Origins and Demographics of Super-Earth and Sub-Neptune Size Planets

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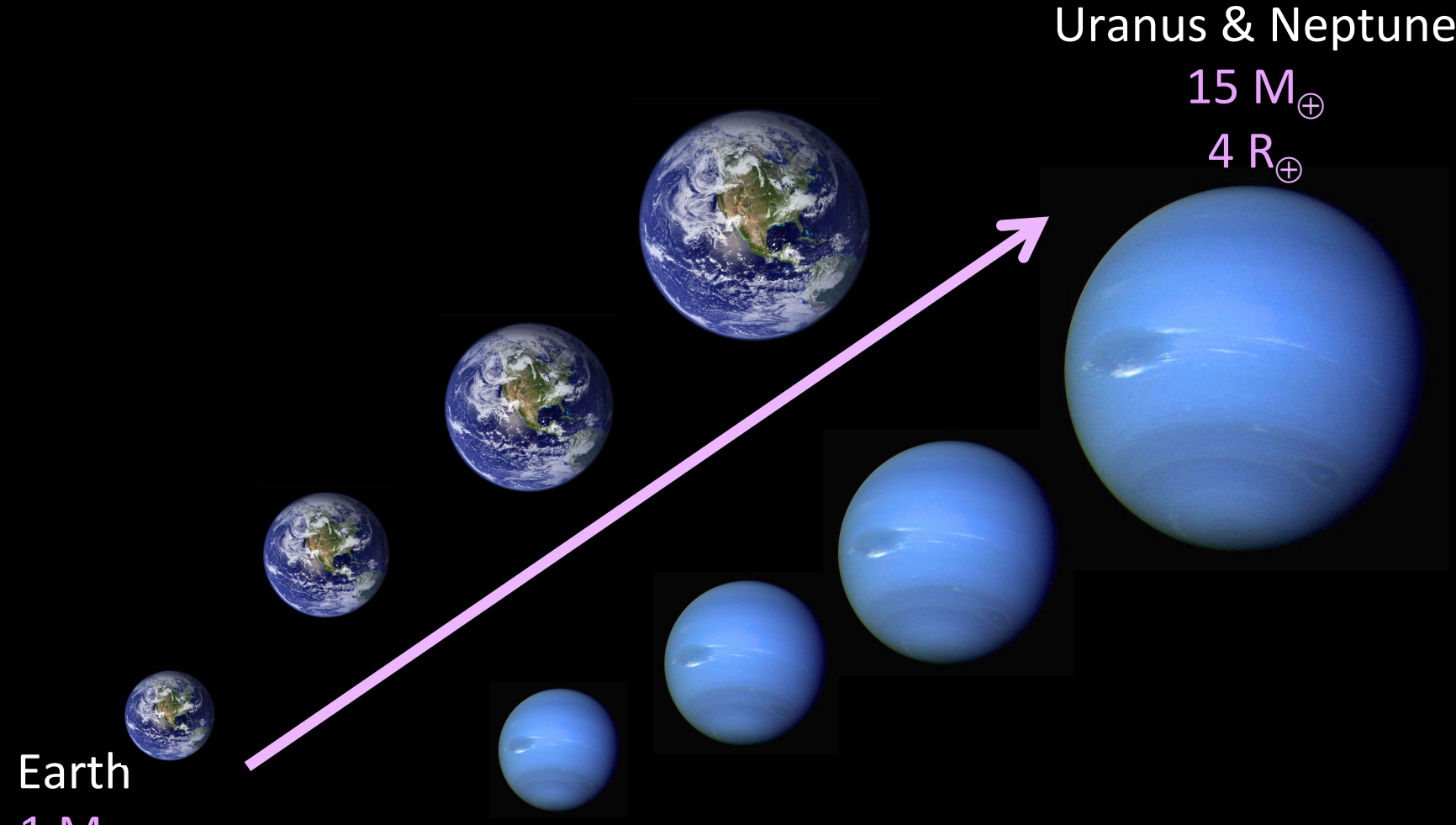
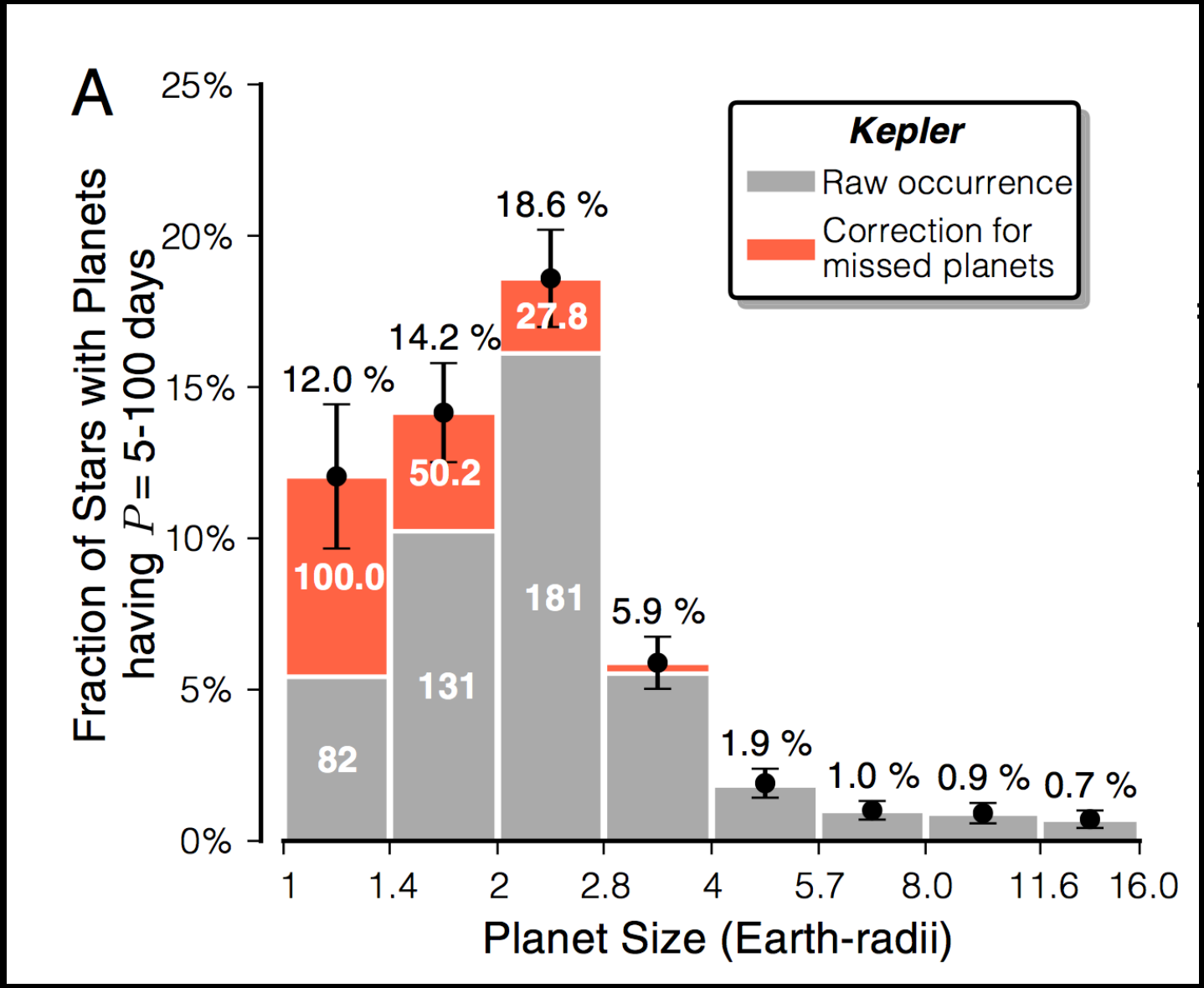
Super-Earth and Sub-Neptune Planets



Sub-Neptune-Size planets are common!



Petigura et al. (2013)

What fraction of planets are rocky (as a function of planet size)?

Kepler-22b

($R_p = 2.4\ R_\oplus$):

Rocky

OR

Volatile Rich?

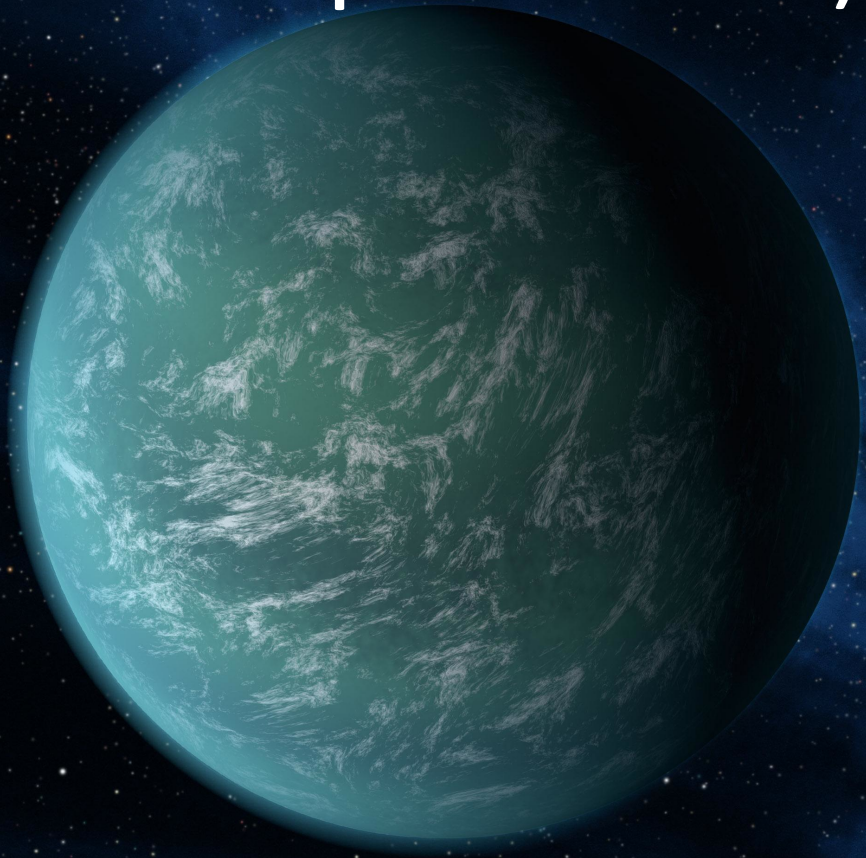
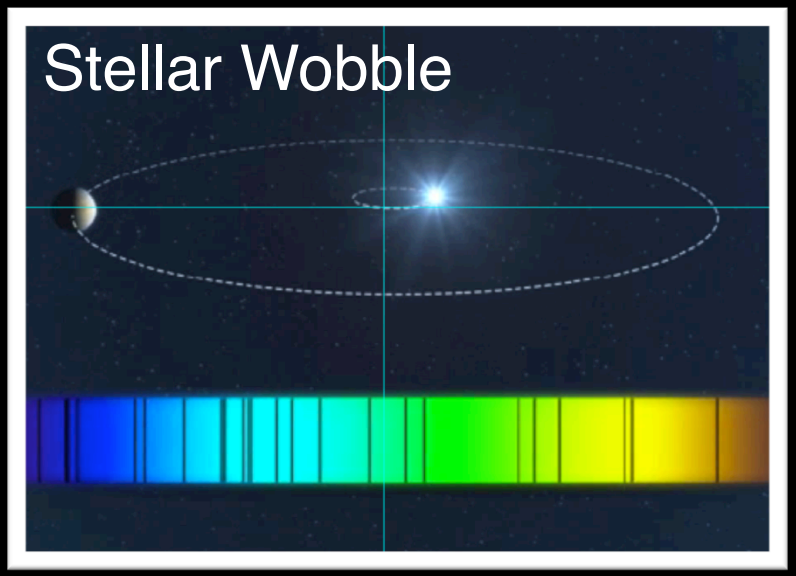
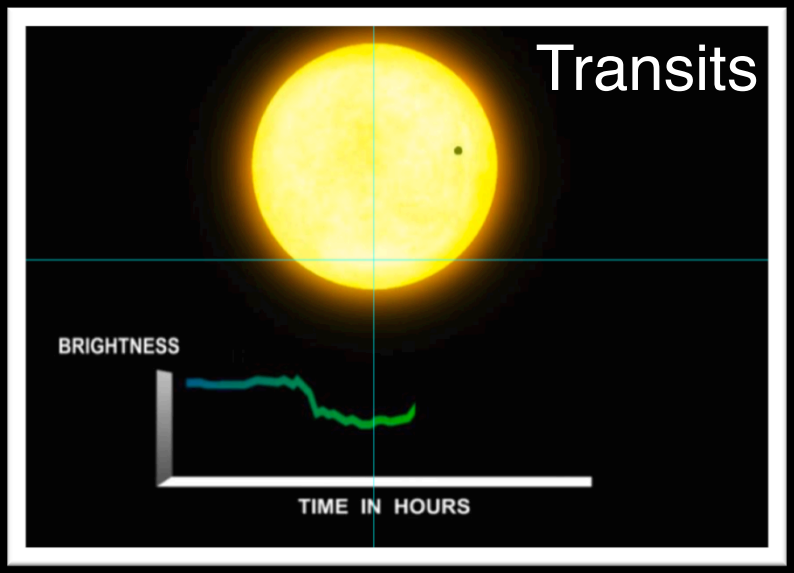


Figure Credit: *NASA/Ames/JPL-Caltech*

Planets Detected both Dynamically and in Transit are Valuable!



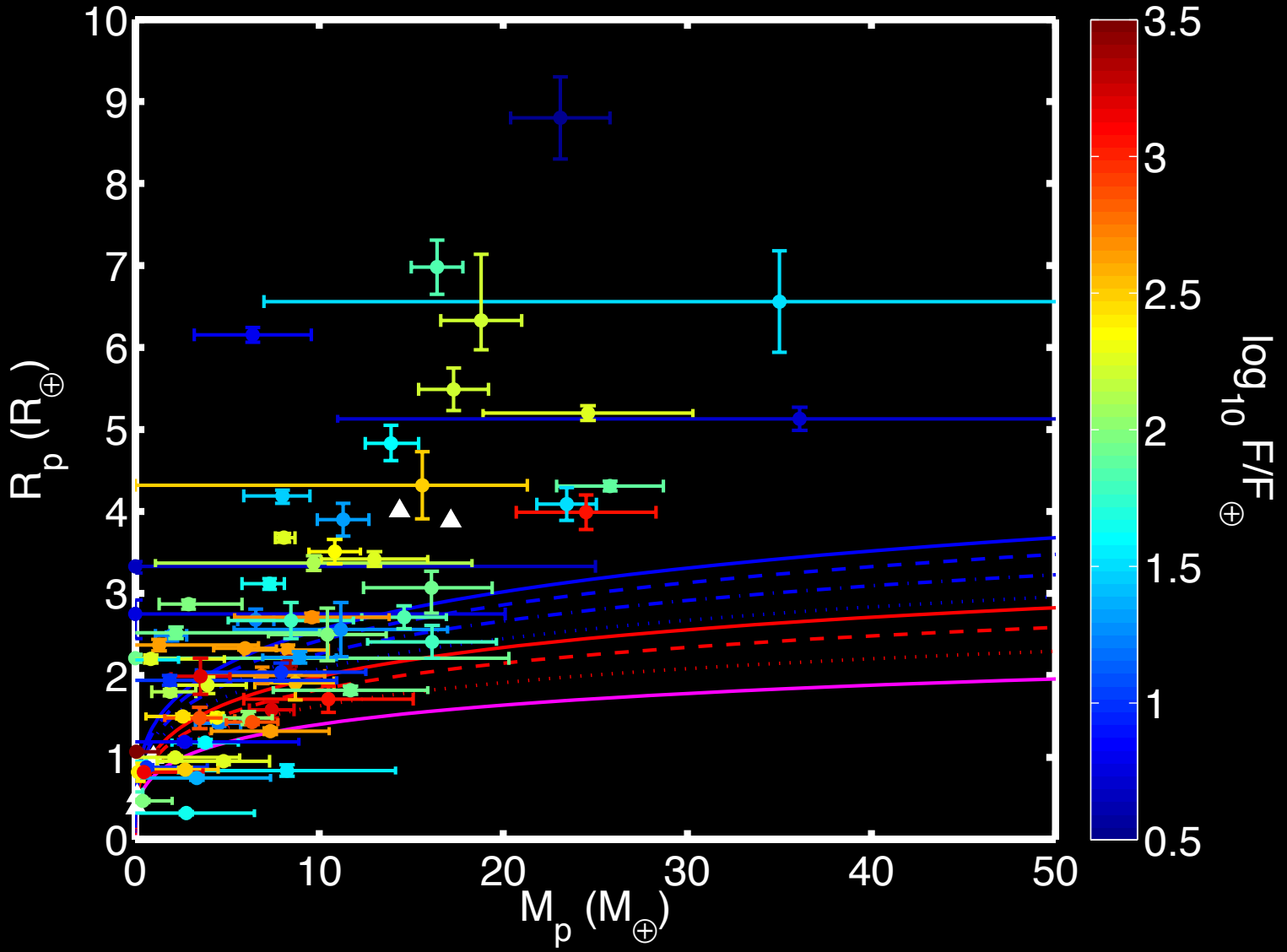


Planet Mass

Planet Radius

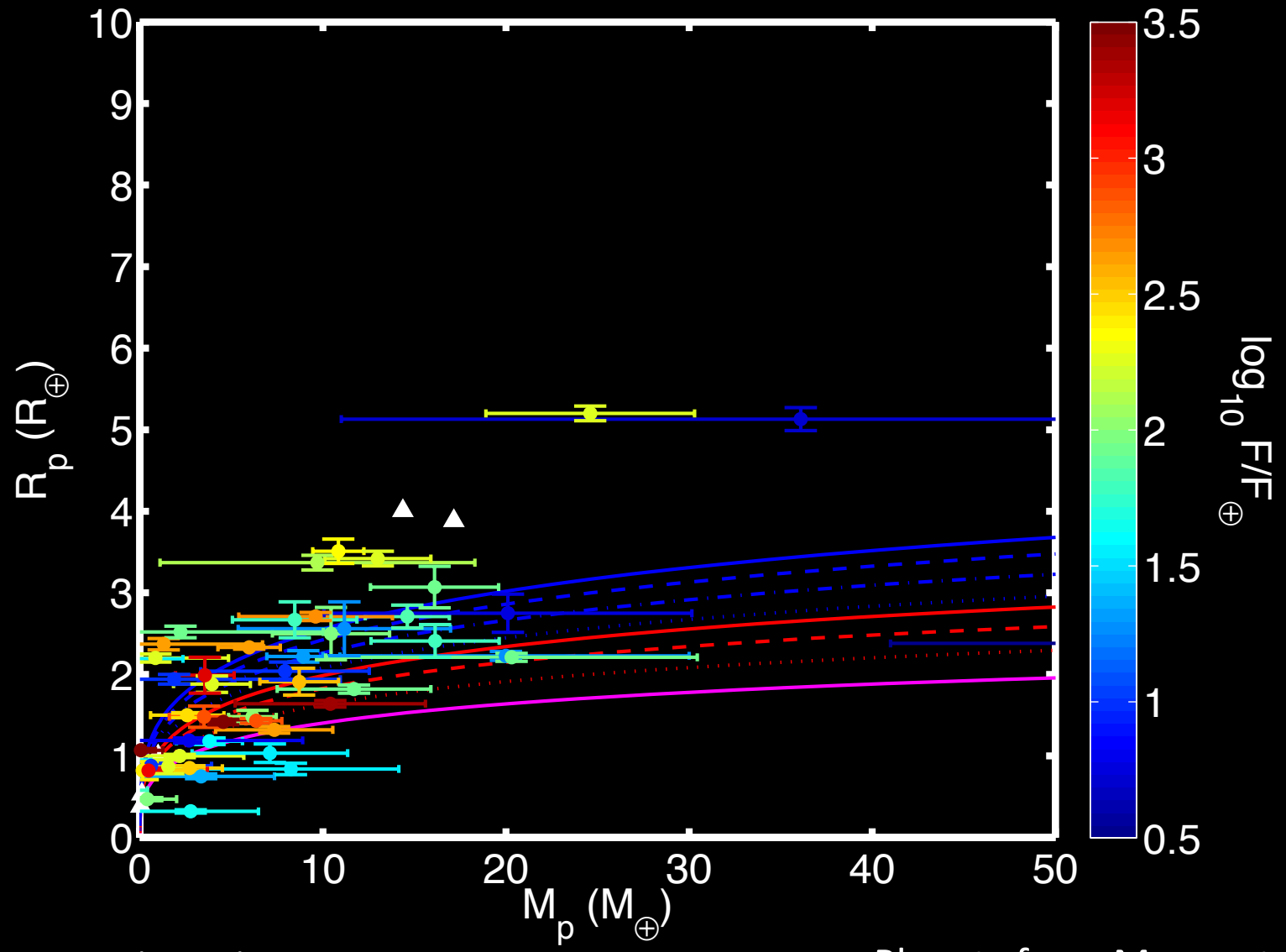
Planet Density

Full Sample of Planets with Measured M and R



Seager et al. (2007) M-R Relations

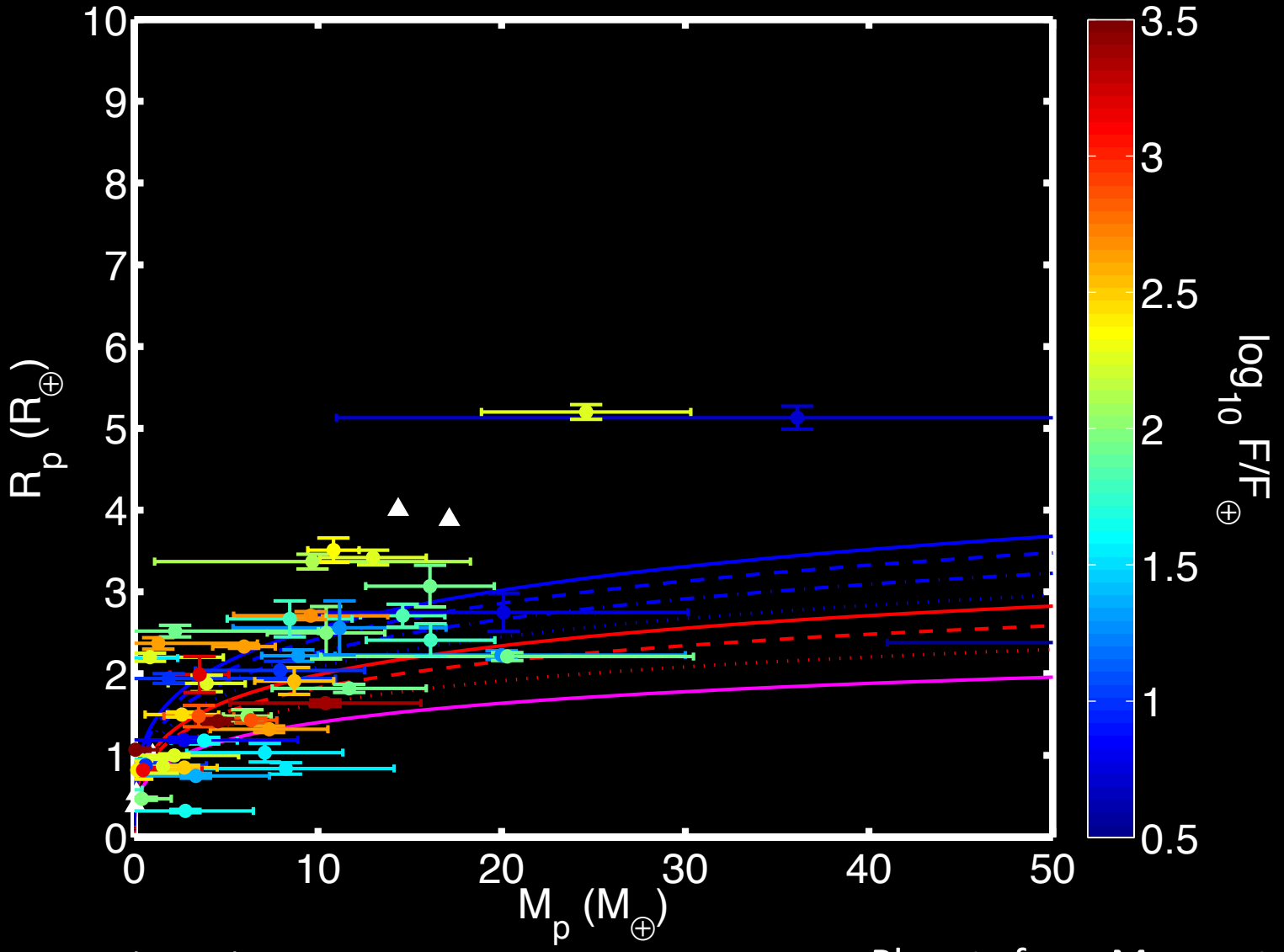
Kepler Planets with RV Follow-Up



Seager et al. (2007) M-R Relations

Planets from Marcy et al. (2014)

Which Planets Are Rocky?



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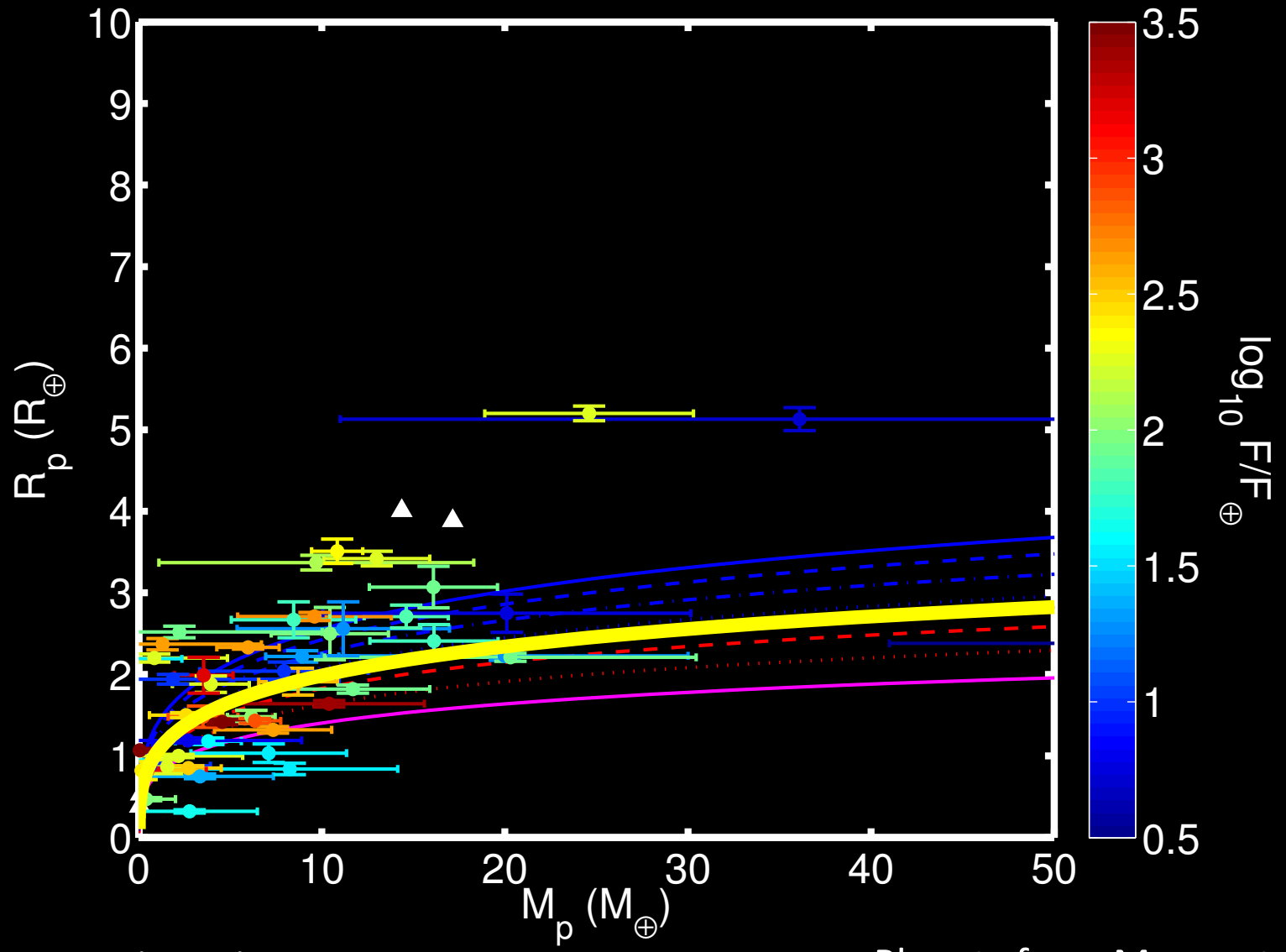

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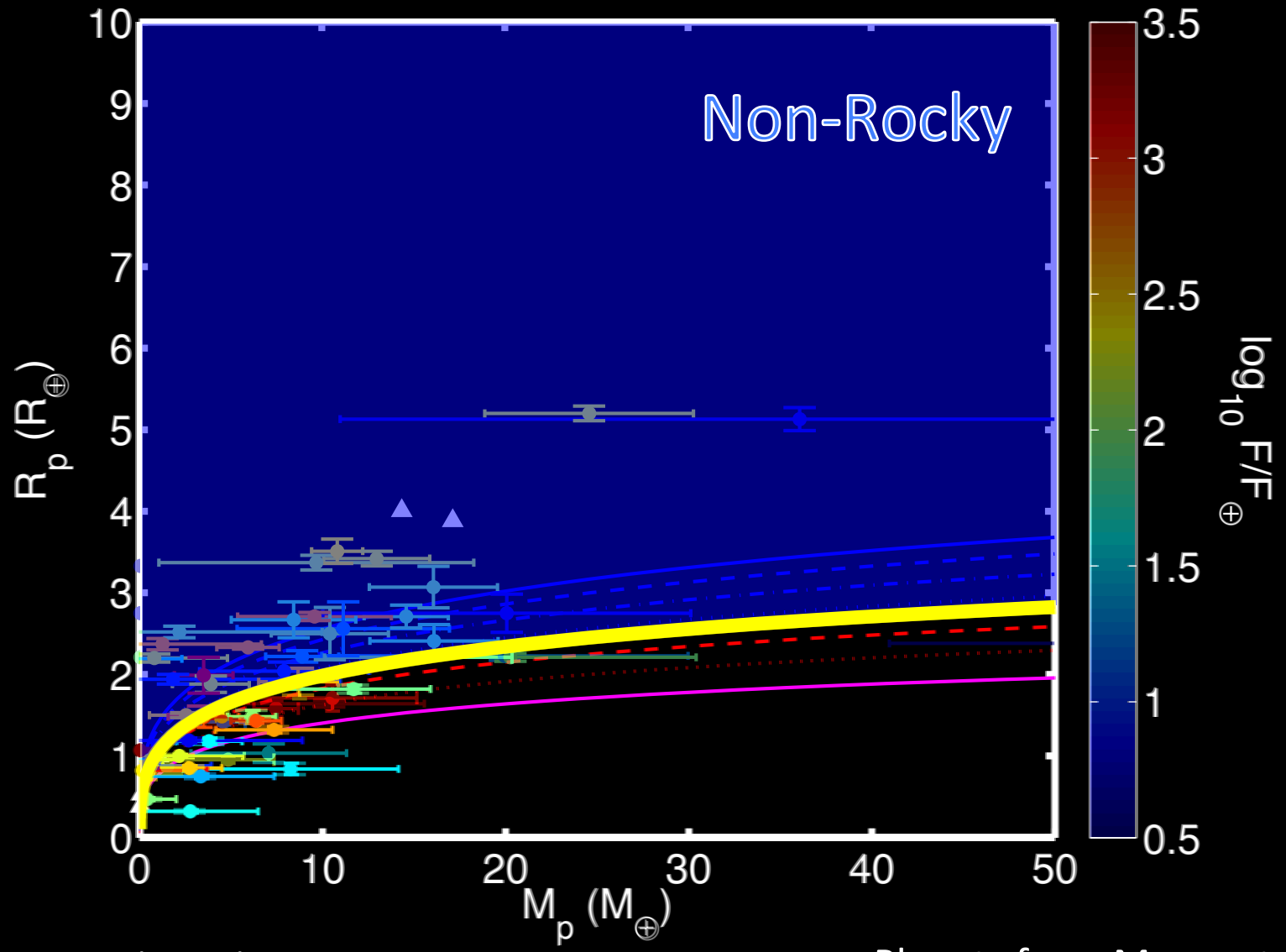

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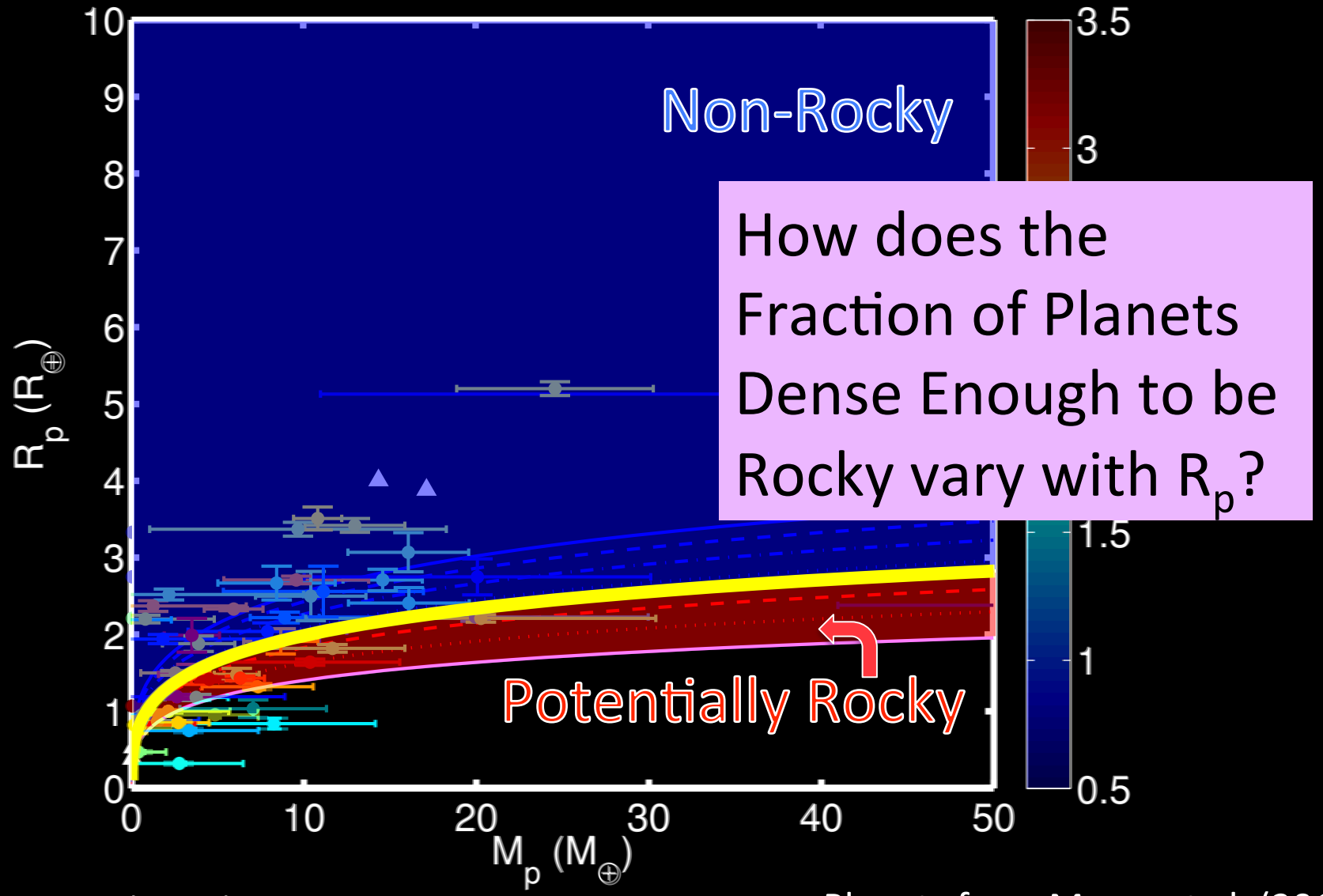


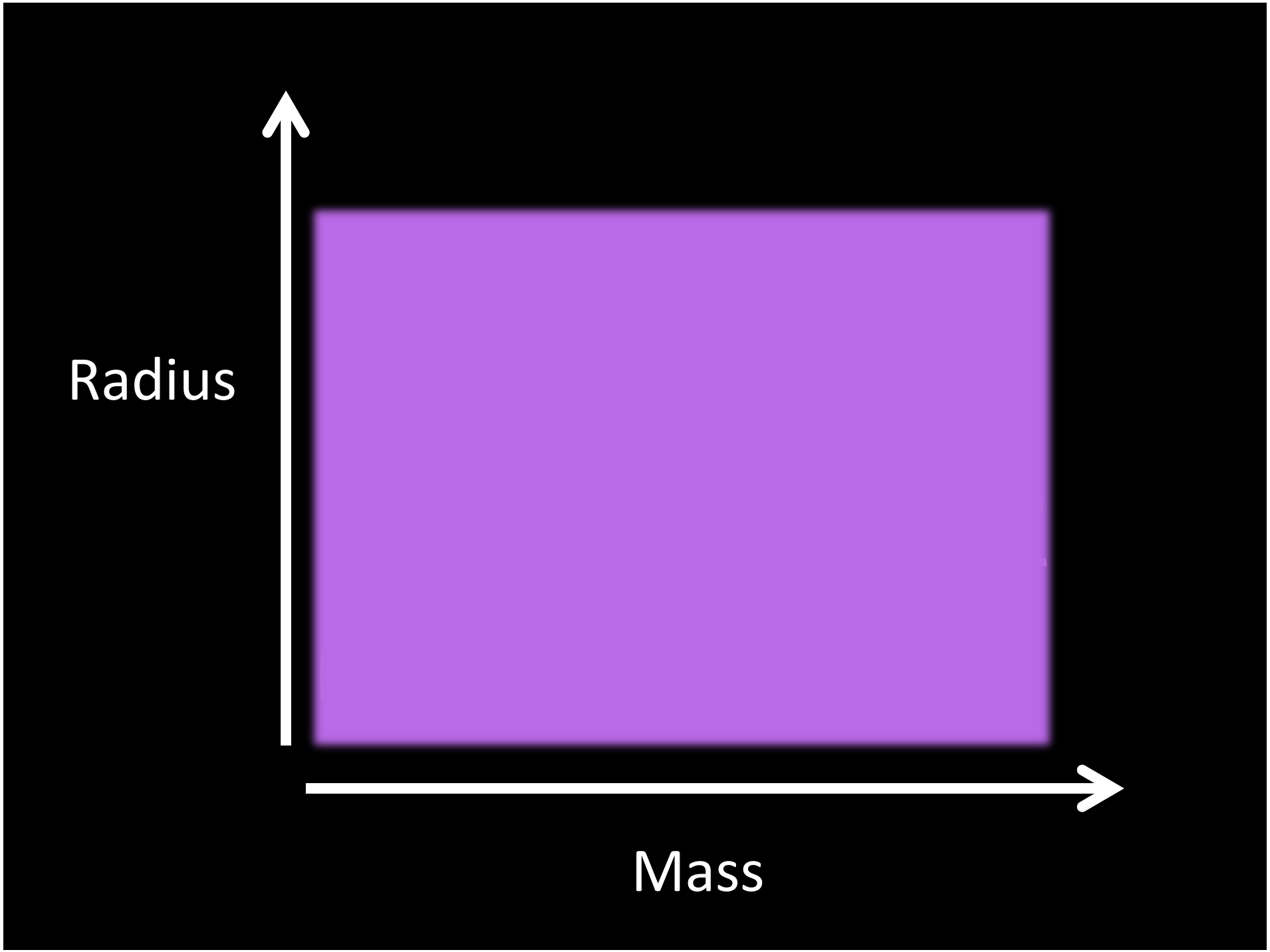
Seager et al. (2007) M-R Relations

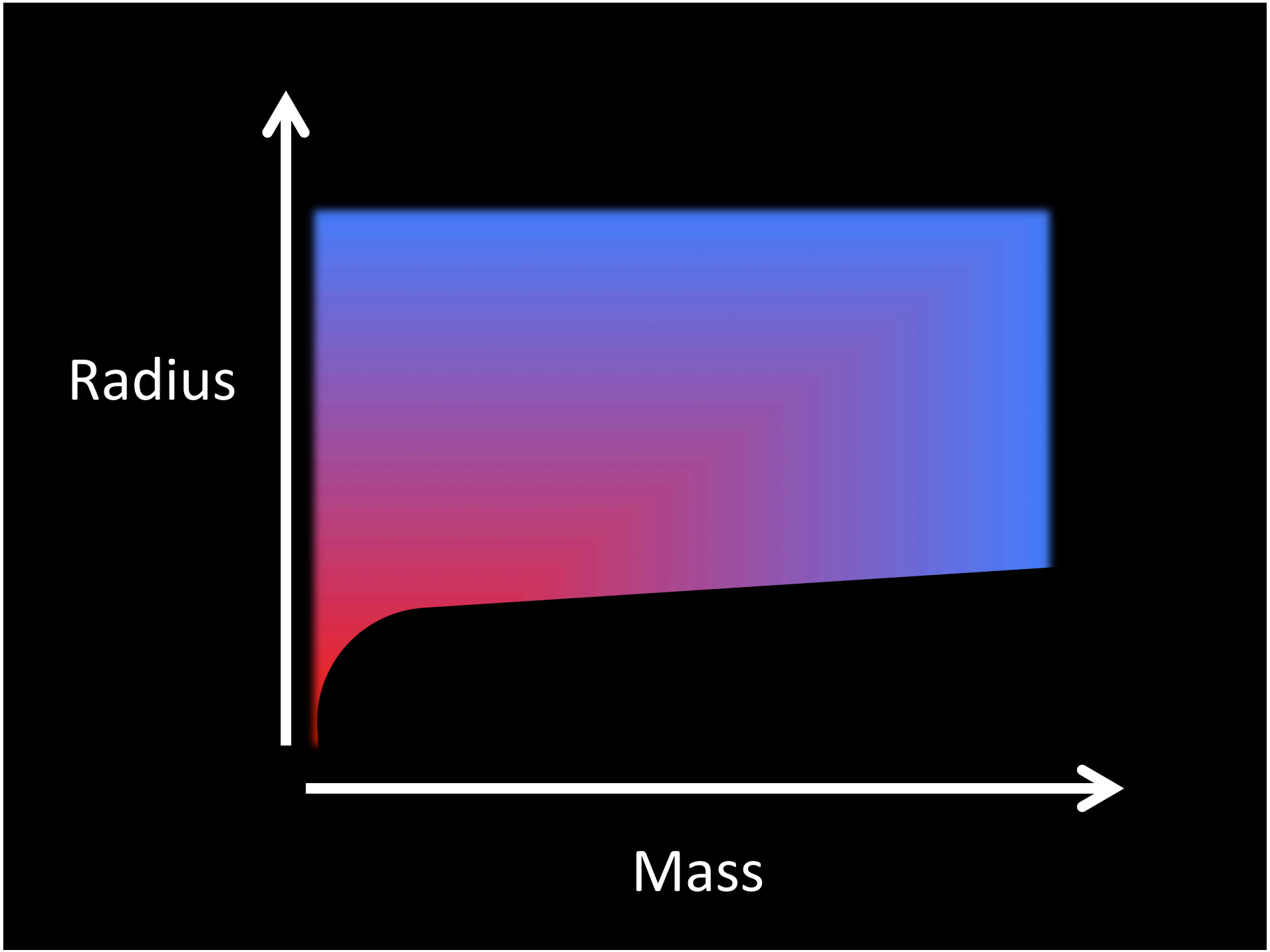
Planets from Marcy et al. (2014)

Model:

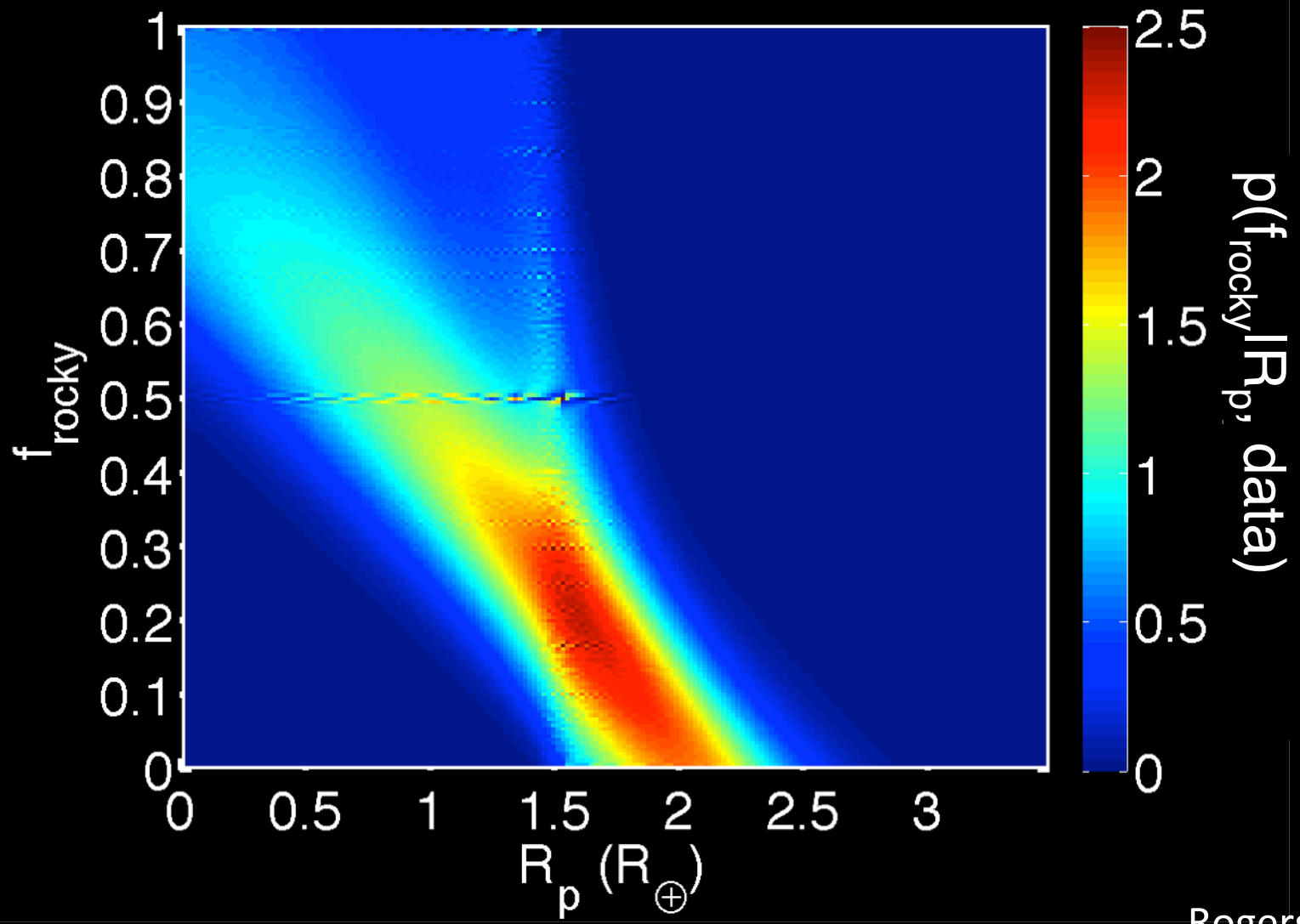
$$\mathbf{f_{rock}}\left(\mathbf{R_p}, \mathbf{a}\right) \equiv \text{fraction of planets dense enough to be rocky}$$

$$\mathbf{a} \equiv \text{model parameters (to be constrained)}$$


Radius
Mass


Radius
Mass

Linear Transition Model: Posterior Distribution for $f_{rocky}(R_p)$



Rogers (2015)

Main Take Away: Most planets larger than 1.6 $R_\oplus$ are not Rocky.

Kepler-22b

(R_p = 2.4 $R_\oplus$):

~~Rocky~~

OR

Volatile Rich?

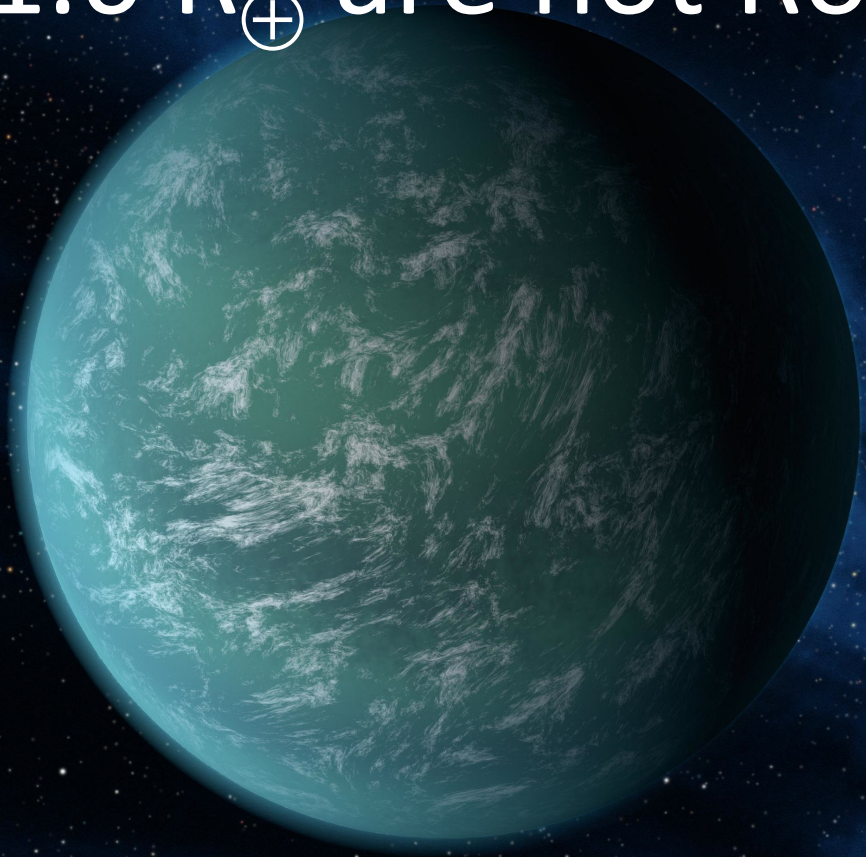
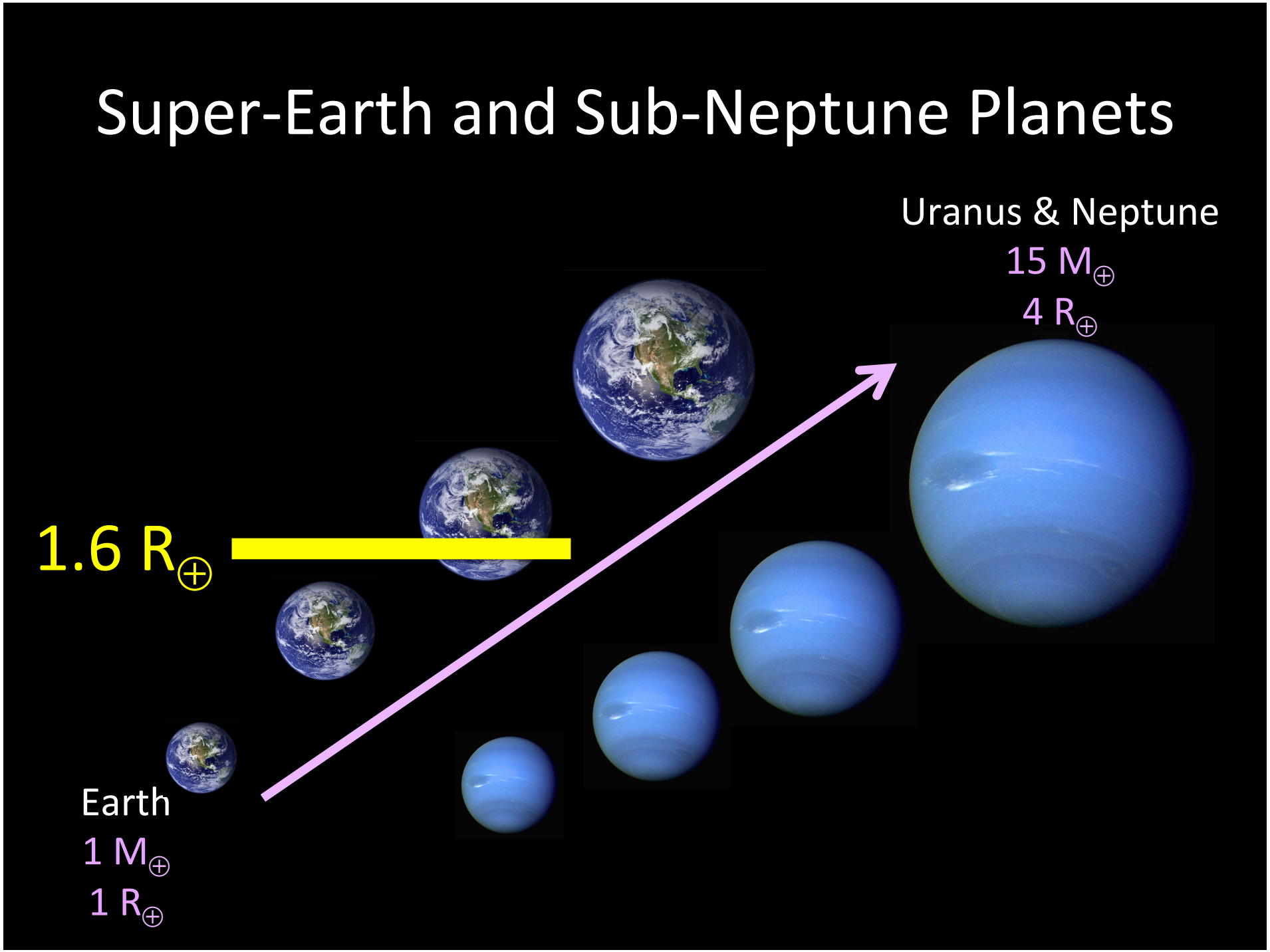


Figure Credit: *NASA/Ames/JPL-Caltech*

Super-Earth and Sub-Neptune Planets



"Most 1.6 $R_\oplus$ planets are not Rocky," is the first step.

We'd really like to know:

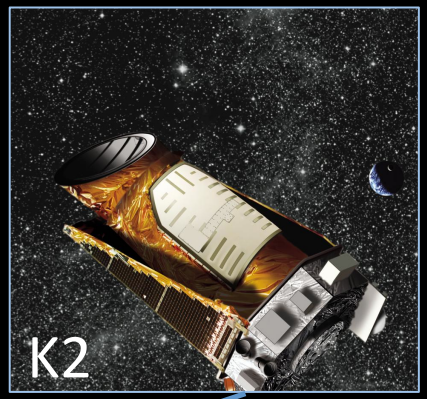
What is $f_{rocky}(R_p)$ in the Habitable Zone?

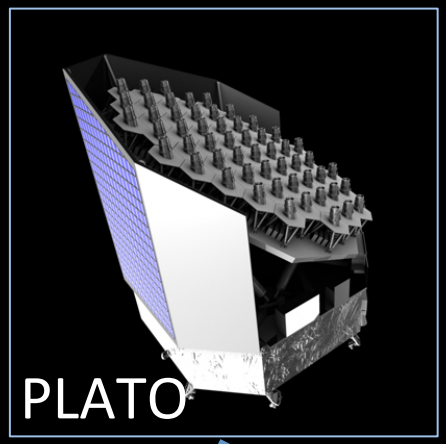
Rock/non-rocky transition gradual or abrupt?

How does $f_{rocky}(R_p)$ depend on incident flux?
Stellar mass?

Figure Credit: *NASA/Ames/JPL-Caltech*

Upcoming space-based surveys will discover many transiting planets around bright stars!



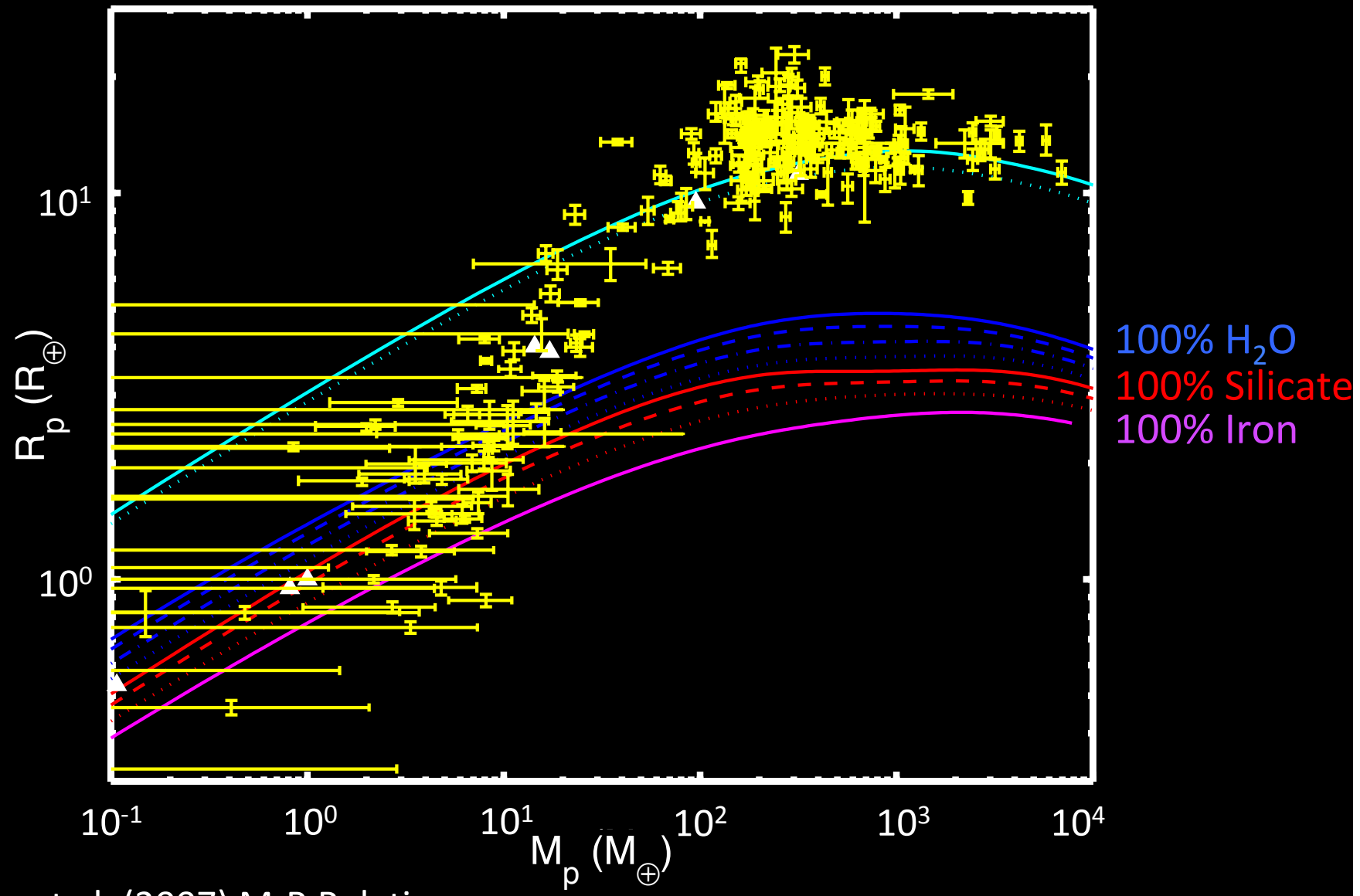


2014 2017 2024

Many Precision RV Spectrographs Under Development:
e.g., SHREK (Keck), SPIRou (CFHT), MAROON-X (Magellan), HPF (HET), CARMENES (Calar Alto), Espresso (VLT), EXPRES, G-CLEF (GMT)

Let’s Look to the Future

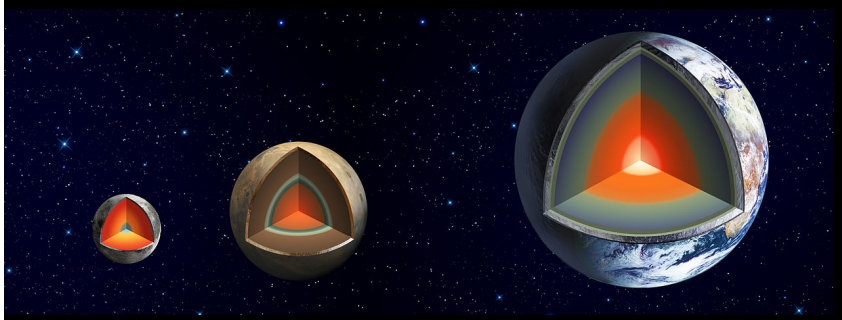
Accumulating a Statistical Sample of Planet M-R

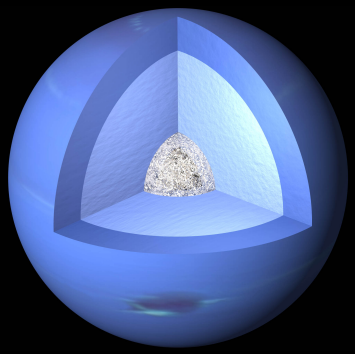


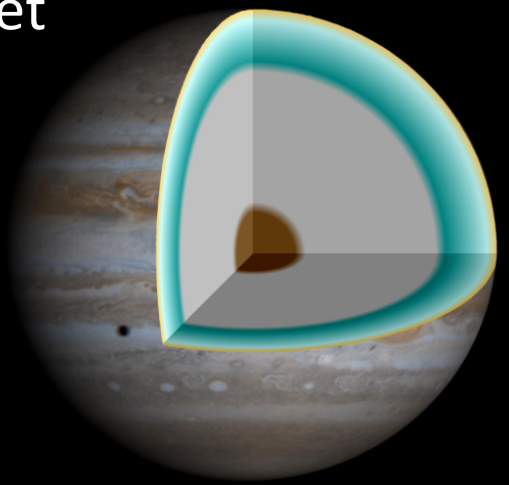
Seager et al. (2007) M-R Relations

Planet composition distribution wish list:

- What is the typical mass scale for rocky planets?
- For planets with gas envelopes, what is the relationship between planet core mass and envelope mass?
- Is there evidence for distinct planet sub-populations formed through different planet formation pathways?
- How much physical scatter is there in exoplanet compositions?







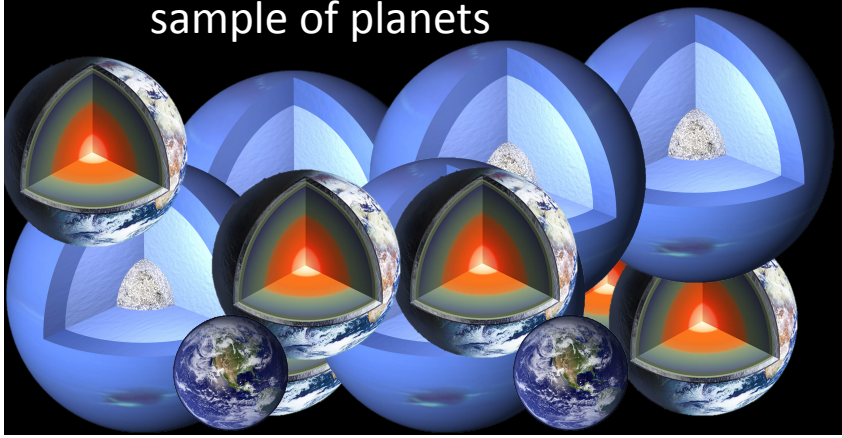
How well can we hope to constrain the planet composition distribution?

Input Parameters

50 planets: 40% Relative Uncertainty
250 planets: 10% Relative Uncertainty

Parameterized Model of Planet Mass-Composition Distribution

Generate simulated sample of planets



Add Noise

Simulated

$M_p + R_p + F_p$

Measurements

Output Parameters

Apply Hierarchical analysis using

Parameterized Model of Planet Mass-Composition Distribution

Rogers et al. (2015) in prep.

Main Take Away Points

- Present:
  - Most planets larger than 1.6 $R_{\oplus}$ are not Rocky.
- Future Prospects:
  - From the accumulating sample of planet M-R measurements we can gain largely empirical constraints on the planet composition distribution
    - e.g., typical mass scale of rocky planets
    - M_{core}-M_{env} relationship of gas-laden planets
    - extent of physical scatter in exoplanet compositions