Science Enabled by The *Roman* Galactic Exoplanet Survey

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Matthew T. Penny, B. Scott Gaudi, *Roman* GES-SIT

NASA Exoplanet Explorers Science Series

2021-02-12

@sonofmany

ROMAN SPACE TELESCOPE

THE OHIO STATE UNIVERSITY

- Overview of survey and microlensing
- Earth-analogs in the Habitable Zone
- Free-floating planets

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Nancy Grace Roman – first NASA Chief of Astronomy

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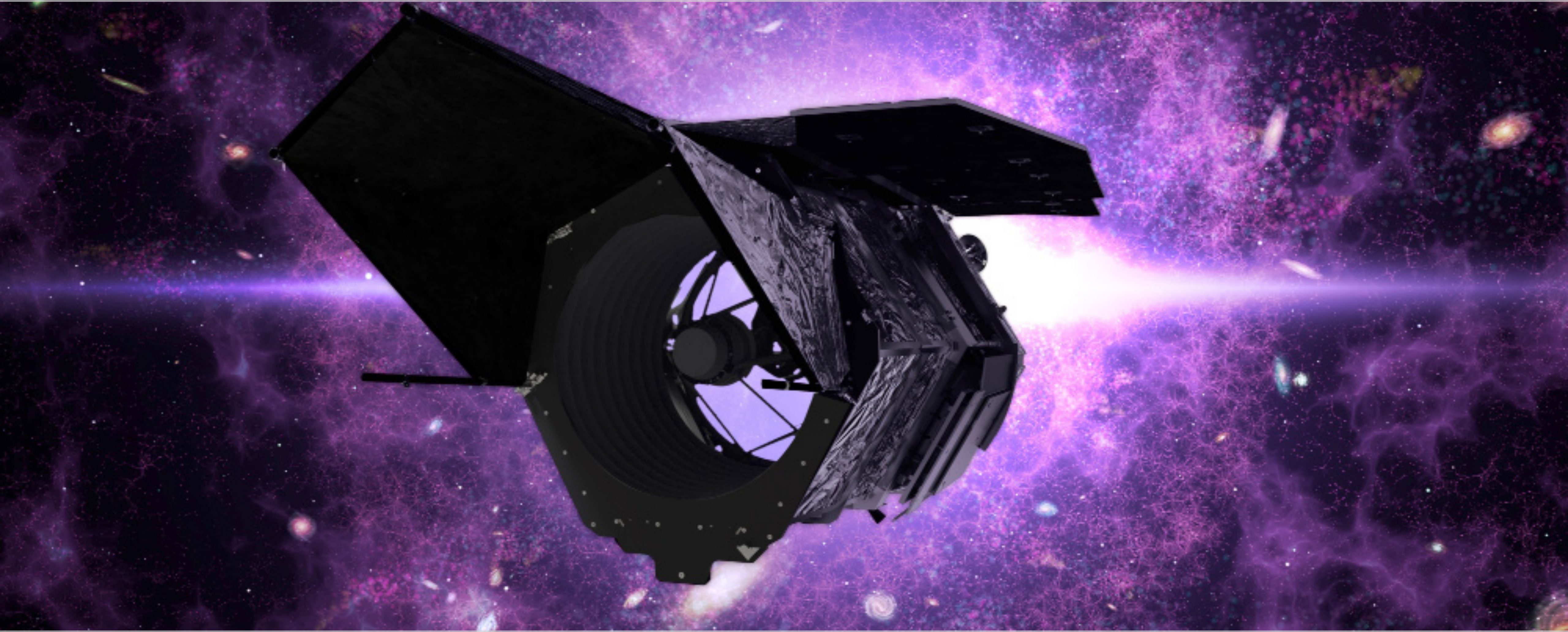
The *Nancy Grace Roman Space Telescope* (Roman)



- Mission in Phase C (Final Design and Fabrication) as of 03/2020
- Passing Design Reviews, 2/3 flight detectors, on track to launch late 2026
- Cosmology, exoplanets (microlensing/coronography), general observing

The *Roman* Galactic Exoplanet Survey

The first space-based microlensing survey of the Galactic Bulge

“The exoplanet mission that nobody asked for.”–overheard from a senior NASA scientist

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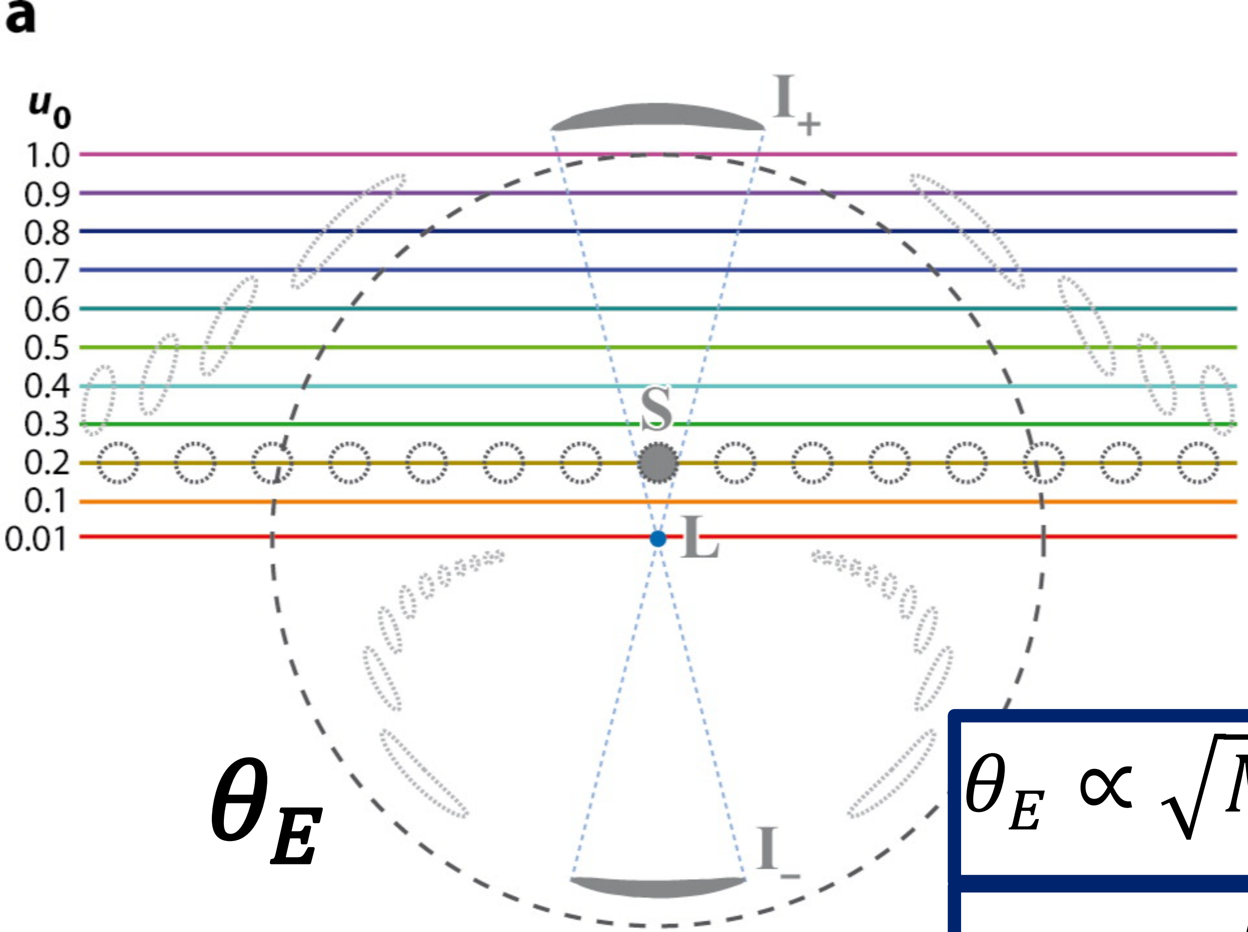
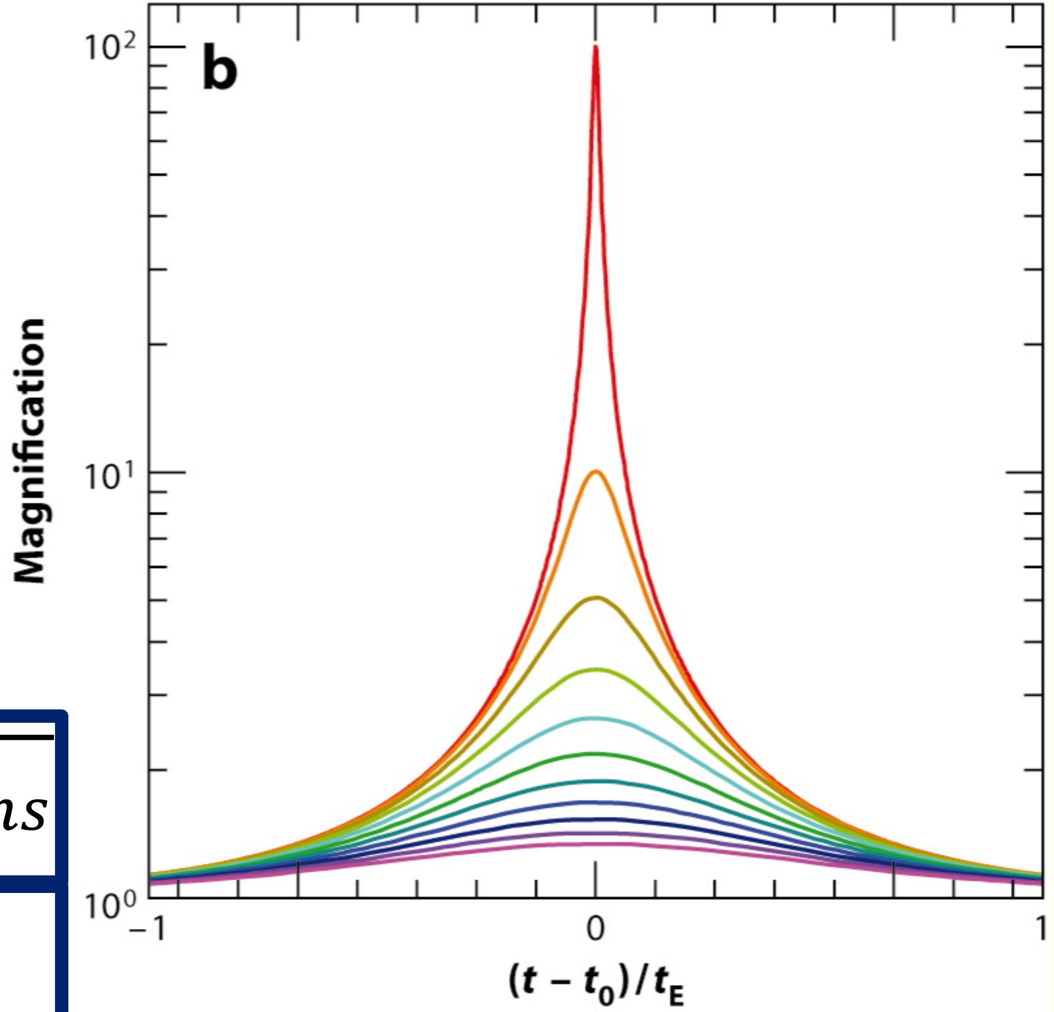


θ_E

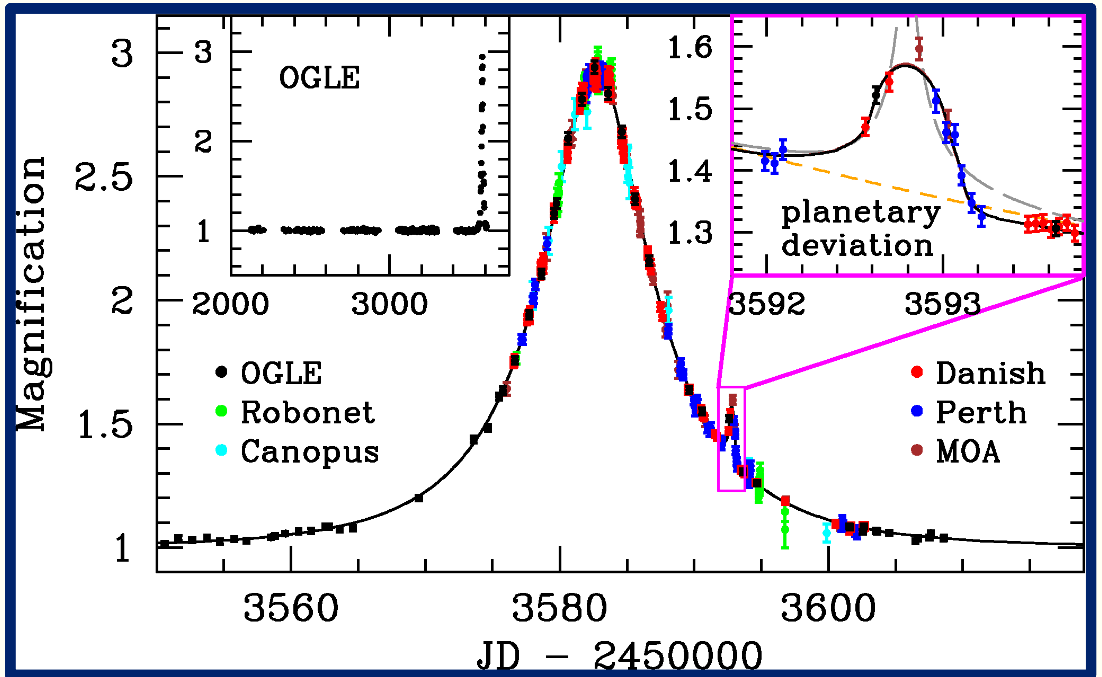
$$\theta_E \propto \sqrt{M_{lens}}$$

$$t_E = \frac{\theta_E}{\mu_{rel}}$$

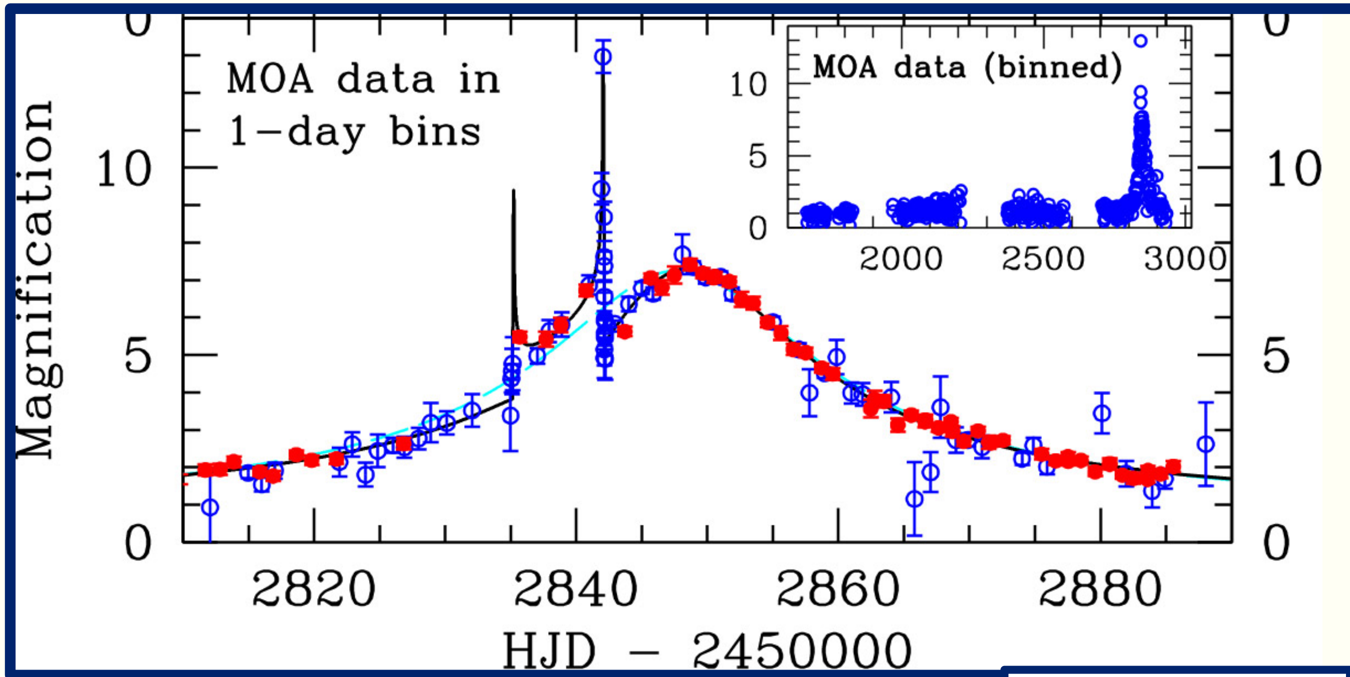


Gaudi BS. 2012.
Annu. Rev. Astron. Astrophys. 50:411–53

Example microlensing events



Bond et al., 2004



Bond et al., 2004

Perceived weaknesses of microlensing

- Microlensing events are transient signals, do not repeat
- Microlensing planets can’t be followed up or characterized
- Microlensing is hard to understand/steep learning curve

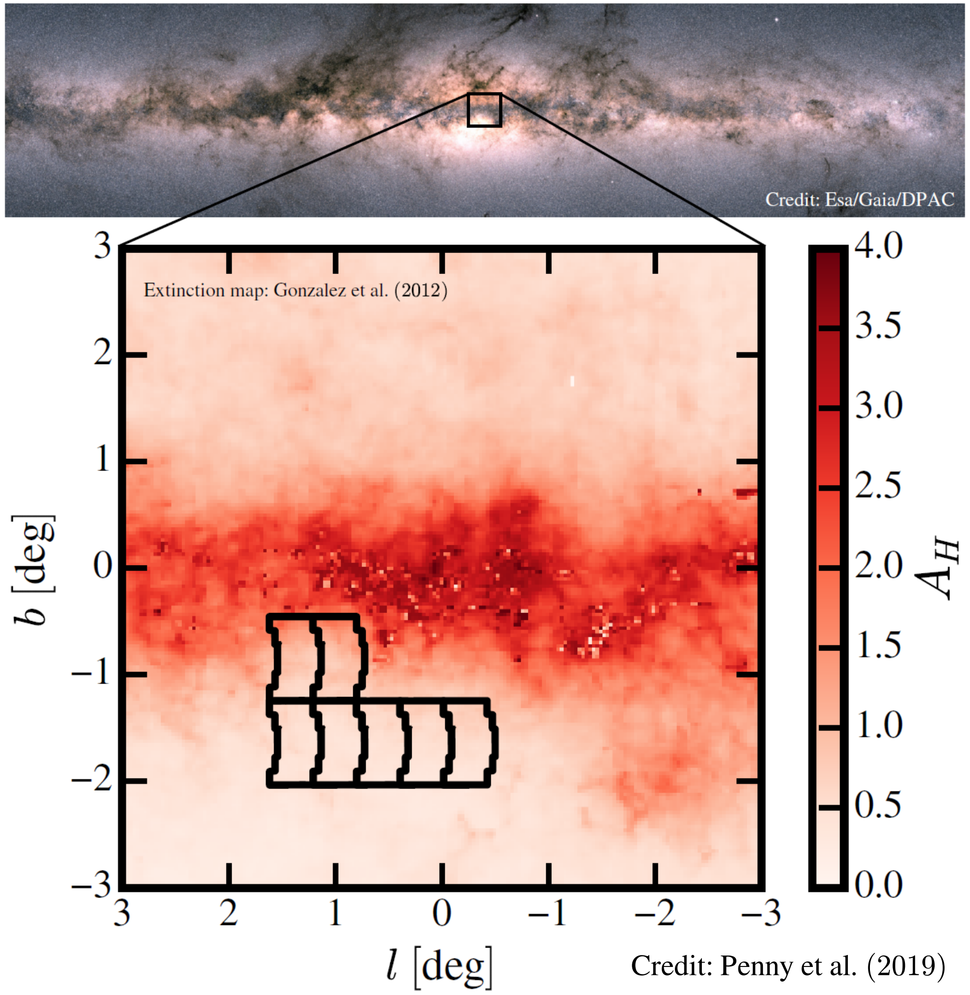
Strengths of microlensing

- Microlensing is sensitive to planets with large orbits
- Microlensing can detect planets throughout the Galaxy
- Microlensing surveys produce robust statistics

CURRENT *Roman* survey parameters

Survey details

- 0.28 $\deg^2$ FOV, 7 fields → $\sim 2\ \deg^2$ total
- Six 72-day seasons
  - $\sim 5-$ year baseline
- 15 min cadence in wide infrared bandpass
  - ≤12 hr cadence in bluer bandpass
- 10^8 stars, >30,000 microlensing events



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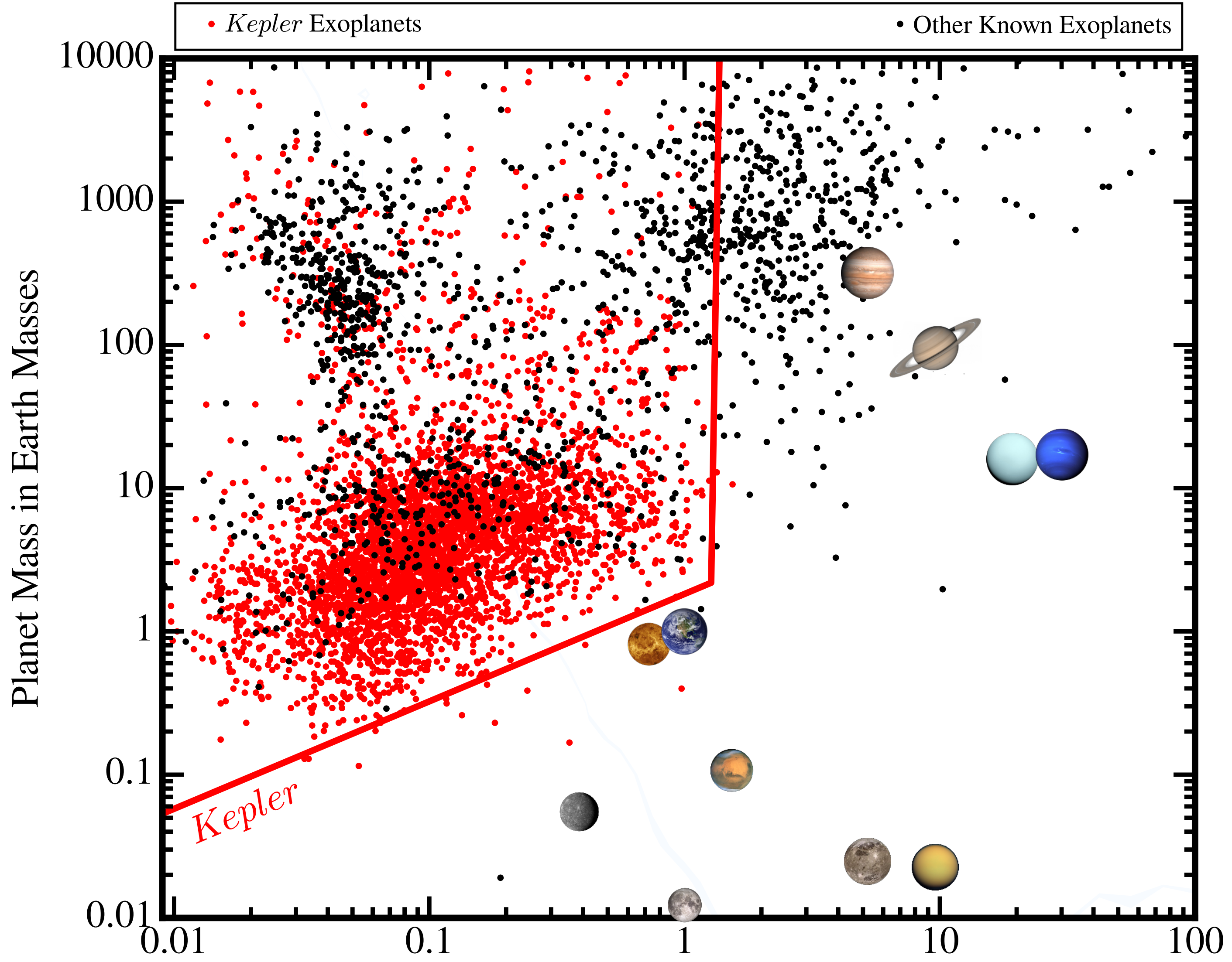
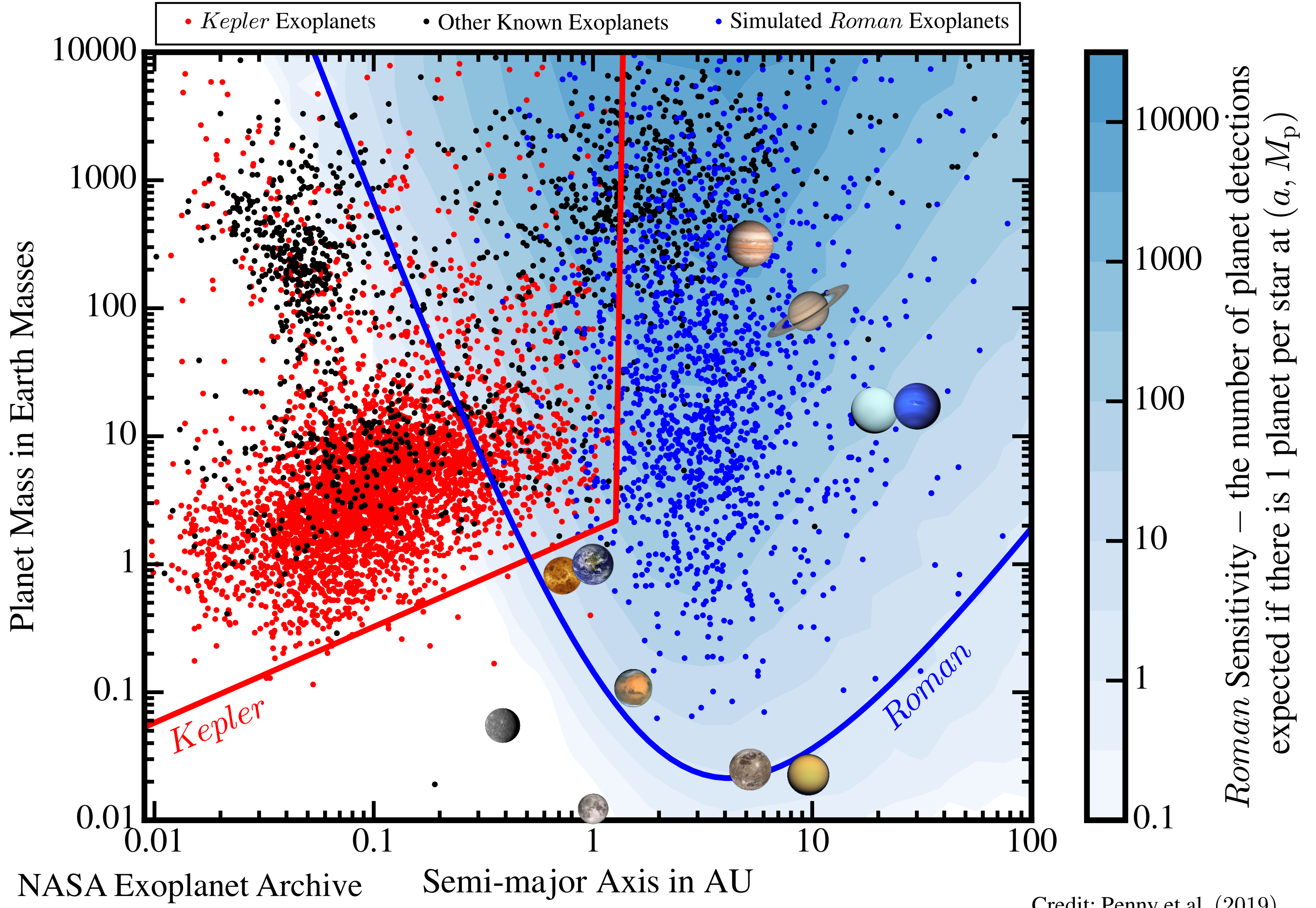


NASA Exoplanet Archive

Credit: Penny et al. (2019)



Credit: Penny et al. (2019)

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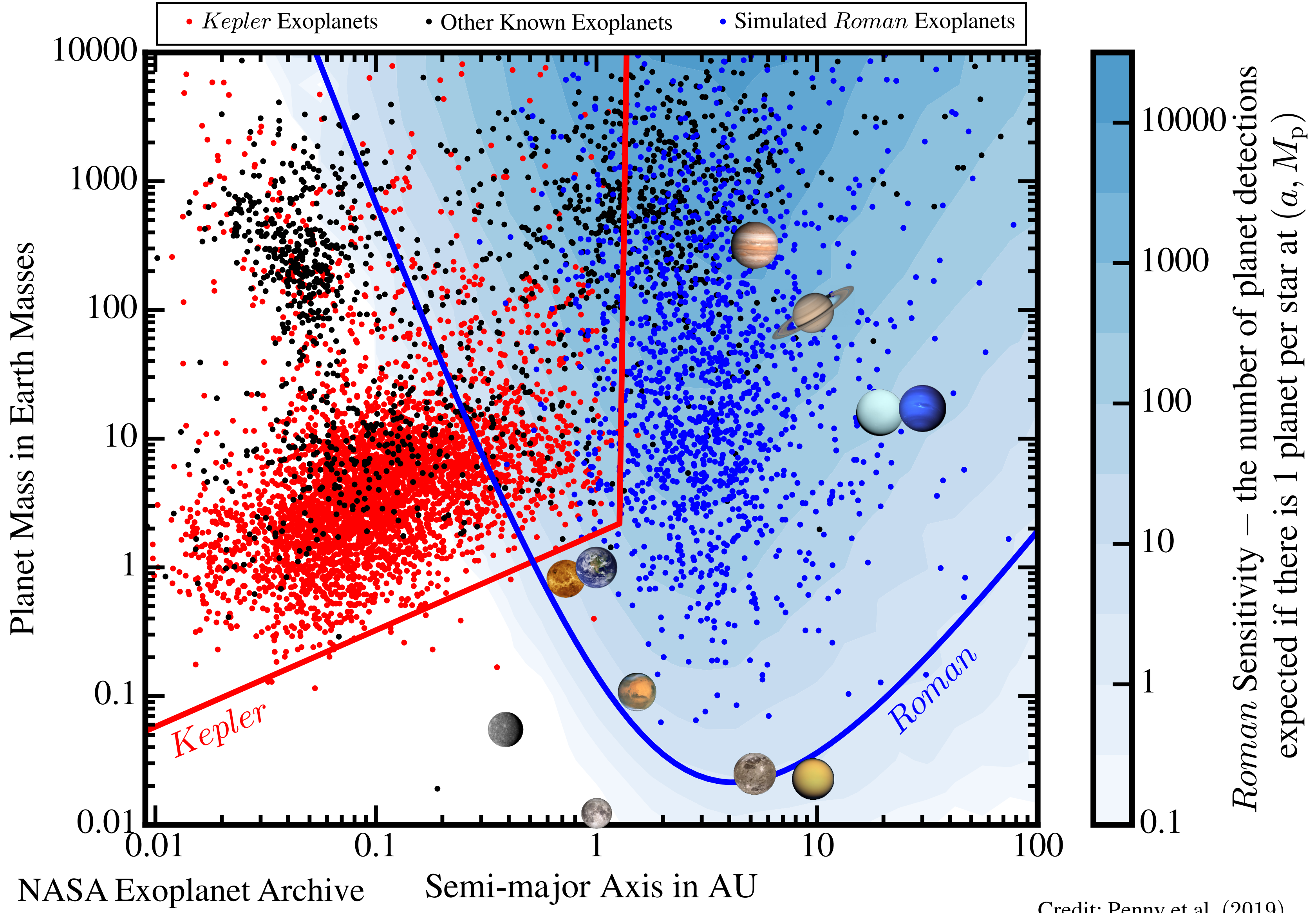

Credit: Penny et al. (2019)

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- Overview of survey and microlensing
- Earth-analogs in the Habitable Zone
- Free-floating planets

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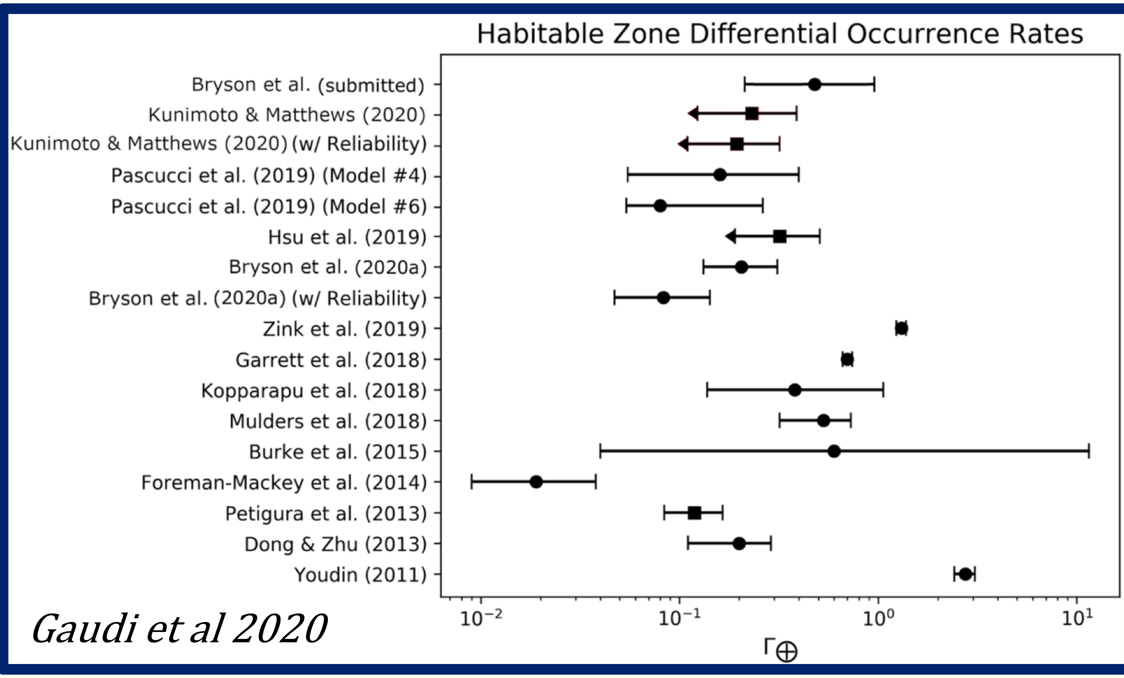
The Frequency of Earth-Analogs

- Important input for designing future direct im
missions that can detect and characterize pot
habitable planets.



Gaudi et al 2020

- Currently best estimate(s) are from *Kepler*
  - Earth-analogs on edge of *Kepler* sensitivity function
  - Relies on extrapolation from shorter-period/larger-radii planets

HZ and microlensing

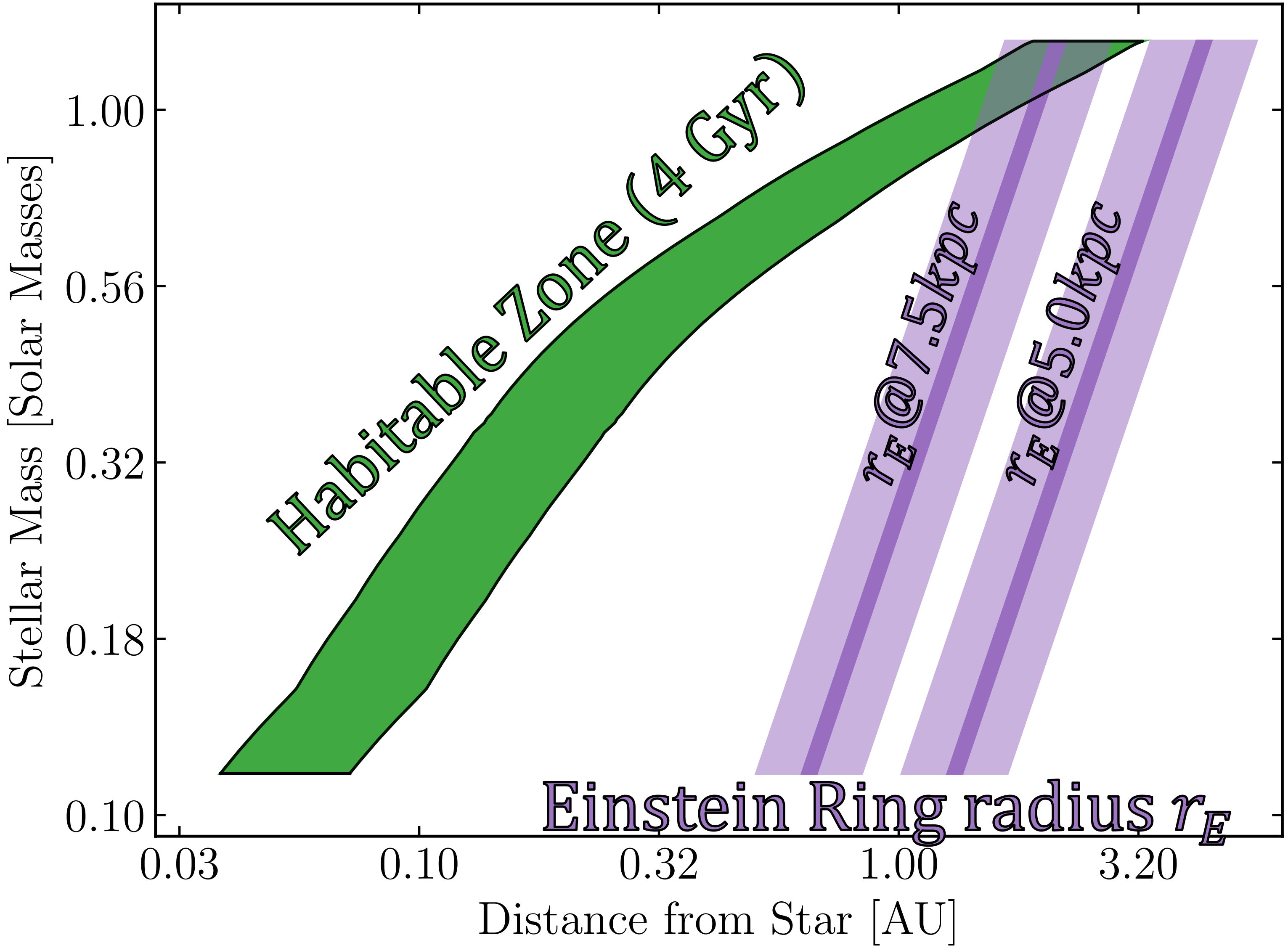
Habitable Zone (Kopparapu+ 2013)

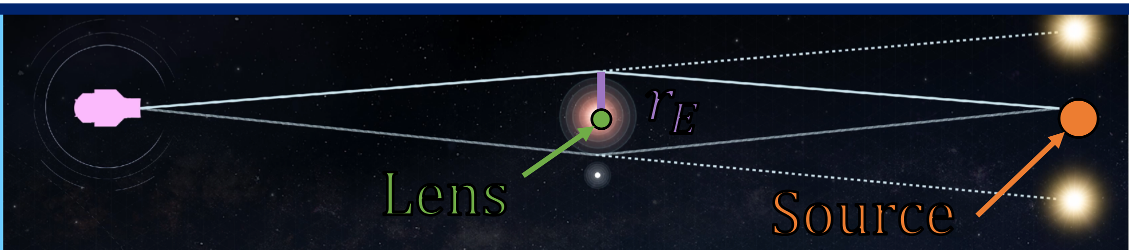
- Function of host mass, age, etc.

Einstein Ring Radius

- Peak sensitivity to planets
- Depends on host (lens) star mass
- Function of lens/source distance

$$r_E \propto \sqrt{M_*}$$





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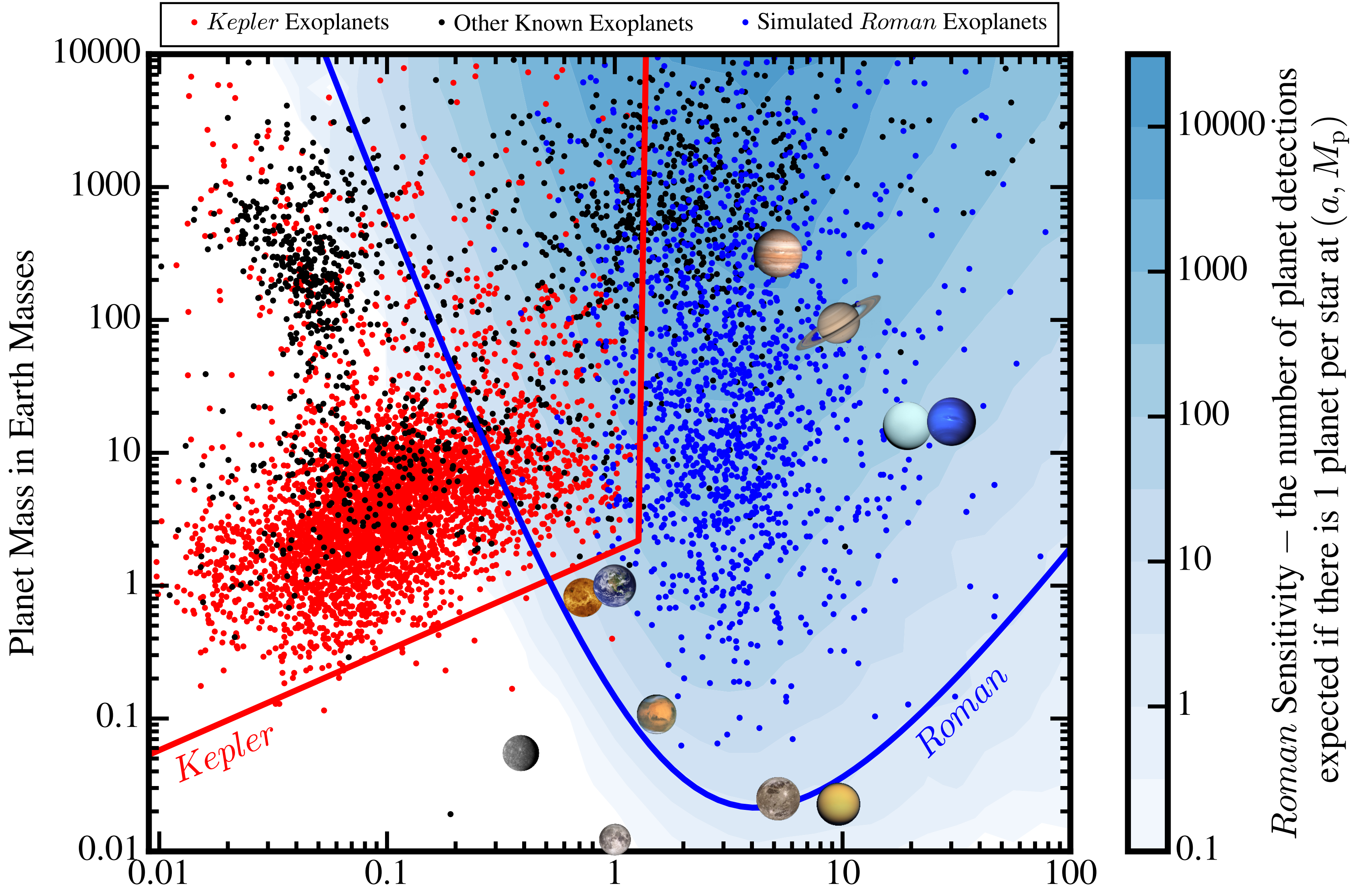

NASA Exoplanet Archive

Credit: Penny et al. (2019)

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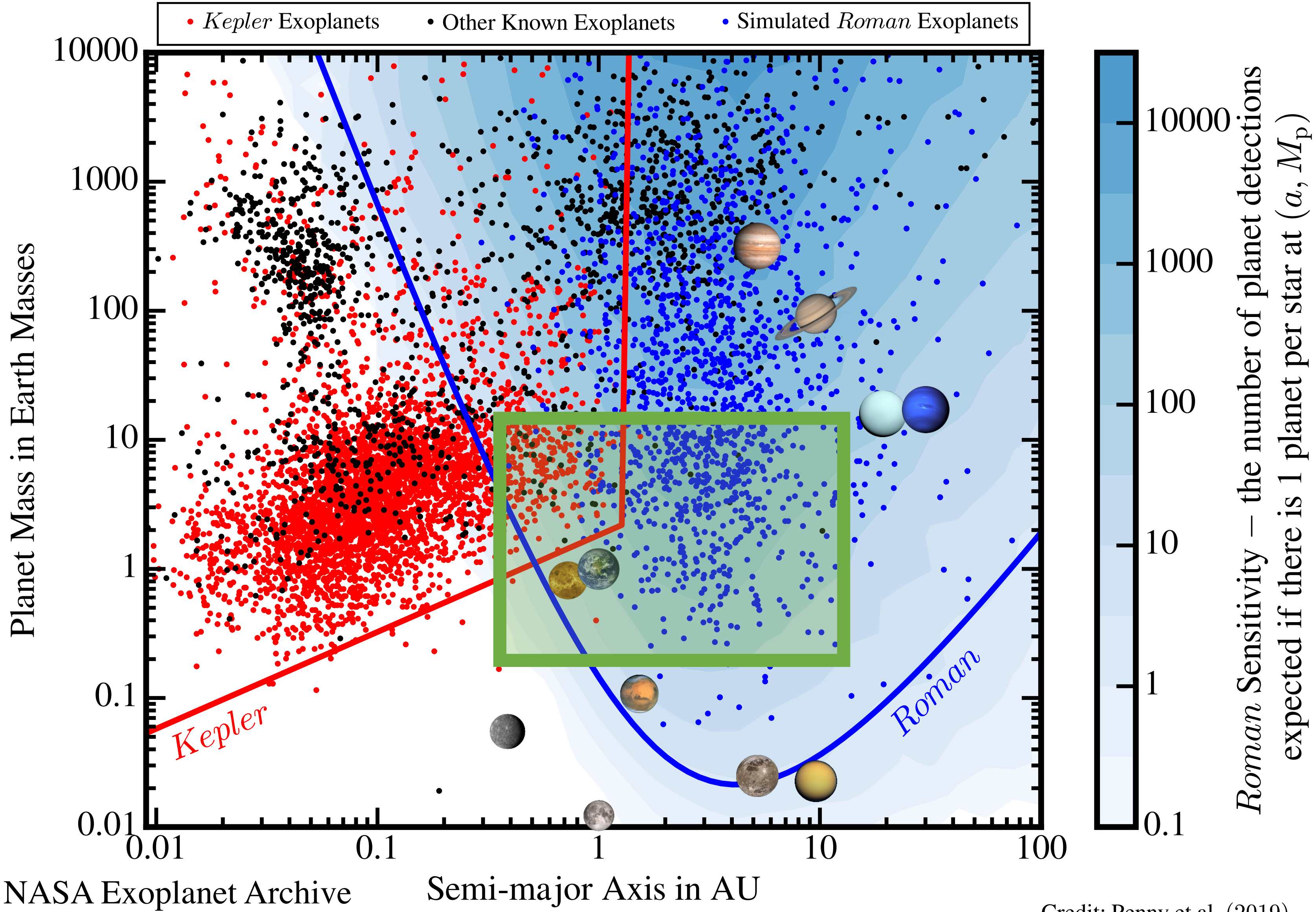

NASA Exoplanet Archive

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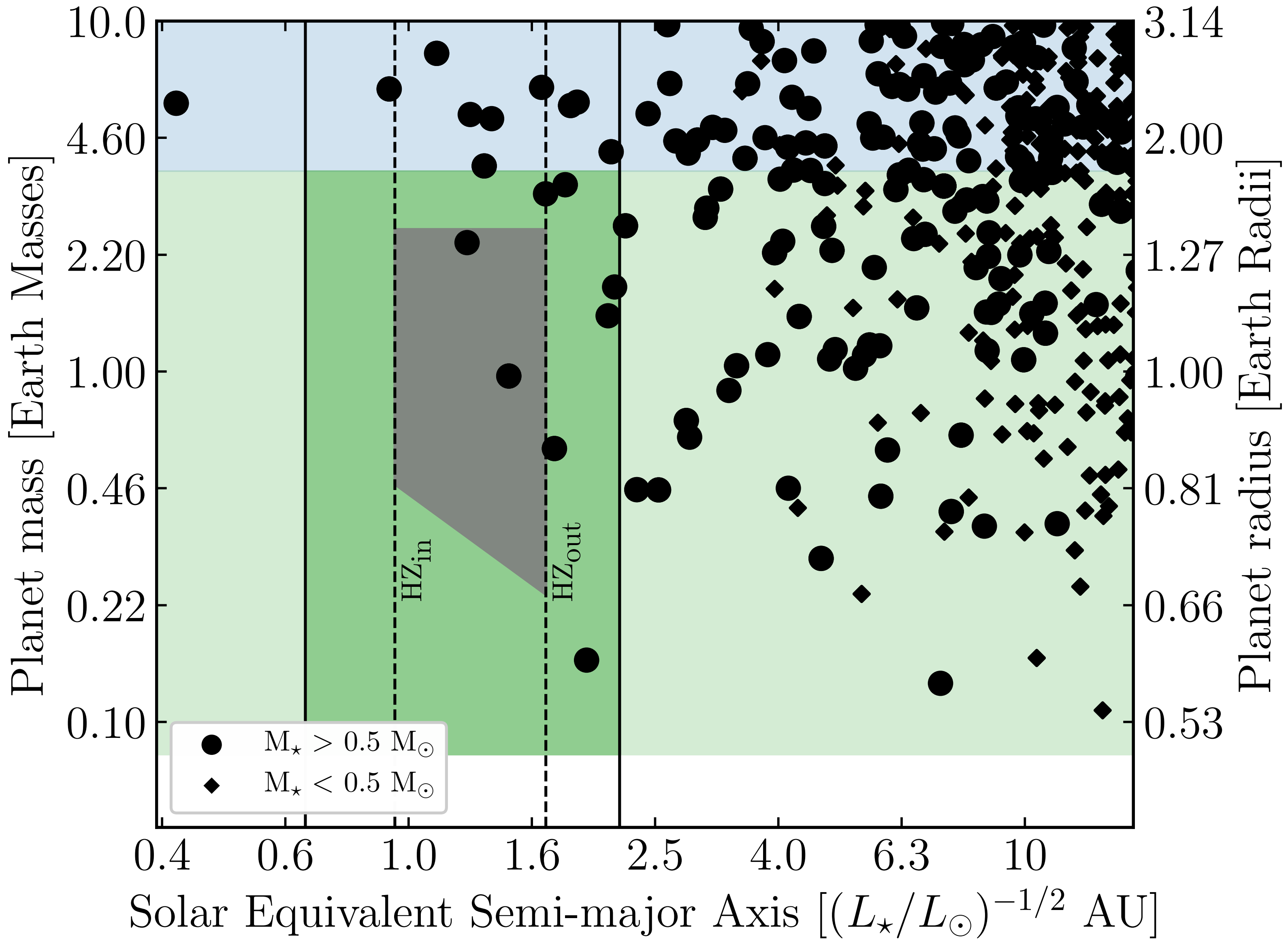


- *M-R relationship from Chen & Kipping (2016)*
- *See HabEx Final Report figure 3.3-9*

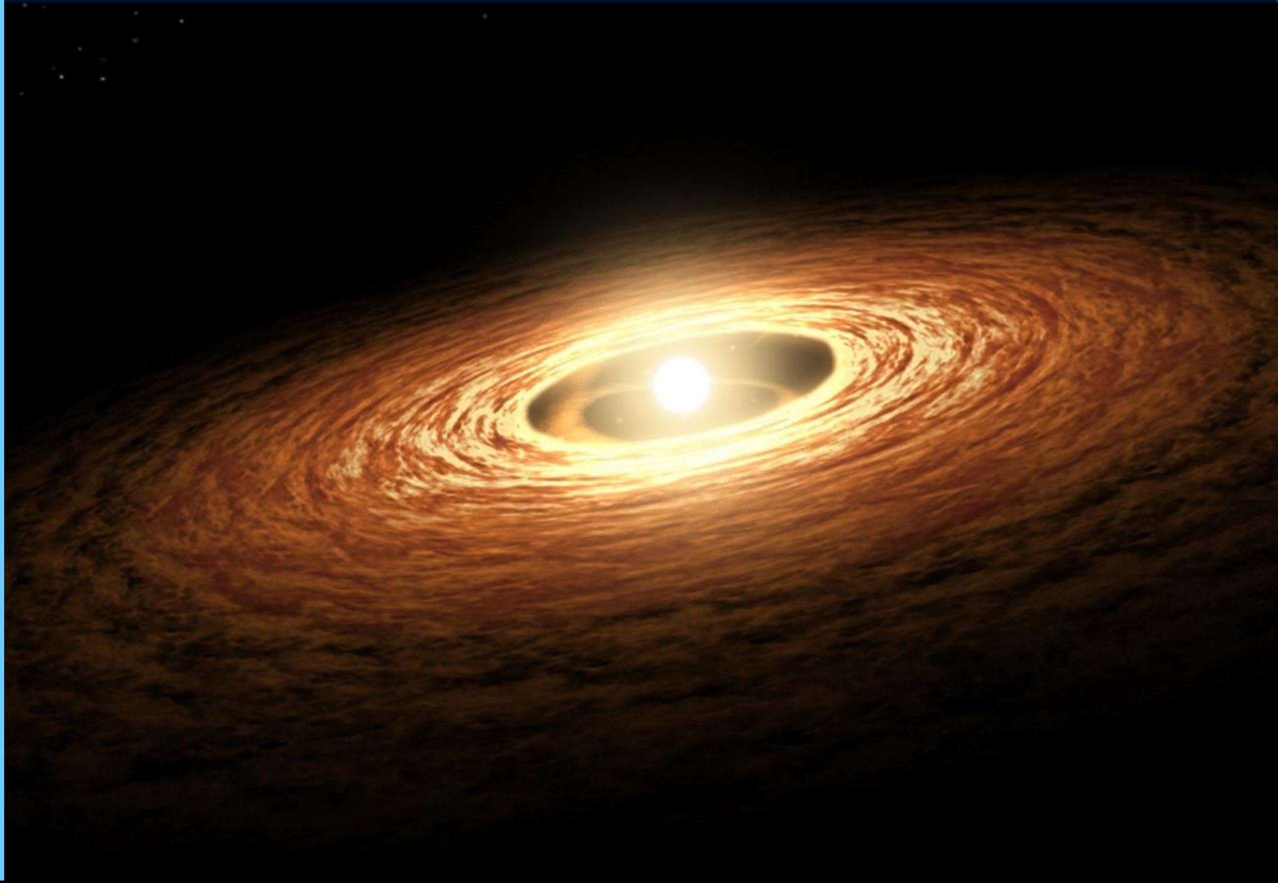
Johnson et al., in prep

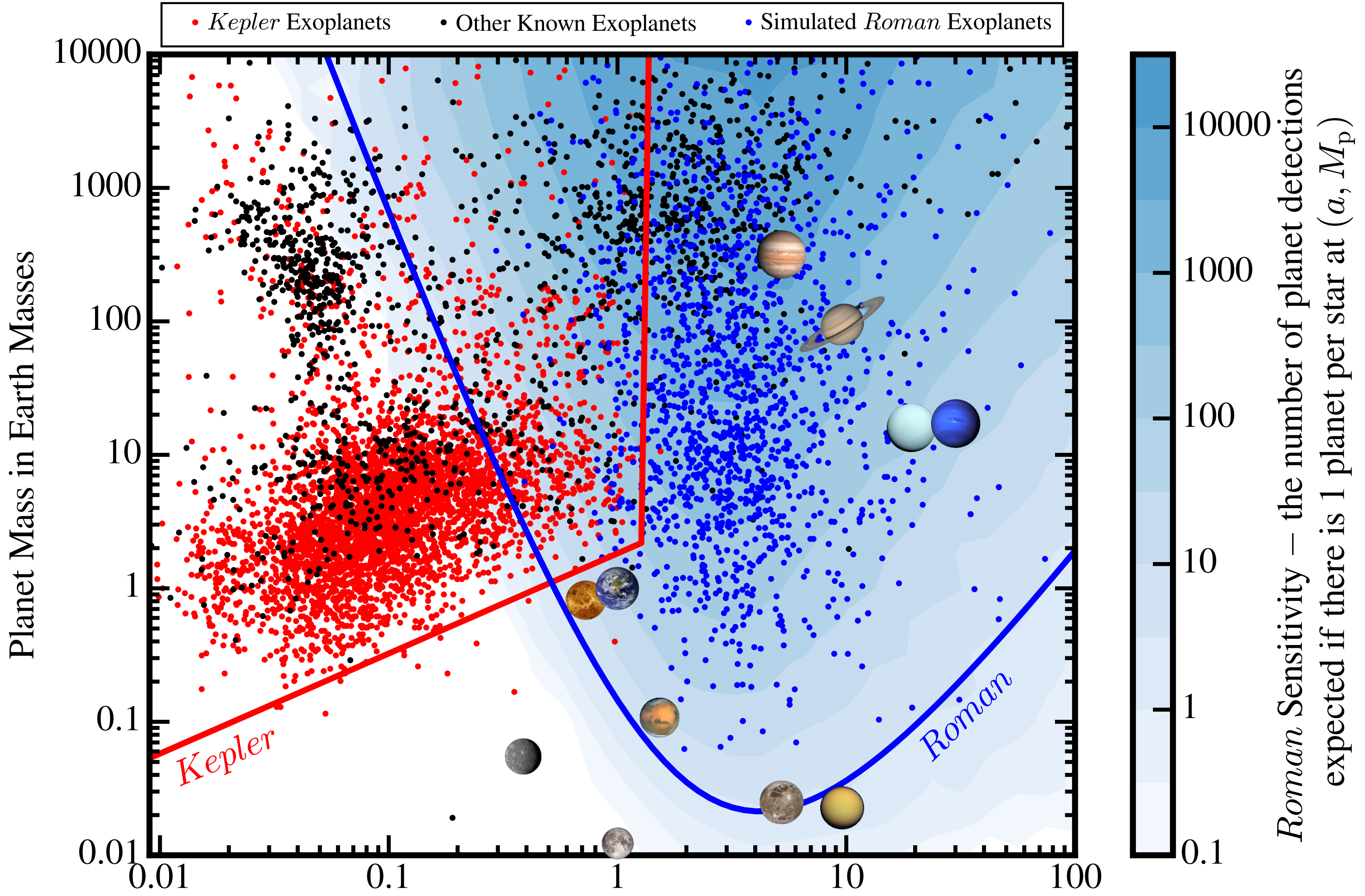
- Overview of survey and microlensing
- Earth-analogs in the Habitable Zone
- Free-floating planets

Free-floating planetary mass objects (FFPs)

could be lowest mass stars formed

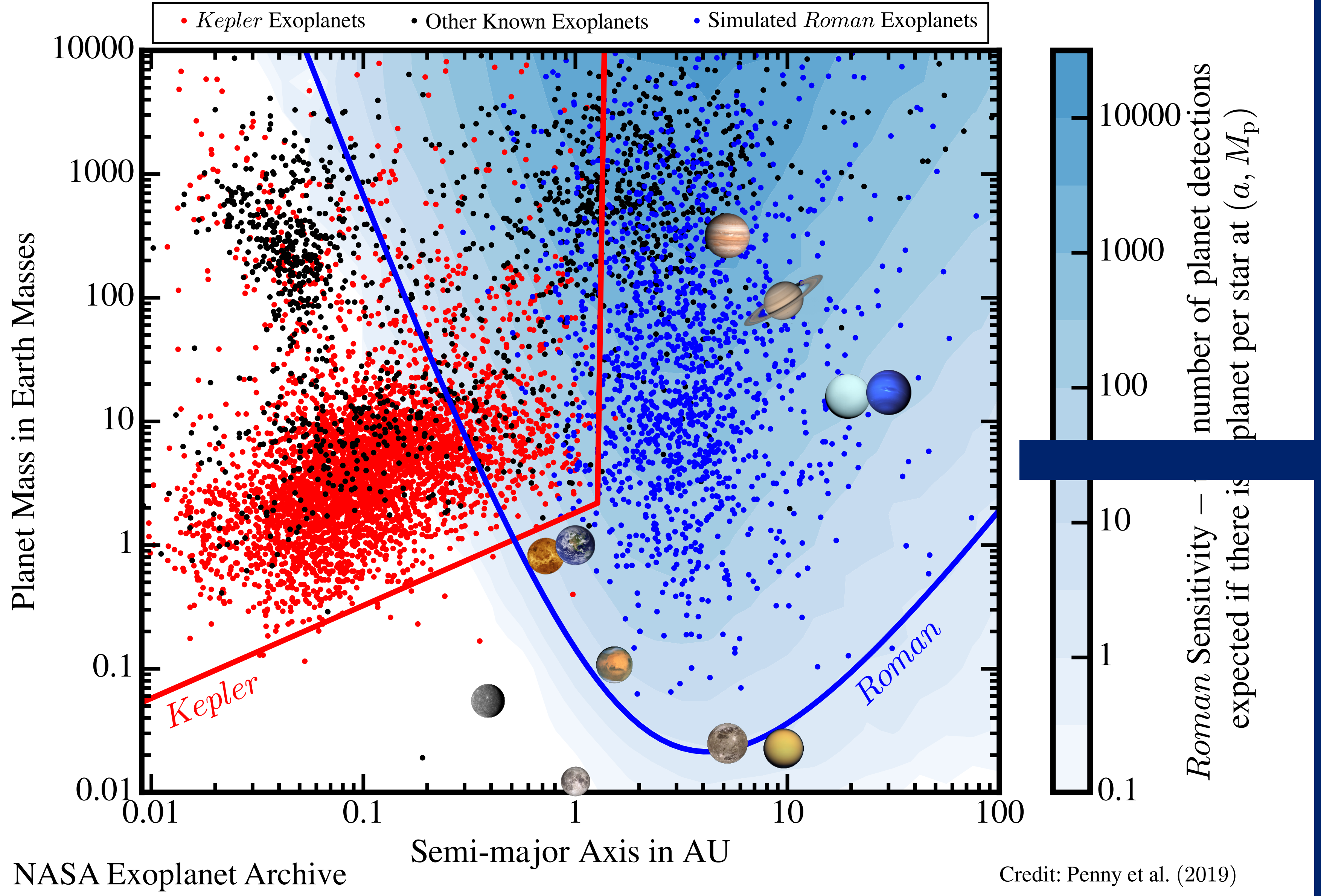
could be formed in disks and later be ejected





NASA Exoplanet Archive

Credit: Penny et al. (2019)



FFPs

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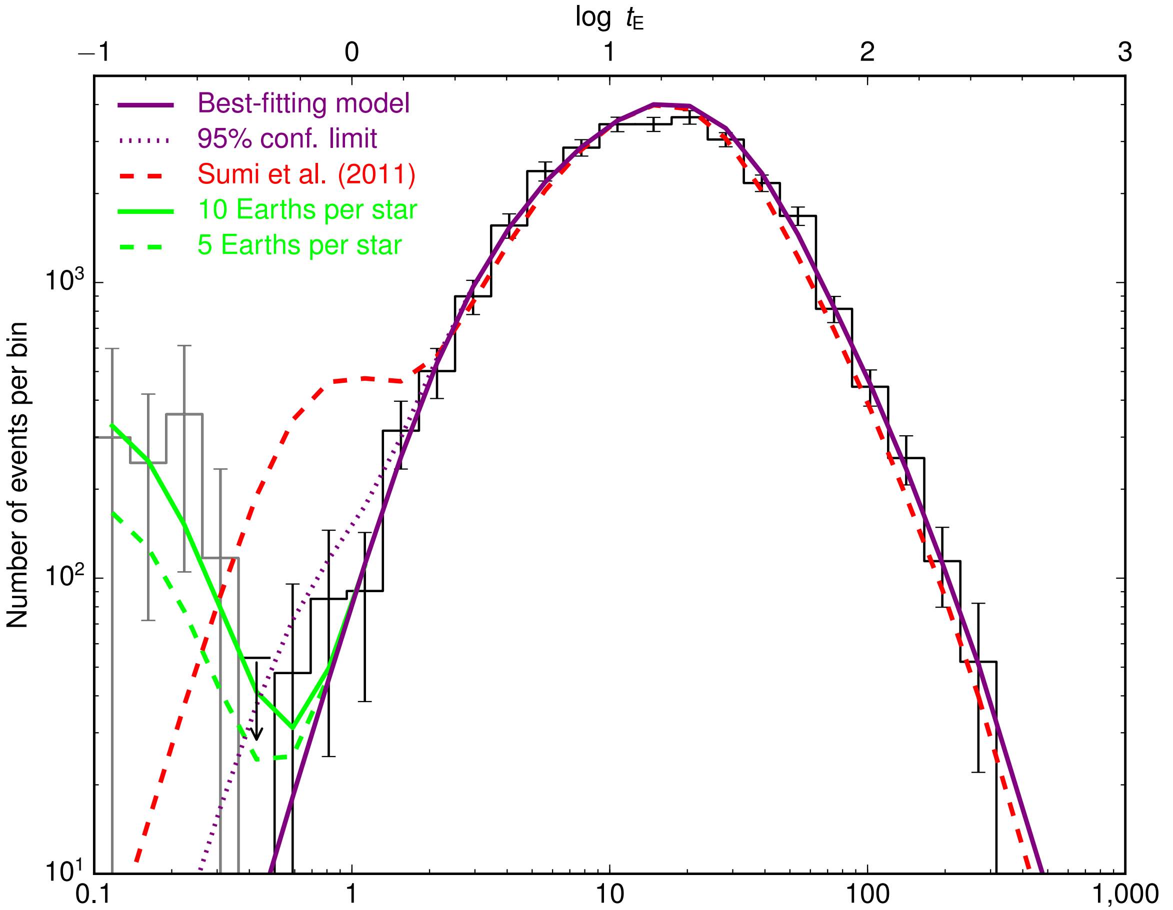
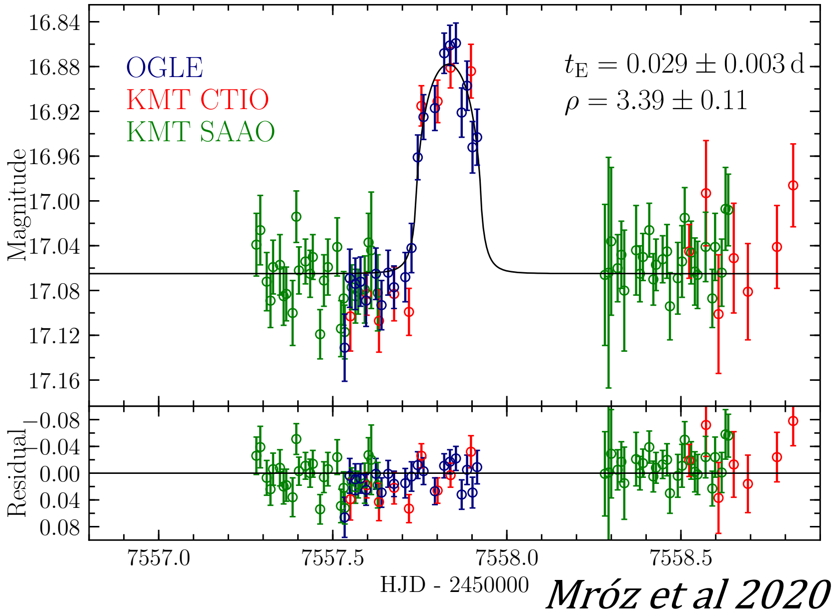
Evidence for free floating planets



Mróz et al 2017

$$t_E = \frac{\theta_E}{\mu_{rel}} \propto \sqrt{M_{lens}}$$



Mróz et al 2020

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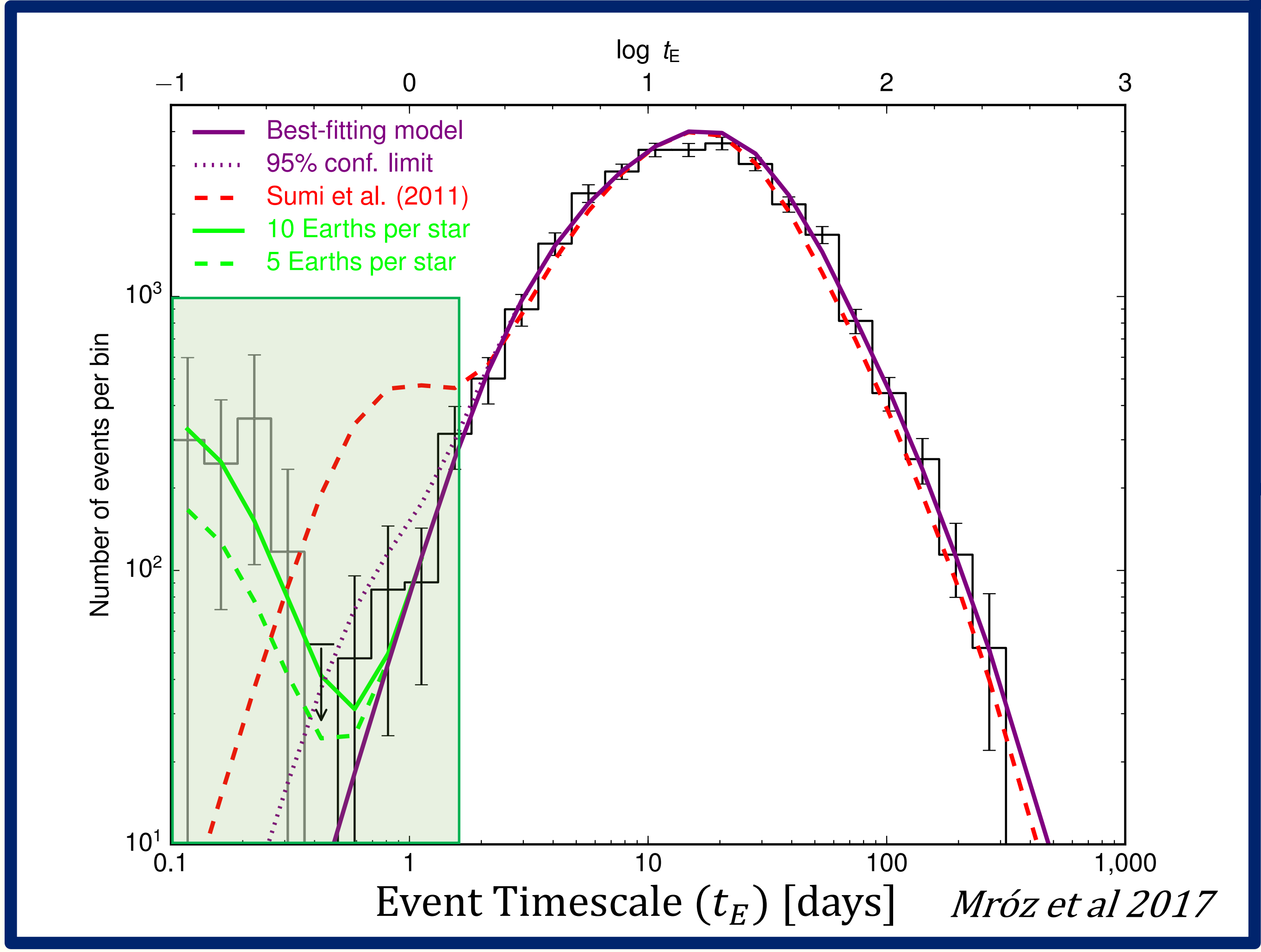

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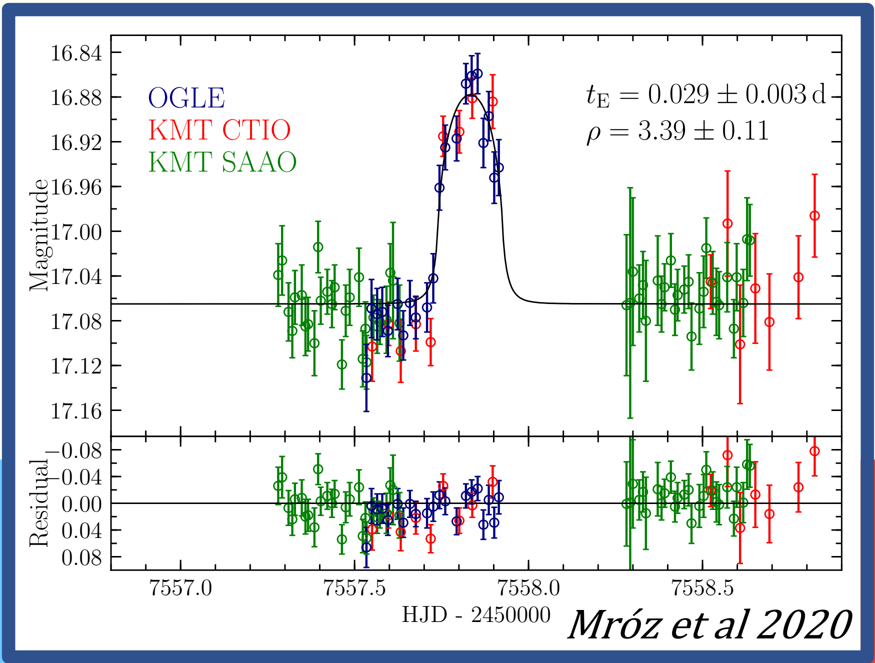

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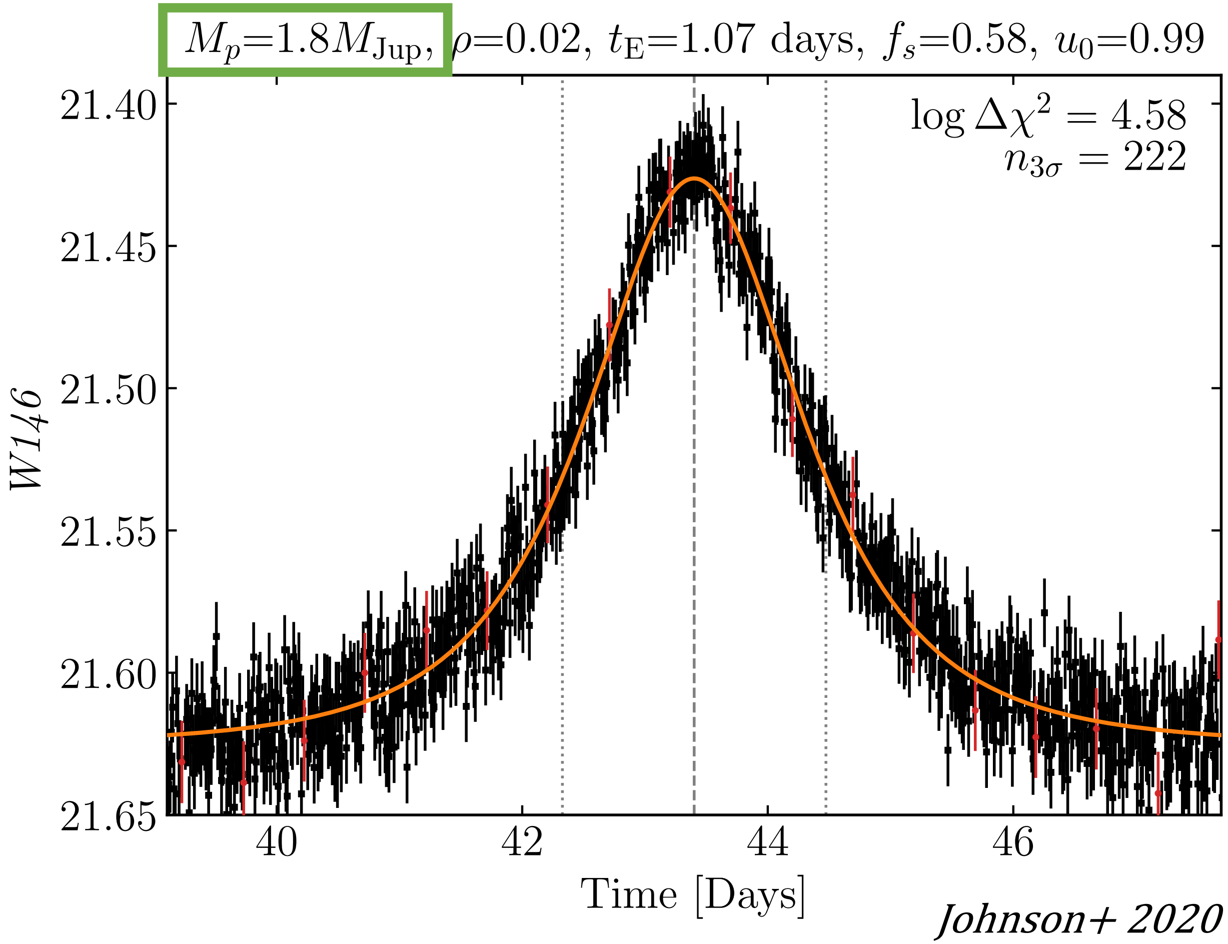
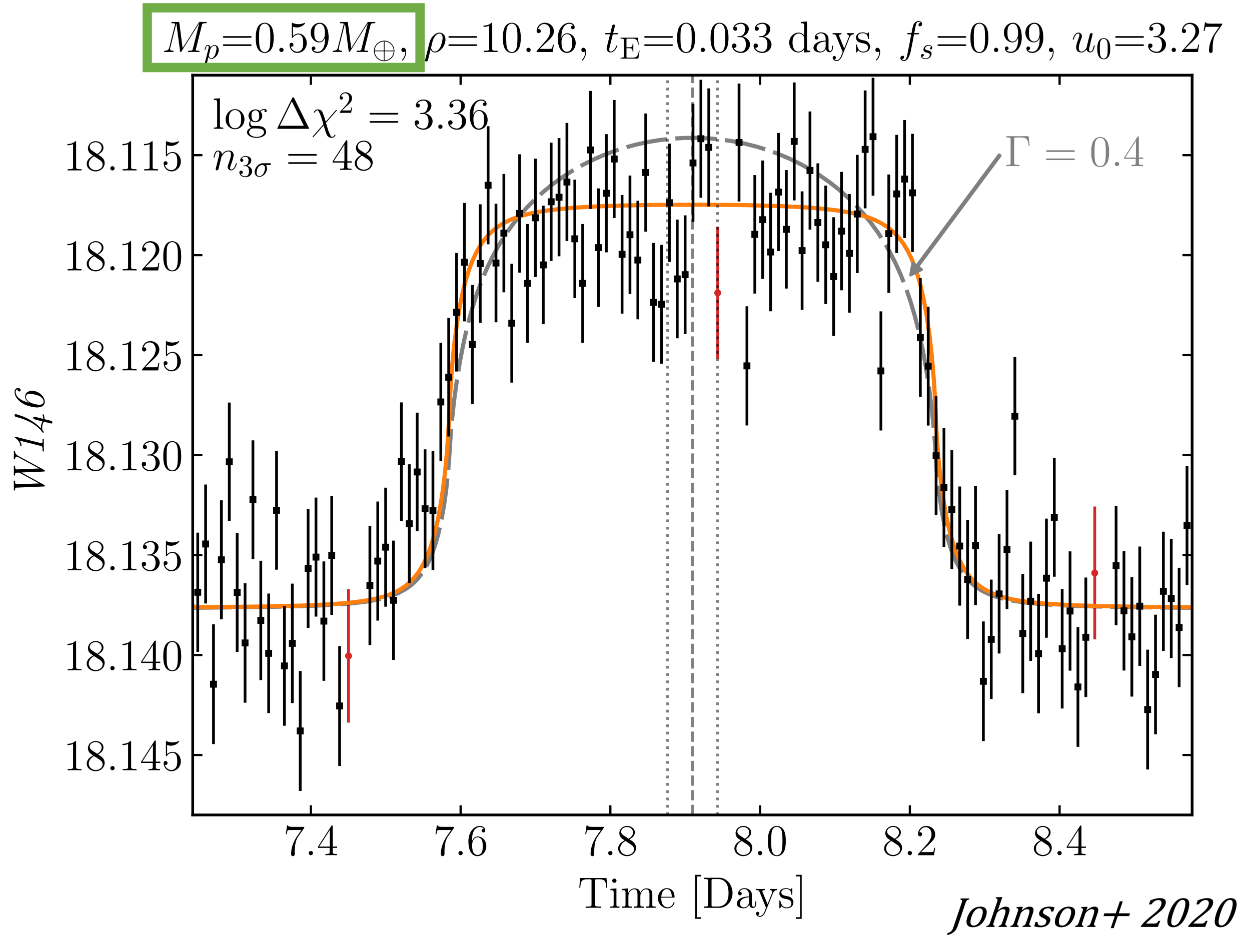
What will FFPs look like to *Roman?*





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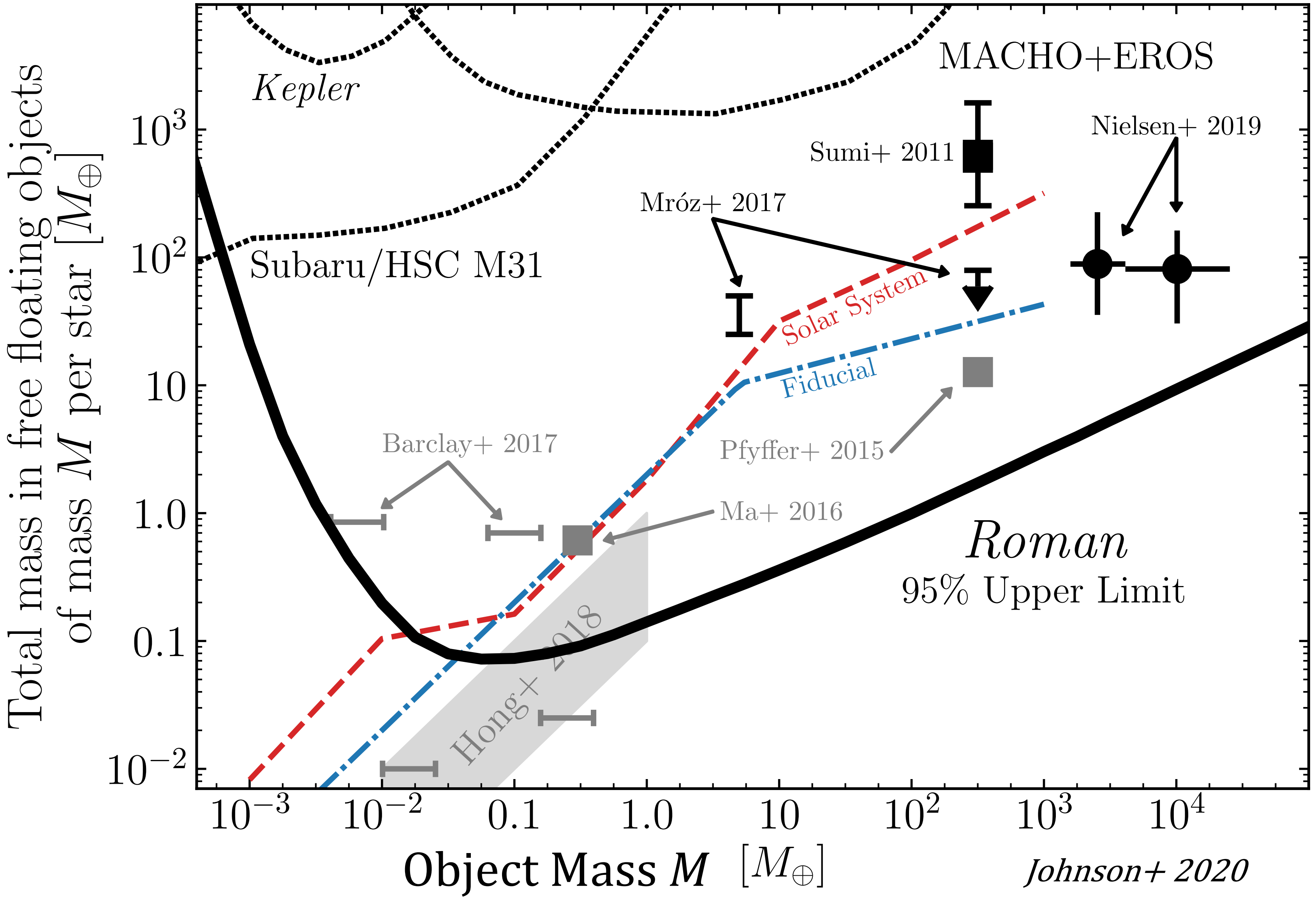
What can *Roman* teach us about free-floating planets?

- *Roman* will improve on previous limits
- *Roman* will test predictions from planet formation theories
- ~250 FFP events assuming fiducial mass function



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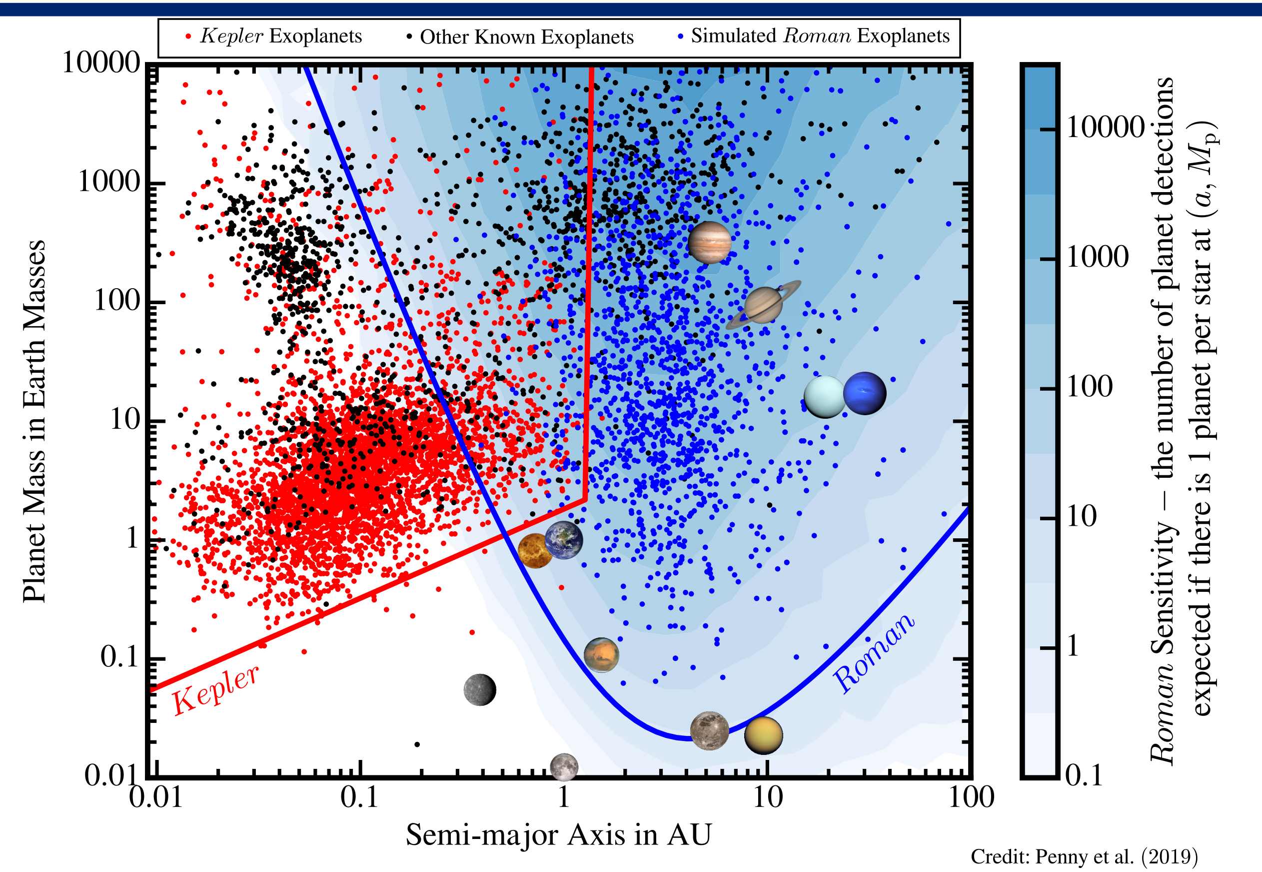
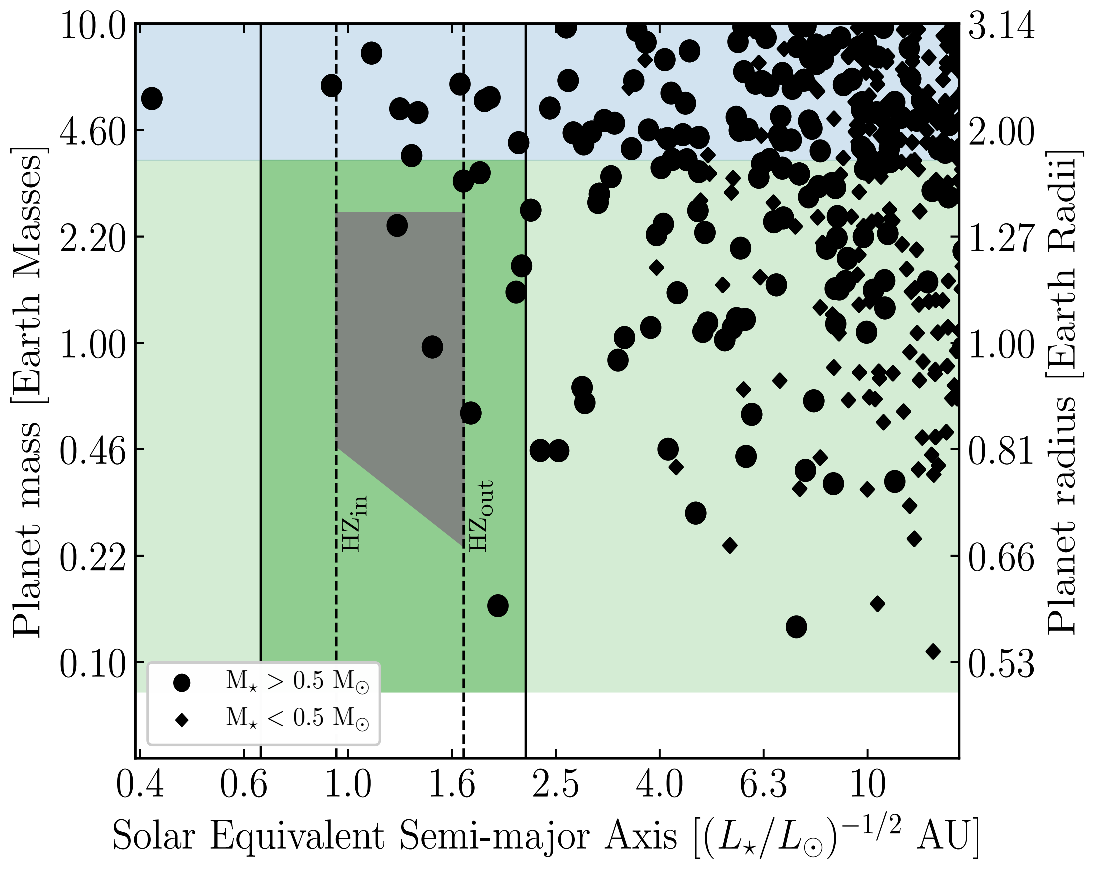
Key Takeaways

- *Roman* will conduct the first space-based microlensing survey
- Survey will provide exoplanet demographics statistics otherwise unattainable
- Will complement our current picture of planets in the Galaxy

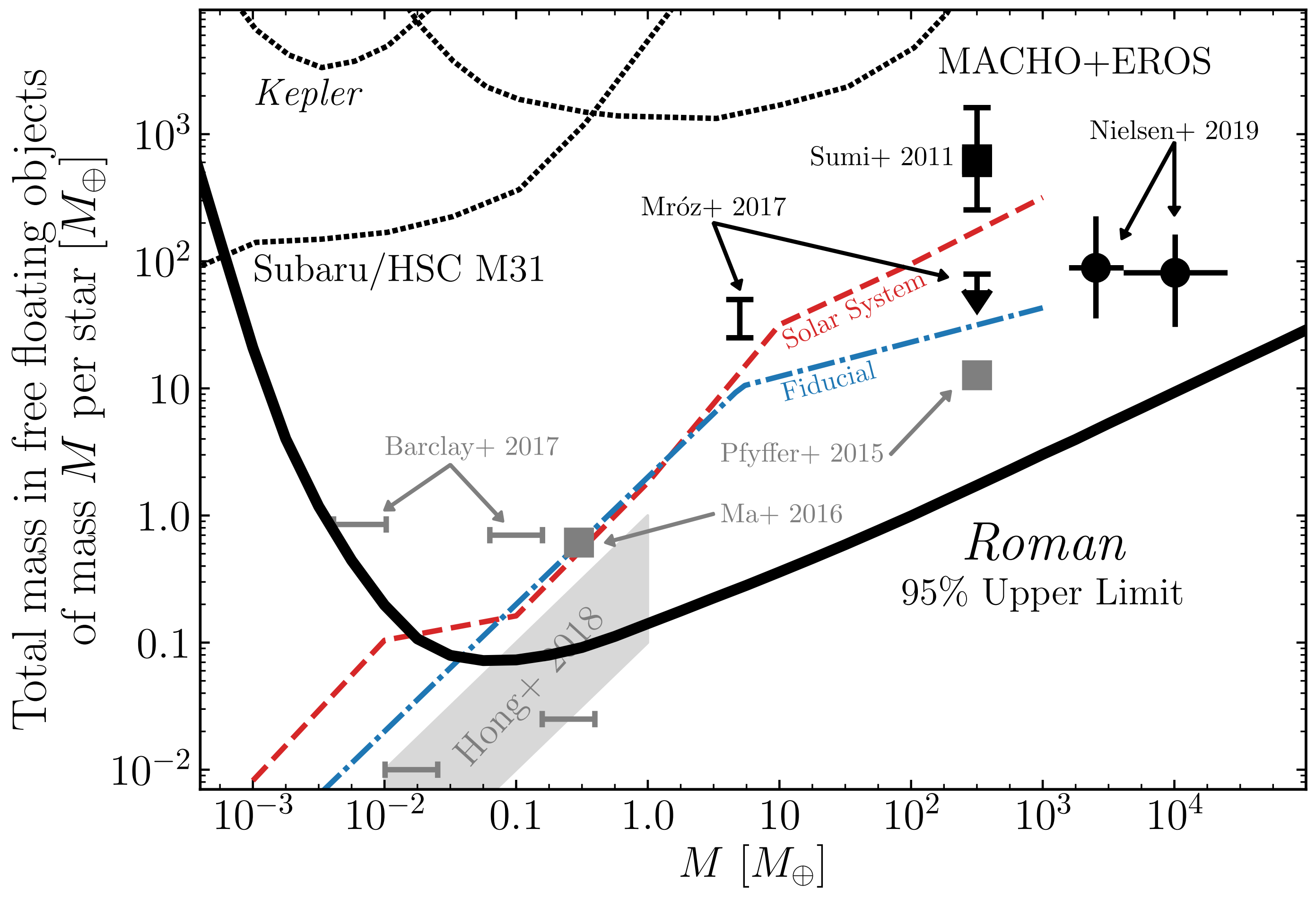


Credit: Penny et al. (2019)

Thank you!



Johnson et al., in prep



Johnson+ 2020

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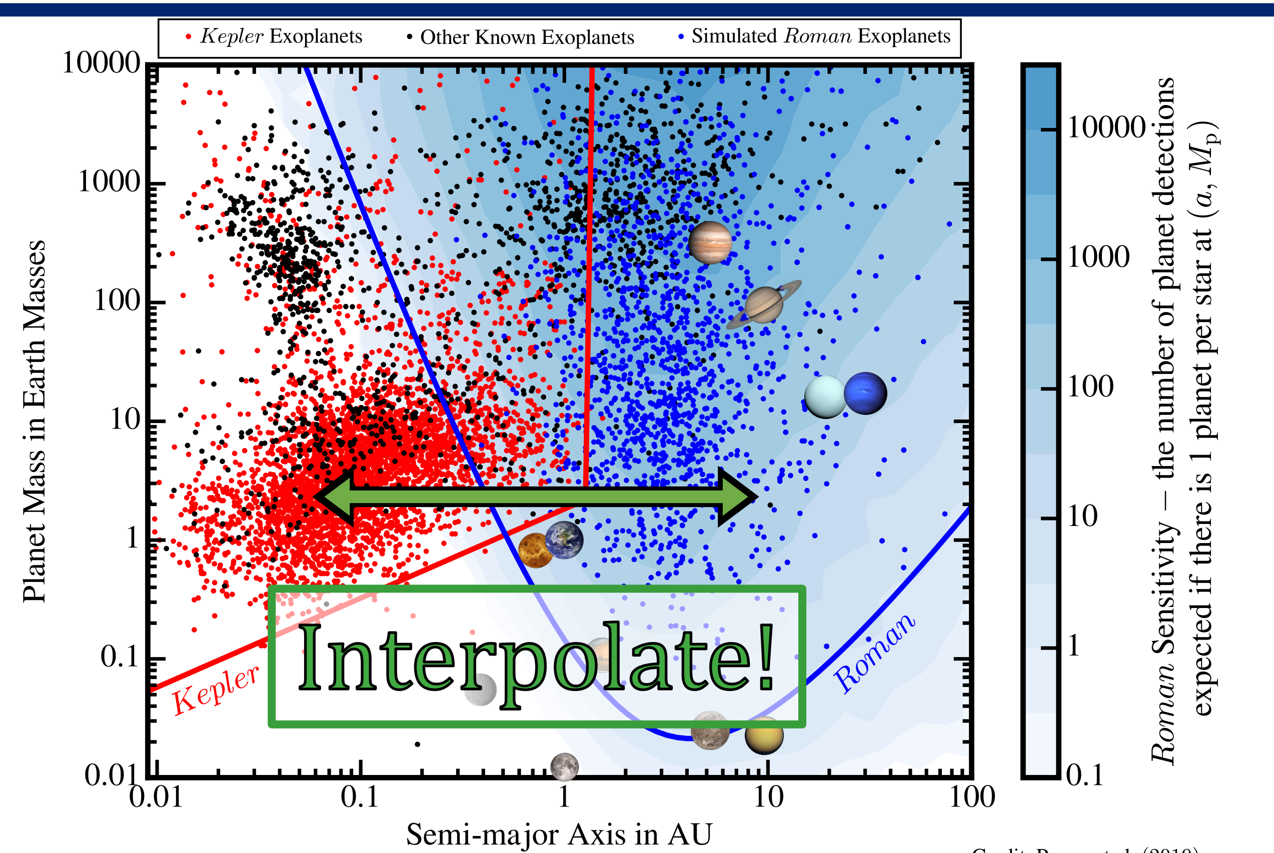
Further prospects

- Combining *Roman* with *Kepler*
  - Interpolation, not extrapolation for Earth-analog frequency
  - Complex sensitivity function
    - different host-star populations
    - different planet populations?
  - Mass-radius relationship important
- Ultimately, we want to combine as much information as possible in exoplanet demographics



Credit: Penny et al. (2019)

Other Considerations

Understanding *Roman's* sensitivity function

- Changes in galactic model (e.g. bar angle) will impact lens distributions
- Developing in-house Galactic Population Synthesis model
  - A. Aronica (OSU), M. Huston (Penn State), M. Penny (LSU)

Microlensing event rates uncertain in a subset of likely *Roman* fields due to dust

- Being mapped by precursor near-infrared microlensing surveys (e.g, Schvartzvald+2016, PRIME)

Survey design not finalized

- Input sought from the general community on all Core Community Surveys
- Survey design hinges on mission design (e.g., slew and settle times changed again)

A. Aronica
OSU Senior

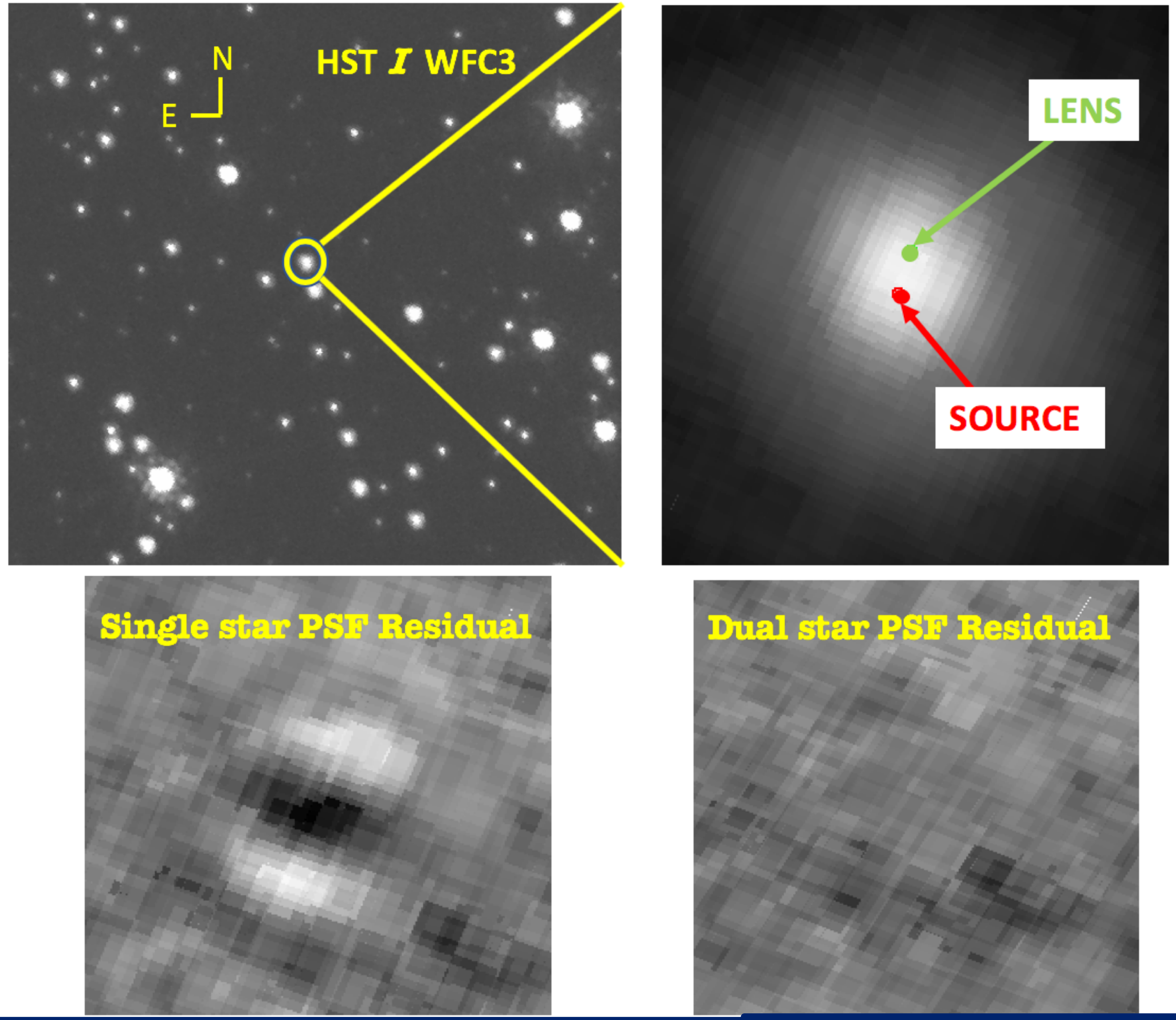
More likely to measure the true mass of Earth-analog systems

Microlensing is sensitive to the mass ratio between the planet and the host star

Model of the event

$$t_E = \frac{\theta_E}{\mu_{rel}}$$

$$\theta_E \propto \sqrt{M_*}$$



Bhattacharya et al., 2018

Use 4.5-year survey-baseline to measure lens-source separation (μ_{rel})

Planets with higher mass (brighter) host stars more likely to have μ_{rel} measured

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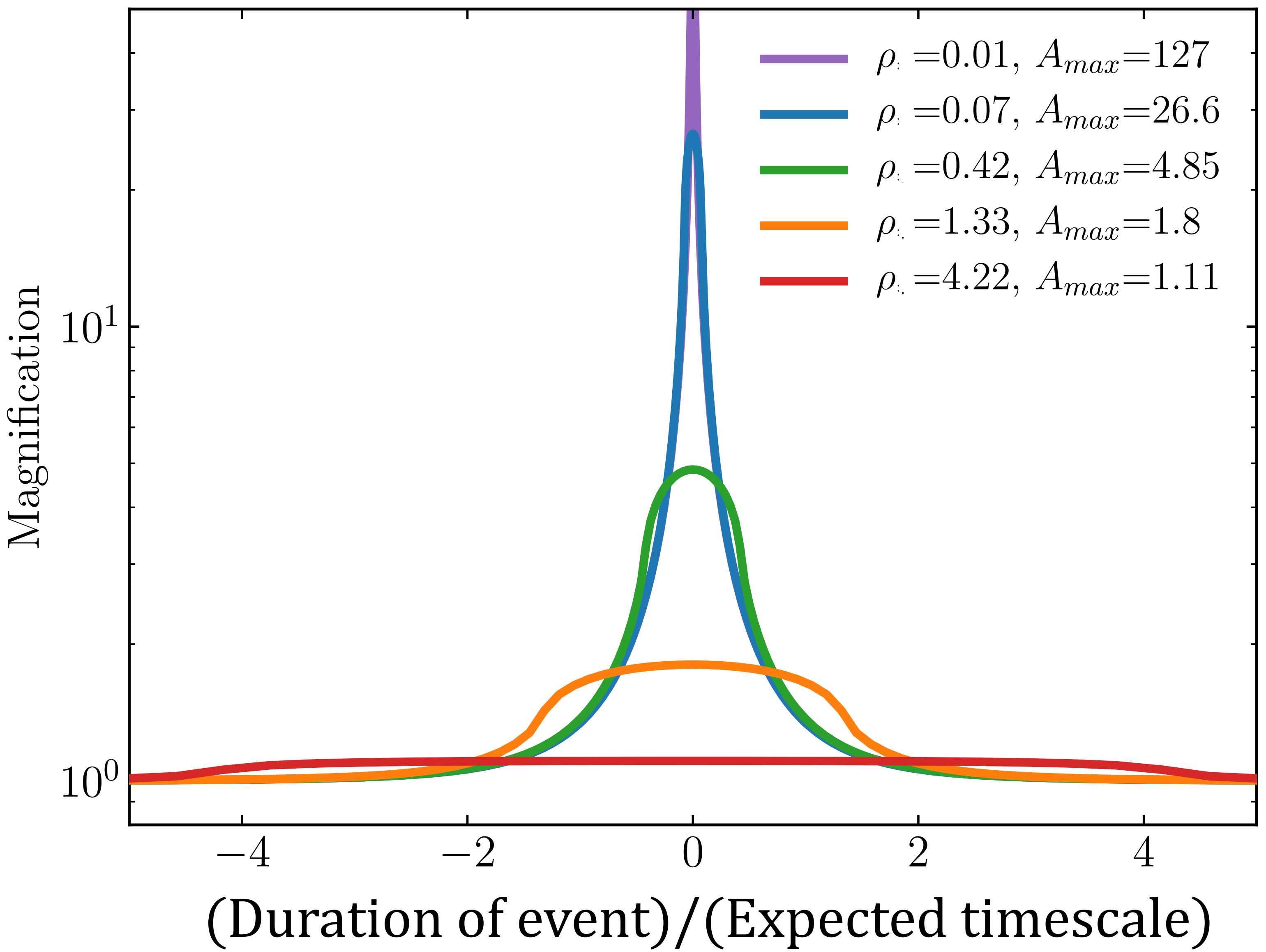
Finite Source Effects in a nutshell

$$\theta_E \propto \sqrt{M_{lens}}$$

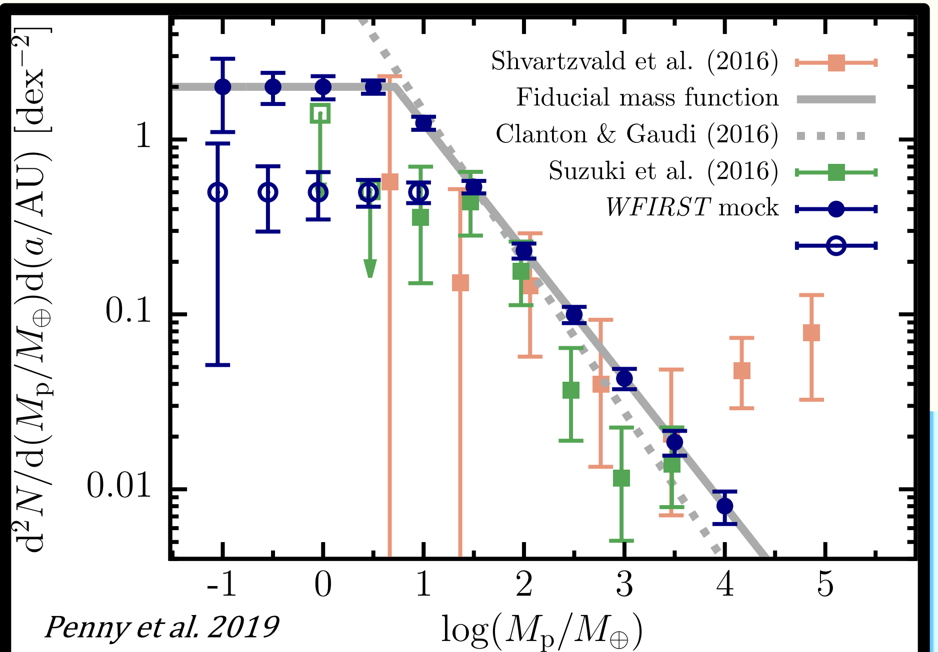
Source size, θ_*



$$\frac{\theta_*}{\theta_E} = \rho$$

Fiducial mass function adapted from *Cassan et al.* 2012

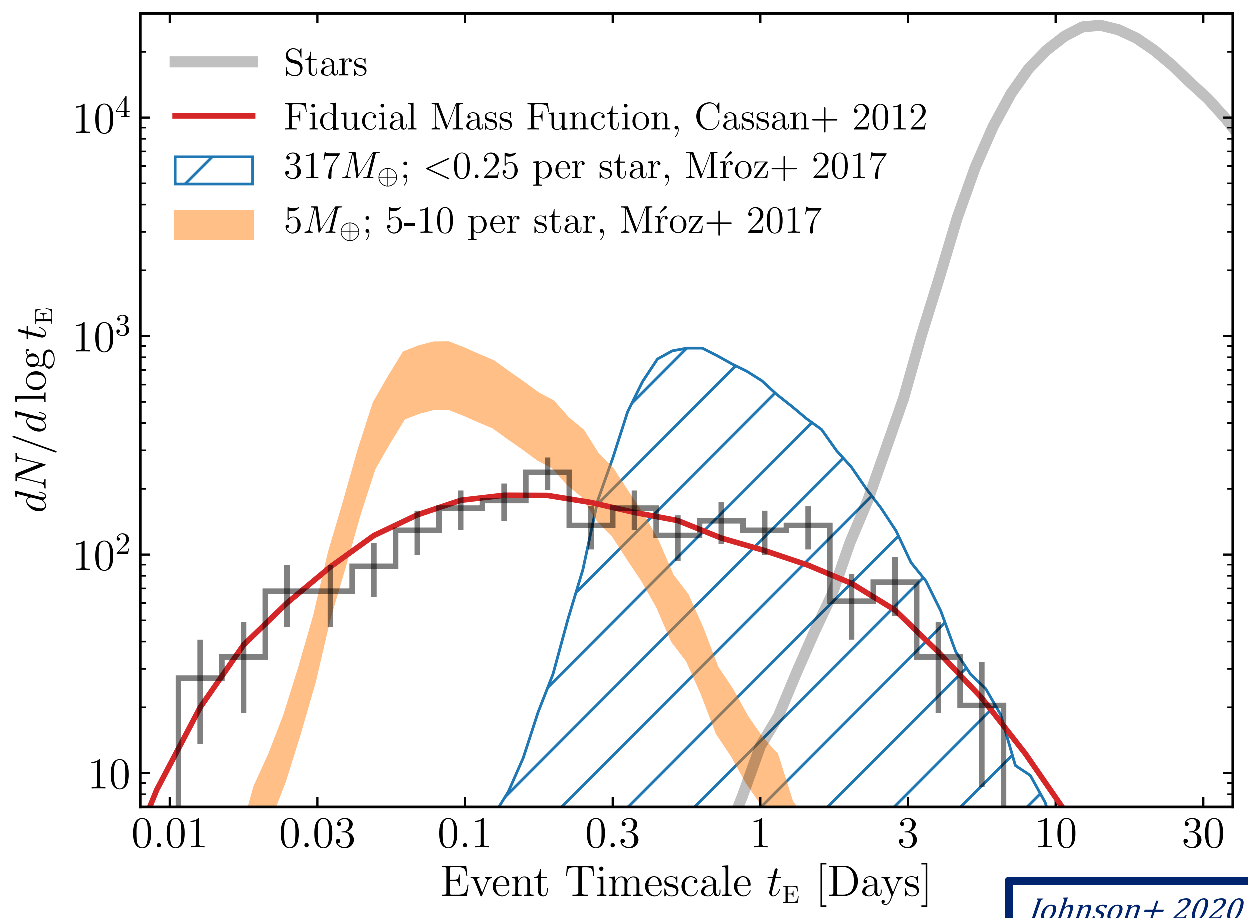
$$\frac{d^2N}{d\log m_p d\log a} = \begin{cases} \frac{0.24}{\mathrm{dex}^2}\left(\frac{m_p}{95M_\oplus}\right)^{-0.74} & \text{for} \quad M_p > 5\,M_\oplus \\ \frac{2}{\mathrm{dex}^2} & \text{for} \quad M_p > 5\,M_\oplus \end{cases}$$



Penny et al. 2019

Not just bound planets, but free-floating ones too!

$t_E \propto M_{lens}^{1/2}$



Johnson+ 2020

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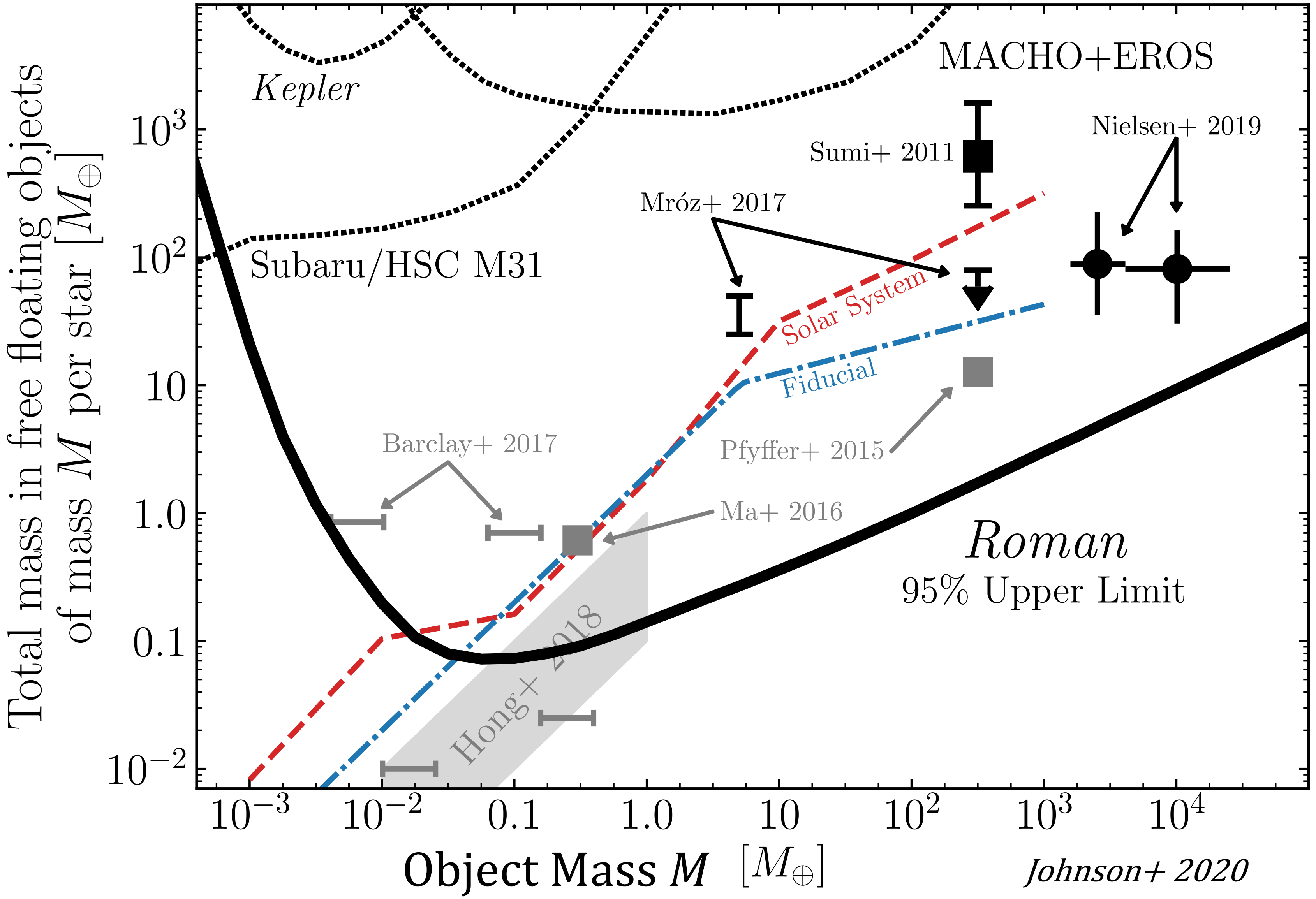


Johnson+ 2020

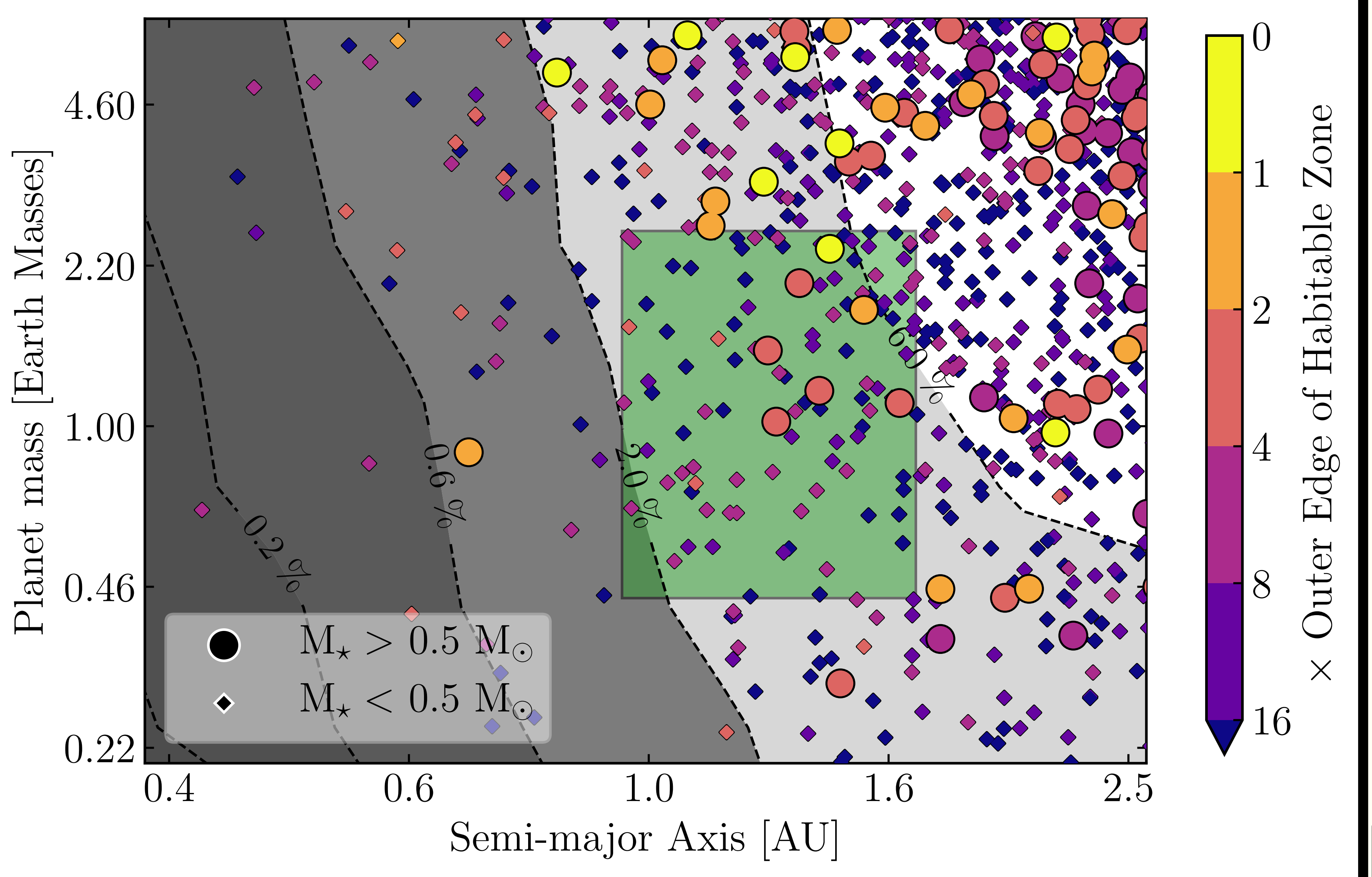
Scaling θ_E and t_E

$$\boldsymbol{\theta_E} \approx 700\mu as\left(\frac{M}{0.5M_{\odot}}\right)^{\frac{1}{2}} \approx \mathbf{30}\boldsymbol{\mu as}\left(\frac{M}{\boldsymbol{M_J}}\right)^{\frac{1}{2}} \approx \mathbf{2}\boldsymbol{\mu as}\left(\frac{M}{\boldsymbol{M_\oplus}}\right)^{1/2}$$

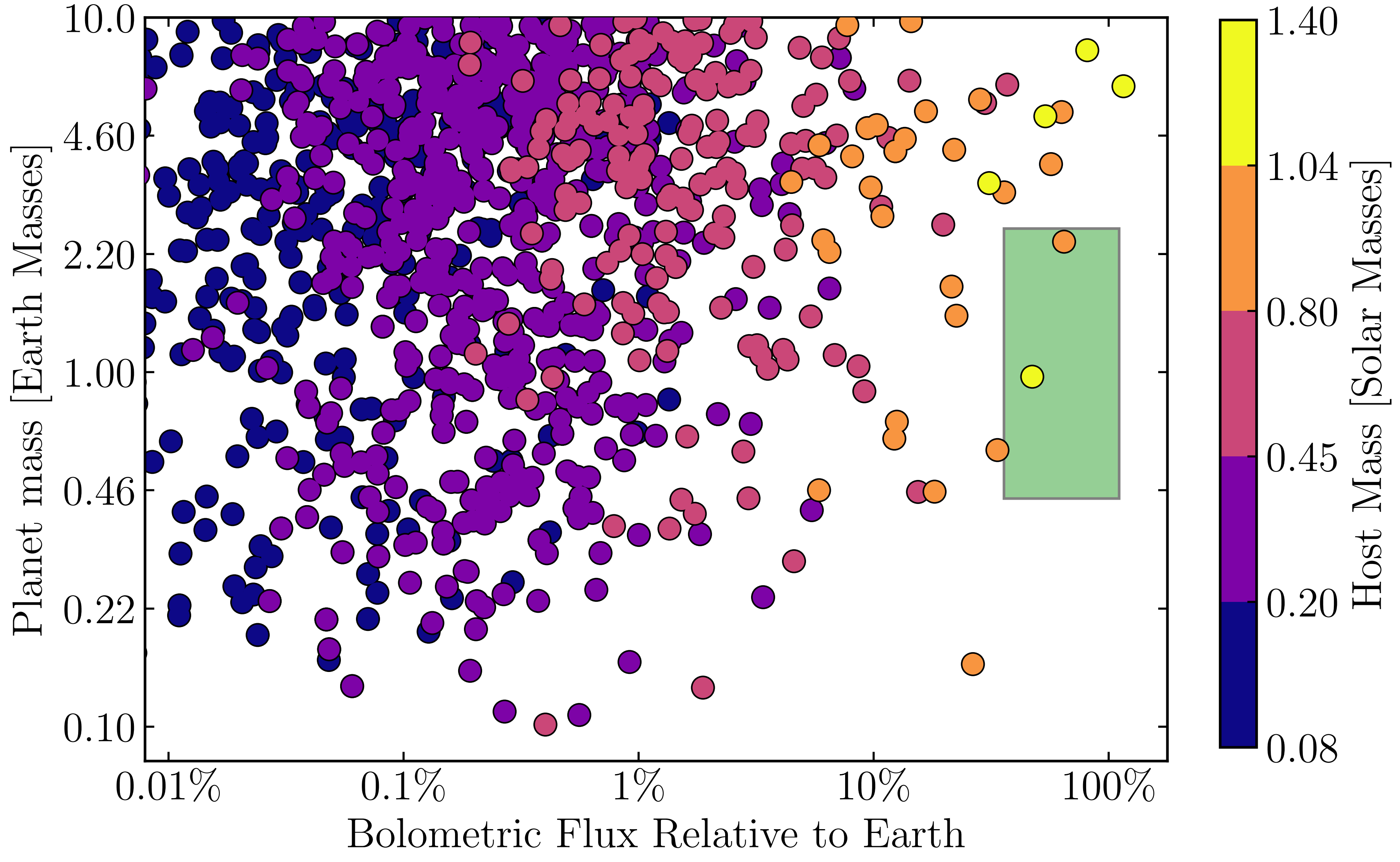
$$\boldsymbol{t_E} \approx 25days\left(\frac{M}{0.5M_{\odot}}\right)^{\frac{1}{2}} \approx \mathbf{1}\boldsymbol{day}\left(\frac{M}{\boldsymbol{M_J}}\right)^{\frac{1}{2}} \approx \mathbf{1.5}\boldsymbol{hours}\left(\frac{M}{\boldsymbol{M_\oplus}}\right)^{1/2}$$

Mission design changes

	IDRM	DRM1	DRM2	AFTA	***WFIRST* Cycle 7**
Reference	Green et al. (2011)	Green et al. (2012)	Green et al. (2012)	Spergel et al. (2015)	—[1,2]
Mirror diameter (m)	1.3	1.3	1.1	2.36	**2.36**
Obscured fraction (area, %)	0	0	0	13.9	**13.9**
Detectors	7×4 H2RG-10	9×4 H2RG-10	7×2 H4RG-10	6×3 H4RG-10	**6×3 H4RG-10**
Plate scale ("/pix)	0.18	0.18	0.18	0.11	**0.11**
Field of view (deg^2)	0.294	0.377	0.587	0.282	**0.282**
Fields	7	7	6	10	**7**
Survey area (deg^s)	2.06	2.64	3.52	2.82	**1.97**
Avg. slew and settle Time (s)	38	38	38	38	**83.1**
Orbit	L2	L2	L2	Geosynchronous	L2
Total Survey length (d)	432	432	266	411**	**432**
Season length (d)	72	72	72	72	**72**
Seasons	6	6	3.7	6	**6**
Baseline mission duration (yr)	5	5	3	6	**5**
Primary bandpass (μm)	1.0–2.0 (W149)	1.0–2.4 (W169)	1.0–2.4 (W169)	0.93–2.00 (W149)	**0.93–2.00 (W149)**
Secondary bandpass (μm)	0.74–1.0 (Z087)	0.74–1.0 (Z087)	0.74–1.0 (Z087)	0.76–0.98 (Z087)	**0.76–0.98 (Z087)**



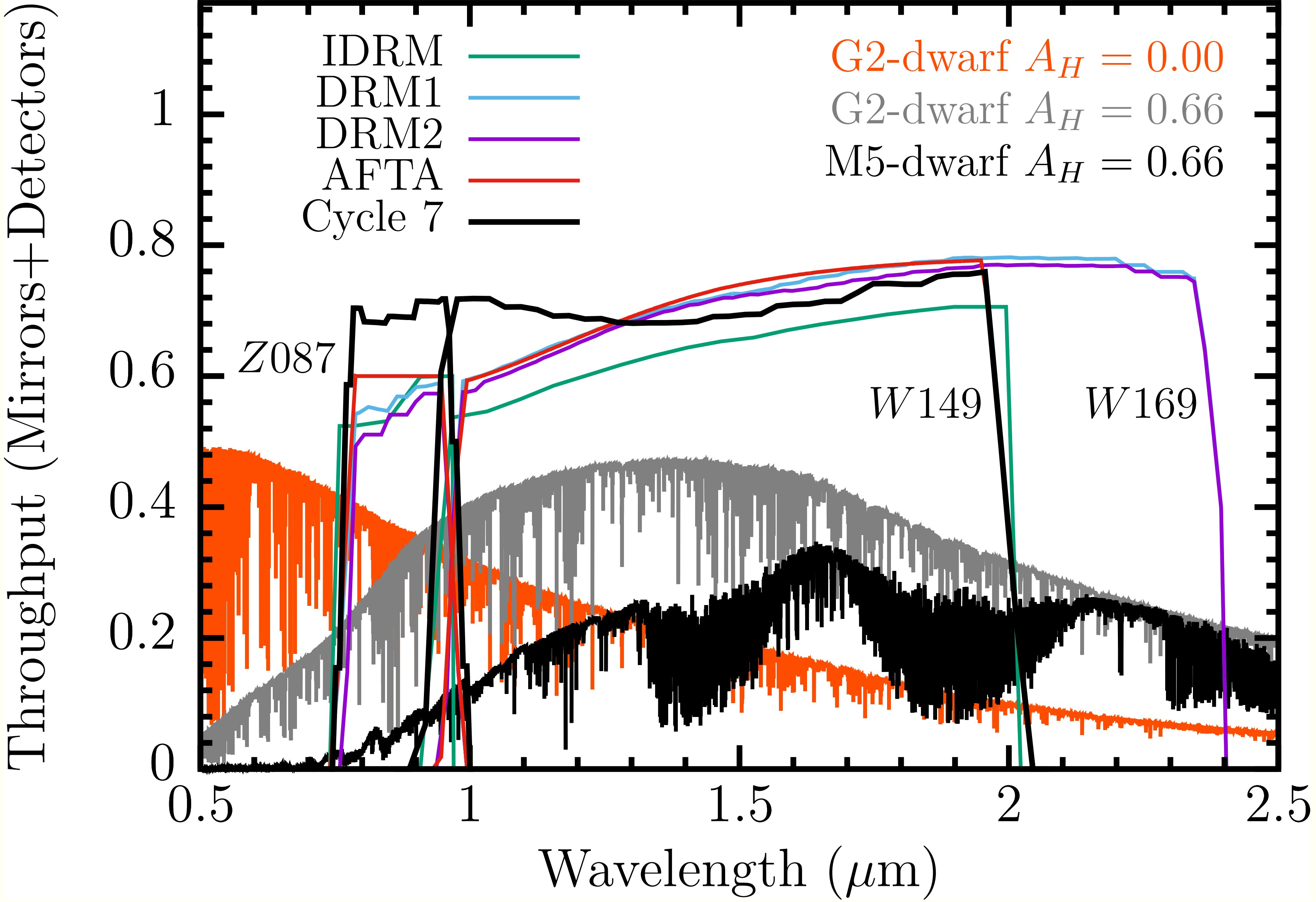
Johnson et al., in prep

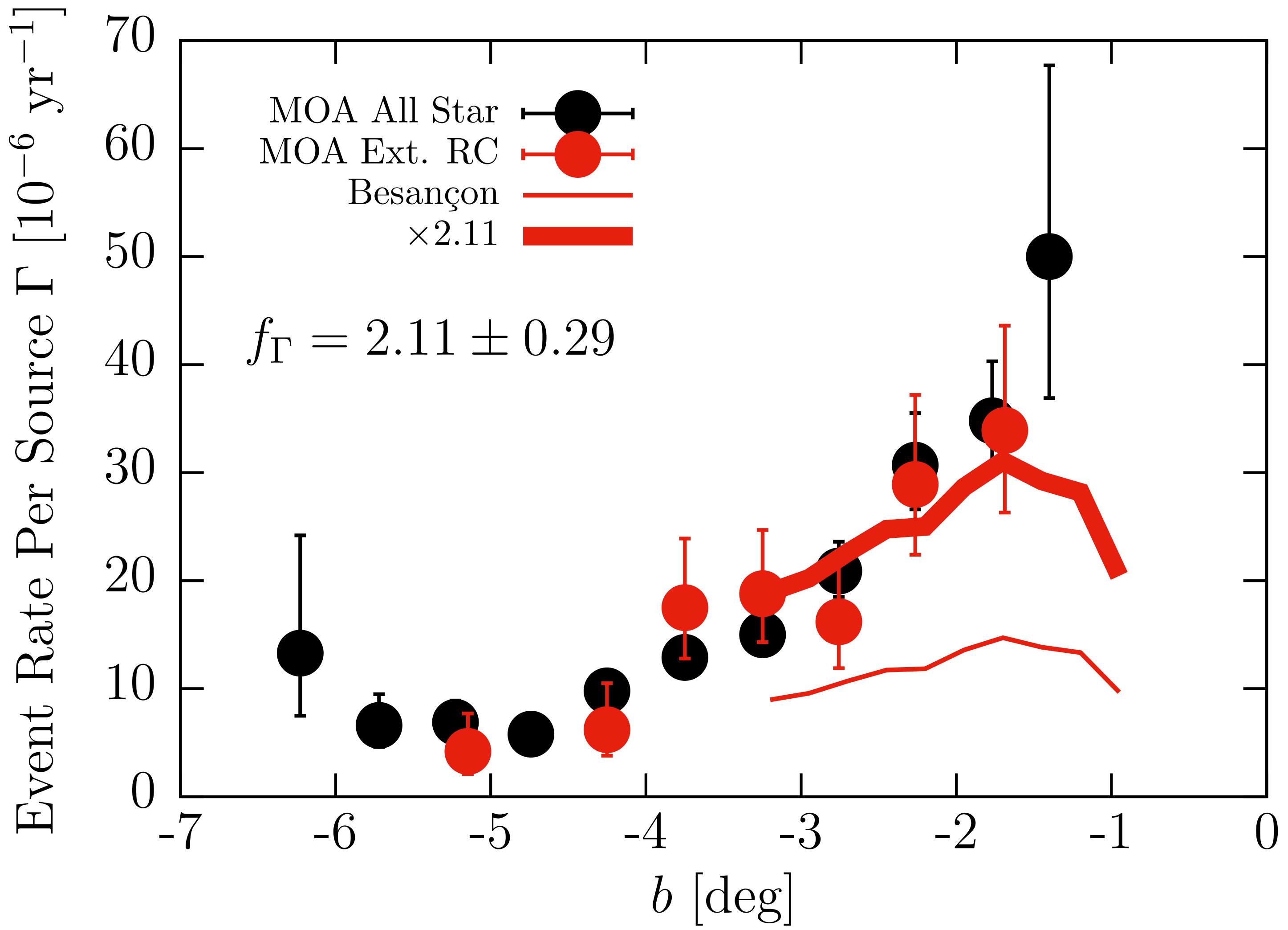

Planet mass [Earth Masses]
10.0
4.60
2.20
1.00
0.46
0.22
0.10
0.01%
0.1%
1%
10%
100%
Bolometric Flux Relative to Earth
Host Mass [Solar Masses]
1.40
1.04
0.80
0.45
0.20
0.08

Event rate weighting

$$w_i = 0.25\,\mathrm{deg}^2\, f_{1106WFIRST}\Gamma_{\mathrm{deg}^2}T_{sim}u_{0,max}\,\frac{2\mu_{rel,i}\theta_{E,i}}{W}$$

$$W = \sum_i 2\mu_{rel,i}\theta_{E,i}$$


IDRM
DRM1
DRM2
AFTA
Cycle 7
G2-dwarf $A_H = 0.00$
G2-dwarf $A_H = 0.66$
M5-dwarf $A_H = 0.66$
$Z087$
$W149$
$W169$
Throughput (Mirrors+Detectors)
1
0.8
0.6
0.4
0.2
0
0.5
1
1.5
2
2.5
Wavelength (μm)



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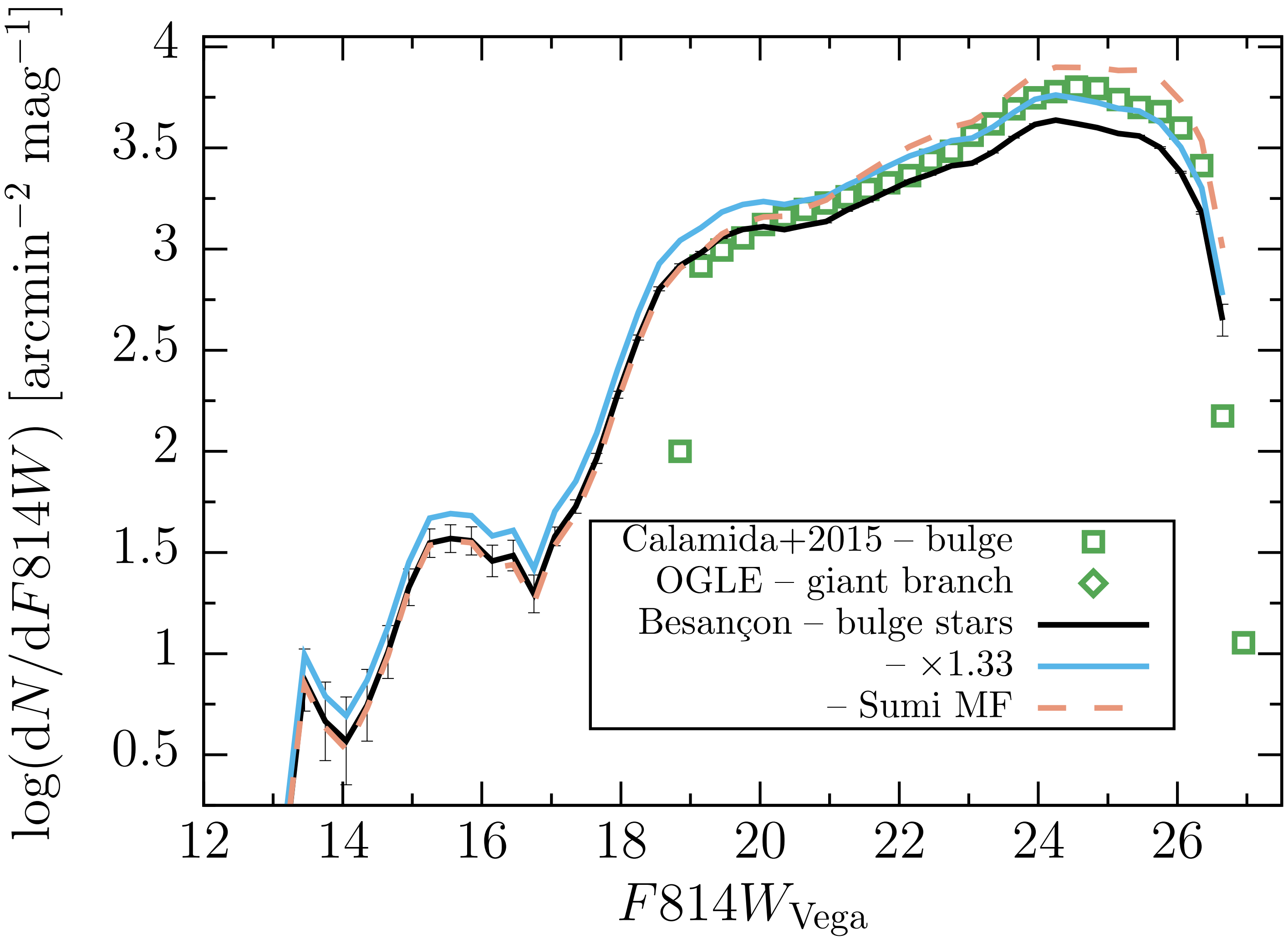

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