

Micro lensing based studies of the unresolved structure of AGN and the composition of lens galaxies

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Index

- Introduction to gravitational lensing and microlensing.
- Statistical analysis of caustics concentration based on caustics crossings counts. Application to QSO 2237+0305
- Results and future work.



Introduction to gravitational lensing and microlensing



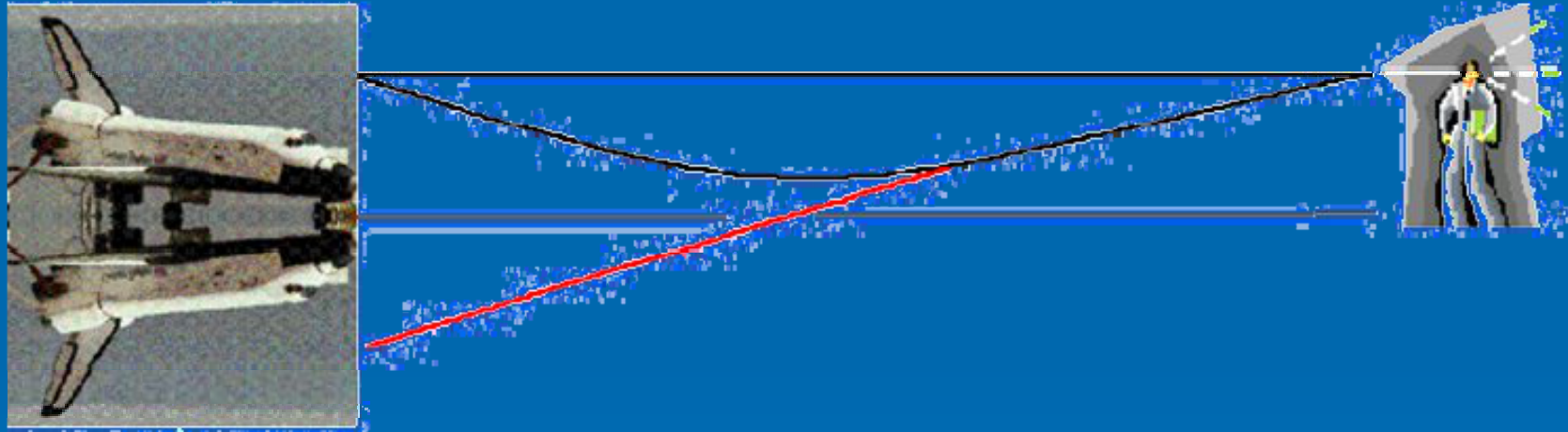


STS 1 in Desert Mirage, Edwards AFB ~ 1981

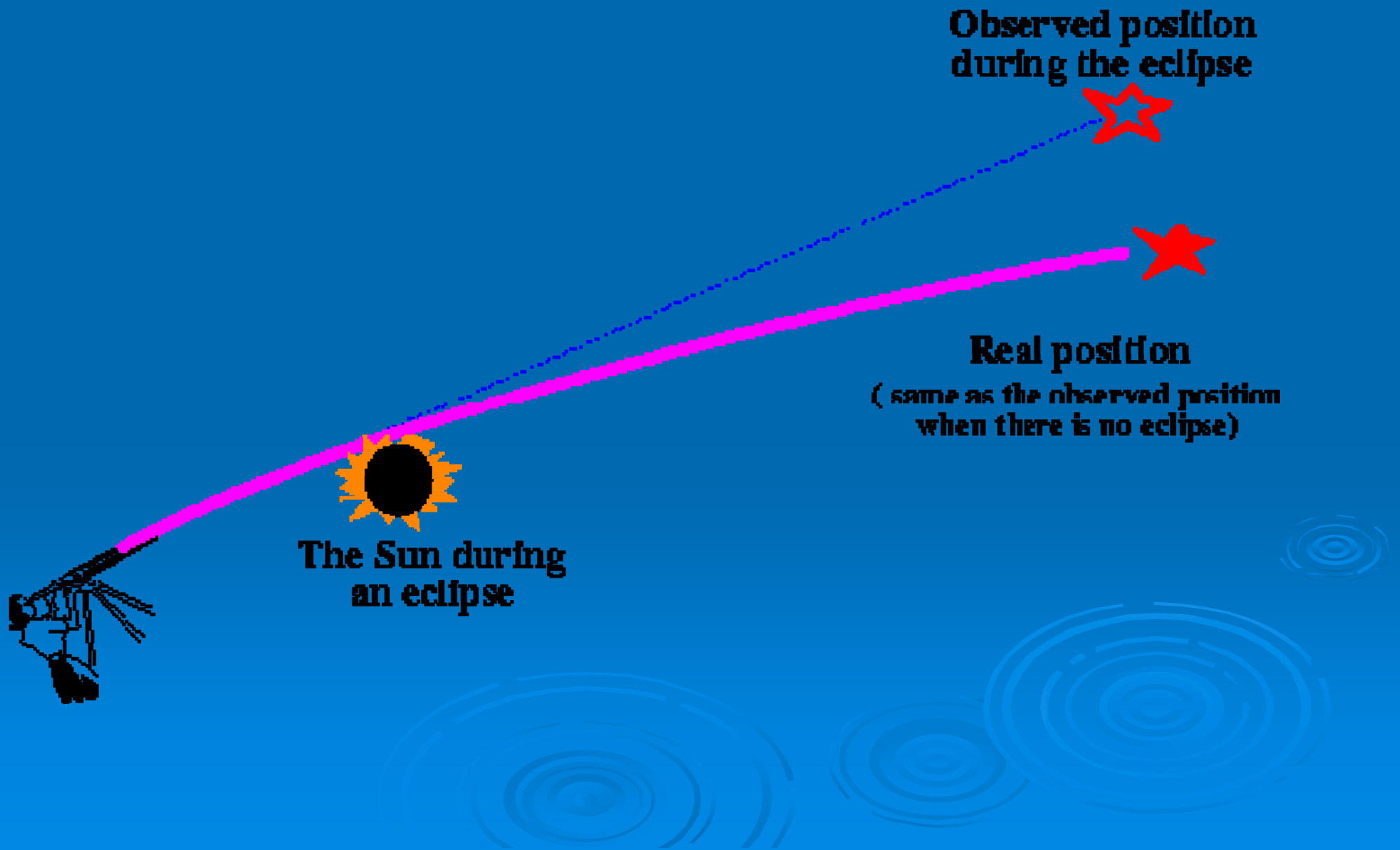
Copyright © 2003 by Ctein



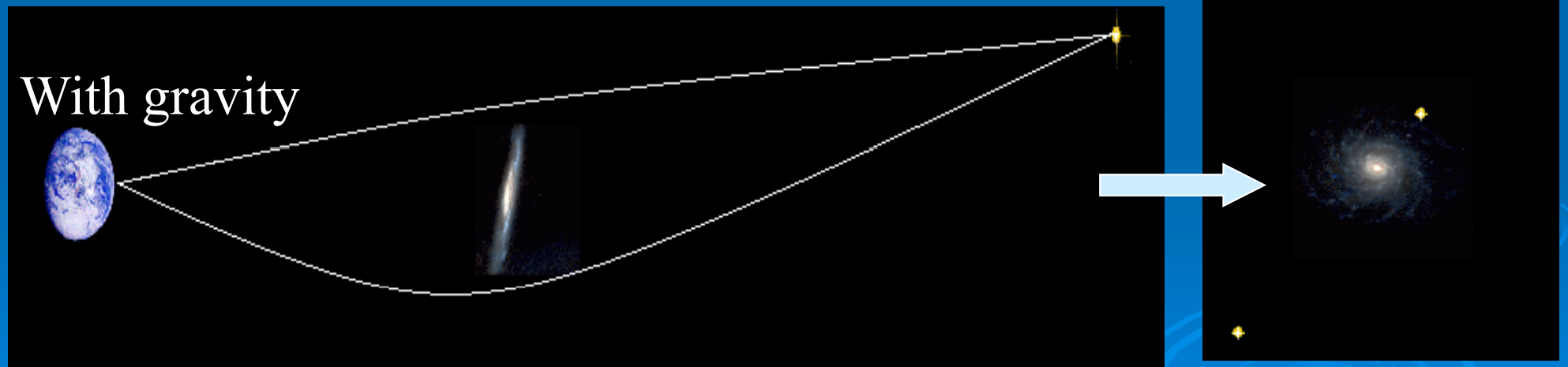
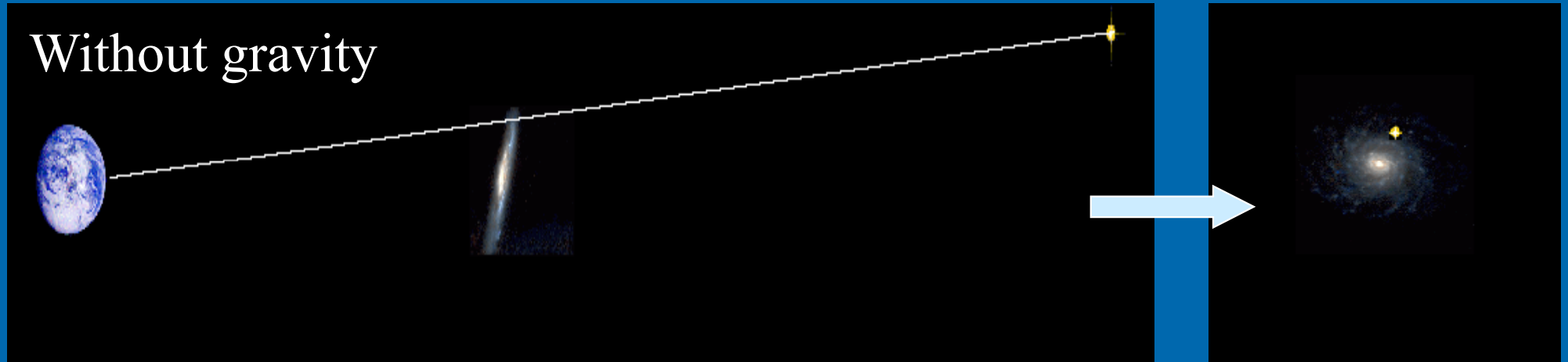
Terrestrial mirage



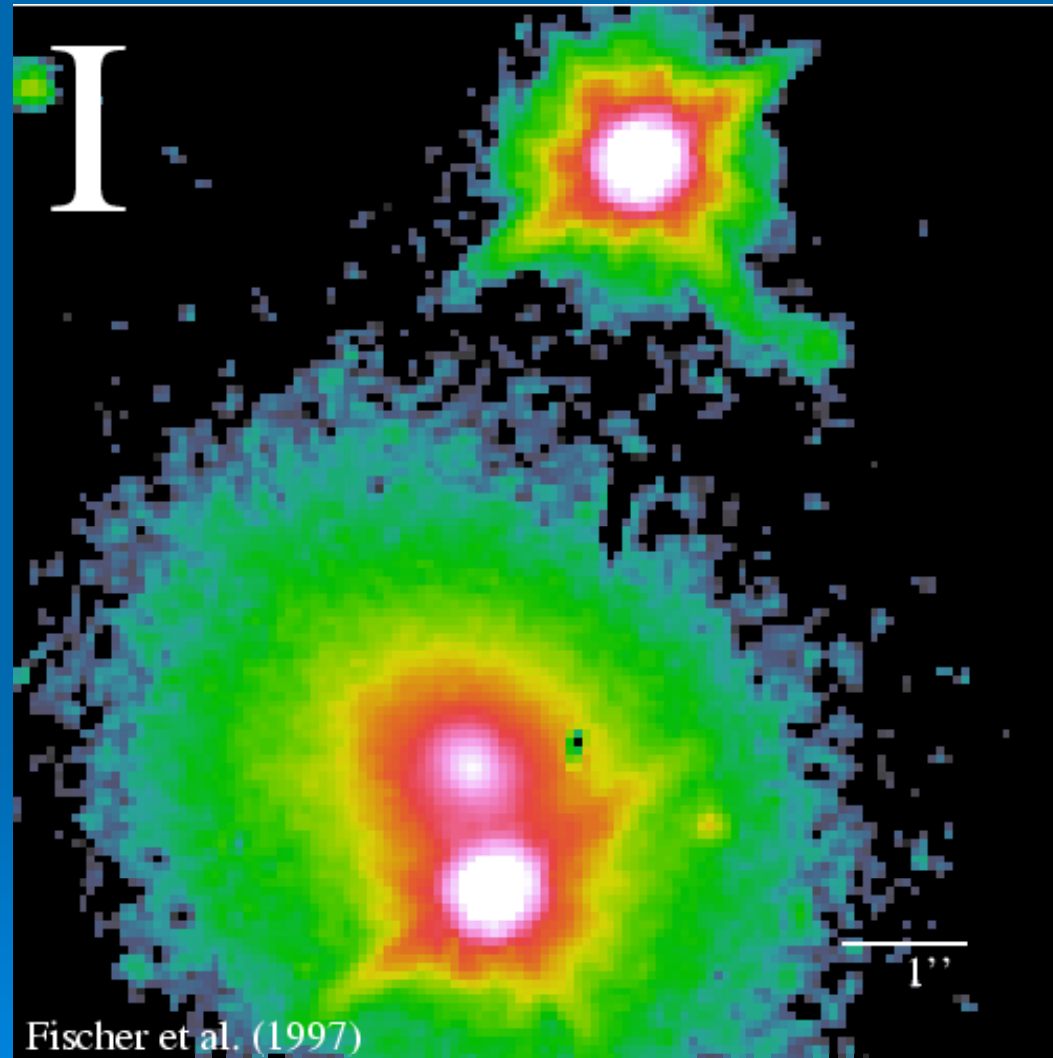
Light deflection by the Sun – 1919 eclipse



Gravitational mirage

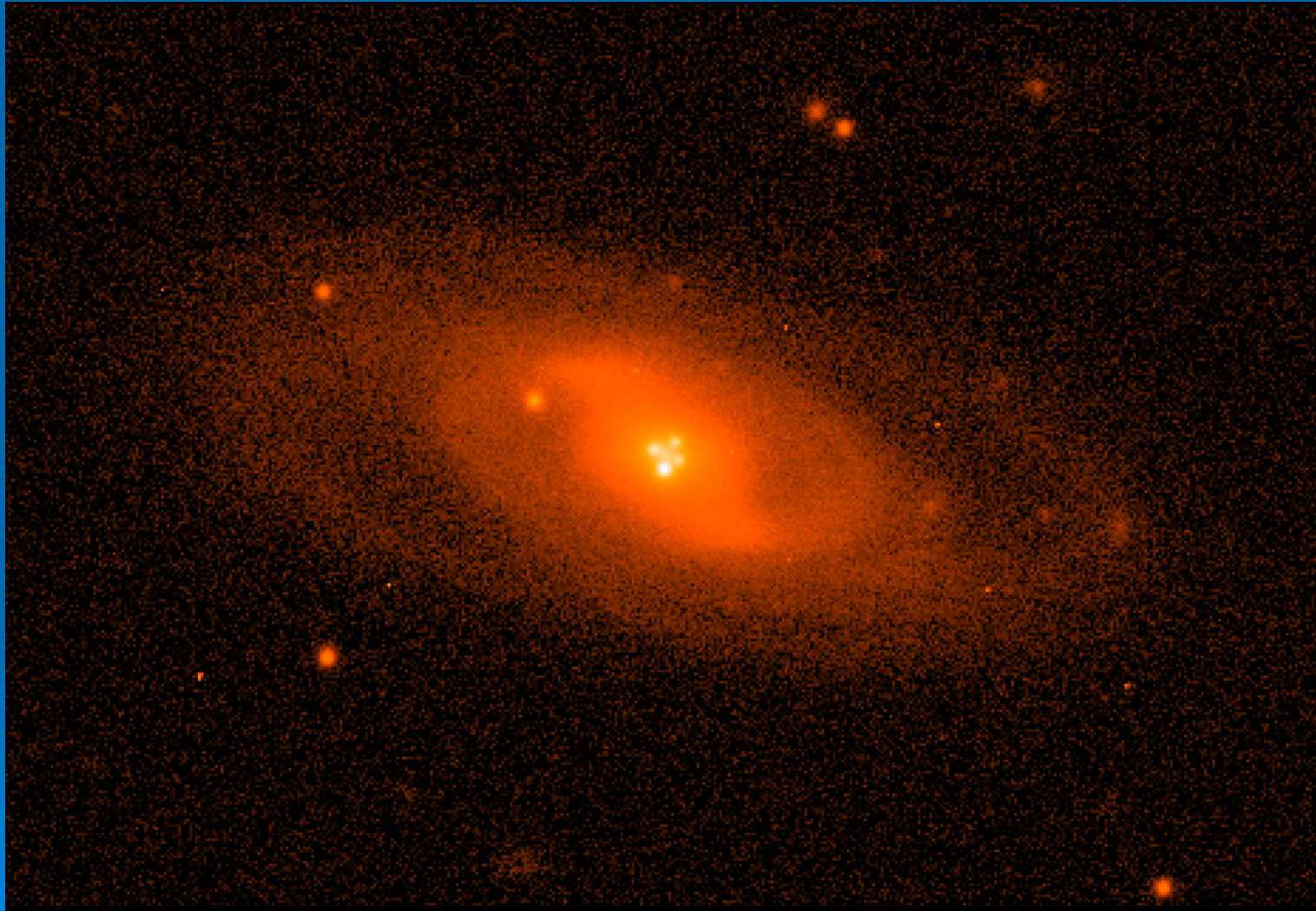


First discovered gravitational lens

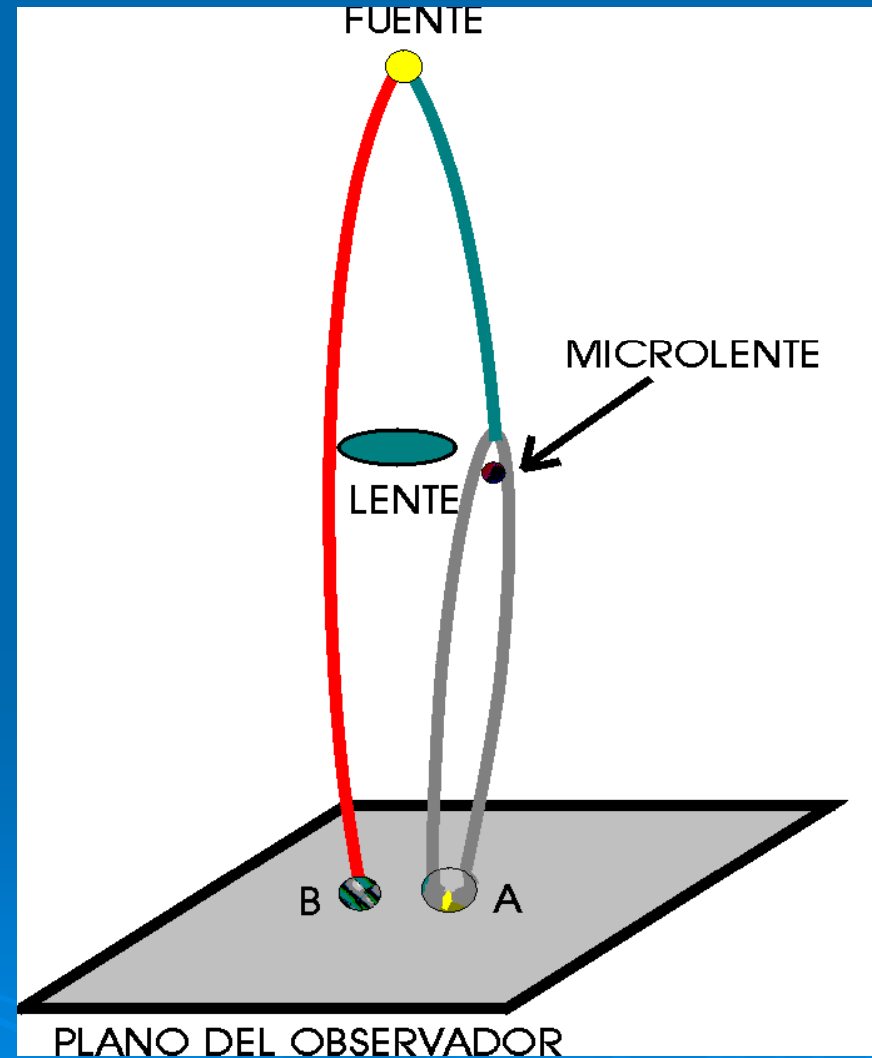
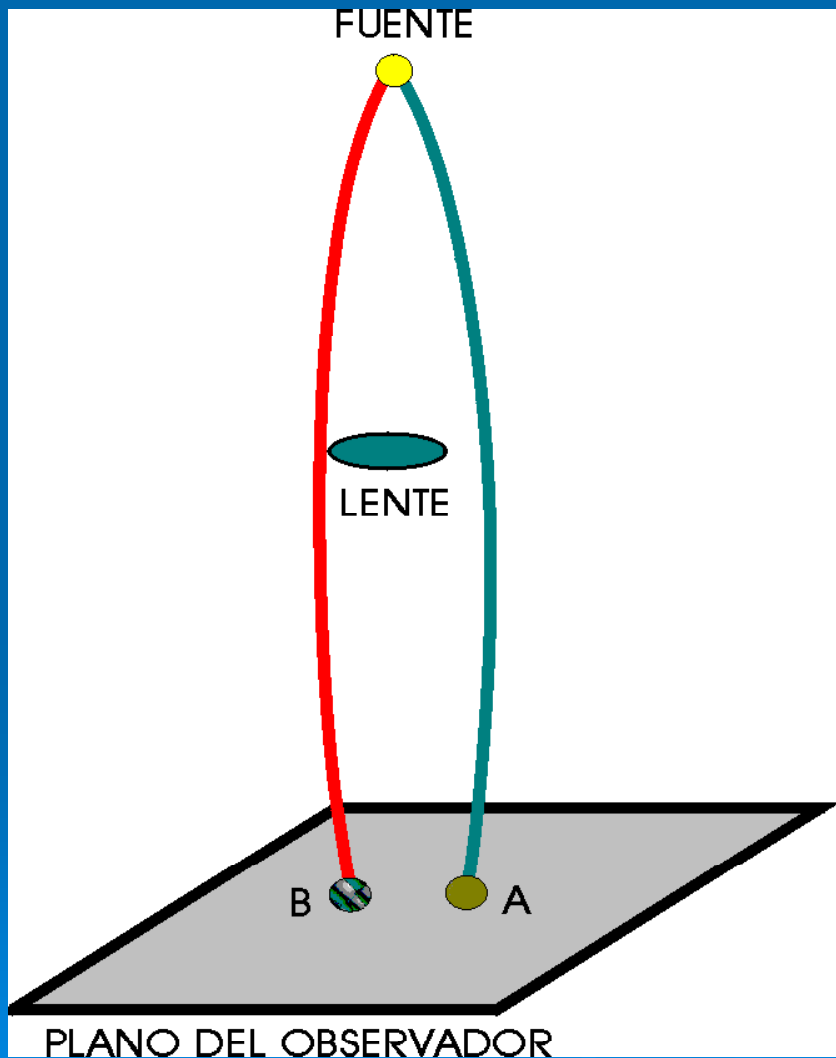


(QSO 0957+561)

QSO 2237+0305



Microlensing

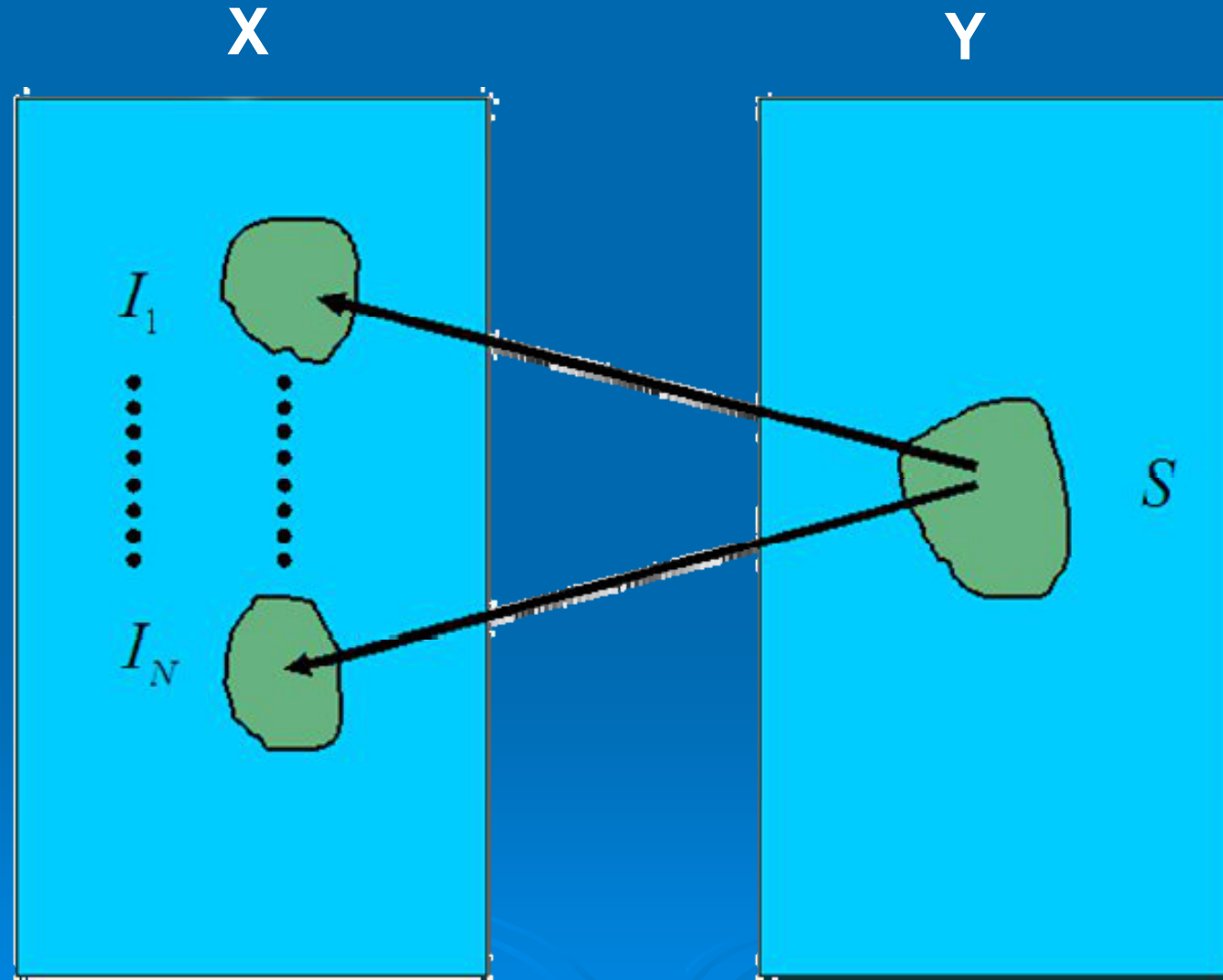


One Source several images Magnification

$$\mu = \frac{\sum_i F_{I_i}}{F_S}$$

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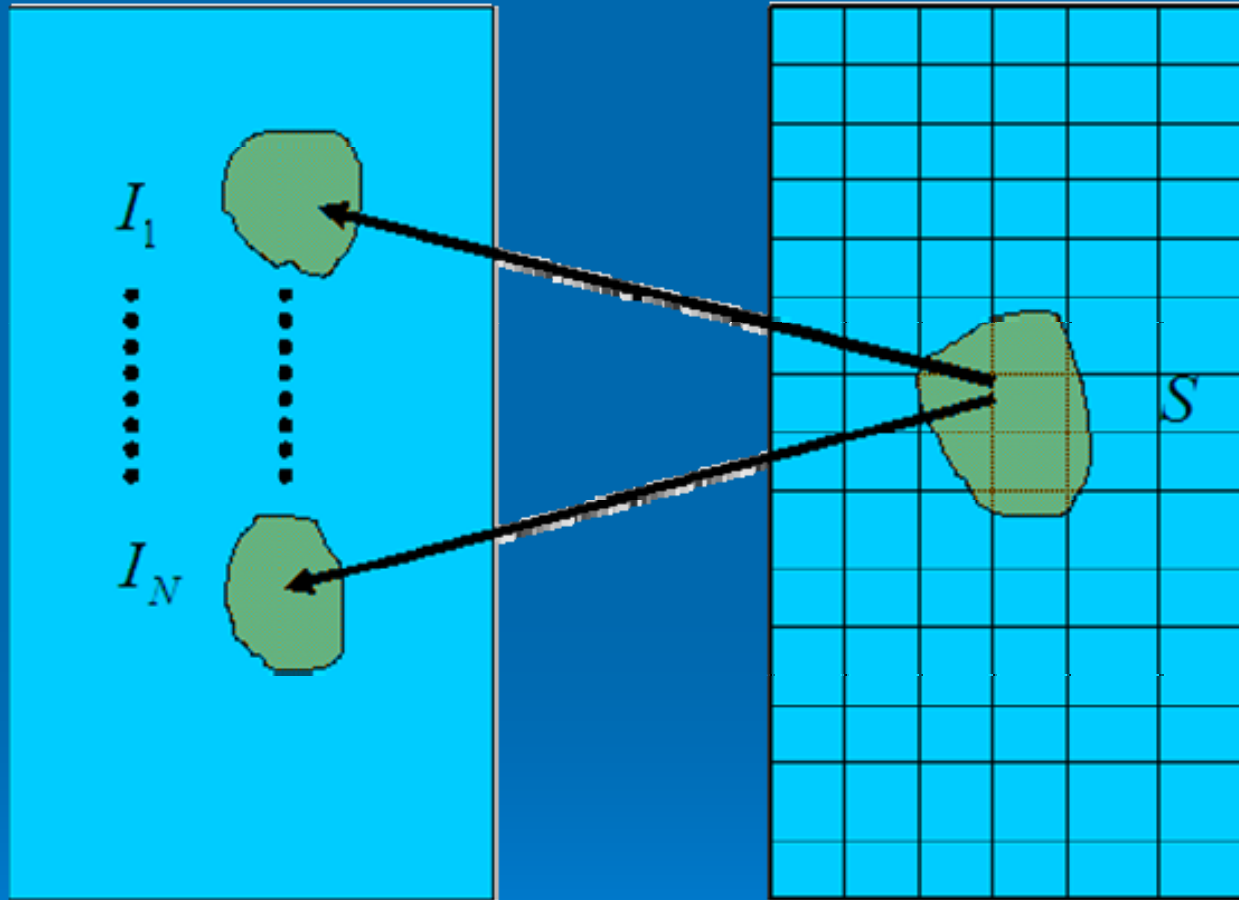
$$\mu = \frac{\sum_i S_{I_i}}{S_S}$$



Pixels-magnification map

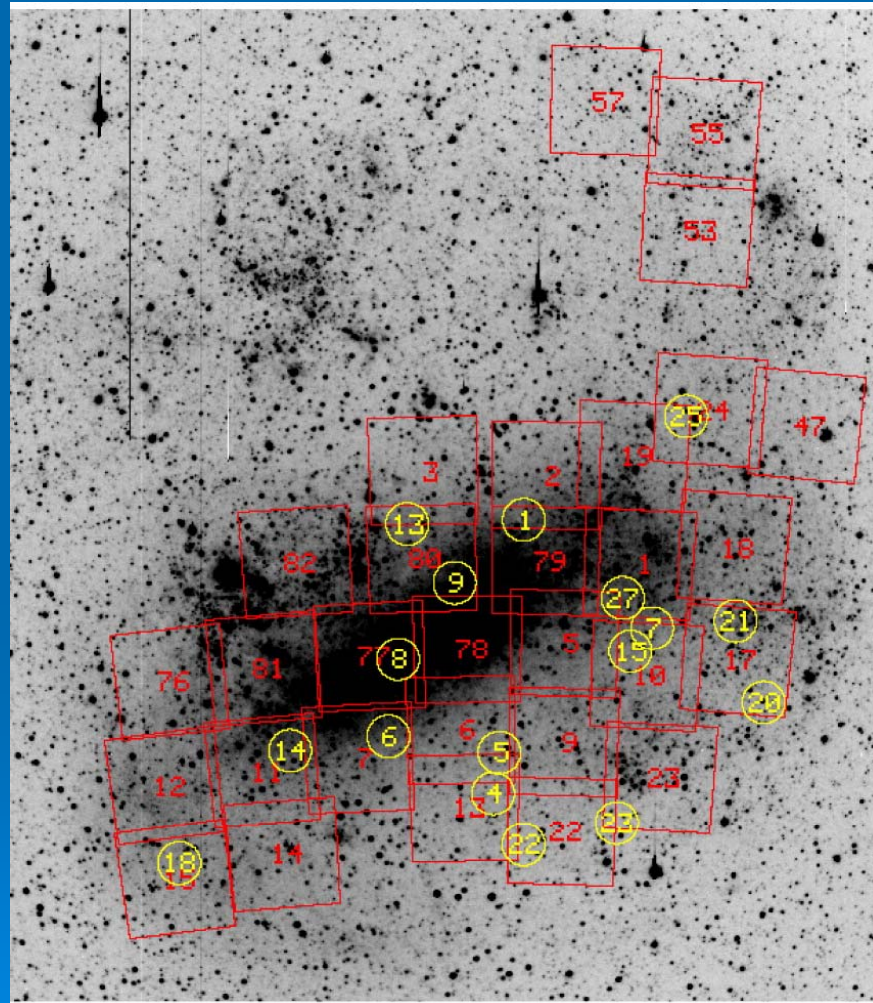
X

Y

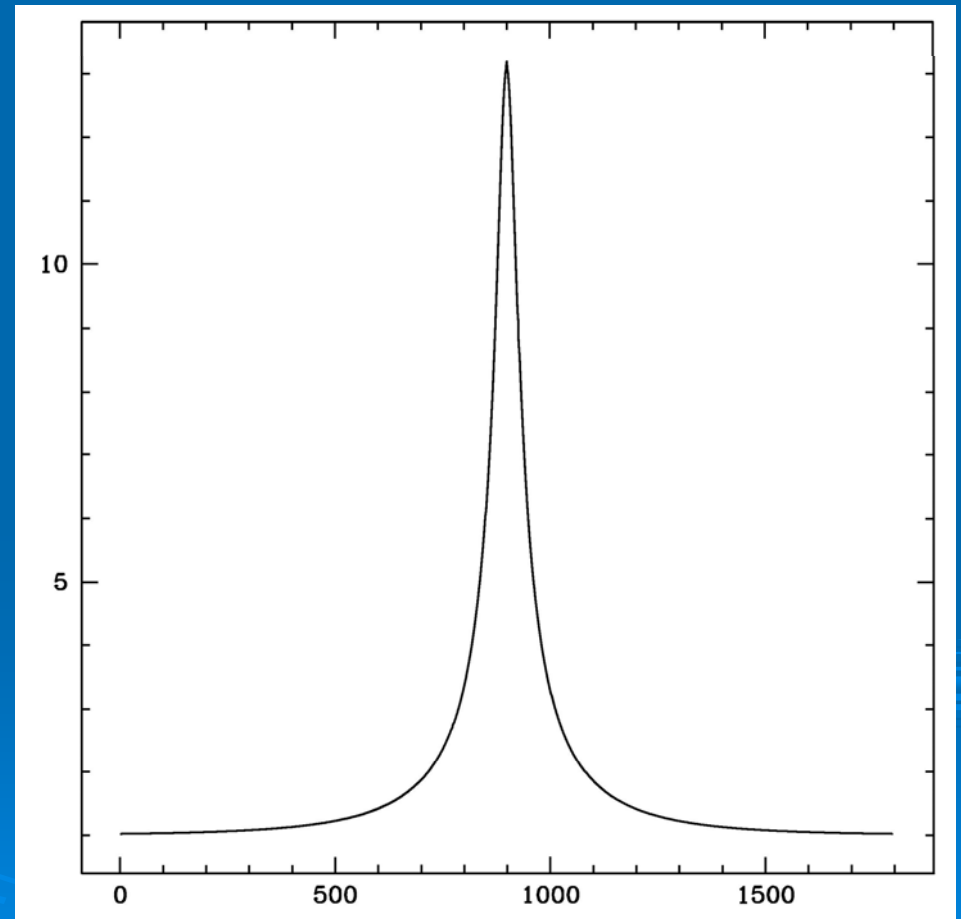
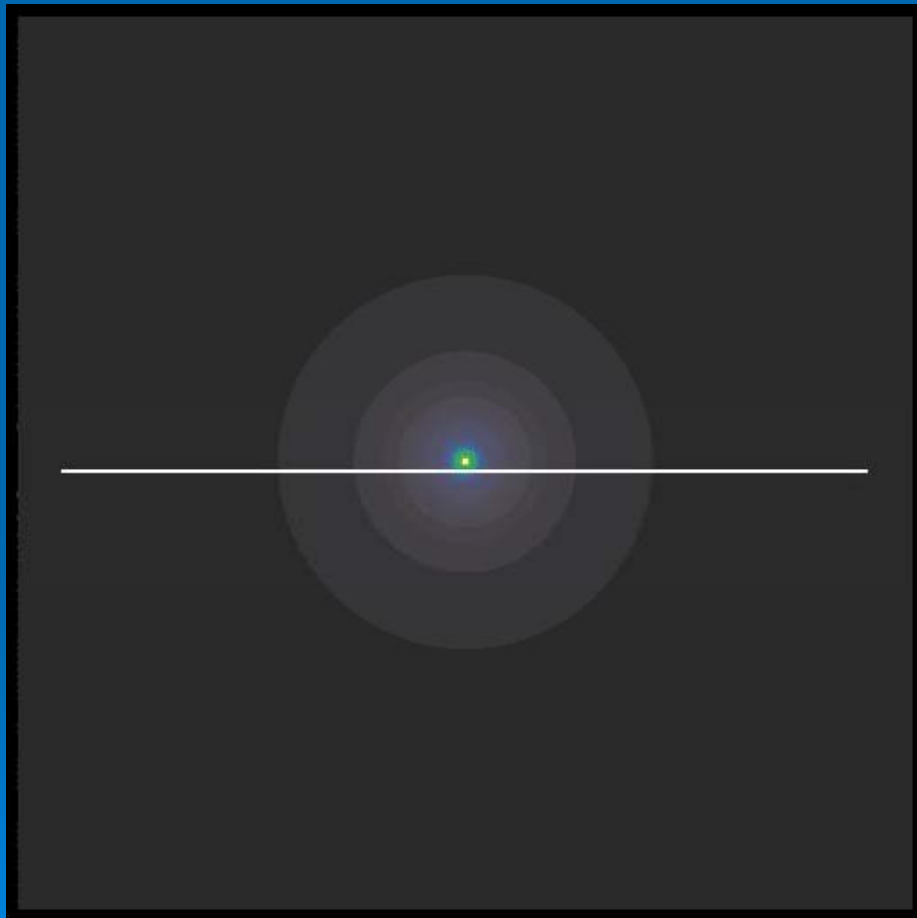


$$\mu_S = \sum_{\eta_1, \eta_2} I_S(\eta_1, \eta_2) \mu_P(\eta_1, \eta_2)$$

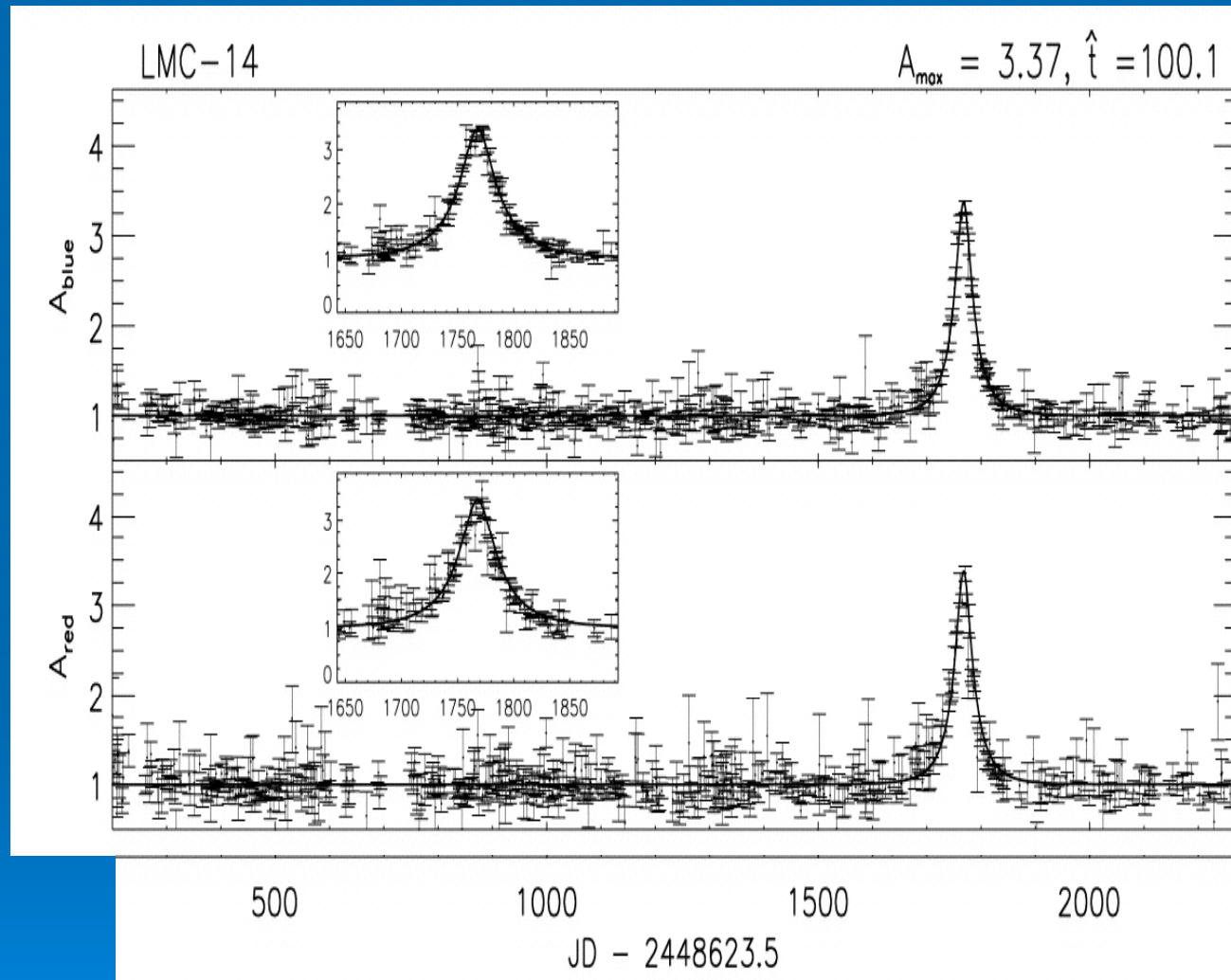
MACHO experiment



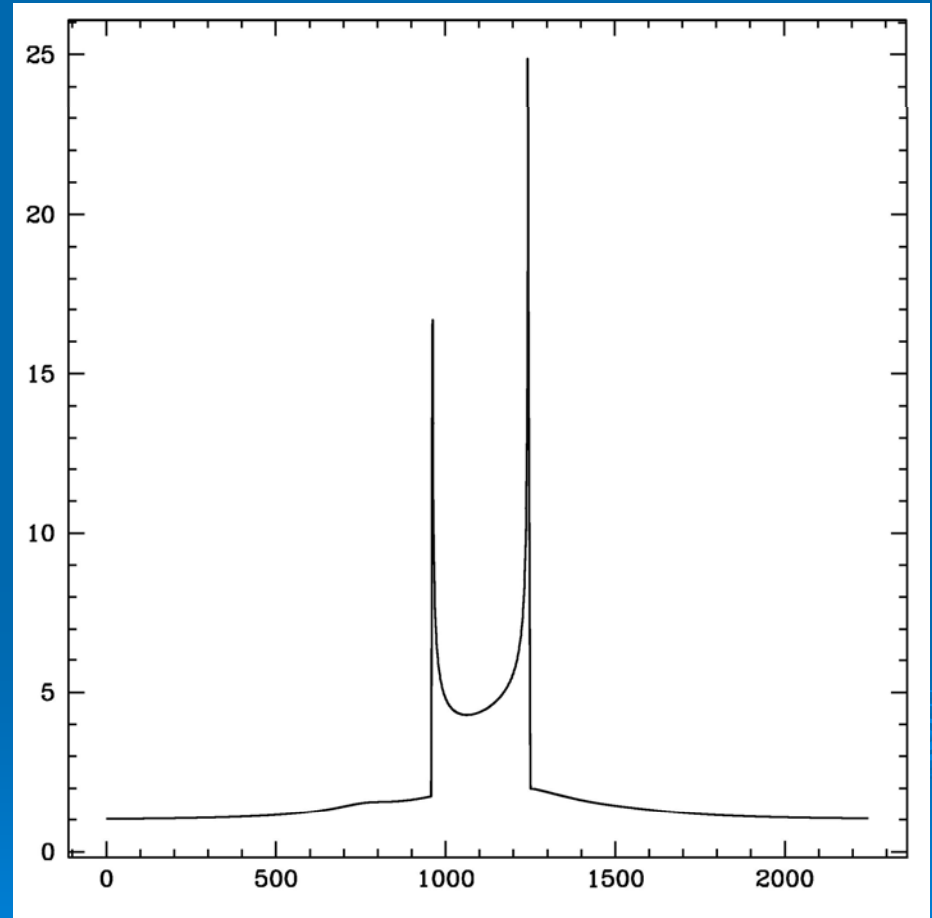
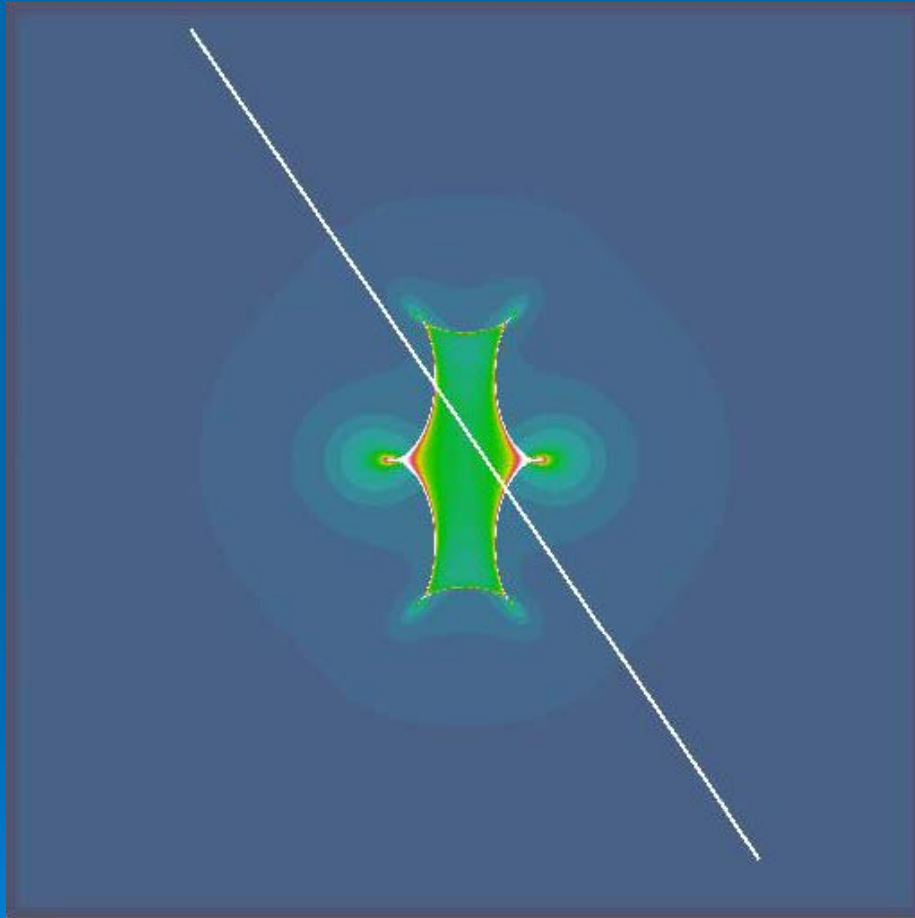
Magnification map and light curve associated to point-like lens



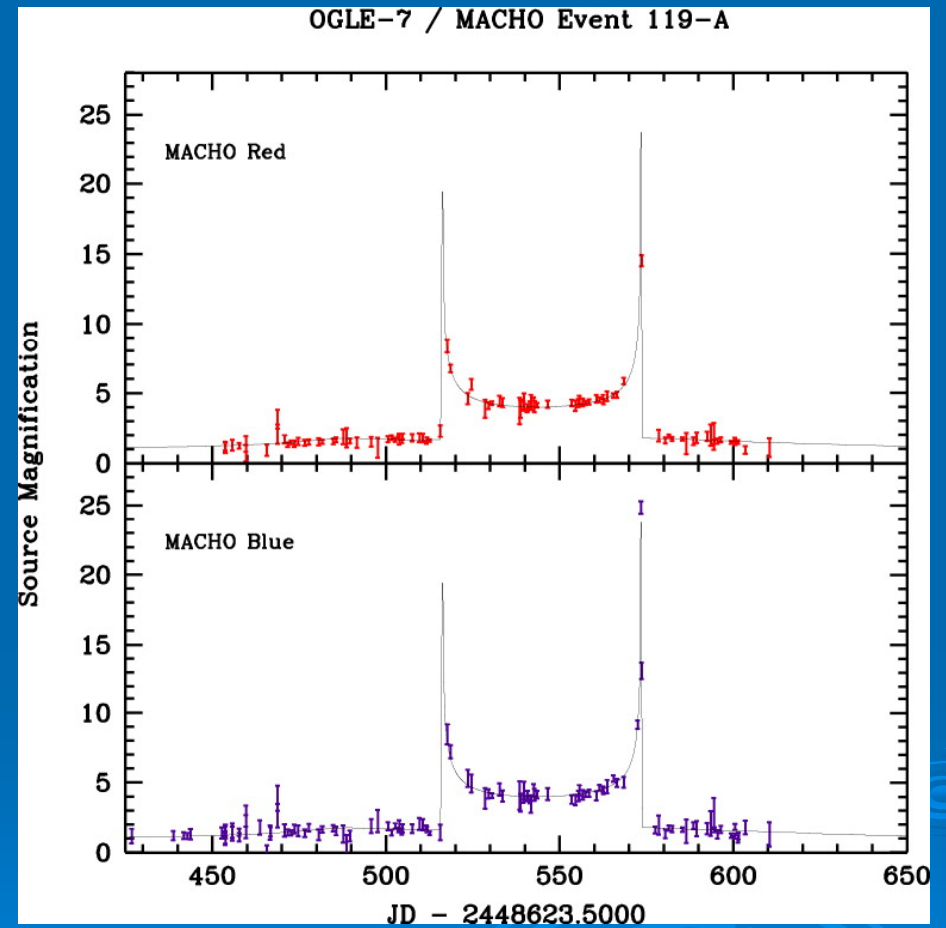
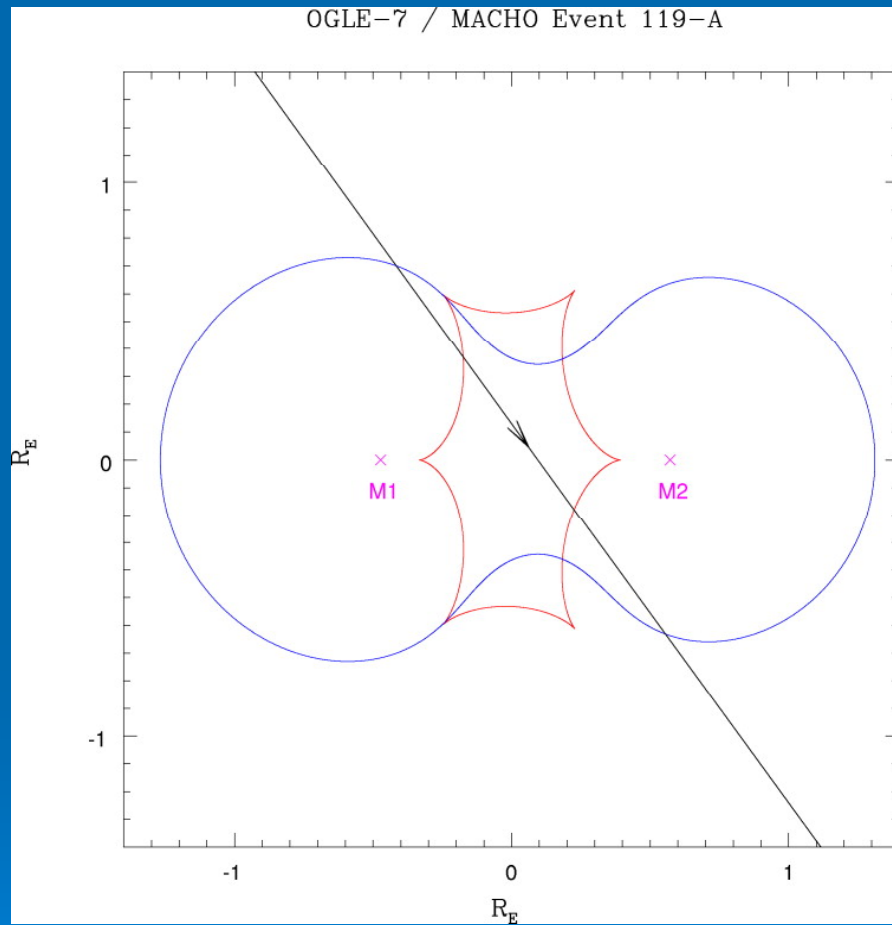
MACHO experiment



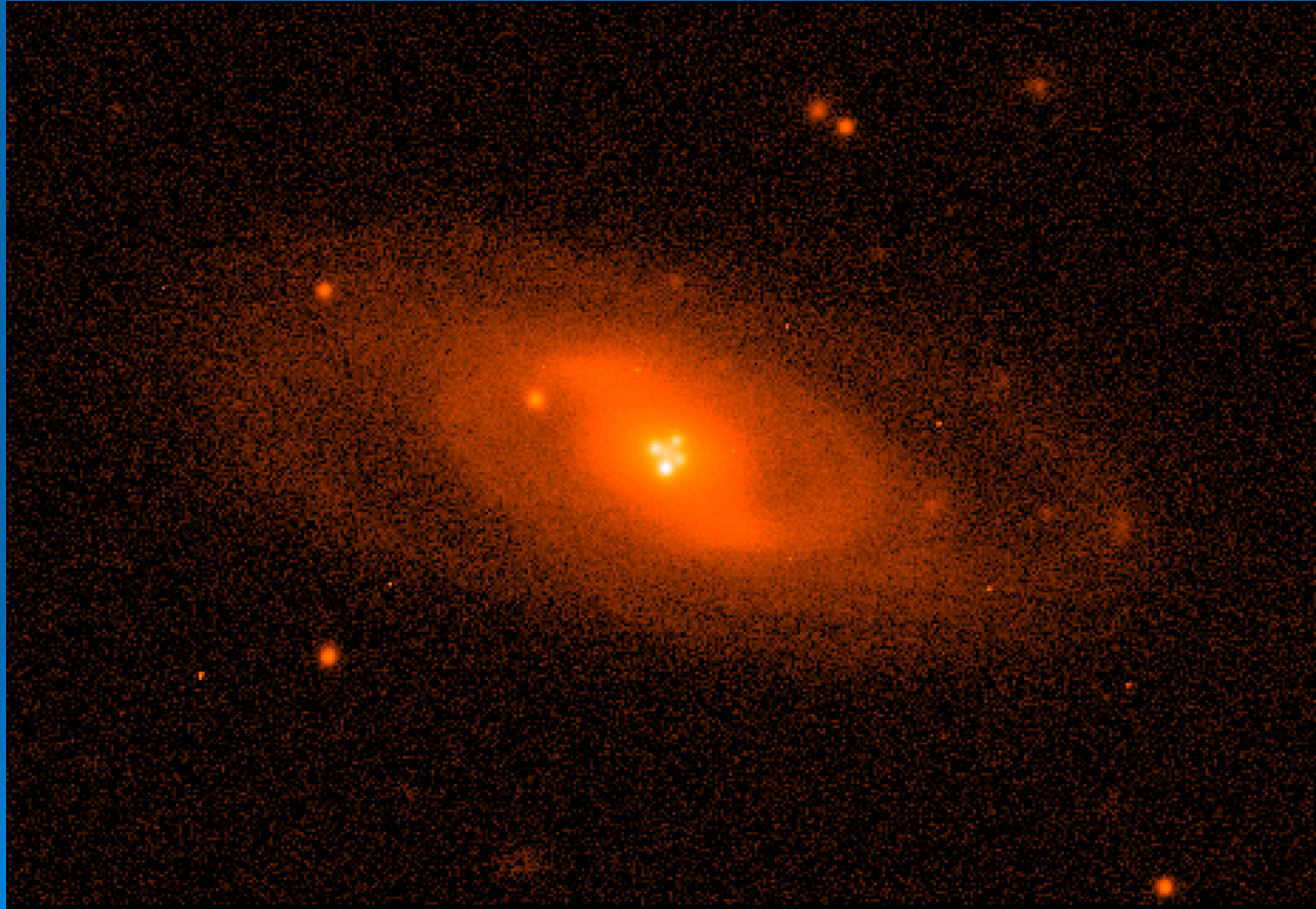
Magnification map and light curve associated to binary lens



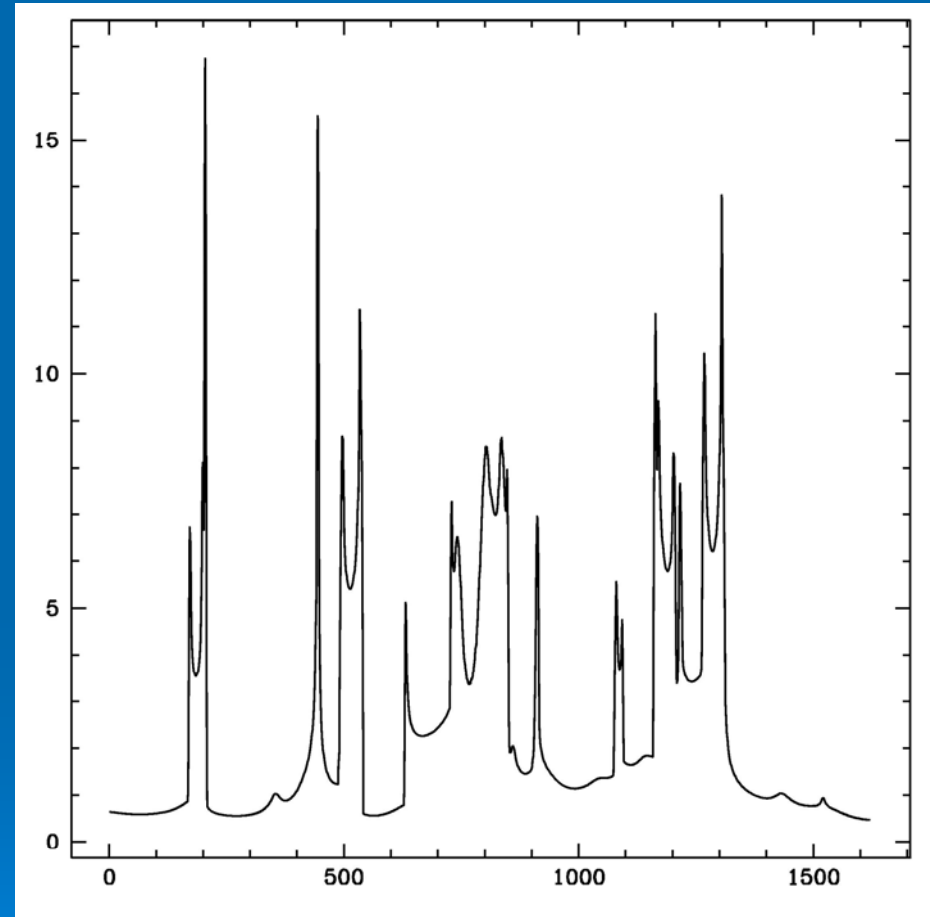
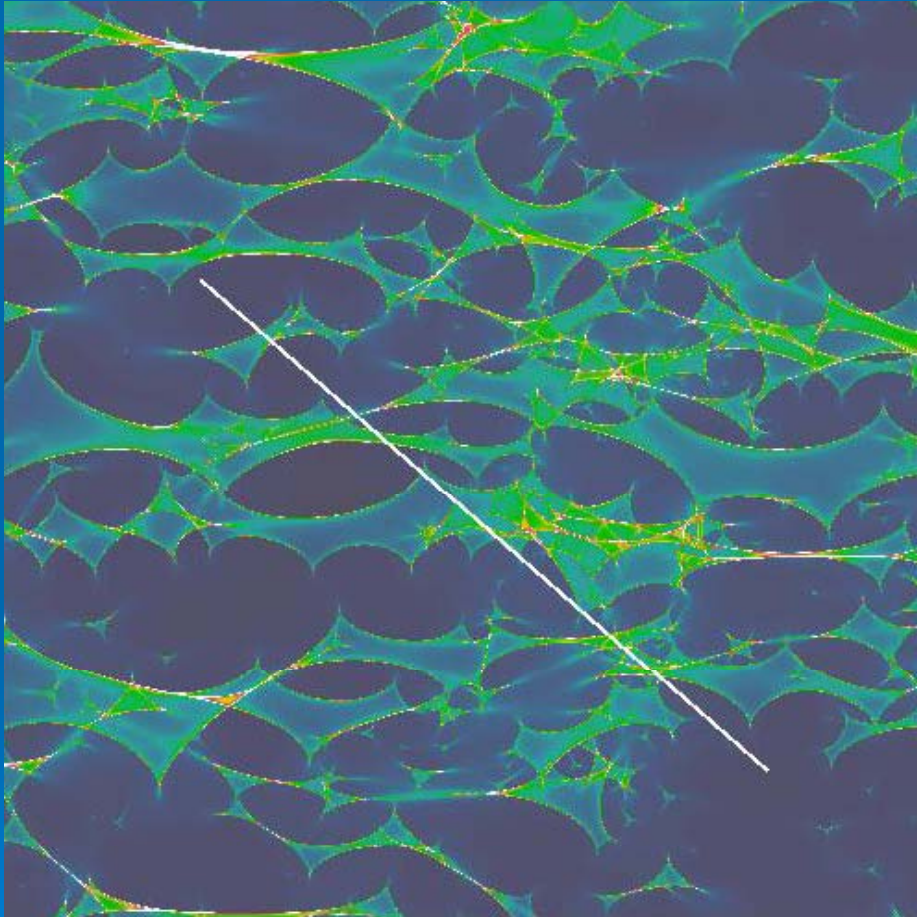
MACHO experiment



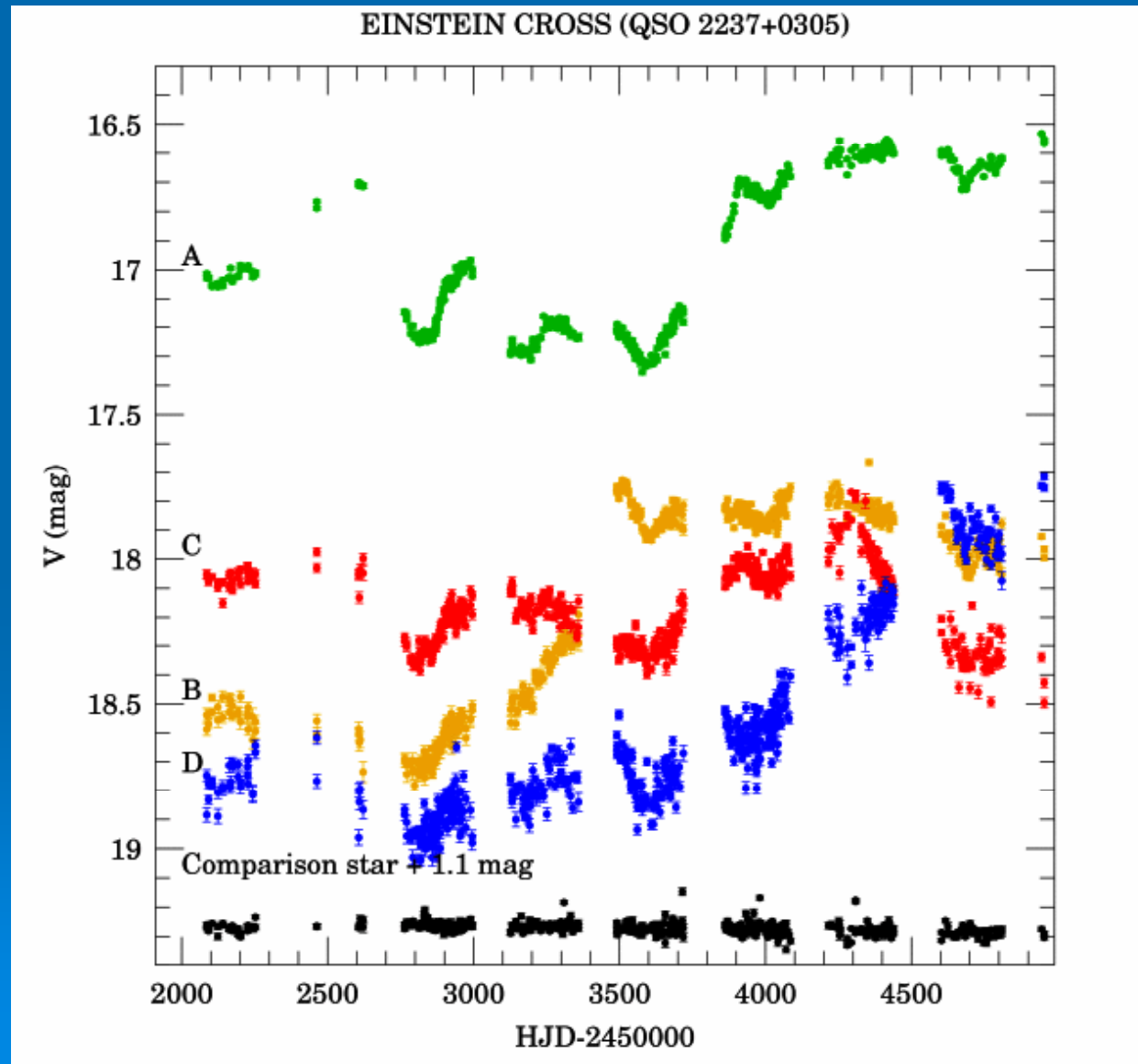
QSO 2237+0305



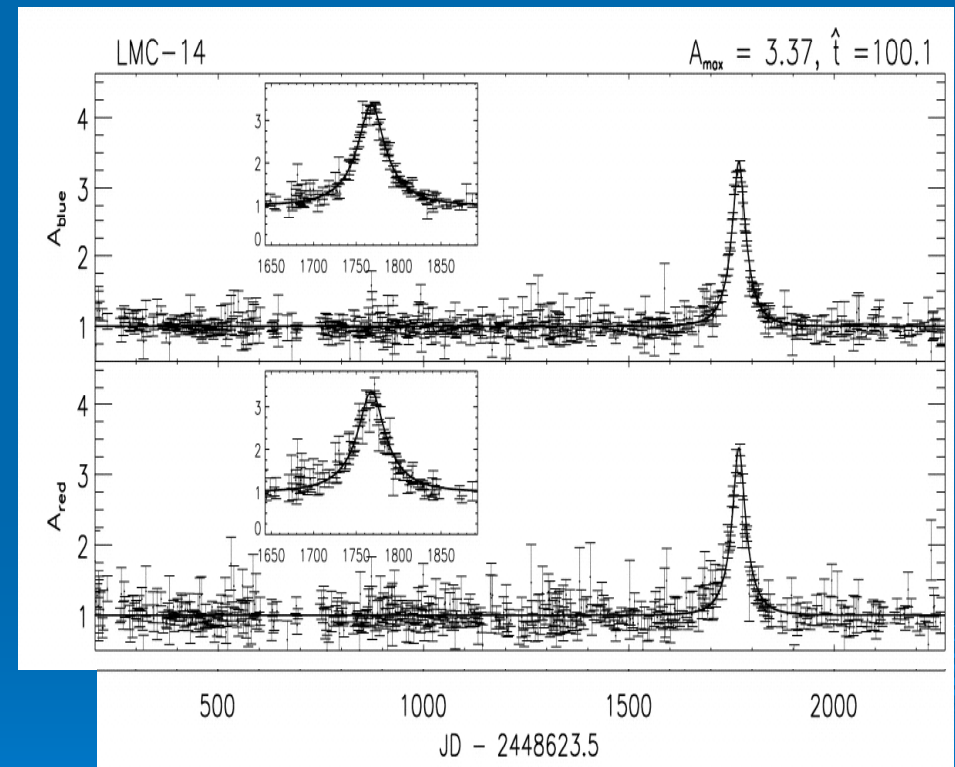
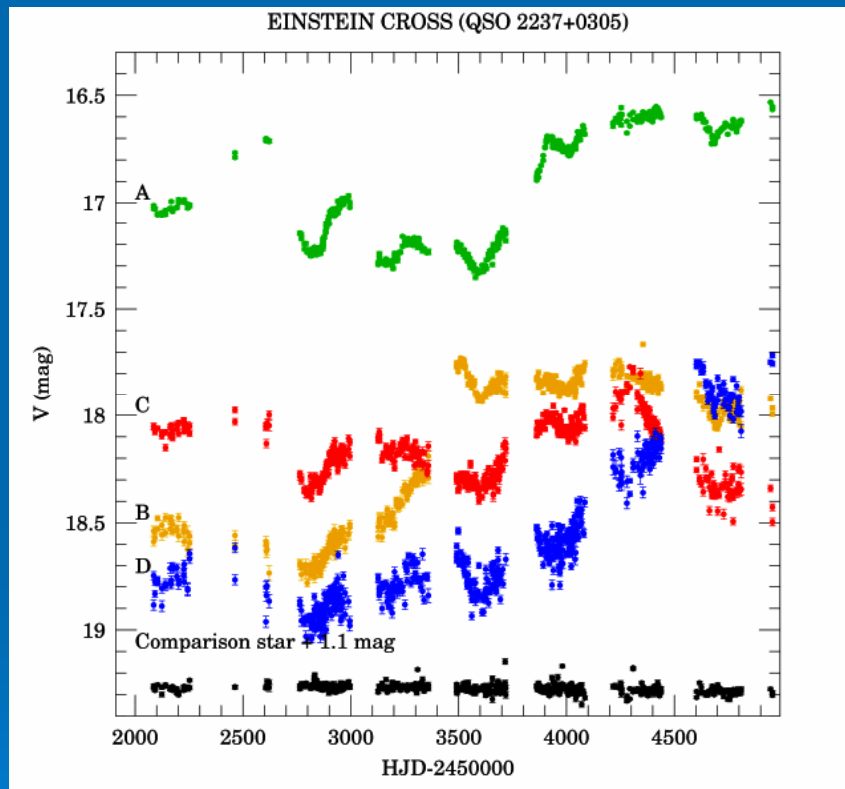
Magnification map and light curve associated to QSO 2237+0305



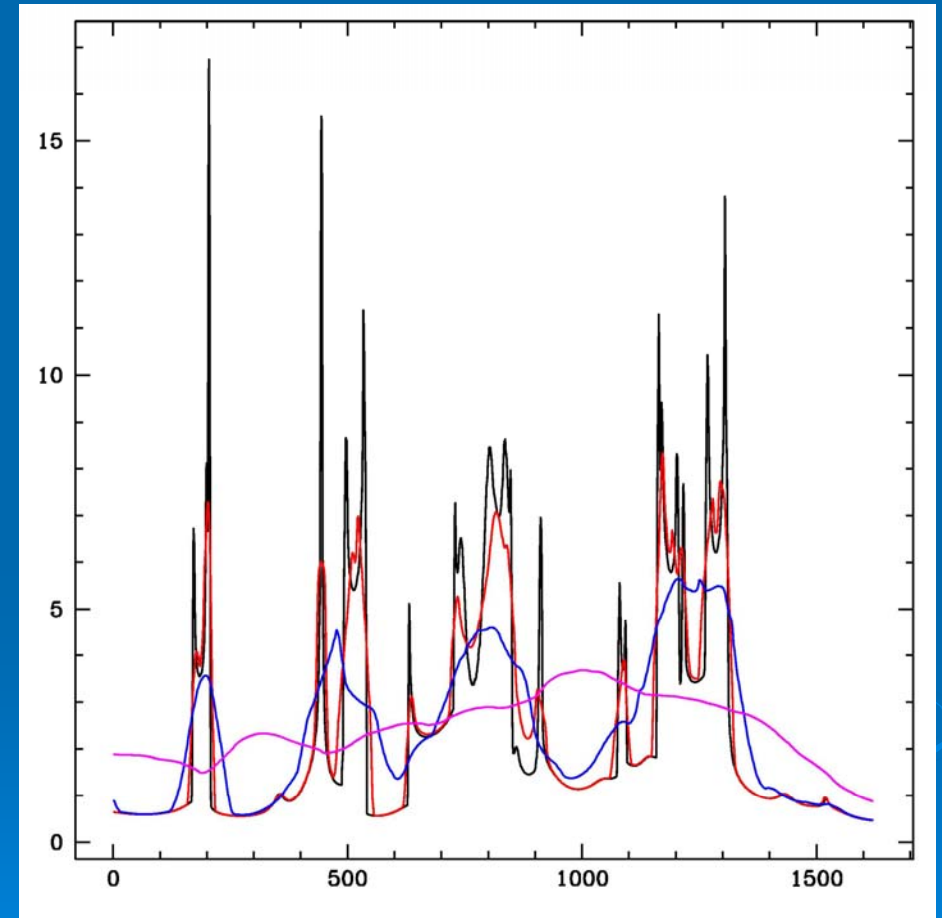
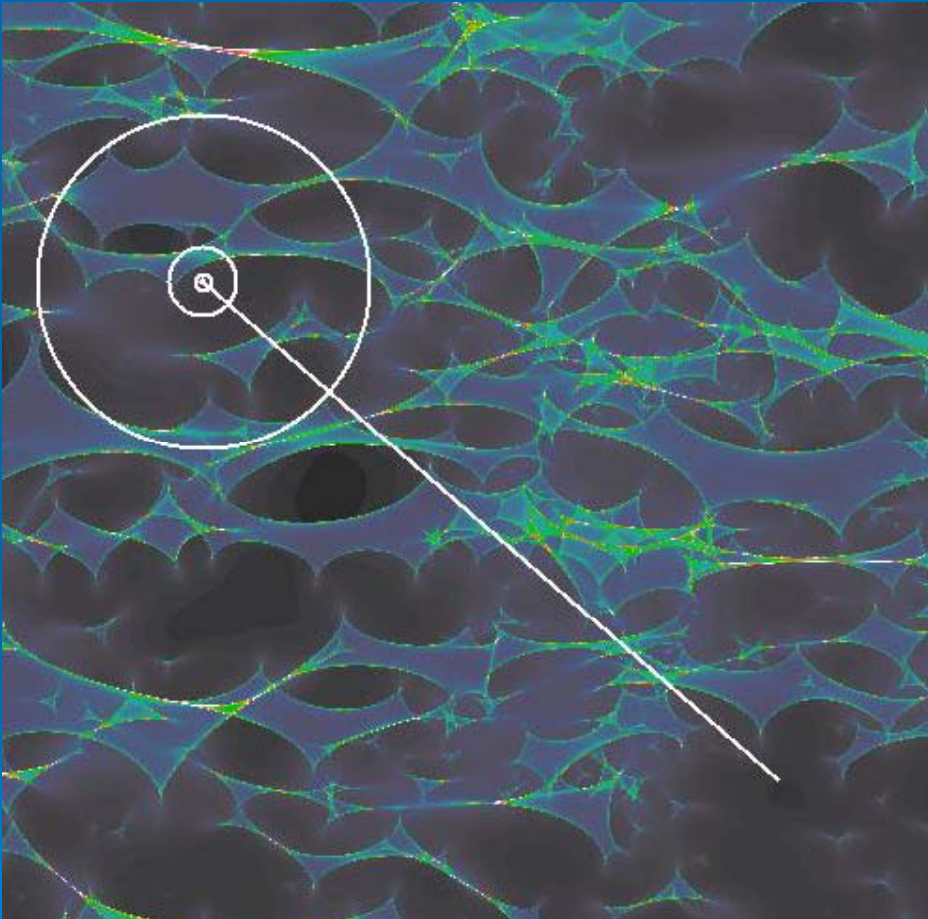
Experimental curves of light for the four images of Einstein's Cross



Comparison with light curve of a microlensing event in the Milky Way



Map and profiles with different sizes



$$m_{\text{micro}} \sim m_{\text{cont.}} - m_{\text{NLR}}$$

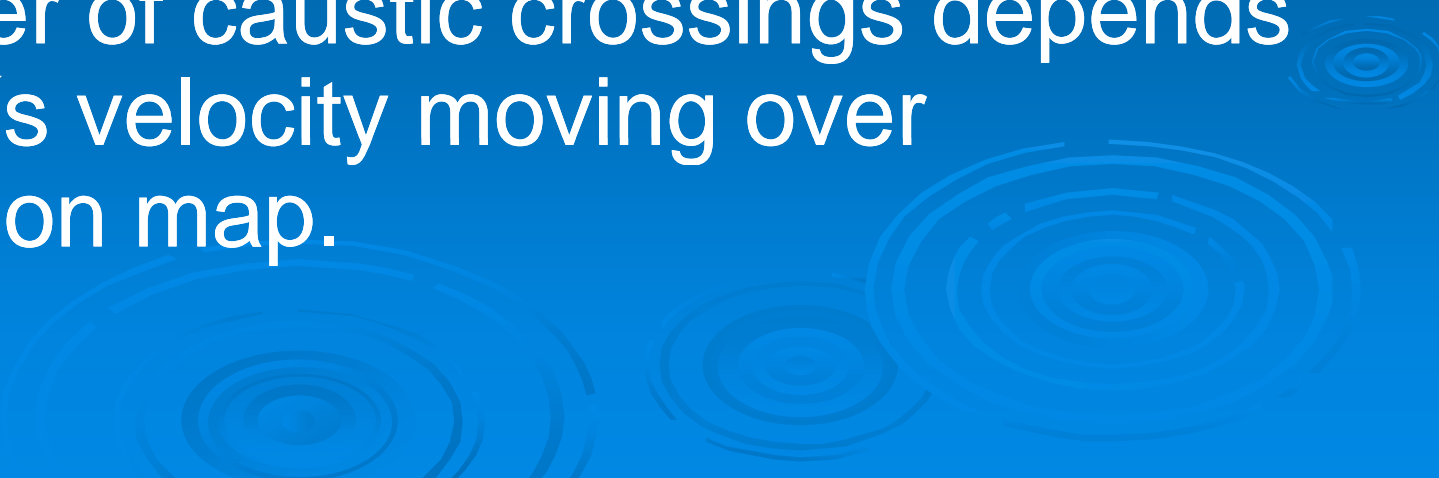
Simulation and statistical analysis

- Comparison between observed and simulated microlensed effect allows to study:
 - Source
 - Size at different wavelengths.
 - Quasar luminosity profile
 - Lens galaxy
 - Mass distribution
 - Microlenses
 - Abundance
 - Mass
 - Lens system
 - Transversal velocity
- Determination of these parameters can be only statistically done.

Simulation and statistical analysis

- Comparison between observed and simulated microlensed effect allows us to study:
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Transversal velocity

- We need to know transversal velocity of quasar to define observing window in suitable Einstein radii units.
 - Difficult to measure.
 - In many experimental studies estimates of parameters depend on it.
 - The number of caustic crossings depends on quasar's velocity moving over magnification map.
- 

Statistical study problems

- Experimental errors and intrinsic variability can affect data and results



Objectives

- Simplify the problem reducing microlensing to a series of discrete events, the caustic crossings. If the source size is small enough :
 - They appear well separated
 - They are of high magnification
 - They are difficult to mistake with other variability features

Statistical analysis of
caustics concentration
based on caustics
crossings counts.

Application to QSO

2237+0305

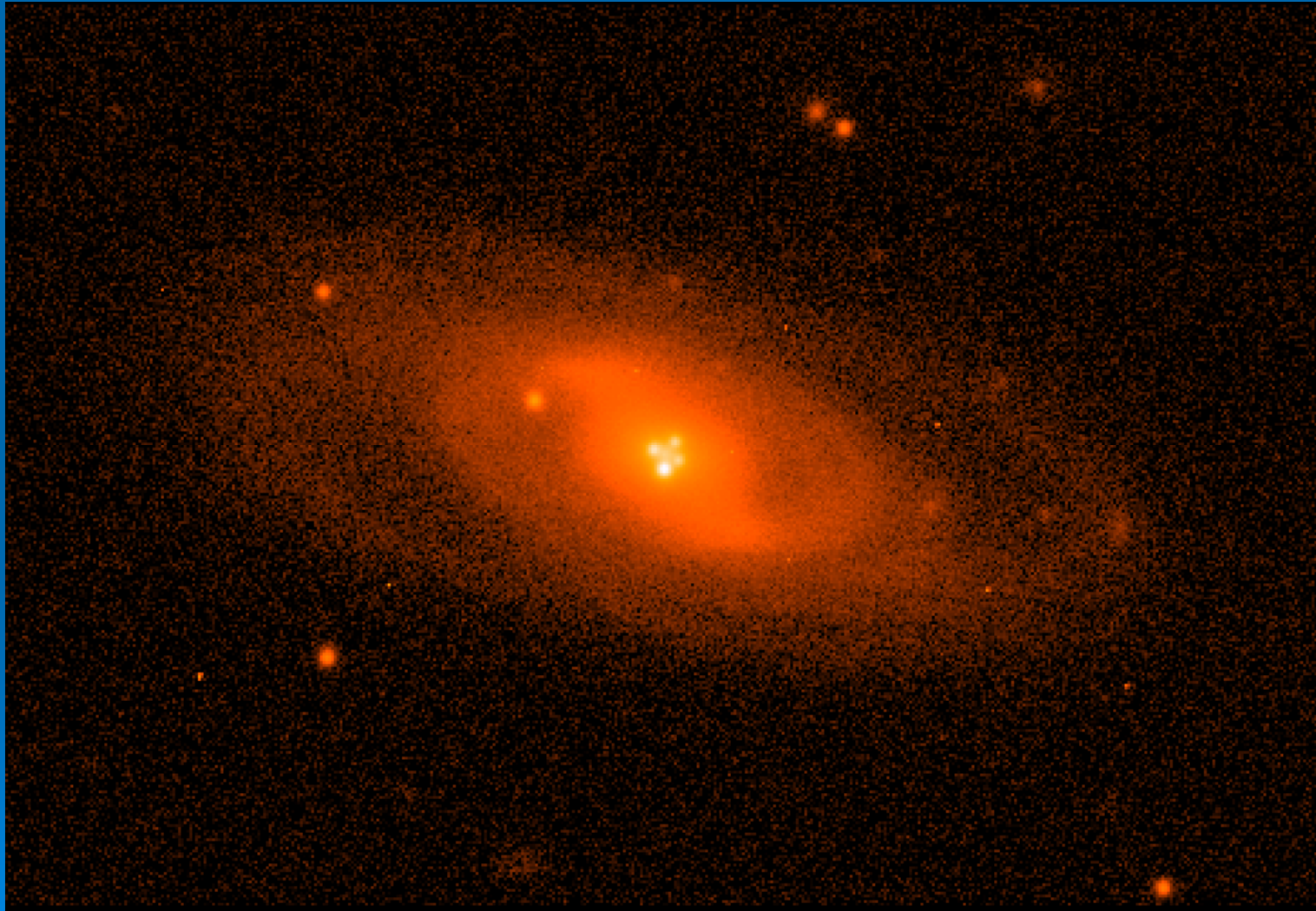
The background is a solid blue color with several faint, concentric circular patterns scattered across the lower half, resembling ripples in water or light waves.

Analysis steps

- Simulate magnification maps for different densities of matter, different mass distribution and shear.
- Identify caustic curves
- Count the number of caustics detected in a one-dimensional window of certain size in pixels for each axis
- Estimate probability of detecting a caustic in a pixel for each axis
- Compare experimental distributions obtained in simulations with theoretical binomial distribution.
- Minimize χ^2 to obtain $\langle M \rangle$ and t_v .

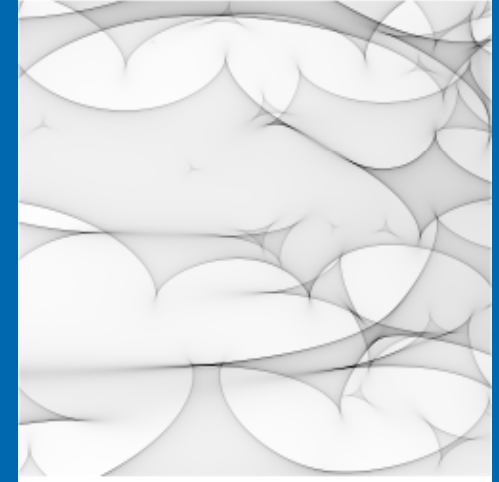
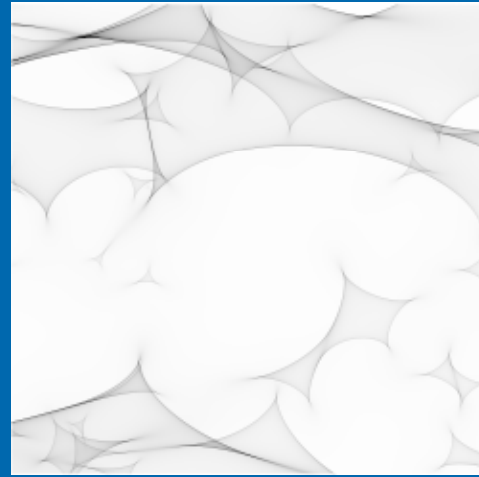
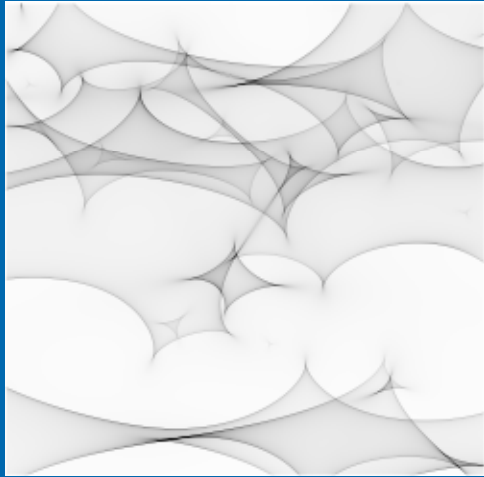
$$\chi^2 = \sum_i \frac{(F_i^{\text{obs}} - F_i^{\text{sim}})^2}{F_i^{\text{sim}}}$$

Application to QSO 2237+0305

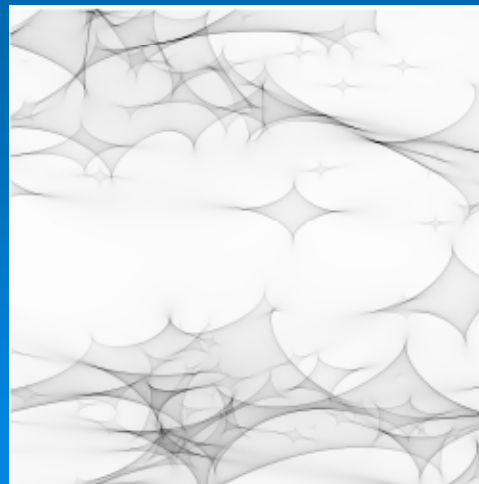


Magnification Maps

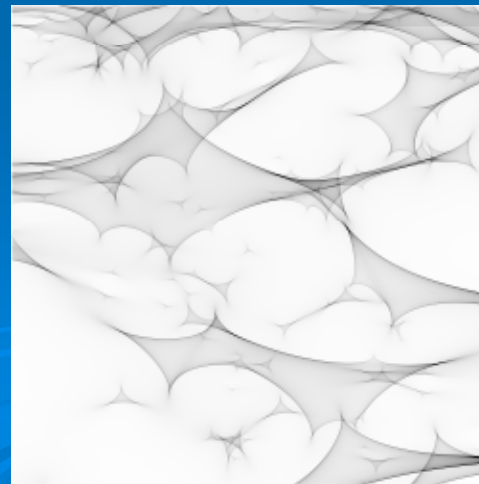
1 solar mass microlenses



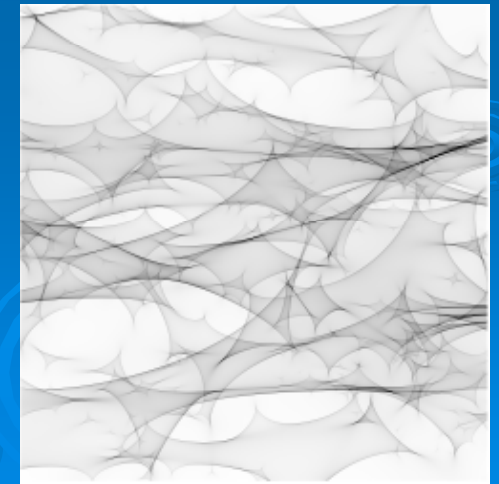
Microlenses distributed in a range of masses



A Y B



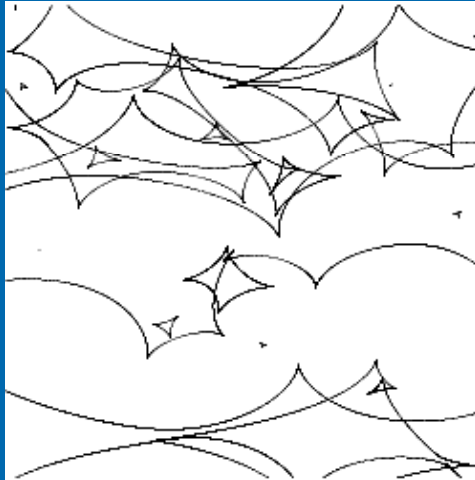
C



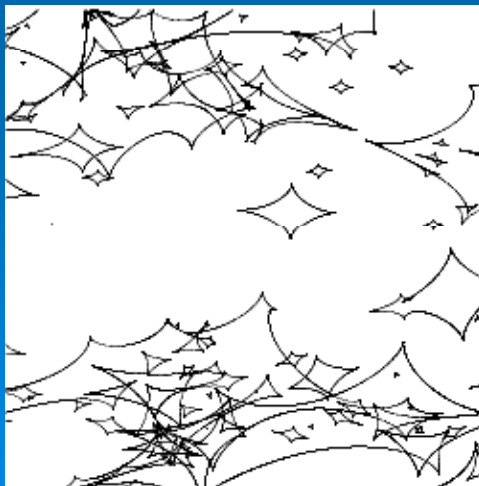
D

Caustics

1 solar mass microlenses



Microlenses distributed in a range of masses



A Y B

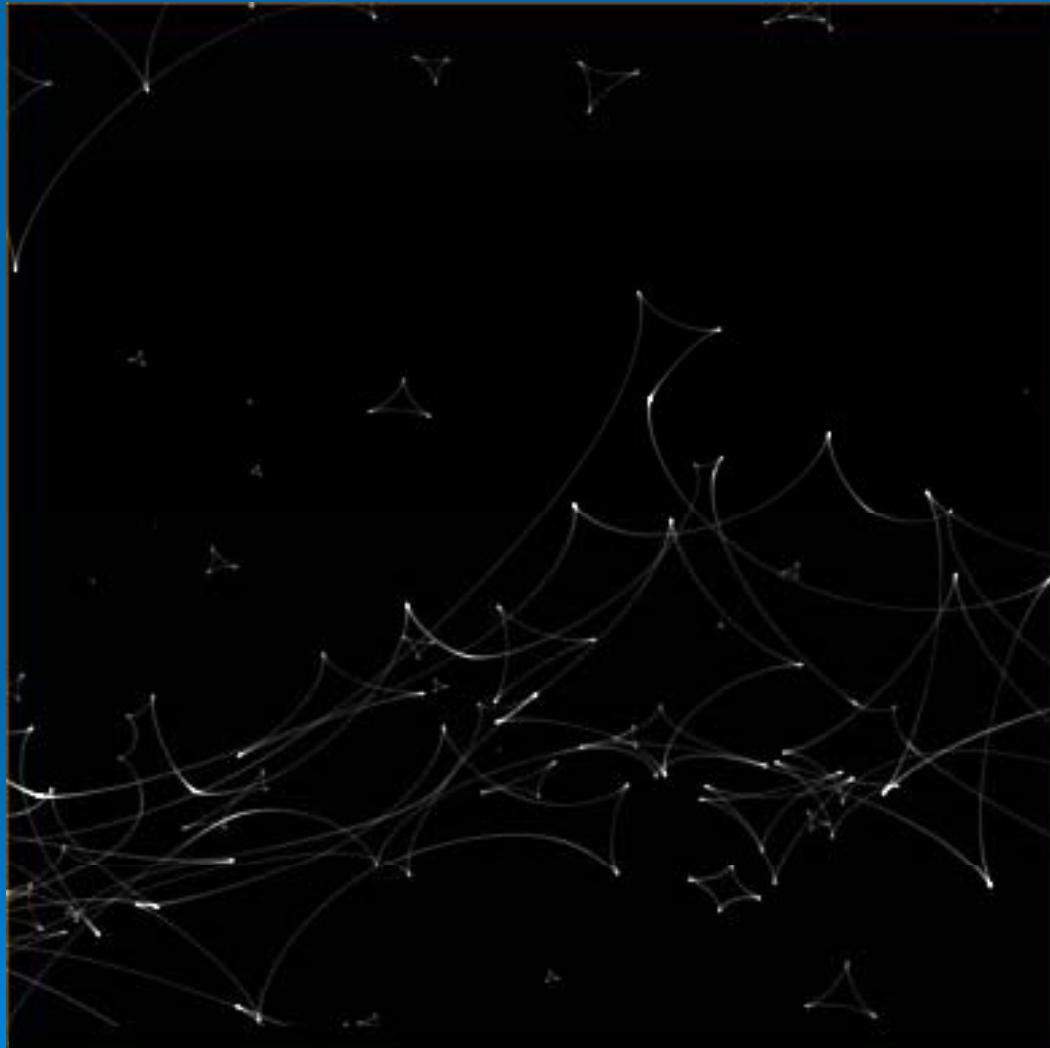


C

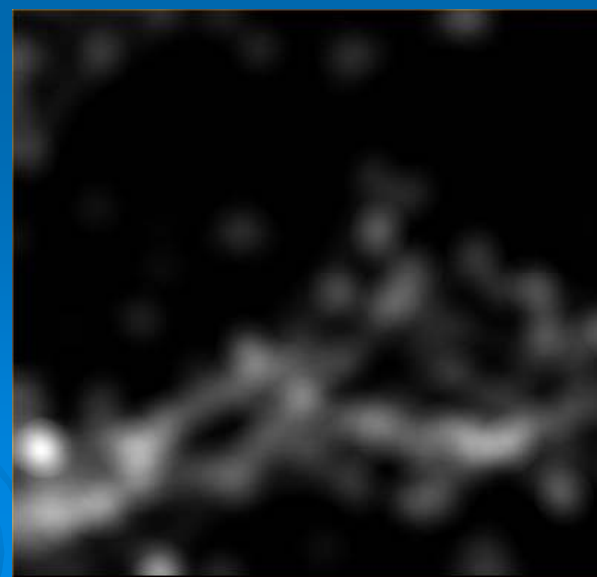
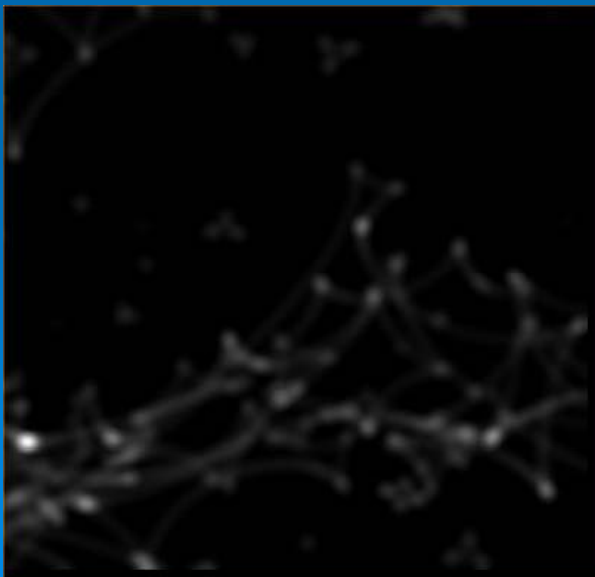


D

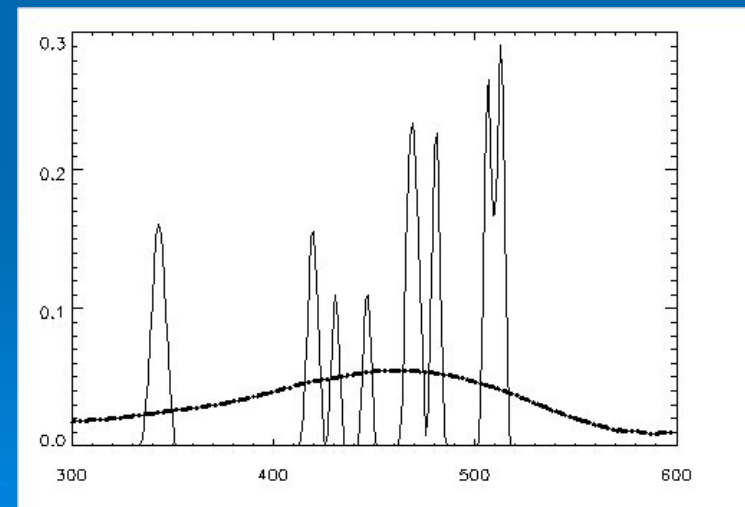
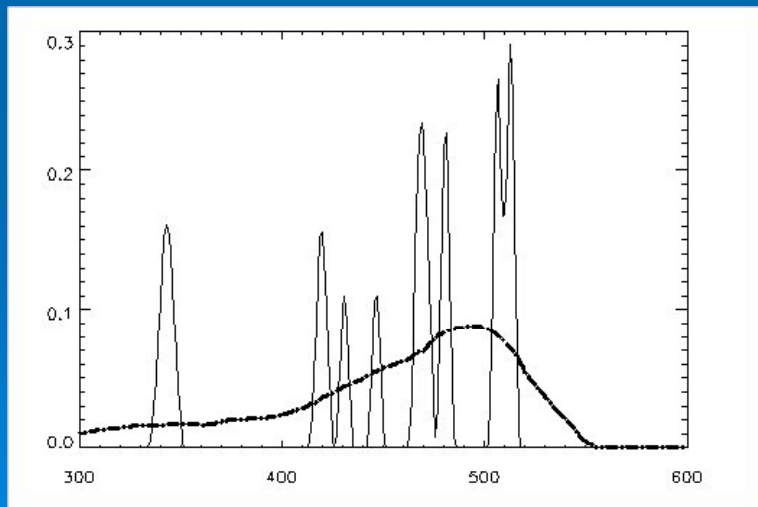
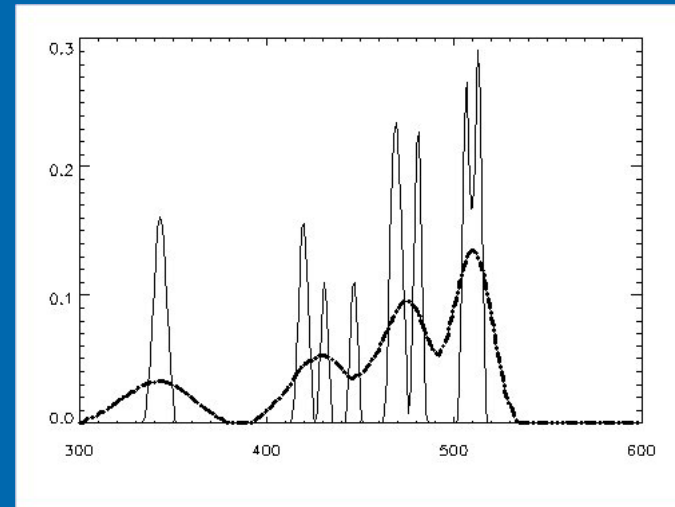
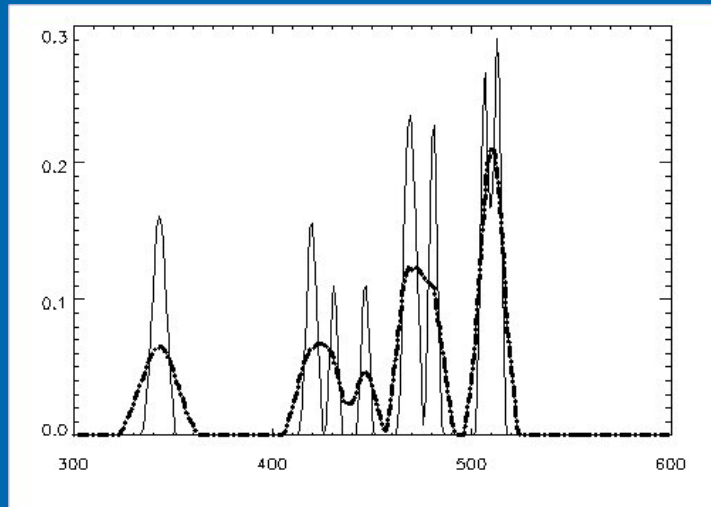
Magnification map of image D hypothesis A



Effects of source size on magnification map

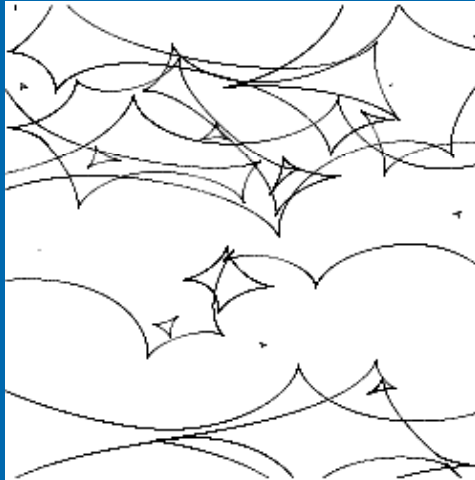


Caustics can only be isolated in X-ray emission

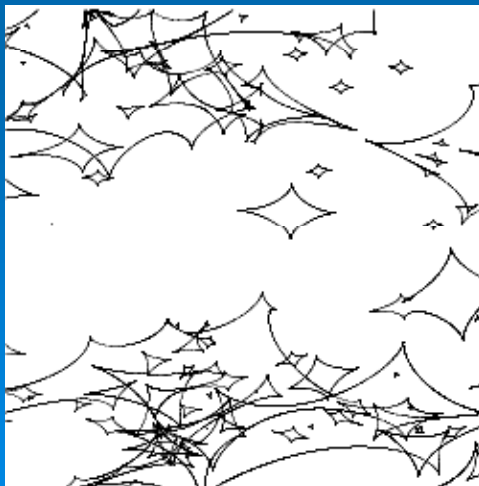


Caustics

1 solar mass microlenses



Microlenses distributed in a range of masses



A Y B

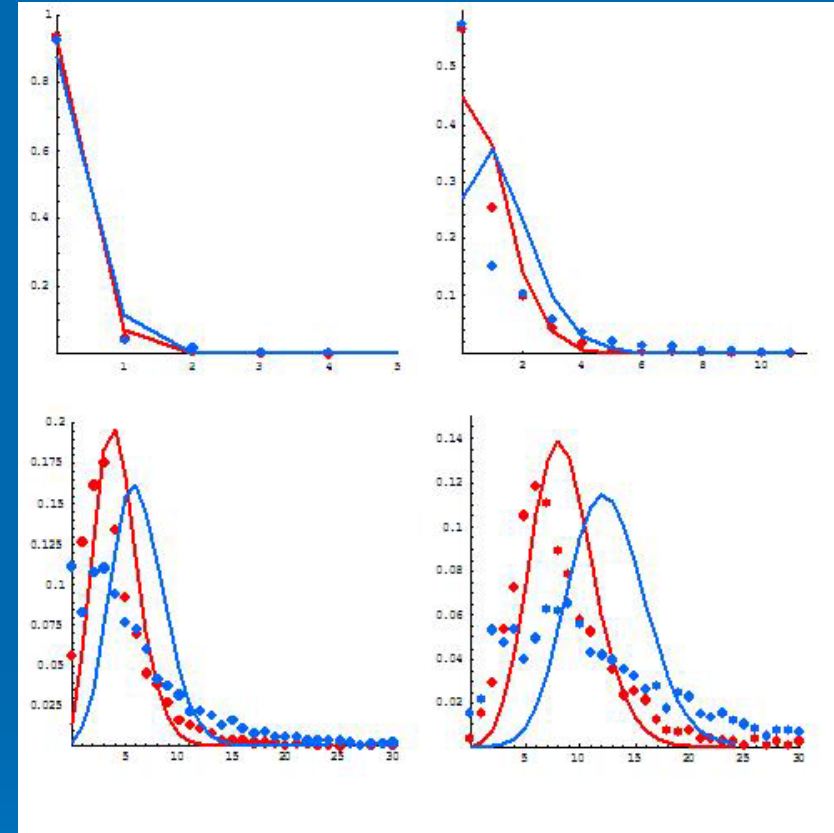
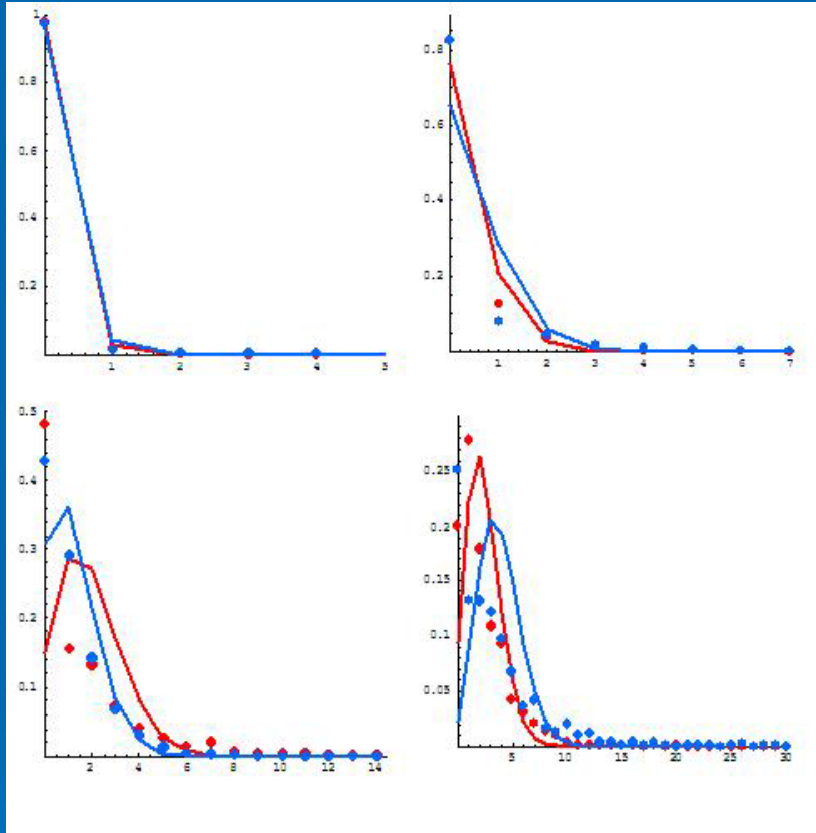


C



D

Comparison with the binomial distribution (D image)



Unimodal distribution	Peak	Centroid
400 pixels X axis	1	1
200 pixels X axis	0	0
400 pixels Y axis	0	2
200 pixels Y axis	0	0

Masses in a range	Peak	Centroid
400 pixels X axis	6	7
200 pixels X axis	3	3
400 pixels Y axis	9	10
200 pixels Y axis	3	4

Results and future work



Results (I)

D IMAGE

X AXIS		Y AXIS	
$n=7, \text{error}=\pm 3$ $P(7\pm 3/A)=0.63$ $P(7\pm 3/B)=0.22$	$n=1, \text{error}=\pm 1$ $P(1\pm 1/A)=0.049$ $P(1\pm 1/B)=0.66$	$n=10, \text{error}=\pm 3$ $P(10\pm 3/A)=0.37$ $P(10\pm 3/B)=0.12$	$n=2, \text{error}=\pm 1$ $P(2\pm 1/A)=0.12$ $P(2\pm 1/B)=0.38$
$P(A/7)=0.75$ $P(B/7)=0.25$	$P(A/1)=0.07$ $P(B/1)=0.93$	$P(A/10)=0.76$ $P(B/10)=0.24$	$P(A/2)=0.24$ $P(B/2)=0.76$

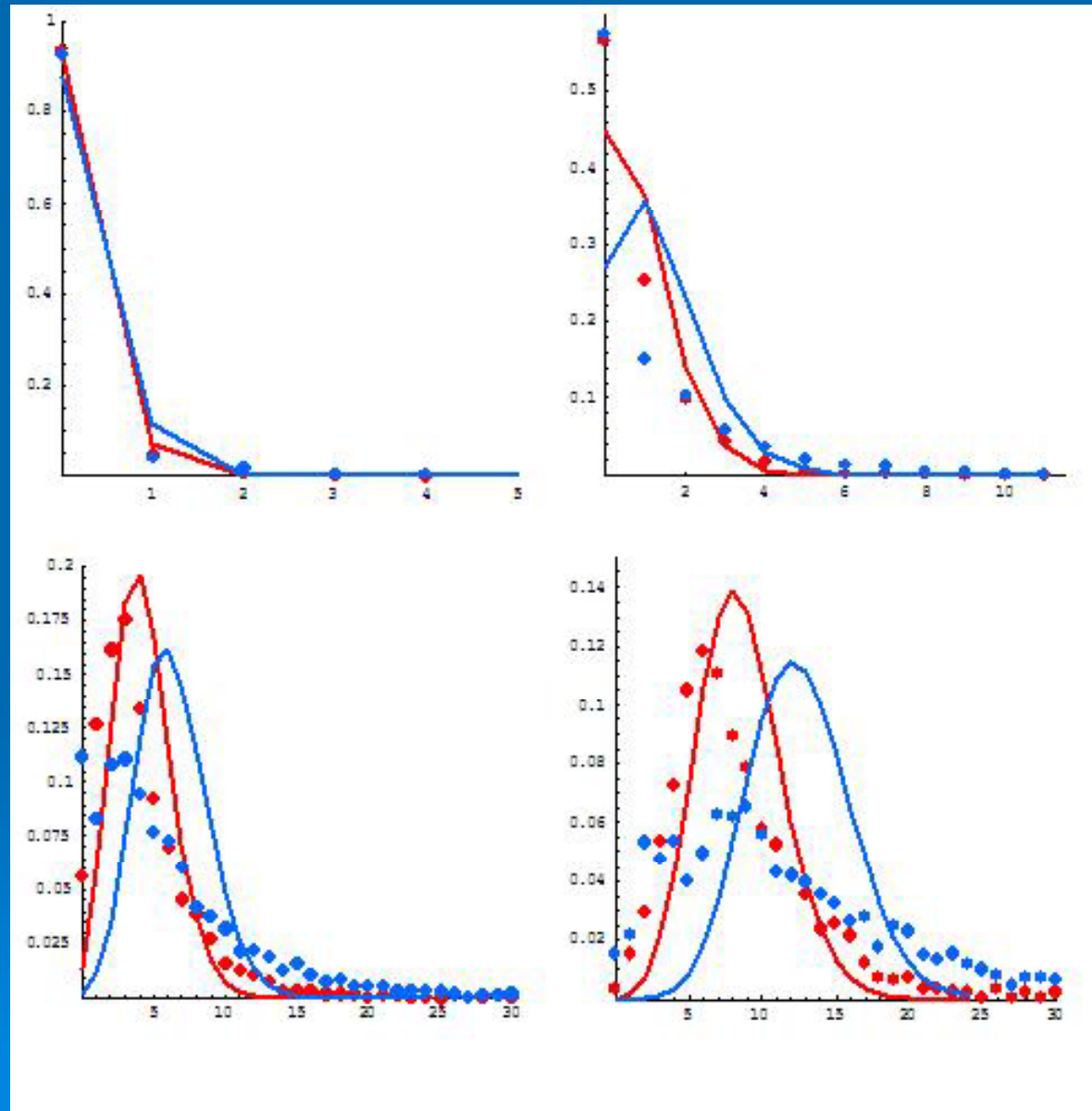
We can distinguish between A and B hypothesis

Results (II)

Can we solve the size / transversal velocity degeneracy?



Results (II)



Results (II)

D image microlenses distributed in a range of masses

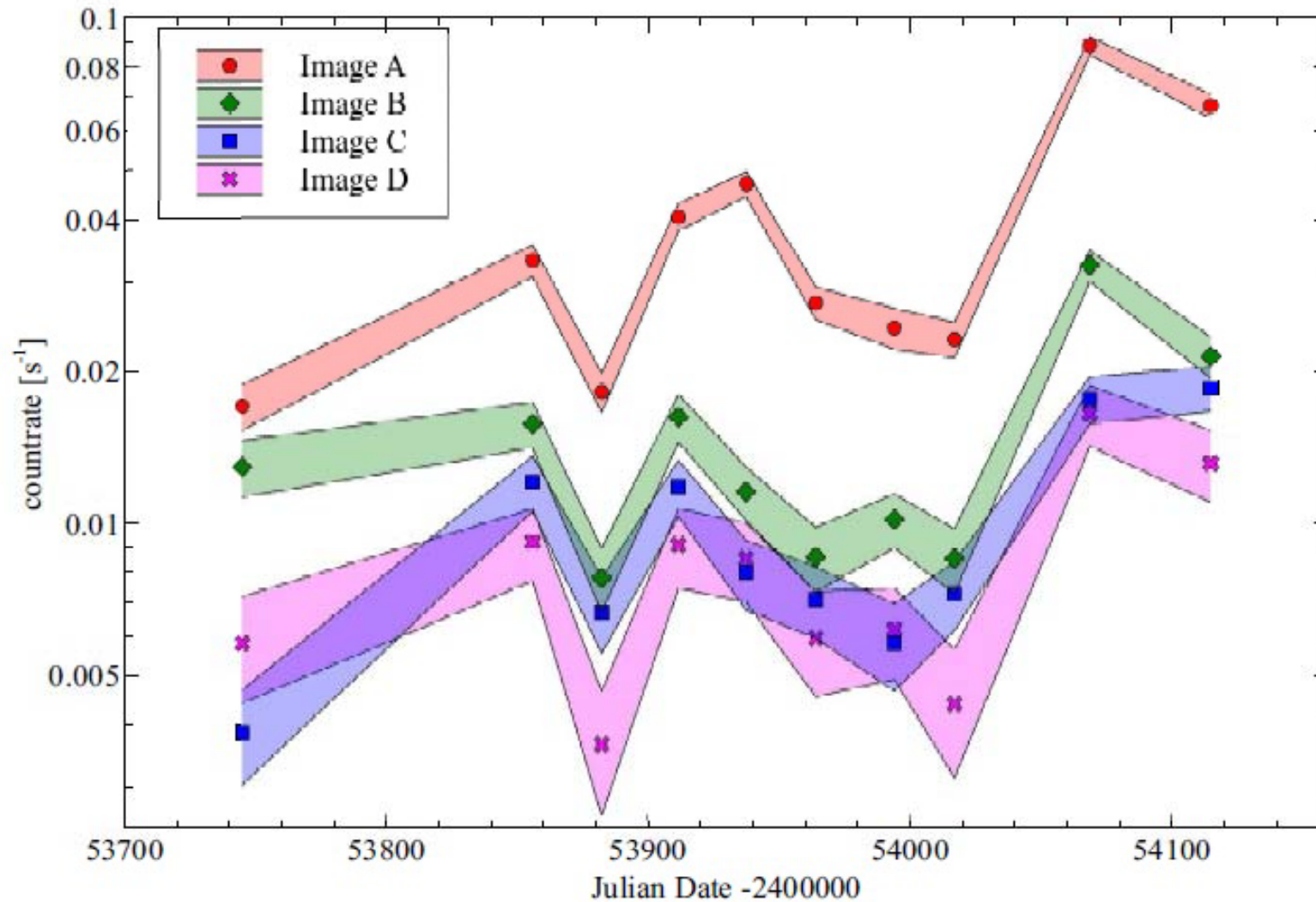
Number of caustics (X axis) > 6 \longrightarrow Window > 1.2 Einstein radii

Number of caustics (X axis) < 3 \longrightarrow Window < 1.2 Einstein radii

Number of caustics (Y axis) > 9 \longrightarrow Window > 1.2 Einstein radii

Number of caustics (Y axis) < 3 \longrightarrow Window < 1.2 Einstein radii

X-ray light curve of the four images of Q2237



Zimmer, F., Schmidt, R. W. and Wambsganss, J. (2010).

Comparison with theoretical results

0 caustics crossings in a year



Either of the two cases of distribution of mass in stars

We need to observe during ten years to obtain definitive results

Future work

- Simulate distributions of stars characterized by their average mass, $\langle M \rangle$, and determine probability distribution functions for each $\langle M \rangle$.
- Define a χ^2 function to apply a test to the probability distribution:

$$\chi^2 = \sum_i \frac{(F_i^{\text{obs}} - F_i^{\text{sim}})^2}{F_i^{\text{sim}}}$$

- Obtain an estimate of $\langle M \rangle$ minimizing this function with respect to $\langle M \rangle$.
- Obtain an estimate of transversal velocity minimizing this function with respect to transversal velocity.