Analysis of the Single Lensing Event OGLE-2015-BLG-1482

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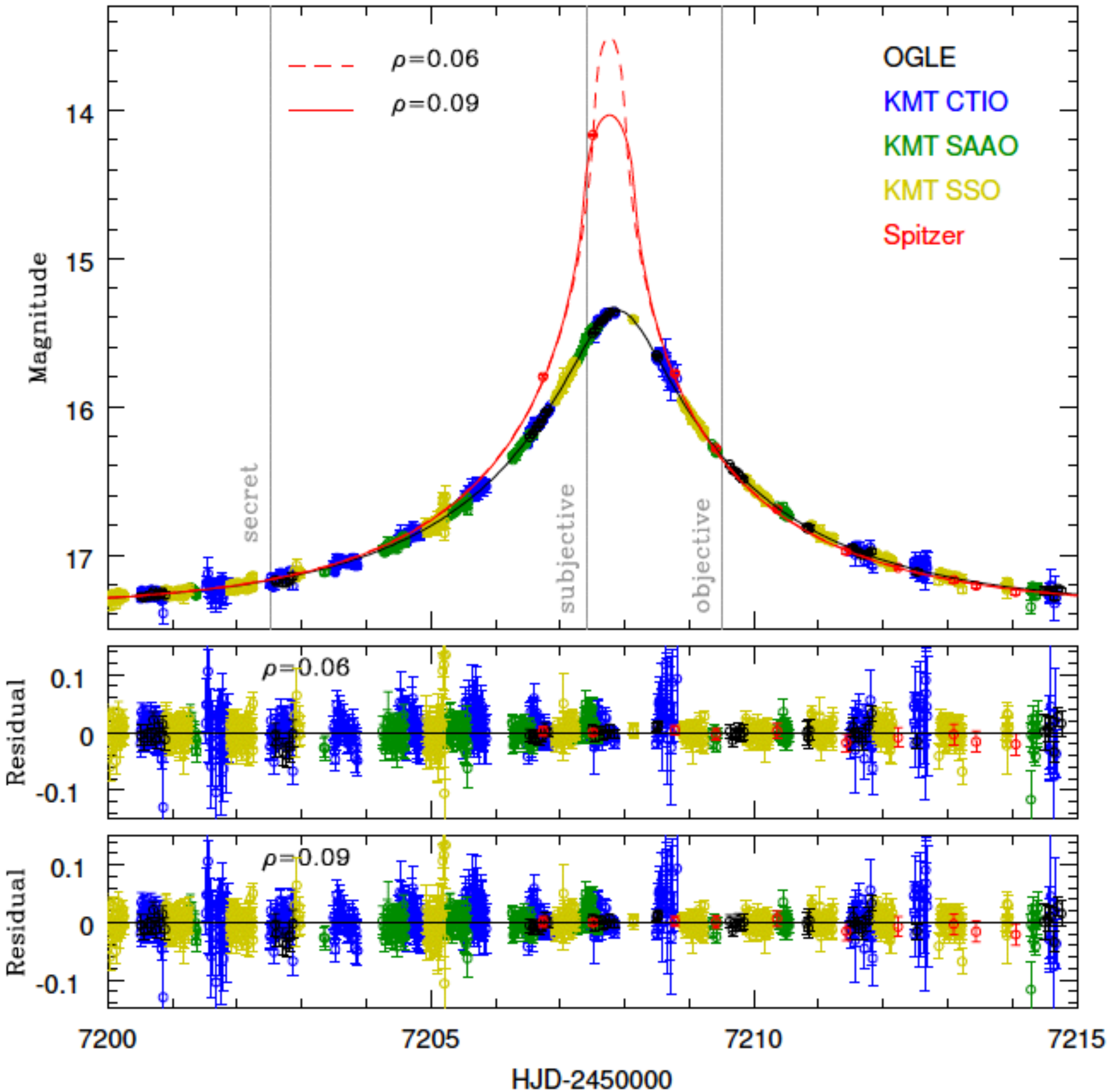
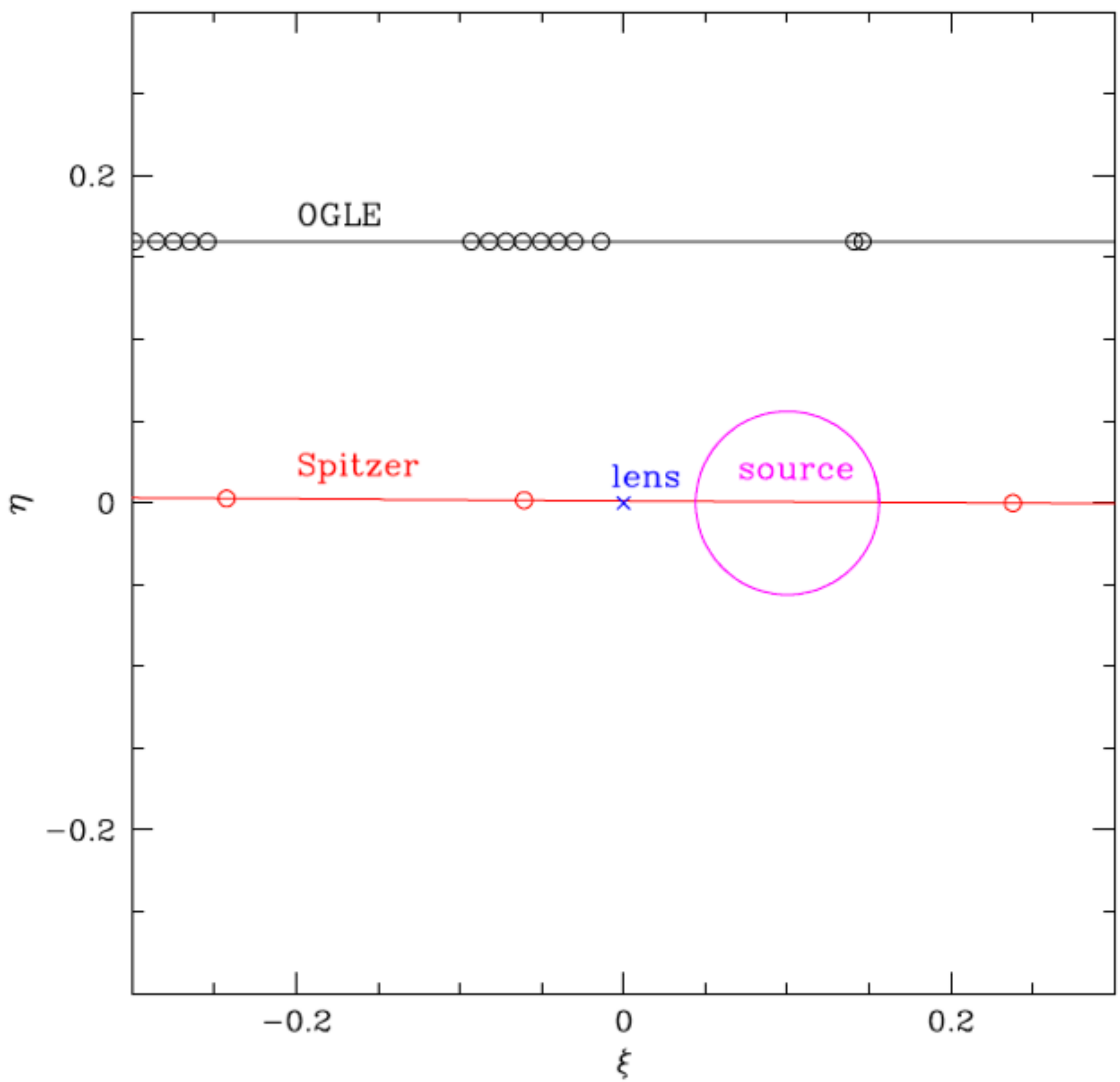
OGLE-2015-BLG-1482



source trajectories



4-fold parallax degeneracy

- For the simultaneous observation from 2 observatories, there is a well-known 4-fold degeneracy for the microns parallax vector (π_E)

$$\boldsymbol{\pi}_{\rm E} = \frac{\rm AU}{D_\perp}(\Delta\tau, \Delta\beta_{\pm\pm}),$$

$D_\perp$: projected separation between two observatories

$$\Delta\tau = \frac{t_{0,\rm sat} - t_{0,\oplus}}{t_{\rm E}}; \quad \Delta\beta_{\pm\pm} = \pm u_{0,\rm sat} - \pm u_{0,\oplus}$$

4 possible values of $\Delta\beta$ → $(+u_{0,\rm sat}, \pm u_{0,\oplus})$, $(-u_{0,\rm sat}, \pm u_{0,\oplus})$

- If $u_{0,\rm sat} \simeq 0$, then $(0, +u_{0,\oplus})$ and $(0, -u_{0,\oplus})$

→ the 4-fold degeneracy reduces to the 2-fold degeneracy

Best-fit lensing parameters

Table 1
Best-fit parameters.

Solutions	Fit parameters								
	χ^2/dof	t_0(HJD′)	u_0	t_E (days)	$\rho(10^{-2})$	$\pi_{E,N}$	$\pi_{E,E}$	$f_{s,ogle}$	$f_{b,ogle}$
(+, 0)	8360.63/8367	7207.893 ± 0.001	0.160 ± 0.002	4.265 ± 0.021	5.55 ± 1.10	−0.1288 ± 0.0169	0.0346 ± 0.0016	1.790 ± 0.015	−0.004 ± 0.015
	8360.92/8367	7207.893 ± 0.001	0.165 ± 0.002	4.258 ± 0.022	9.16 ± 0.60	−0.1342 ± 0.0189	0.0349 ± 0.0017	1.794 ± 0.015	−0.009 ± 0.015
(−, 0)	8360.95/8367	7207.893 ± 0.001	−0.160 ± 0.002	4.265 ± 0.021	5.55 ± 1.08	0.1309 ± 0.0163	0.0159 ± 0.0017	1.790 ± 0.015	−0.005 ± 0.015
	8361.15/8367	7207.893 ± 0.001	−0.164 ± 0.002	4.262 ± 0.022	9.10 ± 0.59	0.1342 ± 0.0188	0.0155 ± 0.0018	1.791 ± 0.015	−0.005 ± 0.015

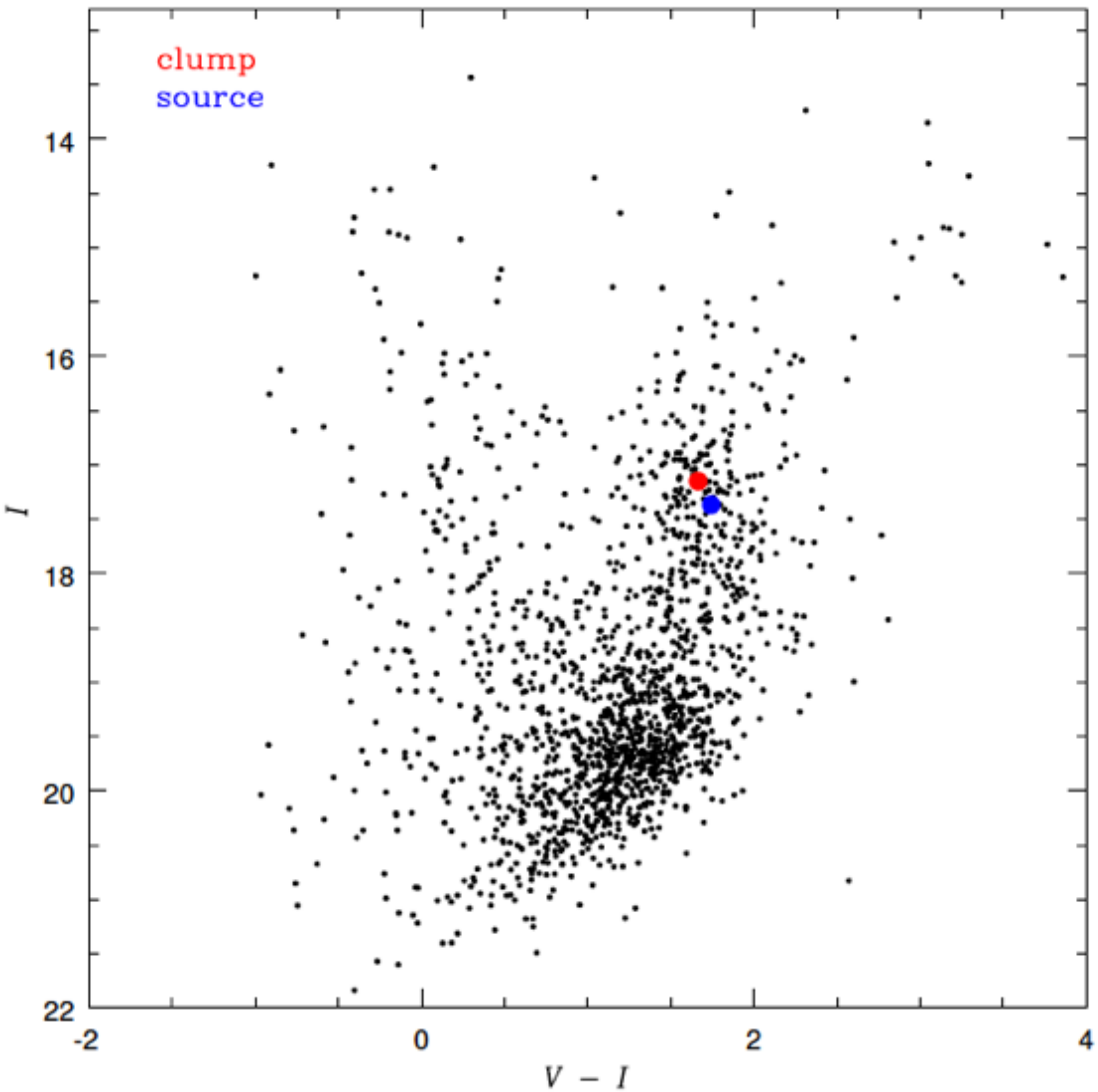
Note. — (+, 0) indicates $u_{0,\oplus} > 0$ and $u_{0,\rm sat} \simeq 0$. HJD′ is HJD − 2450000.

not 2-fold degeneracy, but 4-fold degeneracy.

Appearance of the ρ degeneracy !!!

The biggest $\Delta\chi^2$ between the four solutions is $\Delta\chi^2 = 0.5$ (severe)

Source properties



- offset between the clump and the source :

  $[\Delta(V\text{-}I), \Delta I] = [0.07, 0.22]$

- offset between the instrumental magnitudes of OGLE and KMTNet

  I_{kmt} - I_{ogle} = 0.045

- source magnitude from the best-fit model :

  $I_s = 17.37$

- dereddened color and magnitude of the source

  $[(V\text{-}I), I]_{s,0} = [1.13, 14.76]$

Adopting $(V\text{-}K)_{s,0} = 2.61$ (Bessel & Brett 1988)

- source angular radius :

$$\theta_\star = 5.79 \pm 0.39\ \mu\mathrm{as}$$

K-type giant

Lens properties

- **Einstein ring radius :**

$$\theta_E = \theta_\star/\rho = \begin{cases} 0.104 \pm 0.022 \text{ mas} & \text{for } \rho \simeq 0.06 \\ 0.063 \pm 0.006 \text{ mas} & \text{for } \rho \simeq 0.09 \end{cases}$$

- **relative proper motion :**

$$\mu_{\rm rel} = \theta_E/t_E = \begin{cases} 8.96 \pm 1.88 \text{ mas yr}^{-1} & \text{for } \rho \simeq 0.06 \\ 5.48 \pm 0.48 \text{ mas yr}^{-1} & \text{for } \rho \simeq 0.09 \end{cases}$$

- **lens mass :**

$$M = \frac{\theta_E}{\kappa \pi_E} = \begin{cases} 0.096 \pm 0.023\ M_\odot & \text{for } \rho \simeq 0.06 & \text{(M dwarf)} \\ 0.055 \pm 0.009\ M_\odot & \text{for } \rho \simeq 0.09 & \text{(brown dwarf)} \end{cases}$$

- **lens-source relative parallax :**

$$\pi_{\rm rel} = \theta_E \pi_E = \begin{cases} 0.014 \pm 0.003 \text{ mas} & \text{for } \rho \simeq 0.06 \\ 0.009 \pm 0.001 \text{ mas} & \text{for } \rho \simeq 0.09 \end{cases}$$

- **lens-source distance :**

$$D_{\rm LS} \equiv D_S - D_L = \frac{\pi_{\rm rel}}{\rm AU} D_S D_L \simeq \begin{cases} 0.80 \pm 0.19 \text{ kpc} & \text{for } \rho \simeq 0.06 \\ 0.54 \pm 0.08 \text{ kpc} & \text{for } \rho \simeq 0.09 \end{cases}$$

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the first isolated low-mass bulge object !!!

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- GMTIFS of GMT : ~0.01” in NIR
- GMT first light : maybe 2025

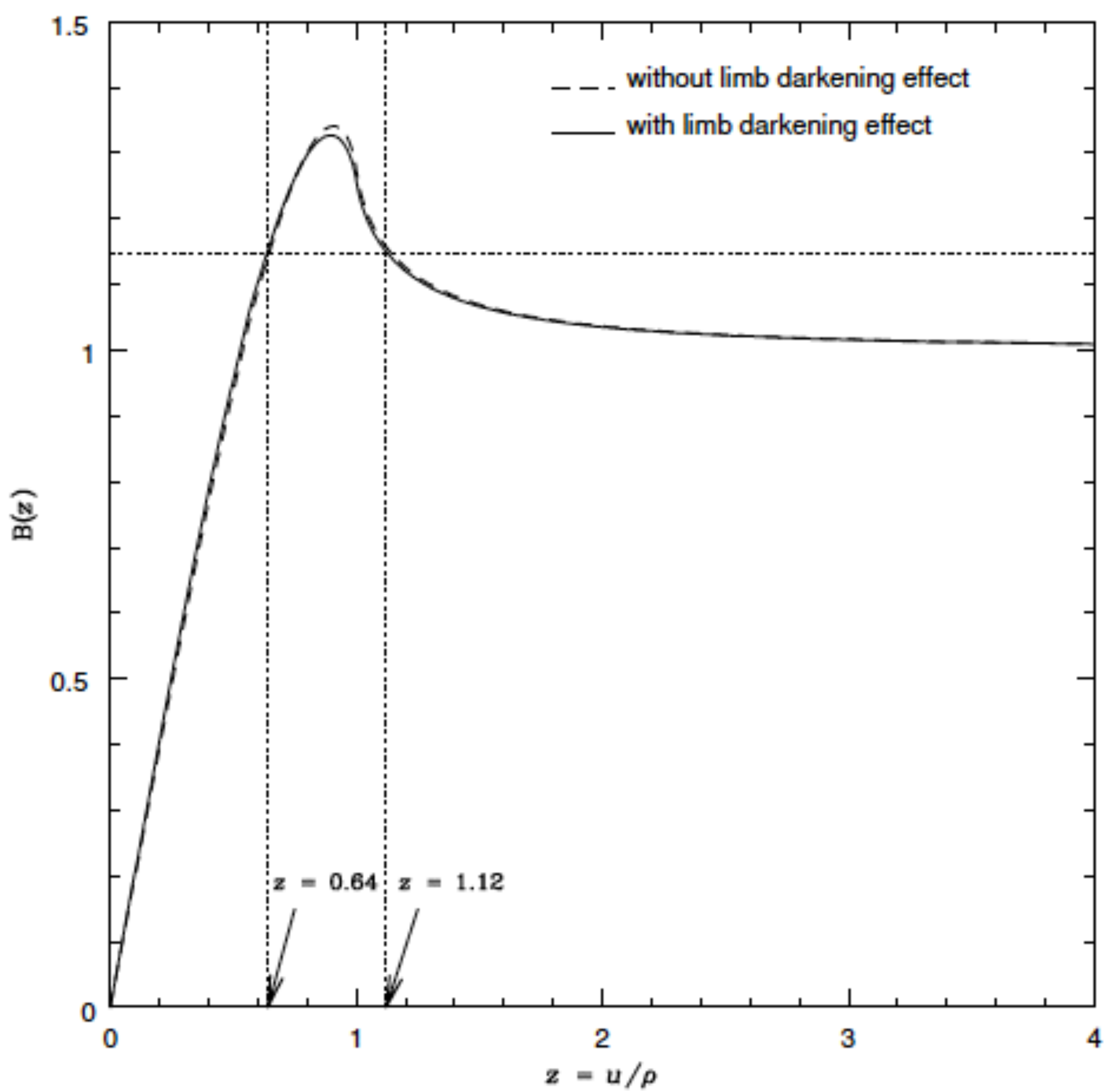
time with 2.5FWHM = 2015 + 2.5*(10 mas/9 mas yr^{-1}) = 2018 for GMT

So, we can confirm the M dwarf solution in 2025 using GMT.

→ If the M dwarf doesn’t appear, the BD solution is correct.

Origin of the ρ degeneracy

- The fundamental reason for this degeneracy is that the finite-source effect is seen only in a single data point from *Spitzer*



- Finite-source effect function

$$B(z) \equiv \frac{A_{\rm obs}}{A_{\rm ps}} \simeq A_{\rm obs} u. \qquad (z \equiv u/\rho)$$

A_{ps} : point-source magnification

$\mathbf{A_{ps} \simeq 1/u}$ for high-mag events

A_{obs} : observed finite-source magnification

- At the nearest point to the peak for *Spitzer*

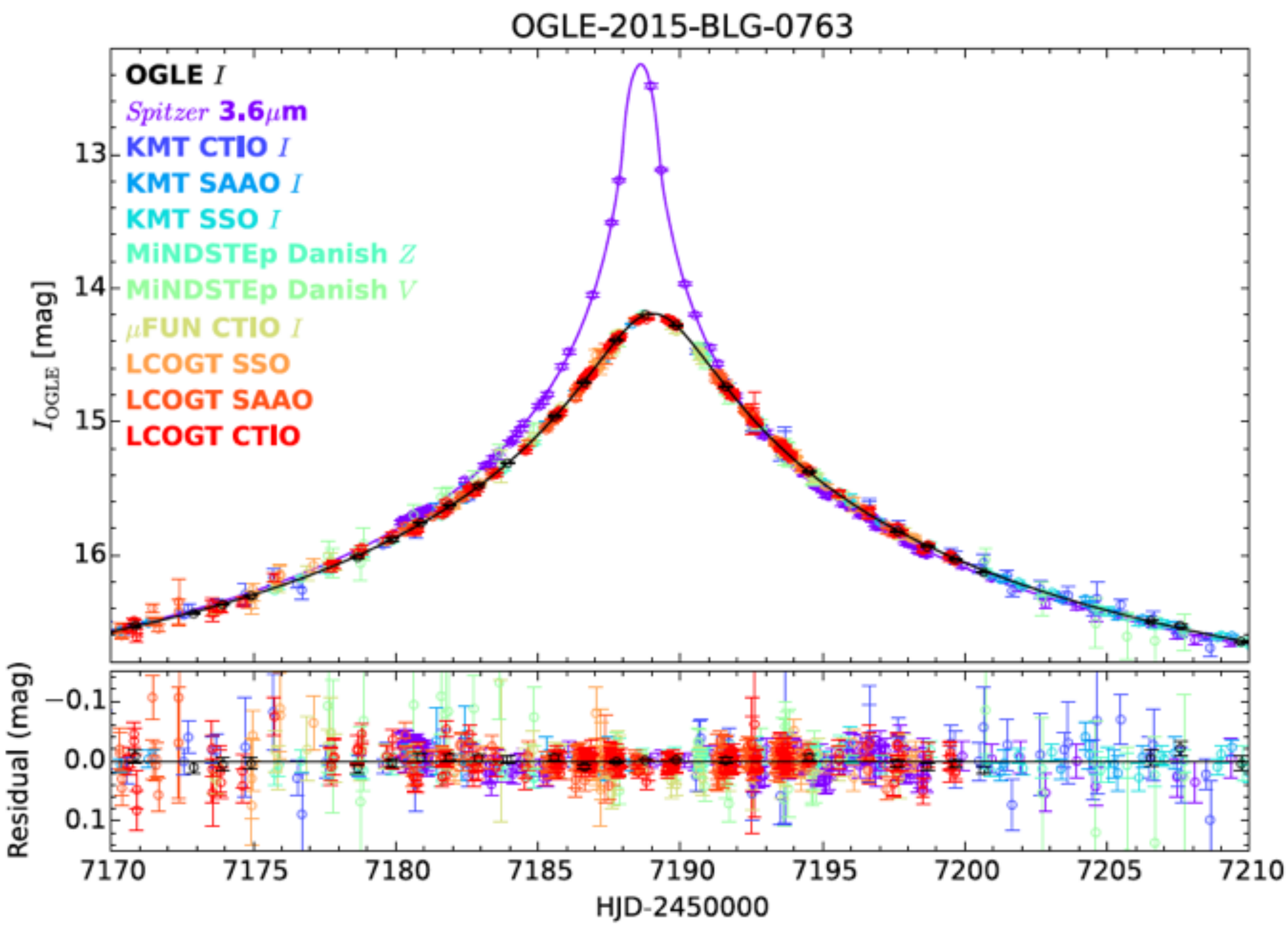
$$B(z) = A_{\rm obs} u = 19.14 \times 0.06 = 1.15$$

It has two different z, z=0.64 and z=1.12

→ there are two ρ values

ρ = 0.094 for z=0.64
ρ = 0.054 for z=1.12

ρ degeneracy of OGLE-2015-BLG-0763 (Zhu et al. 2016)



- best-fit solution :
  - $\rho = 0.0218$
  - $u = 0.016$ at the highest point

$z = u/\rho = 0.73$

→ $B(z) = 1.25$

another solution → $z = 1.01$, $\rho = 0.016$

After reanalysing,

No ρ degeneracy !!!

This implies that although for events in which the finite-source effect is seen only in *Spitzer* the ρ degeneracy can occur frequently due to low observation cadence of the *Spitzer*, it can be resolved by a few data points near the peak.

ρ degeneracy for 2nd-generation ground-based & future space-based surveys

- typical source radius crossing time : $t_\star \equiv \frac{\theta_\star}{\mu_{\rm rel}} = 45\ {\rm min} \left(\frac{\theta_\star}{0.6\ \mu as}\right) \left(\frac{\mu_{\rm rel}}{7\ \ {\rm mas\ yr^{-1}}}\right)^{-1}$

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- *WFIRST* : 15 min cadence, most of sources (M dwarfs : 1/2 ~ 1/4 size of Sun)

  typical $t_\star$ ~ 15 min

→ ρ degeneracy can be usually resolved by obtaining more than 2 data points around the peak

Summary

- We found that the lens of OGLE-2015-BLG-1482 is a very low-mass star with the mass $0.10 \pm 0.02 M_{\odot}$ or a brown dwarf with the mass $55 \pm 9 M_J$, which are respectively located at $D_{\rm LS} = 0.80 \pm 0.19$ kpc and $D_{\rm LS} = 0.54 \pm 0.08$ kpc and thus it is the first isolated low-mass object located in the Galactic bulge

- The fundamental reason for the ρ degeneracy is that the finite-source effect is seen only in a single data point from *Spitzer*.

- Considering that the ρ degeneracy can be resolved only by high cadence observations around the peak and the *Spitzer* cadence is typically ~ 1 day^{-1}, we expect that events for which the finite-source effect is seen only in the *Spitzer* data may frequently exhibit this ρ degeneracy.

- Since the relative lens-source proper motion for M dwarf is $\mu_{\rm rel} = 9.0 \pm 1.9$ mas/yr, while for BD it is $\mu_{\rm rel} = 5.5 \pm 0.5$ mas/yr, the ρ degeneracy can be resolved within ~ 10 yrs from direct lens imaging by using next-generation instruments with high spatial resolution.

Thank you for your attention !!!