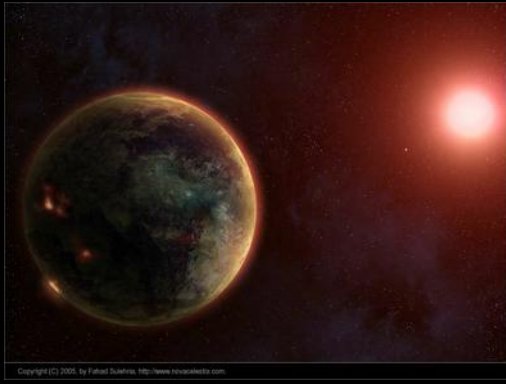
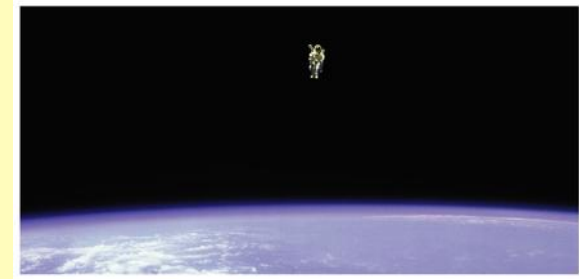


The Search for Extraterrestrial Life



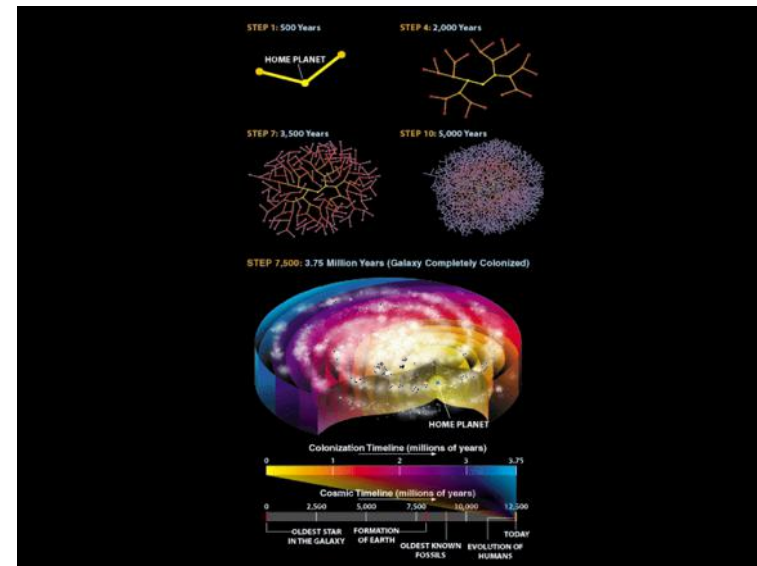
The Fermi Paradox

Q: One of the "big" questions: Are we alone?



• Enrico Fermi, 1950: *"So where is everybody?"*

- if Earth-like worlds are even *somewhat common*, there could be *many civilizations* in our galaxy
- even at *sub-light speeds*, a civilization could "colonize" most of galaxy in ~ *millions of years* (eg) *How much have humans done in 100 years?*
- colonize *even faster: Von Neumann machines*
- *we're already doing this! (eg) MER, Voyager*
- **Fermi Paradox:**
 - (1) If we are *not* unique, galaxy *should* be colonized
 - (2) We see *no evidence* of this
- *so where is everybody?*



- several solutions to **Fermi Paradox**

(1) we are **unique & alone in the universe**

(2) civilizations exist **but do not travel far in space**

Q: Why not?

- **technological problems**
- **sociological issues (eg) NASA funding cuts**
- **self destruction (!)**

(3) civilizations exist **but don't interfere**

- **“The Prime Directive”** - avoid primitive cultures

Life on Earth

- **microscopic fossil** evidence of life ~ **3.5+ Gy** ago

- **some meteorites & comets** contain organic molecules

- **primitive atmosphere:** CH₄, H₂, H₂O

- **Miller-Urey experiment**

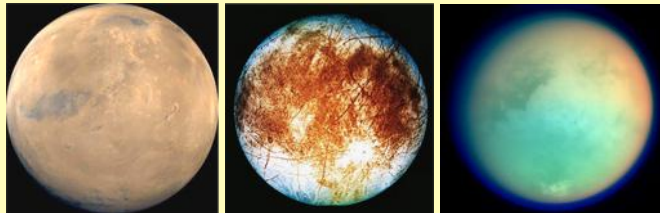
- life arose fairly **quickly** – **but is it likely?**

DVD: Cosmos-“Miller-Urey”



Life in the Solar System

- **Mars, Europa & Titan** all have conditions which approximate **“extremophile”** regions on **Earth**

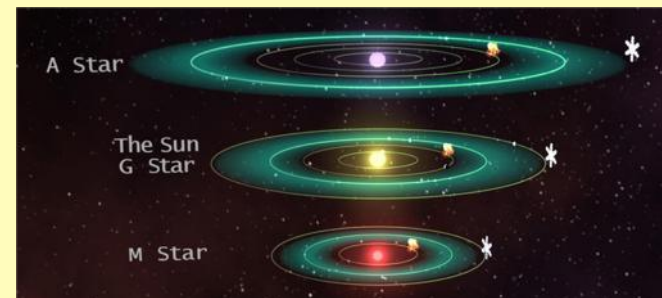


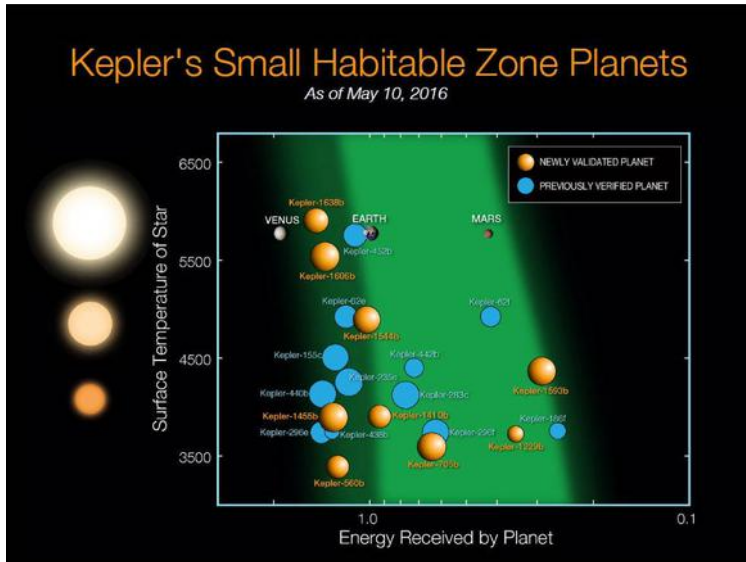
- **in the past, Mars** was likely **much more hospitable**

Habitable Zone

Q: How common are planets that can support life?

- **habitable:** can sustain life **as we know it** (water)
- depends on **parent star, elements available, orbits**





Life in the Universe

- look for **life** beyond our solar system

Q: *Where do we start? How do we look?*

- look for **planets** around a star like **Sol**

Q: *How? Why are extrasolar planets hard to see?*

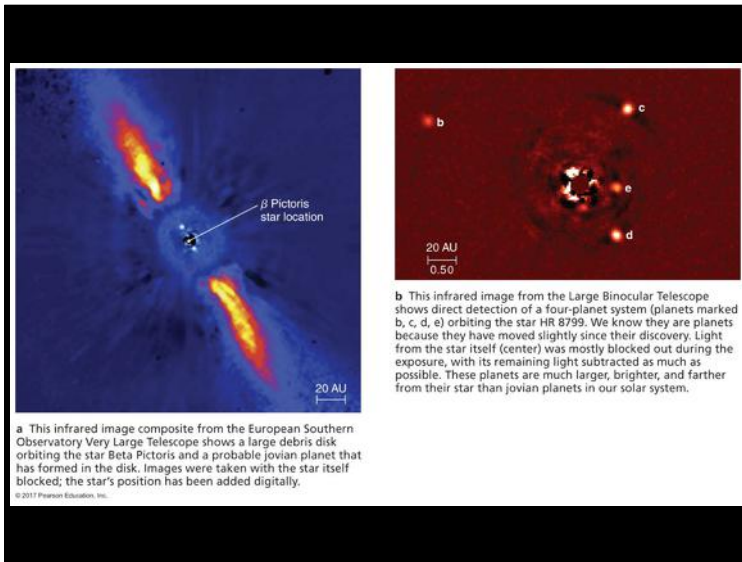
Pale Blue Dot

- Voyager 1, 1990: ~ **6.4 billion km** away

Finding Extrasolar Planets

- viewing extrasolar planets **directly** is a challenge

- most search for planets **indirectly** using **position**, **spectrum** or **brightness** of parent star
- since 1995, ~**400 extrasolar planets** (*pre-Kepler*)
- early exoplanets tended to be **large & close**

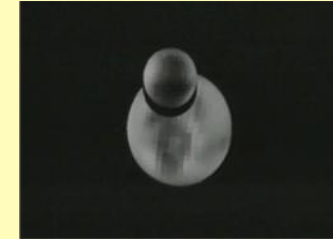


Astrometric method

- carefully view the *position* of a star over time as it *orbits about the center of mass of its solar system*

- “wobble” results from *planets' gravitational pull*

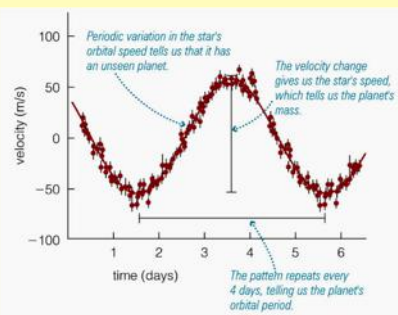
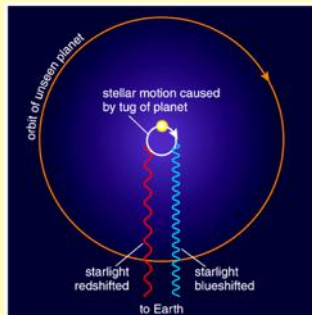
- best for *massive planets* far enough away to result in larger “wobbles”



(eg) Sun @ 10 ly away has 12 year wobble due to Jupiter of $\sim 1/1,000,000^\circ$ (a hair seen from 5 km)

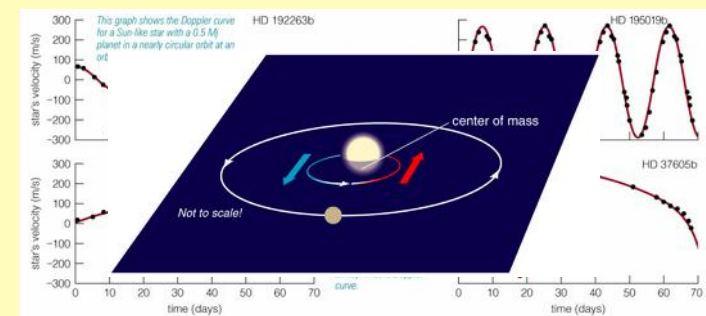
“Radial Velocity” method

- most common technique
- view *spectrum* of a star over time



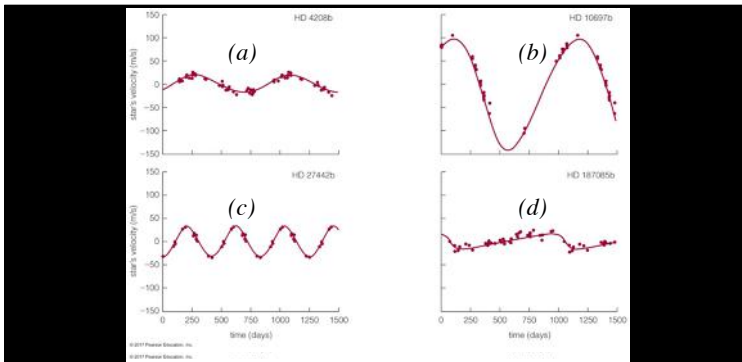
- best for *massive planets* close to the parent star

- doppler shift curve gives *mass, orbit period/shape*



- only works if orbit *at least slightly* “edge on”
- underestimates* velocity (& thus mass) of planets

(eg) Jupiter causes a wobble of ~ 13 m/s in the Sun; Earth 0.1 m/s; we can readily detect ~ 1 m/s.



CLICKER: assuming the same sized star for each graph above, which curve above shows:

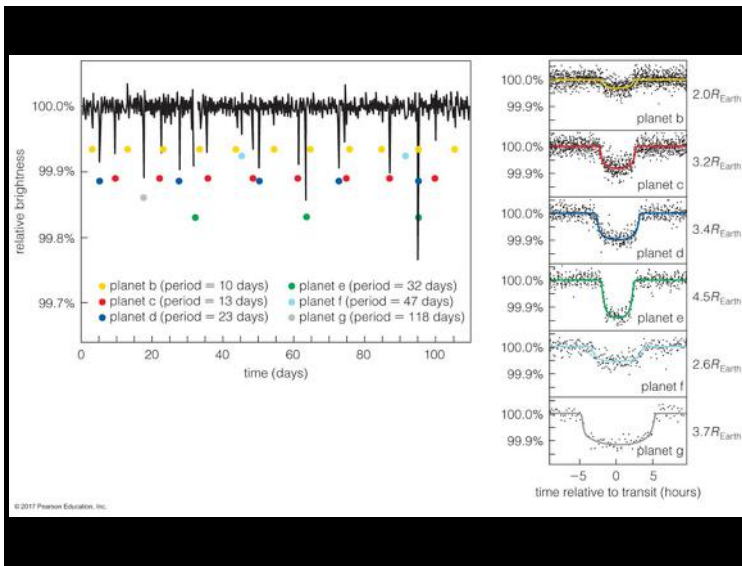
- the planet with the fastest orbit
- the planet with the most elliptical orbit
- the planet with the largest mass

“Light Curve” method

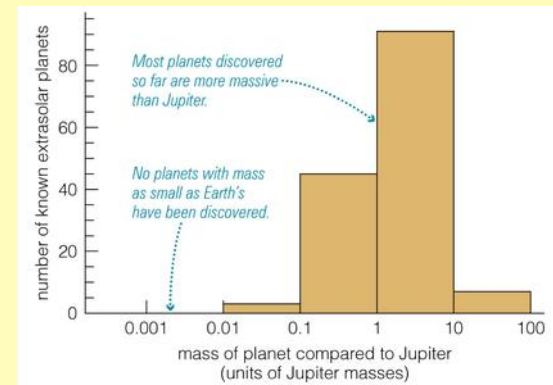
- aka "*transit photometry*" method
- *amount* of light blocked: **size of planet**
- *time* between transits: **orbital period**
- *duration* of transit: **orbital velocity**
- *only* viewpoint to yield **correct mass** *Q: Why?*



(eg) Jupiter transiting Sun results in about a 1% reduction in brightness; can detect ~ 0.01% drop

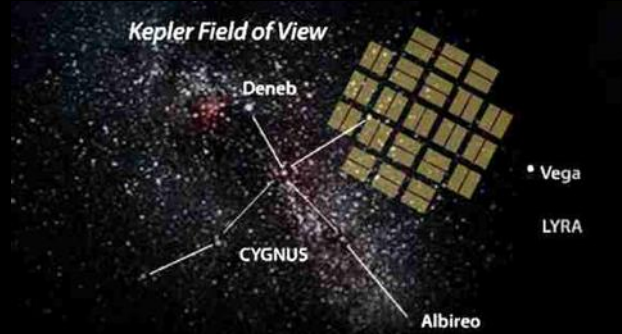


Pre-Kepler findings...



- **biased** to detect **more massive planets**; *Why?*

Kepler (2009-2018)



- *transit method* for 100,000 systems in *Cygnus*
- "*K2*" mission extension 2014 - 2018

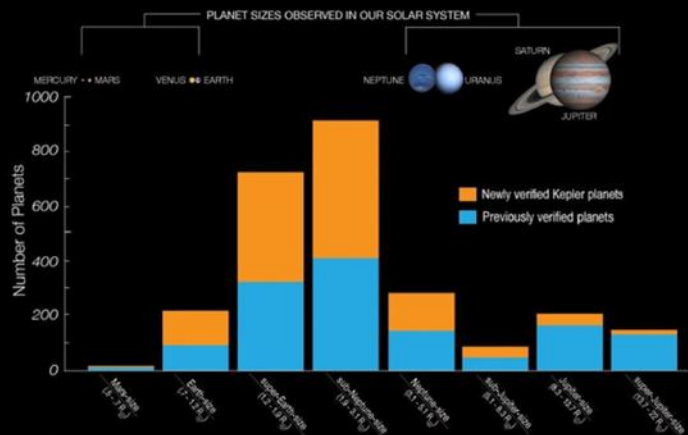
TESS (2018-)



- 2 year "all sky" widefield version of Kepler

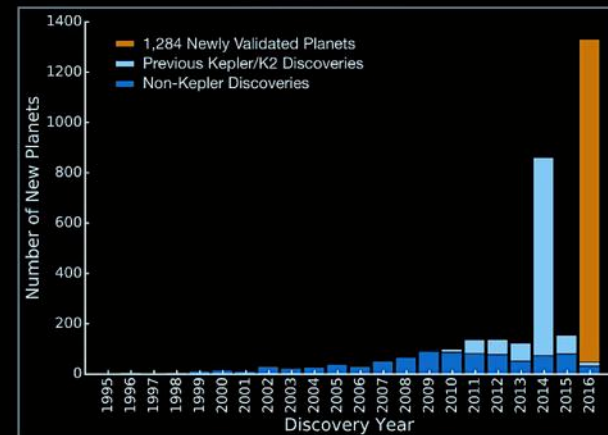
Known Planets by Size

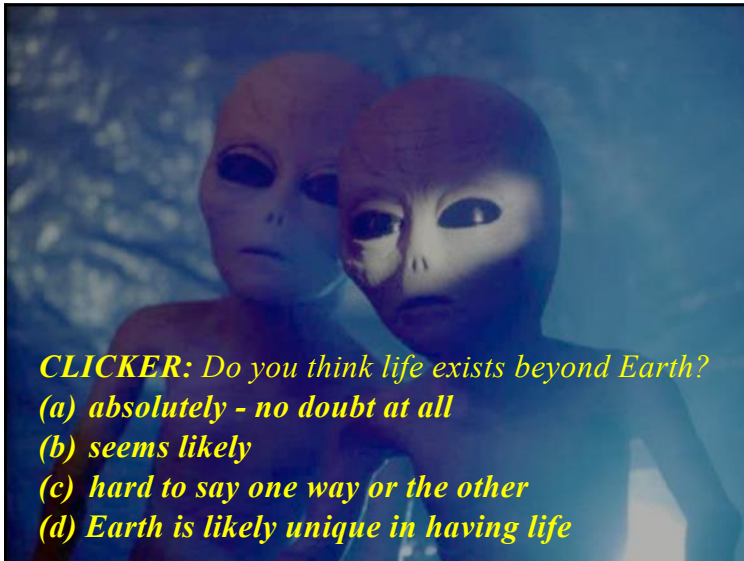
As of May 10, 2016



Exoplanet Discoveries Through the Years

As of May 10, 2016





The Drake Equation

Q: How many technological societies exist?

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

- R_* = *rate* at which *suitable stars form*
- f_p = *fraction* of stars with *planets*
- n_e = *number* of planets (per star) in *habitable zone*
- f_l = *fraction* of planets in zone which *evolve life*
- f_i = *fraction* of those which evolve *intelligent life*
- f_c = *fraction* of those which evolve *technology*
- L = *lifetime* (in years) of the civilization

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

$$= 10 \times 1 \times 0.1 \times 0.1 \times 0.1 \times 1 \times 10000$$

$$N = 100$$

- if spread *equally* throughout the *Milky Way*, the nearest civilization would still be *100's of ly away*

GIGO!

The Language of Aliens

- Egyptian hieroglyphics: *a message through time*

Q: Would a message from space be easier?



- *we can't even talk to dogs!!!*

Q: How might aliens contact us? Why?

- any alien communication (*to or from*) should be:

- *easy* for even young cultures to discover
- *inexpensive* to use
- *fast*
- *obvious*

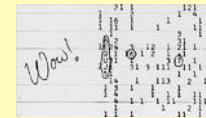


- **radio (astronomy)** fits the bill!

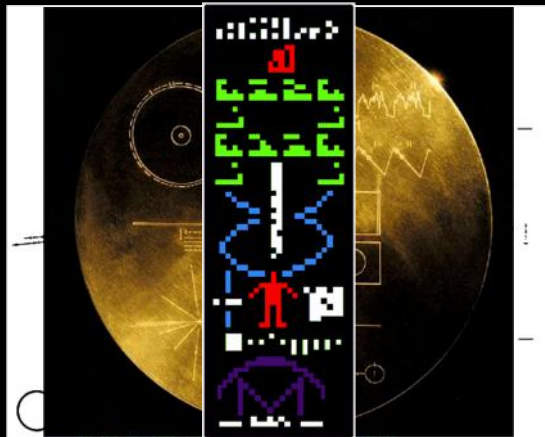
- largest radio telescope: **Arecibo (Puerto Rico)**, 300 m diameter
- two such scopes could “talk” over 15,000 ly apart

SETI

- **Search for Extra Terrestrial Intelligence**
- *interstellar spaceflight* difficult
- so *wait for the aliens to show up* or *call them*
- msg to **M13** (25,000 ly away) by *Arecibo* in 1974
- **listen** at frequencies ~ 1400 MHz
- so far: no extraordinary, repeating signal found
- “Big Ear” @ Ohio State, 1977 - “Wow” signal

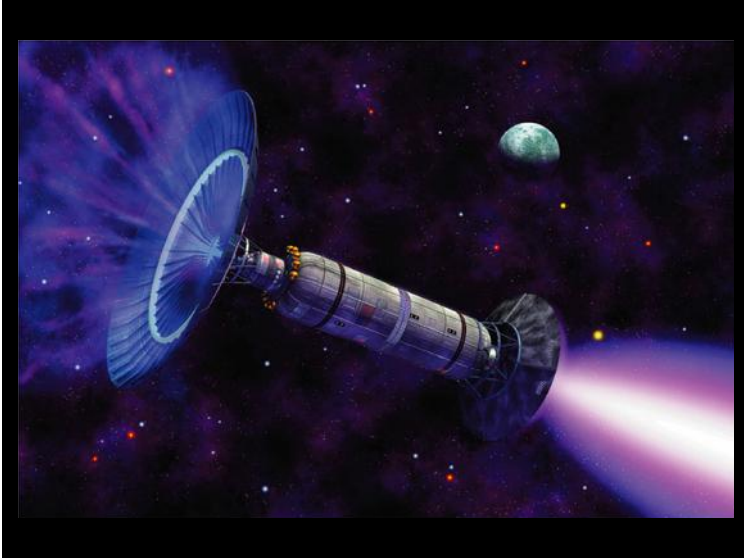


Pioneer, Voyager & Arecibo



Interstellar Travel

- it appears *intelligent life* will probably exist *outside* our solar system, so we'll have to travel
- **Project Orion**: dropping *H bombs behind ship*...
- *current tech*; get us to nearest stars *in a century*
- **Interstellar Ramjet**: scooping up *H gas*...
- saves weight (fuel) but *has to be big (why?)*
- **matter/antimatter engines**: 100% efficient *but*...



Review: ET Life

- *Fermi Paradox: "Where is everyone?"*
- outside Earth, our solar system *appears lifeless*
- we have discovered *hundreds* of extrasolar worlds
- *astrometric, radial velocity, light curve methods*
- *Drake Equation* calculates # of alien civilizations
- despite *SETI, UFO claims* we are still "alone" ...
- ...but the universe is a *big place*