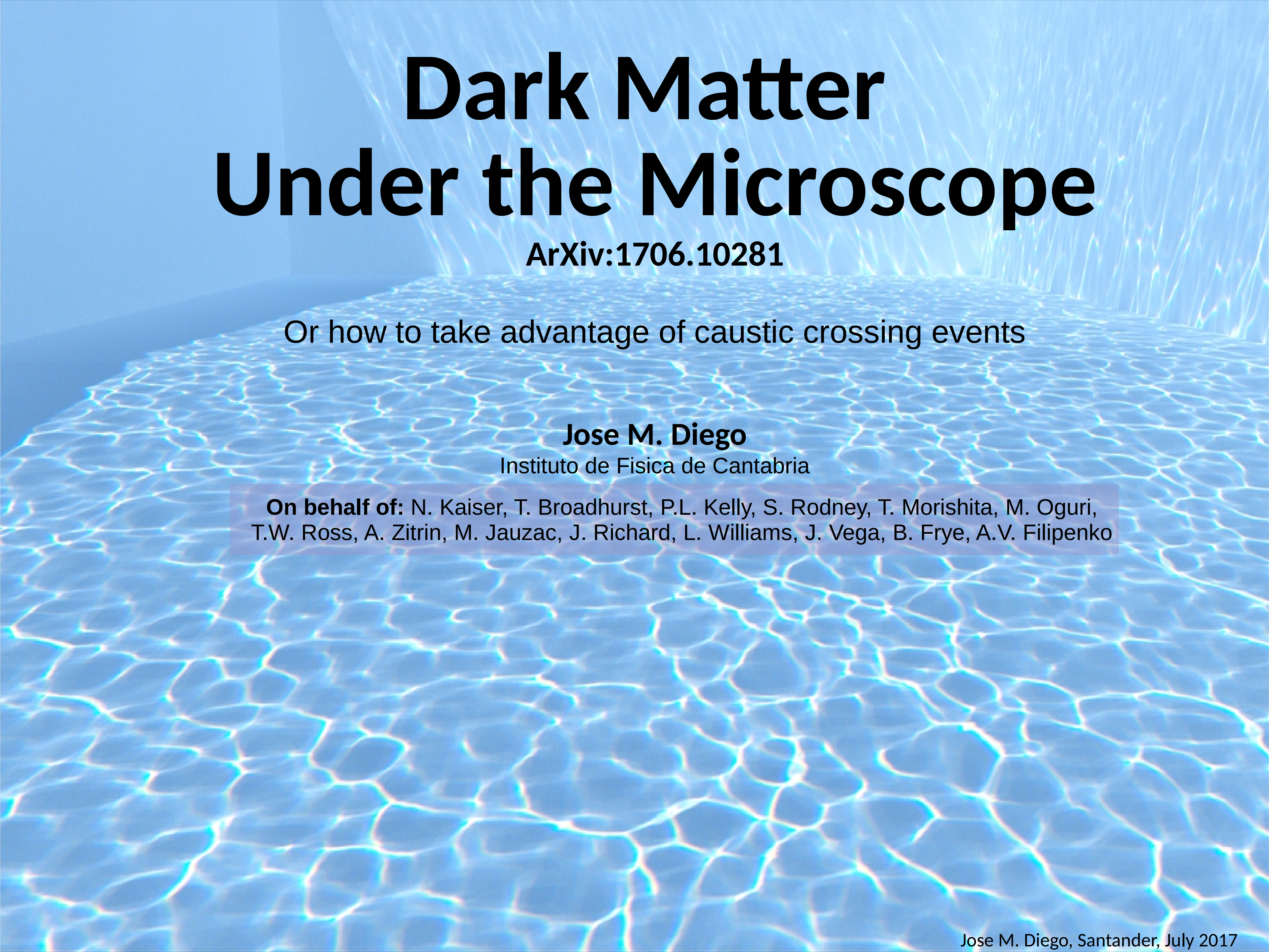

Dark Matter Under the Microscope

ArXiv:1706.10281

Or how to take advantage of caustic crossing events

Jose M. Diego
Instituto de Fisica de Cantabria

On behalf of: N. Kaiser, T. Broadhurst, P.L. Kelly, S. Rodney, T. Morishita, M. Oguri, T.W. Ross, A. Zitrin, M. Jauzac, J. Richard, L. Williams, J. Vega, B. Frye, A.V. Filipenko


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Hubble Space Telescope Discovery of a Probable Caustic-Crossing Event in the MACS1149 Galaxy Cluster Field

ATel #9097; ***Patrick L. Kelly (UCB), Steven Rodney (USC), Jose Maria Diego (Cantabria), Adi Zitrin (Caltech), Tom Broadhurst (Ikerbasque), Jonatan Selsing (DARK), Italo Balestra (INAF), Alberto Molino Benito (IAG/USP), Marusa Bradac (UCD), Larry Bradley (STScI), Gabriel Brammer (STScI), Brad Cenko (GSFC/UMD), Lise Christensen (DARK), Dan Coe (STScI), Alexei V. Filippenko (UCB), Ryan Foley (UIUC), Brenda Frye (UA), Melissa Graham (UW), Or Graur (NYU), Claudio Grillo (DARK), Jens Hjorth (DARK), Andy Howell (UCSB), Mathilde Jauzac (Durham), Saurabh Jha (Rutgers), Nick Kaiser (UH), Ryota Kawamata (Tokyo), Jean-Paul Kneib (Marseille), Jennifer Lotz (STScI), Thomas Matheson (NOAO), Curtis McCully (UCSB), Julian Merten (Oxford), Mario Nonino (INAF), Masamune Oguri (Tokyo), Johan Richard (Lyon), Adam Riess (JHU/STScI), Piero Rosati (Ferrara), Kasper Borello Schmidt (AIP), Keren Sharon (UMich), Nathan Smith (UA), Lou Strolger (STScI), Tommaso Treu (UCLA), Xin Wang (UCLA), Ben Weiner (UA), Liliya Williams (UMN), Weikang Zheng (UCB)***
*on **29 May 2016; 07:50 UT***
Credential Certification: Patrick Kelly (pkelly@astro.berkeley.edu)

Subjects: Infra-Red, Optical, Ultra-Violet, Request for Observations, Transient

While monitoring the MACS1149 (z = 0.54) galaxy cluster as part of the RefsdalRedux program (PID 14199; PI Kelly) with the Hubble Space Telescope (HST) WFC3 IR camera, we have detected a rising transient that appears to be coincident (<0.1 arcsec) with the cluster's critical curve (line of formally infinite magnification) in cluster models (including those of C. Diego, C. Grillo, M. Oguri, A. Zitrin, M. Jauzac, K. Sharon, and J. Merten). Remarkably, the most likely current interpretation of the transient is that of an individual star in the host galaxy of SN Refsdal (z = 1.49) approaching the cluster caustic owing to the relative motion of the host galaxy, the cluster lens, and Earth. If so, we expect that it is currently magnified by a factor of possibly ten thousand to hundreds of thousands.

arXiv:1706.10279

An individual star at redshift 1.5 extremely magnified by a galaxy-cluster lens

Patrick L. Kelly[1], Jose M. Diego[2], Steven Rodney[3], Nick Kaiser[4], Tom Broadhurst[5,6], Adi Zitrin[7], Tommaso Treu[8], Pablo G. Pérez-González[9], Takahiro Morishita[8,10,11], Mathilde Jauzac[12,13,14], Jonatan Selsing[15], Masamune Oguri[16,17,18], Laurent Pueyo[19], Timothy W. Ross[1], Alexei V. Filippenko[1], Nathan Smith[20], Jens Hjorth[15], S. Bradley Cenko[21,22], Xin Wang[8], D. Andrew Howell[23,24], Johan Richard[25], Brenda L. Frye[20], Saurabh W. Jha[26], Ryan J. Foley[27], Colin Norman[28], Marusa Bradac[29], WeiKang Zheng[1], Gabriel Brammer[19], Alberto Molino Benito[30], Antonio Cava[31], Lise Christensen[15], Selma E. de Mink[32], Or Graur[33,34,35], Claudio Grillo[36,15], Ryota Kawamata[37], Jean-Paul Kneib[38], Thomas Matheson[39], Curtis McCully[23,24], Mario Nonino[40], Ismael Perez-Fournon[41,42], Adam G. Riess[28,19], Piero Rosati[43], Kasper Borello Schmidt[44], Keren Sharon[45], and Benjamin J. Weiner[20]

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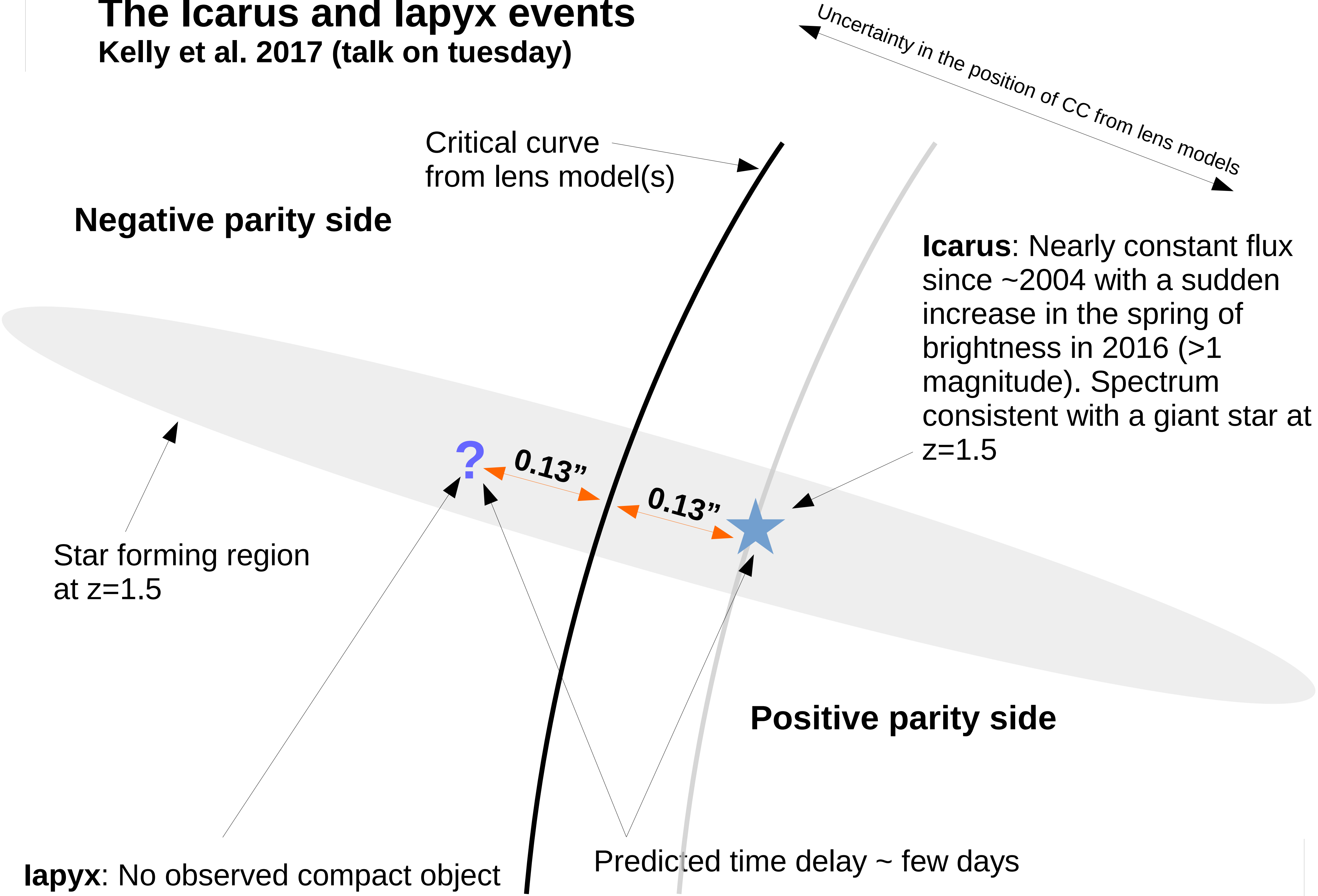
The Icarus and Iapyx events

Kelly et al. 2017 (talk on tuesday)



Uncertainty in the position of CC from lens models

Critical curve
from lens model(s)

Negative parity side

Icarus: Nearly constant flux since ~2004 with a sudden increase in the spring of brightness in 2016 (>1 magnitude). Spectrum consistent with a giant star at z=1.5

Star forming region
at z=1.5

Positive parity side

Predicted time delay ~ few days

Iapyx: No observed compact object since ~2004 until the fall of 2016

Galaxy clusters. Ideal targets for caustic crossing events

Large Einstein radius implies a large maximum magnification

$$\mu \sim \theta_E/d$$

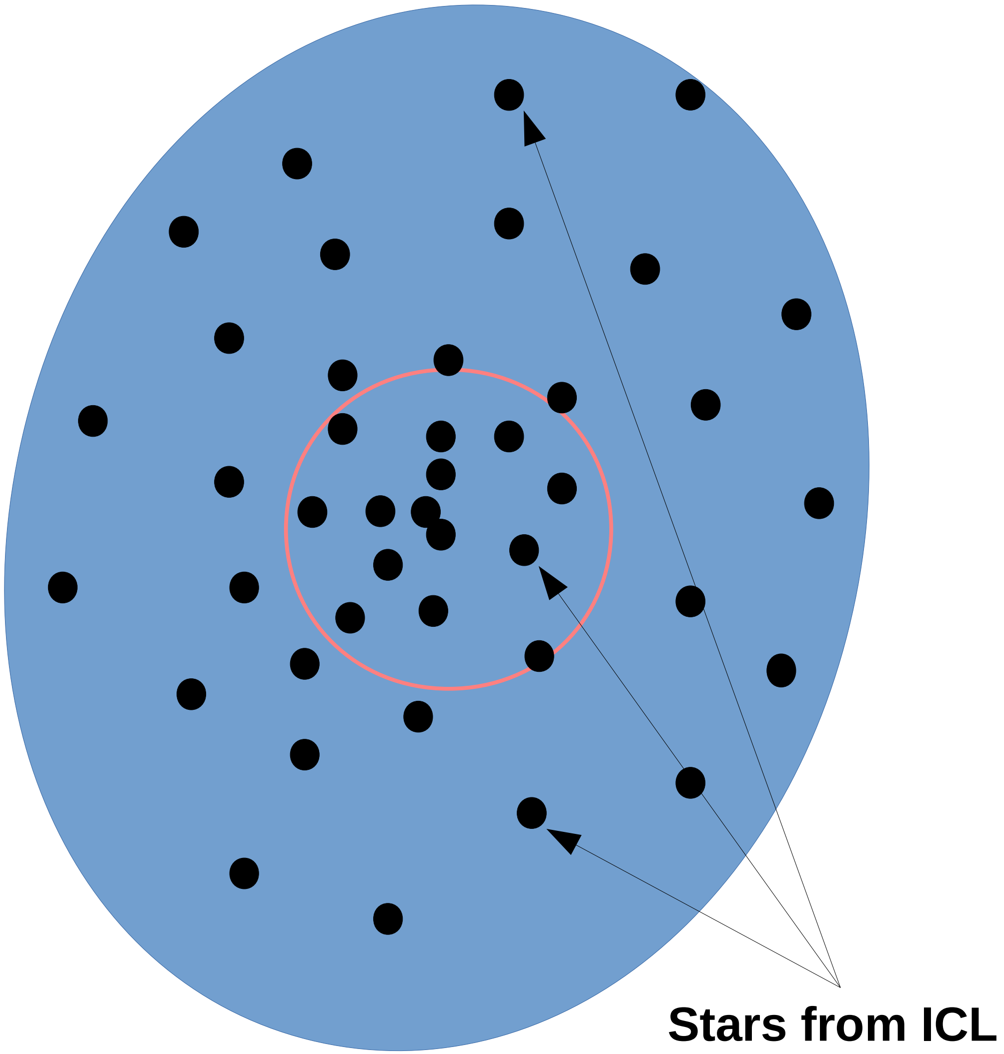
$$\mu_{max} \sim \theta_E/r^{1/2}$$

Radius of background object

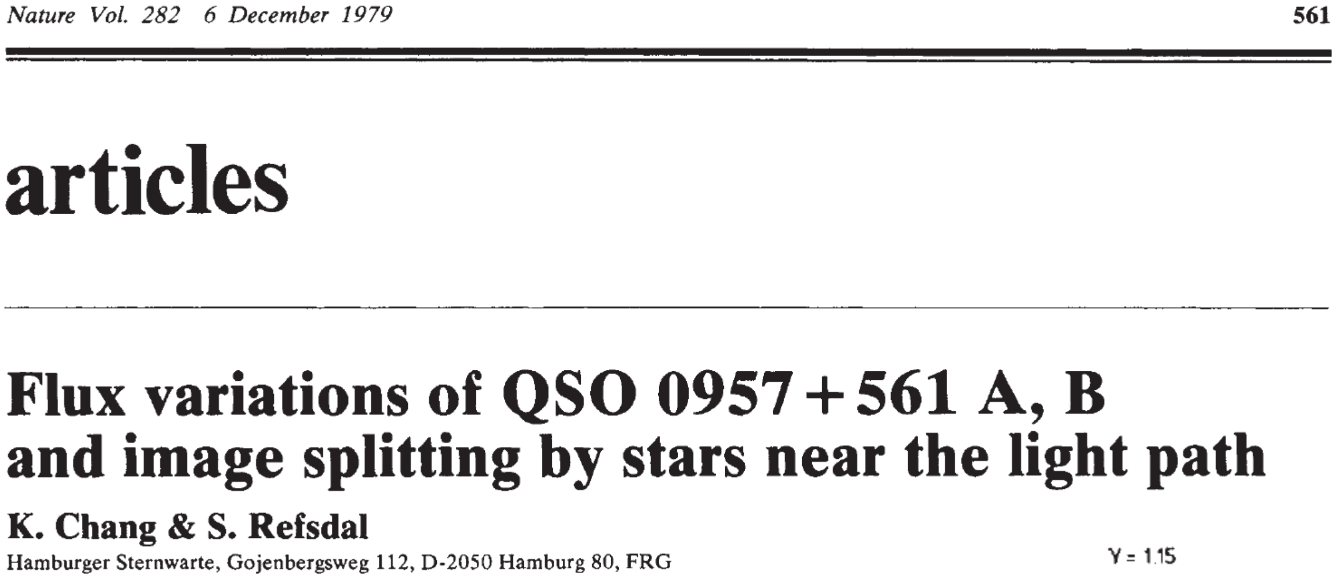
Star-size objects can be magnified by factors of many thousands

Large optical depth of microlensing over a large area near the critical curves.

Perimeter of Crit.Curve > 100”



Early work



Nature *Vol.* *282* *6 December 1979* **561**

articles

Flux variations of QSO 0957+561 A, B and image splitting by stars near the light path

K. Chang & S. Refsdal
Hamburger Sternwarte, Gojenbergsweg 112, D-2050 Hamburg 80, FRG

Chang & Refsdal (1979)

Describes how large amplifications can be obtained if background objects are compact enough.

First time it is shown how microlenses can momentarily demagnify background sources

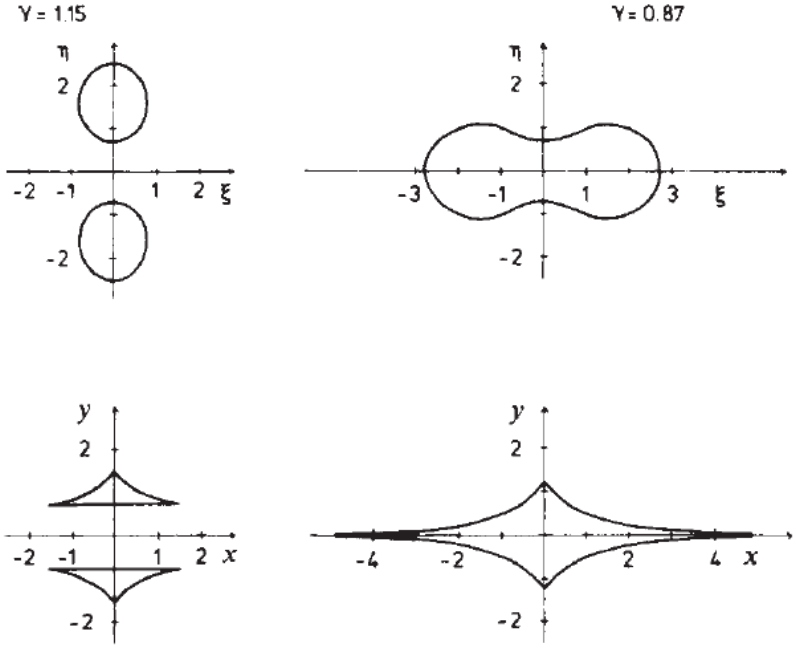
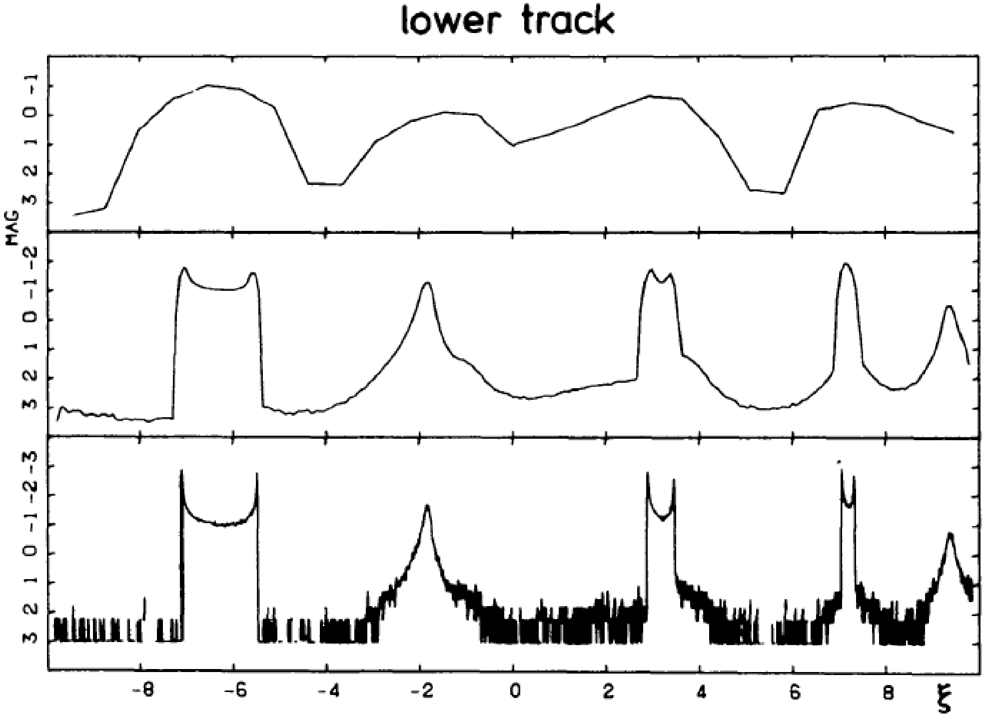


Fig. 2 Critical curves in the deflector plane (ξ, η) and in the observer's plane (x, y) for the cases $\gamma = 0.87$ and $\gamma = 1.15$.

Early work

Kayser, Refsdal & Stebbins (1986)



J. Miralda-Escudé (1991)

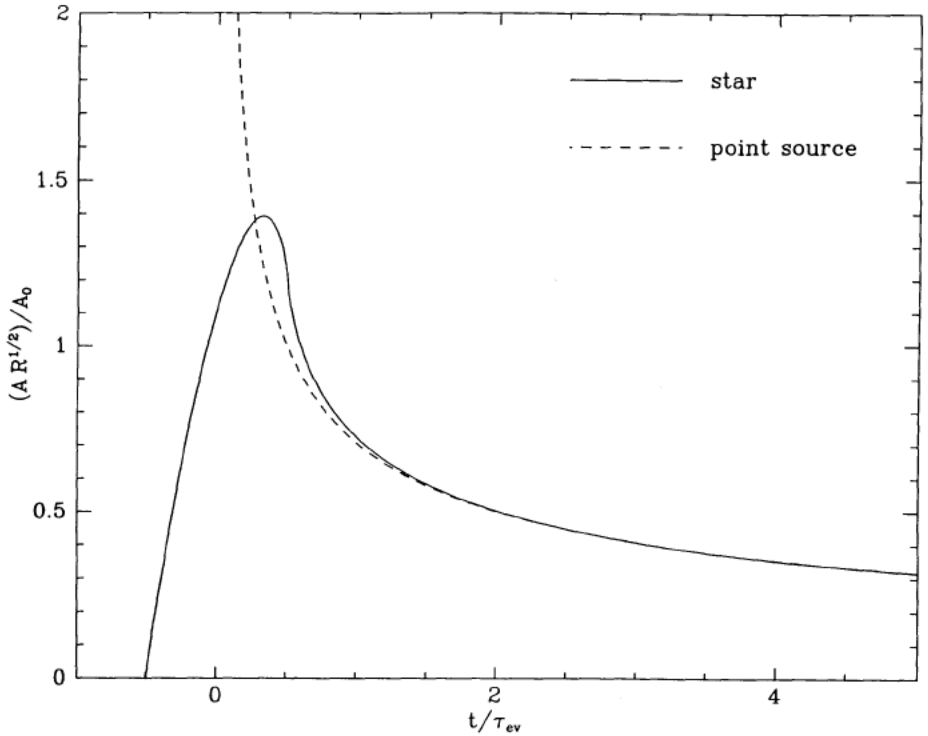


FIG. 2.—Magnification of a star with uniform surface brightness as a function of the time since the center of the star crossed the caustic. Magnification of a point source at the center of the star is also shown. Characteristic time τ_{ev} is given in eq. (12). In 50% of the cases this curve should occur in the reverse order in time.

A field of microlenses can result in complex light curves, involving both magnification and demagnification

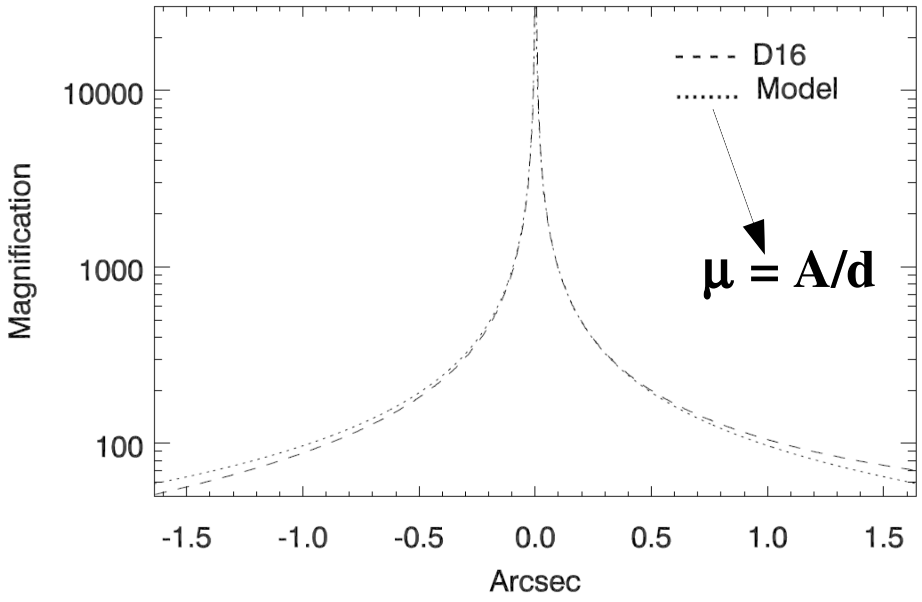
Did not study the particular case of very close distances to the critical curve (computationally very expensive, see also Paczynski's work in the 80's)

Extreme magnifications (>1 million) can be obtained when a star crosses behind a smooth cluster caustic

Shows how images disappear behind a smooth caustic

Did not consider microlenses

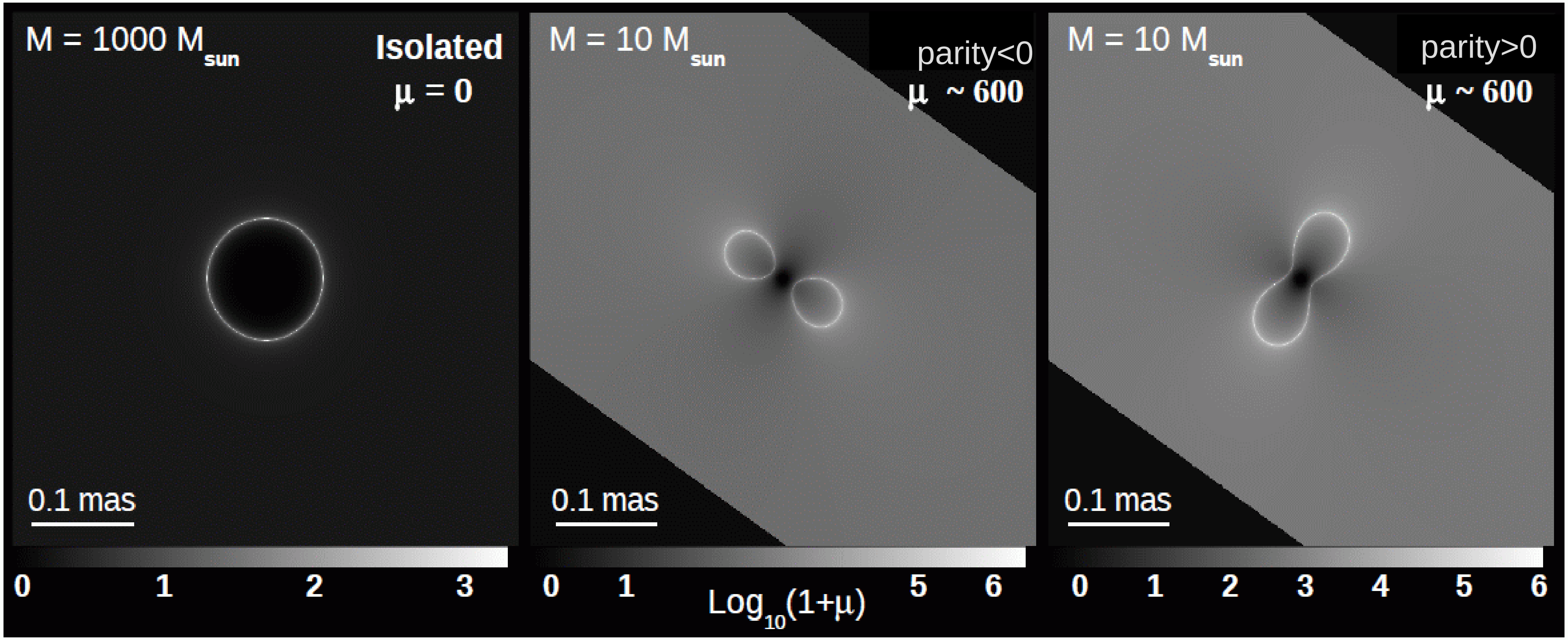
Magnification of small microlenses near a critical curve (Diego et al. 2017)



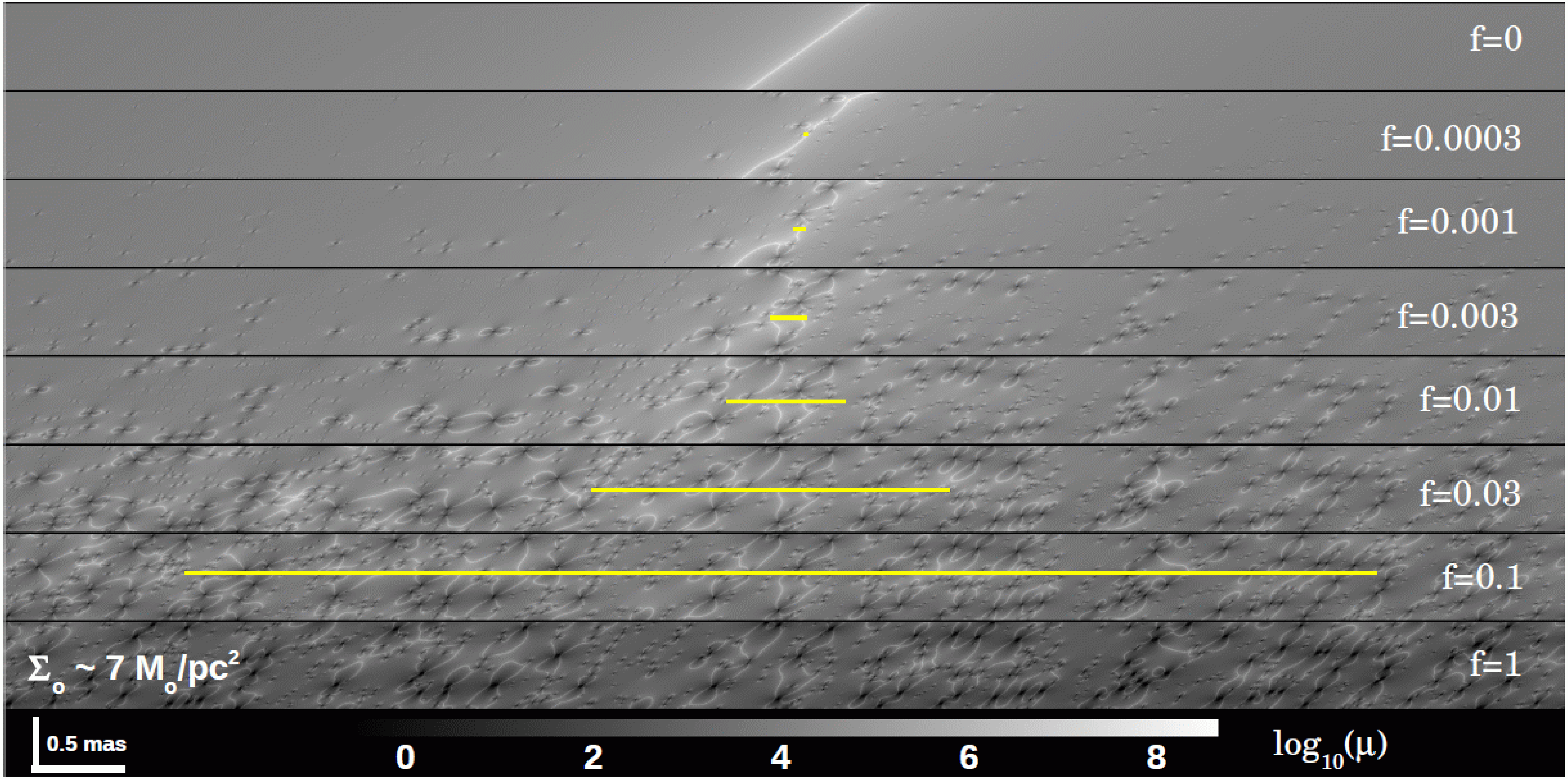
The lensing distortion from a microlenses in the lens plane near the critical curve is magnified by a factor proportional to the magnification of the macrolens (cluster).

Very small microlenses can produce measurable changes in the observed flux of a distant bright and compact object (star) if they are close enough to the cluster critical curve

$$\theta_E = \sqrt{\frac{M\mu_t}{\pi\Sigma_{\rm crit}}}.$$



Disruption of critical curves by ICL stars

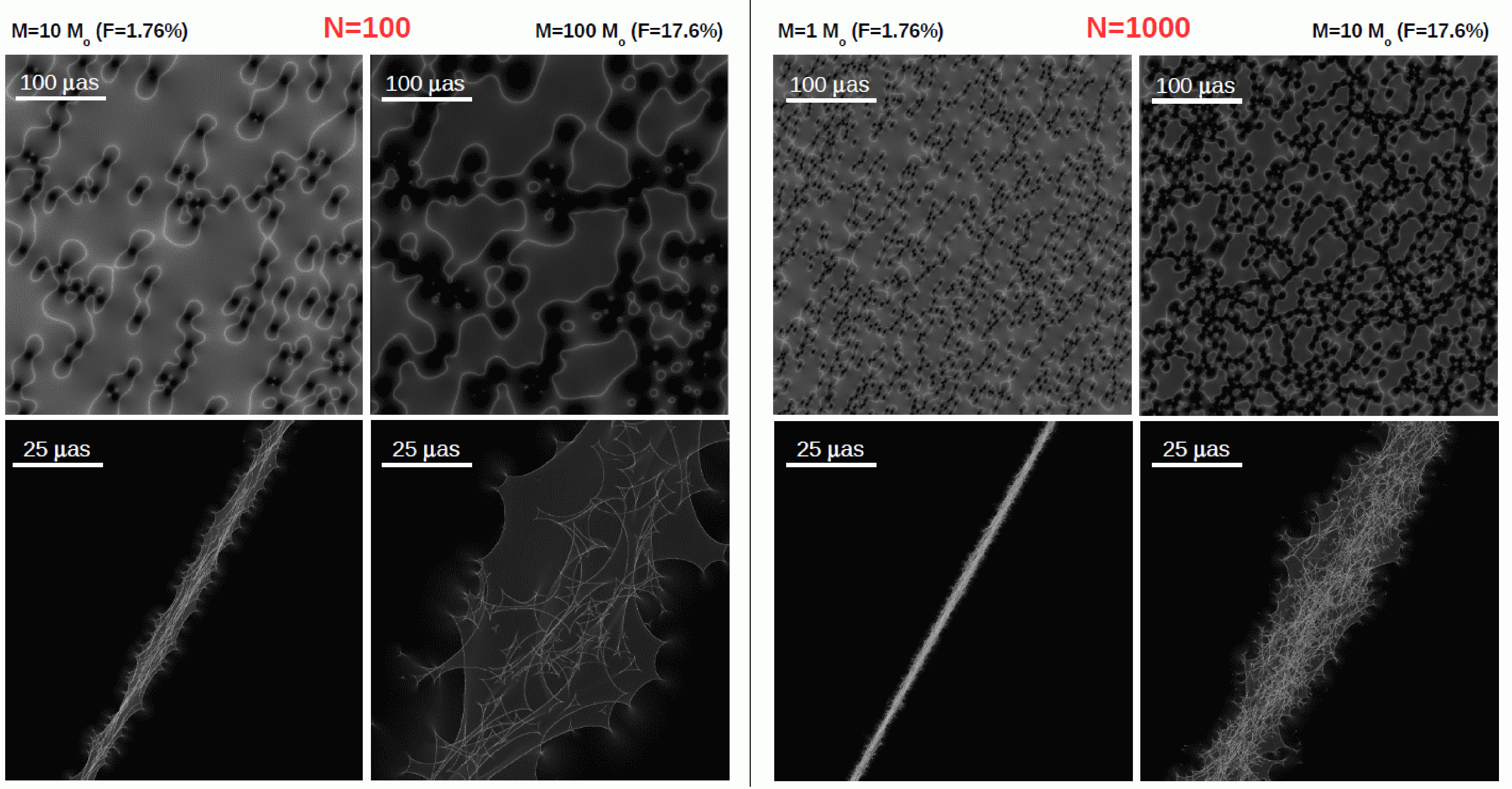


Magnification gets redistributed over a wide region.

Instead of a single very bright peak we would see many smaller peaks.

Total observed flux integrated over over long times is conserved.

Disruption of critical curves by ICL stars



Caustic web sensitive to number and mass of microlenses.

The heavier the microlenses, the wider the microcaustic region.

Smooth caustics ONLY if microlenses are not massive.

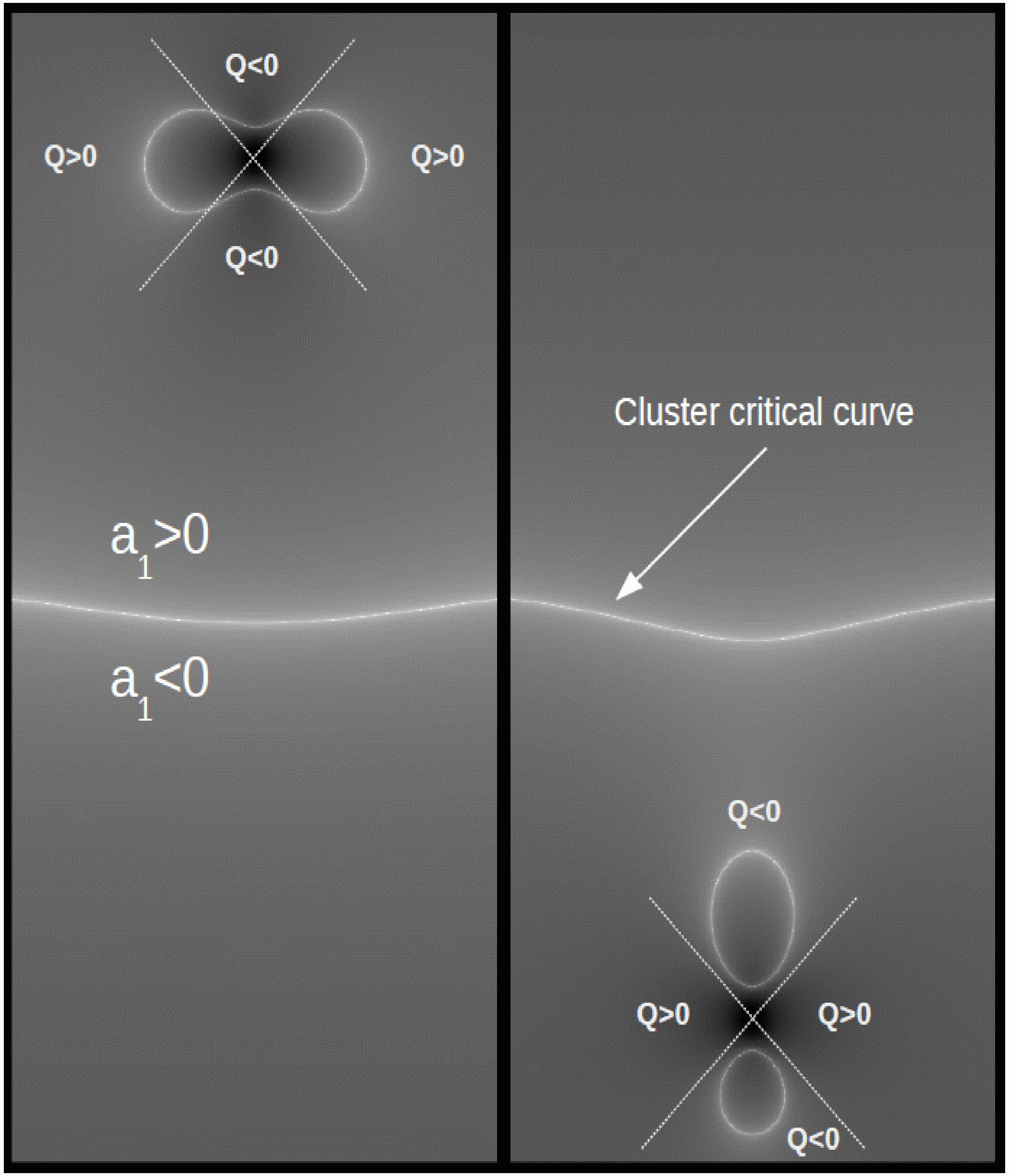
Events can be produced thousands of years before images disappear.

Microlenses near cluster Caustics: Lens equation.

Critical curves (and their corresponding caustics) depend on the “parity”.

On the side with positive parity, counterimages are always magnified by large factors

On the side with negative parity, counterimages can have small magnifications and not be observed



$$\beta = \begin{pmatrix} (x+x_o)/\mu_r \\ (y+y_o)^2/r_E \end{pmatrix} - r_e^2 \begin{pmatrix} x/r^2 \\ y/r^2 \end{pmatrix},$$

Cluster

Microlens

Eq. of the micro-critical curve

$$r^2 = r_e^2 \frac{(a_2-a_1)Q}{2a_1a_2}\left[1 \pm \sqrt{1+\frac{4a_1a_2}{(a_2-a_1)^2Q^2}}\right]$$

Some properties of near-caustic events

Non-symmetric light curves depending on the image parity.
Negative parity side has periods of low magnification (years) where macroimage *disappears*

Chang & Refsdal 1979

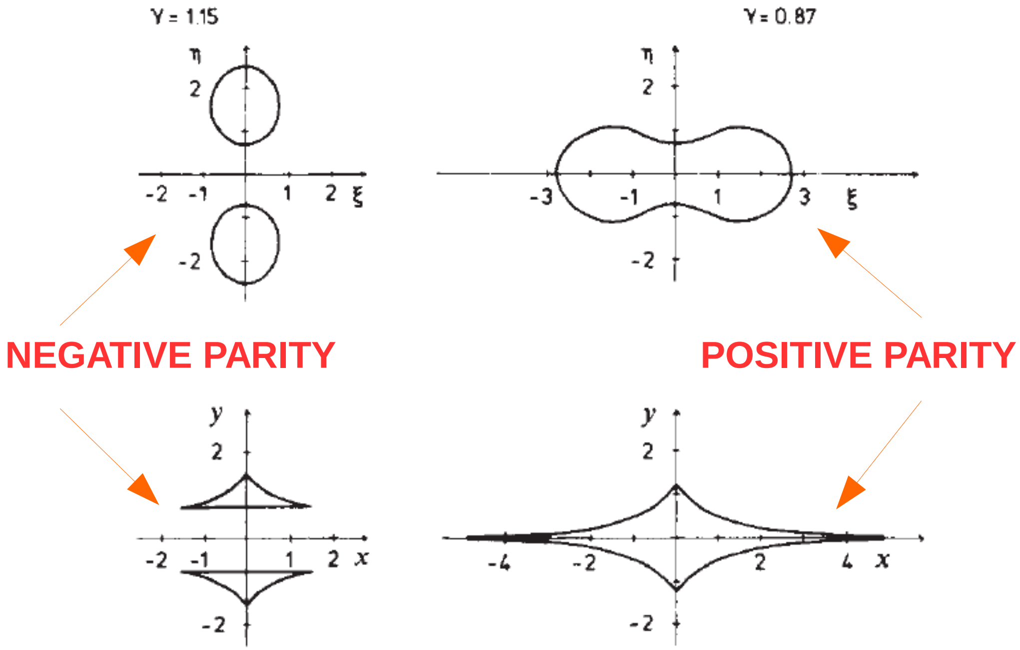
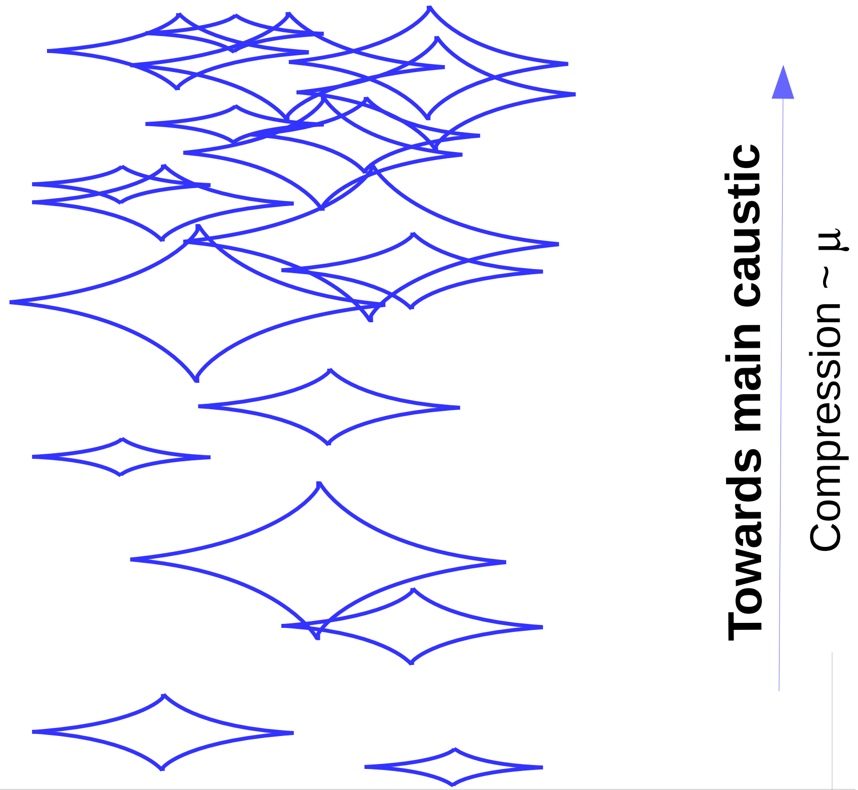


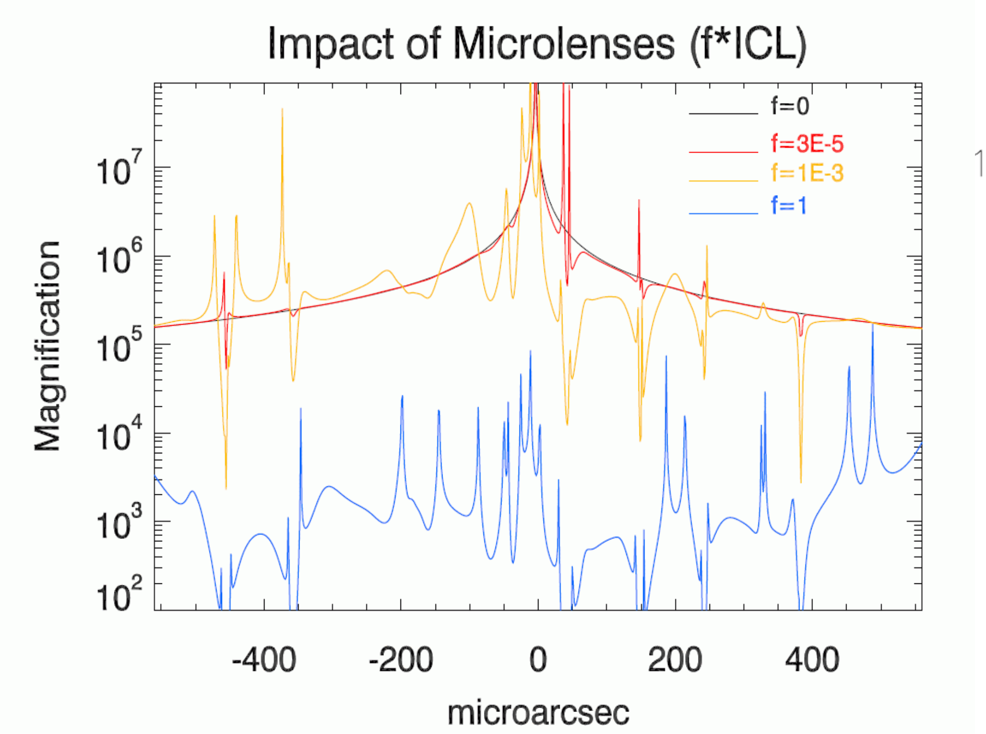
Fig. 2 Critical curves in the deflector plane (ξ, η) and in the observer's plane (x, y) for the cases $\gamma = 0.87$ and $\gamma = 1.15$.

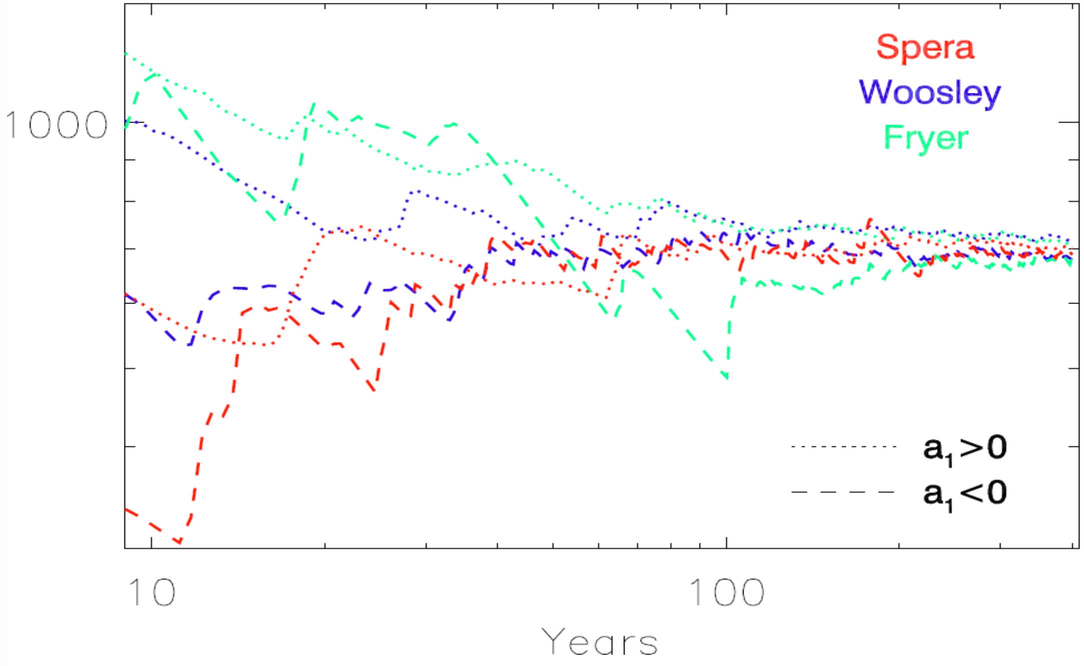
Superluminal apparent speed
The closer to the critical curve (caustic) the more substructure that can be probed.

$$v_{\rm obs} = \frac{d\theta}{dt} = \frac{\Theta}{2\mu_o} v_p \mu,$$



Some properties of near-caustic events



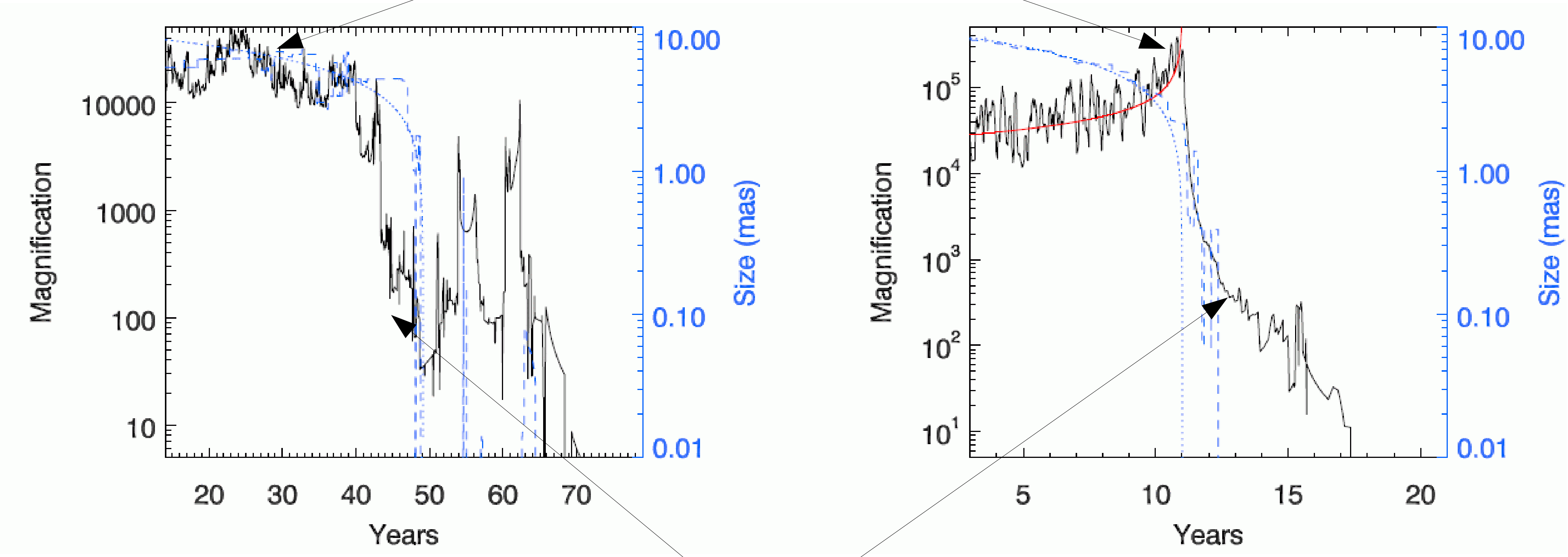


Flux conservation
Reduced maximum magnification but similar total (i.e over time) magnification.

Many-vs-one.
Increased rate of events if background object is bright enough.

The death (or birth) of Icarus

Fewer microlenses → Higher maximum magnification

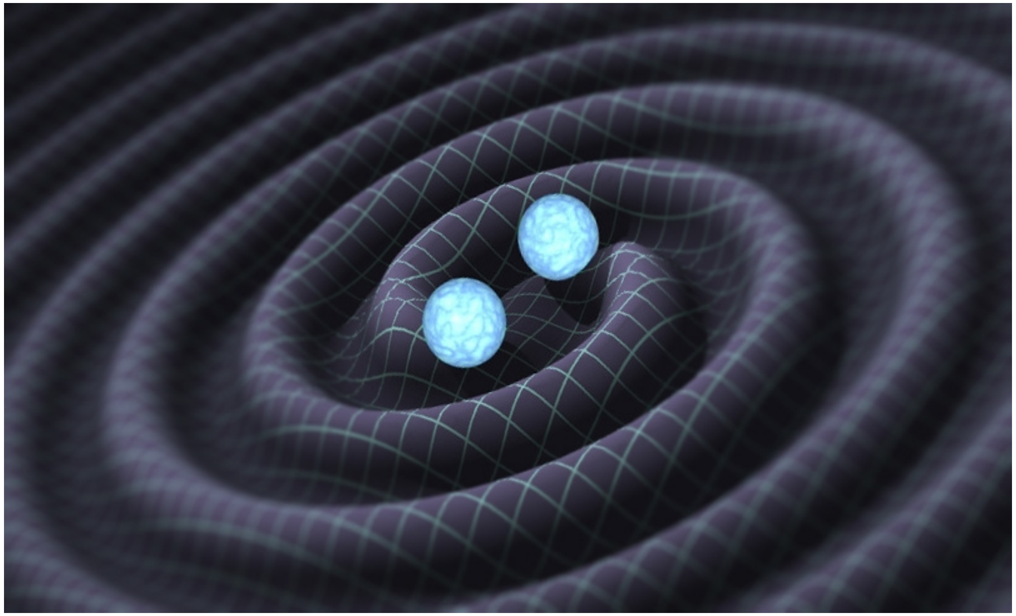


ICL

ICL/30

“Ringdown” very sensitive to substructure

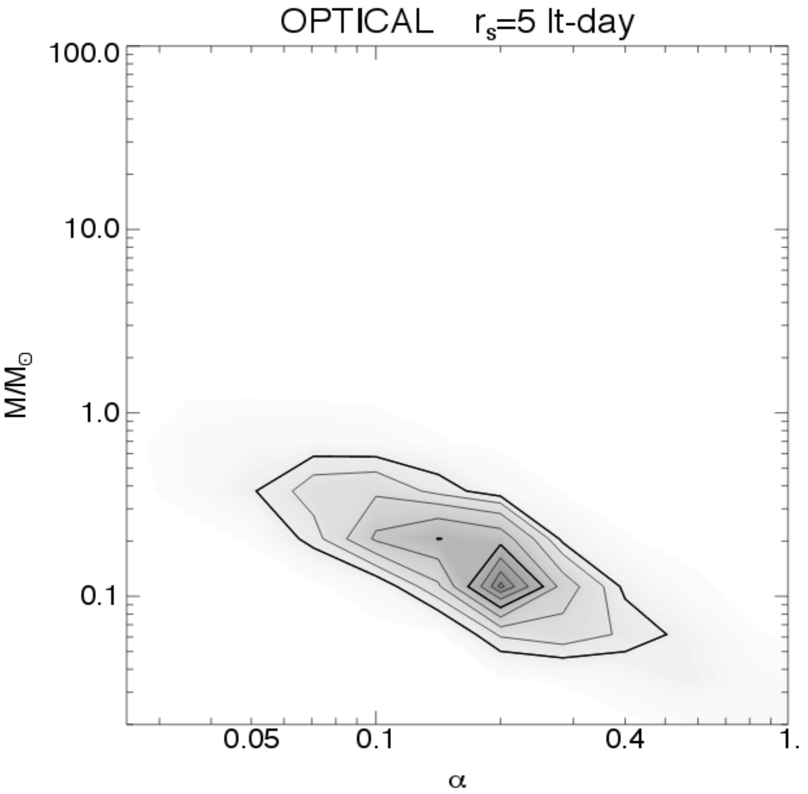
Can we constrain the number of LIGO 30 Msun BH/PBH?



LIGO events seem to favour ~10 times more massive BH (~30 Msun) than expected.

The fraction of BH in the range of ~30 Msun seems to be constrained to be a fraction (<20%) of the dark matter content.

Can we improve on these limits by monitoring a bright star crossing a cluster caustic ?

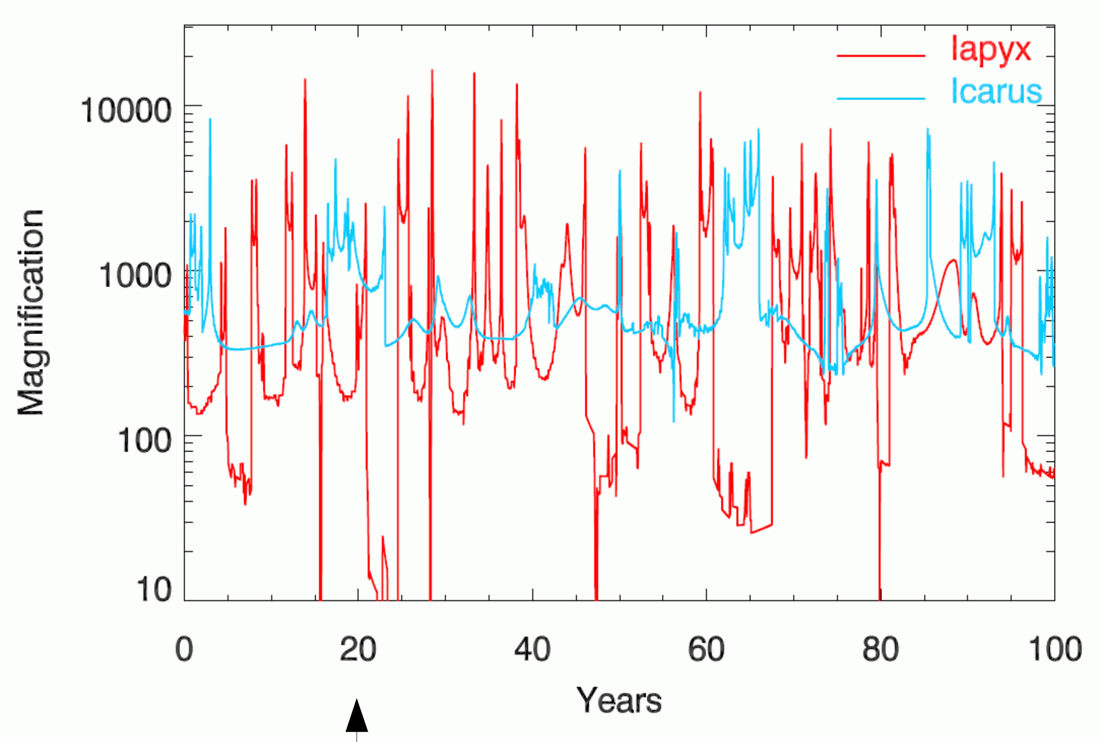


BUT see Mediavilla et al. 2017
PBH with ~ 30 Msun can only account for a few percent of dark matter **IF** accretion discs are a few light-days.

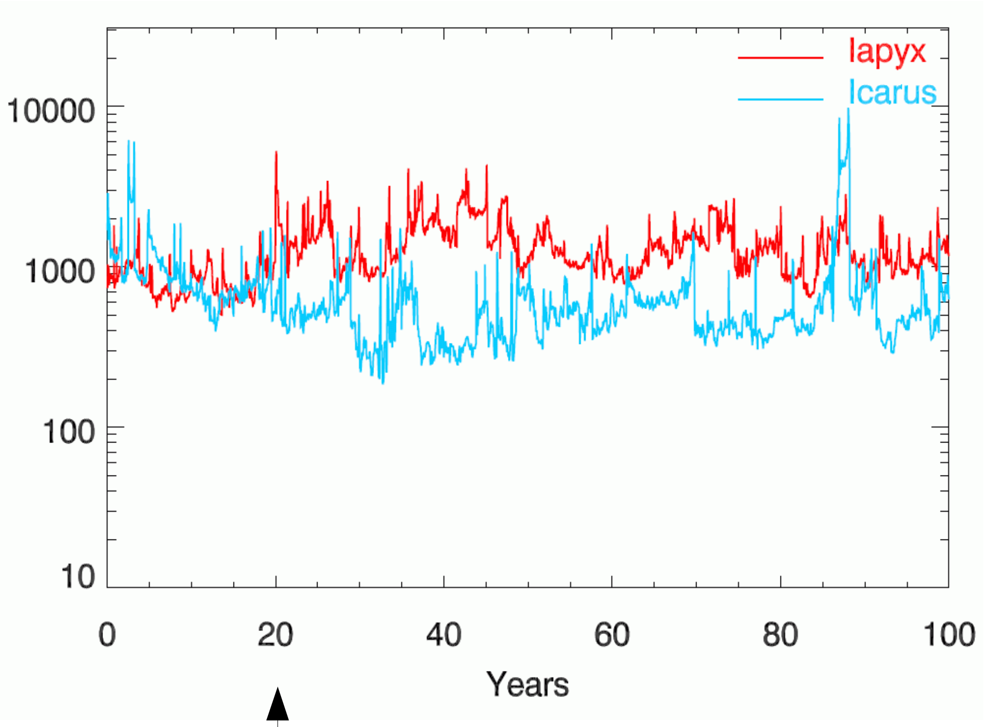
Can we constrain PBH or LIGO massive BH?

Light curves map the underlying substructure near the critical curves.

ICL



ICL+PBH(10%)

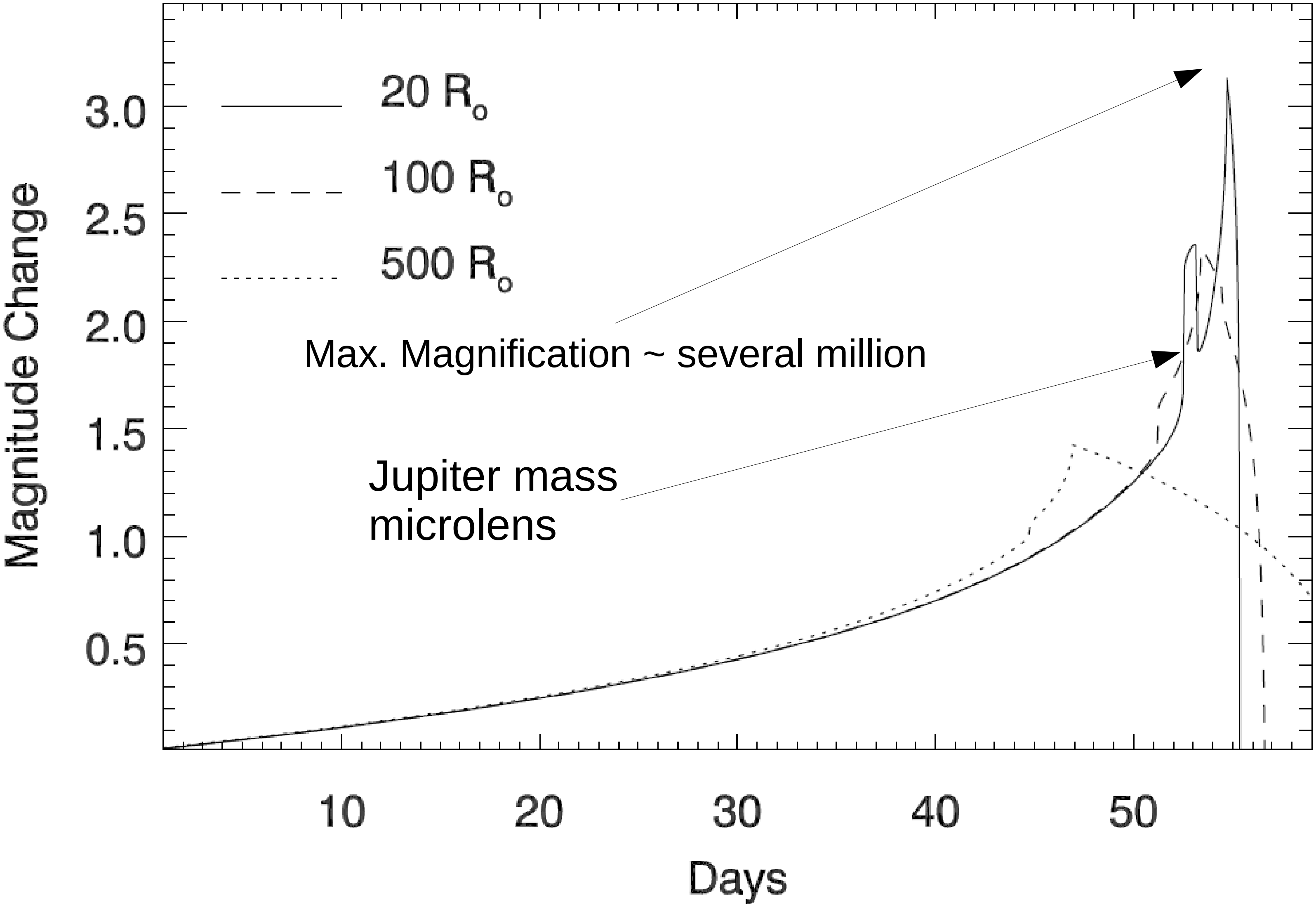


More consistent with observations

Less consistent with observations

The future. Where is the limit?
Light-curve should be sensitive to planet-size masses

with the permission of the ICL stars



Max. Magnification ~ several million

Jupiter mass microlens

Sensitive to planet masses at cosmological distances (but beware of ICL)

IT'S MOVIE TIME !

https://cosmicspectator.org/2017/06/30/dark-matter-under-the-microscope/