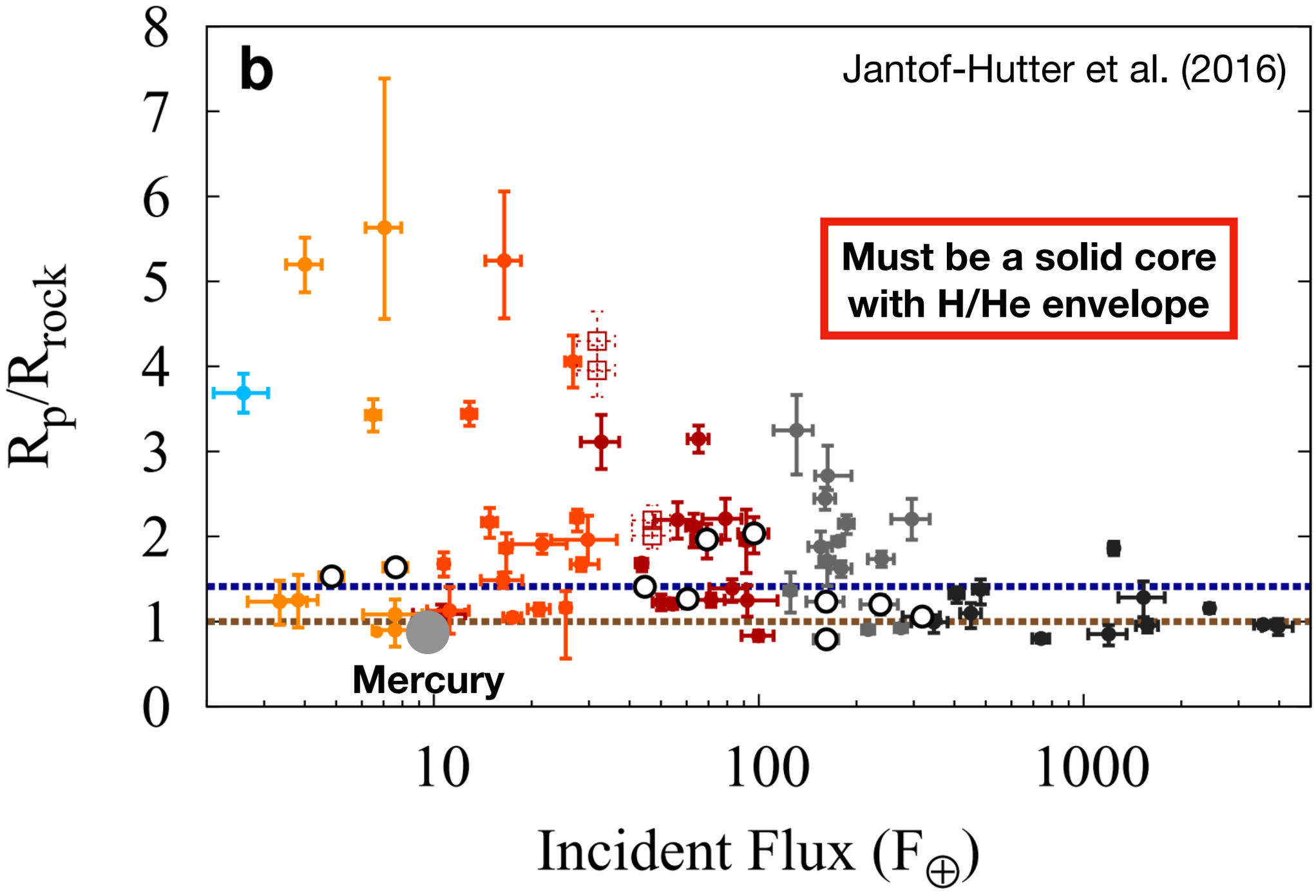
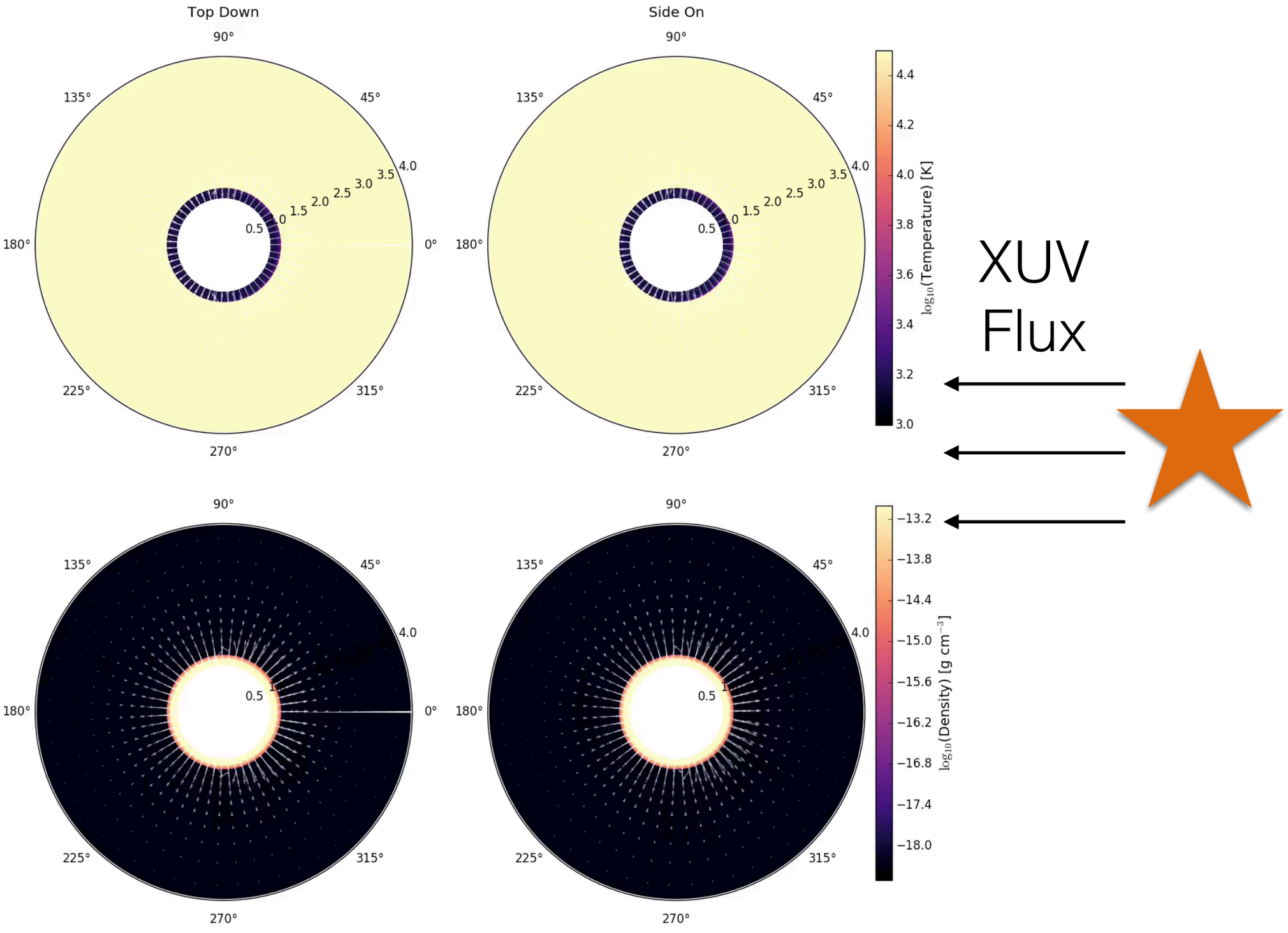
# Sculpting planet radii with atmospheric escape

James Owen (Imperial College London)
Yanqin Wu (Toronto)
Ruth Murray-Clay (UCSC)

# Trends with planet mass, radii and orbital separation



# Atmospheric escape: planet photoevaporation




XUV Flux

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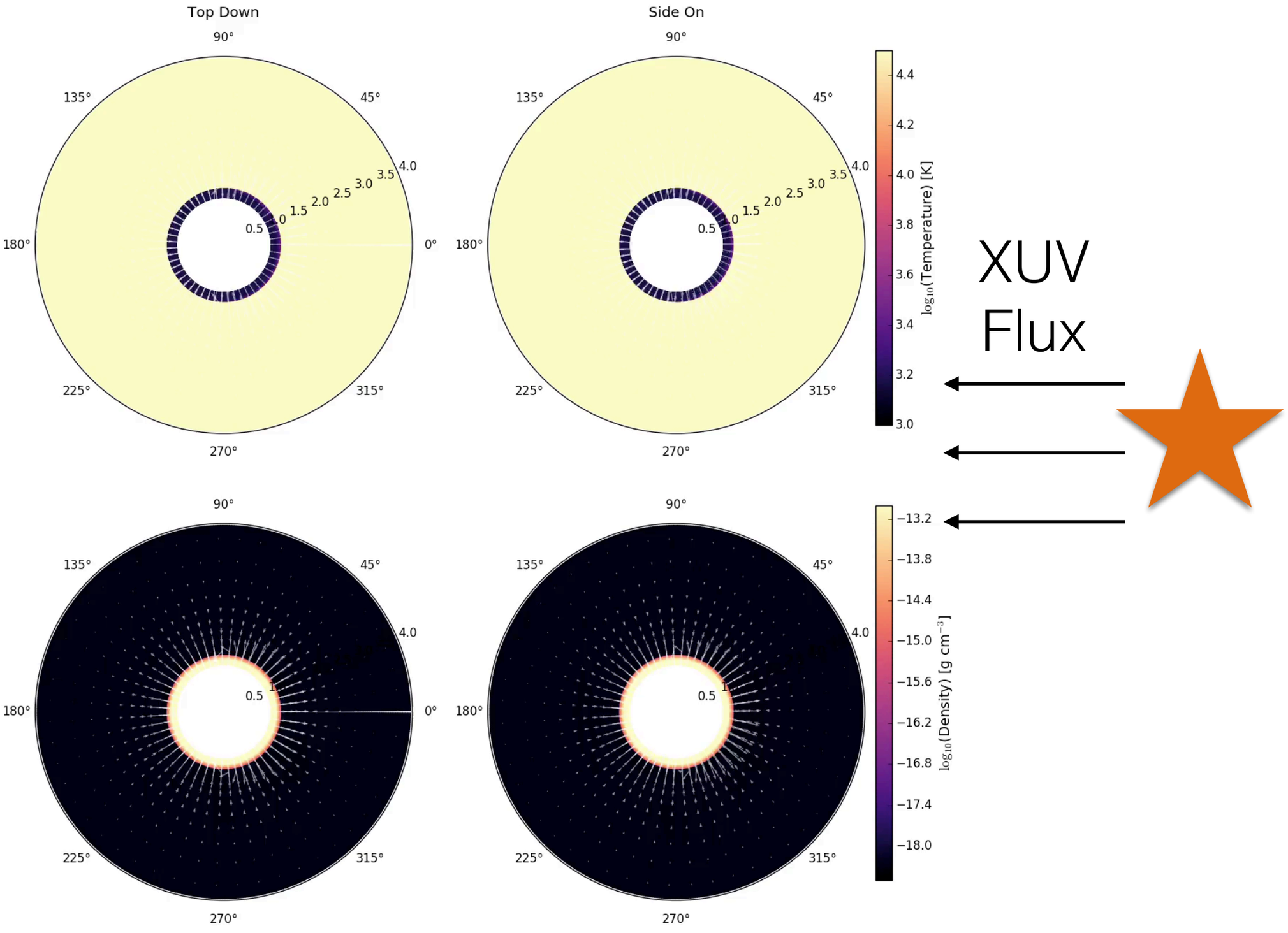
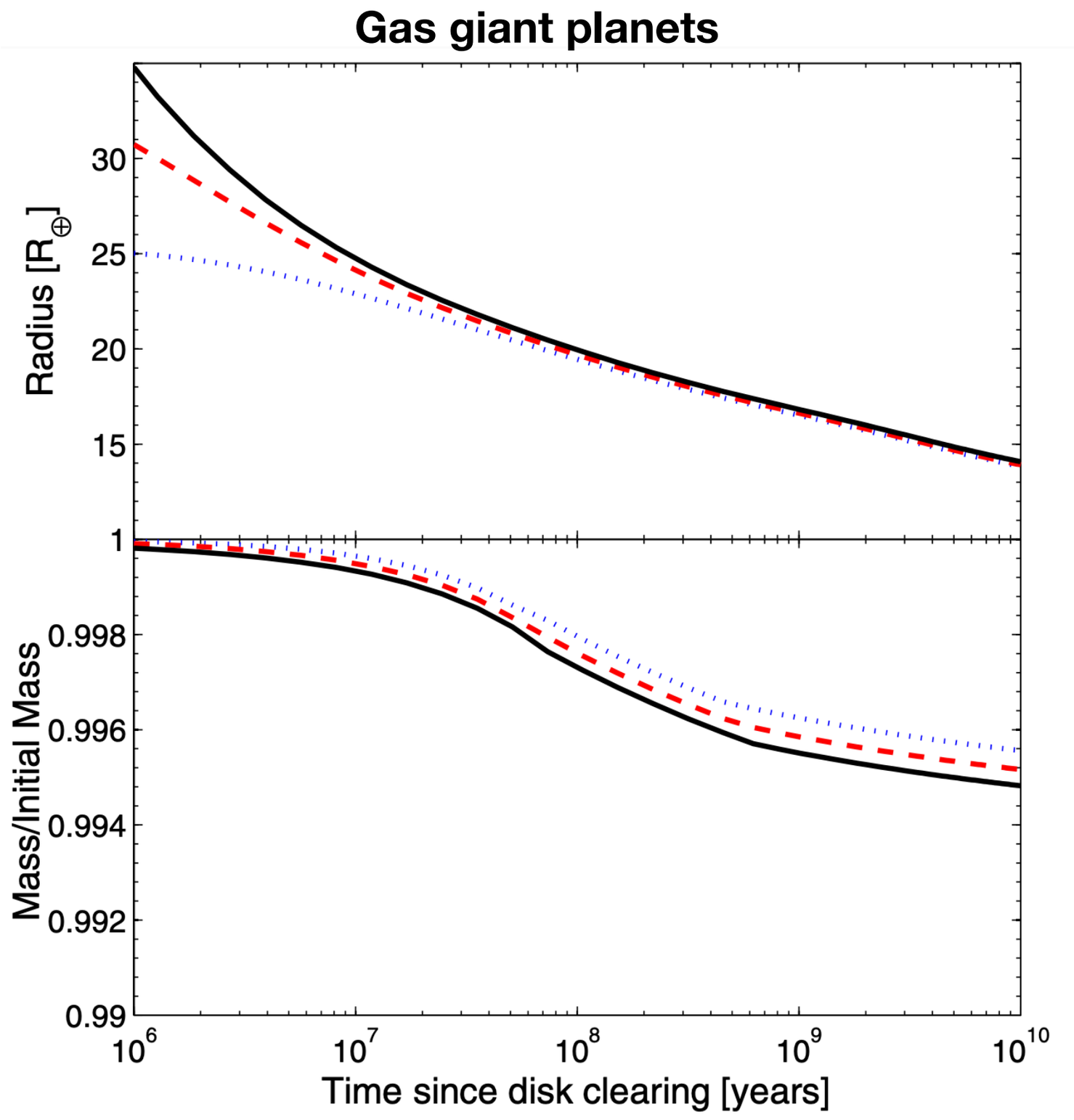



XUV Flux

# Mass-loss driven evolution



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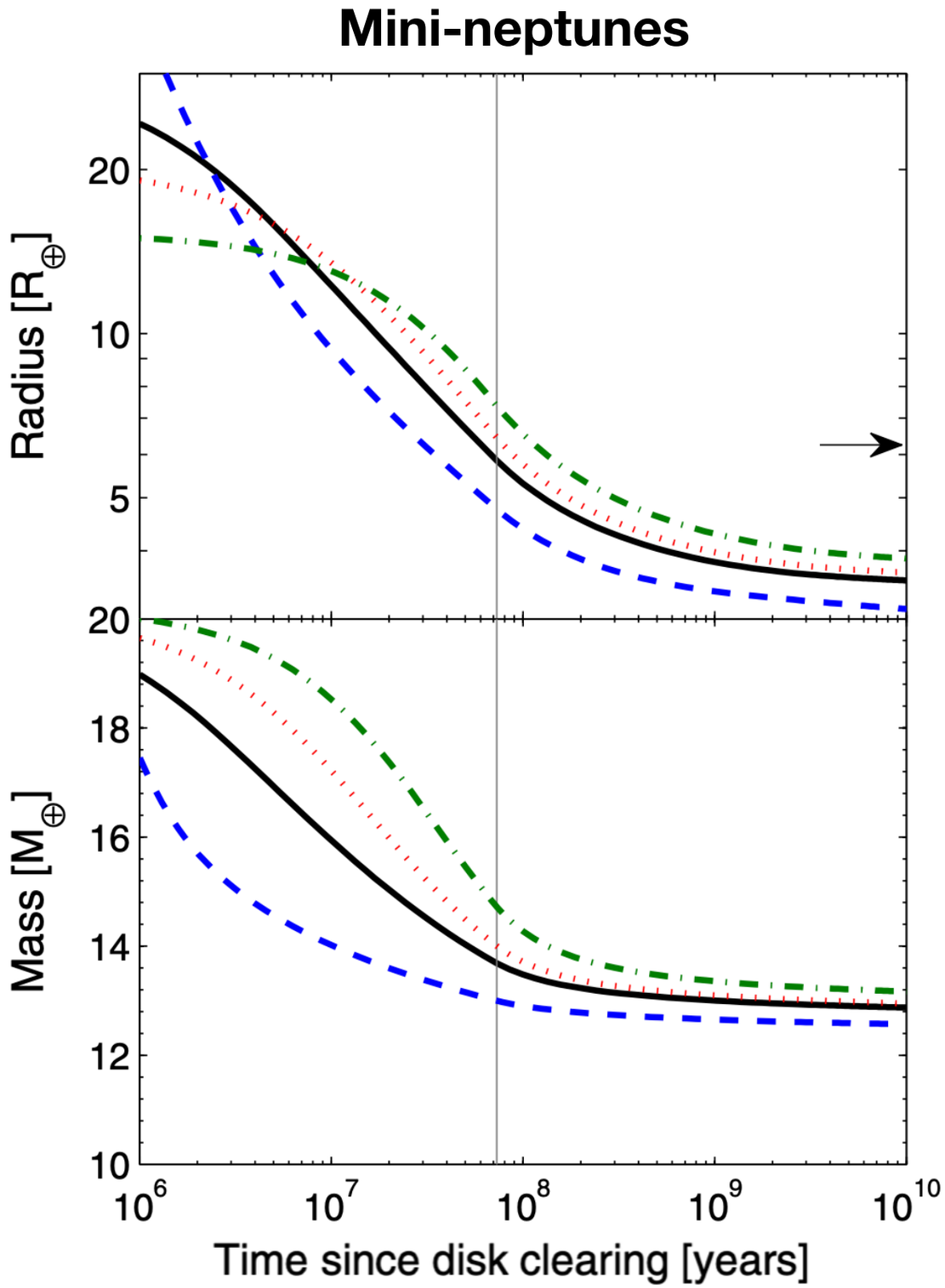
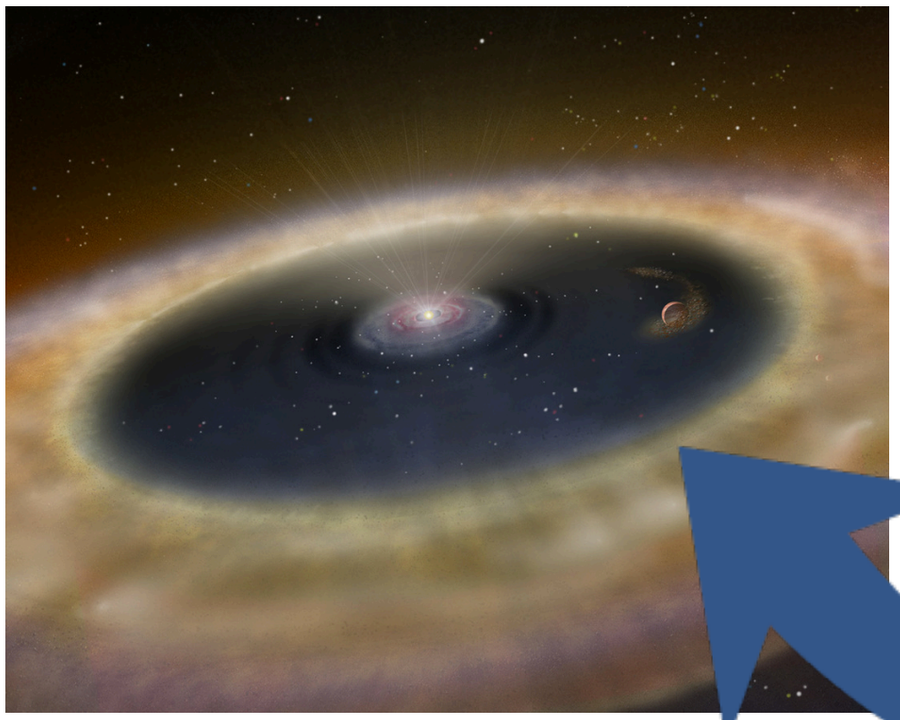
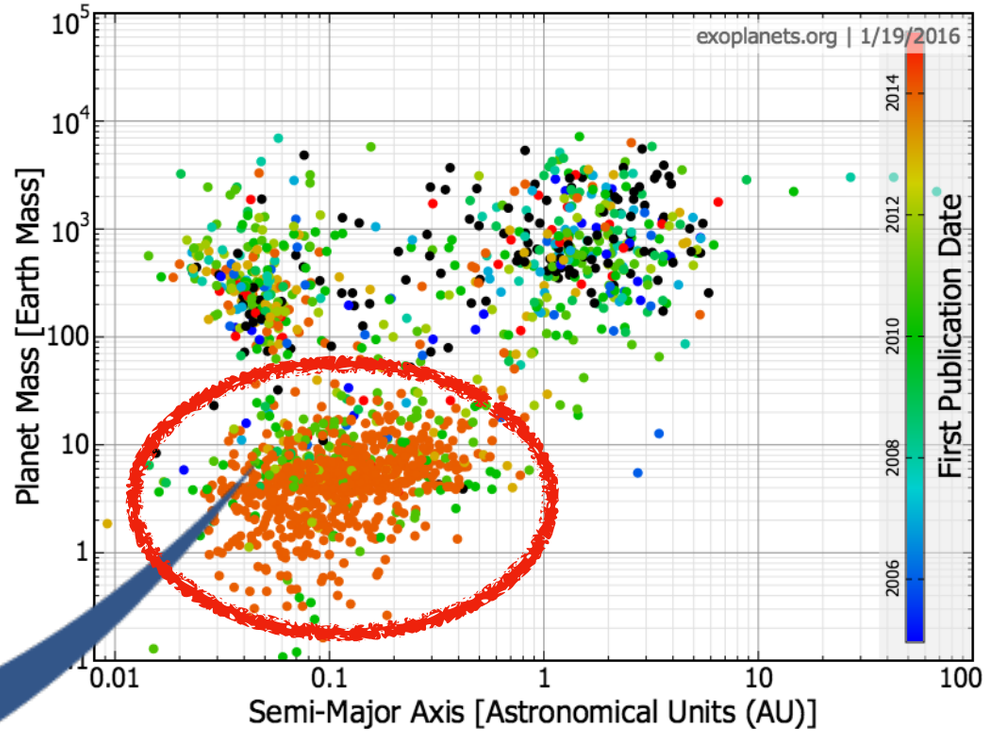


# Sculpting low-mass exoplanets with H/He atmospheres

**Planets at formation**



**Observed exoplanets**



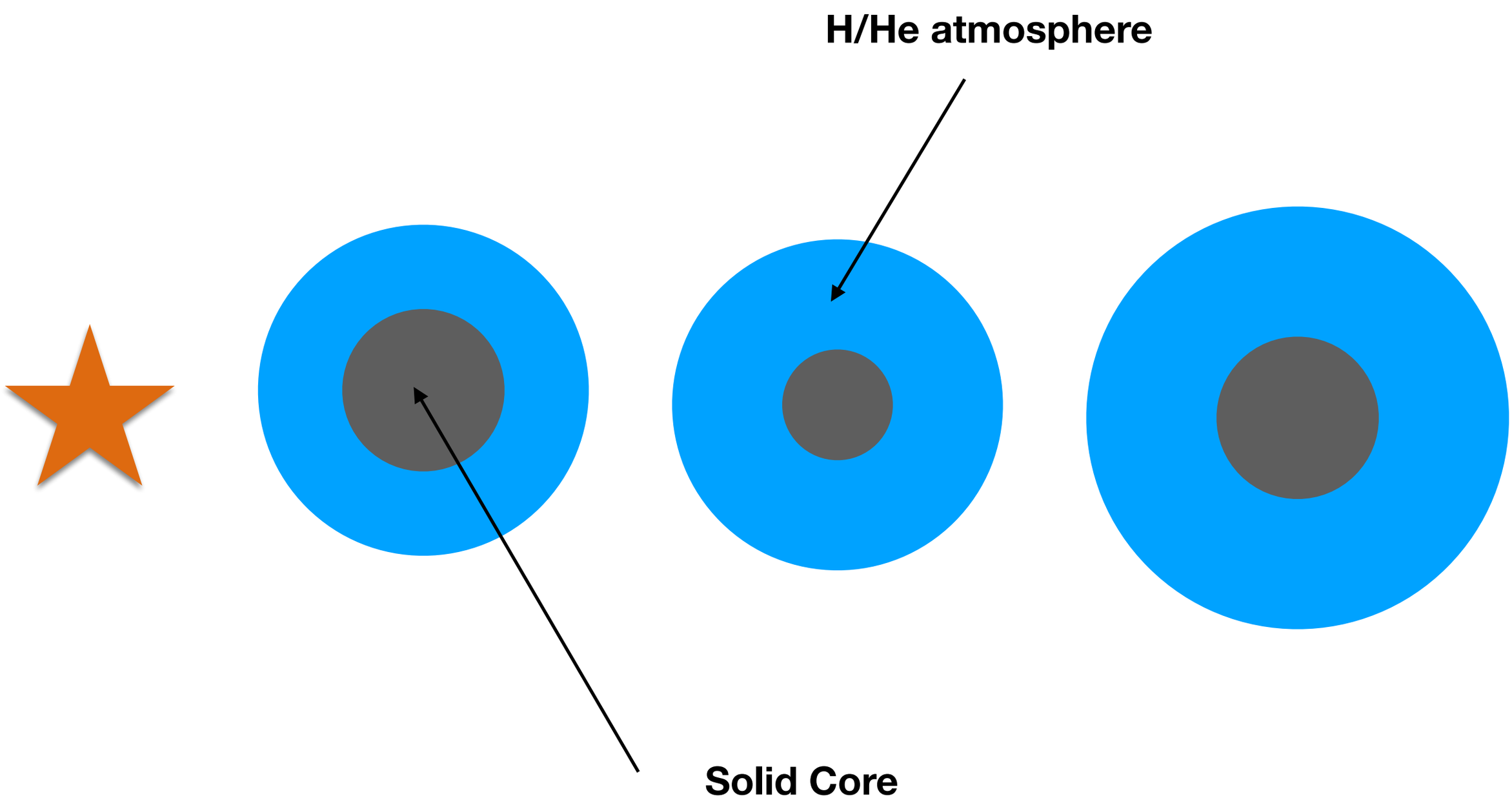

**Mass-loss**

~Myrs

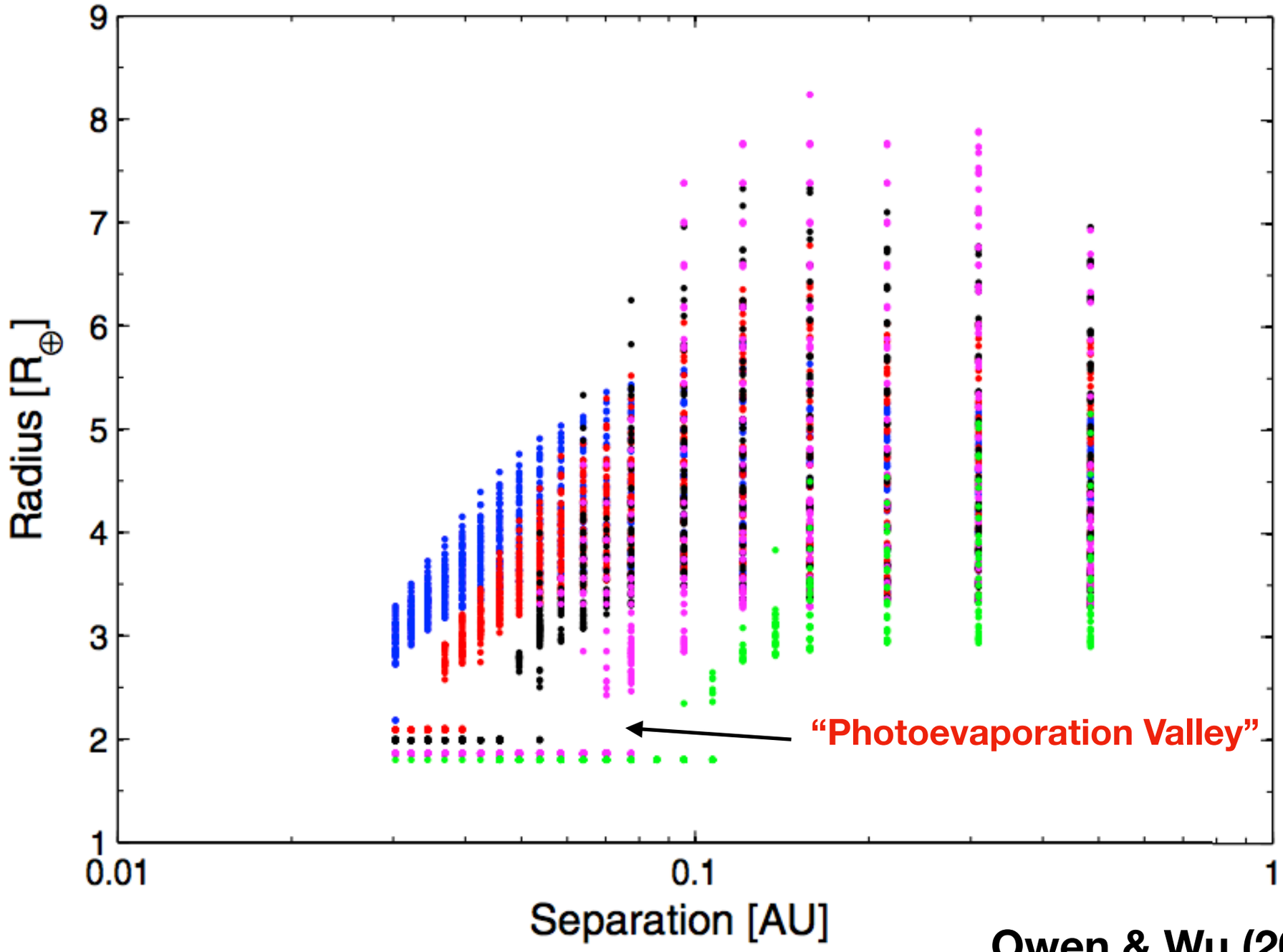
Time

~Gyrs

# A population of planets at birth: all with H/He atmosphere



# Population of evaporating close-in planets @ 3 Gyr




Owen & Wu (2013)

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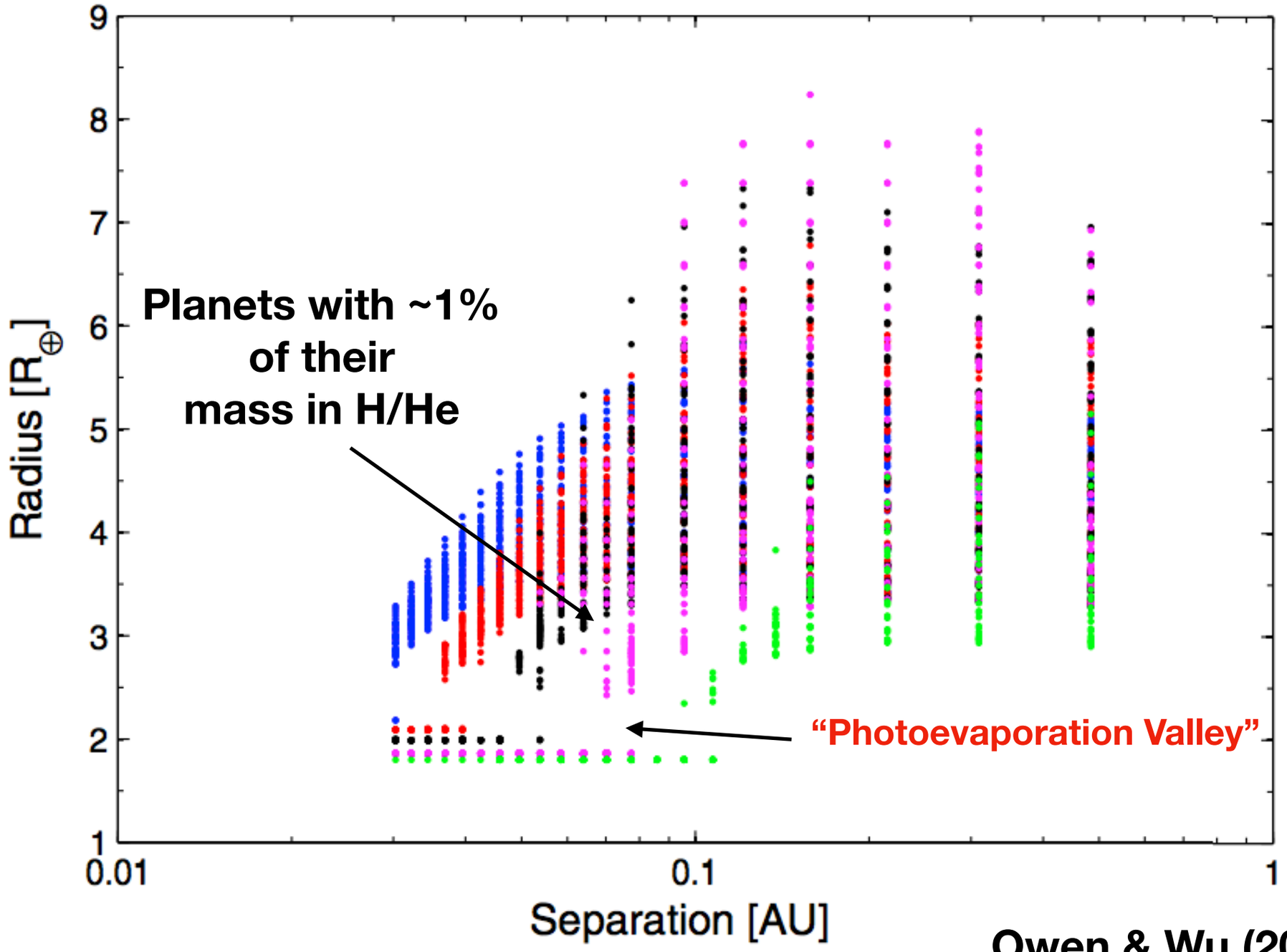


Owen & Wu (2013)

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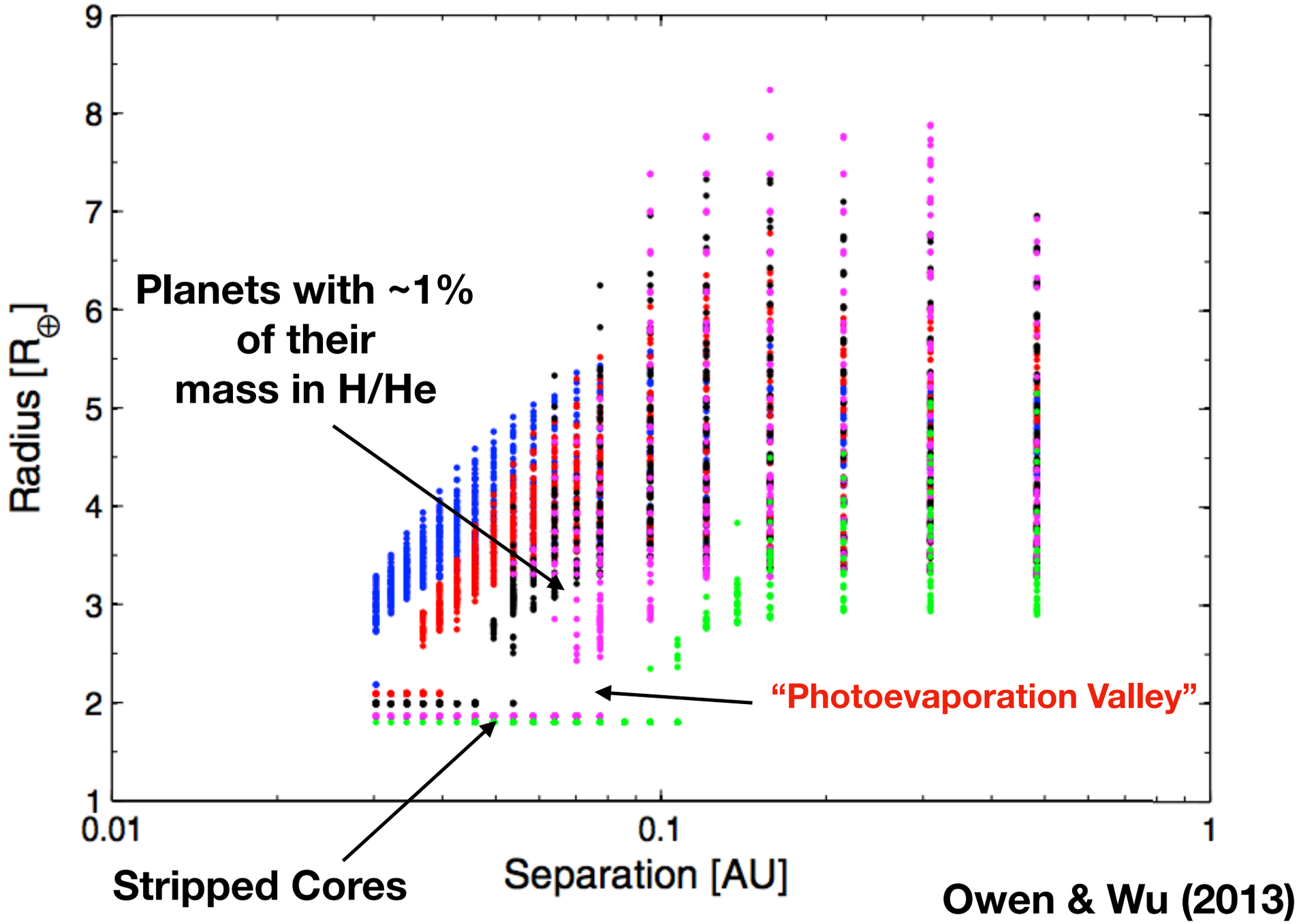
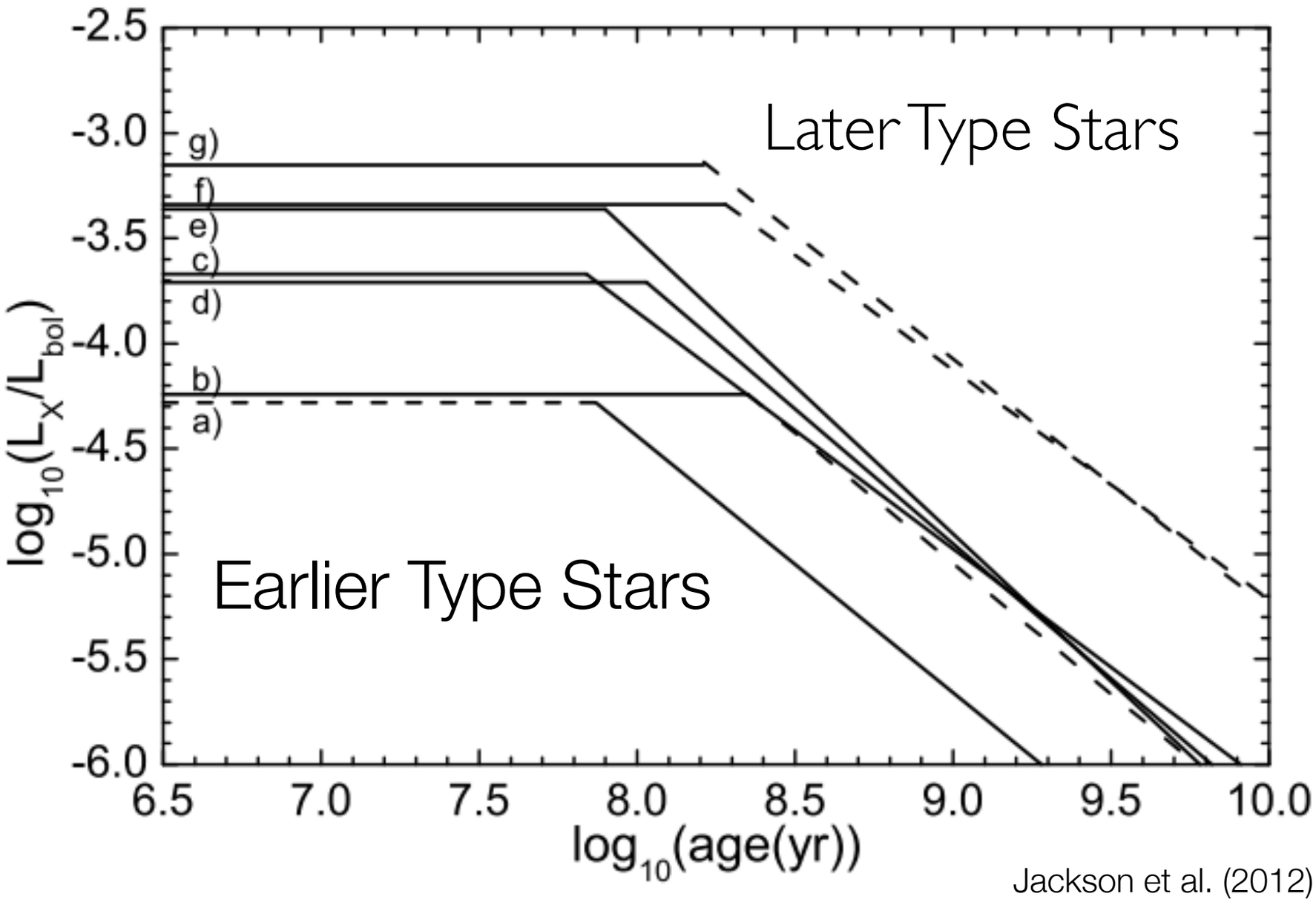



Owen & Wu (2013)

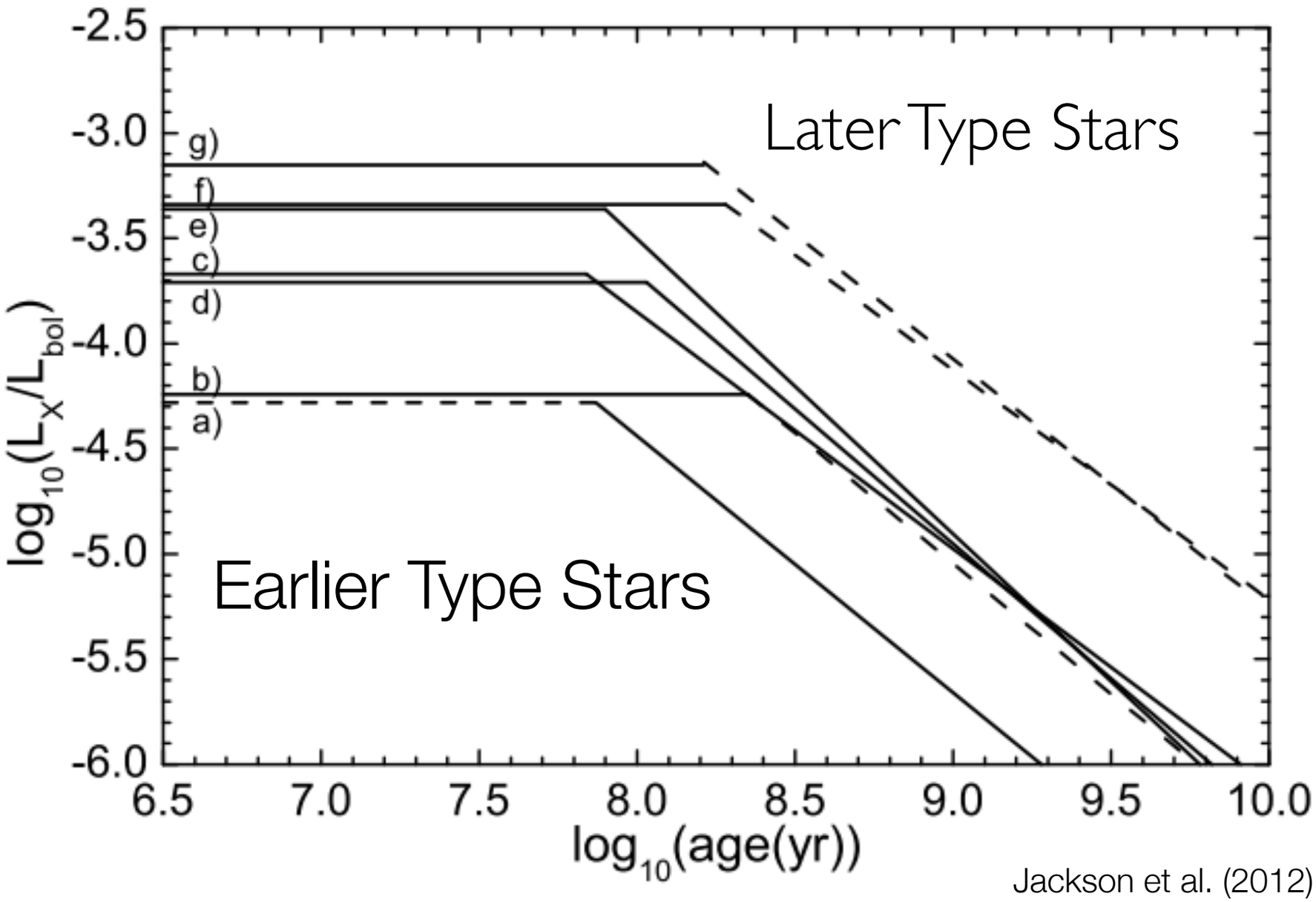
# When is mass-loss important?




Jackson et al. (2012)

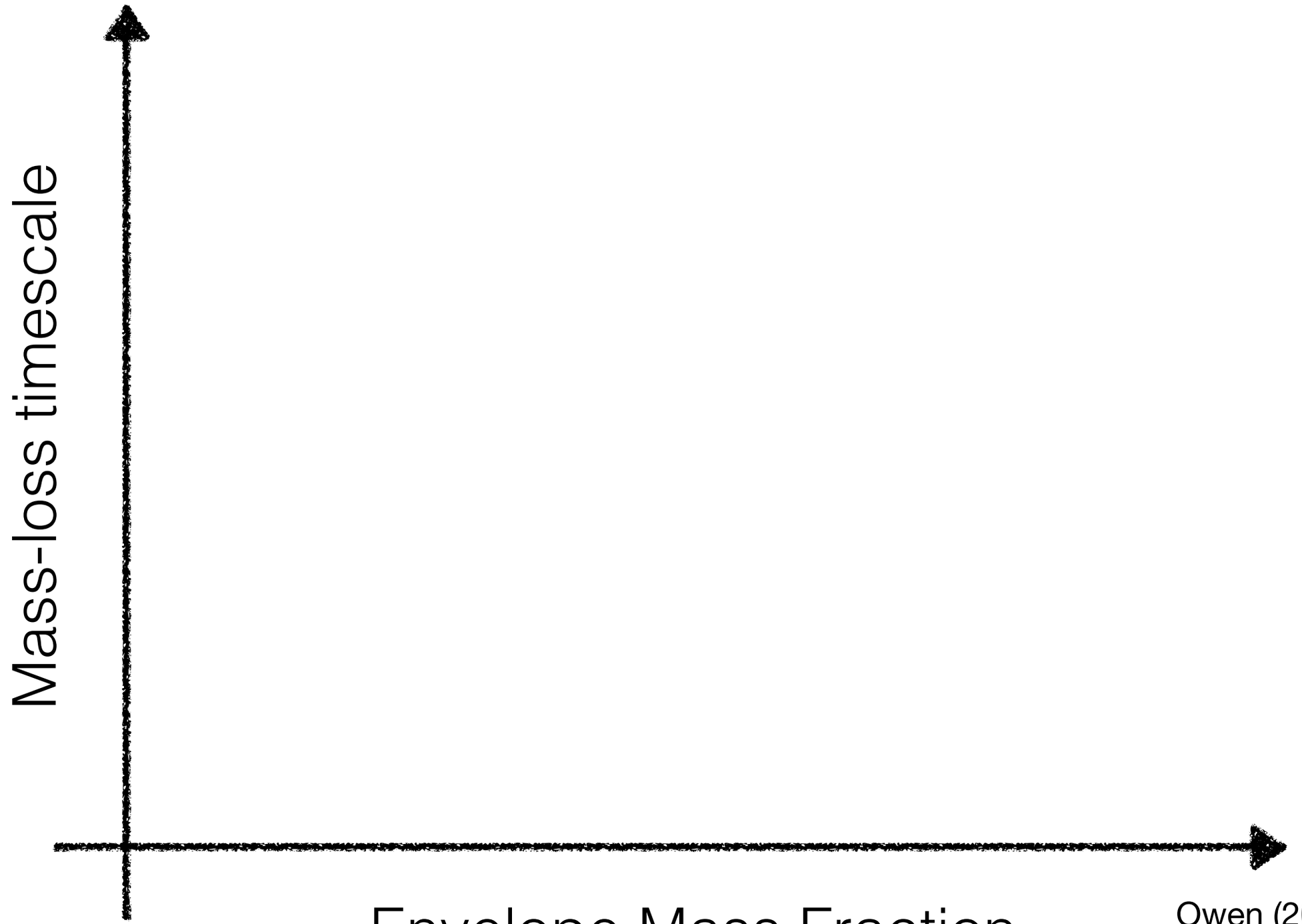
# When is mass-loss important?

**Question: how accurate is this?  star-to-star variability?**




Jackson et al. (2012)

# Simple Model for Mass-loss




Owen (2019),
Annual Reviews of Earth
and Planetary Sciences

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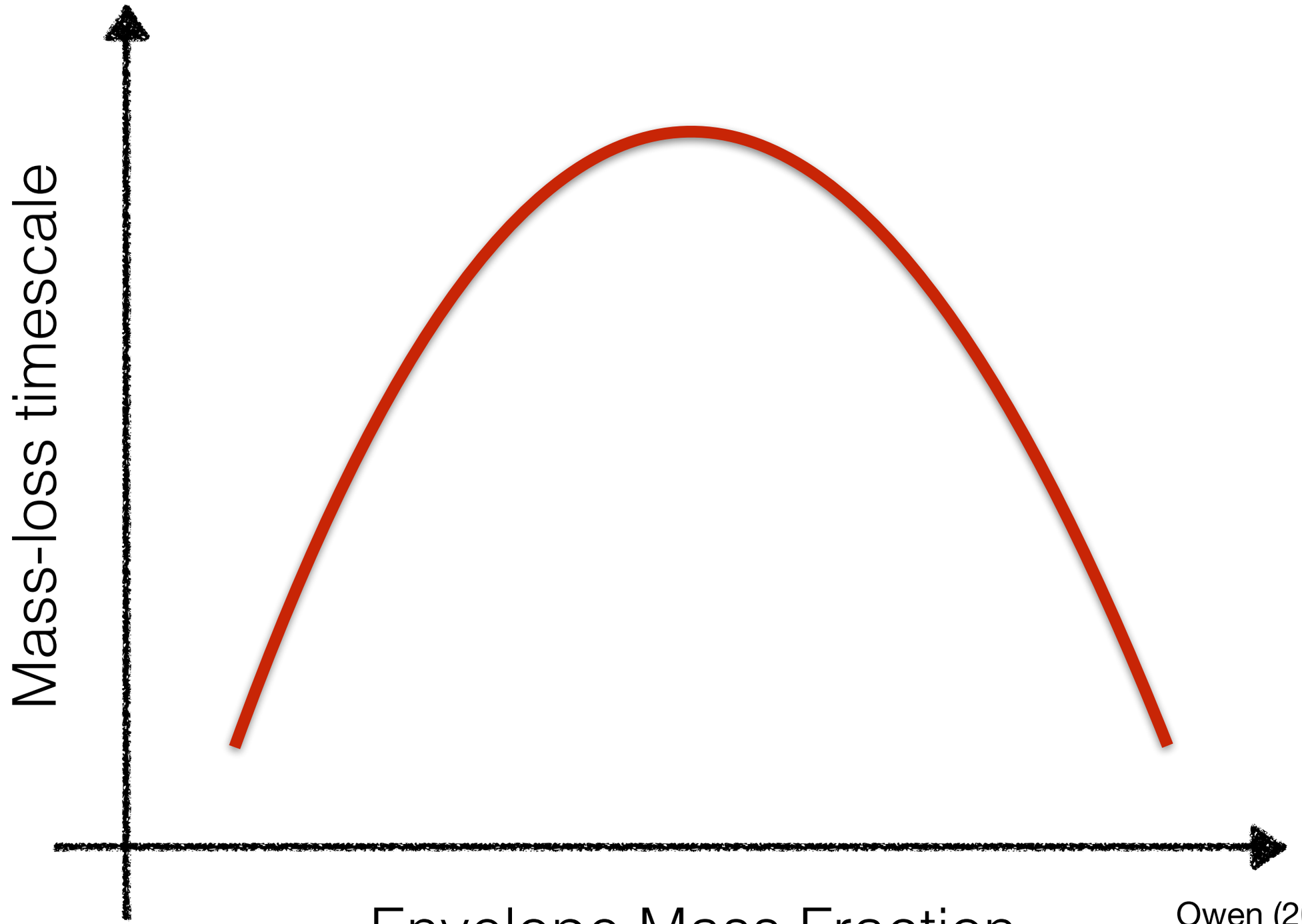


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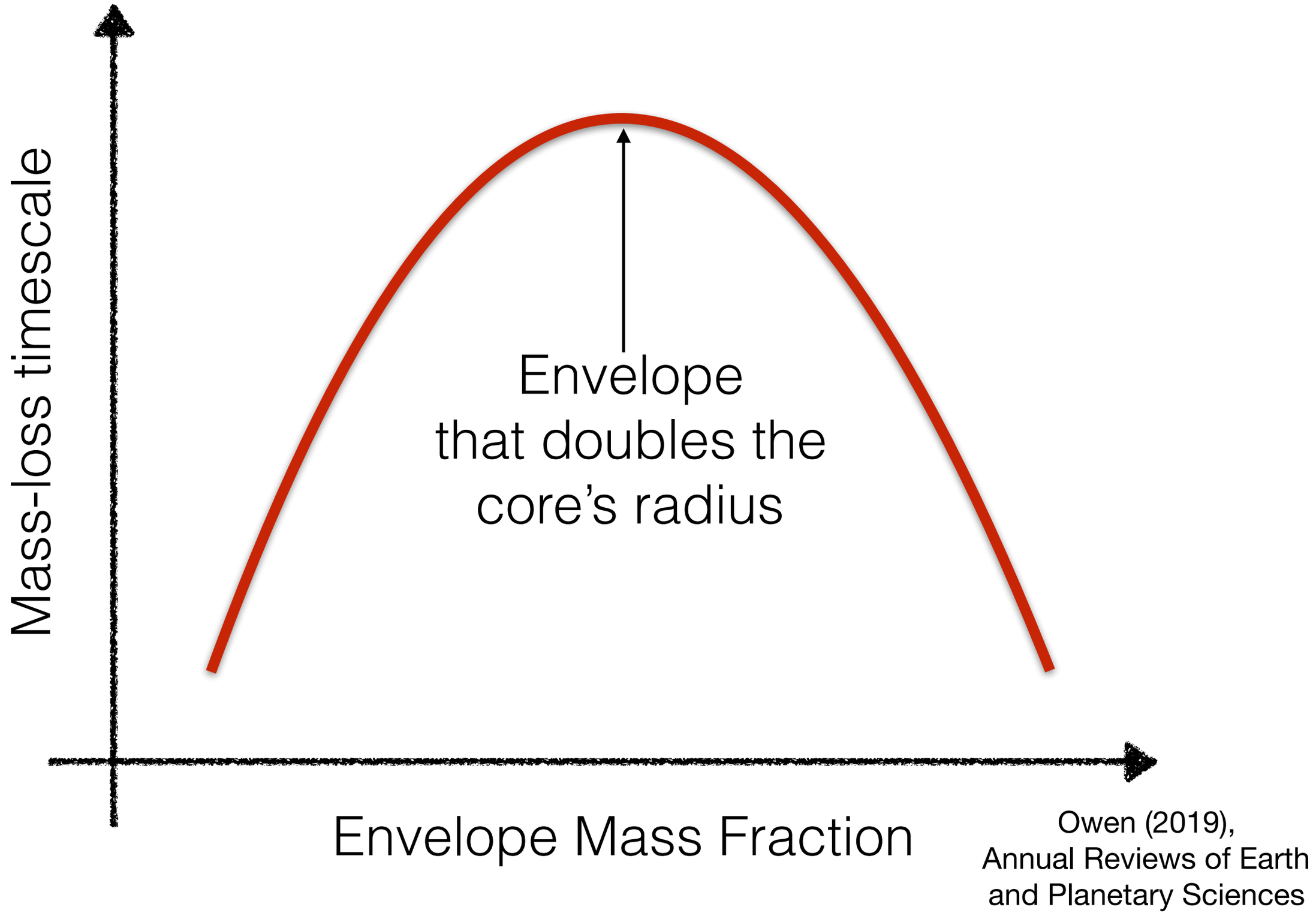


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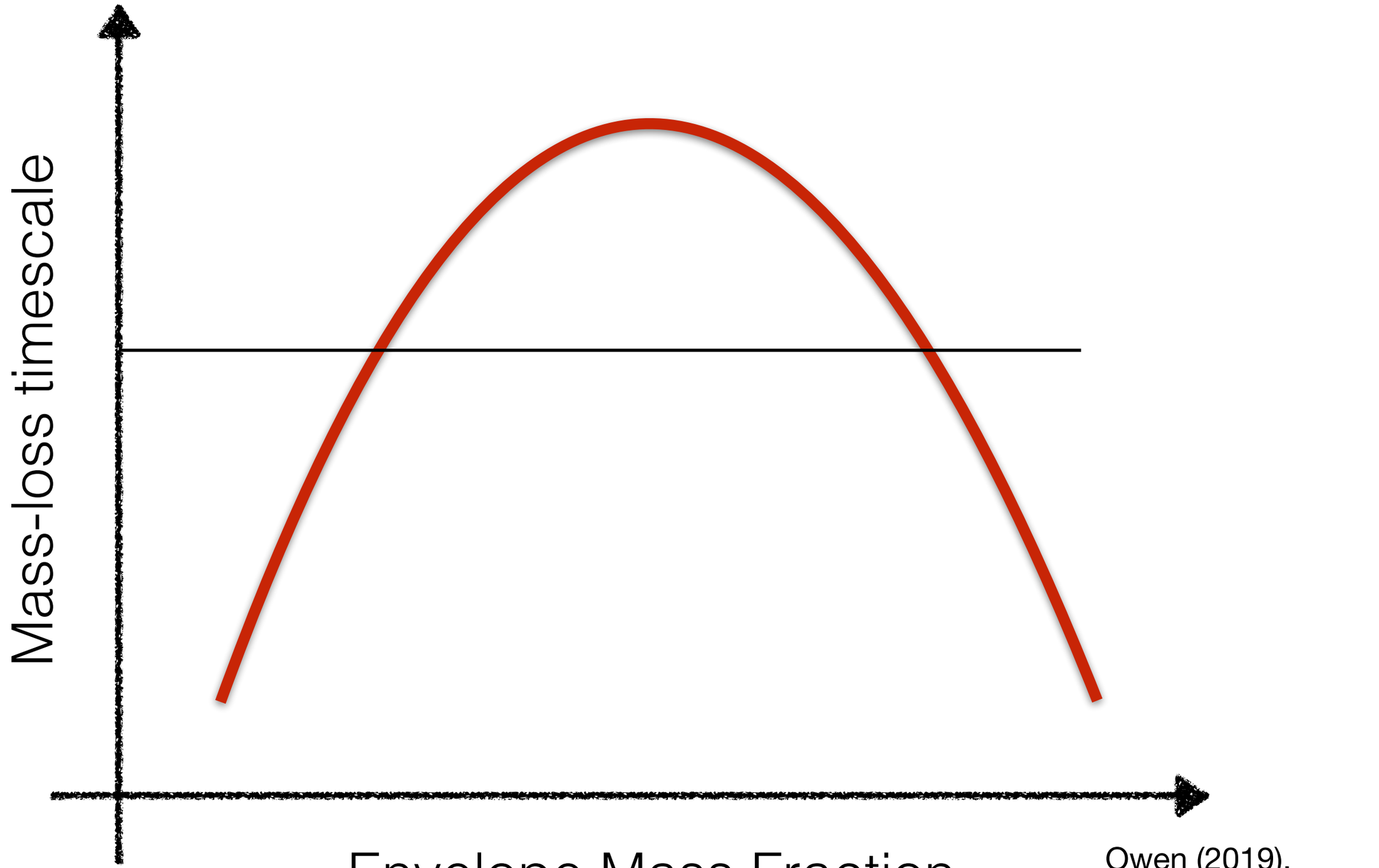


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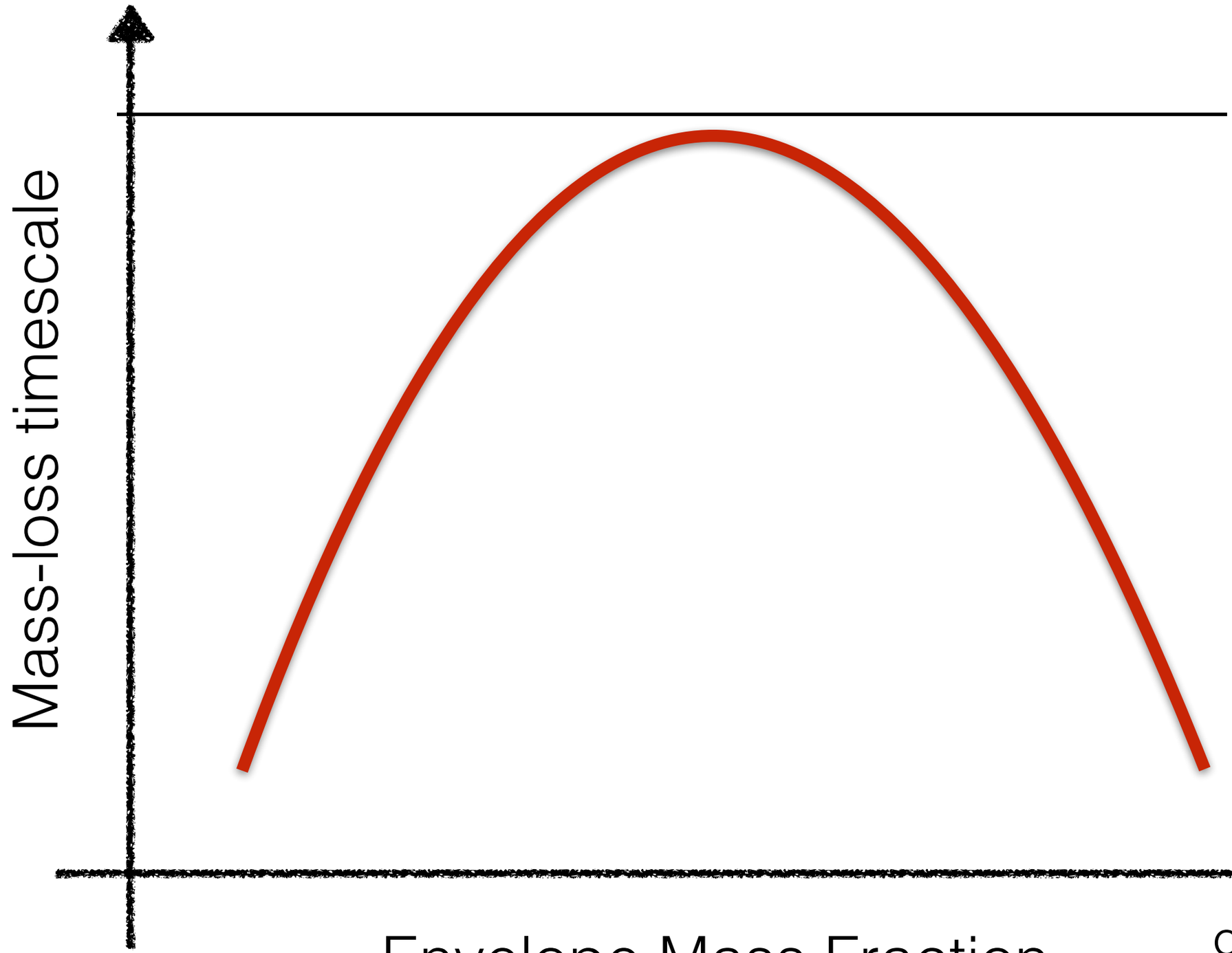
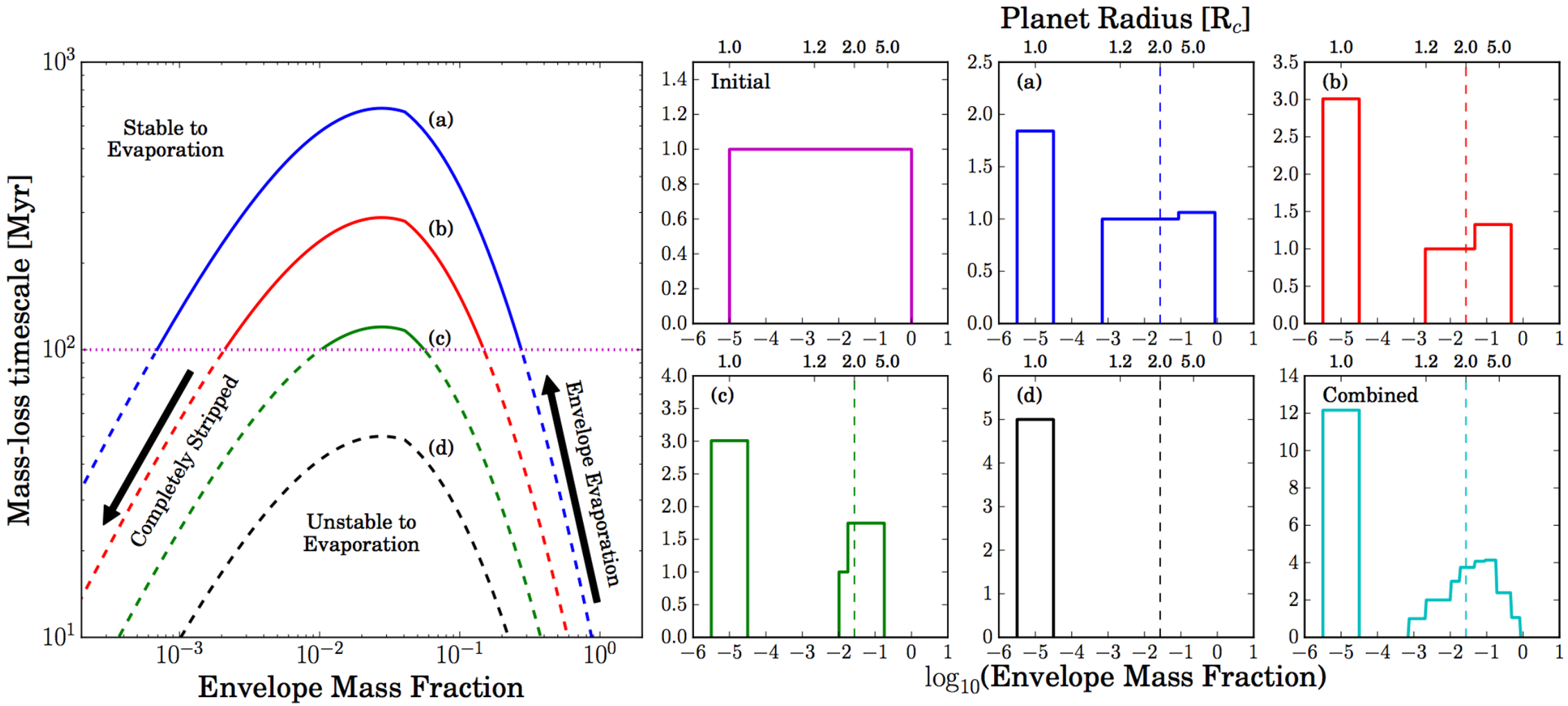



Owen (2019),
Annual Reviews of Earth
and Planetary Sciences

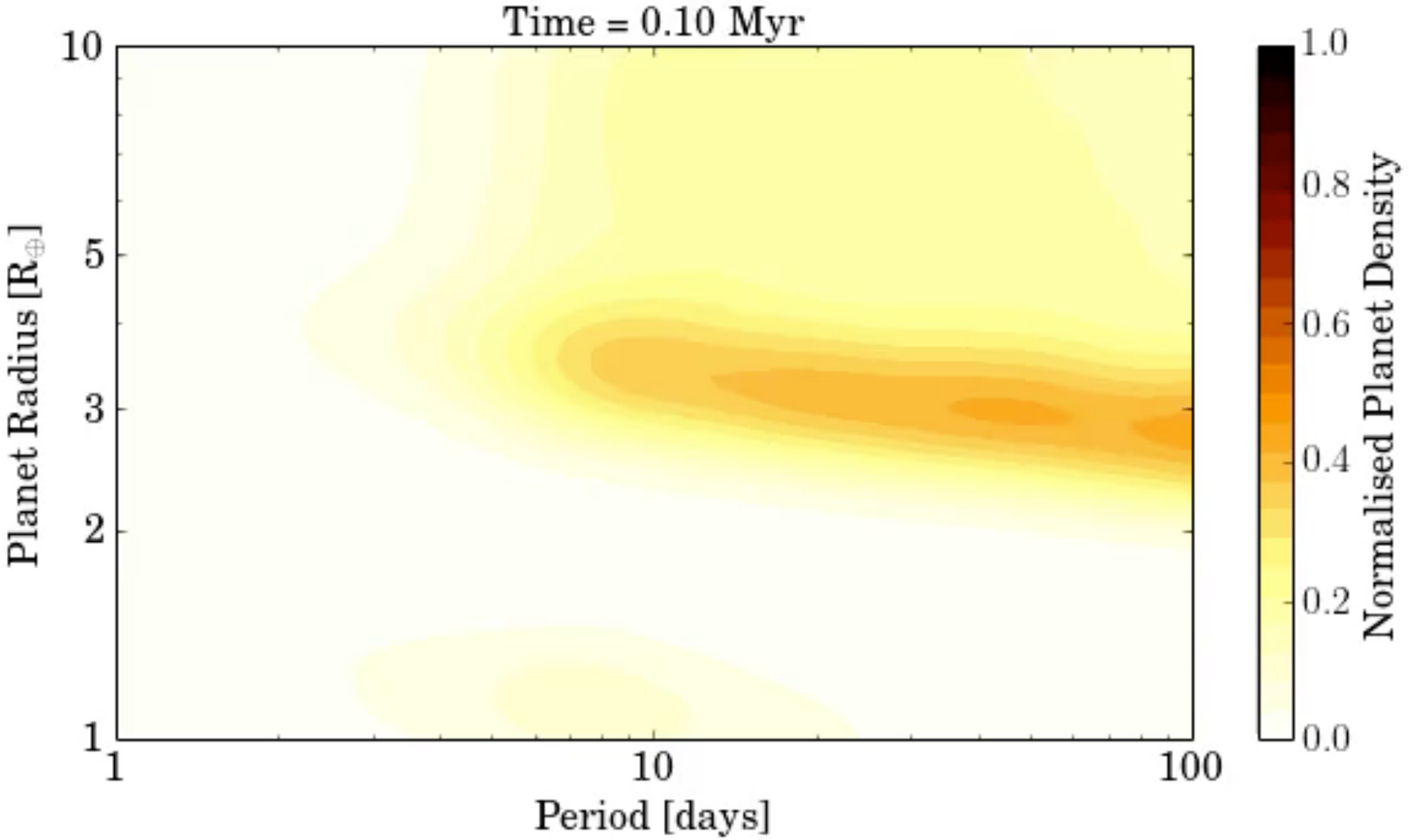
# Simple Model for Evolution




Owen & Wu (2013, 2017)

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

# Evolution of exoplanets



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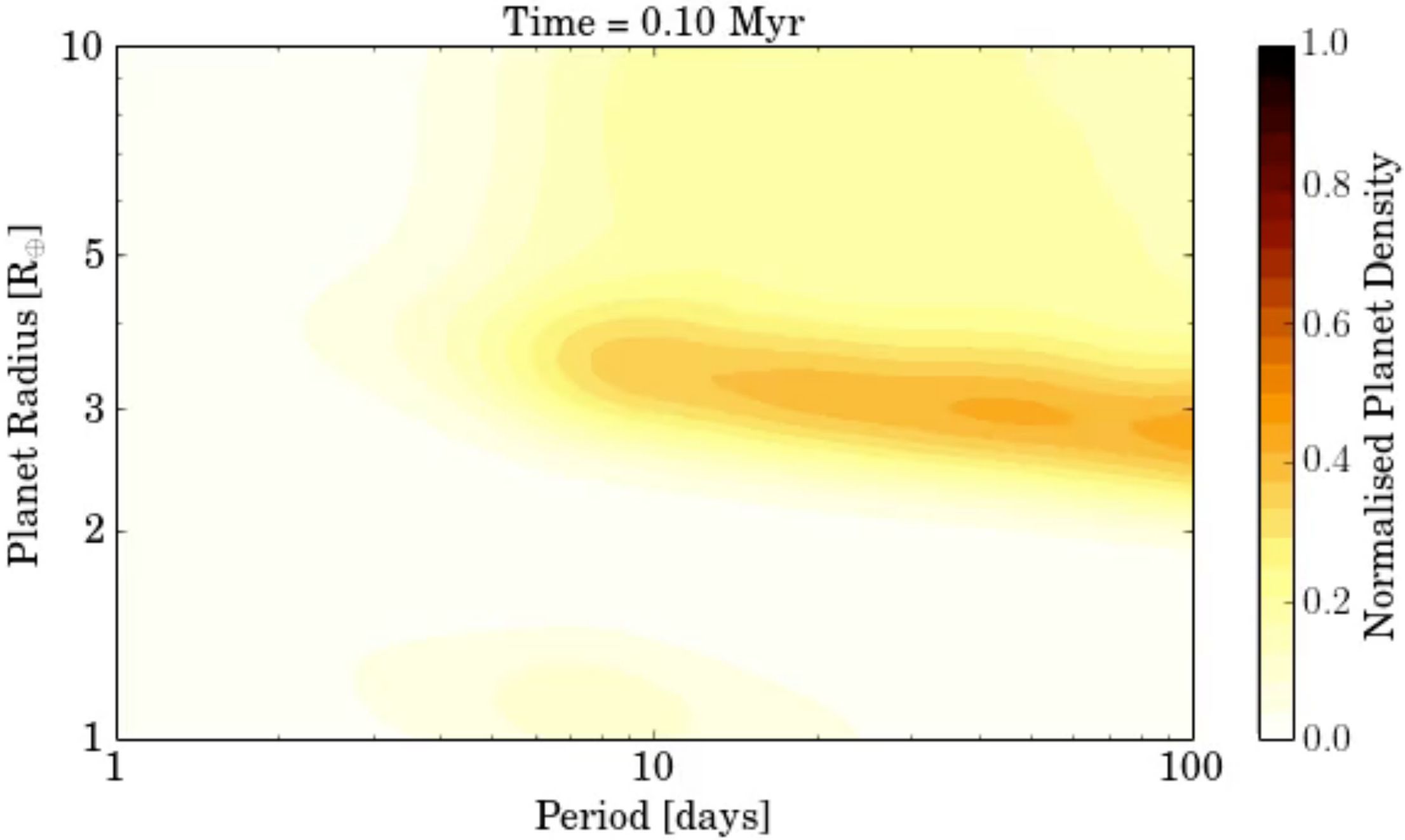
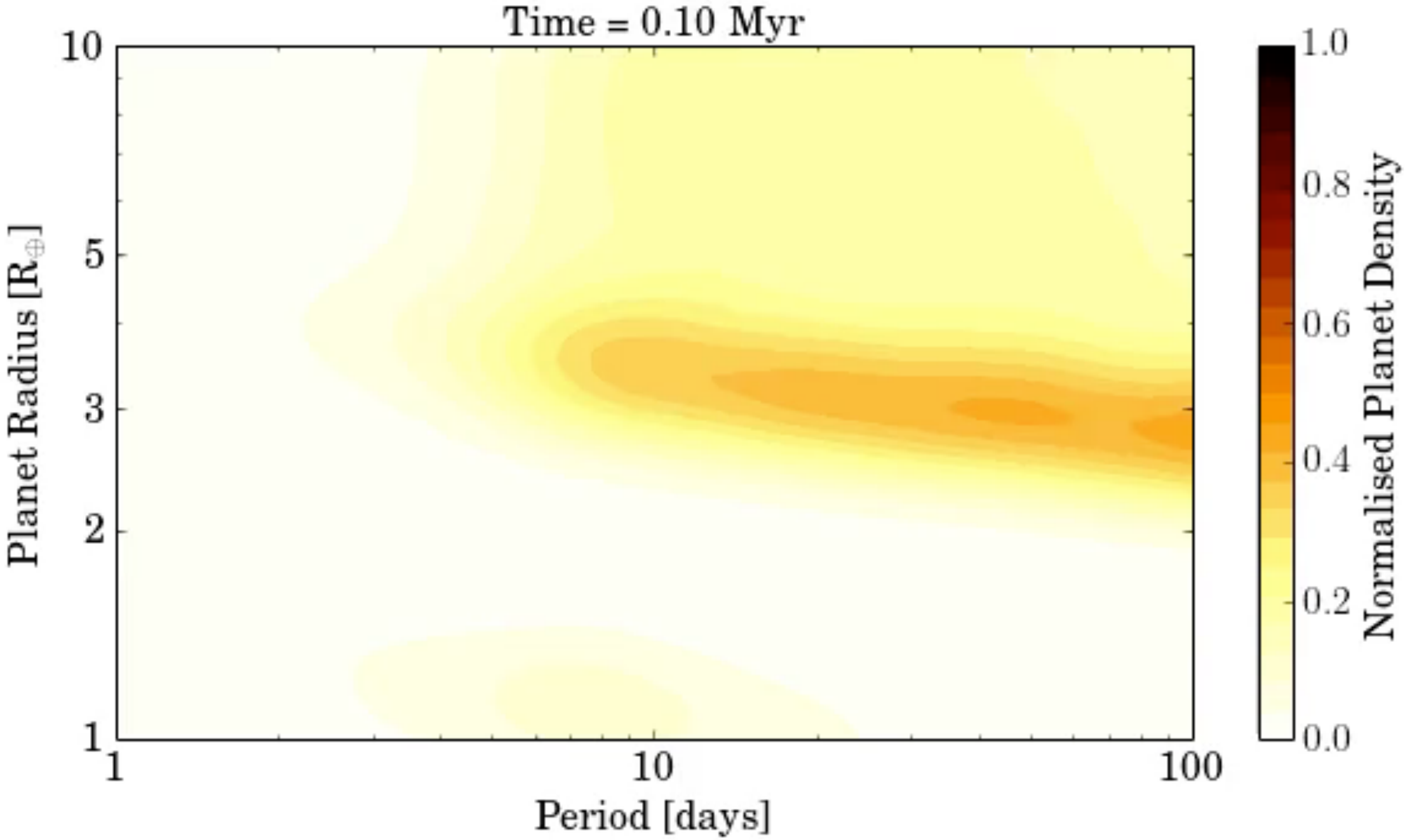



**Fulton et al. (2017)**

# Evolution of exoplanets

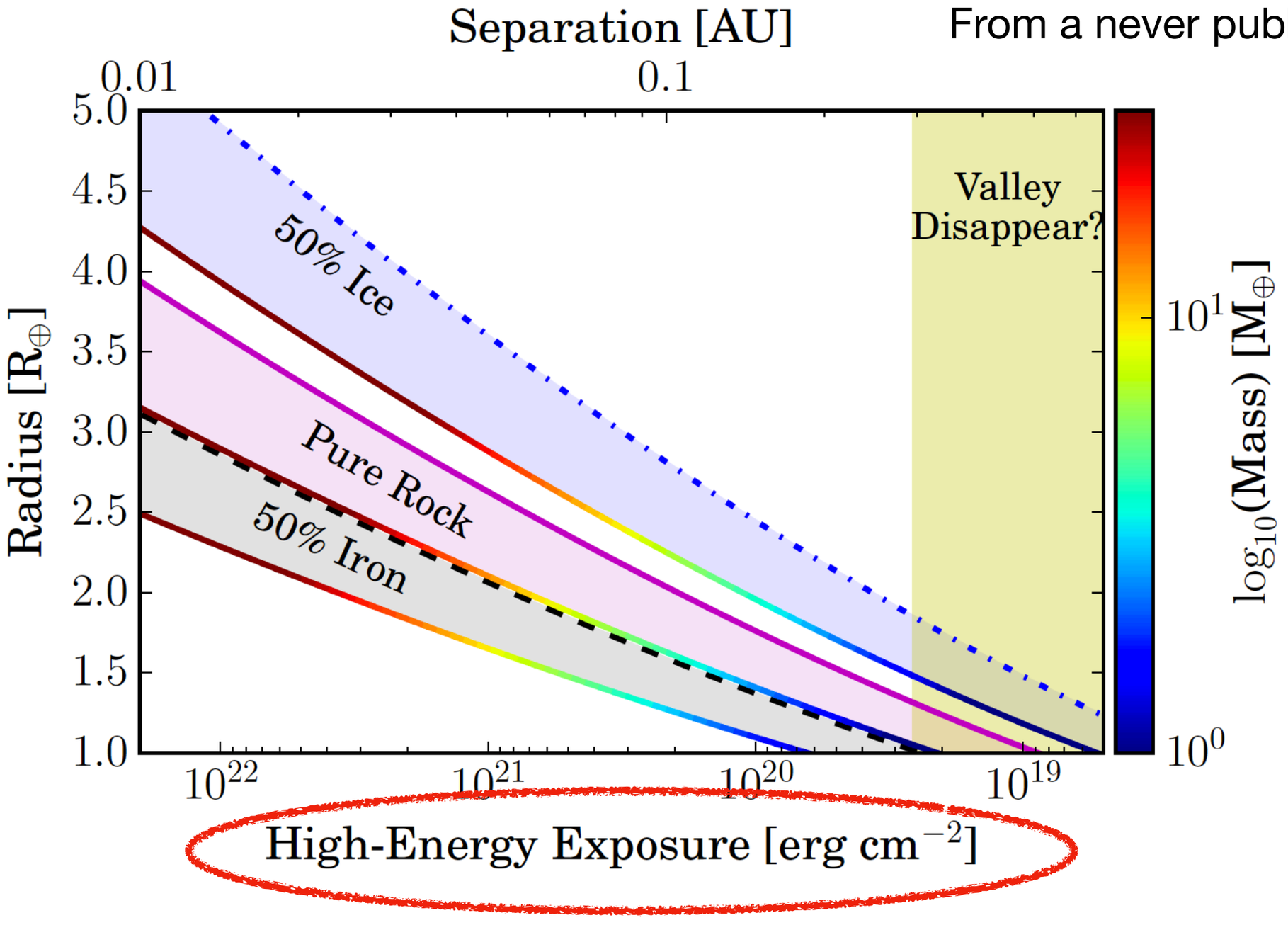
**Question: can we test this time evolution?**




**Fulton et al. (2017)**

# The valley as a probe of core composition

From a never published paper



# Insights into the origin of the close-in exoplanets

- Solid Core Composition : **Rocky (and uniform)** versus Icy —> Formation location in disc? - **Formation inside snow-line**

- Arrival Time at Short Periods : In-situ Formation, Disc Migration, ~~Late-time Dynamical Migration?~~

- Fraction of planets born with and without H/He envelopes: **formation in gas disc (< 10 Myr)** or formation after the gas disc dispersed (> 10 Myr)?

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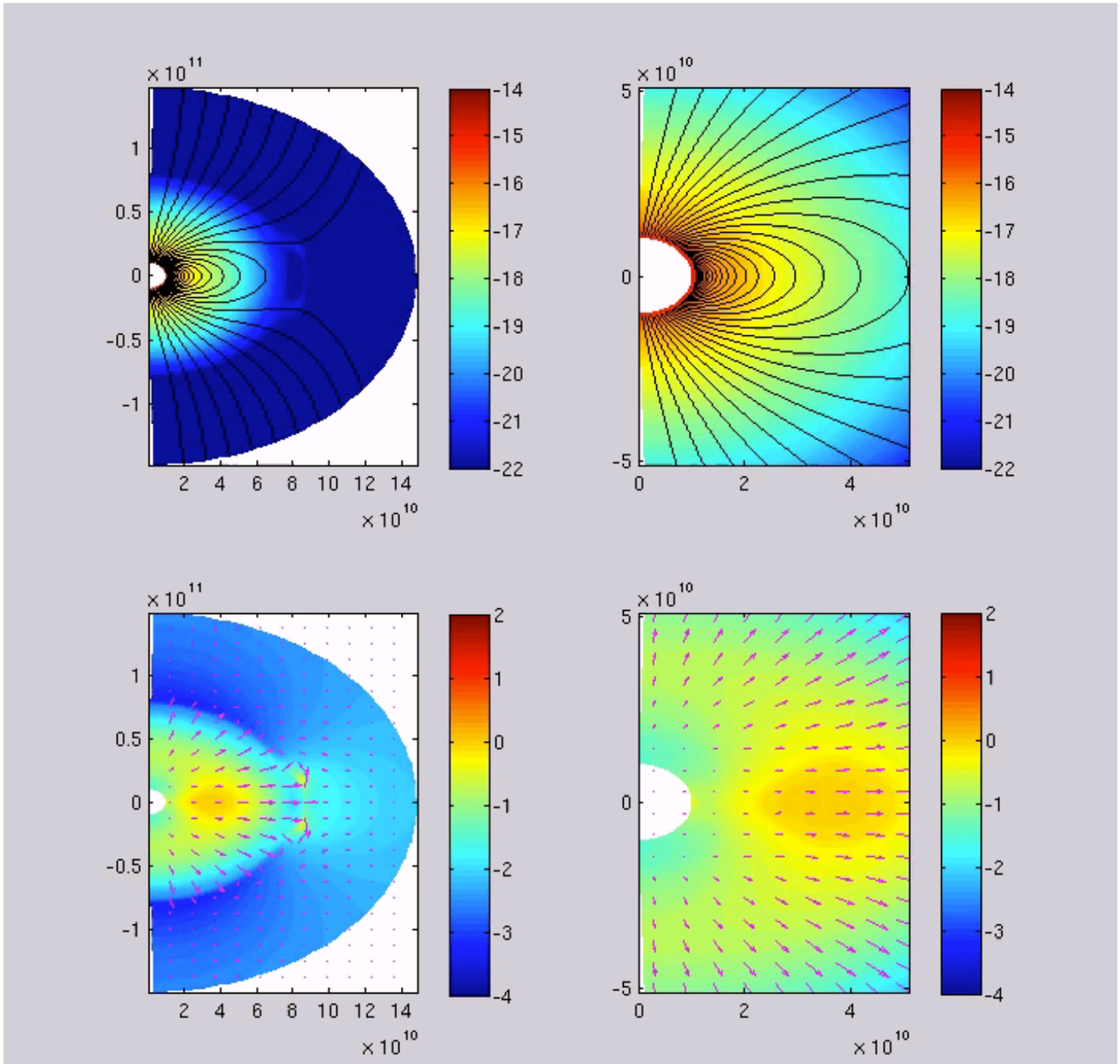
# “Strong” magnetic fields suppress mass-loss




**Owen & Adams (2014)**

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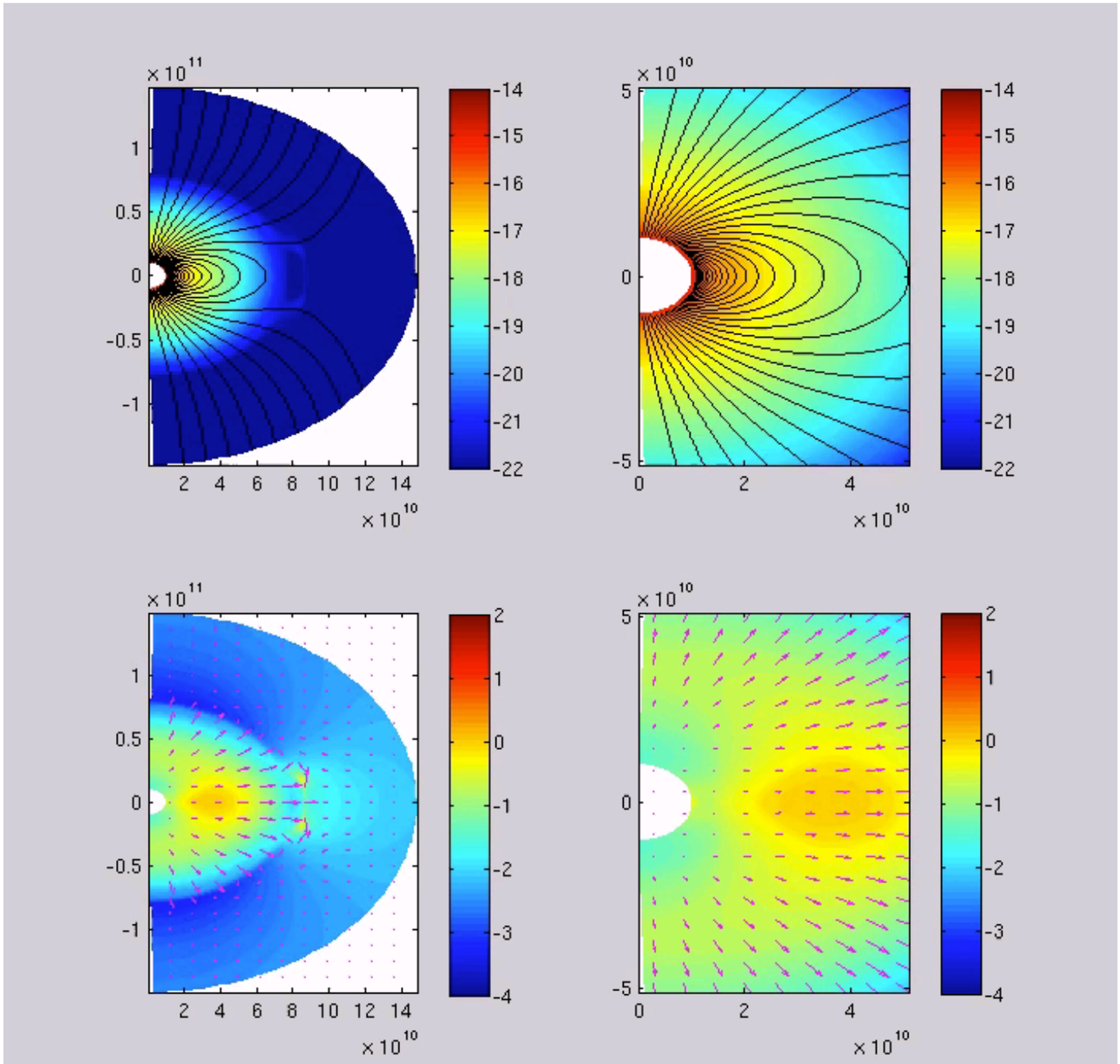
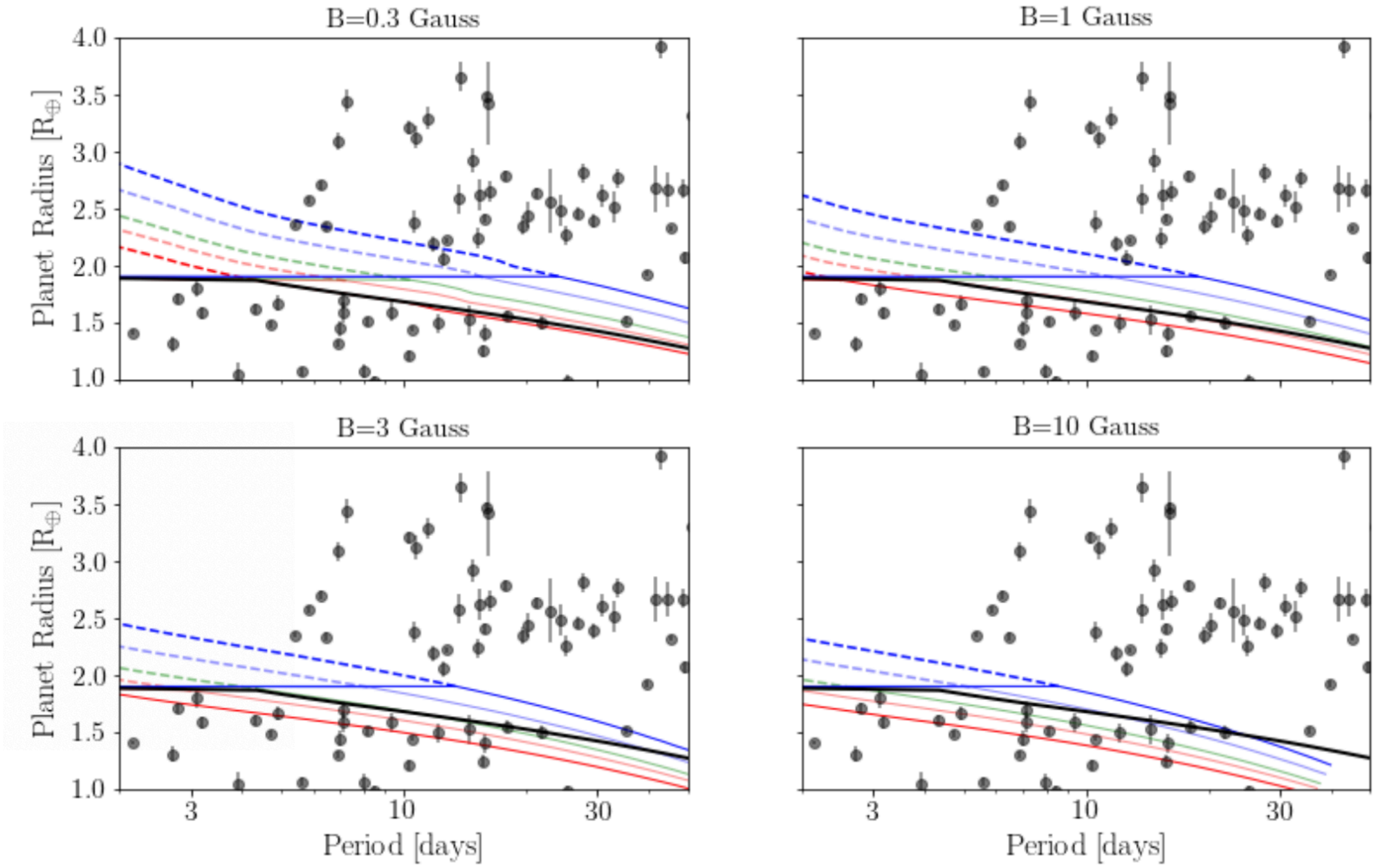


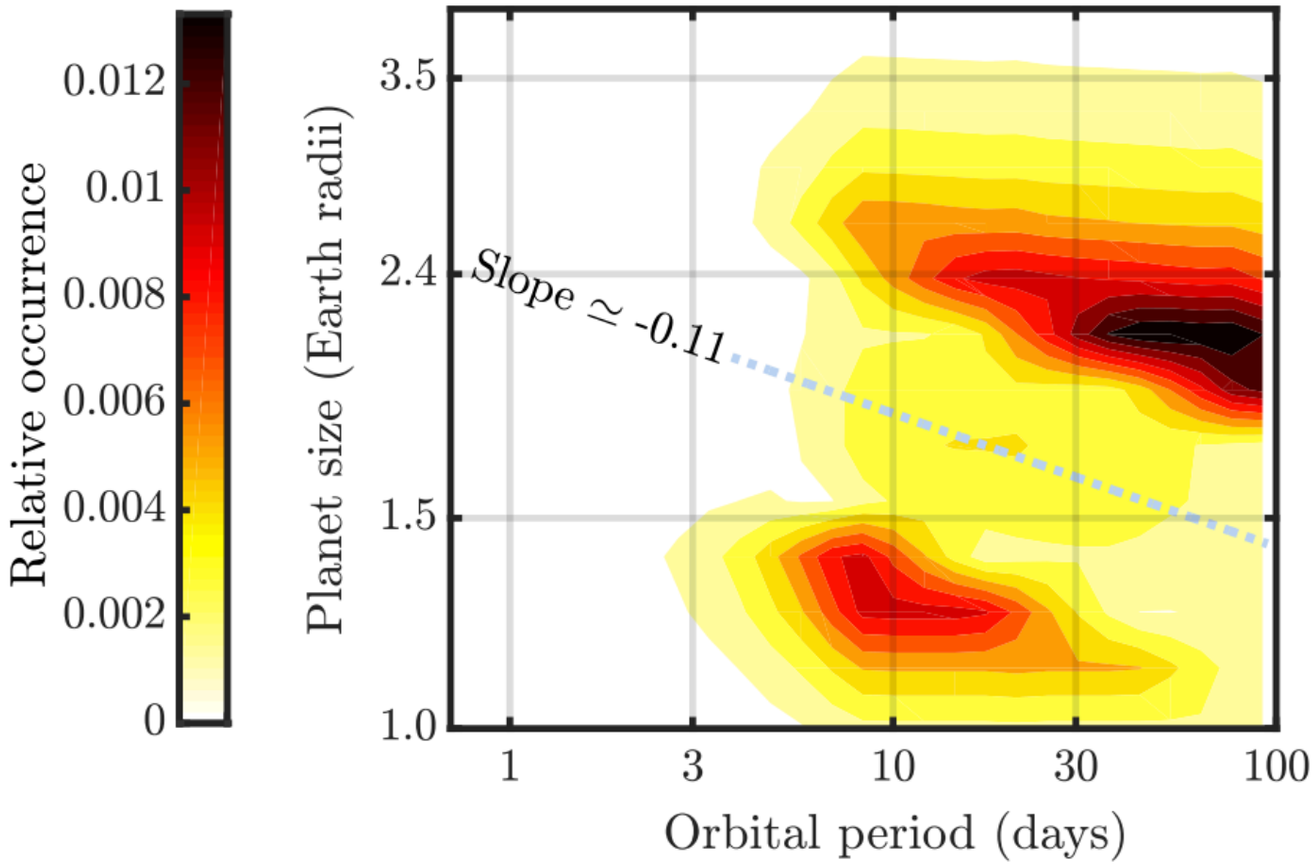

**Owen & Adams (2014)**

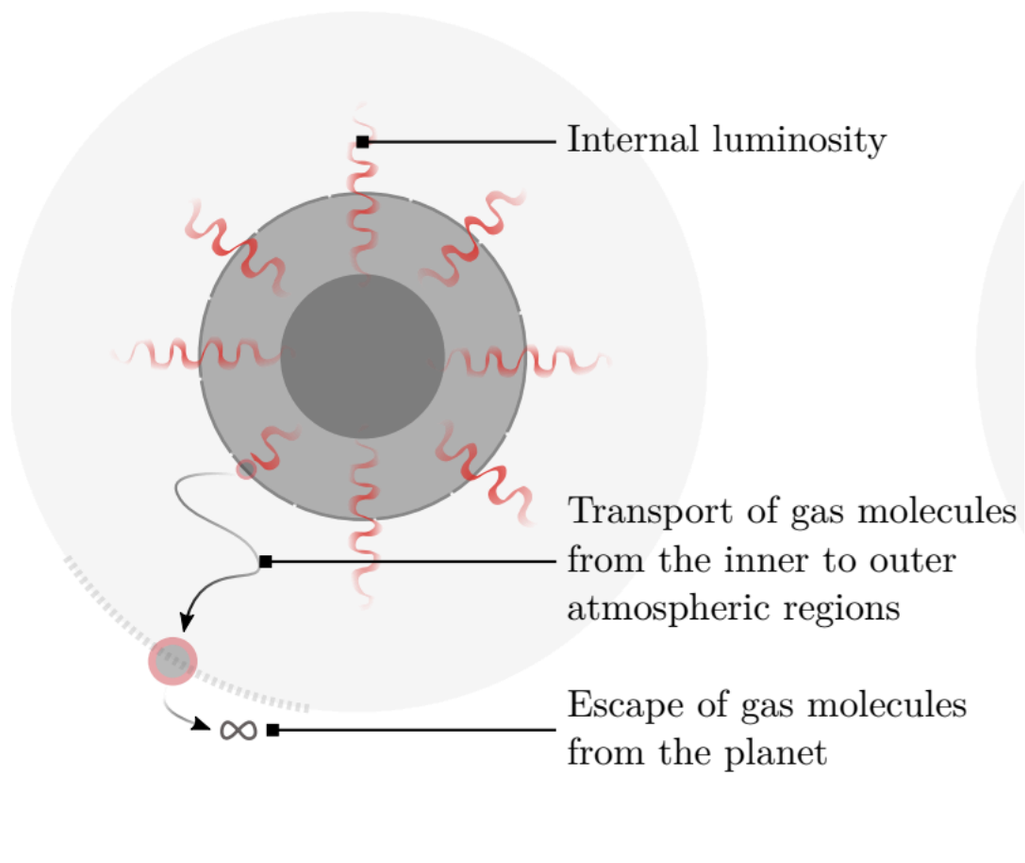
# Degeneracy between magnetic field and core composition




**Owen & Adams in prep**

# Alternative loss-mechanisms

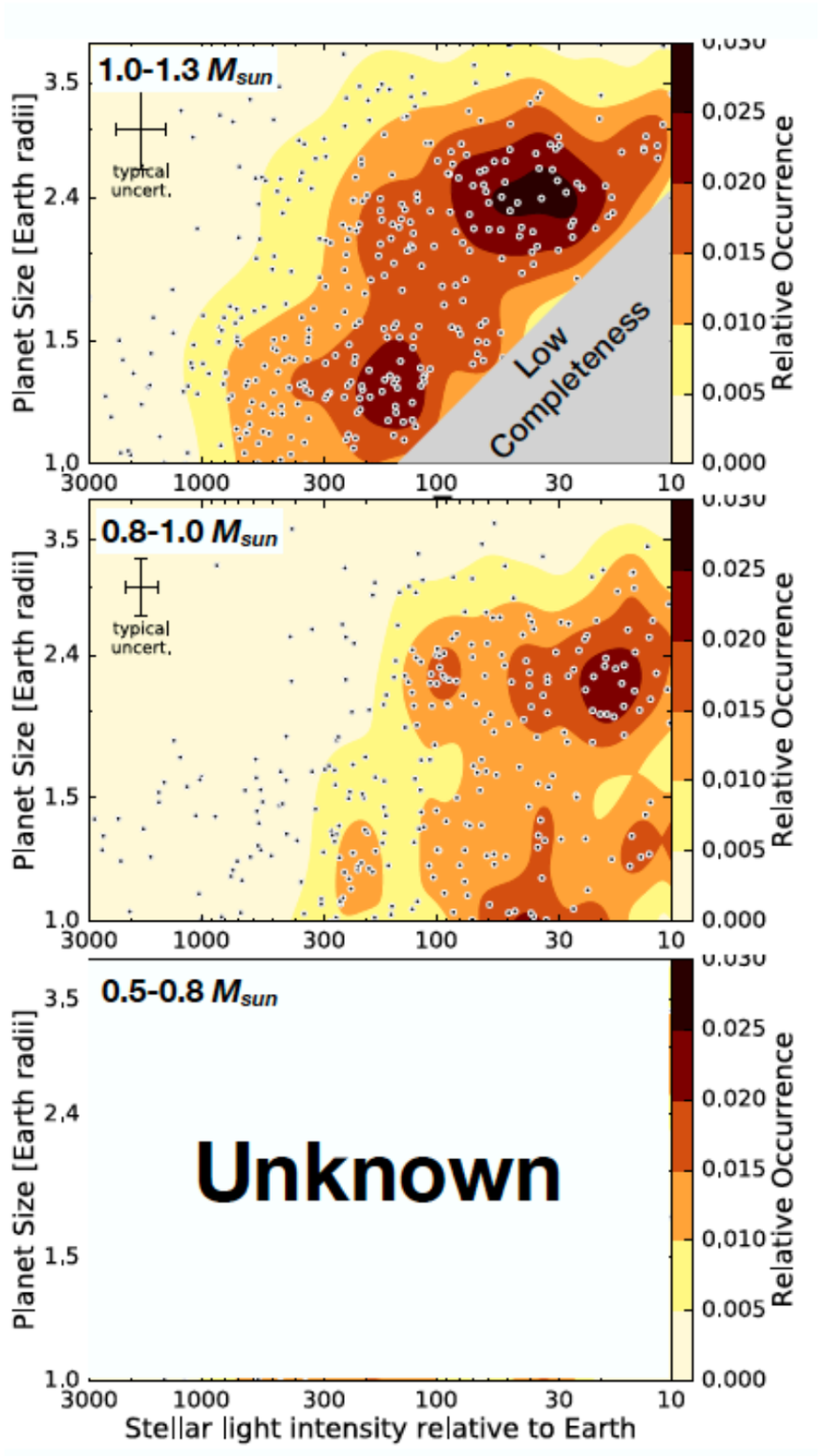


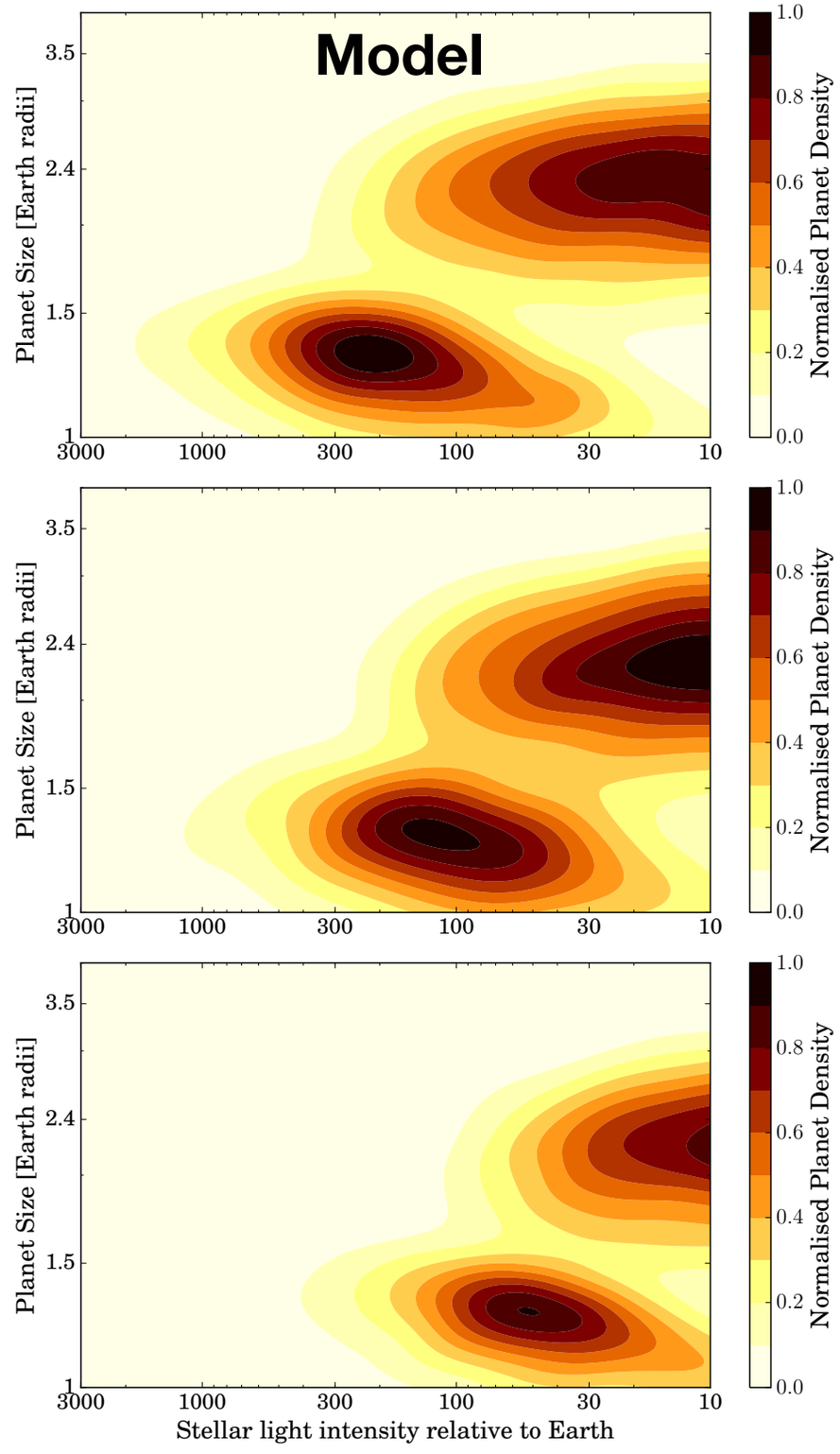

**Ginzburg & Schlichting (2018)**
**Gupta & Schlichting (2019)**

# Test: Stellar Mass

## Observations - CKS




## Model



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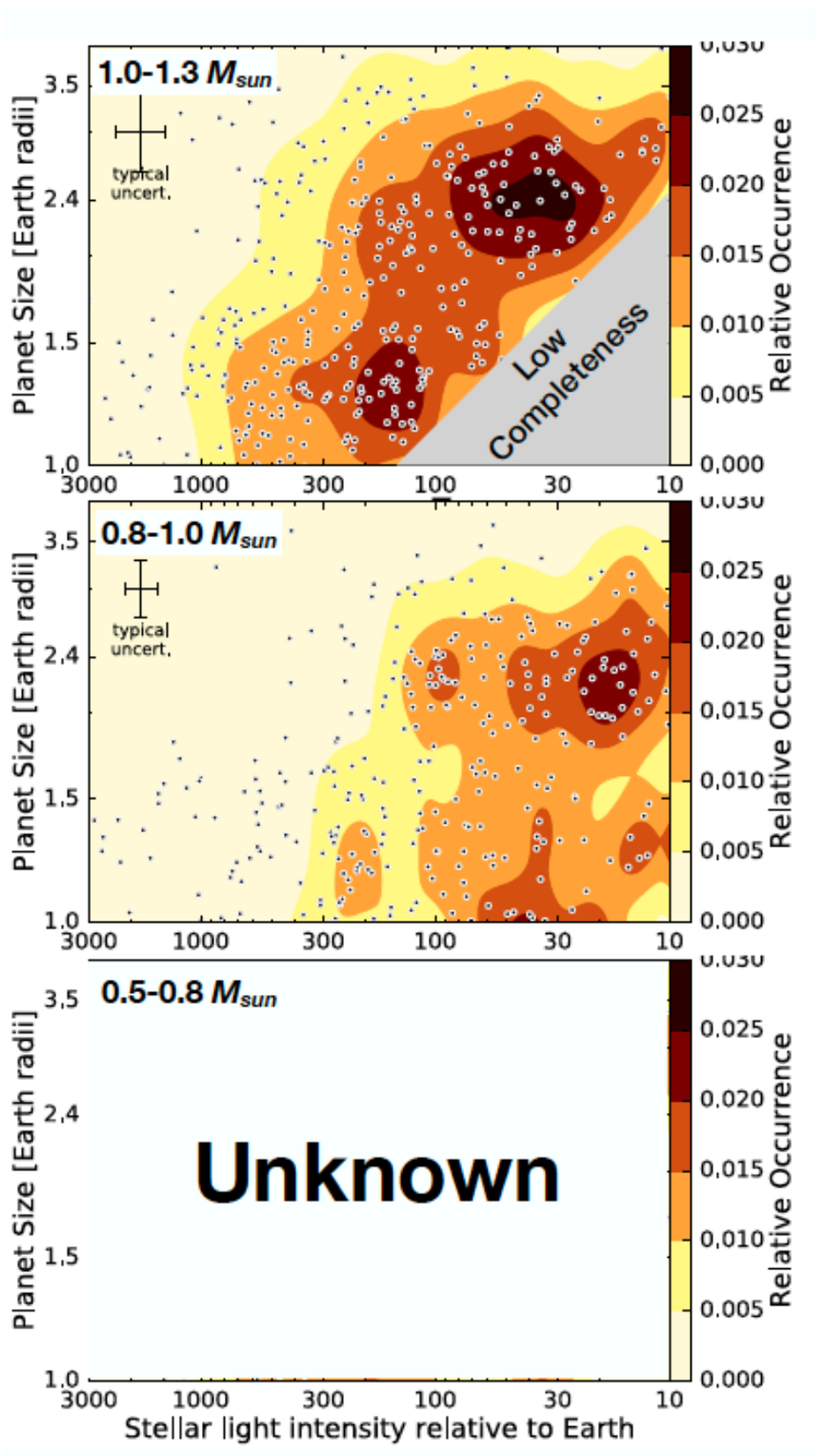


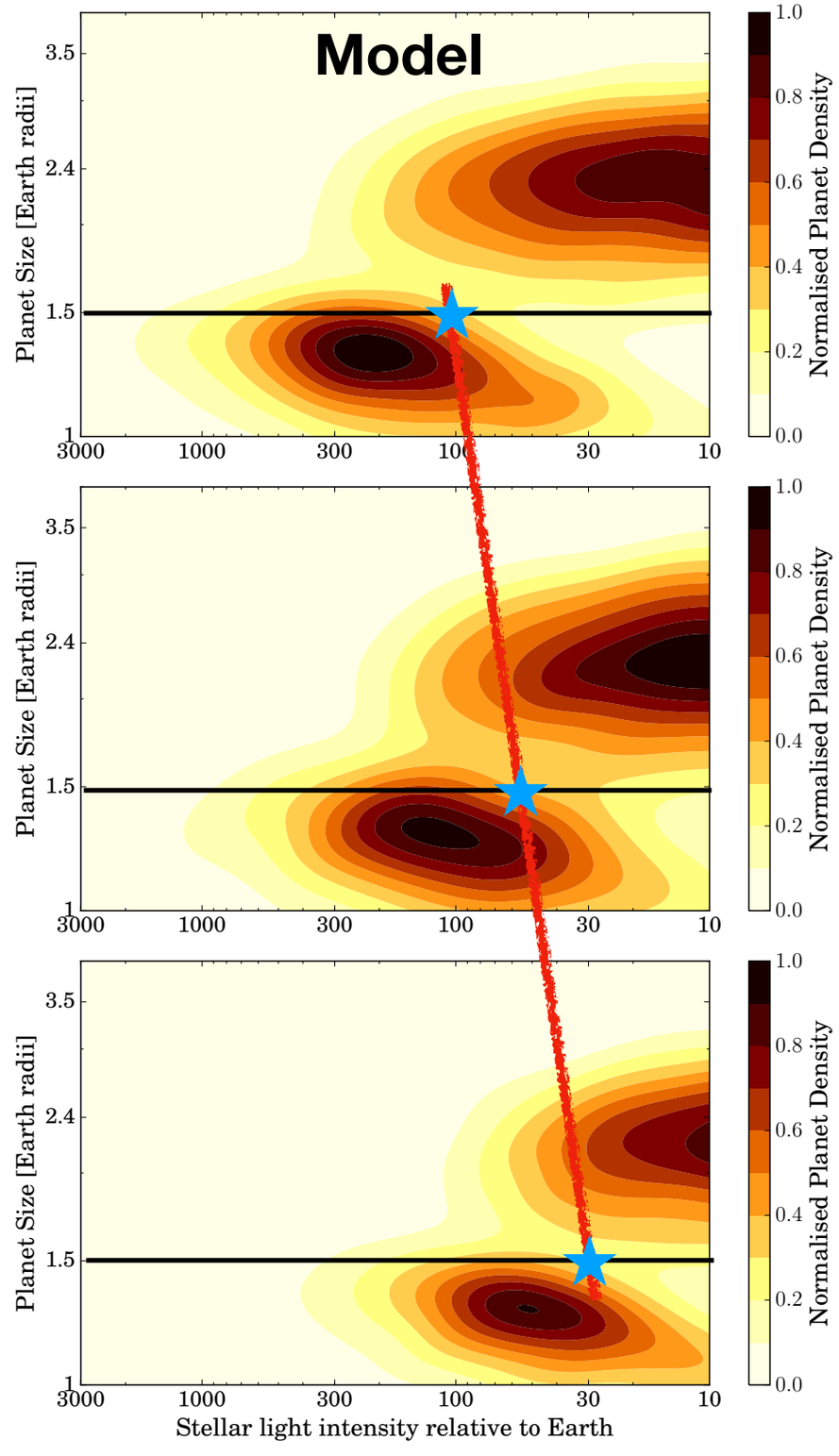

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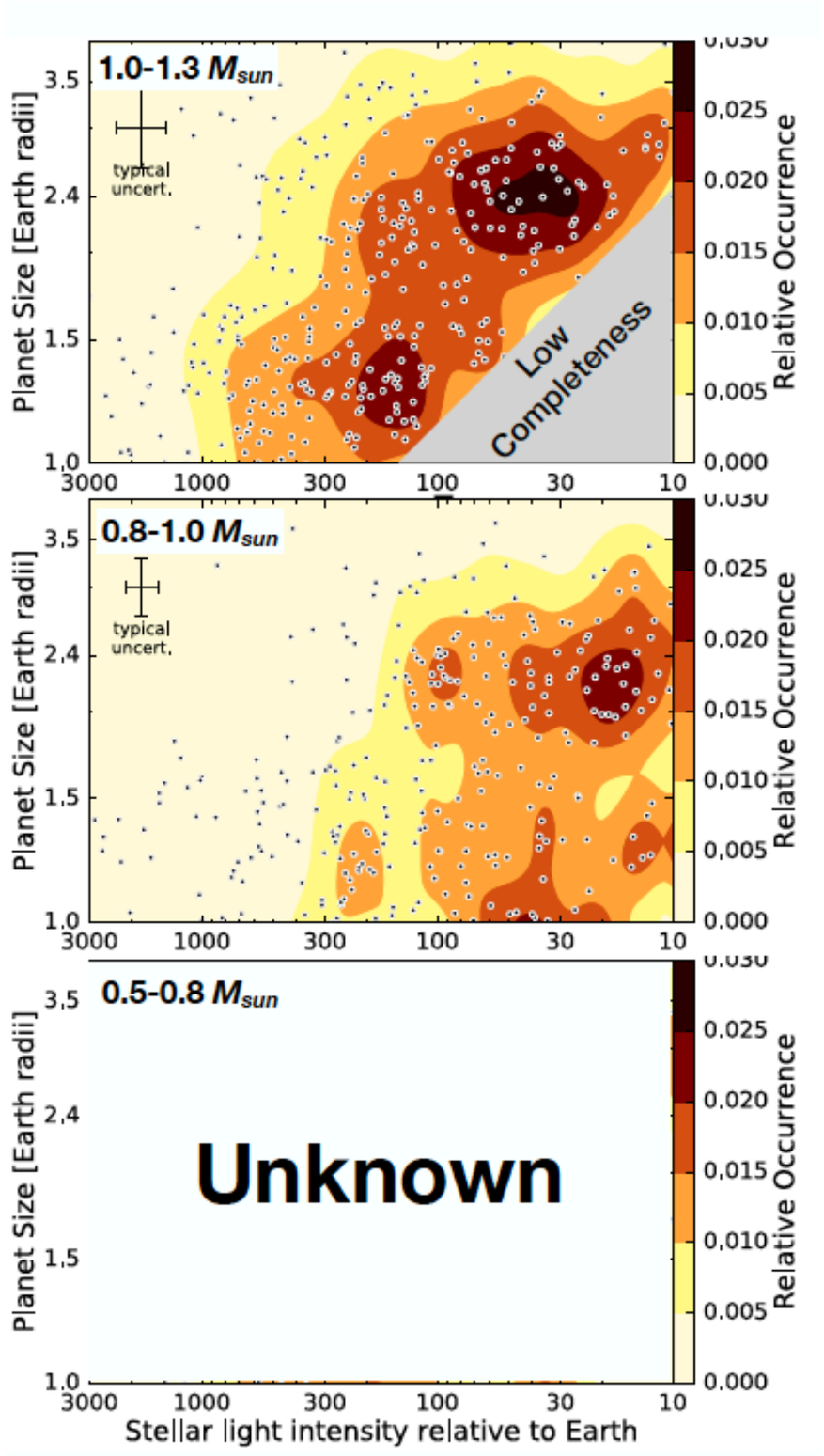
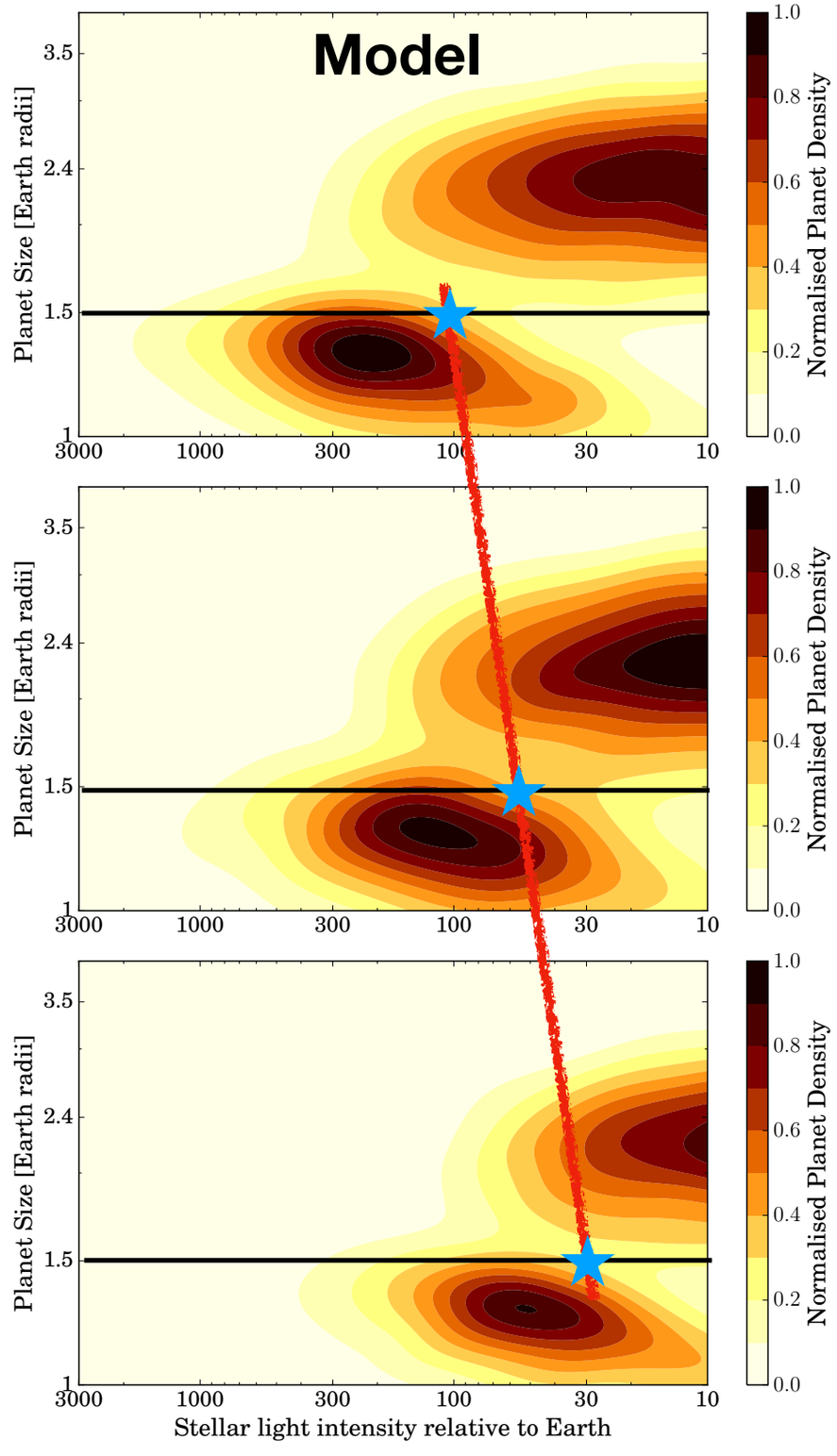
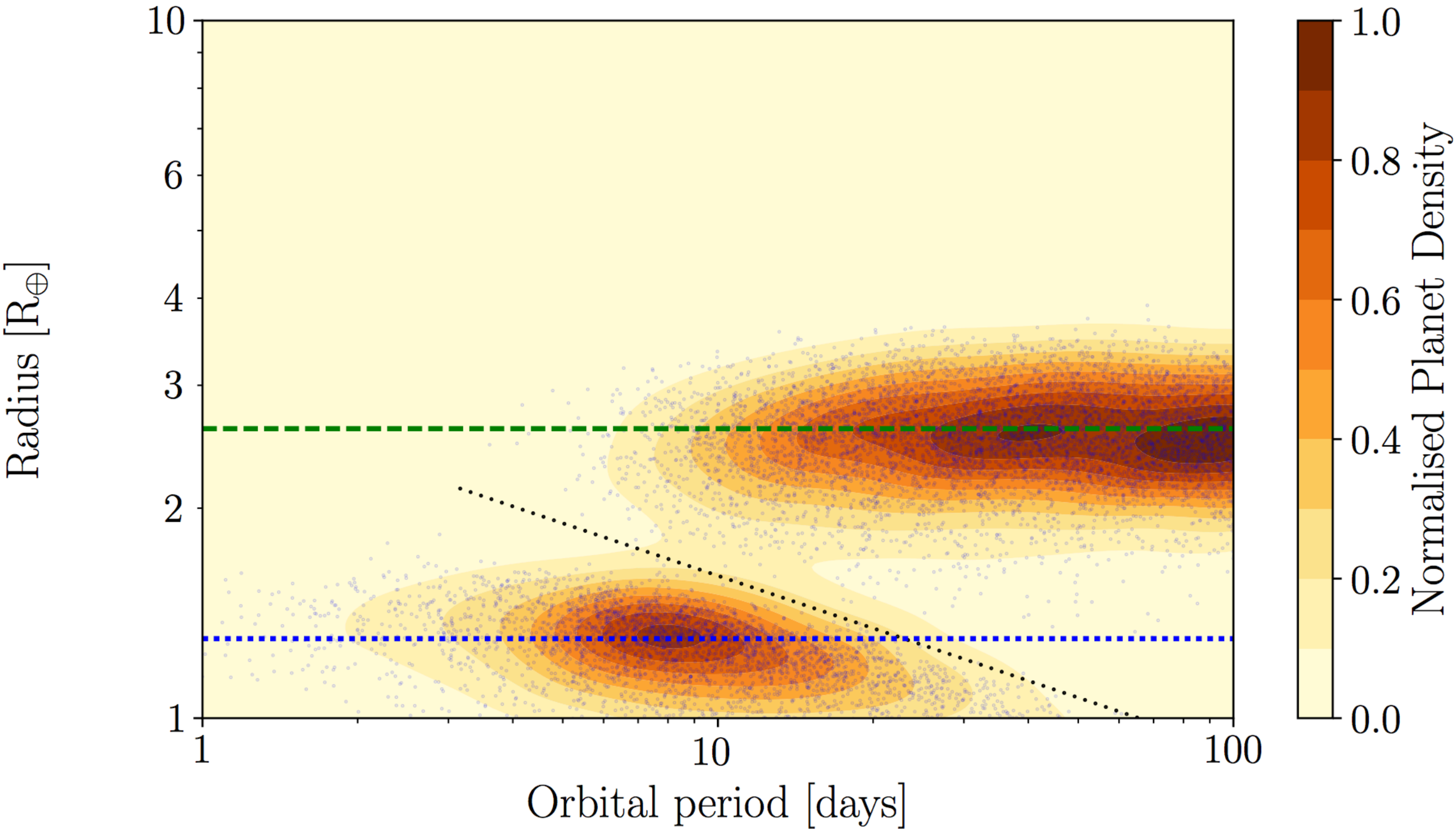
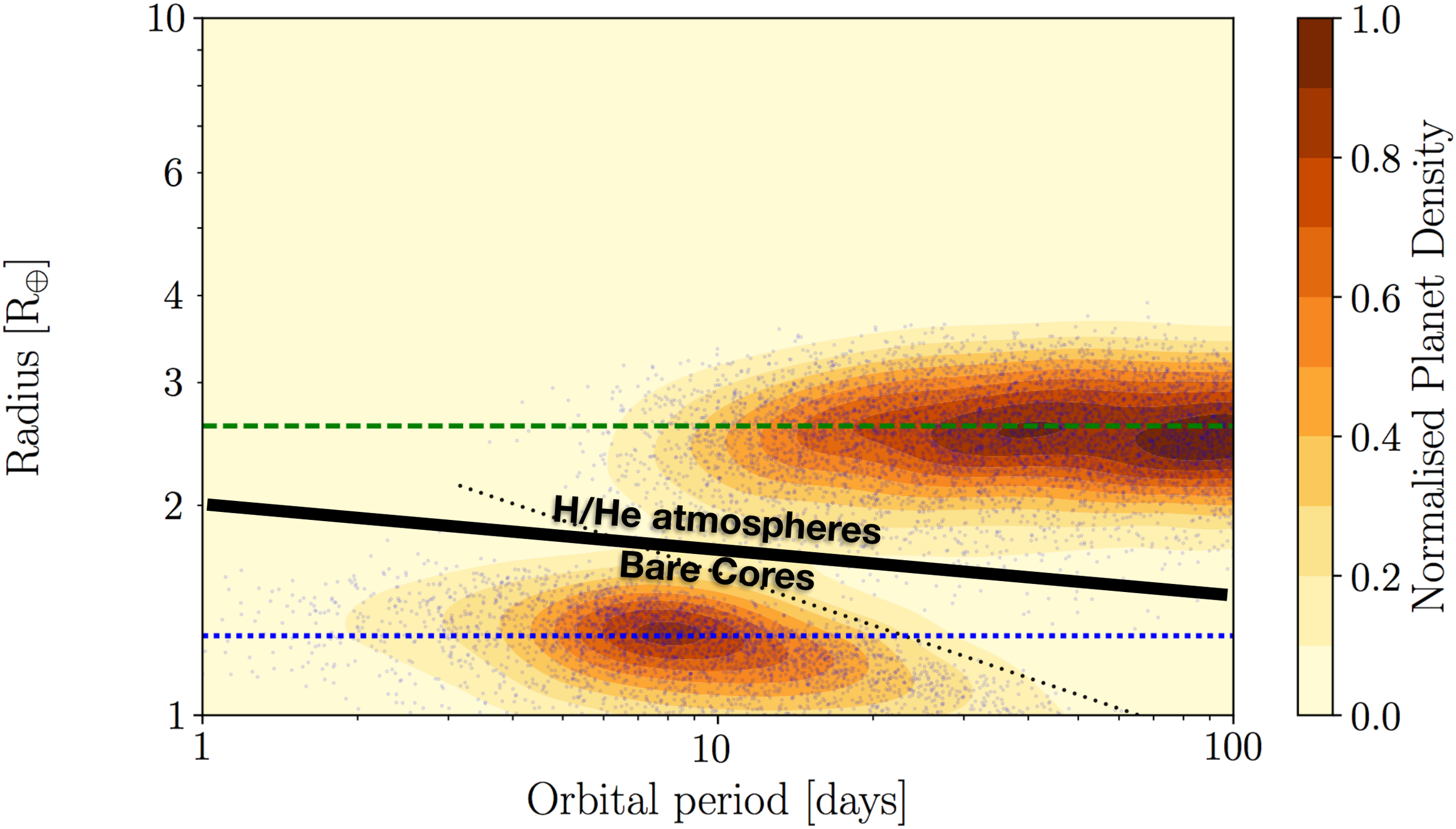



## Question: how to measure this trend?




Radius [R⊕]
10
6
4
3
2
1
1
10
100
Orbital period [days]
1.0
0.8
0.6
0.4
0.2
0.0
Normalised Planet Density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H/He atmospheres
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Completely Evaporated
Unaffected by evaporated
H/He atmospheres
Bare Cores
Radius [$R_\oplus$]
Orbital period [days]
Normalised Planet Density
10
6
4
3
2
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1
10
100
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0.8
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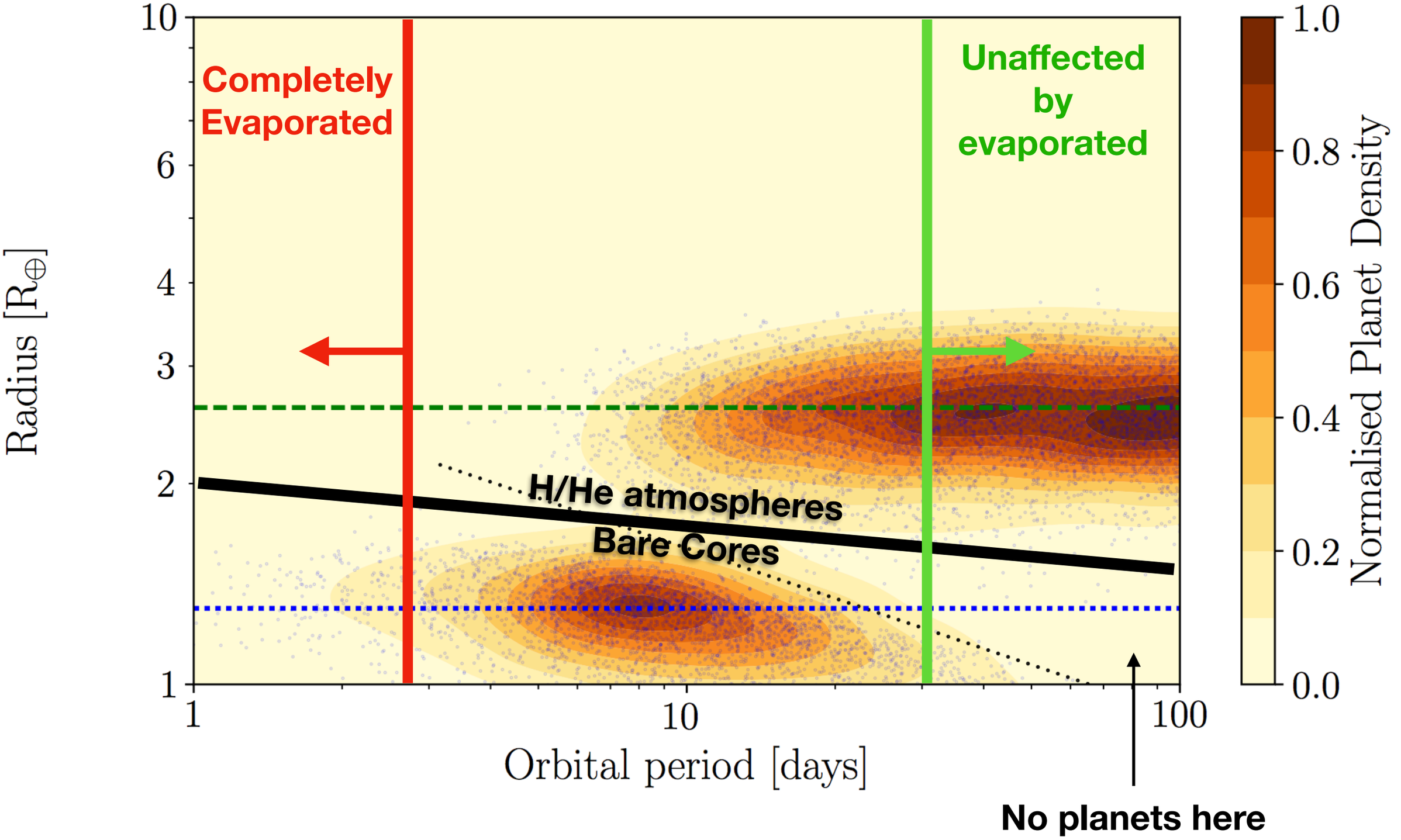
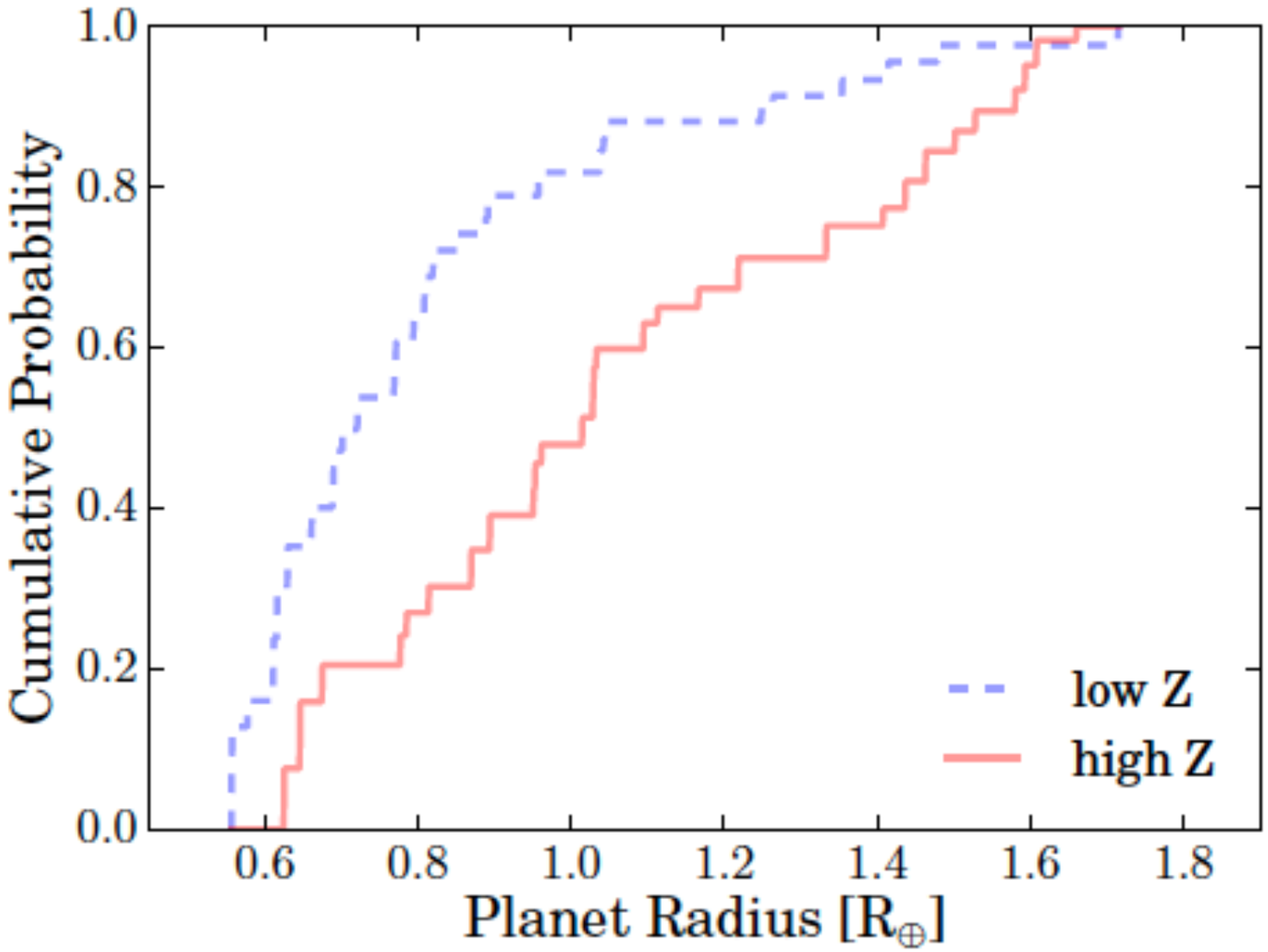
0.0


Completely Evaporated
Unaffected by evaporated
H/He atmospheres
Bare Cores
No planets here
Radius [R⊕]
Orbital period [days]
Normalised Planet Density
10
6
4
3
2
1
1
10
100
1.0
0.8
0.6
0.4
0.2
0.0

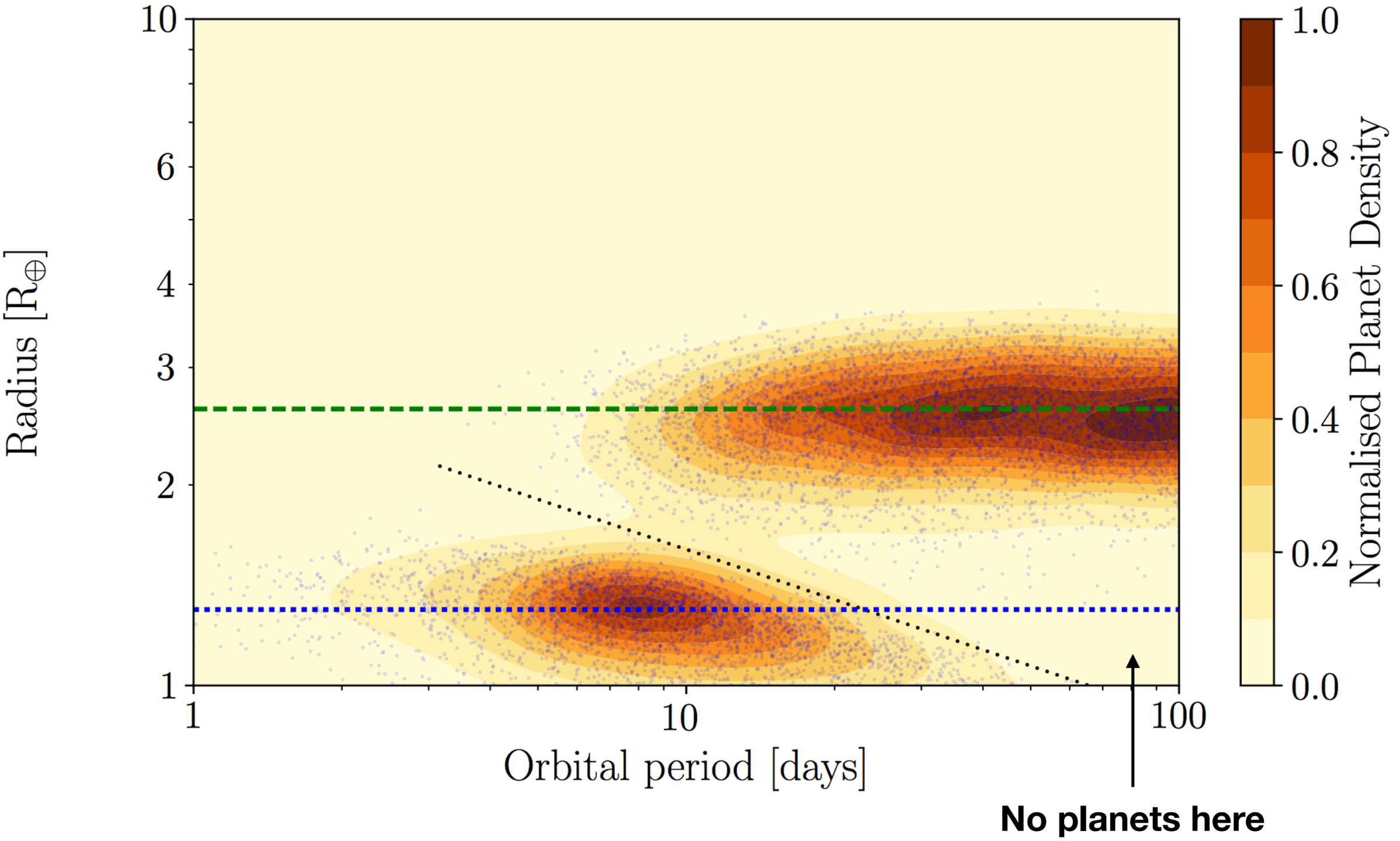
# Planets at short periods - completely stripped by evaporation

**Probe of core properties**




Owen & Murray-Clay (2018)

**Planets around lower metallicity stars have smaller (lower mass) cores**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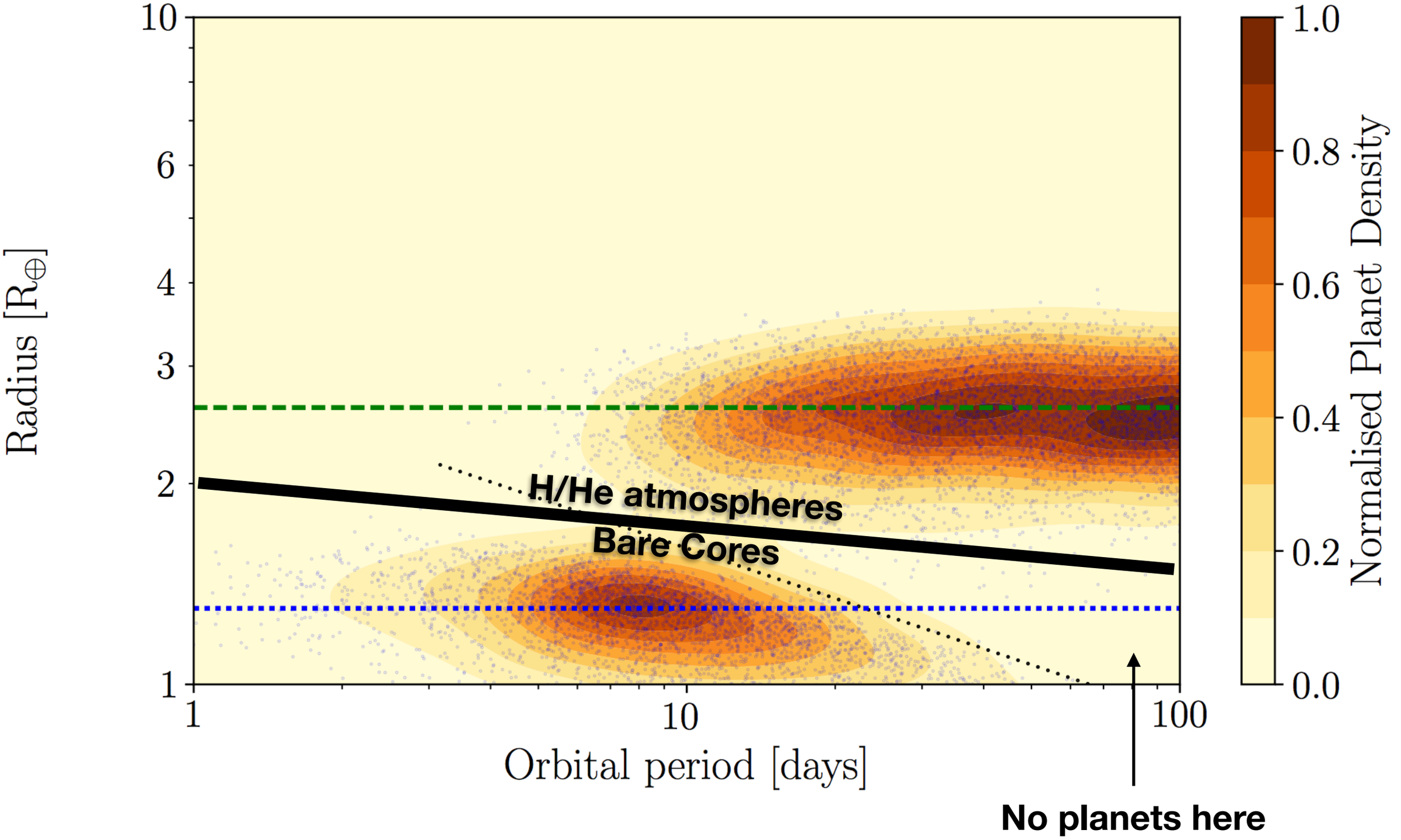
No planets here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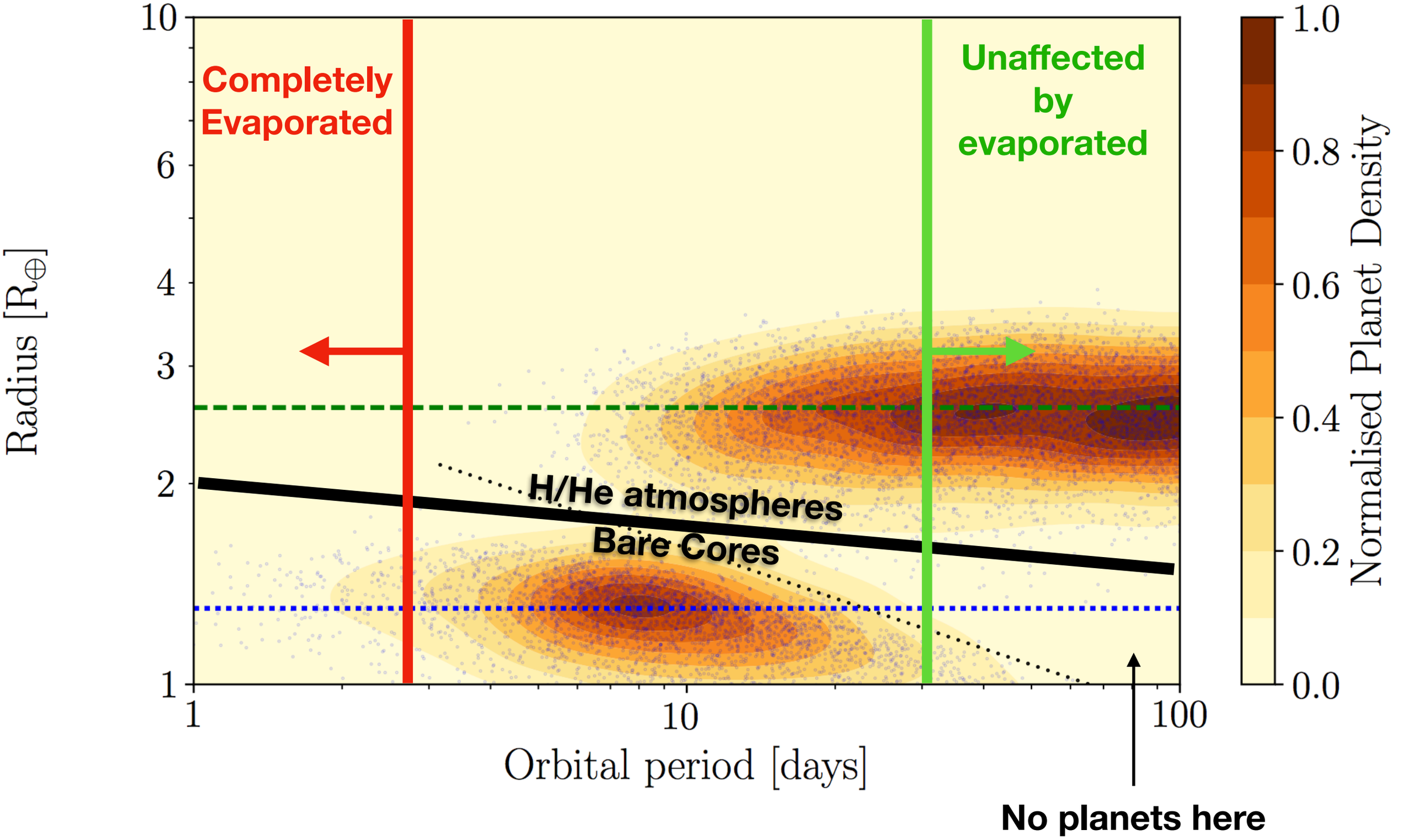
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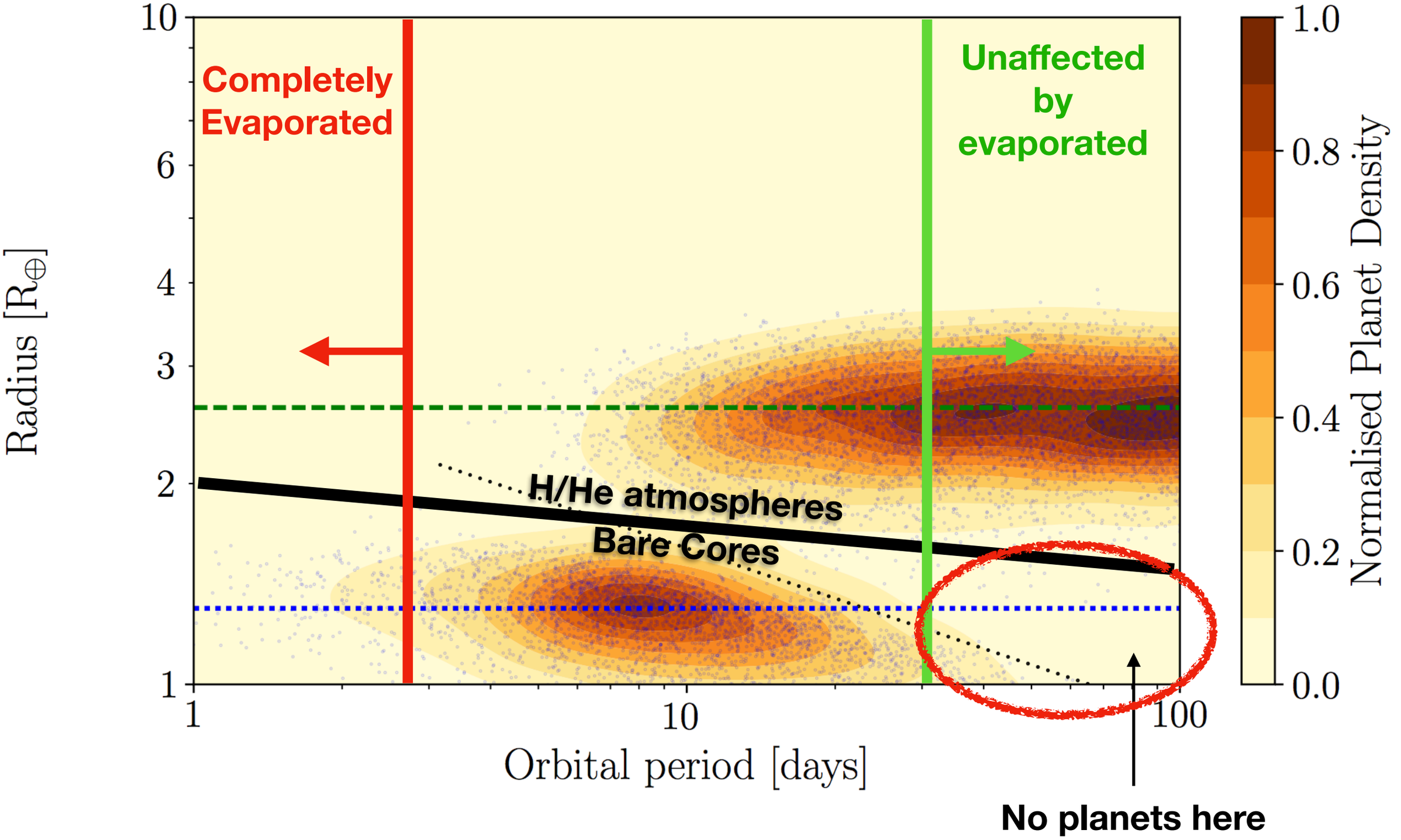
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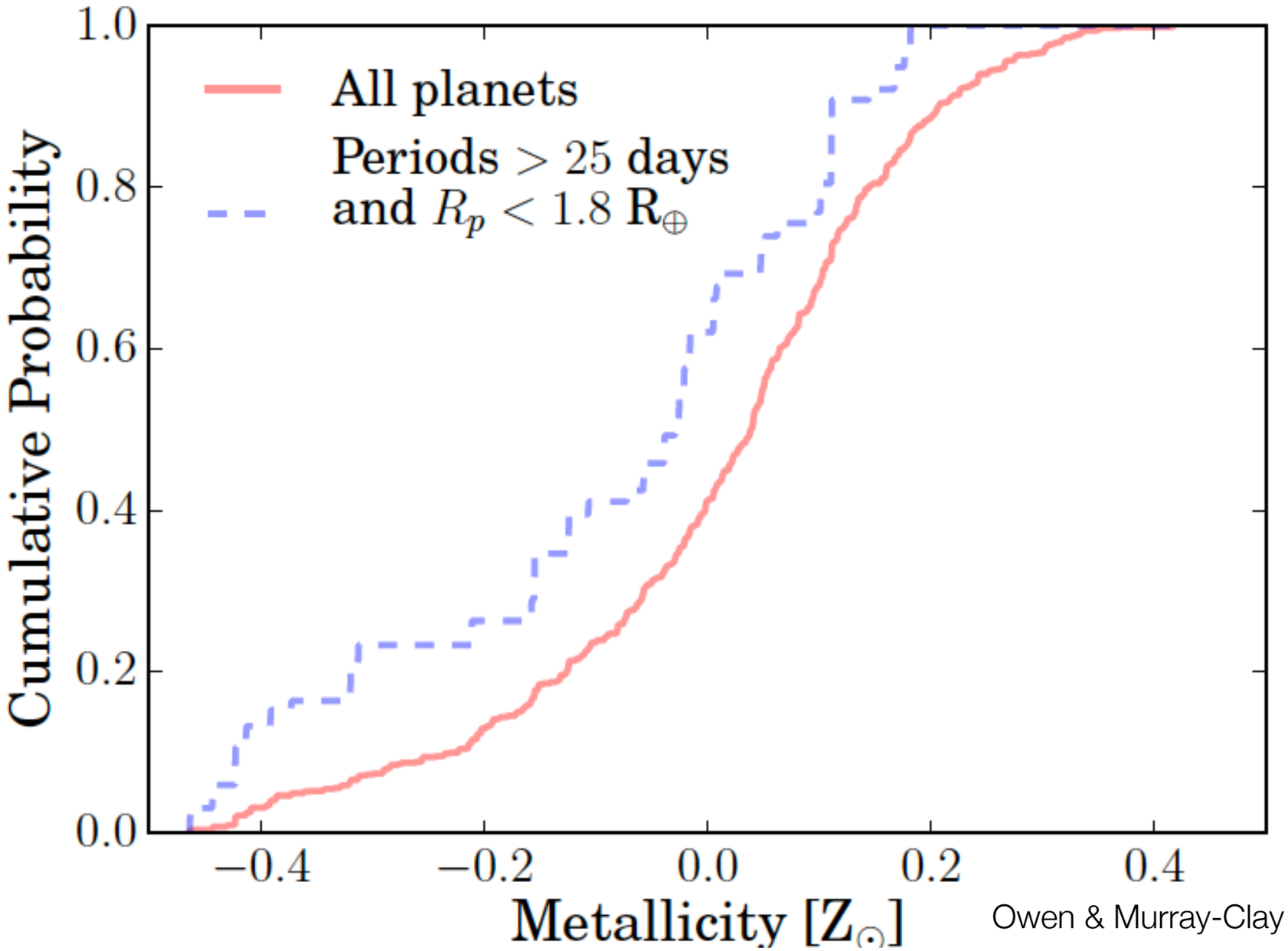
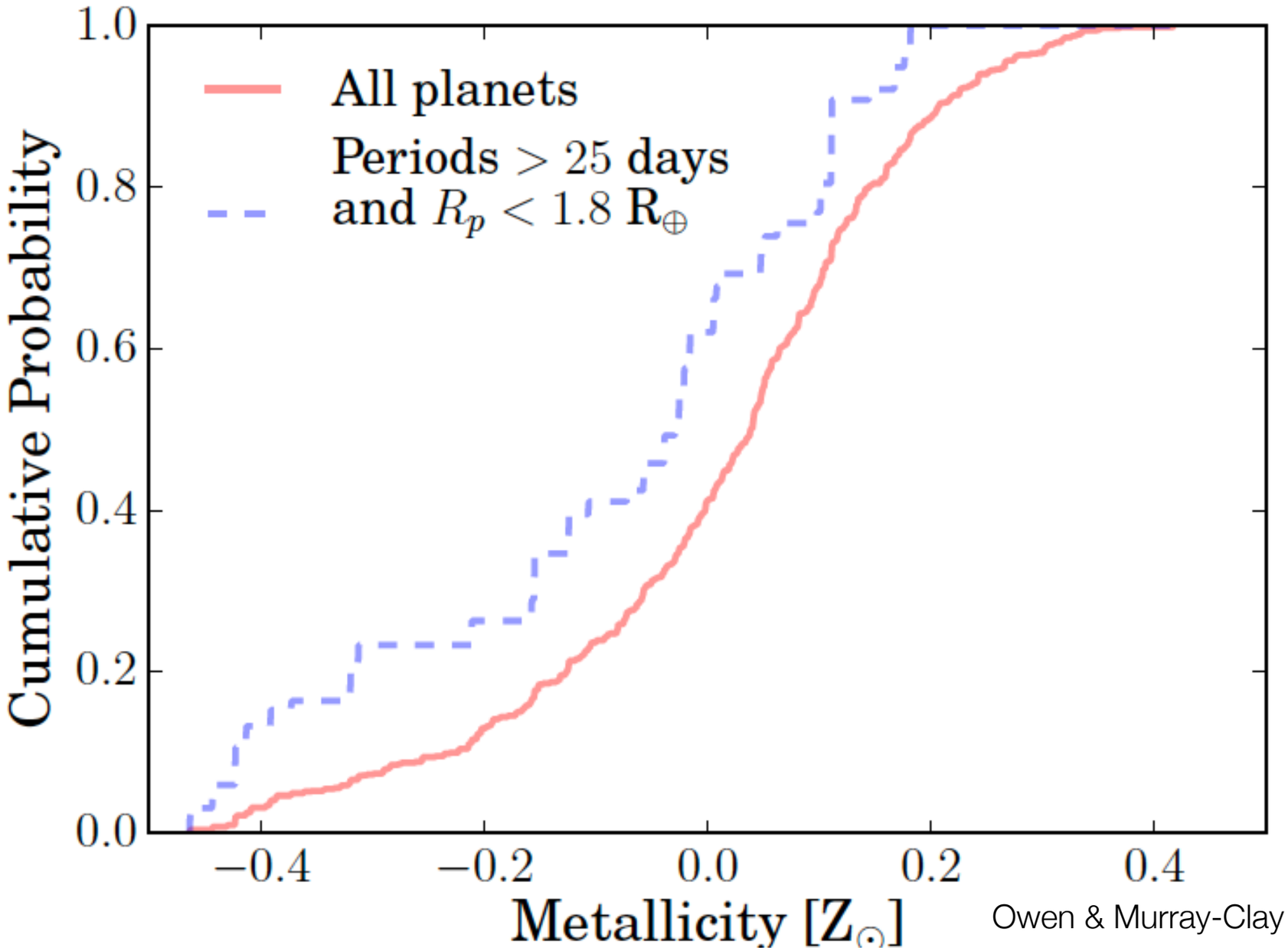
# “Born terrestrial” planets more common at lower metallicity?




Owen & Murray-Clay (2018)

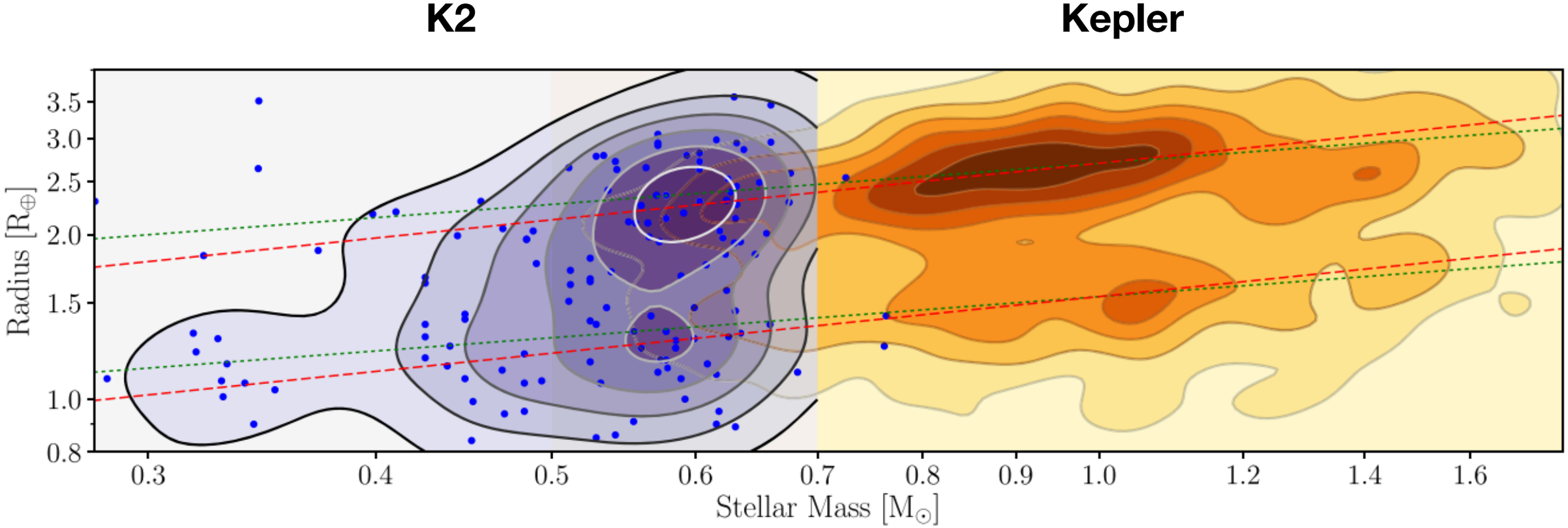
# “Born terrestrial” planets more common at lower metallicity?

**Question: is this real (2.8σ) and what is it telling us?**




Owen & Murray-Clay (2018)

# Stellar mass scaling?




Wu (2019)

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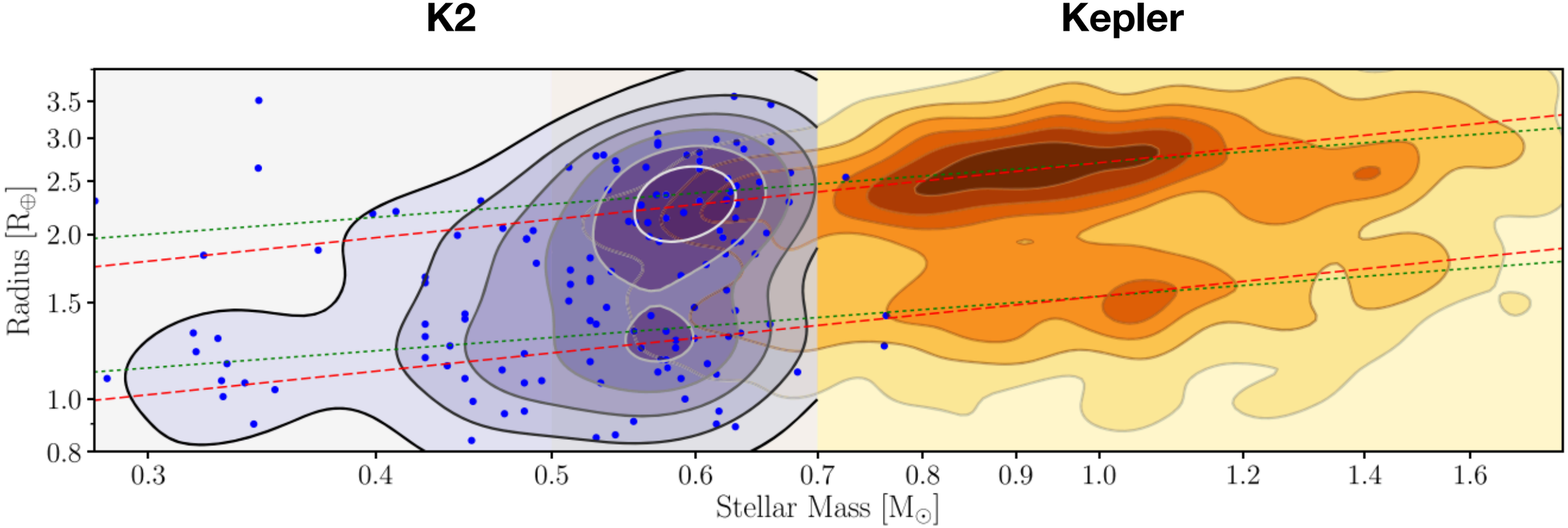


Wu (2019)

**Question: how to tie together different data sets?**

# Summary

- Atmospheric escape can entirely strip a low-mass planet of its significant H/He envelope, leaving behind the solid core.

- The radius gap is a robust prediction of the evaporation model, and constrains core composition.

- **Believing in atmospheric escape** one can extract trends with stellar metallicity.

- With detailed knowledge of the star, one can robustly test the mass-loss scenario and use it to infer unobservable properties.