The *WFIRST* microlensing survey: Predictions for the yield of free-floating planets

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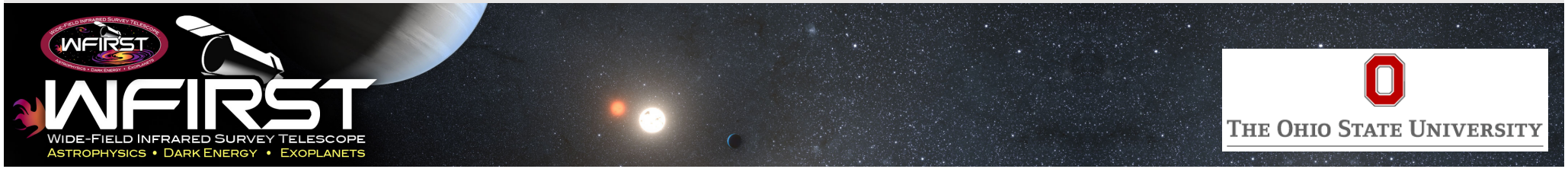
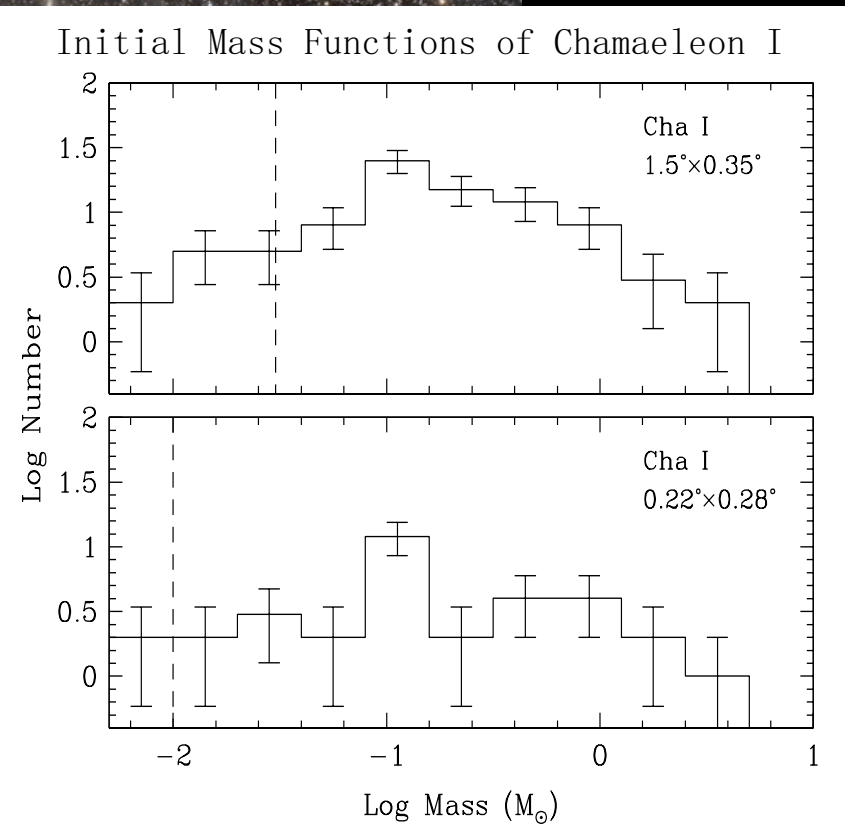
Matthew Penny, B. Scott Gaudi, *WFIRST* microSIT

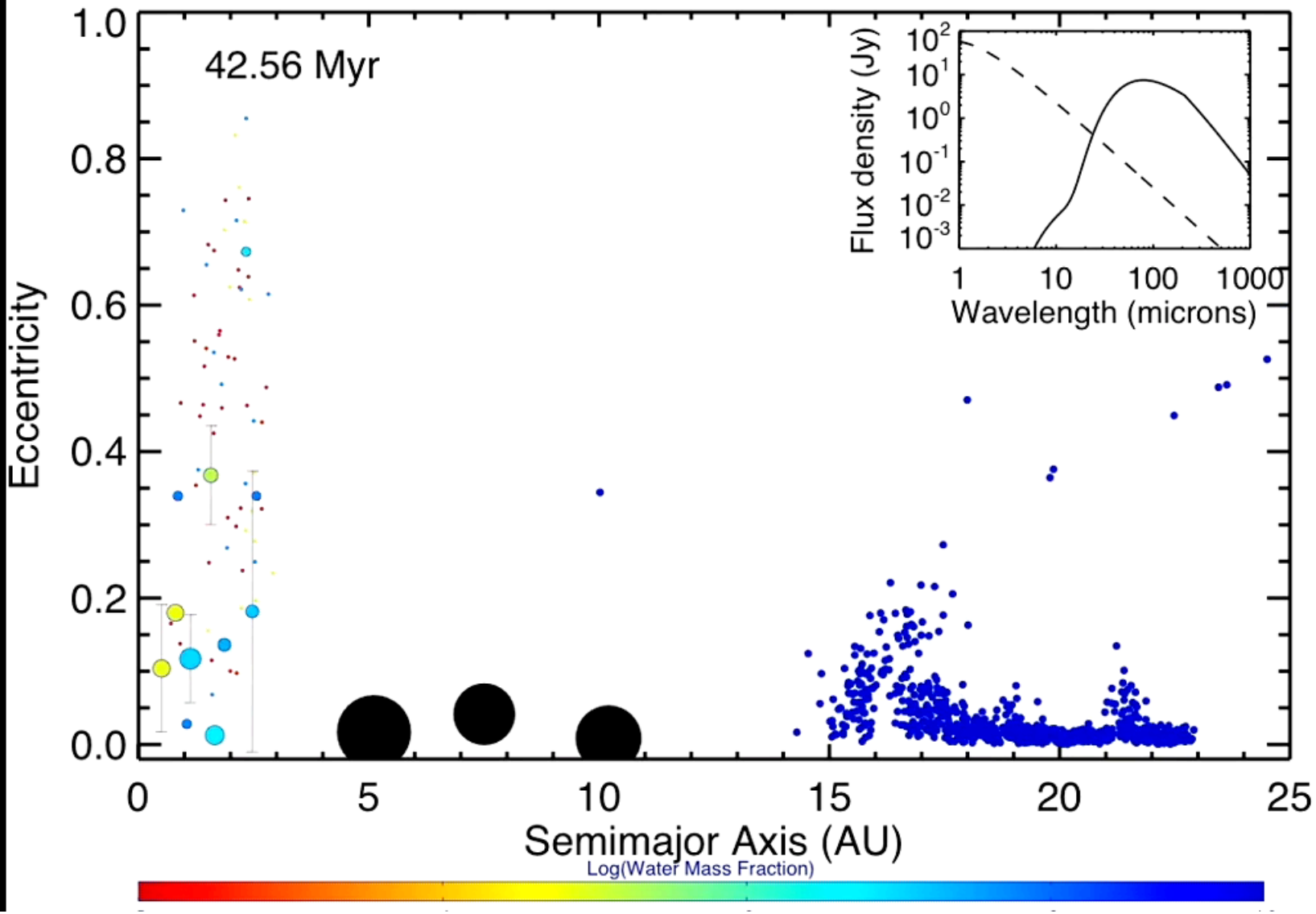
Science in Our Own Backyard with *WFIRST*

2019-06-18



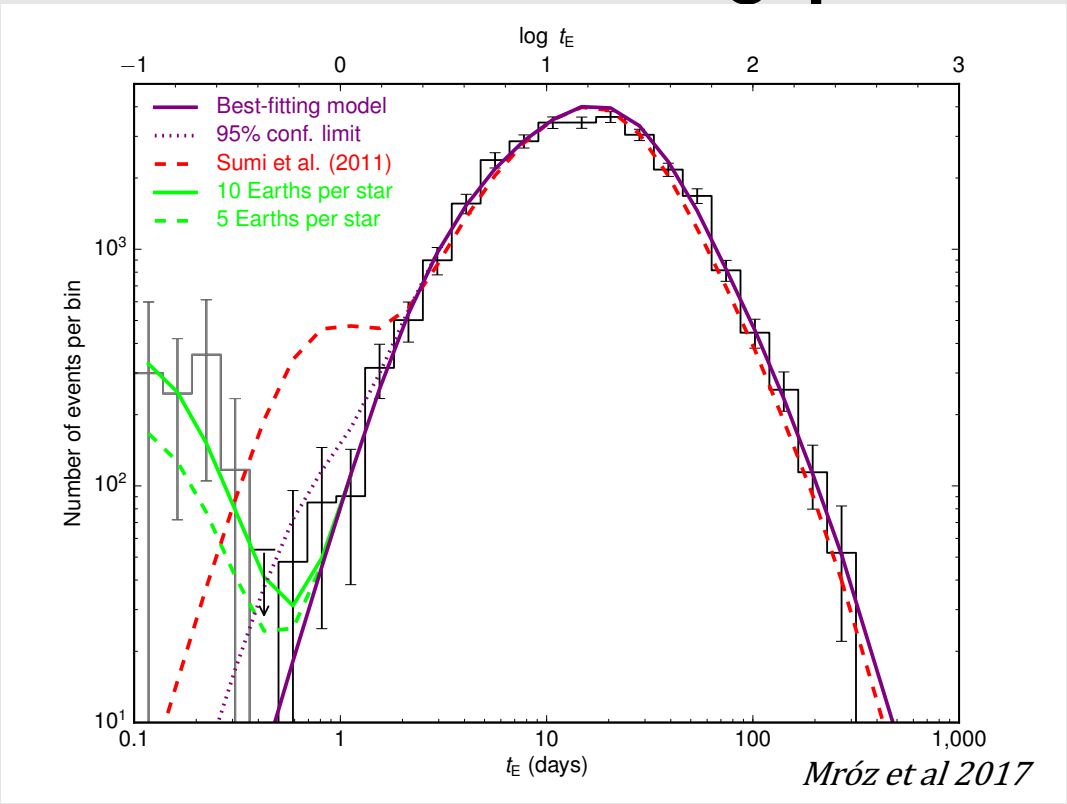


Luhman et al 2007



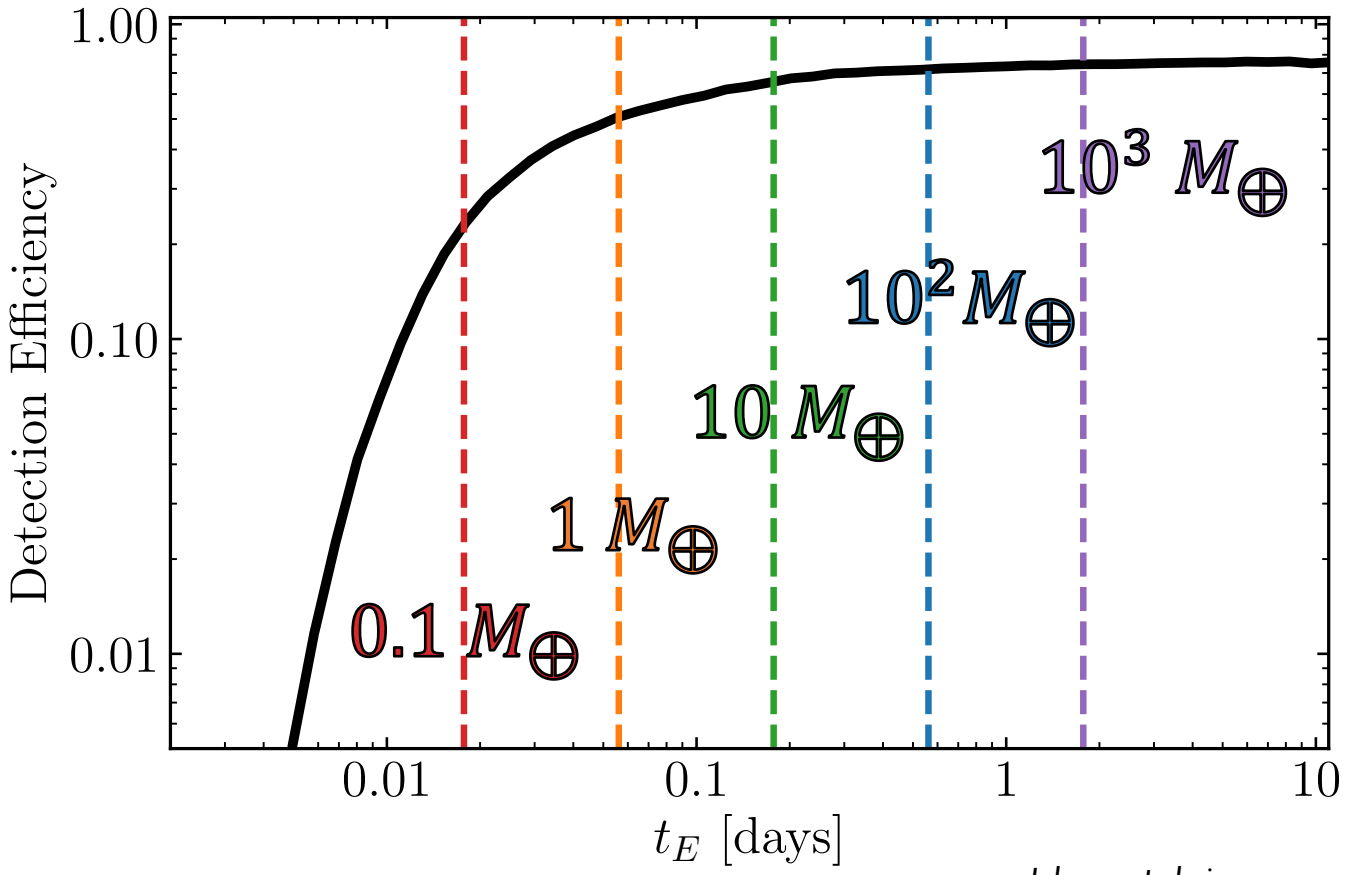
Video from Raymond et al. 2012

Evidence for free floating planets



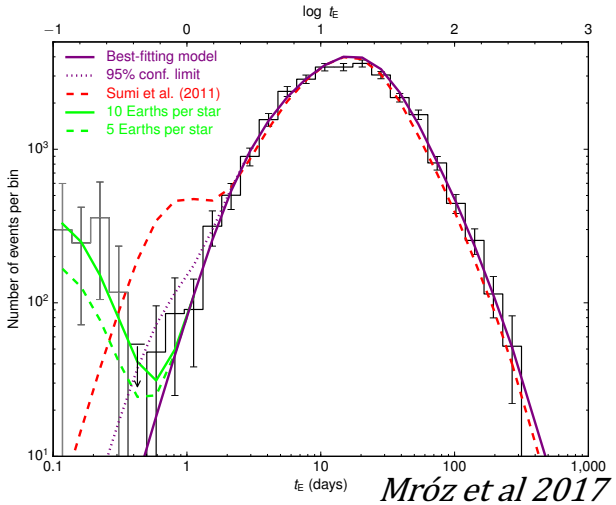
Mróz et al 2017

$$t_E \propto M^{1/2}$$

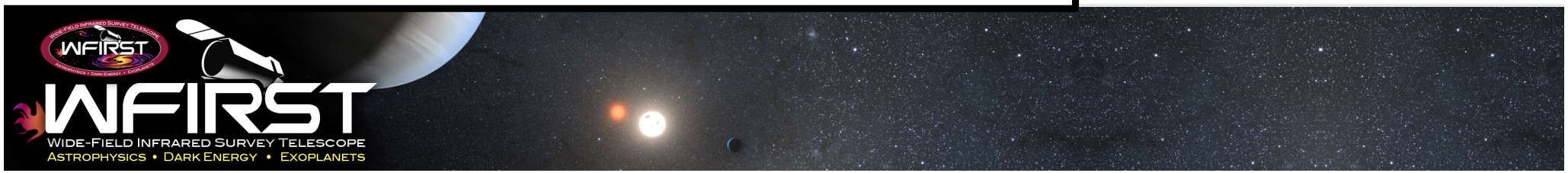


Johnson et al., in prep

WFIRST with 15-minute cadence for a 72-day season

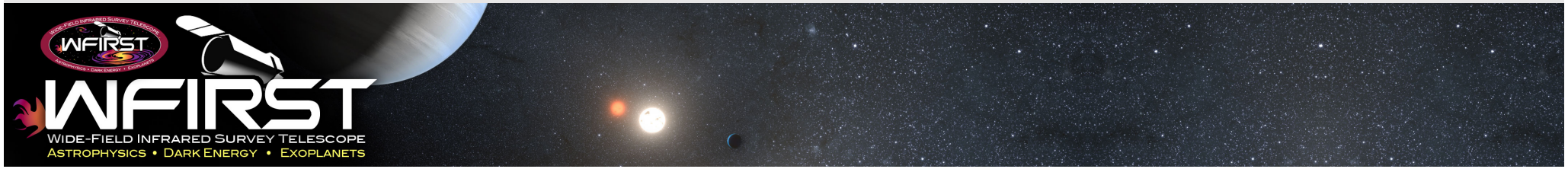


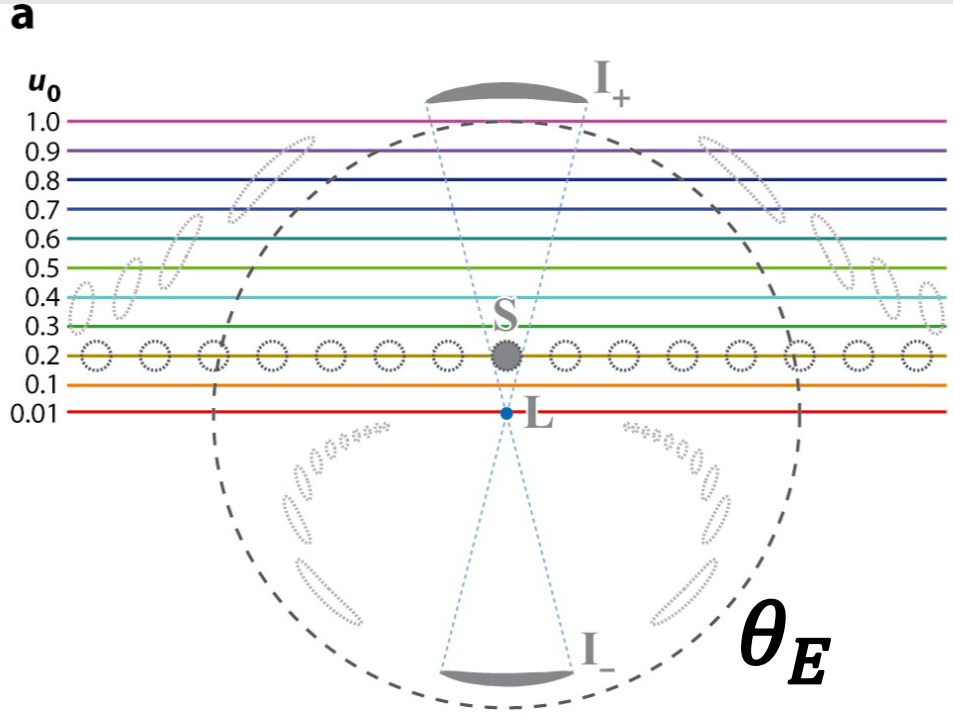
Mróz et al 2017

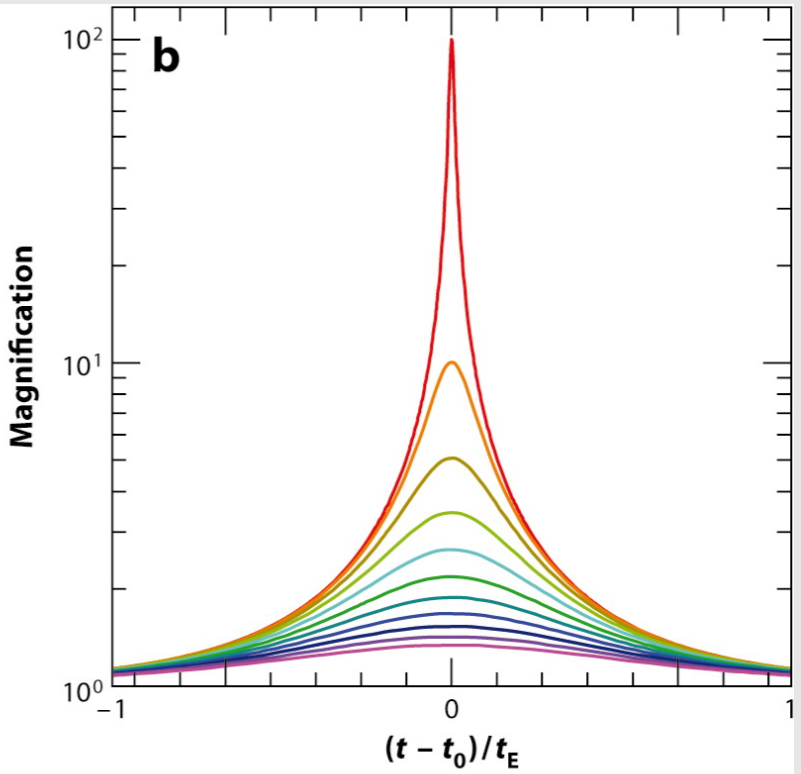


Going beyond event timescales

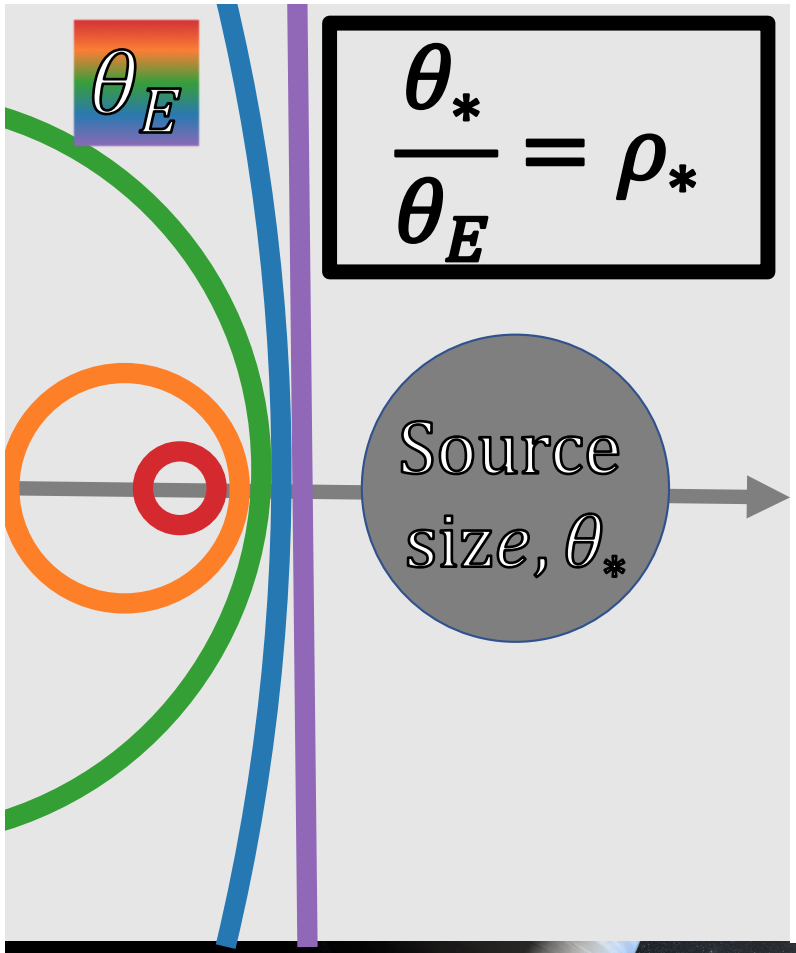
$$t_E = \frac{\theta_E}{\mu_{rel}}, \qquad \theta_E^2 = \kappa M \pi_{rel}, \qquad \kappa = Constant$$

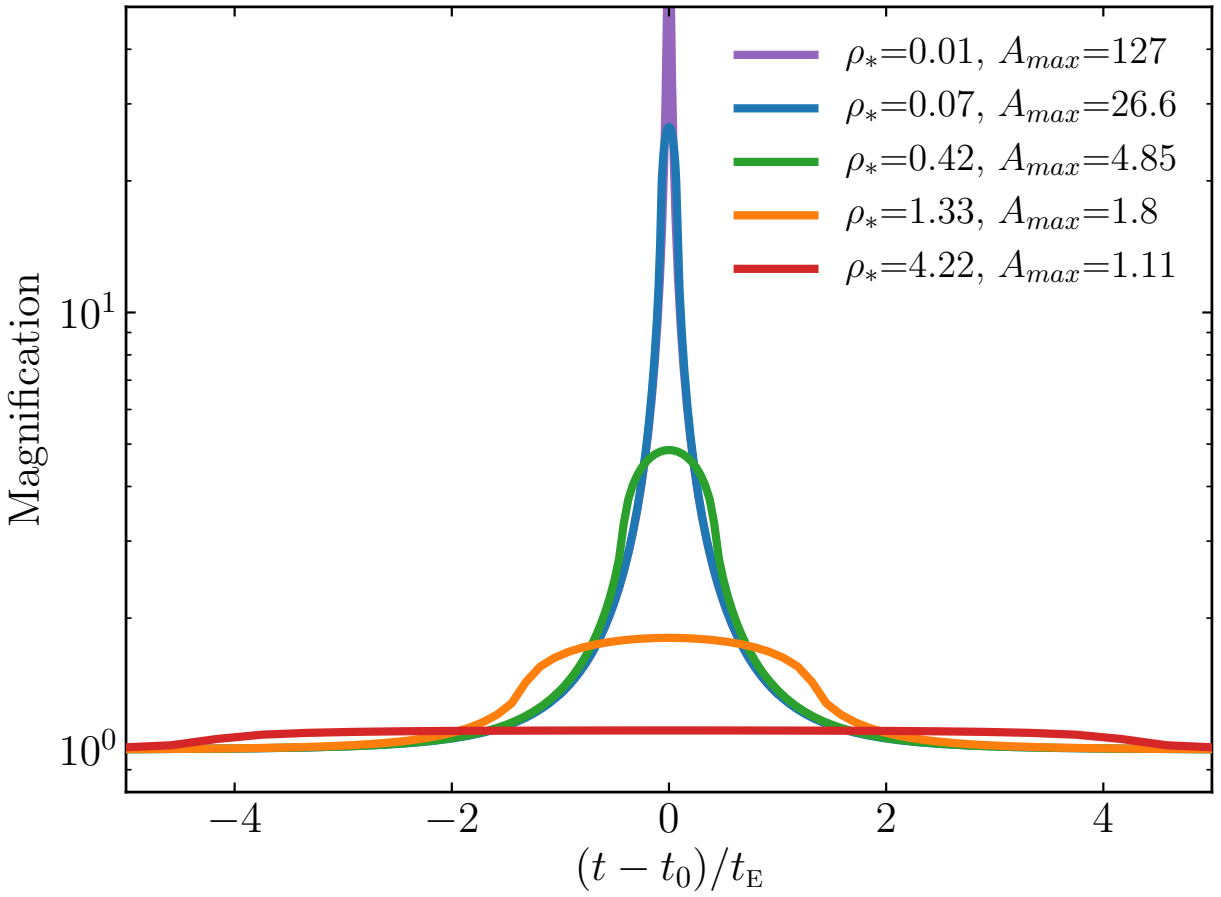


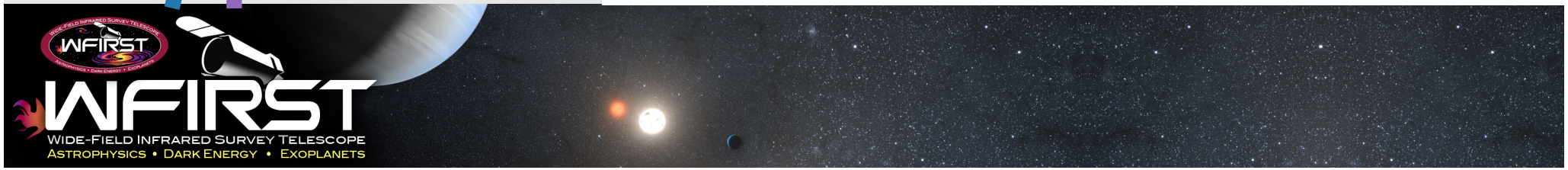




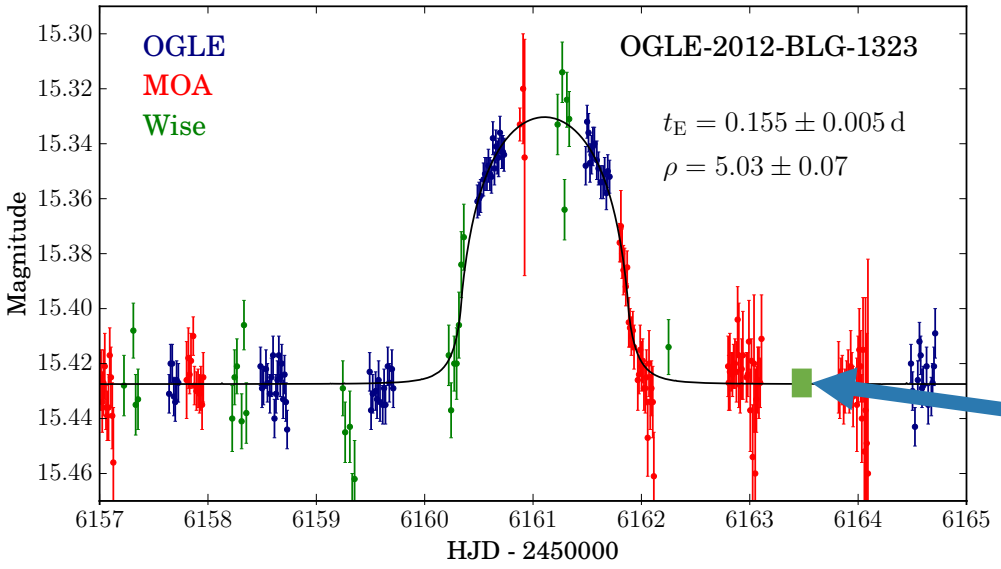
Gaudi BS. 2012.
Annu. Rev. Astron. Astrophys. 50:411–53


θ_E
$\frac{\theta_*}{\theta_E} = \rho_*$
Source size, θ_*

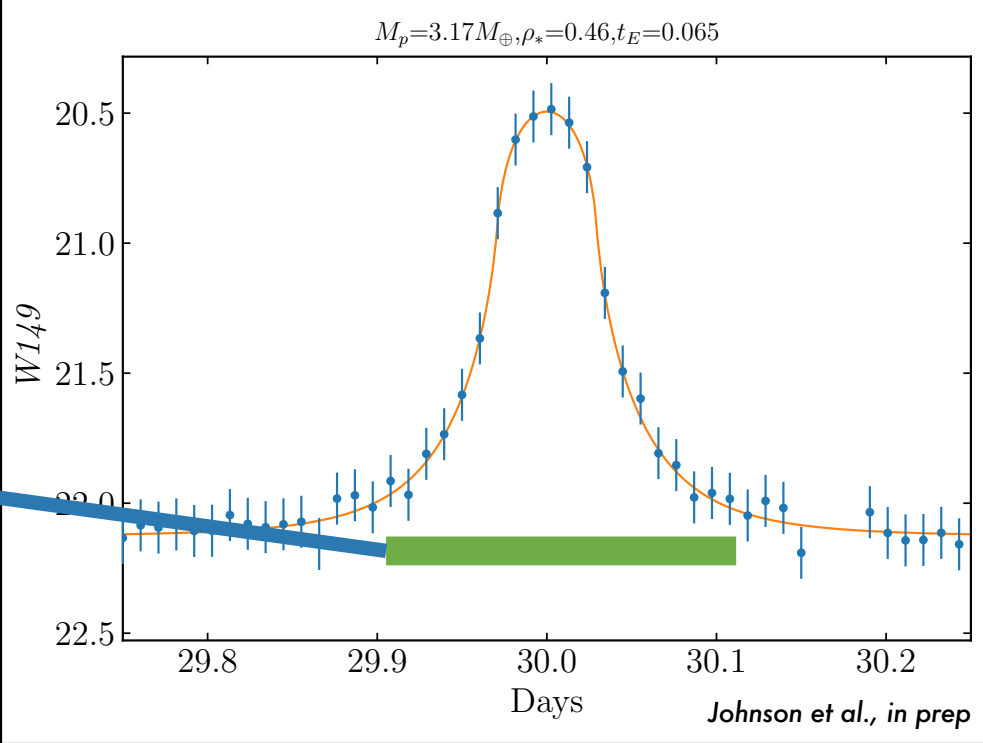

ρ_*=0.01, A_{max}=127
ρ_*=0.07, A_{max}=26.6
ρ_*=0.42, A_{max}=4.85
ρ_*=1.33, A_{max}=1.8
ρ_*=4.22, A_{max}=1.11
Magnification
10^1
10^0
−4
−2
0
2
4
$(t - t_0)/t_E$


WFIRST
WIDE-FIELD INFRARED SURVEY TELESCOPE
ASTROPHYSICS • DARK ENERGY • EXOPLANETS

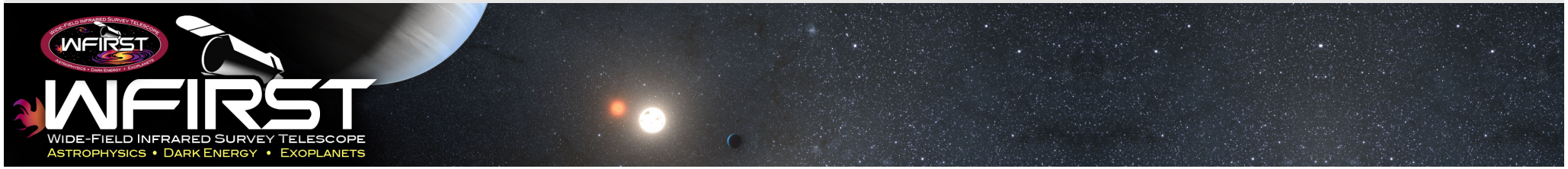
Mróz et al. 2018

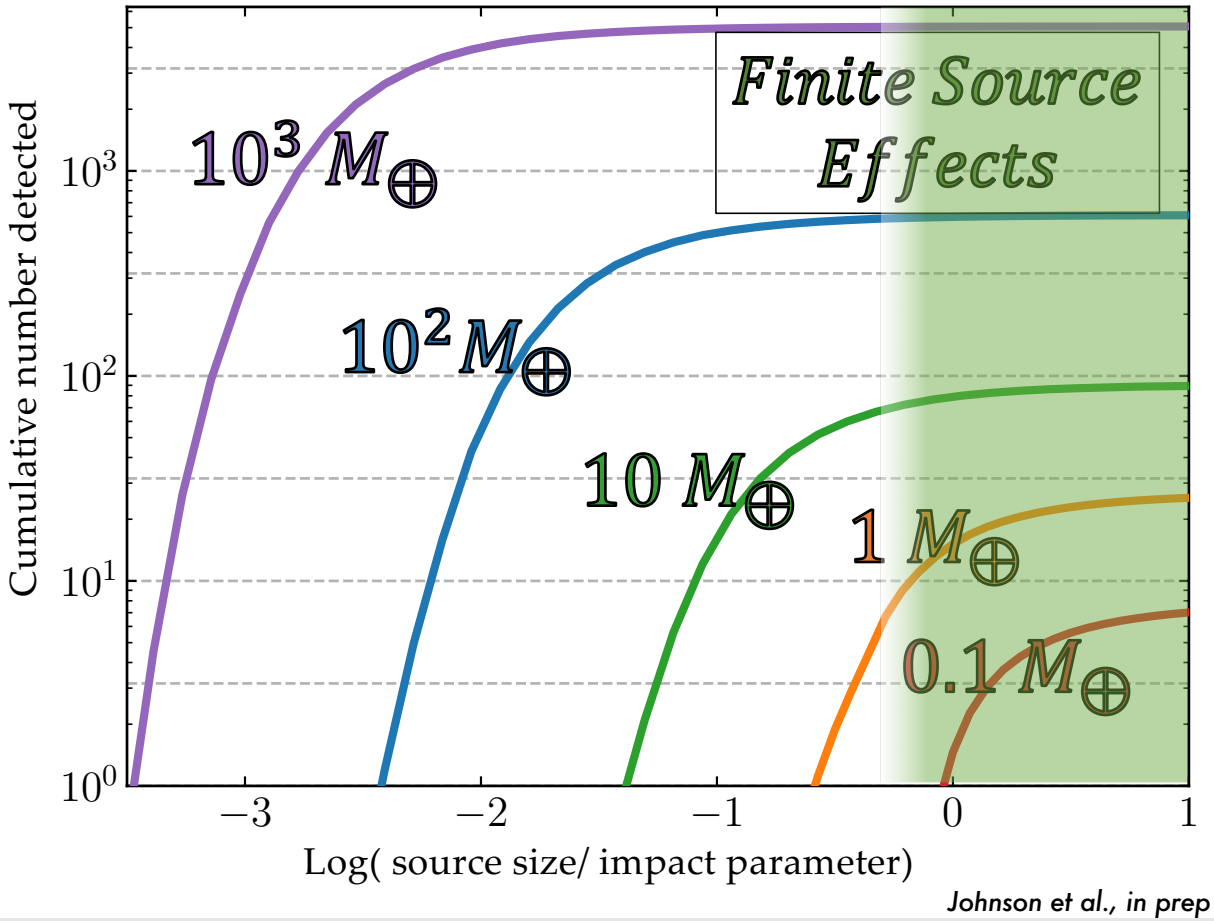


Simulated *WFIRST* event



Johnson et al., in prep





Johnson et al., in prep

Total N_{det}	*% with FSE*
5000	0.2
600	1.7
90	11.2
25	42.9
8	80.8

If 1 per star in MW

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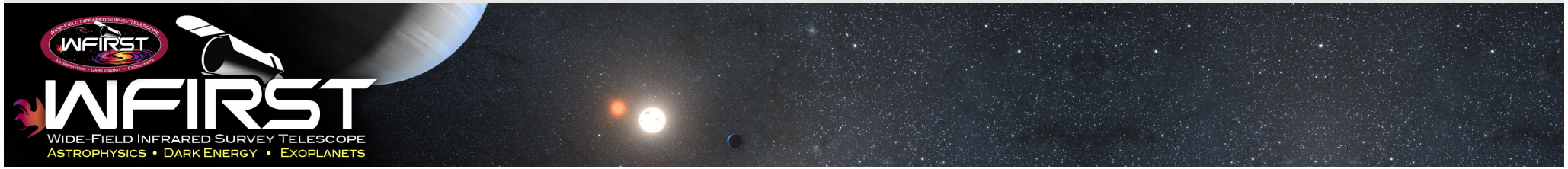
Going beyond event timescales:

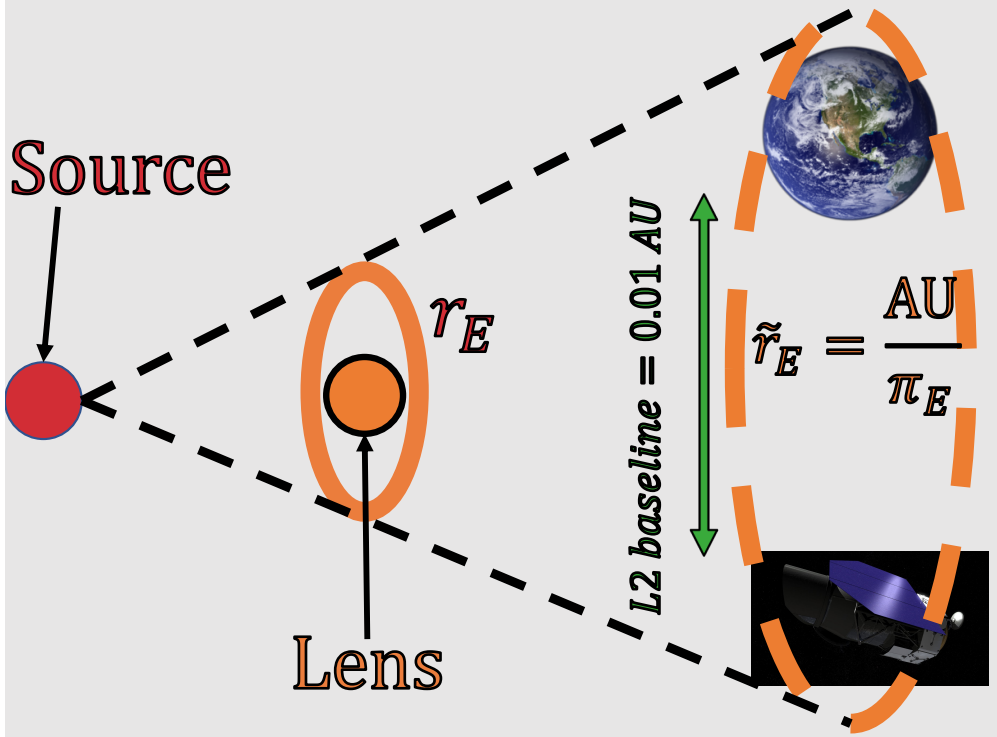
$$t_E = \frac{\theta_E}{\mu_{rel}}, \qquad \theta_E^2 = \kappa M \pi_{rel}, \qquad \kappa = Constant$$

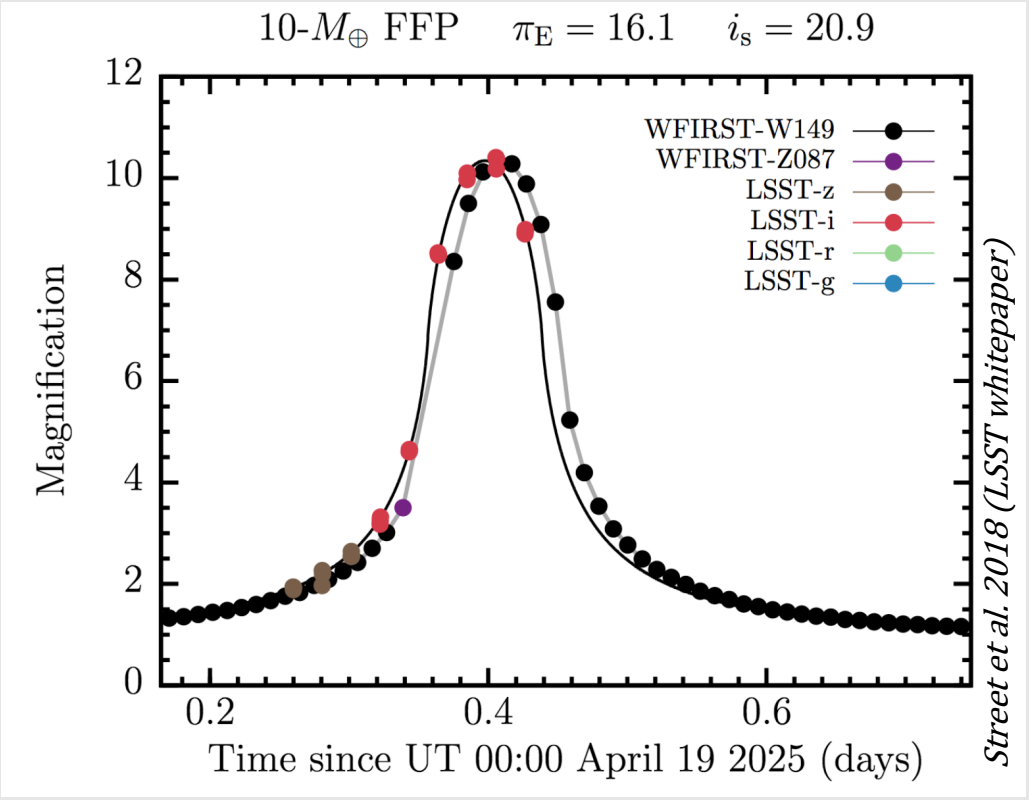
Going beyond finite source effects:

$$\pi_E = \frac{\pi_{rel}}{\theta_E}, \qquad M = \frac{\theta_E}{\kappa \pi_E}$$



Microlens Parallax Measurements





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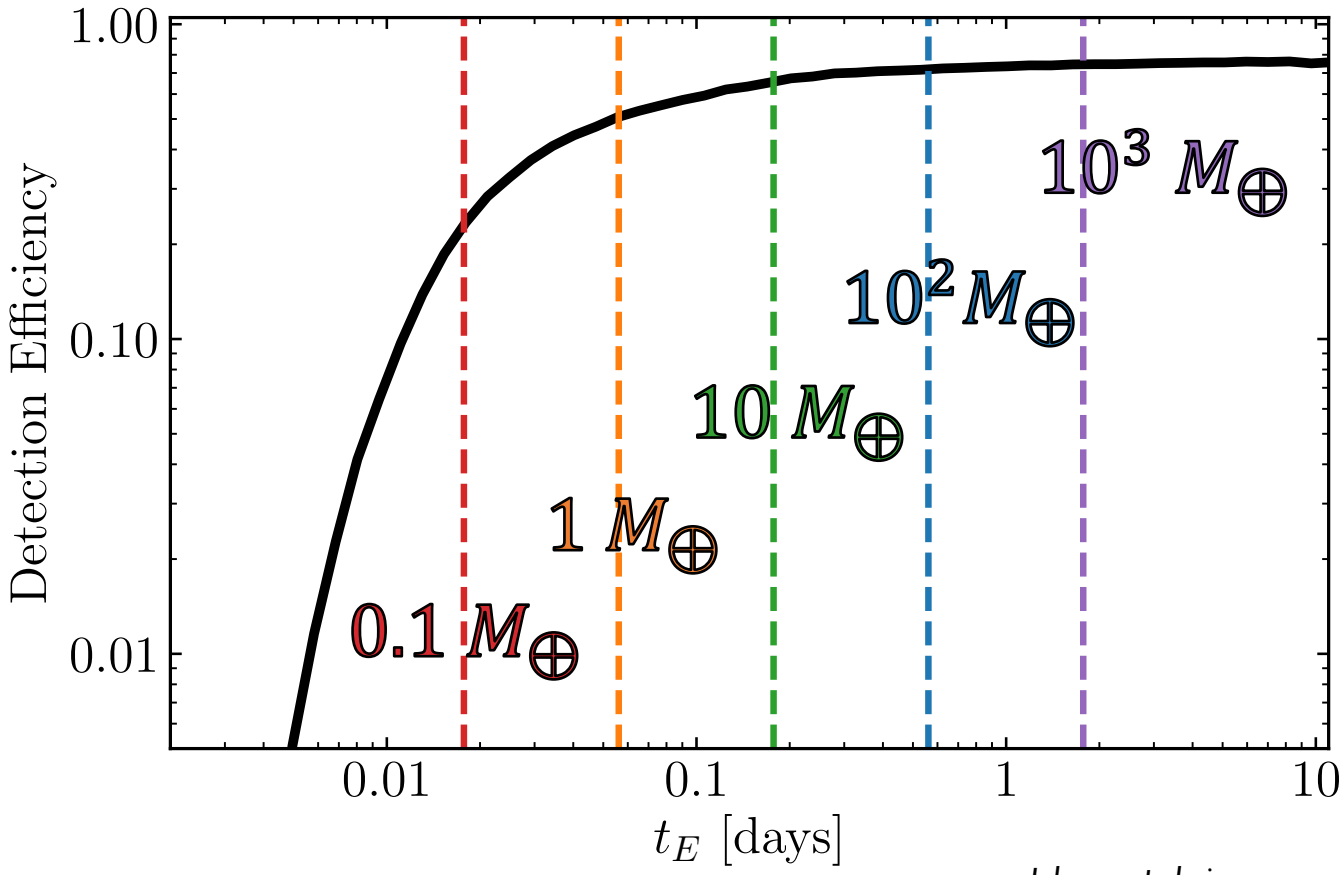
Conclusions

- *WFIRST* will measure short timescale distribution of lensing events
- Could constrain planet formation theories
  - High mass or low mass?
  - (Long or short timescale events)
- Potential for measuring masses with supporting observations

- *Thank you!*



Johnson et al., in prep

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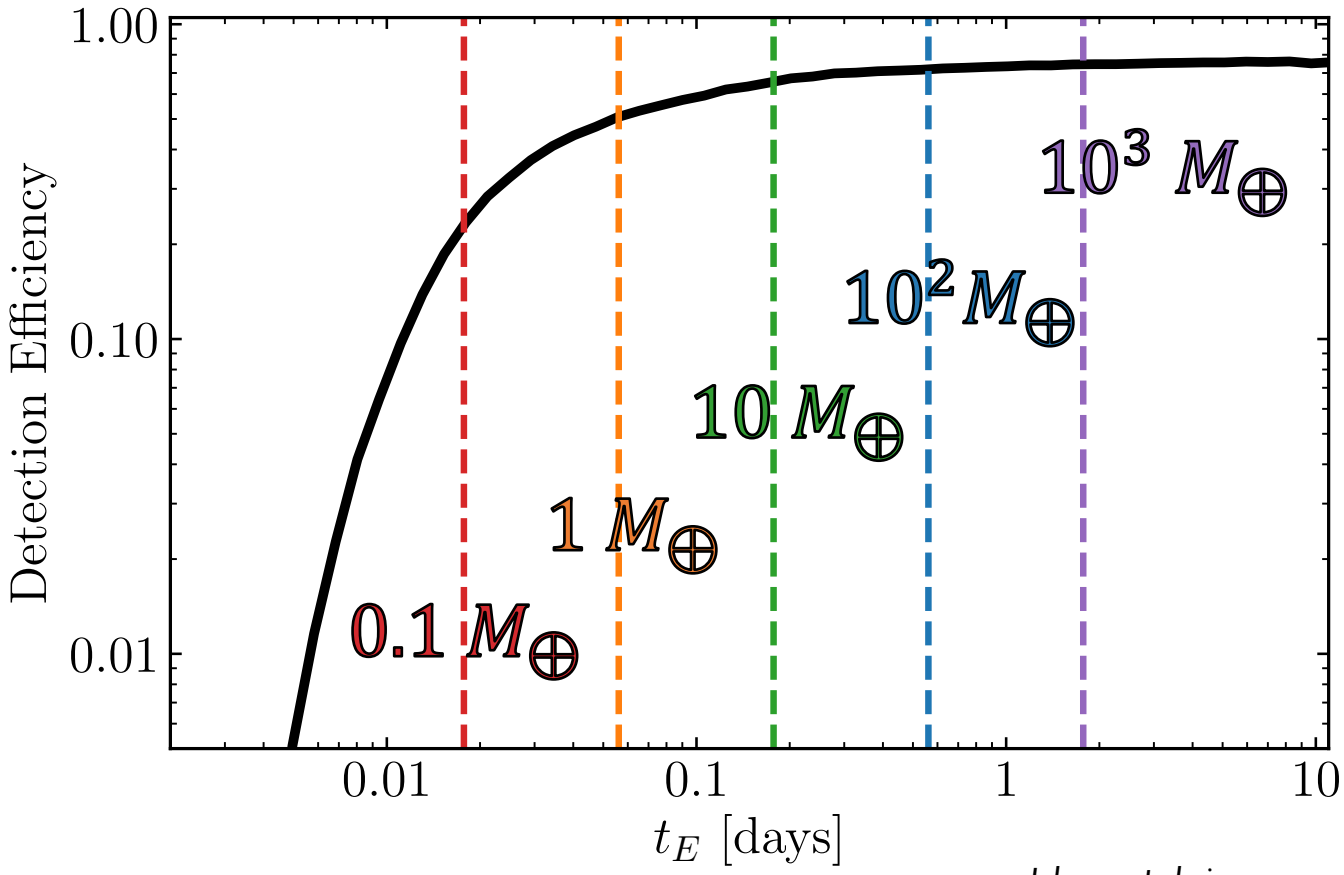

Johnson et al., in prep

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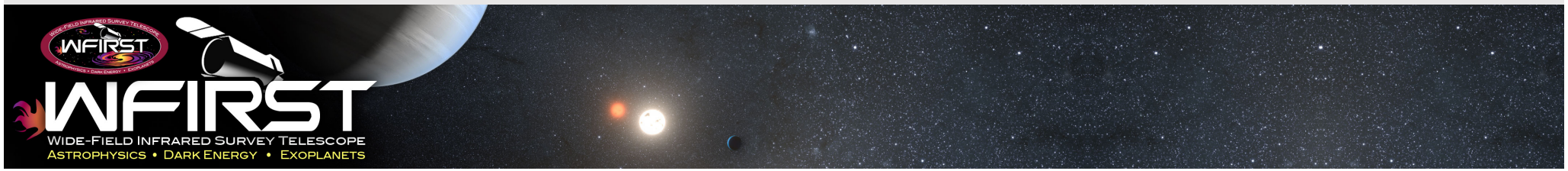
Event rate weighting

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

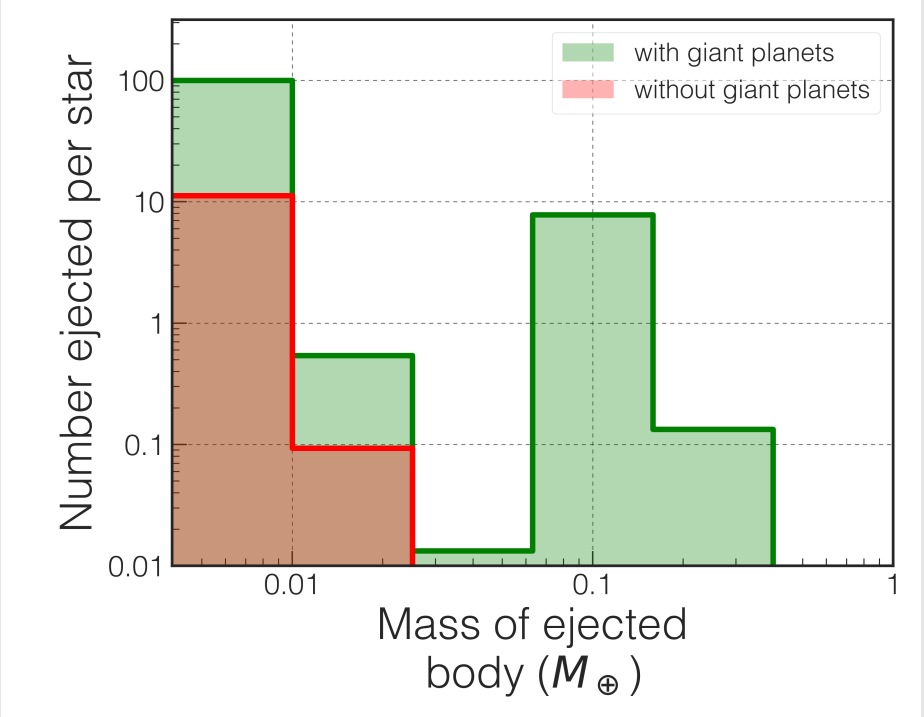
$$W = \sum_i 2\mu_{rel,i}\theta_{E,i}$$



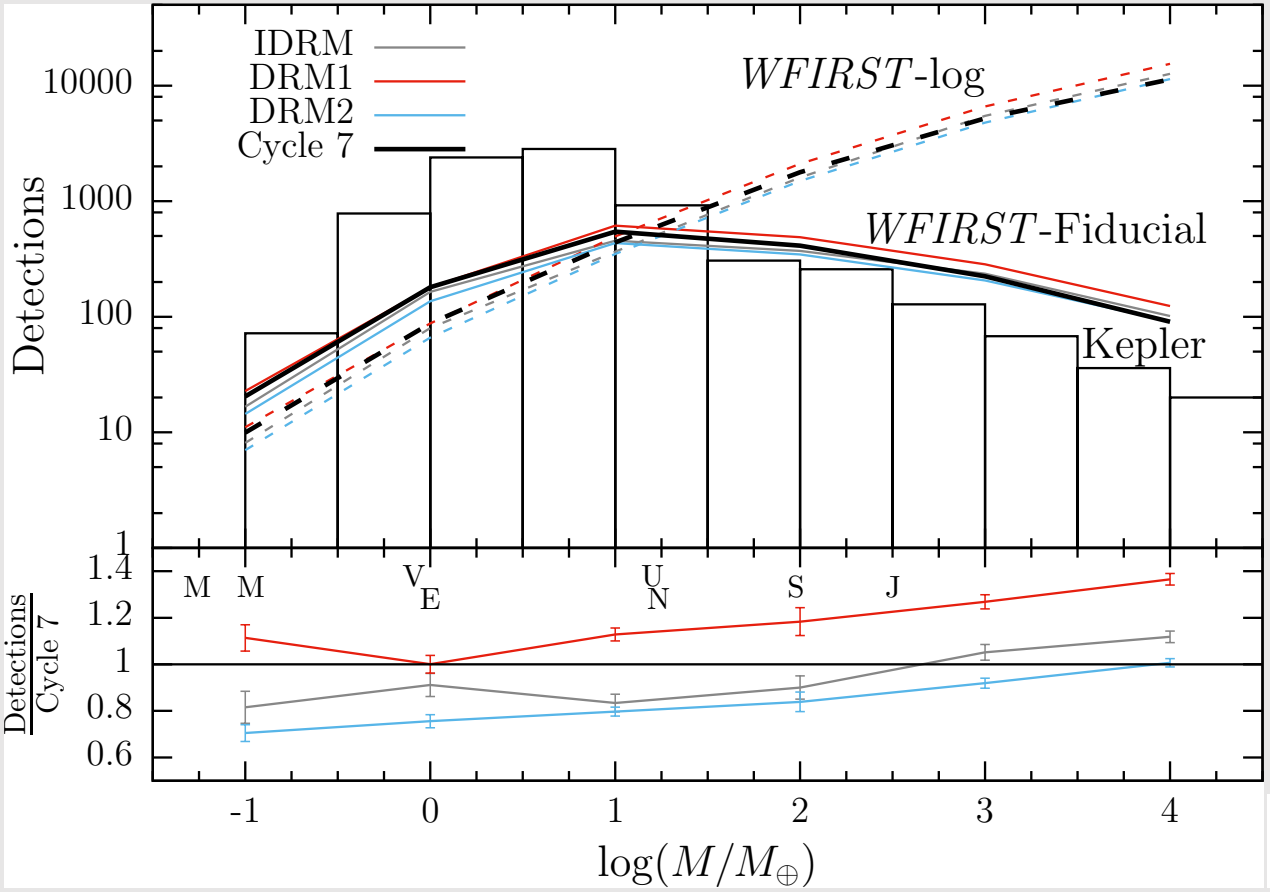
Mission design changes

	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)**

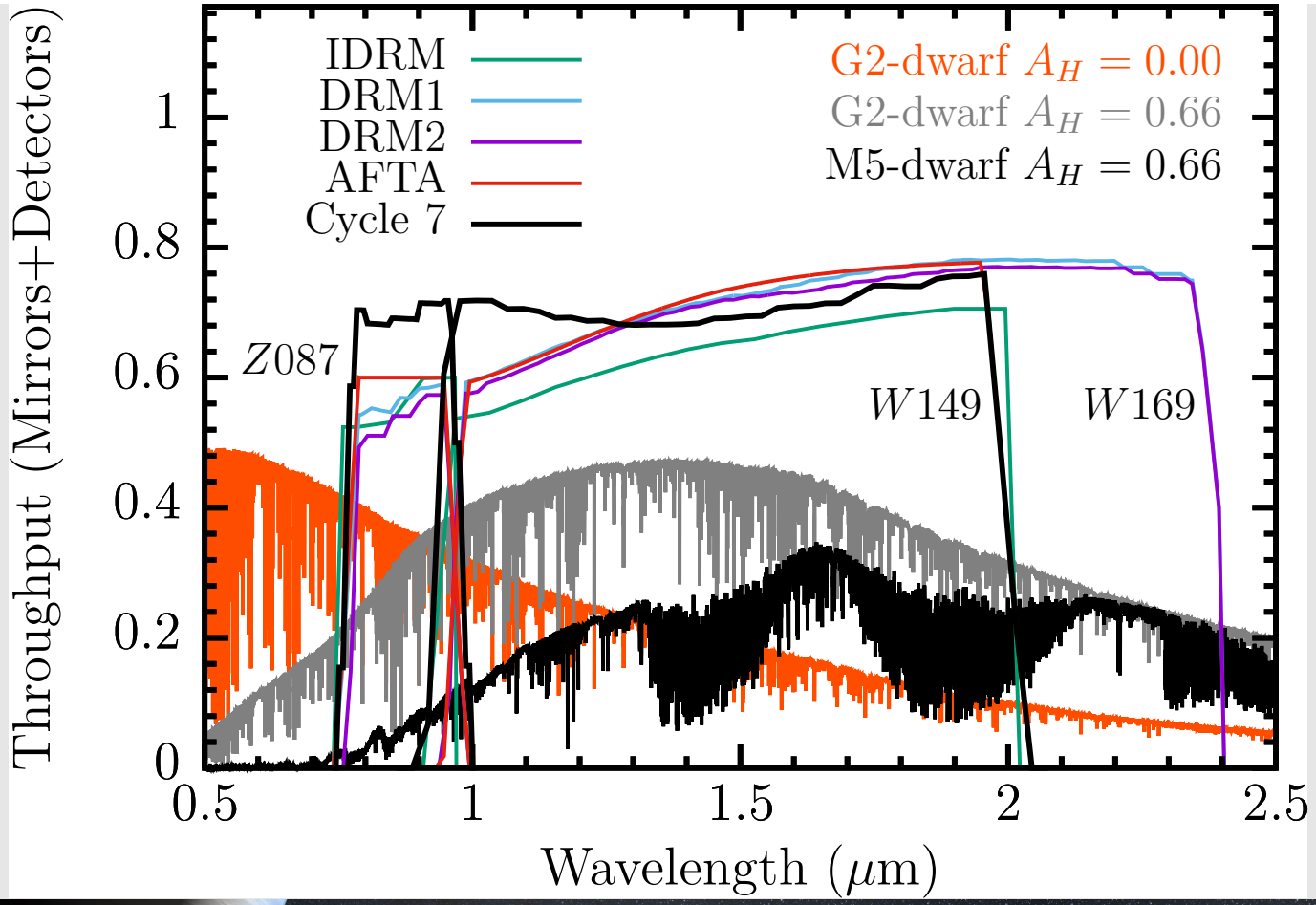
Free floating planets as tests of planet formation



Barclay et al., 2017



Credit: Penny et al. (2018)
arXiv:1808.02490



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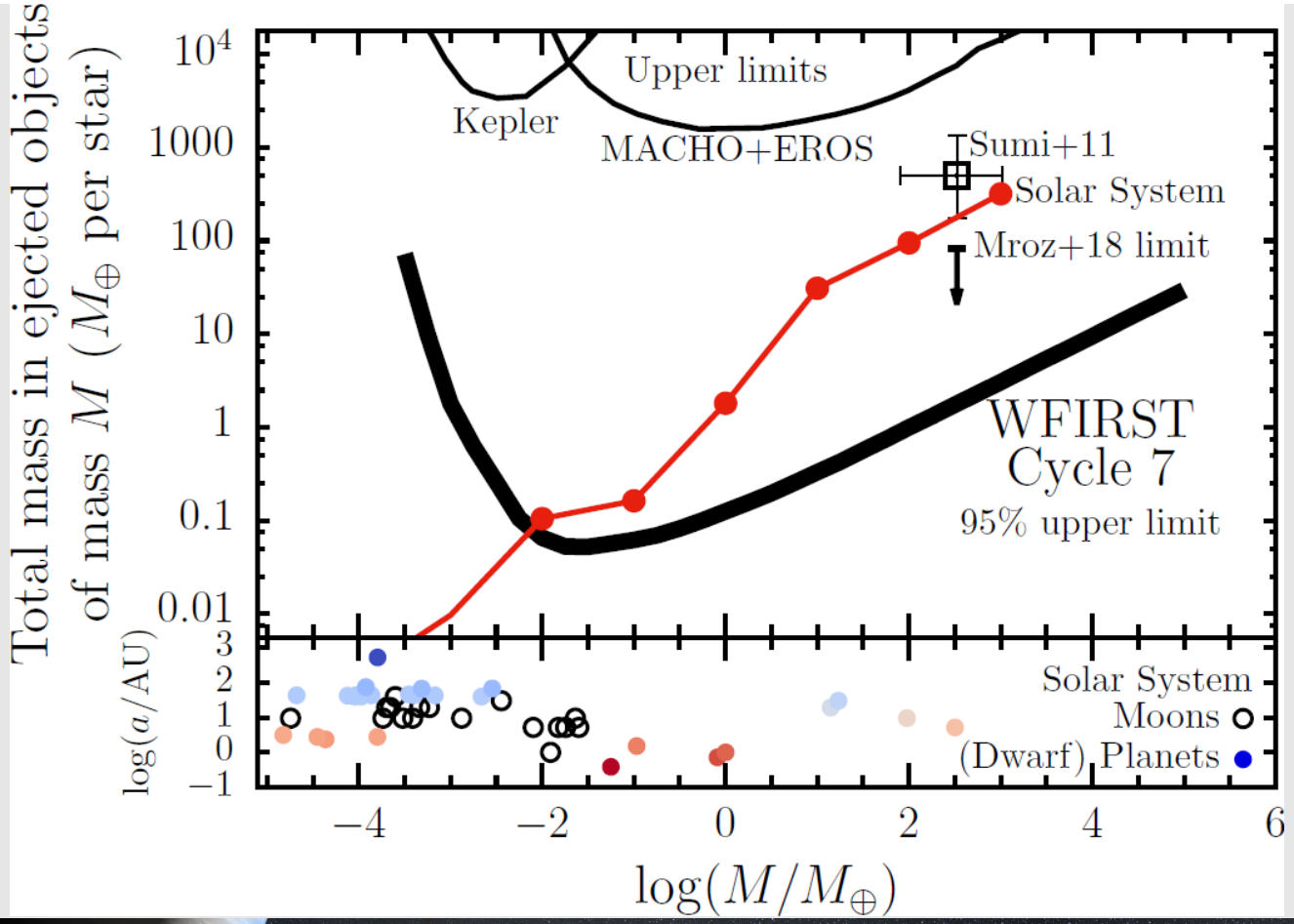
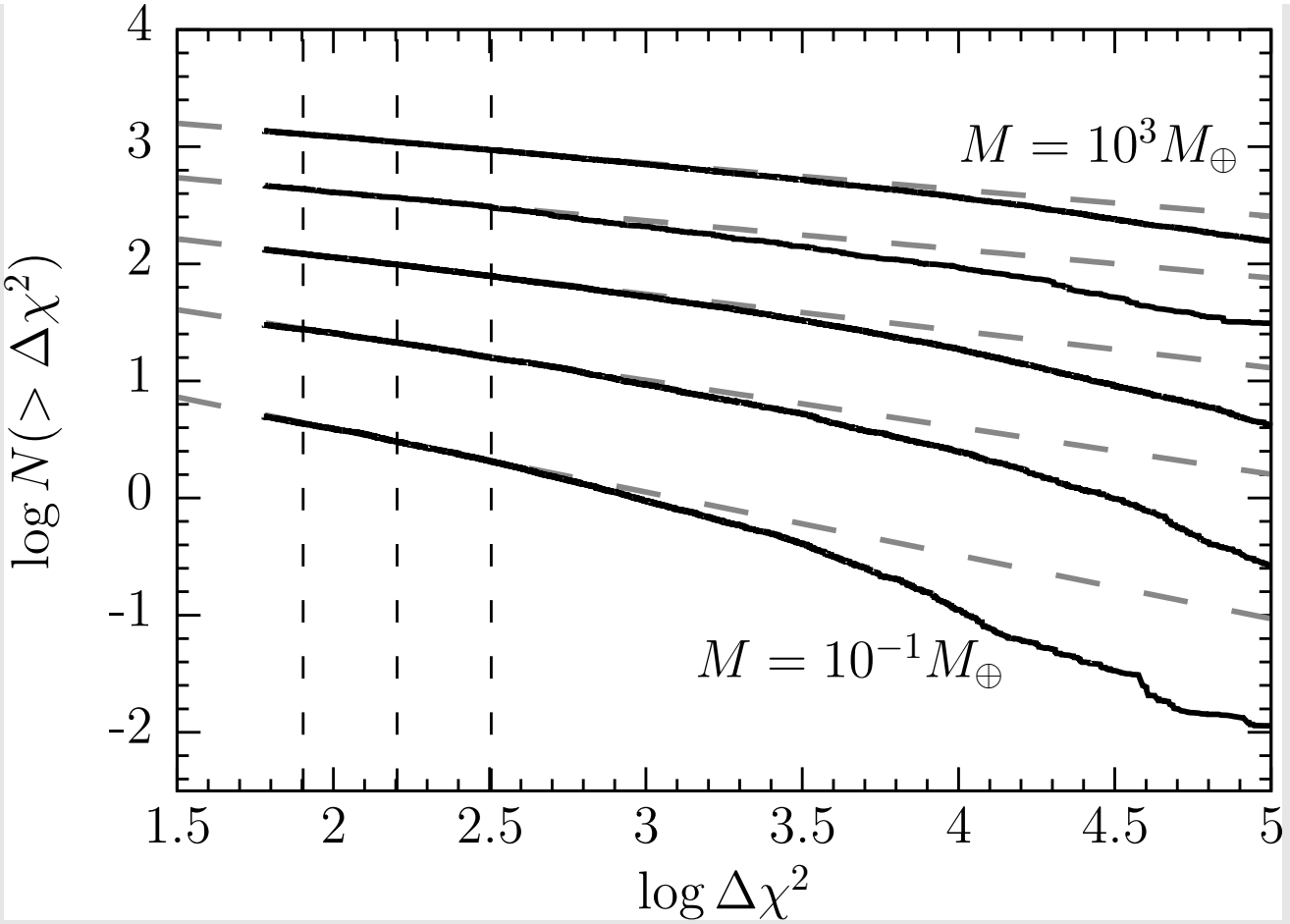
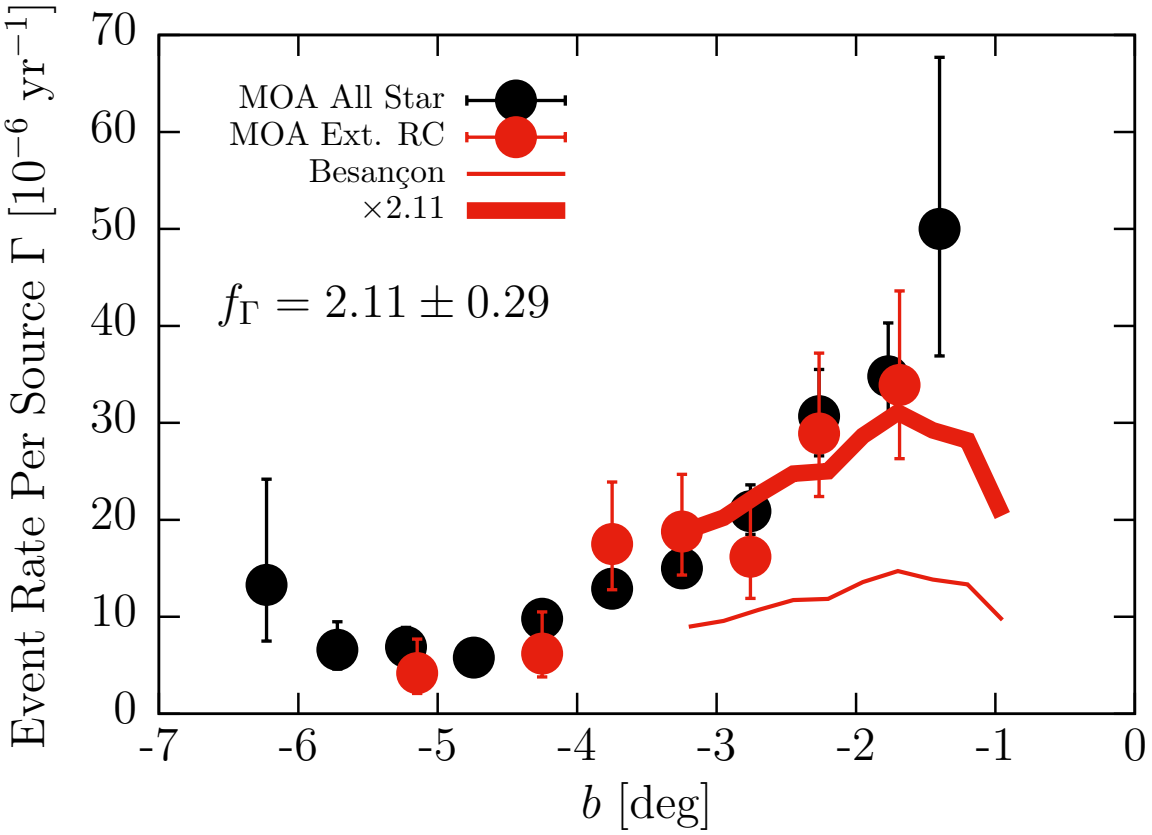
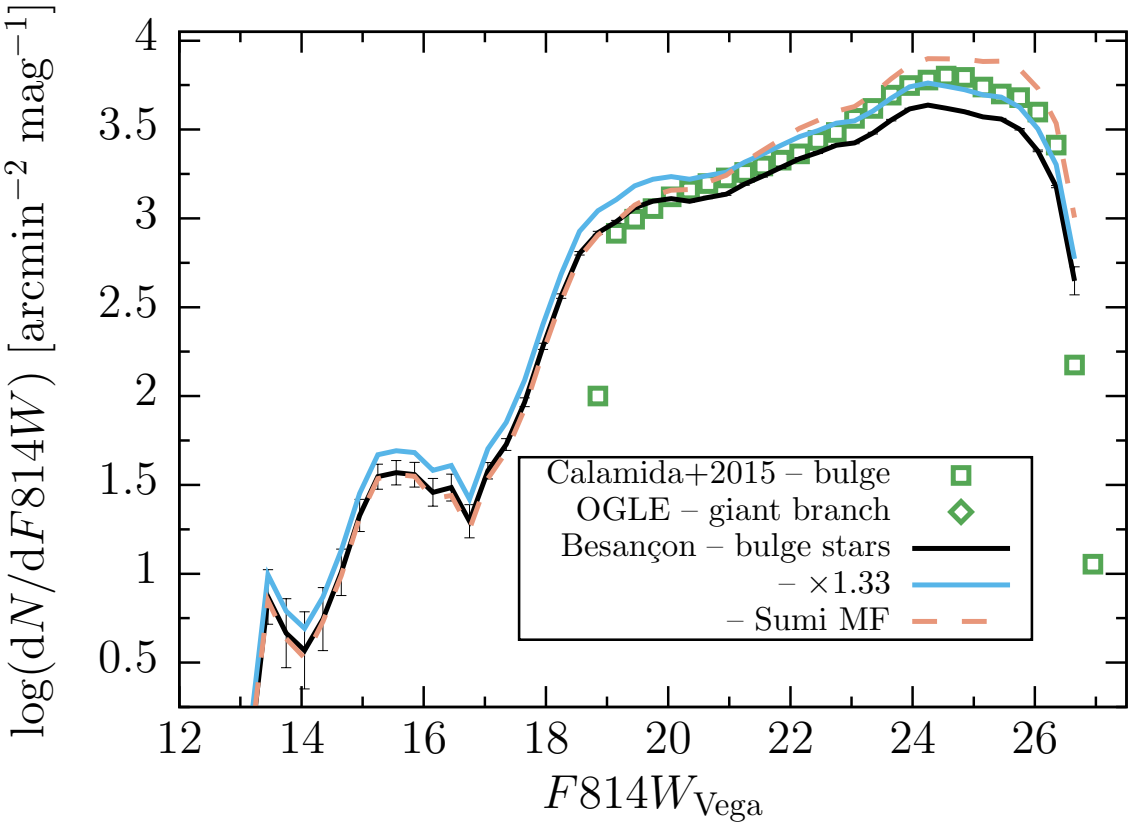

Total mass in ejected objects of mass M ($M_\oplus$ per star)
10^4
1000
100
10
1
0.1
0.01
Upper limits
Kepler
MACHO+EROS
Sumi+11
Solar System
Mroz+18 limit
WFIRST
Cycle 7
95% upper limit
log(a/AU)
3
2
1
0
−1
Solar System
Moons
(Dwarf) Planets
−4
−2
0
2
4
6
log($M/M_\oplus$)


$M = 10^3 M_\oplus$
$M = 10^{-1} M_\oplus$
$\log N(>\Delta\chi^2)$
$\log \Delta\chi^2$
4
3
2
1
0
-1
-2
1.5
2
2.5
3
3.5
4
4.5
5





Scaling θ_E and t_E

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

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