Ultra high magnification microlensing

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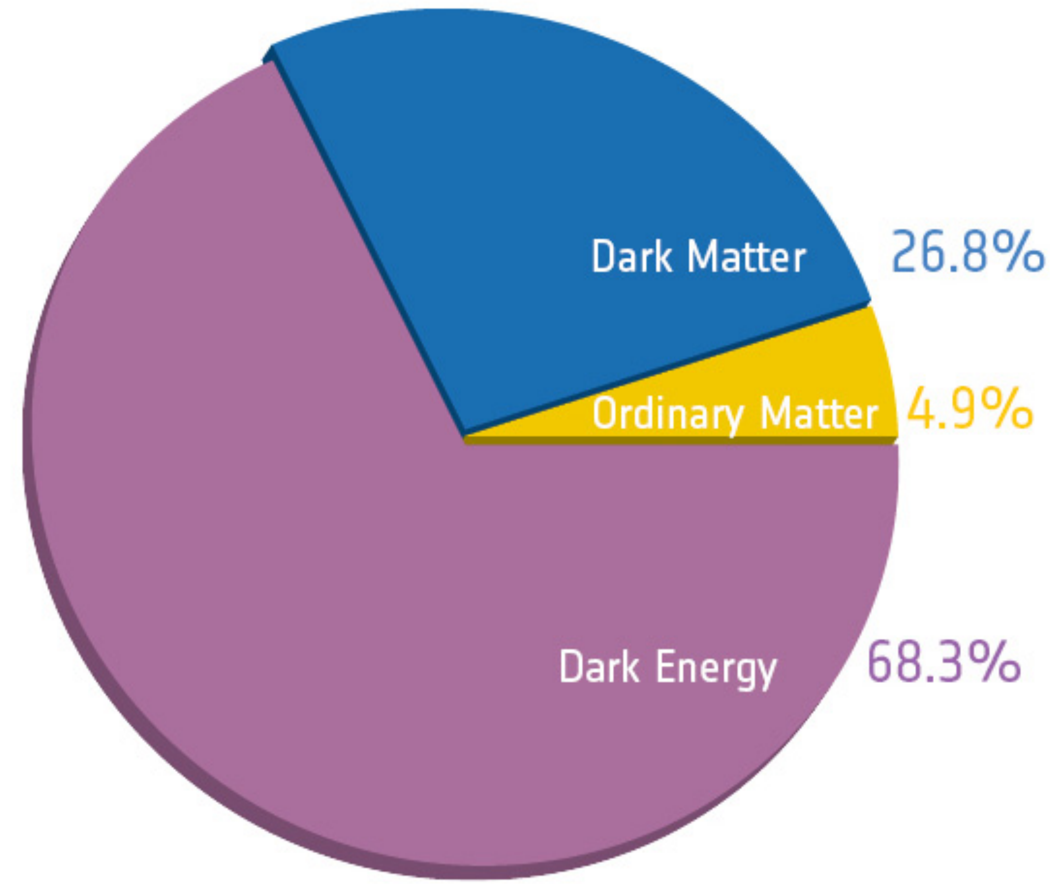
Dark Matter (DM)

- 1/4 of the mass of the Universe is composed of dark matter
- a lot of evidence from CMB, clusters, galaxies,..
- but its true nature is still unknown

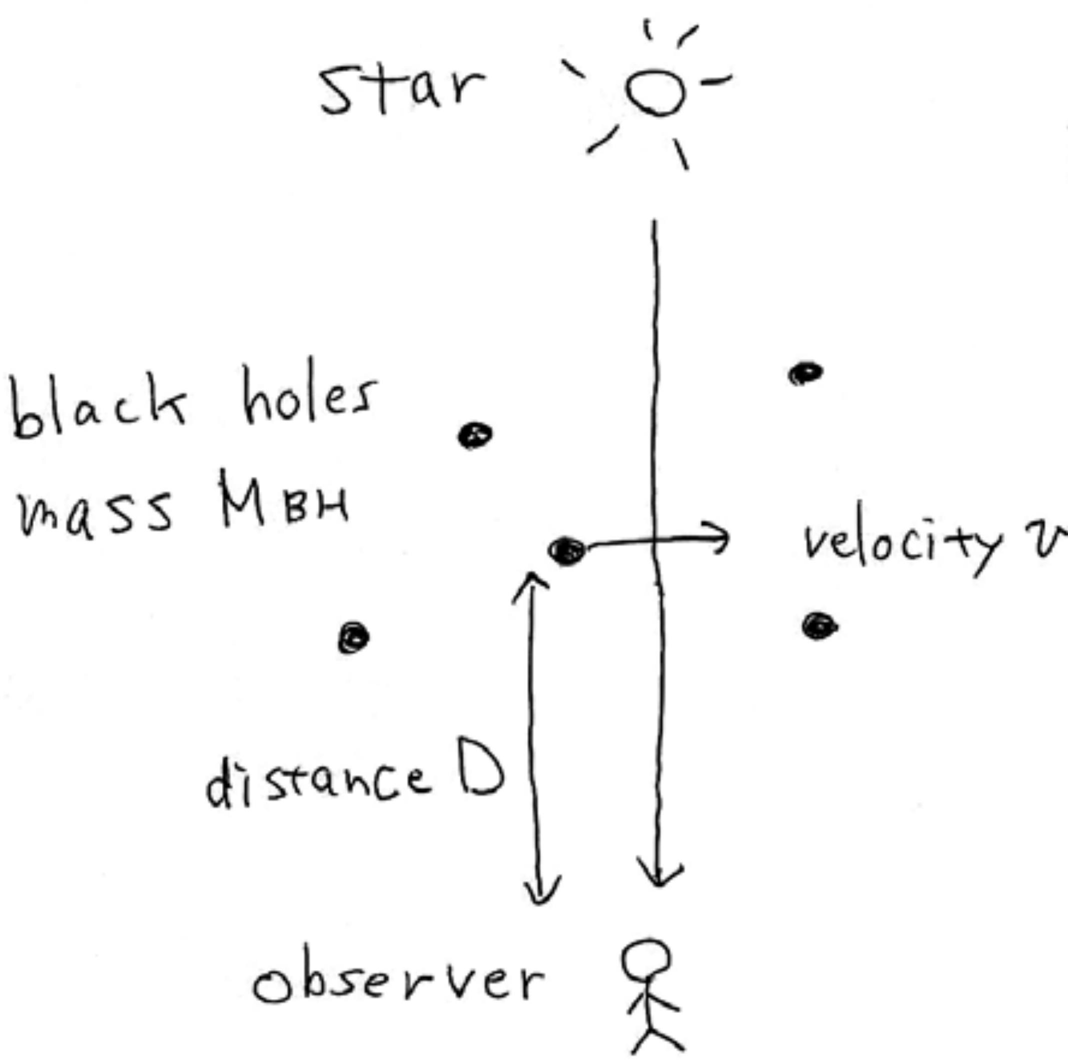


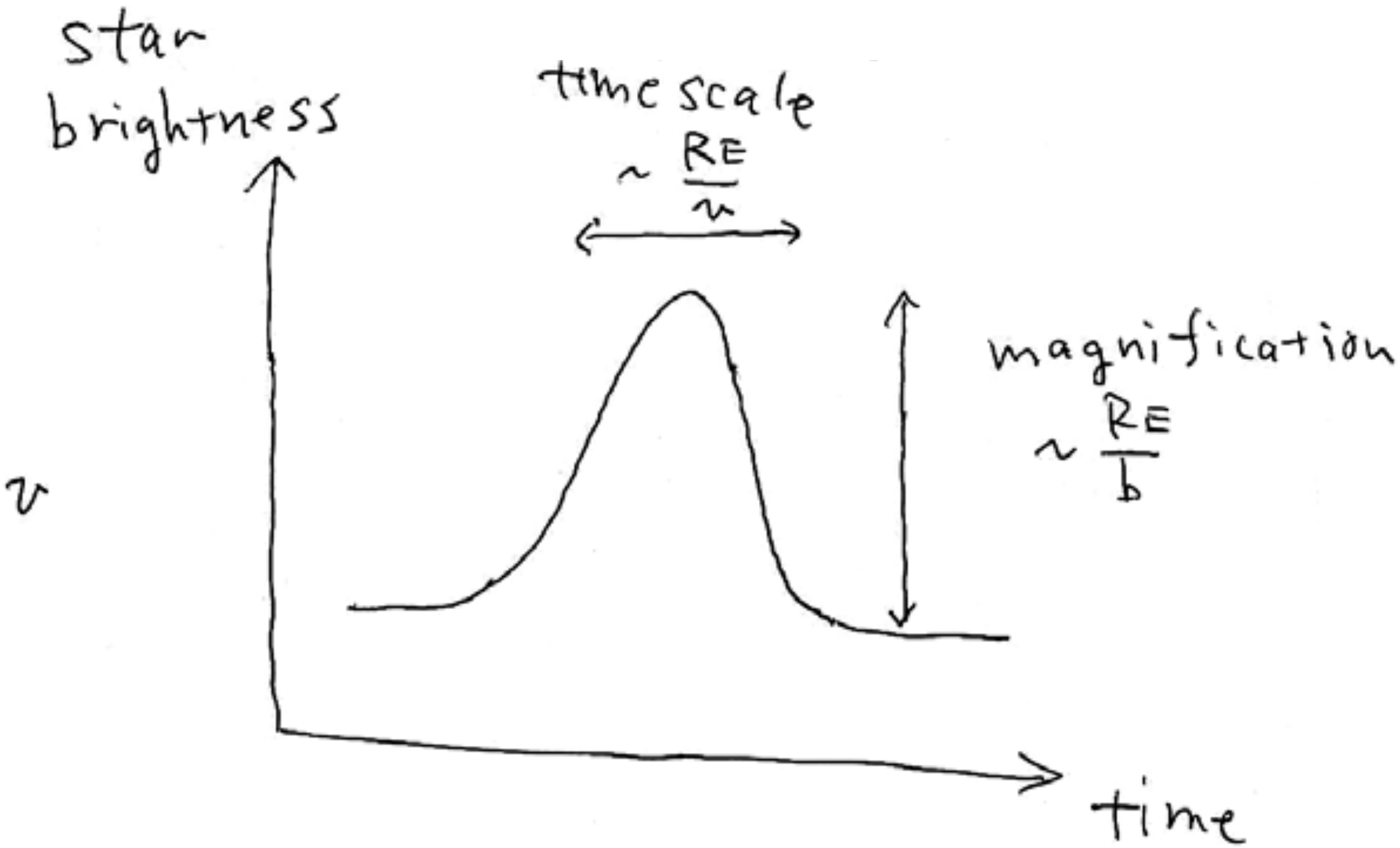
(ESA/Planck)

➡ { unknown particle? (WIMP, axion, …)
unknown compact objects? (PBH, …)

Microlensing

- brightening of a distant star due to gravitational lensing by a foreground compact object (DM)





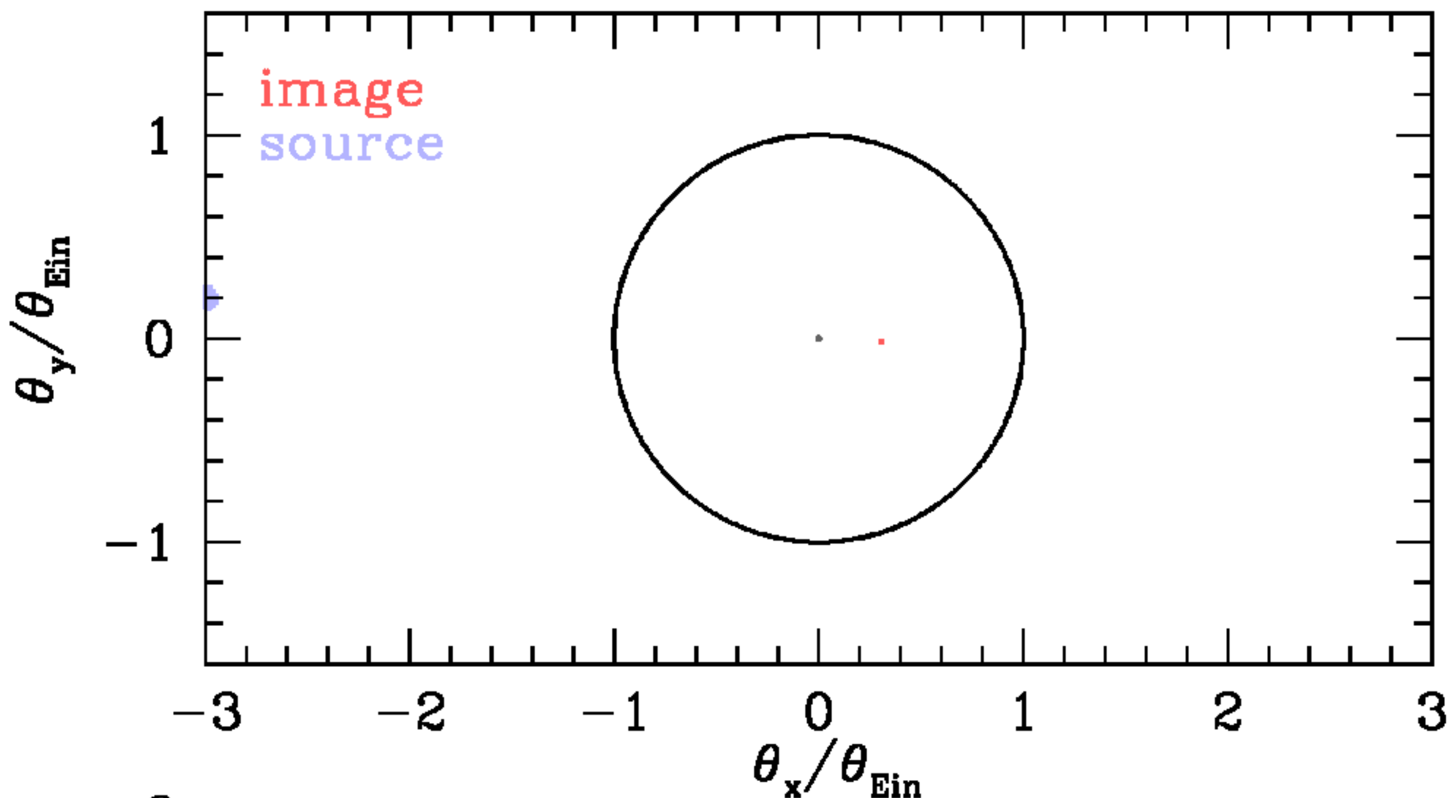
(MO, Kavli IPMU news No. 38)

simulated by *glafic*

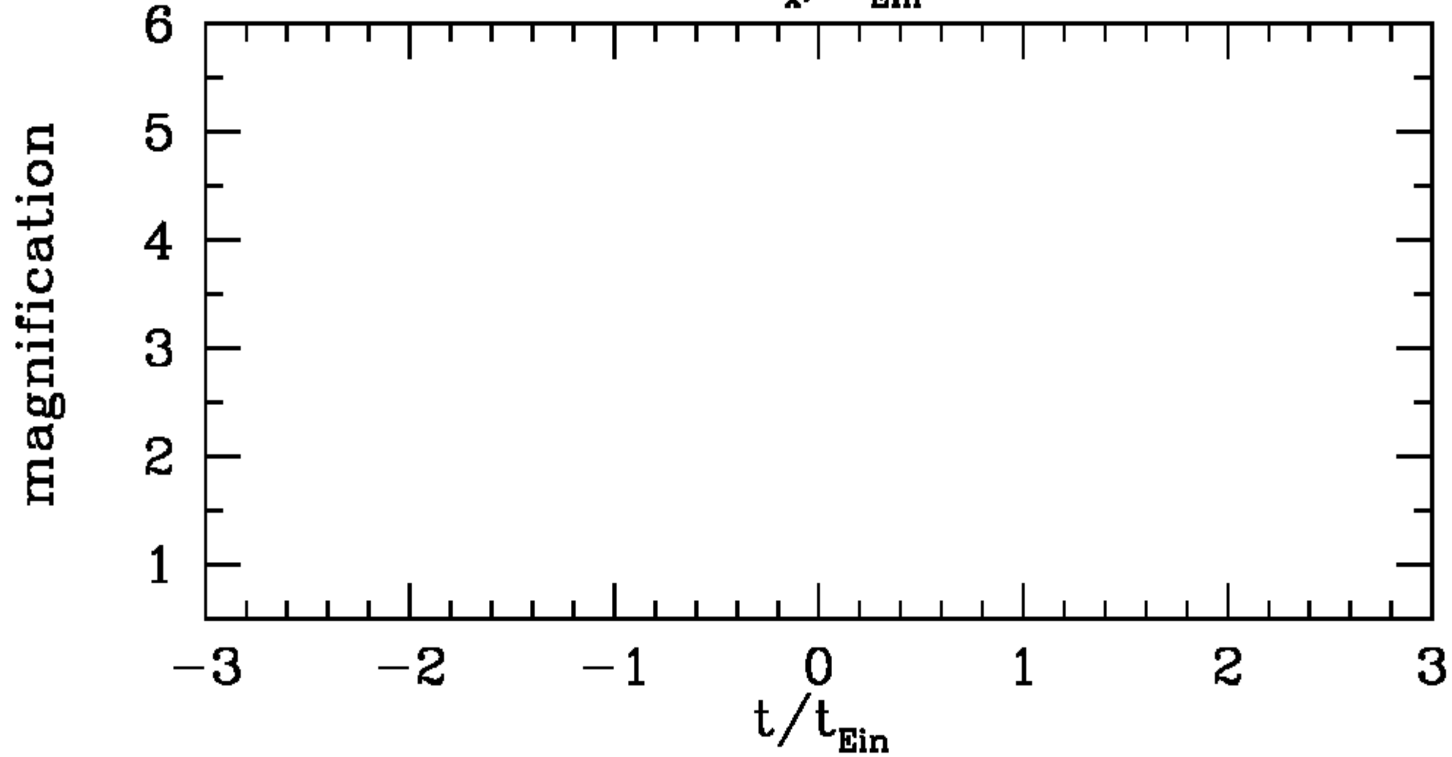
Microlensing simulation

image:
we observe

source:
we would observe if no lensing effect



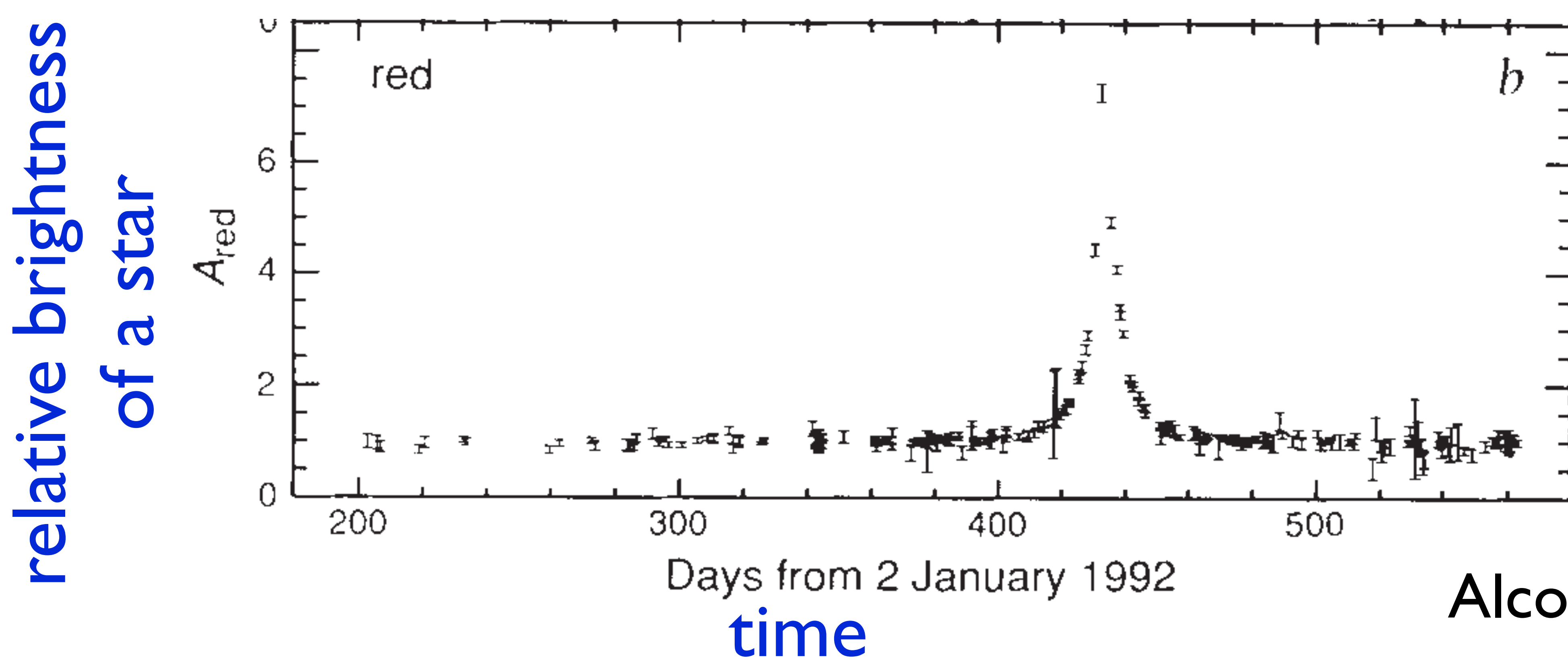
← cannot resolve this due to lack of resolution of observations



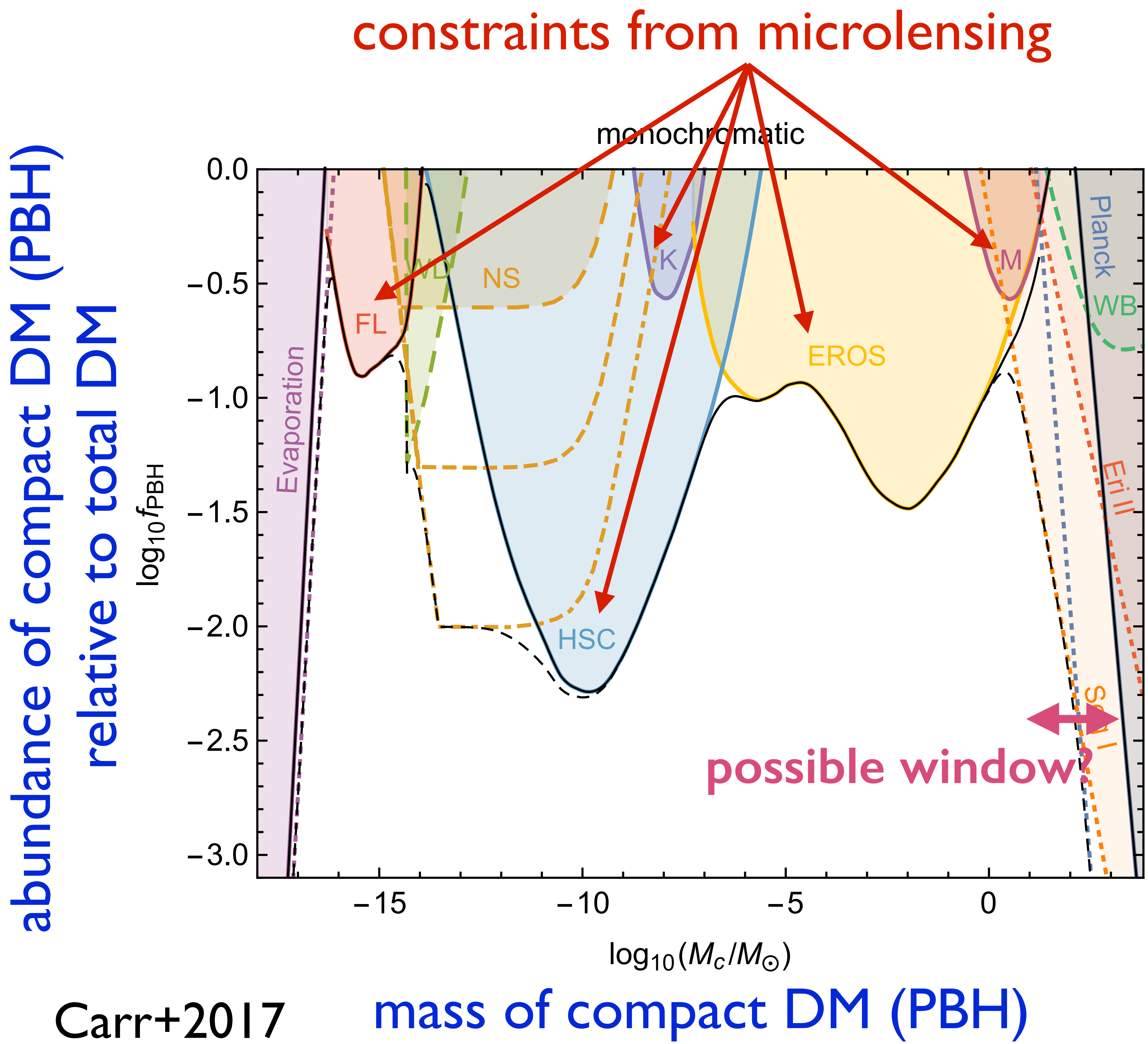
← observe lensing effect via time evolution of brightness of a star

An example of microlensing

- first discovery of microlensing in 1993 from monitoring observations of >10M stars in LMC
- symmetric single peak light curve indicates that this is a real microlensing event



Alcock+ (1993)



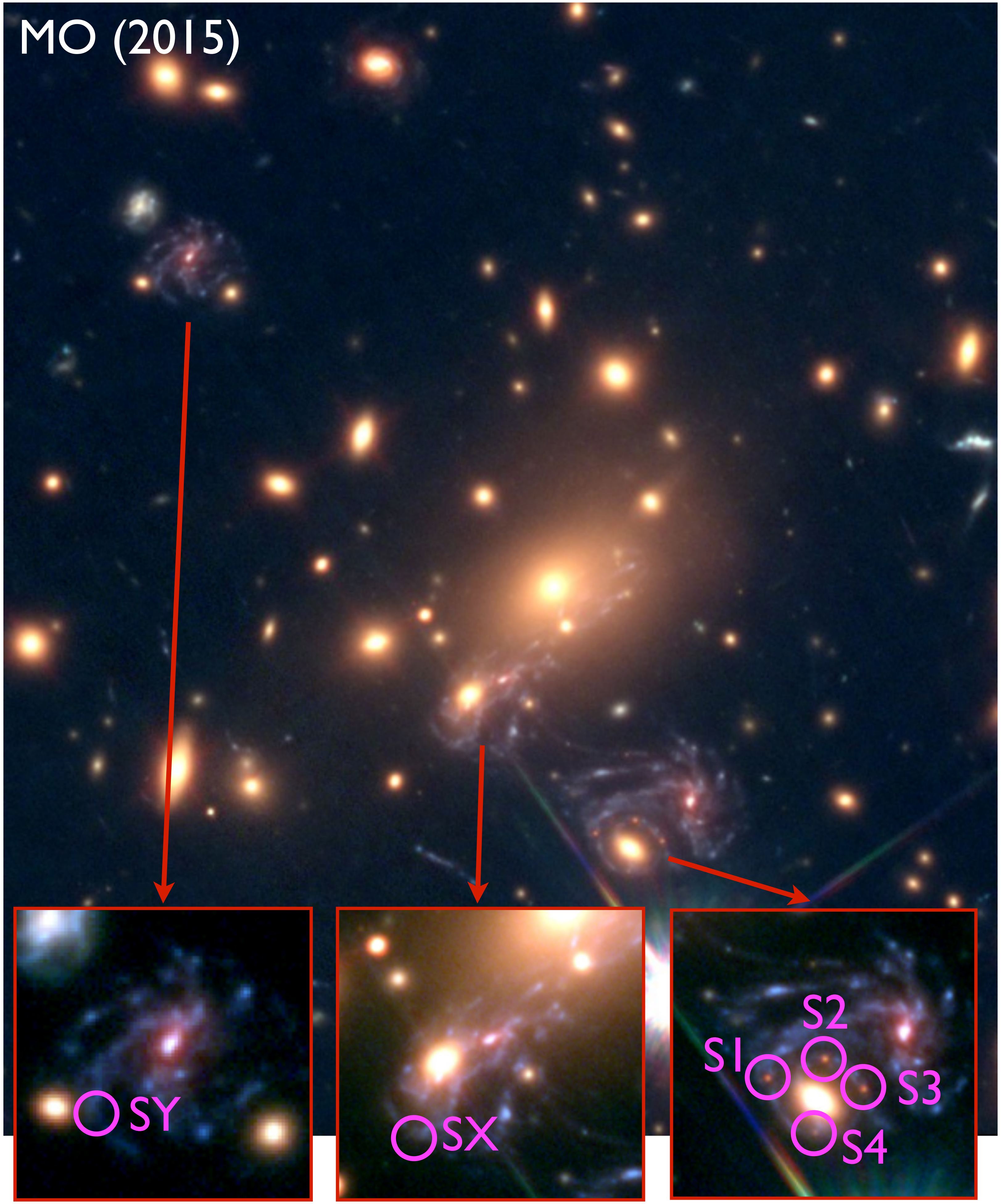
Carr+2017

no discovery of microlensing by compact DM
→constraints on its abundance

possible window to explain all dark matter by compact DM at $M \sim 10\text{-}100 M_{sun}$
(~LIGO BH masses)

Discovery of new microlensing

- recently new fast transient was discovered at the center of a massive cluster of galaxies observed in Hubble Frontier Fields (HFF)
- interpreted as a highly magnified individual star at z=1.49 (magnifications >1000)
- star located *very far* compared with previously known microlensing events of stars (>Gpc, compared with ≲Mpc)
- this opens a new opportunity to constrain compact DM scenarios!



SY (~17 years ago) SX (~1 year later) S1−S4 (ongoing)

SN Refsdal

multiply imaged supernova in HFF

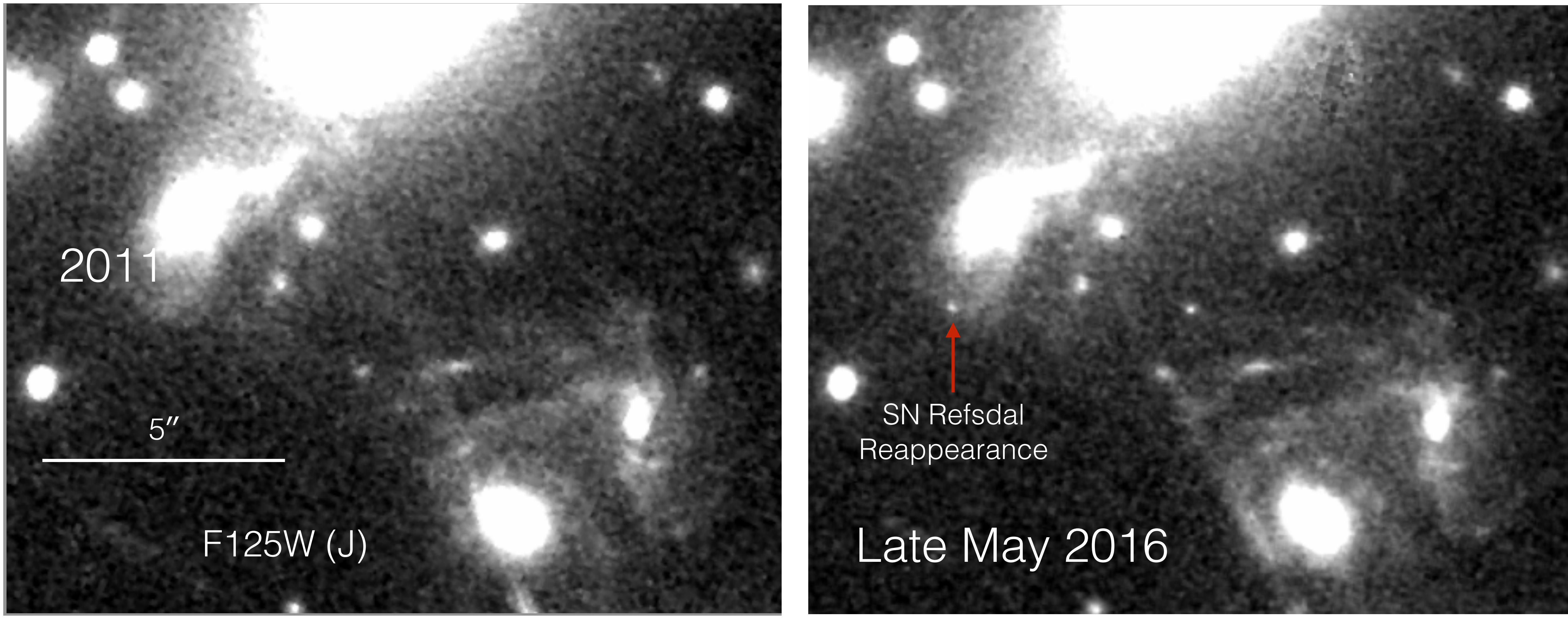
first discovery of *resolved* SN multiple images to measurer time delays

5th image detected at the right time and place as mass models predict

(MO 2015; Treu+ 2016)

Kelly, .., MO+, arXiv:1706.10279

Discovery of Icarus



(cluster MACSJ1149)

Kelly, .., MO+, arXiv:1706.10279

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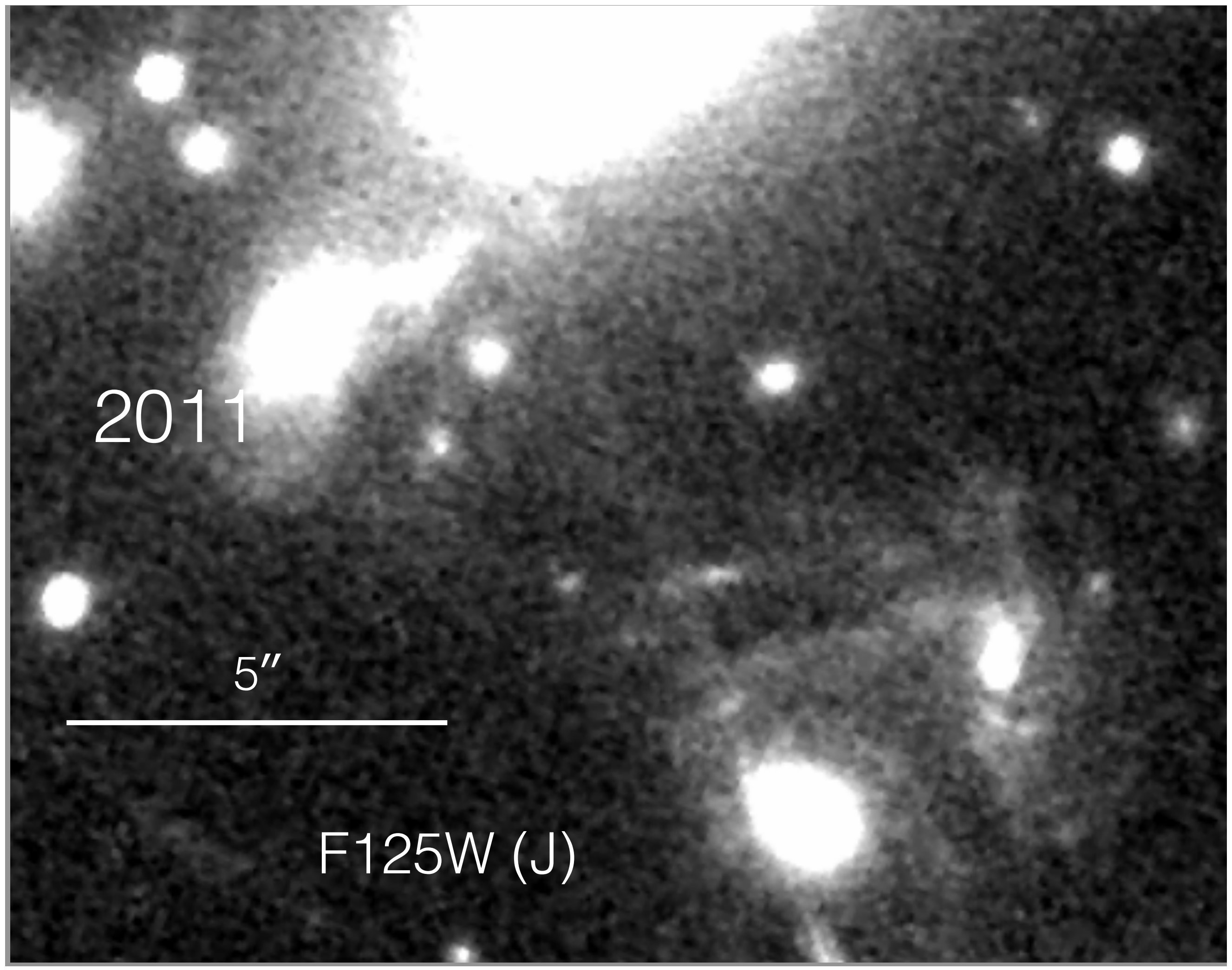

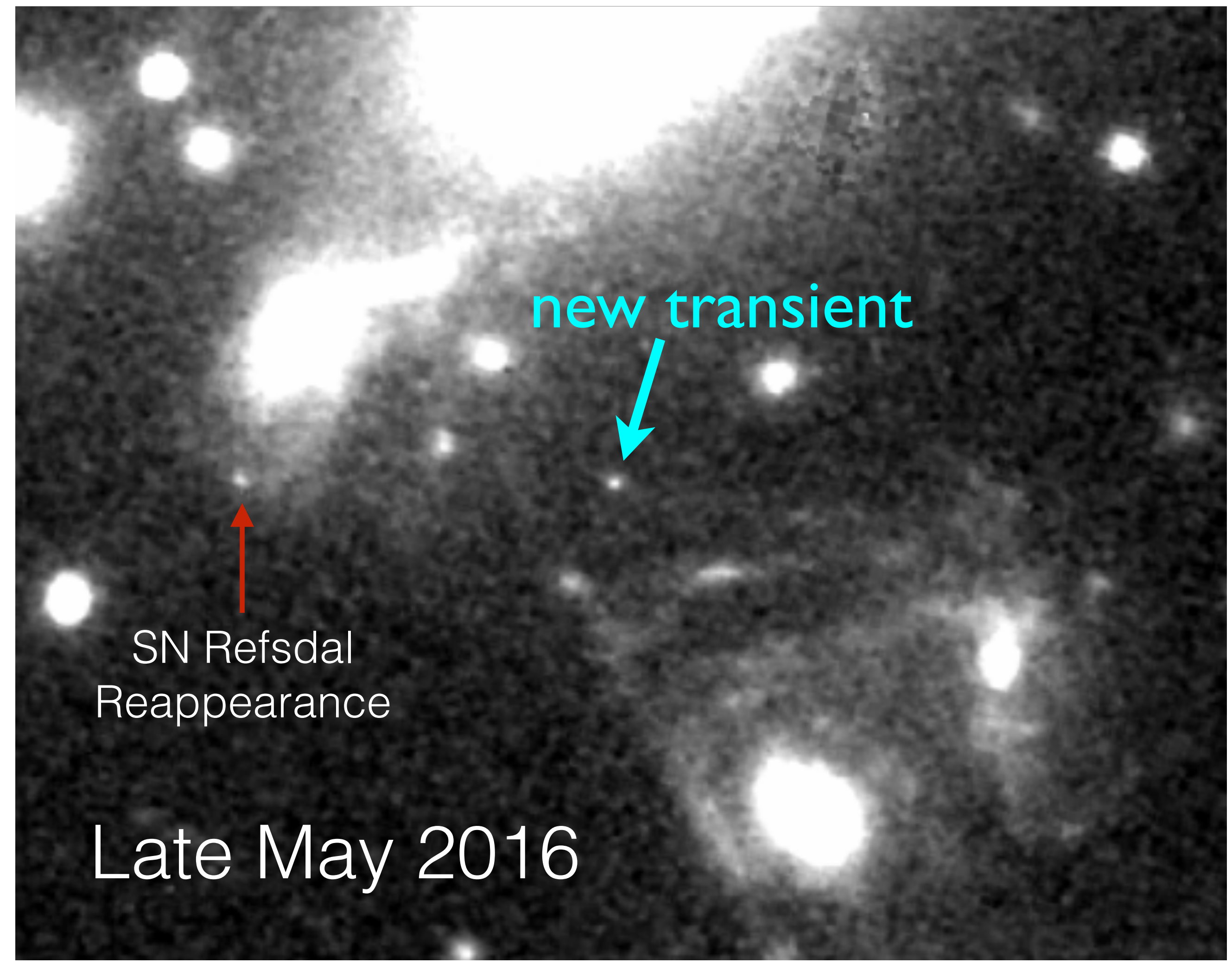

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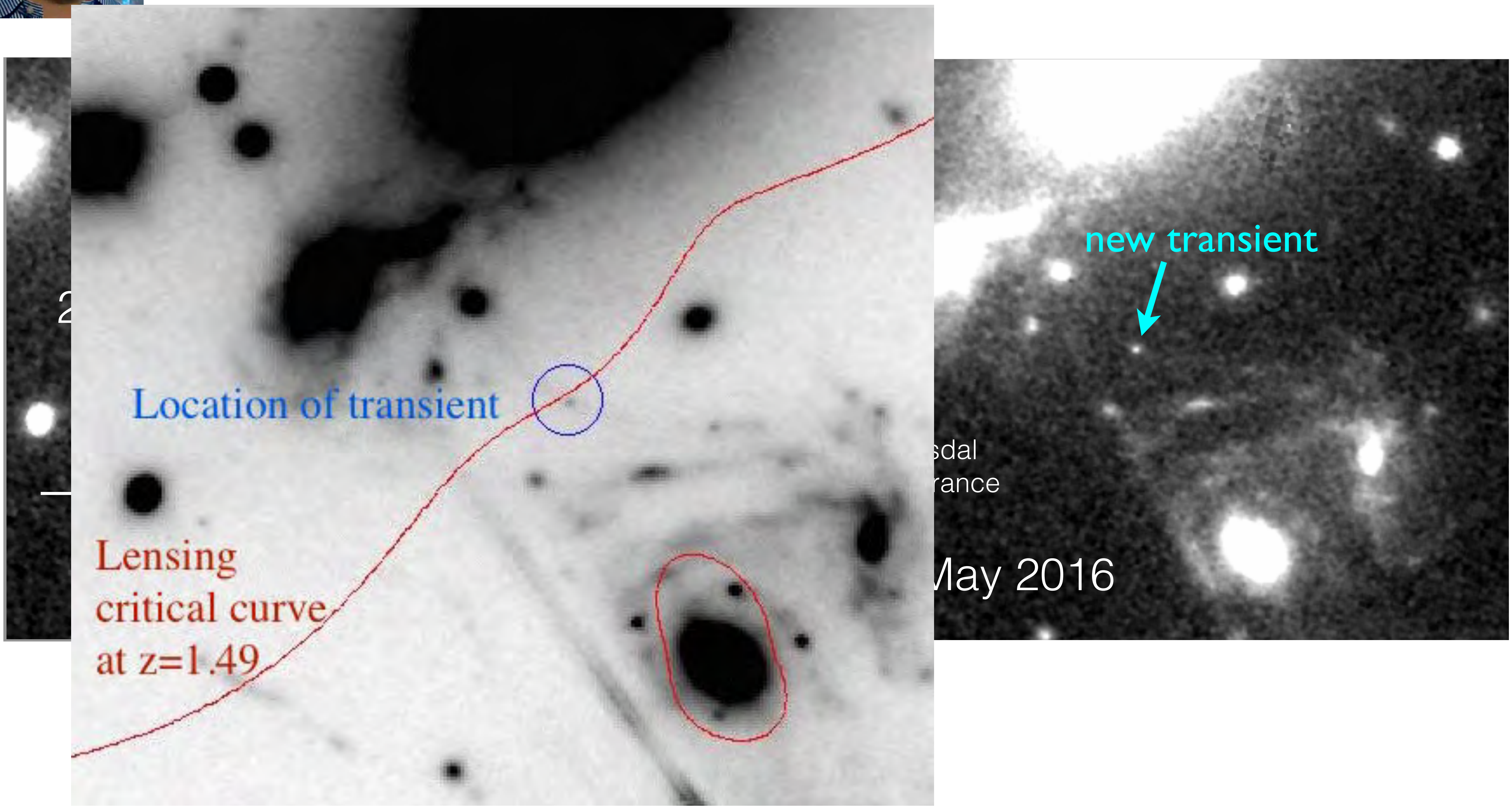

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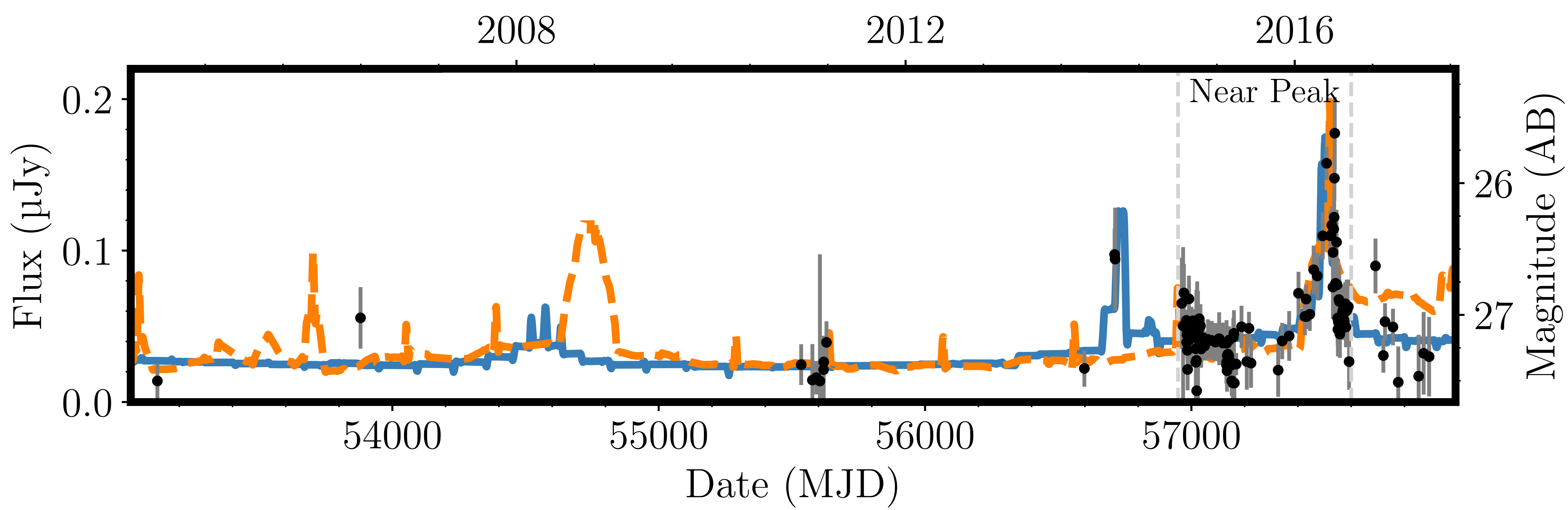
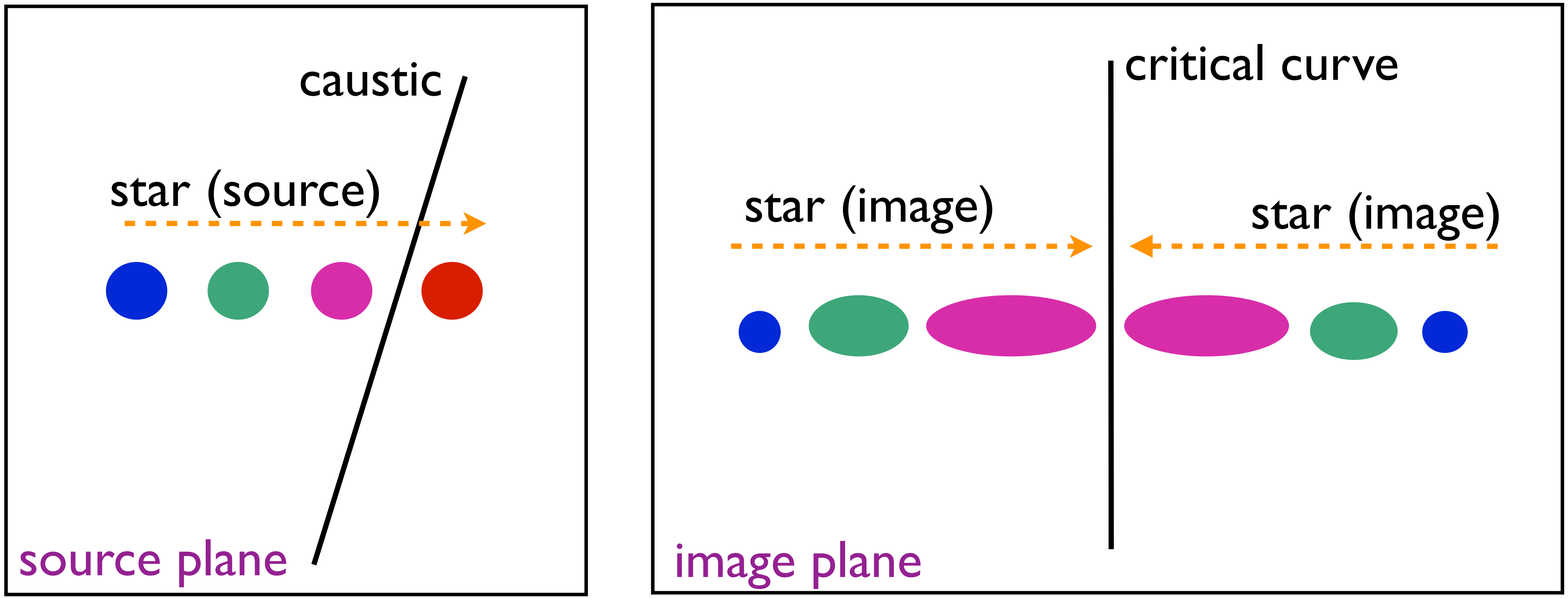
Light curve of Icarus



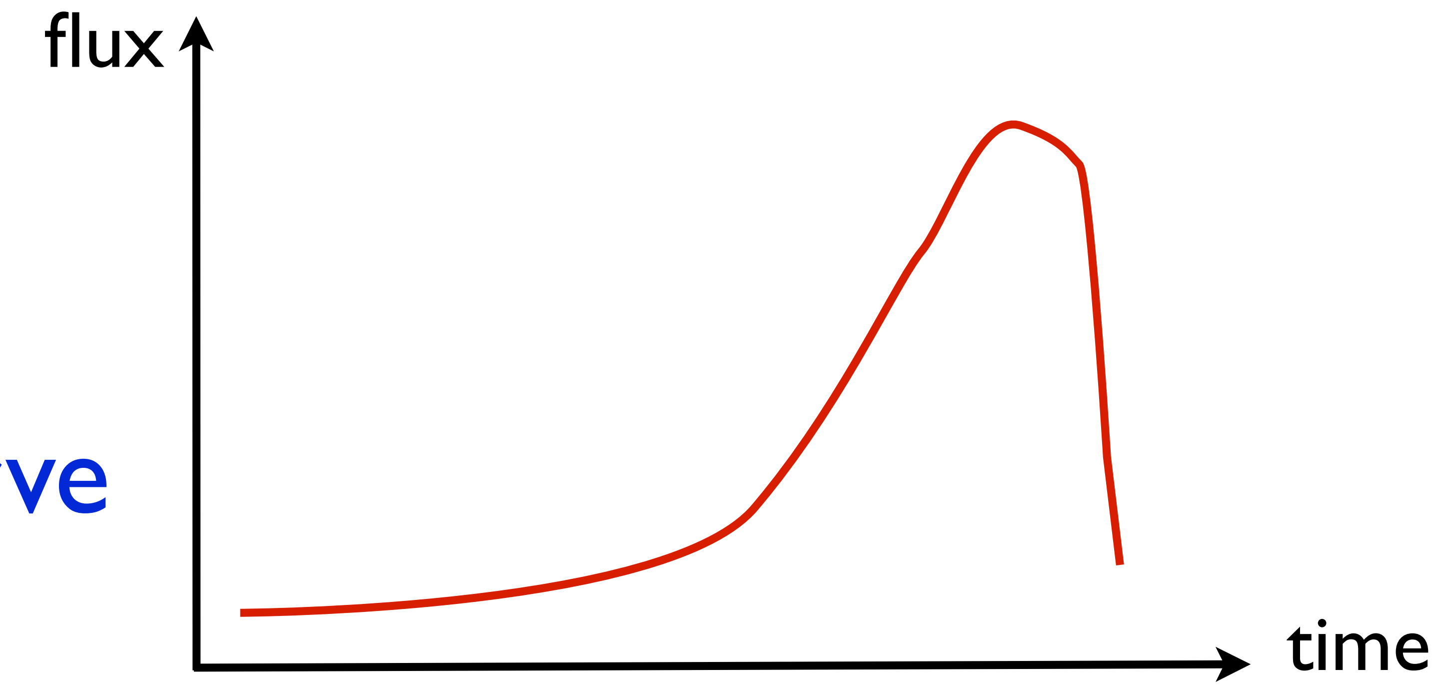
- gradual increase, sharp drop after the peak (asymmetric light curve shape)
- different from traditional microlensing

Caustic crossing



- single star crossing a caustic

→ asymmetric light curve



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Caustic crossing

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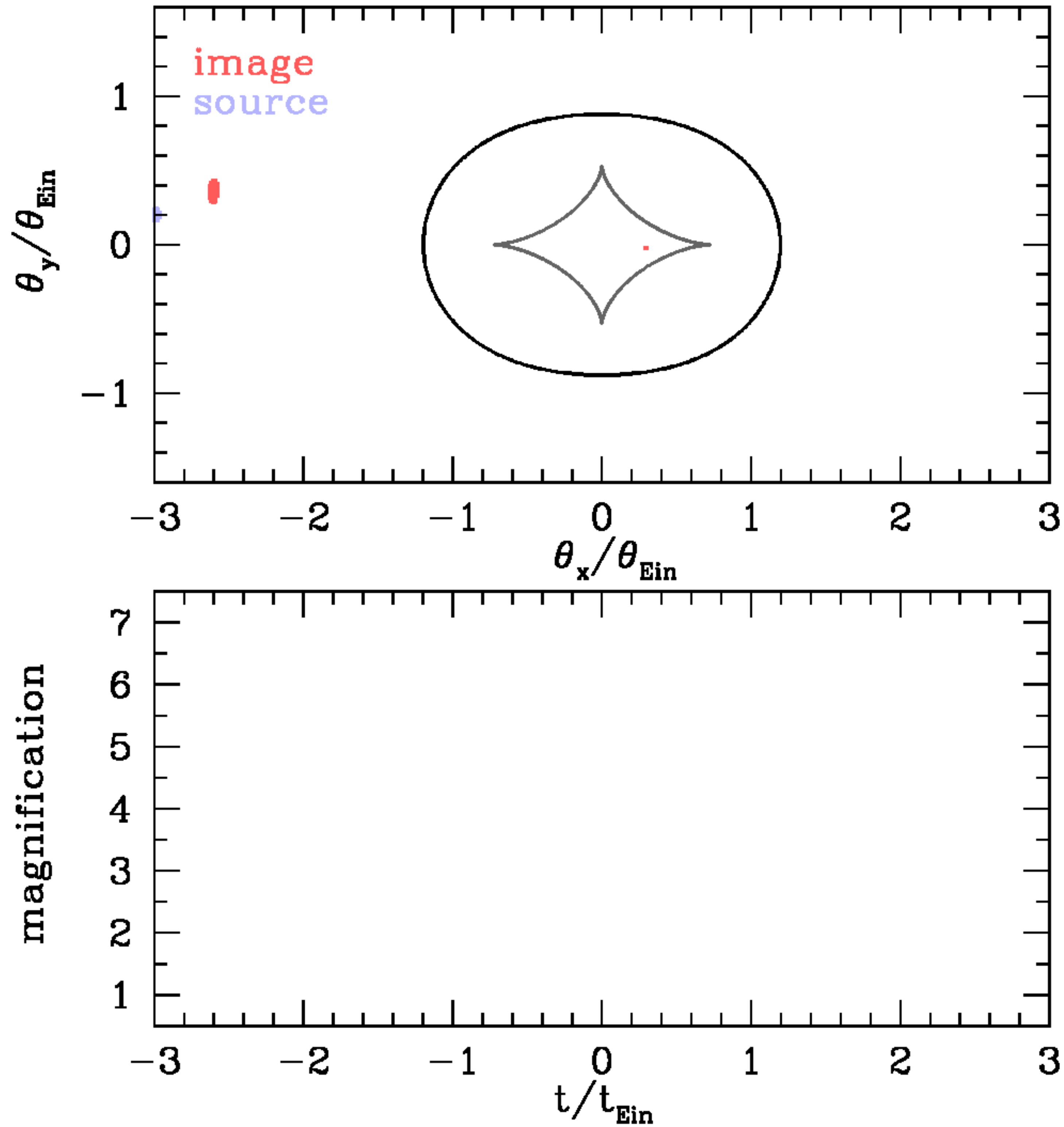

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← observe lensing effect via time evolution of brightness of a star

Miralda-Escude (1991), Diego+ (2017), Venumadhav+ (2017)

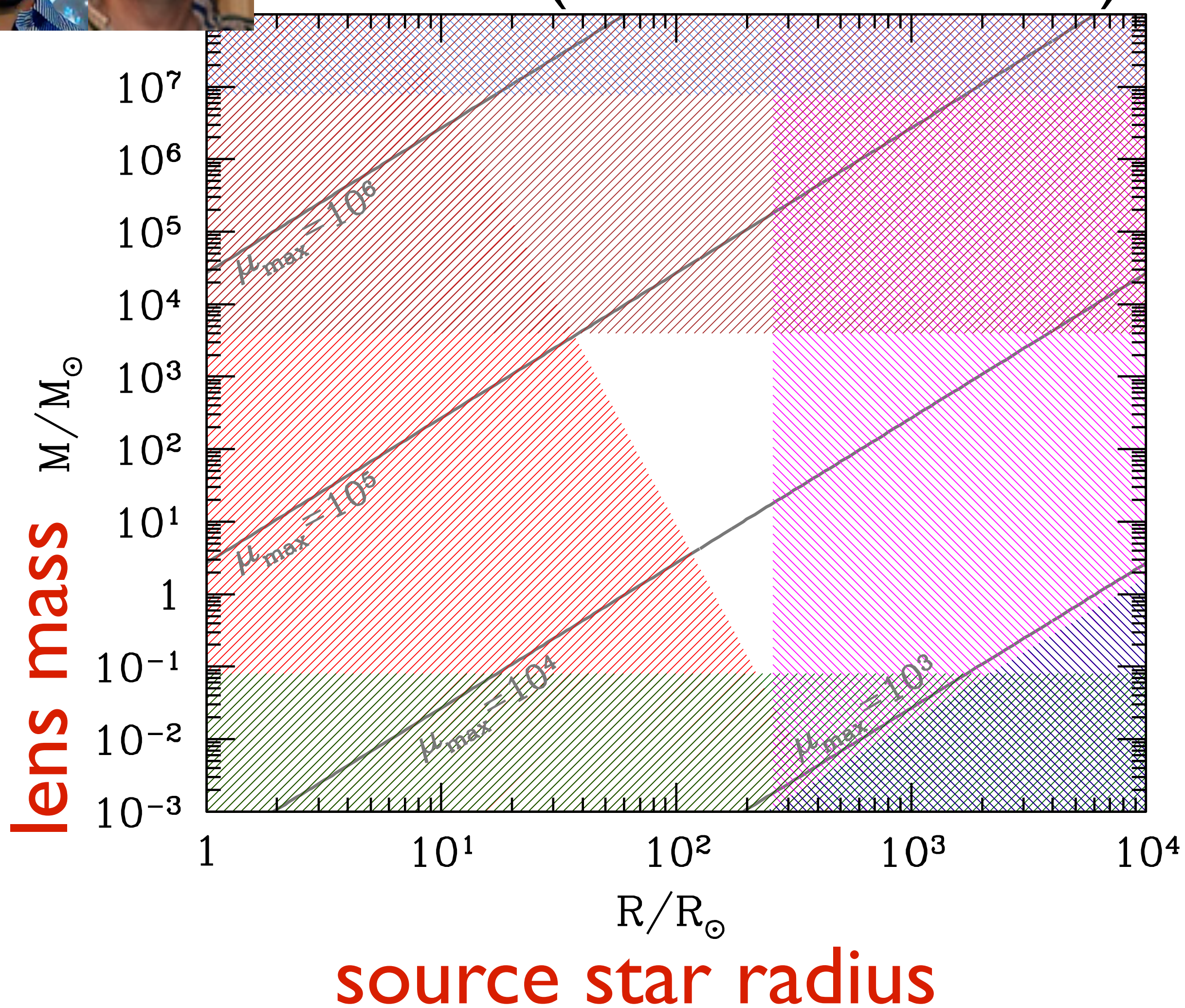
Caustic crossing in massive clusters

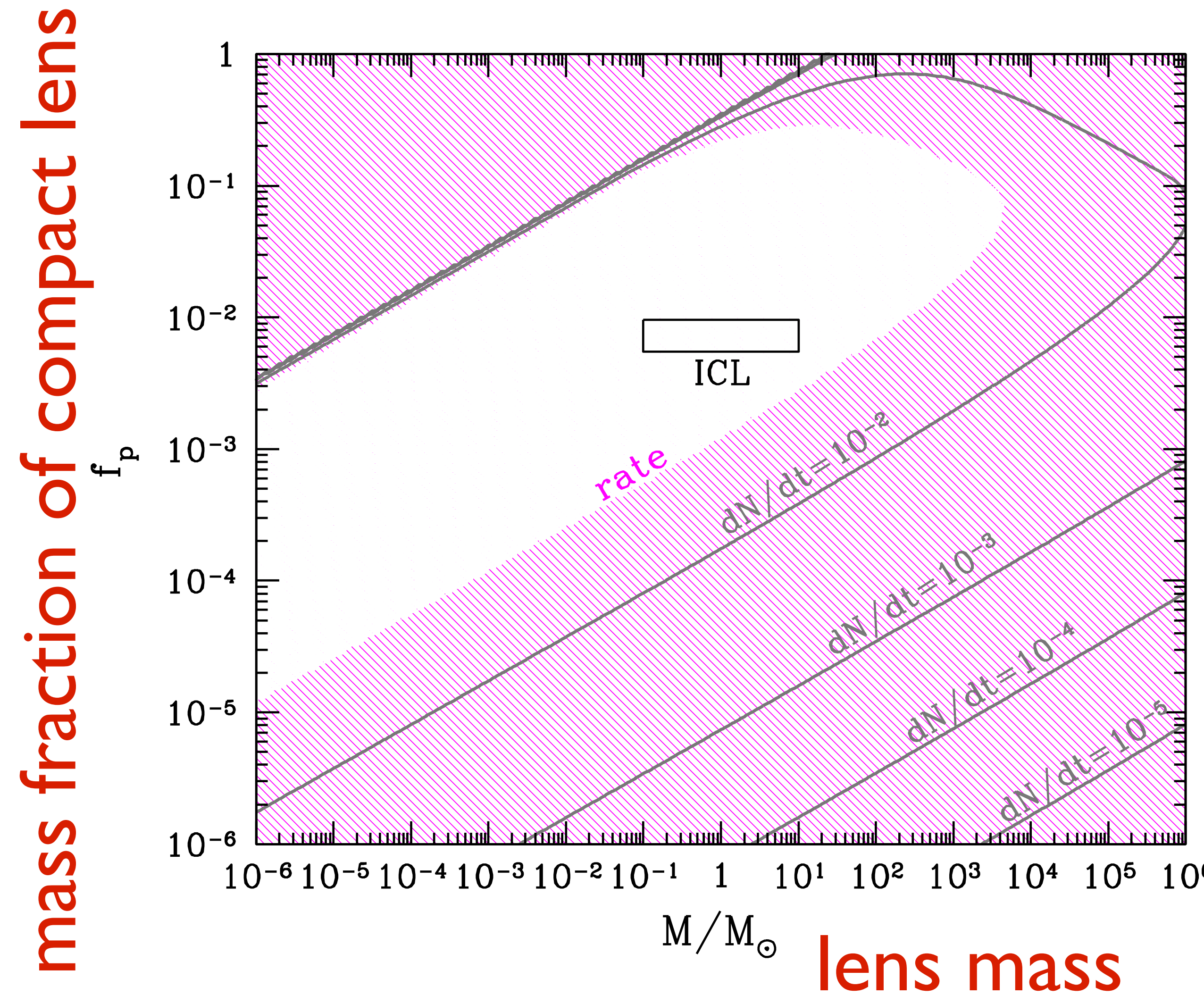
- microlensing by a foreground compact object in high-magnification region of a cluster
- cluster potential adds non circular symmetric perturbation, producing caustics (not seen in microlensing by an isolated lens)
- gravitational lensing both by the cluster potential and the compact object leads to ultra-high magnification, making it possible to observe individual stars even at $z>1$

MO, Diego, Kaiser, Kelly & Broadhurst, arXiv:1710.00148

Understanding Icarus

(shaded: excluded)





- constraints on lens and source properties from observed brightness, light curve, event rates
- peak magnification ≈4300 for most plausible case

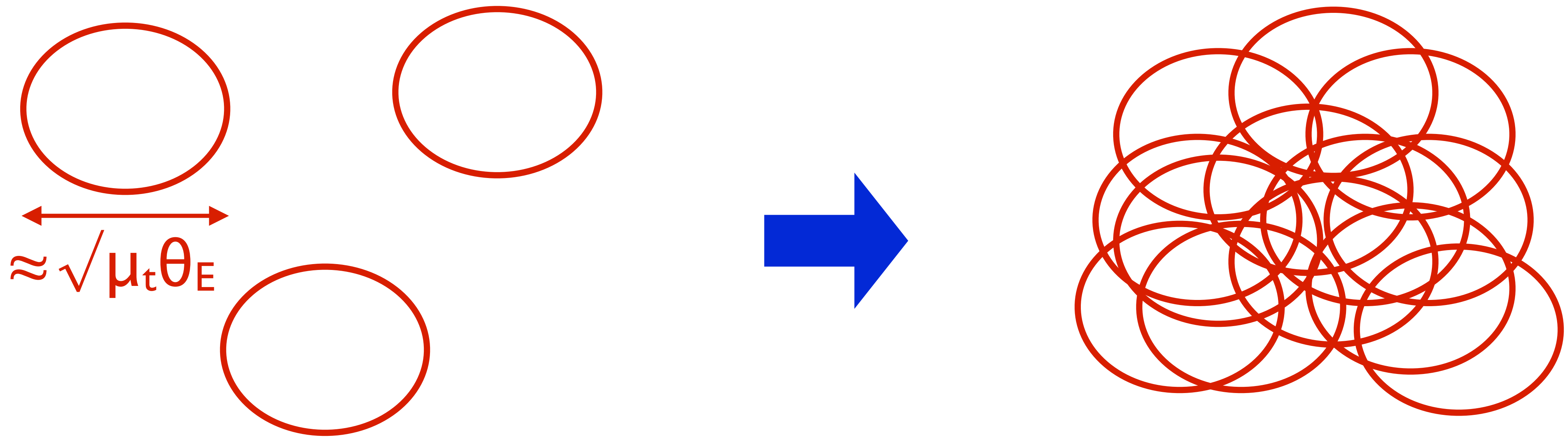
Intra-Cluster Light (ICL)

NASA/ESA/IAC/HFF team, STScI

- diffuse light in clusters
- follow DM distribution
- originates from stars that were tidally stripped from member galaxies
- Icarus event can be fully explained by microlensing due to an ICL star (no need for compact DM)

Diego, .., MO+, arXiv:1706.10281

"Saturation" effect



low surface density Σ

high surface density Σ

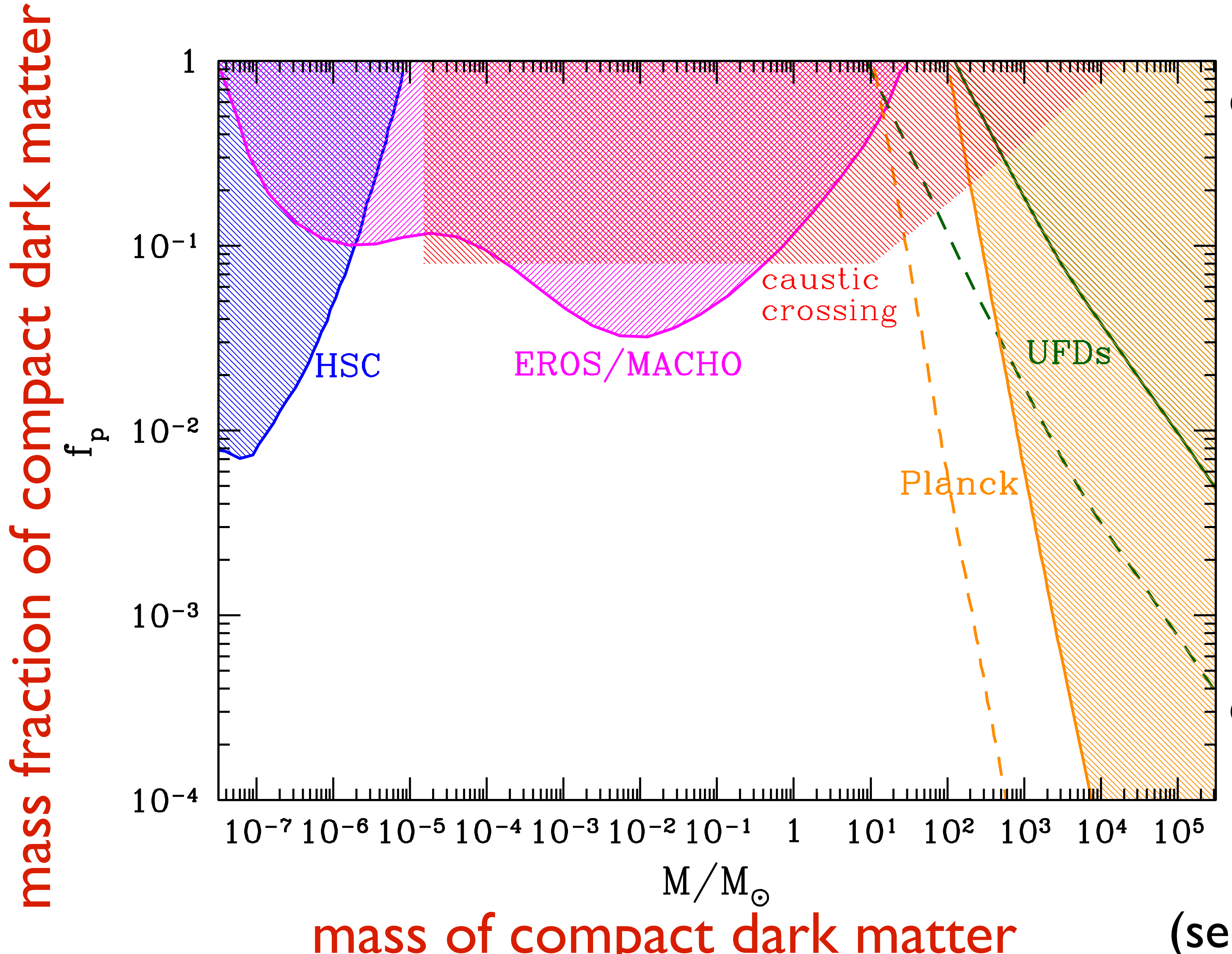
- when the number density of compact DM is very high, Einstein radii highly overlap → peak magnification decreases

$$\tau = \frac{\Sigma}{M}\pi\left(\sqrt{\mu_{\rm t}}\theta_{\rm E}D_{ol}\right)^2$$

$\tau \gtrsim 1$ → saturation

MO, Diego, Kaiser, Kelly & Broadhurst, arXiv:1710.00148

Constraint on compact dark matter



- high number density leads to too strong saturation which cannot explain Icarus
- close window at 10-100 M_{sun}

(see also Inoue & Kusenko 2017; Zumalacarregui & Seljak 2017)

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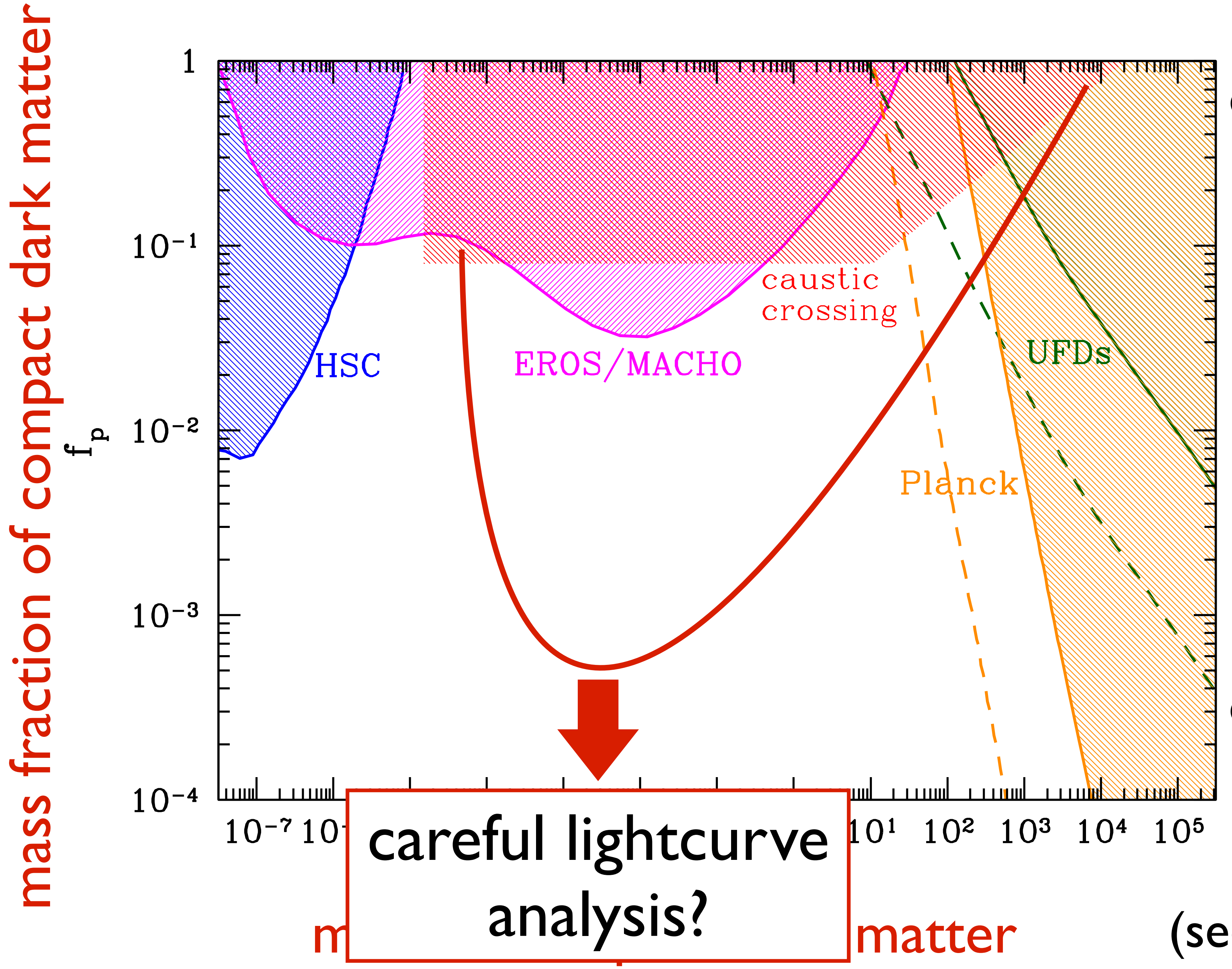

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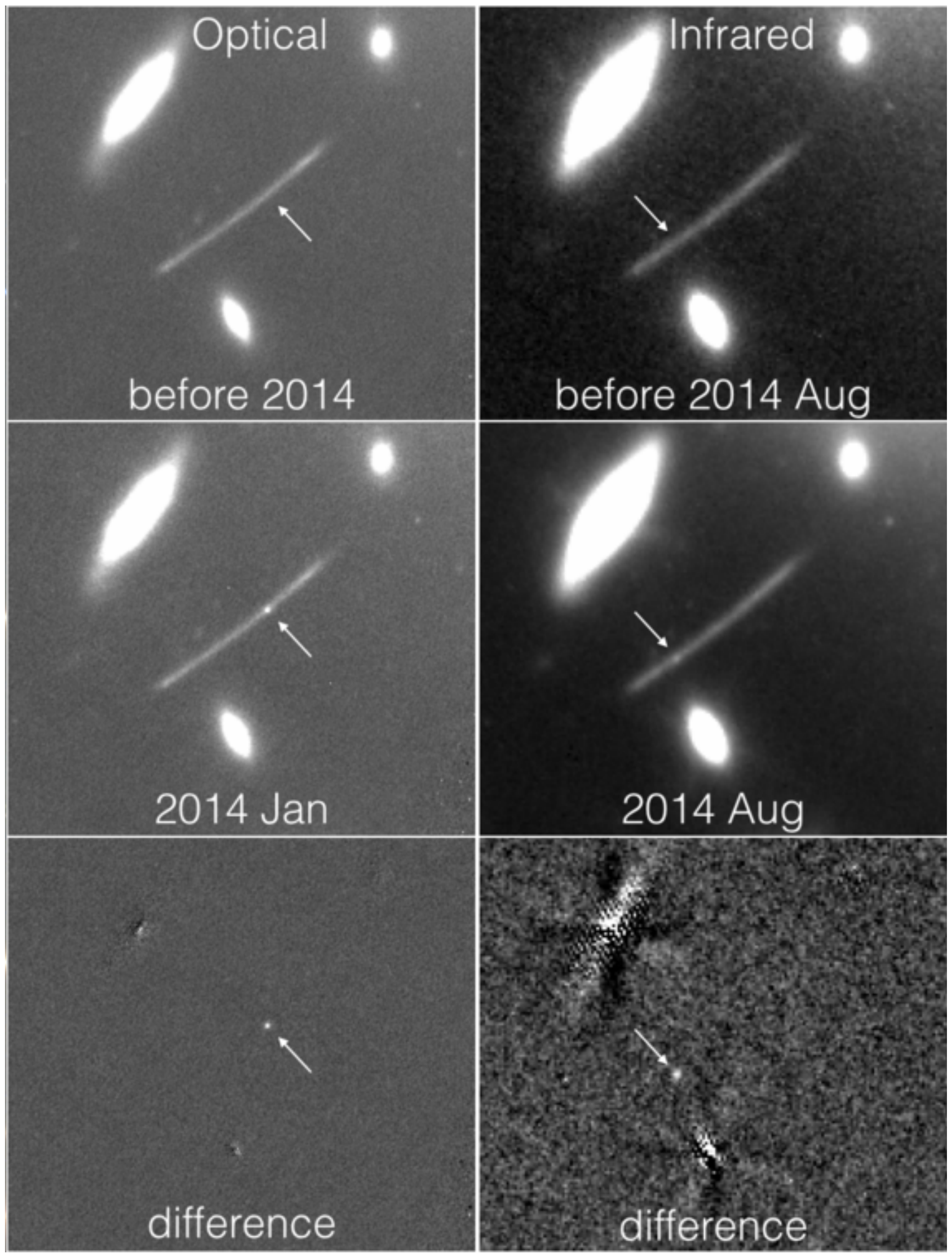
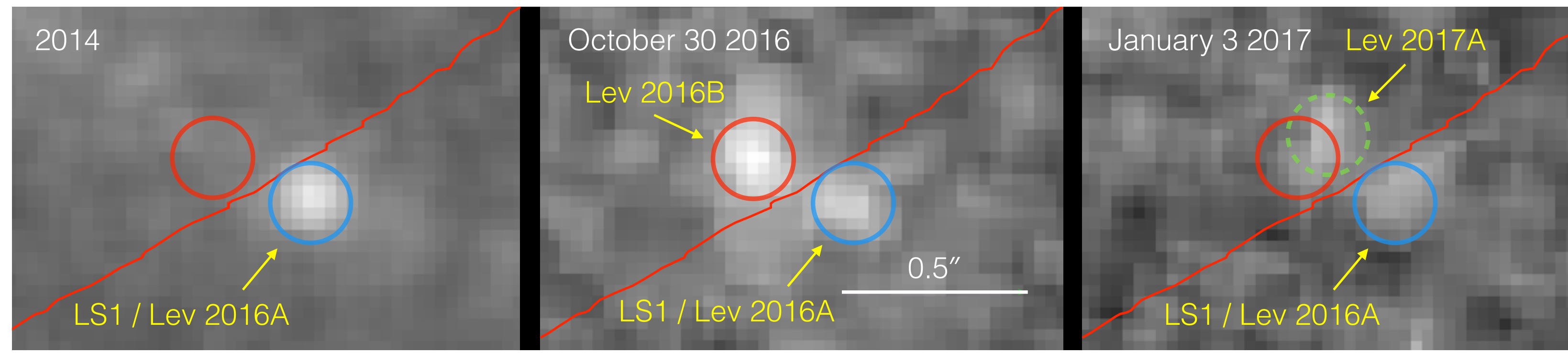
… and more events (?)





↑ additional events near Icarus
(Kelly, .., MO+, arXiv:1706.10279)

← similar fast transients in another HFF cluster
(Rodney, .., MO+, arXiv:1707.02434)

Summary

- new microlensing near the center of a cluster, which led to ultra high magnification of $\gtrsim 4000$, was recently discovered
- most distant individual star and most extreme magnification ever observed
- can place new constraints on compact DM that close high-mass ($10-100\,M_{sun}$) window
- active research for better understanding and tighter constraints ongoing