Seminář Hvězdárny Valašské Meziříčí

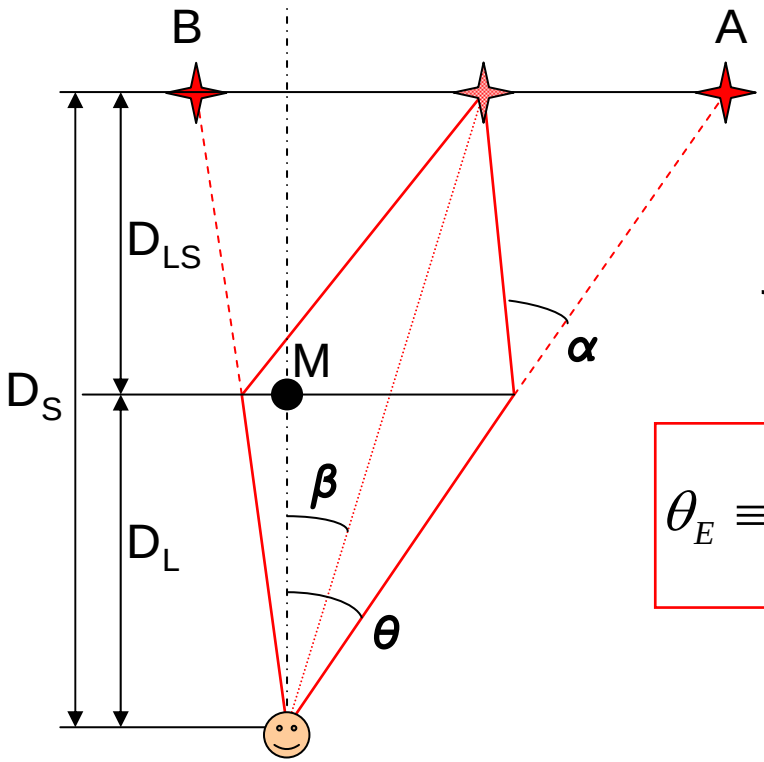
24.10.2009

Detekce planet gravitačním mikročočkováním

David Heyrovský

Ústav teoretické fyziky MFF UK, Praha

Gravitační čočka



čočková rovnice $$\beta = \theta - \frac{D_{LS}}{D_S}\alpha(\theta)$$

jednoduchá čočka: $$\alpha(\theta) = \frac{4GM}{c^2 D_L \theta}$$

$$\theta_E \equiv \sqrt{\frac{4GMD_{LS}}{c^2 D_L D_S}}$$

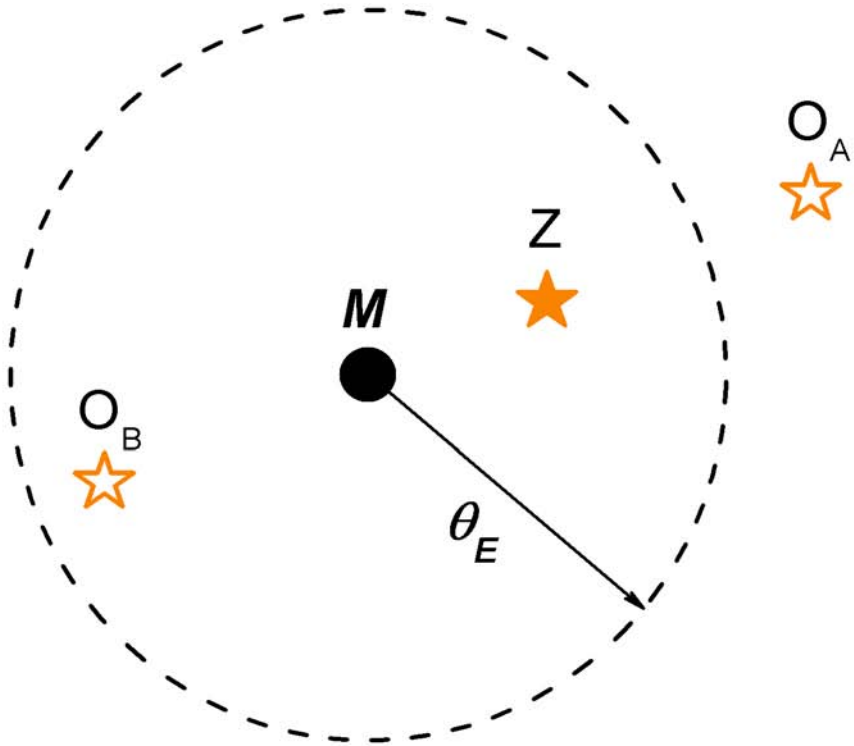
Einsteinův poloměr

poloha obrazů pro

$$\beta = 0 \ \ldots \quad |\theta| = \theta_E$$

$$\beta \neq 0 \ \ldots \quad \theta_{A,B} = \left(\frac{1}{2} \pm \sqrt{\frac{1}{4} + \frac{\theta_E^2}{\beta^2}}\right)\beta$$

viděno na nebi



Režimy gravitačního čočkování

silné čočkování – pozorování násobných obrazů zdroje

(Č: galaxie, kupa galaxií; Z: kvasar, galaxie)

slabé čočkování – měření deformace hlavního obrazu zdroje

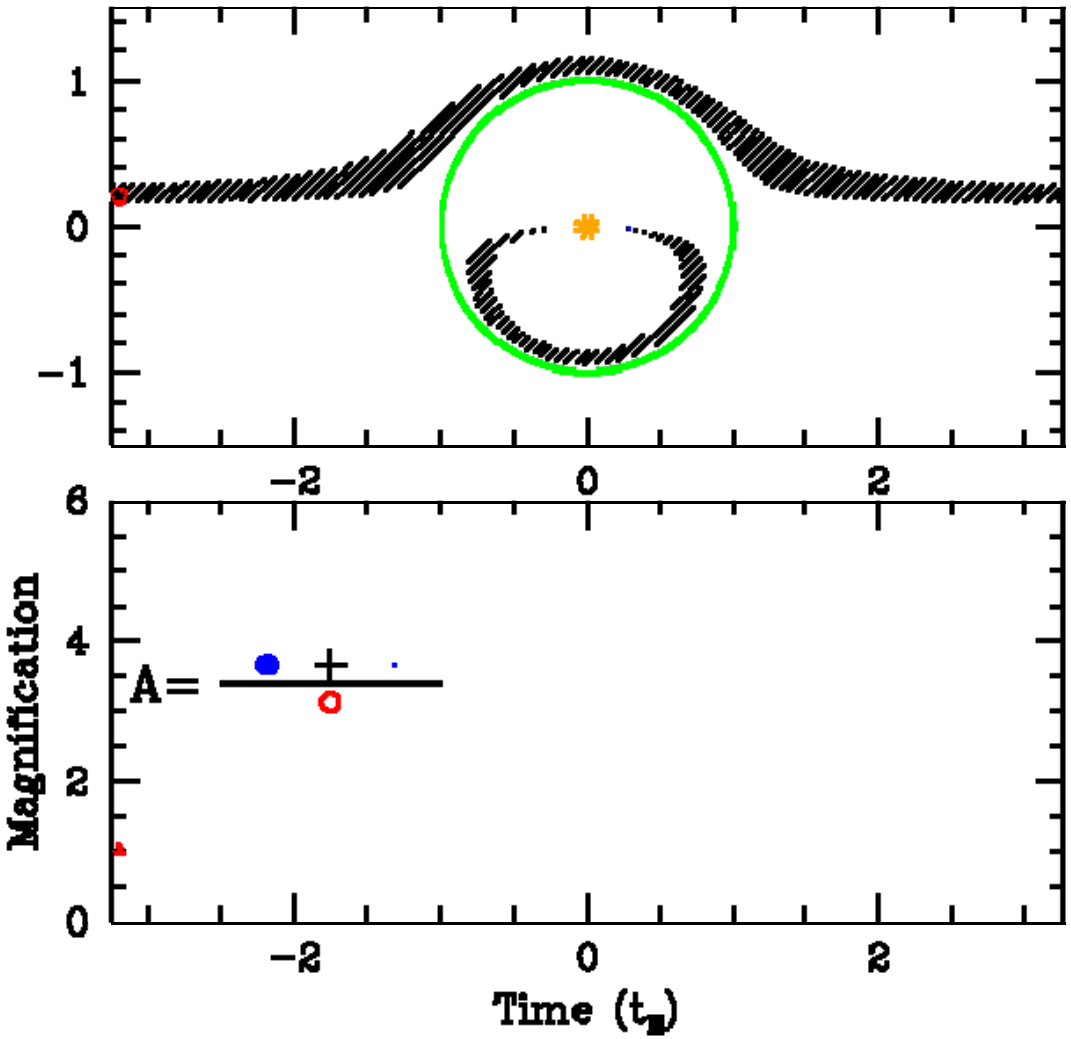
(Č : kupa galaxií, větší struktury; Z: galaxie)

mikročočkování – pozorování časově proměnného zjasnění

(Č : hvězda, hvězdná soustava; Z: hvězda, kvasar)

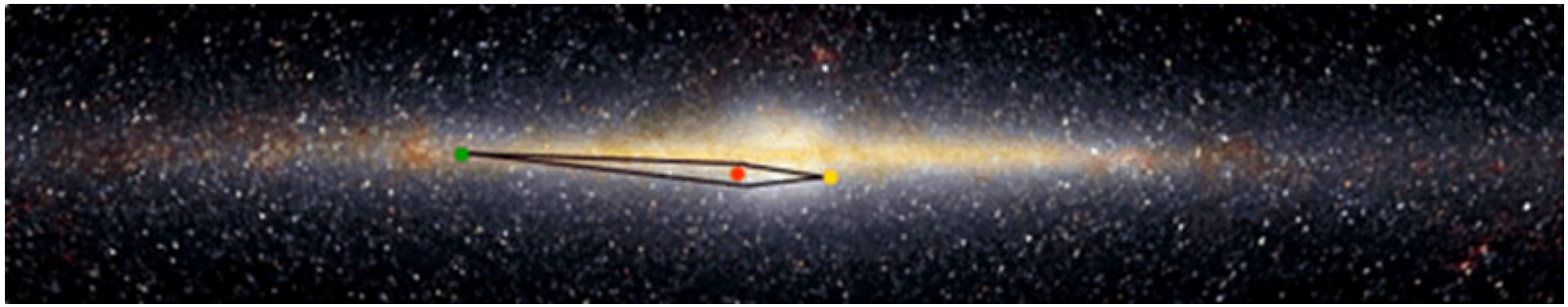
Zjasnění světelného toku

$$A_0(\beta) = \frac{\beta^2 + 2\theta_E^2}{|\beta|\sqrt{\beta^2 + 4\theta_E^2}}$$



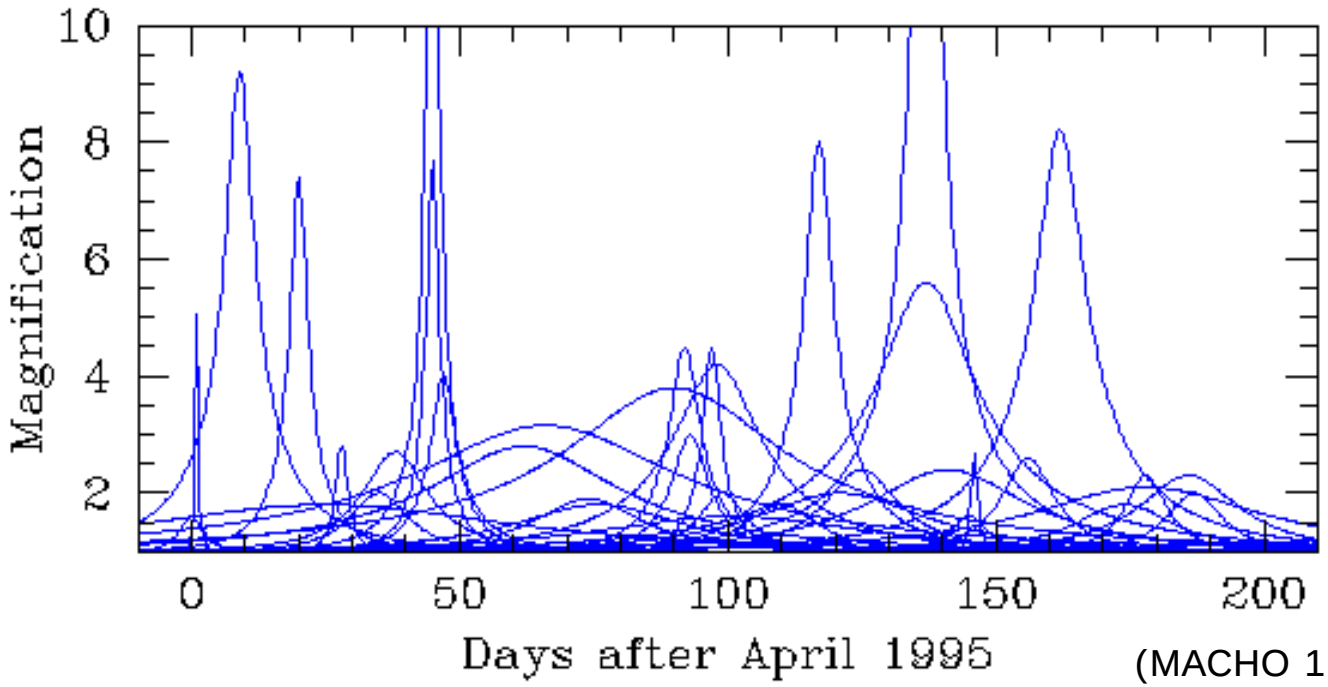
B.S.Gaudi, http://www.astronomy.ohio-state.edu/~gaudi/movies.html

Pozorování: monitorovací projekty (MACHO, EROS, **OGLE**, **MOA**)



MOA

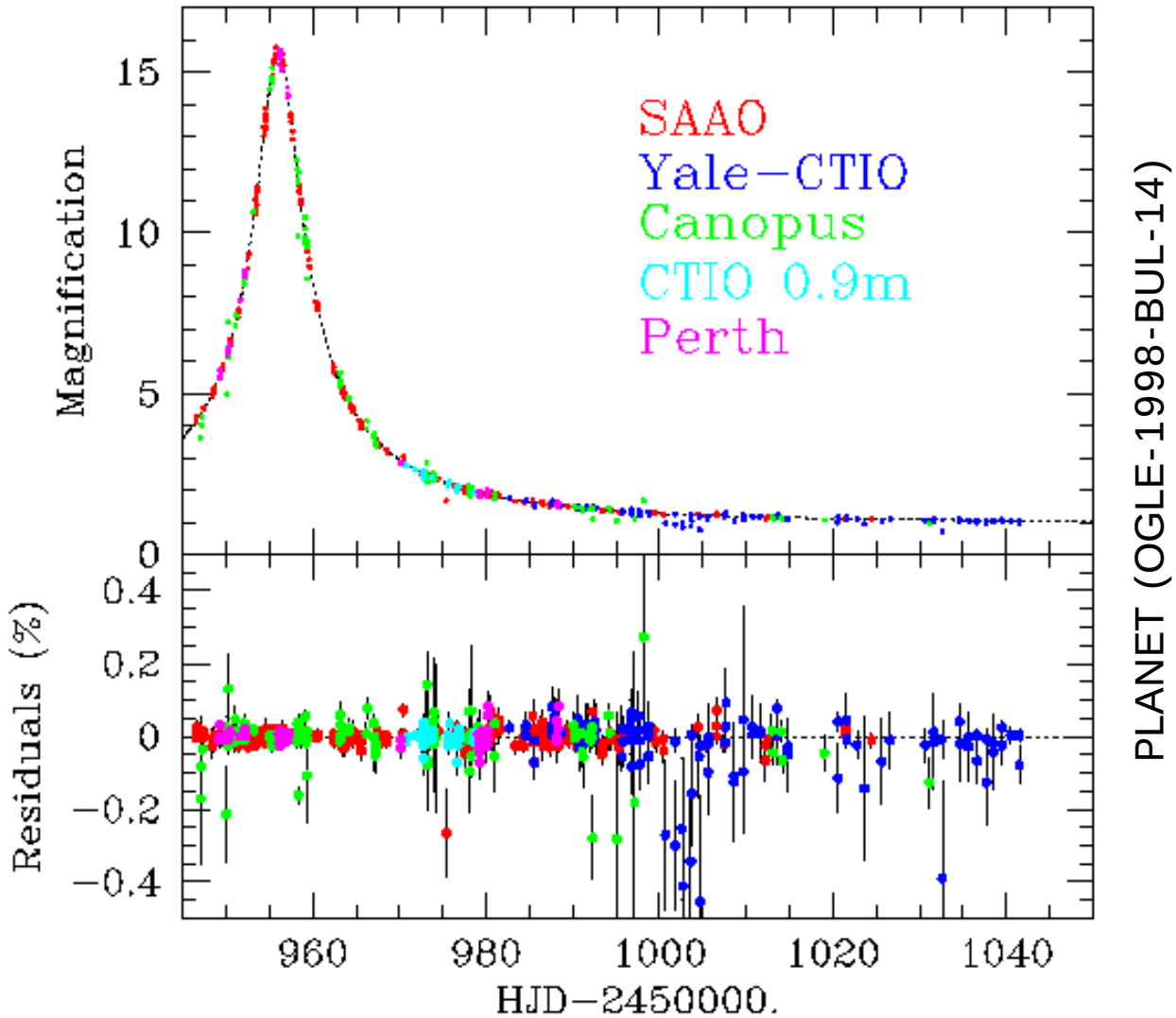
V období 1992 – III/2009 napozorováno ~ 6600 mikročoček



(MACHO 1995)

Návazné projekty (**PLANET**, **μFun**, GMAN, MPS)

PLANET



Dvojitá mikročočka

$$\vec{\alpha}(\vec{\theta}) = \frac{4GM}{c^2 D_L}\left[\mu_A \frac{\vec{\theta}-\vec{\theta}_A}{\left|\vec{\theta}-\vec{\theta}_A\right|^2} + \mu_B \frac{\vec{\theta}-\vec{\theta}_B}{\left|\vec{\theta}-\vec{\theta}_B\right|^2}\right]$$

po přeškálování $\vec{\beta} = \theta_E \vec{y}, \quad \vec{\theta} = \theta_E \vec{x}$

čočková rovnice:

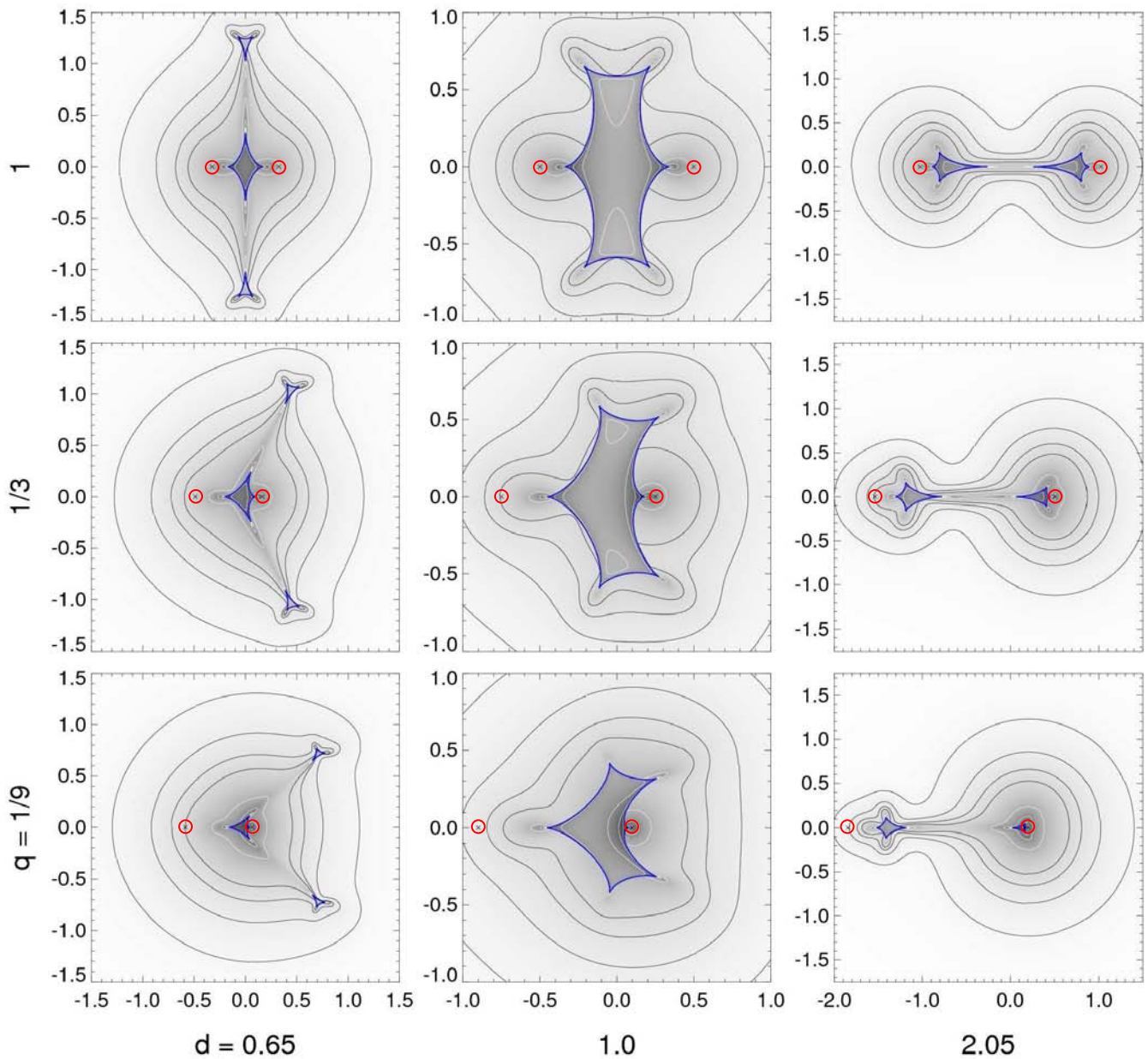
$$\vec{y} = \vec{x} - \mu_A \frac{\vec{x}-\vec{x}_A}{\left|\vec{x}-\vec{x}_A\right|^2} - \mu_B \frac{\vec{x}-\vec{x}_B}{\left|\vec{x}-\vec{x}_B\right|^2}$$

klíčové parametry: $q = \mu_A/\mu_B$ hmotnostní poměr

$d = |\mathbf{x}_B - \mathbf{x}_A|$ průmět vzáj. vzdálenosti

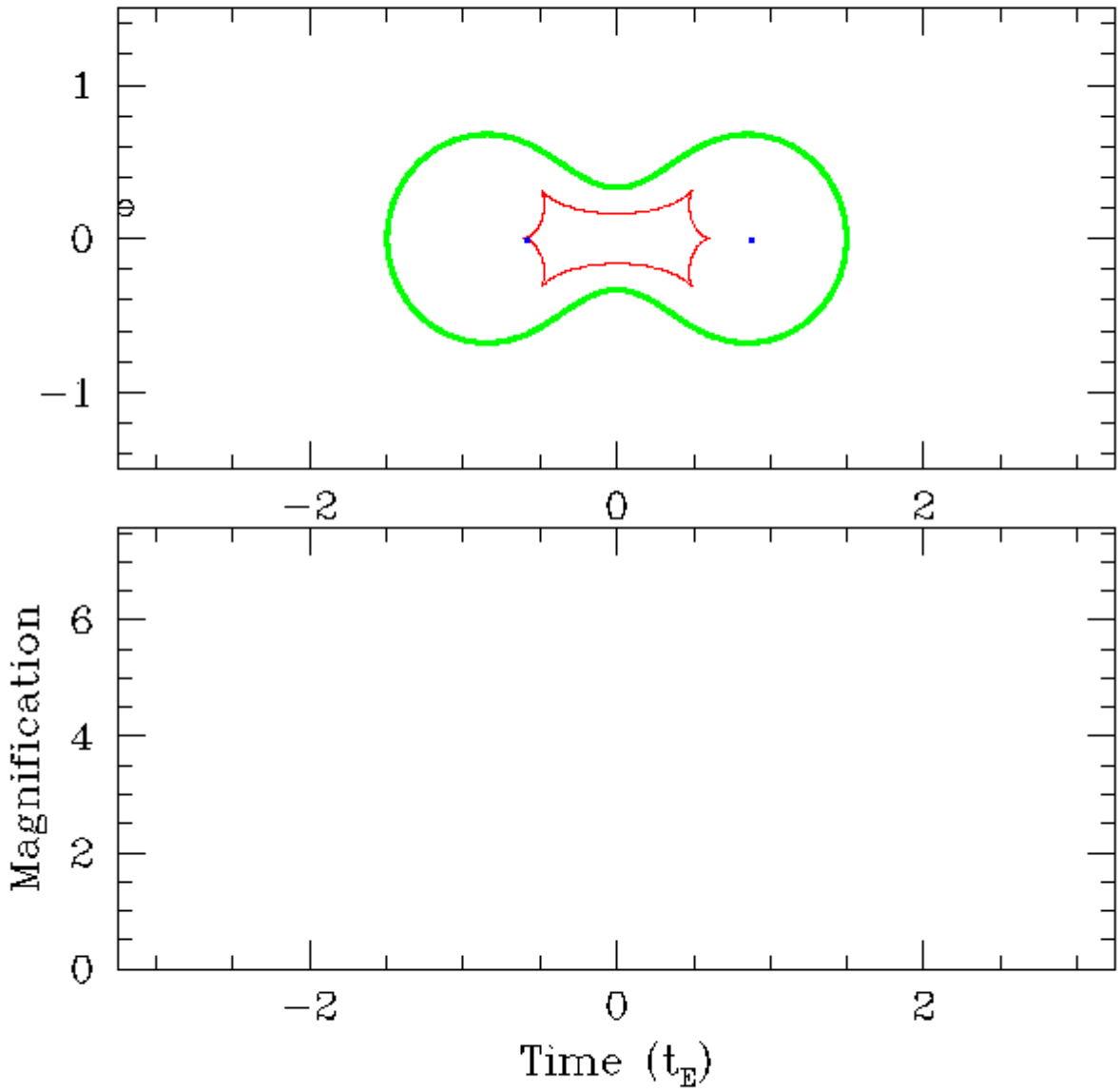
pokud **$q << 1$** $\Longrightarrow$ **Mikročočka s planetou**

Zjasnění bodového zdroje dvojitou mikročočkou



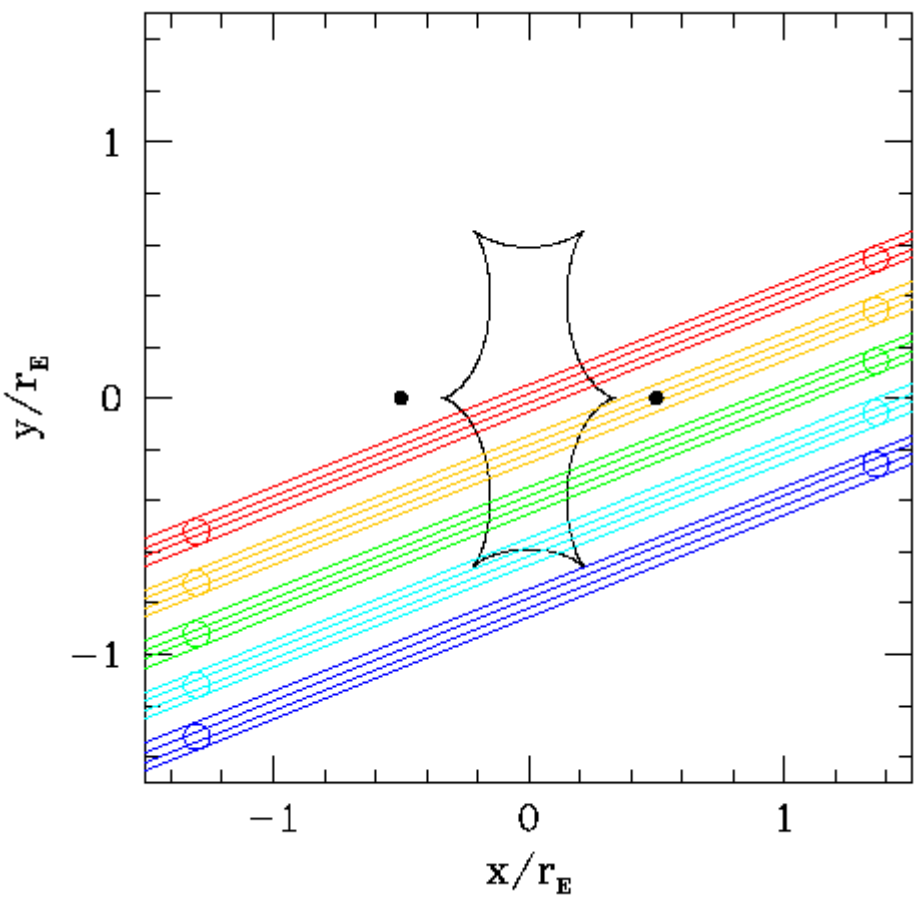
Pejcha & Heyrovský (2009)

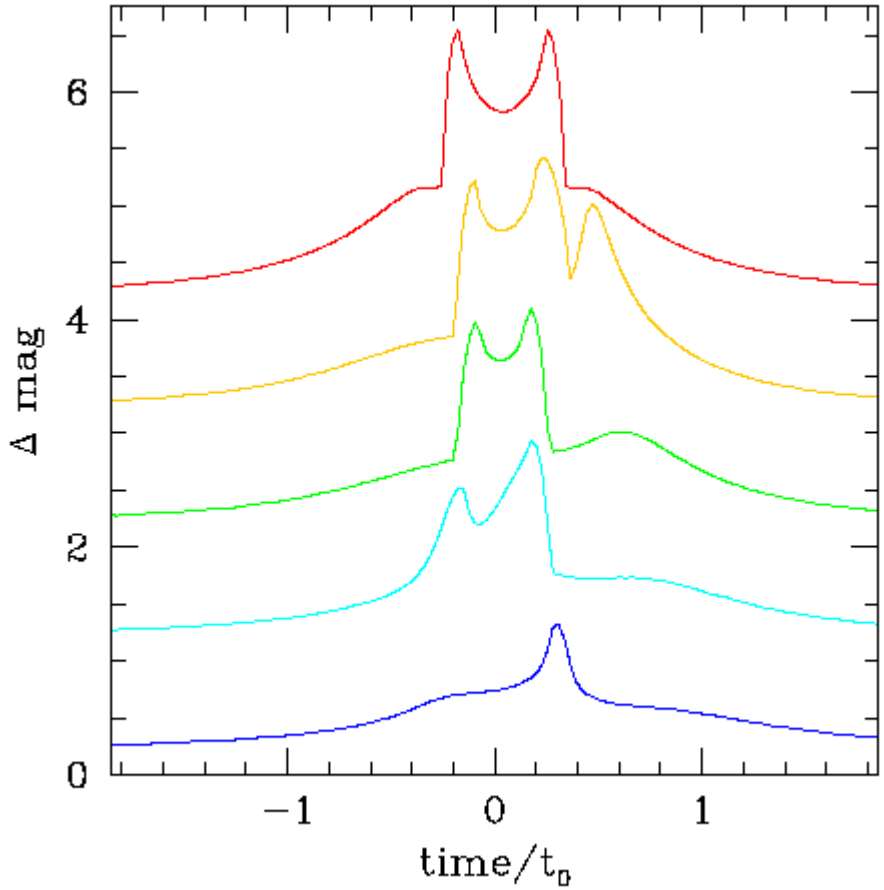
Obrazy + světelná křivka



B.S.Gaudi, http://www.astronomy.ohio-state.edu/~gaudi/movies.html

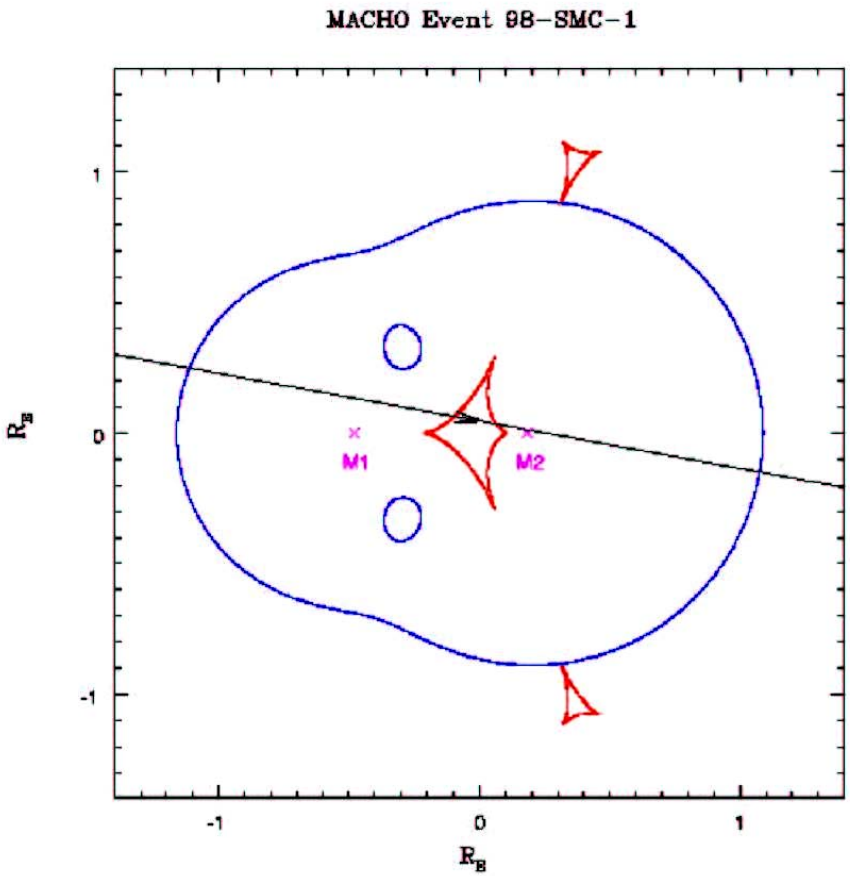
Příklady světelných křivek

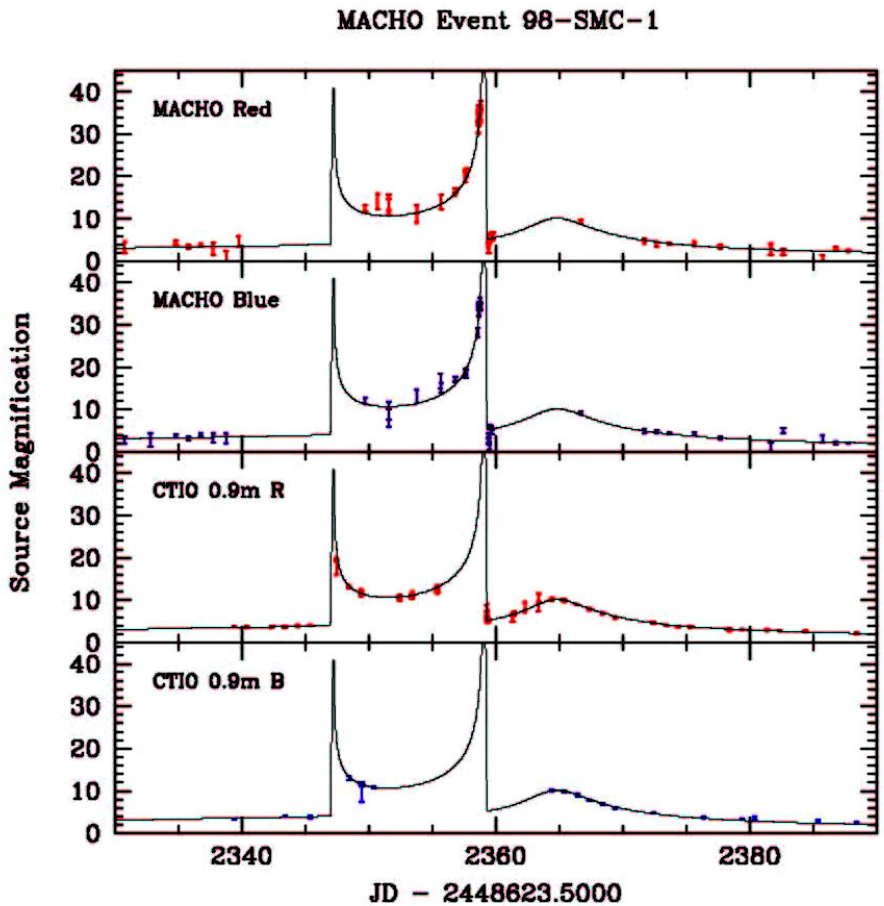




PLANET / P.Sackett

Pozorovaná dvojitá mikročočka





Alcock et al. (2000)

Detekce planet u mikročoček

THE ASTROPHYSICAL JOURNAL, 606:L155–L158, 2004 May 10

OGLE 2003-BLG-235/MOA 2003-BLG-53: A PLANETARY MICROLENSING EVENT

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THE MOA AND OGLE COLLABORATIONS
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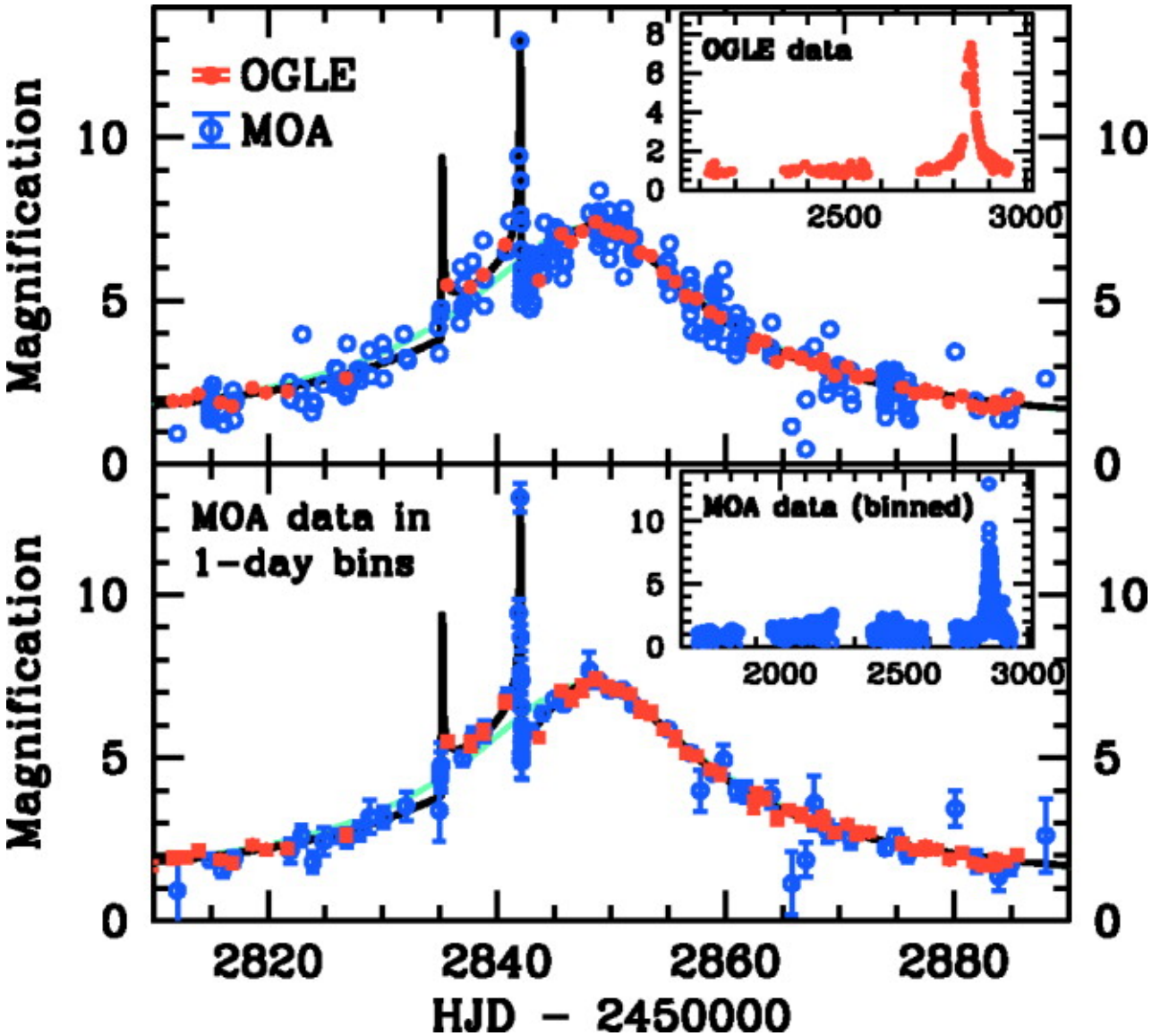
ABSTRACT

We present observations of the unusual microlensing event OGLE 2003-BLG-235/MOA 2003-BLG-53. In this event, a short-duration (~7 days) low-amplitude deviation in the light curve due to a single-lens profile was observed in both the MOA (Microlensing Observations in Astrophysics) and OGLE (Optical Gravitational Lensing Experiment) survey observations. We find that the observed features of the light curve can only be reproduced using a binary microlensing model with an extreme (planetary) mass ratio of 0.0039^{+11}_{-07} for the lensing system. If the lens system comprises a main-sequence primary, we infer that the secondary is a planet of about 1.5 Jupiter masses with an orbital radius of ~3 AU.

OGLE 2003-BLG-235 / MOA 2003-BLG-53 *Bond et al. (2004)*



$q = 0{,}0039^{+0{,}0011}_{-0{,}0007}$

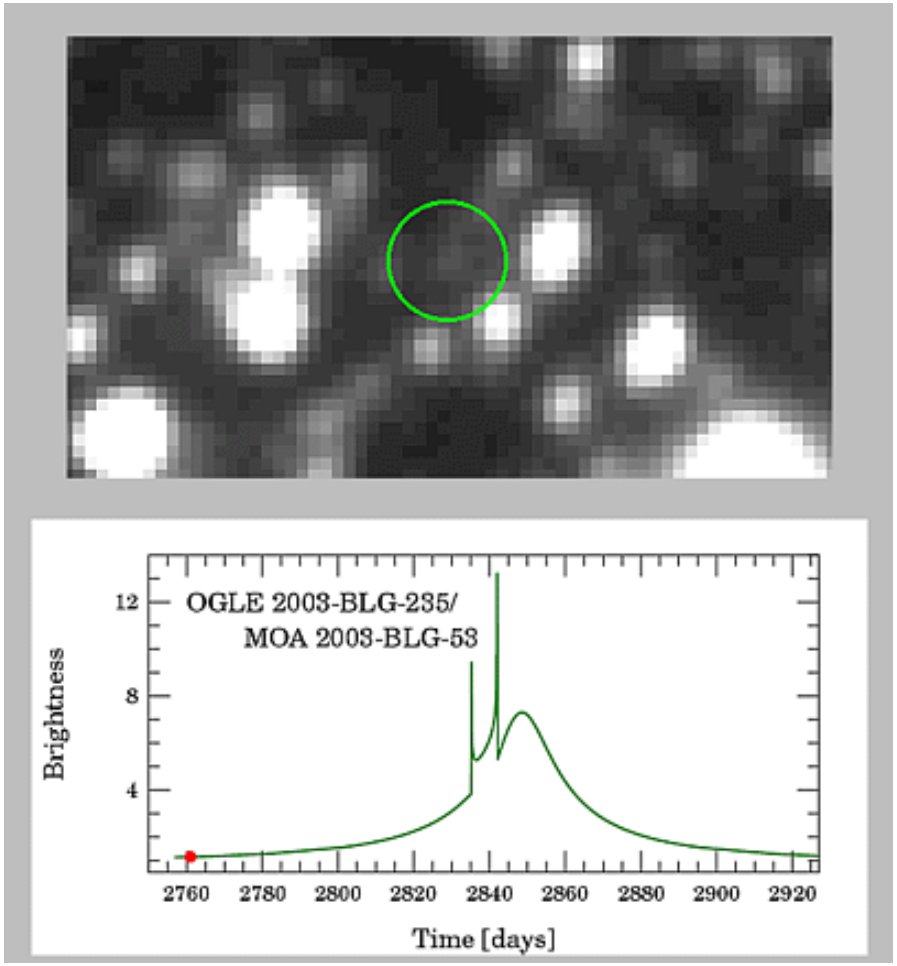
$d = 1{,}120 \pm 0{,}007$

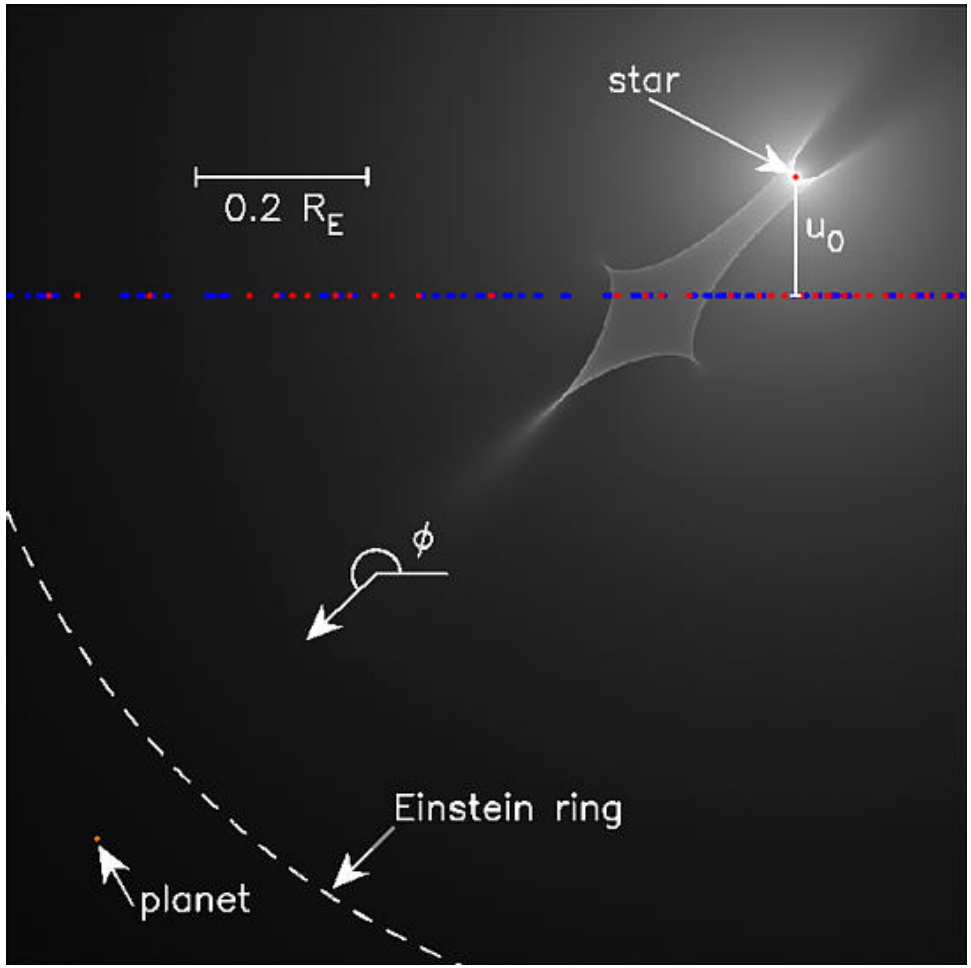
$M_P = 1{,}5^{+0{,}1}_{-1{,}2} M_J$

$r_\perp = 3{,}0^{+0.1}_{-1.7}\, AU$

$M_* = 0{,}36^{+0{,}03}_{-0{,}28} M_\odot$

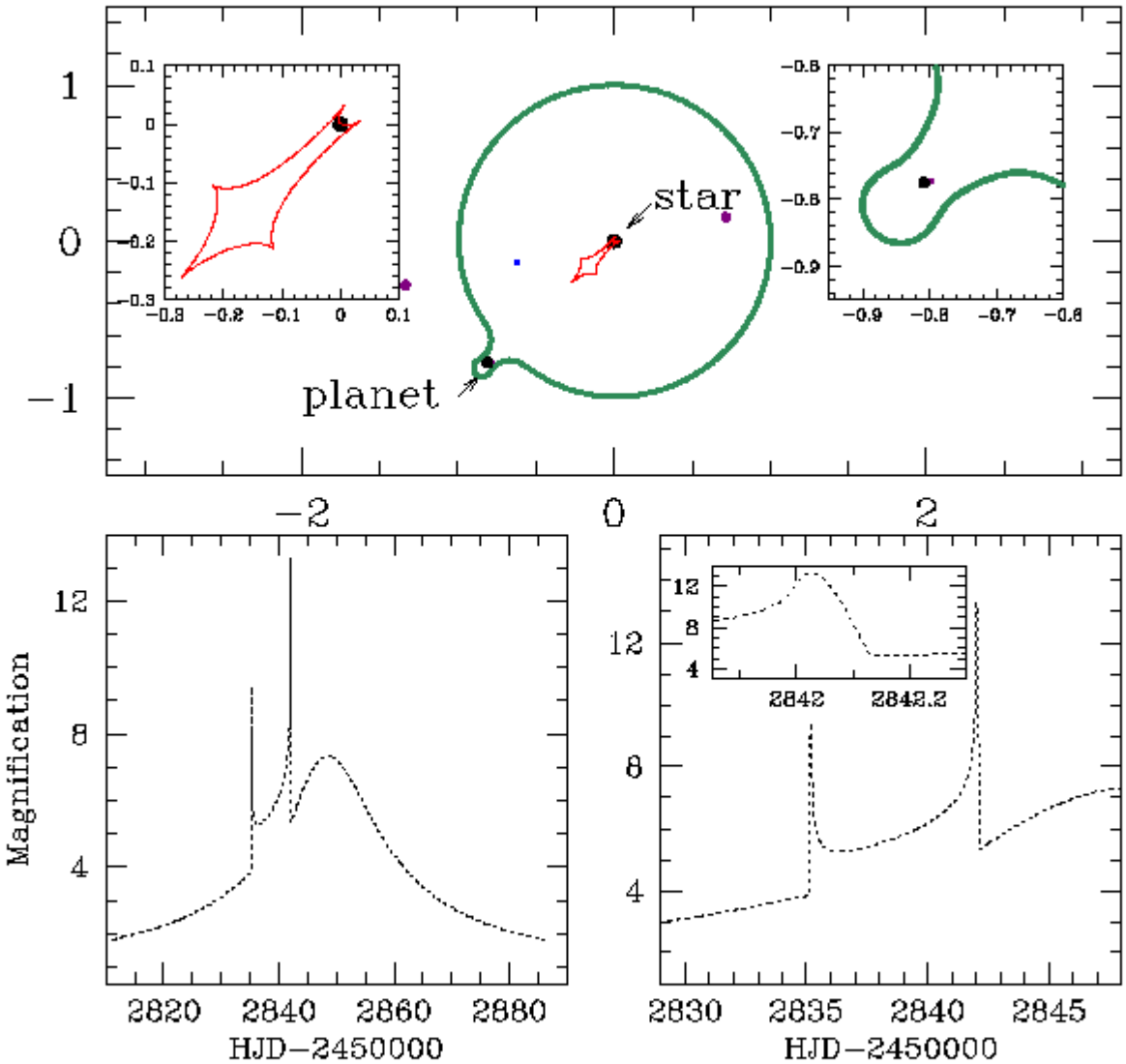
OGLE 2003-BLG-235 / MOA 2003-BLG-53





OGLE / B.S.Gaudi / D.P.Bennett

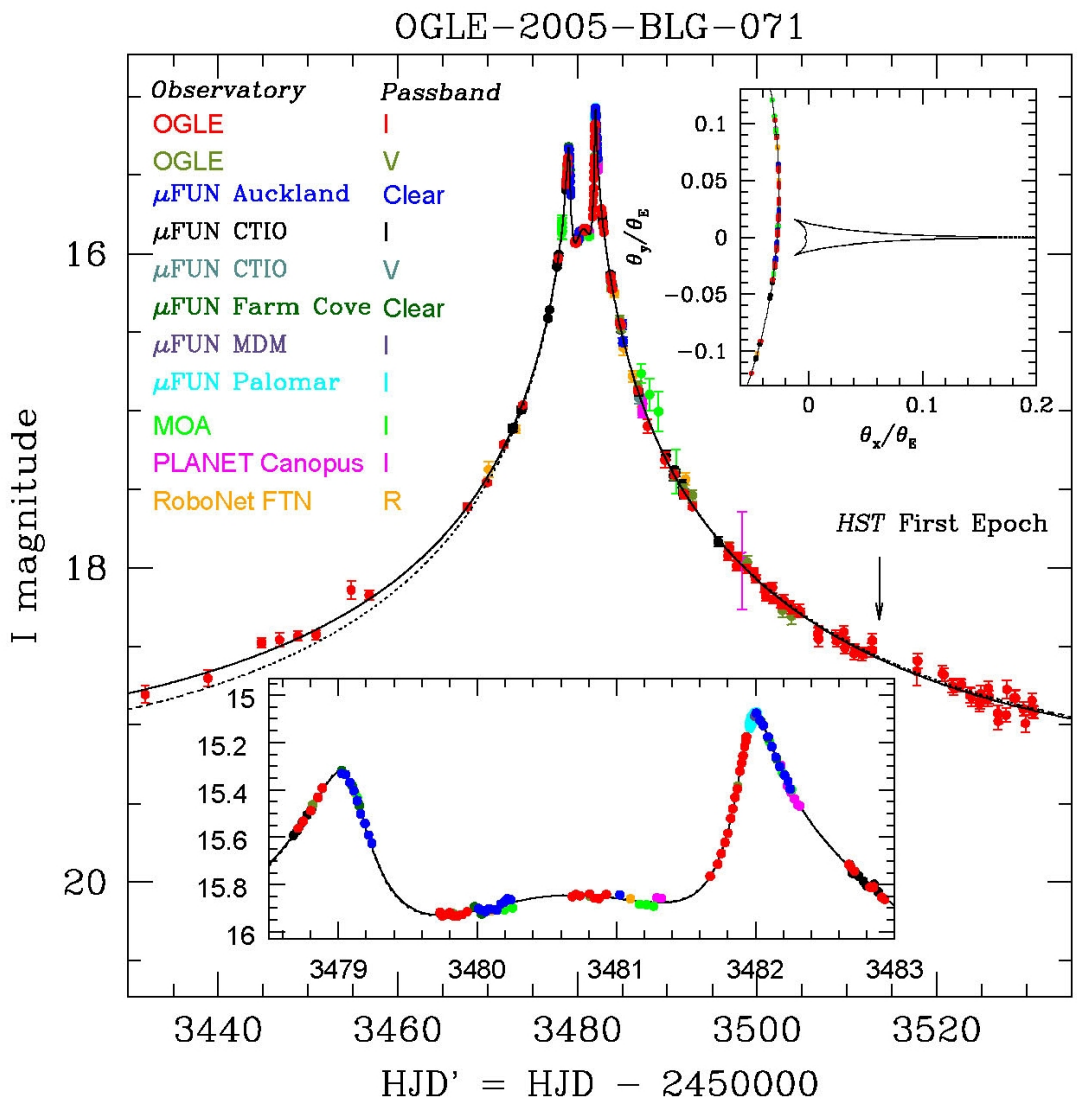
OGLE 2003-BLG-235 / MOA 2003-BLG-53



OGLE / B.S.Gaudi

OGLE 2005-BLG-071

Udalski et al. (2005), Dong et al. (2009)



$$q = 0{,}0072^{+0{,}0004}_{-0{,}0002}$$

$$d = 1{,}285^{+0{,}008}_{-0{,}007}$$

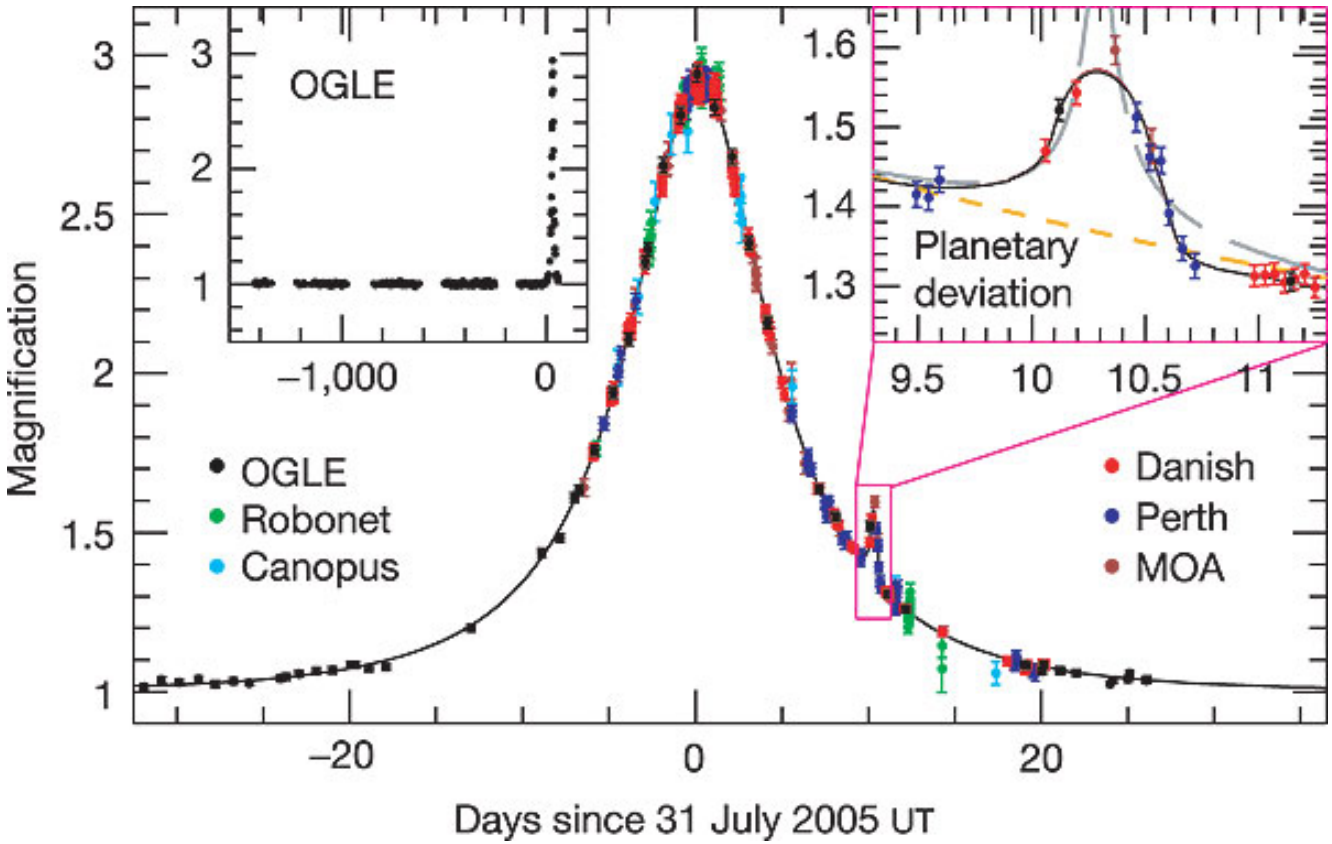
$$M_P = 3{,}5 \pm 0{,}3 M_J$$

$$r_\perp = 3{,}6 \pm 0{,}2 AU$$

$$M_* = 0{,}46 \pm 0{,}04 M_O$$

S.Dong, http://arxiv.org/abs/0804.1354v1

OGLE 2005-BLG-390 *Beaulieu et al. (2006)*



$$q = 7{,}6 \pm 0{,}7 \times 10^{-5}$$

$$d = 1{,}610 \pm 0{,}008$$

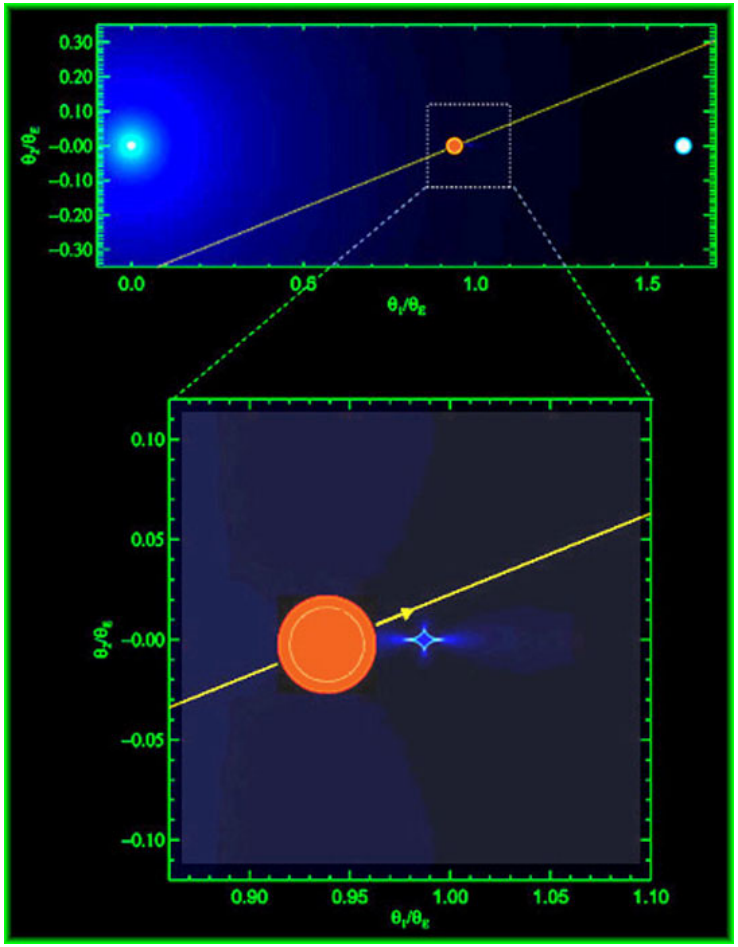
$$M_P = 5{,}5^{+5,5}_{-2,7} M_\oplus$$

$$r_\perp = 2{,}6^{+1,5}_{-0,6}\, AU$$

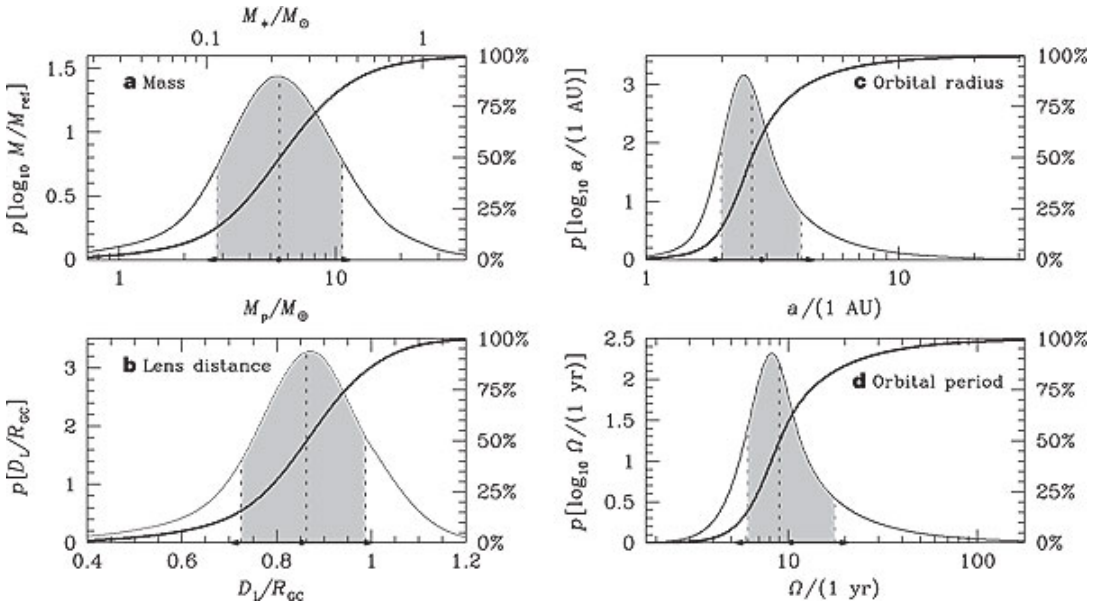
$$M_* = 0{,}22^{+0,21}_{-0,11} M_\odot$$

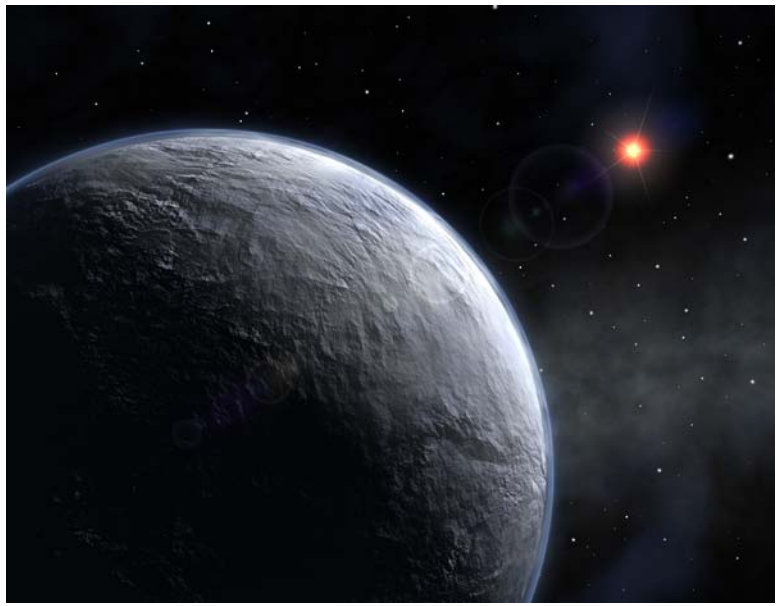
http://planet.iap.fr/OB05390figs/OB05390-adaptive-hires.mp4

OGLE 2005-BLG-390



PLANET / D. Kubas

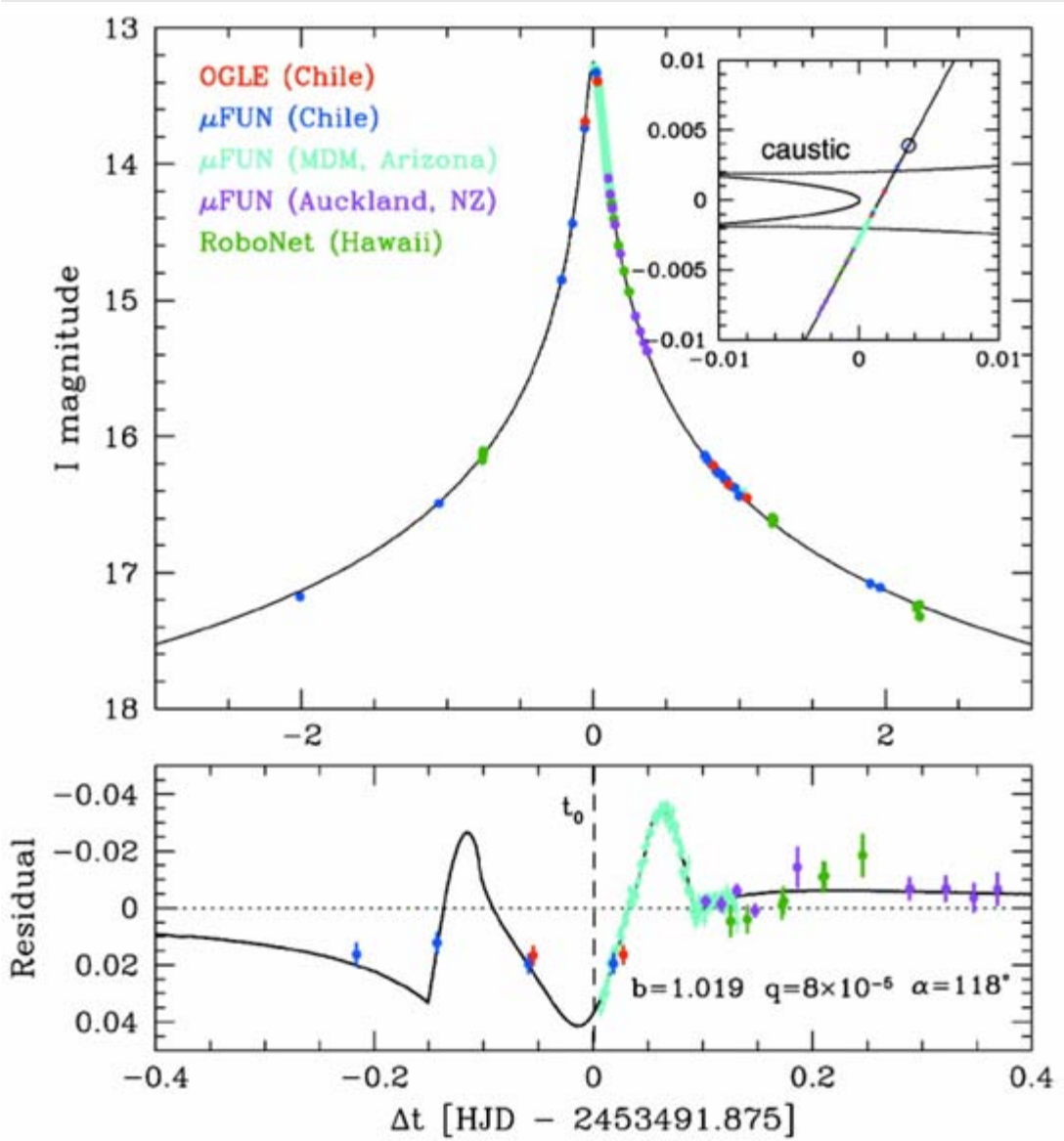




PLANET / ESO

OGLE 2005-BLG-169

Gould et al. (2006)



$q = 8^{+2}_{-3} \times 10^{-5}$

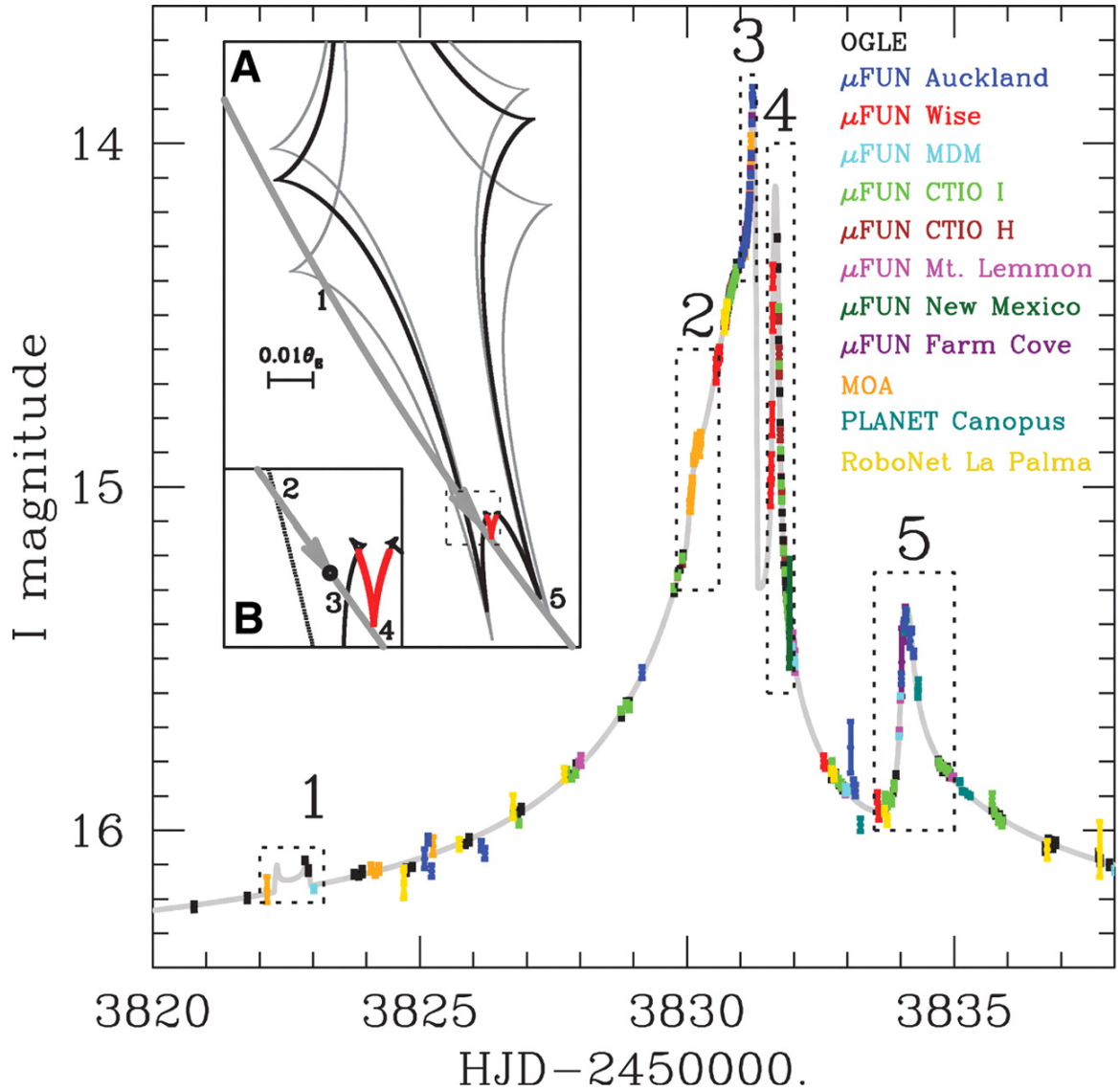
$d = 1{,}00 \pm 0{,}02$

$M_P = 13 M_\oplus$

$r_\perp = 2{,}7\,AU$

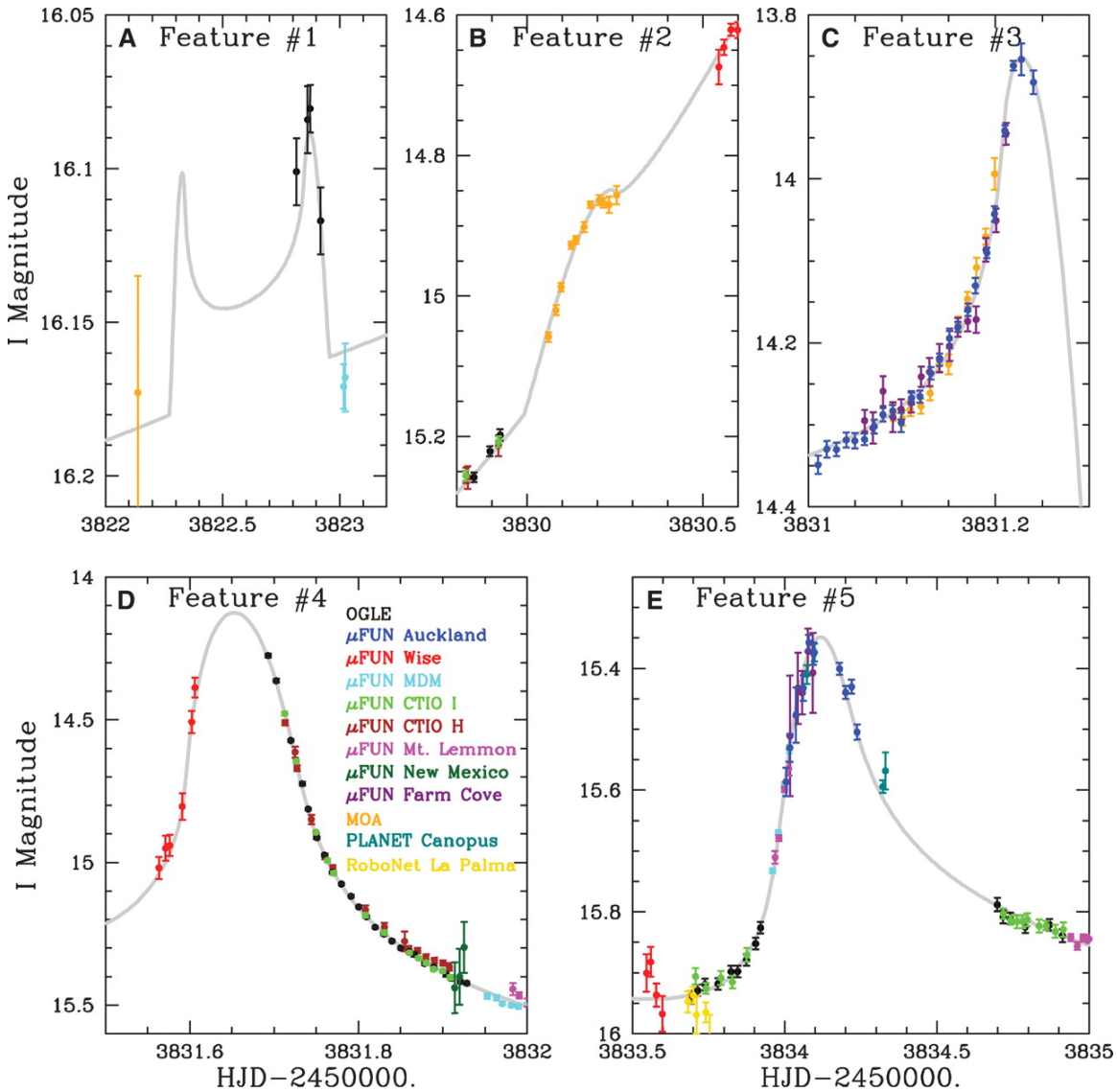
$M_* = 0{,}49^{+0{,}23}_{-0{,}29} M_\odot$

OGLE 2006-BLG-109 *Gaudi et al. (2008)*



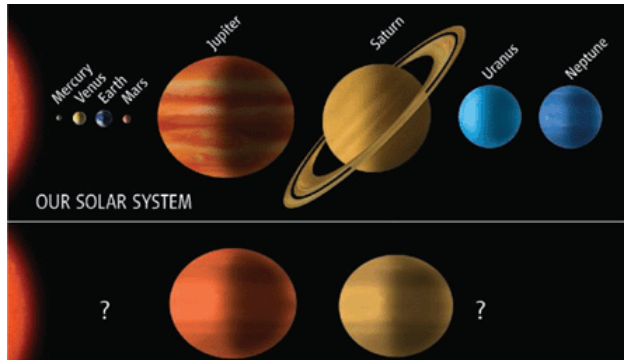
$$M_b = 0{,}71 \pm 0{,}08 M_J$$
$$a_b = 2{,}3 \pm 0{,}2 AU$$
$$M_c = 0{,}27 \pm 0{,}03 M_J$$
$$a_c = 4{,}6 \pm 0{,}5 AU$$
$$M_* = 0{,}50 \pm 0{,}05 M_\odot$$

OGLE 2006-BLG-109

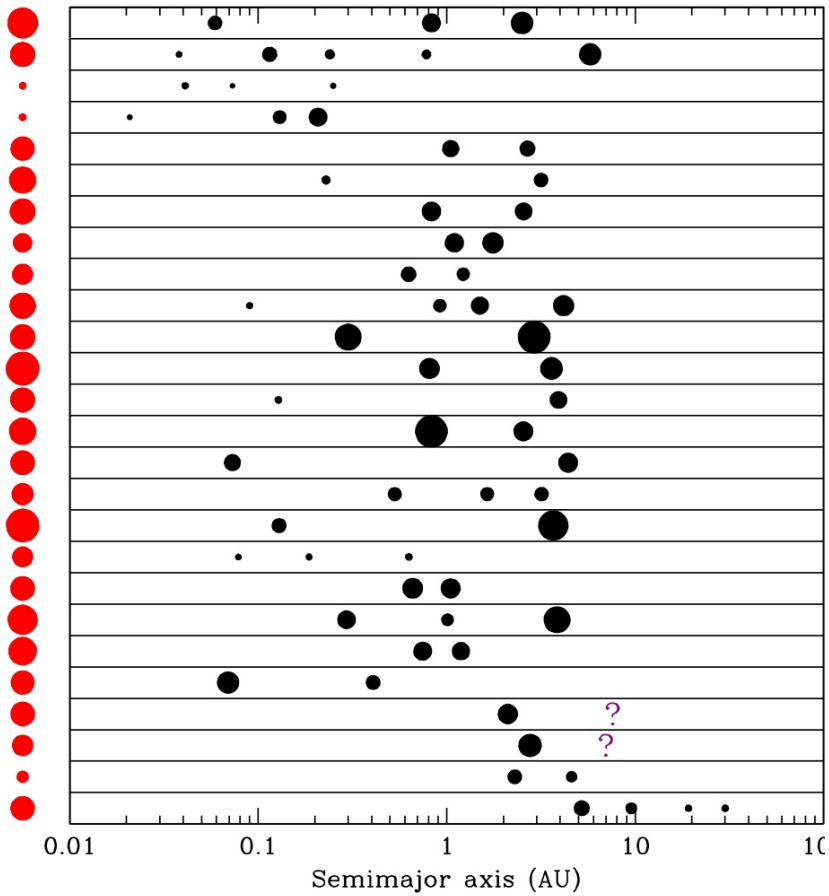


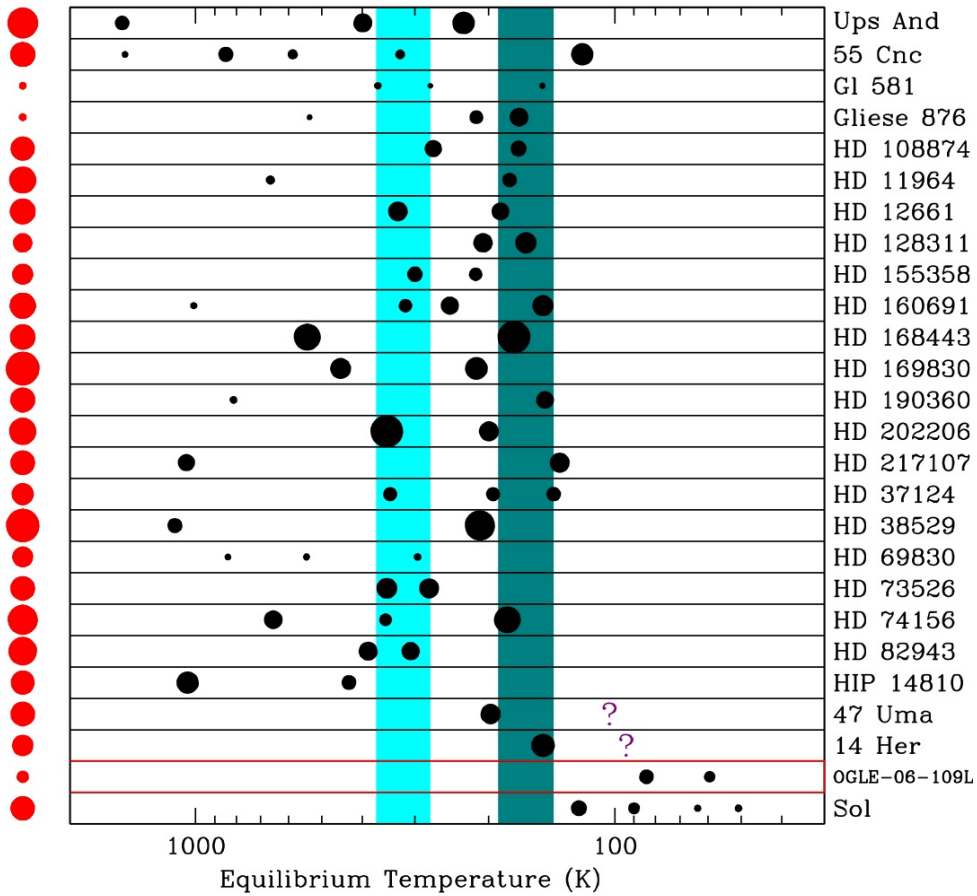
B.S.Gaudi (2008)

OGLE 2006-BLG-109



Science

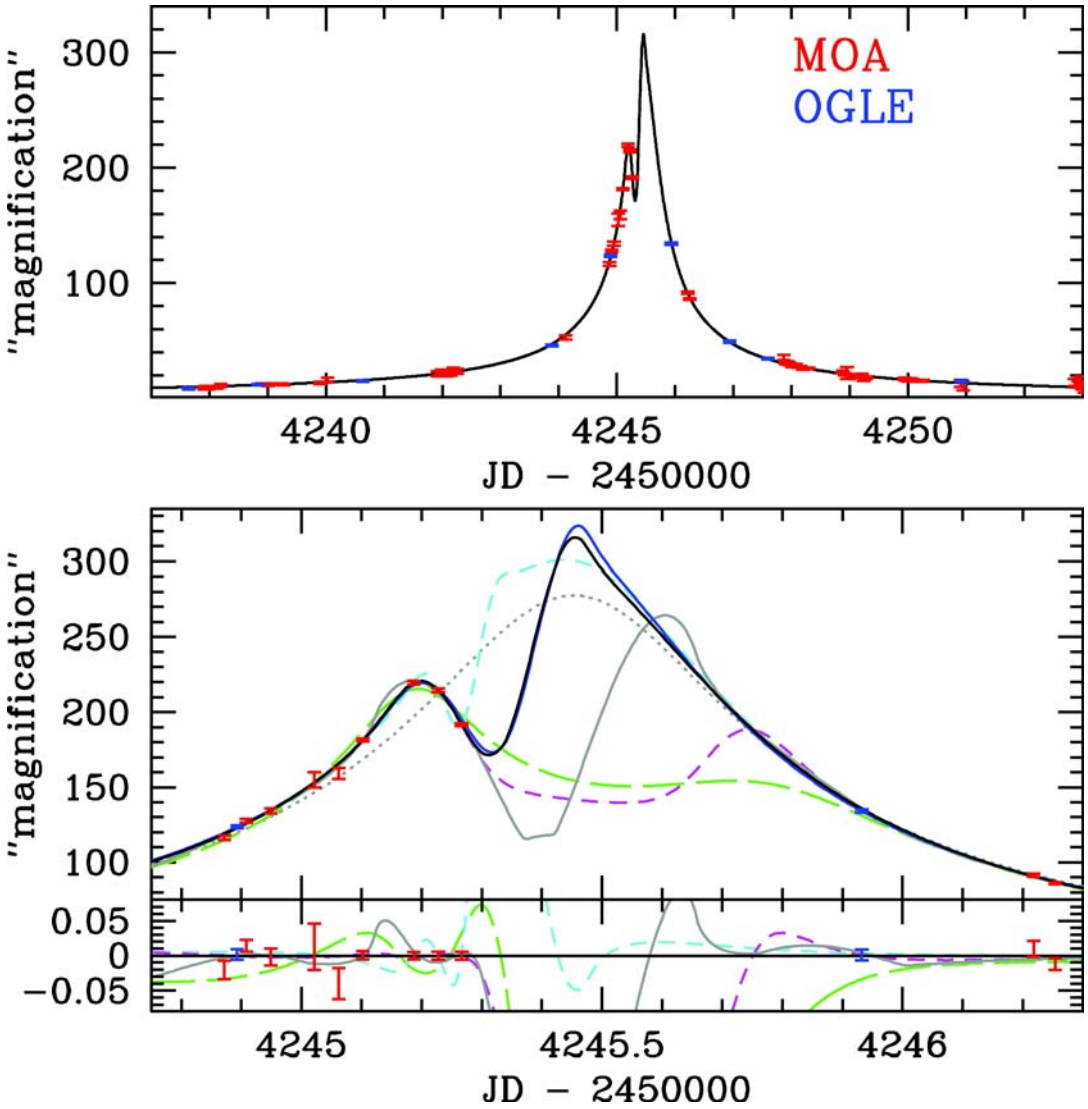




http://www.astronomy.ohio-state.edu/~microfun/ob06109/

MOA 2007-BLG-192

Bennett et al. (2008)



$$q = 1{,}2 \times 10^{-4}$$

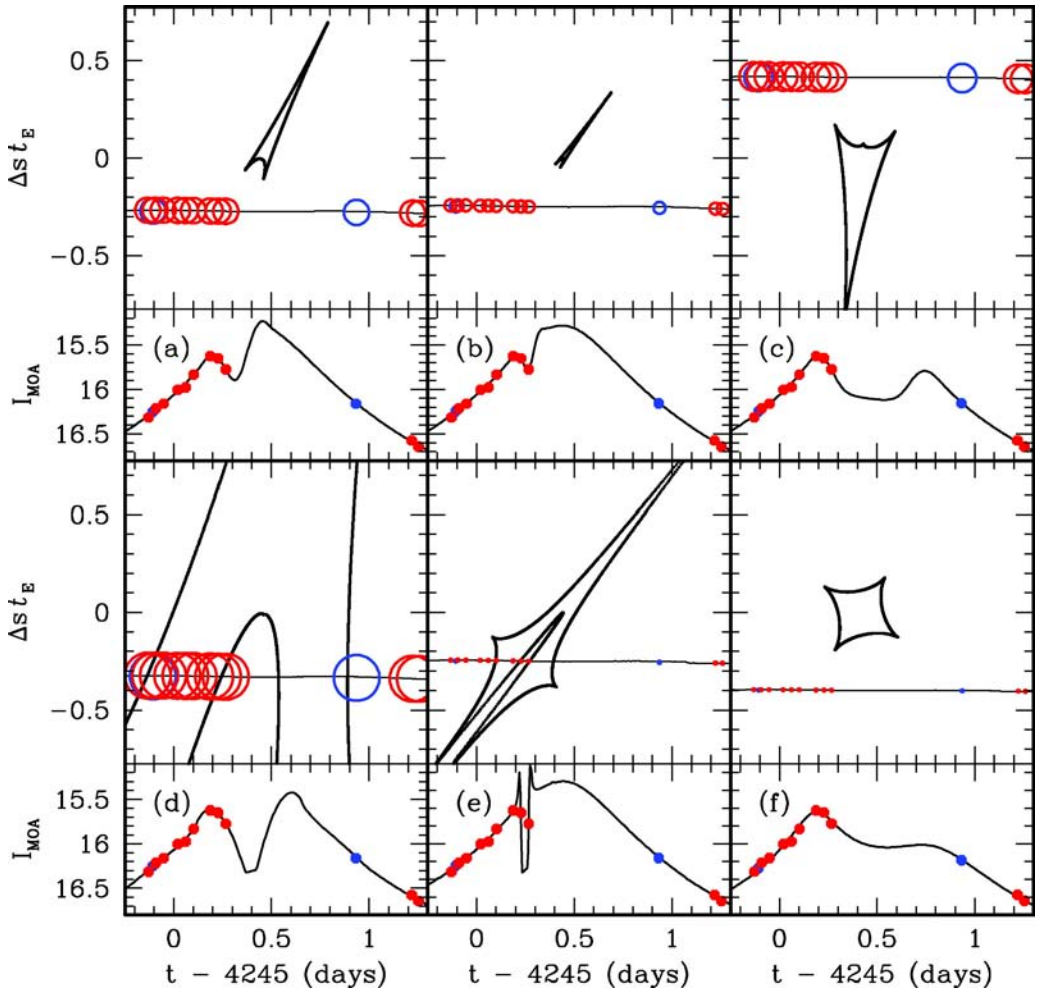
$$d = 1{,}12$$

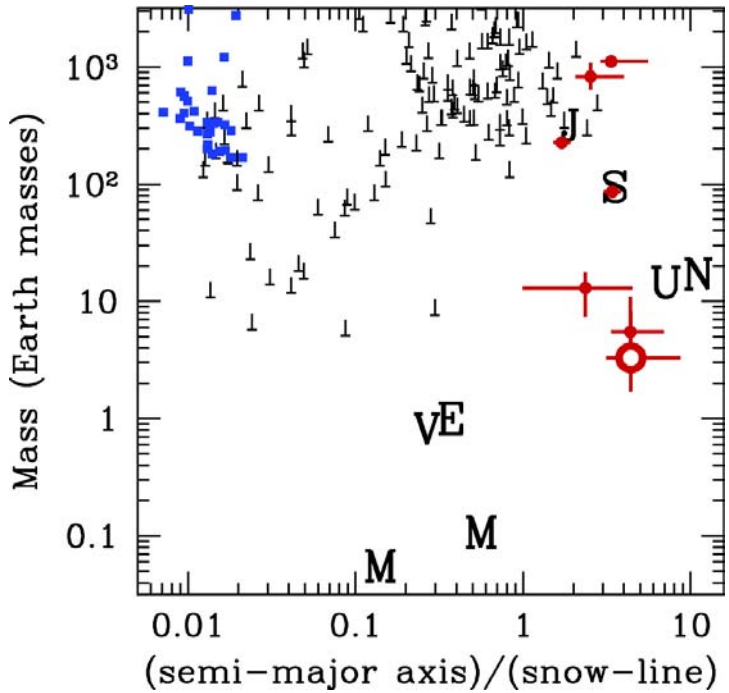
$$M_P = 3{,}3^{+4{,}9}_{-1{,}6}\, M_\oplus$$

$$r_\perp = 0{,}62^{+0{,}22}_{-0{,}16}\, AU$$

$$M_* = 0{,}060^{+0{,}028}_{-0{,}021}\, M_\odot$$

MOA 2007-BLG-192

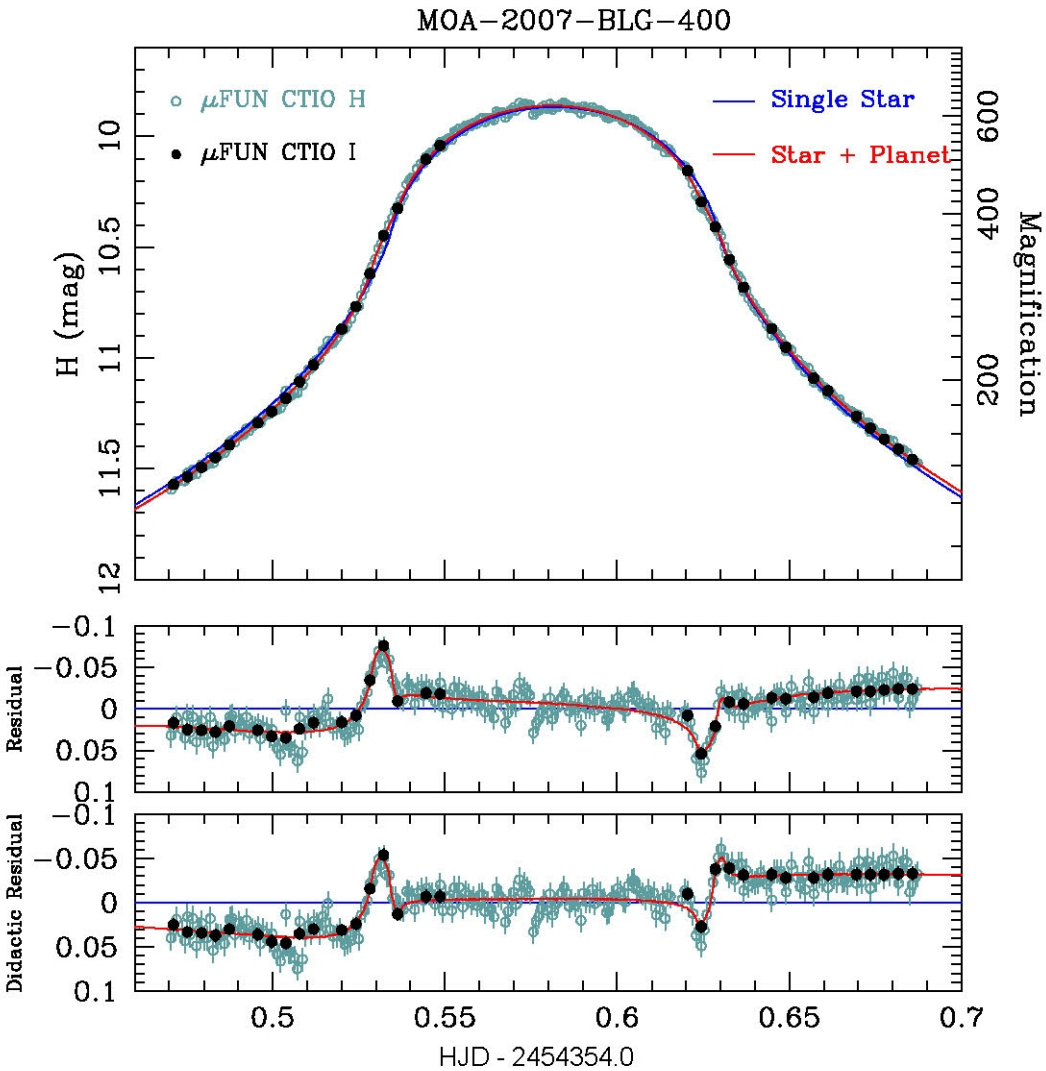


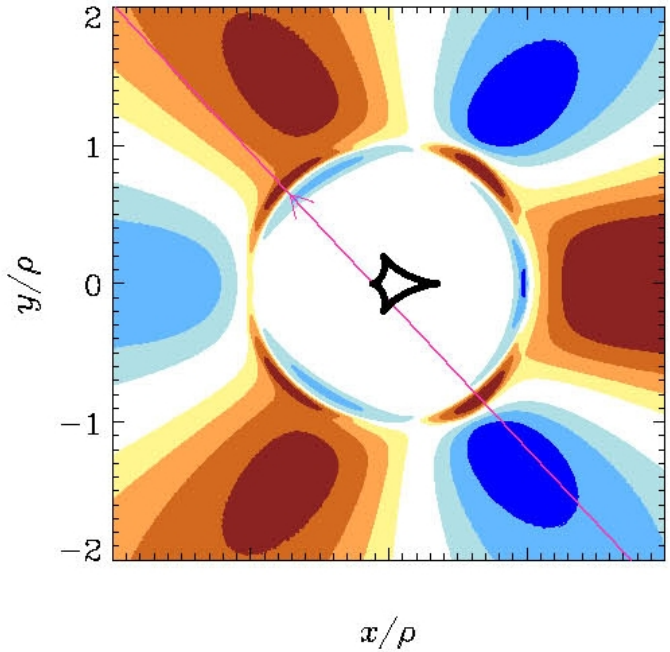


D.P.Bennett (2008)

MOA 2007-BLG-400

Dong et al. (2009)





$$q = 0{,}0026 \pm 0{,}0004$$

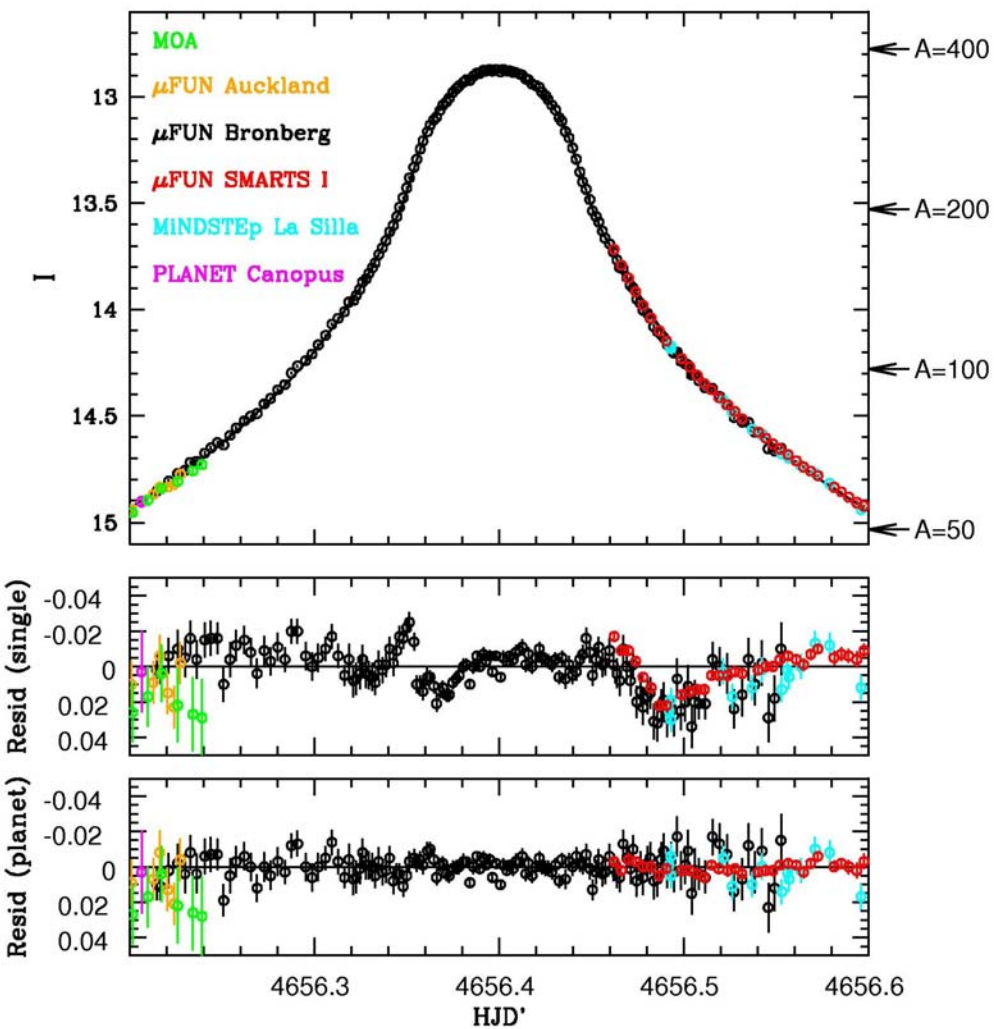
$$d = 2{,}9 \pm 0{,}2$$

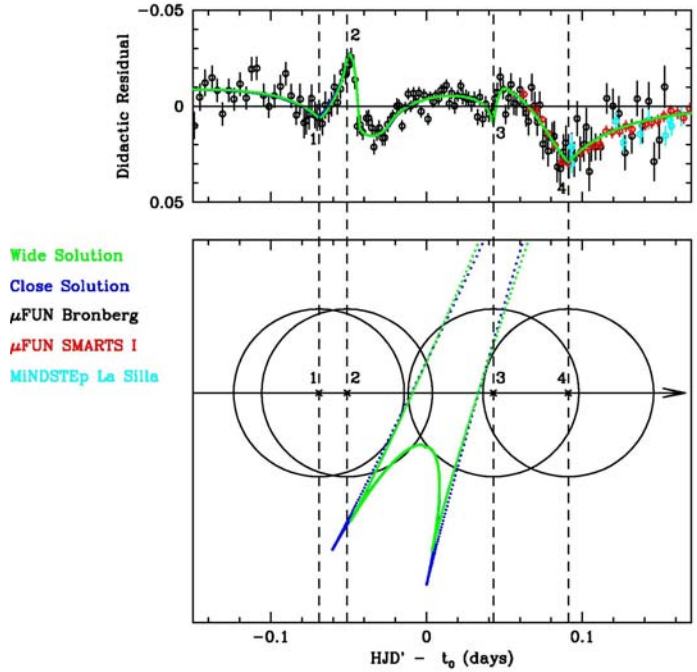
$$M_P = 0{,}82^{+0{,}52}_{-0{,}33} M_J$$

$$a = 6{,}5^{+3{,}2}_{-1{,}2}\, AU$$

$$M_* = 0{,}30^{+0{,}19}_{-0{,}12} M_\odot$$

MOA 2008-BLG-310 *Janczak et al. (2009)*





$$q = (3,31 \pm 0,26) \times 10^{-4}$$

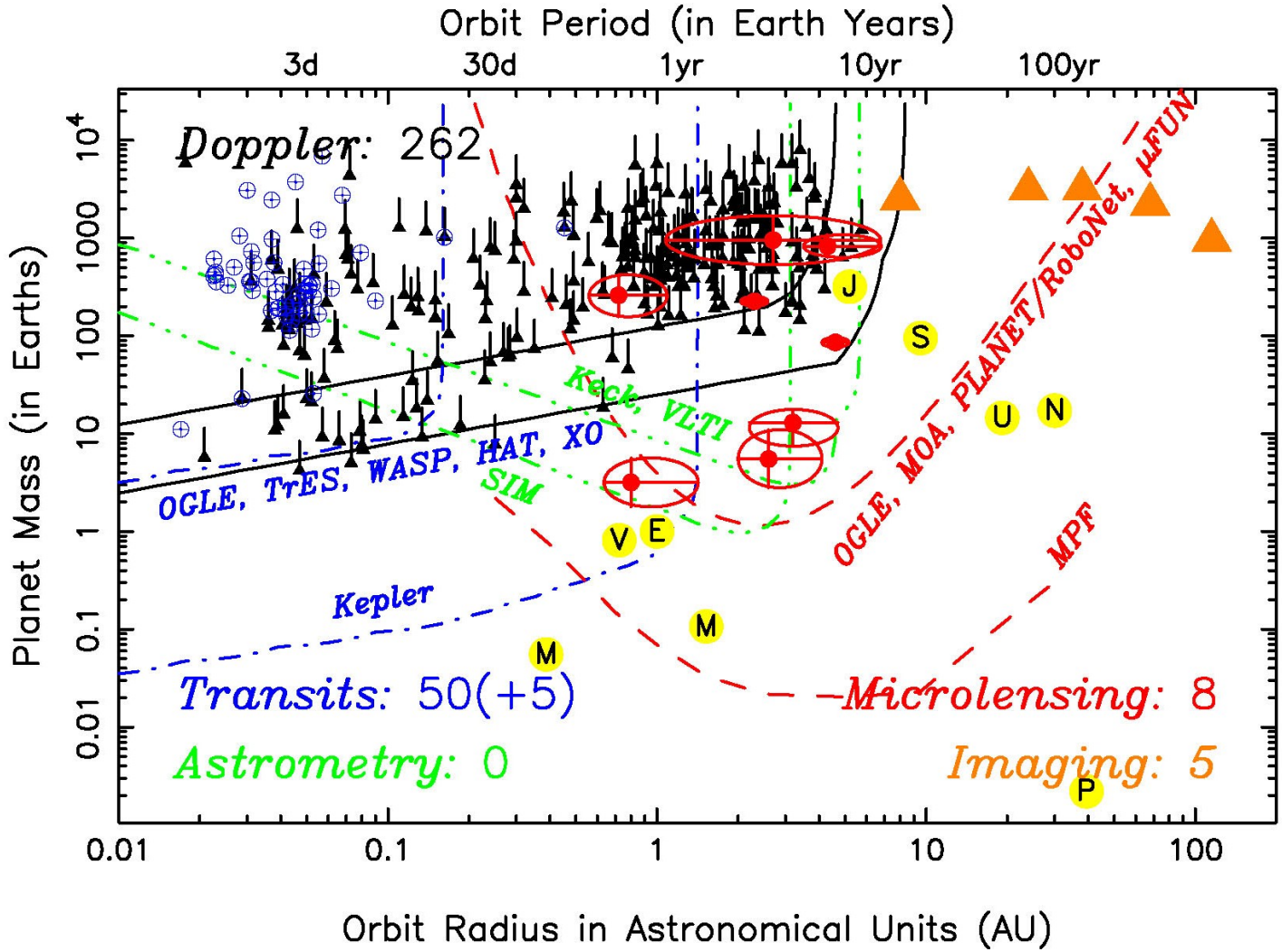
$$d = 1,085 \pm 0,003$$

$$M_P = 74 \pm 17 M_\oplus$$

$$r_\perp = 1,25 \pm 0,10 AU$$

$$M_* = 0,67 \pm 0,14 M_\odot$$

Exoplanets: 50+262+8+5=325 (Mar 2009)



K.Horne