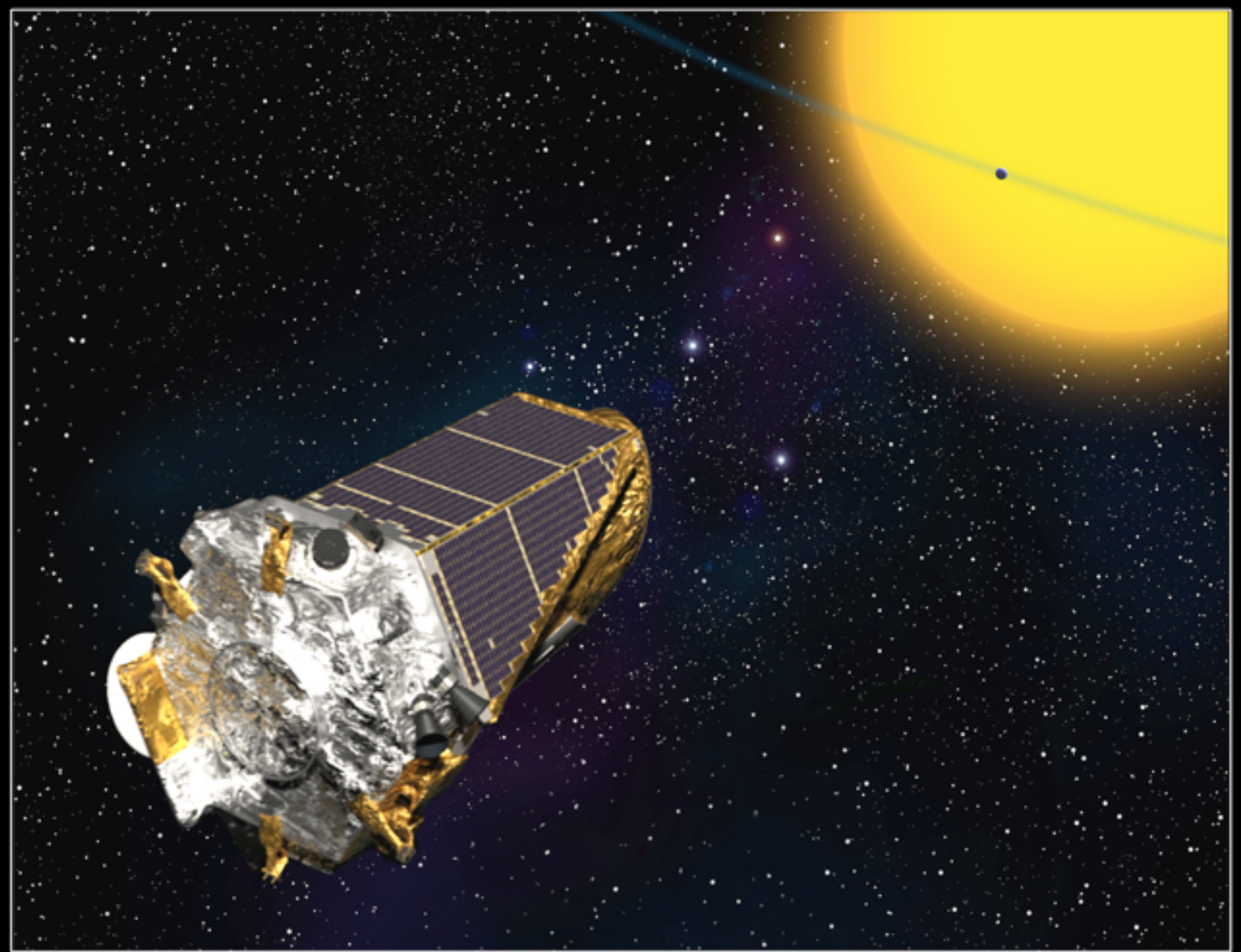
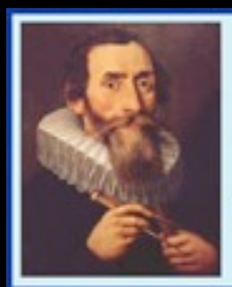
Catching Shadows:
Kepler's Year-Two Transit Census

Natalie Batalha
San Jose State University

Are potentially habitable, earth-size planets abundant in our galaxy?



Design



Kepler
A Search for Terrestrial Planets

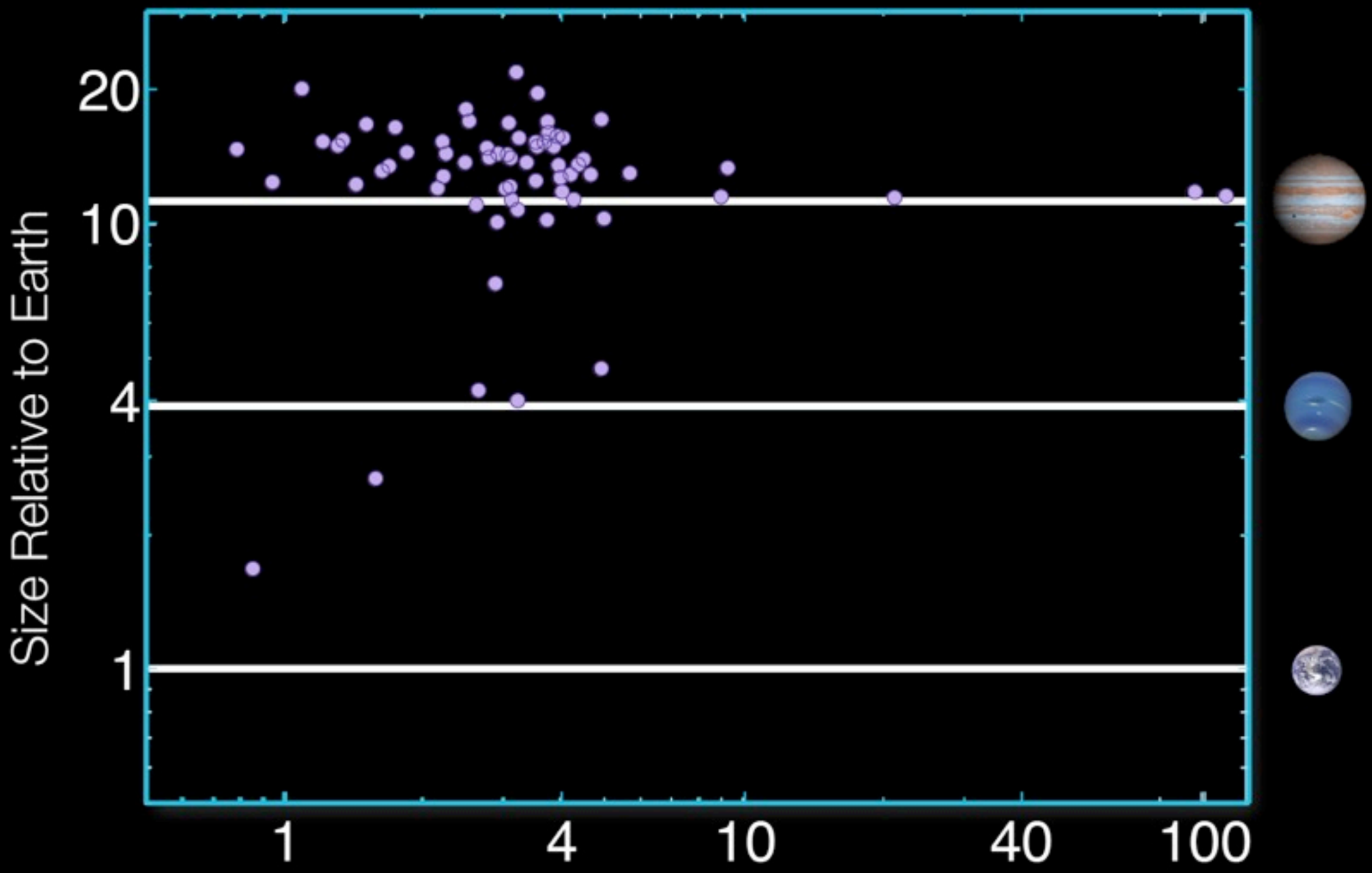
***KEPLER*: A Wide Field-of-View Photometer that monitors ≥100,000 Stars for 3.5 yrs with precision to find Earth-size planets in the Habitable Zone**

Transit Detection using:

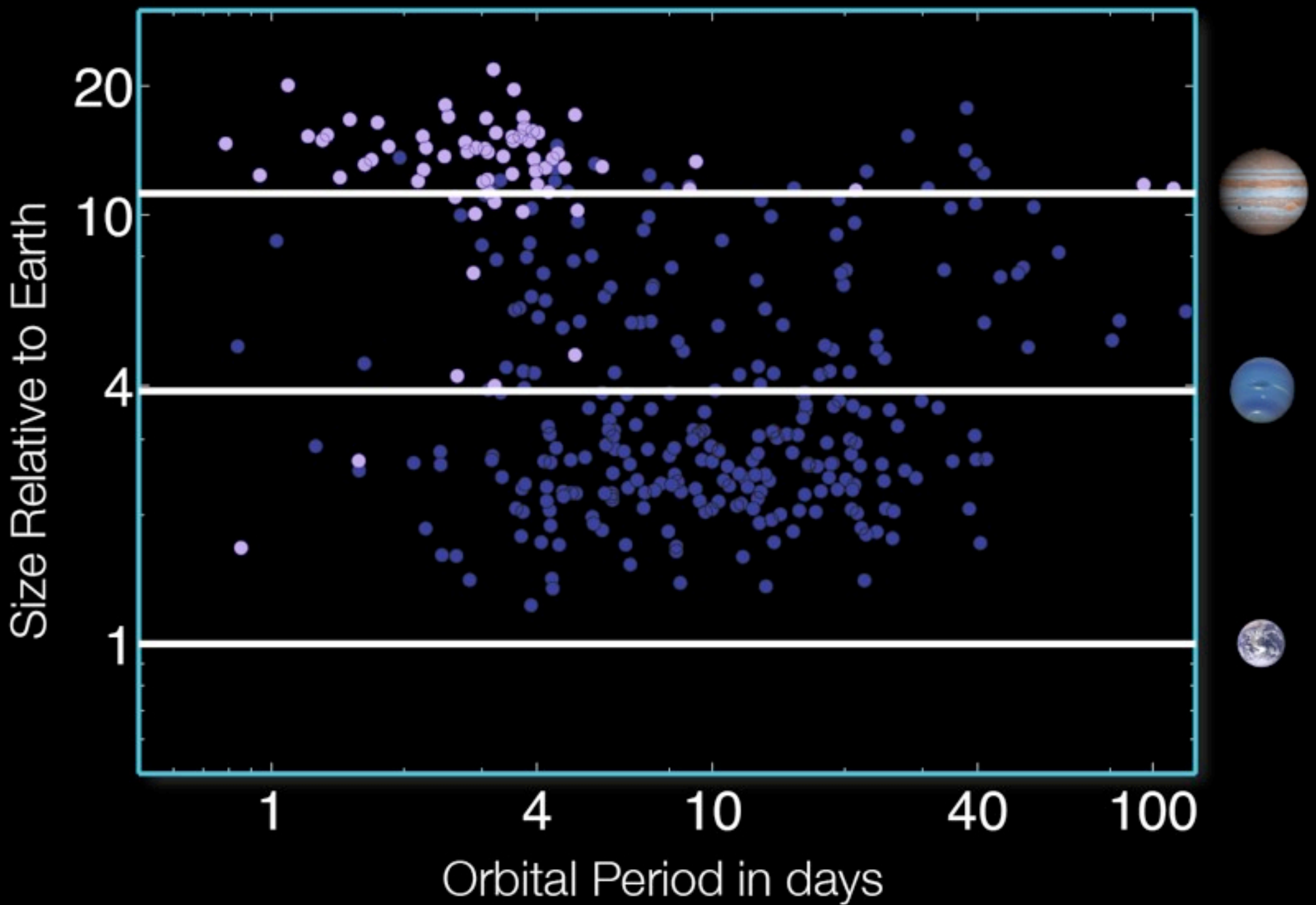
- **0.95 meter aperture**
- **Wide FOV: 100 sq deg**
- **42 CCDs**
- **>= 3.5 years**
- **Fixed pointing**
- **Heliocentric orbit**
- **170k targets: 30 min**
- **512 targets: 1 min**

March 6, 2009

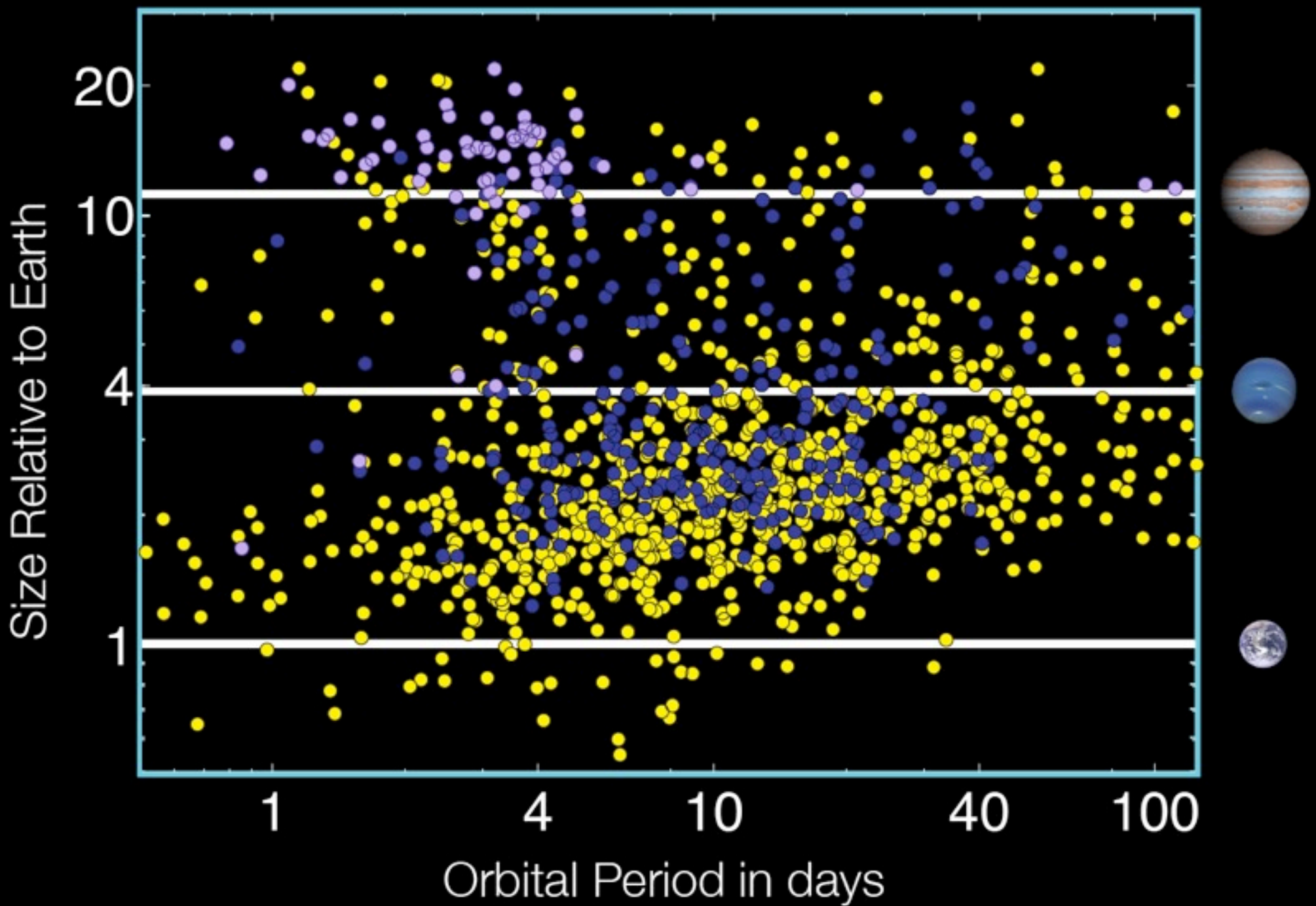
Pre-Kepler Transiting Planets - 2009



Kepler Candidates as of June 2010



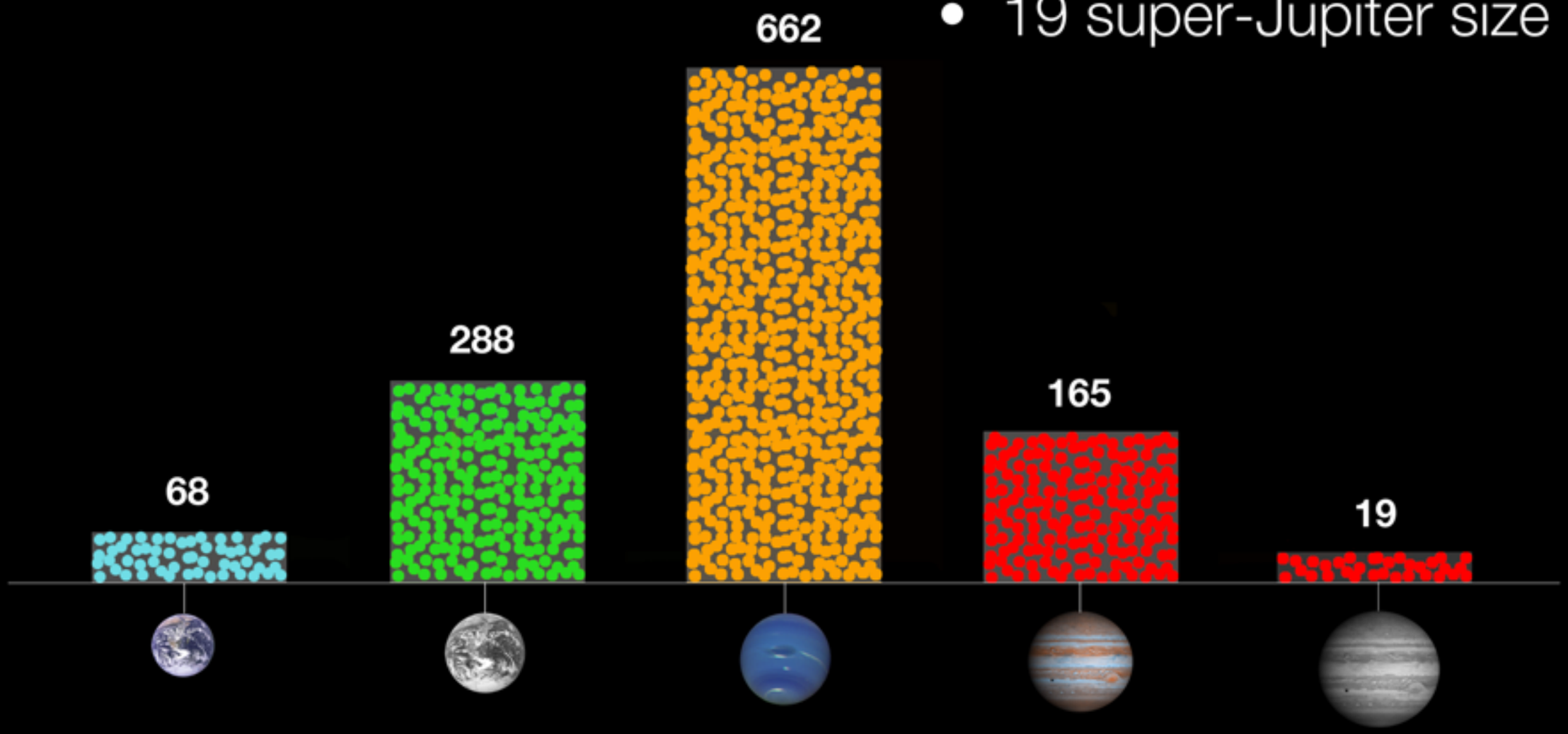
Kepler Candidates as of February 1, 2011



Borucki et al. 2011, arXiv: 1102.0541

Numbers of Planet Candidates

- 68 Earth-size
- 288 super-Earth size
- 662 Neptune size
- 165 Jupiter size
- 19 super-Jupiter size



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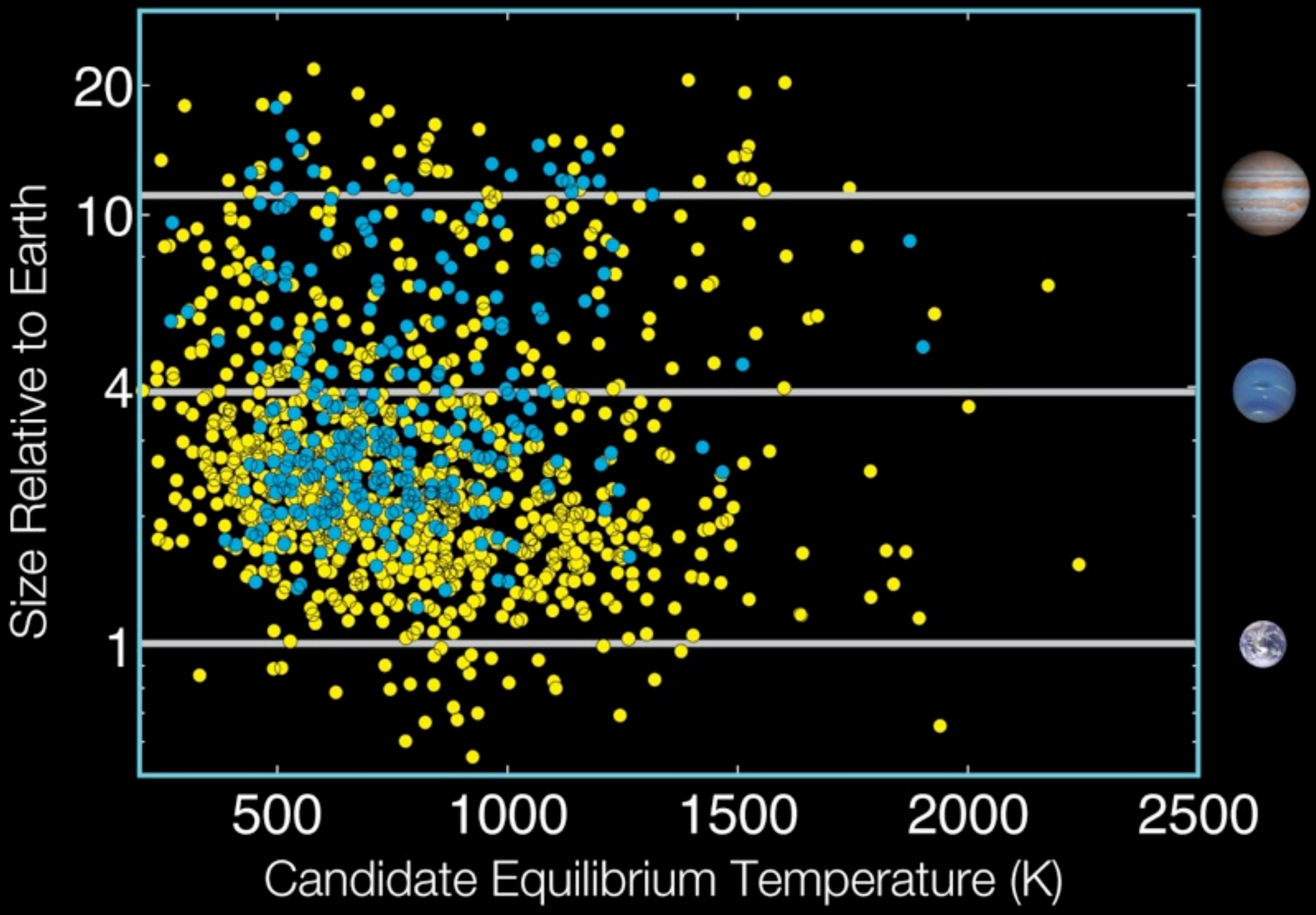
Kepler Candidates as of February 1, 2011



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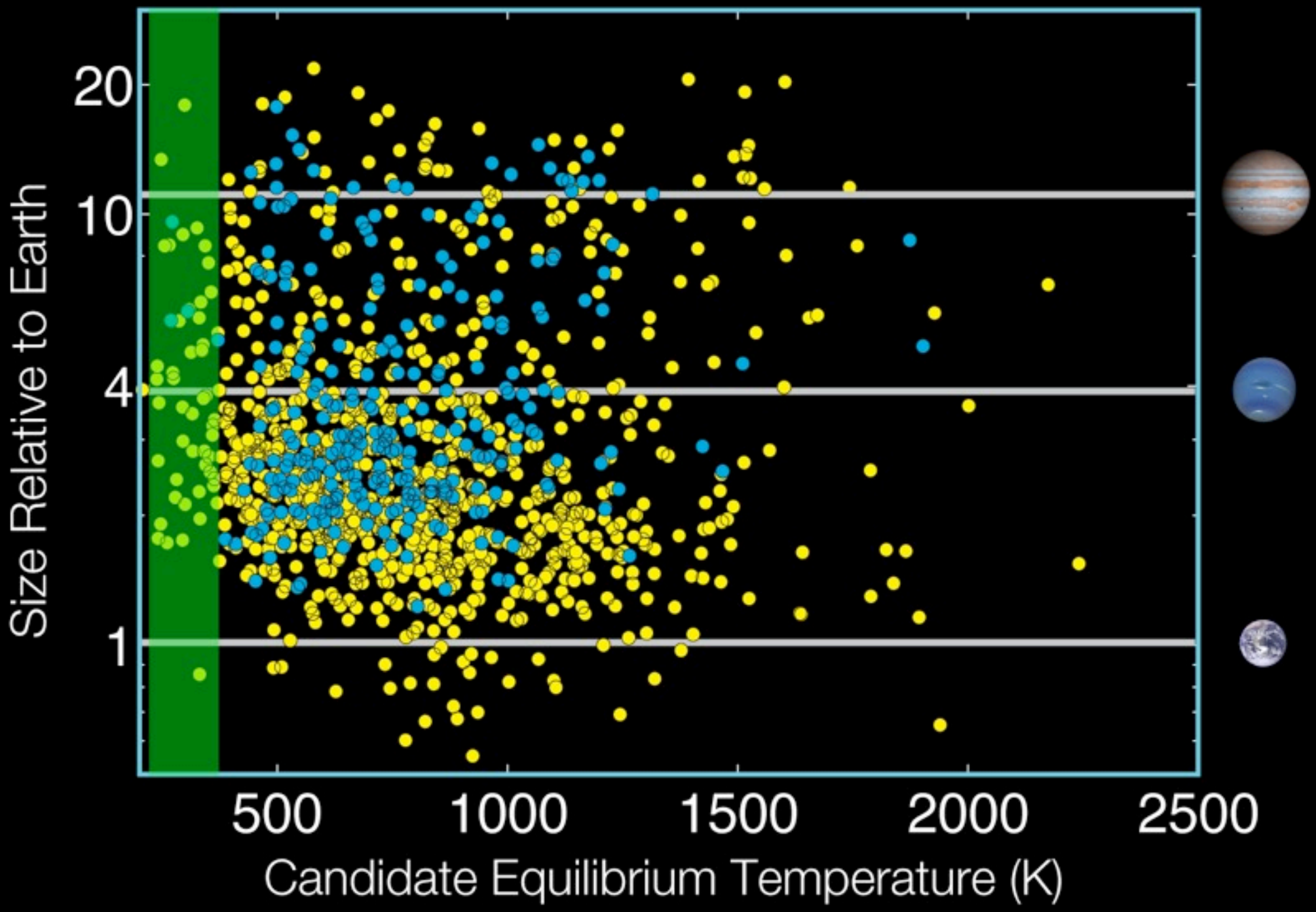
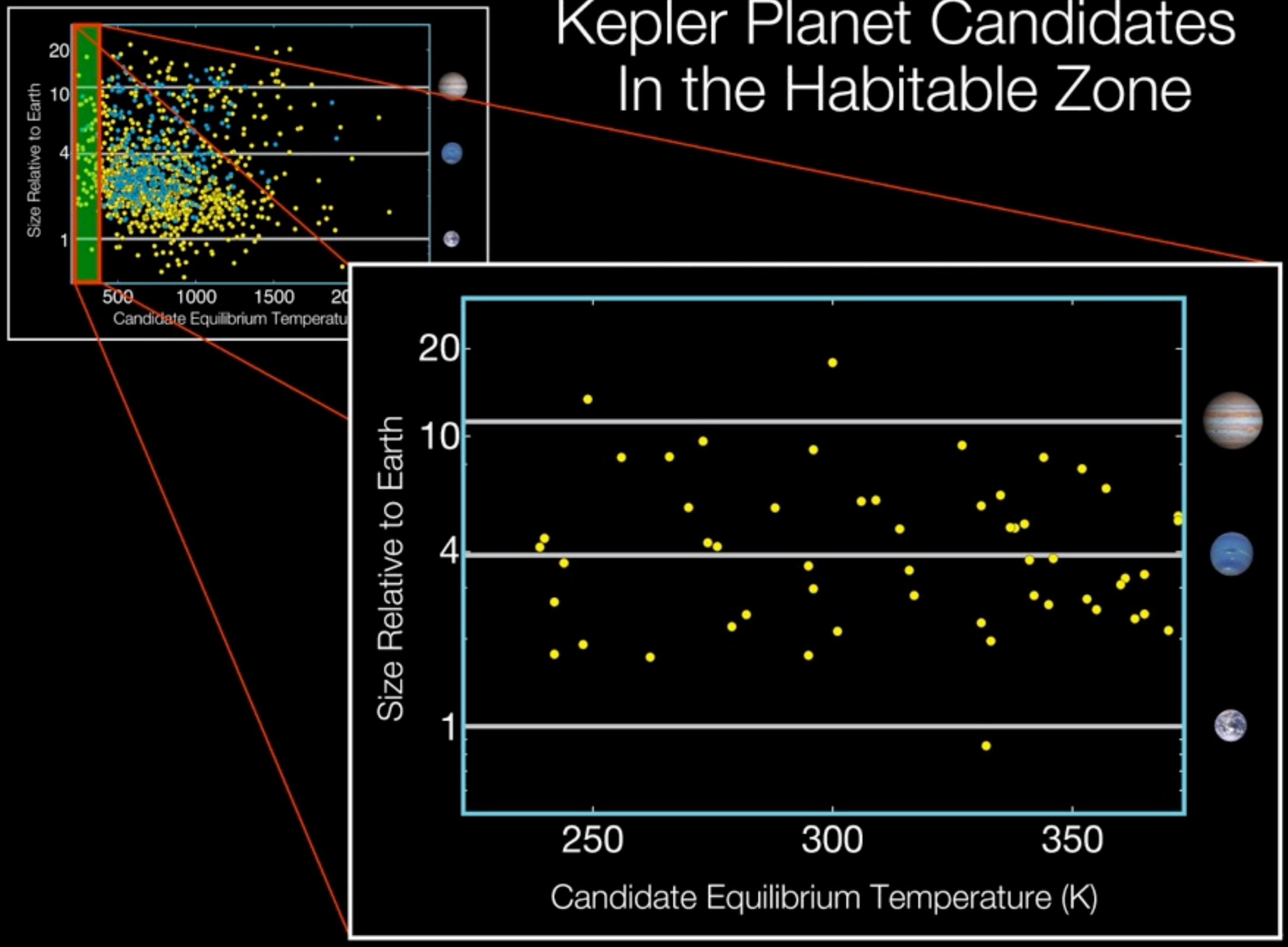
Kepler Candidates as of February 1, 2011



Borucki et al. 2011, arXiv: 1102.0541

Kepler Planet Candidates In the Habitable Zone



170 Stars (17%) with Multiple Transit Signatures

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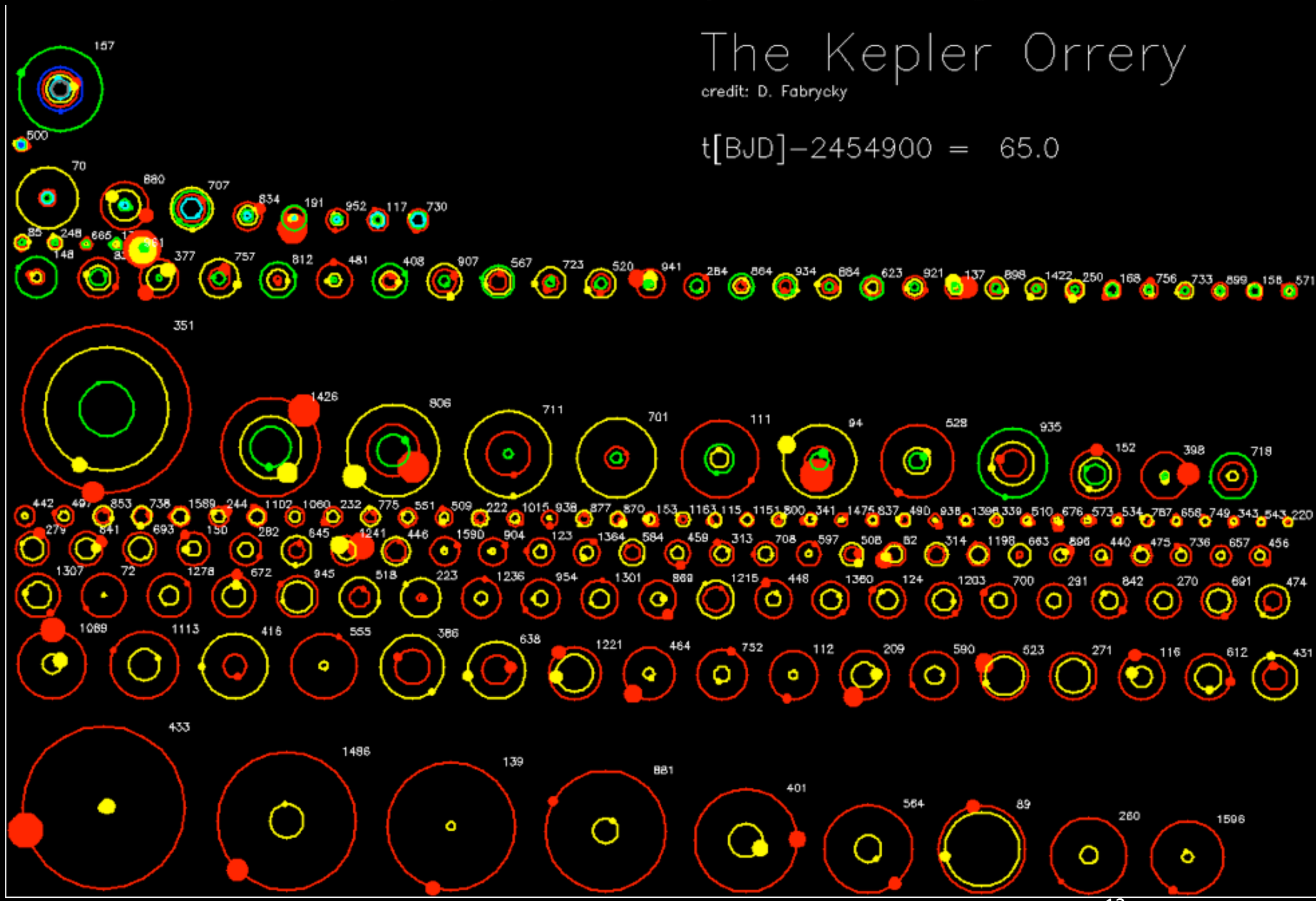

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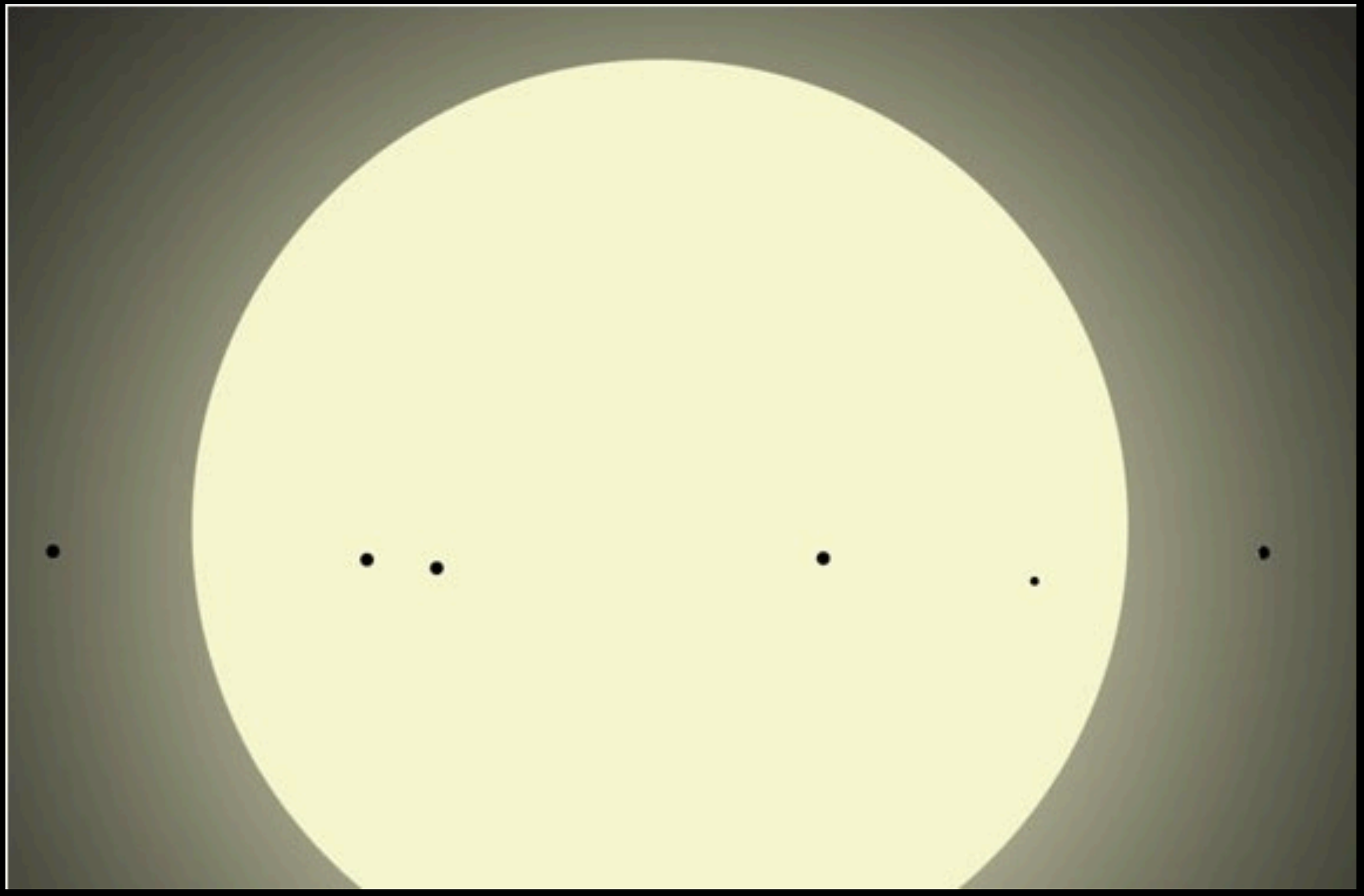
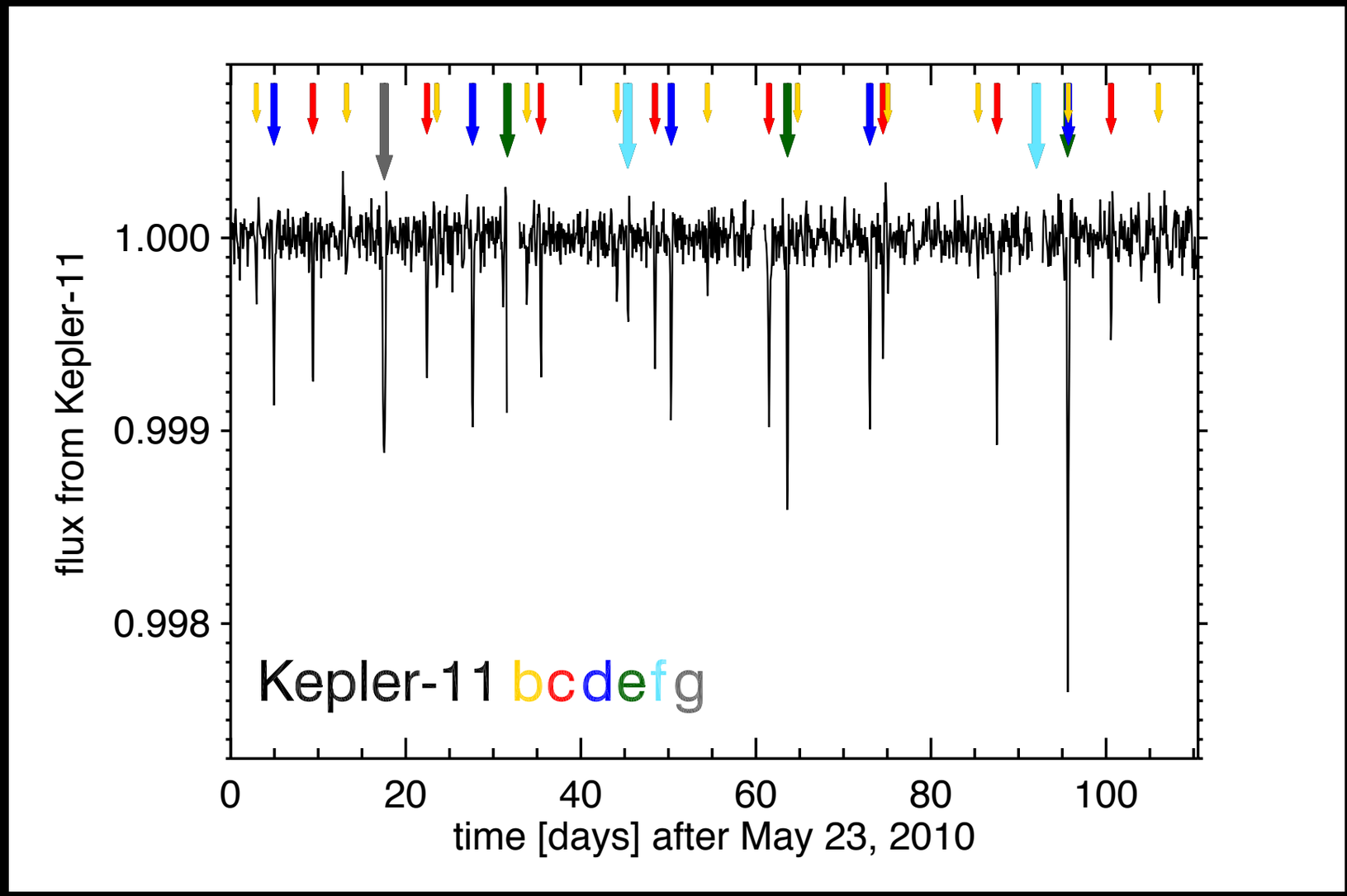


Lissauer et al. 2011, Nature, 470, 53

Kepler-11: Light Curve



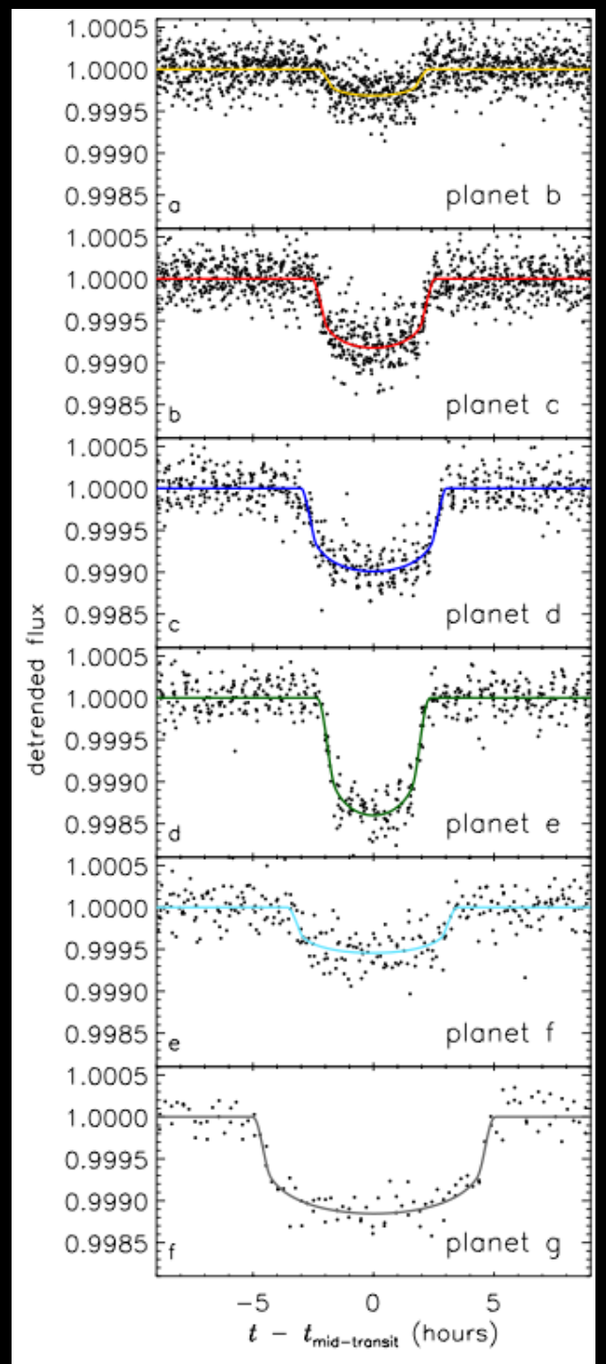
Periods: 10.3, 13.02, 22.69, 32.00, 46.69, 118.38 days

Radii: 1.97, 3.15, 3.43, 4.52, 2.61, 3.66

Masses: 4.3, 13.5, 6.1, 8.4, 2.3, ?

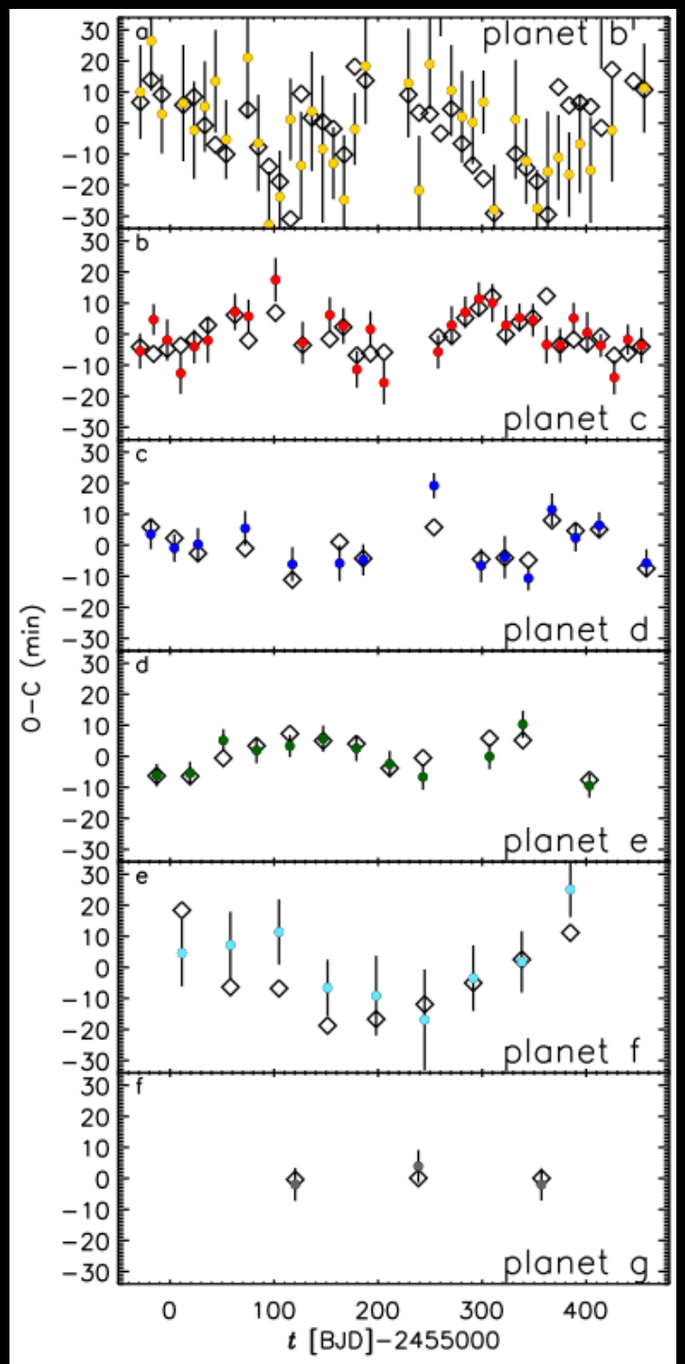
Lissauer et al. 2011, Nature, 470, 53

Transit Timing Variations



← Transits

TTV's →



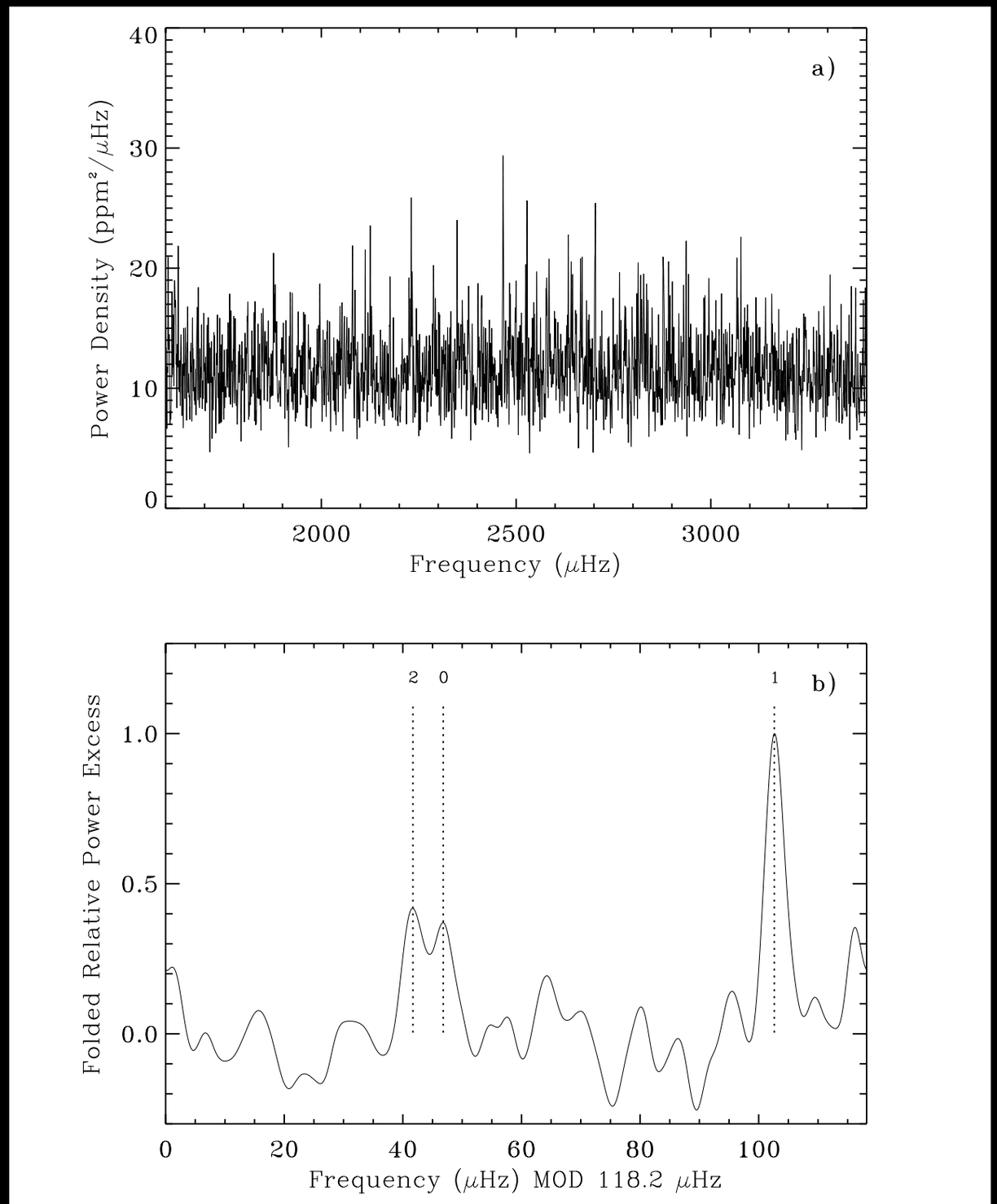
Lissauer et al. 2011, Nature, 470, 53

Stellar Properties

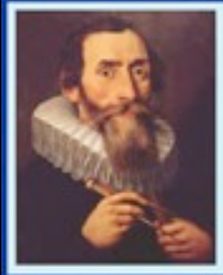
Kepler-10

- G4V
- Mass = 0.90 $M_\odot$
- Radius = 1.06 $R_\odot$
- Age > 8 Gyr
- Distance = 560 Light-years

Asteroseismology



Kepler-10b Light Curve



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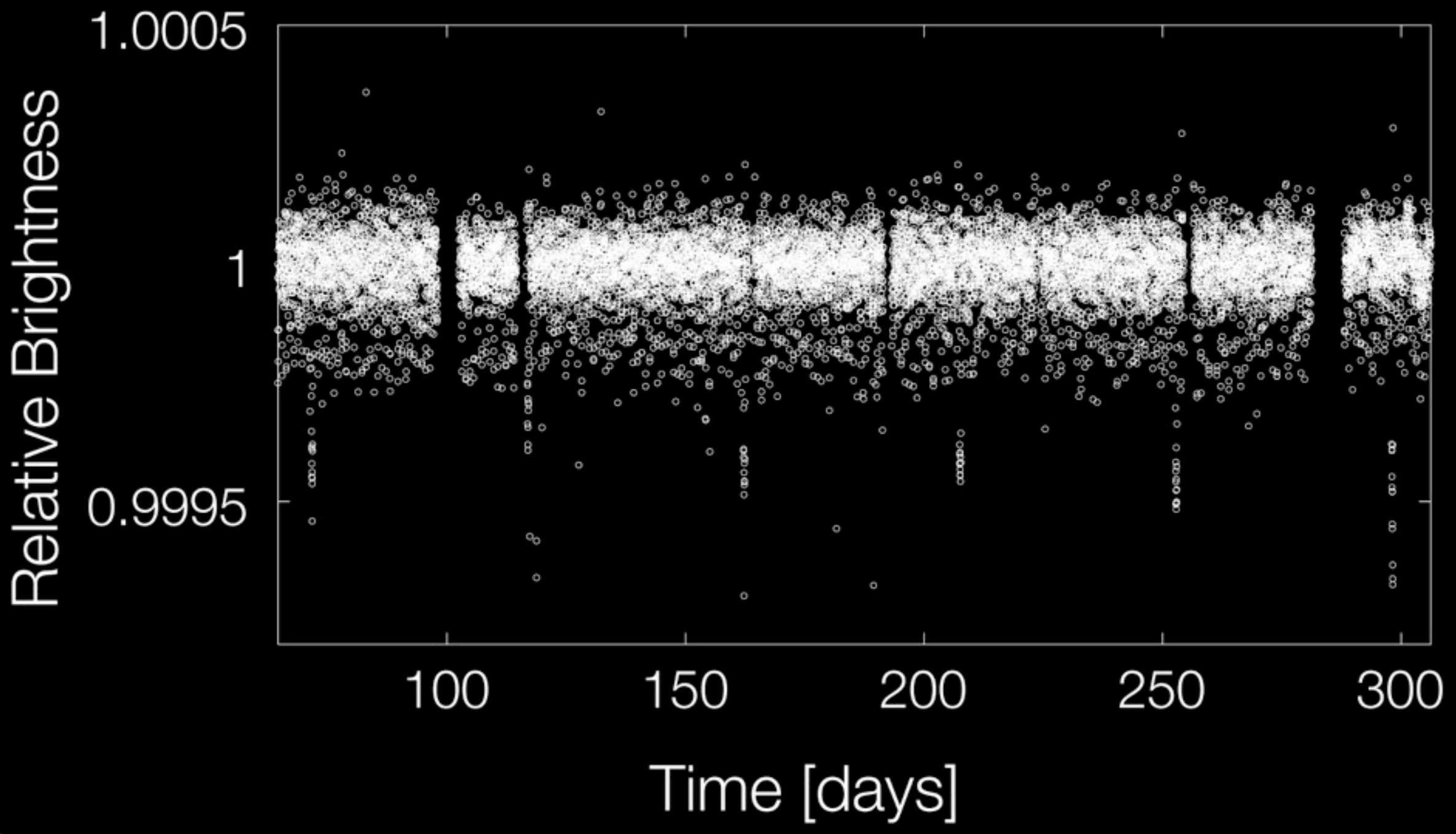
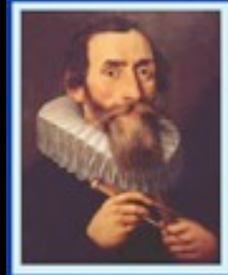
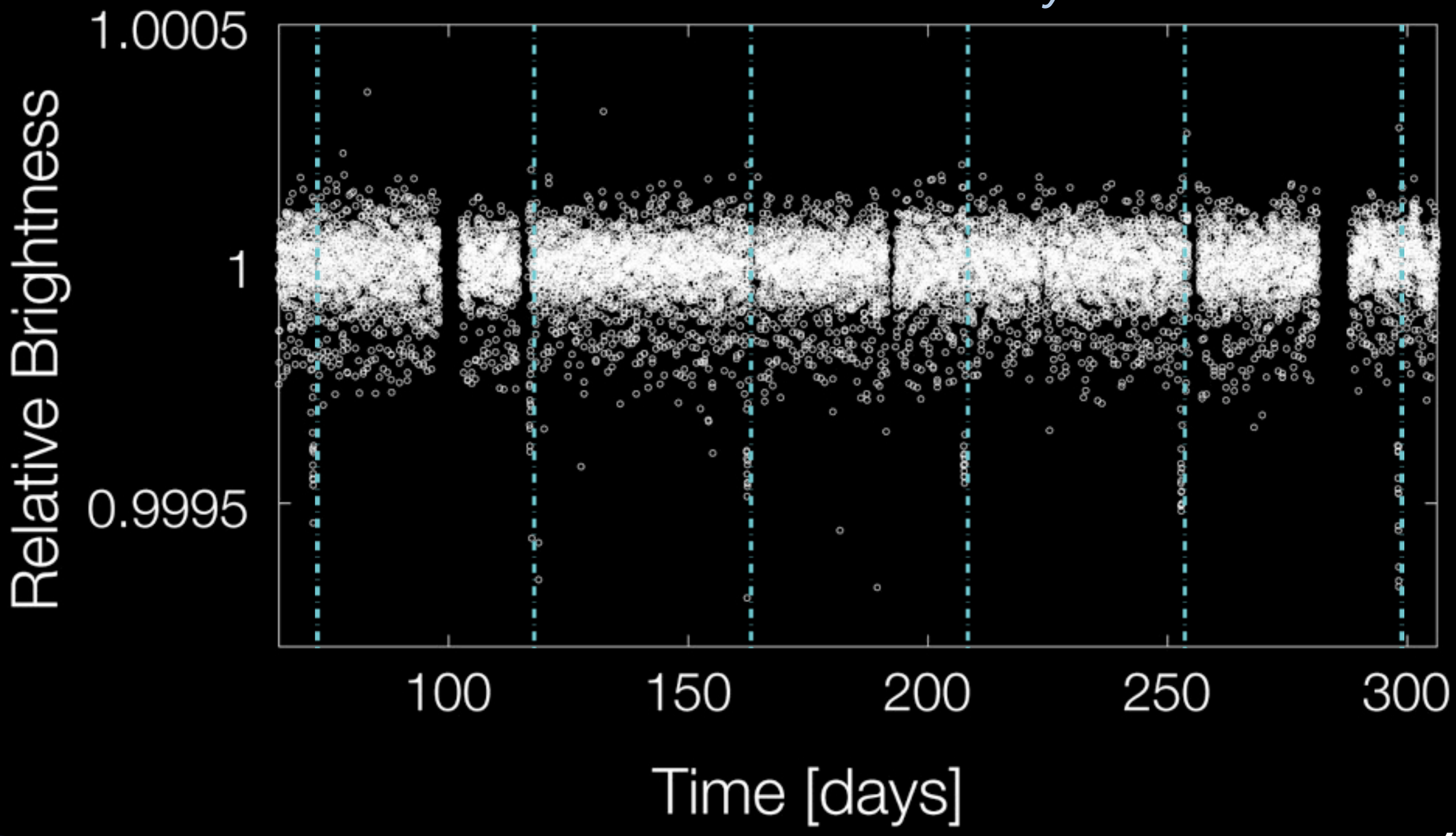


Kepler-10b Light Curve

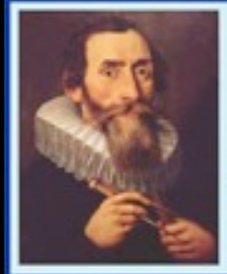


Kepler
A Search for Terrestrial Planets

Period = 45.29 days



Kepler-10b Light Curve



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A Search for Terrestrial Planets

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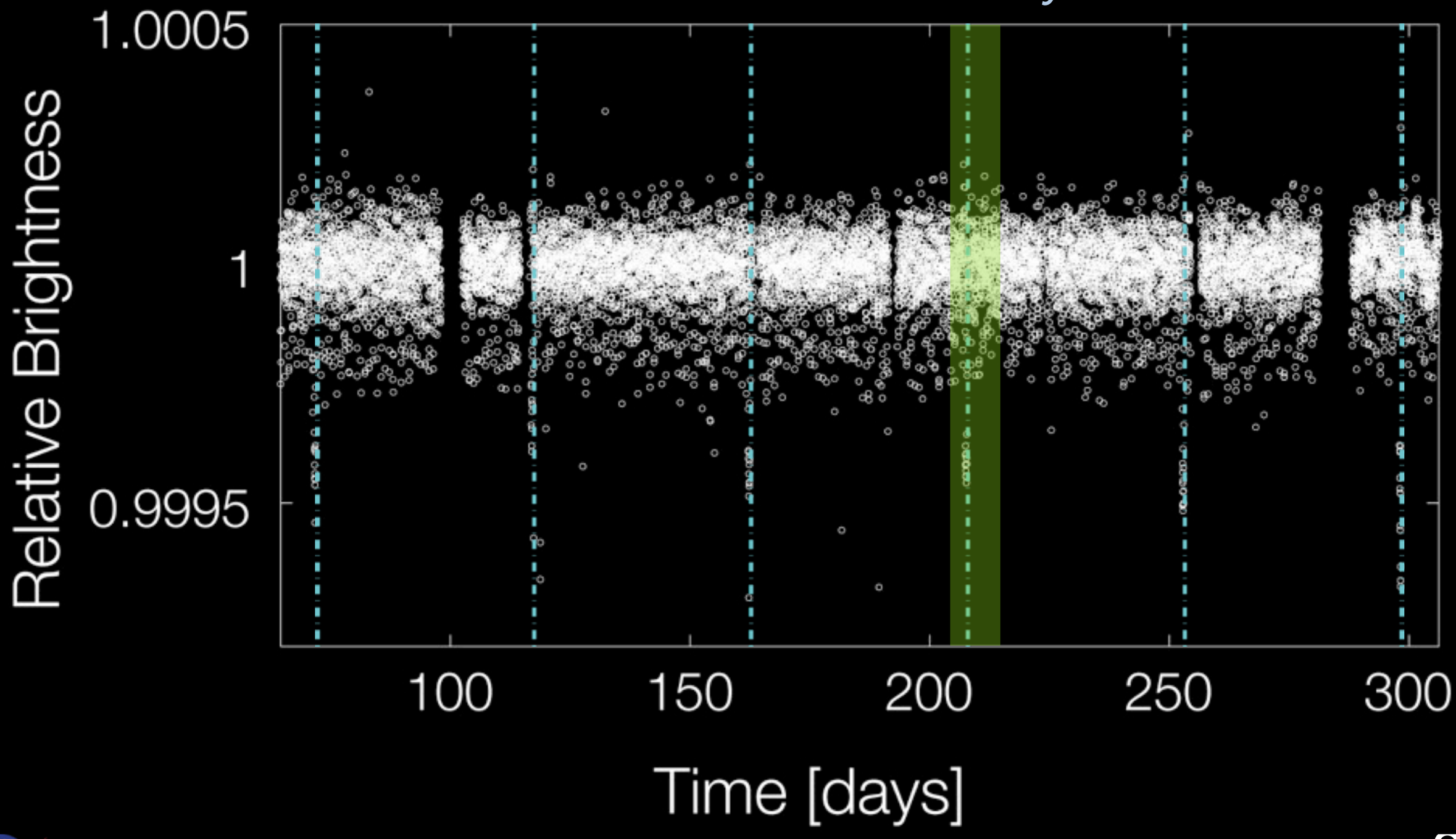
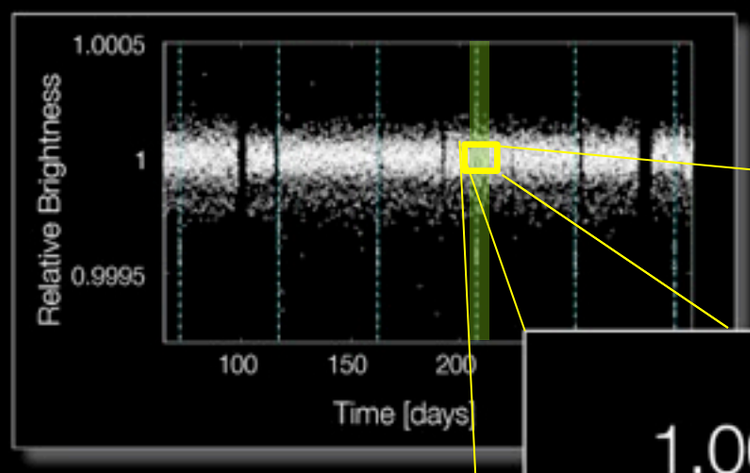
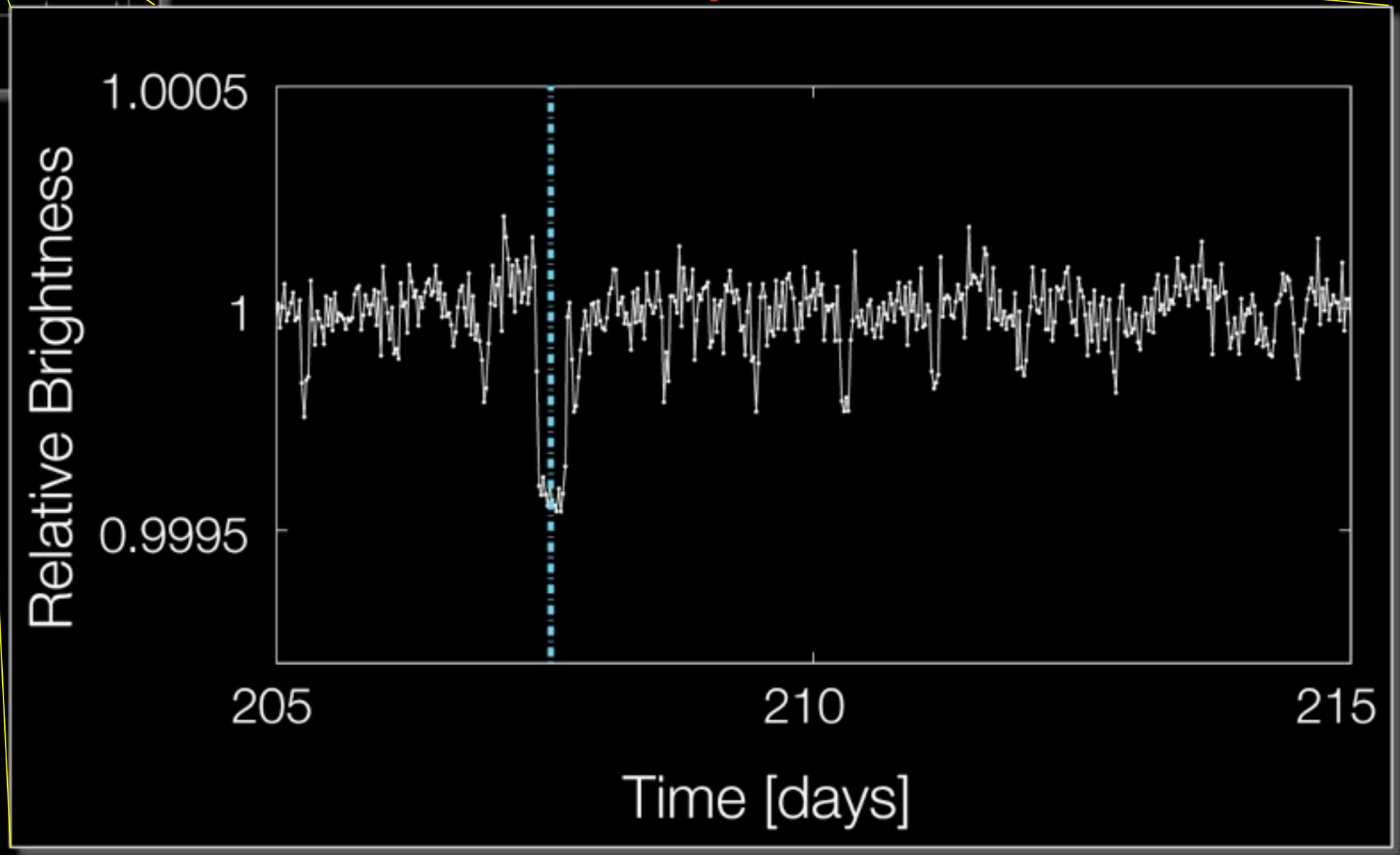


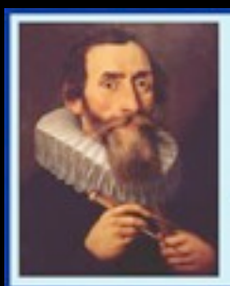
Kepler-10b Light Curve



Period = .84 days



Kepler-10b Light Curve



Kepler
A Search for Terrestrial Planets

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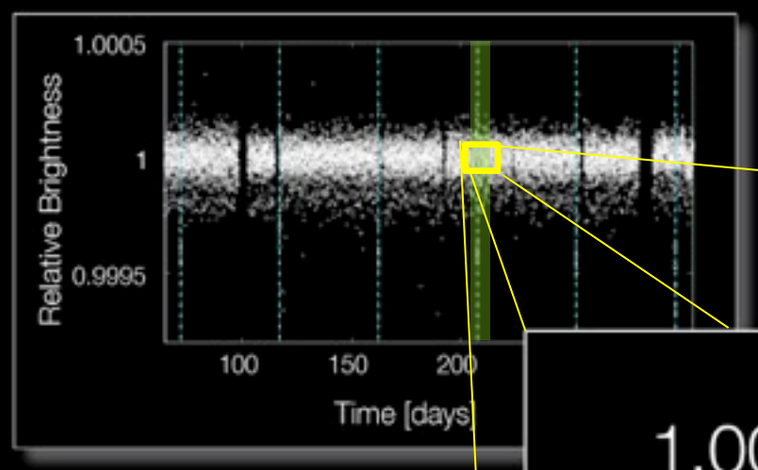
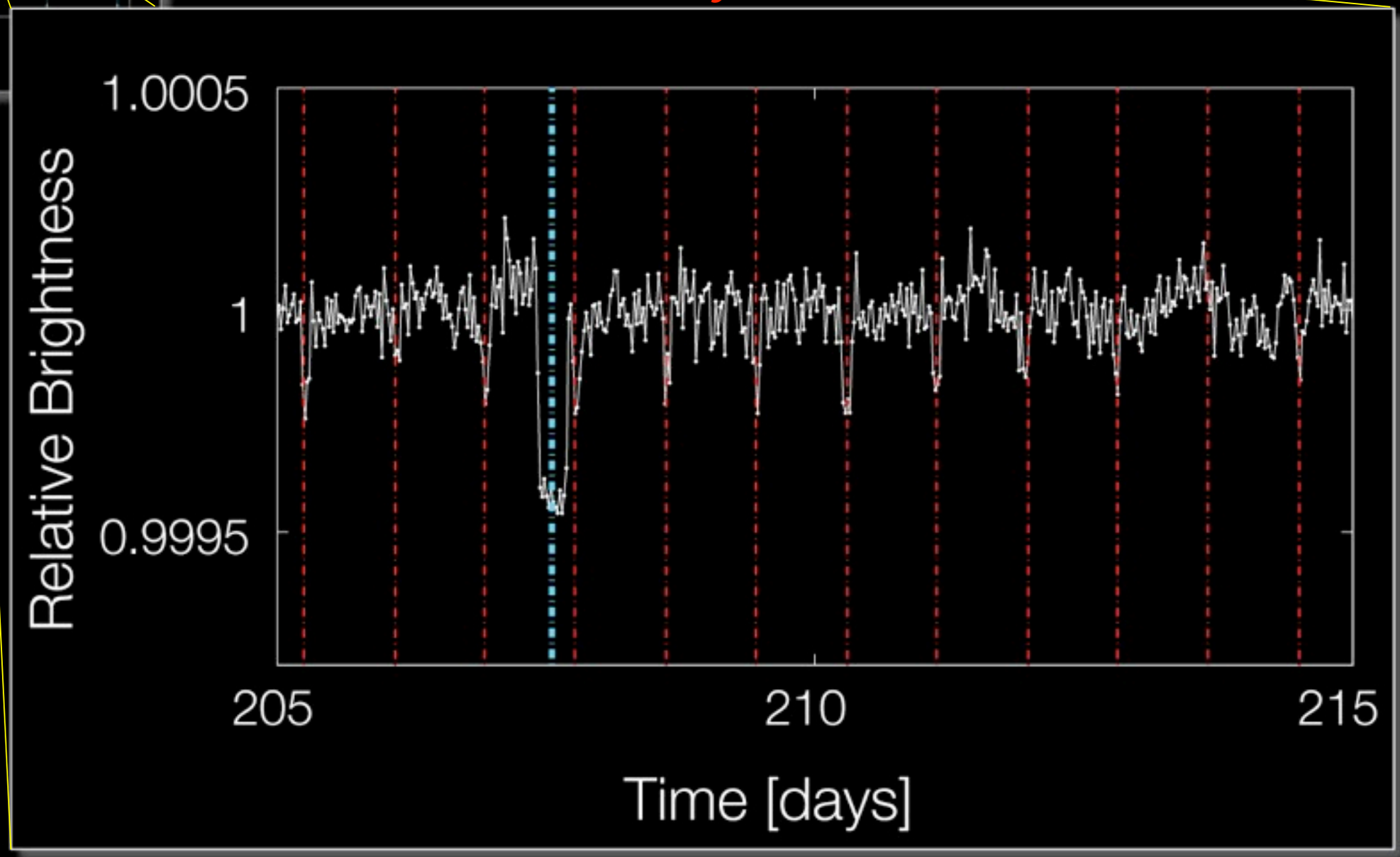
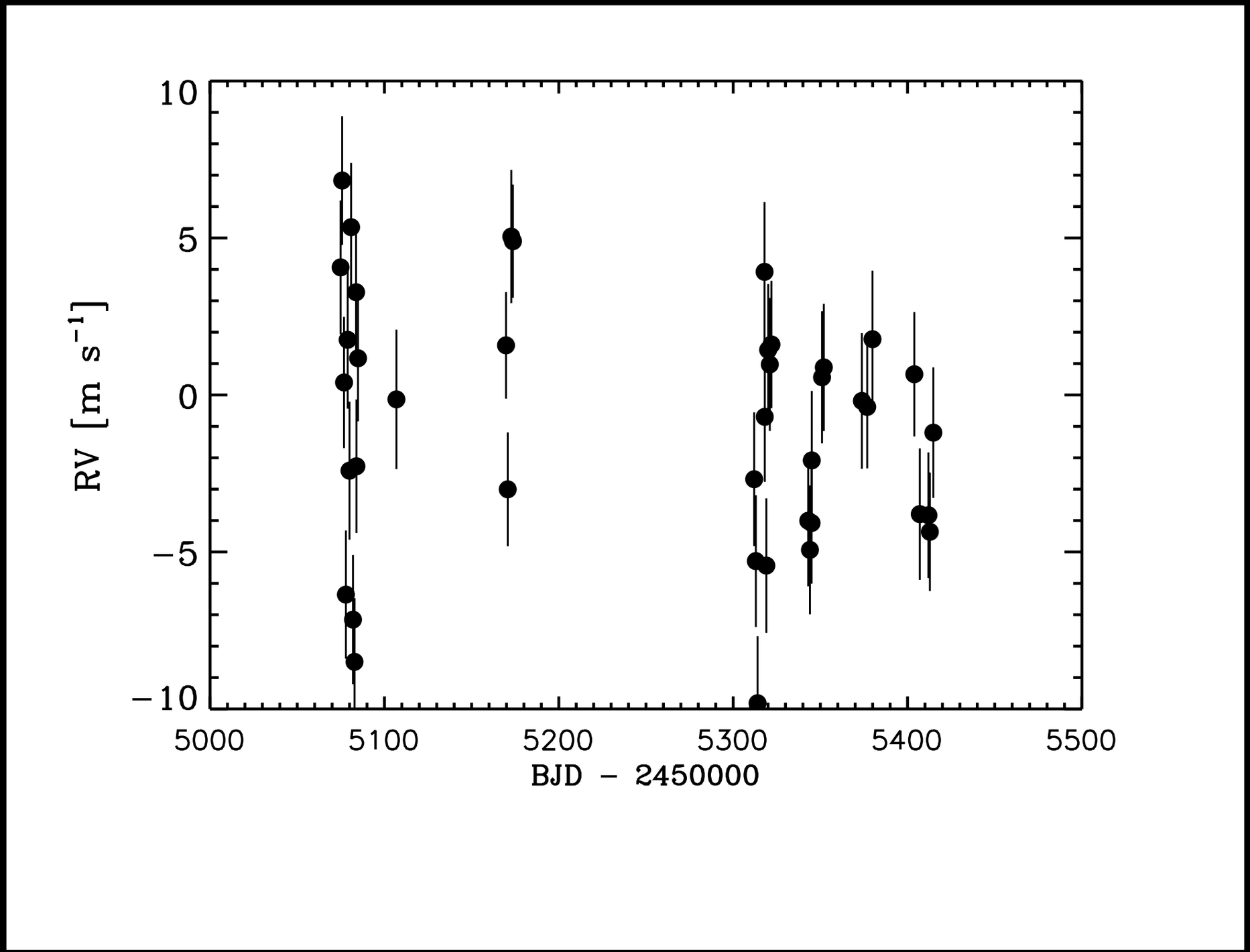


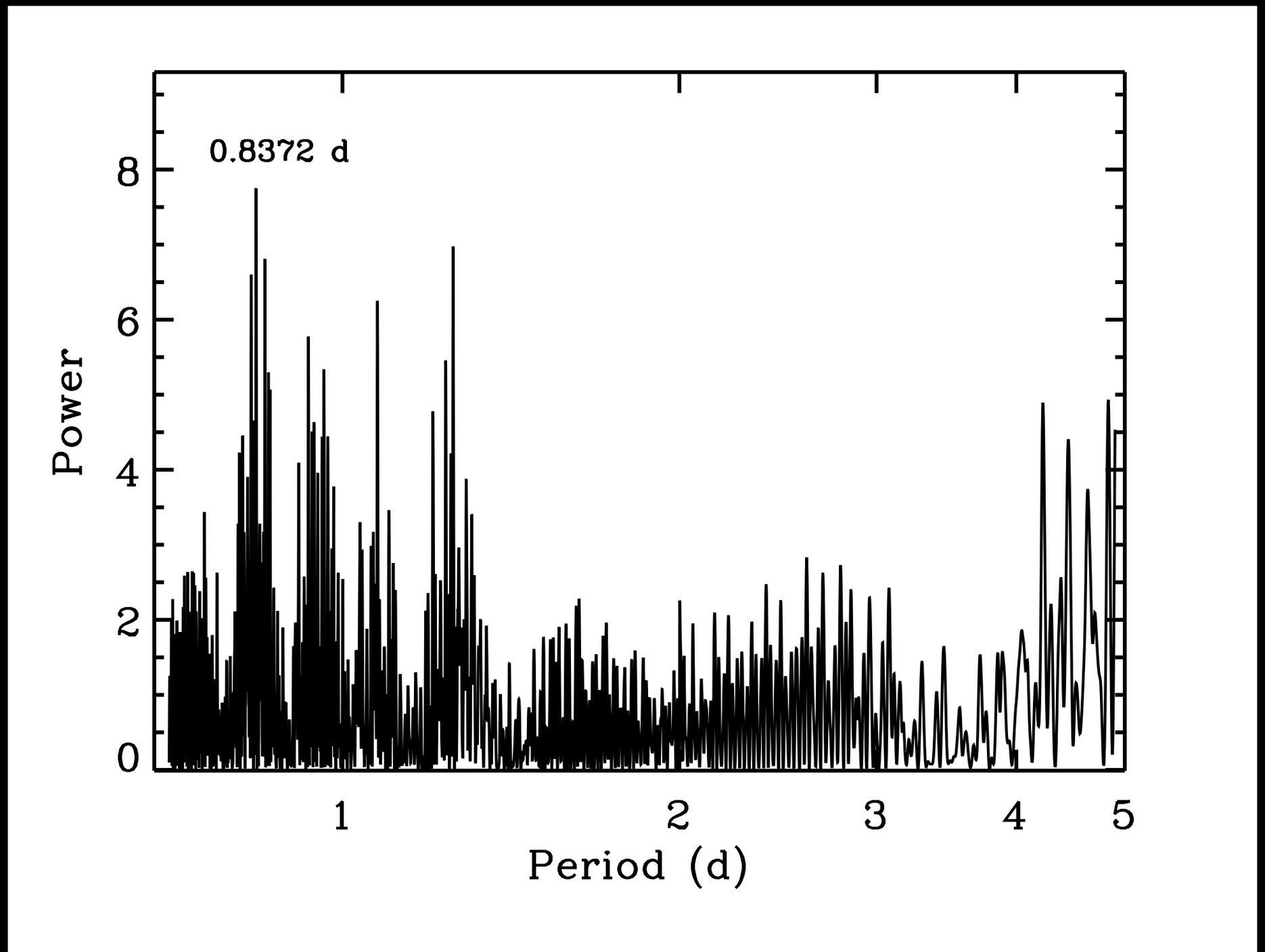
Period = .84 days



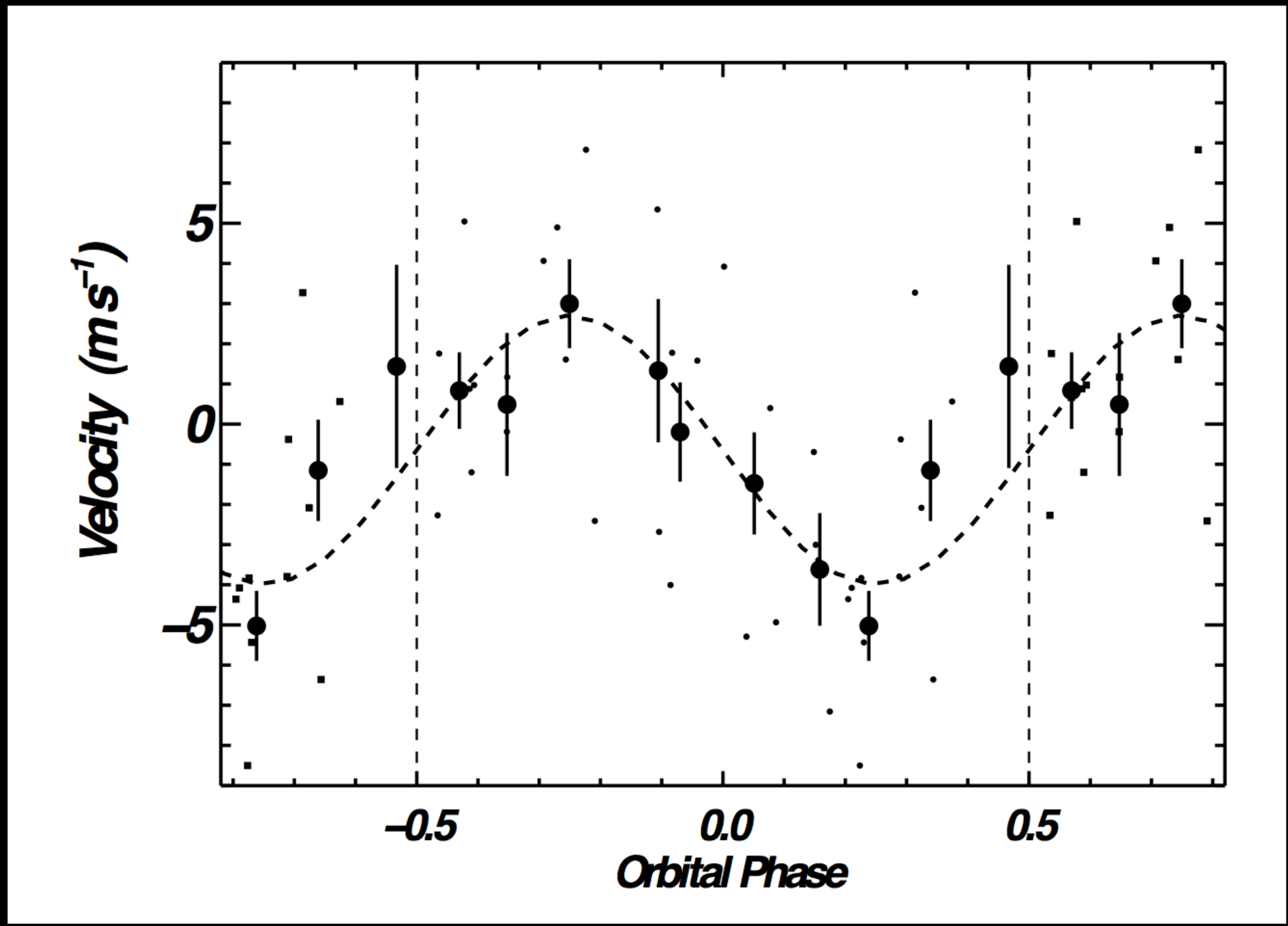
High Precision Doppler



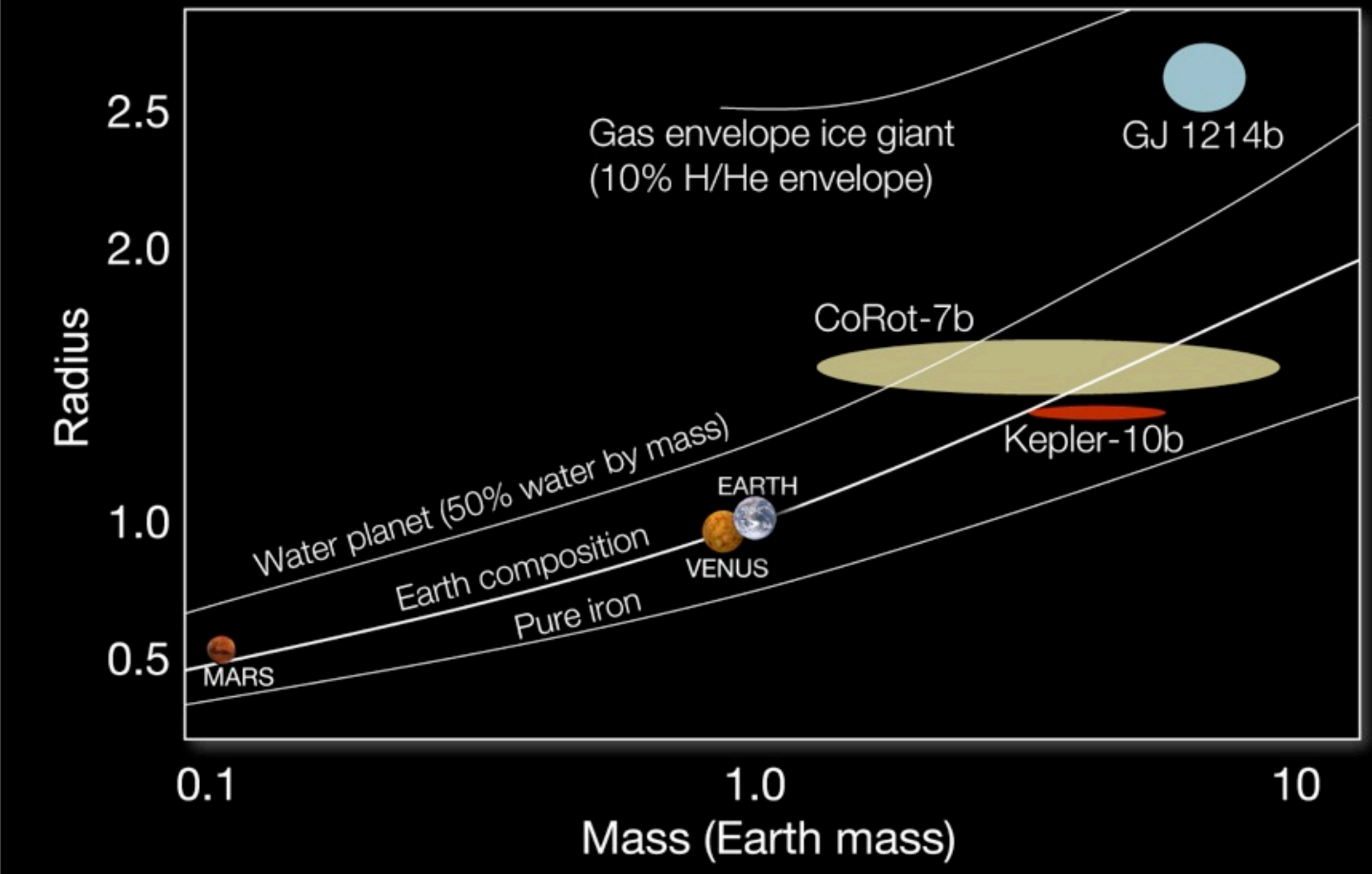
Doppler: Periodogram



Doppler: Model



Kepler-10b: Composition

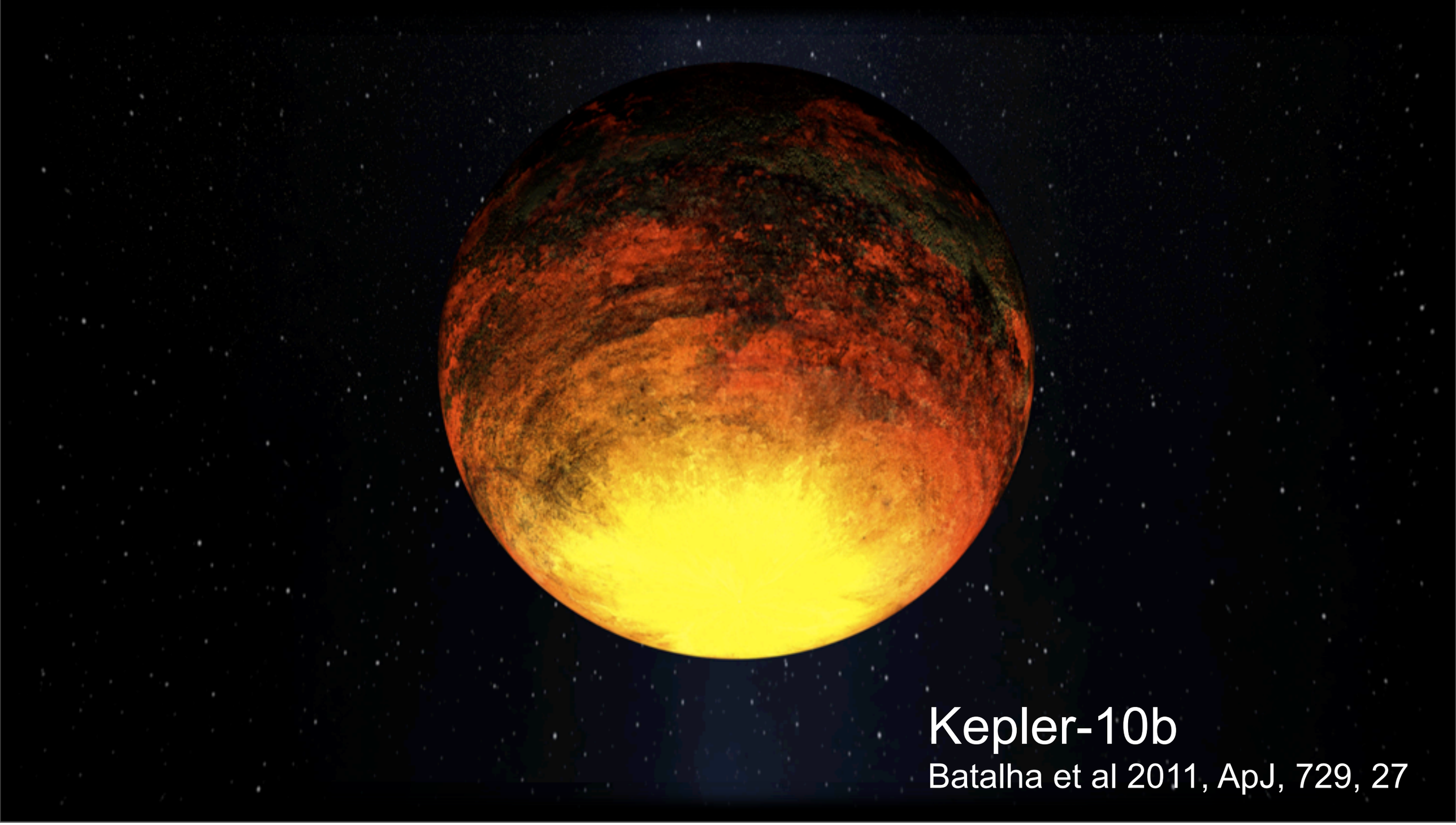


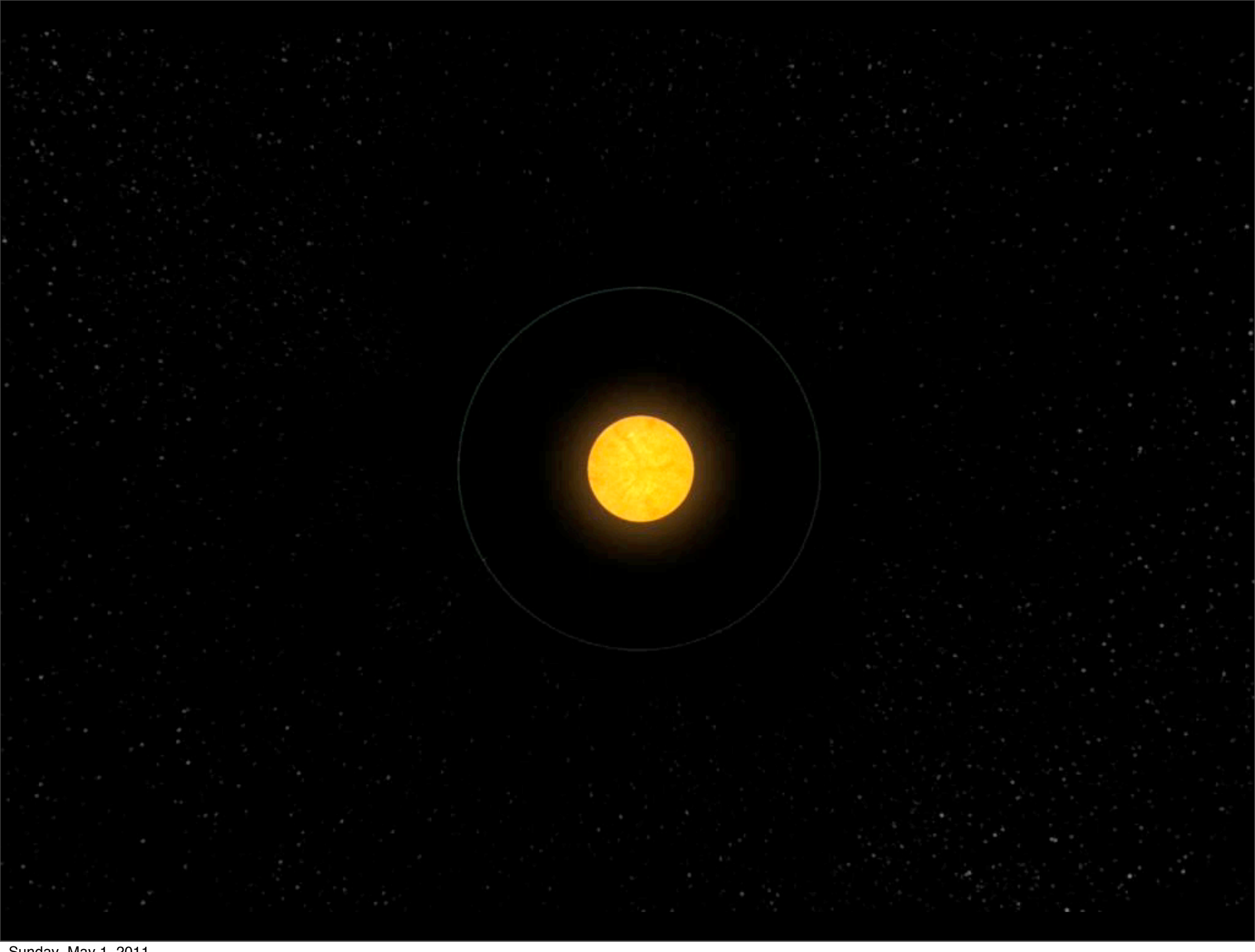
4.6 M_{earth}

1.4 R_{earth}

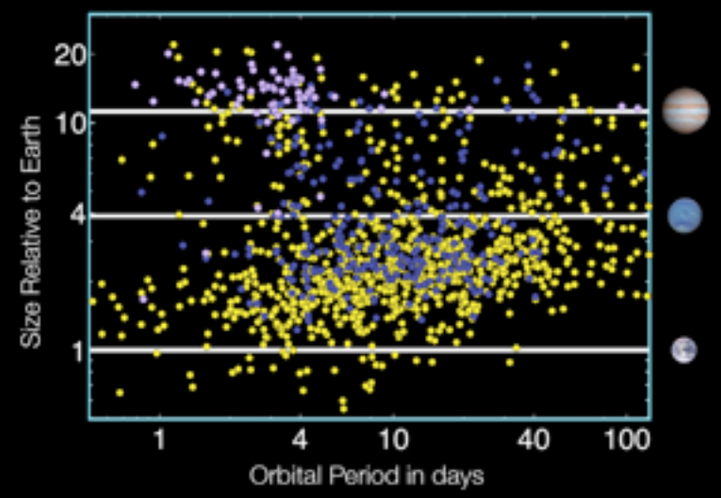
8.8 g/cm^3

Kepler's First Rocky Planet





Occurrence Rates

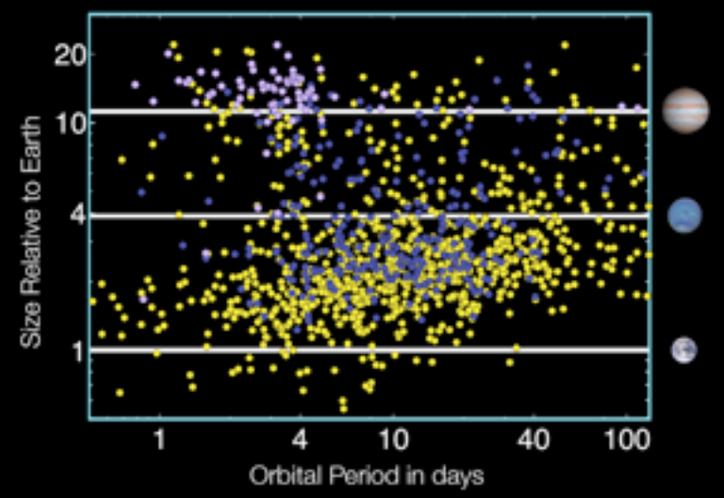


Correcting for:
- geometric probability
- sensitivity biases

Borucki et al 2011, arXiv:1102.0541:
10.5% for Earth-size candidates, 6.5% for super-Earth size candidates, 17.5% for Neptune-size candidates, 2.5% for Jupiter-size candidates.

False positive rate unknown
Pipeline completeness unknown

Occurrence Rates



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Occurrence Rates

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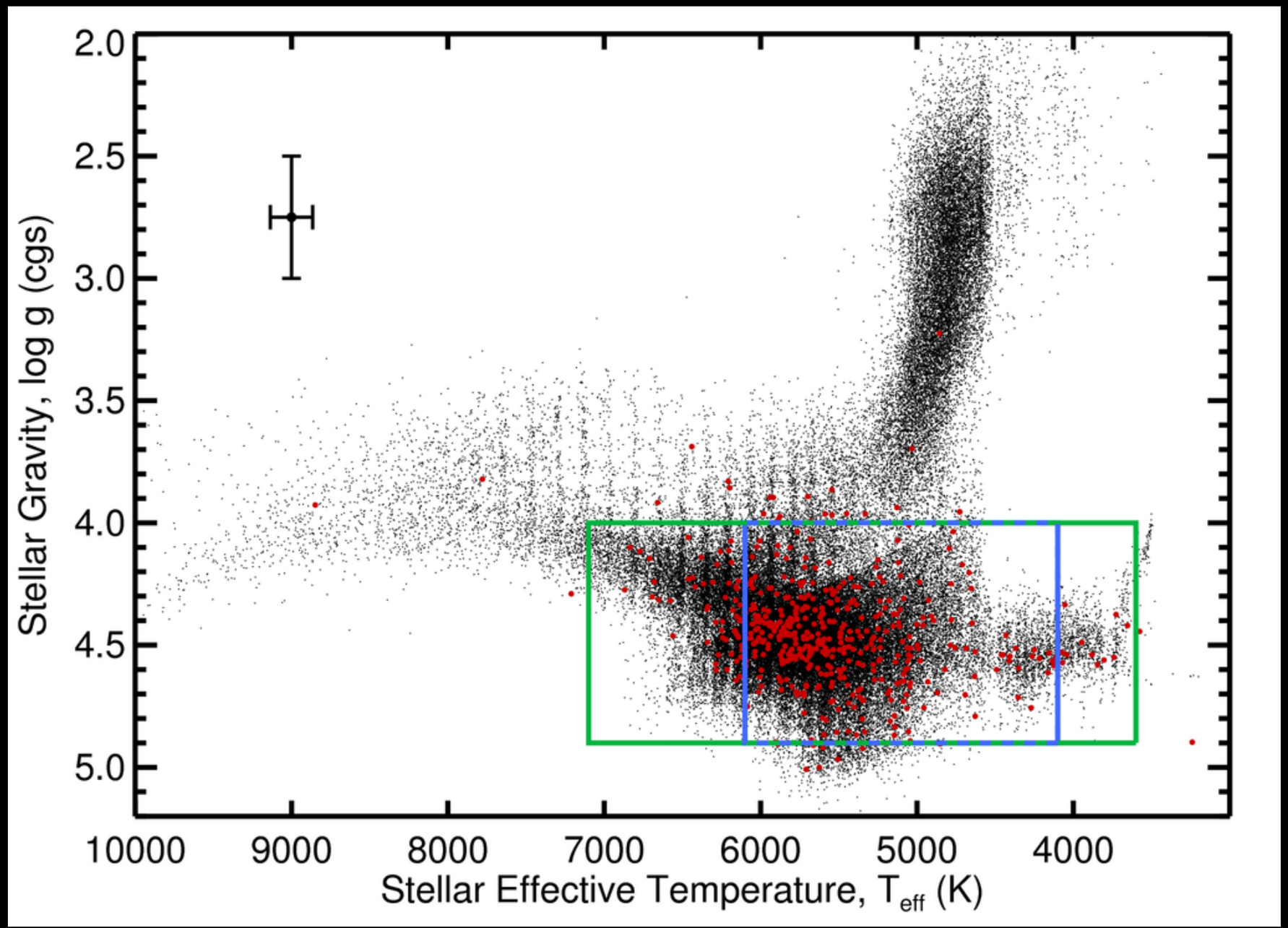
Subsample of stars: bright GK Main Sequence



Teff: 4100-6100 K
logg: 4.0-4.9
Kp: < 15

Subsample of candidates:

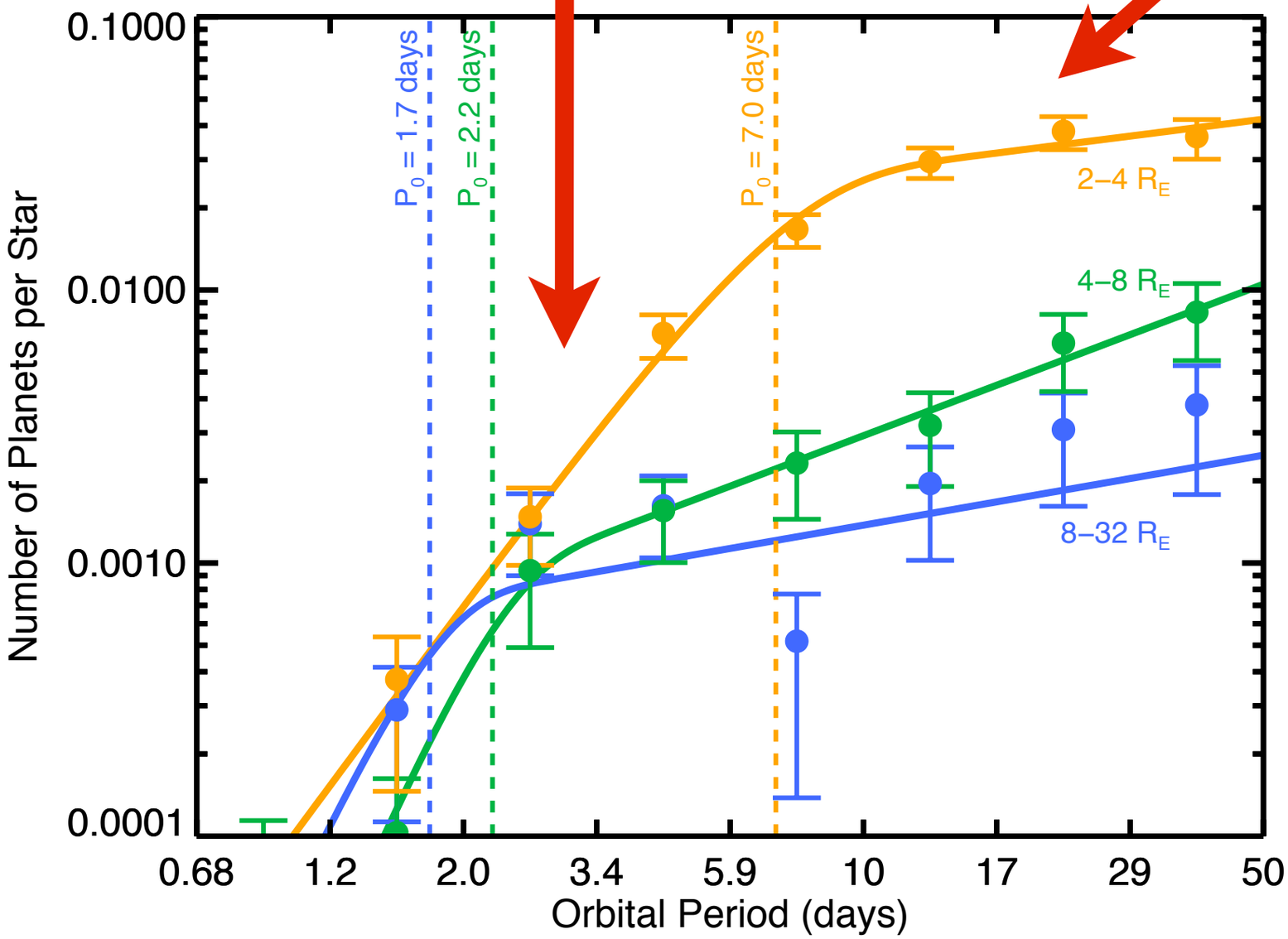
P < 50 days
R_p > 2 R_e
SN > 10

Howard et al. 2011, arXiv: 1103.2541

Occurrence Rate vs. Period

Exponential Cutoff

Power Law



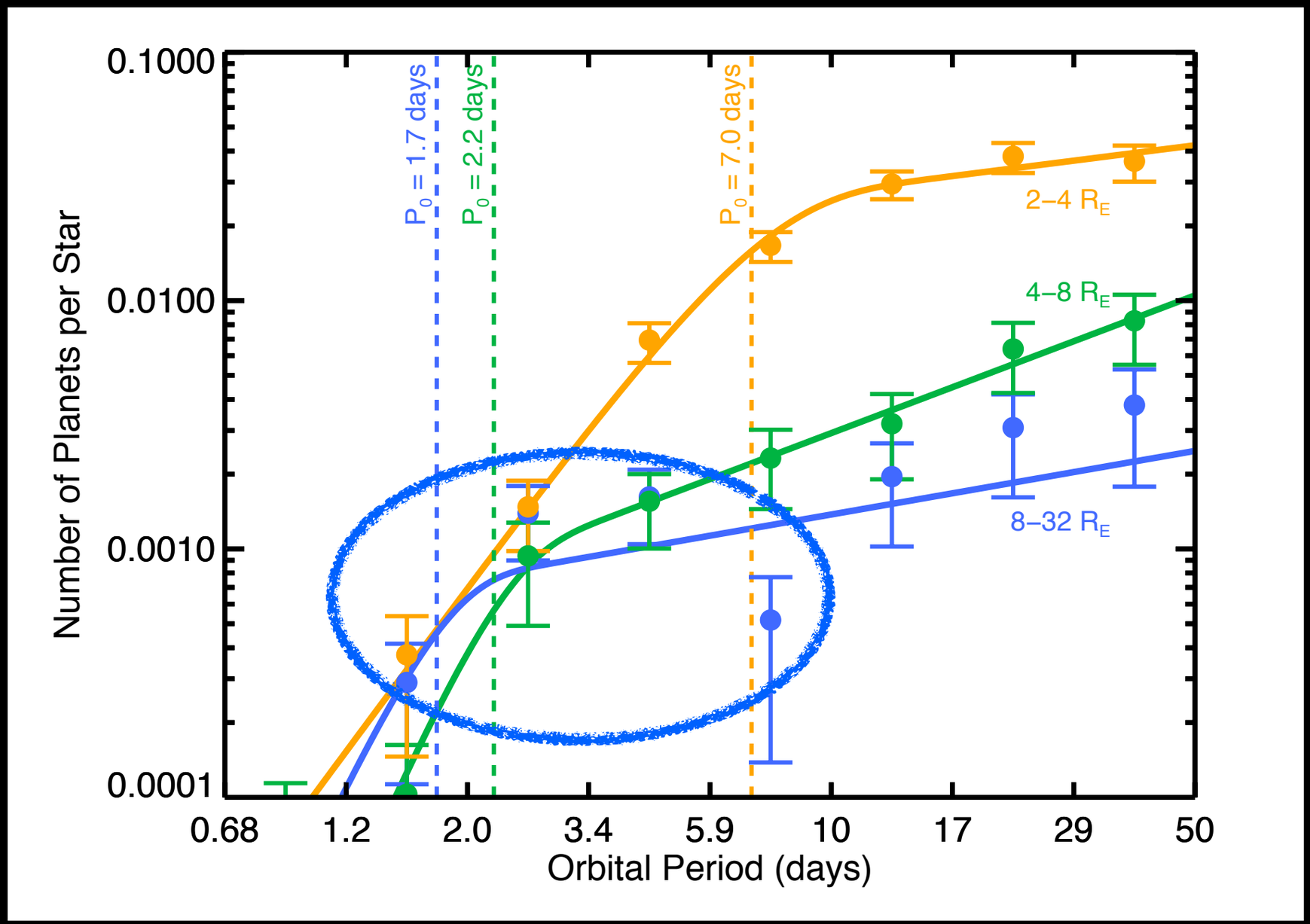
Power law with Exponential Cutoff:

$dN/d\log P = kP^{\beta}(1-\exp((P/P0)^{\gamma}))$

Total occurrence rates qualitatively similar to RV results.

Howard et al. 2011, arXiv: 1103.2541

Occurrence Rate vs. Period



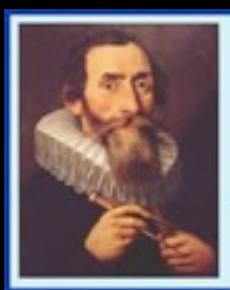
Hot-Jupiters (P < 10 days):

Kepler: 0.004
RV: 0.012

3x's lower in Kepler sample

Howard et al. 2011, arXiv: 1103.2541

Occurrence Rate vs. Radius



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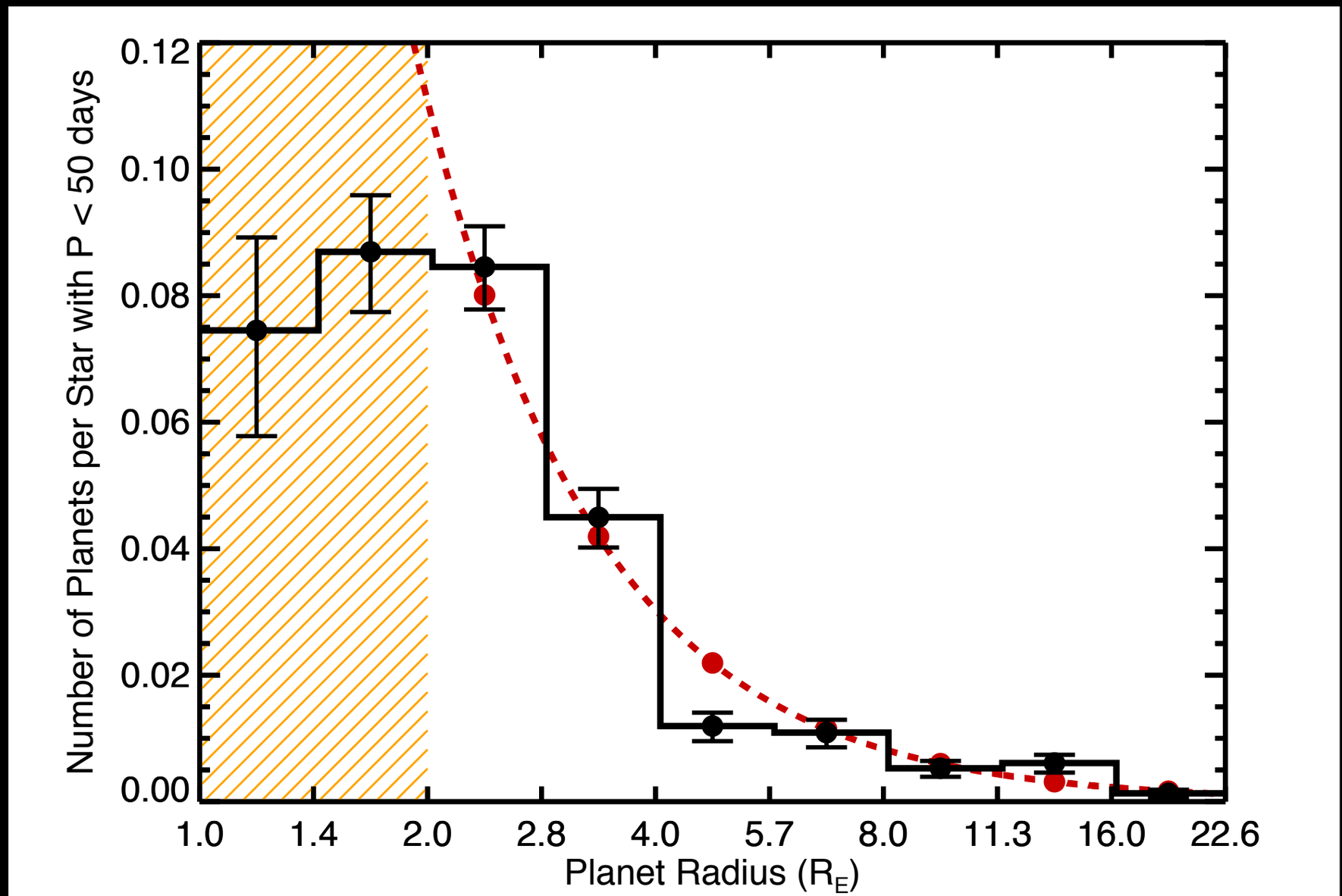
Power law increase in occurrence rate for smaller planets



$dN/d\log R = k R^{\alpha}$

$k = 2.9 \pm 0.5$

$\alpha = -1.92 \pm 0.11$

Howard et al. 2011, arXiv: 1103.2541

Statistics suggest that small planets are going to be common

produced by Dana Berry

"One day, from the shores of a new world, we'll gaze at the sea that took us there. And its waves will be stars."

Rui Borges, Sagan Day Essay Contest
http://kepler.nasa.gov/education/sagan