Lectures on radio astronomy: 8

Life in the universe
Search for exo-planets
SETI

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Speculation about life beyond Earth is probably ancient

- Greek philosophers Thales & Anaximander (7^{th}-6^{th} C. BC) argued for universe full of planets; taken up by atomists: infinite universe should have infinitely many populated planets
- Aristotelian thought – geocentric – made Earth special and contradicted this idea
- Religion – god(s), angels, devils – suggests sort of “extraterrestrial” life (but spiritual)
- Church did not favor others, though Nicholas of Cusa discussed aliens on Moon & Sun

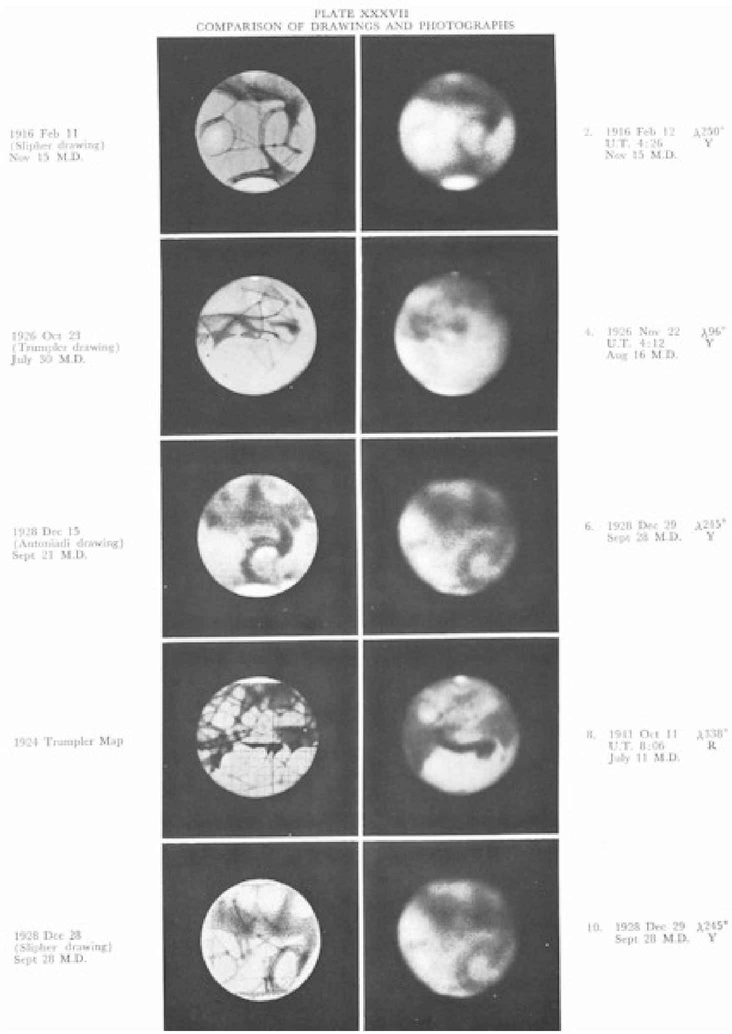
More modern thought on extraterrestrial life

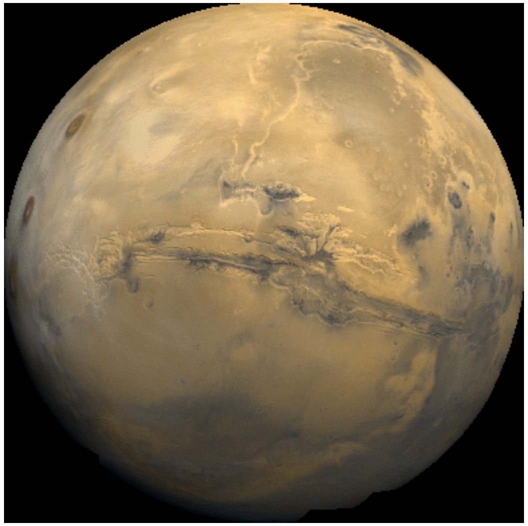
- Giordano Bruno (1548-1600) believed that the Sun was a star, that stars were infinite in number, and that each had its planets
- An infinity of planets would be the potential home for life throughout the universe, and would later be accepted by many scientists

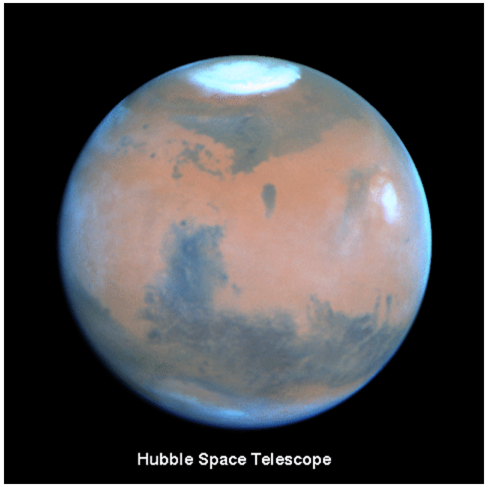
In the 19^{th} C. an inhabited Mars became widely accepted

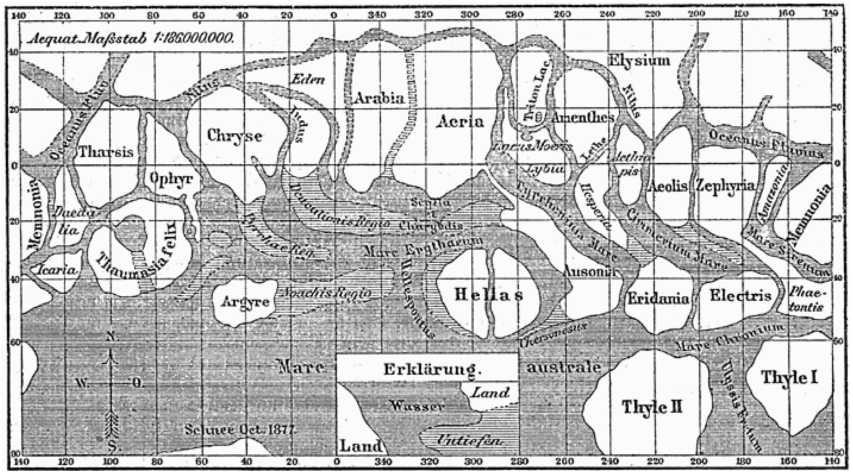
- Schiaparelli in 1877 made a map of Mars, and wrote of what he called *canali*, which was translated as “canals” (but it can also mean “channels” or “gullies”, which can be natural)
- Several other astronomers also thought they saw linear features
- A popular belief was that Mars was inhabited but very dry, and its inhabitants built a system of canals to bring water from the polar ice caps to the populated but arid temperate zone

Percival Lowell was convinced that the canals were real

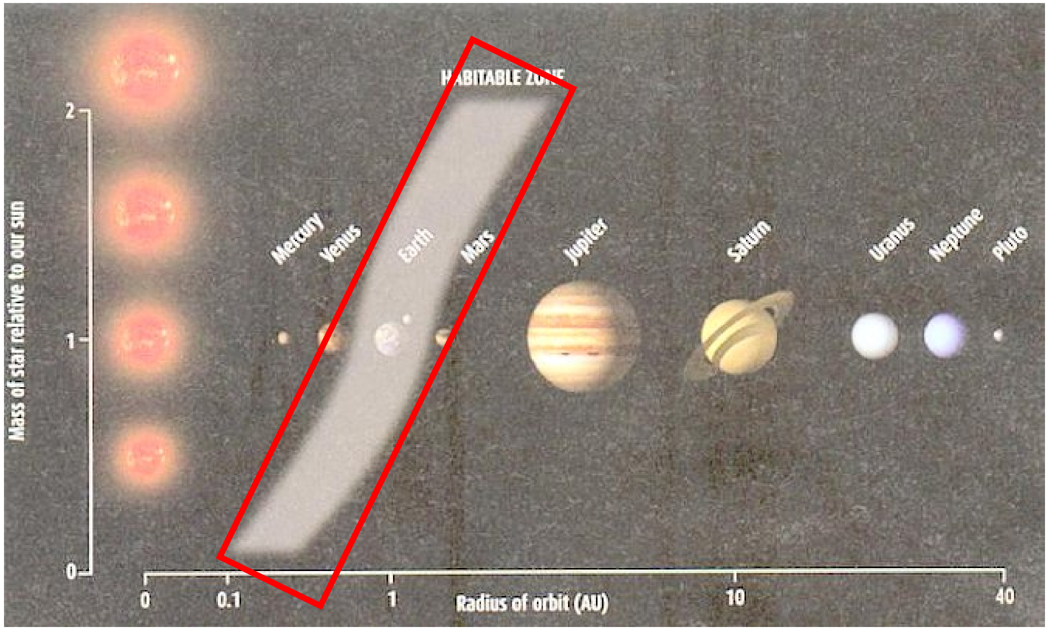






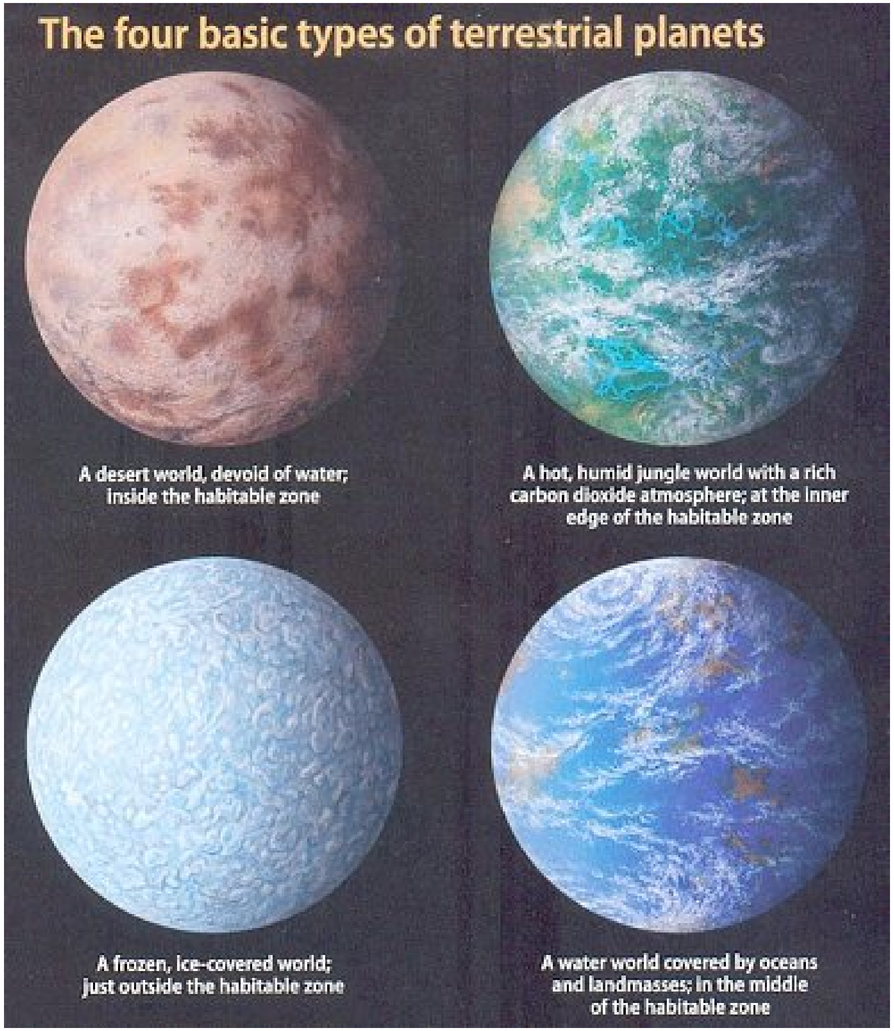


Now clear that Mars is hostile to life – but where should we look?



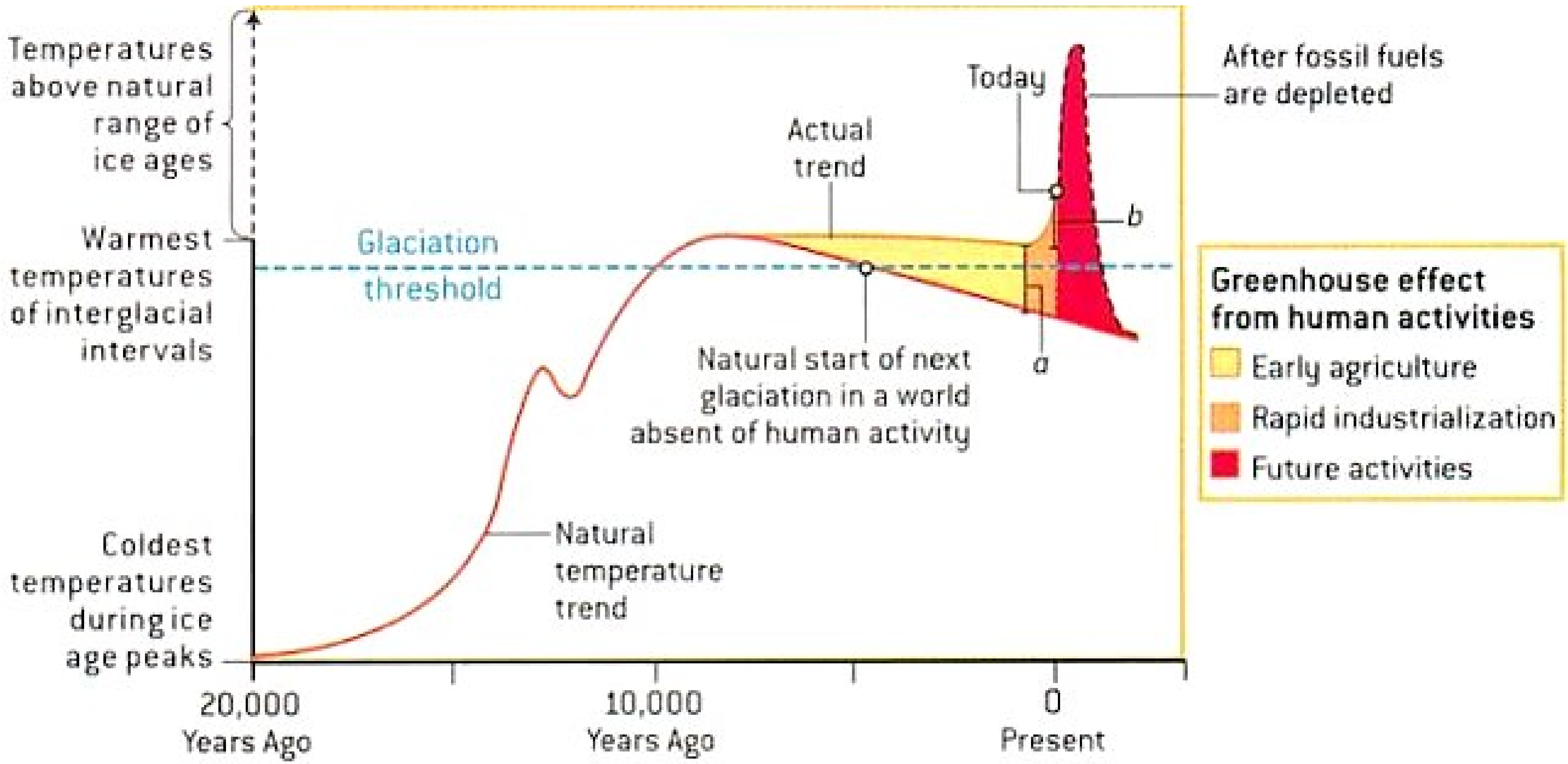
- Stars are too hot, so focus is on planets
- There is a zone, which depends upon a planet's star, where stellar radiation is "just right"
- Here shown for stars of different mass

Within the zone, planet types like Venus – Earth – Mars



- The appearance of each depends upon warmth from its sun, its atmospheric content and stage of evolution
- Mars is now too cold and its atmosphere too thin to support most life
- Venus' atmosphere & the Sun make it too hot
- Earth is just (still) OK

With continued human activity, Earth may become warmer



If we're going to search for it, then what is life?

- General characteristics can be listed:

  - Organization (as in cells)

  - Regulation of internal environment

  - Metabolism (energy conversion)

  - Growth (form & size)

  - Adaptation (evolution)

  - Response to stimuli (heat, pain, food, etc.)

  - Ability to reproduce

    (and other properties have been suggested)

One simple definition:

"Life is a self-sustained [chemical] system capable of undergoing Darwinian evolution."

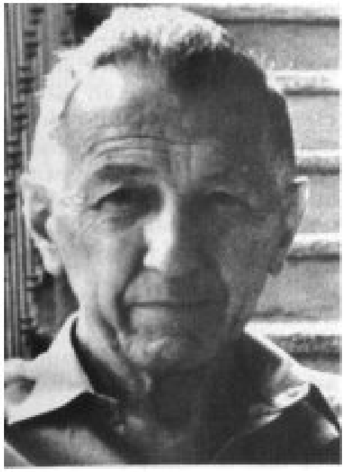
G.F. Joyce (1994)

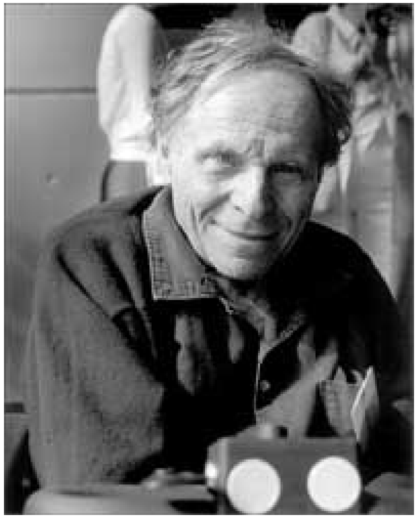
Eukaryotic forms: diverse, but have all life's qualities

Primitive life (single-celled) – difficult to detect

- Remotely, one can only hope to see some chemical sign
- So best chance is to look *in situ* on planets & moons of solar system
- Complex chemistry makes remote experiments difficult to design

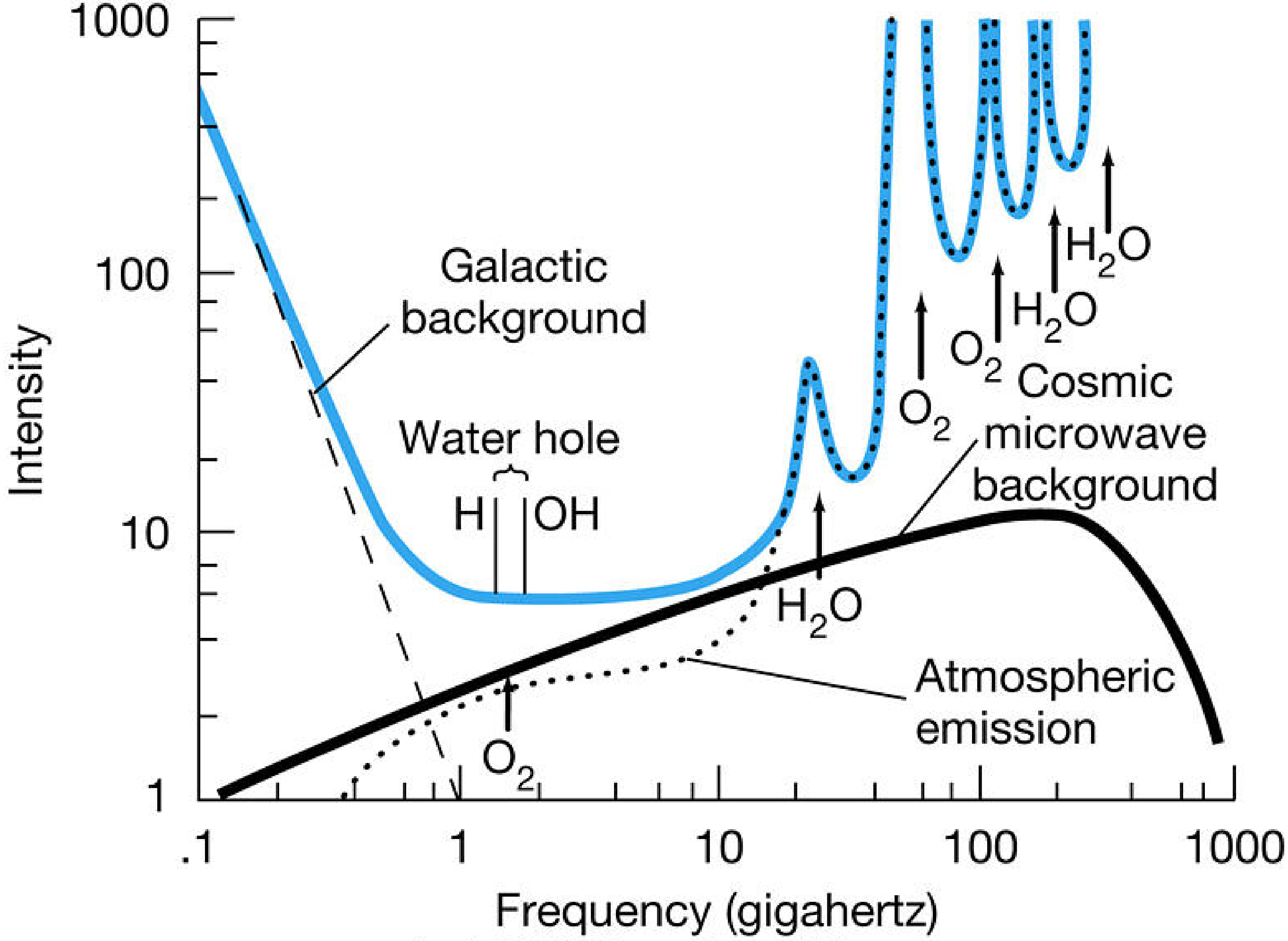
Intelligent life less common, but (probably) easier to detect



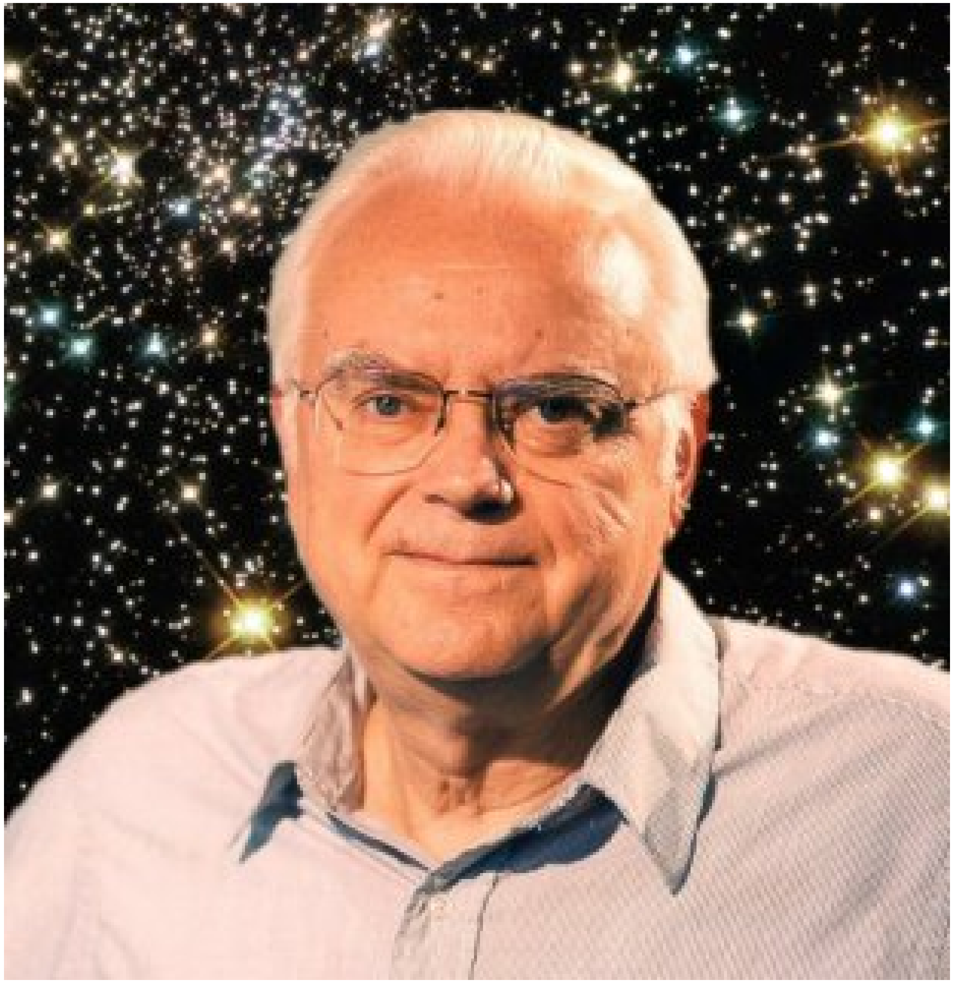


- Giuseppe Cocconi & Philip Morrison published the first scientific paper on “Searching for interstellar communications”
- Originally Cocconi was thinking of using γ-rays to communicate
- Together with Morrison other parts of the electromagnetic spectrum were considered
- They finally argued radio band was the most suitable

Naturally occurring radiation defines least “noisy” frequencies

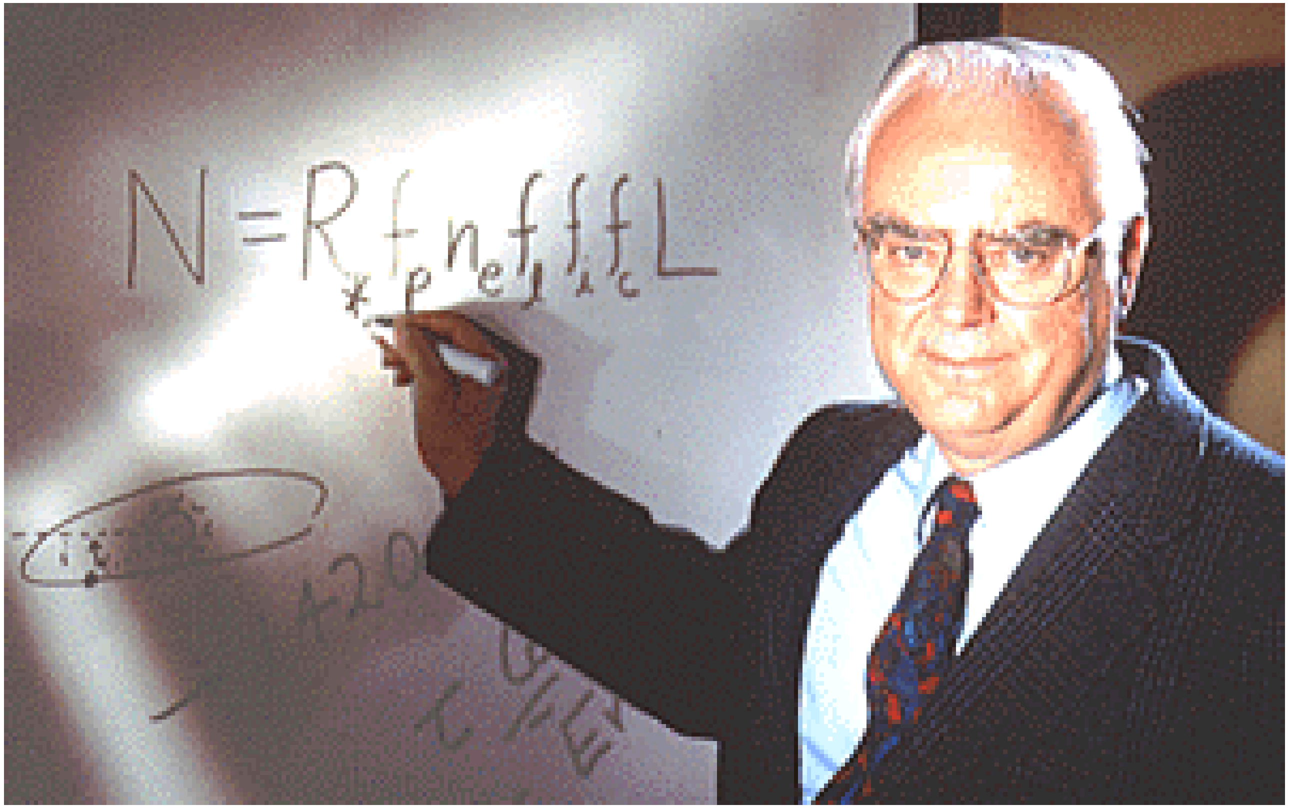


Within a year, Frank Drake was observing…



…with this radio telescope at 21 cm wavelength

This led Drake to his equation for the number of planets we could communicate with

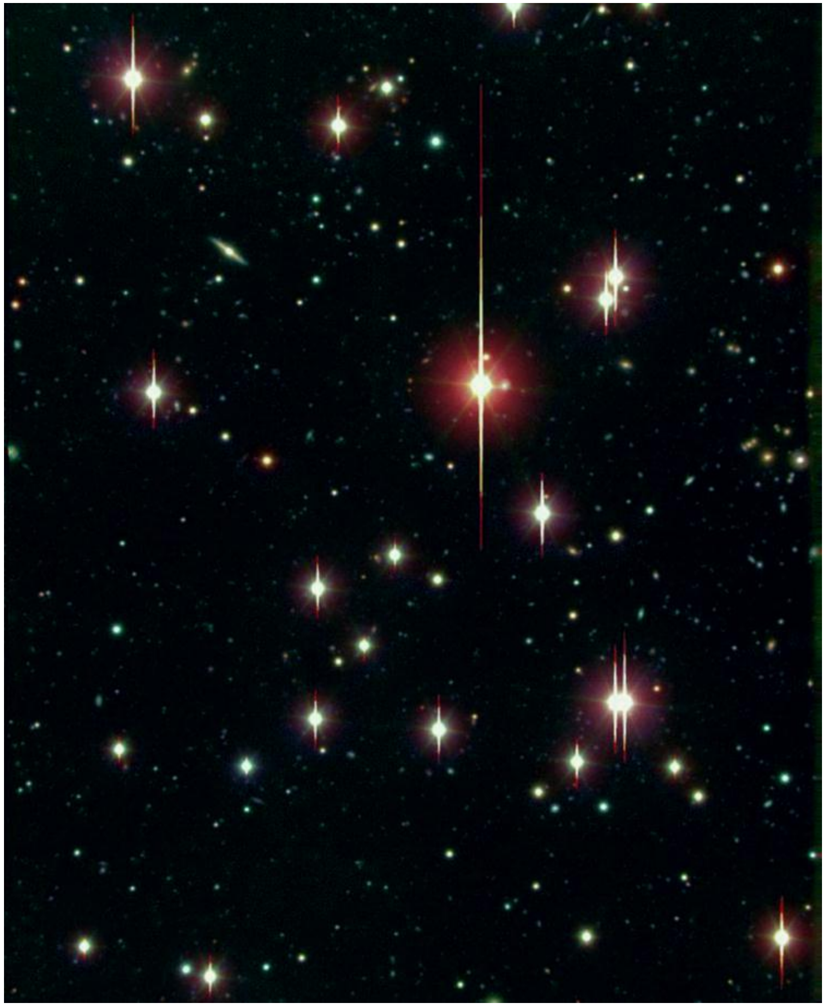


How many civilizations could we contact in the Milky Way?

Step 1:

How many stars are there?

(Drake expressed this in terms of the rate of star formation)



Step 2: How many stars have planets?

Step 3: How many planets are like the Earth?

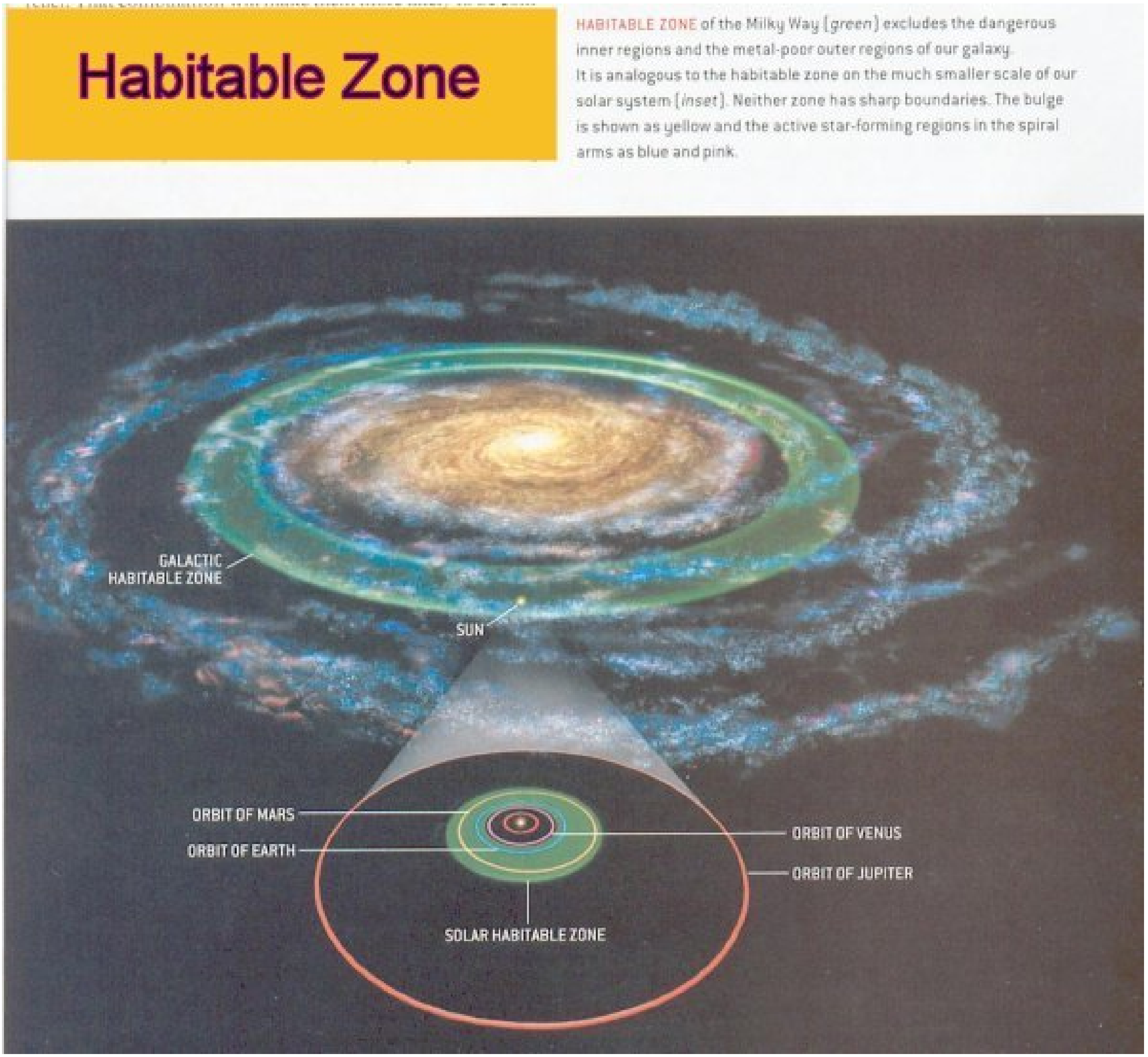
Step 4: How many Earth-like planets have developed life?

Step 5: How many have intelligent life forms?

Step 6: How many have advanced communication?

Step 7: For what fraction of time does communication exist?

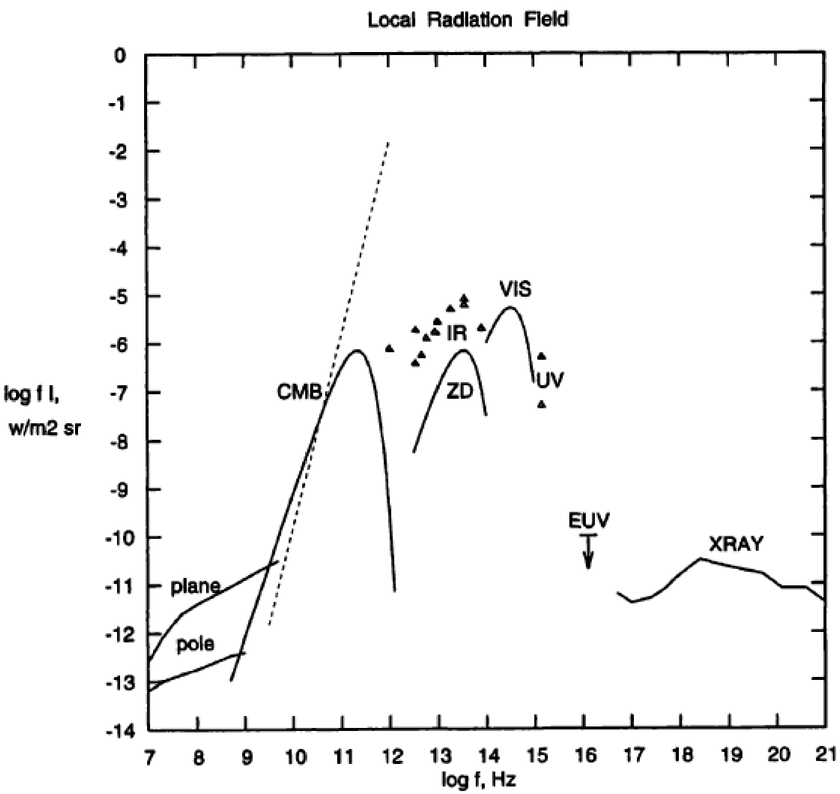
Formula implicitly excludes certain zones in Milky Way



A crude example of how calculation is done

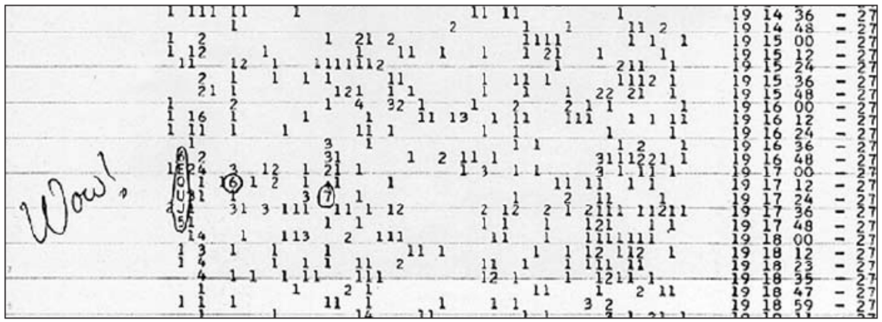
- Suppose there are $\approx 10^{11}$ stars in Milky Way, but only 10% in "habitable zone": leaves 10^{10}
- Suppose 10% have planets: leaves 10^{9}
- If 1% are like Earth, then 10^{7} are left
- Suppose 1% develop life: leaves 10^{5}
- But if only 1% of life is intelligent: leaves 10^{3}
- Suppose 10% develop communication: 100
- If communication lasts 1% of lifetime: 1 left

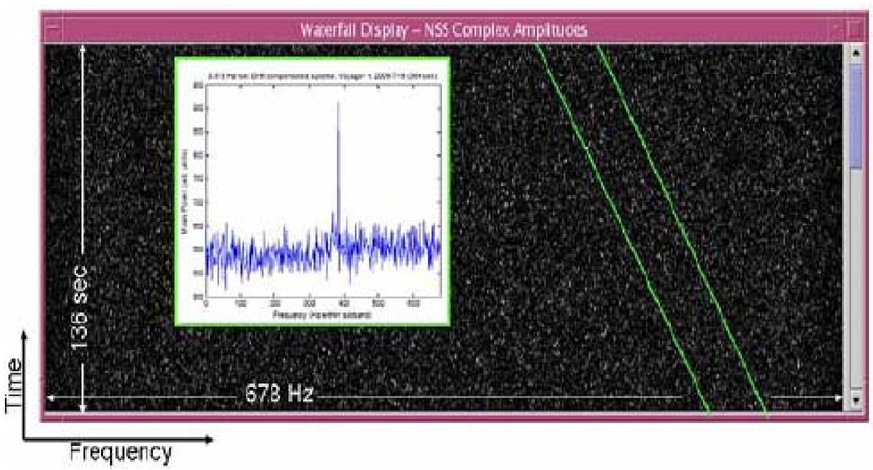
SETI search questions: where to look? And how to search?



- As concluded by Cocconi & Morrison, best place to search is probably the microwave (radio) band
- Over the whole electro-magnetic spectrum, it is one of the quietest
- Only recently, there have been projects to also look in the visual band
- Targets: stars with planets

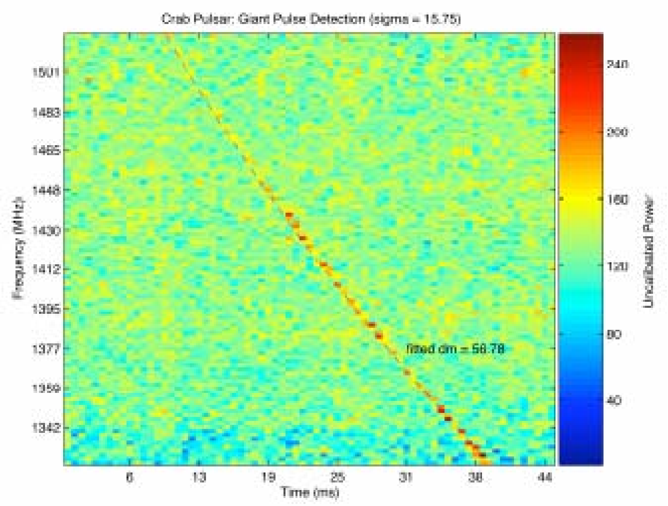
Although nothing has been found, there have been some surprises…





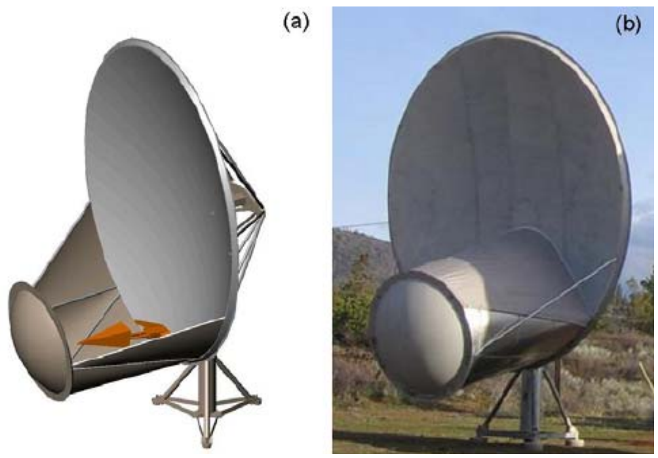
- Large Ohio State Kraus telescope used for searches
- 15 August 1977: “Wow!” signal, strong, narrow-band, in telescope beam
- Weak Voyager I signal was found by accident, and first thought to possibly be from SETI

SETI Institute has built special wide-band electronics



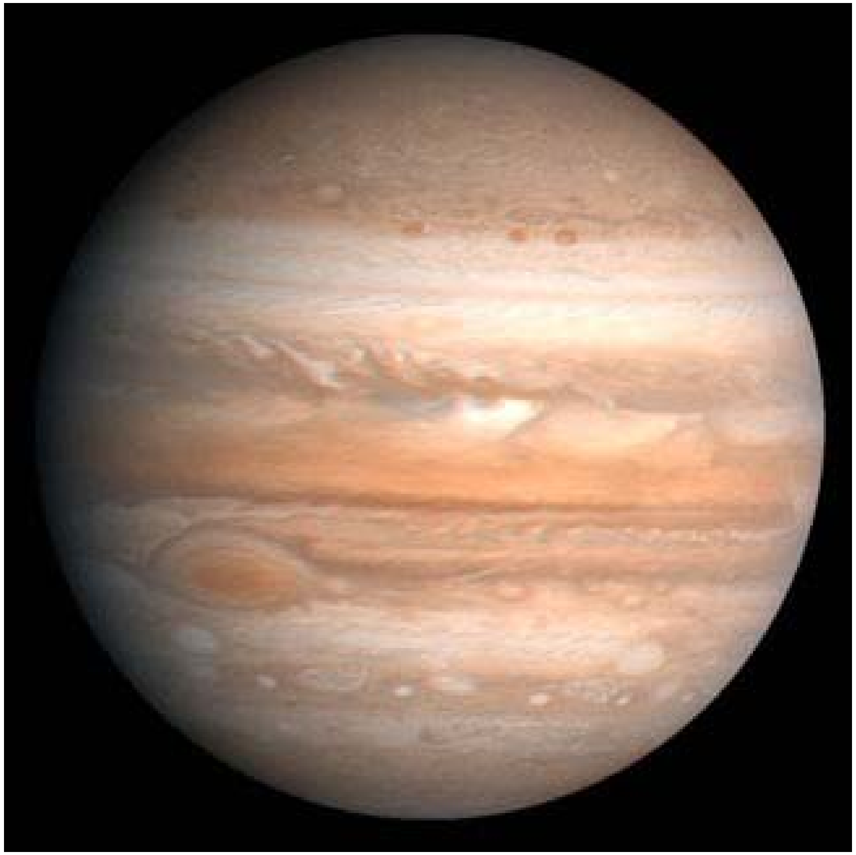
- Searches done with large existing telescopes like Arecibo & Nançay
- Giant pulse from Crab Nebula pulsar: using a natural object to show that search technique works
- Some analysis done with SETI@home software
- So far, no detections

Recently, SETI Institute has begun Allen Telescope Array



- The ATA consists of 6 m antennas, f = 0.5-10 GHz
- They are based on an offset Gregorian design
- At the moment there are 42 elements, located at UC Berkeley's Hat Creek Radio Observatory
- Plan is to build 350 such dishes
- Expect: ETI from planets

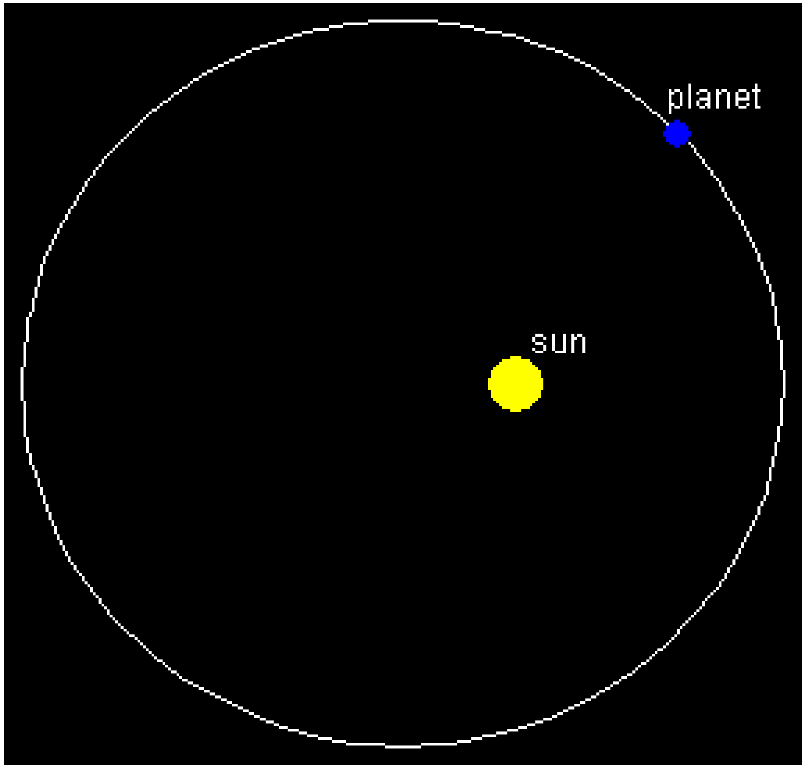
We know about planets in solar system, what about beyond it?



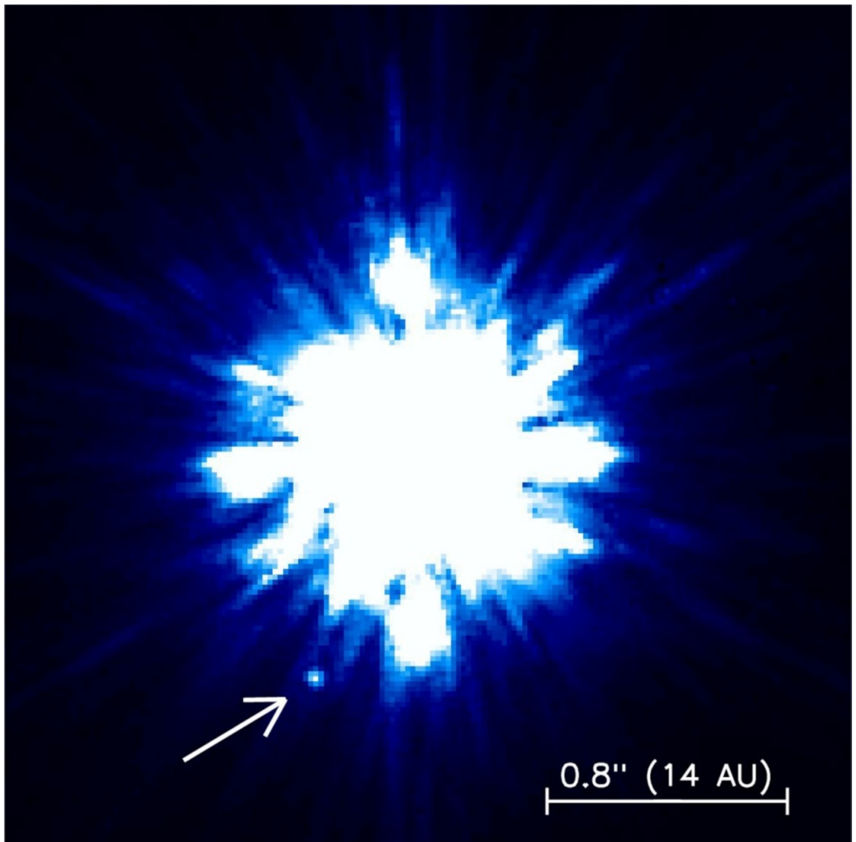
- Directly observing light from a planet is very difficult
- We only see light which a planet reflects from its star
- The amount reflected depends on the albedo (reflectivity) which is always <1 (=100%). For Jupiter, albedo = 0.5

The amount of light from a planet also depends on its orbital radius

- Planet can reflect no more than the light which falls on it
- The relative amount is ratio of planet's area to area of sphere defined by its orbit, or $(r_p/2r_{orb})^2$
- For Jupiter, this is: $(71{,}500/3.9\times10^8)^2$ = 0.00000021% of sunlight shines on Jupiter

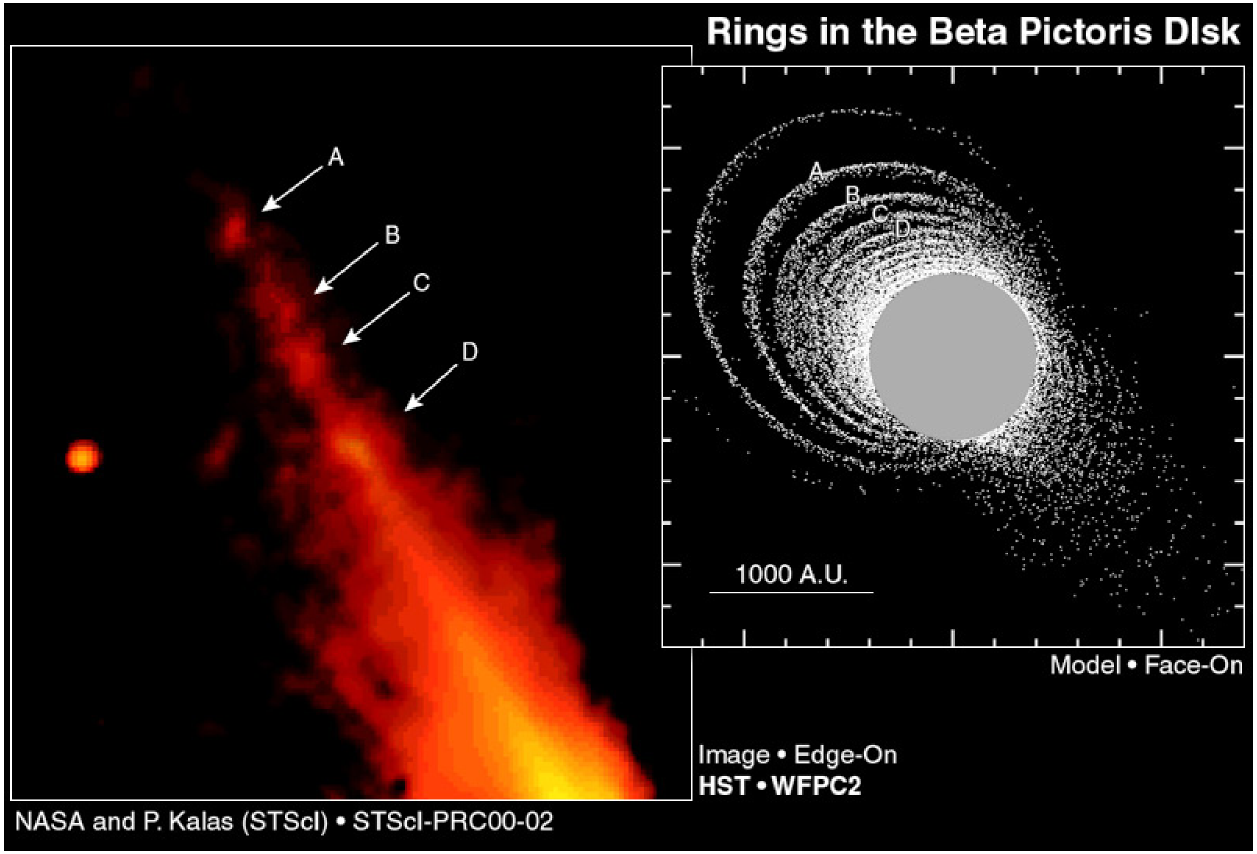


This tiny fraction of light has to be seen close to a star



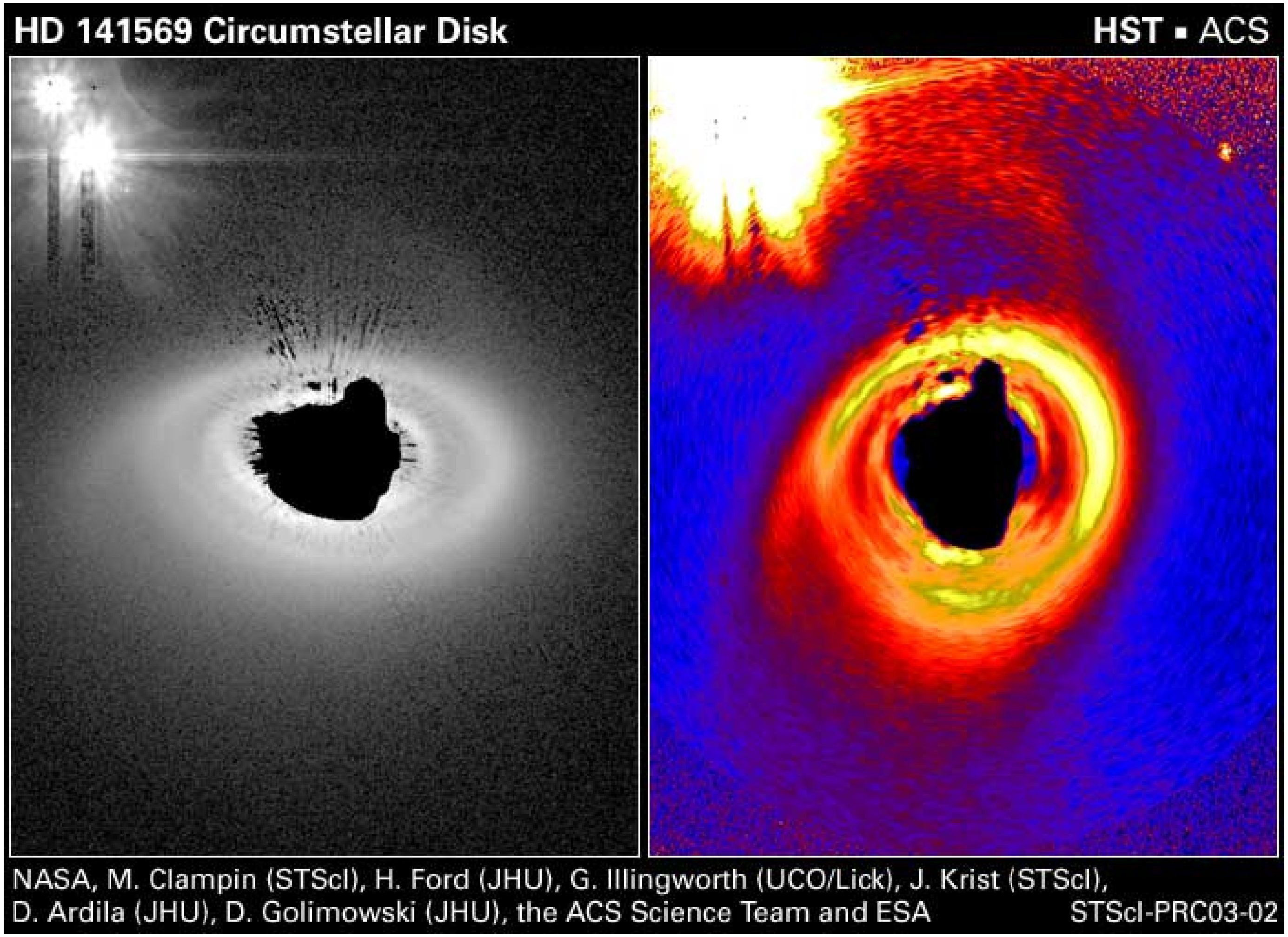
- Here we see a brown dwarf (very cool star, arrow) with a nearby star (bright, irregular blotch) like the Sun
- Light from Jupiter would be much less than that from brown dwarf
- Jupiter would be three times closer to the bright star

Direct observation is difficult, but not impossible

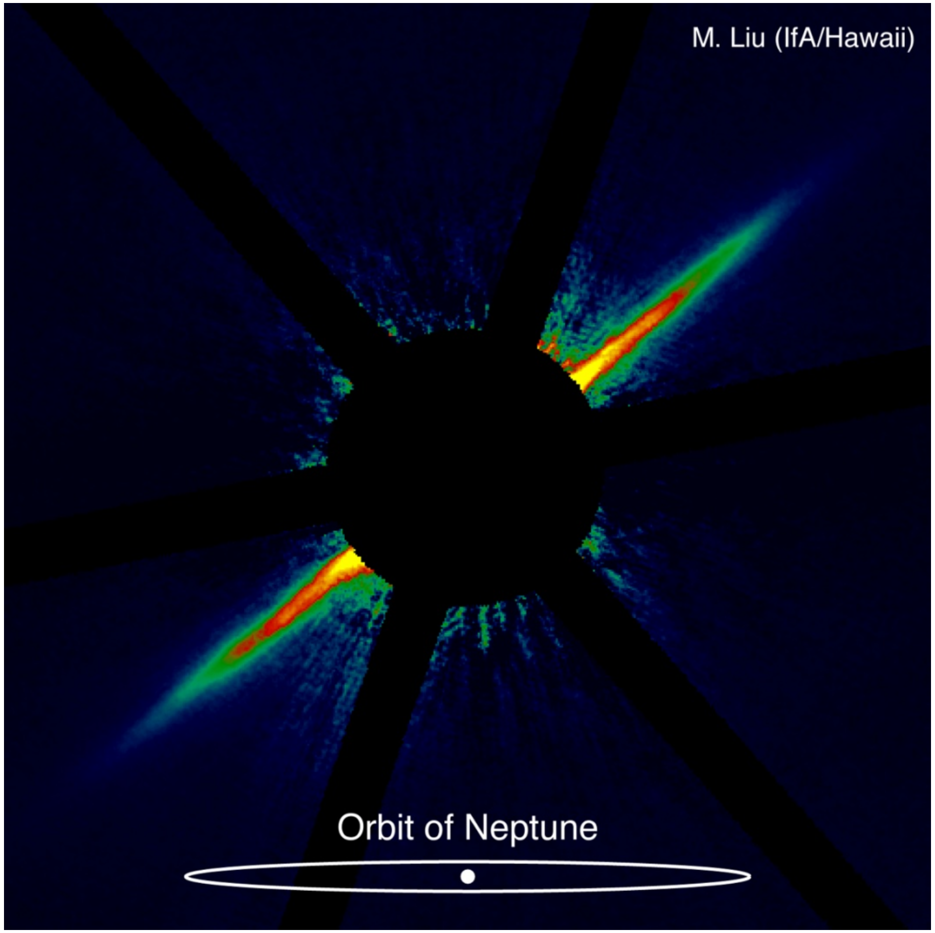


Early evidence for ring-like dust disks around nearby stars – rather like small bodies in outer solar system

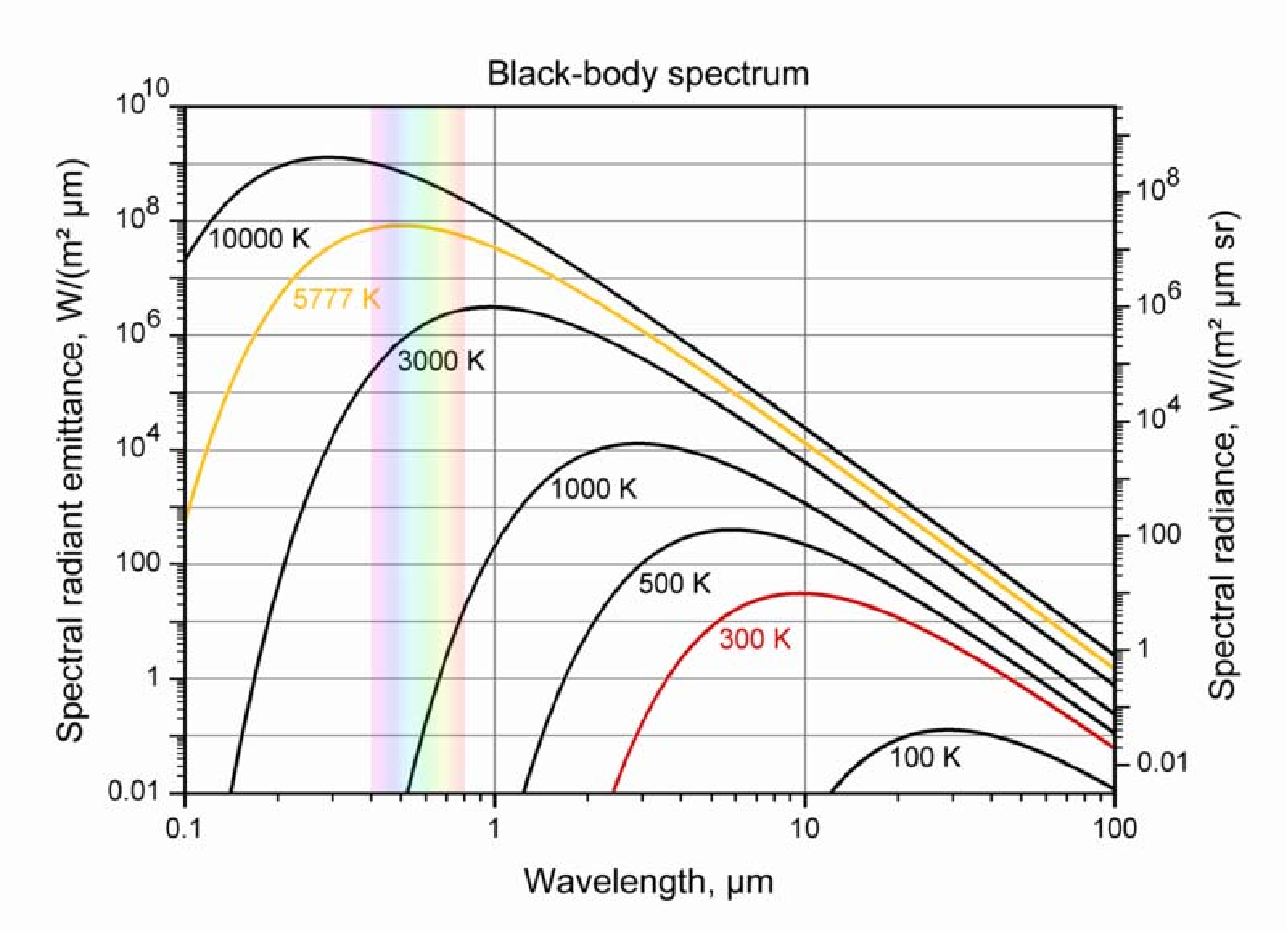
HD 141569, another disk with ring structures seen in infrared



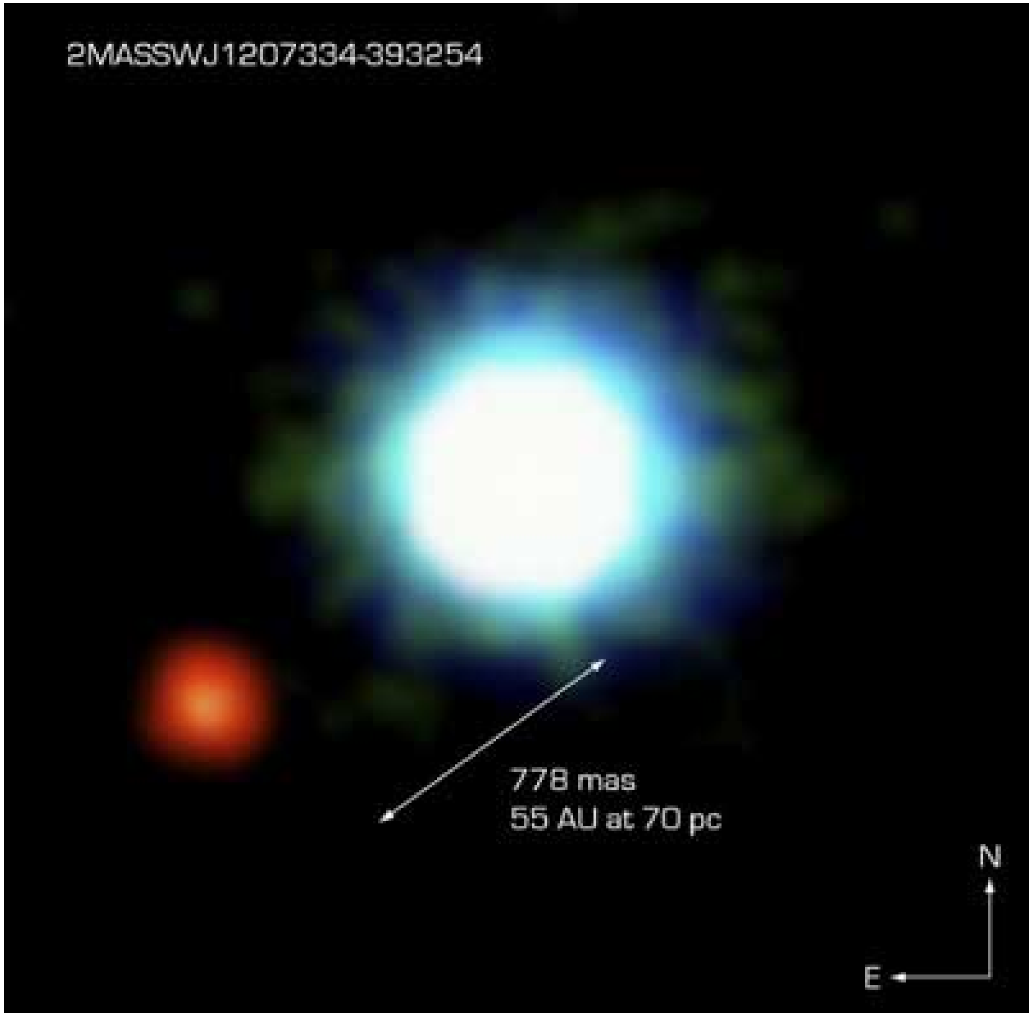
Much smaller disk found around AU Microscopii



A planet's own radiation is heat: better to look in IR

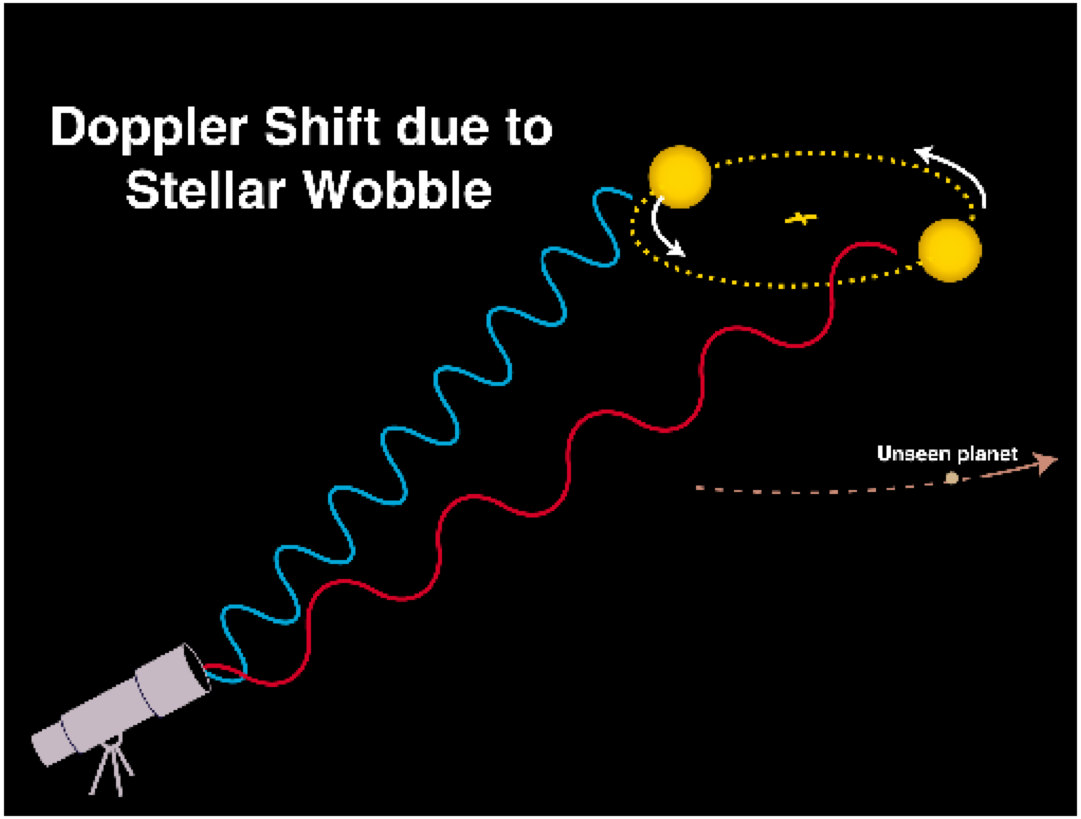


2M1207 illustrates advantage of direct IR imaging

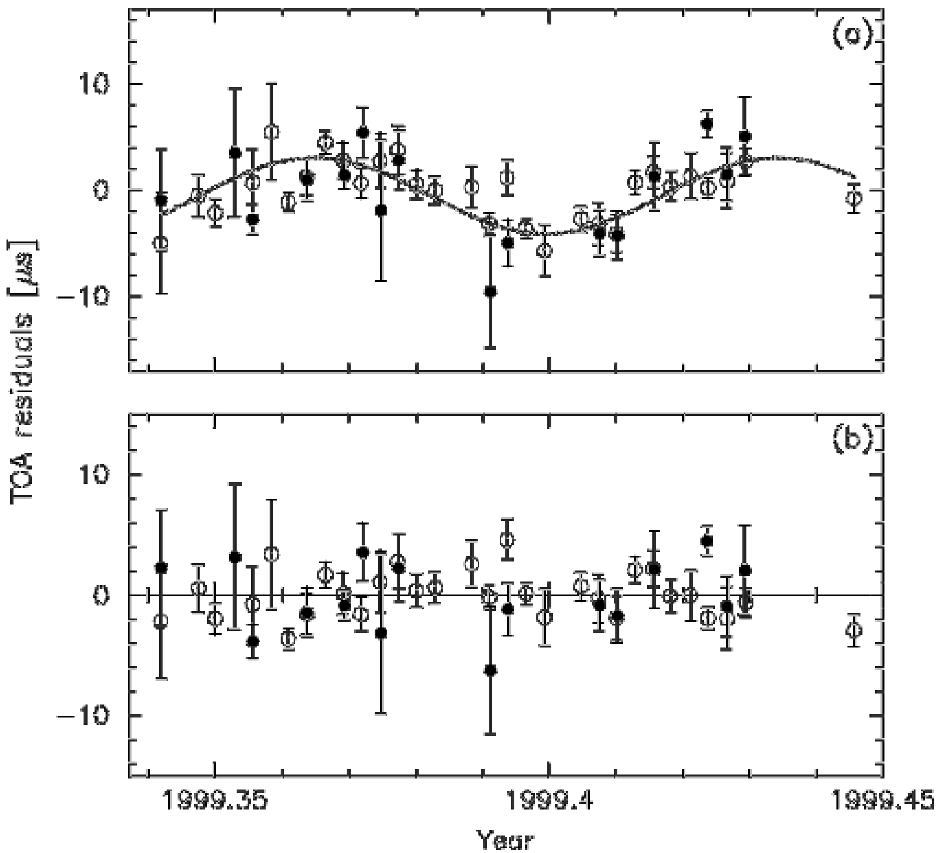


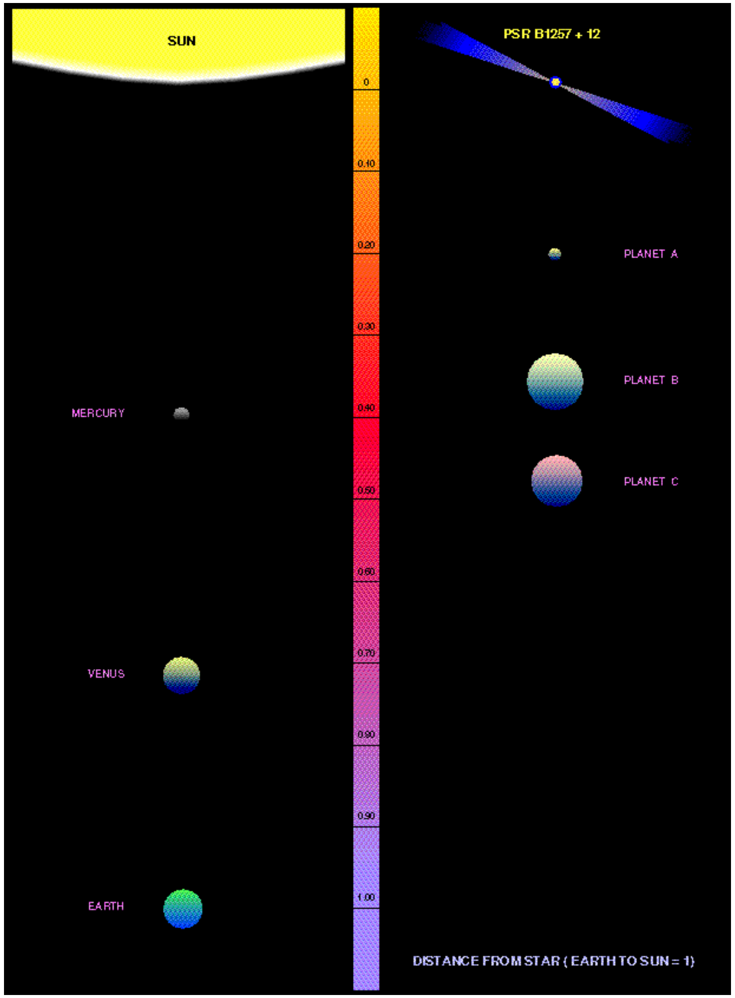
Up to now, indirect methods have proven most successful

In particular, star's small Doppler shift in its orbit around combined barycenter can be used to detect planet



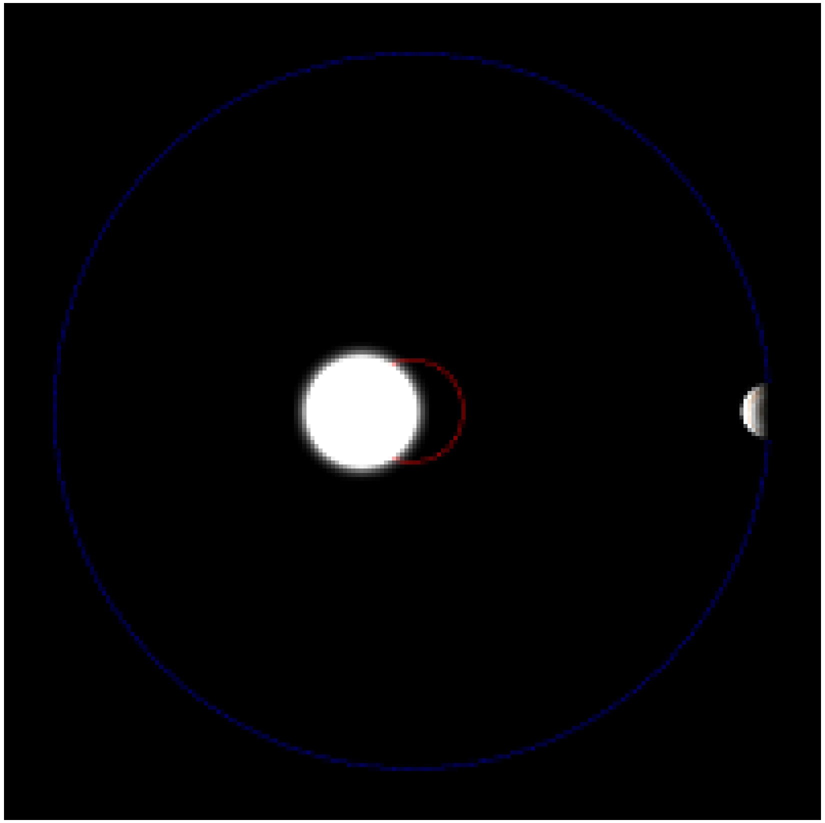
The first planets were detected around a pulsar



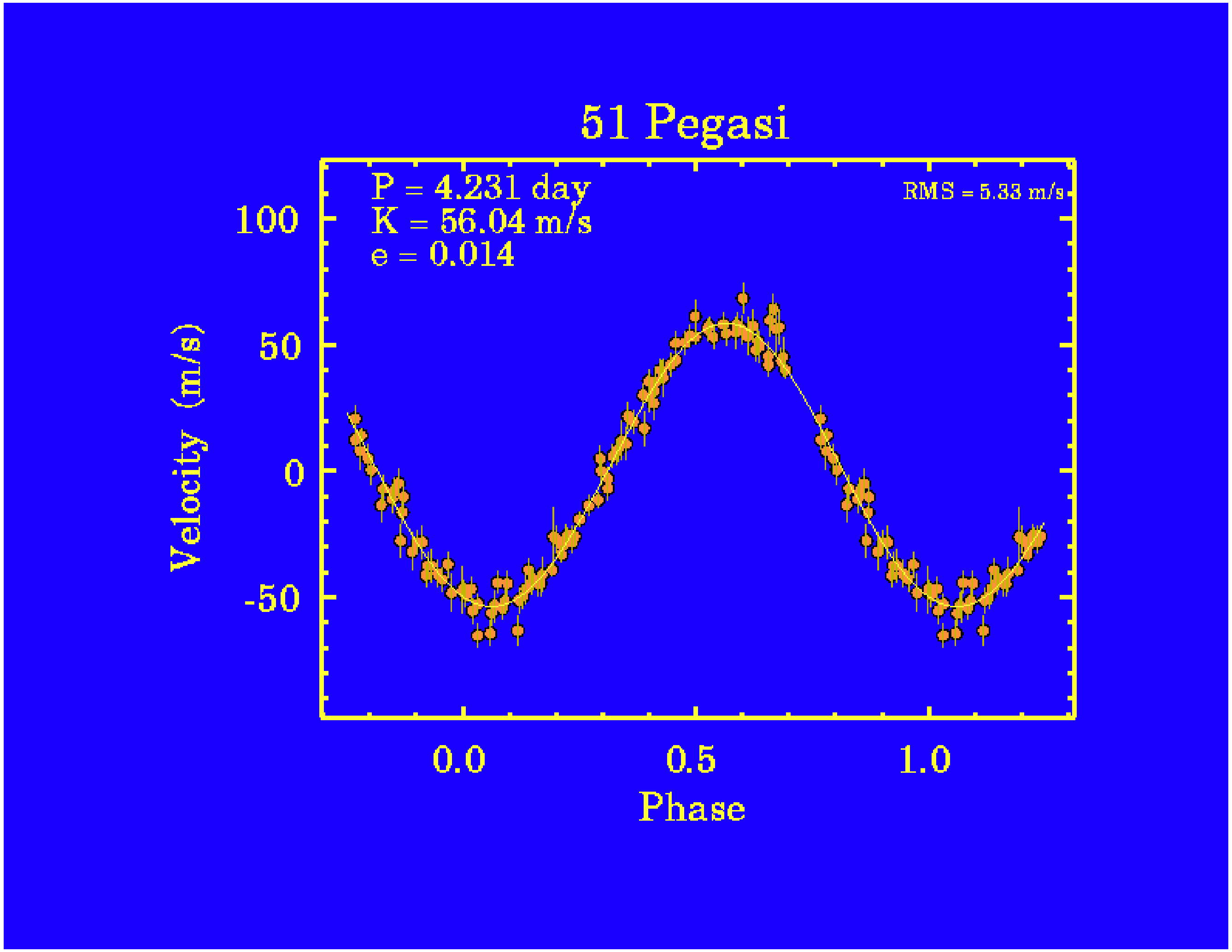


Technique used was just like determining binary period

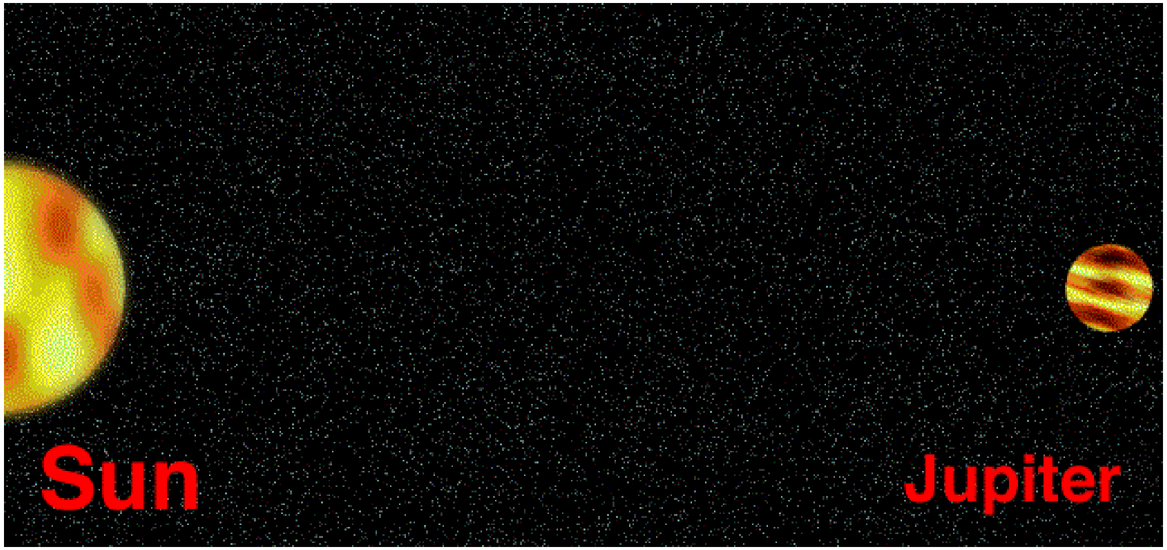
- The planet and star orbit around their common barycenter
- Both planet and star move toward and away from us
- Light from star gets blue- and red-shifted
- These small shifts can be measured

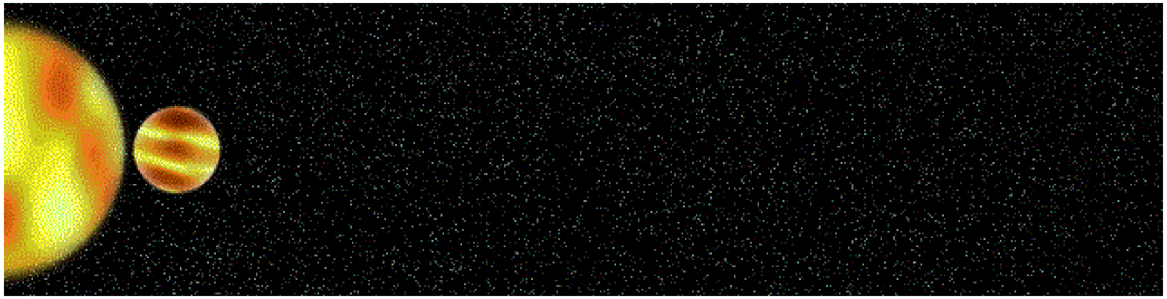


After pulsar, 51 Peg became 1st "real" star with a planet…

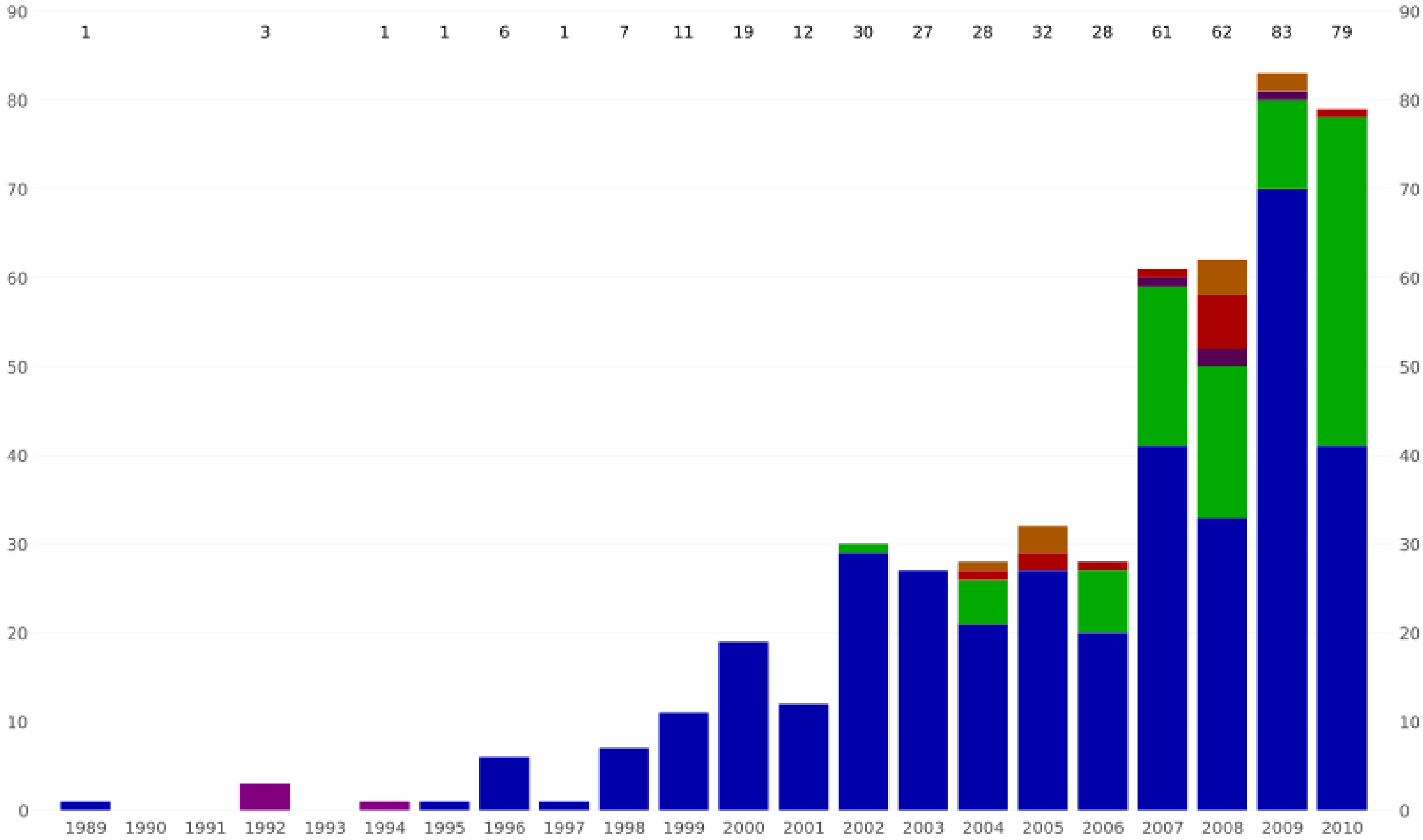


…but not like the solar system – 51 Peg planet: "hot Jupiter"



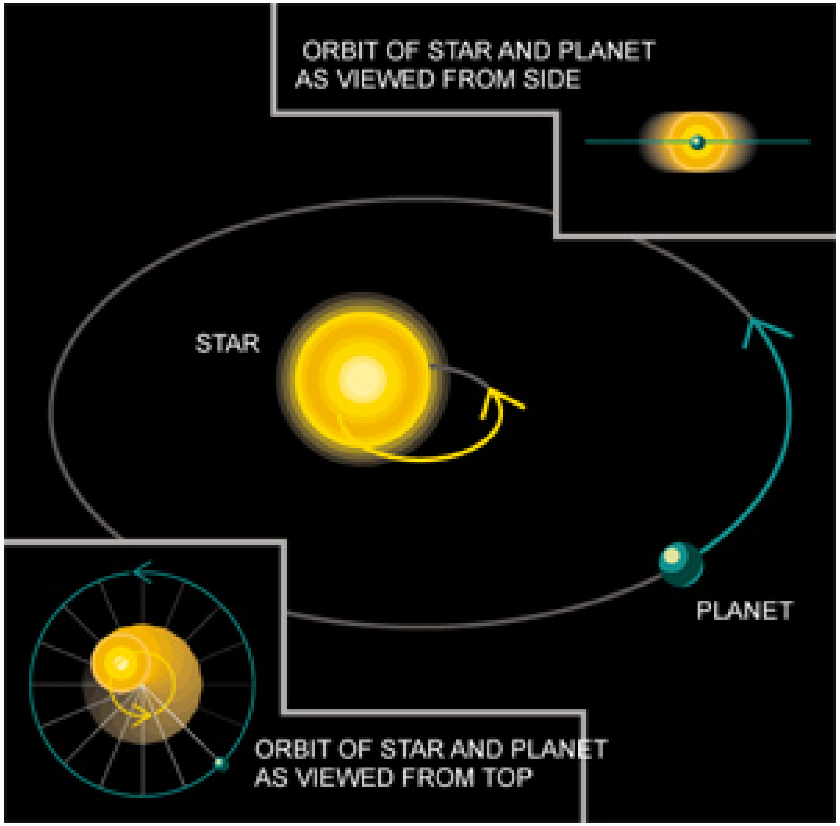


Over 450 exoplanets detected, mostly by the Doppler method

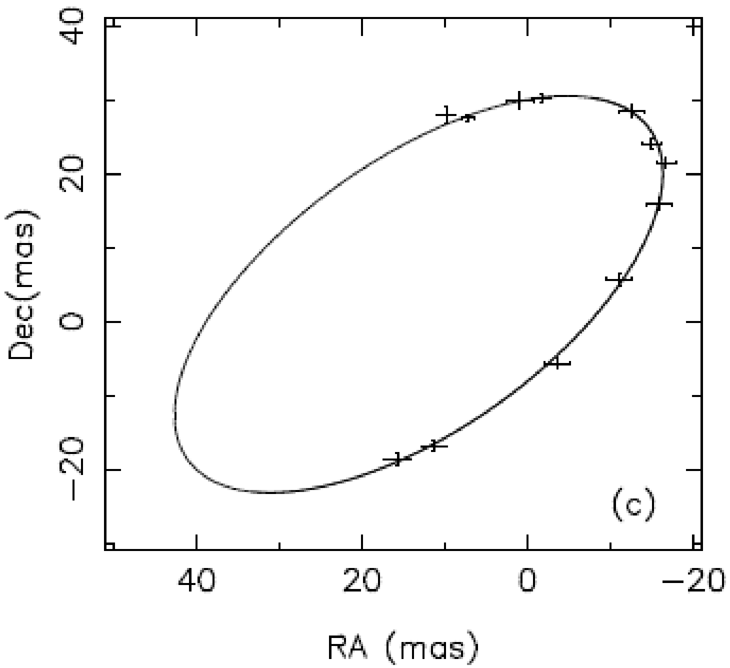


Detection methods are most sensitive to massive planets

- More mass in planet moves star farther from barycenter
- Compact orbit → faster → greater Doppler shift
- Another method uses accurate position to see shift around barycenter
- Easier to do if planet has large orbit, though long period takes time



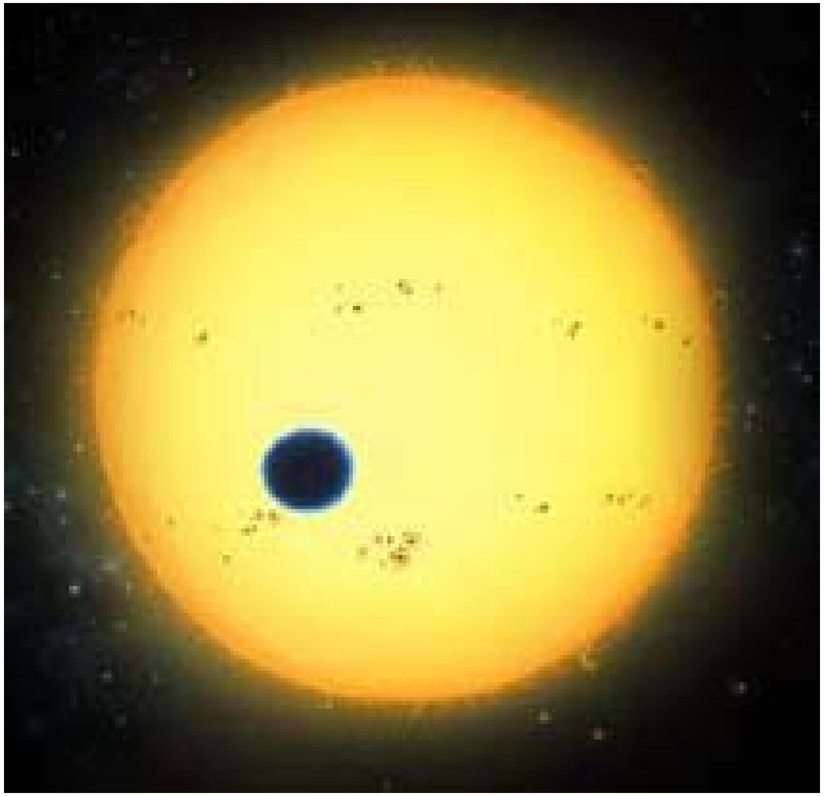
Radio VLBI can be used if star produces radio emission



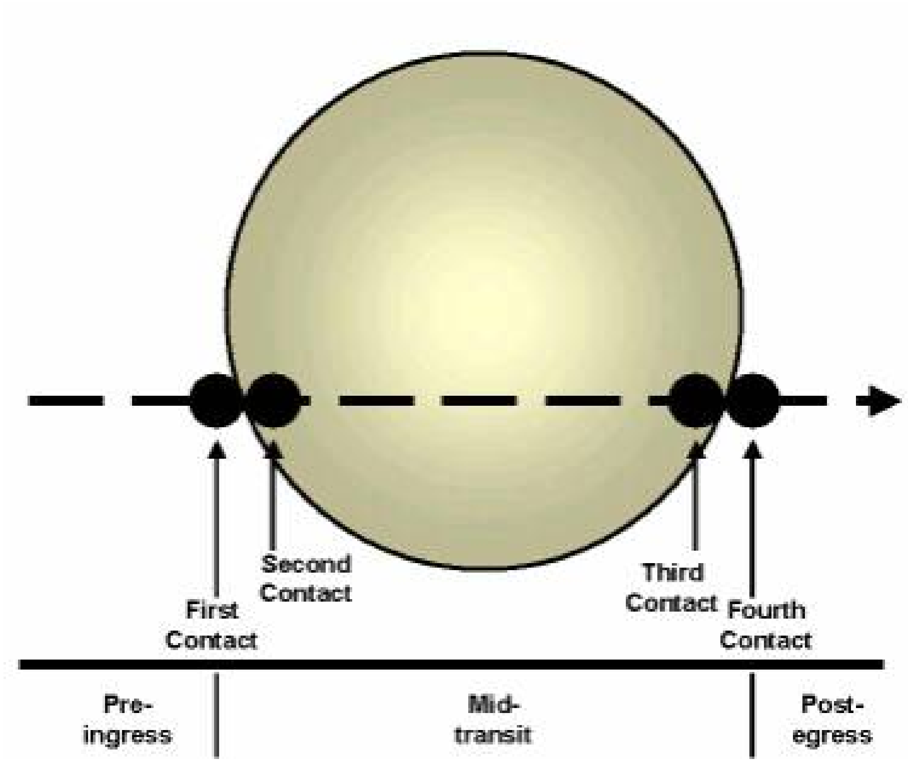
- A number of radio stars are being monitored for possible motion
- In AB Doradus an effect is seen over 6 years
- VLBI data have been augmented with optical
- Companion has m ≈ 0.1 $M_\odot$ (probably low-mass star rather than planet)

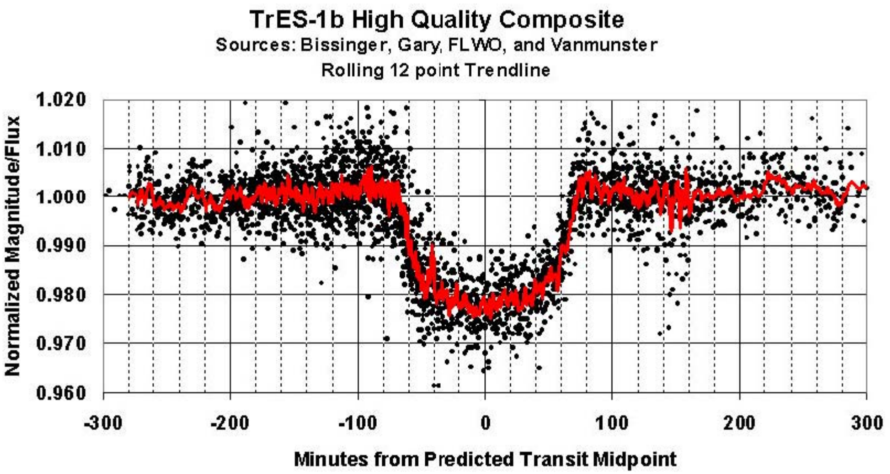
Planet transit (like Venus), another detection method

- Very similar to transits of Venus or Mercury
- Technique works best for planets near a star, and with a large size (hence mass)
- We must be looking in orbital plane of more distant planets
- Has successfully found a few planets

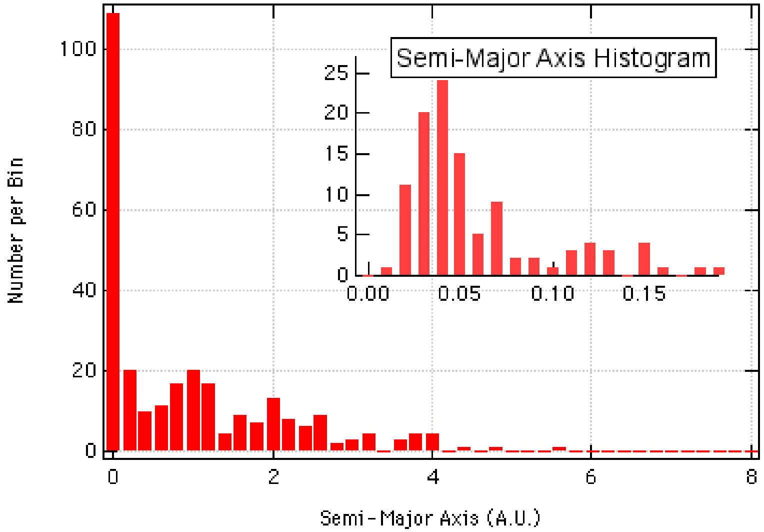


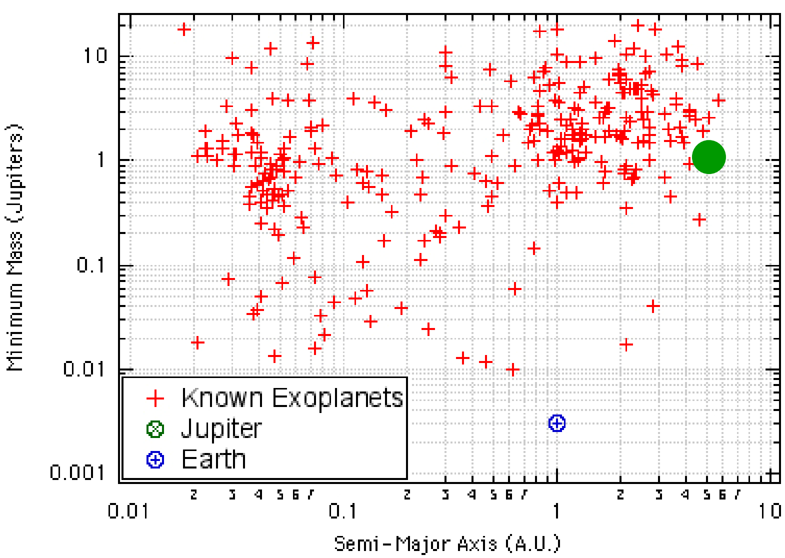
How transit method works, and example of measurement





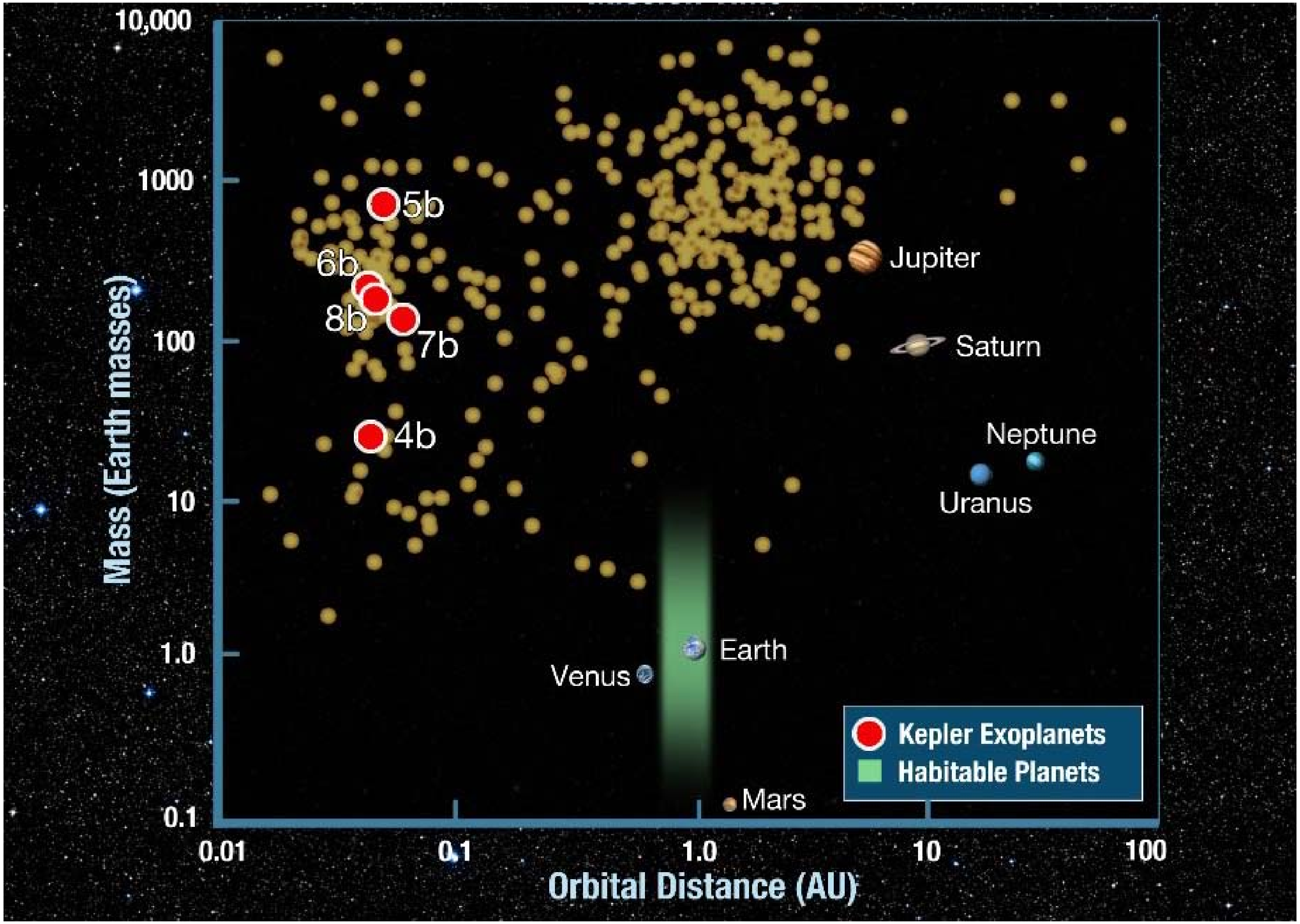
Here was the situation with over 300 exoplanets known



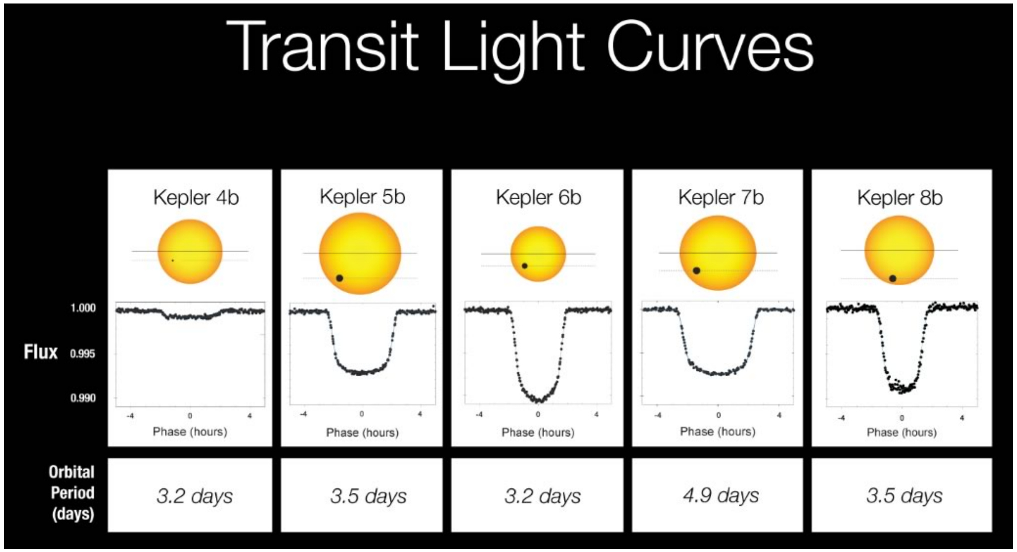


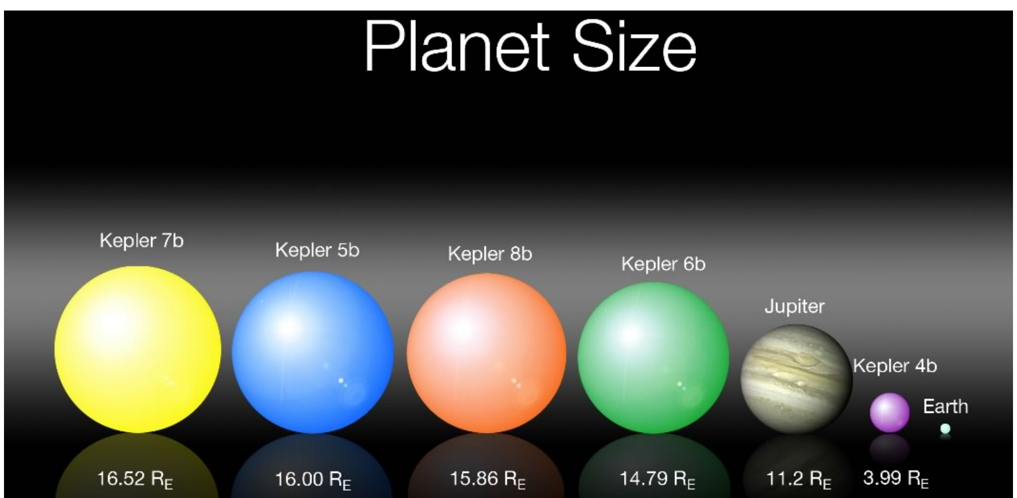
- Histogram shows the planets as function of orbit size
- Most are closer to their star than 1 AU
- 10% of the systems consist of more than one planet
- Most of the planets are as large as or (much) larger than Jupiter

Exoplanet orbital distance as a function of mass



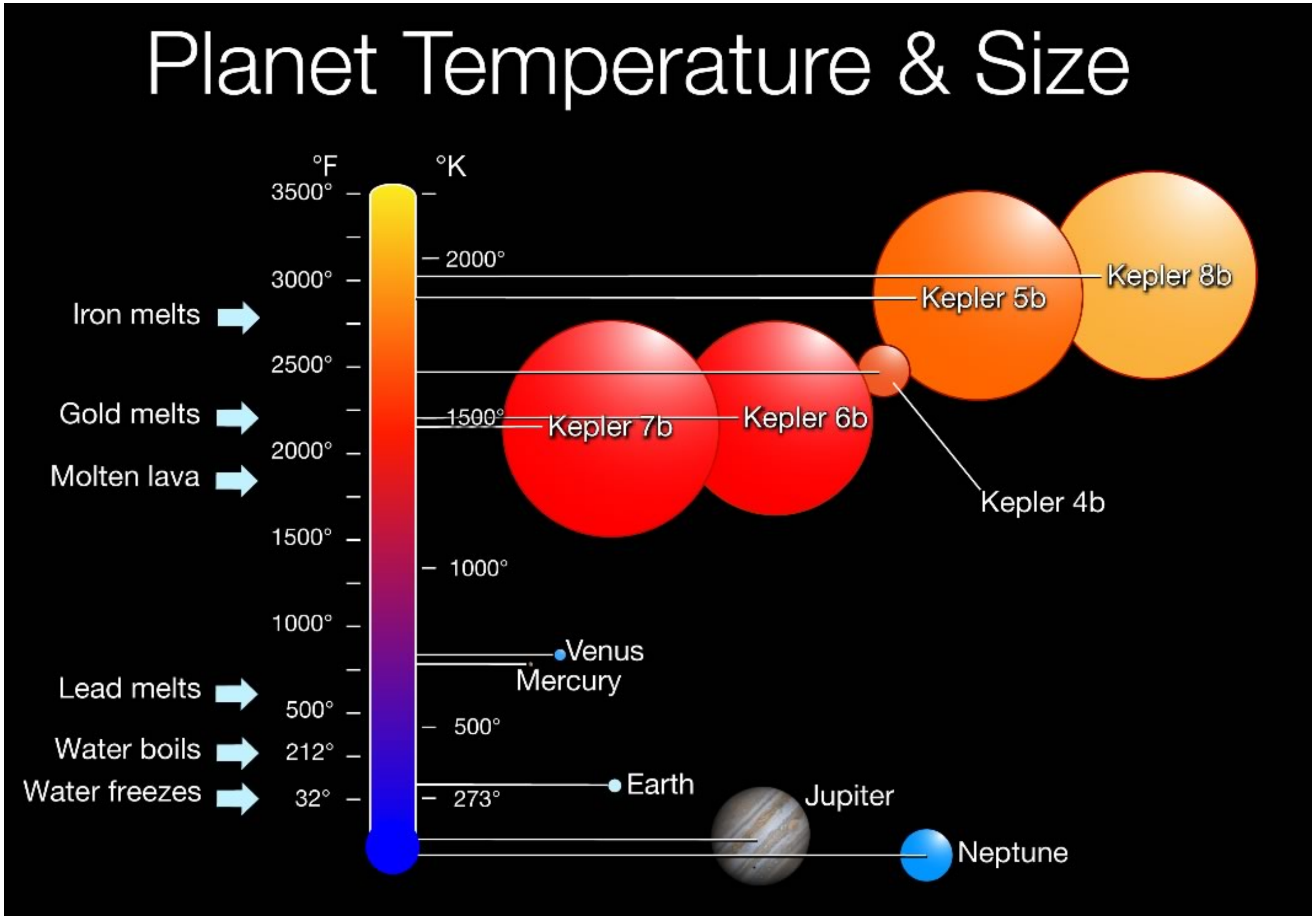
Kepler satellite finds planets by the transit method



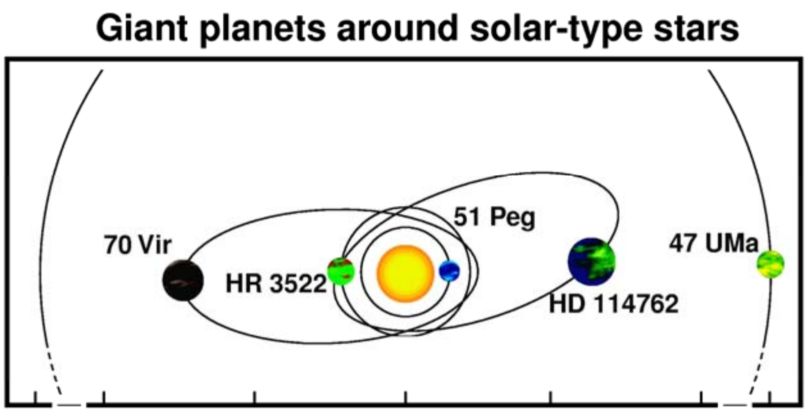


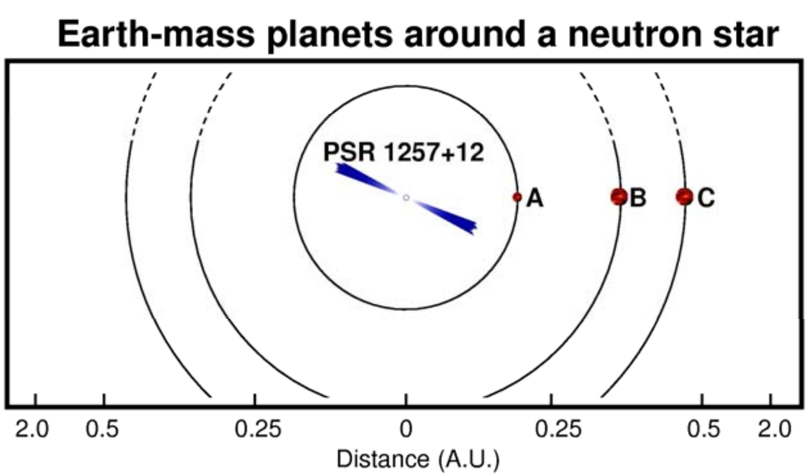
- See starlight dim as planet passes in front of star's disk
- Here are the first 5 detections
- Four of the planets are larger than Jupiter, but one is smaller
- Because they are close to their star…

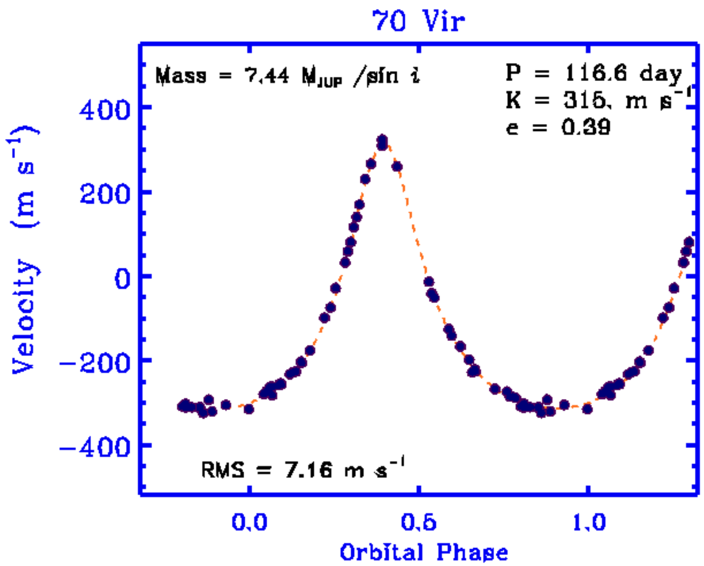
…the Kepler exoplanets are much too hot for our kind of life



Some notable exoplanets around stars and PSR 1257+12

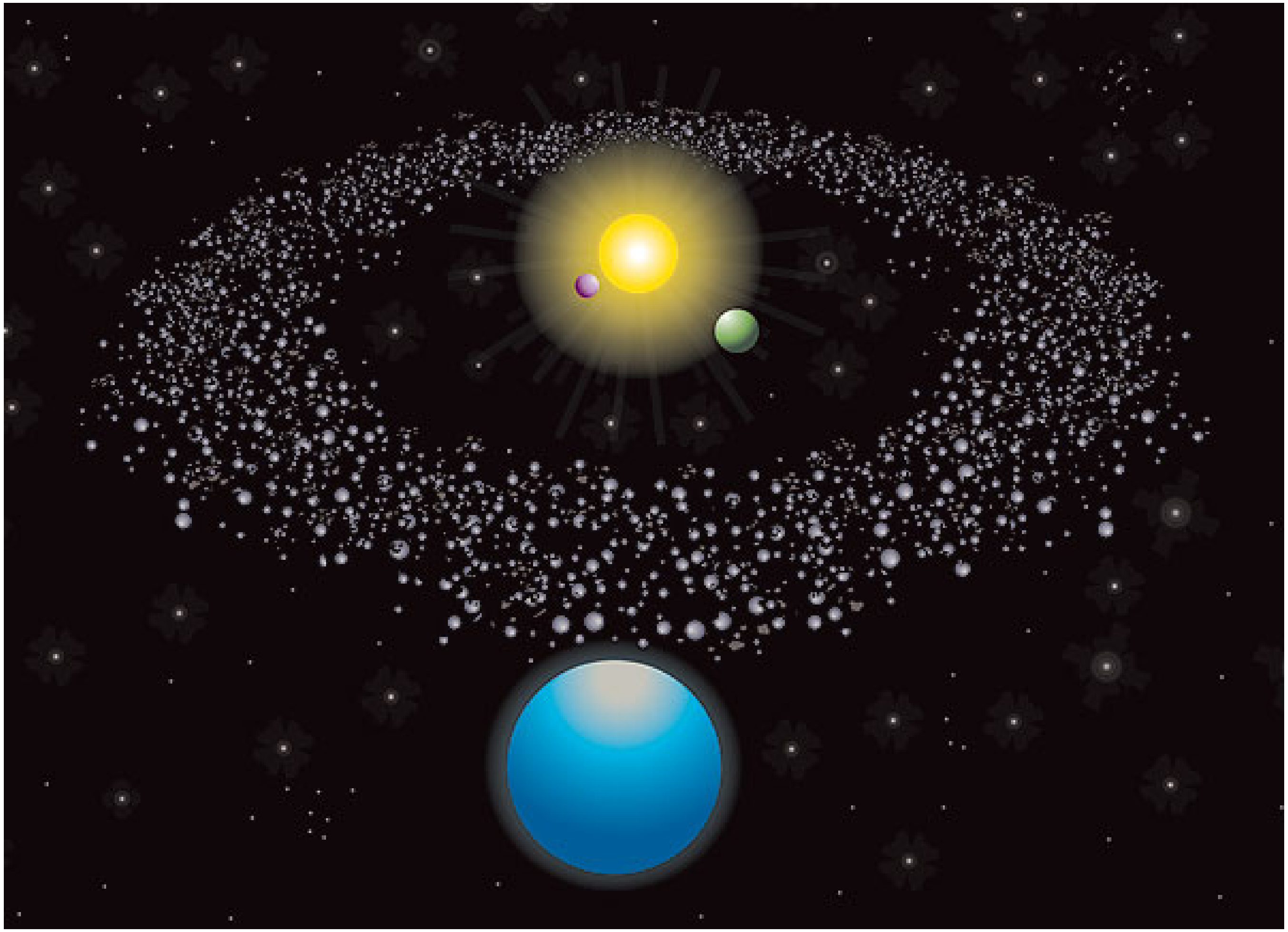




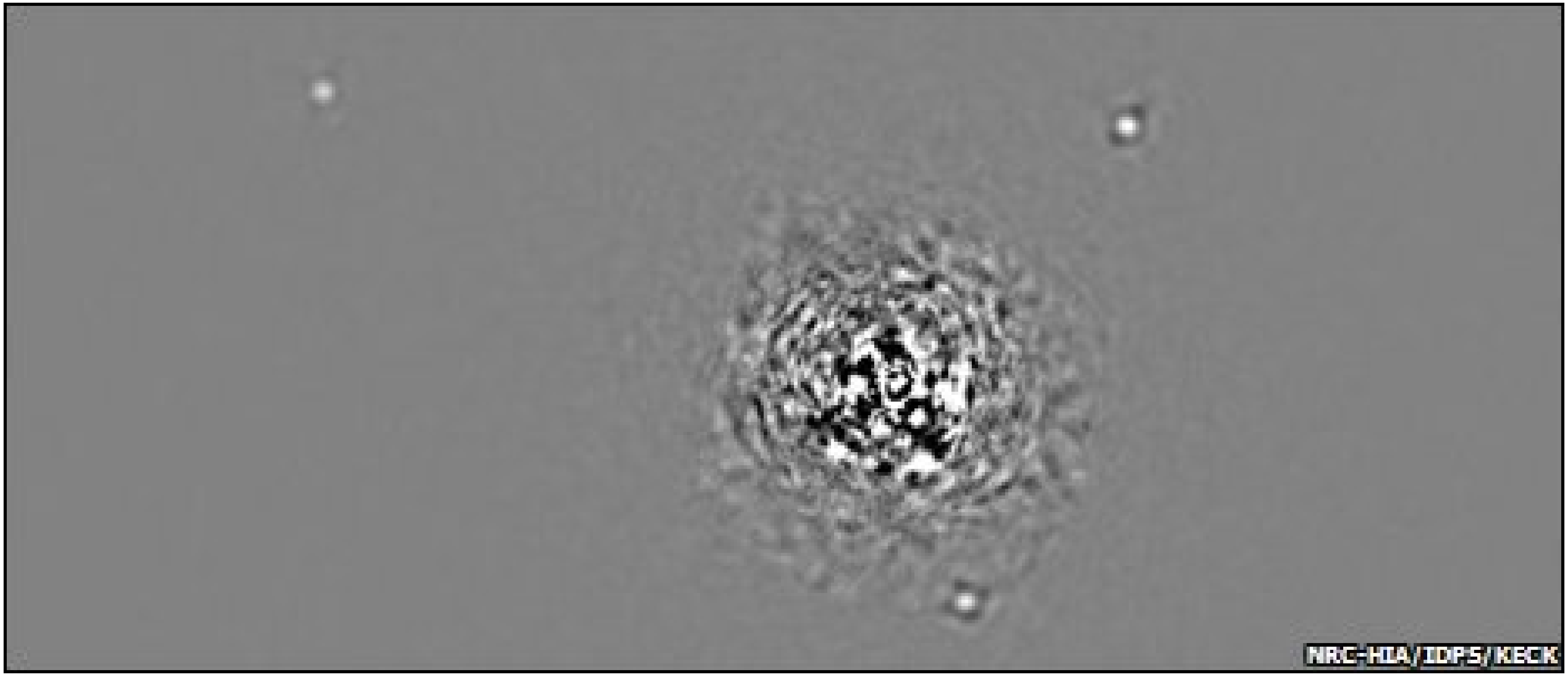


- 70 Vir well detected, with eccentric orbit
- Long orbital periods take more time to detect

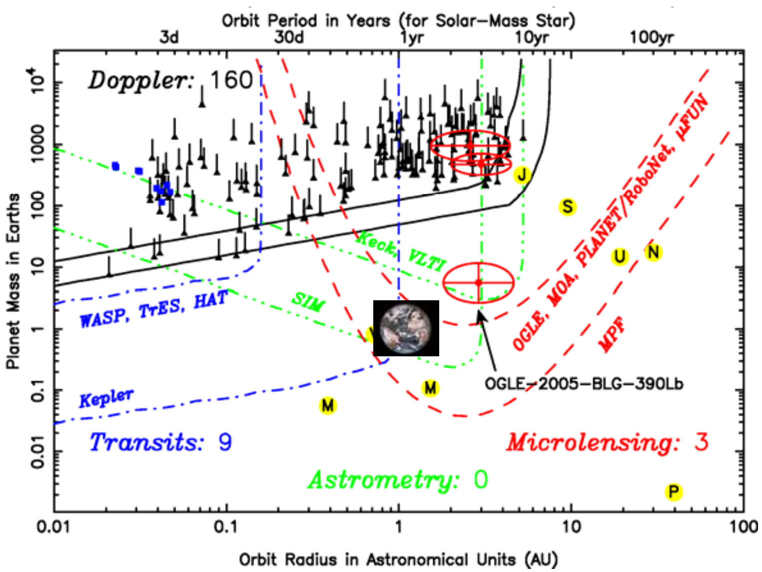
In HD 69830, 3 Neptune-size planets and an asteroid belt

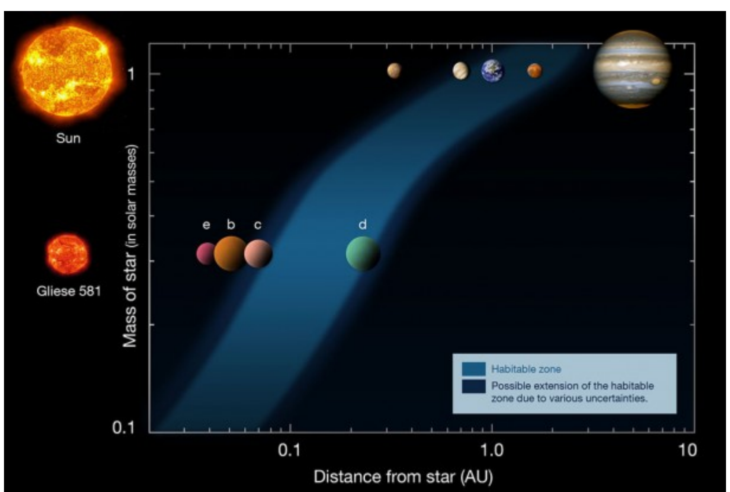


Around HR 8799, 3 planets imaged in infrared with Keck



Exoplanet searches have been very successful



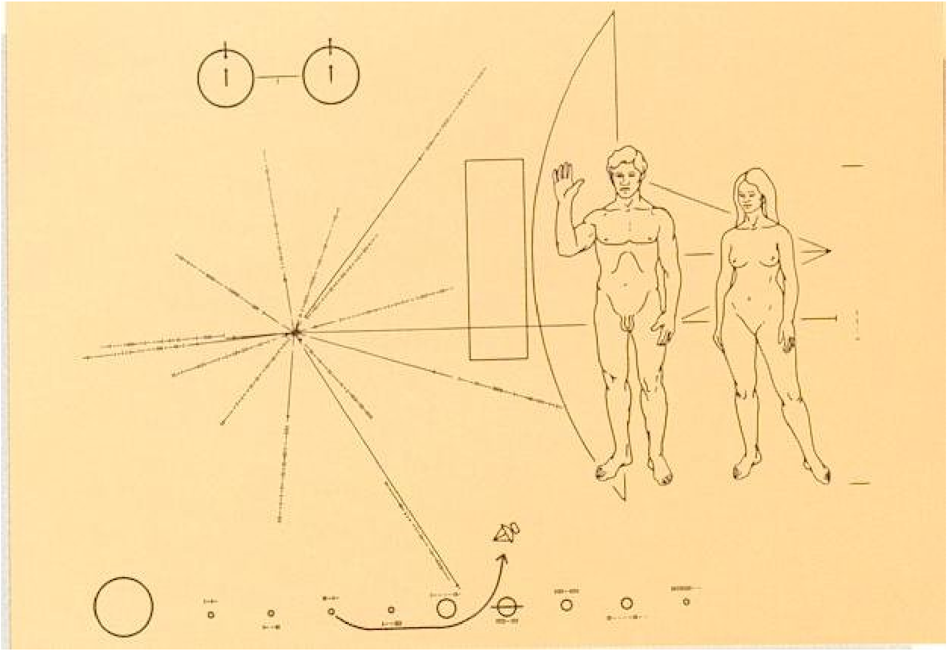


- Quite good at detecting Jupiter-size planets
- Probably not the best candidate places for life
- Less massive planets too close to star, too hot for life (here, Gliese 581)
- For “Earth location” in diagram, present methods are rather insensitive

Communication with other civilizations?

- We're already doing it!
- The radio and especially television signals we use on Earth "leak" into space where they can get picked up by extraterrestrials
- Called "eavesdropping"
- We could also try to listen for such signals from "them"

Pioneer 10 plaque with message for extraterrestrials



- This plaque is attached to spacecraft, now leaving solar system
- Male & female show sexual diversity, antenna for scale
- Sketch of solar system, location of Earth
- Position shown by pulsar directions

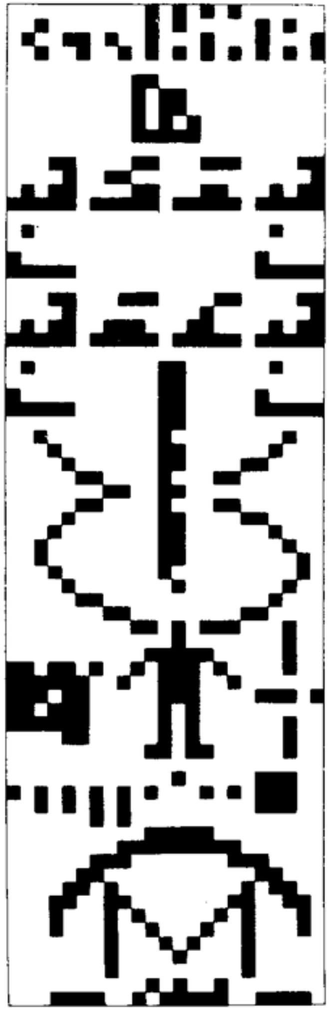
Communicating with extraterrestrials

- Message sent at λ=12.6 cm from Arecibo in 1974
- Used radar transmitter with power of 3×10^{12} W
- Signal could be detected by an antenna similar to Arecibo anywhere in the Milky Way
- 1679 bits sent in 169 s, frequency modulation, toward cluster M13

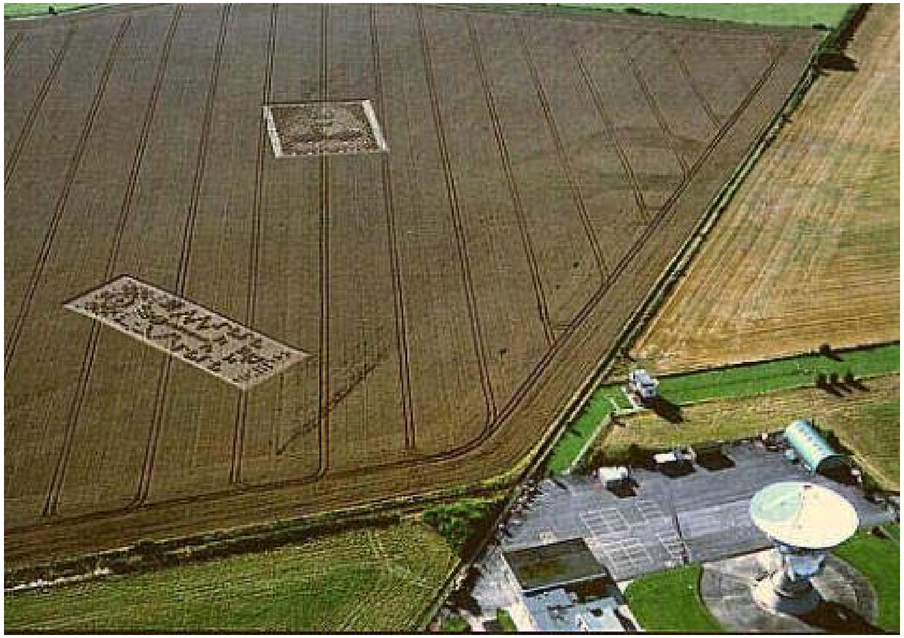
and what was in the message?

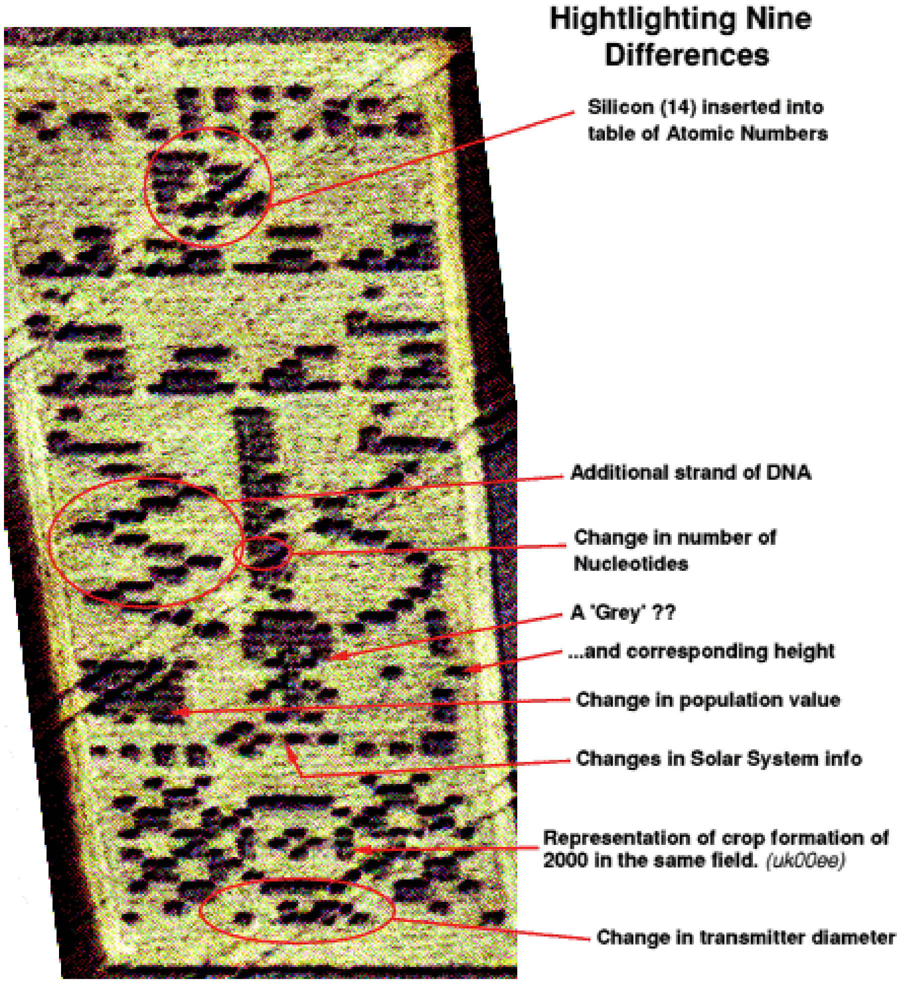
If displayed as 23×73 matrix (prime nos.) – Image with (top to bottom):

1. Numbers 1-10 in binary
2. Atomic numbers of H (1), C (6), N (7), O (8), P (15), elements of DNA
3. The 12 nucleotides making up DNA
4. DNA helix & number of nucleotides
5. Earth population – person – height
6. Solar system: Pluto (!) – Sun
7. Arecibo & signal; diameter



And was there an answer? (crop circle in 2001)





Is there (other) life out there?

- No convincing signals have ever been found
- Biologists feel that life will occur very readily if the conditions are right
- Searches for both planets and signals have only recently begun
- There are still many places to look: in spatial direction, frequency, kind of modulation, time, polarization…

Next lecture: Black holes and gravitational lensing