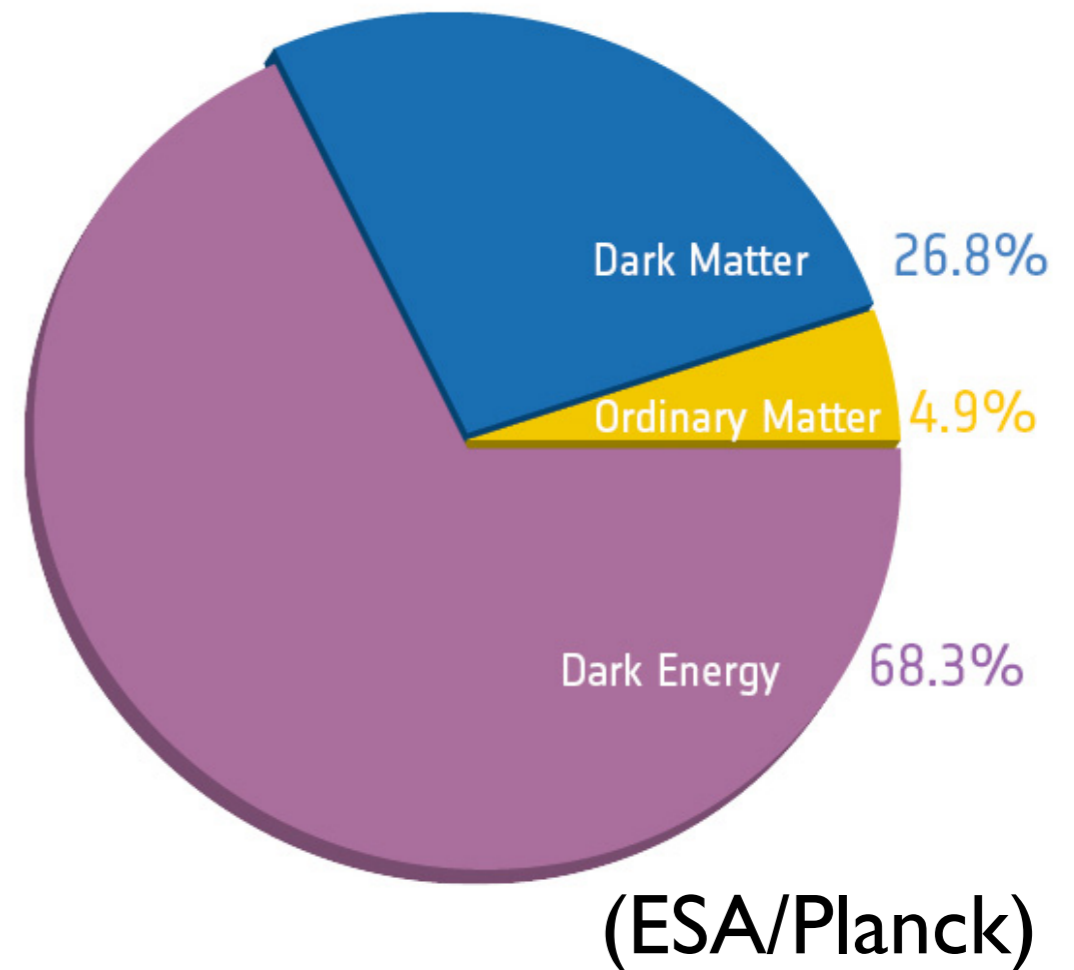


Ultra high magnification microlensing

Masamune Oguri
(University of Tokyo)

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



→ { **unknown particle?** (WIMP, axion, ...)
unknown compact objects? (PBH, ...)

Microlensing

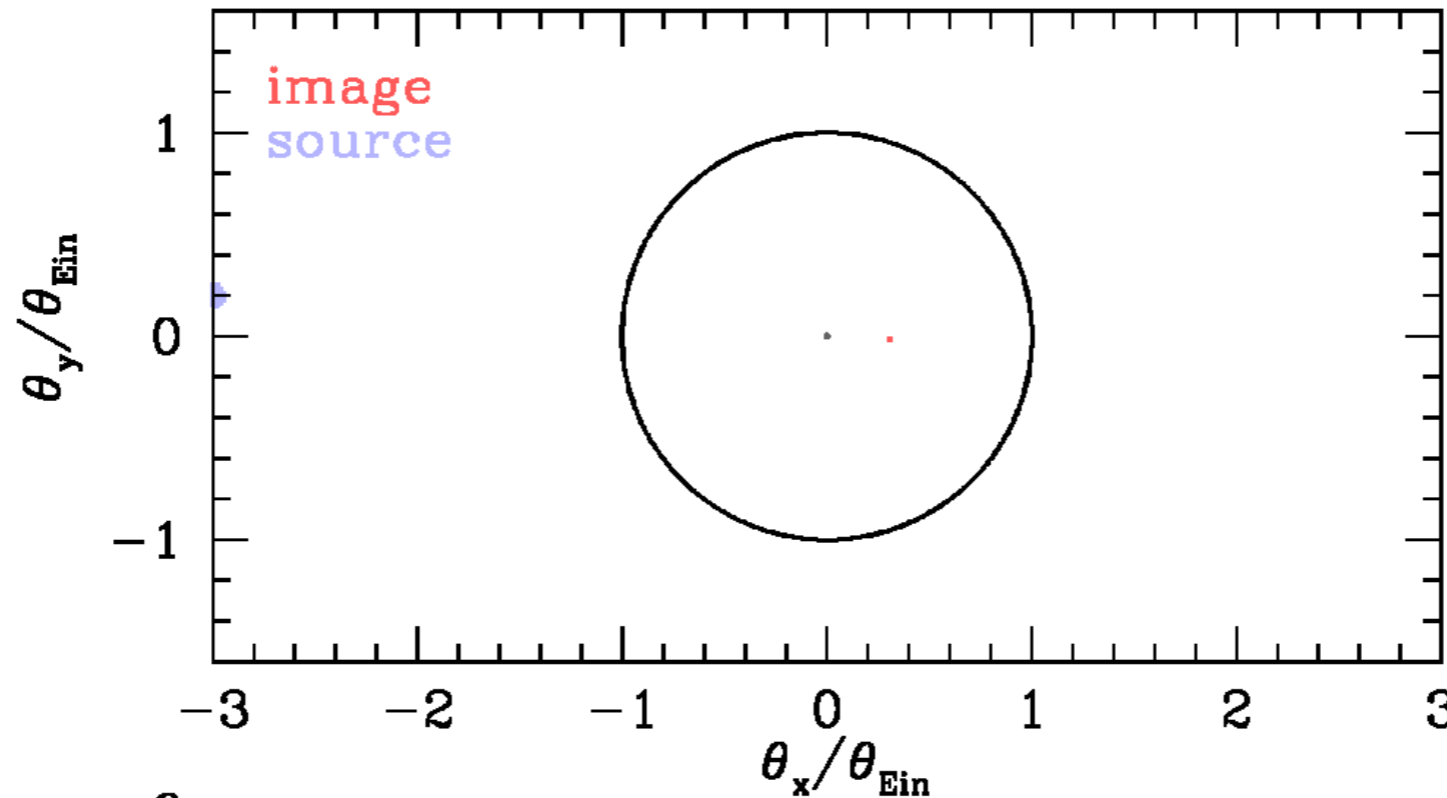
- brightening of a distant star due to gravitational lensing by a foreground compact object (DM)



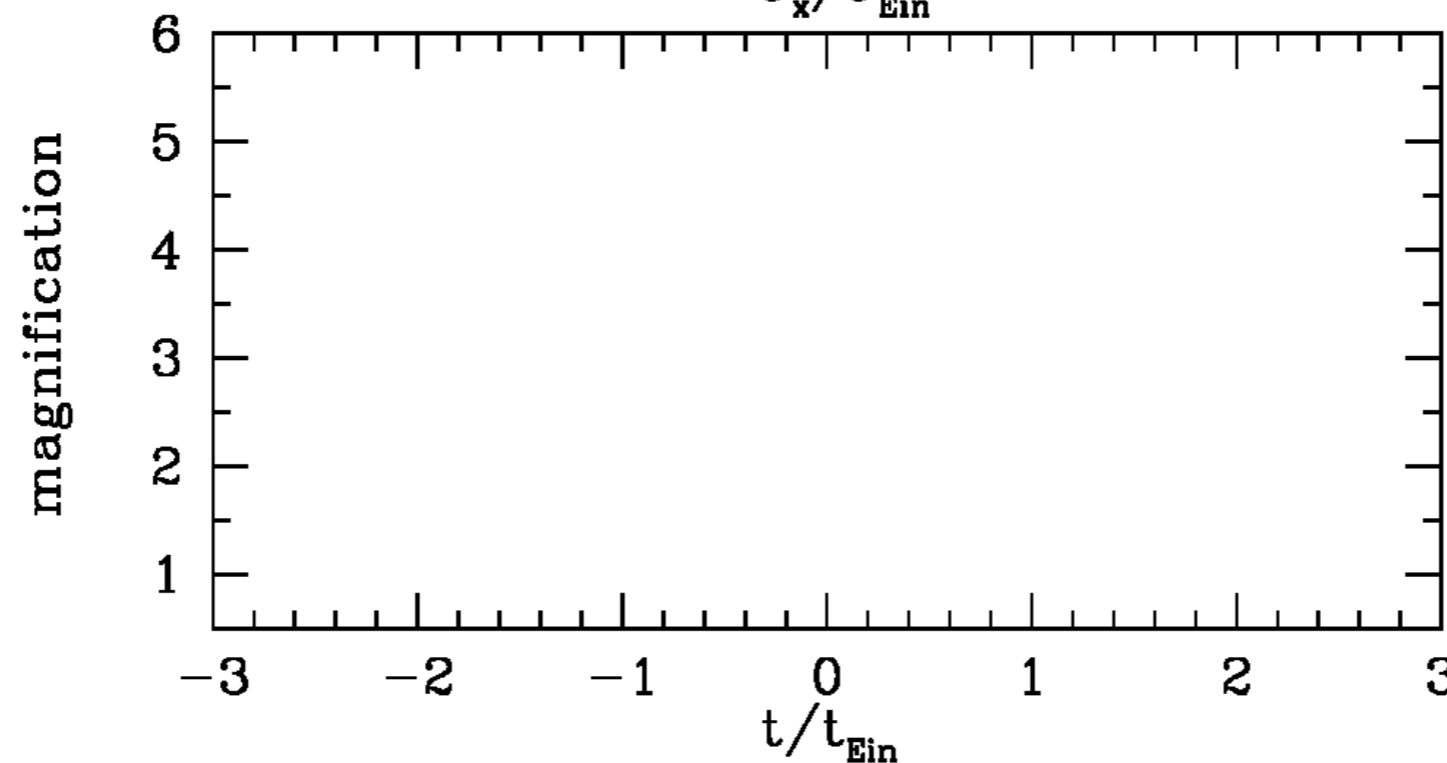
Microensing simulation

image:
we observe

source:
we would observe if no lensing effect



← cannot resolve this due to lack of resolution of observations



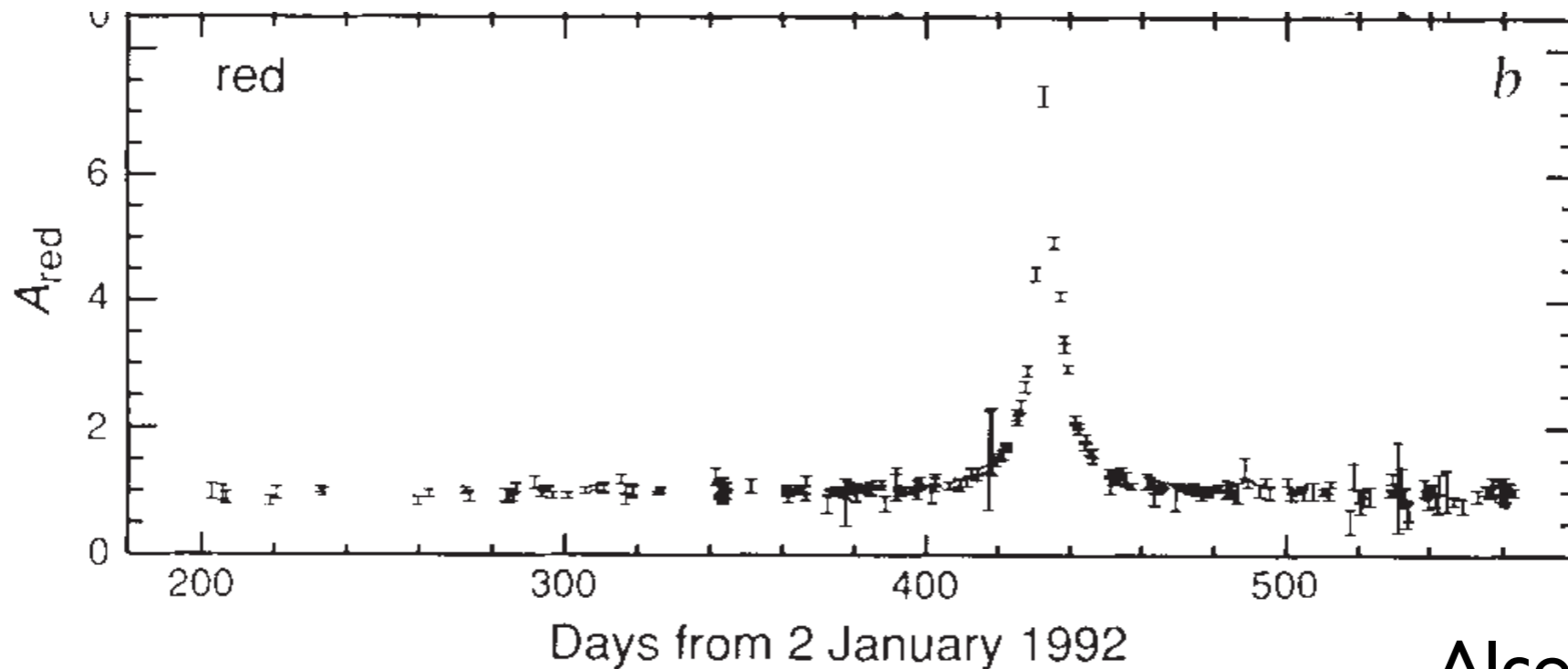
← observe lensing effect via time evolution of brightness of a star

An example of microlensing

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

relative brightness

of a star



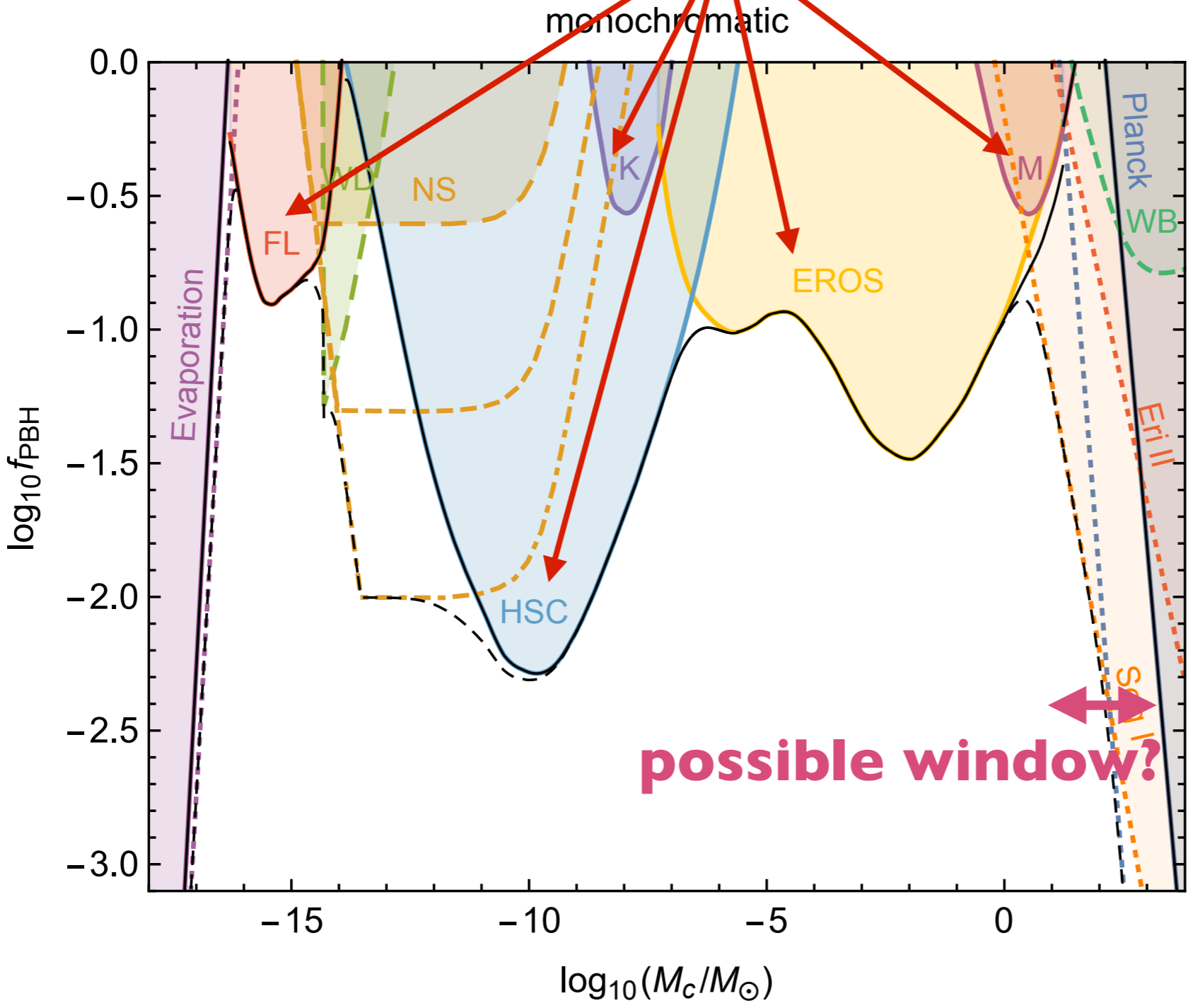
Days from 2 January 1992

time

Alcock+ (1993)

constraints from microlensing

abundance of compact DM (PBH)
relative to total DM



Carr+2017

mass of compact DM (PBH)

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

possible window to explain all dark matter by compact DM at $M \sim 10-100 M_{\text{sun}}$ (\sim 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 $\lesssim Mpc$)
- this opens a new opportunity to constrain **compact DM** scenarios!

MO (2015)

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)



SY (~17 years ago)



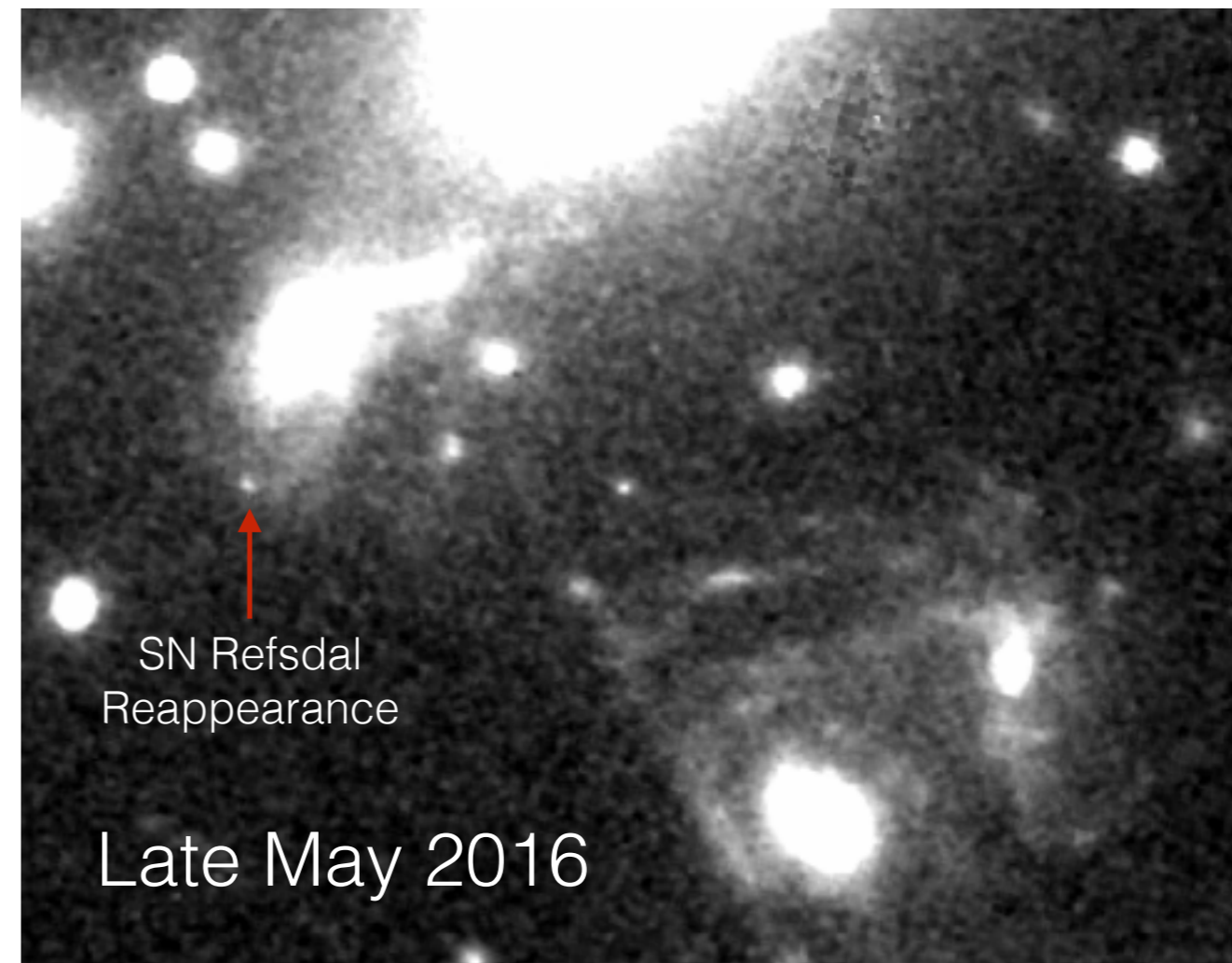
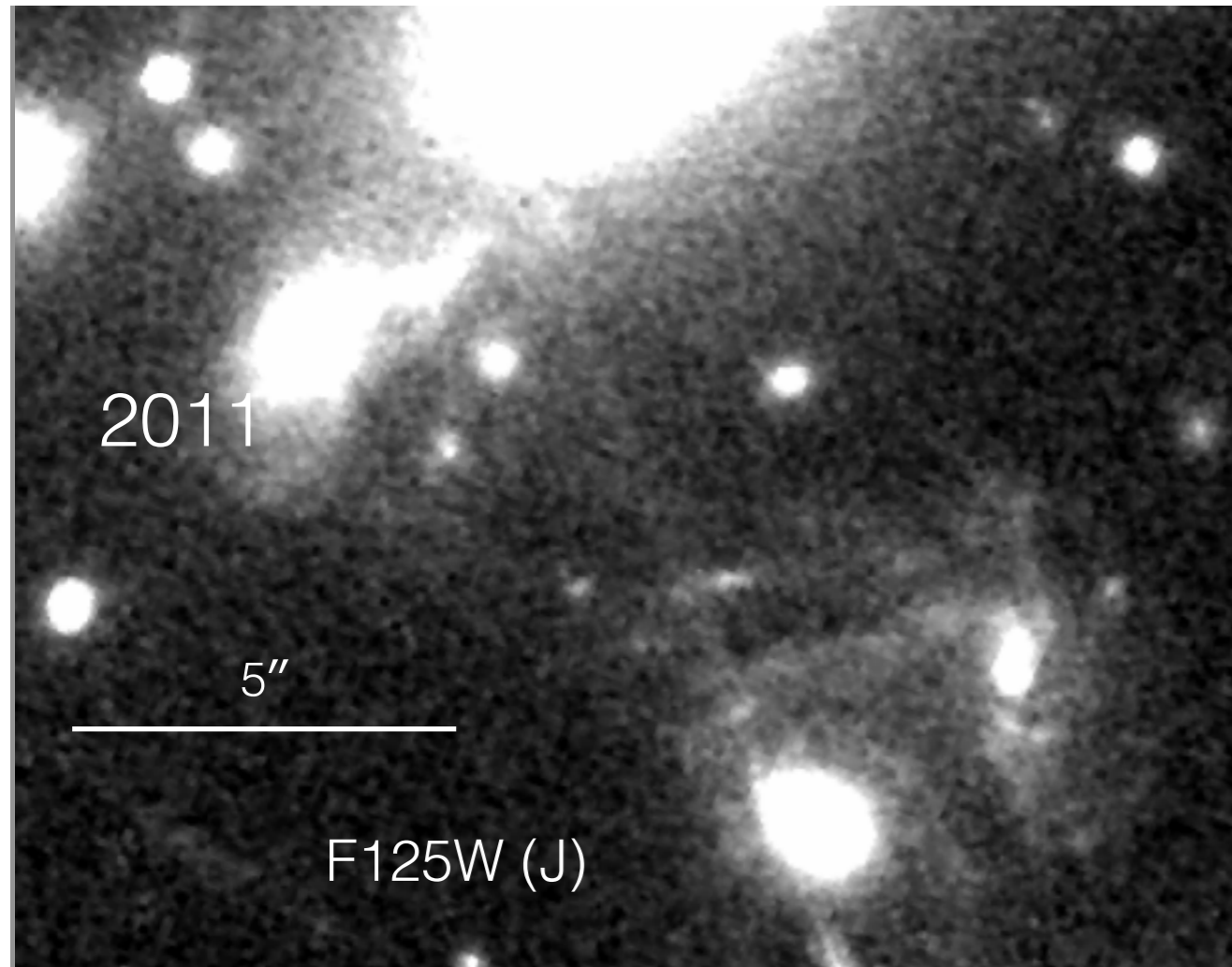
SX (~1 year later)



S1-S4 (ongoing)



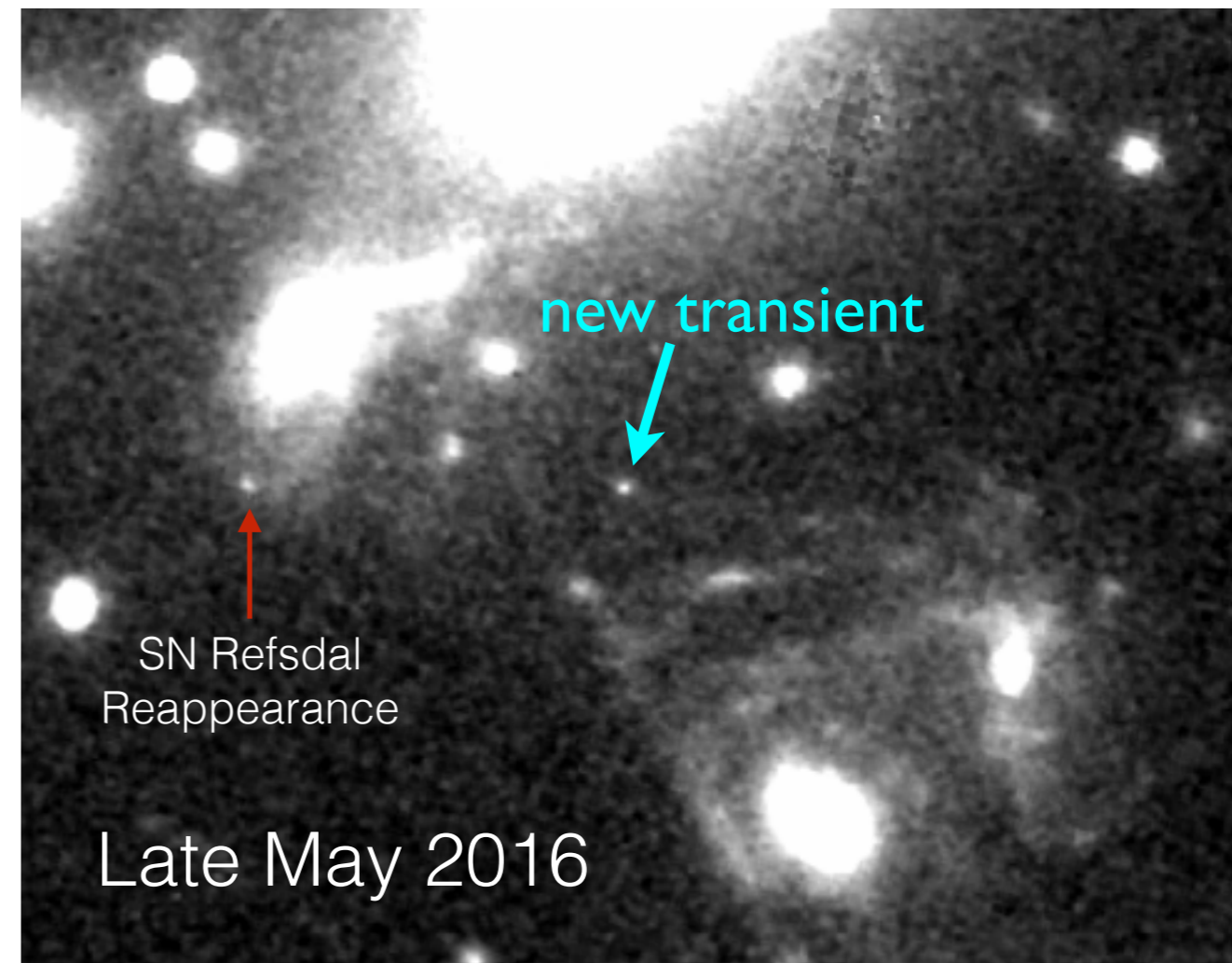
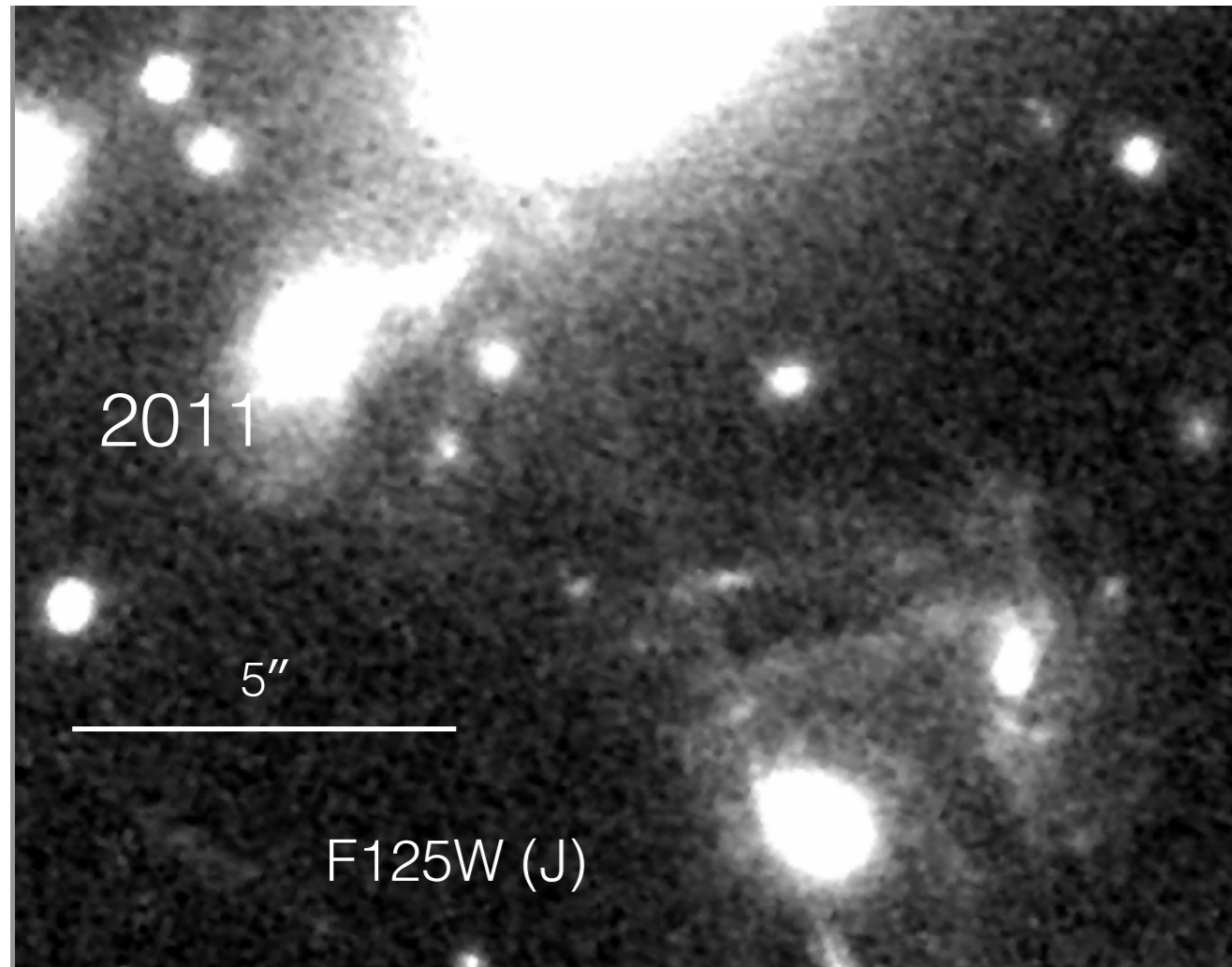
Discovery of Icarus



(cluster MACSJ1149)

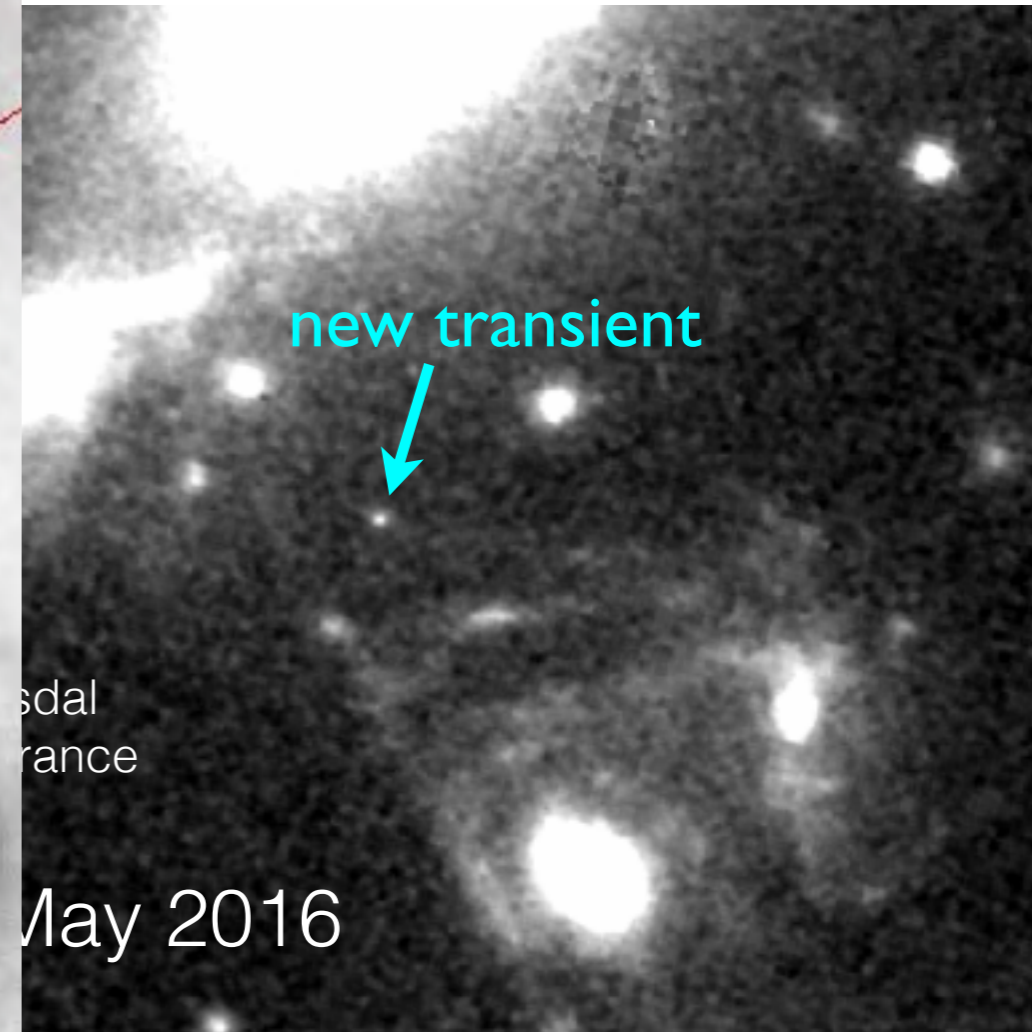
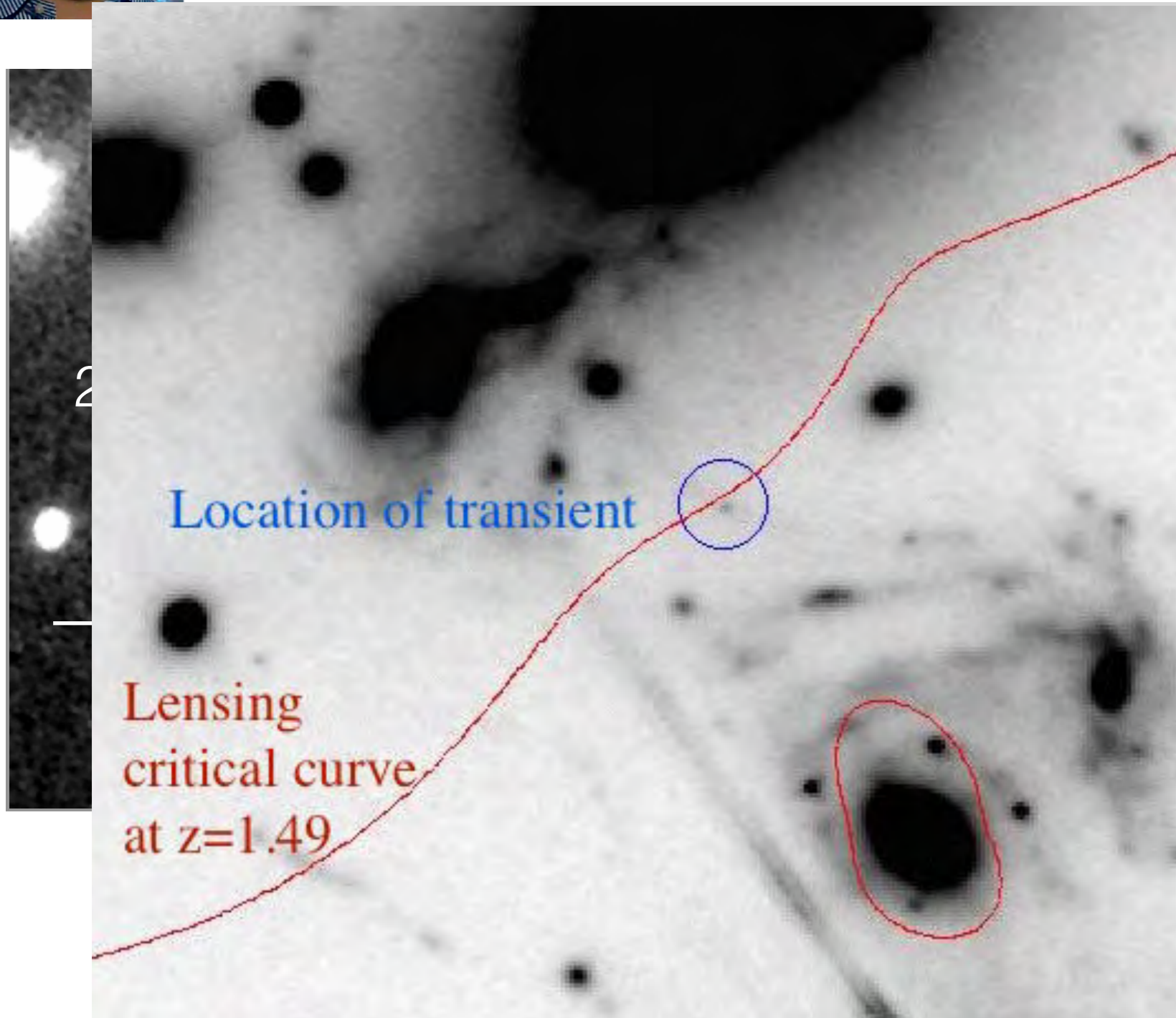


Discovery of Icarus



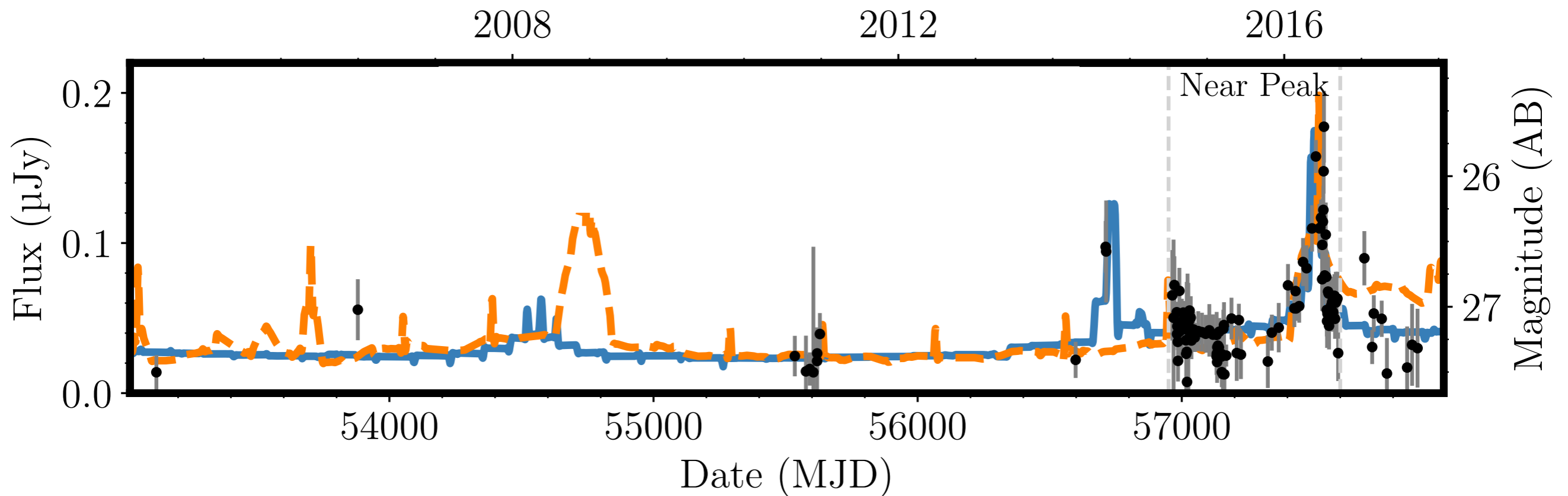
(cluster MACSJ1149)

Discovery of Icarus



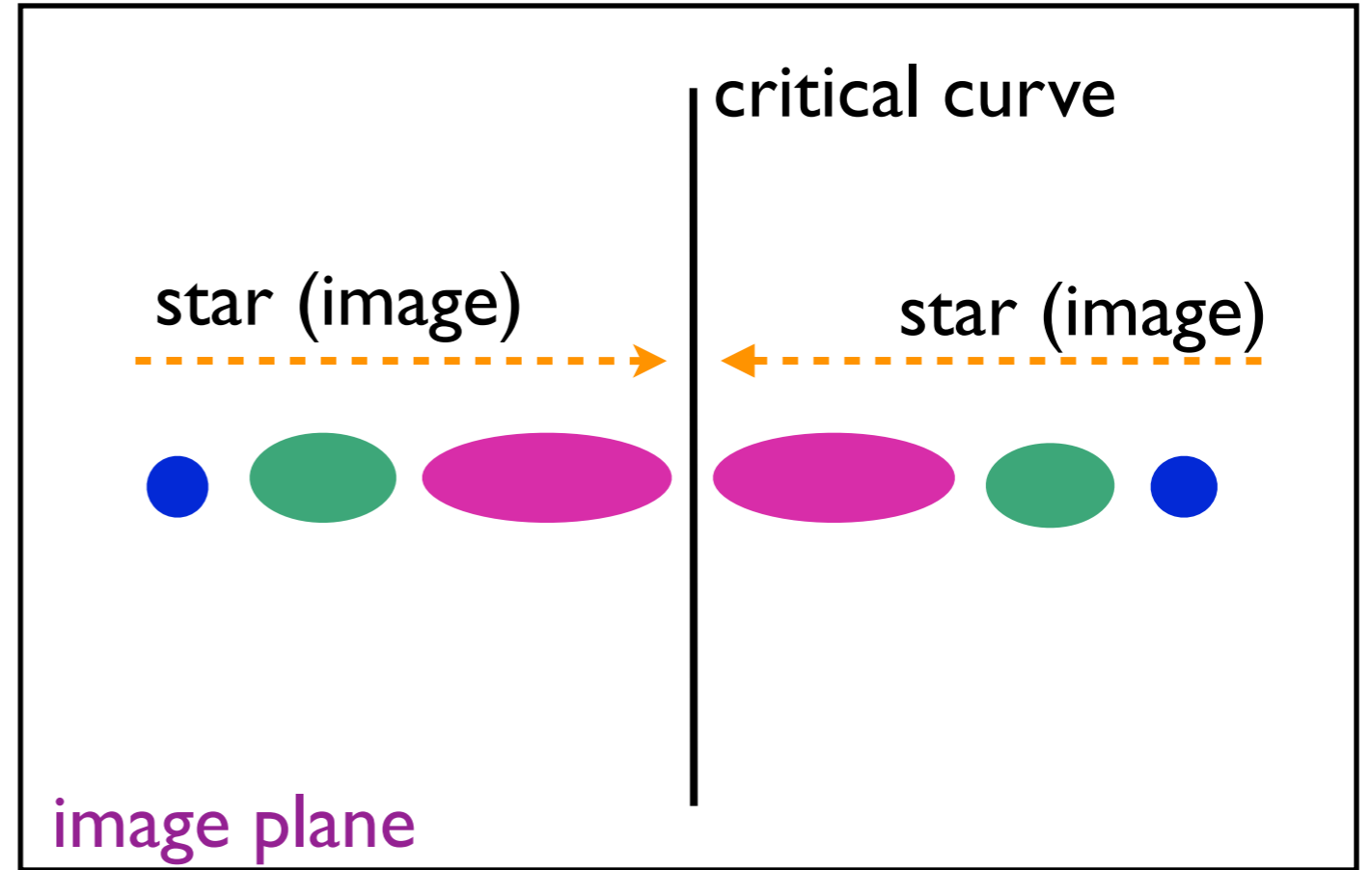
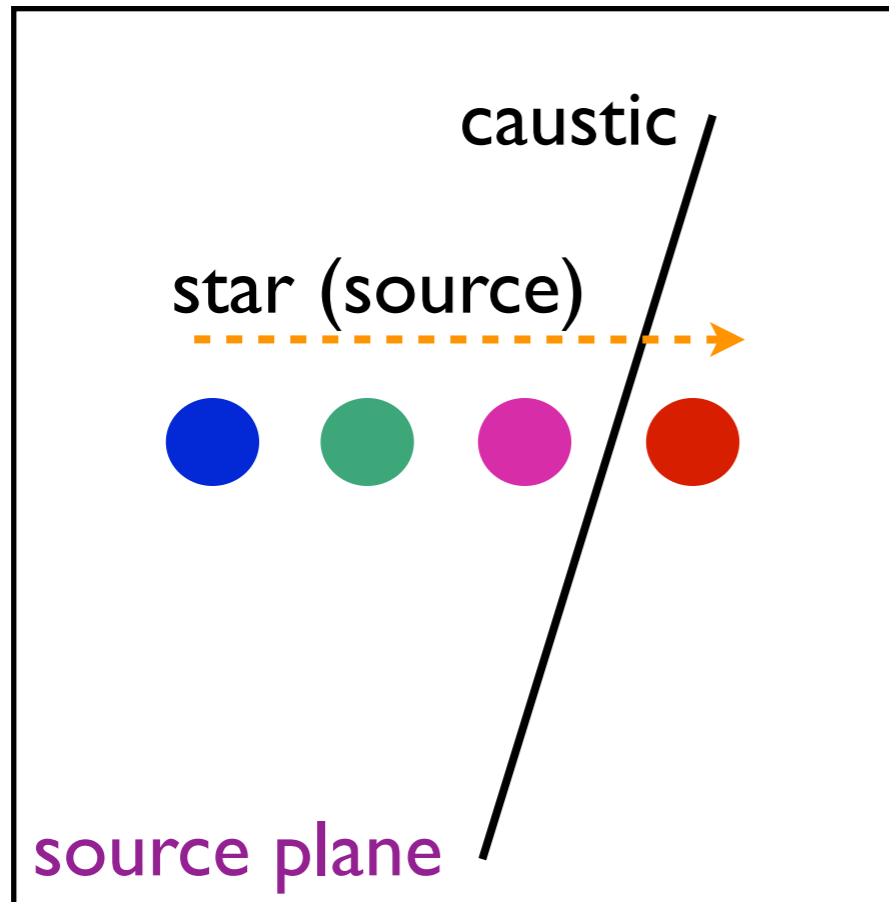
(cluster MACSJ1149)

Light curve of Icarus

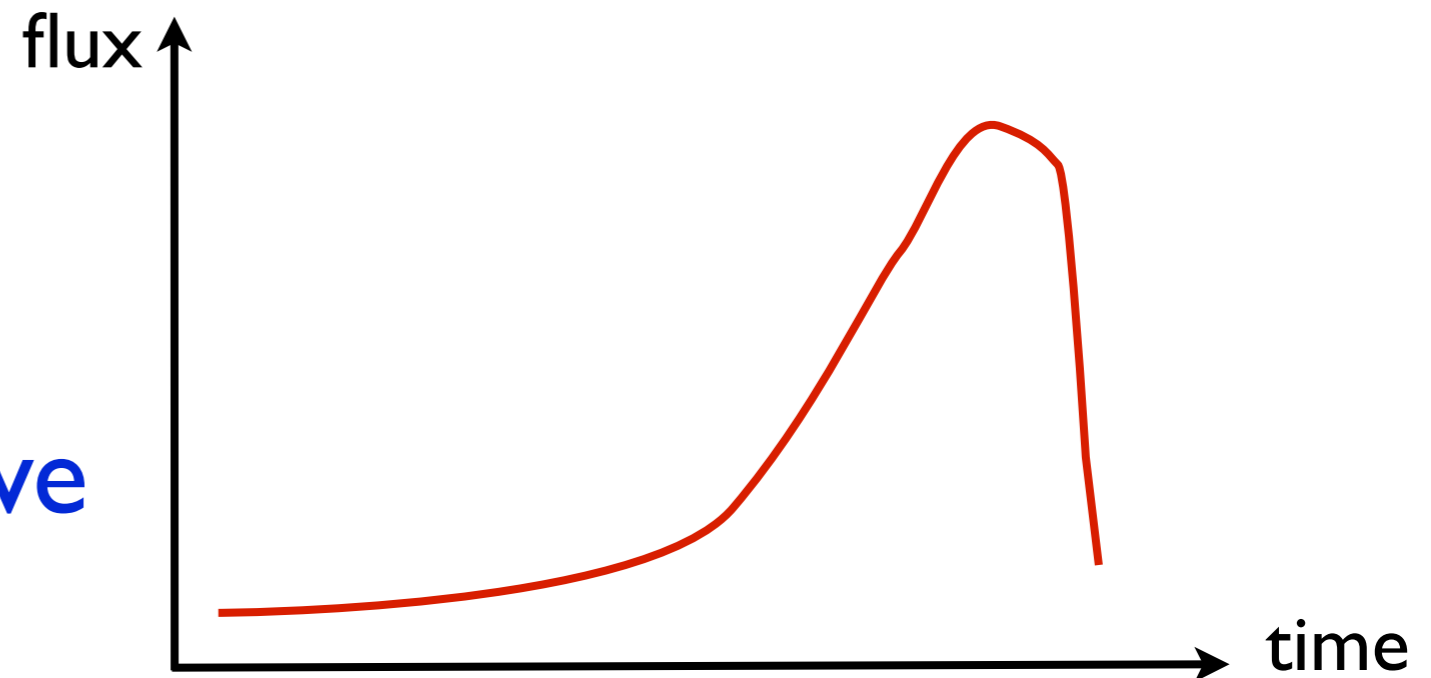


- gradual increase, sharp drop after the peak (asymmetric light curve shape)
- different from traditional microlensing

Caustic crossing



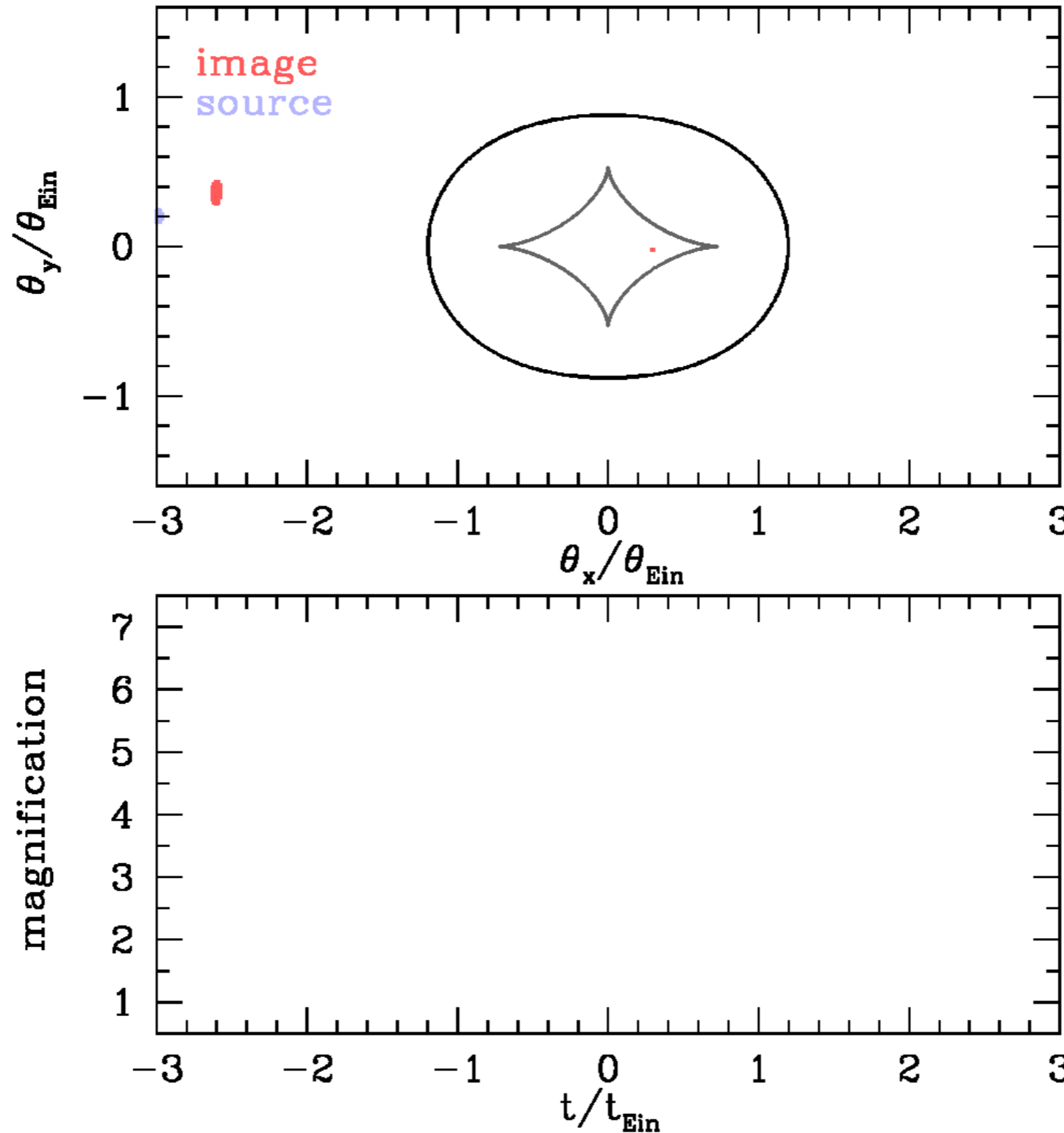
- single star crossing a caustic
- asymmetric light curve



Caustic crossing

image:
we observe

source:
we would observe if no lensing effect



← cannot resolve this due to lack of resolution of observations

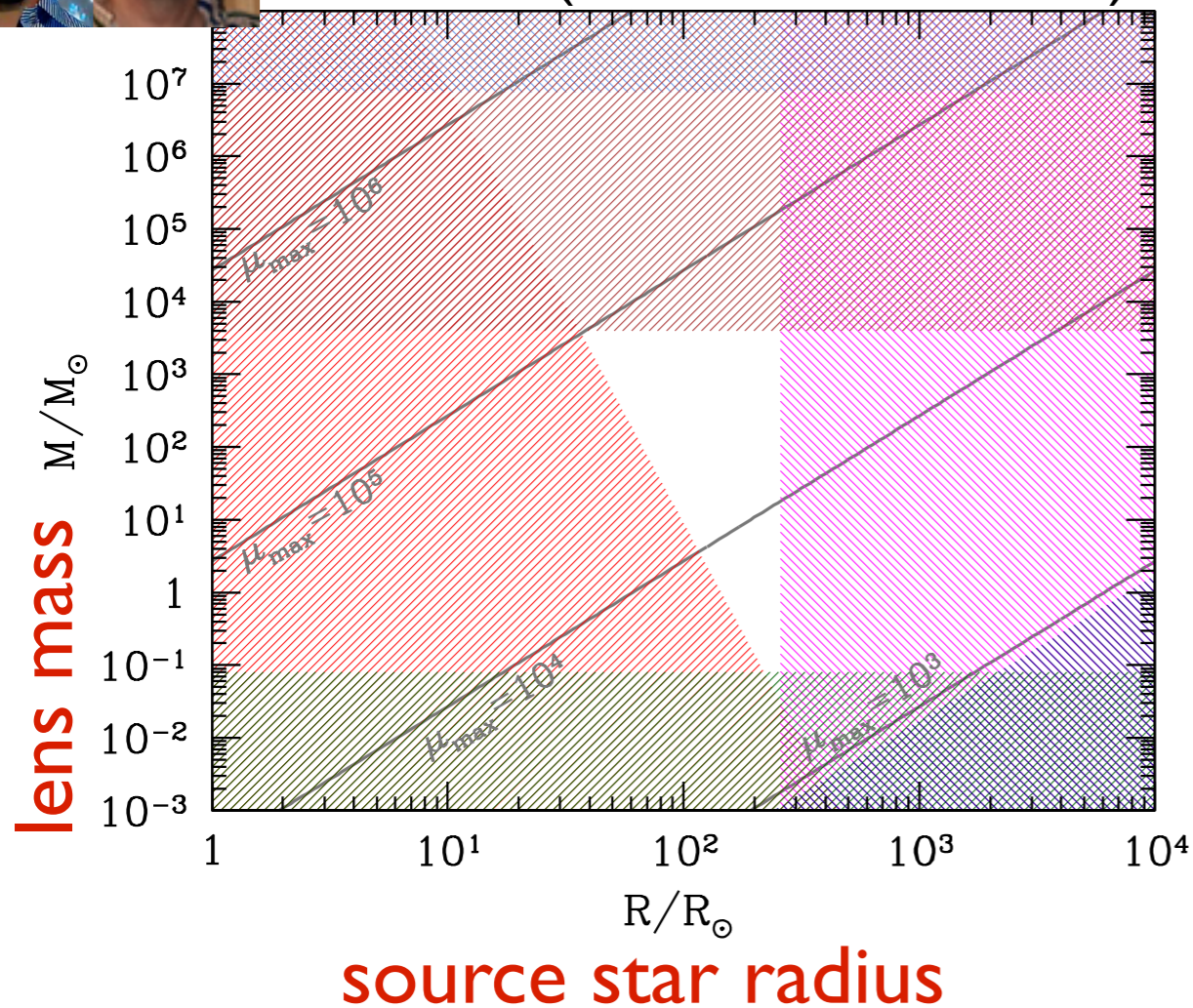
← observe lensing effect via time evolution of brightness of a star

Caustic crossing in massive clusters

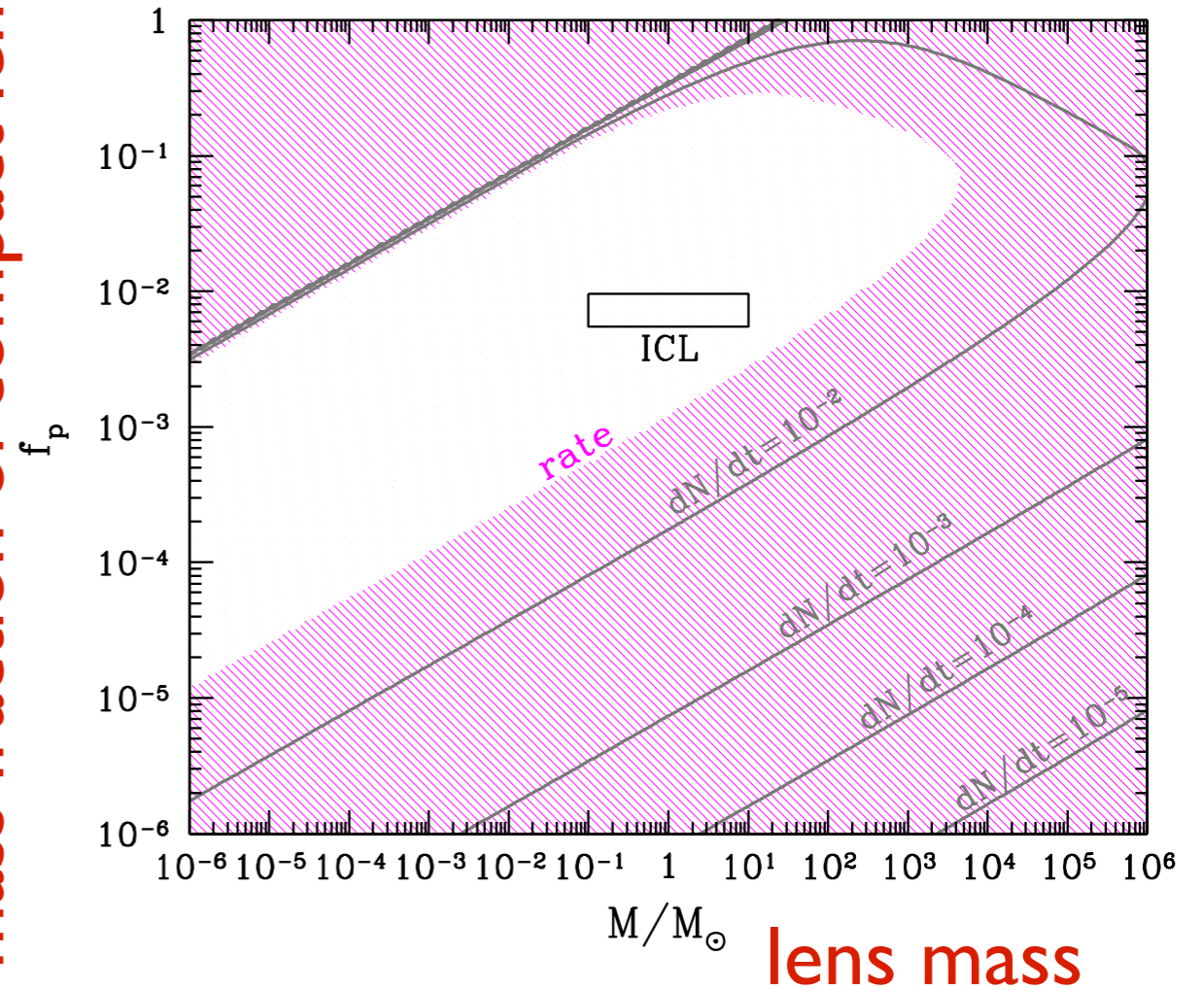
- microlensing by a foreground compact object in high-magnification region of a cluster
- cluster potential adds non circular symmetric perturbation, producing **caustics** (not seen in microlensing by an isolated lens)
- gravitational lensing **both by the cluster potential and the compact object**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

Understanding Icarus

(shaded: excluded)

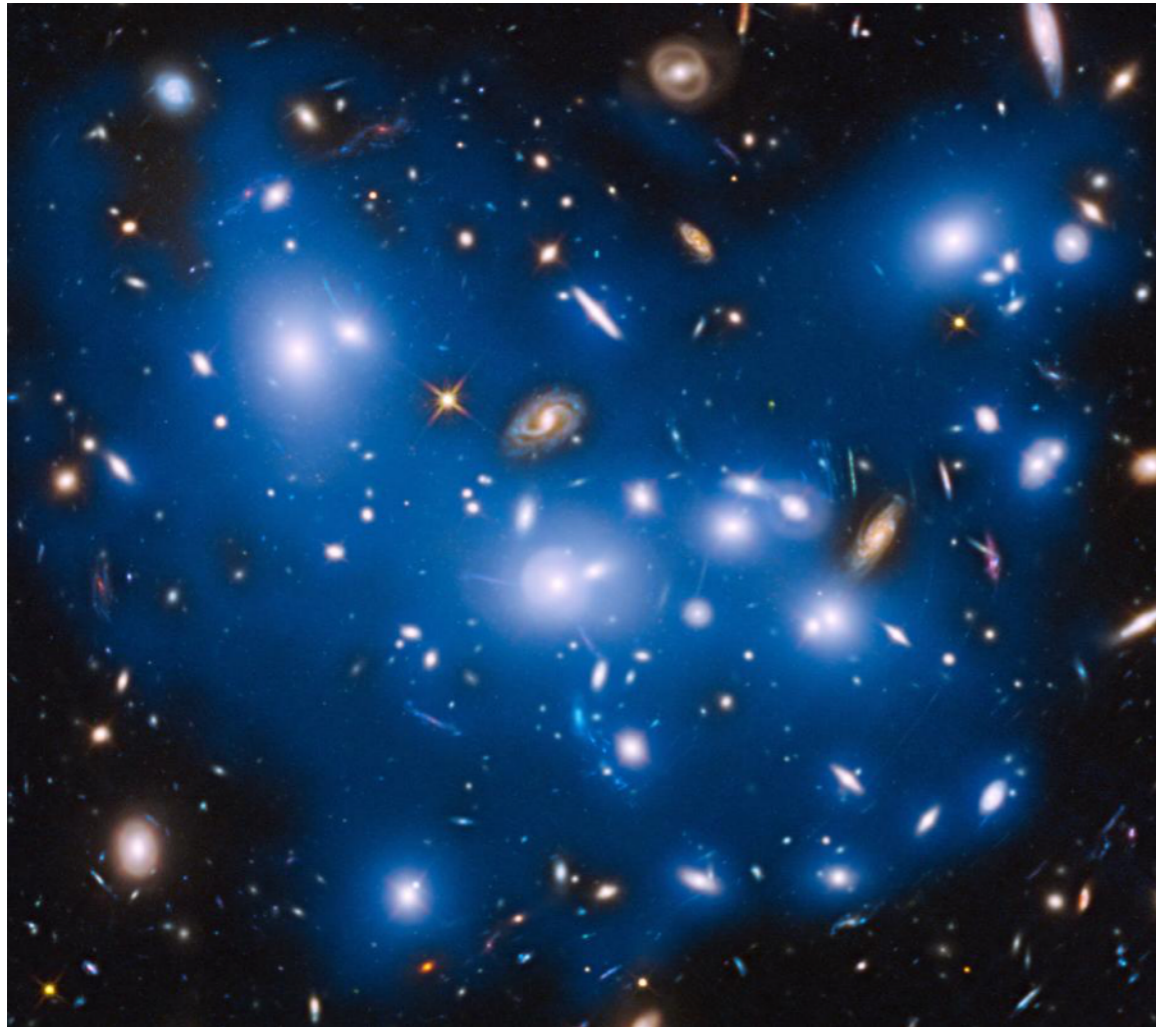


mass fraction of compact lens



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

Intra-Cluster Light (ICL)

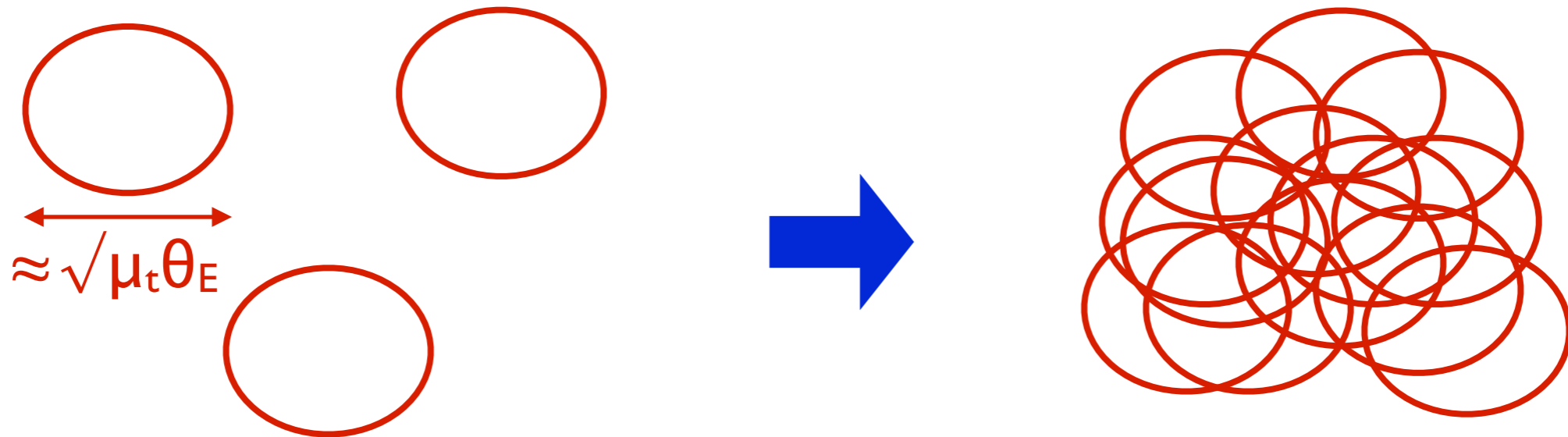


NASA/ESA/IAC/HFF team, STScI

- 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)



“Saturation” effect



low surface density Σ

high surface density Σ

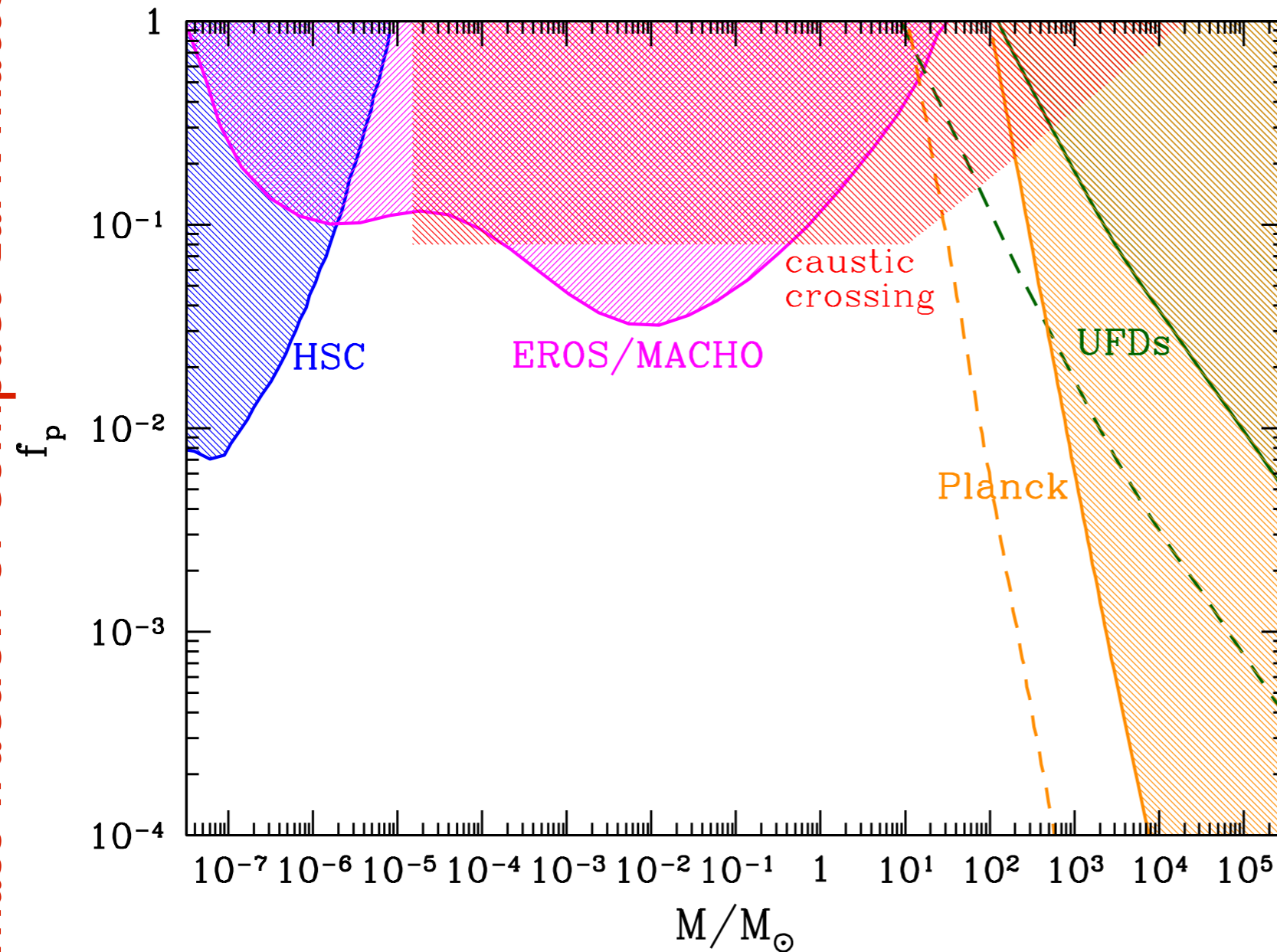
- when the number density of compact DM is very high, Einstein radii highly overlap
→ **peak magnification decreases**

$$\tau = \frac{\Sigma}{M} \pi (\sqrt{\mu_t} \theta_E D_{ol})^2$$

$\tau \gtrsim 1 \rightarrow$ saturation

Constraint on compact dark matter

mass fraction of compact dark matter



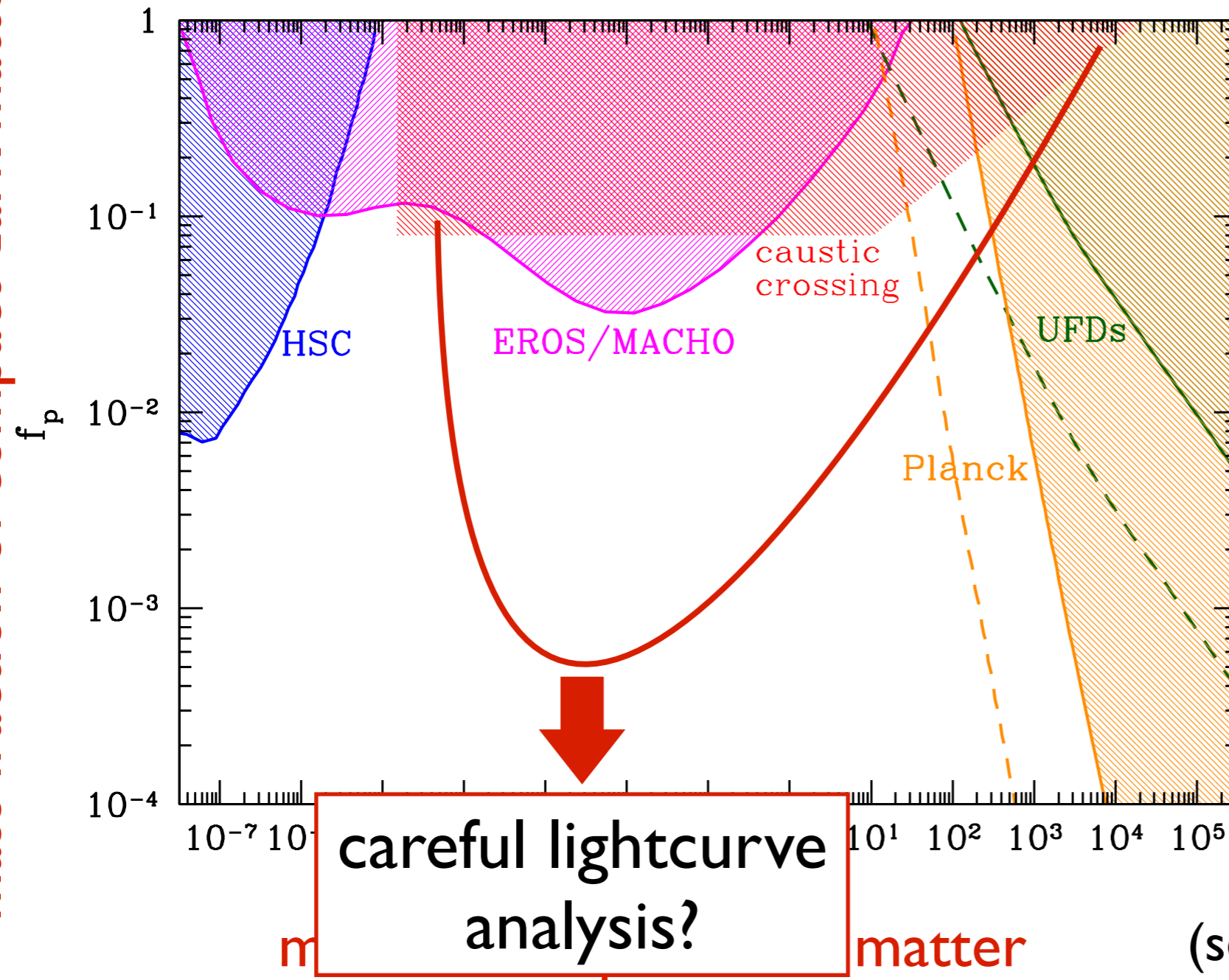
mass of compact dark matter

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

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

Constraint on compact dark matter

mass fraction of compact dark matter

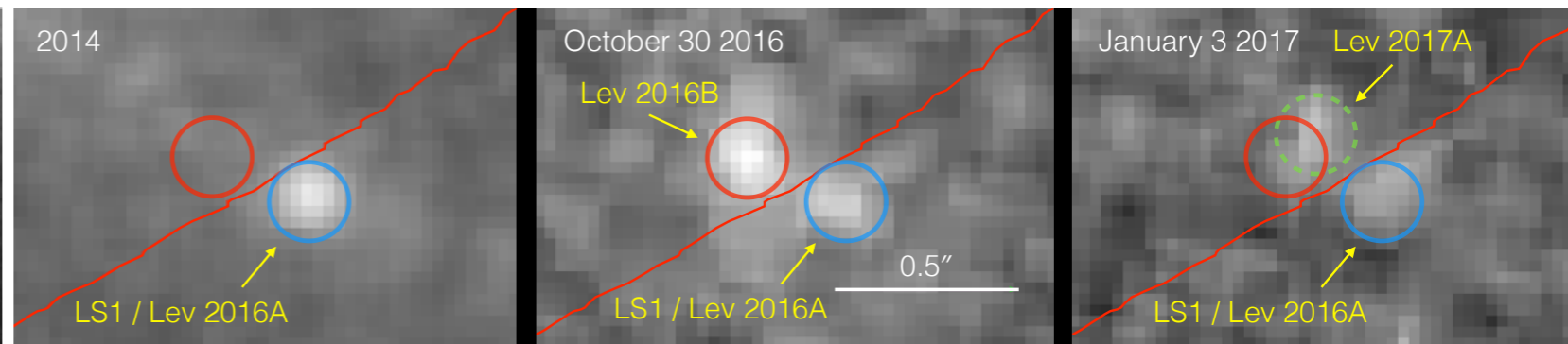
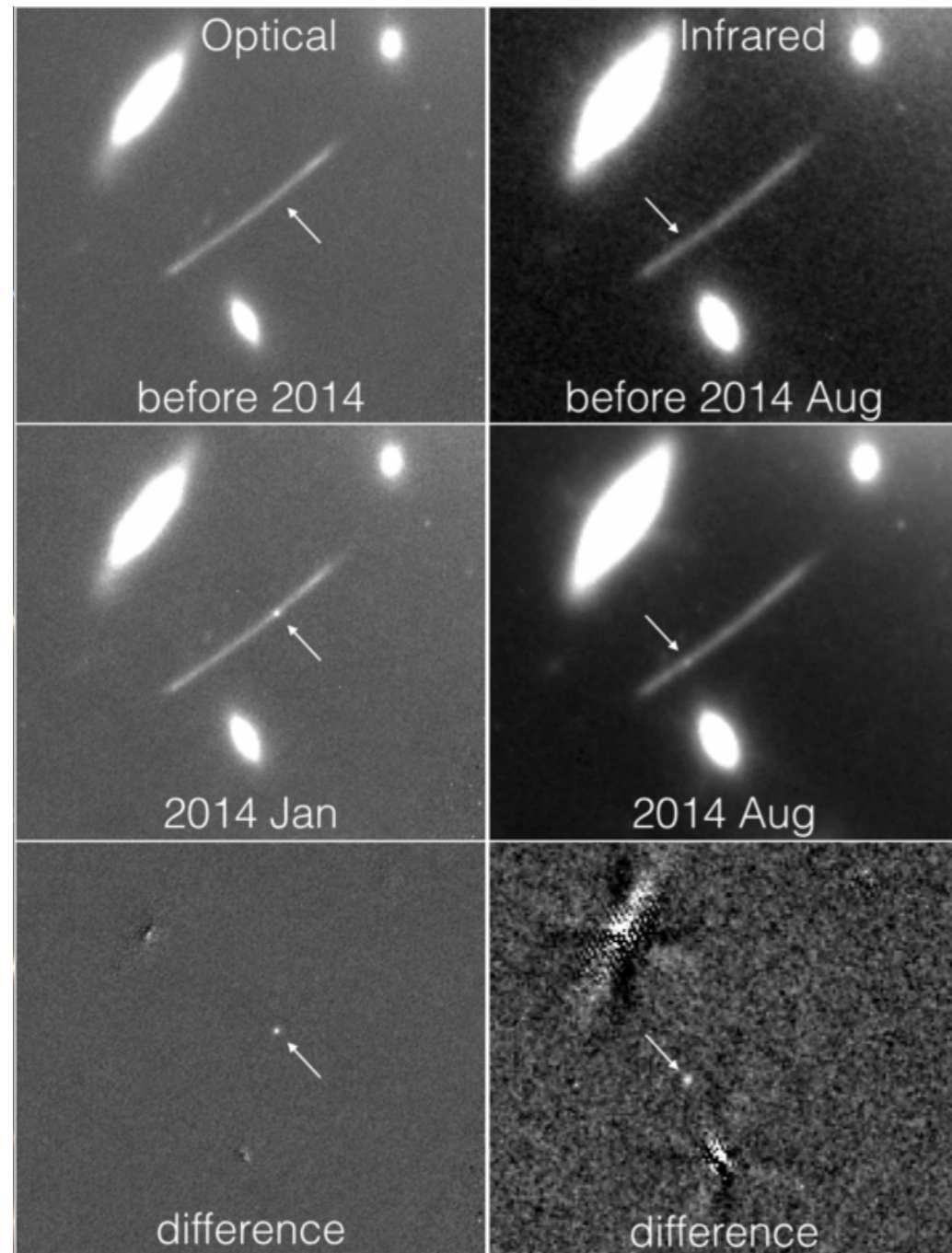


- high number density leads to too strong saturation which cannot explain Icarus
- close window at $10-100 M_{\text{sun}}$

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



... 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 ($10\text{--}100 M_{\text{sun}}$) window
- active research for better understanding and tighter constraints ongoing