The Occurrence Rate and Composition of Small Planets

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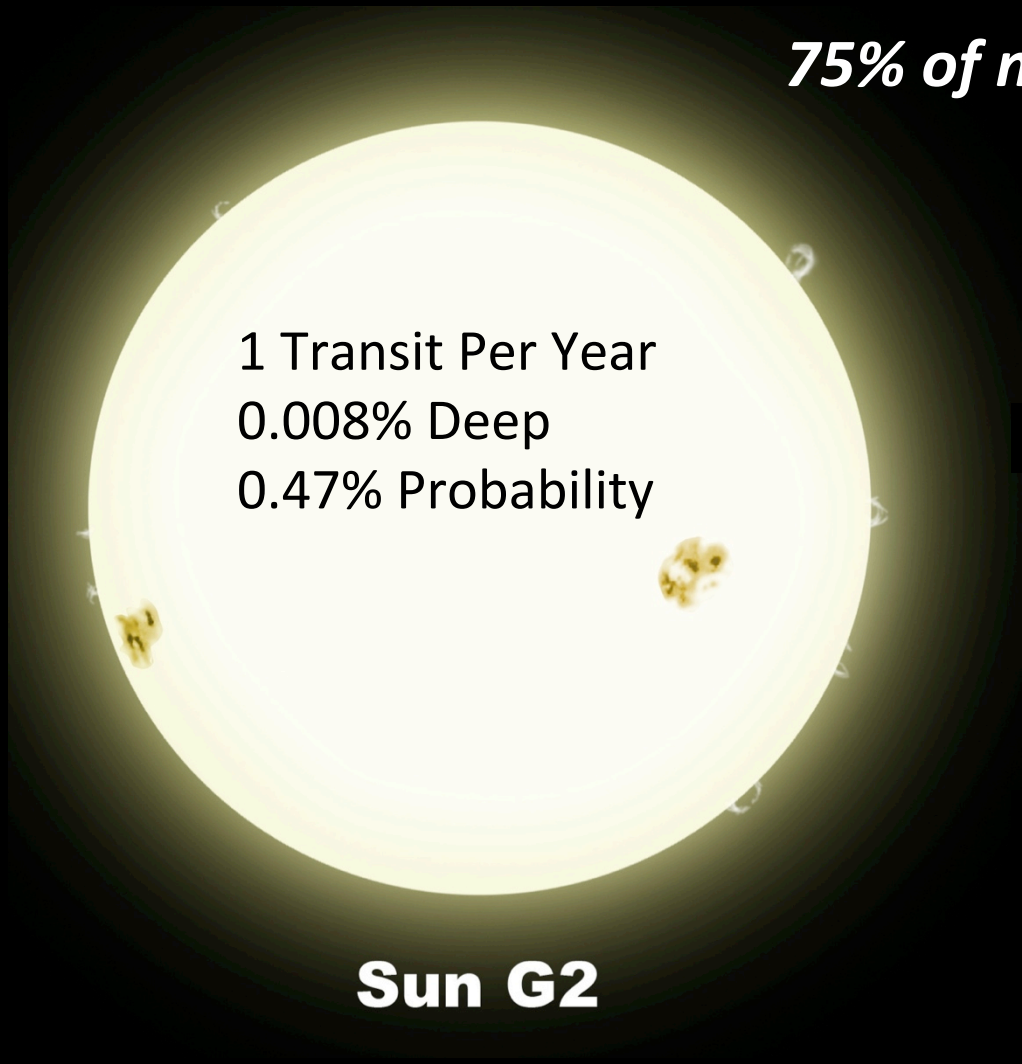
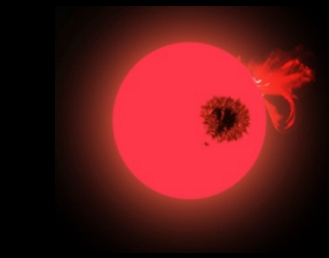
and NASA XRP awarded to David Charbonneau, and the Templeton Foundation

The M Dwarf Advantage

75% of nearby stars are M dwarfs



12 Transits Per Year
0.13% Deep
1.4% Probability



Red Dwarf M4

Computing the Planet Occurrence Rate

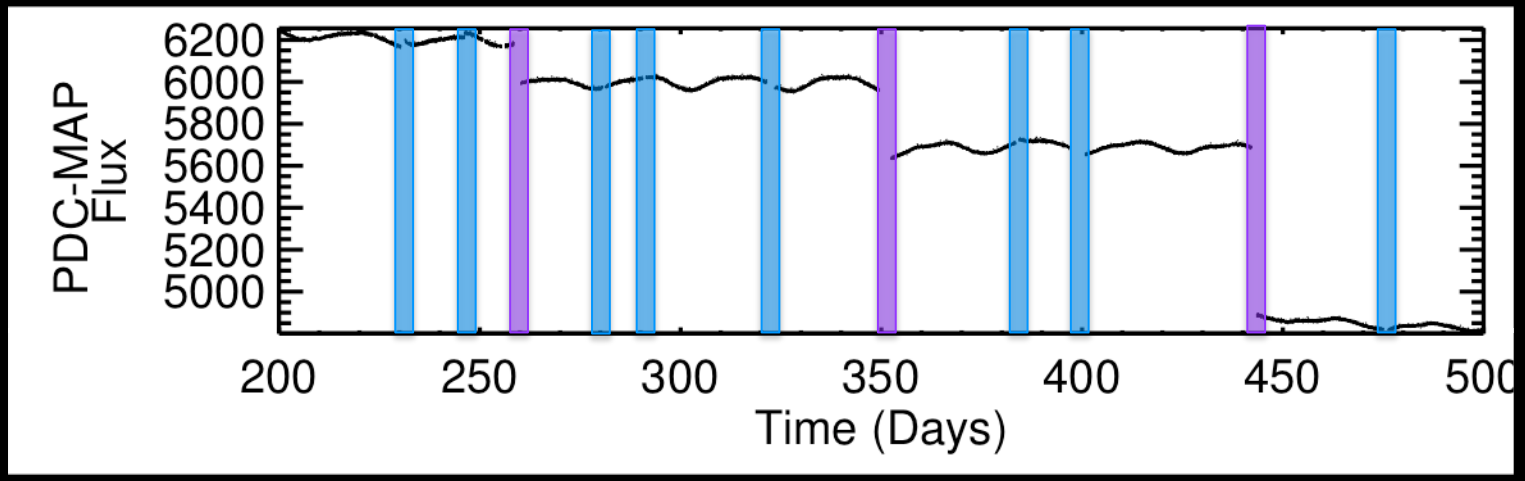
$$\text{Occurrence} = \frac{\text{Number of Planets}}{\text{Number of Stars}}$$

Important Considerations:

- ***We are not sensitive to all planets.***
- ***Some ``planets'' might be false positives.***

Dressing & Charbonneau 2013, ApJ, 767, 95
Dressing & Charbonneau 2015, ApJ submitted, arXiv:1501.01623

Searching for Planets Orbiting *Kepler* M Dwarfs

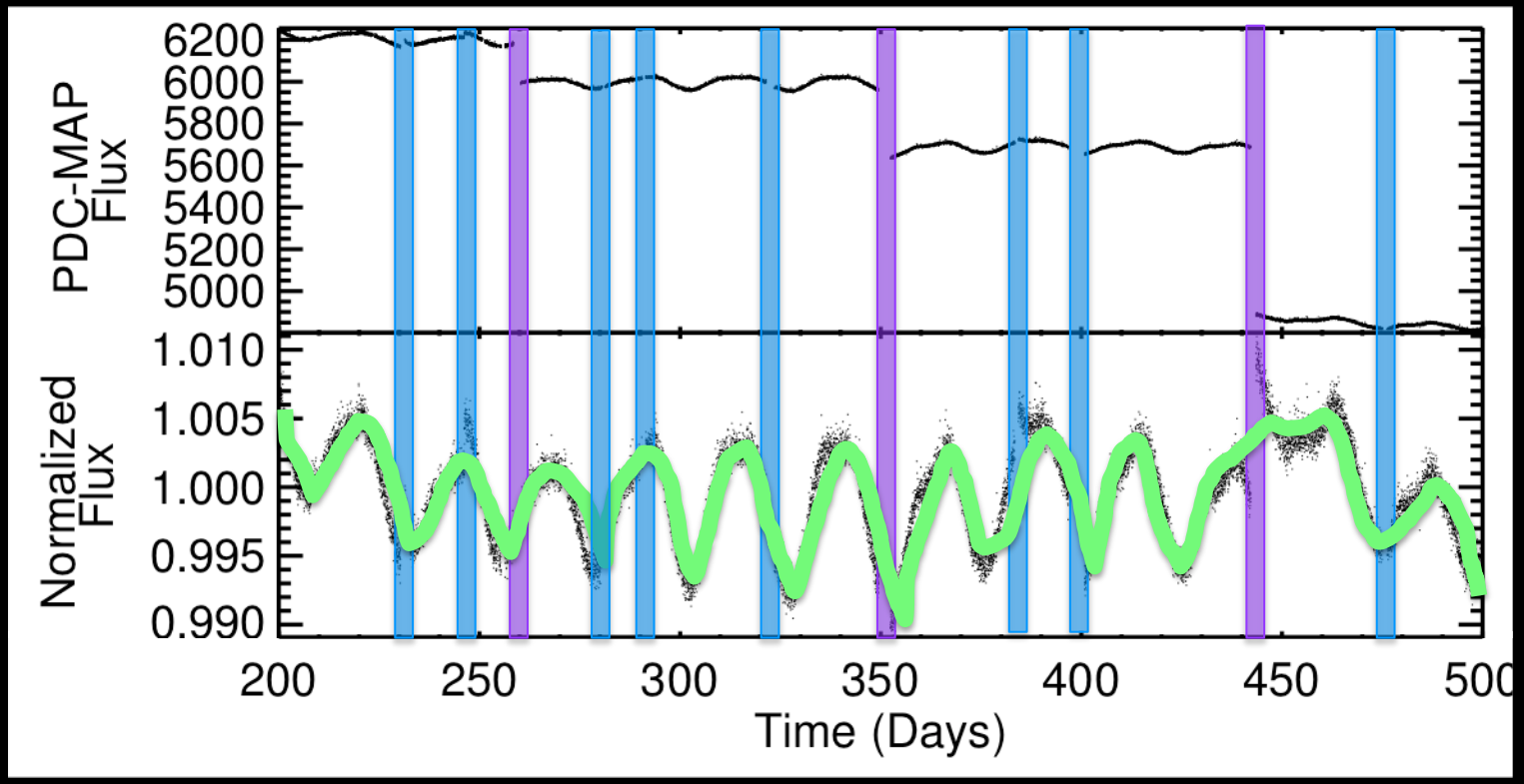


Quarterly Spacecraft Rolls

Data Gaps

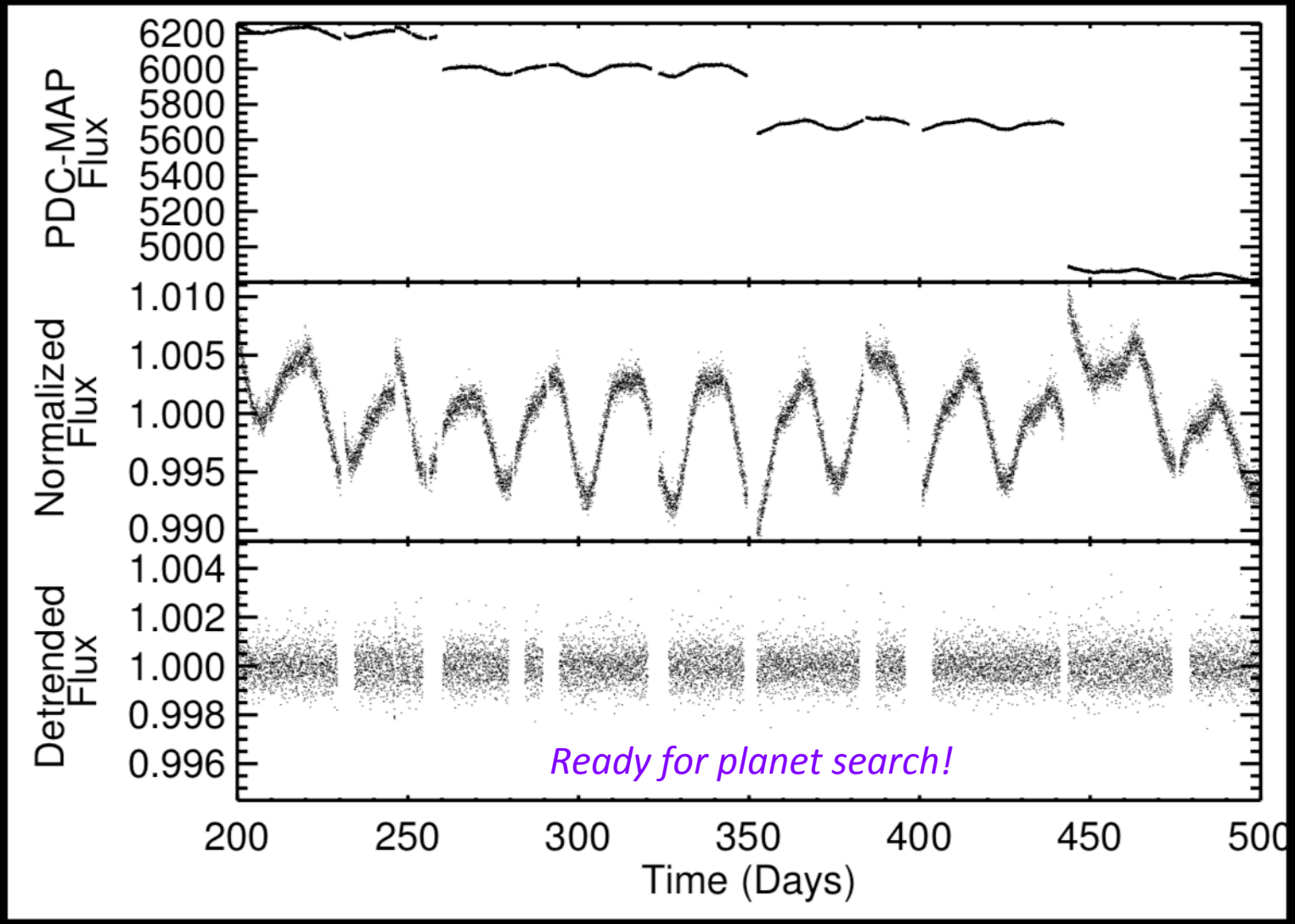
Normalize to remove quarterly offsets

Searching for Planets Orbiting *Kepler* M Dwarfs

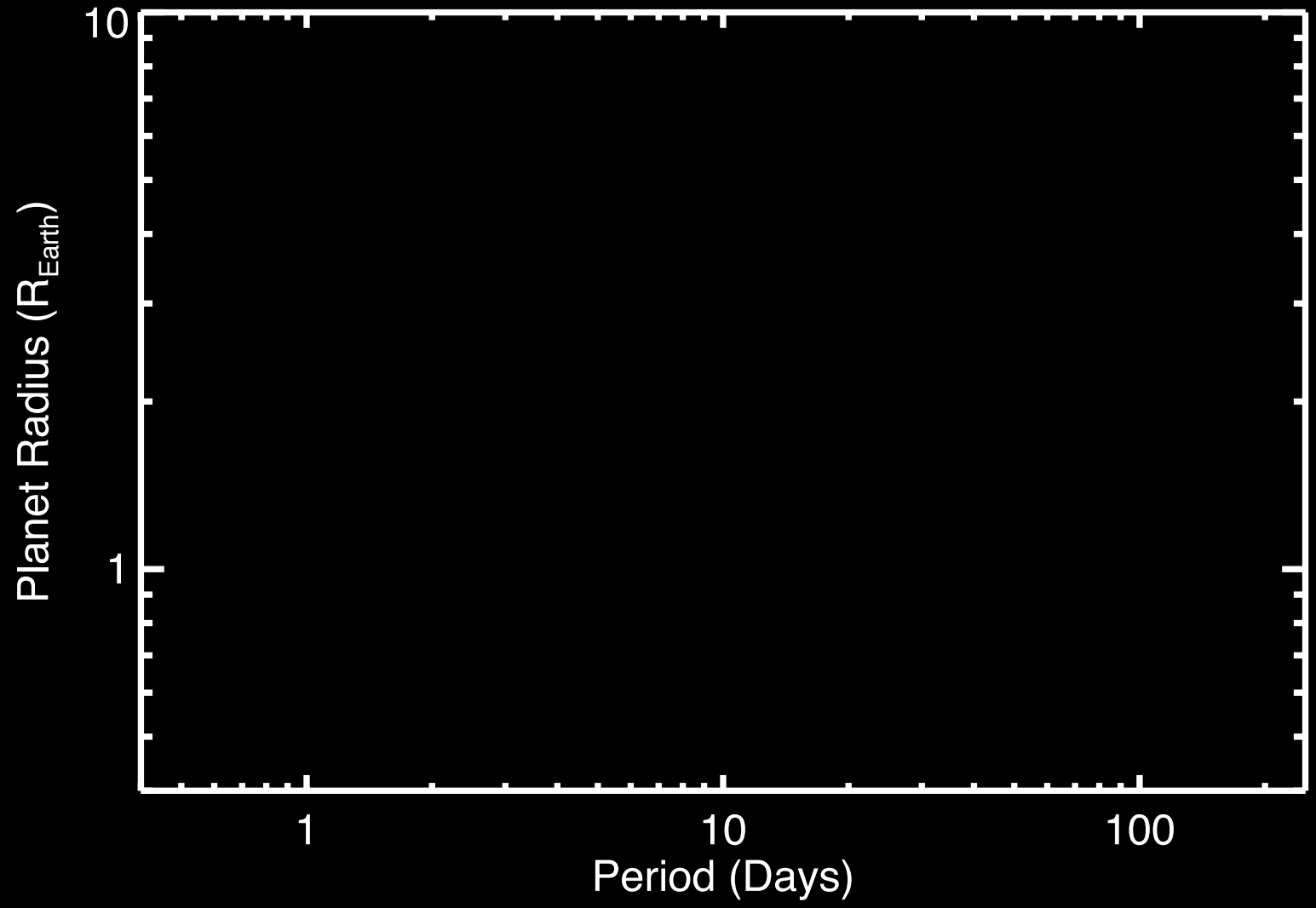


Use median filtering and sigma clipping to remove spots and lingering pointing offsets.

Searching for Planets Orbiting *Kepler* M Dwarfs



Our Pipeline Detects Most Known Planets



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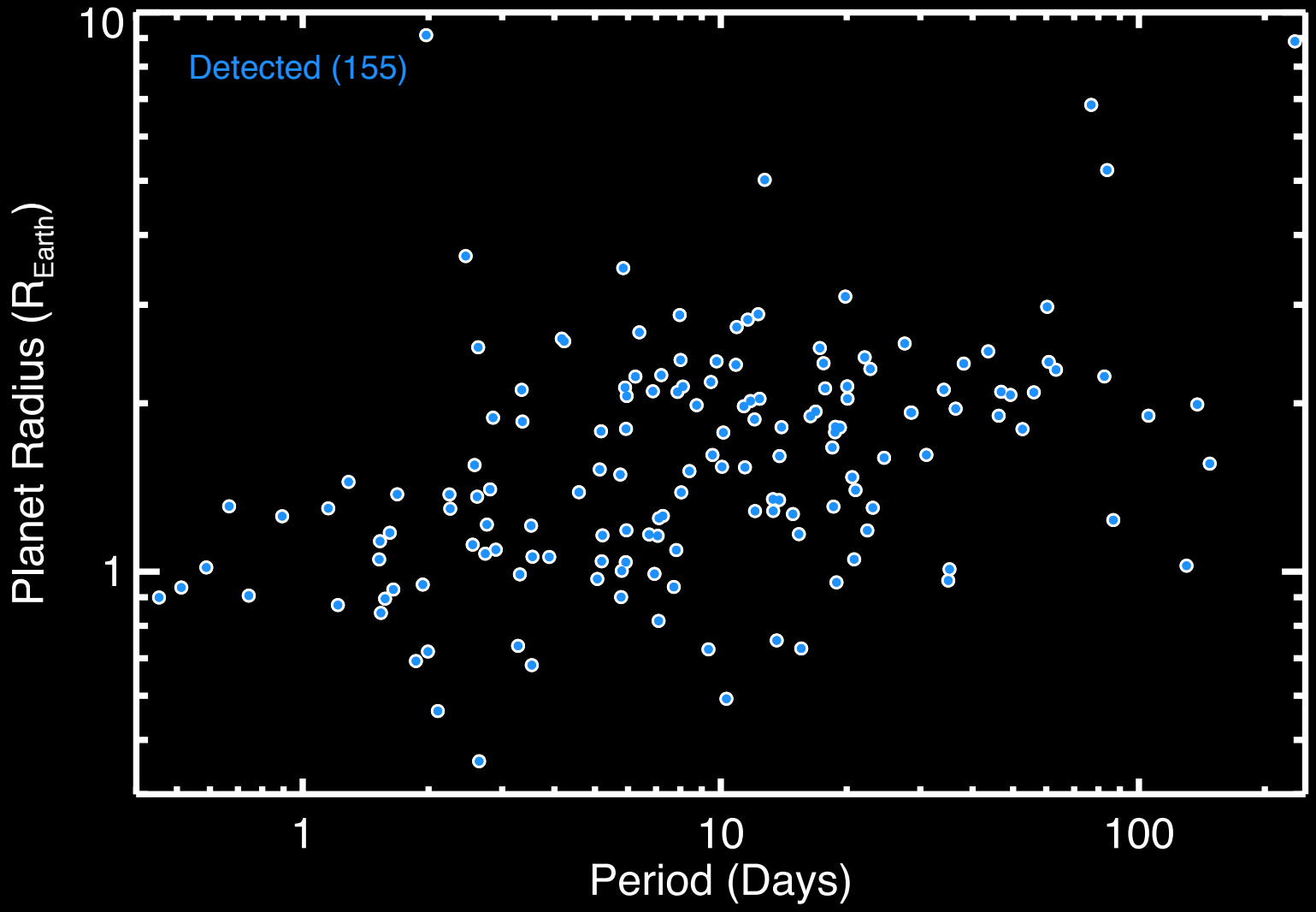

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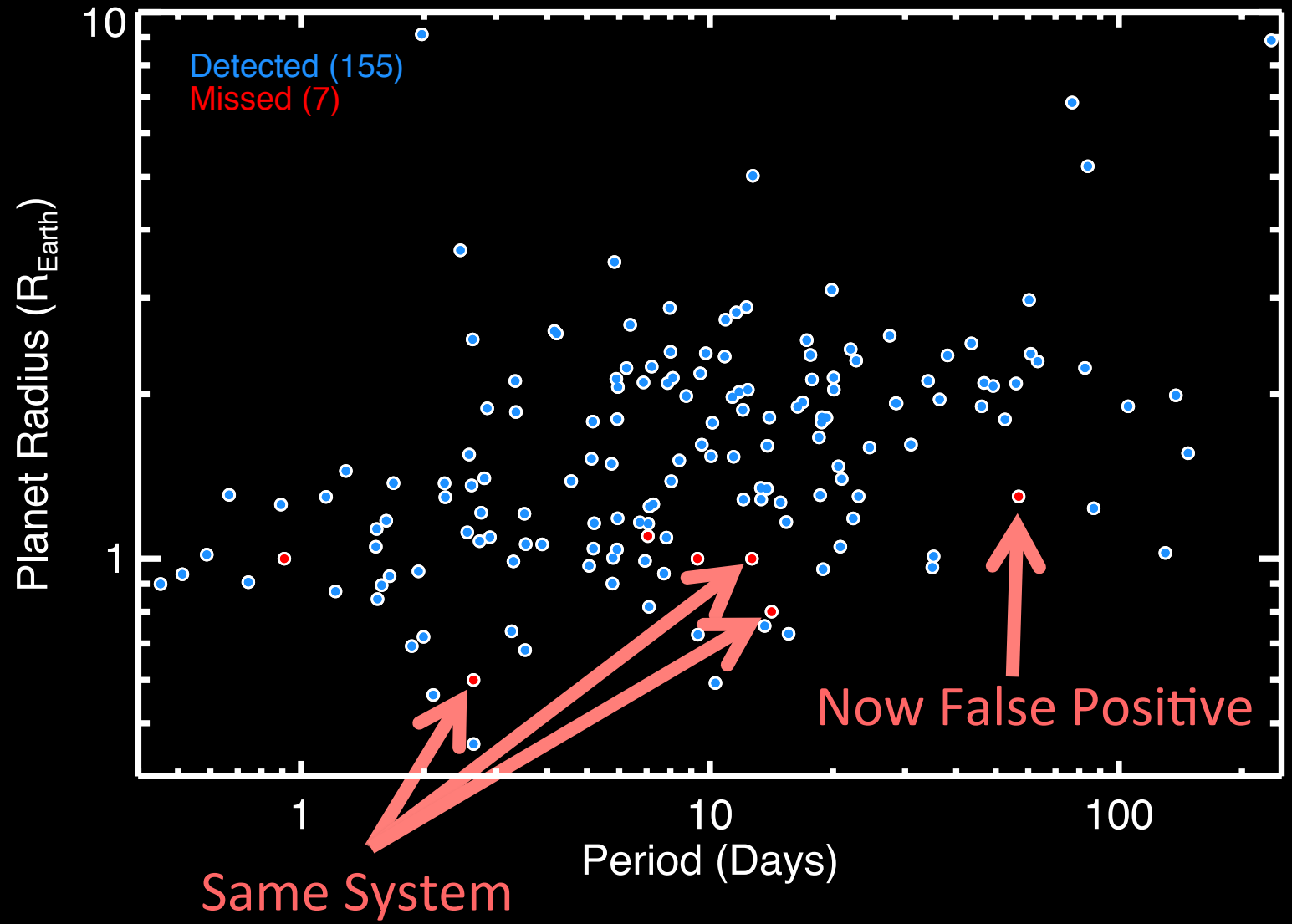

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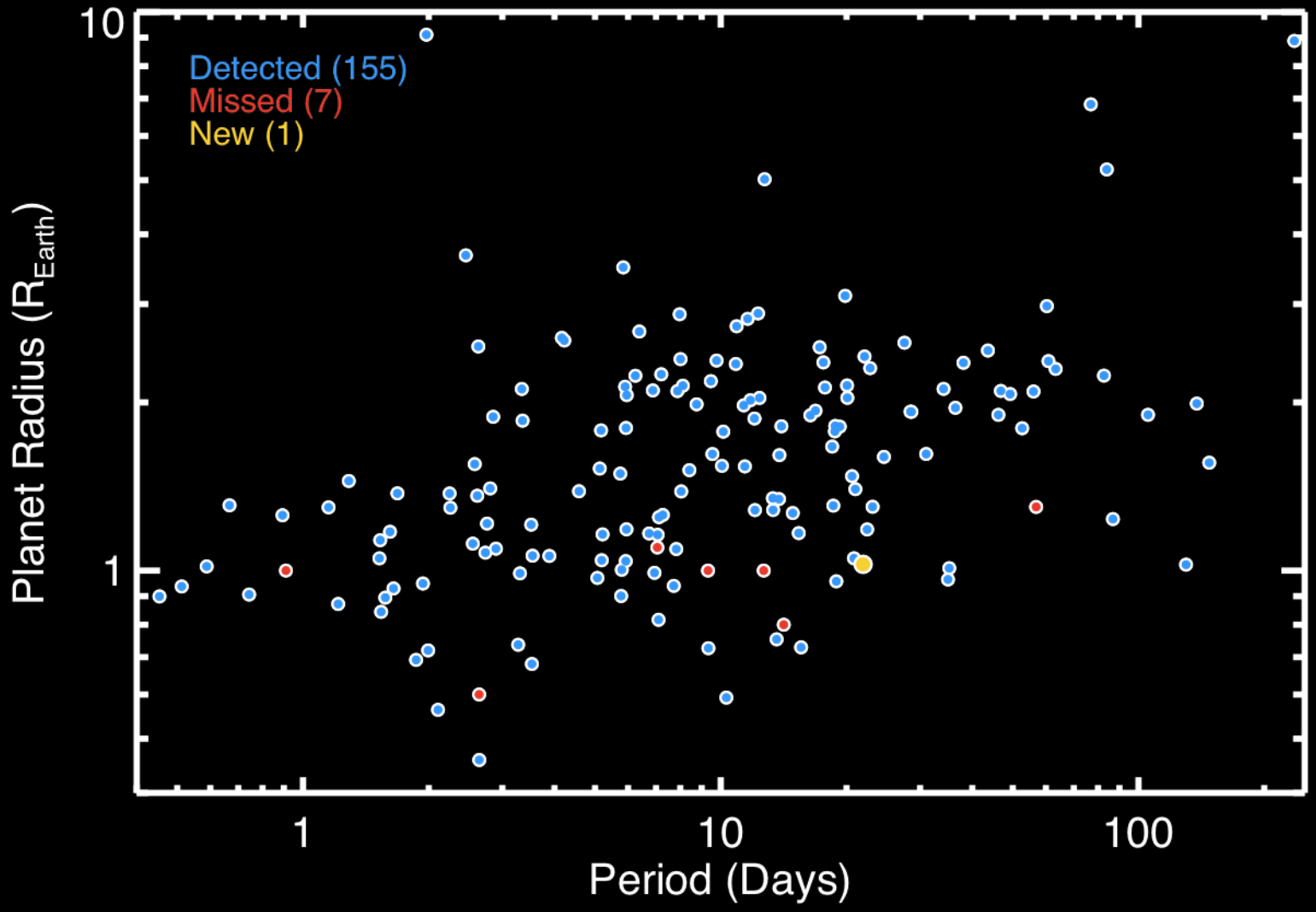
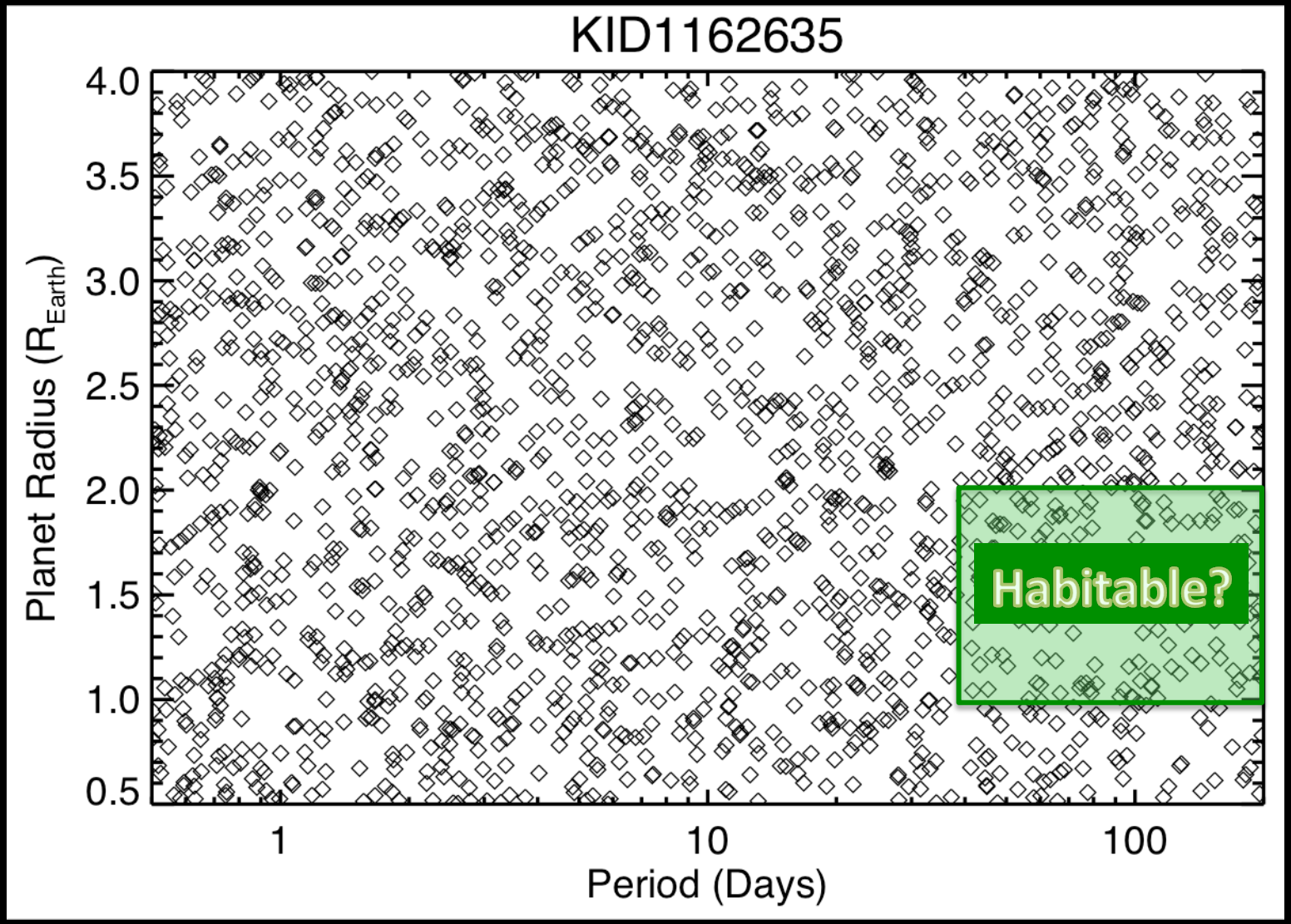
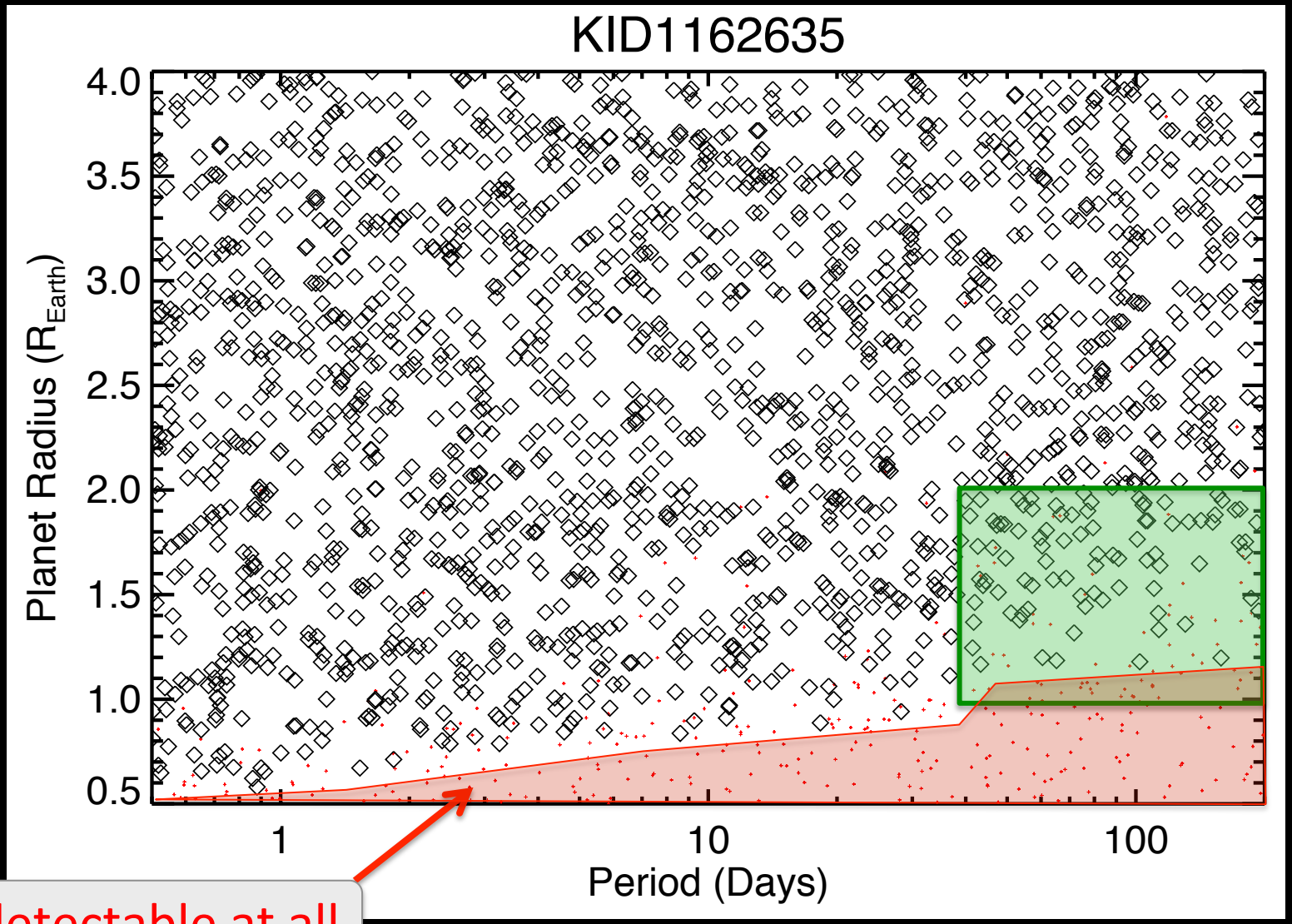


Estimating Pipeline Sensitivity



Dressing & Charbonneau 2015, ApJ submitted, arXiv:1501.01623

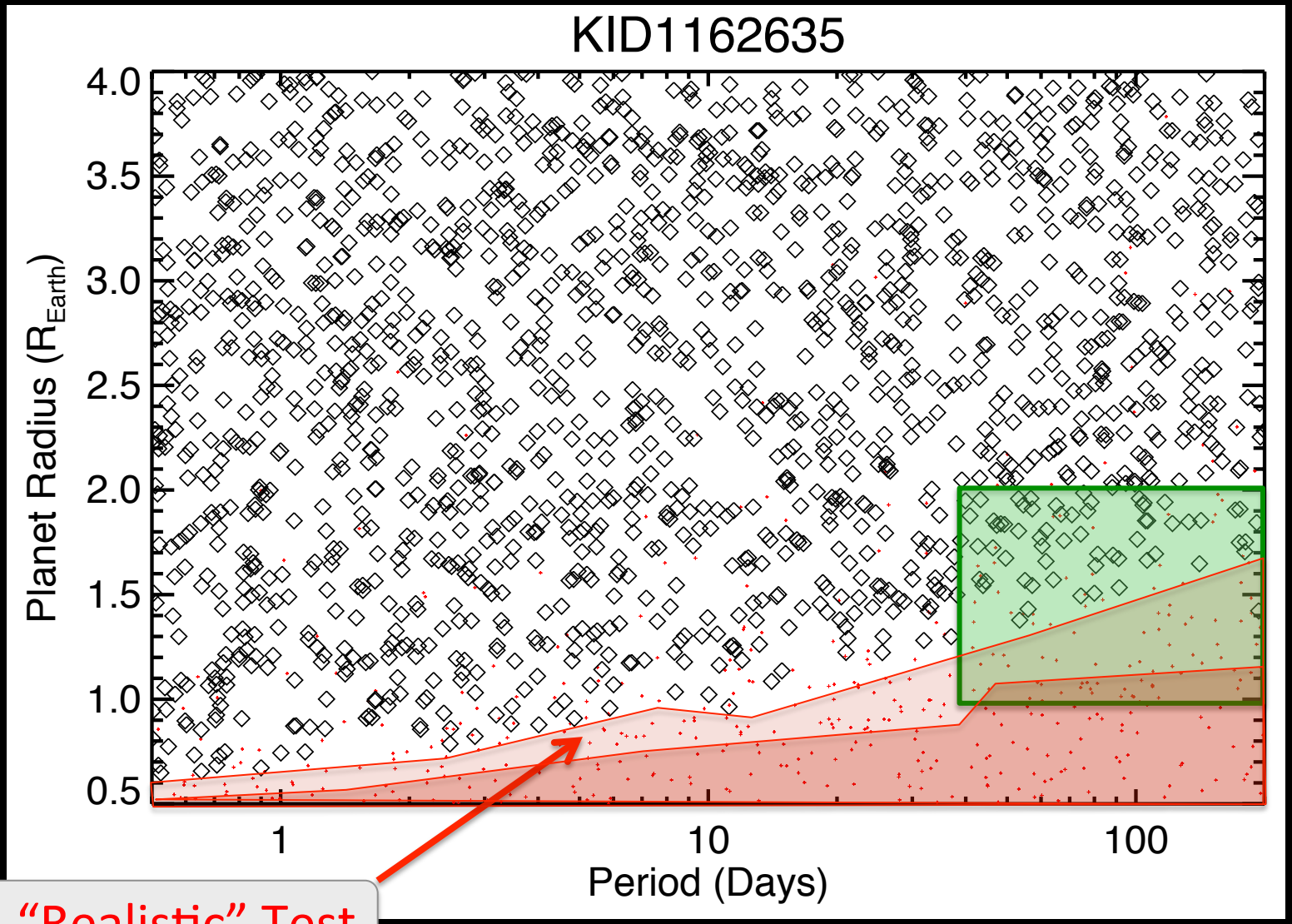
Estimating Pipeline Sensitivity



Not detectable at all

Dressing & Charbonneau 2015, ApJ submitted, arXiv:1501.01623

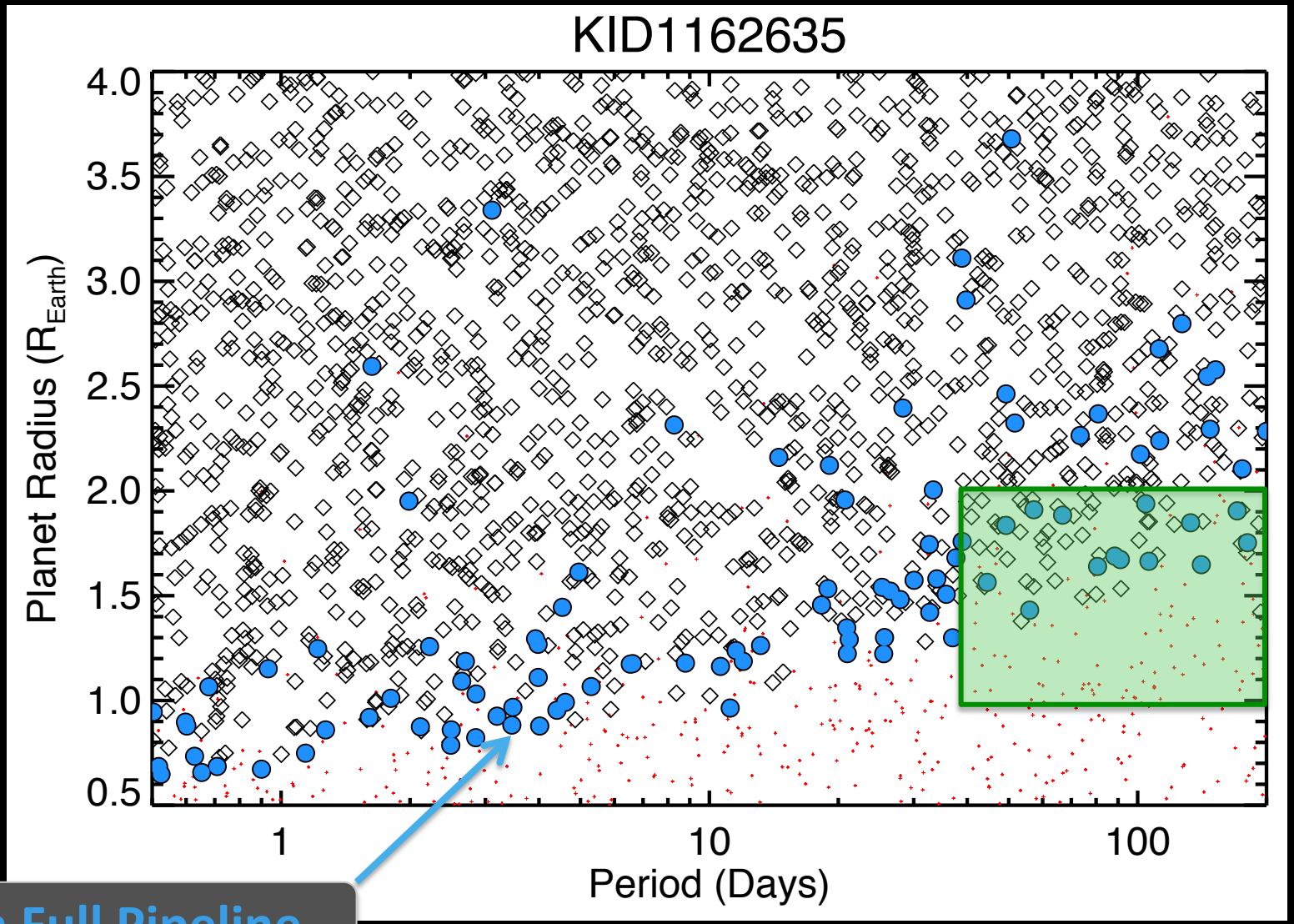
Estimating Pipeline Sensitivity



Failed "Realistic" Test

Dressing & Charbonneau 2015, ApJ submitted, arXiv:1501.01623

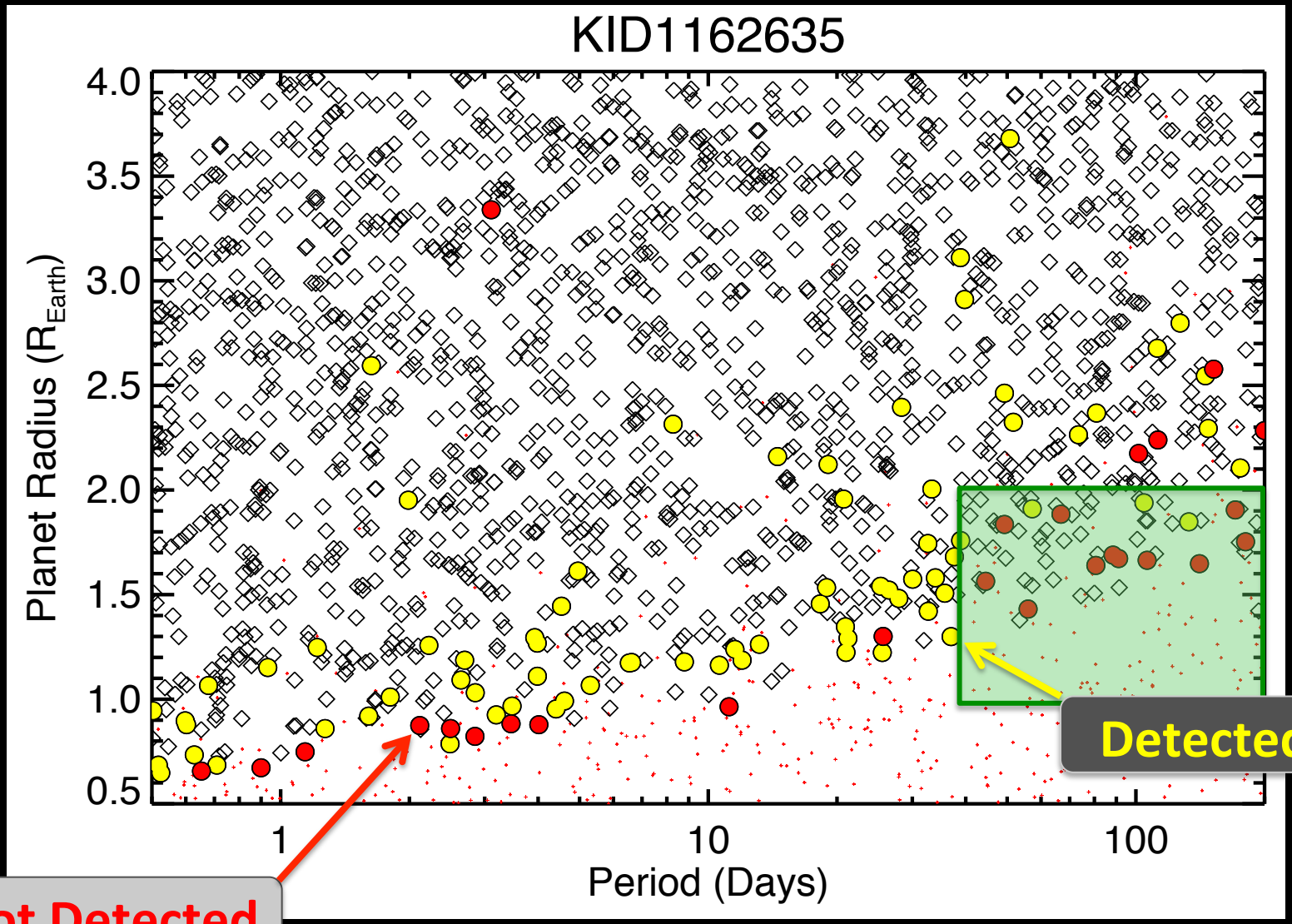
Estimating Pipeline Sensitivity



Ran Full Pipeline

Dressing & Charbonneau 2015, ApJ submitted, arXiv:1501.01623

Estimating Pipeline Sensitivity



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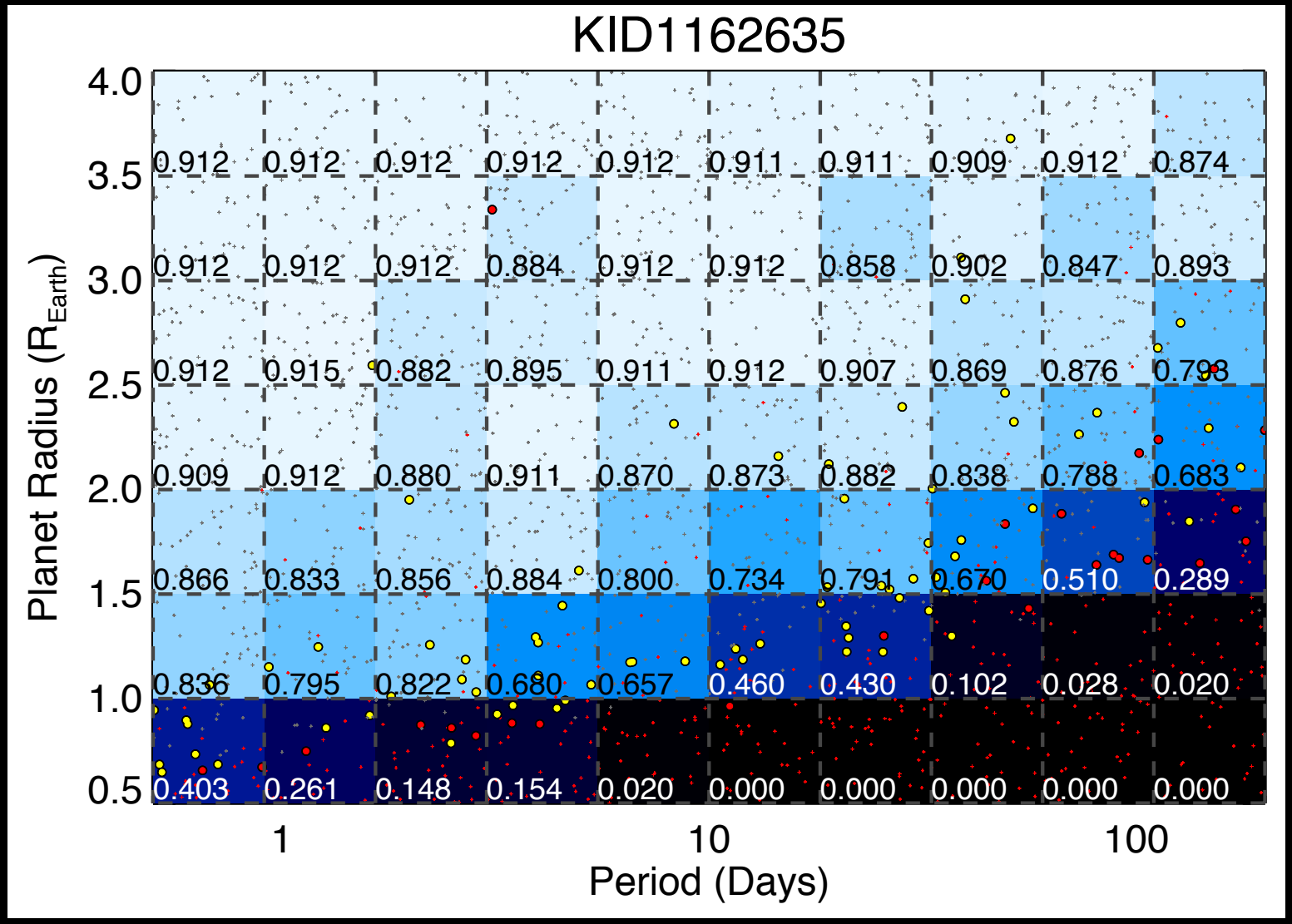
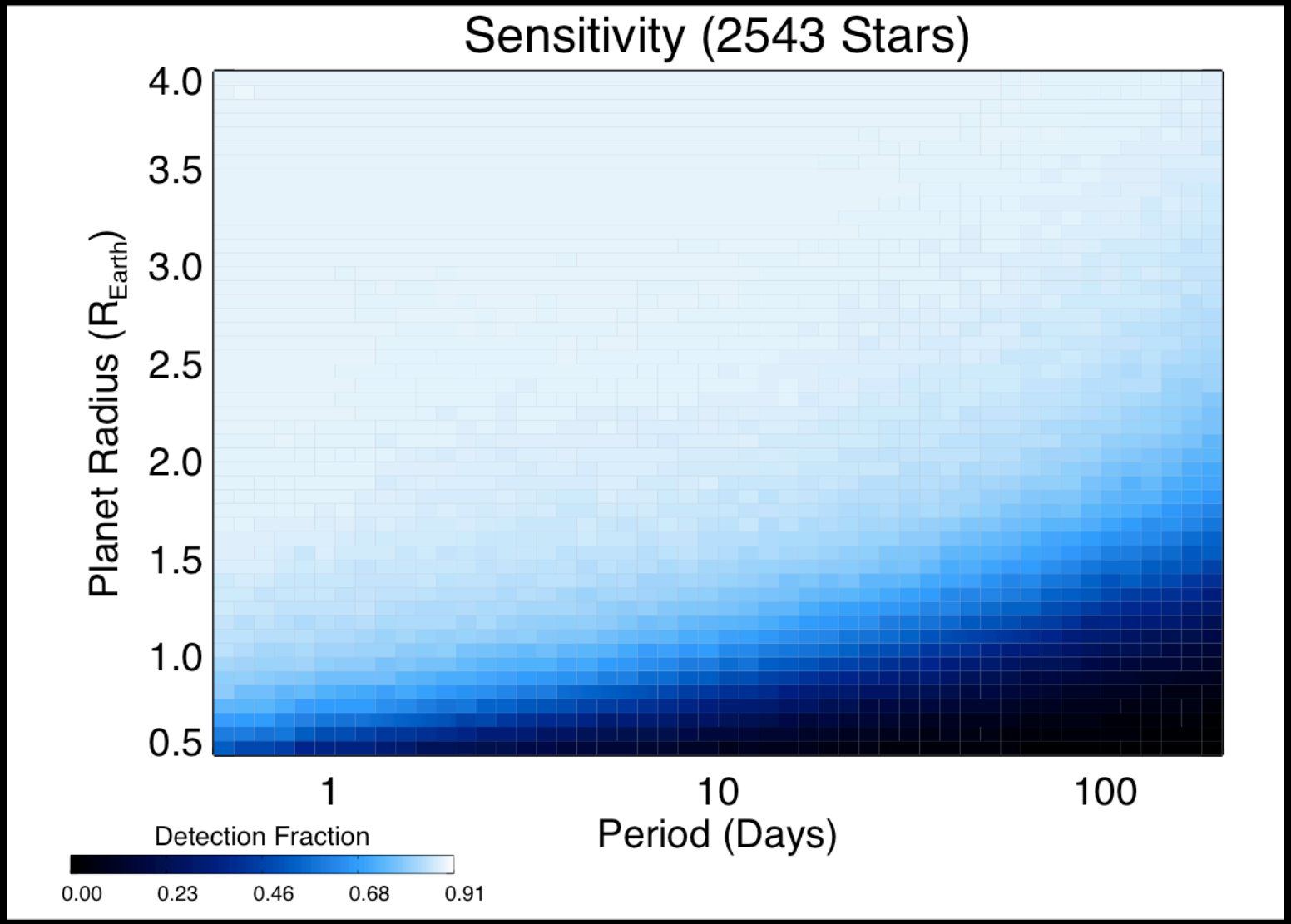
We Produced Star-by-Star Sensitivity Maps



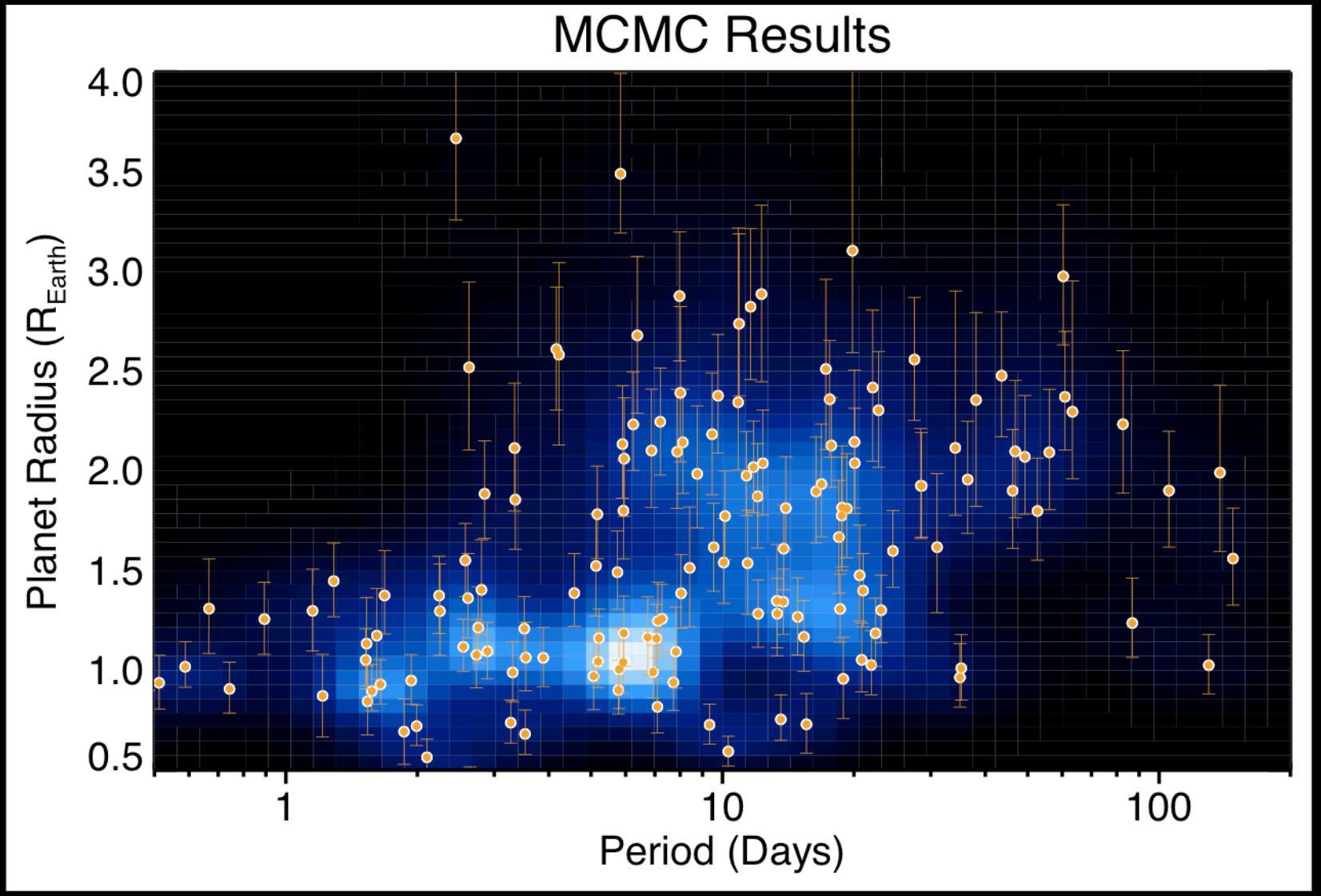
Dressing & Charbonneau 2015, ApJ submitted, arXiv:1501.01623

Sensitivity to Earth-size Planets Depends Strongly on Orbital Period



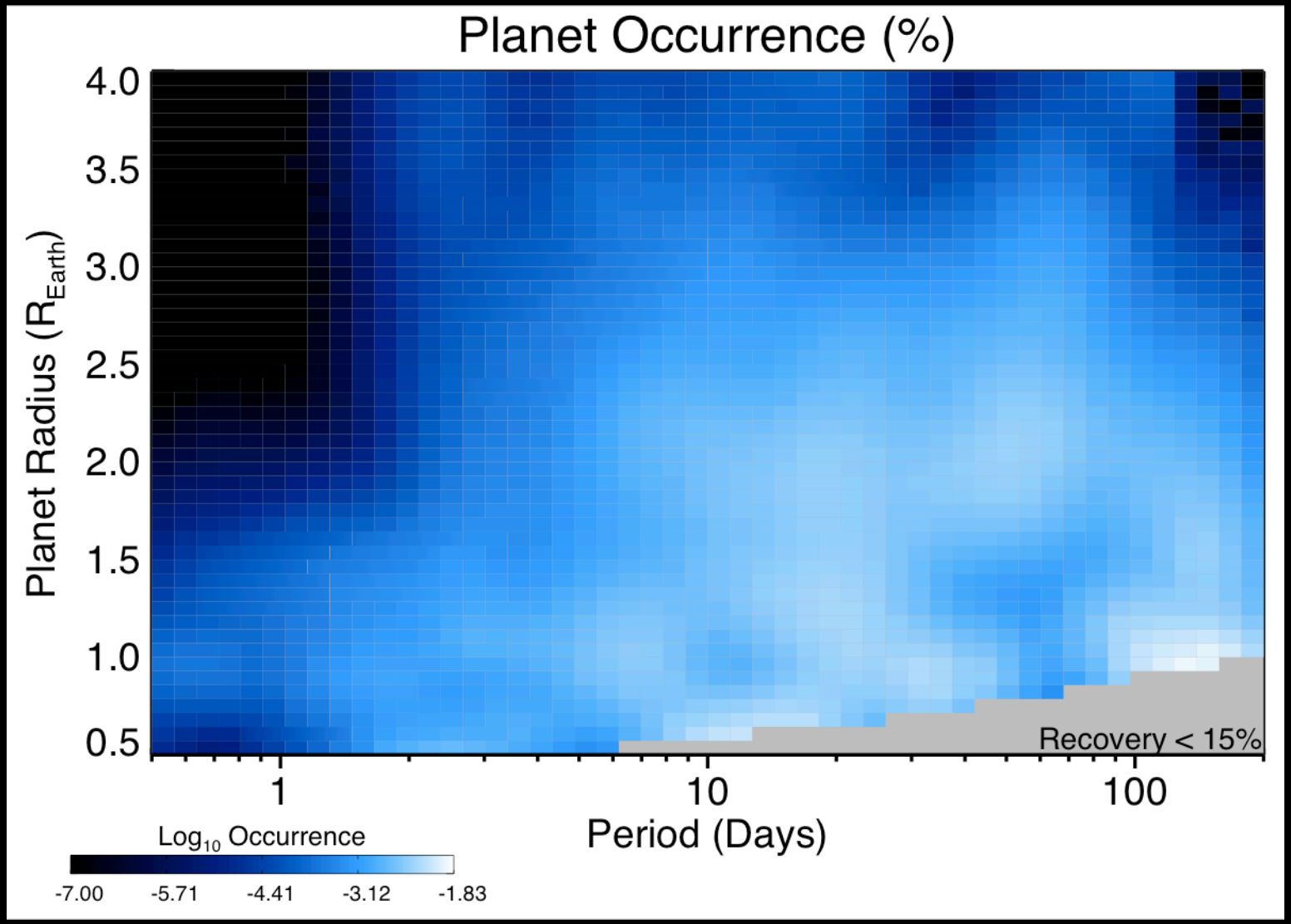
Dressing & Charbonneau 2015, ApJ submitted, arXiv:1501.01623

Smoothed Population of Planet Candidates



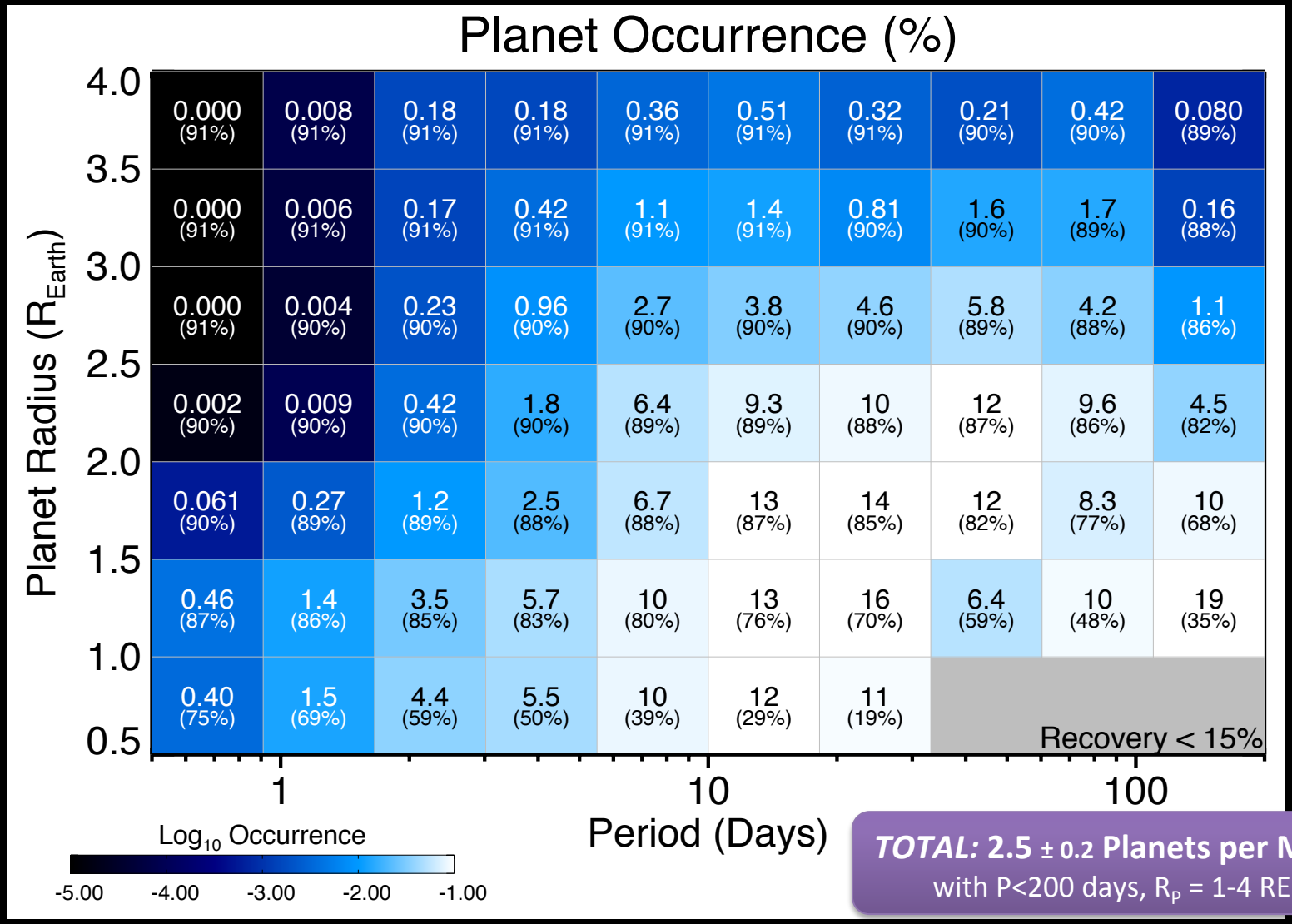
Dressing & Charbonneau 2015, ApJ submitted, arXiv:1501.01623

Smaller Planets Are More Prevalent



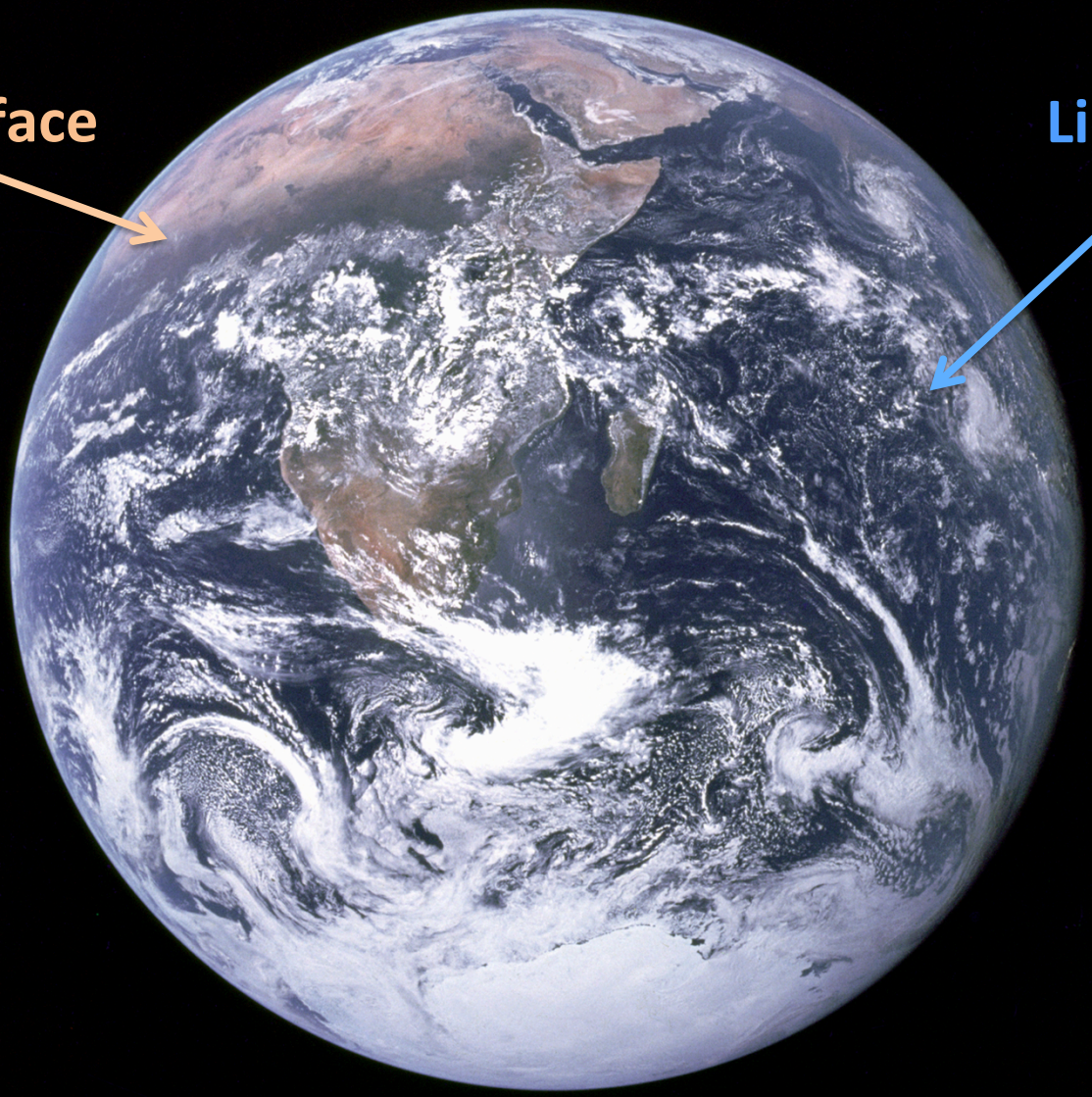
Dressing & Charbonneau 2015, ApJ submitted, arXiv:1501.01623

Small, Long-Period Planets are Common



Dressing & Charbonneau 2015, ApJ submitted, arXiv:1501.01623

Are any of these planets habitable?



Rocky Surface

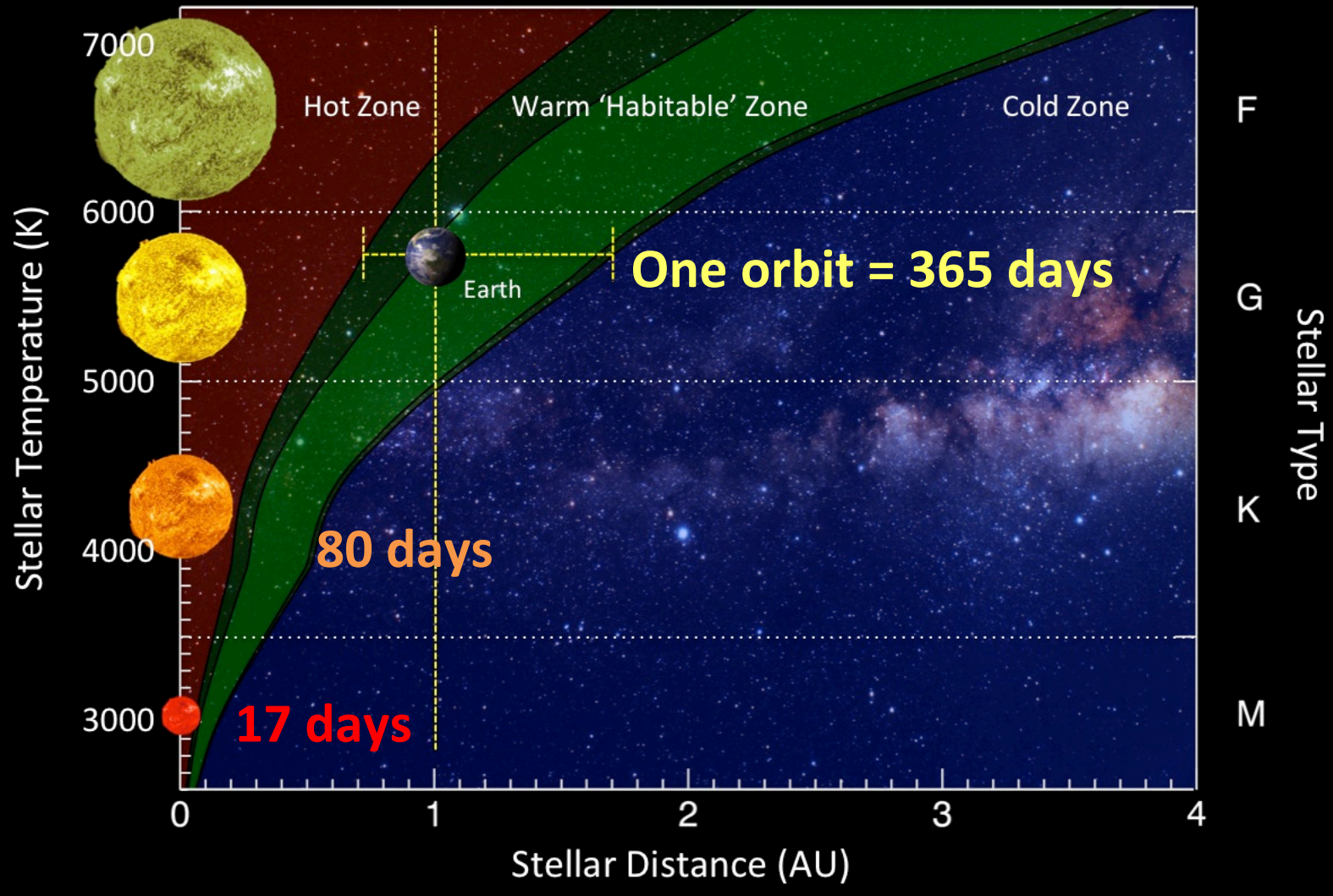
Look for planets smaller than 1.7 Earth Radii

Liquid Water

Look for planets with temperate climates

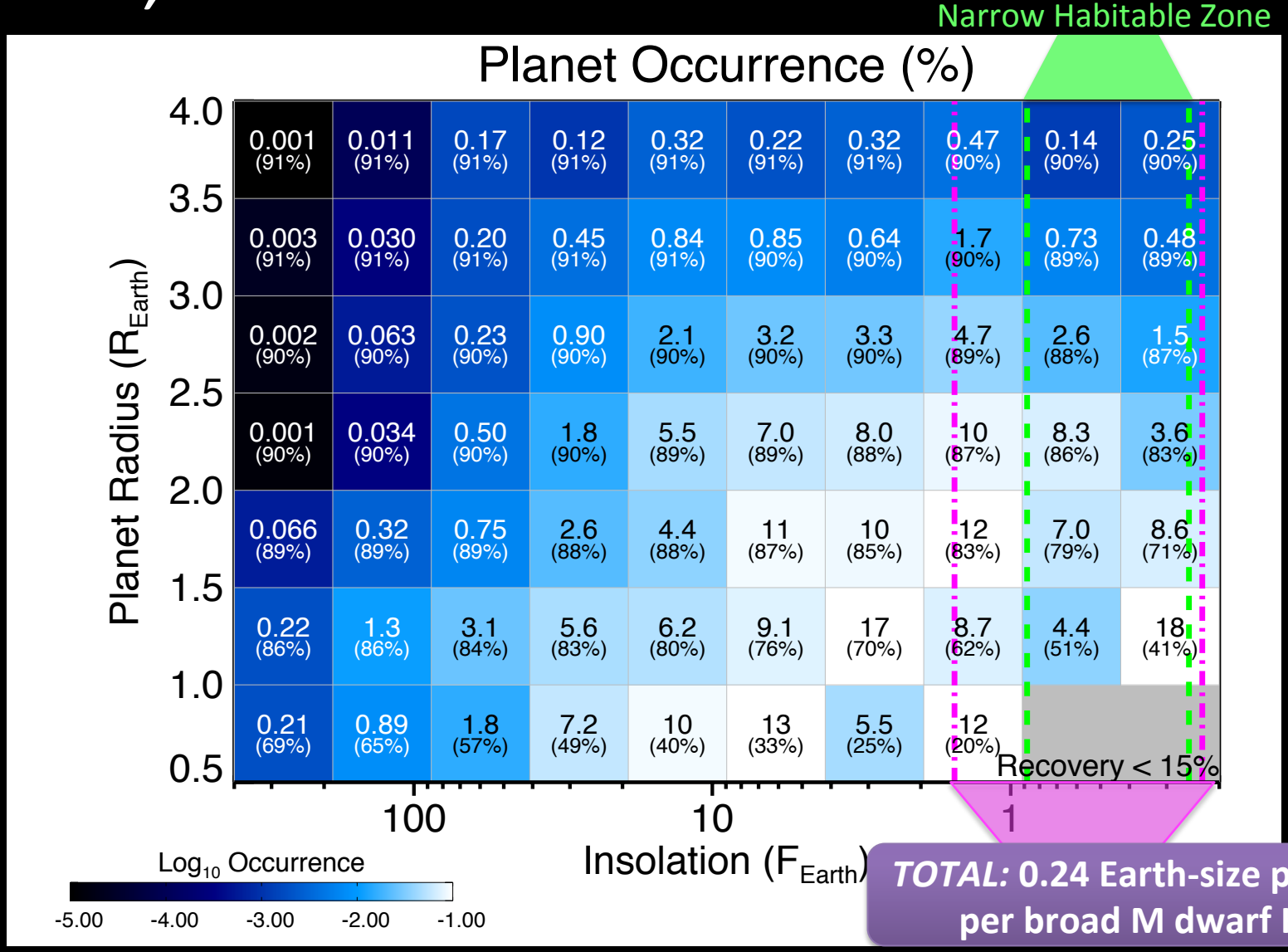
Image credit: NASA/Apollo 17

Likely Locations of Habitable Worlds



CREDIT: PHL @ UPR Arecibo

Smaller, Cooler Planets Are More Common

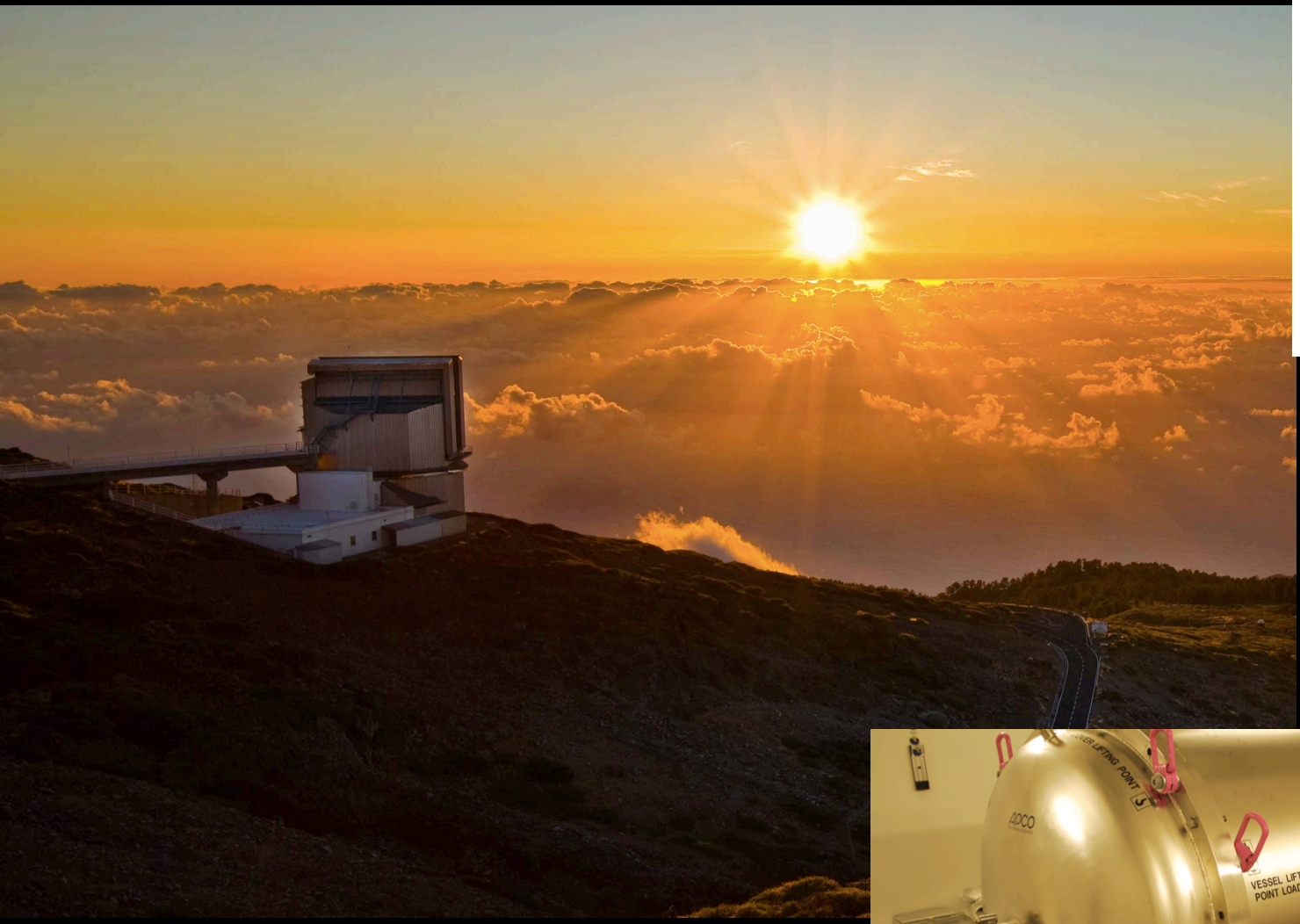


***TOTAL:* 0.24 Earth-size planets per broad M dwarf HZ**

Dressing & Charbonneau 2015, ApJ submitted, arXiv:1501.01623


Nearest HZ Earth 2.6 pc
Transiting HZ Earth 11 pc

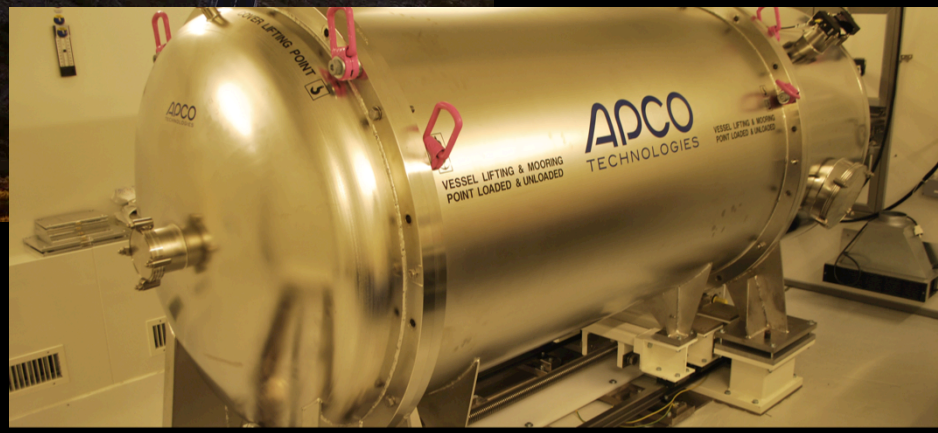
Telescopio Nazionale Galileo



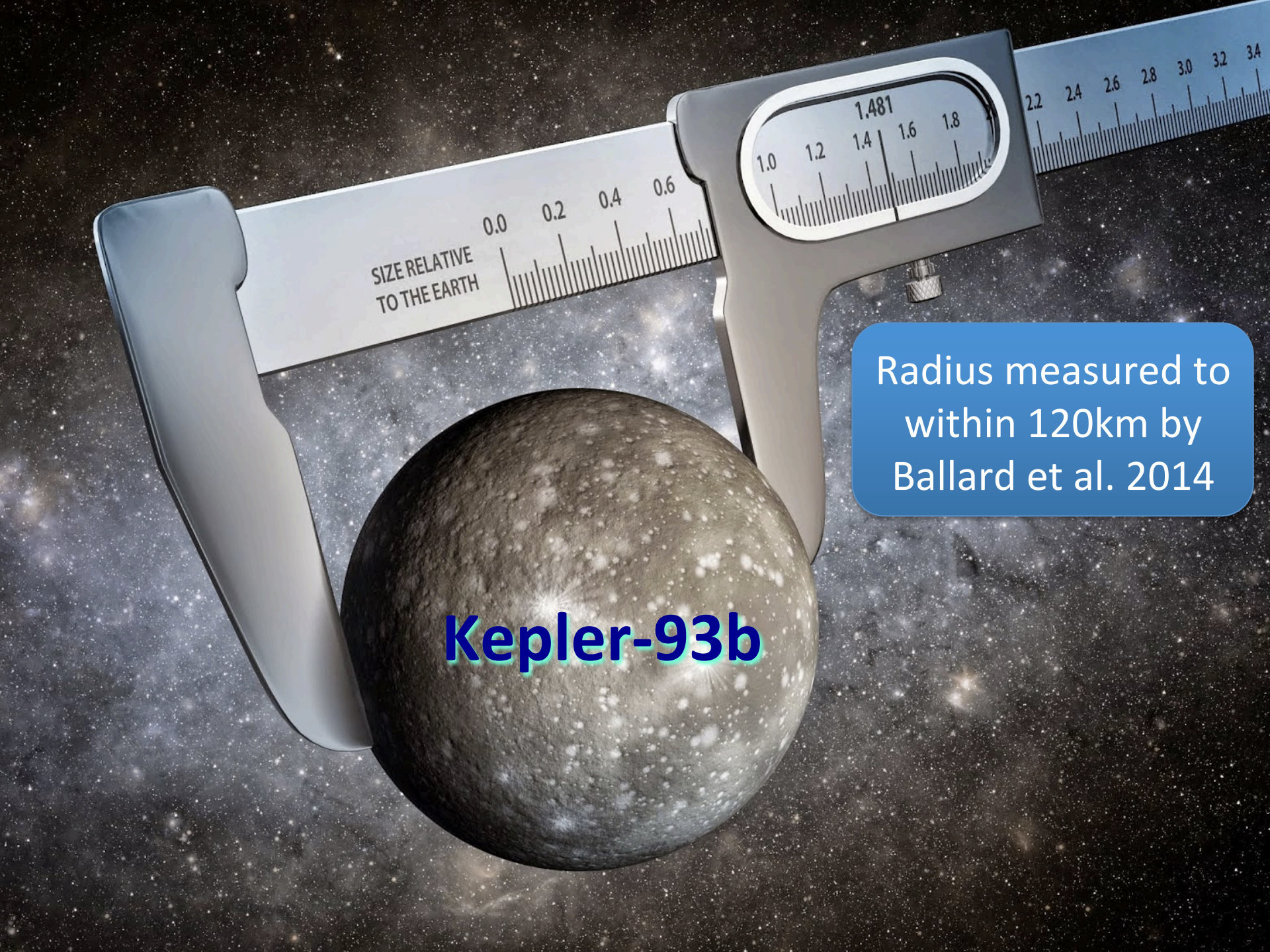
harps-N

International effort led by **Francesco Pepe** (Geneva) with several CfA participants.

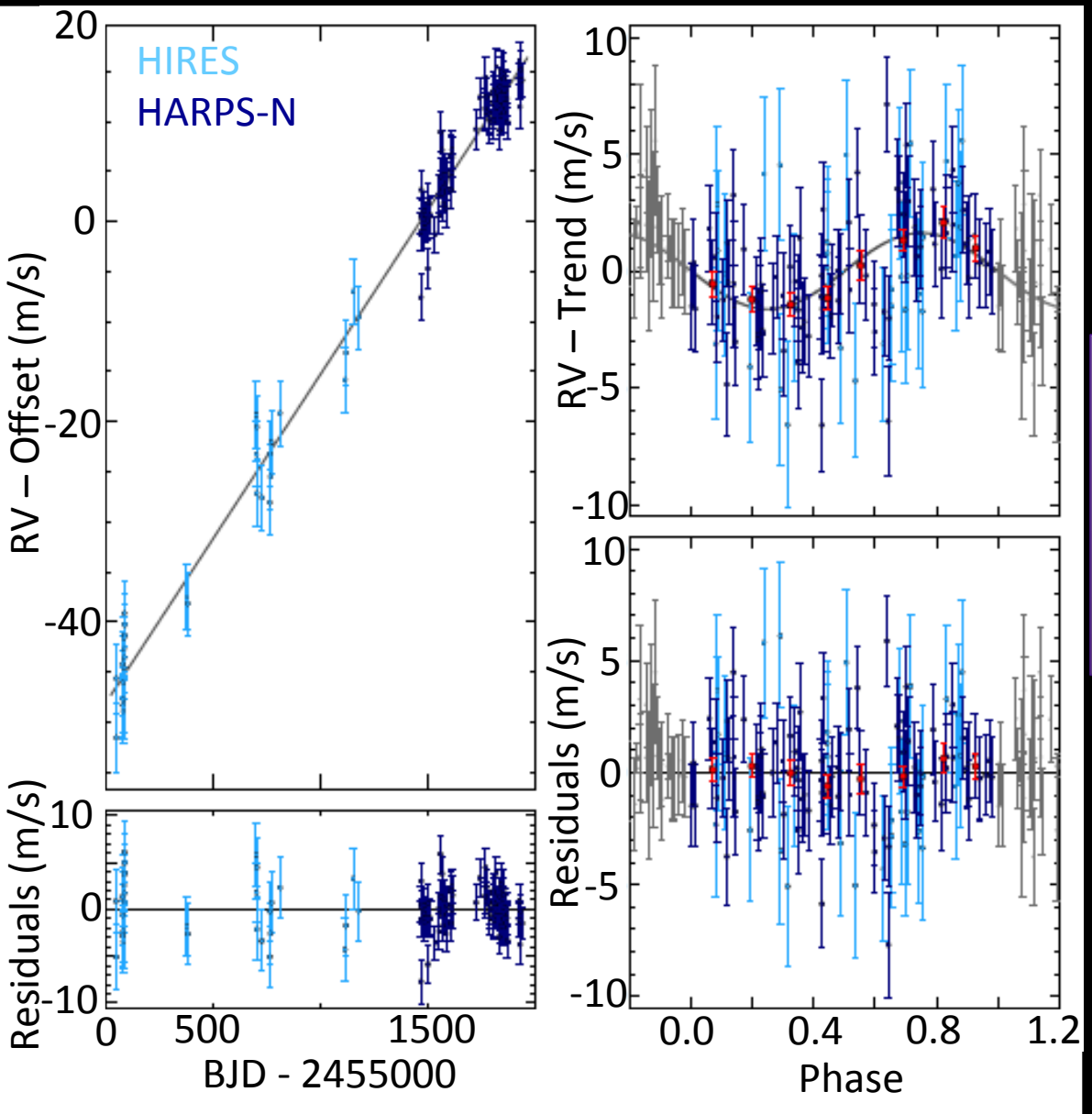
We are conducting an intensive study of the **masses of small planets** using the **Radial Velocity** technique.



HARPS-N Spectrograph


SIZE RELATIVE
TO THE EARTH
0.0
0.2
0.4
0.6
1.481
1.0
1.2
1.4
1.6
1.8
2.2
2.4
2.6
2.8
3.0
3.2
3.4
Kepler-93b
Radius measured to within 120km by Ballard et al. 2014

HARPS-N & HIRES Observations of Kepler-93



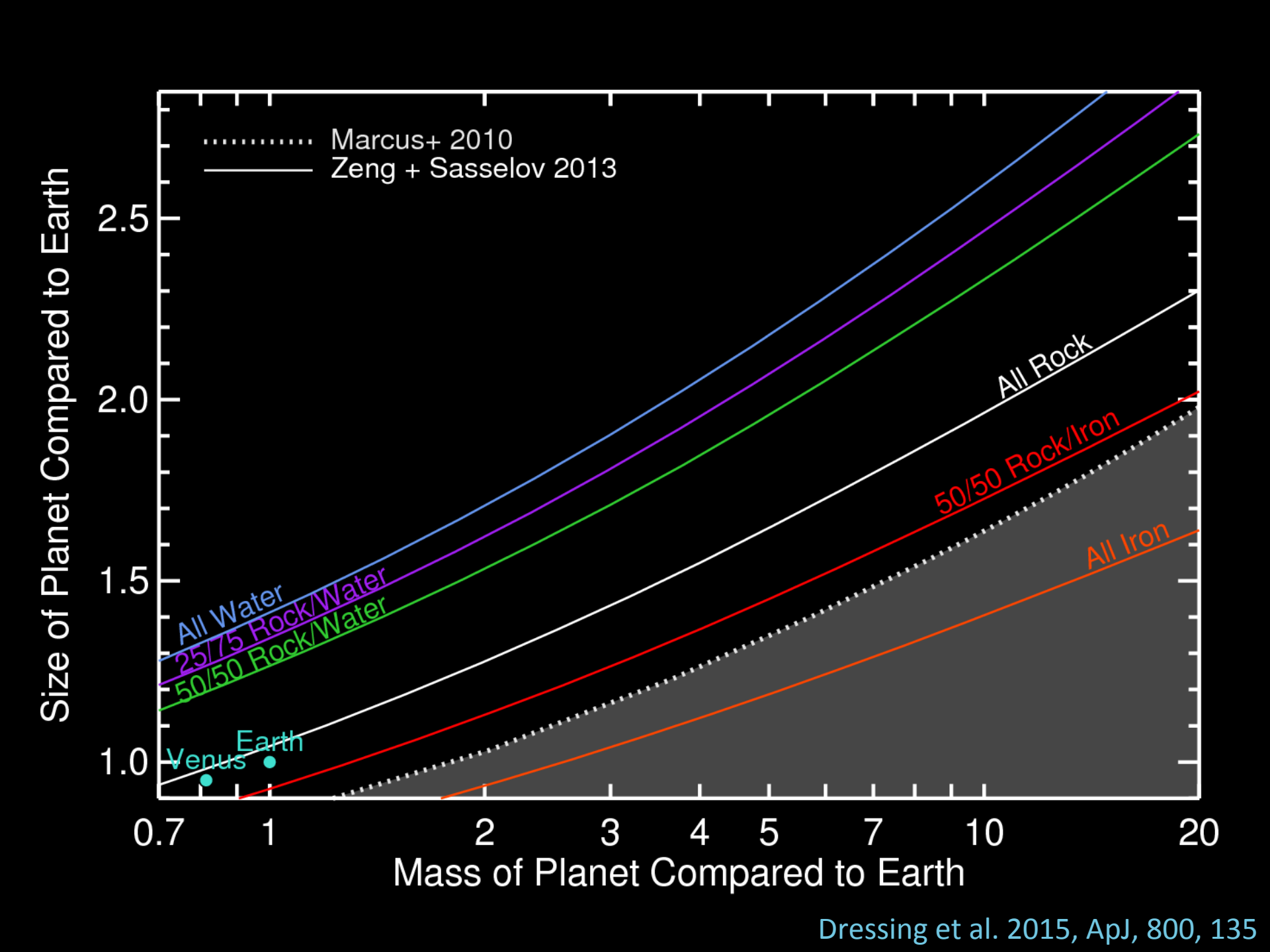
Kepler-93b:

$R_P = 1.478 \pm 0.019\ R_{Earth}$

$M_P = 4.02 \pm 0.68\ M_{Earth}$

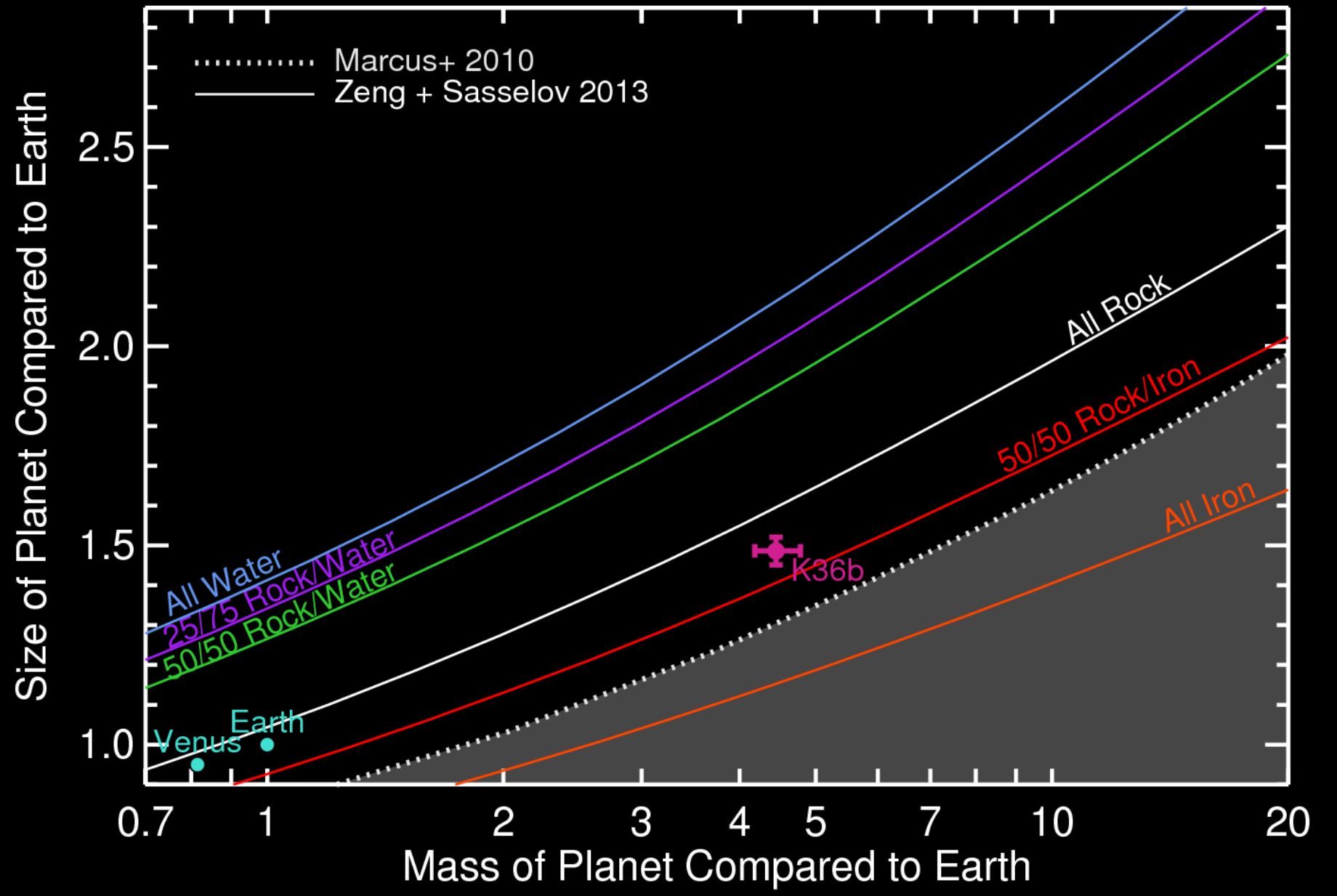
$\rho_P = 6.88 \pm 1.18$ g/cc

Dressing et al. 2015, ApJ, 800, 135



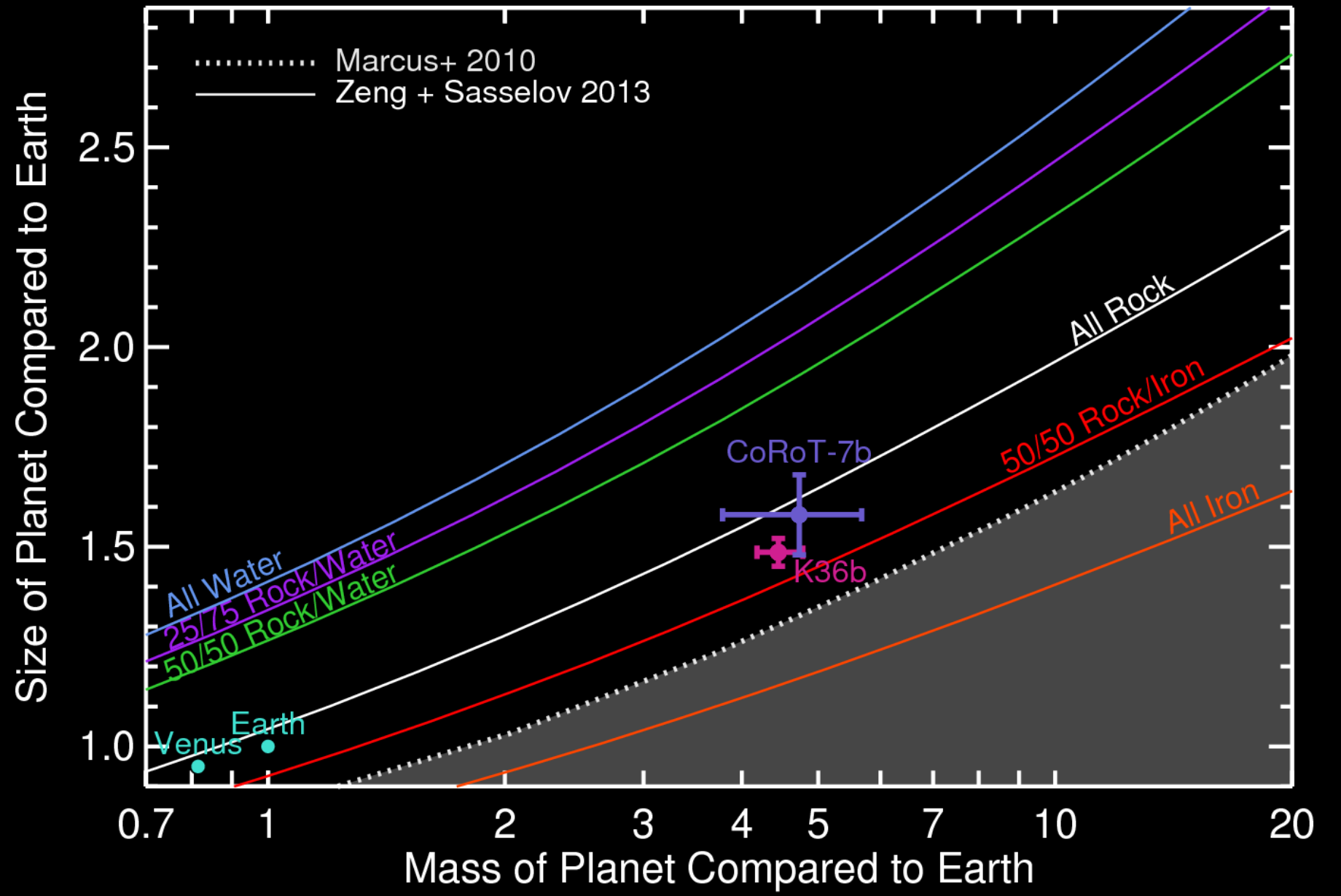
Dressing et al. 2015, ApJ, 800, 135

Carter+ 2012



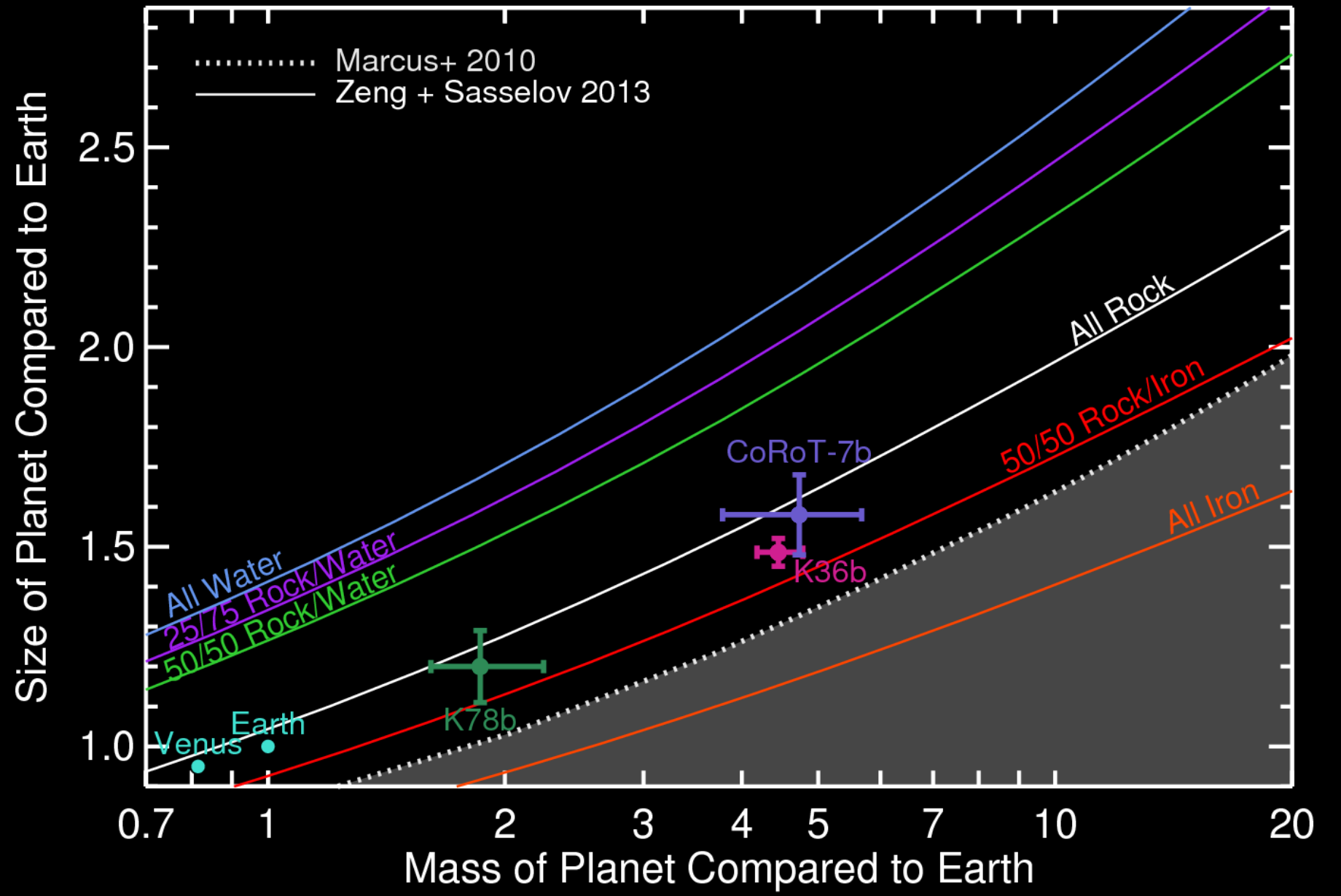
Dressing et al. 2015, ApJ, 800, 135

Carter+ 2012, Barros+ 2014, Haywood+ 2014,



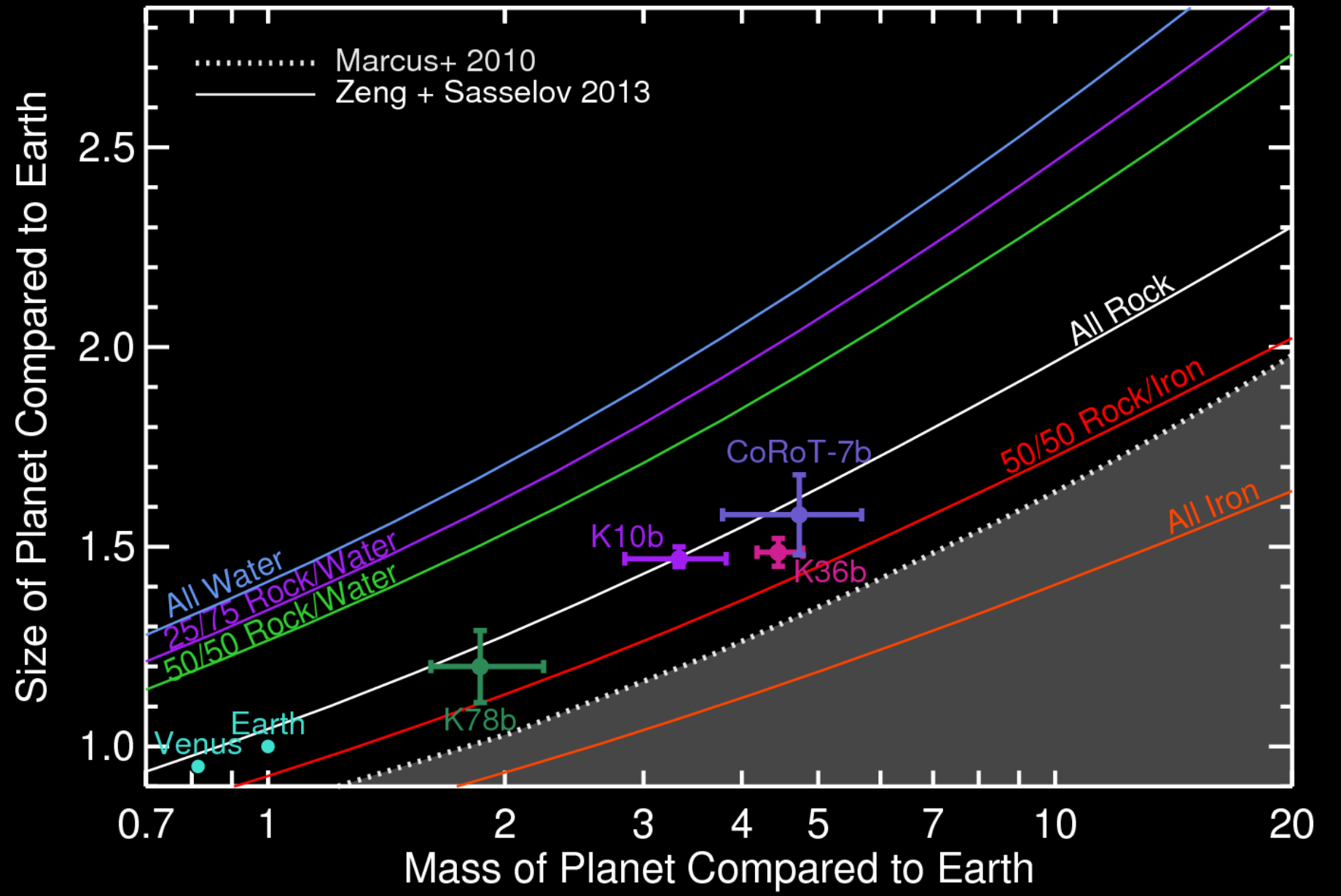
Dressing et al. 2015, ApJ, 800, 135

Carter+ 2012, Barros+ 2014, Haywood+ 2014, Pepe+ 2014, Howard+ 2014



Dressing et al. 2015, ApJ, 800, 135

Carter+ 2012, Barros+ 2014, Haywood+ 2014, Pepe+ 2014, Howard+ 2014, Dumusque+ 2014



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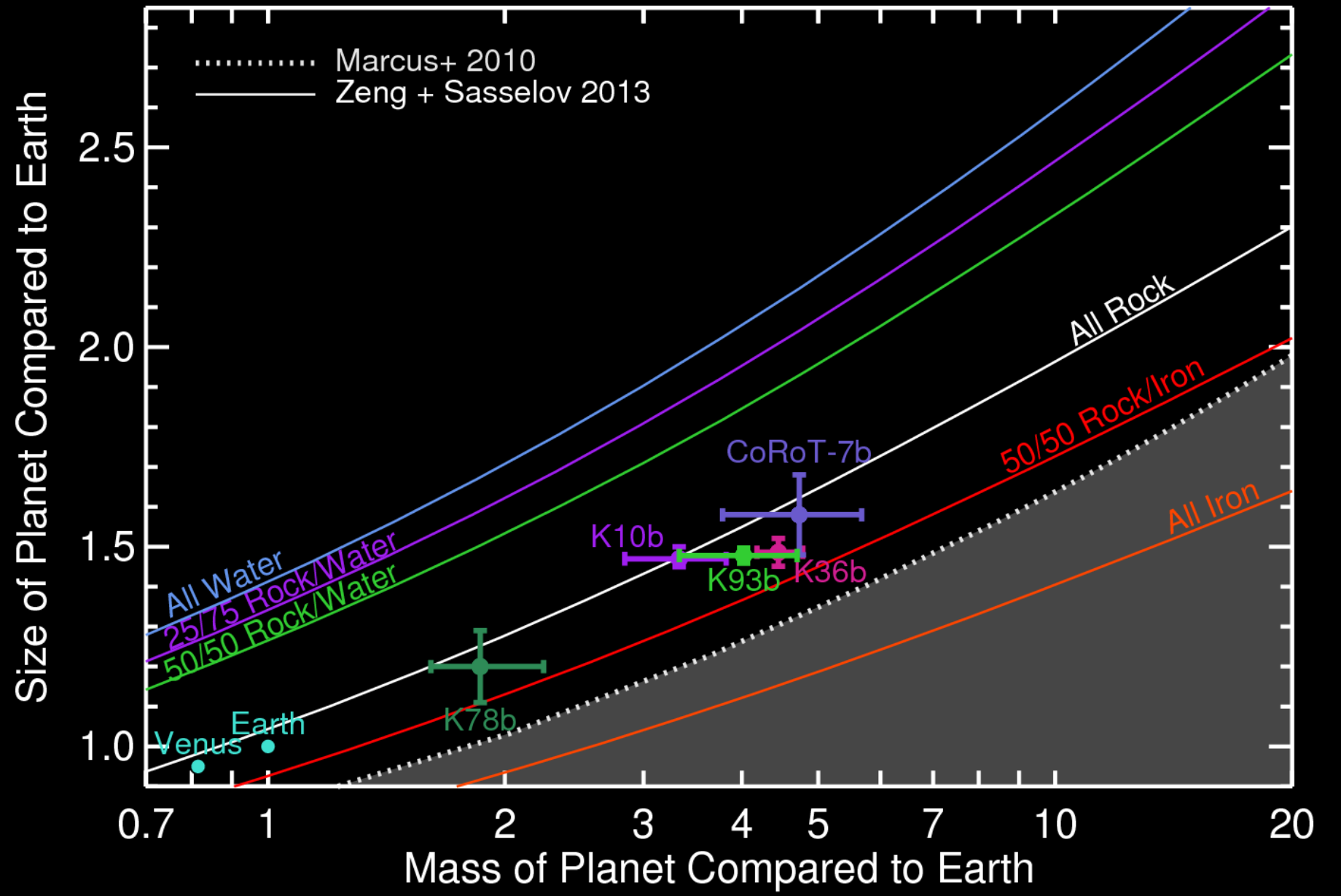

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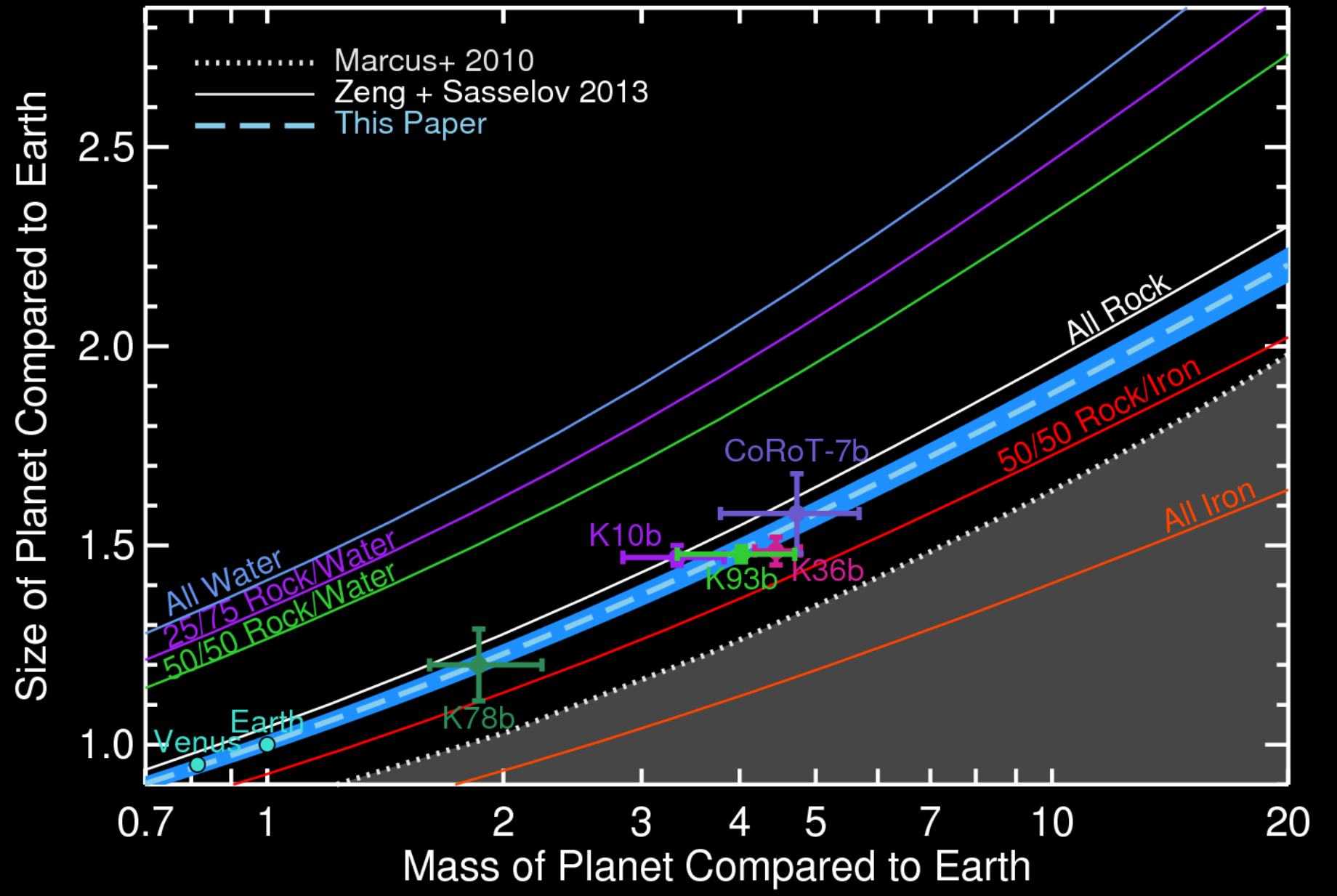

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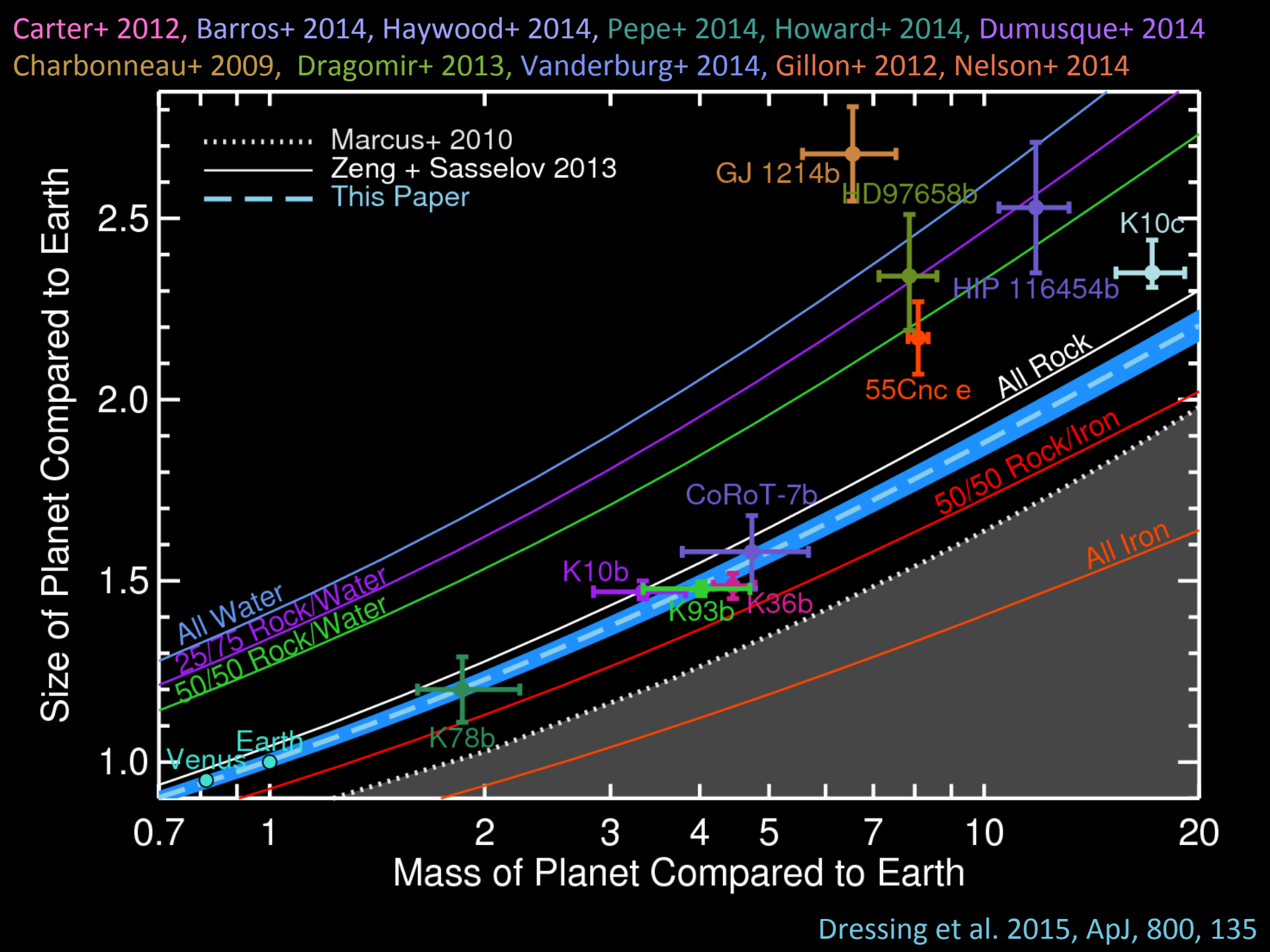


Dressing et al. 2015, ApJ, 800, 135

Thesis in a Nutshell

Part I: **Planet Occurrence for Small Stars**

Dressing & Charbonneau 2013, ApJ, 767, 95

Dressing & Charbonneau 2015, ApJ submitted, arXiv:1501.01623

– **2.5 small planets** per M dwarf

– **11 pc** to nearest **transiting Earth-like planet**

Part II: **Characterizing Planets around Bright Stars**

Dressing et al. 2015, ApJ, 800, 135

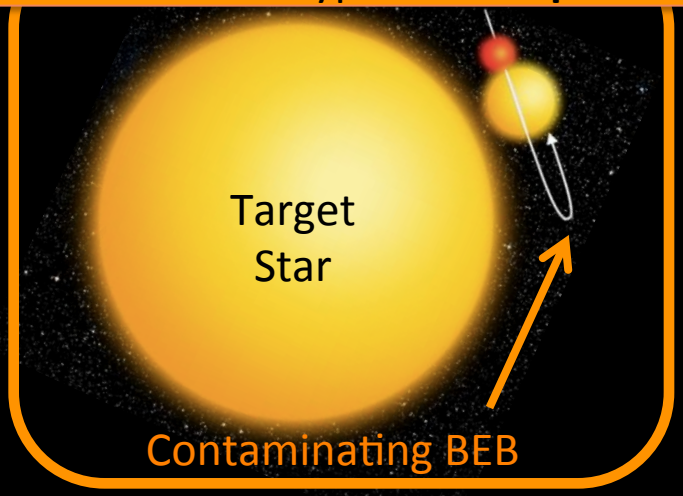
– Small dense exoplanets have **Earth-like compositions**

My Plans as a Sagan Fellow

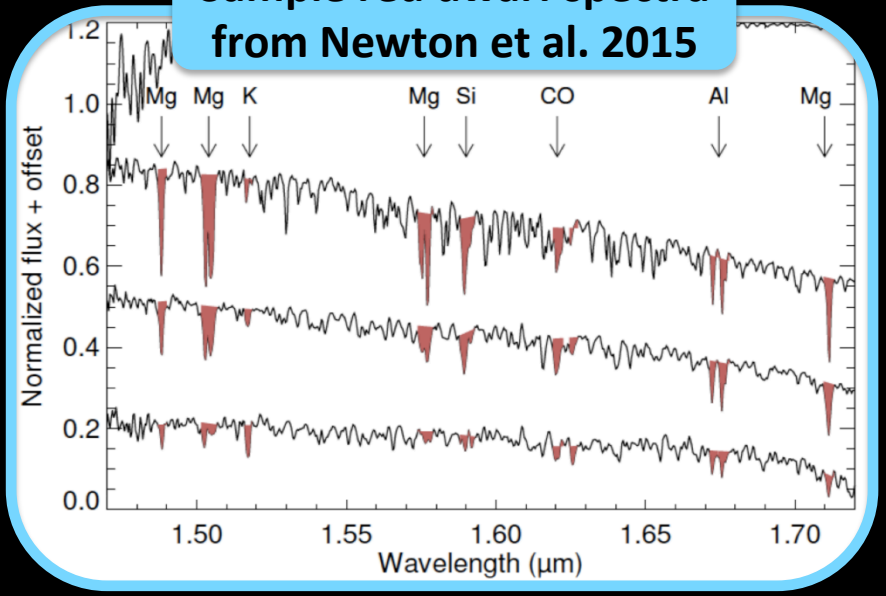
Project 1: Unmask False Positives Masquerading as Planet Candidates

- Inspect K2 light curves
- Acquire high resolution follow-up images
- Look for large RV trends

Background eclipsing binaries (BEBs) are a common type of **false positive**



Sample red dwarf spectra from Newton et al. 2015



Project 2: Characterize red dwarfs hosting small planets

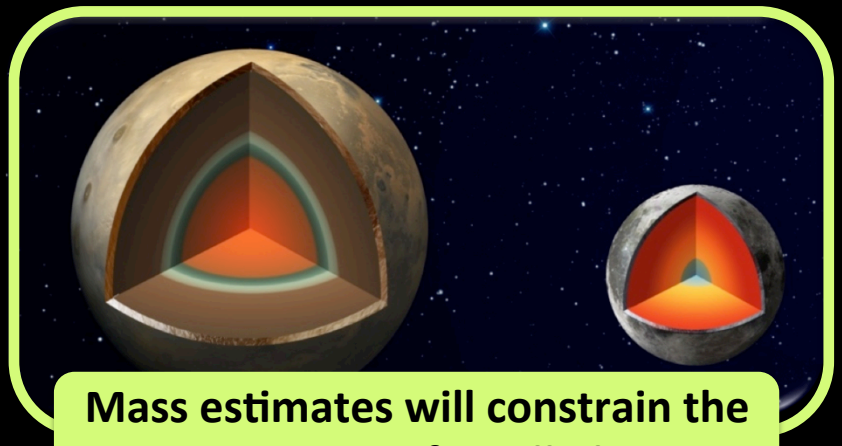
- Obtain near infrared spectra of planet host stars
- Revise system parameters using empirical relations

Image Credit: NASA

My Plans as a Sagan Fellow

Project 3: **Measure the masses of small planets**

- **Obtain radial velocity observations of small planets detected by *Kepler* or K2**
- **Investigate the diversity of small planet compositions**



Mass estimates will constrain the compositions of small planets

Project 4: **Investigate links between stellar and planetary properties**

- **Estimate planet occurrence for mid and late M dwarfs**
- **Investigate whether properties of planets correlate with host star mass and metallicity.**

Artist's rendition of planets orbiting the small red dwarf KOI-961

Image Credits: NASA/JPL-Caltech

Conclusions

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