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

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Super-Earth and Sub-Neptune Planets

Earth
1 $M_⊕$
1 $R_⊕$

Uranus & Neptune
15 $M_⊕$
4 $R_⊕$
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!

Stellar Wobble

Transits

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?

Seager et al. (2007) M-R Relations

Planets from Marcy et al. (2014)
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Planets from Marcy et al. (2014)  
Seager et al. (2007) M-R Relations
Which Planets Are Rocky?

How does the Fraction of Planets Dense Enough to be Rocky vary with $R_p$?

Seager et al. (2007) M-R Relations

Planets from Marcy et al. (2014)
Model:

\[ f_{\text{rock}} (R_p, a) \equiv \text{fraction of planets dense enough to be rocky} \]

\[ a \equiv \text{model parameters (to be constrained)} \]
Linear Transition Model: Posterior Distribution for $f_{\text{rocky}}(R_p)$
Main Take Away: Most planets larger than $1.6 \, R_⊕$ are not Rocky.

Kepler-22b

($R_p = 2.4 \, R_⊕$):

X Rocky

OR

Volatile Rich?
“Most 1.6 $R_\oplus$ planets are not Rocky,” is the first step.

We’d really like to know:

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

Rock/non-rocky transition gradual or abrupt?

How does $f_{\text{rocky}}(R_p)$ depend on incident flux? Stellar mass?
Upcoming space-based surveys will discover many transiting planets around bright stars!

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
- Parameterized Model of Planet Mass-Composition Distribution
- Generate simulated sample of planets

Output Parameters
- Apply Hierarchical analysis using Parameterized Model of Planet Mass-Composition Distribution
- Measurements $M_p + R_p + F_p$

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

Rogers et al. (2015) in prep.
Main Take Away Points

• Present:
  – Most planets larger than $1.6 R_⊕$ 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
    • $M_{\text{core}}-M_{\text{env}}$ relationship of gas-laden planets
    • extent of physical scatter in exoplanet compositions