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Inverse Ray Shooting Tutorial (II)

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Session II

- Playing around with lenses and sources
  - Two point lens
  - Chang Refsdal Lens
  - SIS (+ Shear)
  - NonSIS (+ Shear)
  - SIE (+ Shear)
- Critical Curves and Caustics
- Magnification maps

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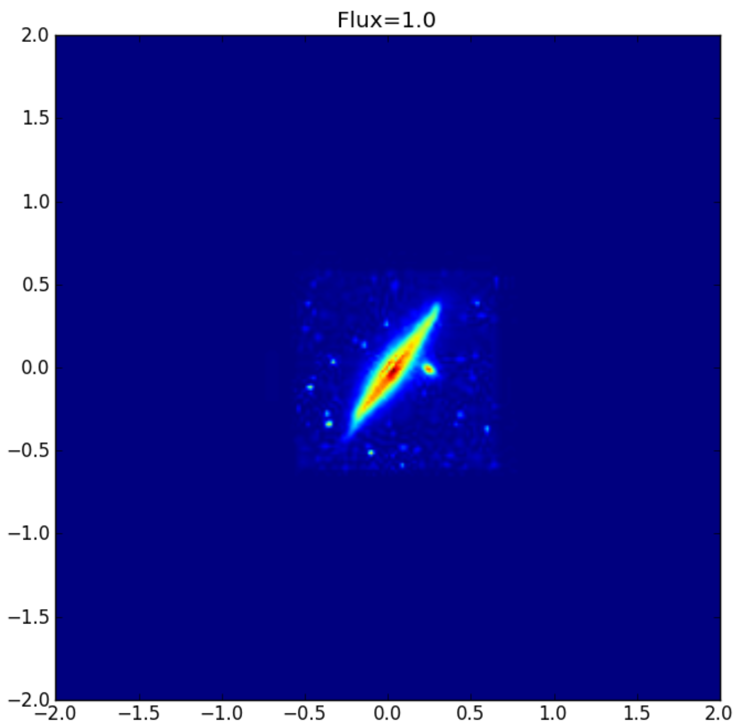
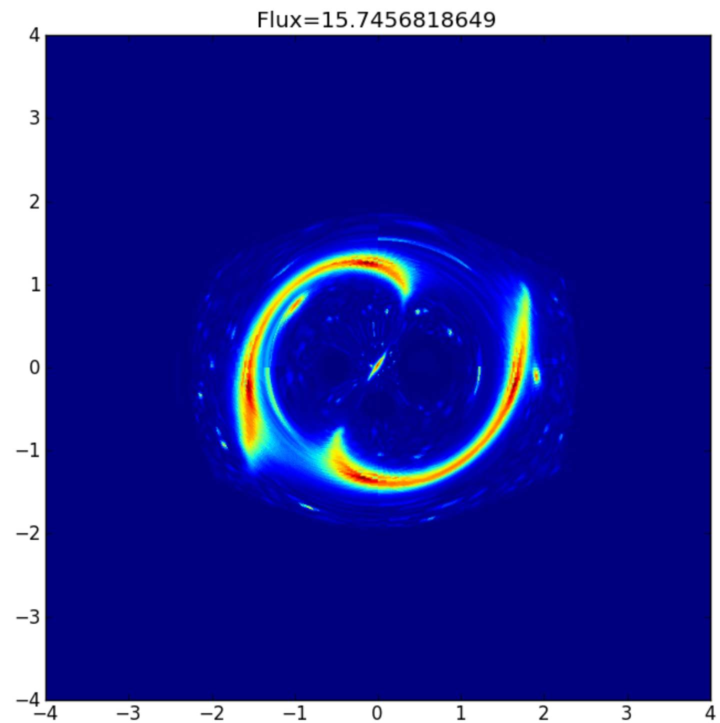
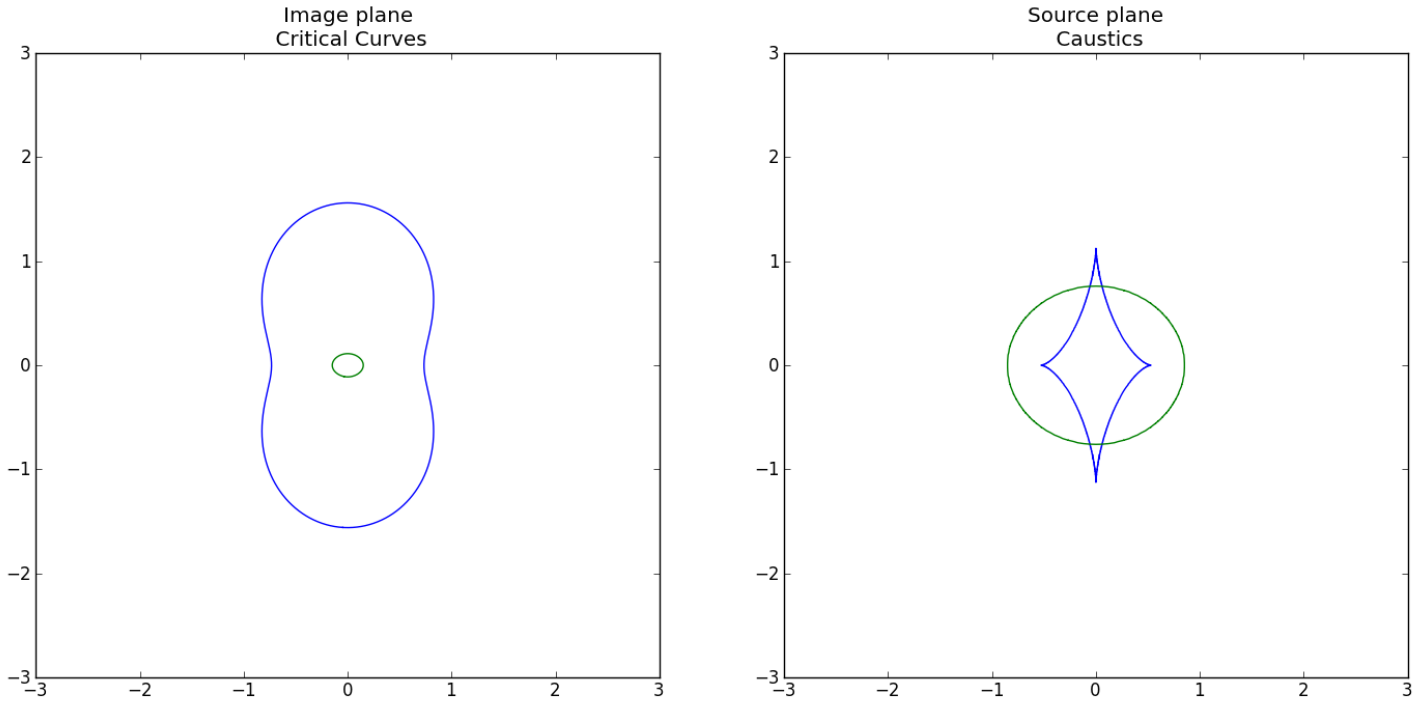
Today's goal #1

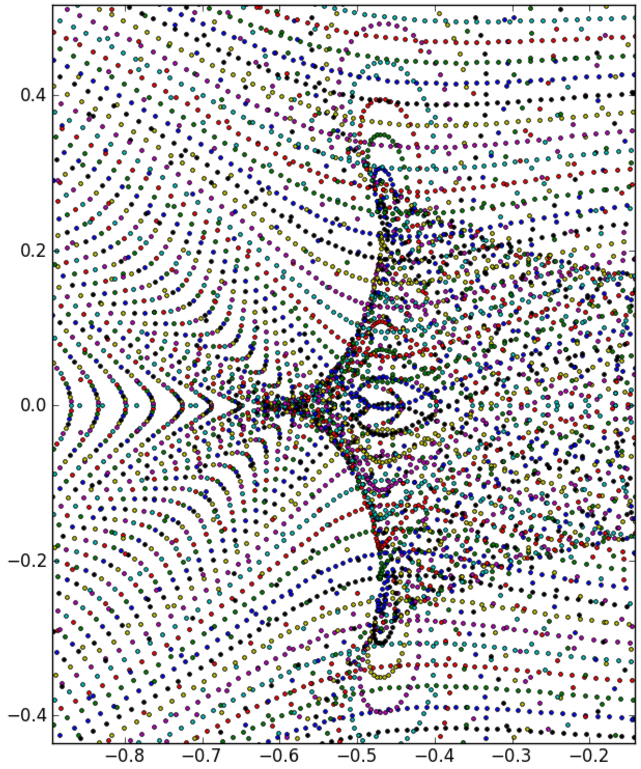




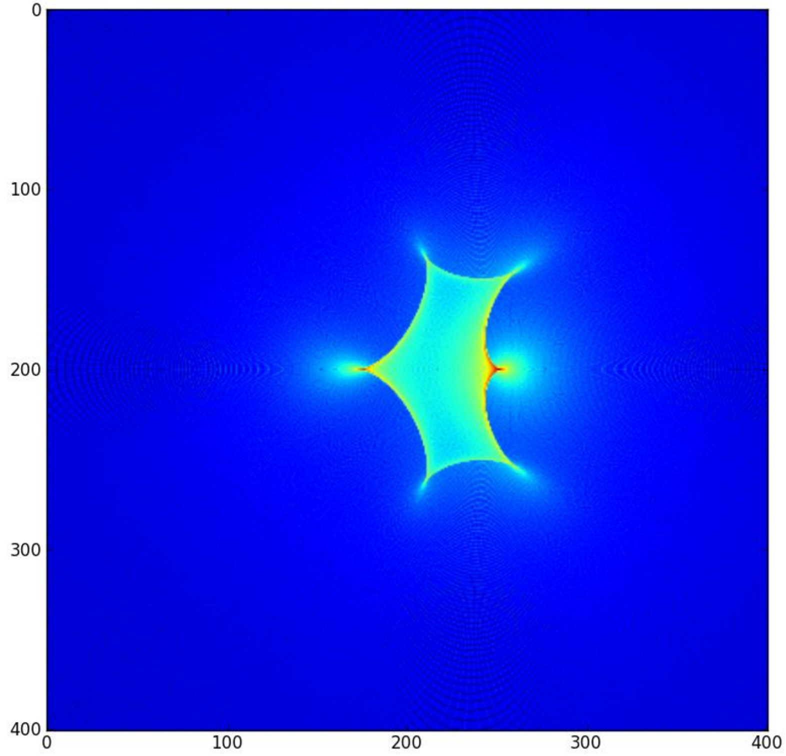
Today's goal #2



Today's goal #3



Today’s goal #4



Play around with lenses/sources

- For the first part of the session we will play around with different combinations of lenses/sources.
- Pay attention to number of images, location, magnification, …

Lenses

- Let's try:
  - Binary point source lens
    αx=m1*(x-x1)/d1^2+m2*(x-x2)/d2^2
  - Point lens + shear (+ kappa)
    αx=(κ+ϒ)*x+m1*(x-x1)/d^2
  - SIS (+ shear)
    αx=k*(x-x1)/d(+ ϒ*x)
  - NonSIS (+ shear)
    Substitute d by sqrt((x-xl)^2+(y-yl)^2+rc^2)
  - SIE(+shear)
    c1=1-e, c2=1+e
    d=sqrt(c1*(x-xl)^2+c2*(y-yl))
    αx=k*(x-x1)/d

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Sources

- We will try:
  - 2D Circular Gaussian
  - Face on disk galaxy ← From fits file ← pyfits
  - Edge on disk galaxy
  - Field of galaxies
  - Whatever takes you fancy

Example: Binary

Schneider & Weiss (1986)

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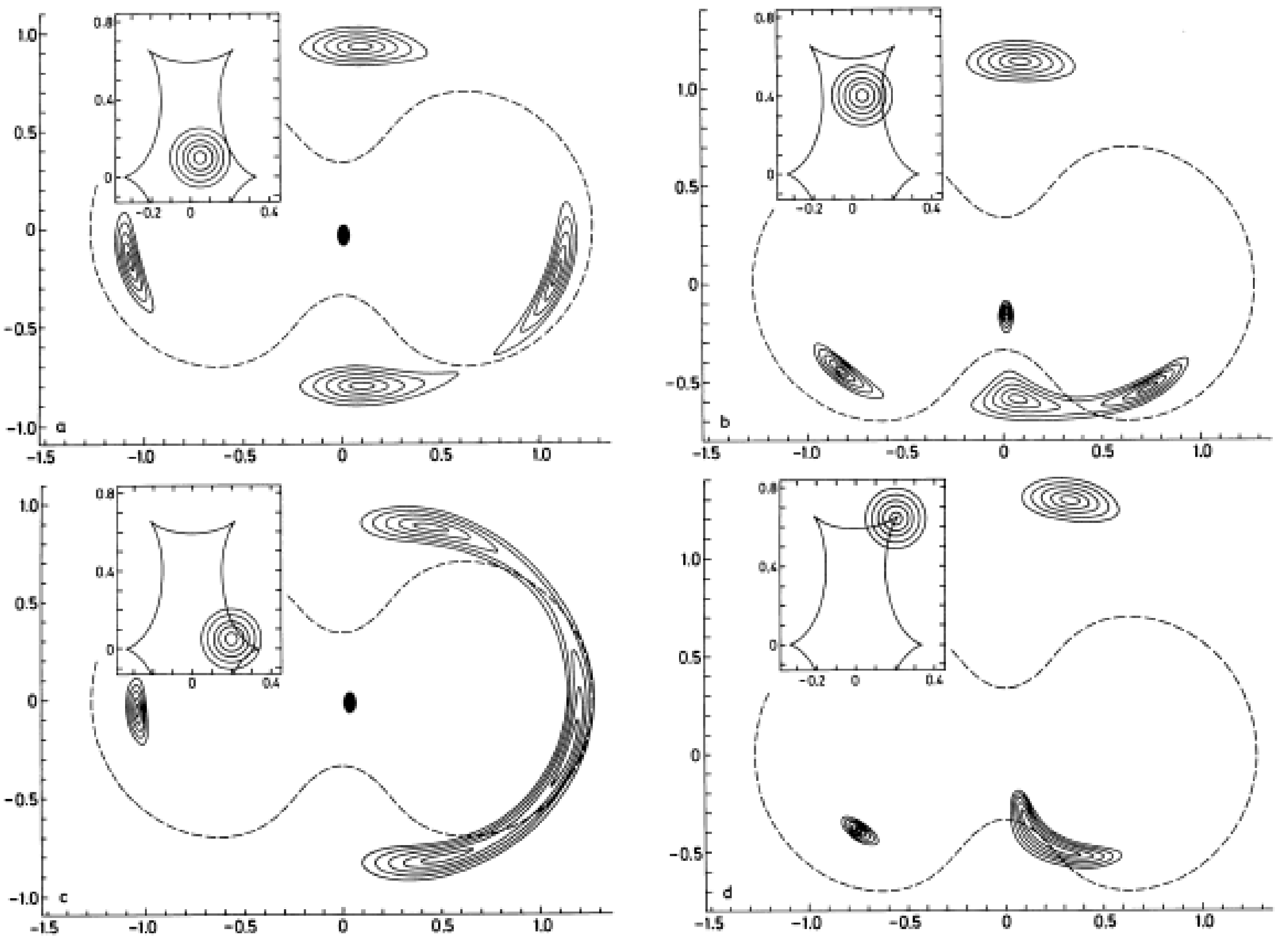

Fig. 6a–d. Imaging of an extended source by the $X=0.5$ gravitational lens. The inserts show the position of the source, which is characterized by isophotes, relative to the critical line in the source plane. The corresponding images of the source in the lens plane are shown. The dashed lines show the critical curve in the lens plane

Tests

- Try to produce:
  - 1 image
  - 2 images
  - 3 images
  - 4 images
  - 5 images
  - Many (micro-)images
  - Arcs
  - Reproduce your favorite lens system..
  - ....

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Critical curves and caustics

- A critical curve is the set of points at the image plane for which det(A)=0.
- Caustic curve is the set of points at the source plane with infinite magnification. The source locations whose images are the critical curves.
- We calculate A from derivatives of the deflection angle and then its determinant.
- Therefore we will:
  - Calculate A from derivatives of the deflection angle.
  - Calculate det(A)
  - Locate the places with det(A)=0 → Critical curves (**auxfun.levloc**)
  - We trace back those rays to the source plane → Caustics
- Its a bit tricky because of topological properties around the critical curve/caustic
- We may use **lens.py** for the lenses from now onwards.

Magnification maps I

- Kayser et al. 1986, Schneider & Weiss 1986, Schneider & Weiss 1987.
- To calculate magnification maps we will use the fact that:

  $\mu = d\Omega_i/d\Omega_s = dS_i/dS_s = N_{hits}/N_{rays}$
- To calculate this we will:
  - Divide the image plane into cells from which we will throw raypix rays per unlensed pixel.
  - Throw the rays backwards from the image/lens plane towards the source plane by deflecting them according to the lens equation.

  We can stop here for a while and have a look at the source plane

  - Collect hits at every pixel of the source plane
  - Compare (divide) to how many rays would have hit in the absence of lensing.

Magnification Maps II

- Shooting rays one at a time needs a nested loop → Python becomes slow.
- Shoot rays one row at a time to speed up calculations.
- Throwing the whole array at once is in principle possible, but will make it very memory demanding with high risk of crash
- What happens if the throwing region is too small?
- Try magnification maps for a few lens configurations :
  - Point mass
  - Binary
  - N point lenses
  - Chang-Refsdal
  - (Non)SIS (+ shear)
  - …