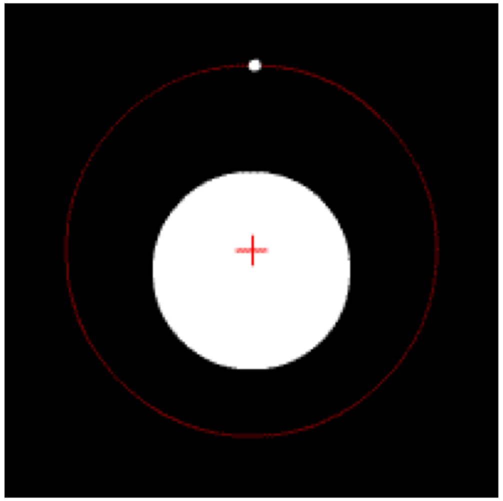
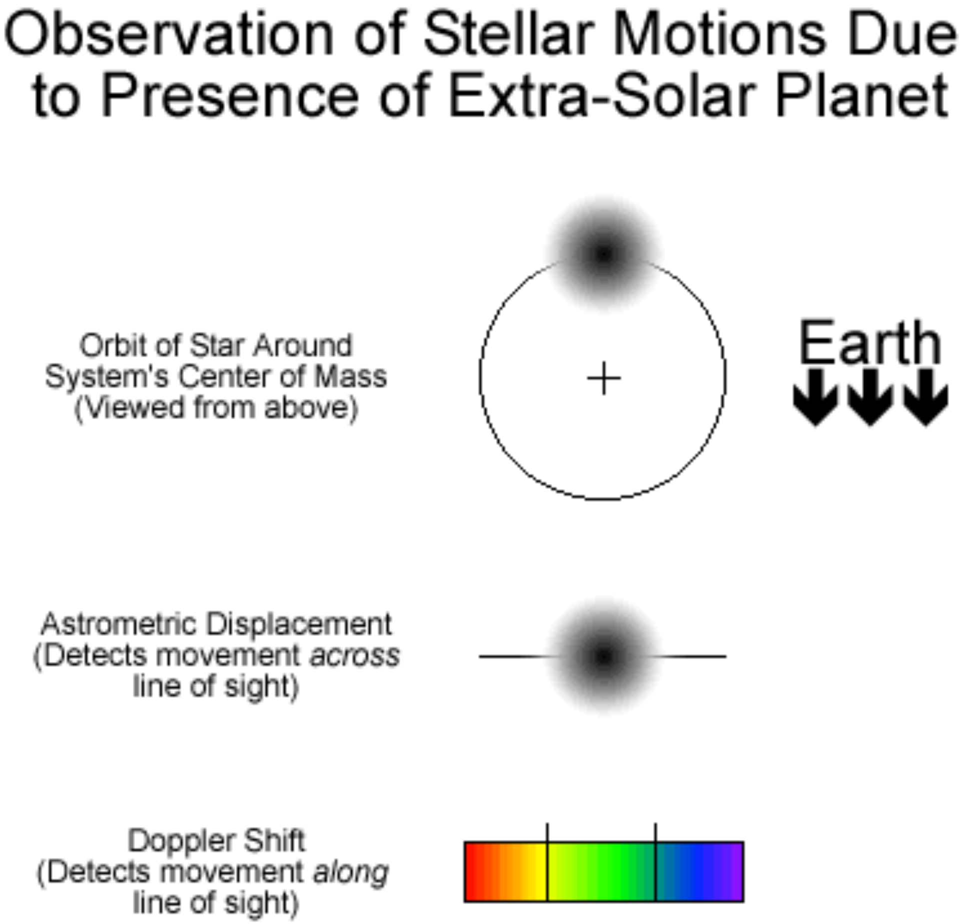
Extra-solar Planet Detection

- Radial Velocity Technique
- Transit technique
- Direct Imaging

Radial velocity technique

• Use same single line spectroscopic binary technique but more accurate





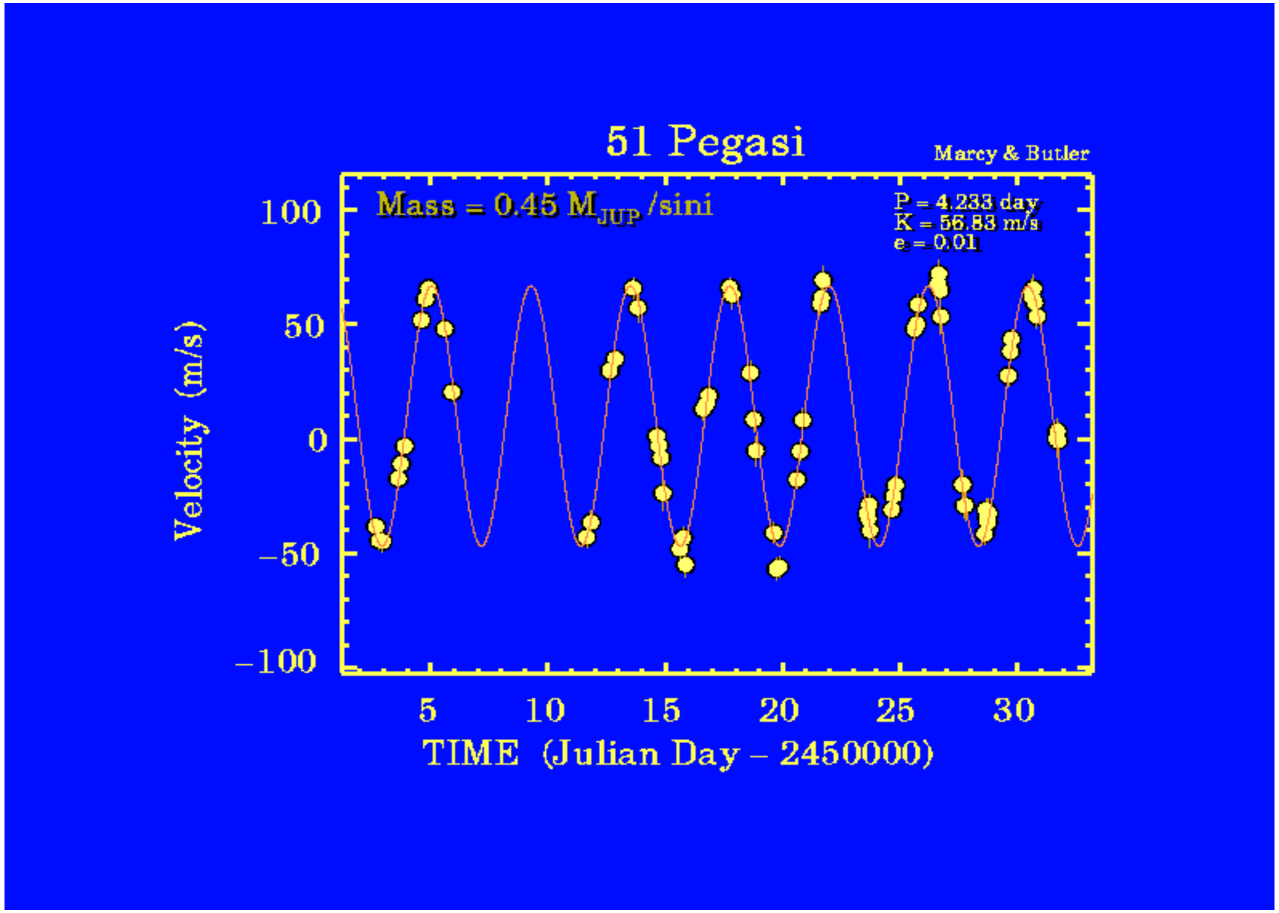
When $M_2 << M_1$ the single-lined spectroscopic binary formula becomes

$$\frac{M_2^3 \sin^3 i}{M_1^2} = \frac{P v_{r1}^3}{2\pi G}$$

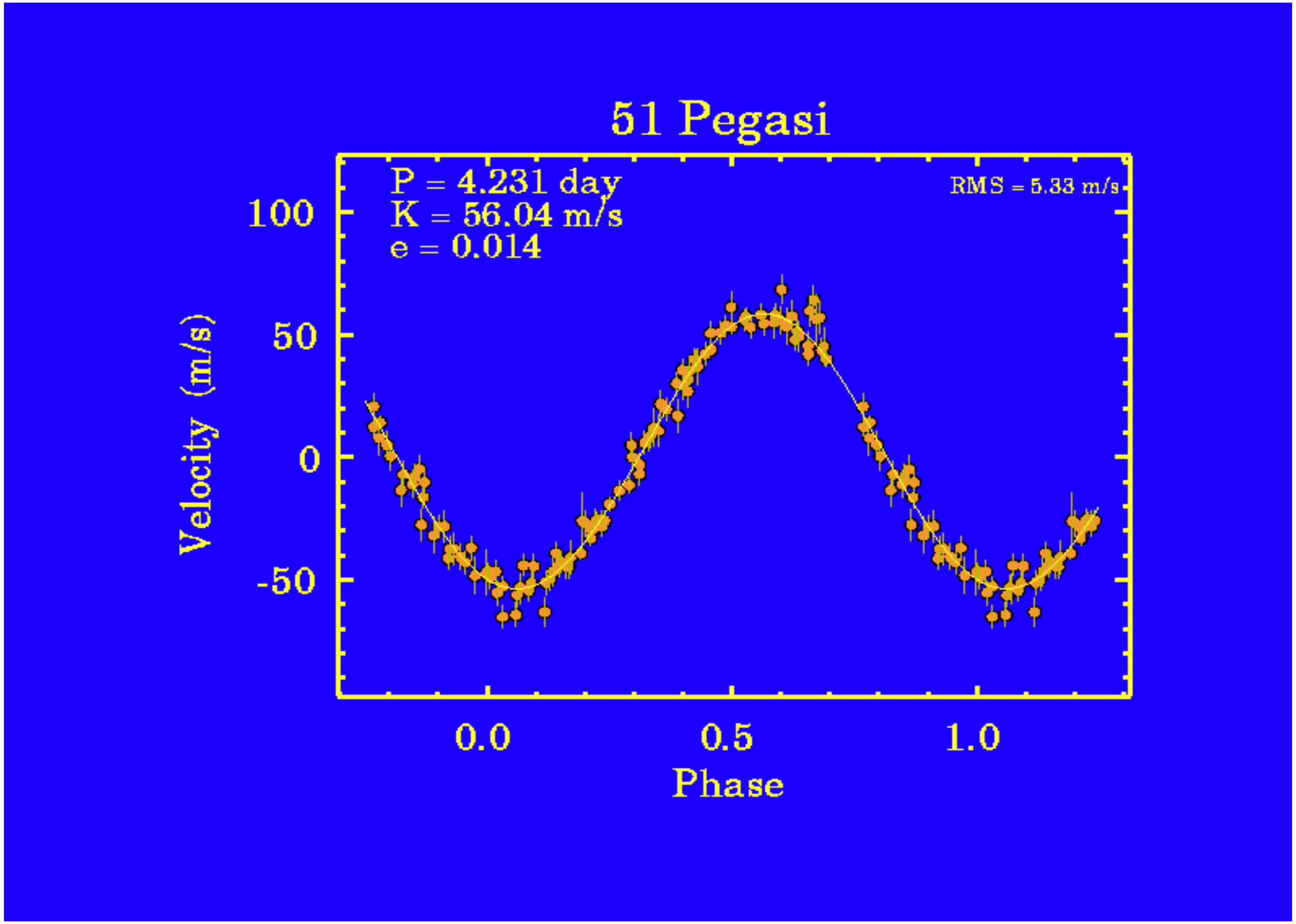
$$M_2 \sin i = \left(\frac{P M_1^2}{2\pi G} \right)^{\frac{1}{3}} v_{r1}$$

51 Pegasi b – the first exo-planet

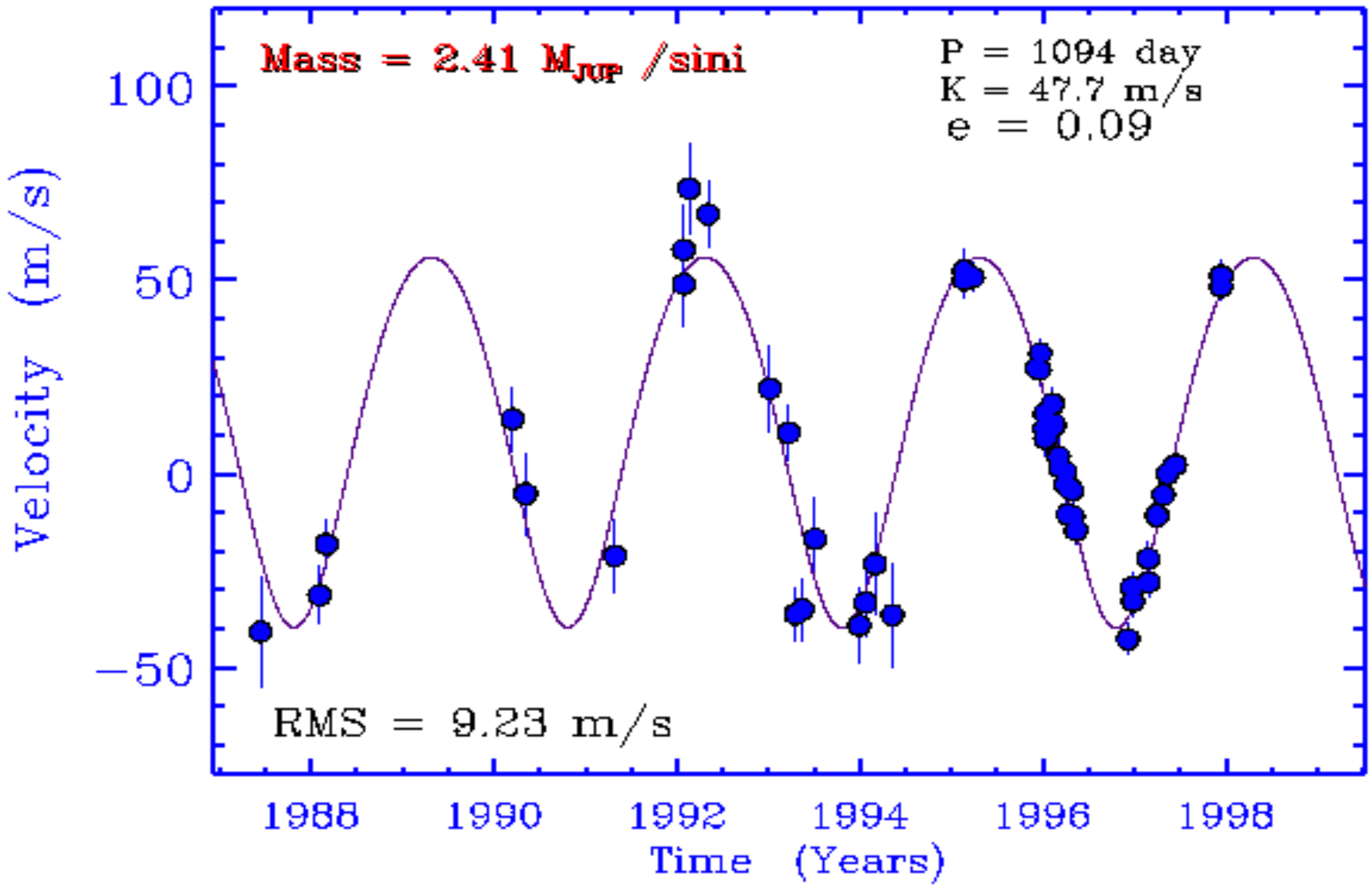
- The radial velocity curve



• The folded radial velocity curve (against orbital phase)

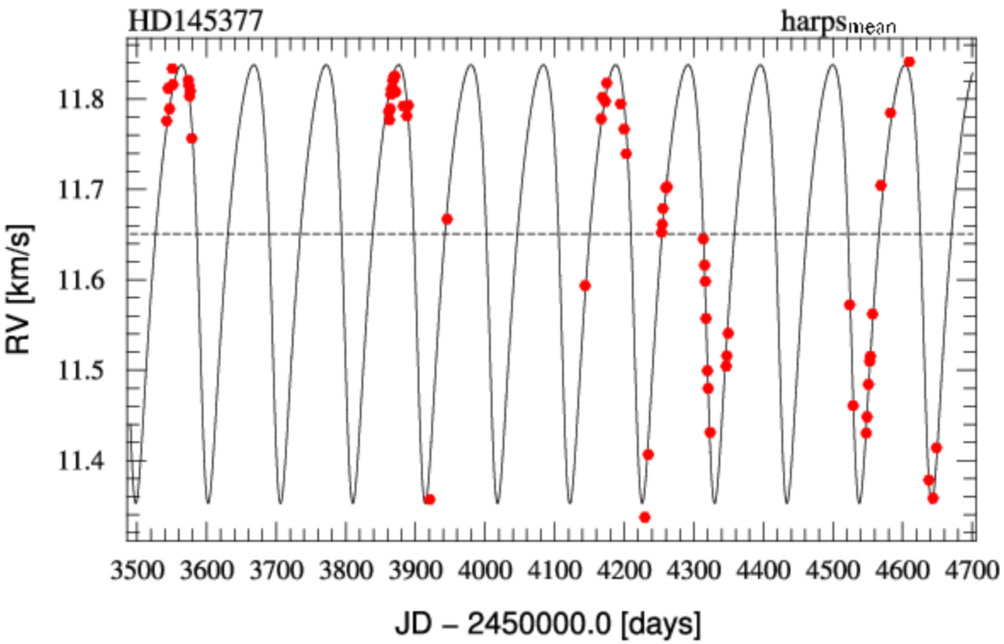


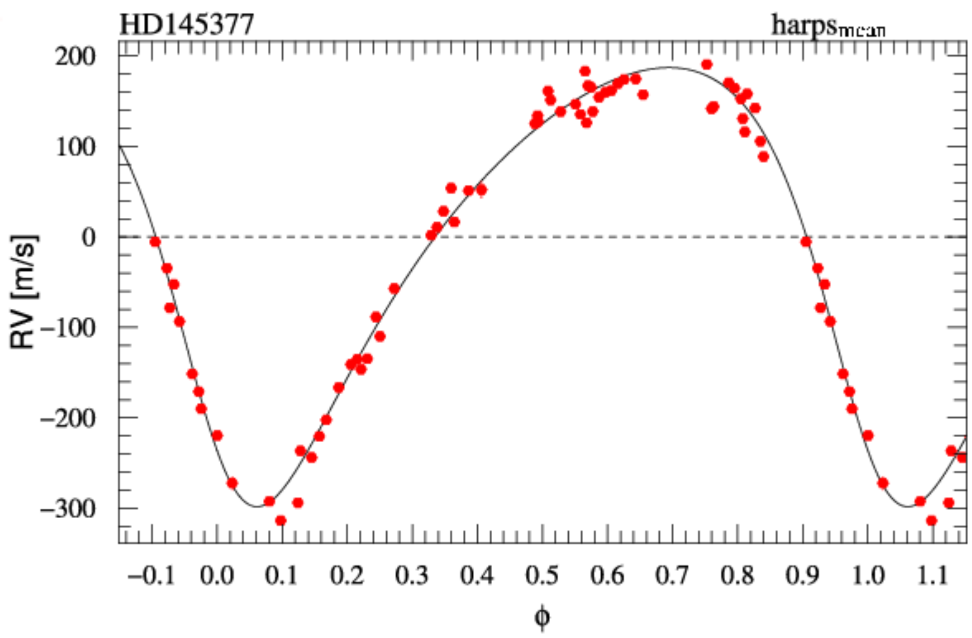
Long Period Planets: 47 UMa b



Eccentric Orbits

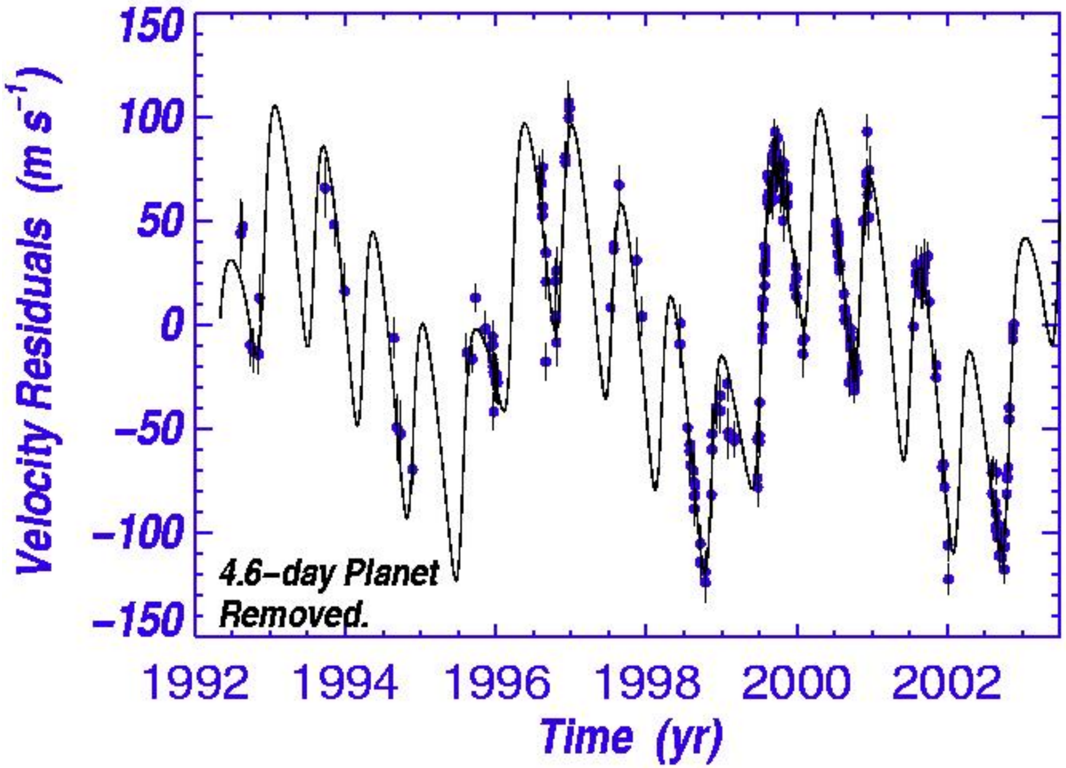
- Non-sinusoidal shape is due to an eccentric orbit.

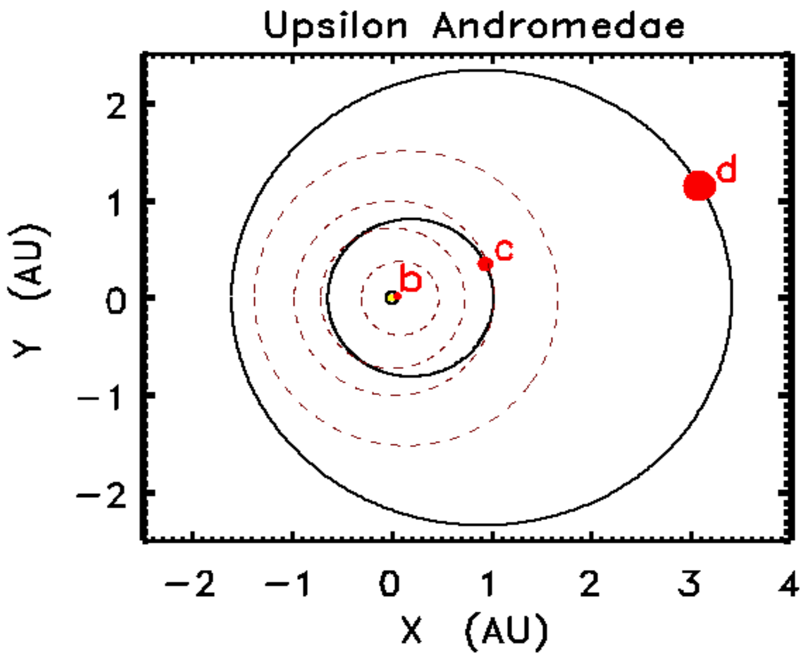


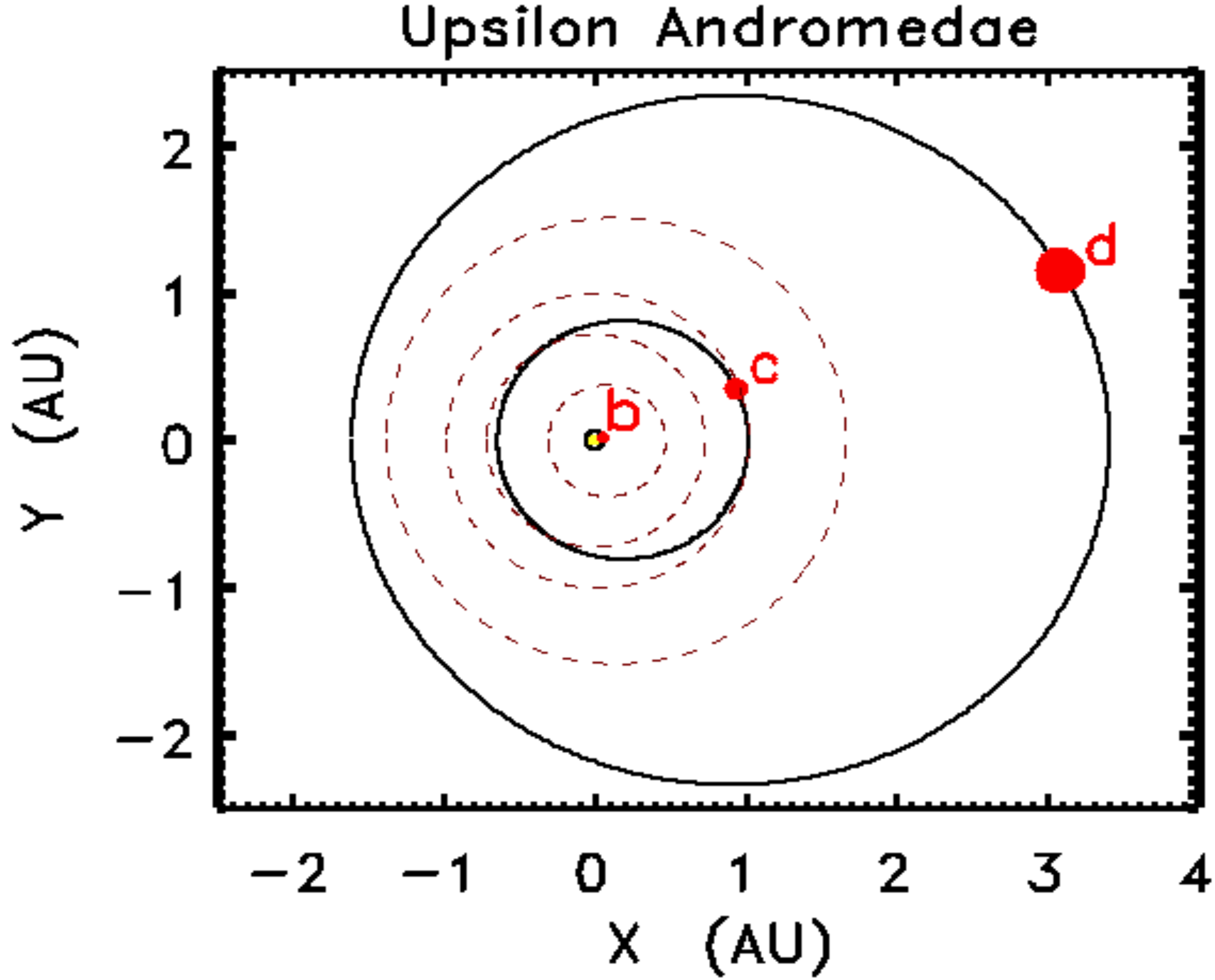


Multiple Planet systems

If more than one period and amplitude is seen in the radial velocity curve it shows that multiple planets are present

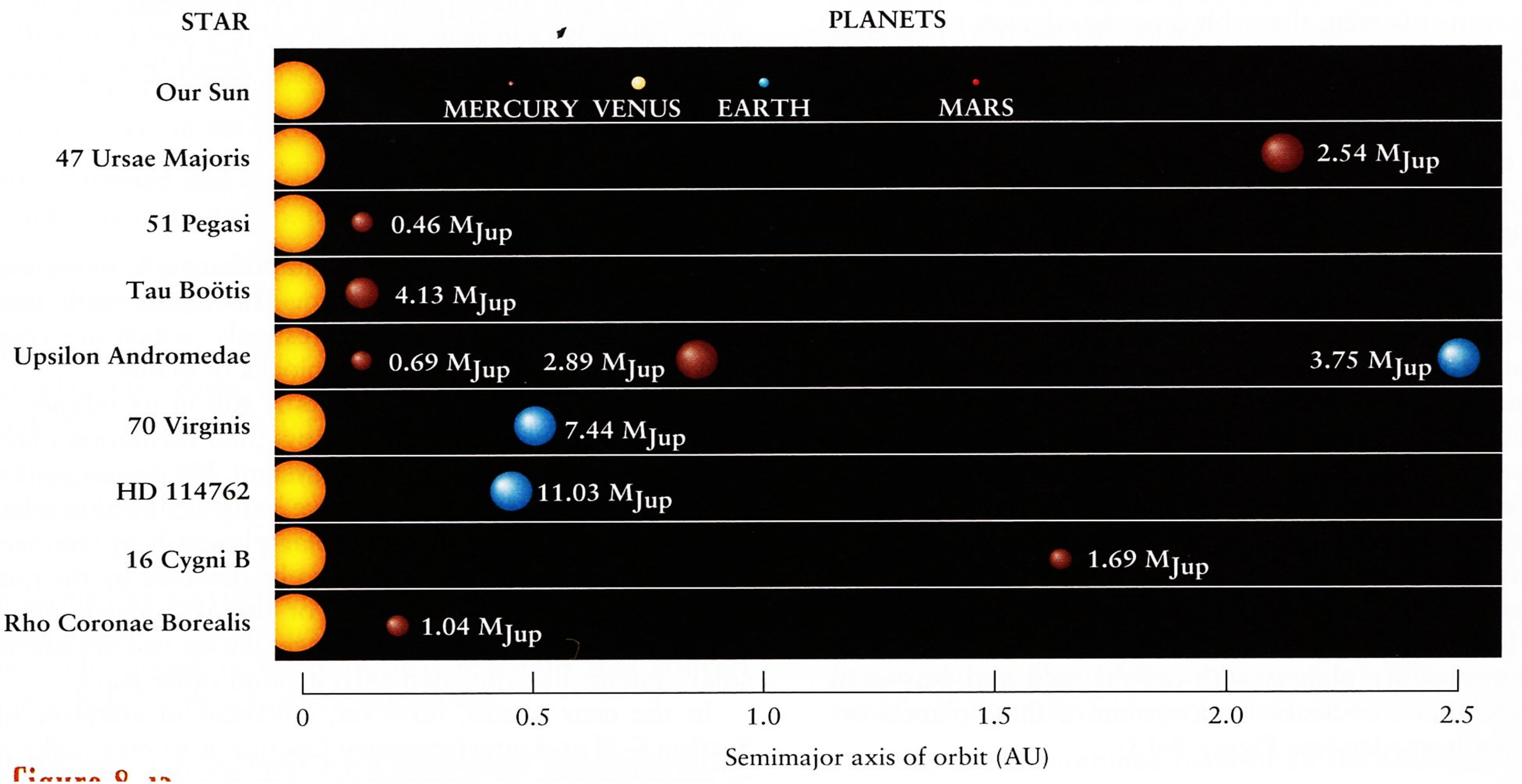






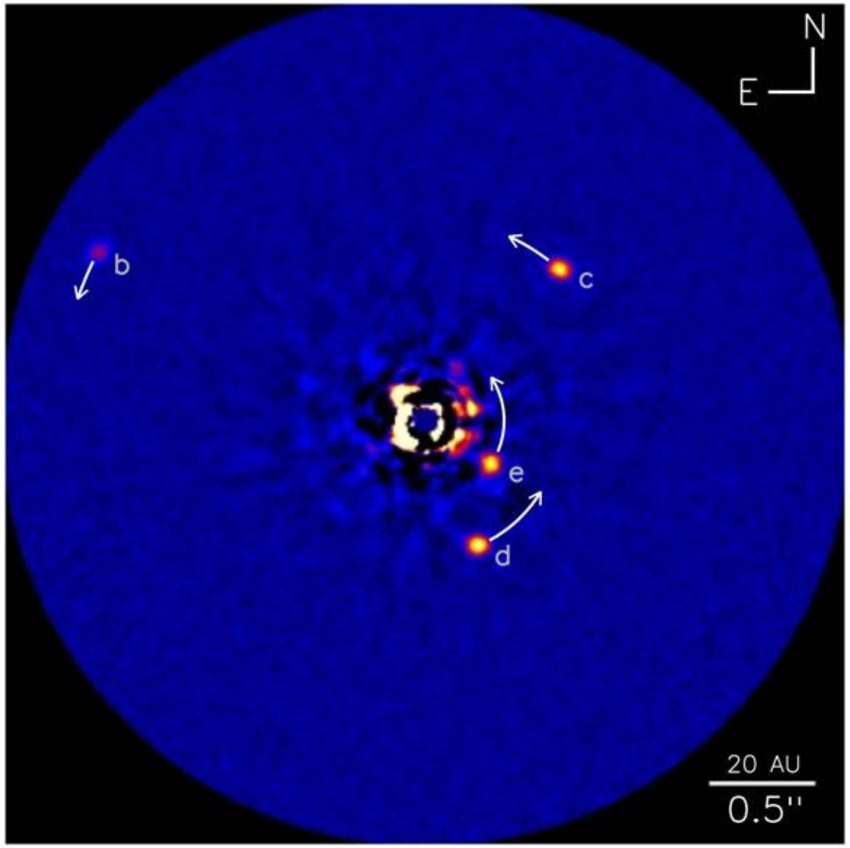
Upsilon Andromedae
d
c
b
2
1
0
−1
−2
Y (AU)
−2
−1
0
1
2
3
4
X (AU)

Radial velocity measurements are most sensitive to massive planets close to their host star



Direct imaging

- Imaging has been used to find large planets far from host star



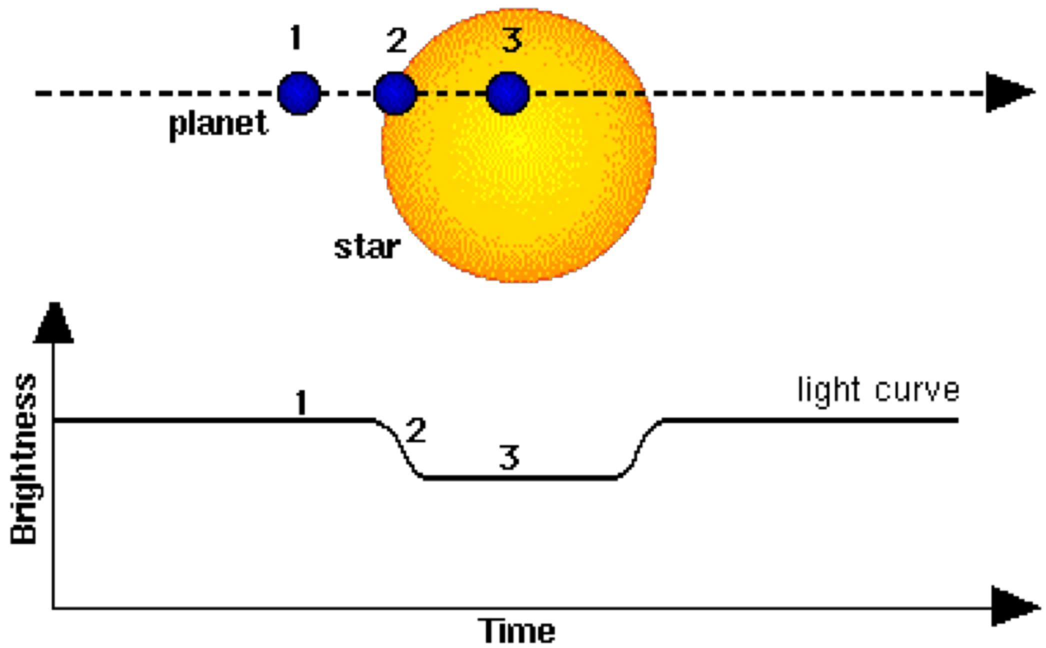
Four planets orbiting the solar-like star HR 8799 seen in the infrared image

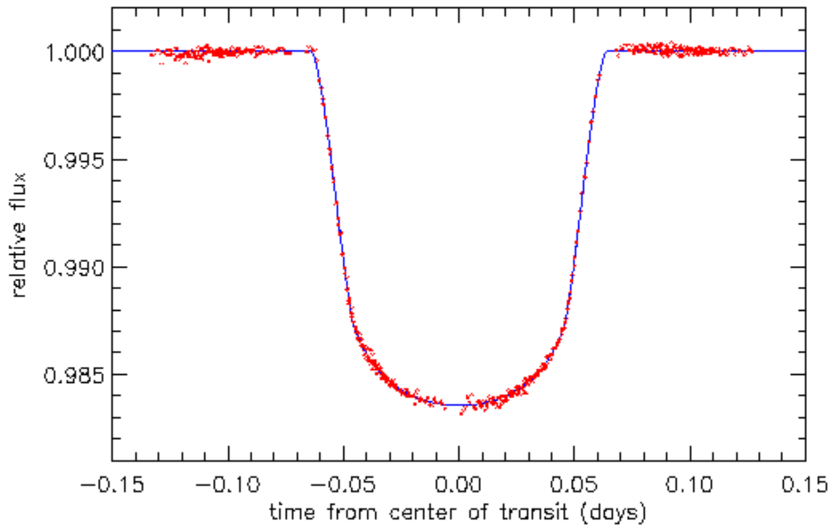
Credit: NRC-HIA, C. Marois & Keck Observatory

www.nature.com/nature/journal/v468/n7327/full/nature09684.html

Transits

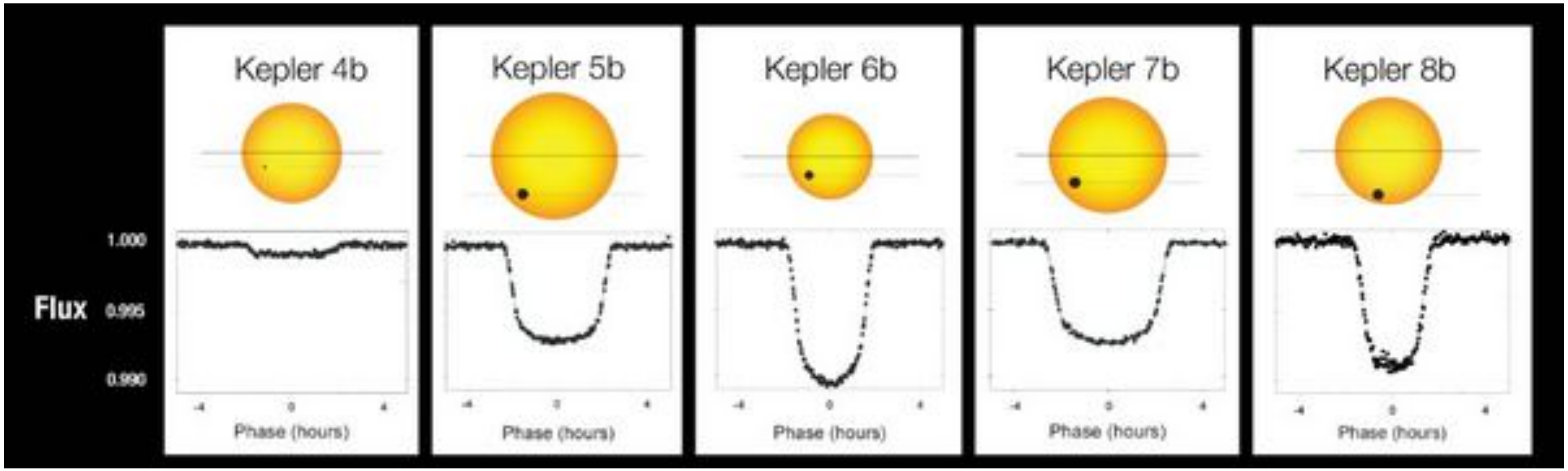
- A transit occurs when a planet crosses in front of the disc of the star
- Like a mini-eclipse it causes the star to dim slightly during the transit



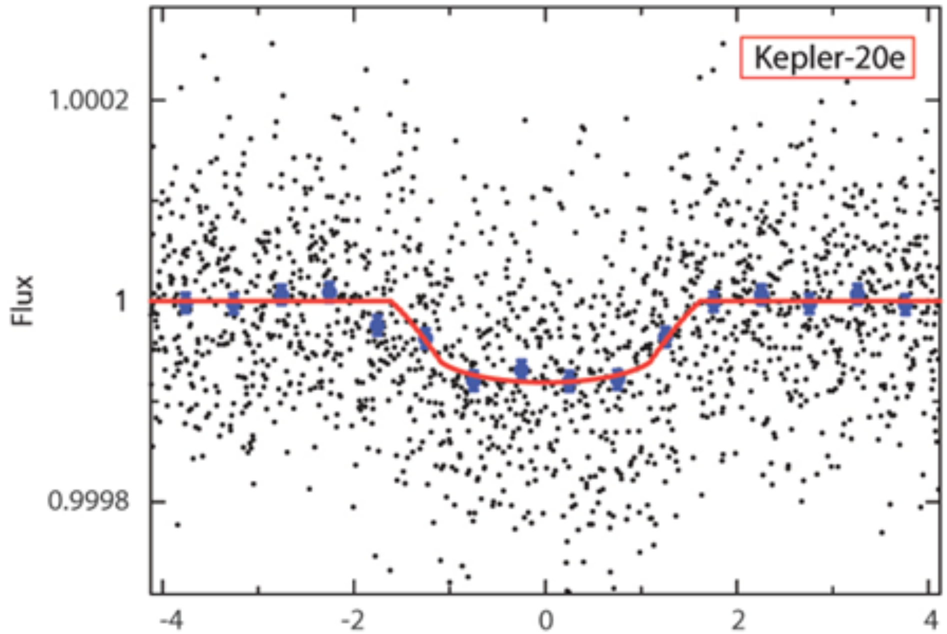


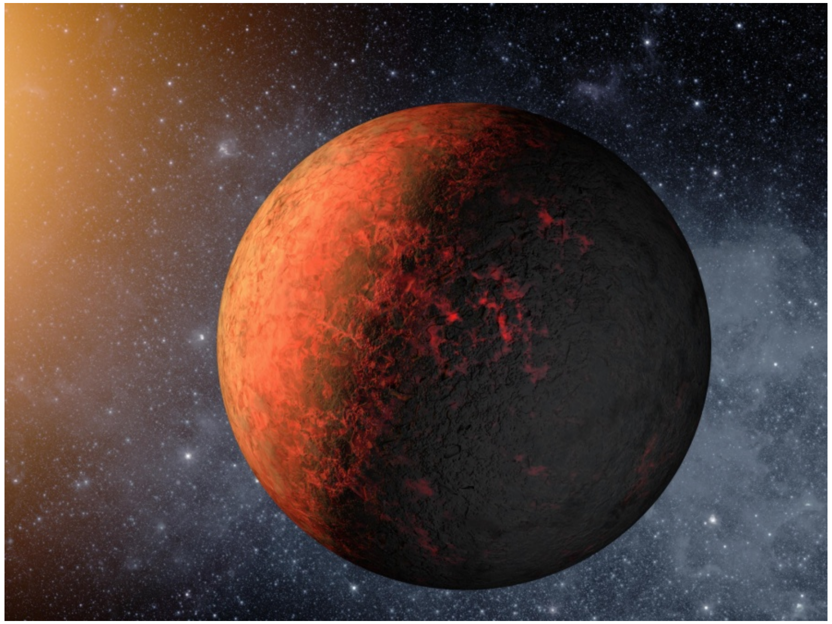
HST measurement of the dip in HD209458

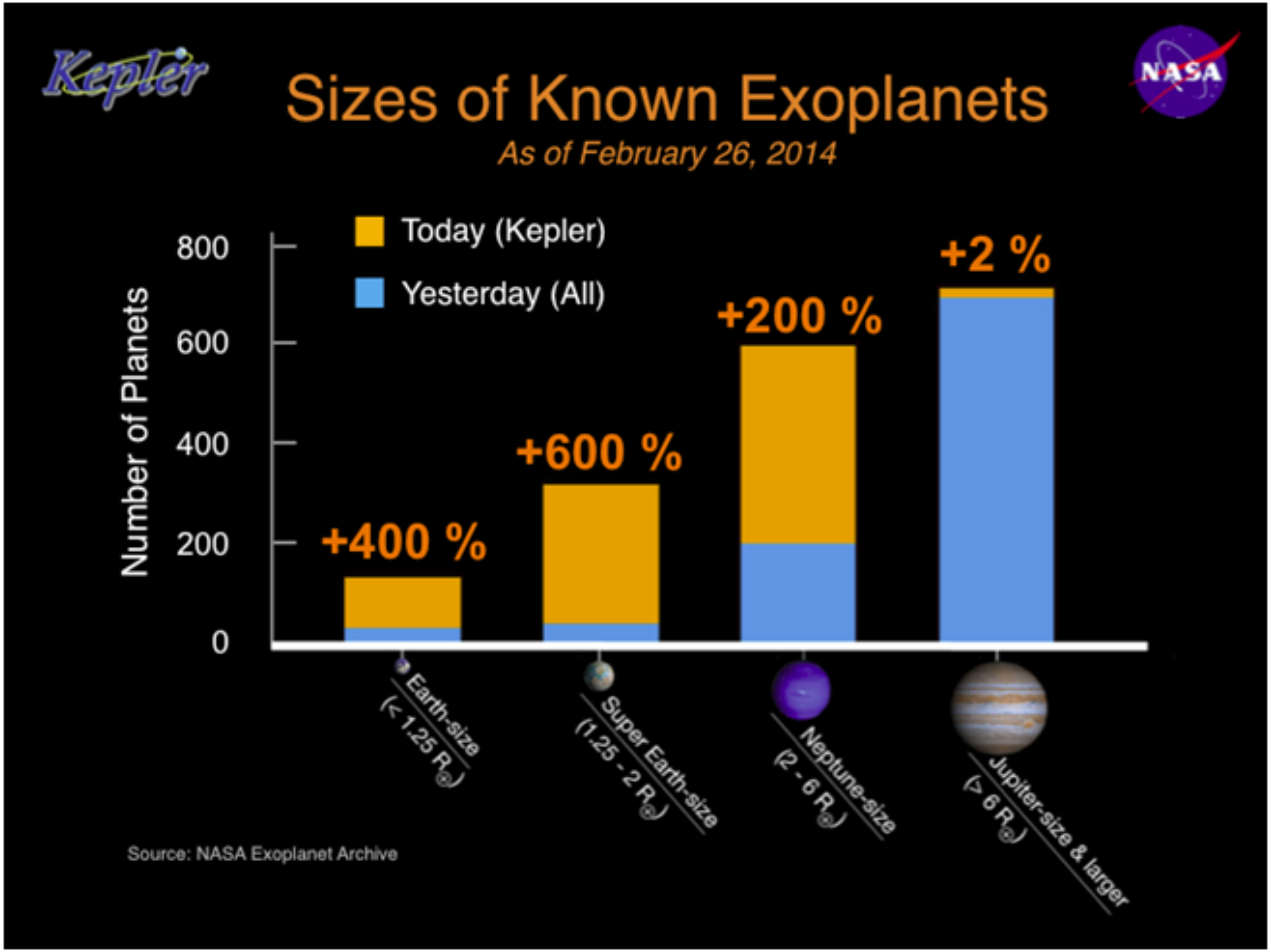
Depth of the transit is determined by
the relative size of the planet to the star



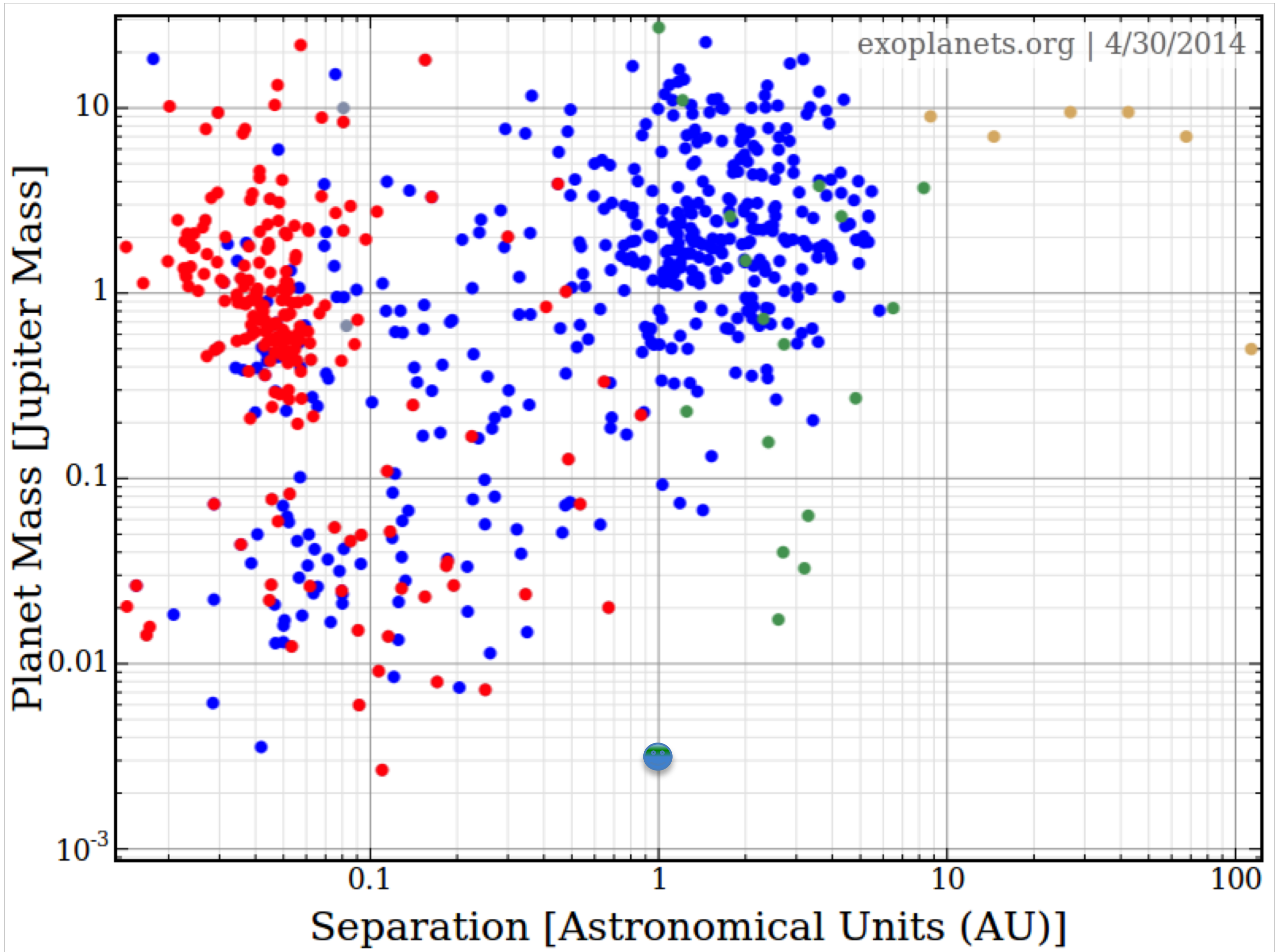
Kepler mission has discovered Earth-sized planets





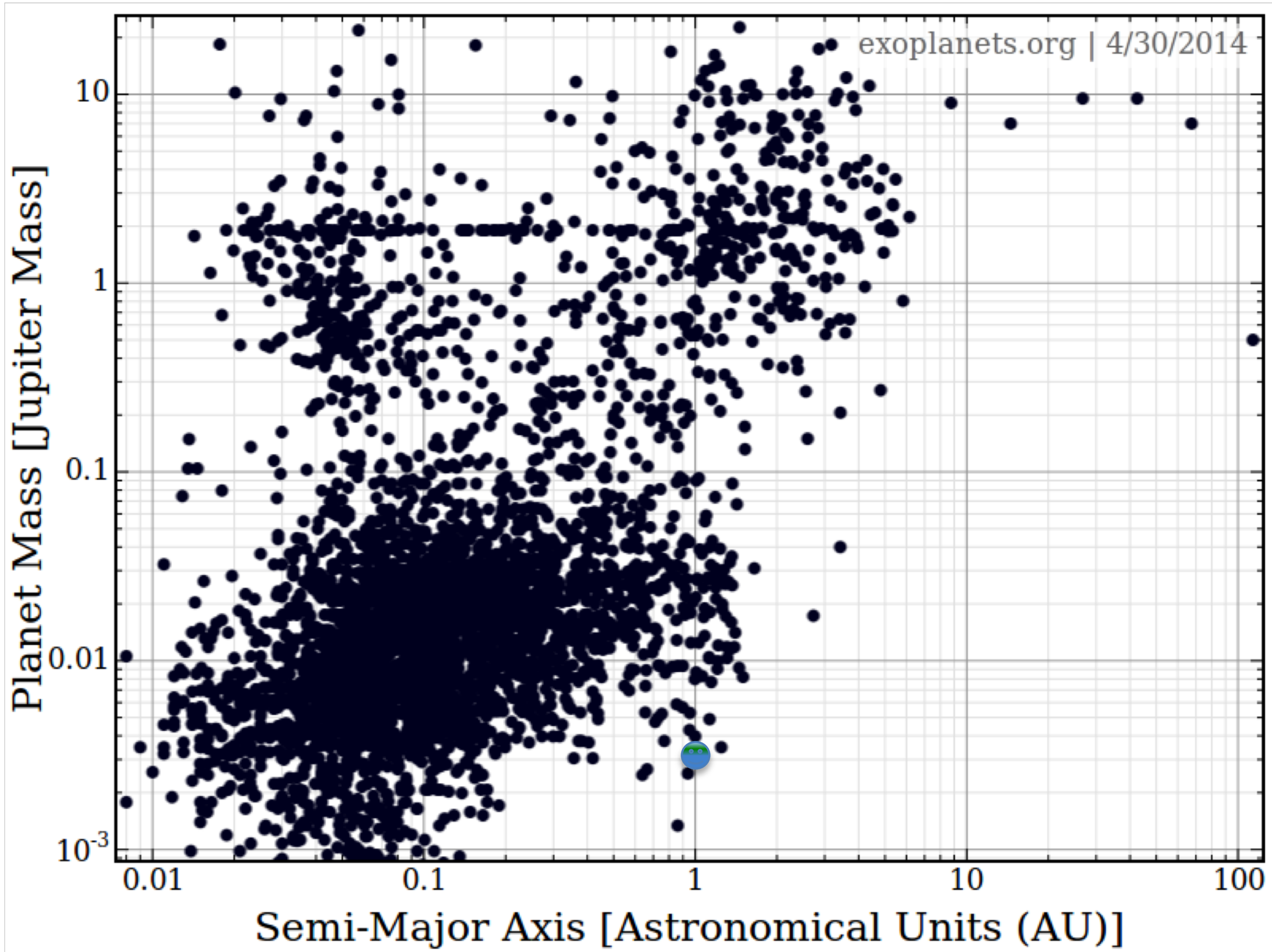

Kepler
NASA
Sizes of Known Exoplanets
As of February 26, 2014
Today (Kepler)
Yesterday (All)
Number of Planets
800
600
400
200
0
+400 %
+600 %
+200 %
+2 %
Earth-size (< 1.25 R⊕)
Super Earth-size (1.25 - 2 R⊕)
Neptune-size (2 - 6 R⊕)
Jupiter-size & larger (> 6 R⊕)
Source: NASA Exoplanet Archive

Mass and Separation



Detection Method

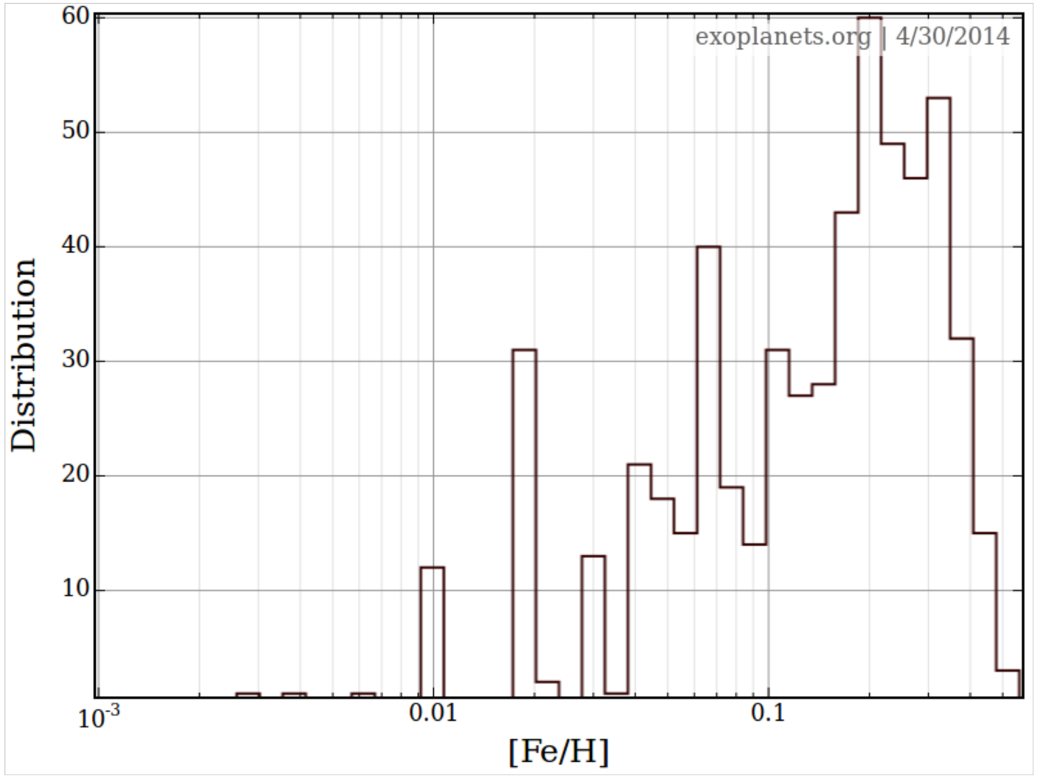
- Radial Velocity
- Transit
- Kepler
- Micro-lensing
- Direct Imaging



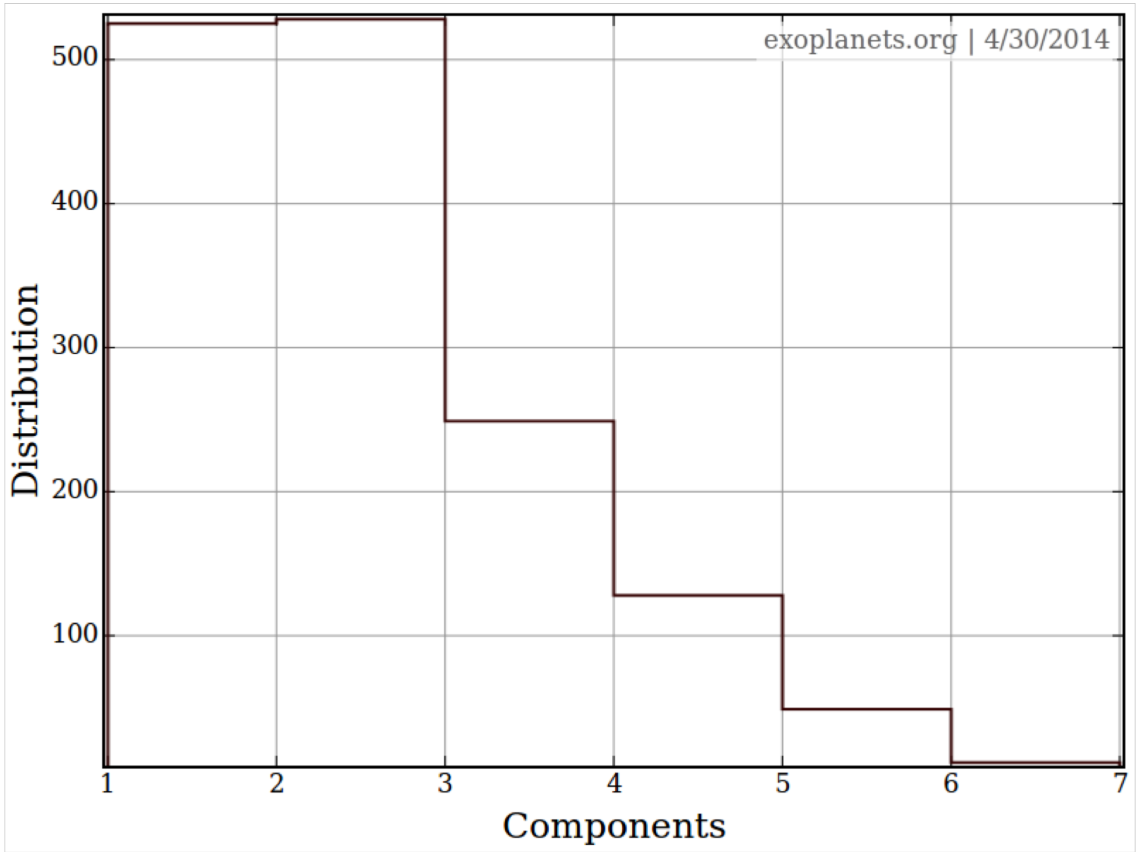
This plot contains Kepler candidate planets with masses estimated from the measured radius

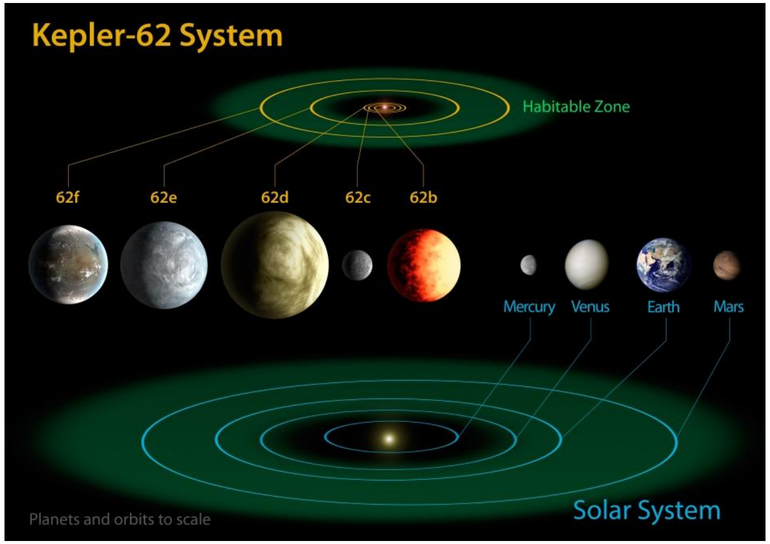
Heavy Element Abundance

- Planets more likely to be found around stars with more heavy elements in them
- Support for core accretion model



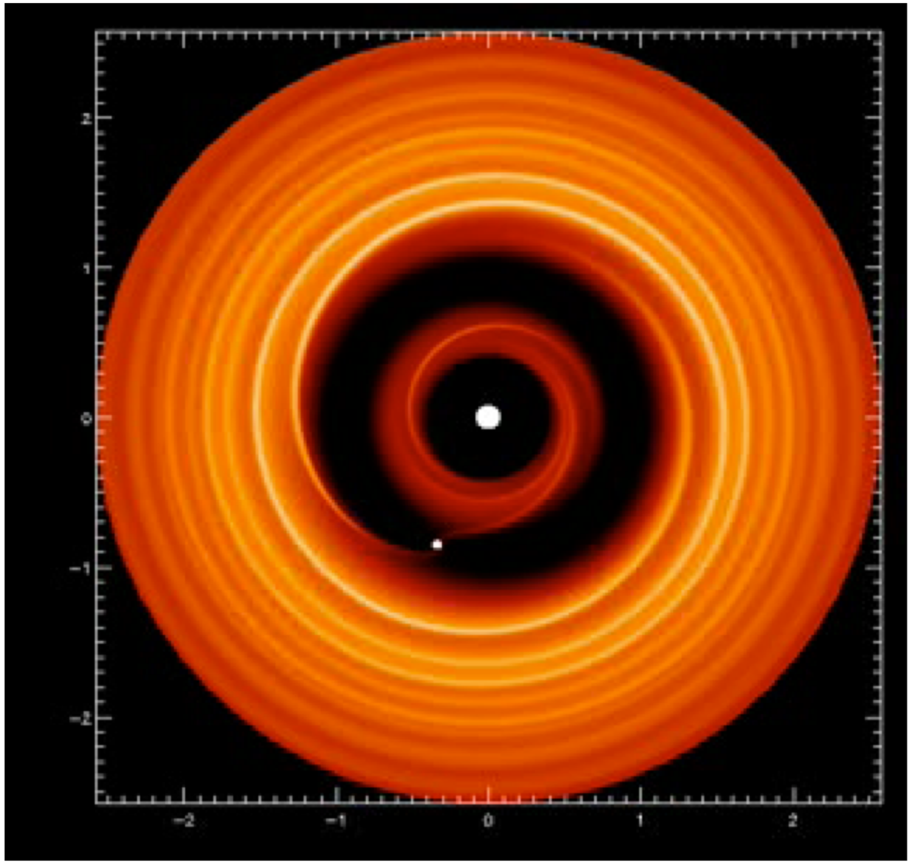
• Multiple planet systems are common





Planetary Migration

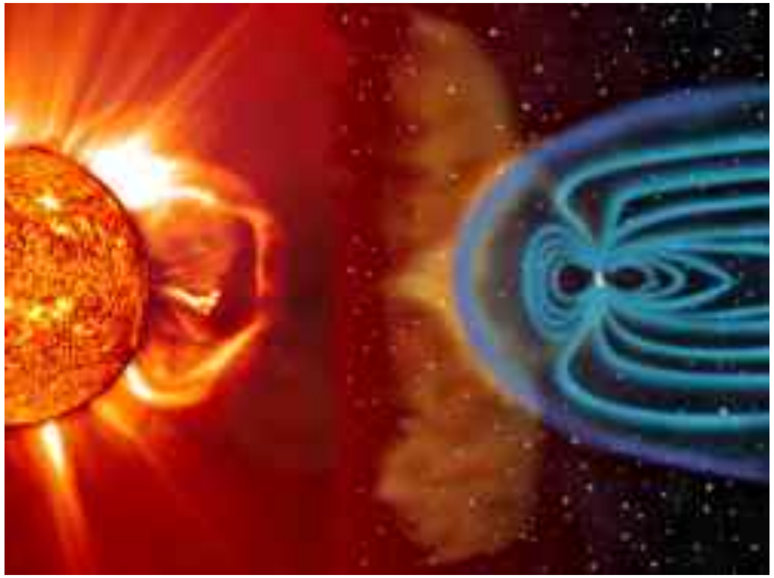
- Interactions between the planet and gas disc cause the planet to migrate inwards and create disk structures

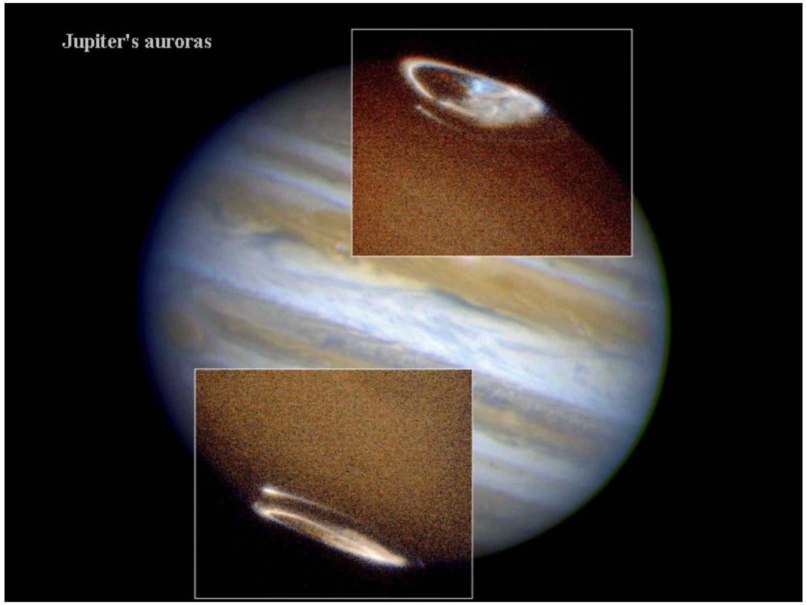


Planetary Magnetic Fields

• Solar winds interacting with planetary magnetic fields and atmospheres create aurorae

• These produce very long wavelength radio emission





Summary

- Radial velocity technique delivers the mass and orbital radius of exoplanets
- Transits deliver radius of the planets and hence average density
- Kepler mission has shown that most stars have planets
- Planetary migration can explain ‘hot Jupiters’ and the eccentric orbits in many planetary systems
- Aurorae may provide new radio window on exoplanets