Roman Galactic Bulge Time Domain Survey: Survey Yield and Optimization

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Roman Science Team Community Briefing

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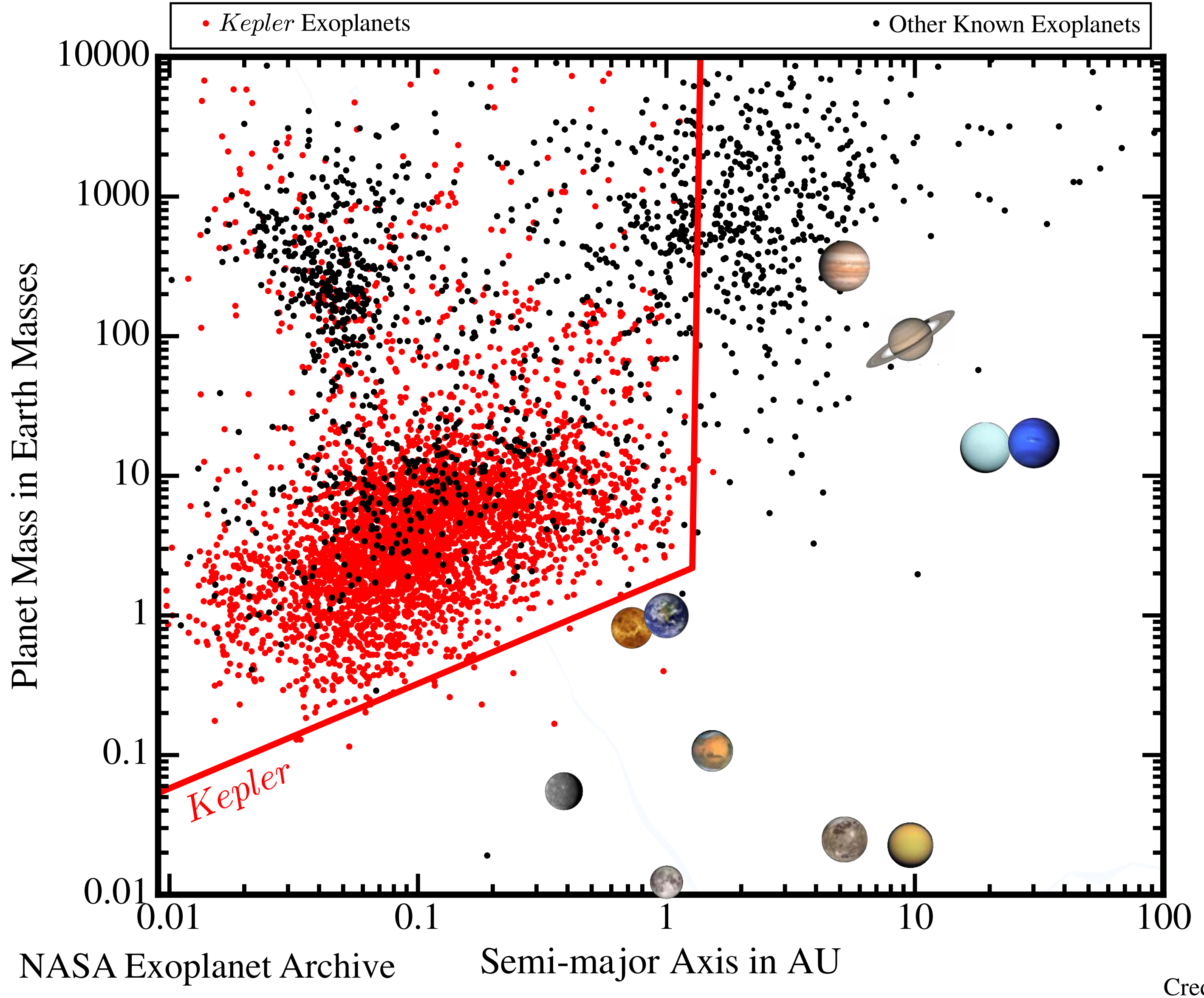
THE OHIO STATE UNIVERSITY



Credit: Penny et al. (2019)

Science Requirements

1. Measure the mass functions of cold exoplanets with masses > 1 M_{Earth} and semimajor axes ≥ 1 AU to better than 15% per decade in mass.

2. Measure the frequency of Mars-mass planets to better than 15%.

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4. Estimate η_{Earth} to better than 0.2 dex through extrapolation from more massive and wider orbit planets.

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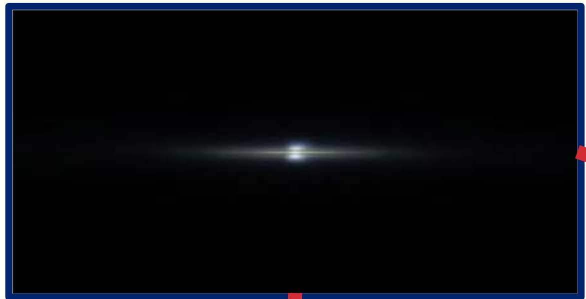
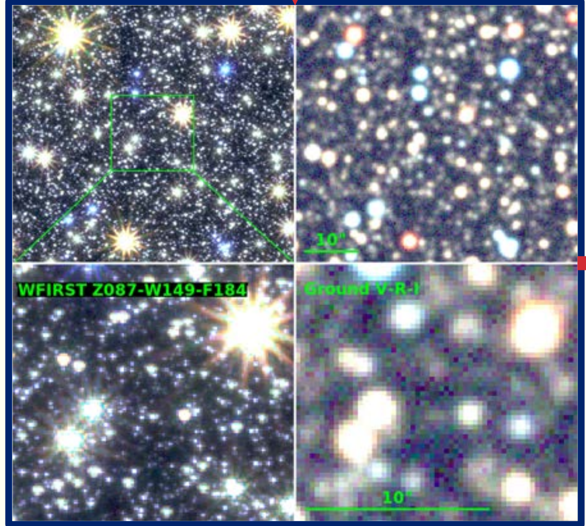
Estimates of Survey Parameters to detect 100 Earth-mass planets (~10% precision)

- Detection Efficiency $\sim 0.01 \rightarrow 10{,}000$ microlensing events
- Event rate is $\sim 5\times 10^{-5}$ per source star per year
- 100 million sources/deg^2 $\rightarrow 5000\,\frac{\text{events}}{\text{deg}^2\text{year}} \rightarrow \sim 2\ \text{deg}^2$ survey area for 1 year
- Minimum timescale of perturbation ~ 1 hour $\rightarrow \lesssim 15 -$ minute cadence
- $\sim$5-year survey baseline and $\mu_{rel} \sim 10\,\frac{\text{mas}}{\text{year}} \rightarrow 50$ mas lens-source separation

Simulated Predictions for the Number of Detections

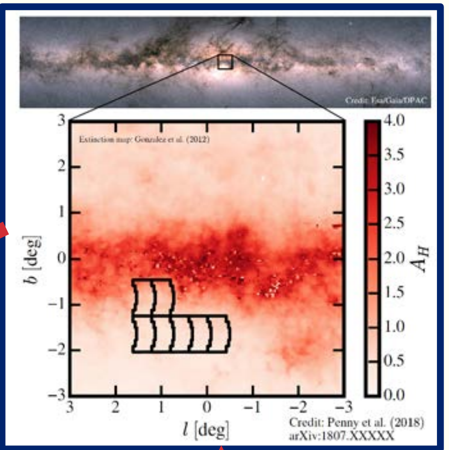


Draw source, lens,
Generate images

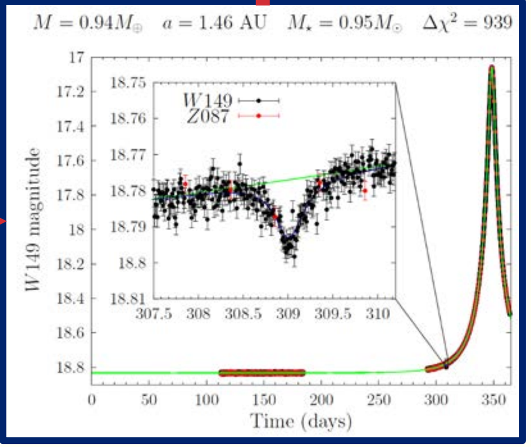


Normalize to
event rates

Number of
detections



Count detections



Generate light curves,
Do photometry

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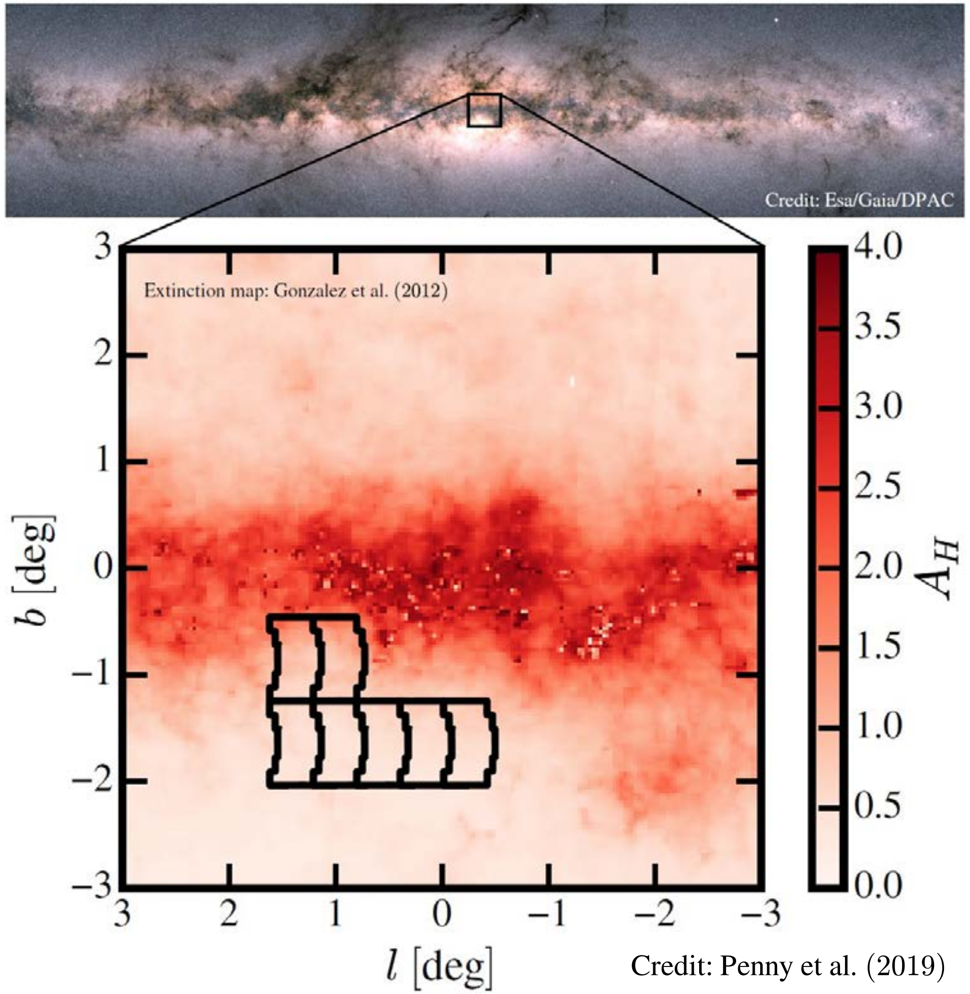
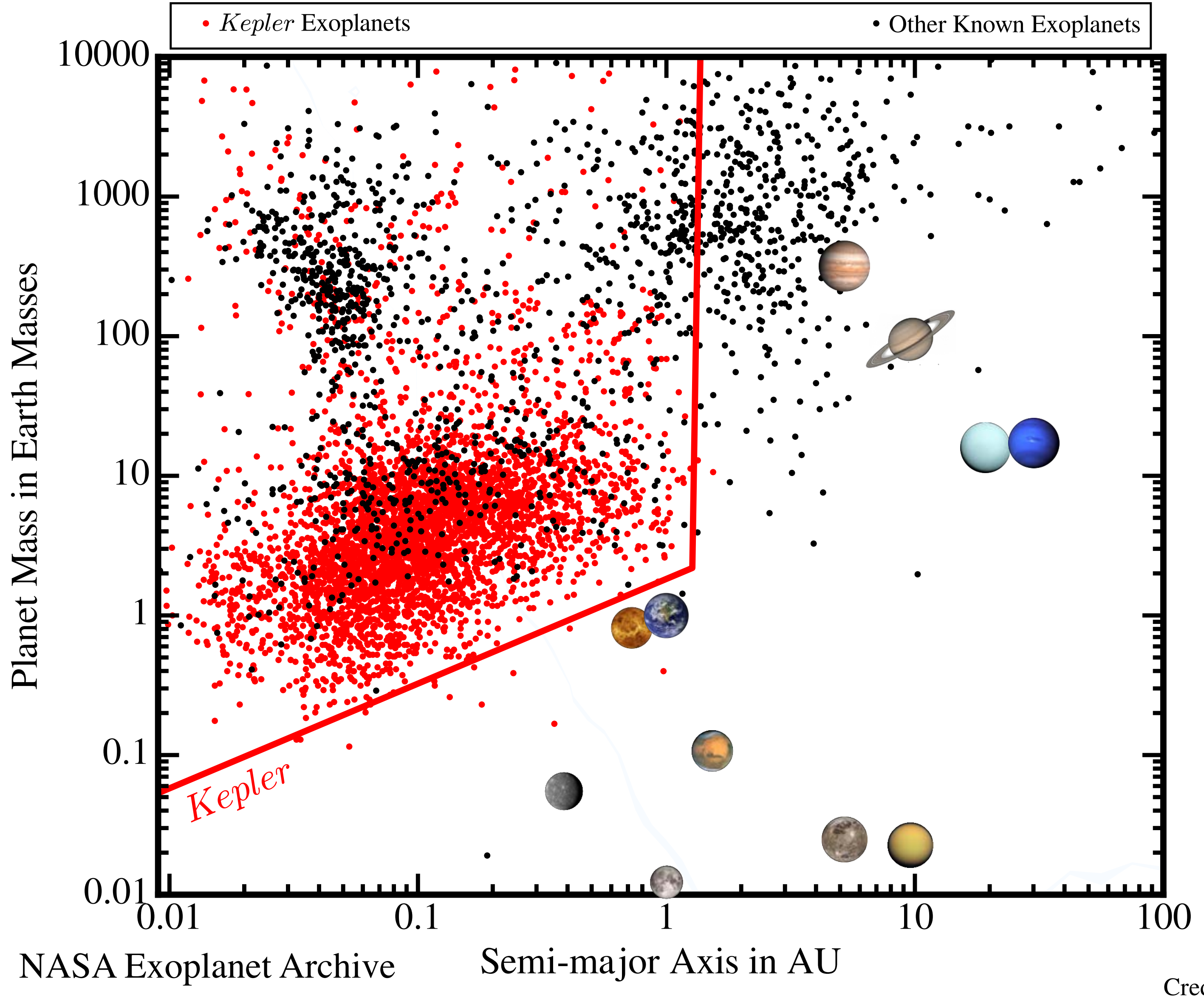
Penny et al. 2013, 2019

CURRENT *Roman* survey parameters

- 0.28 deg^2 FOV, 7 fields → $\sim 2\ \text{deg}^2$ total
  - New slew times → 10 fields
- Six 72-day seasons clustered at start/end
  - $4.5-$ year baseline
- 15 min cadence in wide infrared bandpass
  - ≤12 hr cadence in bluer bandpass
- $2{\times}10^8$ stars, >30,000 microlensing events





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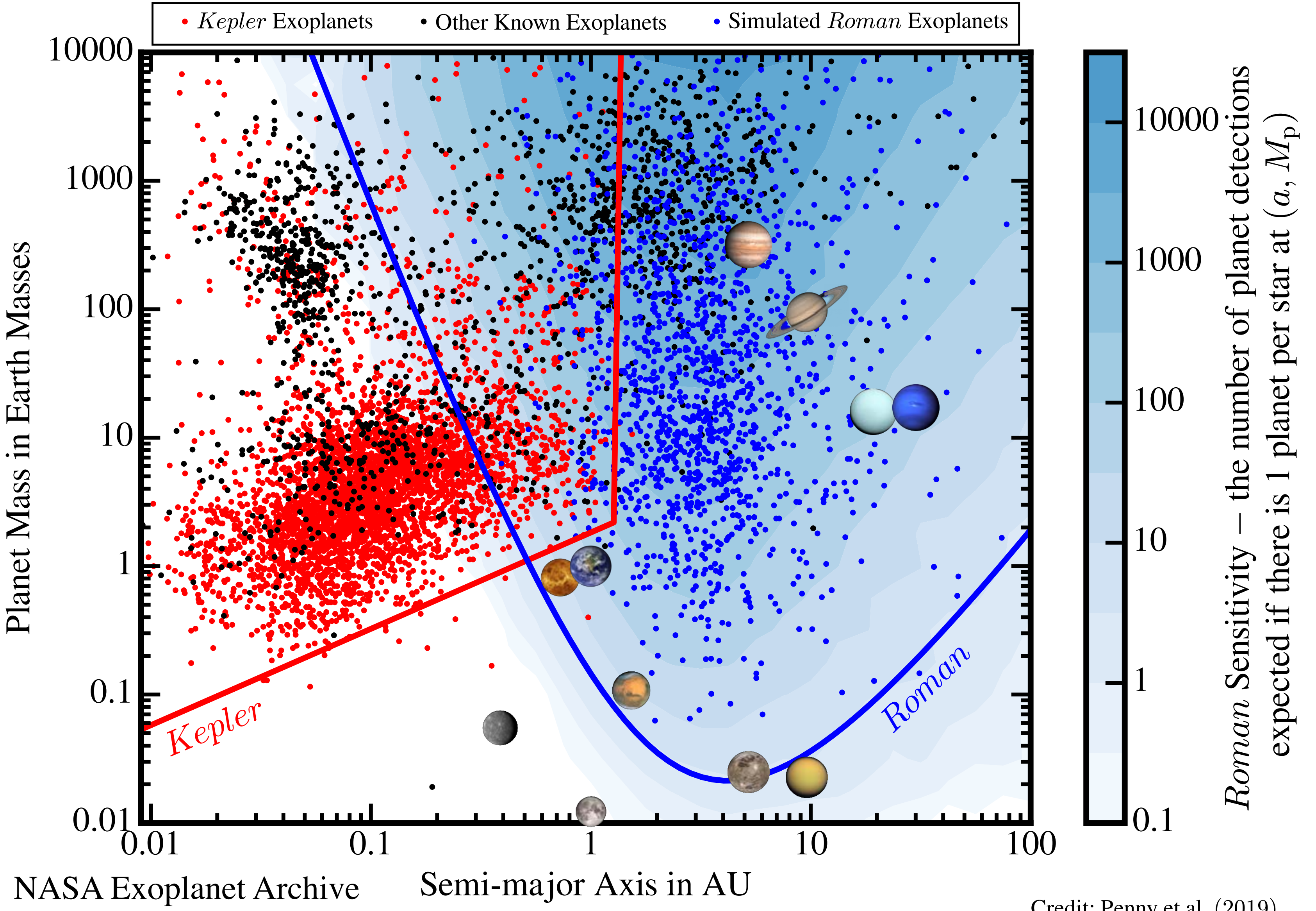
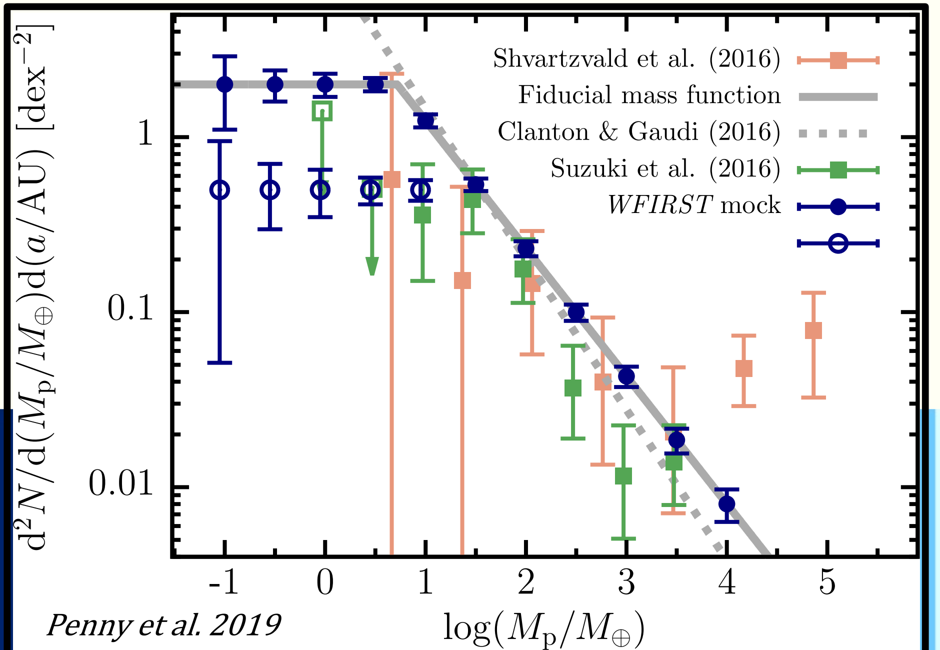


Credit: Penny et al. (2019)

Fiducial mass function adapted from Cassan et al. 2012

$$\frac{d^2N}{d\log M_p\, d\log a} = \begin{cases} \dfrac{0.24}{\mathrm{dex}^2}\left(\dfrac{m_p}{95 M_\oplus}\right)^{-0.74} & \text{for} \quad M_p > 5.2\, M_\oplus \\ \dfrac{2}{\mathrm{dex}^2} & \text{for} \quad M_p < 5.2\, M_\oplus \end{cases}$$



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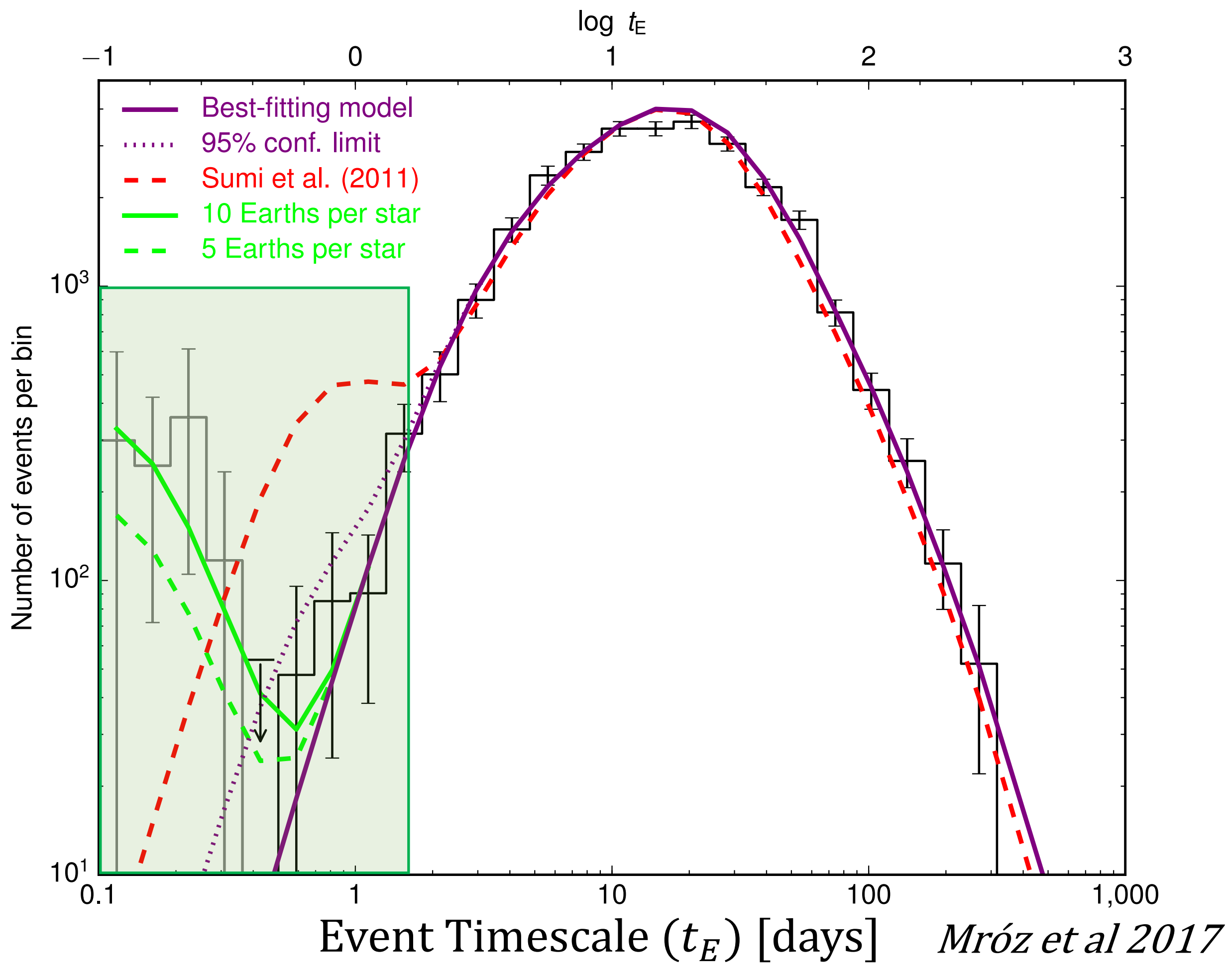
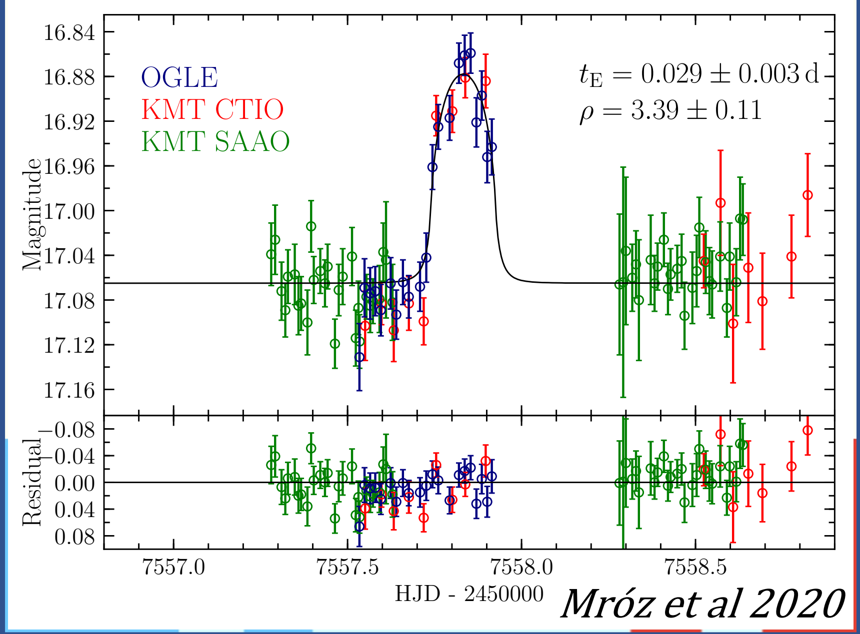
Evidence for free-floating planets



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



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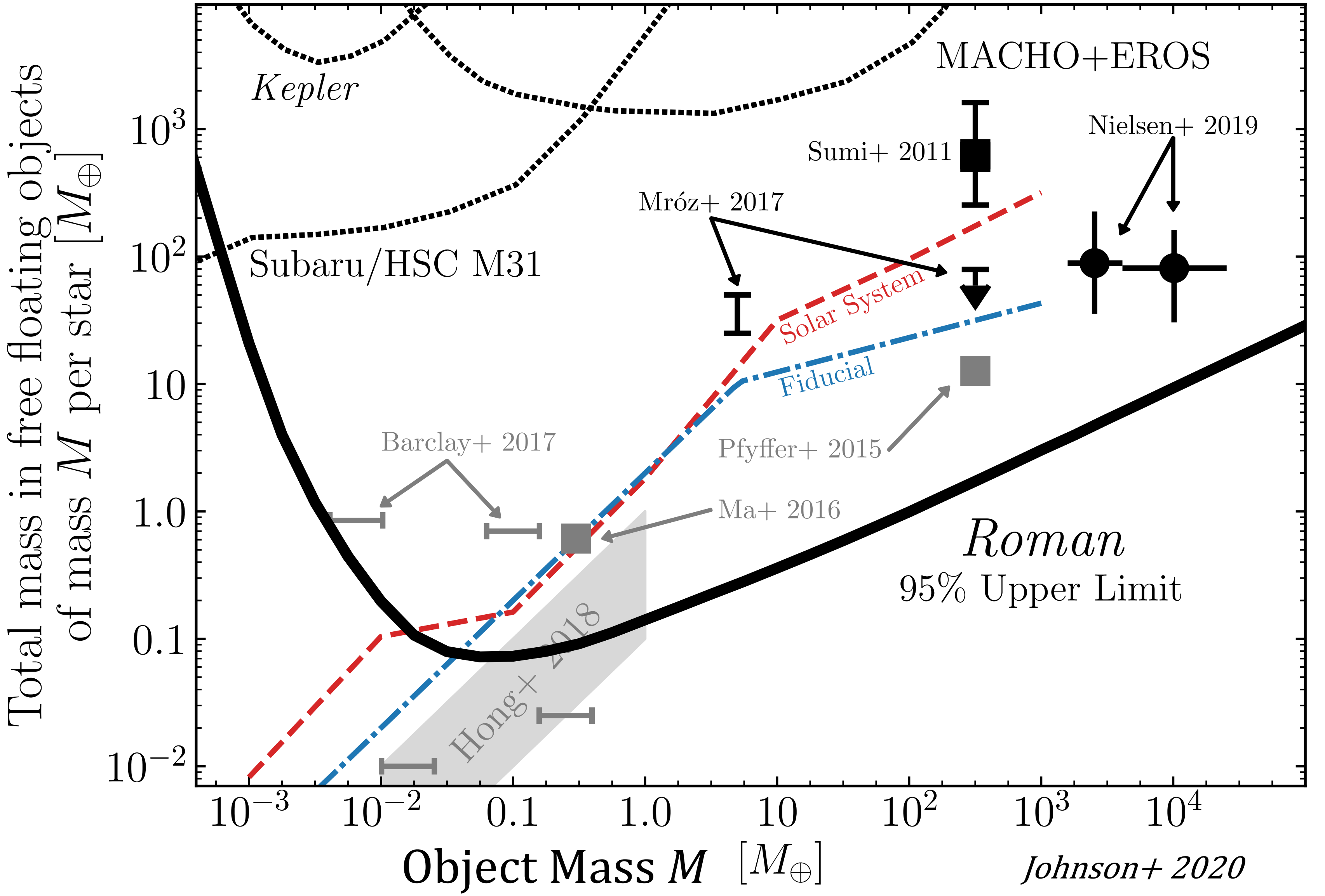
What can *Roman* teach us about free-floating planets?

- *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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HZ and microlensing

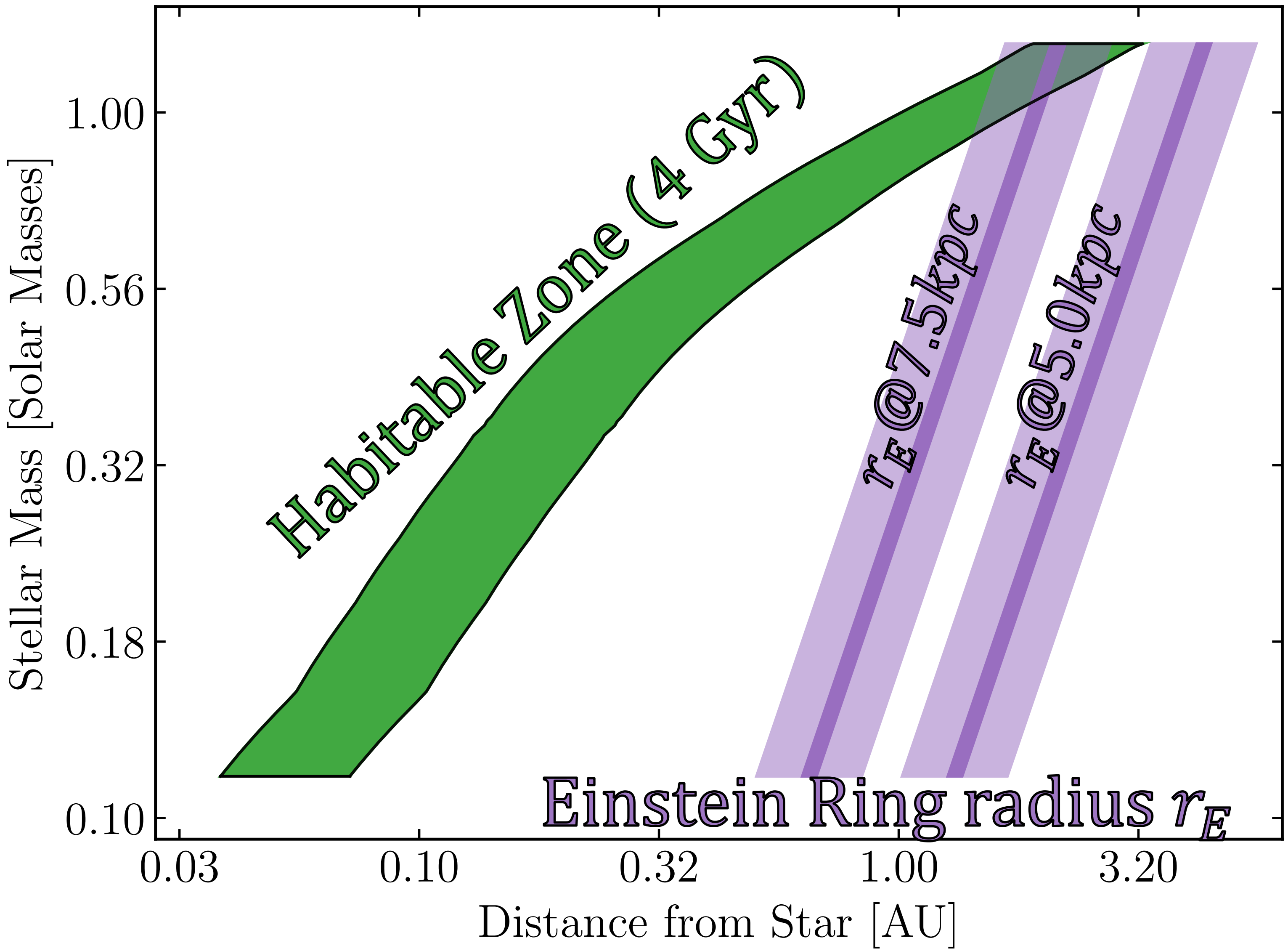
Habitable Zone (Kopparapu+ 2013)

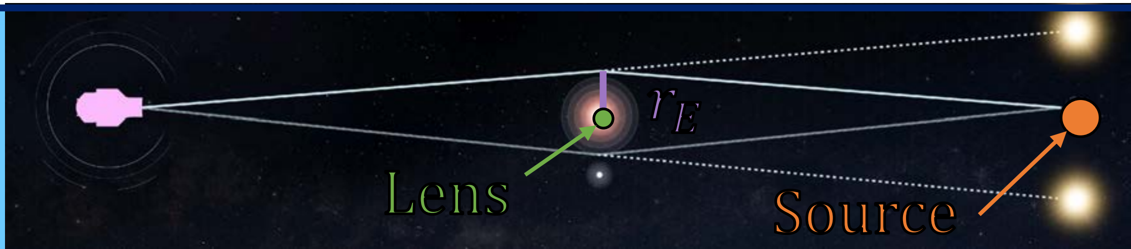
- Function of host mass, age, etc.

Einstein Ring Radius

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

$$r_E = \sqrt{\frac{4GM_L}{c^2}\frac{D_L}{D_S}(D_S - D_L)}$$





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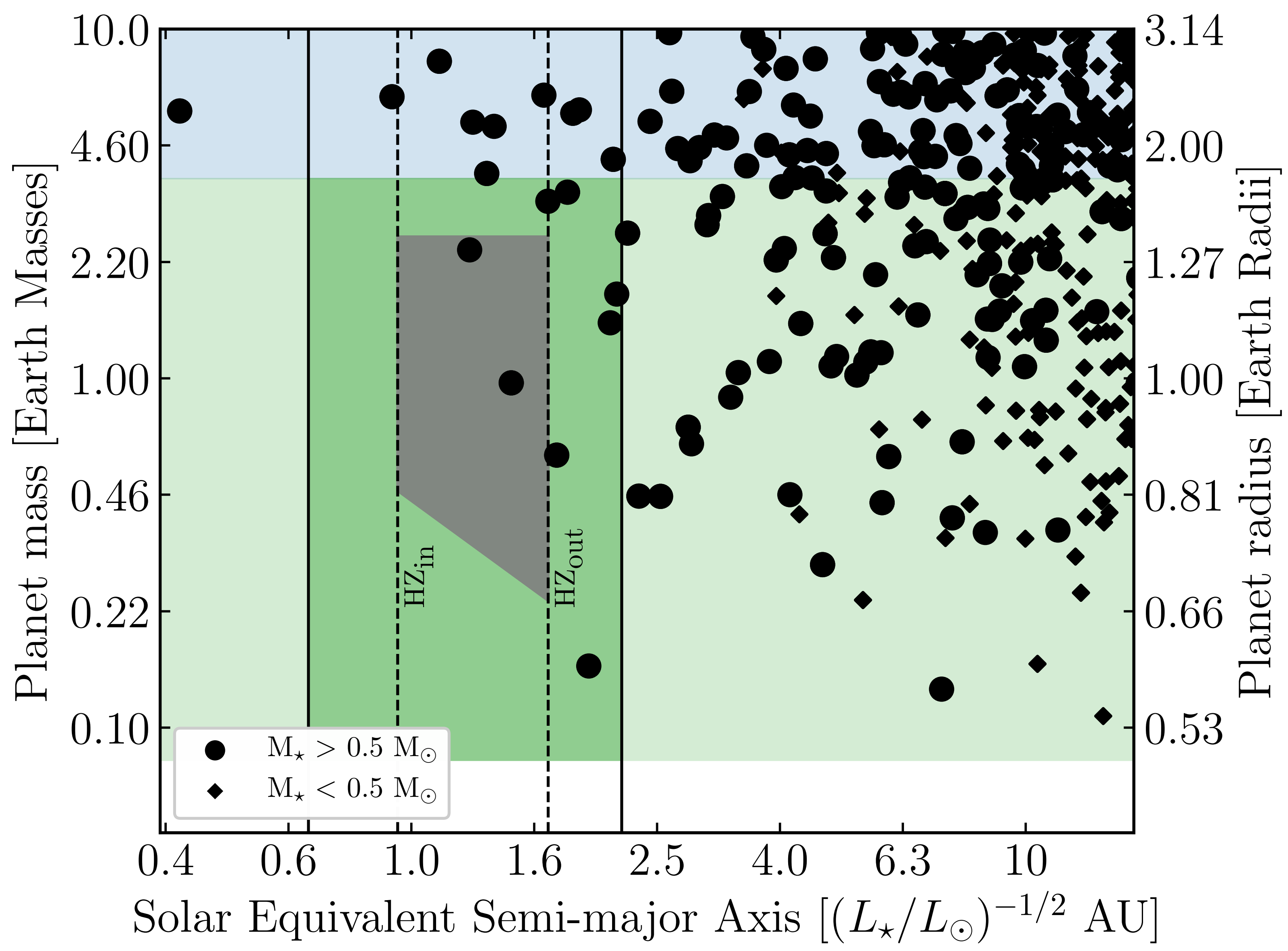

- *M-R relationship from Chen & Kipping (2016)*
- *See HabEx Final Report figure 3.3-9*

Johnson et al., in prep

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New Galactic Model Sampler – "Synthpop"

- Need updates to current Galactic Model for most accurate predictions
  - Most sensitive to Earth-analog systems with lenses near the Galactic Center
  - Known inconsistencies of current Besancon model in this region
    - E.g. bar angle, relative proper motion distribution
- Synthpop is a new, modular Galactic Model Sampling code to generate synthetic star catalogs given any model inputs
  - Default model is will be results from Koshimoto et al. 2021
  - New model required for most accurate results in Earth analog frequency and mass measurements
- Packaging and developing for public distribution release

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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

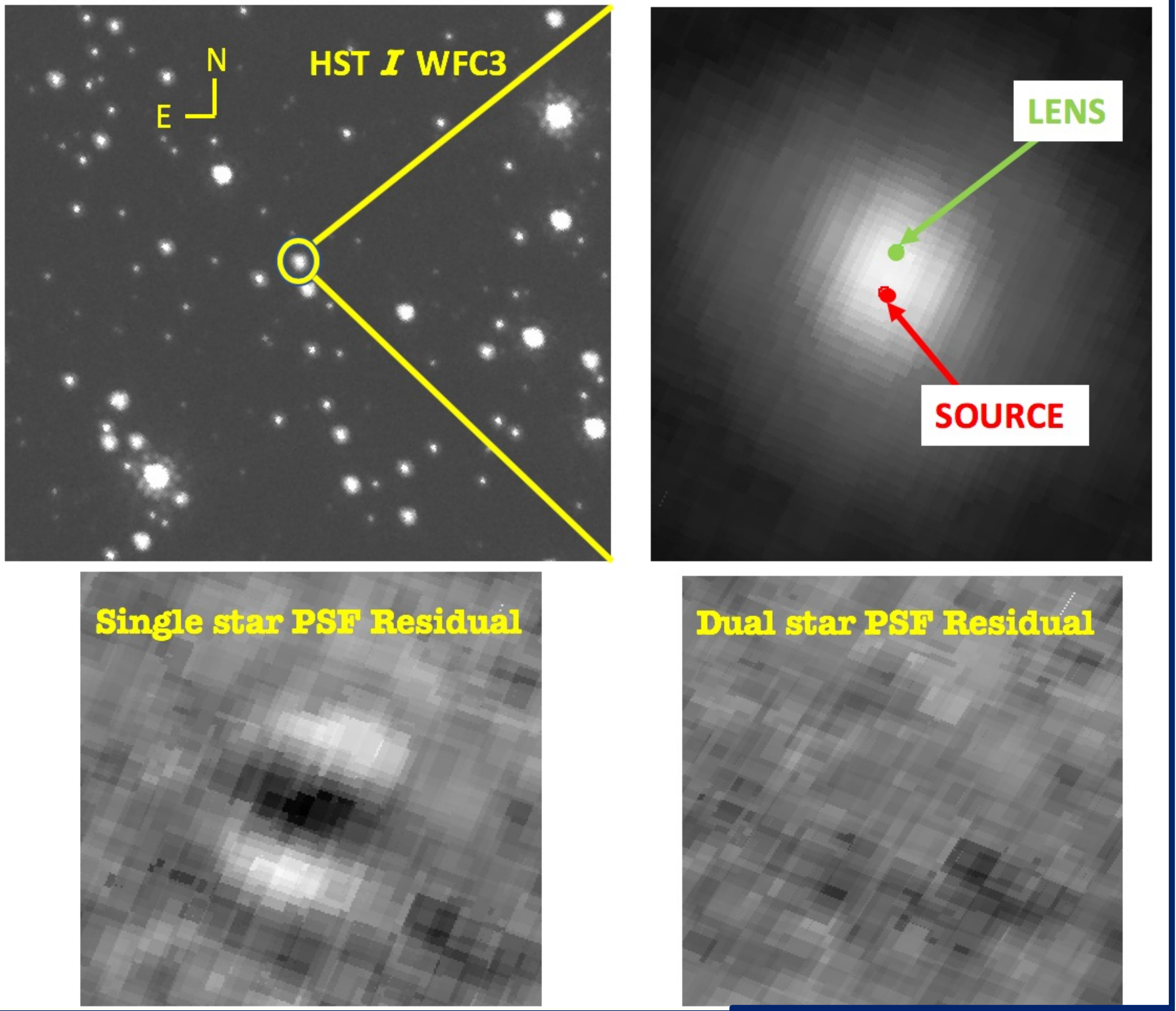
Model of the event

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

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

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



Bhattacharya et al., 2018

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Things To Do and Possible Changes

- Incorporate Koshimoto et al. 2021 Galactic Model
  - Needed for Earth-analog frequency, mass-measurement predictions
- More in-depth trade studies
  - E.g., cadence, number of fields, exposure time
  - Slew/settle times and filter wheel cycles could be major limits
- Study impacts of altering survey to improve science yield
  - E.g., visits to the Galactic Center while pointed in vicinity
  - Contemporaneous observation efforts (e.g., Euclid, PRIME)


Thank you!

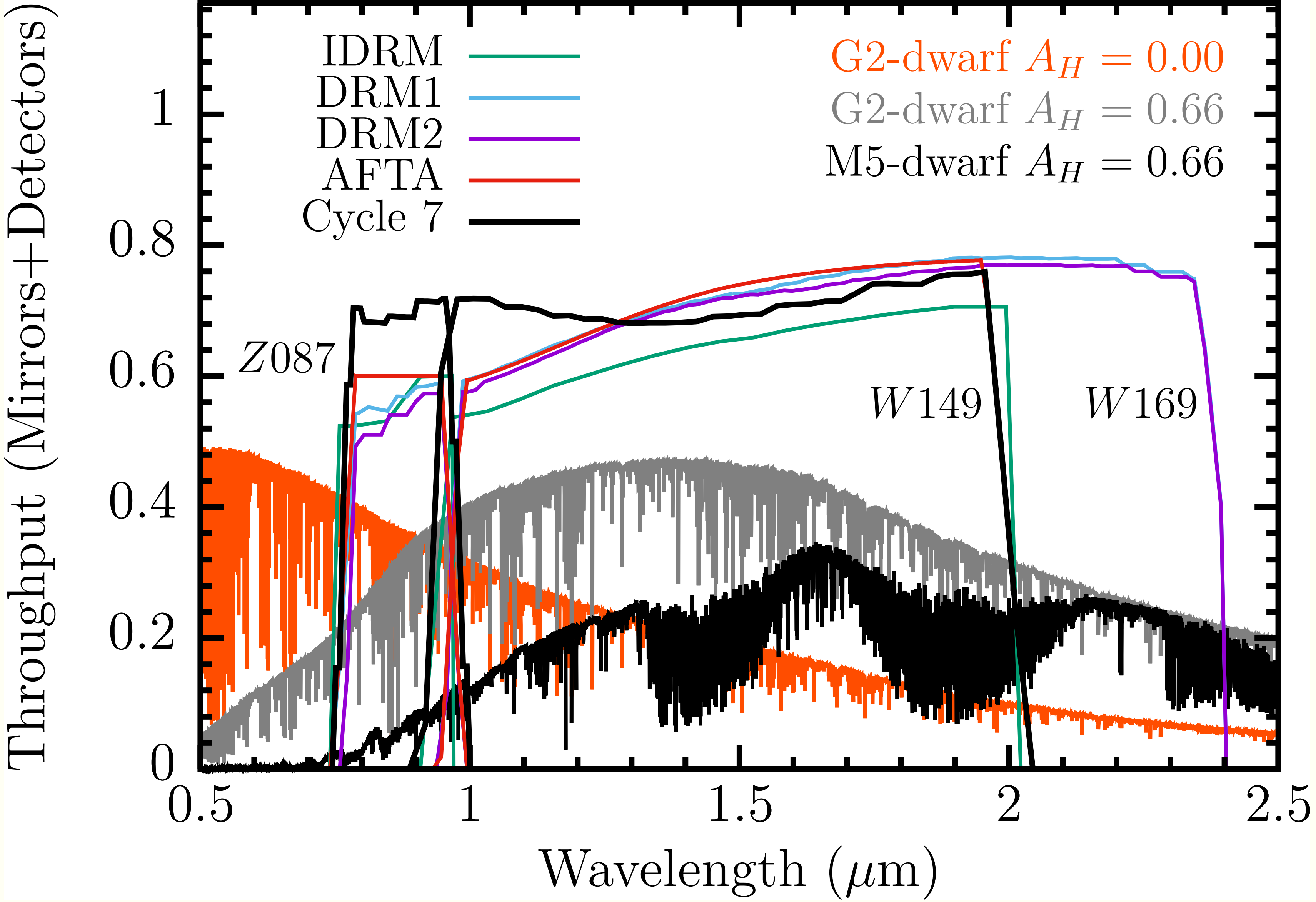
Scaling θ_E and t_E

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

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

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)**



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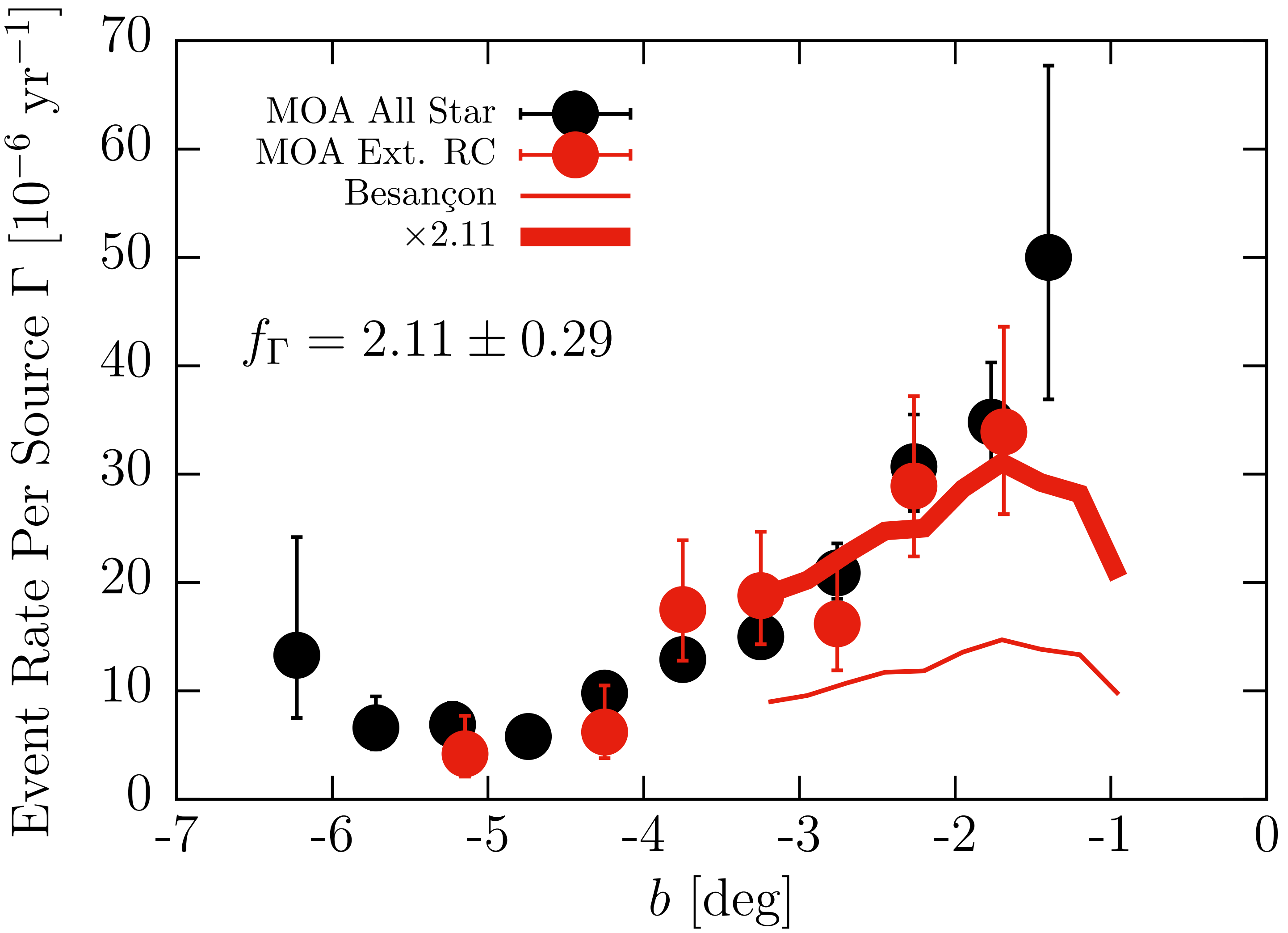
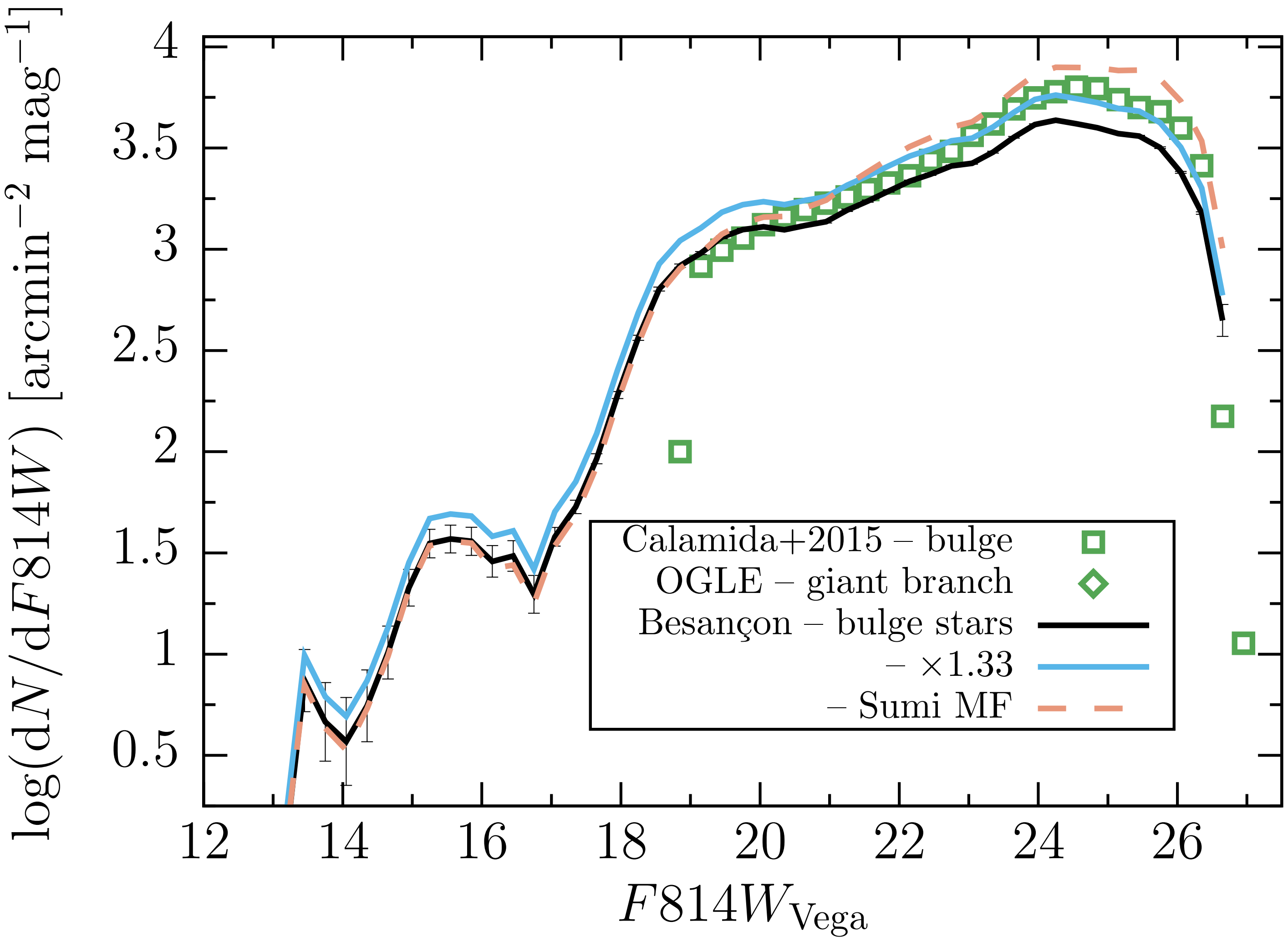
Event rate weighting

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

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


Event Rate Per Source Γ [10^−6 yr^−1]
b [deg]
MOA All Star
MOA Ext. RC
Besançon
×2.11
$f_\Gamma = 2.11 \pm 0.29$
70
60
50
40
30
20
10
0
-7
-6
-5
-4
-3
-2
-1
0



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