Formation clues for close-in exoplanets

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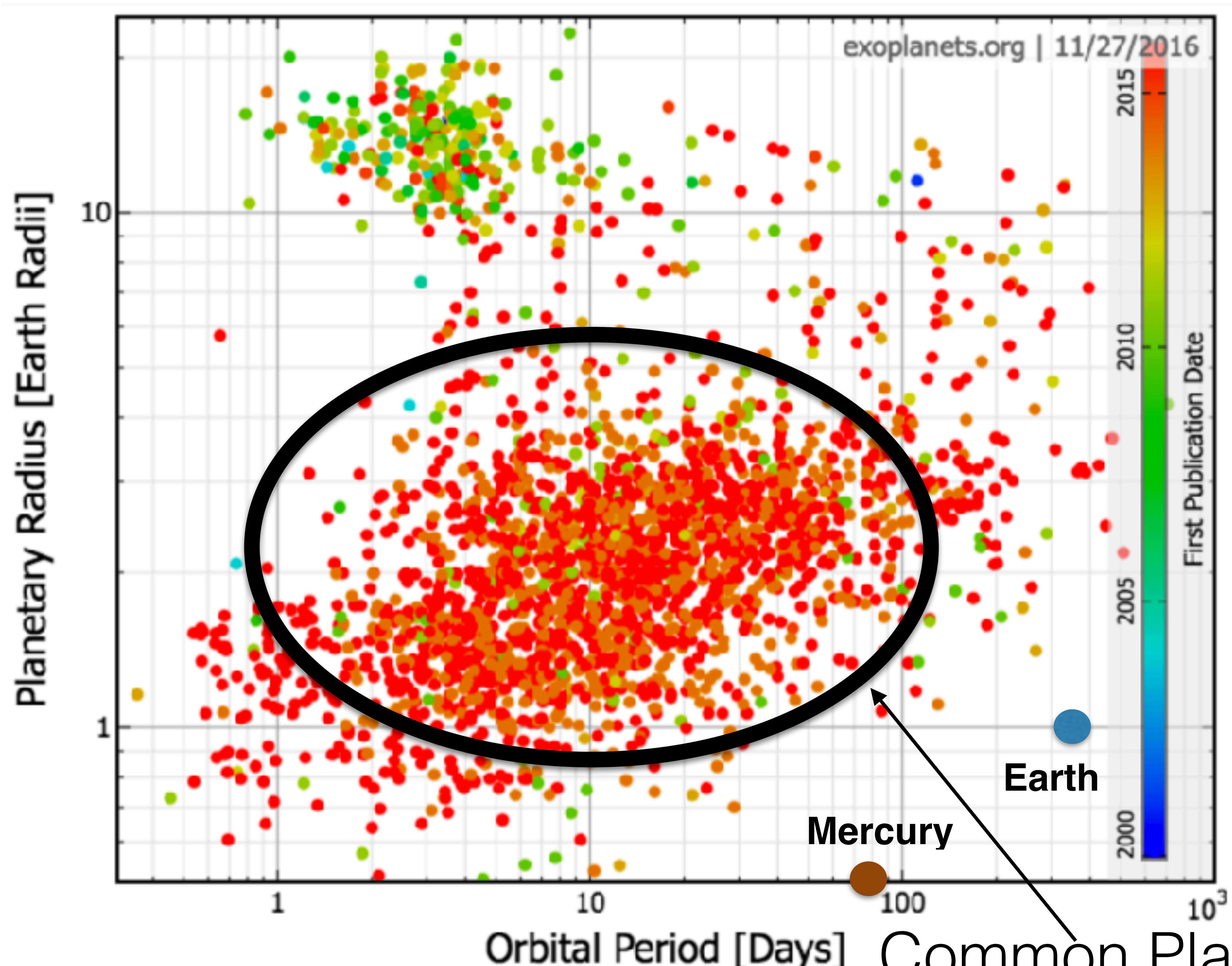
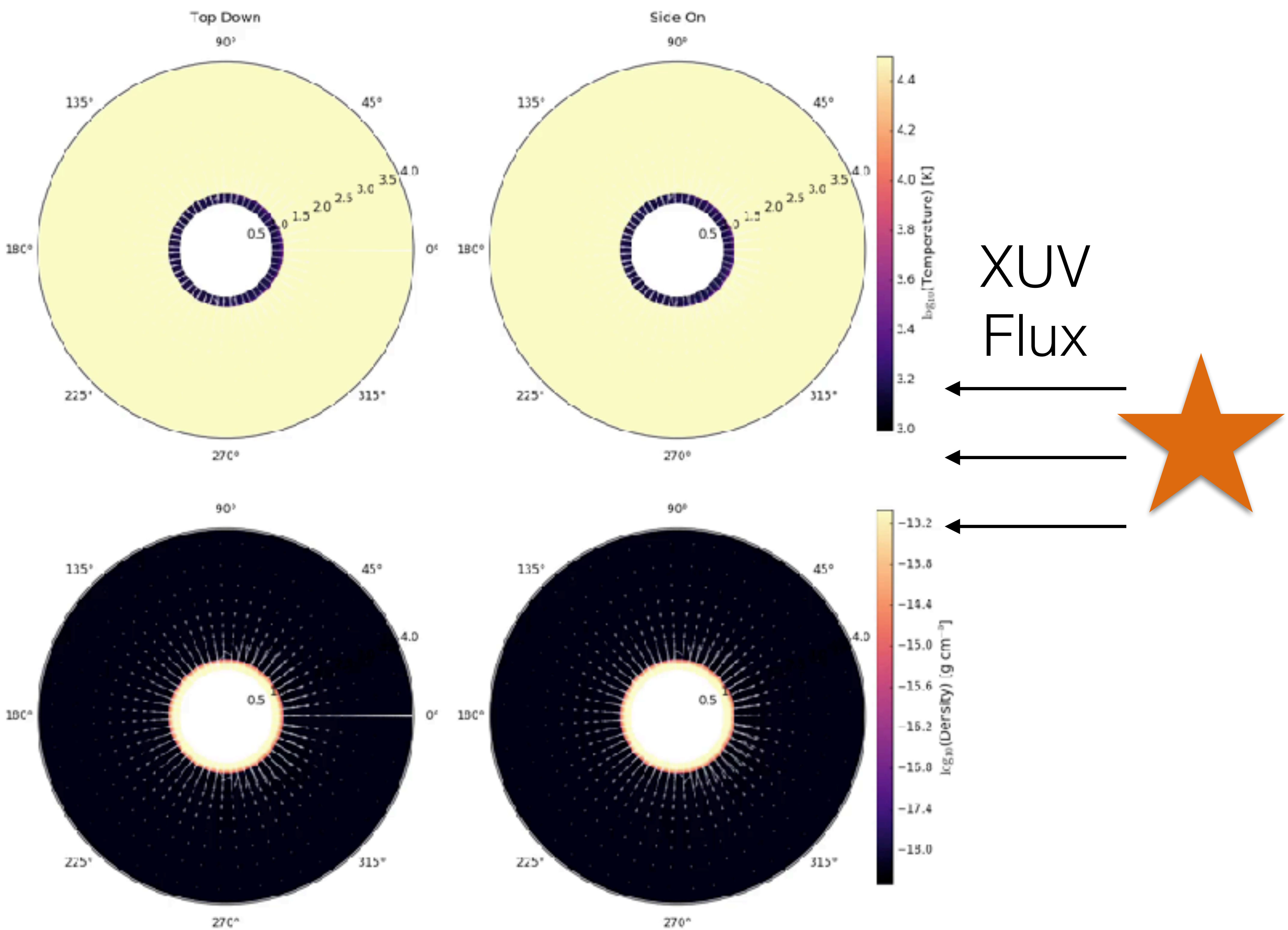
THE ROYAL SOCIETY



Common Planets
>~50% of stars

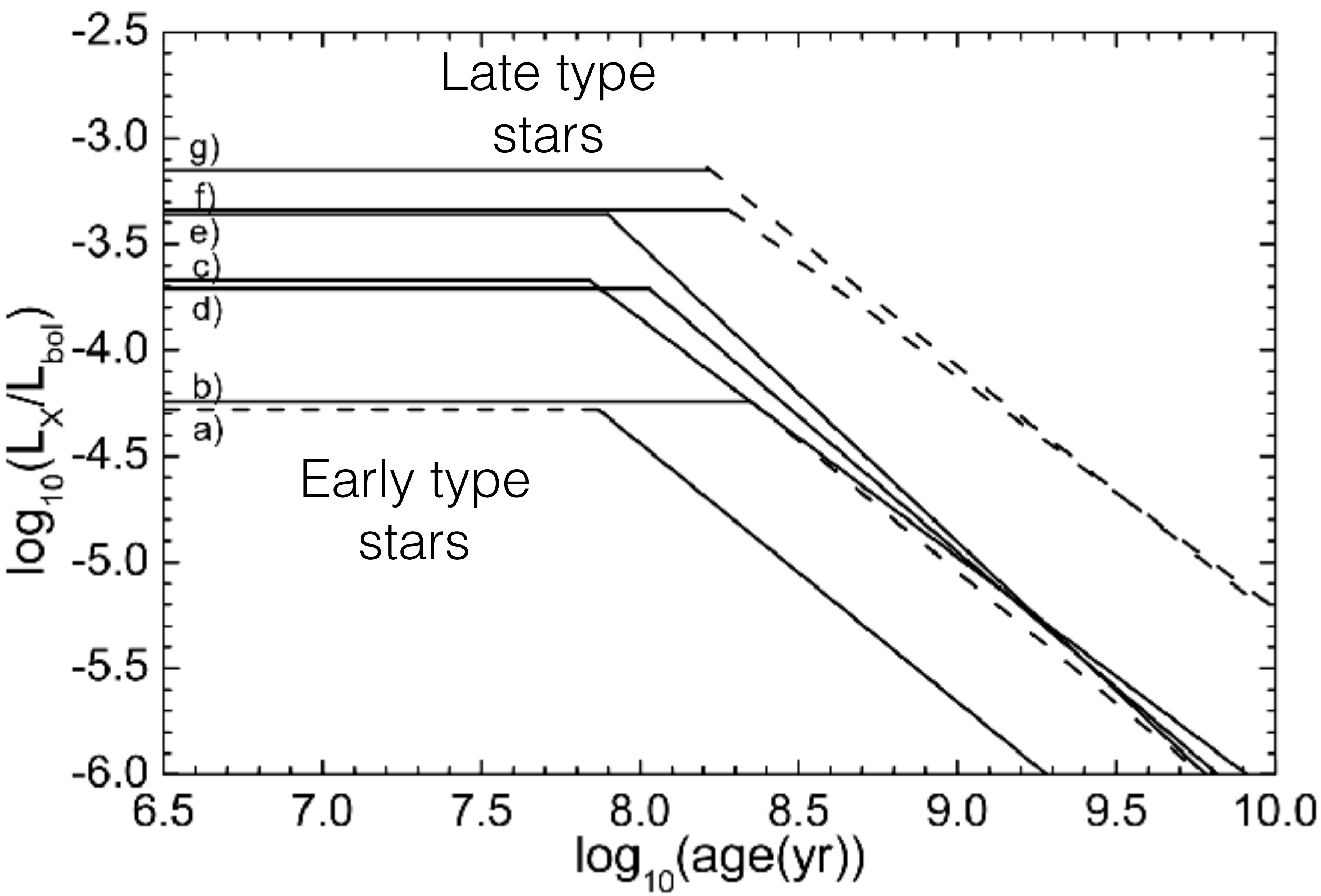
e.g.(Fressin et al. 2013, Petigura et al. 2013
Silburt et al. 2014, Mulders et al. 2016)

Planet photoevaporation

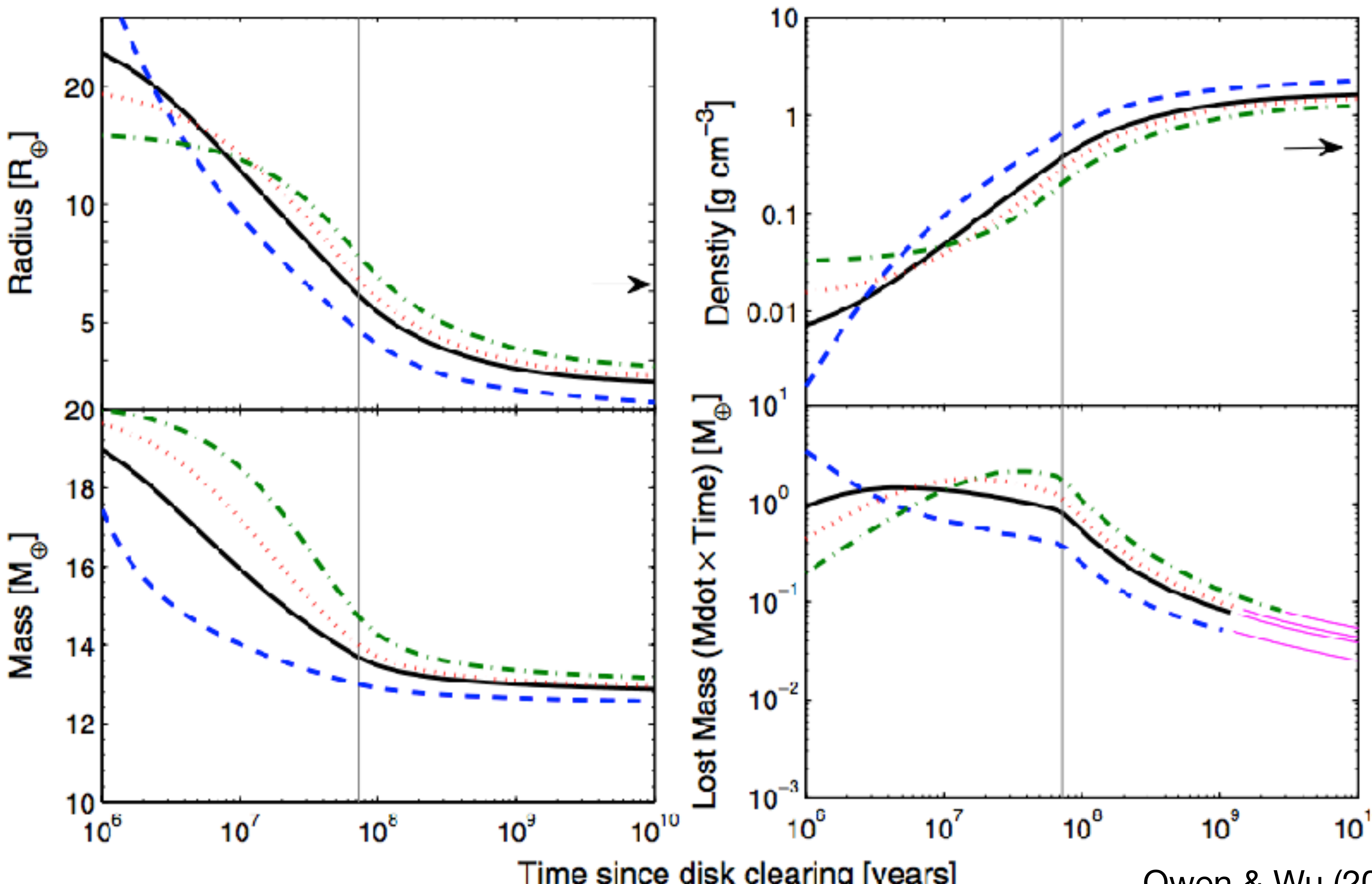


How long does evaporation last? — **First ~100 Myr**

Jackson et al. (2012)



Evolution of close-in evaporating planets

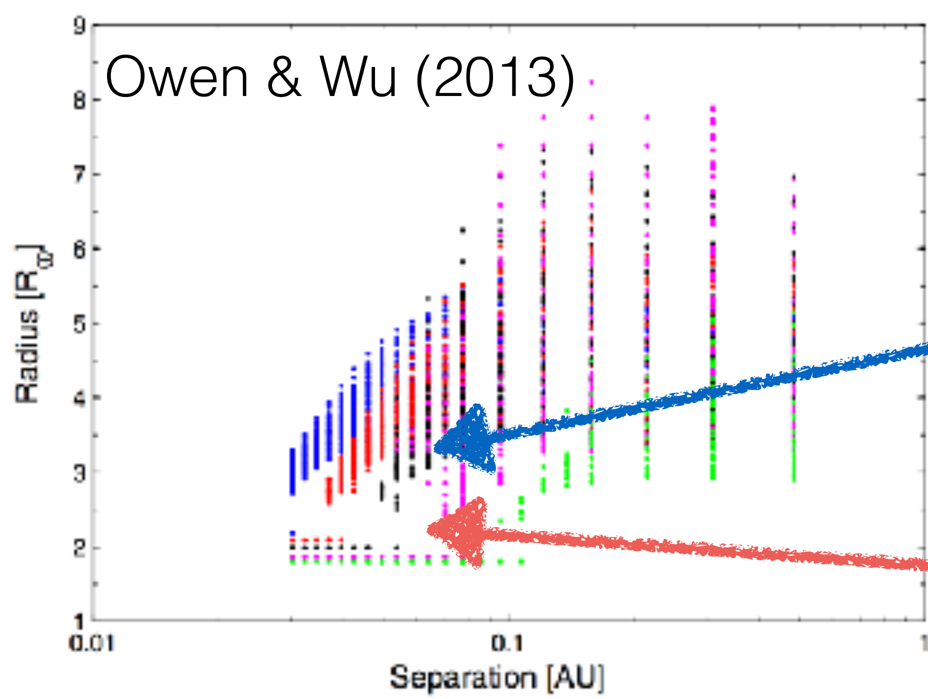


Owen & Wu (2013)

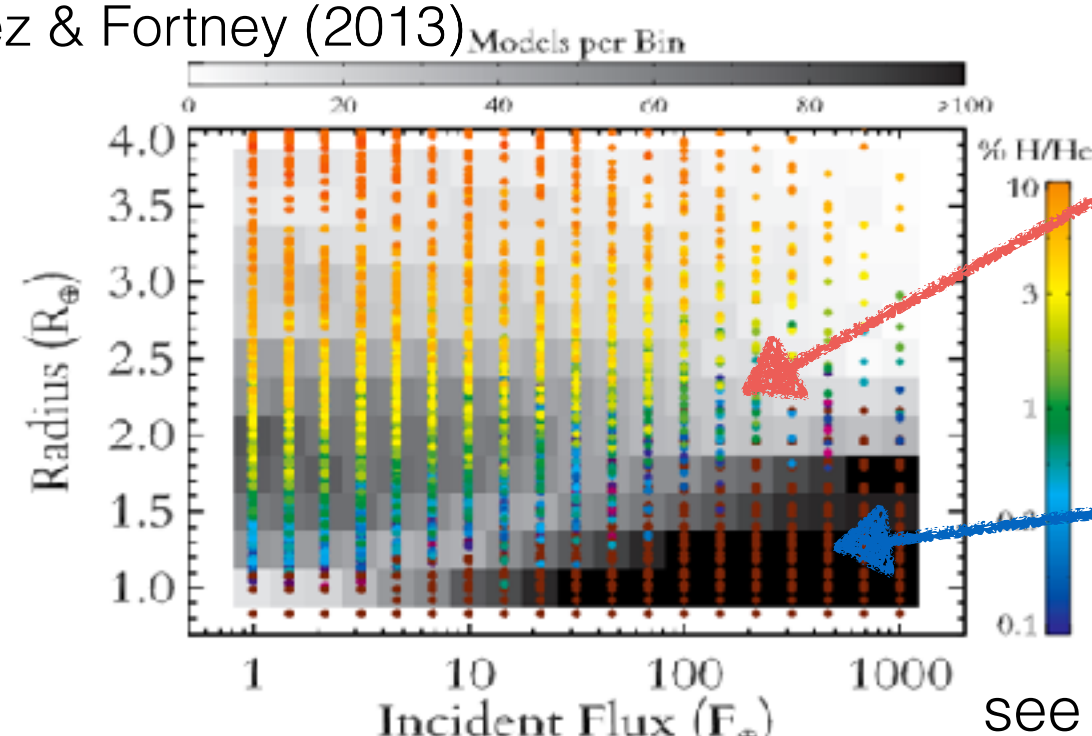
Motivation

Theory

Owen & Wu (2013)



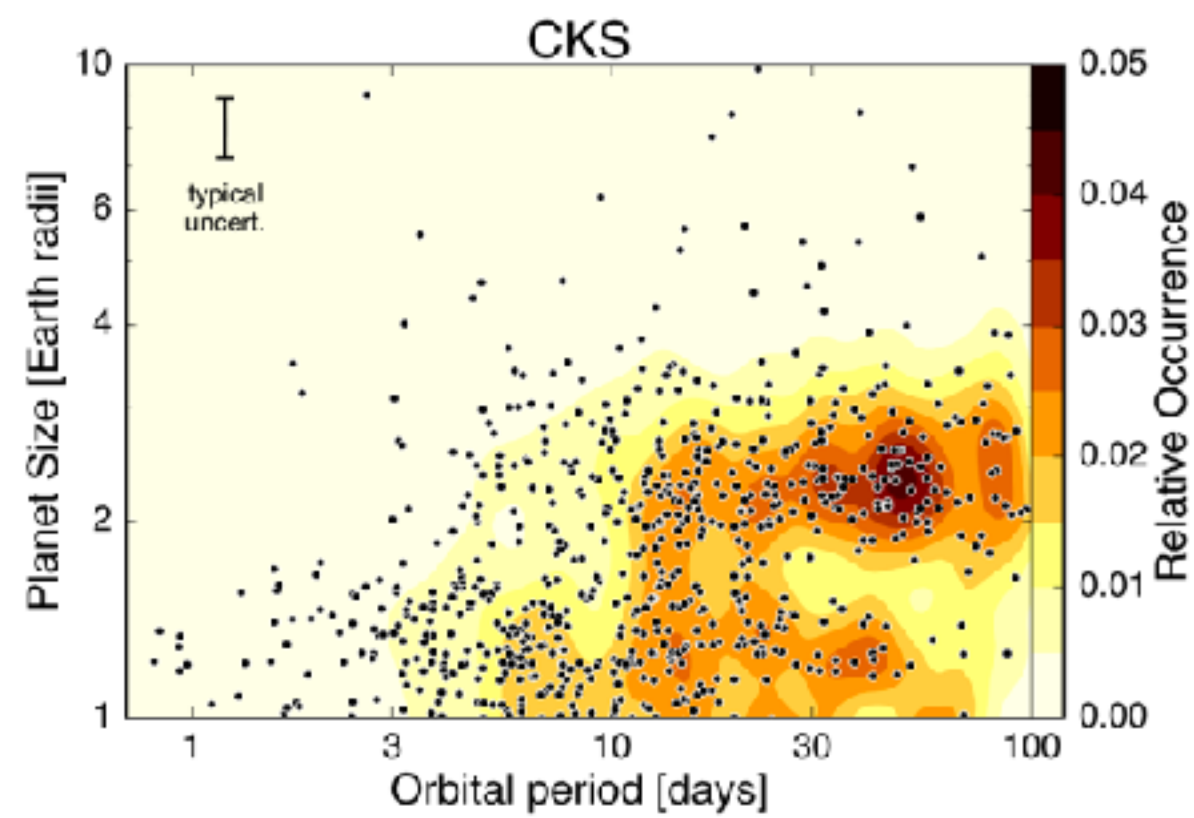
Lopez & Fortney (2013)



Observations

Fulton et al. (2017)

Planets with a few % H/He



Solid Cores.

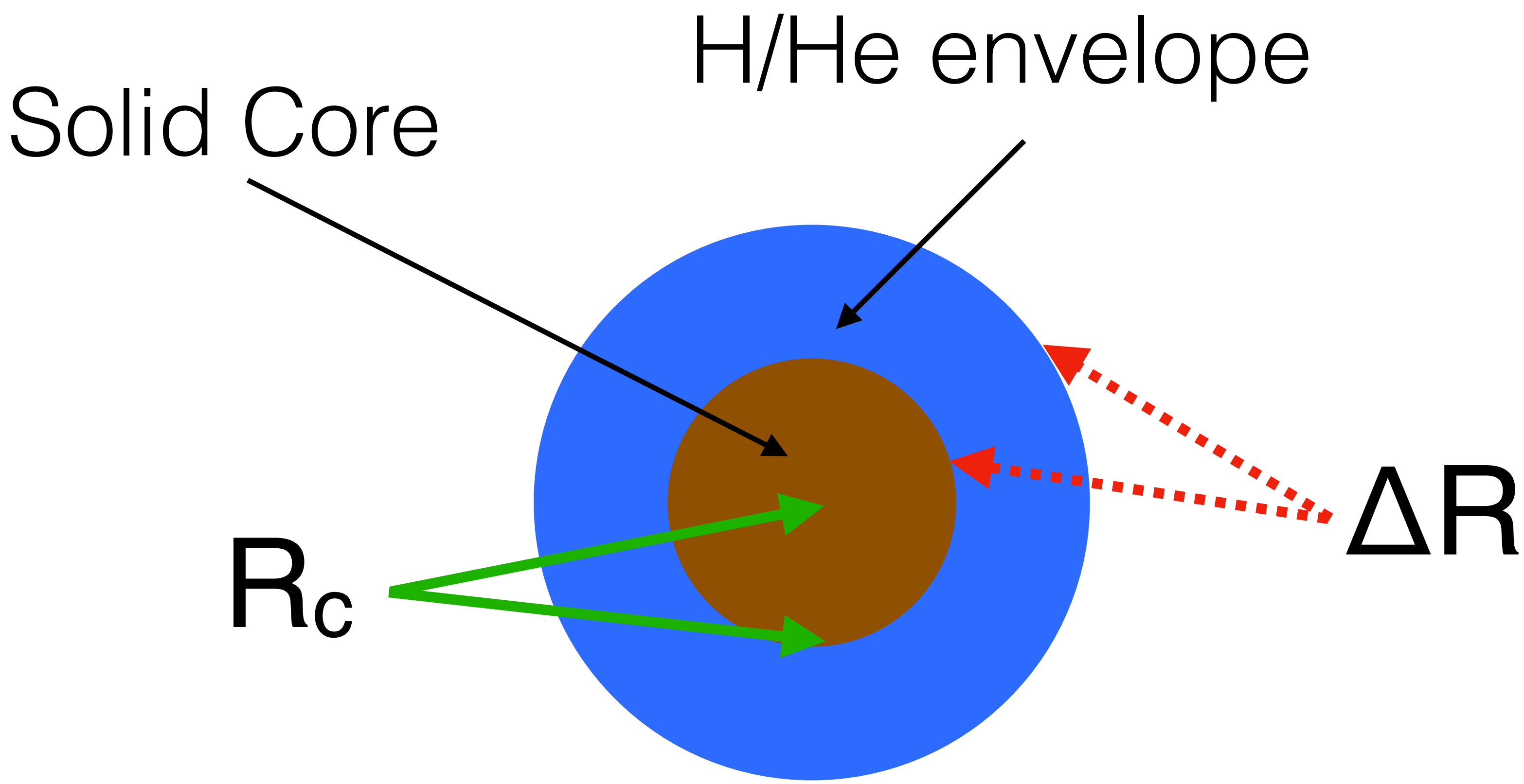
see also Jin & Mordasini (2014), Chen & Rogers (2016)

Questions:

Why do you get an “evaporation valley”?

What does the observed feature tell us about the exoplanet population?

The physics of the "evaporation valley"



How does the planet's radius vary with envelope mass fraction (X_{env})?

$$X \propto \left(\frac{I_1}{I_2}\right)^{n_I} \mu^{n_\mu} \kappa_0^{n_\kappa} T_{\rm eq}^{n_T} \tau_{\rm KH}^{n_\tau} \rho_{M_\oplus}^{n_\rho} M_c^{n_M}$$

$$\times \begin{cases} \left(\frac{\Delta R}{R_c}\right)^{n_a} & \text{if } \Delta R/R_c < 1 \\ \left(\frac{\Delta R}{R_c}\right)^{n_b} & \text{if } \Delta R/R_c > 1 \end{cases}$$

Envelope Mass Fraction:

Radius of envelope only

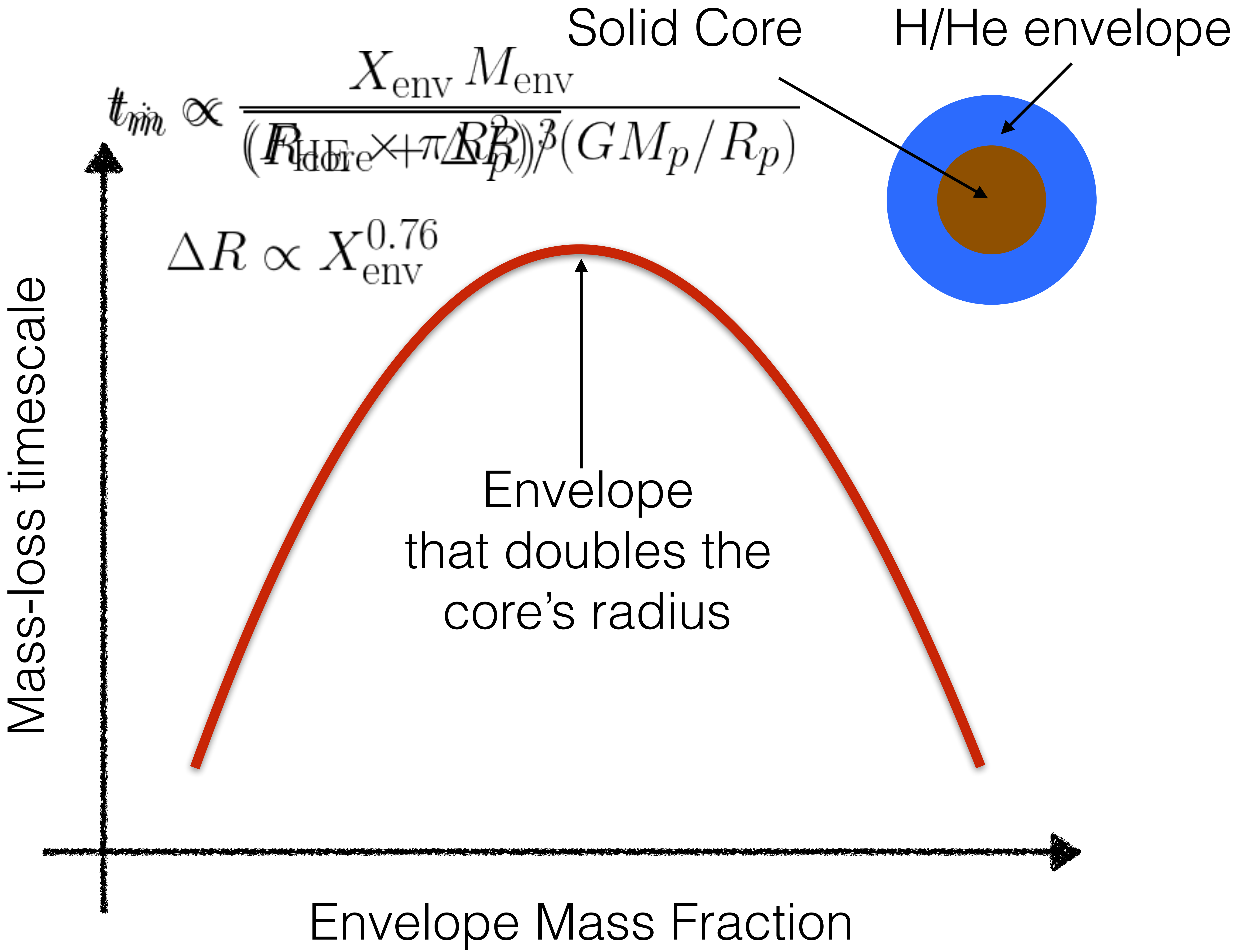
Envelope Mass / Core Mass

ΔR=Planet Radius - Core Radius

$$n_b = \left(\frac{3\gamma - 4}{\gamma - 1} + \frac{1}{\alpha + 1} \right) \frac{\alpha + 1}{\alpha + 2} \approx 1.31$$

Ratio of specific heats

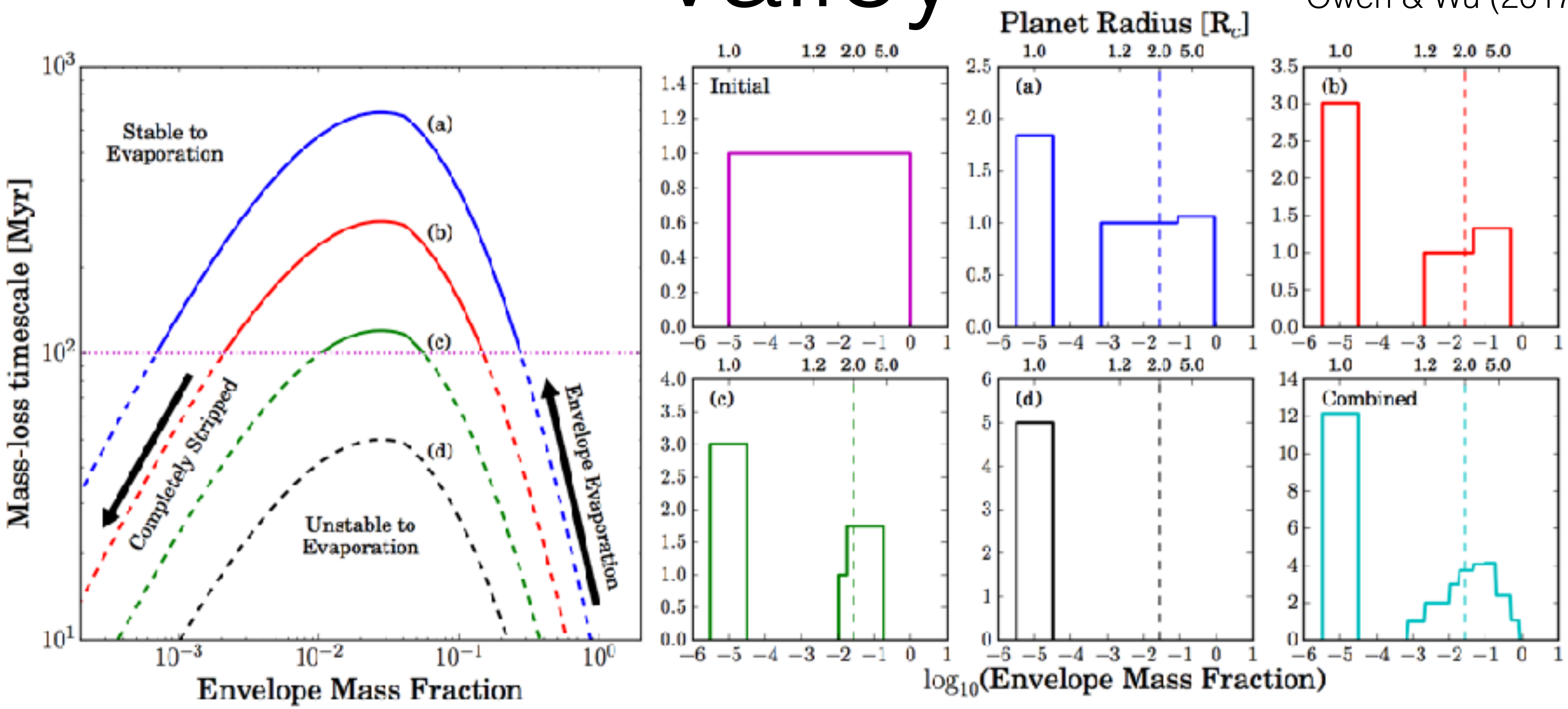
Opacity variation with pressure (at constant temperature)



Solid Core
H/He envelope
$\Delta R \propto X_{\rm env}^{0.76}$
Mass-loss timescale
Envelope
that doubles the
core's radius
Envelope Mass Fraction

Origin of the evaporation valley

Owen & Wu (2017)



Either: Completely strip a planet or evaporate it to a few percent H/He!

The valley as a probe of core composition

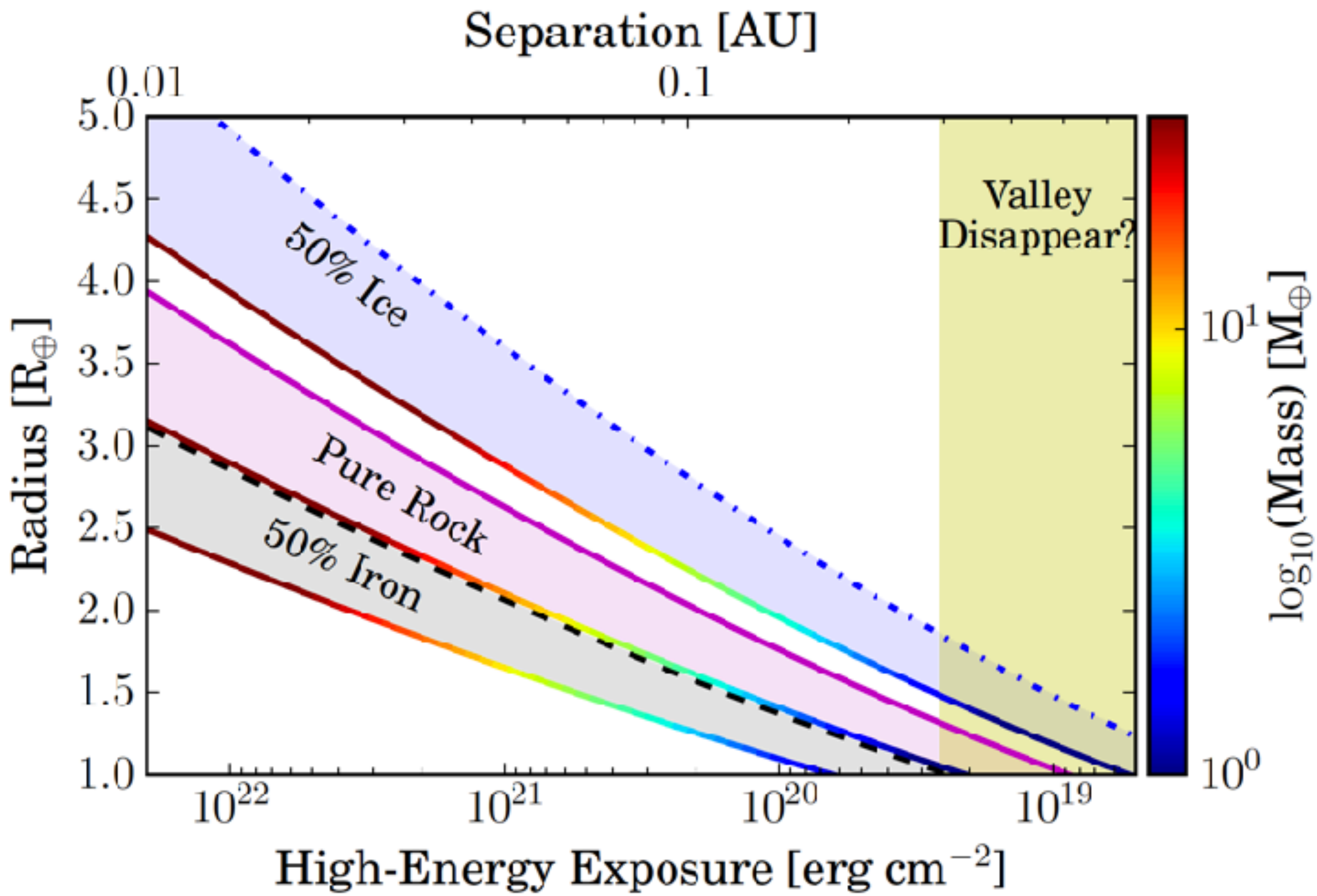
The valley separates those planets that are completely stripped from those that have a 1% H/He atmosphere by mass.

- The separation at which you can completely strip all low-mass planets depends on core (planet) mass. Strip more massive cores closer to the star.

- The planet radius at which you strip a 1% envelope depends on core (planet) radius. Larger cores have the gap at larger planetary radii.

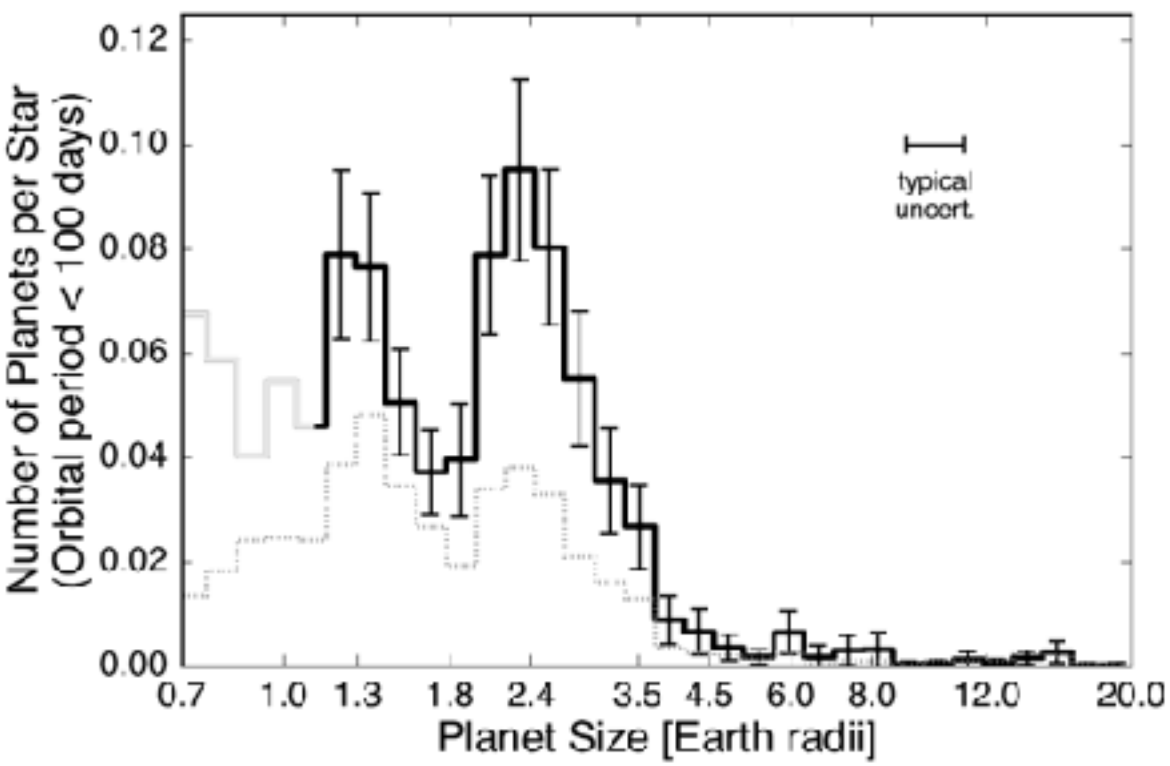
The valley probes both core mass and radius:
probes core composition!

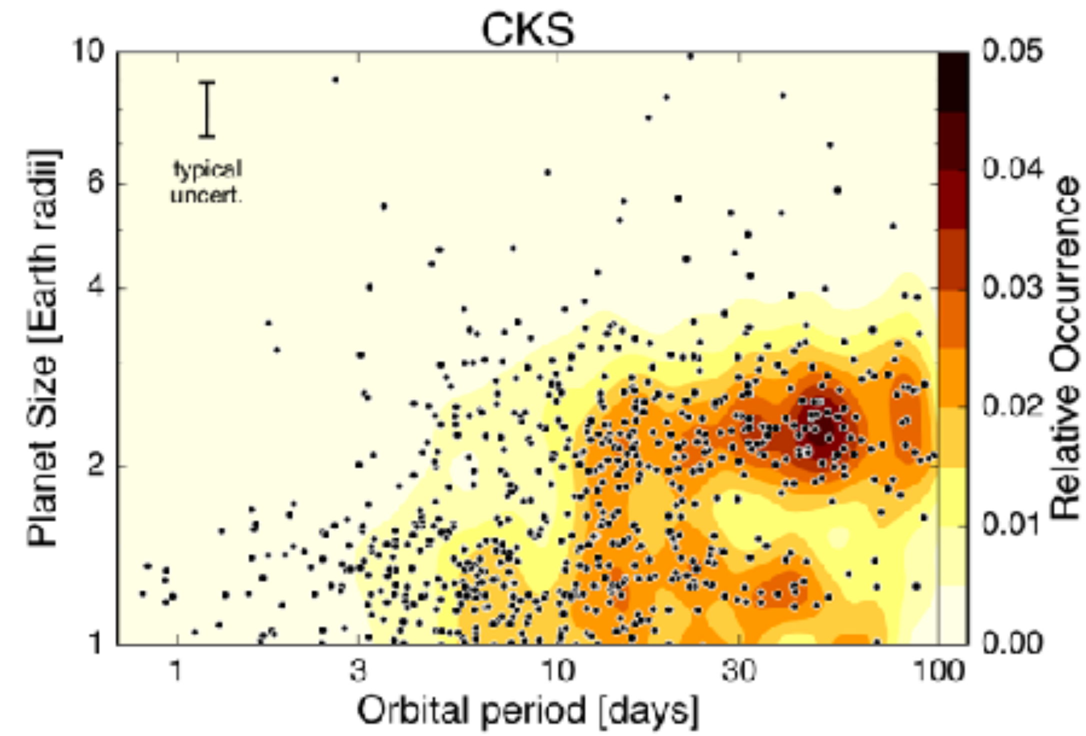
The valley as a probe of core composition



What can we learn from the observed evaporation valley

Fulton et al. (2017)





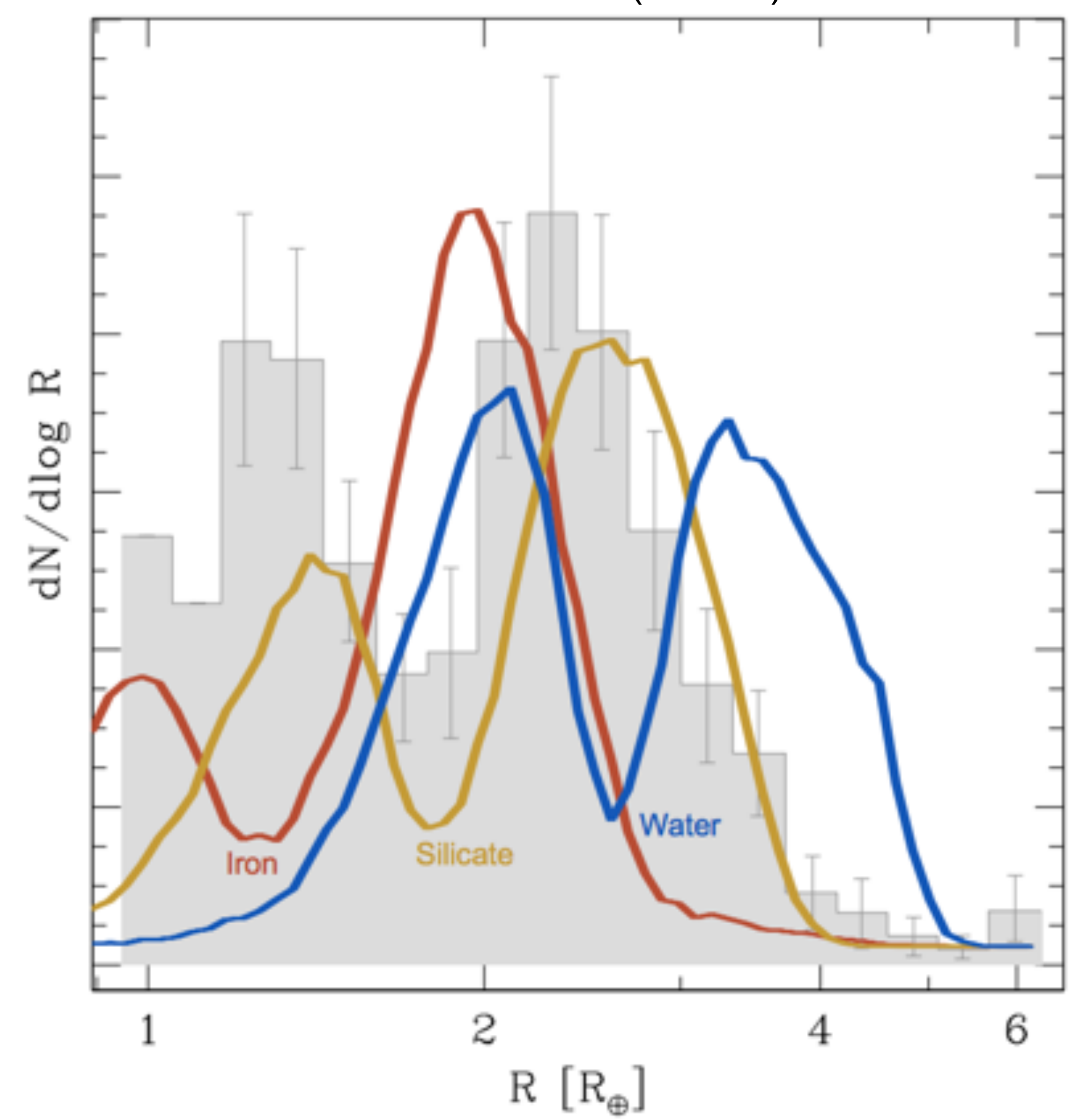
$$t_{\dot{m}} = 100\,\mathrm{Myr} = \frac{M_{\rm env}}{\dot{M}} \propto \eta\, X_2\, \frac{M_c^2}{(2R_c)^3}\, \frac{1}{F_{\rm XUV}}$$

Sensitive to core properties and distance from star

Core composition

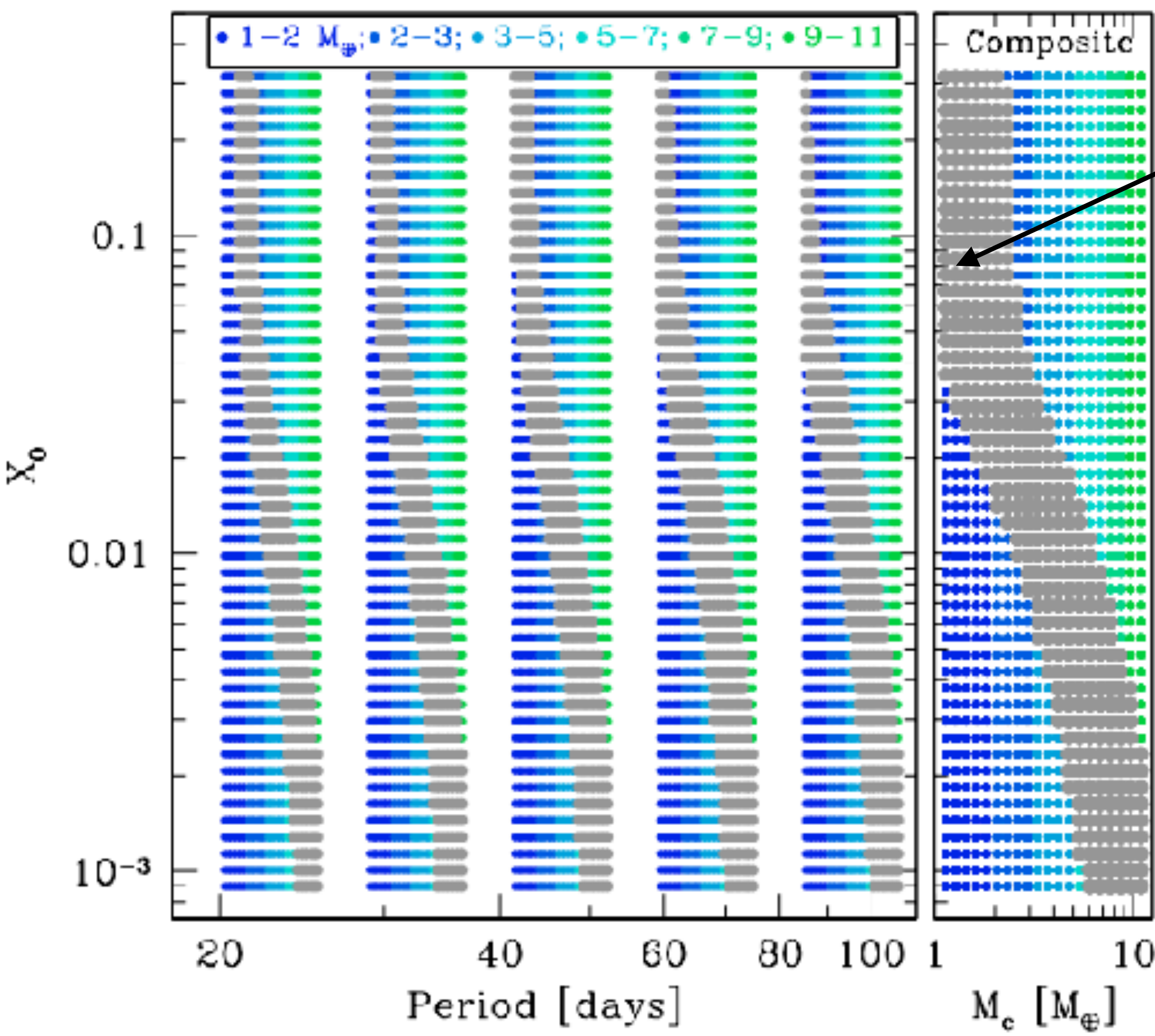
- Spread in core composition must be narrow.
- Cores must have "earth-like" composition. Approximately 1/3 Iron 2/3 Silicates.
- Cores cannot contain ice/water.

Owen & Wu (2017)



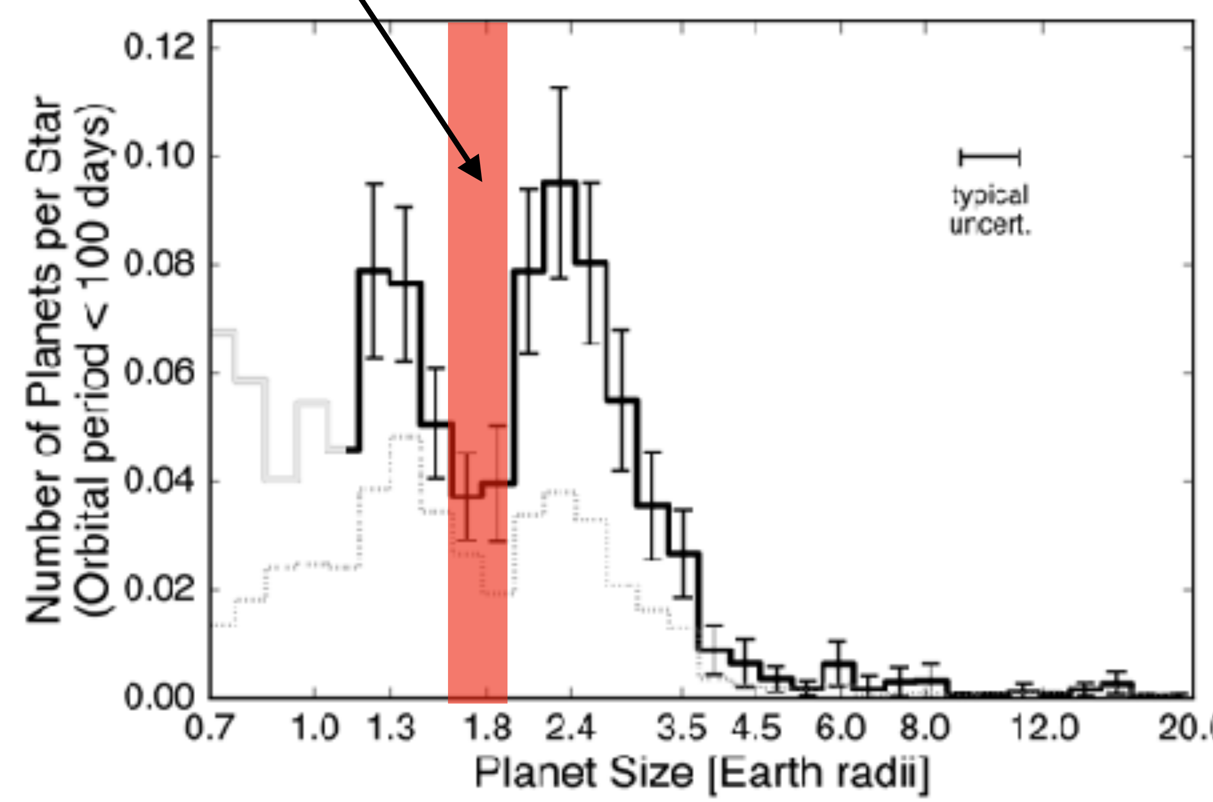
See also Jin & Mordasini (2017)

Comparison to observations: evaporation valley



Owen & Wu (2017)

Disfavored by observations

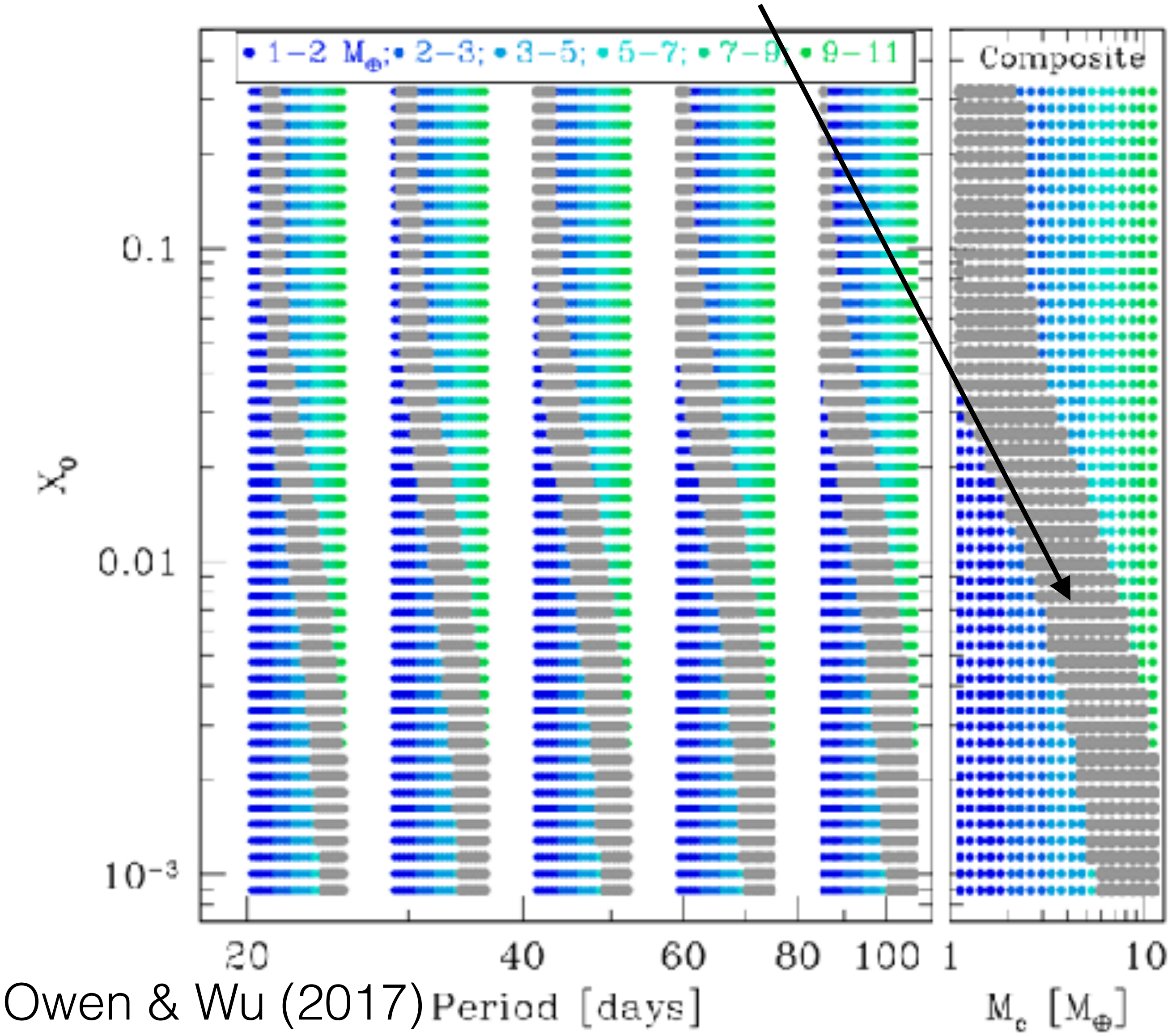


Fulton et al. 2017

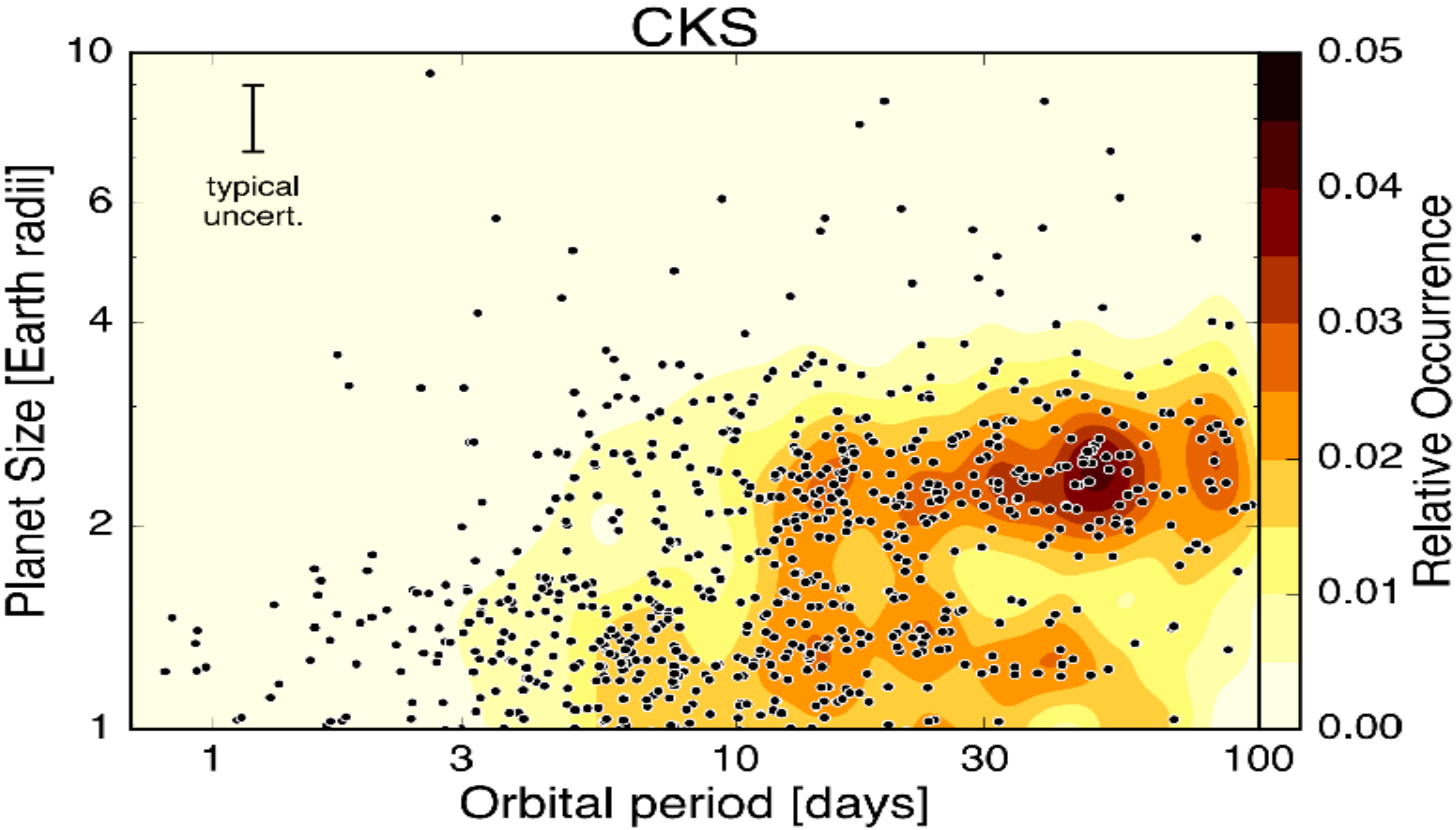
Birth composition

- A single population of planets can explain the observed features.
- Core masses peaking around 3-4 Mearth.
- Initial H/He mass fraction greater than a few percent.

Disallowed by observations



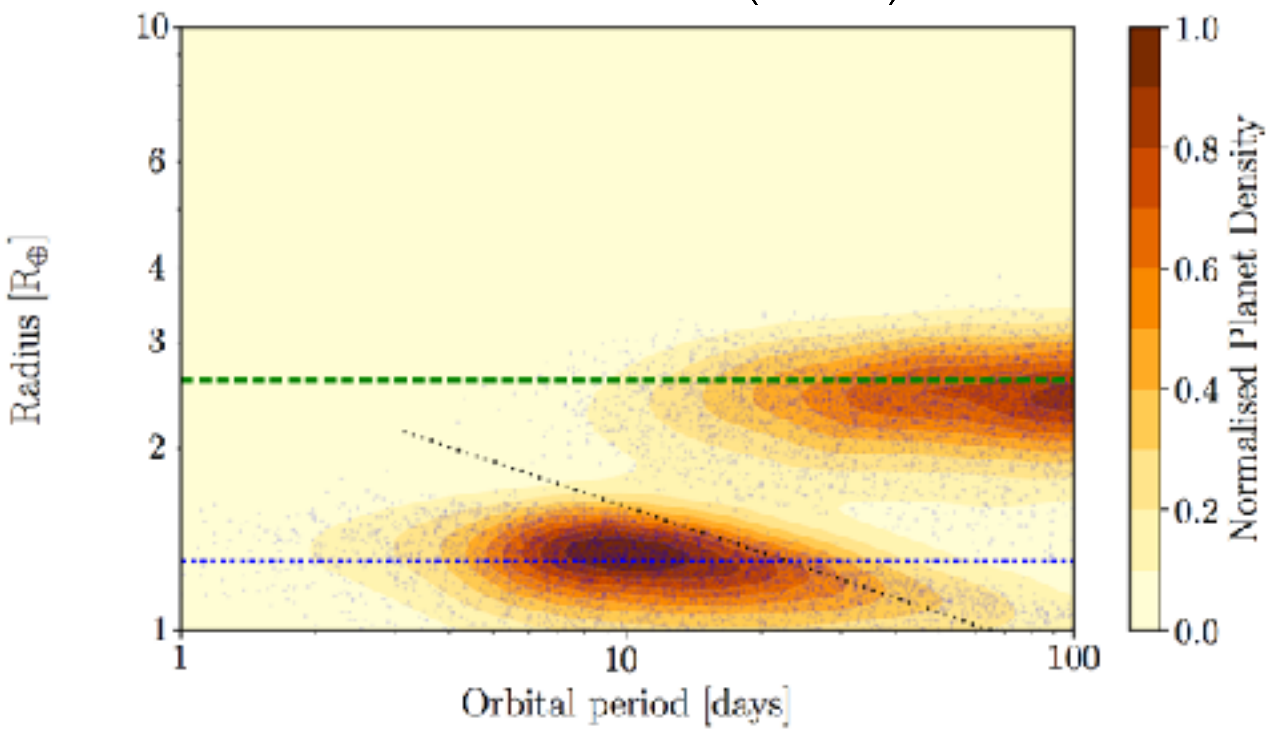
Owen & Wu (2017)



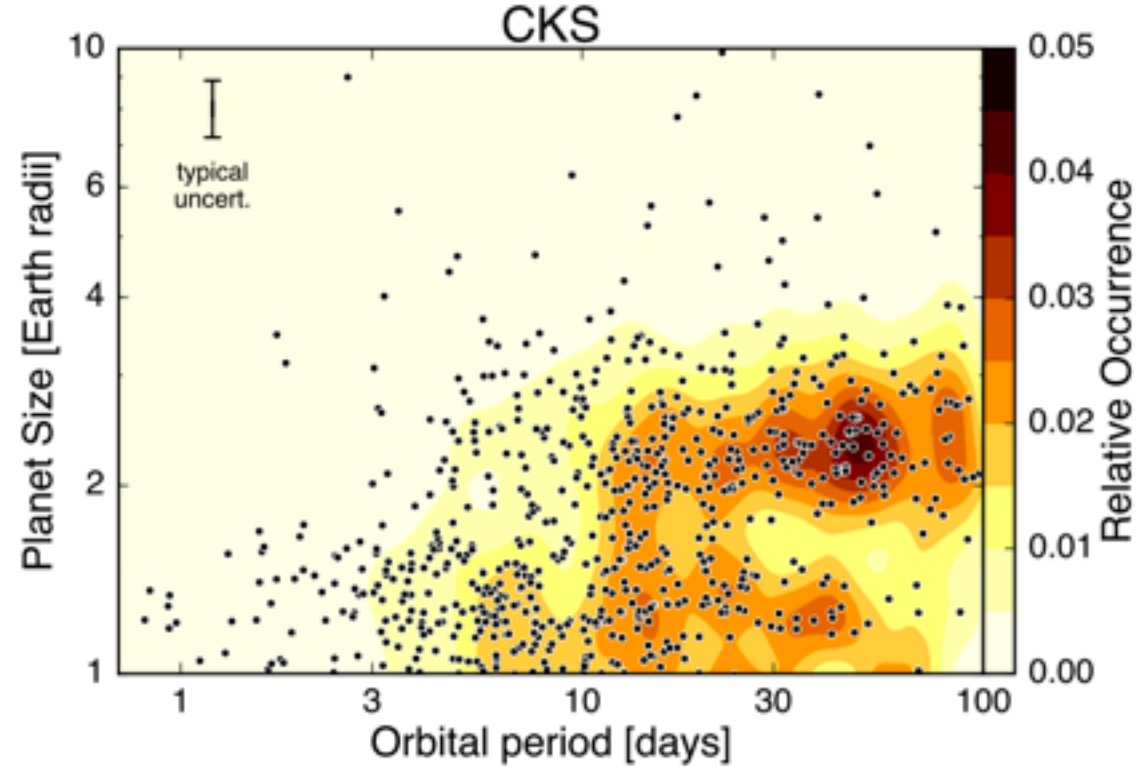
Fulton et al. (2017)

Model Population

Owen & Wu (2017)

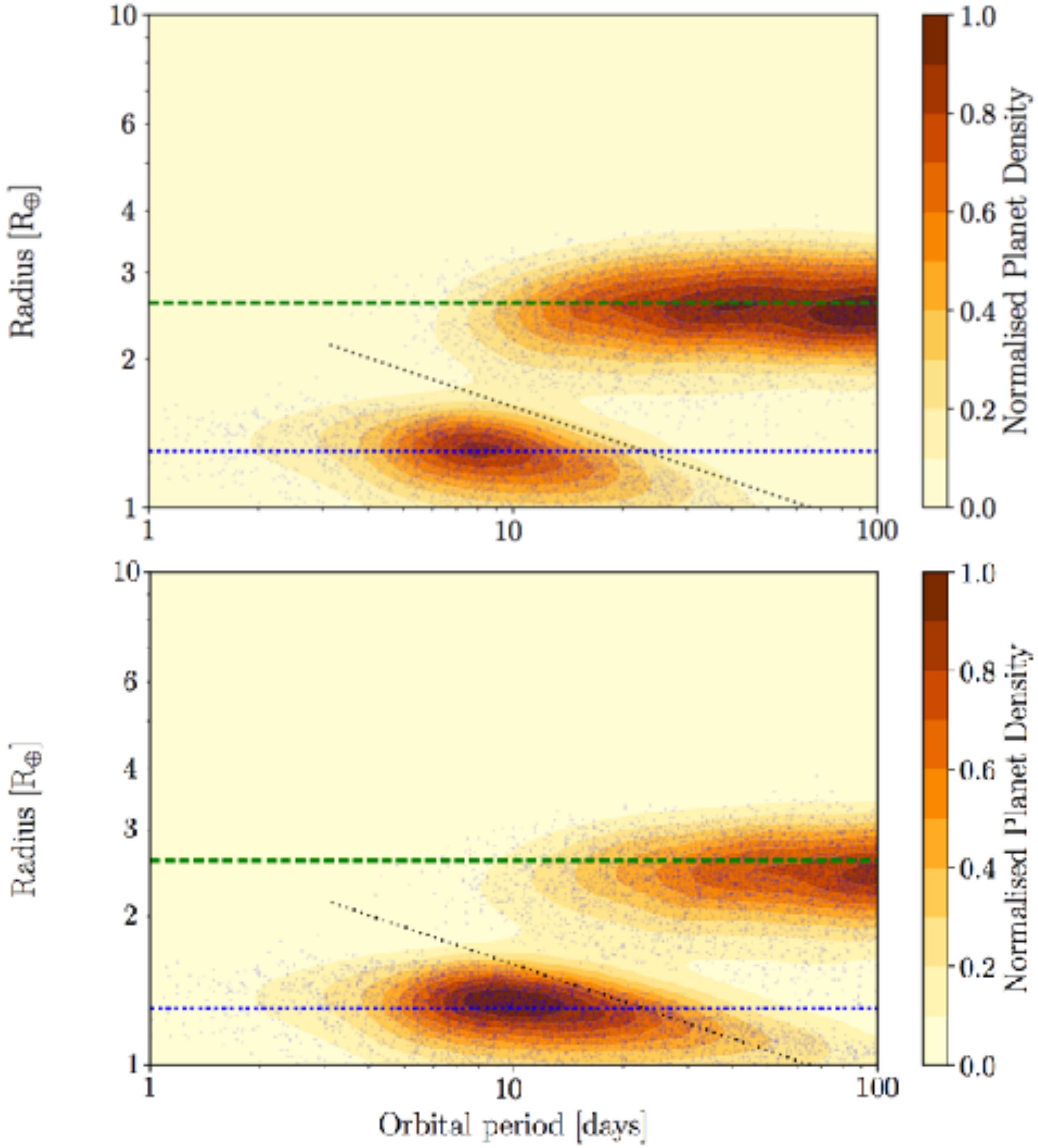


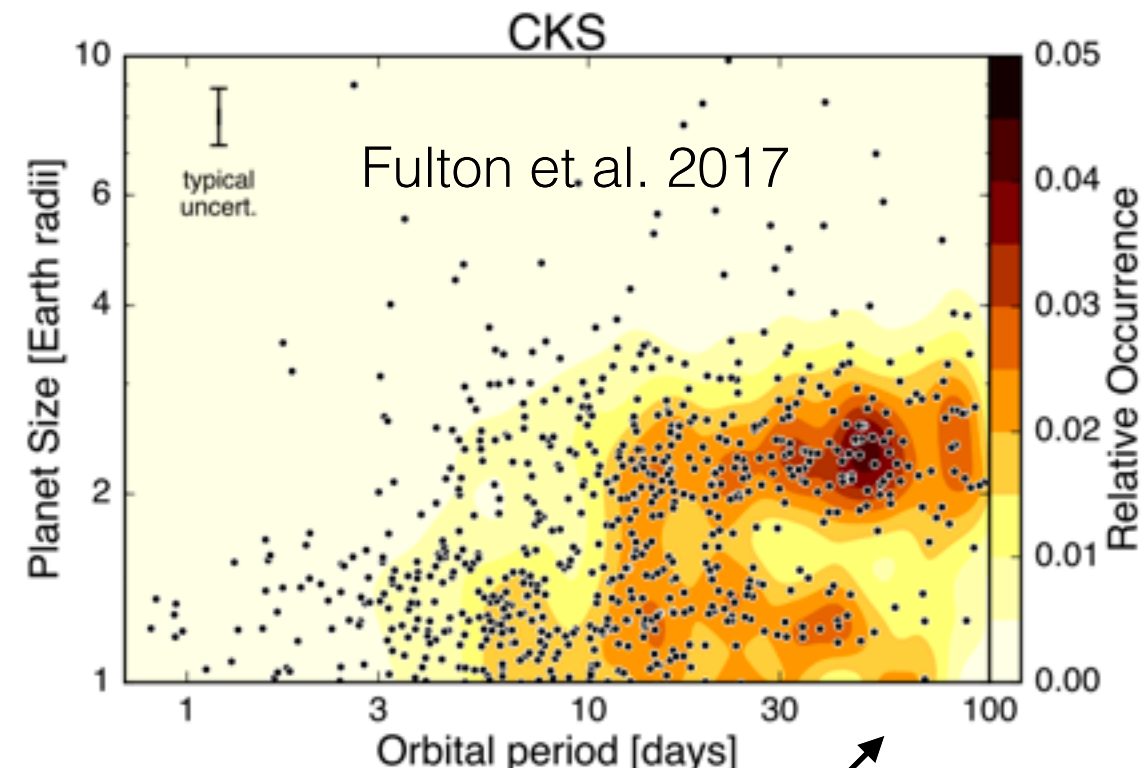
Fulton et al. 2017



Model Population

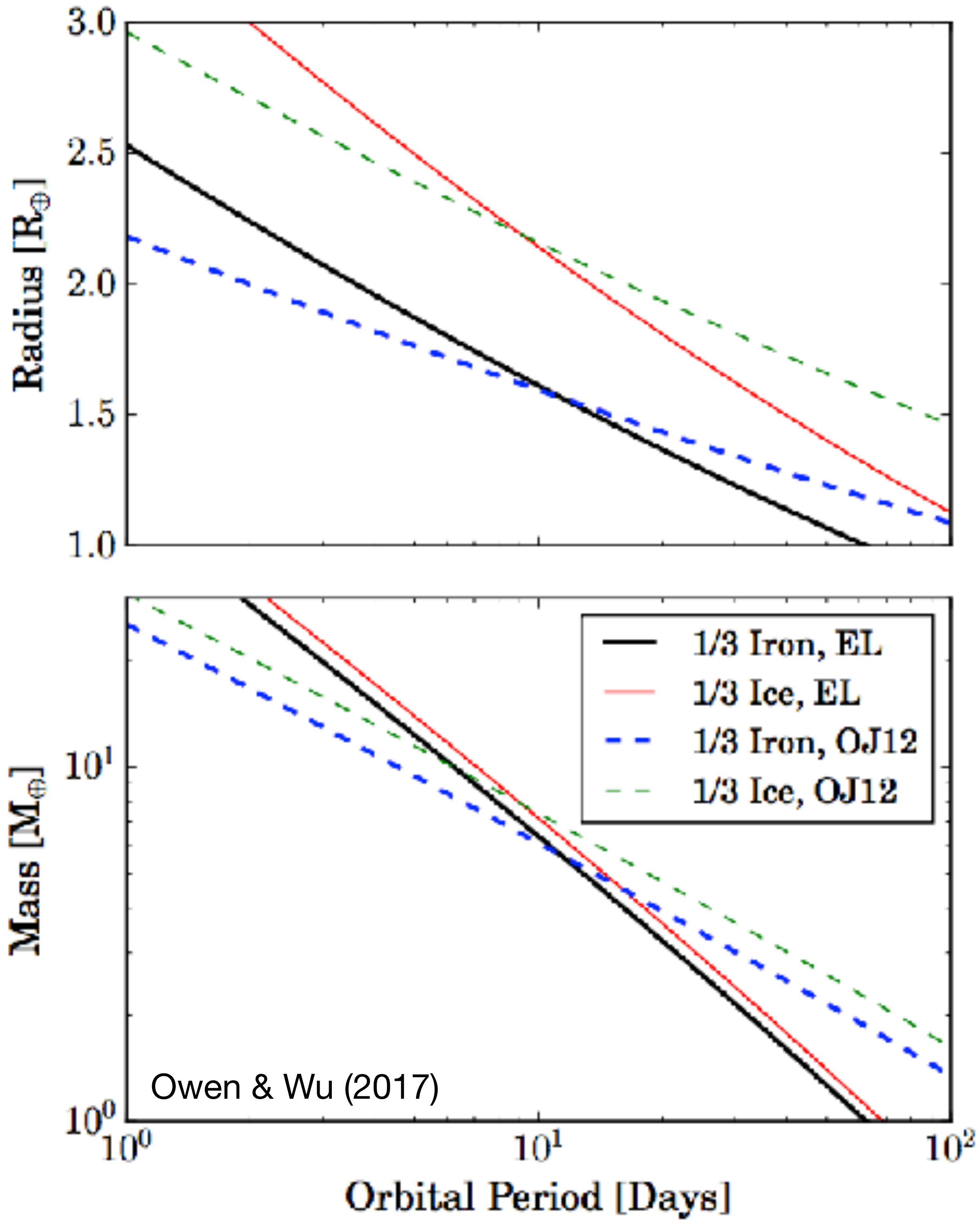
Owen & Wu (2017)



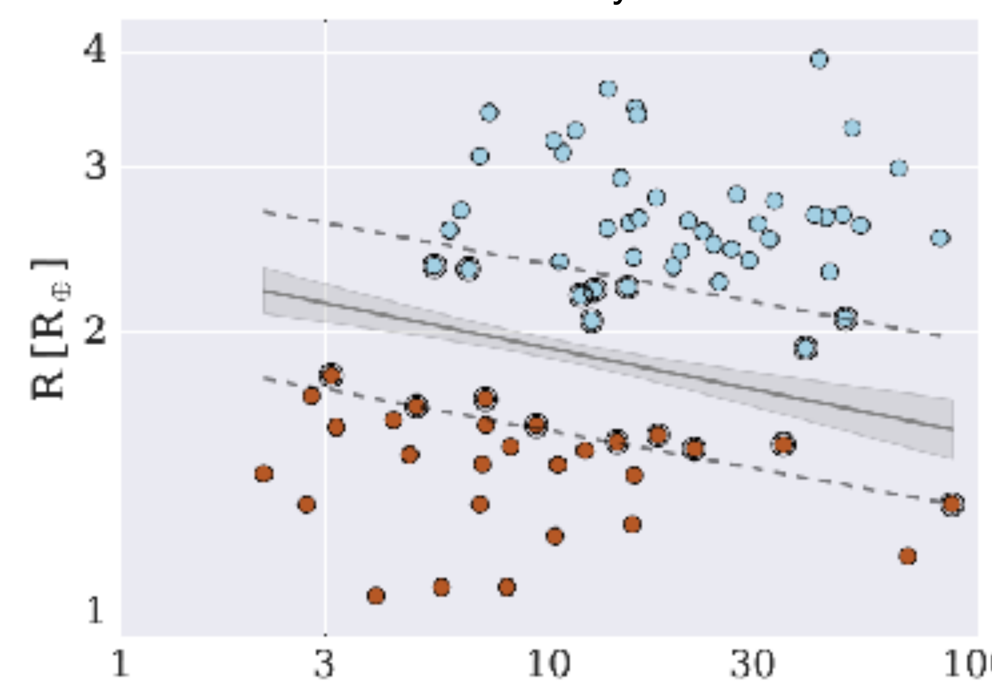


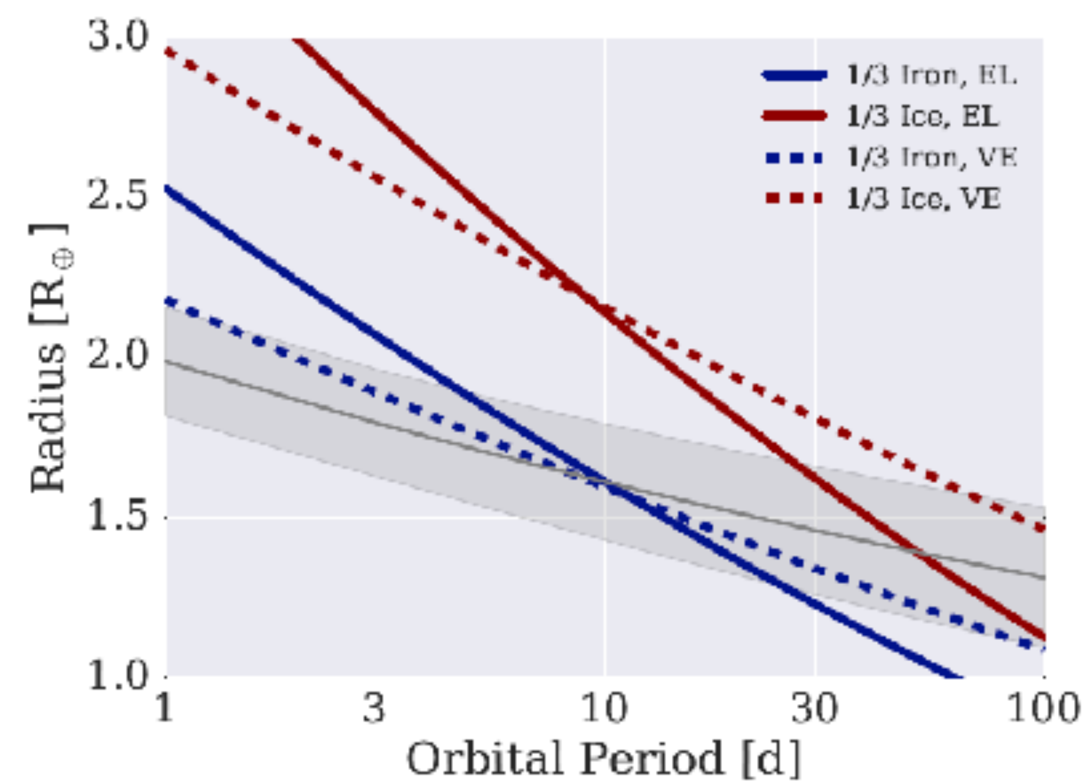
Secondary population
of born terrestrial planets?

Test 1: Valley Slope



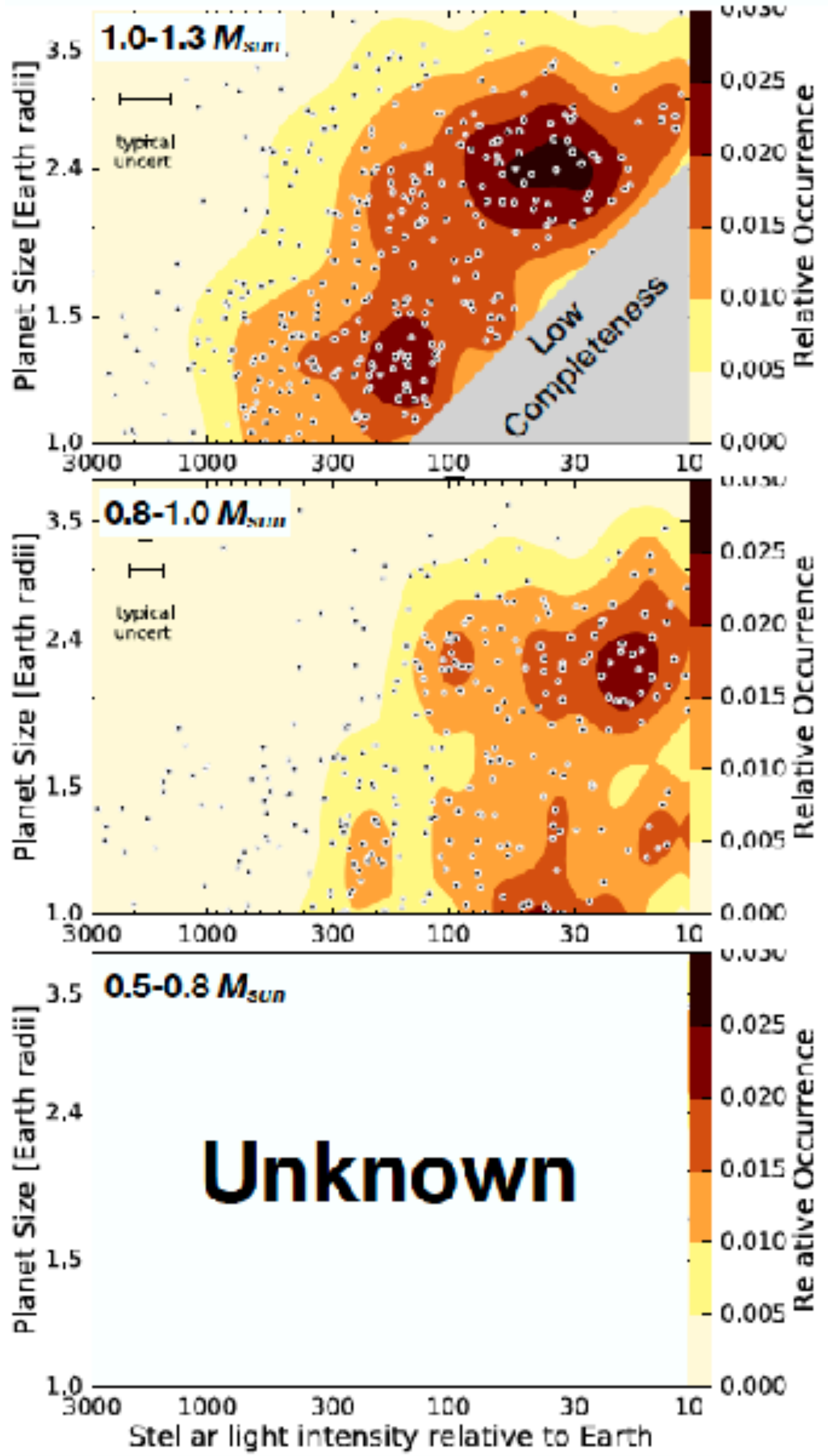
Van Eylen et al. submm.

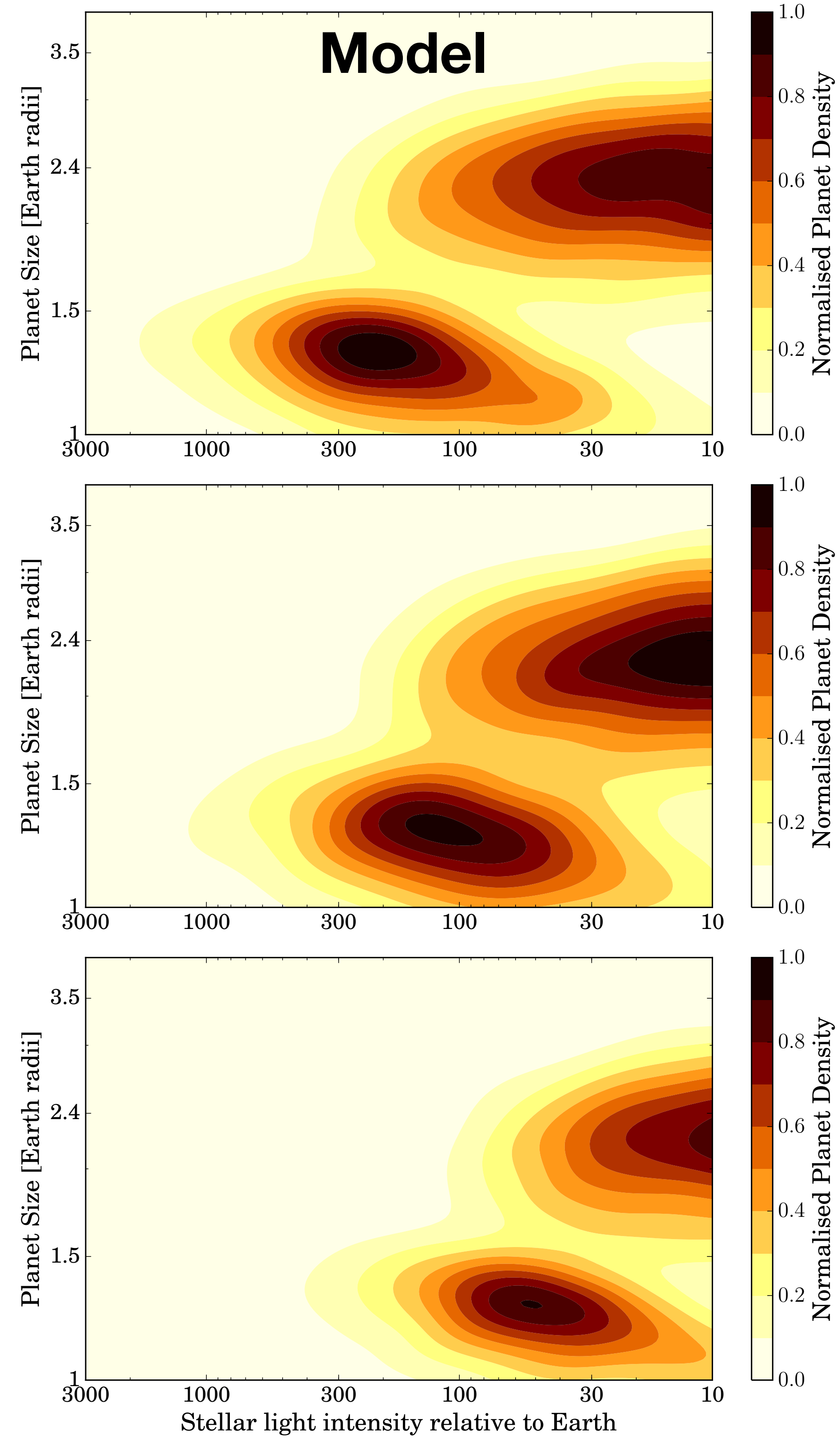




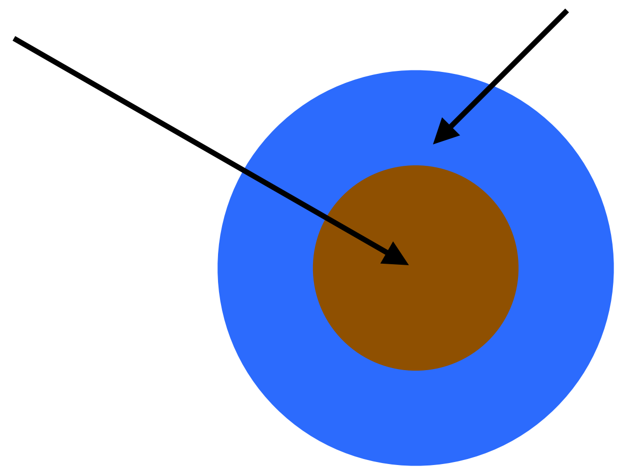
Test 2: Stellar Mass

Observations - CKS cool team proposal (Erik Petigura)





Water Worlds?



Evaporation valley would be at periods of <1 day

now around ~50%

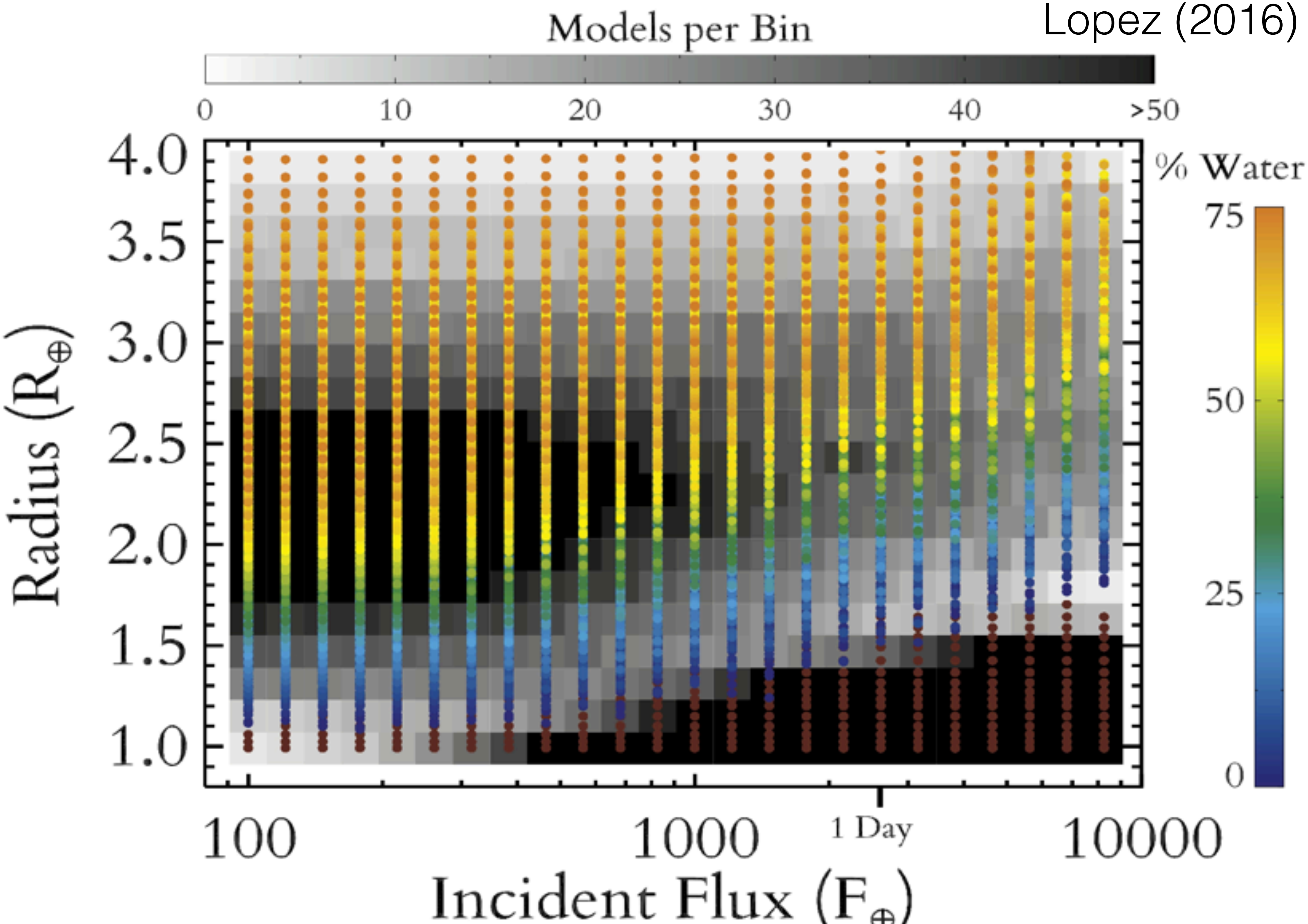
$$t_{\dot{m}} = 100\,\mathrm{Myr} = \frac{M_{\mathrm{env}}}{\dot{M}} \propto \eta\, X_2 \frac{M_c^2}{(2R_c)^3} \frac{1}{F_{\mathrm{XUV}}}$$

Probably much lower due to enchanted cooling from oxygen

much higher flux needed

Water Worlds?

Lopez (2016)



Clues about the formation of the bulk of low-mass, close-in planets

- Cores are “Earth-like” and contain no ice: **must have formed inside the snow-line (maybe?).**
- Must have had initial H/He mass fractions greater than a few percent: **must have formed in gas disc.**
- Must have been at there present locations well before 100 Myr: **no late time migration (e.g. high-eccentricity migration)**