Revisiting the Radius Gap with Gaia DR2

The California-Kepler Survey. VII.
Precise Planet Radii Leveraging Gaia DR2 Reveal the Stellar Mass Dependence of the Planet Radius Gap

BJ Fulton & Erik Petigura

arXiv:1805.01453 (in review)

Caltech
NExScI
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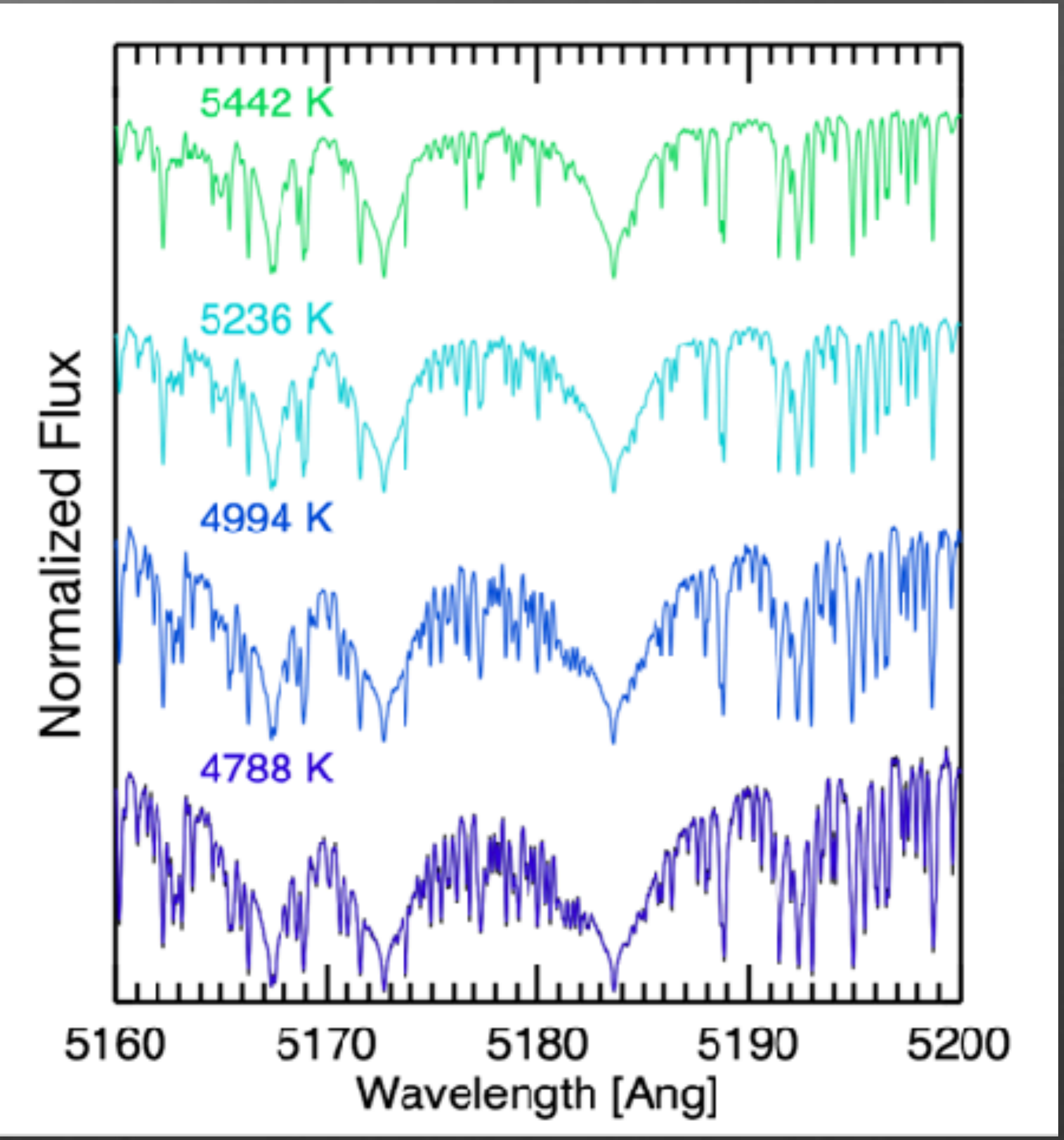
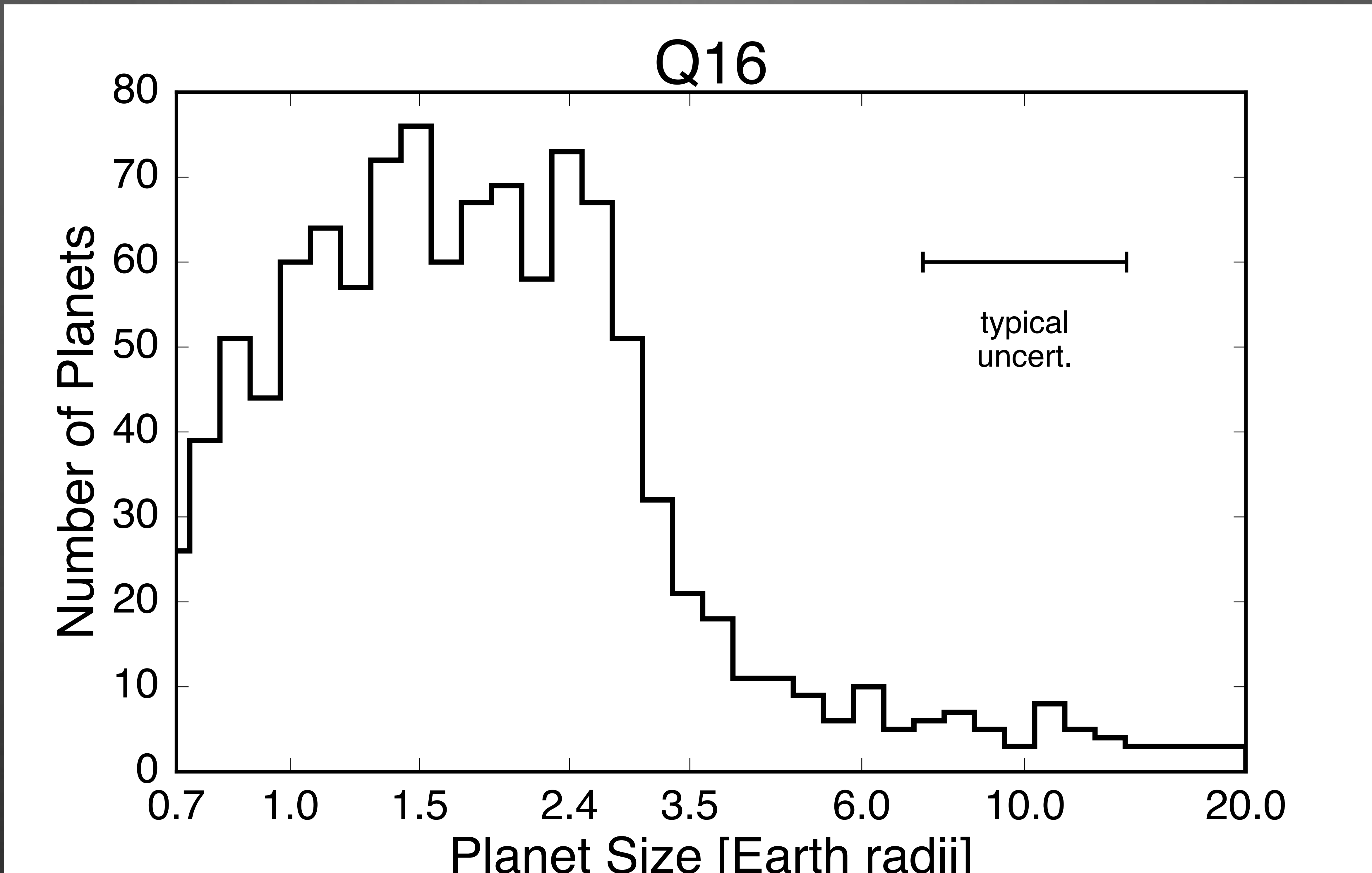
The California-Kepler Survey

- Keck/HIRES high-resolution spectra of 1305 stars hosting 2025 planet candidates
- Precision spectroscopy:
  - Teff, logg, Fe/H, mass, radius, vsini
  - Stellar radius precision: 39% —> 10%



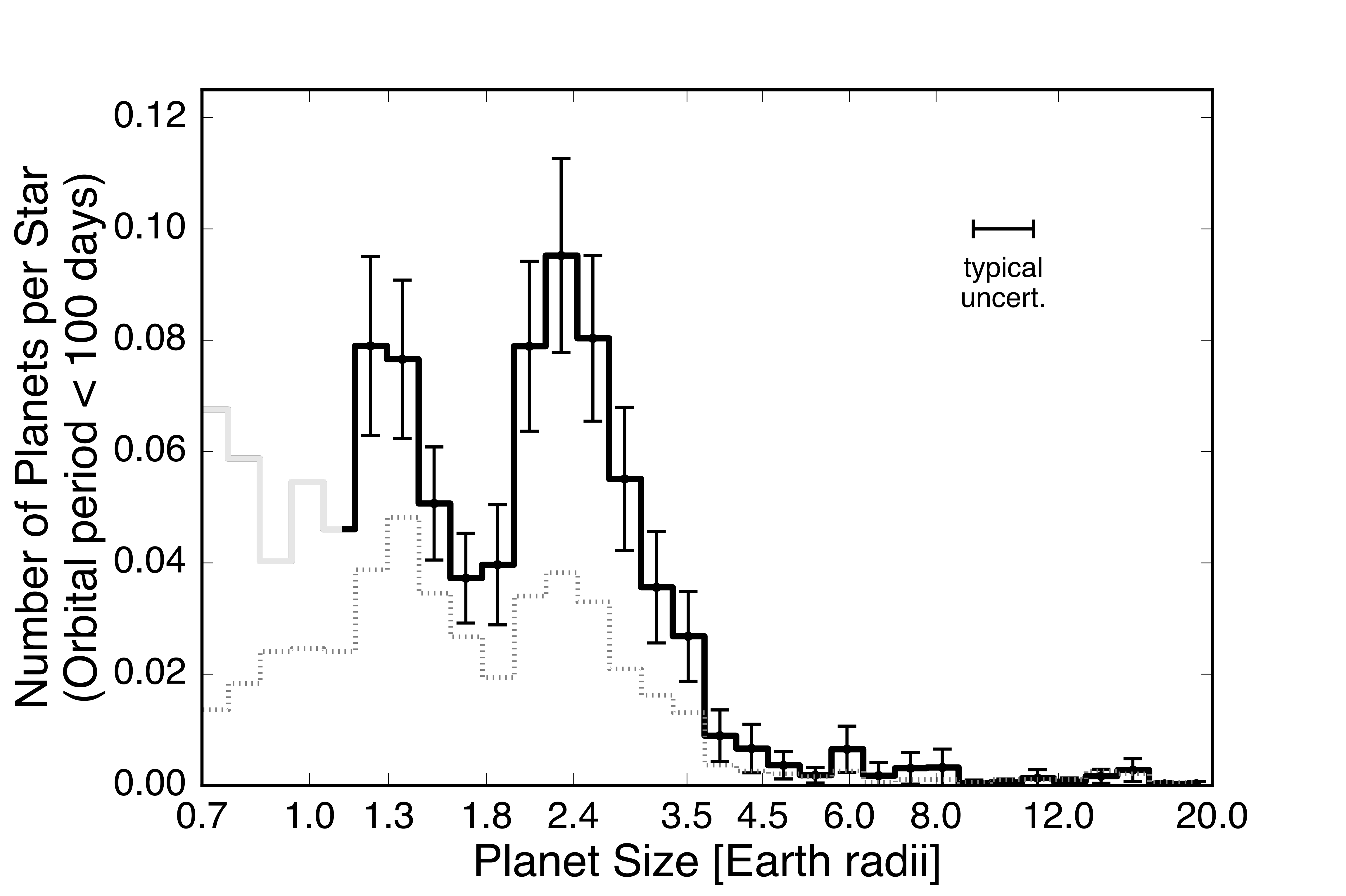
Petigura et al. (*2017*)



Huber et al. (2014); Mullally et al. (2015)

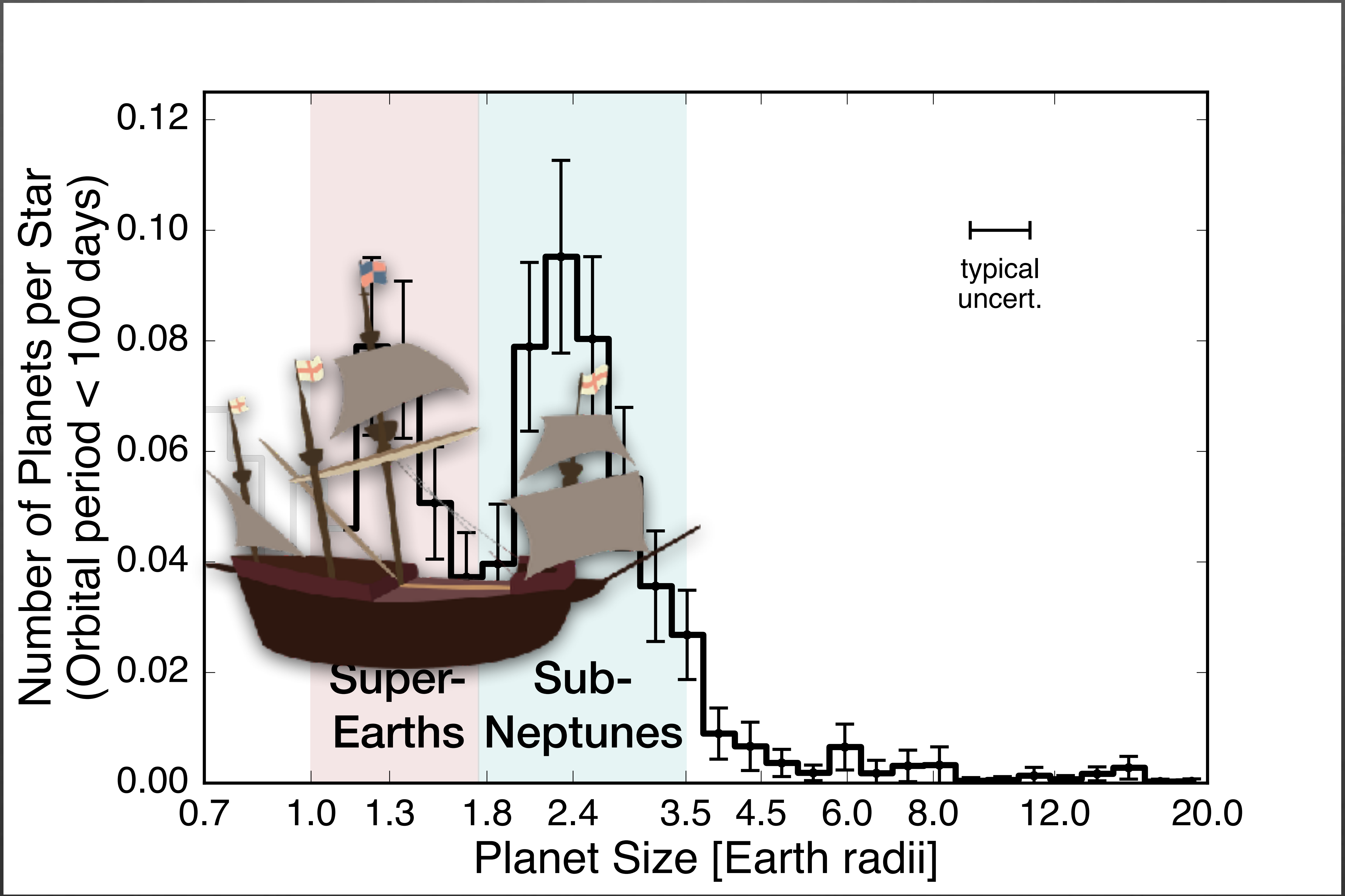
Johnson, Petigura et al. (*2017*)

The Radius Gap

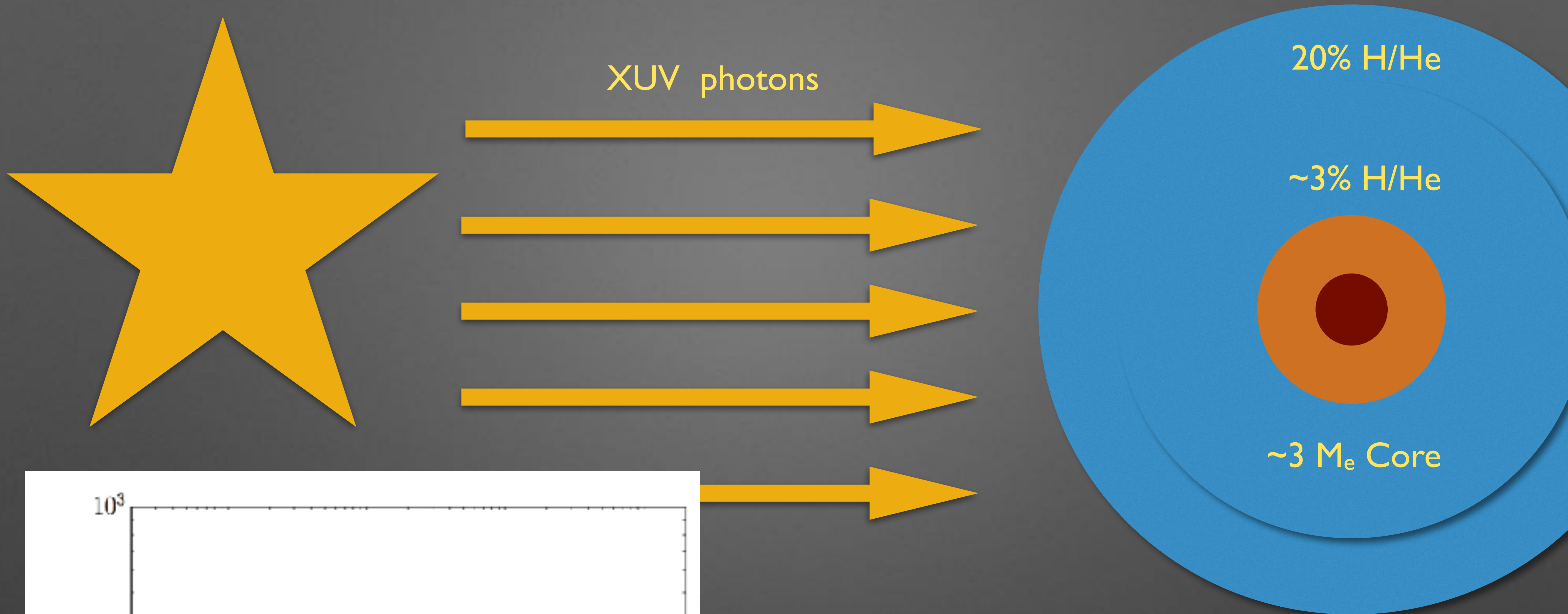


Fulton et al. (*2017*)

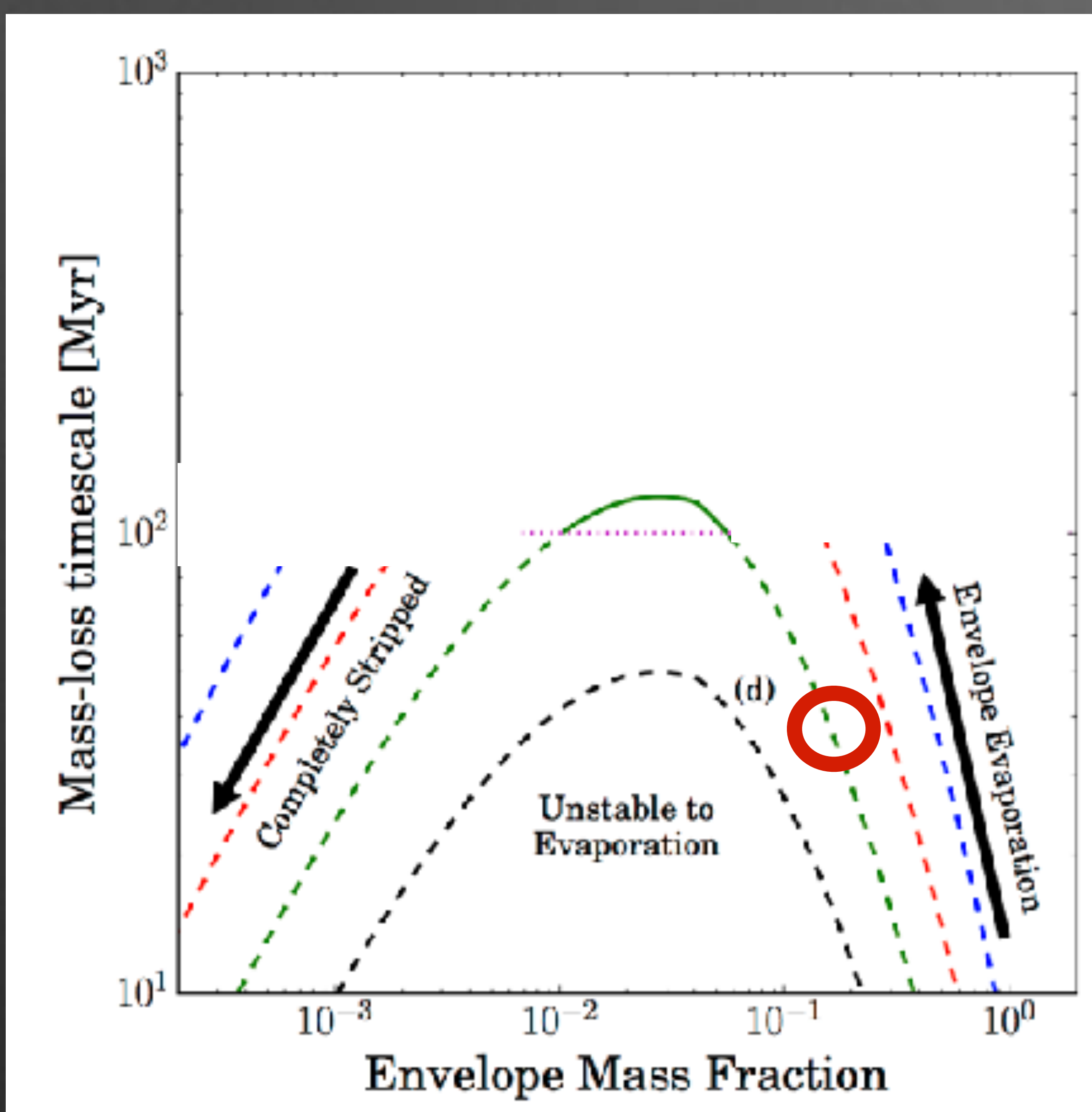
The Radius Gap



Fulton et al. (*2017*)

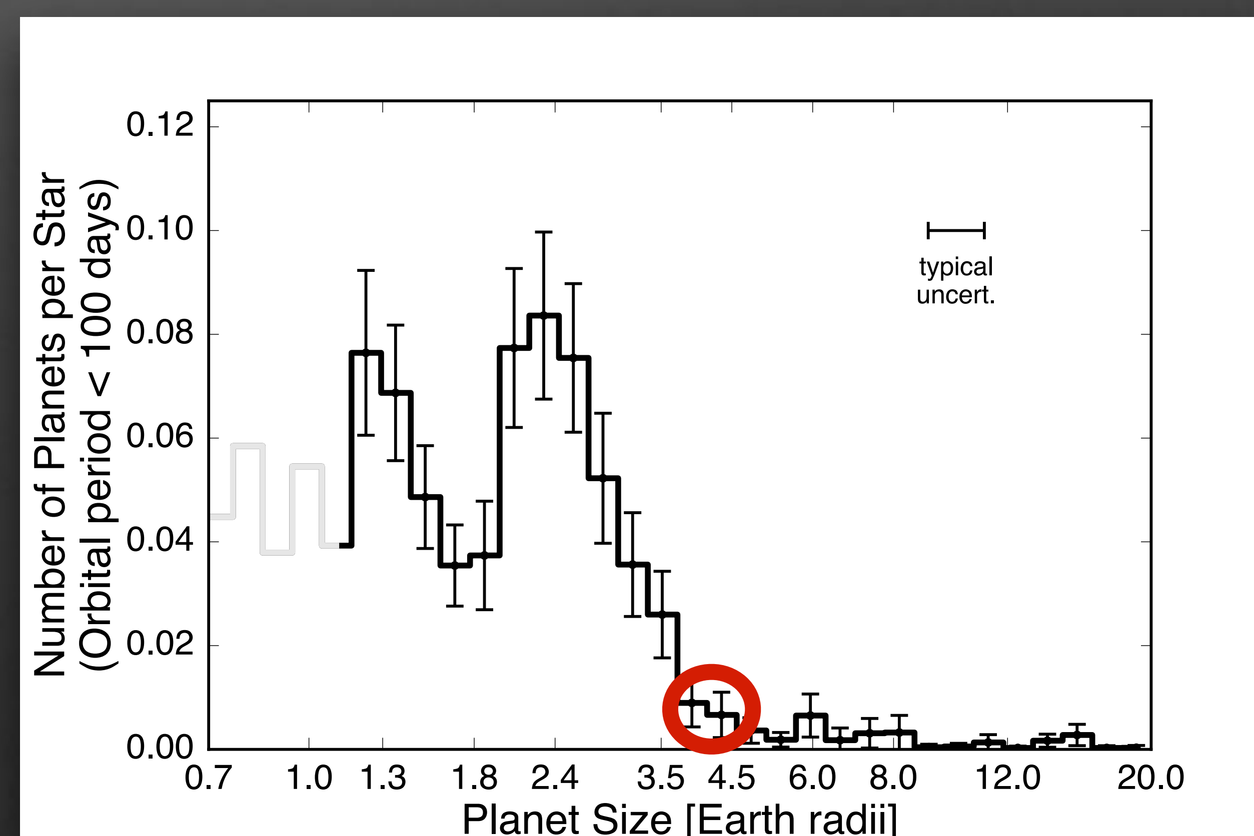


XUV photons
20% H/He
~3% H/He
~3 M_e Core

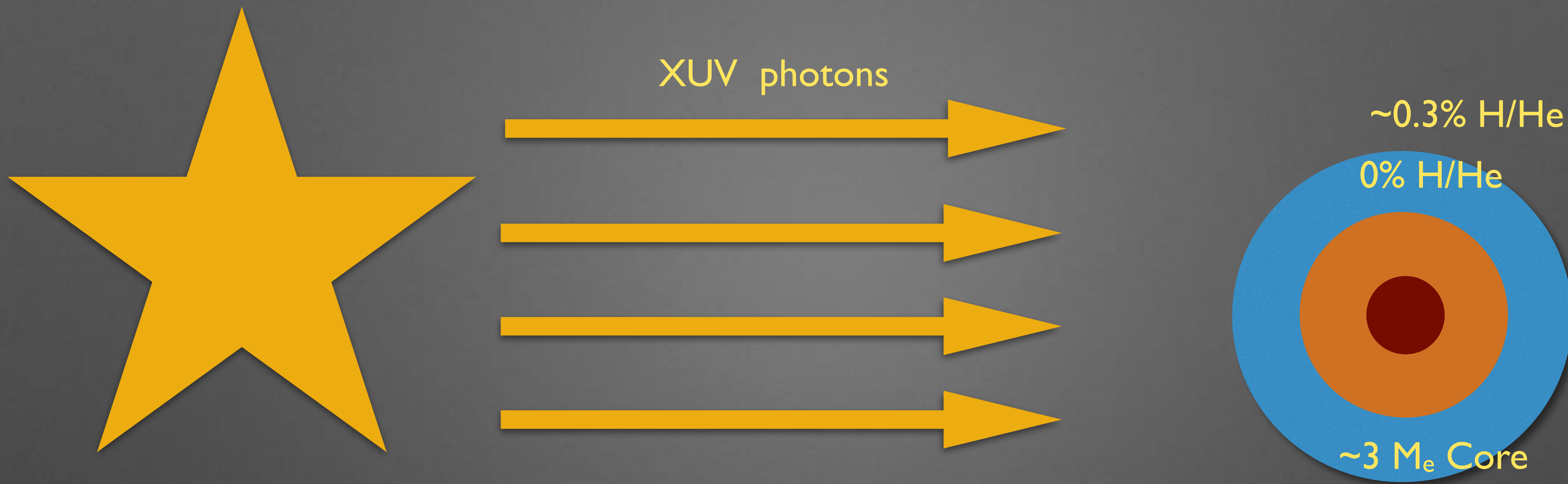


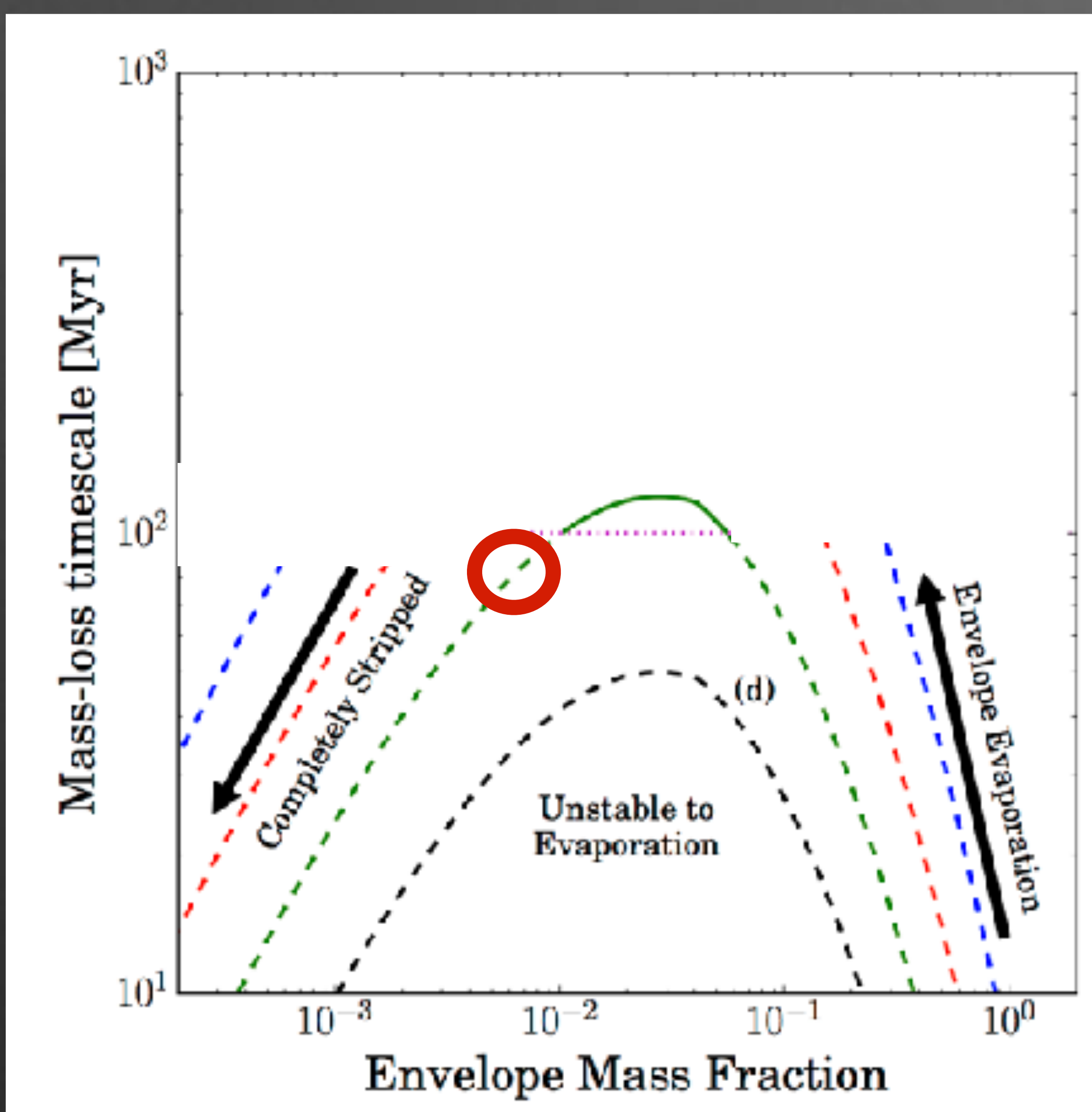
Mass-loss timescale [Myr]
Envelope Mass Fraction
10^1
10^2
10^3
10^{-3}
10^{-2}
10^{-1}
10^0
Completely Stripped
Envelope Evaporation
Unstable to Evaporation
(d)

Oewn & Wu (2017)



Number of Planets per Star
(Orbital period < 100 days)
Planet Size [Earth radii]
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.7
1.0
1.3
1.8
2.4
3.5
4.5
6.0
8.0
12.0
20.0
typical uncert.


XUV photons
~0.3% H/He
0% H/He
~3 Mₑ Core
~3 Mₑ Core


Mass-loss timescale [Myr]
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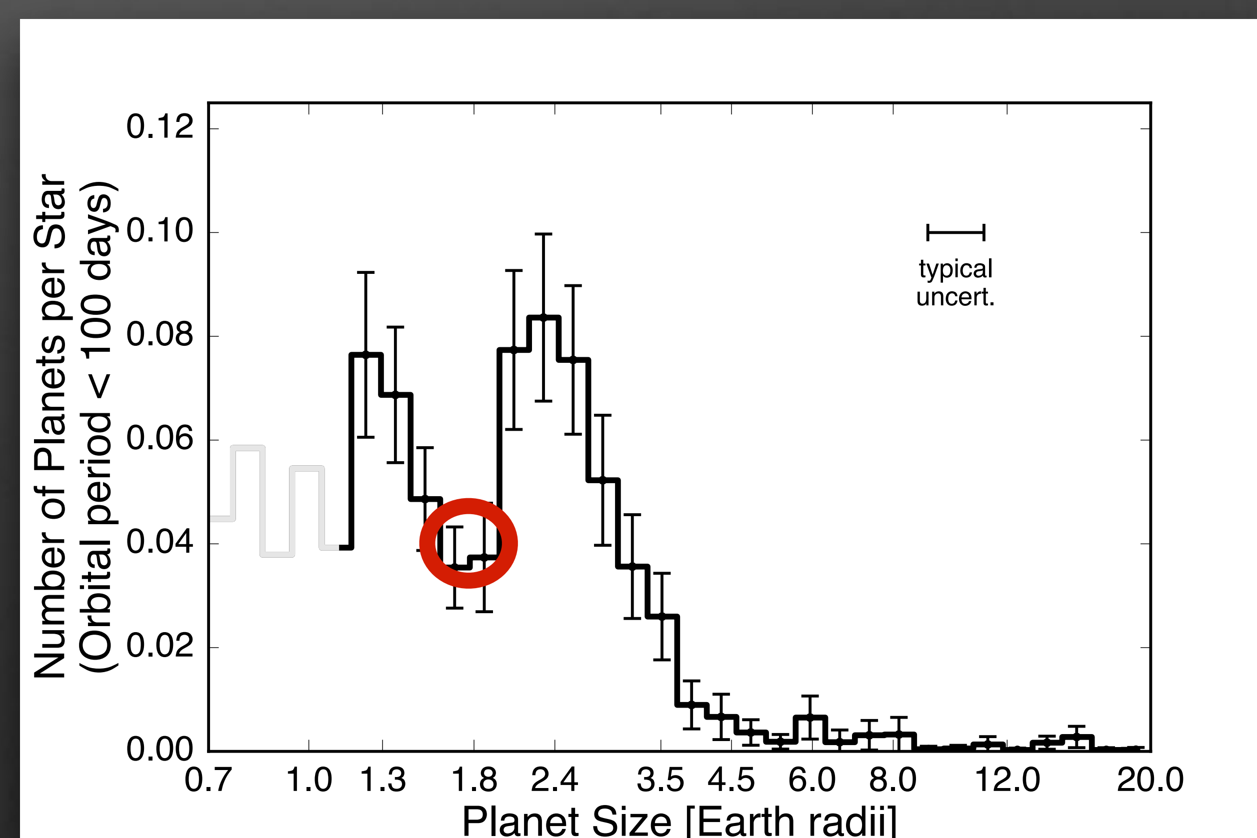
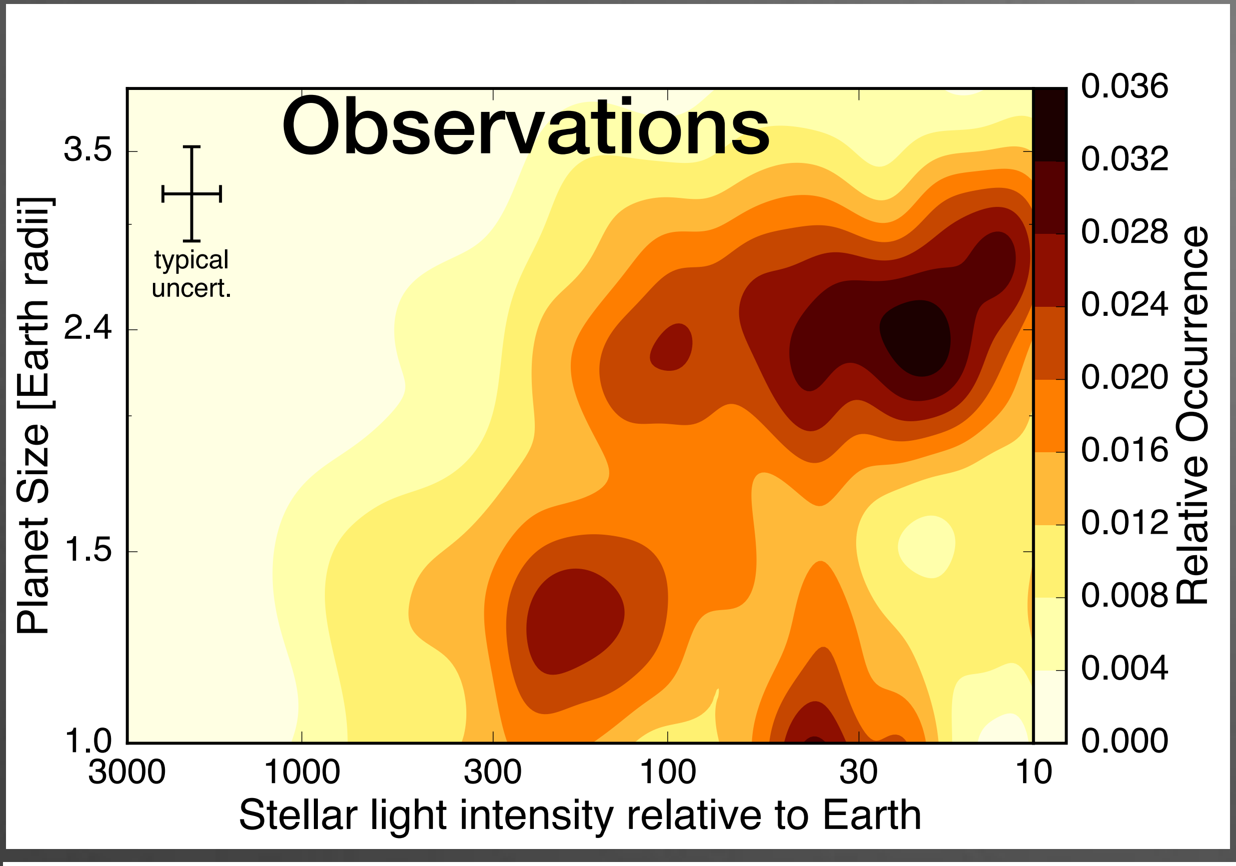
10^2
10^1
Completely Stripped
(d)
Unstable to Evaporation
Envelope Evaporation
10^{-3}
10^{-2}
10^{-1}
10^0
Envelope Mass Fraction

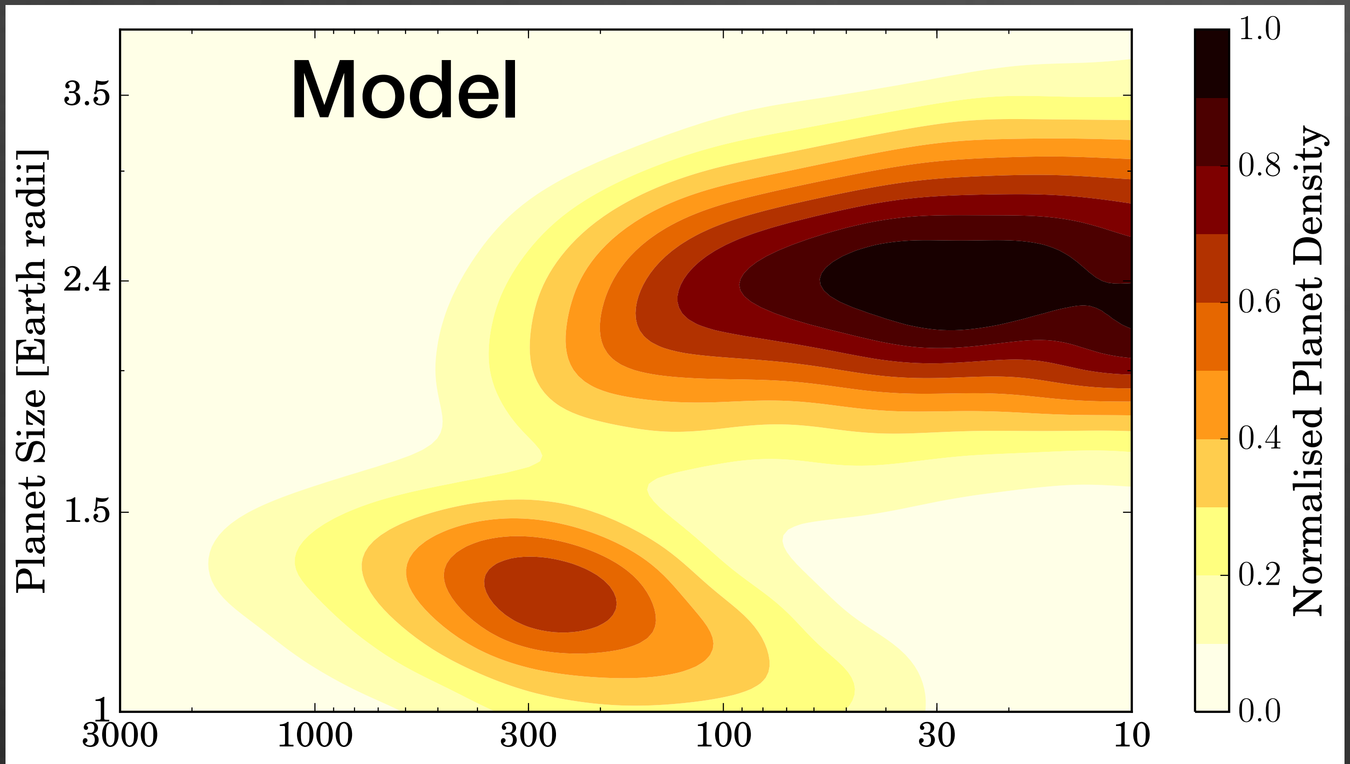
Oewn & Wu (2017)


Number of Planets per Star
(Orbital period < 100 days)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
typical
uncert.
0.7
1.0
1.3
1.8
2.4
3.5
4.5
6.0
8.0
12.0
20.0
Planet Size [Earth radii]

Photoevaporation

Fulton et al. (*2017*)

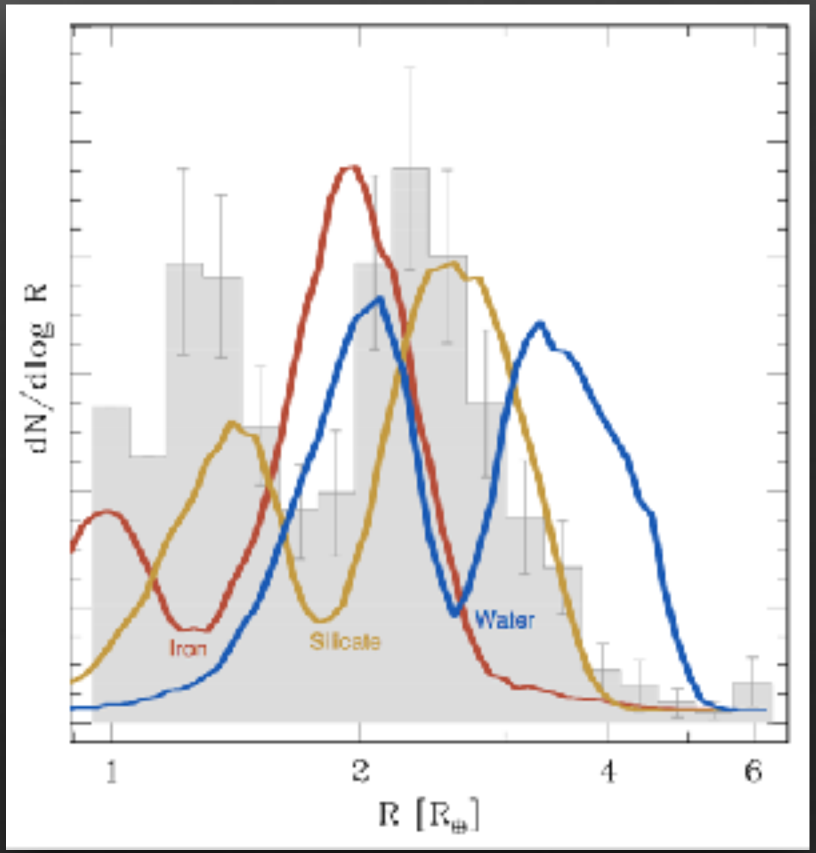




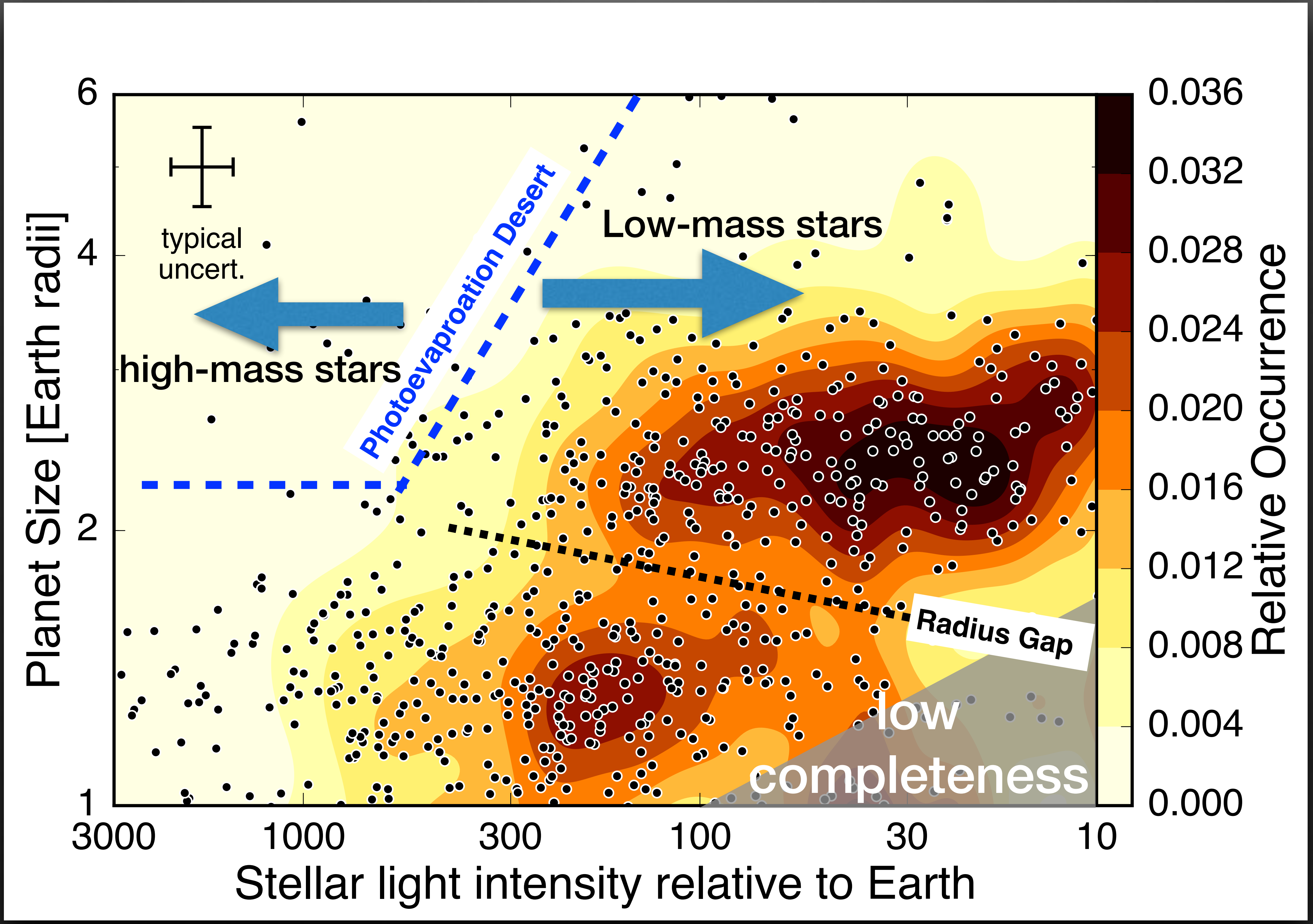
Owen & Wu (2017)

Major Implications

- Constrains core mass distribution
- Earth-density cores (water-poor)
- Large scale migration after 100 Myr is uncommon

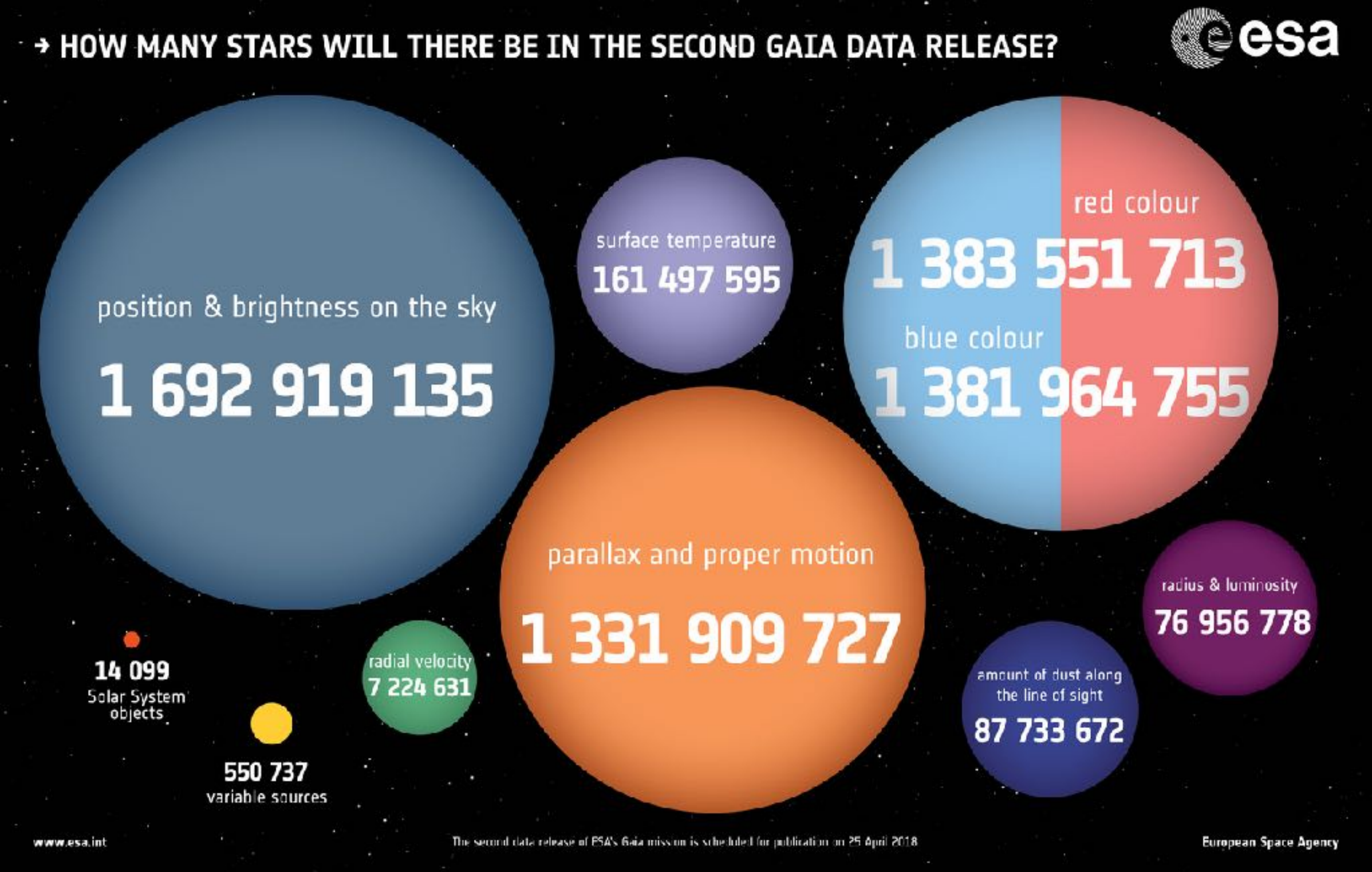


Flux Dependency

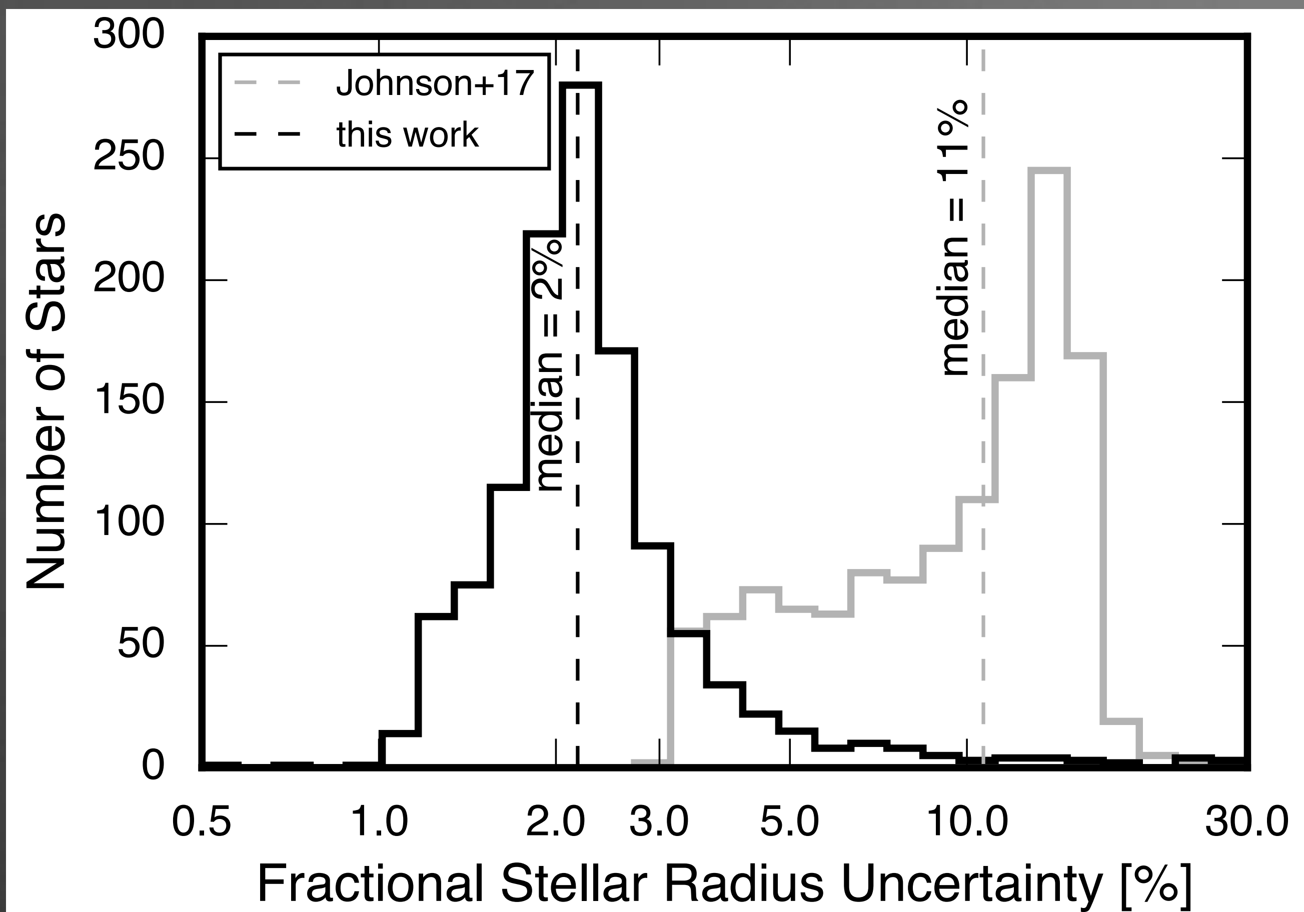


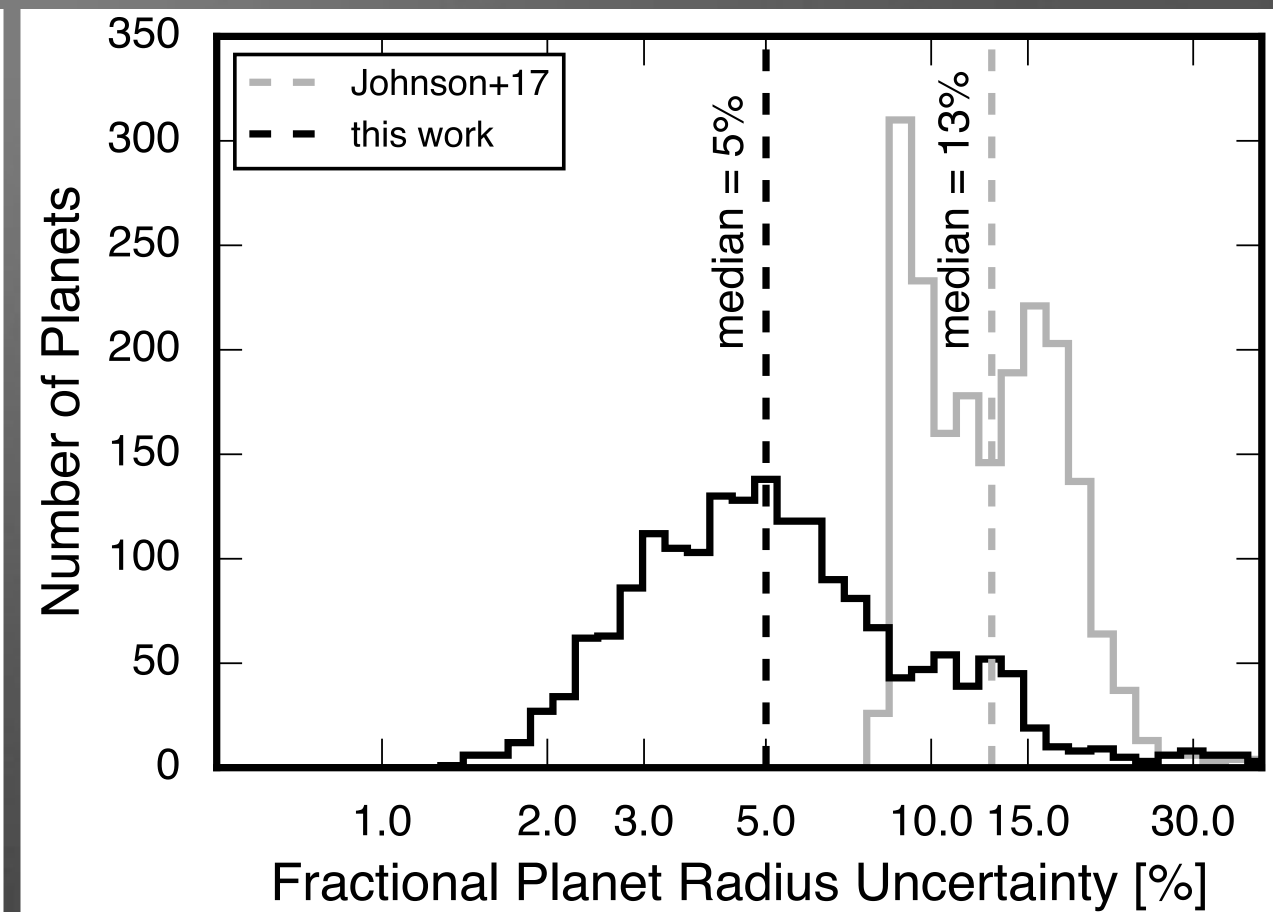
Fulton, et al. (2017)

Gaia DR2


→ HOW MANY STARS WILL THERE BE IN THE SECOND GAIA DATA RELEASE?
esa
position & brightness on the sky
1 692 919 135
surface temperature
161 497 595
red colour
1 383 551 713
blue colour
1 381 964 755
parallax and proper motion
1 331 909 727
radius & luminosity
76 956 778
amount of dust along the line of sight
87 733 672
radial velocity
7 224 631
14 099
Solar System objects
550 737
variable sources
www.esa.int
The second data release of ESA's Gaia mission is scheduled for publication on 25 April 2018
European Space Agency

Spectroscopy + Parallax





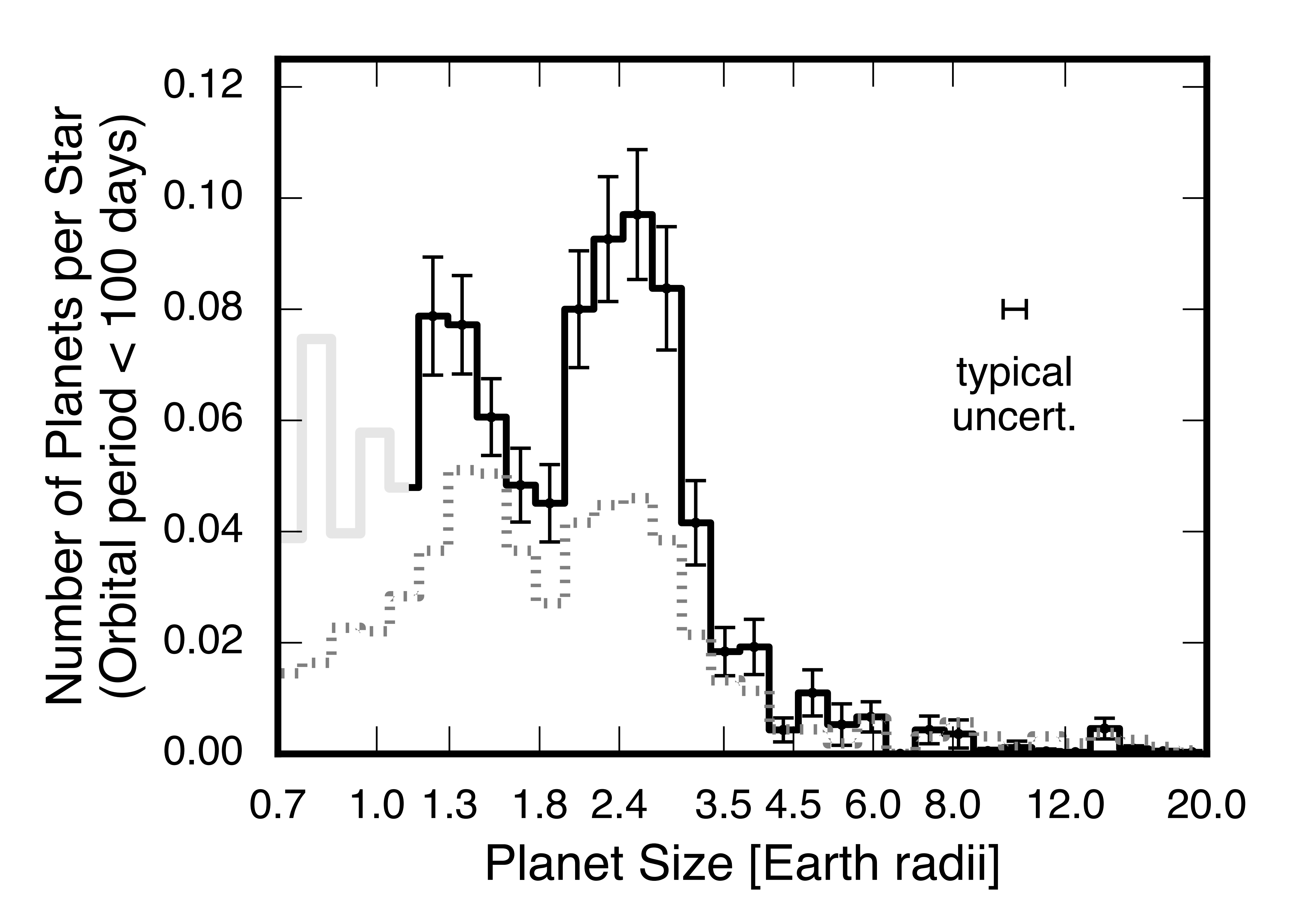
Fulton & Petigura (2018)

Table 1. Error Budget

Parameter	Median Uncert.
$T_{\rm eff}$	60 K
m_K	0.02 mag
A_K	0.004 mag
μ	0.01 mag
BC	0.03 mag
$R_\star$	2.2%
$R_p/R_\star$	4.1%
R_p	4.9%

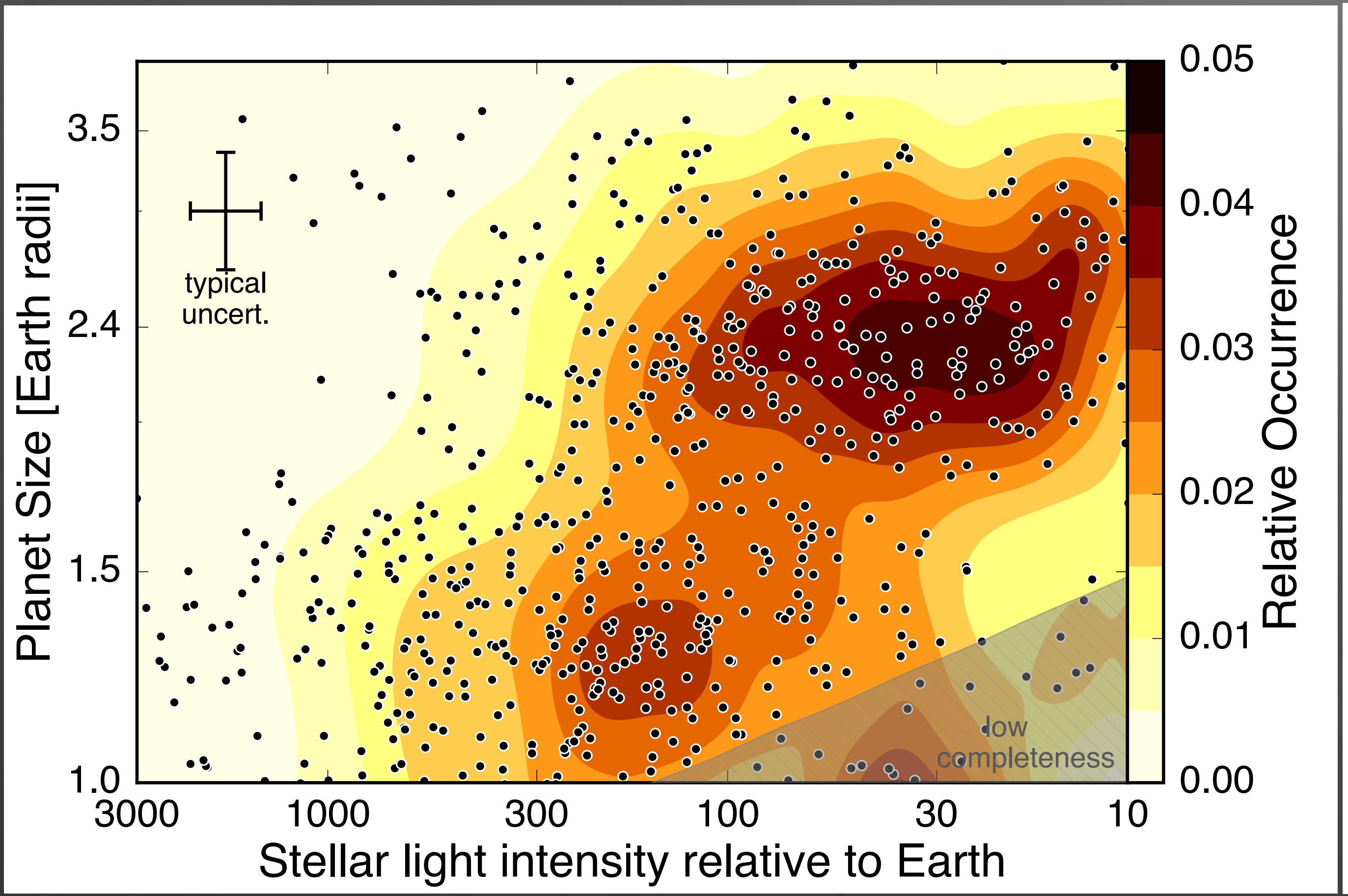
Updated stellar and planetary parameters available upon request prior to publication

Radius Distribution



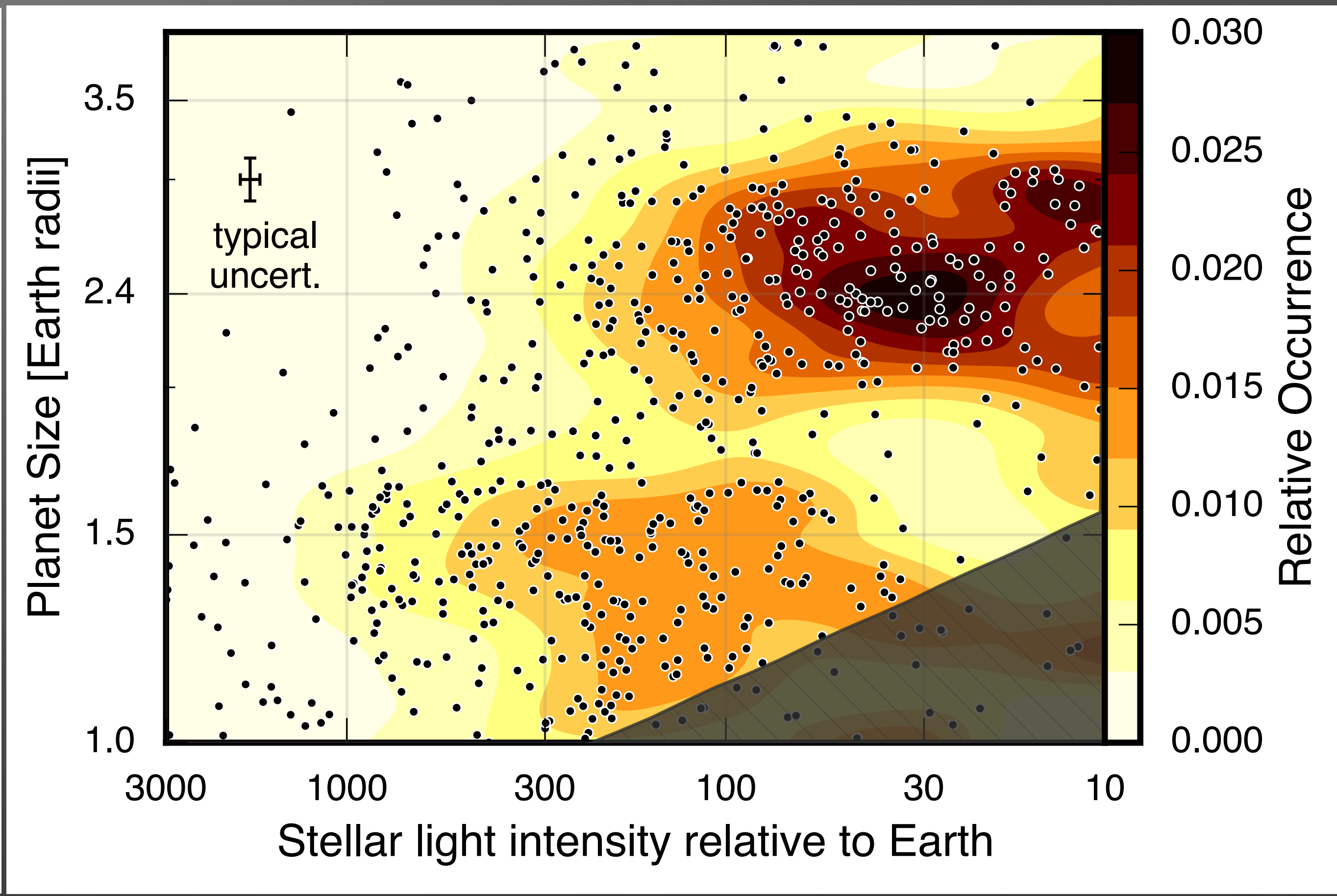
Radius Distribution

CKS Only



Fulton et al. (2017)

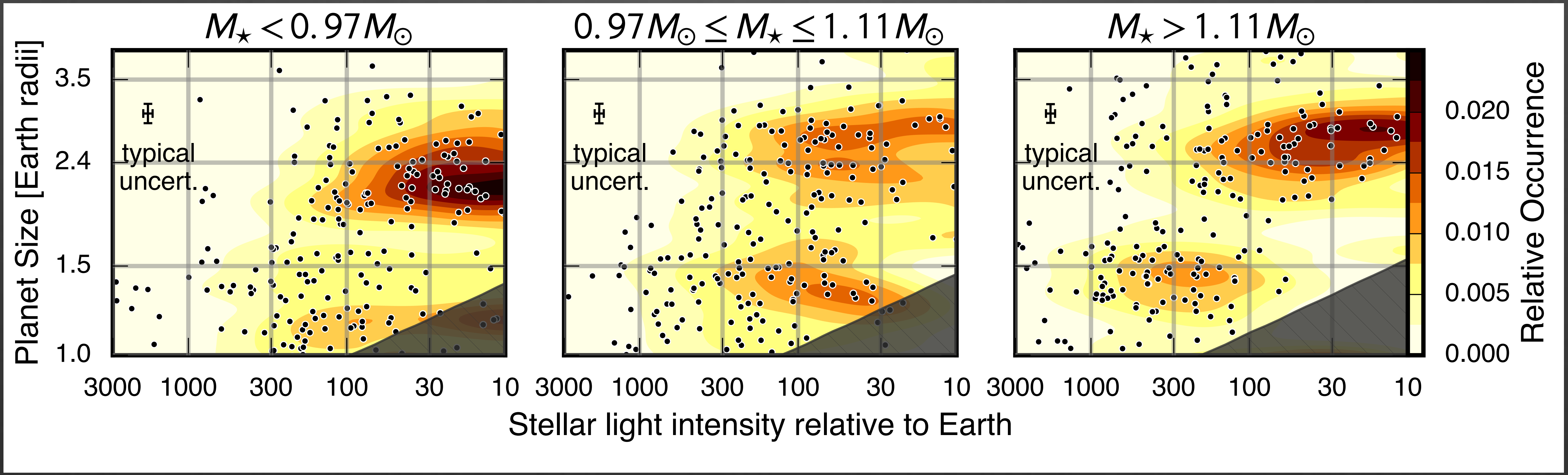
CKS + Gaia



Fulton & Petigura (2018)

Stellar Mass Dependence

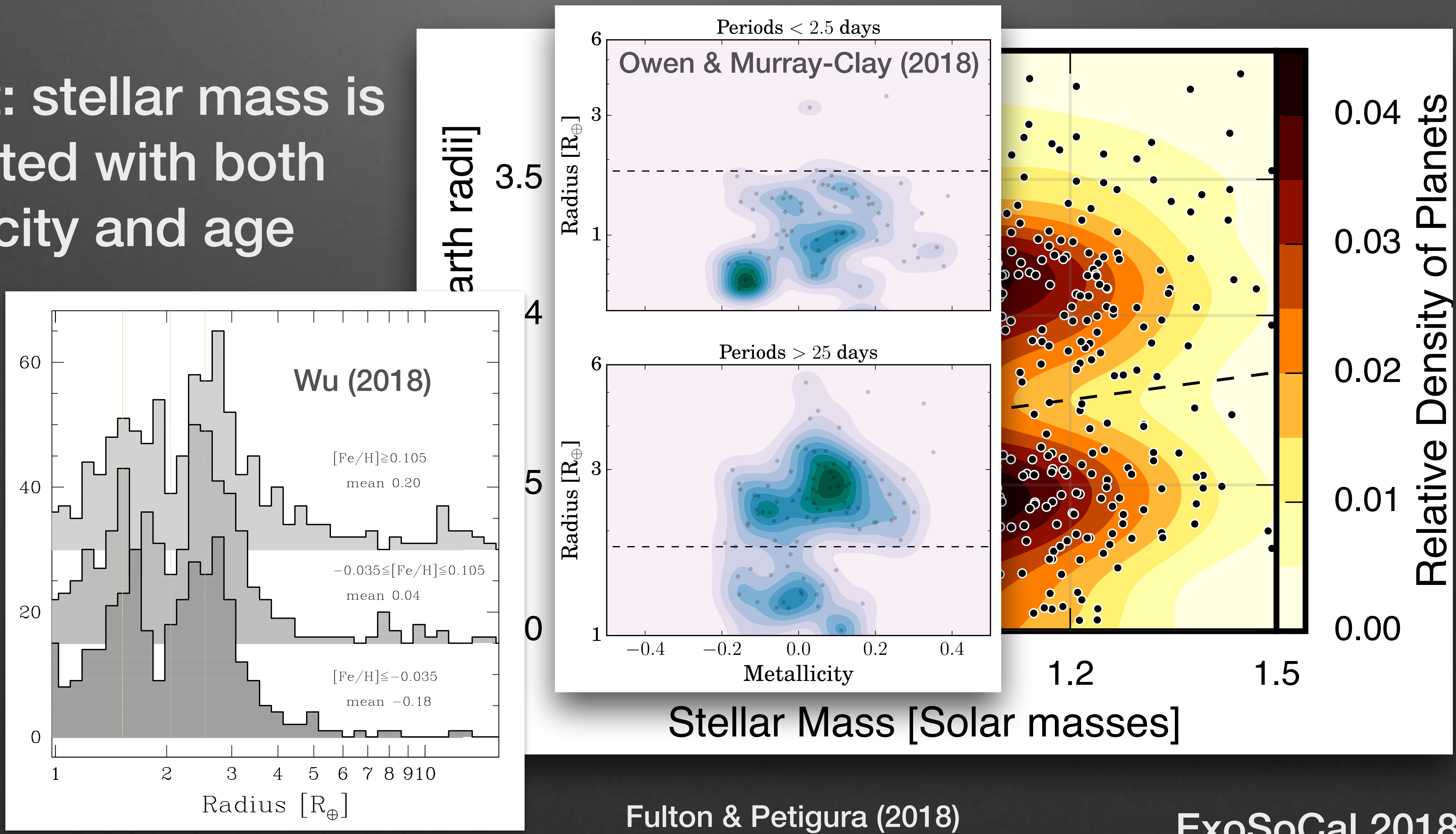
- Photoevaporation desert extends to lower fluxes for more massive stars
- Gap and planets are larger around more massive hosts
- Populations are split more cleanly when split up by mass
- Period distributions are indistinguishable



Fulton & Petigura (2018)

Stellar Mass Dependence

- Planets orbiting more massive stars are, on average, larger and hotter
- Caveat: stellar mass is correlated with both metallicity and age



Fulton & Petigura (2018)

Summary

Updated stellar and planetary radii using Gaia DR2

Table 1. Error Budget

Parameter	Median Uncert.
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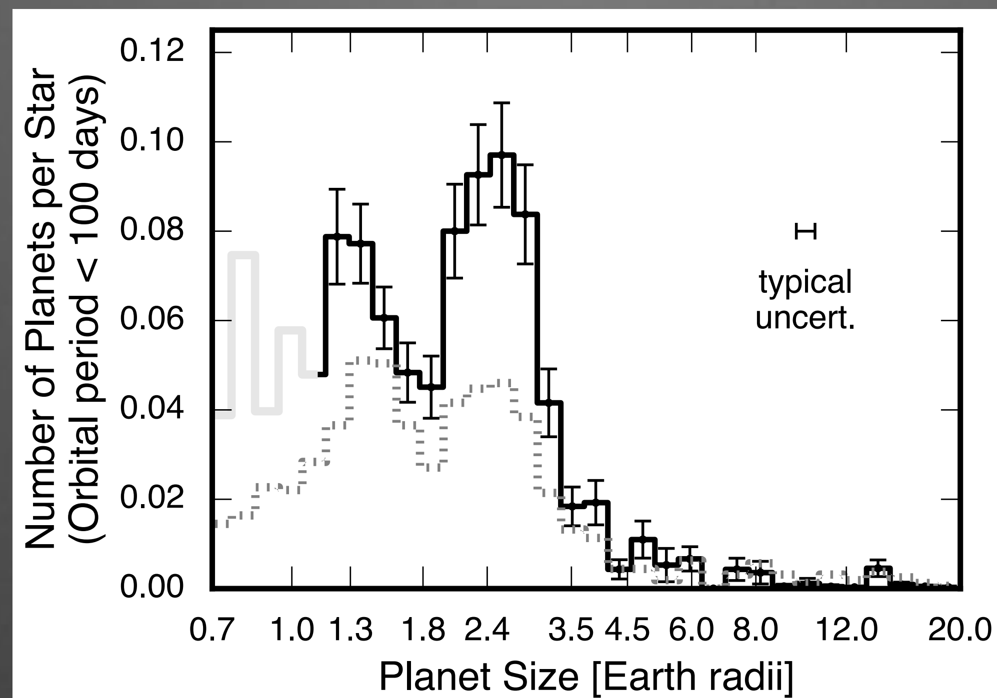
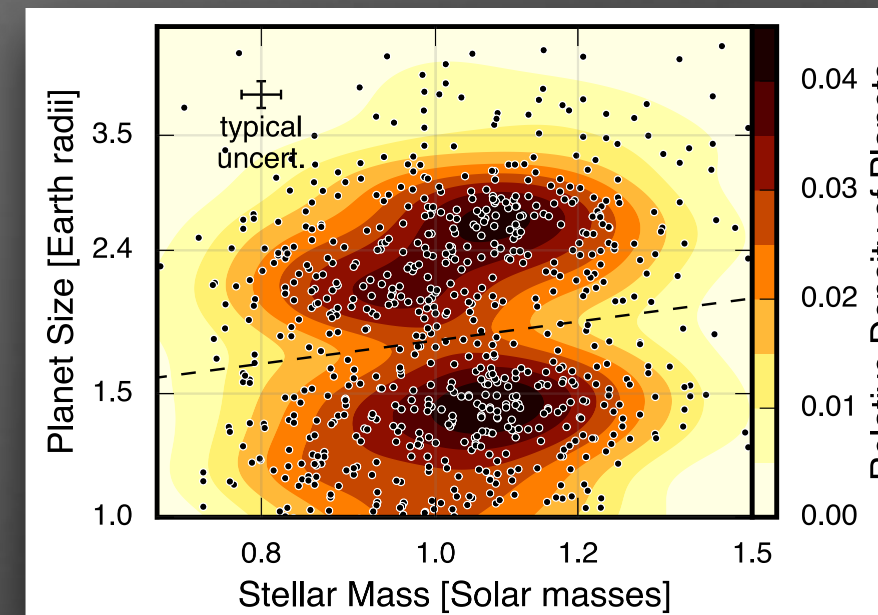
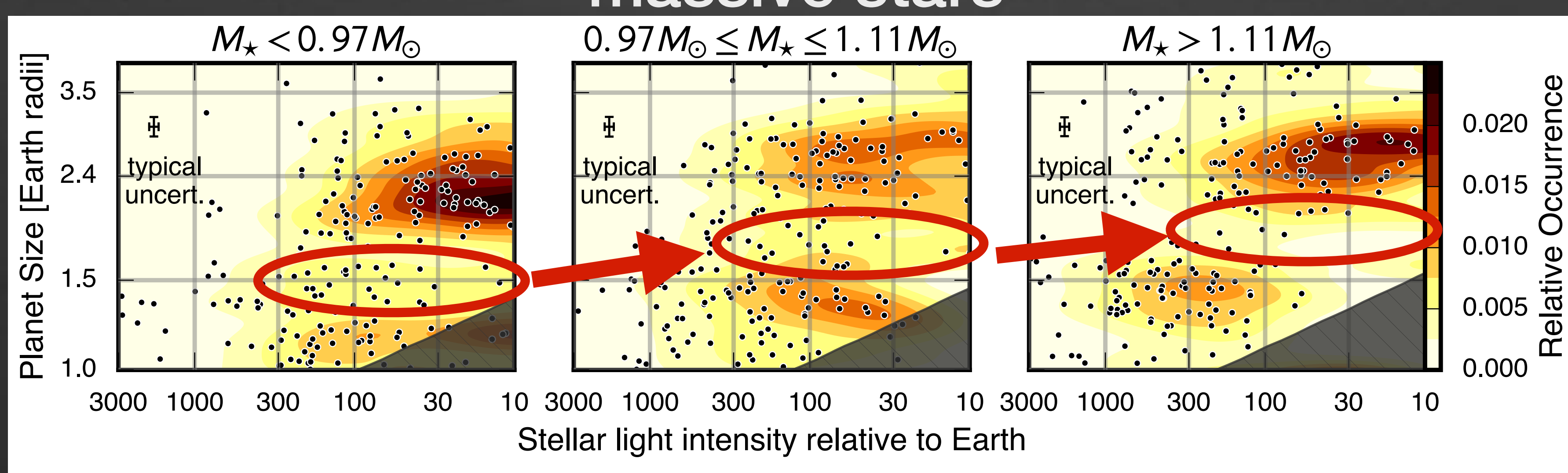
Little change to 1D radius distribution





More massive stars = larger and hotter planets

Gap widens and moves to larger radii for more massive stars



Backup Slides

Spectroscopy + Parallax

Stefan-Boltzmann Law

$$L_{\rm bol} = 4\pi R_\star^2 \sigma T_{\rm eff}^4$$

Teff from CKS spectra

$$R_\star = \left(\frac{L_{\rm bol}}{4\pi\sigma_{\rm sb} T_{\rm eff}^4} \right)^{1/2}$$

$$L_{\rm bol} = L_0 10^{-0.4 M_{\rm bol}}$$

$$M_{\rm bol} = m - A - \mu - BC$$

bolometric correction

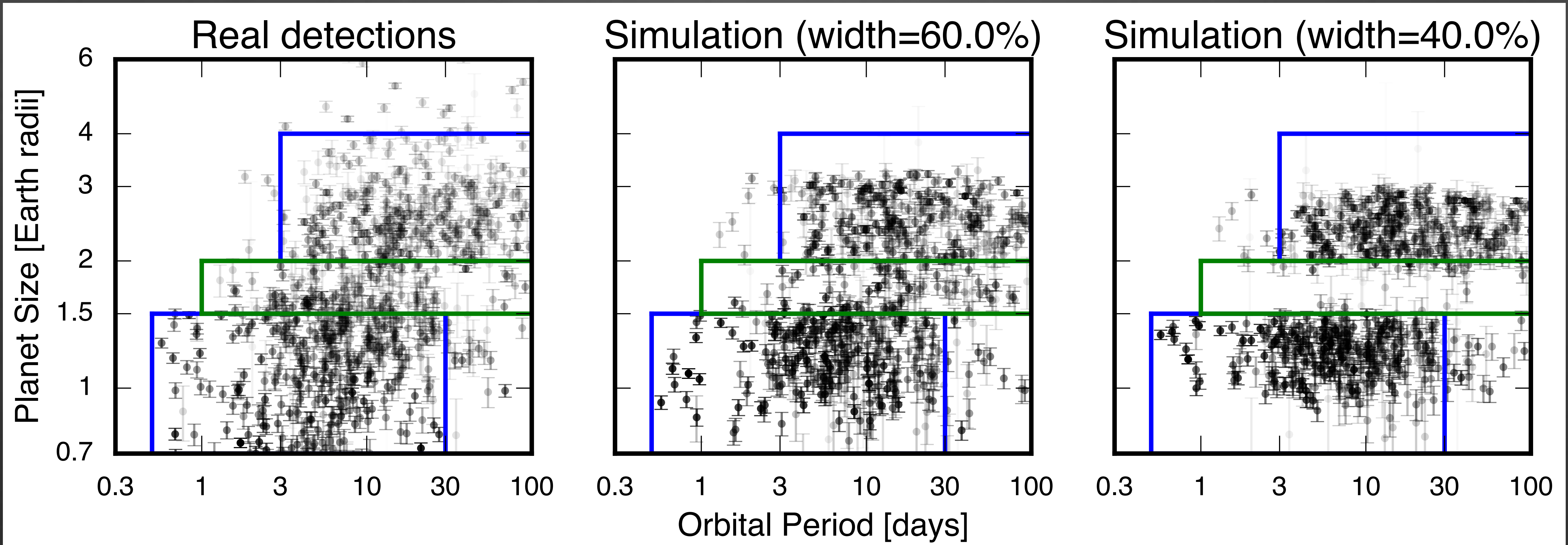
single mag

extinction

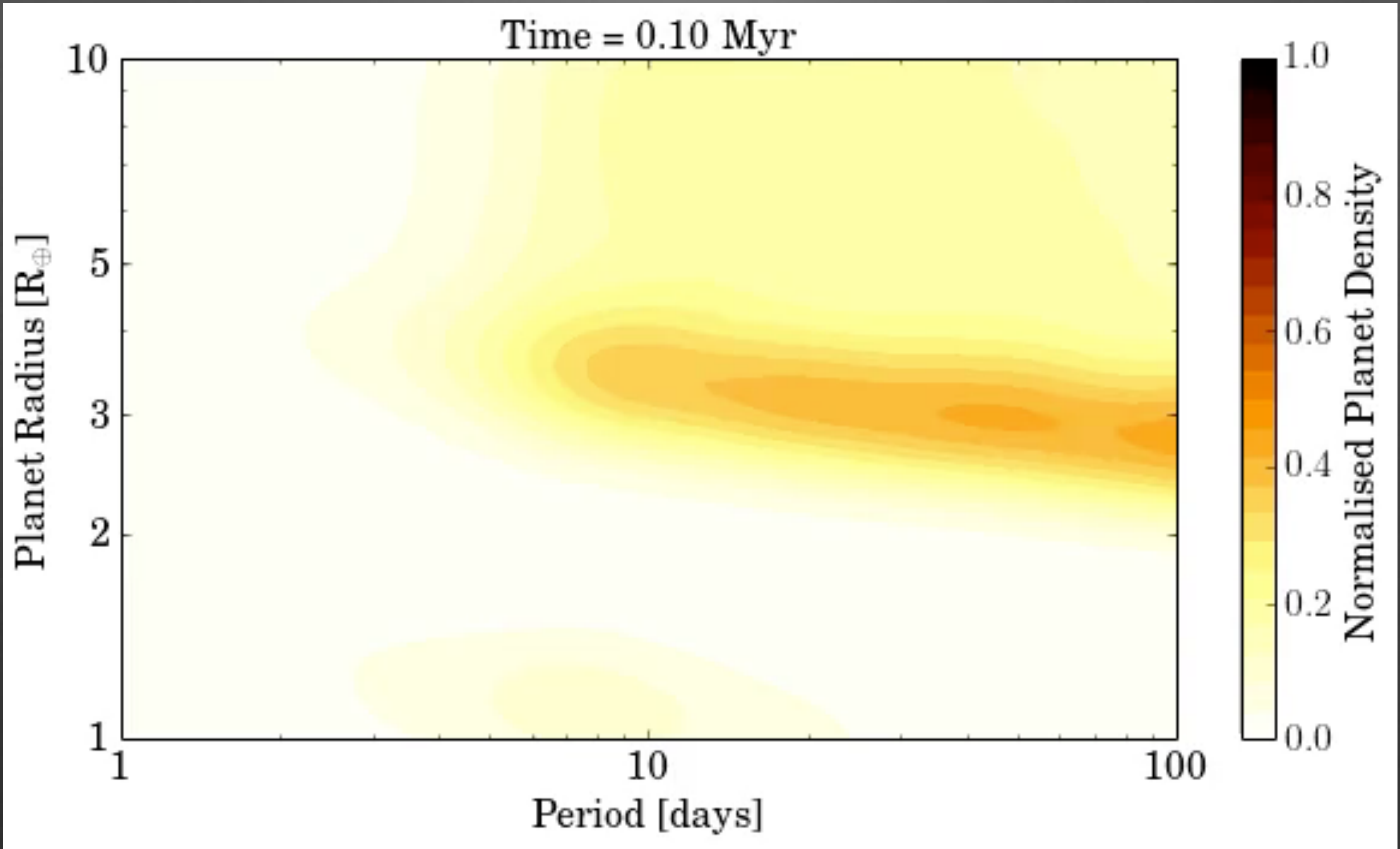
Distance mod. (parallax)

The Gap is Not Empty

- Simple toy model:
  - Count number of planets in several boxes
  - Simulate distributions of planets
  - Compare simulations to real detections



Photoevaporation



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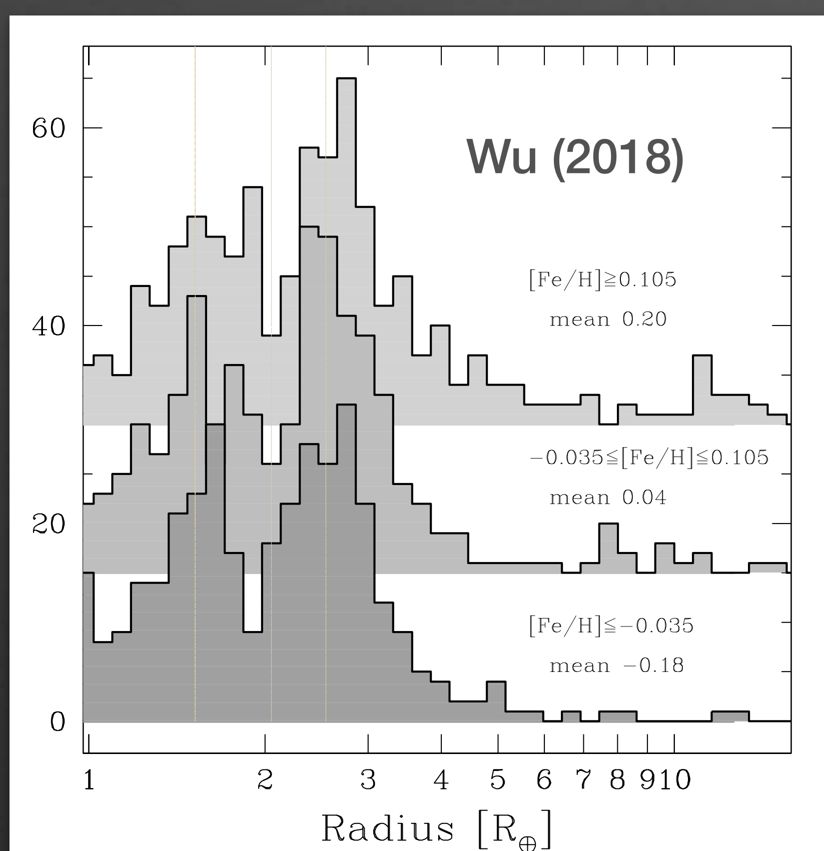
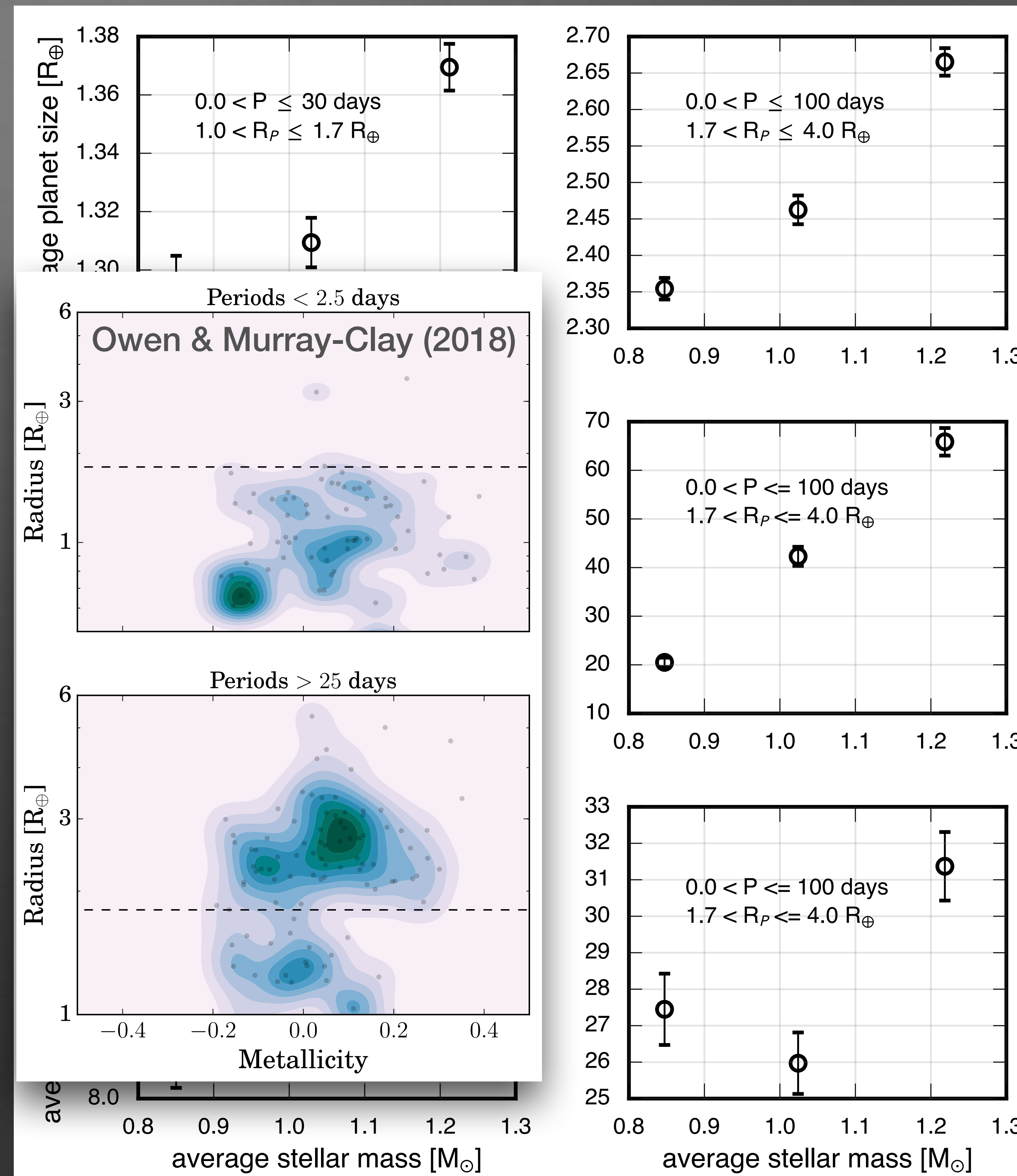
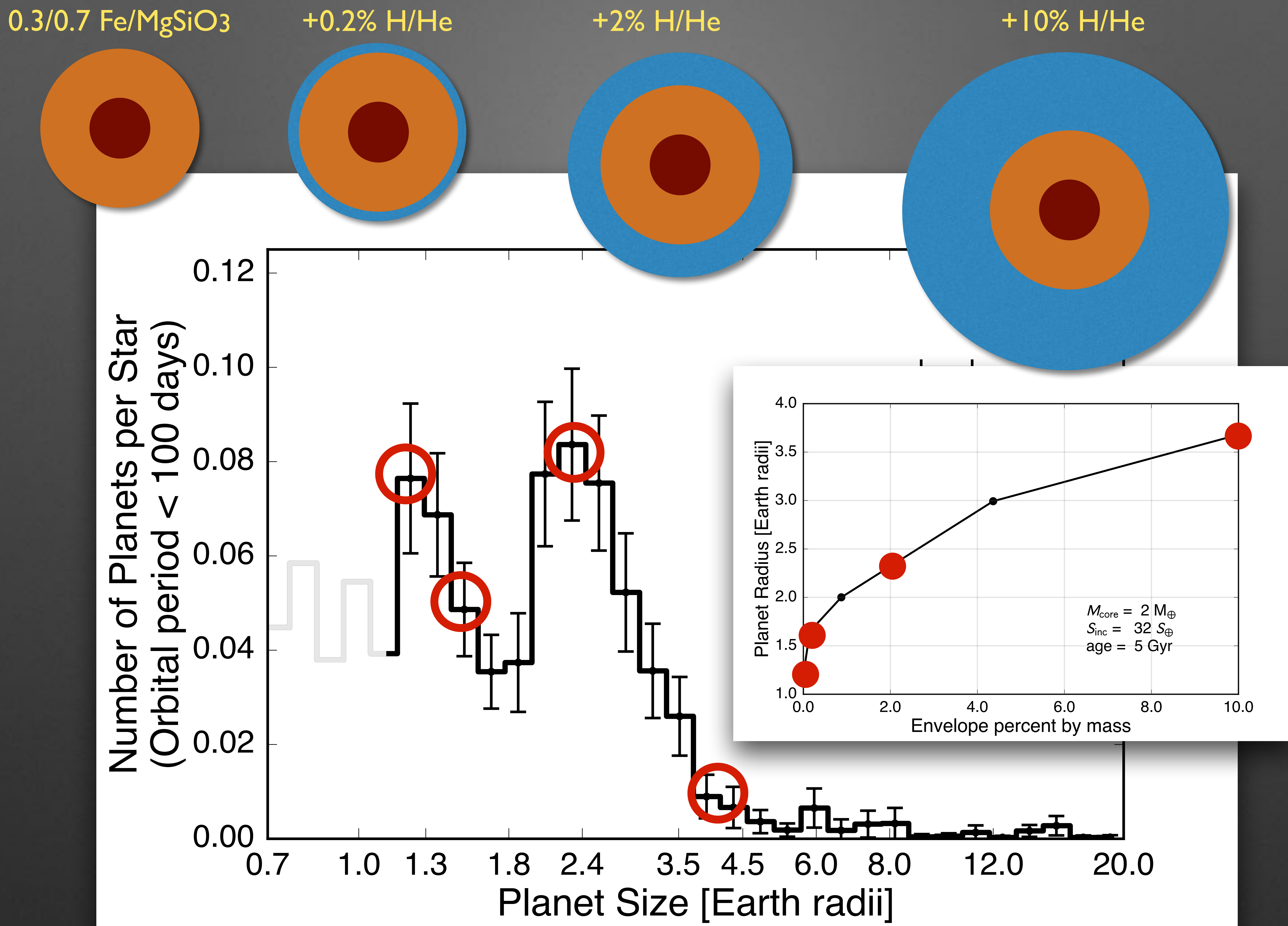


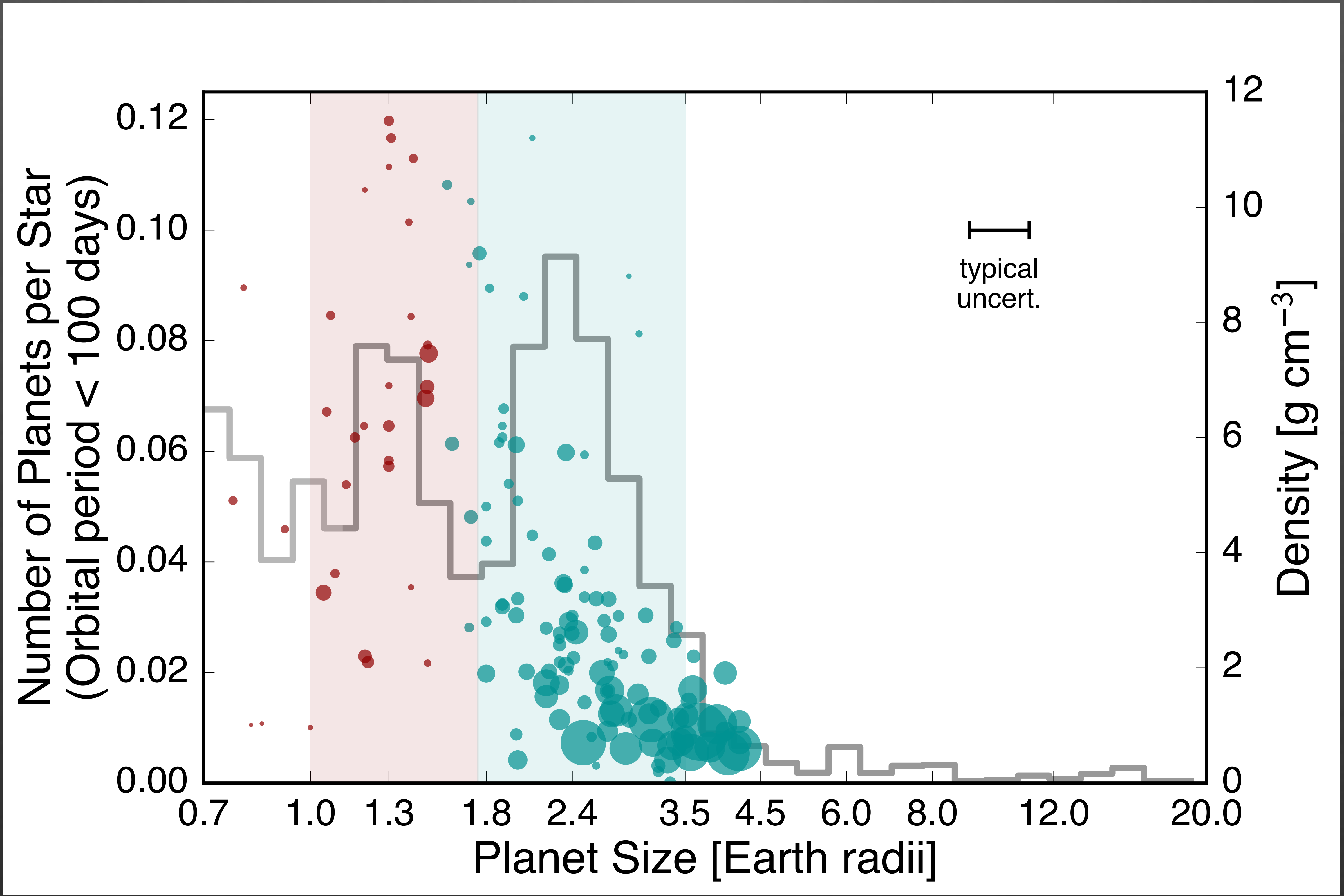


Fulton & Petigura (2018)

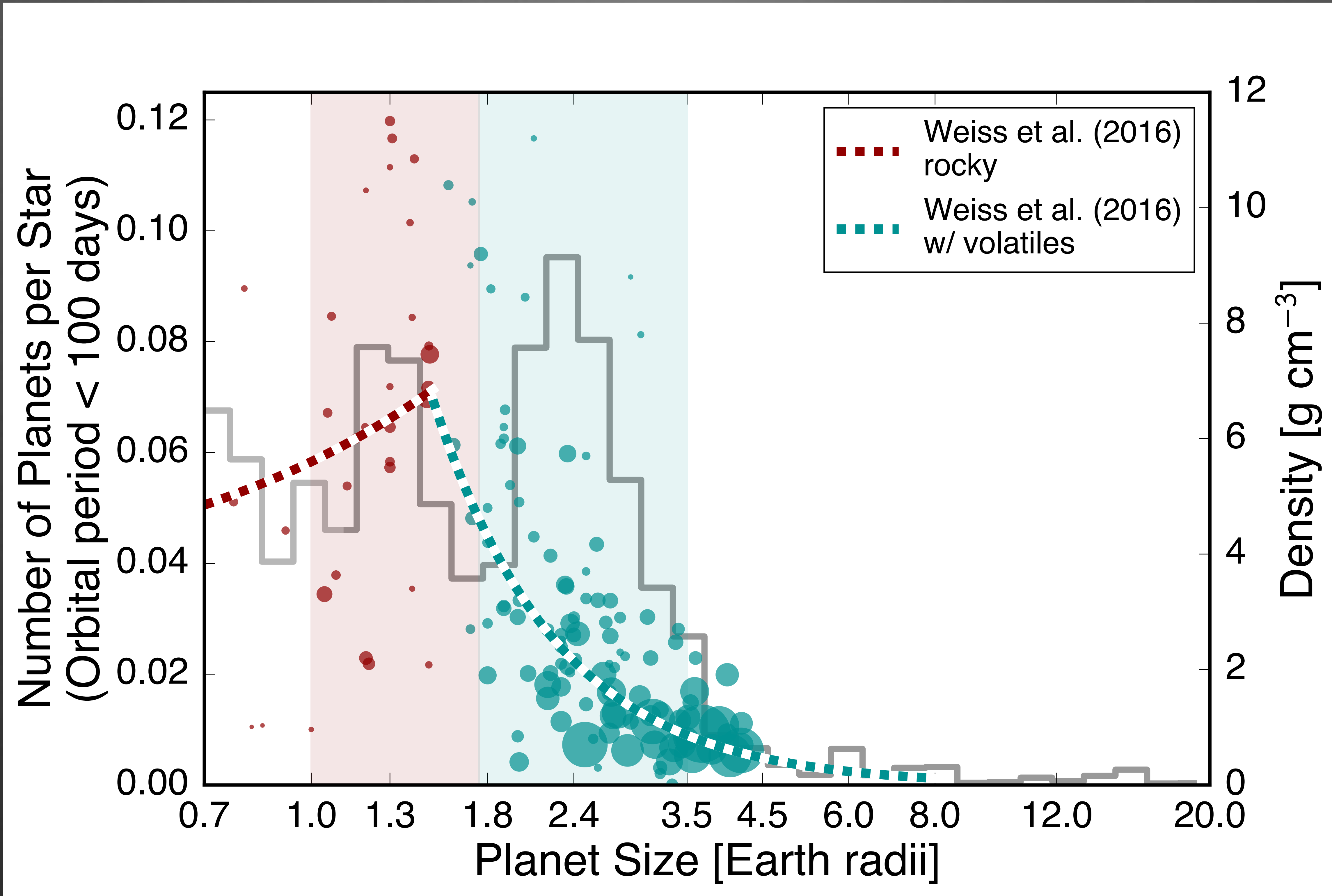


Fulton, Petigura, et al. (*submitted*)

The Radius Gap



The Radius Gap



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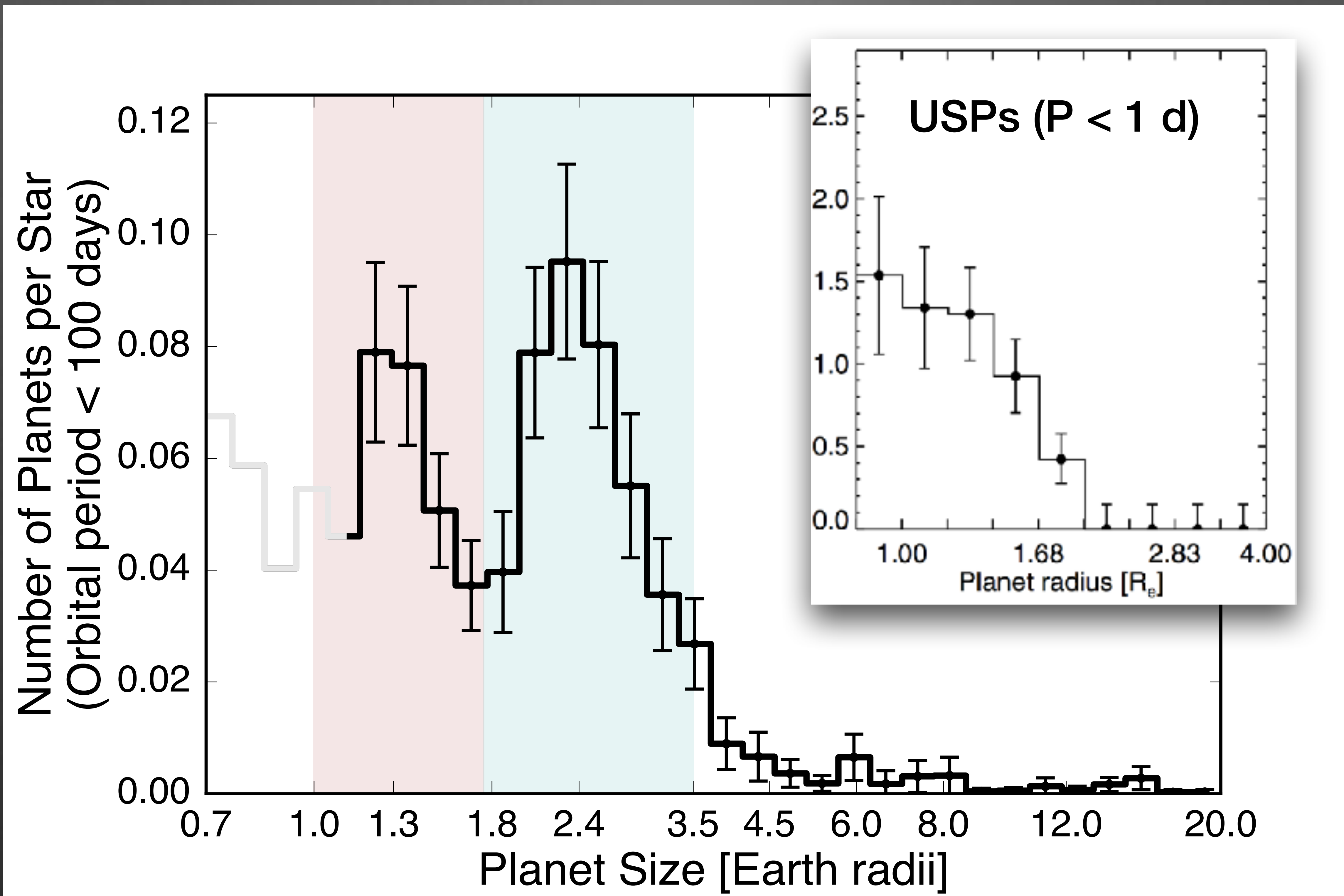

The Radius Gap