Microlensing based studies of the unresolved structure of AGN and the composition of lens galaxies

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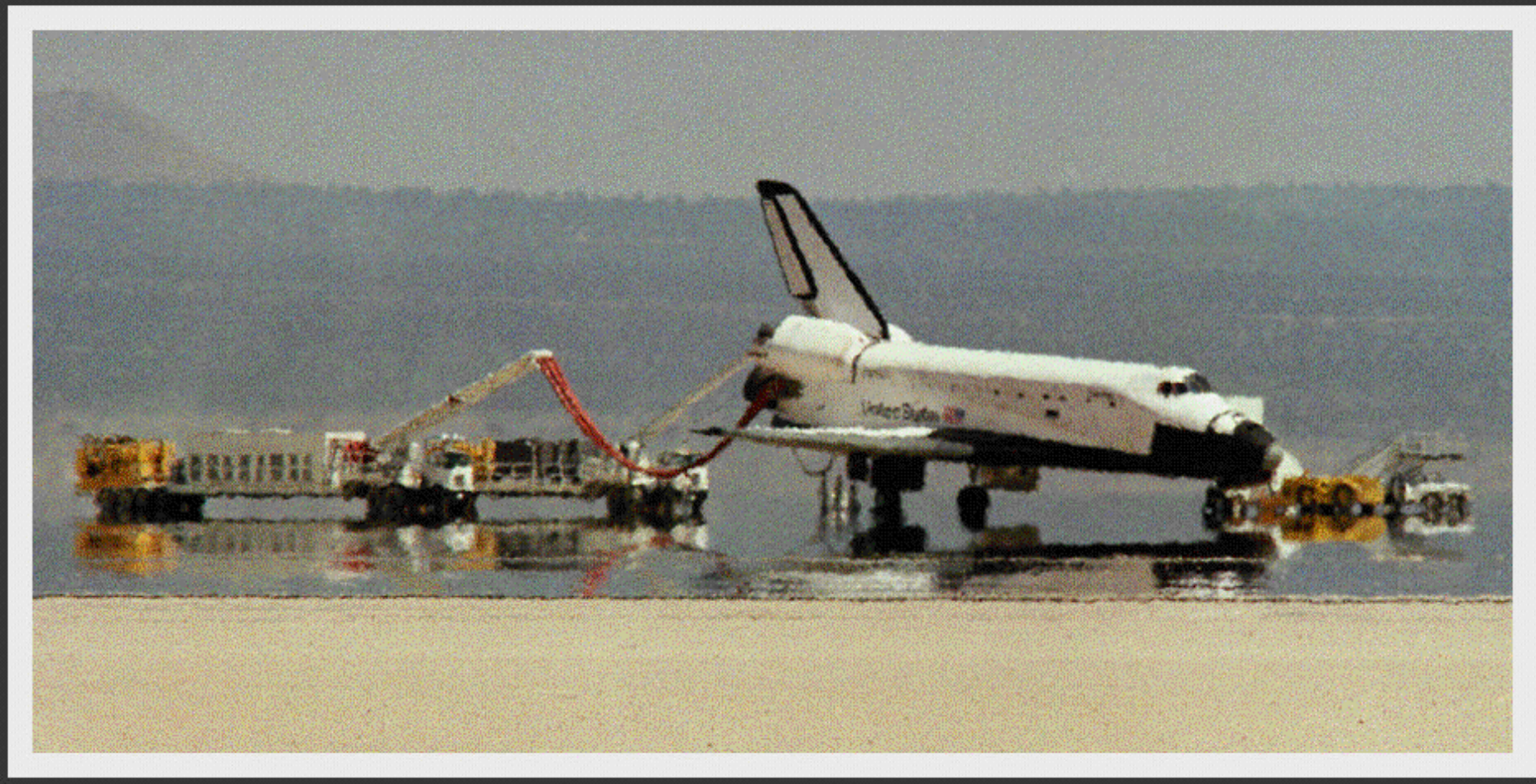
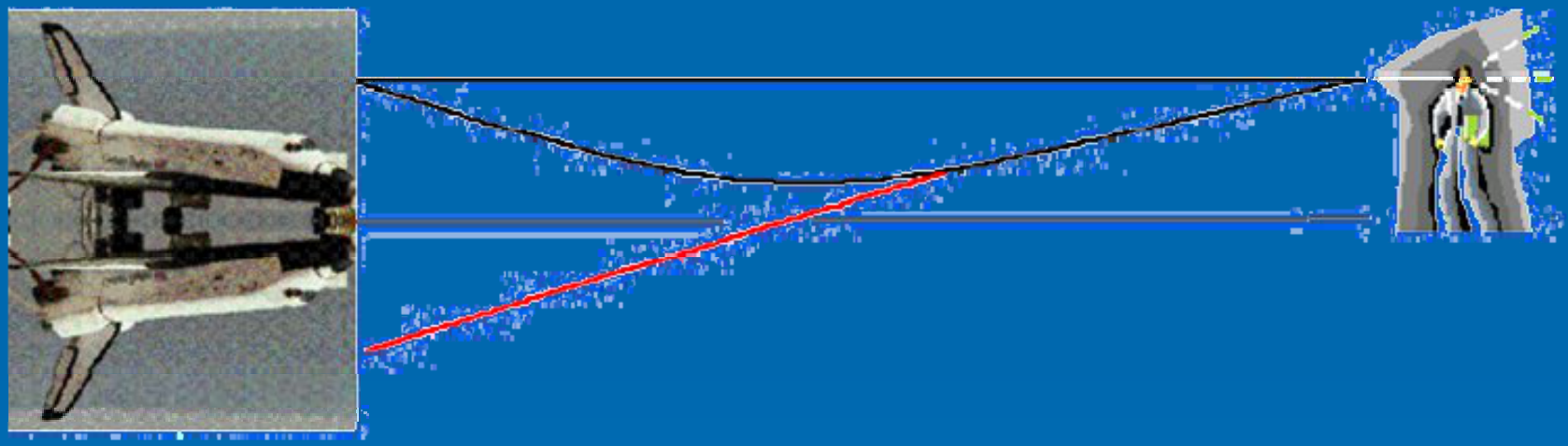
- Introduction to gravitational lensing and microlensing.
- Statistical analysis of caustics concentration based on caustics crossings counts. Application to QSO 2237+0305
- Results and future work.

Introduction to gravitational lensing and microlensing

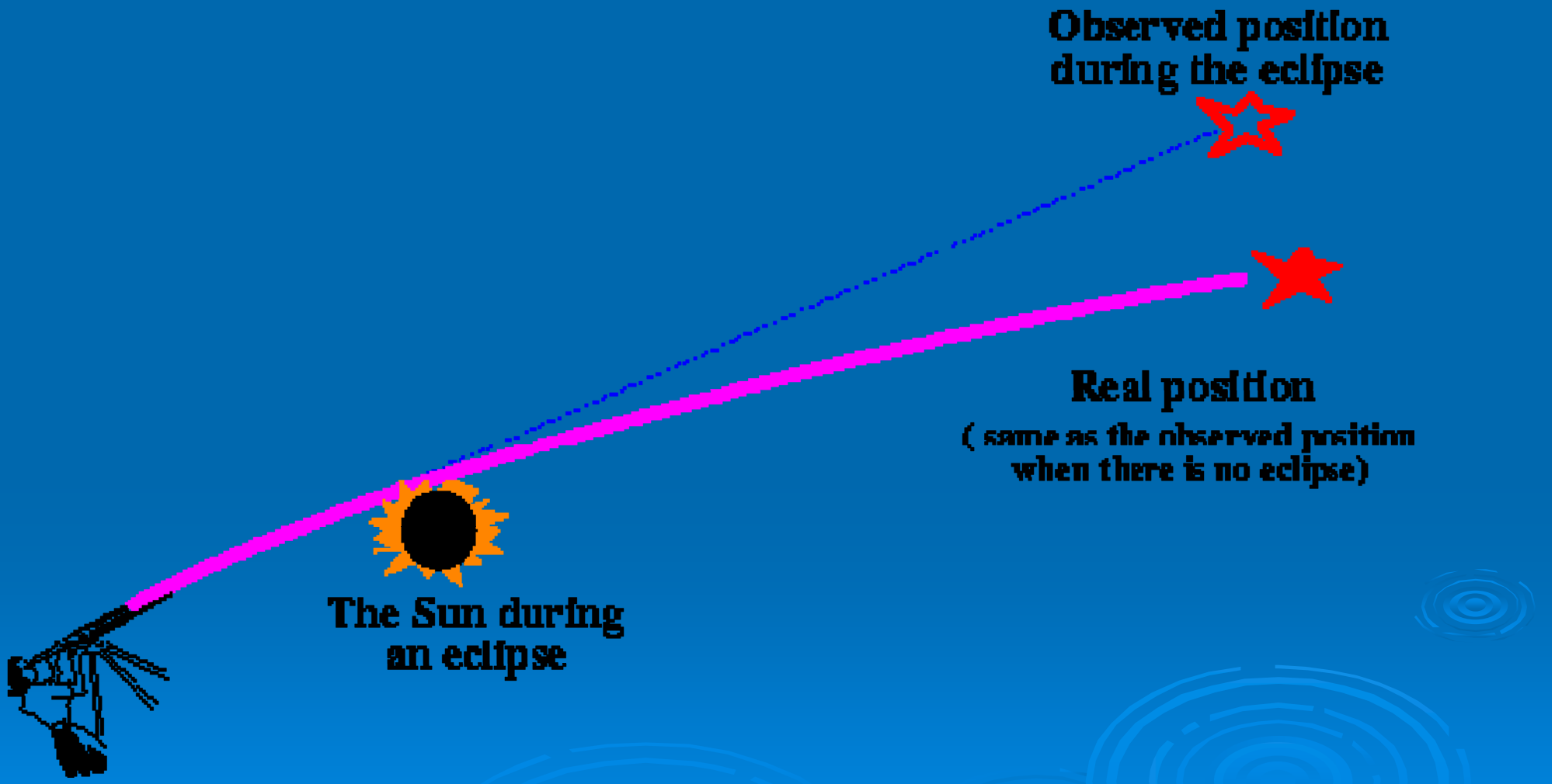


STS 1 in Desert Mirage, Edwards AFB ~ 1981

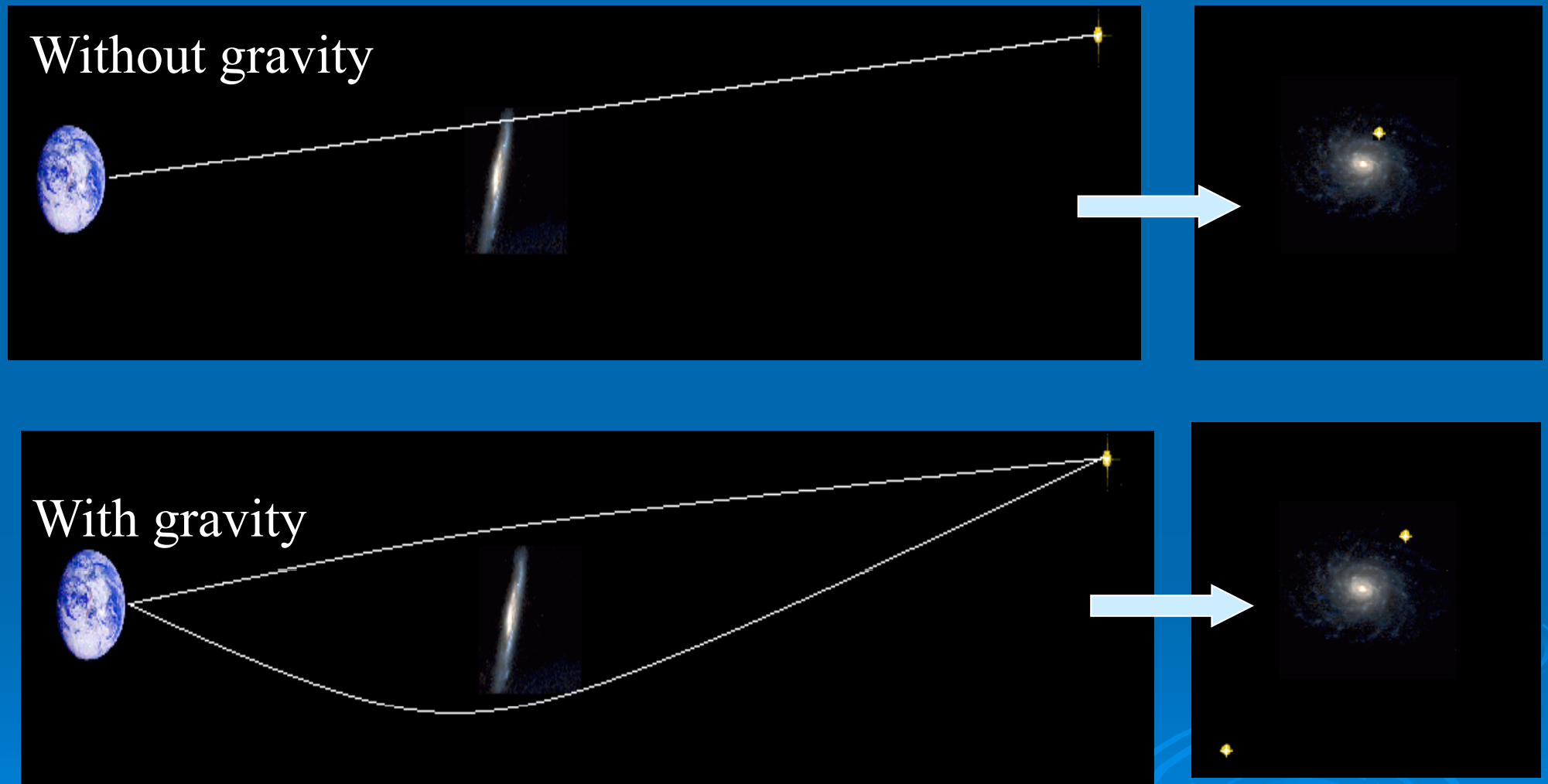
Terrestrial mirage



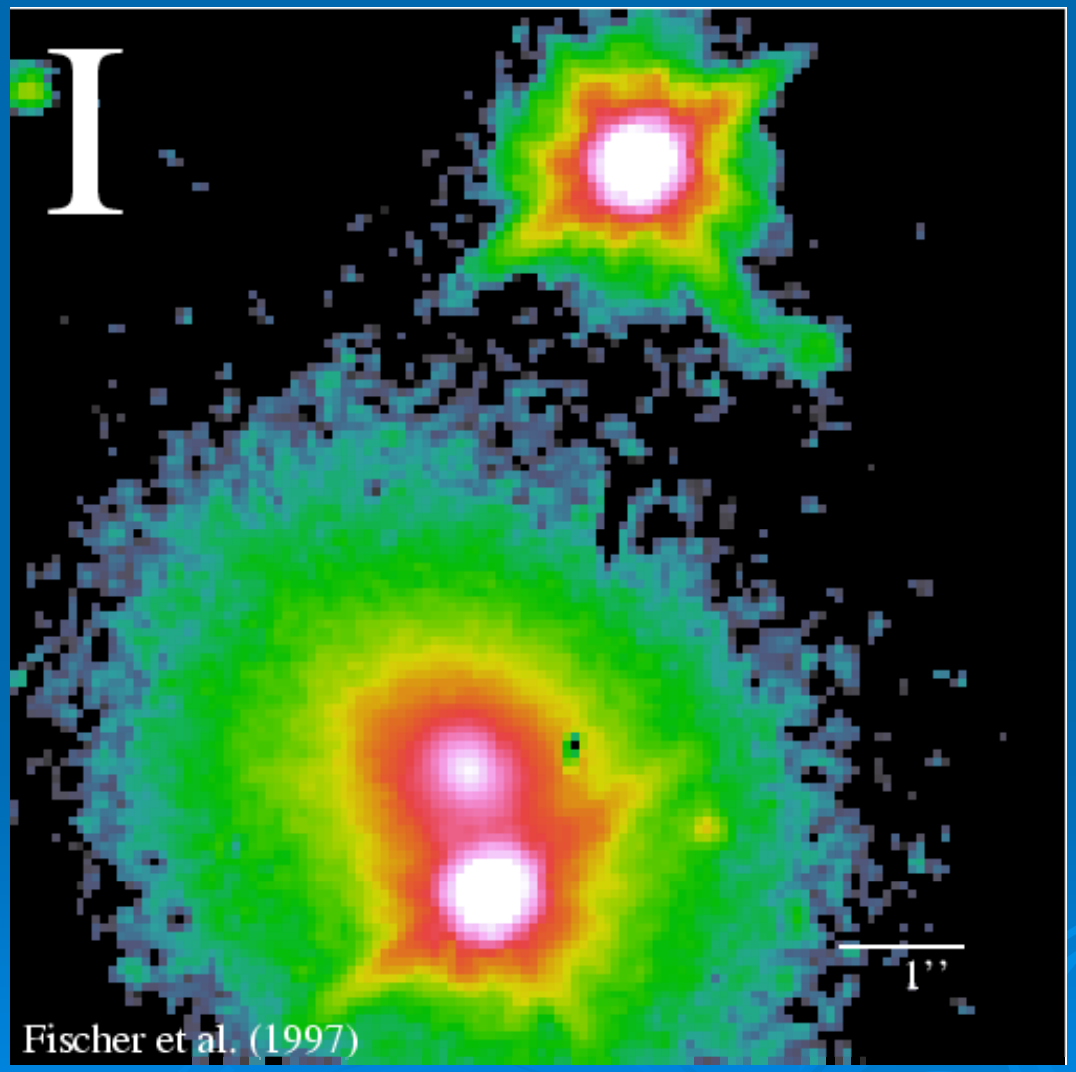
Light deflection by the Sun –1919 eclipse



Gravitational mirage

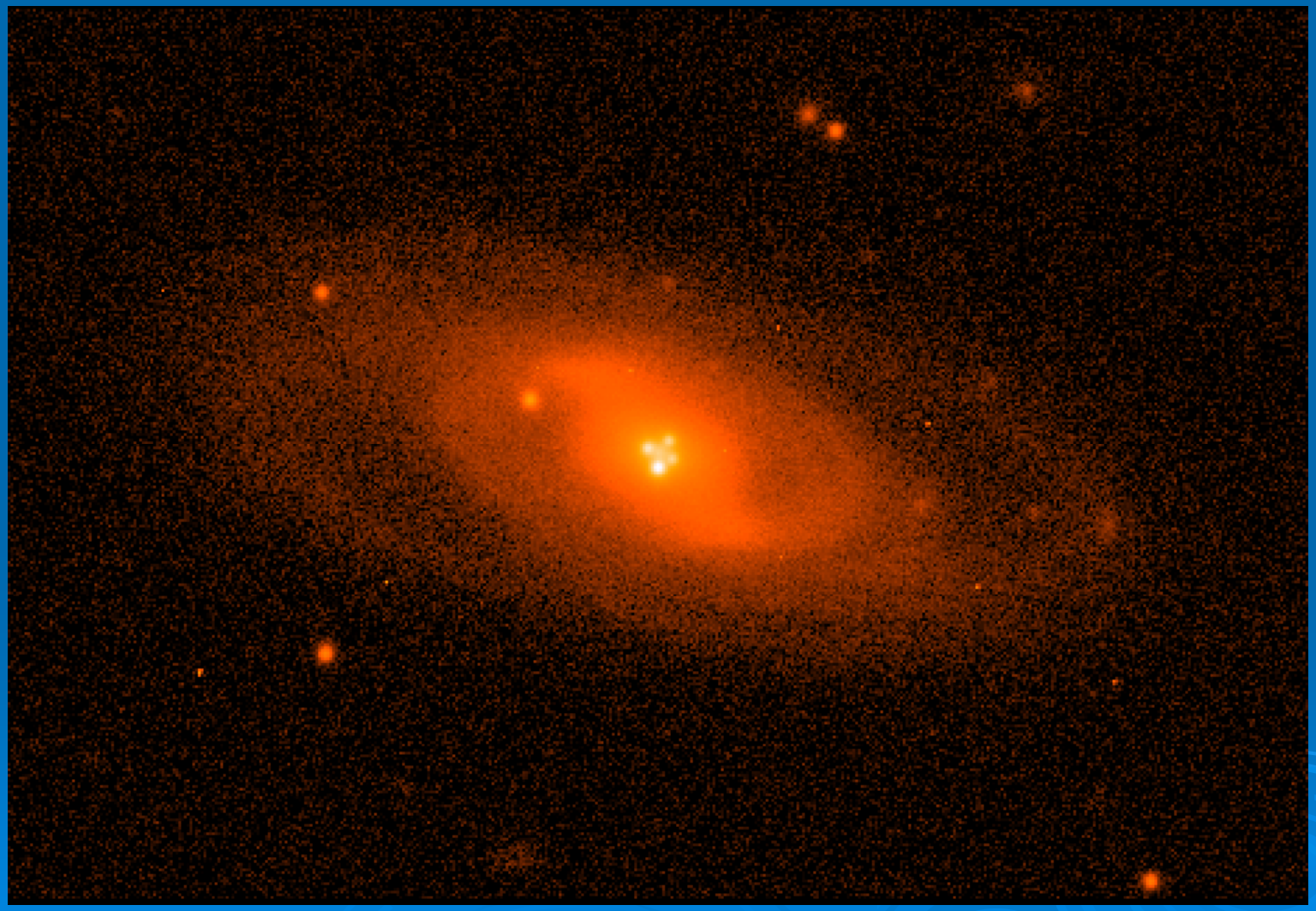


First discovered gravitational lens

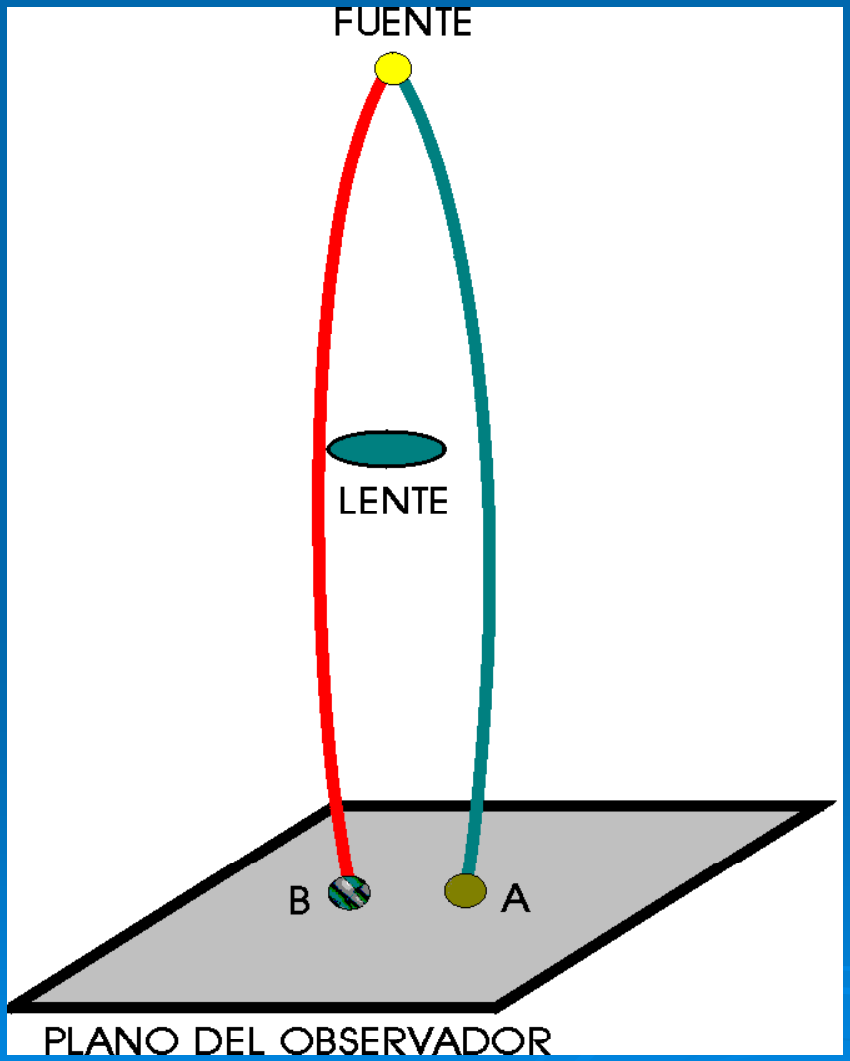


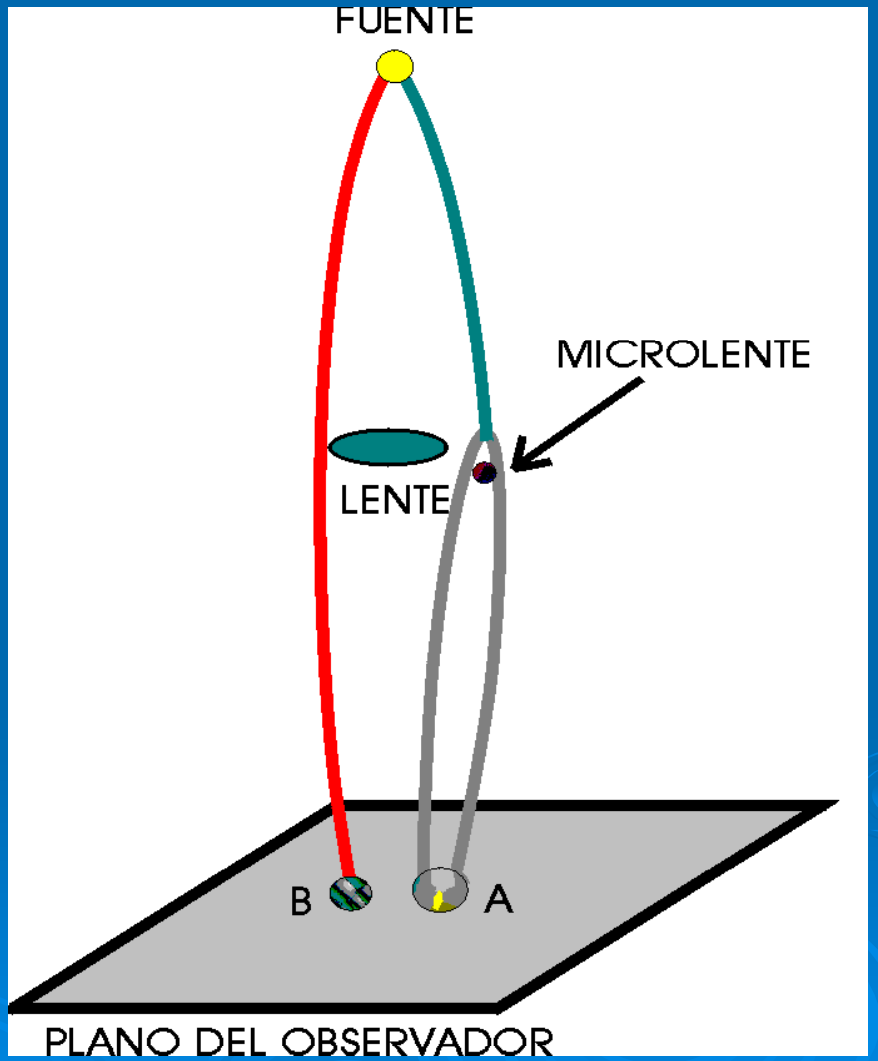
(QSO 0957+561)

QSO 2237+0305



Microlensing



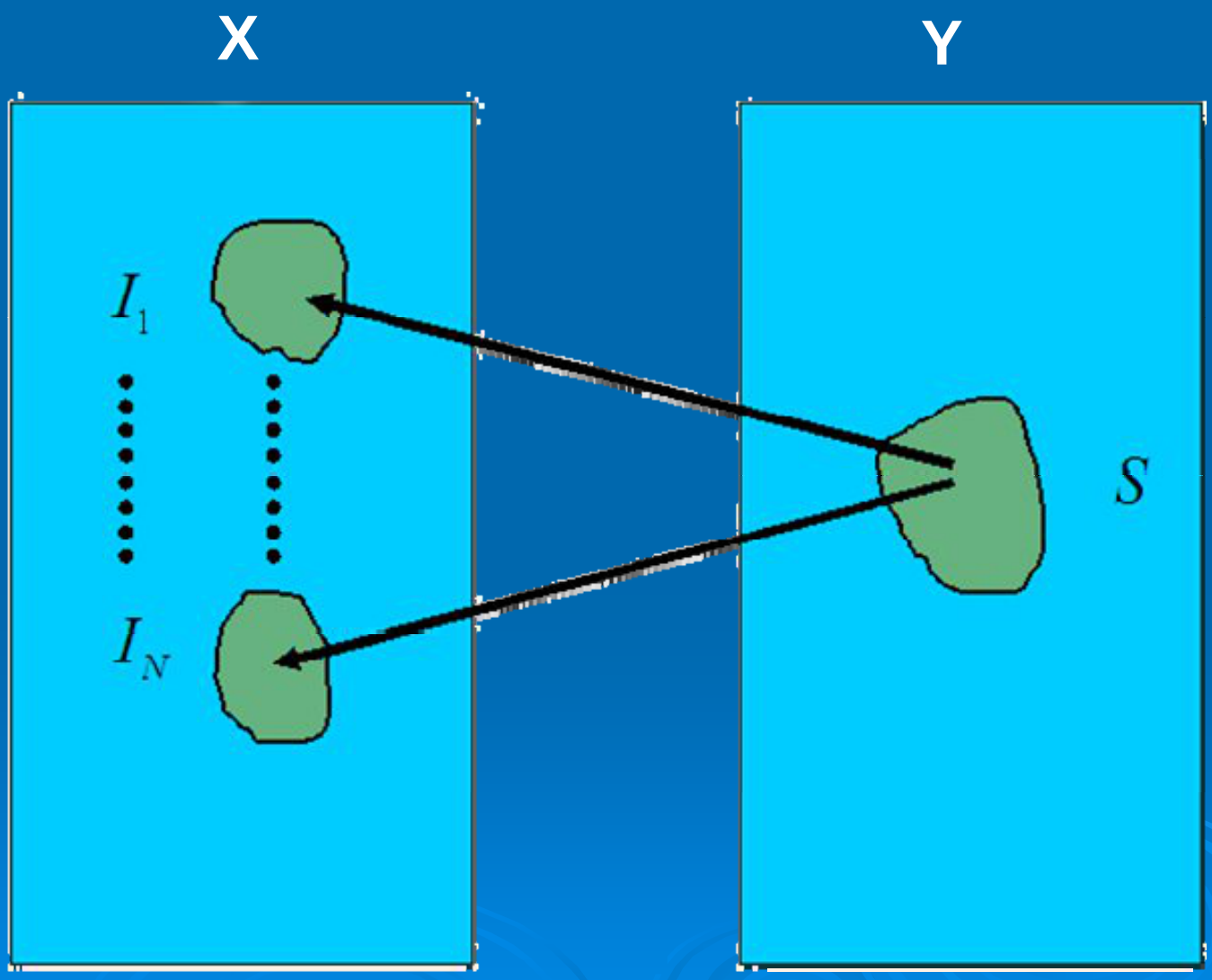


One Source several images Magnification

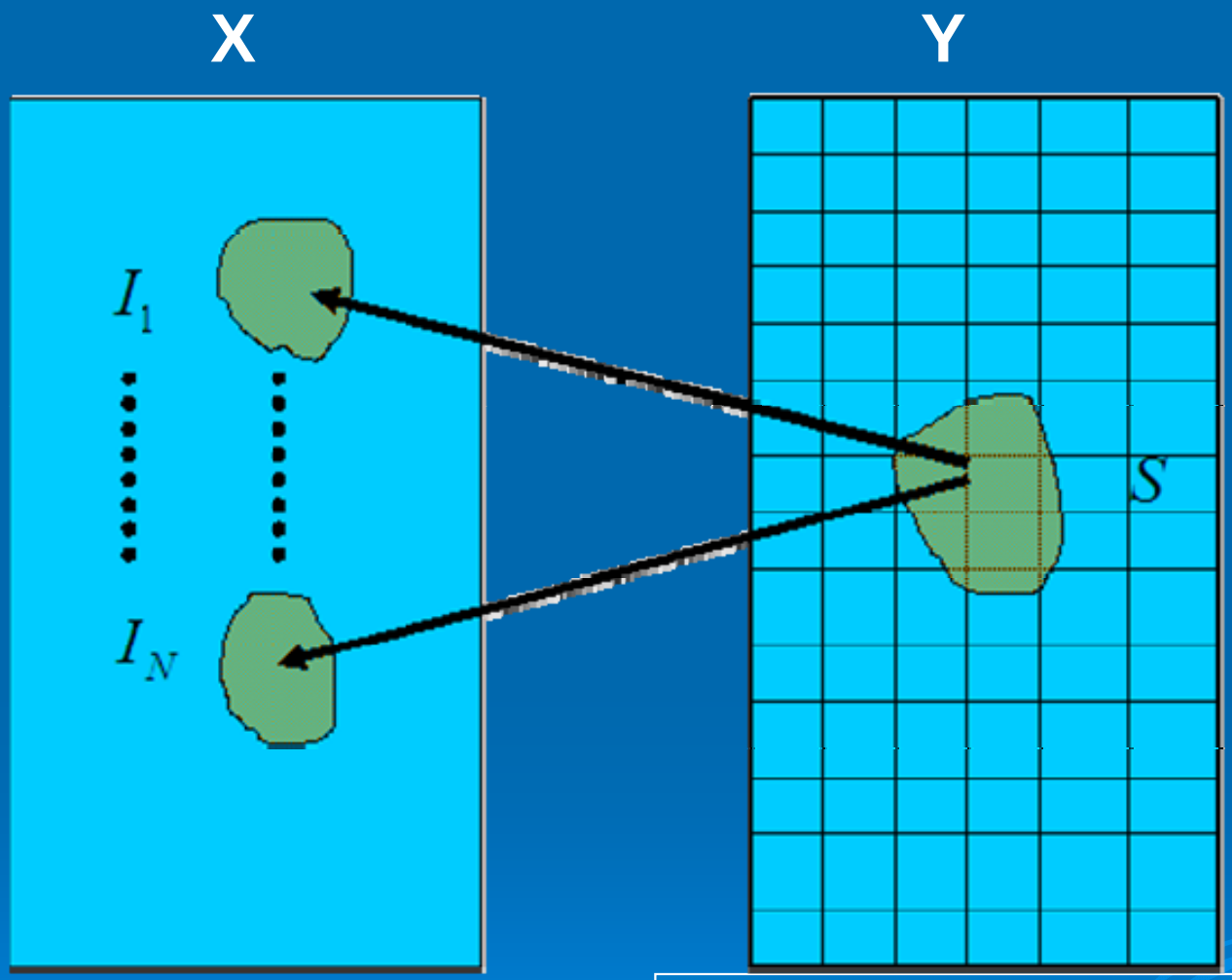
$$\mu = \frac{\sum_i F_{I_i}}{F_S}$$

T. LIOUVILLE

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

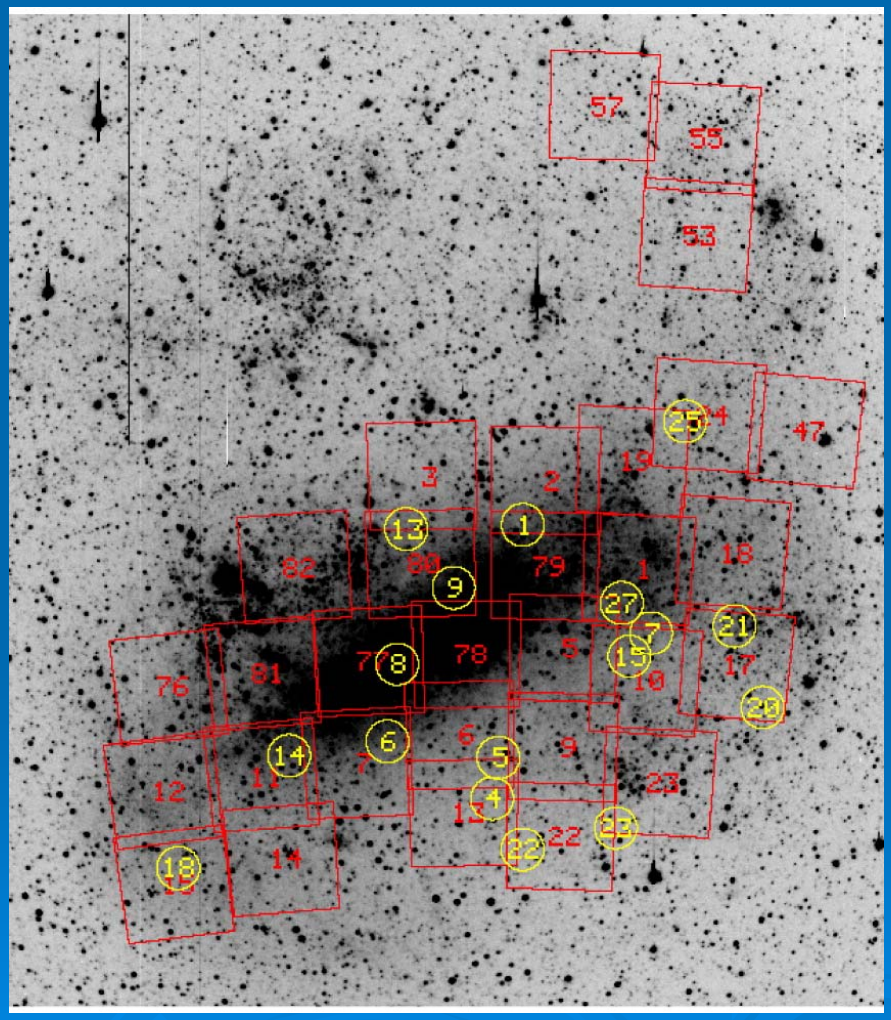


Pixels-magnification map

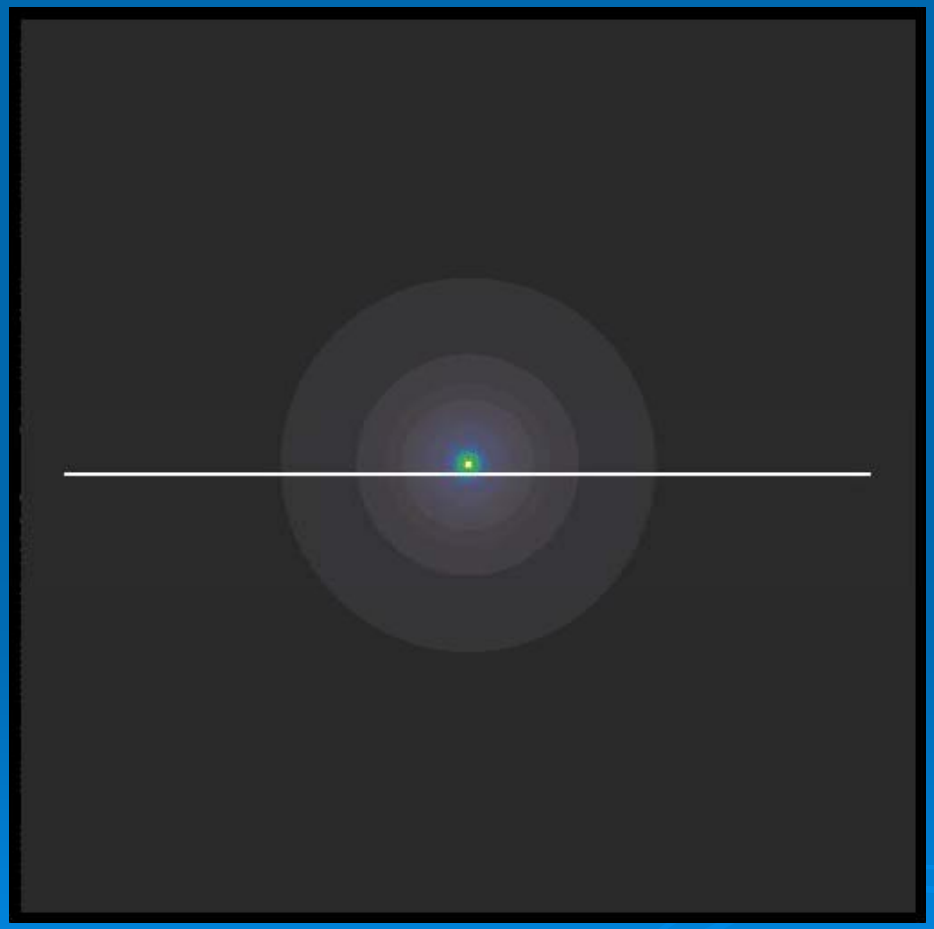


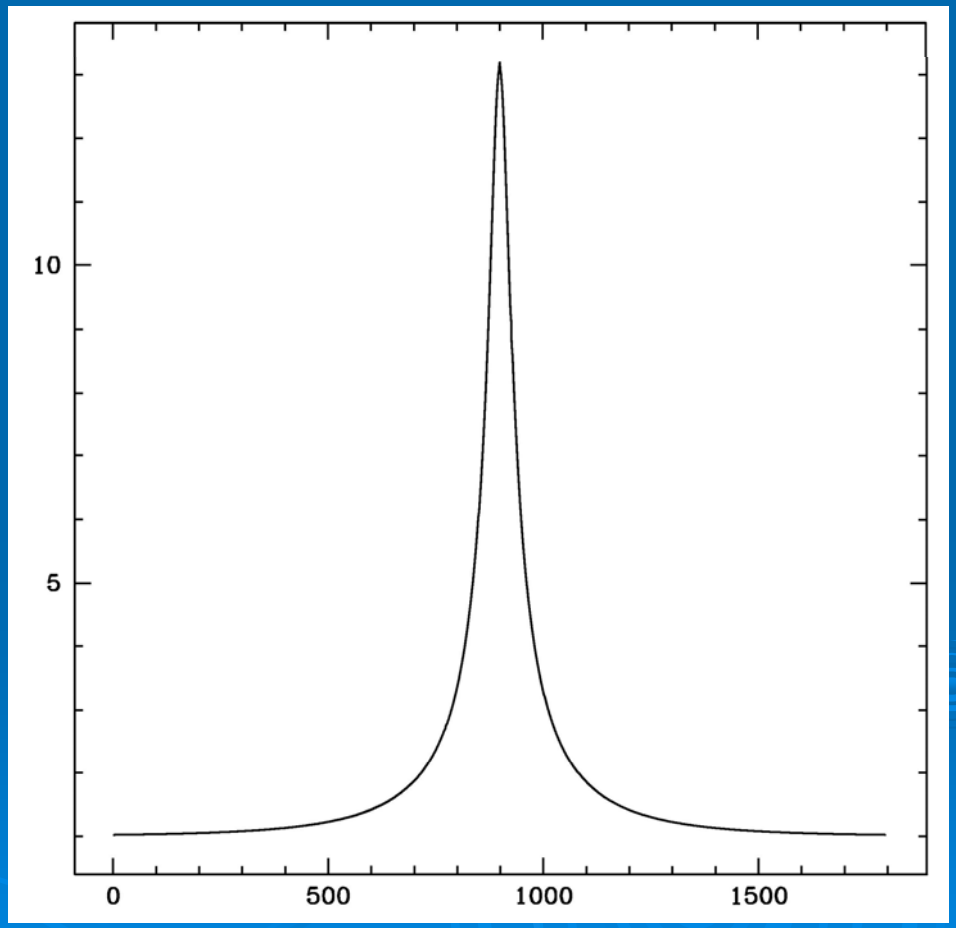
$$\mu_S = \sum_{\eta_1,\eta_2} I_S(\eta_1,\eta_2)\mu_P(\eta_1,\eta_2)$$

MACHO experiment

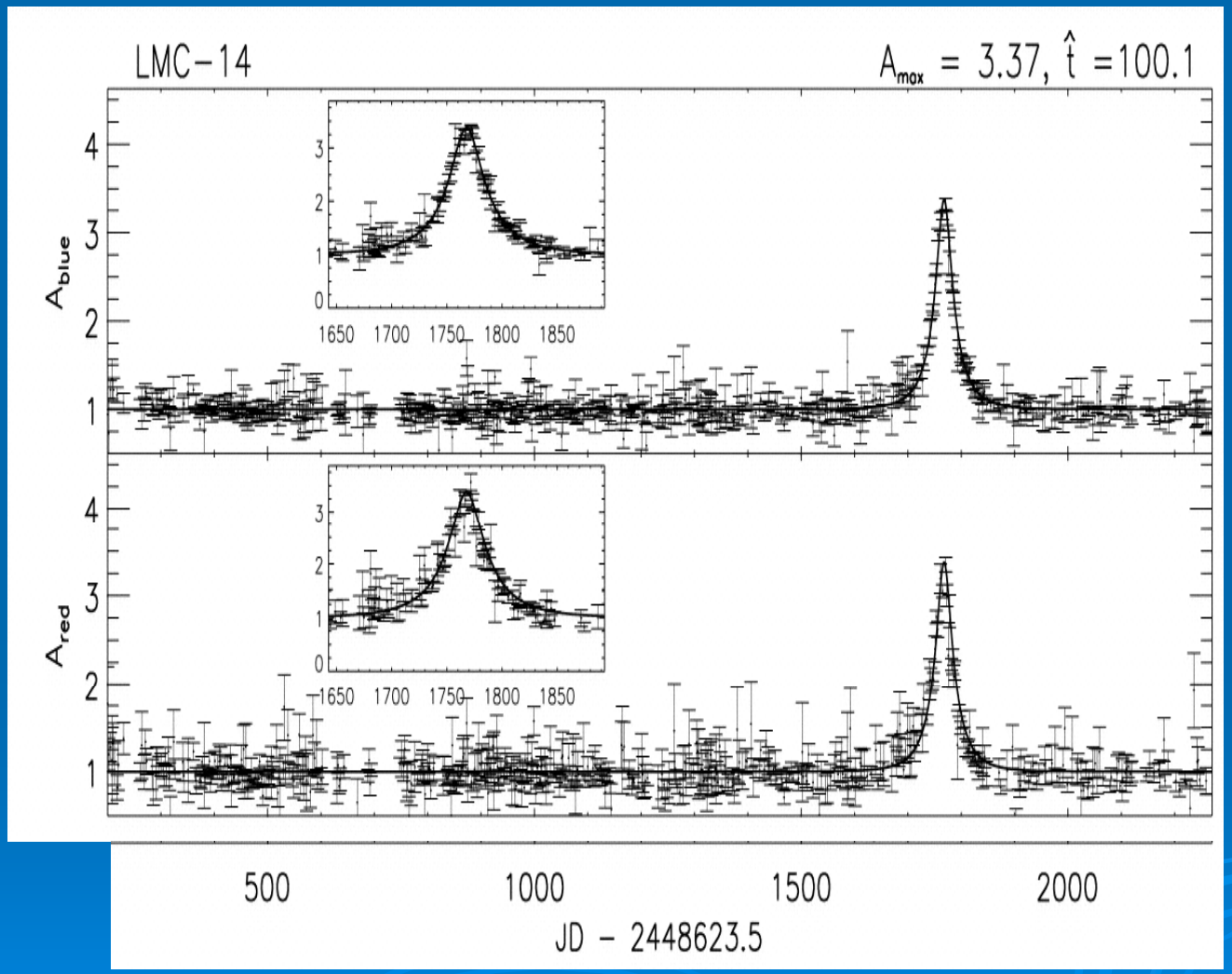


Magnification map and light curve asociated to point-like lens

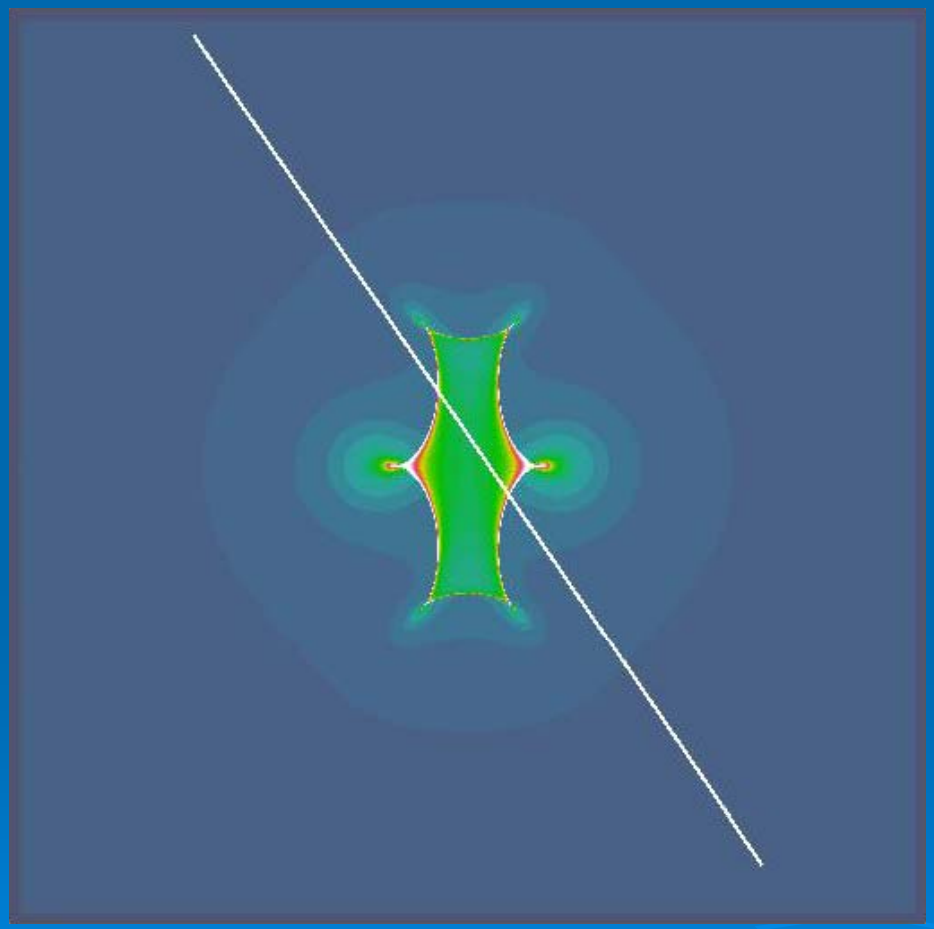


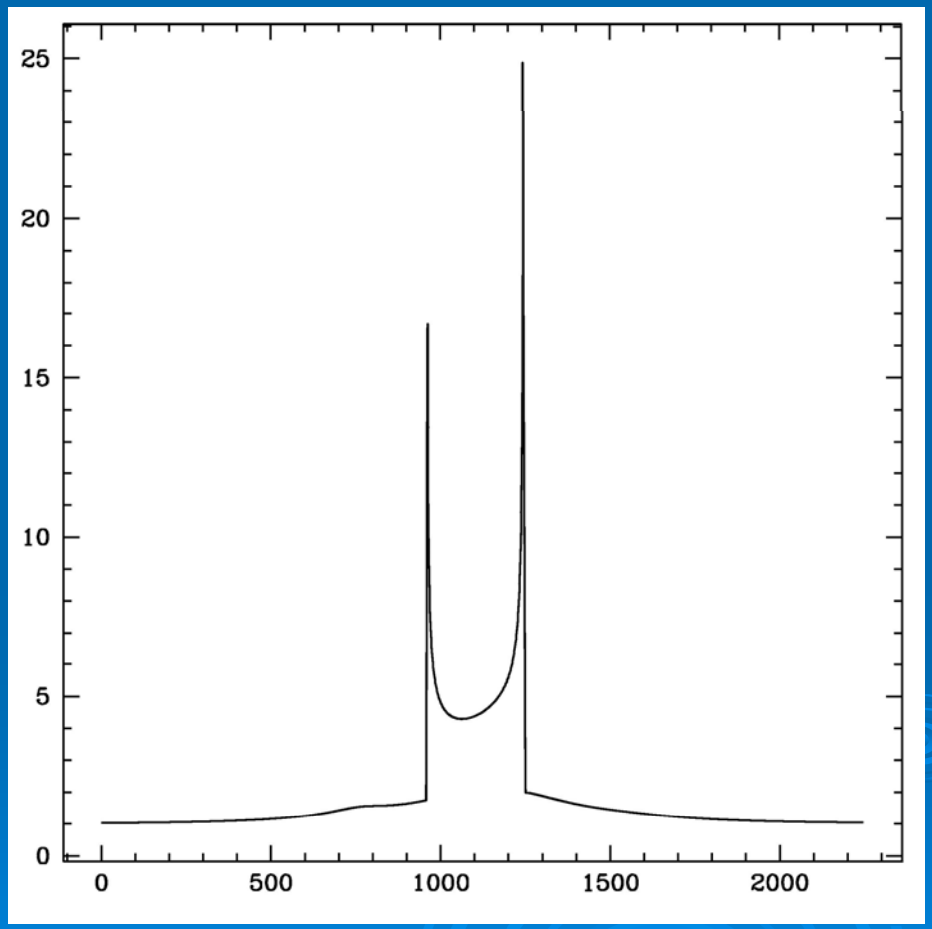


MACHO experiment

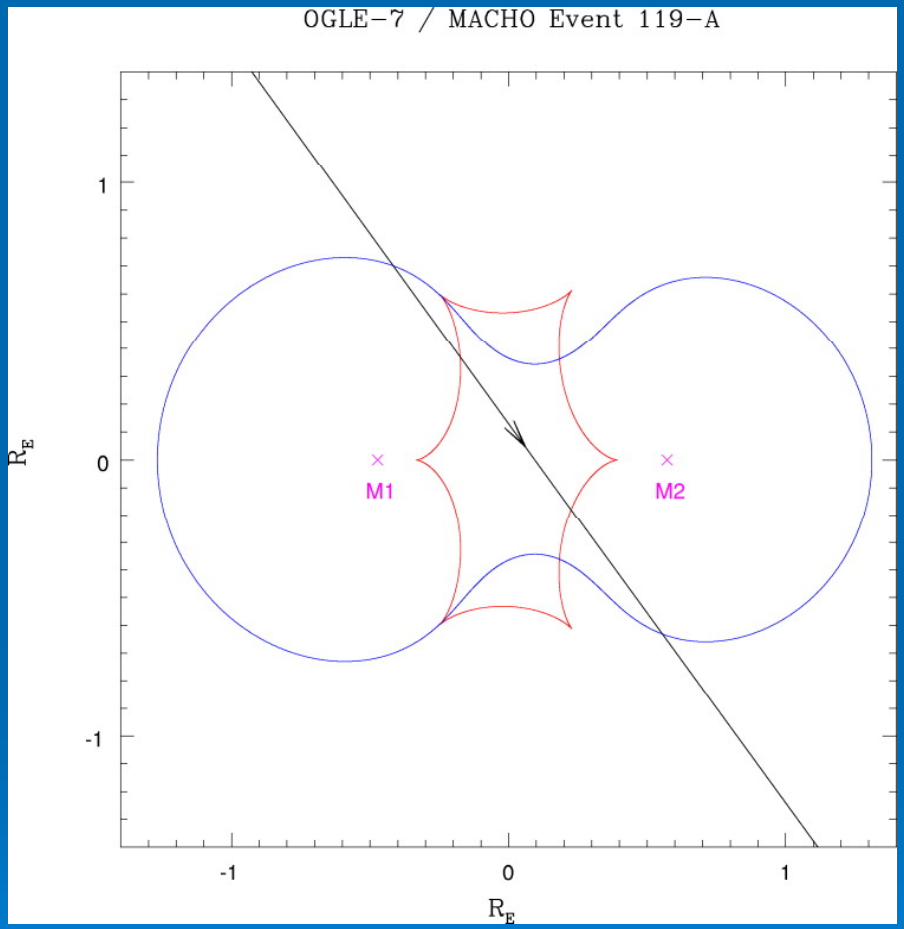


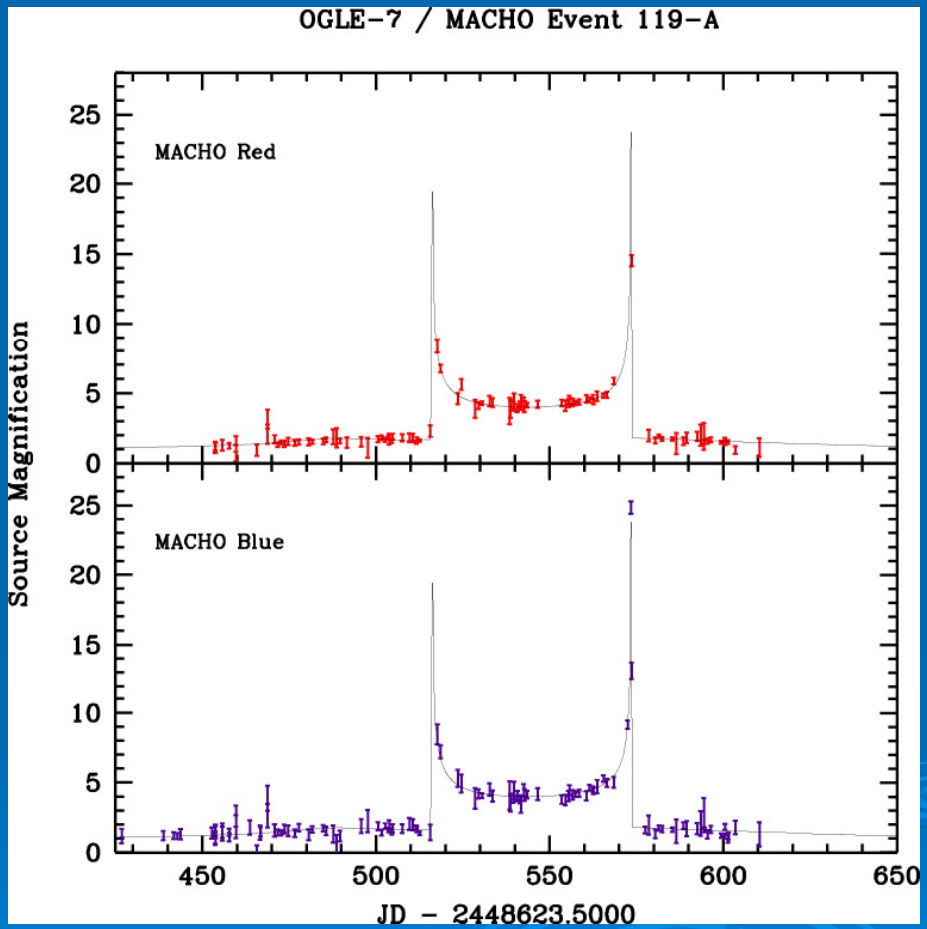
Magnification map and light curve asociated to binary lens



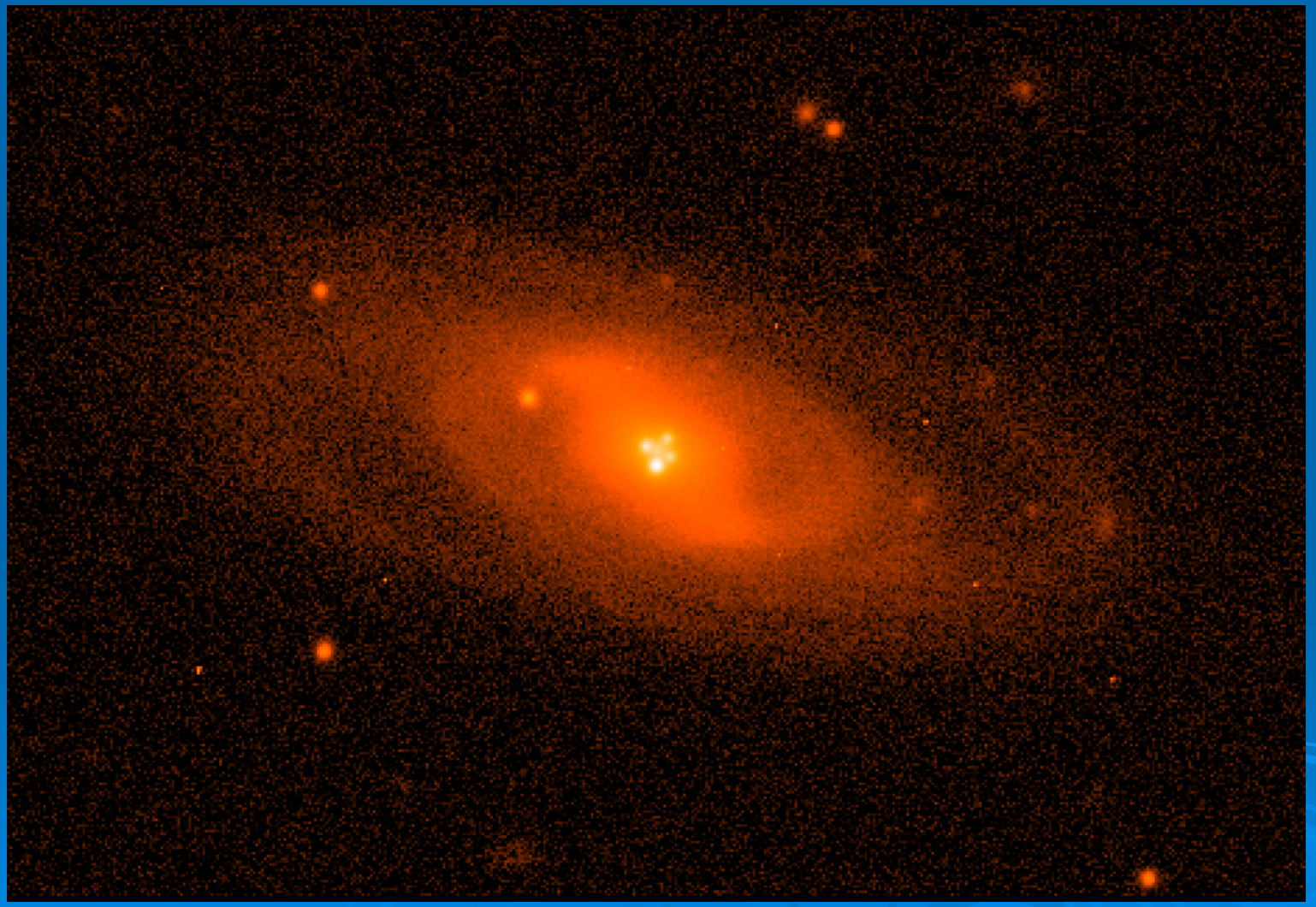


MACHO experiment

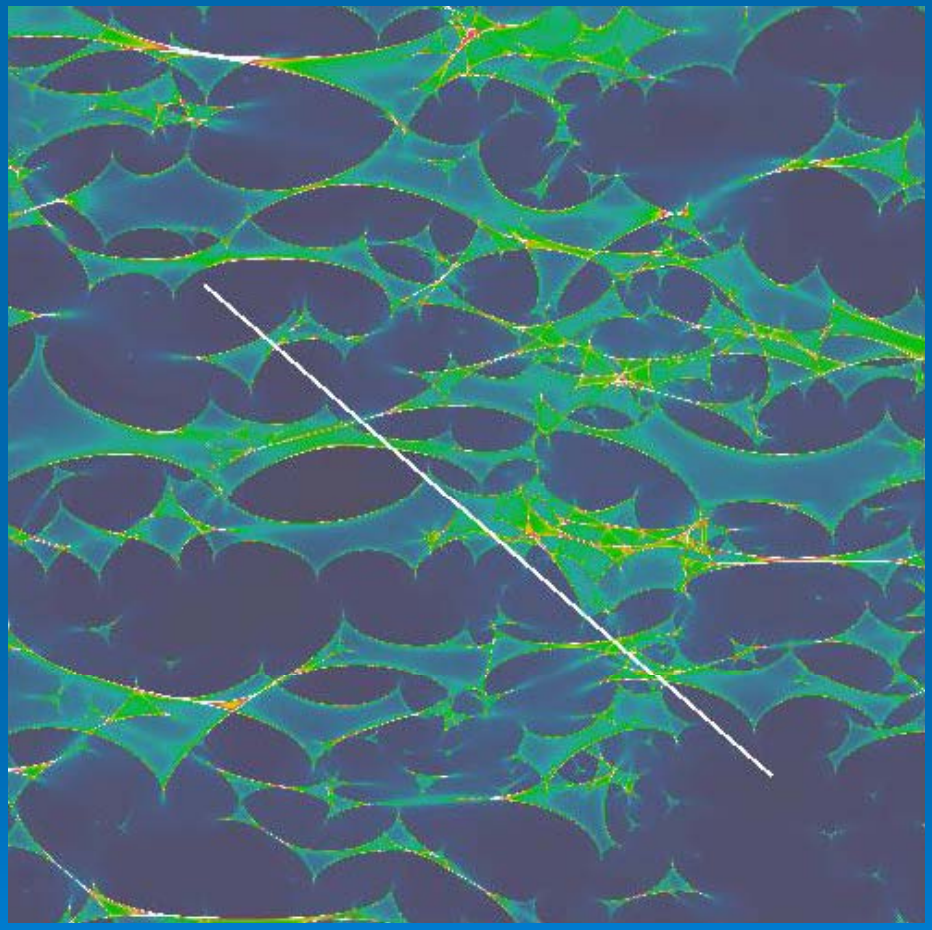


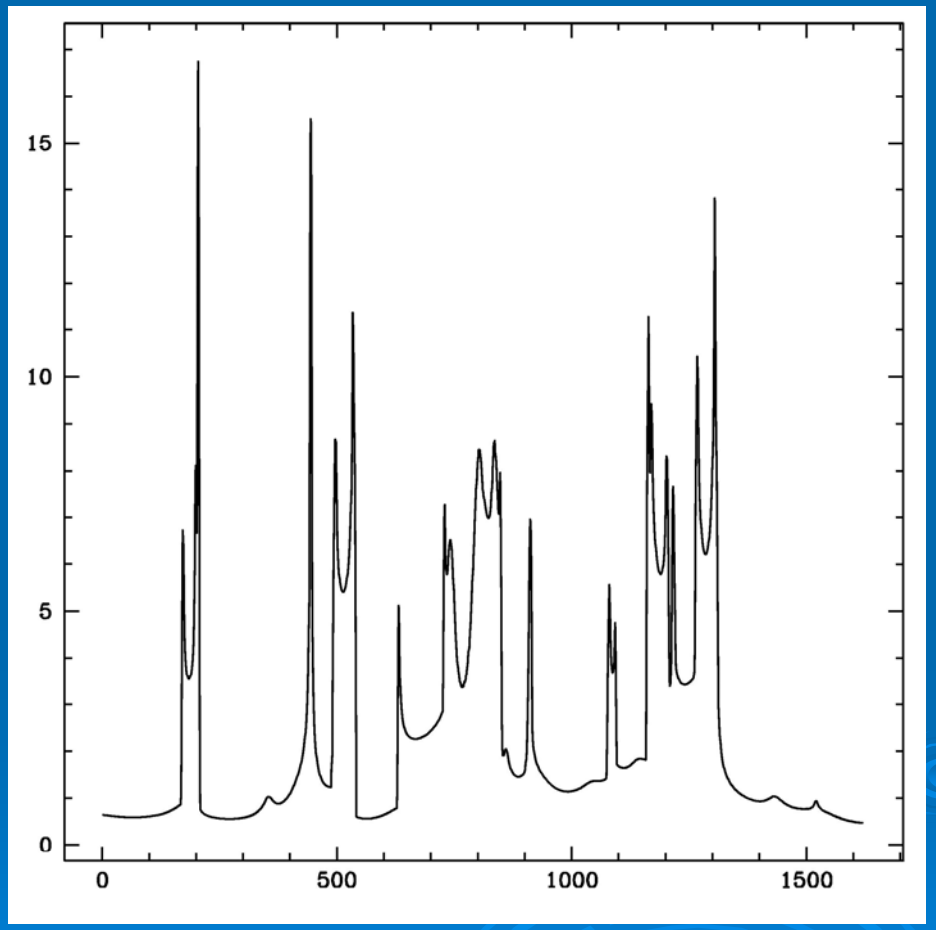


QSO 2237+0305

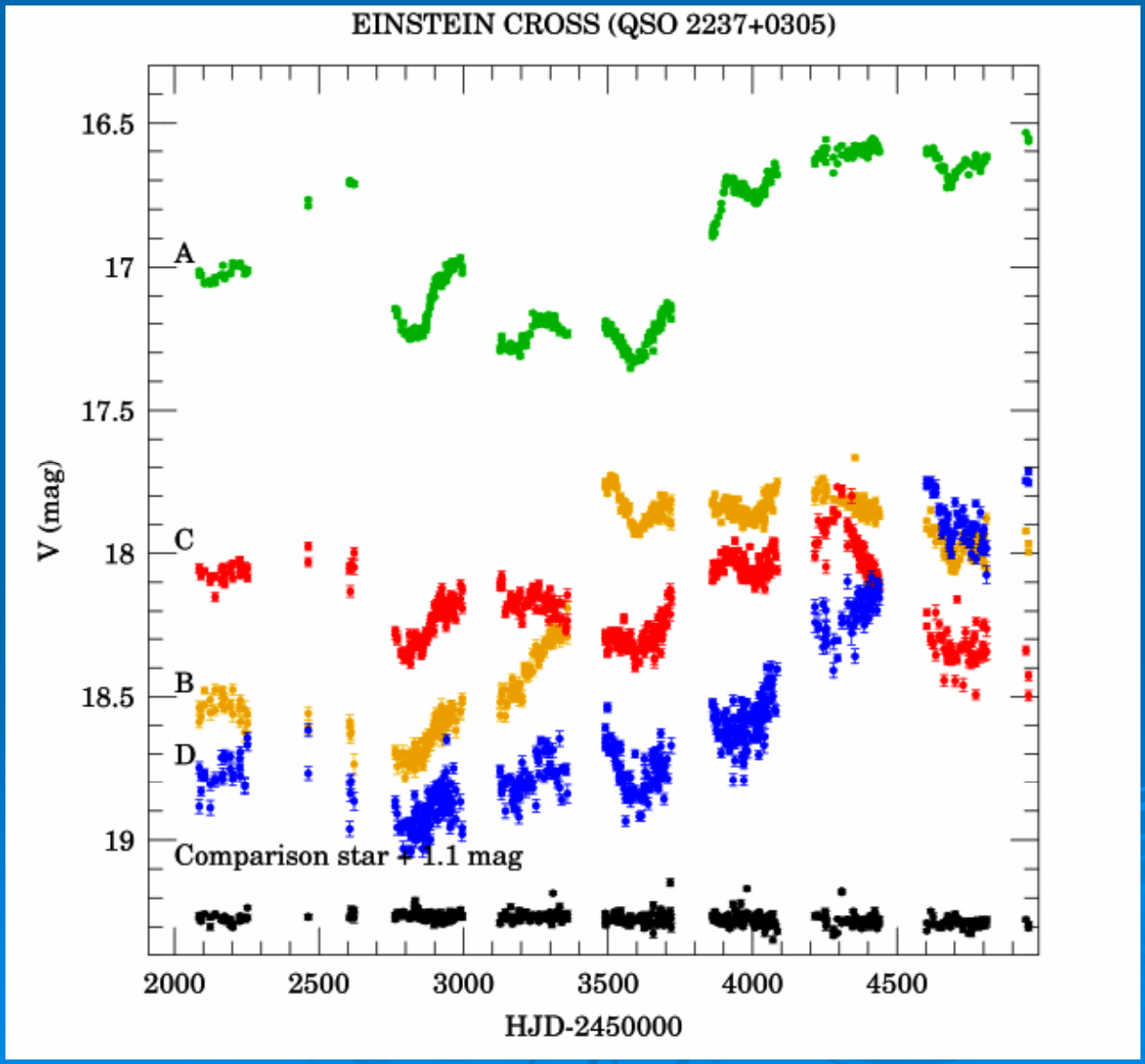


Magnification map and light curve asociated to QSO 2237+0305

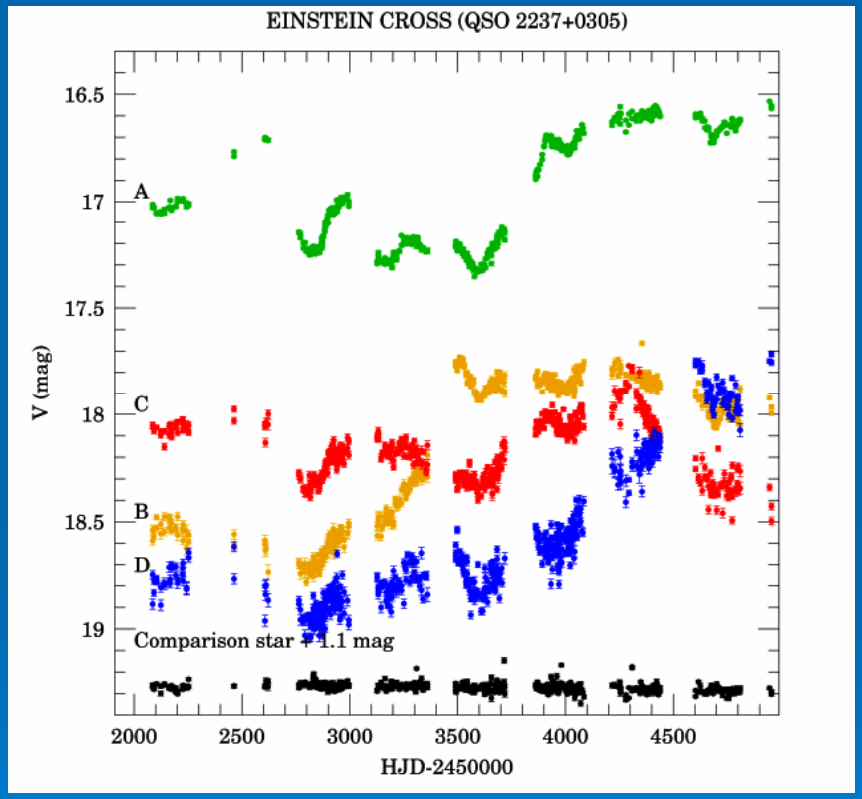


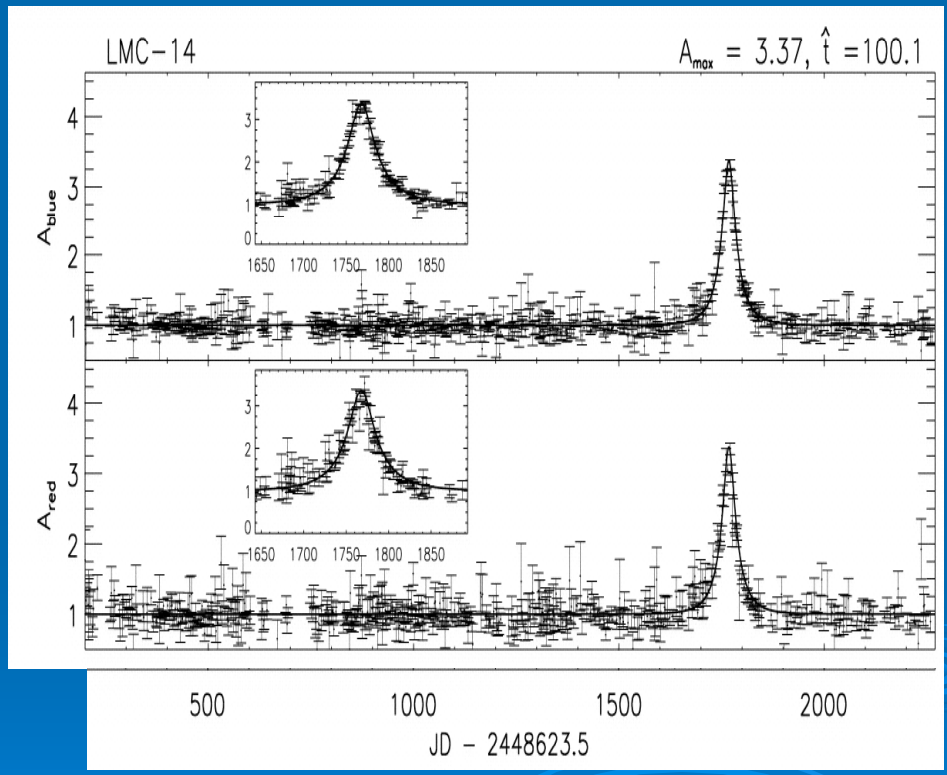


Experimental curves of light for the four images of Einstein´s Cross

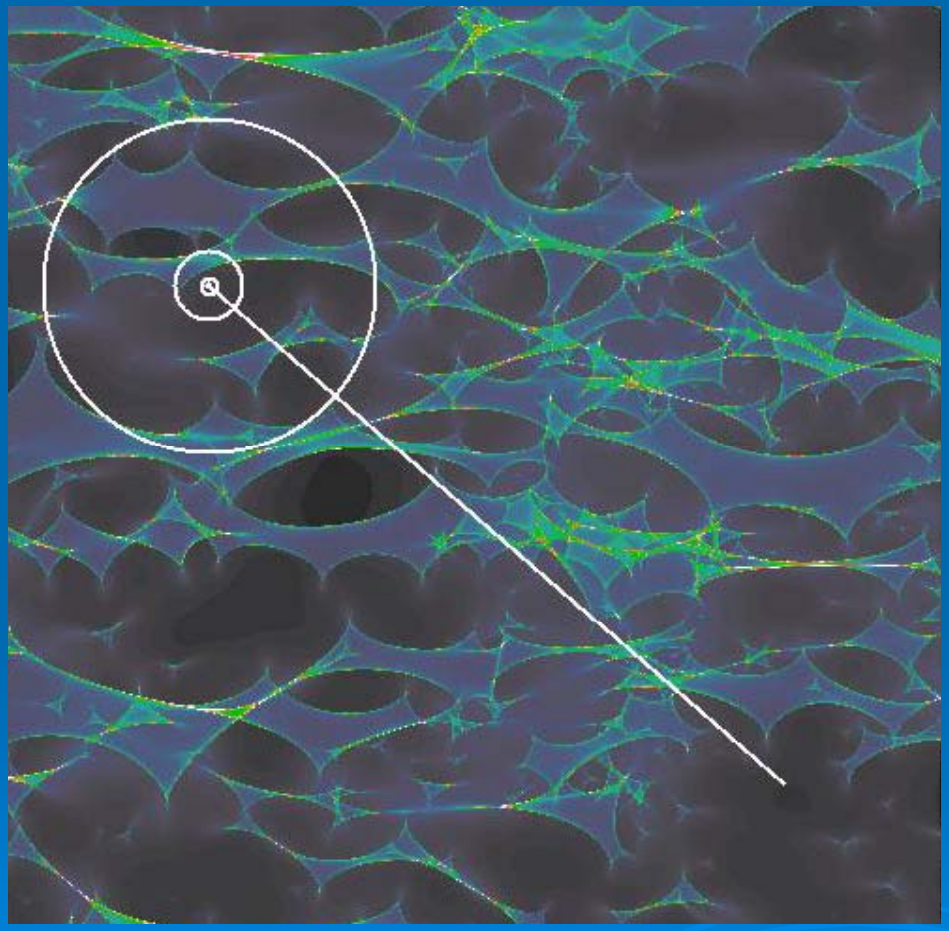


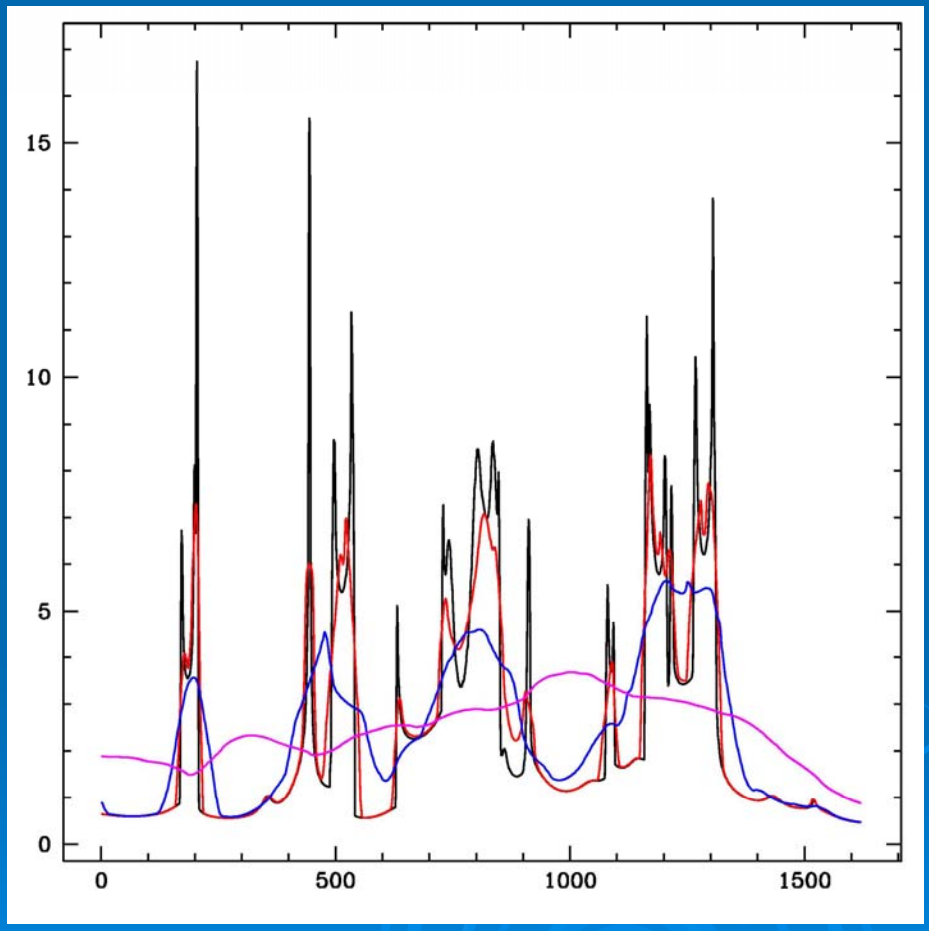
Comparison with light curve of a microlensing event in the Milky Way





Map and profiles with different sizes





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

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.
- Dificult to meassure.
- 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 intrinsical variability can affect data and results

Objectives

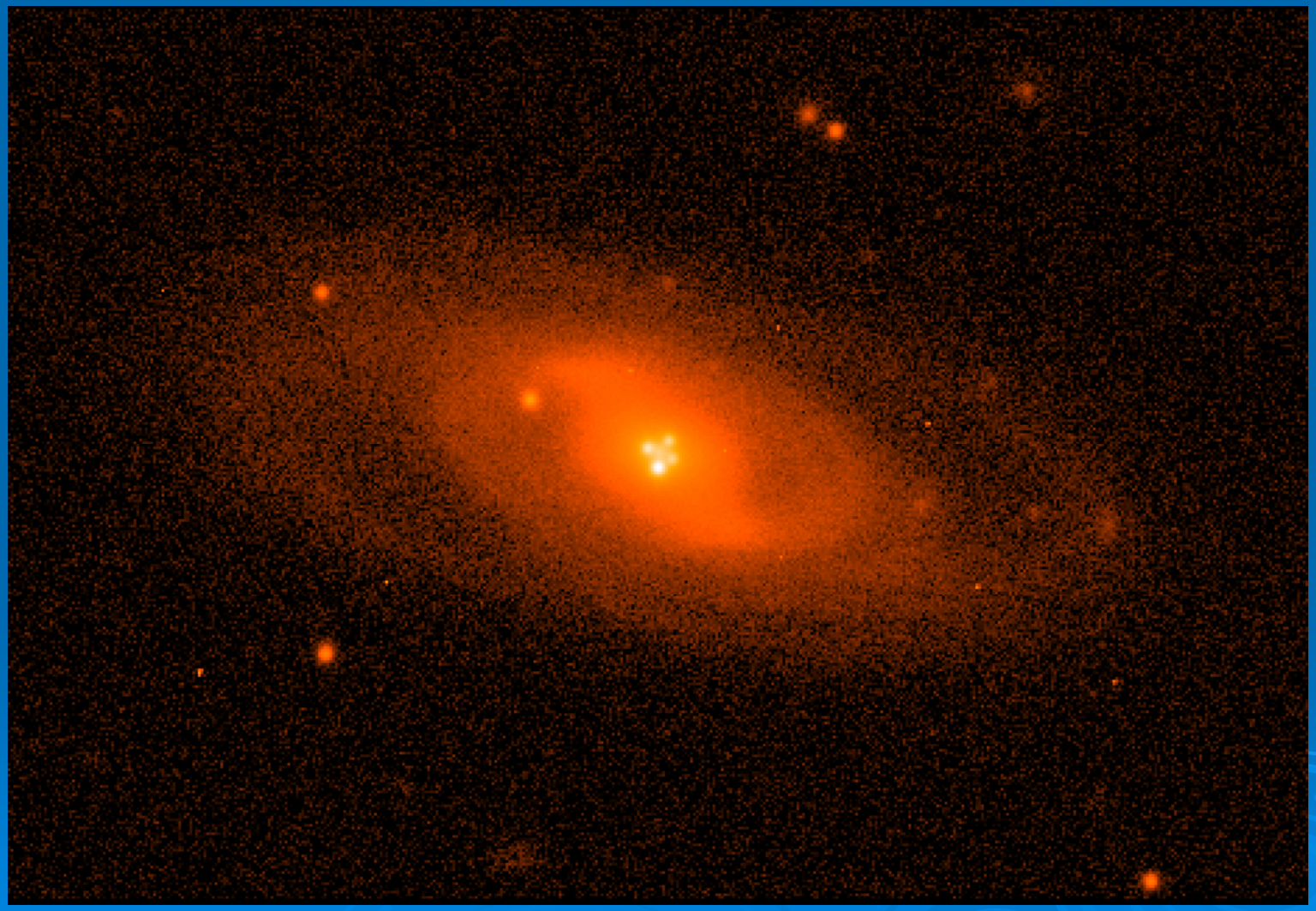
- Simplify the problem reducing microlensing to a series of discrete events, the caustic crossings. If the source size is small enough :
  - They appear well separated
  - They are of high magnification
  - They are difficult to mistake with other variability features

Statistical analysis of caustics concentration based on caustics crossings counts. Application to QSO 2237+0305

Analysis steps

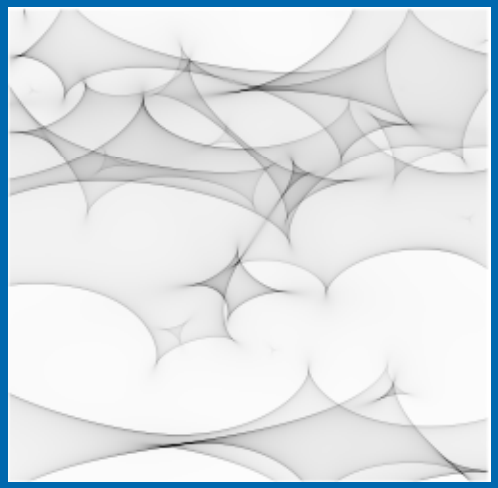
- Simulate magnification maps for different densities of matter, different mass distribution and shear.
- Identify caustic curves
- Count the number of caustics detected in a one-dimensional window of certain size in pixels for each axis
- Estimate probability of detecting a caustic in a pixel for each axis
- Compare experimental distributions obtained in simulations with theoretical binomial distribution.
- Minimize $\chi^2 = \sum_i \frac{(F_i^{obs} - F_i^{sim})^2}{F_i^{sim}}$ to obtain <M> and tv.

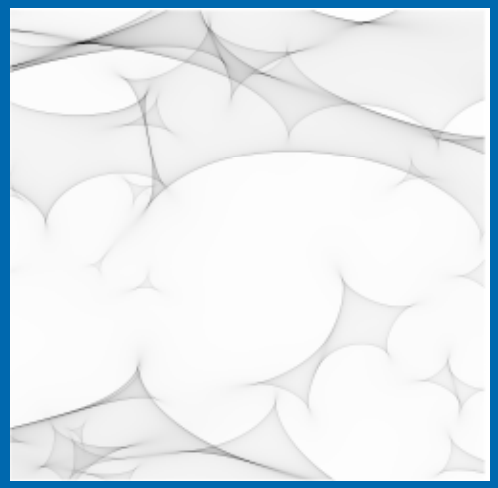
Application to QSO 2237+0305

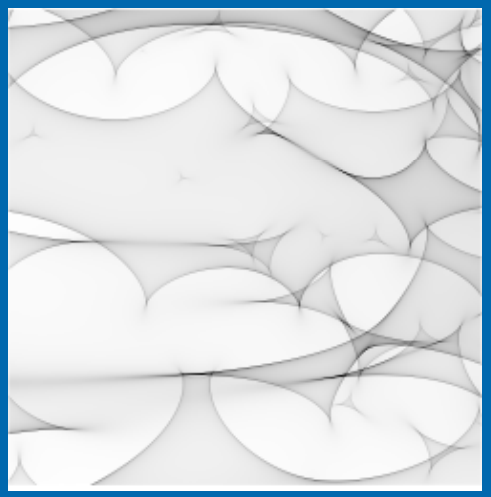


Magnification Maps

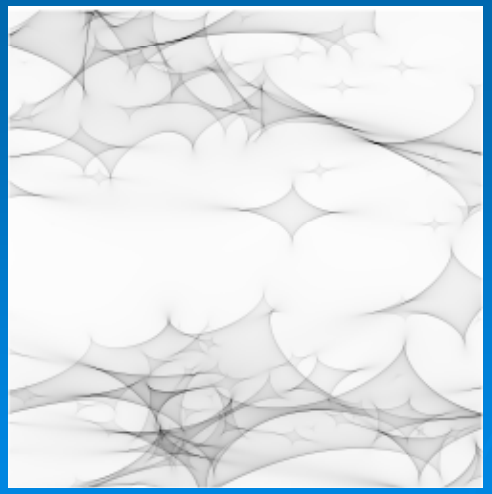
1 solar mass microlenses

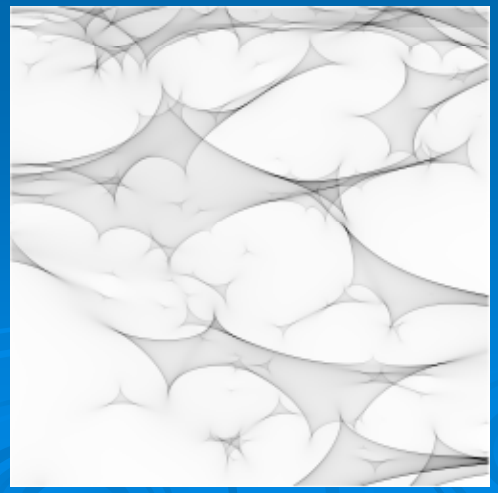


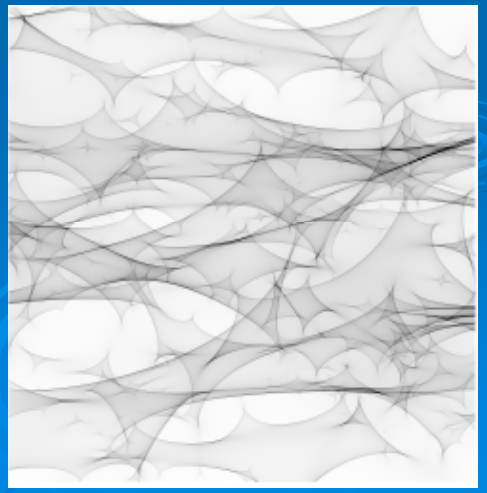




Microlenses distributed in a range of masses



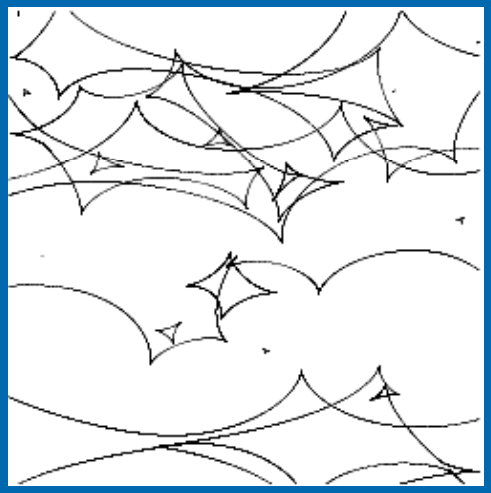


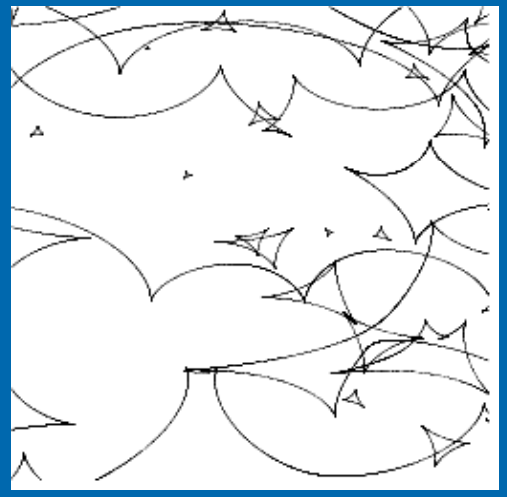


A Y B **C** **D**

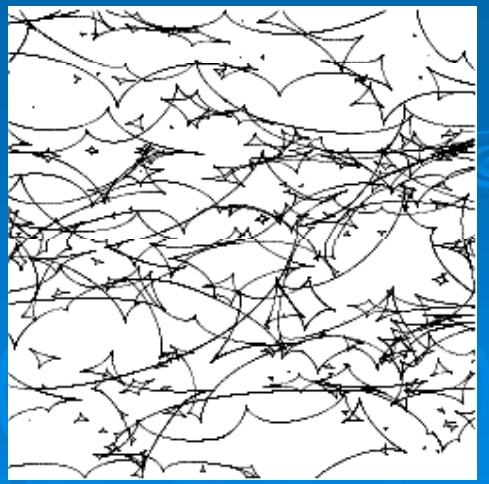
Caustics

1 solar mass microlenses





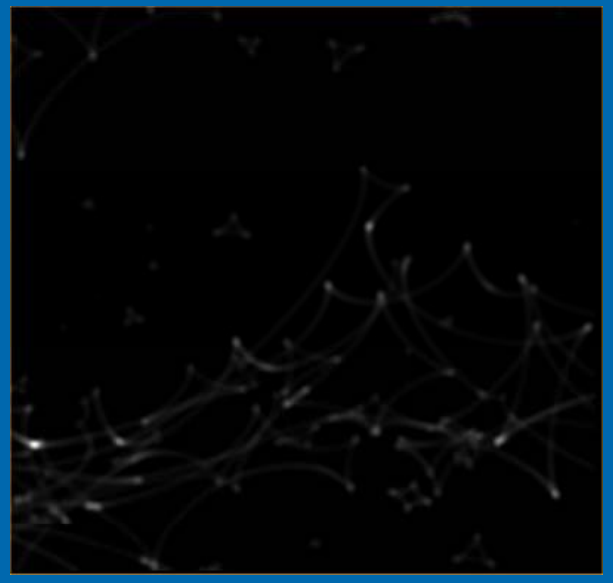
Microlenses distributed in a range of masses

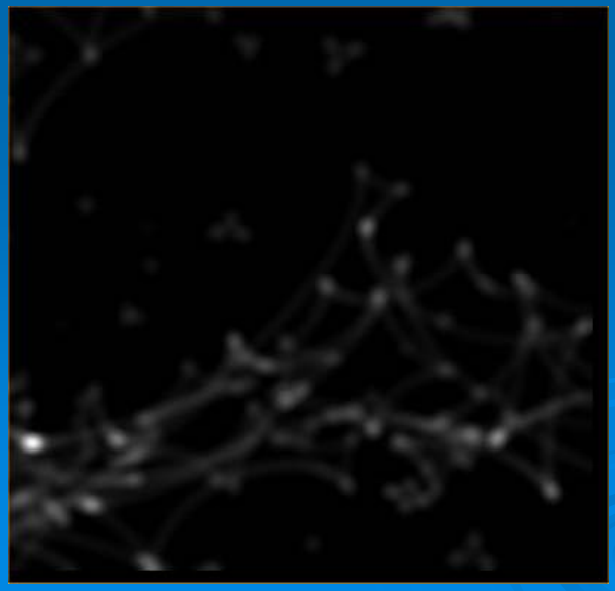


A Y B **C** **D**

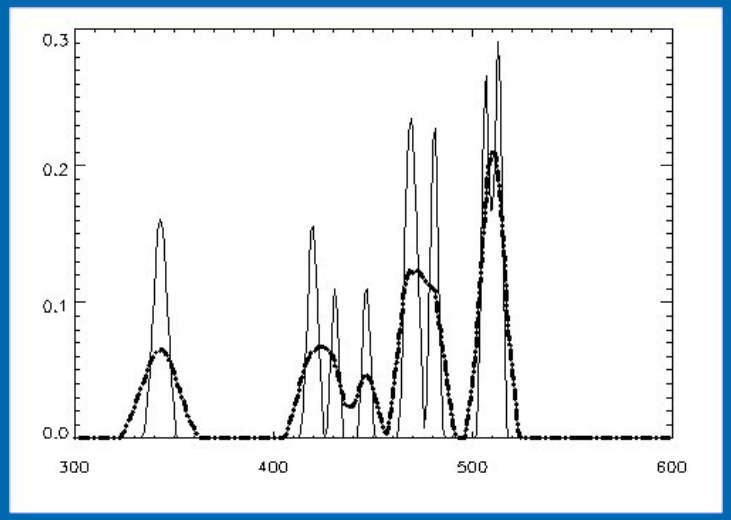
Magnification map of image D hypothesis A

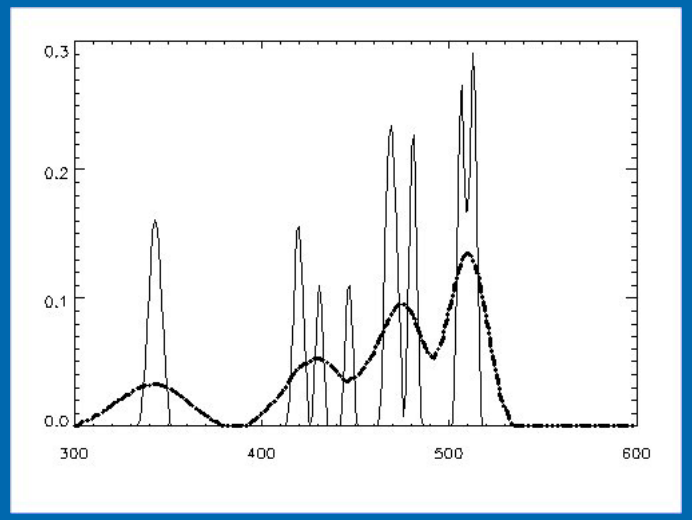
Effects of source size on magnification map

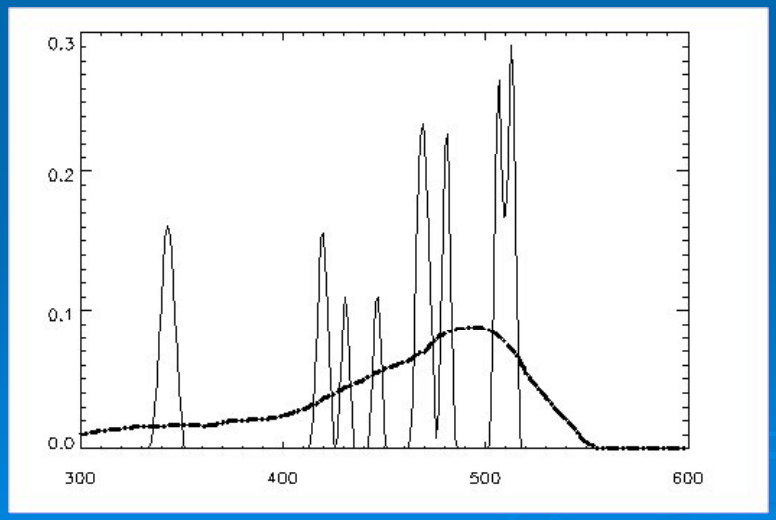


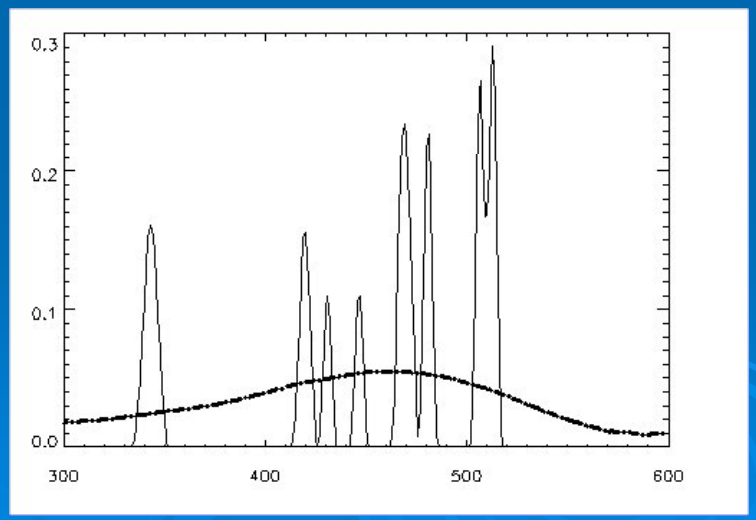


Caustics can only be isolated in X-ray emission



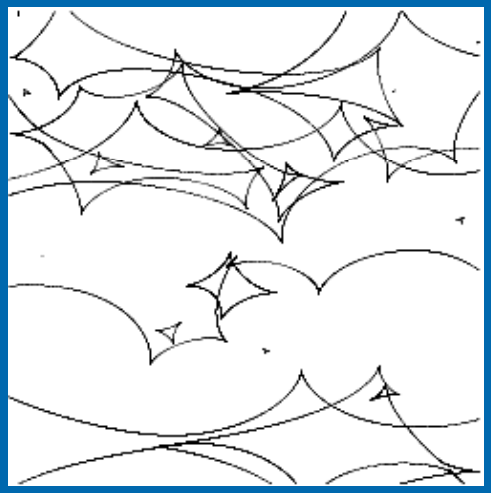


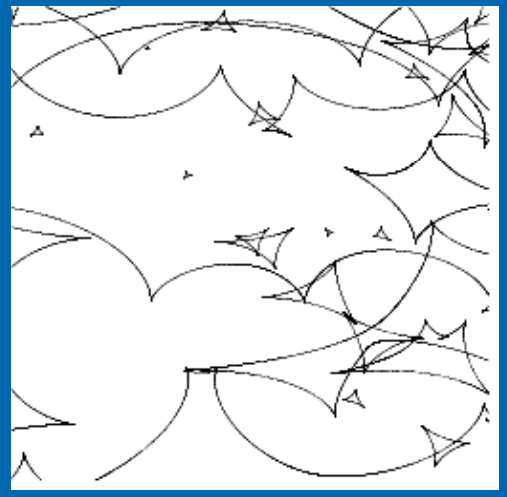




Caustics

1 solar mass microlenses

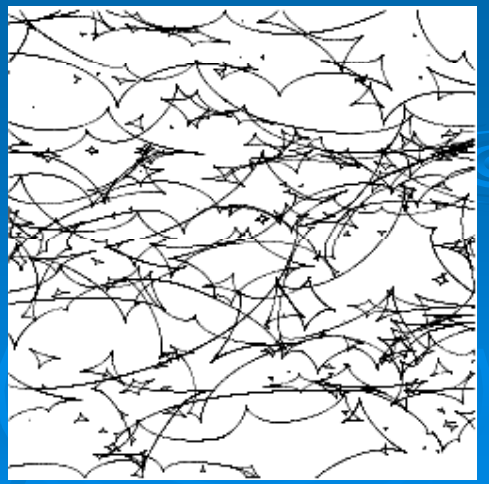




Microlenses distributed in a range of masses

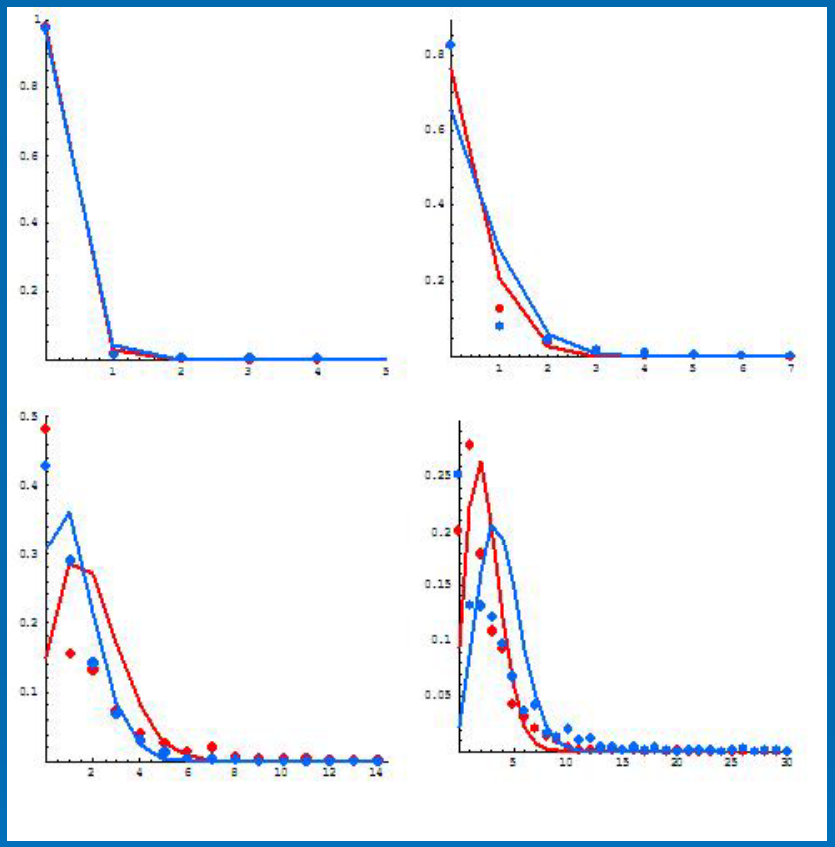
A Y B

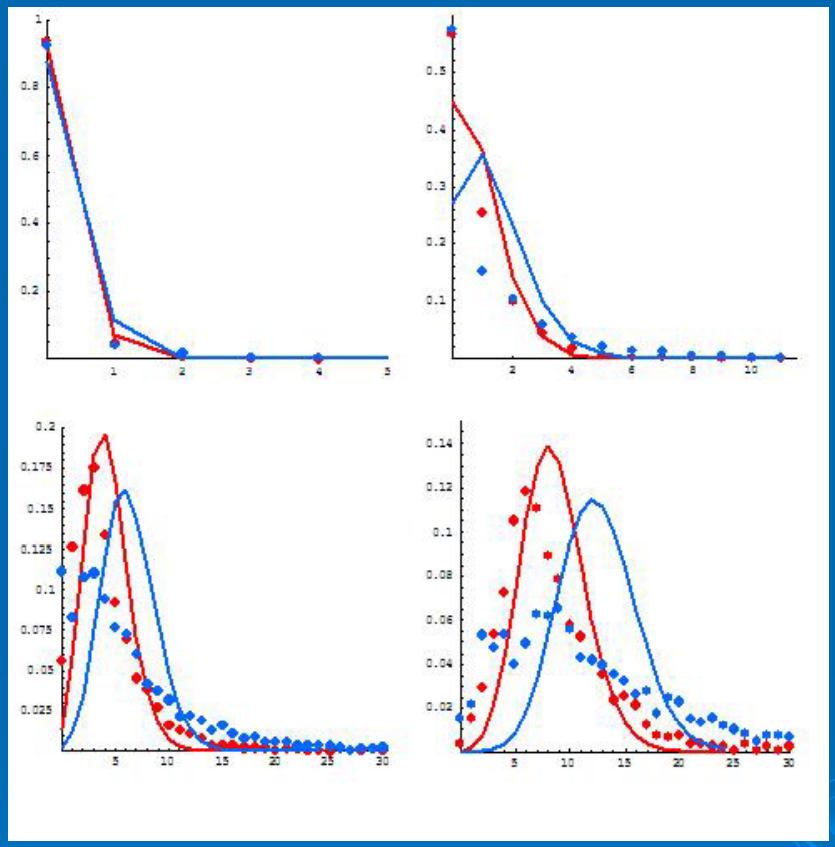
C



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	
n=7, error=$\pm$3	n=1, error=$\pm$1
P(7$\pm$3/A)=0.63	P(1$\pm$1/A)=0.049
P(7$\pm$3/B)=0.22	P(1$\pm$1/B)=0.66
P(A/7)=0.75 P(B/7)=0.25	P(A/1)=0.07 P(B/1)=0.93

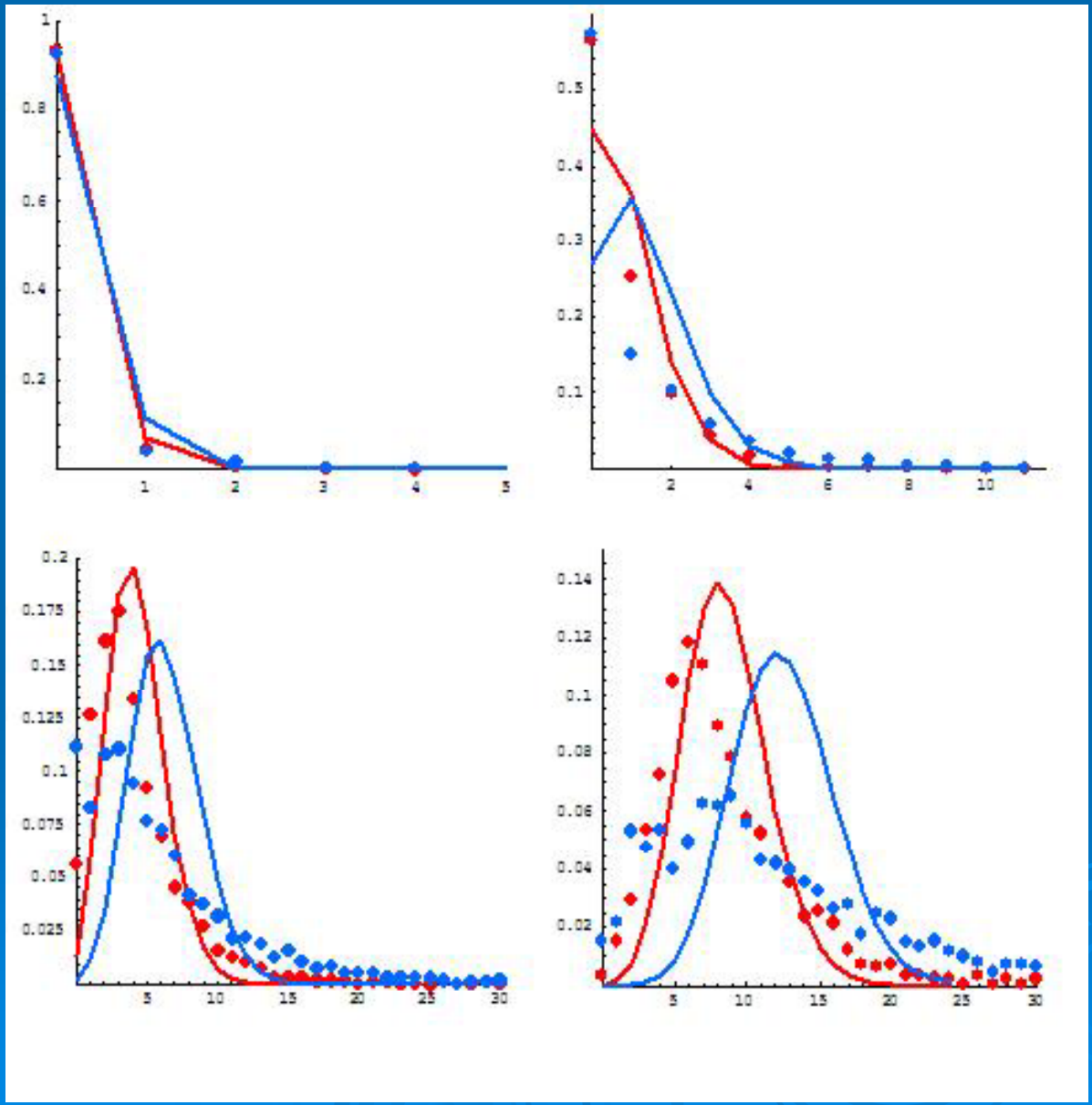
Y AXIS	
n=10, error=$\pm$3	n=2, error=$\pm$1
P(10$\pm$3/A)=0.37	P(2$\pm$1/A)=0.12
P(10$\pm$3/B)=0.12	P(2$\pm$1/B)=0.38
P(A/10)=0.76 P(B/10)=0.24	P(A/2)=0.24 P(B/2)=0.76

We can distinguish between A and B hypothesis

Results (II)

Can we solve the size / transversal velocity degeneracy?

Results (II)


1
0.8
0.6
0.4
0.2
1
2
3
4
5
0.5
0.4
0.3
0.2
0.1
2
4
6
8
10
0.2
0.175
0.15
0.125
0.1
0.075
0.05
0.025
5
10
15
20
25
30
0.14
0.12
0.1
0.08
0.06
0.04
0.02
5
10
15
20
25
30

Results (II)

D image microlenses distributed in a range of masses

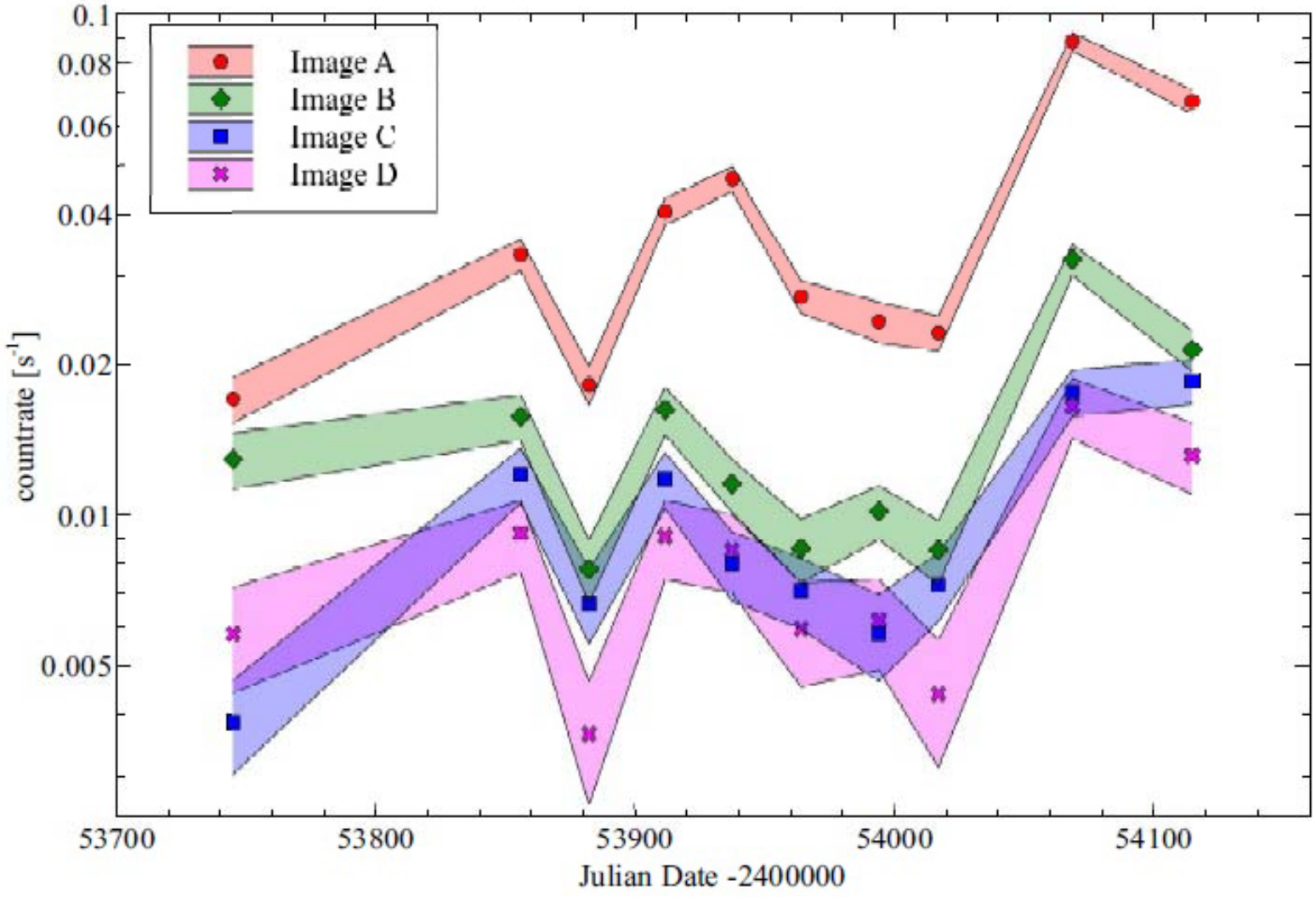
Number of caustics (X axis) > 6 → Window > 1.2 Einstein radii

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

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

Number of caustics (Y axis) < 3 → 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, <M>, and determine probability distribution functions for each <M>.
- Define a Chi^2 function to apply a test to the probability distribution:

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

- Obtain an estimate of <M> minimizing this function with respect to <M>.
- Obtain an estimate of transversal velocity minimizing this function with respect to transversal velocity.