Exploring the shortest microlensing events

Przemek Mróz

Warsaw University Observatory

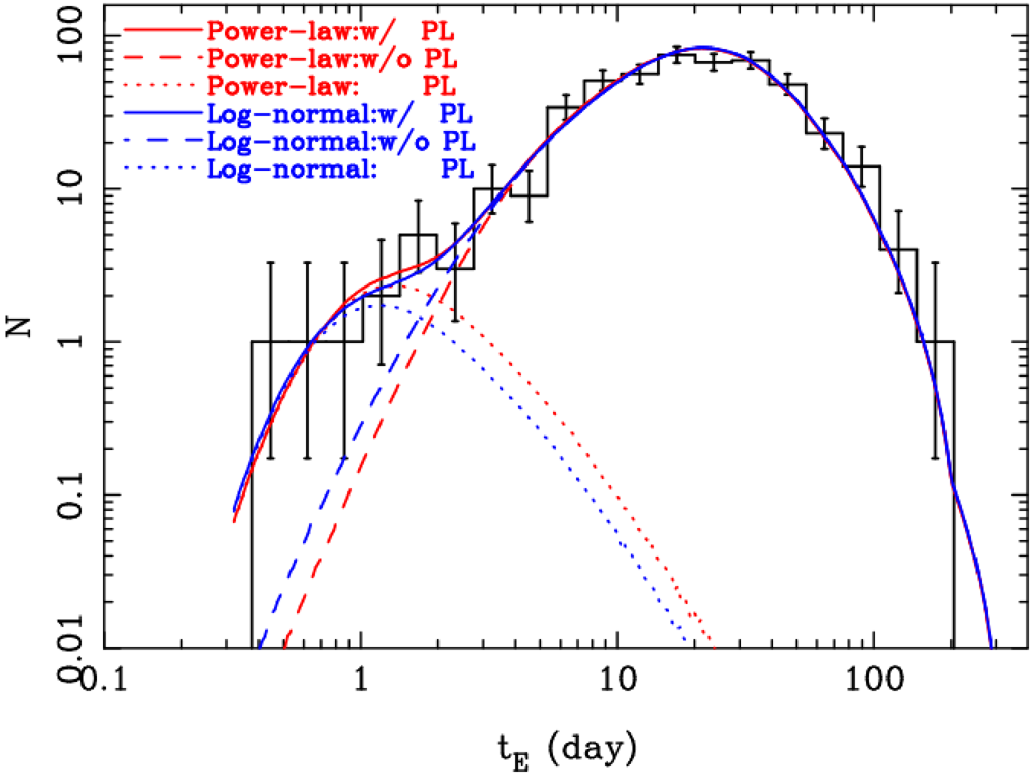
25.01.2018

Outline

- Update on short-timescale events from 2010-15 from OGLE
- Short-timescale binary events
- Short-timescale events from the 2016 season from OGLE+KMT

Free-floating planets (FFPs)

- 474 well-characterized events from 2006-2007
- excess of short events (t_E < 2 d)
- Jupiter-mass free-floating planets: almost twice as common as main-sequence stars



(Sumi et al. 2011, Nature 473, 349)

Surveys of young clusters

- stars are 20-50 times more frequent than FFPs in young stellar clusters and star-forming regions

  (e.g. Scholz et al. 2012, Pena Ramirez et al. 2012)

- inclomplete below < 5-6 M_{Jup}

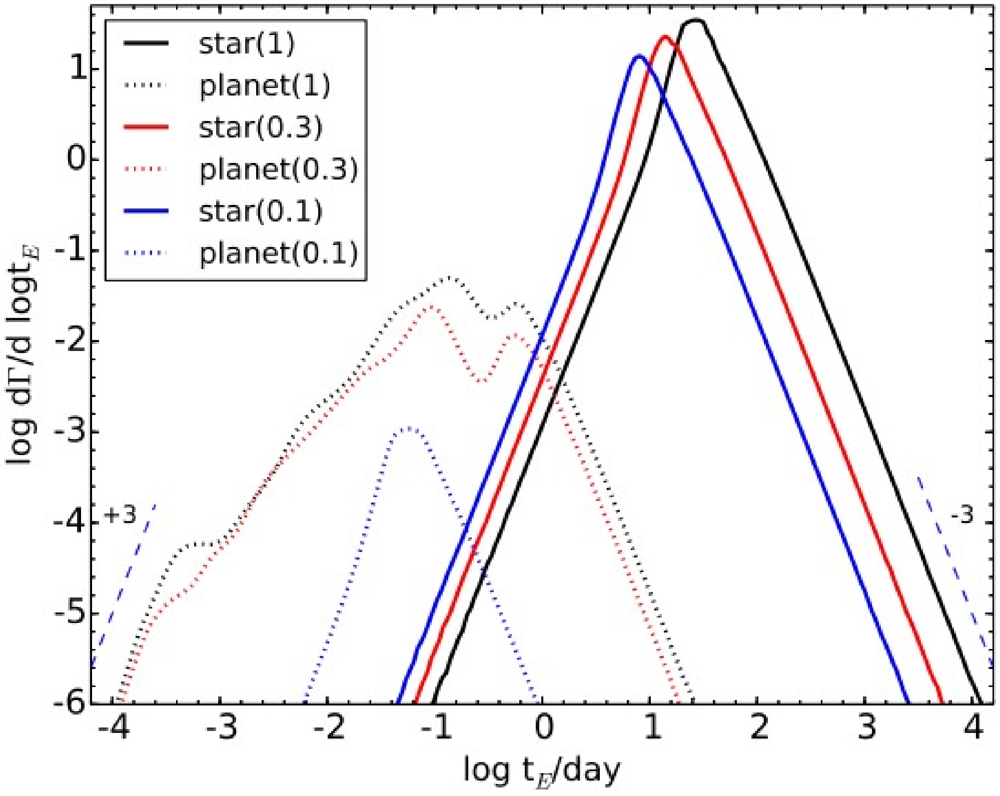
How to eject a planet?

- dynamical interactions between planets
- ejections from multiple-star systems
- stellar flybys
- dynamical interactions in clusters
- post-main-sequence evolution of the host star(s)
- ...

Veras et al. 2009, 2011, 2016, Kaib et al. 2013, Sutherland & Fabrycky 2016, Boley et al. 2012, Veras & Moeckel 2012, Liu et al. 2013, and many more...

FFPs from the core accretion theory

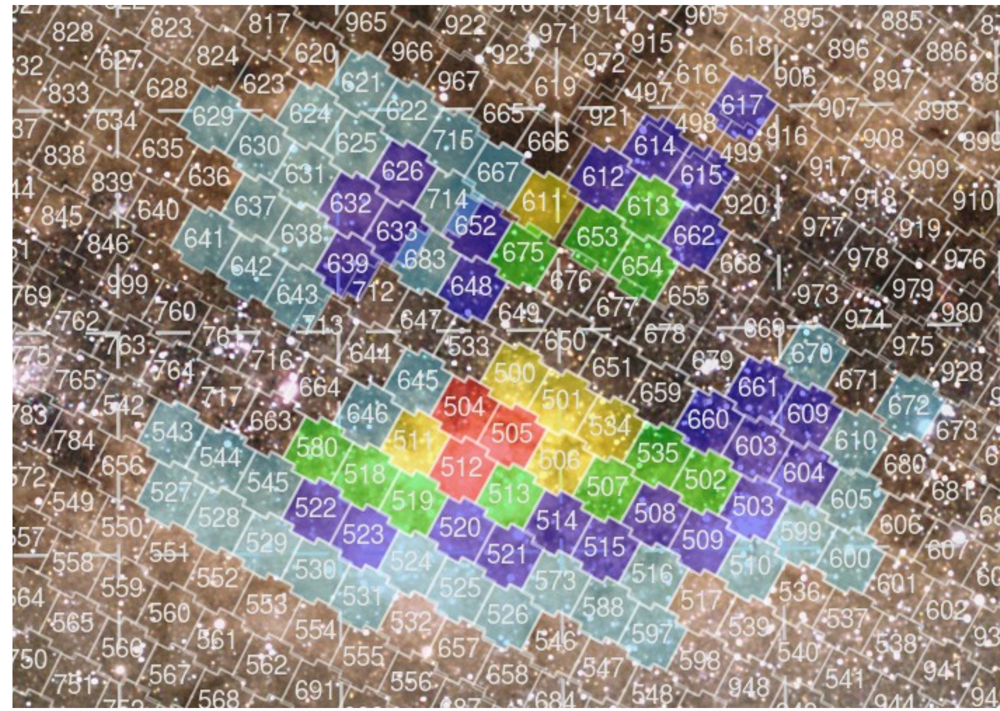
- It is much easier to eject an Earth-mass planet than a Jupiter-mass planet
- Event rate due to FFPs ~13x smaller than in Sumi+ (2011)
- Median timescale ~16x smaller (~0.1 day) than in Sumi+ (2011)



Ma et al. 2016, MNRAS 461, 107

OGLE-IV dataset

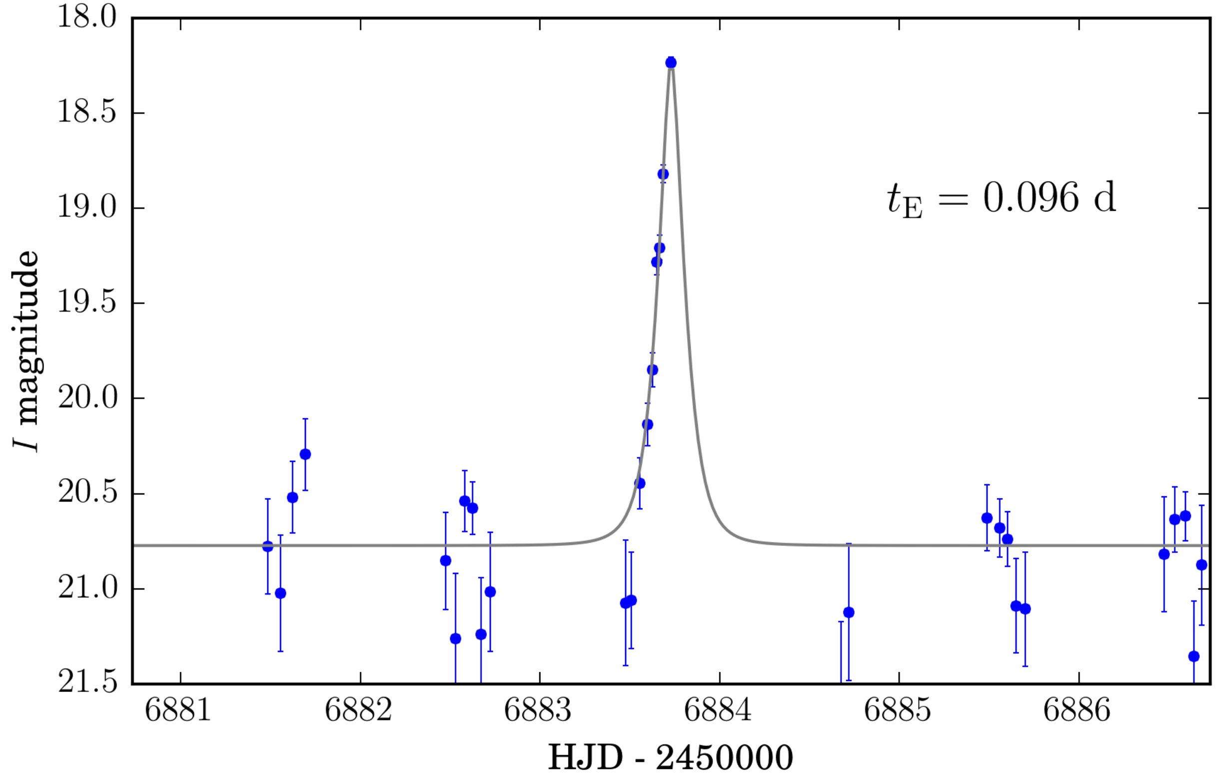
- 9 fields with a cadence of either **20 min** or **60 min**
- 5.5-year-long light curves
- 50 million stars
- 4500-12,000 data points per light curve
- accuracy of the photometry:
  3% @ 18 mag, 10% @ 19.5 mag
- ~4800 microlensing events
- 2617 high-quality microlensing events



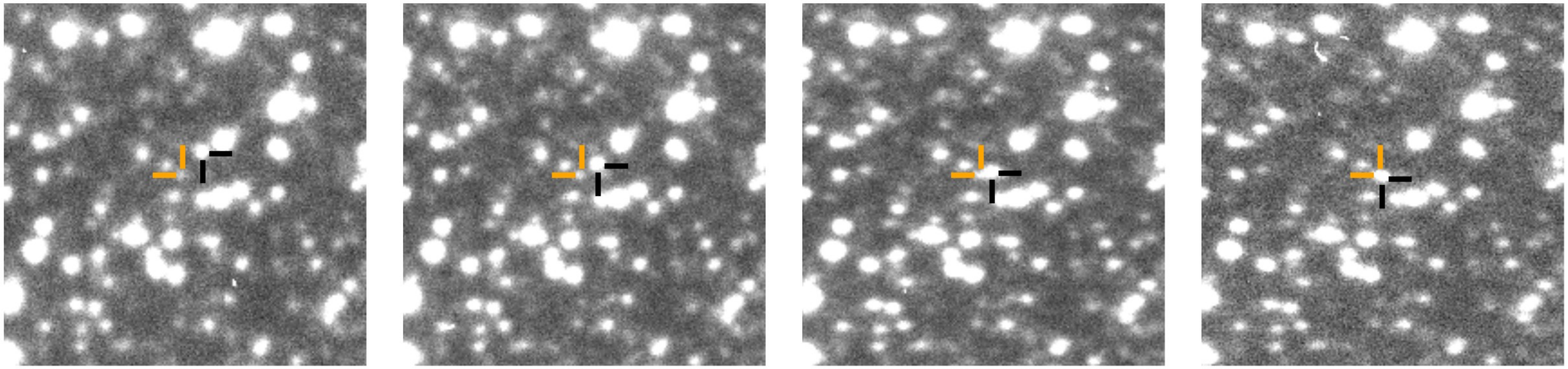
Selection cuts

- at least 3 consecutive points 3σ above the baseline
- no variability outside a 360-day window
- at least 3 detections on subtracted images
- amplitude > 0.1 mag
- χ^2 / dof < 2 for $|t-t_0|<t_E$, $|t-t_0|<2t_E$, $|t-t_0|<5$ d
- $u_0<1$, $I_s < 22$ mag, $F_b > -0.25$ (some negative blending)

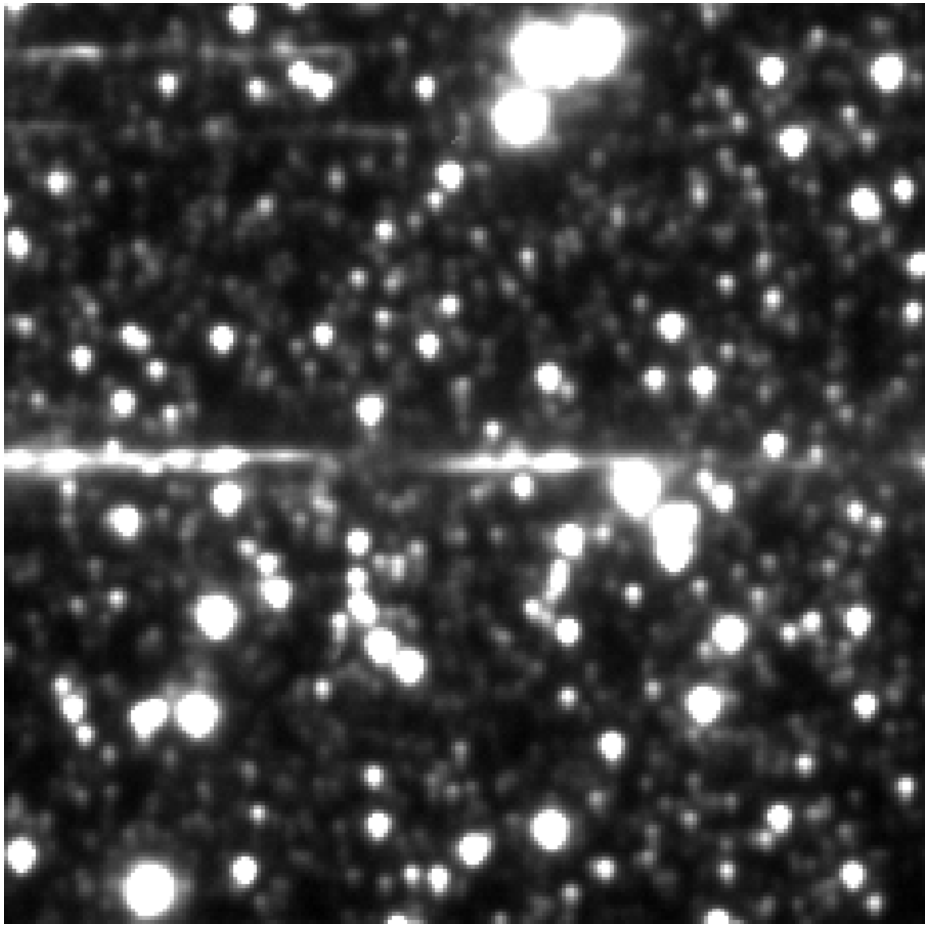
Contaminants: asteroids

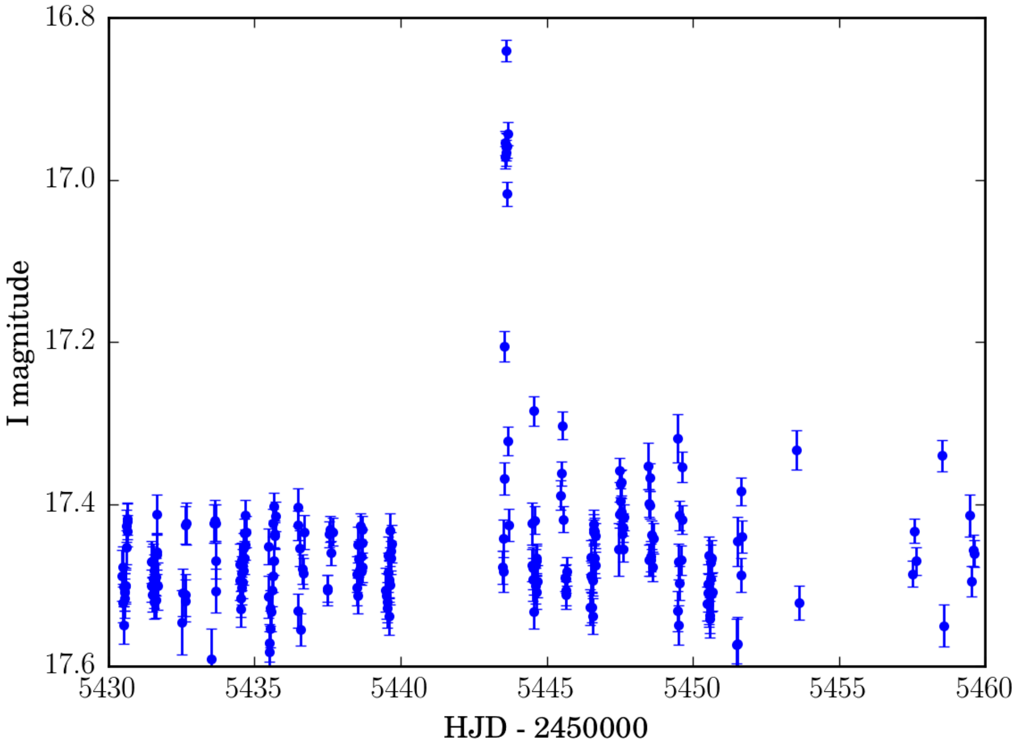


(7294) 1992LM

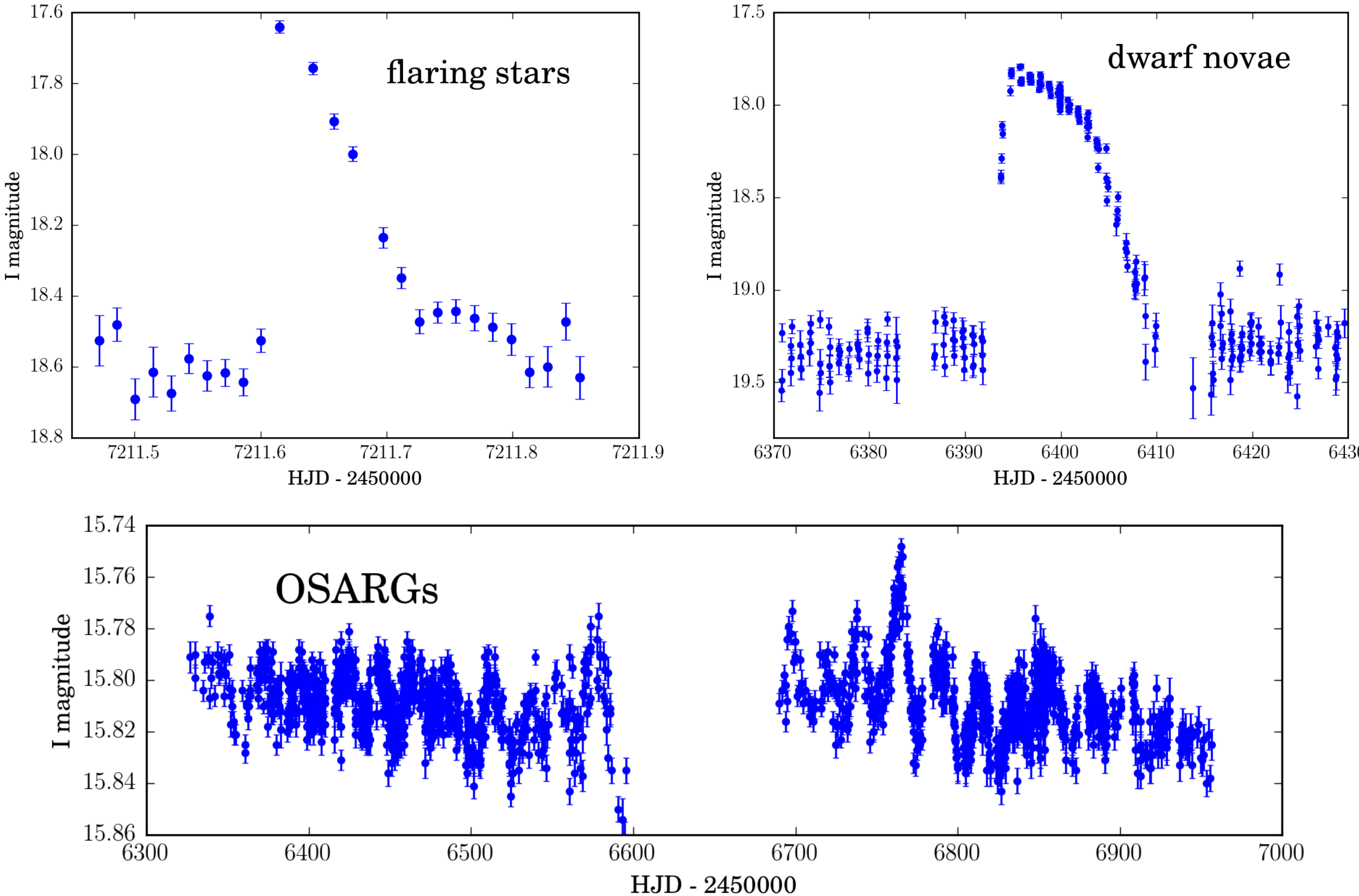


Contaminants: artifacts



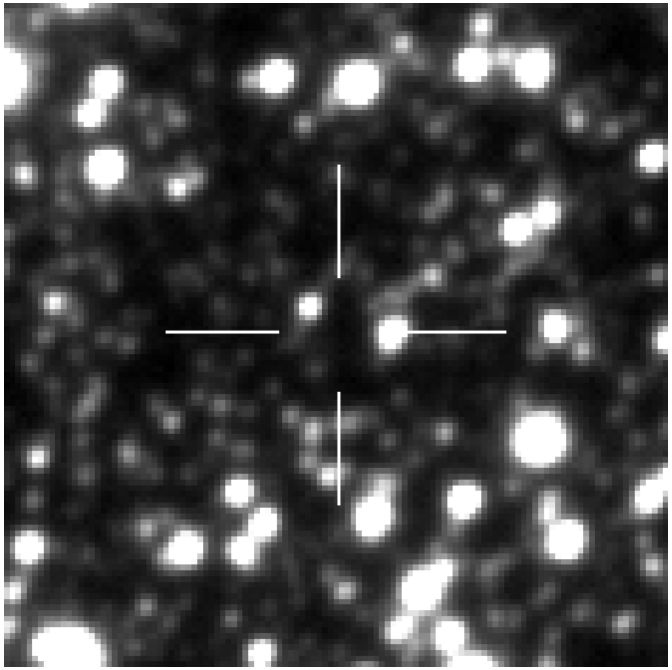


Contaminants: variable stars

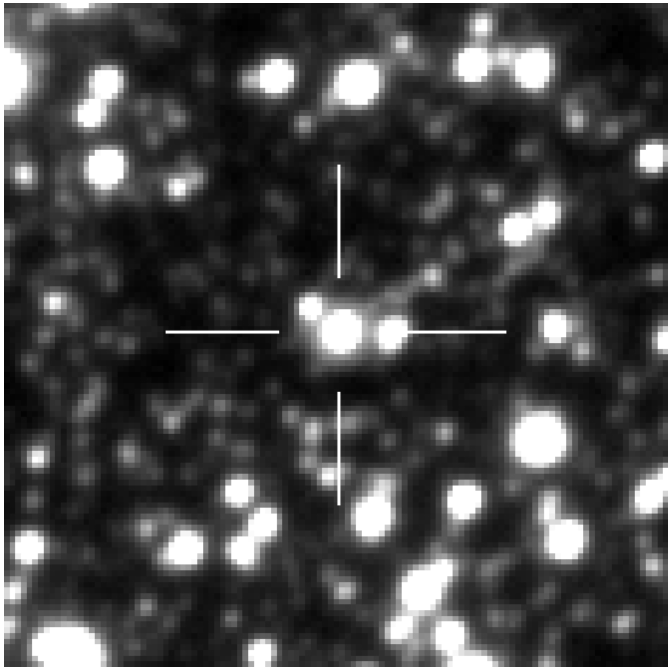


Simulations

- Detection efficiency
- Image-level simulations (all frames processed with the standard OGLE pipeline: Udalski+ 2015)

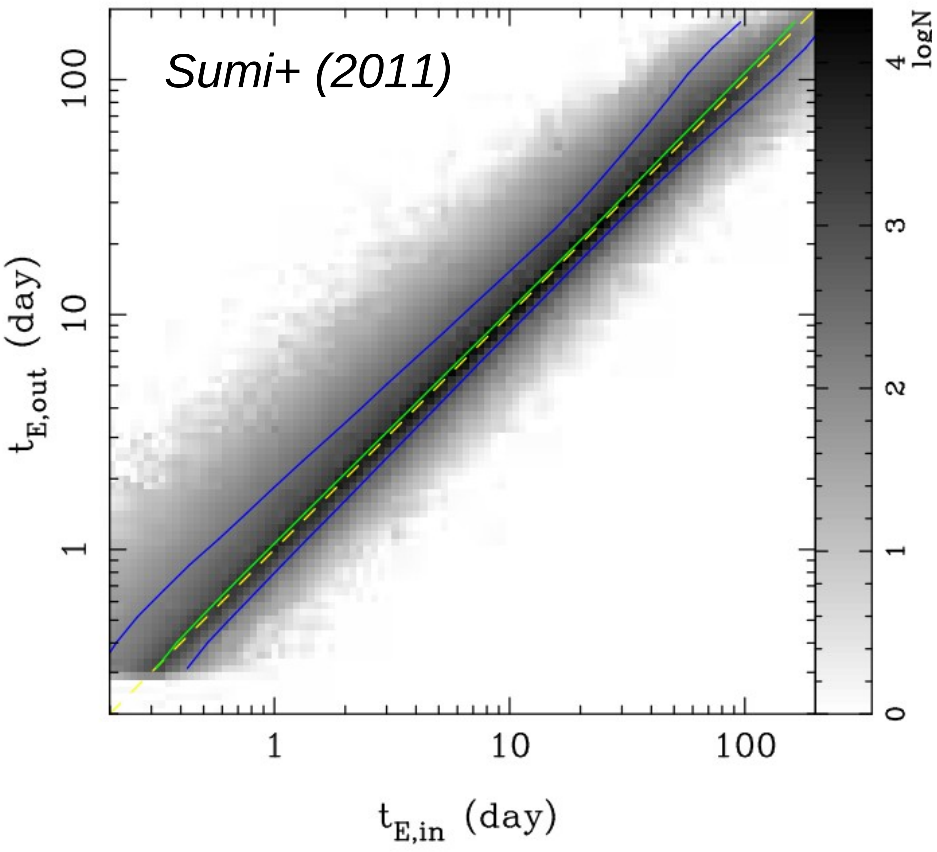


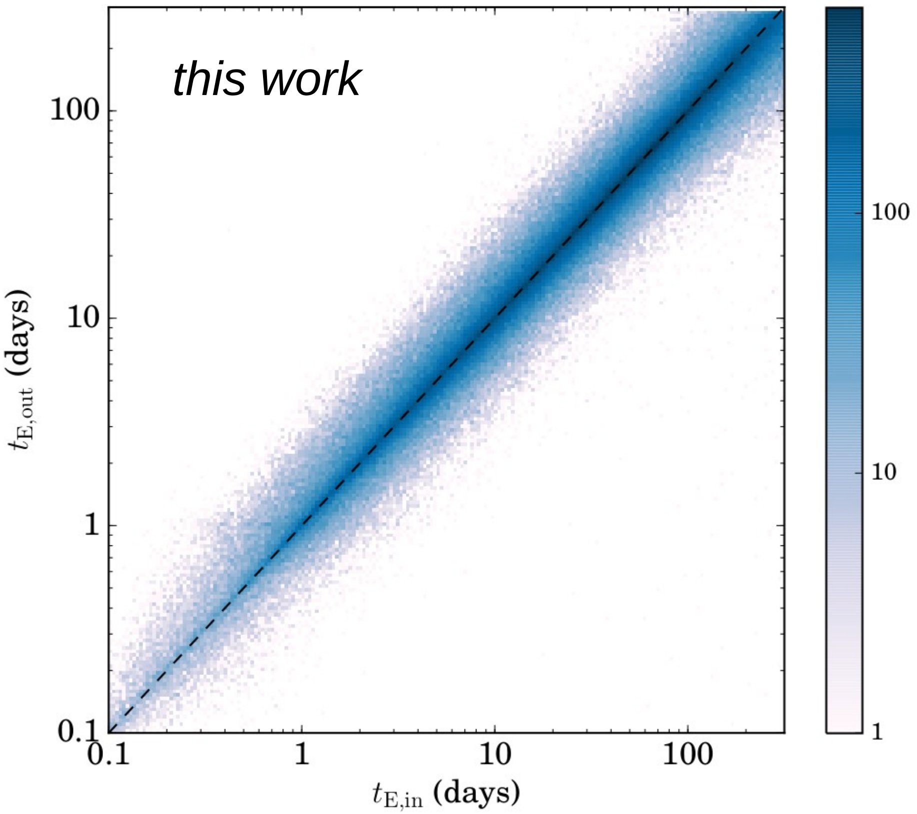
real reference image



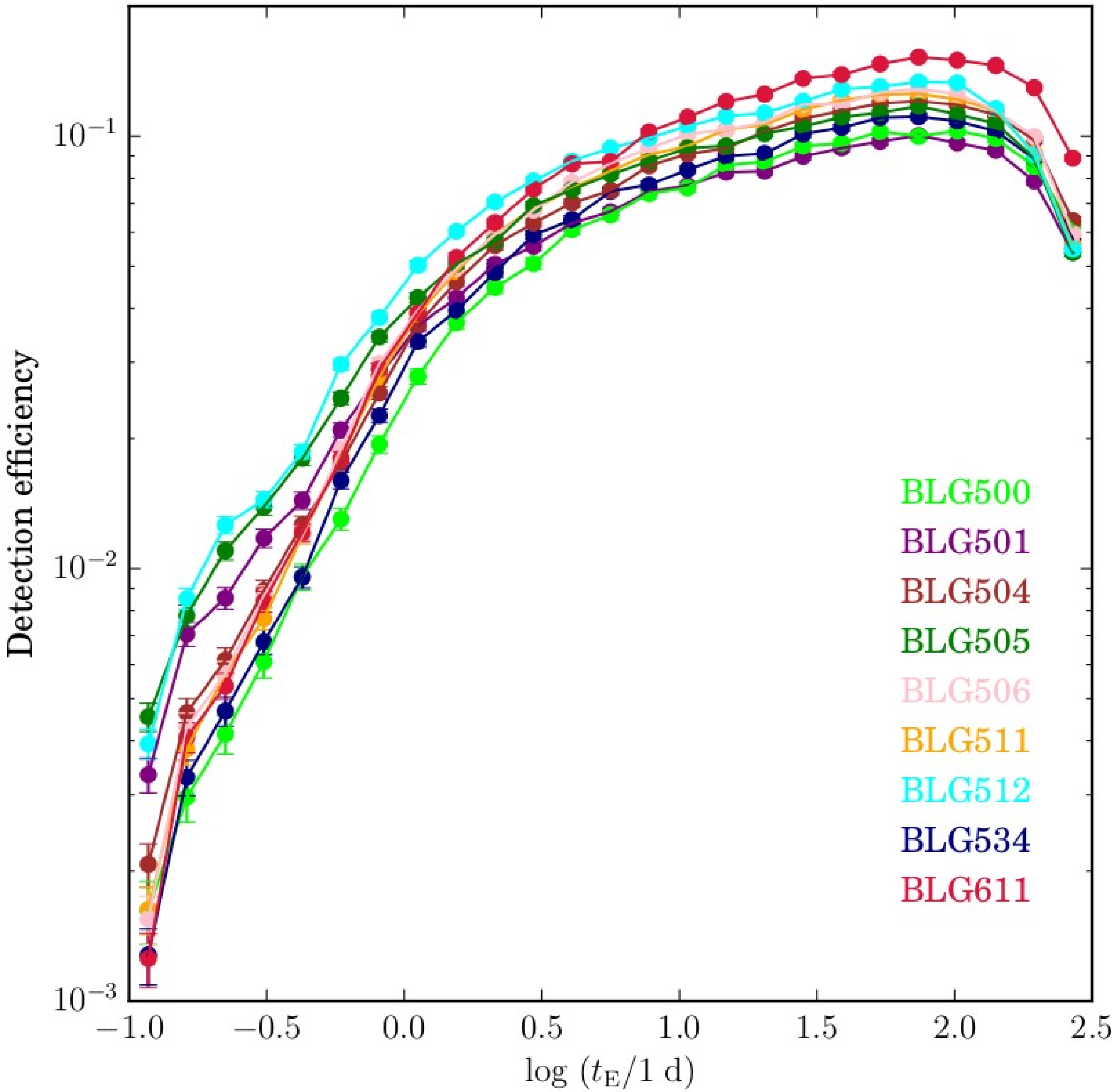
simulated microlensing event

Can we measure real t_E?



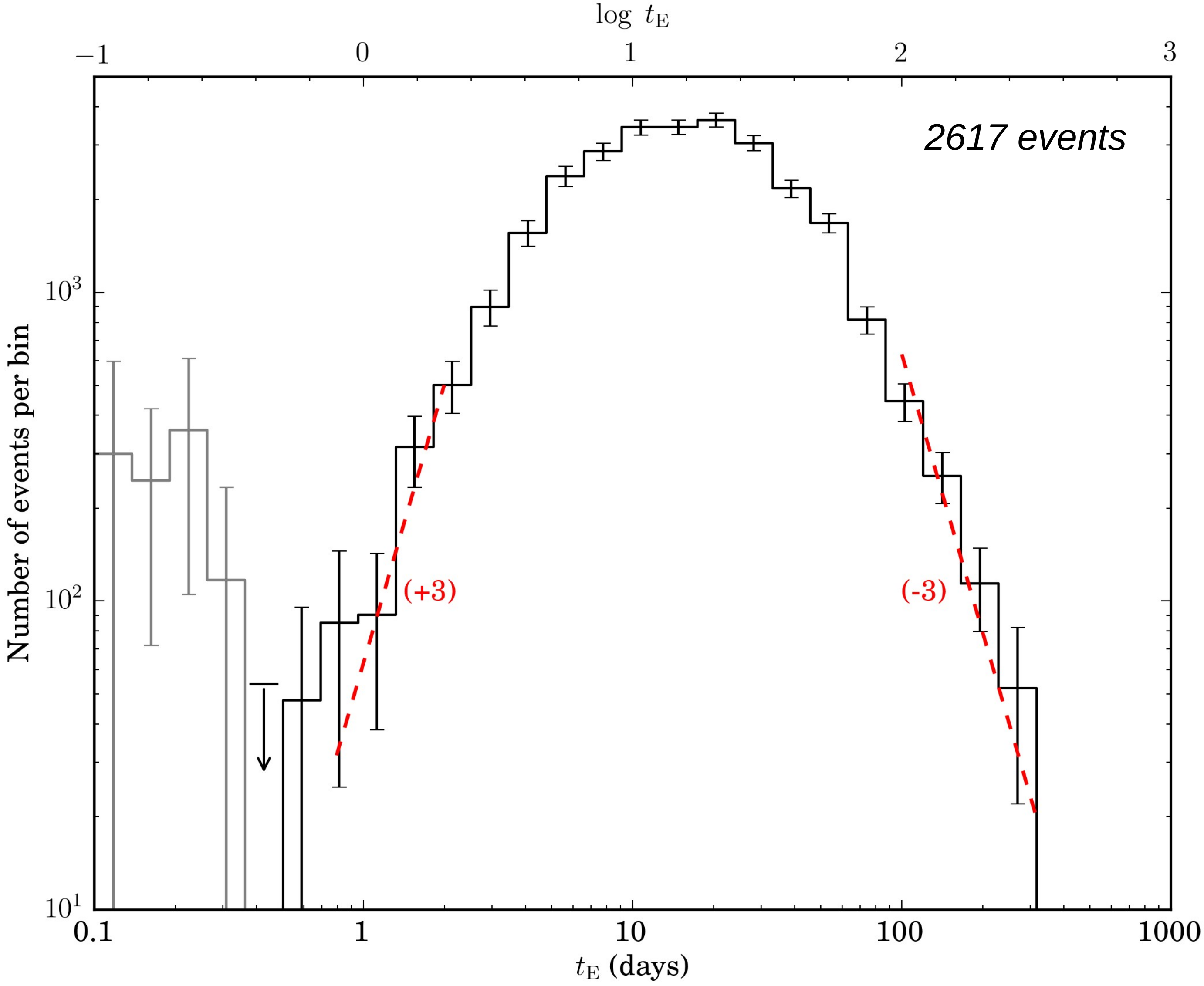


Detection efficiency

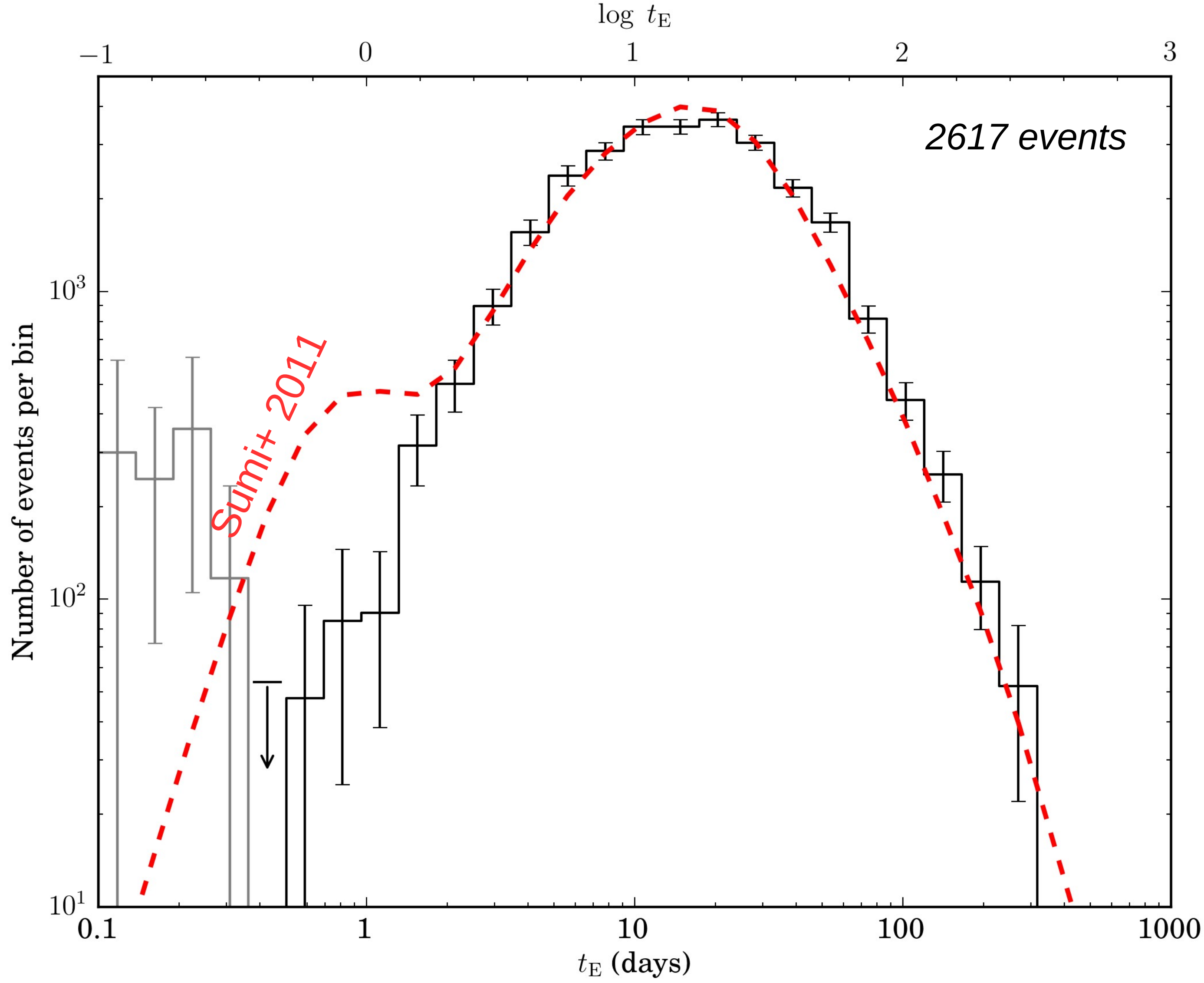


eff (t_E = 2 d) = 53% eff (t_E = 100 d)

Event timescale distribution



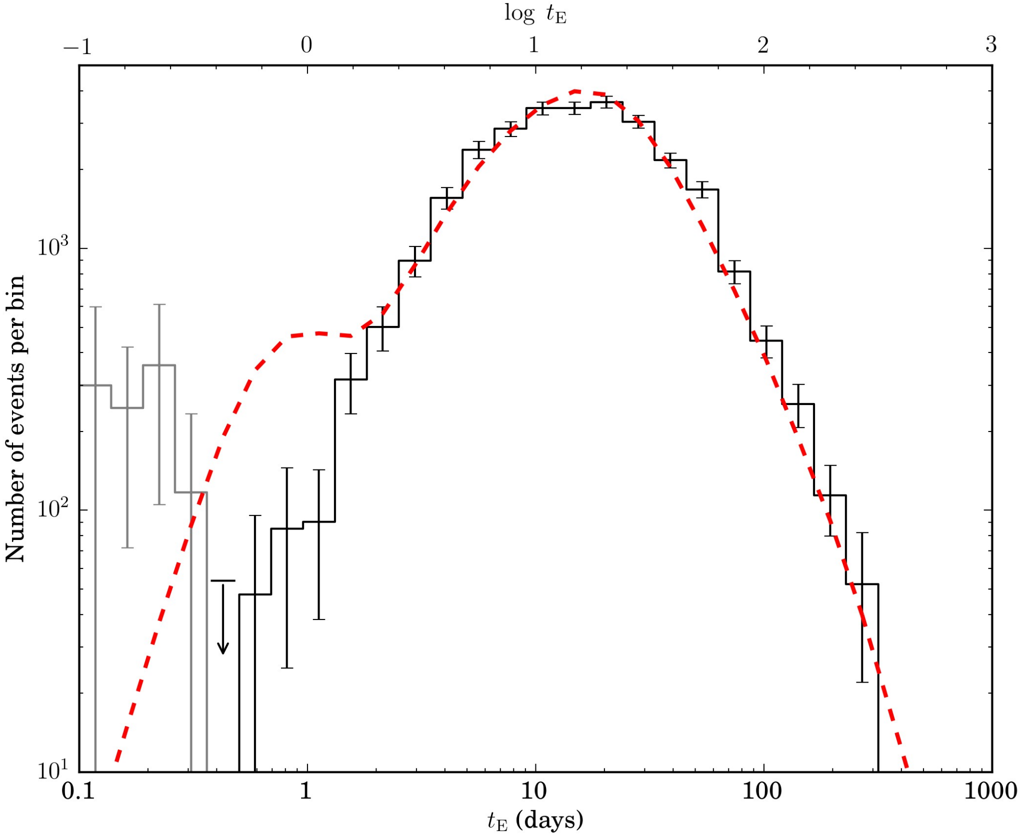
Event timescale distribution



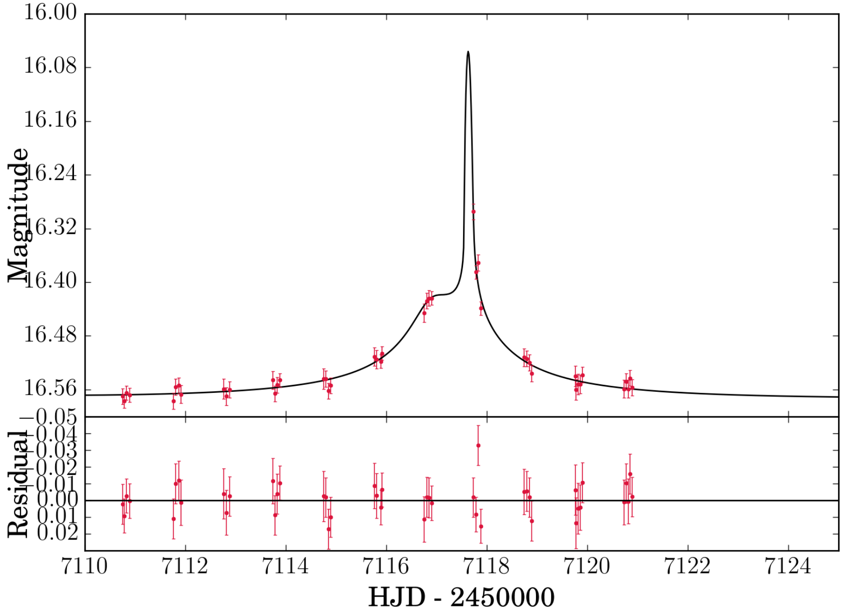
0,3 < t_E < 1,8 d: 21 events (64 expected)
0,3 < t_E < 1,3 d: 6 events (42 expected)

Comparison with Sumi+ (2011)

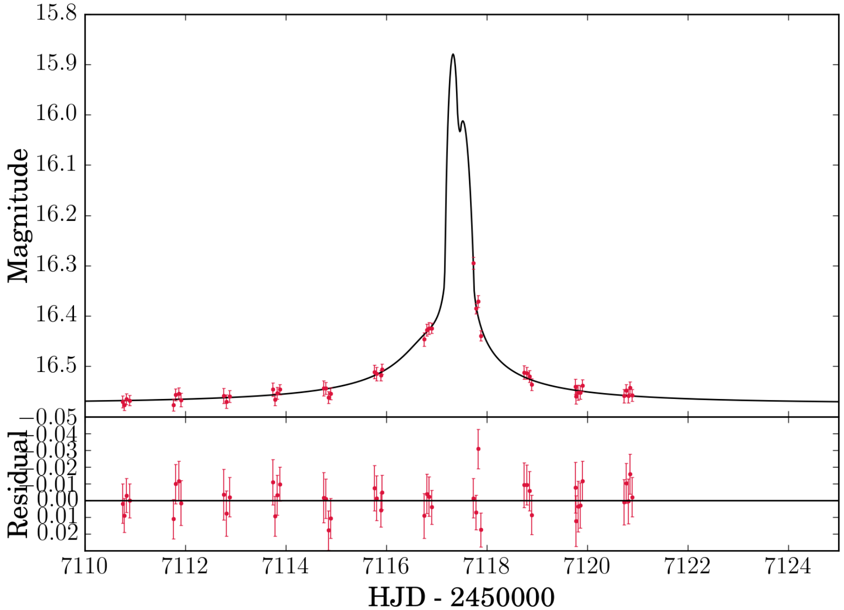
- 2.5σ-3σ difference (small sample?)
- >20 short-duration binary events (could they have been mistaken with single events?)
- systematics in the data? (differential refraction, unphysical treatment of negative blending)

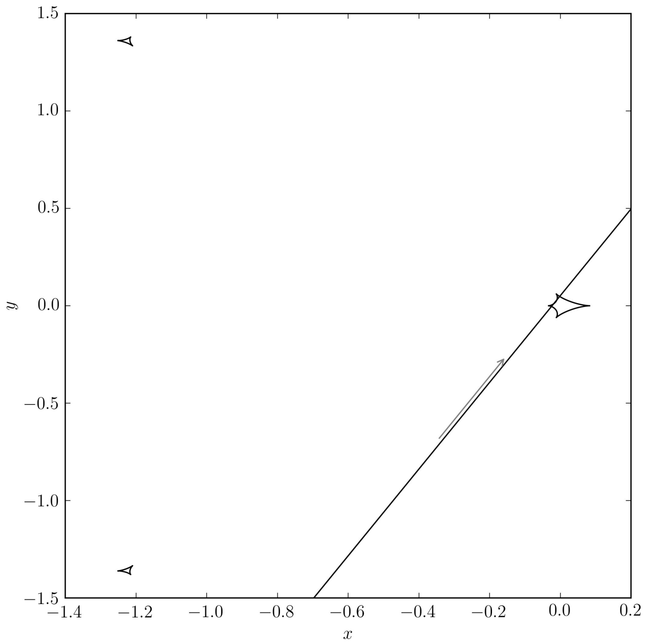


OGLE-BLG511.06.170132

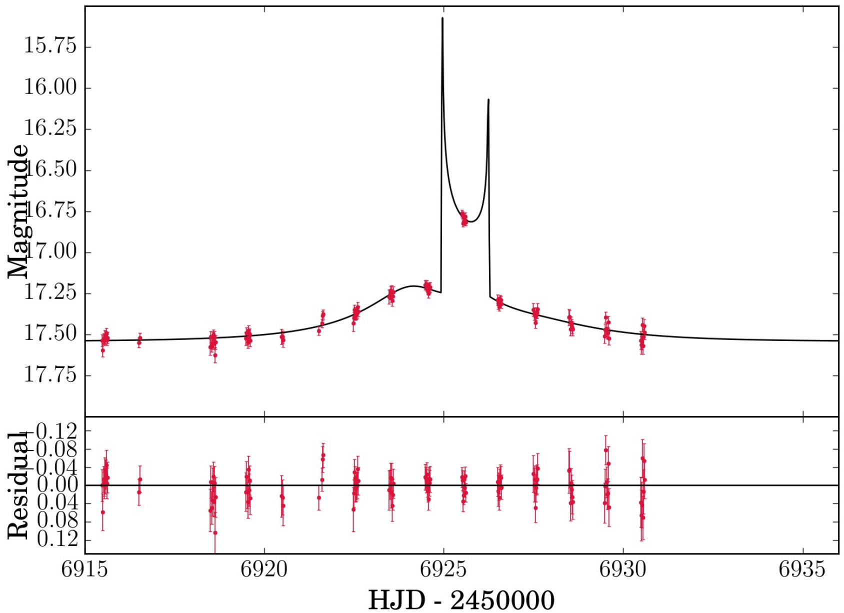


- PSPL: tE = 0.862 d
- binary: tE = 4.3 +/- 1.5 d
  q = 0.32 +/- 0.20
  s = 0.46 +/- 0.10

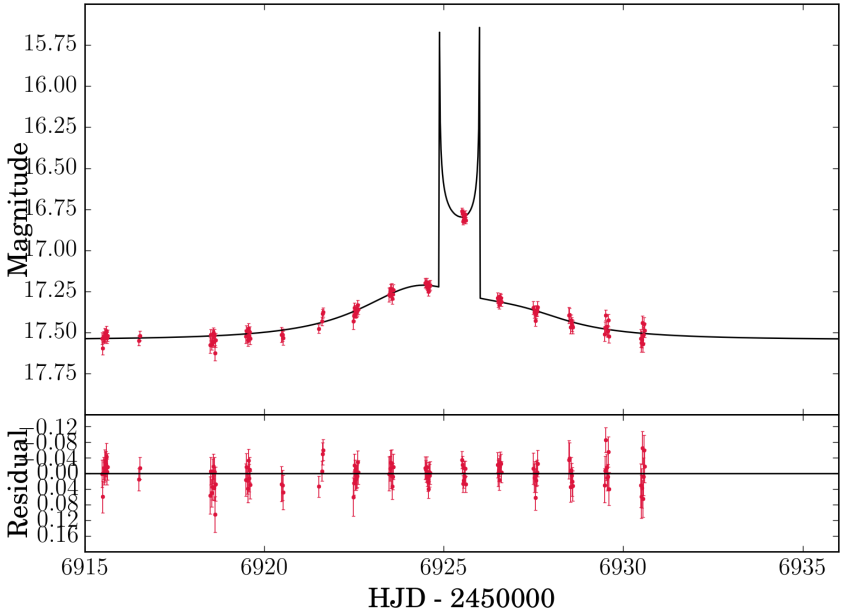


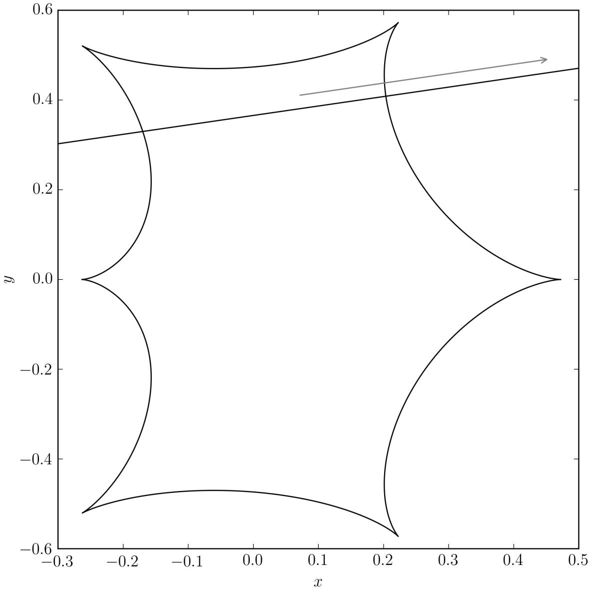


OGLE-BLG512.13.120104



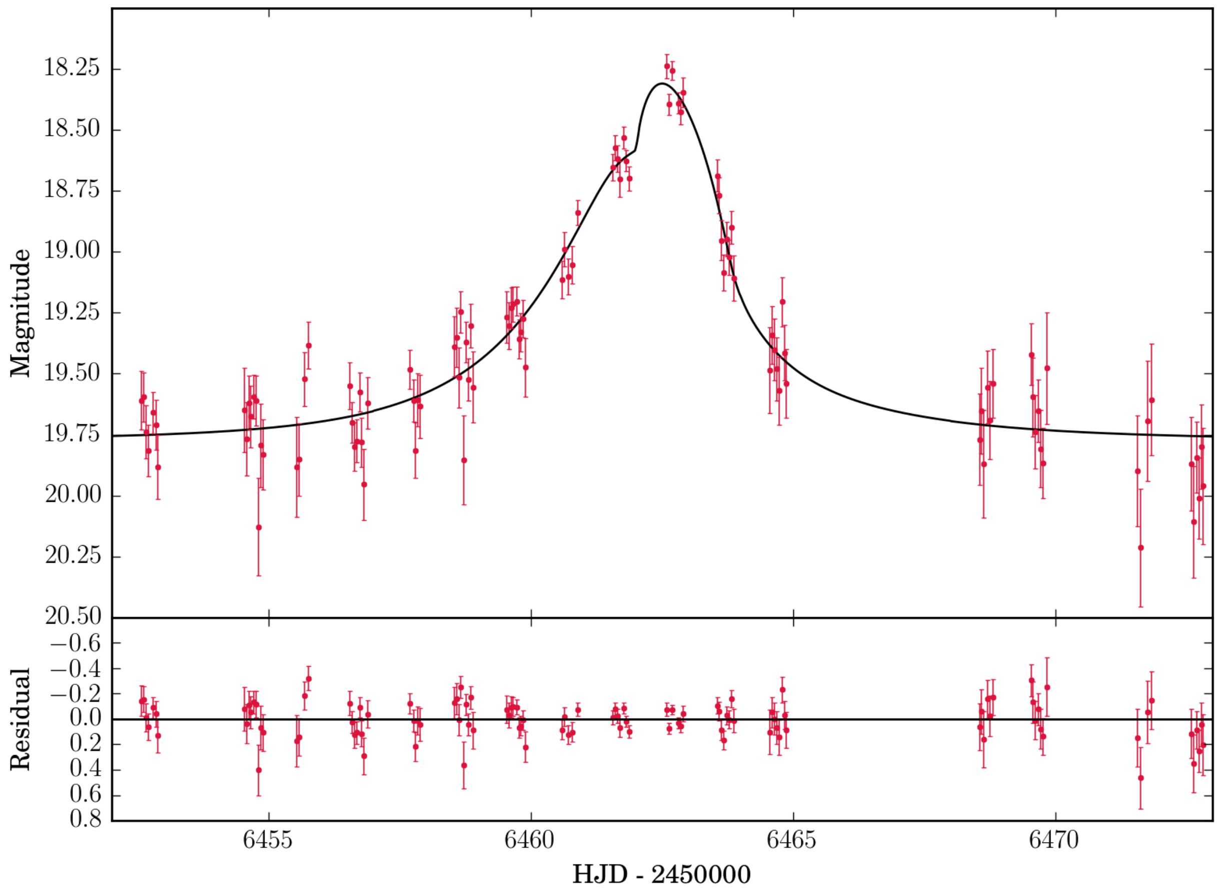
- PSPL: tE = 1.322 d
- binary: tE = 3.5 +/- 0.3 d
  q = 0.45 +/- 0.10
  s = 1.05 +/- 0.04
- three degenerate solutions

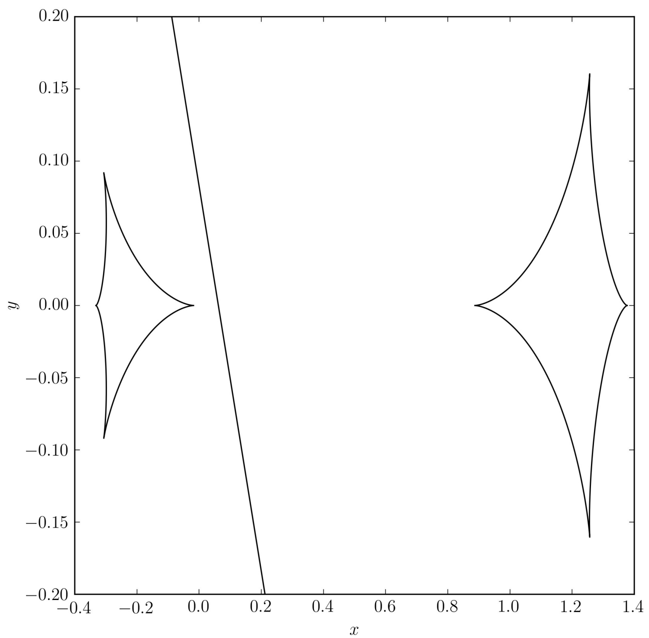




OGLE-BLG506.15.101392

- PSPL: tE = 3.85 d
- binary: tE = 3.6 +/- 0.1 d
  q = 0.18 +/- 0.06
  s = 2.01 +/- 0.22

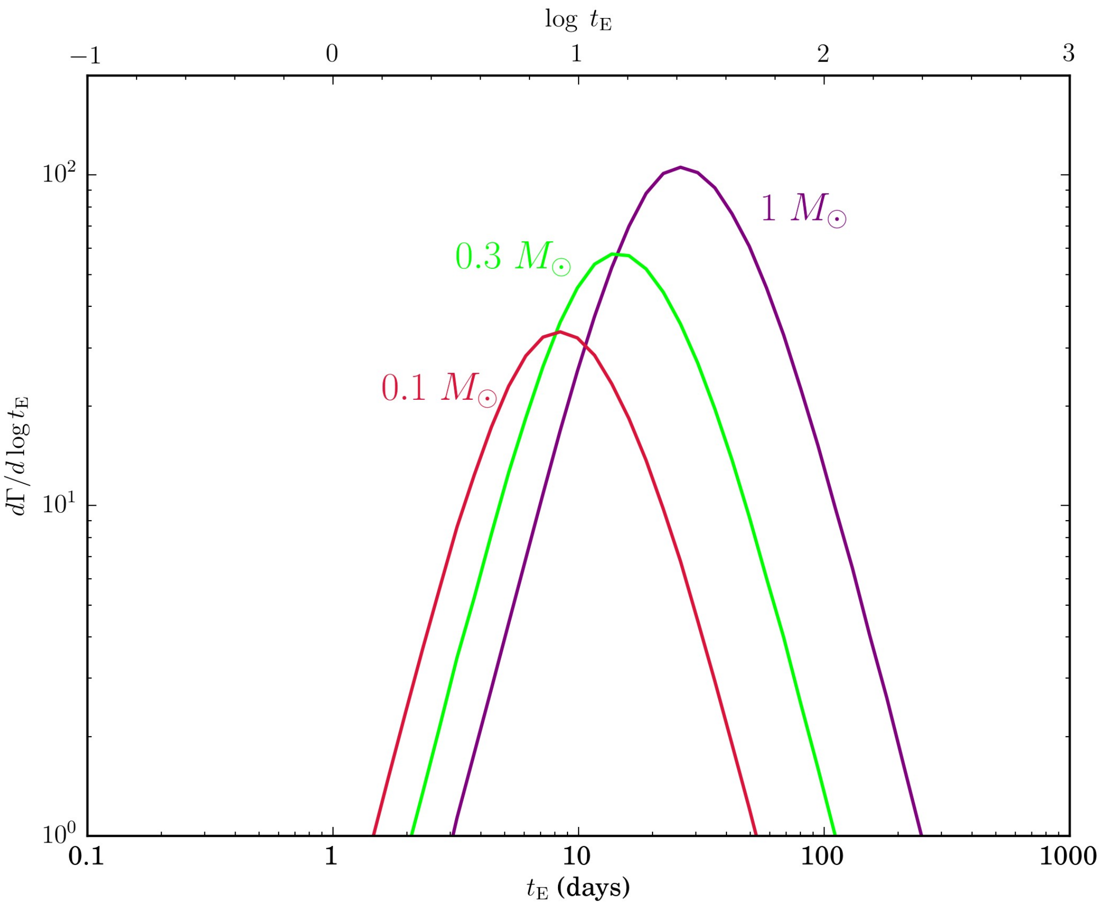




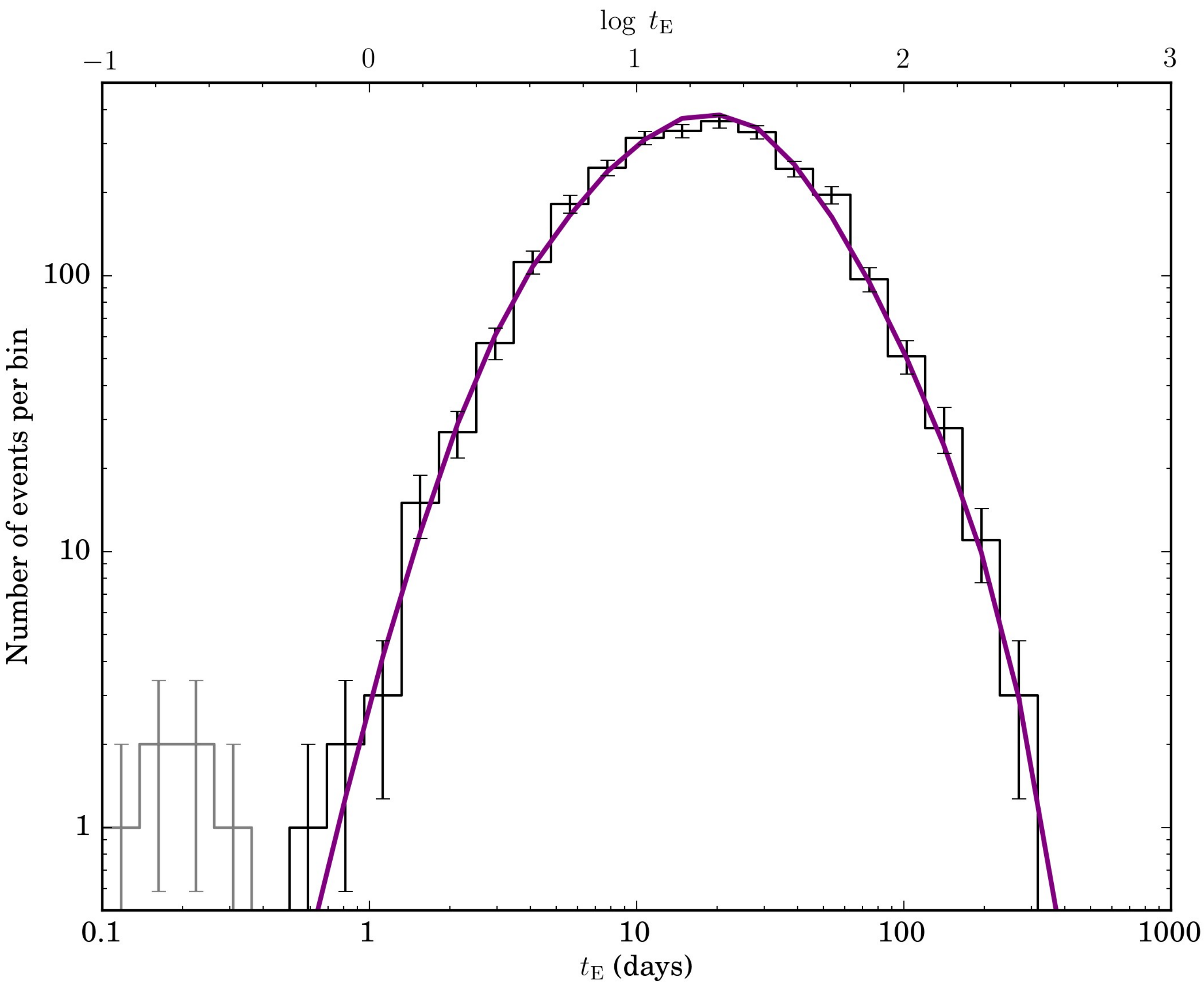
Timescale distribution models

- Milky Way model of Han & Gould (1995, 2003)
- initial mass function:

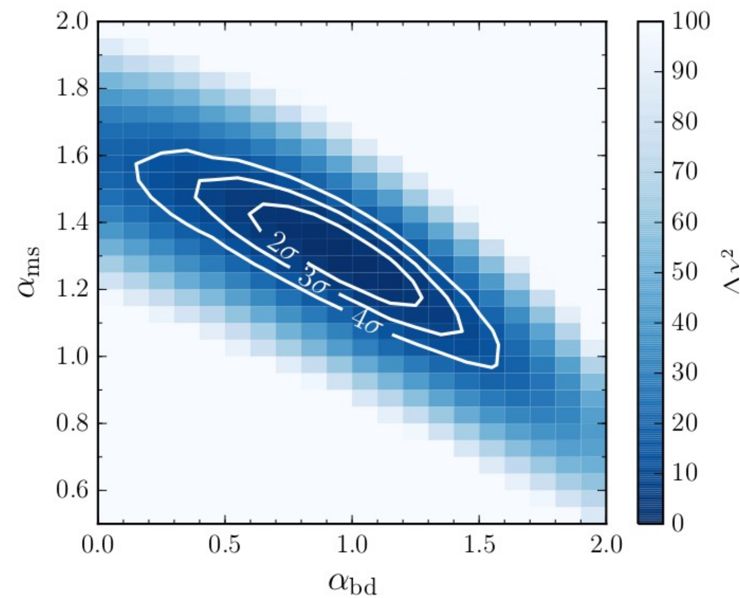
$$\Phi(M) = \begin{cases} a_1 M^{-\alpha_{\rm bd}} & 0.01M_\odot \leq M < 0.08M_\odot \\ a_2 M^{-\alpha_{\rm ms}} & 0.08M_\odot \leq M < M_{\rm break} \\ a_3 M^{-2.0} & M \geq M_{\rm break} \end{cases}$$



Timescale distribution models



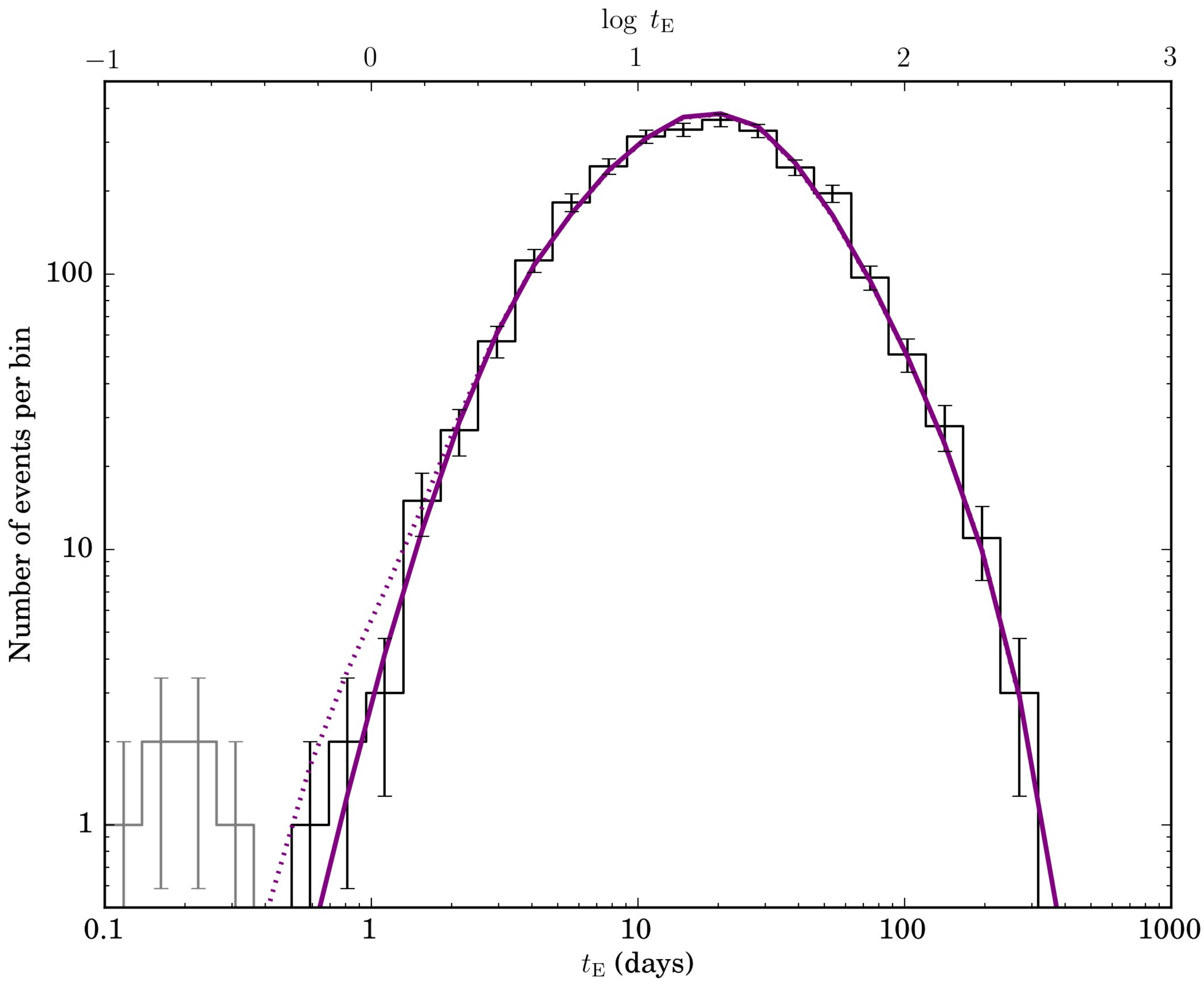
$$\Phi(M) = \begin{cases} a_1 M^{-\alpha_{bd}} & 0.01 M_\odot \leq M < 0.08 M_\odot \\ a_2 M^{-\alpha_{ms}} & 0.08 M_\odot \leq M < M_{break} \\ a_3 M^{-2.0} & M \geq M_{break} \end{cases}$$



- more sophisticated Galactic models are needed!

Mróz et al. 2017, Nature 548, 173

Jupiter-mass planets



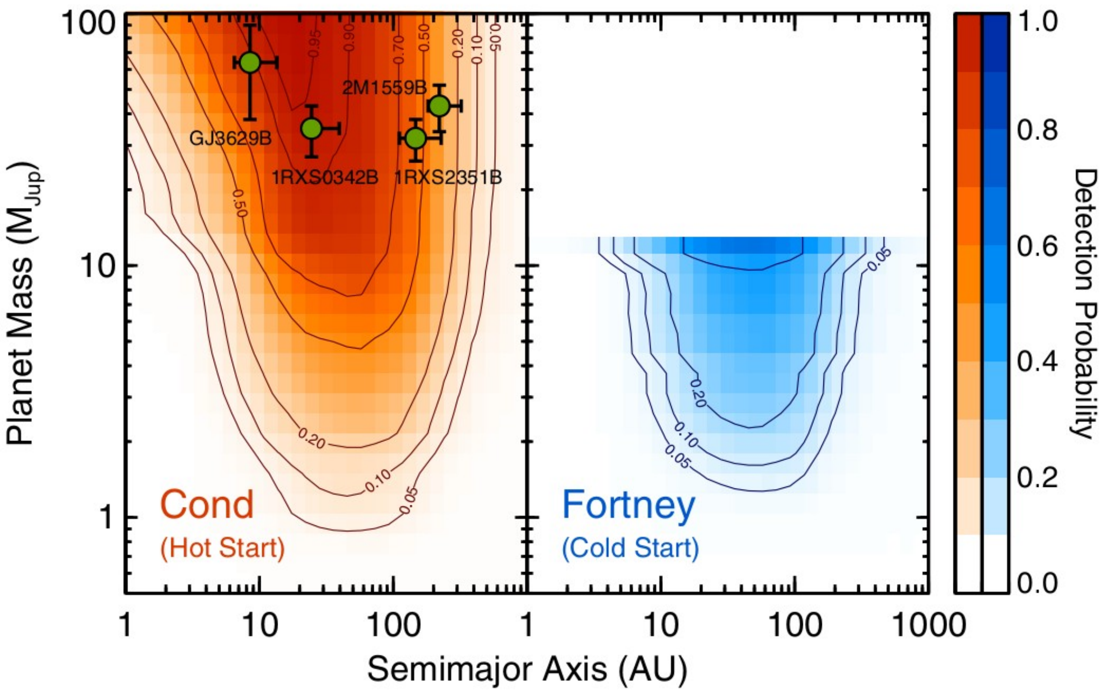
1 sigma: [0,0.12] Jupiter-mass planets per star
95%: < 0.25 Jupiter-mass planets per star

Mróz et al. 2017, Nature 548, 173

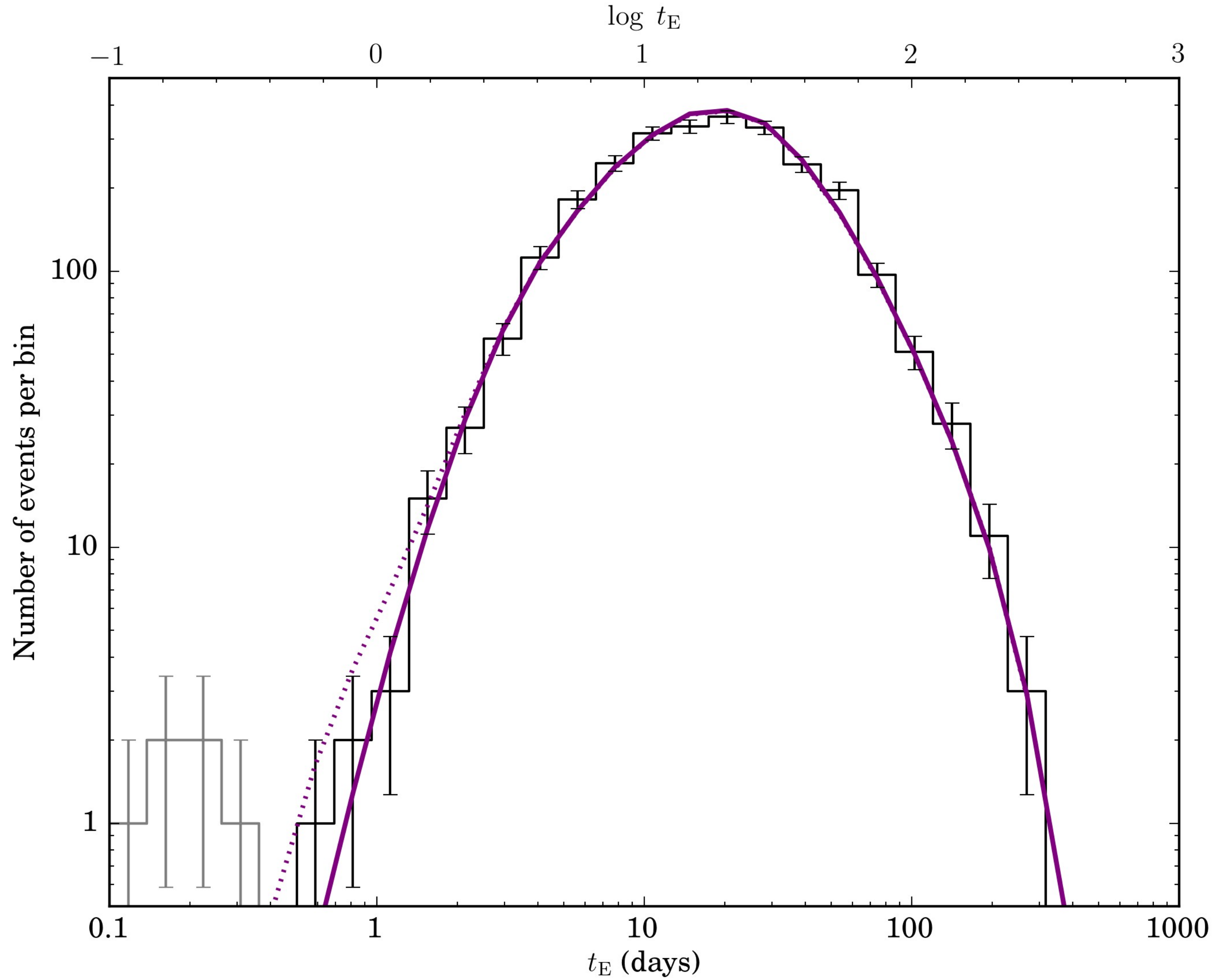
Jupiter-mass planets

- Constraints from direct imaging surveys:

  <10-16% M-type stars host a Jupiter-mass planet 1-13 M_{Jup} at 10-100 AU (Bowler+ 2015)

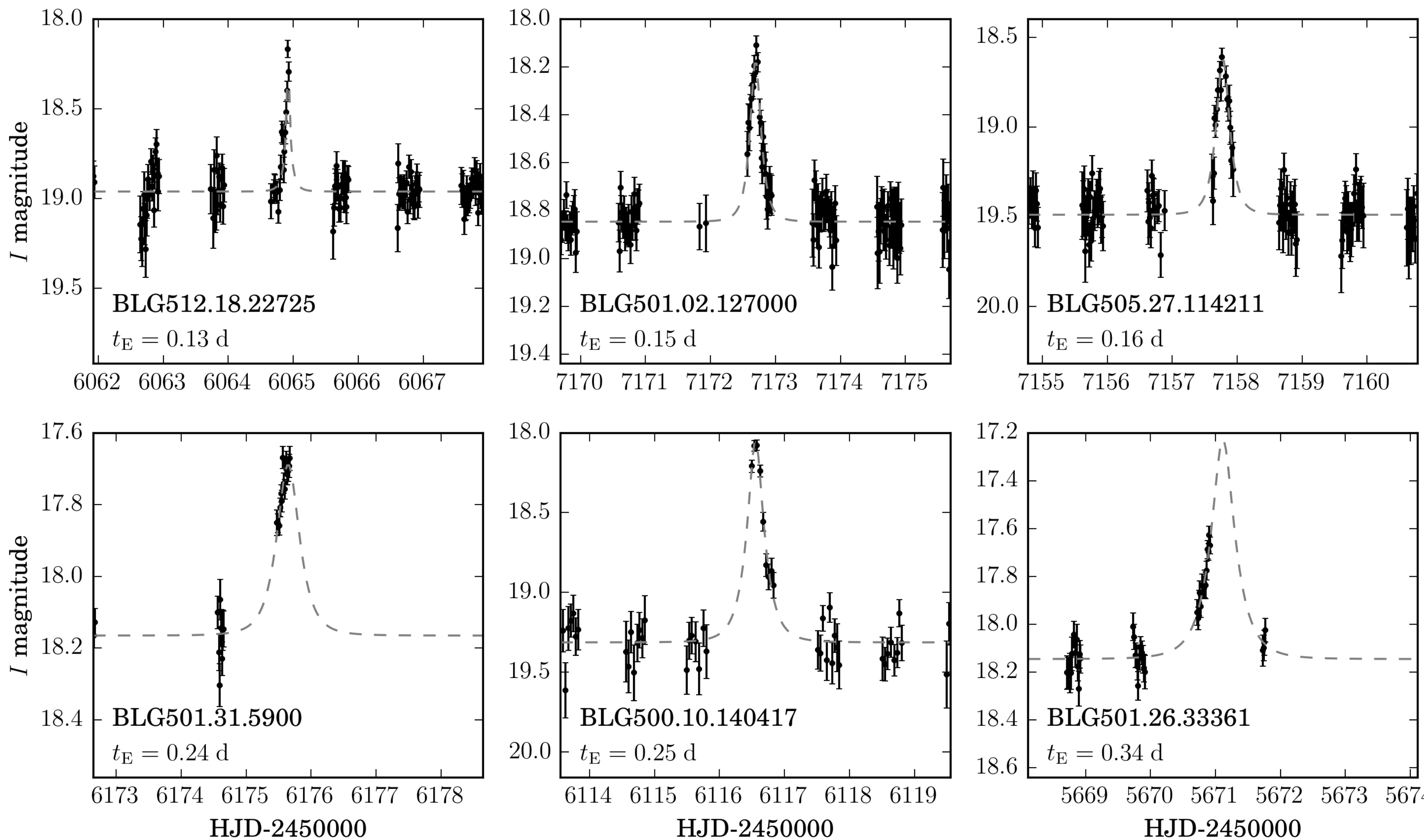


Free-floating Earths?



Mróz et al. 2017, Nature 548, 173

Free-floating Earths?

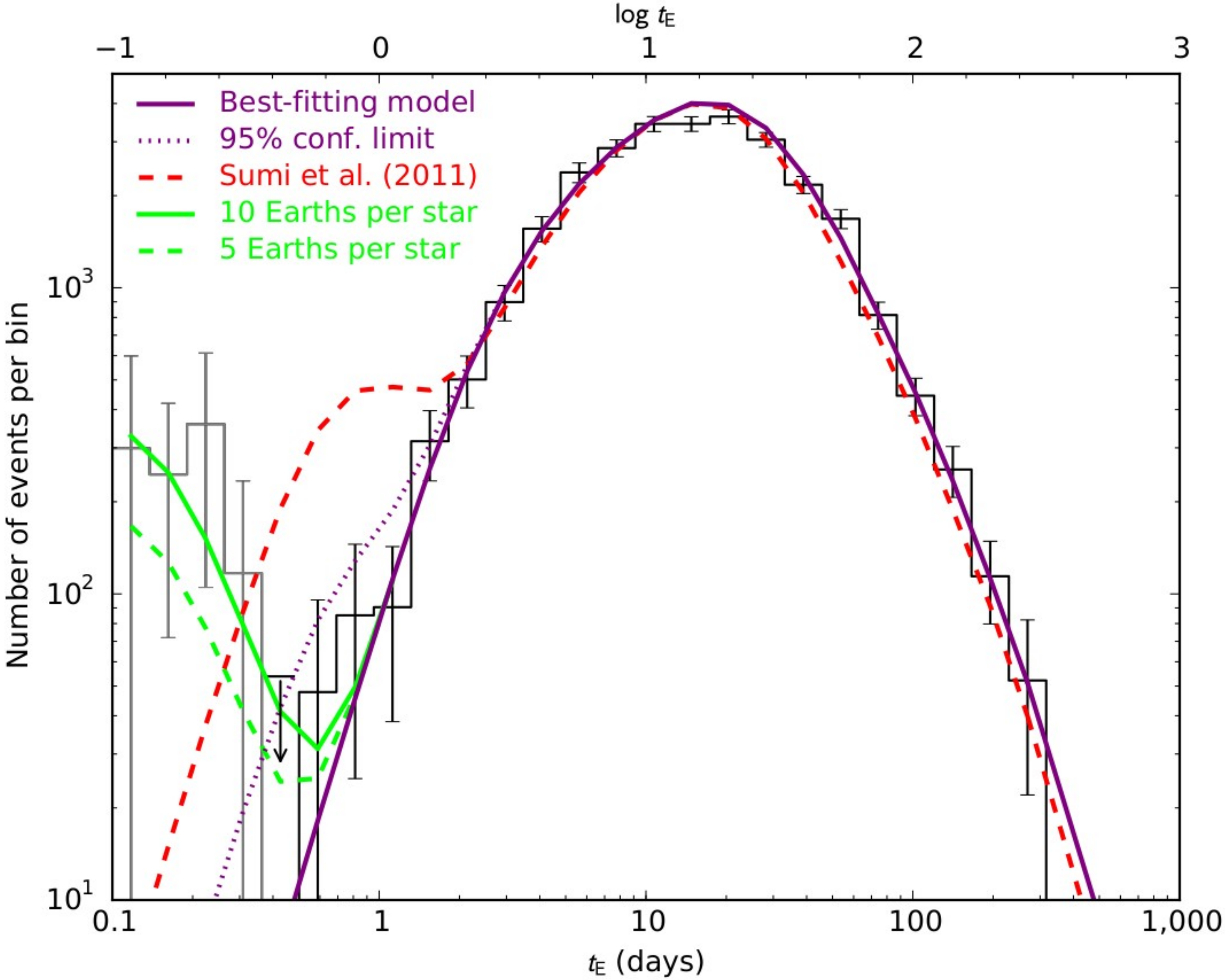


Timescales t_E ~ 0.1 – 0.4 d → mass 1-10 $M_{\oplus}$

No variability for 20 years of OGLE observations.

Mróz et al. 2017, Nature 548, 173

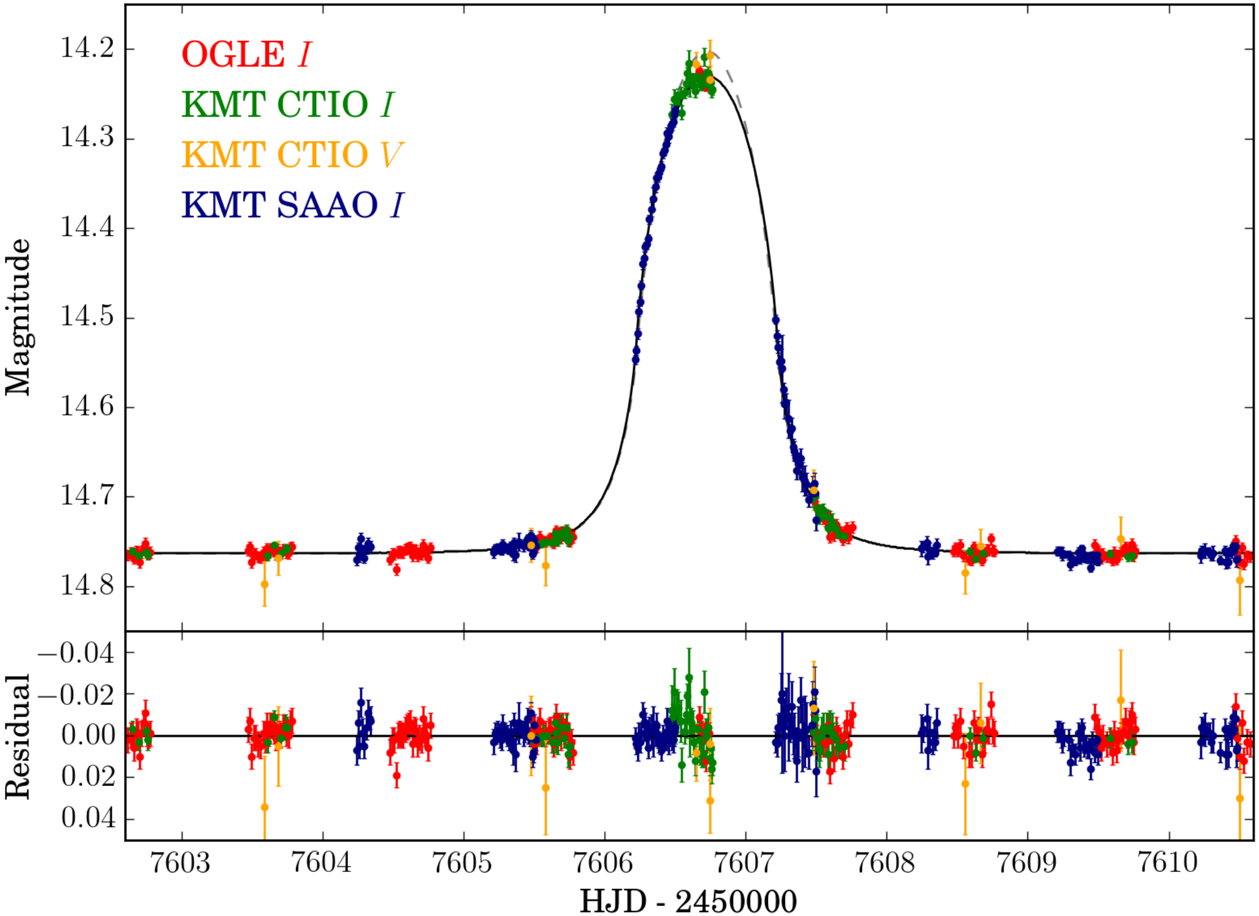
Free-floating Earths?



Are they more common than stars?

Mróz et al. 2017, Nature 548, 173

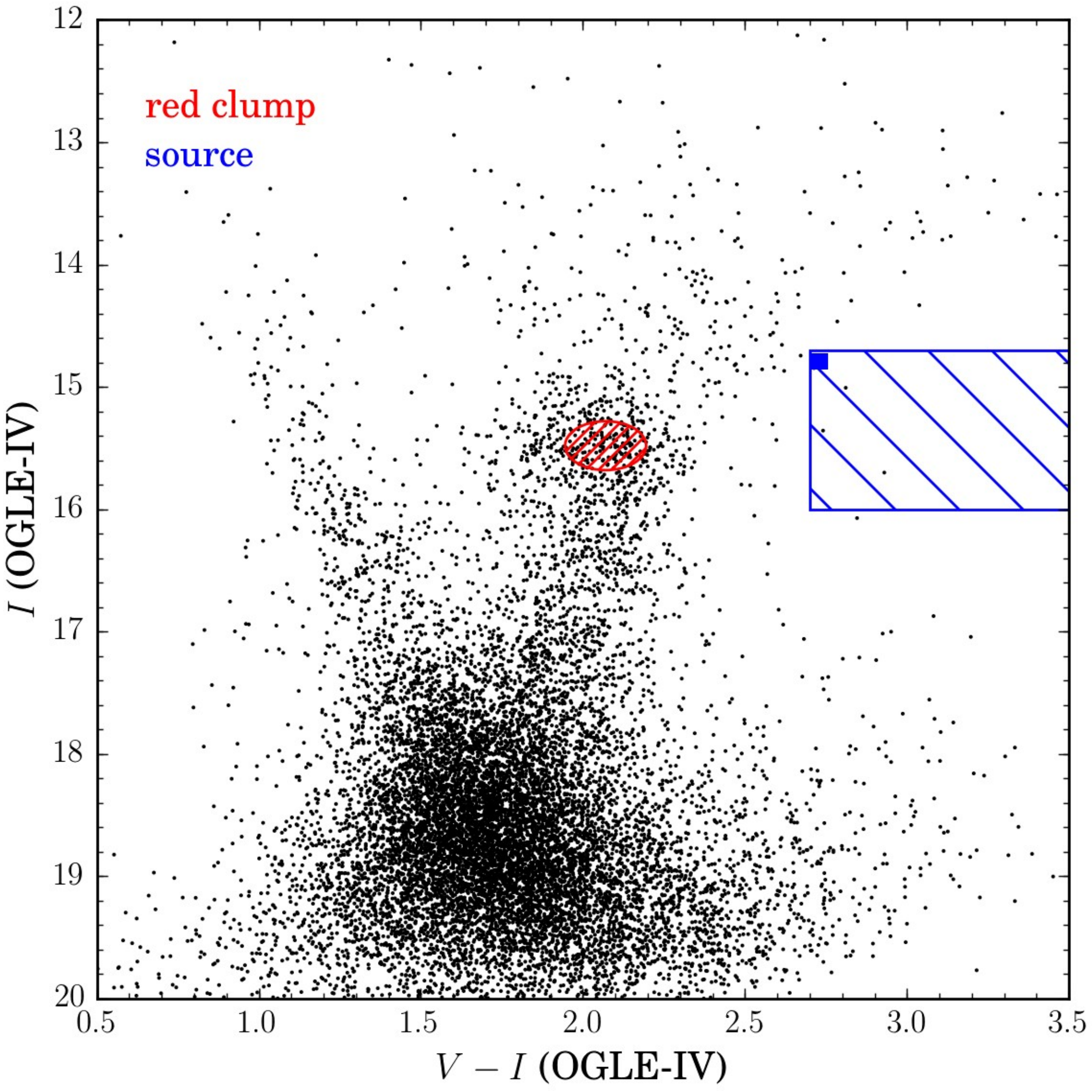
OGLE-2016-BLG-1540: rogue Neptune?



- t_E = 0.320 +/- 0.003 d
- prominent finite source effect
- ρ = 1.65 +/- 0.01
- no blending

Mróz et al., arXiv: 1712.01042

OGLE-2016-BLG-1540: rogue Neptune?

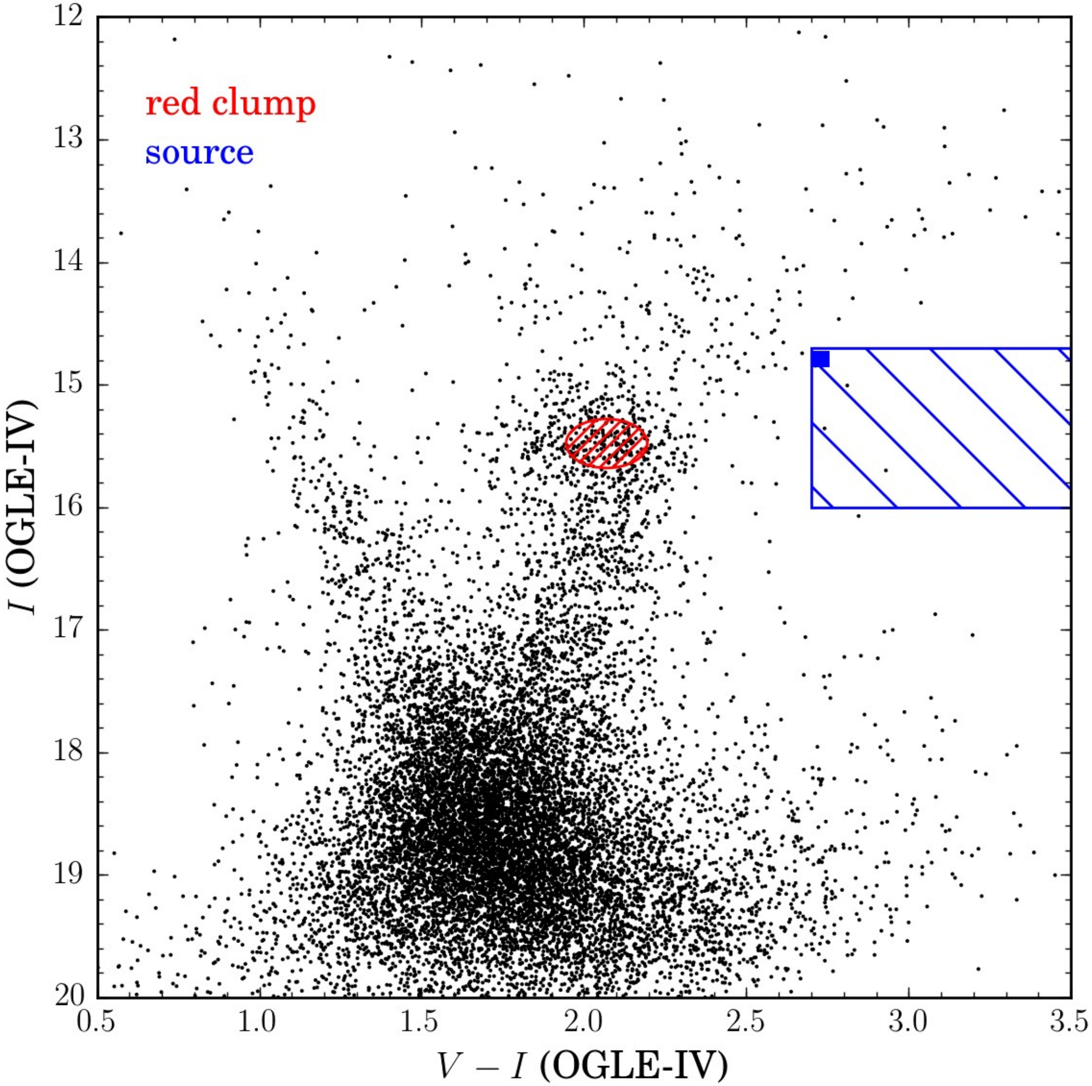


Mróz et al., arXiv: 1712.01042

- giant source

  $\rho_* = 15.1 \pm 0.8$ uas
- Einstein radius:
  $\theta_E = 9.2 \pm 0.5$ uas
- no finite source effect
  if the source were a dwarf

OGLE-2016-BLG-1540: rogue Neptune?



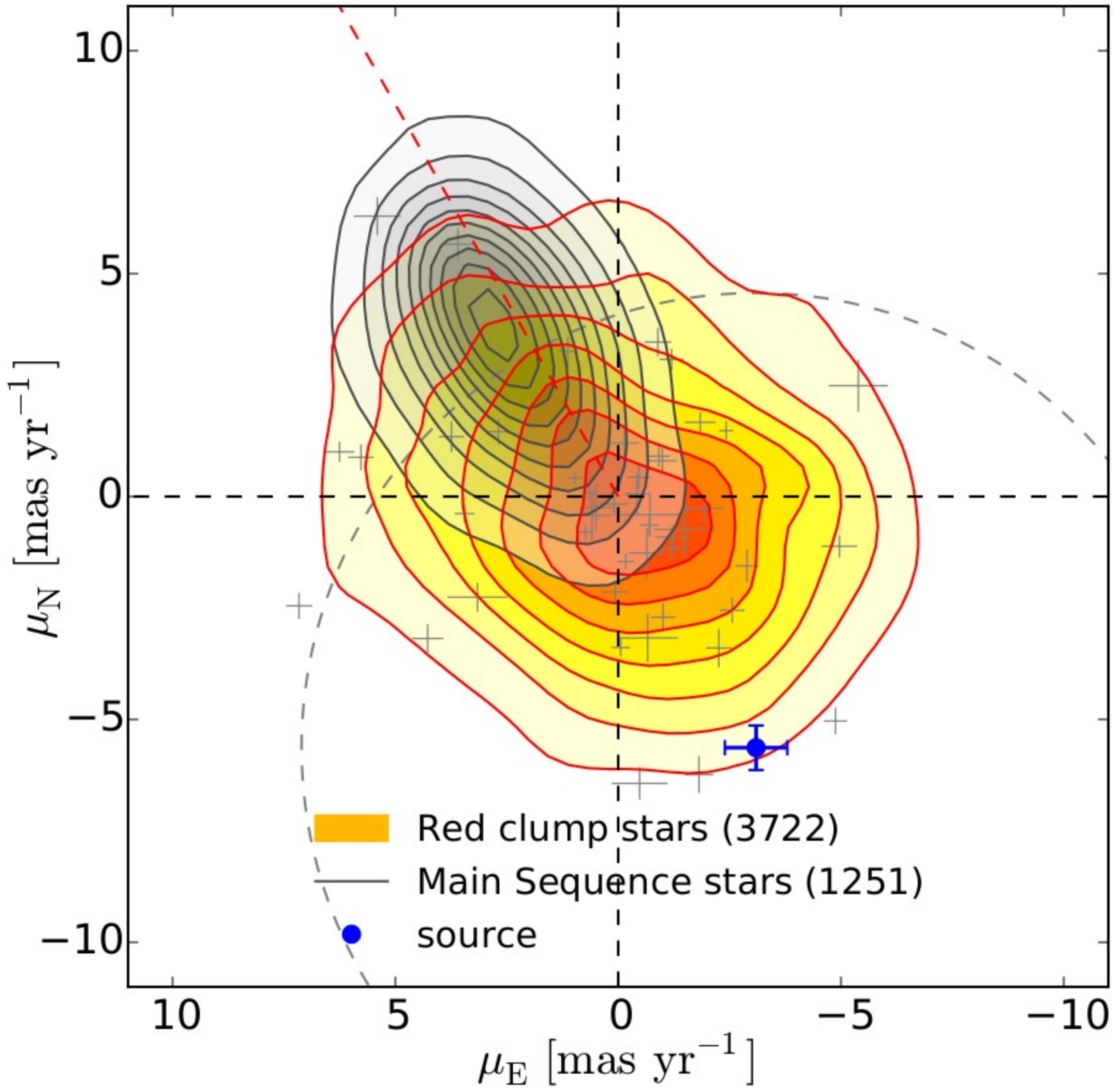
Mróz et al., arXiv: 1712.01042

- giant source

  $\rho_* = 15.1 \pm 0.8$ uas

- Einstein radius:
  $\theta_E = 9.2 \pm 0.5$ uas
- no finite source effect
  if the source were a dwarf
- no reliable terrestrial parallax (max. magnification 1.6)
- inside K2C9 superstamp

OGLE-2016-BLG-1540: rogue Neptune?



- L-S proper motion: μ_{rel} = 10.5 +/- 0.6 mas/yr
- proper motion of the source:

  μ_l = -6.4 +/- 0.8 mas/yr
  μ_b = -0.2 +/- 0.4 mas/yr

  (by Jan Skowron)
- source: bulge or far disk?

$$M = \frac{\theta_E^2}{\kappa \pi_{rel}} = 35\, M_\oplus \frac{0.1\,\mathrm{mas}}{\pi_{rel}}$$

Mróz et al., arXiv: 1712.01042

Summary

- over 2600 high-quality events from 5.5 years of OGLE-IV
- less than 0.25 free-floating Jupiter-mass planets per star
- numerous short-timescale binary events (BD+BD)
- hints of (super)Earth-mass free-floating planets!