

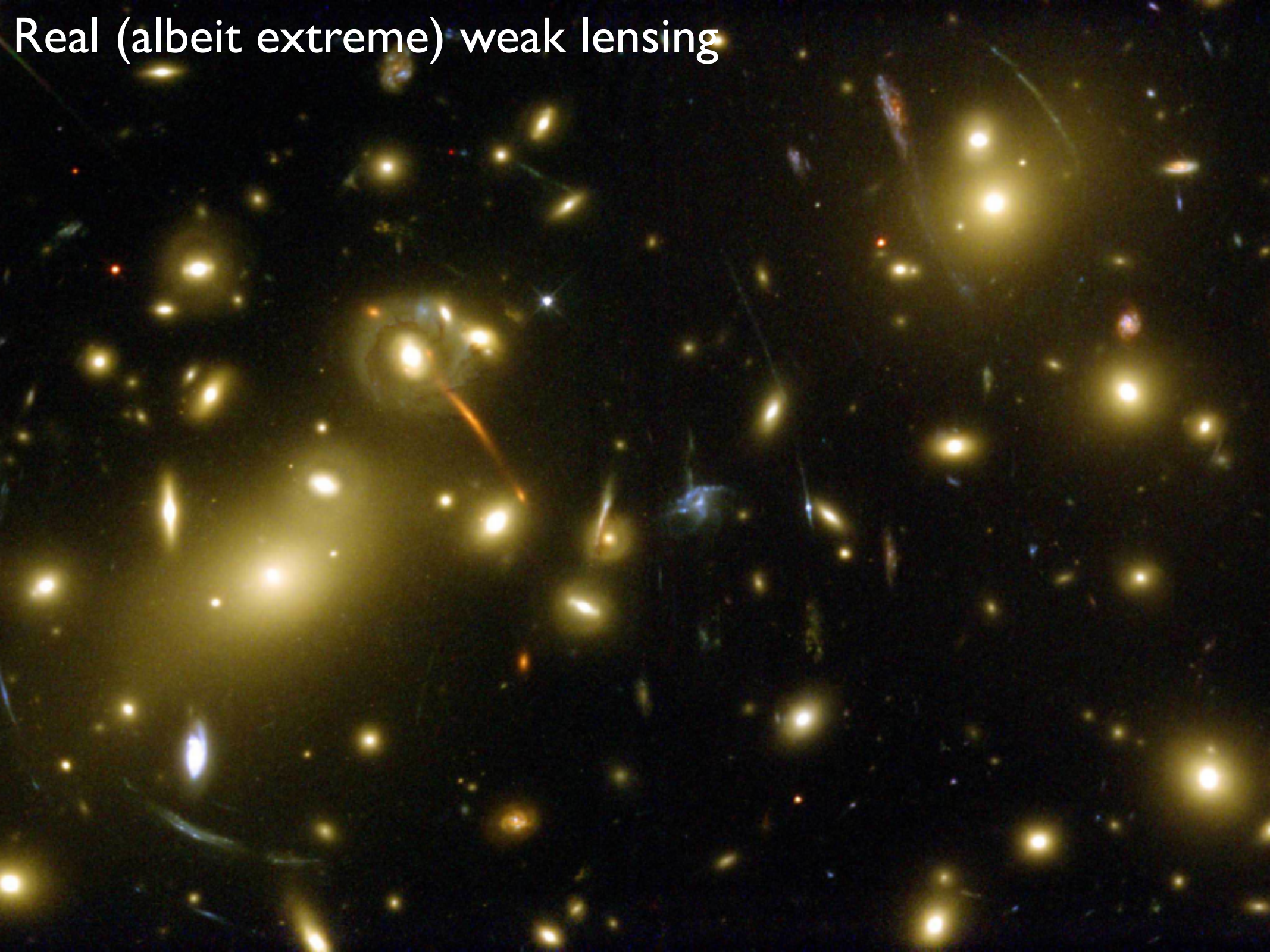
Today: gravitational lensing

- discuss Khoury's talk
- weak lensing
- strong lensing
- microlensing

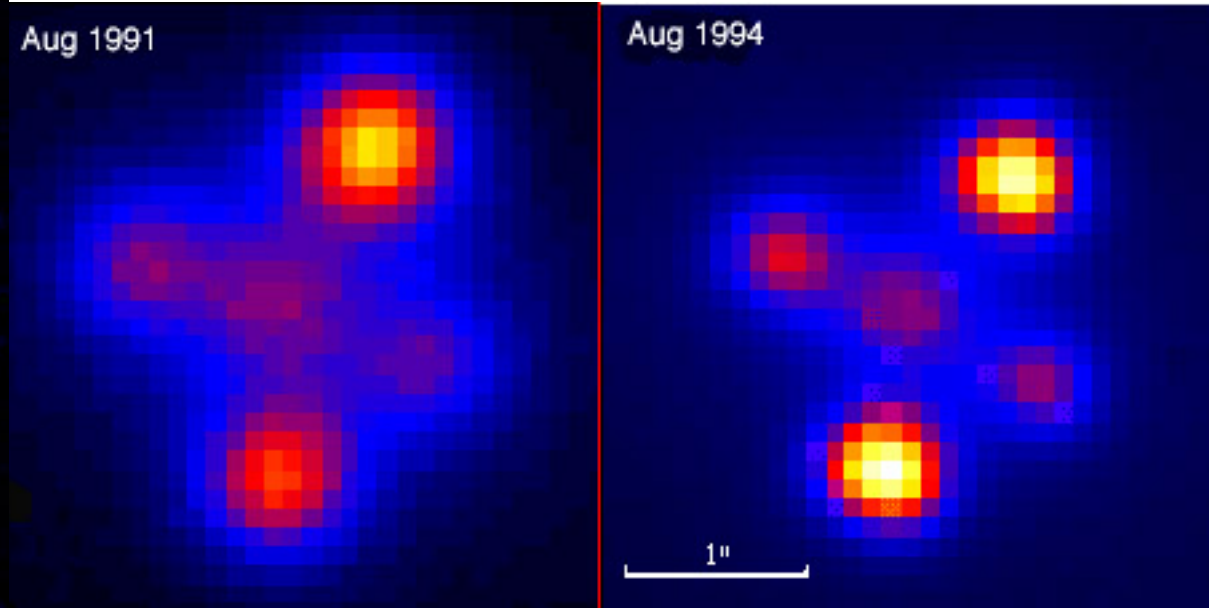
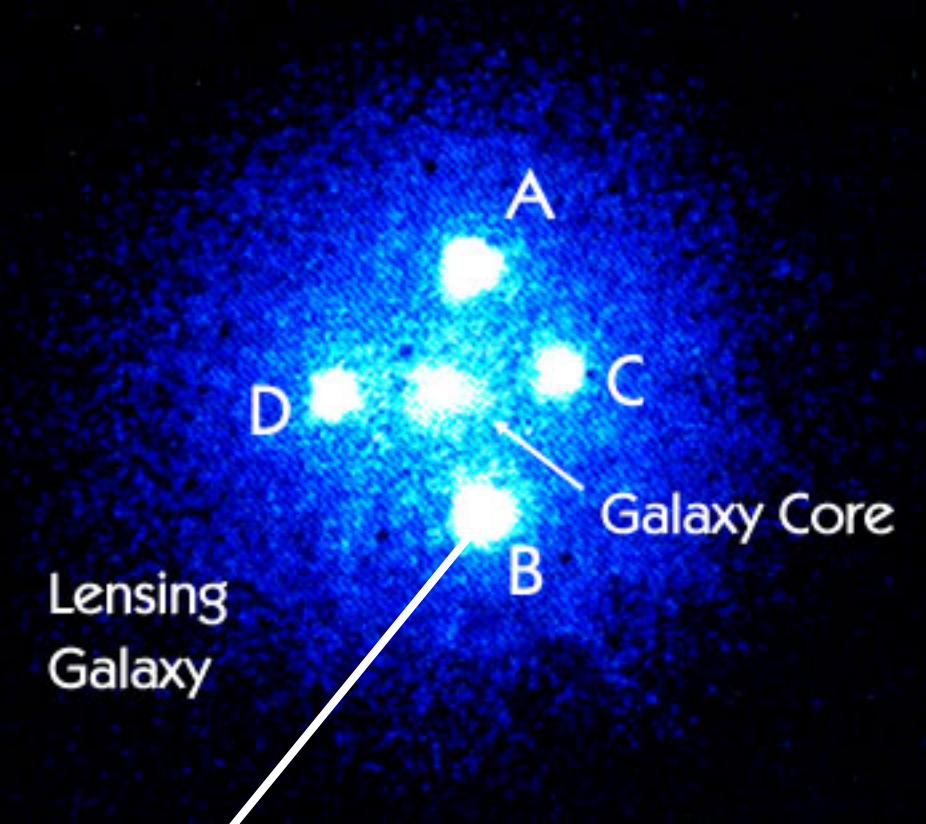
Fake illustration of weak lensing



Real (albeit extreme) weak lensing

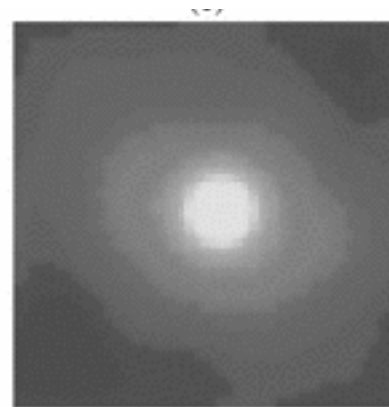
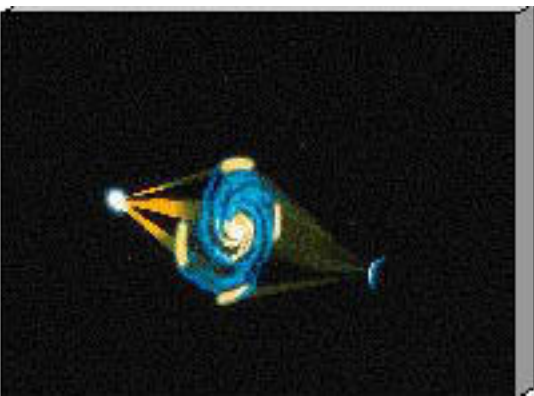


Strong lensing: Einstein Cross

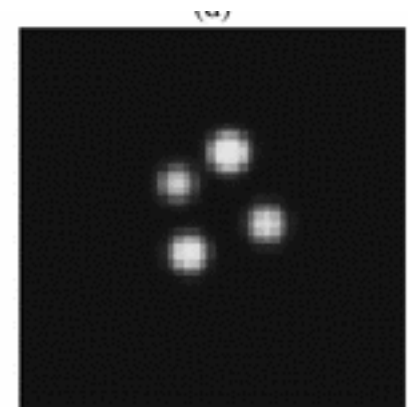


time variable multiple QSO image

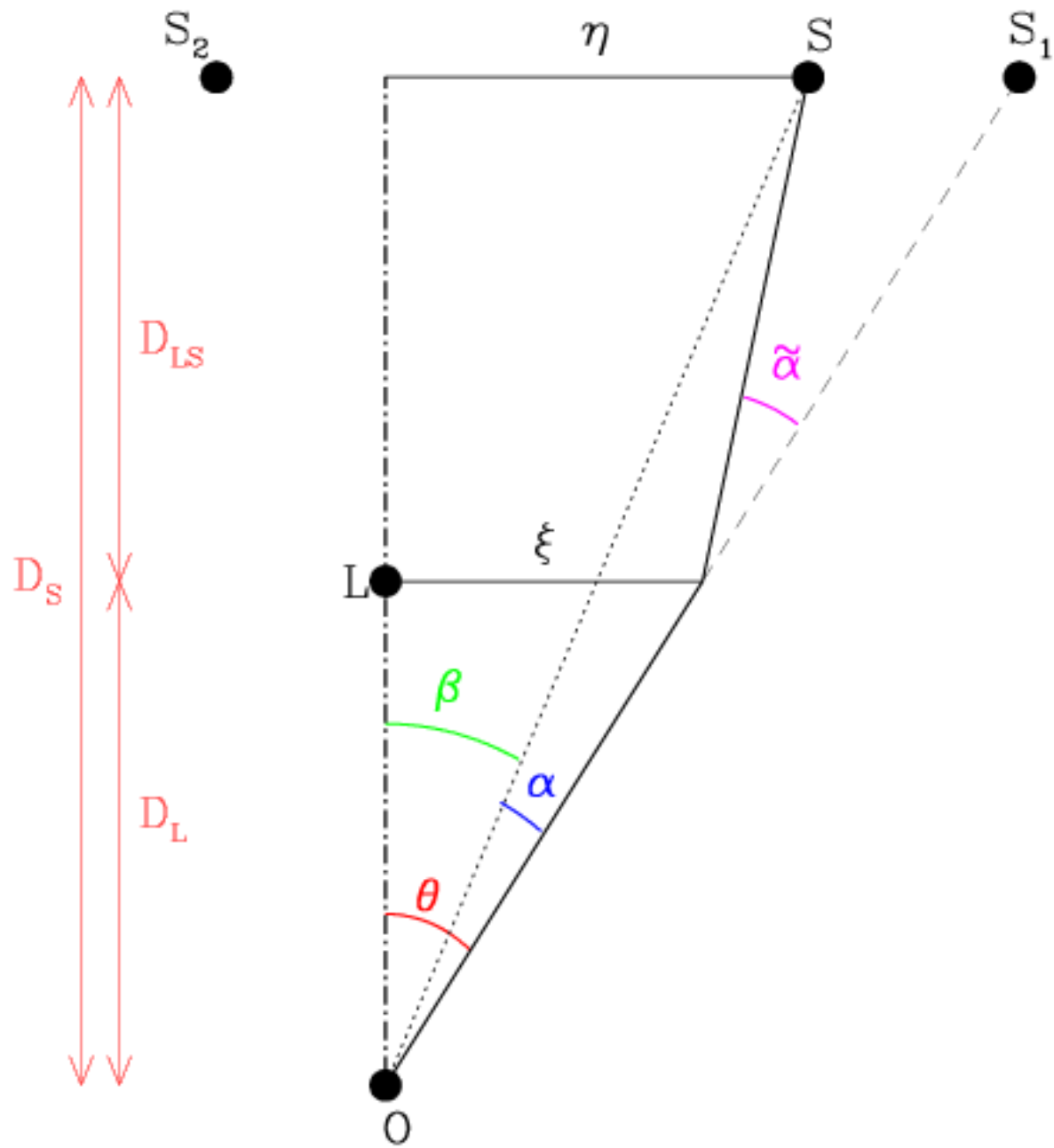
ABCD: same QSO seen 4 times



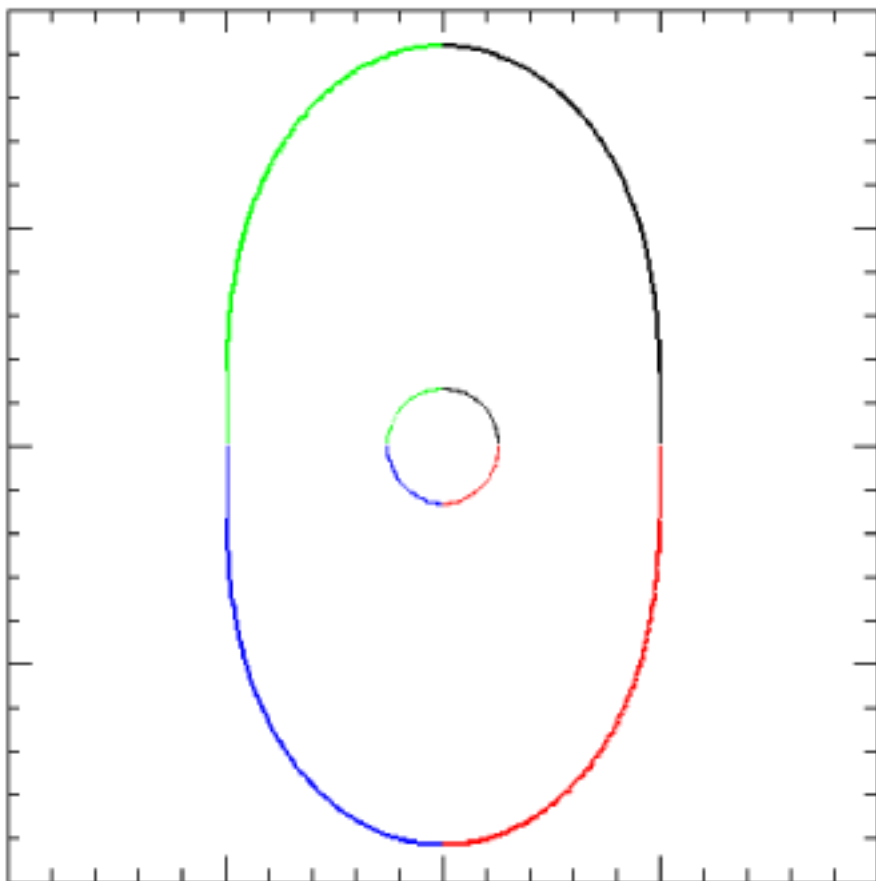
lensing galaxy



lensed QSO

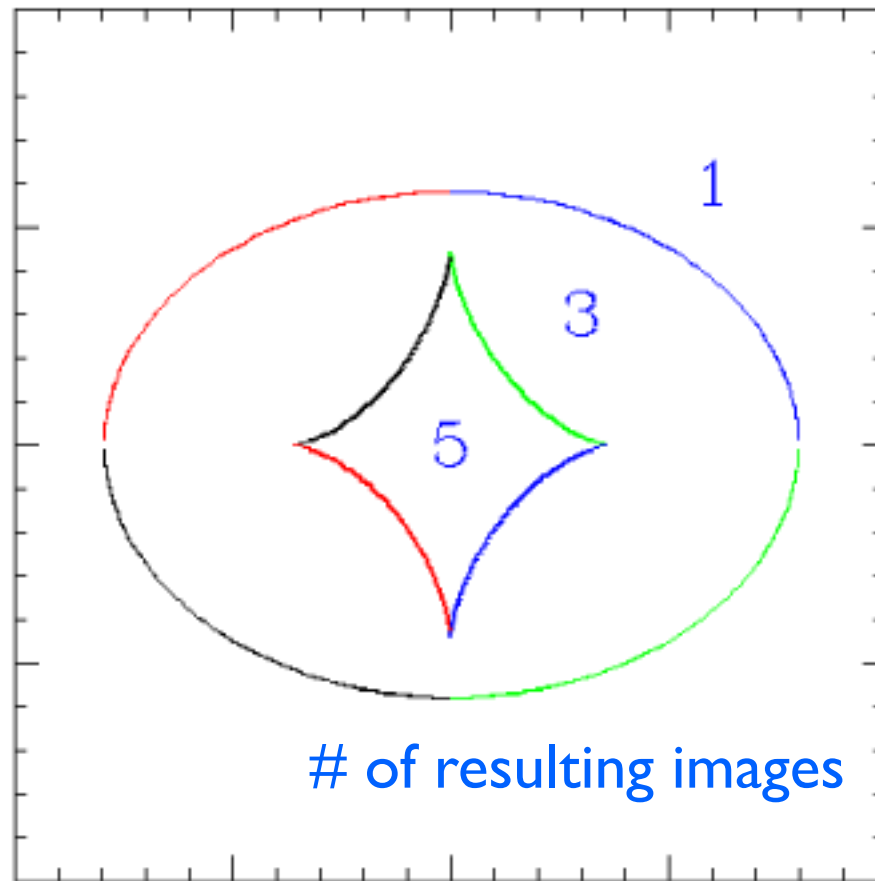


Lens plane



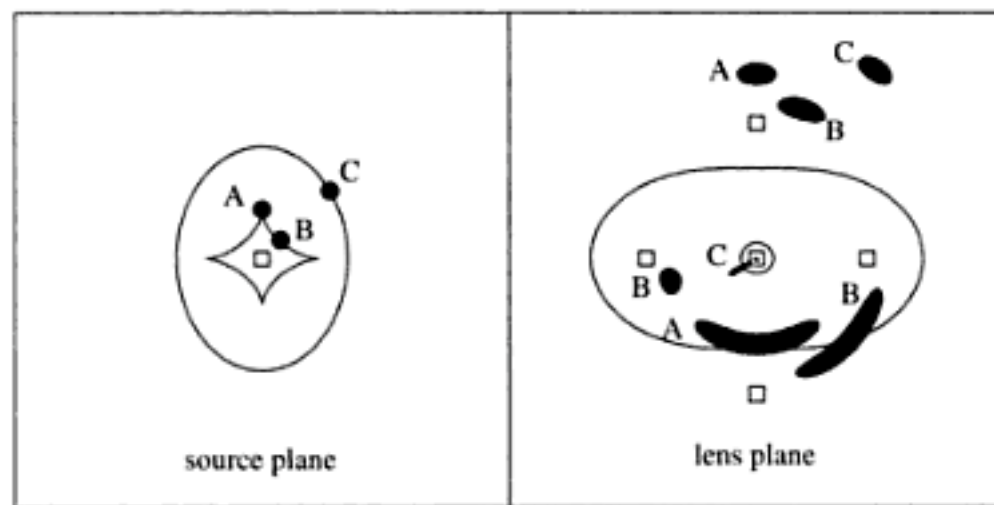
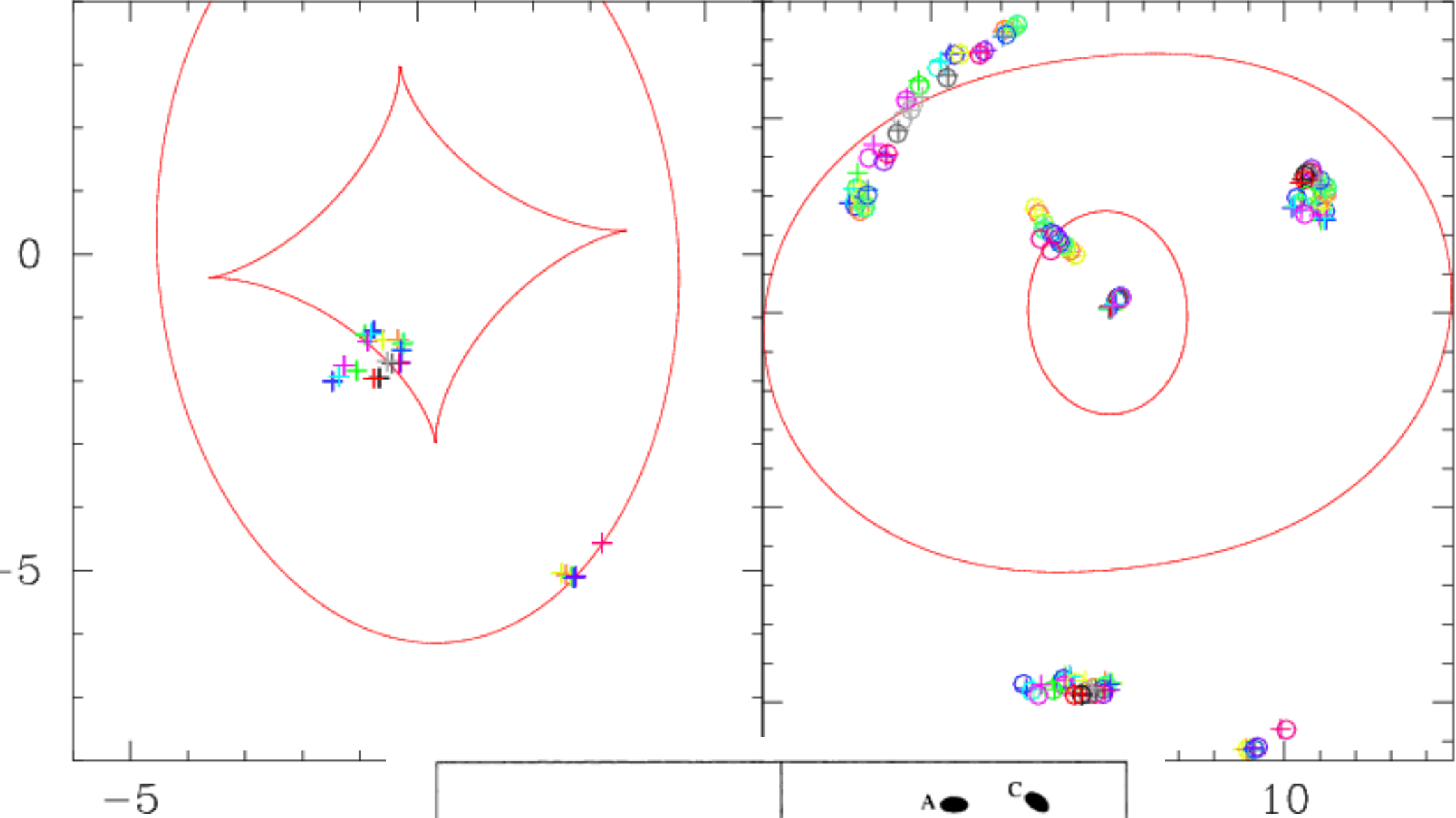
critical curves

Source plane

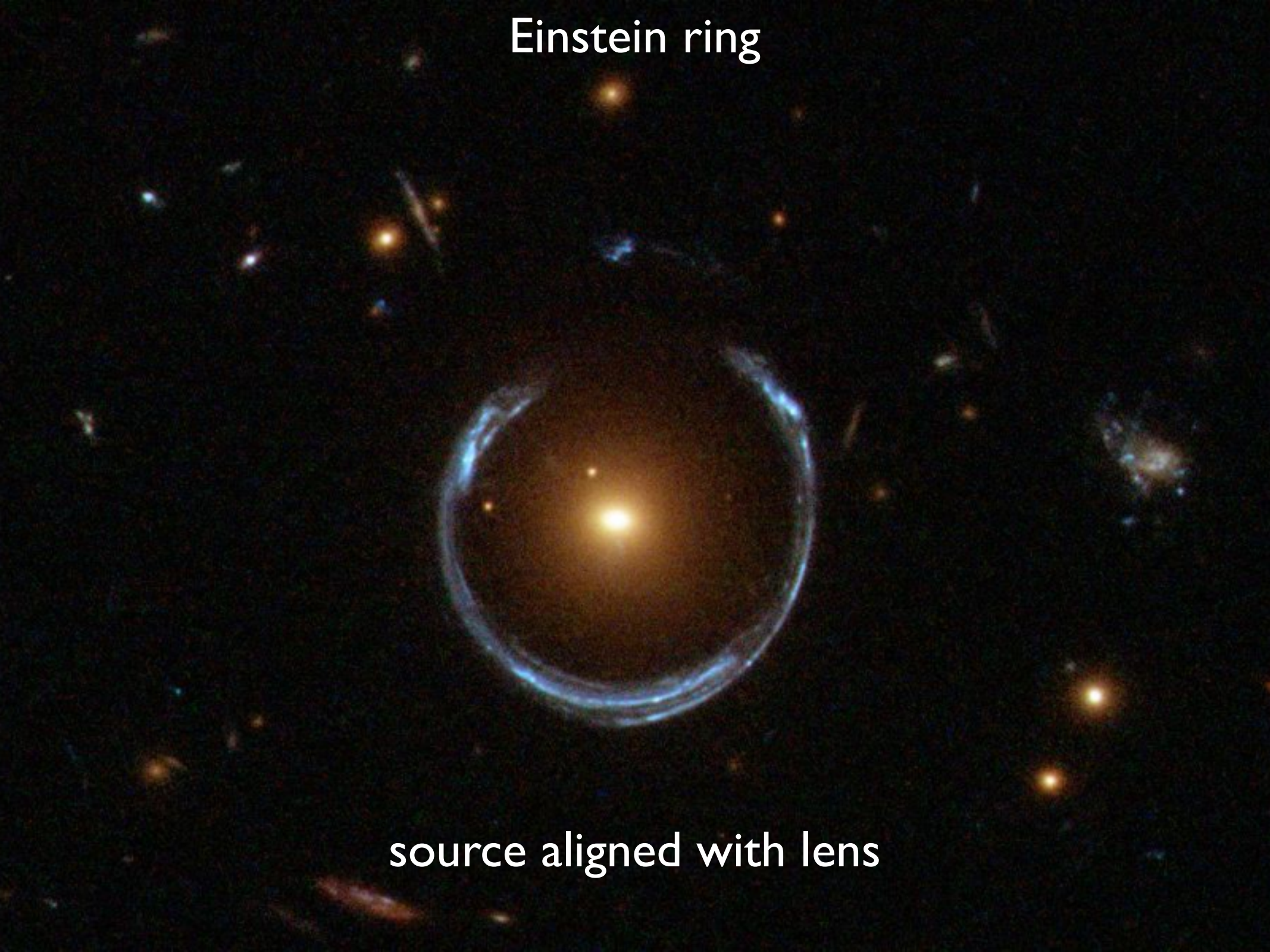


of resulting images

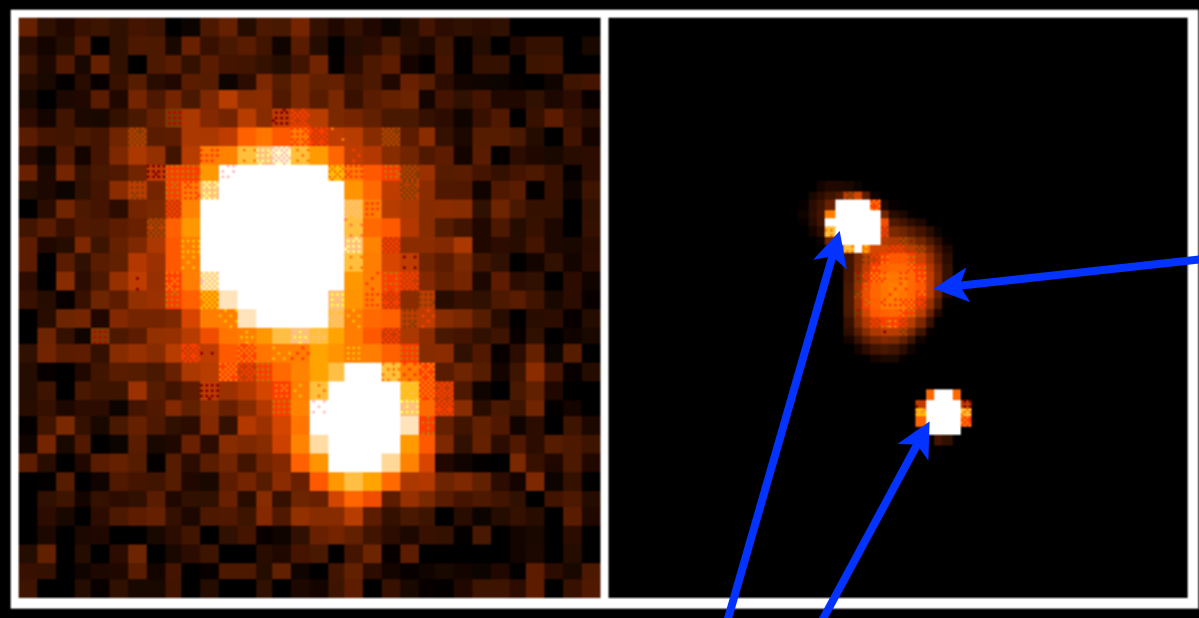
caustics



Einstein ring

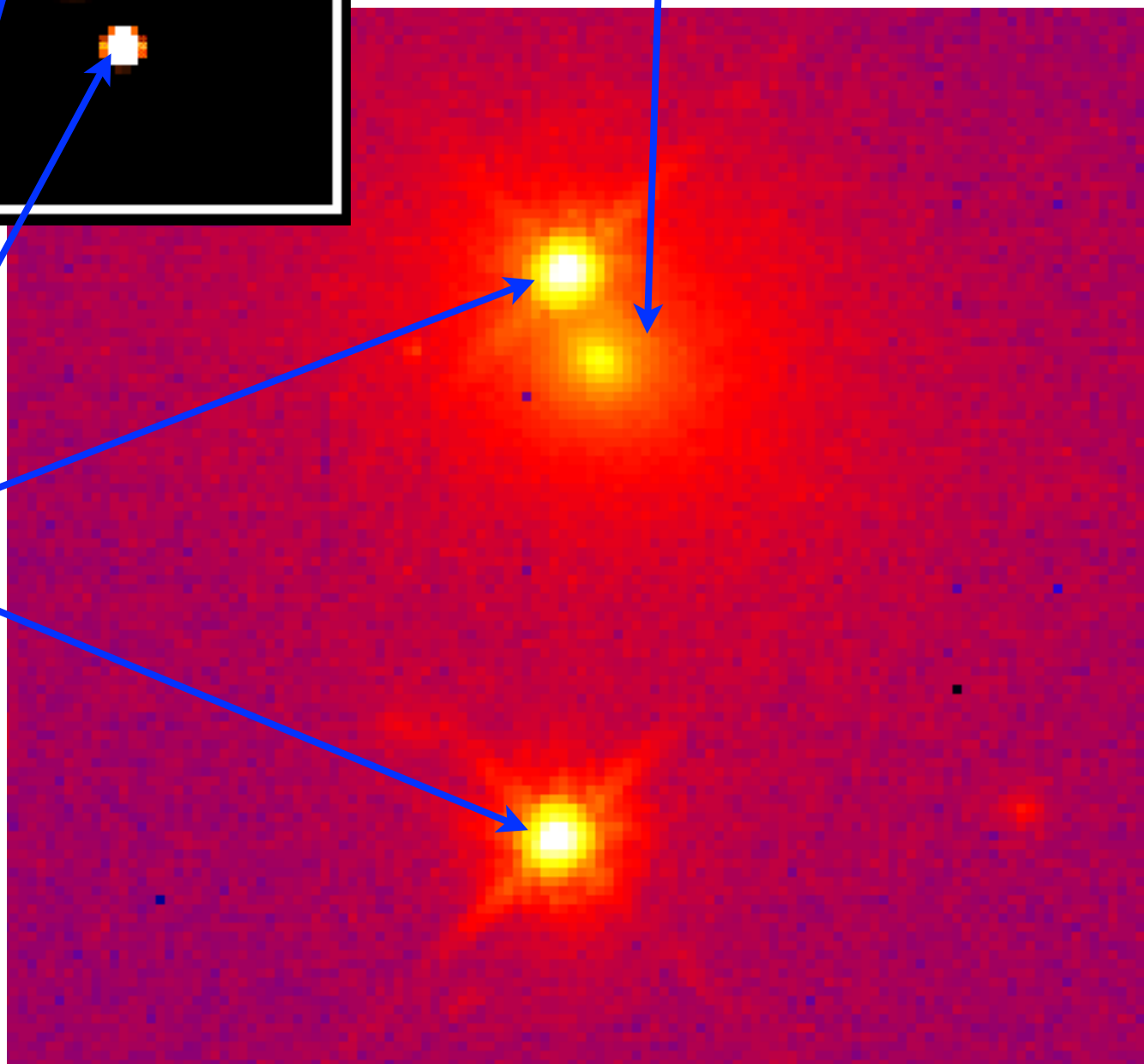


source aligned with lens



Lensing galaxy

Lensed images

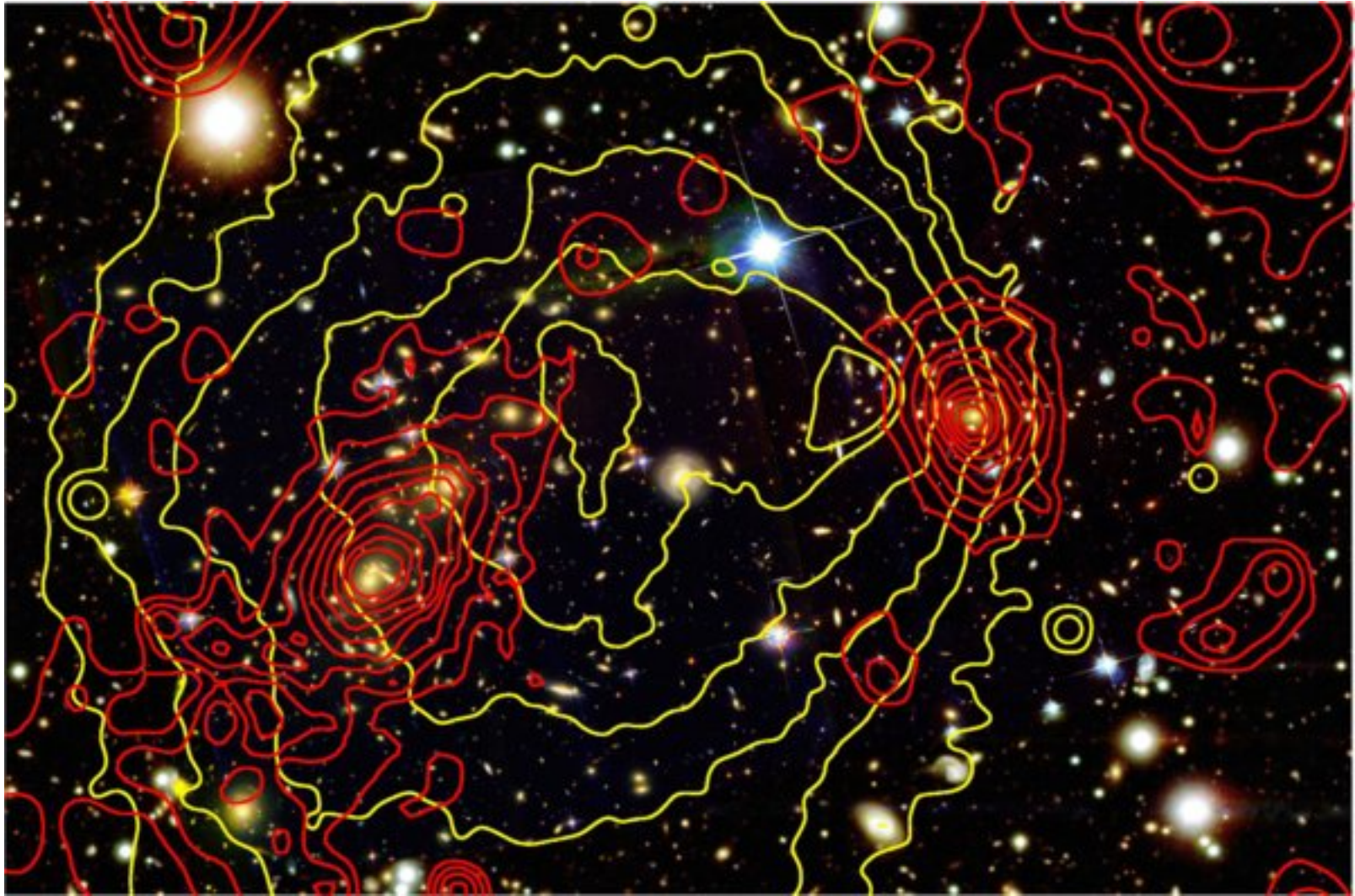


Bullet cluster (press release version)



Bullet cluster (Bradac et al. 2009)

X-ray: yellow contours

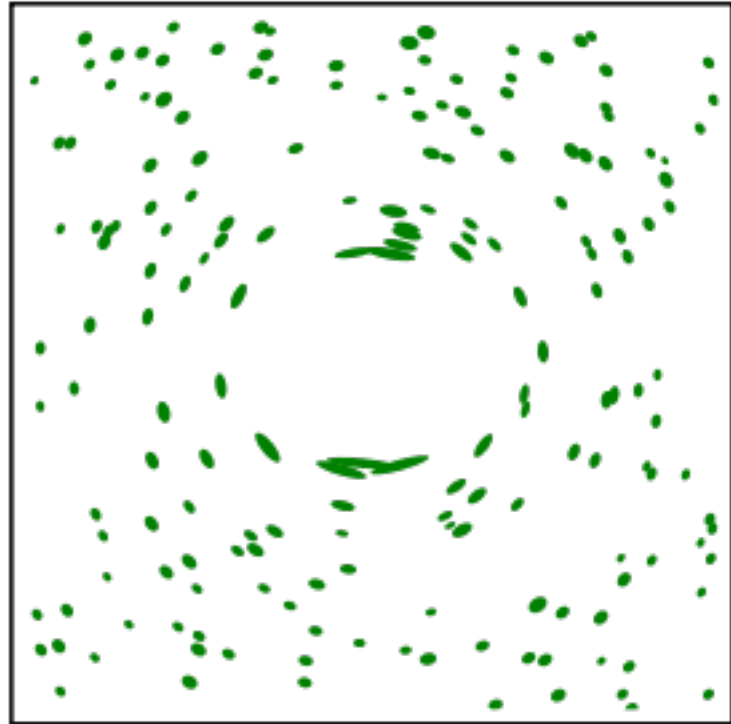
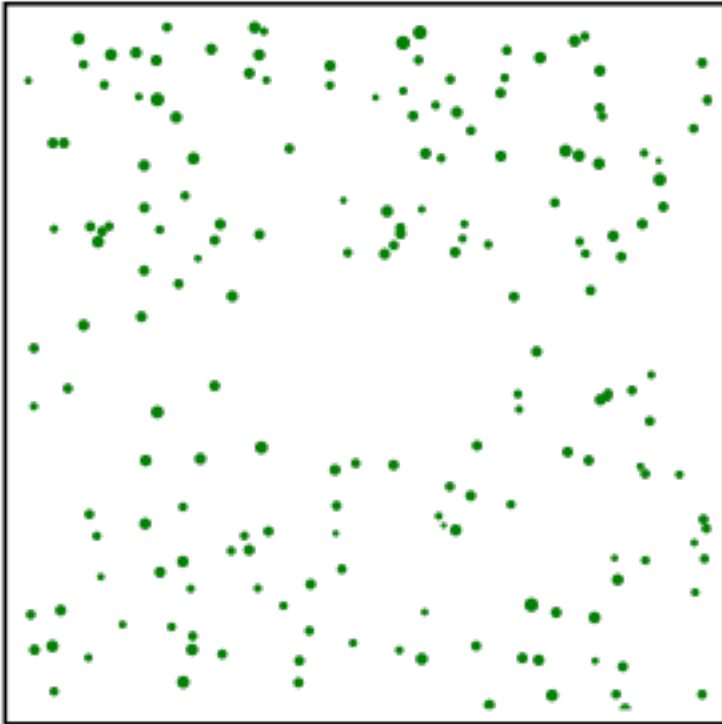


gravitational (strong+weak) lensing: red contours

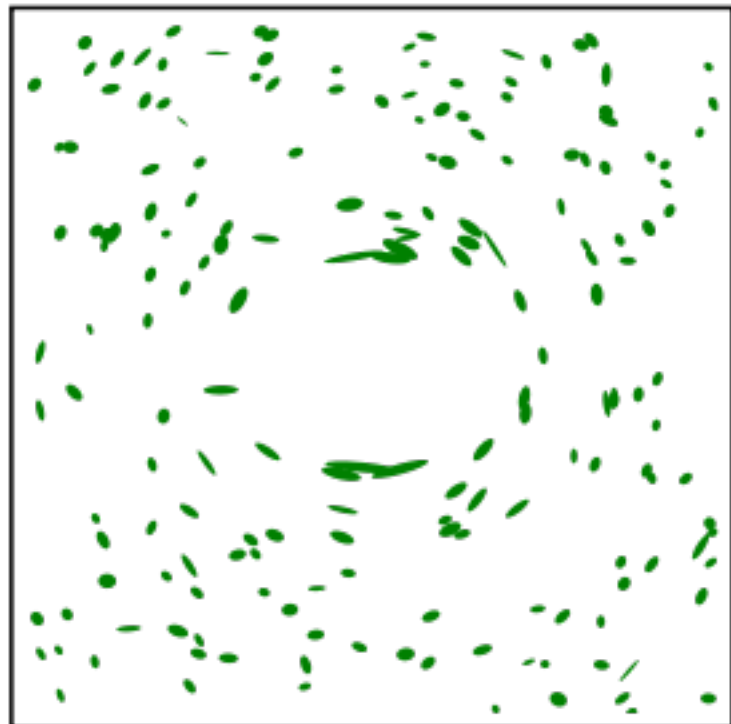
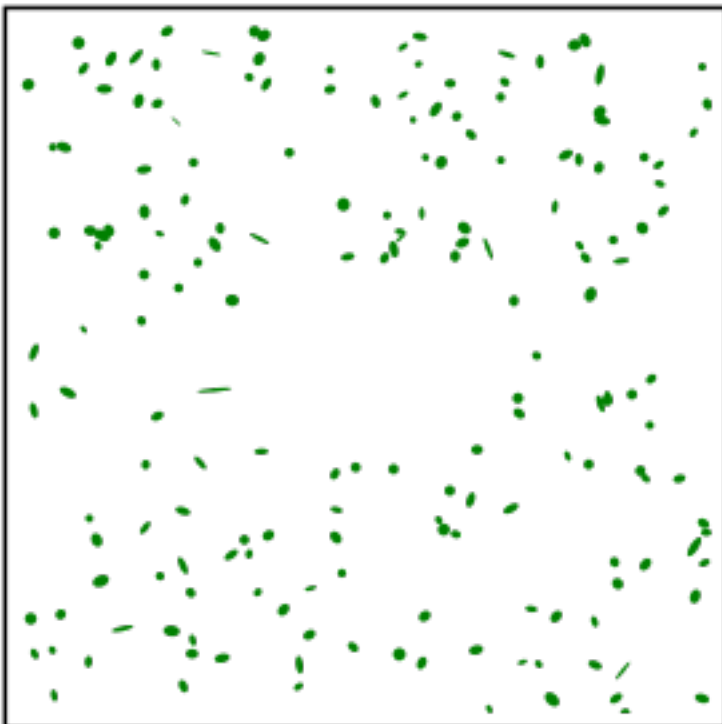
Unlensed

Lensed

Without Shape Noise

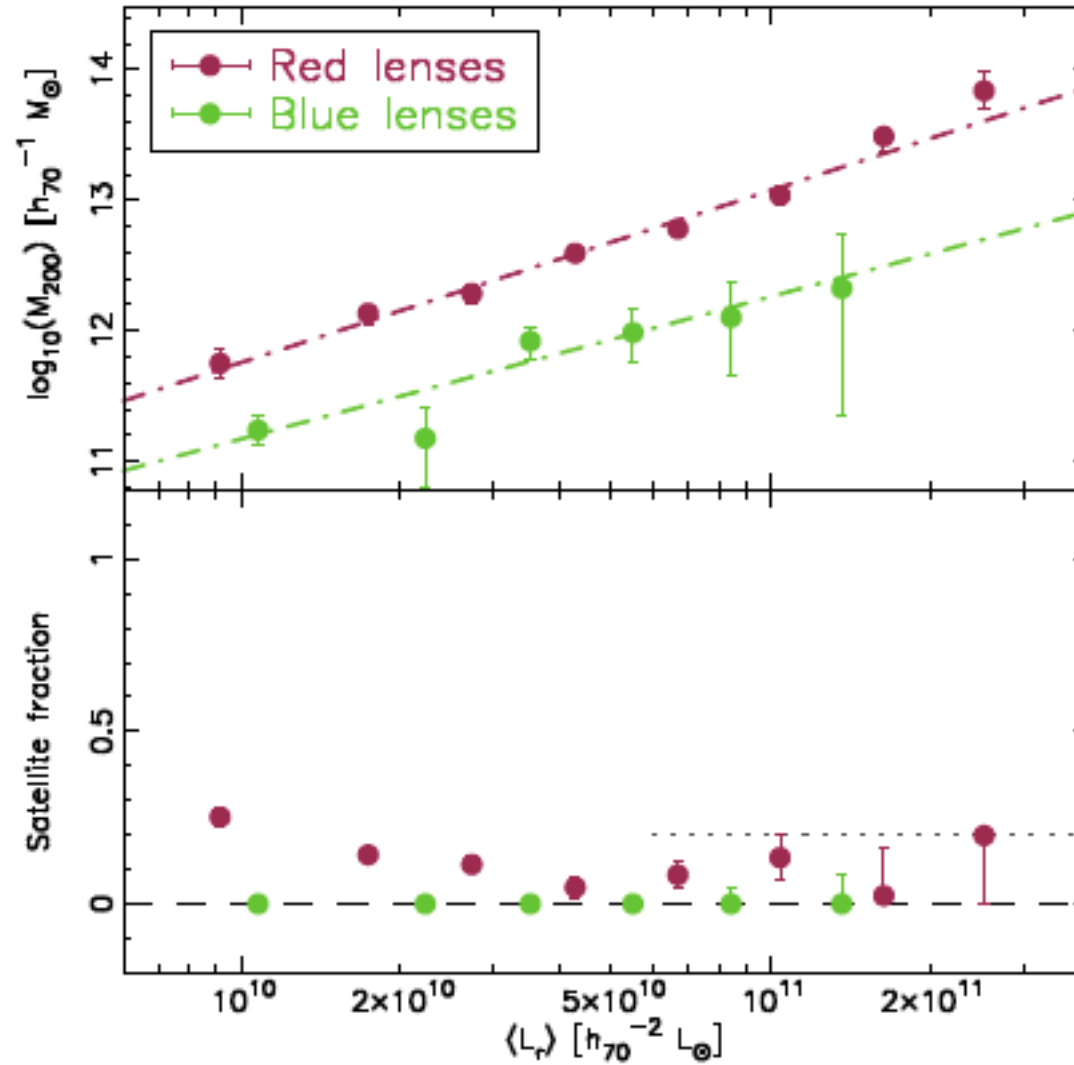


With Shape Noise



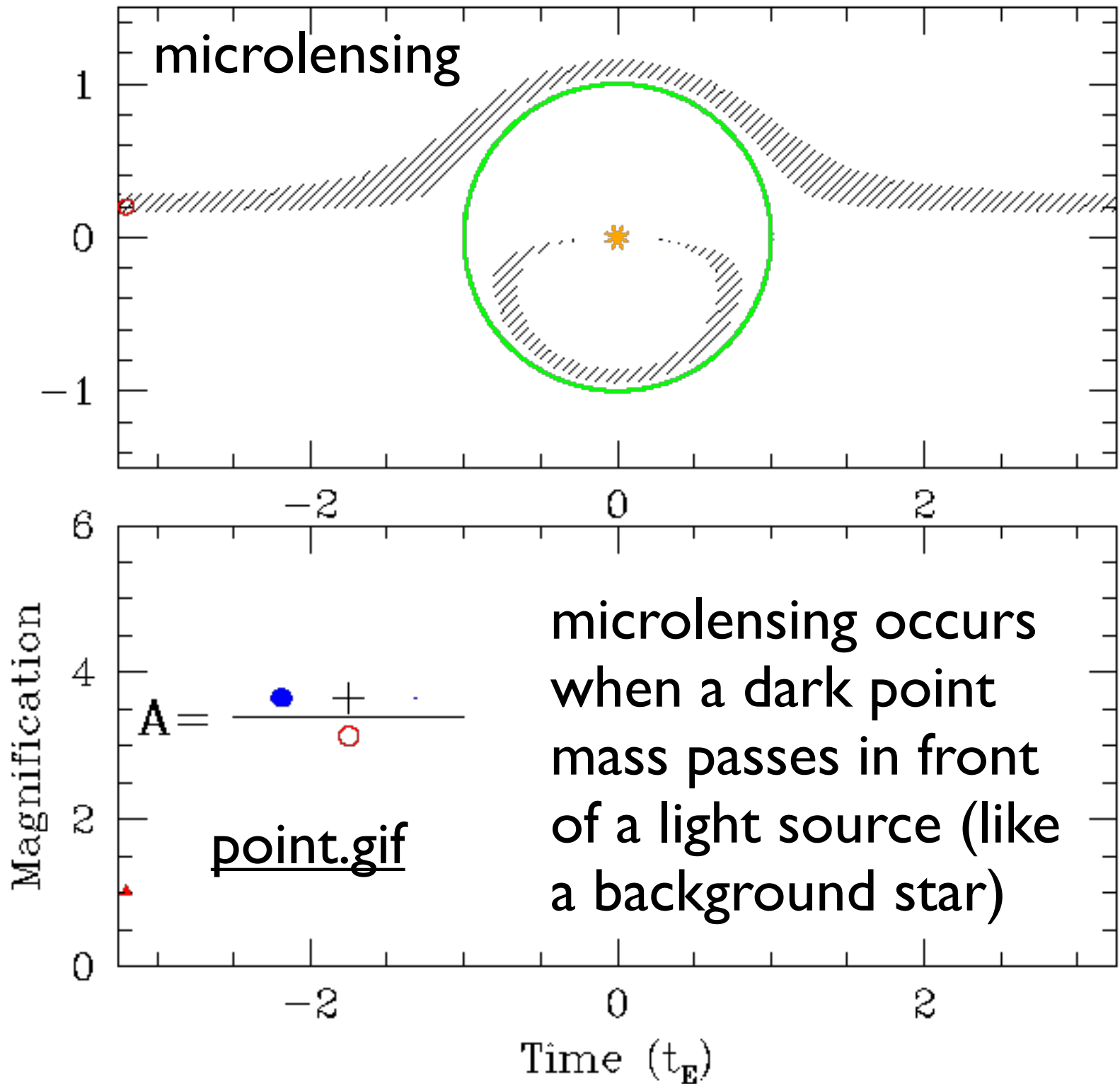
Velander et al (2013) weak gravitational lensing

BIG SCALES

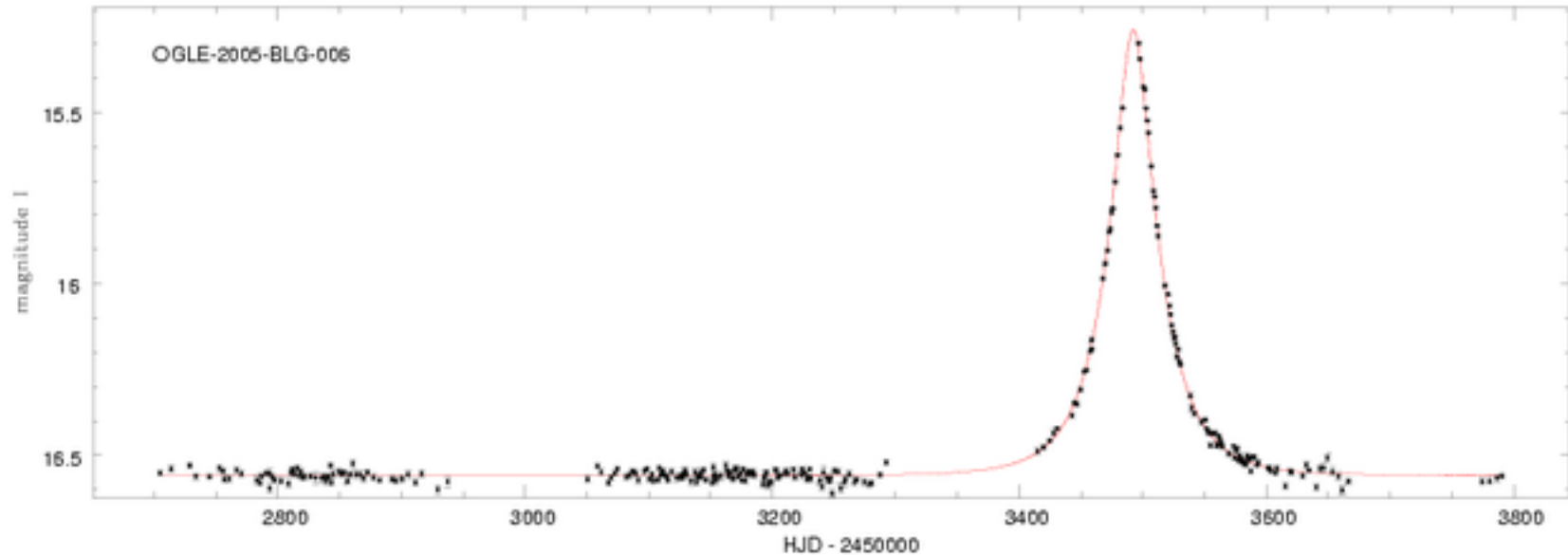


$$M_{200} = 119 L_r^{1.32} \quad \text{for red galaxies}$$

SMALL SCALES

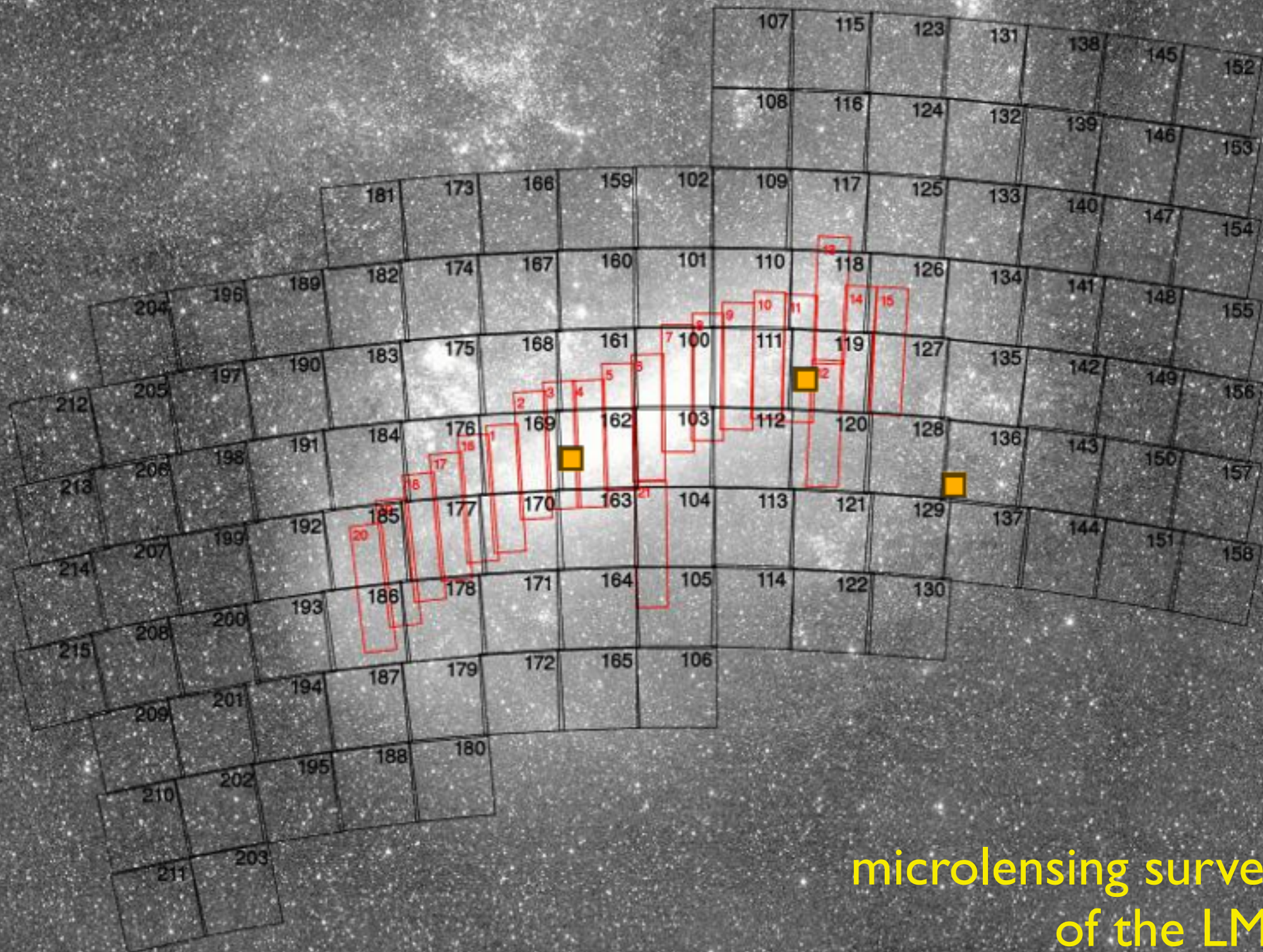


microlensing even observed by OGLE



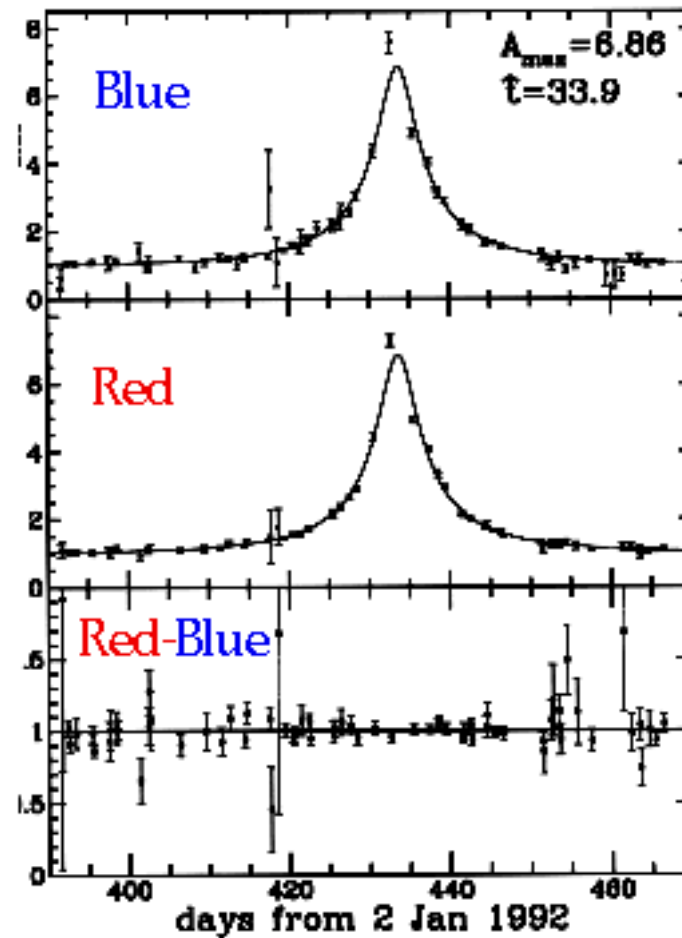
Microensing surveys:
MACHO
EROS
OGLE

stare at LMC/SMC to look for microlensing events due to intervening dark matter. Sensitive to brown dwarfs.



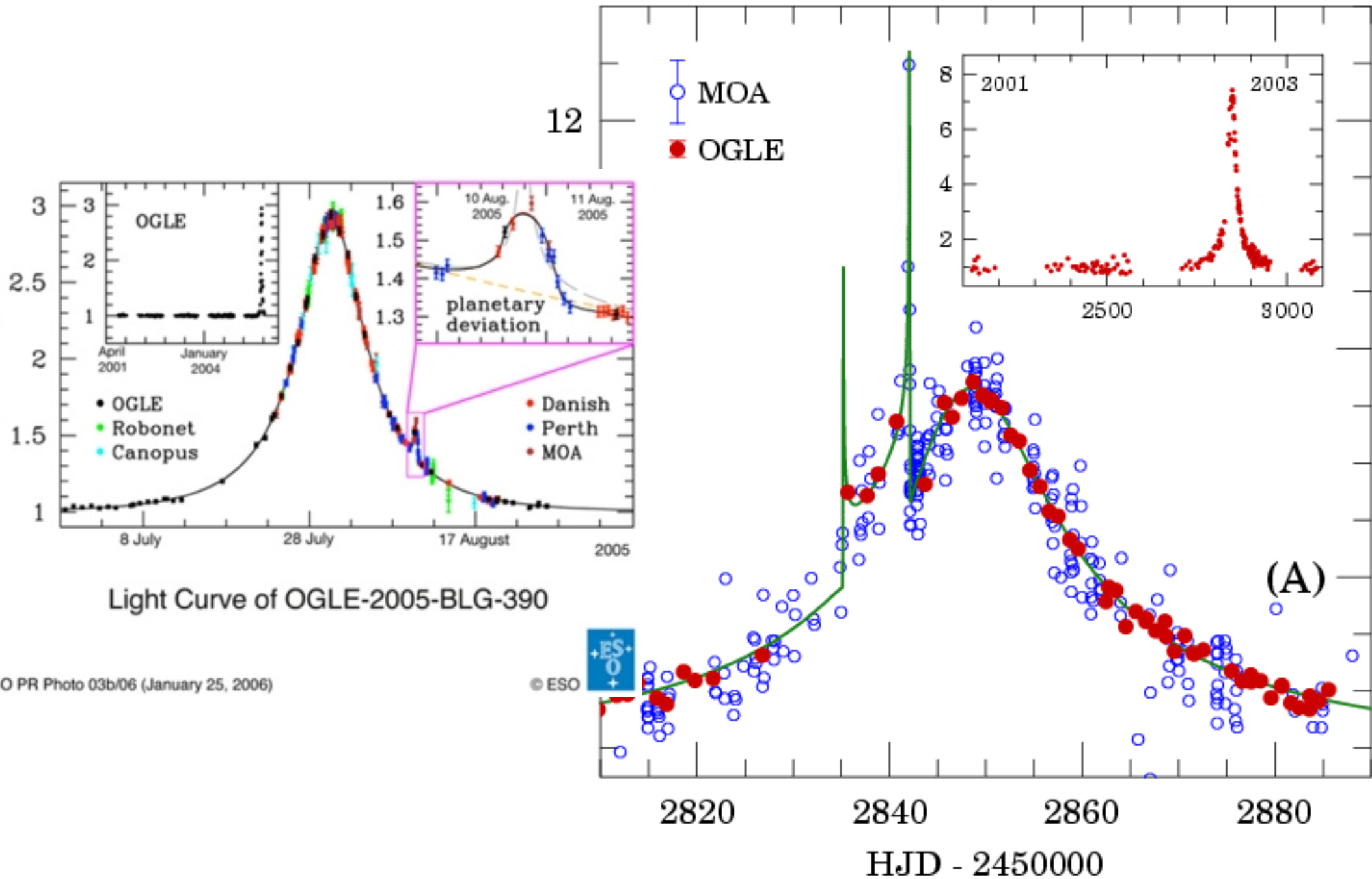
microlensing surveys
of the LMC

microlensing events achromatic

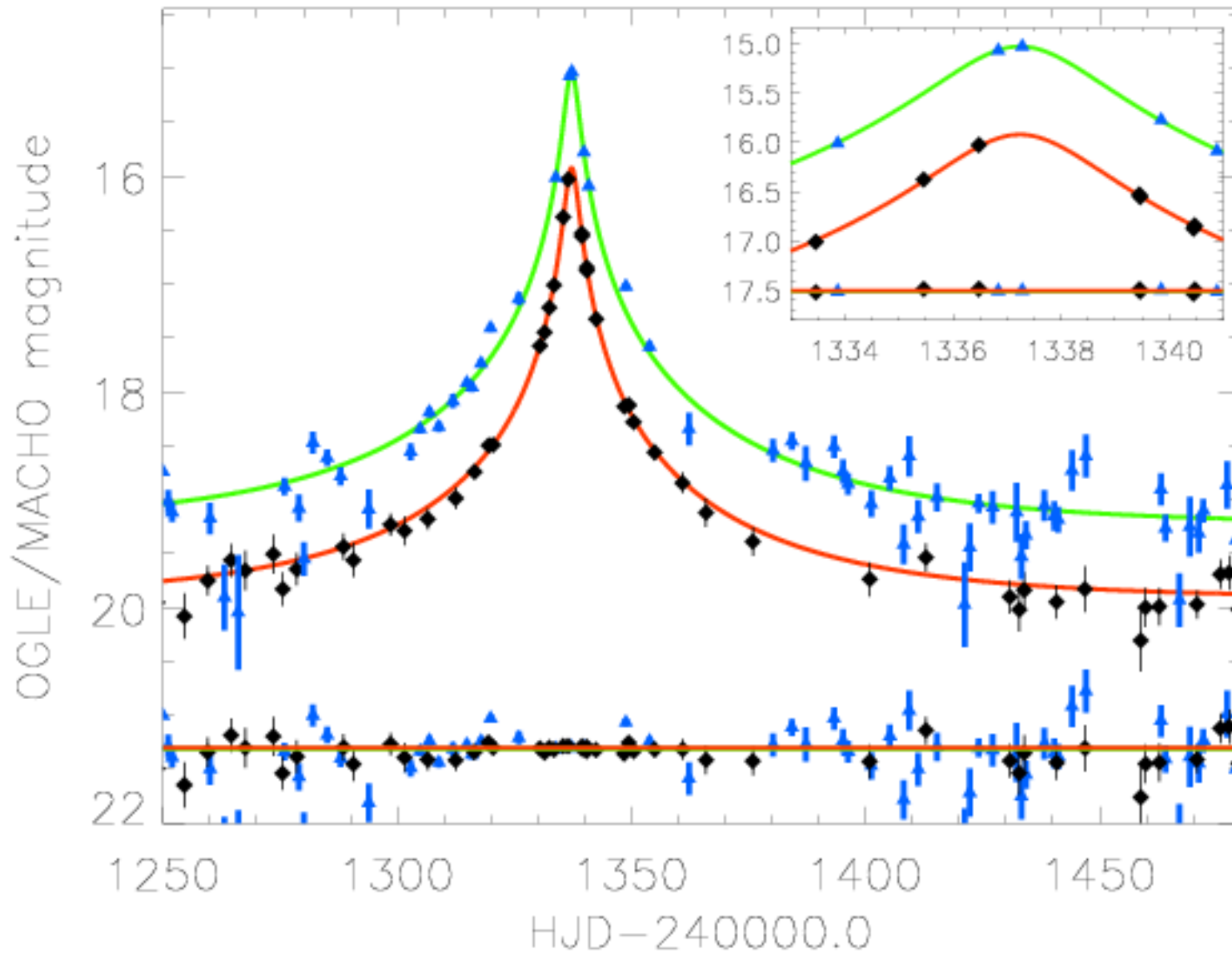


should also be symmetric in time
(unless there is a companion planet)

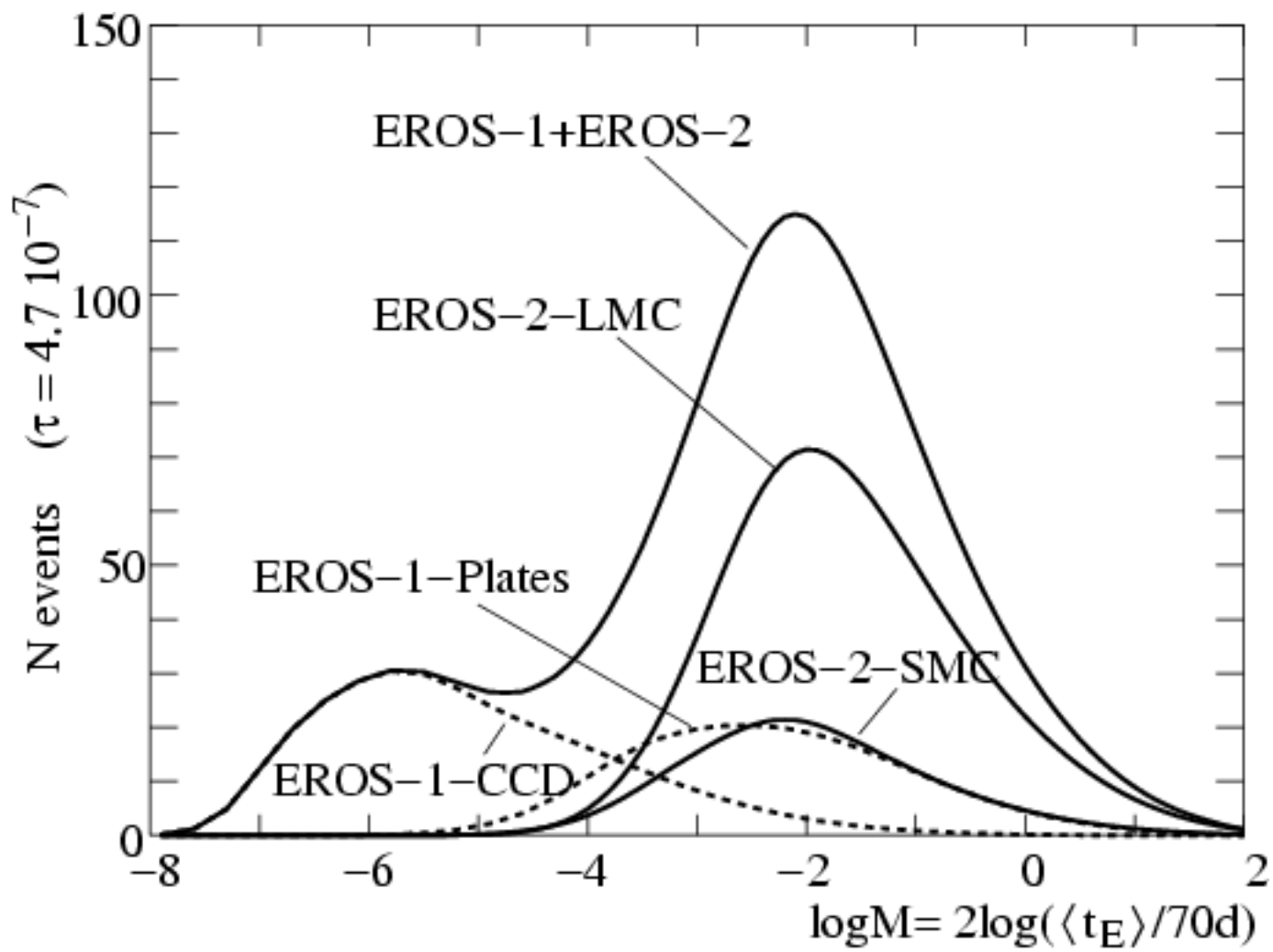
Planet detections by microlensing

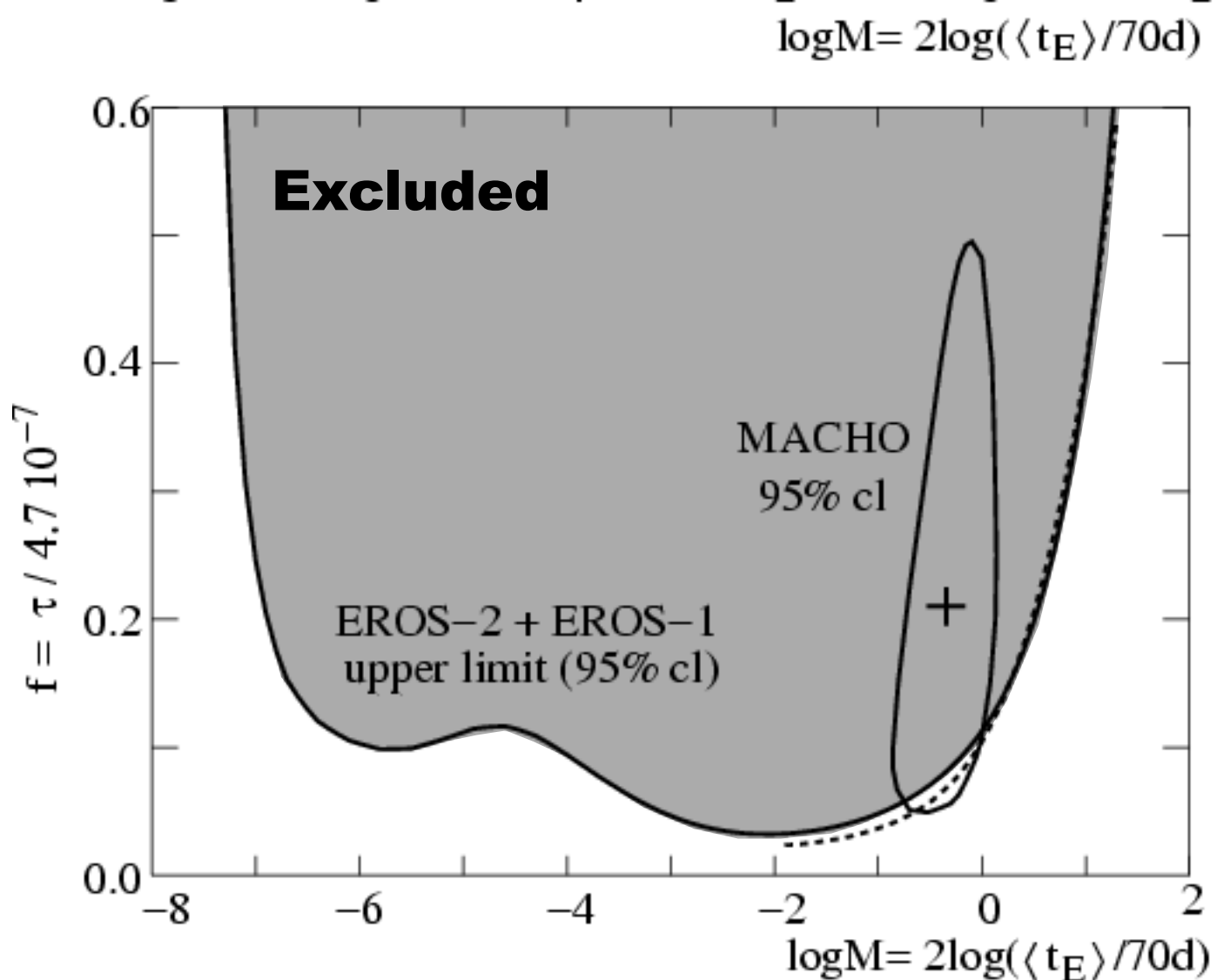


OGLE-LMC-01



achromatic macho candidate event





The observed rate of microlensing events leaves no room for the dark matter halo of the Milky Way to be composed of massive compact objects like brown dwarfs or black holes in the mass range $10^{-7} < M < 10$ solar masses.