Finding Planets with NASA's Kepler Mission

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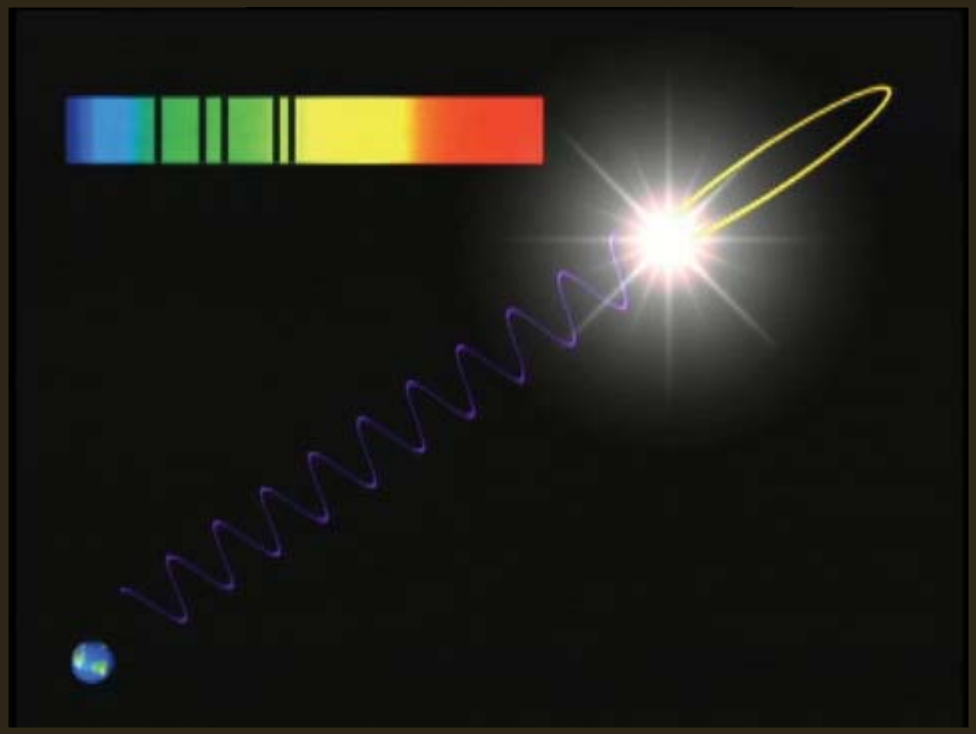
http://kepler.nasa.gov/

Ames Quantum Conference – 18 Jan 2012

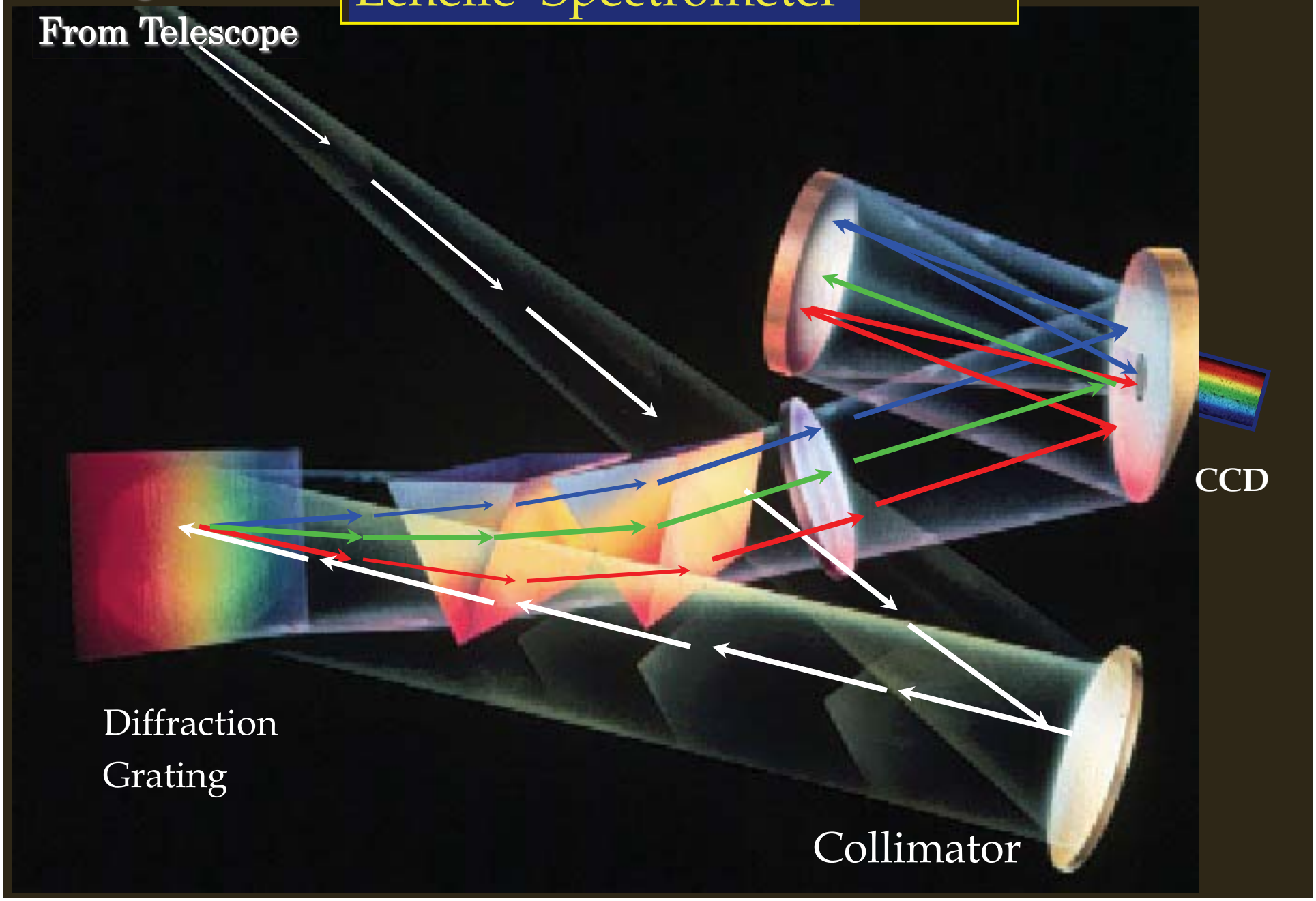
Detecting a Star's "Wobble" using *The Doppler Effect*

Spectrum of starlight

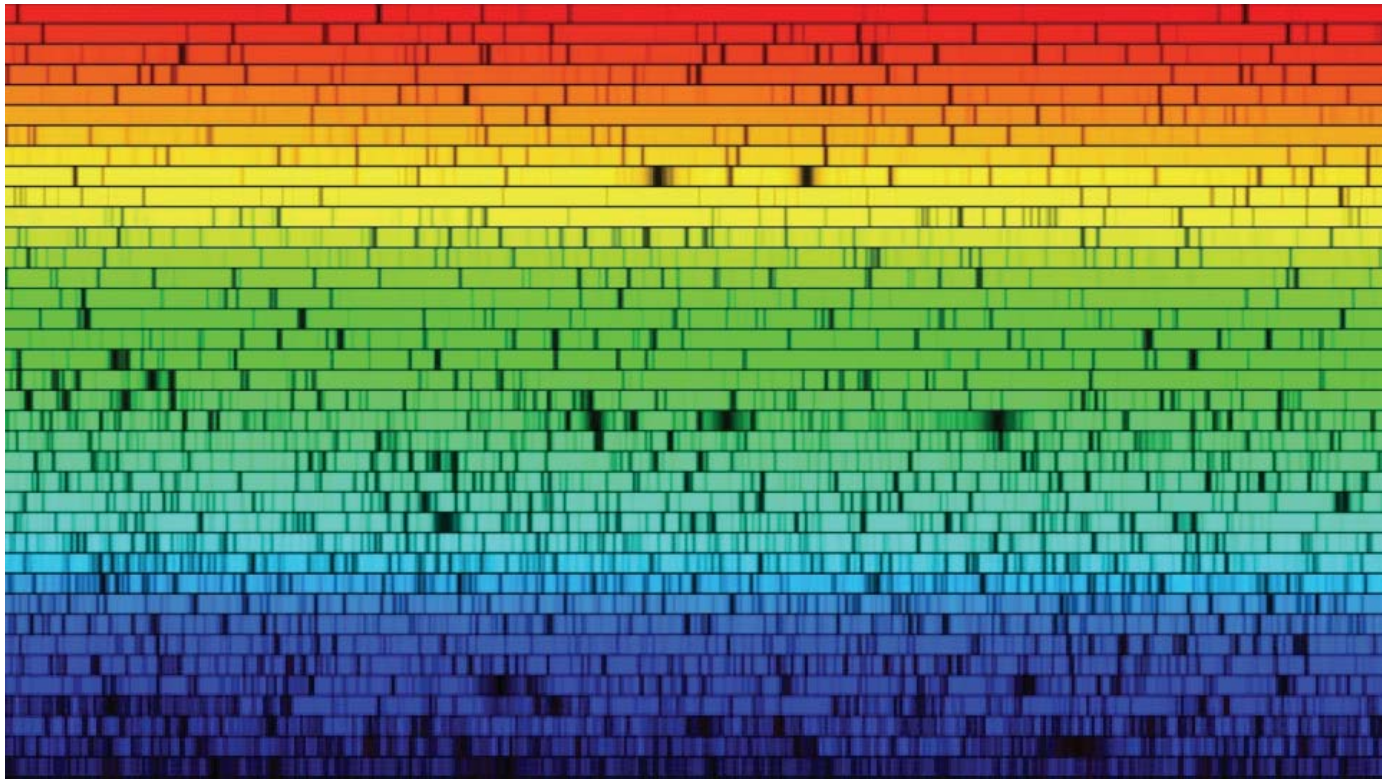


Doppler Effect: The wavelength of detected light increases (redshift) or decreases (blueshift) as the star and planet orbit their center of mass.

Echelle Spectrometer

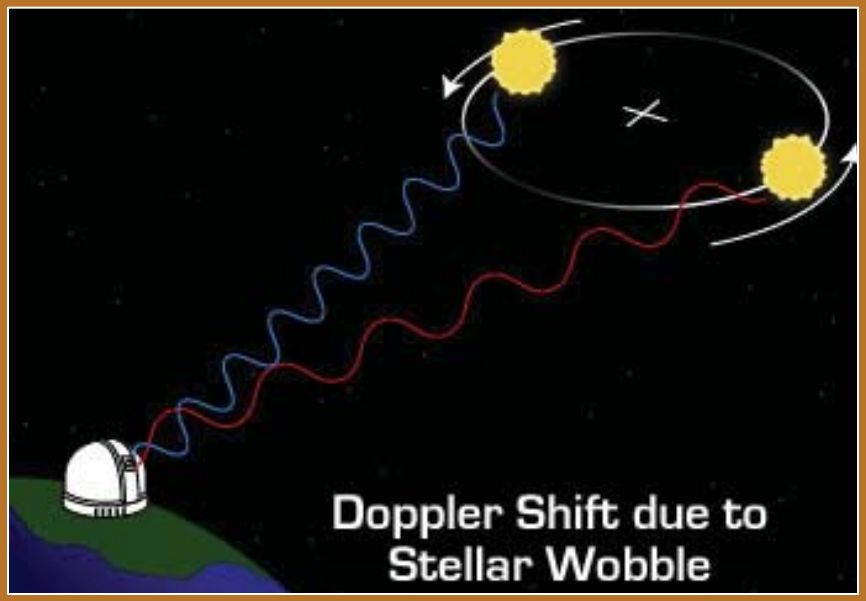


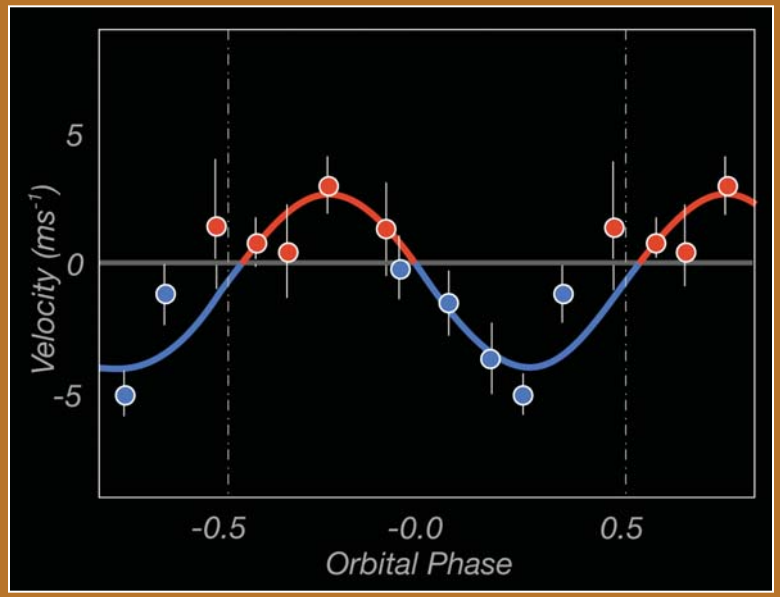
Detecting Star's Reflex Motion as Doppler Shifts



Doppler shifts of 1/1000 pixel are revealed
as small changes in the light in neighboring pixels.
Final Doppler Precision: 1 meter / sec

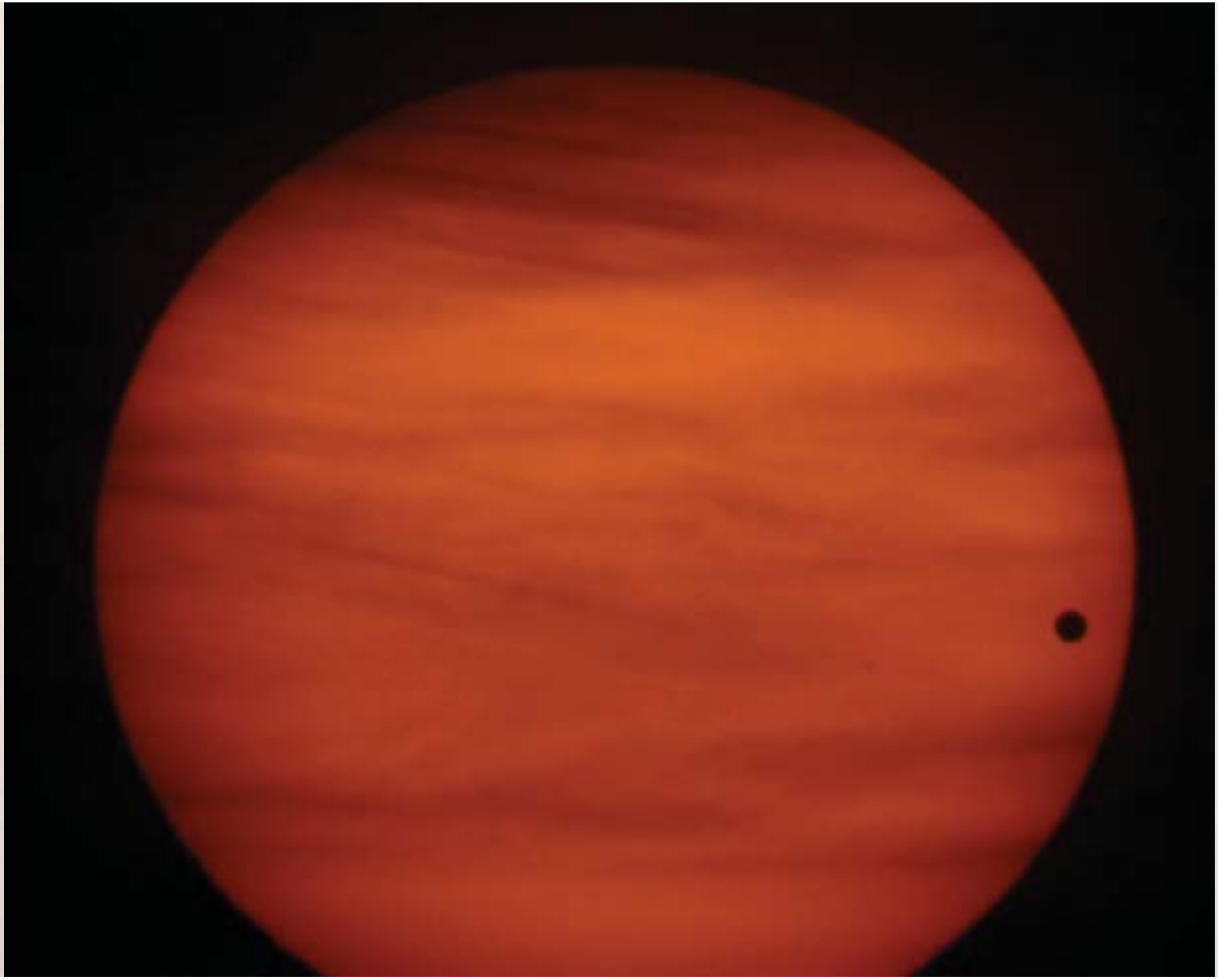
Doppler Measurements Yield Planet Mass



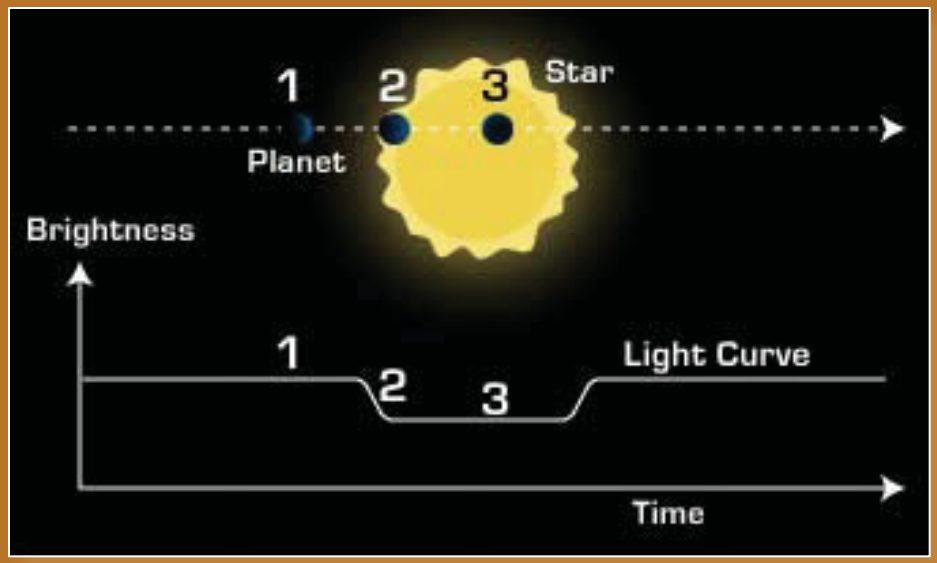


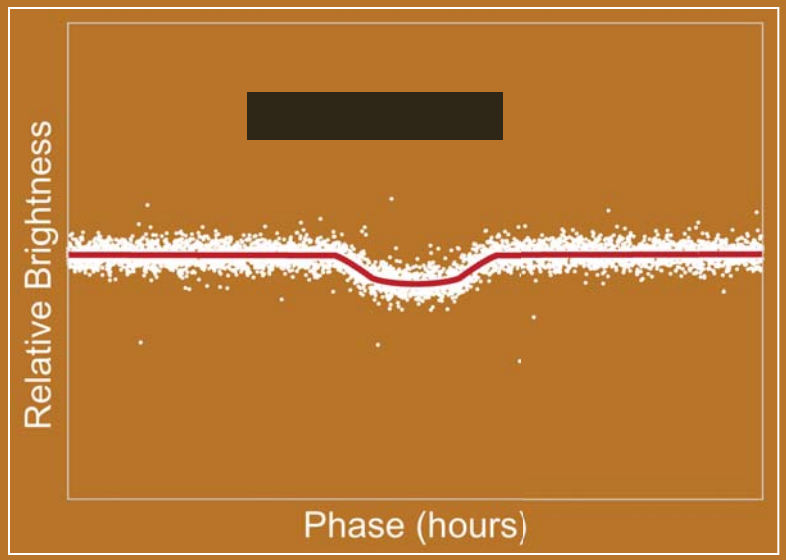
Example shown here - Mass = 4.56 x Earth Mass

2004 Venus Transit at Sunrise



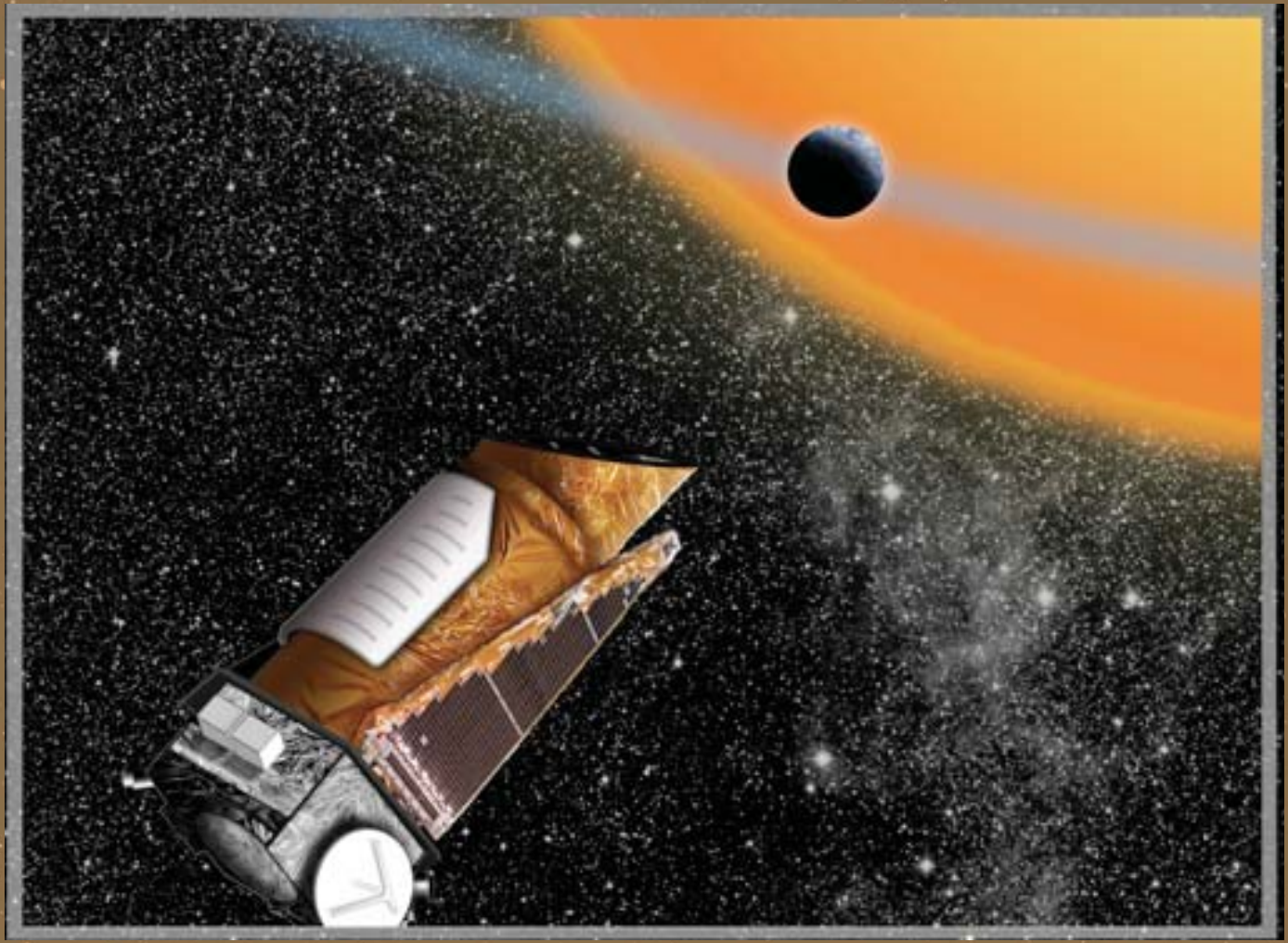
Transit Yields Planet Radius



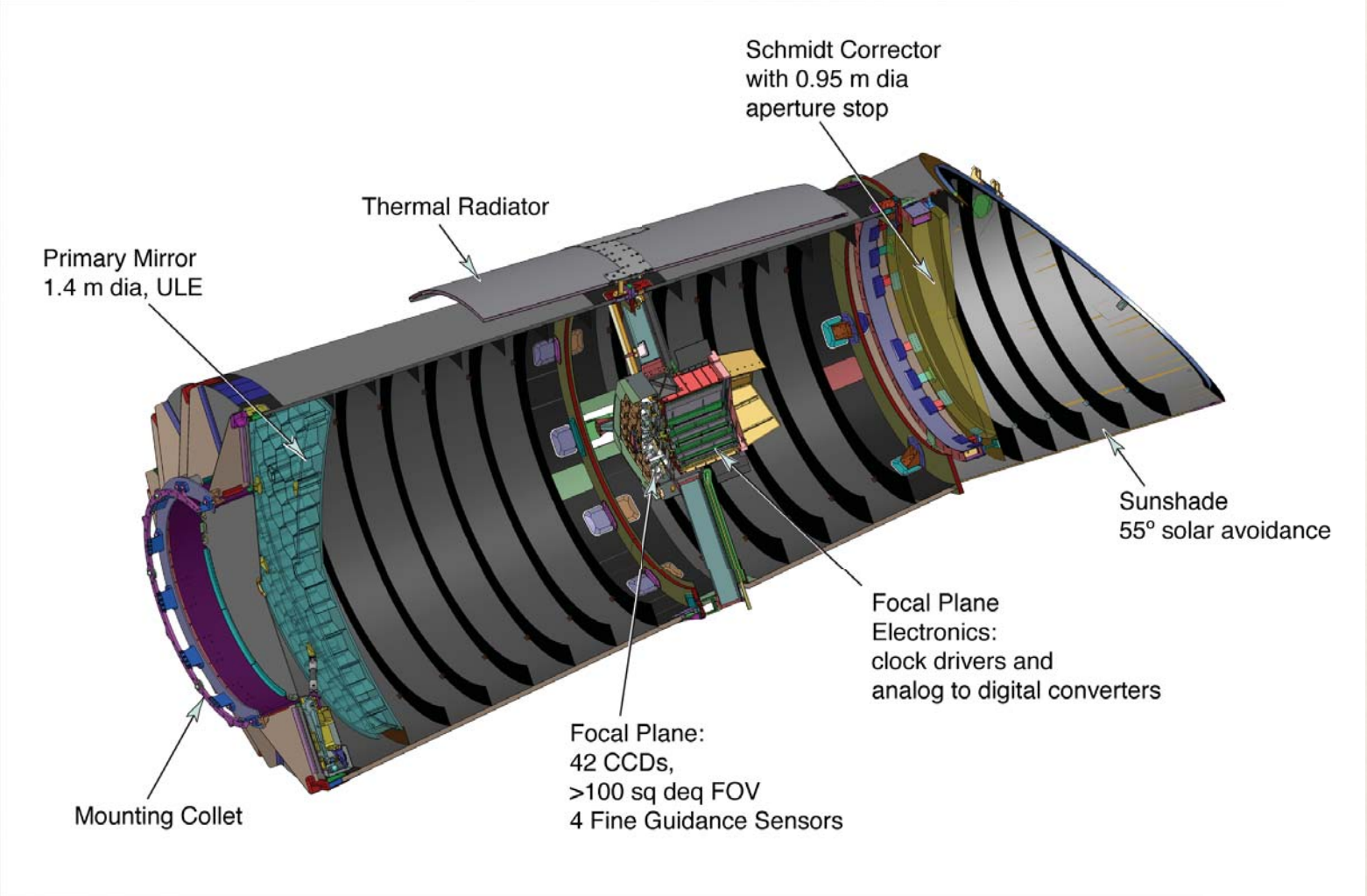


Kepler Mission

Determining the frequency of Earth-size and larger planets in the habitable zone of Sun-like stars

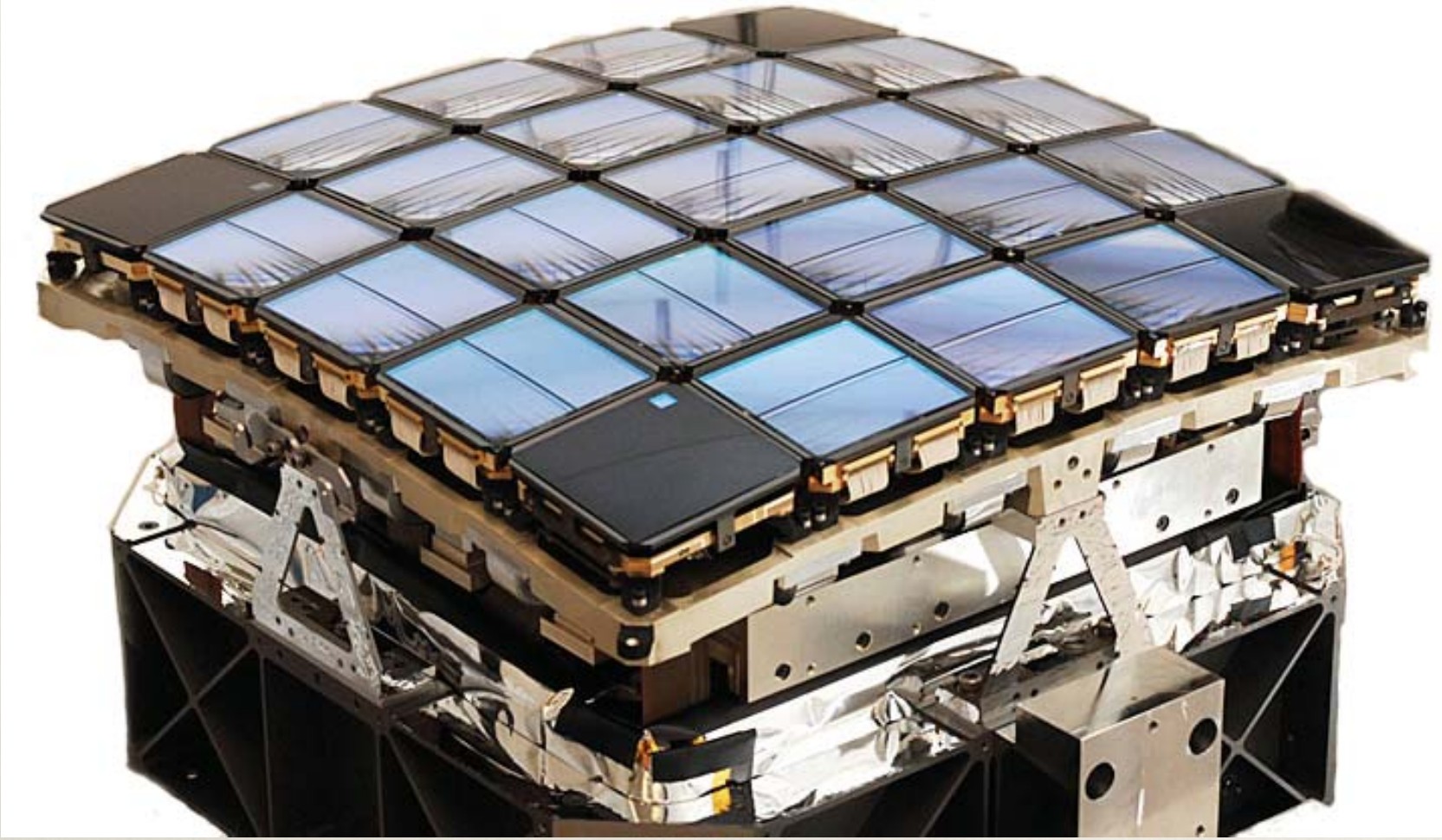


The Kepler Space Telescope



The overall height with the spacecraft and sunshade is 4.3 m.

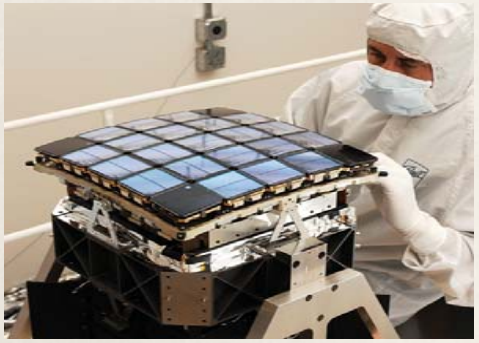
The Focal Plane



THE KEPLER SPACE TELESCOPE

SOURCE: NASA

SPACECRAFT & INSTRUMENT

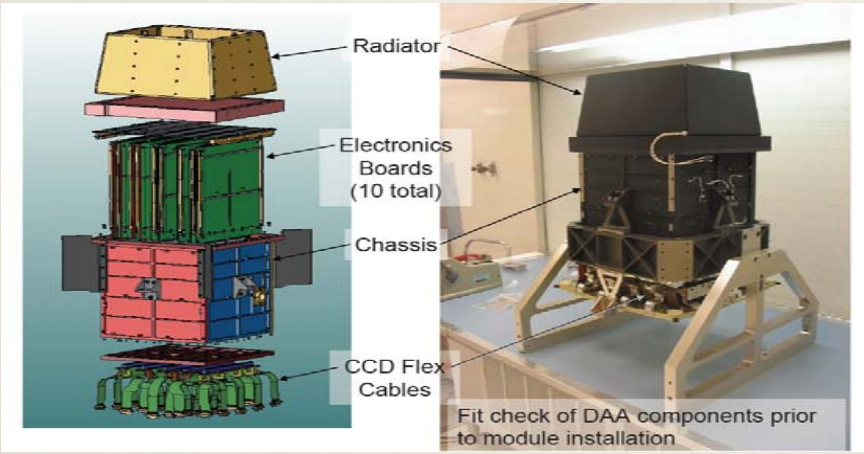


Largest focal plane for a NASA flight mission: 94.6 million science pixels

42 science CCDs, 2 channels each

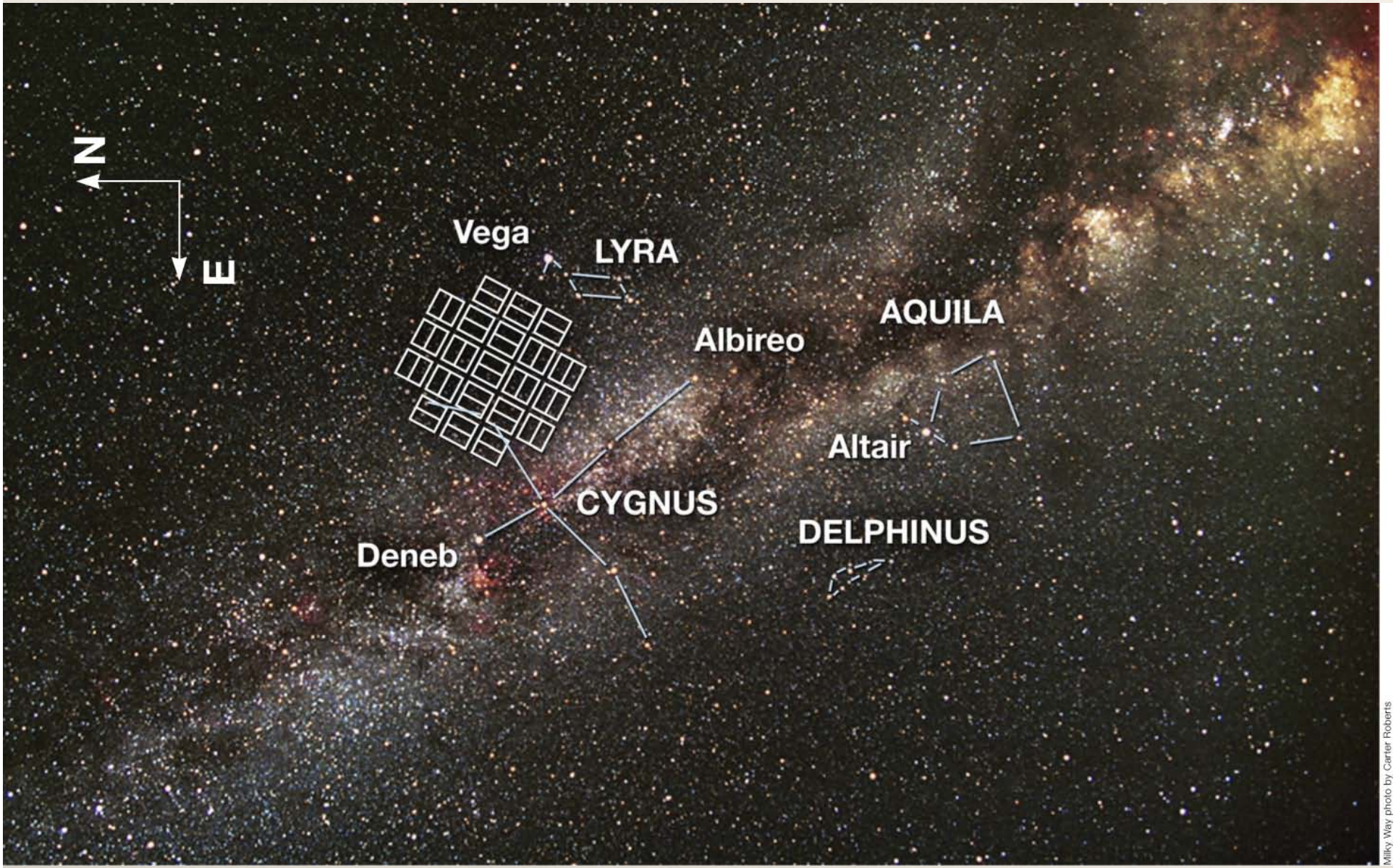
4 fine guidance sensor (FGS) CCDs

CCDs controlled at -85C, Readout electronics at room temperature



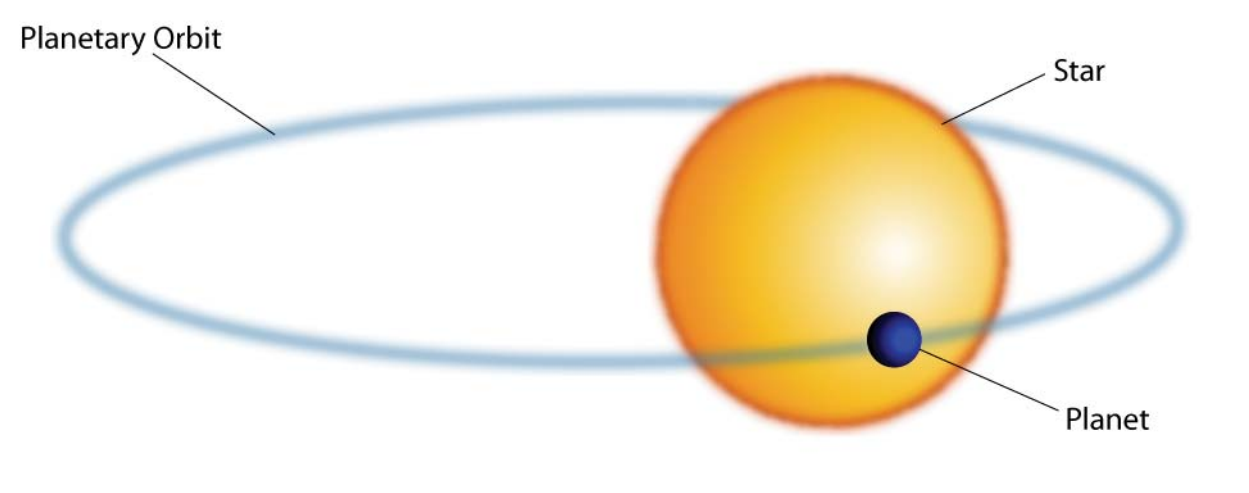
Launched into an Earth-Trailing Orbit

Star Field: Cygnus-Lyra



Milky Way photo by Carter Roberts

Transits Can Reveal Earth-size Planets



From **TRANSIT DATA** obtain:

Duration, depth, orbital period and inclination.

Derive planet sizes and orbital radii (when combined with stellar information)

From **ENSEMBLE of PLANETARY SYSTEMS** obtain:

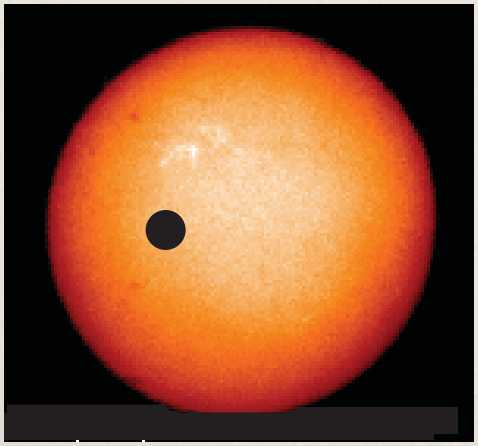
Estimates frequency of planet formation for inner planets.

Requires thousands of stars because most orbits won't be aligned properly: only

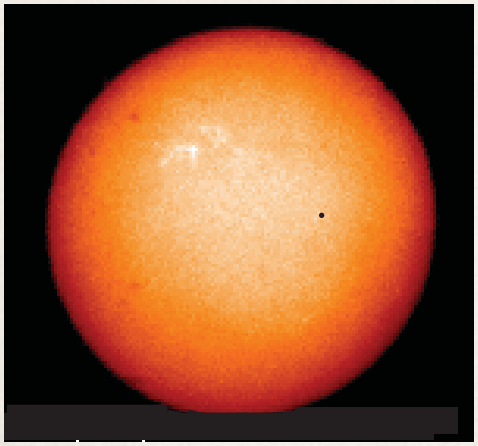
about 0.5-1.0% aligned

Detecting Earth-Size Planets

- The relative change in brightness (ΔL / L) is equal to the relative areas (A_{planet}/A_{star})



Jupiter:
1% area of the Sun (1/100)

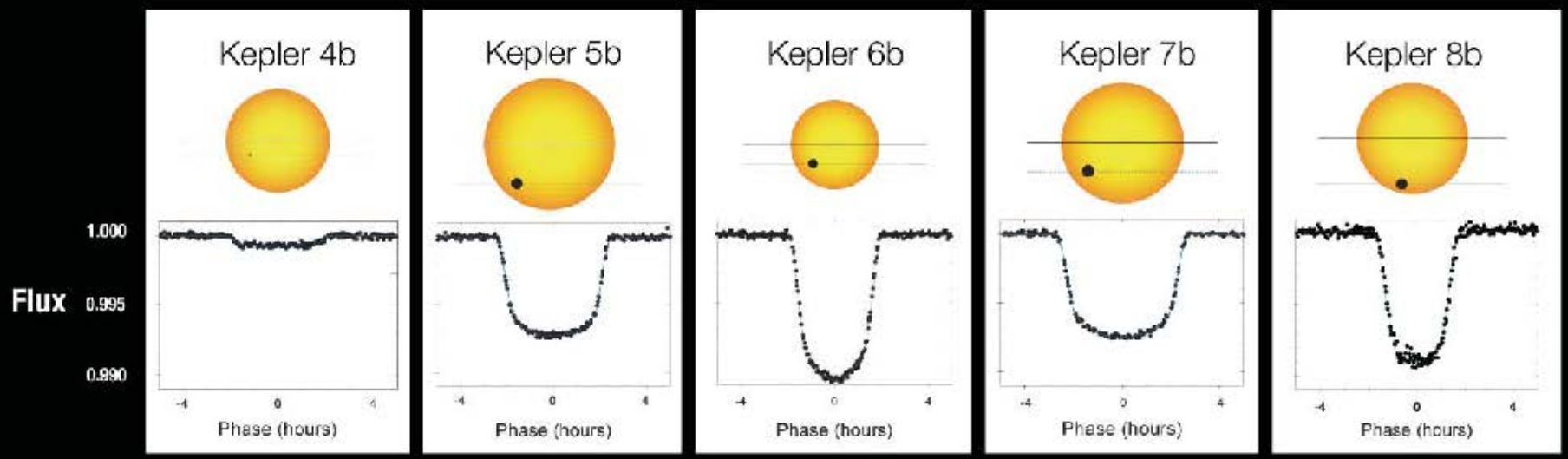


Earth or Venus
0.01% area of the Sun (1/10,000)

- To measure 0.01% must get above the Earth's atmosphere

* Method is robust but you must be patient: Firm detection of 3 transits requires ~3 years or more for detection.

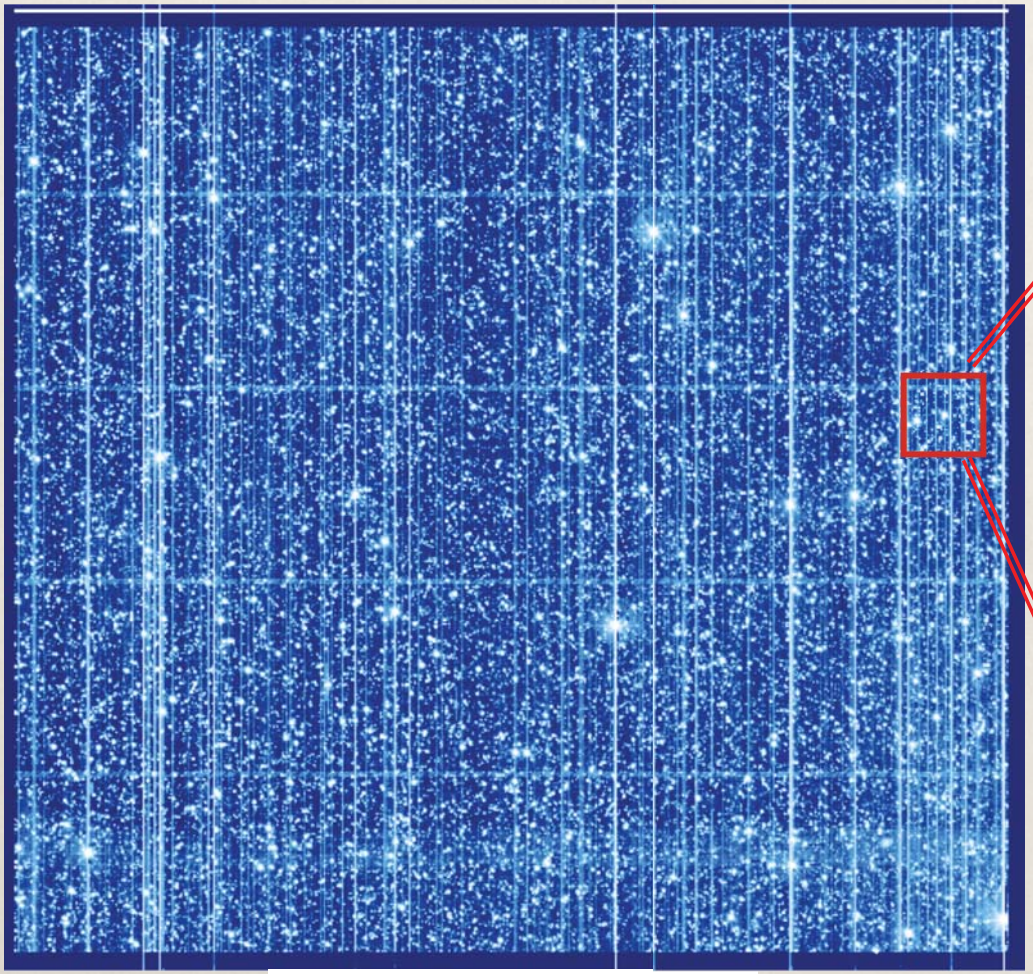
Transit Light Curves



Orbital Period (days)					
	3.2 days	*3.5 days*	*3.2 days*	*4.9 days*	*3.5 days*

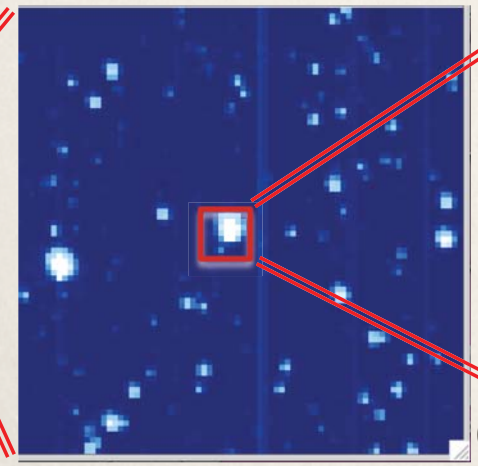
Pixel Level Data From *Kepler*

Module 17 Output 2 x



1.13 (h) x1.22 (w) degrees x

Zoomed Image x
near HAT-P-7b x



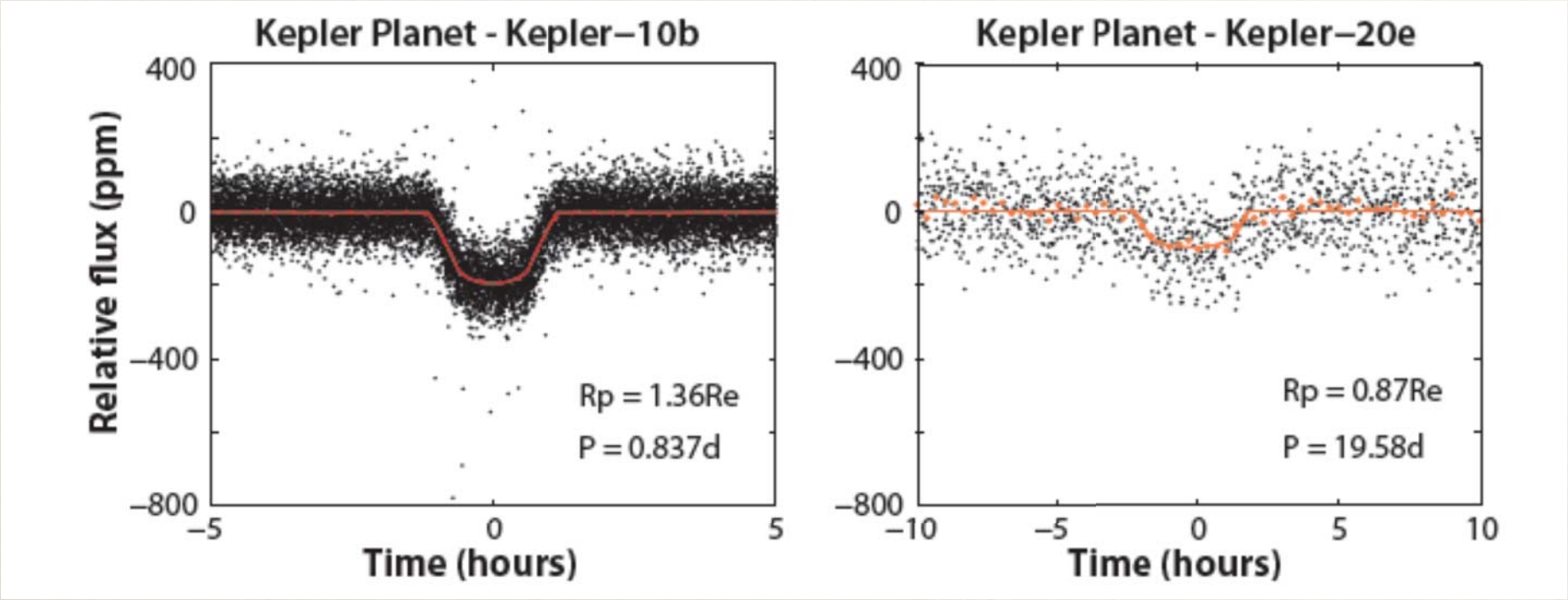
0.09x0.09 degrees x
80x80 pixels x
6400 pixels total x

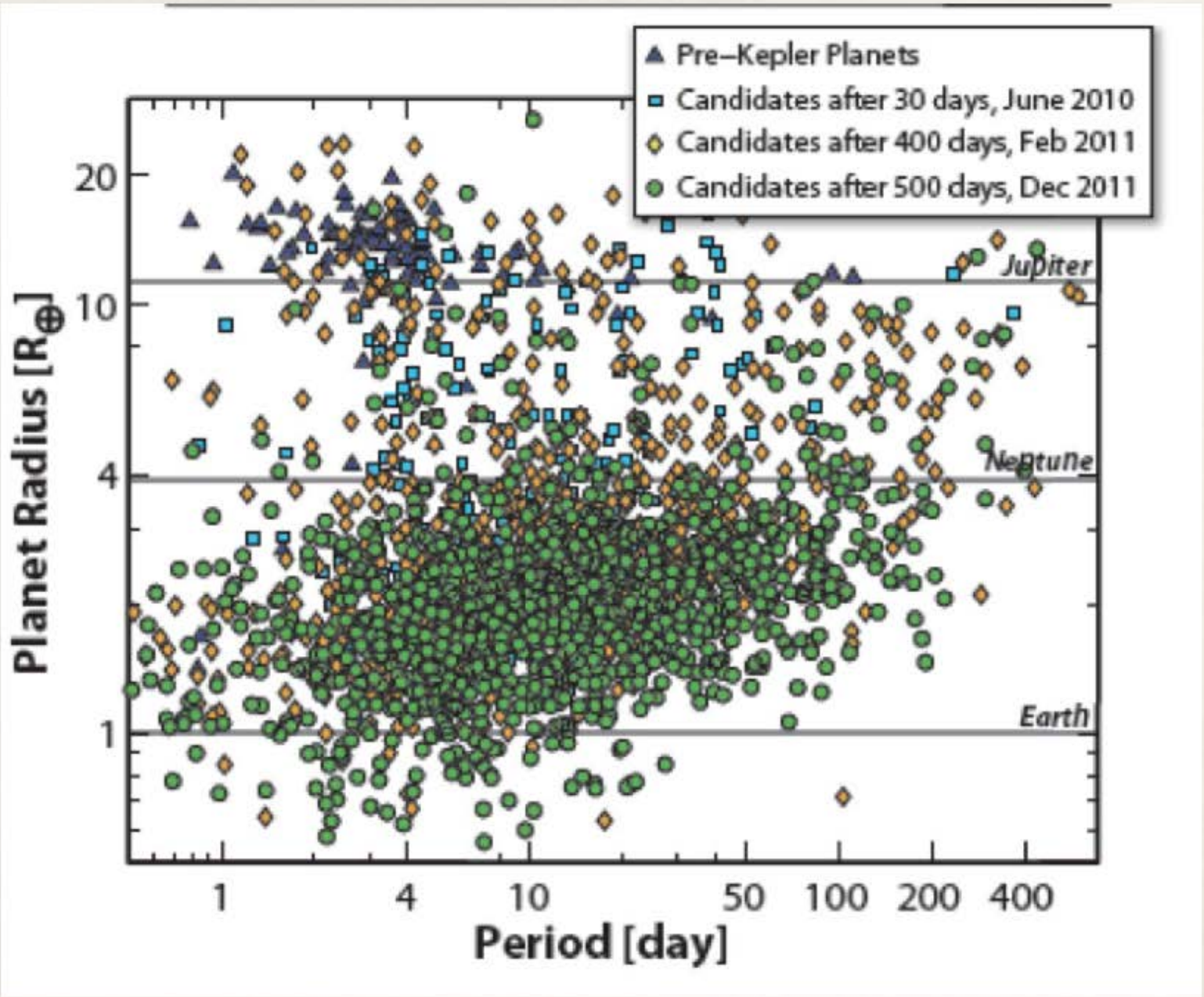
HAT-P-7b x
LC pixels x

6.6x6.6 millidegrees x
28 pixels collected x
Black = no data x

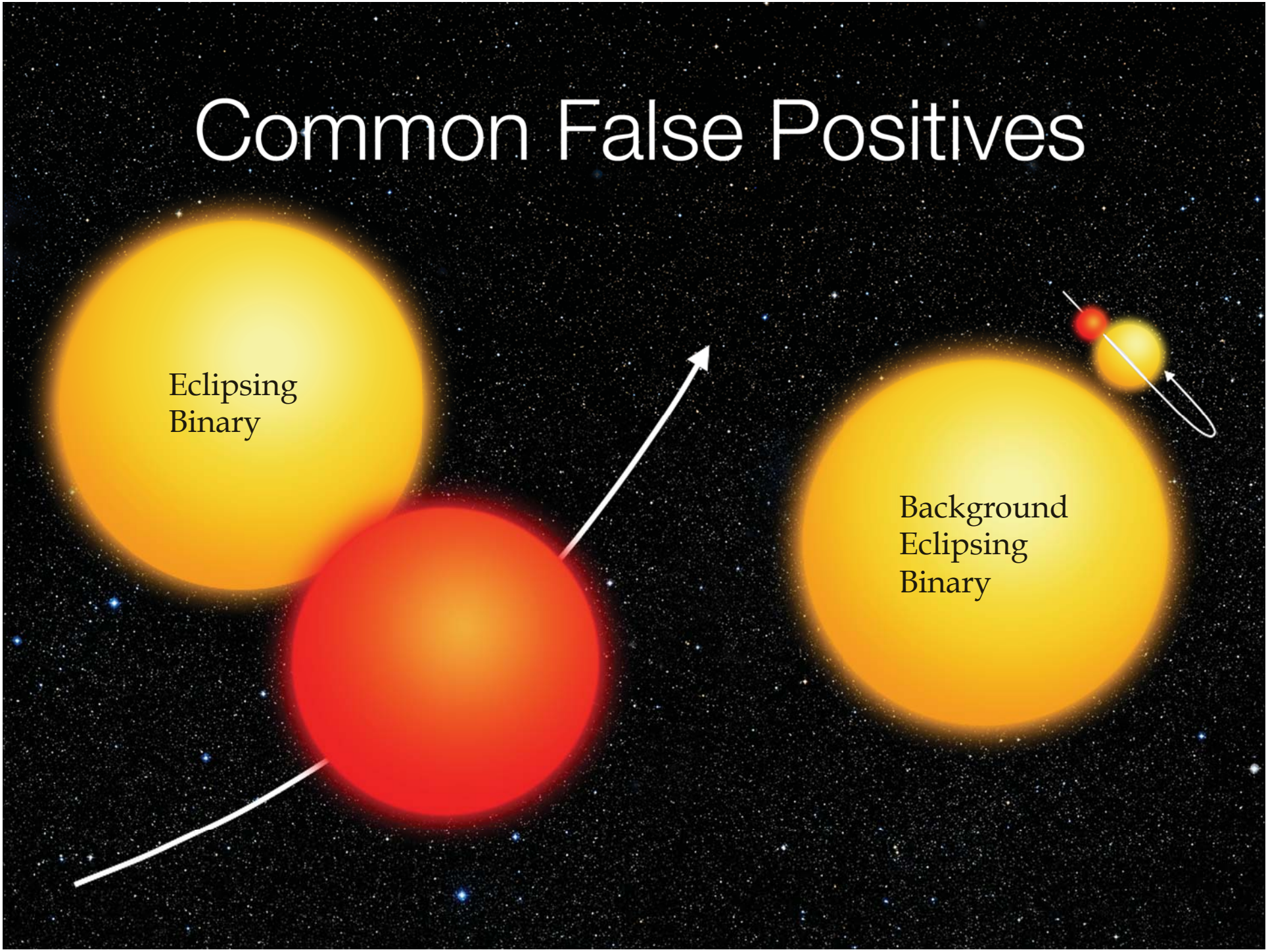
Scaled to show faint detail

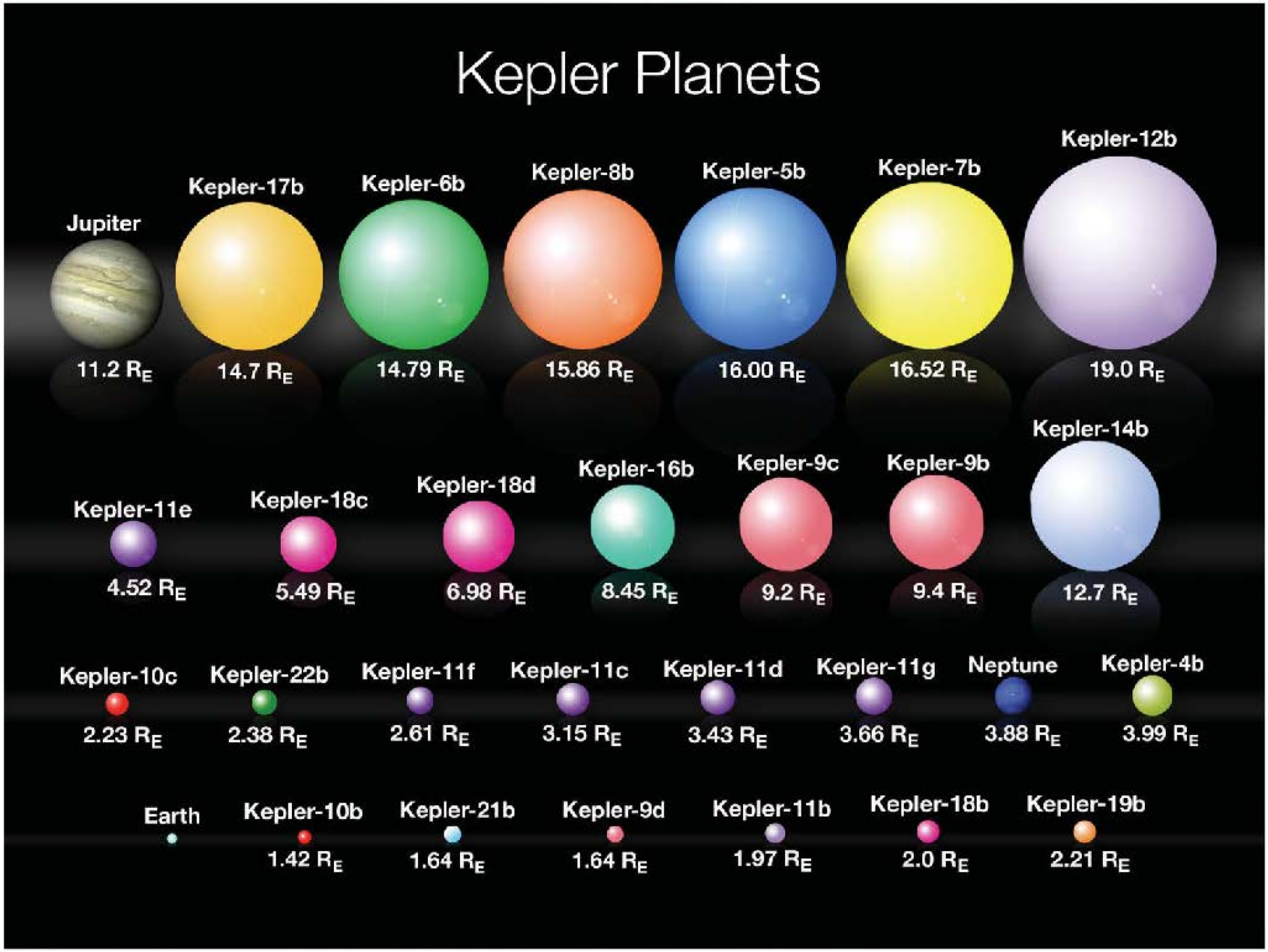
Kepler light curves of small planets



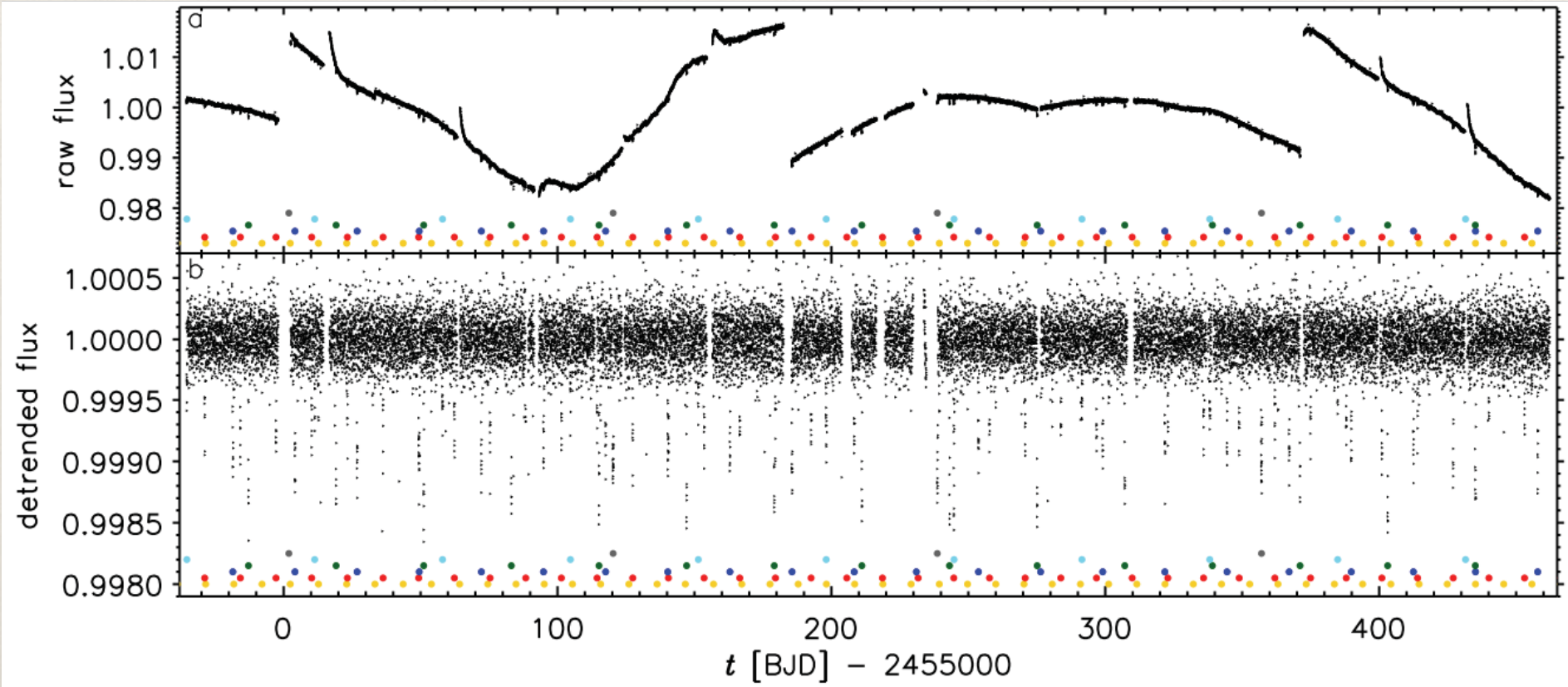

Pre–Kepler Planets
Candidates after 30 days, June 2010
Candidates after 400 days, Feb 2011
Candidates after 500 days, Dec 2011
Jupiter
Neptune
Earth
Planet Radius [R⊕]
20
10
4
1
1
4
10
50
100
200
400
Period [day]

Common False Positives

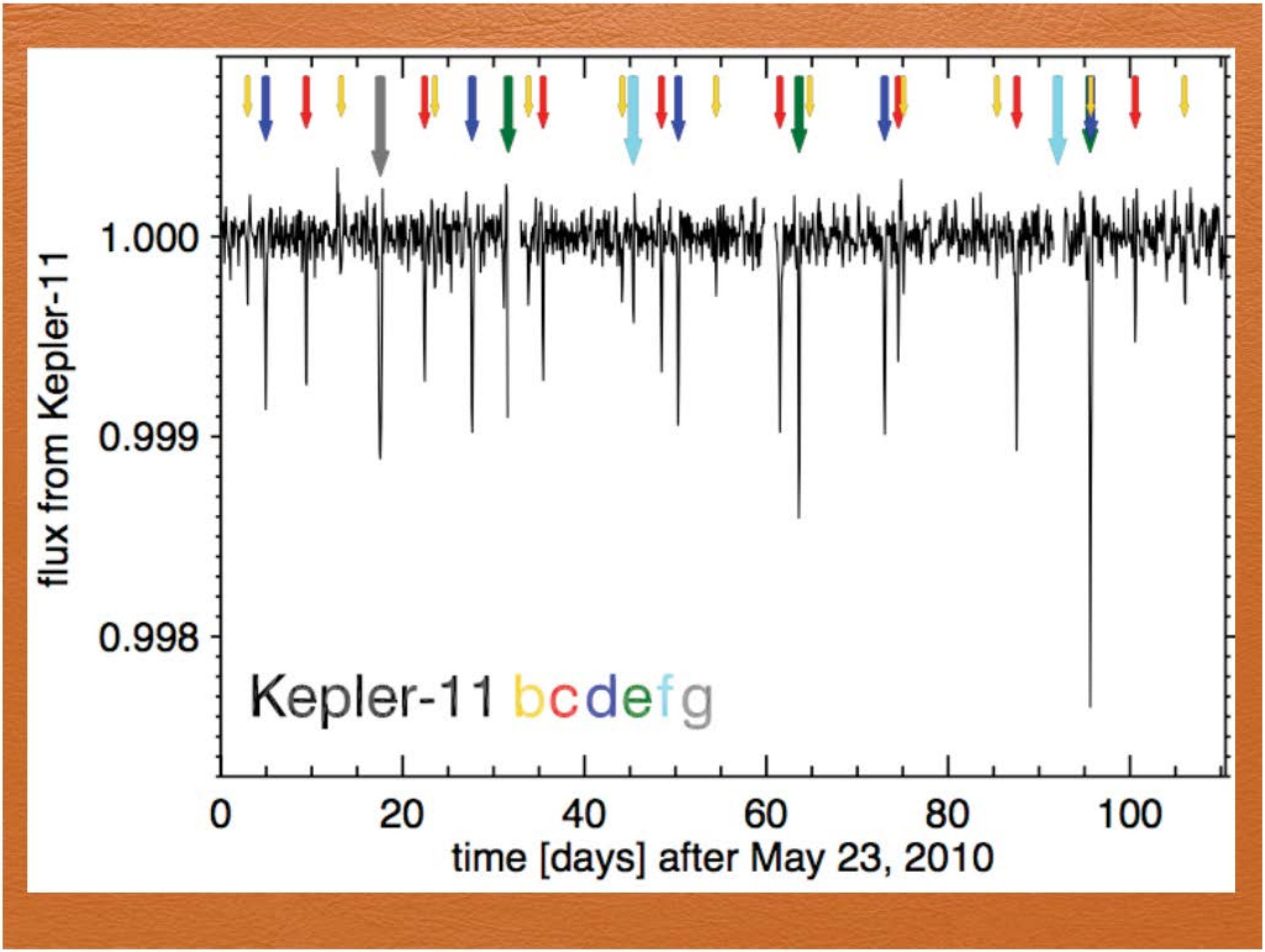


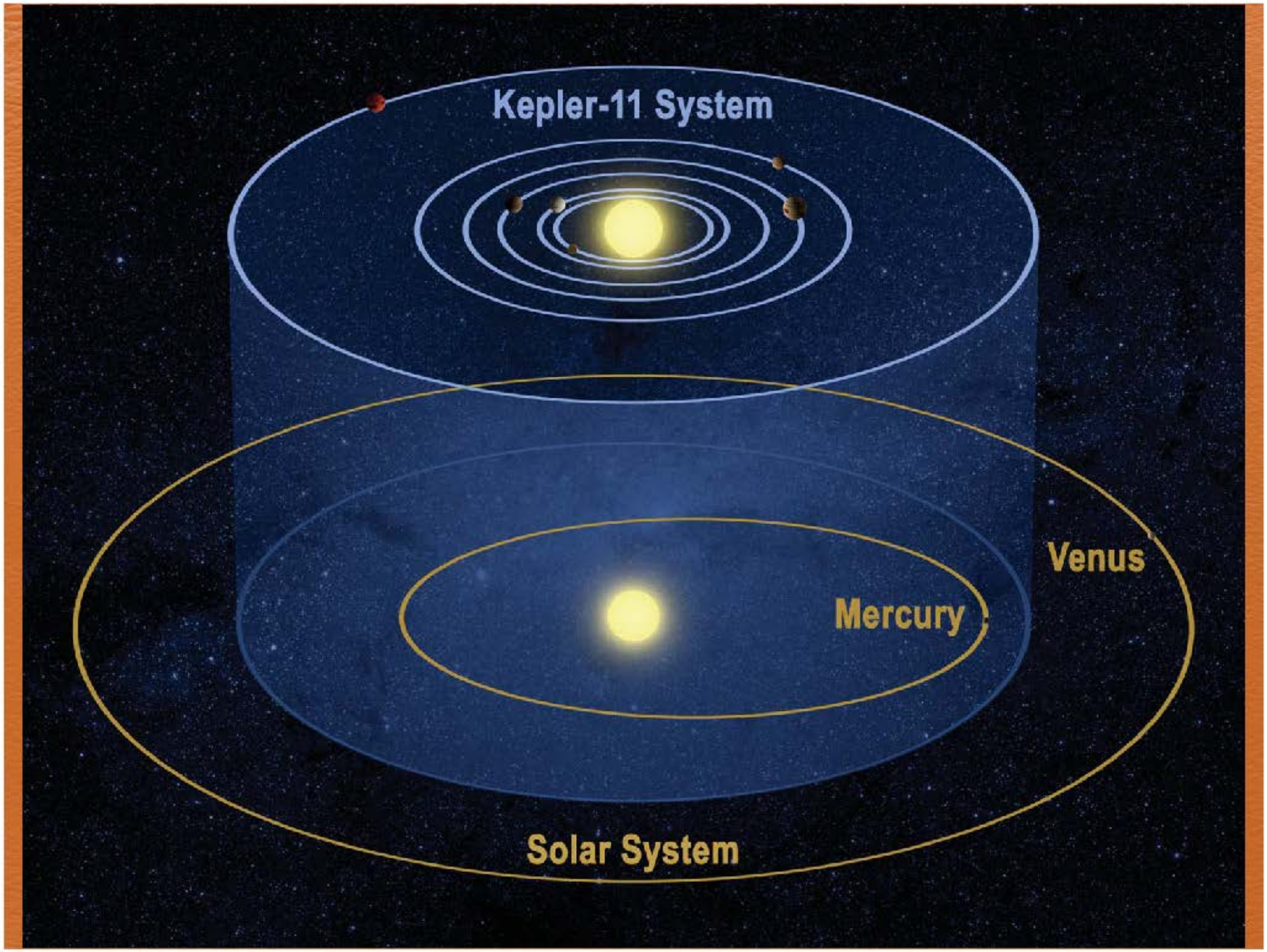

Kepler Planets
Jupiter
11.2 R_E
Kepler-17b
14.7 R_E
Kepler-6b
14.79 R_E
Kepler-8b
15.86 R_E
Kepler-5b
16.00 R_E
Kepler-7b
16.52 R_E
Kepler-12b
19.0 R_E
Kepler-11e
4.52 R_E
Kepler-18c
5.49 R_E
Kepler-18d
6.98 R_E
Kepler-16b
8.45 R_E
Kepler-9c
9.2 R_E
Kepler-9b
9.4 R_E
Kepler-14b
12.7 R_E
Kepler-10c
2.23 R_E
Kepler-22b
2.38 R_E
Kepler-11f
2.61 R_E
Kepler-11c
3.15 R_E
Kepler-11d
3.43 R_E
Kepler-11g
3.66 R_E
Neptune
3.88 R_E
Kepler-4b
3.99 R_E
Earth
Kepler-10b
1.42 R_E
Kepler-21b
1.64 R_E
Kepler-9d
1.64 R_E
Kepler-11b
1.97 R_E
Kepler-18b
2.0 R_E
Kepler-19b
2.21 R_E

Lightcurve Q1-Q6



* Colored dots represent transits of six planets

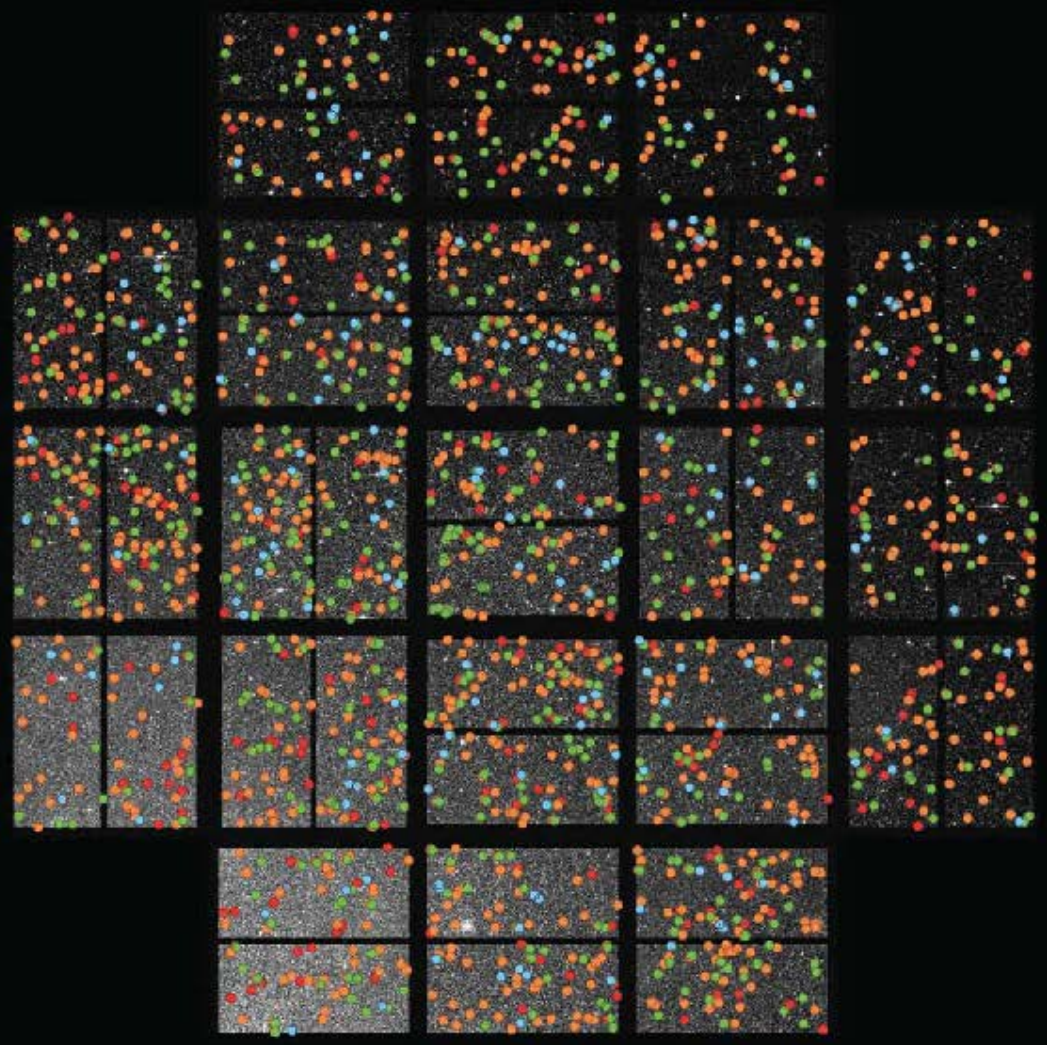

Kepler-11 bcdefg
flux from Kepler-11
1.000
0.999
0.998
0
20
40
60
80
100
time [days] after May 23, 2010


Kepler-11 System
Venus
Mercury
Solar System

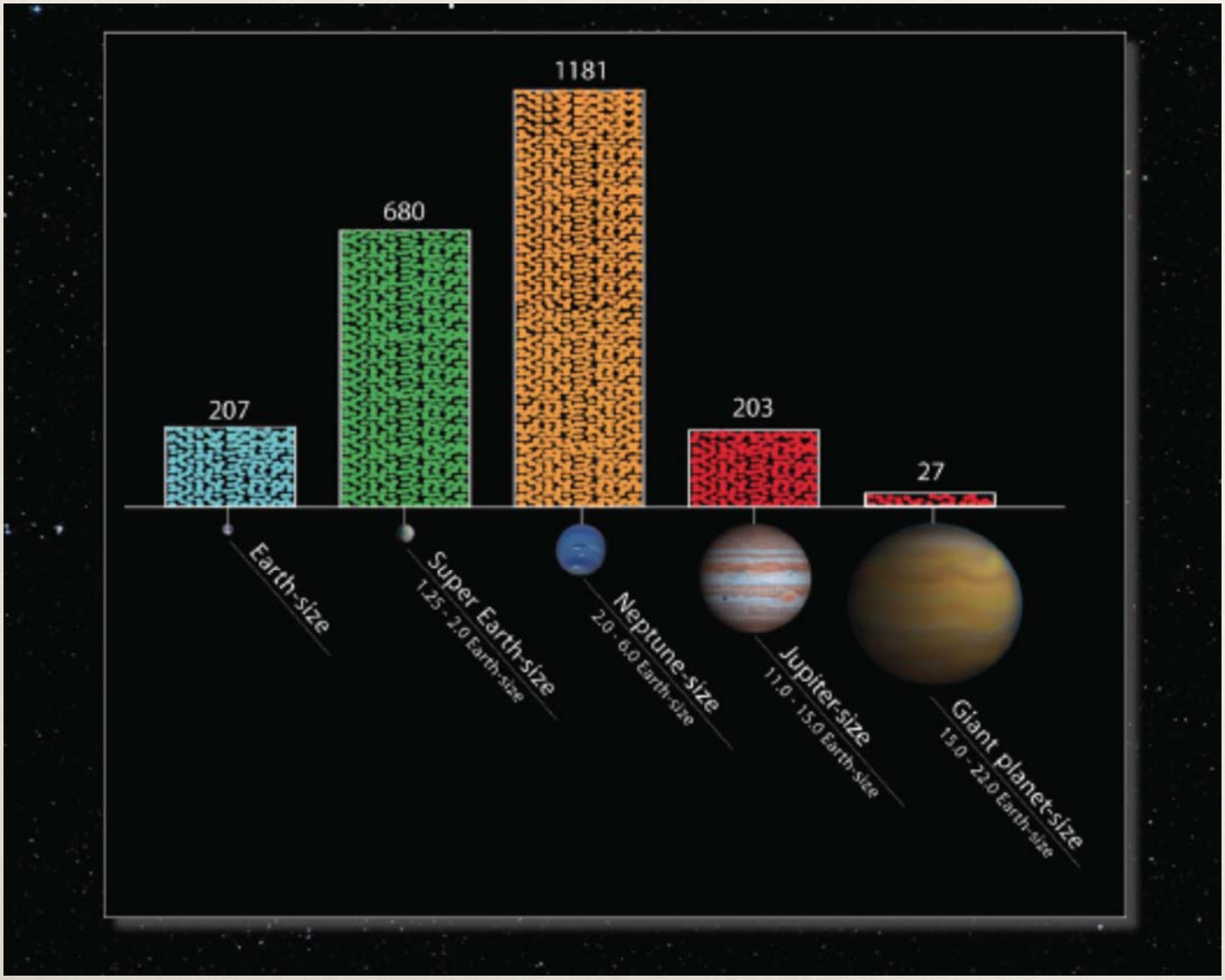
Locations of Kepler Planet Candidates

As of December 5, 2011

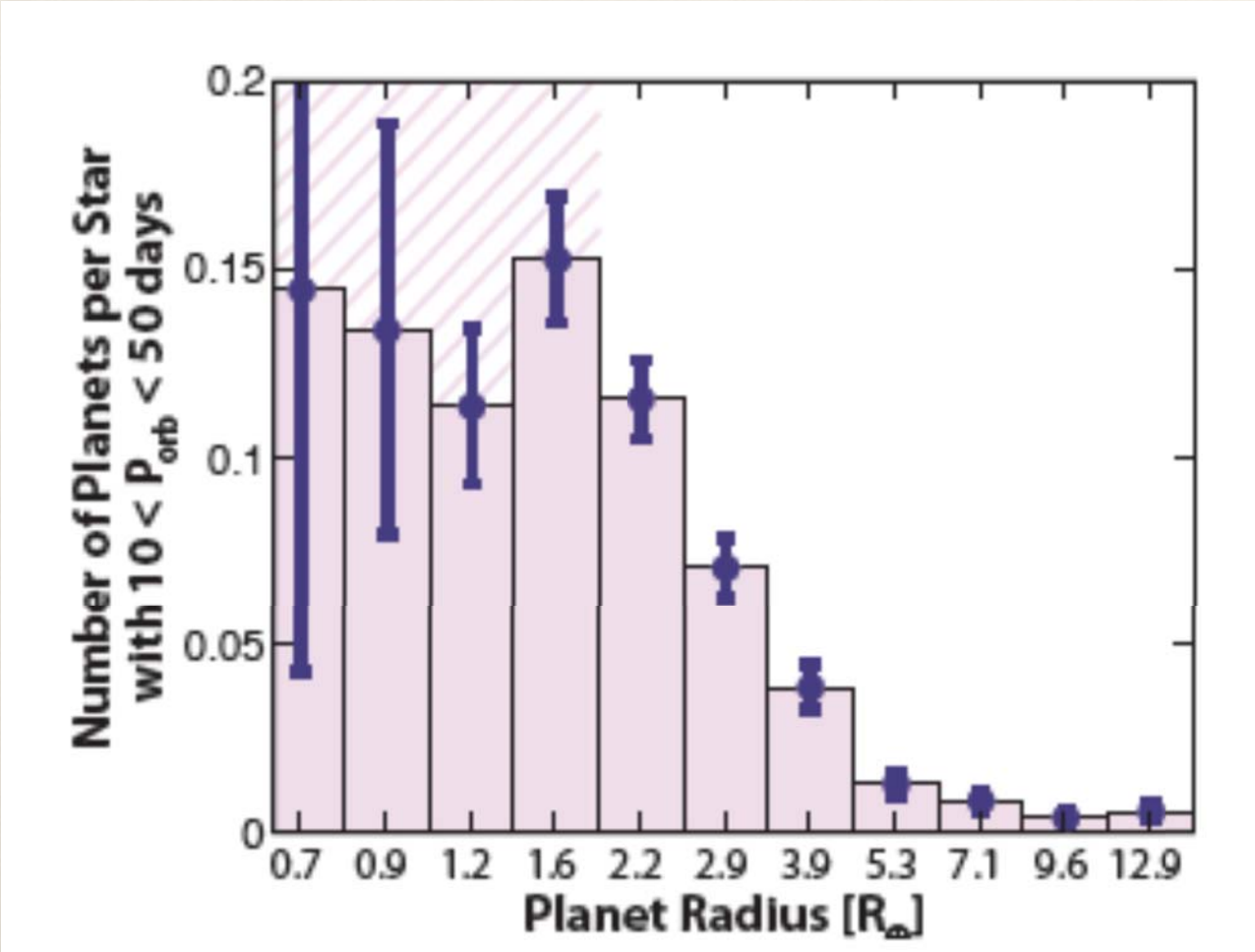
- Earth-size
- Super-Earth size
  1.25 - 2.0 Earth-size
- Neptune-size
  2.0 - 6.0 Earth-size
- Giant-planet size
  6.0 - 22 Earth-size



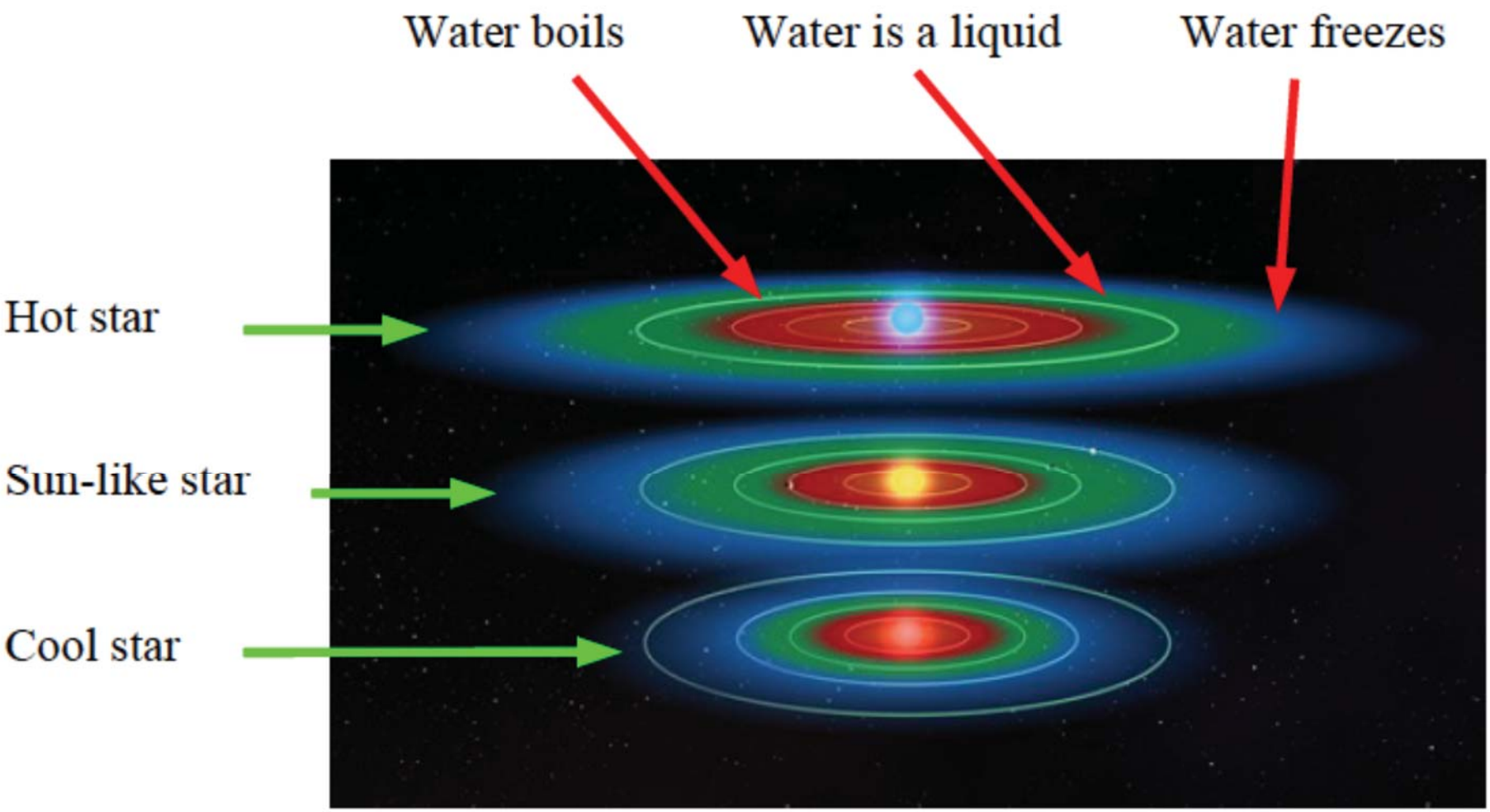
Planet Size Distribution



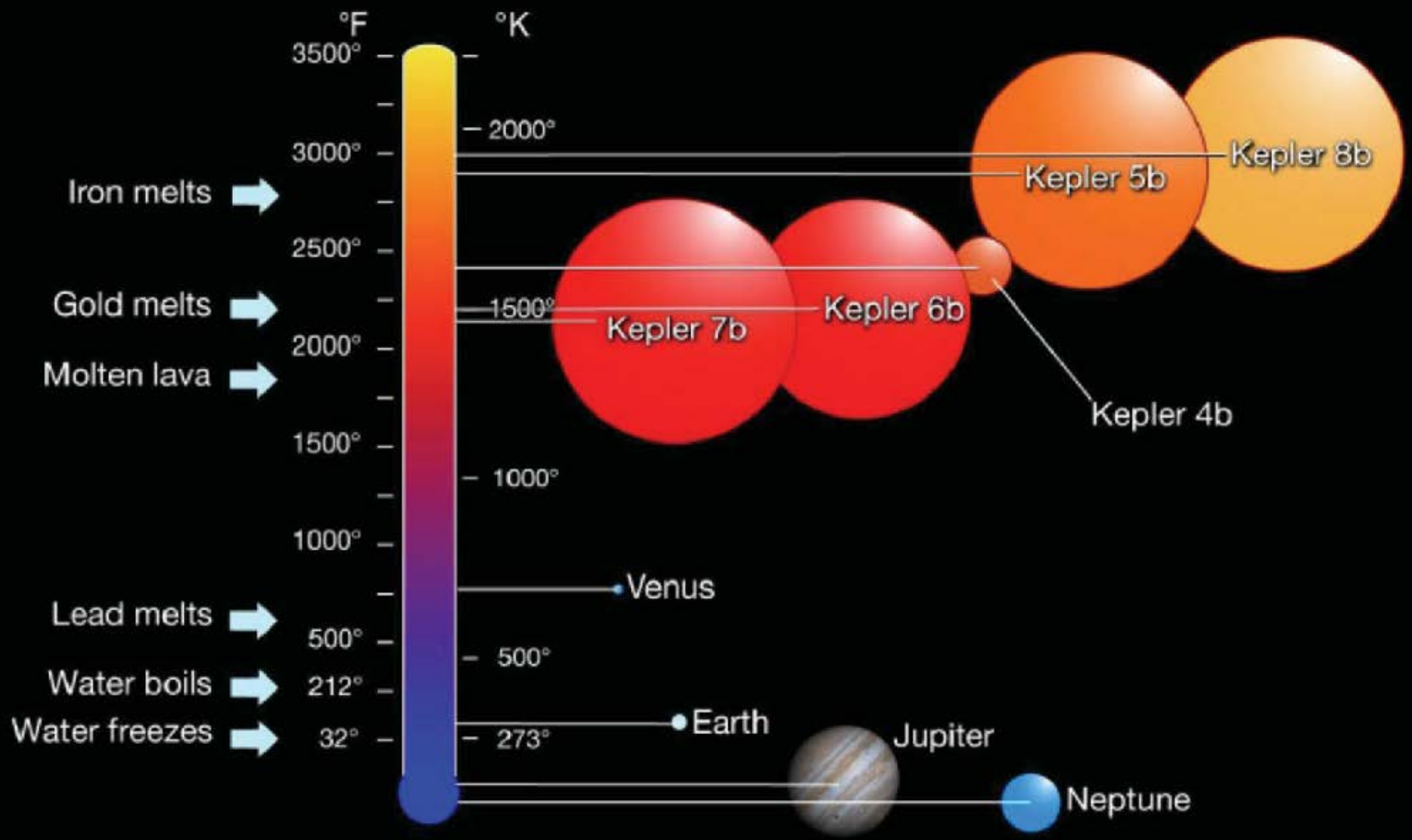
Planet Number Distribution

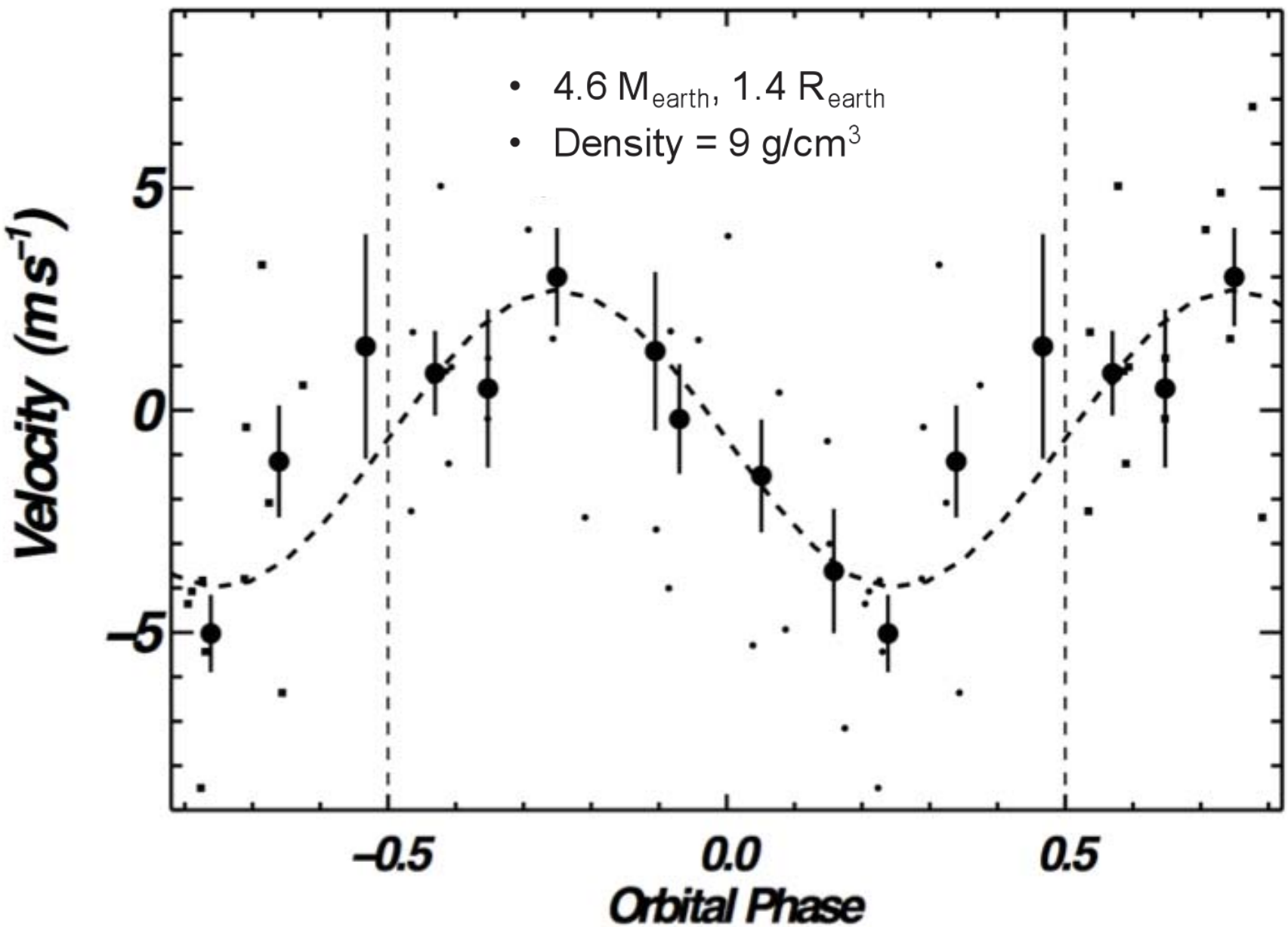


Habitable Zone

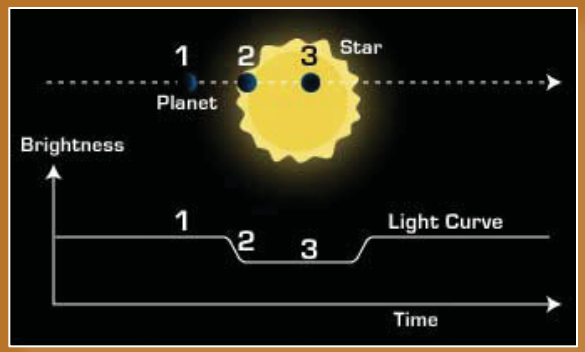


Planet Temperature & Size

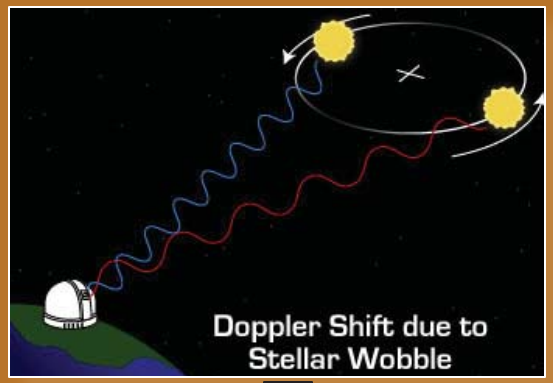


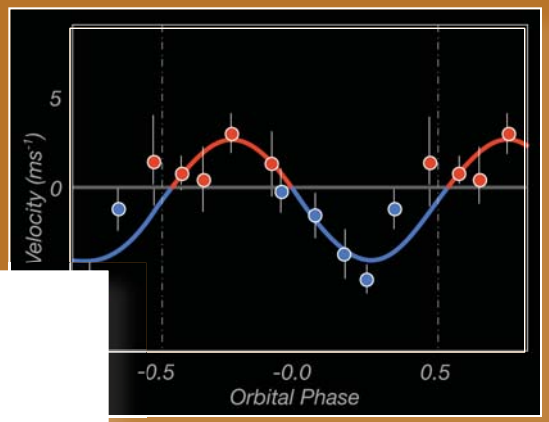

• 4.6 M_{earth}, 1.4 R_{earth}
• Density = 9 g/cm^3
Velocity (m s^{-1})
5
0
–5
–0.5
0.0
0.5
Orbital Phase

Transit and Doppler Measurements Yield Density



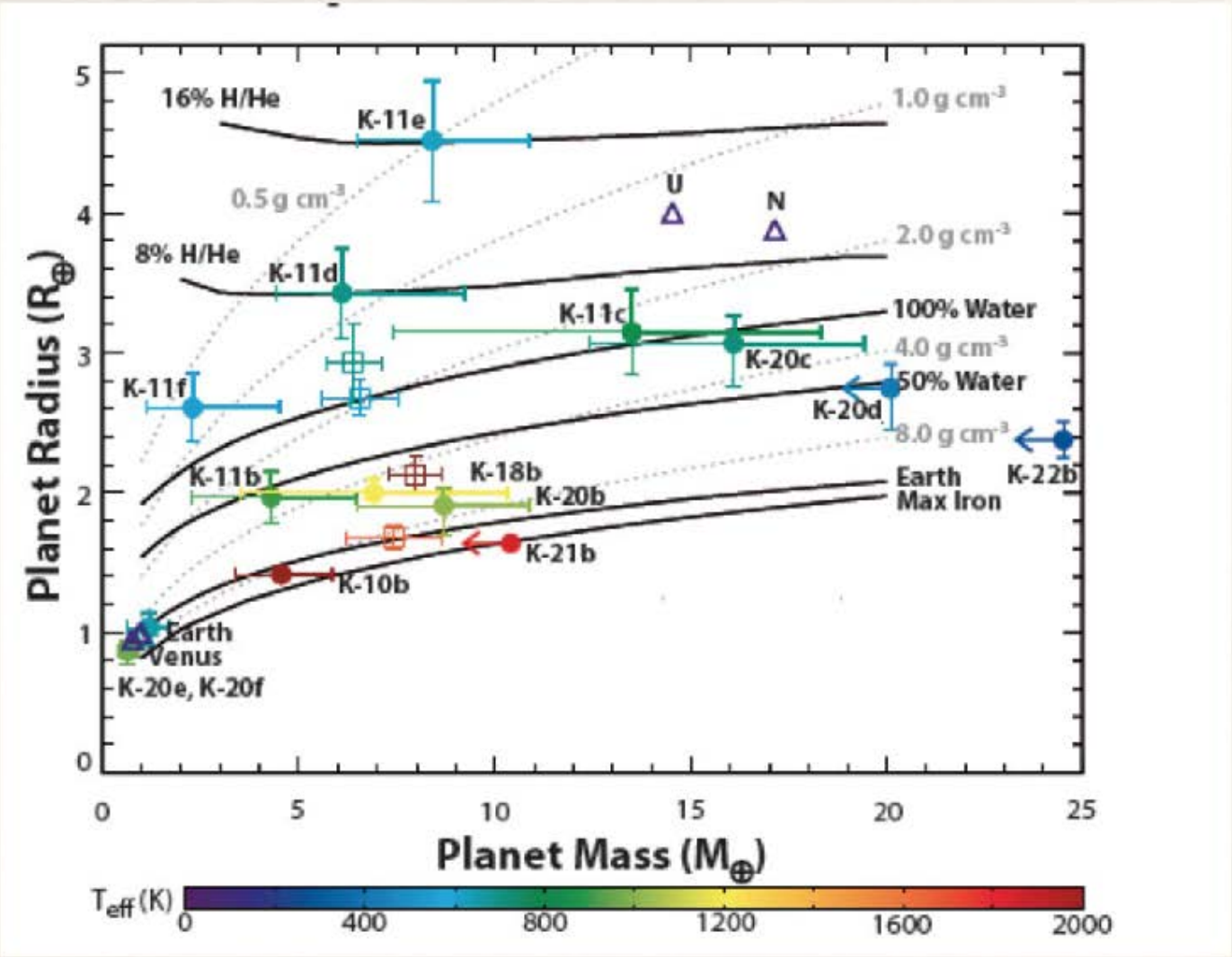
+

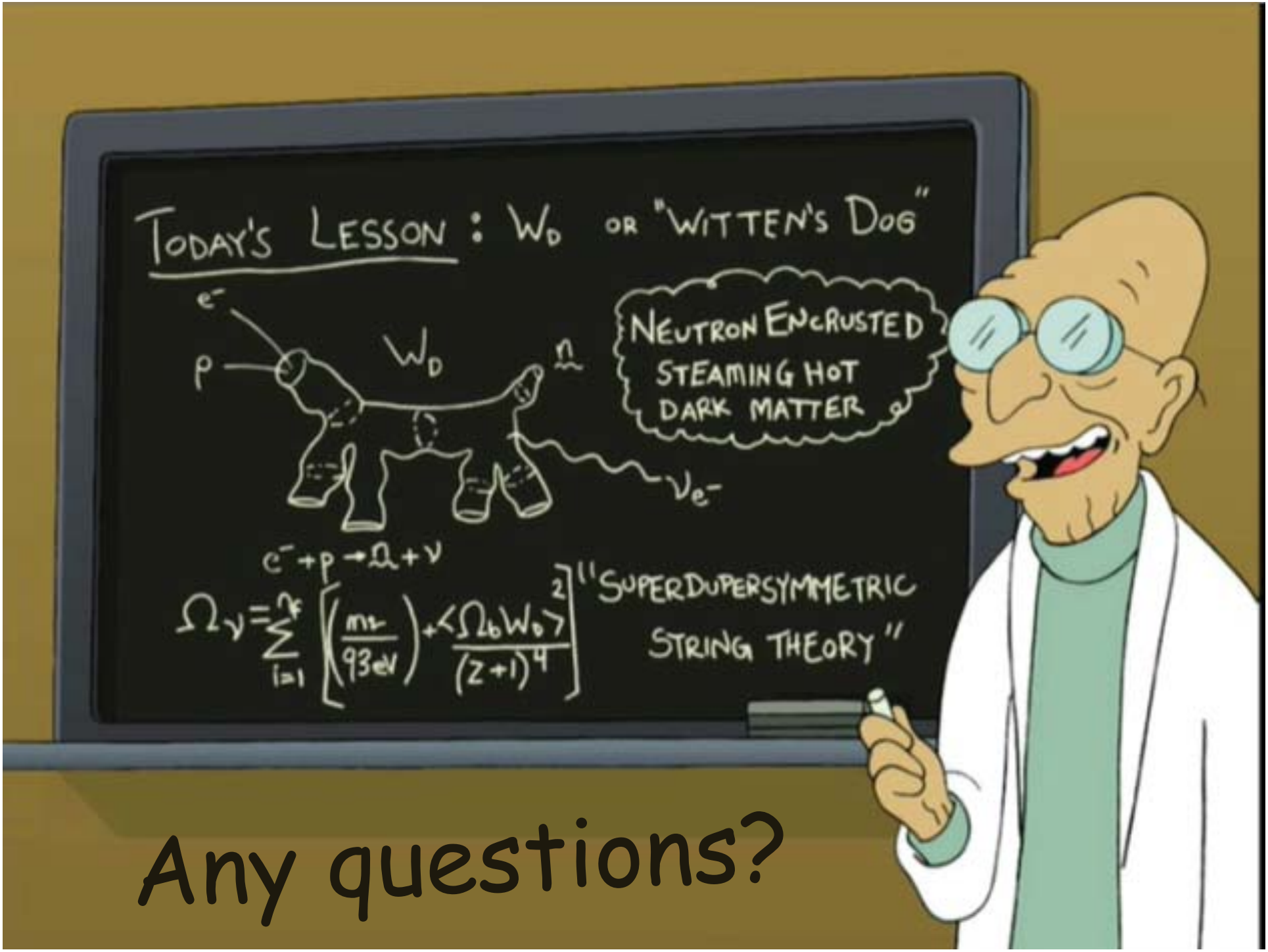




Planet Density:

$$\frac{\text{Mass}}{\text{Volume}} = 8.8\ \text{g/cm}^3$$

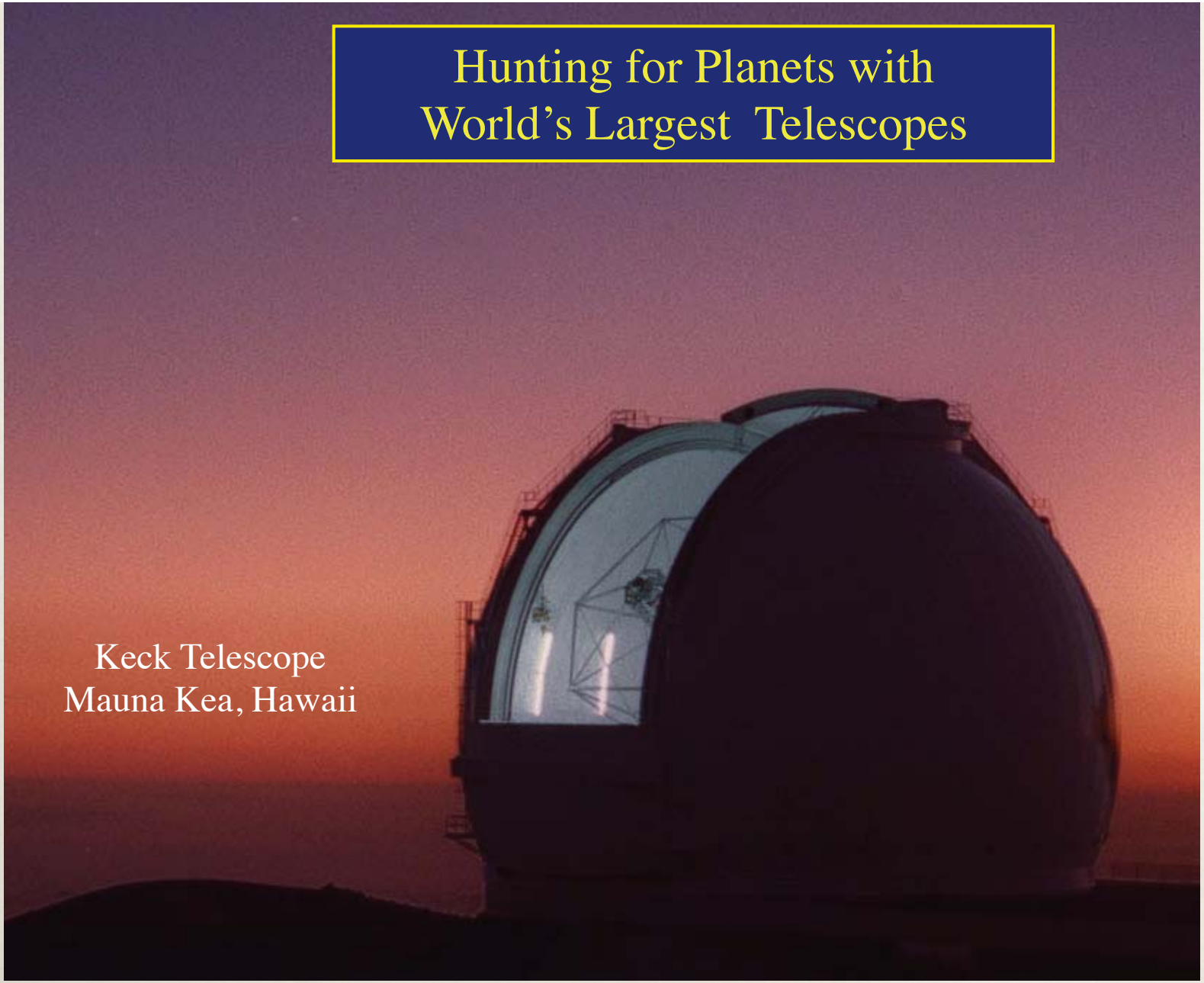

16% H/He
8% H/He
K-11e
K-11d
K-11c
K-11f
K-11b
K-18b
K-20b
K-21b
K-10b
K-20c
K-20d
K-22b
U
N
Earth
Venus
K-20e, K-20f
1.0 g cm⁻³
0.5 g cm⁻³
2.0 g cm⁻³
4.0 g cm⁻³
8.0 g cm⁻³
100% Water
50% Water
Earth
Max Iron
Planet Radius (R⊕)
Planet Mass (M⊕)
T_eff (K)
0
400
800
1200
1600
2000



Any questions?

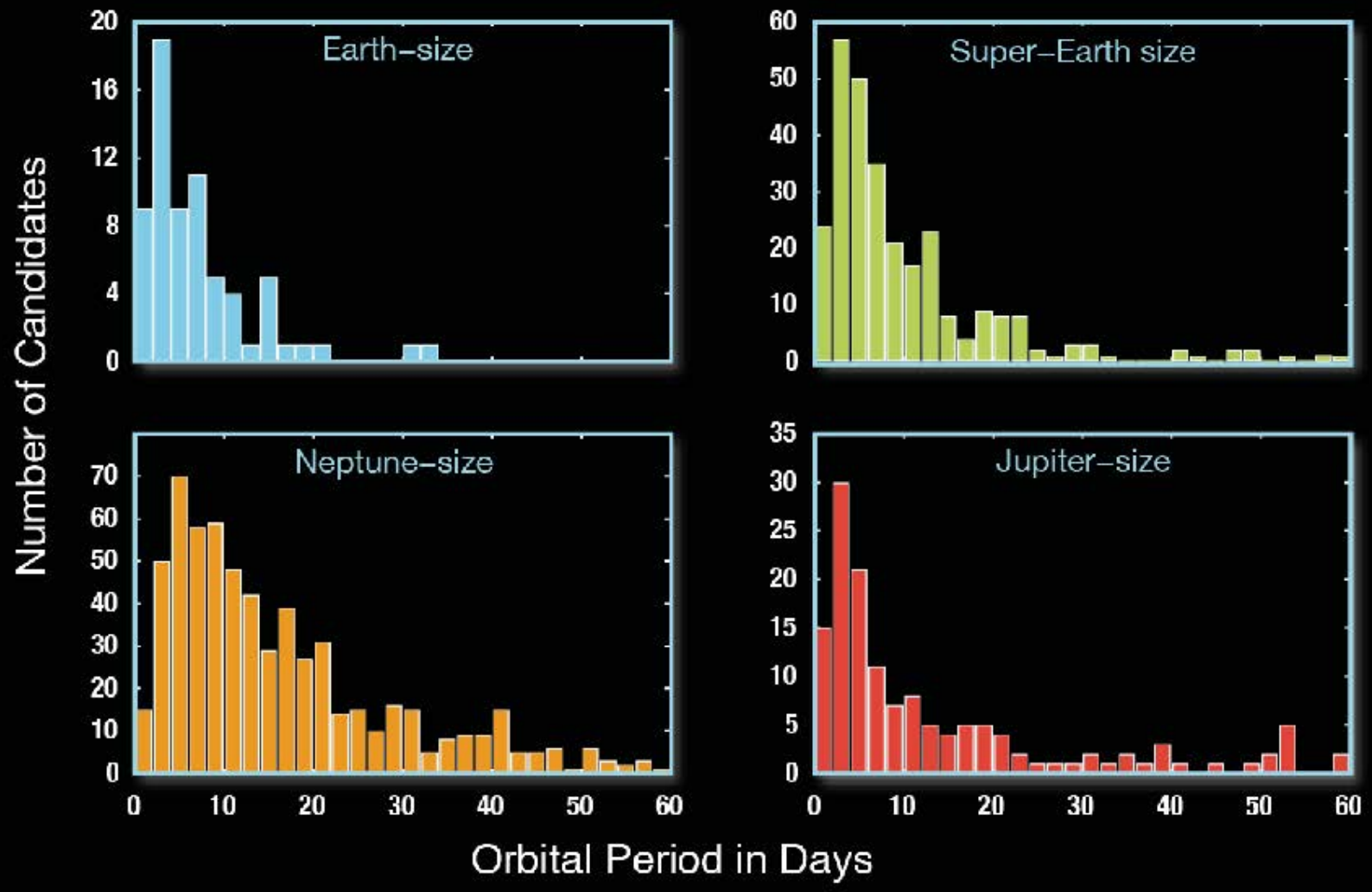
Backup Slides

Hunting for Planets with World's Largest Telescopes

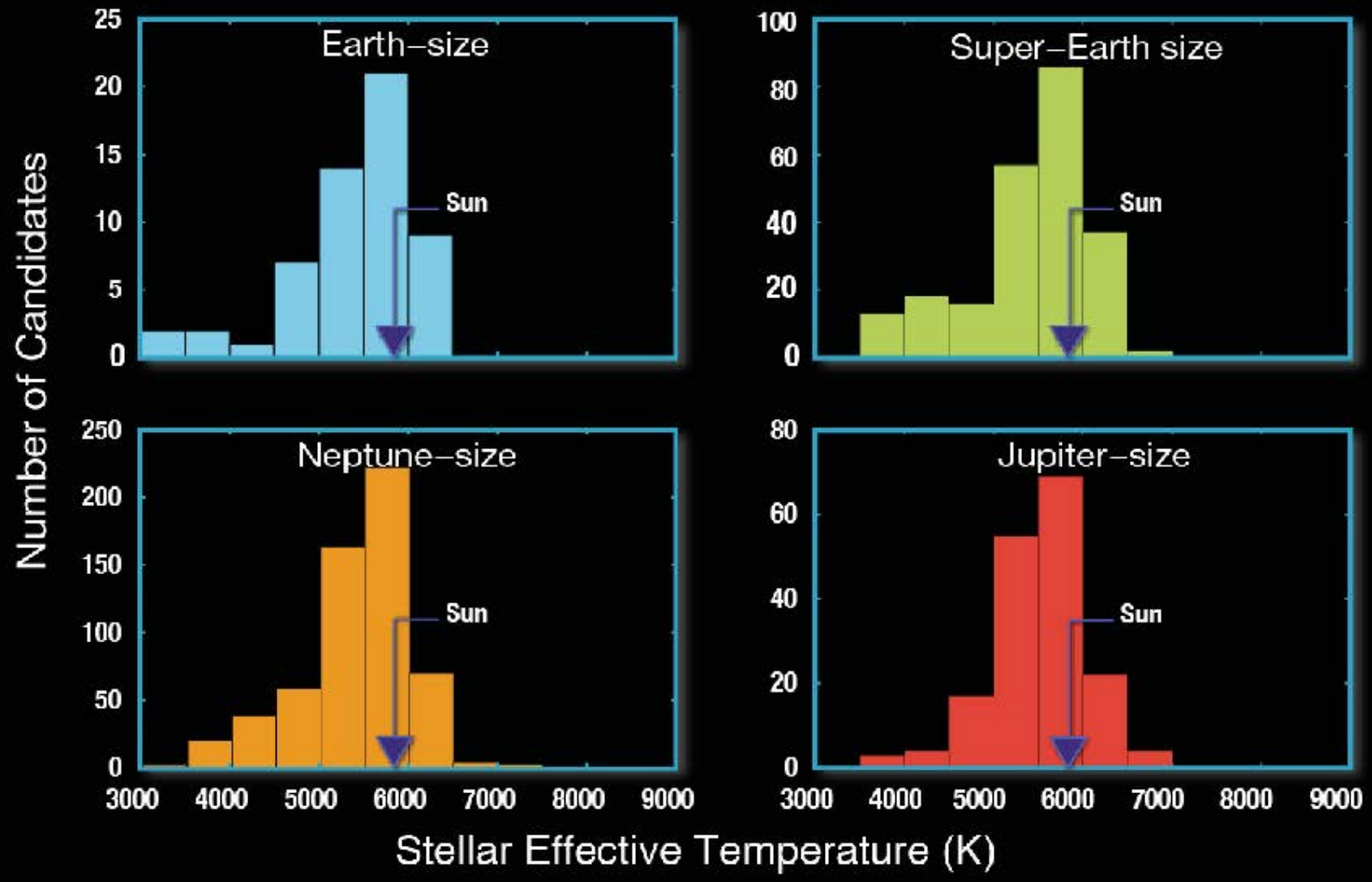


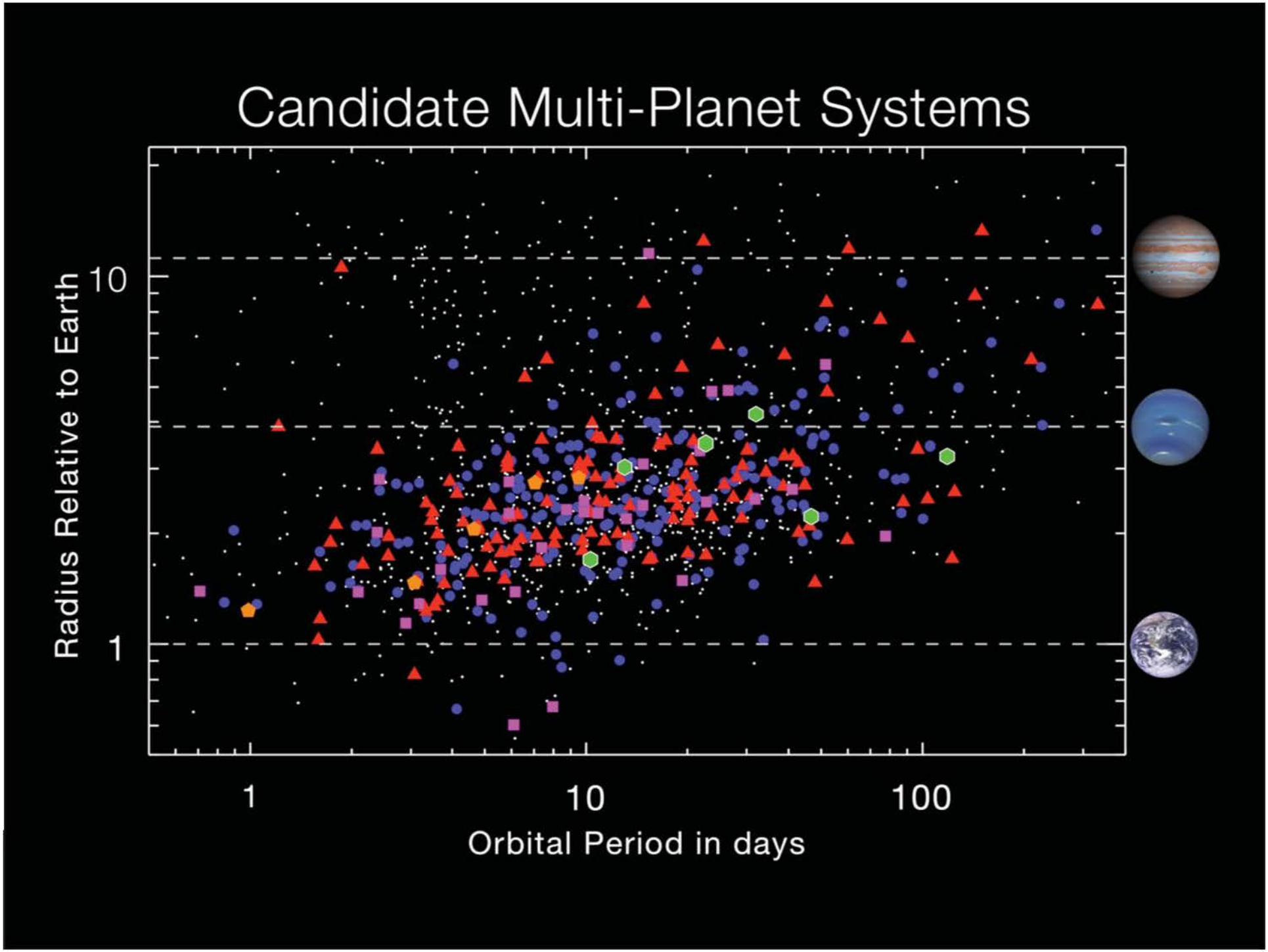
Keck Telescope
Mauna Kea, Hawaii

Candidates Show Drop Off for Shortest Orbital Periods



Most of the Candidates Orbit Stars Like our Sun




Candidate Multi-Planet Systems
Radius Relative to Earth
10
1
1
10
100
Orbital Period in days