Journey Back in Time

Astronomy, Physics, Geology and Biology have extended the history of our planet and universe back to the beginning time.

The cosmic calendar:
Midnight January 1st - the beginning of the universe.
12:59:59 PM December 31st - today
Compresses all of cosmic evolution into a single year

Review: The Scientific Search for Origins
How did our world come to be?

The formation of stars
The formation of planets
The origin and evolution of life

January-December
January

January 1st: The Big Bang 13.7 billion years ago – leaving the cosmic microwave background.

Early January: Dark ages - no stars just gas (first 400,000 years). Cosmic web forms and concentrates matter.

Mid January: The first stars (400 million years)

By end of January: The first galaxies formed (< 1 billion years)

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February – December (1 Billion years to present)

Galaxies continue to form, stars continue to form and die in galaxies

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January to December

The Creation of the Elements

Elements heavier than hydrogen and helium created in the centers of stars (Carbon, Oxygen, Nitrogen, Iron, Aluminum)

When stars die, they release some of these elements into the universe.

New stars form from the gas with the new elements.

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September 3rd (9 billion years): Our Solar System Forms

Protostar 300,000 years

Dust collects into planetesimals and eventually planets: 3 million years

Sun surrounded by disk of gas and dust: 1 million years

Planetesimals collide to form planets: 1-30 million years

Artist conception of supernovae explosion.
The Young Earth covered in oceans of lava: 30 million years

The Creation of the Terrestrial Planet Atmosphere Through Outgassing

Pu‘u O‘o crater on Hawaii’s big island. (Lanting, National Geographic)

After 500 Myr, the crust cools enough to solidify, and an atmosphere and oceans can begin to form. Atmosphere probably came from outgassing.

September 22nd: 11 billion years

First Single Cell Life - Bacteria
Layered rocks thought be mats of fossilized bacteria are found on the Canadian shores of Lake Superior

October - November (11.5-12.5 billion years)
Life Alters Earth’s Atmosphere and produces Oxygen
Bacteria convert CO₂ in O₂ through photosynthesis
Bacteria may have lived in stromatolites

Shark’s bay Australia
December: last billion years

- December 8: single cell animals (Eukaryotes)
- December 13: Jellyfish
- December 20: Fish first appear
- December 22: Animals first take to land
- December 26 to December 29: Dinosaurs
- December 31, 9 PM: early hominids
- December 31, 11:56 PM: modern Humans
- December 31, 11:59:35 PM: Agriculture begins
- December 31, 11:59:49 PM: Pyramids
- December 31, 11:59:59 PM: Galileo, Copernicus and Kepler
  - show how the planets go around the sun

Why do we think there could be life elsewhere in the universe?

The Copernican Principle: we do not occupy a special position in the Universe.
Since there is abundant life on Earth, there should be life elsewhere in the Universe.
But to this day, scientists have found no evidence for life around other planets. Due to
the vastness of space, detecting life around other planets is difficult.

Is there Life on Other Planets in our Solar System

In 1950s, there was optimism that life may exist elsewhere in our solar system - perhaps Venus or Mars.
Starting in the 1960, NASA began to explore the solar system with unmanned space probes.
Venus far too hot (800 Kelvin)
Mars cold and dry (but may have microbial life hidden somewhere).
Moons of Jupiter and Saturn may have oceans below their surfaces - could potentially harbor life.
Some possibility of life - but not of intelligent life.

SETI: The Search for Extraterrestrial Intelligence

Intelligent civilizations may occur around other stars, but those stars are very distant.
Proposed by Cocconi and Morrison in 1959 that radio waves can be used to communicate across the Galaxy.
SETI experiments look for either deliberate signals sent by other civilizations or leakage from radar, radio, television.
The difficulty is where to look and at what frequency.
The Galactic Water Hole

Frequencies between 1 and 8 GHz show lowest noise from atmosphere and galactic sources. Since any civilization with radio telescopes should know at the the atomic Hydrogen line at 21 cm, another civilization might choose a frequency close to the 21 cm line. Other approaches have been suggested.

Deliberate Signals

In 1974, a message was sent to the Globular Cluster M13 Coded 1679 bits (1 and 0) - designed to be a 23 x 73 picture. M13 is 25,000 light years away Globular clusters poor places for life to exist.

Leakage

Leakage is hard to detect since the signal is spread out over a larger range of frequencies. Leakage from Earth:

- Radar
- Television (60-600 MHz)
- Radio (FM is 78-105 MHz)
- Leakage is perhaps only 60-70 years old.

Alpha Centauri

The atomic Hydrogen HI line is at 1423 MHz
**SETI Searches to Date**

- **SERENDIP (II - IV)** - receiver piggy backs on radio telescope.

- **META and BETA** - Million/Billion Channel ExtraTerrestrial Assay (1995-1999) scanned 1400 to 1720 MHz

- **Project Phoenix** - scanned 800 stars at frequencies from 1200 MHz to 3000 MHz, could pick up leakages from nearest star (150 light years)

Under construction:
- **Allen Telescope Array**

**Optical SETI**

- In 1961, Schwartz and Townes suggested that optical pulses from lasers are a viable means of interstellar communication.

  - **Advantages** are that a precise frequency is not necessary.
  - **Disadvantage** is that the light would have to compete with light from the central star.

  - However, a high powered lasers coupled to a large telescope could create a pulses which could briefly be 10,000 times brighter than the Sun.

  - A number of optical SETI searches are underway.

**The Drake Equation**

Number of civilizations of which we might contact us:

\[ N = R \times f_p \times n_e \times f_l \times f_i \times f_c \times L \]

- **R** = rate of star formation in the Milky Way
- **f_p** = fraction of stars with planets
- **n_e** = number of habitable planets per star
- **f_l** = fraction of planets that develop life
- **f_i** = fraction of planets with life that develop intelligent life and civilizations
- **f_c** = fraction of civilizations that can communicate with us
- **L** = lifetime of civilizations

**To date nothing has been found**

What does this mean?

How many civilizations would we expect?
The Drake Equation

Number of civilizations of which we might contact us:

\[ N = R \times f_p \times n_e \times f_l \times f_i \times f_c \times L \]

Example:

- \( R = 10 \) stars form per year in our Galaxy
- \( f_p = 0.5 \)
- \( n_e = 1 \)
- \( f_l = 0.001 \)
- \( f_i = 0.0001 \)
- \( L = 10,000 \) years

\[ N = 10 \times 0.5 \times 0.01 \times 0.001 \times 10^4 \text{years} = 5 \times 10^{-5} \]

The Megeath Equation

Number of left handed, near sighted, red haired optometrist in Ohio:

\[ N = R \times f_p \times f_n \times f_l \times f_o \times L \]

- \( R \) = rate of people born in Ohio
- \( f_p \) = fraction of people with red hair
- \( f_n \) = fraction which are nearsighted
- \( f_l \) = fraction which are left handed
- \( f_o \) = fraction which become optometrist
- \( L \) = average lifespan

The Drake equation is just a standard approach of breaking the problem into smaller pieces.
What Fraction of Stars Have Planets:
First approach: how many have disks capable of forming planets

- Start: disk of gas and dust
- Dust grains start sticking together to form larger and larger objects.
- Planets form in disk, the larger planets accreting gas and forming gas giants.
- 3,000,000 years

Around 75% of all young stars have disks

Dust in disk absorbs and scatters visible light from nebula, creating shillouette.

Around 75% of all young stars have disks

- What Fraction of Stars Have Planets:
  - First approach: how many have disks capable of forming planets

Second Approach: Detecting Planets
Detecting Planets by Watching Stars Wobble

- Measuring a star’s Doppler shift can tell us its motion toward and away from us
- Current techniques can measure motions as small as 1 m/s (walking speed!)

First Extrasolar Planet

- Doppler shifts of star 51 Pegasi indirectly reveal a planet with 4-day orbital period
- Short period means small orbital distance: 0.05 AU (same as Mercury)
- But mass = 0.5 \( M_{Jupiter} \)
- First extrasolar planet to be discovered (1995) Mayor & Queloz

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Second Approach:
Detecting Planets with Planetary Transits

Known Exoplanets to Date
This figure is out of date, now there are 346!!

Most found by measuring the motions of stars being tugged by planets.
You can find lists of exoplanets at:
http://exoplanets.org
http://exoplanets.eu

What are the Characteristics of Planets: Sizes and Masses

But many (all?) of these are not habitable: Many are too big and hot
Astronomers have measured their orbital motions!

Second Approach: Direct Imaging of Planets

These Planets are too Big and Too Cold

Current status:

About 75% of young stars have the raw material needed to make planets.

12% of stars have giant planets

So there are a large number of stars with planets!!

What is the number of habitable planets per planetary system?

Where can life survive?

Earth is only planet in our solar system with abundant life

Three requirements for life on Earth

1. A source of nutrients
2. Energy from sunlight, chemical reactions, or from the Earth itself
3. Liquid Water - water important solvent and plays an essential role in the chemistry of life.

The presence of liquid water is perhaps the most stringent of the requirements.
Are habitable planets likely?

The Habitability Zone (HZ)

Gliese 581 bcde

Gliese 581 bcde

M3 stars only 20 light years from Earth. Stars is 0.013 solar luminosities. Two planets of edge of habitable zone.
Gliese 581 bcde

Detected Earth-like Planets with Kepler

Launch of Kepler Satellite on March 6, 2009

Where Kepler will look...
Kepler Mission

None of these are habitable – but the mission has just started

If we find planets, will they have life?

What kind of life will it have?

Can we determine the fraction of planets with life?

Or at least, can we determine the fraction of planets with slime.....?

Kepler Planets So Far

Microbial Mats in Yellowstone National Park

Microbial mats are colonies of microbes. Currently they exist typically in extreme environments. However, for much of the Earth’s history, they were probably the dominant form of life.
The Earth was a Slime Worlds

Fossil Microbial mats found in Sweden

The History of Life

- Cyanobacteria paved the way for more complicated life forms by releasing oxygen into atmosphere via photosynthesis.
- Oldest fossils show that bacteria-like organisms were present over 3.5 billion years ago.
- About 2.4 billion years ago, Oxygen became abundant.
- Multicellular organisms appear 1.2 billion years ago.
- Animals appear less than 1 billion years ago, they become abundant around 500 Myr ago.

Origin of Oxygen

- Cyanobacteria paved the way for more complicated life forms by releasing oxygen into atmosphere via photosynthesis.
- Oldest fossils show that bacteria-like organisms were present over 3.5 billion years ago.
- Carbon isotope evidence pushes origin of life to more than 3.85 billion years ago.
- About 2.4 billion years ago, Oxygen became abundant.

Measuring the Fraction of Planets with Life: The Transformation of Earth’s Atmosphere

It may be possible to search for life on other planets by using spectroscopy looking for Oxygen.
Spectral Signatures of Life on Exoplanets

Detection of O₃ (Ozone) by future space telescopes would indicate presence of life.

How difficult is interstellar travel?

Fermi’s Paradox

- Plausible arguments suggest that civilizations should be common, for example:
  - Even if only 1 in 1 million stars gets a civilization at some time ⇒ 100,000 civilizations
  - Many should be more advanced than we (?)
  - So why we haven’t they contacted us?

Possible solutions to the paradox

1) We are alone: life/civilizations much rarer than we might have guessed.
   - Our own planet/civilization looks all the more precious...
Possible solutions to the paradox

2) Civilizations are common but interstellar travel is not. Perhaps because:
   - Interstellar travel more difficult than we think.
   - Desire to explore is rare.
   - Civilizations destroy themselves before achieving interstellar travel

3) Interstellar Nature Reserve hypothesis
4) We will contact a civilization in the future.

Current Spacecraft

- Current spacecraft travel at <1/10,000 c; 100,000 years to the nearest stars.

Where are Voyager and Pioneer Spacecraft Now?

Most distant objects is Voyager 1 at 100 AU (0.0016 light years) and moving at 6 x 10^-5 c (the speed of light)

Difficulties of Interstellar Travel

- Far more efficient engines are needed
- Energy requirements are enormous
- Ordinary interstellar particles become like cosmic rays
- Time dilation makes space travel possible in a human lifetime, but with social complications.
Project Daedalus

Concept for unmanned probe to Banard's star (5.9 light years away).

Fusion Rocket

50 year flight time

12% speed of light

Would send probes in advance to search for planets around Banard star.

Time Dilation: A Result of Einstein’s Theory of Relativity

- The distance to Vega is about 25 light-years
- But if you could travel to Vega at 0.999c, the round trip would seem to take only two years!
- At that speed, the distance to Vega contracts to only 1 light-year in your reference frame
- Going even faster would make the trip seem even shorter!

A Journey to Vega

- However, your twin on Earth would have aged 50 years while you aged only 2
- Thus, it is possible to travel to the stars, but you would leave behind everyone you knew on Earth.
- We don’t possess the technology to travel near the speed of light.
- Accelerating the space shuttle to 0.999 speed of light would require 40,000 times the total amount of energy produced in one year in the U.S.

Shortcut through Spacetime

- Some mathematical solutions of the equations of general relativity allow for shortcuts called wormholes that are tunnels through hyperspace
- We have no idea how to build one!!
But we can’t leave now….

--and the earth is getting more crowded:

there are 50 people per square kilometer of non-ice covered land

(that is 128 people per square mile)

Pale Blue Dot

Look again at that dot. That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives. The aggregate of our joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every king and peasant, every young couple in love, every mother and father, hopeful child, 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
1934-1996

Summary

Events leading up to life on Earth
SETI - search for radio signals and light pulses from other civilizations (no signals yet).

Drake equation - simple method for quantifying the uncertainties in estimating the number of civilizations. We don’t know all the terms in this equation, but we are improving our knowledge by:

Determining the number of stars with planets by searching for planets and nascent planetary systems (in progress – 75% of young stars have material needed to make planets – 12% of stars have giant planets)

Determining the number of planets in the habitable zone – i.e. at the right distance where liquid water can exist (some larger planets in habitable zones have been detected – but the detection of Earthlike planets in habitable zones has not yet been achieved. Kepler mission may detect such a planet in the next year).

Determining the planets with life (may be done by detecting oxygen in atmosphere)

Most planets may be slime worlds without animal life (our planet was a slime world for most of its lifetime).

Travel to other star systems very difficult (but not impossible).