Toward an Earth'sister !

Hunting cool low-mass exoplanets by gravitational microlensing

Roadmap

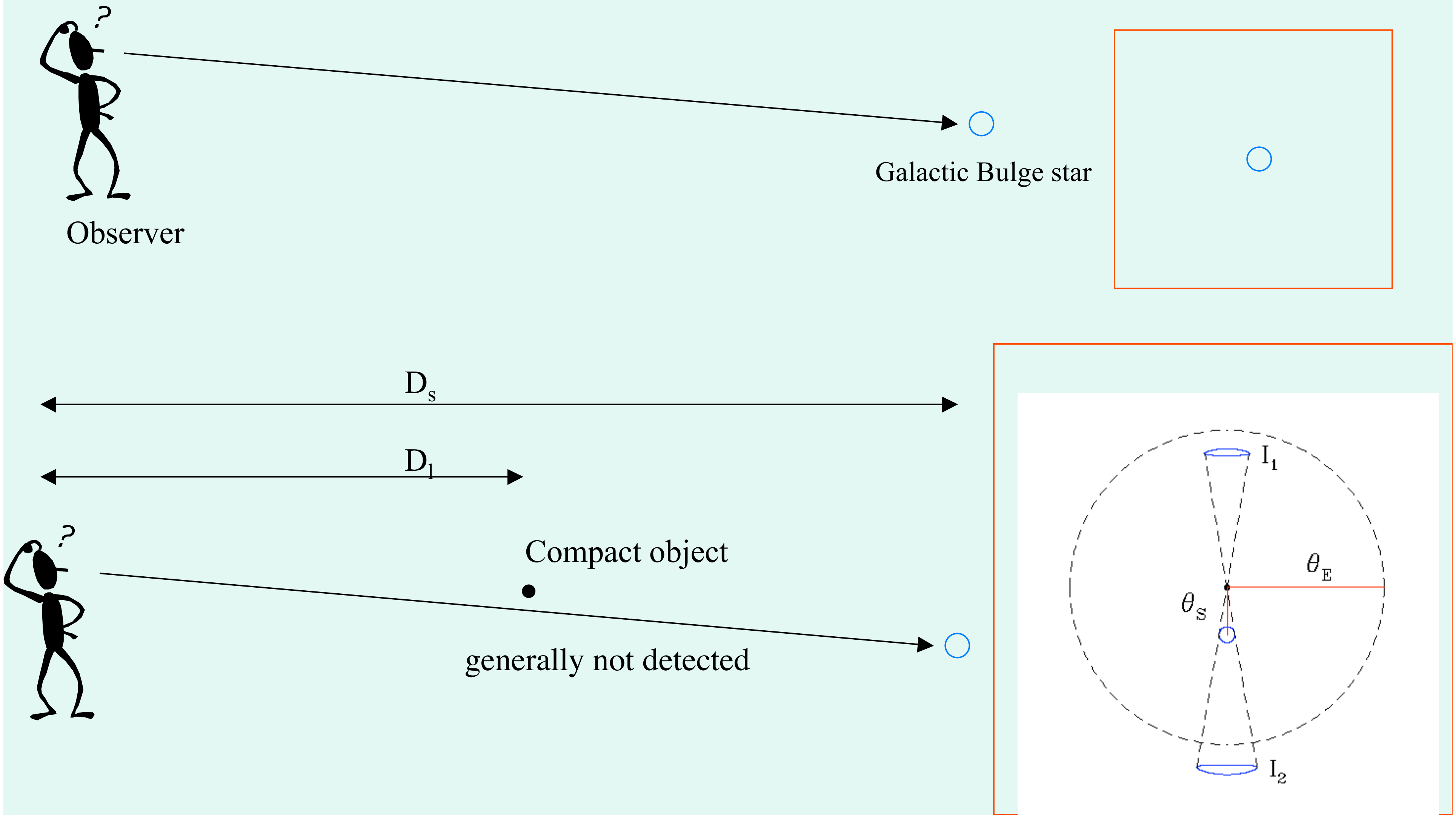
Introduction to gravitational microlensing

Photometric follow-up of alerts

Data reduction (image subtraction)

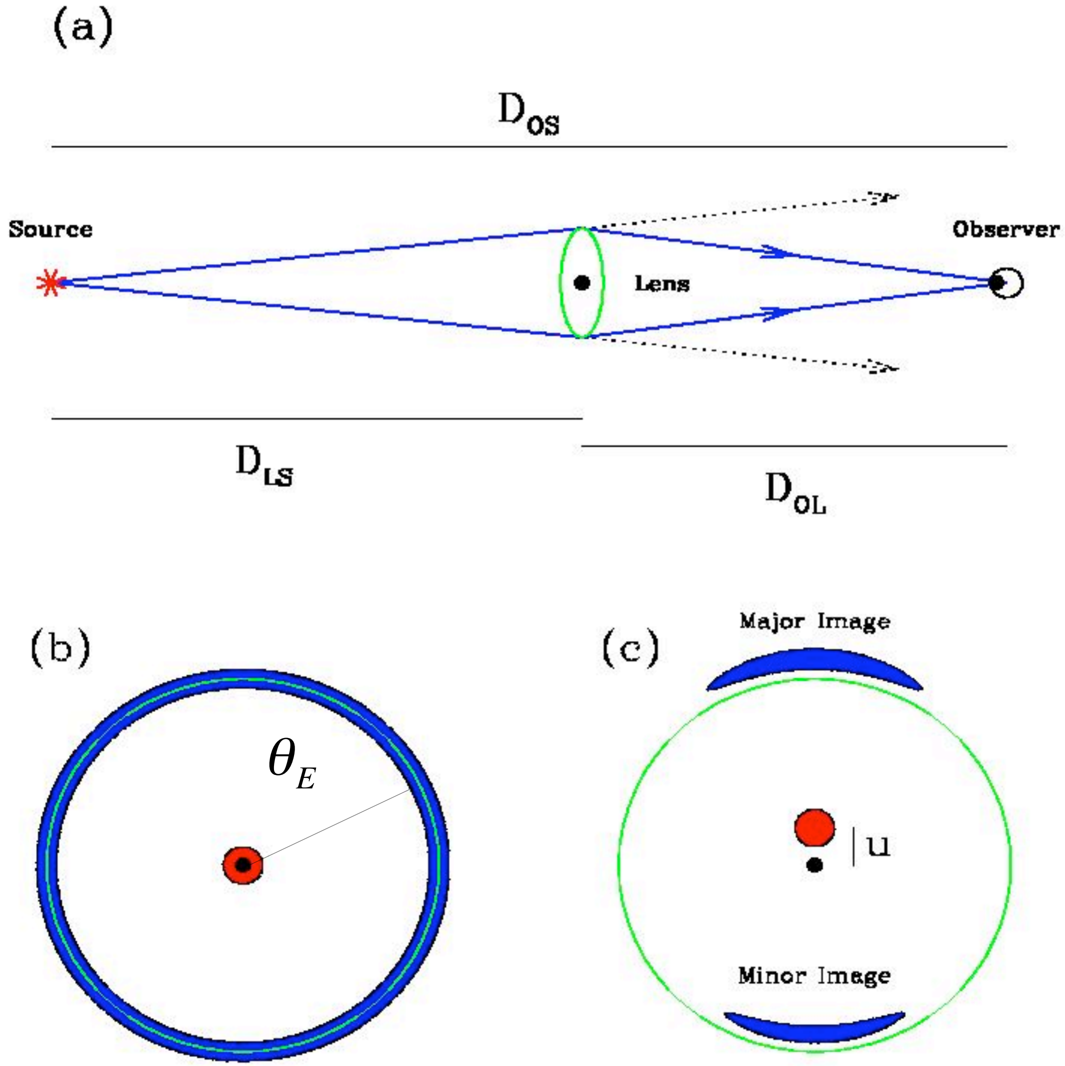
First exoplanets detected by microlensing

Geometry



Observer
Galactic Bulge star
D_s
D_l
Compact object
generally not detected
I_1
θ_E
θ_S
I_2

Scheme and typical values



$$\alpha = -\nabla\psi = \frac{4GM}{Rc^2}$$

$$R_{\mathrm{E}}(\mathrm{AU}) = 2.854\ M^{1/2} D_{\mathrm{OL}}^{1/2}\left(1 - \frac{D_{\mathrm{OL}}}{D_{\mathrm{OS}}}\right)^{1/2}$$

$$\theta_{\mathrm{E}}(\mathrm{mas}) = 2.854\ M^{1/2} D_{\mathrm{OL}}^{-1/2}\left(1 - \frac{D_{\mathrm{OL}}}{D_{\mathrm{OS}}}\right)^{1/2}$$

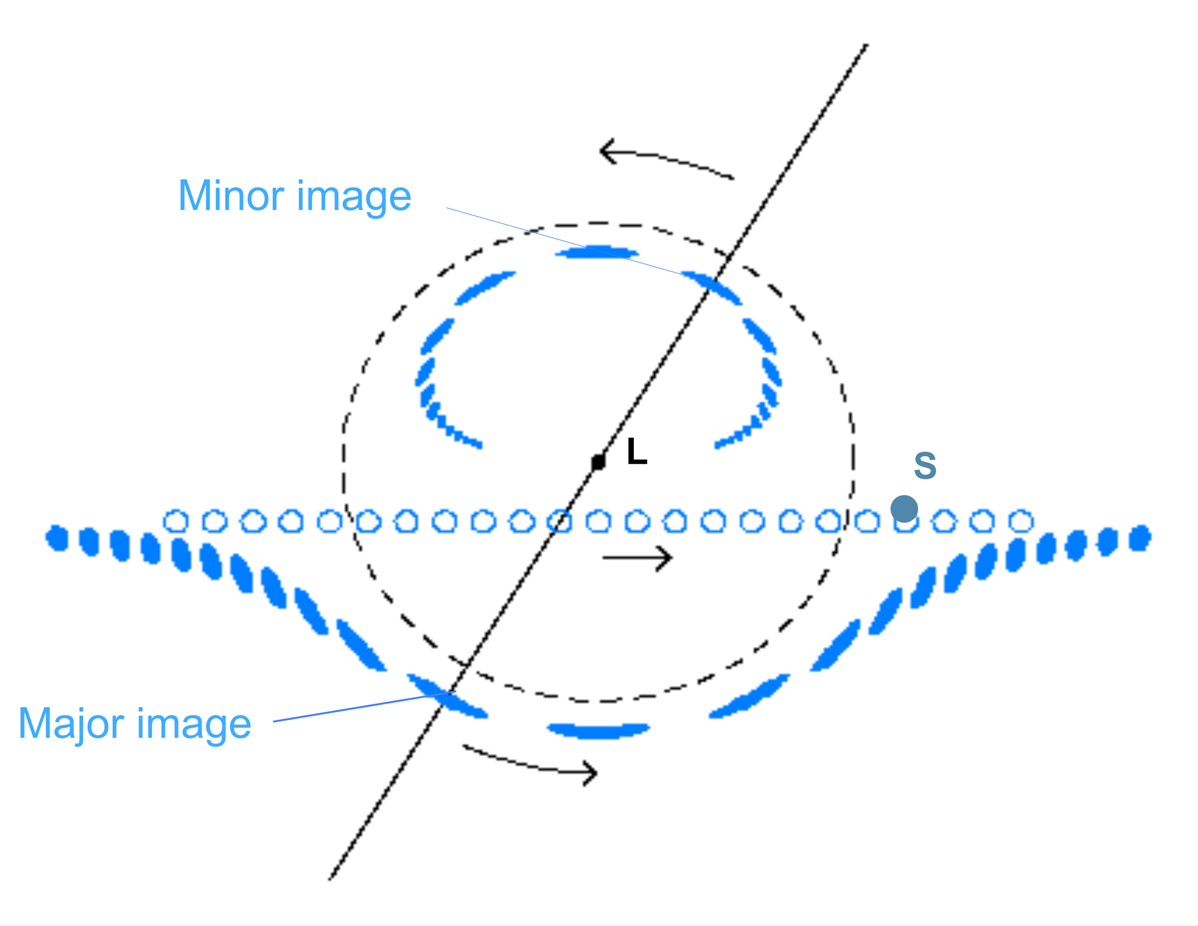
$$M = 0.3 M_{\mathrm{sun}}, D_{\mathrm{OL}} = 6\ \mathrm{kpc}, D_{\mathrm{OS}} = 8\ \mathrm{kpc}:$$
$$R_{\mathrm{E}} = 1.9\ \mathrm{AU},\ \theta_{\mathrm{E}} = 0.32\ \mathrm{mas}$$

Images are not resolved; size similar to distances in solar system

Relative motion of lens and source

$$t_E = \frac{R_E}{v_\perp}$$

$$\mu = \frac{\theta_E}{t_E} = \frac{v_\perp}{D_{OL}}$$

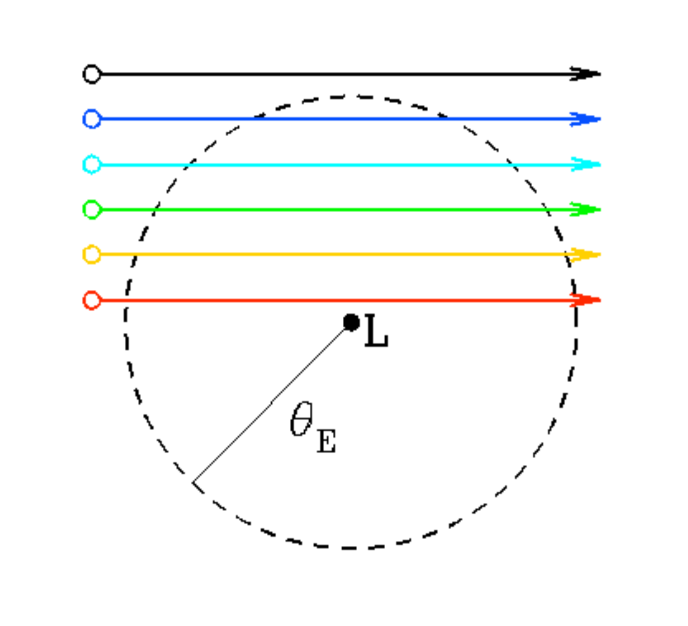


$$\text{Typical value: } \mu = 15\ \mu\text{as/d} = 5.5\ \text{mas/yr} = 26\ \text{km s}^{-1}\ \text{kpc}^{-1}$$

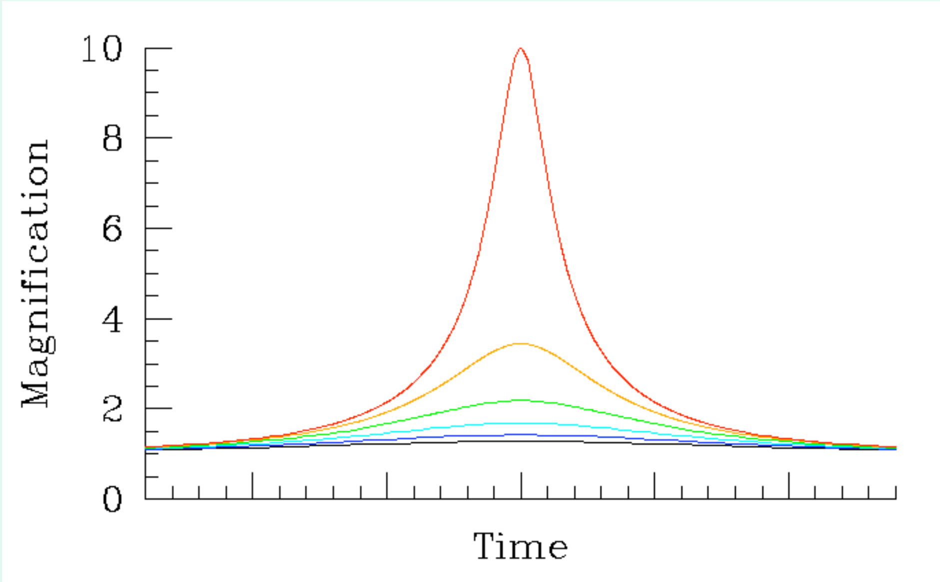
$$t_E = 20\ \text{d} \qquad v_\perp = 150\ \text{km s}^{-1}$$

Relation impact parameter – magnification

Impact parameter

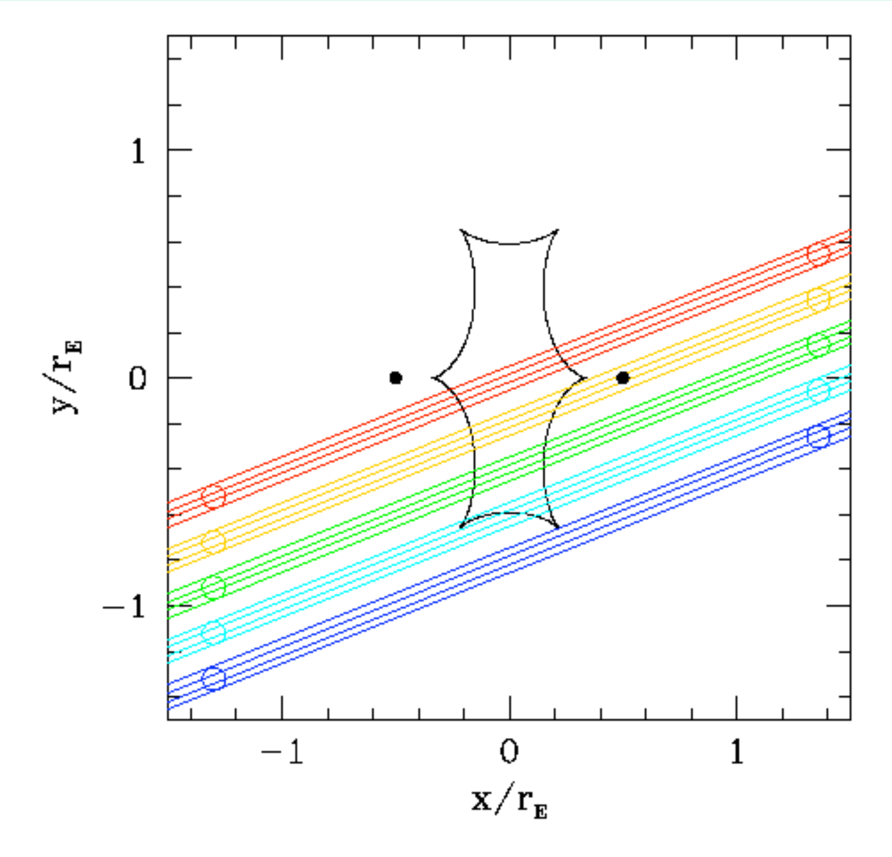


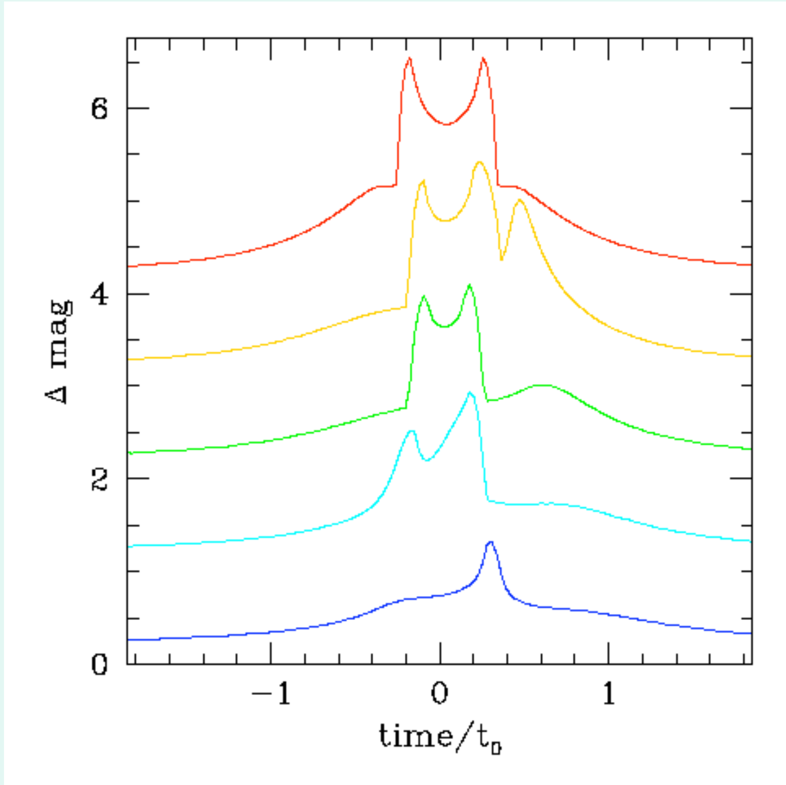
'PSPL' light curve



$$u = \frac{\theta}{\theta_E} \qquad A(u) = \frac{u^2 + 2}{u\sqrt{u^2 + 4}} \qquad u = 1 \Rightarrow A = 1.34 \qquad u << 1 \Rightarrow A(u) \approx \frac{1}{u}$$

Binary lens : caustic(s)





The caustic curve links the positions where a point source would be magnified to infinity (in lens plane)

Caustics for planetary lenses

Three topologies:

- close, intermediate, wide

Caustics:

- 1 central caustic

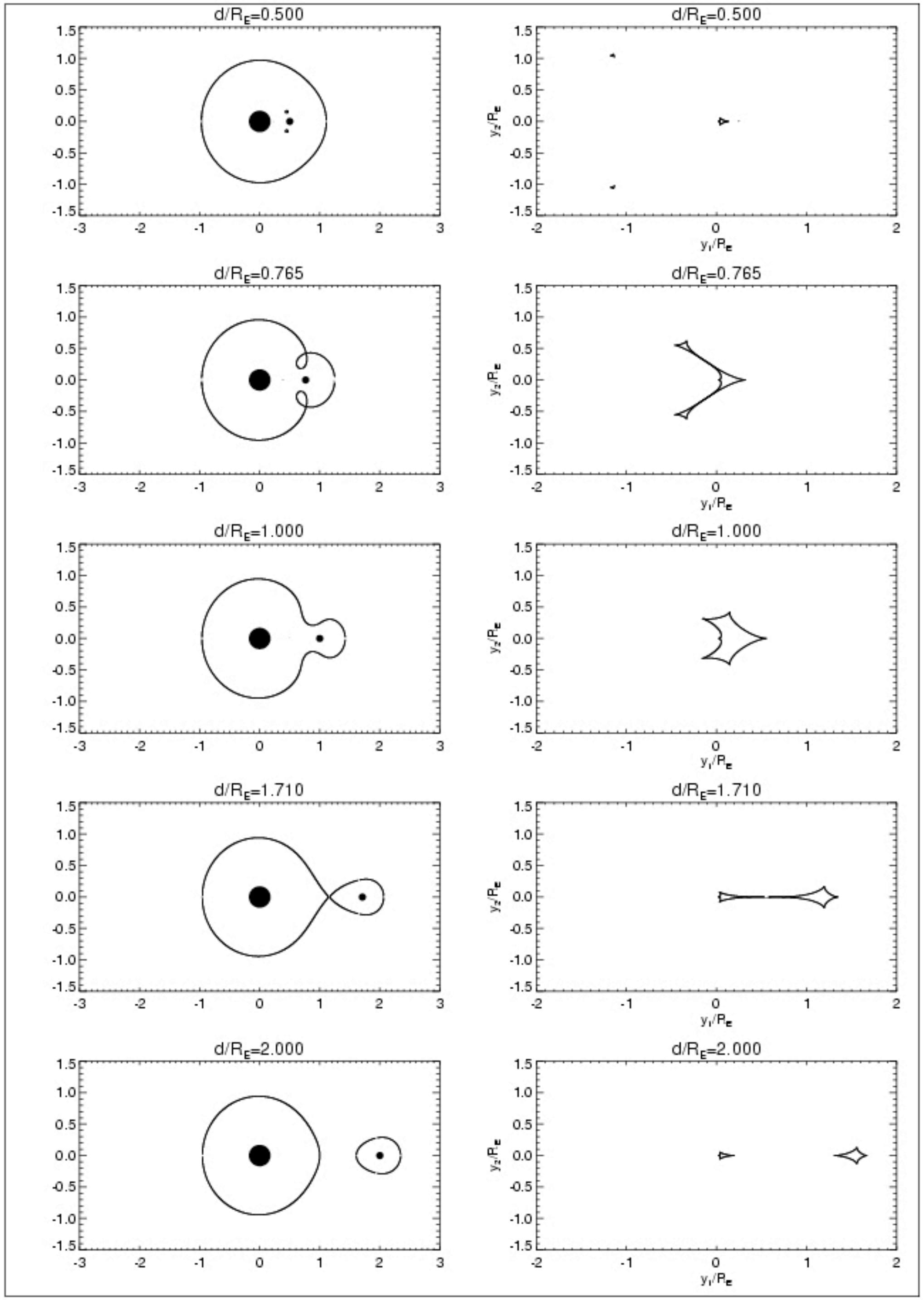
- 0-2 planetary caustics

Separation of regimes:

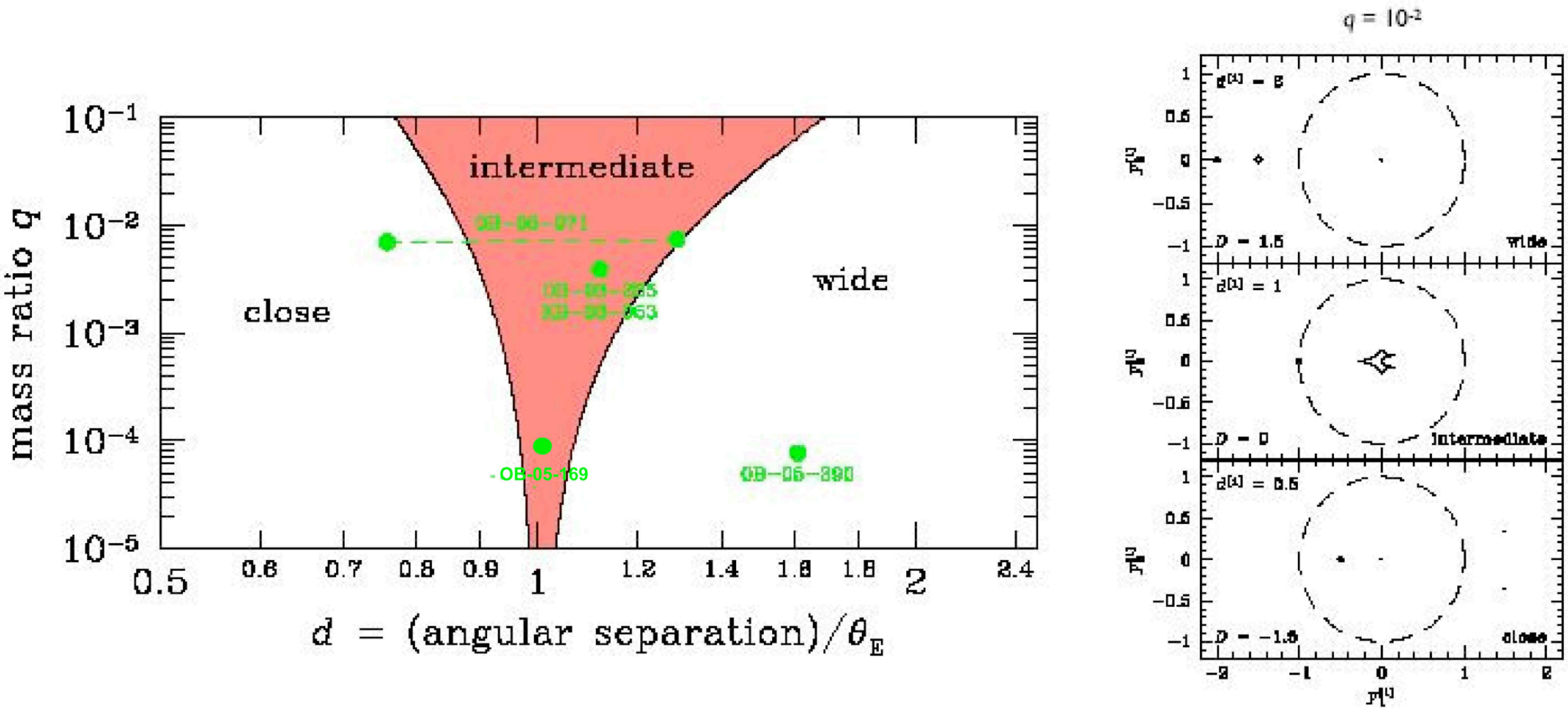
(Erdl & Schneider 1993)

$$\frac{d_c^8}{(1-d_c^4)^3} = \frac{(1+q)^2}{27q} \Rightarrow (q << 1): d_c \approx 1 - \frac{3}{4}q^{1/3}$$

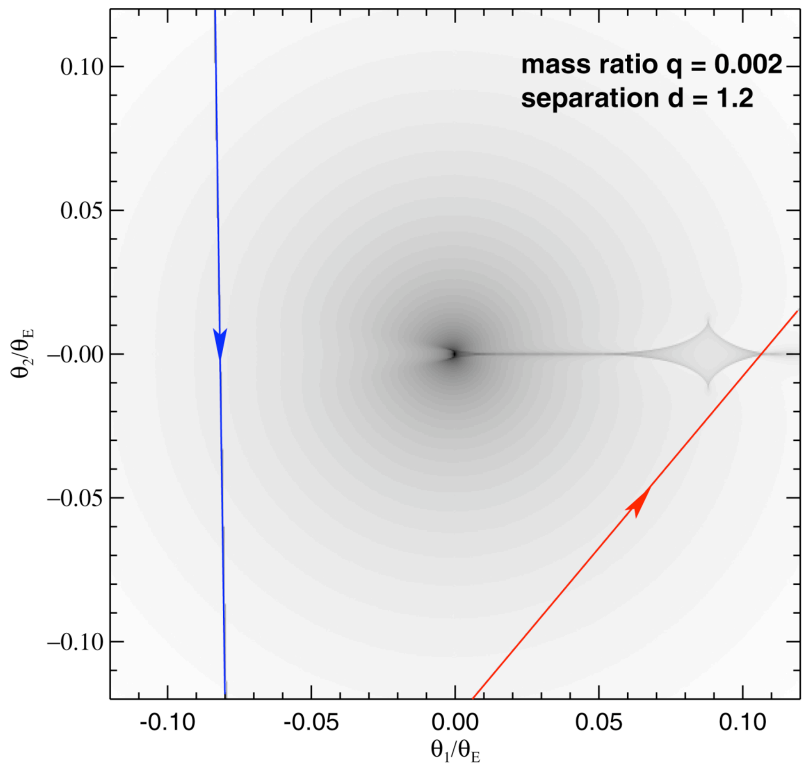
$$d_w = \frac{(1+q^{1/3})^{3/2}}{(1+q)^{1/2}} \Rightarrow (q << 1): d_w \approx 1 + \frac{3}{2}q^{1/3}$$

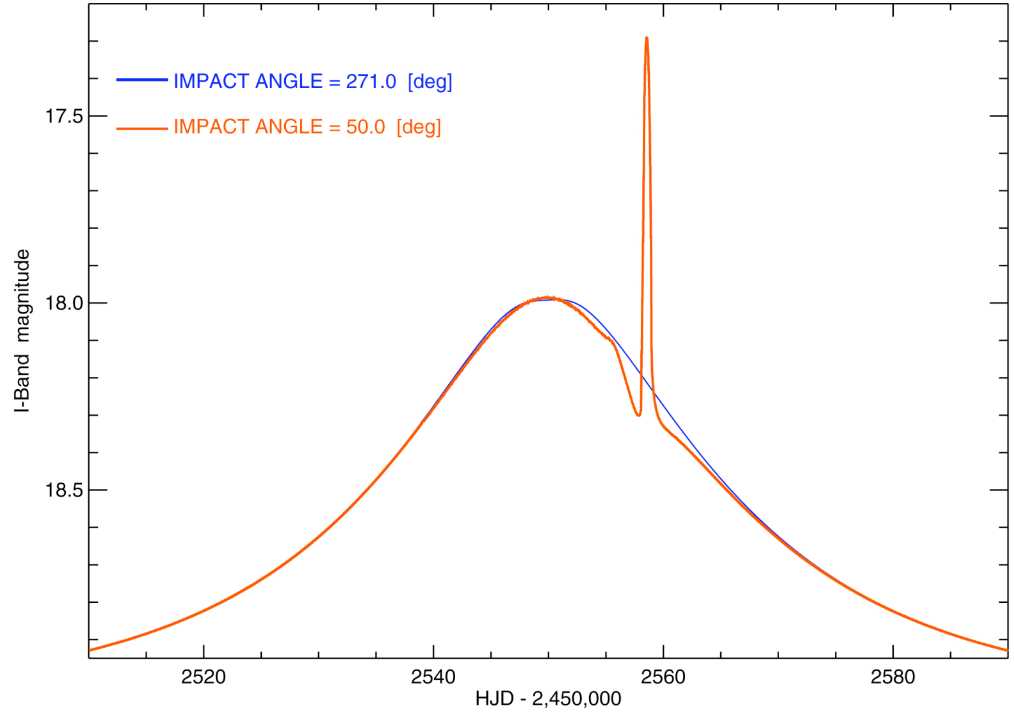


Separation of regimes



How to detect a planetary companion?



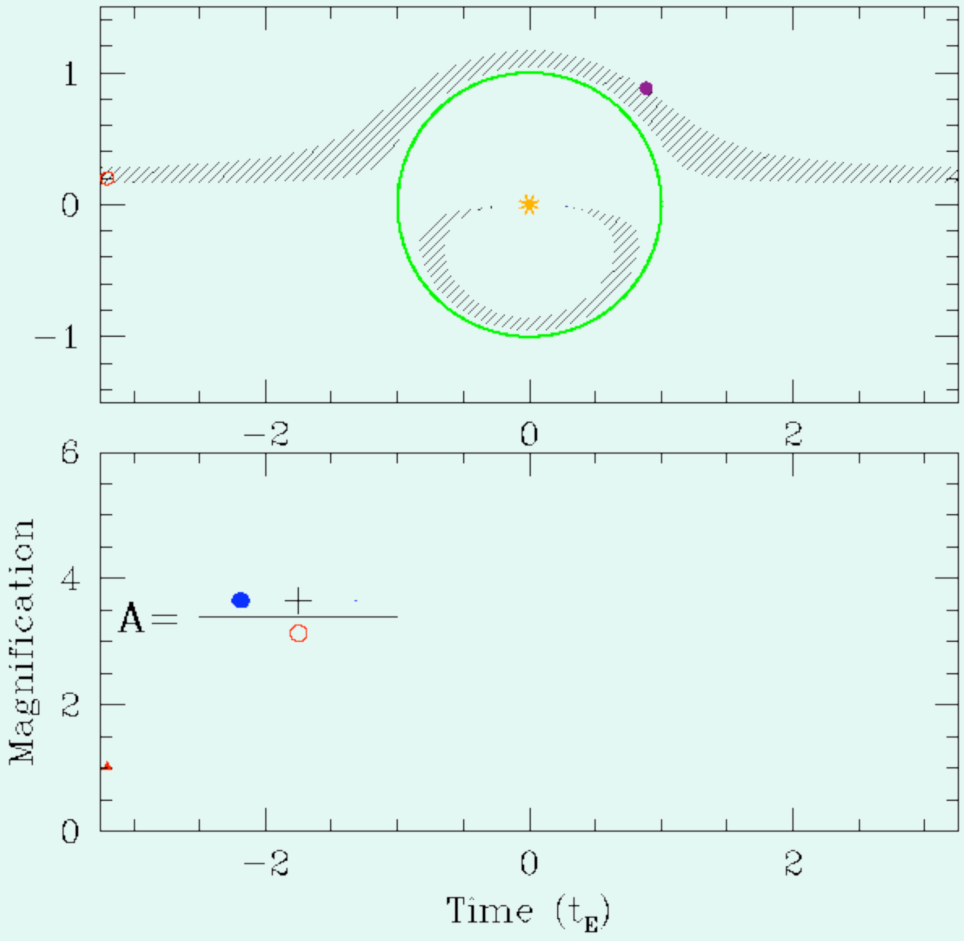


$t_E = 20$ d, $M = 0.3\, M_{sun}$: $\quad t_p = \sqrt{q}\, t_E$

Jupiter : $q = 3\ 10^{-3} \Rightarrow t_p = 1$ j

Earth : $q = 10^{-5} \Rightarrow t_p = 1.5$ h

Image perturbation

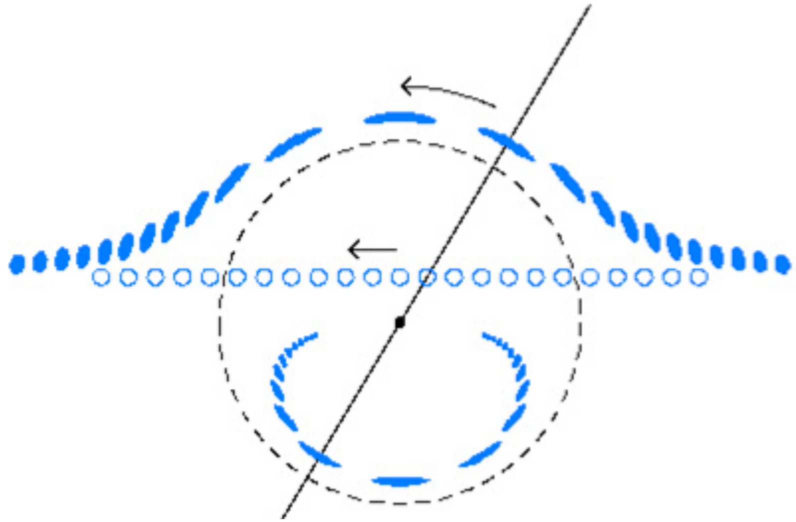


Lensing zone

$$d = 0.618\ \text{-}\ 1.618\ R_E$$

$$d = 1.2\ \text{-}\ 3.1\ \text{AU}$$

$$\langle a \rangle = \frac{4}{\pi}\ d = 1.5\ \text{-}\ 3.9\ \text{AU}$$



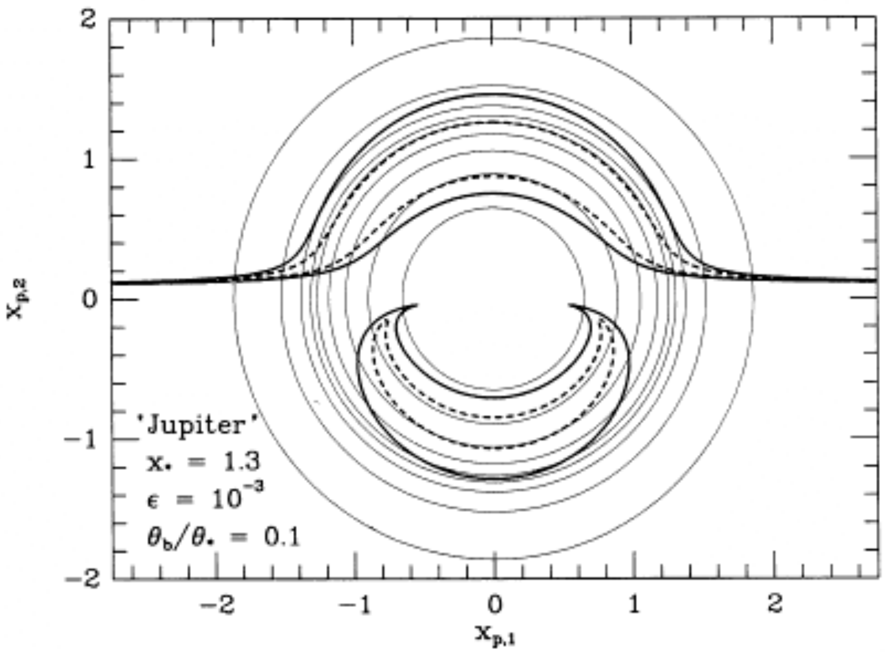
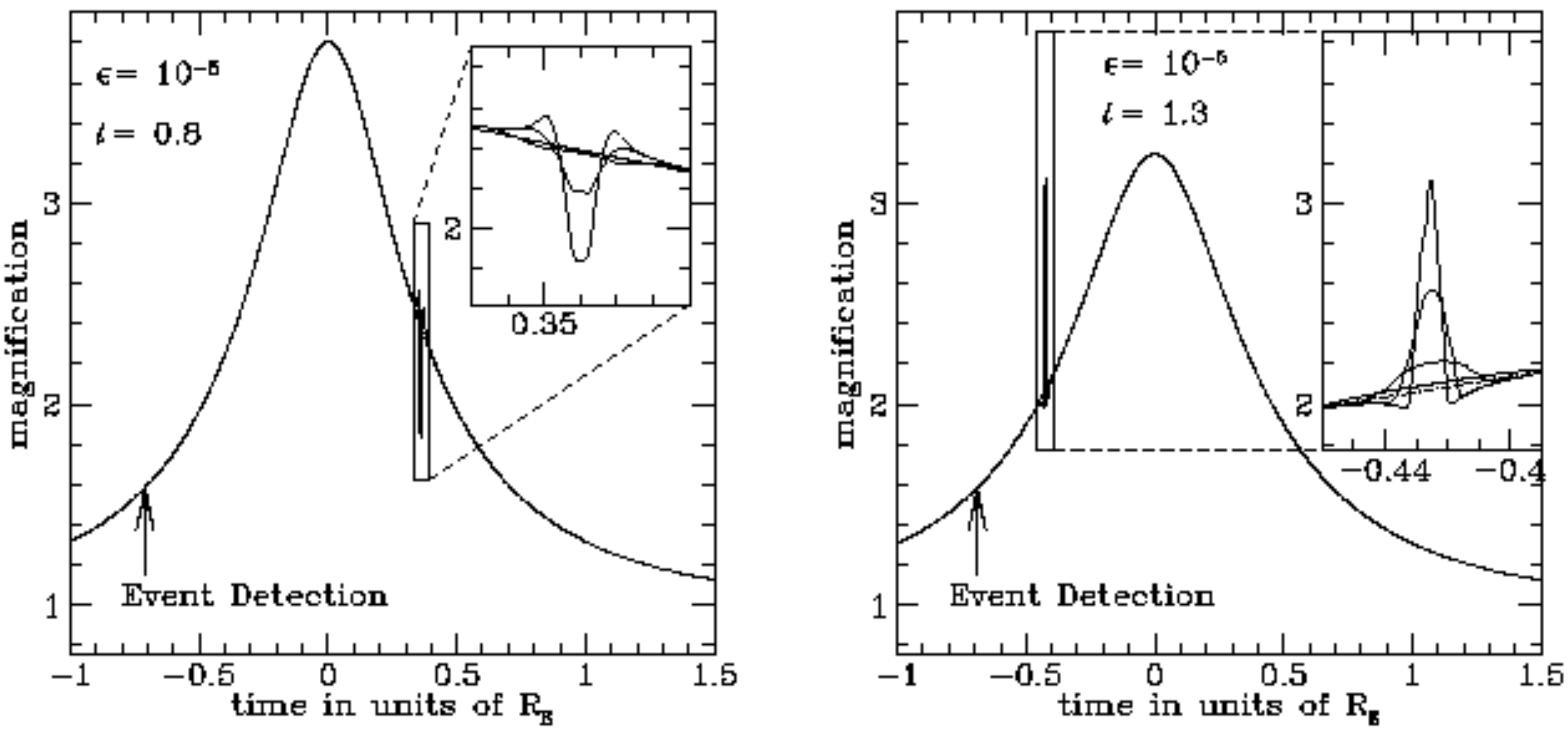


FIG. 4.—Probability distribution of a Jupiter-like planet ($\epsilon = 10^{-3}$, $x_* = 1.3$) on the lens plane (*circles*) and contours of constant perturbation $\delta_{min} = \pm 5\%$ (*bold solid*) and $\pm 20\%$ (*bold dashed*). Angular distances are in units of the Einstein ring, θ_*. Impact parameter is $\theta_b = 0.1\theta_*$. The area between successive concentric circles contains 10% of the planet's probability. The bold contours in the upper part of the figure are positive perturbations and arise when the planet is close to the brighter unperturbed image. Those in the lower part of the figure are negative and arise when the planet is close to the fainter unperturbed image.

Finite source size effect

$\rho_* = 0.003,\ 0.006,\ 0.013,\ 0.03$ if $M = 0.3\ M_{\rm sun}$ and $D_{\rm OS} = 9$ kpc



Clump giant: $R = 13\ R_{\rm sun} \Rightarrow \theta_* = 6.7\ \mu{\rm as} \Rightarrow \rho_* = 0.013$ if $D_{\rm OL} = 0.5\ D_{\rm OS}$

Turn-off M.S.: $R = 3\ R_{\rm sun} \Rightarrow \theta_* = 1.6\ \mu{\rm as} \Rightarrow \rho_* = 0.006$ if $D_{\rm OL} = 0.8\ D_{\rm OS}$

Estimate of source size

- *Model gives:* $\rho_* = \dfrac{\theta_*}{\theta_E} = \dfrac{t_*}{t_E}$
- *CMD allows to estimate the source size via a surface brightness relation:*

$$\log\, \theta_*\ (\mu\text{as}) = 3.20 + 0.49\ (V - I)_0 - 0.066\ (V - I)_0^2 - 0.2\ I_0$$

- *Red giant clump method: analog to HB for metal-rich stars; calibrated from local giants measured by Hipparcos:*

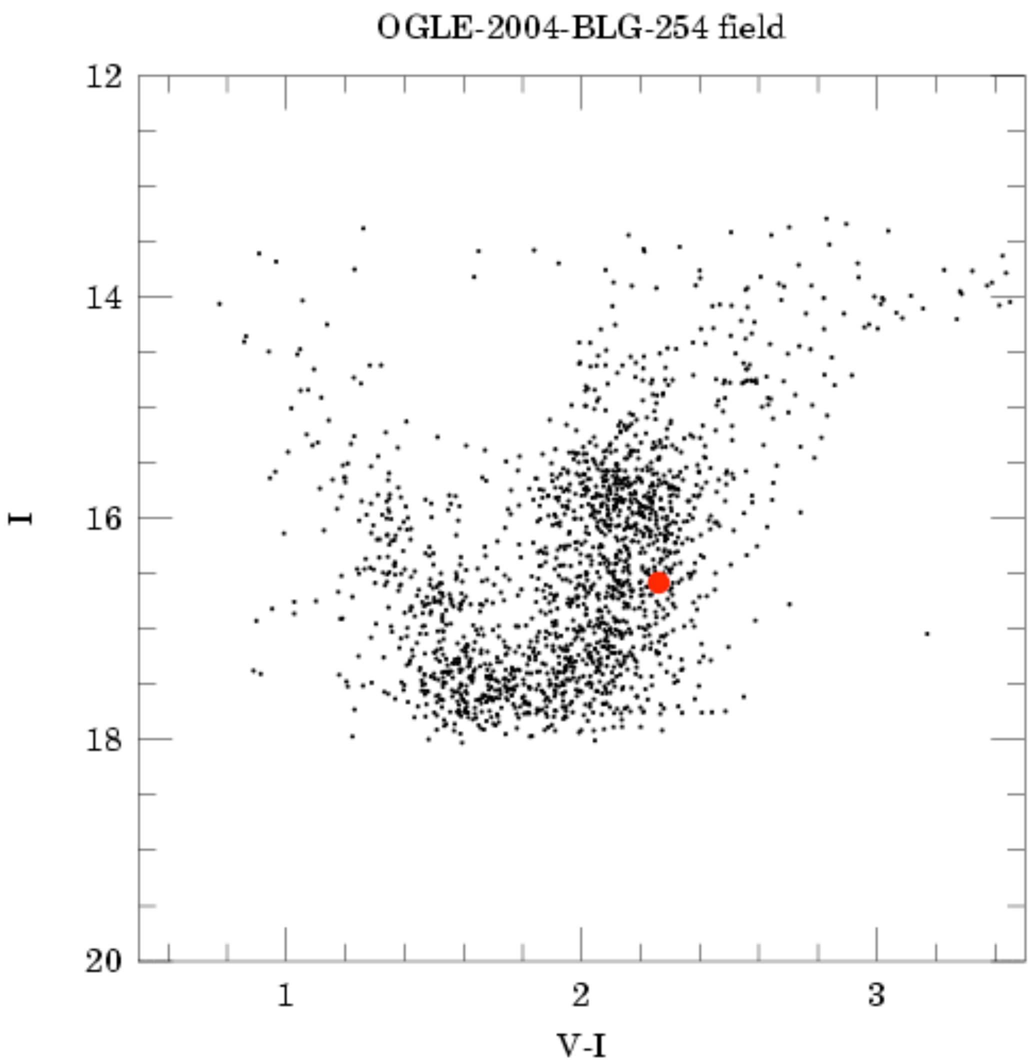
$$(V - I)_0 = 1.00\ \pm\ 0.05 \qquad M_I = -0.23\ \pm\ 0.03$$

- *Clump distance depends upon Galactic bar geometry:*

$$R_0 = 7.62\ \pm\ 0.32\ \text{kpc} \qquad \mu_0 = 14.41\ \pm\ 0.09$$

- *Relative position of source wrt clump gives* $(V\text{-}I)_0$ *et* I_0

Colour Magnitude Diagram (CMD)



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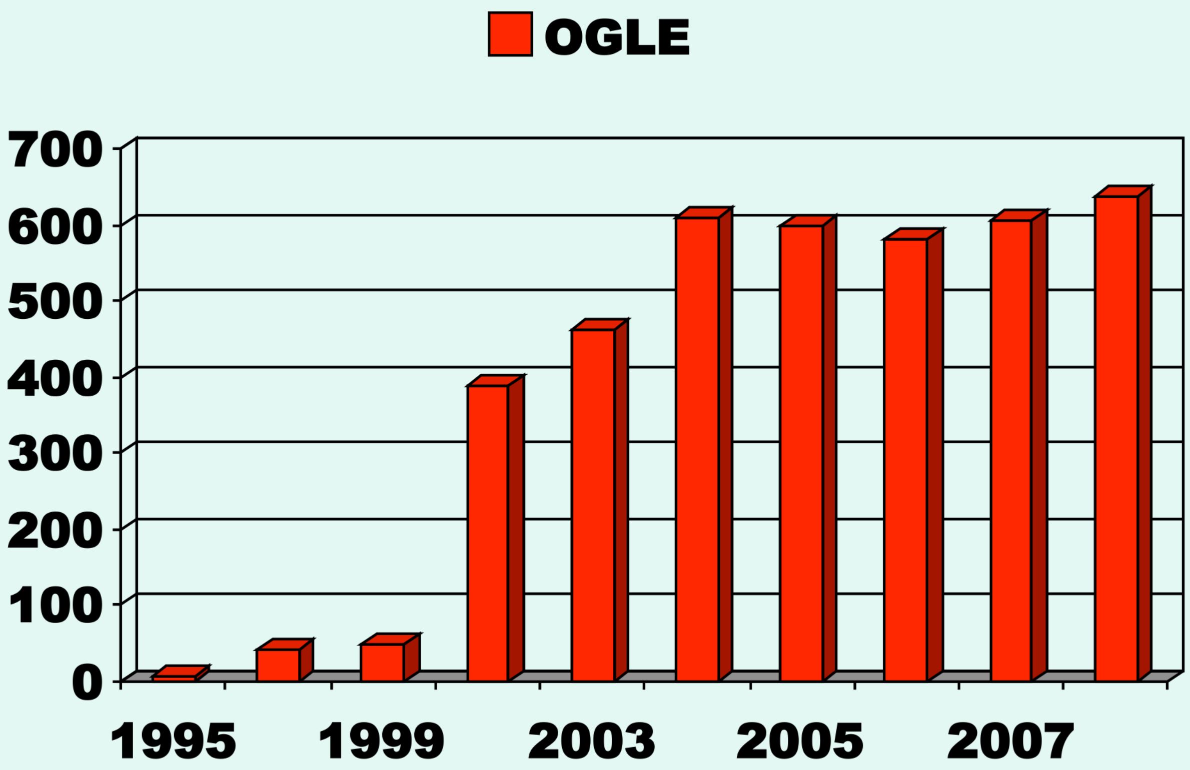
Alert telescopes

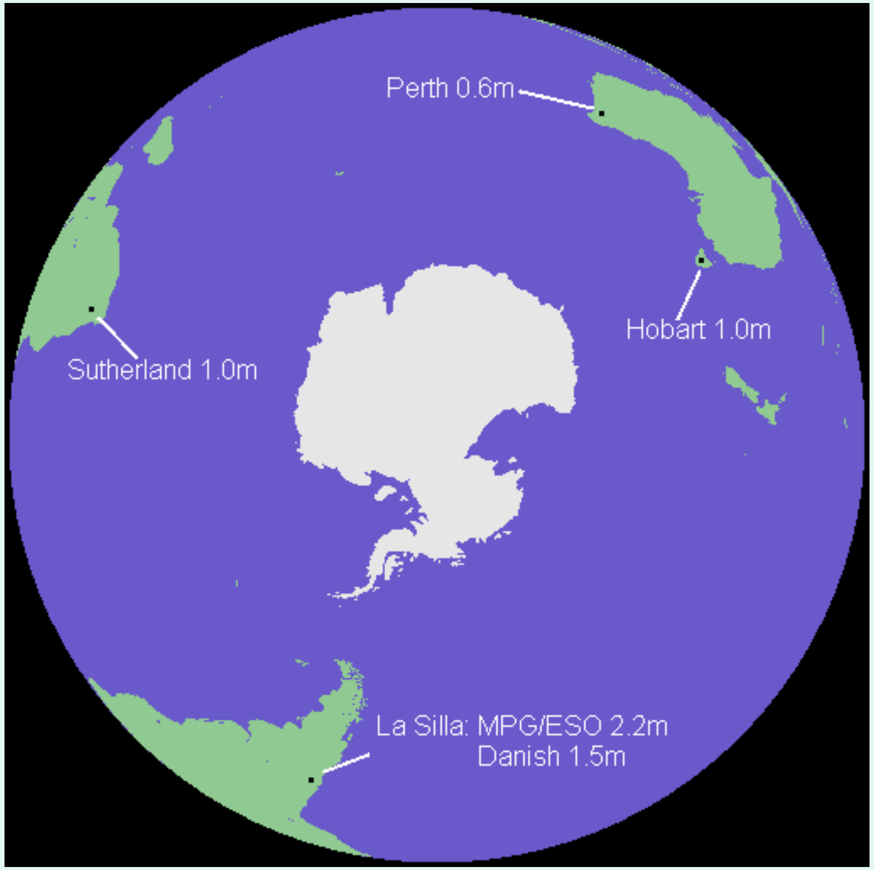
1993: Macho (†1999), Ogle, EROS (†2003)
1995: MOA



PLANET
(1995–2008)
Probing Lensing Anomaly NETwork

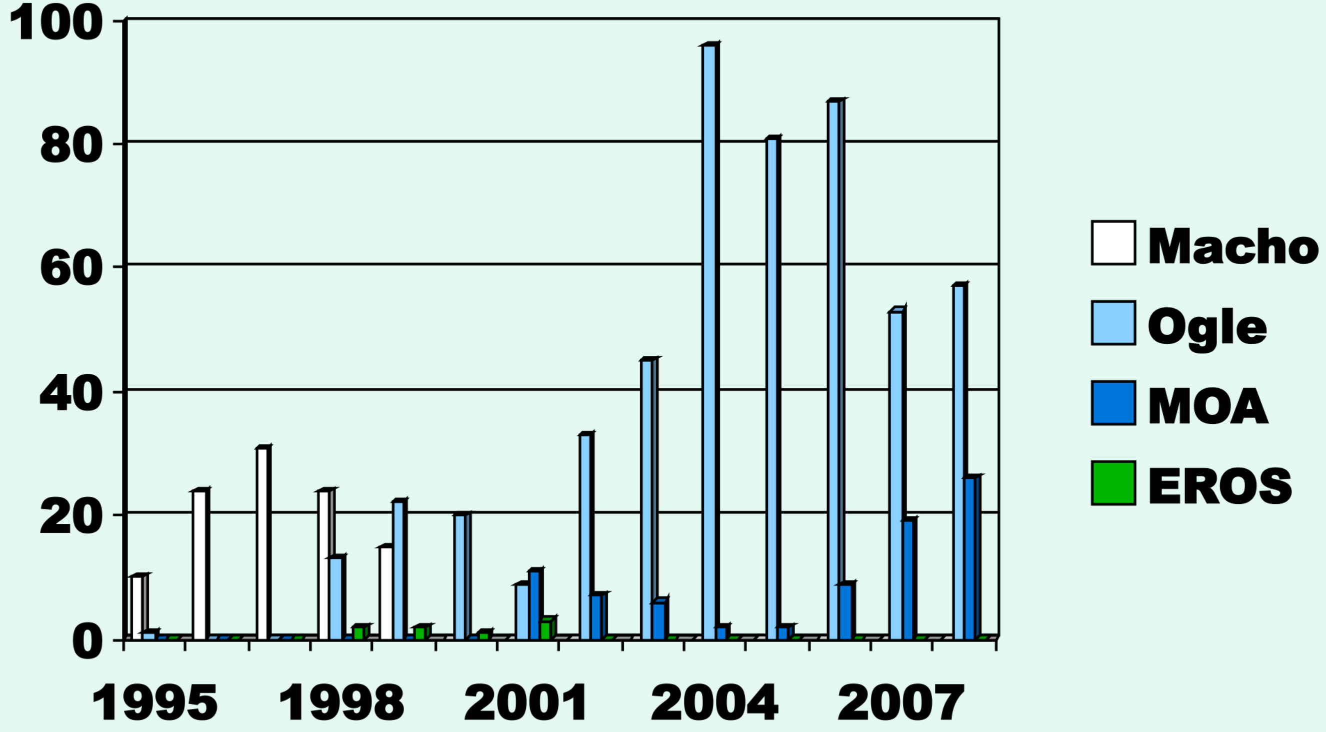
- *33 members, 20 institutes, 11 countries*
- *3-6 telescopes in Southern hemisphere*
- *Collaborative agreement with LCOGT and RoboNet (network of 3 robotic telescopes)*

PLANET telescope network



« Sun never rises over PLANET »

Origin of followed alerts



Other follow-up collaborations (« friends »)

- GMAN (Global Microlensing Alert Network): 1995 – 1999, CTIO 0.9m
- MPS (Microlensing Planet Search): 1997 - 1999, 1.9m Mount Stromlo
- MicroFUN (Microlensing Follow-Up Network): 2003, CTIO 1.3m, Wise 1.0m, Palomar 1.5m, MDM 2.4m, LOAO 1.0m + amateur telescopes
- RoboNet: 2004, Faulkes-N 2m, Liverpool 2m, Faulkes-S 2m -> LCOGT
- OGLE-III EEWS: 2003
- MOA-II: 2007

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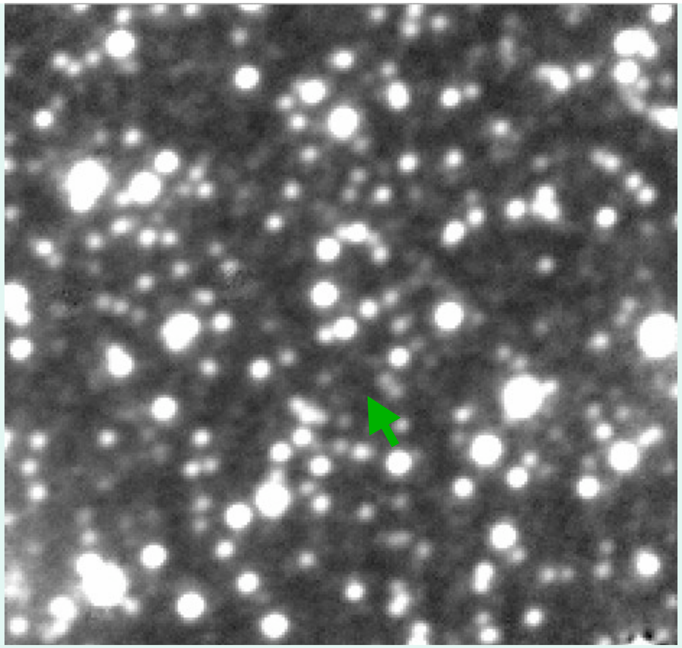
Data reduction

- *Problem: crowded fields*
- *Old days: DoPhot*

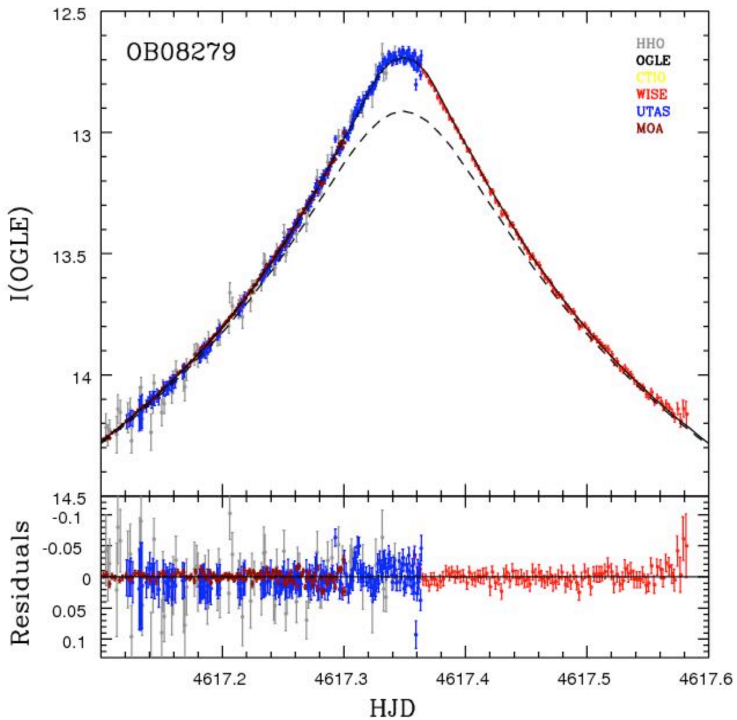
- *Solution: image subtraction*
- *Until recently: ISIS*

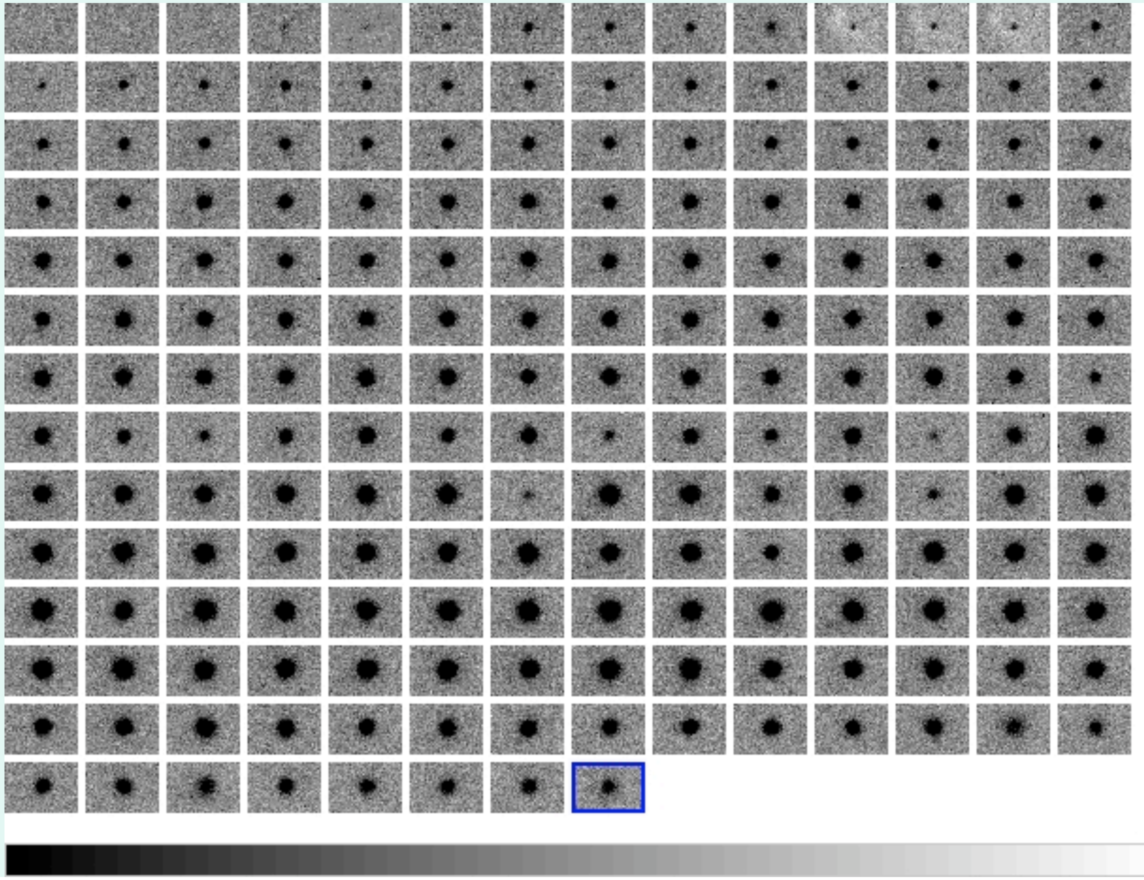
- *Now: numerical kernel (Bramich)*
- *Registration to integer pixel (no resampling)*
- *pySIS 3.0 (Albrow)*
- *Photometry*



Canopus reference image of OGLE-2008-BLG-279

Normalized subtracted images vs time





Roadmap

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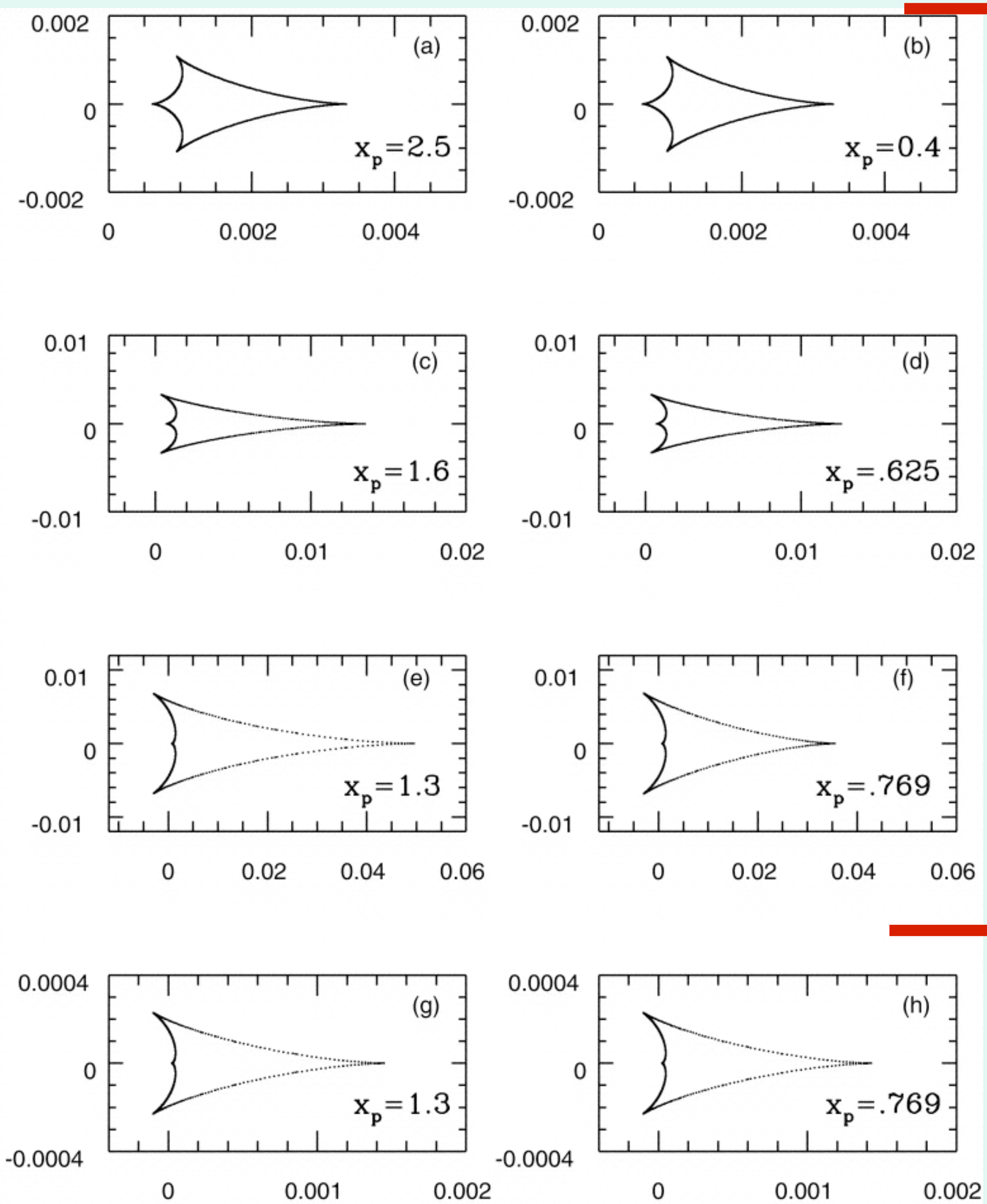
First steps …

- *Several ads then withdrawn:*
  - MACHO 1997-BLG-41
  - OGLE 2000-BLG-012
- *Explanations:*
  - Uniqueness of model: planet vs. rotating binary
  - Photometric accuracy
  - Finite source size effect
  - Parallax
  - Blending
- *Once detected, difficult to characterize*

Central caustic



Jupiter:
degeneracy d-1/d

1/30 Jupiter:
degeneracy in q

2003: MOA 2003-BLG-53/OGLE 2003-BLG-235

Bond et al., 2004, ApJ 606, L155

BEST FIT
(Bennett et al. 2006):

Lens distance = 5.8 kpc

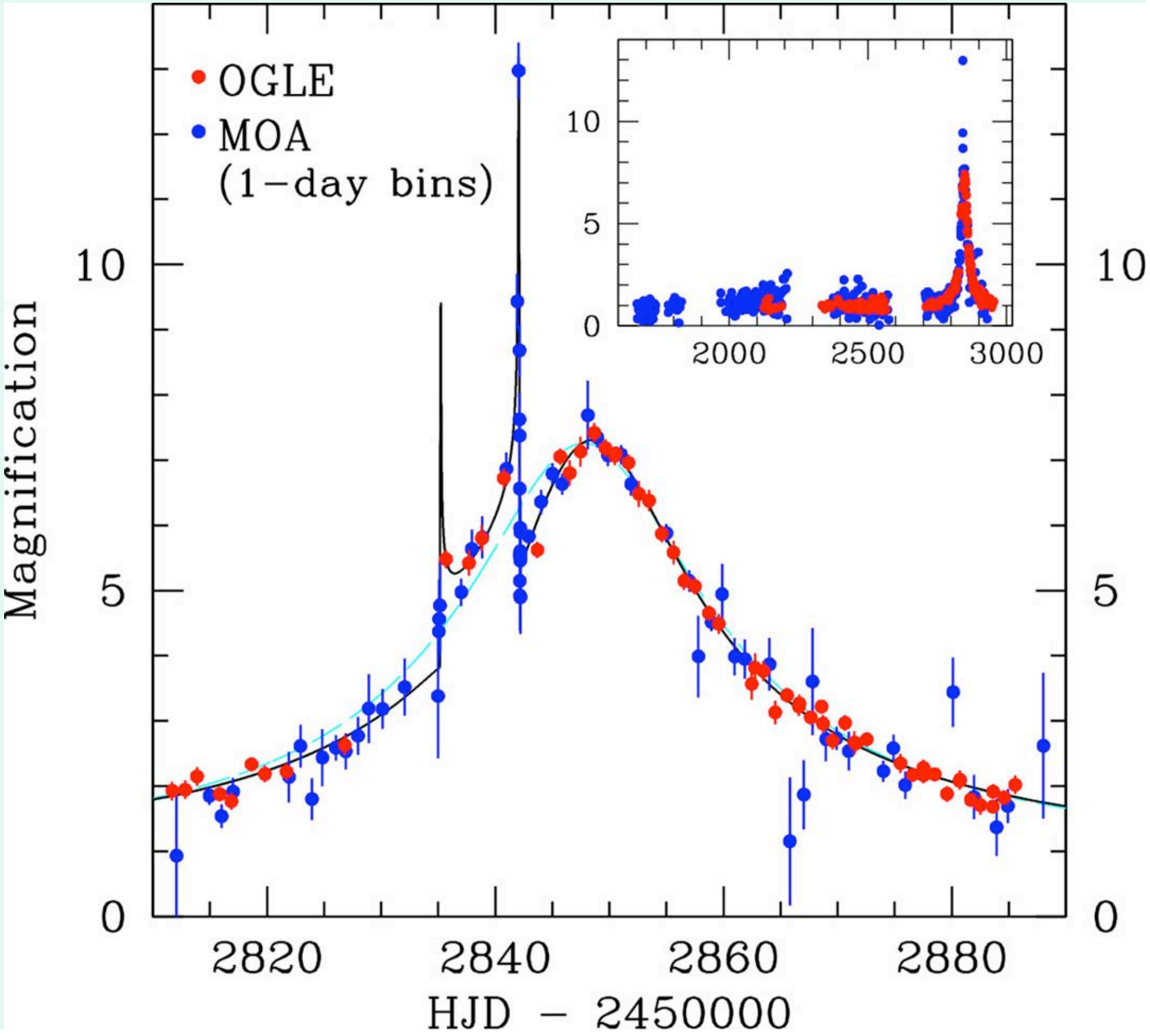
Proj. separation = 3.6 AU

Stellar mass = 0.63 $M_\odot$

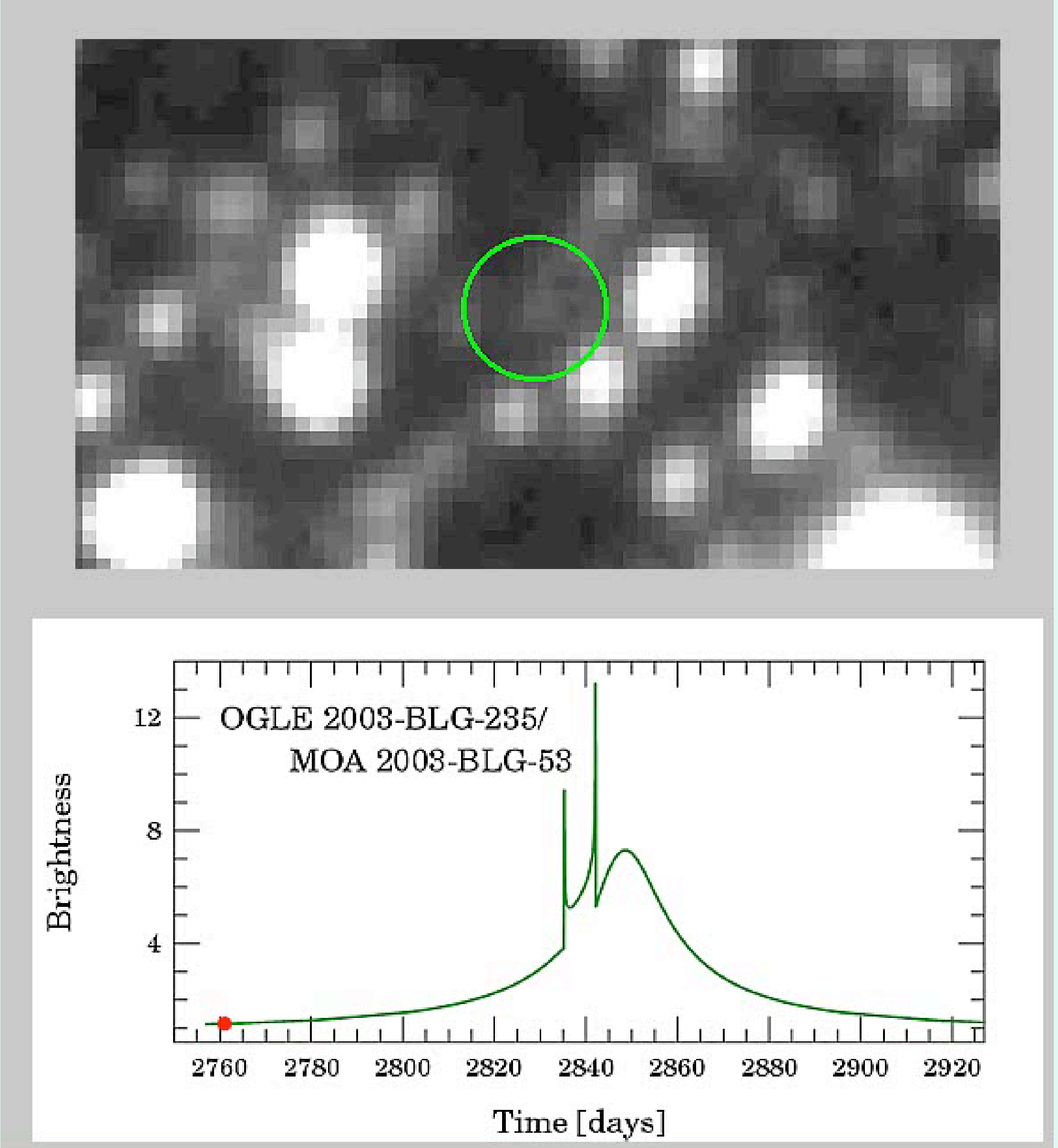
Planet mass = 2.6 M_{JUP}

HST images discard that the lens is a 0.6 $M_\odot$ white dwarf

Cold Jupiter

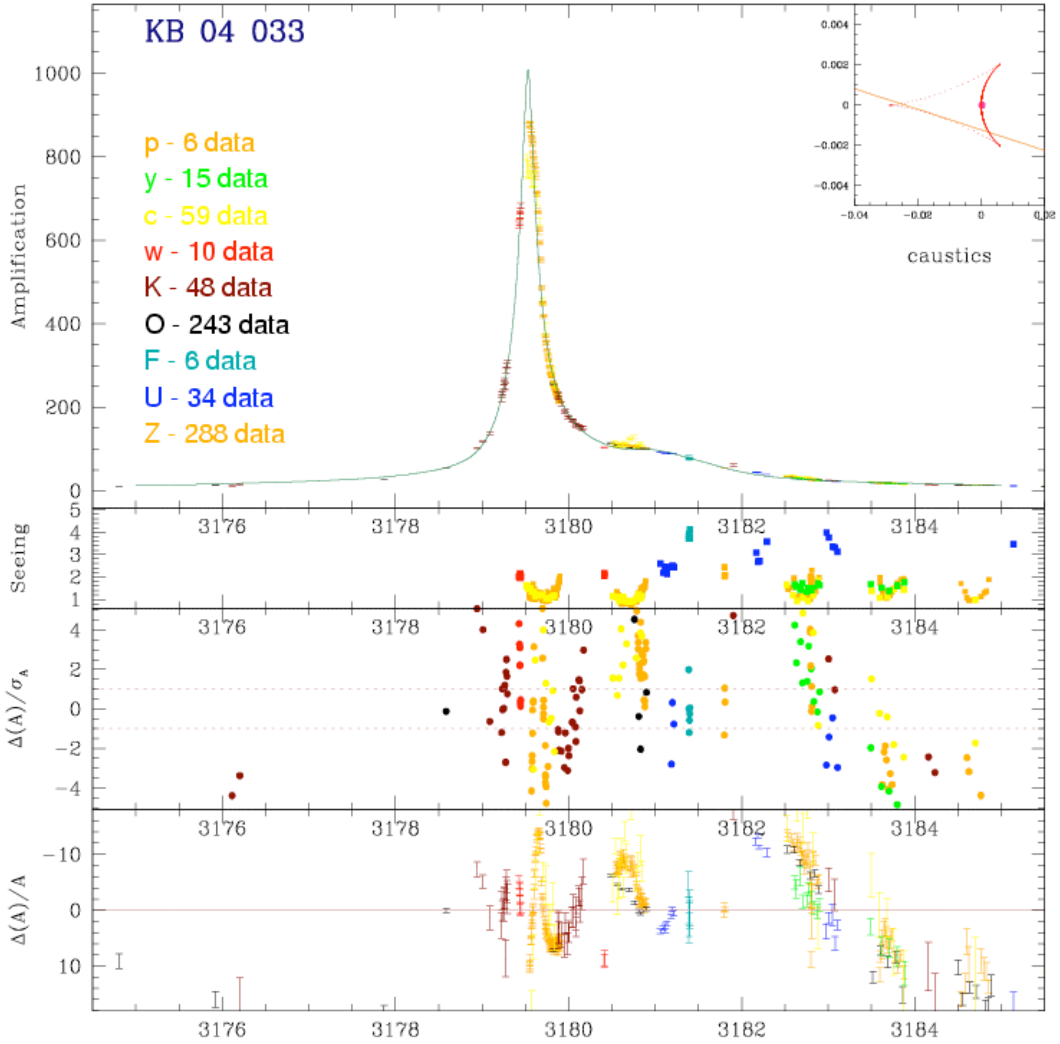


Animation (Gaudi)

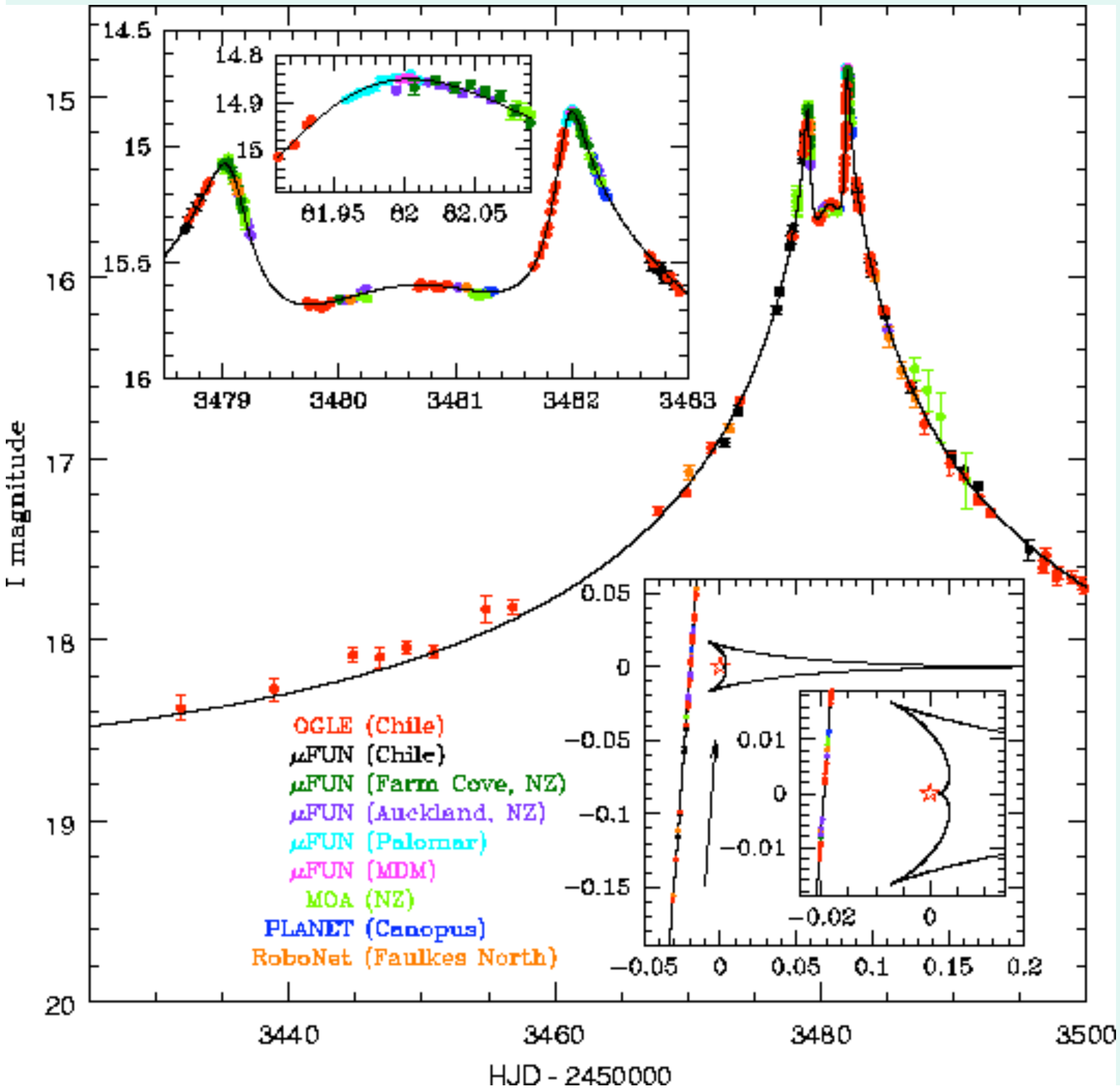


2004: MOA 2004-BLG-33

No convincing model (yet)



2005 (1): OGLE 2005-BLG-071



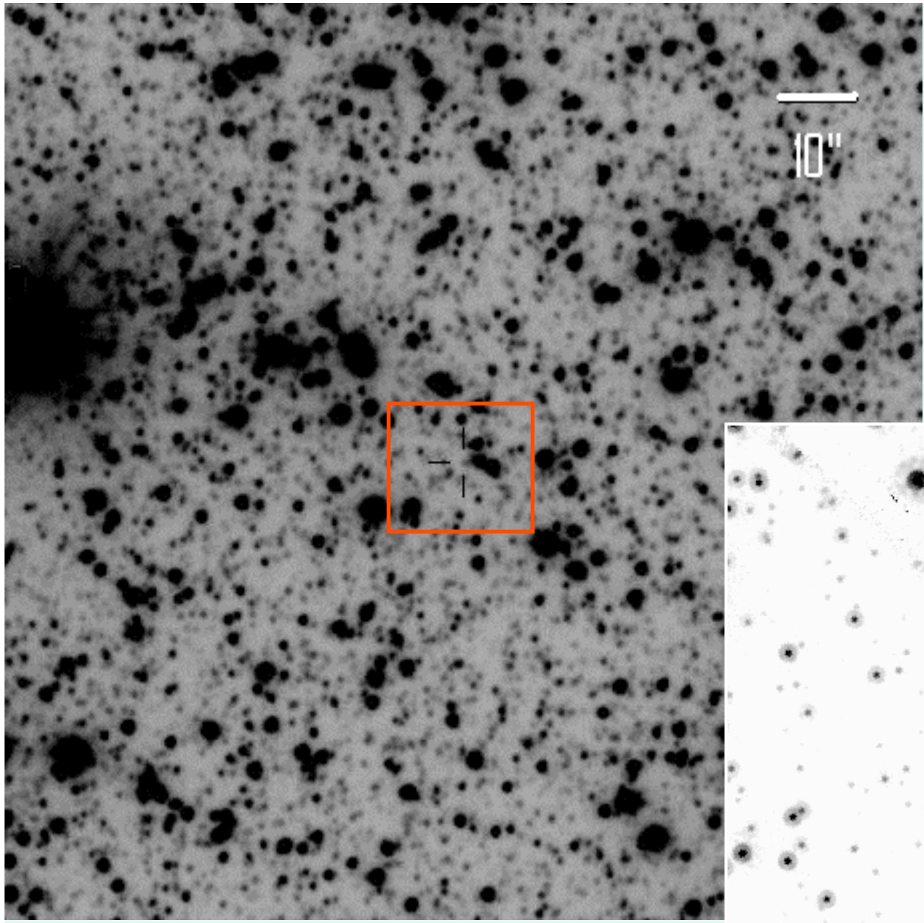
Two models:

close binary :
d=0.766
$q=6.8\ 10^{-3}$

wide binary :
d=1.285
$q=7.2\ 10^{-3}$

Wide slightly favoured

$M_* \sim 0.46 \pm 0.04\ M_{sun}$
$D_{OL} = 3.3 \pm 0.4$ kpc
$M_p = 3.5 \pm 0.3\ M_{JUP}$
a ~ 4.7 (2.8) AU
P ~ 15 (7) yr

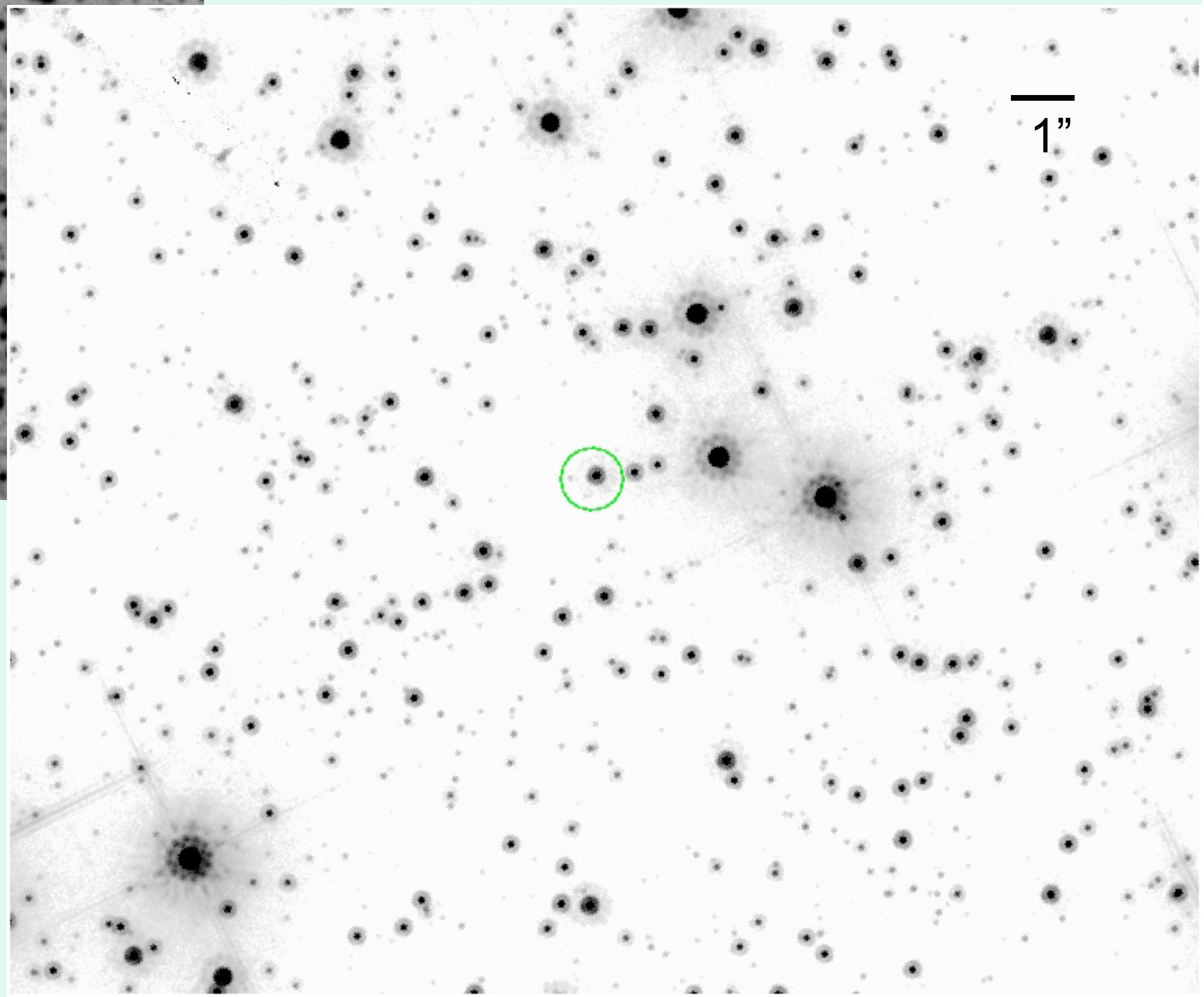


Subo Dong©

E

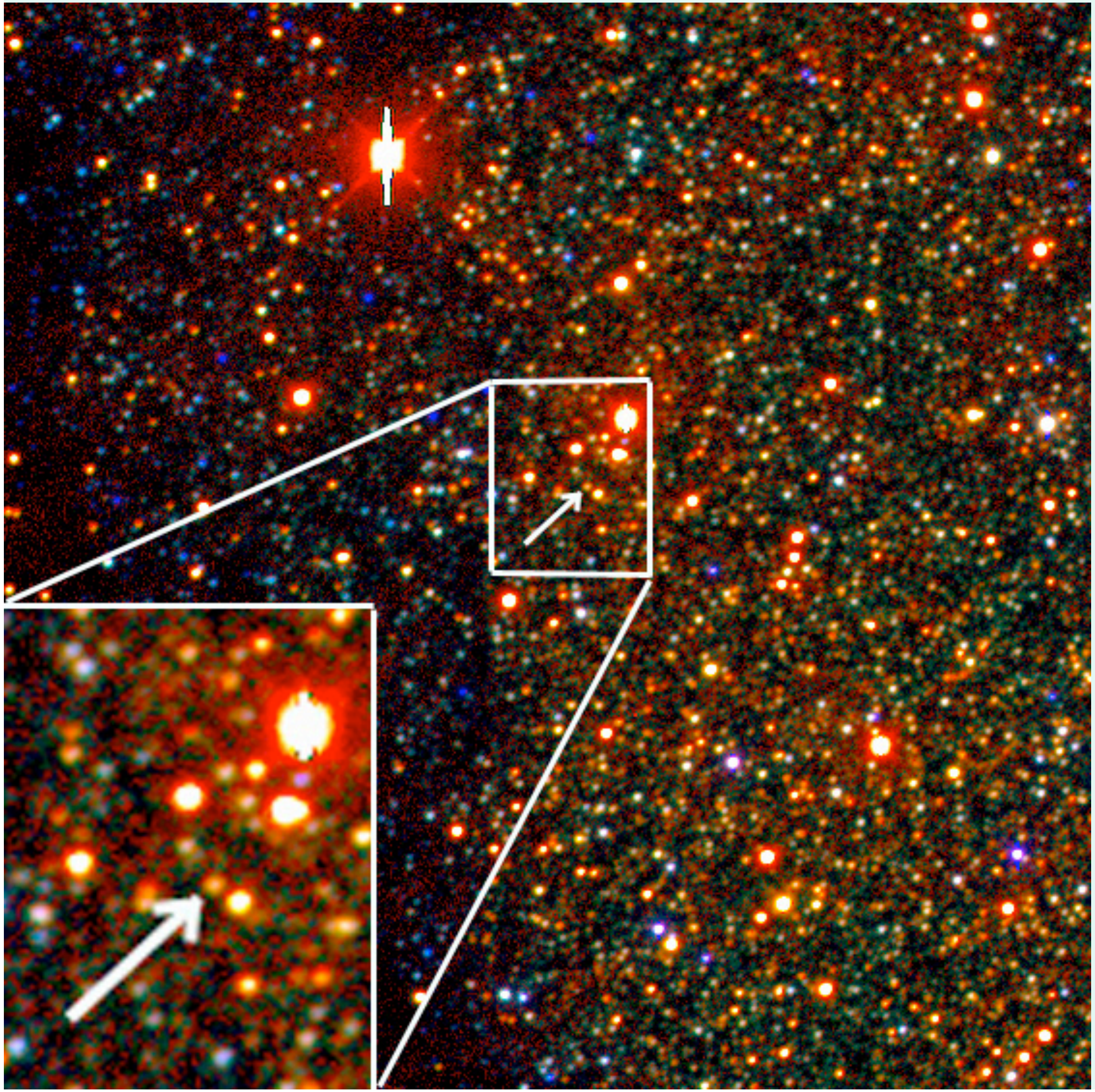
N

HST Image

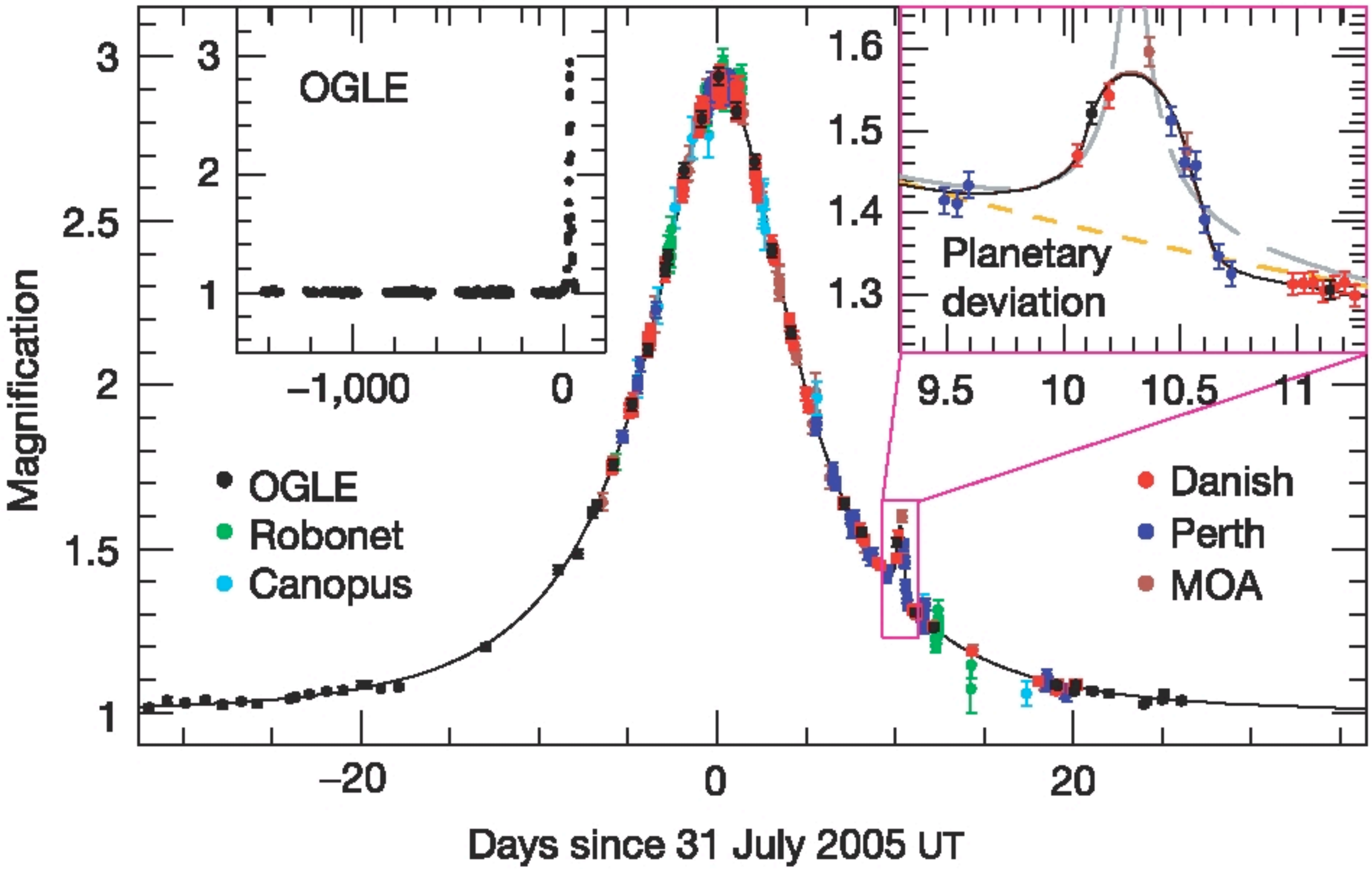


OGLE Field

2005 (2): OGLE 2005-BLG-390



A PLANET/RoboNet, OGLE, MOA-II cooperation



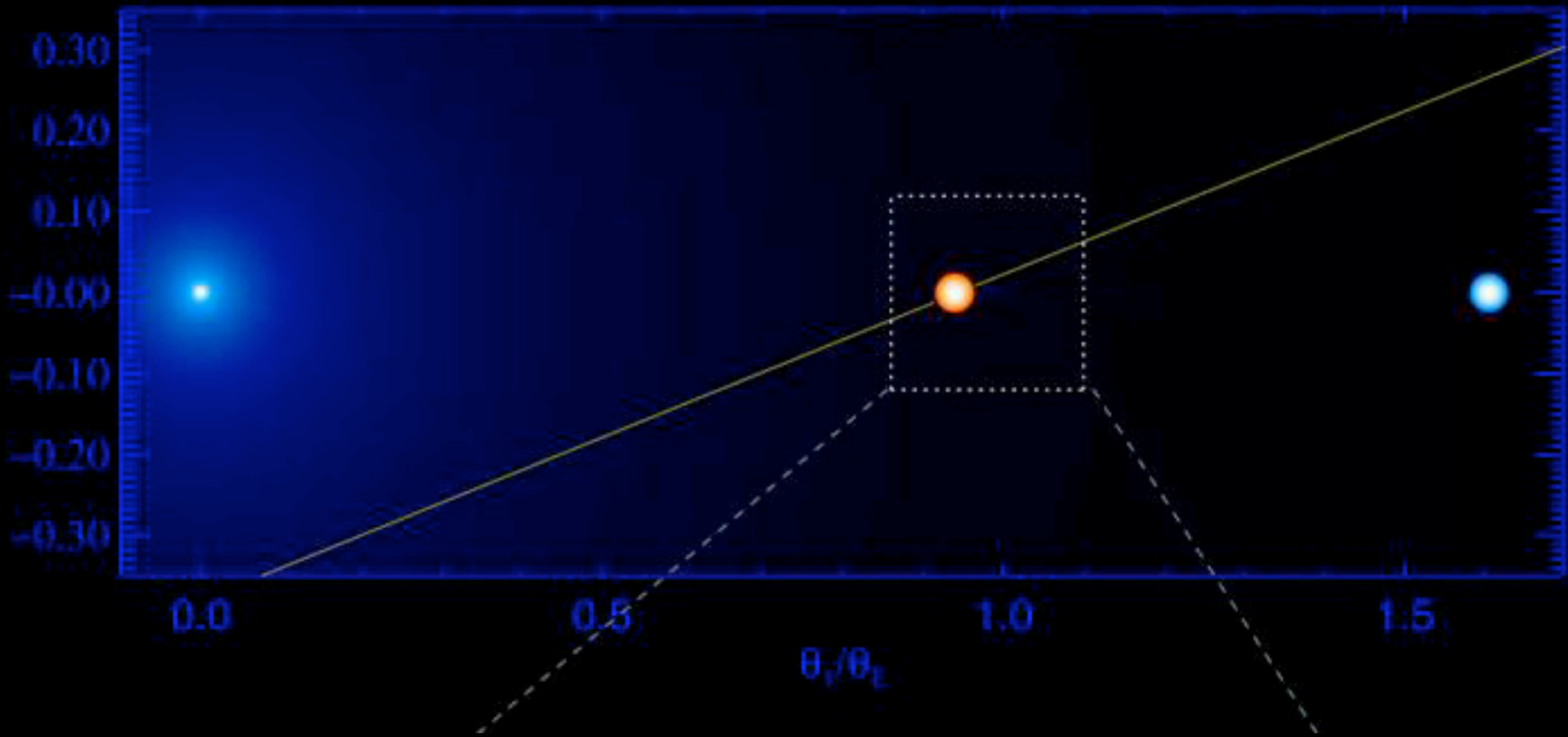
January 26, 2006: Nature

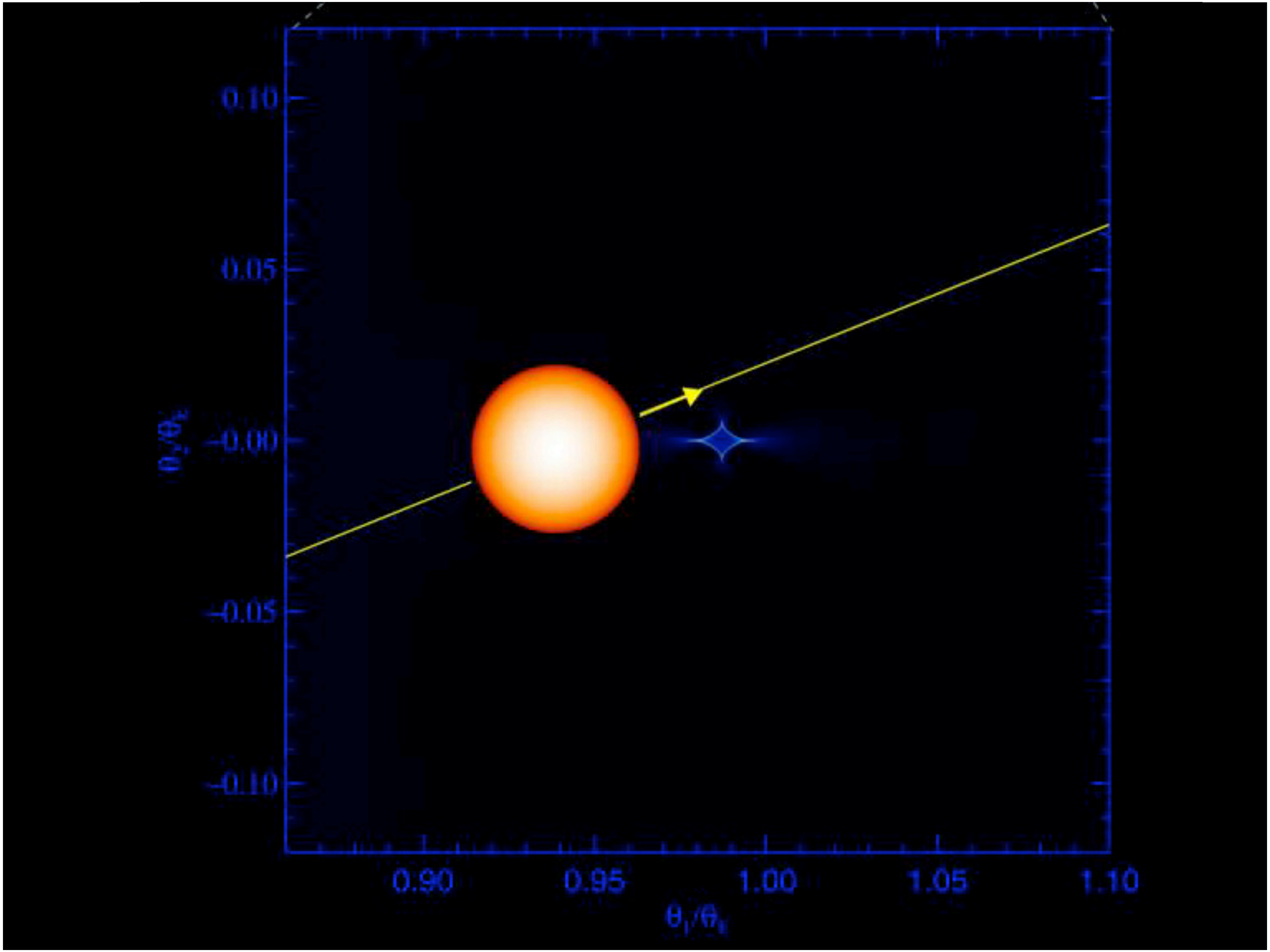
LETTERS

Discovery of a cool planet of 5.5 Earth masses through gravitational microlensing

J.-P. Beaulieu[1,4], D. P. Bennett[1,3,5], P. Fouqué[1,6], A. Williams[1,7], M. Dominik[1,8], U. G. Jørgensen[1,9], D. Kubas[1,10], A. Cassan[1,4], C. Coutures[1,11], J. Greenhill[1,12], K. Hill[1,12], J. Menzies[1,13], P. D. Sackett[1,14], M. Albrow[1,15], S. Brillant[1,10], J. A. R. Caldwell[1,16], J. J. Calitz[1,17], K. H. Cook[1,18], E. Corrales[1,4], M. Desort[1,4], S. Dieters[1,12], D. Dominis[1,19], J. Donatowicz[1,20], M. Hoffman[1,19], S. Kane[1,21], J.-B. Marquette[1,4], R. Martin[1,7], P. Meintjes[1,17], K. Pollard[1,15], K. Sahu[1,22], C. Vinter[1,9], J. Wambsganss[1,23], K. Woller[1,9], K. Horne[1,8], I. Steele[1,24], D. M. Bramich[1,8,24], M. Burgdorf[1,24], C. Snodgrass[1,25], M. Bode[1,24], A. Udalski[2,26], M. K. Szymański[2,26], M. Kubiak[2,26], T. Więckowski[2,26], G. Pietrzyński[2,26,27], I. Soszyński[2,26,27], O. Szewczyk[2,26], Ł. Wyrzykowski[2,26,28], B. Paczyński[2,29], F. Abe[3,30], I. A. Bond[3,31], T. R. Britton[3,15,32], A. C. Gilmore[3,15], J. B. Hearnshaw[3,15], Y. Itow[3,30], K. Kamiya[3,30], P. M. Kilmartin[3,15], A. V. Korpela[3,33], K. Masuda[3,30], Y. Matsubara[3,30], M. Motomura[3,30], Y. Muraki[3,30], S. Nakamura[3,30], C. Okada[3,30], K. Ohnishi[3,34], N. J. Rattenbury[3,28], T. Sako[3,30], S. Sato[3,35], M. Sasaki[3,30], T. Sekiguchi[3,30], D. J. Sullivan[3,33], P. J. Tristram[3,32], P. C. M. Yock[3,32] & T. Yoshioka[3,30]

System geometry





0.10
0.05
-0.00
-0.05
-0.10
0.90
0.95
1.00
1.05
1.10
θ_1/θ_E
θ_2/θ_E

Model parameters

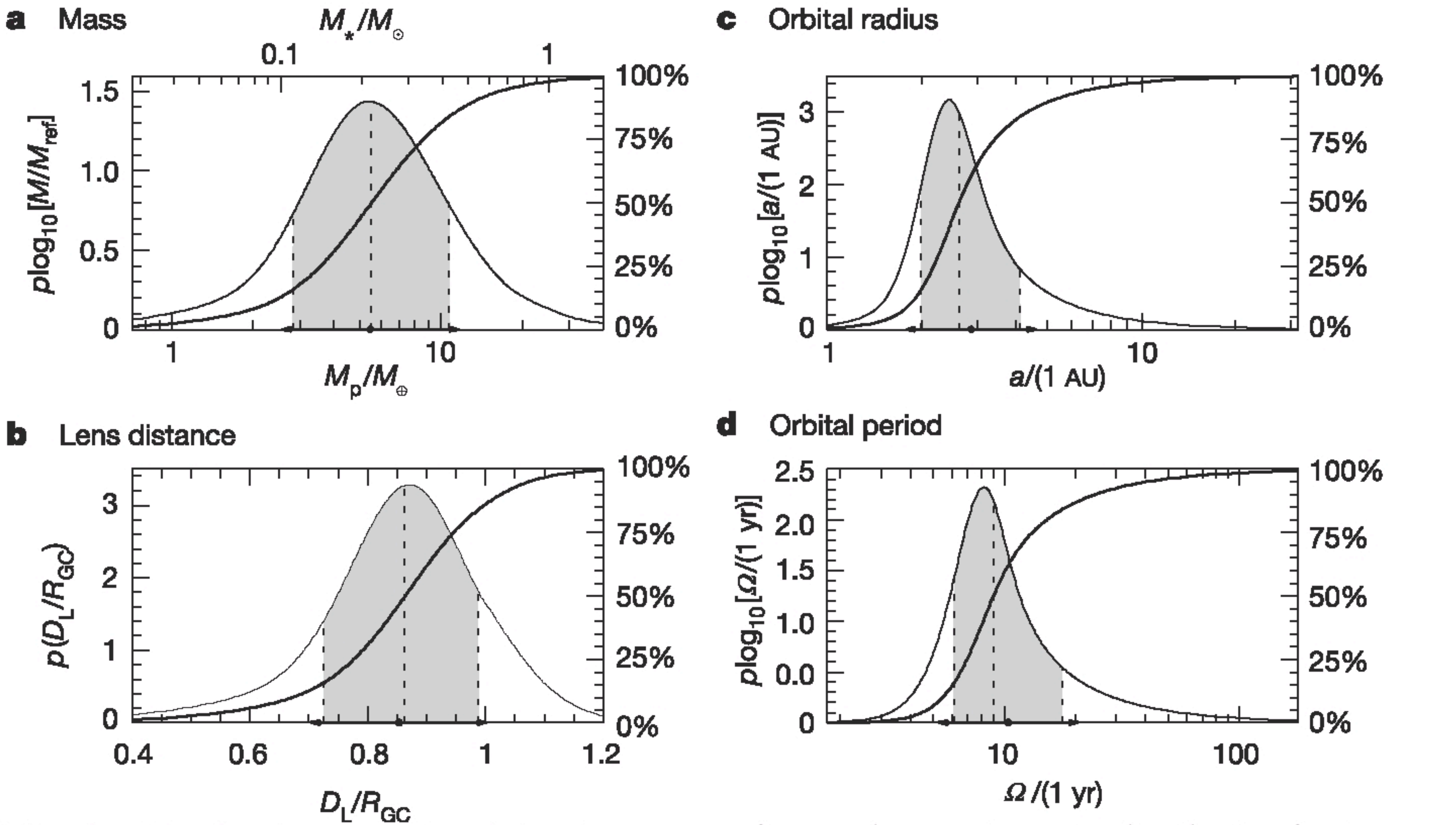
Canonical example of a microlensing planet (Gould & Loeb 1992, Bennett & Rhie 1996)

Table 1 | Microlensing fit parameters

d	$1.610 \pm 0.008 R_E$
q	$(7.6 \pm 0.7) \times 10^{-5}$
Closest approach	$0.359 \pm 0.005 R_E$
Einstein ring radius crossing time	11.03 ± 0.11 days
Time of closest approach	31.231 ± 0.005 July 2005 UT
Source star radius crossing time	0.282 ± 0.010 days
θ	2.756 ± 0.003 rad

The parameters for the best binary lens model for the OGLE 2005-BLG-390 microlensing event light curve are shown with their 1σ uncertainties. Some of these parameters are scaled to the Einstein ring radius, which is given by $R_E = 2\sqrt{GMD_L(D_S - D_L)/(c^2 D_S)}$, where M is the mass of the lens, G is the newtonian constant of gravitation,c the speed of light in vacuum, and D_L and D_S are the lens and source distances, respectively.

Probability density of deduced parameters from a galactic model



Adopted parameters

- Source distance $D_S = 1.05 \pm 0.25\ R_{GC}$ (R_{GC}=7.62 ± 0.32 kpc)
- Source star: a Galactic Bulge giant G4 III, $R_S = 9.6 \pm 1.3\ R_{SUN}$
- Primary lens mass: $M_* = 0.22^{+0.21}_{-0.11}\ M_{SUN}$
- Primary lens distance: $D_L = 6.6 \pm 1.0$ kpc
- Planet mass: $M_p = 5.5^{+5.5}_{-2.7}\ M_{EARTH}$
- Planet separation: $a = 2.6^{+1.5}_{-0.6}$ AU
- Orbital period: $P = 9.0^{+8.7}_{-2.9}$ years

Temperature and radius of the OGLE 2005-BLG-390Lb planet

- *Star characteristics:*

$$L_* = 0.0057\ L_{SUN},\ R_* = 0.23\ R_{SUN},\ T_* = 3320\ \mathrm{K}$$

- *Equilibrium temperature:*

$$T_p = T_* \sqrt{\frac{R_*}{430\ a}}\ (1 - A)^{1/4} \qquad T_p = 42\ \mathrm{K} = -230\ °\mathrm{C}\ \text{if}\ A = 0.4\ \text{(Neptune)}$$

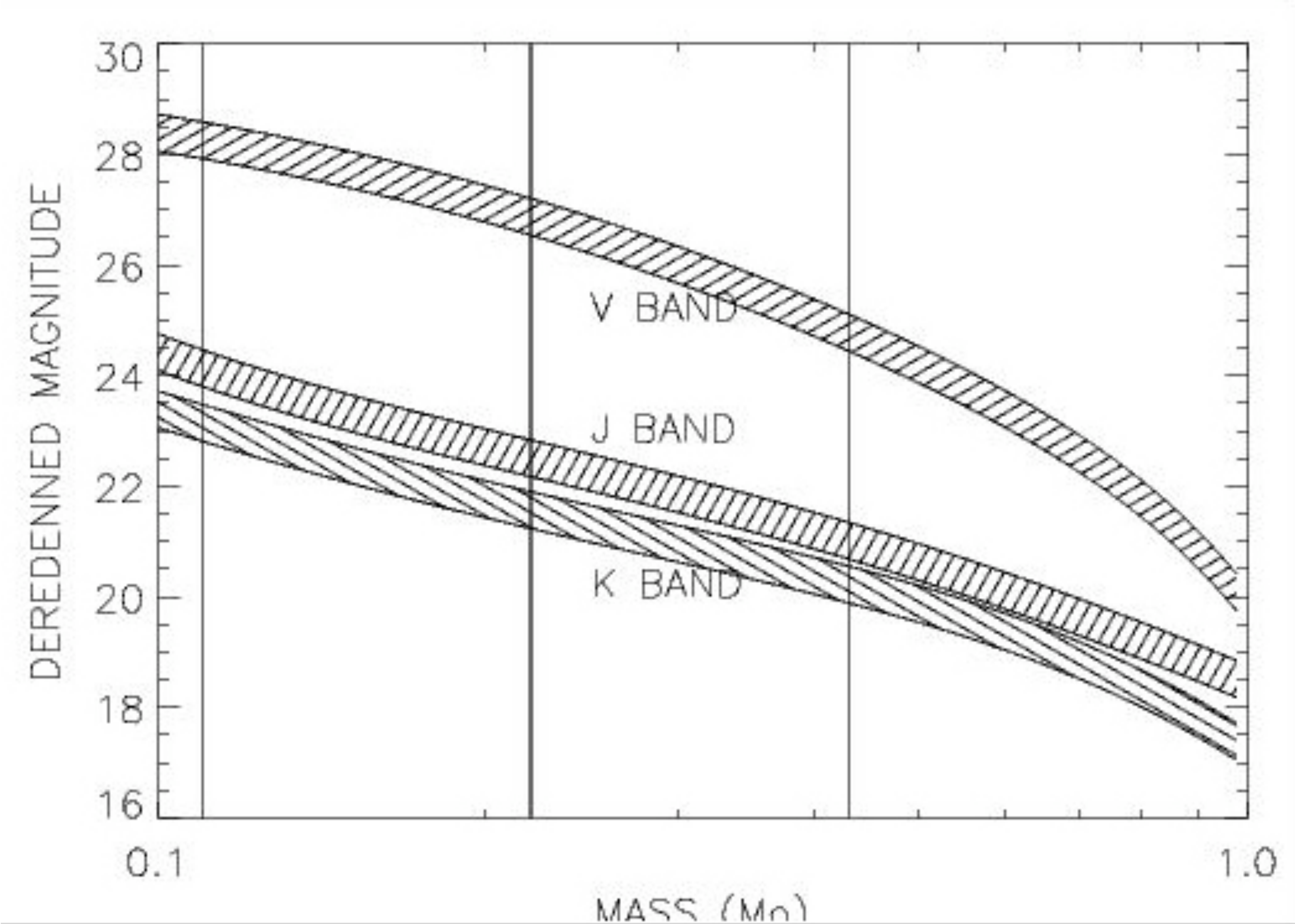
- *Léger et al. (2004) model:*

$$R_p = 1.9\ R_{EARTH}\ \text{if}\ \rho = 4.34\ \mathrm{g\ cm^{-3}}\ :\ \text{ocean planet}$$

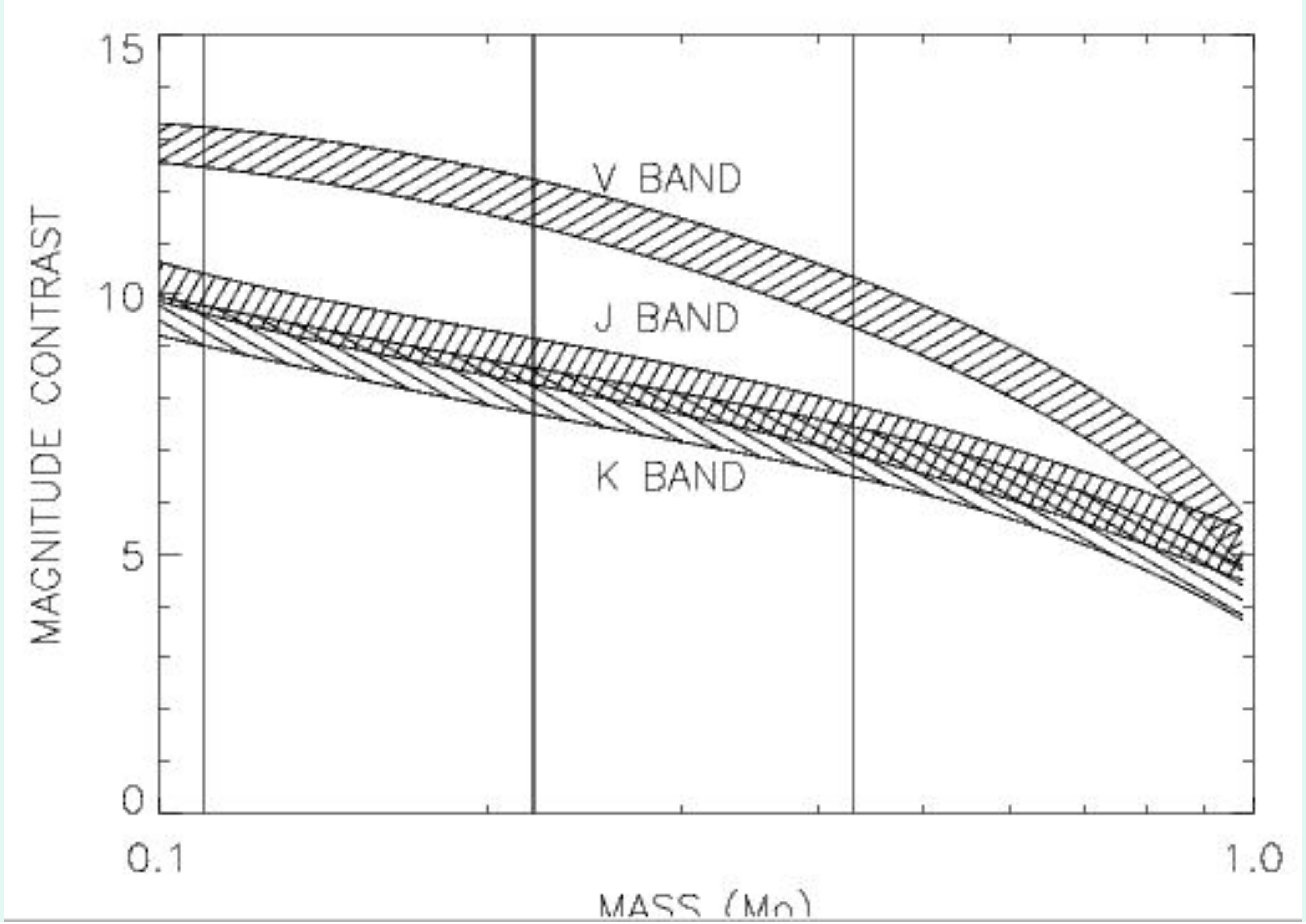
$$R_p = 1.6\ R_{EARTH}\ \text{if}\ \rho = 7.74\ \mathrm{g\ cm^{-3}}\ :\ \text{rocky planet}$$

And now …

Lens star detection in 10 years? $\mu = 6.8 \pm 1.0$ mas yr^{-1}



Key parameter is contrast: ~4000 in J

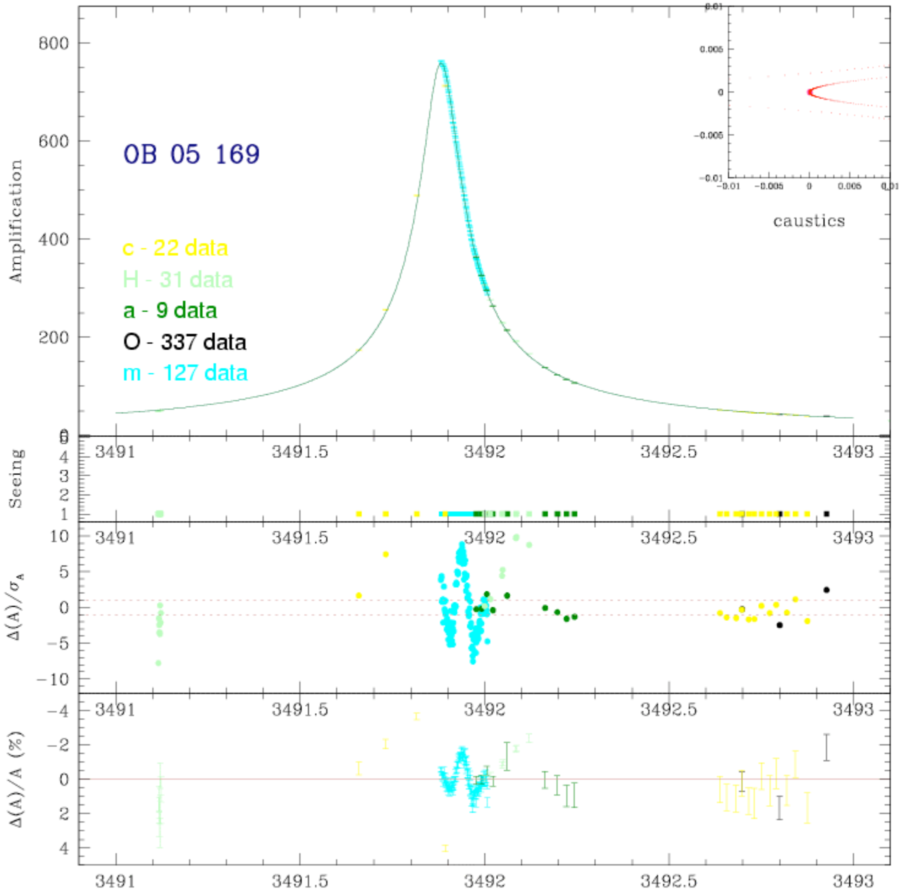


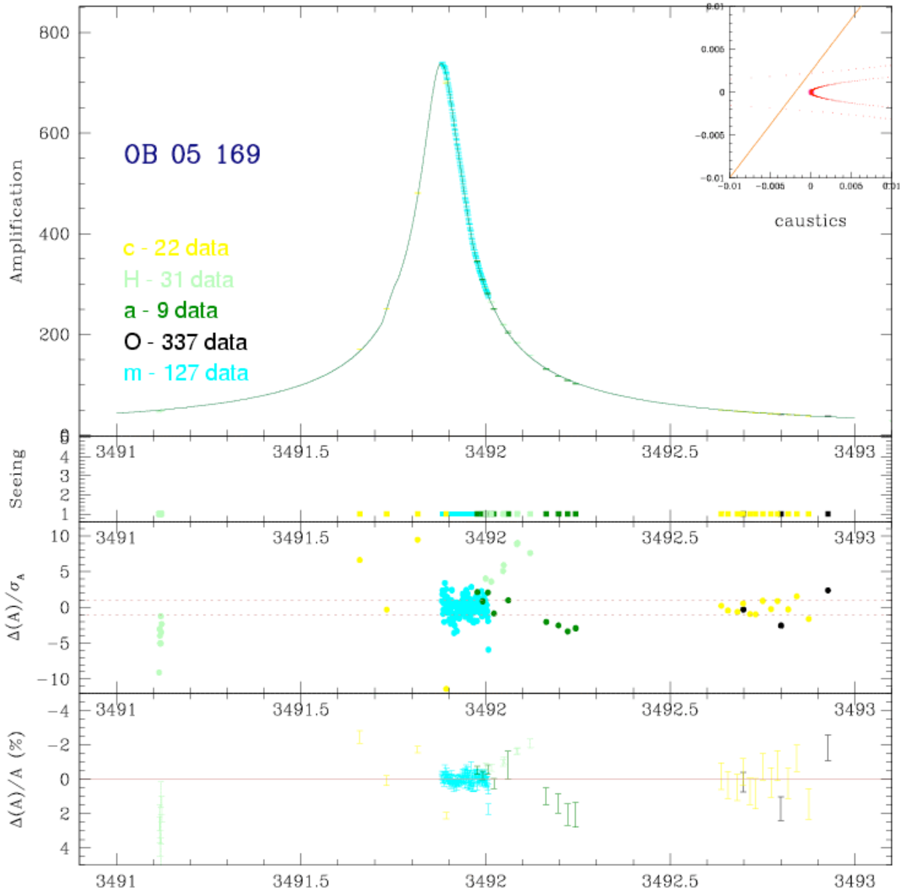
2005 (3): OGLE 2005-BLG-169

- *Neptune planet of 13 Earth masses detected by microFUN and OGLE in a high magnification event (800, or 7.3 mag)*

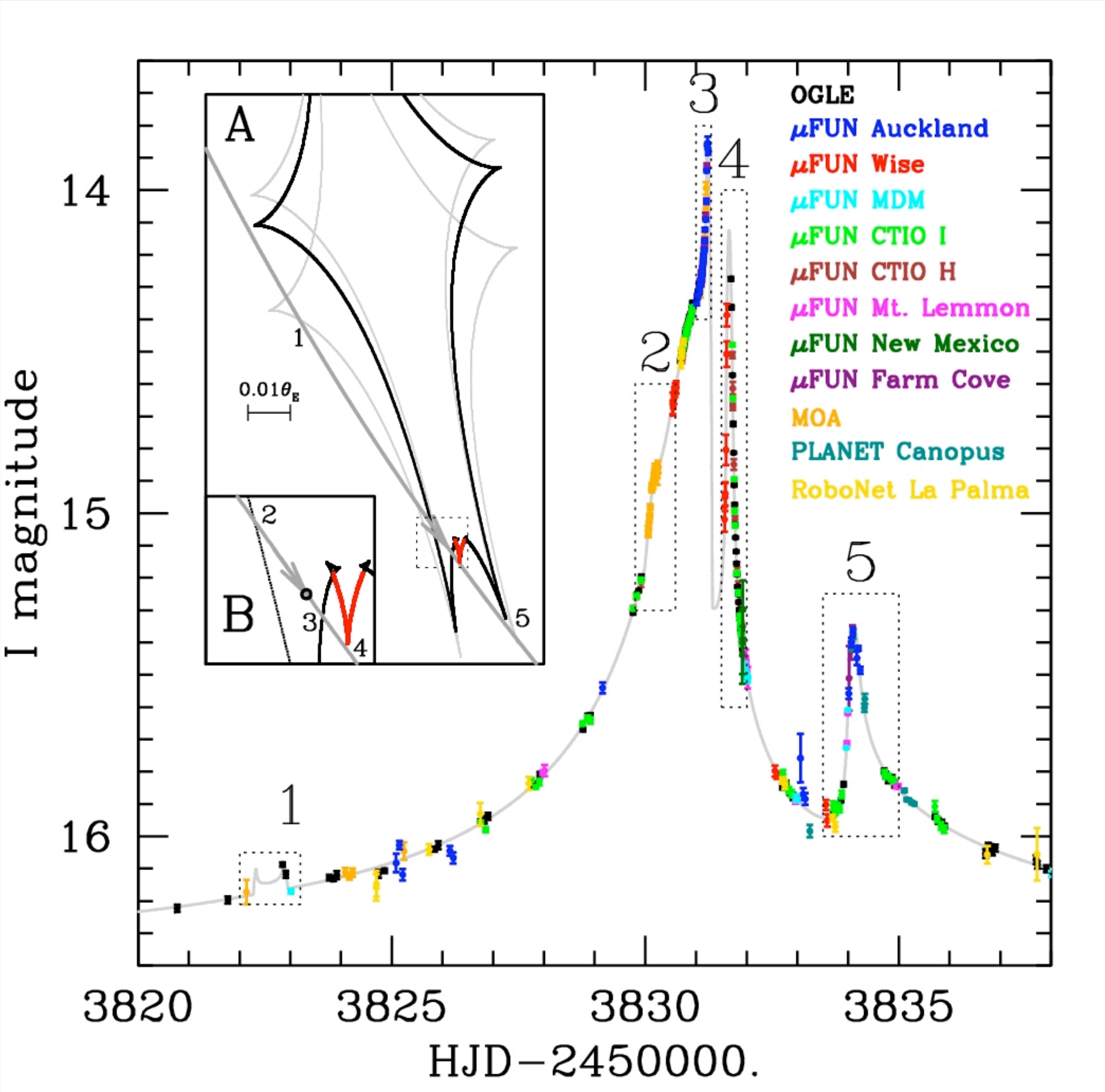
- *Very promising for a lens detection: 8.6 mas/yr, lower contrast (dwarf source)*

Comparison between PSPL and ESBL fits

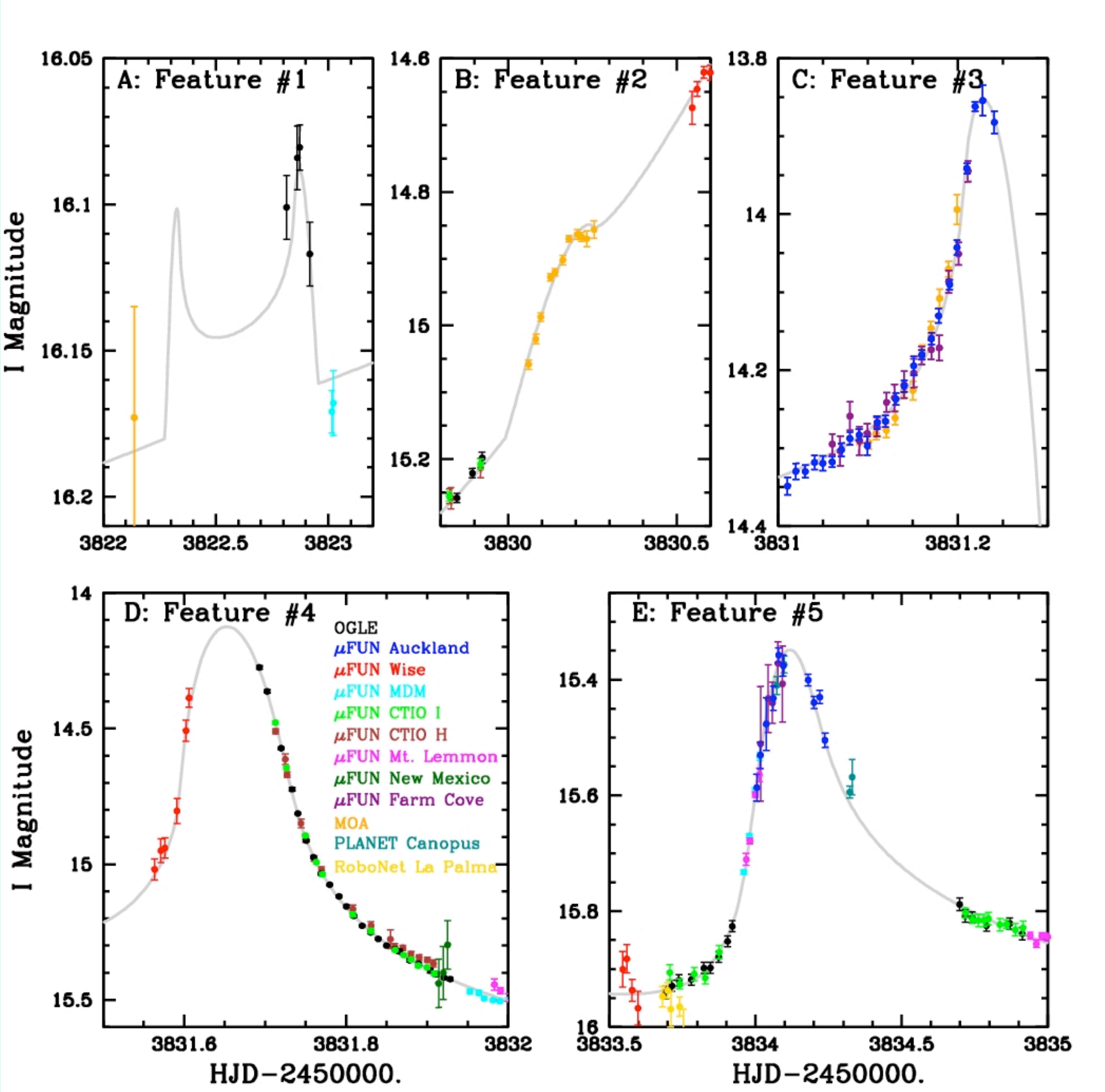




2006: OGLE 2006-BLG-109



2006: OGLE 2006-BLG-109



2006: OGLE 2006-BLG-109

Science Feb. 15, 2008

Discovery of a Jupiter/Saturn Analog with Gravitational Microlensing

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Searches for extrasolar planets have uncovered an astonishing diversity of planetary systems, yet the frequency of solar system analogs remains unknown. The gravitational microlensing planet search method is potentially sensitive to multiple-planet systems containing analogs of all the solar system planets except Mercury. We report the detection of a multiple-planet system with microlensing. We identify two planets with masses of ~0.71 and ~0.27 times the mass of Jupiter and orbital separations of ~2.3 and ~4.6 astronomical units orbiting a primary star of mass ~0.50 solar mass at a distance of ~1.5 kiloparsecs. This system resembles a scaled version of our solar system in that the mass ratio, separation ratio, and equilibrium temperatures of the planets are similar to those of Jupiter and Saturn. These planets could not have been detected with other techniques; their discovery from only six confirmed microlensing planet detections suggests that solar system analogs may be common.

2007 campaign

- *May 1 - August 31: 9 telescopes*
- *72 followed anomalous or high magnification events*
- *Promising events: MOA 192 (ApJ 684, 663), 197, 400, OGLE 50, 349, 355, 368, 472*

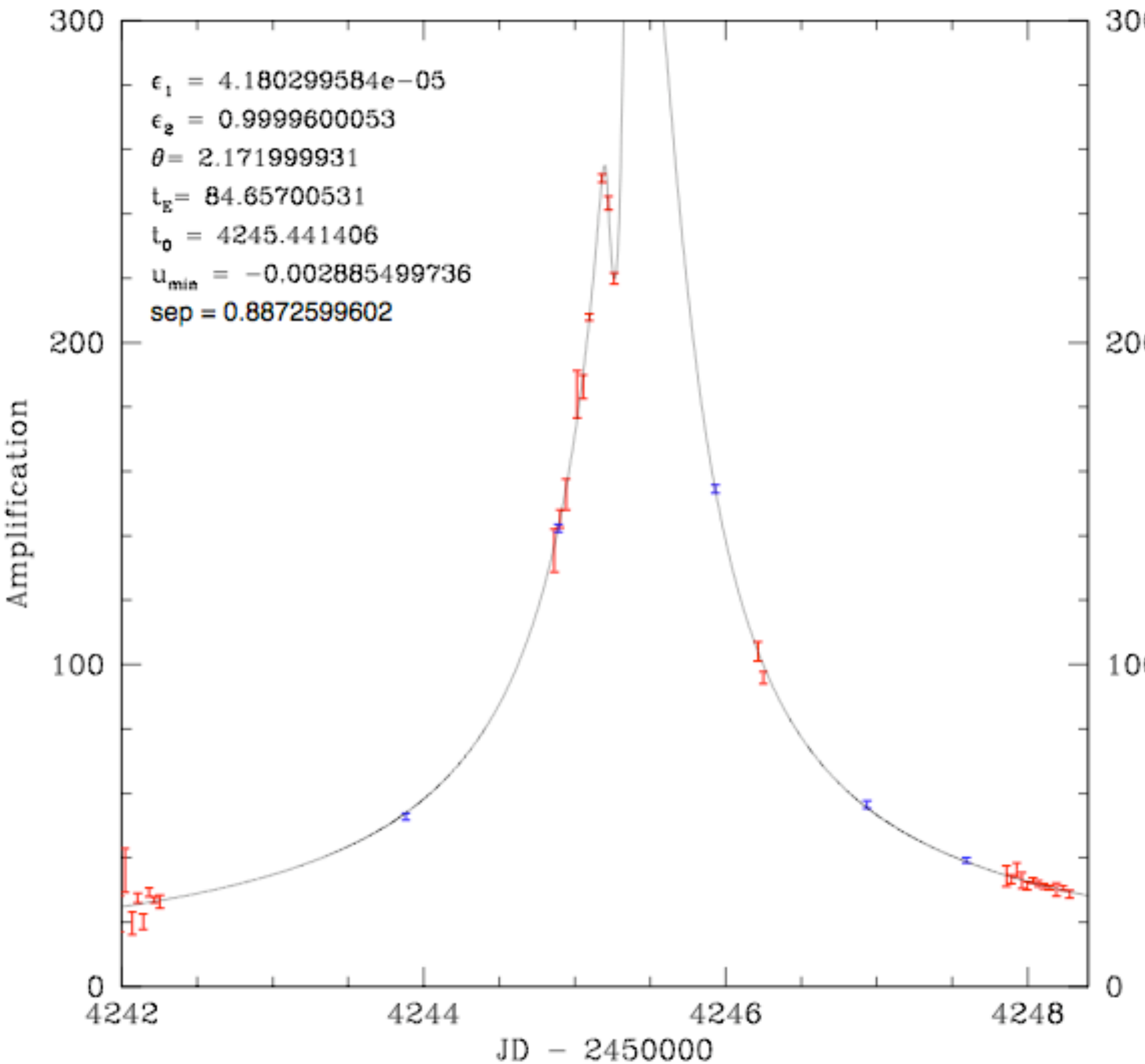
2008 campaign

- *May 1 - August 31: 7 telescopes*
- *83 followed anomalous or high magnification events*
- *Promising events: MOA 96, 159, 310, 325, 384, OGLE 13, 210, 270, 279, 290, 426, 513*

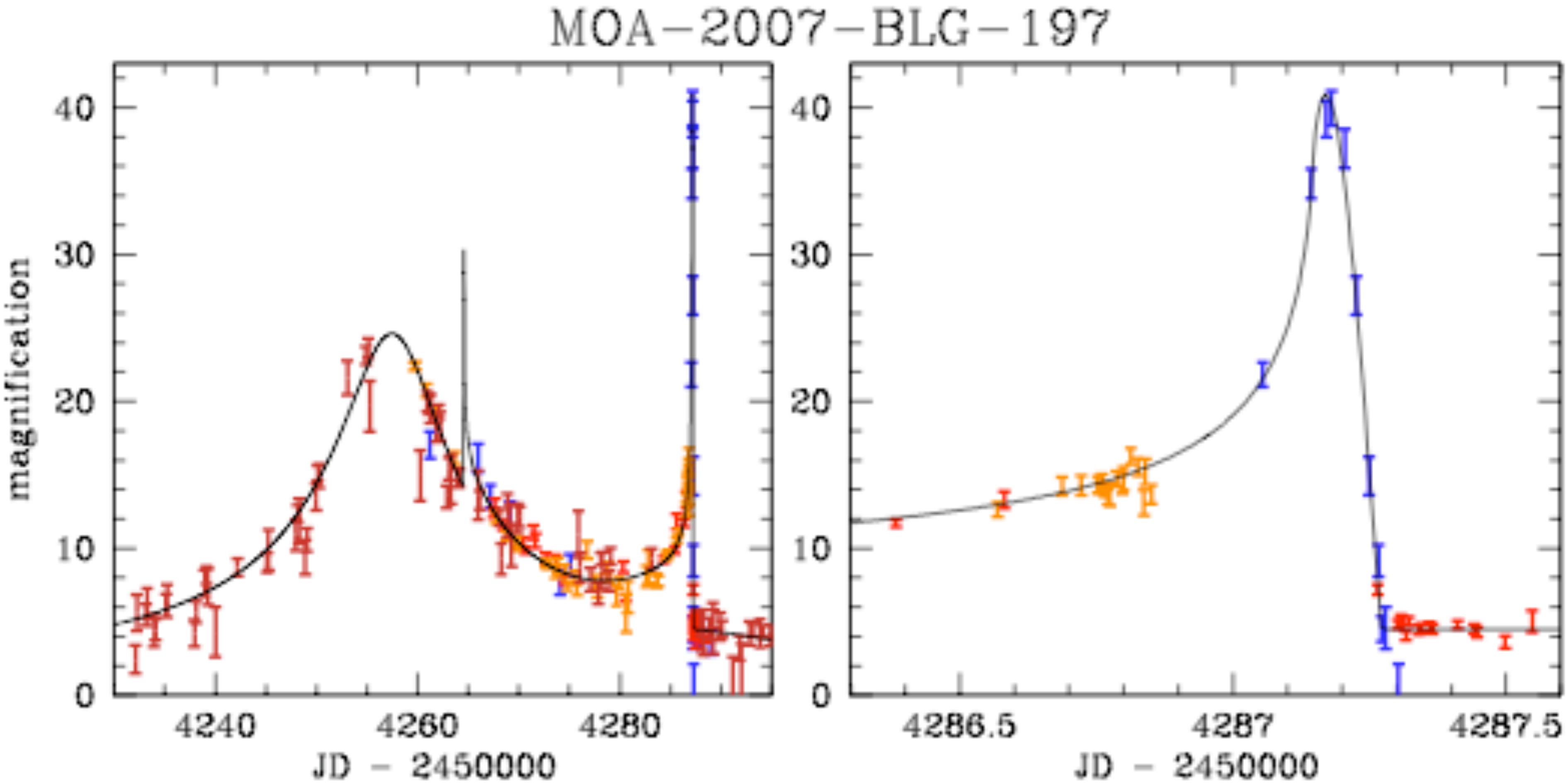
2007 (1): MOA 2007-BLG-192

3 Earth mass planet !

ApJ 684, 663 (2008)

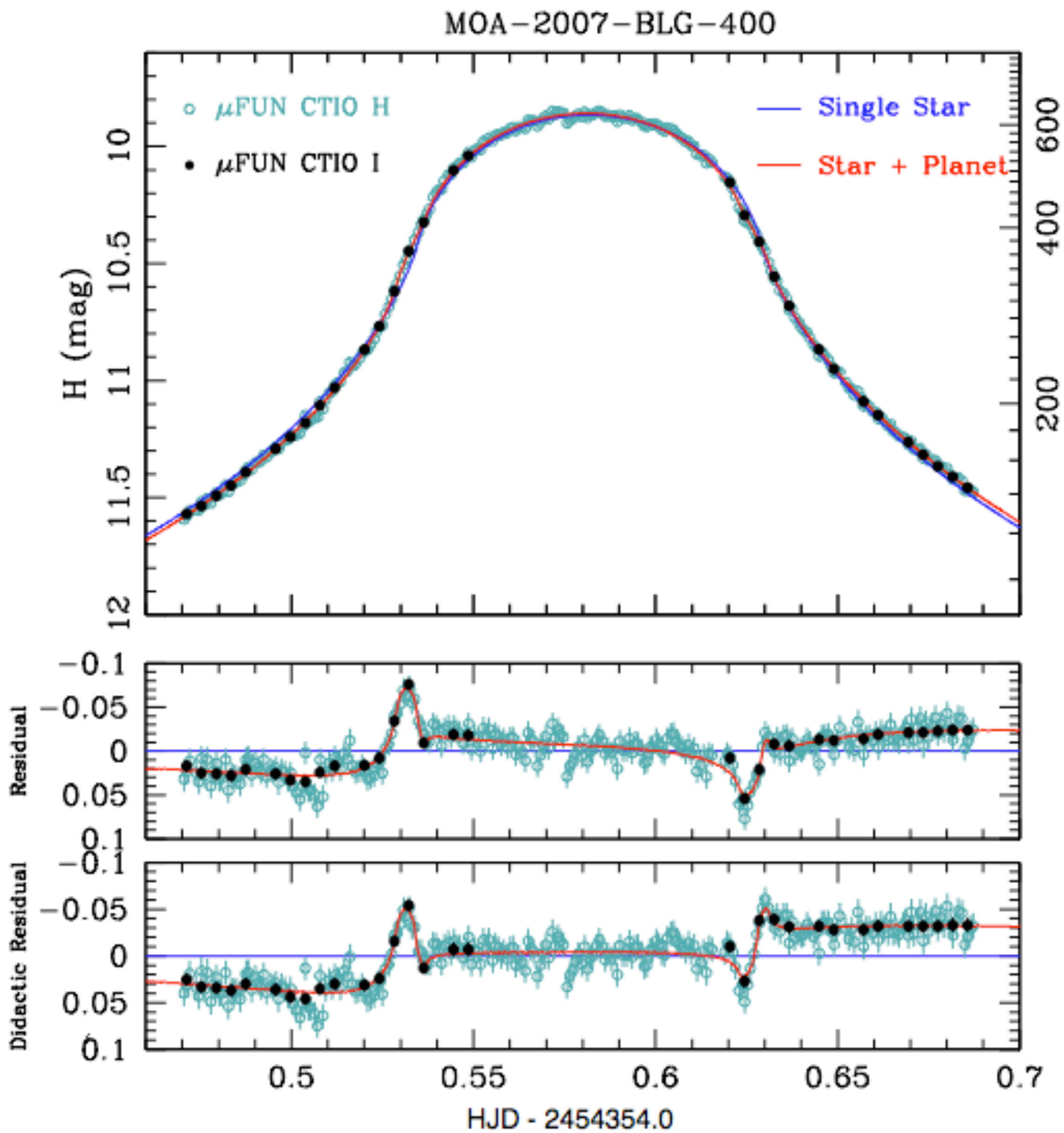


2007 (2): MOA 2007-BLG-197

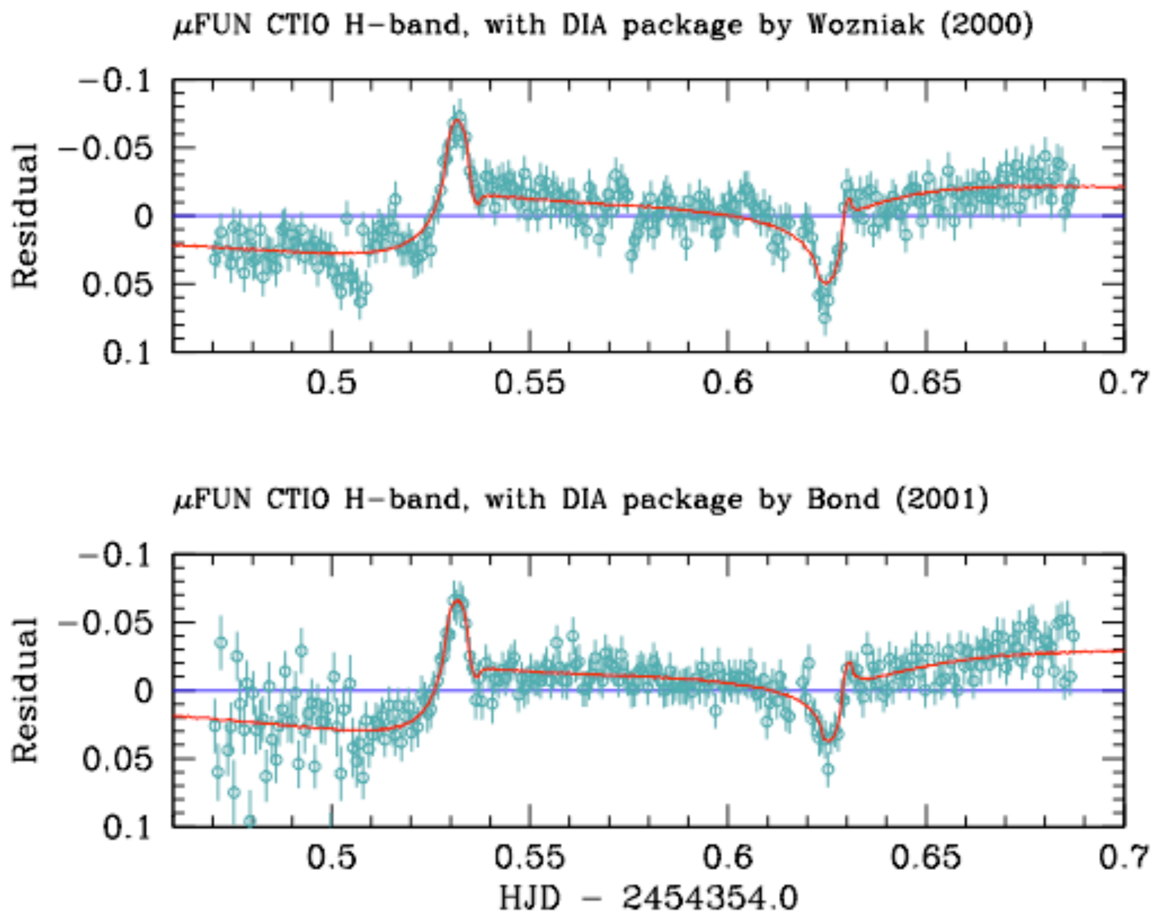


2007 (3): MOA 2007-BLG-400

Planet hidden in a HME with extended source effect

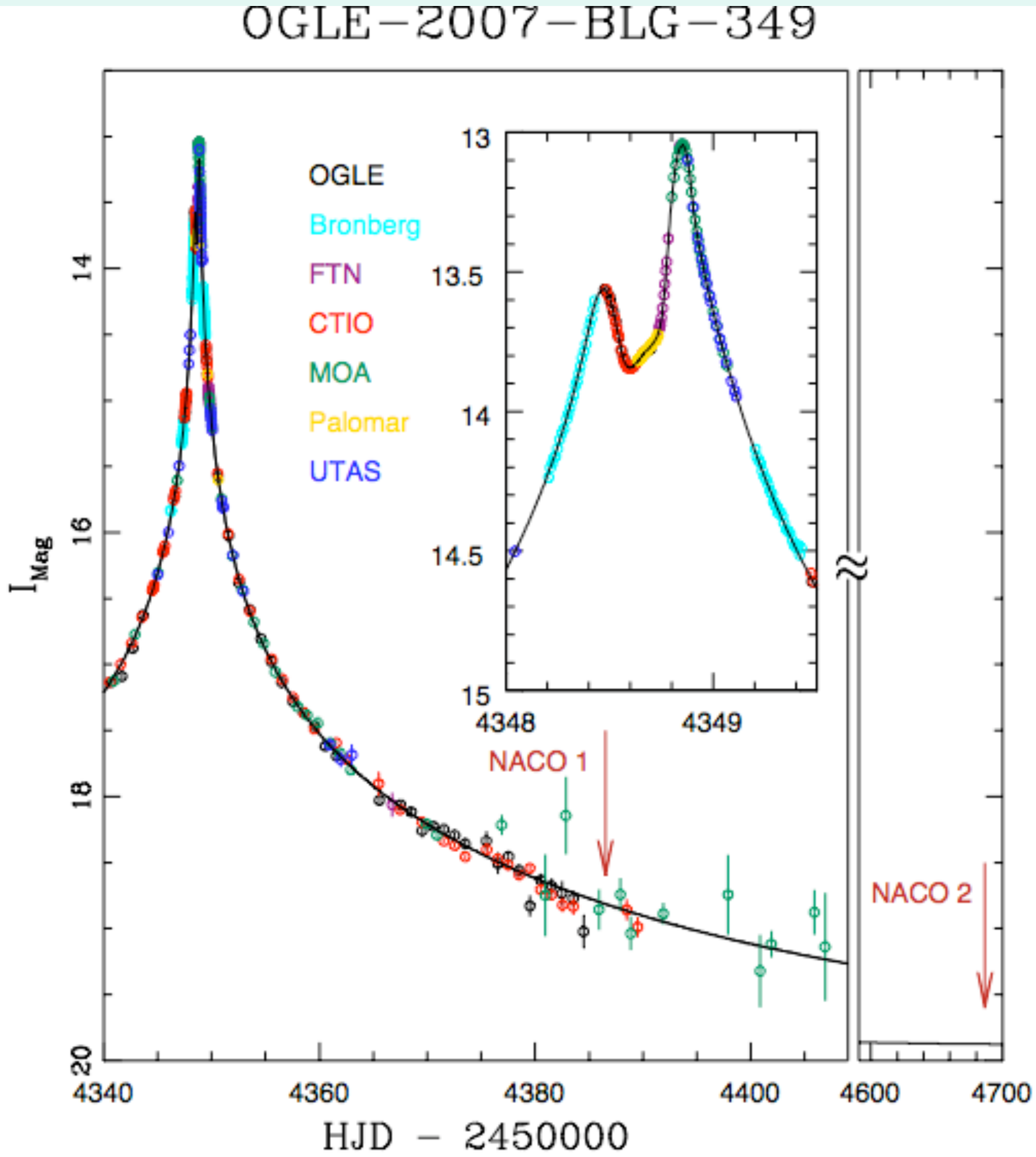


2007 (3): MOA 2007-BLG-400

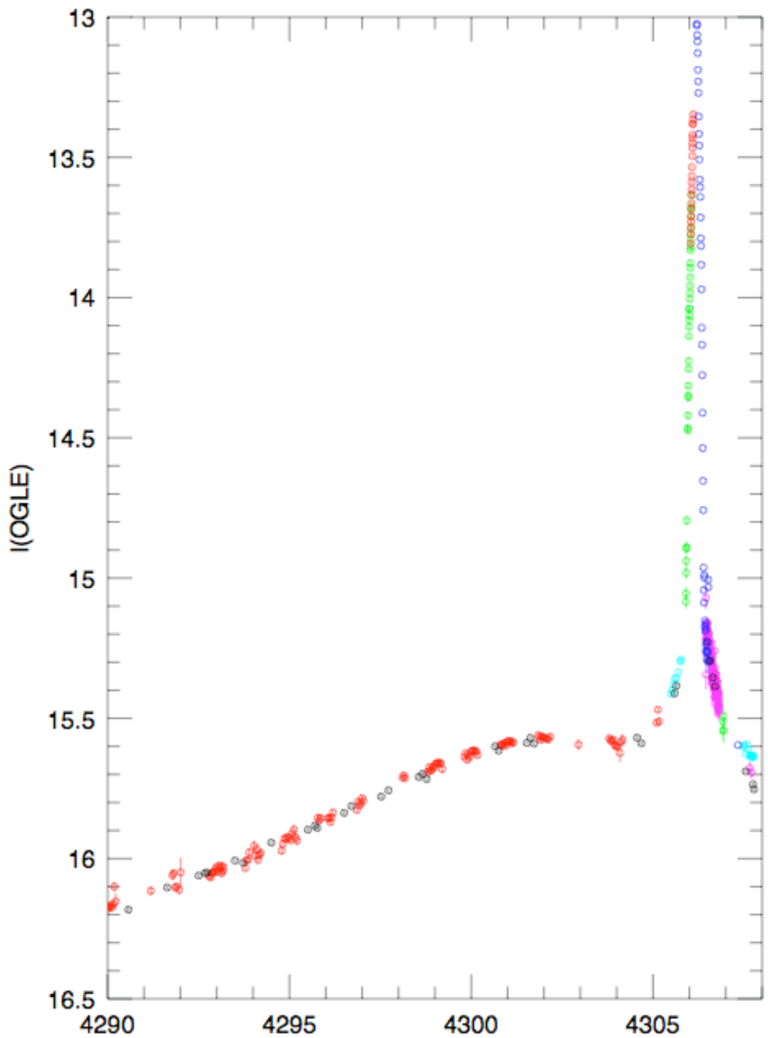


2007 (4): OGLE 2007-BLG-349

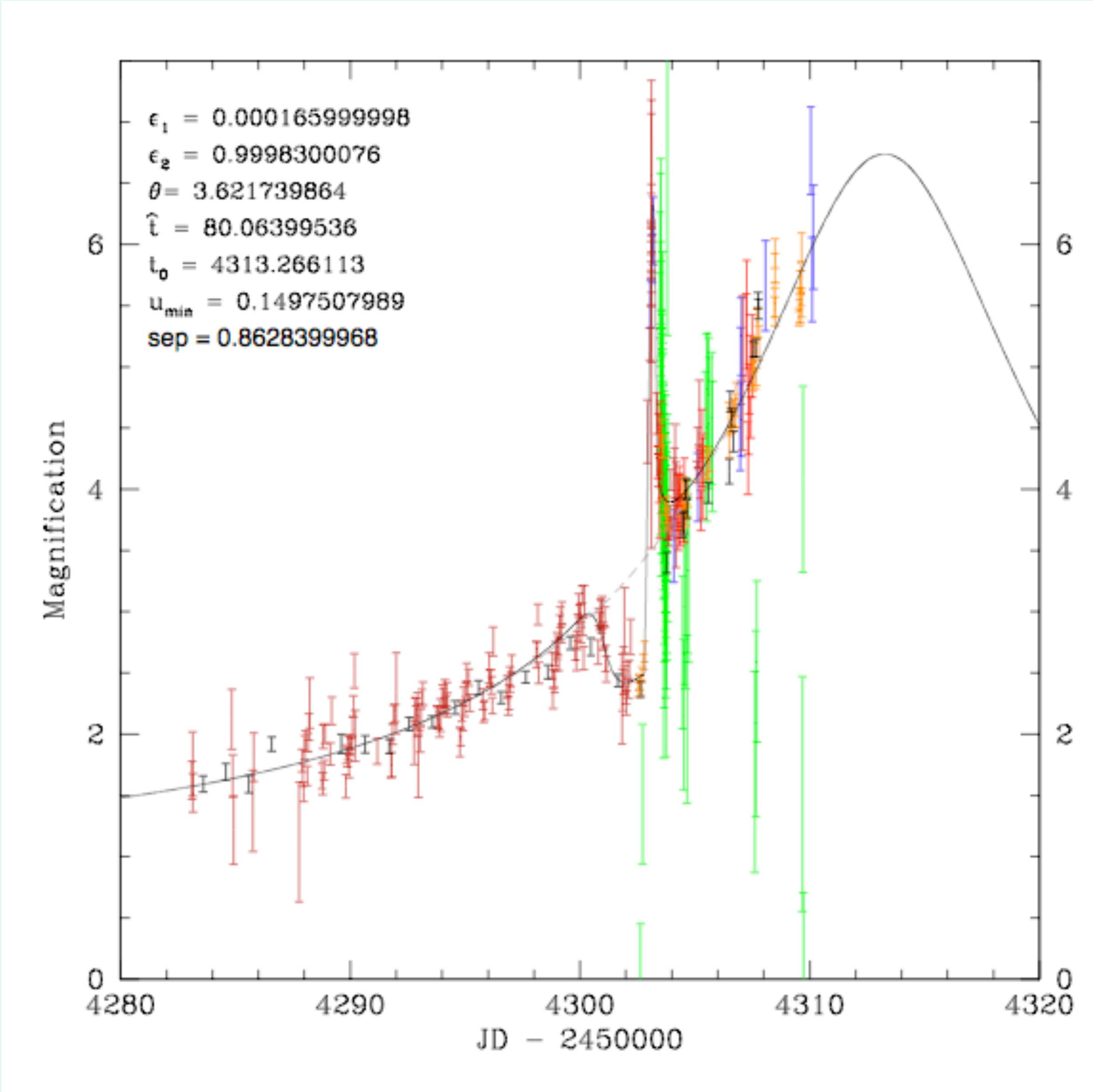
2 planets: 1 Saturn and 1 ?



2007 (5): OGLE 2007-BLG-355

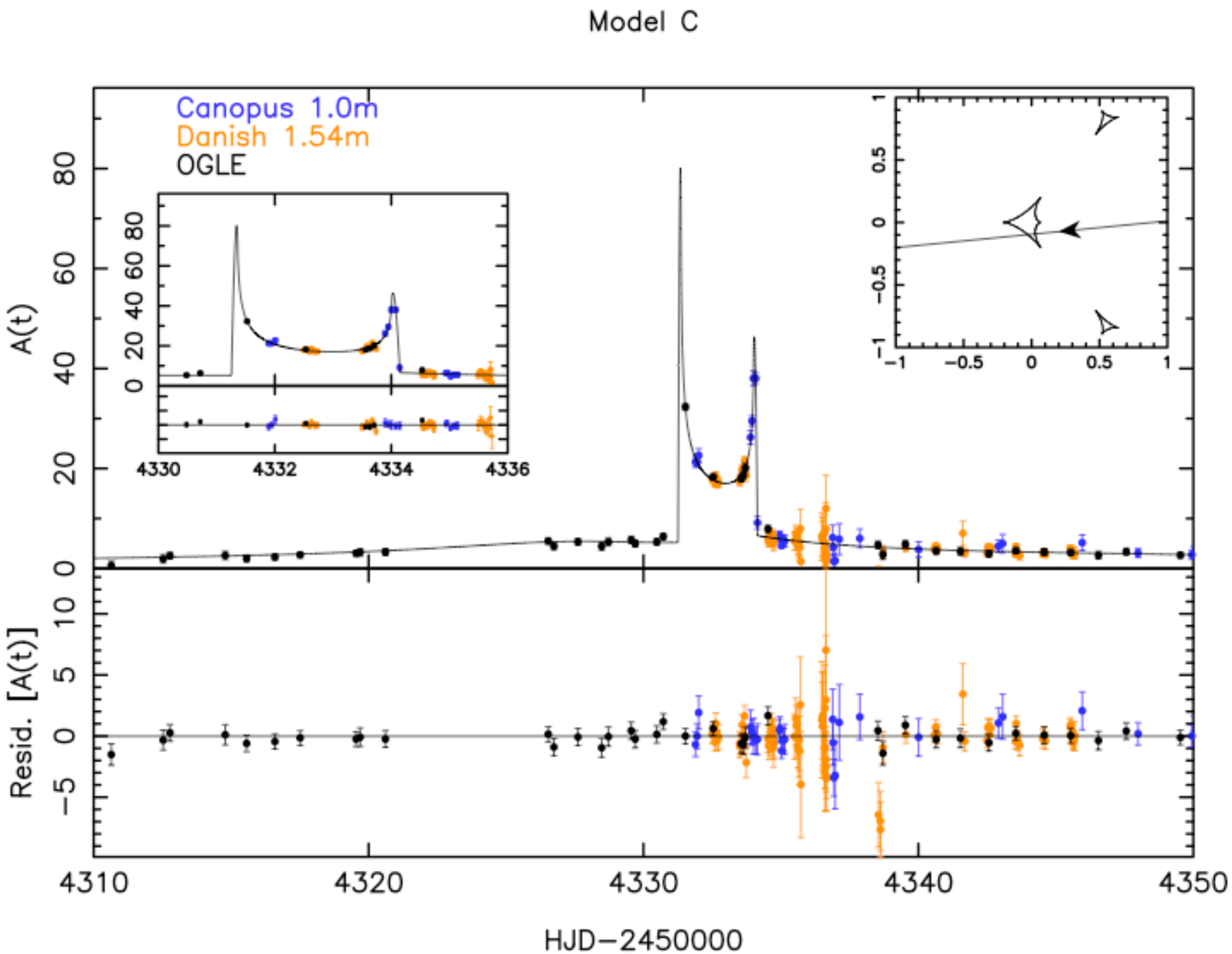


2007 (6): OGLE 2007-BLG-368

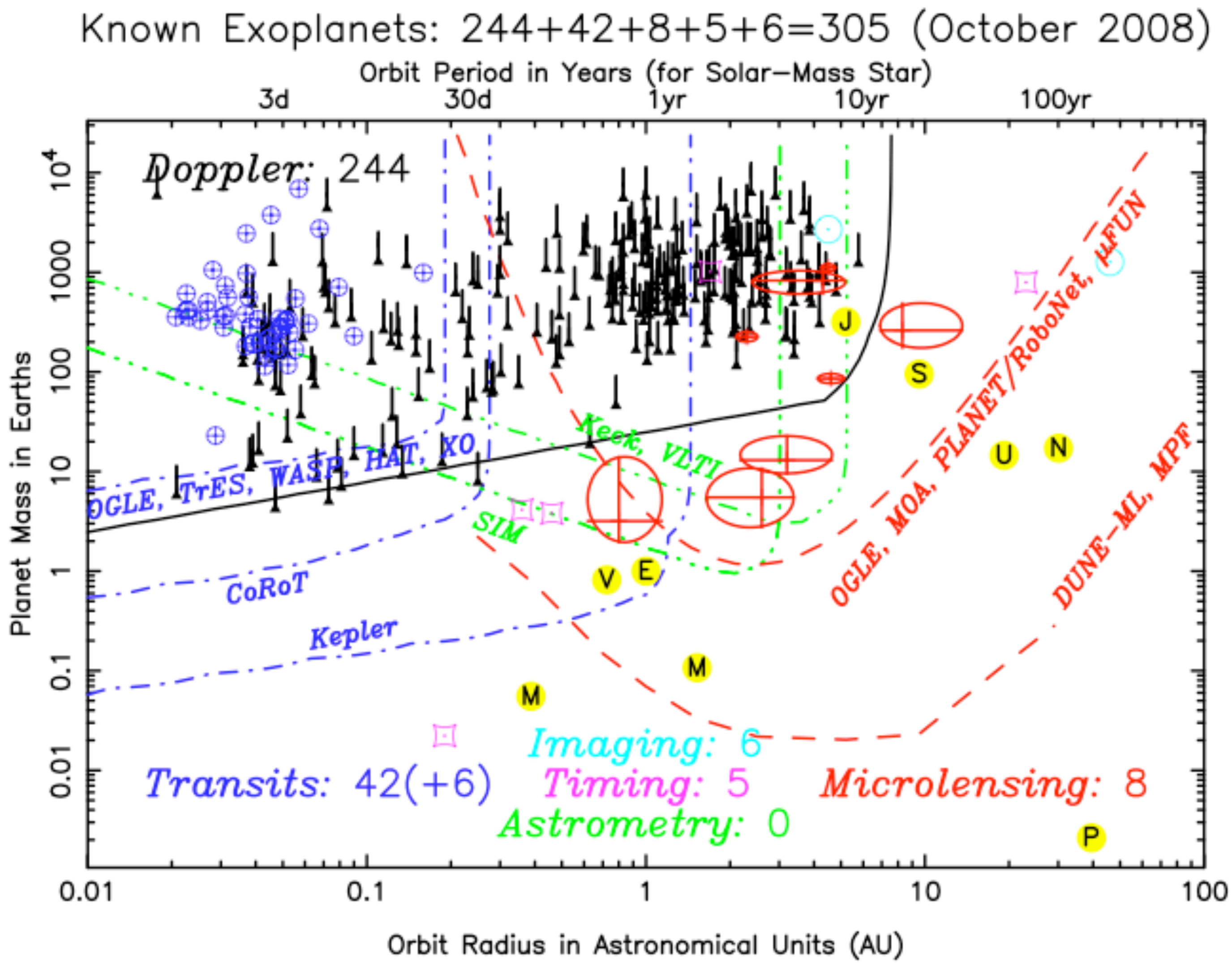


2007 (7): OGLE 2007-BLG-472

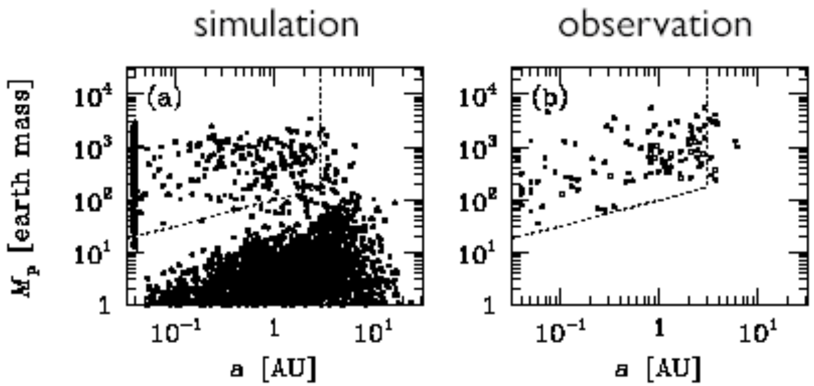
Model ambiguity: planet or binary star?



Mass – distance diagram of known exoplanets (all techniques)

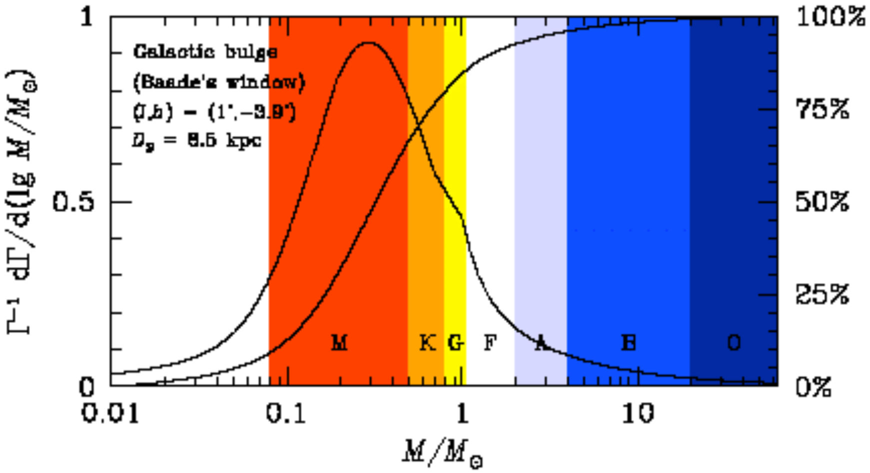


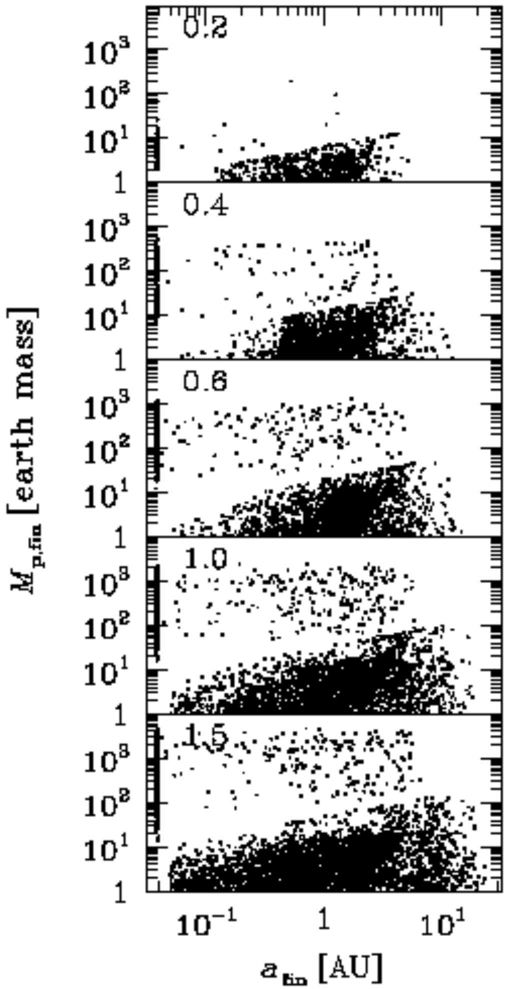
Core-accretion model predictions



Ida S., Lin D. N. C., 2004, ApJ 616, 567

Stellar mass probed by microlensing

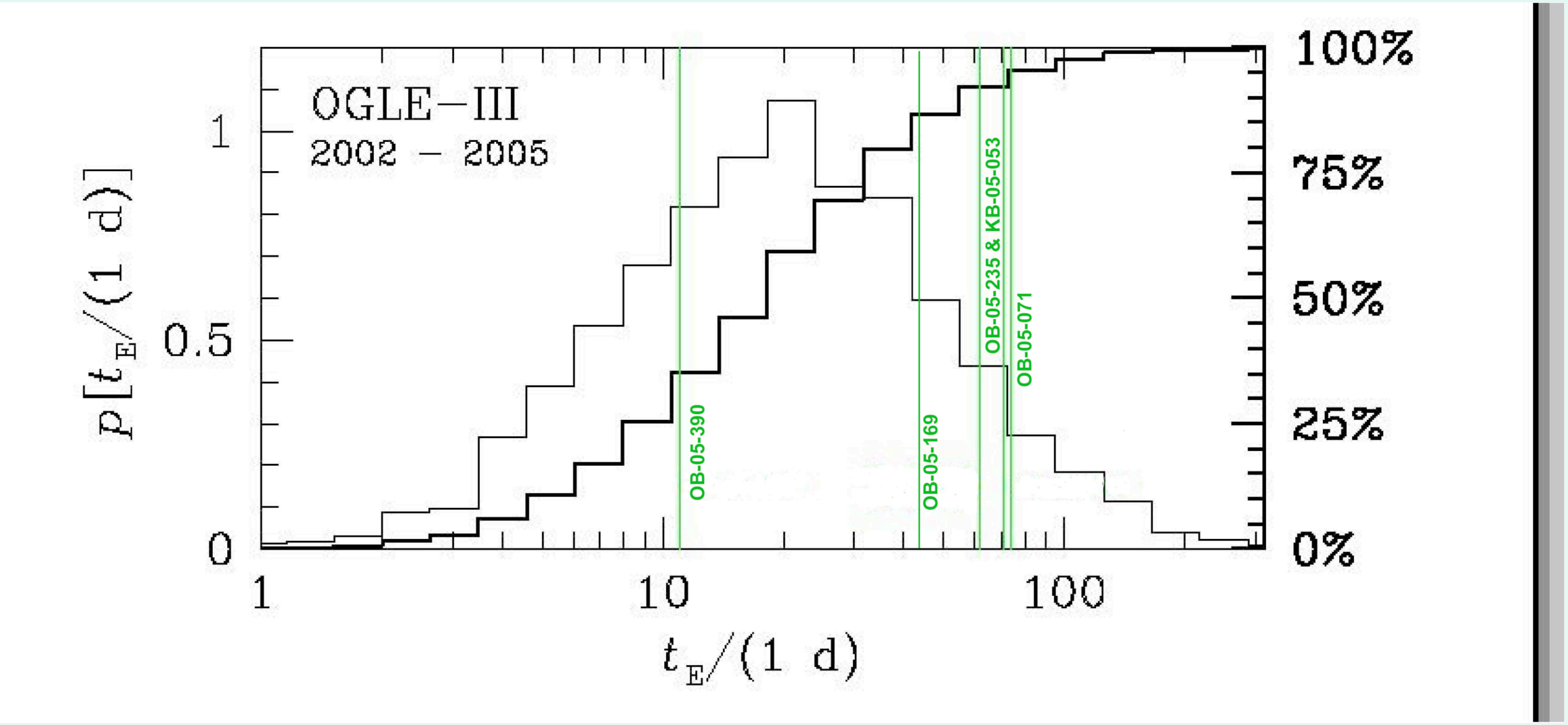




Ida S., Lin D. N. C., 2005, ApJ 626, 1045

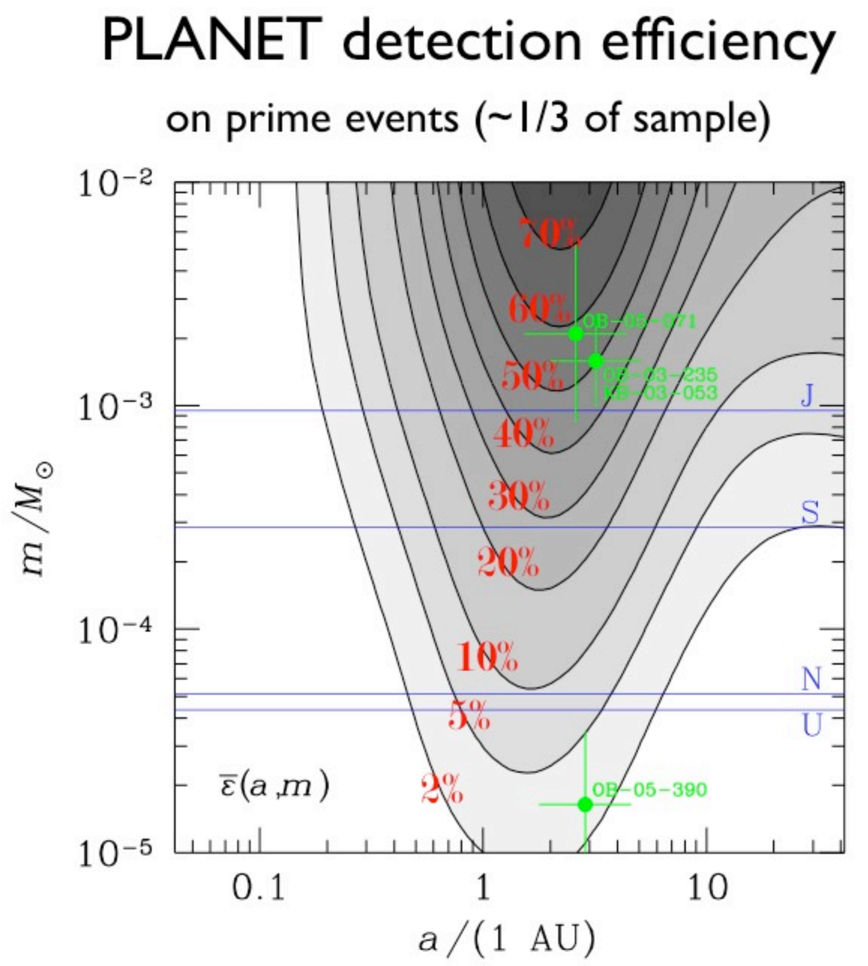
Characteristic duration

Do giant planets prefer longer events (more massive stars) ?



Detection efficiency

Normal events give constraints about the number of planets



A. Cassan et al. (PLANET collaboration), in preparation

Observational strategy: central or planetary caustic ?

- *Central: can be predicted, but only in a few HME; difficult to characterize (degeneracies); well adapted to amateur telescopes: microFUN strategy*
- *Planetary: many common events of low magnification, larger and easier to characterize, but impossible to predict; well adapted to allocated telescope time with : PLANET strategy*

$x_c = x_p - \frac{1}{x_p}$: planetary caustic position

$u_c = \frac{q x_p}{(x_p - 1)^2}$: central caustic tip

Comparison of 8 planets (1)

Event	q	b	caustic	A_{max}	source
OB03235 = KB03053	0.0039	1.120	resonant d_w=1.243	7.6	MS
OB05071 close+ OB05071 wide+	0.0067 0.0070	0.766 1.283	central resonant d_w=1.296	40	MS
OB05169 close OB05169 wide	0.000083 0.000086	0.9819 1.0198	resonant d_c=0.969 resonant d_w=1.067	800	MS
OB05390	0.0000757	1.6097	planetary	2.9	RG
OB06109b OB06109c	0.00135 0.00050	0.6277 1.0419	resonant d_w=1.121	515	MS
KB07192 cusp c- KB07192 cusp w- KB07192 cc c- KB07192 cc w-	0.00015 0.00012 0.00021 0.00016	0.881 1.120 0.985 1.007	central resonant d_c = 0.958	320	MS
KB07400 c KB07400 w	0.0026 0.0025	0.34 2.87	central central	628	subgiant

Comparison of 8 planets (2)

	t_E days	u_0 R_E	θ_* μas	θ_E mas	μ mas yr^{-1}	D_L kpc	M_* M_{sun}	M_p M_{earth}	a AU	K m s^{-1}
OB03235	61.5	0.133	0.53	0.55	3.3	5.8	0.63	830	4.3	44
OB05071			0.52							
close+	69.2	0.0239		0.85	4.5	3.2	0.46	1050	2.7	80
wide+	69.4	0.0277		0.84	4.4	3.3	0.46	1110	4.6	60
OB05169 wide	42.3	0.0012	0.44	1.00	8.6	2.7	0.49	13	3.4	1.1
OB05390	11.0	0.359	5.25	0.20	6.8	6.5	0.22	5.5	2.7	0.65
OB06109b	128.2	0.003463	0.47	1.48	4.2	1.49	0.50	230	2.3	
OB06109c								90	4.6	
KB07192			0.50			1.0	0.060	3.3	0.8	
cusp c-	75.0	-0.00364		0.56	2.7					
cc c-	75.1	-0.00433		0.32	1.6					
KB07400										
close	14.4	0.00025	1.05	0.32	8.2	5.8	0.30	260	0.92	
wide	14.3	0.00027							8.3	

Accuracy of these parameters?
Case of OGLE 2005-BLG-071

- *Results of galactic model depend of constraints: only t_E, t_E and finite source size, t_E and parallax:*

  $M_* = 1.27, 0.67, 0.25\ \mathrm{M_{sun}}$

- *When both finite source size and parallax effects are measured (e.g.: Dong et al. 2008):*

  $$\pi_E = 0.44 \pm 0.28$$

  $$\pi_{rel} = \pi_E \theta_E = 0.195 \pm 0.035 \text{ mas} \Rightarrow \mathrm{D_L} = 3.1 \pm 0.4 \text{ kpc si } \mathrm{D_S} = 8.2 \text{ kpc}$$

  $$M_* = \frac{1}{8.15} \frac{\theta_E}{\pi_E} = 0.46 \pm 0.04\ \mathrm{M_{sun}} \Rightarrow M_p = 3.4 \pm 0.3\ \mathrm{M_{jup}}$$

- *Agreement with blend predictions assuming that blending comes from lens itself:*

$$I_s = 19.52 \quad I_b = 21.3\ A_I = 1.30 \Rightarrow I_{0,b} \geq 20.0 \Rightarrow M_{I,lens} \geq 7.5 \Rightarrow \mathrm{ST} \geq \mathrm{M2V} \Rightarrow M_* \leq 0.56\ \mathrm{M_{sun}}$$

Blending constraints

	I_s	I_{blend}	$(V\text{-}I)_s$	I_0	$(V\text{-}I)_0$	E(V-I)	A_I $=I_s - I_0$	$I_{bl,0}$ ≥	$M_{I,lens}$ ≥	ST_{lens} ≥	M_* ≤
OB03235	19.63 ± 0.06 HST	21.4 ± 0.3 HST	1.58 ± 0.02 phm	18.6	0.76	0.82 Sumi		20.5	6.7	M0V	0.65
OB05071	19.51 model	21.32 HST	1.34	18.31 CMD	0.45 CMD	0.89	1.20	20.12	7.5	M2V	0.56
OB05169	20.43 Ogle nc	19.91 Ogle nc		19.17 CMD	0.75 CMD		1.26	18.6	6.5	K7V	0.7
OB05390	15.66 Ogle nc	18.18 Ogle nc		14.25 CMD	0.85 CMD		1.41	16.8	2.7	F2V	1.5
OB06109	20.94 ± 0.03	16.42	2.17 ± 0.04	19.01	0.66	1.52 Sumi	1.93	14.5	3.6	G0V	1.0
KB07192	21.45	J=19.84	2.23	19.84	1.11	1.12	1.61				
KB07400				17.57 CMD	0.81 CMD						

Conclusions

Detection ≠ characterization: 8 detections AND 8 characterizations ☺

8 planets (7 events) by gravitational microlensing: 3 scenarii :
- 2 central caustic, 4 resonant: 5 high magnification, 1 low
- 1 planetary caustic, low magnification

5 ~Jupiter, 1 ~Neptune, 2 ~few Earth
- Good indication that small planets are more numerous than Jupiters around low mass stars, because detection efficiency ratio is 1 over 50
- In agreement with core accretion model predictions

5 long events, 2 short
- Good for characterization, because of parallax detection

Inaccuracy of the star-planet system parameters:
Depends on additional detected effects, such as source resolution or parallax; after 10 years, possibility of separating lens and source

Exoplanets around « M » stars

- Radial velocity searches: 12 exoplanets around 8 M dwarfs (2 have 3 planets): 4 Super-Earth (5.0-8.4 Me), 3 Neptune (12-23 Me), 5 Jupiter (0.56-1.935 Mj)
- Microlensing: 8 exoplanets around 7 « M » dwarfs: 2 Super-Earth (3.3-5.5 Me), 1 Neptune (13 Me), 5 Jupiter (0.27-3.5 Mj)
- Total: 15 « M » dwarfs, 20 exoplanets: 6 SE, 4 N, 10 J