

**Characterizing Lenses and Lensed Stars of
High-Magnification
Gravitational Microlensing Events With
Lenses Passing Over Source Stars**

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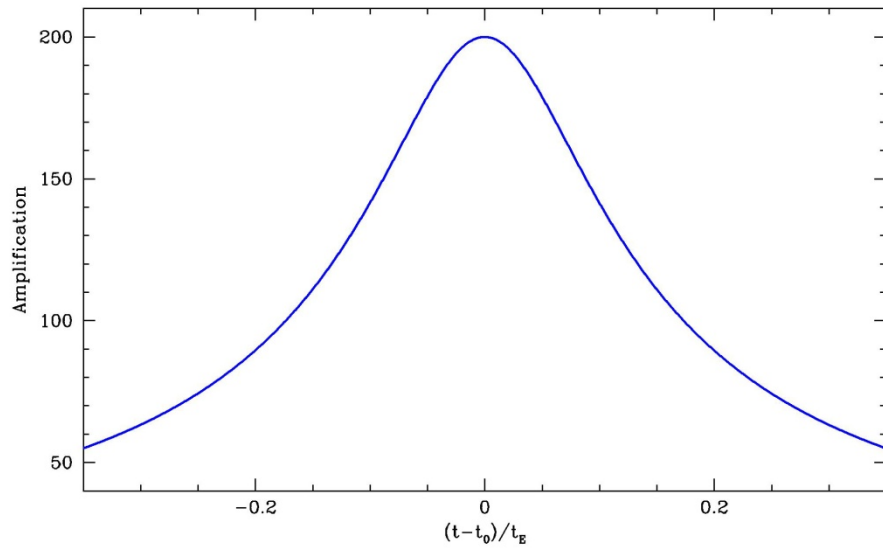
Outline

- Characteristics
- Scientific importance
- Sample events
- Modeling
- Light curves
- Results

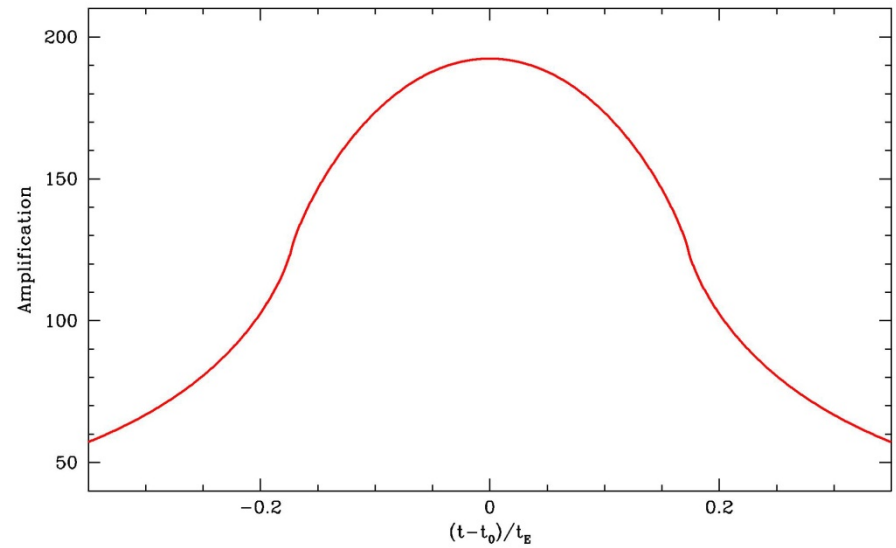
Characteristics

$$u_0 = 0.005, t_E = 20 \text{ days}, \rho_* = 0.01 (\Delta t_C = 0.346 \text{ days})$$

PSPL (Point Source Point Lens)



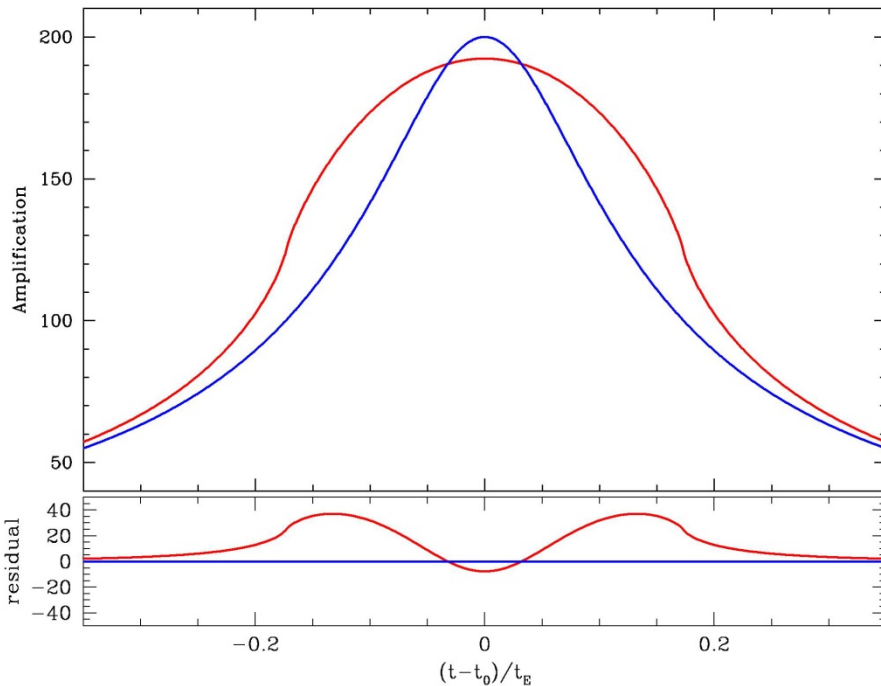
FSPL (Finite Source Point Lens)



Characteristics

$$u_0 = 0.005, t_E = 20 \text{ days}, \rho_* = 0.01 (\Delta t_C = 0.346 \text{ days})$$

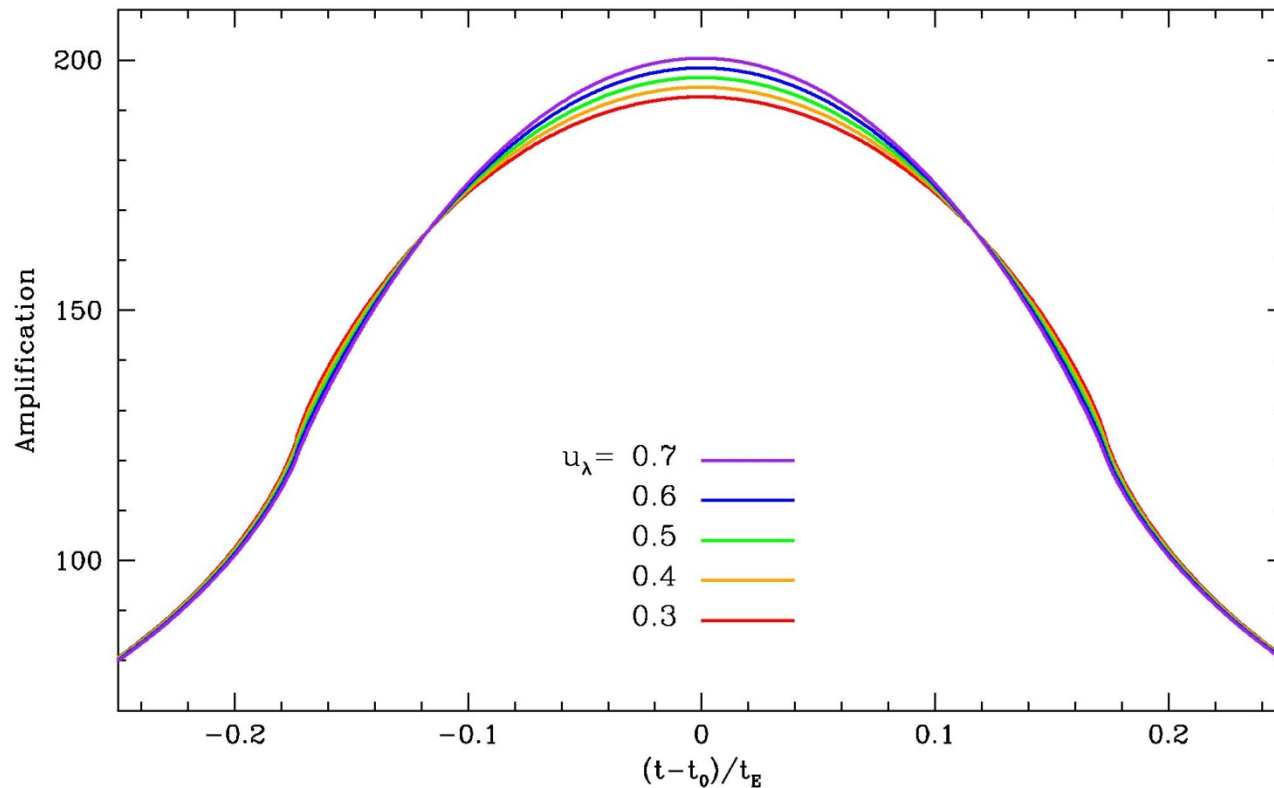
PSPL + FSPL



- Broader and Smoothed peak compared with PSPL model
- Symmetric “M” shape of FSPL-PSPL residual
- $\rho_* > u_0$: the lens passes over the surface of the source star.

Scientific importance

- Limb-darkening coefficients



Scientific importance

- **The Einstein radius**
- **The relative lens-source proper motion**
- **Planetary companions**
 - MOA-2007-BLG-400 (Dong et al. 2009)
 - MOA-2008-BLG-310 (Janczak et al. 2010)
- **Spectroscopic study**
 - (Johnson et al. 2008; Bensby et al. 2009, 2011;
Cohen et al. 2009; Epstein et al. 2010)

Sample events

event	reference
OGLE-2004-BLG-254	Cassan et al. (2006), this work
OGLE-2004-BLG-482	Zub et al. (2011)
MOA-2006-BLG-130/OGLE-2006-BLG-437	Baudry et al. (2012), under analysis
OGLE-2007-BLG-050/MOA-2007-BLG-103	Batista et al. (2009)
MOA-2007-BLG-176	this work
OGLE-2007-BLG-224	Gould et al. (2009)
MOA-2007-BLG-233/OGLE-2007-BLG-302	this work
MOA-2008-BLG-279	Yee et al. (2009)
OGLE-2008-BLG-290/MOA-2008-BLG-241	Fouque et al. (2010)
MOA-2009-BLG-174	this work
MOA-2009-BLG-411	Fouque et al. (2012), under analysis
MOA2010-BLG-311	Hung et al. (2012), under analysis
MOA-2010-BLG-436	this work
MOA-2010-BLG-523	Gould et al. (2012), under analysis
MOA-2011-BLG-093	this work
MOA-2011-BLG-274	this work
OGLE-2011-BLG-0990/MOA-2011-BLG-300	this work
OGLE-2011-BLG-1101/MOA-2011-BLG-325	this work

Modeling

Markov Chain Monte Carlo (MCMC) method The ray-shooting method

Single-lens
3 parameters

$$t_0, u_0, t_E$$

Finite source
effect

$$\rho_*$$

Limb-
darkening
coefficients

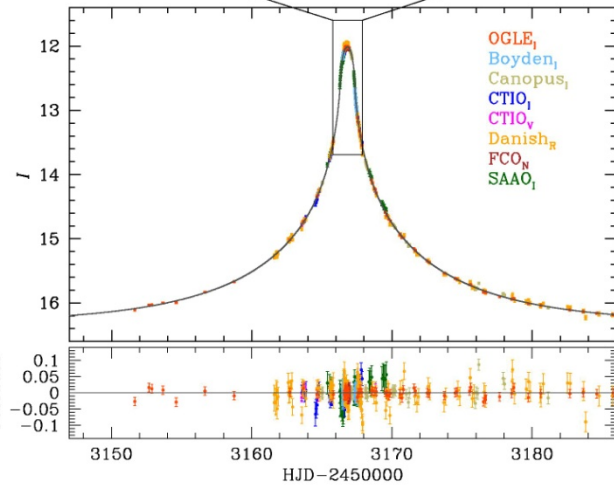
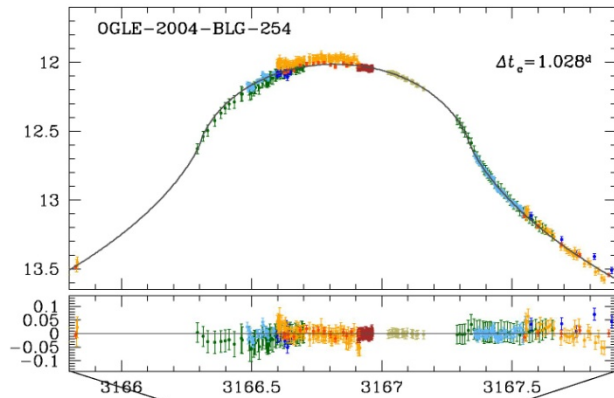
$$u_\lambda$$

Parallax
effect

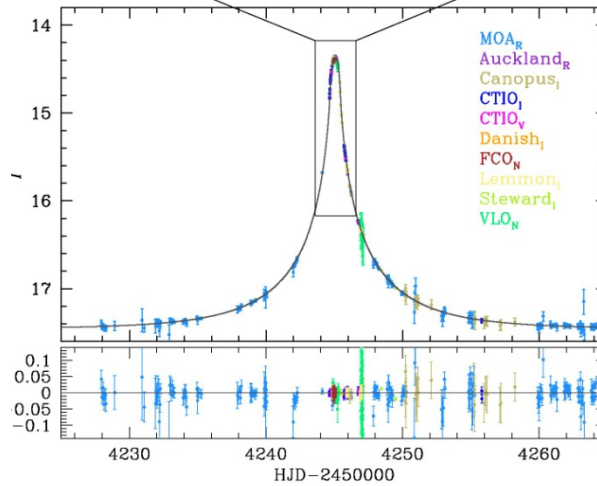
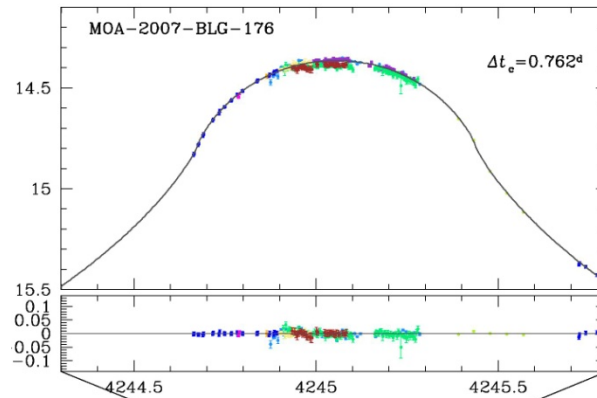
$$\pi_{E,N}, \pi_{E,E}$$

Light curves

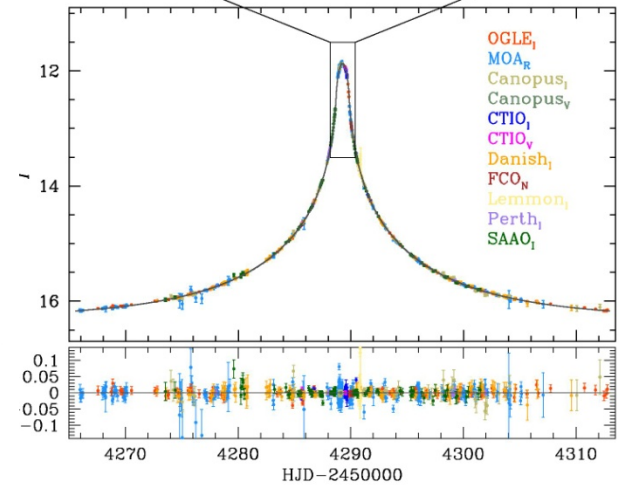
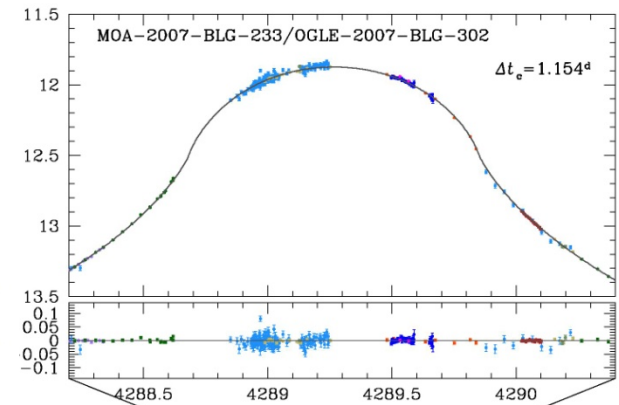
OB04254



MB07176

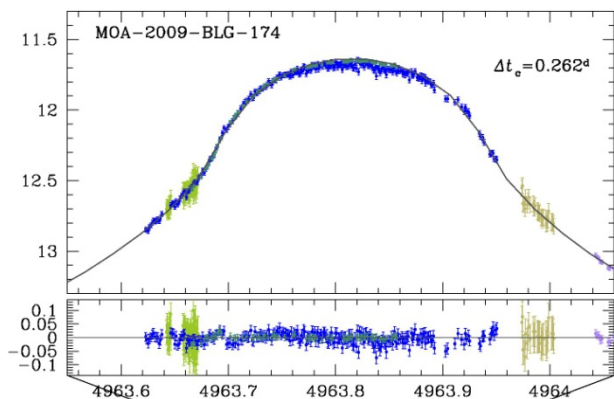


MB07233/OB07302

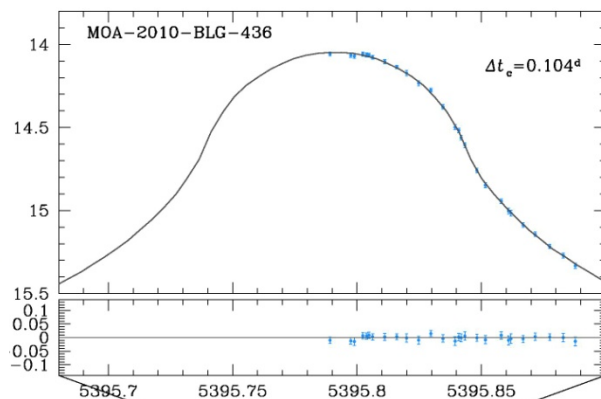


Light curves

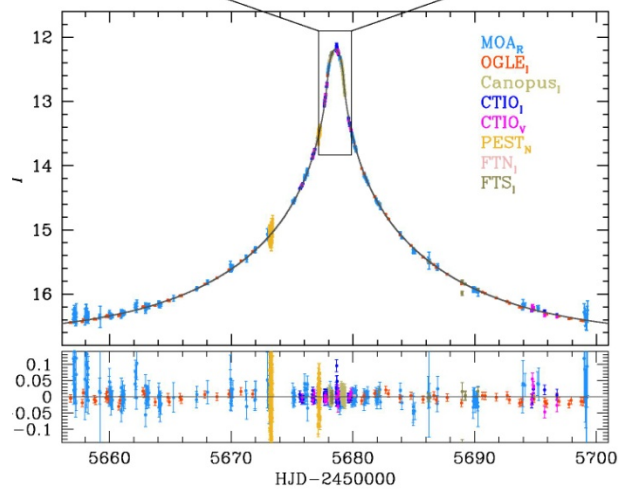
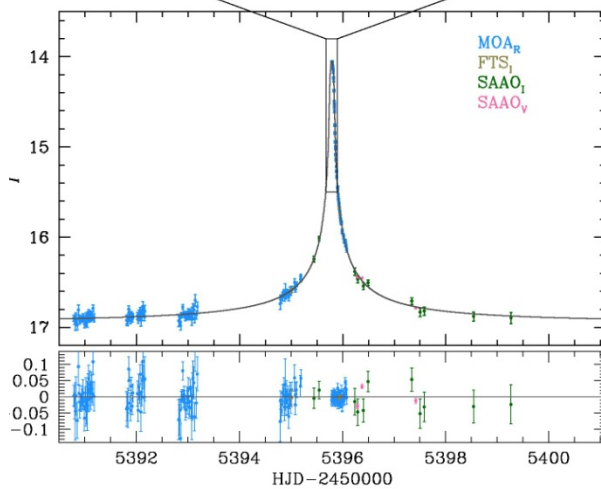
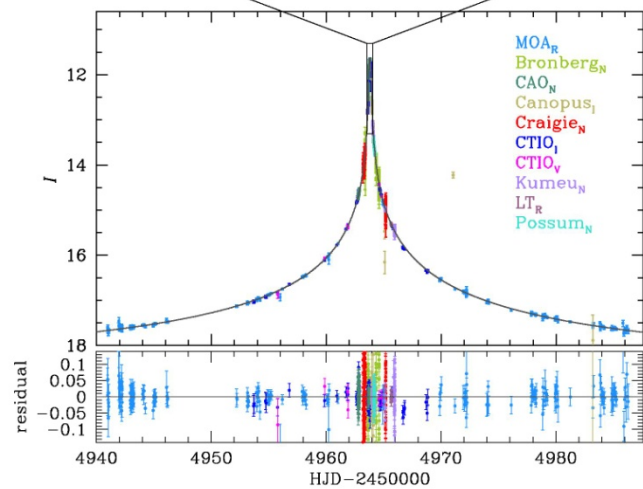
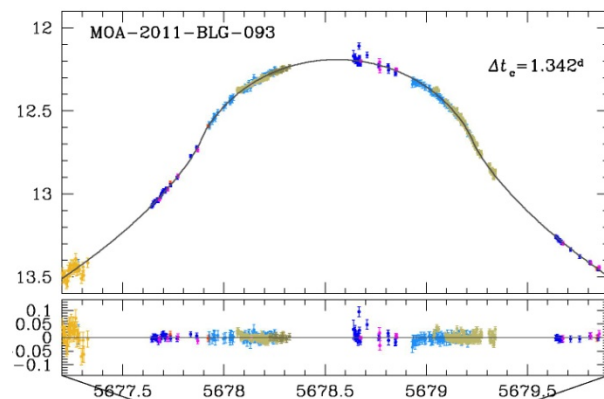
MB09174



MB10436

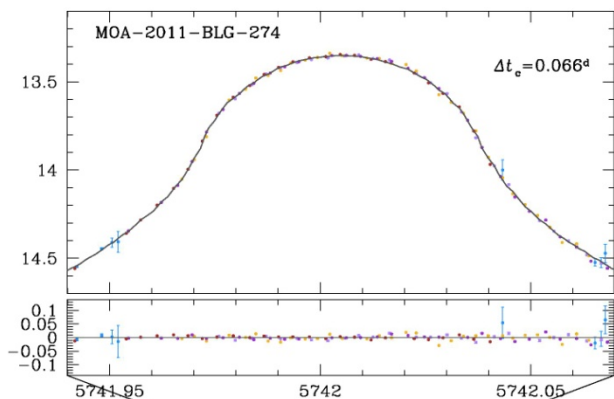


MB11093

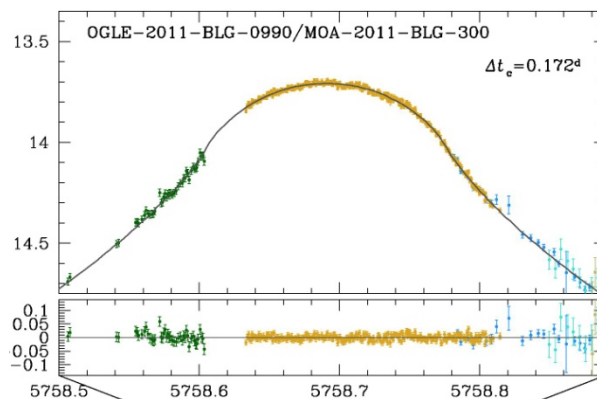


Light curves

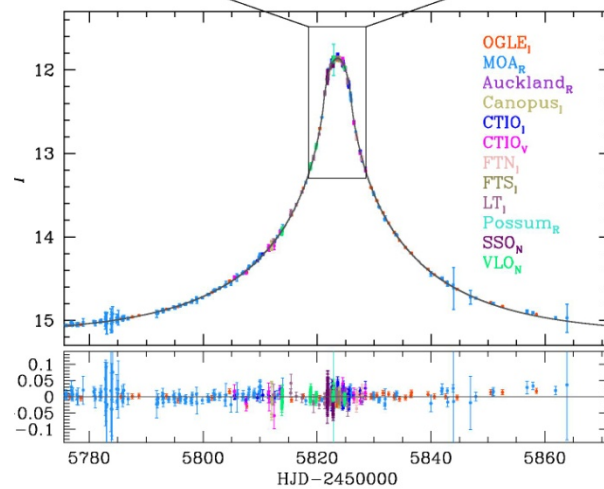
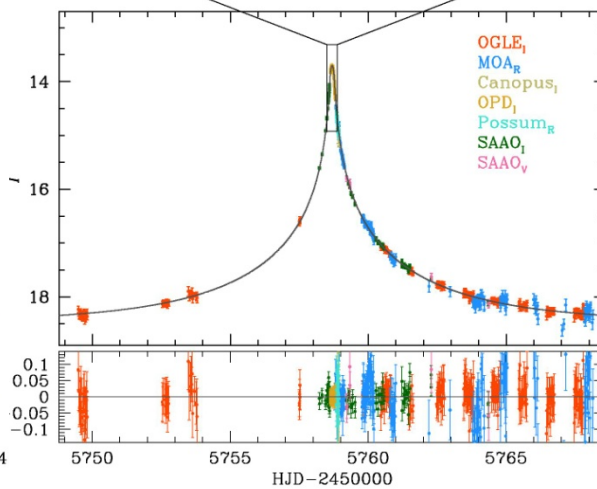
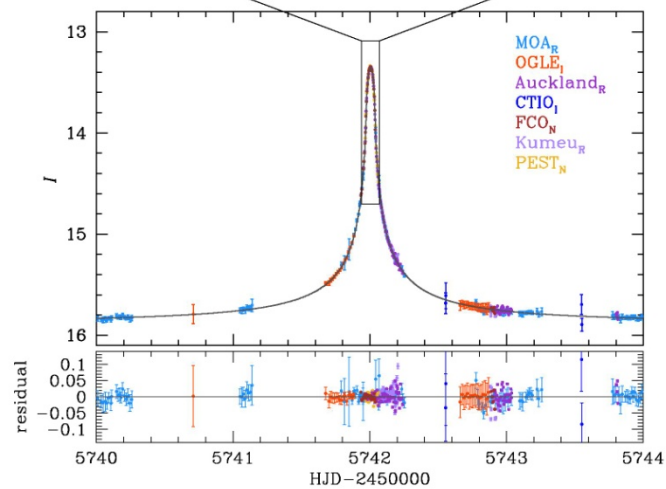
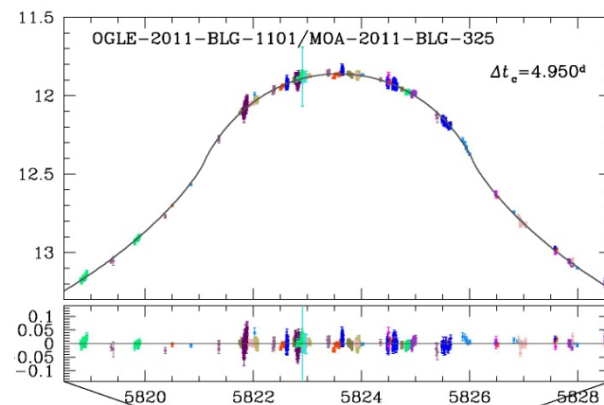
MB11274



OB110990/MB11300

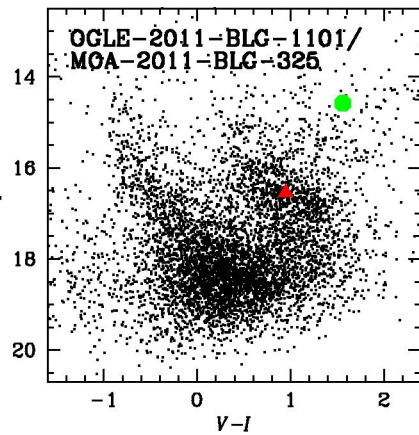
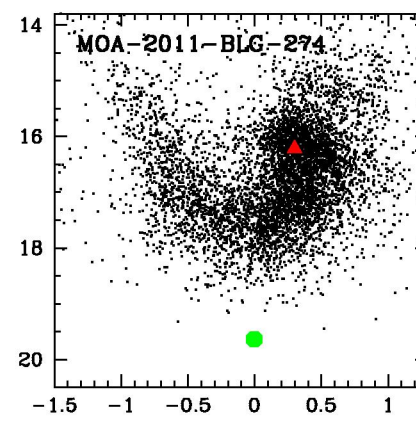
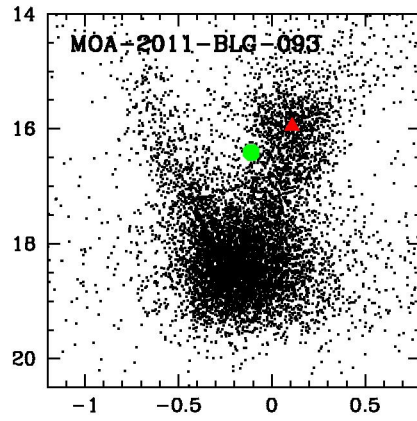
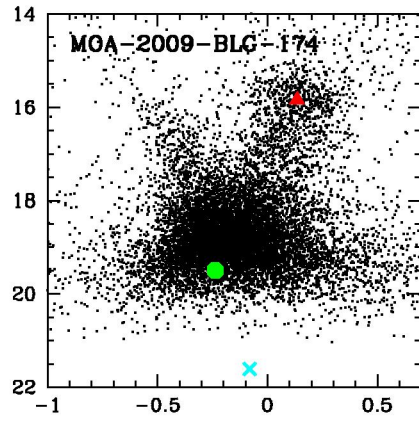
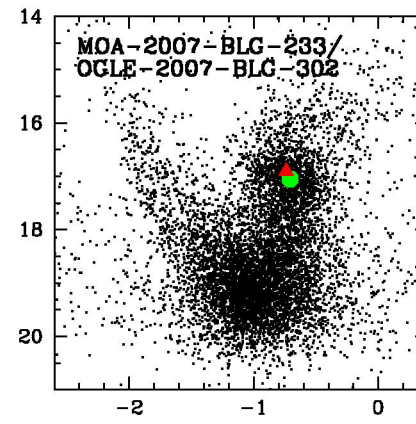
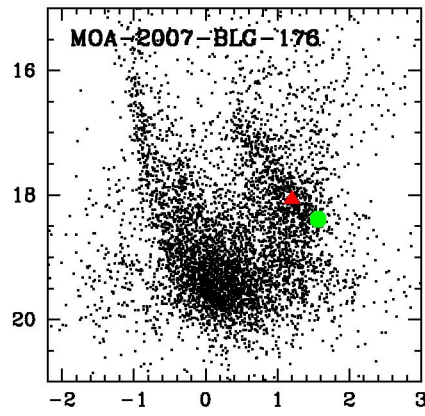
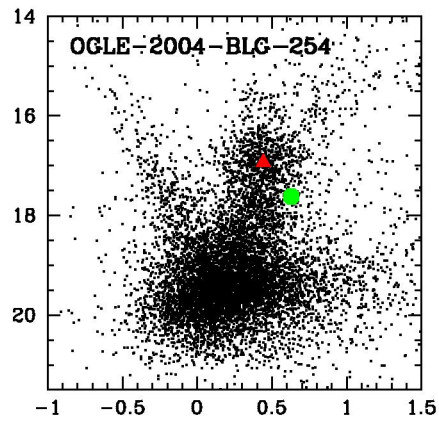


OB111101/MB11325



Results - Lensing parameters of best-fit solutions

event	u_0	t_E	ρ_*	π_E
OGLE-2004-BLG-254	0.0046±0.0008	13.23±0.05	0.04±0.0002	--
OGLE-2004-BLG-482	0.000±0.002	9.61±0.02	0.1309±0.0005	--
OGLE-2007-BLG-050	0.002±0.000	68.09±0.66	0.0045±0.0001	0.12±0.03
OGLE-2007-BLG-224	0.00029	6.91±0.13	0.0009±0.0002	1.97±0.13
MOA-2008-BLG-279	0.00066±0.00005	106±0.9	0.00068±0.00006	0.15±0.02
OGLE-2008-BLG-290	0.00276±0.0002	16.36±0.08	0.022±0.0001	--
OGLE-2004-BLG-254	0.0059±0.0010	12.93±0.09	0.0402±0.0005	--
MOA-2007-BLG-176	0.037±0.0004	8.02±0.06	0.0601±0.0005	--
MOA-2007-BLG-233 /OGLE-2007-BLG-302	0.0056±0.0003	15.82±0.05	0.0371±0.0002	--
MOA-2009-BLG-174	0.0005±0.0001	65.51±0.67	0.0019±0.0001	0.06+0.03-0.02
MOA-2010-BLG-436	0.0003±0.0003	11.89±0.93	0.0044±0.0003	--
MOA-2011-BLG-093	0.029±0.0002	15.01±0.07	0.0533±0.0003	--
MOA-2011-BLG-274	0.0028±0.0001	2.84±0.07	0.012±0.0003	--
OGLE-2011-BLG-0990 /MOA-2011-BLG-300	0.0156±0.0003	6.61±0.08	0.0203±0.0003	--
OGLE-2011-BLG-1101 /MOA-2011-BLG-325	0.0477±0.0005	29.19±0.11	0.0973±0.0006	--



Color-magnitude diagrams (CMDs)

Results - Limb-darkening coefficients

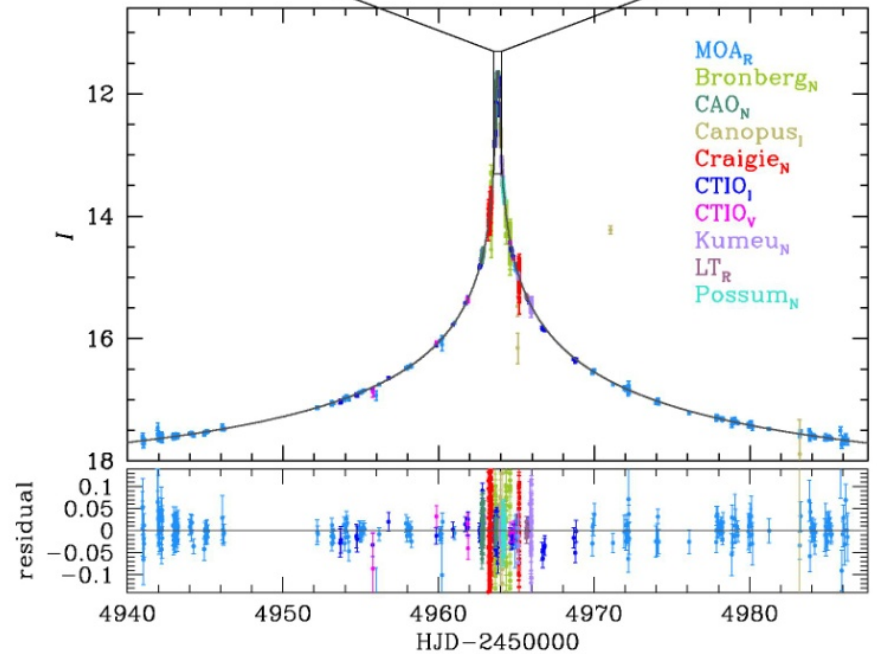
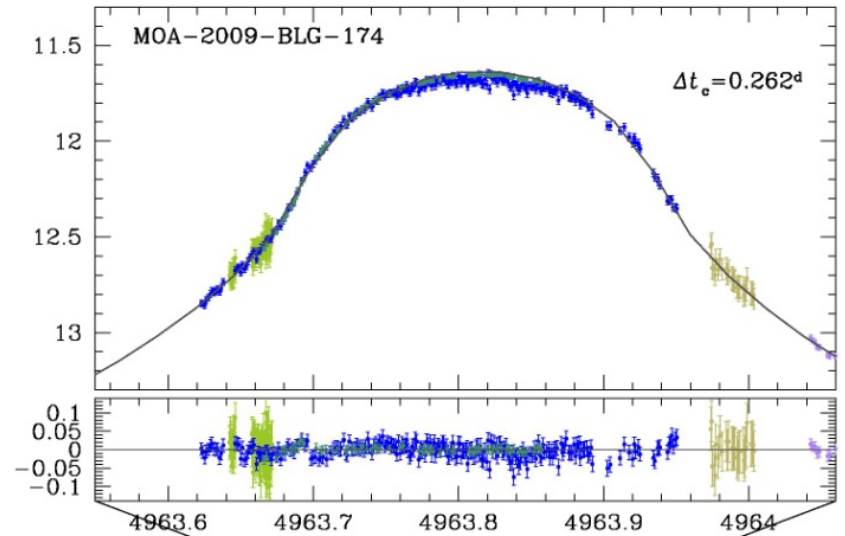
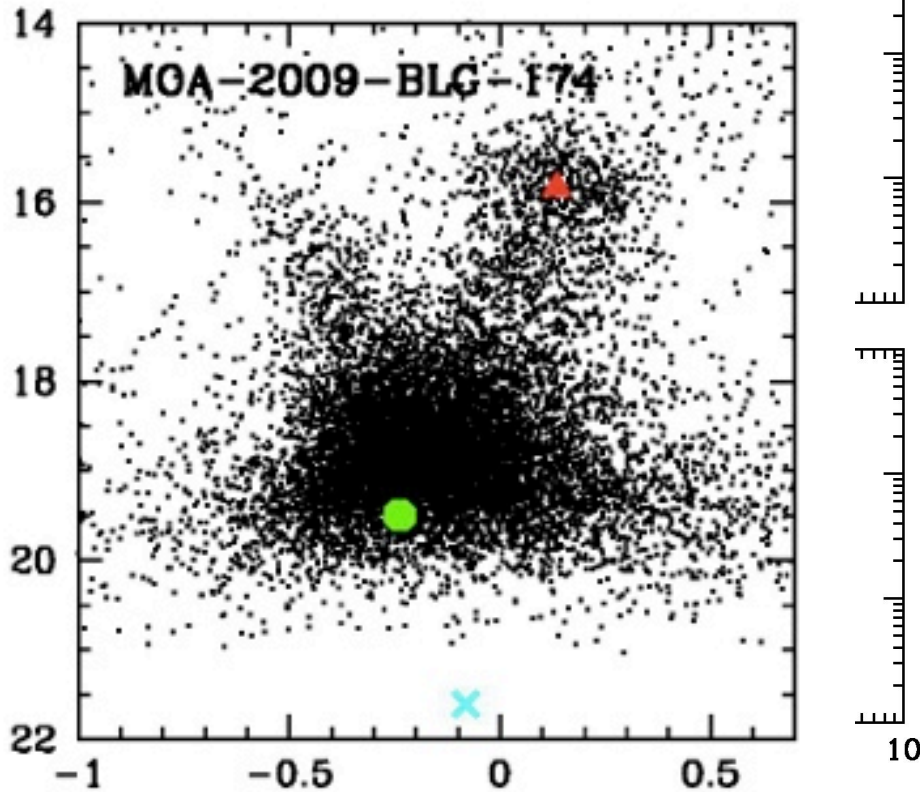
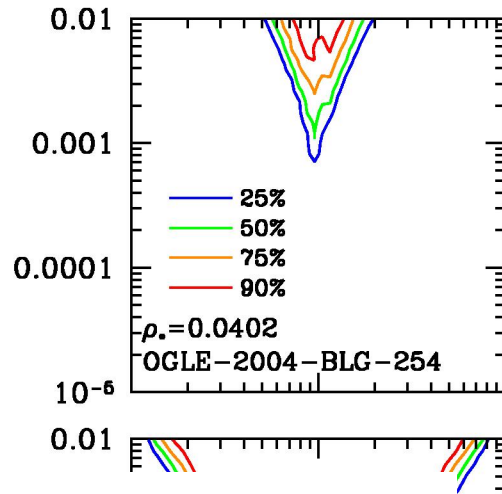
event	u_V	u_R	u_I	u_N
OGLE-2004-BLG-254	--	0.70 ± 0.05	0.55 ± 0.05	--
OGLE-2004-BLG-482	--	0.88 ± 0.02	0.71 ± 0.01	0.65 ± 0.02
OGLE-2007-BLG-050	--	--	--	--
OGLE-2007-BLG-224	--	--	--	--
MOA-2008-BLG-279	--	--	--	--
OGLE-2008-BLG-290	0.77 ± 0.01	0.62 ± 0.07	0.55 ± 0.01	--
OGLE-2004-BLG-254	--	0.63 ± 0.09 (0.70)	0.36 ± 0.09 (0.61)	--
MOA-2007-BLG-176	--	--	0.54 ± 0.04 (0.63)	--
MOA-2007-BLG-233 /OGLE-2007-BLG-302	--	0.60 ± 0.04 (0.68)	0.56 ± 0.04 (0.59)	--
MOA-2009-BLG-174	--	--	0.29 ± 0.02 (0.46)	0.46 ± 0.01
MOA-2010-BLG-436	--	0.55 ± 0.11	--	--
MOA-2011-BLG-093	0.57 ± 0.06 (0.70)	0.55 ± 0.05 (0.63)	0.49 ± 0.03 (0.54)	--
MOA-2011-BLG-274	--	0.51 ± 0.03 (0.59)	--	0.53 ± 0.03
OGLE-2011-BLG-0990 /MOA-2011-BLG-300	--	--	0.57 ± 0.04	--
OGLE-2011-BLG-1101 /MOA-2011-BLG-325	0.86 ± 0.14 (0.83)	0.84 ± 0.06 (0.76)	0.78 ± 0.05 (0.65)	0.80 ± 0.07

Results – Physical lens parameters

event	θ_E (mas)	μ (mas yr ⁻¹)	M (M _⊙)	D _L (kpc)
OGLE-2004-BLG-254	0.114	3.1	--	--
OGLE-2004-BLG-482	0.4	16	--	--
OGLE-2007-BLG-050	0.48±0.01	2.63±0.08	0.50±0.14	5.5±0.4
OGLE-2007-BLG-224	0.91±0.04	48±2	0.056±0.004	0.53±0.04
MOA-2008-BLG-279	0.81±0.07	2.7±0.2	0.64±0.10	4.0±0.6
OGLE-2008-BLG-290	0.30±0.02	6.7±0.4	--	--
OGLE-2004-BLG-254	0.15±0.01	4.10±0.36	--	--
MOA-2007-BLG-176	0.14±0.01	6.22±0.54	--	--
MOA-2007-BLG-233 /OGLE-2007-BLG-302	0.17±0.01	3.87±0.34	--	--
MOA-2009-BLG-174	0.43±0.04	2.40±0.24	0.94±0.43	6.49±1.14
MOA-2010-BLG-436	--	--	--	--
MOA-2011-BLG-093	0.07±0.01	1.81±0.16		
MOA-2011-BLG-274	0.09±0.01	11.13±0.97		
OGLE-2011-BLG-0990 /MOA-2011-BLG-300	--	--	--	--
OGLE-2011-BLG-1101 /MOA-2011-BLG-325	0.24±0.02	2.99±0.26	--	--

**A sub-stellar object
or a free-floating planet**

Exclusion Diagrams



Thank You