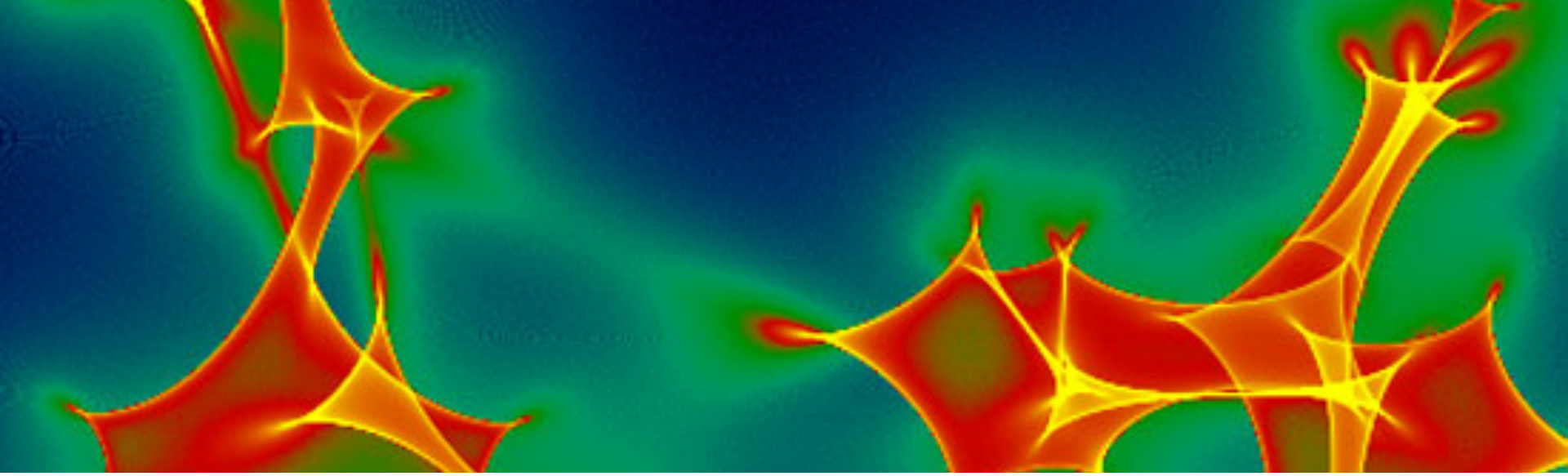

Caustic Crossing at Giga-Parsecs Away and Micro-Lensing

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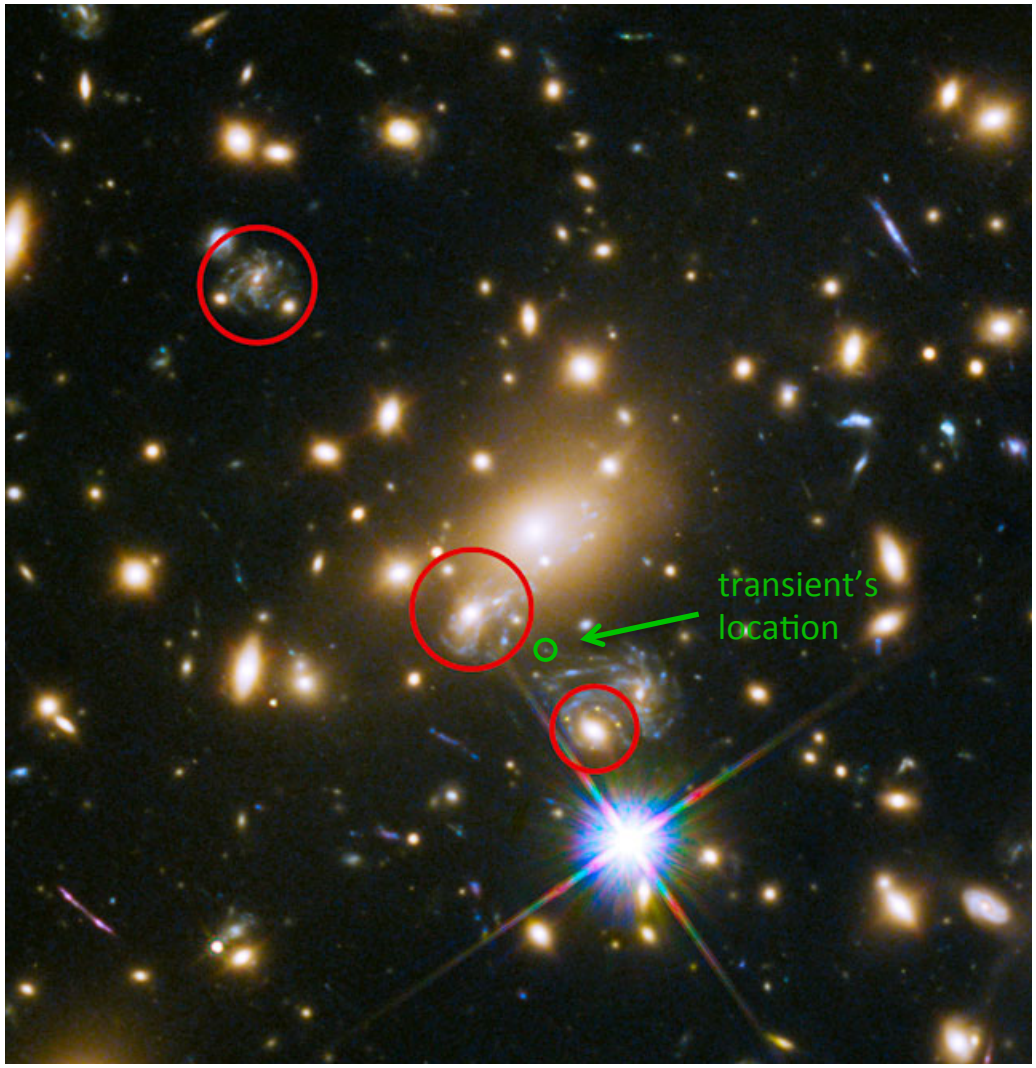
In collaboration with
Tejaswi Venumadhav & Jordi Miralda-Escudé

Einstein Fellowship Symposium
Oct 2015

HST saw an intriguing transient

Astronomer's Telegram #9097 by Kelly+ in May 2016



Merging cluster MACS J1149+2223 at z~0.54

Lensing quad of SN Refdal in 2014 and reappearance of another image in late 2015

Host galaxy in the bkg. at z~1.5

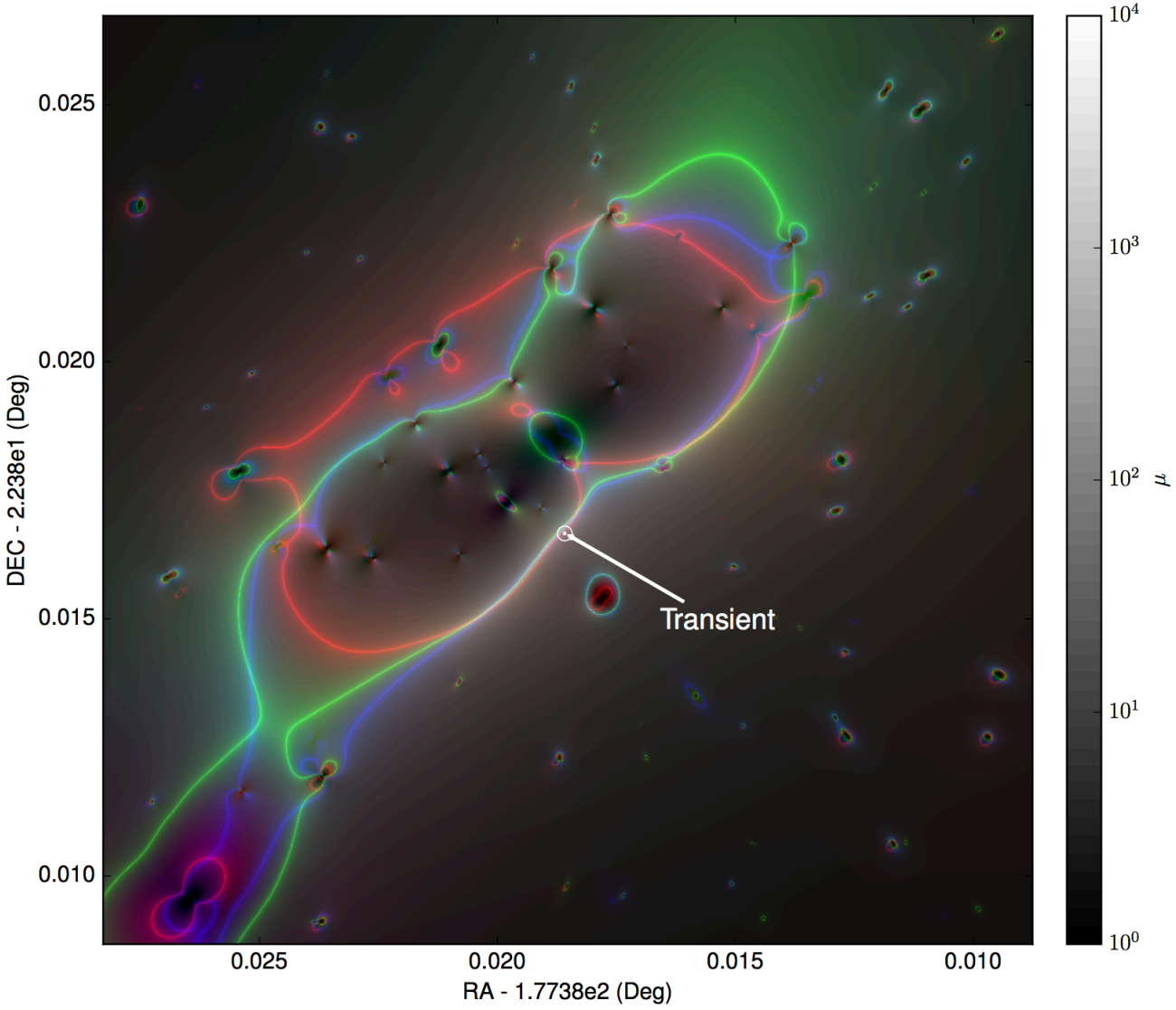
Point-like transient, slowly brightened to peak mag. 25.7 (F125W)

Quickly faded away in late June

Color resembles a B-type star at z~1.5 with a strong Balmer break

A caustic-crossing star at cosmological distance?

magnification map predicted by mass reconstruction for source at z = 1.5

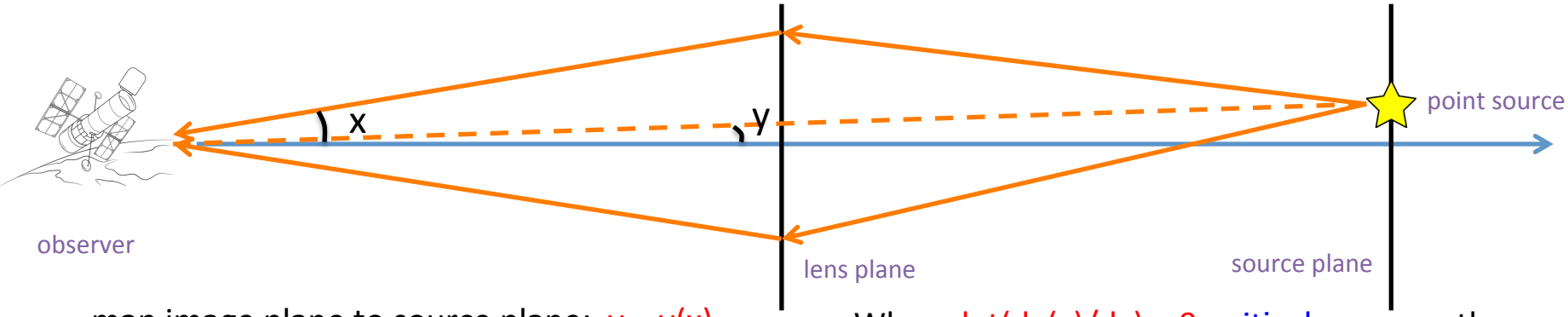


Frontier Field Lens Models

Zitrin-ltm
Sharon
GLAFIC

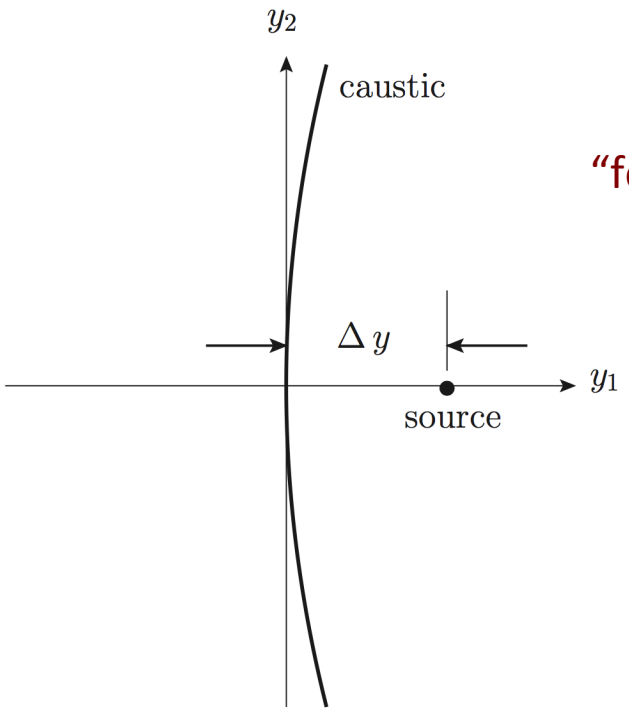
Coincidence with critical curve by foreground cluster lens!

Caustic & critical curves in gravitational lensing



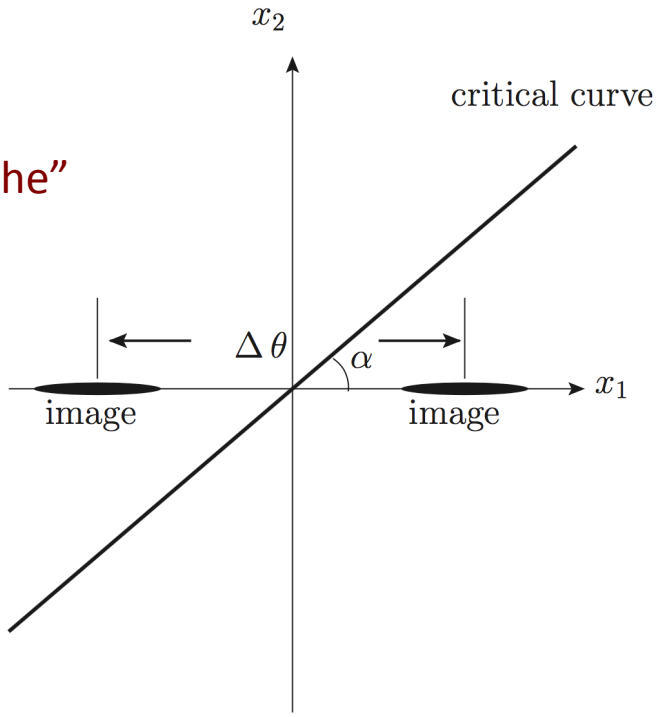
map image plane to source plane: y = y(x)
magnification: μ(x)=1/det(dy(x)/dx)

When det(dy(x)/dx) = 0, critical curve on the lens plane, and caustic on the source plane



source plane

"fold catastrophe"



lens plane

Light curve during caustic crossing

Miralda-Escudé 1991

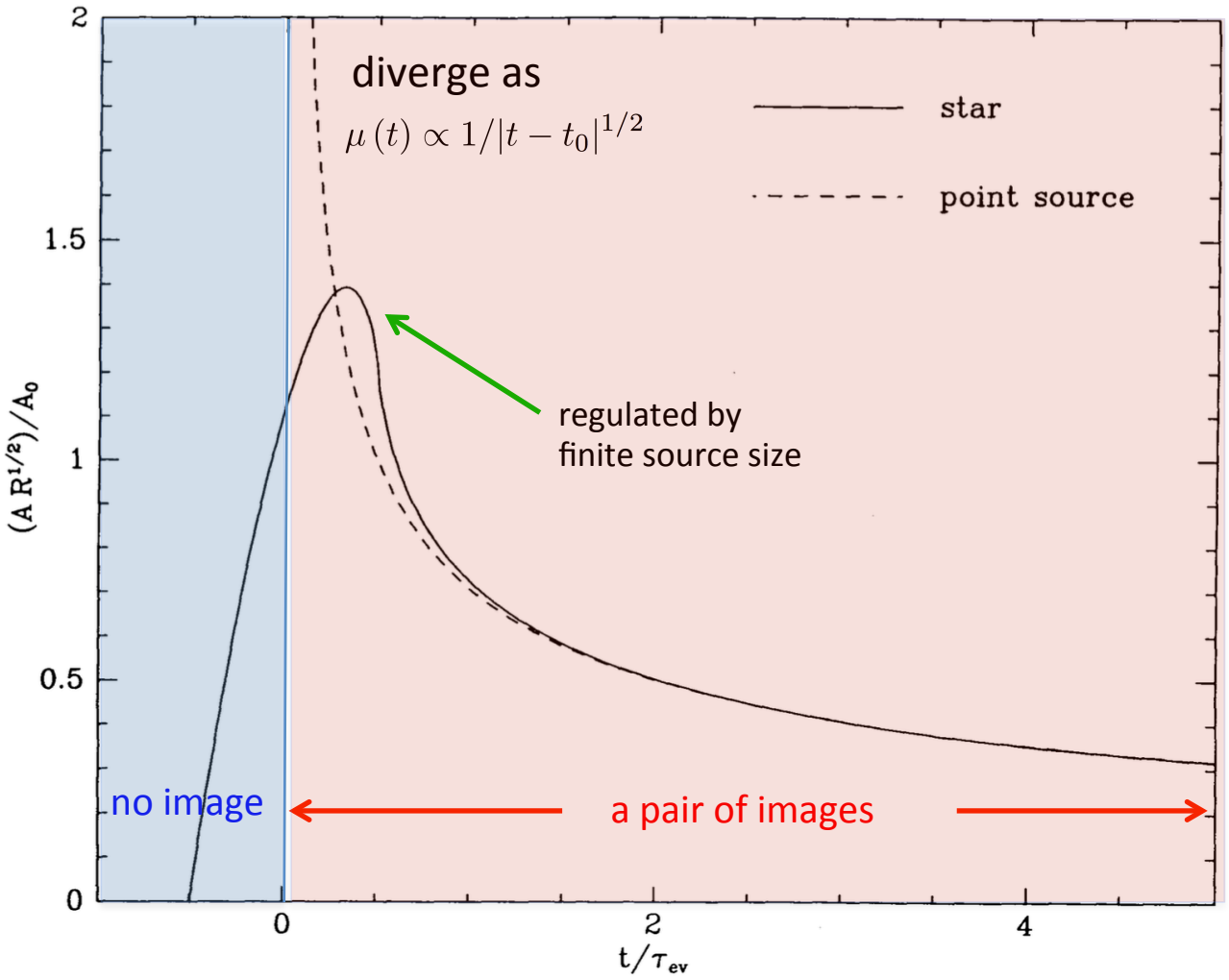


Image separation ~ micro arcsec, unresolvable

infinite magnfication can be regulated for two reasons:

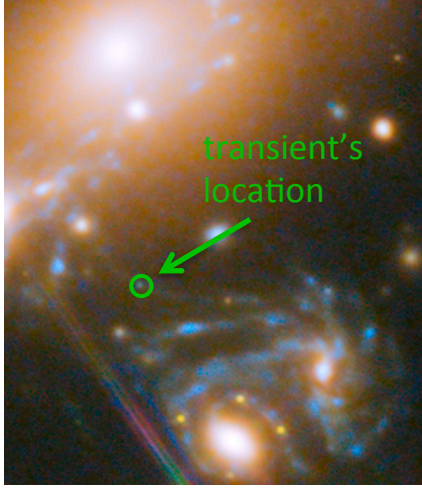
(1) Finite source size < 10^7 for one solar radius

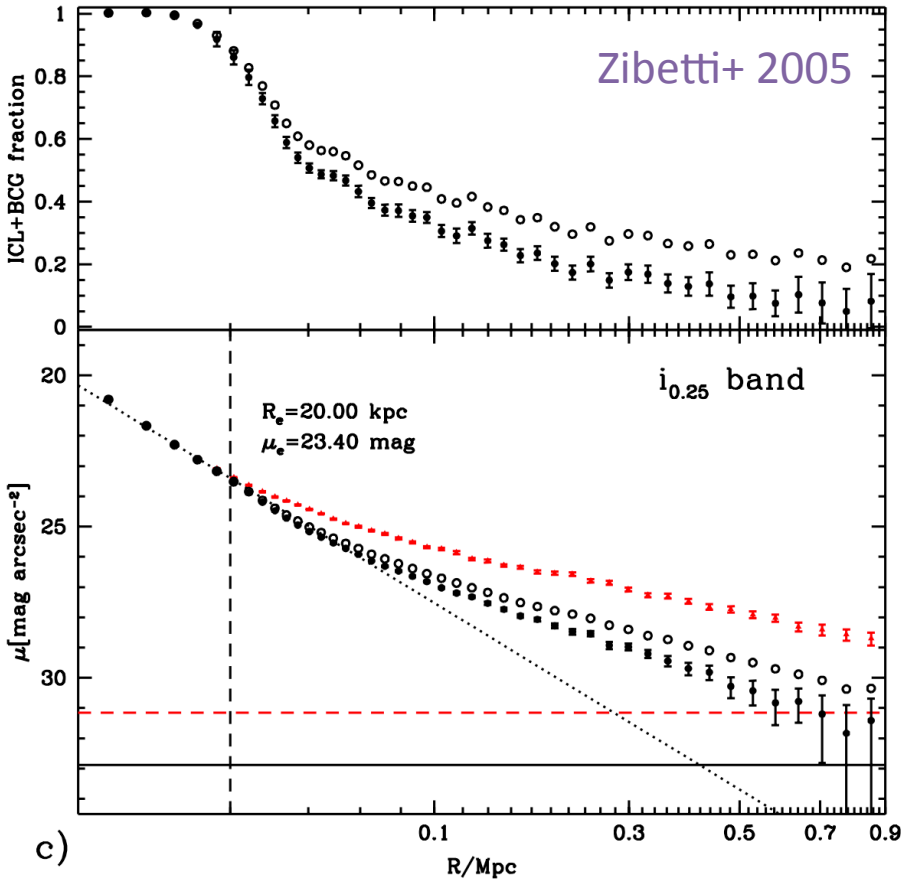
(2) Diffraction < 10^9 at ~ 10^{15} Hz

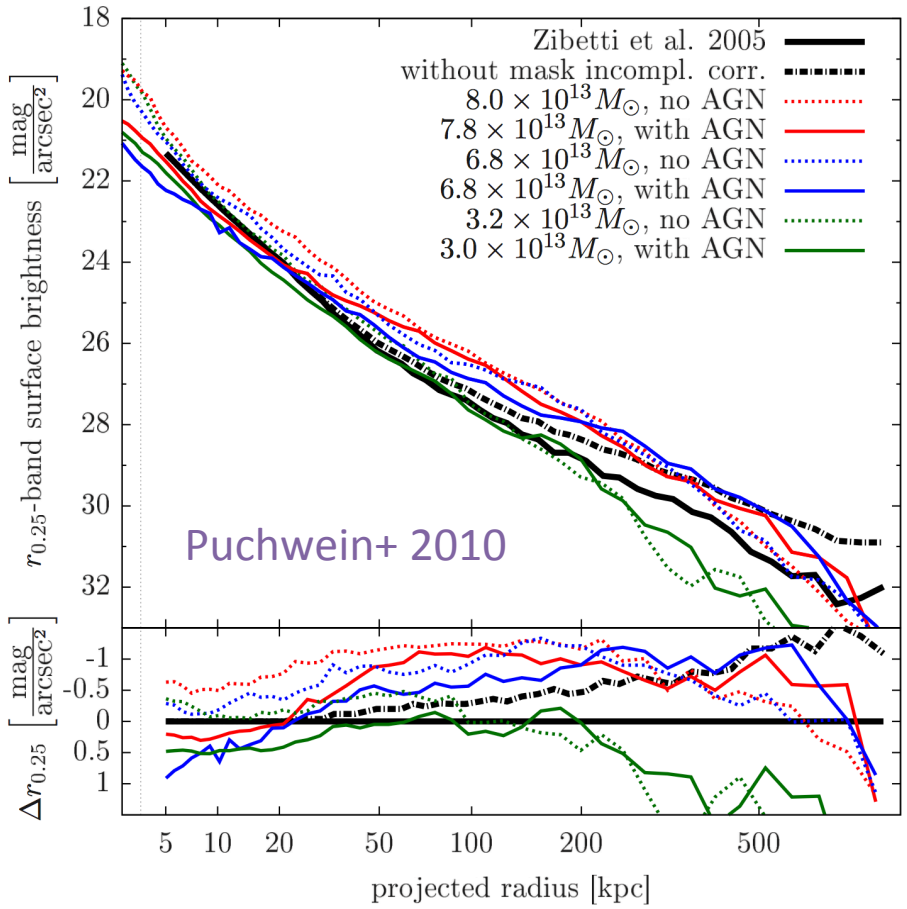
KEY ASSUMPTION: smooth mass distribution on the lens plane

Why should mass not be smoothly distributed?

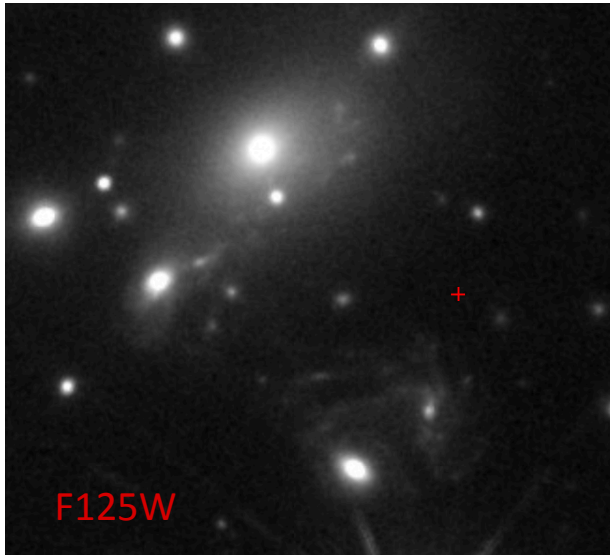
Line of sight ~ 60kpc away from the BCG
Expected to traverse a halo of intracluster stars !
Formation: merger assembly and tidal disruption

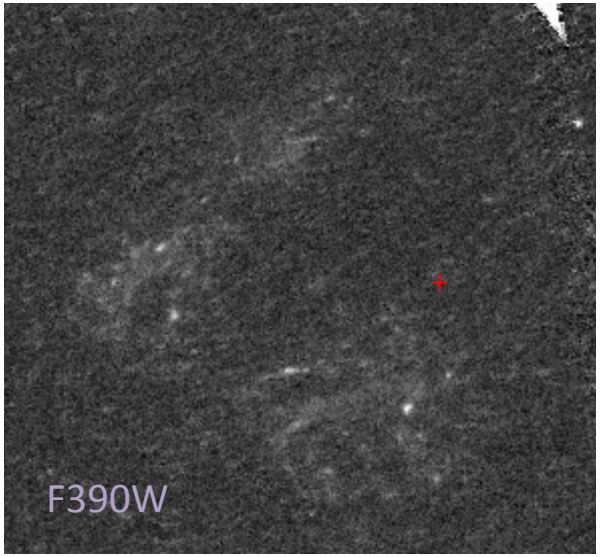




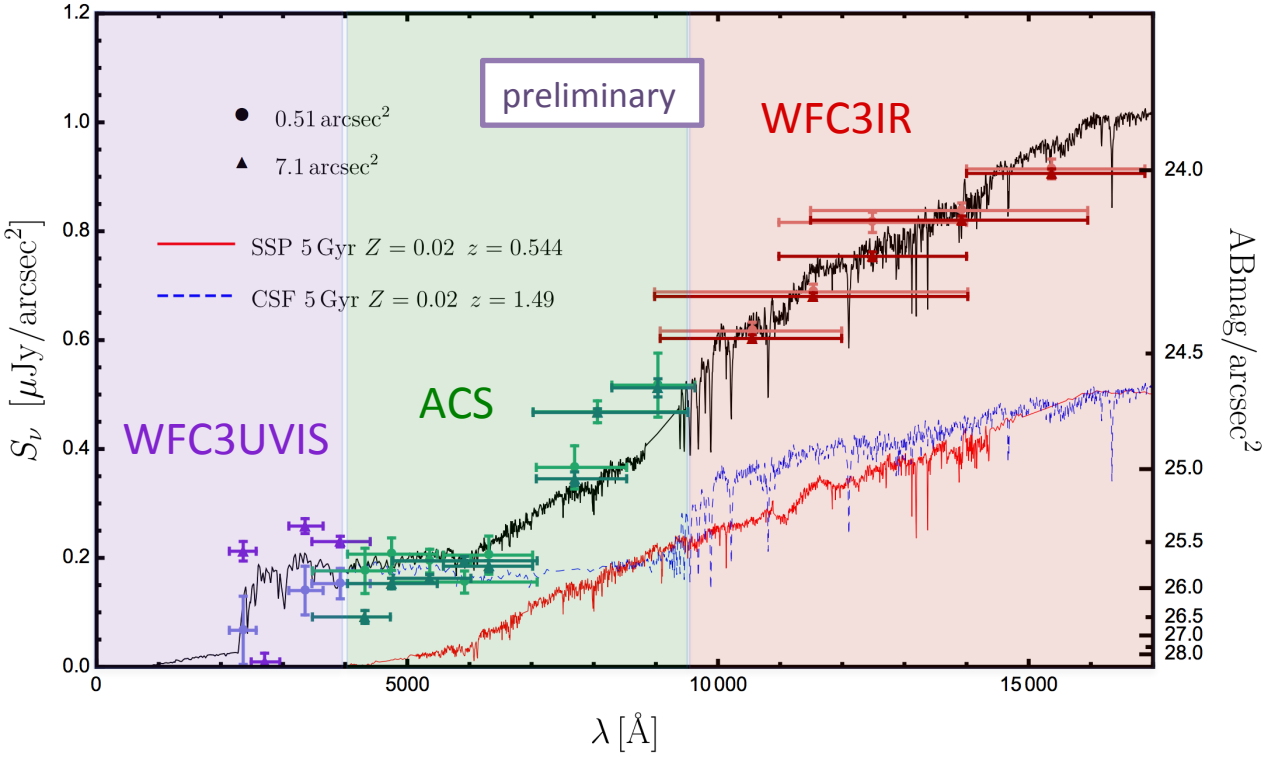


Significant projected density of intracluster stars as micro-lenses





Measure surface brightness color prior to transient (HST images from 2014)



Foreground intracluster stars

+

Background star-forming galaxy

$$\Sigma_\star \sim 10^9 M_\odot/\mathrm{arcsec}^2$$

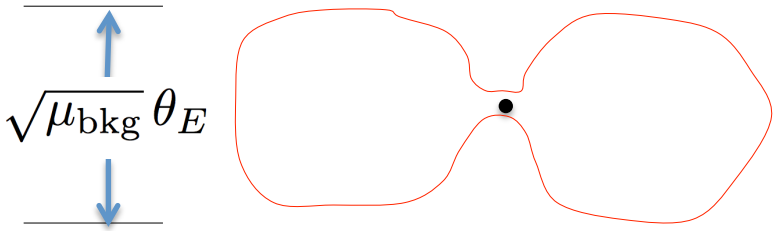
Why stellar micro-lensing is significant?

An isolated star: tiny Einstein cross section, very unlikely to cause strong lensing

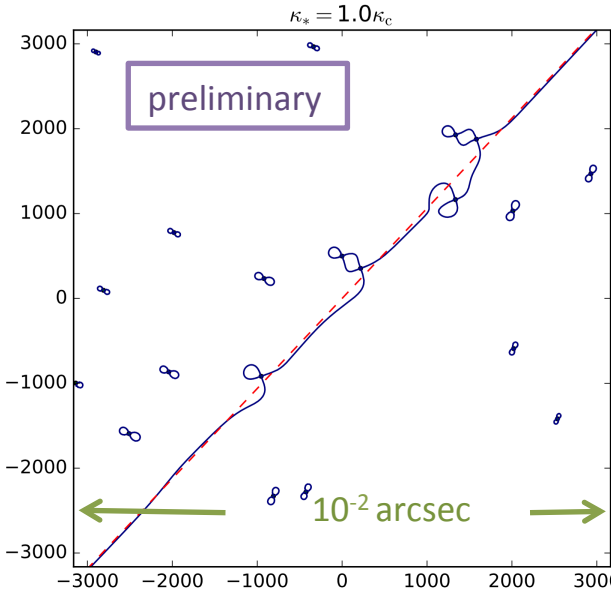
$$\theta_E = \left[4GM\frac{D_{LS}}{D_L D_S}\right]^{1/2} \sim 10^{-6}\mathrm{arcsec}$$

By contrast, cluster lensing has typical angular scale ~ arcmin

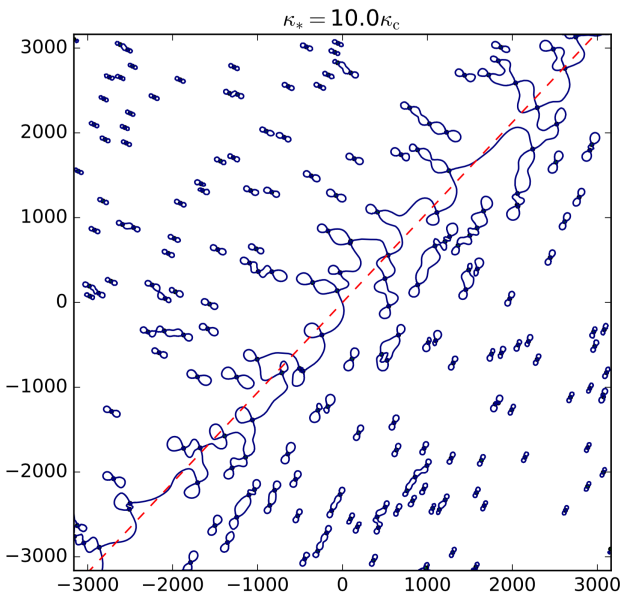
Under the influence of a massive cluster:
Bkg. Magnification and shear ~ 10^3 – 10^6 near macro-critical curve!



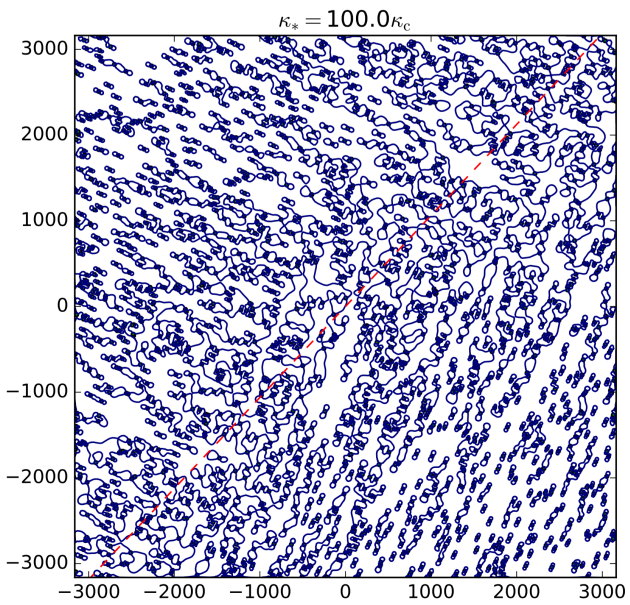
Disruption of smooth critical curve



occasionally perturbed



entirely disrupted



corrugated network

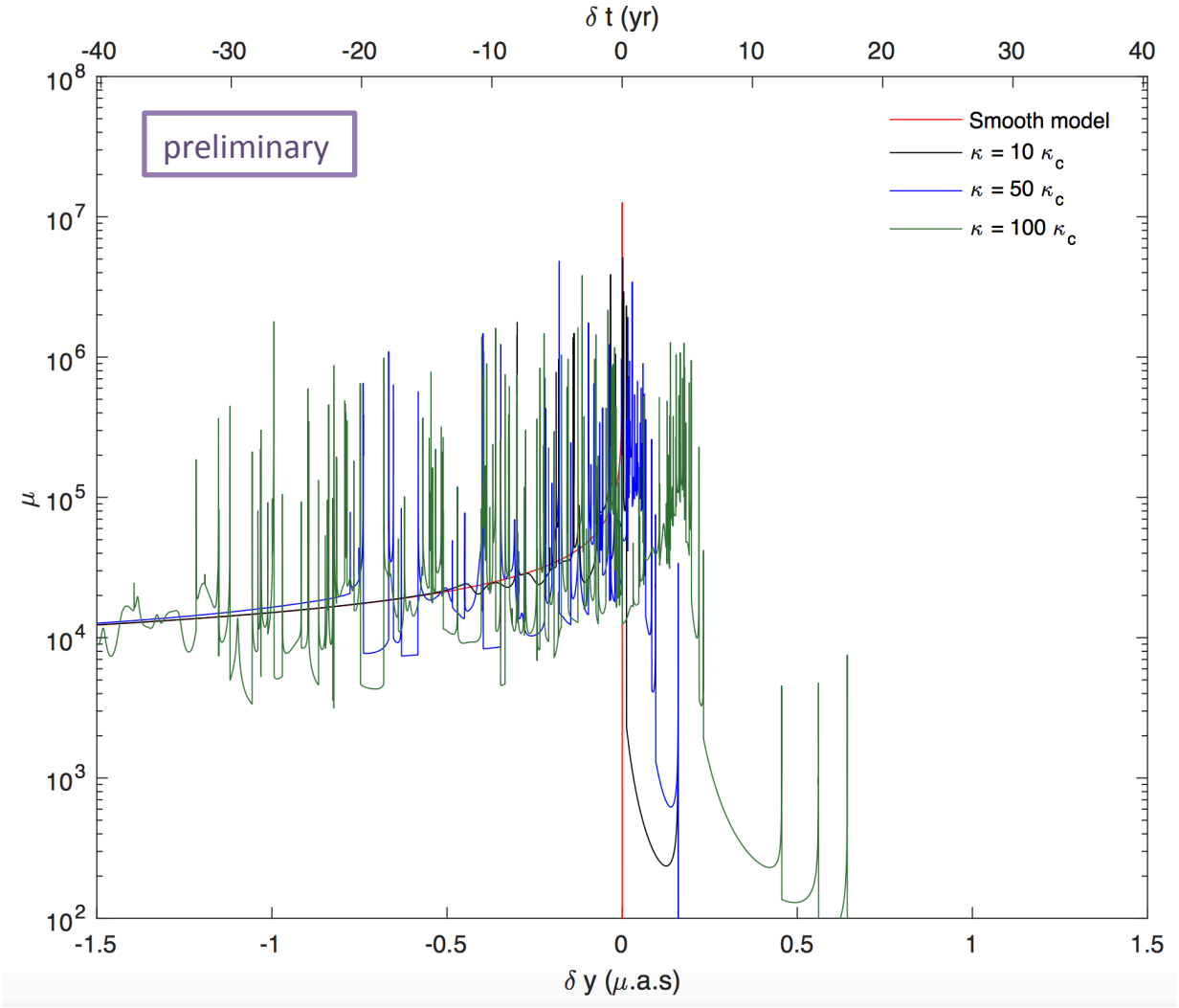
critical surface density for stars $\kappa_c \sim (\theta_E/\theta_C)^{2/3} \sim 10^{-5}\left(\frac{\theta_E}{10^{-6}arcsec}\right)^{2/3}\left(\frac{arcmin}{\theta_C}\right)^{2/3} \ll 1$

Light-to-mass conversion: $\kappa_\star = \frac{\Sigma_F}{\Sigma_{\rm crit}} = 4\pi\, G\, \Sigma_F\, \frac{D_{LS}}{D_L\, D_S} = 0.01\left(\frac{\Sigma_F}{10^9\, M_\odot/{\rm arcsec}^2}\right)$

Deep in super-critical regime, very costly to simulate numerically:

- finding all images
- accurately resolve every micro-caustic crossing

Effects on the transient's light curve



- Brightness spikes from micro-caustic crossing.
- Reduction of peak magnification; This constrains the source's intrinsic luminosity

$$\mu_{\max} \sim \frac{1}{|1-\kappa_0|}\left(\frac{D_S}{2\,R\,d}\right)^{1/2}\left(\frac{\kappa_c}{\kappa_\star}\right)^{3/2}$$

- A prolonged ``disappearing'' phase
- Duration above detection threshold.

Conclusion & Outlook

- If the transient really is a caustic-crossing star, smooth model of lens mass is not applicable. Microlensing by intracluster stars are expected to entirely disrupt the smooth critical curve and cause huge fluctuations in the light curve.

- Interesting to estimate the rate of this kind of event. Strong lensing systems with background galaxies lying behind critical curves are excellent targets. Microlensing appears to have a big effect on the detectability of caustic-crossing stars. Even unresolvable events can cause non-trivial brightness variation in individual pixels.

- Constraint can be put on clumpy dark matter substructure (e.g. MACHOs, compact halos). Dark matter clumps should not cause more microlensing fluctuations than observed.