24. Life Beyond Earth: Prospects for Microbes, Civilizations, and Interstellar Travel

We, this people, on a small and lonely planet Traveling through casual space
Past aloof stars, across the way of indifferent suns To a destination where all signs tell us
It is possible and imperative that we learn
A brave and startling truth.

Maya Angelou (1928 –)
American poet, from A Brave and Startling Truth

Agenda

- Announce
  - Observation 8pm Wednesday
  - Solar Labs due
- Lab: Instead do "Fate of the Universe" tutorial
- Ch. 24—Astrobiology
- Evolution

Arguments for Why Quotes from Yesterday are not science?

- Don't come from a scientist
- Not published in peer reviewed journal
- Do not support claims with evidence
- Do not refer to previous work
- Do not address huge literature addressing the issues raised
- Do not make testable predictions

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Richard Dawkins

- **So powerful is the illusion of design, it took humanity until the mid-19th century to realise that it is an illusion.** In 1859, Charles Darwin announced one of the greatest ideas ever to occur to a human mind: cumulative evolution by natural selection. Living complexity is indeed orders of magnitude too improbable to have come about by chance. But only if we assume that all the luck has to come in one fell swoop. When cascades of small chance steps accumulate, you can reach prodigious heights of adaptive complexity. That cumulative build-up is evolution. Its guiding force is natural selection.

How could an eye evolve?

24.1 The Possibility of Life Beyond Earth

Our goals for learning:

- Why do so many scientists now think that it's reasonable to image life on other worlds?

Are We Alone?

- Humans have speculated throughout history about life on other worlds.
  - it was assumed by many scientists & thinkers of the 17th & 18th Centuries
  - and widely accepted by the public at the turn of the 20th Century
  - scientists became more skeptical once we began to explore the planets
- Recent advances in astronomy and biology have renewed interest.
  - discovery of extrasolar planets indicate that planetary systems are common
  - indications that liquid water can exist on other worlds
  - organic molecules are found throughout the Solar System and Galaxy
  - geological evidence suggests life on Earth arose as soon as it was possible
  - discovery that living organisms can survive in the most extreme conditions
- This interest has spawned a new science called **astrobiology**.
  - the study of life in the Universe

24.2 Life in the Solar System

Our goals for learning:

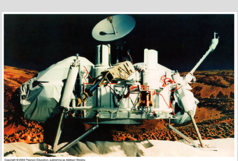
- Why does Mars seem a good candidate for life?
- What evidence have we so far collected concerning life on Mars?
- Which outer Solar System moons seem to be candidates for life, and why?

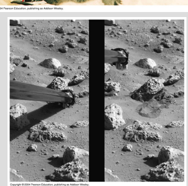
Best Candidate for Extraterrestrial Life

Mars at 2001 opposition
Hubble Space Telescope image

- Exploration of the Solar System has revealed…
  - no sign of large life forms/civilizations
  - we must search for <u>microbial</u> life
- Mars is the best candidate to host such life for these reasons:
  - Mars was apparently warm & wet for some periods in its distant past
  - these conditions, similar to early Earth, made it possible for life to evolve
  - it had the chemical ingredients for life
  - it has significant amounts of water ice
  - pockets of underground liquid water *might* exist if there is still volcanic heat

Viking Lander (1976)

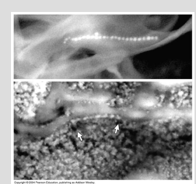


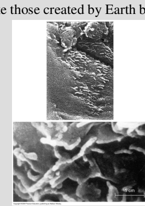


- We have searched for life on Mars.
- Viking scooped up soil and ran tests
  - looked for products of respiration or metabolism of living organisms
  - results were positive, **but** could have been caused by chemical reactions
  - no organic molecules were found
  - results inconsistent with life
- This is not the final word.
  - Viking only sampled soil on surface
  - took readings at only two locations
  - life could be elsewhere or underground

Martian Meteorites

- Rocks ejected by impact from Mars have been found in Antarctica.
- Analysis of one revealed…
  - it was 4.5 billion years old
  - landed on Earth 13,000 yrs ago
  - contained complex organic molecules & chains of crystals
  - like those created by Earth bacteria





- Also found fossils of nanobacteria.
  - recently discovered on Earth
  - not sure if life, but they have DNA
- Made the news, but since then…
  - structures seen could also be formed by chemical & geological processes
  - Earth bacteria have been found living in the meteorite
  - CONTAMINATED!

Possible Life on Jovian Moons

- Beneath its icy surface, Europa may have an ocean of liquid water.
  - tidal heating keeps it warm
  - possibly with volcanic vents on the ocean floor
  - conditions may be similar to how Earth life arose
  - life need not only be microbial
- Ganymede & Callisto may also have subsurface oceans, but tidal heating is weaker.

- Titan has a thick atmosphere and oceans of methane & ethane.
  - water is frozen
  - perhaps life can exist in liquids other than water
- Pockets of liquid water might exist deep underground.

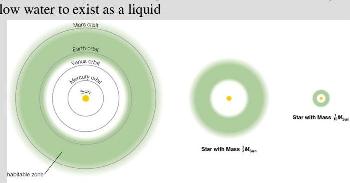
24.3 Life Around Other Stars

Our goals for learning:

- What do we mean by a star's habitable zone?
- Have we discovered habitable planets around other stars?
- Are Earth-like planets rare or common?

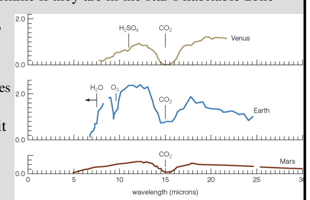
Which Stars make Good Suns?

- Which stars are most likely to have planets harboring life?
  - they must be old enough so that life could arise in a few x 10^8 years
    - this rules out the massive O & B main sequence stars
  - they must allow for stable planetary orbits
    - this rules out binary and multiple star systems
  - they must have relatively large **habitable zones**
    - region where large terrestrial planets could have surface temperature that allow water to exist as a liquid



Have We Detected Habitable Planets Around Other Stars?

- NO…our current technology is insufficient. A planet like Earth…
  - is too small to resolve or notice its gravitational pull on its parent star
  - would be lost in the glare of its parent star
- In 2007, we expect launch of the *Kepler* mission which will…
  - measure the light curves of stars to look for transits of Earth-sized planets
  - measure planets' orbits to determine if they are in the star's habitable zone
- In the next decade, NASA plans to launch *Terrestrial Planet Finder*.
  - an interferometer in space
  - take spectra and make crude images of Earth-sized extrasolar planets
- Spectrum of a planet can tell us if it is habitable.
  - look for absorption lines of ozone and water



Earth-like Planets: Rare or Common?

- Most scientists expect Earth-like planets to be common.
  - billions of stars in our Galaxy have at least medium-size habitable zones
  - theory of planet formation indicates terrestrial planets form easily in them
- Some scientists have proposed a "rare Earth hypothesis."
- Life on Earth resulted from a series of lucky coincidences:
  - terrestrial planets may only form around stars with high abundances of heavy elements
  - the presence of Jupiter deflects comets and asteroids from impacting Earth
  - yet Jupiter did not migrate in towards the Sun
  - Earth has plate tectonics which allows the CO_2 cycle to stabilize climate
  - our Moon, result of a chance impact, keeps tilt of Earth's axis stable
- There is debate about how unique these "coincidences" truly are.
  - we will not know the answer until were have more data on other planets in the Galaxy

24.4 The Search for Extraterrestrial Intelligence

Our goals for learning:

- What is the Drake equation and how is it useful?
- What is SETI?

How Many Civilizations Exist in the Galaxy with Whom We could make Contact?

N_{HP} = number of habitable planets in the Galaxy

f_{life} = fraction of habitable planets which actually contain life

f_{civ} = faction of life-bearing planets where a civilization has *at some time* arisen

f_{now} = fraction of civilizations which exist *now*

$$\text{Number of civilizations} = N_{HP} \times f_{life} \times f_{civ} \times f_{now}$$

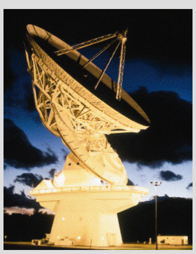
- This simple formula is a variation on an equation first expressed in 1961 by Cornell University astronomer Frank Drake.
- It is known as the **Drake equation**.

How Many Civilizations Exist in the Galaxy with Whom We could make Contact?

- We can not calculate the actual number since the values of the terms are unknown.
- The term we can best estimate is N_{HP}
  - including single stars whose mass < few $M_{\odot}$ AND…
  - assuming 1 habitable planet per star, $N_{HP} \approx 100$ billion
  - unless the "rare Earth" ideas are true
- Life arose rapidly on Earth, but it is our only example.
  - f_{life} could be close to 1 or close to 0
- Life flourished on Earth for 4 billion yrs before civilization arose.
  - value of f_{civ} depends on whether this was typical, fast, or slow
- We have been capable of interstellar communication for 50 years out of the 10 billion-year age of the Galaxy.
  - f_{now} depends on whether civilizations survive longer than this or not

Search for ExtraTerrestrial Intelligence

- IF we are typical of intelligent species and…
- IF there are many intelligent species out there…
  - then some of them might also be interested in making **contact**!
- That is the idea behind the SETI program.



- Use radio telescopes to listen for encoded radio signals.
  - search strategies are used to decide which stars to observe
  - now they scan millions of frequencies at once
- We sent a powerful signal once in 1974 to the globular cluster M13.
  - now we just listen
- Due to low chance of success and large amount of time required, SETI is now privately funded.

24.5 Interstellar Travel

Our goals for learning:

- Why is interstellar travel difficult?
- Will we ever achieve interstellar travel?

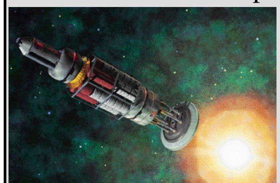
Why is Interstellar Travel Difficult?

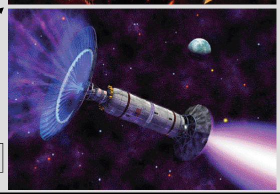
- The distance between the stars in HUGE!
- We will most likely be limited by the speed of light.
- Our current interstellar spacecraft, *Pioneers 10* & *11* and *Voyagers 1* & *2*, will take 10,000 yrs to travel 1 light-year.
  - our spacecraft need to go 10,000 times faster in order to travel to the stars within human lifetimes
- This will require new types of engines and new energy sources.
  - accelerating the *USS Enterprise* to half the speed of light would require 2,000 times the total annual energy output of the entire world
- Constructing a starship would be expensive.
  - would require political will and international cooperation
- Theory of Relativity will complicate life for space travelers.
  - a 50 l.y. round trip to *Vega* might seem like 2 years to the crew…
  - while 50 years has passed on Earth!

Starship Propulsion

- Chemical rockets are impractical for interstellar travel.
  - going faster requires more fuel, which make the ship more massive and harder to accelerate
- Nuclear powered ships produce more energy per kg of fuel.
  - two designs, employing fission & fusion, have been studied
  - the best they could achieve is 10% of the speed of light
  - travel to the nearby stars would take decades
- Matter-Antimatter engines would convert 100% of fuel to energy.
  - problem is where to get the fuel! antimatter does not exist naturally
  - producing large amounts of antimatter takes tremendous amounts of energy
  - storing antimatter is a big problem as well
- Ships that do not carry their own fuel:
  - solar sails would harness the photon pressure from sunlight
  - interstellar ramjets would scoop up Hydrogen from the ISM to fuel its nuclear fusion engine

Starship Propulsion





nuclear (H-bomb) powered

solar sail

interstellar ramjet

24.6 A Paradox: Where are the Aliens?

Our goals for learning:

- In what way is it surprising that we have not yet discovered alien civilizations?
- Why are the potential solutions to the paradox of “Where are the aliens?” so profound?

Where are the Aliens?

- With our current technology it is plausible that…
  - within a few centuries, we could colonize the nearby stars
  - in 10,000 years, our descendants could spread out to 100s of light years
  - in a few million years, we could have outposts throughout the Galaxy
- Assuming, like us, most civilizations take 5 billion yrs to arise.
  - the Galaxy is 10 billion yrs old, 5 billion yrs older than Earth
  - IF there are other civilizations, the first could have arisen as early as 5 billion yrs ago
  - there should be many civilizations which are millions or billions of years ahead of us
  - they have had plenty of time to colonize the Galaxy
- So…where is everybody? Why haven’t they visited us?
  - this is known as **Fermi’s paradox**
  - named after physicist Enrico Fermi, who first asked the question in 1950

Possible Solutions to Fermi’s Paradox

- We are alone.
  - civilizations are extremely rare and we are the first one to arise
  - then we are unique, the first part of the Universe to attain self-awareness
- Civilizations are common, but no one has colonized the Galaxy.
  - perhaps interstellar travel is even harder or costlier than we imagine
  - perhaps most civilizations have no desire to travel or colonize
  - perhaps most civilizations have destroyed themselves before they could
  - we will never explore the stars, because it is impossible or we will destroy ourselves
- There *is* a Galactic civilization.
  - it has deliberately concealed itself from us
  - we are the Galaxy’s rookies, who may be on the verge of a great adventure
- We may know which solution is correct within the near future!!

What have we learned?

- Why do many scientists now think that its reasonable to imagine life on other worlds?
  - Discoveries in astronomy and planetary science suggest that planetary systems are common and that we can reasonably expect to find many habitable worlds. Meanwhile, discoveries in biology suggest that life can survive in a wide range of environments and that it may arise relatively easily under conditions that ought to exist on many habitable planets.

What have we learned?

- Why does Mars seem a good candidate for life?
  - Mars was apparently warm and wet during at least some periods in its distant past, conditions that may have been conducive to an origin of life. It still has significant amounts of frozen water, and might have some pockets of liquid water underground.
- What evidence have we so far collected concerning life on Mars?
  - We do not now have any clear evidence of life on Mars. The Viking landers conducted experiments on the martian surface, but its overall results do not seem consistent with the presence of life in the samples it studied. One martian meteorite shows several intriguing lines of evidence of life, but each can also be explained in other ways.

What have we learned?

- Which outer solar system moons seem to be candidates for life, and why?
  - Europa probably has a deep, subsurface ocean of liquid water, and Ganymede and Callisto might have oceans as well. If so, it is possible that life has arisen and survived in these oceans. Titan may have other liquids on its surface, though it is too cold for liquid water. Perhaps life can survive in these other liquids, or perhaps Titan has liquid water deep underground.

What have we learned?

- What do we mean by a star's habitable zone?
  - The habitable zone extends over distances from the star at which a suitably sized terrestrial planet could have a surface temperature that might allow for oceans and life.
- Have we discovered habitable planets around other stars?
  - No, our current technology is not quite up to the task. However, upcoming missions should soon tell us whether terrestrial planets exist within the habitable zones of nearby stars, and missions a decade or two away may tell us whether these planets are habitable and perhaps even whether they have life.
- Are Earth-like planets rare or common?
  - We don't know. Arguments can be made on both sides of the question, and we lack the data to distinguish between them at present.

What have we learned?

- What is the Drake equation and how is it useful?
  - The Drake equation says that the number of civilizations in the Milky Way Galaxy is $N_{HP} \times f_{life} \times f_{civ} \times f_{now}$, where N_{HP} is number of habitable planets in the galaxy, f_{life} is the fraction of these habitable planets actually have life on them, f_{civ} is the fraction of the life-bearing planets upon which a civilization capable of interstellar communication has at some time arisen, and f_{now} is the fraction of all these civilizations that exist now. Although we do not know the value of any of these terms, the equation helps us organize our thinking as we consider the search for extraterrestrial intelligence.
- What is SETI?
  - It stands for the search for extraterrestrial intelligence, and generally refers to efforts to detect signals — such as radio or laser communications — coming from civilizations on other worlds.

What have we learned?

- Why is interstellar travel difficult?
  - The technological requirements for engines, the enormous energy demands, and social considerations all make interstellar travel a difficult undertaking. In addition, the limitation of travel at speeds less than the speed of light means that journeys will always take a long time as seen by people on Earth, although at substantial speeds the journeys may be much shorter for the travelers.
- Will we ever achieve interstellar travel?
  - Some technologies that could make interstellar travel possible, such as some methods of nuclear rocket propulsion or the use of solar sails, are already within our reach — at least in principle. Whether we ever achieve interstellar travel is thus primarily a question of political will and budgets.

What have we learned?

- In what way is it surprising that we have not yet discovered alien civilizations?
  - Given that we are already capable in principle of colonizing the galaxy in a few million years, and the fact that the galaxy was around for at least 5 billion years before the Earth was even born, it seems that someone should have colonized the galaxy long ago.
- Why are the potential solutions to the paradox of "Where are the aliens?" so profound?
  - Every category of its possible solutions has astonishing implications for our species and our place in the universe.

Suppose that someday we discover living organisms on Mars. How will we be able to tell whether these organisms arose independently from life on Earth or share a common ancestor with life on Earth?

a. Common ancestors should have a similar appearance.
b. Common ancestors should have many chemical similarities such as using DNA as its hereditary material.
c. If organisms arose independently on Mars they would likely be silicon, not carbon, based.
d. It would be impossible to tell, because even if they shared a common ancestor they would have evolved to be radically different organisms due to the different environments on each planet.

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a. This is likely because biosignatures were already detected on Europa by the Voyager 2 spacecraft.
b. This could happen because there is evidence for an ocean underneath the icy surface of Europa and water is a good place to look for life.
c. This is fantasy because it would take more than 20 years for a spacecraft to reach Saturn using current rocket technology.
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