Planet detections with the transit method

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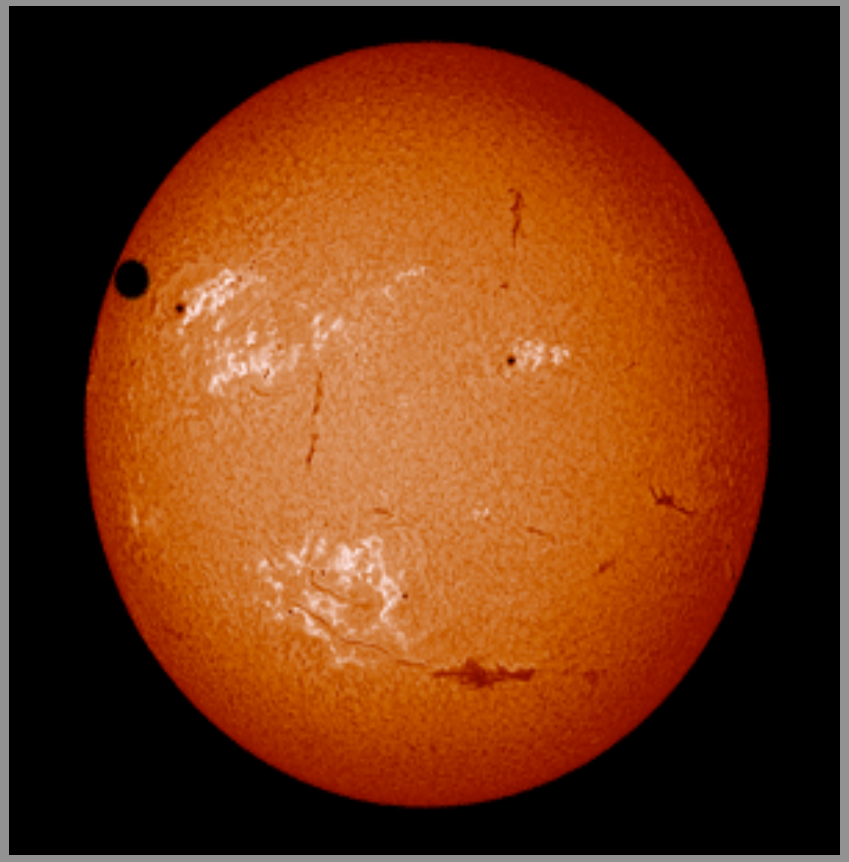
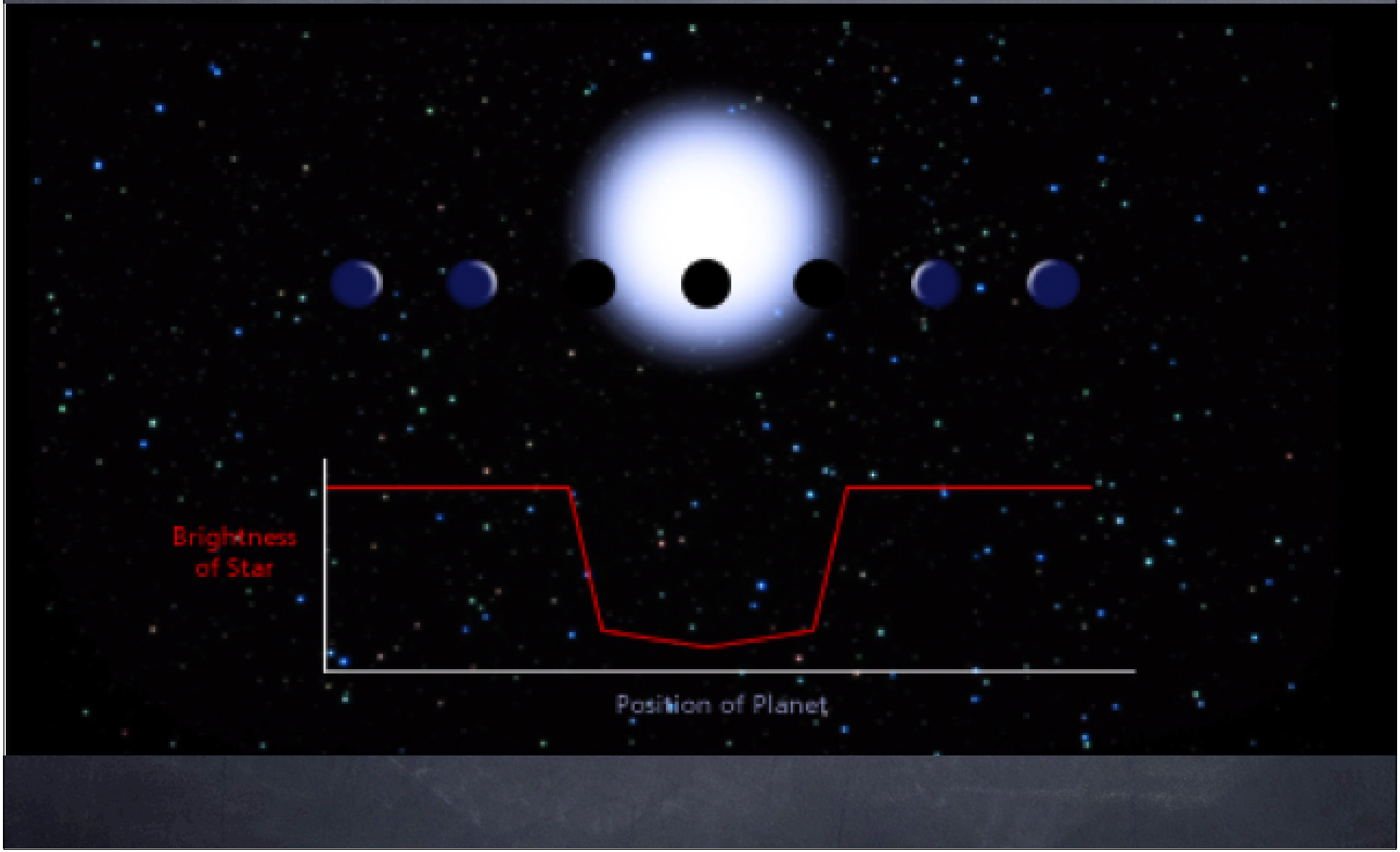
What are you going to do on June 6 2012?

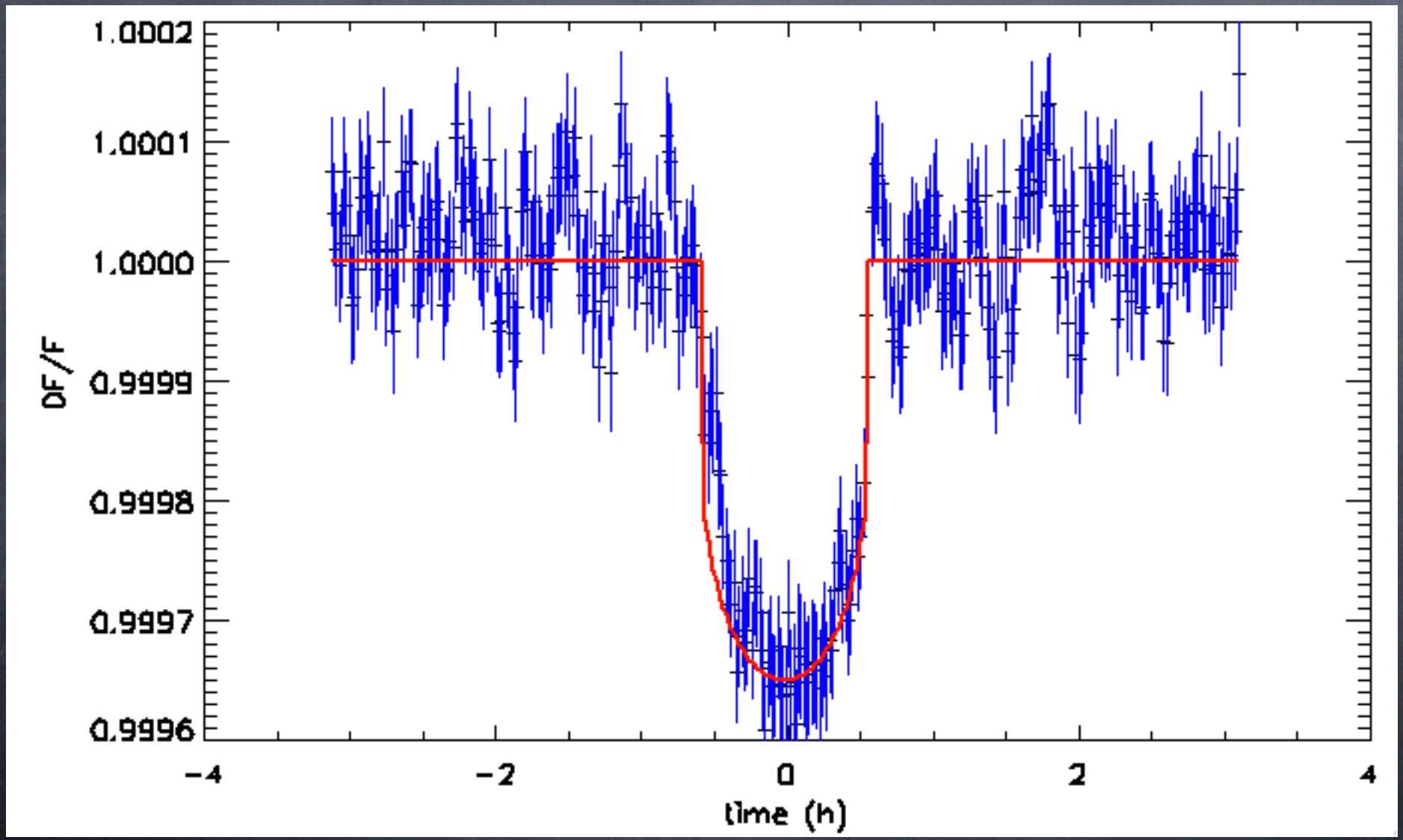


Venus in front of the Sun in 2004
(again in 2012
and 2117)

The transit method



Transit Corot 7b



Exo-planet transits Periodicity

- The transit is periodic with the orbit of the planet.
- Period from Kepler's laws $P^2 = M_* a^3$
  - a = distance star planet in astronomical Unitis (distance Sun Earth)
  - P = orbital period in years
  - M* = Stellar Mass in Solar mass units

Exo-planet transits
Duration of a transit

- For a central transit

$$t_c = 13 d_* \sqrt{\left(\frac{a}{M_*}\right)} = 13\sqrt{a} \quad \text{hours}$$

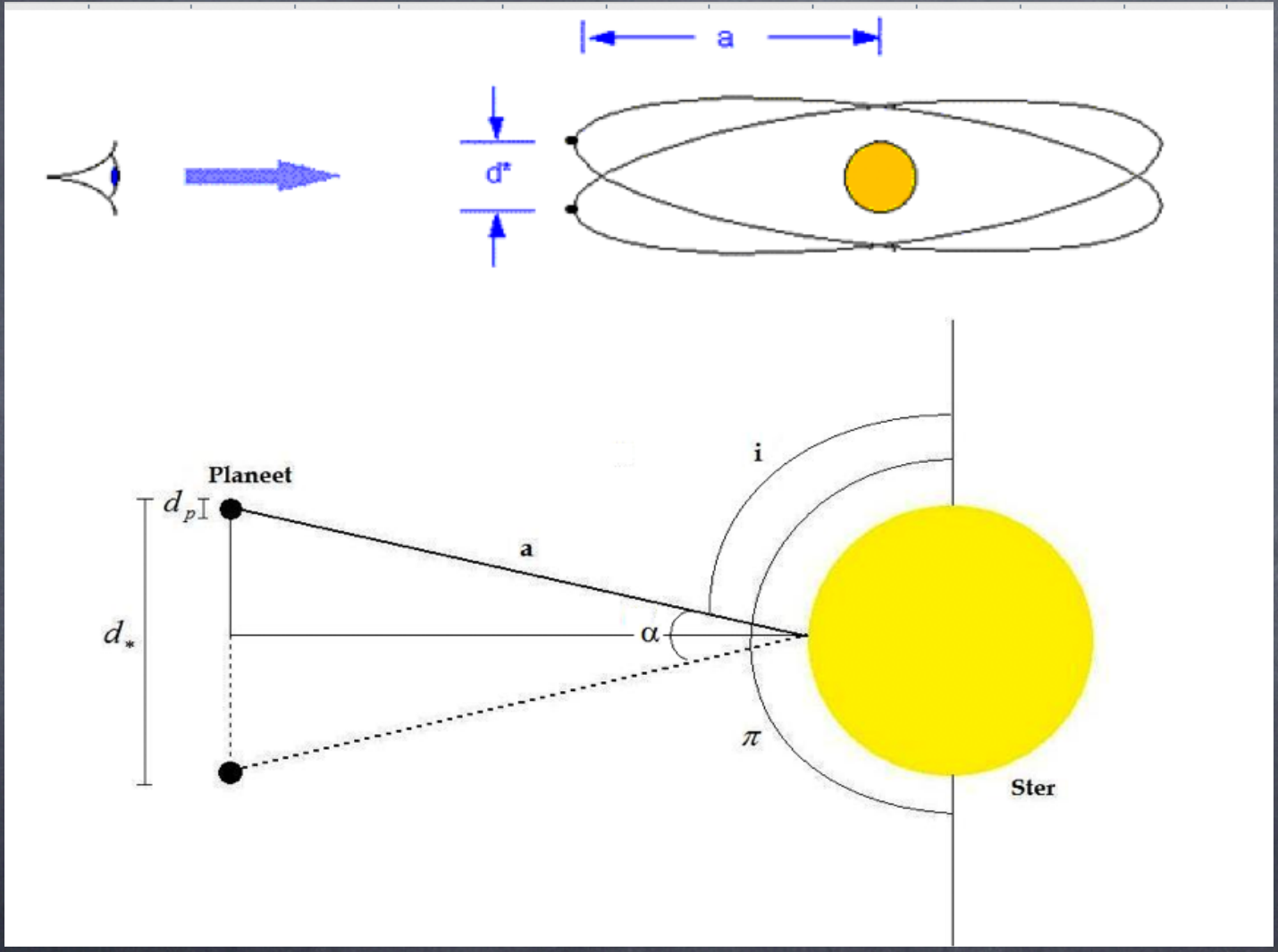
  - d* = diameter of the star in solar diameters

Exo-planet transits
Depth of the transit

- Fractional change in flux from the star

$$1 - \frac{F_{\rm transit}}{F_0} = \left(\frac{R_p}{R_*}\right)^2$$

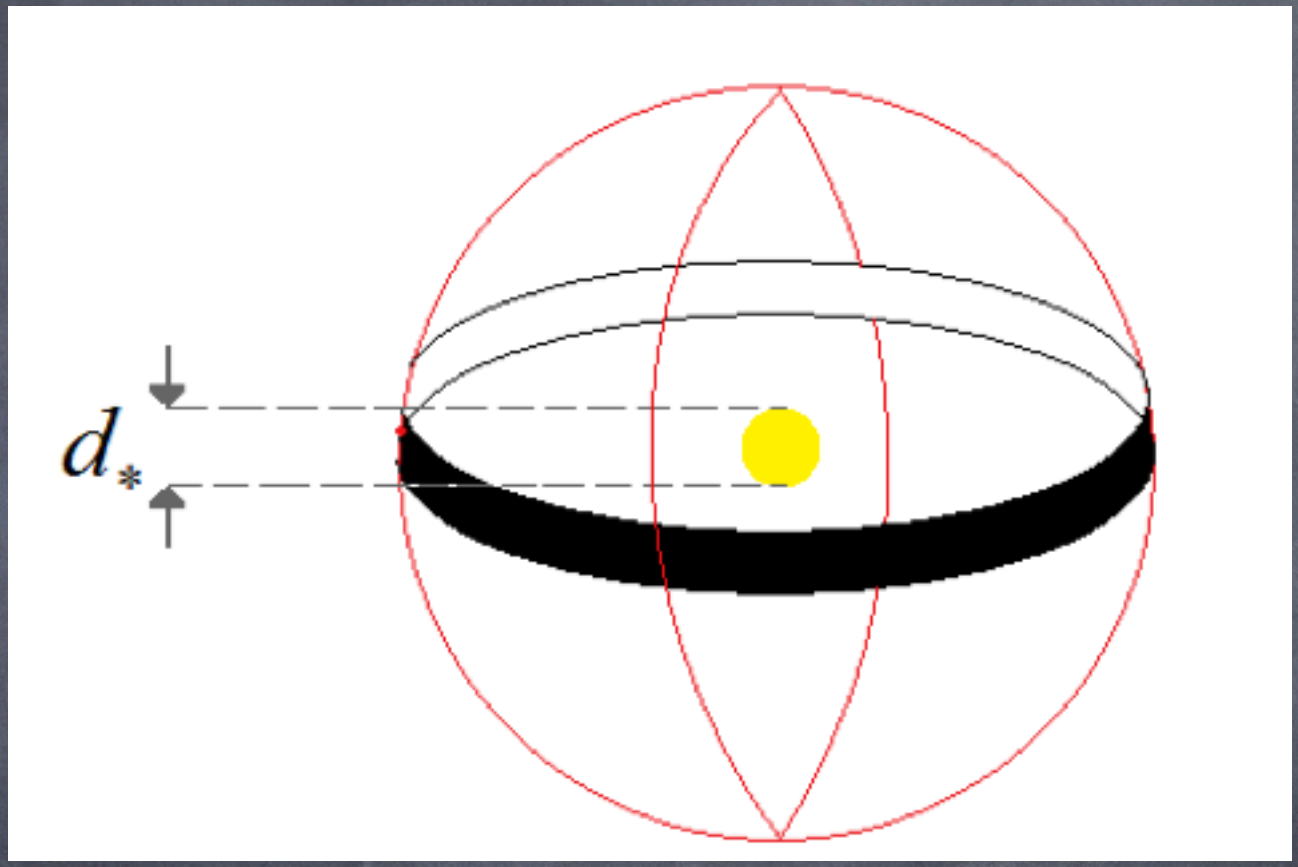
Probability that we do see the transit



Simple estimate: $P=\alpha/\pi \sim d_*/(\pi\ a)$

Wrong!

Better estimate

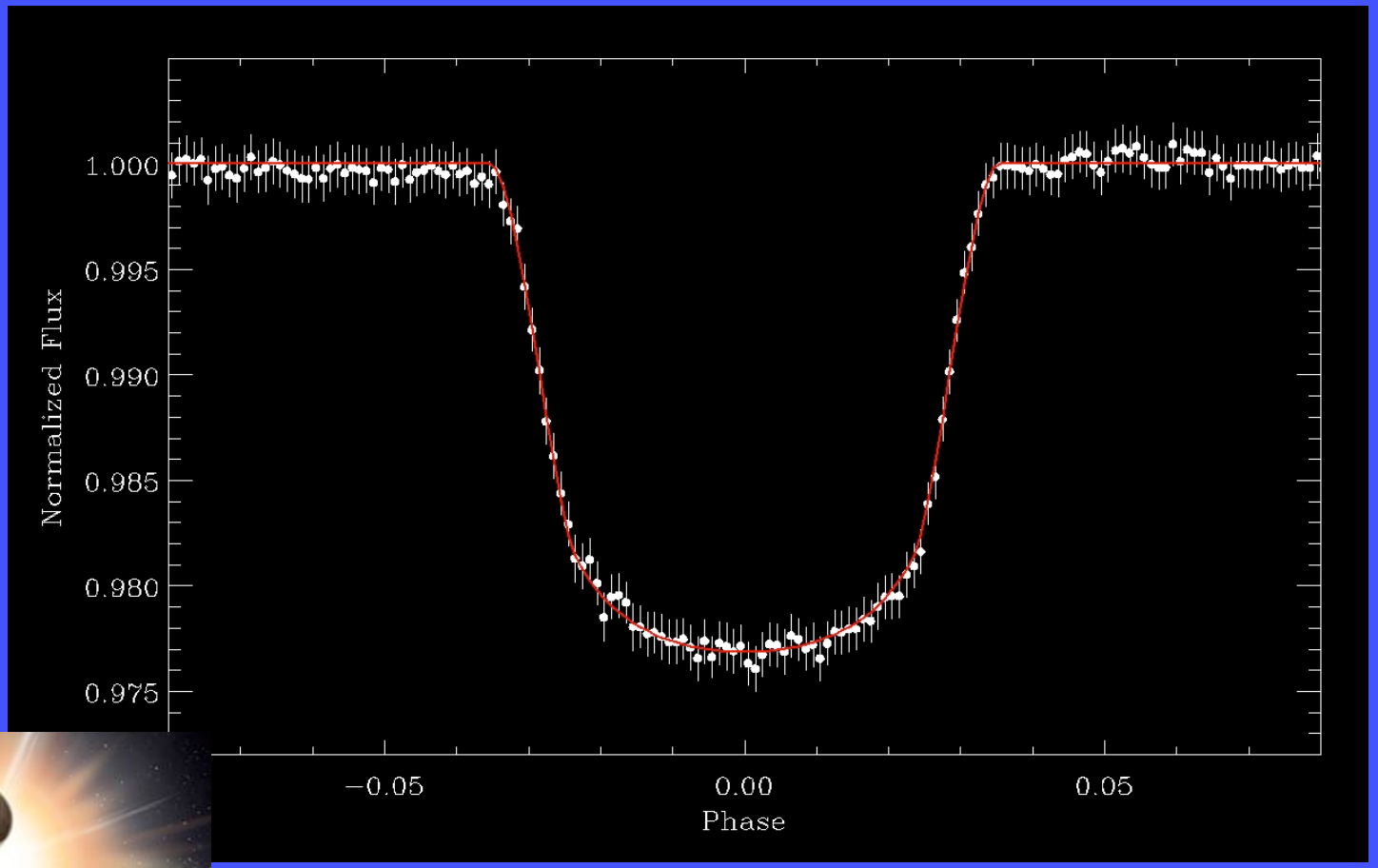


$$P = \frac{2\pi a d_*}{4\pi a^2} = \frac{d_*}{2a} = \alpha$$

So this is 3.14 times larger than the simple estimate

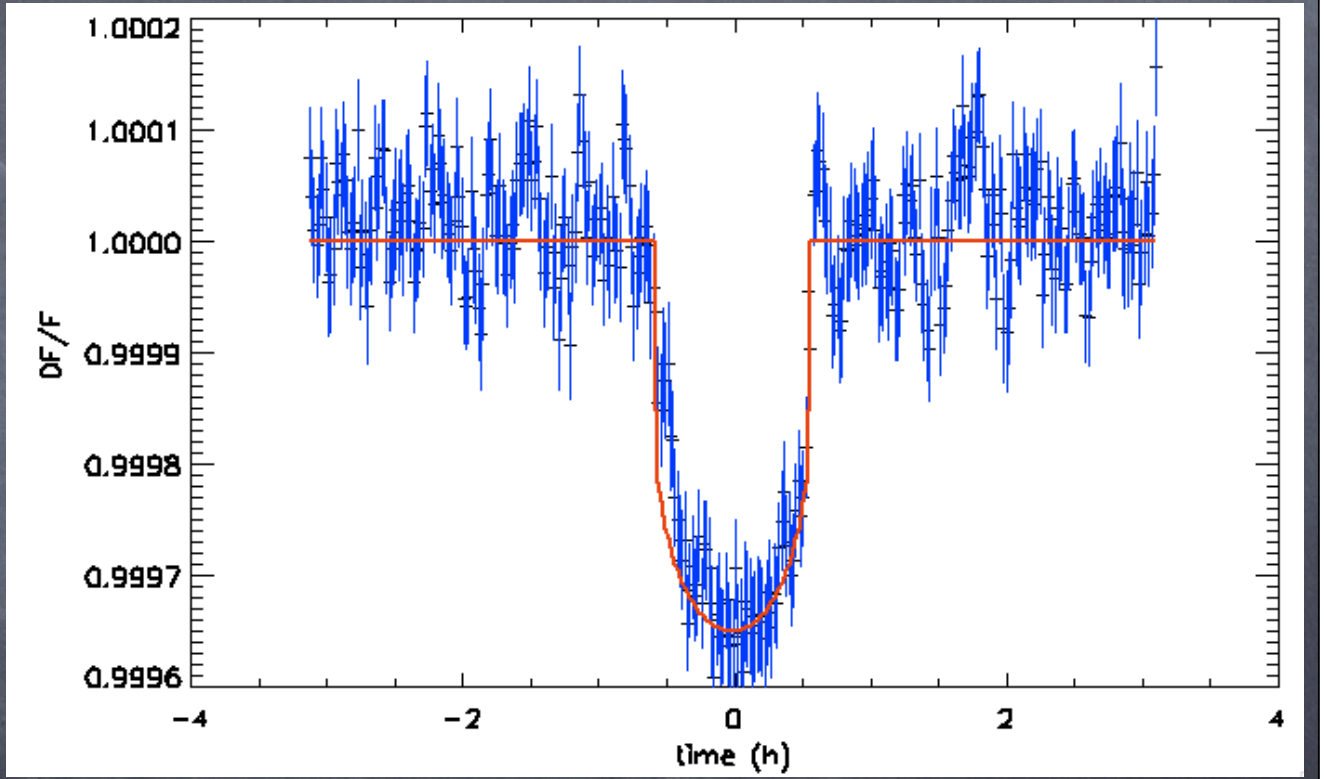
	Orbital period	S-m axis	Transit time	Transit depth	Geom prob.	
	(Years)	(AU)	hrs	(%)	(%)	
Planet						
mercury	0.241	0.39	8.1	0.0012	1.19	
venus	0.615	0.72	11.0	0.0076	0.65	
earth	1.000	1.00	13.0	0.0084	0.47	
mars	1.880	1.52	16.0	0.0024	0.31	
jupiter	11.86	5.20	29.6	1.01	0.089	
saturn	29.5	9.5	40.1	0.75	0.049	
uranus	84.0	19.2	57.0	0.135	0.024	
neptunus	164.8	30.1	71.3	0.127	0.015	

Exoplanets with Corot



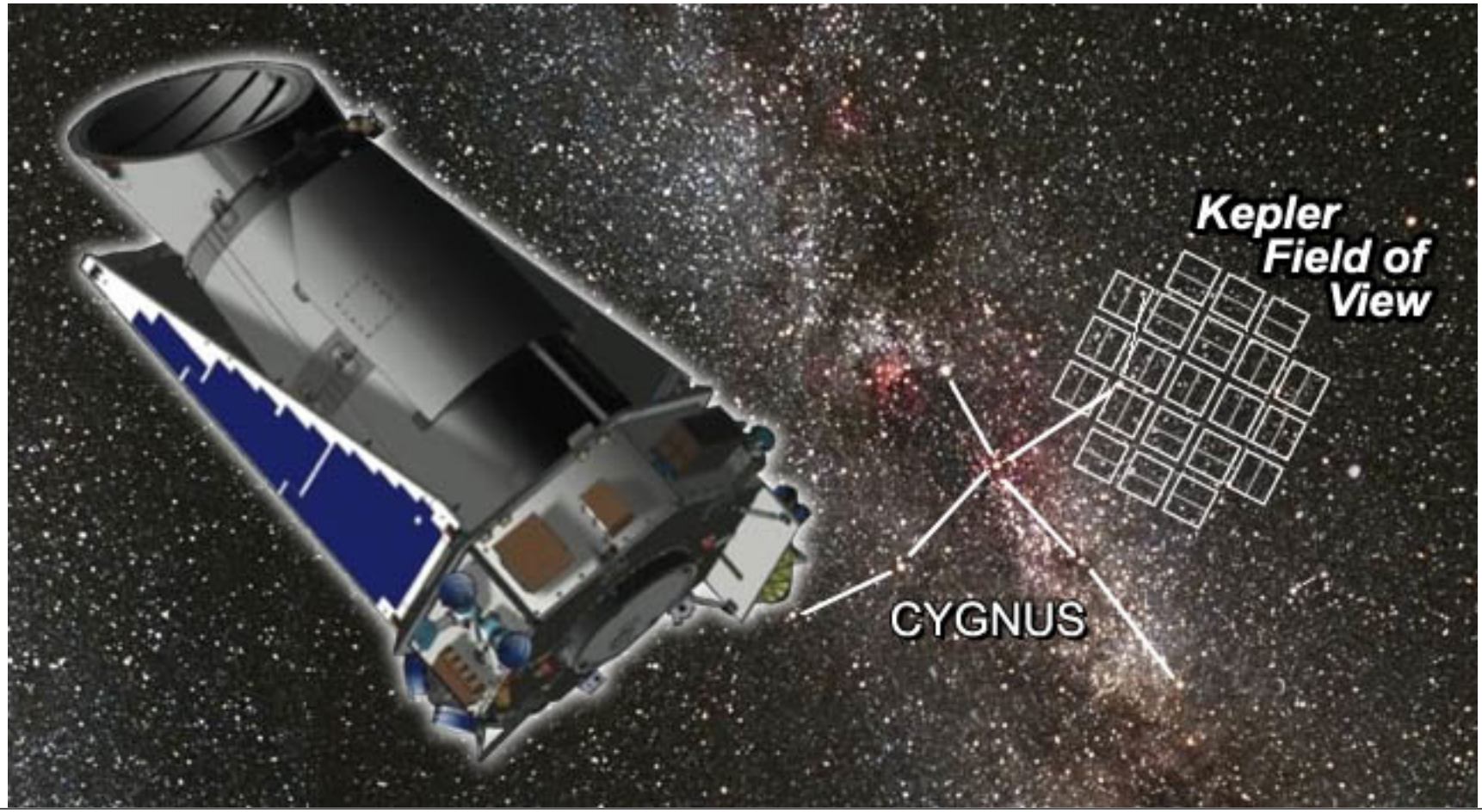
Corot exo-7b: Super-earth

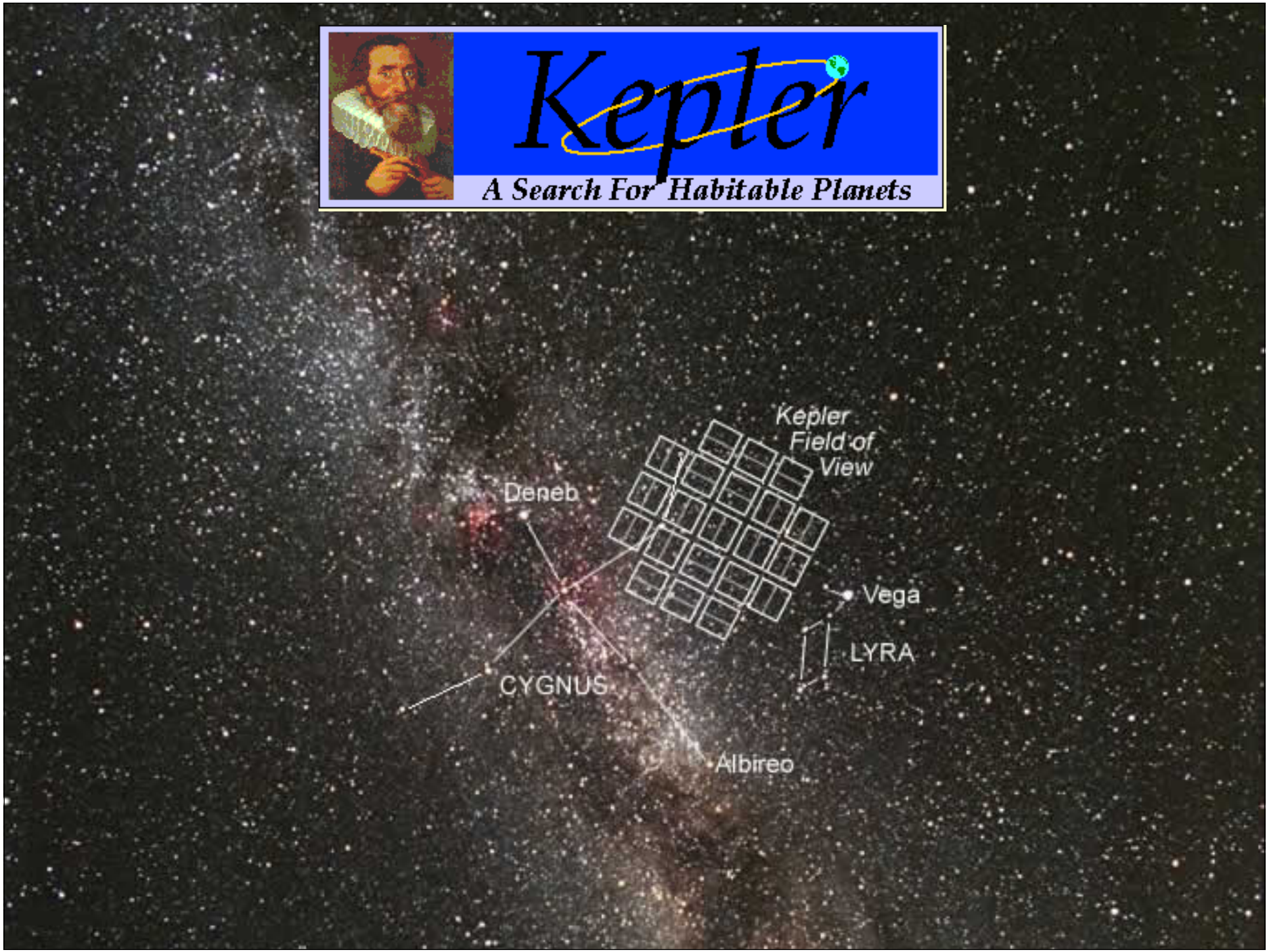
- Porb = 20 hours
- R: 1.6 R (Earth)
- M: 5 M (Earth)



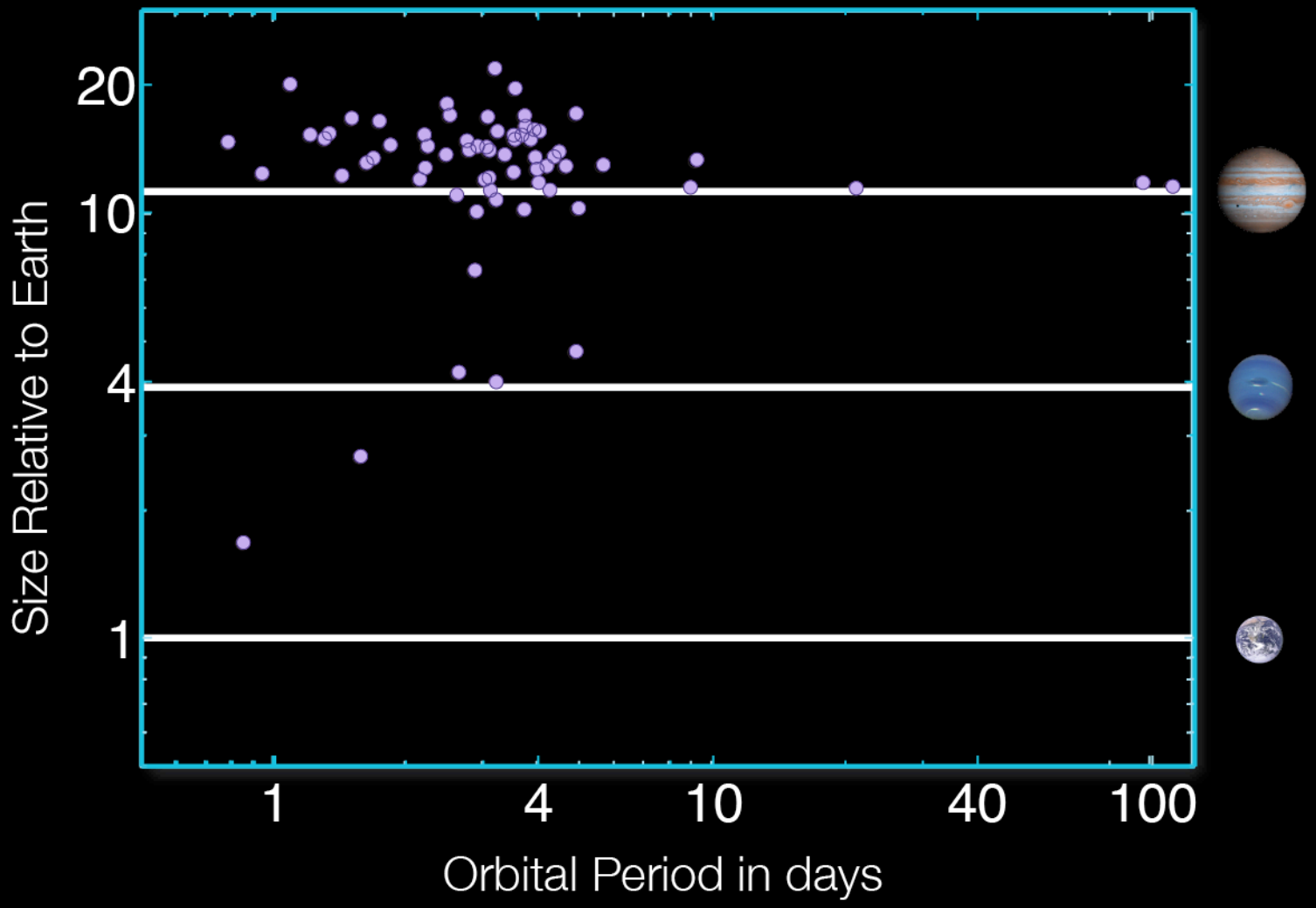
Kepler

- NASA, photometry of >150,000 stars
- Looking for Earth-like planets in transit
- 50μmag in 6 hours; 30 minute cadence
- First ~210 days went public this Sept.

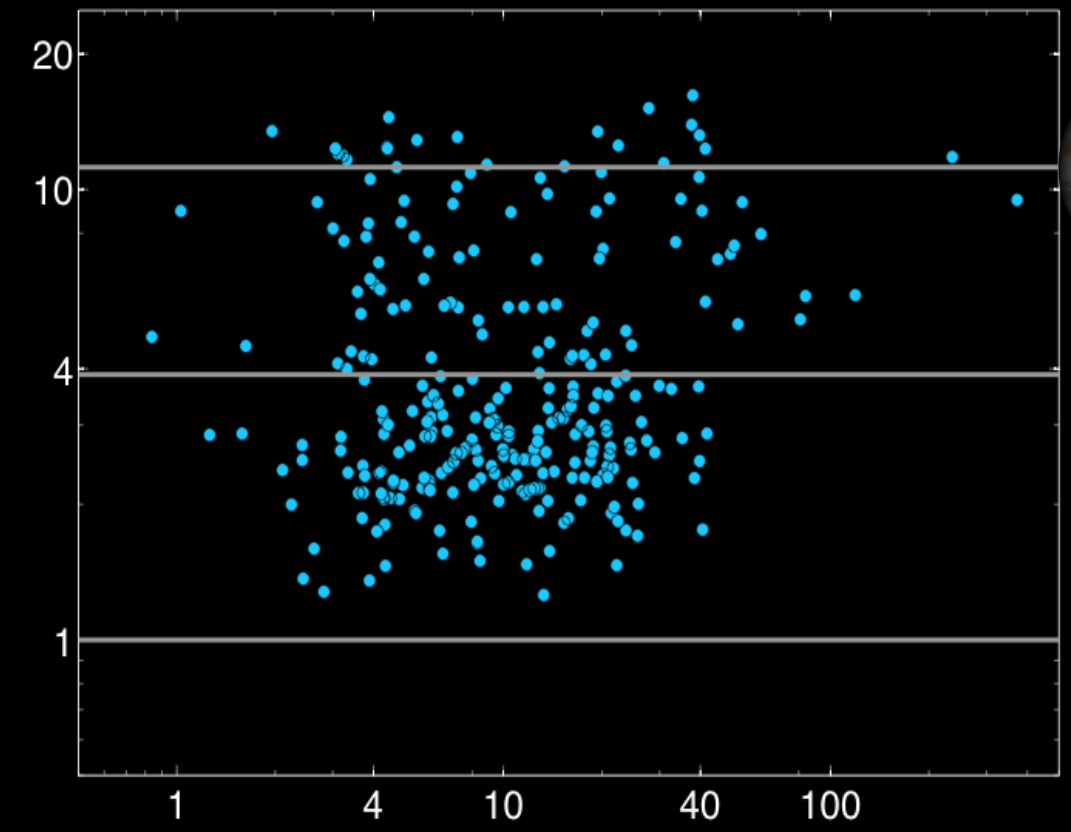


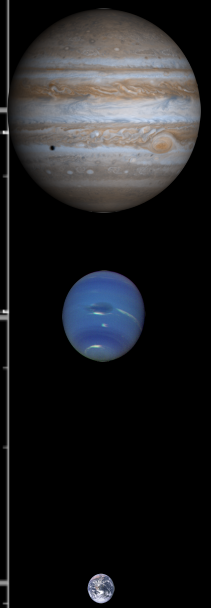

Kepler
A Search For Habitable Planets
Kepler
Field of
View
Deneb
Vega
LYRA
CYGNUS
Albireo

Pre-Kepler Transiting Planets - 2009

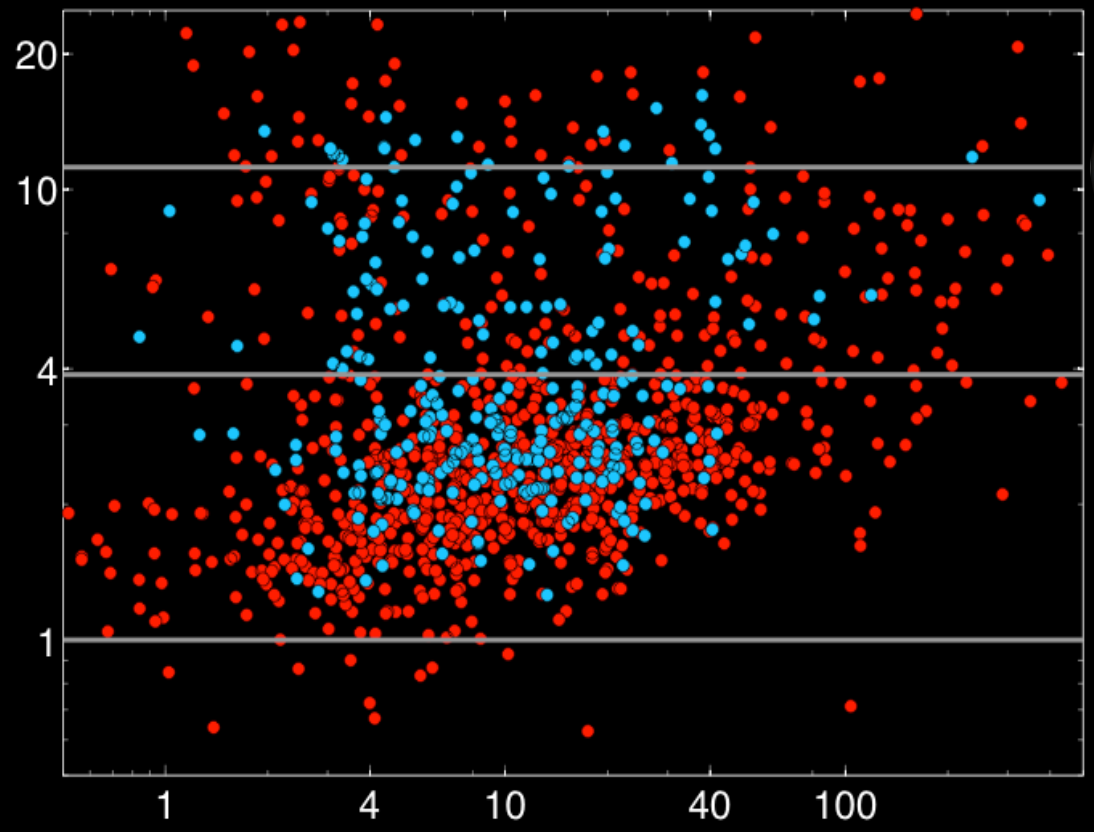


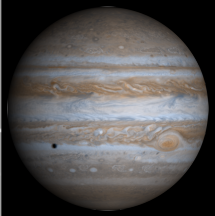
Kepler Planet Candidates as of June 2010

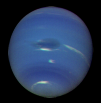




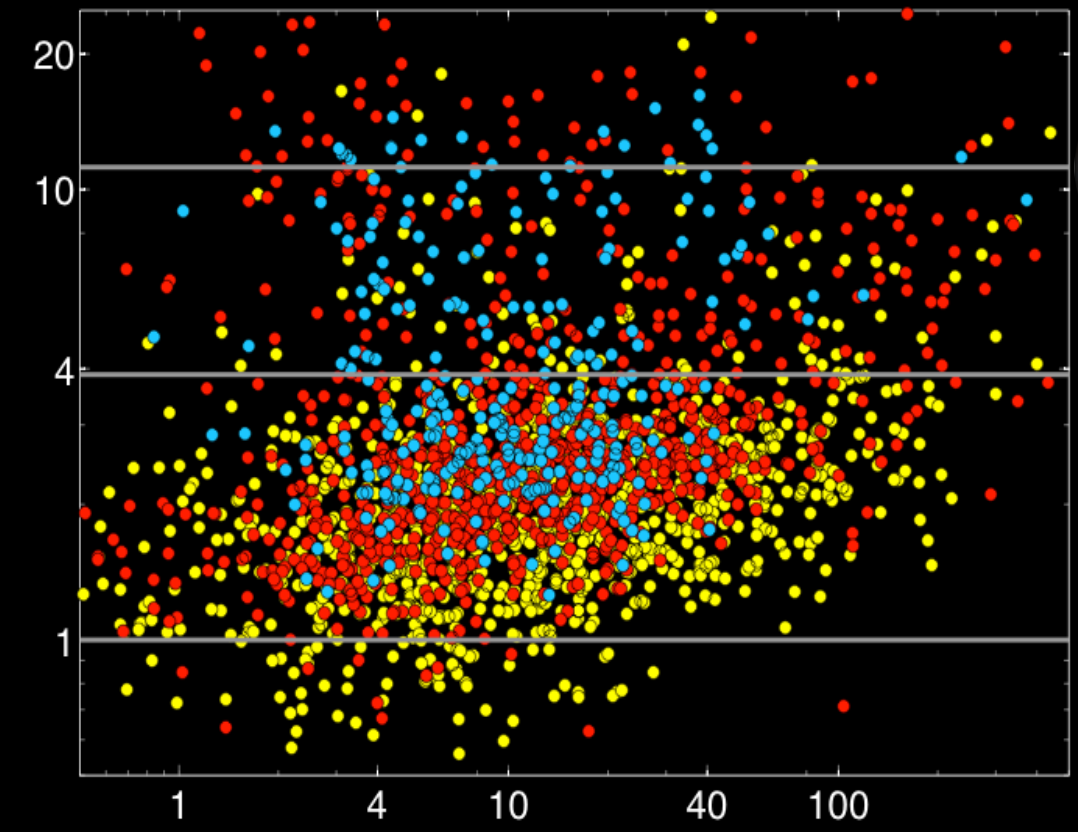
Kepler Planet Candidates as of Feb 2011

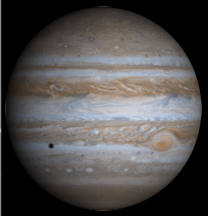


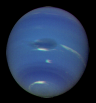




Kepler Planet Candidates as of Dec 2011

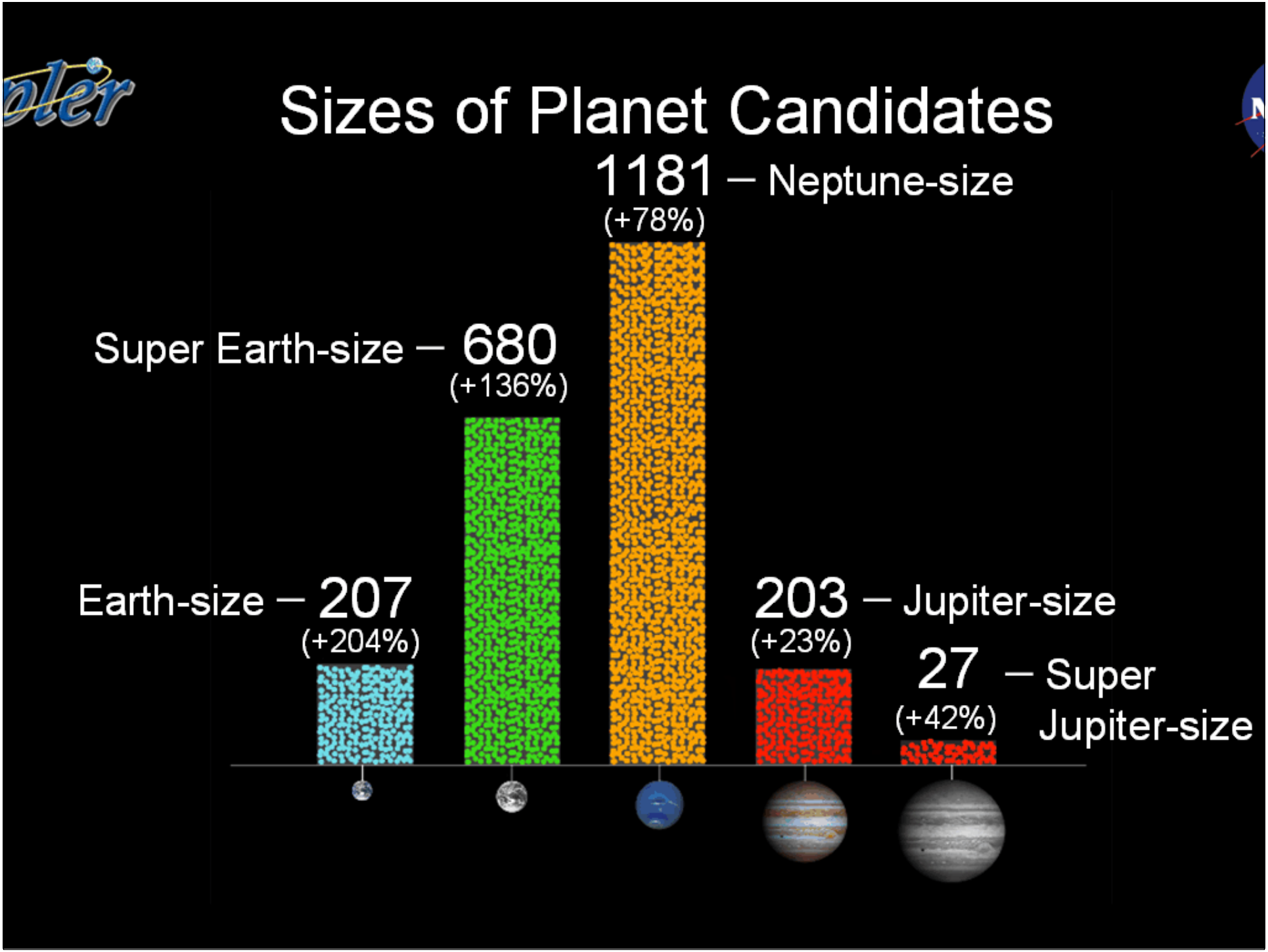




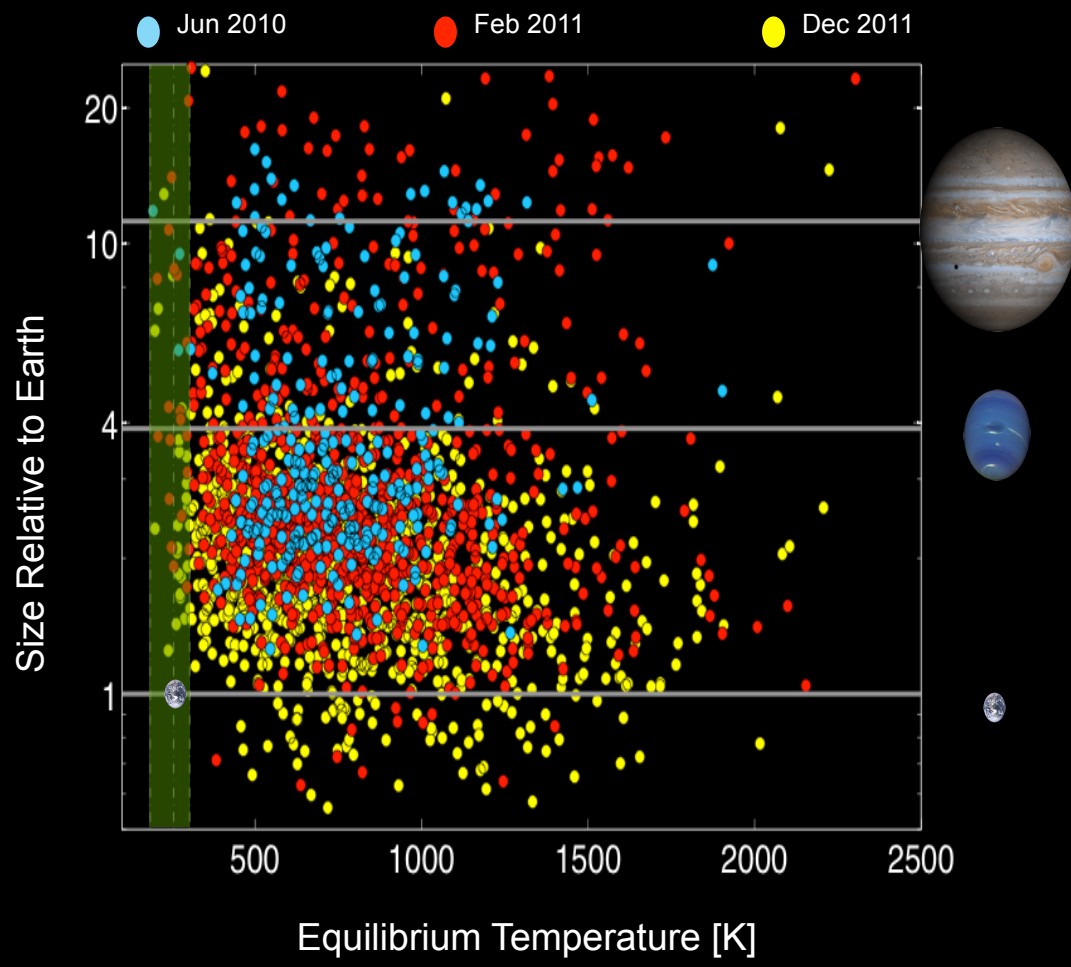


2326

Sizes of Planet Candidates



Kepler Candidates in the Habitable Zone

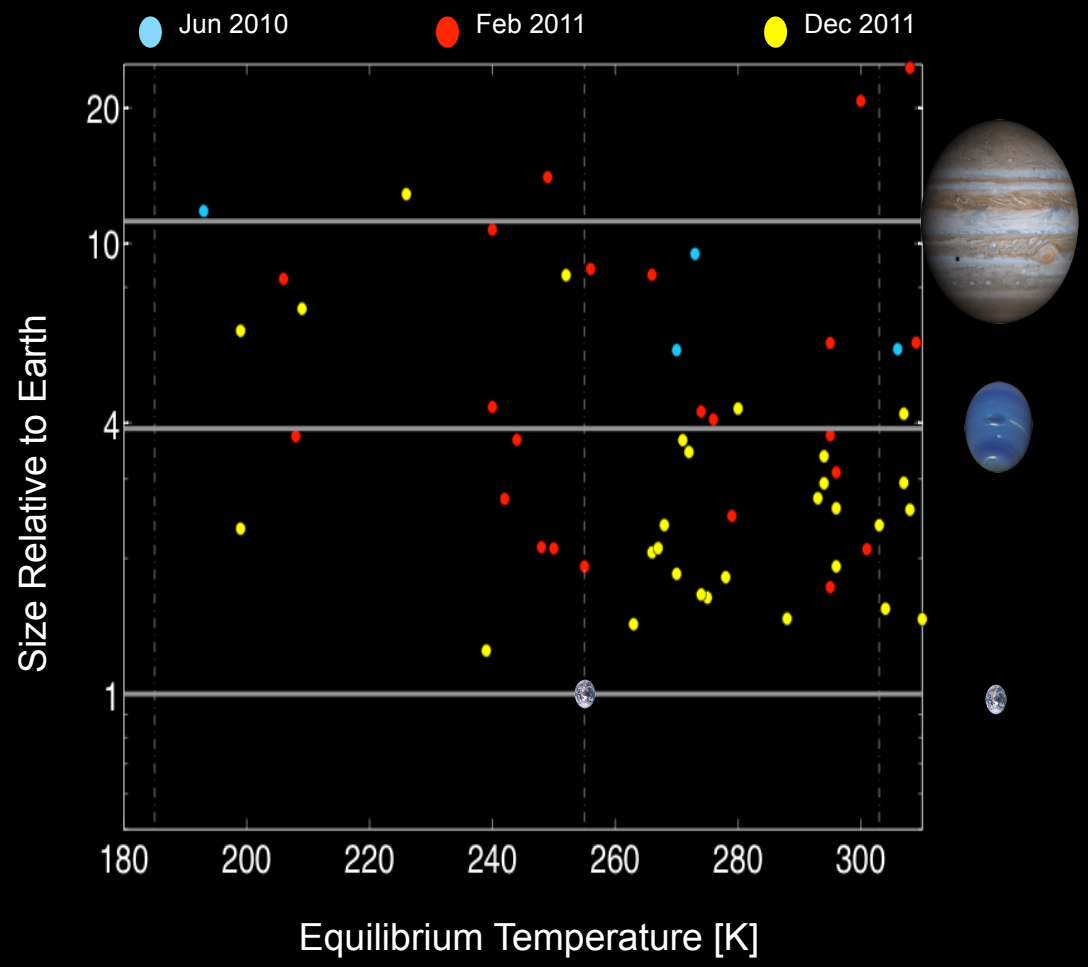


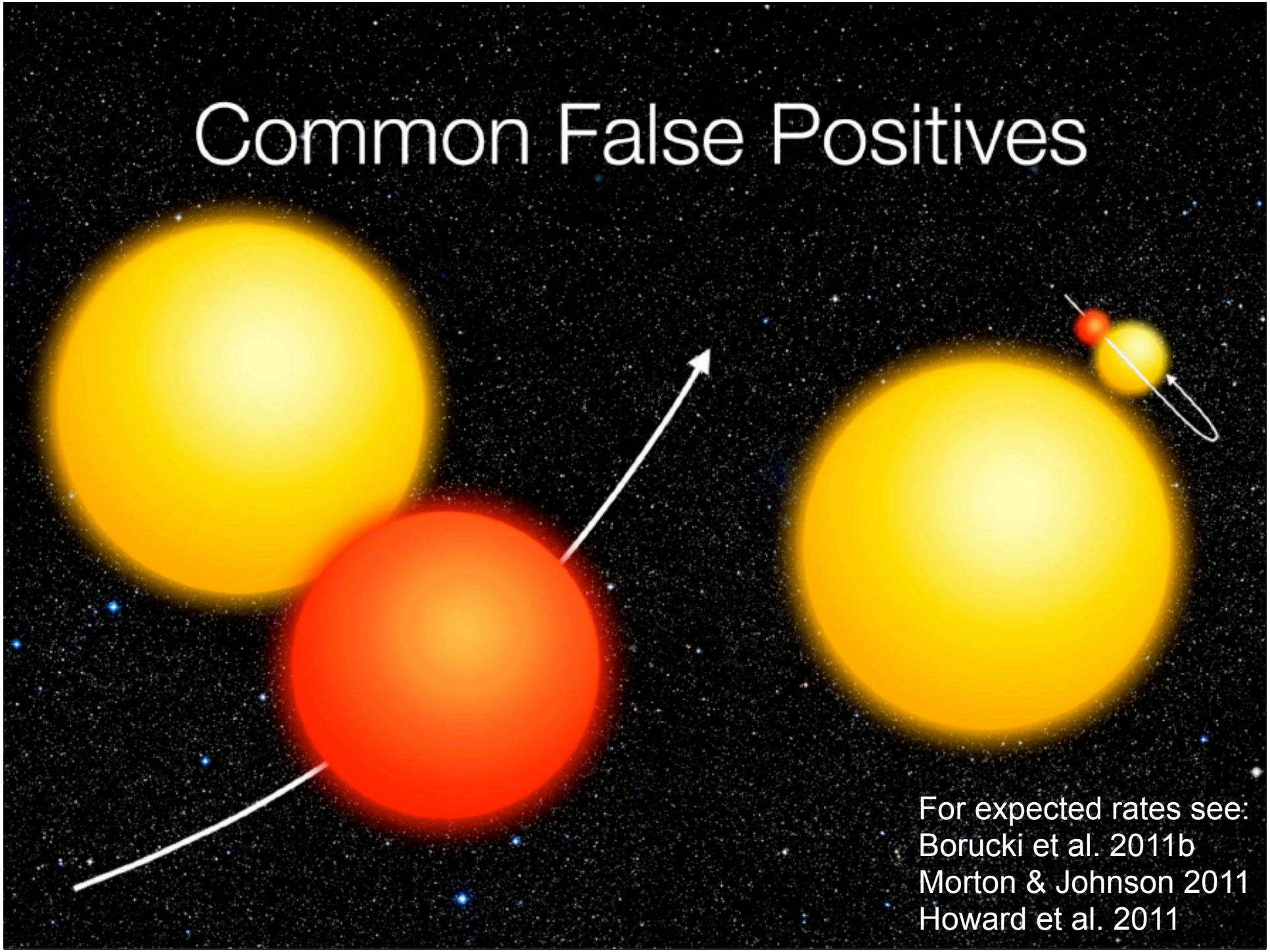
185K - 303K

Dec: 48

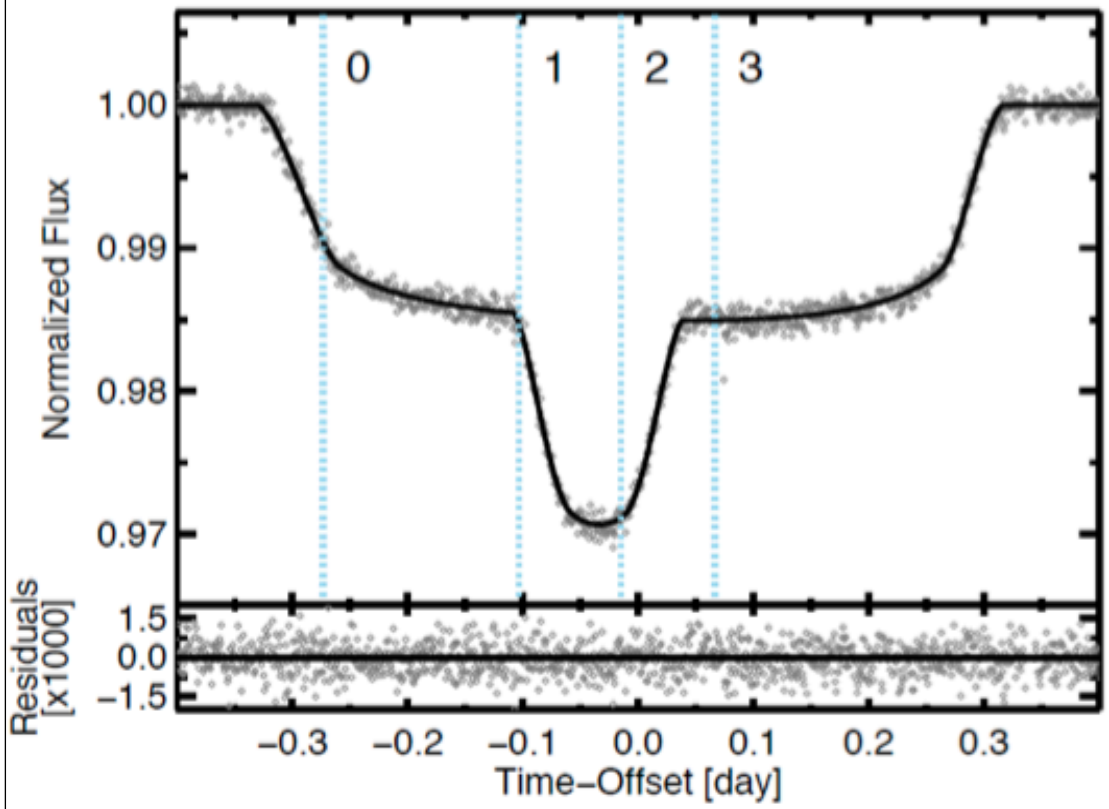
Feb: 25

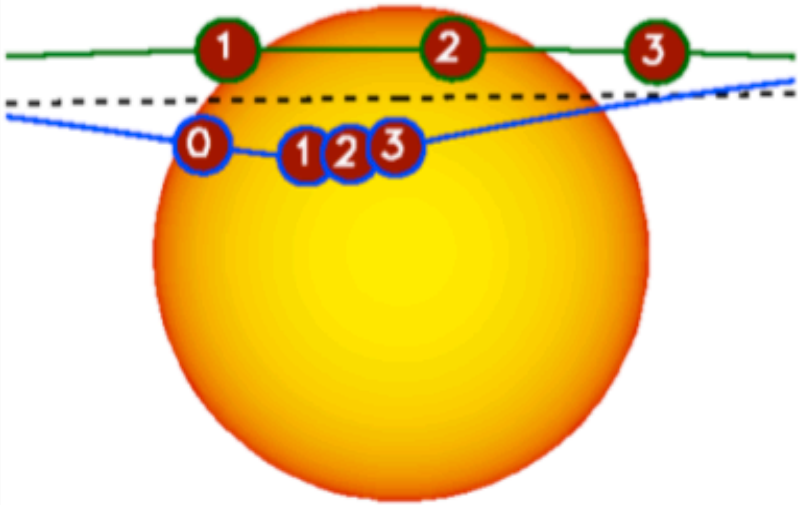
Ten Near-Earth-Size Candidates in the Habitable Zone (185-303 K)



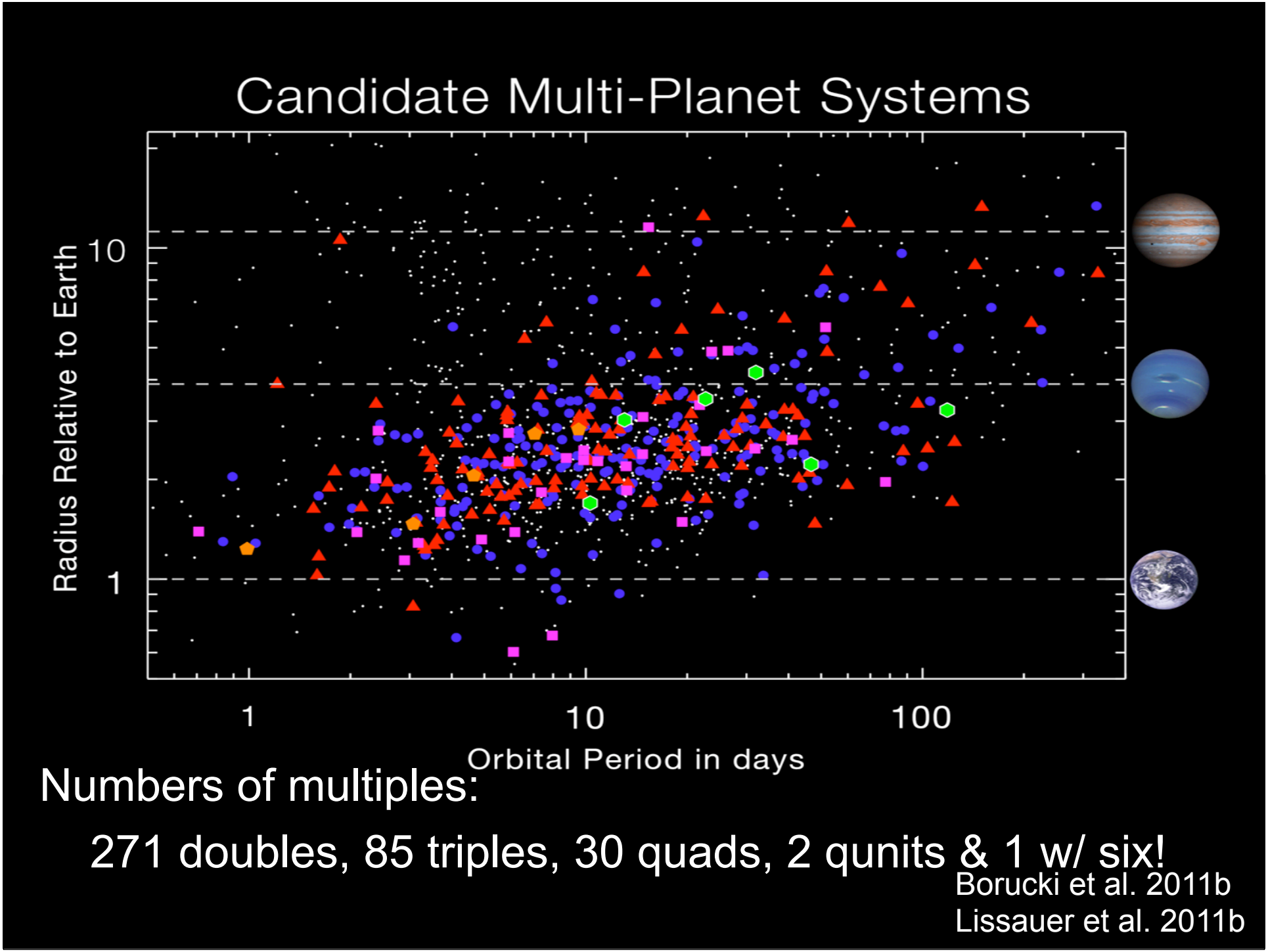

Common False Positives
For expected rates see:
Borucki et al. 2011b
Morton & Johnson 2011
Howard et al. 2011

- KOI-126





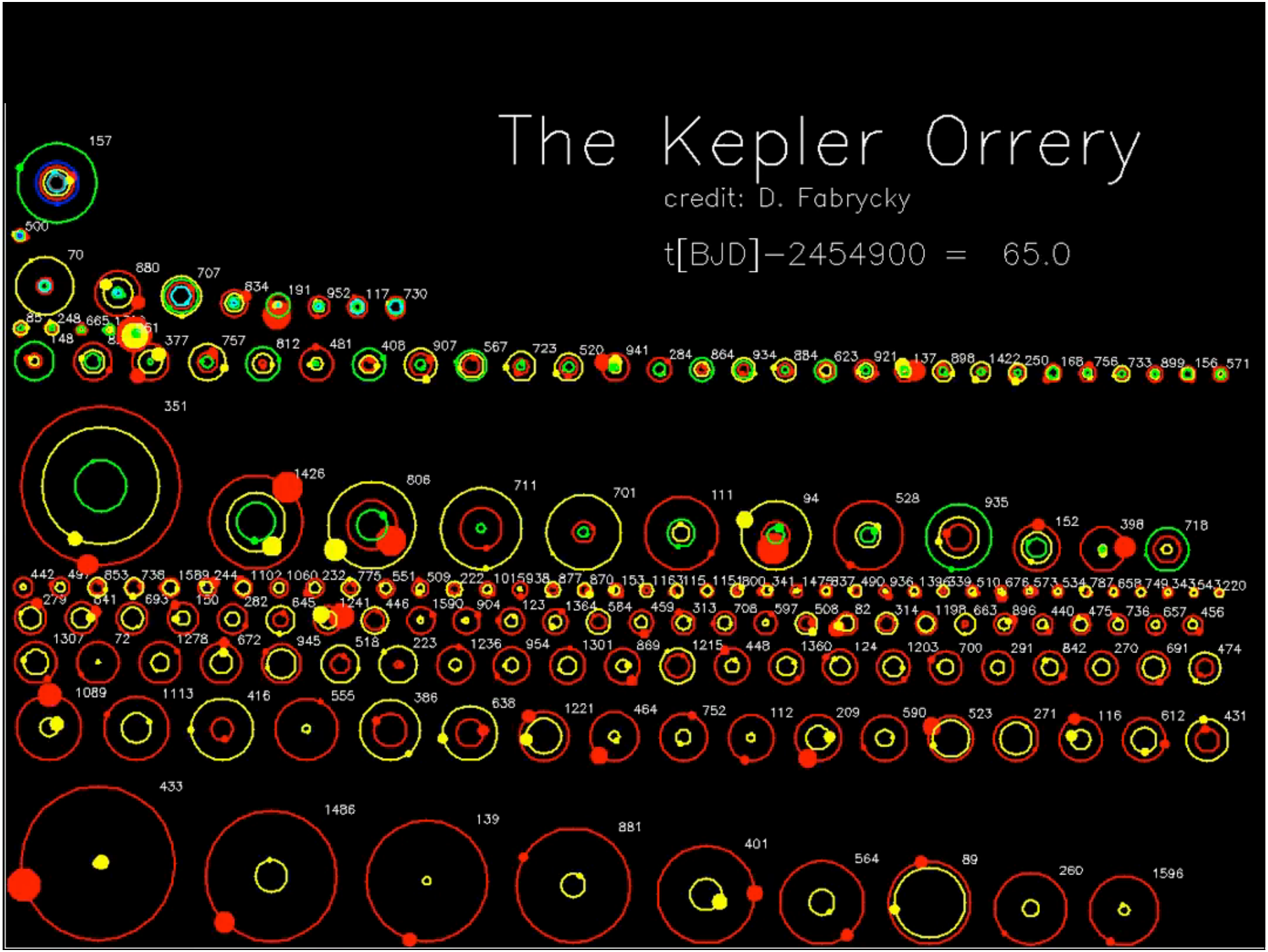
Carter et al. 2010



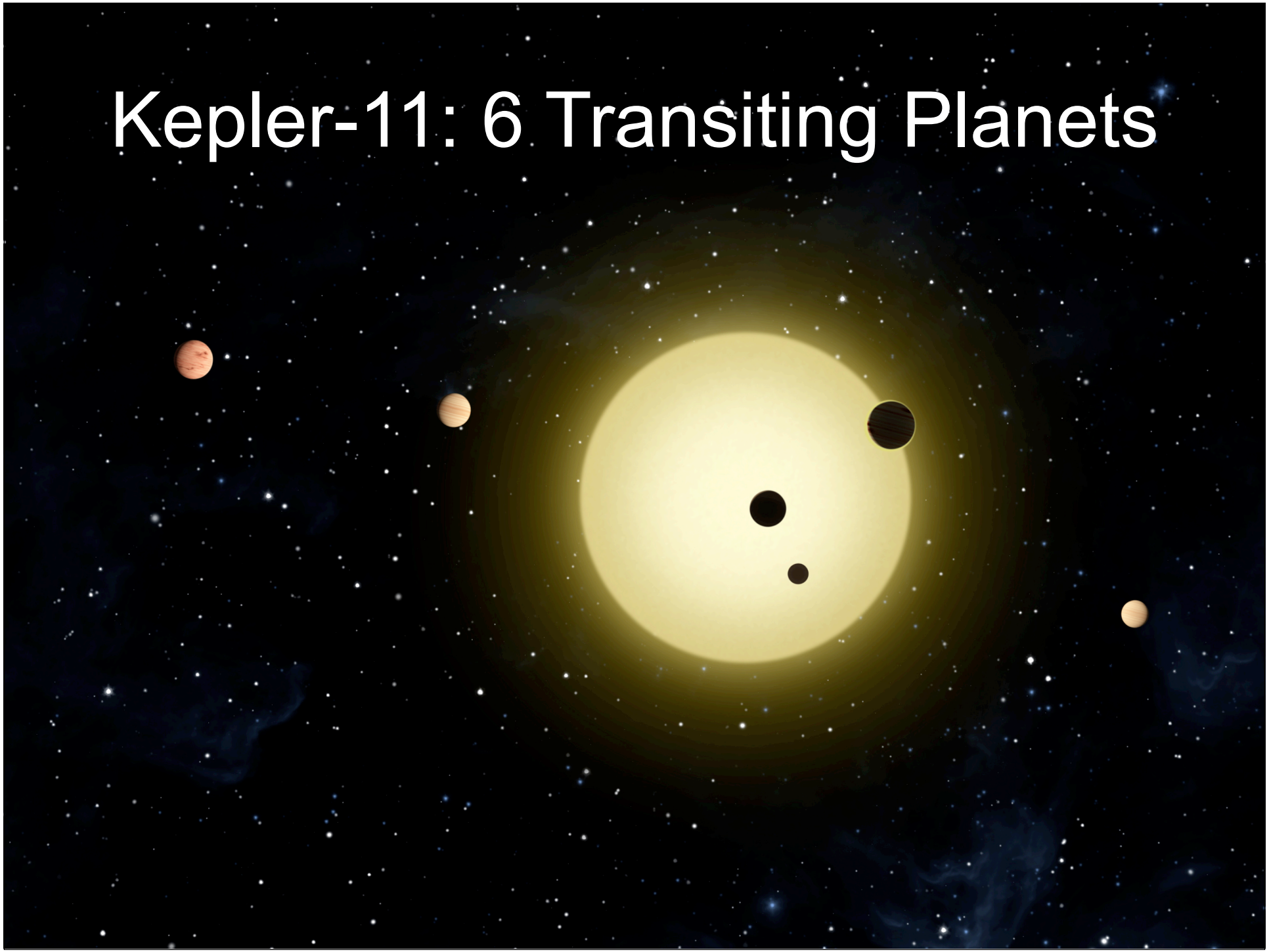
Numbers of multiples:

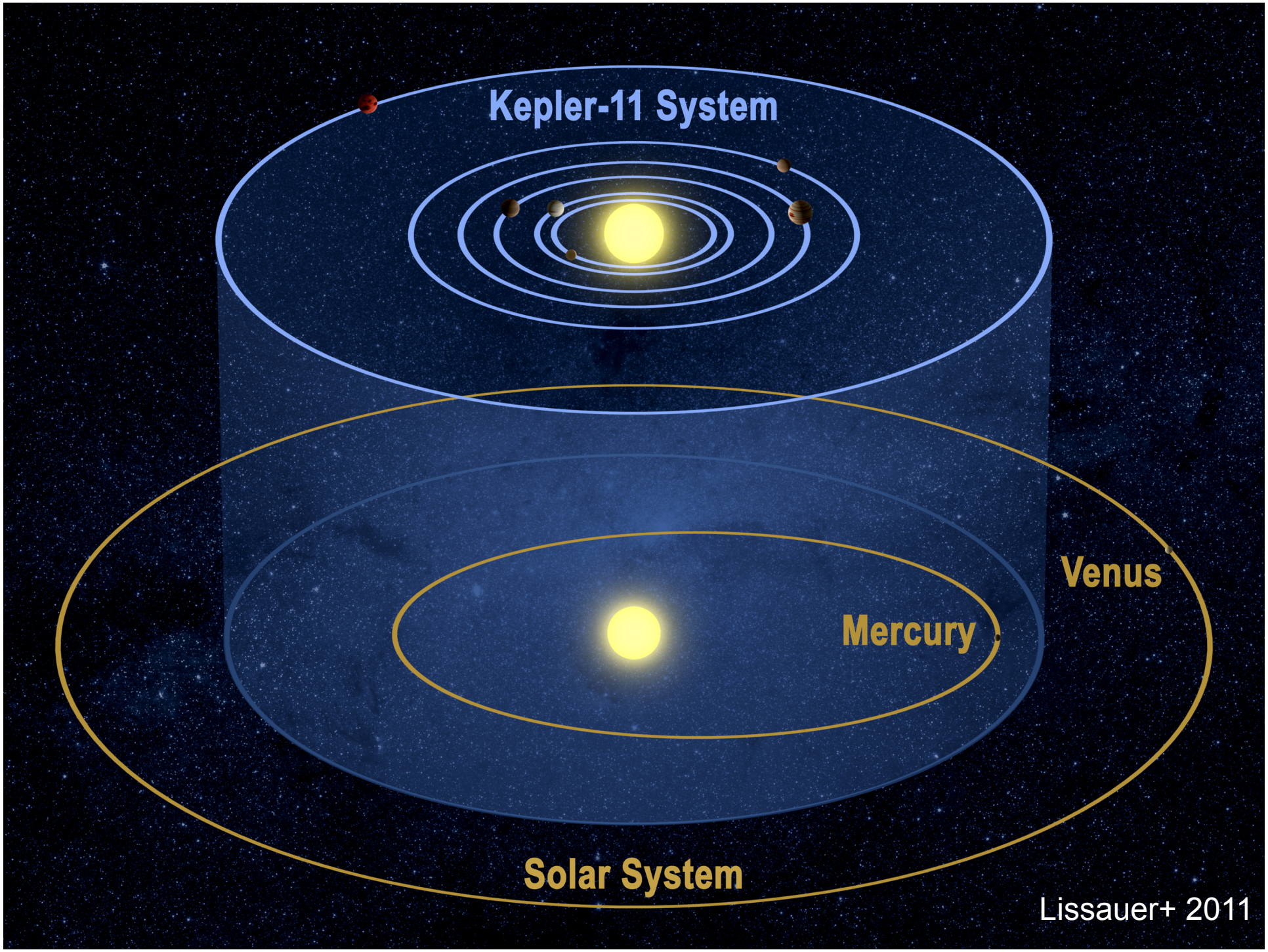
271 doubles, 85 triples, 30 quads, 2 qunits & 1 w/ six!

Borucki et al. 2011b
Lissauer et al. 2011b

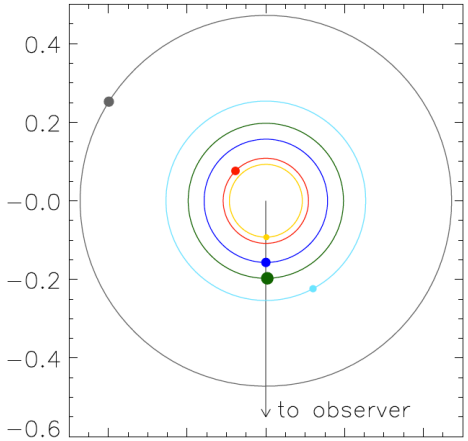

The Kepler Orrery
credit: D. Fabrycky
t[BJD]−2454900 = 65.0

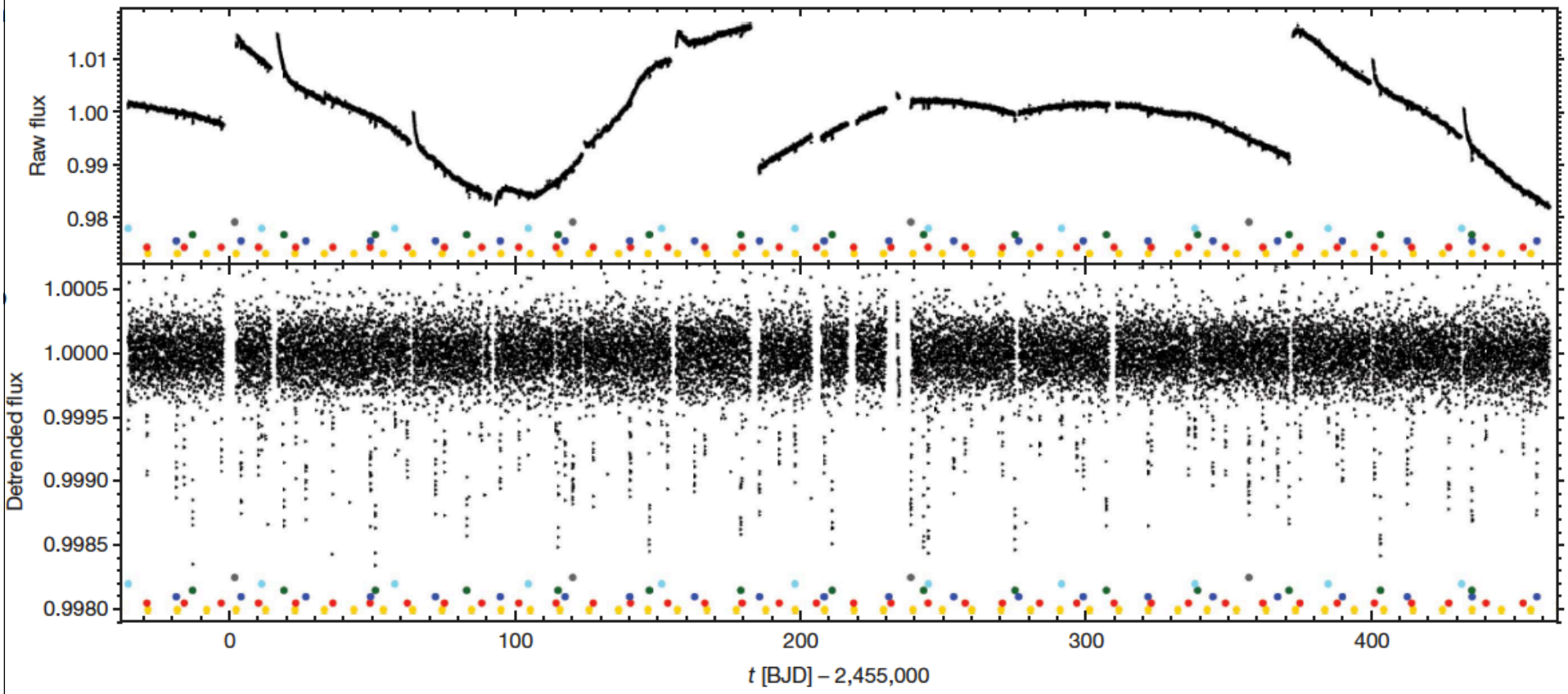
Kepler-11: 6 Transiting Planets



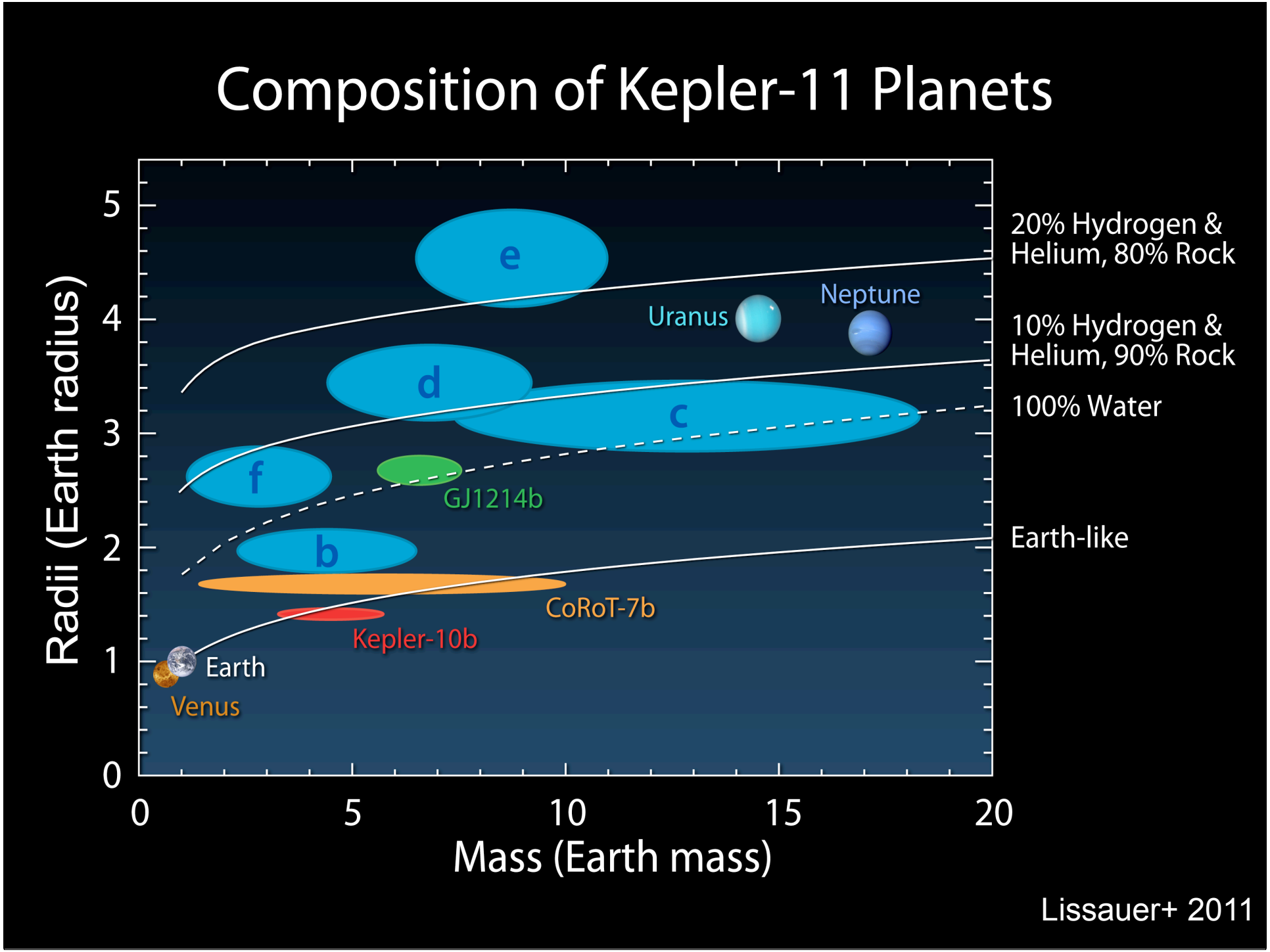

Kepler-11 System
Venus
Mercury
Solar System
Lissauer+ 2011

Kepler-11



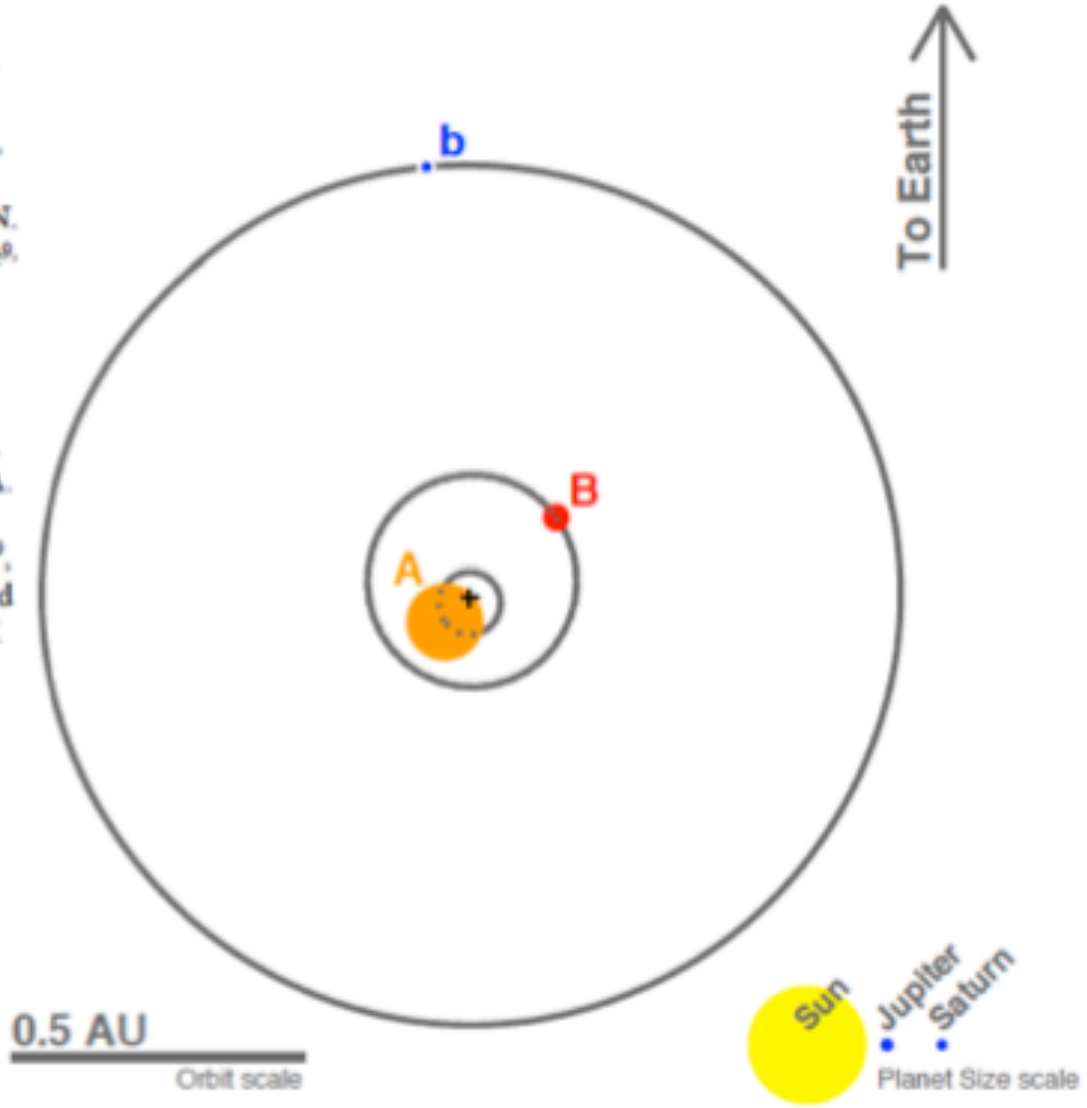


Lissauer, Fabrycky, Ford et al. 2011

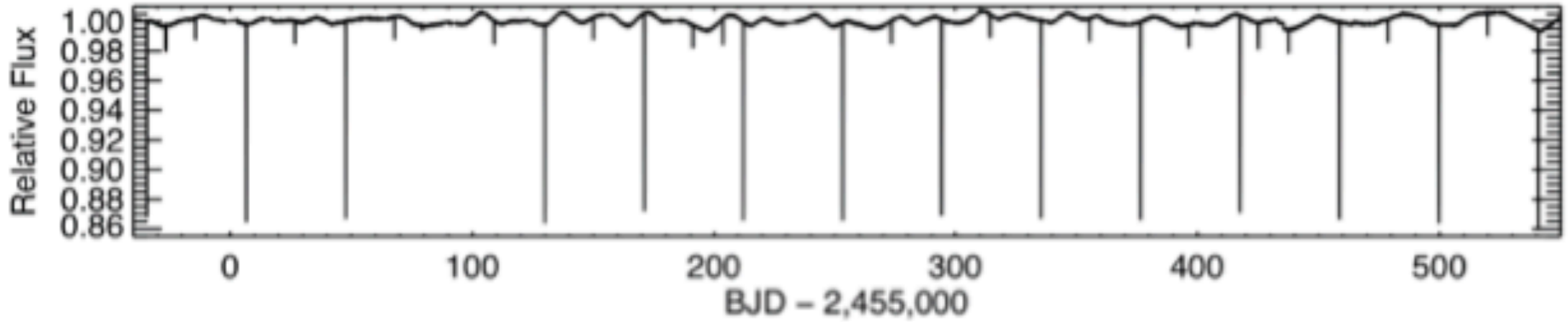

Composition of Kepler-11 Planets
Radii (Earth radius)
Mass (Earth mass)
0
1
2
3
4
5
0
5
10
15
20
e
d
c
f
b
Uranus
Neptune
GJ1214b
CoRoT-7b
Kepler-10b
Earth
Venus
20% Hydrogen & Helium, 80% Rock
10% Hydrogen & Helium, 90% Rock
100% Water
Earth-like
Lissauer+ 2011

Kepler-16: A Transiting Circumbinary Planet

Laurance R. Doyle[1], Joshua A. Carter[2], Daniel C. Fabrycky[3], Robert W. Slawson[1], Steve B. Howell[4], Joshua N. Winn[5], Jerome A. Orosz[6], Andrej Pr˘sa[7], William F. Welsh[6], Samuel N. Quinn[8], David Latham[8], Guillermo Torres[8], Lars A. Buchhave[9, 10], Geoffrey W. Marcy[11], Jonathan J. Fortney[12], Avi Shporer[13,14], Eric B. Ford[15], Jack J. Lissauer[4], Darin Ragozzine[2], Michael Rucker[16], Natalie Batalha[16], Jon M. Jenkins[1], William J. Borucki[4], David Koch[4], Christopher K. Middour[17], Jennifer R. Hall[17], Sean McCauliff[17], Michael N. Fanelli[18], Elisa V. Quintana[1], Matthew J. Holman[8], Douglas A. Caldwell[1], Martin Still[18], Robert P. Stefanik[8], Warren R. Brown[8], Gilbert A. Esquerdo[8], Sumin Tang[8], Gabor Furesz[8,19], John C. Geary[8], Perry Berlind[20], Michael L. Calkins[20], Donald R. Short[21], Jason H. Steffen[22], Dimitar Sasselov[8], Edward W. Dunham[23], William D. Cochran[24], Alan Boss[25], Michael R. Haas[4], Derek Buzasi[26], Debra Fischer[27]



Kepler-16



Kepler

Eccentricities, Inclinations & Multiplicity

Three key probes of planet formation:

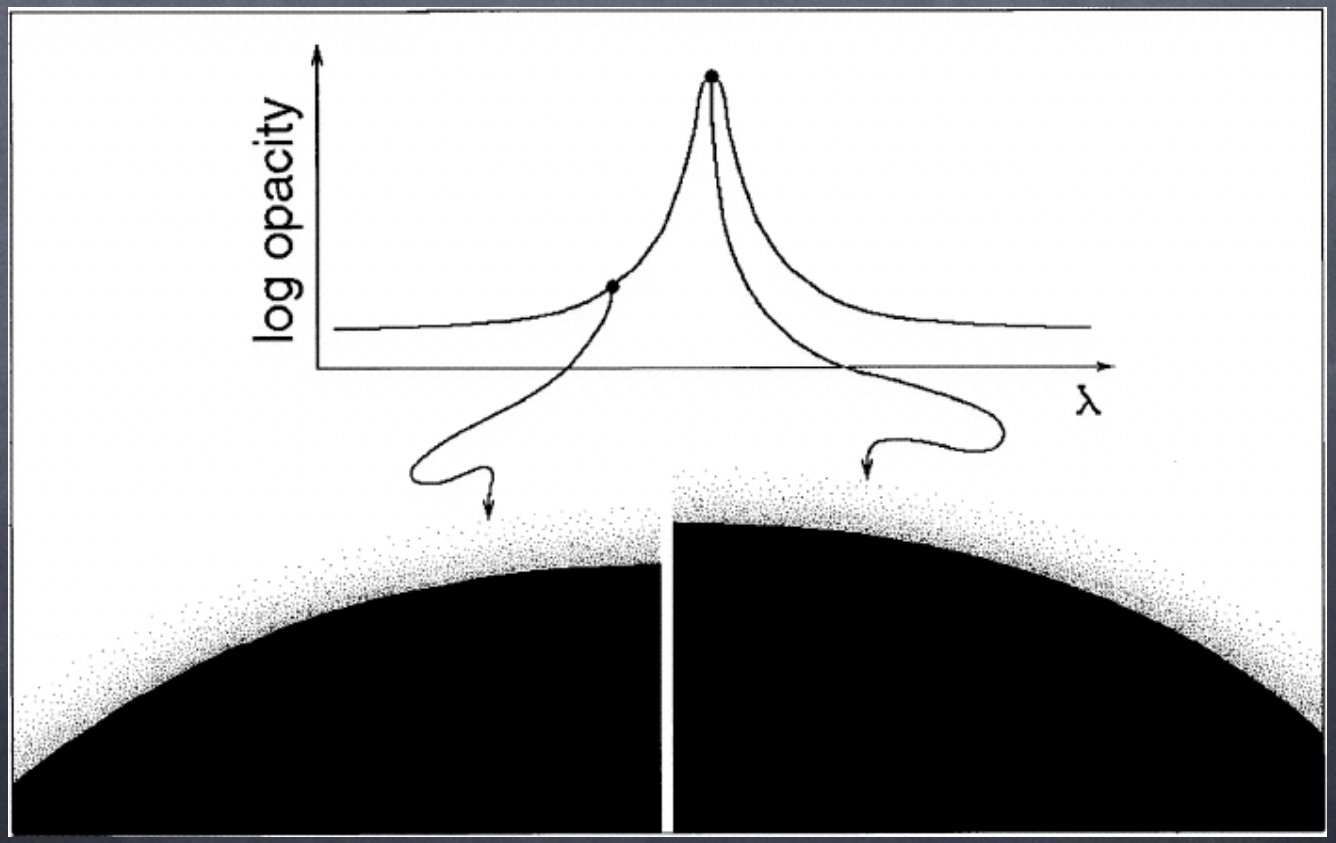
- Eccentricity distribution (+ stellar densities) →
  Transit duration distribution
- Inclination distribution + Frequency of multiple planet systems (+ Period distribution) →
  Frequency of multiply transiting systems
- Frequency of multiple planet systems + Eccentricity Distribution (+ Period distribution) →
  Distribution of TTV signatures

One complex inverse problem!

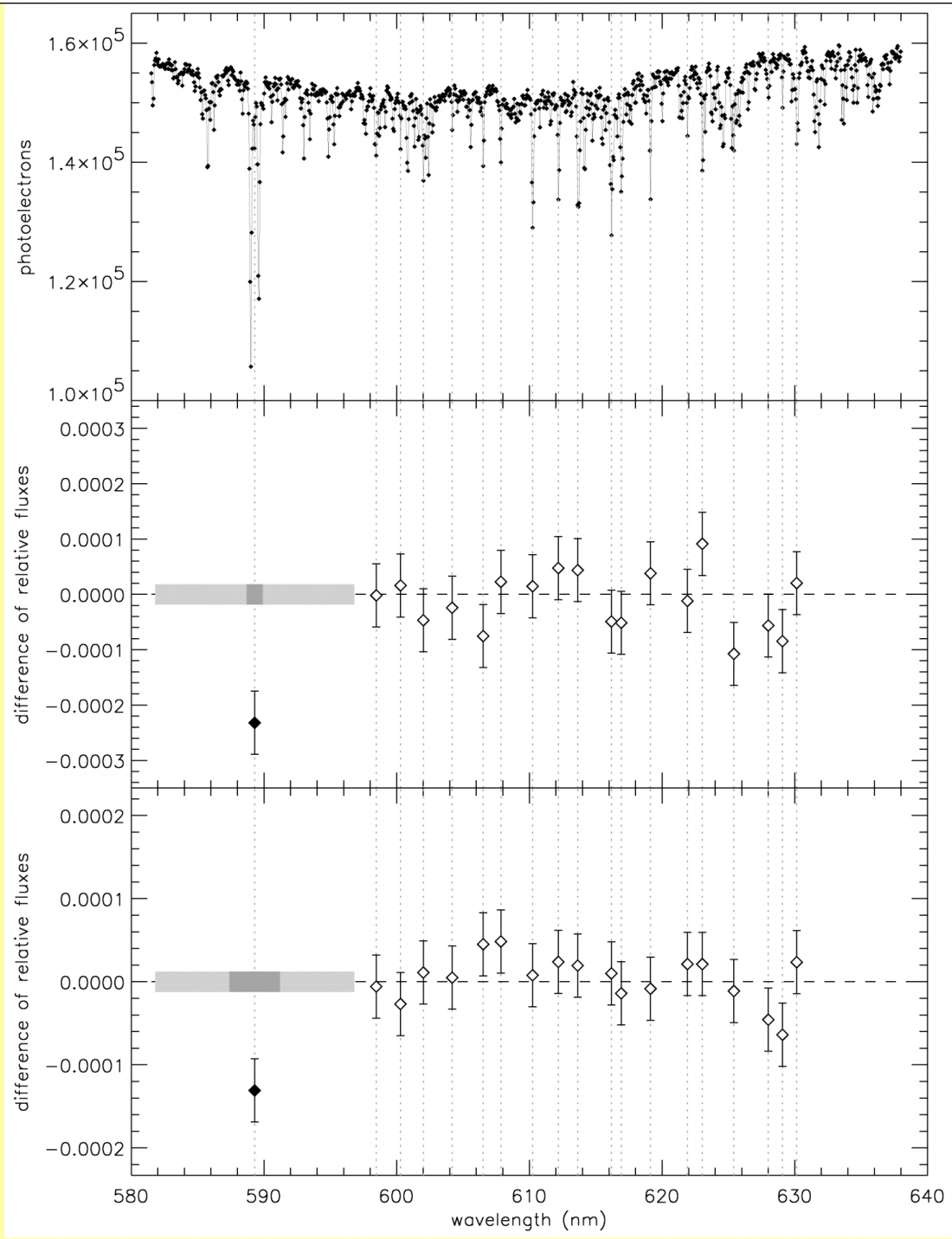
(Observables, Desired Distributions, Both)

Atmosphere:

The tricks of transmission spectroscopy:



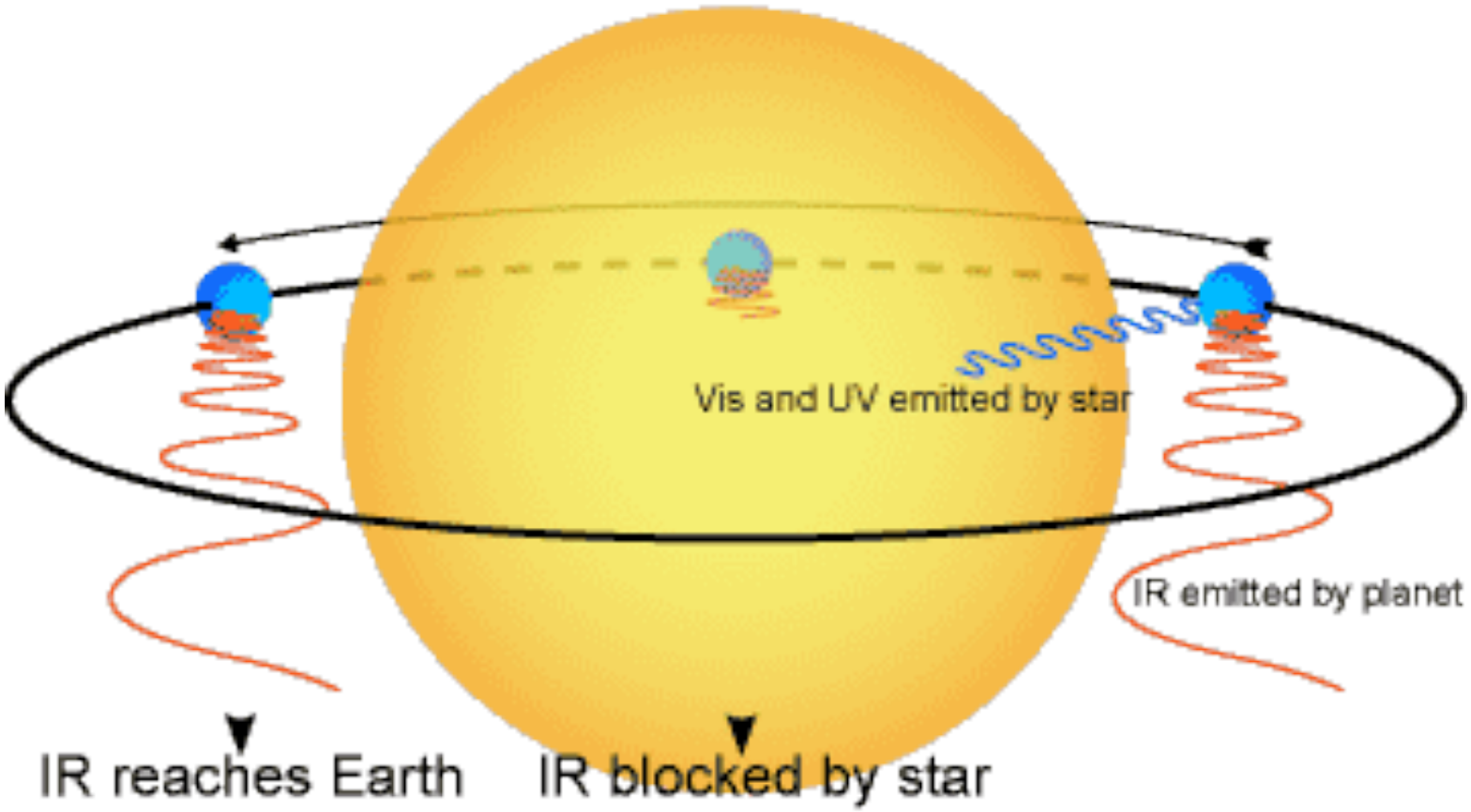
The actual detection (with the HST):

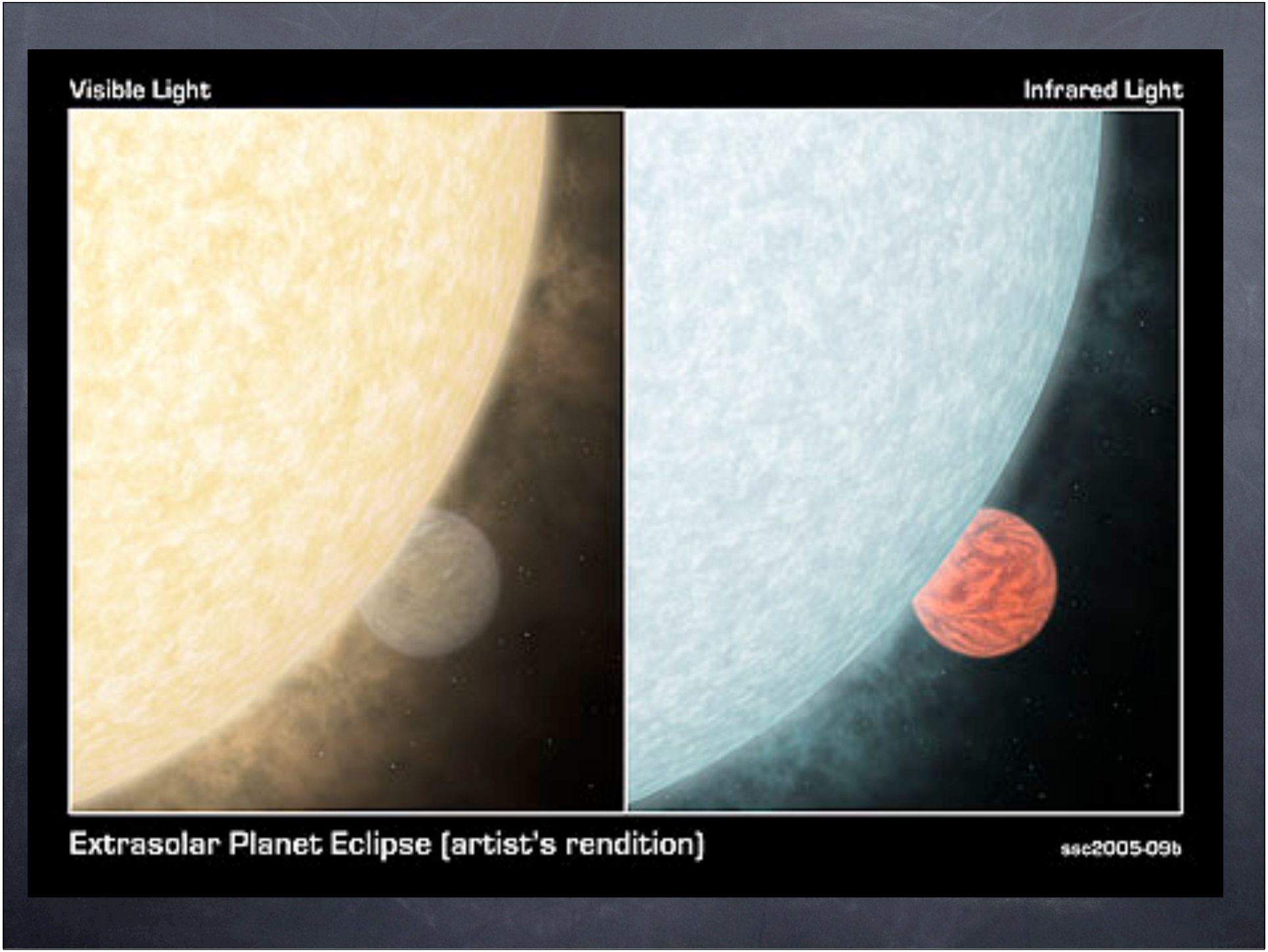


Charbonneau et al. (2002)

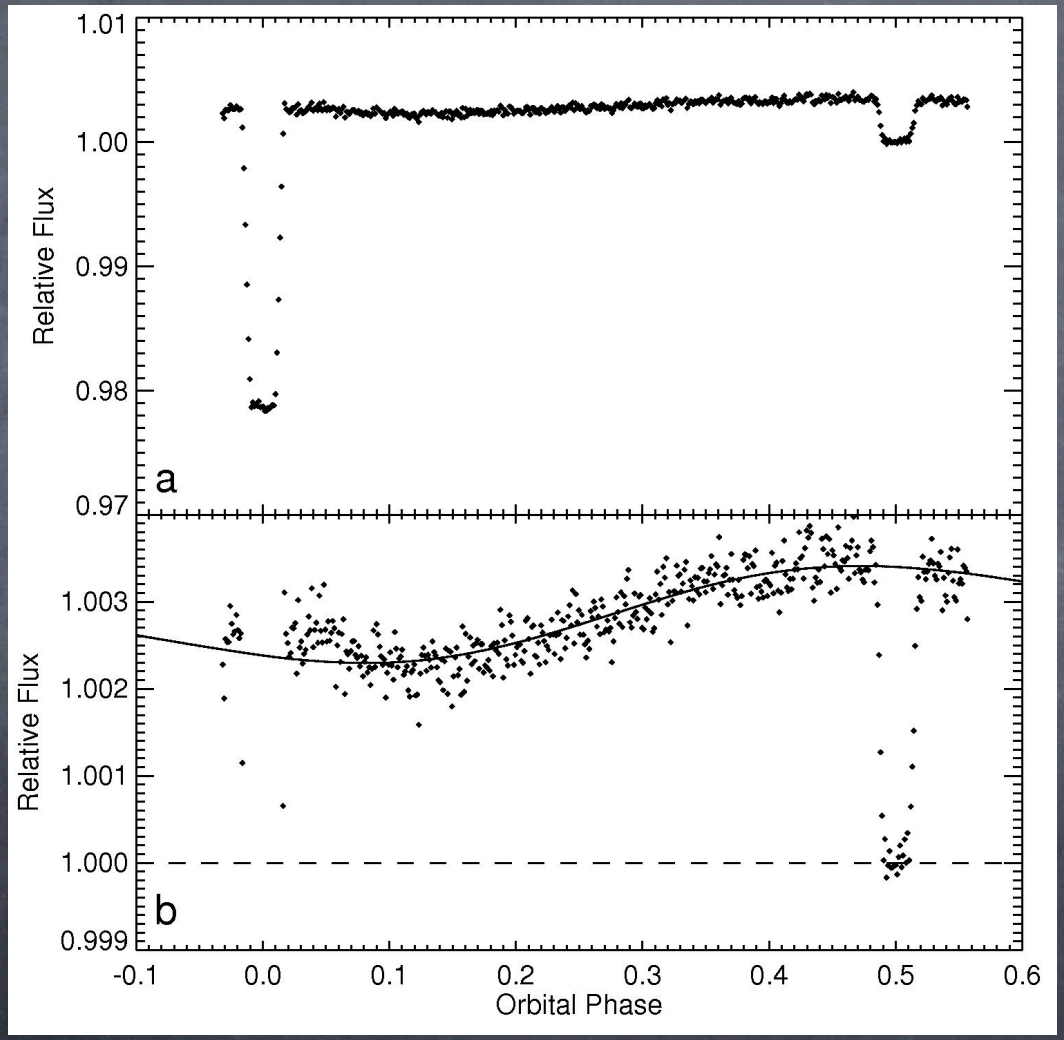
Secondary Transits

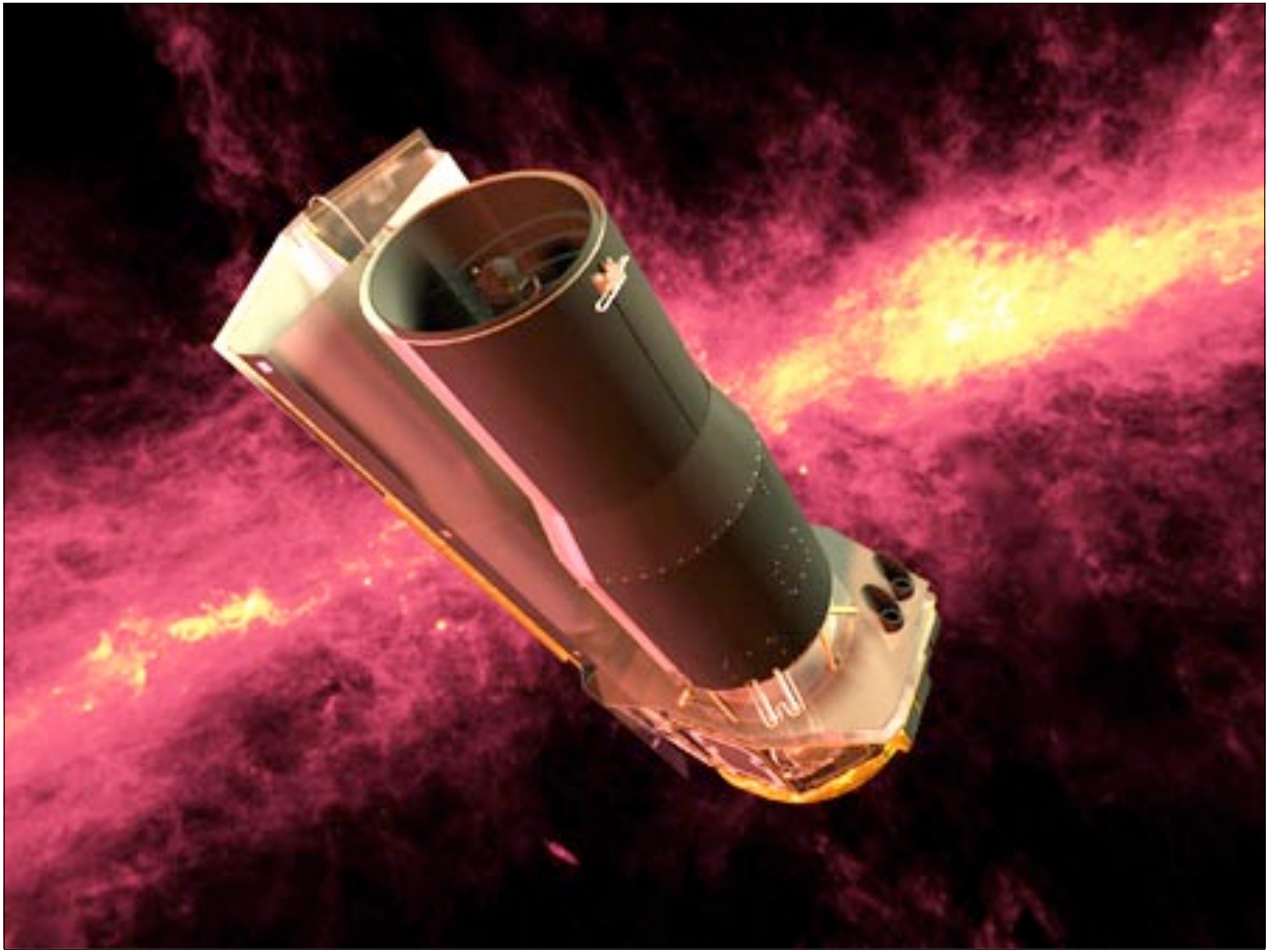
Planet TrES-1 Passing Behind Its Star

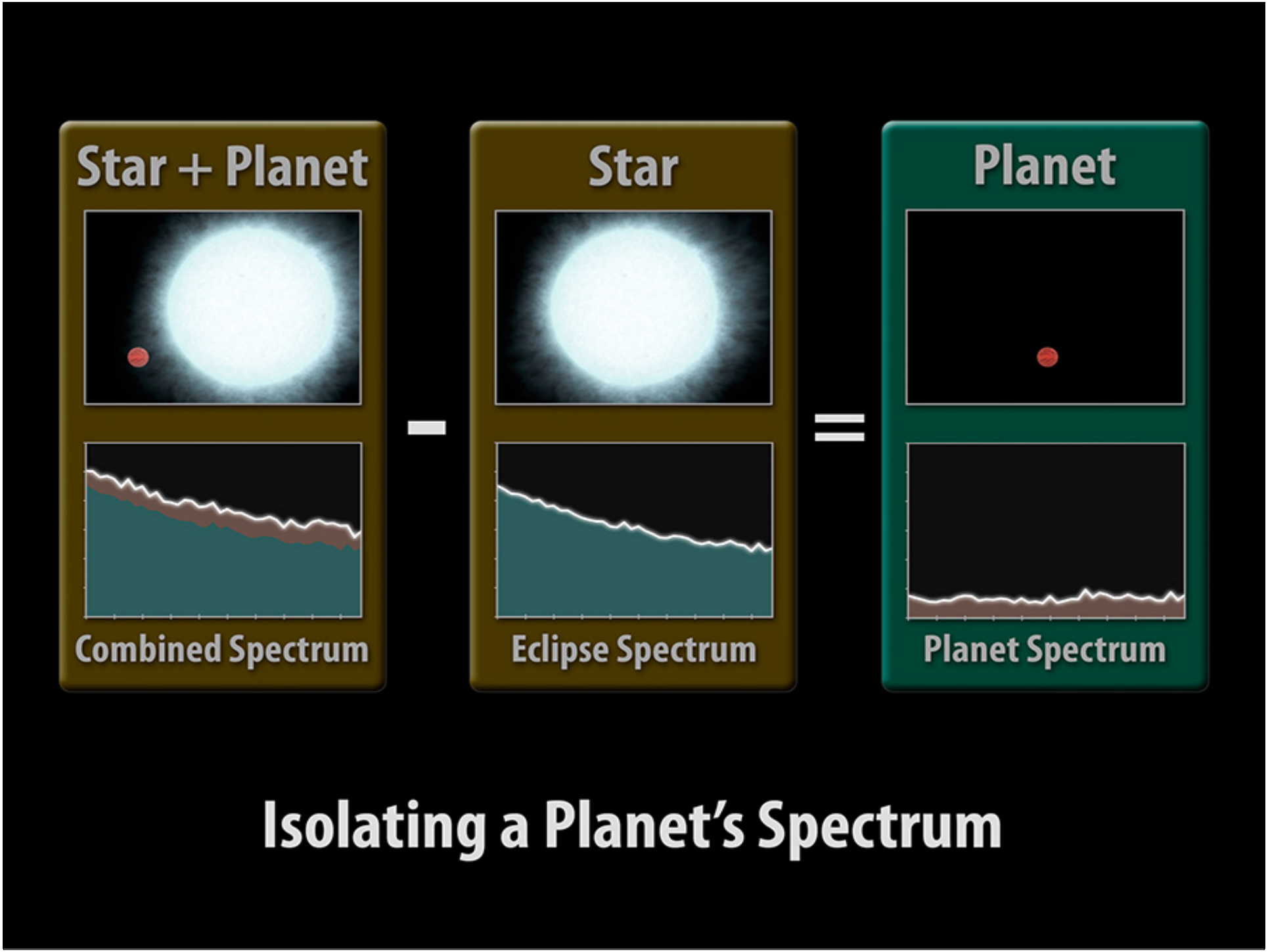



Visible Light
Infrared Light
Extrasolar Planet Eclipse (artist's rendition)
ssc2005-09b

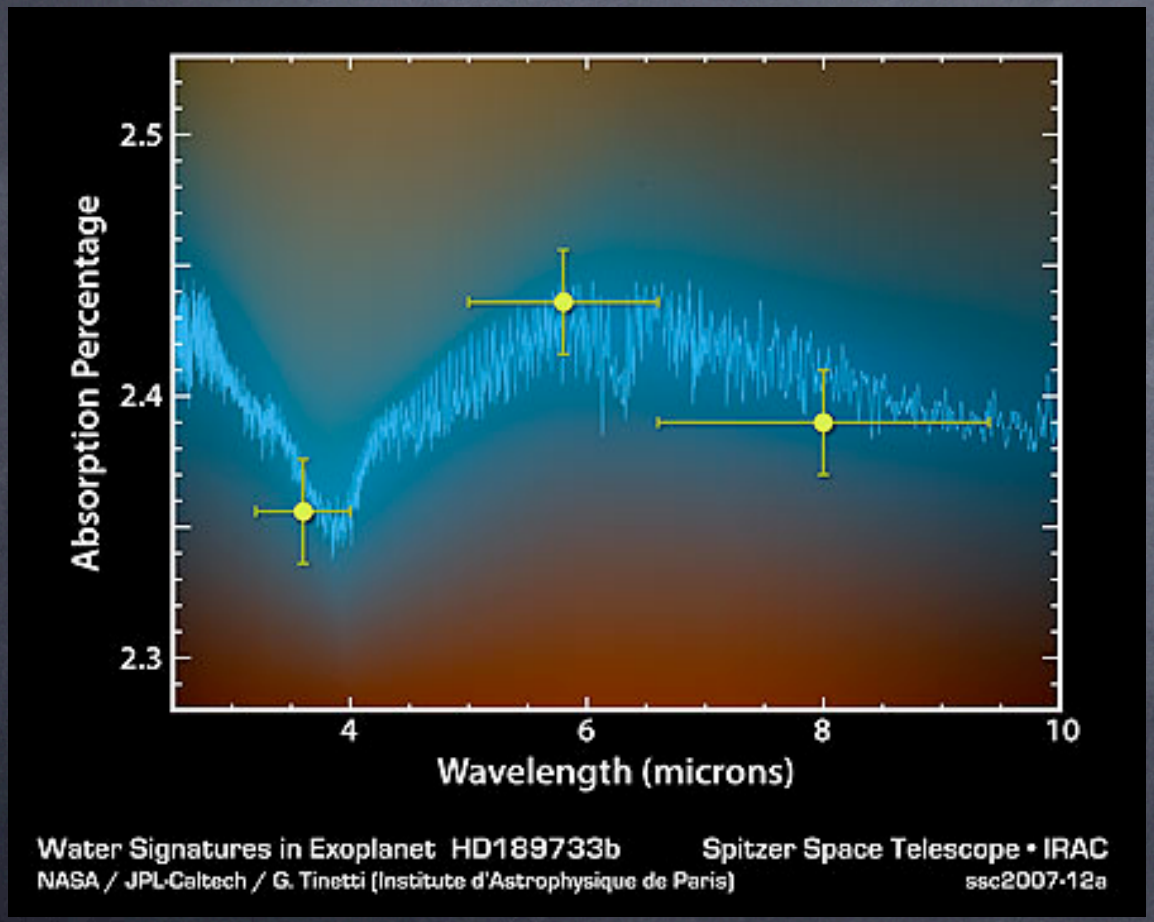
Transit lightcurve HD189733






Star + Planet
Star
Planet
Combined Spectrum
Eclipse Spectrum
Planet Spectrum
Isolating a Planet's Spectrum

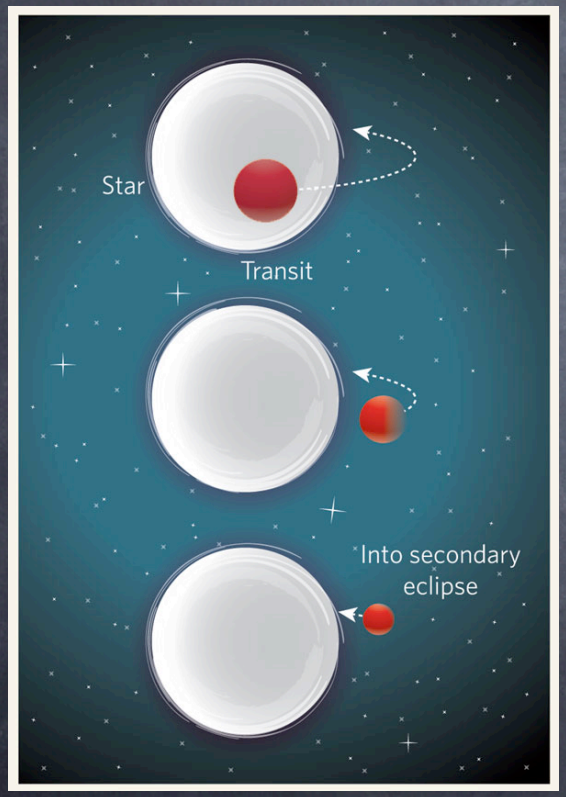
HD 189733b

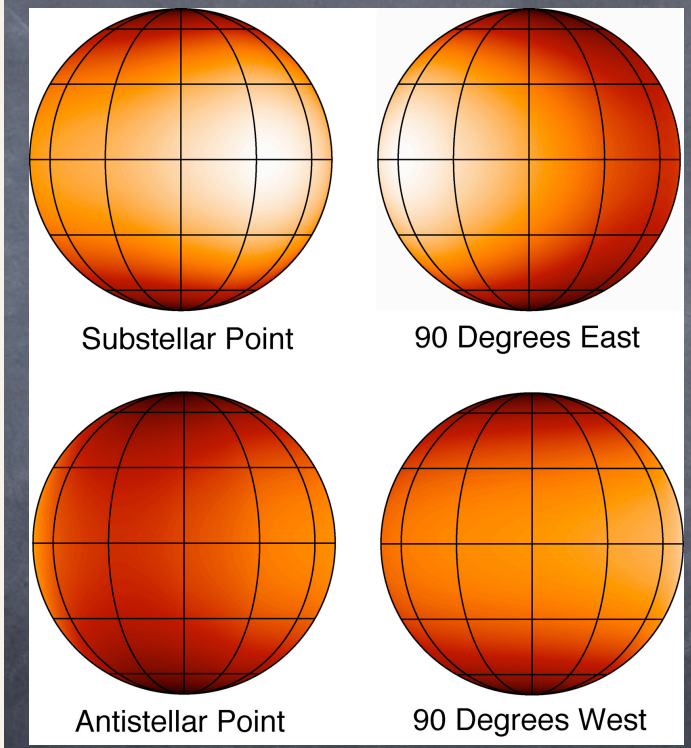


- Detection of H_2O

Tinetti et al. 2007, Nature 448, 169

Warm spot: HD 189733b





- Planet is in co-rotation, warmest spot should be toward star.
- Shifted because of winds

Knutson et al. 2007, Nature 447, 183

Map of surface temperature HD 189733b