Spitzer as Microlens Parallax Satellite

Binary Event OGLE-2014-BLG-1050

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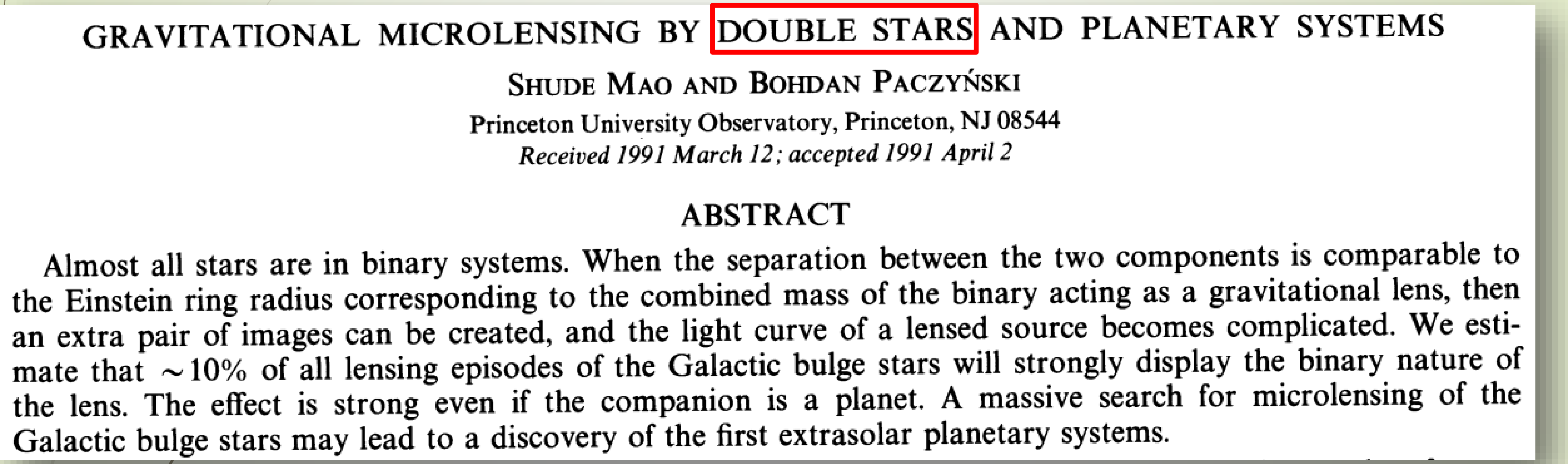
Microlensing: not only planets!



GRAVITATIONAL MICROLENSING BY DOUBLE STARS AND PLANETARY SYSTEMS

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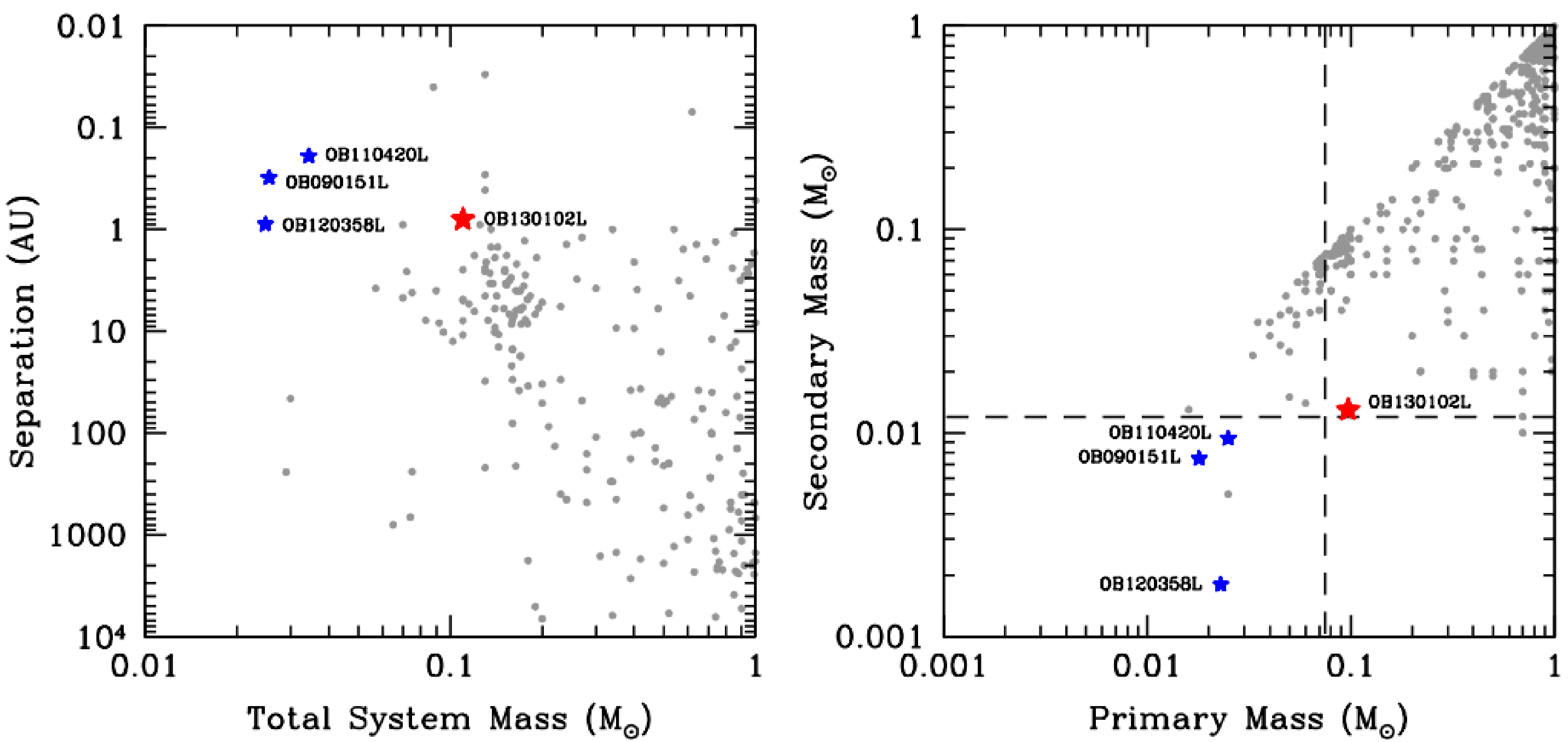
ABSTRACT

Almost all stars are in binary systems. When the separation between the two components is comparable to the Einstein ring radius corresponding to the combined mass of the binary acting as a gravitational lens, then an extra pair of images can be created, and the light curve of a lensed source becomes complicated. We estimate that ~10% of all lensing episodes of the Galactic bulge stars will strongly display the binary nature of the lens. The effect is strong even if the companion is a planet. A massive search for microlensing of the Galactic bulge stars may lead to a discovery of the first extrasolar planetary systems.

- Binary events
  - More than planetary events
  - More often crossing caustics
  - Full Keplerian orbits

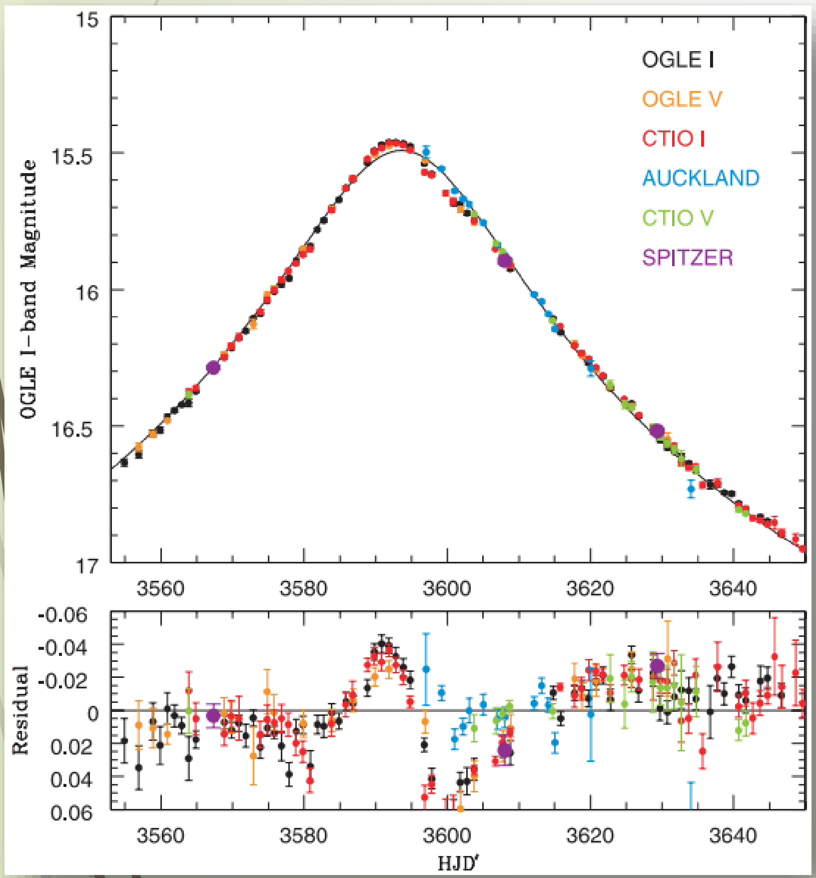
Previous interesting systems

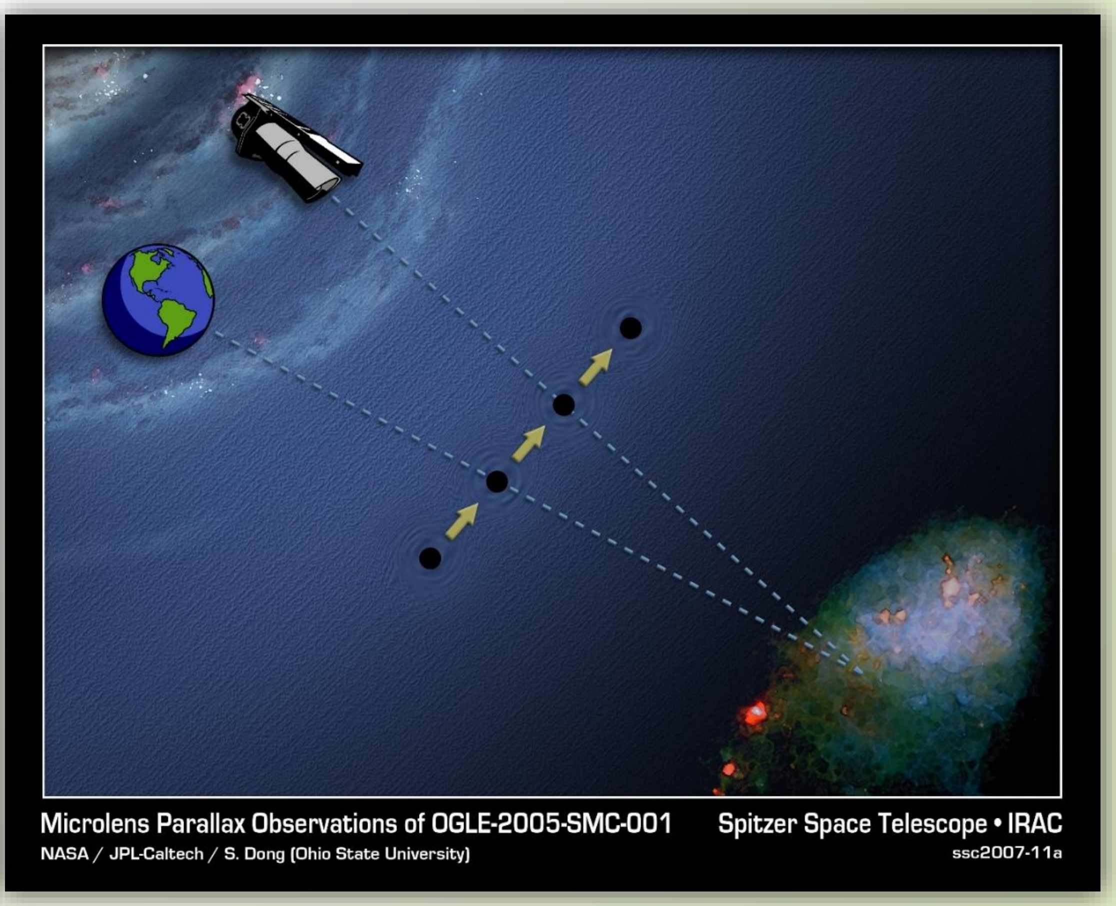
- BD binaries (Choi et al. 2013; Han et al. 2013; Jung et al. 2015)



Previous interesting systems

- Stellar remnants: ~20% (Gould 2000)
  - OGLE-2005-SMC-001(?), (Dong++2007)




Microlens Parallax Observations of OGLE-2005-SMC-001 Spitzer Space Telescope • IRAC
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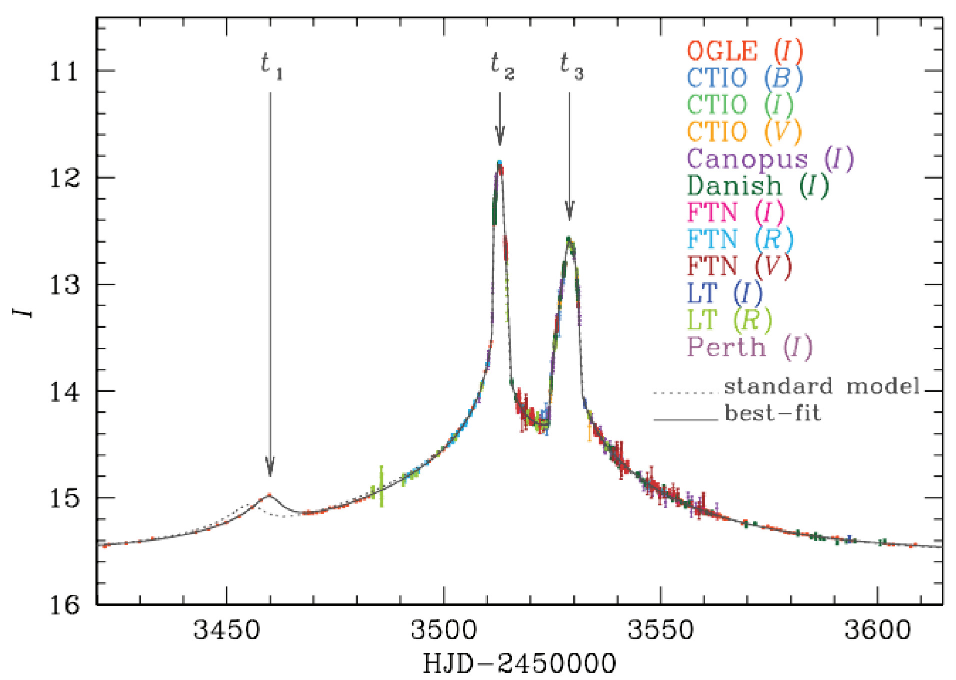
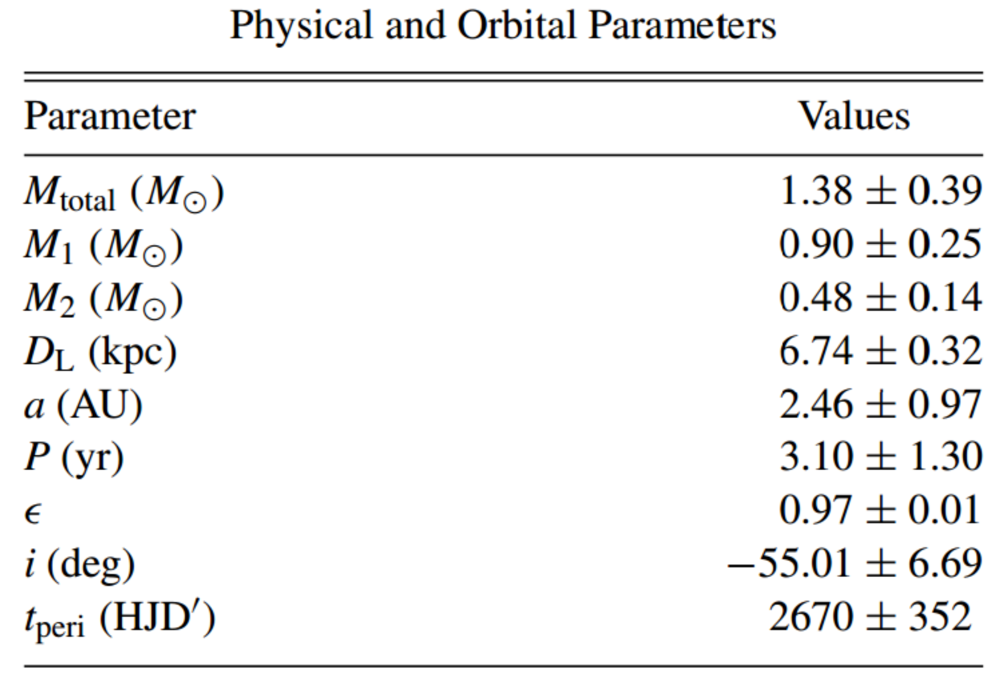
Interesting systems

- Full Keplerian orbit
  - e.g., OGLE-2005-BLG-018, Shin++2011





Physical and Orbital Parameters

Parameter	Values
$M_{\rm total}$ ($M_\odot$)	1.38 ± 0.39
M_1 ($M_\odot$)	0.90 ± 0.25
M_2 ($M_\odot$)	0.48 ± 0.14
$D_{\rm L}$ (kpc)	6.74 ± 0.32
a (AU)	2.46 ± 0.97
P (yr)	3.10 ± 1.30
ϵ	0.97 ± 0.01
i (deg)	-55.01 ± 6.69
$t_{\rm peri}$ (HJD$'$)	2670 ± 352

Microlensing: why go to space?

- **What we need to measure mass:**
  - Finite-source effect (proper motion measurement)
  - Parallax measurement

Finite-source effect;
Relative proper motion

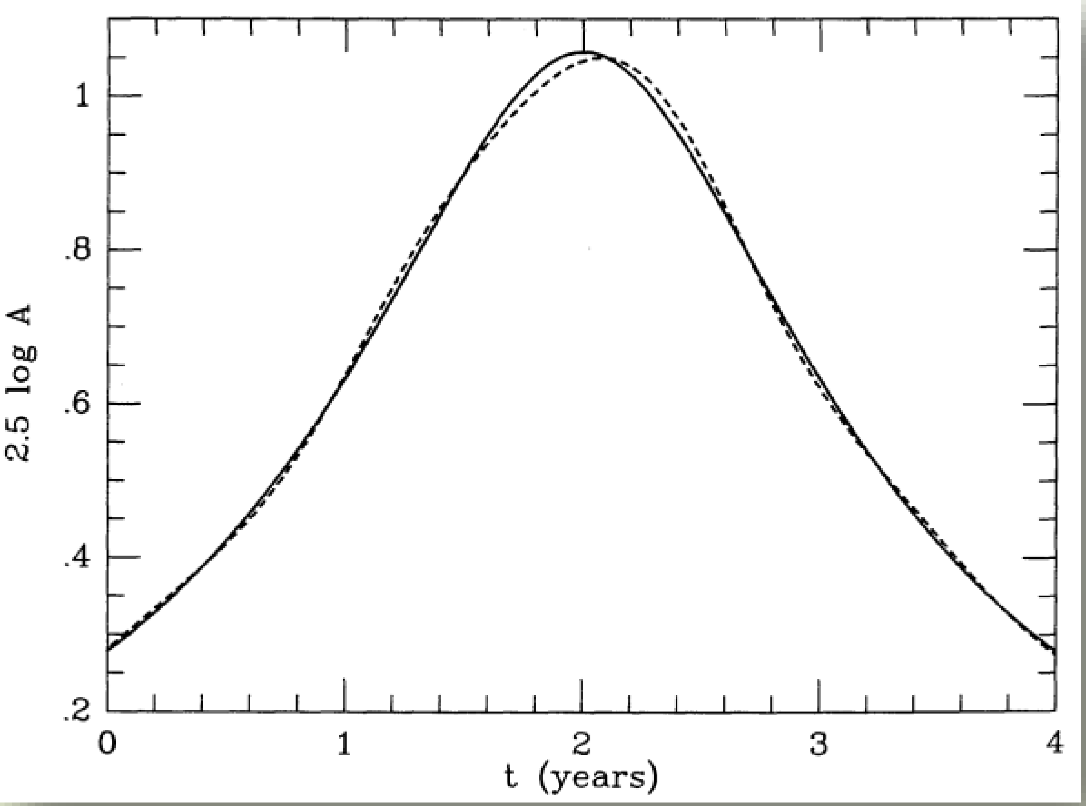
Parallax parameter

$$\theta_{\mathrm{E}} = \sqrt{\kappa M_{\mathrm{L}} \pi_{\mathrm{rel}}}; \quad \kappa \equiv \frac{4G}{c^2 \mathrm{AU}} \approx 8.14 \frac{\mathrm{mas}}{M_\odot}$$

$$\pi_{\mathrm{rel}} \equiv \pi_{\mathrm{L}} - \pi_{\mathrm{S}} = \mathrm{AU}\left(\frac{1}{D_{\mathrm{L}}} - \frac{1}{D_{\mathrm{S}}}\right)$$

Microlensing: why go to space?

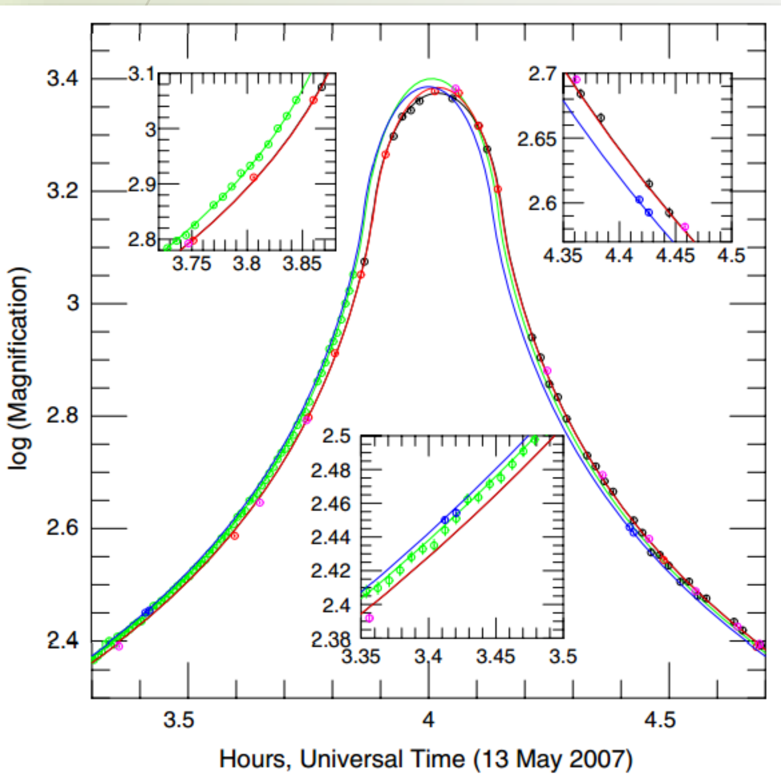
- **Earth acceleration**
  - Biased: nearby, large t_E
  - Degeneracy: xallarap; orbital motion

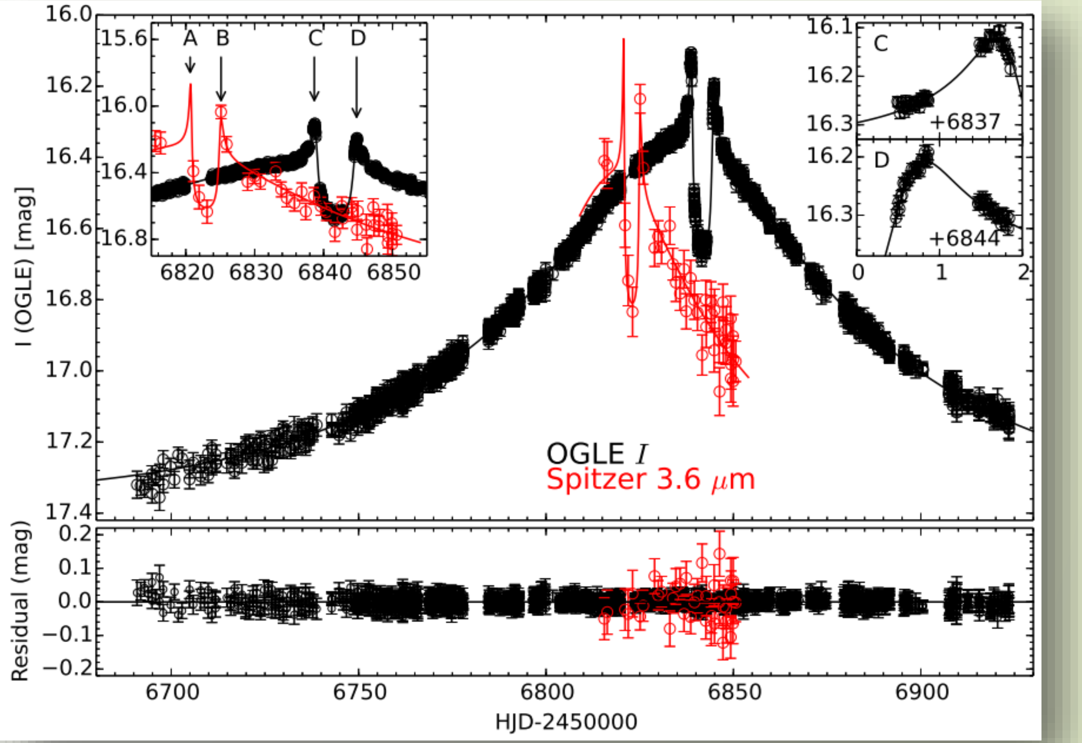


Gould (1992)

Microlensing: why go to space?

- **Terrestrial parallax** *vs.* **space-based parallax**





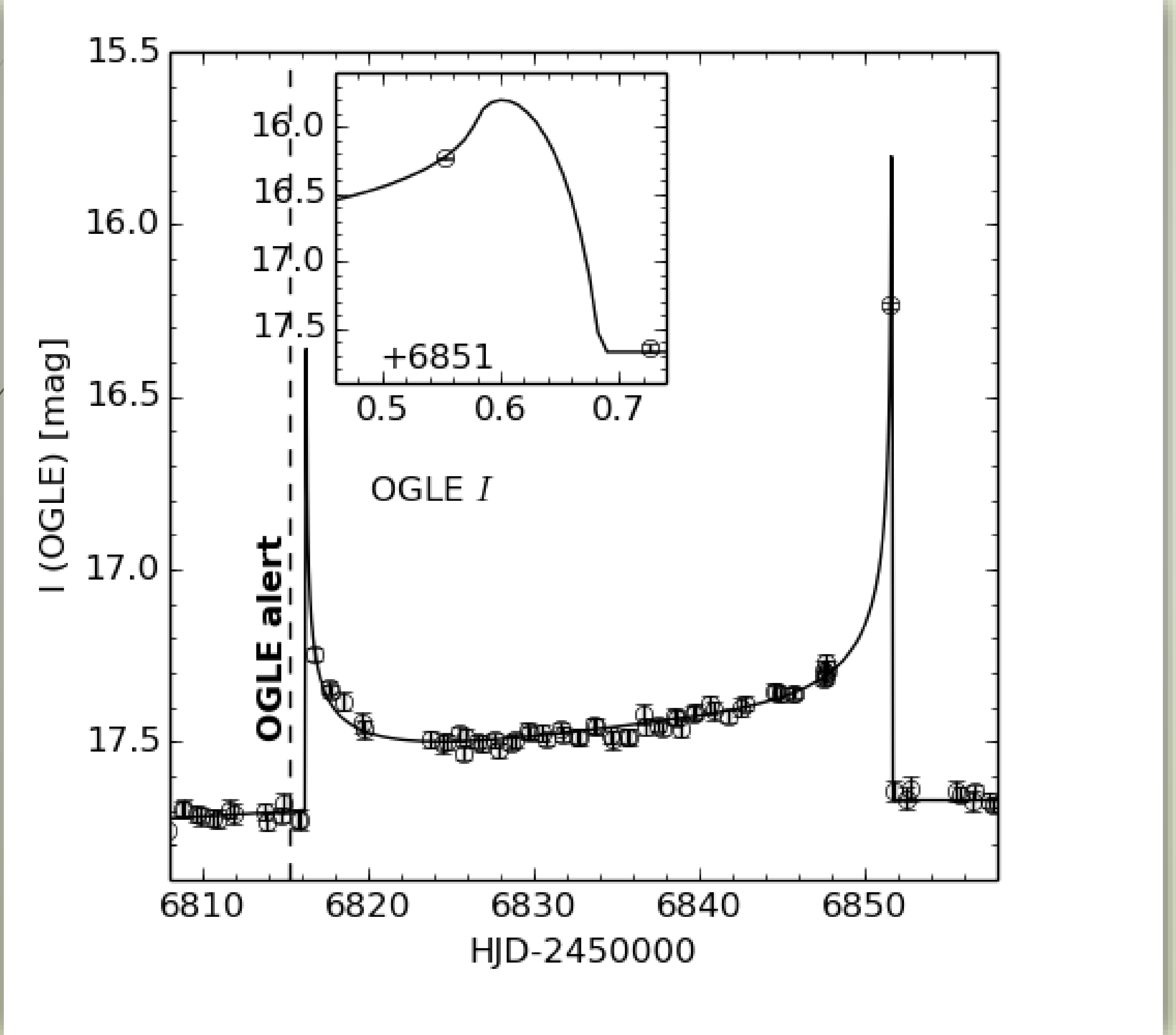
OGLE-2007-BLG-224 (Gould et al. 2009)

OGLE-2014-BLG-0124 (Udalski et al. 2014)

Why Spitzer?

- Earth-trailing orbit
- large projected separation

OB141050 **Observations**



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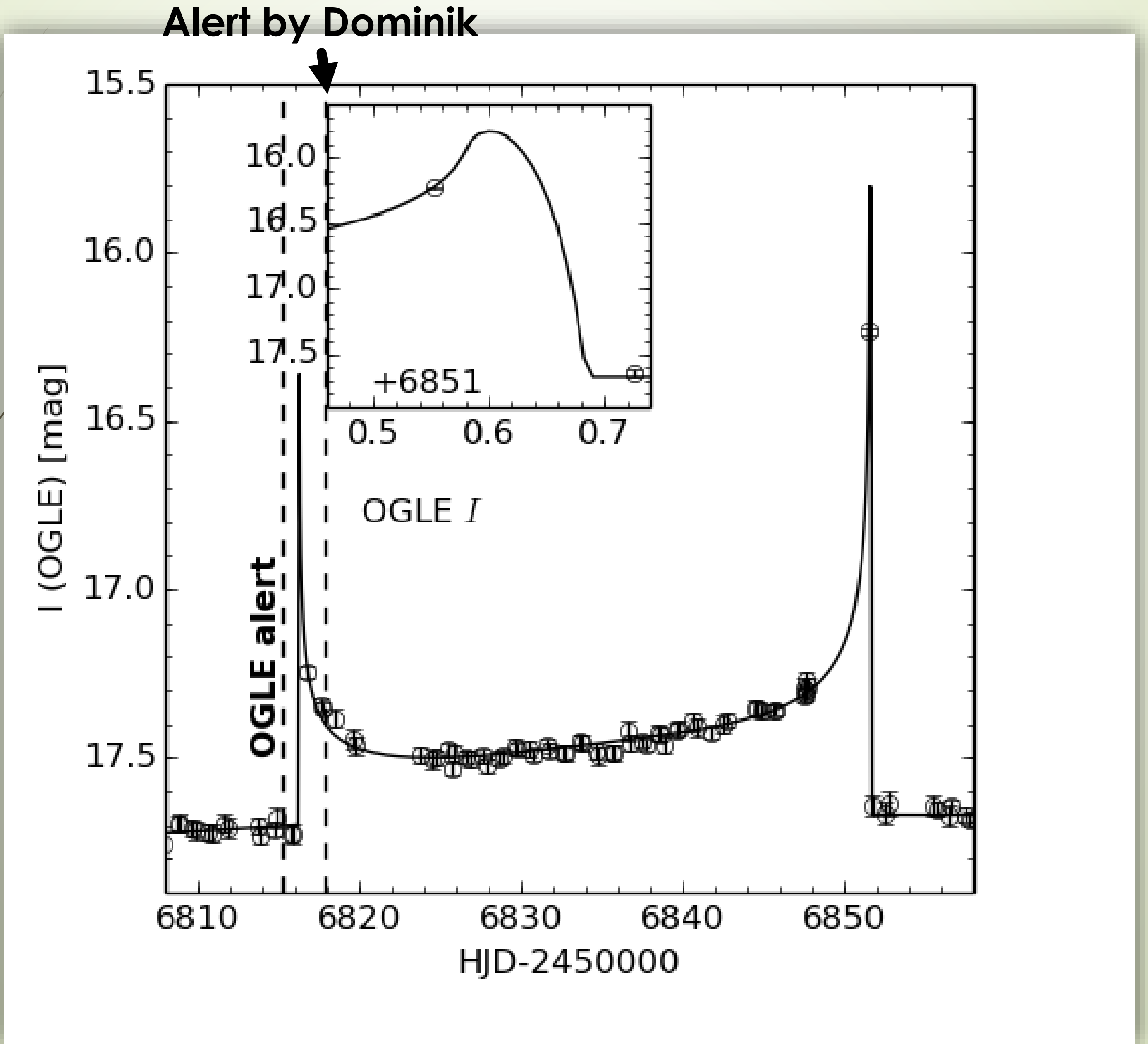
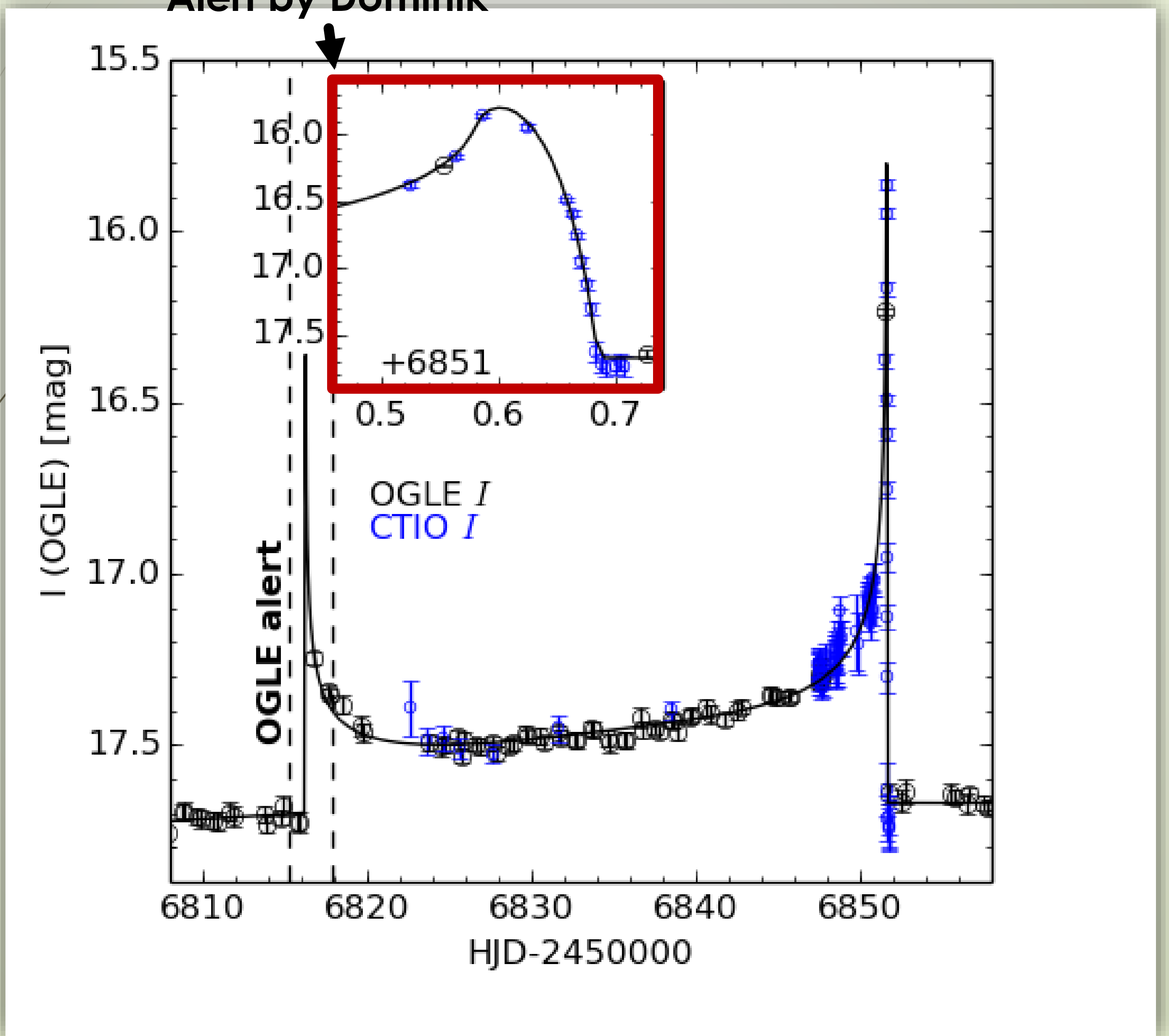
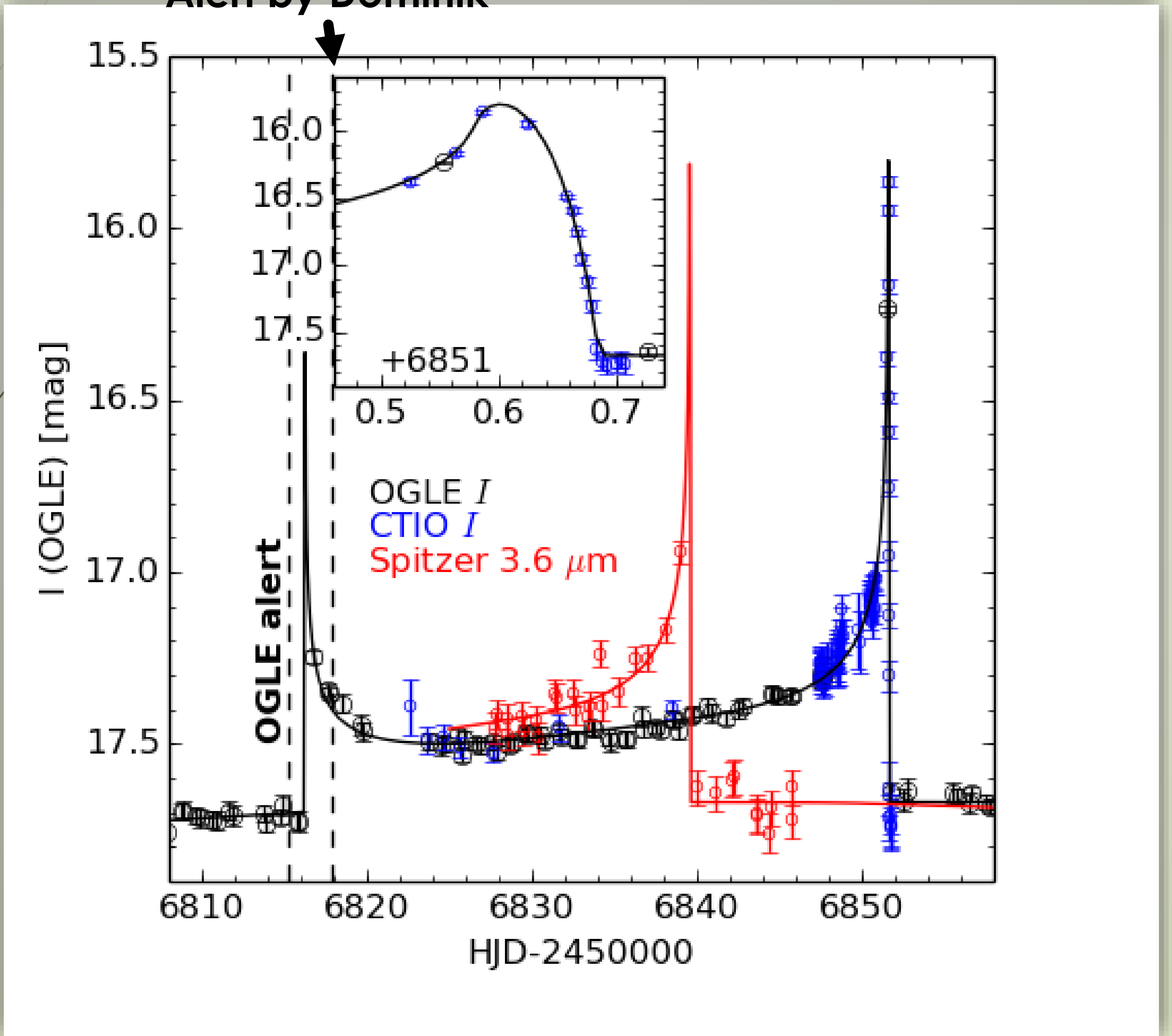


Follow-ups: capture caustic exit

Alert by Dominik

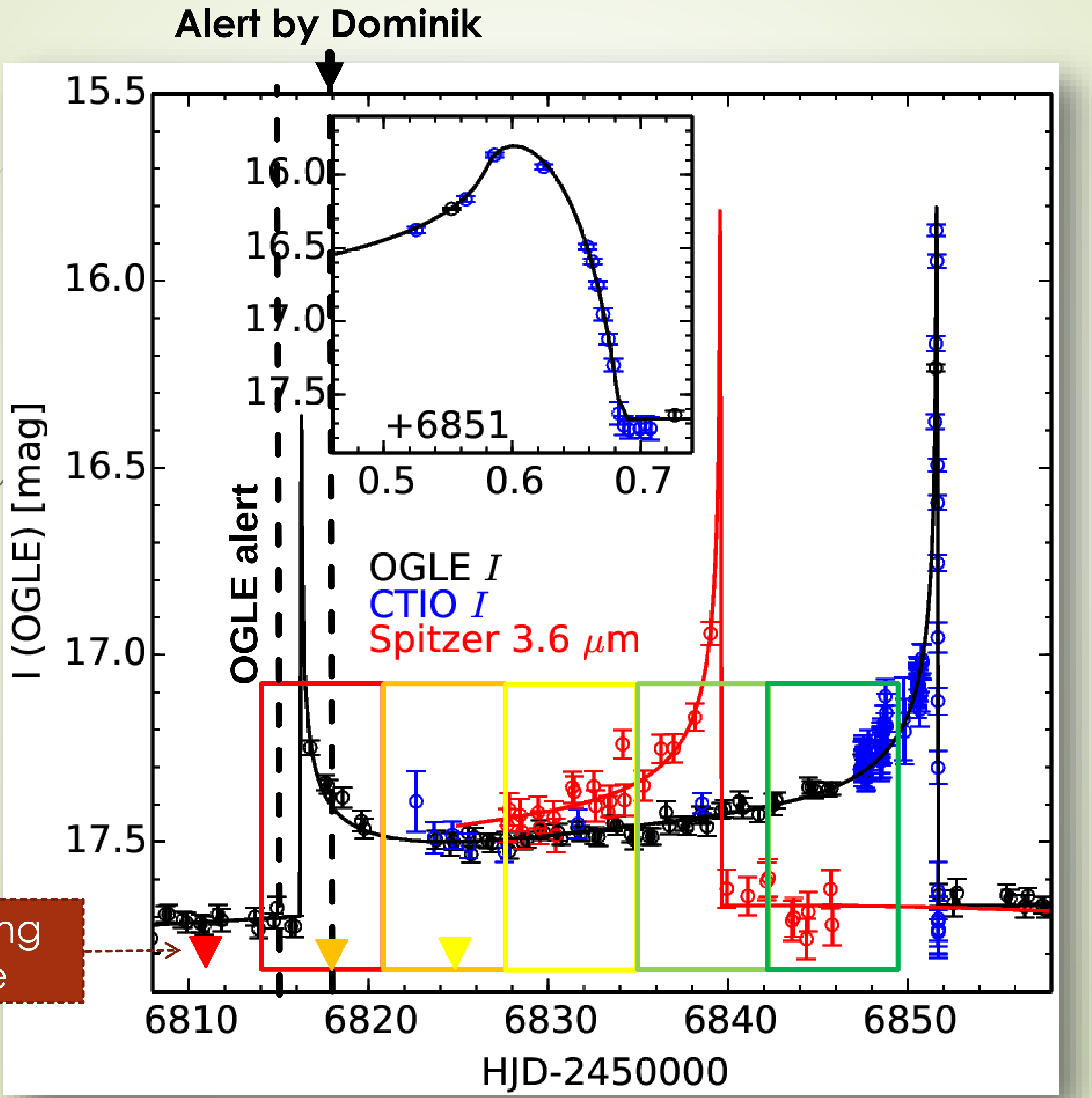


Spitzer observations



Alert by Dominik

Follow-up observations: Spitzer

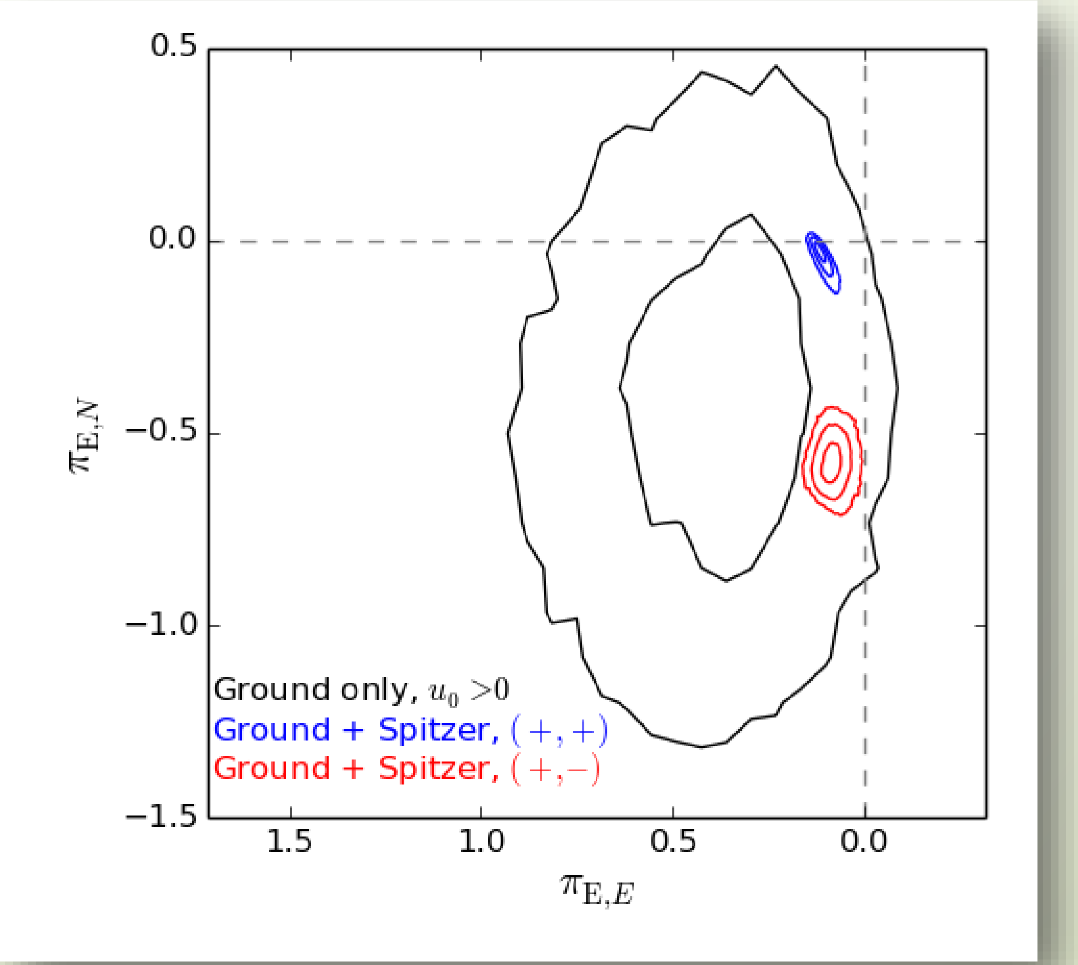


Week 1
Week 2
Week 3
Week 4
Week 5

Spitzer observing protocol due

Light curve modeling

- Parameterization: t_{ce} (Cassan 2008)
- Inclusion of Spitzer data

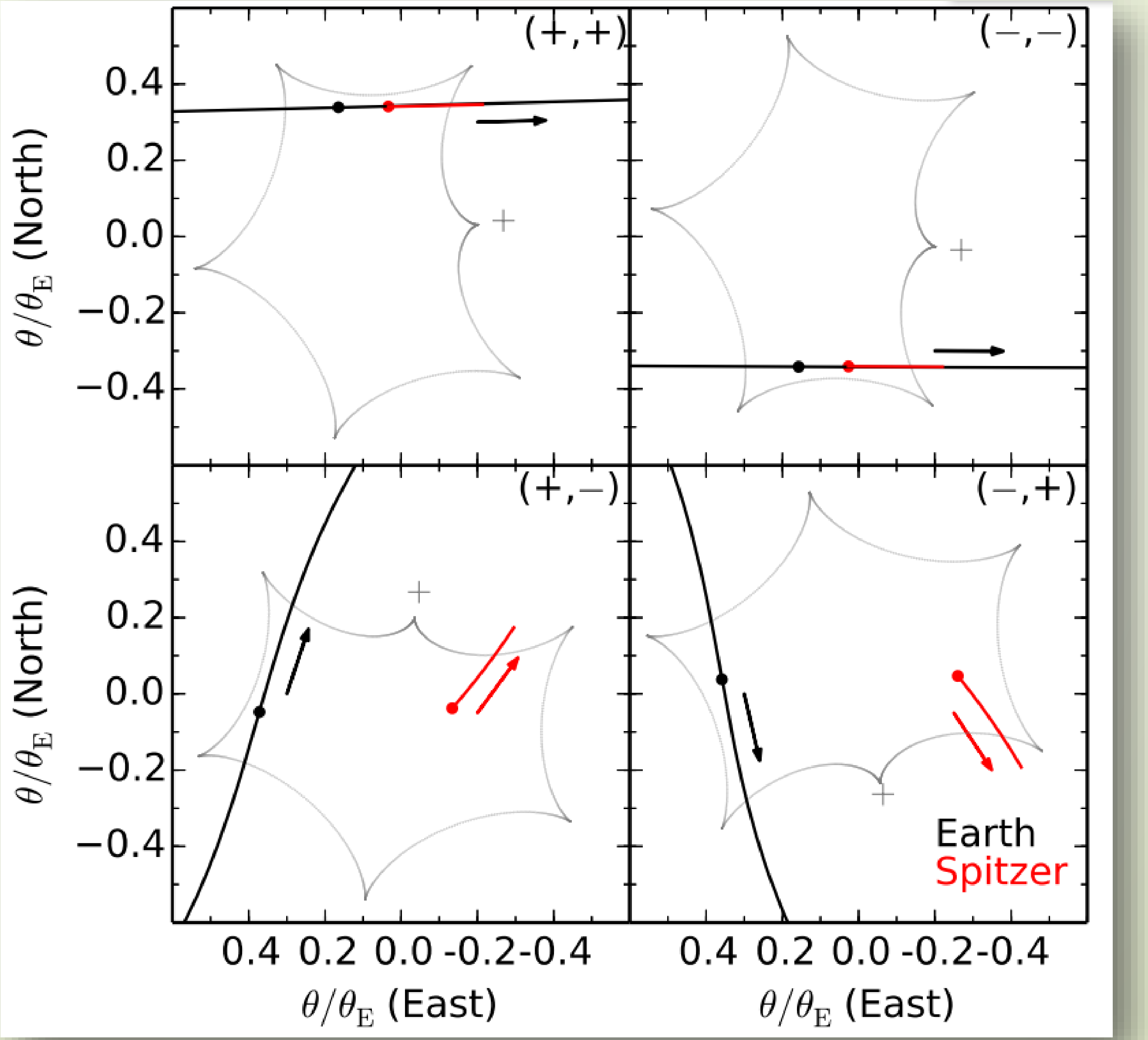


Light curve modeling

- Parameterization: t_{ce} (Cassan 2008)
- Inclusion of Spitzer data
- Inclusion of binary orbital motion
    - dchi^2 ~ 5
    - Enlarges uncertainty on q (Park et al. 2013)

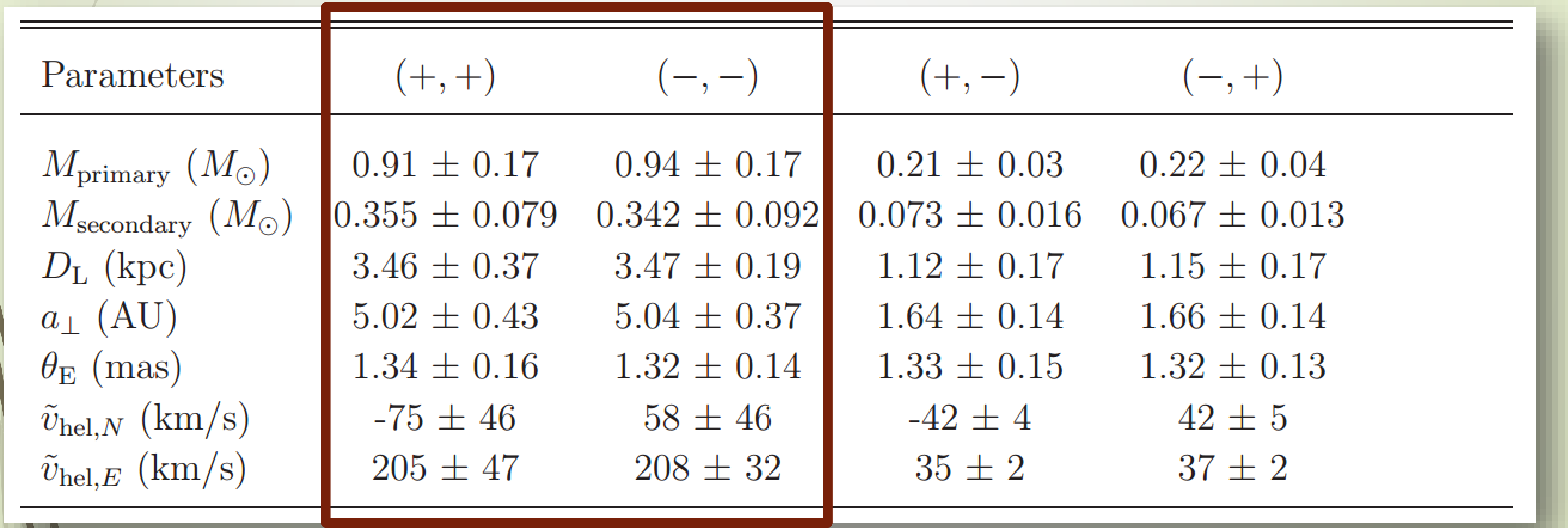
Light curve modeling

- Four-fold degeneracy



Physical Parameters

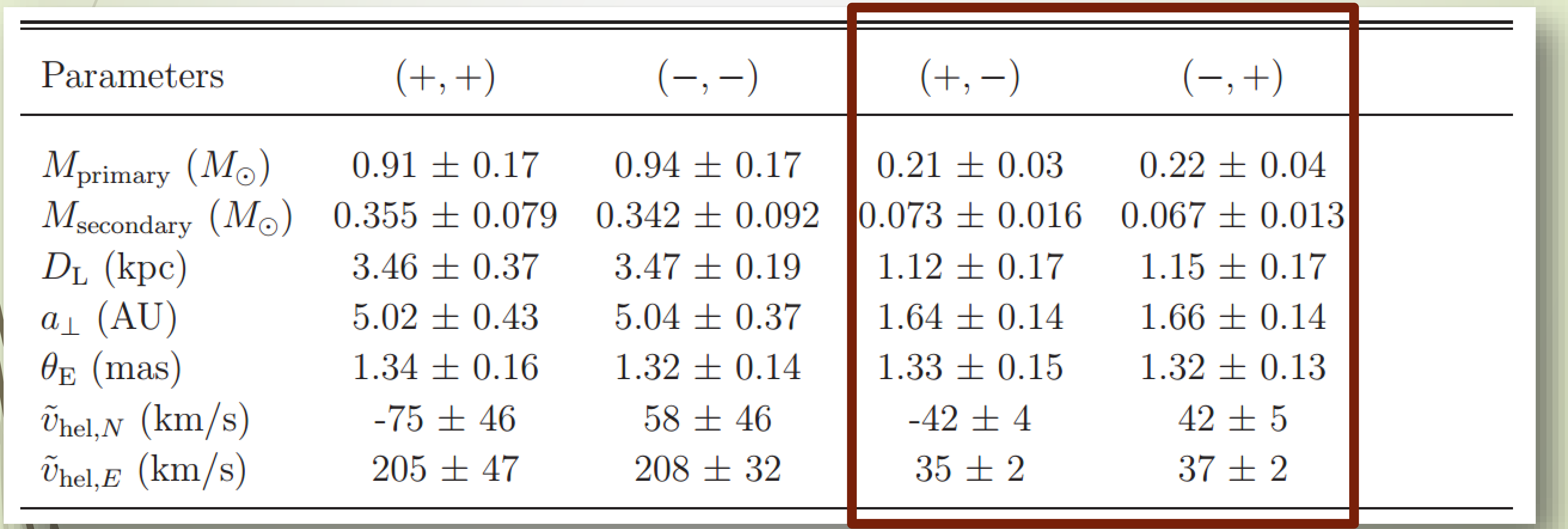
- Two physical solutions
  - **High-mass binary**
  - Low-mass binary



Parameters	$(+,+)$	$(-,-)$	$(+,-)$	$(-,+)$
M_{primary} $(M_\odot)$	0.91 ± 0.17	0.94 ± 0.17	0.21 ± 0.03	0.22 ± 0.04
$M_{\text{secondary}}$ $(M_\odot)$	0.355 ± 0.079	0.342 ± 0.092	0.073 ± 0.016	0.067 ± 0.013
D_{L} (kpc)	3.46 ± 0.37	3.47 ± 0.19	1.12 ± 0.17	1.15 ± 0.17
$a_\perp$ (AU)	5.02 ± 0.43	5.04 ± 0.37	1.64 ± 0.14	1.66 ± 0.14
θ_{E} (mas)	1.34 ± 0.16	1.32 ± 0.14	1.33 ± 0.15	1.32 ± 0.13
$\tilde{v}_{\text{hel},N}$ (km/s)	-75 ± 46	58 ± 46	-42 ± 4	42 ± 5
$\tilde{v}_{\text{hel},E}$ (km/s)	205 ± 47	208 ± 32	35 ± 2	37 ± 2

Physical Parameters

- Two physical solutions
  - High-mass binary
  - **Low-mass binary**



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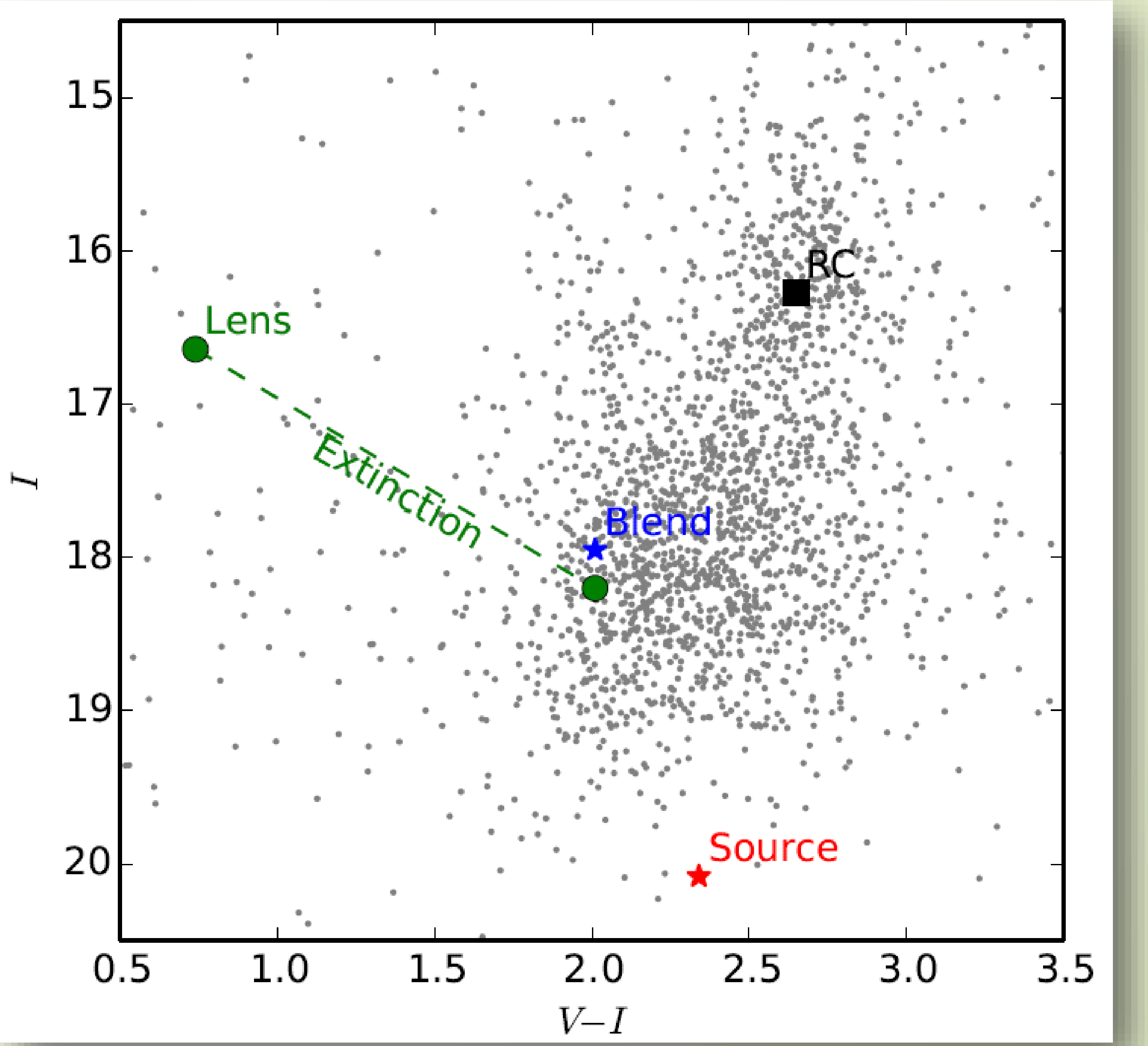
Source & Blend characterization

Use *I* & *H*

Source: turn-off star in the Bulge

Severely blended



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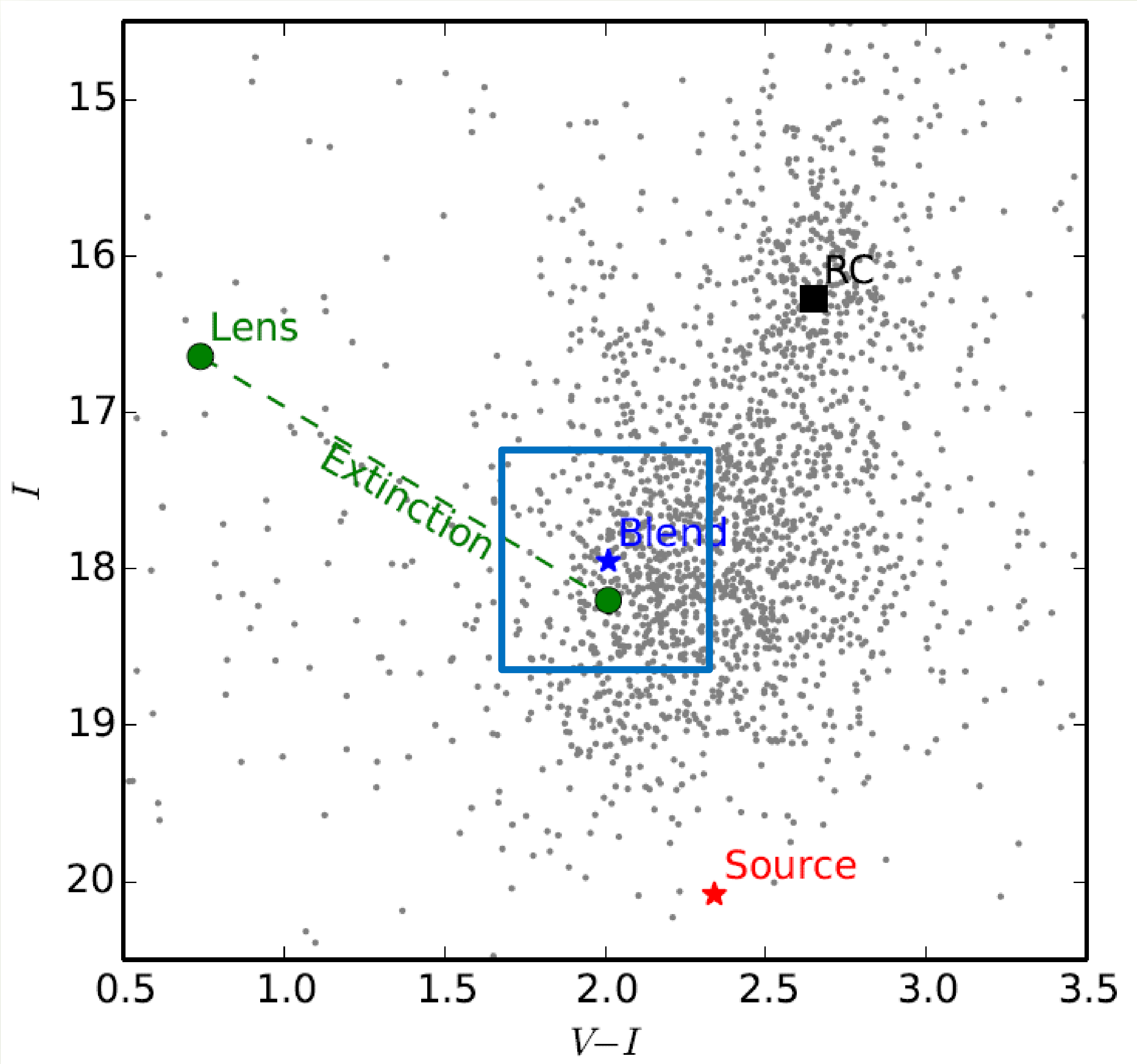
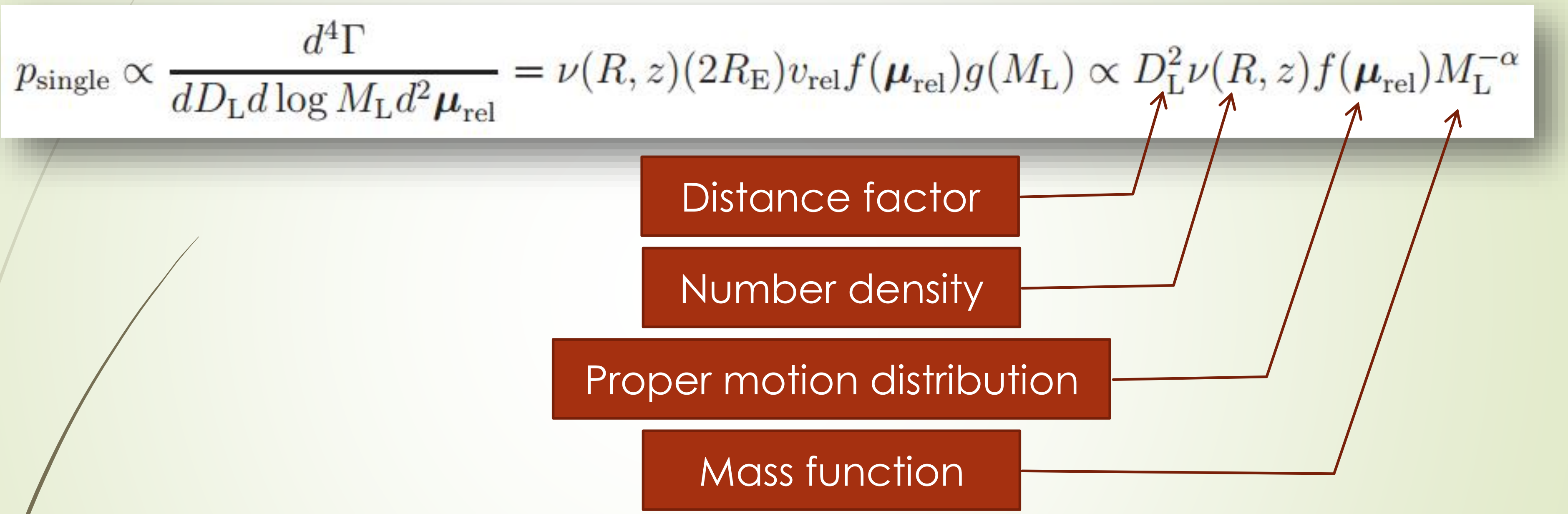


Lensing probability

- Single-lens prob (Batista et al. 2011)



$$p_{\mathrm{single}} \propto \frac{d^4\Gamma}{dD_{\mathrm{L}}\,d\log M_{\mathrm{L}}\,d^2\boldsymbol{\mu}_{\mathrm{rel}}} = \nu(R,z)(2R_{\mathrm{E}})v_{\mathrm{rel}}f(\boldsymbol{\mu}_{\mathrm{rel}})g(M_{\mathrm{L}}) \propto D_{\mathrm{L}}^2\nu(R,z)f(\boldsymbol{\mu}_{\mathrm{rel}})M_{\mathrm{L}}^{-\alpha}$$

Distance factor

Number density

Proper motion distribution

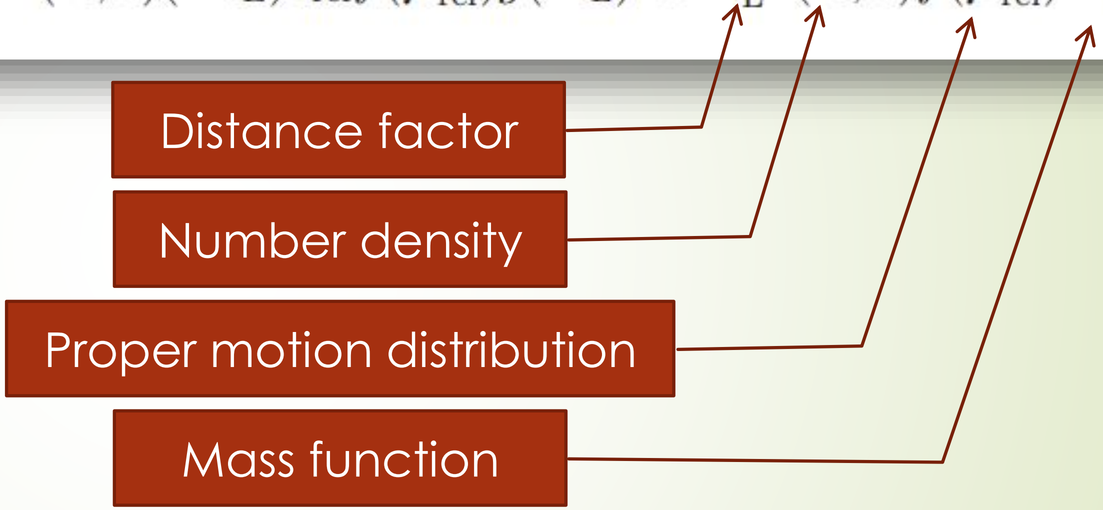
Mass function

- Double-lens correction
  - Mass ratio
  - Semi-major axis
  - Multiplicity

Lensing probability

- Single-lens prob (Batista et al. 2011)

$$p_{\rm single} \propto \frac{d^4\Gamma}{dD_{\rm L}\,d\log M_{\rm L}\,d^2\boldsymbol{\mu}_{\rm rel}} = \nu(R,z)(2R_{\rm E})v_{\rm rel}f(\boldsymbol{\mu}_{\rm rel})g(M_{\rm L}) \propto D_{\rm L}^2\nu(R,z)f(\boldsymbol{\mu}_{\rm rel})M_{\rm L}^{-\alpha}$$



Distance factor

Number density

Proper motion distribution

Mass function

- Double-lens correction
  - Mass ratio
  - Semi-major axis
  - Multiplicity

$P_{\text{high-mass binary}} / P_{\text{low-mass binary}} \approx 2$

Comparison with ob0124

- Uncertainty in π_E
  - Can be improved with more Spitzer observations
- Four-fold degeneracy
  - Coincidence for ob1050
  - Not for K2 & WFIRST

Summary

- Microlensing can find interesting binary systems
- Caustic-crossing binary event OGLE-2014-BLG-1050
    - Four-fold degeneracy in binary event
    - Blending & lensing probability
    - 0.9 M_sun + 0.35 M_sun @ 3.5 kpc
- Galactic distribution of binaries from microlensing

Towards a Galactic distribution of binaries?

Why interesting?

- Binary formation in different environment
- Binary vs. planets