Los mundos de otros soles

María Rosa Zapatero Osorio

Centro de Astrobiología (CSIC-INTA)

Barcelona, 21 Octubre 2010

Los mundos de otros soles

María Rosa Zapatero Osorio
Centro de Astrobiología (CSIC-INTA)

Barcelona, 21 Octubre 2010

Los mundos de otros soles

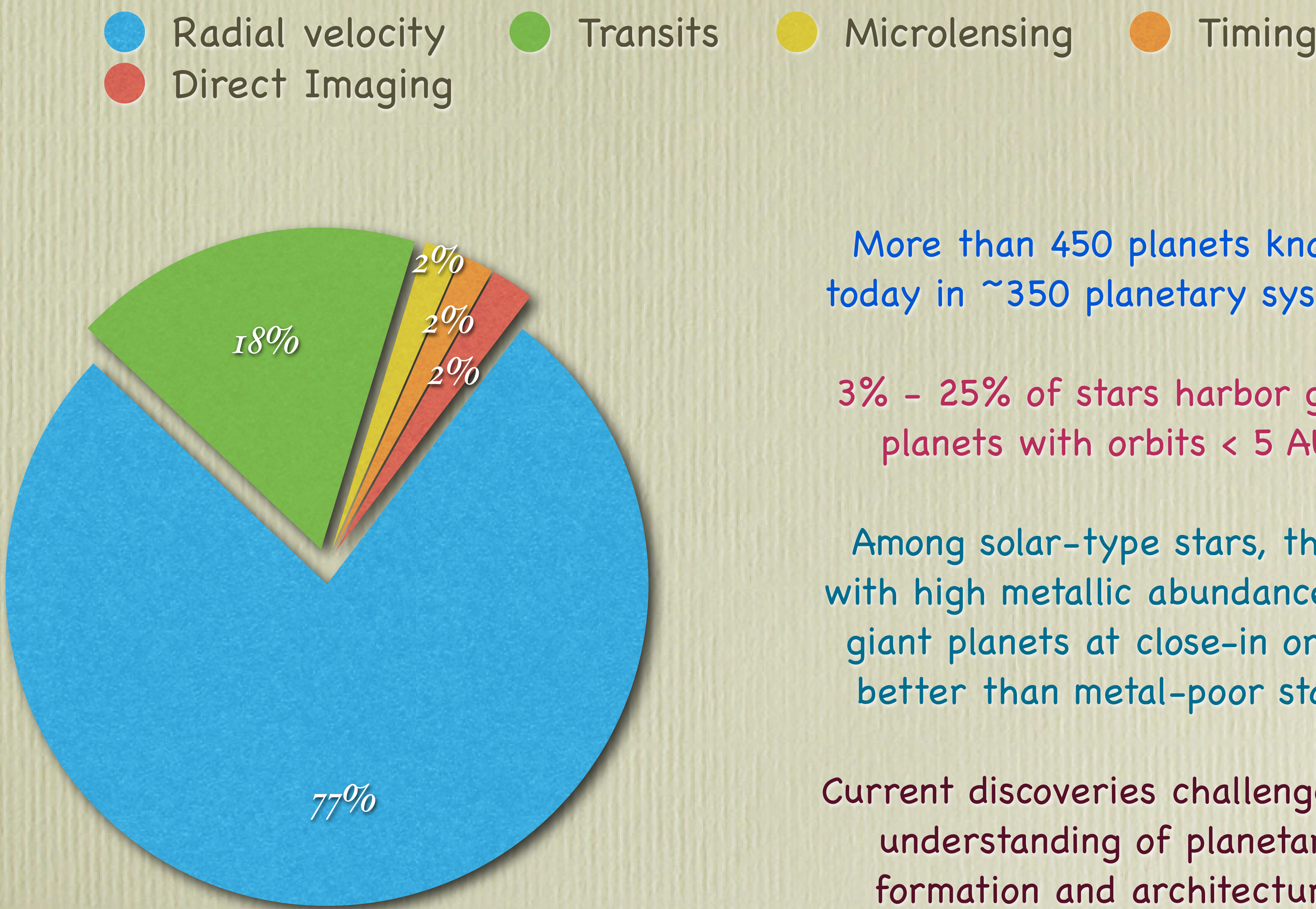
Outline

- Brief remark on detection methods
- Relevant discoveries
- How do these worlds look like?
- Future: Earth-like planets in the habitable zones

María Rosa Zapatero Osorio
Centro de Astrobiología (CSIC-INTA)

Barcelona, 21 Octubre 2010

Current methods for planet detection



More than 450 planets known today in ~350 planetary systems.

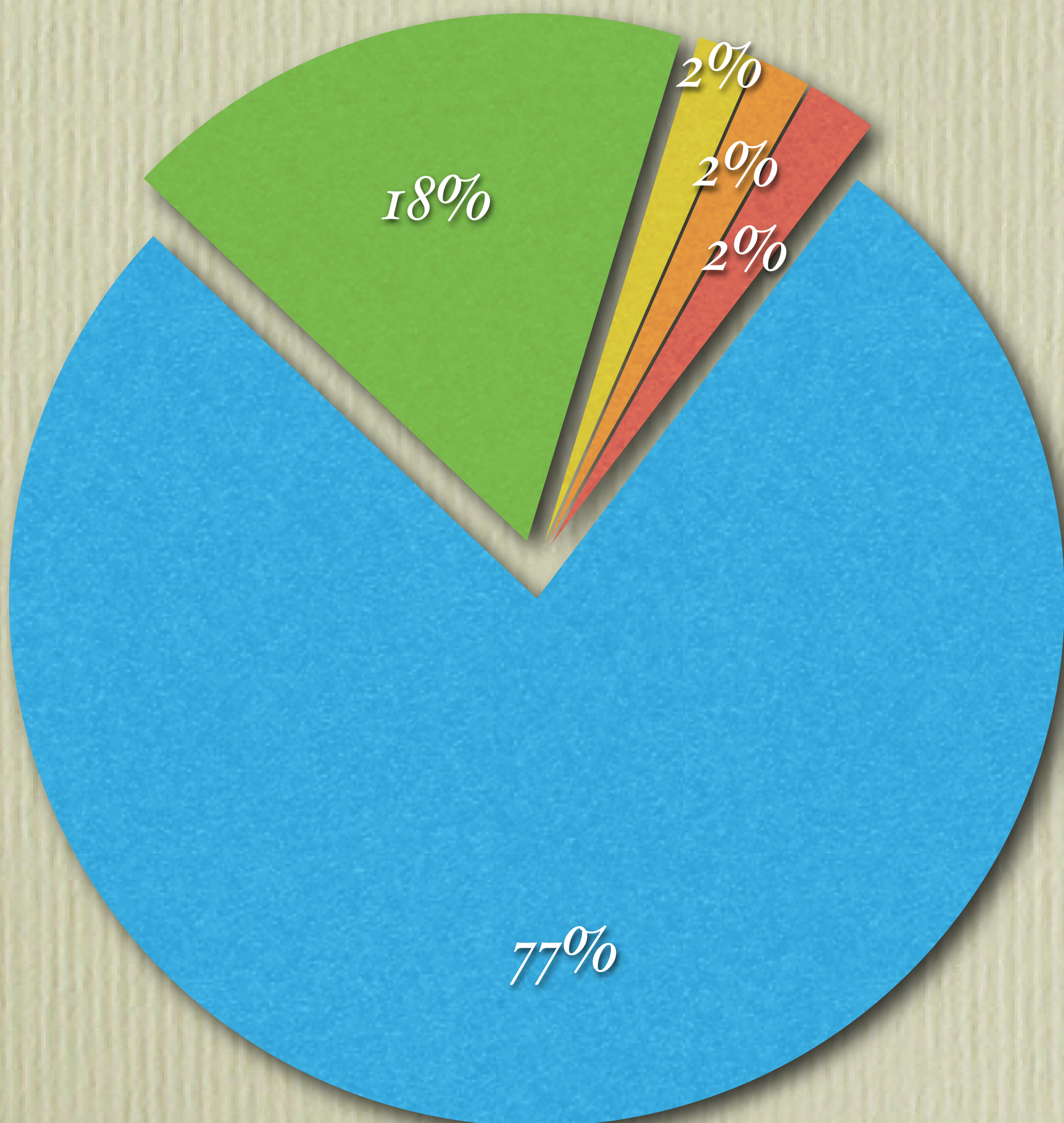
3% - 25% of stars harbor giant planets with orbits < 5 AU.

Among solar-type stars, those with high metallic abundance like giant planets at close-in orbits better than metal-poor stars.

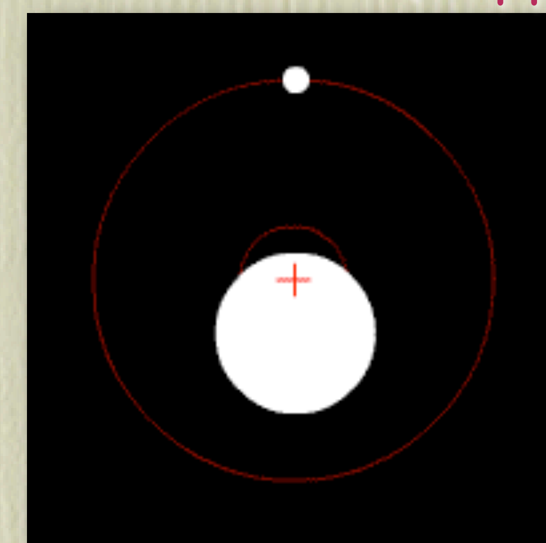
Current discoveries challenge our understanding of planetary formation and architecture.

Current methods for planet detection

Radial velocity Transits Microlensing Timing
Direct Imaging



Spectroscopic method:
radial velocities (Doppler)

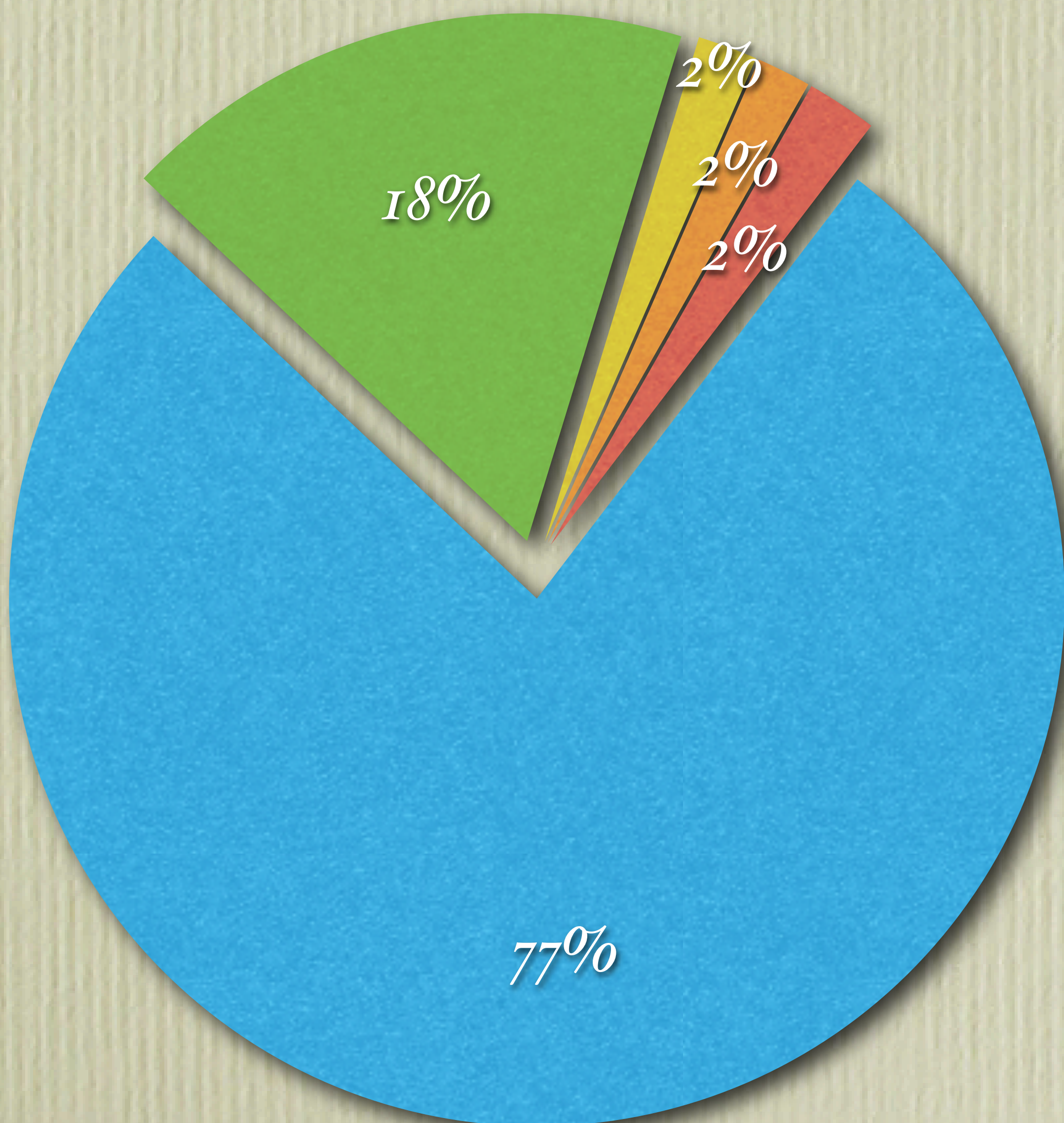


Both planet and star move around the center of gravity of the system (cross symbol). We cannot see close-in planets directly, but we can measure the velocity and/or positional displacement induced on the star by the presence of the planets.

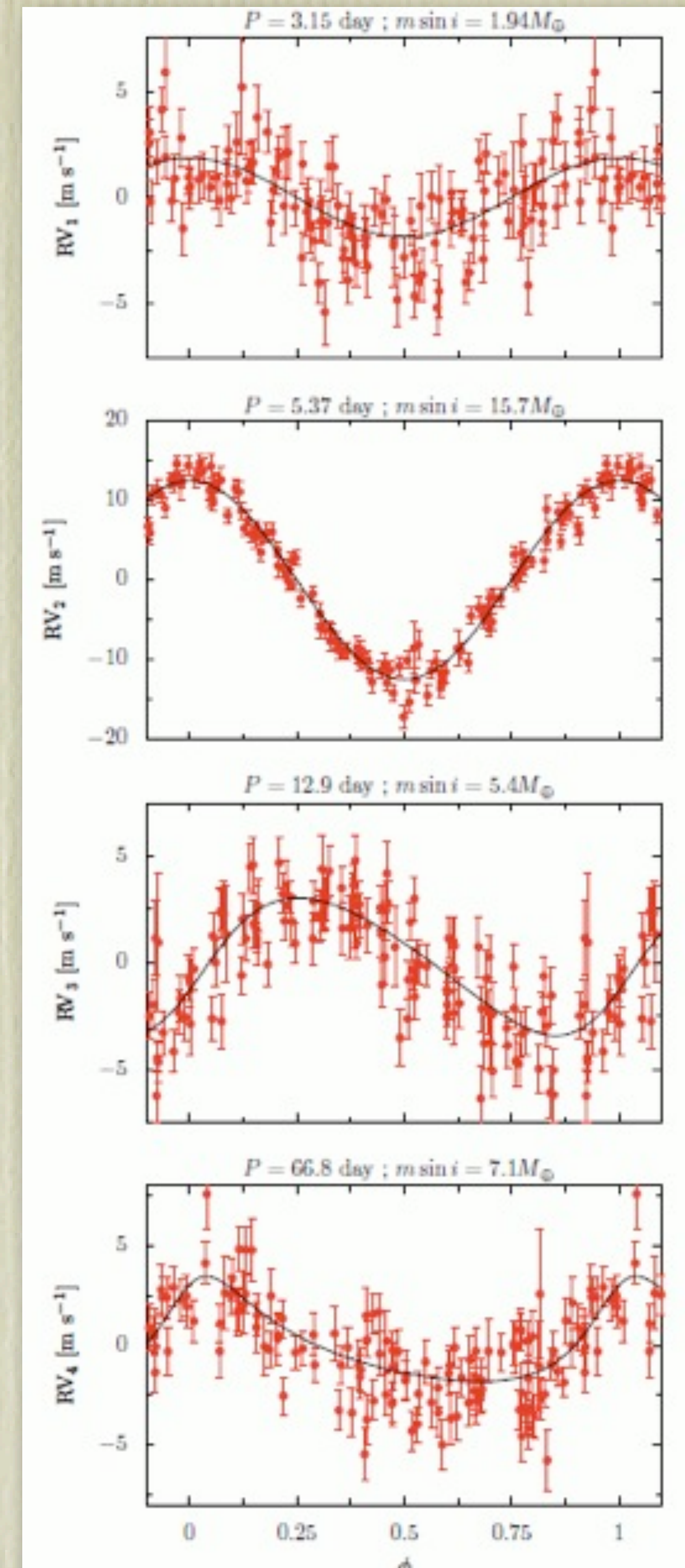
The **"radial velocity"** spectroscopic technique is very efficient in detecting planets at close-in orbits. This technique requires very high spectral resolution, high precision, and stable instruments.

Current methods for planet detection

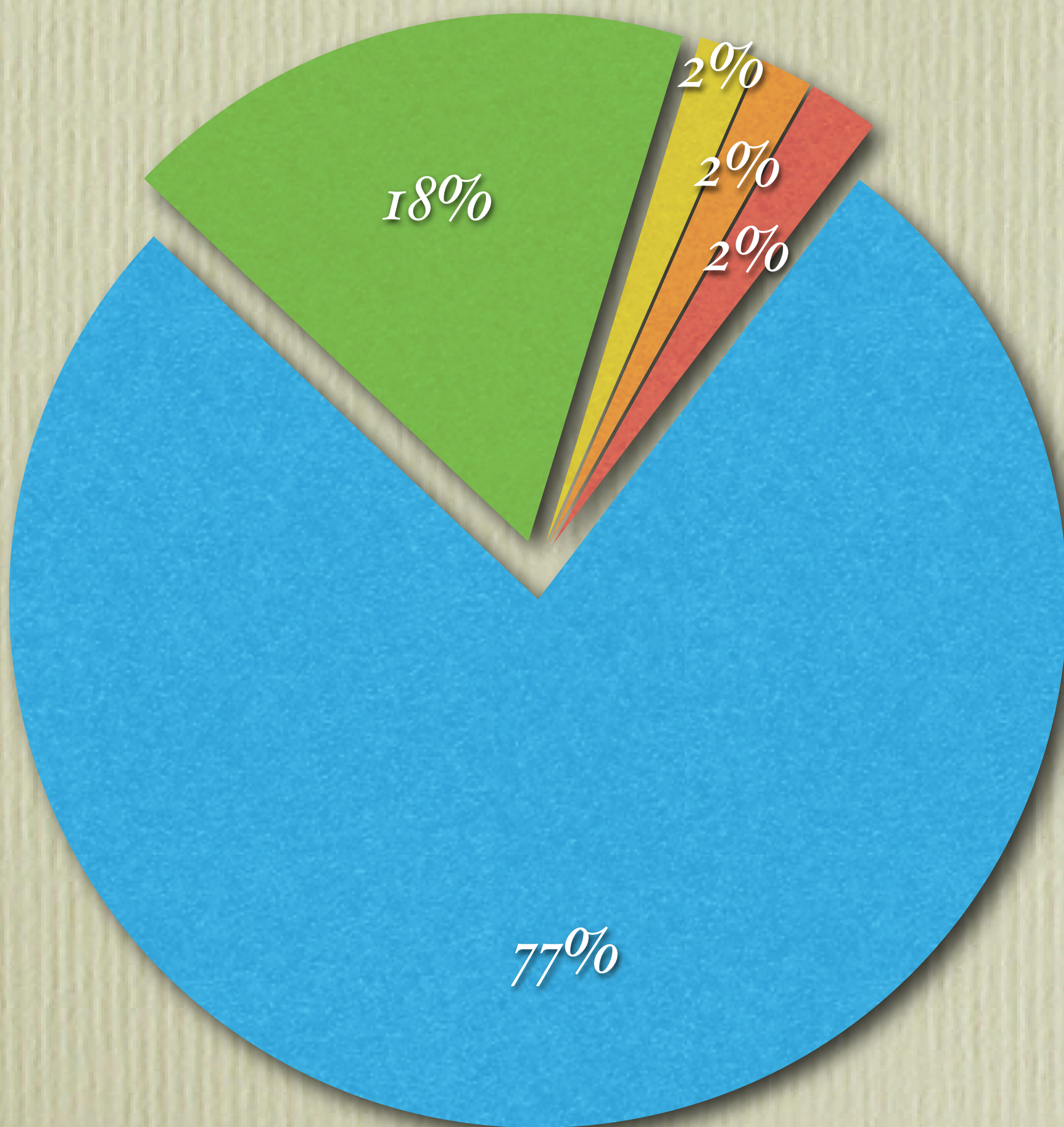
Radial velocity · Transits · Microlensing · Timing · Direct Imaging



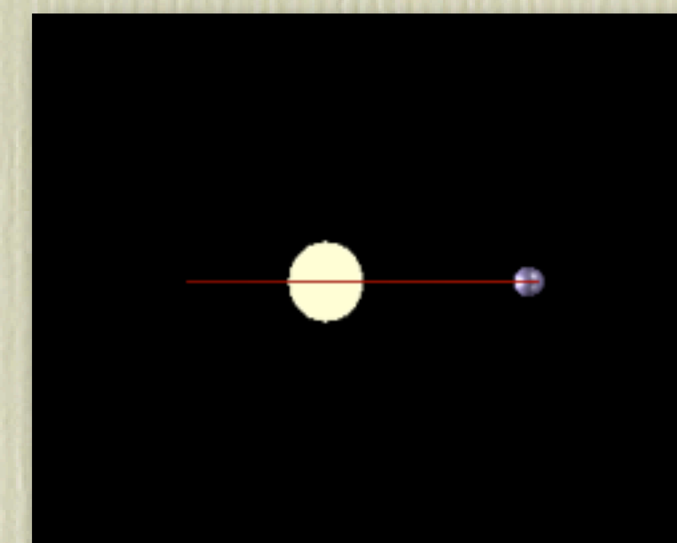
Four planets around the M3-type star GJ 581 in rather close-in orbits. The minimum mass of the smallest planet is 1.94 times that of Earth! (Mayor et al. 2009). HARPS data.



Current methods for planet detection



Photometric method:
Transits



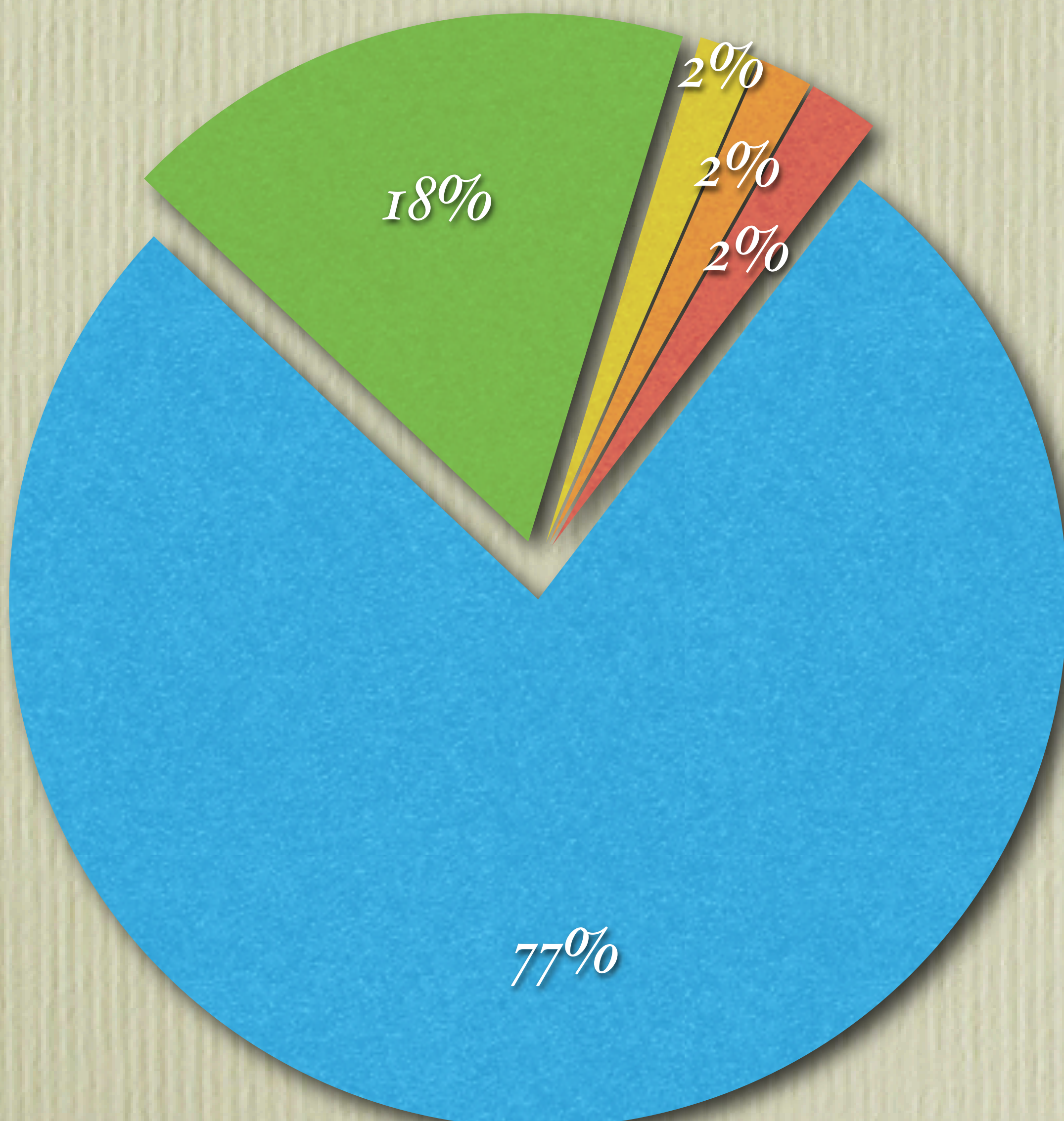
The **"transit" photometric** method is based on the observation of a star's small drop in brightness that occurs when the orbit of one of the star's close-in planets passes ("transits") in front of the star.

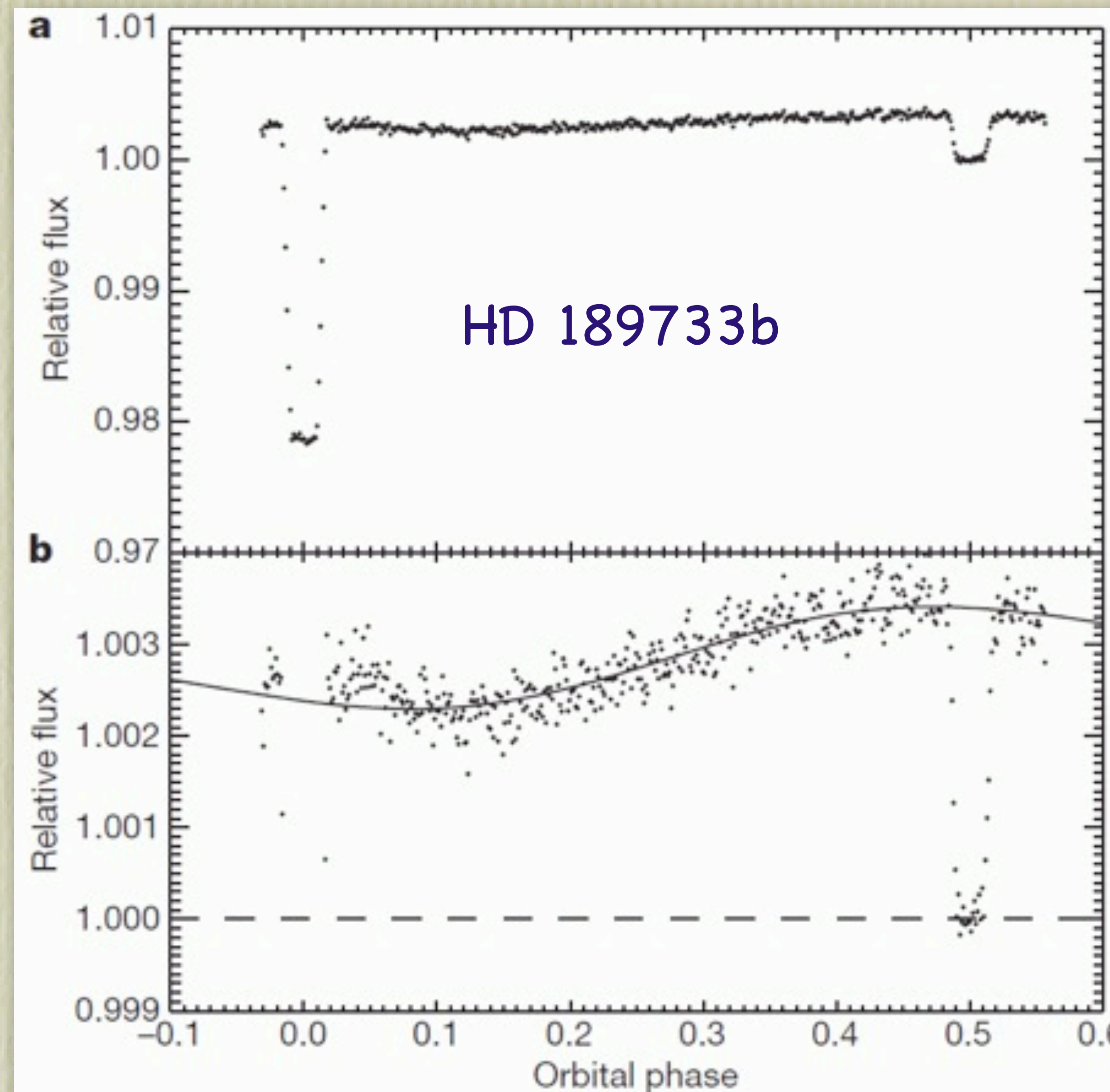
The combination of "radial velocity" and "transit" observations allows the absolute determination of the planet mass, size, and density.

Observations of "transiting" planets allow us to study the planetary atmospheres.

Current methods for planet detection

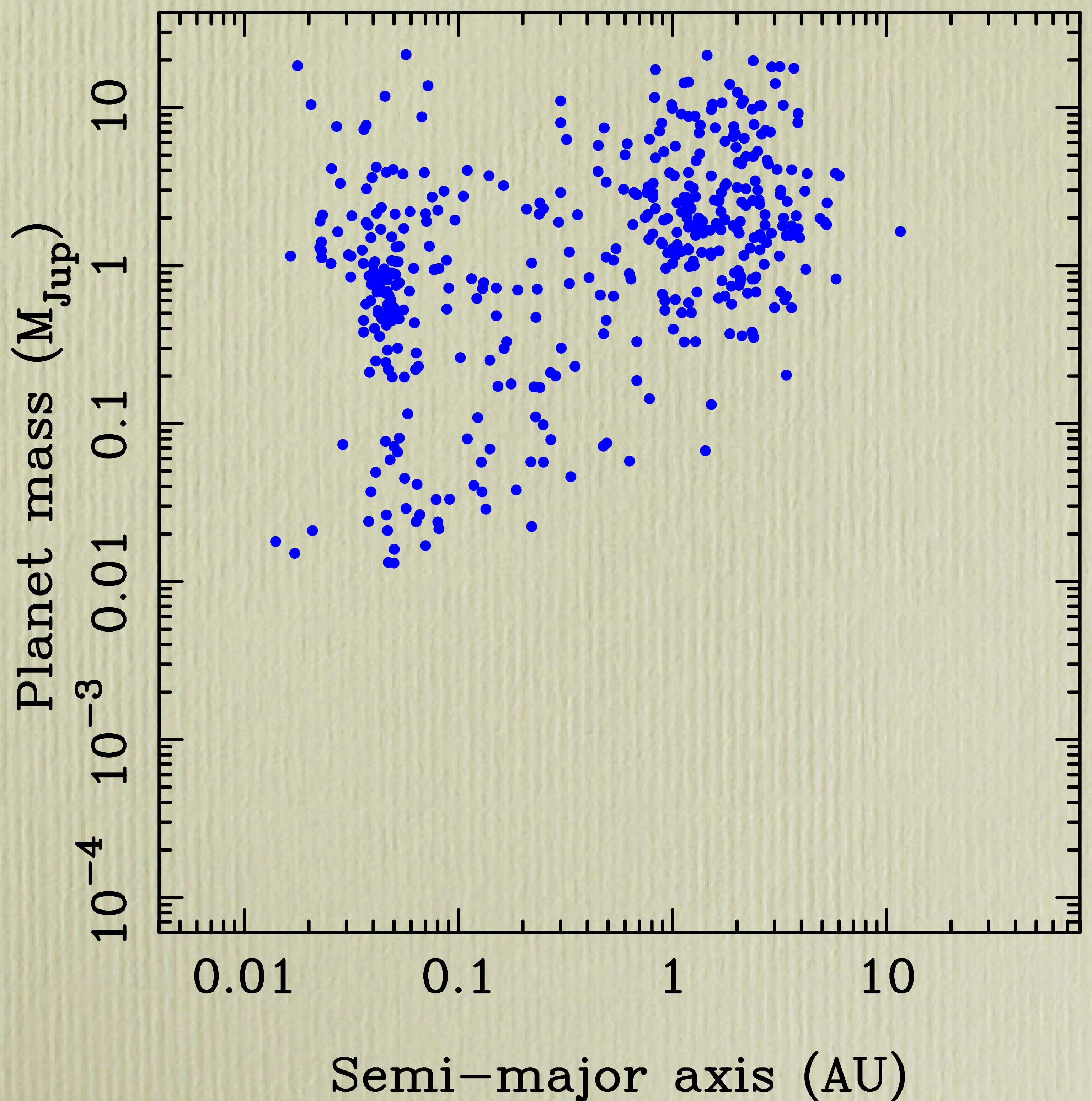
- Radial velocity
- Direct Imaging
- Transits
- Microlensing
- Timing





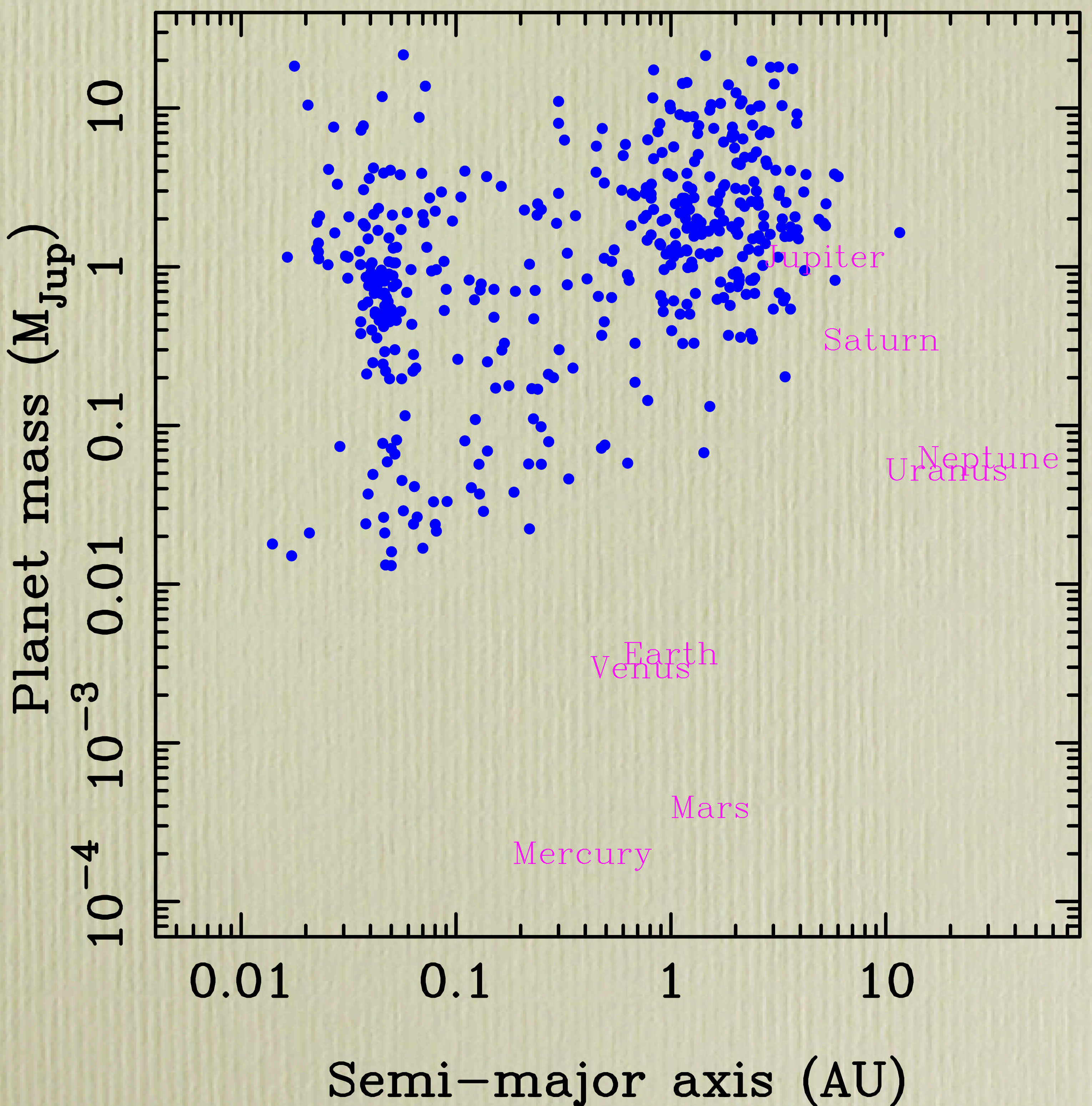
Primary and secondary transit of a warm (~1000 K), gas giant (1.13 M_{jup}) planet in a close-in orbit (0.03 AU) around the solar-type star HD 189733 (Knutson et al. 2007). Spitzer/IRAC data.

Current methods for planet detection



Radial velocity planets

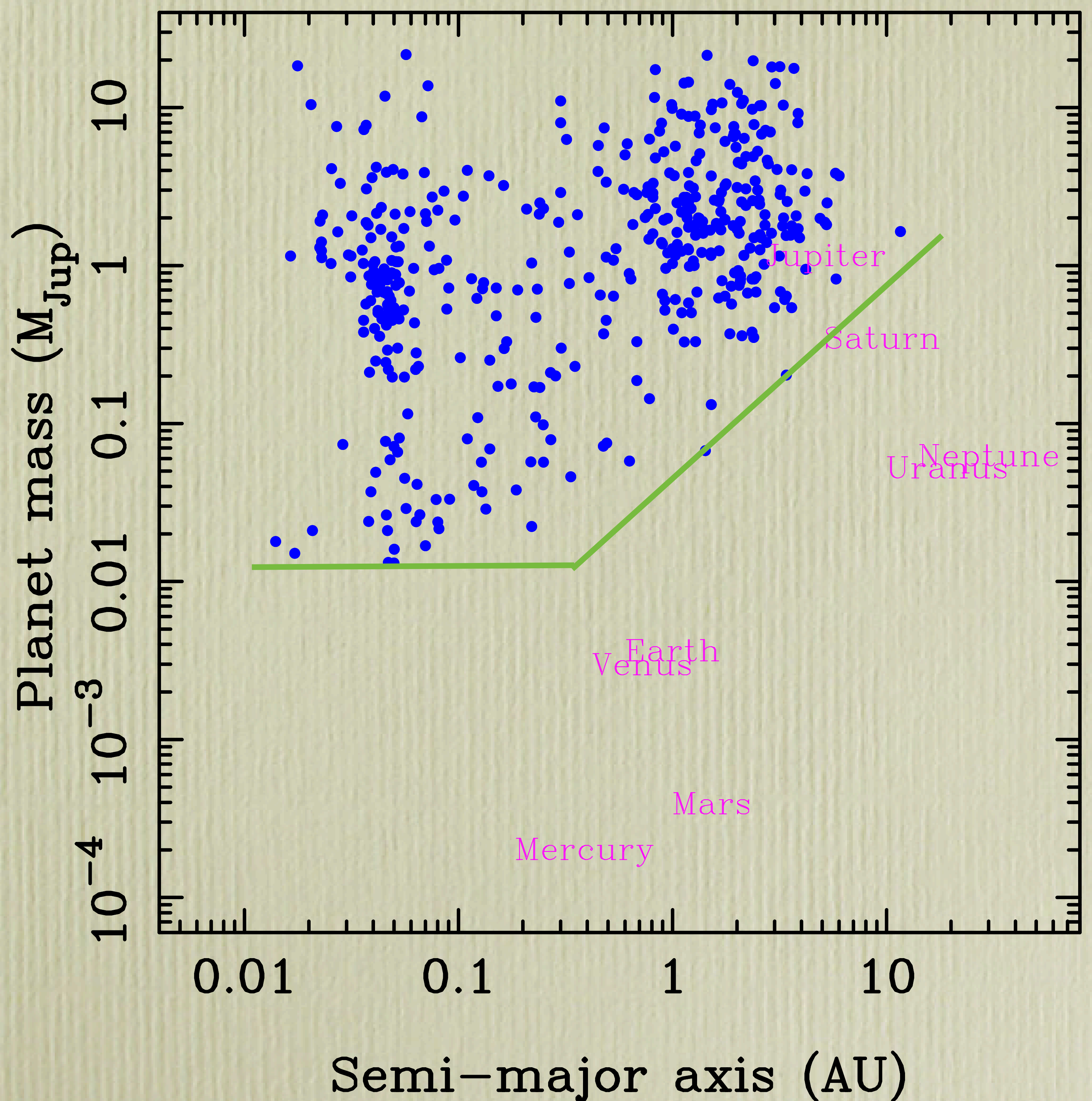
Current methods for planet detection



Radial velocity planets

Solar System planets

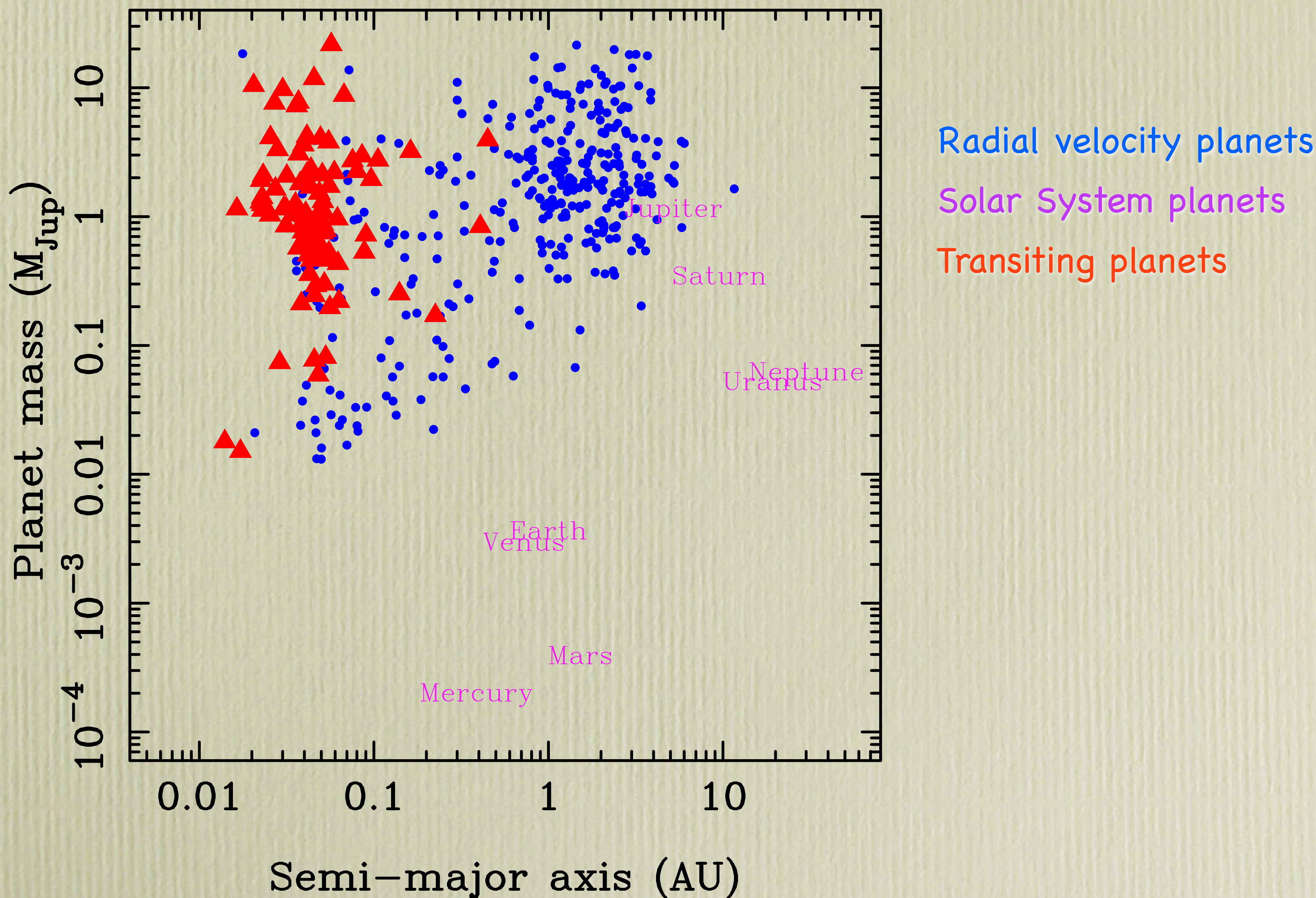
Current methods for planet detection



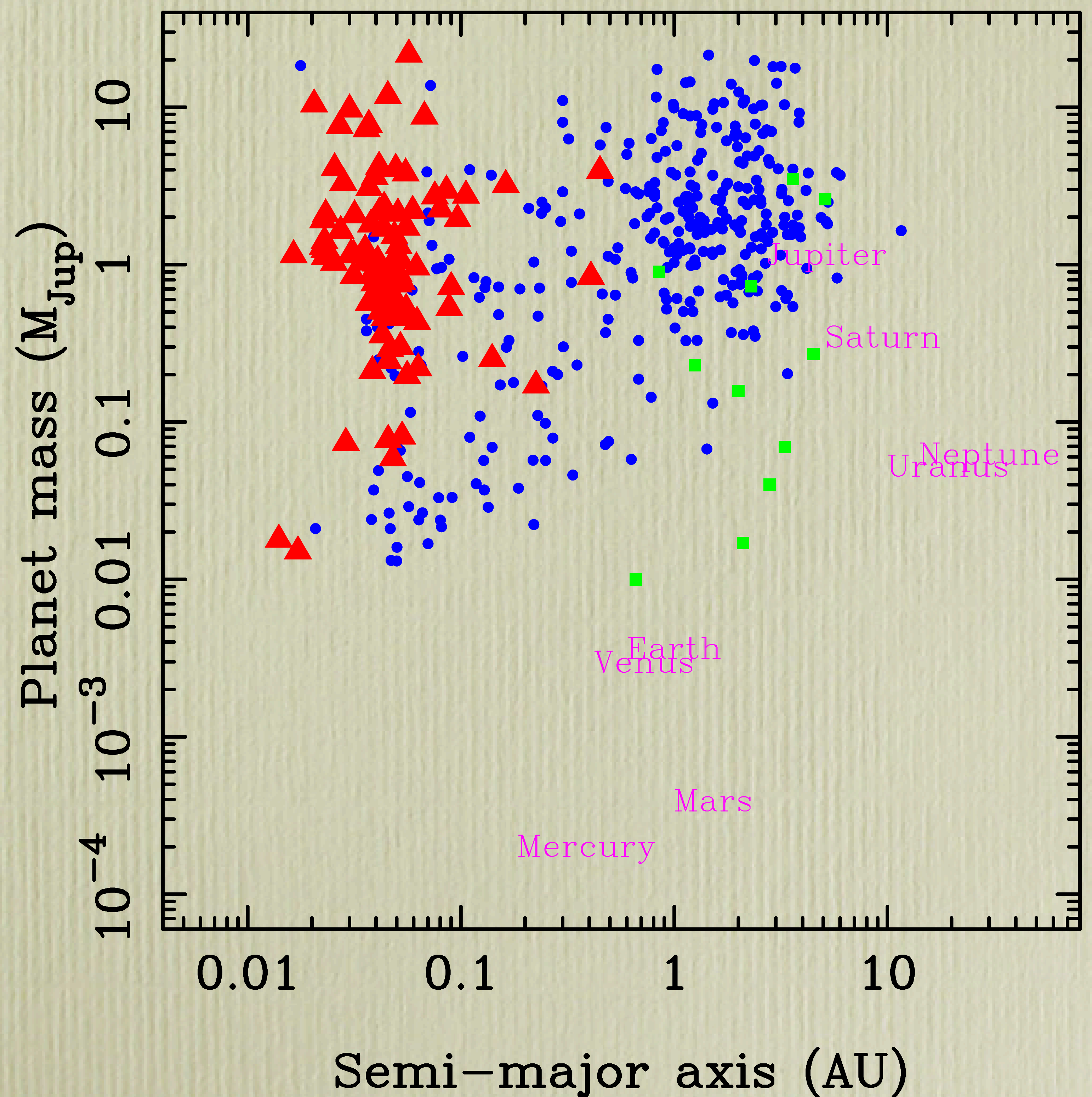
Radial velocity planets

Solar System planets

Current methods for planet detection



Current methods for planet detection



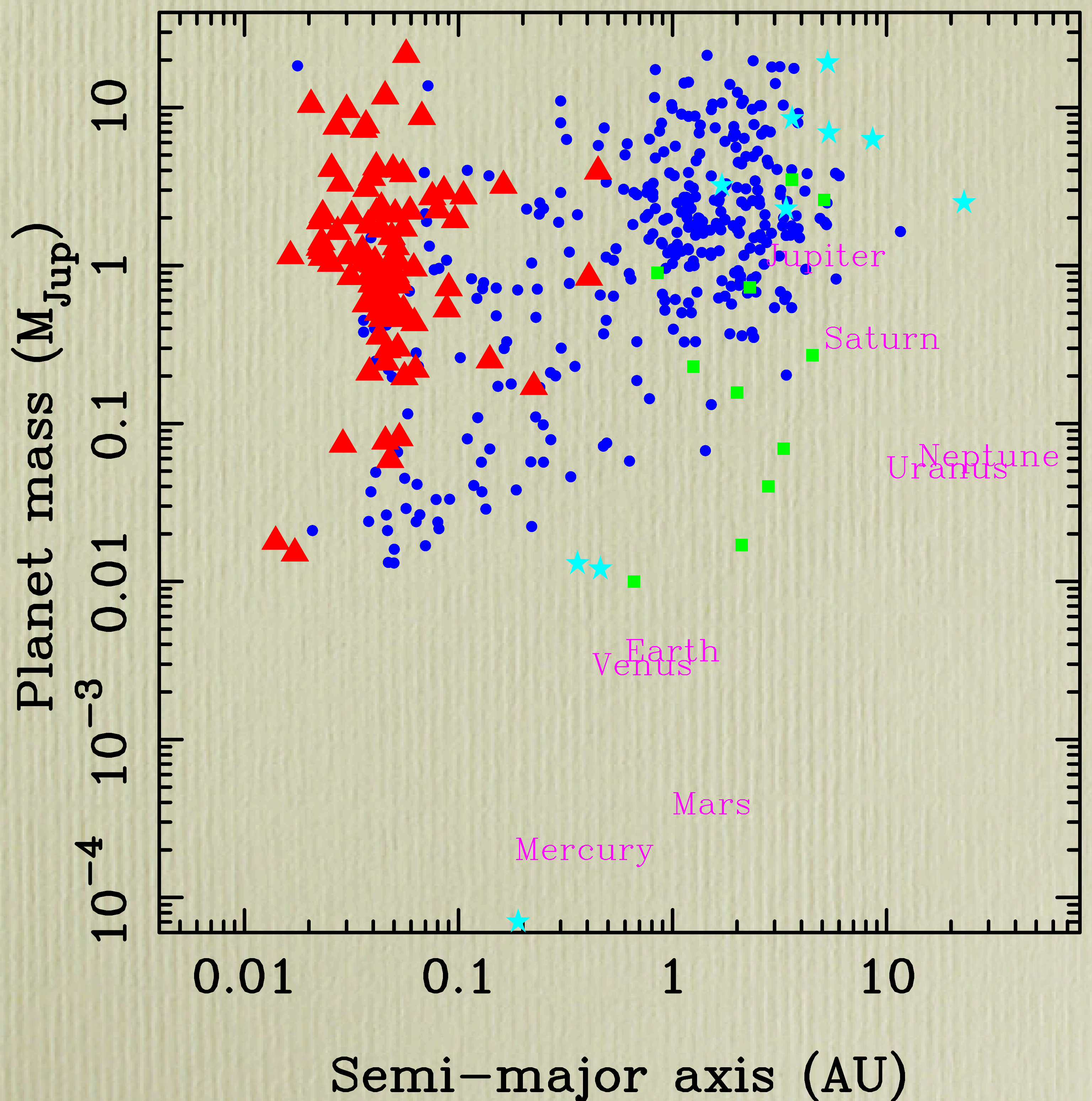
Radial velocity planets

Solar System planets

Transiting planets

Microlensing planets

Current methods for planet detection



Radial velocity planets

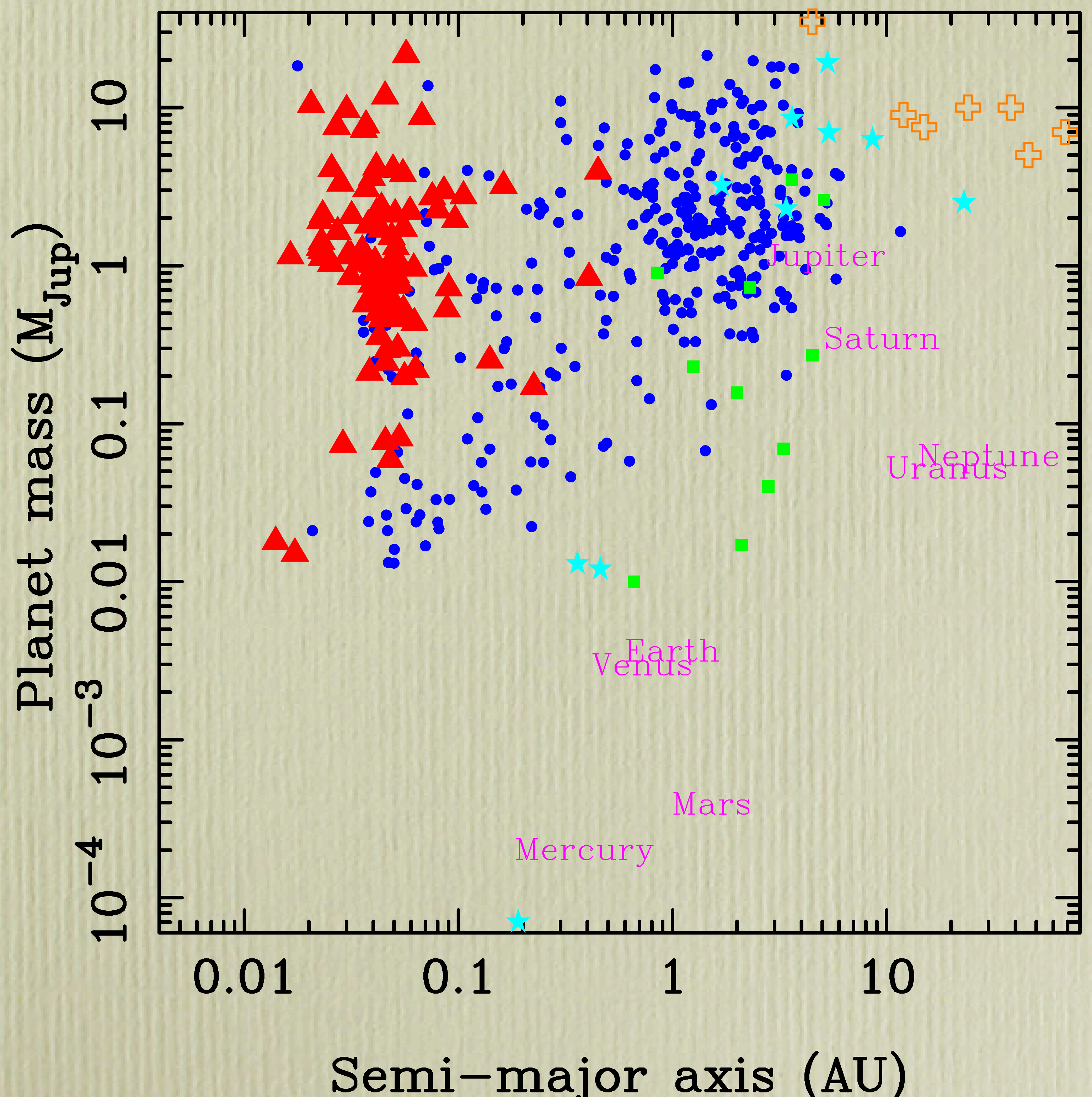
Solar System planets

Transiting planets

Microlensing planets

Timing planets

Current methods for planet detection



Radial velocity planets

Solar System planets

Transiting planets

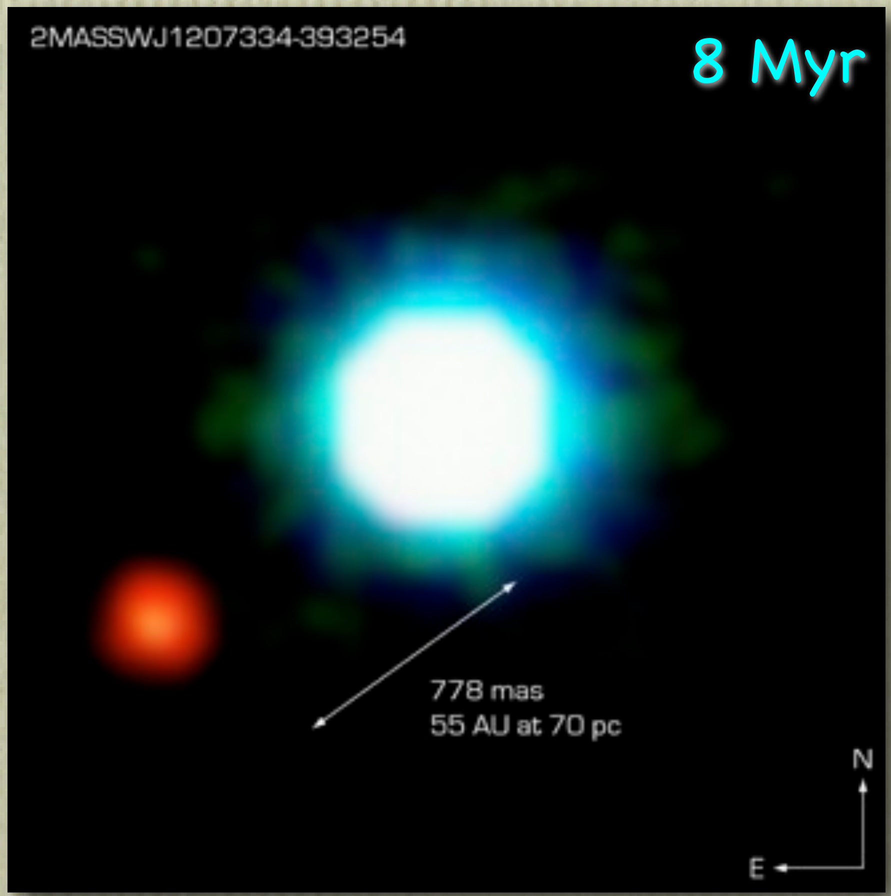
Microlensing planets

Timing planets

Direct imaging planets (?)

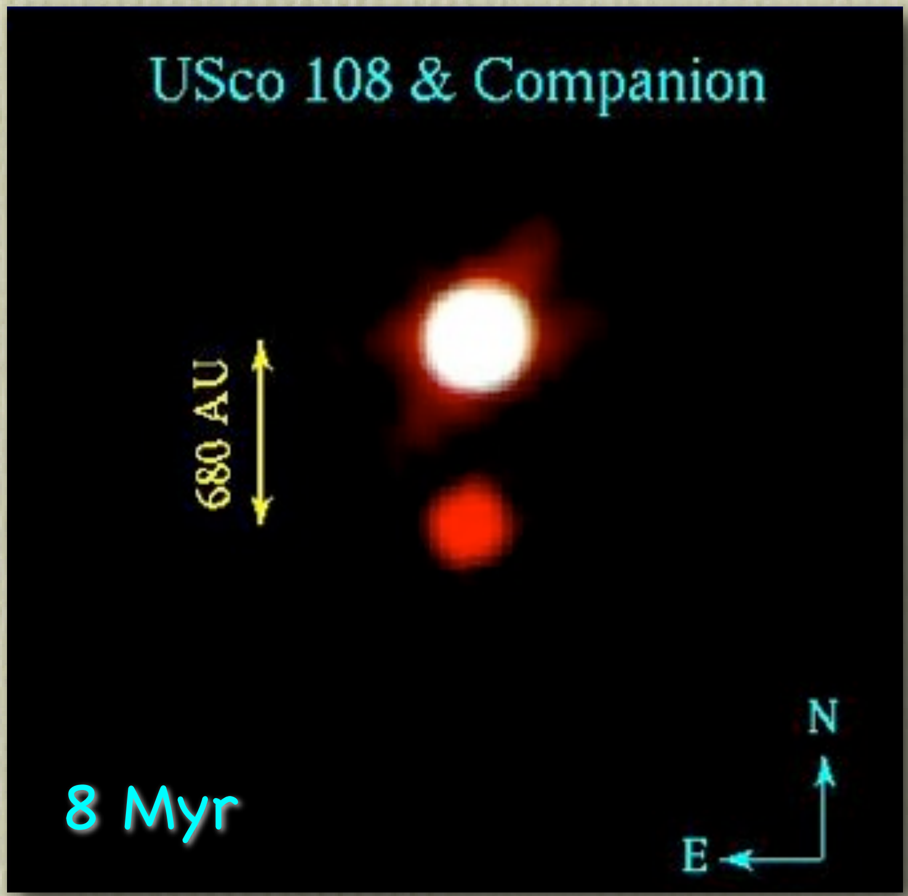
Direct images of substellar companions around stars and brown dwarfs

2MASS J1207334-393254



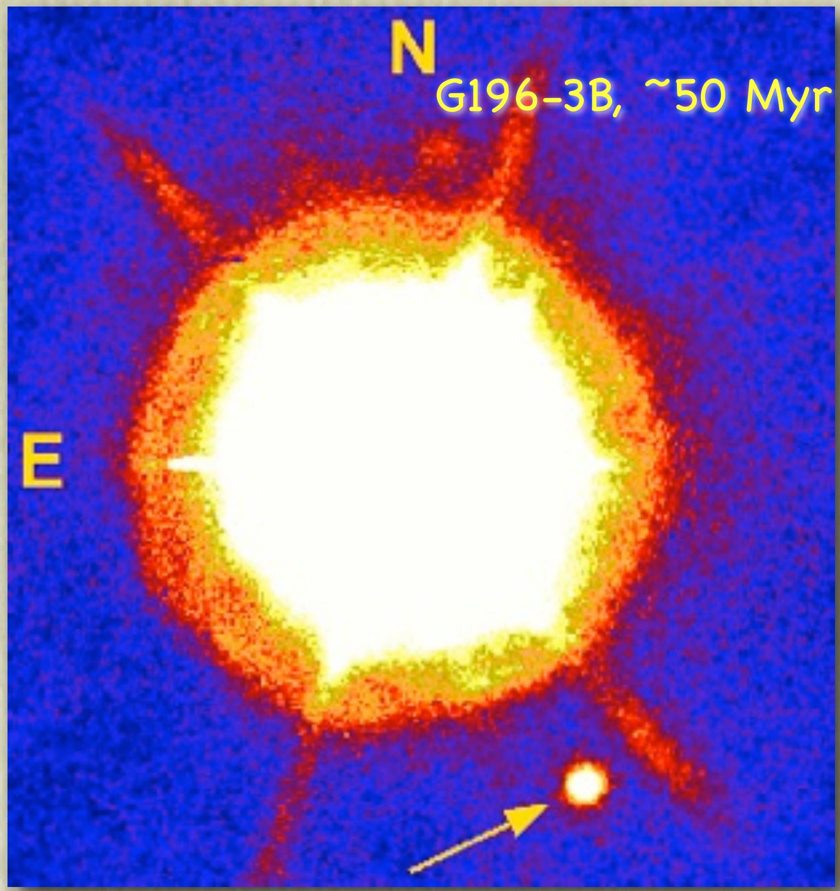
Planet (5 M_{jup}) around a brown dwarf (25 M_{jup}) in the TW Hya association (Chauvin et al. 2004).

USCO 108



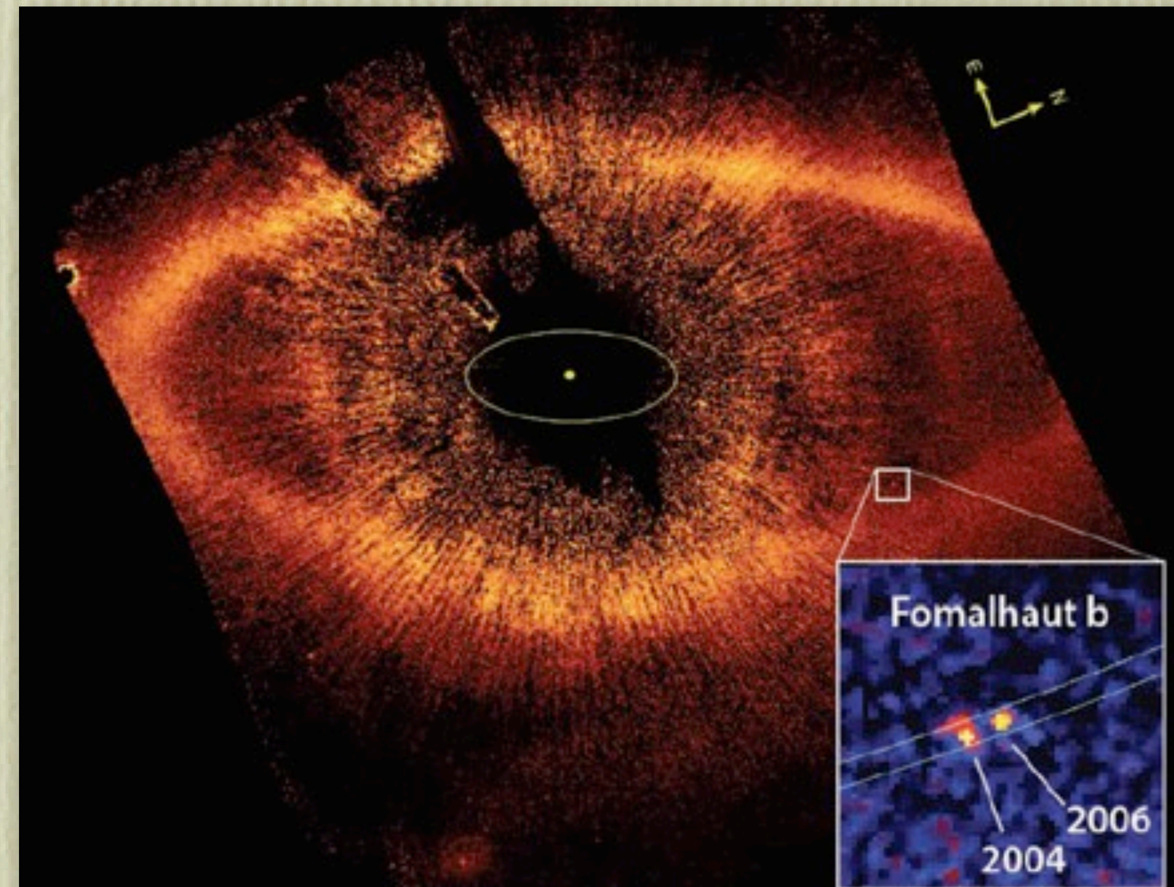
Planet (13 M_{jup}) around a brown dwarf (50 M_{jup}) in the Upper Sco association (Béjar, Zapatero Osorio, et al. 2008).

G 196-3B



Brown dwarf (10-25 M_{jup}) around a low-mass star (0.4 M_{sol}) in the field, orbital separation of ~350 AU (Rebolo, Zapatero Osorio, et al. 1998).

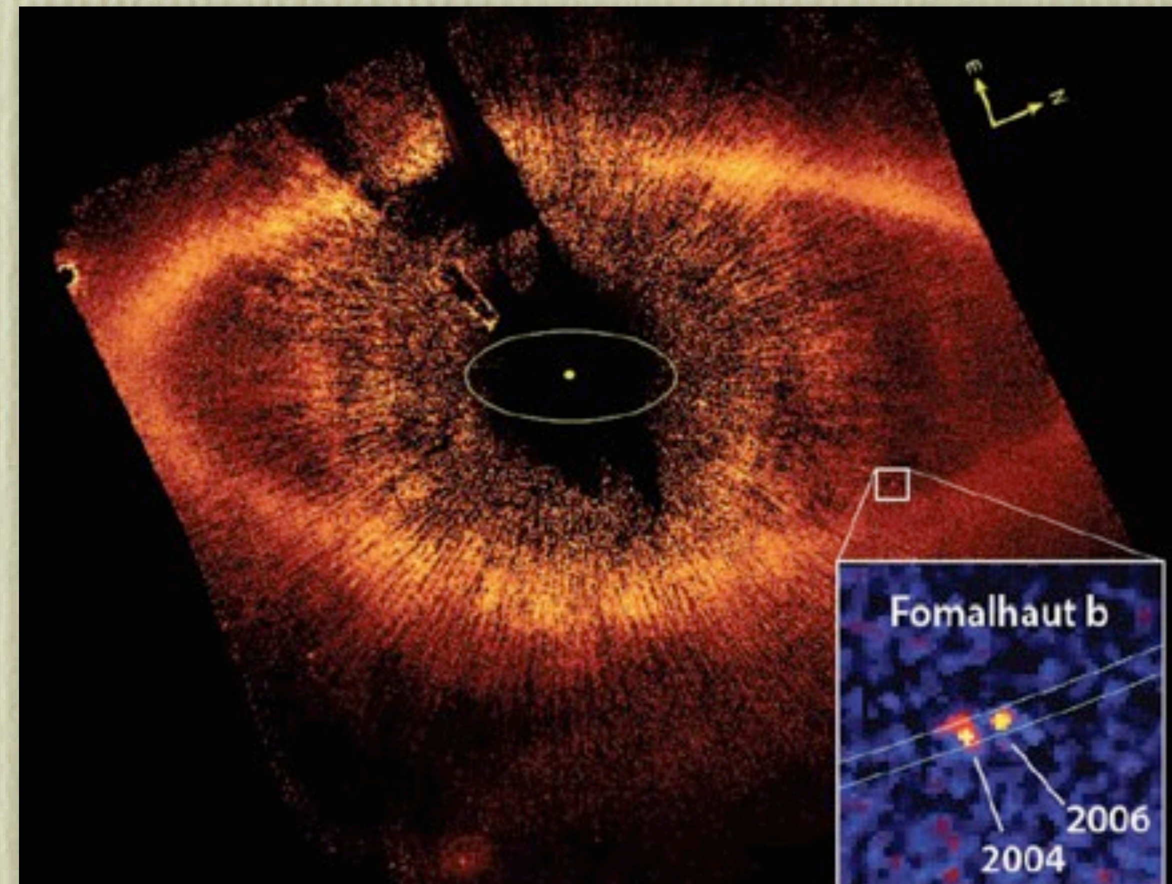
Images of planets orbiting massive stars with debris disks



A planet (**Fomalhaut b**) orbiting at 115 AU from the A3V-type star Fomalhaut, which has an age of 100-300 Myr. The orbital motion of the planet was detected when comparing the 2004 and 2006 epochs shown in the inset (Kalas et al. 2008). The estimated mass of the planet is < 10 M_{jup}.

The debris disk of the star is seen through the scattered light in visible wavelengths.

Images of planets orbiting massive stars with debris disks



A planet (**Fomalhaut b**) orbiting at 115 AU from the A3V-type star Fomalhaut, which has an age of 100-300 Myr. The orbital motion of the planet was detected when comparing the 2004 and 2006 epochs shown in the inset (Kalas et al. 2008). The estimated mass of the planet is < 10 M_{jup}.

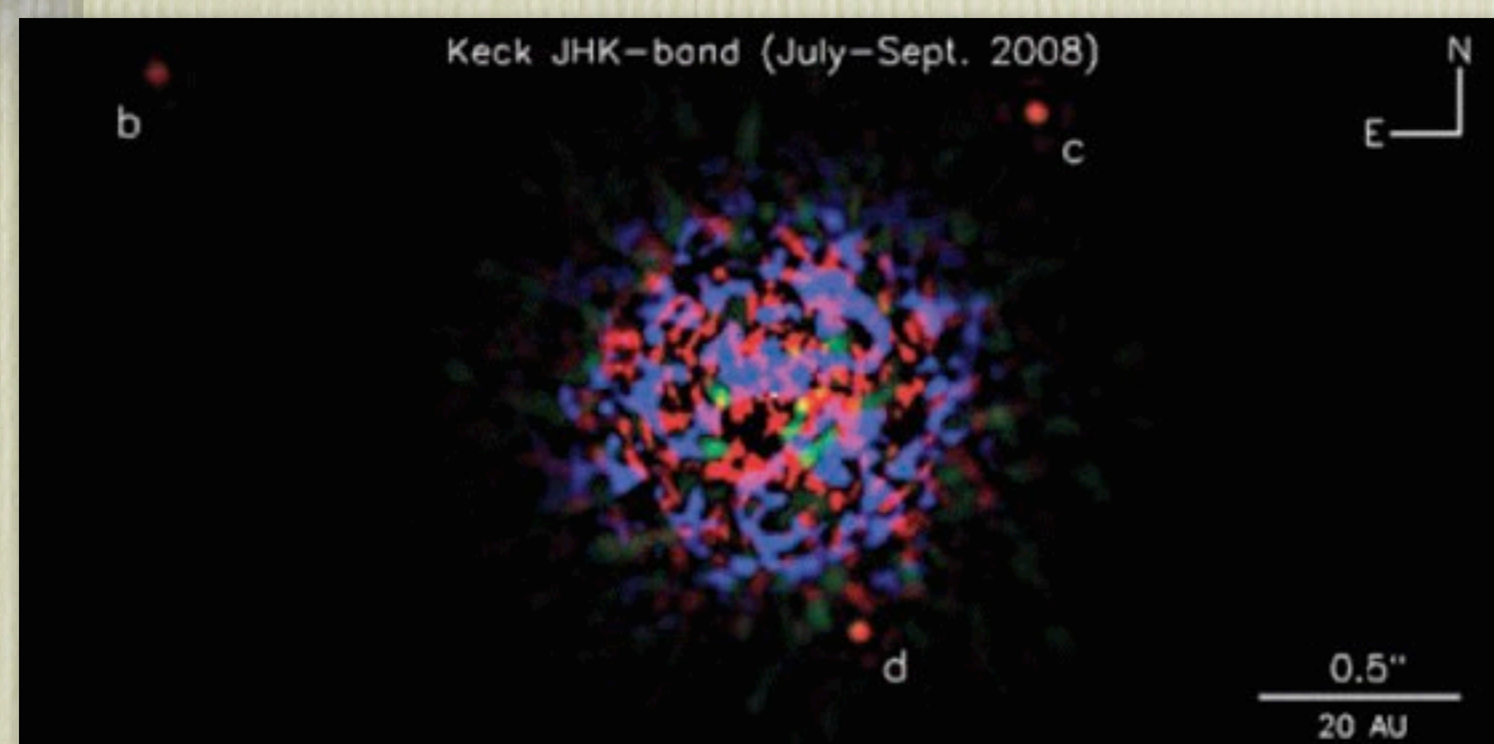
The debris disk of the star is seen through the scattered light in visible wavelengths.

Three planets (**HR 8799 b,c,d**) in counter clockwise orbits around the 1.5-M_{sol} star HR 8799, which has an age of 30-160 Myr (Marois et al. 2008):

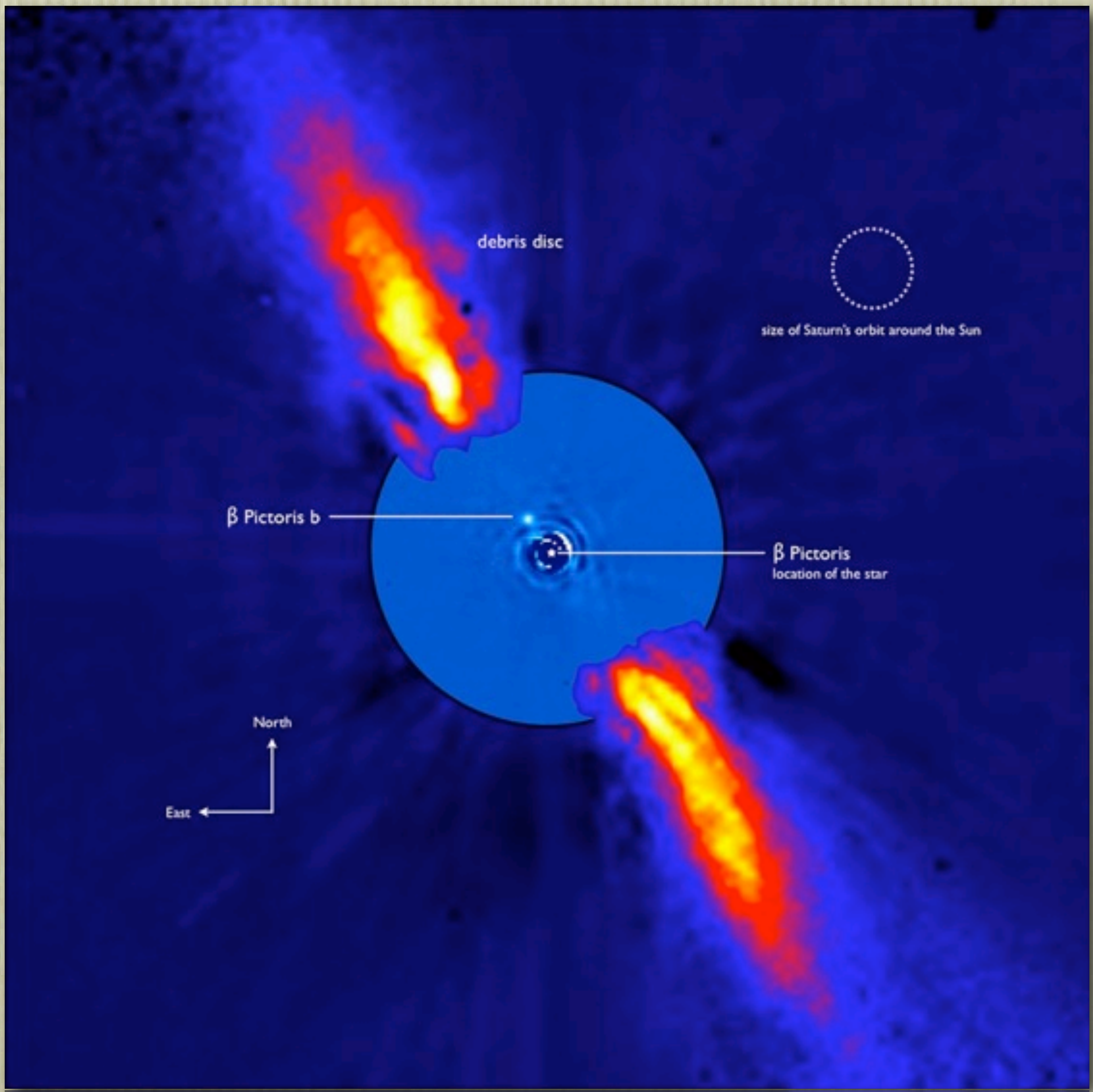
b = 7 M_{jup}, 68 AU

c = 10 M_{jup}, 38 AU

d = 10 M_{jup}, 24 AU



Images of planets orbiting massive stars with debris disks



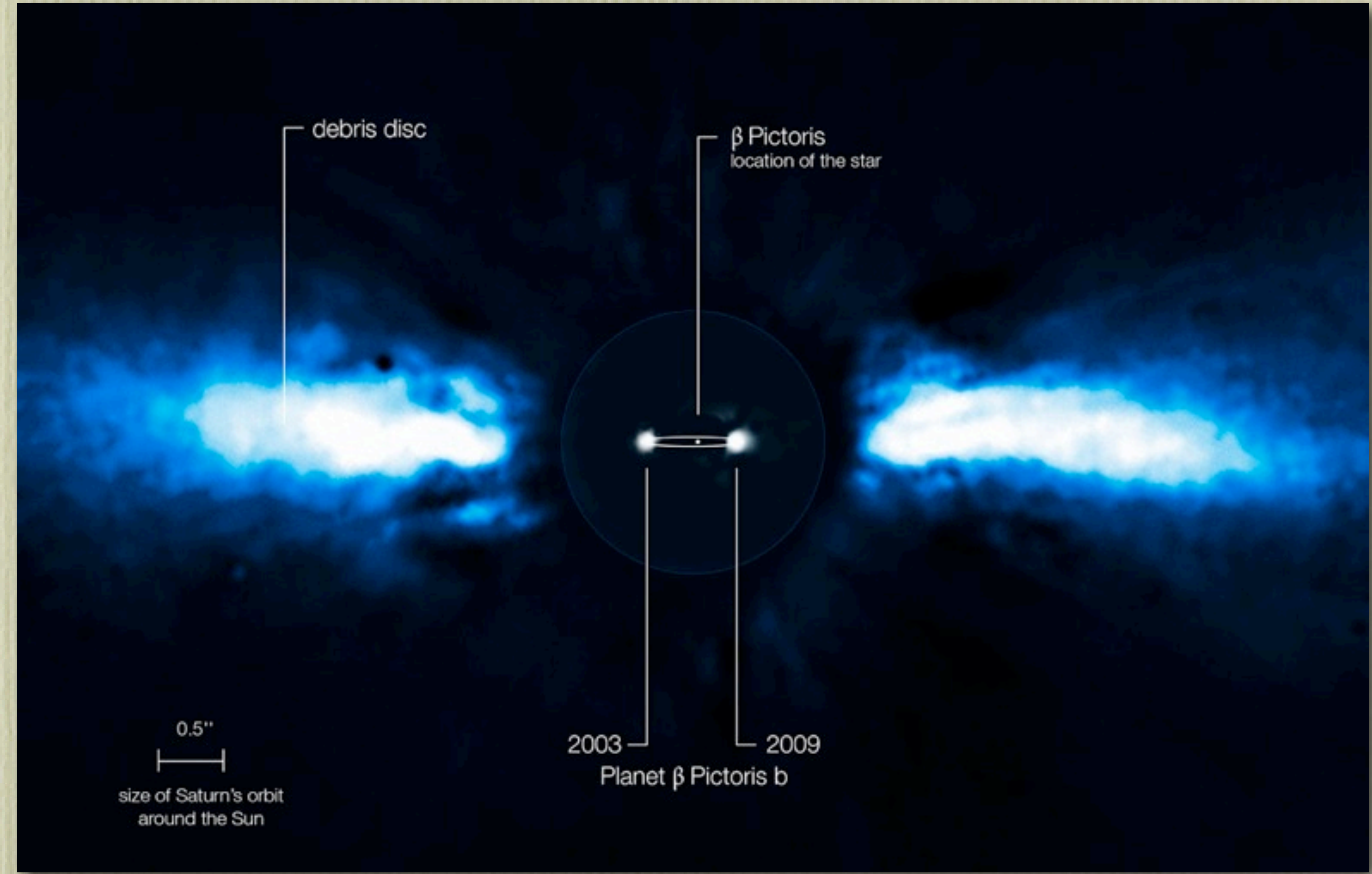
Lagrange et al. (2008)

Planet **β Pictoris b** orbiting the 1.75-M_{sol} star β Pictoris, which has an age of 12 Myr and one of the largest debris disks ever seen (1100 AU).

The planet has an estimated mass of 8-10 M_{jup} and it is located at about 10 AU from its parent star.

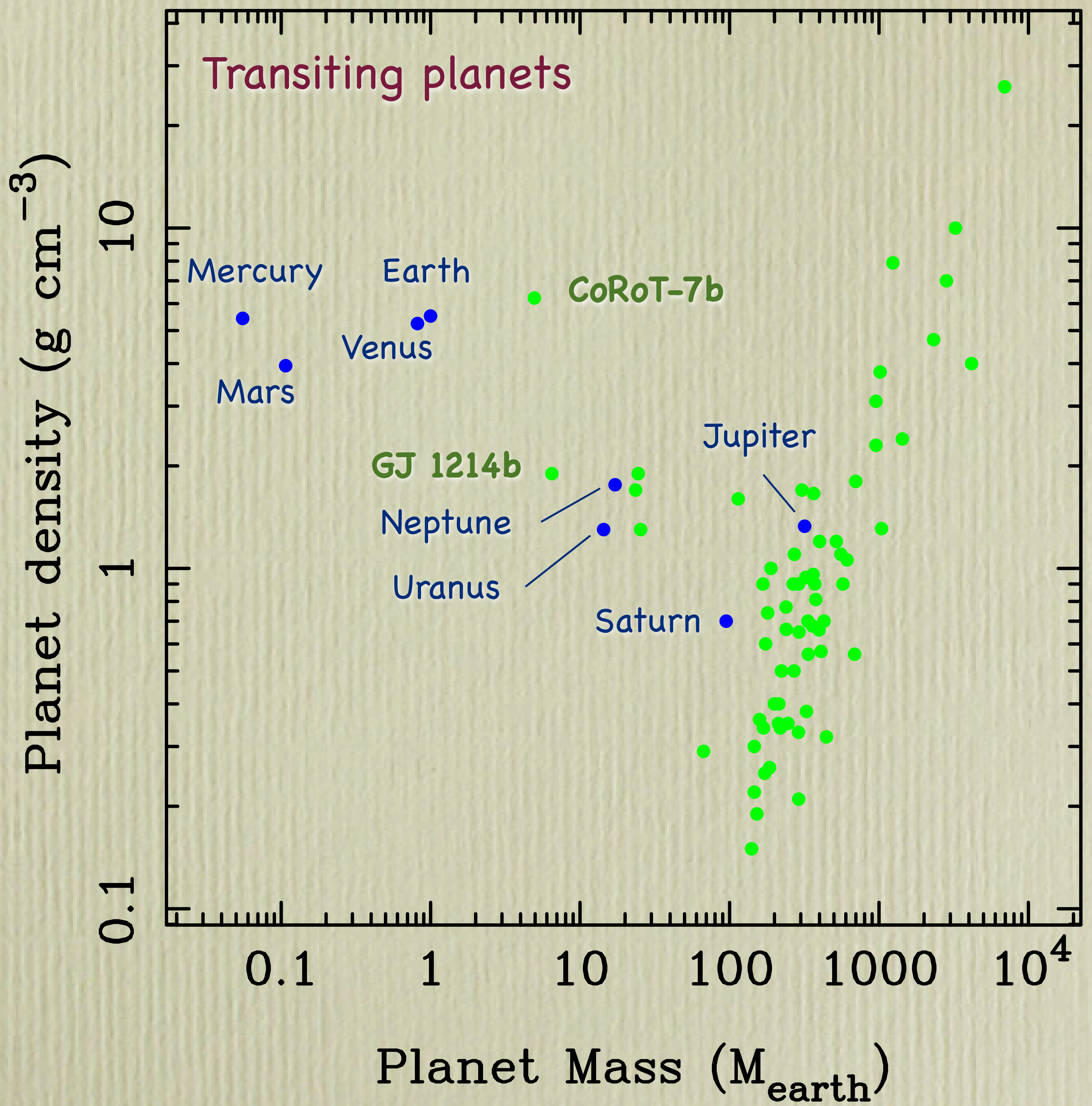
The young age of this planetary system (12 Myr) proves that giant gas planets can form in a few Myr.

Images of planets orbiting massive stars with debris disks

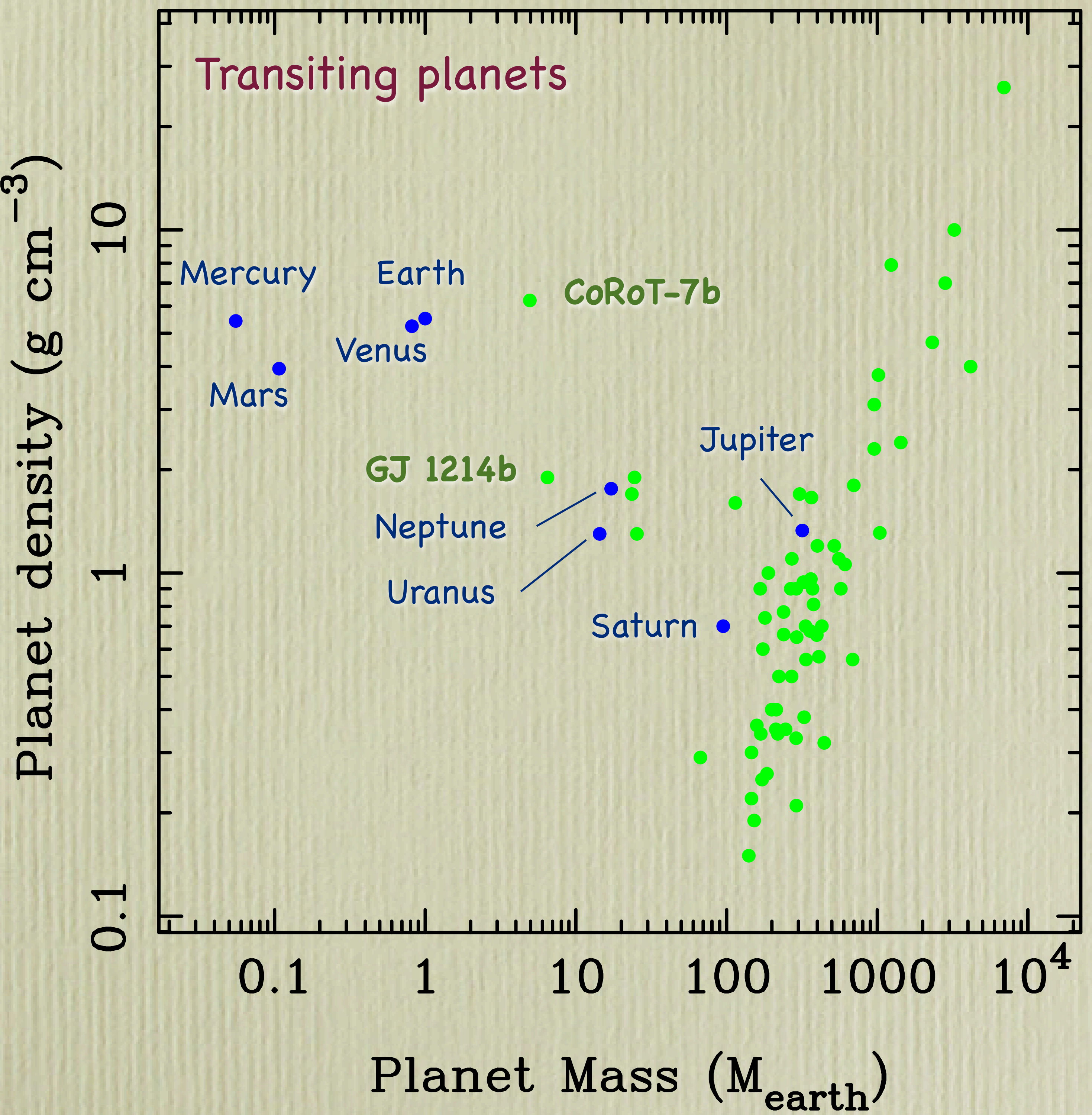


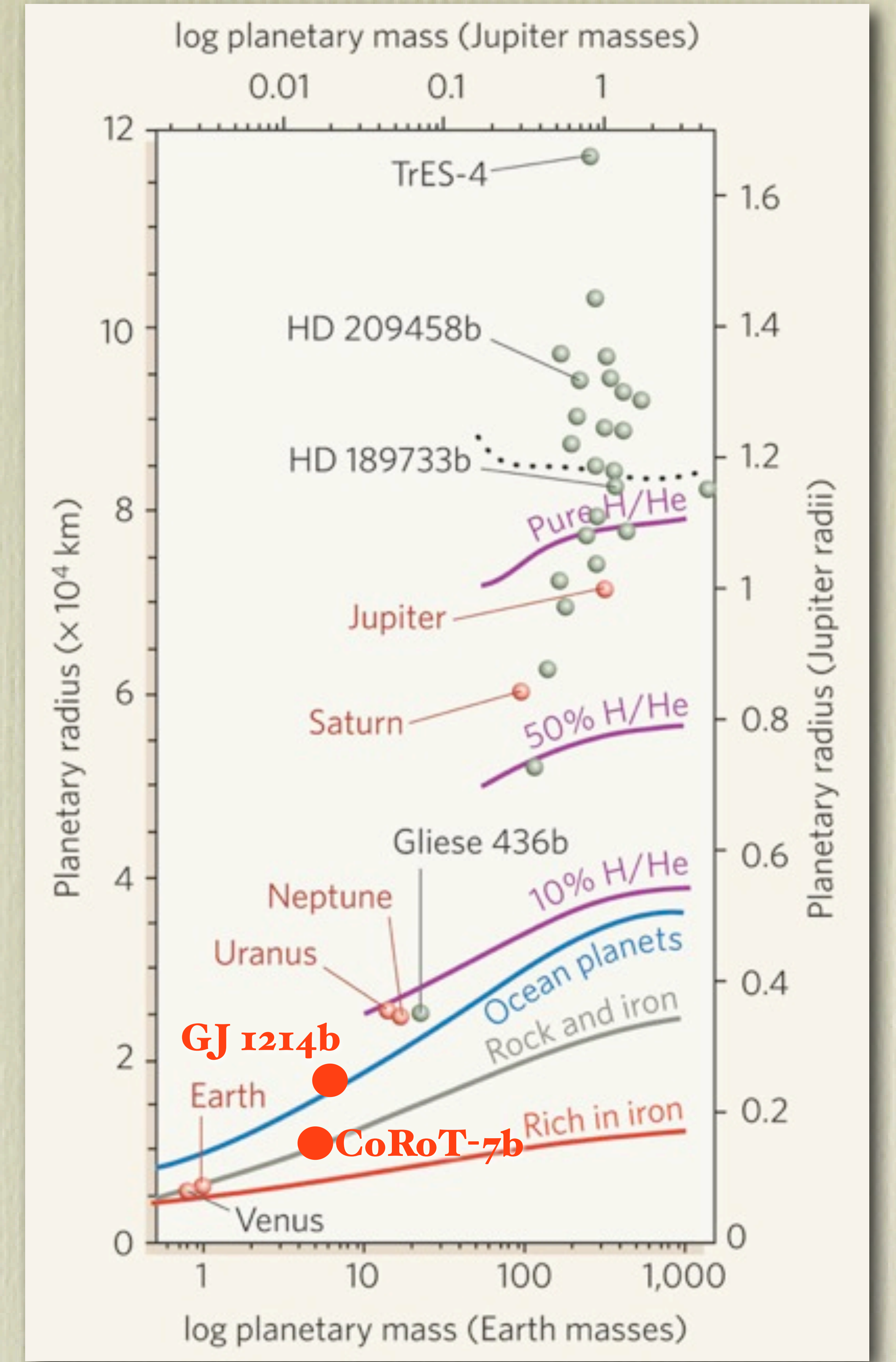
Since discovery, **ß Pictoris b** was reobserved twice in the last few years. The planet has moved from one side of the star in 2003 to the other side in 2009 (Lagrange et al. 2010), suggesting that ß Pictoris b may complete one full orbit in about 17 yr.

How do these planets look like?



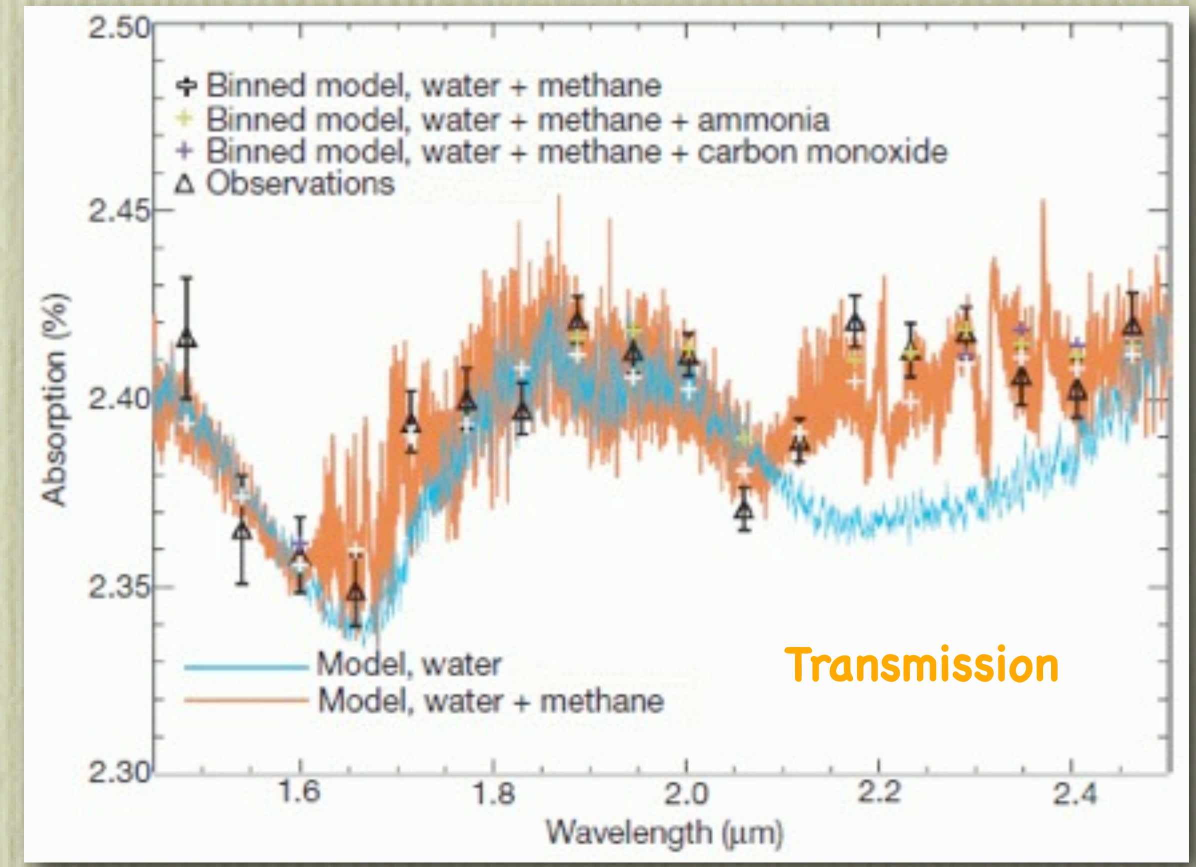
How do these planets look like?

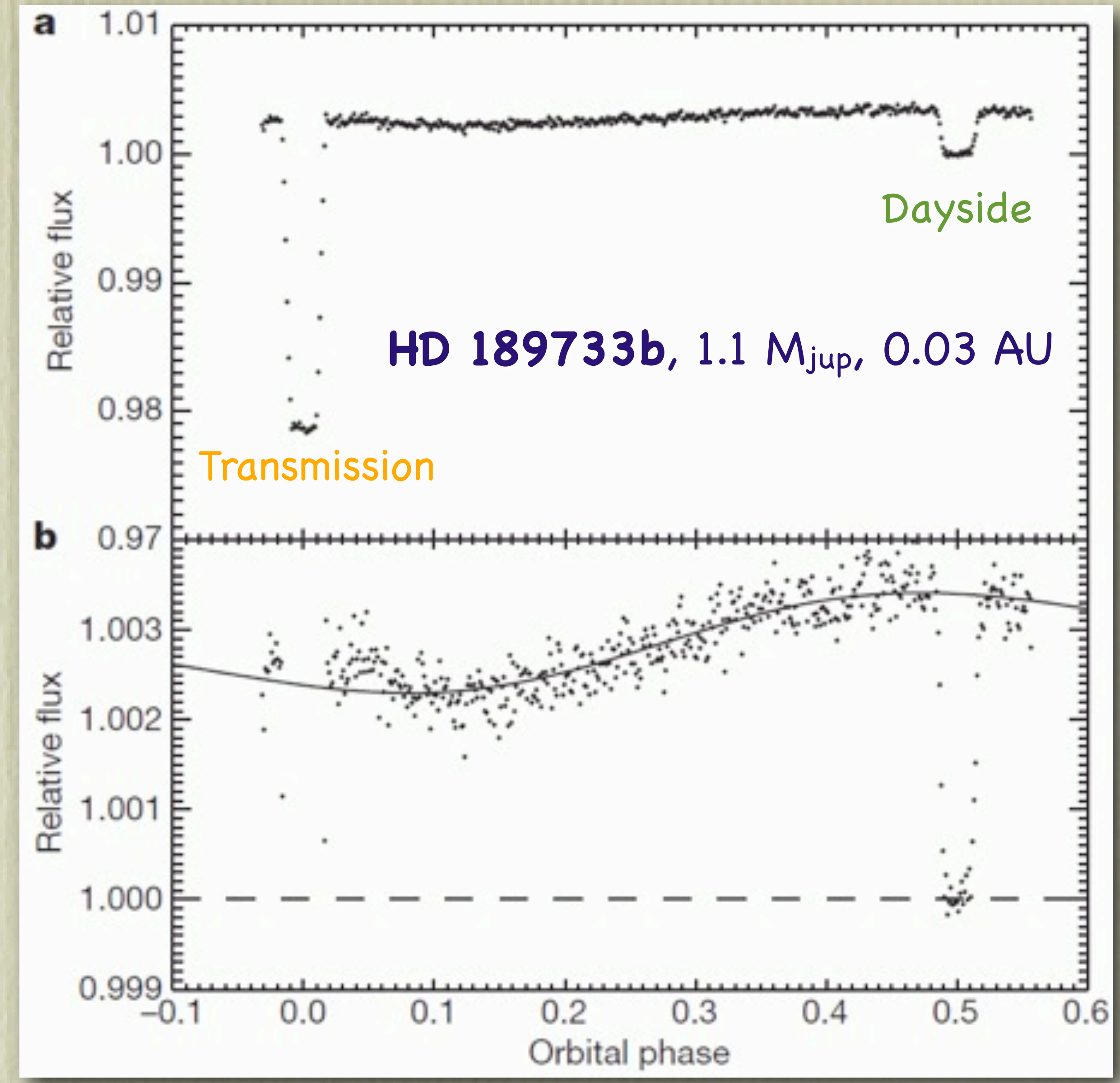




Although NOT in the habitable zones of their parent stars, CoRoT-7b (5 M_{earth}, Léger et al. 2009) may be a rocky planet, and GJ 1214b (6.5 M_{earth}, Charbonneau et al. 2009) may be an ocean planet.

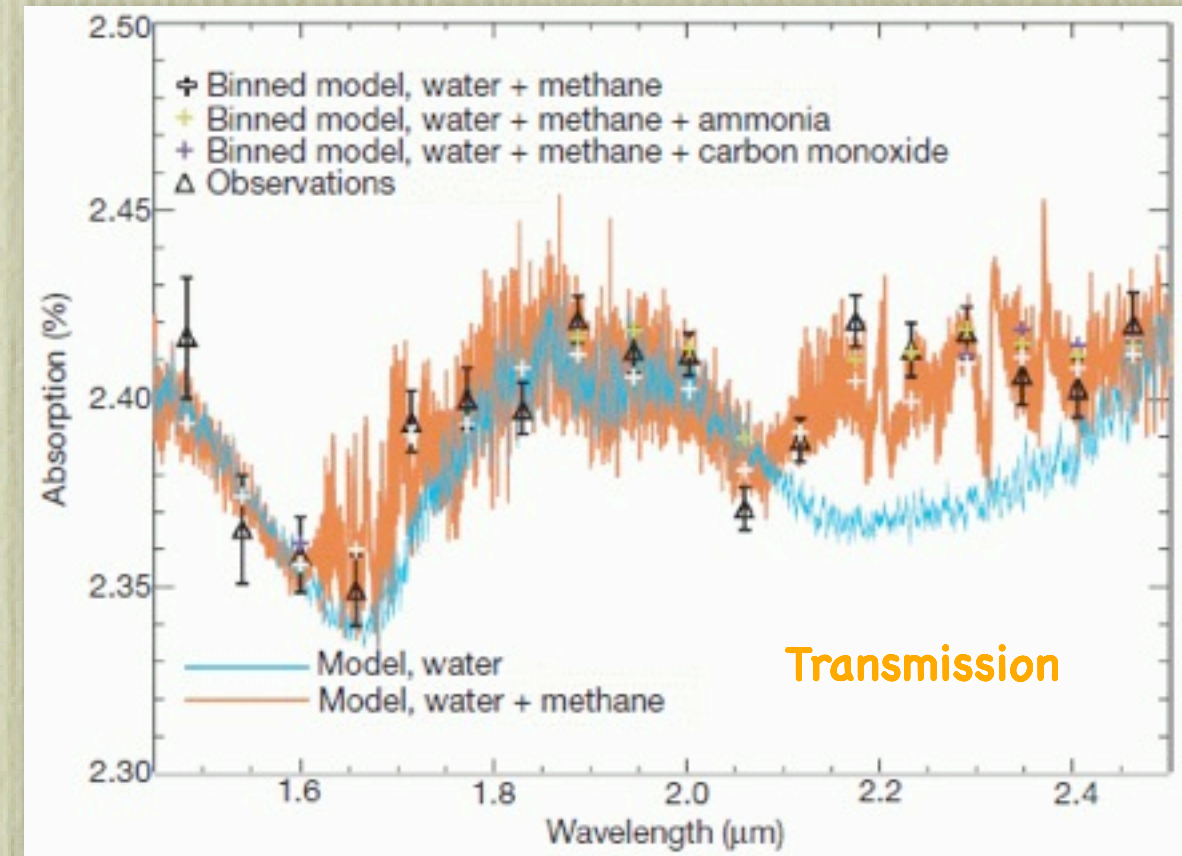
How do these planets look like? Atmospheres of giant planets

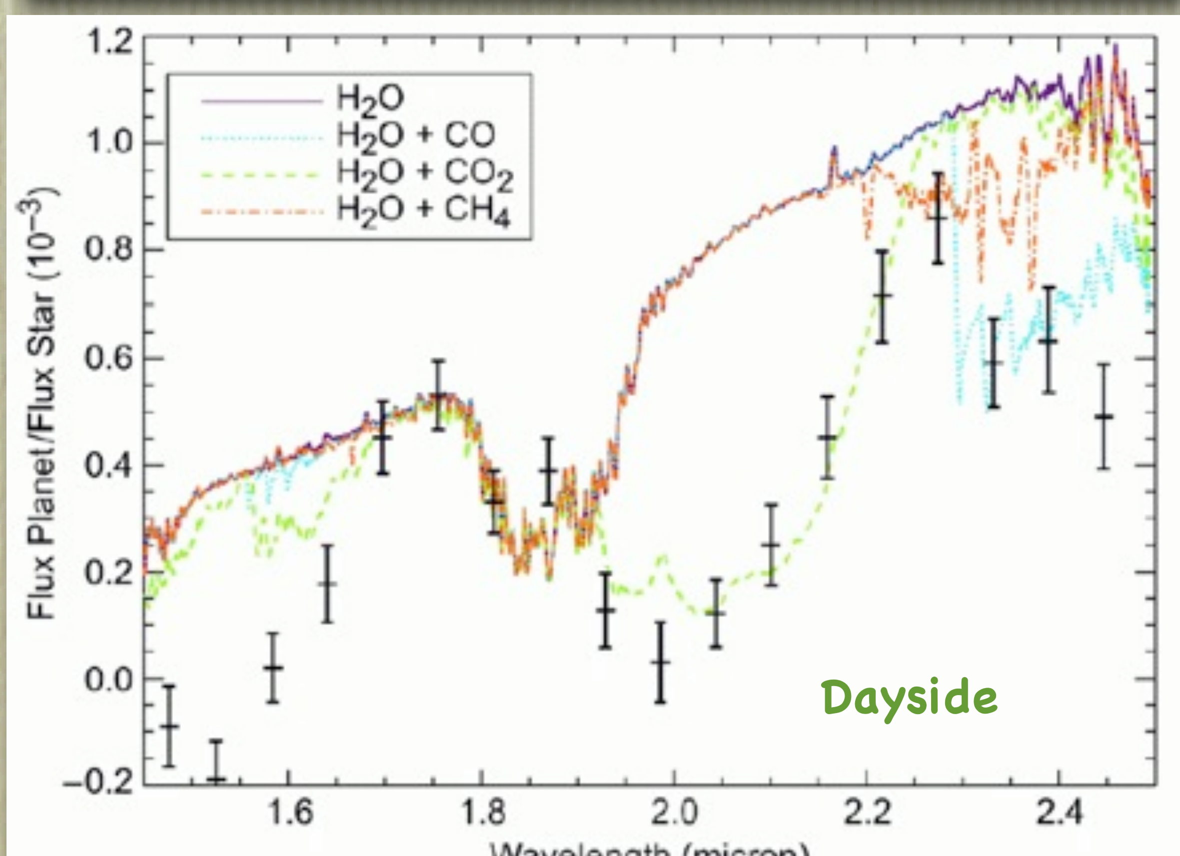


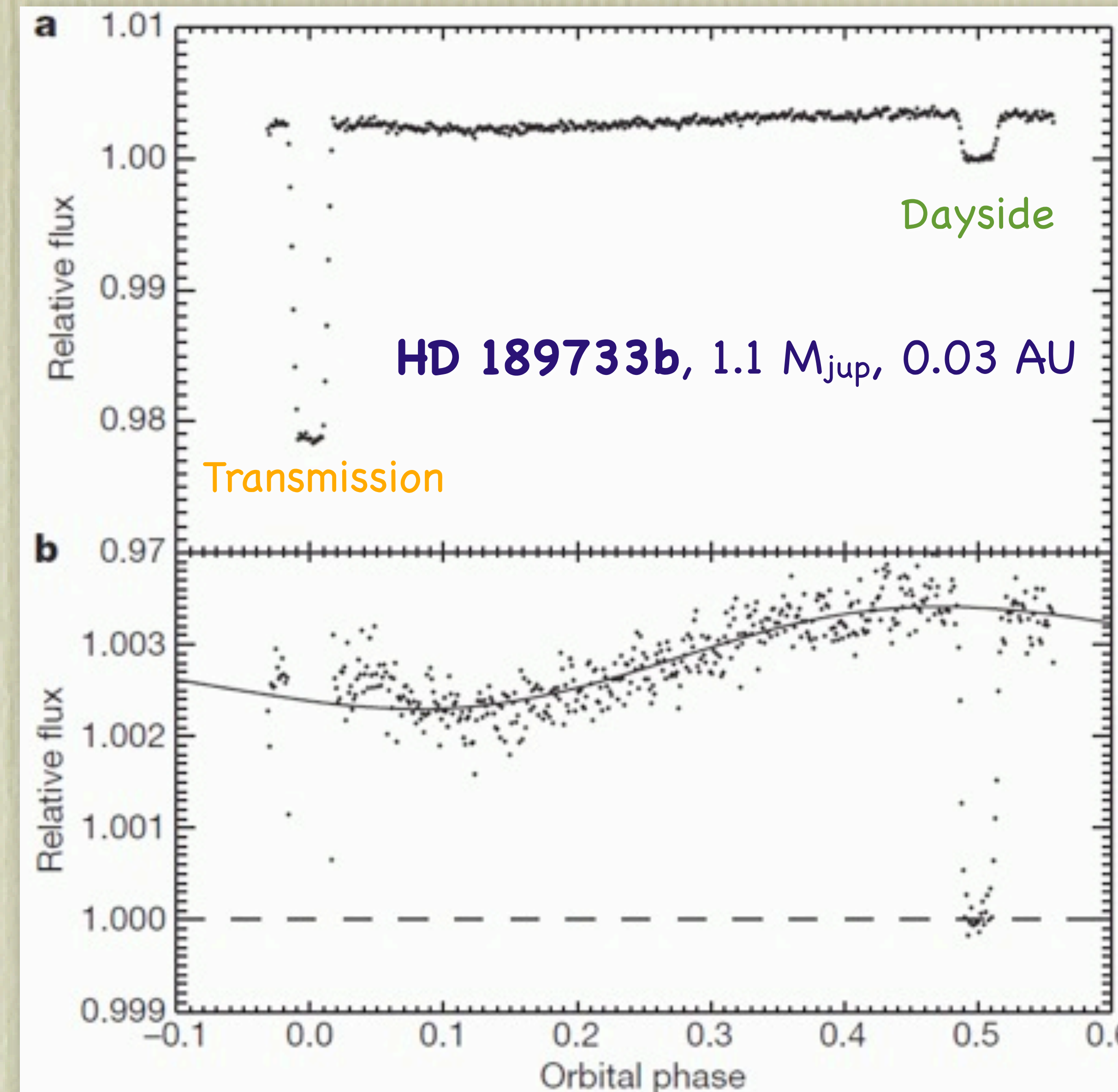


Transmission spectrum of HD 189733b is explained by the presence of water vapor and methane (Swain et al. 2008), like Jupiter.

How do these planets look like? Atmospheres of giant planets





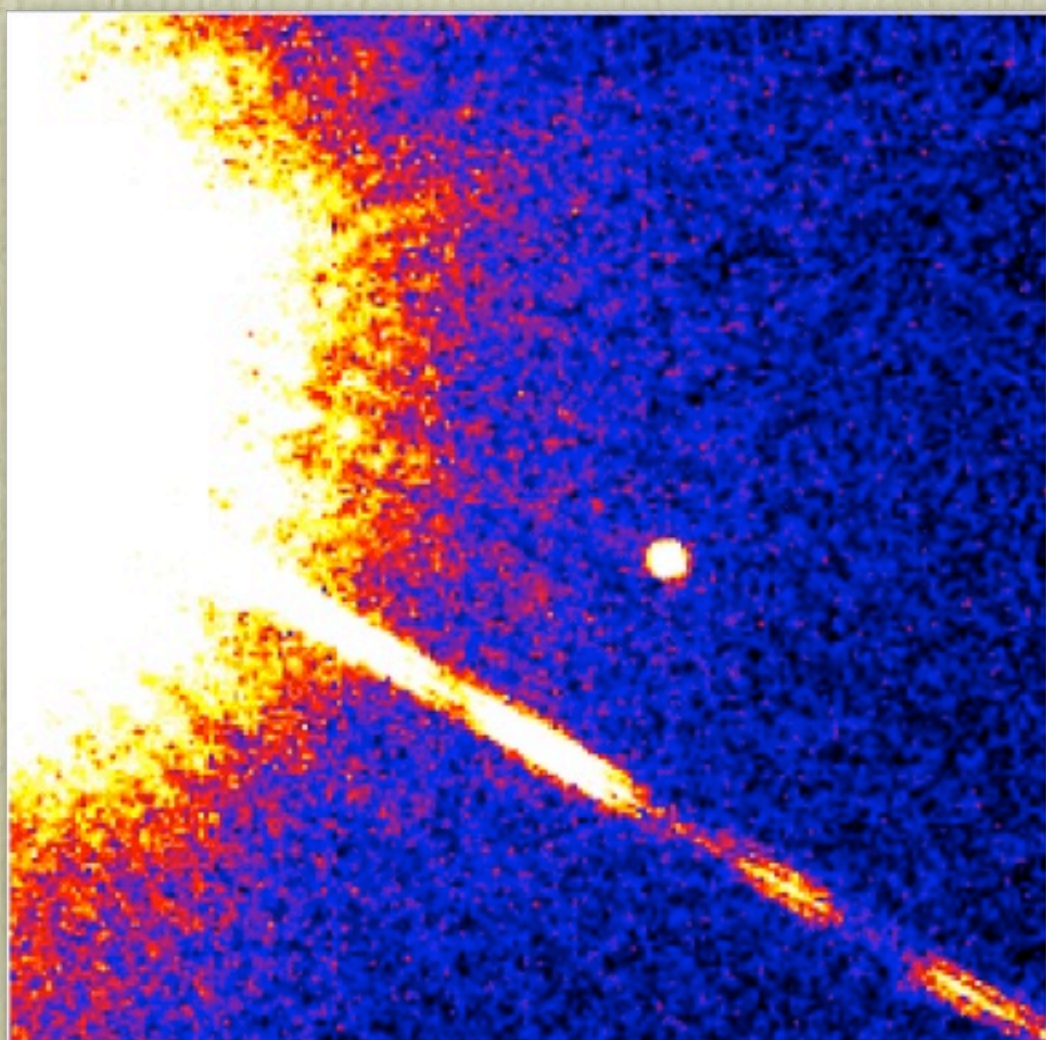


Transmission spectrum of HD 189733b is explained by the presence of water vapor and methane (Swain et al. 2008), like Jupiter.

Dayside spectrum is explained by the presence of water vapor and carbon dioxide (Swain et al. 2009).

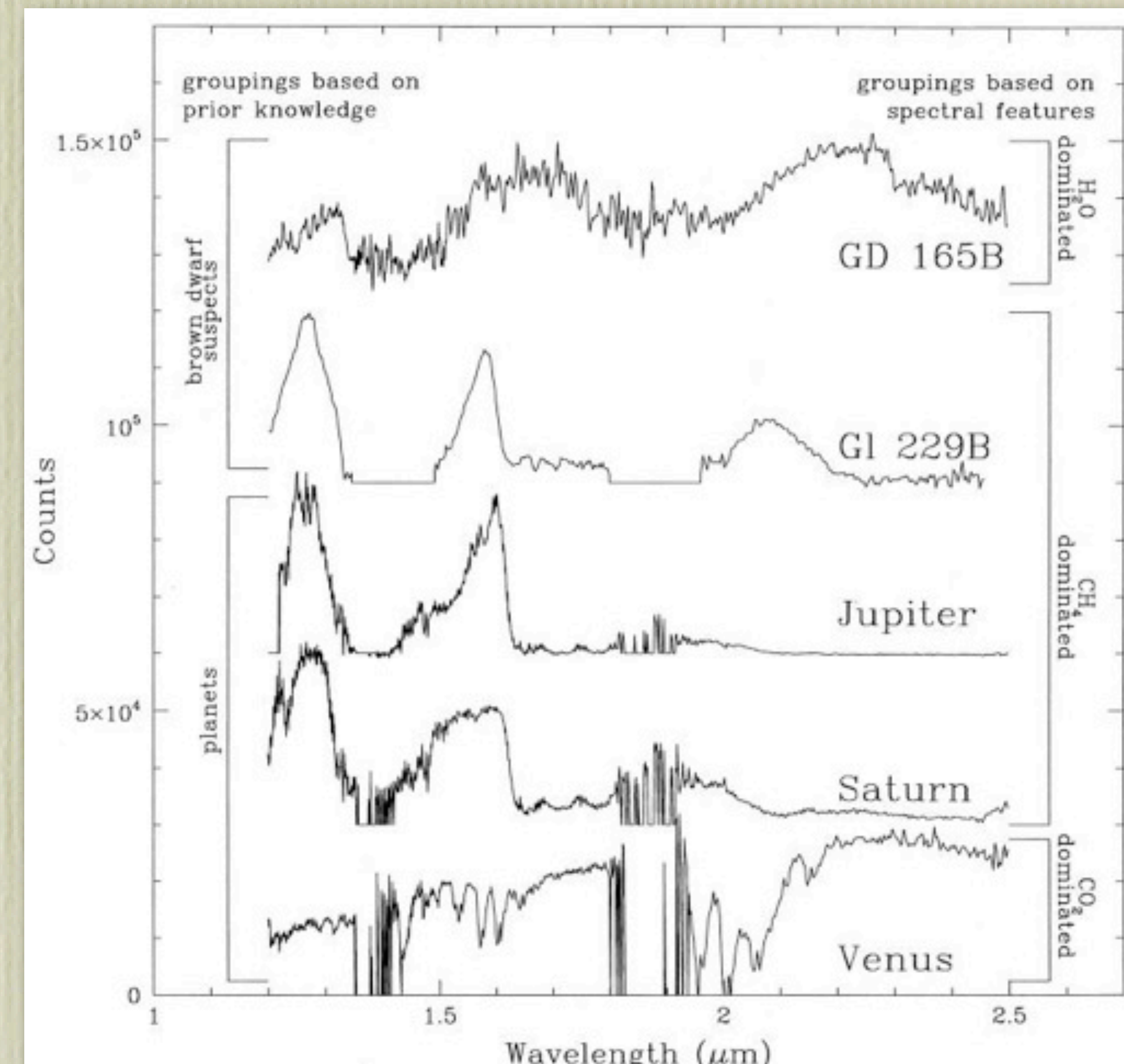
How do they look like? Ultra-cool atmospheres

Gl 299B (50-60 M_{jup}), methane brown dwarf companion to a low-mass star at an orbital separation of 44 AU. Distance of 5.8 pc, age similar to the Sun (Nakajima et al. 1995)



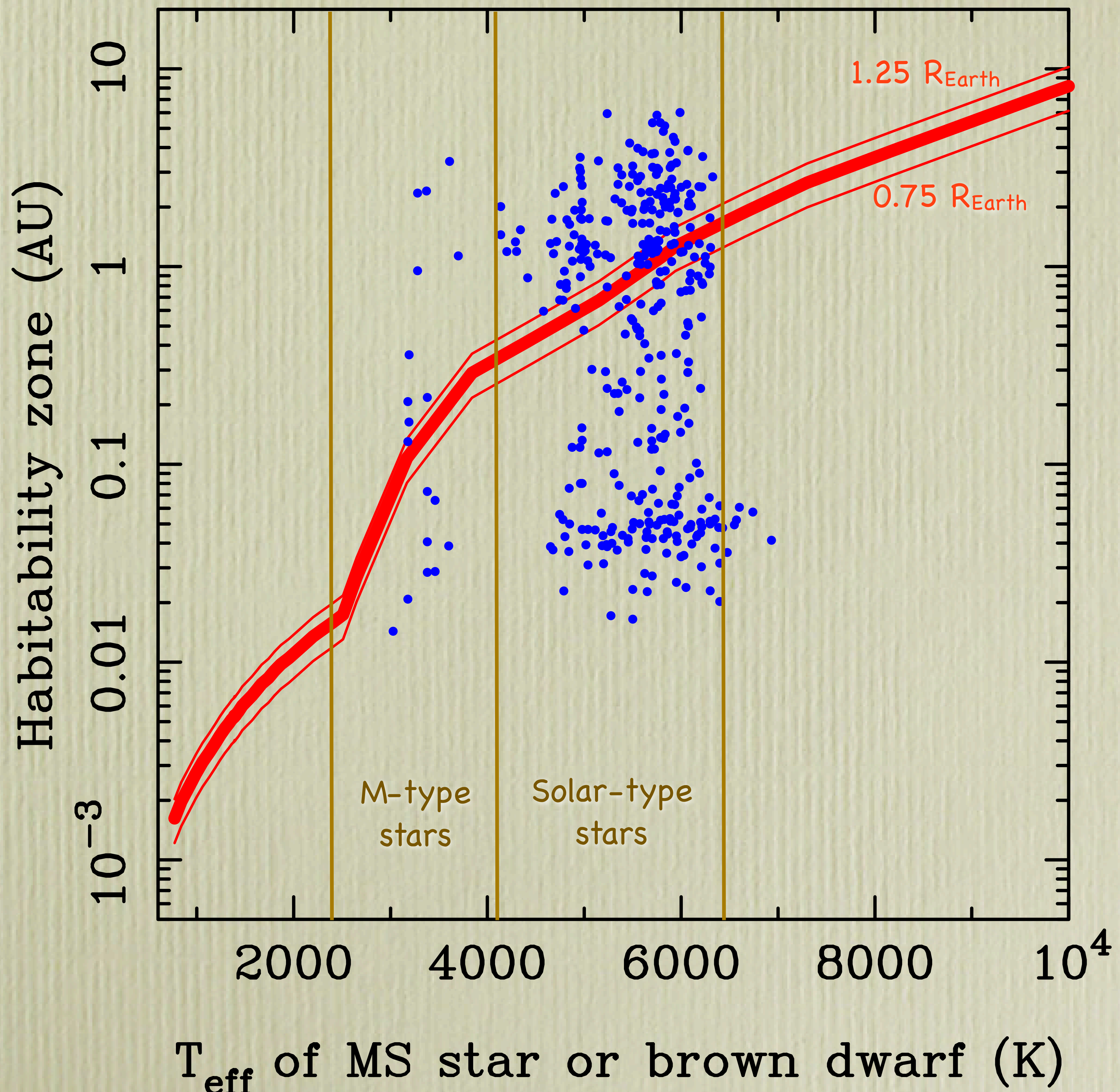
HST image

With a surface temperature of 1000 K, the near-infrared spectrum of Gl 299B shows strong methane and water vapor absorption, similar to Jupiter's spectrum.



Courtesy of J. Davy Kirkpatrick

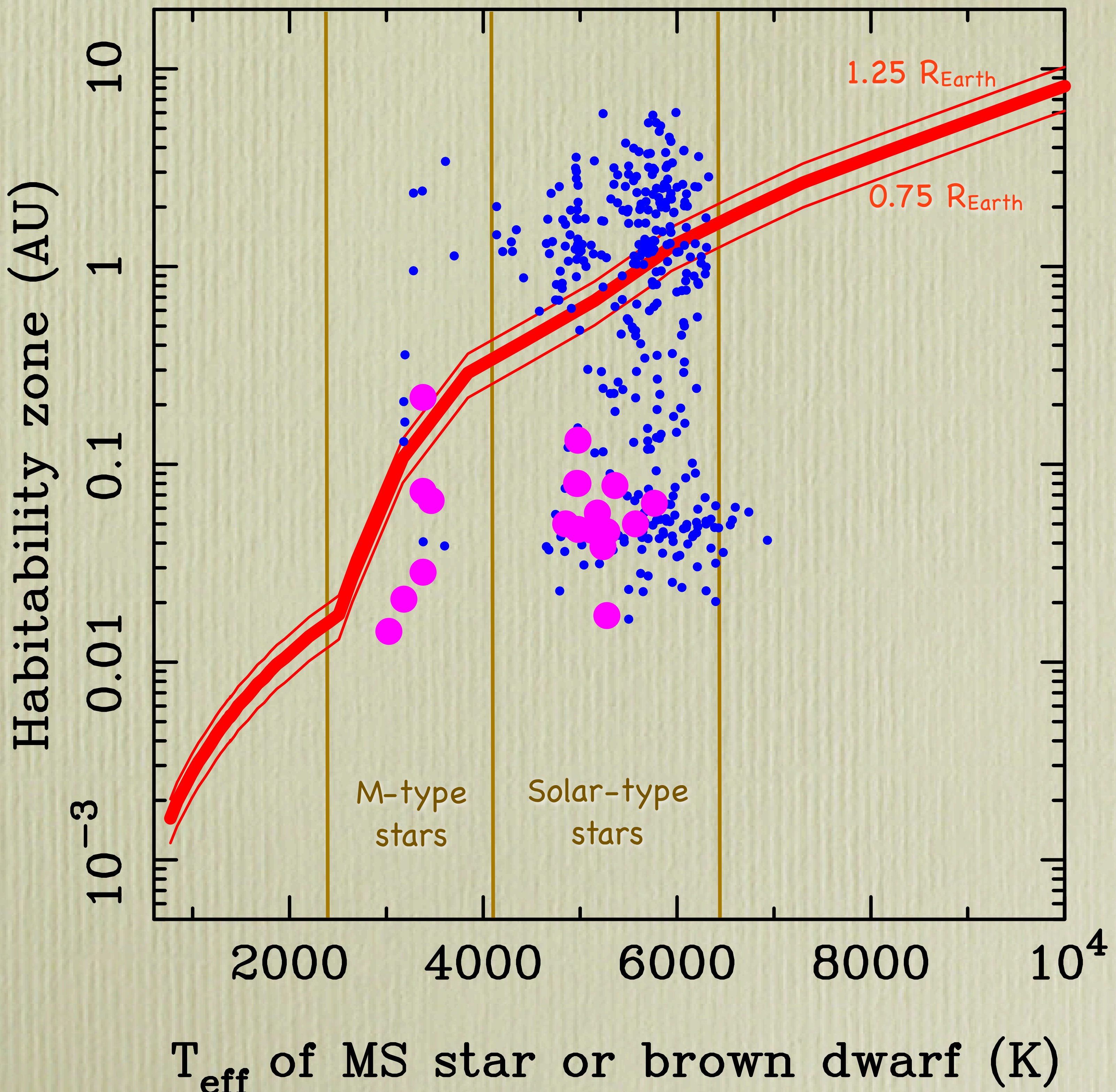
Planets in Habitable Zones?



From astrophysical considerations, working definition of habitability zone (HZ) of stars: orbits where **Earth-twin** planets can maintain liquid water on its surface and **Earth-twin** life.

This implies a stellar light insolation identical to that received by the Earth from the Sun. HZs are proportional to the size of the rocky or liquid planets and to the square root of the parent star luminosities.

Planets in Habitable Zones?

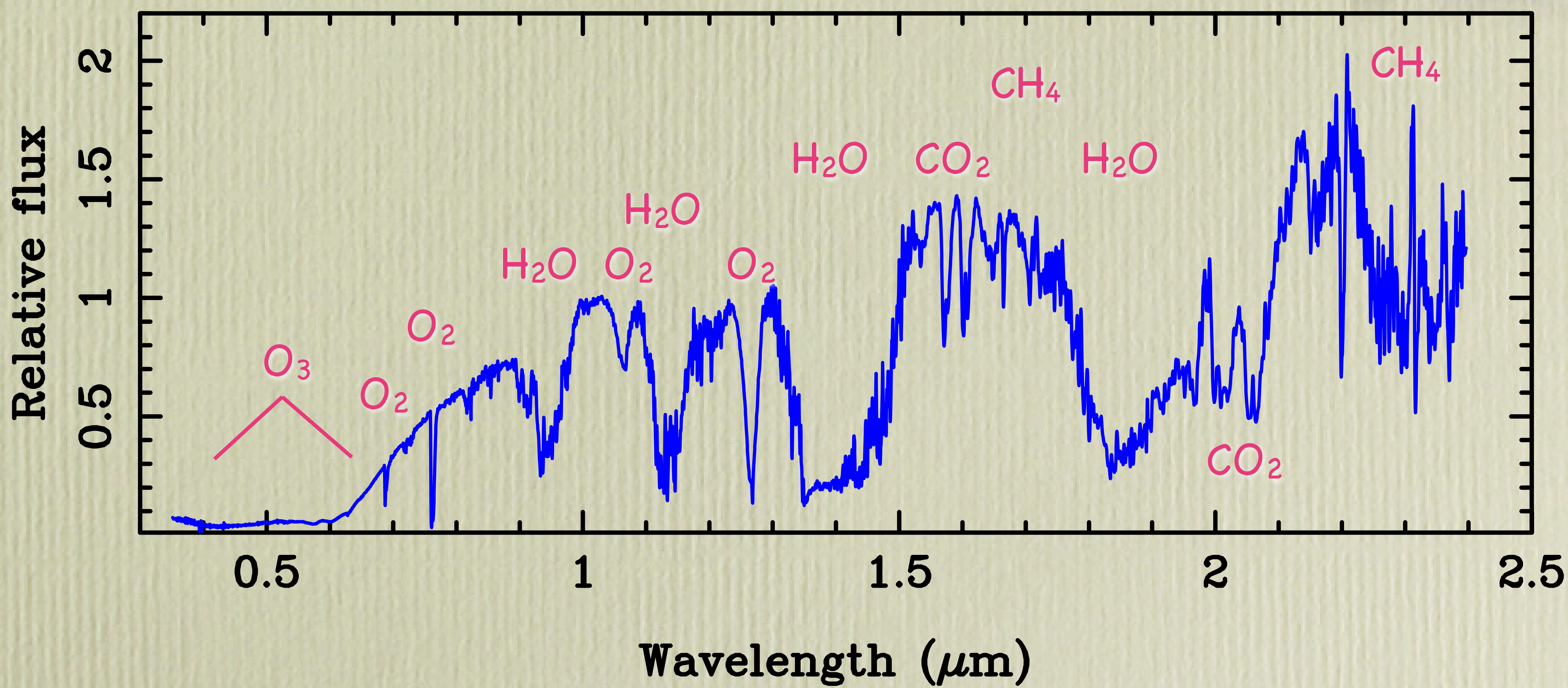


Super-earths with < 10 M_{earth}

None of the super-Earth planets lie in the habitable zone (HZ) of their parent stars. Only the radial velocity planet GJ 581 d lies close to the HZ borderline. The mass of this planet is still uncertain, and its radius (size) is unknown.

Top goal: Earth-twin planet

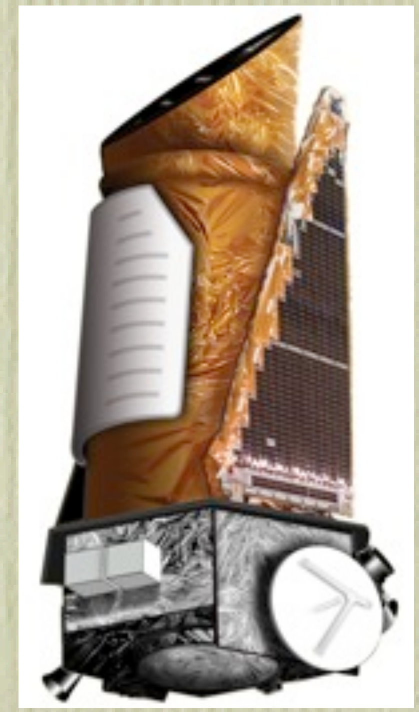
Transmission spectrum of the Earth (Pallé et al. 2009)



The Earth seen in transmission is markedly "red" at optical and near-infrared wavelengths due to strong ozone and water vapor absorption, and blue scattering. On the contrary, Earth's reflected light is "blue".

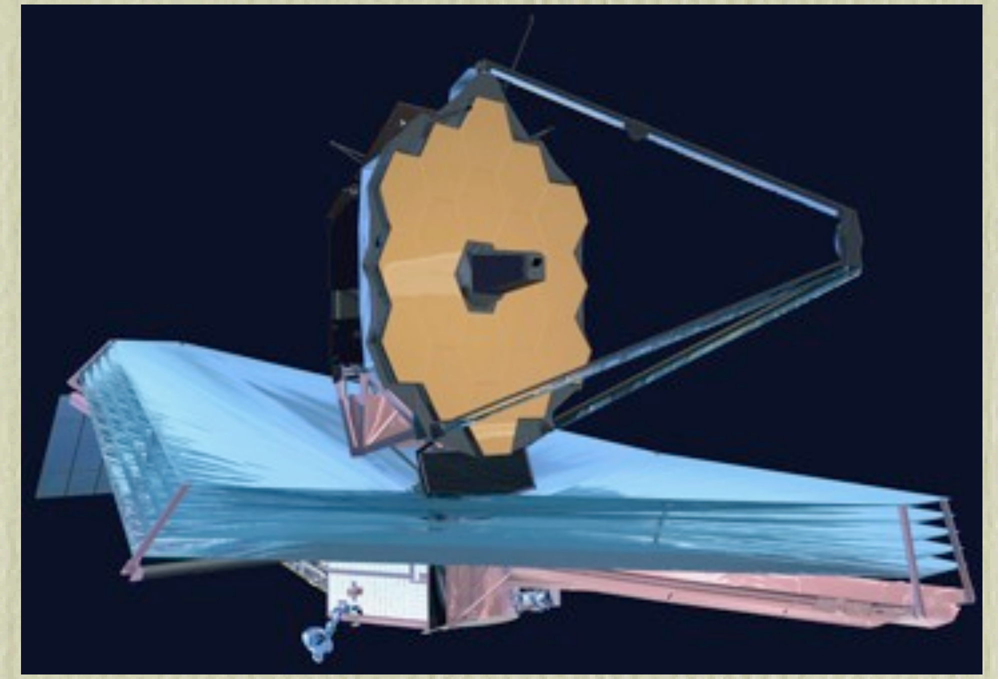
Some examples of future "Earth-like planet hunter" tools ...

Kepler mission



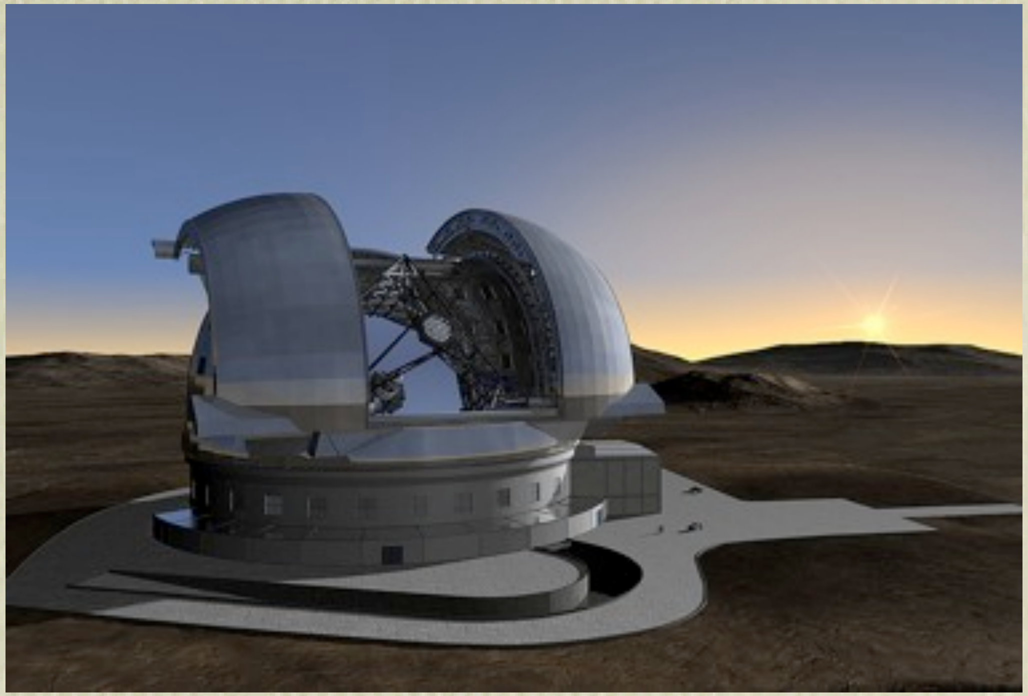
Launched in 2009 and particularly designed to search for low-mass planets using the "transit" technique, it may detect the first Earth-like planets and super-Earths around small stars over the duration of the mission (>4 yr).

JWST mission



Launch date: 2014-2015.
JWST (near- and mid-infrared wavelengths) will be able to photograph planets at wide orbits and to characterize the atmospheres of super-Earths around M-type stars.

E-ELT



Ground-based telescope first light: >2018.
It may have the capacity to identify Earth-like planets in the habitable zone of solar-type stars and to characterize the atmospheres of Earth-like planets in the habitable zones of M-type stars.