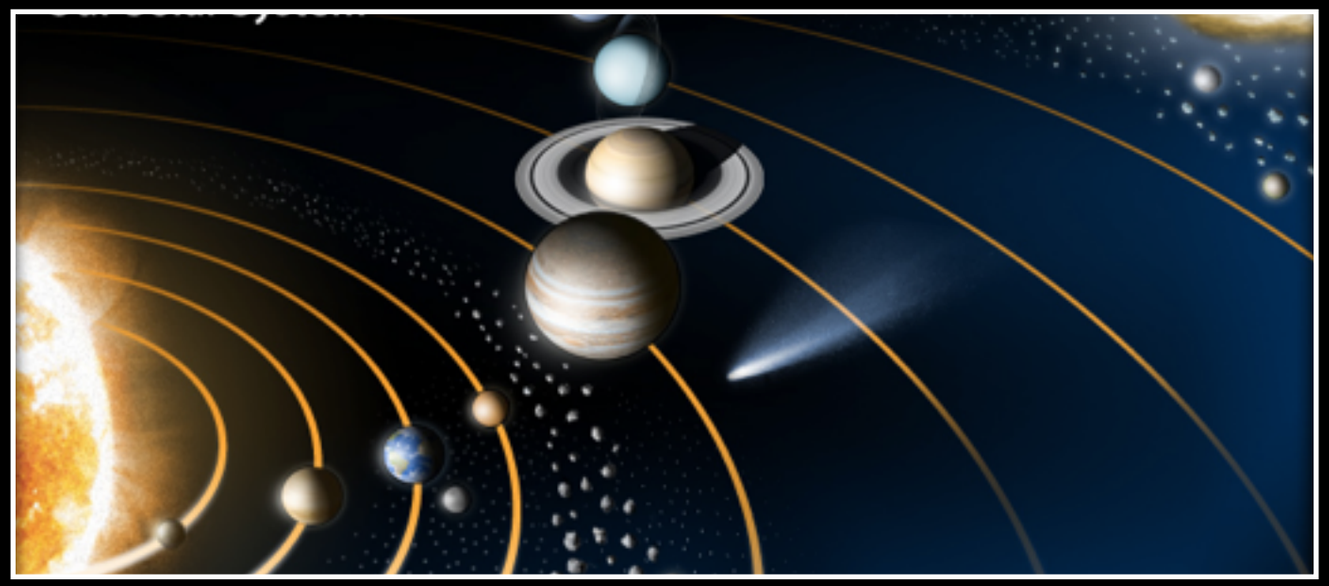
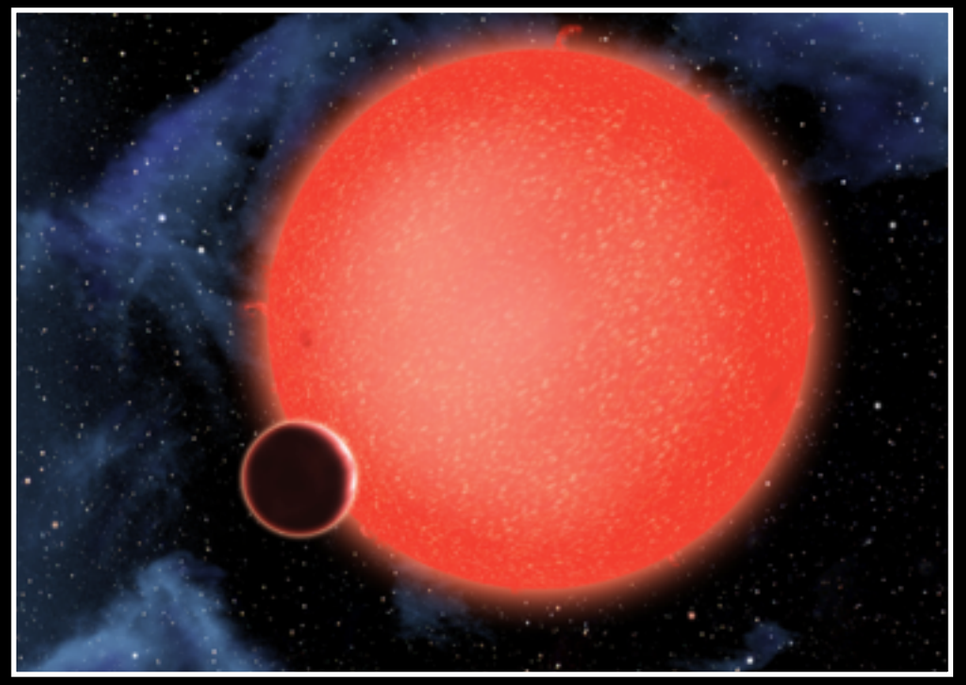
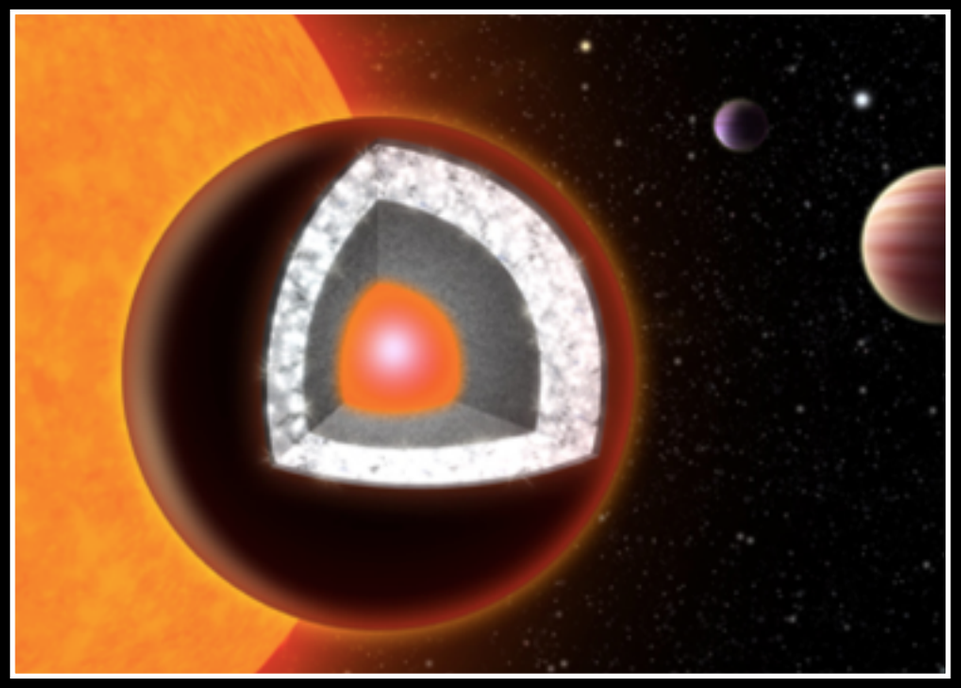
Insights from Exoplanet Exceptions

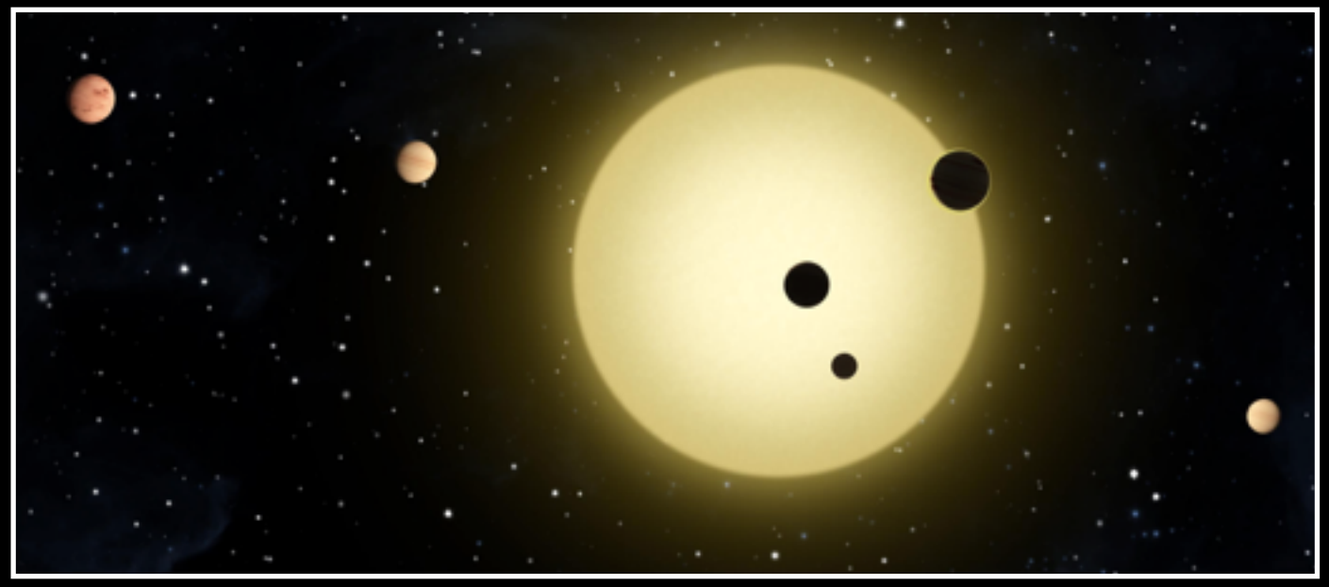
Rebekah (Bekki) Dawson (Miller Fellow, UCB)

Exceptional Planets

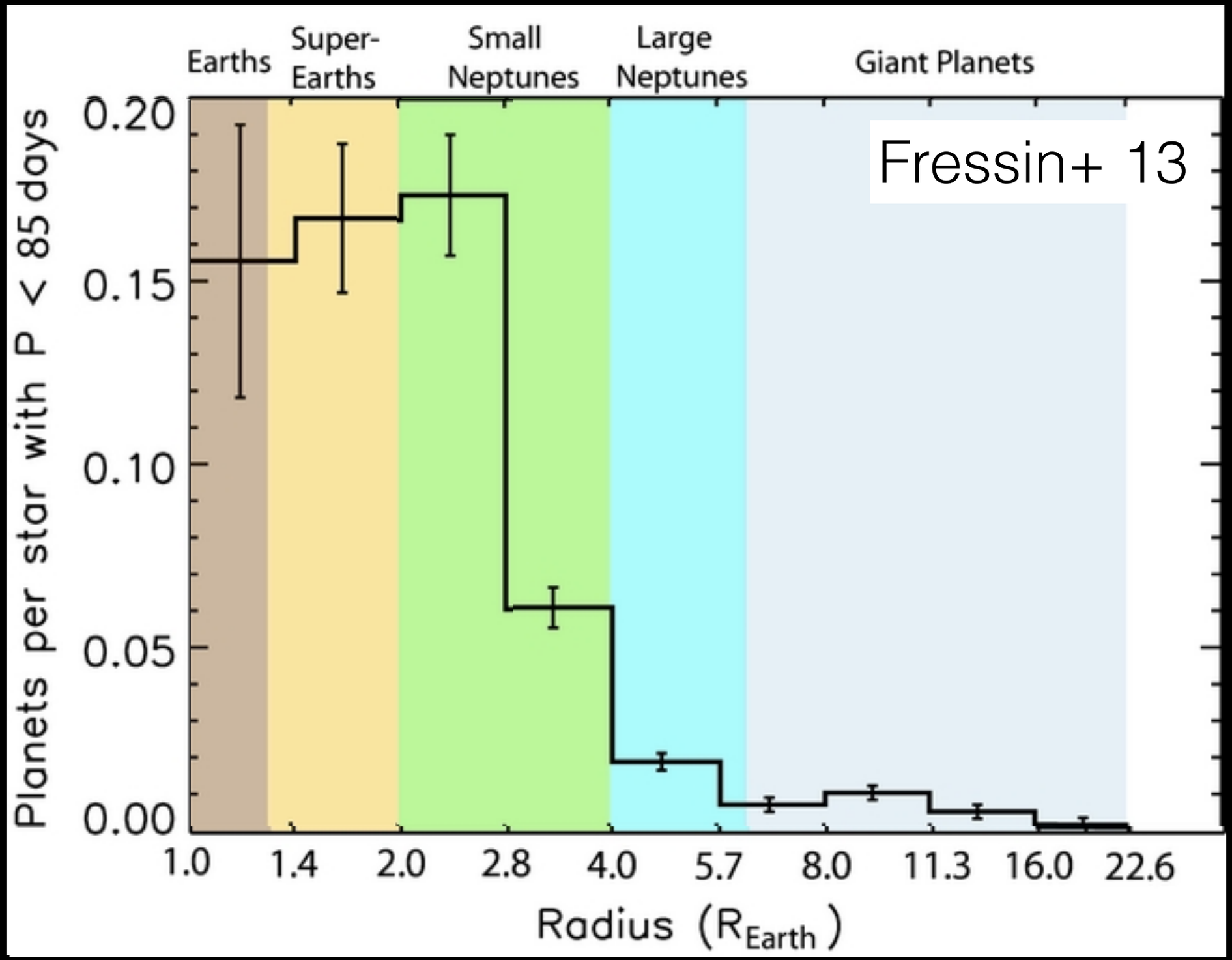






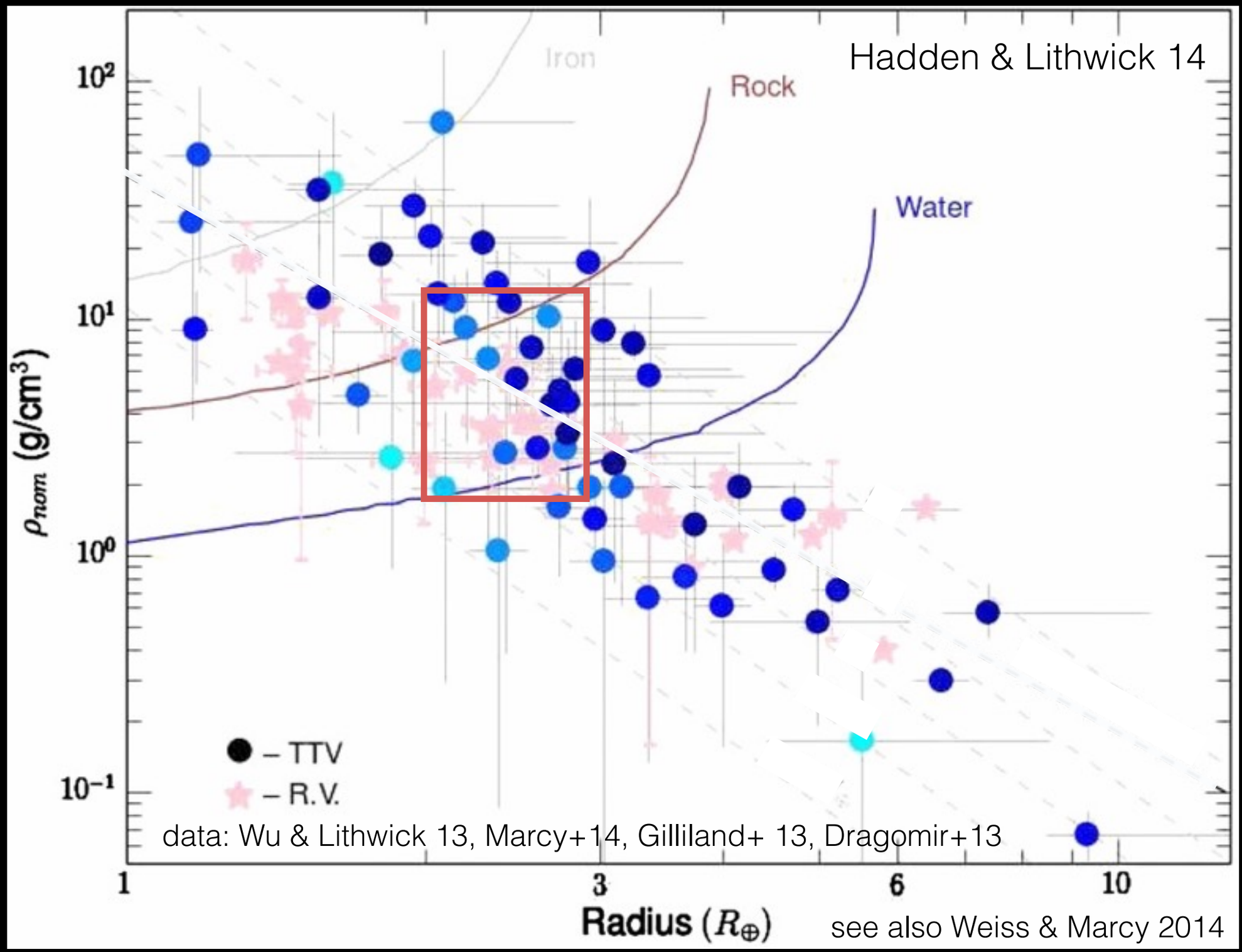


Planets of 2-3 Earth radii are common



see also Howard+ 12, Petigura+ 13ab, Dong & Zhu 13, Batalha 2014

Planets of 2-3 Earth radii have ambiguous compositions/formation histories

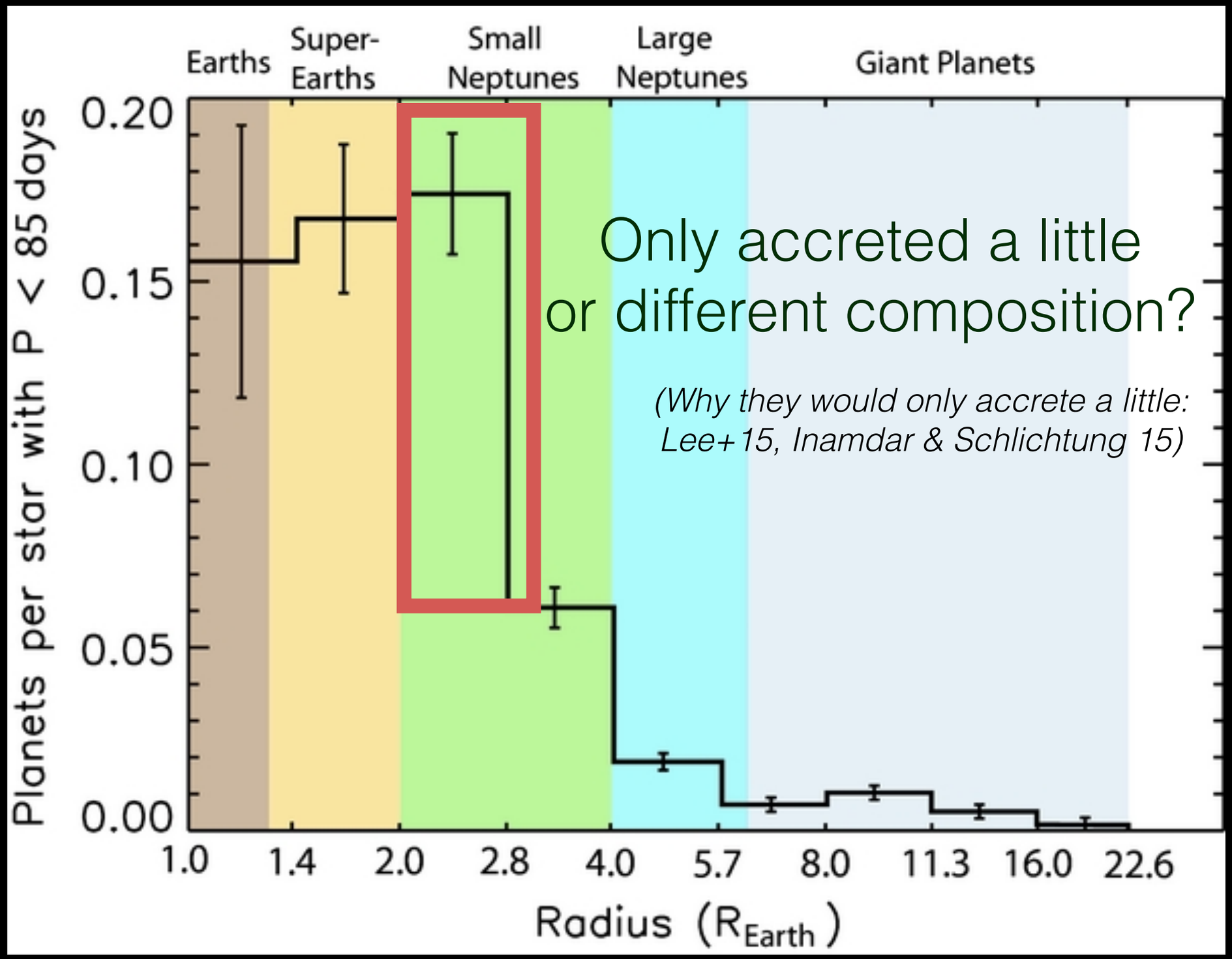


2-3 Earth radii planets are dense enough not to **require** H/He but too rarefied to be pure rock*

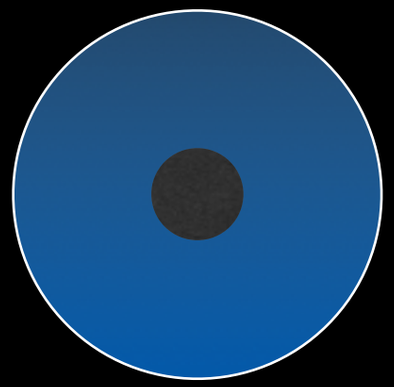
- Nebular or outgassed H/He
- Water, ices
- Steam (or other high mean molecular weight)

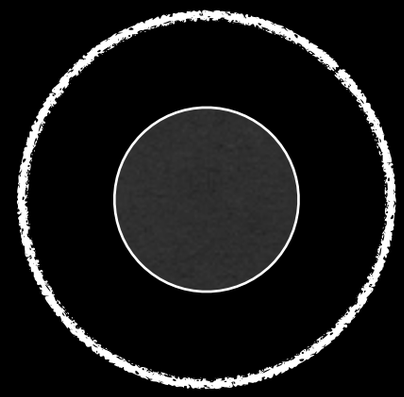
*See Rogers 2014 for rocky-gas transition

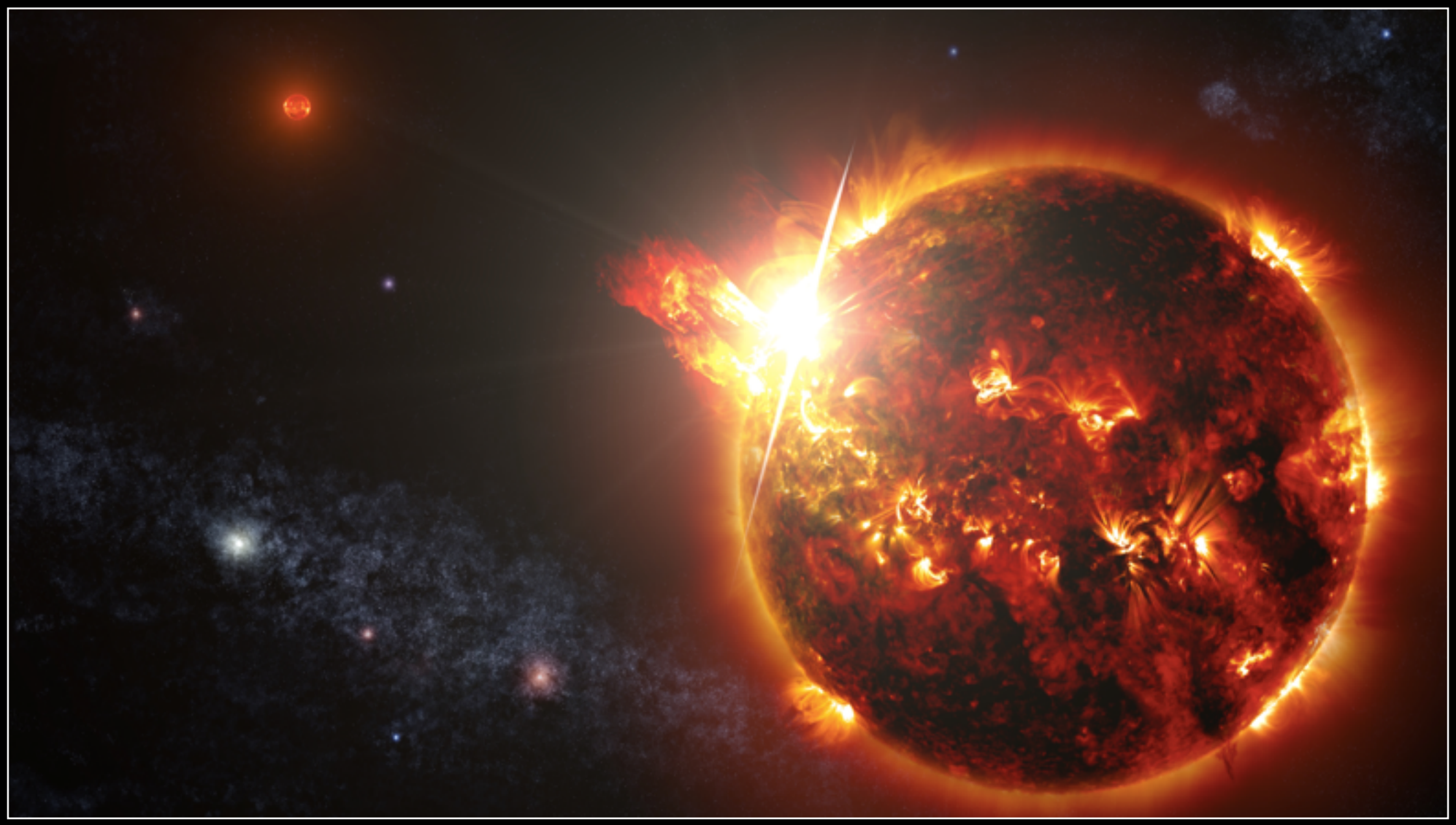
Compositions of 2-3 Earth radii planets are a necessary ingredient for understanding when and where they formed



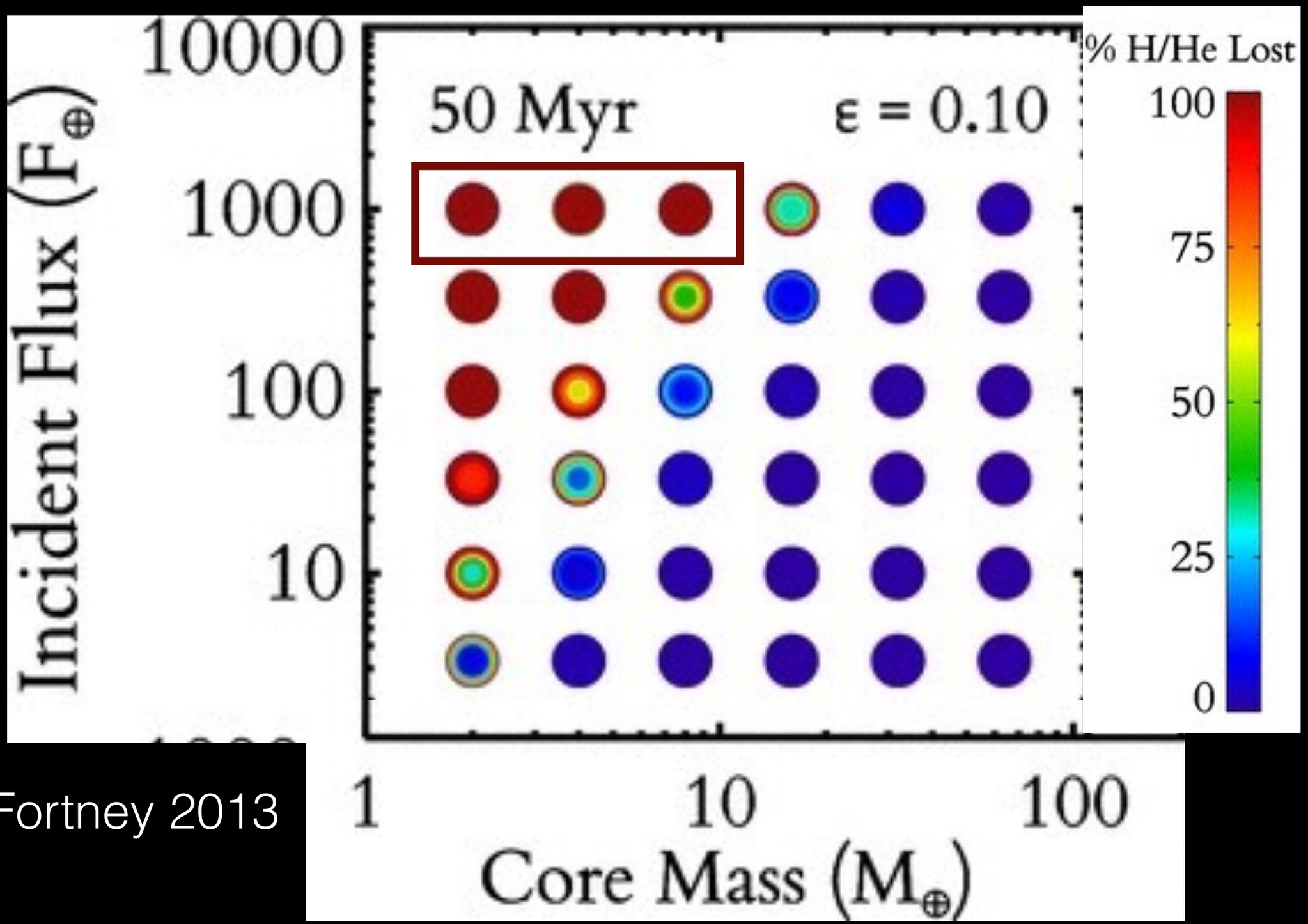
Let's do an experiment





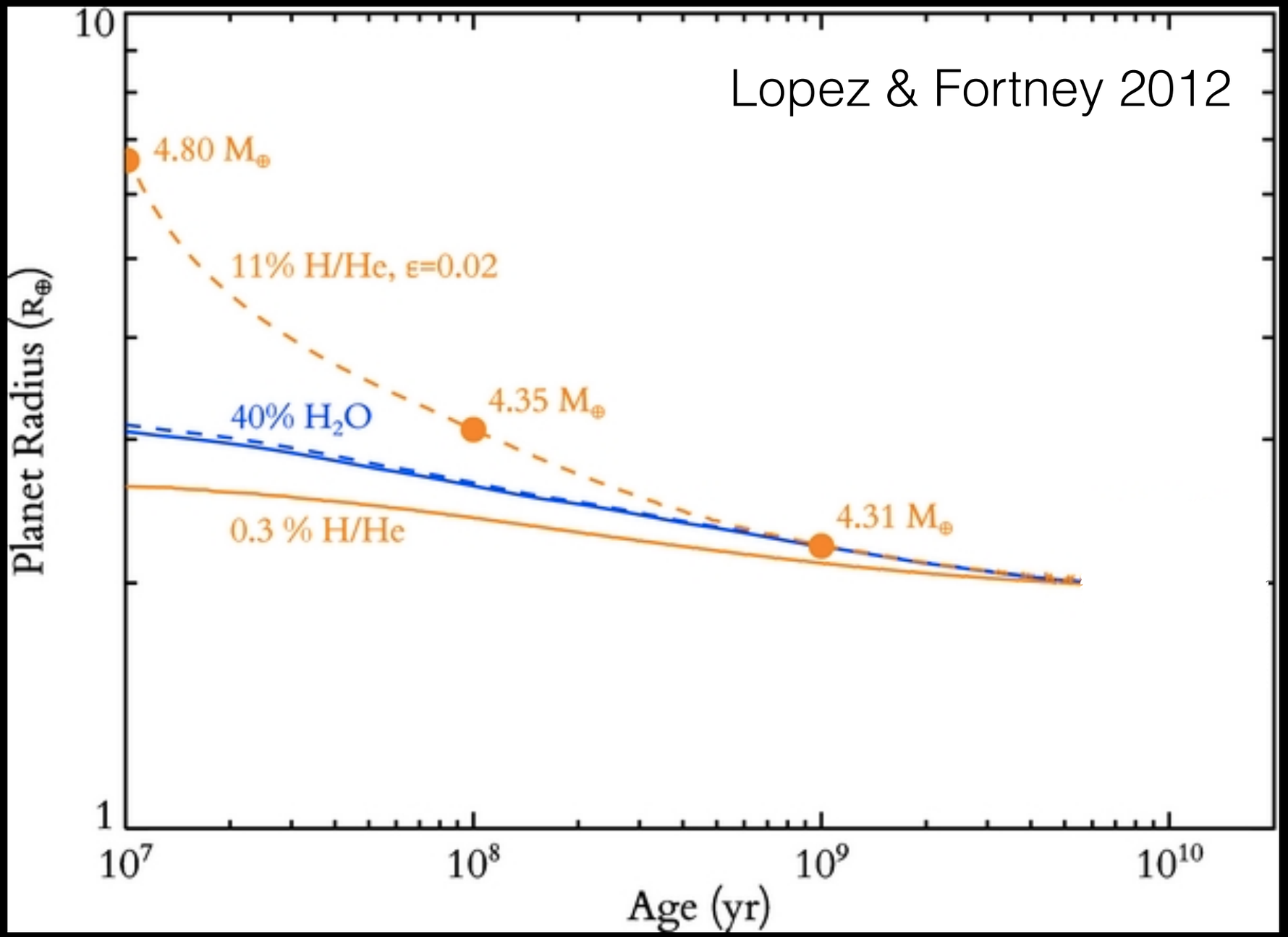


Short Period Planets Would Lose a Primordial H/He Atmosphere

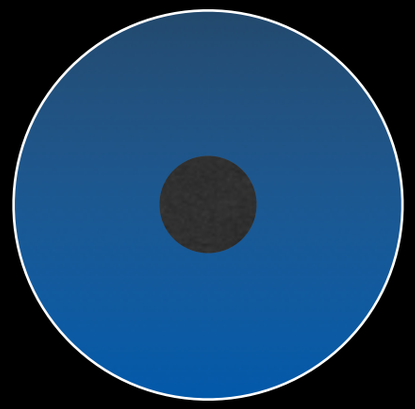


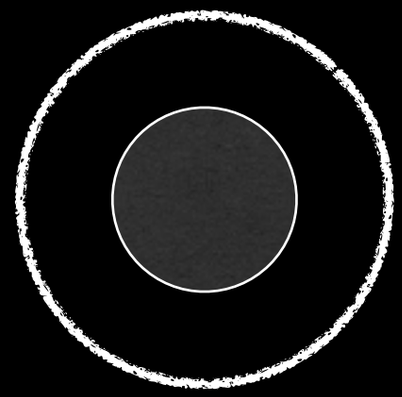
Lopez & Fortney 2013

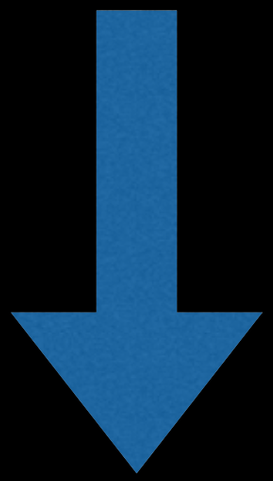
Easier to keep H2O envelope (or even a gradually outgassed atmosphere)

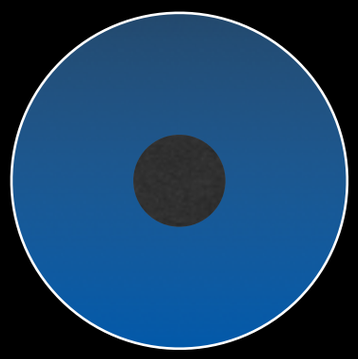


Let's do an experiment

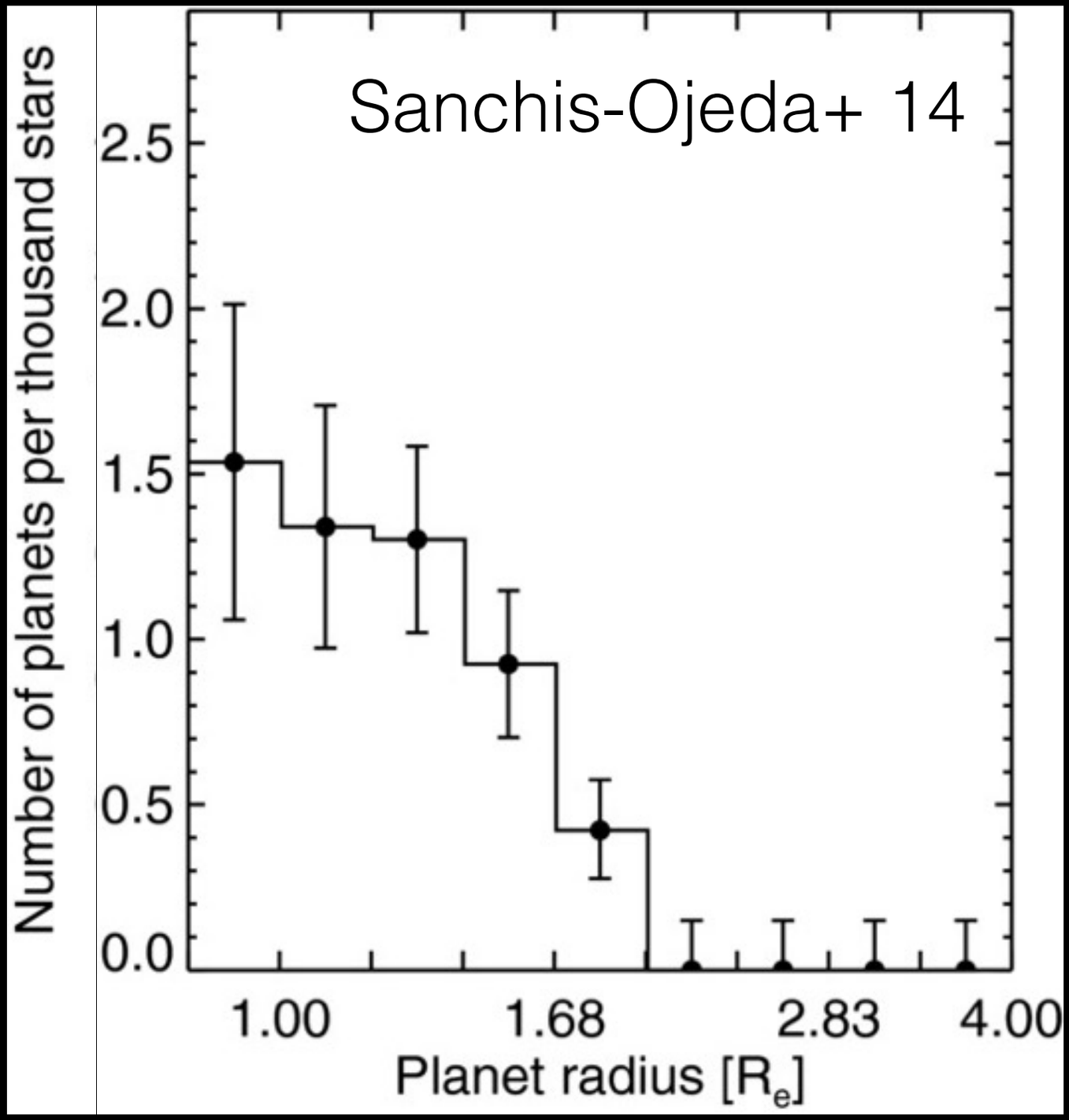




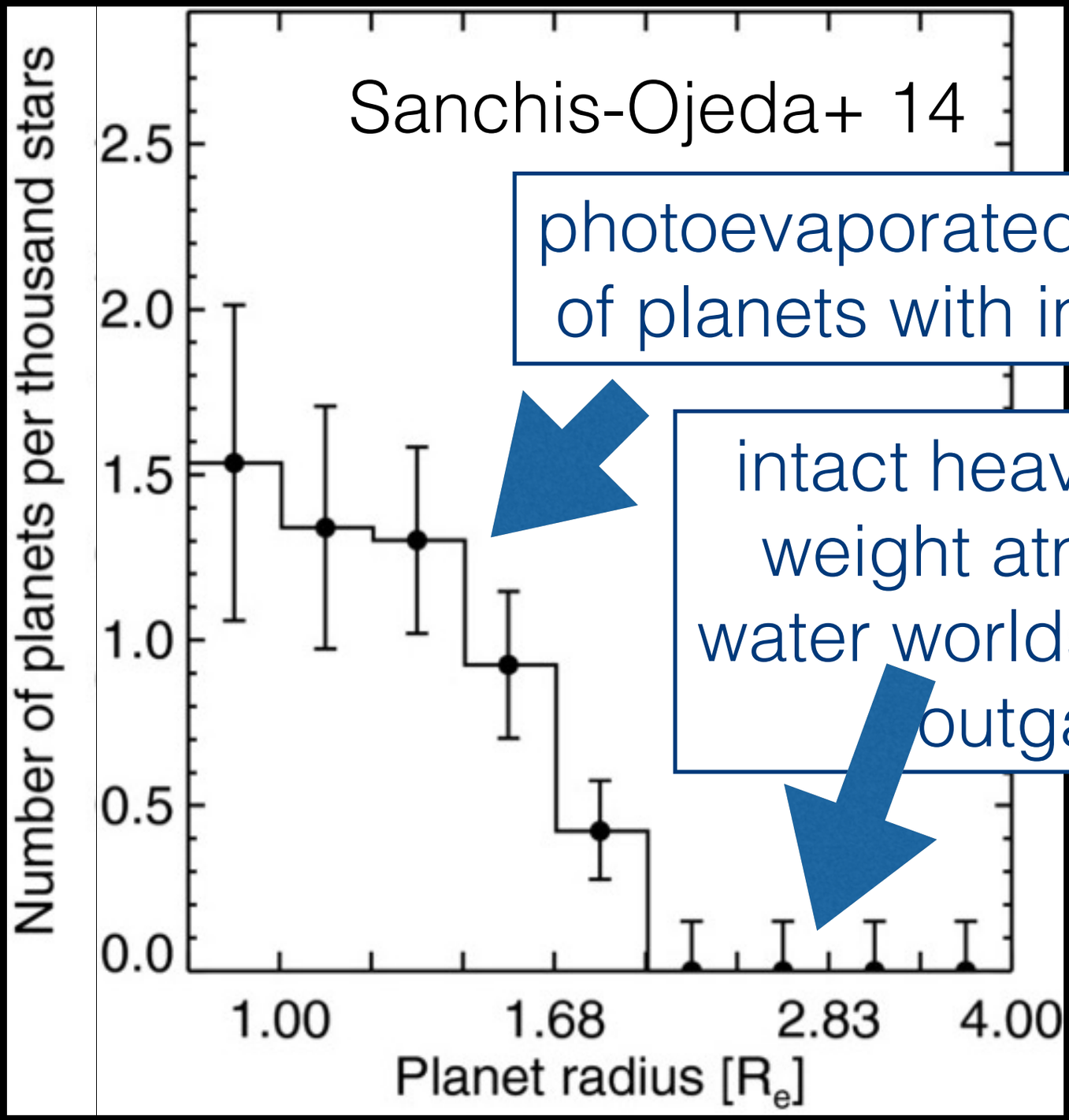




2-3 Earth radii planets are missing at short (<1 day) orbital periods



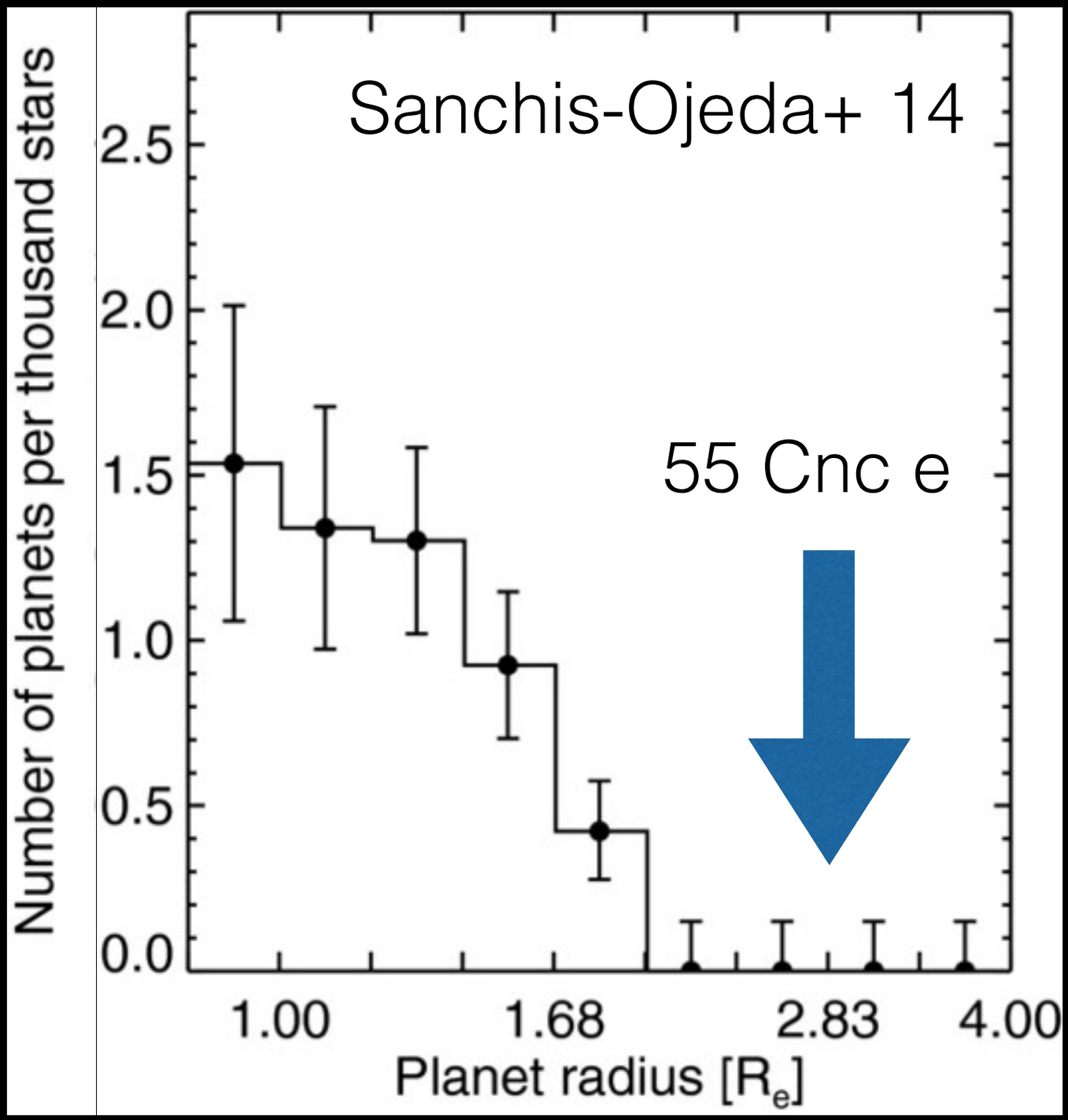
2-3 Earth radii planets are missing at short orbital periods



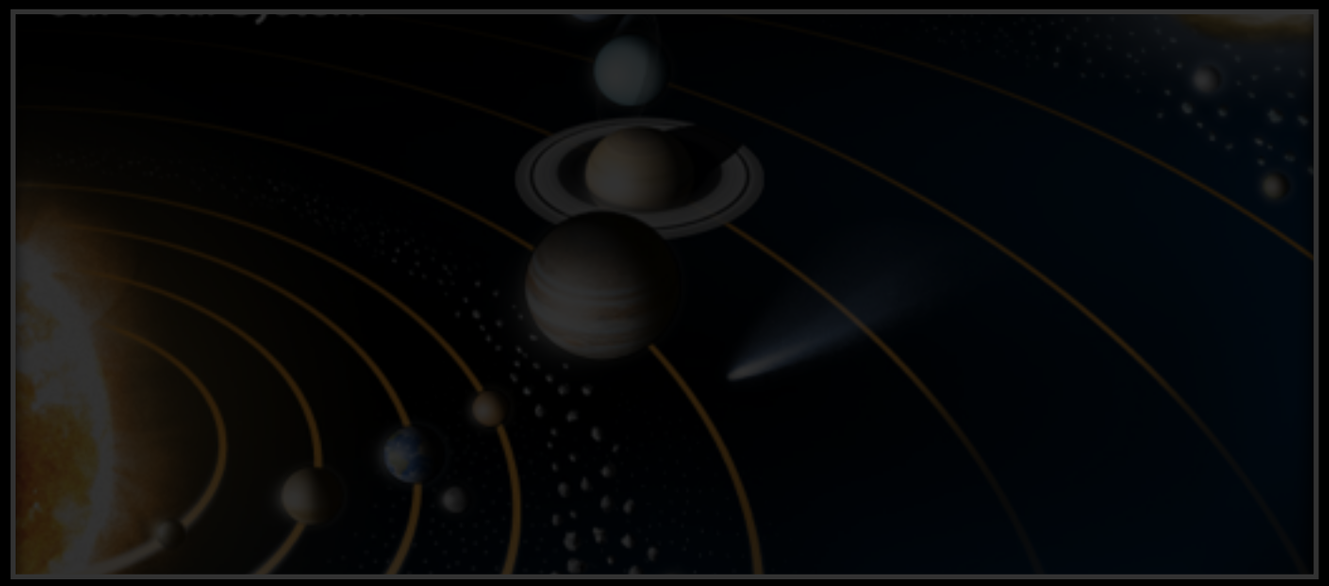
photoevaporated remnants of planets with initial H/He

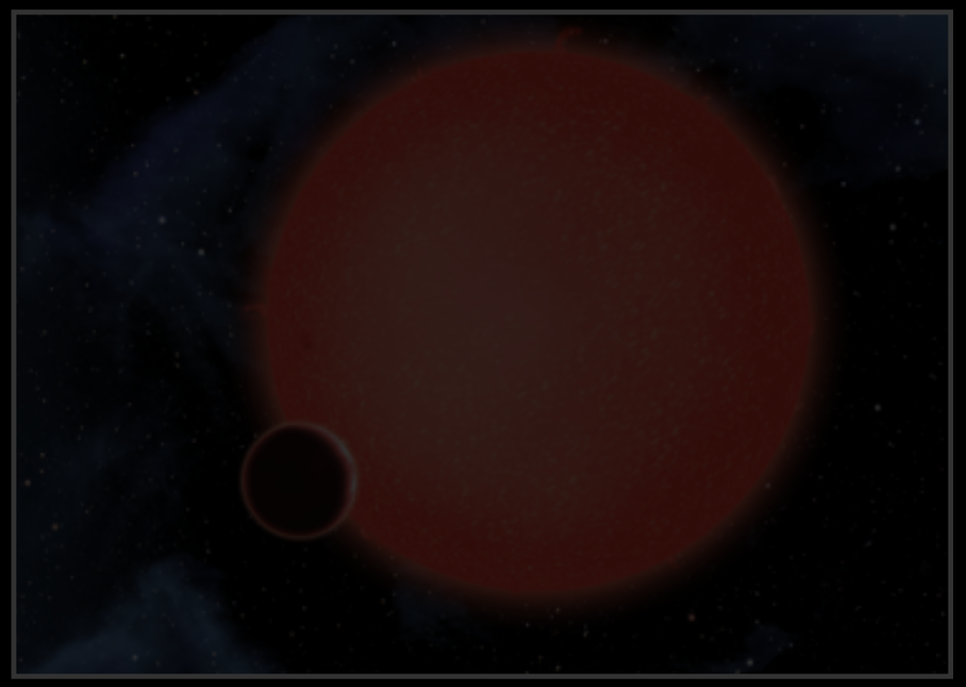
intact heavy molecular weight atmospheres, water worlds, continuous outgassing

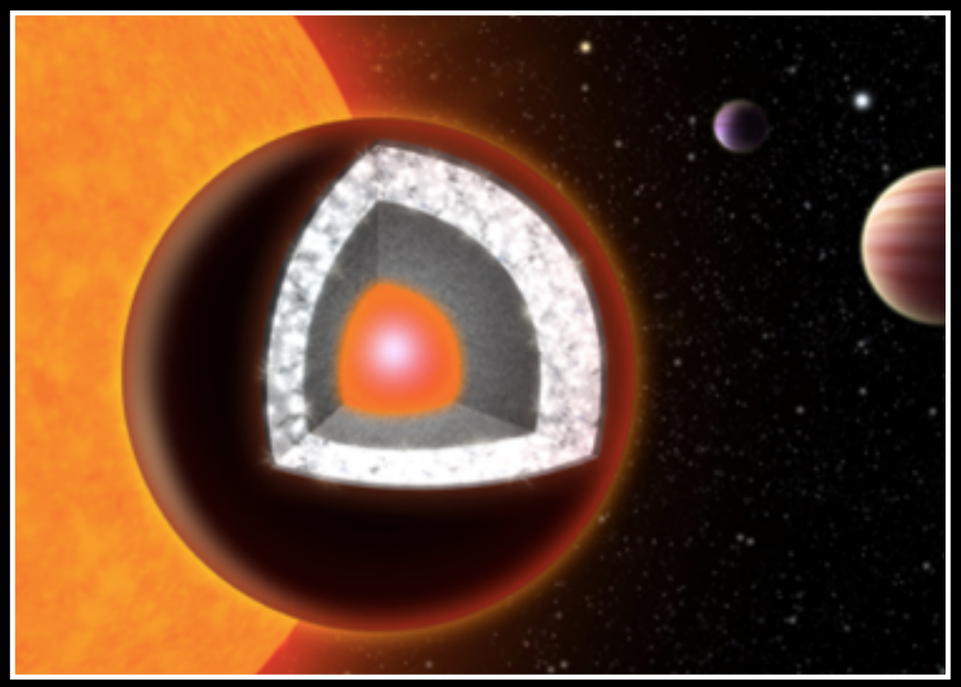
But there is at least one (non-Kepler) short period planets here

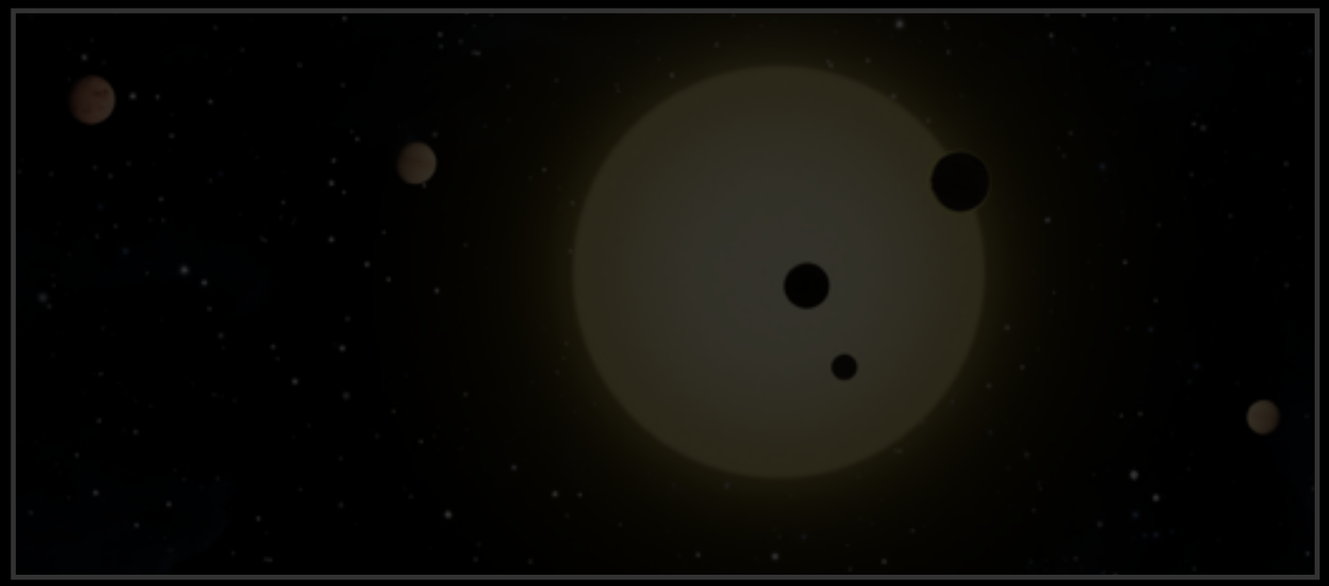


Exceptional Planets

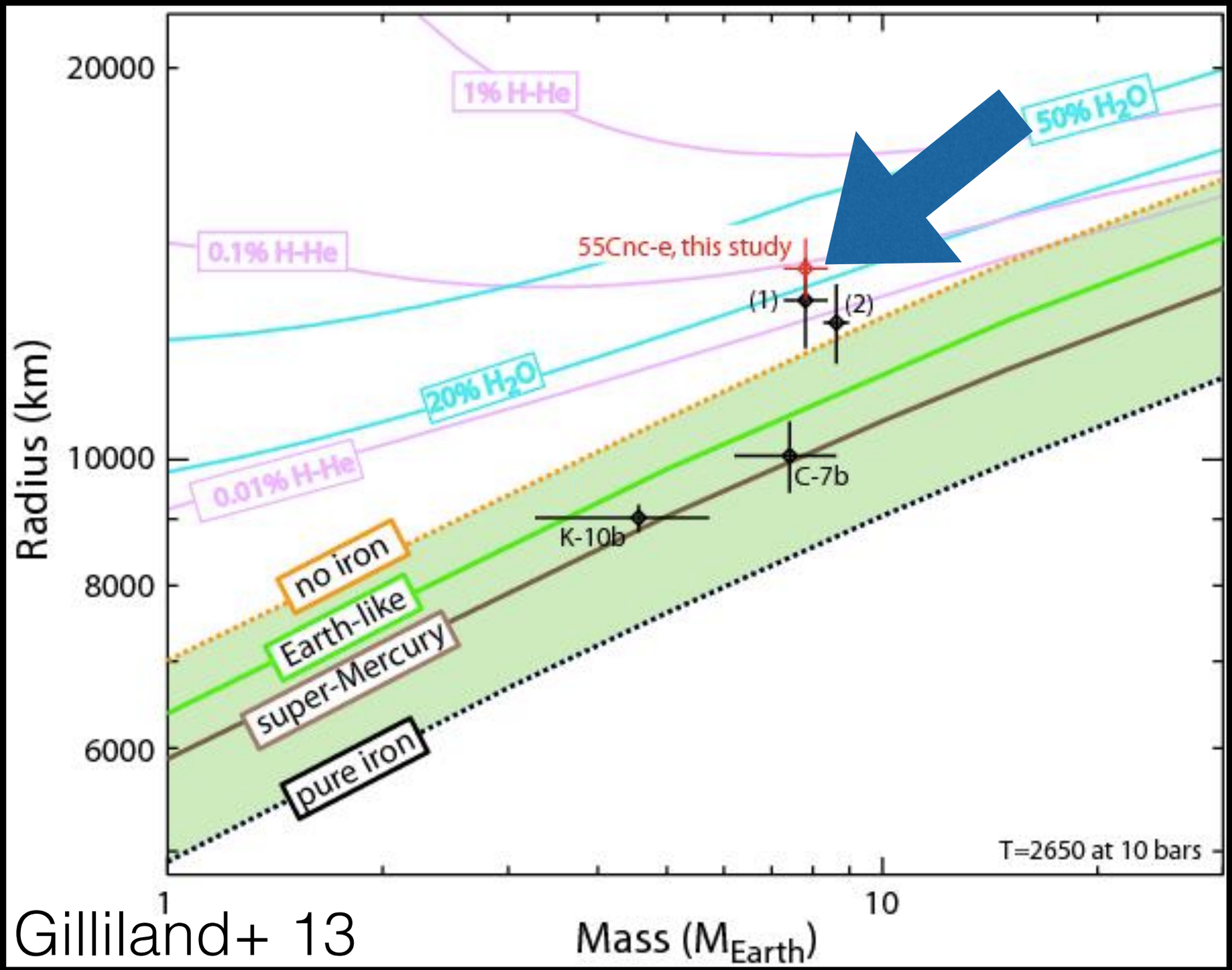






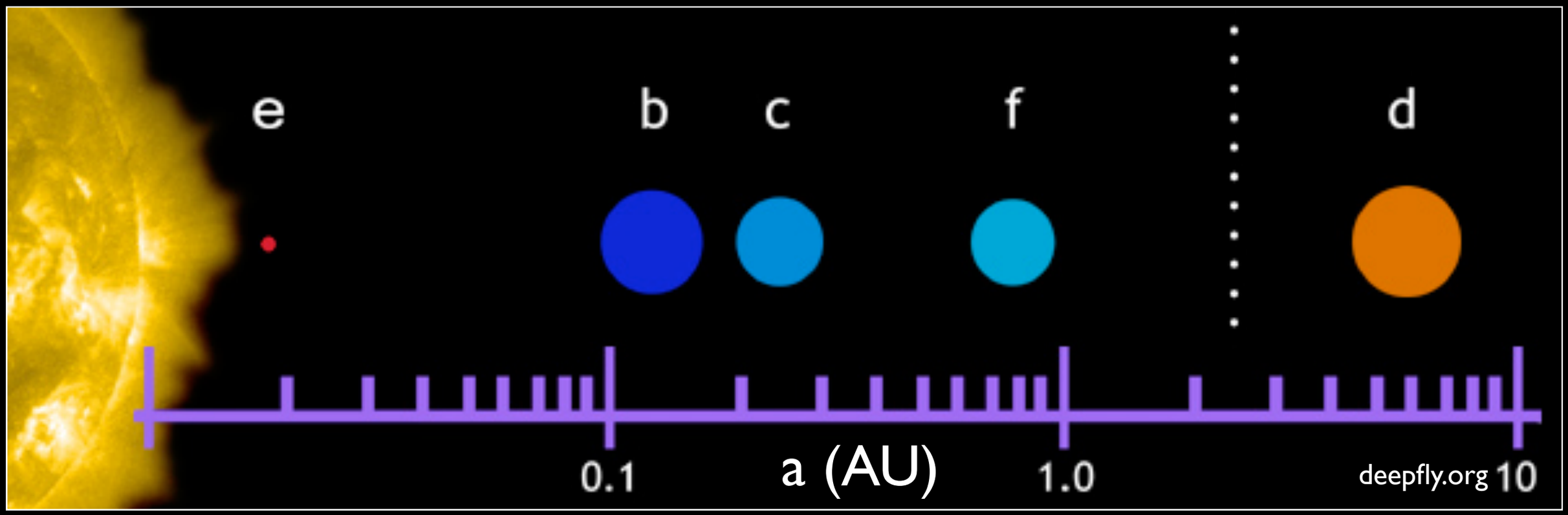


Exception: 55 Cnc e: 2 Earth radii, 0.74 day orbital period



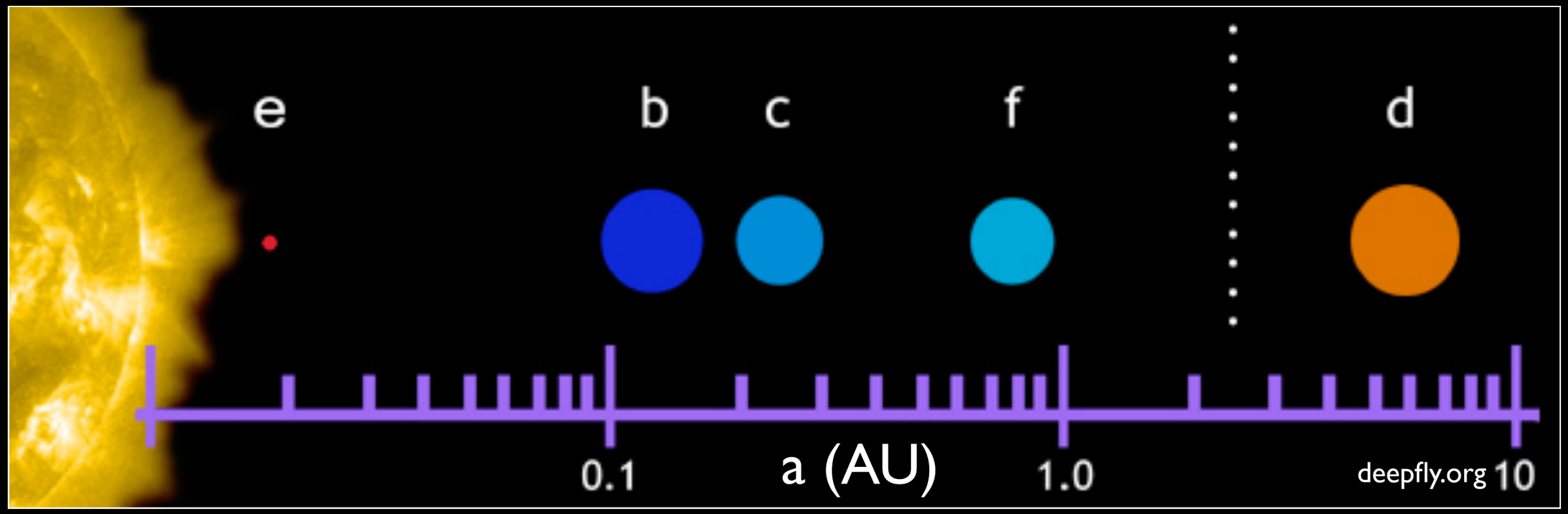
Gilliland+ 13

55 Cnc e in context



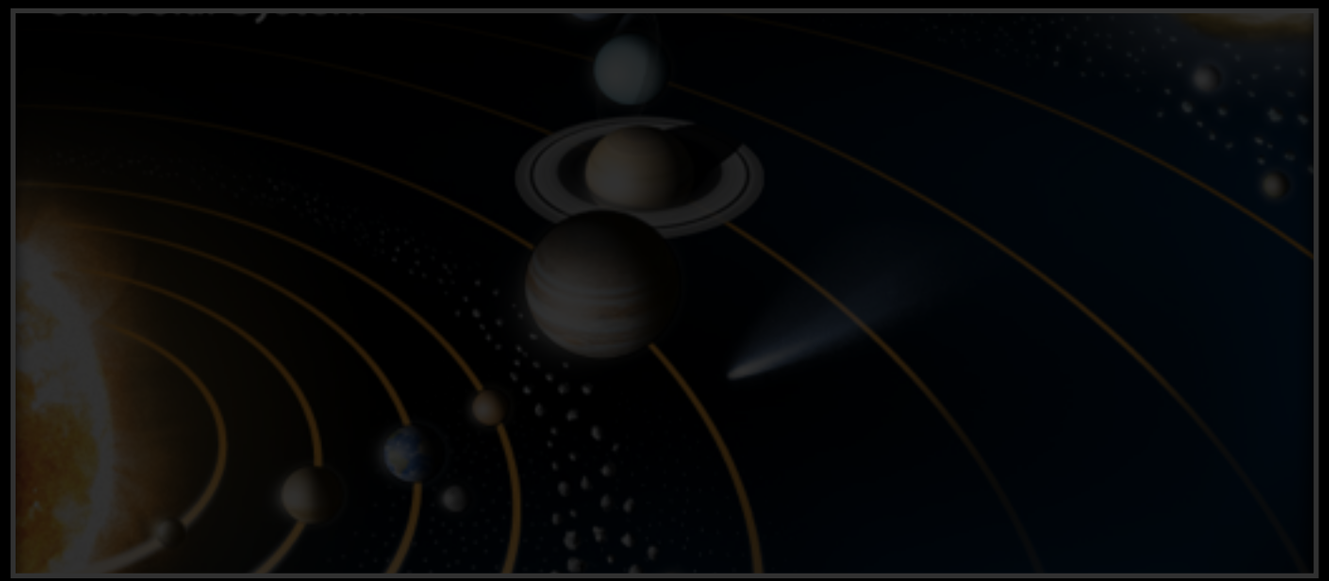
Five planets: Fischer+ 08, dynamics: Nelson+ 14
55 Cnc e: McArthur+ 2004, Dawson & Fabrycky 2010

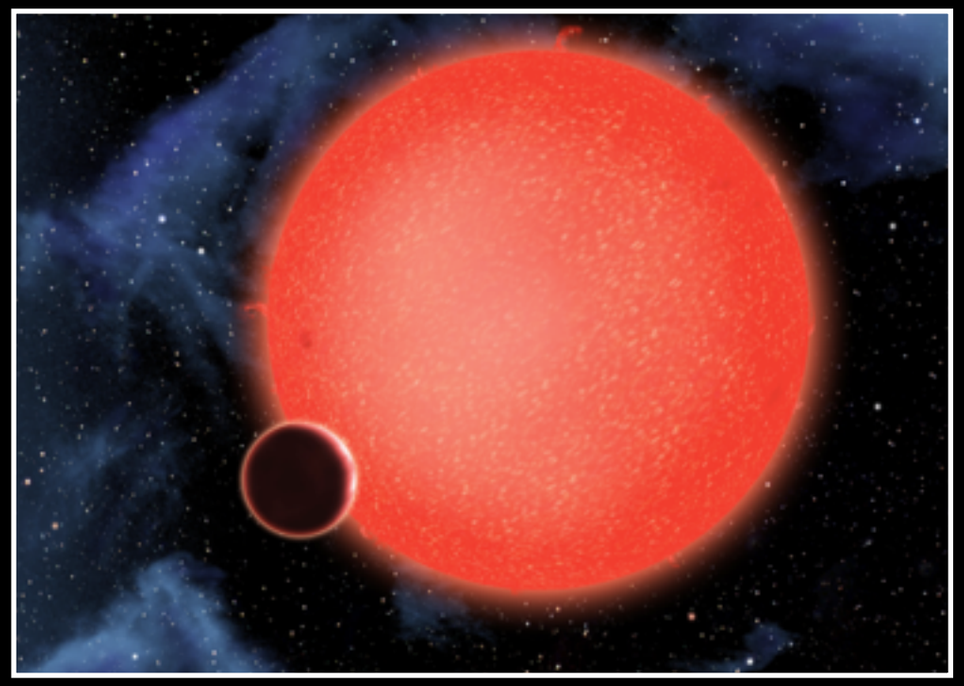
55 Cnc e in context

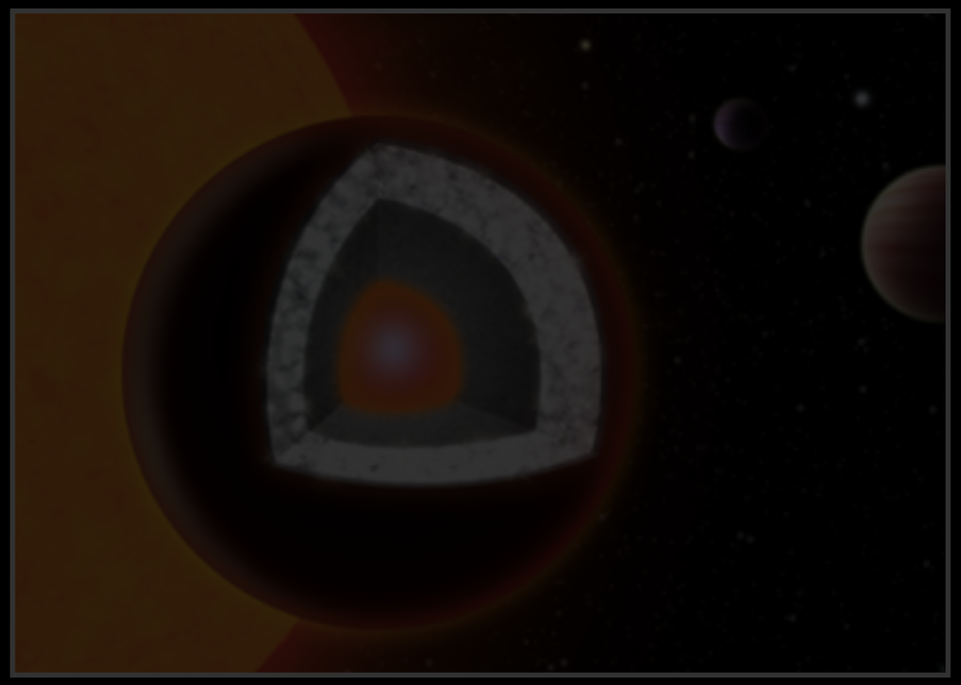


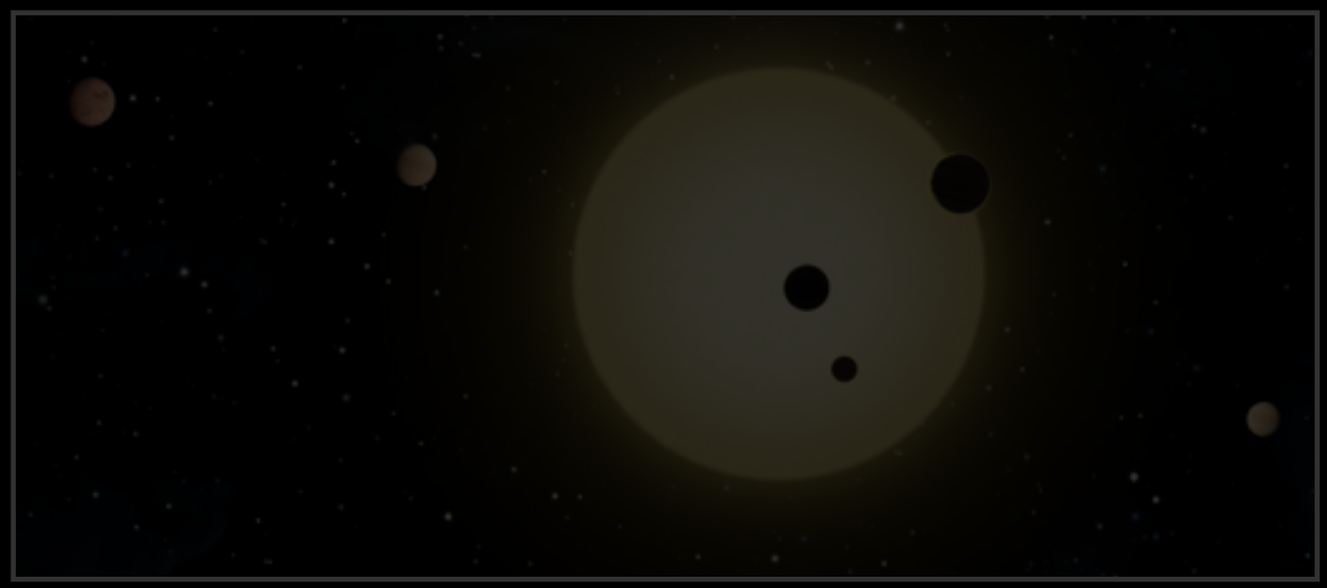
-Warm Jupiters very rare (<1%) and very unlikely to have formed in situ
-Planet e could have been part of migration and have outgassed/steam atmosphere acquired abroad
-See also GJ 876, Kepler-9, even Kepler-30

Exceptional Planets

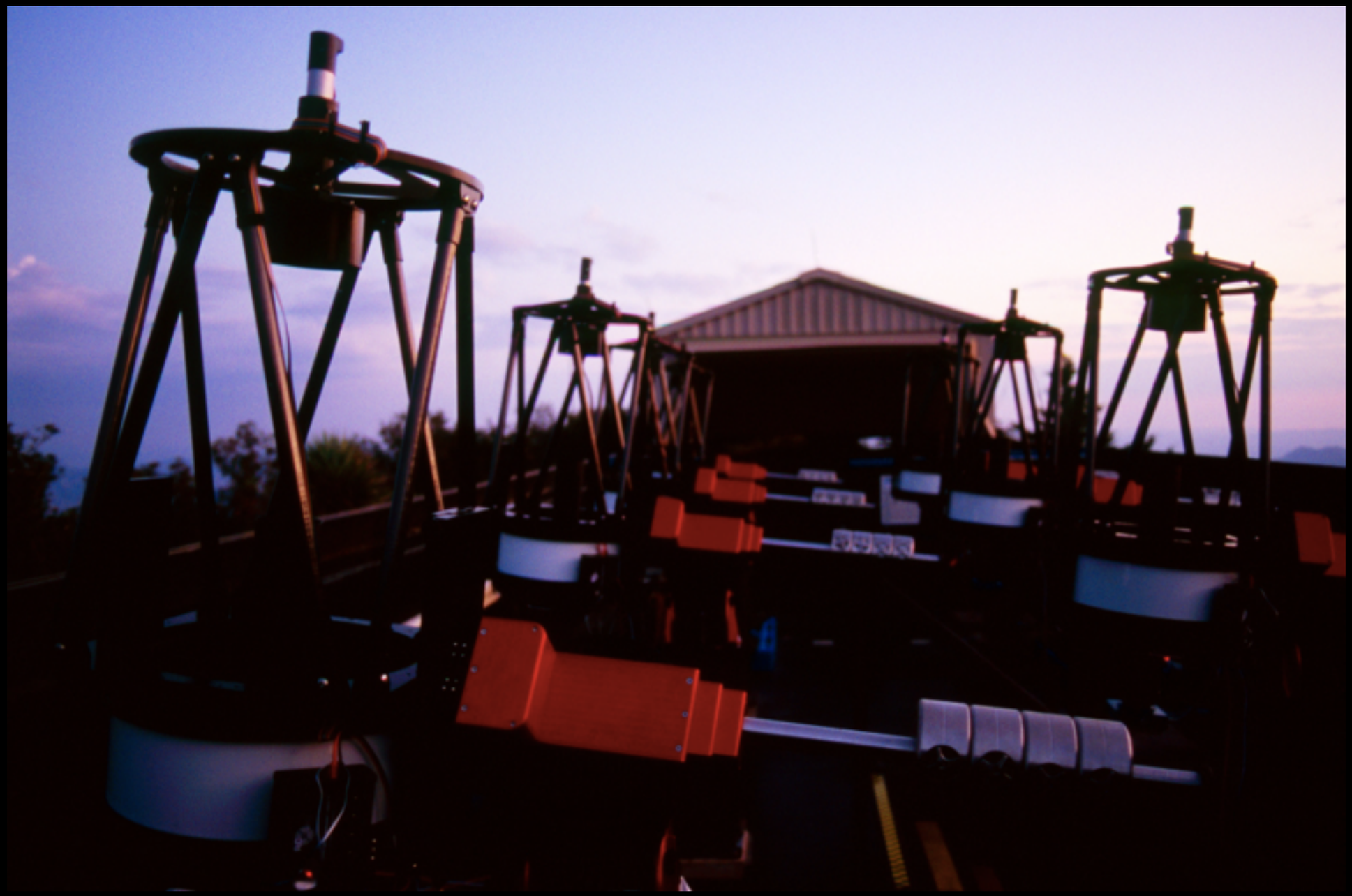








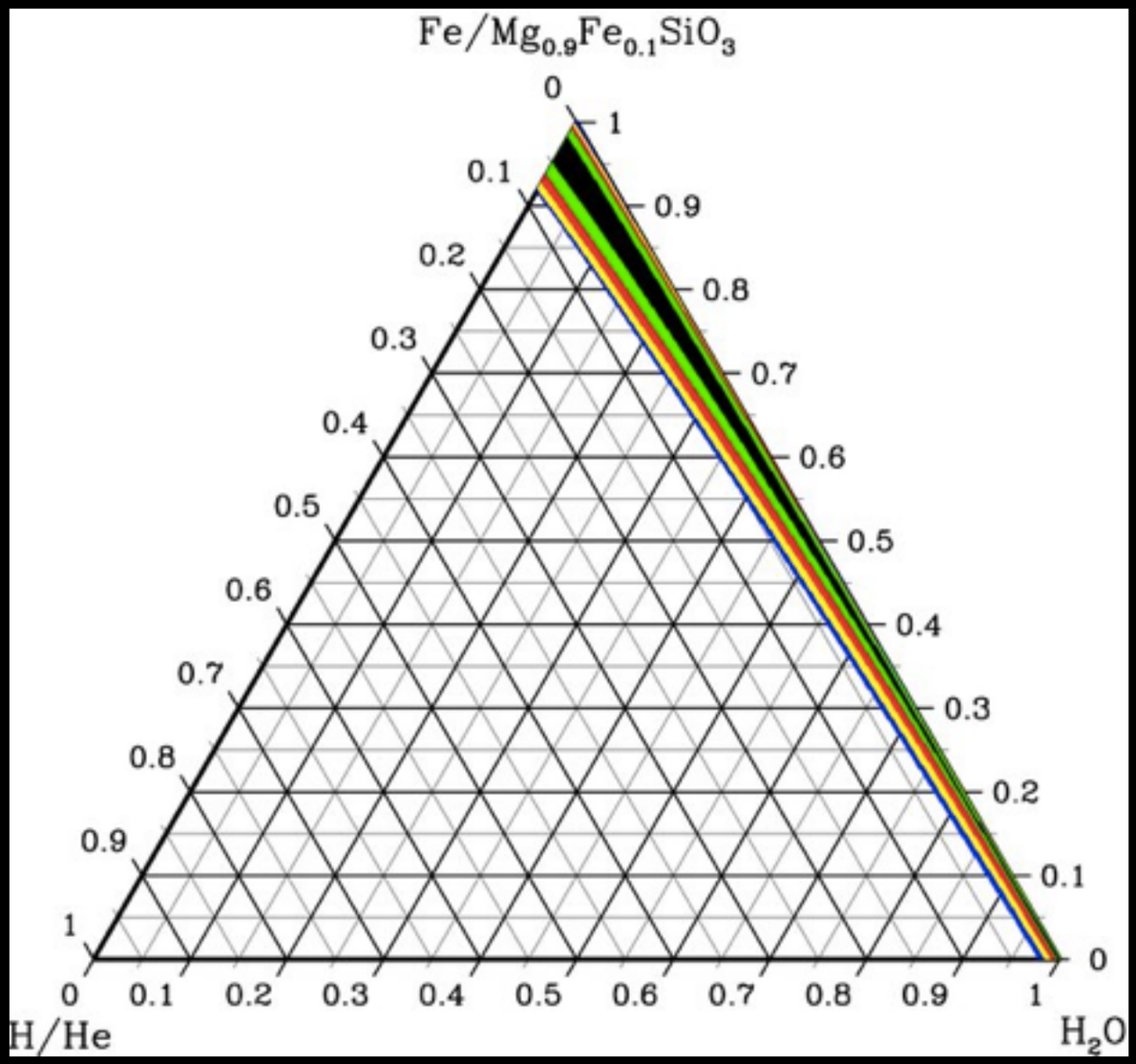
GJ 1214b

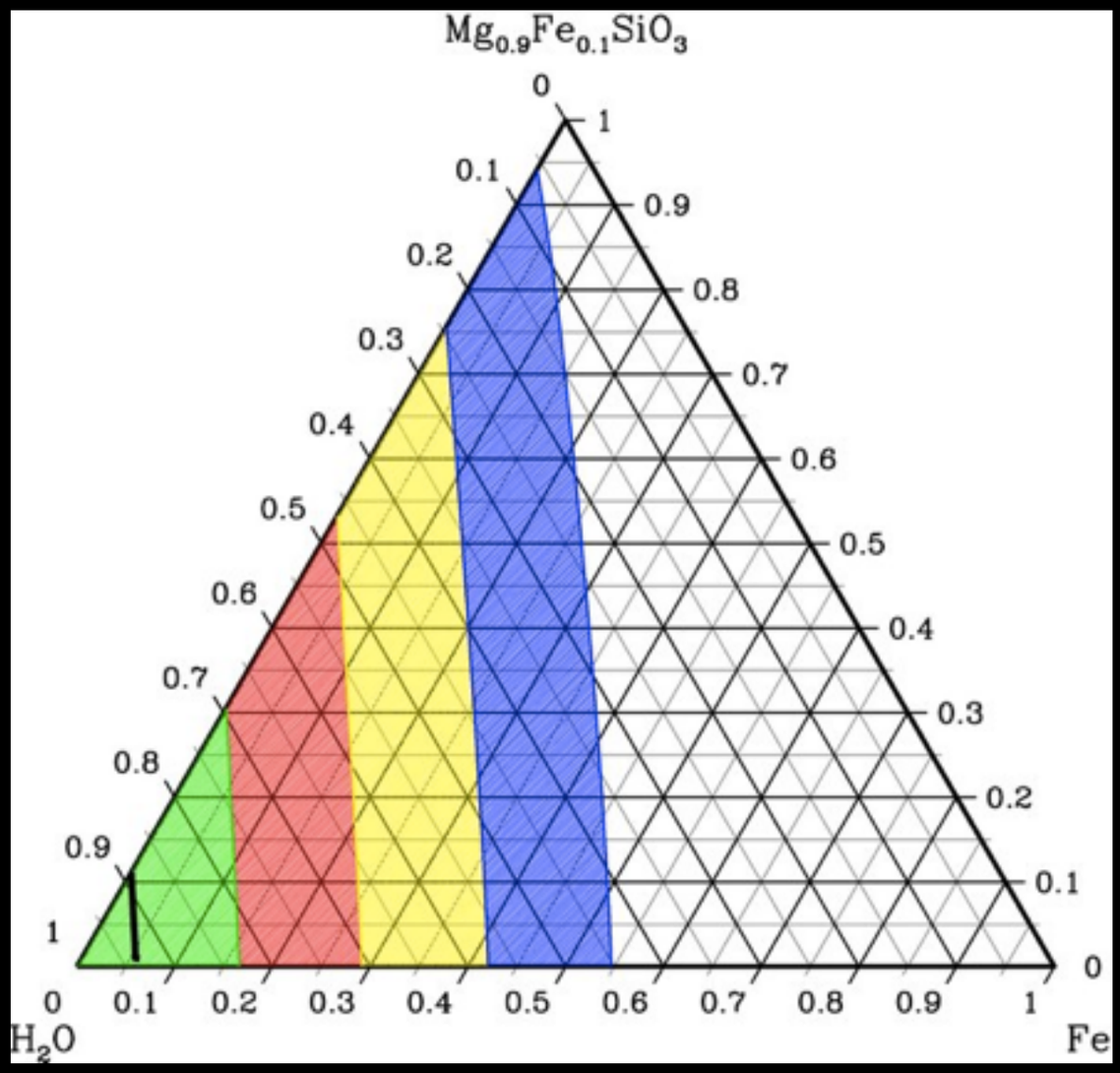


discovered by ground-based MEarth telescopes,
Charbonneau+ 2009

GJ 1214b: compositional ambiguity

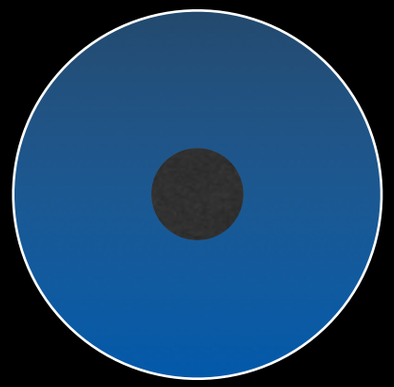
2.7 Earth radii, 6 Earth masses

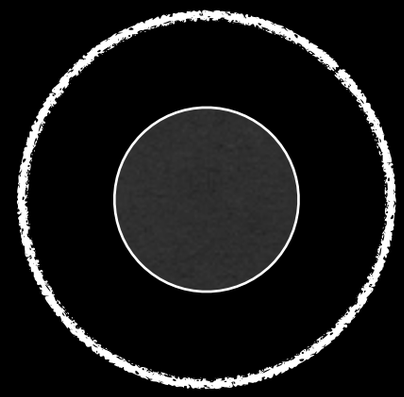


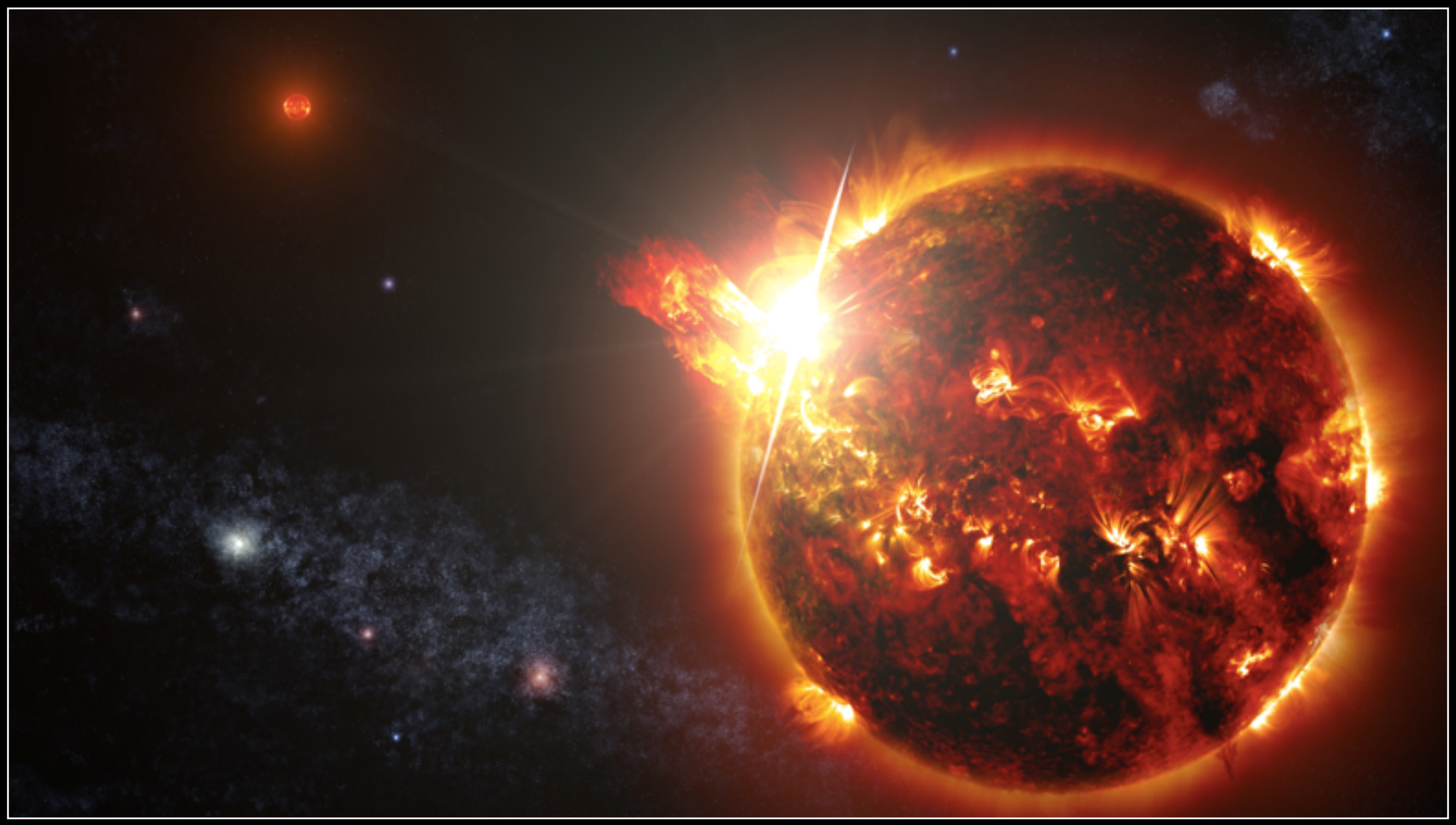


Two of three possible compositions, Rogers & Seager 2010

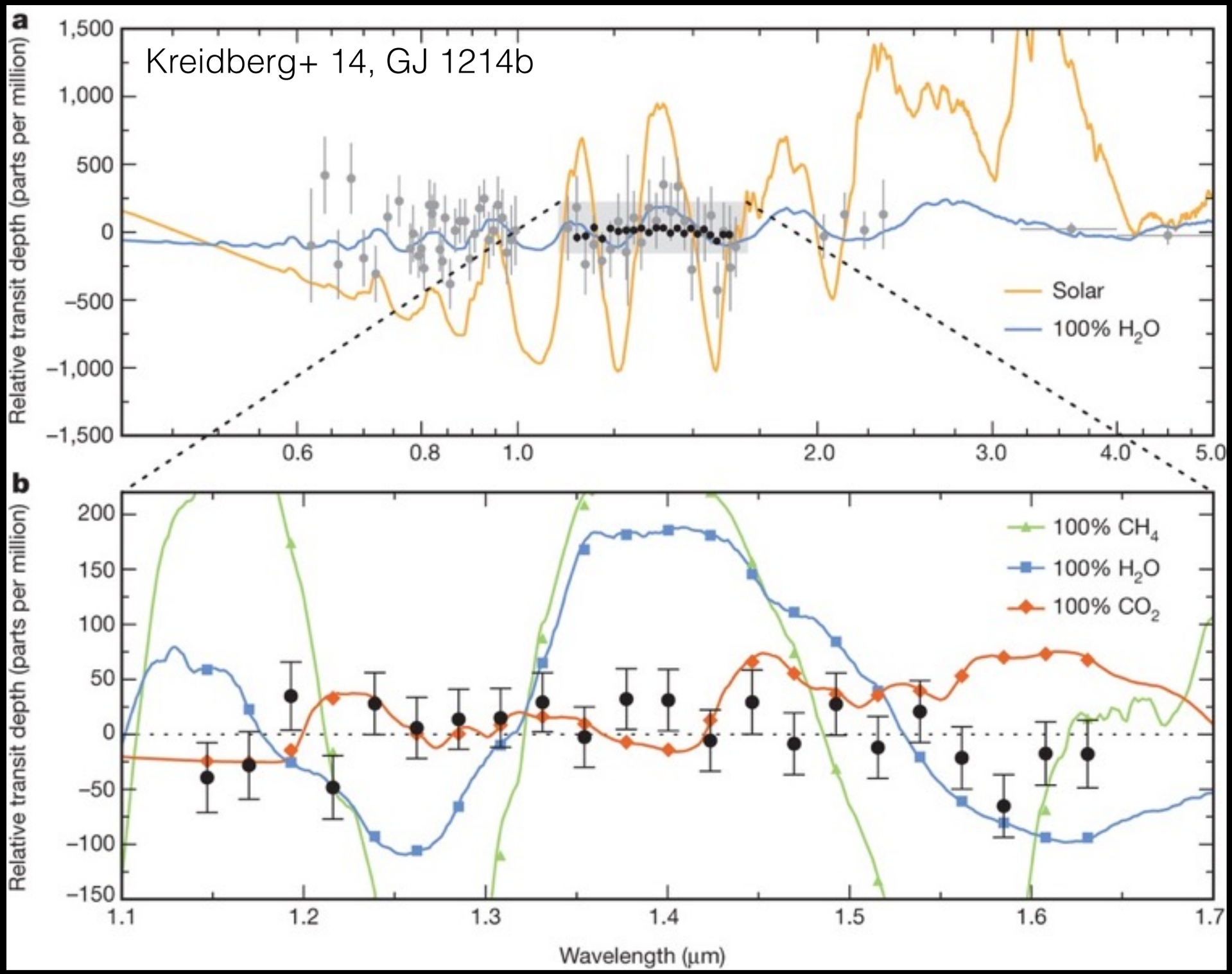
Let's do an experiment







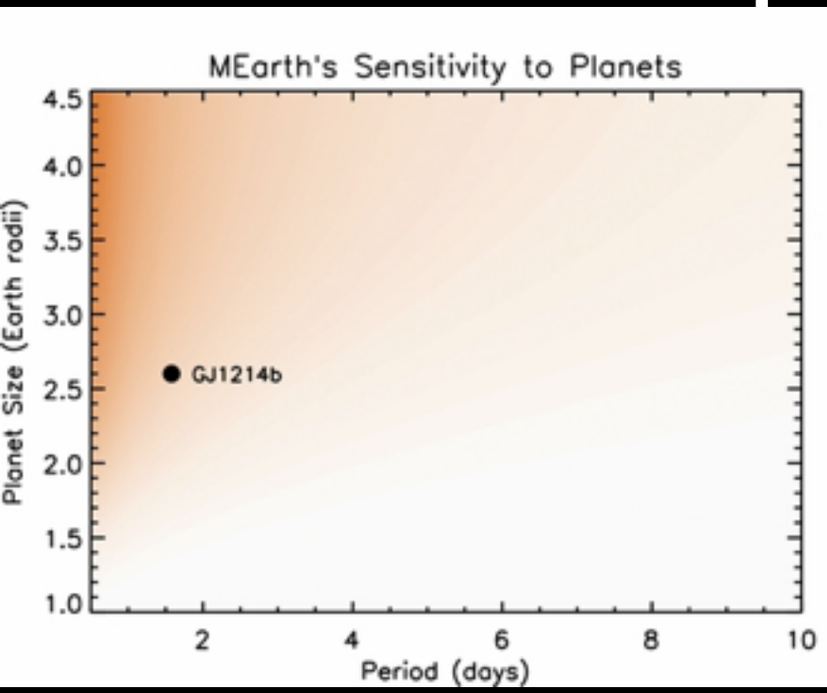
Spectrum unable to distinguish due to hazes

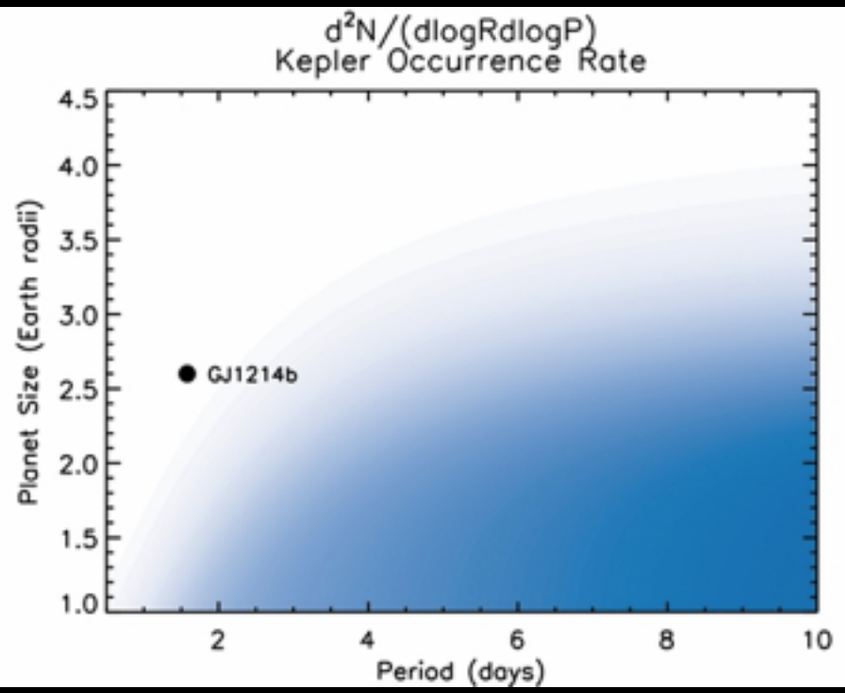


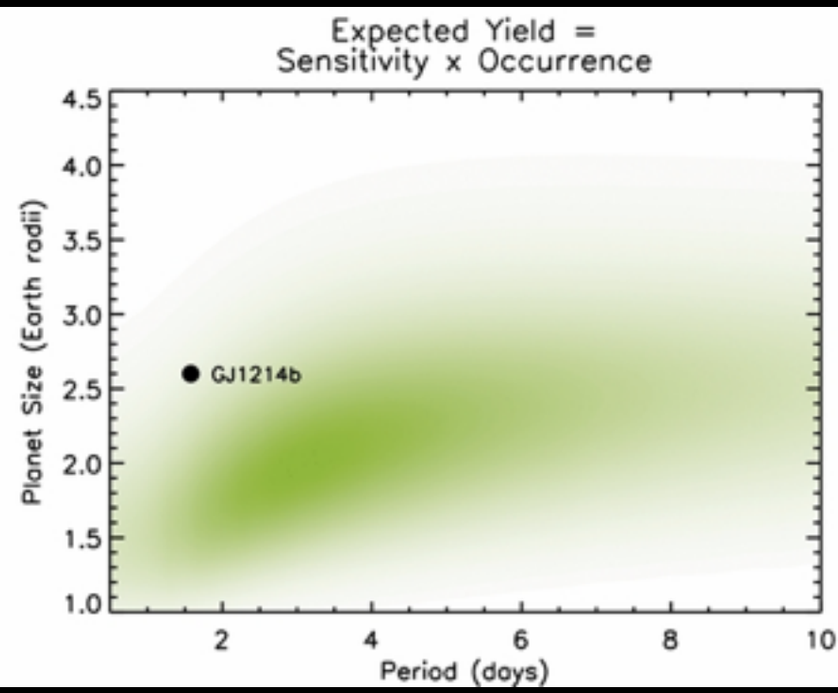
transit depth (ppm)

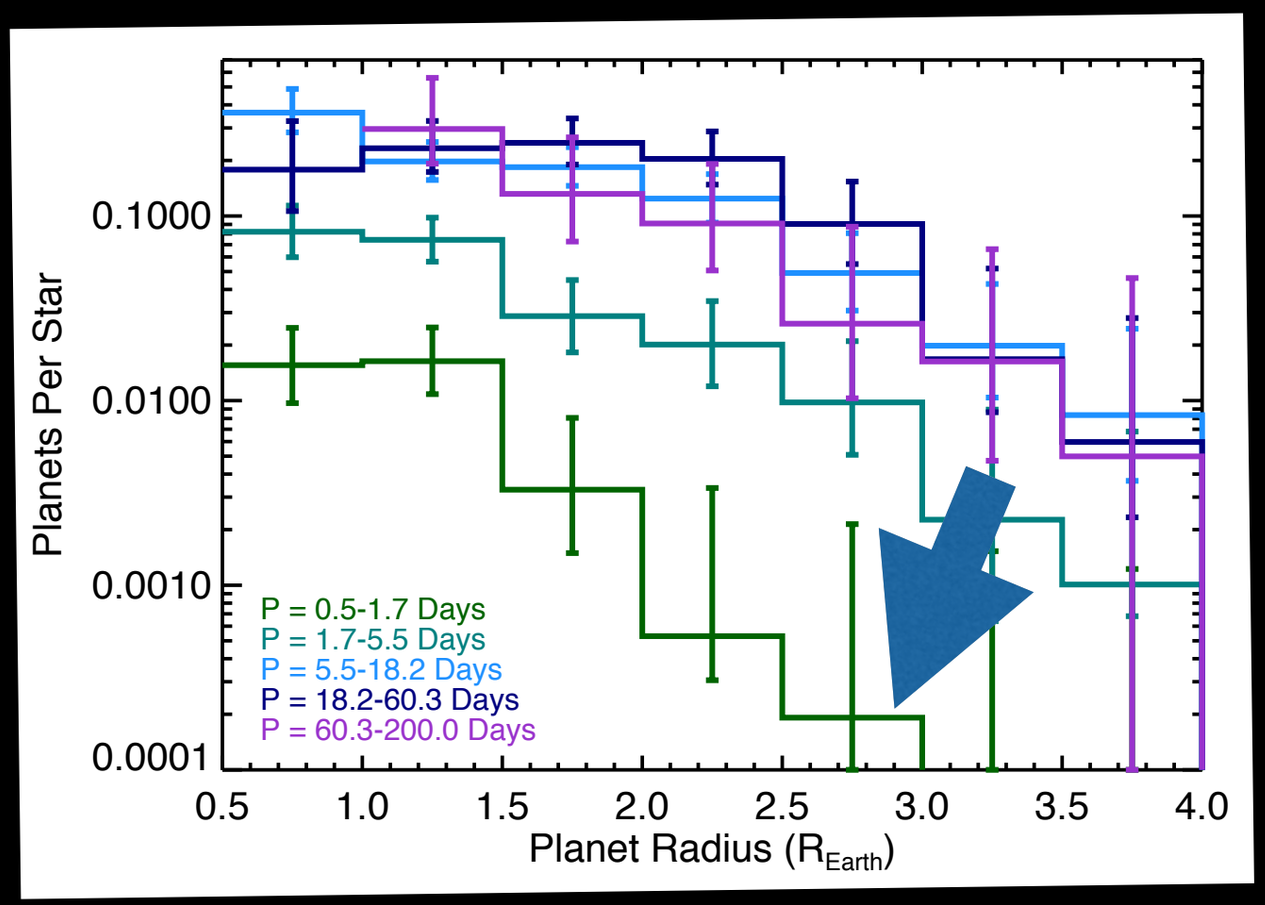
wavelength (micrometer)

Exceptional GJ 1214b





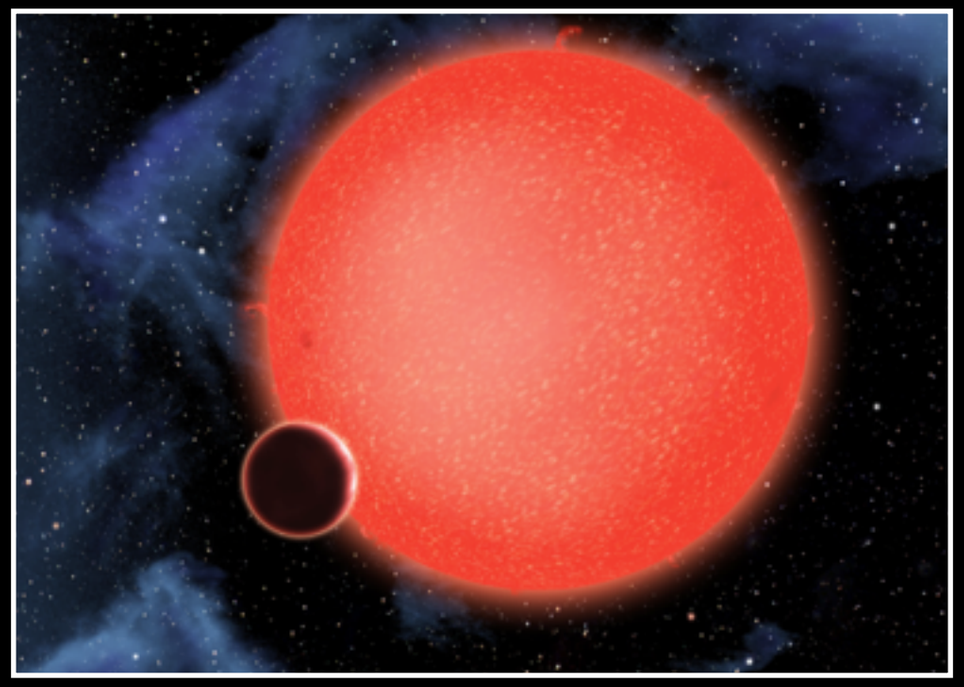




Berta+ 13

Dressing & Charbonneau 15

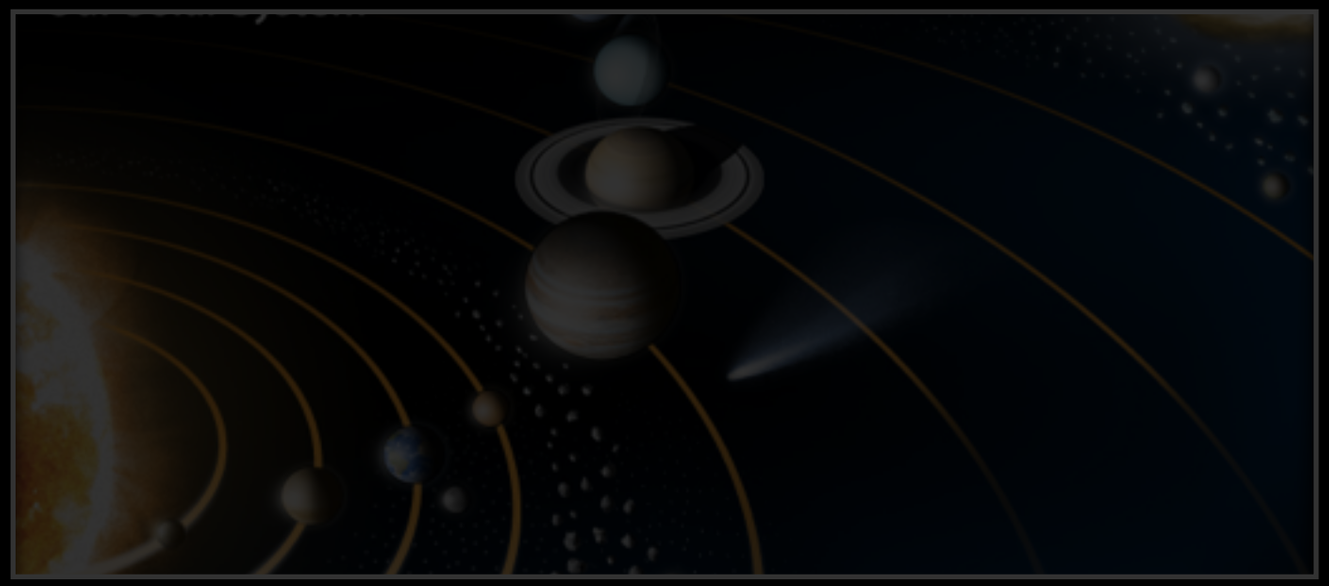
GJ 1214b is an usual object

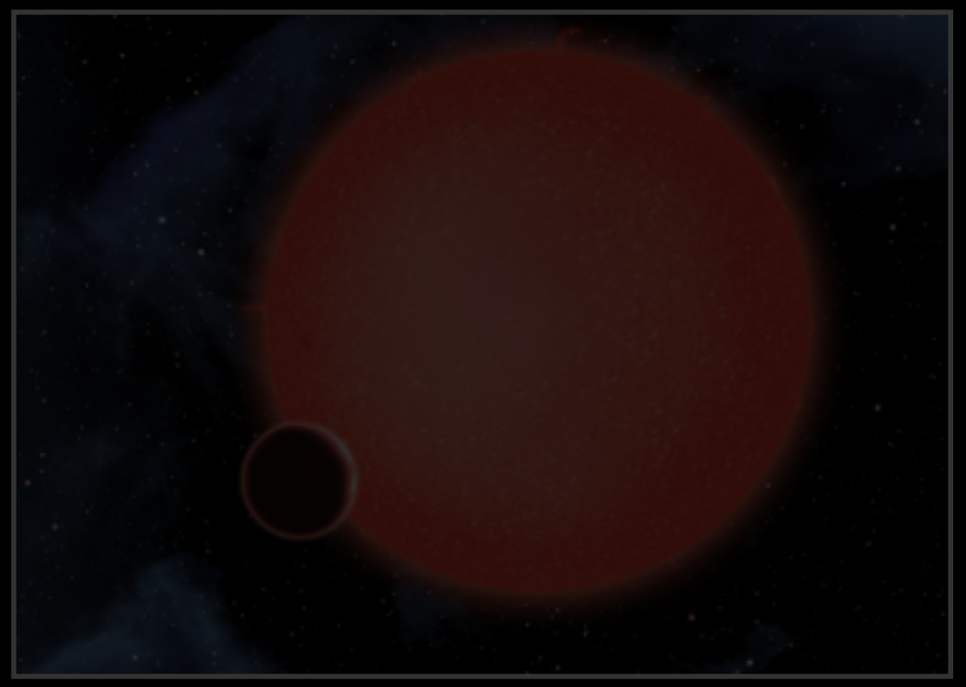


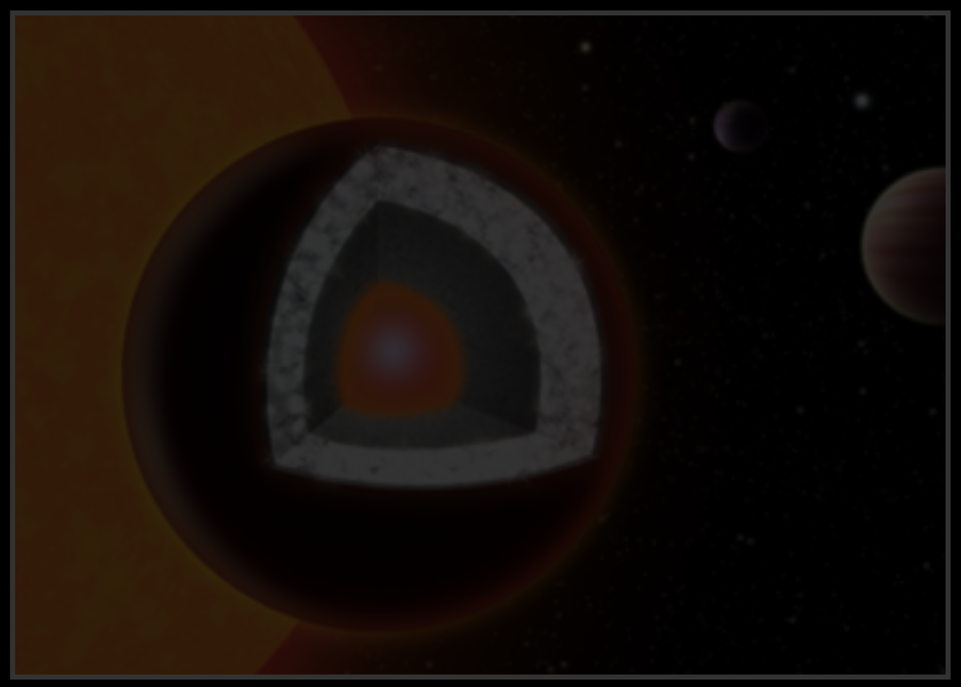
And we should bear in mind that will often be true of objects we can study best

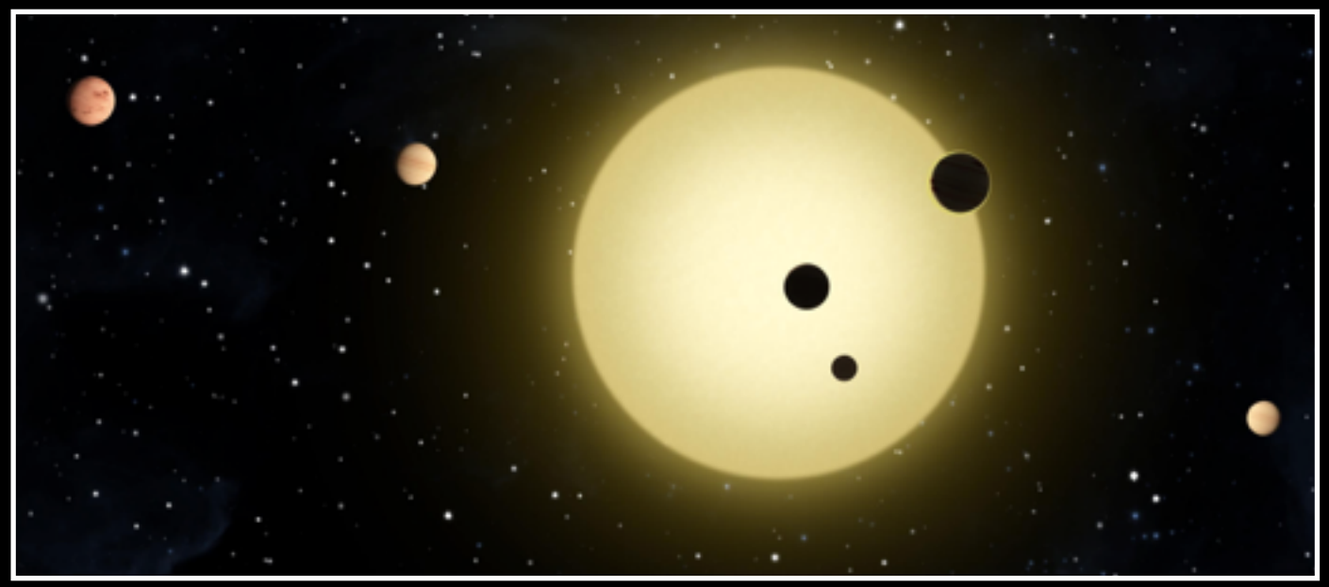
Are its composition and photochemistry typical?
e.g. haze conditions, Morley et al. 2013

Exceptional Planets

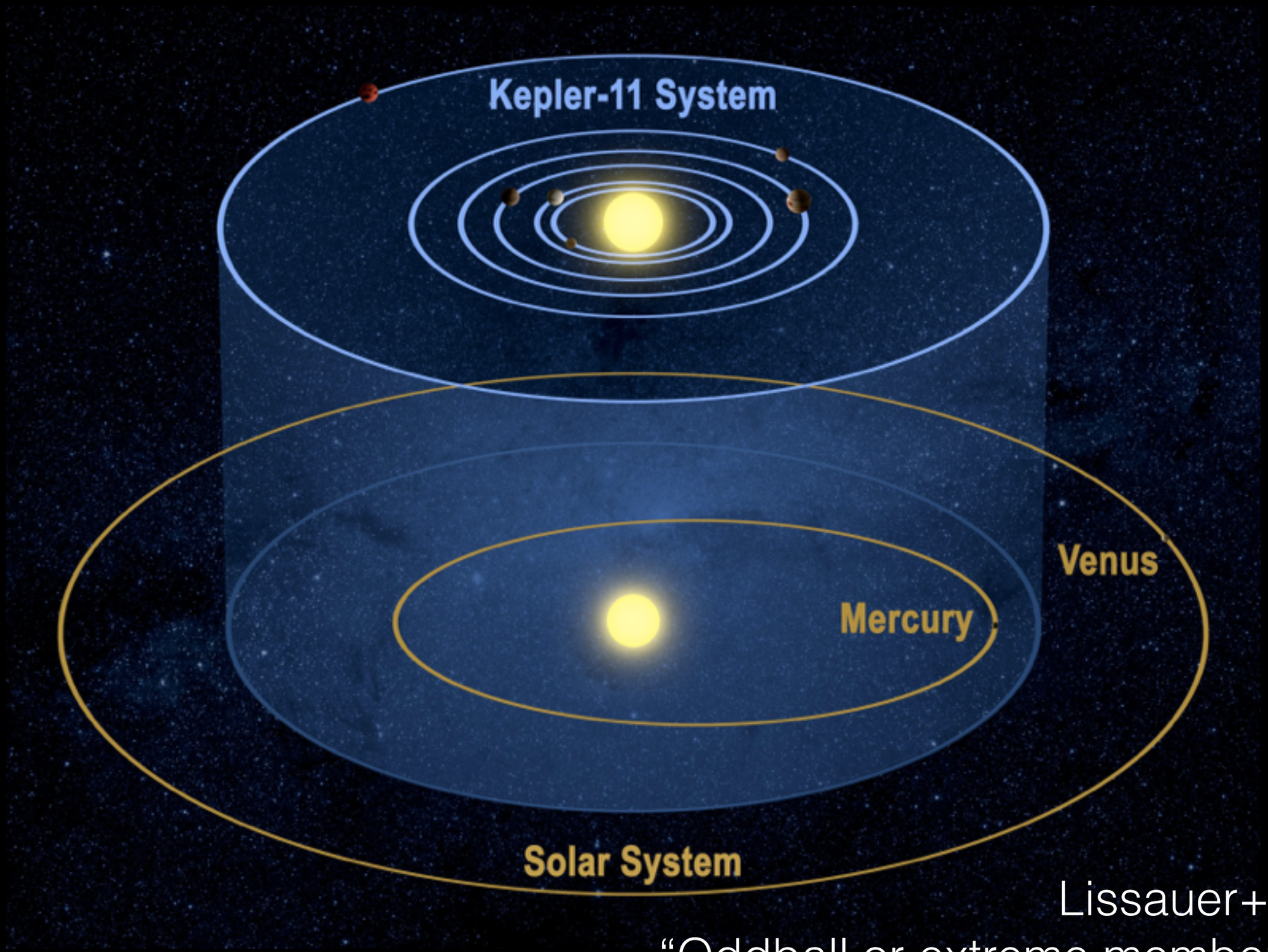








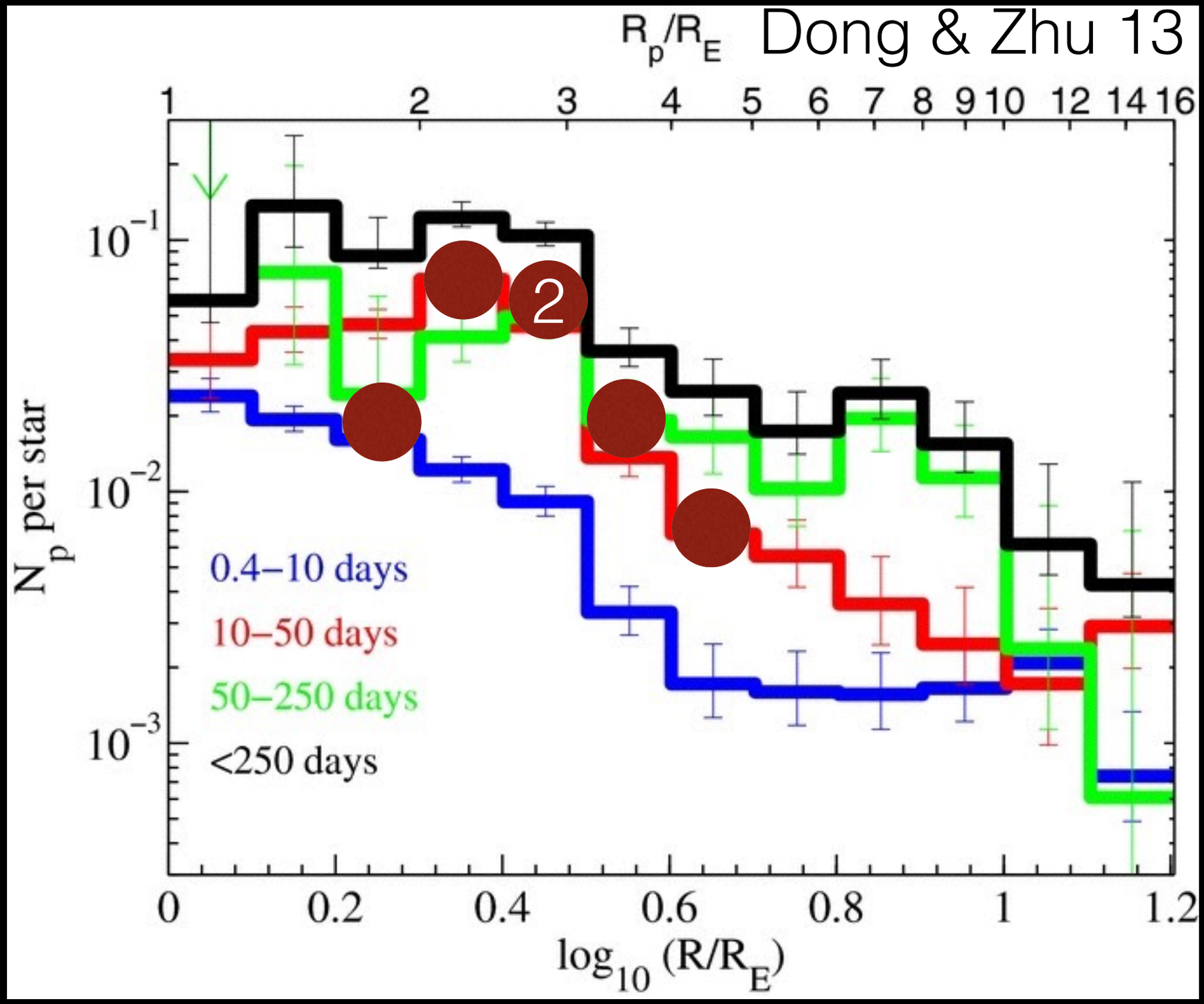
Kepler-11: a prototype?



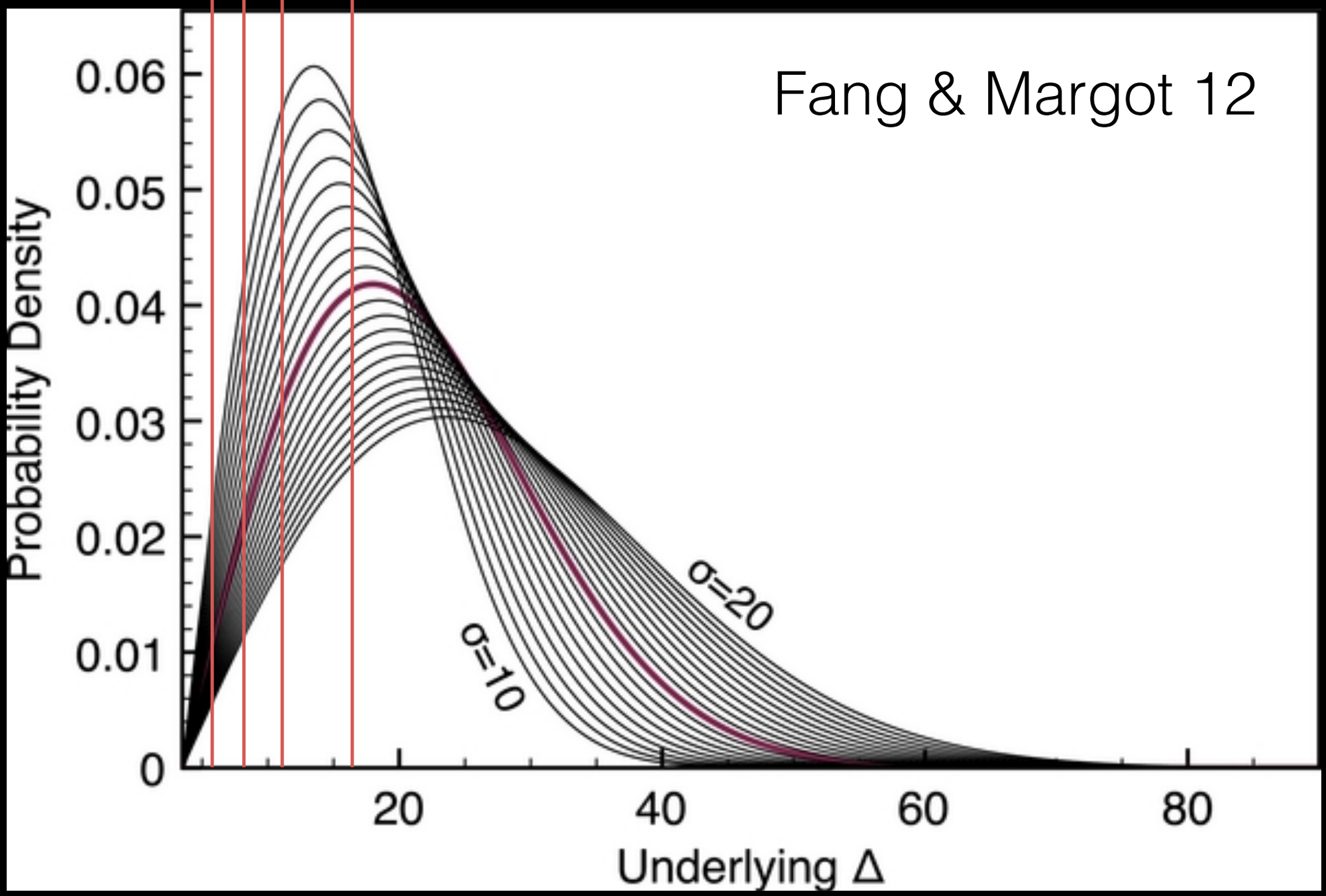
Lissauer+11

"Oddball or extreme member?"

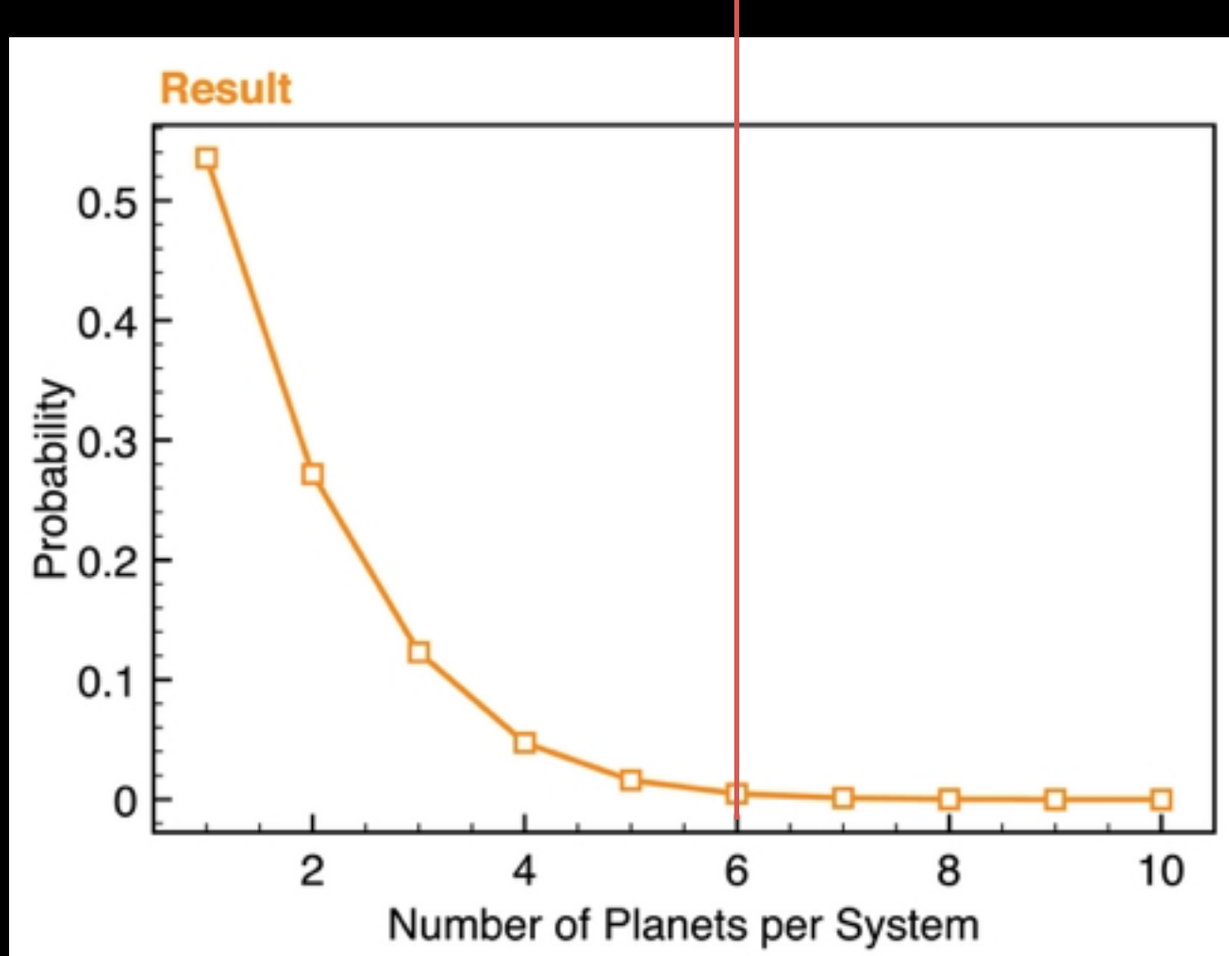
Kepler-11 in context

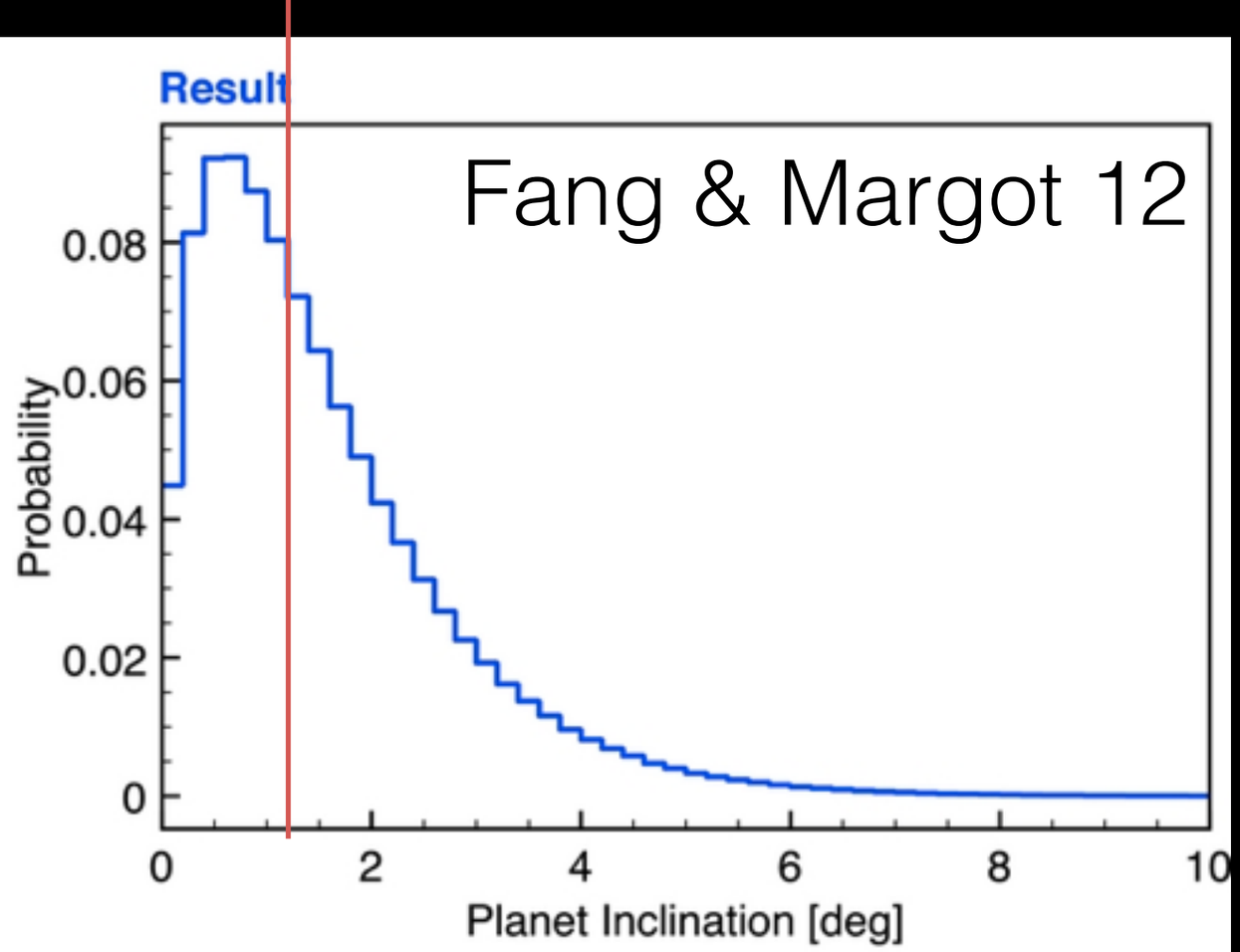


Kepler 11 in context: close spacing



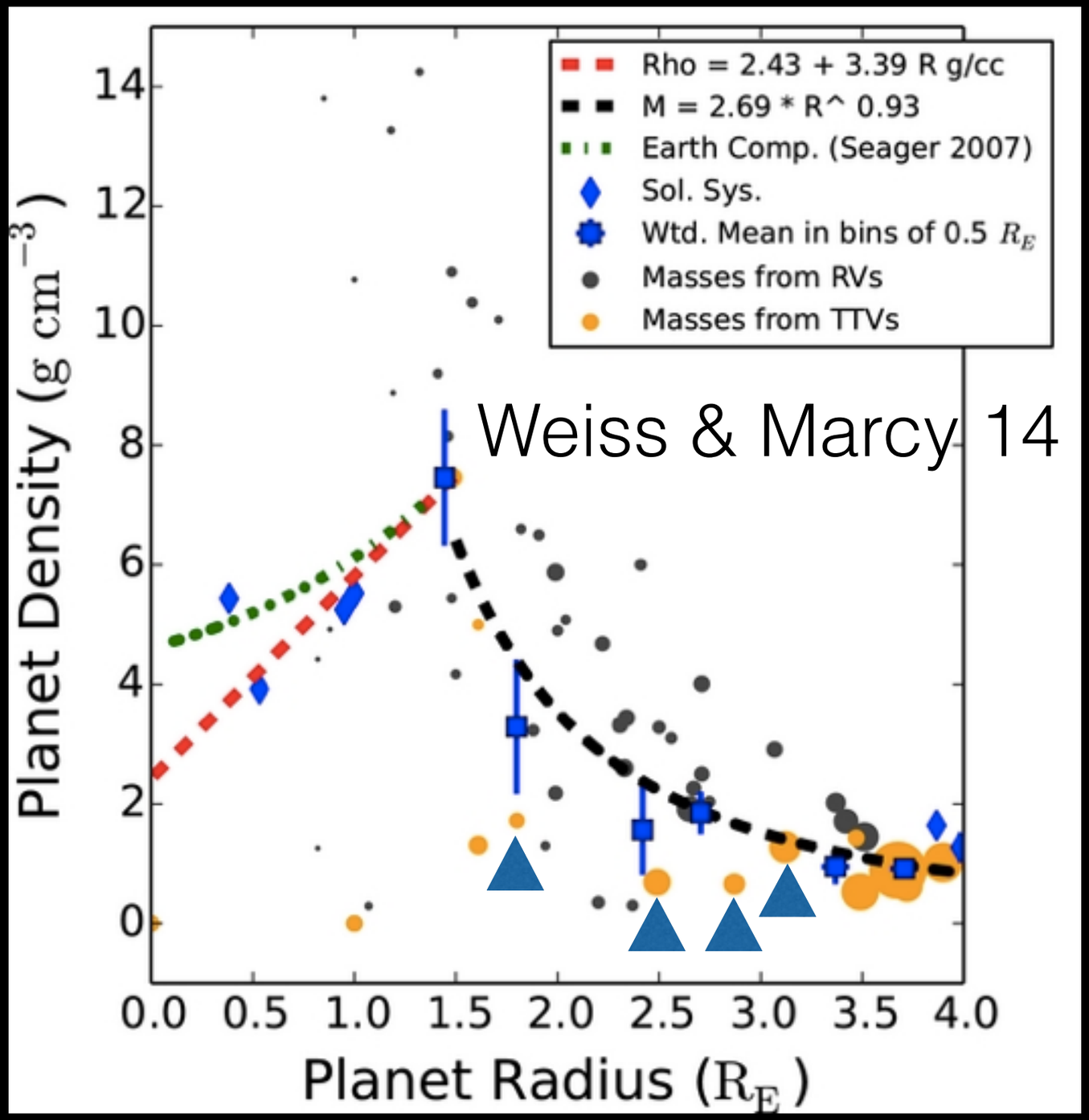
Kepler 11 in context: high multiplicity (P<200, Rp>1.5), typical mutual inclinations





Fang & Margot 12

Kepler-11 in context: low densities



Kepler-11: links between dynamics and compositions may be selection effects

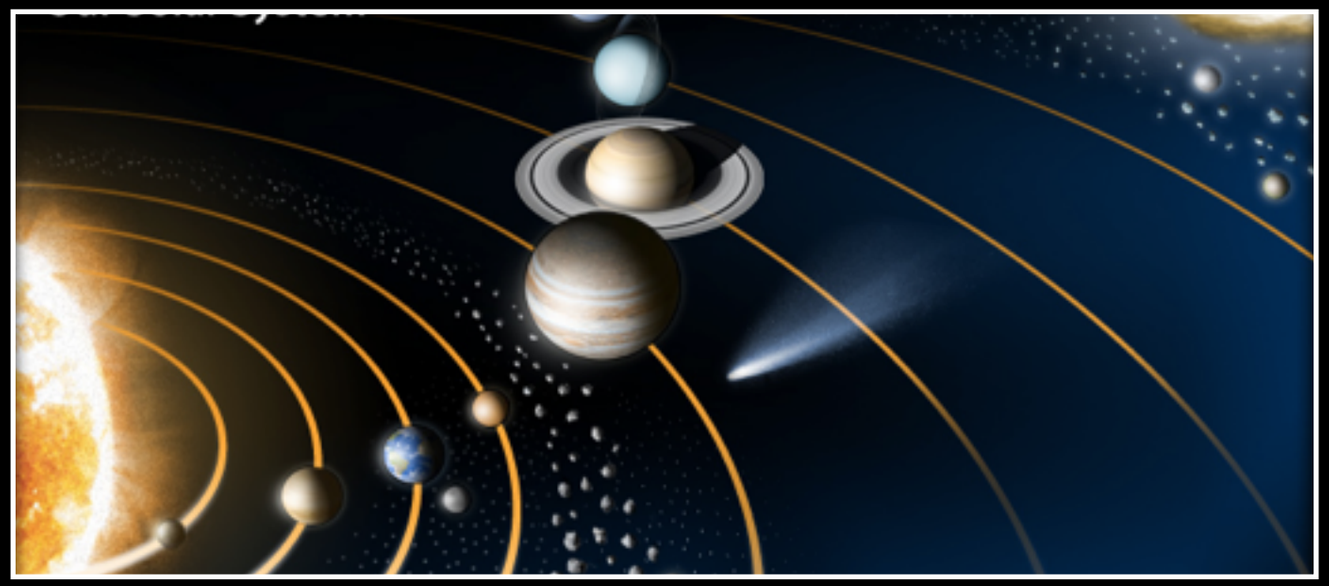
- Large radii and close spacings go hand in hand for large TTVs (allowing for density measurement)

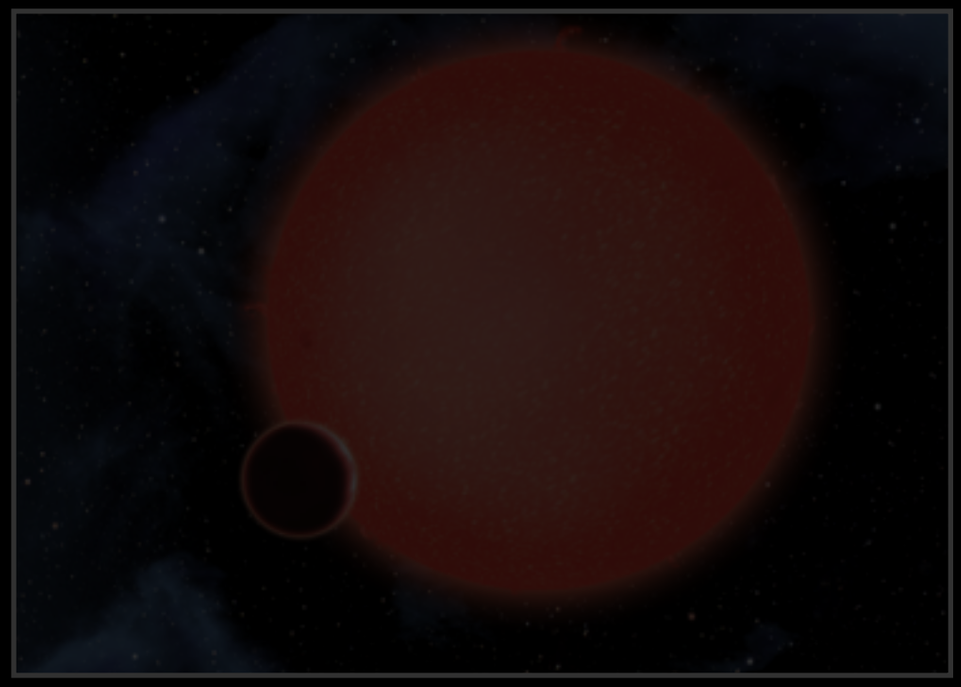
- Low densities optimize tight packing + detection (allowing our complete sample to expand to fainter/noisier stars), i.e. a system packed like Kepler-11 but with small radii would be detectable around fewer stars

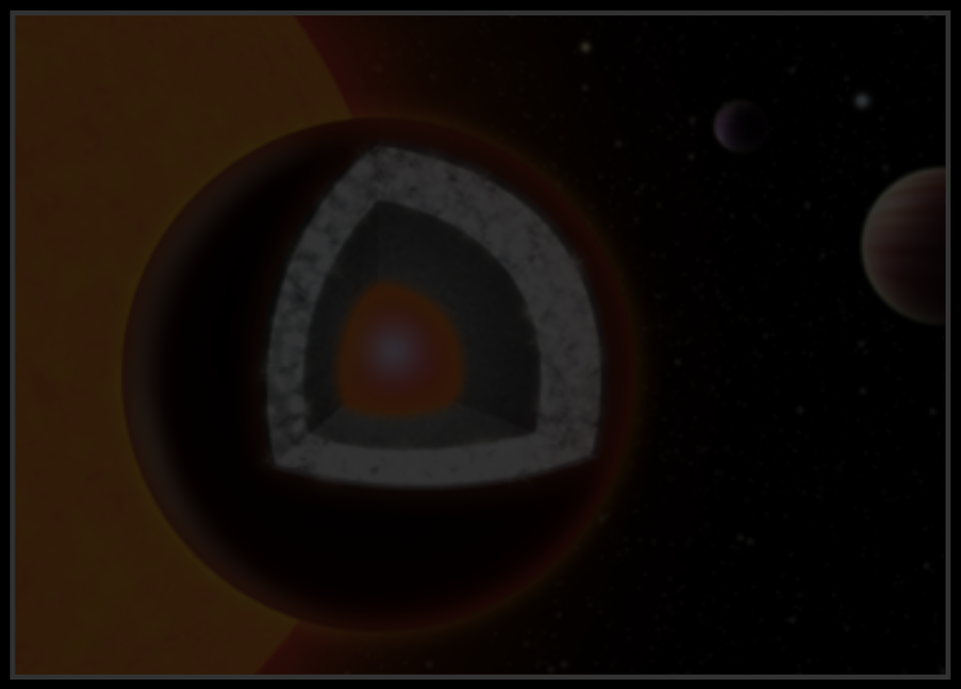
- Peculiarities all allowed to it be observed as a 6 “tranet" system

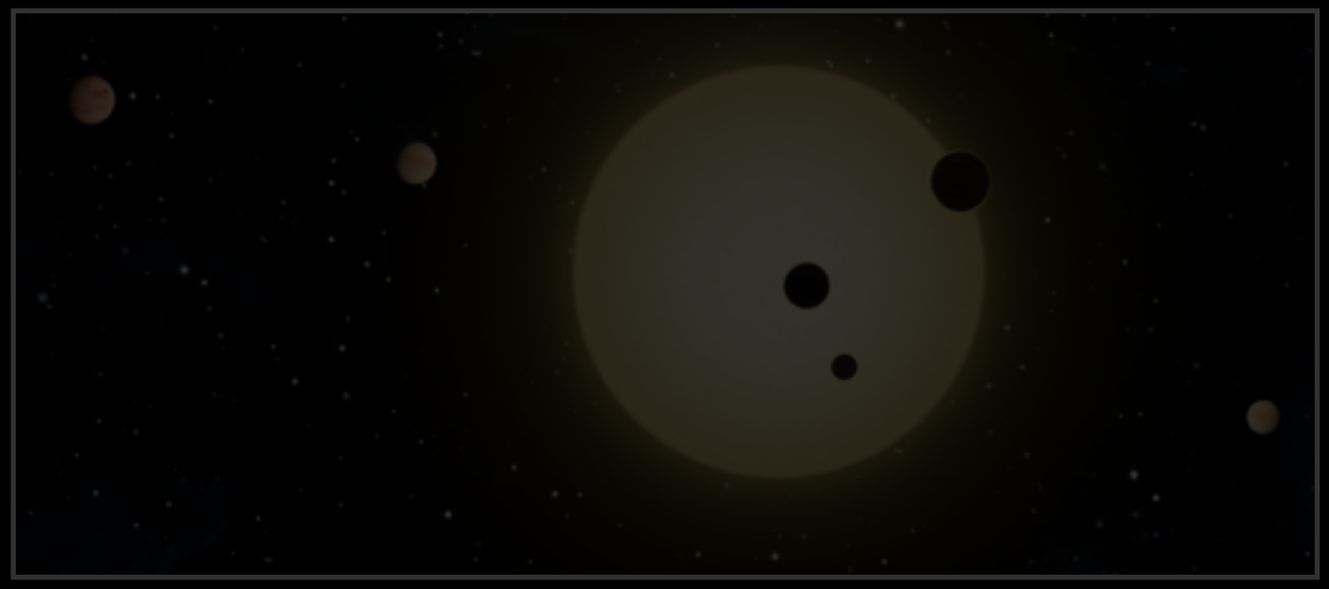
- Therefore may be an “extreme member” rather than “oddball”

Exception Exoplanets

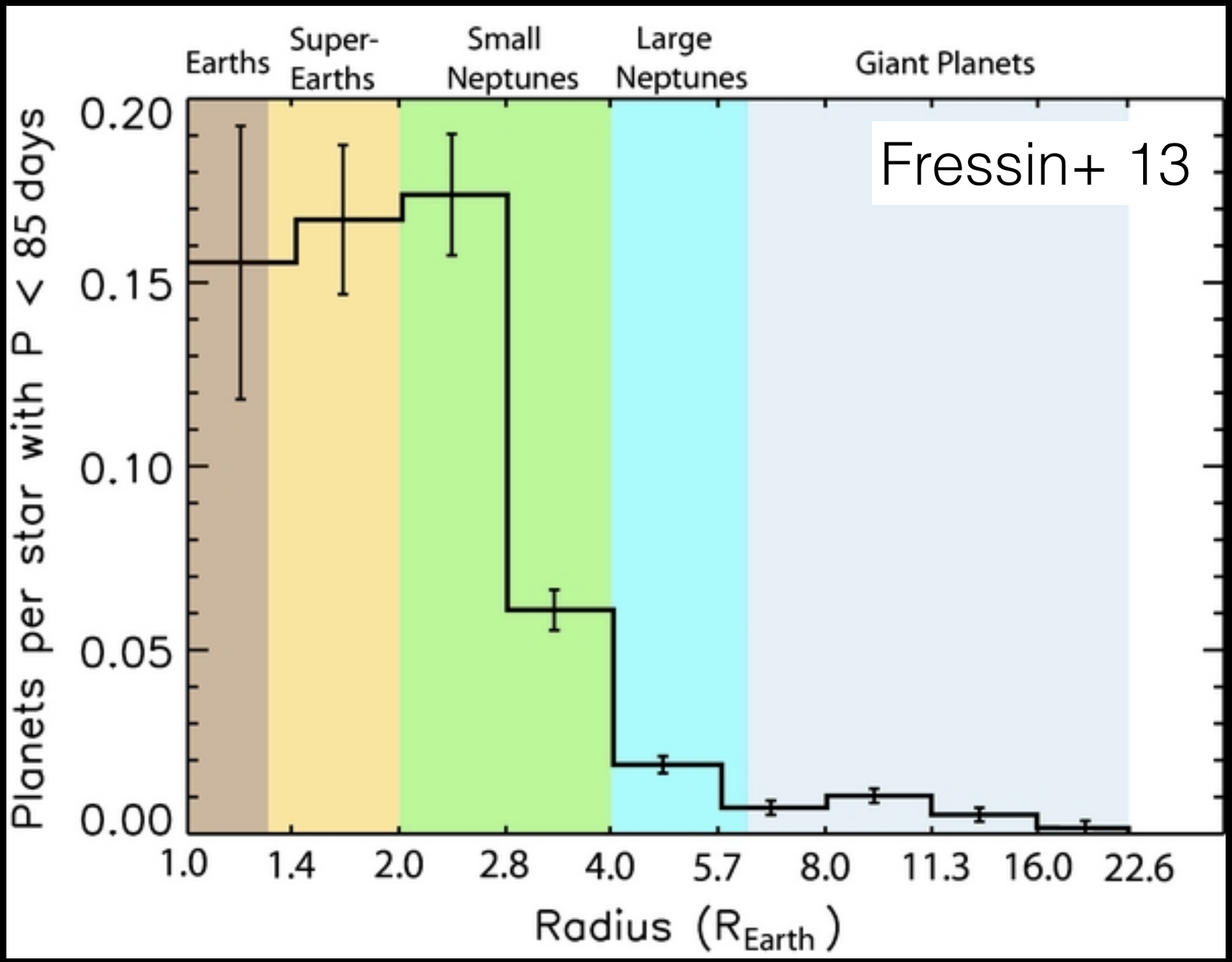








The Solar System is not in the minority for lacking such a planet



Interpretations, Speculations, Conclusions

- Maybe: Most low-density 2-3 Earth radii planets are enveloped by nebular H/He accreted nearly in situ. A minority, incl. 55 Cnc e, formed further out from water rich planetesimals and migrated in; their atmospheres are steam and/or outgassed volatiles; but do not make significant contribution to “plateau”

- GJ 1214 is an unusual object. Its hazes/clouds are a function of its photochemistry. Maybe: typical compositions are less (or more) haze-y (but see also HD 97658 b, Knutson+ 14)

- Compared to typical Kepler systems, the Kepler-11 planets have low densities, high multiplicity, tight spacing, typical flatness; but these are arguably selection effects rather than links reflecting formation/evolution

- The solar system is not in the minority for lacking a typical Kepler planet