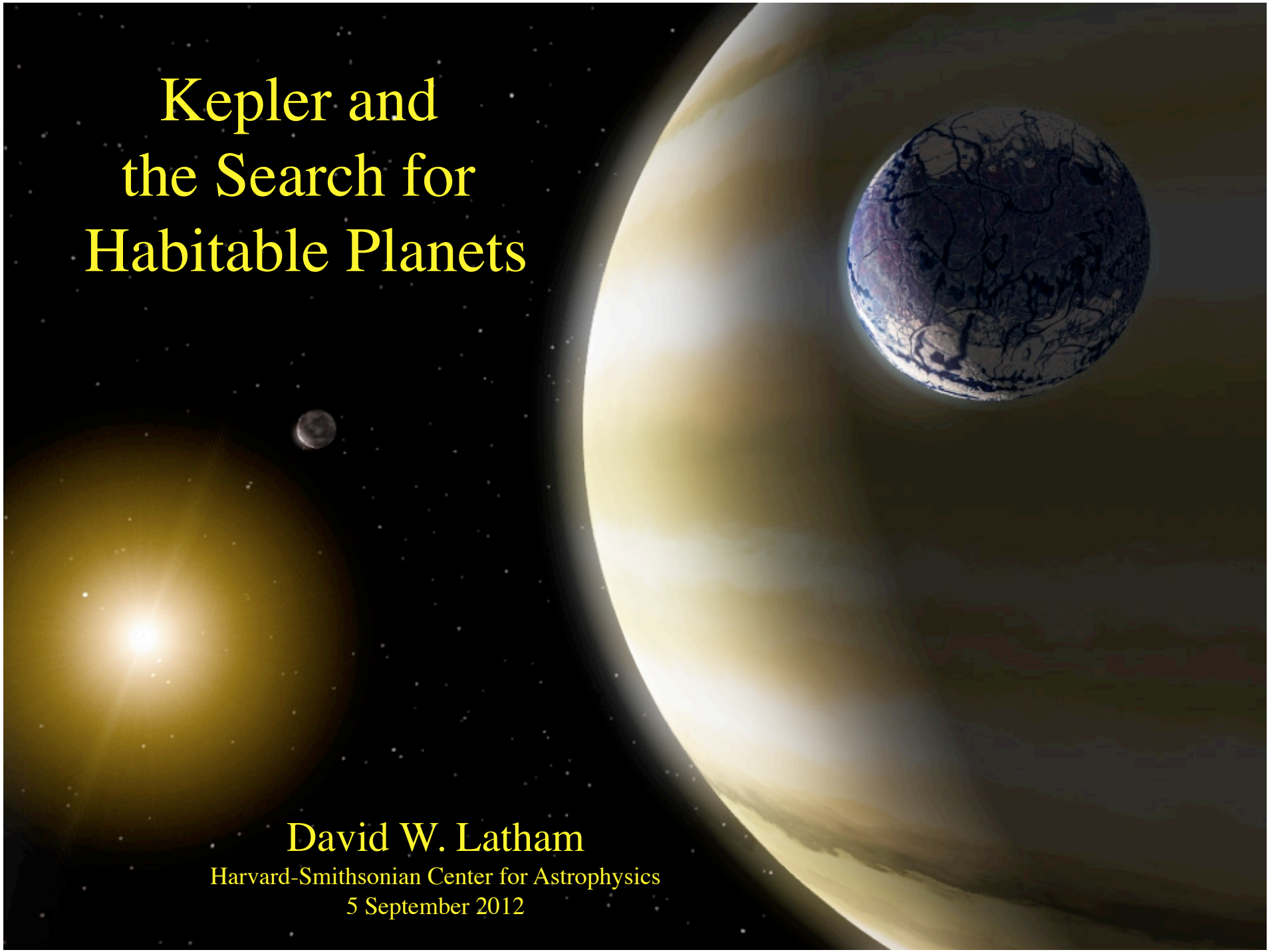
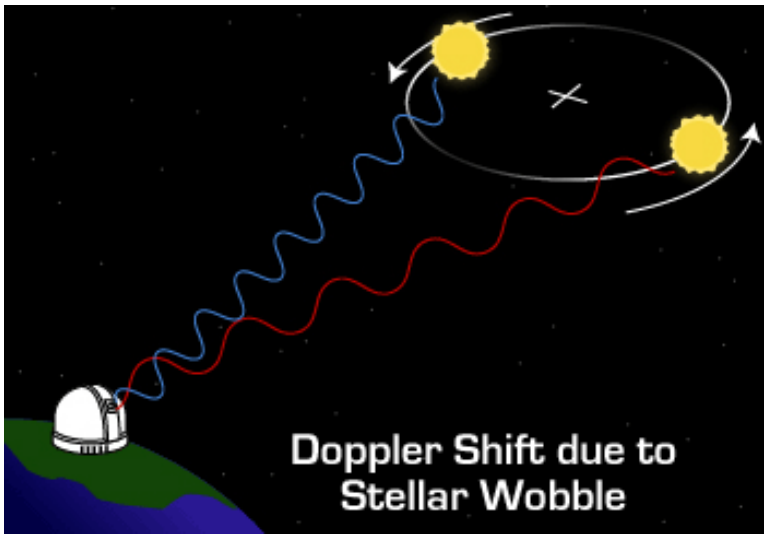
Kepler and the Search for Habitable Planets



David W. Latham
Harvard-Smithsonian Center for Astrophysics
5 September 2012

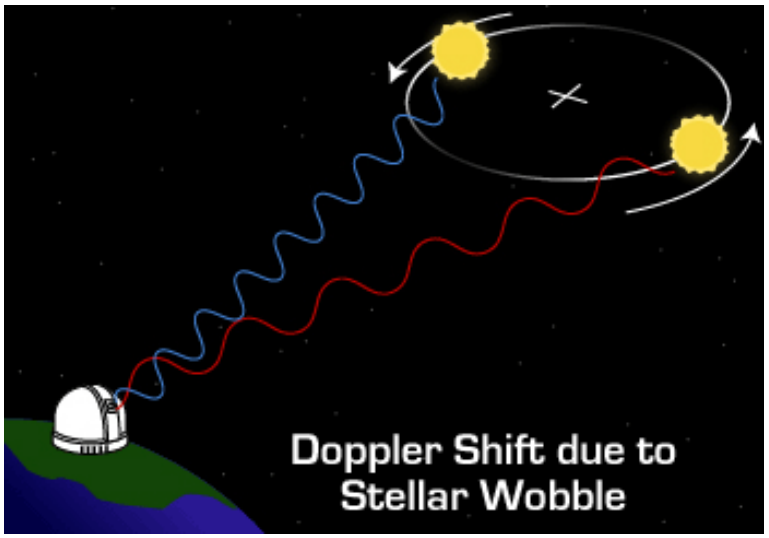
Astronomers have developed two clever *(but indirect)* methods to find exoplanets



Doppler Method

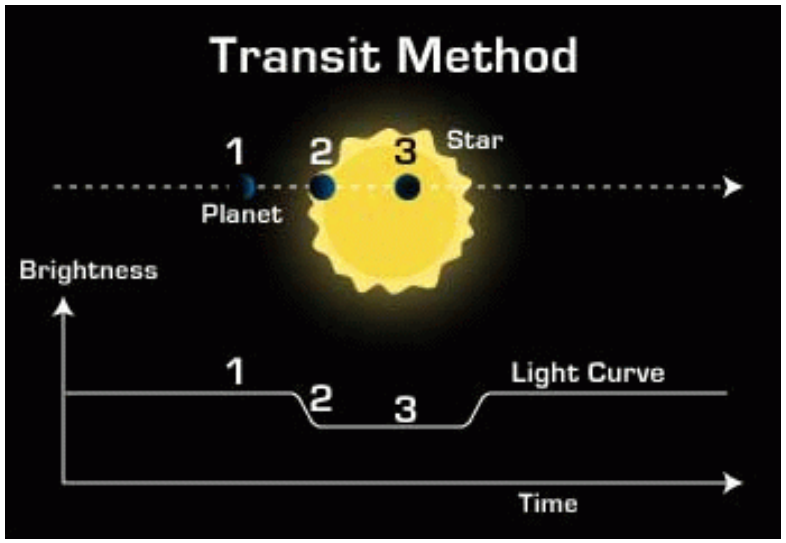
Determine Planet Mass

Astronomers have developed two clever *(but indirect)* methods to find exoplanets



Doppler Method

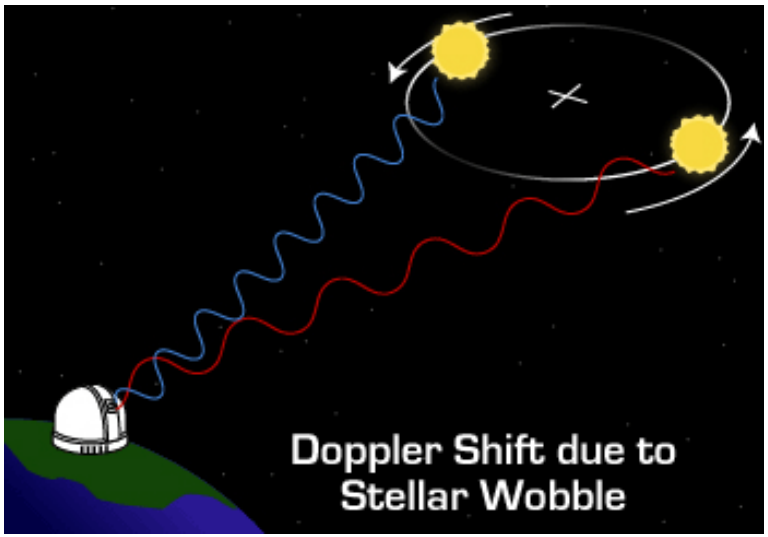
Determine Planet Mass

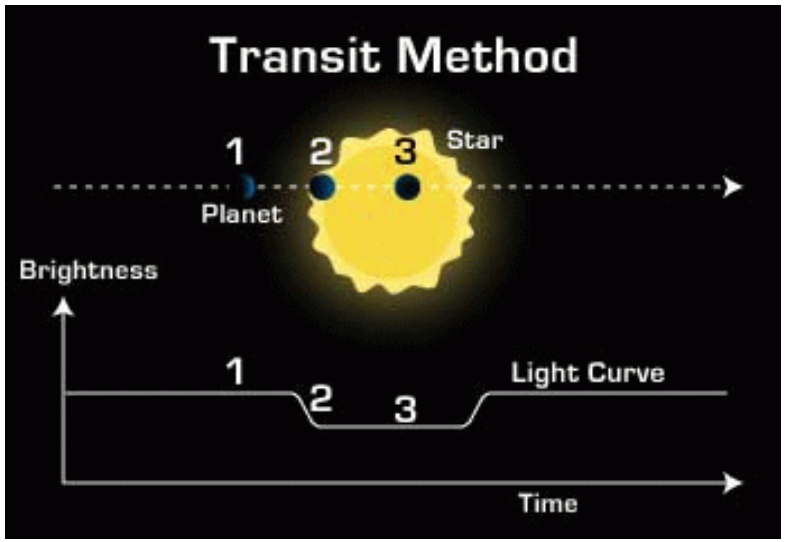


Transit Method

Determine Planet Diameter

Astronomers have developed two clever *(but indirect)* methods to find exoplanets





Doppler Method

Determine Planet Mass

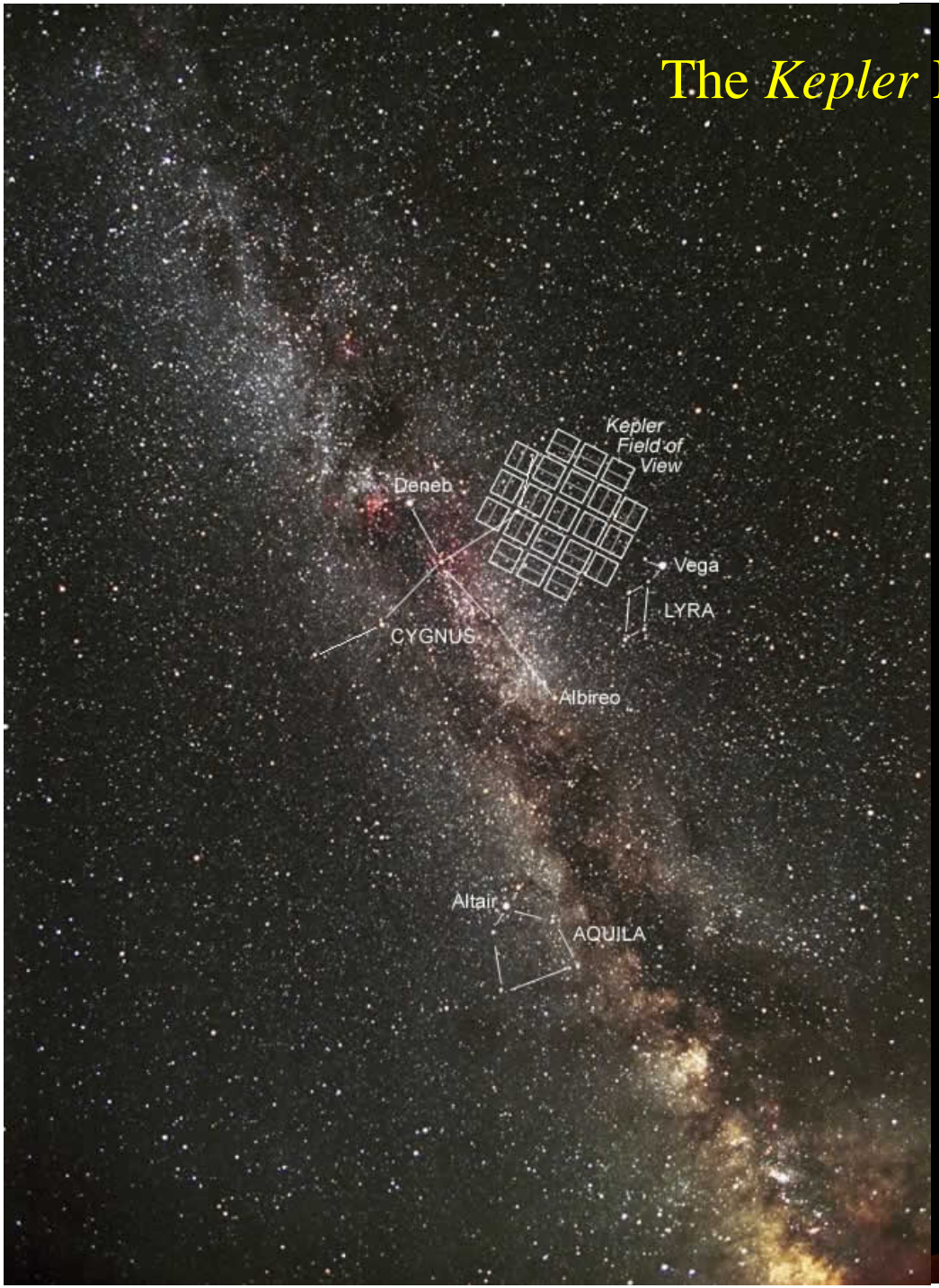
Transit Method

Determine Planet Diameter

Calculate Planet Density and Infer Composition:

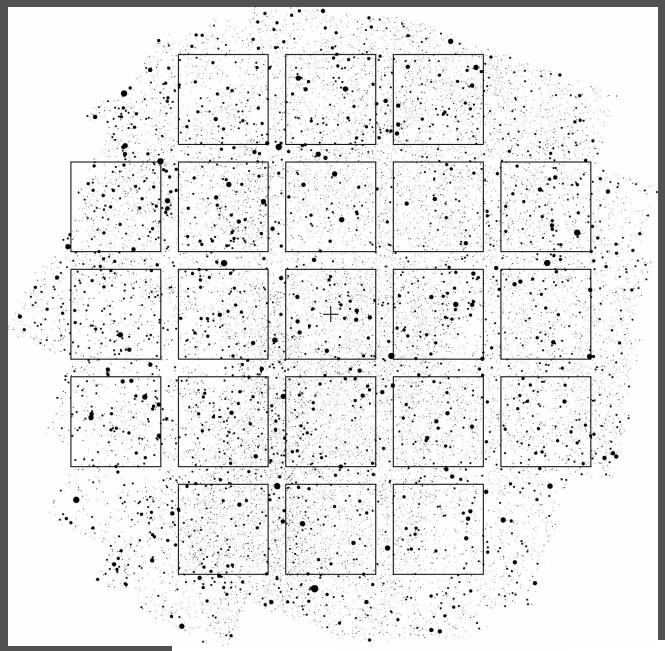
Gas giant (Jupiter), Ice giant (Neptune), or Rocky planet (Earth)

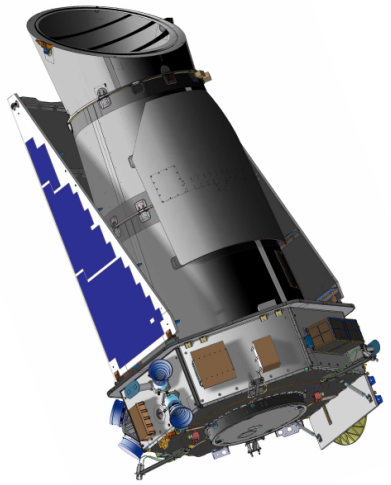
The *Kepler* Mission



Kepler Mission Concept

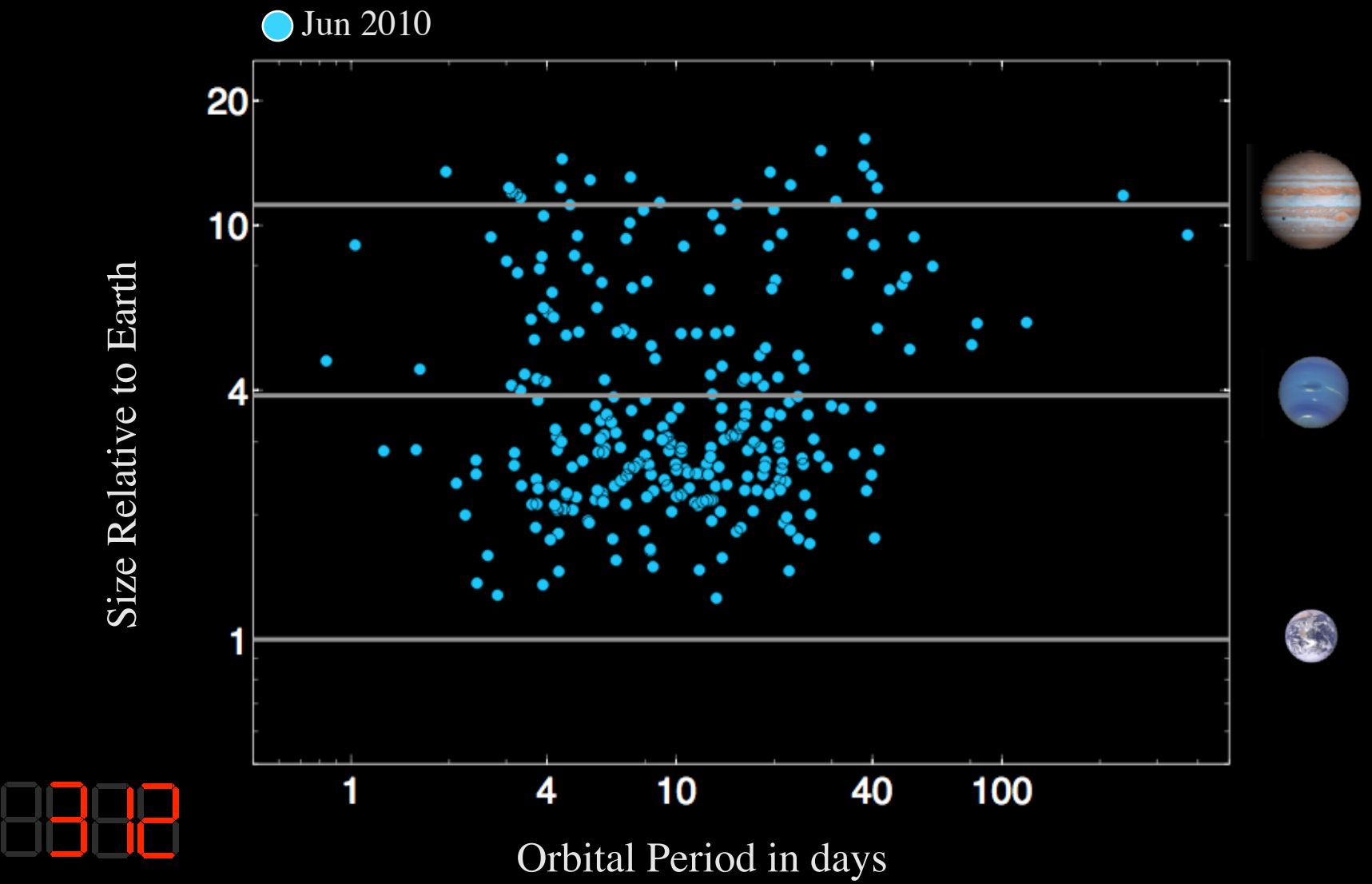
- *Kepler* is optimized to find transiting Earth-like planets
  - Radius down to 1 $R_{\oplus}$
  - Sun-like host star
  - Orbit out to 1 AU = 1 year
- Mission characteristics
  - 150,000 selected targets
  - Earth-trailing orbit for stability
  - Stare at one FOV for 3.5 years





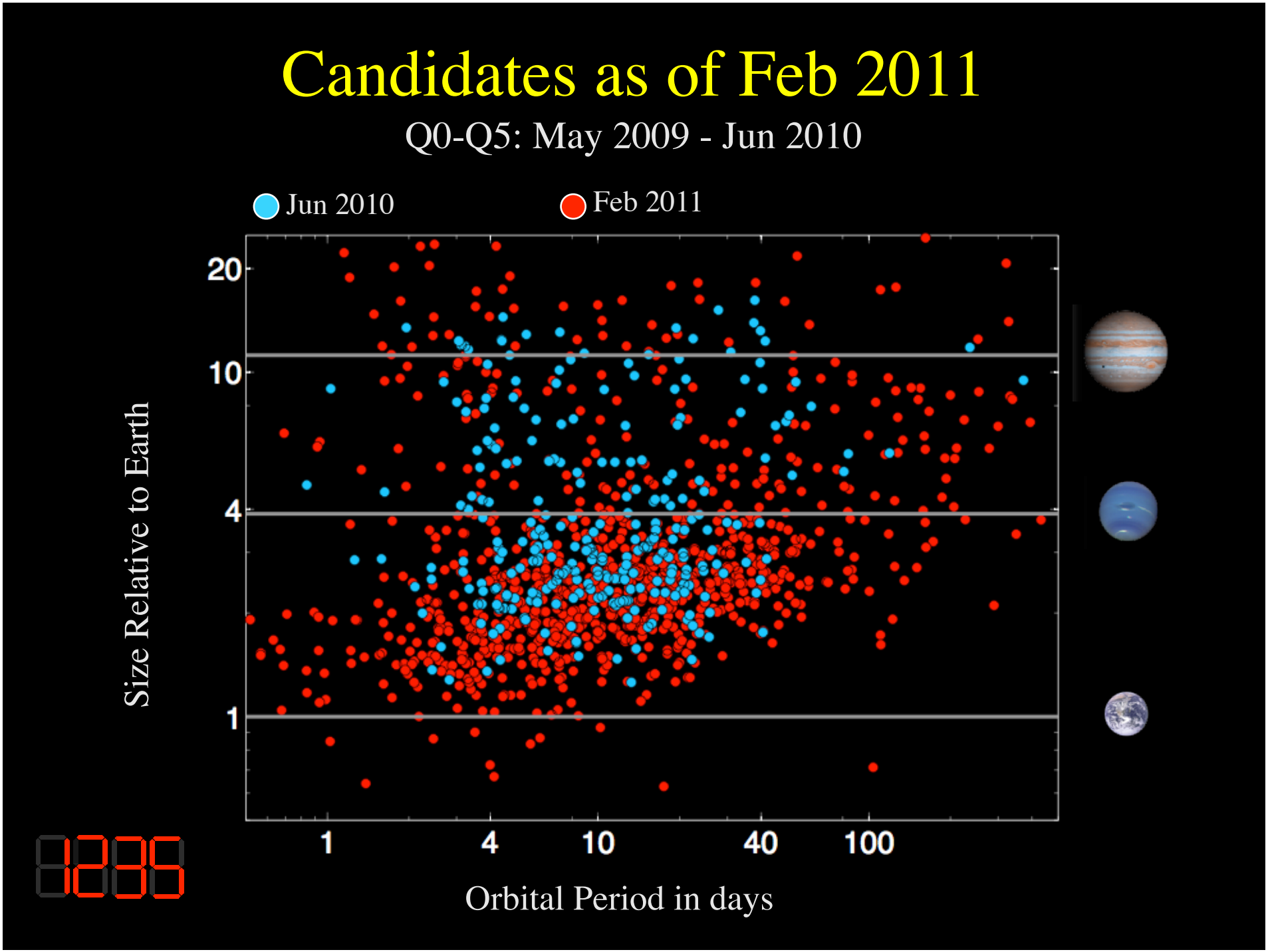
Candidates as of June 2010

Q0-Q1: May-June



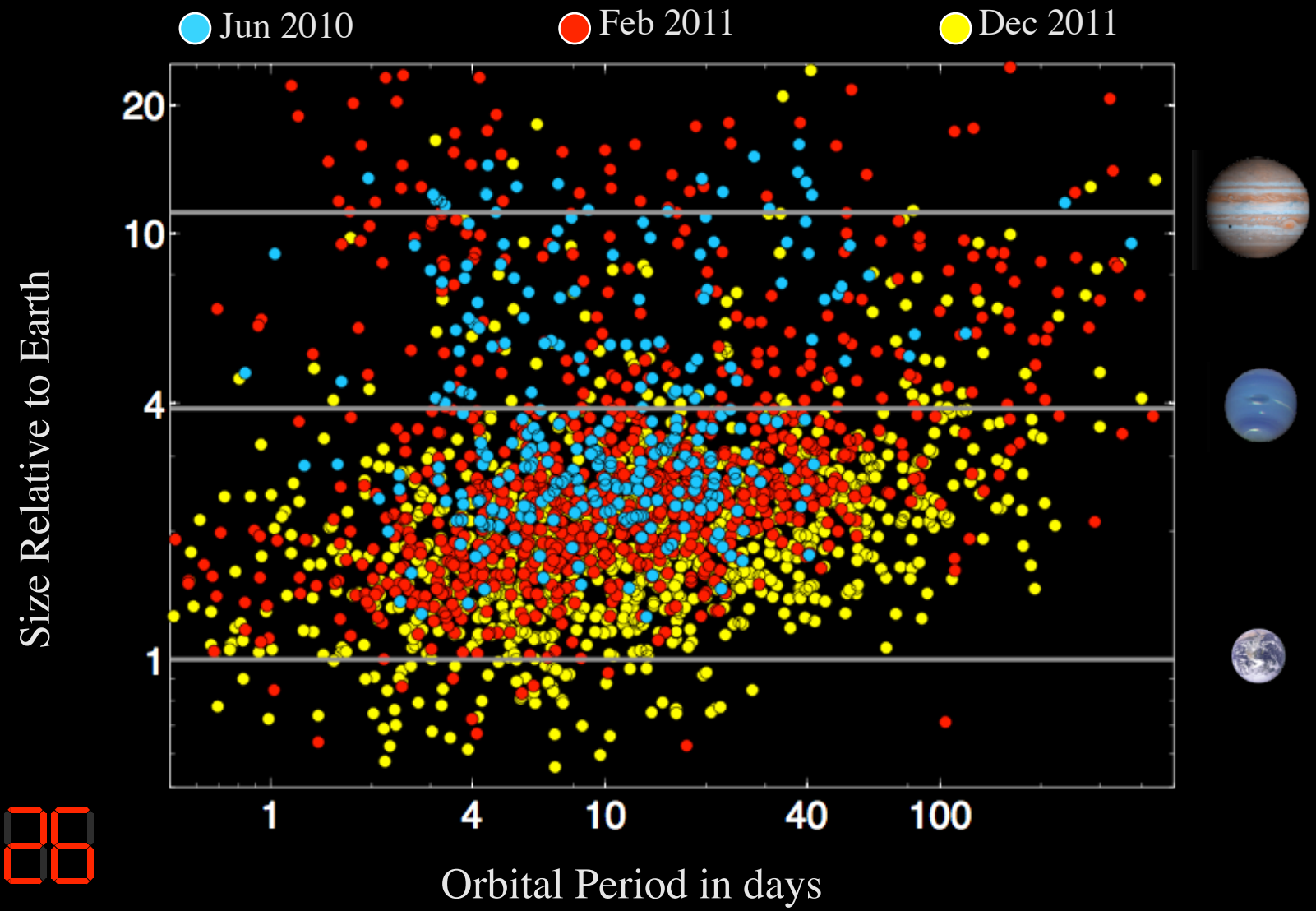
Candidates as of Feb 2011

Q0-Q5: May 2009 - Jun 2010

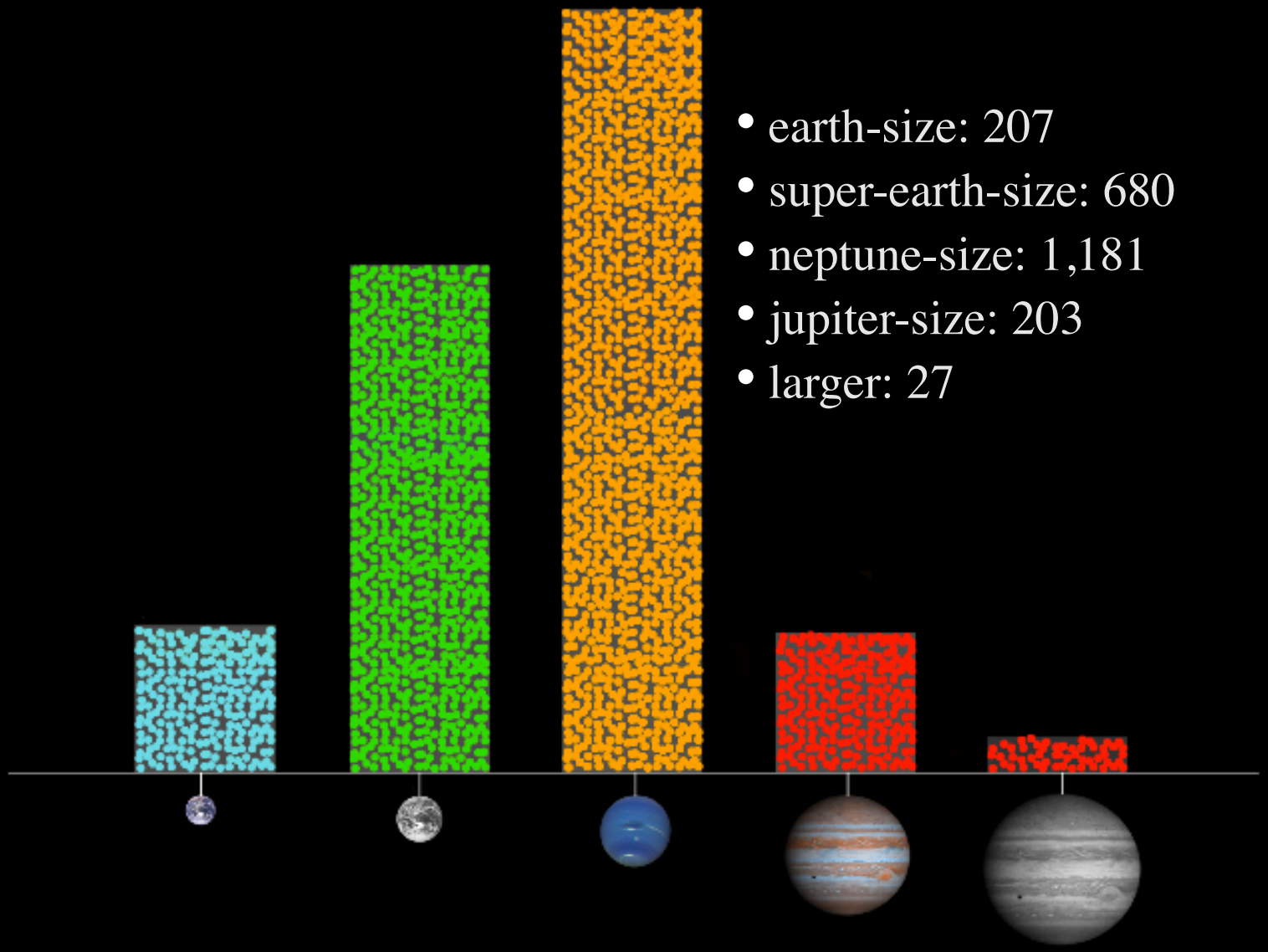


Candidates as of Dec 2011

Q0-Q6: May 2009 - Sep 2010



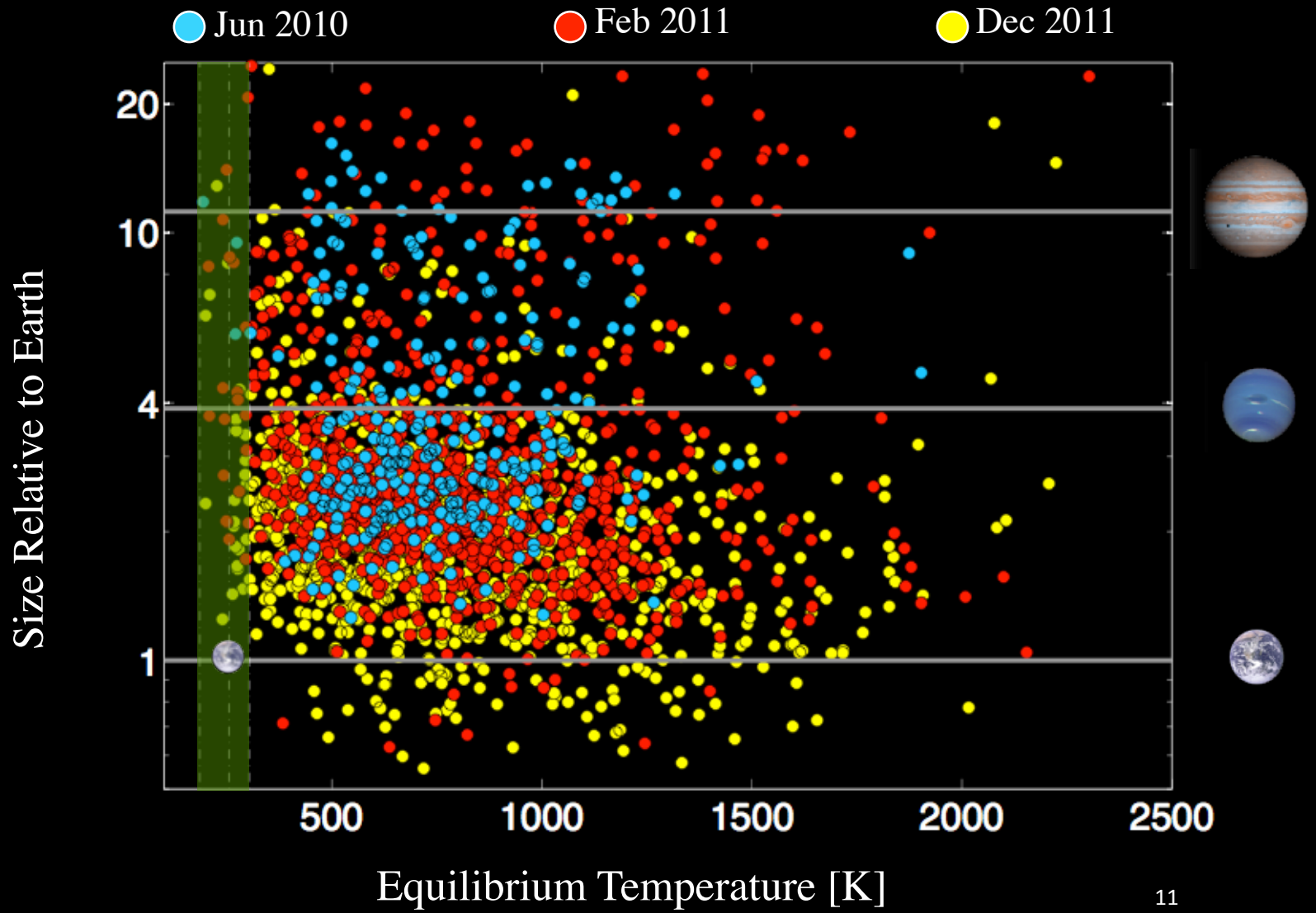
Size Distribution



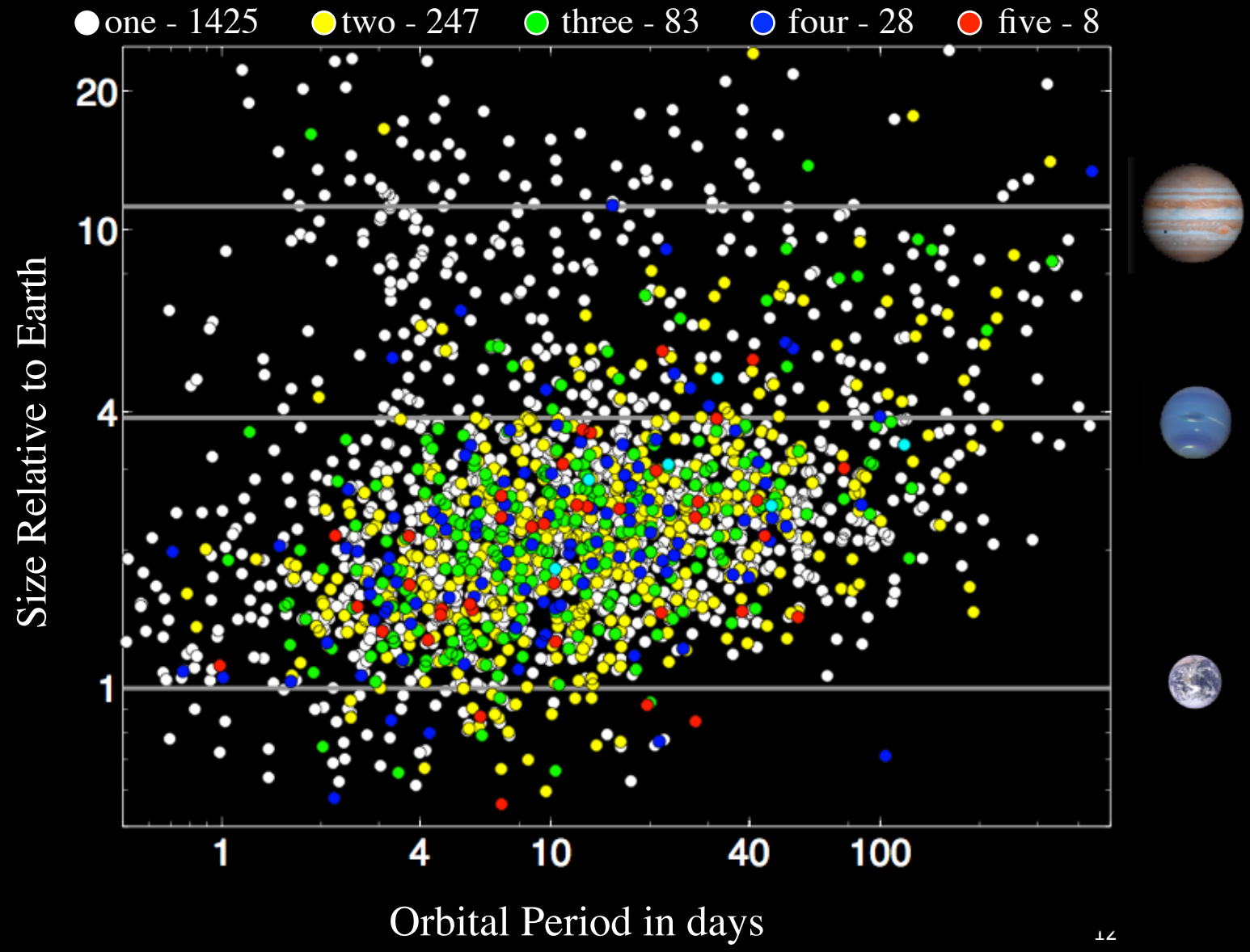
- earth-size: 207
- super-earth-size: 680
- neptune-size: 1,181
- jupiter-size: 203
- larger: 27

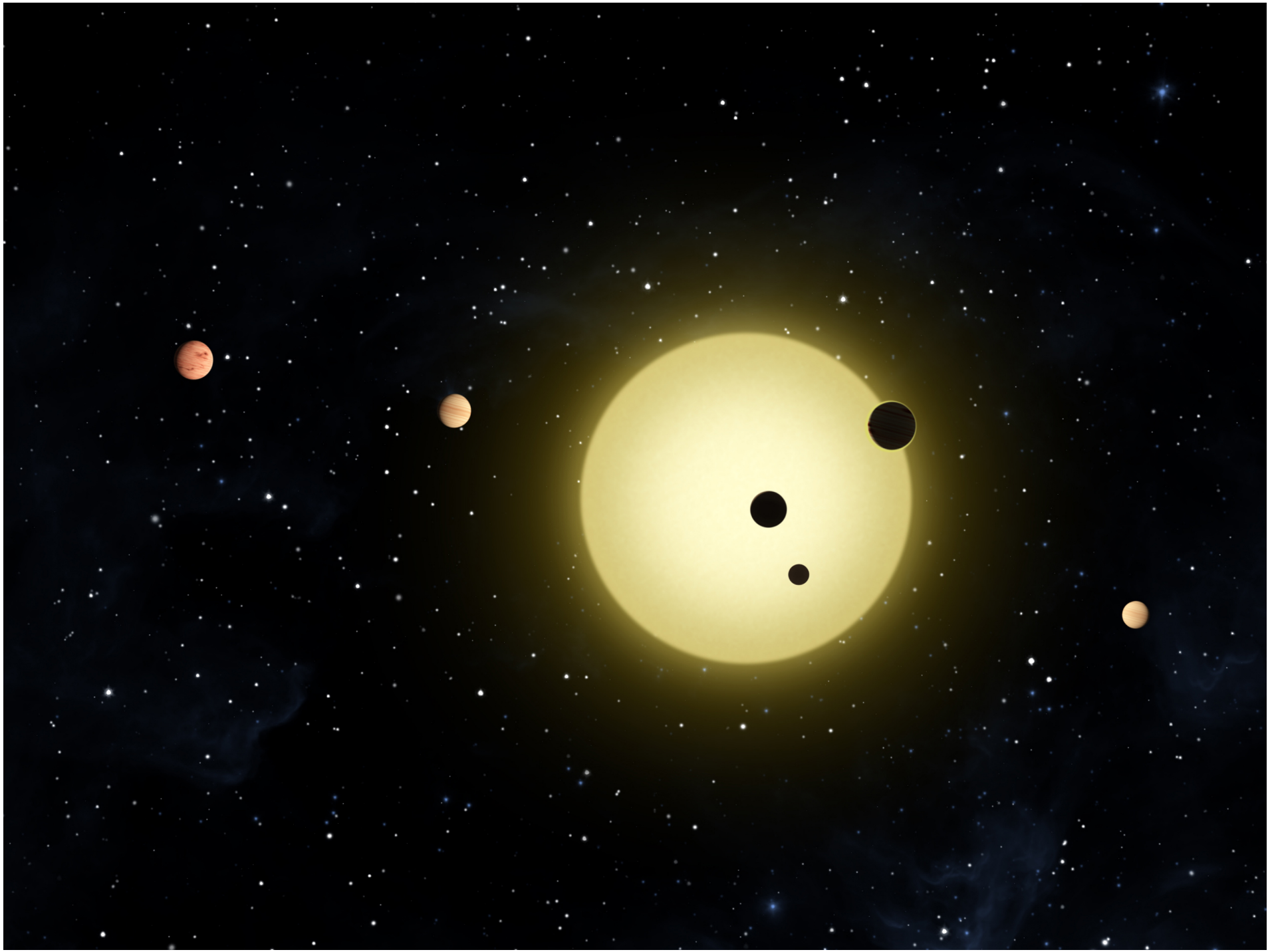
HZ Candidates

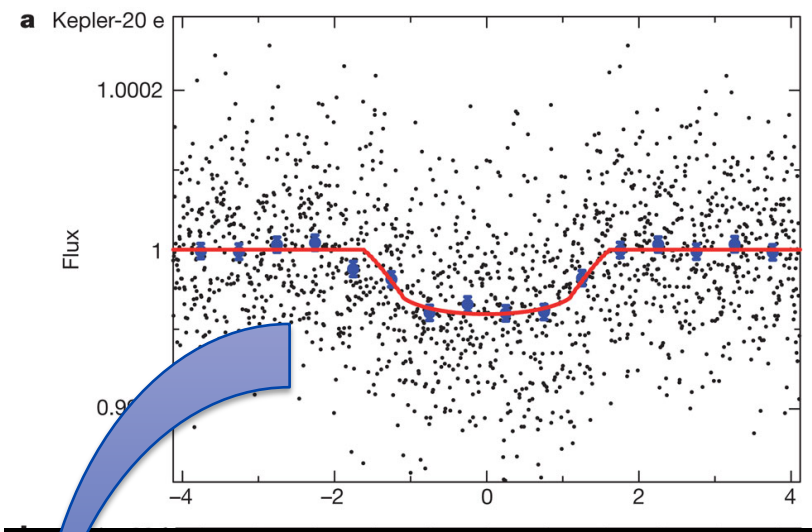
48 with T_{eq} between 185 and 303 K

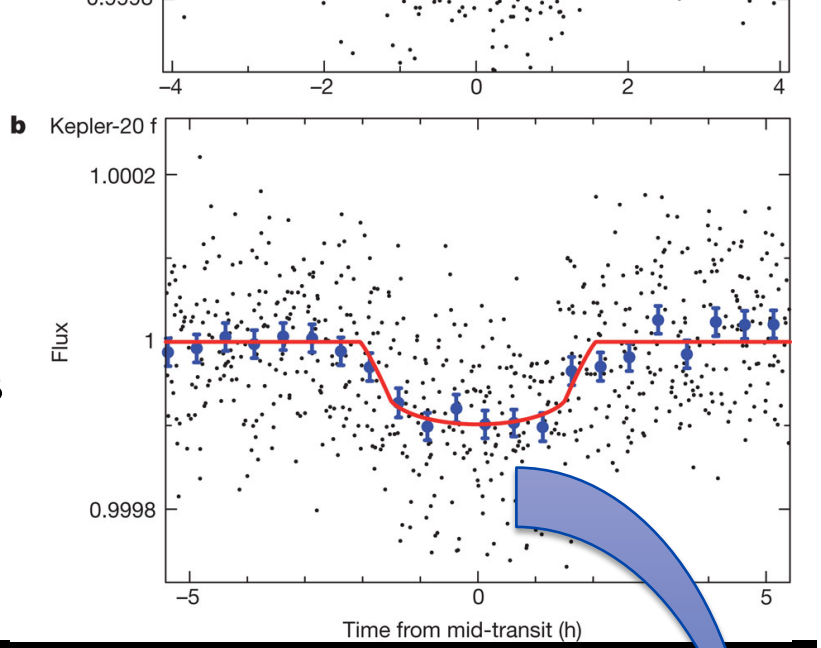


The Multiples

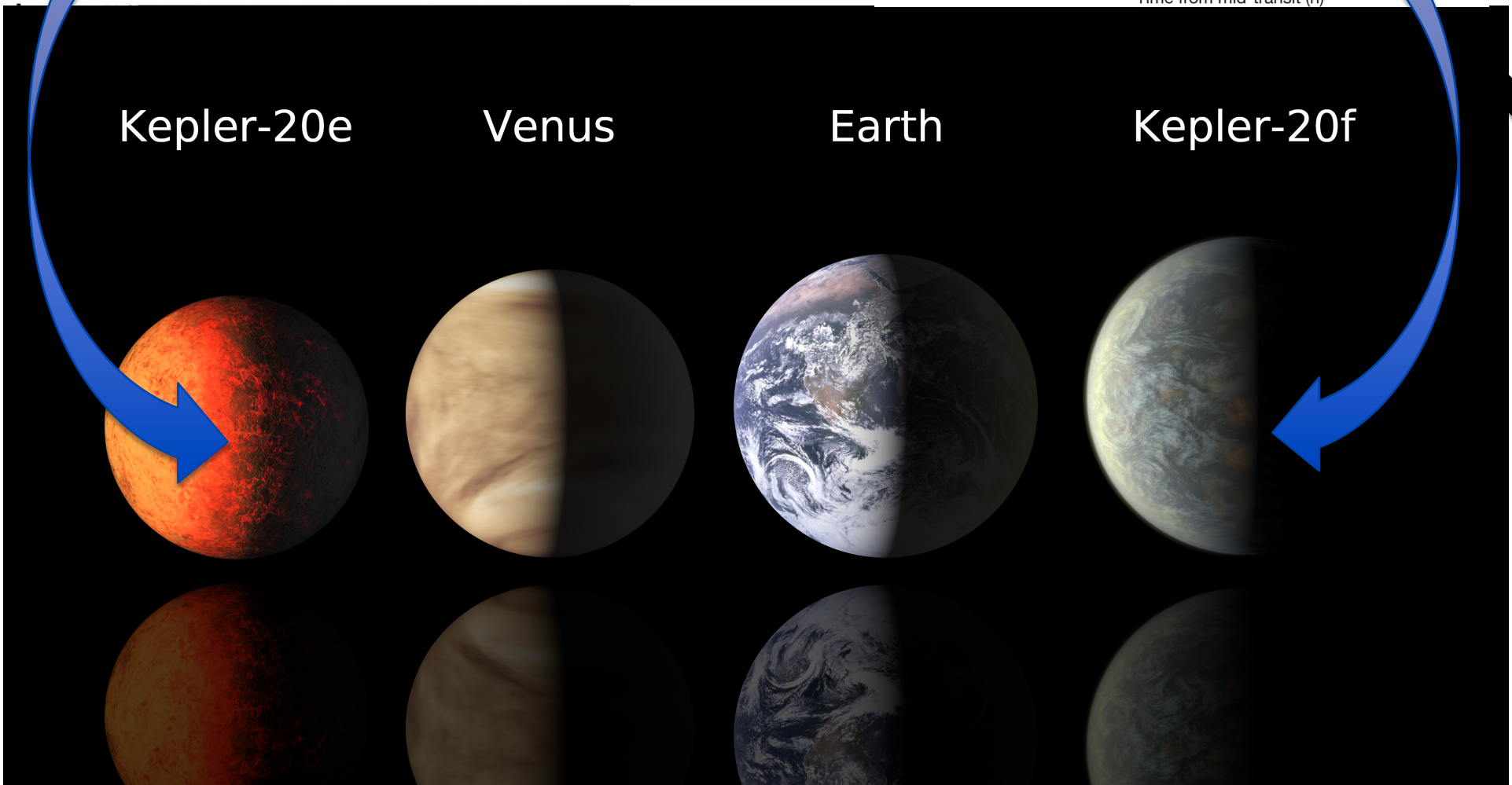


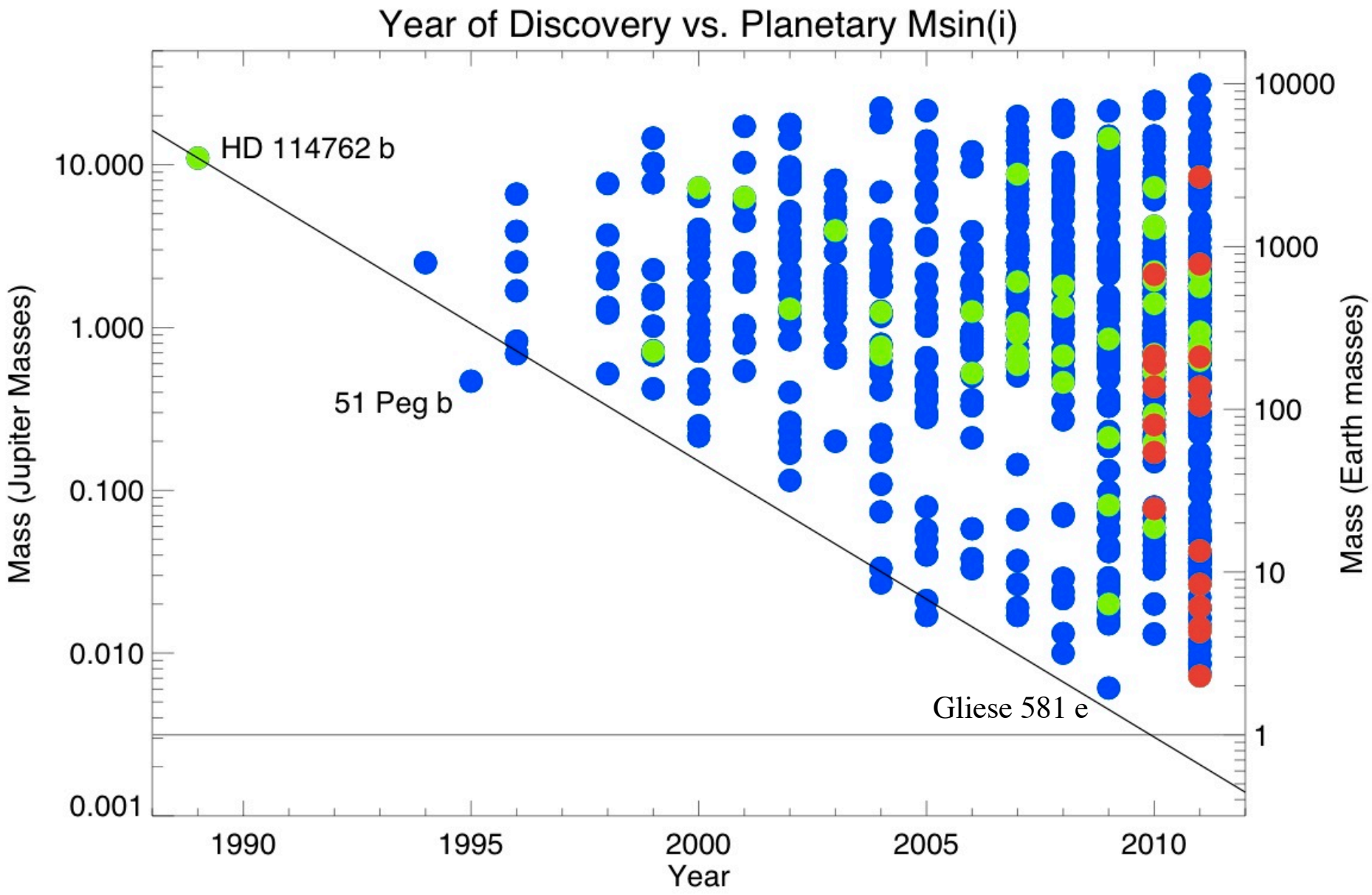






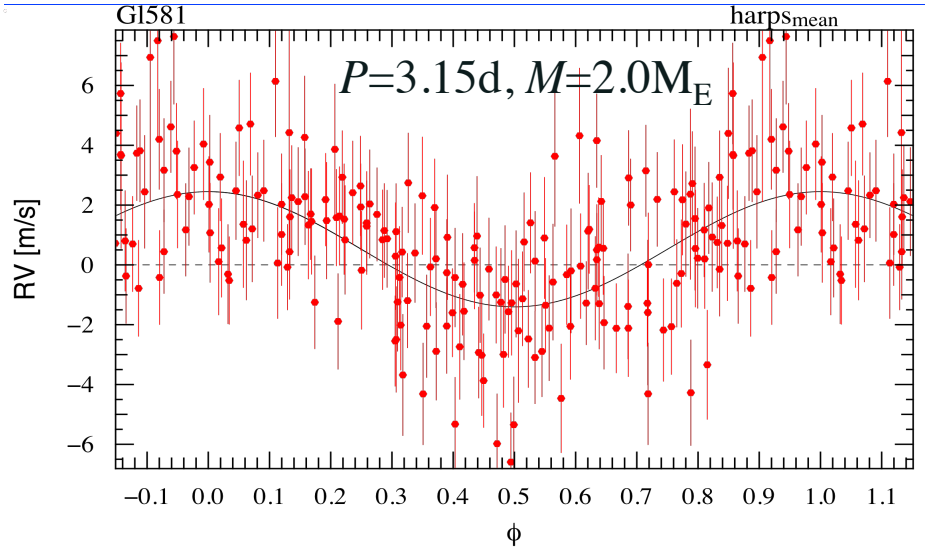
The First Validated Earth-sized Exoplanets (but they are too hot)



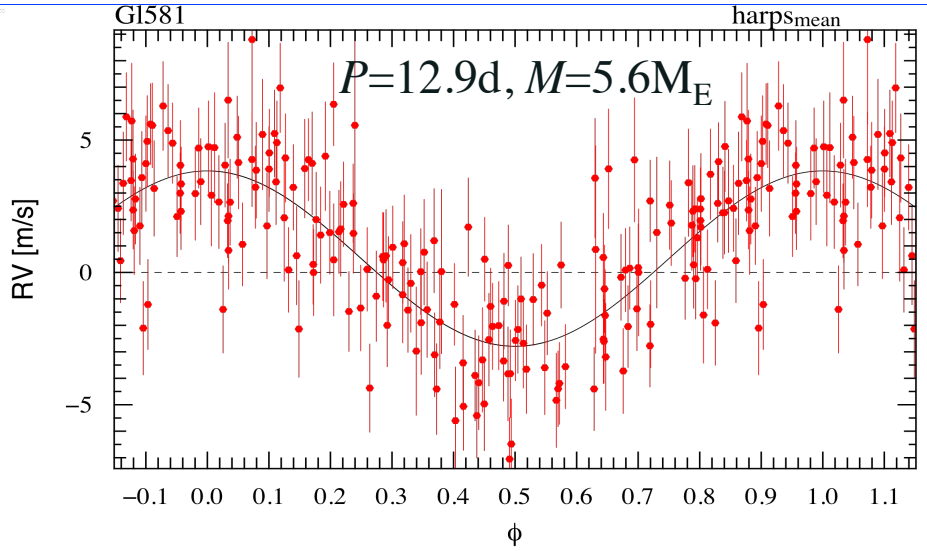


Green = CfA

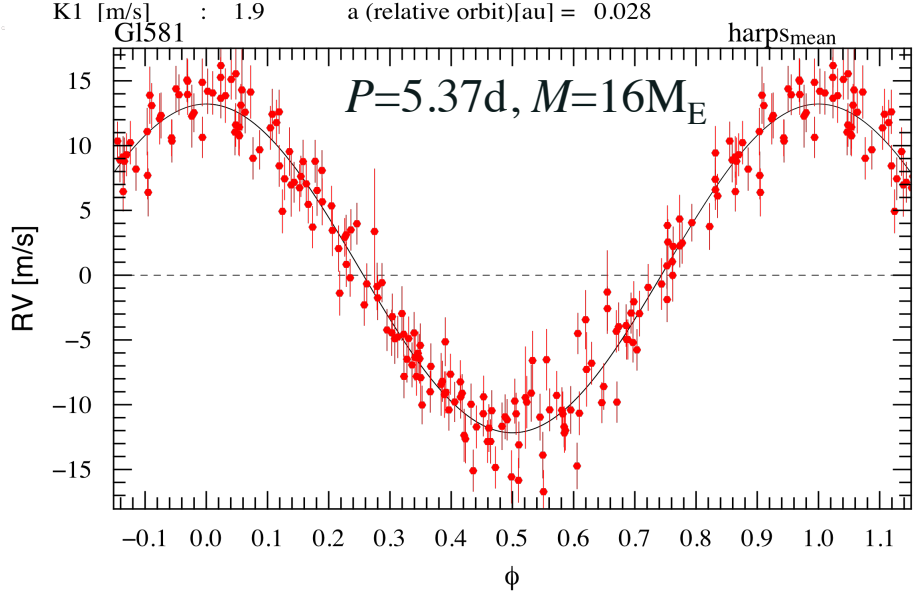
Red = Kepler



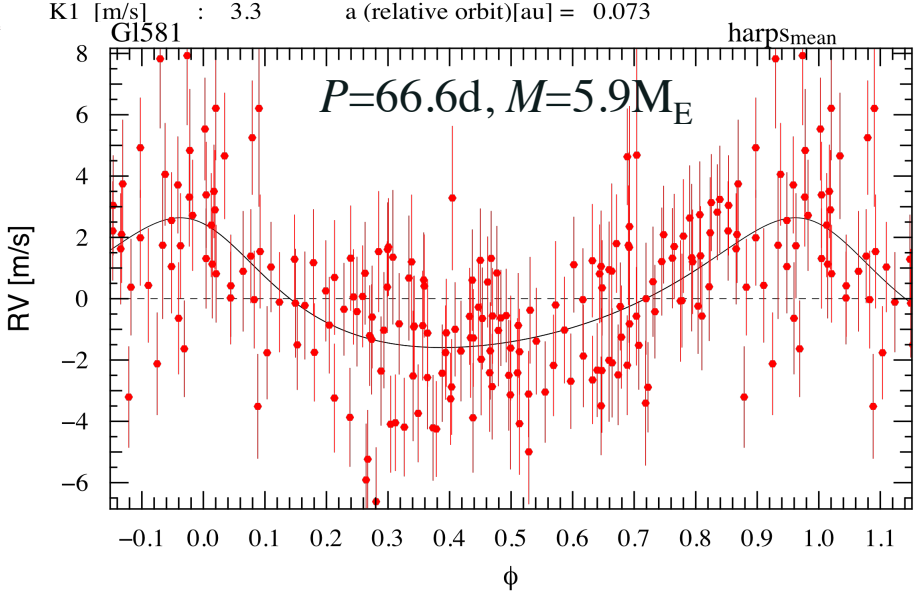
P [days] : 3.150 a_1.sin(i) [1E−3 au] = 0.00056
e : −0.000 f(m) [1E−9 Msol] = 0.00000
ω [deg.] : 0.0 m_1 [Msol]=0.31
phi$_0$: 54525.79 m_2.sin(i) = 0.00636[M$_{jup}$], 0.118[M$_{nept}$], 2.02[M$_{earth}$]
K1 [m/s] : 1.9 a (relative orbit)[au] = 0.028



P [days] : 12.917 a_1.sin(i) [1E−3 au] = 0.00393
e : −0.000 f(m) [1E−9 Msol] = 0.00005
ω [deg.] : 0.0 m_1 [Msol]=0.31
phi$_0$: 54529.76 m_2.sin(i) = 0.01752[M$_{jup}$], 0.324[M$_{nept}$], 5.57[M$_{earth}$]
K1 [m/s] : 3.3 a (relative orbit)[au] = 0.073



P [days] : 5.369 a_1.sin(i) [1E−3 au] = 0.00626
e : −0.000 f(m) [1E−9 Msol] = 0.00114
ω [deg.] : 0.0 m_1 [Msol]=0.31
phi$_0$: 54524.91 m_2.sin(i) = 0.05007[M$_{jup}$], 0.925[M$_{nept}$], 15.91[M$_{earth}$]
K1 [m/s] : 12.7 a (relative orbit)[au] = 0.041

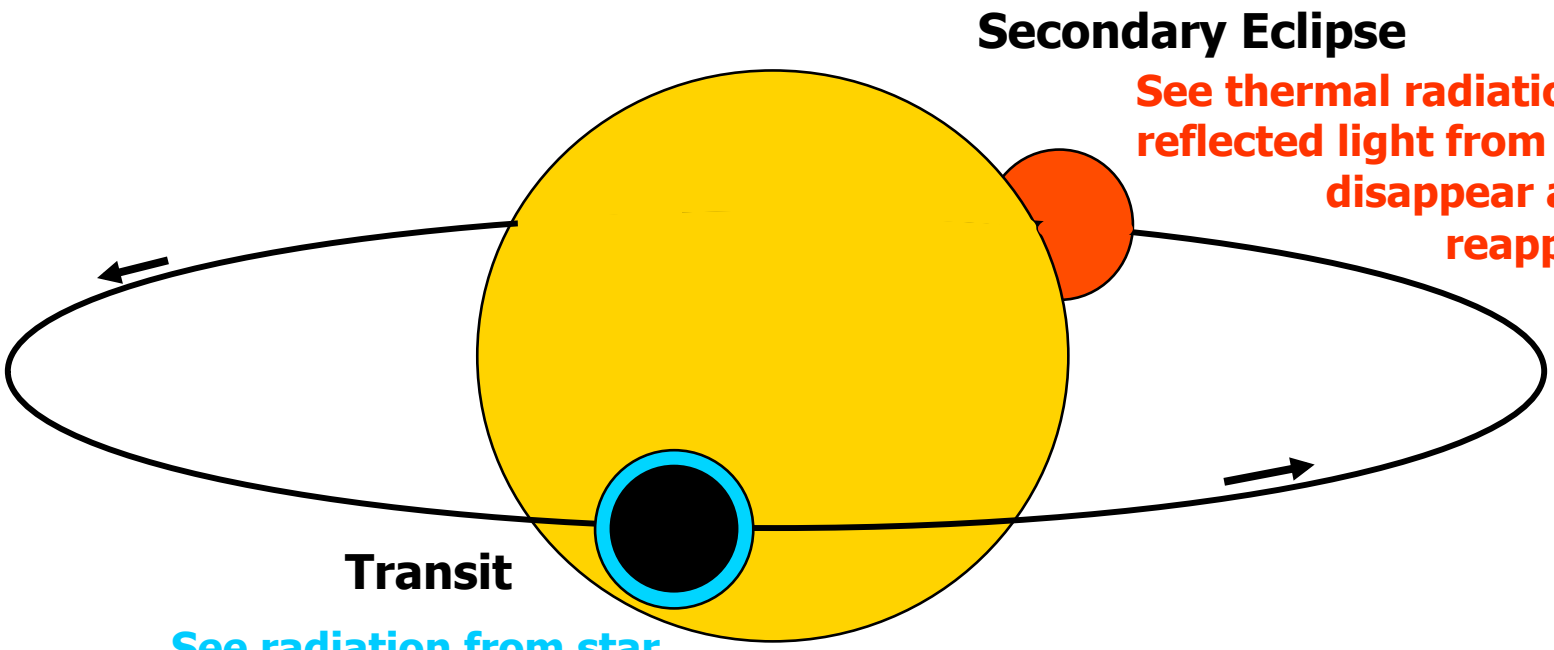


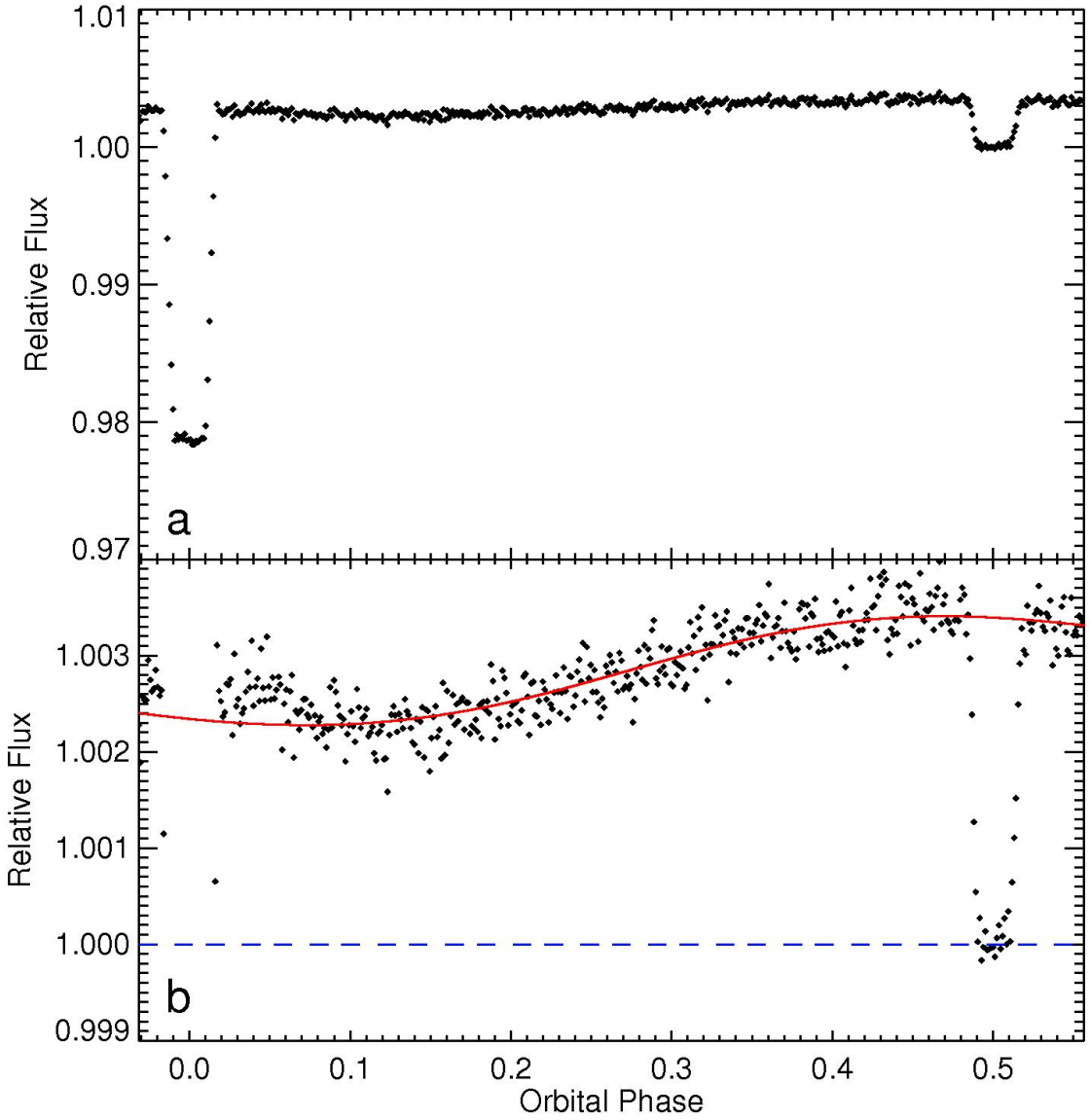
P [days] : 66.641 a_1.sin(i) [1E−3 au] = 0.01248
e : 0.271 f(m) [1E−9 Msol] = 0.00006
ω [deg.] : 24.5 m_1 [Msol]=0.31
phi$_0$: 54538.75 m_2.sin(i) = 0.01861[M$_{jup}$], 0.344[M$_{nept}$], 5.92[M$_{earth}$]
K1 [m/s] : 2.1 a (relative orbit)[au] = 0.218


HARPS-N Collaboration:
Geneva, CfA, UK, INAF-TNG
tessi 2007


HARPS-N first light April 2012
COVER LIFTING POINT
APCO

Transits Allows Studies of the Atmospheres That Are Not Possible for Non-Transiting Planets





HD 189733

Spitzer IRAC 8μ

Knutson et al

Nature 2007

Phase curve

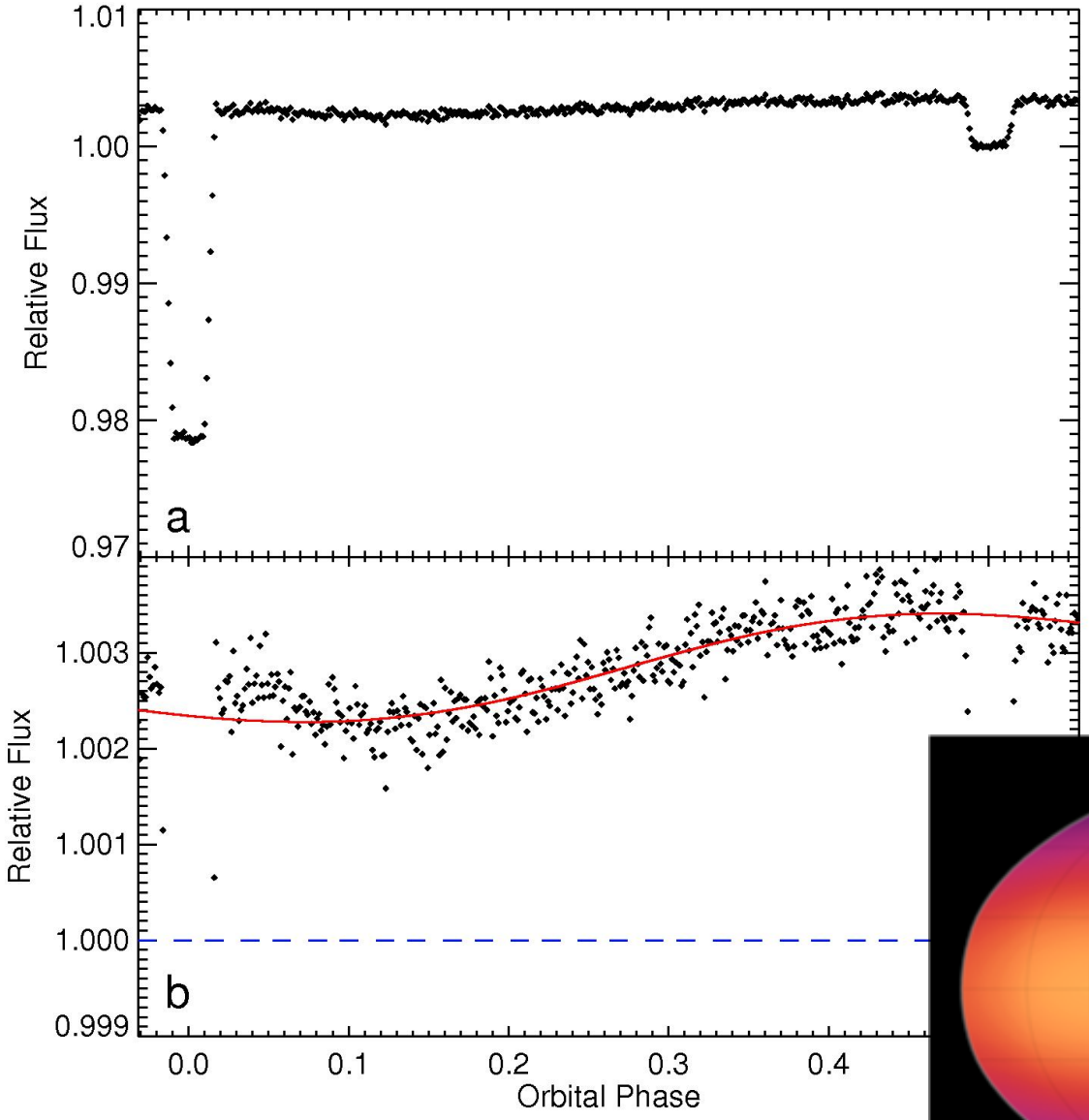
HD 189733

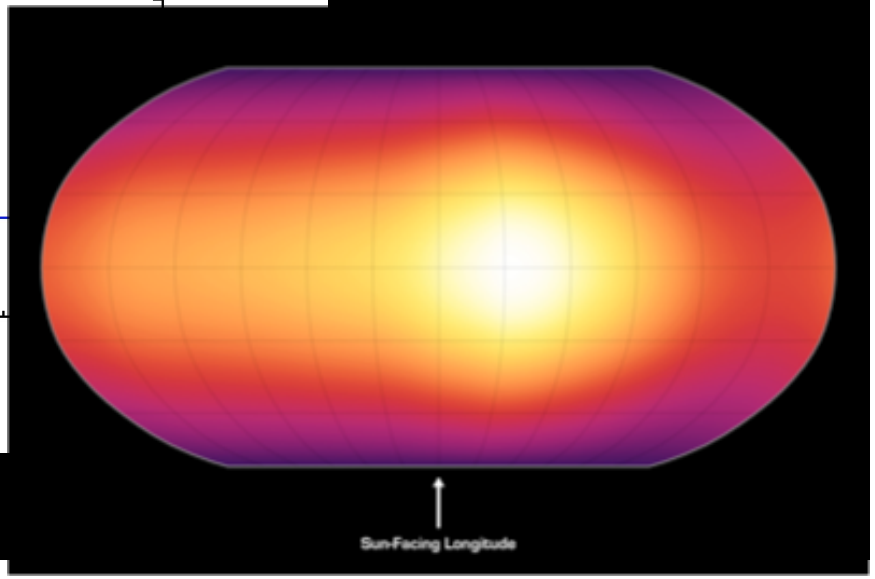
Spitzer IRAC 8μ

Knutson et al

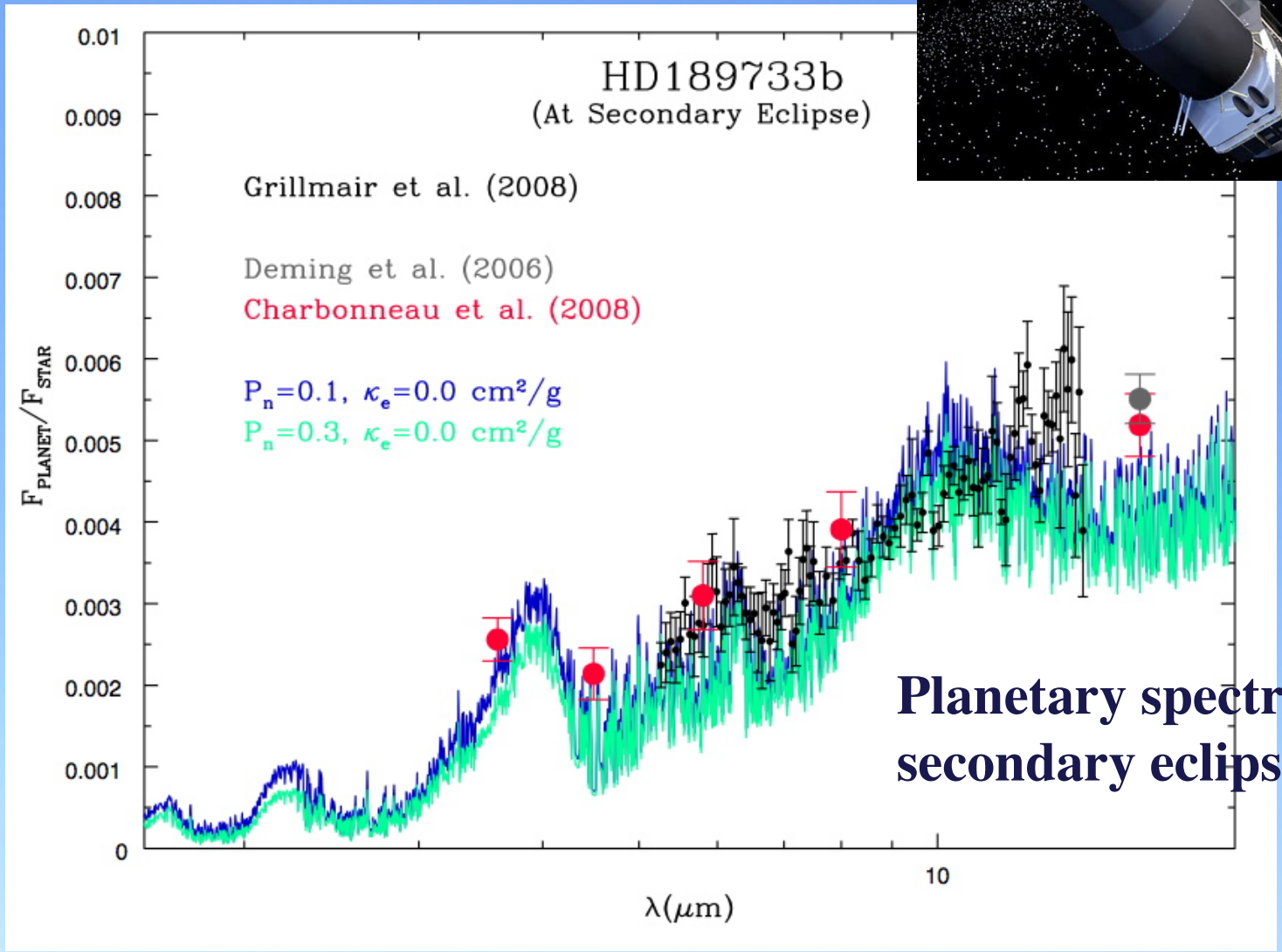
Nature 2007

Phase curve





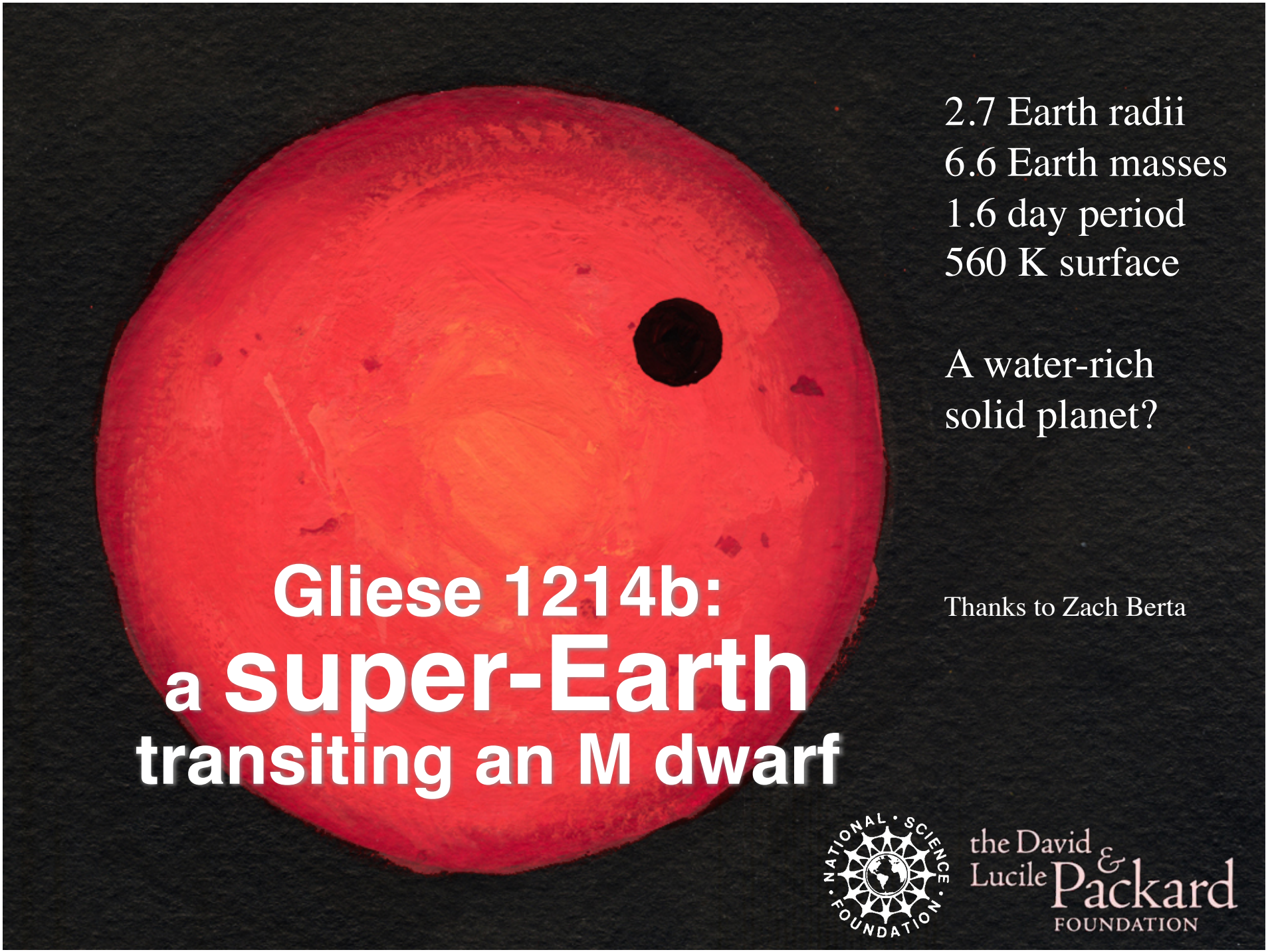
Spitzer spectrum of the most favorable transiting Hot Jupiter is shaped by water absorption



Planetary spectrum via secondary eclipse

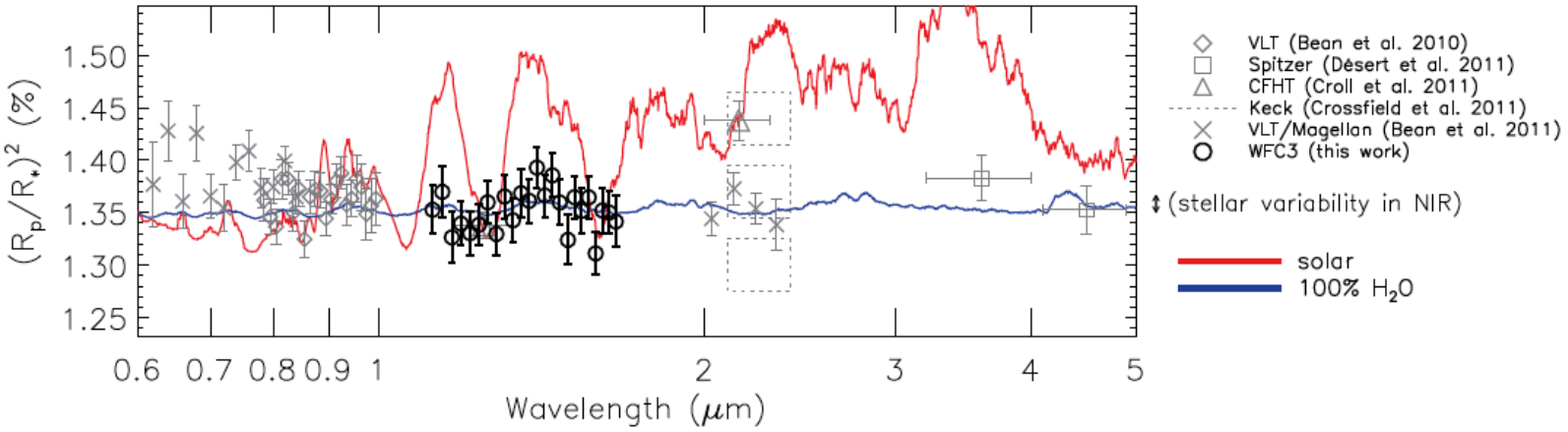
The MEarth Project

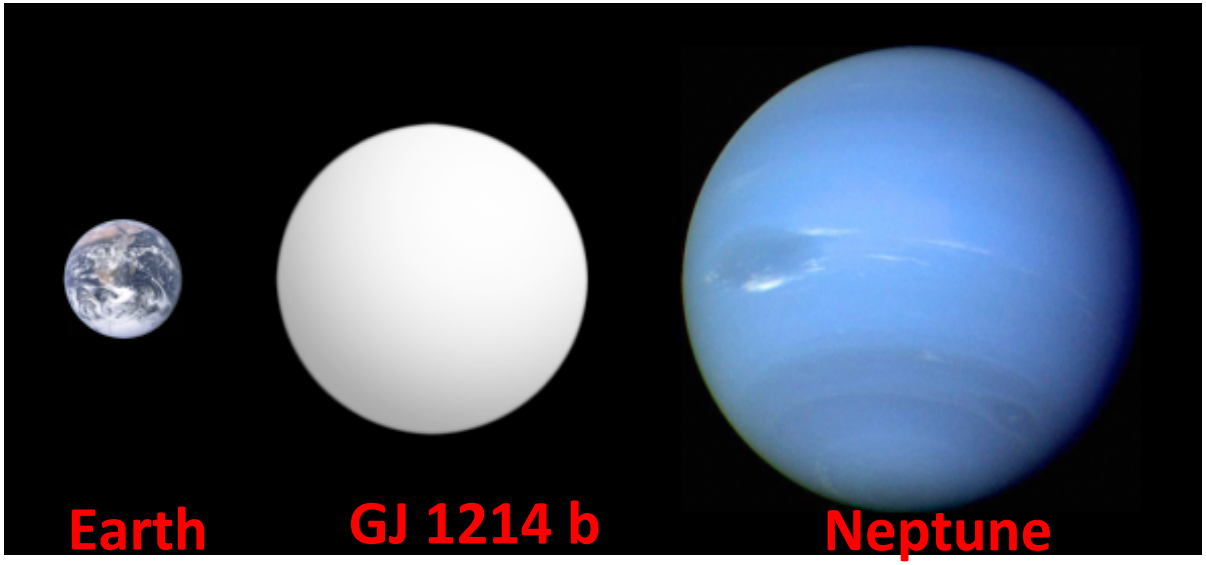
- A ground-based survey for super-Earths in the Habitable Zone
- Target 2000 M dwarfs, the coolest and smallest stars
- Eight robotic 18” telescopes at SAO’s Whipple Observatory
- Led by David Charbonneau


2.7 Earth radii
6.6 Earth masses
1.6 day period
560 K surface
A water-rich
solid planet?
Gliese 1214b:
a super-Earth
transiting an M dwarf
Thanks to Zach Berta
NATIONAL SCIENCE FOUNDATION
the David & Lucile Packard FOUNDATION

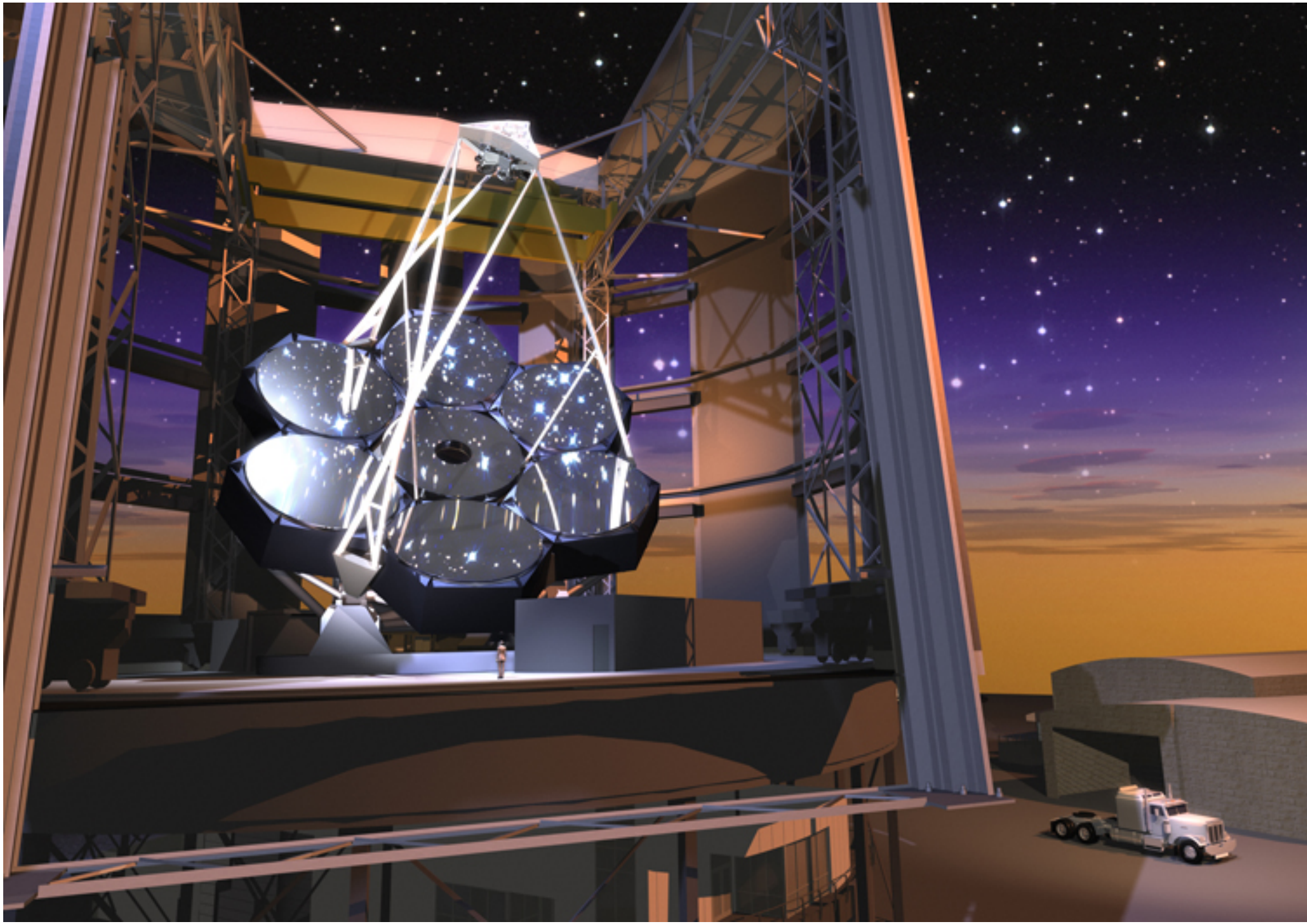
Current Results

Flat transmission spectrum of GJ 1214b (Berta et al. 2012)





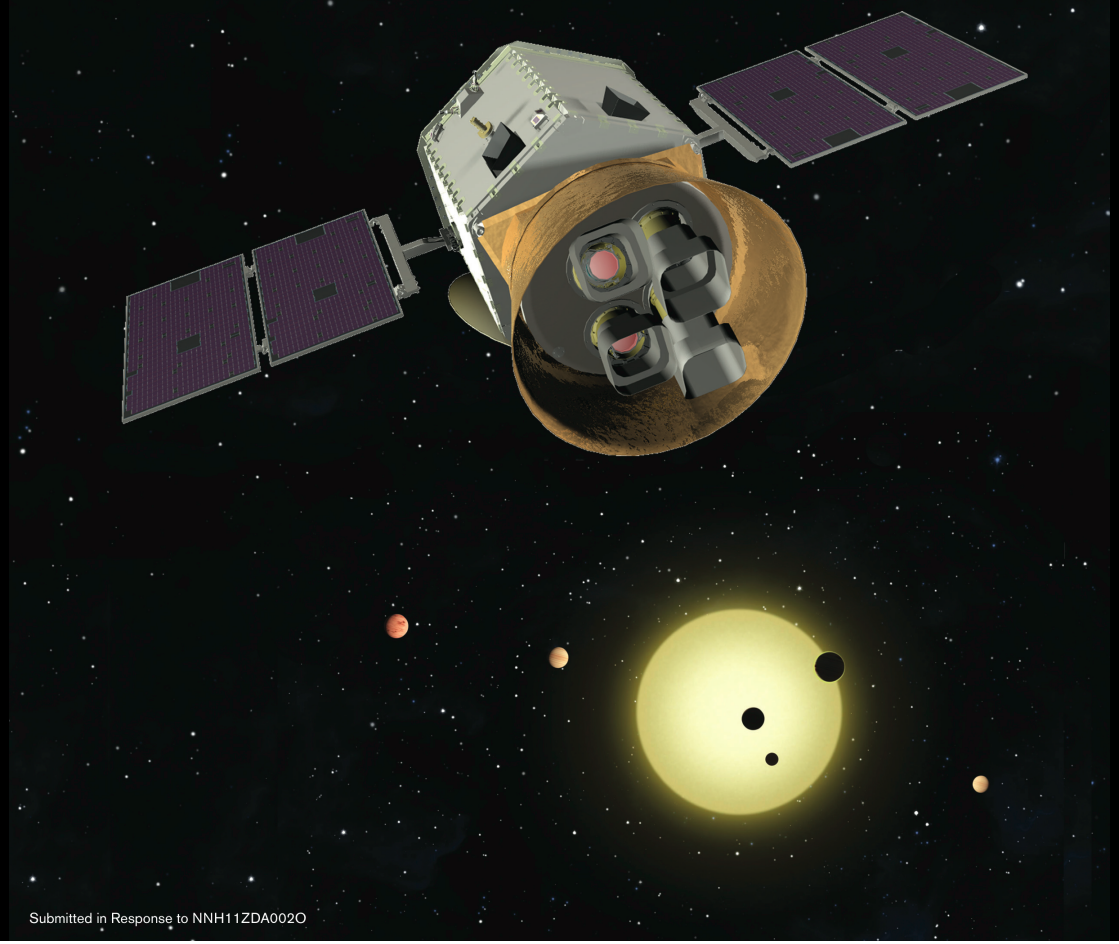
- Flat spectrum.
- No evidence of strong absorptions features.
- Result consistent with opaque atmosphere, >50% water by mass.



Explorer Proposal

Transiting Exoplanet Survey Satellite

Dr. George R. Ricker, PI, MIT



Submitted in Response to NNH11ZDA002O

In Concept Study Phase
Report due 21 Sep 2012

Led by Dimitar Sasselov

Research focus:

Does the diversity of planetary environments map onto a diversity of biochemistries?

Super Earths and Life sub-project:

Study the diversity of global geochemistry on Super-Earths and Earth analogs.