Demographics of Earth-sized Planets in the Habitable Zone

from *Kepler* to the Habitable Worlds Observatory

Galen Bergsten
University of Arizona/LPL + Caltech/IPAC

+ Ilaria Pascucci, Gijs Mulders, Kevin Hardegree-Ullman,
Rachel Fernandes, David Ciardi, Jessie Christiansen, Tommi Koskinen

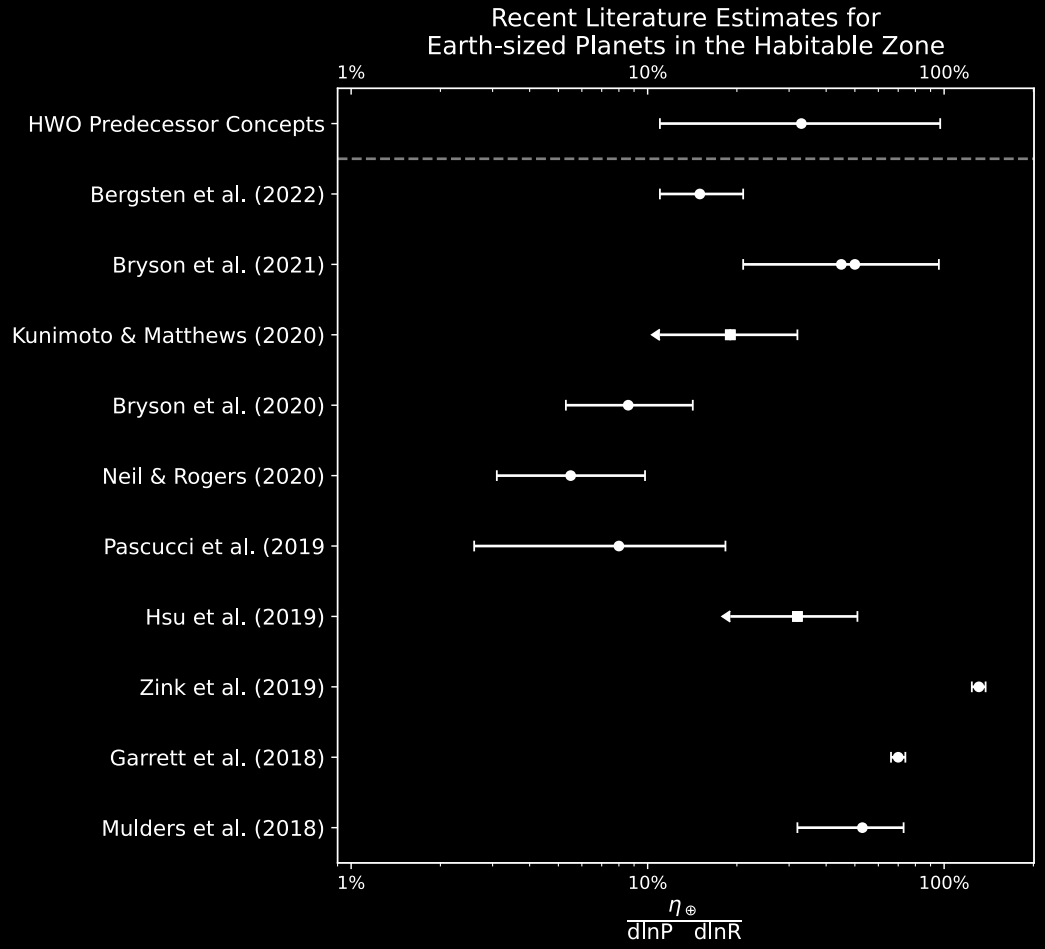
@galen_bergsten | @gbergsten.bsky.social | gbergsten@arizona.edu | gbergsten.github.io

Occurrence Rates (η)
the frequency of planets

e.g., Hot Jupiters: $\eta_{HJ} \approx 1\%$
1 planet / 100 stars

Earths in the Habitable Zone
$\eta_{\oplus} = ??\%$

- Astro2020, $\eta_{\oplus} = 24^{+46}_{-16}\%$
- More recently, $\eta_{\oplus} \approx 10 - 15\%$



Fressin et al. (2013)

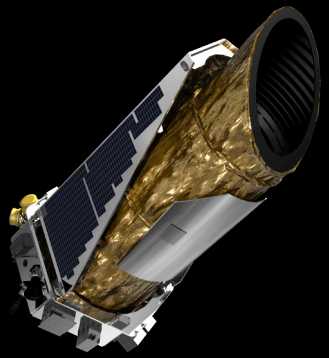
@galen_bergsten | @gbergsten.bsky.social | gbergsten@arizona.edu | gbergsten.github.io

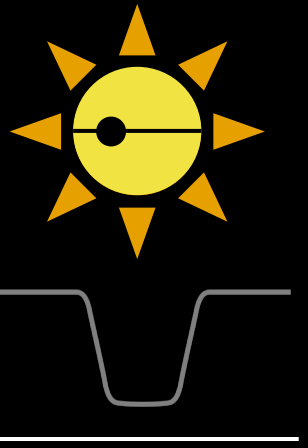
Sun-like Stars
Bergsten et al. (2022)

$\eta_\oplus = ??\%$

M Dwarfs
Bergsten et al. (2023)

$\eta_\oplus = ??\ \%$

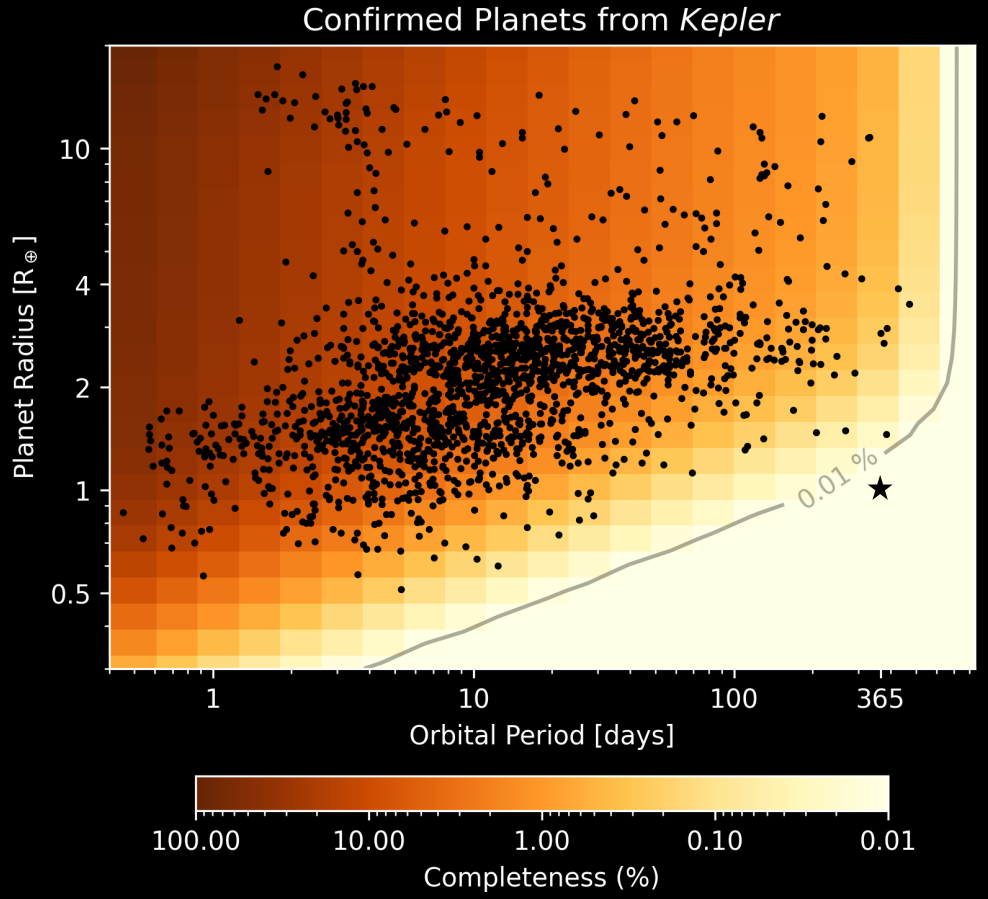




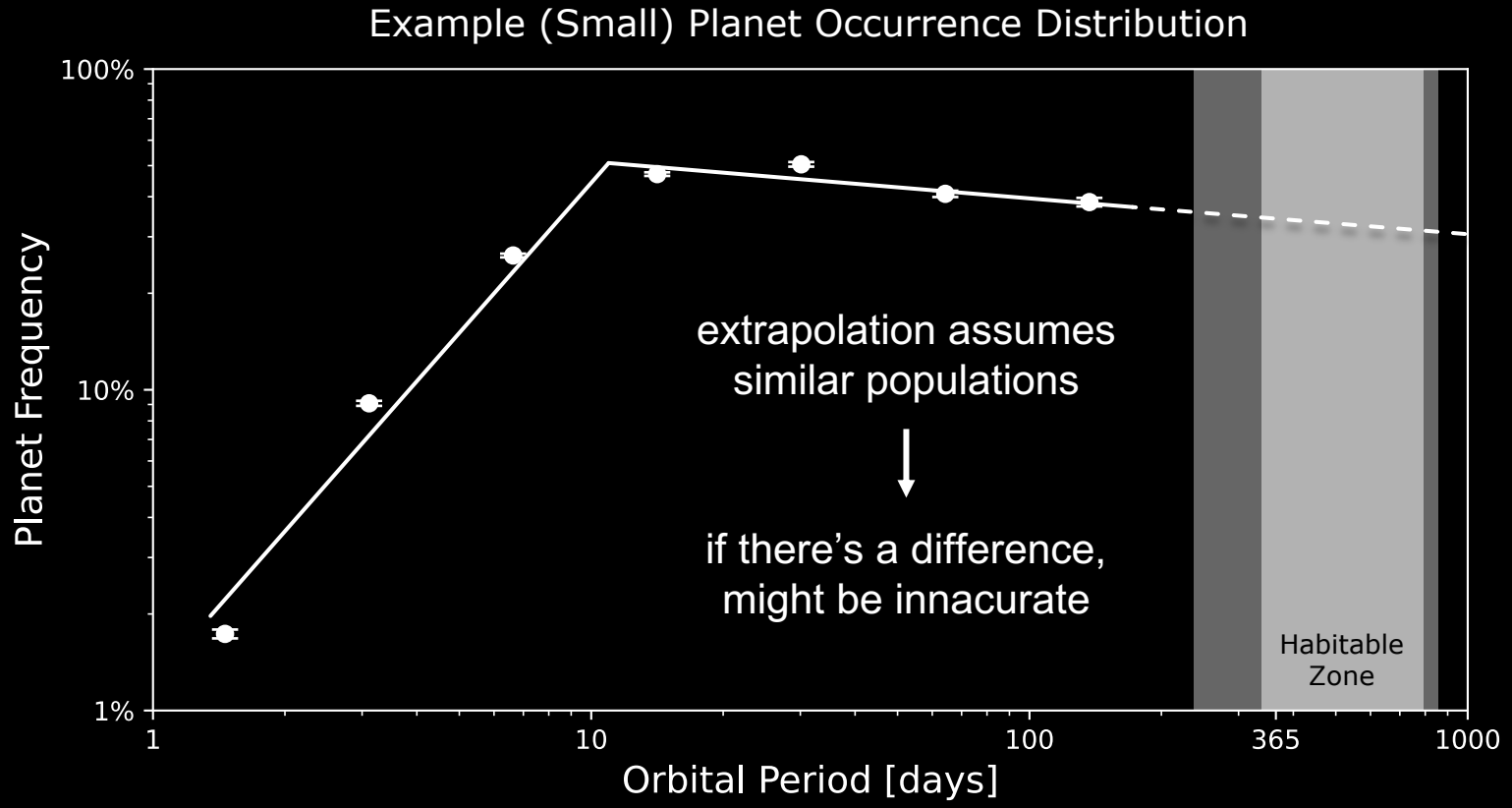
NASA Exoplanet Archive

5,630
Confirmed Planets
05/14/2024

2,774
Discovered by *Kepler*



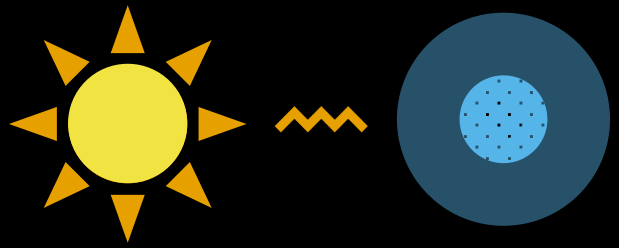
@galen_bergsten | @gbergsten.bsky.social | gbergsten@arizona.edu | gbergsten.github.io


Example (Small) Planet Occurrence Distribution
100%
10%
1%
Planet Frequency
extrapolation assumes
similar populations
if there's a difference,
might be innacurate
Habitable
Zone
1
10
100
365
1000
Orbital Period [days]

< 5 days

20 days

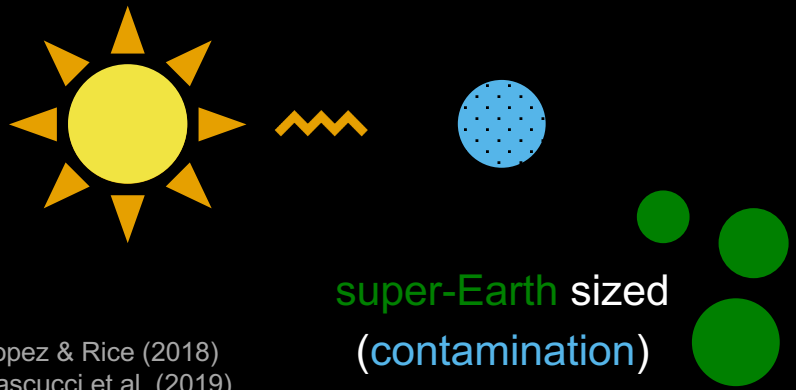
> 100 days



sub-Neptune sized

sub-Neptune sized

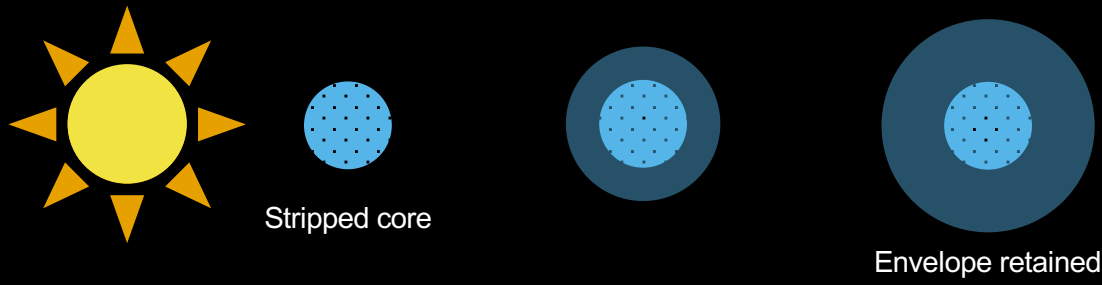
Time

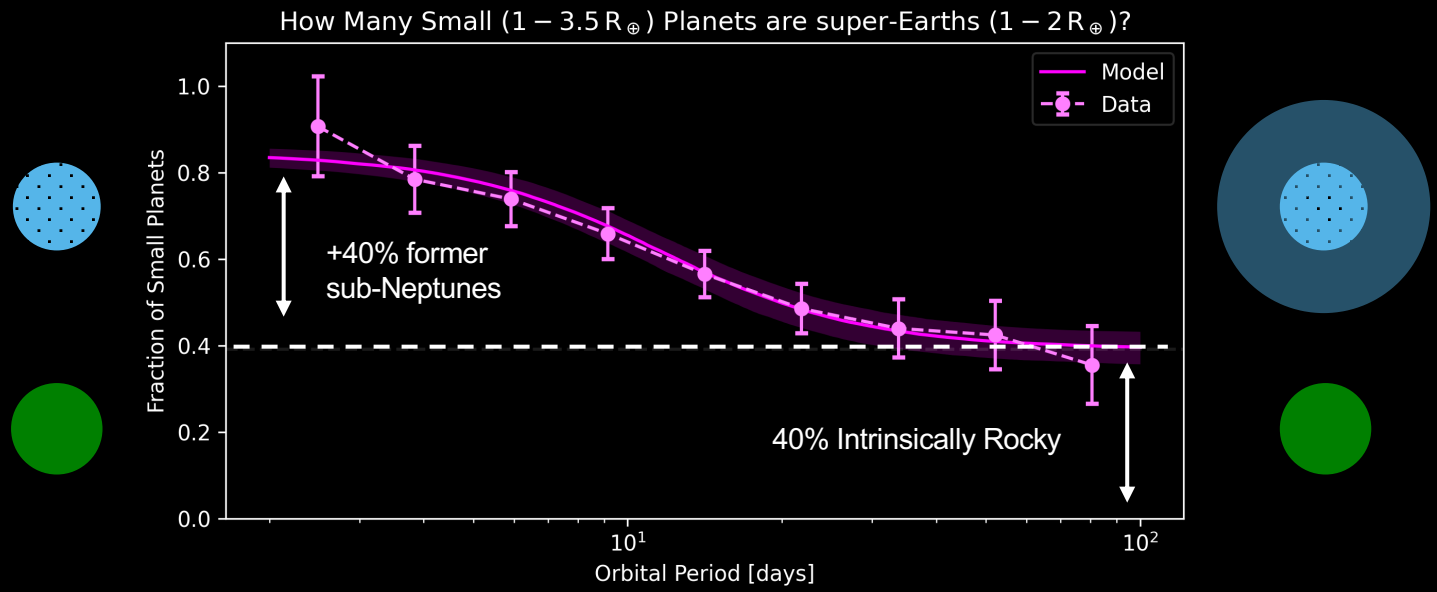


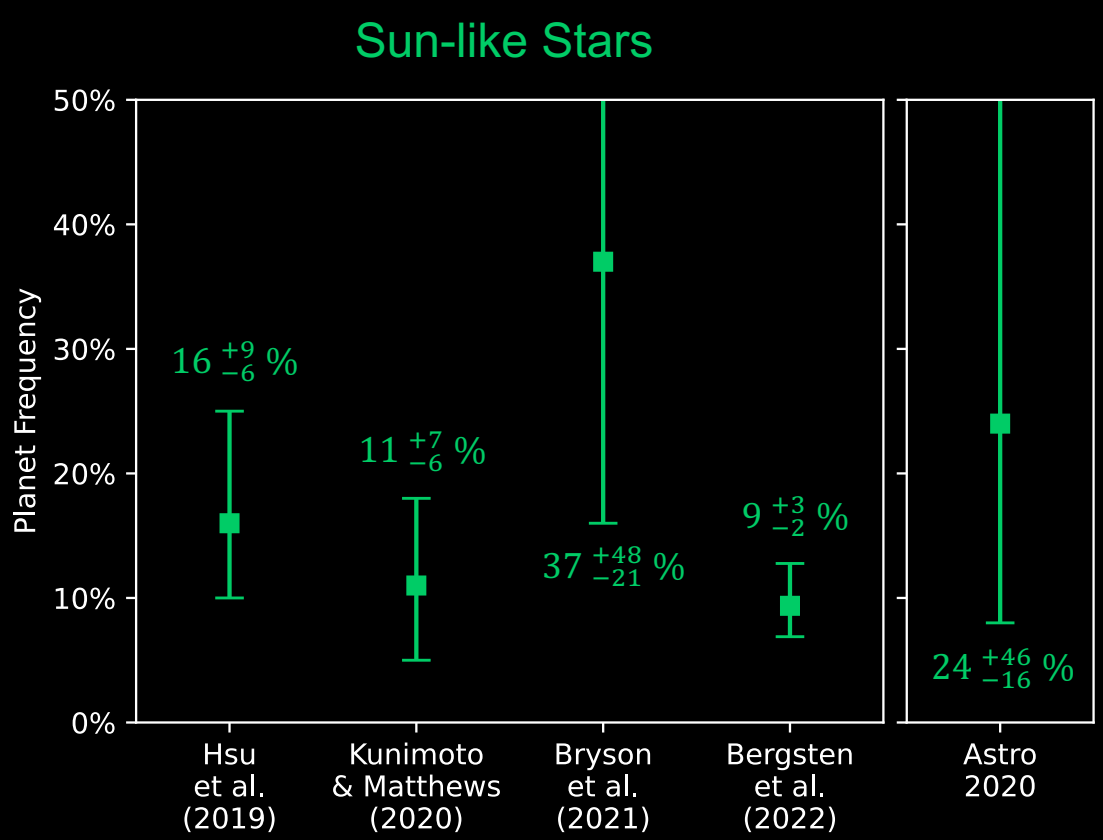
super-Earth sized
(contamination)

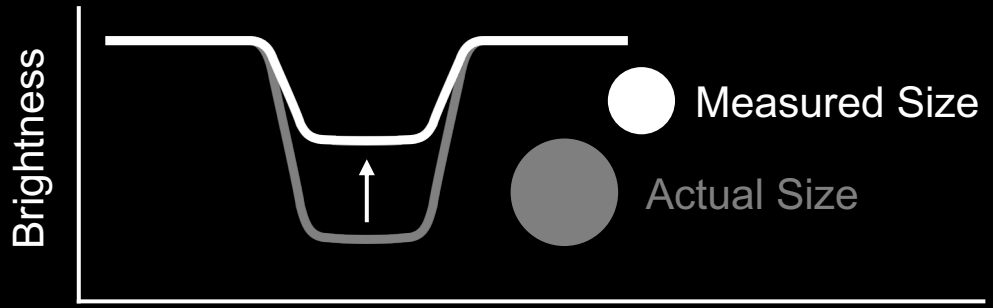
sub-Neptune sized
(no contamination)

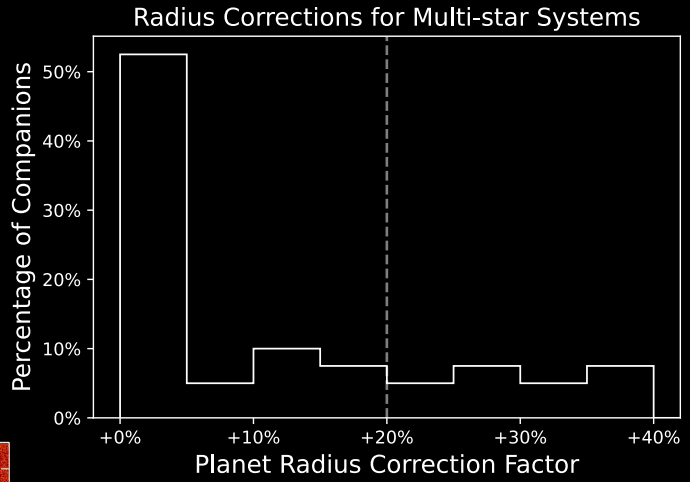
Lopez & Rice (2018)
Pascucci et al. (2019)

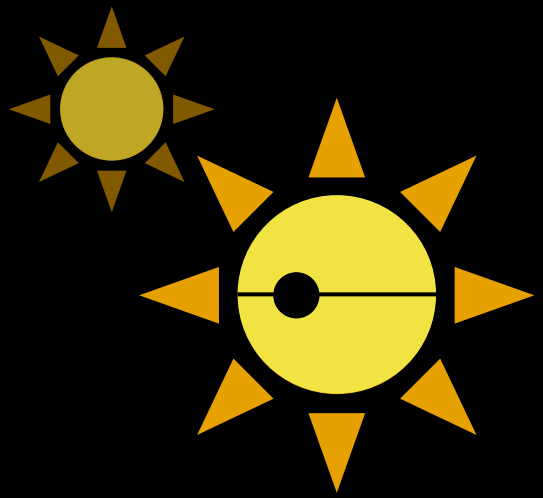

Stripped core
Envelope retained

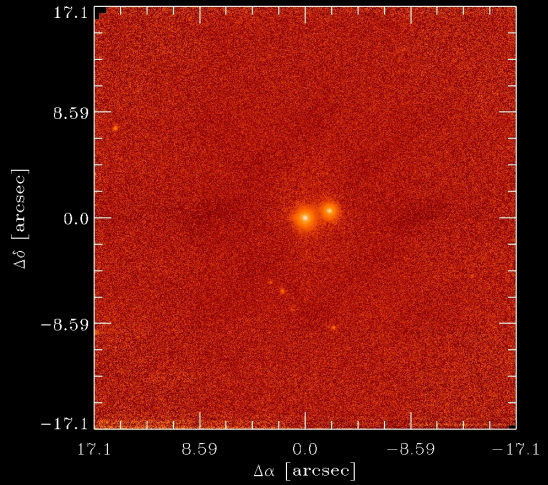

How Many Small (1 – 3.5 R⊕) Planets are super-Earths (1 – 2 R⊕)?
Model
Data
Fraction of Small Planets
1.0
0.8
0.6
0.4
0.2
0.0
+40% former
sub-Neptunes
40% Intrinsically Rocky
10¹
10²
Orbital Period [days]


Sun-like Stars
Planet Frequency
50%
40%
30%
20%
10%
0%
16^{+9}_{-6} %
11^{+7}_{-6} %
37^{+48}_{-21} %
9^{+3}_{-2} %
24^{+46}_{-16} %
Hsu et al. (2019)
Kunimoto & Matthews (2020)
Bryson et al. (2021)
Bergsten et al. (2022)
Astro 2020









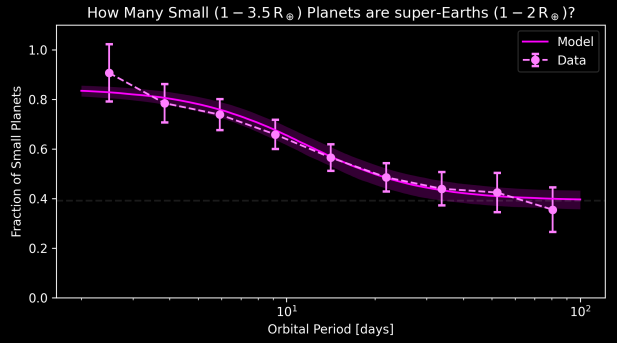
1-in-4 stellar companion systems would underestimate planet radii by 20% or more.

also check out:
Furlan et al. (2017)
Sullivan et al. (2022)

@galen_bergsten | @gbergsten.bsky.social | gbergsten@arizona.edu | gbergsten.github.io

Sun-like Stars
Bergsten et al. (2022)

$\eta_\oplus = 9^{+3}_{-2}\ \%$



- Modeled an occurrence signature of atmospheric evolution
- Isolated an intrinsically rocky population for the HZ

Currently working on a treatment of stellar companions

M Dwarfs
Bergsten et al. (2023)

$\eta_\oplus = ??\ \%$

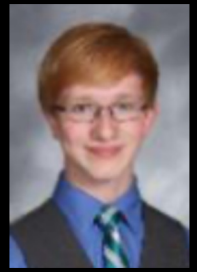
M Dwarfs

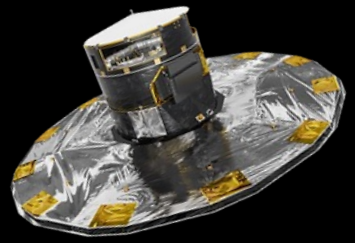
$T_{\rm eff} \approx [2000, 4000]\ K$

Dressing & Charbonneau (2015)

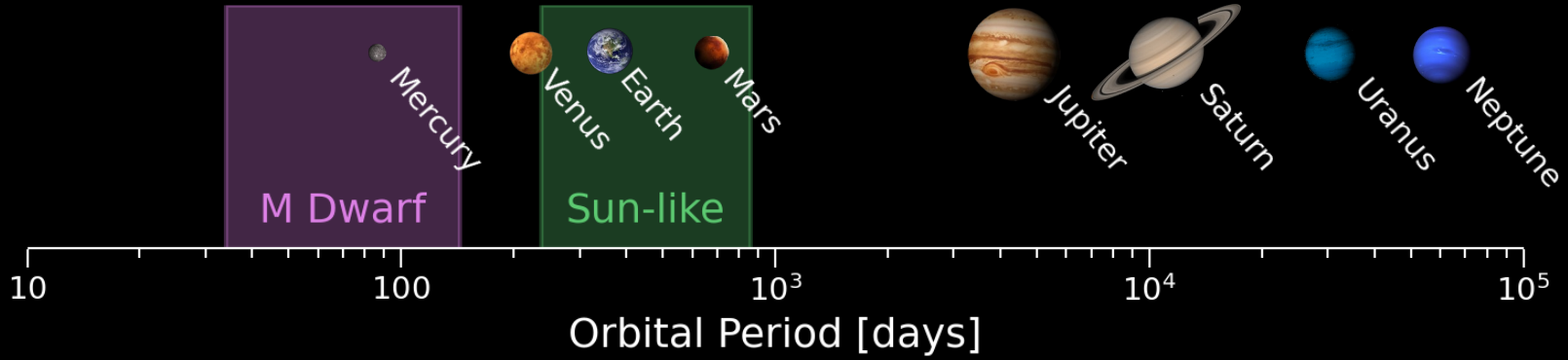
$\eta_\oplus = 24\ ^{+18}_{-8}\ \%$

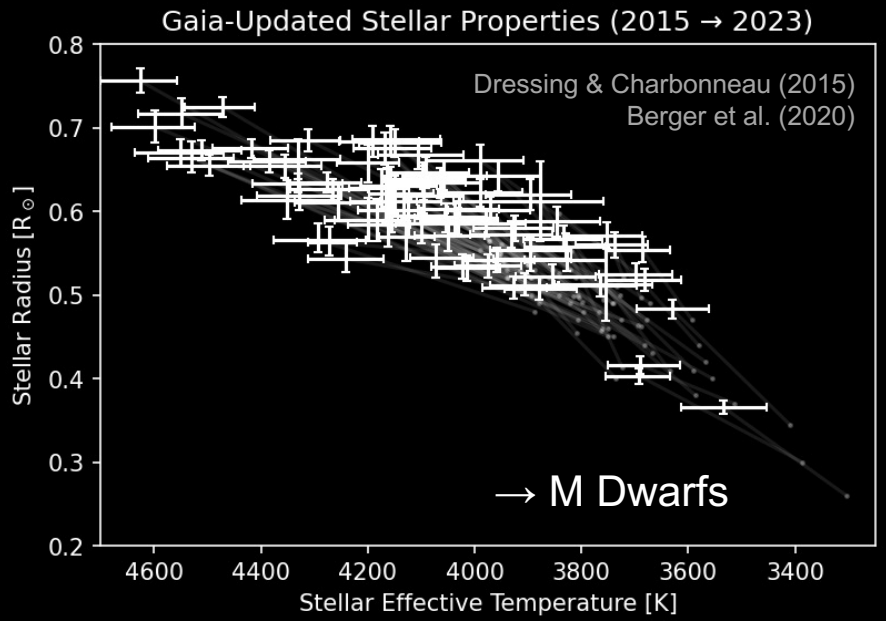
2015 was a long* time ago!



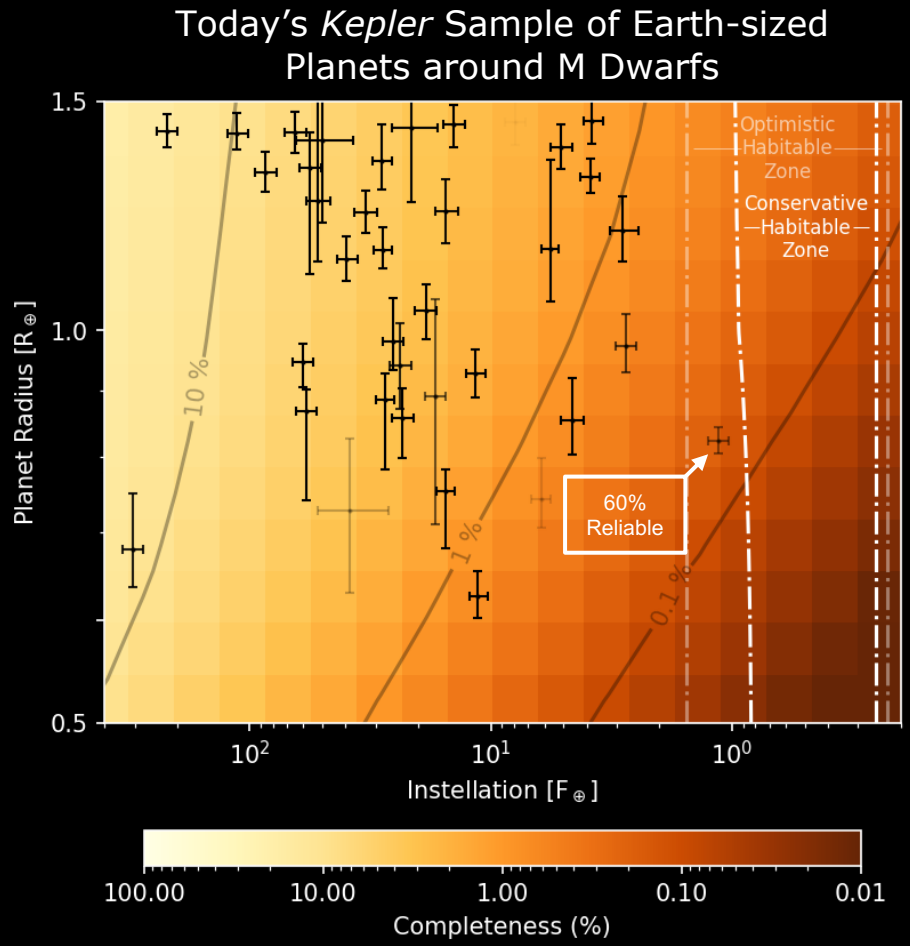


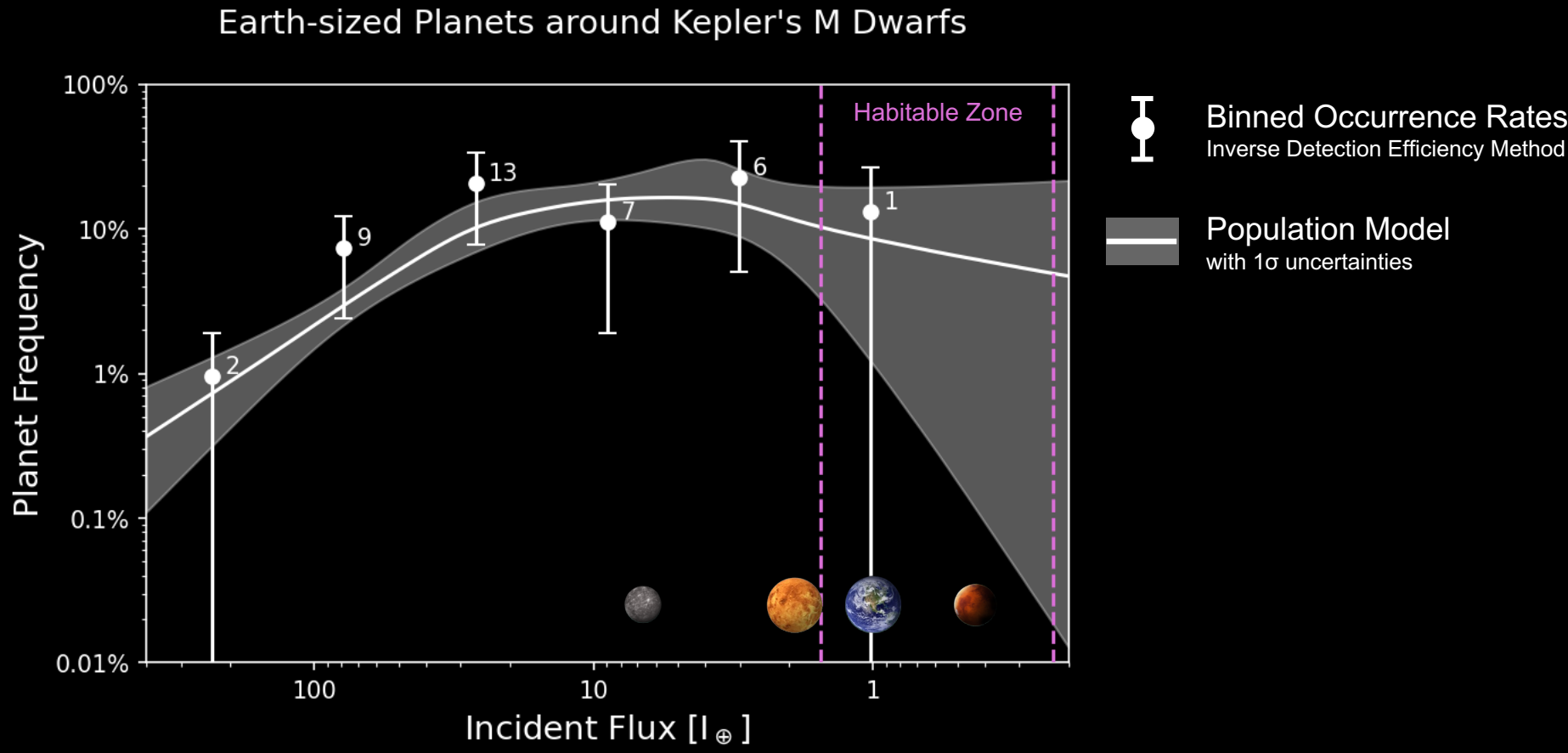
*long enough to get *Gaia*-updated properties for *Kepler* stars



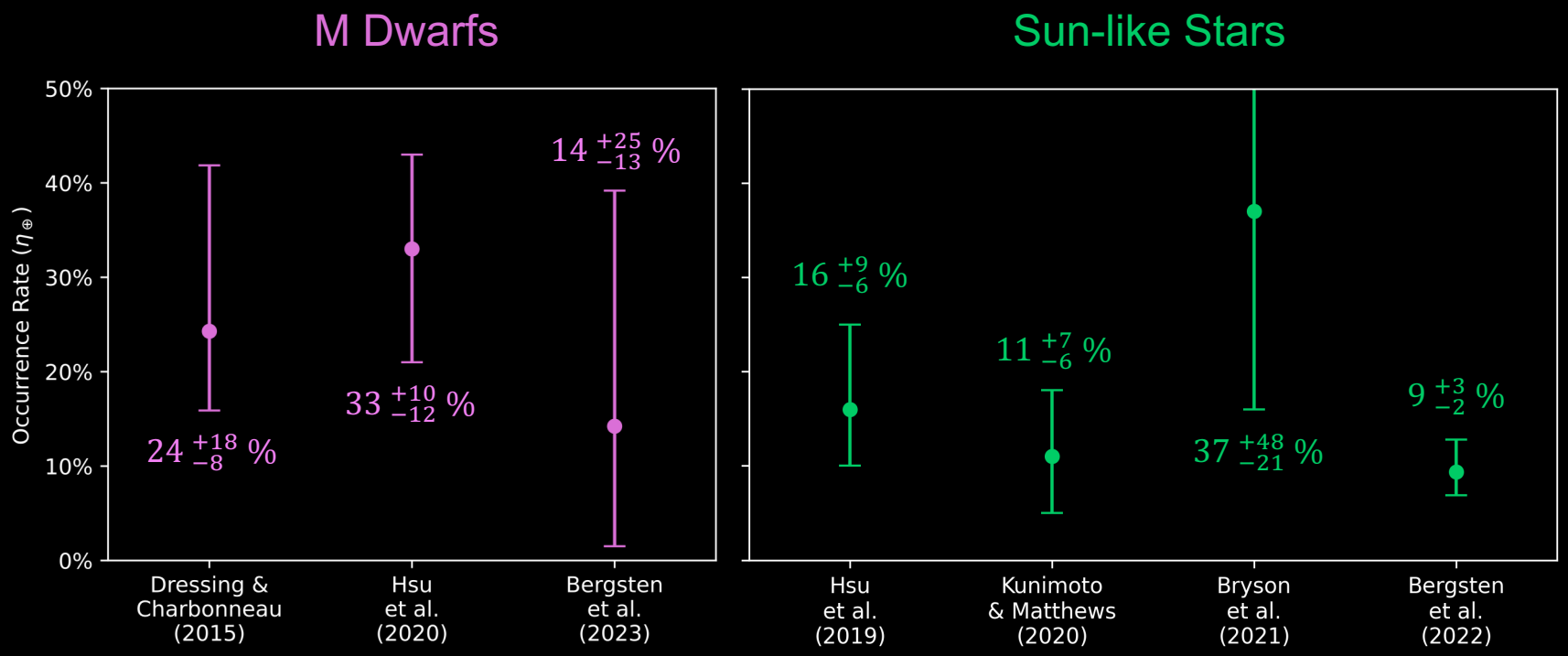


Today's version of the *Kepler* sample doesn't have much information on M dwarfs.





@galen_bergsten | @gbergsten.bsky.social | gbergsten@arizona.edu | gbergsten.github.io



For M dwarfs, $\eta_\oplus$ is less observationally constrained than previously believed.

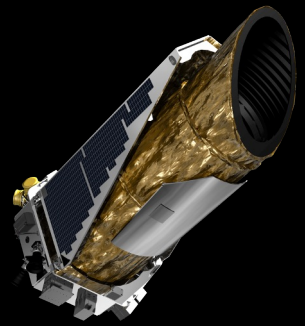
Kepler offers no evidence for higher $\eta_\oplus$ around M versus FGK stars.

@galen_bergsten | @gbergsten.bsky.social | gbergsten@arizona.edu | gbergsten.github.io

TESS

check out Ment & Charbonneau (2023)!

K2



check out works by the Scaling K2 team!

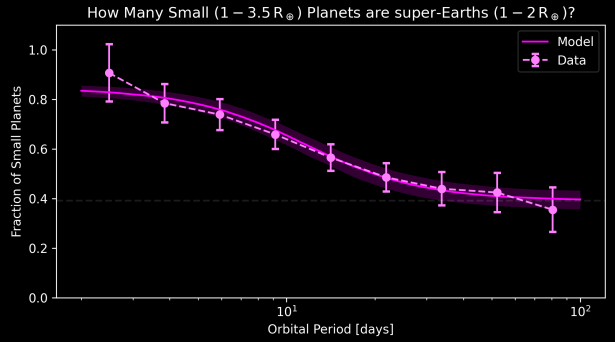
Abstract 789

Poster Round 2 – June 18

@galen_bergsten | @gbergsten.bsky.social | gbergsten@arizona.edu | gbergsten.github.io

Sun-like Stars
Bergsten et al. (2022)

$\eta_\oplus = 9^{+3}_{-2}\ \%$

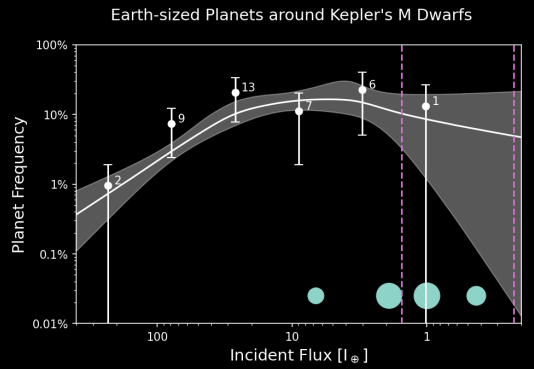


- Modeled an occurrence signature of atmospheric evolution
- Isolated an intrinsically rocky population for the HZ

Currently working on a treatment of stellar companions

M Dwarfs
Bergsten et al. (2023)

$\eta_\oplus = 14^{+25}_{-13}\ \%$



- *Kepler* has very little information on M dwarfs after *Gaia*, but we tried our best

Visit my poster (#789) at ExoV!

@galen_bergsten | @gbergsten.bsky.social | gbergsten@arizona.edu | gbergsten.github.io