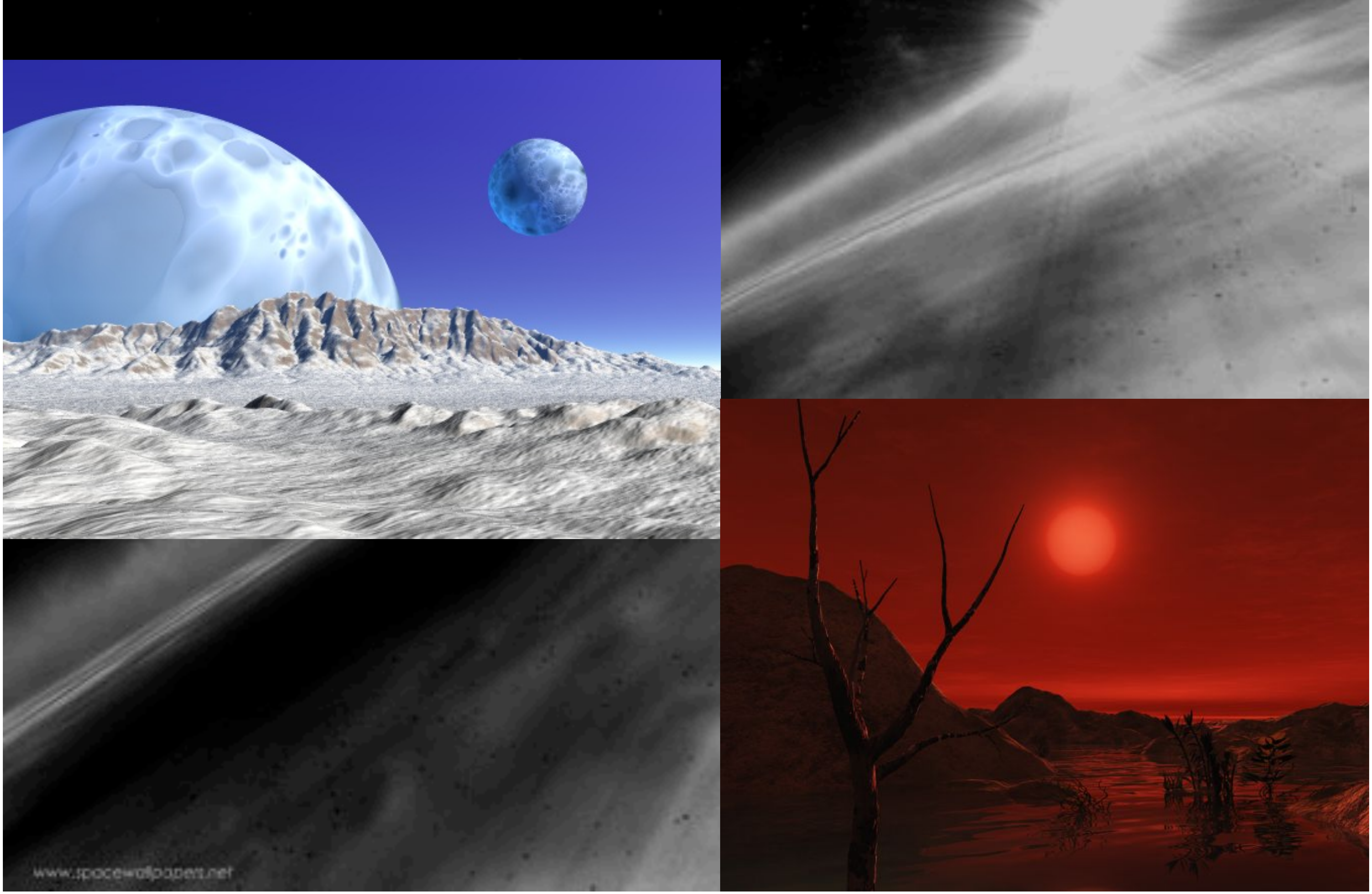
# The Hunt for Extrasolar Planets



# Overview

- How do we find planets?
- What have we found? (diversity of planets)
- How are properties of planets determined? (composition)
- Is there life beyond the Earth?

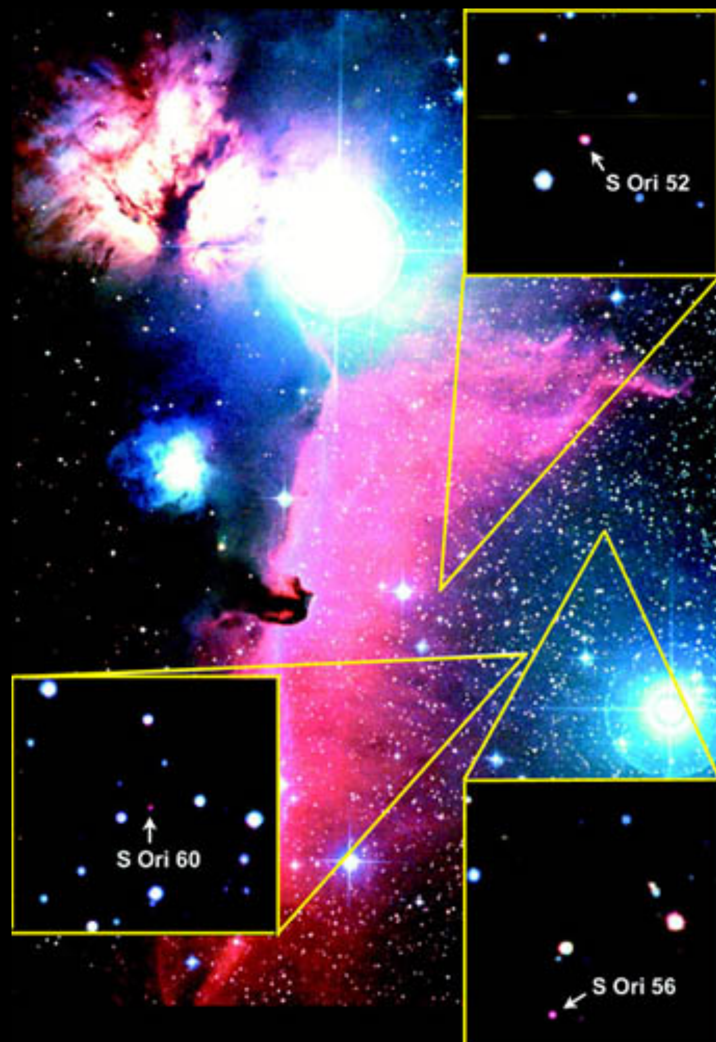
# Planet Detection: Direct(-ish) Methods

- Direct refers to actually seeing the planet itself as separate from the star.

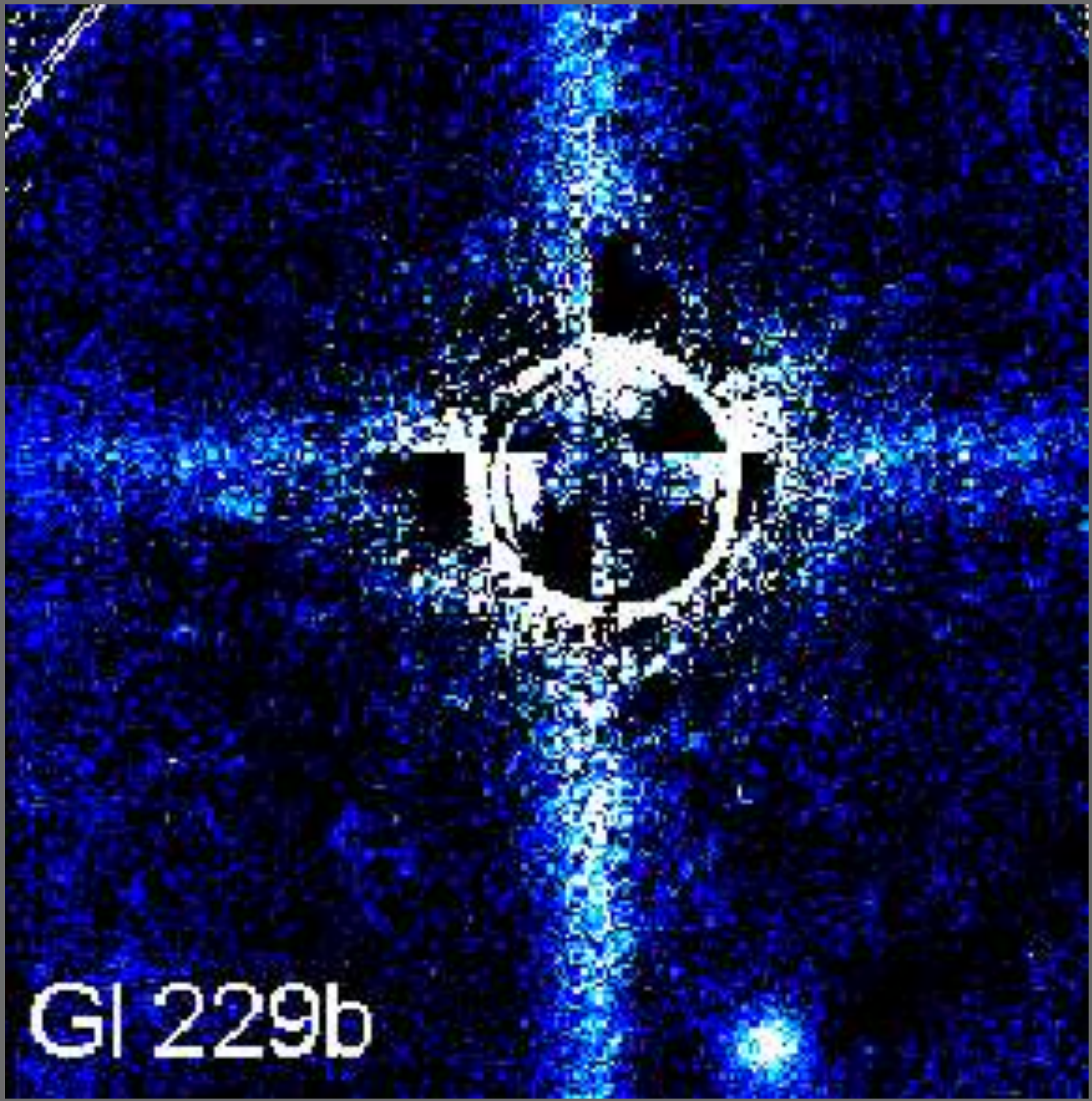
- Extremely difficult for two reasons:
  1. Planets are quite faint – faintness challenge
  2. Planets orbit stars that are quite bright – contrast challenge

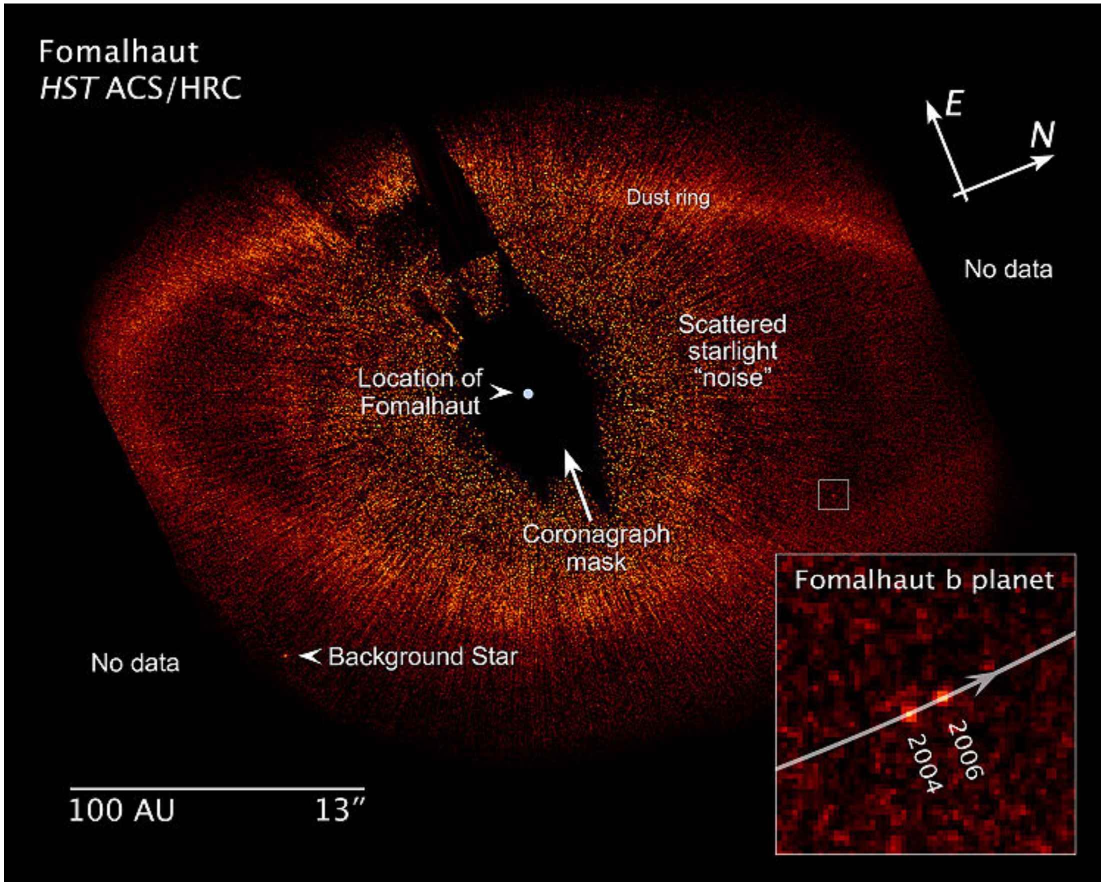
- Transits are somewhat direct. Refers to when a planetary system is seen edge-on so that planet eclipses the star and the stellar brightness is temporarily diminished.

# Direct Detection of Free-Floating Hot "Rogue" Planets

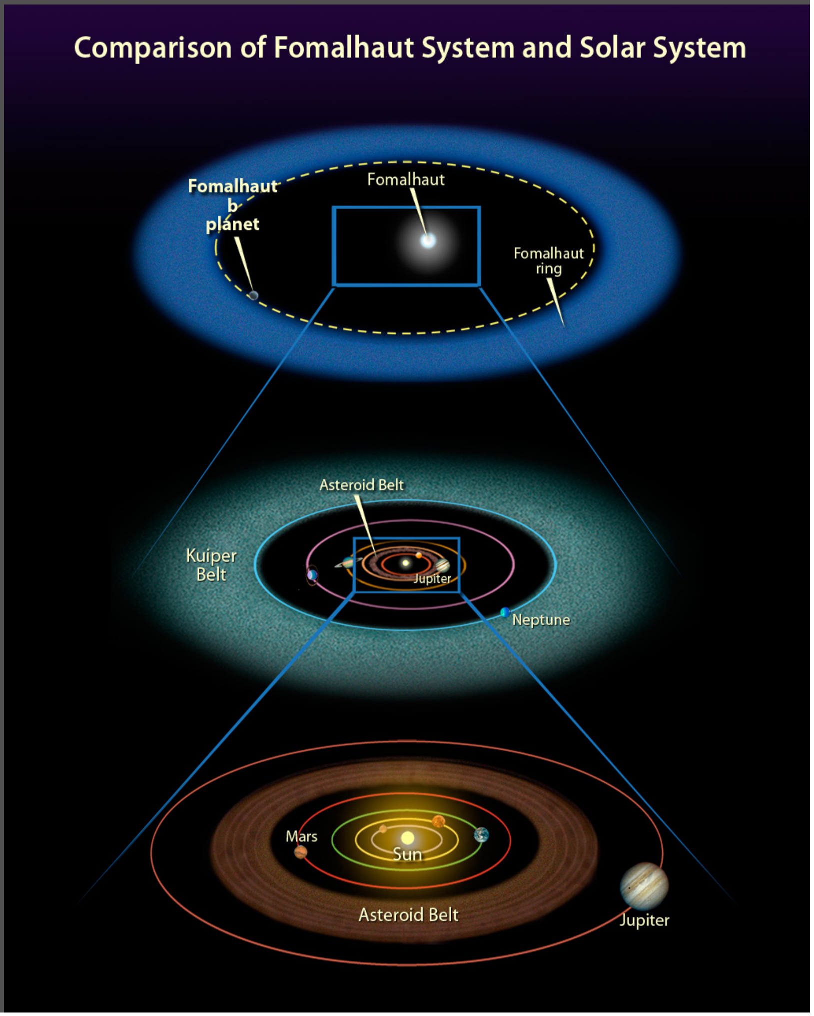


# Direct Imaging of a Failed Star: A Brown Dwarf

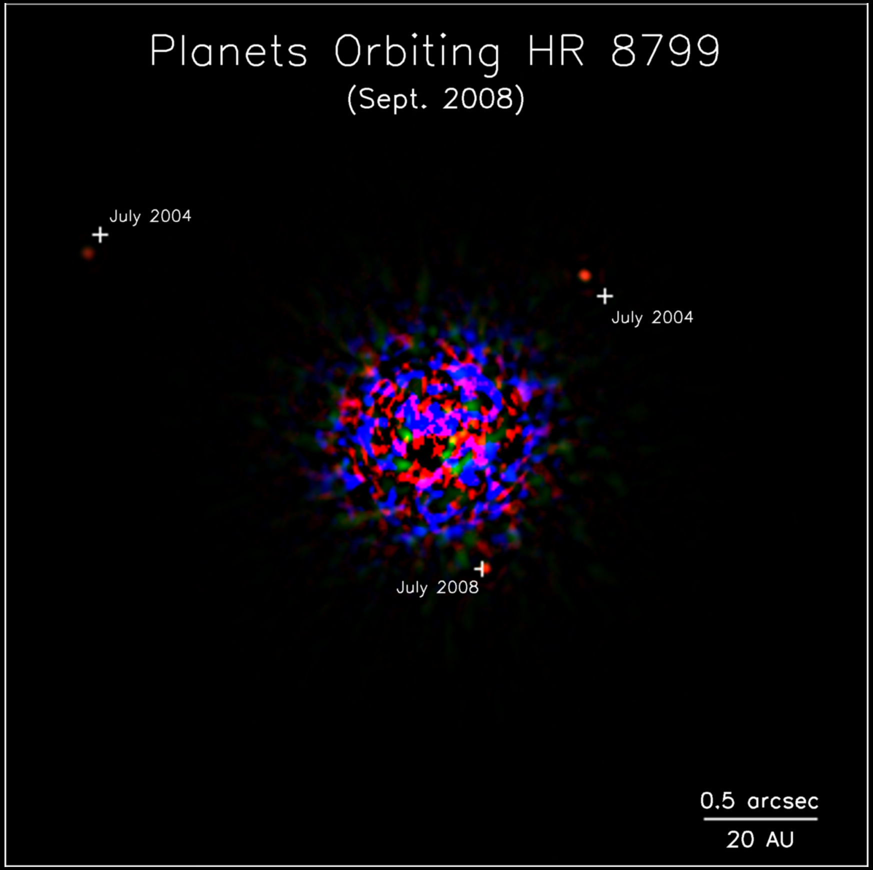


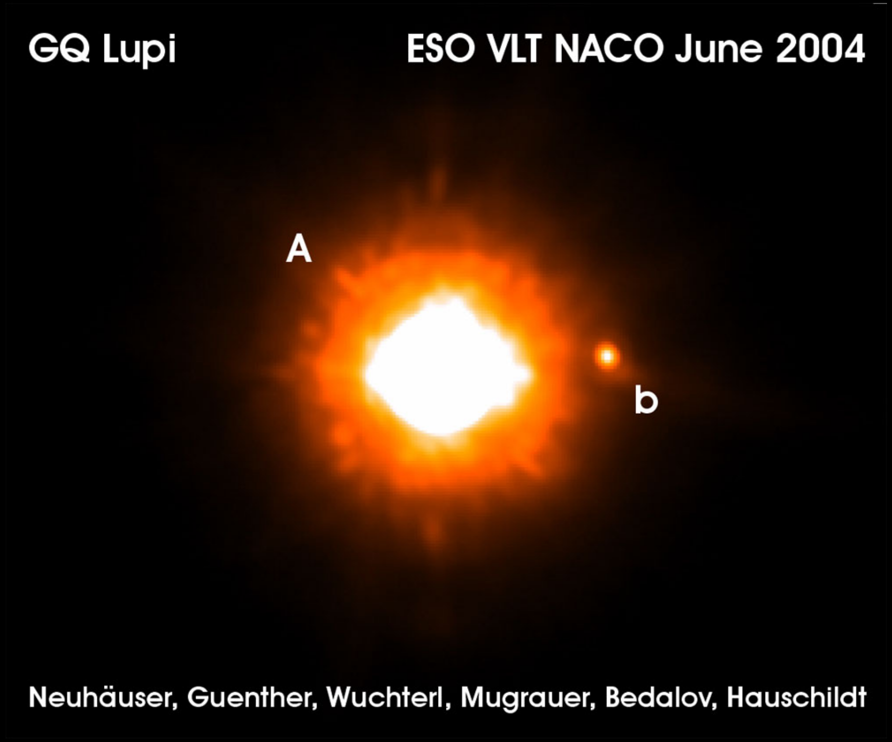



Direct imaging of a planetary companion to a star at 25 LY away from the Earth. Similar to Jupiter in mass, the planet orbits once every 900 years.



# More Planets Actually Imaged!



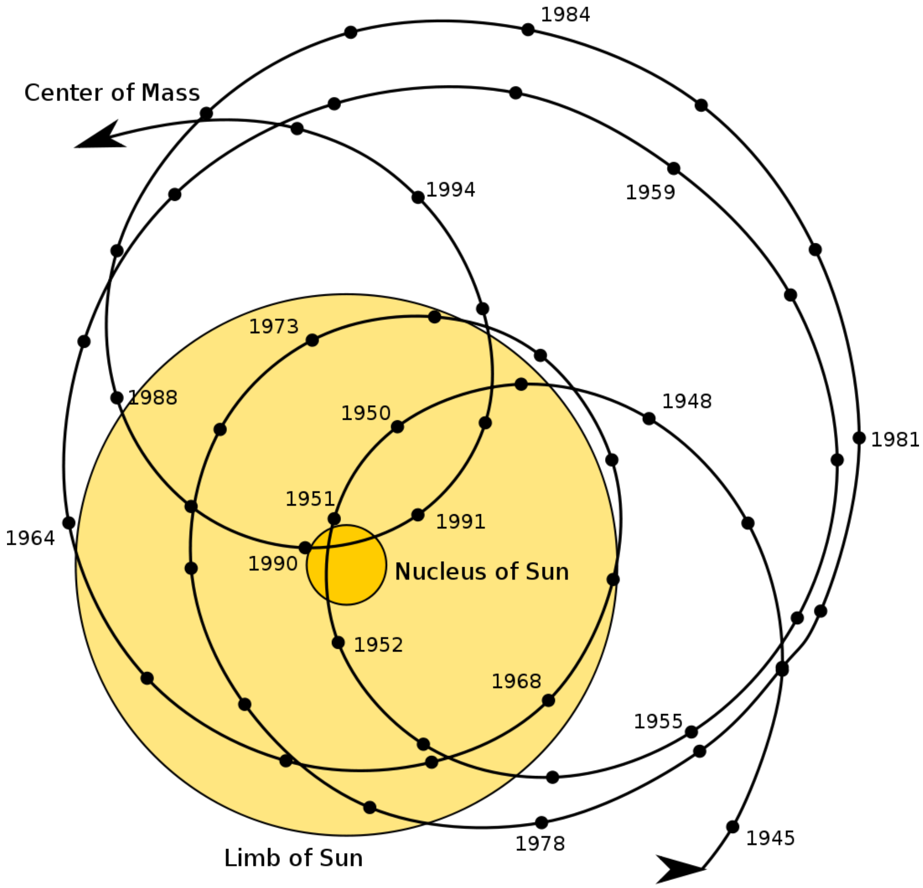
# Planet Detection: Gravity Methods

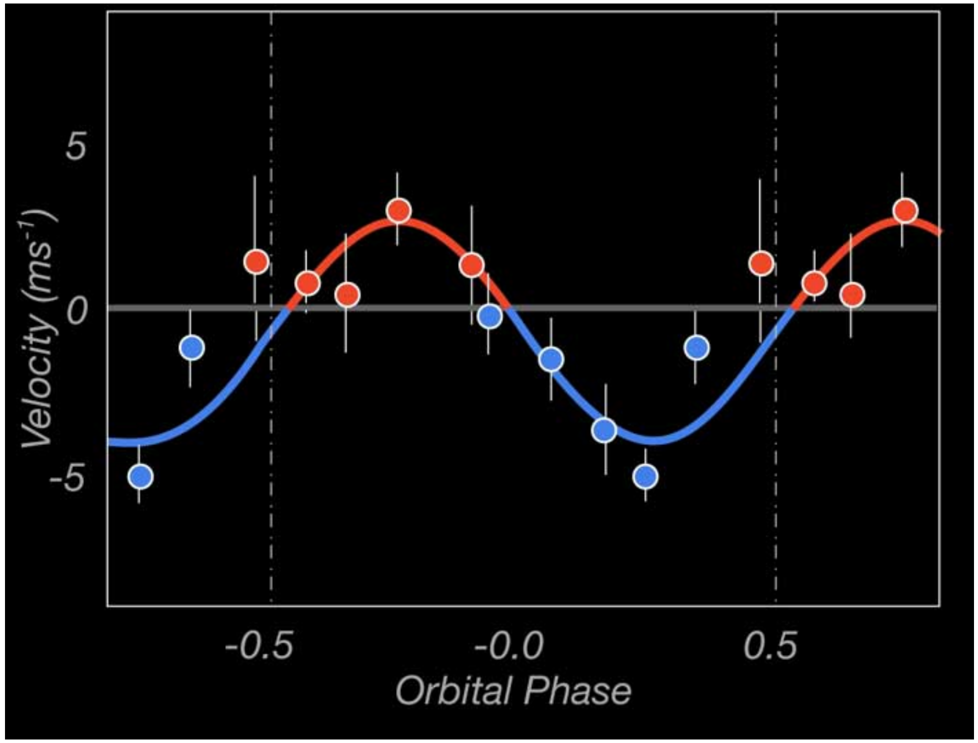
Indirect, since planet not actually observed; only its influence on the star about which it orbits is inferred.

- ***Astrometry***: observe "wobble" motion of star in sky as reflex motion owing to planetary companion
- ***Doppler Shift***: observe "wobble" motion as evidenced by spectral line shifts

  This is the method yielding the most extrasolar planet discoveries to date
- ***Microlensing***: if lens is a star+planet, the planet influences the lensing light curve

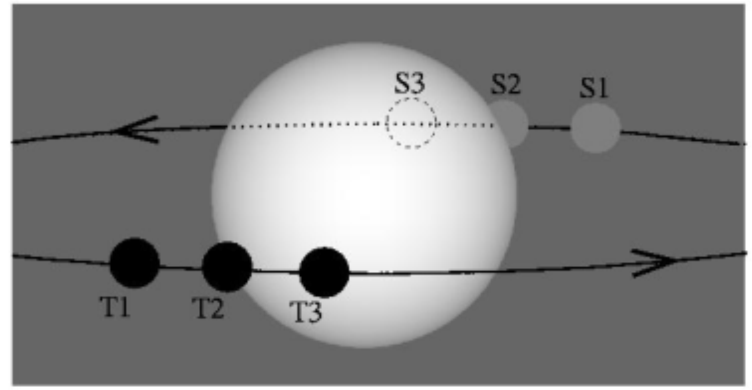
# Astrometry vs Doppler

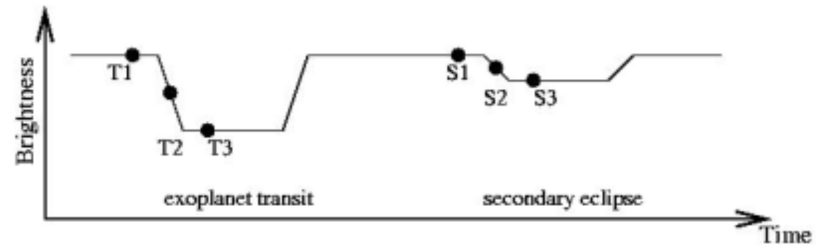


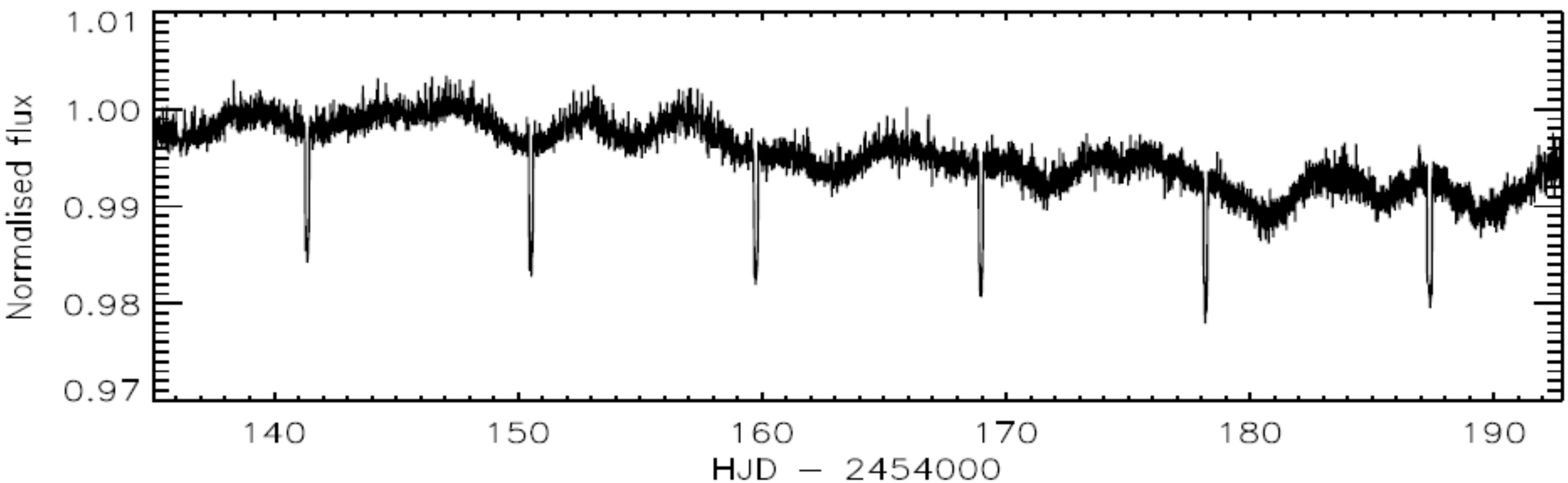
# Transit Searches

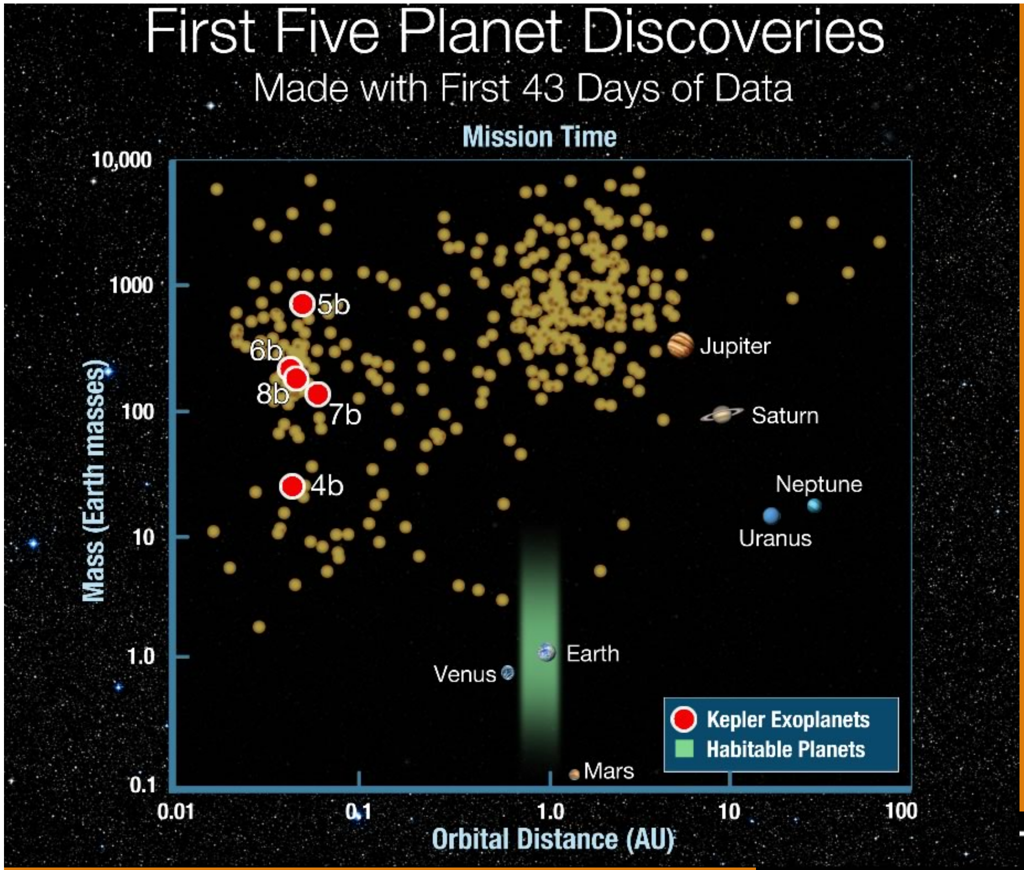
- Ground based missions continue
- Two new space-based missions:
    - COROT (European)
    - Kepler (American)
- These space-based telescopes use the transiting method, and they are now getting results.



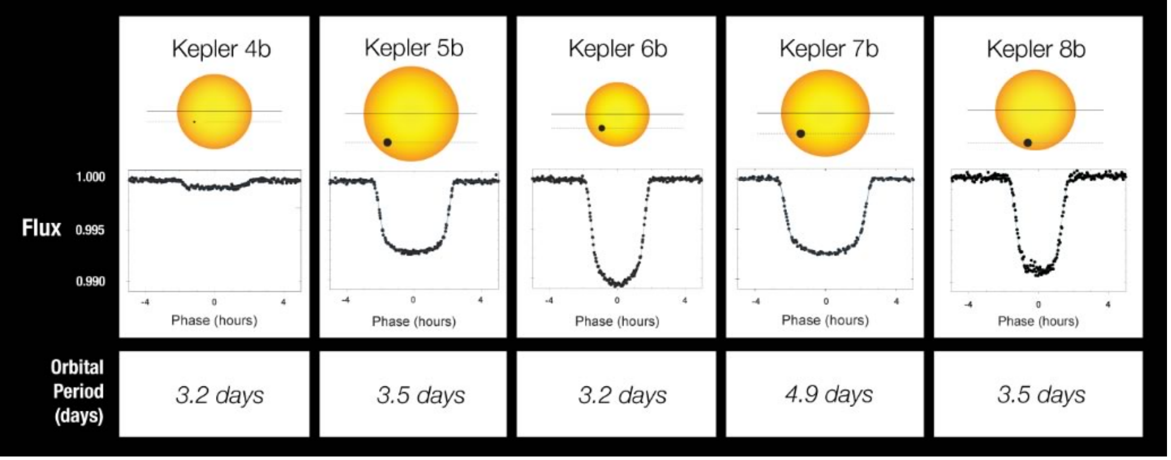

*Below is a COROT light curve with dropouts from a planet transit*






# Kepler

## Transit Light Curves



# Comparison of Methods

1. ***Imaging***: best for big, hot planets far from star
2. ***Transit***: bias toward large planets (hence massive) in small to medium sized orbits
3. ***Astrometric***: bias toward massive planets far from star
4. ***Doppler***: bias toward massive planets near the star
5. ***Microlensing***: complicated, but is sensitive even to Earth mass planets

**Pattern:** Selection effect for discovery of massive planets.s

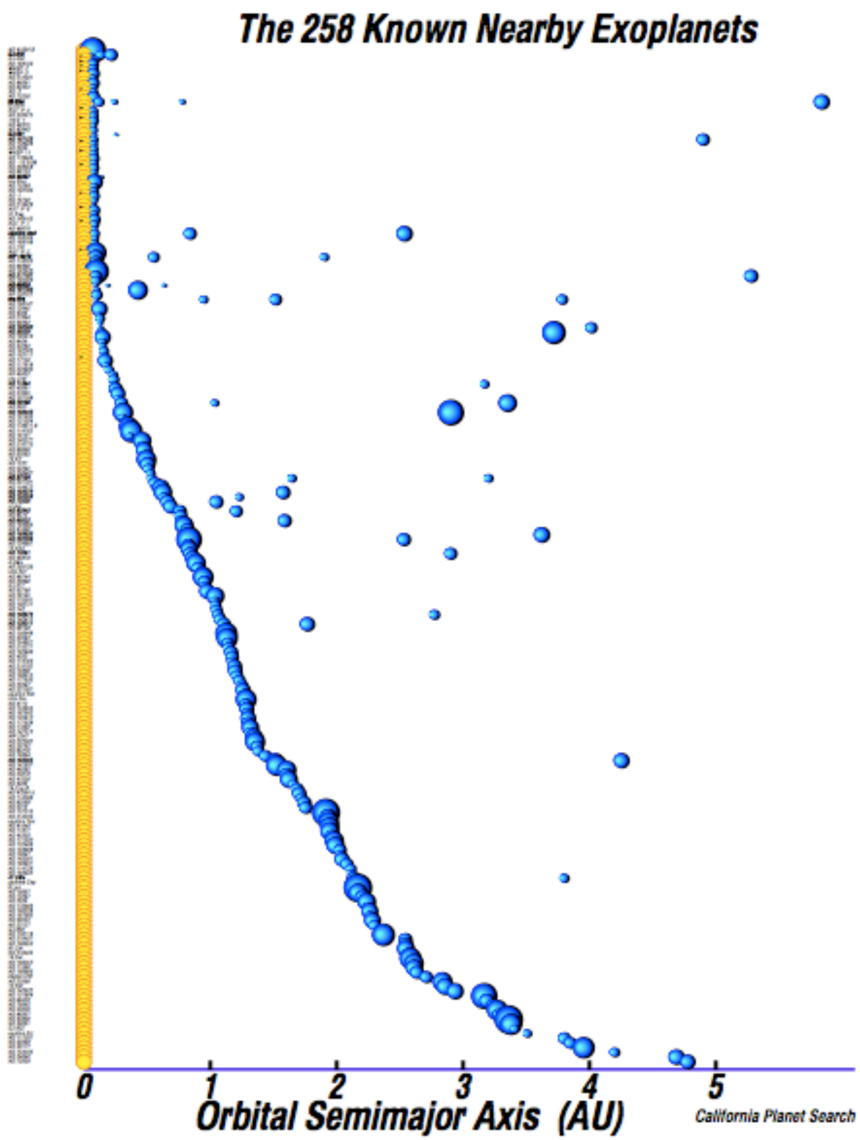
# Properties of Extrasolar Planets

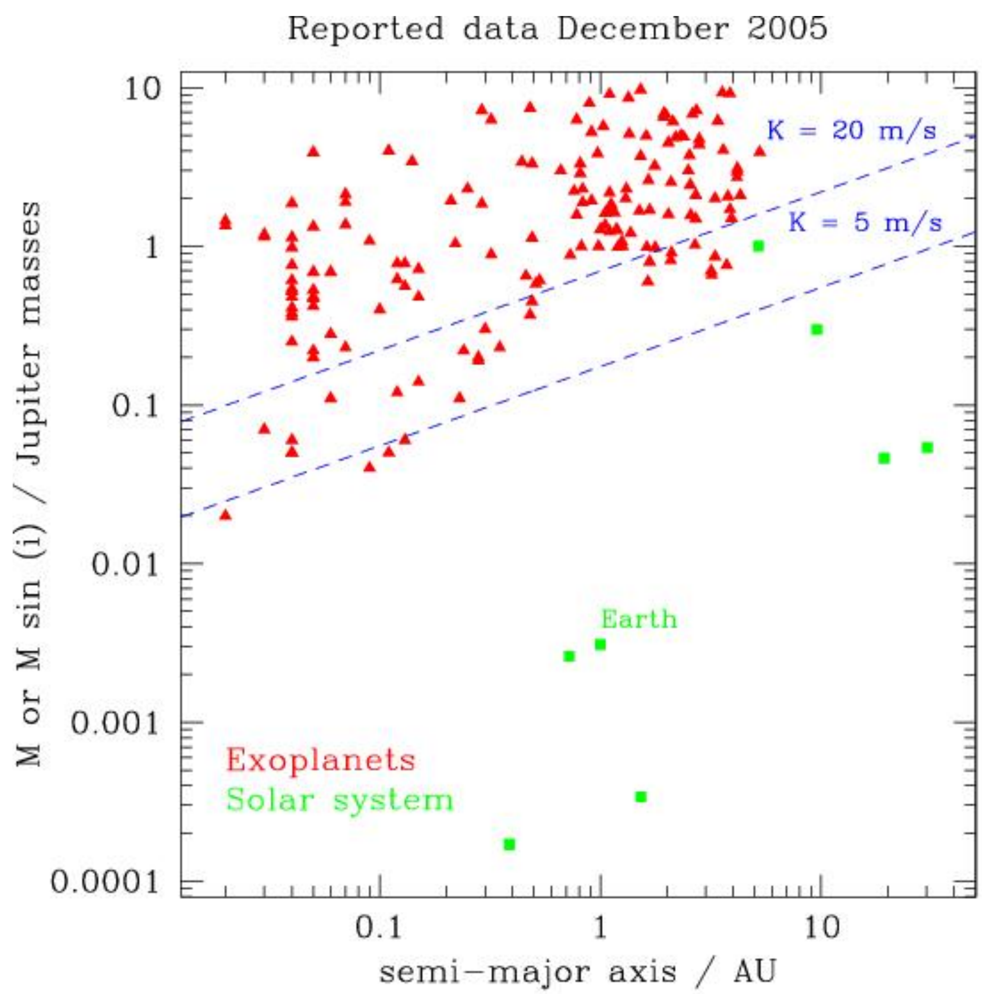
- 1995 – 1st discovery of giant exoplanets from long term monitoring of Doppler shift effect
- Selection criteria:
    1. Solar type stars
    2. Old and inactive
    3. Slow rotation
    4. Single stars
- Success rate is a few for every 100 stars
- Results – several unusual and unexpected systems

# Properties (cont.)

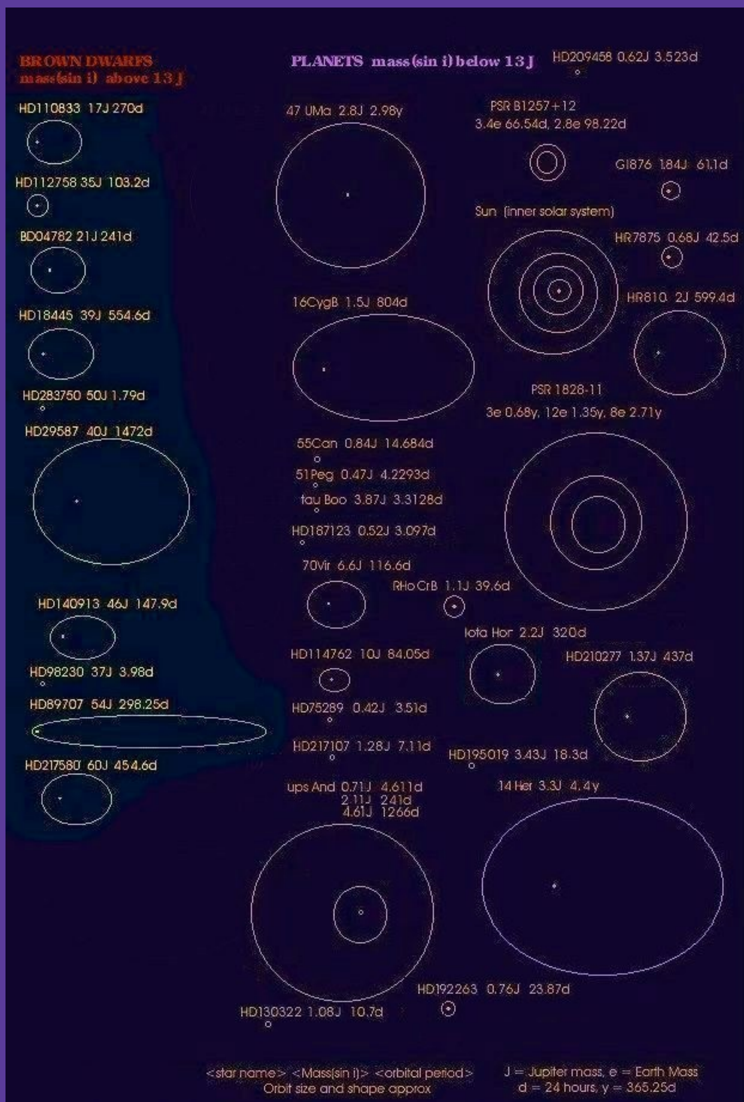
- Several planets are very close to their star (closer than Mercury!) with orbits under just 1 week. Perhaps these formed further out and spiraled in toward star via interactions with the proto-planetary disk.
- Some have large eccentricities, which is similar to binary stars and may indicate Brown Dwarf companions (recall that Doppler gives only lower limits to companion mass).
- Planets are "Jupiter-ish" and not likely habitable; however, such planets may possess habitable moons.

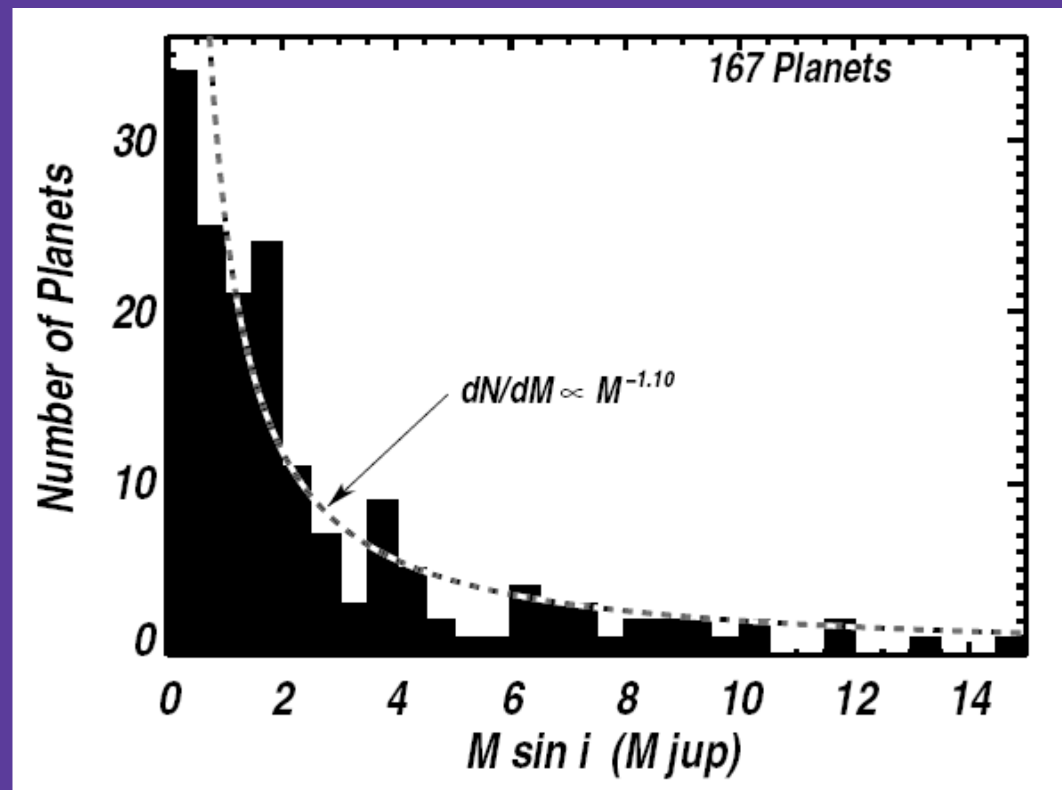
# Sampling of Planets We Have Found!



# Orbits and Masses of Extrasolar Planets



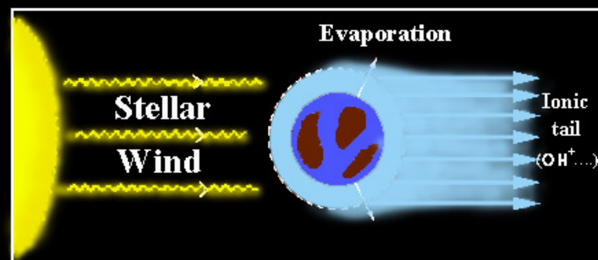
# First Rocky Exoplanet Detected

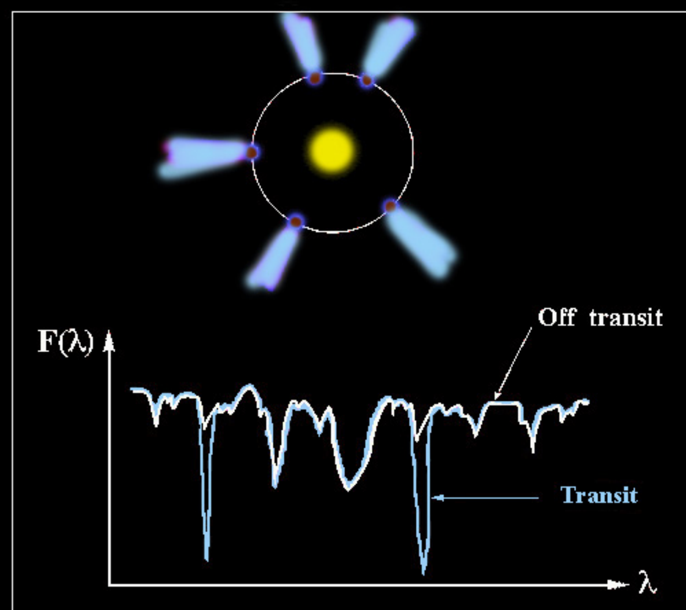
- Most known exoplanets are large and have low densities - similar to jovian planets in our solar system
- A space telescope recently discovered a planet with radius only 70% larger than Earth's
- Groundbased observations show the planet's mass is less than 5 times Earth's
- Together, the observations reveal that the planet's density is similar to Earth's - the first confirmation of a "rocky" exoplanet

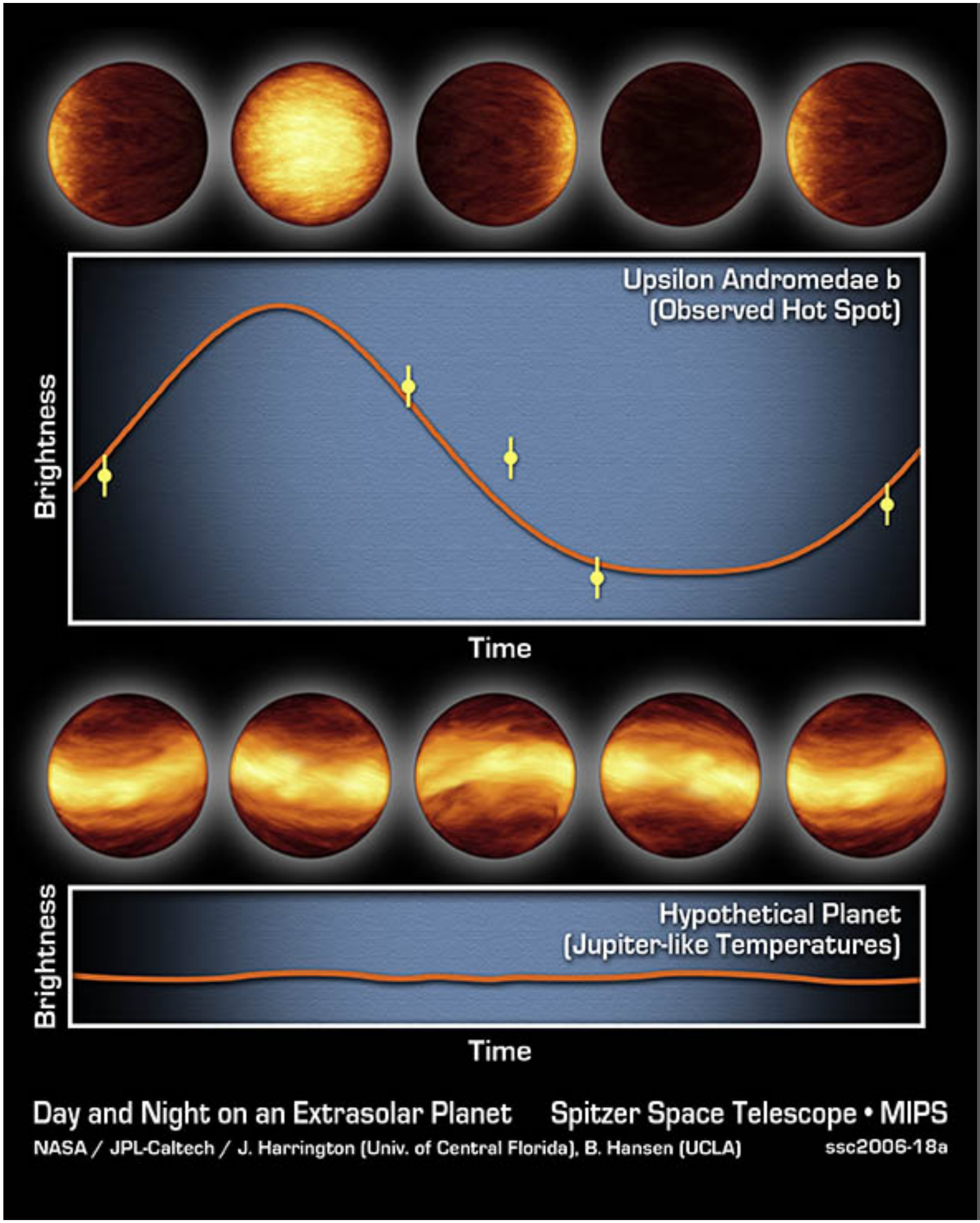
*Artist's conception of the view of the rocky planet's parent star (Corot-7) from above the surface of the planet (Corot-7b). Image from ESO / L. Calcada.*

# Probing Extrasolar Planets: Absorption Line Effects

Tail
Close orbit planet (51 Peg)





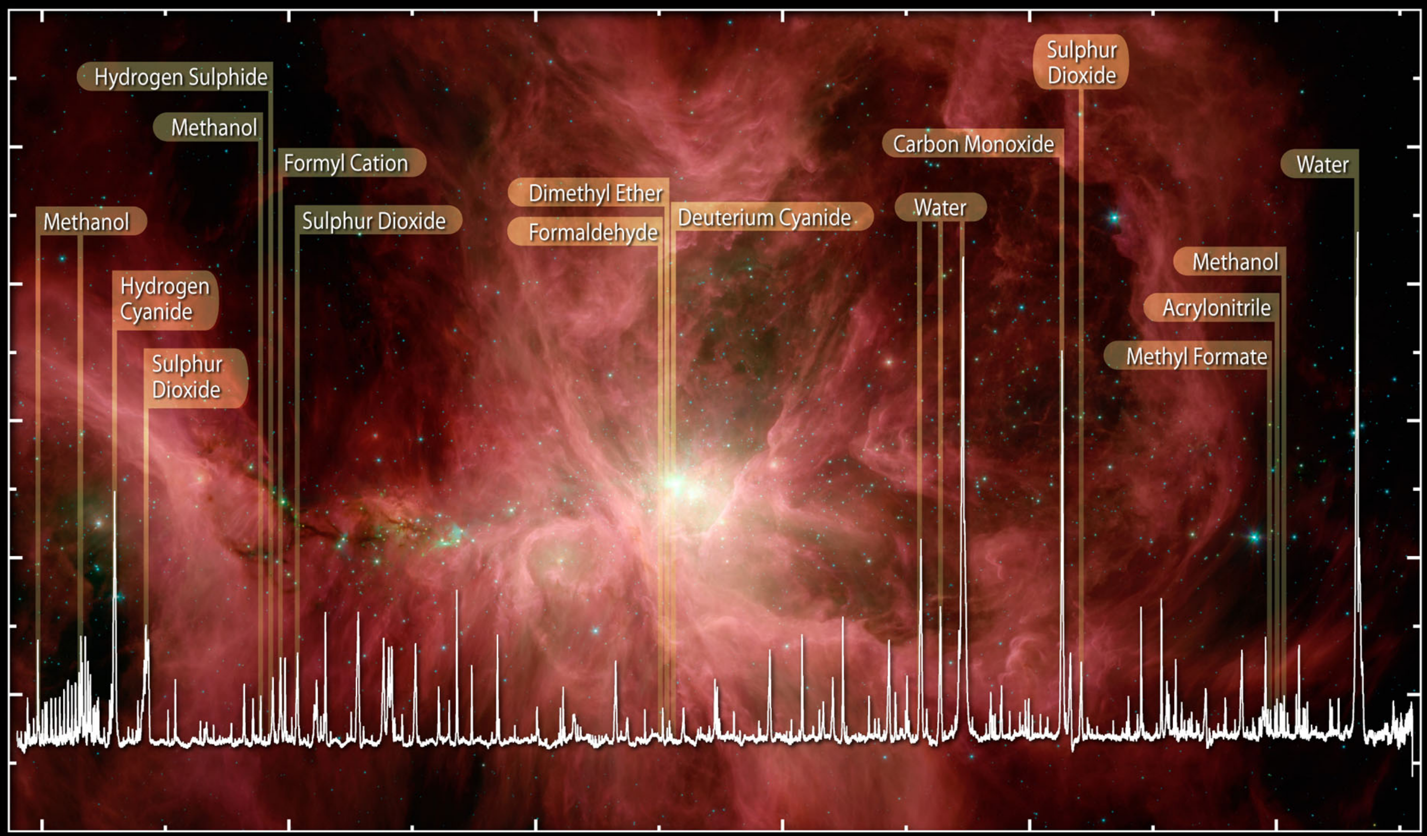

# Mapping Exoplanets Through Light Curve Analysis


# "Necessary" Conditions for Life

Not entirely clear. No reason to think that life elsewhere will bear <u>any</u> resemblance to life here EXCEPT possibly in some microscopic ways.

1. ***Reproduction***: Not merely a matter of sex! Something like DNA/RNA must operate. (Some mechanism for species propagation.)
2. ***Carbon***: Carbon atoms are chemically robust, being able to form large molecules involving many kinds of atoms. Silicon is next best, but not as good.
3. ***Water***: Clearly key to Terrestrial life. Good solvent and has a large heat capacity. Next best is ammonia and methyl alcohol.
4. ***Starlight***: Radiation and heat.

# Interstellar clouds show complex molecules




HIFI Spectrum of Water and Organics in the Orion Nebula

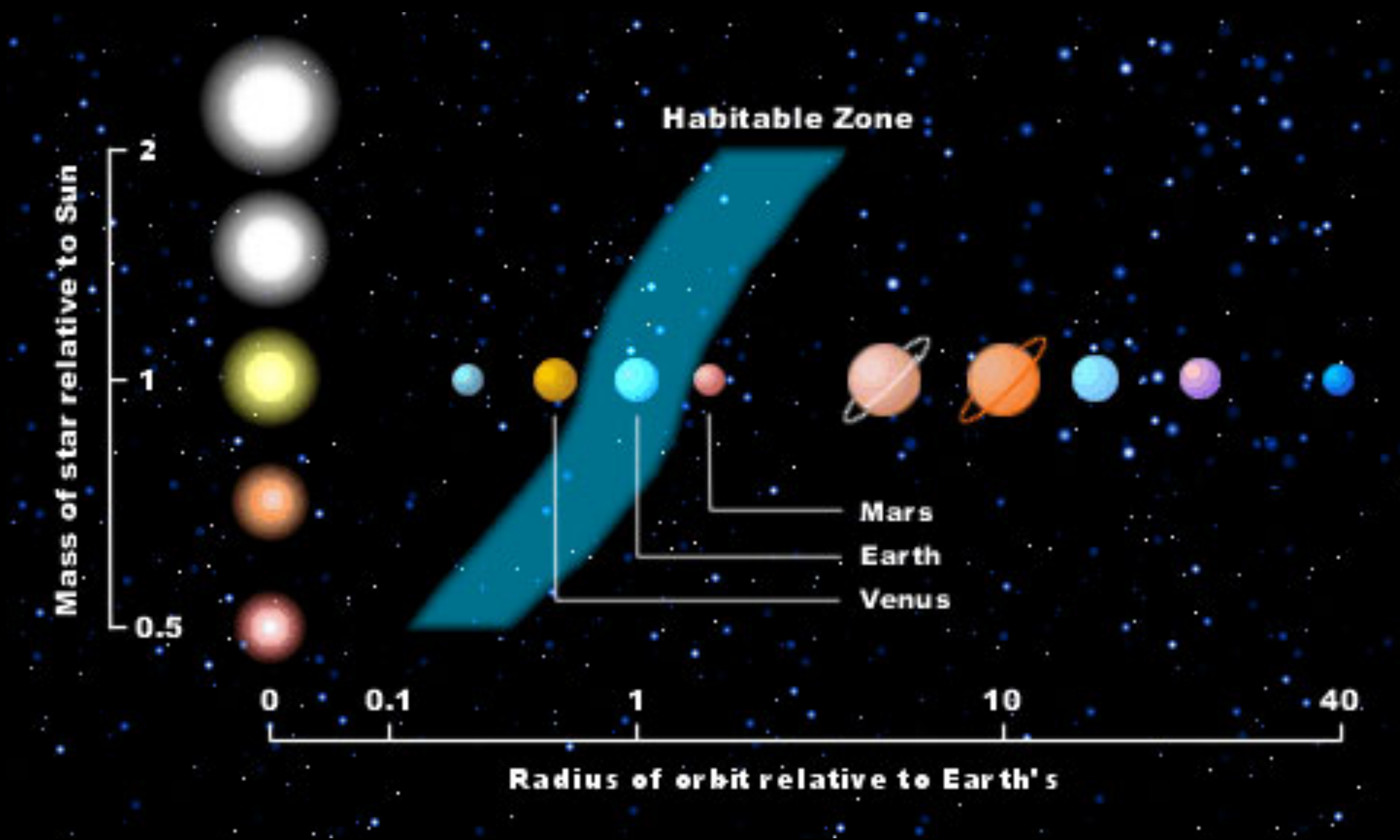
# The Habitable Zone

Water is likely key to life

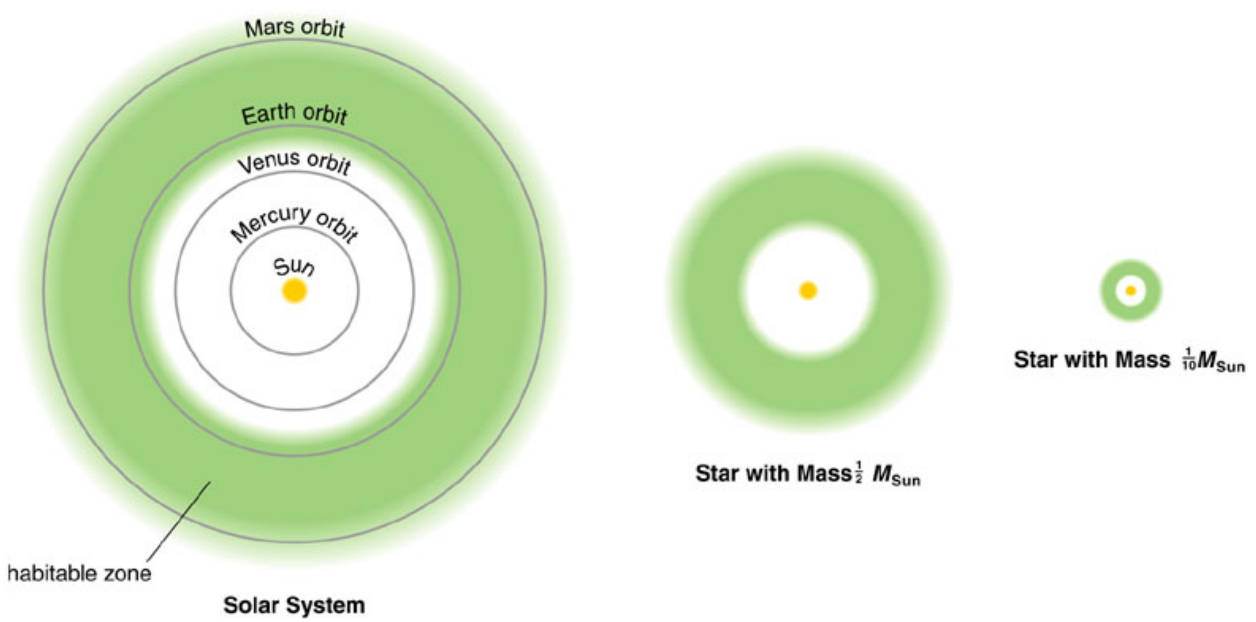
The Earth resides at a place where water can be liquid – defines a habitable zone!

- Inner edge: the distance from a star where runaway Greenhouse occurs
- Outer edge: the distance from a star where water freezes ($CO_2$ becomes dry ice; NO Greenhouse to keep $H_2O$ from freezing)

# Habitable Zones for Different Stars



# Examples of Habitable Zones



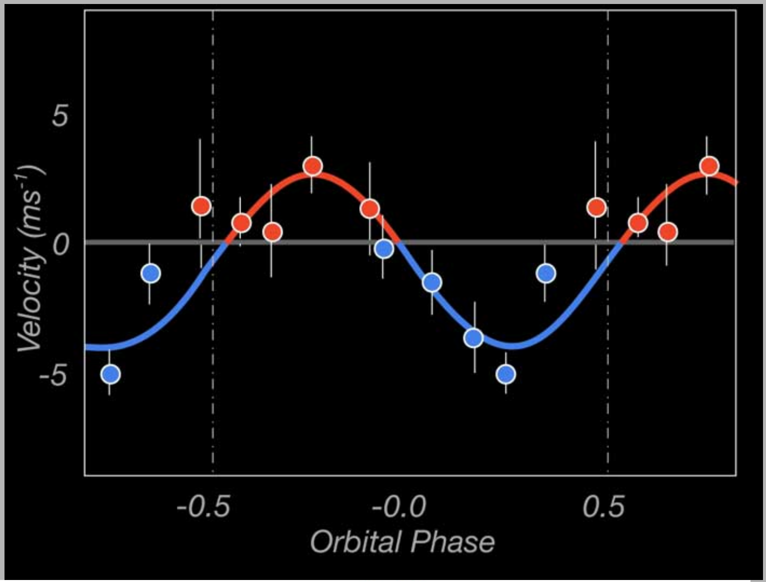
# Habitable Zone (cont.)

- The habitable zone typically has a width of a several tenths of an AU
- One can easily imagine other key criteria for life to flourish:
  1. Planet must retain an atmosphere
  2. Stable orbit
  3. Planet should not retain H and He
  4. Stable climate
  5. Stellar activity?
  6. Frequency of bombardment?
  7. Single vs binary stars?
  8. No nearby SNe?
  9. …

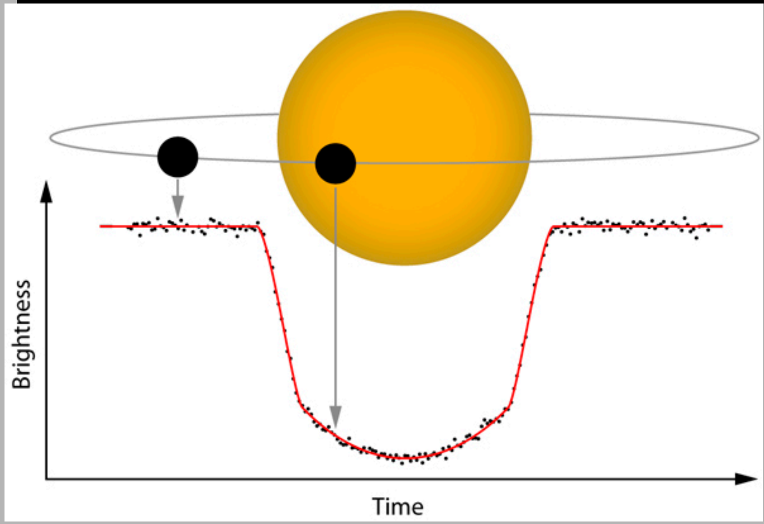
# A Twist on the Traditional Habitable Zone:

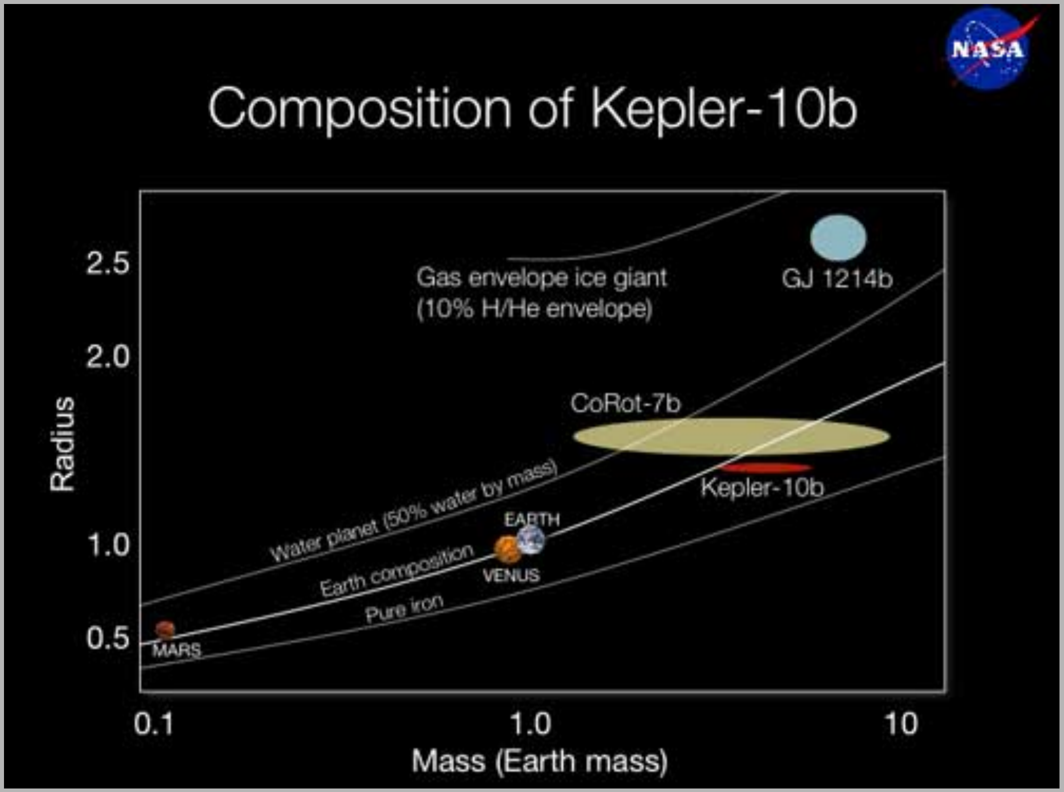
Suppose a gas giant lies in the habitable zone. Although unlikely to support life, perhaps one of its moons could.

# Getting Exoplanet Densities



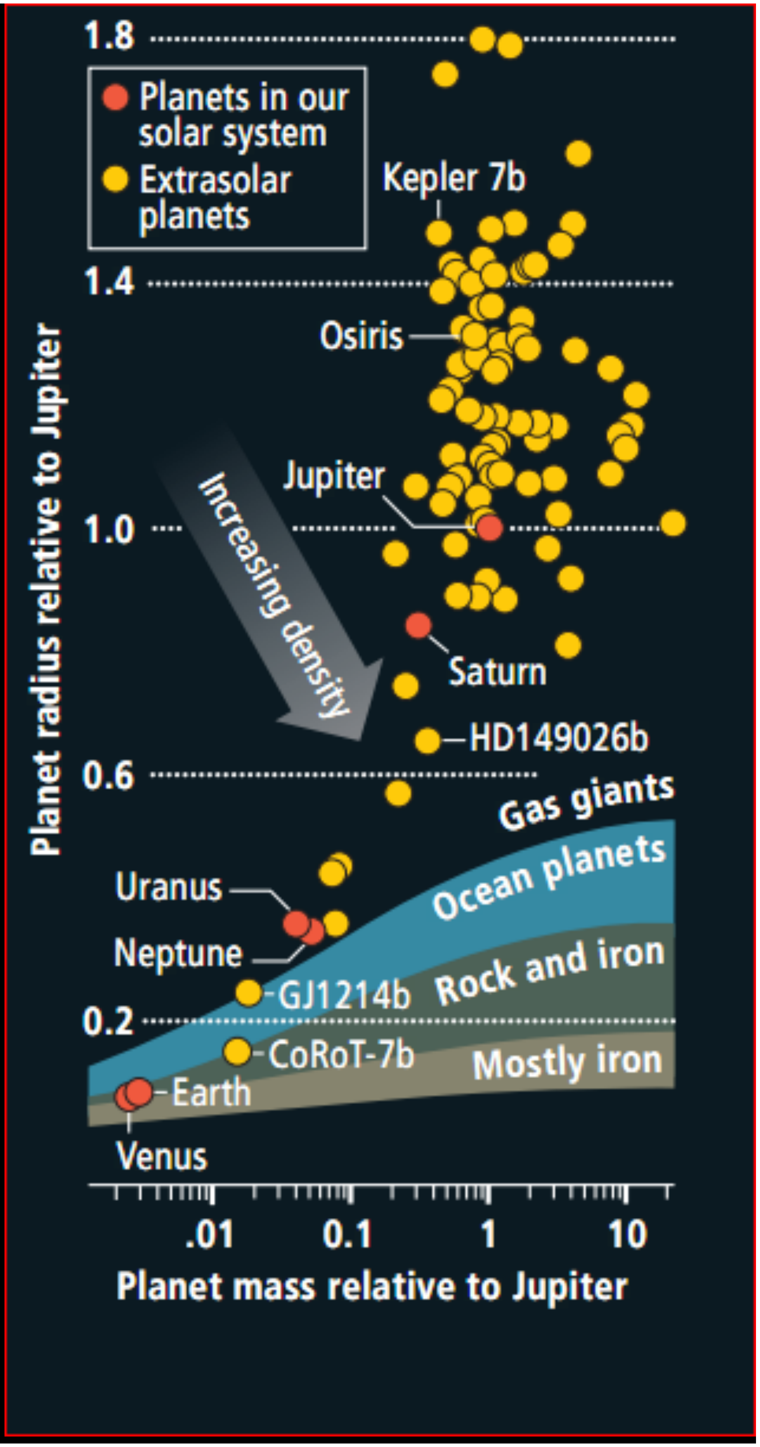

Densities come from knowing mass (using the Doppler effect and gravity) and size (using transit eclipse effect).



The density of a world reveals its composition, or at least it limits the compositional mix.

A good example is the Earth and Moon. Both have rocky surfaces, but Earth's density lies between rock and iron. The Moon's density is like rock. As a result, the Earth must have an iron core, but the Moon does not.

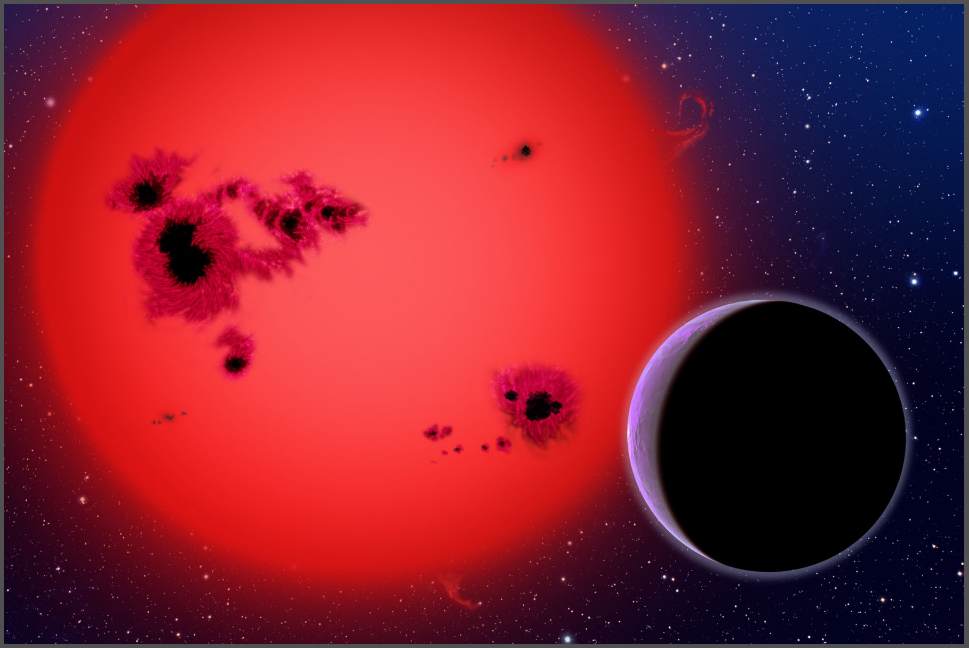


# Possible 'Water World' at 40 LYs

- A configuration of 8 small telescopes detected an exoplanet passing in front of a nearby small star

- Observations provide estimates of the planet's size (~2.7 x Earth) and mass (~6.5 x Earth)

- The density of ~1.8 g/cm$^3$ implies that the planet may be composed primarily of water, which has density of ~1 g/cm$^3$

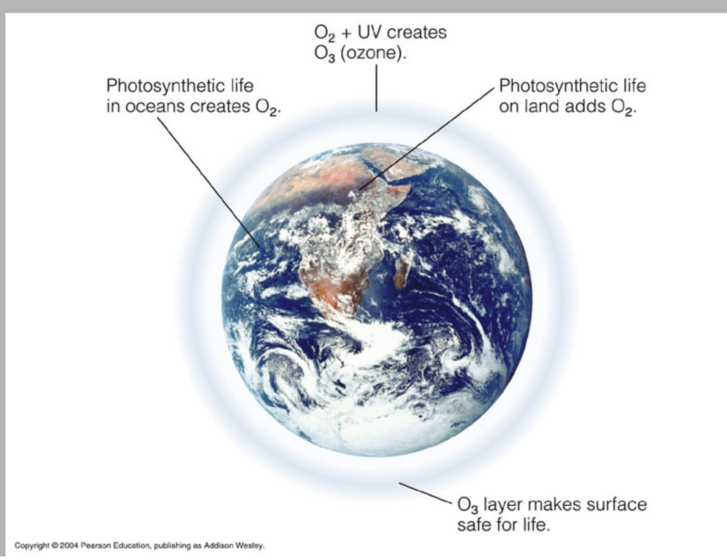


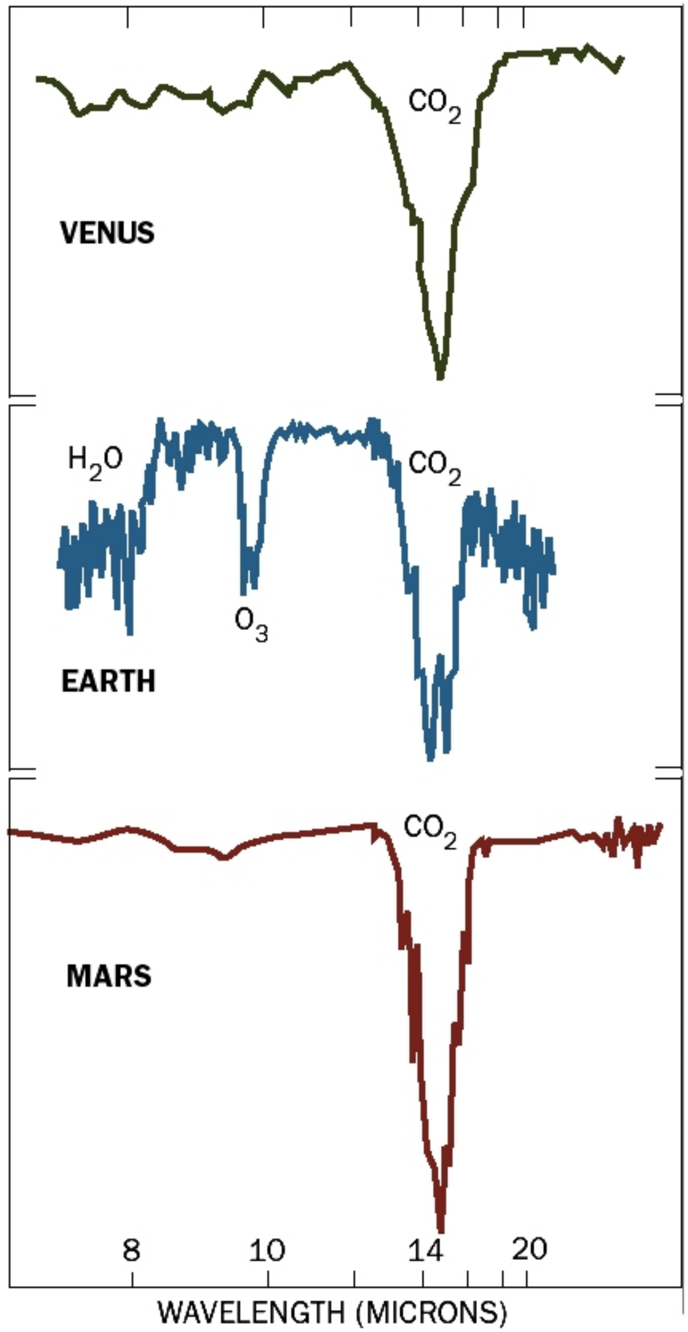
*Artist's conception of GJ 1214b - a 'Super Earth' orbiting a star ~40 light-years away. The planet orbits at a distance of only ~15 stellar radii. Image from David Aguilar.*

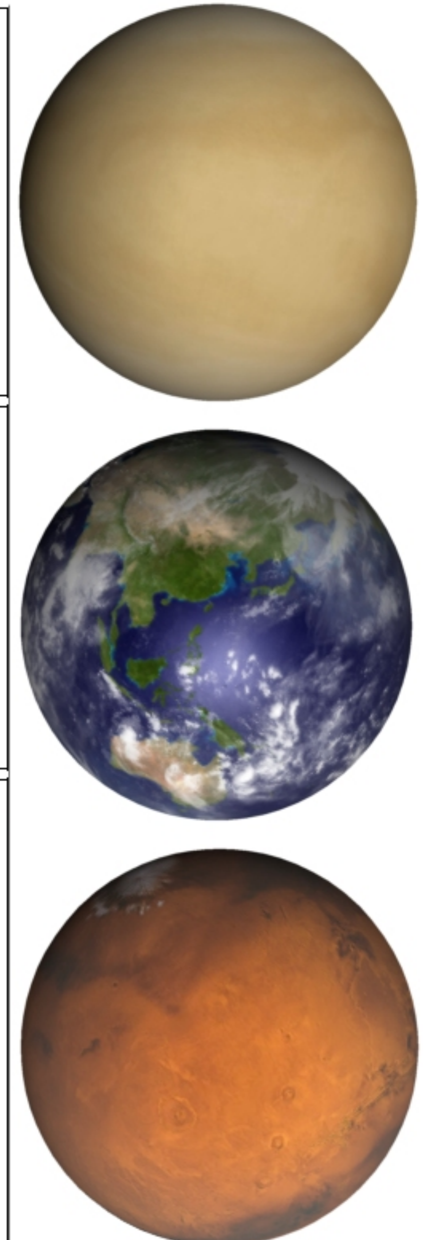
# SIGNATURES OF LIFE:

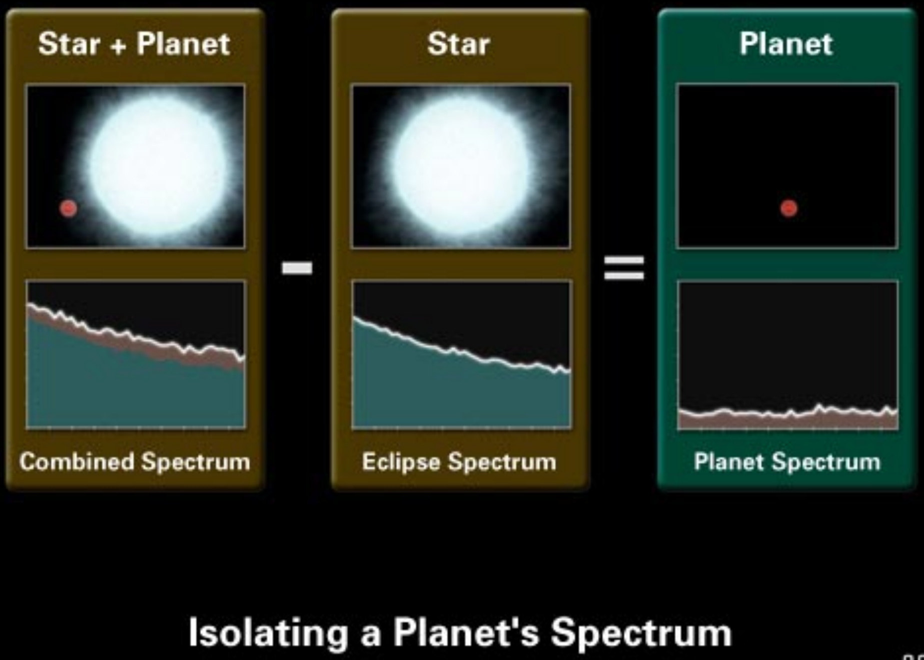
Free oxygen is relatively rare. Oxygen can quickly bind with other atoms to form molecules. On Earth free oxygen is sustained because of photosynthesis by living plant life. However, oxygen can in principle be sustained by non-biological means.

Overall, the detection of free oxygen (such as ozone) in an exoplanet is a strong, but not definitive, indicator of life there.

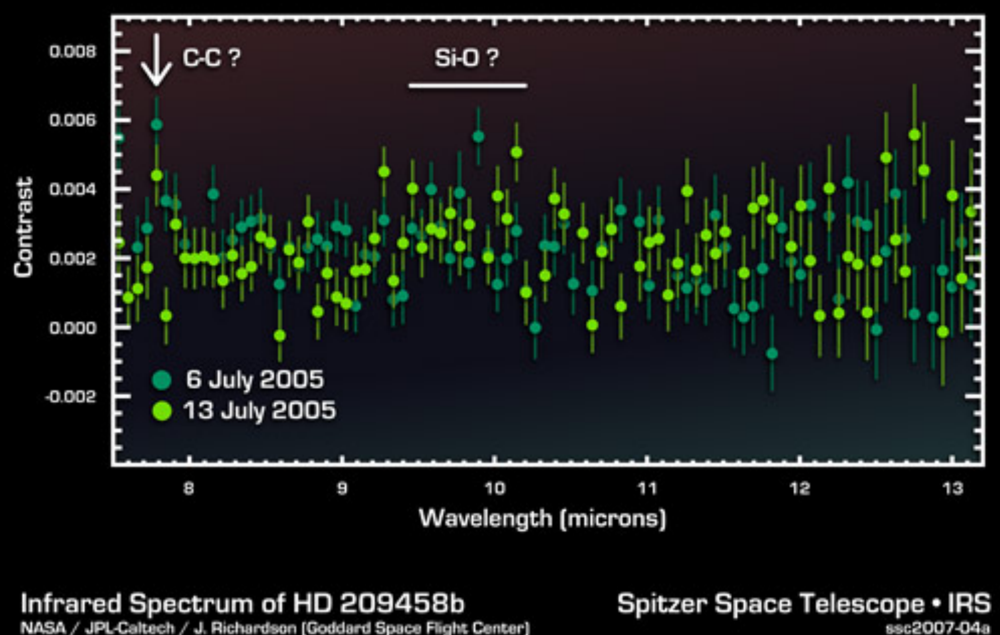




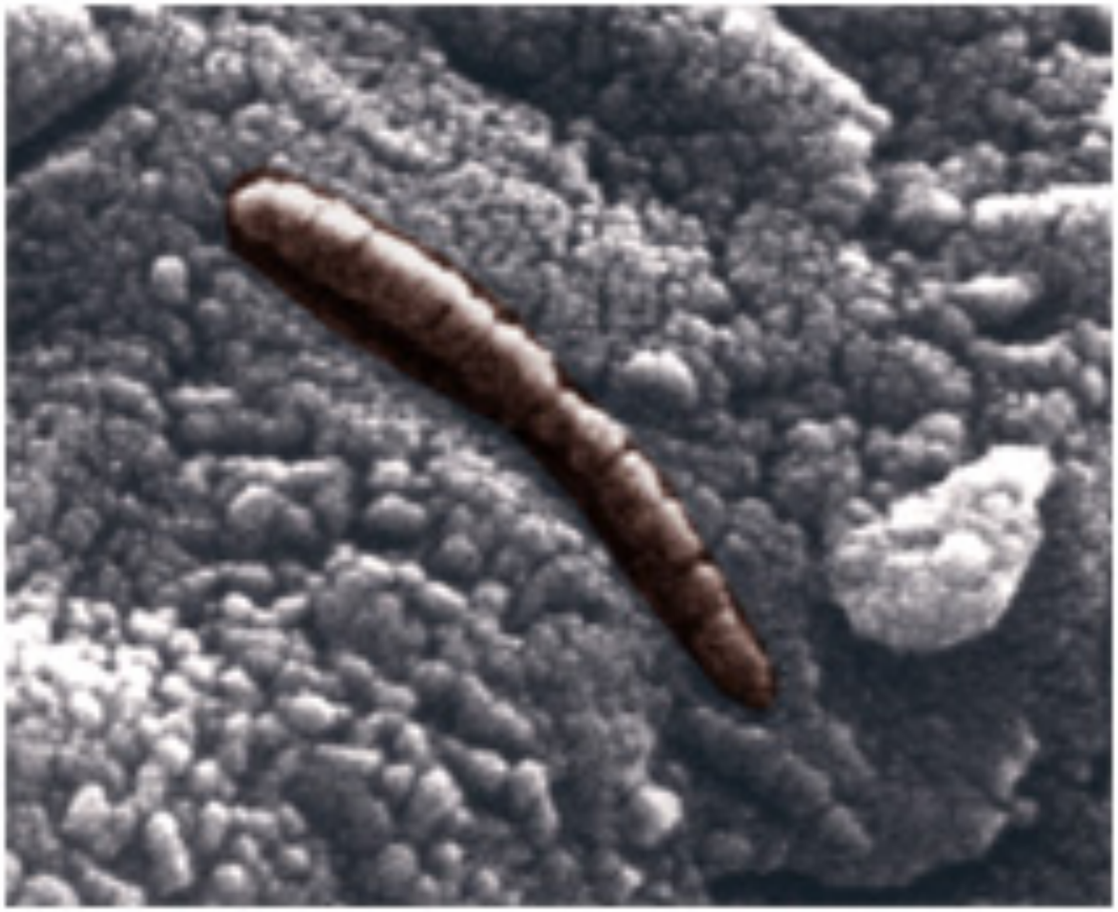

**An illustration and triumph in extracting a spectrum of an exoplanet.**



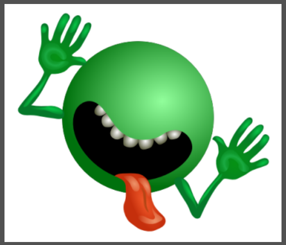
# Life in the Solar System

- Mars:
  - speculation since 19th century
  - Aug 1996, discovery of Martian meteorite claimed to have fossilized microscopic life; debate continues
  - Future missions hope to return Mars samples to Earth
- Europa:
  - Evidence for subsurface liquid water oceans
- Titan:
  - Thick $N_2$ atm. with methane and ethane
  - Lakes of liquid $CH_4$
  - Images captured by "Huygens" probe that descended through Titan's smog

# LIFE?



**Feature found in Martian Meteorite**



# Intelligent Life

- Alien plants may be tasty, but they are no good for conversation!
- What is "intelligent life"?
  - Language
  - Technology
  - "Dominance"?
- Is intelligence advantageous?
  - Weapons (nuclear, bio)
  - Space travel
  - Reasoning
  - Communication
  - Experimentation (cloning)

# Messages We Have Sent: Signals

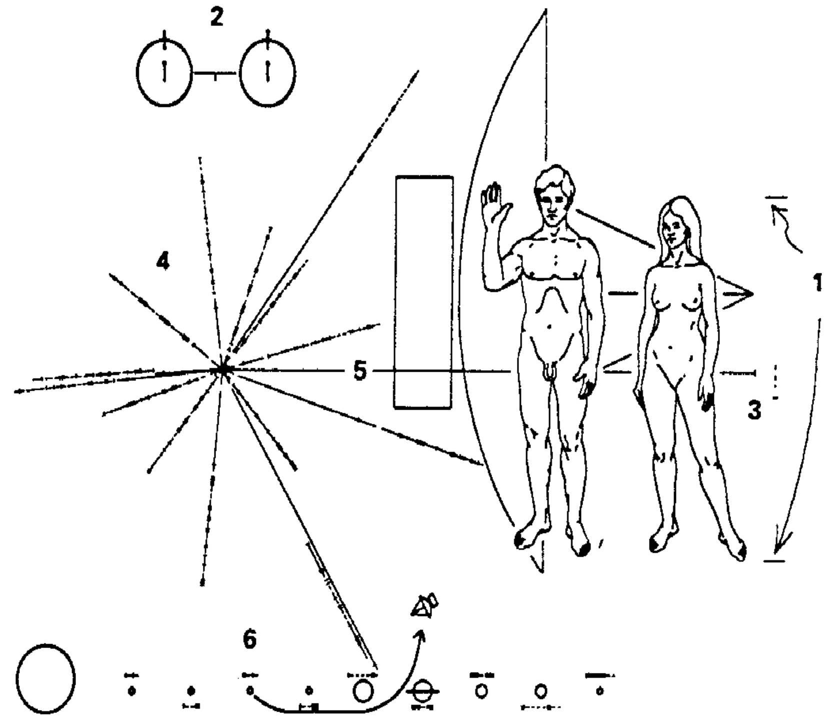
*Arecibo: (1974)*

- Radio message beamed to the globular cluster M13 in Hercules
- About 300,000 stars at a distance of 21,000 LY
- Would be detectable by our technology
- The message contains info on S.S., DNA, etc

# Messages We Have Sent: Satellites

*Pioneer 10 & 11: (1970s)*

- 1st to pass thru asteroid belt, visit Jupiter and Saturn, and journey beyond inner Sol Sys
- Each possesses a gold plaque with info about us and how to find us

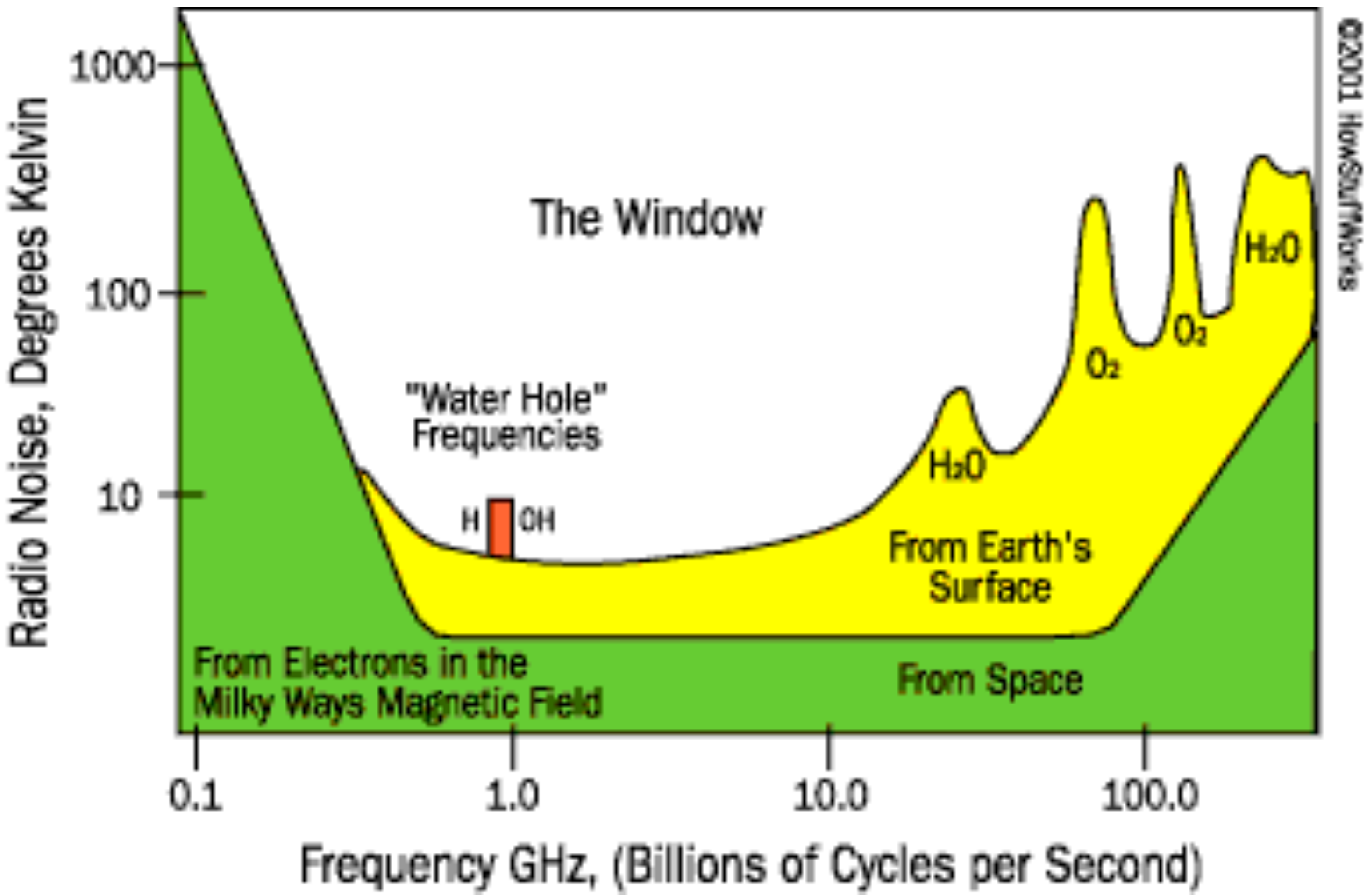



If extraterrestrial civilizations are monitoring our TV broadcasts, then this is what they are currently watching.

# Alien "Connections"

- It may be difficult to detect life outwith the Sol Sys unless "they" signal us requires intelligence!
- Interstellar Communication:
  - SETI=Search for Extra-Terrestrial Intelligence
  - Mostly a listening effort
  - What frequency? Most "favorable" is where universe is least noisy, in the radio regime around 1-10 GHz (or 3-30 cm)
  - Where to look? Nearby stars, or sweep sky for a beacon
  - Why not beam signals? Elapse time is long! (Decades and centuries for nearest stars.)

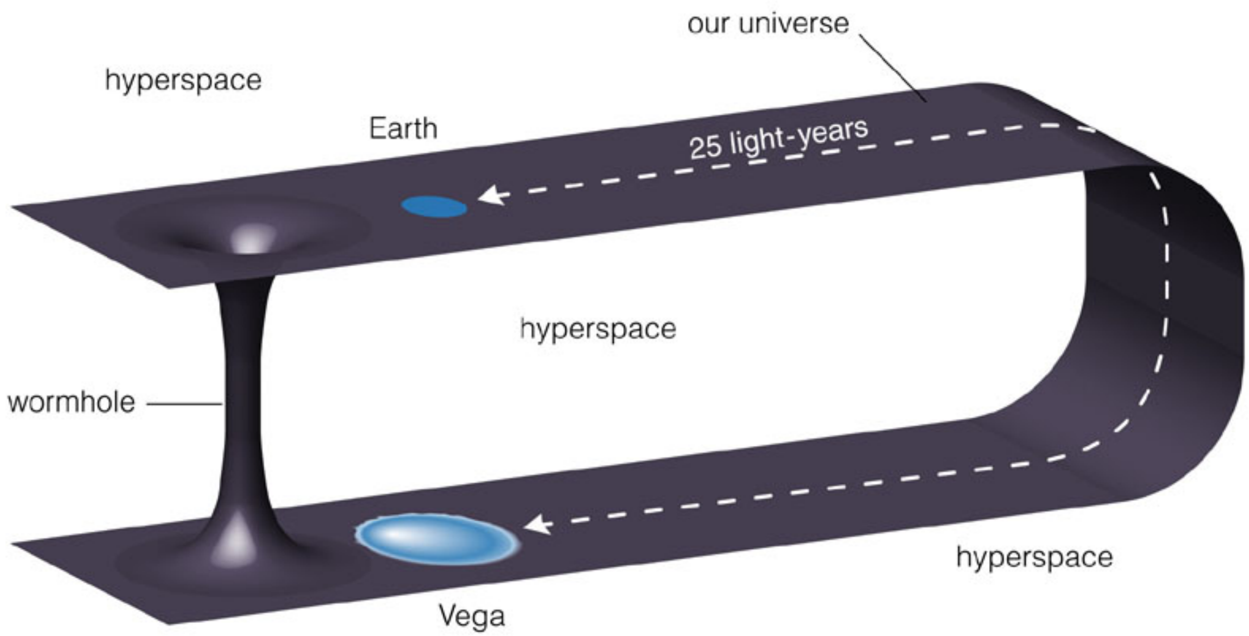
# Radio Search Strategy



# Interstellar Travel

- It is thought that the speed of light, c, is fixed at 300,000 km/s every place and for all time.
- At 4 LY distance, it takes sunlight 4 years to reach nearest star. Light takes 150,000 years to traverse the entire Milky Way.
- Traveling at 1% of c, it would take 400 years to reach nearest star.
- ***Moral***: space is vast, and travel is slow
- Go faster! Tachyons, warp drive, wormholes

# Wormholes as Shortcuts



# Galactic Colonization

- Issues:
  1. Size of galaxy
  2. Distance between stars
  3. Speed of travel
  4. Development time (colonies and new ships)
- Traveling at just 30 km/s with no stops, a "ship" could traverse MW in ~1 billion yrs
- Fermi asks, "Where are they?"

- Possible reasons:
  - Zoo hypothesis (prime directive)
  - ET is rare (other galaxies)
  - ET not motivated
  - Intelligence kills (better…)
  - Intelligence rate
  - Maybe we have been visited! (X-files)
  - Future intended malice (?)
  - Infrequent visits (tourism?)
  - Development out of phase (are we the first?)

# Colonization (cont.)

- On the whole, scientists do not believe we have been visited.
- Reports of UFOs have risen dramatically with rise of aviation and space capability
- BUT, galactic colonization seems "feasible", so why no contact? (Not even indirect – no confirmed detections by SETI)

# Drake Equation

- A way of assigning probabilities to estimate the # of intelligent civilizations in the MW.

$$N_{\mathrm{civ}} = \mathcal{P}_{\mathrm{planets}} \times \mathcal{P}_{\mathrm{hab}} \ldots \mathcal{P}_{\mathrm{intel}} \times N_*$$

- Highly opinionated and biased! Nevertheless, it breaks down a complex problem into pieces that can be individually addressed.

# Visual of the Drake Approach