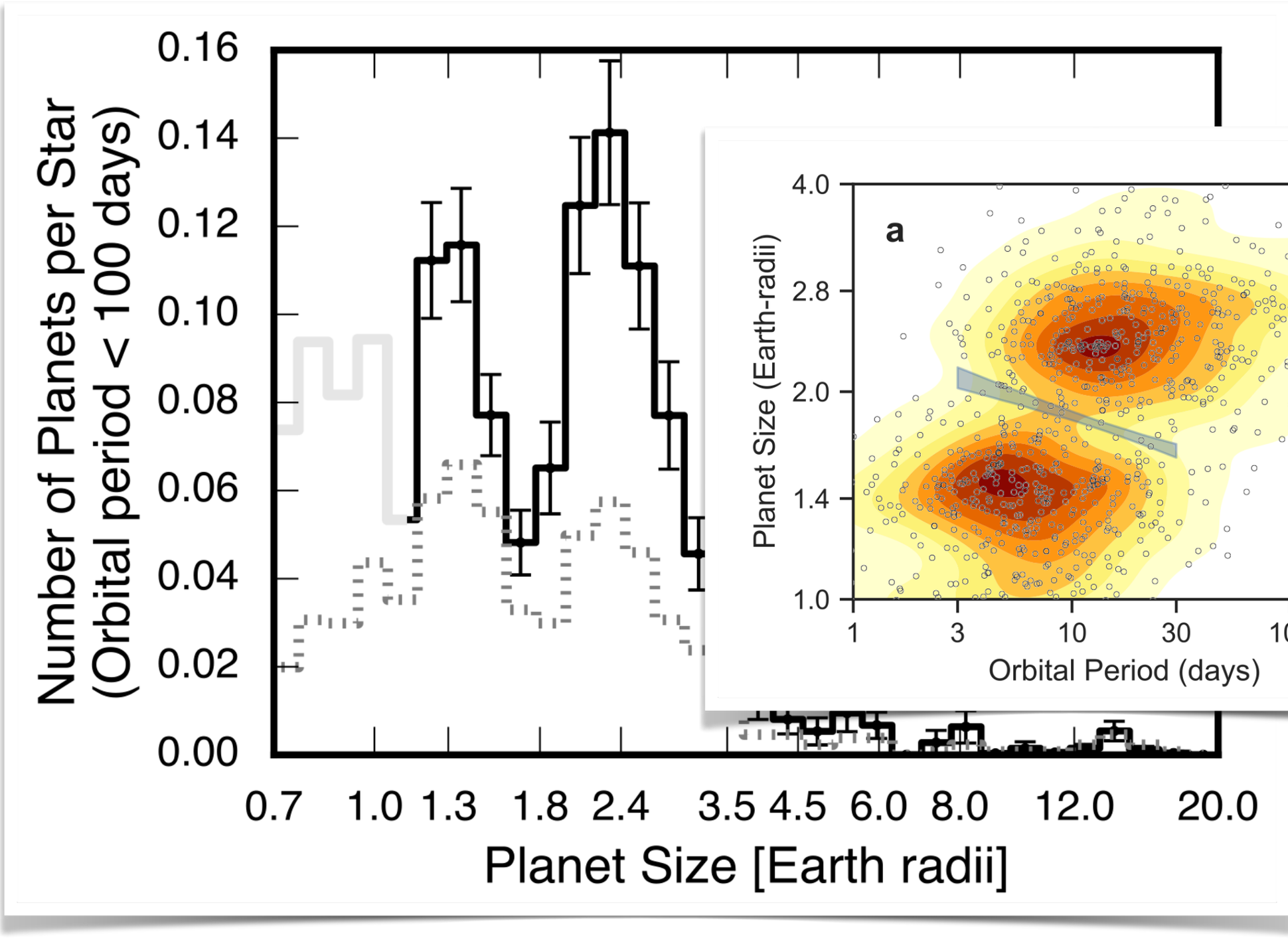
The Impact of Stellar Evolution on the Road to the Radius Valley

James Rogers

Kavli Institute Senior Fellow

8th Feb 2025

The Radius Valley



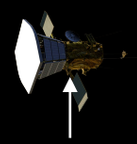
Fulton & Petigura 2018
Petigura, Rogers et al. 2022

Distances are to scale

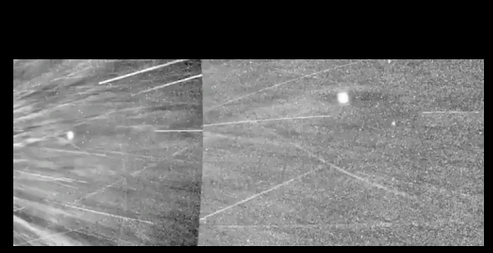
CoRoT - 7 b

0.017 AU

Parker Probe
Closest Approach
December 2024



0.053 AU

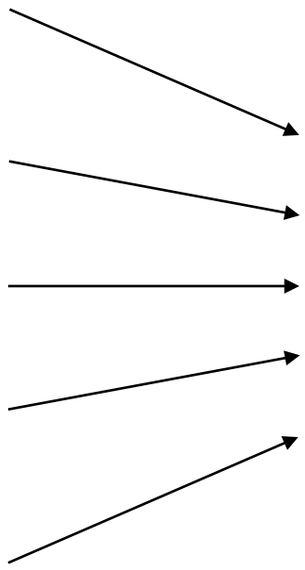


Parker
Solar
Probe

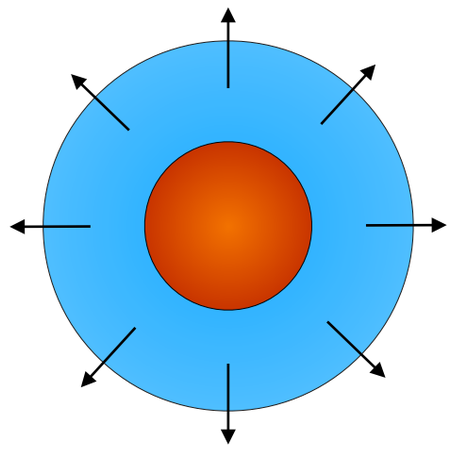
A Mission to Touch the Sun

Photoevaporation

Owen & Wu 2013, 2017, Rogers & Owen 2021



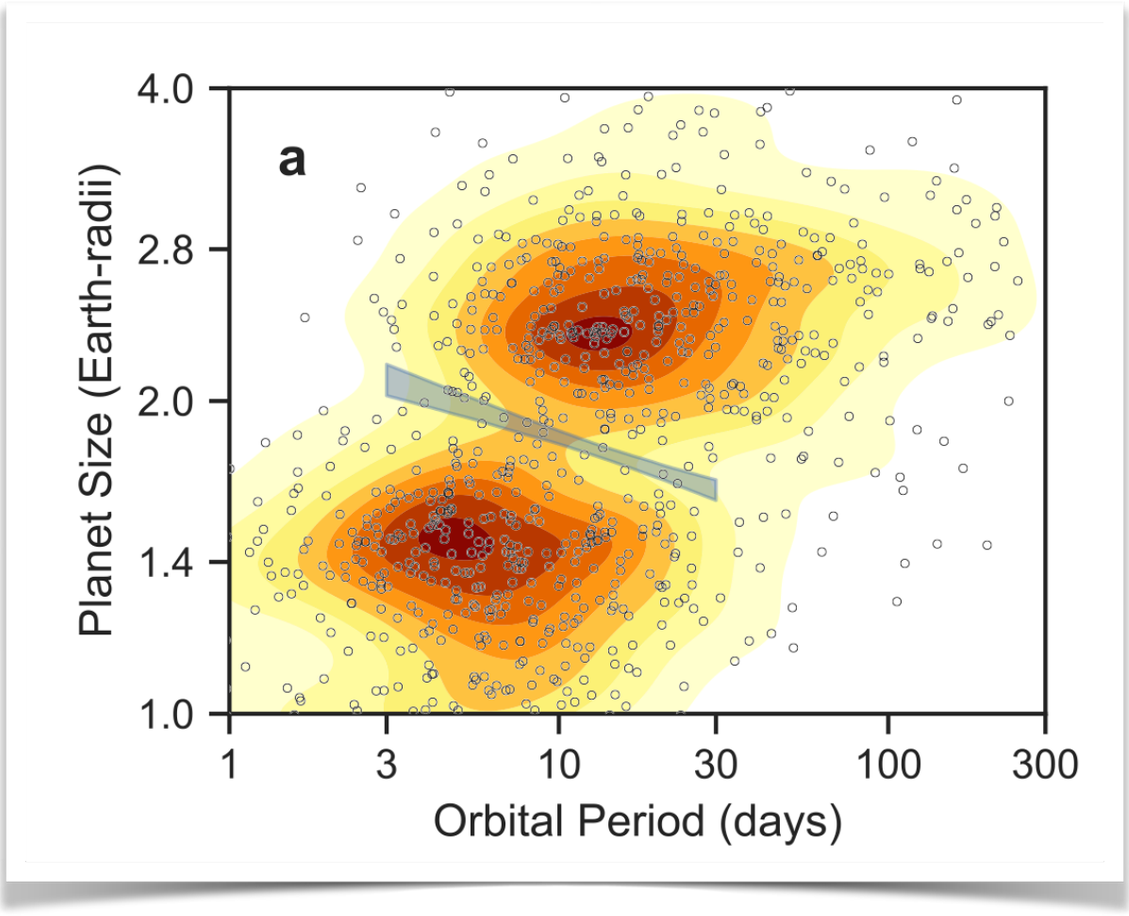
EUV/X-Rays

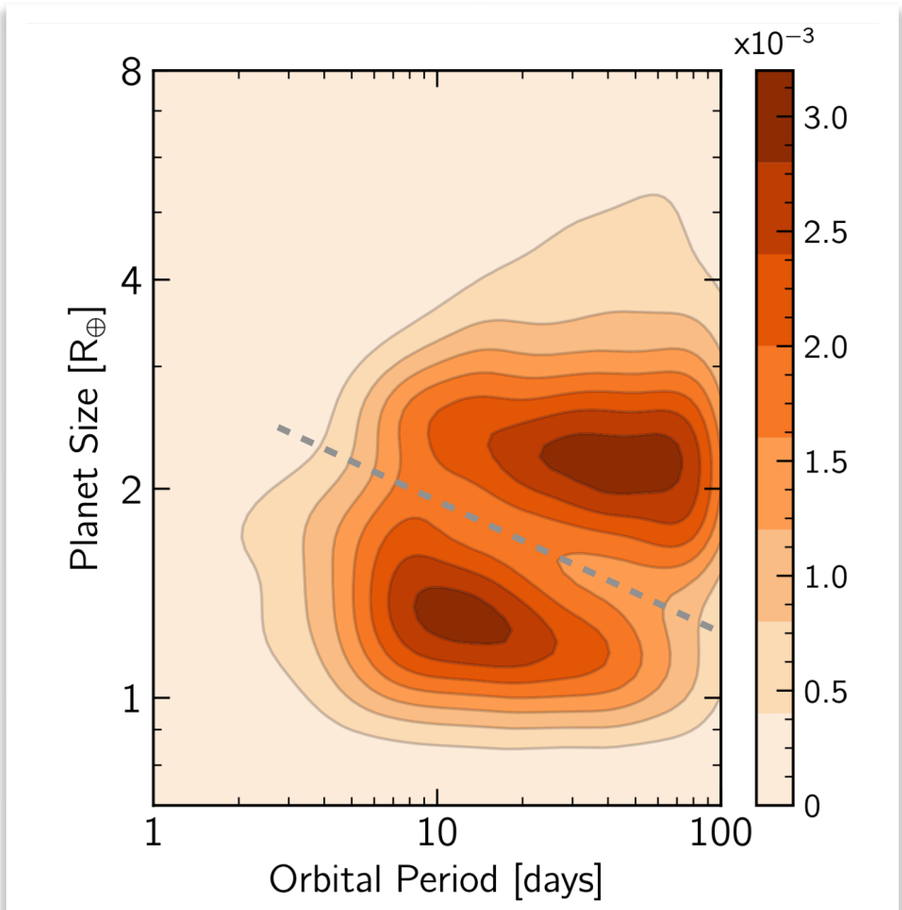


Outflow

Photoevaporation

Owen & Wu 2013, 2017, Rogers & Owen 2021

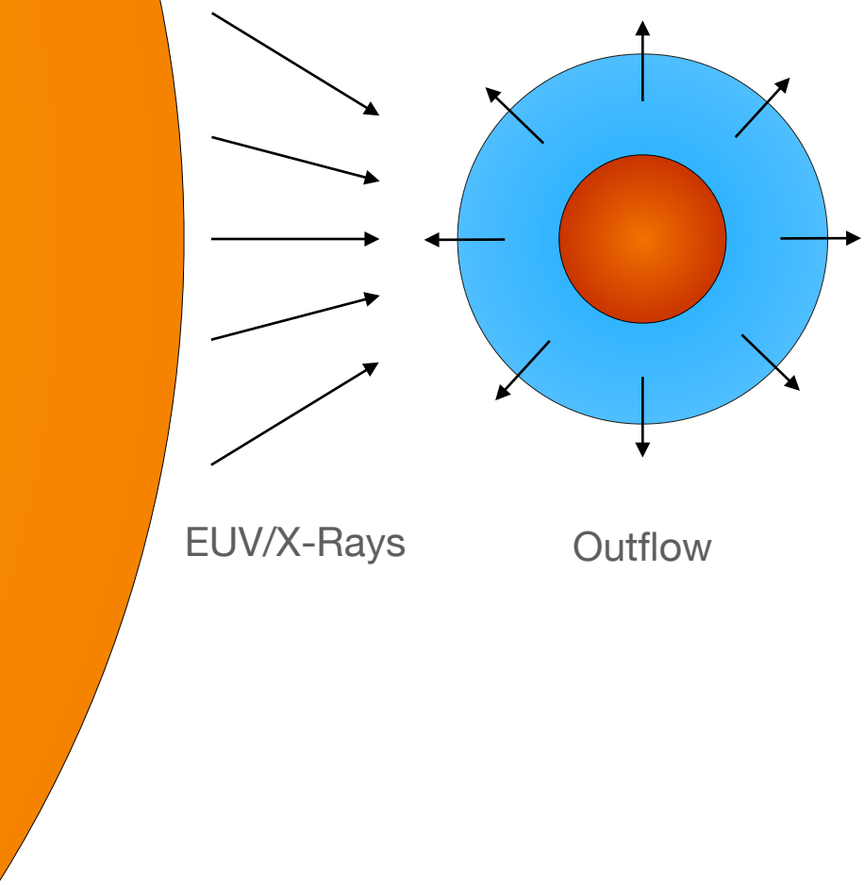




Petigura, Rogers et al 2022

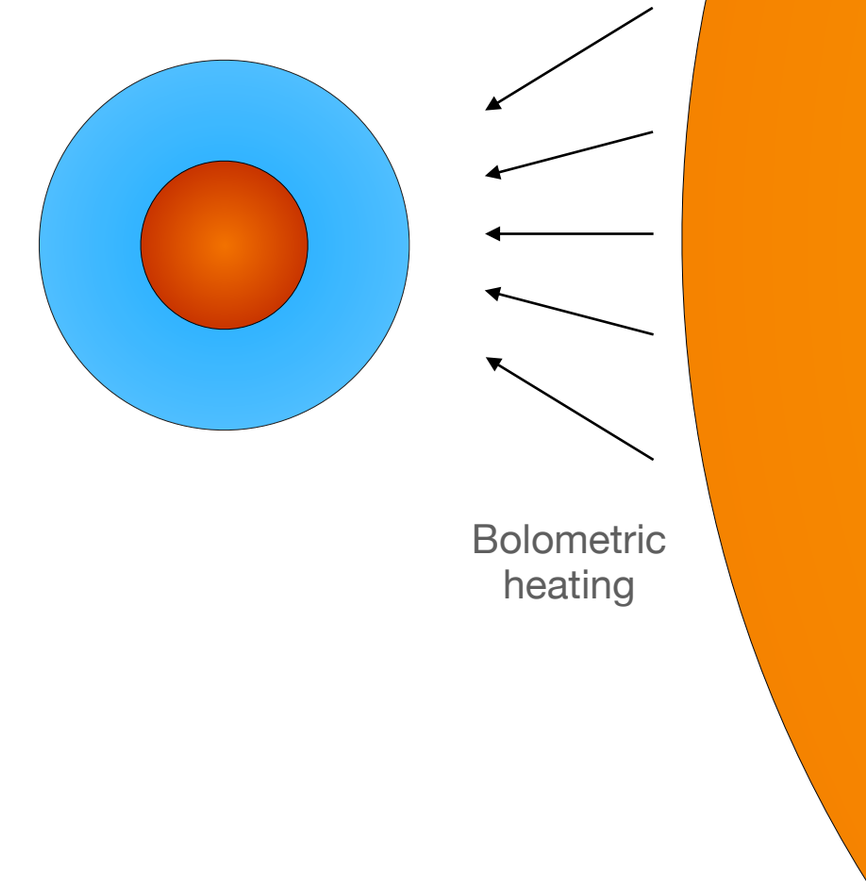
Photoevaporation

Owen & Wu 2013, 2017, Rogers & Owen 2021



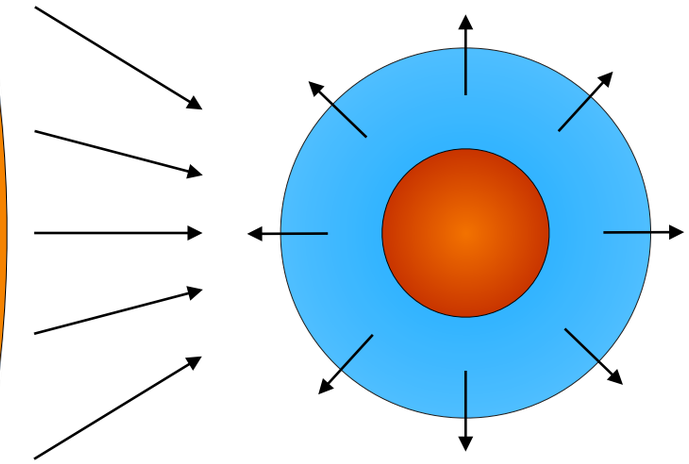
Core-Powered Mass-Loss

Ginzburg et al. 2018; Gupta & Schlichting 2019



Photoevaporation

Owen & Wu 2013, 2017, Rogers & Owen 2021

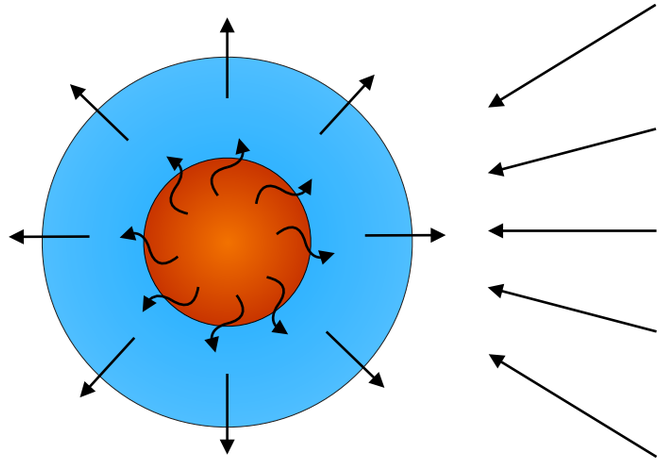


EUV/X-Rays

Outflow

Core-Powered Mass-Loss

Ginzburg et al. 2018; Gupta & Schlichting 2019

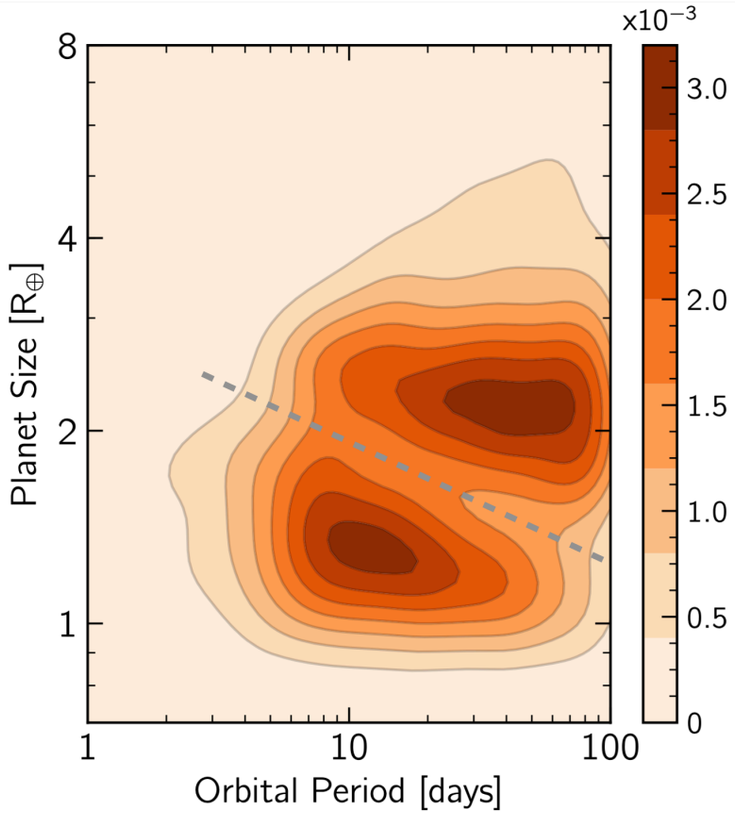


Outflow

Bolometric heating

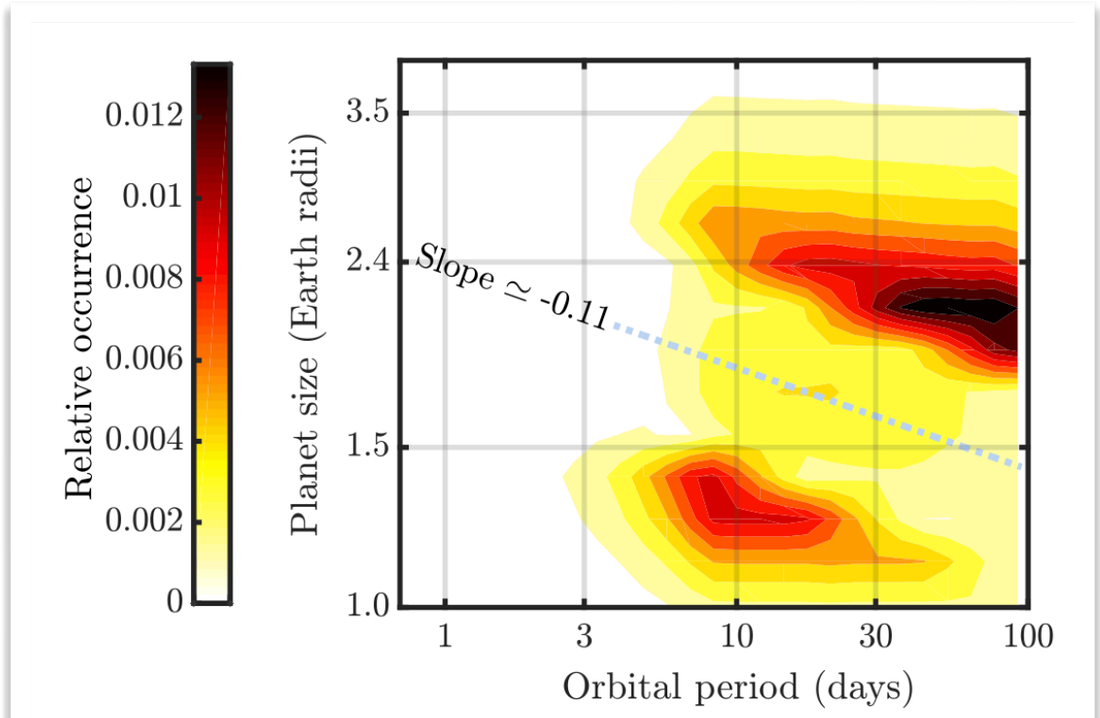
Photoevaporation

Owen & Wu 2013, 2017, Rogers & Owen 2021

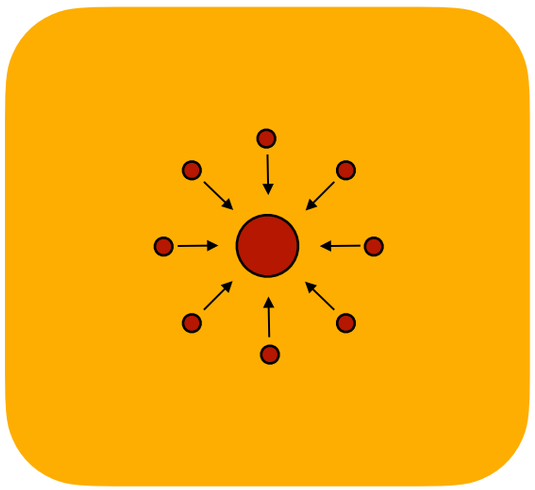


Core-Powered Mass-Loss

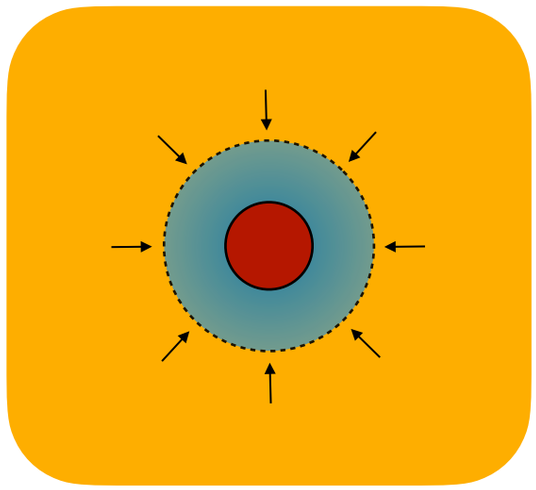
Ginzburg et al. 2018; Gupta & Schlichting 2019



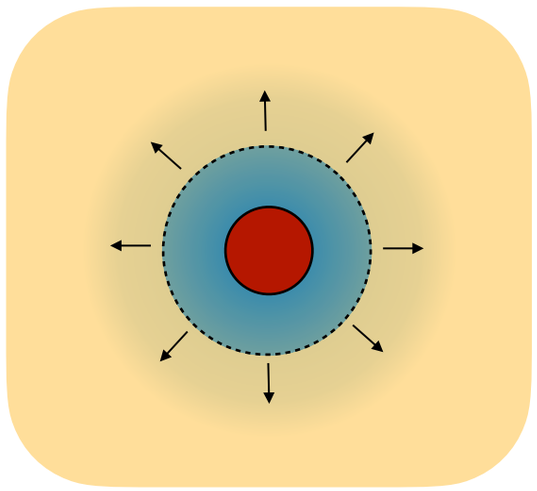
Know Thy Star, Know Thy Protoplanetary Disc, Know Thy Planet



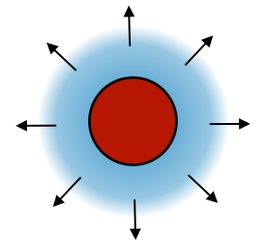
Solid core accretion



Gas accretion

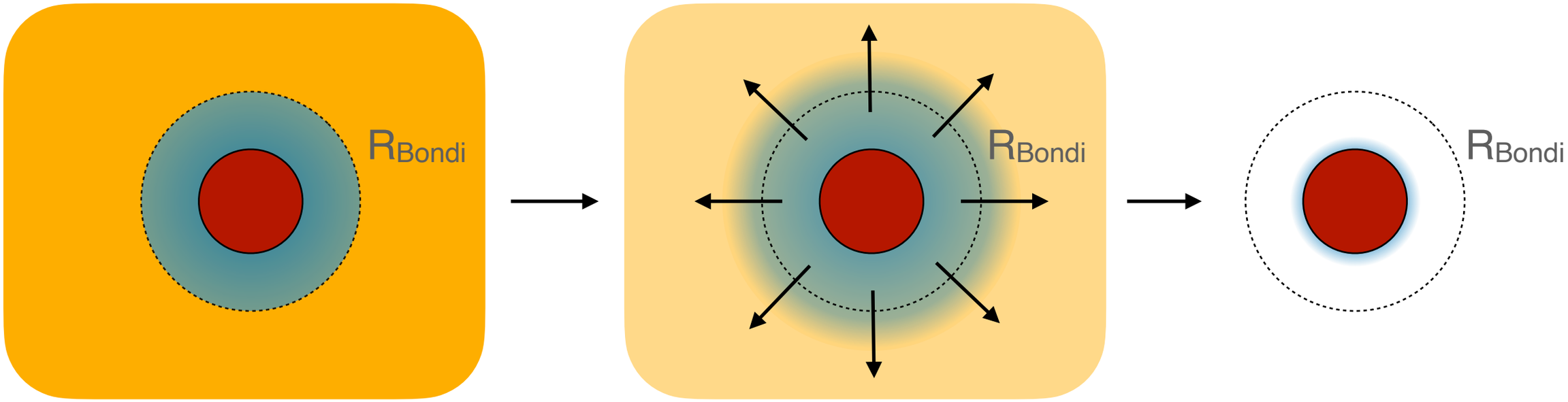


Boil-off



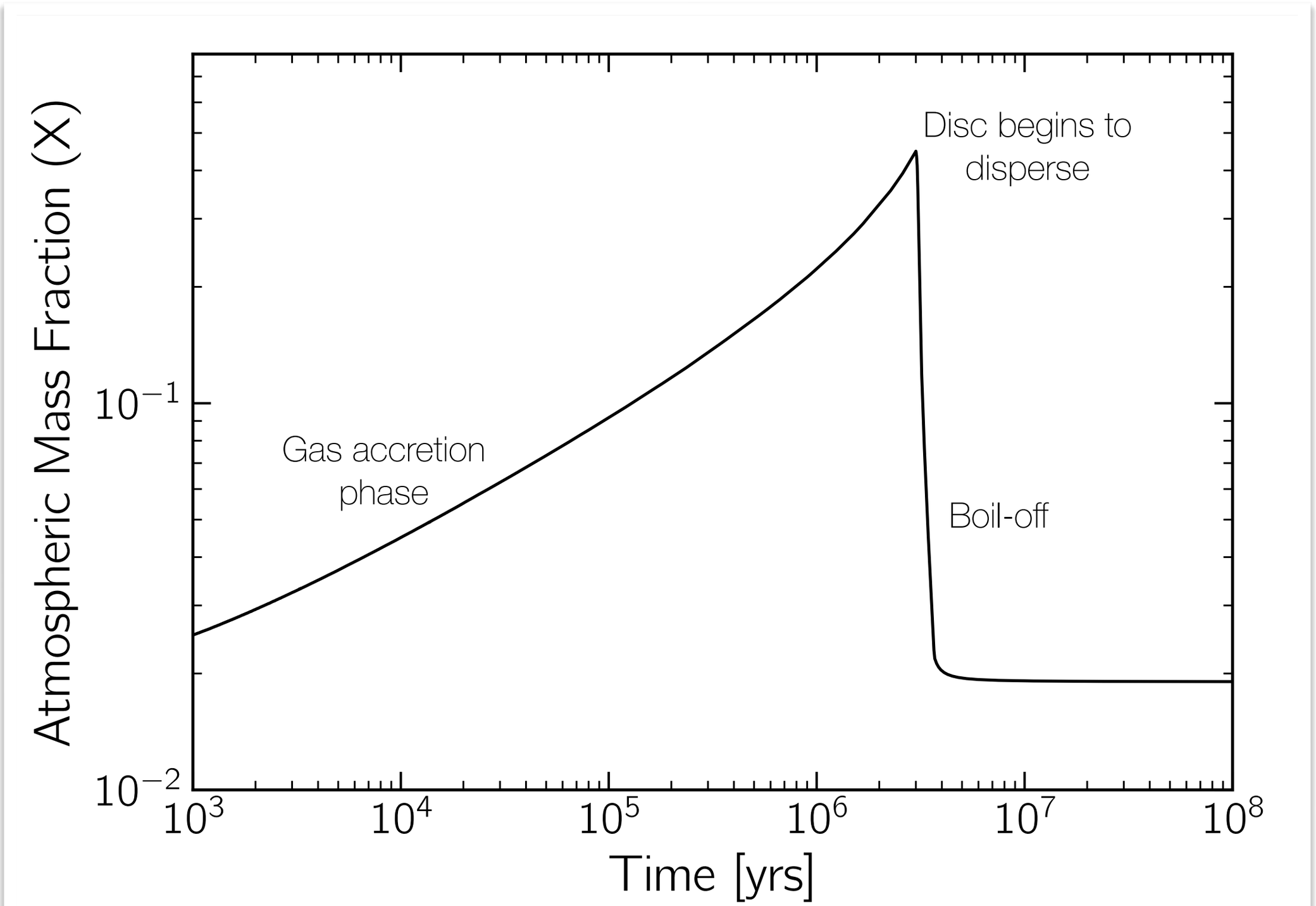
Photoevaporation
+
Core-powered mass-loss

Boil-off



See Owen and Wu (2016)

Boil-off



Rogers, Owen and Schlichting (2024)

<u>Boil-off</u> → core-powered mass-loss → photoevaporation

R_{Bondi}

Internal luminosity

Thermal contraction

Escape

Bolometric heating
(star+disc)

Owen and Schlichting (2024)
Rogers, Owen and Schlichting (2024)

Boil-off → core-powered mass-loss → photoevaporation

R_{Bondi}

Subsonic

Supersonic

Internal luminosity

Core cooling

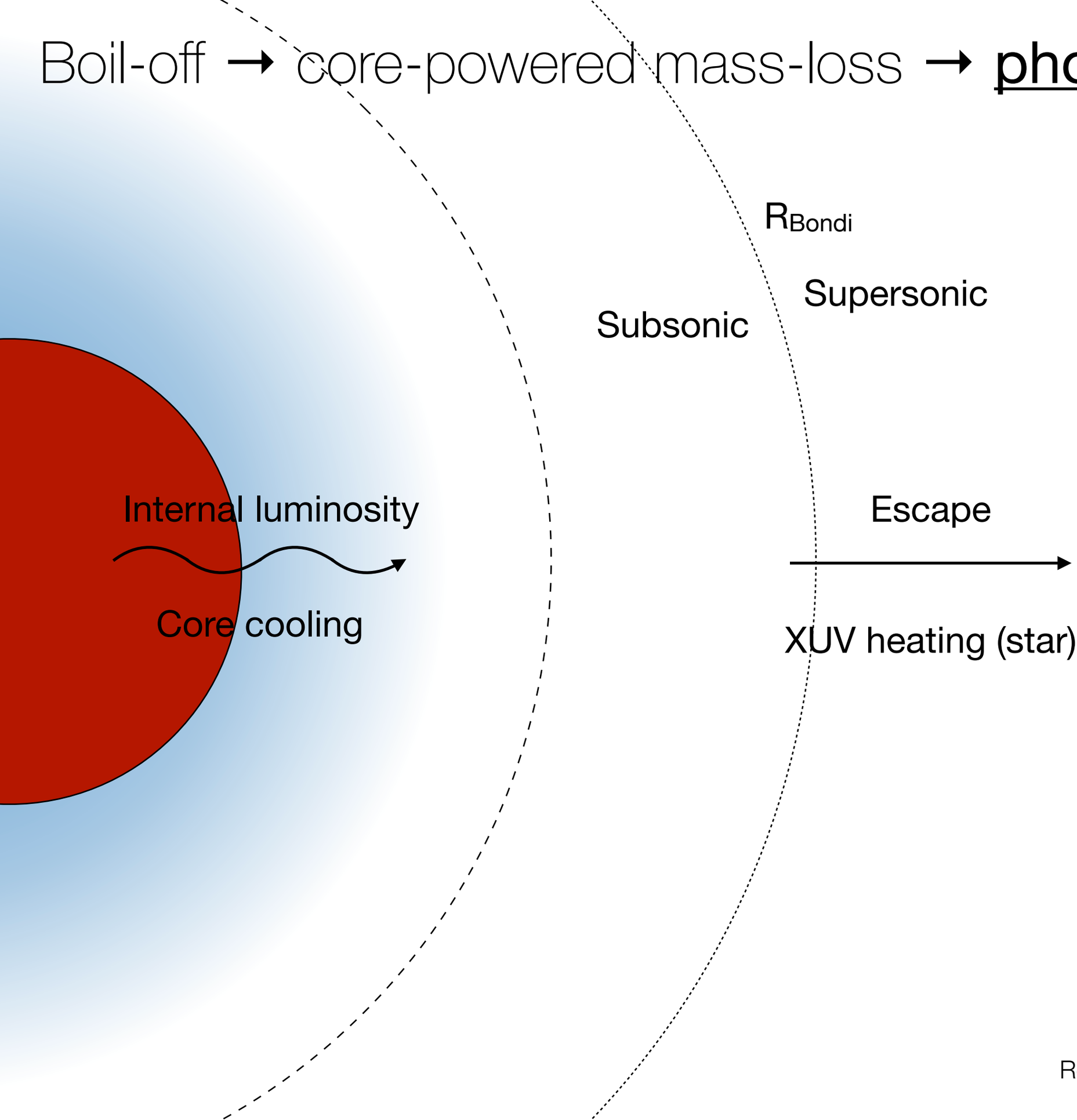
Escape

Bolometric heating
(star+disc)

XUV
heating

Owen and Schlichting (2024)
Rogers, Owen and Schlichting (2024)

Boil-off → core-powered mass-loss → photoevaporation



Owen and Schlichting (2024)
Rogers, Owen and Schlichting (2024)

For <u>most</u>* sub-Neptunes:

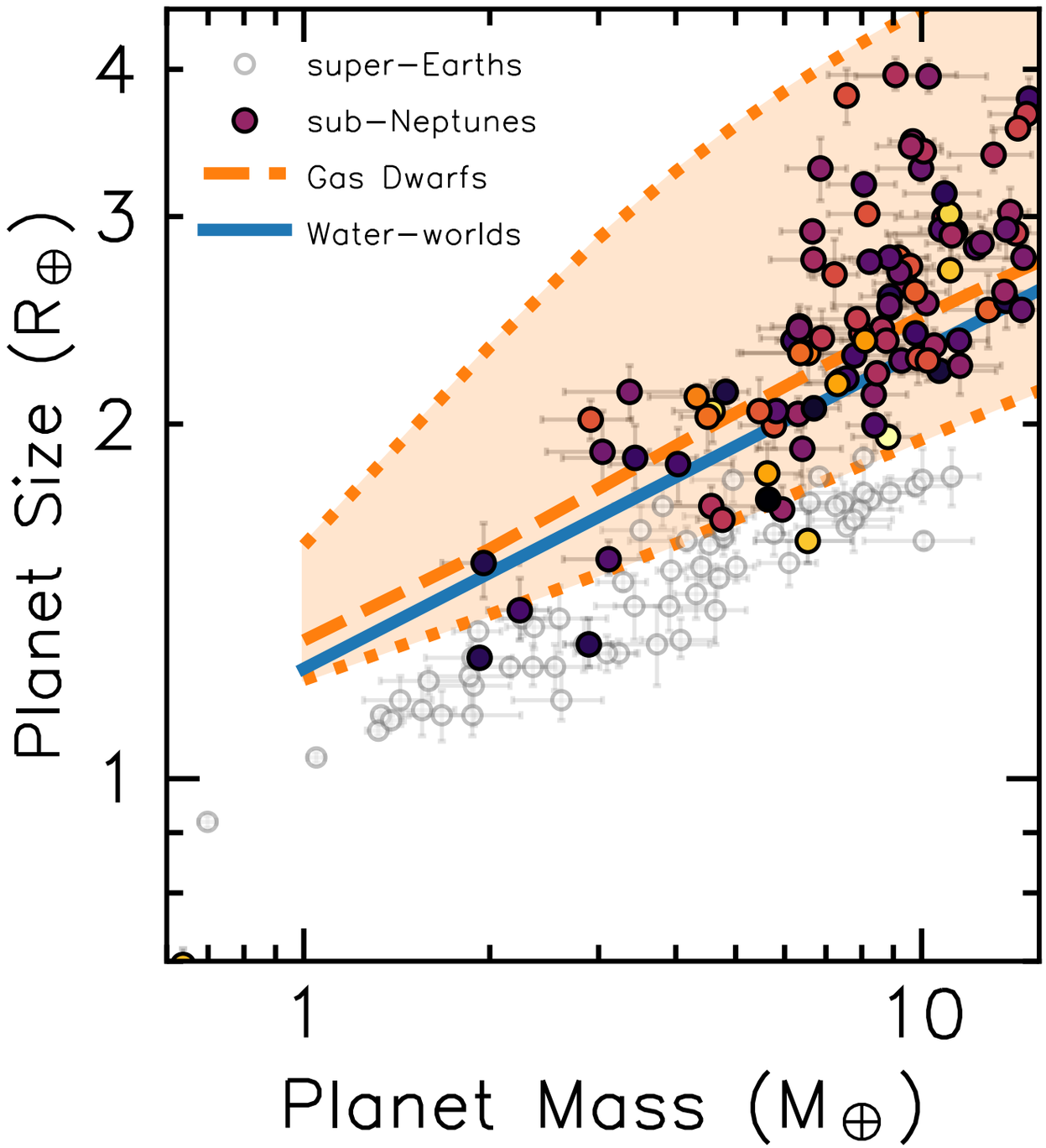
Early (bolometric mass loss) | **Late (XUV mass loss)**

Boil-off → core-powered mass-loss → photoevaporation

** Your sub-Neptune's experience may differ*

Owen and Schlichting (2024)
Rogers, Owen and Schlichting (2024)
Tang, Fortney and Murray-Clay (2024)

Sub-Neptune Composition



Rogers, Schlichting & Owen (2023)

Are sub-Neptunes…

Gas Dwarfs (Earth-like interiors with H/He-rich envelopes)

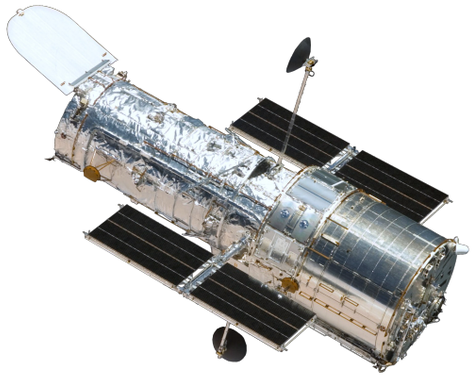
- Radius valley is a product of <u>evolution</u> (sub-Neptunes are converted into super-Earths via atmospheric escape)

- Super-Earths and sub-Neptunes formed from same underlying population

Water Worlds (~ 50% rock, 50% H_2O)

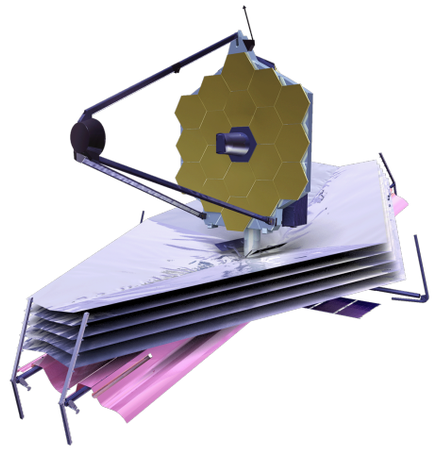
- Radius valley is a product of <u>formation</u> (sub-Neptunes have a fundamentally different composition to super-Earths)

- Super-Earths and sub-Neptunes formed through different channels



Sub-Neptune Composition

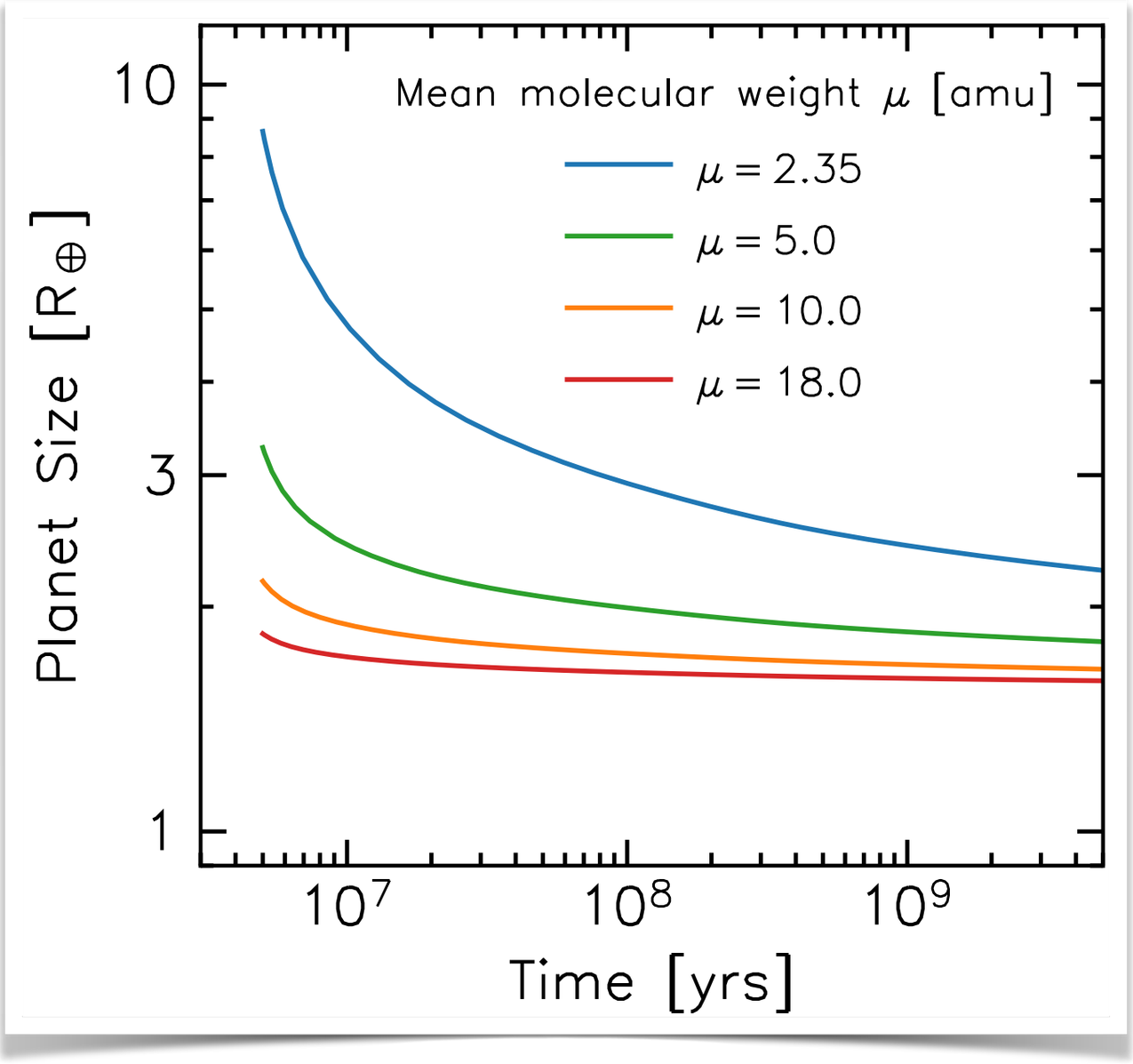
Can transit spectroscopy help?



Planet	**Mean molecular weight (amu)**	
Gas Dwarfs (Earth-like interiors with H/He-rich envelopes)	~ 2.3 - 5	(Schlichting & Young 2021)
Water Worlds (~ 50% rock, 50% H_2O)	~ 10 - 18	(Burn et al. 2024)
TOI-421 b	~ 2.3	(Davenport et al. 2025)
TOI-776 c	~ 2.3	(Loyd et al. 2025)
TOI-270 d	~ 5	(Benneke et al. 2024)
GJ 9827 d	~ 18	(Piaulet-Ghorayeb et al. 2024)

Sub-Neptune Composition

Can young planets help?

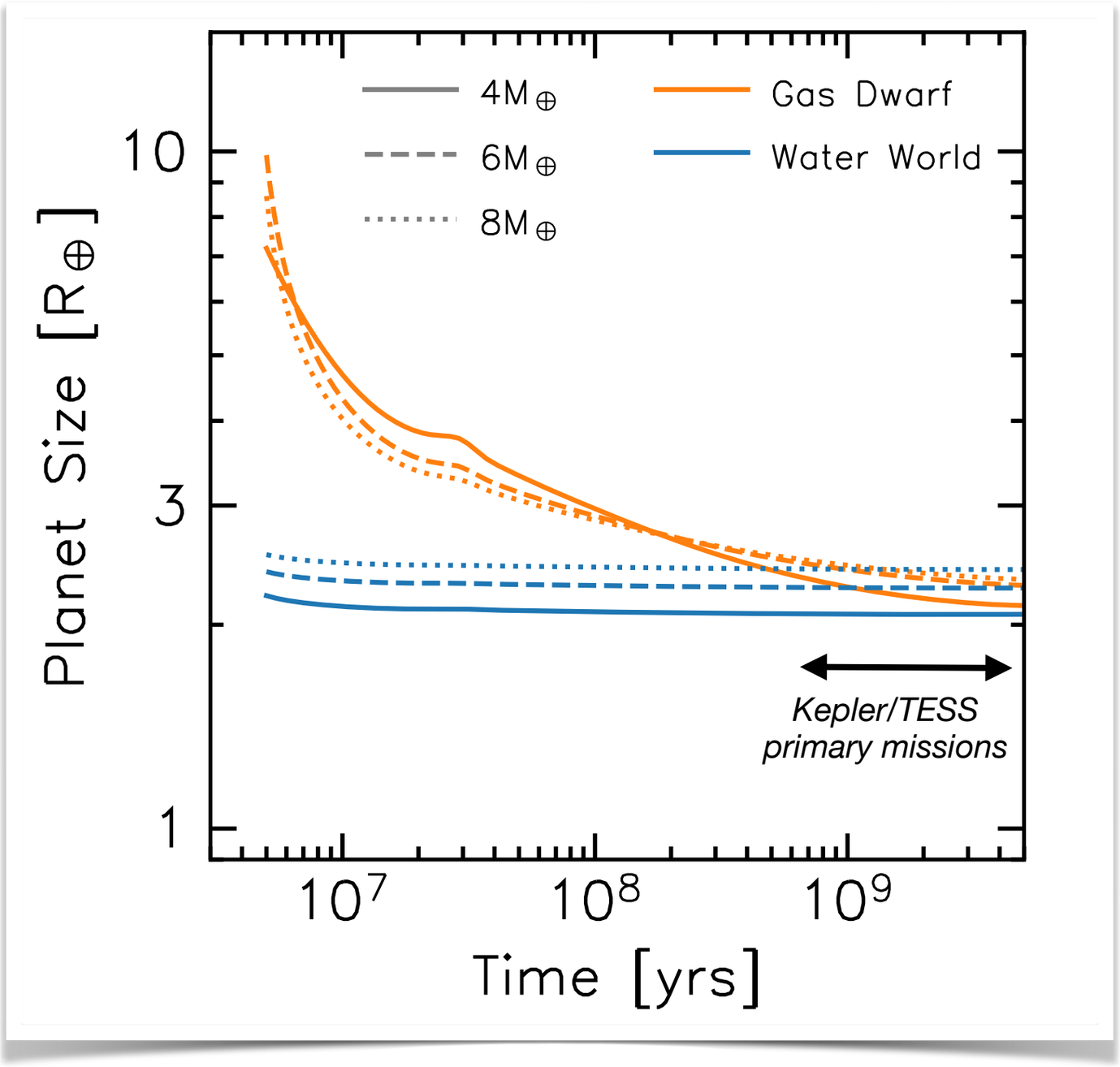


$$H(r) = \frac{c_s^2}{g} = \frac{k_B T}{\mu} \frac{r^2}{G M_p} \propto \frac{1}{\mu}$$

Rogers (2025, in review)

Sub-Neptune Composition

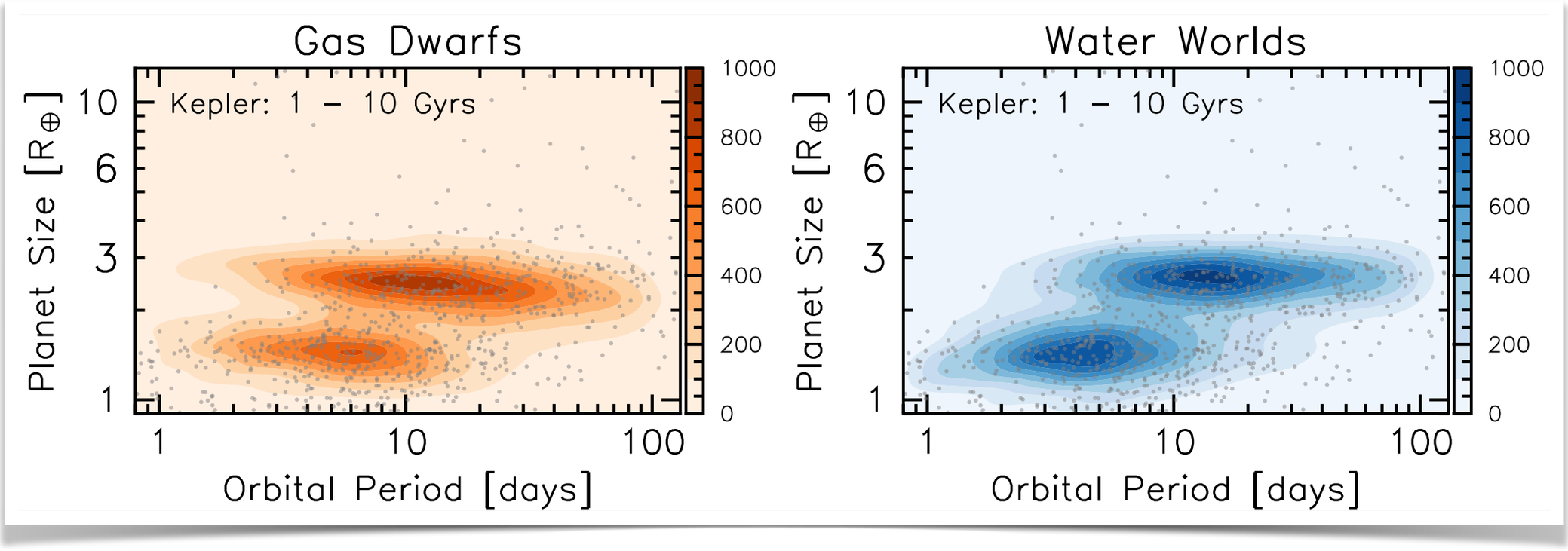
Can young planets help?



Rogers (2025, in review)

Sub-Neptune Composition

Can young planets help?

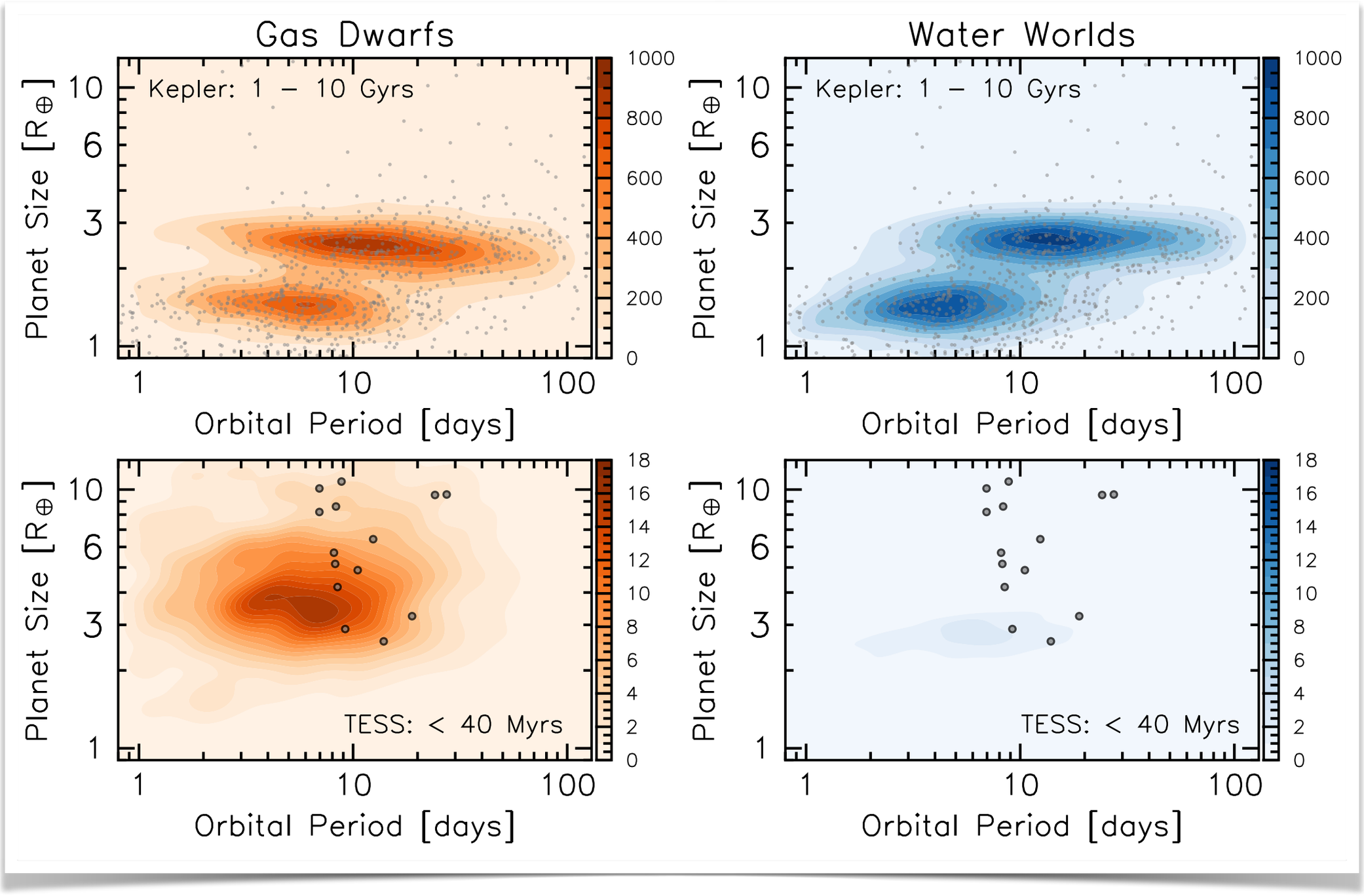


Rogers (2025, in review)

See Vach et al. (2024)

Sub-Neptune Composition

Can young planets help?

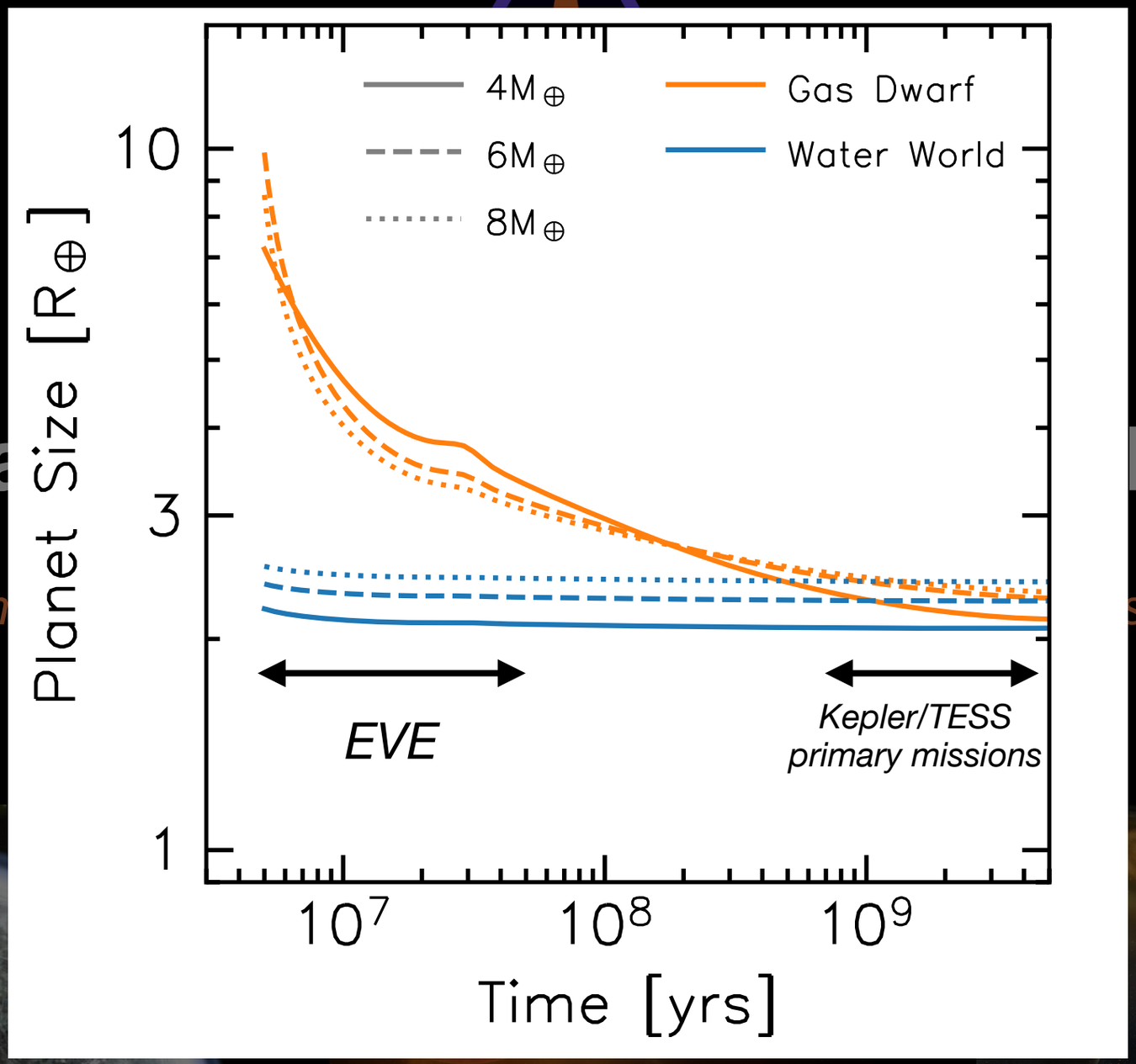


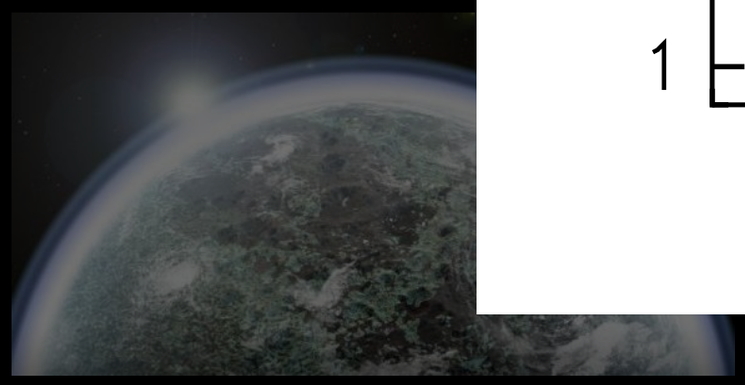
Rogers (2025, in review)

See Vach et al. (2024)

Ea E)

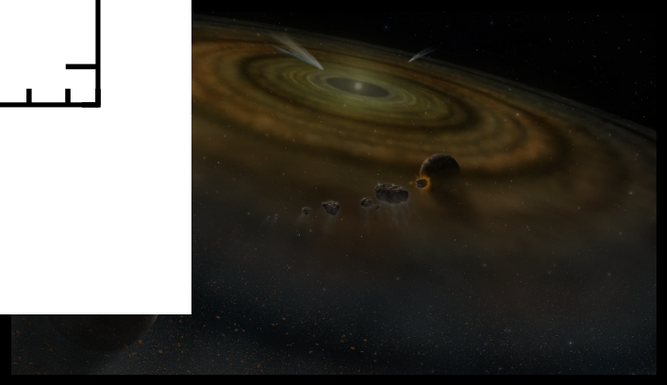
A panch stems to





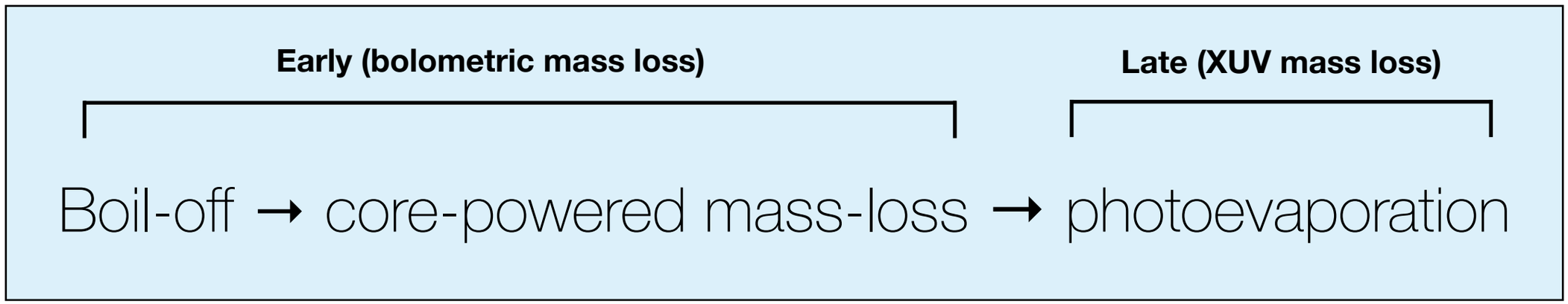
First transit survey focused on discovering young, small planets and constraining their early atmospheric composition and evolution

First large survey of optical and NUV flares to measure the photochemically active stellar flux that young planets receive



First multiband survey of young stars and their disks to determine how accretion processes set planetary system architectures

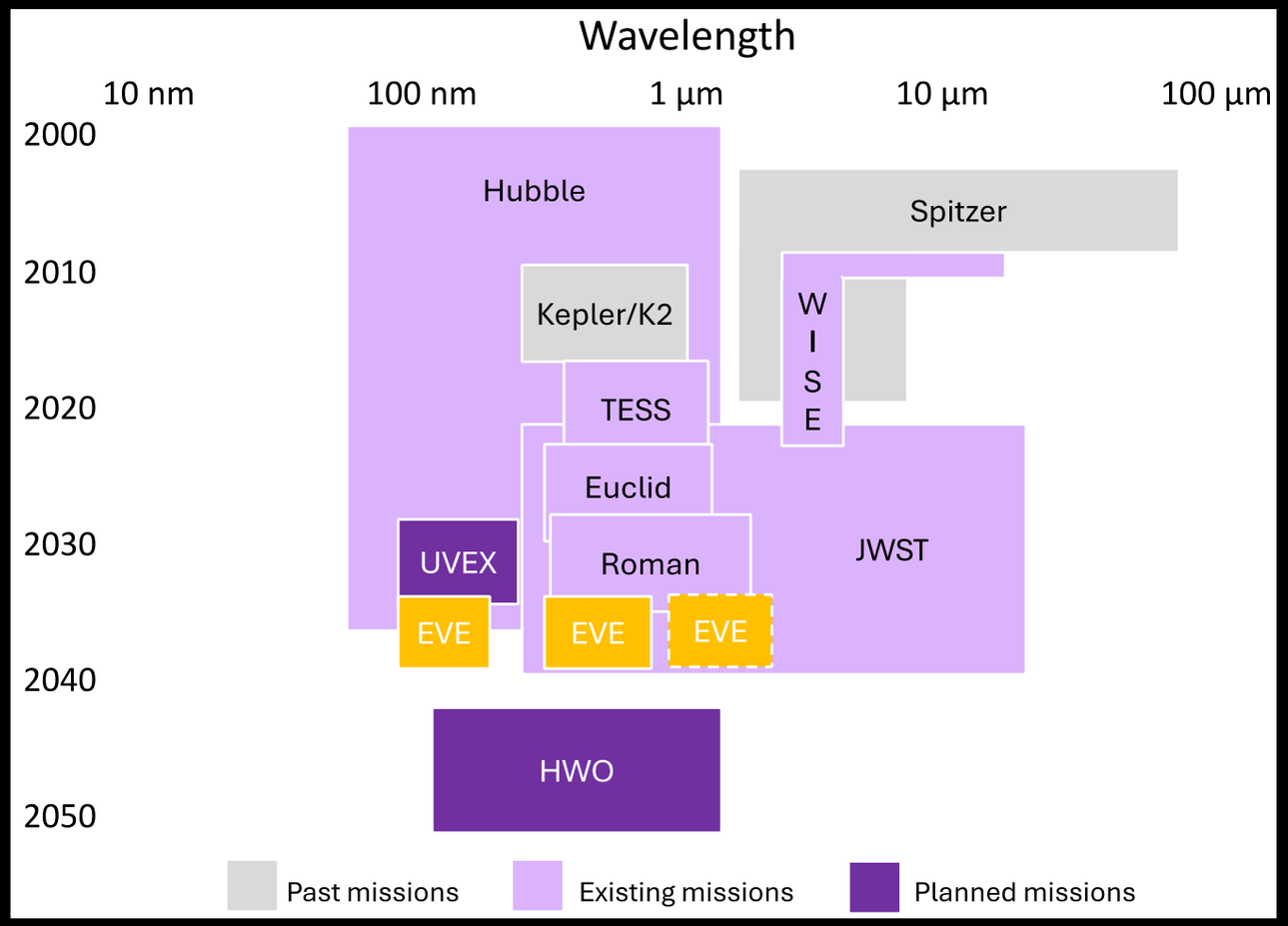
Conclusions



Detecting planets around young stars (< 100 Myrs) may reveal the composition of sub-Neptunes

Thank you for listening

EVE delivers new observing capabilities



Simultaneous photometry in NUV, optical, and near-IR bands

Fast (30 sec) observing cadence

Roughly 30 day stare duration for each pointing

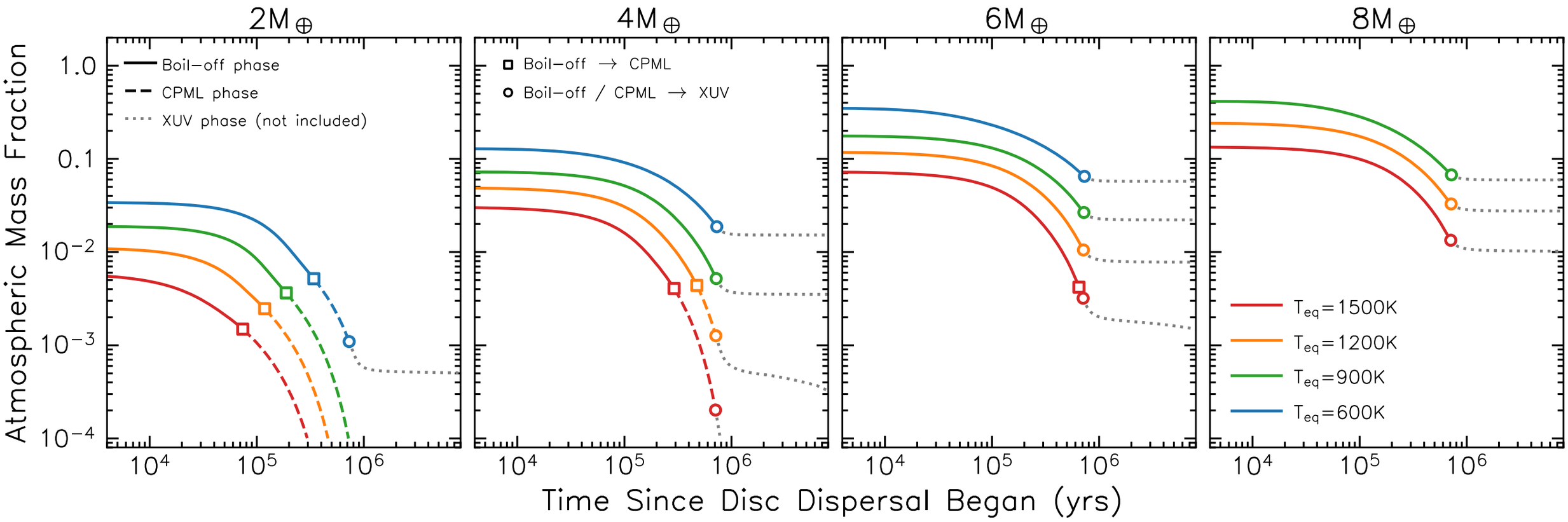
<20” resolution over 25 deg^2 FOV

Targeting young (<100 Myr) clusters

PI: Meredith MacGregor
Deputy PI: Evgenya Shkolnik
Assistant Deputy PI: Ann Marie Cody
Project Scientist: Mark Swain
Capture Lead: Jaime Nastal
Systems Engineering: Alan Didion
Instrument Lead: Dave Makowski

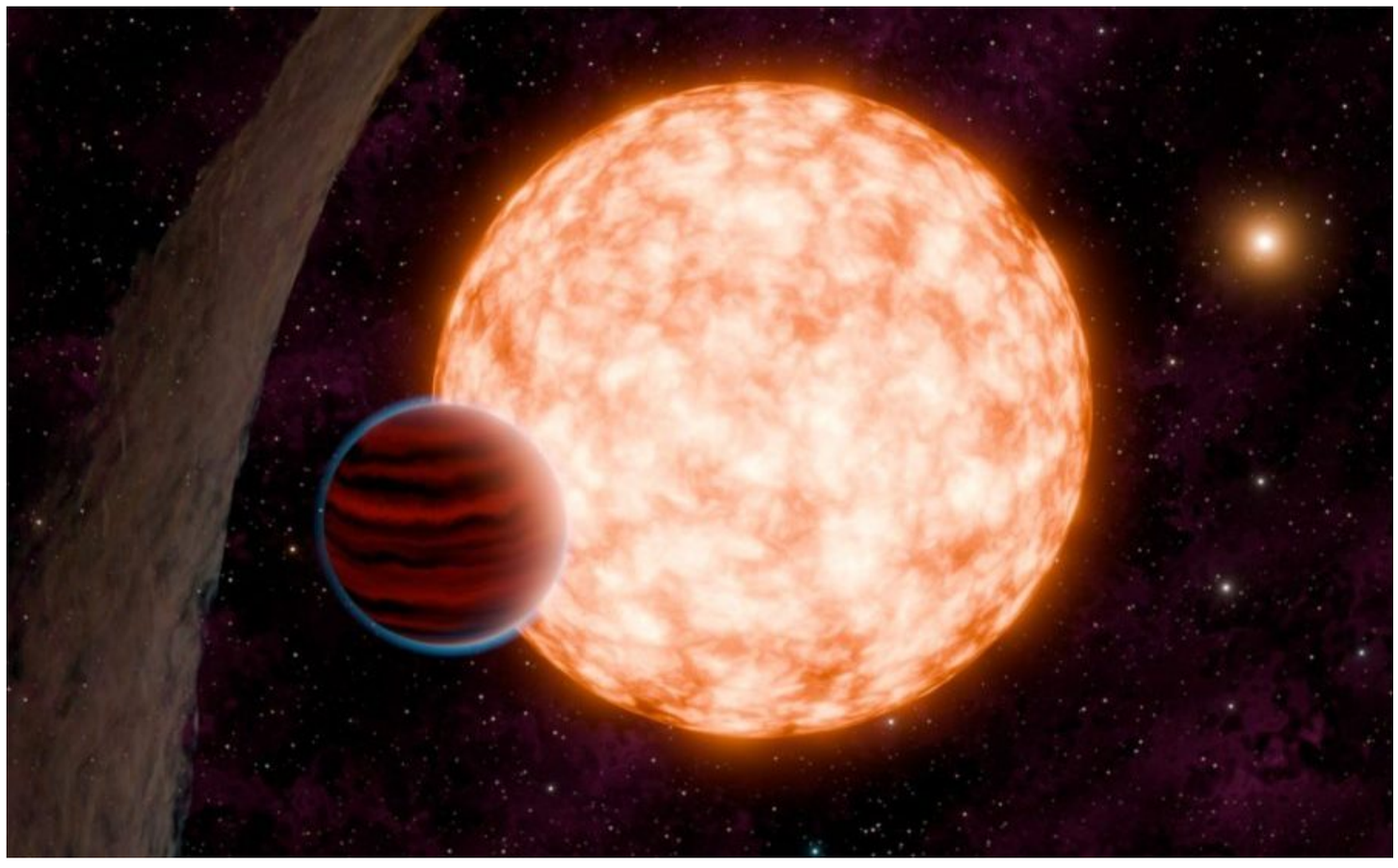
Detectors: April Jewell
Optical Design: Christine Bradley
Exoplanet Lead: Jennifer Burt
Flares Lead: Ward Howard
Accretion Lead: Laura Venuti
Science Team: Adina Feinstein, Eric Gaidos, Dan Huber, Andrew Mann, Rachel Osten, James Rogers, Guadalupe Tovar Mendoza, Neal Turner, Nick Wogan, George Zhou

Boil-off



Rogers, Owen and Schlichting (2024)

Testing boil-off



IRAS 04125+2902 b

Barber et al. (2024)

~ 3 Myrs
~ 10 R_{earth}
~ 10 days