generator
  - Computer - speed + memory
  - Communication - speed
  - Sensors - camera (for PR) + other instruments
    - What are the power + data requirements
  - Overall redundancy of spacecraft
- Must juggle / balance all these variables
  - If you go over budget, someone else's mission gets cut

- Marsbound Mission to the Red Planet
marsed.mars.asu.edu/marsbound



(Current) Solar System Missions by Olaf Frohn



http://www.planetary.org/multimedia/space-images/charts/whats-up-in-the-solar-system-frohn.html

Uncrewed Missions to Planets

- 1962 - Venus - Mariner 2
- 1965 - Mars - Mariner 4
- 1973 - Jupiter - Pioneer 10
- 1974 - Mercury - Mariner 10
- 1979 - Saturn - Pioneer 11
- 1986 - Uranus - Voyager 2
- 1989 - Neptune - Voyager 2
- 2015 - Pluto - New Horizons

Uncrewed Missions to Planets - Mercury

- 1973 - Mariner 10 (NASA)
- 2004 - Messenger (NASA)

Uncrewed Missions to Planets - Venus

- 1967-1983 - Venera 4-16, including 8 landers (Soviet Union)
- 1989 - Magellan (NASA)
- 2006 - Venus Express (ESA)

Uncrewed Missions to Planets - Earth

- Landsat (NASA)
  - 40 years of exploring Earth
- Seasat (NASA)
- NOAA weather satellites (NASA)

Uncrewed Missions to Planets - Moon

- Clementine (BMDO + NASA)
- Lunar Reconnaissance Orbiter (NASA)
    - Return to the Moon
    - Image Apollo landing sites
    - LCROSS looking for polar water

Uncrewed Missions to Planets - Mars

- 1964 - Mariner 4 - Mars is dead (NASA)
- 1971 - Mariner 9 - Mars was alive (NASA)
- 1975 - Viking - No life on Mars (NASA)
- 1996 - Mars Global Surveyor + Pathfinder rover (NASA)
- 2001 - Mars Odyssey + 2003 Mars Exploration Rover (NASA) - follow the water
- 2003 - Mars Express (ESA)
- 2005 - Mars Reconnaissance Orbiter (NASA)
- 2007 - Phoenix (NASA) - water ice on Mars
- 2012 - Mars Science Laboratory (NASA)
- 2020 - Mars 2020 Rover (NASA)
- 2020 - Rosalind Franklin ExoMars Rover (ESA / Roscosmos)

Computing Case Study Summary - Mars Climate Orbiter

- Goal
  - Gather data on Mars's atmosphere + serve as communications link for other probes
- Center of Gravity (Strategy)
  - Orbit Mars
- Technology / Equipment ~ Training ~ Leadership ~ Morale
  - Jet Propulsion Laboratory - tremendous experience sending missions to Mars
  - Lockheed Martin - tremendous experience building spacecraft
- Tactics
  - Spacecraft launched December 11, 1998
- Intangibles
  - Spacecraft disappeared / burned up in Martian atmosphere during orbital insertion around Mars on September 23, 1999
- Mistakes
  - Investigation traced crash to software engineer at NASA contractor who had neglected to convert English units to metric ones causing the force of the engine's orbital insertion thrust to be off by factor of 4.5
- Outcome
  - Bug had been overlooked several times
  - Cost of the bug = $125 million

- Elizabeth Kolbert, Project Exodus, New Yorker, June 1, 2015

Uncrewed Missions to Planets - Asteroids and Comets

- 1999 - Stardust (NASA)
- 2003 - Hayabusa (JAXA)
- 2004 - Rosetta + Philae (ESA)
- 2005 - Deep Impact (NASA)
- 2007 - Dawn (NASA)

Uncrewed Missions to Planets - Jupiter

- 1972 + 1973 - Pioneer 10 + 11 (NASA)
- 1975 - Voyager 1 + 2 (NASA)
- 1989 - Galileo (NASA)

Case Study Summary - Pioneer 10 + 11 (1972)

- Goal
  - Prove exploration of outer solar system was possible
- Center of Gravity (Strategy)
  - Create a deep space probe
- Equipment
  - Simplicity in construction
  - 2 Radioisotope Thermoelectric Generators (RTGs) powered by Plutonium 238 provide power for 50 years
  - Did <u>not</u> have conventional cameras
- Training
- Leadership
- Morale

- Richard Corfield, O, Pioneers!, Astrobiology Magazine, Feb. 27, 2012 + Mar. 5, 2012

Case Study Summary - Pioneer 10 + 11 (1972)

- Tactics
  - Overcome hazards of radiation (from Jupiter), distance (from Earth for communications + from Sun for energy), traversal of asteroid belt, ring planes of Saturn
  - Pioneer 10 - study Jupiter in 1973
  - Pioneer 11 - study Jupiter in 1974 + Saturn in 1979
    - Does it go inside rings close to Saturn or thru outer E ring to blaze trail for Voyager 2 behind it which would like to use E ring to slingshot it to Uranus
- Intangibles ~ Mistakes
  - Pioneer plaques designed by Carl Sagan offended some
- Outcome
  - First true deep space probe
  - "Humanity went from Galileo's first glimpse of moons of Jupiter through telescope to visiting them in 12 generations" - Charles Hall, Pioneer Program Manager
  - Made the outer planets places
  - First spacecraft to leave solar system

- Richard Corfield, O, Pioneers!, Astrobiology Magazine, Feb. 27, 2012 + Mar. 5, 2012

Case Study Summary - Voyager 1977

- Goal
  - Explore outer solar system in depth
- Center of Gravity (Strategy)
  - Complete Grand Tour of solar system
- Equipment
  - Golden Record time capsule produced by Carl Sagan
  - Radioisotope Thermoelectric Generators (RTGs) power by Plutonium 238
  - Deep Space Network today picks up its signals as < 1 femtowatt = a millionth of a billionth of a watt
- Training
- Leadership
  - Ed Stone as Project Scientist for whole mission
- Morale
- Tactics
  - Voyager 2 goes to Jupiter, Saturn, Uranus, Neptune
  - Voyager 1 goes to Jupiter, Saturn
- Intangibles
- Mistakes

- Timothy Ferris, Voyager's Never-Ending Journey, Smithsonian, May 2012
- Voyager at 35, Astrobiology Magazine, Aug.25, 2012
- Voyager Officially Reaches Interstellar Space, Astrobiology Magazine, Sep. 15, 2013
- Voyager Encounters New Region in Deep Space, Astrobiology Magazine, Dec. 5, 2012

Case Study Summary - Voyager 1977

- Outcome
  - Voyager 1 + Voyager 2 visit Jupiter in 1979, Saturn in 1980 + 1981
  - Voyager 2 visits Uranus in 1986, Neptune 1989
  - Voyager 1 discovered volcanoes on Jupiter's moon Io + icy Europa, braided outermost ring on Saturn, atmosphere of Saturn's moon Titan
  - Voyager 2 discovered geysers on Neptune's moon Triton
  - Voyager 1 is most distant man-made object - 122 AU from Sun - has now entered interstellar space
  - Voyager 2 is longest operating spacecraft - may last until 2025 - has now entered interstellar space
  - Are our first starships

    - Timothy Ferris, Voyager's Never-Ending Journey, Smithsonian, May 2012
    - Voyager at 35, Astrobiology Magazine, Aug.25, 2012
    - Voyager Officially Reaches Interstellar Space, Astrobiology Magazine, Sep. 15, 2013
    - Voyager Encounters New Region in Deep Space, Astrobiology Magazine, Dec. 5, 2012

Case Study Summary - Galileo

- Goal
  - Explore Jovian system
- Center of Gravity (Strategy)
  - Orbit Jupiter + its moons
- Equipment
  - Conceived in 1970's
  - Computer CPU was RCA 1802 - early 8 bit microprocessor
  - NASA's Deep Space Network used to communicate with spacecraft
    - Is a "million-mile screwdriver" - provides ability to fix spacecraft by sending radio signals from Earth
- Training ~ Leadership ~ Morale
  - Excellent
- Tactics
  - Designed to be carried into space aboard space shuttle and launched towards Jupiter using Centaur liquid fuel upper stage
  - Centaur was banned from the shuttle after Challenger loss so mission was redesigned using smaller solid fuel upper stage + gravity assist from Venus + Earth
  - Launched 7 years late in 1989, took 6 years to get to Jupiter

- Michael Benson, What Galileo Saw, New Yorker, Sept. 8, 2003

Case Study Summary - Galileo

- Intangibles ~ Mistakes
  - Hi gain antenna with data rate of 134,000 bps (can send 1 image / minute) could not deploy - it was damaged during repeated handlings during launch delays
  - Had to use low gain antenna of 10 bps (can send 1 image / month)
  - Solution was to rewrite software to take advantage of new data / image compression algorithms (can send 200 images / month) though low gain antenna
    - "A complete brain transplant over a 400 million mile radio link"
  - Do this by using tape recorder for entry probe to store data temporarily, then have computer compress it, then send compressed data to Earth

- Michael Benson, What Galileo Saw, New Yorker, Sept. 8, 2003

Case Study Summary - Galileo

- Outcome
  - First to orbit an outer planet
  - First to document volcanic eruptions from Io + first to fly through plumes of Io
  - Established Europa has ocean beneath its crust - largest in our solar system
    - "How often is an ocean discovered? The last one was the Pacific, by Balboa, and that was five hundred years ago." - Richard Terrile, Galileo designer
  - Sept. 21, 2003 at end of mission it crashed into Jupiter to avoid contaminating Europa
    - "Galileo Galilei only got house arrest by his sponsor the Roman Catholic Church for discovering things they didn't want to be true, whereas our Project Galileo gets a death sentence from NASA for its greatest discovery: the prospect of life on Europa." - Bill O'Neil, Galileo project director

  - Michael Benson, What Galileo Saw, New Yorker, Sept. 8, 2003

Uncrewed Missions to Planets - Saturn

- 1973 - Pioneer 11 (NASA)
- 1975 - Voyager 1 + 2 (NASA)
- 1997 - Cassini (NASA) / Huygens (ESA)

Uncrewed Missions to Planets - Uranus

- 1975 - Voyager 2 (NASA)

Uncrewed Missions to Planets - Neptune

- 1975 - Voyager 2 (NASA)

Uncrewed Missions to Planets - Pluto + Kupier Belt

- 2006 - New Horizons (NASA)

Uncrewed Missions to Planets - Interstellar Medium

- 1972 + 1973 - Pioneer 10 + 11 (NASA)
- 1975 - Voyager 1 + 2 (NASA)
- 2006 - New Horizons (NASA)

Uncrewed Missions to Planets - Sun

Robots vs. Humans as Space Explorers

- Robots
  - Cheaper (usually 1/50th the cost)
  - Operate in vast range of temperatures
  - Don't need life support systems
  - Not very worried by ionizing radiation
  - Don't lose bone mass
  - Don't worry about hygiene
  - Don't need food + water
  - Don't need to come home
- Humans
  - More flexible
  - Can make serendipitous discoveries
  - Have common sense

Human Explorers vs. Robot Explorers

"The science you can do with robots pales in comparison to what human explorers can do. I mean, what Spirit and Opportunity have done in six and a half years on Mars, you and I could have done in a good week or 10 days."

- Steve Squyres, planetary scientist

"The unfortunate truth is that most things our rovers can do in a perfect sol [a martian day] a human explorer could do in less than a minute"

- Steve Squyres, planetary scientist, in Roving Mars

Would You Prefer To Send Humans Or Robots To Explore?

"I would send a human and I'll give you two reasons for that.

One reason is that what humans can do is so much greater than what robots are capable of now or for the forseable future. I have spent the last 20 years of my life trying to design and operate robots that can replicate what a human might be able to do on the Martian surface. What our rovers do in a day you and I could do in about 30 seconds.

The other thing is that humans have a capability to synthesize information, to digest it, to figure out the next thing to do and to improvise. Robots can't improvise the way humans can.

The other reason I would send humans is that humans have a capability to inspire that robots simply lack."

- Steve Squyres, planetary scientist

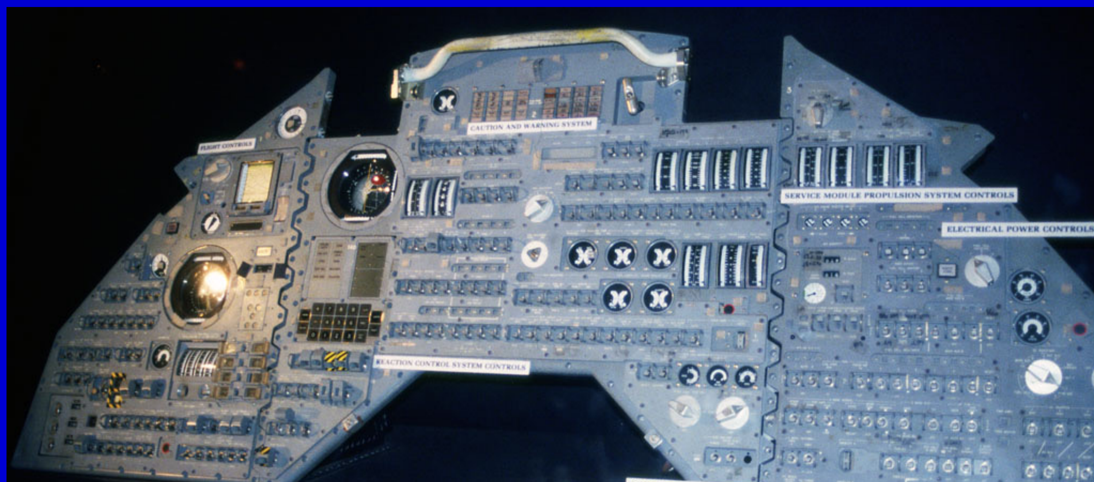
Distances Traveled by Rovers

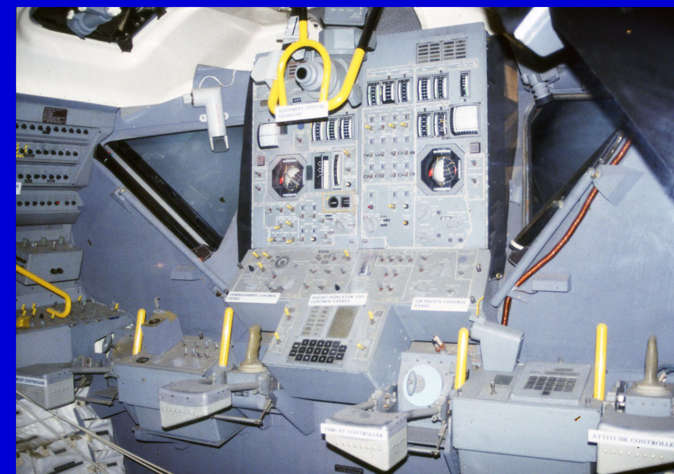
- Moon
  - Crewed lunar rovers in Apollo 17 - 36 km over 3 days
  - Uncrewed near-realtime remotely driven Lunakhod 2 rover - 39 km over 120 days
- Mars
  - Uncrewed remotely driven Mars Exploration Rover Opportunity - 40 km over 3,650 days

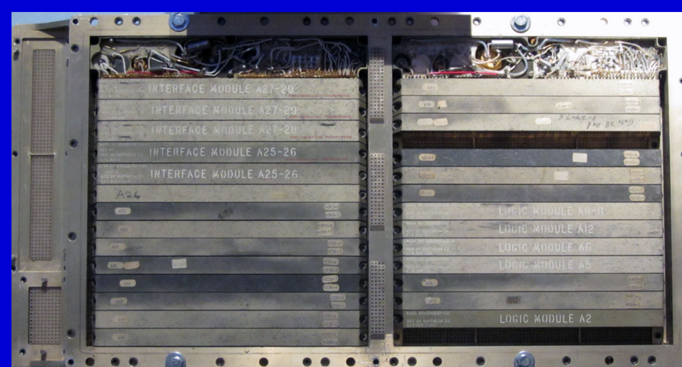
"If you understand something the first time you see it, you probably knew it already. The more bewildered you are, the more successful the mission was."

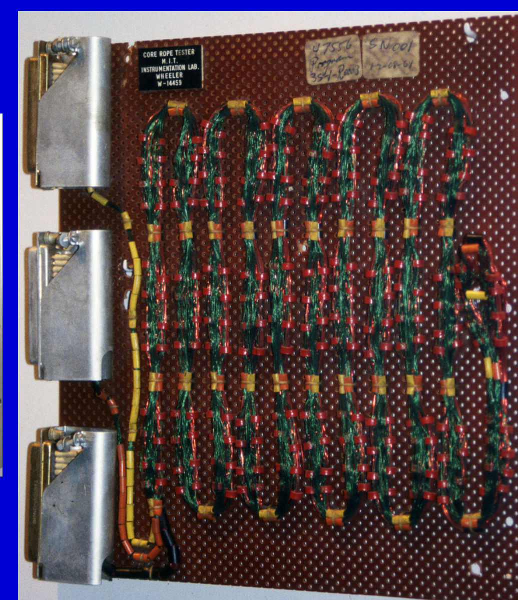
- Ed Stone, Voyager mission project scientist

Apollo Guidance Computer









Top - Command Module control panel, Lunar Module control panel
Bottom - Guidance + Navigation computer (GNC), GNC logic module, Core rope memory

Thing / Hardware - Apollo Guidance Computer

- Firsts / Achievements / Uniqueness / Significance
  - Made possible President Kennedy's dream of "landing a man on the Moon and returning him safely to the Earth"
- Place Produced (Company / Institution) ~ Year ~ Country
  - MIT Instrumentation Laboratory (Designed) + Raytheon (Produced) ~ 1965 ~ USA
- People involved (Designer)
  - Charles Stark Draper
- Type
  - Text
- Price / Cost
  - Text
- Size
  - 6" x 24" x 16"
  - Weight = 70 pounds
- Computing technology
  - Integrated circuits from Fairchild Semiconductor
- Computing speed (in MIPS)
  - Clock speed was 11.7 milliseconds ~ 20 microsecond / add
- Primary memory type / technology ~ Size ~ Word length
  - Magnetic core rope ~ 36K words of ROM + 2K words of RAM ~ 16 bit [4K RAM + 24K ROM magnetic core rope]
- Secondary memory type / technology ~ Size
  - Text
- Uses / Applications / Software
  - To monitor, steer, communicate with guidance system ~ In Command Module - navigation, In Lunar Module - landing
  - Strict software engineering practices to avoid bugs -> Still had 1201 and 1202 program alarms on Apollo 11 final descent due to rendezvous radar being inadvertently left on
- Predecessors - N/A ~ Successors - N/A

Communications Case Study Summary - Deep Space Network

- Goal
  - Communicate with interplanetary spacecraft
- Center of Gravity (Strategy)
  - Worldwide network of 3 tracking sites spaced 120 degrees apart, as Earth rotates antennas at sites maintain continuous contact with spacecraft in deep space
- Technology / Equipment
  - Antennas now in California, Australia, Spain
  - From 26 to 34 to 64 to 70 meter single antennas to arrays of 4 x 34 meter antennas
- Training ~ Leadership ~ Morale
  - Text
- Tactics
  - Locate antennas in valleys to shield them from nearby radio frequency signals
- Intangibles ~ Mistakes
  - Text
- Outcome
  - Data rates have advanced from 8.33 bits per second in 1963 to over 1 million bits per second

- Deep Space Network's 50th Anniversary, Astrobiology Magazine, Jan. 1, 2014

Deep Space Network

- Founded in 1963
- Located in Mojave Desert at NASA's Goldstone Deep Space Communications Complex (largest is 230 feet in diameter, smallest is 112 feet in diameter), in Madrid Spain, in Canberra Australia
  - Arraying antennas gives them the strength of one giant antenna
- Transmitter on Voyager spacecraft just strong enough to power refrigerator light bulb - by time that signal reaches Earth it is one-tenth of a billionth-trillionth of a watt

- Two Voyagers Taught Us How to Listen to Space, Astrobiology Magazine, Aug. 3, 2017

Computing Case Study Summary - Space Shuttle General Purpose Computers

- Goal
  - Provide fly by wire flight control system to shuttle orbiter during launch, orbit, landing
- Center of Gravity (Strategy)
  - Use proven mainframe technology
- Technology / Equipment
  - 5 IBM System / 4 Pi computers (AP-101), descendants of IBM System / 360 mainframes with 32 bit processor, first core and then semiconductor memory, and capable of 480,000 instructions / second
- Training ~ Leadership ~ Morale
- Tactics
  - 4 of the computers operated redundantly in sync cross checking each other 500 times / second
  - 1 of the computers with independently written software served as a backup if the 4 computers could not agree
- Intangibles ~ Mistakes
- Outcome
  - Worked great

    - IBM and the Space Shuttle, IBM Archives

Personal Case Study - Memories of Spaceflights

- Role - Astrofan
- Story- From Amazement to Disillusionment to Exhilaration
  - 1968 - Apollo 8 - As a 5 year old recall reading of Genesis from lunar orbit
  - 1969 - Apollo 10 - Stafford + Cernan were so close to the moon in the LEM, I wondered what if they mutinied and landed the LEM anyway just so they could be the first men on the moon?
  - 1969 - Apollo 11 - I saw Neil Armstrong's giant step sitting on the couch in the den, up well past my bedtime, on a black + white TV
  - 1969 - Apollo 12 - The moonwalks were shown as simulations, with actors on a lunar soundstage acting out what Conrad + Bean were doing on lunar surface. Perhaps this was because the camera burned out early in the mission?
  - 1970 - Apollo 13 - Being at a family party at my Uncle Frank's house, and my cousin Patrick leading the whole family in prayer for the astronauts safe return
  - 1971 - Apollo 14 - Seeing a demonstration of the escape slides and watching kids zoom down them before the launch, and then seeing Al Shepherd - in my mind at that time the most experienced astronaut - hit a golf ball on the moon
  - 1973-1974 - Skylab - Saw it on the evening news at dinner time when they would break a record
  - 1975 - Apollo-Soyuz - Saw the spacecraft on the launchpad at the Kennedy Space Center, I remember playing at the park, waiting for the launch which I watched along with the splashdown
  - 1981 - Stated in high school newspaper I wanted to be an physician astronaut
  - 1981 STS-1 - Writing satellite tracking software in WATFIV Fortran in order to observe mission at night, was extremely excited we were getting back into space...
  - 1981 STS-2 - Had an Apple II by now, trying to learn to fly the Shuttle on a shuttle simulator by Harvey's Space Ship Repair, writing my own shuttle simulator in Applesoft Basic

Personal Case Study - Memories of Spaceflights

- Role - Astrofan
- Story
  - 1982 - Had a computer science teaching assistant who had gone to medical school and wanted to be a physician astronaut
  - 1982 - Saw Jack Lousma + Gordon Fullerton at Wayne State University Student Center after their flight on STS-3 and thought boy are they short - and they looked like normal people
  - 1989 - Watched Voyager 2's encounter at Neptune on NASA Select TV via University of Iowa TV all night - watching the raw images come in live, seeing a new world for the first time, and watching the mission scientists doing instant science
  - February 1, 2003 - STS-107 Columbia burning up on re-entry and watching the pieces fall to Earth live on CNN during breakfast
  - January 2004 - Watched Mars Exploration Rovers land on Mars in evening on CNN with Evan who was 4 years old, telling him to remember this
  - January 14, 2005 - Huygens landing on Titan - watching live feed from ESA TV at breakfast table and then taking kids to day care where their teacher's spouse had an instrument on Cassini
  - July 4, 2005 - Saw Deep Impact hit the comet live on NASA TV - Impressive!
  - October 9, 2009 - LCROSS - watched it hit the Moon on NASA TV - was unimpressive
  - November 25, 2011 - Saw Mars Science Laboratory blast off today via NASA TV while at work and on August 5/6, 2012 saw Curiosity land on Mars via NASA TV + Planetary Society PlanetFest Live Webcast

Personal Case Study - Memories of Spaceflights

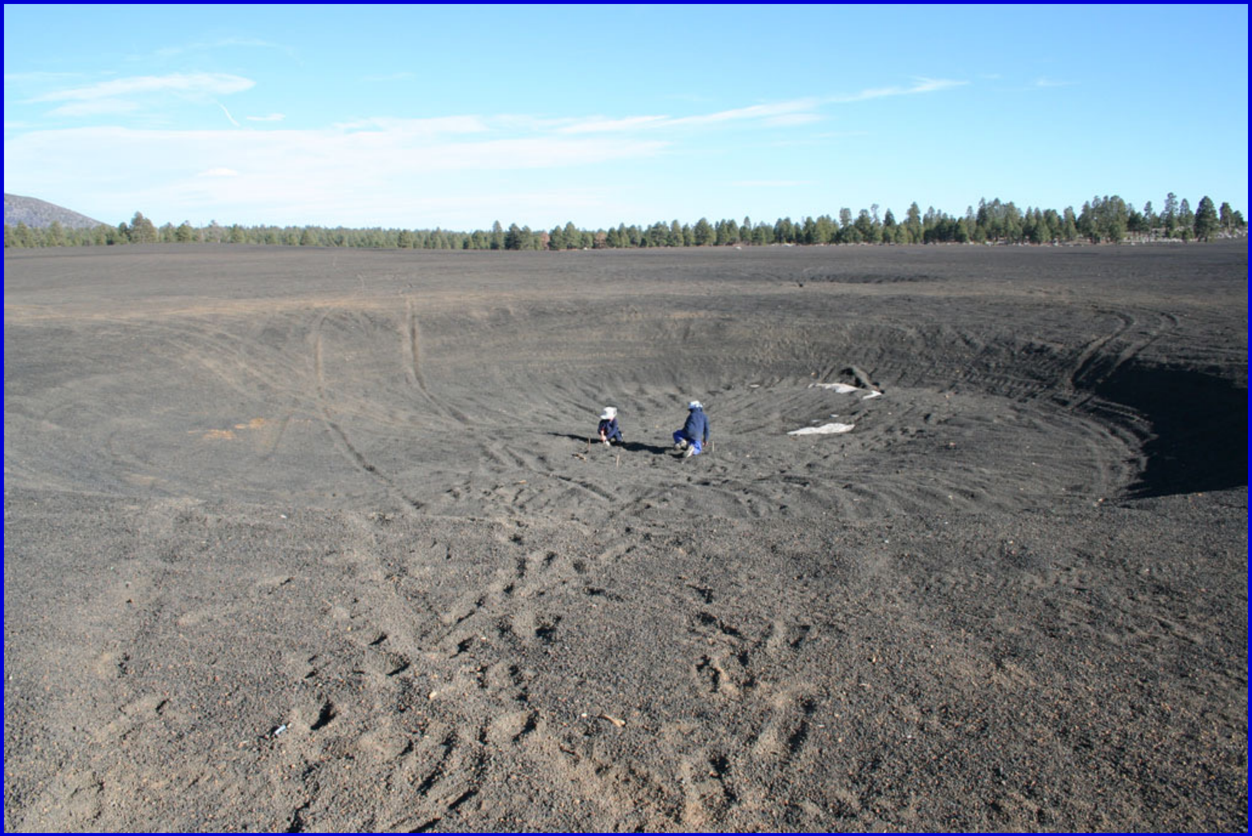
- Role - Astrofan
- Story
  - November 15, 2014 - Rosetta + Philae lander on Comet 67P - Watched live on Ustream - Where did they land or not?
  - December 5, 2014 - Exploration Flight Test 1 of Orion Multi Purpose Crew Vehicle - saw whole mission while at work over several hours on NASA TV including great in-air shots from Predator of Orion reentry under parachutes
  - July 14, 2015 - New Horizons encounter with Pluto - Encounter was anticlimactic as only spacecraft status was sent with no images, but watching the encounter and ensuing press conference I was struck by how many reporters in the room I read regularly - Jonathan Amos of the BBC, Emily Lakdawalla of the Planetary Society, Frank Morring of Aviation Week

Personal Case Study - CAPT Laurel Clark, USN

- Role - Astronaut
- Story - Business card said "Laurel Clark - Astronaut"
  - Gus Grissom said you are not an astronaut until you fly
  - Selected in 1996, flew on Columbia on STS-2007 in 2003
    - Functioning as a research scientist
  - Received astronaut wings posthumously
- Had the Right Stuff
  - Drove a BMW
  - Intense, driven, brave
  - Was Underwater Medical Officer and Flight Surgeon

From NASA

Astrobiology Analog Case Study - Walking On The Moon



- **Location**
  - **Cinder Lake artificial crater field**
- **Story**
  - **Artificially created craters to simulate walking + roving on the moon**

Drake Equation

$$N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

- N = The number of communicative civilizations
- R* = The rate of formation of suitable stars (stars such as our Sun)
- fp = The fraction of those stars with planets. (Current evidence indicates that planetary systems may be common for stars like the Sun.)
- ne = The number of Earth-like worlds per planetary system
- fl = The fraction of those Earth-like planets where life actually develops
- fi = The fraction of life sites where intelligence develops
- fc = The fraction of communicative planets (those on which electromagnetic communications technology develops)
- L = The "lifetime" of communicating civilizations

Class Simulation

- Topic aspects

Poem

Abandon in Place.
No Further Maintenance Authorized.
Abandon. Turn away your face.
No more the mad high wanderings of thought
You once surmised. Let be!
Wipe out the stars. Put out the skies.
What lived as center to our souls
Now dies - *so what?* - now dies.
What once as arrow to our thoughts
Which target-ran in blood-fast flow
No longer flies.
Cut off the stars. Slam shut the teeming skies.
Abandon in Place.
Burn out your eyes.

- Abandon in Place, Ray Bradbury

Questions for Further Discussion

- Who won the space race?
- Was the right way to space chosen:
  - Expendable vs. reusable rockets?
  - Crewed capsules vs. space planes?
- Why is access to space so expensive?
- Why wasn't the year 2001 our space odyssey?
- Where would we be if we had followed the Von Braun paradigm of space exploration (reusable shuttle / space station / voyages to planets) instead of a one-off race to the moon?

Reading Assignments

- Astrobiology Primer 2.0 (2016) Chapter
  - https://doi.org/10.1089/ast.2015.1460
- TED Talks for this Topic
  - http://www.astrobiologysurvey.org/ToLearnMore.html

Recommended Reading to Learn More

- Non-fiction
  - Andrew Chaikin - A Man on the Moon
  - Mike Gray - Angle of Attack: Harrison Storms and the Race to the Moon
  - Charles Murray and Catherine Bly Cox - Apollo: The Race to the Moon
  - Tom Wolfe - The Right Stuff
- Fiction
  - James Michener - Space
- Movies
  - Apollo 13
  - The Dish
  - For All Mankind
  - From the Earth to the Moon
  - The Right Stuff
- Simulations

Conclusion

"If I have seen further, it is because I have stood on the shoulders of giants."

- Sir Isaac Newton, physicist

Conclusion

"…Because we were on our way to Mars, and someday we would settle Mars and then we'd go to Alpha Centauri and we'd live forever so this was the first step to living forever and mankind has to beat the Sun going out or the Sun flaring up so we're going to survive because of this very first step tonight."

- Ray Bradbury, author, on July 20, 1969 and why it was the most important night in the history of mankind and why it was important that we were on the Moon

Conclusion

""Men Walk On Moon" - The only positive event in the last 50 years for which everyone remembers where they were when it happened.

Apollo 11, July 1969. No other act of human exploration ever laid a plaque saying "We Come In Peace For All Mankind.""

- Neil deGrasse Tyson, astrophysicist, from Twitter

Conclusion

"Once you have tasted flight, you will forever walk the Earth with your eyes turned skyward, for there you have been, and there you will always long to return."

- Leonardo da Vinci

"Whether outwardly or inwardly, whether in space or time, the farther we penetrate the unknown, the vaster and more marvelous it becomes."

- Charles A. Lindbergh, aviator

"Oh! I have slipped the surly bonds of Earth...put out my hand and touched the face of God."

- John G. Magee, in "High Flight"

"Ad astra per aspera." (To the stars, despite adversity)

- Motto of the Royal Air Force

Conclusion

"If you can't be good, be colorful"

- Pete Conrad, astronaut

Topic 10

Future Astrobiology Missions

Song

She packed my bags last night pre flight
Zero hour nine a.m.
And I'm gonna be high, as a kite by then
I miss the earth so much, I miss my wife
It's lonely out in space
On such a timeless flight

And I think it's gonna be a long long time
Till touch down brings me round again to find
I'm not the man they think I am at home
Oh no, no, no, I'm a rocket man
Rocket man burning out his fuse up here alone

Mars ain't the kind of place to raise your kids
In fact it's cold as Hell
And there's no one there to raise them if you didn't
And all this science, I don't understand
It's just my job, five days a week
A rocket man, a rocket man

- Elton John, Rocket Man

Thematic Quote

"Too soon from the cave. Too far from the stars."

- Ray Bradbury, author, on Mankind

Thematic Quote

"It's tough to make predictions, especially about the future."

- Yogi Berra, baseball manager

The Painting

2001 A Space Odyssey

- Robert McCall

(National Air and Space Museum)

Artifact

- Name
  - CubeSat
- Year
  - Launched in 2003
- Story
  - AAU CubeSat from Aalborg University in Germany

The Question

Why explore?

Future Astrobiology Missions - Big Picture

- Exploring for life in our solar system
  - Crewed missions to asteroids, Phobos, Mars
  - Uncrewed missions to Mars, Europa, Titan, Enceladus
  - Backing up life to space
  - Space settlements
  - Mars settlements / terraforming Mars
- Exploring for life in the universe
  - 100 Year Starship Project

Future Astrobiology Missions - Details

- Why go?
- Who to send?
- Where to go to?
- How to get there?
- What to do once you get there?
- When can we go to the stars?

Why Go?

Why Explore

"A review of history's most ambitious projects demonstrates that only defense, the lure of economic return, and the praise of power can garner large fractions of a nation's GDP."

- Neil deGrasse Tyson, astrophysicist

"In all eras, across time and cultures, only war, greed, and the celebration of royal or religious power have fulfilled that [sustained] funding requirement"

- Neil deGrasse Tyson, astrophysicist

Why Explore

"To do something, say something, see something,
before anybody else -
these are the things that confer a pleasure
compared with which other pleasures are tame and commonplace,
other ecstasies cheap and trivial."
- Mark Twain, author

Why Explore

"To confine our attention to terrestrial matters would be to limit the human spirit."

- Stephen Hawking, physicist

Why Explore?

"We're the only mammal comfortable sleeping on our backs, which means that if you wake up in the middle of the night, you're looking up. Maybe that fact has imbued us with a sense of wonder that no other mammal can even approach. So maybe it's kind of our obligation to ourselves and our species to explore where we haven't been before."

- Neil deGrasse Tyson, astrophysicist

Why Explore?

"Everywhere there are side gulches and canyons, so that these gulches are set about ten thousand dark, gloomy alcoves. One might imagine that this was intended for the library of the gods; and it was. The shelves are not for books, but form the stony leaves of one great book. He who would read the language of the universe may dig out letters here and there, and with them spell the words, and read, in a slow and imperfect way, but still so as to understand a little, the story of creation."

- Powell, John Wesley: Exploration of the Colorado River of the West, pages 193-94. (John Wesley Powell, explorer, said of the Grand Canyon)

Why Explore?

"There is no way back into the past; the choice, as Wells once said, is the universe-or nothing. Though men and civilizations may yearn for rest, for the dream of the lotus-eaters, that is a desire that merges imperceptibly into death. The challenge of the great spaces between the worlds is a stupendous one; but if we fail to meet it, the story of our race will be drawing to its close."

- Interplanetary Flight: An Introduction to Astronautics, Arthur C. Clarke

Why Explore?

"Houston, this is Snoopy! We is Go and we is down among 'em Charlie!"

- Apollo 10 LMP Gene Cernan while in lunar orbit at 50,000 feet above lunar surface at a speed of 3,700 miles per hour to CAPCOM Charlie Duke

Why Explore?

"Building a boat isn't about weaving canvas, forging nails, or reading the sky. It's about giving a shared taste for the sea..."

- Antoine de Saint-Exupery, pilot

Who To Send?

Exploring For Life in Our Solar System - Future Crewed vs. Uncrewed Misions

- Crewed
  - Advantages
    - More efficient science, sample return, inspirational
  - Disadvantages
    - Less persistent science, cost, safety
- Uncrewed
  - Advantages
    - More persistent science, cost, safety
  - Disadvantages
    - Less efficient science, often no sample return, not as inspirational

The Middle Way - Telepresence

- Flags + footprints is the past
- Robotic + human exploration are not rivals - they compliment each other
- Telerobotics / Telepresence is the future - humans operating robotic surrogates from afar
- Analogous to what is happening in military - Uncrewed aerial vehicles, uncrewed underwater vehicles, etc.

- Adam Man, Almost Being There: Why the Future of Space Exploration is Not What You Think, Wired, Nov. 12, 2012

Where To Go To?

Steve Squyres Recommended Future Astrobiology Missions

Question: Where is there life today in our solar system other than Earth?

"I would say Europa. If I knew how to do submarines on Europa I would not be screwing around with rovers on Mars."

- Steve Squyres, planetary scientist

Neil deGrasse Tyson's Recommended Future Astrobiology Missions

- Search Mars for fossils, find out why liquid water no longer runs on surface
- Visit asteroids and learn to deflect them
- Drill through Europa's ice and explore its liquid ocean for living organisms
- Explore Pluto and Kupier Belt Objects for clues to our planetary origins
- Probe Venus' thick atmosphere to understand why greenhouse effect went awry

- Neil deGrasse Tyson, Space Chronicles

Exploring For Life In Our Solar System - Future Uncrewed Missions - Mercury

Exploring For Life In Our Solar System - Future Uncrewed Missions - Venus

Proposed Case Study Summary - Venus Landsailing Rover / Zephyr

- Goal
  - Overcome difficulty of exploring surface of Venus
- Center of Gravity (Strategy)
  - Must account for thick highly reflective clouds of sulfuric acid, dense atmosphere that at surface has atmospheric pressure of 92 times Earth, extremely hot surface temperatures
- Equipment
  - Build 3 wheeled rover that sails across land using Venus winds of 2 mph as propulsive force using 22 foot high solar cell laden sail
- Training ~ Leadership ~ Morale
- Tactics
  - Most of Venus is very flat so you just sail / roll across it
- Intangibles
  - Venus is phenomenally difficult to explore
- Mistakes
- Outcome

- Windsurfing on Venus, Astrobiology Magazine, Aug. 24, 2013

Exploring For Life In Our Solar System - Future Uncrewed Missions - Moon

- Google X Prize
  - No one succeeded, but many contestants still trying, now as companies offering landing services to NASA

Exploring For Life In Our Solar System - Future Crewed Missions - Moon

- Artemis

Exploring For Life In Our Solar System - Future Uncrewed Missions - Mars

- Sample return is holy grail
  - Mars Rover 2020 is first step

Exploring For Life In Our Solar System - Future Crewed Missions - Mars

- Sample return is holy grail
- Will SpaceX Starship be first to land humans on Mars?

Proposed Case Study Summary - Inspiration Mars

- Goal
  - Send 2 person crew around Mars + back to Earth in 501 days
- Center of Gravity (Strategy)
  - Leave January 2018, head towards Sun as close as Venus for gravity assist, then swing around dark side of Mars + return to Earth
- Equipment
  - No new technology needed, customize existing technology for environmental control and life support system + thermal protection system needed to handle space environment along with fastest reentry into Earth's atmosphere ever
  - Capsule + inflated or rigid habitat with 600 cubic feet of volume
  - 3,000 pounds dehydrated food, exercise equipment to mitigate weightlessness effects
  - No spacesuits, no airlock
- Training
  - Crew needs mechanical skills to maintain spacecraft systems which will be simple + reliable + easy to maintain, rather than being automated
- Leadership
  - Astronaut Dennis Tito + private industry
- Morale

  "You're jammed into an RV [driving] the equivalent of 32,000 times around Earth and you can't get out for about a year and a half" - Jane Poynter
  - Expect Biosphere 2-like conditions to emerge including mood swings, loss of energy, interpersonal tensions
  - Crew needs to have resilient personalities - Would like to send a couple that has been married for long time
- Tactics
  - Space radiation - use upper stage + water-shielded shelter to guard against high-energy solar coronal mass ejections, for cosmic background radiation mission would be in ballpark of NASA lifetime limit on astronaut radiation exposure for middle-aged crew + would boost their chance of getting cancer by 3%
- Intangibles ~ Mistakes ~ Outcome
  - Never flown

- Frank Morring, Space Race, Aviation Week + Space Technology, Mar. 4/11, 2013

Proposed Case Study Summary - Icebreaker

- Goal
  - Drill into Mars to find signs of life
- Center of Gravity (Strategy)
  - Drill down 3 feet + scan ice shavings for organic biomarkers which are molecules too complex to be produced non-biologically and could therefore be evidence of life
- Equipment
  - Rotary-percussive drill from Honeybee Robotics that must operate autonomously so that it drills without melting ice - if ice melts drill can get stuck
  - Signs of Life Detector that can detect cells, complex organic molecules, simple compounds of potential biological origin using digital camera + lab-on-a-chip
- Training ~ Leadership ~ Morale
- Tactics
  - Pick site to drill on northern plains of Mars where the ice-cemented ground may have been water up to 5 million years ago because it is possible that during periods of recent high Mars obliquity the ice was warmed + became as habitable as soils in Antarctic dry valleys
  - Near-surface ice is good place to look as it can preserve life for millions of years + protect organic biomarkers from destruction from radiation from space + harsh chemicals on Mars
- Intangibles ~ Mistakes
- Outcome

- Charles Choi, Mars Icebreaker Life Mission, Astrobiology Magazine, May 16, 2013
- Aaron Gronstal, Icebreaking Mars, Astrobiology Magazine, Apr. 17, 2014

Proposed Case Study Summary - Spelunking on Mars

- Goal
  - Search for life on Mars in the ideal place for it - beneath the surface
- Center of Gravity (Strategy)
  - Explore extraterrestrial caves because 1) they are protected from weather / meteors / radiation, 2) are likely place for liquid water on Mars, 3) temperature relatively stable
- Equipment
  - Use rovers
- Training ~ Leadership ~ Morale
- Tactics
  - Land as close as possible to cave opening to save energy, lower robot from skylight to cave floor, once inside robot must crawl through cave, look for macroscopic biosignatures of microscopic life
- Intangibles
  - Communication - radios used by rovers to receive commands + send data can't penetrate rock
  - How do rovers see in dark of caves?
- Mistakes
- Outcome

- Mark Betancourt, Mars Underground, Air and Space, Jun. 2016

Exploring For Life In Our Solar System - Future Uncrewed Missions - Asteroids / Comets

Exploring For Life In Our Solar System - Future Uncrewed Missions - Jupiter

- Europa

Proposed Case Study Summary - Europa Clipper Orbiter

- Goal
  - Perform landing site reconnaissance + global mapping, study thickness of ice shell, analyze surface materials + thin atmosphere
- Center of Gravity (Strategy)
  - Orbit Jupiter and do 45 flybys of Europa over 3 years to confirm ocean exists + its depth + saltiness + thickness of ice crust
- Equipment
  - Topographic camera to produce high-resolution images of Europa's surface
  - Spectrometer to determine composition of Europa's surface + subsurface materials
  - Ice penetrating radar to determine thickness of Europa's icy shell + search for subsurface lakes
  - Magnetometer to measure strength + direction of moon's magnetic field to allow scientists to determine depth + salinity of ocean
  - Thermal instrument to search Europa's frozen surface to search for recent eruptions of warmer water
  - Other instruments to search for water in Europa's thin atmosphere
- Training ~ Leadership ~ Morale
- Tactics
  - Solar powered ~ Radiation shielding of spacecraft is key
- Intangibles
  - An active cryovolcano plume from Europa could be flown through + sampled with mass spectrometer
- Mistakes
- Outcome
  - Launch in 2025

- Sheyna Gifford, Ship of Dreams, Astrobiology Magazine, May 1, 2014
- Guy Norris, Frozen Four, Aviation Week + Space Technology, Mar 16-29, 2015
- NASA's Europa Mission Begins With Selection of Science Instruments, Astrobiology Magazine, May 26, 2015

Europa Lander

- Instruments in radiation hardened case
- Powered by battery so mission will last 20 days
- Dig down 10 cm below surface, where Jupiter's radiation effects are negligible
- Collect + investigate 5 samples of 7 milliliters each
- Has a microscope capable of seeing cells down to 0.2 microns, gas chromatograph + mass spectrometer to detect organics, UV spectrometer to characterize organic material
- $8 billion mission

- Eric Berger, Inside NASA's Daring $8 Billion Plan to Finally Find Extraterrestrial Life, Ars Technica, Mar. 7, 2017

- Jason Davis, NASA's Audacious Europa Missions Are Getting Closer to Reality, Planetary Society Blog, Feb. 21, 2017

Proposed Focused Case Study - Getting Through Europa's Ice

- Ice Penetrator
  - Weighs 150 kg
  - Crashes into ice during re-entry, inside penetrator is microscope / mass spectrometer that could analyze frozen slivers
  - Cheapest + simplest
- Cryobot
  - Weighs 180 kg
  - Stone Aerospace device melts its way through ice shooting jets of heated meltwater to clear way ahead + steer
  - Once through ice cryobot launches submersible into ocean = underwater rover
  - Nuclear powered
- Drill
  - Honeybee Robotics wireline drill called Auto-Gopher, weighs 22 kg, is 2 meter long tube with diameter of soda can suspended from wire tether with tungsten carbide drill teeth that operates as rotary-percussive system
  - By suspending drill on wire you save weight - 10 km of tether would weight 100 kg
  - Requires less power than cryobot - 350 watts
  - Captures samples / data all way through ice

\- Meghan Rosen, The Ice of a Distant Moon, Science News, May 2, 2014

Proposed Case Study Summary - Europa DADU Submersible

- Goal
  - Explore ocean of Europa
- Center of Gravity (Strategy)
  - Use submersible
- Equipment
  - Submarine the size of two soda cans with 8 small thrusters connected by fiber optic cable to surface, autonomously + remotely operated
  - Sensors are camera, sonar, microorganism collecting device
- Training ~ Leadership ~ Morale
- Tactics
  - Mole-like drill to melt through kilometers of ice
- Intangibles ~ Mistakes
- Outcome

- Jeremy Hsu, Tiny Submersible Could Search for Life in Europa's Ocean, Astrobiology Magazine, Jun. 10, 2013

Proposed Case Study Summary - Stone Aerospace Europa Cryobot

- Goal
  - Get under ice of Europa
- Center of Gravity (Strategy)
  - Tunnel through 20-30 kilometers of ice, while communicating with surface, and withstanding pressures underneath ice
- Equipment
  - Stone Aerospace VALKYRIE + ARTEMIS robots
- Training ~ Leadership ~ Morale
- Tactics
  - Stone Aerospace VALKYRIE uses lasers to melt its way through ice, power source left on surface, energy transmitted via laser down optical fiber to cryobot to heat water + melt ice in front of it, water freezes behind it around fiber which is spooled out while descending, thus leaving communications + power intact
  - Stone Aerospace ARTEMIS robot used once bottom of ice broken through - an underwater mothership that could deploy small probes to explore further underwater
- Intangibles ~ Mistakes
  - Would need 250 - 1,000 kilowatts on Europa
- Outcome
  - Currently with 5 kilowatt laser has descended 31 meters into a glacier ~ 250 kilowatt laser could go through kilometers of ice
  - Next step is equip VALKYRIE with protein fluorescent cytometer that could detect microbes deposited in ice

    - Keith Cooper, Robotic Tunneler May Explore Icy Moons, Astrobiology Magazine, Jun. 11, 2015

Exploring For Life In Our Solar System - Future Uncrewed Missions - Saturn

- Titan
- Enceladus

Proposed Case Study Summary - Titan Mare Explorer

- Goal
  - Investigate methane hydrological cycle on Titan
- Center of Gravity (Strategy)
  - Land in Ligeia Mara, large lake on Titan
- Equipment
  - Boat-probe
- Training ~ Leadership ~ Morale
- Tactics
  - Listen for rainfall, look for cloud formation / rain shafts / methane rainbows
- Intangibles ~ Mistakes
- Outcome

- Rare Rains on Titan, Astrobiology Magazine, Mar. 27, 2012

Proposed Case Study Summary - TALISE

- Goal
  - Determine what is Titan's seas composition (is it sea of complex organic compounds), what is sea depth, how often does it rain
- Center of Gravity (Strategy)
  - Land in middle of Ligeia Mare, biggest lake on Titan
- Equipment
  - Boat-probe powered by wheels / paddles / screws
  - Instruments include panoramic camera, acoustic sounder, LIDAR, microphone
- Training ~ Leadership ~ Morale
- Tactics
  - Sail for the coast collecting data along way for about a year
- Intangibles ~ Mistakes
- Outcome

- Navigating the Seas of Titan, Astrobiology Magazine, Oct. 2, 2012

- Ray Villard, Next Planetary Frontier: Navigating an Alien Sea, Discovery News, Oct. 10, 2012

Proposed Case Study Summary - Enceladus Flyby

- Goal
  - Determine whether there is life on Enceladus
- Center of Gravity (Strategy)
  - Sample return mission
- Equipment
  - Aerogel, sample return capsule
- Training ~ Leadership ~ Morale
- Tactics
  - Send spacecraft to Enceladus, fly through cryovolcano icy plumes near south pole, capture geyser particles in cushioning aerogel, send collected particles back to Earth in return capsule, study particles for organic molecules
- Intangibles
  - Stardust proved this can be done
- Mistakes
- Outcome

- Mike Wall, Saturn Moon Enceladus Eyed for Sample-Return Mission, Space.com, Dec. 6, 2012

Proposed Case Study Summary - Enceladus Explorer

- Goal
  - Search for life on Enceladus
- Center of Gravity (Strategy)
  - Drill into subsurface water
- Equipment
  - Base station connected to IceMole ice drill probe by cable for power + communications
- Training ~ Leadership ~ Morale
- Tactics
  - IceMole melts its way down ~ 100-200 meters where it finds water-bearing crevasse where it obtains sample of liquid water + studies it in situ for presence of microorganisms
  - Once in crevasse it can sail around in it
- Intangibles
  - Landing on cryovolcano too risky, traces of life could be destroyed during their ejection from cryovolcano + exposure to hostile conditions of space, so land near cryovolcano + melt towards it
- Mistakes
- Outcome

\- Searching for Life in the Depths of Enceladus, Astrobiology Magazine, Feb. 26, 2012

Exploring For Life In Our Solar System - Future Uncrewed Missions - Uranus

Exploring Ice Worlds

- They are far away - mission to orbit Uranus could take 12 years to get there
- Formed far from Sun where ices are common, so are water worlds, with water in an ionic state under tremendous pressure + mixed with ammonia + methane
- Above water are atmospheres of hydrogen + helium, below water are rocky cores
- One reason to explore them - planets of this size are common class of worlds orbiting other stars

- Van Kane, How We Would Explore Uranus or Neptune, Planetary Society Blog, Jul 6, 2017

Exploring For Life In Our Solar System - Future Uncrewed Missions - Neptune

Exploring For Life In Our Solar System - Future Uncrewed Missions - Pluto / Kupier Belt

Exploring For Life in Universe - Ground Based Telescopes

- Giant Magellan Telescope
  - May study atmospheres of potentially habitable Earth-like worlds
- European Extremely Large Telescope
  - May study atmospheres of potentially habitable Earth-like worlds
  - Goal is to discover, image, characterize Earth-sized exoplanets

Exploring For Life in the Universe - Space Based Telescopes - Wide-Field Infrared Survey Telescope (WFIRST)

- Launch in 2024
- Will discover + then characterize exoplanets by performing spectroscopy of their atmospheres + search for chemical signs of environments suitable for life
  - Will have internal starlight occulter (coronograph) that will allow direct imaging of Jupiter-Neptune mass planets about as far out from a star as Mars (just outside habitable zone)
  - May also receive an external occulter which would allow closer imaging to a star than coronograph would - into the habitable zone

- NASA Introduces New, Wider Set of Eyes on Universe, Astrobiology Magazine, Feb. 18, 2016

Exploring For Life in the Universe - Space Based Telescopes - ATLAST: Proposed Successor to James Webb Space Telescope

- Next question to answer in space science is whether or not we are alone
- We know what kind of telescope we need to look for life around stars - we know where all closest stars are, we know right distance habitable planet will be from its star, we know how bright planet is, we know how to suppress star's light + get spectrum from planet to tell us about its atmosphere
- If we assume every single star has planet around it in right place
  - With 4 meter telescope you can look at tens of star systems (Hubble has 2.4 meter mirror and James Webb has 6 meter mirror)
  - With 8 meter telescope you can look at hundreds of star systems
  - With 16 meter telescope you can look at thousands of star systems
- We don't know how many stars have planet in right place + we don't know how many planets have atmospheres
  - Kepler is telling us that 1 in 10 stars has planet in habitable zone
- You need sample size of 1000 stars to study, so you need 16 meter telescope, it should be built with adaptive optics, way to do it is leverage adaptive optics technology being developed for spy satellites to investigate atmospheres of exoplanets

- Ross Anderson, ATLAST: The Gargantuan Telescope Designed to Find Life on Other Planets, The Atlantic, Oct. 11, 2012

Exploring For Life in the Universe - Space Based Telescopes

- Frank Drake's gravitational lensing telescope

How To Get There?

Beyond Apollo

- Wernher Von Braun had crewed exploration of the solar system all planned
  - Saturn V rocket architecture could have been extended to take astronauts to Venus + Mars
  - Utilized conventional + NERVA nuclear rocket engines
- …but the US threw it all away

"…the way the American people are, now that they have all this capability, instead of taking advantage of it, they'll probably just piss it all away."

- President Lyndon Johnson in 1967, upon hearing that the Congress slashed to just $122 million the $450 million he requested to start the Apollo Applications Program which had been intended to exploit Apollo hardware and operational experience to accomplish new lunar and Earth-orbital missions

- Extremely well documented in blogs by David S.F. Portree
  - www.wired.com/wiredscience/beyondapollo/
  - spaceflighthistory.blogspot.com

How to Pay For This?

"Many will ask, "Why are we spending billions of dollars up there in space when we have pressing problems down here on Earth?" That question should be replaced by a more illuminating one: "As a fraction of one of my tax dollars today, what is the total cost of all US spaceborne telescopes and planetary probes, the rovers on Mars, the International Space Station, the recently terminated space shuttle, telescopes yet to orbit, and missions yet to fly?" The answer is one-half of one penny. During the storied Apollo era, peak NASA spending (in 1965-66) mounted to a bit more than four cents on the tax dollar. If the United States restored funding for NASA to even a quarter of that level - a penny on the tax dollar - the country could reclaim its preeminence in a field that shaped its twentieth-century ascendancy."

- Neil deGrasse Tyson, Why We Should Keep Reaching for the Stars, Foreign Affairs, Mar. / Apr. 2012

Our Biggest Barrier to Space

- Current cost of launching payload to Low Earth Orbit (LEO) - $10,000 - $20,000 / kg
  - Price has barely changed since Apollo, in constant dollars

Exploring For Life in Our Solar System - Future Crewed Missions - The Way Forward - Commercial Space - Space 2.0

- Space Tourism - Virgin Galactic
- Space Hotels - Bigelow Aerospace
- Lowering cost of access to LEO to $2,000 / kg - Space X

Case Study Summary - SpaceX

- Goal
  - Make spaceflight routine + affordable
  - Extend life beyond Earth ~ Make humans a multi-planet species
    - Create new civilization on Mars by making cost of moving to Mars $500,000 / person
- Center of Gravity (Strategy)
  - Vertically integrated for 80% of components for rocket + capsule
  - Simplicity enables reliability + low cost
- Equipment
  - Falcon 9 launcher - $2,500 / pound [$5,000 / kg] to low Earth orbit
  - Dragon capsule for cargo + people - next version will land on legs
  - Falcon Heavy launcher - $1,000 / pound [$2,000 / kg] to low Earth orbit
  - Grasshopper is path to complete resuablity of Falcon 9 with landing gear that can take off + land vertically
- Training ~ Leadership ~ Morale
  - Elon Musk is demanding perfectionist
- Tactics
  - Build upon lessons of NASA
- Intangibles ~ Mistakes
  - Try to learn from NASA's mistakes from their monographs
- Outcome
  - Founded 2002
  - Falcon 1 - first privately built rocket to reach orbit in 2008
  - Falcon 9 - first privately built spacecraft launched into orbit + recovered in 2010
  - Falcon 9 - first privately built rocket to resupply ISS in 2012

    - Andrew Chaikin, 1 Visionary + 3 Launchers + 1,500 Employees =?, Air & Space Magazine, Jan. 2012

    - Chris Anderson, Elon Musk's Mission to Mars, Wired, Oct. 21, 2012

Command-P

"Everything manmade that's ever been in space had to be built and launched from the ground. And that puts enormous constraints on what you can actually do in space, because everything has to survive launch. So how do you get around that?"

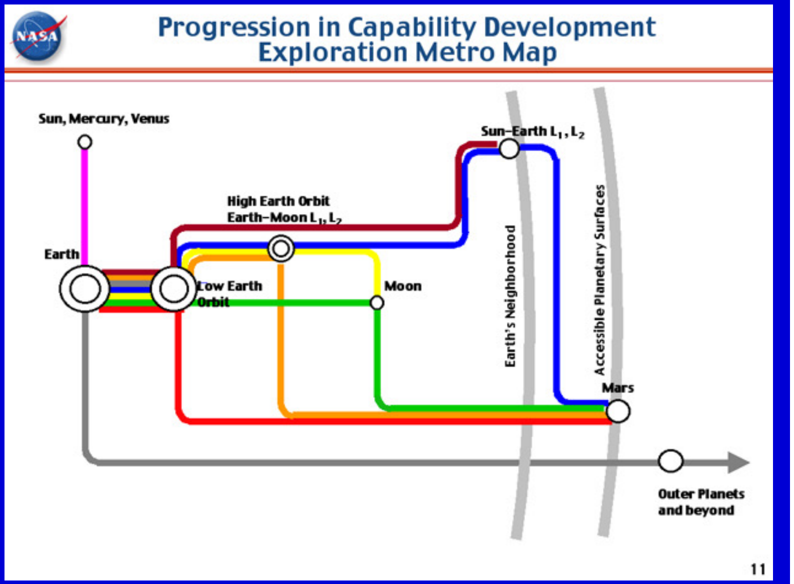
- Jason Dunn outlining his philosophy of why, after more than 50 years of space exploration, humans are not yet living in space settlements.

"His suggestion: Don't manufacture things on the ground. Dunn's Silicon Valley startup company, Made In Space Inc., would reinvent the space industry by putting into orbit a cheap, easy mode of manufacturing: the 3D printer."

- Mark Betancourt, Printed in Space, Air & Space, Nov. 2012

Exploring For Life in Our Solar System - Future Crewed Missions

- **New NASA crewed space exploration architecture**
  - **New booster + Orion capsule for crewed missions to asteroids, Phobos, Mars**
  - **Don't bet on it - is Congressionally mandated make work project for NASA to save jobs in districts**
- **Failure of prior NASA projects**
  - **Bush I Space Exploration Initiative**
  - **Bush II Vision for Space Exploration**



From NASA

Future Crewed Spacecraft Design - Controlled Environmental Life Support

- Going to Mars on 1000 day mission
  - 3 months out - 600 days for planets to realign - 3 months back
  - How do you design life support for this mission
    - Need 1 kg of oxygen, 1/2 kg of dehydrated food, 3.5 liters of water for a person per day on ISS = 5 kg total for Spartan living conditions
    - Cost to launch a kg into orbit = $10,000 to LEO so it is $50,000 / person / day for air / water / food
    - Need water for toilet / clothes / dishes
      - Need 10 kg of water / person / day for hygiene = $100,000 / day
    - For 6 man crew this adds up to $1 billion for mission

- Mark Kliss, NASA

- Need to close water and oxygen loops
- Look at work done on closed loop system in desert (Biosphere 2)

Effect of Space on Human Body

- How does body change in space
  - Nervous system + endocrine system are disrupted in space
  - Circadian system is disrupted
  - "Space dopiness"
  - Balance is affected
  - Hearing is affected
  - Taste + smell affected
  - Touch is affected
  - Lose bone density in space - like bedrest - if you don't use it you lose it
  - Cardiovascular system - body fluids shift from legs to head so blood volume goes down through increased renal excretion
  - ?Immune suppression -> Increased infection

Effect of Space on Human Body

- Habitability issues in space
  - Locomotion
  - Orientation - what is up + down
  - Takes time to adapt to space
- Nonverbal communication difficult due to changes in body morphology
- Environment in spaceship is noisy
- There are psychiatric issues on long voyages
- Earth sickness
  - Takes time to readapt to Earth
- What is difference between going to Moon vs. Mars
  - Moon is 1/2% the distance to Mars
  - Mars is 200 times further away from Earth than the Moon
- The more often you fly in space the quicker you adapt to it

Journey Gently

- Two forms of radiation pose health risks to astronauts in deep space
  - Chronic low dose of galactic cosmic rays (GCRs)
    - Highly energetic, highly penetrating particles not stopped by modest shielding on typical spacecraft
  - Possibility of short-term exposures to solar energetic particles (SEPs) associated with solar flares + coronal mass ejections
    - Solar events produce large numbers of low energy particles that spacecraft shielding is effective against
- Exposure to radiation increases a person's lifetime cancer risk, exposure to a dose of 1 sievert (Sv) is associated with 5% increase in fatal cancer risk
- Vehicle carrying humans in deep space needs storm shelter to protect against SEPs but GCRs are harder to stop
- Average GCR dose equivalent rate is 1.8 mSv / day in cruise so total dose during transit phases of Mars mission would be 0.66 Sv for round trip
  - Astronauts are currently not allowed to exceed 1 Sv

- Radiation Exposure on a Trip to Mars, Astrobiology Magazine, May 31, 2013

Psychology of Space Travel

- Psychological, psychiatric, interpersonal issues affecting astronauts working in Earth orbit and on expeditions to Mars
  - May displace on-board tension to people working in mission control
  - View support role of their leader as important factor fostering crew cohesion
  - Value observations of Earth as significant positive aspect of being in space
  - People from different cultures have different experiences
- Supportive activities from flight surgeons + psychologists on Earth can help prevent + counter psychosocial problems in space on longer missions but such support may be less effective on missions to Mars due to long mission durations + long distances leading to delayed communication times

- Nick Kanas, To the Outer Solar System and Beyond: Psychological Issues in Deep Space, Analog, May 2011 pp.38-43

Spacecraft Design Key Questions

- What do you want to fly?
  - How big is it?
  - How high do you want to go?
  - How long do you want to be there?

Case Study Summary - Future Uncrewed Spacecraft Design - Cubesat / Nanosat / Picosat

- Goal
  - Why hasn't spacecraft design followed computer miniaturization trend?
  - Broaden access to space by decreasing size + weight of spacecraft needed to do serious science
- Center of Gravity (Strategy)
  - Faster, better, cheaper
- Equipment - Cubesat
  - 10 cm x 10 cm x 10 cm in size = 1 unit (U)
  - 1 kg in weight [Nanosat weights 1-10 kg, Picosat weighs < 1 kg]
  - Costs few thousand dollars to make + ~ $40,000 launch cost
  - Can be put together as modular spacecraft - 3U, 6U, 12U, etc.
  - Can be networked into clusters
  - Launched as secondary payloads
- Training ~ Leadership ~ Morale
- Tactics
  - Combine Maker movement (open source hardware) and smartphones (Android for software + all the hardware for cameras, accelerometers, magnetometers, GPS receivers, radios, gyroscopes, barometers, etc.)
- Intangibles ~ Mistakes
  - Limiting factors are communications (due to small size of antennas + lack of access to ground stations) and propulsion (when launched as secondary payload not allowed to carry hazardous propellants)
- Outcome
  - "What if everyone had their own personal satellite?"
    - Personal Space, The Economist, Sep 19, 2012
    - Jeff Foust, CubeSats Get Big, The Space Review, Sep. 10, 2012
    - Nanosats Are Go!, The Economist, Jun. 7, 2014

From Amazon.com

Planetary CubeSats

- CubeSat is 10 x 10 x 10 cm (1 liter) in size + weighing no more than 1.3 kg
  - Can be stacked as units (U), 3U CubeSat is size of loaf of bread
  - Must perform all essential functions of satellites: power, command + control, communications, operate payload that makes some type of measurement - all within tight space / weight / power / communications restraints
- To operate in deep space to explore solar system, CubeSat must be made reliable + long-lived, working for months to years rather than days to weeks
  - Additions include radiation hardening as they are outside Earth's protective magnetosphere, propulsion systems for trajectory changes + entering orbit, power (especially further from Sun), instruments that make meaningful measurements, long-range communication systems that work far from Earth
  - Must also develop new ways to run missions at fraction of what traditional missions have cost

- Van Kane, The Potential of CubeSats, Planetary Society Blog, Oct. 23, 2015

- Van Kane, Planetary CubeSats Begin to Come of Age, Planetary Society Blog, Feb. 17, 2015

Future Propulsion Systems To Move Around The Solar System

- **Space elevator - to get into orbit**
- **Ion engine - for gradual / prolonged acceleration**
- **Solar sail - for low / steady acceleration**
- **Nuclear propulsion**

Space Elevator

- Goes from equator to geosynchronous orbit
  - Start in a quiescent area of ocean, weather wise
- Elevator tether cable is 1 meter wide, goes up to 100,000 km
  - Have 7 cars on elevator, 1 car goes up each day, each car carries 14 tons of payload
- What is needed to make it work
  - Mastery of carbon nanotubules, 1000 times stronger than steel, will take 5-15 years
- End result
  - Cost to launch 1 kg of payload into orbit via space elevator = $500 / kg or $250 / pound
    - This is 100 times cheaper than rockets

- Peter Swan, Big Picture Science, Oct. 15, 2012

Space Elevator

- Is cable stretching from Earth's surface into + beyond geosynchronous orbit
- Anchor + Earth's gravity at lower end along with counterweight + centrifugal force at top end keep cable taut + stationary over ground
- Robotic climbers pull themselves up the cable into space, potentially powered by lasers
- Balanced by its own mass + outward centrifugal force of spinning Earth
- Ideal tether should be tapered, widest at geosynchronous orbit + narrowest at Earth and at its far end
- Cable must be light, strong flexible + be 100,000 km long
- Biggest problem is finding strong enough material for cable - carbon nanotubes not yet stable enough in such great length
- Would cost $10-$50 billion (cheaper than International Space Station) - could be built within 10 years of material science breakthrough for cable
- Cost of sending cargo could drop to $100 / kg
- Moon may be better place to start due to its lower gravity + lack of wind / ice, meaning cable would not have to be as strong + could be made of Kevlar

- Richard Hollingham, Space Elevators: Going Up?, BBC News, Aug. 20, 2012

- David Appell, Space Elevator Enthusiasts Push On Despite Lengthy Time Frames and Long Odds, Scientific American, Sept. 4, 2012

- Rachel Feltman, Why Don't We Have Space Elevators? Popular Mechanics, Mar. 7, 2013

Ion Engine

- Chemical propulsion
  - Spacecraft with this means of propulsion spend most of their time coasting
  - Is the conventional means of propulsion
- Ion propulsion
  - Spacecraft with this means of propulsion spend most of their time in powered flight by emitting a thin but high velocity beam of ions
  - Gives persistent but gentle propulsion

VASIMR Engine

- Humans crossing long distances in space requires long amount of time which means long-term radiation exposure, extended microgravity environment exposure, consuming vast quantities of supplies
  - Solar radiation can be cut down by storm shelter of water or hydrogen fuel where crew can shelter during solar events
  - Constant rain of high-energy cosmic rays penetrates everything - Earth is shielded from these by its magnetosphere, perhaps a ship could generate a protective magnetic field
  - Best thing to do would be to speed the spaceship up…
- Variable Specific Impulse Magnetoplasma Rocket (VASIMR)
  - Electric engine that uses microwaves to heat propellant to turn it into plasma
  - Typical ion engine has low power, about a kilowatt (Dawn + Deep Space 1 spacecraft)
  - VASIMR has 200 kilowatts of power
  - Could shorten 6 month Mars trip to a few weeks
  - Problem is that it requires 200 kilowatt power supply - would need more advanced solar panels

- Michael Carroll, Really Big Tourism, Analog, June 2015

Ion Engines

- Dawn + Deep Space 1 ion engines use xenon as a propellant, electricity heats xenon to make plasma, then electric fields helped the plasma to shoot out an ion beam, with a power level of 1 kilowatt
- VASIMR ion engine uses microwaves to heat propellant, turning it into a plasma, with a power level of 200 kilowatts, can trim mission to Mars from 6-8 months to 6 weeks

- Michael Carroll, Alien Archeology, Searching For the Fingerprint of Advanced Extraterrestrial Civilizations, Analog, May/June 2017

Solar Sailing

- "Clipper Ships of Space" by Carl A. Wiley
  - First detailed article on solar sailing to reach large audience, being published in the May 1951 issue of Astounding Science Fiction

Solar Sailing

"Hold your hands out to the sun. What do you feel? Heat, of course. But there's pressure as well - though you've never noticed it, because it's so tiny. Over the area of your hands, it only comes to about a millionth of an ounce. But out in space, even a pressure as small as that can be important - for it's acting all the time, hour after hour, day after day. Unlike rocket fuel, it's free and unlimited. If we want to, we can use it; we can build sails to catch the radiation blowing from the sun."

- John Merton in Arthur C. Clarke's short story Sunjammer (The Wind from the Sun)

Solar Sailing

- Tsiolkovsky rocket equation states rocket gains speed linearly as its starting mass of propellant rises exponentially
- Solar sail removes Tsiolkovsky rocket equation from your voyage
- Get tiny thrust by momentum imparted by photons from Sun with small thrust over time building continuously
- Light impinging on sail varies inversely by square of distance from Sun
- At distance of Earth from Sun, solar flux is 1.4 kw / square meter, which is 9 times weaker than the force of wind on Earth's surface - thus sails must be lightweight + large
- …and when you run too far from the Sun to be powered by the Sun, you use solar power satellites to power a laser to beam light at the sail + now you have a light sail to take to to nearby stars

- Paul Gilster, An Updated Look at Solar Sailing, Centauri Dreams, Nov. 3, 2014

Nuclear Propulsion

- Rely on nuclear fission to generate propulsion rather than chemical propellants
  - Advantages - virtually unlimited energy density compared to rocket fuel, has superior thrust relative to amount of propellant used (specific impulse) which leads to reduced trip times
  - NERVA engine built, tested, and considered for use on S-IVB stage of Saturn V rocket in 1960's
- Types
  - Nuclear Thermal Propulsion
    - Uranium or deuterium reactions used to heat liquid H inside a fission reactor, turning it into ionized hydrogen gas (plasma) which is channeled through rocket nozzle to generate thrust
  - Nuclear Electric Propulsion
    - Use fission reactor that converts its heat + energy into electrical energy which powers electrical engine

- Matt Williams, Exploring the Universe with Nuclear Power, Universe Today, Jan. 30, 2015

Nuclear Propulsion

- Nuclear thermal rockets (NTR)
  - Have capability of generating high thrust + 100% more specific impulse than best chemical rockets
  - Engine based around compact fission reactor core that generates hundreds of megawatts of thermal power to heat liquid hydrogen propellant to high exhaust temperatures for rocket thrust
- NASA would like test flight of small NTR within 10 years
  - Would like to use NTR with 16,700 pounds of thrust which would leverage work performed on same-sized small nuclear rocket engine (SNRE) that came out of NASA's Nuclear Engine for Rocket Vehicle Applications (NERVA) program in 1960's
  - Cluster of 3 of these engines could support reusable lunar cargo delivery, crewed landings + asteroid survey missions
  - NTR could cut travel time to Mars to 6 months

- Guy Norris, Nuclear Option, Aviation Week, Sep. 25-Oct. 11, 2015

What To Do Once You Get There?

Drilling Up vs. Drilling Down for Energy Security

- **1968 - Peter Glaser**
  - **Proposes to collect solar energy on satellites + beam it to earth**
  - **Cleanest + safest option for generating Earth's electricity**
- **1970 - 80's - Gerald O'Neill**
  - **Keeps flame alive ~ But collecting + beaming back energy too inefficient ~ launching too costly**
- **2007 - US Department of Defense**
  - **Wants to be catalyst to make this happen**
  - **Collecting + beaming back energy becoming more efficient ~ launching becoming cheaper**
  - **Advantages**
    - **Tactically - Forward deployed troops get electricity from sky rather than gasoline powered generators**
    - **Strategically - Eases developed nations addiction to oil (and conflict over it), decreases greenhouse gases + climate change**

"…there is enormous potential for energy security, economic development, improved environmental stewardship, advancement of general space faring, and overall national security for those nations who construct and possess a space based solar power capability"

- National Security Space Office, Space-Based Solar Power As An Opportunity for Strategic Security, 2007
- Gerald K. O'Neill, The World's Energy Future (Still) Belongs in Space, 1992

"The possibility of cooperation among nations, in an enterprise which can yield new wealth for all rather than a conflict over the remaining resources of the Earth, *may be* far more important in the long run than the immediate return of energy to the Earth. So, too, may be the sense of hope and of new options and opportunities which space colonization can bring to a world which has lost its frontiers."

- NASA/Ames-Stanford ASEE 1975 Summer Study of Space Colonization

Case Study Summary - Solar Power Satellites

- Goal
  - Energy independence for US through clean energy from space
- Center of Gravity (Strategy)
  - Space-based solar power satellites
- Equipment
  - Develop low-cost access to space
  - Mine moon / asteroids for raw materials, send them to earth orbit via mass driver / catapult
  - Build solar power satellites in orbit
  - Build space settlements to house workers
  - Beam solar energy to Earth via microwaves
- Training
  - Emphasis on STEM
- Leadership
  - Required at the national level

Case Study Summary - Solar Power Satellites

- Morale ~ Tactics
  - Can help make Americans feel great again
- Intangibles
  - How can you decrease launch costs?
  - Can you legally mine moon / asteroids for raw materials?
- Mistakes
  - Not dreaming large enough
- Outcome
  - Make US energy independent
  - Open a new frontier for Americans
  - Establish US lead in space manufacturing industry
  - Stop providing petrodollars to those who despise us - drain the swamp monetarily
  - Decouple US foreign policy from US energy needs
  - Space settlements provide back up of human race

Is The Moon Made of Green Resources?

"The moon has no biosphere, there's no life there, it's already a big open strip mine in the sky, so it's actually a wonderful opportunity for us to be able to obtain the resources that humanity needs without devastating the environment of Earth. So the moon actually is a territory that belongs to all of the peoples of the Earth and it's the entrepreneurs who will be going there who will bring back the value and that is an opportunity for the first time in the history of humanity to conquer a frontier without conquering each other."

- Bob Richards, Moon Express, wants to mine the Moon by 2013

Cost Of Doing Business

"During World War II, supporting one soldier on the battlefield took 1 gallon of fuel per day - today [it is more than] 22 gallons per day. These energy needs require a vast yet vulnerable supply chain that our enemies target."

- Chairman of the Joint Chiefs General Martin Dempsey, 2011

Solar Power Satellites

- Can eliminate many of civilization's problems
  - Pollution from fossil fuel burned for electricity
  - Environmental damage caused by extracting fossil fuels - oil spills, strip mining, mountain-top removal, fracking
  - Use of military force to gain control of fossil fuel resources unevenly distributed around planet

- Frank Morring, Sun Power, Aviation Week and Space Technology, Jun. 9, 2014

Is It Time To Return To The Moon?

- ~ 100 years ago the Antarctic / South Pole was first explored by man
  - It took 50 years for mankind to return and stay in the Antarctic, enabled by new technologies such as aircraft
- ~ 50 years ago the Moon was first explored by man
  - Is it time now for mankind, again enabled by new technologies, to return and stay there?

\- Kevin Fong, Scott's Legacy, Discovery, BBC News, April 16+23+30, 2012

Is It Time To Return To The Moon?

"I think the history of Antarctic exploration gives us a good model that we could apply to the Moon and Mars with early initial very hard one off expeditions, but then moving into a period of essentially steady continuous exploration where permanent bases are established by various nations and there is the scientific and non-scientific exploration of that continent going on now continuously for over 55 years or so. That's what I'd like to see on the Moon and Mars, follow up on these initial Apollo style missions with the establishment of a permanent base and a permanent base where we are planning to be there for 50-100 years. Only in Antarctica do we find an environment where humans cannot survive without a technological bubble surrounding them and that's what we've learned in the Antarctic, how to stay." - Chris McKay

"It's an interesting parallel you draw there, that we've been at the South Pole for 100 years now, but actually the scientific exploitation really proliferated in the middle of the last century. We didn't go back to the South Pole, after Scott and Amundsen first went, for nearly half a century and its interesting that it is getting on for near half a century after the Moon now, do you think this is the time we might finally leave Earth orbit properly?" - Kevin Fong

"Your point is a good one, and maybe it's not exactly 50, its not a clock ticking down, maybe it will take 60 or 70 but it is clear there's going be a big interval of time between the initial exploration and the establishment of a real scientific research outpost. We have to follow that model and push towards that, using the Antarctic as our paradigm." - Chris McKay

...

"But perhaps in the future the exploration of Mars won't be the sole preserve of government space agencies. For Antarctica, after the flags and footprints laid by Amundsen and Scott, no one set foot at the South Pole again for nearly 50 years. And when they returned, it was not with dogs, horses, or man hauled sledges, but with aircraft. And these vehicles had been designed and built not by governments but by the commercial aviation industry. Is there a role then, for the private sector, in space exploration?" - Kevin Fong

- Kevin Fong, Scott's Legacy, Discovery, BBC News, April 16+23+30, 2012

Golden Spike

"Mount A Lunar Expedition With Us... It's The 21st Century"

"Private sector human expeditions to the Moon are now feasible, primarily using existing space systems or those in development. The Golden Spike Company is working to implement and operate a human space transportation system at commercially successful price points. Our company is comprised of veteran space program executives, managers, engineers and entrepreneurs focused on generating a sustainable human lunar exploration business that generates profits through multiple high value revenue streams."

Reasons To Go To Near Earth Asteroids / Objects

- 1. Human exploration
  - Near earth asteroids are great targets to practice exploring on
- 2. Science
  - Near earth asteroids are left over building blocks of solar system
  - We can learn how solar system formed + Earth / Moon system formed and how we came to be on Earth
- 3. Resources
  - Presence of precious metals may allow us to mine them for profit
  - Presence of water would allow us to practice in situ resource utilization by using asteroids as supply depots to help us explore solar system
    - Phobos + Deimos can help us to explore Mars
- 4. Planetary Defense
  - More you learn helps you develop mitigation technologies + strategies to defend Earth

"The dinosaurs became extinct because they didn't have a space program. And if we become extinct because we don't have a space program, it'll serve us right!"

- Larry Niven, author

Case Study Summary - OSIRIS-REx

- Goal
  - Study of + sample return from carbonaceous asteroid 101955 Bennu
- Center of Gravity (Strategy)
  - Learn more about time before formation + evolution of solar system, initial stages of planet formation, sources of organic compounds which lead to formation of life
- Equipment
  - Robotic arm to sample, sample return capsule
- Training ~ Leadership ~ Morale
- Tactics
  - Fly to asteroid, study it, obtain sample, return sample to Earth for study
- Intangibles
- Mistakes
- Outcome
  - Launch in 2016, return to Earth in 2023

Asteroid Mining 101

- There are 9,000 near-Earth objects that are big enough + close enough to pose impact threats to Earth…or to be mineable for resources
  - 1,500 of these are no harder to reach than our Moon
  - In 2005 Hayabusa landed on 25143 Itokawa + returned few mg of samples to Earth in 2010
  - In 2016 OSIRIS Rex will launch + return 2 ounces of samples
- Platinum series metals
  - 500 meter platinum rich asteroid could contain as much of these metals as have been mined everywhere throughout history
- Water
  - Valuable as rocket propellant + radiation shielding
- Carbonaceous chondrites are best for mining as they have it all - water, other volatiles, rock for shielding, metals for construction

- Richard Lovett, The Golden Age Comes to Seattle: Is Asteroid Mining Really Part of Our Near Future?, Analog, May 2013

Asteroid Mining 101

- Steps to mining
  - 1. Scan the skies for asteroids
  - 2. Use spectral + orbital data to pick likely candidates for prospecting
    - Spectral data will tell you what asteroid is made of
    - Orbital data will tell you how easy asteroid is to reach + how useful it might be as way station en route to another planet or moon
  - 3. Go to asteroid
  - 4. Mining + return of minerals to Earth orbit
- We don't know how to mine asteroids
- Asteroid capture as asteroid mining
  - Choose asteroid < 7 m in diameter, weighing hundreds of tons
  - If lose control of it, will burn up in Earth's atmosphere
  - Put it in a bag, attach bag to spacecraft, fire up engines to bring it home relying on solar electric power

\- Richard Lovett, The Golden Age Comes to Seattle: Is Asteroid Mining Really Part of Our Near Future?, Analog, May 2013

Planetary Resources Inc.

"Redefining Natural Resources

Planetary Resources is establishing a new paradigm for resource discovery and utilization that will bring the solar system into humanity's sphere of influence. Our technical principals boast extensive experience in all phases of robotic space missions, from designing and building, to testing and operating. We are visionaries, pioneers, rocket scientists and industry leaders with proven track records on - and off - this planet."

- www.planetaryresources.com

Case Study Summary - Planetary Resources

- Goal
  - Build a sustainable business in space
  - Supply Earth with precious metals - expand world's resource base so humanity can grow + prosper
  - Provide stepping stones for deep space exploration
- Center of Gravity (Strategy)
  - Detect near Earth asteroids with space telescope + characterize them
  - Mine for precious metals
  - Mine for water for life + hydrogen fuel cells, O2 to breathe, H2 for rocket fuel
  - Mine for radiation shielding
- Equipment
  - Arkyd-100 space telescope for detecting - 44 pounds with 9" diameter mirror at cost of $10 million
  - Swarm of prospecting robots which are low cost with ion propulsion that look at asteroids < 1 mile in diameter and then dock with them and analyze them spectroscopically using laser induced spectroscopy system like ChemCam
  - Digging via swarm of mining bots
- Training ~ Leadership ~ Morale

- Ross Anderson, Robots Platinum and Tiny Space Telescopes: The Pitch for Mining Asteroids, The Atlantic, May 2012

- Michael Belfiore, How to Mine an Asteroid, Popular Mechanics, Aug. 2012

Case Study Summary - Planetary Resources

- Tactics
  - Water 1 gallon = 4 kg which costs $40-80,000 to launch from Earth
  - C type asteroids (carbonaceous chondrite) best for water
  - M type asteroids - take to Earth or mine asteroids that are not pure metal with magnet
  - Platinum group metals
  - Asteroids don't undergo planetary differentiation where heavy elements sink deep inside planet, therefore they are easier to mine and with low gravity are easier to take off from again
  - You want to mine at asteroid to save on mass + cost…or you could capture asteroid + put it in lunar orbit
  - Capture asteroid 7 m in diameter would weigh 300-700,000 kg
- Intangibles
  - Who owns space? What effect will Outer Space Treaty have?
  - Could their space telescopes be networked together to directly image exoplanets?
- Mistakes
- Outcome
  - What they want to end up with
    - Water for rocket fuel, breathable air, drinkable water
    - Platinum group metals

- Ross Anderson, Robots Platinum and Tiny Space Telescopes: The Pitch for Mining Asteroids, The Atlantic, May 2012

- Michael Belfiore, How to Mine an Asteroid, Popular Mechanics, Aug. 2012

Case Study Summary - Deep Space Industries

- Goal
  - Use resources harvested in space to make permanent space development affordable
- Center of Gravity (Strategy)
  - Harvest asteroids for metals + building materials to construct initially large communications platforms to replace communications satellites + ultimately solar power stations to beam carbon-free energy to Earth
  - Produce fuel for communications satellites
  - Harvest platinum group metals
- Equipment
  - FireFly CubeSats for asteroid prospecting - missions take 2-6 months, weigh 25 kg
  - DragonFly spacecraft for sample return - missions take 2-4 years, weigh 35 kg will return 30 to 75 kg of samples
- Training ~ Leadership ~ Morale
- Tactics
  - Will use Microgravity Foundry, a 3D printer, to transform raw asteroid material into complex metal parts in zero gravity printing with nickel
- Intangibles
- Mistakes
- Outcome
  - Pending

\- Developing a Robotic Fleet to Mine Asteroids, Astrobiology Magazine, Jan. 23, 2013

Mining the Sky Profitably
According to John Lewis

- In short term, concentrate on extracting H, C, N, O - volatiles from nearby asteroids - to make propellants + life-support materials - then use those to move any other commodity around solar system
- Resource transportation + extraction costs from asteroids are high enough so that very few commodities in space would be worth returning to surface of Earth - market for them is in low-Earth orbit
- Any scheme based solely on retrieving platinum-group metals from space + bringing them to Earth would not work economically
- But if you were processing large amounts of metal in space for iron + nickel to make solar-powered satellites, you would end up with platinum-group metals as a byproduct which would be valuable

- Diane Tedeschi, The Extraterrestrial Commodities Market, Air and Space Magazine, Sep. 2015

Not Quite Yet…

- By 2019, both Planetary Resources and Deep Space Industries had been acquired for their assets by non-asteroid mining companies

Are Asteroids Our Future?

"Dyson has pointed out that the fundamental problem with planets is that there's not much real estate for the mass involved.Spheres have the minimum surface area for a given volume of stuff. You can improve things by chopping the Earth in two and rolling up each of the halves like clay balls. This will increase the acreage by 26%. Do it again (now four balls), and you'll win another 26%.Reconfiguring Earth is a big job, and would probably run afoul of environmental protection agencies. But there's no need: as Dyson has noted, if more space is your thing, then the asteroids are already available as bite-size hunks of matter, close enough to the Sun to intercept interesting amounts of energy, and composed of materials suitable for supporting life. There's at least ten thousand times as much surface area on the asteroids as on our home planet. So our future, Dyson suggests, lies in exploiting this abundant acreage, for otherwise we may crowd ourselves into a nasty situation here on Earth."

- Seth Shostak, Dyson's Bet, Astrobiology Magazine, Oct. 14, 2003

- (And asteroids are rubble piles with low porosity so you could easily burrow into it and make a habitat and be shielded…you could spin it at 1 G for gravity…and make air and water from materials on the asteroid)

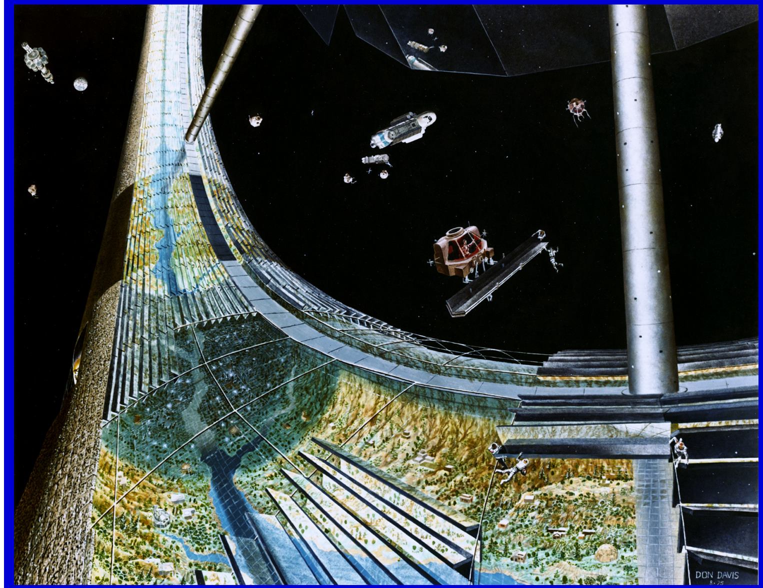
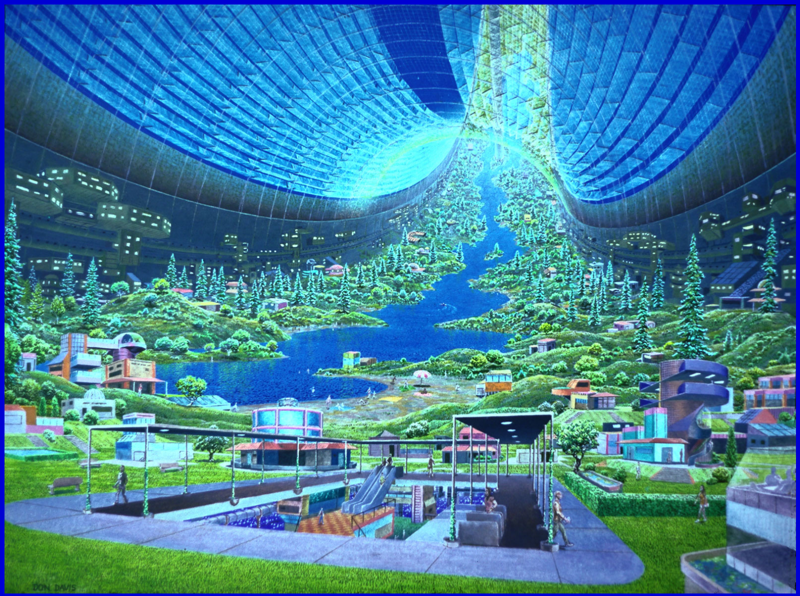
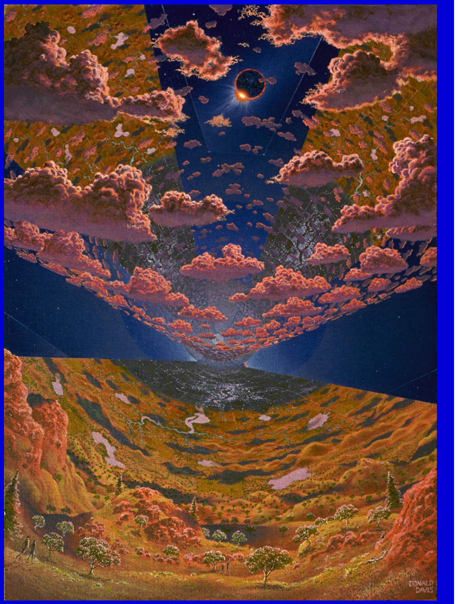
Hollywood's View of Empire

"Historically its been gold, its been spices, its been animal pelts, its been diamonds, its been all kinds of things that have caused colonialism and imperialism…there's always some damn thing that one group needs that the other group is sitting on or has that causes them to get in a ship, go somewhere and shoot 'em - that's my thumbnail history of the last 500 years."

- James Cameron, Director, in panel on the science behind the movie Avatar

What To Do Once You Get There?

Backing Up Life to Space - Space Settlements

All From Don Davis / NASA

Case Study Summary - Biosphere 2

- **Goal**
  - **Earth (Biosphere 1) is doomed, need to learn how to replace it to allow the settlement of planets + space**
- **Center of Gravity (Strategy)**
  - **Build prototype closed-loop biosphere**
- **Equipment**
  - **$150 million, 3 acres in size, consists of 5 areas based on natural biomes + agricultural area of ½ acre + living / working space**
- **Training ~ Leadership ~ Morale**
  - **8 Biospherians were members of a theater troop / cult?**
- **Tactics**
  - **Biomes were intended to naturally recycle food + water without help from outside world**

- Biosphere Under the Glass, Astrobiology Magazine, Feb. 28, 2004

- Biosphere 2 Bounces Back, Astrobiology Magazine, June 30, 2007

- Michael Winerip, A Second Act For Biosphere 2, New York Times, June 10, 2013

Case Study Summary - Biosphere 2

- Intangibles ~ Mistakes
  - Can you bottle up complex ecosystem and expect it to live?
- Outcome
  - Could not make feedback circuit work as happens on Earth
  - Suffocated, starved, went mad during 2 year mission in 1991
    - Gases were being adsorbed into building's foundation - oxygen levels were decreased threatening respiration + CO_2 levels decreased limiting plant productivity…thus could not grow enough food to sustain themselves + had to supplement diet by eating food stock
    - Broke into factions arguing about their research
    - Seal broken to let 1 person out to seek medical treatment for hand injury
    - Used CO_2 scrubber to combat rising CO_2 levels
  - Now is world's largest Earth Science laboratory allowing controlled experiments on a large scale

- Biosphere Under the Glass, Astrobiology Magazine, Feb. 28, 2004
- Biosphere 2 Bounces Back, Astrobiology Magazine, June 30, 2007
- Michael Winerip, A Second Act For Biosphere 2, New York Times, June 10, 2013

Kalpana One Orbital Space Settlement

- Population is 3,000 residents
- Shape is cylinder with radius of 250 m + length of 325 m
  - Cylinder minimizes shielding mass, radiation shielding dominates mass of most space settlement designs
  - Radius is minimum necessary to provide 1 g at the hull when rotating at <= 2 rpm
  - Length is longest possible while ensuring rotational stability
- Axis of rotation aligned with solar system's north-south axis to provide continuous natural light via transparent end caps
- Exterior maintenance via teleoperated semi-autonomous robots
- Primary power from solar power satellites beaming energy to body-mounted rectenna, emergency power via body-mounted solar cells
- Thermal rejection via thermal array disk
- 1g living area in hull supplemented by internal cylinders at lower g for industry, storage, agriculture, retirement, recreation
- Located in Low Earth Orbit at 600 km, high enough to minimize reboost requirements + low enough for Van Allen belts to provide partial radiation protection

- Al Globus, Nitin Arora, Ankur Bajoria, Joe Straut, The Kalpana One Orbital Space Settlement, National Space Society

Terraforming Mars

- Terraforming = transforming a planet's environment through global engineering approach
- How to do it
  - Providing planet with life's three requisites - organic molecules, water, energy
    - Water there already
    - Human technology might provide organics + boost amount of available energy
  - For example
    - Giant mirrors in space would warm surface
    - Genetically engineered plants + trees replenish atmosphere
    - Over time planet would bloom, air would become breathable
  - You need to warm it up
    - Make super greenhouse gases -> let volatiles out
      - Could do it in 100 years using technology we are using to accidentally warm up the Earth
      - It would take 100,000 years to produce enough O_2 on Mars to breathe

      \- Life Beyond Earth, Timothy Ferris, 1999

Terraforming Mars

- Two phase approach to terraforming Mars using technologies not far from contemporary state-of-the-art
  - Mars is first warmed by a massive release of carbon dioxide
    - Takes 100 years
  - This is followed by a modification of the atmosphere to scrub out the carbon dioxide and increase the oxygen content.
    - Takes up to 100,000 years

- Christopher McKay, Owen Toon, James Kastings, Making Mars Habitable, Nature, Volume 352, 8 August 1991

Terraforming Mars

"The fact that a scenario for the full terraforming of Mars can be conceived within the parameter space of current planetological models, and without violating any known laws of physics, demonstrates that such an idea is, at least, feasible in principle. To bring such a project to fruition would require engineering capabilities greater than those of the present day, but not necessarily out of the question for a future civilization several centuries ahead of our own."

- Martyn Fogg, A Synergistic Approach to Terraforming Mars, Journal of the British Interplanetary Society, Volume 45, 1992

Terraforming Mars

- We can do it - should we do it?

  "What I cannot create I do not understand"

  - Richard Feynman

  - This is the reason to do it - we can learn about our Earth by rebuilding it on Mars

    - Chris McKay, NASA

Backing Up Life to Space - Mars Settlements

- Role of synthetic biology
- SpaceX says this is their goal - backing up life to space

Synthetic Biology

- Could make crewed space missions more practical
- Biological manufacturing's big advantage over abiotic manufacturing is its ability to transform very simple starting substrates (CO2, H2O, minerals) into materials needed by astronauts on long-term missions
  - During flight - augment fuel + other energy needs, provide needed materials (biopolymers) + food + drugs on demand
  - At destination - make even more effective use of catalytic activities of diverse organisms to manufacture food + drugs

- Synthetic Biology for Space Exploration, Astrobiology Magazine, Nov. 6, 2014

Case Study Summary - Mars Settlement From SpaceX

- Goal
  - Establish a self-sustaining Mars settlement
- Center of Gravity (Strategy)
  - Fully reusable rocket + spacecraft - Mars Colony Transport or Mars Cargo Transport
  - In situ resource utilization
    - Produce fertilizer, methane, oxygen from Mars' atmospheric N + CO_2 + subsurface water ice
    - Build transparent domes, pressurize with CO_2 to grow Earth crops in Martian soil
- Equipment
- Training ~ Leadership ~ Morale

"I think we have a duty to maintain the light of consciousness, to make sure it continues into the future." - Elon Musk

"If we're going to have any chance of sending stuff to other star systems, we need to be laser-focused on becoming a multi-planet civilization. That's the next step." - Elon Musk

- Rob Coppinger, Huge Mars Colony Eyed by SpaceX Founder Elon Musk, Space.com, Nov. 26, 2012

- Ross Anderson, Exodus, Aeon, Sep. 30, 2014

Case Study Summary - Mars Settlement From SpaceX

- Tactics
  - Start with 10 people ~ Settlement up and running by 2040
  - Eventual cost of ticket to Mars is $500,000 - sell all your possessions + move to Mars
  - Attract 1/100,000 people on Earth (8 billion people on Earth -> 80,000 head for Mars)
  - Total cost = $36 billion - should be 0.25% to 0.5% of a nation's GDP
  - Ultimately would like to have 1 million people to form sustainable + diverse population as need to recreate entire industrial base on Mars in more difficult environment
  - Get to Mars via Mars Colonial Transporter carrying 100 people at a time - also need 10 cargo trips for every human trip so need total of 100,000 trips to Mars for 1 million person settlement
- Intangibles
  - Is a form of cosmic manifest destiny
- Mistakes
- Outcome

- Rob Coppinger, Huge Mars Colony Eyed by SpaceX Founder Elon Musk, Space.com, Nov. 26, 2012

- Ross Anderson, Exodus, Aeon, Sep. 30, 2014

Mars Colonial Transport

- Mars Colonial Transport (MCT)
  - Giant powerful first stage
    - Reusable booster which lands propulsively
  - Second stage which is spacecraft
    - Initially carry 100 people / flight, later will carry several hundred / flight
  - Second stage / spacecraft will be refueled in orbit
  - Once planets are aligned, a "colonial fleet" of MCTs will take off for Mars
  - 3-6 months later MCTs land on Mars propulsively
  - 2 years later when planets are again aligned, MCTs on Mars head back to Earth, taking back anyone who wants to leave Mars for free
  - 3-6 months later MCTs arrive back on Earth, land propulsively, get refurbished to be reused in next 2 year window
  - For every MCT carrying people, 10 MCTs will need to go carrying cargo + supplies

- Tim Urban, How (and Why) SpaceX Will Colonize Mars, Wait But Why, Aug. 16, 2015

Mars Colonial Transport

- What supplies will be needed
  - Energy (mostly solar)
  - Oxygen (oxygen producing plant for in-situ production)
  - Water (need way to get at in-situ water), Food (fertilizer + greenhouse)
  - Inside (large domes to project humans from lack of air pressure which will boil blood, temperature that will freeze you, sun radiation without much atmosphere or magnetic field to block it will kill you)
  - Rocket Fuel (fuel producing plant for in-situ production)
  - Communications

- Tim Urban, How (and Why) SpaceX Will Colonize Mars, Wait But Why, Aug. 16, 2015

Mars Colonial Transport

- Cost of ticket decreases with each 26 month cycle
- By 2040 there will be a thriving Martian city
- Will take 40-50 years of fleet migrations until Mars' population hits 1 million and settlement will then be self-sustaining + the hard drive will be backed up
- "There will be lots of interesting opportunities for anyone who wants to create anything new…This is going to be a real exciting thing for people who want to be part of creating a civilization" - Elon Musk
- Two reasons to settle Mars according to Musk
  - Defensive reason
  - It will be "The greatest adventure in history...Life has to be more than about solving problems. There have to be things that inspire you - that make you proud to be a member of humanity."

- Tim Urban, How (and Why) SpaceX Will Colonize Mars, Wait But Why, Aug. 16, 2015

Elon Musk

- Recipe for Elon Musk's success
  - Dream, system approach, talent, resources
  - Created own ecosystem, designed own rocket, vertically integrated design + production, acquired own test range
- Walt Disney's genius was exploring things from 3 different perspectives
  - Dreamer, realist, spoiler
- Disney meets Musk
  - Dreamer asks why not? + sets dream goal
    - Why not save humanity by extending its footprint to other planets? Let's send humans to Mars
  - Realist ask how?
    - How can we send humans to Mars repeatedly + economically? By having reusable space vehicles
  - Spoiler asks yes but what about?
    - What about rocket equation + huge financial resources needed? Go where space money is - satellite launches + transport to International Space Station

- Antoine Gelain, When Musk Meets Disney, Aviation Week + Space Technology, Nov. 3/10, 2014

When Can We Go To The Stars?

"Earth is the cradle of the mind, but humanity must not remain in its cradle forever."

- Konstantin Tsiolkovsky, rocket scientist

"Starflight is difficult and expensive, but not impossible."

- Robert Forward, physicist

Peopling of the Pacific Islands as Analog to Peopling the Stars

"The whole history of Hominidae has been one of expansion from an East African homeland over the globe and of developing technological means to spread into habitats for which we are not biologically adapted. Various peoples in successive epochs have taken the lead in this expansion, among them the Polynesians and their ancestors. During successive bursts lasting a few hundred years, punctuated by long pauses of a thousand or more years, these seafarers seem to have become intoxicated with the discovery of new lands, with using a voyaging technology they alone possessed to sail where no one had ever been before."

...

"Once their attempts to cope with the rising sea levels of the Holocene committed them to sea, the first pioneers of this lineage of seafarers had good reasons to keep going. The continental mindset of their distant ancestors would have faded as successive generations pushed farther and farther east, to be eventually replaced by the more accurate view that the world was covered with water through which bits of land were scattered. They therefore knew that in pushing into the open ocean they were entering not a vast empty region but one teeming with islands. What is more, after leaving the Bismarck Archipelago and outdistancing their less sea-adapted rivals, they would have realized that before them lay an ocean of islands accessible to themselves alone. What more invitation did they need?"

- Ben Finney, Interstellar Migration and the Human Experience

Would You Like To Swing On A Star…

- Humanity's fastest artifact = Voyager 1 - traveling 38,000 miles per hour would take 70,000 years to reach Alpha Centauri, the nearest star to us, which is 4.4 light years away

"Now, granted Voyager is pretty slow. There are a lot of people who think we have the capabilities to get to a tenth of the speed of light. People are using that number as a benchmark of what they think is attainable, whether it's with a solar sail or nuclear pulse propulsion. If we could achieve that speed, then we could get to Alpha Centauri in just over 40 years.

Whenever I give a talk to a public audience I explain the hazards of living on a spacecraft for 40 years, the fact that life could be extremely tedious, and could possibly even include some kind of induced hibernation. But then I always ask if anyone in the audience would volunteer for a 40+ year journey, and every single time I get a show of hands. And then I say "oh I forgot to mention, it's a one way trip," and even then I get the same show of hands. This tells me that our drive to explore is so great that if and when engineers succeed at traveling at least 10 percent of the speed of light, there will be people willing to make the journey. It's just a matter of time."   - Sara Seager, astronomer

- Ross Anderson, Could We One Day Send Humans to the Newly Discovered Planet Orbiting Alpha Centauri B?, The Atlantic, Oct. 2012

Exploring For Life In The Universe - 100 Year Starship Study

- Goal
  - Develop business plan for designing interstellar spacecraft
    - Found private organization to develop interstellar vision without government help for next 100 years, developing valuable technology along the way
    - Jules Verne published "From The Earth to the Moon" in 1865, 104 years before it became true
  - Study what it would take to send humans to another star - organizationally, technically, sociologically, ethically
    - Rocket technology, legal / social / economic considerations of interstellar migration, philosophical + religious concerns, where to go, how to inspire public support for an expensive vision
- Reasons to summon political will to go
  - Human restlessness
  - Escape killer asteroid
  - Discovery of habitable planet
- Humanity's fastest artifact = Voyager 1 - traveling 38,000 miles per hour would take 70,000 years to reach Alpha Centauri the nearest star to us
- Funded initially by DARPA ~ www.100yss.org

- Dennis Overbye, Offering Funds, US Agency Dreams of Sending Humans to Stars, New York Times, Aug. 17, 2011

Case Study Summary - 100 Year Starship Project

- Goal
  - Take first step to a journey between the stars
  - "The 100-Year Starship study will examine the business model needed to develop and mature a technology portfolio enabling long-distance manned space flight a century from now. This goal will require sustained investments of intellectual and financial capital from a variety of sources."
- Center of Gravity (Strategy)
  - Develop business model needed to develop + mature technology portfolio enabling long distance crewed spaceflight 100 years from now
- Equipment
  - Current propulsion technology can move spacecraft at 0.005% speed of light (=0.00005 c) so it would take 80,000 years to get to nearest star Alpha Centauri
  - Voyager I, in 35 years of travel, is at 0.002 light years away from Earth
- Training
- Leadership
  - Initially DARPA + NASA, then the 100 Year Starship Foundation
- Morale
  - Why go to the stars? - Human survival, contact with other life, evolution of human species, scientific discovery, belief and faith

Case Study Summary - 100 Year Starship Project

- **Tactics**
  - **Propulsion**
    - **Traditional chemical rocket can't carry enough fuel to keep going + reach respectable fraction of c**
    - **Matter-antimatter annihilation - but antimatter hard to make**
    - **Nuclear pulse production - Orion - nuclear bombs detonated against pusher plate - can reach 0.033 c**
    - **Nuclear fusion in reaction chamber - Project Daedalus - uncrewed - reach Barnard's star 5.9 light years away in 50 years travelling at 0.12 c**
    - **Use laser light from terrawatt laser powered by solar power satellite to power sail to 0.13 c**
    - **Faster than light travel violates special relativity - "No breakthroughs appear imminent" - Marc Millis, NASA head of Breakthrough Propulsion Physics Program**
  - **Life support**
    - **Multigenerational ship, suspended animation, take human DNA + print humans at destination**
- **Intangibles**
- **Mistakes**
- **Outcome**
  - **How similar is building a starship to building a medieval cathedral? Both are multigenerational spiritual quests that rally humanity to common cause**

"Per aspera ad astra" - Through hardship to the stars

"The difficult we do at once, the impossible takes a bit longer" - Seabees

Case Study Summary - 100 Year Starship Project

- The 100-Year Starship Study, Strategy Planning Workshop Synthesis and Discussions
- Lou Friedman, Fly Me To The Stars, The Space Review, Jan. 24, 2011
- Jeff Foust, It's Not (Just) About the Starship, The Space Review, June 20, 2011
- Jeff Foust, The Journey a 100 Years Begins With a Single Weekend, The Space Review, Oct. 10, 2011
- Sidney Perkowitz, Ad Astra! To the Stars!, Physics World, Jan. 12, 2012
- Sharon Weinberger, 100 Year Starship: An Interstellar Leap for Mankind?, BBC News, Mar. 22, 2012
- Jeff Foust, Building a Starship's Foundation, The Space Review, Sept. 24, 2012
- Douglas Yazell, 100 Year Starship Public Symposium, AIAA Houston Section Horizons, Sept/Oct. 2012
- Alan Boyle, How to Take a Trip to Alpha Centauri, NBC News, Oct 23, 2012
- John Cramer, The 2013 Starship Century Symposium, Analog, Dec. 2013

100 Year Starship Project 2013

- Most practical path to stars is via solar sails
  - Require fewer scientific breakthroughs, use ultra-thin sails that use pressure of sunlight or high-powered lasers to propel them to few percent of speed of light
  - To propel craft to Alpha Centauri, solar sail would have to be as big as Alabama + need 1,000 years using solar radiation to travel 4.3 light years
  - Change power source to terrawatt laser cuts Alpha Centauri trip to 100 years but such power is equivalent to total output of humanity today

- Les Johnson, Deputy Manager of Advanced Concepts Office at NASA's Marshall Space Flight Center

- Damond Benningfield, Going Interstellar, Air & Space Magazine, Jan. 2014

100 Year Starship Project 2014

- 7 Major Hurdles to Interstellar Flight
  - Before we can make an Enterprise, we have to make an enterprise
    - Create an econosphere around long-term space travel - that makes money + produces spinoff products - so it can support itself
  - We have to move fast
    - Have to figure out how to move fast through space
  - Staying alive
    - Starship must be sustainable + life-sustaining - is closed ecosystem that must have oxygen, food, water + our microbiomes
  - Space hospital
    - Limited machinery, limited medicine, limited doctors
  - Crew-on-crew interaction
    - Getting on each other's nerves - small-town social dynamics in space
  - Oops
    - Steampunk approach - teach spacefarers how to make high-tech things work with low-tech MacGyvered solutions
  - Stepping stones
    - Have to send humans to space regularly + cheaply, start mining + manufacturing off-planet, establish human settlements on Moon + Mars

- Sarah Scoles, What It Will Take to Become an Interstellar Civilization, Discover Magazine, Oct. 28, 2014

Starship Century Symposium 2013

- Ongoing questions
  - Is this the century we build starships?
  - Why go to the stars?
    - Religion, survival, vast wealth, discovery of E.T.
  - Can we go to the stars?
  - Should we go to the stars?

Starship Century Symposium 2013

- Warning: Space Will Kill You!
  - Fire
  - Radiation
  - Low gravity
  - Air leak
  - Low oxygen
  - Carbon dioxide
  - Bad food

    - Richard Lovett, science fiction author

Starship Century Symposium 2013

- Can we go to the stars?
  - Hard problem for 2 reasons - enormous energy required to drive far + fast and vast amount of time it takes to get anywhere
  - Choices for life support
    - Generation ships - mini-societies commit to voyages their descendants will complete
    - Sleep ships - travelers go into hibernation
    - Relativistic ships - at near speed of light, time compresses, so travelers may experience 10 years while 100 pass on Earth
    - Download ships - download your consciousness into machine
    - Star hopping via comets that could be used for fuel, water, food - get to the stars by steps like Polynesians
- 4 scenarios
  - Stuck in the mud - we can't or won't muster the ability to travel far
  - God's galaxy - interstellar race to save alien's souls via generation ships
  - Escape from a dying planet - save the species via sleep ships
  - Trillionaires in space - have means + desires to explore the universe via relativistic / download / faster than light ships

- Peter Schwartz, futurist

Starship Century Symposium 2013

- What type of ship?
  - Orion pusher
  - Daedalus / Icarus / Bussard Ramjet
  - Sailships
  - Exotic technologies - warp drives, wormholes

Starship Century Symposium 2013

- Cost of interstellar travel
  - Apollo program cost 1% of Earth's GDP in 1968, which is $120 billion in 2013 dollars
  - 1% of Earth's GDP in 2013 dollars is $841 billion
  - Robert Zubrin of Mars Society estimates to build a starship capable of 10% of speed of light + supporting a few score human voyagers would cost $125 trillion
- Perhaps main challenge is financial rather than technical - what is payback to society that makes starship since they will never see it again?

- Elise Ackerman, Three Scenarios for Funding Interstellar Travel, Forbes, Sep. 29, 2013

Starship Century Symposium 2013

- Seven Scenarios for Interstellar Travel
  - Nuclear thermal rockets
    - Gets around the tyranny of the rocket equation - these are real
  - Nuclear fusion rockets
    - Hard physics + engineering problem
  - Interstellar ramjet
    - Spaceship that fuels itself using magnetic field in front of ramjet to suck in hydrogen + feed it to fusion reactor - problems are that we don't know how to build it + interstellar hydrogen is not easy to fuse
  - Solar sailships
    - Not fast enough for interstellar travel
  - Beam-driven sailships
    - Powered by beams of lasers or microwaves with laser in orbit powered by solar power satellite - advantage is you leave propulsion system behind + we know how to build them
  - Wormholes
    - Shortcuts in spacetime that can be used for interstellar travel - but do they exist?
  - Comet hopping
    - Use unattached comets to hop from star to star

- Elise Ackerman, Seven Sci-Fi Scenarios For Interstellar Space Travel That Could Happen in This Century, Forbes, Sep. 29, 2013

Starship Century Symposium 2013

- Noah's Ark conundrum

  "In the absence of sending the entire terrestrial biosphere, a fundamental unsolved problem arises: what is the minimum complexity of an ecosystem - dominated, as I have explained, by microbes - necessary for long-term sustainability? At what point, as more and more microbial species are dropped from the inventory of interstellar passengers, does the remaining ecosystem go unstable and collapse? Which microbes are crucial and which would be irrelevant passengers as far as humans (and their animal and plant food supply) are concerned?" - Paul Davies, physicist

- ...And what happens when this ecosystem mixes with its counterpart on the alien world when you arrive at it?
  - Extrasolar life is likely to be biologically very different in structure from life on Earth + we can expect massive incompatibilities

    - Paul Gilster, Starship Century: A Review of the Book, Centauri Dreams, Jul. 1, 2013

    - John Cramer, The 2013 Starship Century Symposium, Analog, Dec. 2013

Starship Century Symposium 2013

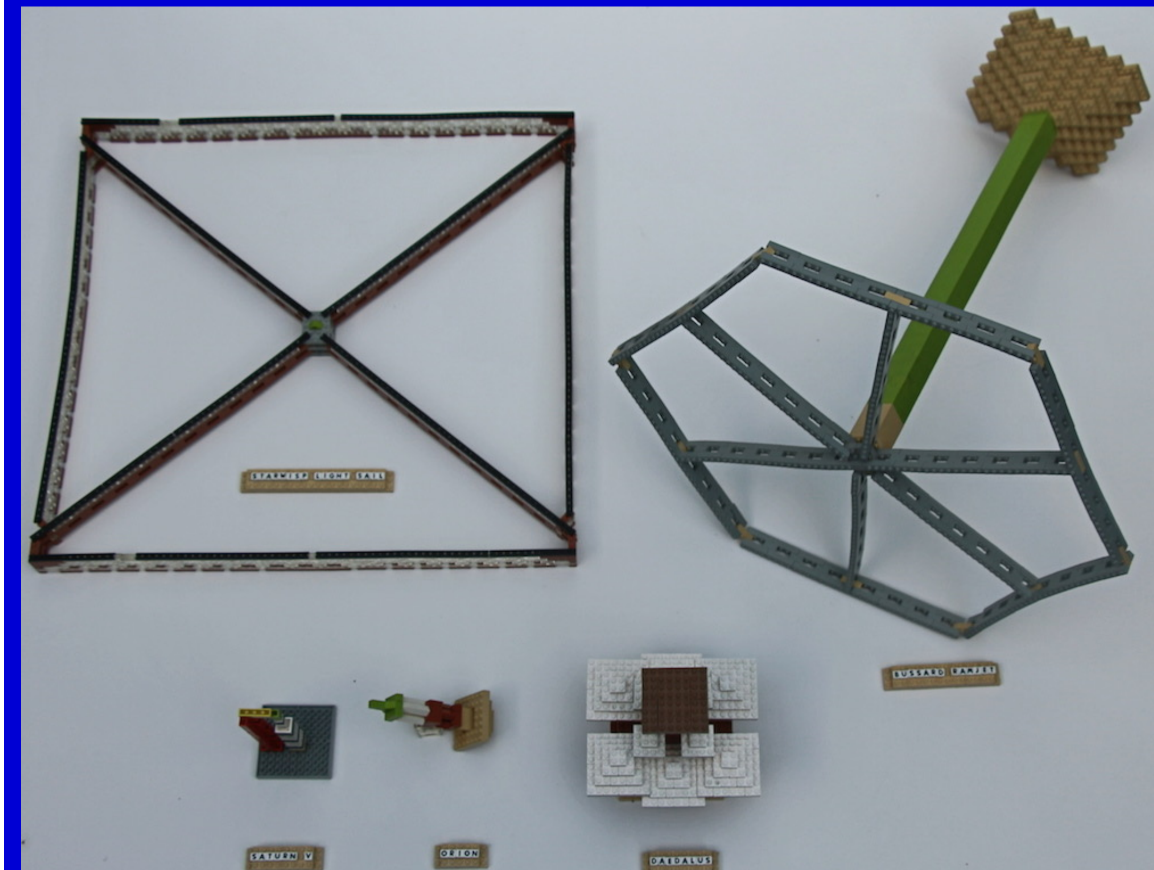
- Interstellar ships
  - Voyager 1
    - Using combination of chemical rocketry + gravitational kicks from planets boosted its velocity to 17 km / sec, would take 75,000 years to reach Alpha Centauri B, which is 4.4 light years away
  - Orion
    - Powered by nuclear fission bombs, would take 130 years to reach Alpha Centauri B but it could not slow down at other end (which would more than double energy needed)
  - Daedalus
    - Uncrewed fusion rocket that would attain 12% speed of light, would take 50 years to reach Barnard's Star, which is 6 light years away, but it would zoom past its target
  - Icarus
    - Spiritual successor to Daedalus, would slow down when reaching its target
  - Sailships
    - Leave fuel behind, use orbiting transmitter to fill their sails with energy in the form of lasers or microwave beams that would push them to significant fraction of speed of light, would be small + easy to accelerate, might be able to stop at destinations by employing solar wind of target star to slow down using a second magnetic sail
    - Small slow probe that would explore space just outside solar system would require as much electrical power as small country
    - True interstellar machine moving at 1/10th speed of light would consume more electricity than all of present day civilization

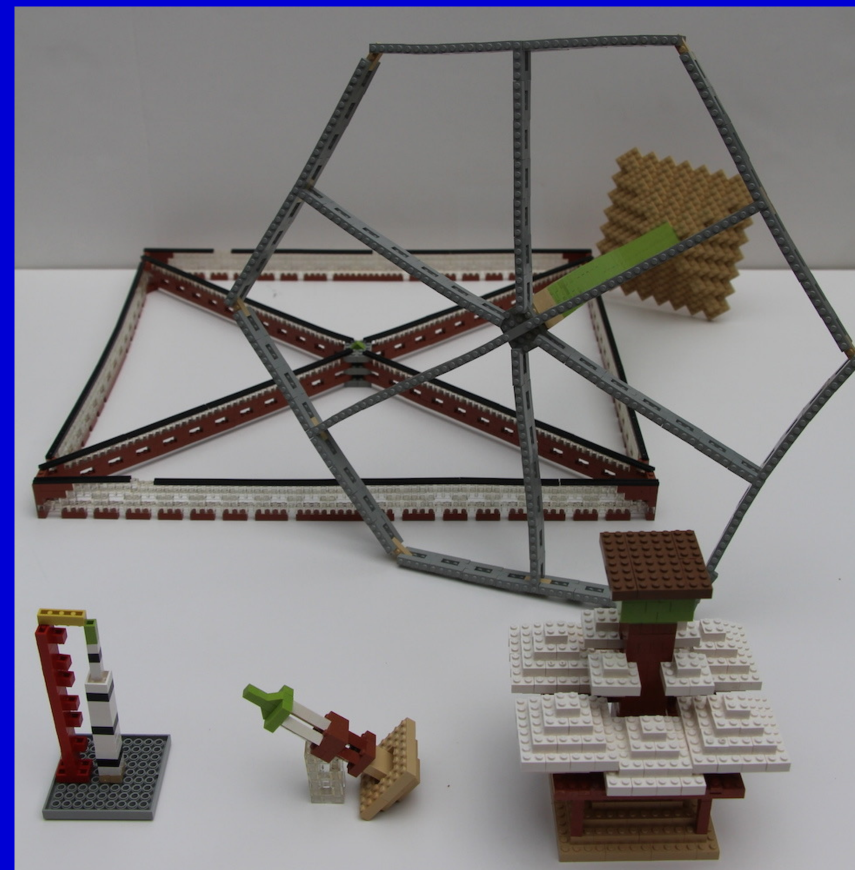
- Starship Troupers, The Economist, Oct. 26, 2013

Modeling Starship Century

- **Saturn V Moon Rocket**
  - Size - 363 feet (length) x 33 feet (diameter)
  - Crew - 3
  - Propulsion system - Chemical rocket of 3 stages
  - Significance - First and only launch vehicle to transport humans beyond Earth orbit
- **Orion Interplanetary Ship to Jupiter**
  - Size - 240 feet (length) x 60 feet (diameter)
  - Crew - 20
  - Propulsion system - Nuclear pulse rocket using nuclear fission bombs ejected from rear of ship, explosion presses on pusher-plate on bottom of ship, transferring momentum via a series of shock absorbers
  - Significance - Can be scaled to a starship cruising at 3 percent of light speed
- **Daedalus Starship**
  - Size - 600 feet (length) x 300 feet (diameter)
  - Crew - Uncrewed
  - Propulsion system - 2 stage nuclear pulse rocket with nuclear fusion engine powered by deuterium/helium-3 pellets
  - Significance - Cruising at 12 percent of light speed, would take 50 years to reach Barnard's Star 5.9 light years from Earth, would perform fly by of its solar system using autonomous sub probes
- **Bussard Ramjet Starship**
  - Size - 1,500 feet (length) x 300 feet (diameter of hull) x 1,200 feet (diameter of magnetic hydrogen scoop support) [whole scoop is 3 million feet in diameter and not shown]
  - Crew - Uncrewed but unknown
  - Propulsion system - Uses magnetic scoop to gather hydrogen atoms that are compressed and fed into fusion reactor
  - Significance - Cruises close to light speed, does not need to carry any fuel
- **Starwisp Light Sail Starship**
  - Size - Less than 1 foot (length) x 3,000 feet (diameter of sail)
  - Crew - Uncrewed
  - Propulsion system - Light from a 10 gigawatt microwave laser, in orbit around Earth and powered by a solar power satellite, is focused by a Fresnel Lens 3 million feet in diameter (not shown) onto the sail. Light sail would be illuminated at launch for 2 weeks to propel it and again at encounter for power
  - Significance - Cruising at 10-20 percent of light speed it would take 21 years to reach Alpha Centauri, weight of sail is 16 grams, weight of payload is 4 grams, sensors are built into sail

Modeling Starship Century





The starships are all built to the standard identification model scale of 1 inch = 100 feet (1/1200 scale). For size purposes, the Saturn V serves as our yardstick, 363 feet long.

The parts of the starships are color-coded:

Green = Crew + payload area | **White = Fuel tanks** | **Tan = Propulsion system**

Rust = Supporting structure | **Gray = Hydrogen scoop** | **Brown = Shield** | **Clear = Solar sail**

How To Build a Starship

- We have built 5 starships so far - Pioneers 10 + 11, Voyagers 1 + 2, New Horizons
- To reach nearby star in decades rather than millennia, need to travel at ~ 10% speed of light (Voyager travels at 0.005% speed of light)
- Top contenders
  - Nuclear rocket
    - Most well thought out
  - Light sails pushed by lasers based in solar system
    - For scientifically useful payload would require lasers concentrating more power than current electrical generating capacity of entire Earth - would need vast space-based solar arrays to power them
  - Antimatter rocket
    - Can't currently produce + store enough antimatter to make it work
  - Interstellar ramjet
    - Fusion rocket using large electromagnetic field as ram scoop to collect + compress interstellar H for fusion drive - hard to construct
    - Project Daedalus - accelerate 450 ton payload to 12% speed of light which would get you to Barnard's star in 36 years but you would fly right past it
    - Project Icarus - revision of Project Daedalus that could slow down at its destination
- All designed to be built in space - too big + dangerous to launch from Earth - need to become a spacefaring + space resource extracting civilization first

- Ian Crawford, How to Build a Starship - and Why We Should Start Thinking About it Now, The Conversation, Jan. 27, 2016

Previous Starship Proposals - Project Orion

- Late 1950's / early 1960's
- Theodore Taylor of General Atomics + Freeman Dyson of Institute for Advanced Study
- Propel a ship by pressure waves from atomic bombs dropped one after another out of back, every three seconds = nuclear pulse rocket
- Could reach Jupiter in 1 year, Alpha Centauri in hundreds of years

- Dennis Overbye, Offering Funds, US Agency Dreams of Sending Humans to Stars, New York Times, Aug. 17, 2011

Case Study Summary - Orion

- Goal
  - Create interplanetary space ship powered by atomic bombs
- Center of Gravity (Strategy)
- Equipment
  - Baseline
    - 4,000 ton vehicle, 135 feet in diameter, 20 stories high
    - Carries 2,600 5 kiloton atomic bombs
    - Is 1 cylinder external combustion engine - single piston reciprocating within combustion chamber of vacuum of space
    - Ship is the piston, armored by 1,000 ton pusher plate attached to shock absorber legs
    - First 200 explosions, fired at half-second intervals with total yield of 100,000 tons of TNT lift ship from launch pad to 125,000 feet
    - 600 more explosions, gradually increasing to 5 kilotons each, put you in 300 mile orbit around Earth
    - Delivers 1,600 tons to 300 mile orbit, 1,200 tons to soft lunar landing, 800 tons to Mars orbit + return
  - Advanced
    - Powered by 15 kiloton bombs, weighted 10,000 tons, 185 feet in diameter, 280 feet high
    - Delivers 6,100 tons to 300 mile orbit, 5,7000 tons to soft lunar landing, 1,300 tons to land on moon of Saturn + return

- George Dyson, Project Orion: Saturn by 1970, Make, Vol. 12

- George Dyson, Project Orion: Deep Space Force, Make, Vol. 13

Case Study Summary - Orion

- Training ~ Leadership ~ Morale
- Tactics
- Intangibles ~ Mistakes
  - Fallout in atmosphere from bombs
  - Funded by ARPA which was an orphan
    - Military space mission went to US Air Force ~ Civilian space mission went to NASA
- Outcome
  - Technology was feasible
  - Worked on for 7 years, stopped by 1963 Nuclear Test Ban Treaty
  - …could have evolved into starship that could have travelled at few percent of speed of light and got to Alpha Centauri in 130 years

"You will perhaps recognize the mixture of technical wisdom and political innocence with which we came to San Diego in 1958, as similar to the Los Alamos of 1943. You had to learn political wisdom by success, and we by failure." - Freeman Dyson to J. Robert Oppenheimer

"What would have happened to us if the government had given full support to us in 1959, as it did to a similar bunch of amateurs in Los Alamos in 1943? Would we have achieved by now a cheap and rapid transportation system extending all over the Solar System? Or are we lucky to have our dreams intact? - Freeman Dyson

- George Dyson, Project Orion: Saturn by 1970, Make, Vol. 12

- George Dyson, Project Orion: Deep Space Force, Make, Vol. 13

Previous Starship Proposals - Project Daedalus

- 1970's
- British Interplanetary Society
- Uncrewed
- Propelled by tiny thermonuclear explosions caused by compressing pellets of deuterium and helium-3 with laser blasts, reaching speed of 12% speed of light = nuclear pulse rocket
- Could carry 500 ton scientific probe to Barnard's Star, a red dwarf, 5.9 light years away, in 50 years
- No means of deceleration upon arrival so jettison probes to do exploring

- Dennis Overbye, Offering Funds, US Agency Dreams of Sending Humans to Stars, New York Times, Aug. 17, 2011

Proposed Case Study Summary - Project Dragonfly

- Goal
  - Design an uncrewed interstellar mission that is capable of delivering useful scientific data about the Alpha Centauri System, associated planetary bodies, solar environment and the interstellar medium
- Center of Gravity (Strategy)
  - Spacecraft will use current or near-future technology
  - Alpha Centauri system shall be reached within a century of its launch
  - Spacecraft propulsion for acceleration must be mainly light sail-based
  - Mission shall maximize encounter time at the destination
  - Laser beam power shall not exceed 100 gigawatts
  - Laser infrastructure shall be based on existing concepts for solar power satellites
- Equipment
  - Laser communication is promising approach for achieving communication over interstellar distances
  - Magnetic sails are most promising way to achieve deceleration from velocities of a few percent of the speed of light
  - RTGs used as power supply

- Andreas Hein, Small Interstellar Probes, Riding Laser Beams - The Project Dragonfly Design Competition Workshop, Centauri Dreams, Jul. 17, 2015

Proposed Case Study Summary - Project Dragonfly

- **Training ~ Leadership ~ Morale**
- **Tactics**
  - **Small interstellar probe, less than 10 tons, has advantage of needing less energy to accelerate**
  - **Laser-sail propelled because similar to solar sails which use Sun's energy directly, laser-sails use the Sun's energy once it is harvested through solar panels**
- **Intangibles**
  - **Beam pointing requirements over distance of several to thousands of astronomical units**
  - **Manufacturing + deploying kilometer sized solar sails would be an issue**
  - **Spacecraft autonomy during mission is an issue**
  - **Deployment of magnetic sails that are several kilometers in radio is an issue**
- **Mistakes**
  - **N/A**
- **Outcome**
  - **Small, several to 10 ton, laser-sail propelled interstellar mission is feasible by using laser infrastructure using 100 gigawatt beam ~ No longer need the whole energy output of Earth to power the mission**
  - **Alpha Centauri system can be reached within 100 years**

- Andreas Hein, Small Interstellar Probes, Riding Laser Beams - The Project Dragonfly Design Competition Workshop, Centauri Dreams, Jul. 17, 2015

Directed Energy Approach

- The problem
  - Voyager 1 travels at 17 kilometers / sec, at that speed would take 70,000 years to reach Proxima Centauri, nearest star to us
  - Interstellar ship needs speed of at least 10,000 kilometers / sec (3.3% speed of light)
- Advantages of directed energy approach
  - Spacecraft does not need to carry propulsion system which leads to smaller vehicle
  - Can launch any size of sail driven ship - but the larger the ship, the lower the velocity
  - Low cost, reusable launcher
  - Solidly grounded in current science + technology
- Wafersat - Directed Energy Propulsion for Interstellar Exploration project
  - 10 cm in size probe, weighs 1 gram (weight of paperclip), has 1 meter sail
  - Use 50 million, 1 kilowatt laser amplifiers, each weighing 1 kilogram, which are launched into orbit + joined into scalable laser array 10 kilometers long
  - Photons from laser are projected onto sail, boosting probe to 60,000 kilometers / sec (20% speed of light)
  - Could reach Alpha Centauri in 20 years
  - Could launch a new wafer every few minutes

  - Michael Peck, Proxima Centauri by 2099, Aerospace America, April 2016

"There will certainly be no lack of human pioneers when we have mastered the art of flight… Let us create vessels and sails adjusted to the heavenly ether, and there will be plenty of people unafraid of the empty wastes. In the meantime, we shall prepare for the brave sky-travelers maps of the celestial bodies. I shall do it for the moon, you Galileo, for Jupiter."

- Kepler writing to Galileo

Case Study Summary - Breakthough Starshot

- Goal
  - Create a practical starship today to go to Alpha or Proxima Centauri star systems 4.37 light years away in ~ 20 years at 20% light speed, pass within 1 AU (93 million miles) of a habitable planet + image it with 4 megapixel camera array + send image back with a laser
- Center of Gravity (Strategy)
  - Bring Silicon Valley approach to space travel
- Equipment
  - StarChip - fully functional spacecraft on gram scale / postage stamp sized wafer that carries cameras, photon thrusters, power supply, navigation + communication equipment - thanks to Moore's Law
  - Lightsail - 4 meter-scale sail no more than a few hundred atoms thick + at gram scale mass using thin + light-weight metamaterials - thanks to nanotechnology
  - Light Beamer - Phased array of 10 million 10 kilowatt ground-based lasers at high altitude in desert, 1 kilometer in size, powered by solar energy, scaled up to 100 gigawatts - thanks to rising power + falling cost of lasers
  - [Light Beamer doubles as vast + sensitive telescope to receive StarChip's laser transmissions]
- Training
  - Text
- Leadership
  - Yuri Milner is funding it ~ Pete Worden is directing it

- Ross Anderson, Inside a Billionaire's New Interstellar Mission, The Atlantic, Apr. 12, 2016

- Starchip Enterprise, The Economist, Apr. 16, 2016

- Graham Warwick, Starshot Initiative Aimed at Interstellar Nanocraft, Aviation Week, Apr. 15, 2016

Case Study Summary - Breakthough Starshot

- Morale
  - Try to put Robert Forward's theories for StarWisp into practice ~ Much research required
- Tactics
  - StarChip is mass produced at cost of iPhone + sent on missions in large numbers to provide redundancy + coverage
  - Large number of StarChips with their Lightsails are launched into orbit on a mothership, each is then individually accelerated by Light Beamer using adaptive optics over ten minutes to 20% light speed
- Intangibles
  - Will the spacecraft survive the acceleration of 60,000 Gs?
  - Will the spacecraft survive impacts with interstellar dust?
- Mistakes
  - Text
- Outcome
  - Ultimate budget would be $10 billion dollars but each launch would be a few hundred thousand dollars
  - Will spend $100 million on research over 5 years to see if it is possible, launch in 20-25 years

- Ross Anderson, Inside a Billionaire's New Interstellar Mission, The Atlantic, Apr. 12, 2016
- Starchip Enterprise, The Economist, Apr. 16, 2016
- Graham Warwick, Starshot Initiative Aimed at Interstellar Nanocraft, Aviation Week, Apr. 15, 2016

Breakthrough Starshot 2017

- Two Components
  - Nanocraft
    - Starchips - gram scale vehicles
    - Laser/Lightsails - meter-scale sails
  - Photon Engine
    - Gigawatt-scale ground-based laser that propels Nanocraft to approximately 20% speed of light
- Three phases
  - Technology Development
  - Prototype Missions
  - Alpha-Centauri / Proxima-Centauri Missions

Faster Than Light Travel

- Distances
  - Alpha Centauri C (Proxima Centauri) is red dwarf ~ 4.22 light years from Earth = ~ 39.9 trillion km = 3.99 x 10E13 km
  - 1 astronomical unit (AU) ~ 1.5 x 10E08 km
  - 33 years after launch, Voyager 1, fastest moving object ever launched from Earth is ~ 17.4 billion km (116.5 AU) from Sun which is only small fraction of 1% of distance to Alpha Centauri C
- Chemical rockets won't support interstellar travel - we need fuels of much higher energy density
  - Solar sailing, beam propulsion, magnetic sailing, Orion, fusion rocket, Bussard ramscoop
- Why interstellar travel is hard
  - Joule is energy that produces one watt of power for one second
  - Typical nuclear power plant has capacity of 1 gigawatt
  - Kinetic energy of 1 kg mass moving at 1/10th speed of light = energy output of 100 nuclear power plants running at full capacity for 5.2 days

- Edward Lerner, Faster Than a Speeding Photon, Analog, Jan. / Feb. 2012

Journey to the Stars

- Three kinds of propulsion systems for interstellar missions
  - Interstellar vehicles using internal energy sources - carry along their reaction mass, energy source, engine
    - Nuclear fission rocket = NERVA
      - Uses nuclear reactor to thermally accelerate hydrogen atoms to provide thrust
      - Does not produce enough thrust to reach a star in reasonable amount of time
    - Nuclear pulse rocket = Orion
      - Propelled by small nuclear bombs ejected + exploded against heavy-duty pusher plate which absorbs each impulse from hot plasma + transfers it to vehicle through large shock absorbers
      - Would use 300,000 atomic bombs for propulsion, accommodate crew of several hundred, weigh 400,000 tons
    - Fusion-powered interstellar rocked = Daedalus
      - Pellets of helium-3 + deuterium are compressed + heated in combustion chamber inside ship by high-energy electron beams or lasers with resulting fusion reaction powering ship
      - Helium-3 would come from gas giant, deuterium could be mined from Oort cloud
      - Project Icarus - successor to Daedalus + would decelerate when it reached target star
    - Matter + anti-matter to provide energy
      - Antimatter is very rare + difficult to handle

- Nick Kanas, Challenges of Manned Interstellar Travel: An Overview, Analog, May 2015

Journey to the Stars

- Three kinds of propulsion systems for interstellar missions
  - Hybrid interstellar propulsion system
    - Solve major problem that decreases efficiency of internal energy system - the need to take along large amounts of heavy fuel
    - Bussard interstellar ramjet
      - Consists of payload, fusion reactor, large electrical or magnetic scoop to collect charged particles along flight path such as interstellar hydrogen
      - Hydrogen fusion leads to energized helium exhaust to propel ship forward
  - Interstellar vehicles using external energy sources
    - Use momentum of massless light photons from Sun to push against solar sail, moving vehicle in direction of beam
    - No need for heavy intrinsic fuel or engine
    - Beaming system could be monitored + maintained close to home
    - Spaceship would accelerated slowly, larger the payload the larger the sail, so best for uncrewed missions
- Closet stars to us
  - Proxima Centauri (4.2 light years), Alpha Centauri A + B (4.4 light years), Barnard's Star (5.9 light years)

- Nick Kanas, Challenges of Manned Interstellar Travel: An Overview, Analog, May 2015

Journey to the Stars

- Economic considerations
  - Technology for starship would be complicated + expensive
    - Starship with dry mass of 1,000 tons, cruising at 10% speed of light, operating at 100% efficiency with ~ 50 settlers on a trip several decades long would have energy costs of $12.5 trillion (assuming using a fusion reactor using helium-3 + deuterium)
    - Addition of research + development and manufacturing costs raises price to $125 trillion = 1,000 times cost of Apollo program in todays dollars
    - To keep cost of interstellar mission at Apollo levels in proportion to total wealth of humanity (1% of GDP) the spacefaring civilization will need GDP 200 times greater than today + human population of 40 billion

- Nick Kanas, Challenges of Manned Interstellar Travel: An Overview, Analog, May 2015

Journey to the Stars

- Psychological + Social Issues
  - Selection issues - Who wants to go? Who could go? How much diversity is there?
  - Feelings of isolation + loneliness in deep space
  - Earth-out-of-view phenomenon
  - Lack of novelty + social contacts in deep space
  - Dealing with monotony + leisure time through meaningful activities + habitability design
  - Autonomy from Earth + over-dependence on on-board resources
  - Dealing with mental + medical issues in confined space
  - Unknown physical + psychological effects of radiation when traveling at near-relativistic speeds
  - Starship environment - sustainable resources, artificial gravity, population control
  - Intolerance of diversity - cultural, religion, language differences
  - Feelings of homesickness in first generation
  - Dealing with myths + folklore of Earth in later generations
  - Keeping the original settlement goals
  - Dealing with criminals + sociopaths in small social network
  - Psychological + ethical effects of social engineering - regulating reproduction
  - Psychological + medical issues related to suspended animation

- Nick Kanas, Challenges of Manned Interstellar Travel: An Overview, Analog, May 2015

Journey to the Stars

- Suspended animation
  - Ability to freeze + then thaw complete organ systems + whole bodies composed of differentiated cells with different freeze-thaw rate profiles beyond our abilities
- Once you get there - 3 stages of organization following a migration
  - Pioneering phase - 2 to 4 years - new settlement experiences tension + factionalism over issues related to physical survival
  - Consolidation phase - settlement crystallizes + formalizes social institutions + associations with sense of group solidarity developing
  - Stabilization - ways of resolving disagreements are established, settlement continues to develop in ways not directly related to resettlement, often old social class structure reestablishes itself

- Nick Kanas, Challenges of Manned Interstellar Travel: An Overview, Analog, May 2015

Problems With Interstellar Flight

- Sheer size of universe
  - Tau Ceti, 12 light years away, is 100 billion times farther from Earth than our moon
  - It would take centuries to get there, spaceship is too impoverished an environment to support humans over that time period, must use space ark that could support community of humans + plants / animals in a fully recycling ecosystem
- Size of ark
  - Needs to be small enough to accelerate to fairly high speed to shorten voyage time to decrease cosmic radiation exposure + ark breakdowns, but being small creates problems for resource metabolic flow + ecologic balance
  - If it is big it it harder to accelerate + has to carry more fuel for it to slow down at destination
- Biological problems
  - Our microbiome (80%) of DNA in our bodies co-evolved with us on Earth's surface influenced by Earth's gravity, magnetic field, chemical make-up, atmosphere, insolation, bacterial load - how do we replace them?
- Sociological + psychological problems
  - Descendants of first generation did not volunteer for this small space
  - Government would have to be totalitarian - reproduction + work would not involve free choice
  - Permanent enclosure, exile from planetary surface, probability of health problems can lead to mental illness
- Problems at new planet
  - If there is indigenous life, would trying to live in contact with it be fatal?
  - If there is no indigenous life, you will have to terraform it using local resources + power over centuries while hoping the ark keeps working

- Kim Stanley Robinson, What Will It Take for Humans to Colonize the Milky Way?, Scientific American, Jan. 13, 2016

Show Me Your Business Plan

- From 1405 - 1433 Zheng He led massive naval expeditions from China to Mecca + Mobasa with more than 300 vessels and 28,000 crew - far larger than Columbus 50 years later
- Extremely expensive, technically sophisticated, unprecedented in national commitment, these voyages may serve as analog to cost, effort + risk required for interstellar voyages
- Ming government - especially emperor - backed Zheng for decades even though voyages were not sensible use of time, money, effort
- In 1433 Ming bureaucrats finally convinced elite that voyages did not make economic sense + they were stopped
- In 1978 economist Paul Krugman laid out basic economics of interstellar trade - to justify the cost starfarers must bring back something worth more than what they would have earned by putting same money in interest-bearing account + staying on Earth (= compound interest)
- Lesson of Zheng He is exploration of distant lands will be short-lived unless it yields something really, really valuable

- Charles Mann, The Tricky Ethics of Intergalactic Colonization, Wired, Nov. 2014

Risks / Benefits of Exploration

One could look at Christopher Columbus as a failure: "His business model did not pan out: no Western route to Asia, hardly any gold, abandonment by his investors, not much of an enduring first-mover advantage for Spain... but he f*cking discovered America"

- Kurt Andersen, Inside Magazine

How Much Could Be Spent to Go To The Stars?

- Over time, the world's economy grows
- G7 countries spend average of 0.1% of their Gross Domestic Product (GDP) on spaceflight, the US spent 0.4% of its GDP on the Apollo program
- Mission costs
  - Daedalus-class ~ $100 trillion
  - Budget Daedalus ~ $20 trillion
  - Orion ~ $65 billion
- These missions would be economically feasible in 21st to 24th centuries

- Paul Gilster, The Cost of Interstellar Flight, Centauri Dreams, Oct. 22, 2014

Columbus, Magellan, and Mars

- Sending humans to Mars has some parallels to earlier human voyages
- Trip time important - drives water / food / oxygen consumption by crew, duration of exposure to microgravity environment + space radiation dosages, evolution of crew interpersonal relations + psychology
- One way trip times

Today	For Columbus
Launch to LEO - 10 minutes	Left port
Launch to ISS - 6 hours	½ way to Gibraltar
LEO to GEO - 12 hours	All way to Gibraltar
LEO to Moon - 3-5 days	Canary Islands
LEO to Mars - 6 months	Spain to Philippines via Cape Horn, back to Spain, back to Philippines

- For Columbus, Canary Islands were forward base
- When Magellan went to Philippines he had crew of 237 men on 5 ships - only 1 ship + 18 men survived and returned home

- Rex Ridenoure, The Earth, Moon, Mars, and Christopher Columbus, The Space Review, Mar. 9, 2015

Arctic Voyages as Analogs for Mars Exploration

- Journey to Mars + back would take 3 years

"Future space expeditions will resemble sea voyages much more than test flights, which have served as models for all previous space missions" - Jack Stuster, Bold Endeavors

- How can you maintain crew productivity in cases of prolonged isolation + confinement? How can crew maintain focus / avoid rancor?
- By studying voyages of discovery, Stuster learned:
  - Crews united by special spirit of expedition exceled
  - Praised Nansen's Fram expedition to Arctic in 1893 for planning, crew selection, morale
  - Careful habitat design + crew compatibility could avoid psychological + interpersonal problems
  - Artificially impose diurnal cycle of light + dark to avoid insomnia
  - Monotony + boredom can be threat to expedition's well-being - mind grows stressed + makes mistakes
  - Trivial annoyances can grow unbearable
  - Before humans go to Mars, they should be run through high fidelity mission simulations in remote environment to stress them

- Tom Kizzia, Moving to Mars, New Yorker, April 20, 2015

Arctic Voyages as Analogs for Mars Exploration

- Hawaii Space Exploration Analog and Simulation
  - 9 month test, 3 men + 3 women, live in 1200 square foot dome with kitchen, exercise area, sleeping quarters
  - Water rationed to 1 brief shower / week, keep in touch with mission control by computer with 20 minute time lag in each direction, leave dome only on EVA, dome has porthole
- Time lag is argument against robots - time lag means you need a crew that works well in isolation, without mission control
- Stuster has found ISS astronauts are irritated by mission control's overscheduling, patronizing requests, pointless-seeming tasks
- Need to change from mission control to mission support
  - If humans in space could be monitored like robots, mission support could spot emotional cliff coming before astronauts stumbled over it

- Tom Kizzia, Moving to Mars, New Yorker, April 20, 2015

Case Study Summary - Voyage of HMS Challenger 1872 - 1876

- Goal
  - Victorians recognized the importance of the oceans + felt need to document it
- Center of Gravity (Strategy)
  - Journey into unknown - undertake a voyage akin to the Apollo trips to the moon
- Equipment
  - Royal Navy corvette HMS Challenger, 200 feet long, sail + steam powered, outfitted with laboratories
  - Crew was 21 officers, 216 crew (61 of which deserted), 5 scientists, 1 artist
  - Royal Society got British government to finance expedition for 20,000 pounds (~ 10 million pounds today)
- Training ~ Leadership ~ Morale
- Tactics
  - Spent half time in port, half time at sea
- Intangibles ~ Mistakes
- Outcome
  - Led to birth of oceanography as multidisciplinary subject
  - Discoveries made - first maps of ocean currents + sea temperatures, first geological maps of sea floor, underwater mountain ranges (Mid Atlantic Ridge), deepest part of ocean (Marianas Trench), thousands of new species, animals live at all depths in oceans
  - Published 50 volumes of reports over 20 years

\- The HMS Challenger Expedition, Exploring Our Oceans course, FutureLearn, 2014

Case Study Summary - Fram Arctic Expedition 1893 - 1896

- Goal
  - Reach geographical North Pole
- Center of Gravity (Strategy)
  - Harness natural east to west current of Arctic Ocean
  - Freeze ship in pack ice, use transpolar drift to reach North Pole
- Equipment
  - Fram had rounded hull designed to withstand pressure from ice + float above it
  - 128 feet long, 12 crew, powered by sail + engine, provisions for 5 years, crew area insulated, windmill to provide electricity for lamps
- Training
- Leadership
  - Fridtjof Nansen
- Morale
  - Excellent
- Tactics
  - Use native expertise in regards to methods of travel
  - After 18 months became inpatient with transpolar drift so tried to make it to North Pole on dog sledges
- Intangibles
- Mistakes
- Outcome
  - Failed to reach North Pole
  - Scientific observations contributed to new science of oceanography
  - Confirmed polar region was deep ice covered sea without land masses
  - North Pole is on ice, not on land

- David Shukman, Voyage to the North Through Ramparts of Ice, BBC News, May 5, 2015

Case Study Summary - British National Antarctic Expedition 1901-1904 = Discovery Expedition

- Goal
  - Carry out scientific research + geographical exploration on untouched continent of Antarctica
- Center of Gravity (Strategy)
  - Sail to Antarctica + establish a base, travel from there around continent via land
- Equipment
  - RRS Discovery - last wooden 3-masted sailing ship built in Britain, designed to work in ice
  - Observation balloon for aerial surveys
  - Planned resupply ship one year into voyage
- Training ~ Leadership ~ Morale
  - Captain Robert Falcon Scott RN, Ernest Shackleton
  - Co-sponsored by Royal Society, Royal Geographic Society, Royal Navy
  - Tension between scientific work vs. naval adventure led to resignation of first scientific director + therefore a weak scientific team leading ultimately to long term disputes over accuracy of some of expedition's data
- Tactics
  - Walked all over continent - preferred to manhandle sledges
- Intangibles
  - Scurvy
  - Got stuck in ice for 2 years, needed expensive relief mission to free them
- Mistakes
  - Unable to master techniques of efficient polar travel using skis + dog sledges
- Outcome
  - Made important geological + zoological discoveries
  - Traveled to 82 degrees 18 minutes furthest South
  - Launched Antarctic careers of leading figures of Heroic Age of Antarctic Exploration
  - RRS Discovery was namesake of spaceship Discovery in 2001: A Space Odyssey

Surgery During Antarctic Exploration

- During heroic age of Antarctic exploration there were 18 exploration / scientific expeditions to Antarctic
  - 14 expeditions took doctors who performed 11 surgical procedures with general anesthesia + many other surgical procedures were done with local anesthesia or no anesthesia
  - Doctors often had little training + experience
  - Surgical conditions were makeshift
- When planning medical care for expedition, consideration needs to be given to fact that doctor is as likely to become ill or injured as any other expedition member

- HR Guly, Surgery and Anesthesia During the Heroic Age of Antarctic Exploration (1895-1922), BMJ 2013; 347:f7242

Computing Case Study Summary - Star Trek

- **Date**
  - USS Enterprise in The Original Series / The Animated Series - Early 23rd century
- **Goal**

  "Deep in the heart of this ship are our computer banks. They operate the entire ship. They also contain the whole of human + humanoid knowledge. They are indisputably reliable. Our lives depend on them."
- **Center of Gravity (Strategy) [Deliver results in]**

  "In a matter of a few seconds, we can obtain an answer to any factual question, regardless of its complexity."
- **Technology / Equipment**
  - Data center 1,900 square meters
- **Training ~ Leadership ~ Morale**

- Schmucker KJ, Tarr RM, The Computers of Star Trek, Byte, December 1977

Computing Case Study Summary - Star Trek

- Tactics [Interface]
  - Unrestricted conversational voice input / output
  - Automatic programming in natural language
  - Computer analysis of complex, ill defined problems
    - Semantic comprehension of natural language ~ Computer understanding of the meaning of a statement ~ Has an English compiler which can accept + correctly process unrestricted English
- Intangibles [Indexes]
  - Indexes everything - cached copy of United Federation of Planets knowledge because transmission speed in space via subspace radio is too slow
  - Estimated to be 10^{22} bits = 10^{14} volumes, each volume = 1,000 pages => 10^{17} pages - each page is 1,000 words => 10^{20} words - each word is 6-8 letters =>10^{21} words => each word represented by 8 bits => 10^{22} bits
- Mistakes
  - Computer security still a problem
- Outcome
  - Works quite well

- Schmucker KJ, Tarr RM, The Computers of Star Trek, Byte, December 1977

Personal Case Study - To Change the World You Must Leave NASA

- **Role**
  - **Participant in NASA Pillars of Biology Initiative - Biomedicine Workshop in 1998 at Manned Space Flight Center**
- **Story**
  - **Presentation on TransHab inflatable space station by Horacio de la Fuente**
  - **"These (TransHab) guys are the future of NASA" - NASA employee**
  - **2 years later Congress bans NASA from further developing TransHab to eliminate a competitor to delayed + over cost International Space Station**
  - **Bigelow Aerospace purchased technology from NASA, launched prototype commercial space stations / hotels into orbit, they are awaiting their first guests + in 2015 will install a module on International Space Station**

From Wikimedia Commons

- Dan Schrimpsher, Interview With TransHab Developer William Schneider, The Space Review, Aug. 21, 2006

Personal Case Study - Almost As Good As The Sims / That Wasn't In The Sims

- **Role**
  - **Participant in NASA Pillars of Biology Initiative in 1998 at Johnson Space Center**
- **Story**
  - **Tour of NASA's training and simulator facilities**
    - **They can simulate anything and everything!**

Personal Case Study - Blockhouse Lite

- Role
  - Visitor at Air Force Space and Missile Museum, Cape Canaveral
- Story
  - Volunteer told me she had been inside SpaceX headquarters next door
    - Described employees as being young kids dressed in hoodies who launch their rockets off of laptops

Personal Case Study - Michael Barratt, M.D.

- Role
  - Astronaut and Physician
- Story
  - Long term effect of space travel on human body - Microgravity induced intracranial hypertension
    - In males older than 45 years, long term exposure to spaceflight of greater than several months leads to idiopathic intracranial hypertension which leads to vision impairment for reasons we don't know. This could affect ability of individuals to go on longer duration flights

From NASA

- Rich Phillips, Astronaut feels space's toll on his body, CNN, Feb. 13, 2012

- Prolonged Space Travel Causes Brain and Eye Abnormalities in Astronauts, Astrobiology Magazine, Mar. 16, 2012

Astrobiology Analog Case Study - Cold Faithful

- Location
  - Yellowstone National Park
- Story
  - Old Faithful Geyers
  - Analog to cryovolcanism on Enceladus

Astrobiology Analog Case Study - Name

- Location
  - Craters of the Moon National Park
- Story
  - Hiking through lava tubes
  - Analog to caves on Mars

Drake Equation

$$N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

- N = The number of communicative civilizations
- R* = The rate of formation of suitable stars (stars such as our Sun)
- fp = The fraction of those stars with planets. (Current evidence indicates that planetary systems may be common for stars like the Sun.)
- ne = The number of Earth-like worlds per planetary system
- fl = The fraction of those Earth-like planets where life actually develops
- fi = The fraction of life sites where intelligence develops
- fc = The fraction of communicative planets (those on which electromagnetic communications technology develops)
- L = The "lifetime" of communicating civilizations

Class Simulation

- Topic aspects

Poem

Slide text

Questions for Further Discussion

- Where should we send future astrobiology missions?
- What are the advantages + disadvantages of crewed + uncrewed spaceflight?
- How should we conduct future astrobiology missions - crewed or uncrewed - and why?
- Is humankind's destiny in space?
- Should we back up humanity to space?
- Why is it that the same people who believe we can live off-Earth tend to believe we can't live on it?
- Should we travel to the stars? If yes, how would you propose to do it?

Reading Assignments

- Astrobiology Primer 2.0 (2016) Chapter
  - https://doi.org/10.1089/ast.2015.1460
- TED Talks for this Topic
  - http://www.astrobiologysurvey.org/ToLearnMore.html

Recommended Reading to Learn More

- Non-fiction
  - Robert McCall and Isaac Asimov - Our World in Space
  - Gerard O'Neill - The High Frontier
- Fiction
  - Arthur C. Clarke - 2001: A Space Odyssey
- Movies
  - 2001: A Space Odyssey
- Simulations

Conclusion

"Far better it is to dare mighty things, to win glorious triumphs, even though checkered by failure, than to rank with those poor spirits who neither enjoy nor suffer much, because they live in the gray twilight that knows not victory nor defeat."

- President Theodore Roosevelt

Conclusion

"When an elderly but distinguished scientist says something is possible, he's more than likely right; when he says something is impossible, he's almost certainly wrong"

- Arthur C. Clarke, author

"Any sufficiently advanced technology is indistinguishable from magic"

- Arthur C. Clarke, author

Conclusion

"Exploration is in our nature. We began as wanderers, and we are wanderers still. We have lingered long enough on the shores of the cosmic ocean. We are ready at last to set sail for the stars."

- Carl Sagan, planetary scientist

Conclusion

"Given ships or sails adapted to the breezes of heaven, there will be those who will not shrink from even that vast expanse. Therefore, for the sake of those who attempt this voyage, let us establish the astronomy..."

- Johannes Kepler, astronomer, in Dissertatio cum Nuncio Sidereo (1610)

Topic 11

The Arts in Astrobiology

En plein vac

Song

Starry, starry night
Paint your palette blue and gray
Look out on a summer's day
With eyes that know the darkness in my soul

Shadows on the hills
Sketch the trees and the daffodils
Catch the breeze and the winter chills
In colors on the snowy linen land

Now I understand
What you tried to say to me
And how you suffered for your sanity
And how you tried to set them free

They would not listen, they did not know how
Perhaps they'll listen now
- Don McLean, Vincent (Starry, Starry Night)

Thematic Quote

"We've been so slow to realize these things. It's kind of been a failure of imagination. Scientists don't go off and think completely wild and crazy things unless they have some evidence that leads them to that. It's almost like our contract says that we're not supposed to do that. Science fiction writers can get as crazy as they want, but we can't get too crazy or we'll wreck our reputations."

- Carolyn Porco, planetary scientist

Thematic Quote

"By limiting interpretations or placing blinders on our telescopes, we risk missing discoveries…The scientific community's prejudice or closed-mindedness - however you want to describe it - is particularly pervasive and powerful when it comes to the search for alien life, especially intelligent life. Many researchers refuse to even consider the possibility that a bizarre object or phenomenon might be evidence of an advanced civilization."

"Extraordinary conservatism keeps us extraordinarily ignorant."

- Avi Loeb, astronomer, in Extraterrestrial

Thematic Quote

"Science is my territory, but science fiction is the landscape of my dreams."

- Freeman Dyson, physicist

The Painting

The Starry Night

- Vincent van Gogh

(Museum of Modern Art)

Artifact

- Name
  - Books illustrating the art of Alan Bean, Chesley Bonestell, and Robert McCall
- Year
  - 1940's -> present
- Story
  - Inspiration of things that were and things to be

The Question

What is the role of the artist in astrobiology?

Focused Case Study - Artist as Visionary / Futurist - Chesley Bonestell

- Architect - helped design Chrysler Building + Golden Gate Bridge
- Matte artist - Citizen Kane
- Special effects artist - Destination Moon
- Illustrated Willy Ley's Conquest of Space + Beyond the Solar System and von Braun's Collier's space series
- Turned blueprints into romantic visions of space travel + space destinations
- Always step ahead of space program
  - Showed us Earth from orbit, surfaces of planets + moons with astonishing accuracy

Bonestell was "the original Kilroy - he's been there ahead of all of them. Tranquility Base was established over Bonestell's tracks and discarded paint tubes."

- Werner von Braun

"Chesley Bonestell's pictures…are far more than reproductions of beautiful ethereal paintings of Worlds Beyond. They present the most accurate portrayal of these faraway heavenly bodies that modern science can offer."

- Werner von Braun

- A.R. Hogan, Chesley Bonestell, Ad Astra, July/August 1991

- Phil Patton, To the Moon Chesley, Esquire, January 1992

- Ron Miller, Chesley Bonestell's Astronomical Vsion, Scientific American, May 1994

"No artist had more impact on the emerging popular culture of space in America than Chesley Bonestell. Bonestell did for space what Albert Bierstadt and Thomas Moran had accomplished for the continental frontier. Like Bierstadt and Moran, Bonestell transported viewers to places they had never been before…Through his visual images, he stimulated the interest of a generation of Americans and showed how space travel would be accomplished."

- Howard E. McCurdy, Space and the American Imagination

Focused Case Study - Artist as Illustrator - Robert McCall

- Loved aviation
- Influenced by science fiction pulp magazines
- In US Army Air Corps in World War II
- After art school became advertising artist and then became magazine illustrator
- Joined USAF Art Program
- Felt space was frontier of aviation so joined NASA Art Program
- Then moved to future, illustrating movie 2001: A Space Odyssey and never looked back

\- Biography, McCallStudios.com

Focused Case Study - Artist as Recorder - Alan Bean

- Had the Right Stuff - Navy fighter pilot + test pilot
- Lunar Module Pilot on Apollo 12 (Three Friends Go To The Moon), 4th man to walk on the moon
- Attended art school at night
- Commander Skylab 3, lived in space for 59 days
- Returned from space to paint what he had seen on the Moon
- Works the canvas with his lunar geology tools + boots and adds moondust to them
- A modern-day Frederic Remington or Charles Russell
- An artist who experienced the frontier he painted…an artist who painted this generation's frontier of space

  "I feel that I am not an astronaut who paints but rather an artist who was once an astronaut" - Alan Bean

- Karen Geeting, Alan Bean: The Human Dimension of Outer Space, Southwest Art, No. 1984, pp.90-95

Focused Case Study - Digital Artist - Michael Benson

- Selects images from NASA spacecraft of planets and moons
  - Stitches them together to created larger landscapes, digitally enhances them, renders them into color, composites them
- Sees himself as curator of spacecraft images

"The visual legacy of 50 years of interplanetary spaceflight constitutes a significant chapter in the history of photography, not just science."

- Michael Benson

- Published in Beyond: Visions of Interplanetary Probes

- Michael Benson, A Space in Time, The Atlantic, Jul./Aug 2002

- Michael Benson, Celestial Sightseeing, Smithsonian, July 2003

- Steven James Snyder, The Cosmos in Living Color: Michael Benson's Interstellar Imagery, Time, Oct 11, 2012

Focused Case Study - Hubble Heritage Project

- From Space Telescope Institute
- Mission statement

  "The Hubble Heritage Project sees this instrument also as a tool for extending human vision, one that is capable of building a bridge between the endeavors of scientists and the public. By emphasizing compelling HST images distilled from scientific data, we hope to pique curiosity about our astrophysical understanding of the universe we all inhabit."
- Raw images from Hubble use gray scale + have artifacts
- Project selects images, cleans them up + combines them with images taken at different wavelengths to create color images with some artistic touches so they look right
  - May even acquire new data to improve the image

    - Hubble Heritage Project, Hubble Heritage Information Center

Focused Case Study - UnmannedSpaceflight.com

- Community of space enthusiasts who make the most of image archives of uncrewed space missions by reprocessing them and sharing them
- Sponsored by the Planetary Society

Focused Case Study - NASA Art Program

- Established in 1962 to record history of space exploration through eyes of artists

  "Important events can be interpreted by artists to provide unique insight into significant aspects of our history-making advances into space. An artistic record of this nation's program of space exploration will have great value for future generations and may make a significant contribution to the history of American art."

  - James Webb, NASA Administrator

- Contains thousands of art works by hundreds of artists in all mediums

Focused Case Study - Illustrator of Exploration - Walt Disney + Werner Von Braun

- Collier's magazine published Werner von Braun's blueprint for space exploration from 1952-1954 as a series entitled "Man Will Conquer Space Soon"
- Disney turned this into 3 animated films in 1955-1957: Man in Space, Man and the Moon, Mars and Beyond
- By the time of Apollo, Americans had <u>already</u> been to the Moon via Disney

Focused Case Study - Storyteller of Exploration - Walter Cronkite

- "Most trusted man in America" - "Uncle Walter"
- Journalist for United Press in WWII
- Makes jump to CBS TV in 1950
- Daredevil - raced sports cars
- Realized Apollo program was story of his lifetime + immersed himself in it + befriended astronauts and brought country along with him
- Shed a tear on air when Apollo 11 landed
- Only non-NASA recipient of a Moon-rock award

Focused Case Study - Storyteller of Science - Carl Sagan

- Ph.D. in astronomy, Professor at Cornell University
- Intelligent / flamboyant / controversial as young scientist on early uncrewed missions to other planets
- Realized the public needed to be educated about science - started appearing on Tonight Show with Johnny Carson to explain science - "billions and billions"
- Greatest gift was Cosmos - the book + television series to explain how the cosmos works and Contact - the novel + movie to explain how science works

Focused Case Study - Science Fiction Pulps

- Hugo Gernsback
  - Founded first magazine devoted to science fiction - Amazing Stories in 1926
  - Premier award in science fiction is the Hugo
- Astounding Stories started in 1930, now is Analog Science Fiction & Fact
  - Edited by John W. Campbell, launched careers of Asimov, Heinlein, etc.
- Importance of science fiction is that it provides a vision for us to strive towards, identifies problems that need to be overcome to achieve the vision, and creates and tests possible solutions to those problems
- First US astronauts admired and were influenced by it

What is the Universal Appeal of Star Trek?

Its optimistic view of the future:

- Mankind survives by getting along on Earth
- Model is generalizable to the universe

Mr. Roddenberry's belief (was) that "When human beings get over the silly little problems of racism and war, then we can tackle the big problems of exploring the universe."

- David Gerrold, author

Case Study Summary - Mission

- Goal
- Center of Gravity (Strategy)
- Equipment
- Training
- Leadership
- Morale
- Tactics
- Intangibles
- Mistakes
- Outcome

Computing Case Study Summary - Photoshop

- Goal
  - Democratize access to raster graphics editing
- Center of Gravity (Strategy)
  - Create a raster graphics editor for personal computers
- Technology / Equipment
  - Photoshop 1.0 raster graphics editor released in 1990 for Macintosh
- Training
- Leadership
  - Thomas Knoll (PhD student at University of Michigan) + John Knoll (at Industrial Light and Magic)
- Morale
- Tactics
  - Plug-ins extend functionality
- Intangibles
- Mistakes
- Outcome
  - Roots of image processing come from Jet Propulsion Laboratory who developed first editing tools for use on data from early interplanetary missions in 1960's - 1990's - VICAR software
  - Photoshop provided these tools to everyone
  - Today enables work of artists at UnmannedSpaceflight.com + Michael Benson who process current + reprocess past NASA data

Personal Case Study - Alan Bean

- Role
  - Only person who walked on the moon that became an artist
- Story
  - In 1981, as a college freshman, I tried to purchase a painting from his studio. At $10-15,000 it was too expensive for me
  - Today, one of his paintings from his studio sells for $100-400,000

Astrobiology Analog Case Study - Name

- Location
- Story

Drake Equation

$$N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

- N = The number of communicative civilizations
- R* = The rate of formation of suitable stars (stars such as our Sun)
- fp = The fraction of those stars with planets. (Current evidence indicates that planetary systems may be common for stars like the Sun.)
- ne = The number of Earth-like worlds per planetary system
- fl = The fraction of those Earth-like planets where life actually develops
- fi = The fraction of life sites where intelligence develops
- fc = The fraction of communicative planets (those on which electromagnetic communications technology develops)
- L = The "lifetime" of communicating civilizations

Class Simulation

- Topic aspects

Poem

"There's not the smallest orb which thou behold'st

But in his motion like an angel sings,

Still choiring to the young-eyed cherubins.

Such harmony is in immortal souls…"

- Lorenzo in The Merchant of Venice by Shakespeare

(The Music of the Spheres)

Questions for Further Discussion

- How detached should the artist be from their subject in astrobiology?
- How has astrobiology affected artists of the period?
- How has art served as a propaganda tool to help spread the cause of astrobiology?
- Has planetary imagery from uncrewed space probles lessened the need for space art?
- What are the ways that astrobiology influences and is influenced by culture?

Reading Assignments

- Astrobiology Primer 2.0 (2016) Chapter
  - https://doi.org/10.1089/ast.2015.1460
- TED Talks for this Topic
  - http://www.astrobiologysurvey.org/ToLearnMore.html

Recommended Reading to Learn More

- Non-fiction
- Fiction
- Movies
- Simulations

Conclusion

"Tell me, I'll forget. Show me, I may remember. But involve me and I'll understand."

- Chinese proverb

Conclusion

"The astronomical artist will always be far ahead of the explorer. They can depict scenes that no human eye will ever see, because of their danger, or their remoteness in time and space."

-Arthur C. Clarke, author

Conclusion

"Art bookends science"

- Loren O'Laughlin

(Art can inspire at the beginning of the process and help package science in culturally appealing ways)

Topic 12

Astrobiology and the Divine

Astrotheology

Song

- Johannes Kepler, Harmonices Mundi (Harmony of the World)

(Pythagoreans felt distances between the planets would have the same ratios as produced harmonious sounds in a plucked string. Solar system was ten spheres revolving in circles about a central fire, each sphere gives unique sound - closer spheres gave lower tones while farther spheres gave higher tones. All sounds combined together into the music of the spheres, a divine music)

Thematic Quote

"An age is called Dark not because the light fails to shine, but because people refuse to see it."

- Professor Karl Anderssen in Space by Michener p. 709

"Space exploration leads directly to religious and philosophical questions."

- Carl Sagan in The Cosmic Question

"Not really, though it depends, of course, on your religious views."

- Albert Einstein on being asked whether science + religion conflict

"Science is the work of God, engineering is the work of man."

- Bruce Murray, planetary scientist

The Painting

The School of Athens

- Raphael

(Vatican)

Artifact

- Name
  - Music of the Spheres
- Year
  - Ancient Greece
- Story
  - The sound of the universe according to Pythagoras

The Question

How do you reconcile the latest astrobiology discoveries with your religious beliefs?

Are they compatible or not?

The Question

"If God created this fertile universe, how could he limit life to just the grain of sand we call Earth?"

- George Coyne, Director of Vatican Observatory + Jesuit Priest

How Can a Priest Teach Evolution…

…given Genesis says God made the world in 7 days

"Genesis is a beautiful story. It it is not science.

There can be no science in any of the holy books. Modern science began let's say with Gallileo.

The scriptures were written between 5,000 years before Christ and 200 years after Christ.

How could there be any science? There is 1500 years if not 2 millenia between the closing of the book of scripture and science."

- George Coyne, Director of Vatican Observatory + Jesuit Priest

Timeline of Universe

- If 13.7 billion year old universe is compressed into 1 year
  - Human beings came to be 2 minutes before midnight on December 31st
  - Jesus Christ was born 2 seconds before the end of the year
  - Galileo is born 1 second before end of the year
  - God has only spoken to man for 2 seconds in a 14 billion year old universe

- George Coyne, Director of Vatican Observatory + Jesuit Priest

Why is the Church Suspicious of Evolution?

- If it is really true God is losing control - God is not important
  - But he feels God does not want to be in control
  - Religion feels that because of scientific theories - especially evolution - we are not going to need God
  - But if you are a believer, an evolutionary universe tells you about a magnificent God
    - A God that created a dynamic, creative universe that he is working alongside

- George Coyne, Director of Vatican Observatory + Jesuit Priest

SETI and Religion

"SETI does share some traits with religion. It is motivated by deep human desires for connection and transcendence. It concerns itself with questions about human origins, about the raw creative power of nature, and about our future in this universe-and it does all this at a time when traditional religions have become unpersuasive to many."

- Ross Andersen, What Happens if China Makes First Contact?, The Atlantic, Dec. 2017

The Tension

- SETI is guided by 3 principles
  - Nature's uniformity
    - Physical processes found on Earth are found throughout Universe, so processes that produce life on Earth produce life everywhere
  - Plentitude
    - Everything that is possible will be realized, so life will form as long as there are no impediments to life forming

    "The origin of life on suitable planets seems built into the chemistry of the Universe" - Carl Sagan
  - Mediocrity
    - There is nothing special about Earth's status or position in Universe

    "We find that we live on an insignificant planet of a humdrum star lost in a galaxy tucked away in some forgotten corner of a universe in which there are far more galaxies than people" - Carl Sagan
- Faith tells a believer that humans are the crowning achievement of God's creation
  - The discovery of intelligent aliens would cause us to question our uniqueness in the Universe and thus to question our faith, like Copernicus did with his discovery of heliocentric solar system

- Brandon Ambrosino, If We Made Contact With Aliens How Would Religions React?, BBC Future, Dec. 16, 2016

SETI and Theology

- SETI provides a means of gaining a better perspective on our place in the universe, which is consistent with theological goals

"As a theologian, I would say that this proposed search . . . is also a search of knowing and understanding God through His works -- especially those works that most reflect Him. Finding others than ourselves would mean knowing Him better."

- Father Theodore Hesburgh, CSC, President Emeritus of the University of Notre Dame

"What is interesting for man is to know both his importance and that this importance should not be built up on the basis of illusions of uniqueness and absoluteness."

- Krister Stendahl, Bishop of Stockholm

Belief in Extraterrestrial Life by Religion

- 55 percent of Atheists
- 44 percent of Muslims
- 37 percent of Jews
- 36 percent of Hindus
- 32 percent of Christians
  - 41 percent of Eastern Orthodox faithful
  - 37 percent of Roman Catholics
  - 37 percent of Methodists
  - 35 percent of Lutherans
  - 29 percent of Baptists
- Buddhist cosmology includes thousands of inhabited worlds

- Are the World's Religions Ready for E.T.?, Astrobiology Magazine, Oct. 4, 2014

Young Earth Creationism

- A literal interpretation of the account of the creation of the Earth as told in the Book of Genesis, the first book in the Bible
- Believes heavens + Earth created by God in 6 days
- Use biblical genealogies to determine age of Earth which is ~ 6,000-10,000 years old

American's Views on Creation + Evolution

- 46% believe in creationism
- 32% believe in evolution guided by God
- 15% believe in atheistic evolution

- Over the past 30 years creationism has been most popular answer with 40-47% of Americans believing in it

- Gallup Poll 2012

US Public's Views On Human Evolution

- **60% of US adults say that humans and other living things have evolved over time**
  - **32% of US adults say that humans and other living things have evolved over time and that evolution is due to natural processes**
  - **24% of US adults say that humans and other living things have evolved over time and that a supreme being guided evolution**

- **43% of Republicans + 67% of Democrats say that humans and other living things have evolved over time**

- Public's Views on Human Evolution, Pew Research Religion & Public Life Project, 2013

Evolution and the Future

"Denial of evolution is unique to the United States."

"The idea of deep time of billions of years explains so much of the world around us. If you try to ignore that, your worldview becomes crazy, untenable, itself inconsistent."

"I say to the grownups, if you want to deny evolution and live in your world, that's completely inconsistent with the world we observe, that's fine. But don't make your kids do it. Because we need them. We need scientifically literate voters and taxpayers for the future. We need engineers that can build stuff and solve problems."

- Bill Nye (The Science Guy), in the video Creationism is not Appropriate for Children

Creationism, Evolution, and Christianity

"The age of the Earth and the rejection of evolution aren't core Christian beliefs. Neither appears in the Nicene or Apostle's Creed. Nor did Jesus teach them. Historical Christianity has not focused on how God created the universe, but on how God saves humanity through Jesus' death and resurrection."

"The "good news" is how God saves us. Not how he created us. "

- S. Joshua Swamidass, Rubio and the Age-of-Earth Question, Wall Street Journal, Nov. 29, 2012

History of Relationships Between Religion and Science - 1

"Some people want to put warning stickers on biology textbooks, saying that the theory of evolution is just one of many theories, take it or leave it. Now, religion long predates science; it'll be here forever. That's not the issue. The problem comes when religion enters the science classroom. There's no tradition of scientists knocking down the Sunday school door, telling preachers what to teach. Scientists don't picket churches. By and large-though it may not look this way today-science and religion have achieved peaceful coexistence for quite some time. In fact, the greatest conflicts in the world are not between religion and science; they're between religion and religion.

This is not simply an academic point. Let's go back a millennium. Between A.D. 800 and A.D. 1200 the intellectual center of the Western world was Baghdad. Why? Its leaders were open to whoever wanted to think stuff up: Jews, Christians, Muslims, doubters. Everybody was granted a seat at the debating table, maximizing the exchange of ideas. Meanwhile, the written wisdom of the world was being acquired by the libraries of Baghdad and translated into Arabic. As a result, the Arabs made advances in farming, commerce, engineering, medicine, mathematics, astronomy, navigation. Do you realize that two-thirds of all the named stars in the night sky have Arabic names? If you do something first and best, you get naming rights. The Arabs got naming rights to the stars twelve hundred years ago because they charted them better than anybody had done before. They pioneered the fledgling system of Hindu numerals in the new field of algebra, itself an Arabic word-which is how the numerals came to be called "Arabic numerals." "Algorithm," another familiar word, derives from the name of the Baghdad-based mathematician who also gave us the basics of algebra.

- Neil deGrasse Tyson, Space Chronicles, 2012

History of Relationships Between Religion and Science - 2

So what happened? Historians will say that with the sack of Baghdad by Mongols in the thirteenth century, the entire nonsectarian intellectual foundation of that enterprise collapsed, along with the libraries that supported it. But if you also track the cultural and religious forces at play, you find that the influential writings of the eleventh-century Muslim scholar and theologian Al-Ghazali shaped how Islam viewed the natural world. By declaring the manipulation of numbers to be the work of the devil, and by promoting the concept of Allah's will as the cause of all natural phenomena, Ghazali unwittingly quenched scientific endeavor in the Muslim world. And it has never recovered, even to this day From 1901 to 2010, of the 543 Nobel Prize winners in the sciences, two were Muslims. Yet Muslims comprise nearly one-fourth of the world's population.

Today among fundamentalist Christians as well as Hassidic Jews, there is a comparable absence. When societies and cultures are permeated by nonsecular philosophies, science and technology and medicine stagnate. Putting warning stickers on biology books is bad practice. But if that's how the game is to be played, why not demand warning stickers on the Bible: 'Some of These Stories May Not Be True.'"

- Neil deGrasse Tyson, Space Chronicles, 2012

Balance Between Scientific Ignorance + Religious Knowledge

"They are assigning scientific ignorance to religious knowledge...but what happens when scientific ignorance goes away because you made a discovery?"

- Neil deGrasse Tyson, astrophysicist

"As we know, there are known knowns. There are things we know we know. We also know there are known unknowns. That is to say we know there are some things we do not know. But there are also unknown unknowns, the ones we don't know we don't know."

- Donald Rumsfeld, US Secretary of Defense

"I believe in (Baruch) Spinoza's God, who revealed himself in the harmony of all being, not in the God who concerns himself with the fate and actions of men"

- Einstein, meaning that he considered God to be the sum total of the physical laws which describe the universe

"Out yonder there was this huge world, which exists independently of us human beings and which stands before us like a great, eternal riddle, at least partially accessible to our inspection and thinking. The contemplation of this world beckoned like a liberation...The road to this paradise was not so comfortable and alluring as the road to the religious paradise; but it has proved itself as trustworthy, and I have never regretted having chosen it."

- Einstein describing his lifelong quest

Einstein's Cosmic Religion

"The human mind, no matter how highly trained, cannot grasp the universe. We are in the position of a little child, entering a huge library whose walls are covered to the ceiling with books in many different tongues. The child knows that someone must have written those books. It does not know who or how. It does not understand the languages in which they are written.

The child notes a definite plan in the arrangement of the books, a mysterious order, which it does not comprehend, but only dimly suspects. That, it seems to me, is the attitude of the human mind, even the greatest and most cultured, toward God.

We see a universe marvelously arranged, obeying certain laws, but we understand the laws only dimly. Our limited minds cannot grasp the mysterious force that sways the constellations."

"I cannot conceive of a God who rewards and punishes his creatures, or has a will of the type of which we are conscious in ourselves. An individual who should survive his physical death is also beyond my comprehension, nor do I wish it otherwise… . Enough for me the mystery of the eternity of life, and the inkling of the marvelous structure of reality, together with the single-hearted endeavour to comprehend a portion, be it never so tiny, of the reason that manifests itself in nature."

"He who can no longer pause to wonder and stand rapt in awe, is as good as dead."

"What is a scientist after all? It is a curious man looking through a keyhole, the keyhole of nature, trying to know what's going on."

- Jacques Yves Cousteau, marine biologist

"Do not go where the path may lead, go instead where there is no path and leave a trail"

- Ralph Waldo Emerson, author

"Genius is 99% perspiration and 1% inspiration"

- Thomas Alva Edison, inventor

"Nothing shocks me. I'm a scientist."

- Indiana Jones

"Nothing is so dangerous to the progress of the human mind than to assume that our views of science are ultimate, that there are no mysteries in nature, that our triumphs are complete, and that there are no new worlds to conquer"

- Humphry Davy, chemist

"Every truth passes through three stages before it is recognized. In the first it is ridiculed, in the second it is opposed, in the third is recognized as self evident."

- Arthur Schopenhauer, philosopher

"First they ignore you. Then they laugh at you. Then they fight you. Then you win"

- Mohandas Gandhi, political leader

"There is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in success, than to take the lead in the introduction of a new order of things…Innovation makes enemies of all those who prospered under the old regime, and only lukewarm support is forthcoming from those who would prosper under the new"

- Niccolo Machiavelli, historian

"The sequence of events described in Genesis is very similar to the sequence of events described by evolutionary biologists. The only thing at issue there is that of the time scale, whether it took place in seven days or whether it took billions of years.

The idea that you have to be a true believer in science or a true believer in the literal interpretation of the Bible, and there is no middle ground-I flatly reject that. I think that a science-based society that has no ethical foundations is doomed. And I think that a Biblical literalist society that pays no attention to science is constantly going to be making gigantic policy errors. I much favor the union of the two."

- John Lewis, planetary scientist

Majority of Humanity Say We Are Not Alone

- Glocalities study on the existence of alien life was completed among 26,492 people from 24 countries:
  - 61% of people believe that there is some form of life on other planets. 17% rule this out and only 22% say that they don't know
  - 47% of people believe in the existence of intelligent alien civilizations in the universe. 26% rule this out and 28% say that they don't know
  - 25% believe that the first form of life on Earth arrived here from another place in the universe. 39% rule this out and 36% say they don't know
  - Of the 47% people who believe that advanced alien civilizations exists, 60% say that humans should try to get in contact with these civilizations. 21% say that we should not try and seek contact and 19% say that they don't know

- Glocalcities, Majority of Humanity Say We Are Not Alone in the Universe, 2017

Effects of First Contact on Religions

- Buddhism - Faith already assumes infinite universe of untold antiquity, its every corner alive with the vibrating energies of living beings
- Hinduism - Cosmos is grand and teeming
- Islam - Koran references Allah's "creation of the heavens and the earth, and the living creatures that He has scattered through them."
- Judaism - God's power has no limits, certainly none that would restrain his creative powers to this planet's cosmically small surface.
- Christianity - Contemporary Christian theology debates whether Christ's salvation extends to every soul that exists in the wider universe, or whether the sin-tainted inhabitants of distant planets require their own divine interventions
- - Ross Andersen, What Happens if China Makes First Contact?, The Atlantic, Dec. 2017

Focused Case Study

- Slide text

Case Study Summary - Mission

- Goal
- Center of Gravity (Strategy)
- Equipment
- Training
- Leadership
- Morale
- Tactics
- Intangibles
- Mistakes
- Outcome

Computing Case Study Summary - Multivac

- Date - 2061 to end of time
- Goal

  "How can the net amount of entropy of the universe be massively decreased?" => "How may entropy be reversed?"
- Center of Gravity (Strategy) [Deliver results in]
  - Minutes to seconds
- Technology / Equipment
  - 2061 - Multivac - "miles and miles" to Planetary AC's "hundreds of square miles" in size ~ Self adjusting + self correcting
  - 2161 - Microvac - half the volume of a space ship
  - 22061 - Galactic AC - 1,000 feet across on its own planet
  - 1,022,061 - Universal AC - 2 foot diameter globe, diffusely woven into fabric of hyperspace ~ self designing + self replicating
  - 100,000,000 - Cosmic AC - in hyperspace, neither matter nor energy
  - 10,000,000,000 - AC

  - Asimov, Isaac, The Last Question

Computing Case Study Summary - Multivac

- Training ~ Leadership ~ Morale
- Tactics [Interface]
  - Multivac - Typing input ~ Printing output
  - Microvac - Voice input ~ Printing output
  - Galactic AC - Voice input + output
  - Universal AC - Thought input + output
  - Cosmic AC + AC - Complete assimilation of man into computer
- Intangibles [Indexes]
  - Indexes everything
- Mistakes
  - Once last question was answered there was no man left to give answer to…so AC does a demonstration instead
- Outcome

"Insufficient data for a meaningful answer."=> "Let there be light!"

- Asimov, Isaac, The Last Question

Are We Living in a Simulation?

- Humanity will reach a "post-human" stage = culture that has mastered artificial intelligence + has achieved capability of "perfect" simulations of reality + human consciousness with near-infinite computing resources
  - Individuals in a post-human civilization can perform near perfect "ancestor simulations" of the past, including today
  - If over a given time period there are many simulations of present period of history, each containing simulated sentient individuals who think they are experiencing the real world, the probability that a given sentient individual is actually experiencing true reality rather than simulated reality is extremely small
- Can be ruled out on basis of physical size of computer required
  - A lattice simulating our Universe with a diameter of 10E27 meters would be very large
  - Simulation array would need 10E50 elements on a side with each point on lattice requiring storage of ~ 20 bits to represent its state
  - Such a Universe simulation, using 3D cube would be 10E35 meters / side
  - There is not enough matter in Universe to construct such an object, and if it was constructed it would collapse into giant black hole

- John Cramer, Is Our World Just a Computer Simulation?, Analog, Jul./Aug. 2013

Personal Case Study - Richard Dawkins

- Role
  - Evolutionary biologist, Atheist
    - "Meme"
- Story
  - Was a keynote speaker with him at computer meeting in Australia
  - Brilliant scientist but a militant atheist
    - Gives atheism a bad name…

Personal Case Study - Music of the Spheres

- Role
  - Beginning computer programmer
- Story
  - In 1981, I was given access to an Atari 800 personal computer.
  - Inspired by Carl Sagan's Cosmos, I attempted to make it play the Music of the Spheres
  - I obtained the musical score for the 6 planets and programmed it into the Atari's musical synthesizer
  - Unfortunately the Atari had only 4 audio channels, so I could not hear all 6 planets at once
  - …but it did sound interesting…

Astrobiology Analog Case Study - Name

- Location
  - Text
- Story
  - Text

Drake Equation

$$N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

- N = The number of communicative civilizations
- R* = The rate of formation of suitable stars (stars such as our Sun)
- fp = The fraction of those stars with planets. (Current evidence indicates that planetary systems may be common for stars like the Sun.)
- ne = The number of Earth-like worlds per planetary system
- fl = The fraction of those Earth-like planets where life actually develops
- fi = The fraction of life sites where intelligence develops
- fc = The fraction of communicative planets (those on which electromagnetic communications technology develops)
- L = The "lifetime" of communicating civilizations

Class Simulation

- Topic aspects

Poem

"This day before dawn I ascended a hill and look'd at the crowded heaven,

And I said to my spirit When we become the enfolders of those orbs,

and the pleasure and knowledge of every thing in them, shall we

be fill'd and satisfied then?

And my spirit said No, we but level that lift to pass and continue beyond."

- Walt Whitman, Song of Myself

Questions for Further Discussion

- The universe appears to be fine-tuned for life…who exactly tuned it?
- What are the views of the other major religions on creationism, evolution, and astrobiology?
  - Buddhist
  - Hindu
  - Islam
  - Judaism
- Do we exist in a Created Computed Universe as is portrayed in Asimov's "The Last Question?"
- Is biology simply a brief but necessary stage between inanimate matter and intelligent inanimate matter / machine intelligence?

Reading Assignments

- Astrobiology Primer 2.0 (2016) Chapter
  - https://doi.org/10.1089/ast.2015.1460
- TED Talks for this Topic
  - http://www.astrobiologysurvey.org/ToLearnMore.html

Recommended Reading to Learn More

- Non-fiction
- Fiction
- Movies
- Simulations

Conclusion

"In some respects, science has far surpassed religion in delivering awe. How is it that hardly any major religion has looked at science and concluded, 'This is better than we thought!'"

- Carl Sagan, planetary scientist

Conclusion

"It almost seems as if the Universe must in some sense have known that we were coming"

- Freeman Dyson, physicist

Conclusion
The Last Word

"The greater the continent of knowledge, the longer the coastline of the unknown"

- Sir Isaac Newton, physicist

(The more we know, the more we know we don't know, and thus the continued need for religion)

Conclusion
The Last Emotion

"I know that I am mortal and the creature of a day, but when I search out the mass wheeling circles of the stars, my feet no longer touch the earth but side by side with Zeus himself I take my fill of ambrosia, the food of the gods"

- Ptolemy, mathematician

Conclusion
From One Who Was There

"We all think about, 'I hope to go to heaven when I die.' Ladies and gentlemen, you go to heaven when you're born. You arrive on a planet with the positive mass that provides the gravity that contains water and an atmosphere and the essentials of life...God has given mankind a stage that we saw out there for us to perform on. How that play turns out is up to us."

- James Lovell, astronaut

Topic 13

Contact and Conclusion

Song

When I was young I told my mum
I'm going to walk on the Moon someday
Armstrong and Aldrin spoke to me
From Houston and Cape Kennedy
And I watched the Eagle landing
On a night when the Moon was full
And as it tugged at the tides, I knew deep inside
I too could feel its pull

I lay in my bed and dreamed I walked
On the Sea of Tranquillity
I knew that someday soon we'd all sail to the moon
On the high tide of technology
But the dreams have all been taken
And the window seats taken too
And 2001 has almost come and gone
What am I supposed to do?

Now that the space race is over
It's been and it's gone and I'll never get to the moon
Because the space race is over
And I can't help but feel we've all grown up too soon

Now my dreams have all been shattered
And my wings are tattered too
And I can still fly but not half as high
As once I wanted to

Now that the space race is over
It's been and it's gone and I'll never get to the moon
Because the space race is over
And I can't help but feel we've all grown up too soon

My son and I stand beneath the great night sky
And gaze up in wonder
I tell him the tale of Apollo And he says
"Why did they ever go?"
It may look like some empty gesture
To go all that way just to come back
But don't offer me a place out in cyberspace
Cos where in the hell's that at?

Now that the space race is over
It's been and it's gone and I'll never get out of my room
Because the space race is over
And I can't help but feel we're all just going nowhere
- Billy Bragg, The Space Race Is Over

Thematic Quote

"The easiest way to predict the future is to invent it

Build what you use. Use what you build.

You let what you build change you, then you move on"

- Philosophy of the Xerox Palo Alto Research Center (PARC)

Thematic Quote

"The reasonable man adapts himself to the world; the unreasonable man persists in trying to adapt the world to himself. Therefore, all progress depends on the unreasonable man"

- George Bernard Shaw, playwright

The Painting

A Cosmic View

- Robert McCall

(Smithsonian National Air and Space Museum)

Artifact

- Name
- Year
- Story

The Question

True or False:

"Luck is what happens when opportunity and preparation meet"

- James Martin, Viking project manager

Grand Extraplanetary Strategy For Humanity

"At the most basic level, a strategy is simply a thoughtful way of dealing with one's environment to improve one's prospects for success. A grand strategy for the human species would be one designed to improve our ability to survive, to grow, to diversify, and to increase our influence on our environment and our future.

There are many elements to such a strategy, including the better management of our resources, reducing undesirable impacts on our biosphere, limiting conflict among humans, and maintaining the conviction that our future can be better than our past. Most conceptions constrain the design of such a strategy to the biosphere of our origin - a stage that many find unnecessarily narrow. The environment of a technological species is much larger than the planetary biosphere that gave it birth.

Here we may have the common purpose that underlies the four outward-looking revolutions of our time. Astronomy, planetary exploration, and SETI are reconnaissances of our larger environment. They are essential elements of any rational extraplanetary strategy for the human species; without them, we could not conduct intelligent operations beyond the Earth.

Human spaceflight is partly for reconnaissance and partly for operations, depending on the objectives of particular missions. Extraterrestrial mining and macaroengineering, including the building of large structures in space, clearly would be operations.

Whatever our differences about specific missions may be, we could share a broad vision of human activity beyond the Earth, placing astronomy, planetary spaceflight, SETI, and proposals for extraterrestrial macroengineering in a common context."

- Michael Michaud, An Outward-Looking Grand Strategy, Centauri Dreams, Apr. 18, 2014

Themes

What we are going to discuss / What we have discussed
Everything is deeply intertwingled

- Introduction
  - Astrobiology is the study of the origins, evolution, distribution and future of life in universe
  - Astrobiology's three primary questions
    - Where do we come from / What is the history of life? and Are we alone? and Where are we going / What is the future of life?
- In the Beginning (Life, the Universe and Everything)
  - Size of universe - large
  - History of / timeline of universe and Earth - long ~ Universe is 13.7 billion years old + Earth is 4.5 billion years old
- Sensors
  - New instruments change our view and understanding of universe

Themes

What we are going to discuss / What we have discussed
Everything is deeply intertwingled

- What is Life?
  - Astrochemistry - interstellar medium filled with chemical building blocks of life - they are ubiquitous in universe
  - How do you define life / what is life
    - NASA definition - Life is a self-sustained chemical system capable of undergoing Darwinian evolution
  - What is needed for life - where all these exist and persist is where you look for life
    - Chemical building blocks, liquid solvent (water best), energy (chemosynthesis or photosynthesis)
  - How does life begin / Origin of life
    - Astrochemistry becomes astrobiology somehow (RNA world or protein first)
  - Extremophiles help us explore limits of life to appreciate what is possible
    - Extremophiles show life extremely tenacious + can survive in extraordinary conditions
  - Timeline for development of simple life = short on Earth
  - Timeline for evolution of intelligent life = long on Earth
  - Astrobiology is evolutionary biology writ large
- Life in our Solar System
  - Extremophiles and where does life exist on Earth - subsurface, deep oceans, oceans, land, atmosphere
  - Tour of habitable planets + moons of our solar system searching for life - Mars, Europa, Titan, Enceladus
  - Planetary protection

Themes

What we are going to discuss / What we have discussed
Everything is deeply intertwingled

- Life in the Universe
  - Exoplanets - cosmos is filled with exoplanets ~ all solar systems are different
  - Habitable zone - initially defined by distance from star / liquid water, now widened by tidal heating from gravity
  - Simple life probably common, intelligent life probably rare (Rare Earth Hypothesis)
  - Is evolution predictable / what would life look like on other planets?
- Impact Events (The Good, the Bad, and the Ugly)
  - Panspermia / Alh 84001 / Are we Martians?
  - Impact events: frequency / results - Tunguska sized event from 50 meter asteroid every few hundred years
  - Asteroid defense - detection + deflection
- Search for Extraterrestrial Intelligence (SETI)
  - Techniques for searching ~ What to say ~ Should we speak at all?
  - Drake equation
- Crewed + Uncrewed Spaceflight
  - Crewed SETI (or SET) - history of crewed spaceflight organized by planet
  - Uncrewed SETI (or SET) - history of uncrewed spaceflight organized by planet

Themes

What we are going to discuss / What we have discussed
Everything is deeply intertwingled

- Future Astrobiology Missions
  - Exploring for life in solar system
    - Future crewed missions to asteroids / Phobos / Mars
    - Future uncrewed missions to Mars, Europa, Titan, Enceladus
  - Backing up life to space
    - Space settlements and Terraforming Mars with synthetic biology / Mars settlements
  - Exploring for life in universe
    - Starships
- The Arts
  - Art provides a vision for us to strive towards, identifies problems that need to be overcome to achieve the vision, and creates and tests possible solutions to those problems
- The Divine
  - How to reconcile latest scientific discoveries with your religious beliefs
- Contact + Conclusion
  - How will we make contact

Case Study Summary - Mission

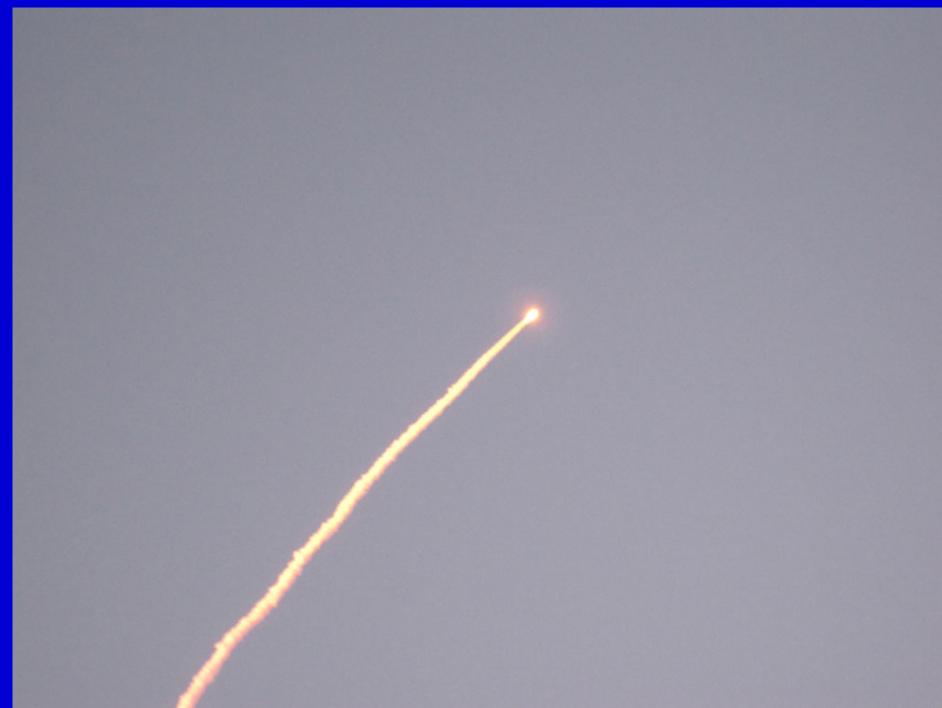
- Goal
- Center of Gravity (Strategy)
- Equipment
- Training
- Leadership
- Morale
- Tactics
- Intangibles
- Mistakes
- Outcome

Computing Case Study Summary - Mars Curiosity Rover

- Goal
  - Land on Mars + then explore it safely
- Center of Gravity (Strategy)
  - Meticulous attention to detail
- Technology / Equipment
  - 2 computers
- Training / Leadership / Morale
  - High level of training for hardware engineers + programmers
  - Leadership experienced
  - High morale
- Tactics
  - Extraordinary measures taken in hardware + software design to ensure spacecraft reliability + that system can be debugged + repaired from millions of miles away
- Intangibles
  - Embedded software for spacecraft designed for one-of-a-kind device with uncommon array of custom-built peripherals
  - Code targets one user (mission) ~ For most critical parts of mission code is used once
  - Software can be difficult to test in accurate representation of environment in which it must operate ~ Must work first time
- Mistakes
  - Software that controls interplanetary spacecraft must have a high standard of reliability, any small mistake can lead to loss of mission
- Outcome
  - Spacecraft performed flawlessly in delivering Curiosity to surface of Mars + in exploration of planet

- Gerard Holzmann, Mars Code, Communications of the ACM, Feb. 2014

Personal Case Study - Blastoff!



- Role
  - Observed launches in person
- Story
  - May 1992 - Delta rocket with Indonesia Palapa-B communications satellite (night launch)
  - March 2011 - NROL-27 Satellite Data Systems satellite launch on Delta 4 (dusk launch)
  - April 18, 2017 - OA-7 / CRS-7 "S.S. John Glenn" resupply mission on Atlas V to International Space Station (day launch - almost missed it

Astrobiology Analog Case Study - Name

- Location
- Story

Class Simulation

- Topic aspects

Poem

"We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started.
And know the place for the first time."

- T.S. Eliot, "Little Gidding"

Questions For Further Discussion - First Contact

- What are the ethics of / how should humans approach meeting with new cultures + races?
  - How have we done it in the past?
  - How should we do it in the future?
- Looking at the history of first contacts between human cultures, what are the implications (peaceful / warlike / beneficial / exploitative / etc.) for first contact with aliens?
- What first contact lessons can be drawn from the Europeans' first contact with native Americans?
- How would you manage a first contact to allay fears of Earthlings?
- What should a first contact protocol look like?

Questions for Further Discussion

- What would a grand strategy for humanity look like?
- Is 42 the answer to the ultimate question of life, the universe and everything?

Questions for Further Discussion

- Time for Reflection:
  - Take an hour and reflect back upon the Learning Objectives / Astrobiology Frequently Asked Questions for this course found in Topic 1
    - Where do we come from? (What is the history of life?)
    - Are we alone?
    - Where are we going? (What is the future of life?)
  - What is it about this class that has changed you or changed the way you look at knowledge or yourself or your life or the physical world around you?

Reading Assignments

- Astrobiology Primer 2.0 (2016) Chapter
  - https://doi.org/10.1089/ast.2015.1460
- TED Talks for this Topic
  - http://www.astrobiologysurvey.org/ToLearnMore.html

Recommended Reading to Learn More

- Non-fiction
- Fiction
- Movies
- Simulations

Conclusion

"A message of the DEEP Survey for humankind is that our universe is hospitable to life, that there are billions and billions of galaxies everywhere cooking elements and making stars that are ripe for solar systems, that this process started early, and that, in most galaxies, you could have formed solar systems way before our own Milky Way formed. The habitat for life is everywhere.

The message of the DEEP Survey and all the other information that we're getting is a beautiful story. It's a new version of Genesis, a new version of the cosmic myth, only this time it's scientifically based, from the Big Bang to now. Big Bang, formation of galaxies, formation of heavy elements in supernovae, Sun, Earth, life-one unbroken great chain of being.

And as we look out into the universe, we see this happening all over. It's as though the universe is a giant garden where flowers hospitable to life, habitats hospitable to life, are blooming all over. It remains for us to see if we can verify that these potentially powerful and favorable habitats are actually giving rise to life as we see it here."

- Sandra Faber, astronomer

[DEEP (Deep Extragalactic Evolutionary Probe) is a large scale survey of distant galaxies]

Conclusion

"Just in the last few years, we've reached the point that we can start with the origins of the universe, we can end with a conversation among intelligent beings about how things work, and have an awfully good understanding of every step that came in between the two."

- Jeff Hester, astronomer

"For almost all of human history, the heavens have been beyond our reach. For our ancestors, it was a place where the gods lived, or else simply a vast, untouchable realm of lifeless beauty. But now, the study of cosmic origins tells a different story. It tells us that the story of life, of us, extends far beyond Earth. It tells us that the emergence of the conditions for our kind of life was no accident. Instead, it was a natural outcome of almost 14 billion years of cosmic evolution, a chain of connections that links the birth of the universe to us, right here, right now."

- Neil deGrasse Tyson, astrophysicist

Conclusion

"The future is unknowable."

- Donald Rumsfeld, US Secretary of Defense

Conclusion

"The future never just happened. It was created."

- Will and Ariel Durant, historians

Conclusion

"The future is here. It's just not widely distributed yet."

- William Gibson, science fiction author

Conclusion

"Somewhere, something incredible is waiting to be known"

- Carl Sagan, planetary scientist

Conclusion

"We are all in the gutter, but some of us are looking at the stars."

- Oscar Wilde, writer

Conclusion

"Man must rise above the Earth to the top of the atmosphere and beyond, for only then will he fully understand the world in which he lives."

- Socrates

Conclusion

"The more clearly we can focus our attention on the wonders and realities of the universe about us, the lass taste we shall have for destruction."

- Rachel Carson, environmentalist

The Painting

The Angel Of The Lord Rolling Up The Scroll Of Heaven At The End Of Time

- Unknown 14th Century Artist

(Chora Church, Constantinople - from Evan D'Alessandro)

Appendix

How I Teach This Course

How To Use This Course -
Learning and Teaching Suggestions for Astrobiology Survey

- If you are a student you may simply read the slides of those topics that interest you
- If you are a teacher you may use the slides to teach either a
  - 1. Lecture-based course if you have a large amount of time
    - Teacher uses slides to cover the entire syllabus by giving 1 topic / class session, without or with student preparation / review of the slides before lecture
  - 2. Seminar-based course if you have a small amount of time
    - At first class meeting, students decide which topics they want to cover and design their own syllabus - or - teacher may assign a topic to each student based upon their major
    - For each class session, the teacher assigns beforehand the questions from the beginning and end of the topic ("The Question" + "Questions for Further Discussion") to be discussed by the students
    - The students must read the topic before class, and come prepared to answer the questions using information from the topic's case studies to illustrate their answers
    - The teacher will lead and guide the student's discussions and offer their own insight and expertise

Philosophically…

- I see a course as a way of organizing a discussion, using readings and viewings to provide a common ground for discussion of the topics and questions in the course

Preparation For This Course - If You Are Taking The Whole Course

- Before the first class meeeting, students should prepare for this course in the following manner
  - Review all the slides in all of the topics
  - Select 3 areas of interest from amongst the topics
    - These areas of interest are what you will focus on in your readings, field trips, and essays

Expectations For Students

- I have high expectations for you as students in this course. By the end of this course I expect you to accomplish the Goal of This Course. To do so I expect you to do the following:
  - Attend every class
  - Come to class prepared to discuss the day's topic by reading the assigned topic in the Astrobiology Survey before class
  - Participate in class in a challenging yet respectful manner
  - Participate online in discussions + simulation in a challenging yet respectful manner
  - Turn in assignments on time

What I Hope To Avoid

"College is a place where a professor's lecture notes go straight to the student's lecture notes, without passing through the brains of either."

- Mark Twain, author

What I Hope To Do

"The mind is not a vessel that needs filling, but wood that needs igniting."

- Plutarch, Greek historian

Personal Case Study - About Me

- Who am I?
  - A physician
  - A professor
  - A researcher
    - Area of research interest is educational informatics (www.educationalinformatics.org), including digital libraries that support naval, humanitarian and exploratory medicine (Virtual Naval Hospital)
    - Designed but never built Virtual Space Hospital for NASA
      - Regret that I *could* have been a rocket scientist
  - An amateur astrobiologist (amateur = love)

Personal Case Study - About Me - What I Do Professionally

- I am in medical intelligence
- I have a number of sensor platforms working in various parts of the electromagnetic spectrum that gather data for me around the clock
- I gather + analyze data / interpret images + use scientific method to synthesize it into new information useful to others and try to draw new inferences about the bigger picture from it
- I do my best work when working closely with a multidisciplinary team
- I give briefs and written reports
- My field is always changing and I am always learning
- Does this sound like astrobiology?

Personal Case Study - About Me - Why I Am Interested in Astrobiology

- I am a child of Apollo
- As a child I thought anything was possible in terms of crewed space exploration and I wanted to be an astronaut
- …and then crewed space exploration was taken away from us by short-sighted politicians
- As a teen I became interested in space settlements
- As an adult I become interested in uncrewed space exploration - a JPL junkie
- I am a geek
- …and yes, I am a Trekkie

Personal Case Study - About Me
My First Exposure to Astrobiology

ICARUS 15, 515–554 (1971)

A Search for Life on Earth at 100 Meter Resolution

CARL SAGAN AND DAVID WALLACE

Laboratory for Planetary Studies, Cornell University, Ithaca, New York 14850

Received June 10, 1971

A study of several thousand photos indicates that $\sim 10^{-2}$ of Gemini and Apollo photographs of the Earth at 100m resolution reveal signs of life—rectangular arrays due to human agricultural and urban territoriality, roads, canals, jet contrails, and industrial pollution. Potential false positives—e.g., dunes, sand bars, jet stream clouds—abound. A curve is derived for the detectivity of contemporary life on Earth, in a plot of ground resolution versus global coverage. A comparable biology on Mars would not have been detected by all observations of Mars through Mariner 7. Forthcoming Mars orbiter and lander imaging experiments hold significant promise of detecting life on Mars of contemporary terrestrial extent and advancement, should such life exist.

Because the close-up reconnaissance of another terrestrial planet, Mars, is imminent, it is of some interest to reconsider the appearance of our own planet as seen from space. Some years ago a study was published (Kilston, Drummond, and Sagan, 1966) which analyzed several thousand Tiros and Nimbus photographs of the Earth taken at ~1km resolution. It was found that, particularly for the manifestations of biology on the planet Earth, such photographs were generally uninteresting. No sign of major engineering works or of the largest metropolises could be found. It was argued that, for reasons of economy and geometry, technical civilizations tend to construct rectilinear features which have a markedly artificial appearance. But the number of such rectilinear features visible at 1km resolution are very few. It was concluded that 1 in $\sim 10^3$ Tiros and Nimbus photos of the Earth showed signs indicative of our technical civilization; and that a significant number of false positives existed even in that data set—e.g., natural peninsulas, seif dunes, sand bars, and possibly jet stream clouds. Had the Mariner 4 space vehicle been directed at the Earth rather than at Mars and roughly 20 photographs of no better than 1km resolution acquired, no sign of life, intelligent or otherwise, would have been discerned on Earth.

Since that time approximately one order of magnitude more photographs of Mars have been obtained by Mariners 6 and 7; and, as of this writing, one to two orders of magnitude further improvement can be expected by United States and Soviet Mars orbiters in 1971–72. In these missions resolutions of approximately 100m are obtainable. Accordingly it is of interest to continue our calibration studies and examine the Earth at ~100m resolution. Fortunately the successful series of Gemini and Apollo manned missions has produced a very rich library of high resolution color photographs of the Earth. With the cooperation of the Goddard Space Flight Center and particularly of Dr. Paul D. Lowman, Jr., we have examined several thousand Gemini and Apollo photographs in an attempt to detect life on Earth. Photographs from Gemini 3–12 and Apollo 6 and 9 were inspected. Displayed in Table I are the relevant particulars of camera and film for those photographs selected in this study. Ordinary color film was used in all magazines relevant here, except for Magazine 26 of Gemini 7, where infrared Ektachrome, a camouflage detection film, was employed. Focal lengths ranged from 38mm on Gemini 9 and 11 to a 250mm telephoto lens on Gemini 7. Slant ranges varied from 160km on Gemini IV to 1200km on Gemini XI. Photographs were

- ~ 1974, 5th Grade, Special course on Moon, Kerby Elementary Library Media Center

Personal Case Study - About Me - Why I Am Interested in Astrobiology

- Astrobiology is like Jacques Yves Cousteau meets the Apollo program

- Astrobiology integrates many disciplines - specifically it weaves together all of the sciences I have studied (*) along with the arts and theology and makes them relevant to the most important question - Are we alone?
  - (*) Anthropology, astronomy, biology, chemistry, computer science, ecology, geology, mathematics, physics, psychology

"Everything is deeply intertwingled"

- Theodor Holm Nelson

Personal Case Study - About Me - Why Am I Here?

- I feel the topic of astrobiology is crucial to our society
  - We are about to find answers to astrobiology's three primary questions:
    - Where do we come from? (What is the history of life?)
    - Are we alone?
    - Where are we going? (What is the future of life?)
  - Unfortunately it is not being taught
  - …even though there is an increasing interest amongst public in space exploration + science fiction
- And - with the rise of religious and political fundamentalism - more and more are turning their backs on science
- How will you responsibly exercise control over astrobiology research through your politicians?
  - By reading, writing, and discussion
  - So this course is a step in that direction
- ...and on a personal level I have two sons
  - If they choose to become astrobiologists, I feel they will have undertaken a noble profession...I just don't want them funded by politicians who are donkeys

Personal Case Study - About You
[First Class Meeting Icebreaker - Ask Every Student]

- Who are you
  - Where are you from?
- What is your science background?
- What is your science fiction background?
- What is your major / what are you interested in studying?
- Why are you here?

First Assignment Before Leaving Class

- Name you prefer
- Telephone number
- E-mail address
- What is your major?
- Why are you here?
    - Why did you take this course?
    - What are your expectations for the course?
    - Are there any specific astrobiology topics you are interested in?
- Write three specific questions about the subject of this course that you want answered during this semester
- Write three reasons about why you enrolled in this course. Be honest

How We Will Do This

- Readings / Viewings / Lectures / Discussions
  - Balance between theory and practice
  - Case studies and simulations to tie it all together
- Note that although for organizational purposes the topics are presented in a linear order, they are all deeply intertwingled
- Our common touchstones will be current astrobiology missions as we are all living through them together
- Curriculum at www.astrobiologysurvey.org

How We Will Do This

- Each topic has
  - Song to start with
  - Thematic quote
  - Painting
  - Artifact
  - (Framing) Question
  - Case studies to bring the topic into focus
  - Relationship to the ongoing simulation
  - Poem
  - Questions for further discussion
  - Recommended readings to learn more
- Look at astrobiology
  - From microscopic to macroscopic levels
  - In the context of everything else

How We Will Do This

- Review Exam Essay Topics at end of this Appendix so you can work on them throughout the course
- I'll do my best to teach to the test

Assignments

- Daily Readings
  - Astrobiology Magazine - www.astrobio.net
- Weekly Readings for class
  - Astrobiology A Very Short Introduction by David Catling

Supplementary Readings

- Nonfiction Readings for What Astrobiology is Like - Choose one:
  - Cosmos by Carl Sagan

Supplementary Readings

- Fiction Readings for What Astrobiology is Like - Choose one:
  - Contact by Carl Sagan

Assignments

- Movie Viewings for What Astrobiology is Like - Choose one:
  - 2001: A Space Odyssey
  - Contact
  - Andromeda Strain

Assignments

- Participate in a class first contact simulation that stretches over the course and is followed by a hot wash-up / after action review

Assignments

- Supplementary Board Games to Play
  - Phylo
- Supplementary Computer Games to Play
  - Seven Cities of Gold
  - The Dig

What Are My Favorite Sources

- To see the information I process regularly look at
  - www.astrobiologysurvey.org/ToLearnMore.html
- See the Bibliography for a list of my Sources

Exams

- Choose from amongst the following topics for your exam essays

Exam Essay Topics
[Learning Objectives of This Course / Astrobiology Frequently Asked Questions (FAQs)]

- Where do we come from? (What is the history of life?)
- Are we alone?
- Where are we going? (What is the future of life?)

Exam Essay Topic

- For the class simulation please explain:
  - Your role
  - Your actions
  - What you learned from your individual actions in relation to what you learned from the course
  - What you learned from your team's actions overall in relation to what you learned from the course

  - One possible way to frame this would be to address some of the Learning Objectives of This Course / Astrobiology Frequently Asked Questions (in Lecture 1) in relation to the simulation

Exam Essay Topic

- Participate in an astrobiology analog visit by yourself or in a group
  - Use what you have learned in this course to understand this analog and afterwards document your
    - Emotions
    - Impressions
    - Lessons learned

Course Evaluation

- Be Honest!

- What did you like about this course?
- What did you dislike about this course?
- What was missing from this course?
- How would you improve this course?

Final Assignment Before Leaving Class

- What ONE thing sticks in your mind as the most valuable, significant, or enjoyable thing you learned during this course?

Bibliography

Notes on Sources

- To read an original article referenced in this course:
  - Go to your favorite Internet search engine
  - Type into the search box within quotation marks the article's title, followed by, within separate quotations, the article's author or place of publication

Sources

- Journals currently read regularly
  - Air and Space Magazine, Analog Science Fiction + Science Fact, Atlantic, Aviation Week and Space Technology, Economist, New Yorker
- Scientists read regularly
  - Neil deGrasse Tyson
- Web sites read regularly
  - Astrobiology Magazine, Astronomy Picture of the Day, Centauri Dreams, Many Worlds, Space Review
- Radio programs listened to regularly
  - Babbage from The Economist, BBC Discovery, BBC In Our Time, BBC Science in Action, Big Picture Science, Planetary Radio, StarTalk Radio
- Television programs currently viewed regularly
  - TED Talks

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- Collins, Michael - Carrying the Fire
- Collins, Michael - Liftoff
- Conrad, Nancy and Klausner, Howard - Rocketman
- Cooke, Hereward - Eyewitness to Space
- Cooper, Henry SF - Apollo on the Moon
- Cunningham, Walter - The All American Boys
- Davies, R.E.G + Salnikov, Yuri - The Chelyuskin Adventure
- Dean, James and Ulrich, Bertram - NASA / Art 50 Years of Exploration
- de Monchaux, Nicholas - Spacesuit: Fashioning Apollo
- Drye, Paul - False Steps The Space Race As It Might Have Been

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- Geiger, Clarence - History of the X-20A Dyna-Soar / Strangled Infant: The Boeing X-20A Dyna-Soar
- Godwin, Robert - The Lunar Exploration Scrapbook: A Pictorial History of Lunar Vehicles
- Godwin, Robert - Apollo Advanced Lunar Exploration Planning
- Gray, Mike - Angle of Attack: Harrison Storms and the Race to the Moon
- Gubitz, Myron - Rocketship X-15: A Bold New Step in Aviation
- Harvey, Brian - Soviet and Russian Lunar Exploration
- Johnson, Adam - 2001: The Lost Science Volumes 1 + 2
- Lay, Beirne - Earthbound Astronauts: The Builders of Apollo-Saturn
- McCall, Robert and Asimov, Isaac - Our World in Space
- McCormick, Roger - Patrick Air Force Base
- Millard, Doug - Cosmonauts: Birth of the Space Age
- Miller, Ron - Space Art A StarLog Photo Guidebook
- Miller, Ron - Spaceships: An Illustrated History of the Real and Imagined
- Murray, Charles and Bly Cox, Catherine - Apollo: The Race to the Moon

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- O'Neill, Gerard - The High Frontier
- Ordway, Frederick - Visions of Spaceflight: Images From the Ordway Collection
- Peebles, Curtis - Probing the Sky: Selected NASA Research Aeroplanes and their Contributions to Flight
- Pelligrino, Charles and Stoff, Joshua - Chariots for Apollo: The Making of the Lunar Module
- Phelan, Dominic - Cold War Space Sleuths: The Untold Secrets of the Soviet Space Program
- Pyle, Rod - Amazing Stories of the Space Age
- Reed, R Dale - Wingless Flight: The Lifting Body Story
- Ross, Stewart + Biesty, Stephen - Into the Unknown

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- Scharmen, Fred - Space Settlements
- Tregaskis, Richard - X-15 Diary: The Story of America's First Space Ship
- Vladimirov, Leonoid - The Russian Space Bluff
- Wendt, Guenter - The Unbroken Chain
- White, Rowland - Into The Black
- Wilford, John Noble - The Mapmakers
- Wolfe, Tom - The Right Stuff
- Wolfe, Tom - Post Orbital Remorse
- Young, Amanda - Spacesuits, The Smithsonian National Air and Space Museum Collection
- Zukowsky, John - 2001 Building for Space Travel

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Selected Fiction - Space Exploration

- **Berryman, John - The Trouble with Telstar**
- **Brennan, Gerald - Zero Phase: Apollo 13 On The Moon**
- **Brennan, Gerald - Public Loneliness: Yuri Gagarin's Circumlunar Flight**
- **Brennan, Gerald - Island of Clouds: The Great 1972 Venus Flyby**
- **Brennan, Gerald - Alone on the Moon: A Soviet Lunar Odyssey**
- **Caidin, Martin - The Cape**
- **Caidin, Martin - Marooned**
- **Caidin, Martin - Four Came Back**
- **Caidin, Martin - No Man's World**
- **Cassutt, Michael - Red Moon**

Bibliography
Selected Fiction - Space Exploration

- Drury, Allen - Throne of Saturn
- Heinlein, Robert - Rocket Ship Galileo
- Heinlein, Robert - Space Cadet
- Jenne, Mike - Blue Gemini, Blue Darker Than Black, Pale Blue
- Michener, James - Space
- Pesek, Ludek - Log of a Moon Expedition
- Searls, Hank - The Pilgrim Project
- Searls, Hank - The Astronaut
- Suarez, Daniel - Delta-V
- Wollheim, Donald - Mike Mars Flies the Dyna-Soar

Bibliography
Astrobiology

- Adler, Charles - Wizards, Aliens and Starships
- Barlowe, Wayne Douglas - Expedition
- Benson, Michael - Cosmigraphics: Picturing Space Through Time
- Boeke, Kees - Cosmic View: The Universe in 40 Jumps
- Catling, David - Astrobiology: A Very Short Introduction
- Chaikin, Andrew - A Passion for Mars
- Cousteau, Jacques-Yves and Diole, Phillipe - Three Adventures: Galapagos, Titicaca, The Blue Holes
- Cousteau, Jacques and Sivirine, Alexis - Jacques Cousteau's Calypso
- Cousteau, Jean-Michel - My Father, The Captain
- De Grasse Tyson, Neil - Space Chronicles
- Dickinson, Terense and Schaller, Adolf - Extraterrestrials
- Diole, Philippe and Falco, Albert - Falco Chief Diver of the Calypso
- Duffield, Wendell - Chasing Lava
- Ferris, Timothy - Galaxies
- Grady, Monica - Astrobiology

Bibliography
Astrobiology

- Green, Dan - Astronomy
- Ishikawa, Kenji and Kawabata, Kiyoshi - Manga Guide to the Universe
- Jenkins, Susan and Jenkins Robert - Life Signs The Biology of Star Trek
- Jones, Tom and Stofan, Ellen - Planetology
- Kofoed, Karl - Galactic Geographic Annual 3003
- Kofoed, Karl - Galactic Geographic Annual 3013
- Matson, Brad - Jacques Cousteau The Sea King
- Mix, Lucas - Astrobiology Primer 2006
- NASA - Astrobiology Graphic Novels 1-9
- Sagan, Carl and Wallace, David - A Search For Life On Earth At 100 Meter Resolution. Icarus 15, 515-554(1071)
- Sagan, Carl - Cosmos
- Skurzynski, Gloria - Are We Alone? Scientists Search for Life in Space
- Turner, Pamela - Life on Earth and Beyond - An Astrobiologist's Quest
- Willis, Kathy - Plants From Roots to Riches (Radio series)

Bibliography
Selected Fiction - Science Fiction

- Adams, Douglas - Hitchhiker's Guide to the Galaxy Trilogy
- Adams, Douglas - Hitchhiker's Guide to the Galaxy Trilogy (radio drama)
- Anderson, Poul - The Enemy Stars
- Askegren, Pierce - Gateway to the Stars
- Asimov, Isaac - Fantastic Voyage
- Asimov, Isaac - Foundation, Foundation and Empire, Second Foundation
- Asimov, Isaac - Foundation, Foundation + Empire, Second Foundation (radio drama)
- Asimov, Isaac - I, Robot
- Baxter, Stephen - Voyage
- Baxter, Stephen - Voyage (radio drama)

Bibliography
Selected Fiction - Science Fiction

- Bova, Ben - Colony
- Bova, Ben - Forward in Time
- Bova, Ben - New Frontiers
- Bova, Ben - My Favorites
- Bova, Ben - Powersat
- Bova, Ben - Voyagers
- Bradbury, Ray - The Golden Apples of the Sun
- Bradbury, Ray - Martian Chronicles

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Selected Fiction - Science Fiction

- Caldwell, Steven - Galactic Encounters (Aliens in Space, Fantastic Planet, Settlers in Space, Space Patrol, Star Quest, Worlds at War)
- Carroll, Michael - Europa's Lost Expedition
- Castro, Adam-Troy and Oltion, Jerry - The Astronaut From Wyoming
- Clarke, Arthur C. - 2001: A Space Odyssey
- Clarke, Arthur C. - A Meeting with Medusa
- Clarke, Arthur C. - Rendezvous With Rama
- Clarke, Arthur C. - Superiority
- Clarke, Arthur C. - The Sentinel
- Clarke, Arthur C. - Islands in the Sky
- Clarke Arthur C. - Sands of Mars
- Clarke, Arthur C. - Prelude to Space

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Selected Fiction - Science Fiction

- Cline, Ernest, - Armada
- Cowley, Stewart - Terran Trade Authority (Spacecraft 2000-2100 AD, Great Space Battles)
- Crichton, Michael - Andromeda Strain
- Dean-Foster, Alan - The Dig
- Dean-Foster, Alan - Star Trek Logs 1-9
- Dick, Phillip K - Do Androids Dream of Electric Sheep?
- Dougherty, Martin - Shadow of the Storm
- Drake, David - Starliner
- Drake, David - With the Lightnings
- Drake, David - Lt Leary Commanding
- Gerrold, David - Yesterday's Children
- Greene, Joseph - Tom Corbett Space Cadet (radio drama)
- Gunn, James - The Listeners

Bibliography
Selected Fiction - Science Fiction

- Haldeman, Joe - The Forever War
- Hanks, Tom - Alan Bean Plus Four
- Heinlein, Robert - Double Star
- Heinlein, Robert - Starship Troopers
- Heinlein, Robert - Orphans of the Sky
- Heinlein, Robert - Citizen of the Galaxy
- Heinlein, Robert - Past Through Tomorrow (Universe)
- Lerner, Edward M - Energized
- Lovecraft, H.P - Shadow Over Innsmouth
- Lovecraft, H.P. - Call of the Cthulhu
- McDevitt, Jack - A Talent For War
- Niven, Larry and Pournelle, Jerry - The Mote in God's Eye
- Novakova, Julie - Strangest of All - Anthology of Astrobiological Science Fiction
- Nowlan, Philip Frances - Armageddon 2419

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Selected Fiction - Science Fiction

- Reynolds, Mack - Lagrange Five
- Reynolds, Mack - Satellite City
- Reynolds, Mac and Ing, Dean - Trojan Orbit
- Reynolds, Mac and Ing, Dean - The Lagrangists
- Reynolds, Mac and Ing, Dean - Chaos in Lagrangia
- Sagan, Carl - Contact
- Saint-Exupery, Antoine - The Little Prince
- Sawyer, Robert - Red Planet Blues
- Silverberg, Robert (editor) - Science Fiction Hall of Fame Volume One 1929-1964
- Steele, Allen - Arkwright
- Sturgeon, Theodore - Microcosmic God

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Selected Fiction - Science Fiction

- Van Vogt, AE - The Voyage of the Space Beagle
- Vardeman, Robert - Fate of the Kinunir
- Von Braun, Wernher - Life on Mars
- Weber, David - On Basilisk Station
- Weir, Andy - The Martian
- Weir, Andy - Artemis
- Weir, Andy - Project Hail Mary
- Wells, H.G. - The War of the Worlds
- Westerfeld, Scott - Behemoth
- Westerfeld, Scott - Leviathan
- Westerfeld, Scott - Goliath

Bibliography
Comics / Pulps / Manga

- Ellis, Warren - Ministry of Space
- Ellis, Warren - Orbiter
- Ellis, Warren - Trees
- Greene, Joseph - Tom Corbett Space Cadet
- Greene, Joseph - Tom Corbett Space Cadet (radio drama)
- Hampson, Frank - Dan Dare Pilot of the Future
- Hampson, Frank - Dan Dare Pilot of the Future (radio drama)
- Herge - The Adventures of TinTin - Destination Moon, Explorers on the Moon, The Shooting Star
- Jordan, Sydney and Patterson, Willie - Jeff Hawke

Bibliography
Comics / Pulps / Manga

- Malibu Comics - Star Trek: Deep Space Nine
- Matsumoto, Leiji - Space Pirate Captain Harlock
- Multiple authors - Star Trek: The Newspaper Comics
- Multiple authors - Star Trek: The Manga
- Multiple authors - Star Trek: The Key Collection
- Nowlan, Philip Frances and Calkins, Dick - Buck Rodgers in the 25th Century
- Nowlan, Philip Frances and Calkins, Dick - Buck Rodgers in the 25th Century (radio drama)
- Yatate, Hajime - Cowboy Bebop
- Yukimura, Makoto - Planetes

Plays

- Beyond Endurance (radio drama)
- Calls From Far Away (radio drama)
- Death of a Cosmonaut (radio drama)
- Goldilocks Zone (radio drama)
- Ground Control (radio drama)
- Moon (radio drama)
- Red Moon (radio drama)
- Rendezvous with Rama (radio drama)
- The First Man on the Moon and How They Done It
- The Soyuz Files (radio drama)

Movies
Space Exploration

- 8 Days: To the Moon and Back
- Apollo 11
- Apollo 13
- Countdown
- The Dish
- Disneyland TV Anthology: Man in Space, Man and the Moon, Mars and Beyond (Television series)
- First Man
- First Orbit
- For All Mankind
- For All Mankind (Television series)
- From the Earth to the Moon (Television series)
- Gravity
- Hidden Figures

Movies
Space Exploration

- In The Shadow of the Moon
- Magnificent Desolation
- Marooned
- The Martian
- October Sky
- Right Stuff
- Space (Television series)
- Wonder of It All
- X-15

Movies
Astrobiology

- 2001: A Space Odyssey
- 2010
- Abyss
- Alien Earths / Alien Planet / Anatomy of An Alien / Extraterrestrial / Cosmic Safari / Journey to an Alien Moon / Natural History of an Alien (Television Series)
- Andromeda Strain
- Apollo 18
- Arrival
- Asteroid City
- Avatar
- Blue Planet (Television series)
- Capricorn One
- Connections (Television series)
- Contact
- Cosmos: A Personal Journal (Television series)
- Cosmos: A Spacetime Odyssey (Television series)

Movies
Astrobiology

- Connections (Television series)
- Cousteau Odyssey (Television series)
- Day the Universe Changed (Television series)
- Don't Look Up
- Europa Report
- Farthest: Voyager in Space
- Finding Life Beyond Earth (Television series)
- Interstellar
- L'odyssee
- Life Aquatic With Steve Zissou
- Life Beyond Earth (Television series)
- Origins - Fourteen Billion Years of Cosmic Evolution (Television series)
- Planet Earth (Television series)
- Prometheus
- Undersea World of Jacques Cousteau (Television series)

Movies
Science Fiction

- Adventures of Buckaroo Banzai: Across the Eighth Dimension
- Alien
- Aria (Television series)
- Armageddon
- Battlestar Galactica (Television series)
- Battlestar Galactica (Miniseries)
- Battlestar Galactica Blood and Chrome
- Bicentennial Man
- Black Hole
- Blade Runner
- Buck Rogers in the 25th Century (Movie serial)

Movies
Science Fiction

- Close Encounters of the Third Kind
- Cowboy Bebop
- Cowboy Bebop (television series)
- Deep Impact
- Destination Moon
- Dune
- Ender's Game
- Fahrenheit 451
- Forbidden Planet
- Hitchhiker's Guide to the Galaxy (Television series)
- Hitchhiker's Guide to the Galaxy (Movie)
- Macross Plus
- Mobile Suit Gundam

Movies
Science Fiction

- Outland
- Phoenix (Hi No Tori)
- Phoenix 2772
- Planetes (Television series)
- Planet of the Apes
- Royal Space Force: The Wings of Honneamise
- Serenity
- Silent Running
- Space Battleship Yamato (film)
- Space Battleship Yamato (anime)
- Space Dandy (Television series)
- Starship Troopers

Movies
Science Fiction

- Star Trek The Original Series (Television series)
- Star Trek The Animated Series (Television series)
- Star Trek The Next Generation (Television series)
- Star Trek Deep Space 9 (Television series)
- Star Trek Enterprise (Television series)
- Star Trek Discovery (Television series)
- Star Trek Strange New Worlds (Television series)
- Star Trek The Movies
- Star Wars Episodes 1 and 4-8
- Tale of Princess Kaguya
- 20,000 Leagues Under the Sea
- Wandering Earth

Board Games Played
Science Fiction

- Exploration in the Age of Sail - Warpspawn
- Ogre - Metagaming
- Phylo - David Ng / Open Source
- Project Discovery - Scott Mansfield
- Sugo-Haya 2 - Science Club of Tokyo Tech High School of Science and Technology
- Time Tripper - SPI
- Traveller - GDW
- Voyage of the BSM Pandora - SPI

Computer Games Played

- PDP-1
  - Spacewar!
- GECOS Basic
  - Lunar Lander, Star Trek (self-written)
- HP2000 Basic
  - Star Trek
- Apple II
  - Rendezvous With Rama
  - Seven Cities of Gold
  - Space I (Traveller)
  - Wreck of the BSM Pandora
- Atari 800
  - Star Raiders
- Commodore 64
  - Heart of Africa

Computer Games Played

- Macintosh
  - The Dig
  - SimEarth
  - Strange Adventures in Infinite Space
  - Weird Worlds Return to Infinite Space
- PS4
  - Abzu
- Wii
  - Endless Ocean

MOOCs Attended

- Astrobiology and the Search for Extraterrestrial Life from University of Edinburgh via Coursera
- Exploring Our Oceans from University of Southampton via FutureLearn
- Stanford Astrobiology Course from Stanford University via iTunes University

Crowd-Sourced Research Projects Participated In

- Galaxy Zoo
- SETI@home

Bases Visited

- Space
  - Advanced Range Instrumentation Aircraft
  - Holiday Inn Cocoa Beach
  - Johnson Space Center
  - Kennedy Space Center / Cape Canaveral
  - NASA Ames
  - Patrick Air Force Base
  - Port Canaveral (range tracking ship General Hoyt S. Vandenberg)
  - US Geological Survey Astrogeology Branch Shoemaker Building, Flagstaff, Arizona
  - V-2 Launch Location Gouvy, Belgium

Space Museums Visited

- Air Force Space and Missile Museum, Cape Canaveral
- Alabama I-65 Welcome Center in Ardmore Alabama - Saturn 1B
- Armstrong Air and Space Museum
- ATK Rocket Garden
- Chicago Museum of Science + Industry Henry Crown Space Center
- EAA Air Adventure Museum / EAA Airventure
- Fabyan Villa Museum / Riverbank Laboratories
- Museum of Flight, Seattle
- Fram Museum, Oslo
- International Manga Museum, Kyoto
- Musee Herge
- Museum of Cosmonautics and Rocket Technology, Saint Petersburg
- National Air and Space Museum
- National Air and Space Museum Steven F. Udvar-Hazy Center

Space Museums Visited

- National Museum of the United States Air Force
- National Museum of the United States Navy
- Patrick Air Force Base Technical Laboratory Missile Park
- Pima Air and Space Museum
- RRS Discovery + Discovery Point Antarctic Museum
- Science Museum of London - Space and Science City 1550-1800
- Strategic Air and Space Museum
- Topkapi Palace - Clocks section
- U.S. Space and Rocket Center, Huntsville Alabama
- USS Hornet

Science Museums Visited

- Aquariums
  - Belle Isle Aquarium
  - National Aquarium, Baltimore
  - National Mississippi River Museum and Aquarium
  - New England Aquarium
  - Shedd Aquarium

Science Museums Visited

- Gardens
  - Brisbane City Botanic Garden
  - Chelsea Physic Garden
  - Kew Gardens
  - National Botanic Garden, Washington DC

Science Museums Visited

- Museums
  - American Museum of Natural History
  - British Museum - Clocks and Watches Gallery
  - Field Museum
  - Henry Ford Museum
  - Museum of Science and Industry
  - National Geographic Museum
  - National Museum of Natural History
  - Ontario Science Center
  - Science Museum, Boston
  - Science Museum, London

Science Museums Visited

- Zoos
  - Brookfield Zoo
  - Detroit Zoo
  - Lincoln Park Zoo
  - Lone Pine Koala Sanctuary
  - National Zoo
  - Omaha Zoo

Spacecraft Launches Seen

- May 1992 - Delta rocket with Indonesia Palapa-B communications satellite (night launch)
- March 2011 - NROL-27 Satellite Data Systems satellite launch on Delta 4 (dusk launch)
- April 18, 2017 - OA-7 / CRS-7 "S.S. John Glenn" resupply mission on Atlas V to International Space Station (day launch - almost missed it)
- August 2024 - Starlink launch on Falcon 9

Spacecraft Seen On Launch Pad

- Spring 1973 - Saturn IB - Skylab 2
- December 1982 - Space shuttle Challenger - STS-6
- March 1991 - Space shuttle Atlantis - STS-37
- March 2009 - Space shuttle Discovery - STS-119

Solar Eclipses Seen

- August 21, 2017 - 92% eclipse in Iowa City, IA

Space Missions I Have Followed Closely

- 1968 - Apollo 8
- 1969 - Apollo 10 / 11 / 12
- 1970 - Apollo 13
- 1971 - Apollo 14
- 1975 - Apollo Soyuz Test Project
- 1977 - Shuttle Approach and Landing Tests
- 1981 - STS-1, STS-2
- 1982 - STS-3, STS-4
- 1986 - STS-51 Challenger loss
- 1989 - Voyager II at Neptune
- 2003 - STS-107 Columbia loss
- 2004 - Mars Exploration Rover
- 2005 - Deep Impact
- 2005 - Cassini - Huygens
- 2009 - Mars Phoenix
- 2009 - LCROSS
- 2011 - Stardust-NeXT mission to Comet Tempel-1
- 2011 - Mars Science Laboratory Curiosity launch + landing in 2012
- 2014 - Rosetta + Philae lander on Comet 67P

Space Missions I Have Followed Closely

- 2014 - Exploration Flight Test 1 of Orion Multi Purpose Crew Vehicle
- 2015 - New Horizons encounter with Pluto

Space Missions I Have Followed Closely

- 2014 - Orion Exploration Flight Test - 1

Astronomy Sites Visited

- Adler Planetarium
- Cahokia Mounds State Park
- Chacchoben Mayan City
- Hayden Planetarium
- Heron Island, Great Barrier Reef
- Kitt Peak National Observatory
- Lowell Observatory
- Old Naval Observatory
- Onizuka Center for International Astronomy on Mauna Kea
- Royal Observatory Greenwich
- SETI Institute
- Stanford Dish Radio Antenna Facility, Palo Alto
- Stonehenge
- US Geological Survey Astrogeology Branch Shoemaker Building, Flagstaff, Arizona
- Very Long Baseline Array, North Liberty
- Yerkes Observatory

Astrobiology Analogs Visited

- Acadia National Park - tidal forces
- Arches National Park - erosive forces
- Briksdale Glacier (Norway)- history of climate change
- Bryce Canyon National Park - erosive forces, dark sky
- Cinder Lake Lunar Training Facility - artificial crater field
- Craters of the Moon - volcanism
- Devonian Fossil Gorge, Coralville Iowa - biosignatures of life
- Dimmuborgir (Iceland) - volcanism
- El Yunque Tropical Rain Forest, Puerto Rico -
- Glacier National Park - history of climate change, stromatolites on US Highway 2, 1.1 miles south of Walton Ranger Station
- Grand Canyon National Park - erosive forces
- Grand Tetons - tectonics

Astrobiology Analogs Visited

- Hakone National Park, Japan - volcanic forces
- Haleakala National Park - volcanic forces
- Hawaii Volcanoes National Park - volcanic forces
- Heron Island, Great Barrier Reef - water world
- Hiroshima - impact forces
- Jungfrau - glaciation
- Meteor Crater - impact forces
- Namafjall Hverir (Iceland) - volcanic forces
- Rocky Mountain National Park - tectonic forces
- Solheimajokull Glacier (Iceland) - history of climate change
- Sunset Crater National Park - volcanic forces
- Yellowstone - volcanism, extremophiles / thermophiles

Sites Snorkeled

- Caribbean
  - Cayman Islands
  - Cozumel
  - St. John
  - Virgin Gorda
- Great Barrier Reef
  - Heron Island
- Hawaii
  - Hawaii
  - Maui - Molokini

Museum Exhibitions

- South: The Race to the Pole. National Maritime Museum - 2001
- 2001 Building for Space Travel, Art Institute of Chicago - 2001
- Art of Engineering from NASA's Aeronautical Research, Art Institute of Chicago - 2003
- Beyond, American Museum of Natural History / Hayden Planetarium - 2008
- Full Moon: Apollo Mission Photographs of the Lunar Landscape, American Museum of Natural History / Hayden Planetarium - 2008
- Mapping the Universe, Adler Planetarium - 2008
- Dan Dare and the Future of High Tech Britain, Science Museum - 2008
- Alan Bean: Painting Apollo - First Artist on Another World, Smithsonian National Air and Space Museum - 2009
- Telescopes Through the Looking Glass, Adler Planetarium - 2010
- The Evolving Planet - The Field Museum 2011
- Out of This World: Science Fiction But Not as You Know It, British Library - 2011

Museum Exhibitions

- NASA I Art: 50 Years of Exploration, Figge Art Museum - 2012
- University of Iowa Space Pioneers: 54 Years of Exploration, Figge Art Museum - 2012
- Life in Space? Lunar Greenhouse, Museum of Science and Industry - 2013
- Leonardo da Vinci's Codex on the Flight of Birds, National Air and Space Museum - 2013
- Suited for Space, National Air and Space Museum - 2013
- Our Universes: Traditional Knowledge Shapes Our World, National Museum of the American Indian - 2014
- Spirit and Opportunity: 10 Years Roving Across Mars, National Air and Space Museum - 2014
- Moving Beyond Earth, National Air and Space Museum - 2014
- Explorer's Legacy: James Van Allen and the Discovery of the Radiation Belts, University of Iowa Libraries - 2016
- 50 Years of Star Trek, University of Iowa Libraries - 2016
- Hawkeyes in Space: UI Physics Past and Present, University of Iowa Old Capitol Museum - 2017

Museum Exhibitions

- Star Trek: Exploring New Worlds, The Henry Ford - 2019
- Apollo in the Archives: Selections From the Neil A. Armstrong Papers, Purdue University Libraries - 2019

Professional Memberships

- Current
  - Experimental Aircraft Association
- Past
  - Fellow, British Interplanetary Society
  - Cousteau Society
  - Planetary Society

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