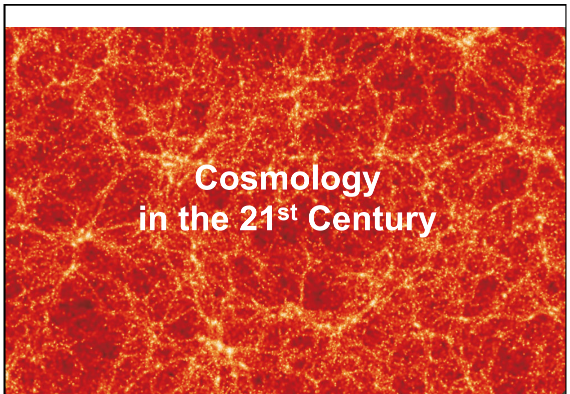


Cosmology

- Cosmology attempts to answer big questions:
  - What was the origin of the Universe?
  - What is fate of the Universe?
  - Is the Universe infinite or limited?

- **The Universe** means everything: all matter, all energy, and even all of space.

- Thus there is no “edge” or “wall” to the universe
- A wall or edge divides inside from outside, but there is nothing “outside” the universe!

Everywhere you look you see a tree/star

Olbers’ Paradox

Is the Universe infinite?

In the 1820’s Heinrich Oblers noted that if the universe is infinite, then every line of sight should end on the surface of a star eventually.

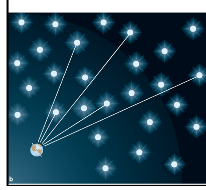
The night sky should be as bright as the surface of stars!

So, why is the sky dark at night?

Solution to Olbers’ Paradox

Why is the sky dark at night?

If the universe had a **beginning**, then we can only see light from galaxies that has had **time to travel** to us since the beginning of the universe.



•The speed of light is not infinite

•The age of the universe is not infinite

We can only see **part** of the universe:

The Observable Universe

Isotropy

- No matter where we look, the Universe looks roughly the same
- No preferred or special direction
- The Universe is “isotropic”

Homogeneity

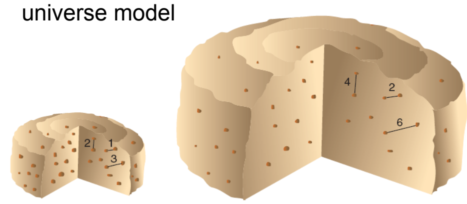
- No matter where we are, the Universe contains the same stuff
- No preferred or special location
- The Universe is “homogeneous”

Isotropic + Homogeneous = Cosmological Principle

- The Cosmological Principle states that any observer in the Universe should see the same basic features
- This reinforces the no edge, no center
- This applies on a **large scale**

Expansion of the Universe

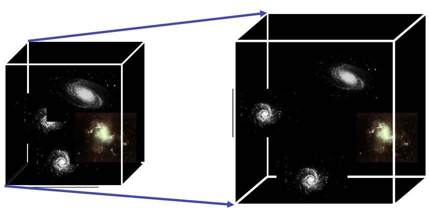
- Almost all galaxies are moving away from us, and more distant galaxies are moving away faster (Hubble's Law).
- We can explain this with an expanding universe model



The Expanding Universe

Space itself is a significant part of the universe.

In the universe, **space** is expanding, carrying the galaxies along!



Cosmology Overview (so far):

- The Universe: Everything
- Observable Universe: Everything we can see
- The Universe has no special locations
  - No edges
  - If no edges, then no center

Expansion of the Universe Lecture Tutorial: Pg. 161-162

- Work with a partner or two
- Read directions and answer all questions carefully. Take time to understand it **now**!
- Discuss each question and come to a **consensus** answer you all agree on before moving on to the next question.
- If you get stuck, ask another group for help.
- If you get **really** stuck, raise your hand and I will come around.

Consider three widely separated galaxies in an expanding universe. Imagine that you are located in Galaxy A and observe that both Galaxies B and C are moving away from you. If you asked an observer in Galaxy C to describe how Galaxy B appears to move, what would he or she say?

A. Galaxy B is not moving
B. Galaxy B is moving towards Galaxy C
C. Galaxy B is moving away from Galaxy C

If our universe is expanding, what are the implications for the separations between two stars within our galaxy?

A. The two stars are moving farther apart
B. The two stars are moving closer together
C. The distance between the two stars is not affected

The Big Bang

- Galaxies are moving away from us now.
- If we play the movie backward, we would see them getting closer
- This initial "explosion" of matter outward is called **The Big Bang**

Not an explosion which occurred in one place: it was everywhere! The Universe was just smaller back then.

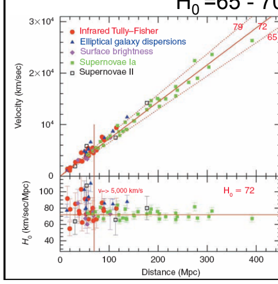
The Age of the Universe

- The Big Bang gives us a start: a point when we can start keeping track of time
- This tells us that the Universe isn't infinitely old; it has an age!
- The Hubble Constant $\mathbf{H_0}$ measures how fast the Universe is expanding: Within every ~3 million light years in space, MORE SPACE is created at a rate of 70 km every second!

The Age of the Universe

Using various techniques, astronomers have determined the Hubble Constant:

H_0 =65 - 70 km/s / Mpc



Using this value of the Hubble Constant it is possible to determine the age of the Universe:

The Universe is about:
13.8 billion years old.

Predictions of the Big Bang Theory

- Like any good theory, the Big Bang Theory must make predictions which are confirmed by observation.
- The Big Bang Theory makes three such predictions:

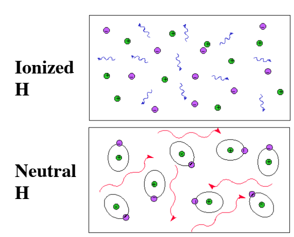
1. It predicts a **Cosmic Microwave Background** (CMB)
2. It predicts small variations in this CMB
3. It predicts the abundances of light elements (Hydrogen, Helium…)

Cosmic Microwave Background

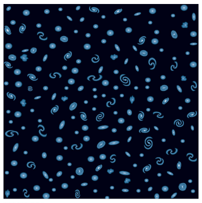
- The early Universe was very hot, ionized, and opaque.
- As the Universe expanded, it cooled.
- 400,000 years after the Big Bang, it had cooled to 3000 K
- Electrons joined protons to form the first hydrogen atoms

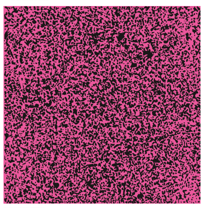
•The universe was no longer opaque, and the light could fly freely.

•The Big Bang Theory says we should *still see this light today.*

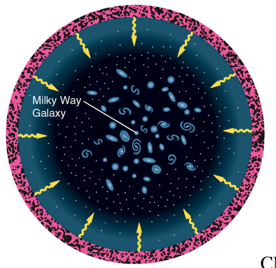


Looking Back Towards the Early Universe



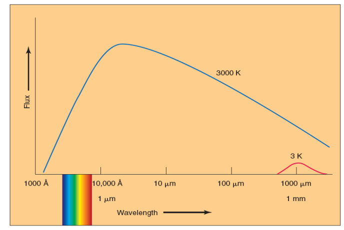


The more distant the objects we observe, the further back into the past of the universe we are looking.



CMB

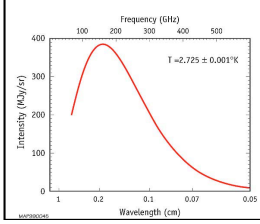
Cosmic Microwave Background



- The wavelength of this light from the Big Bang would have stretched with the expansion of the universe.
- It should have a temperature of about 3º K.
- It would now have a wavelength in the microwave region

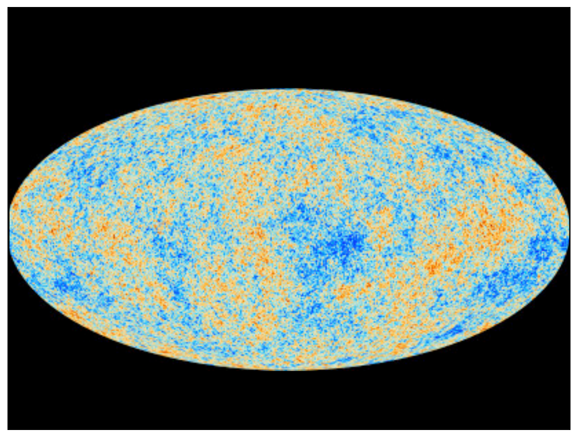
Cosmic Microwave Background

- To their surprise, the static remained.
- It came from every part of the sky.
  - So it could not be from our solar system
- It had a "black body" spectrum with a temperature of about 3º K.



They had discovered the **Cosmic Microwave Background** predicted by the Big Bang Theory

They won the **Nobel Prize** in Physics in 1987!



The Big Bang Lecture Tutorial: Pages 165-168

- Work with a partner or two
- Read directions and answer all questions carefully. Take time to understand it **now**!
- Discuss each question and come to a **consensus** answer you all agree on before moving on to the next question.
- If you get stuck, ask another group for help.
- If you get **really** stuck, raise your hand and I will come around.

Primordial Nucleosynthesis

- The Universe is made up of:
  - Hydrogen (H) & Helium (He)
  - Lithium (Li) & Deuterium
  - Heavier elements like Carbon, (C), Nitrogen (N), Oxygen (O)
- We know that the heavy elements (C,N,O, etc.) are made inside stars by nuclear fusion.
- Stars can also make He, but not as much as is found in the universe…
- Where did the "Primordial" He, H, Li come from?

Primordial Nucleosynthesis

- A long time ago, the universe was:
  - Smaller
  - Denser
  - Hotter
  - Like an ionized gas

Primordial Nucleosynthesis

- Amount of each element created depends on the density of the early universe
- In order to get the abundances of lithium and deuterium that we observe today, the universe had to contain dark matter

Hot vs. Cold Dark matter

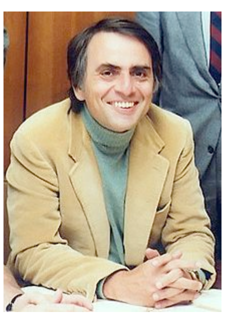
- Temperature -> speed of particles and ability to "clump together"
- Neutrinos would be a form of Hot Dark Matter

- But… most successful theories need Cold Dark Matter

How has Dark Matter affected galaxy formation?

- Early universe is hotter -> more high-energy photons
- Regular matter must be able to cool off and clump up to create stars and galaxies
- Dark matter can form clumps earlier than regular matter

"We are star stuff."
-Carl Sagan



"We are amplified quantum fluctuations."
-Lloyd Knox

The Fate of the Universe

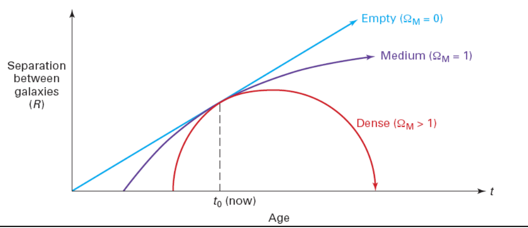
- It's expanding now… will it keep going?
- The universe has several possible fates:
  - The current expansion could continue forever (Big Freeze)
  - The expansion could halt, and reverse (Big Crunch)
  - Or, it could stop expanding and become stable

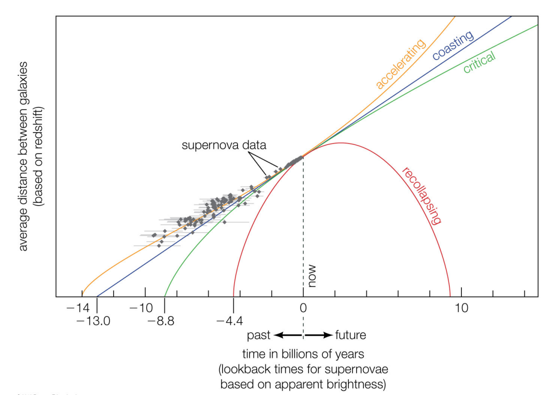
The Fate of The Universe

- The expansion depends upon the gravity that each galaxy feels from the rest of the universe
- If there is enough **mass** in the universe, then it will have enough gravity to halt the expansion.
- The *density* (ρ) of the universe is its average **mass** per volume.
- If the *actual density* is greater than a *critical density* ($\rho_{critical}$), then the universe will collapse.

The Fate of The Universe

- The true density divided by the critical density is called "Omega" $\Omega = \rho_{true} / \rho_{crit.}$
- If Ω >1, universe will collapse. ("Closed" Universe)
- If Ω <1, universe will expand forever. ("Open" Universe)
- If Ω =1, universe will gradually slow its expansion ("Flat" Universe)





Searching for Life:

- What does life look like here?
- How did Earth get life?
- Is Earth ordinary or extraordinary?

If Earth is ordinary, where is everyone else?

Life in the Universe

- The Earth formed about 4.5 billion years ago
- The oceans formed about 4.1 billion years ago
- It appears that life arose very quickly on Earth: 3.8 billion years ago
- Perhaps life could easily form on other planets as well….

Laboratory Experiments

- Miller-Urey experiment (and more recent experiments) shows that building blocks of life form easily and spontaneously under conditions of early Earth.
- Building blocks of life… but no life yet!

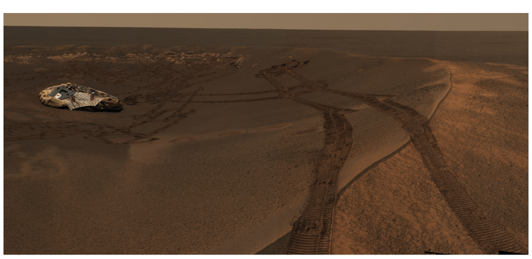
Is Life Possible Elsewhere?

- Life arose early and quickly on Earth
- Complex organic molecules form easily from ingredients and conditions on the young Earth
- Living organisms exist in extreme environments on Earth

Extremophiles

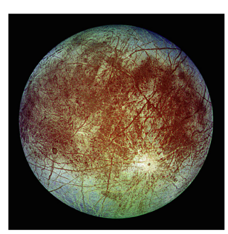
- We find life almost *everywhere* on Earth!
- Organisms that thrive in extreme environments:
  - Volcanoes (high temperatures)
  - Ice Caps (low temperatures)
  - Acidic environments
  - Salty environments
  - Dry environments

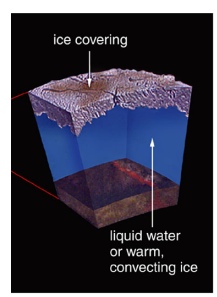
Searches for Life on Mars



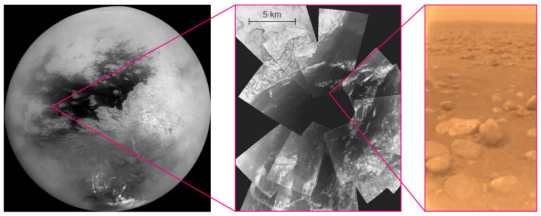
• Mars had liquid water in the distant past
• Still has subsurface ice; possibly subsurface water near sources of volcanic heat.

Could there be life on Europa or other jovian moons?





Titan



- Surface too cold for liquid water (but deep underground?)
- Liquid ethane/methane on surface

Are “habitable planets” common?

Definition:

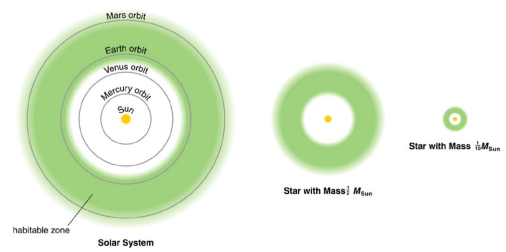
A **habitable** world contains the basic necessities for life as we know it, including liquid water.

- It does *not* necessarily have life.

Constraints on star systems:

1) Old enough to allow time for evolution (rules out high-mass stars - 1%)
2) Need to have stable orbits (*might* rule out binary/multiple star systems - 50%)
3) Size of “habitable zone”: region in which a planet of the *right size* could have liquid water on its surface.

Even so… billions of stars in the Milky Way seem at least to offer the possibility of habitable worlds.



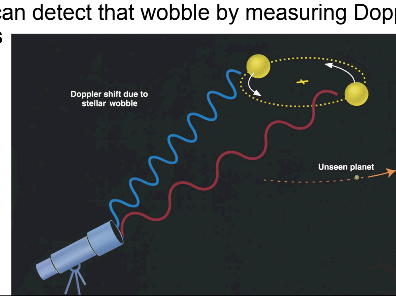
The more massive the star, the larger the habitable zone — higher probability of a planet in this zone.

Planet Search Methods

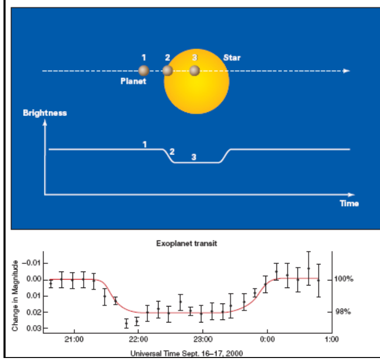
- Doppler Effect
  - Detect wobble toward or away from us
- Astrometry
  - Detect side-to-side wobble
- Transits
  - Search for “eclipses” as the planet passes in front of the star.
- IR imaging
  - A first glimpse at the light from planets!

Doppler Method

- Planets orbiting other stars “tug” on their star a bit
- The star wobbles when the planet tugs on it
- We can detect that wobble by measuring Doppler shifts



Transit Method



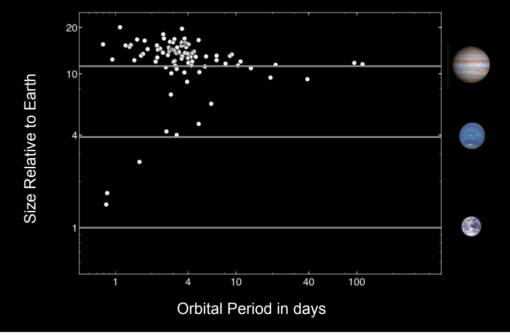
A few planets have now been discovered using the **Transit Method**.

If a planet happens to transit its host star:

We can learn the size of the planet

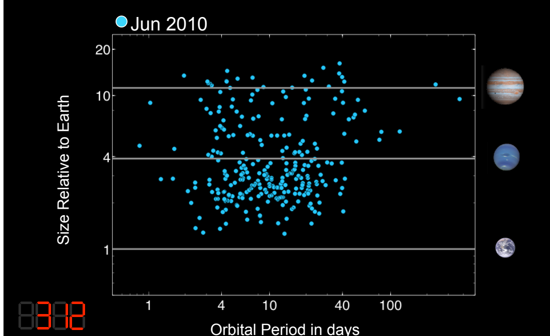
We might see the planet's atmosphere.

Transiting Planets pre-Kepler



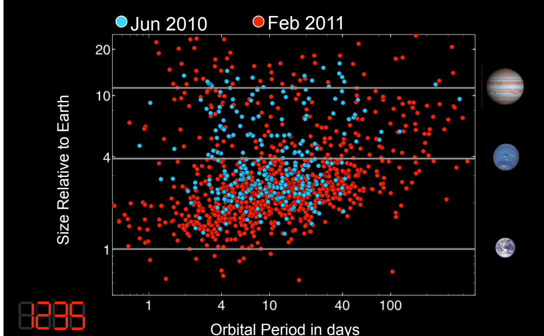
Candidates as of June 2010

Data: May-Sep 2009



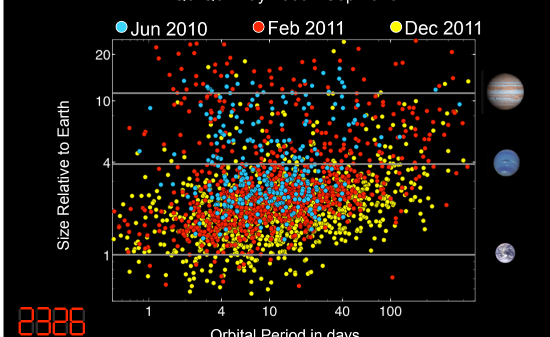
Candidates as of Feb 2011

Q0-Q5: May 2009 - Jun 2010

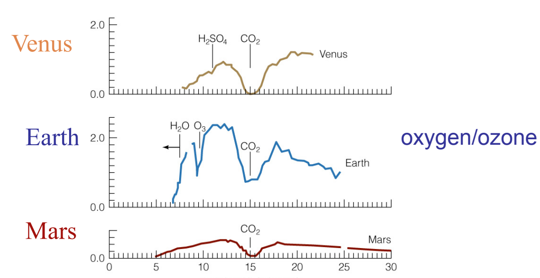


Candidates as of Dec 2011

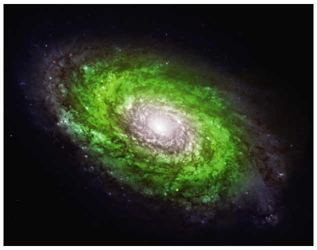
Q0-Q6: May 2009 - Sep 2010



Spectral Signatures of Life



Elements and Habitability

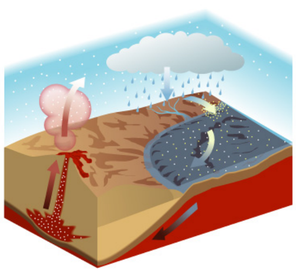


- Do we require heavy elements (Carbon, Iron, Calcium, Oxygen) in precise proportions?
- Heavy elements are more common in stars in the disk of the Milky Way
- A galactic habitable zone?

Impacts and Habitability

- Are large planets (like Jupiter and Saturn) necessary to reduce rate of impacts?
- If so, then Earth-like planets are restricted to star systems with Jupiter-like planets

Climate and Habitability



- Are plate tectonics necessary to keep the climate of an Earth-like planet stable?

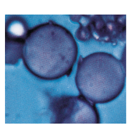
The Bottom Line

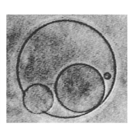
We don't yet know how important or negligible these concerns are.

Looking for Life:

- Any life:
  - bacteria, microbes, blue-green algae
- Intelligent life:
  - beings that can build telescopes and are interested in talking to us

Probes to other planets are very expensive, but radio signals are cheap!

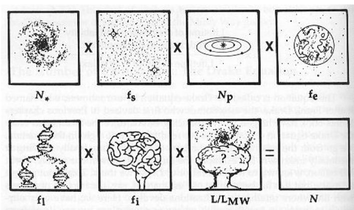




SETI experiments look for **deliberate** signals from E.T.

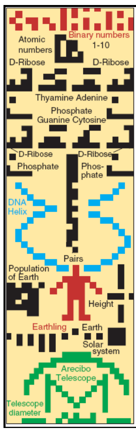
The Drake Equation

- In 1961 Astronomer Frank Drake tried to calculate the number of ET civilizations in our galaxy, **N**
- His calculation is known as the Drake Equation



We do not know the values for the Drake Equation!

Variables	Pessimistic	Optimistic
Number of stars per galaxy	2×10^{11}	2×10^{11}
Fraction of stars with planets	0.01	0.5
Planets per star in life zone for over 4 billion years	0.01	1
Fraction of suitable planets on which life begins	0.01	1
Fraction of planets with life where intelligence evolves	0.01	1
Fraction of star's life during which a technological society survives	10^{-8}	10^{-4}
Number of communicative civilizations per galaxy	2×10^{-5}	10×10^{6}



Communicating with ET

- November 16, 1974, astronomers sent a message about people on Earth toward the globular star cluster M13 in the constellation Hercules.
- The message was intended to be easy to decode.
- M13 is 25,000 light years away

We won't get an answer for at least 50,000 years!


M 13 Globular Cluster

SETI

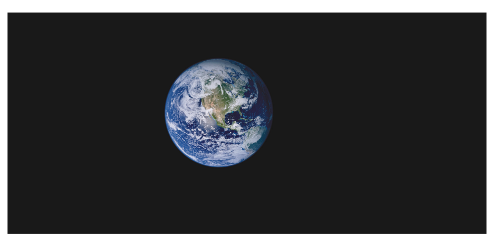
- **Listening:** We can easily listen for signals from ET
- Most searches are done in radio waves because they are low-energy
- The first search was started in 1960.

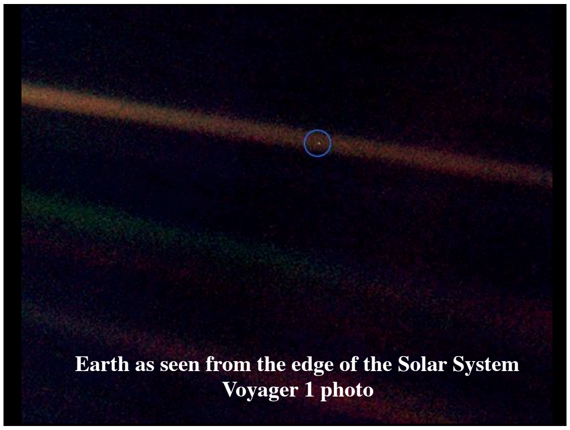
Now, several searches are underway including one at Arecibo in Puerto Rico

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 $\Rightarrow$ 100,000 civilizations
- So why we haven't we detected them?

Possible solutions to the paradox




Earth as seen from the edge of the Solar System
Voyager 1 photo