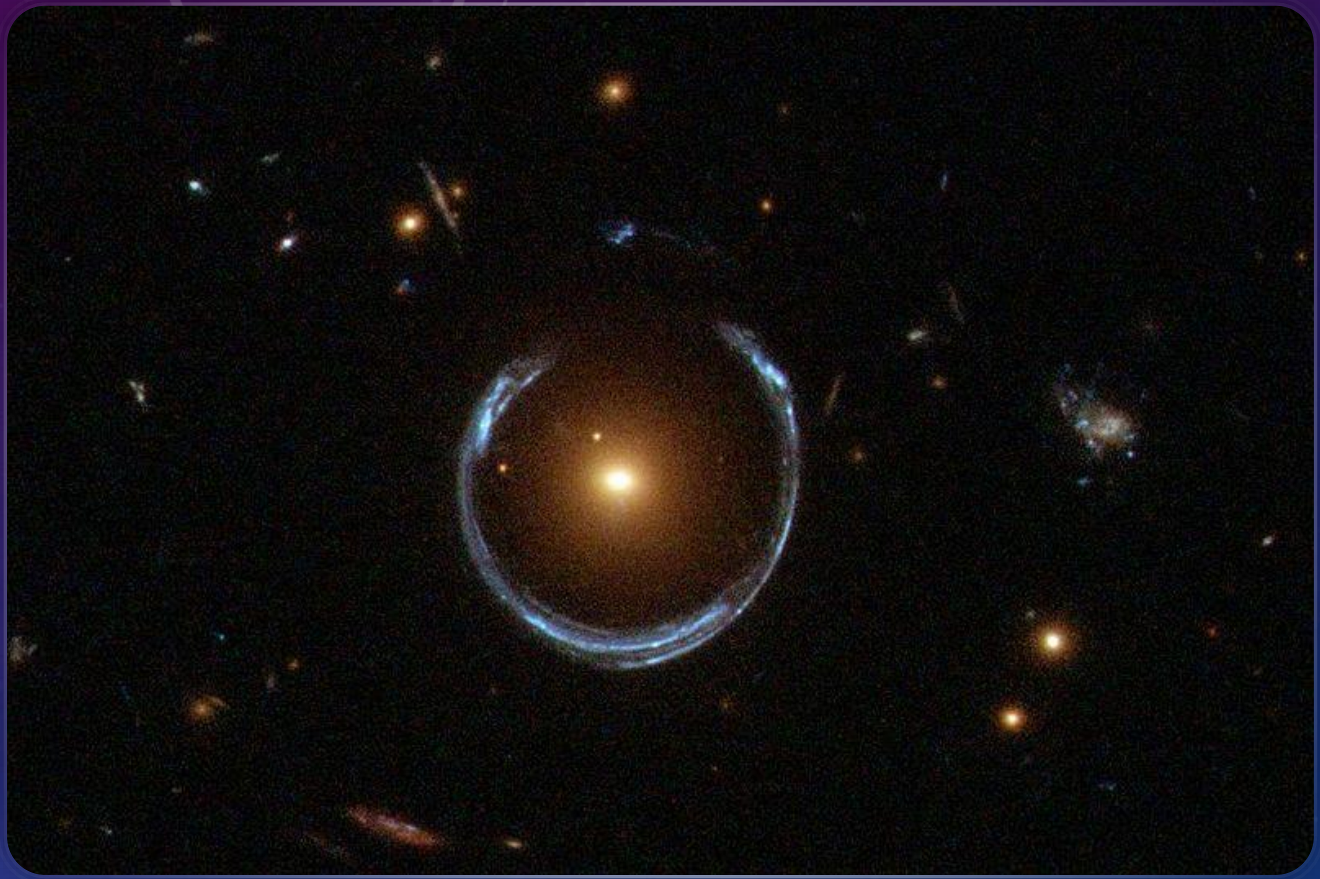
NUMERICAL PROJECT : LENSTOOL



M2 ASTROPHYSICS - ROCHER ANTOINE

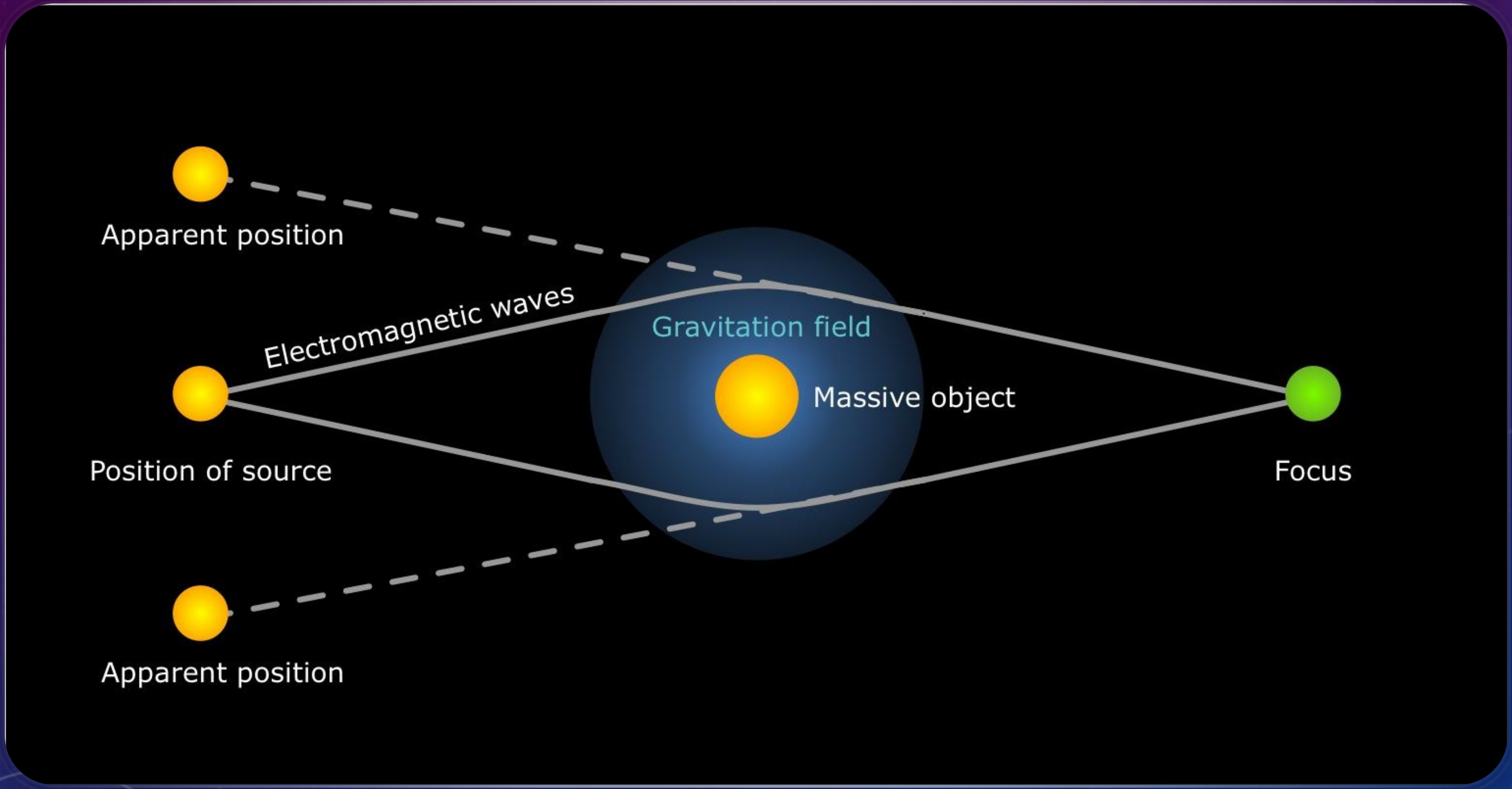
SUPERVISED BY RICHARD JOHAN

CRAL
CENTRE DE RECHERCHE ASTROPHYSIQUE DE LYON

LUPM
LABORATOIRE MONTPELLIER UNIVERS & PARTICULES

département Physique
Faculté des Sciences et Technologies
Université Claude Bernard Lyon 1

GRAVITATIONAL LENSING EFFECT



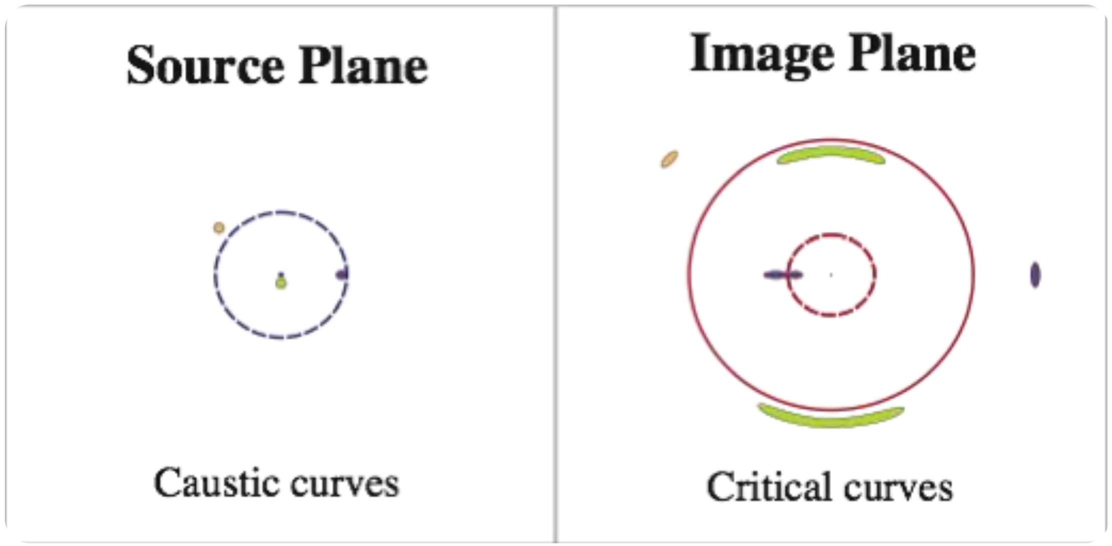
- Source behind a massive object
- Massive object deflects light rays
- Observer sees several images

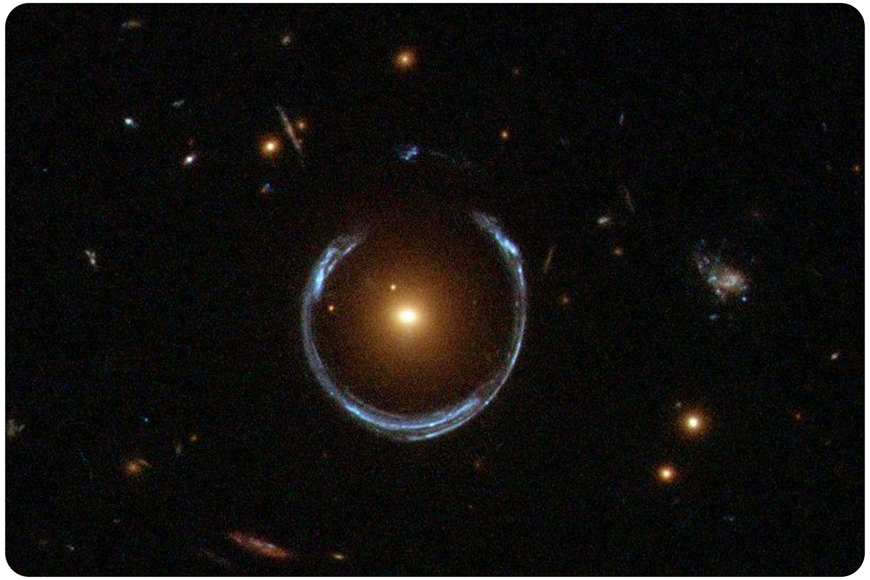
SLACS: The Sloan Lens ACS Survey   www.SLACS.org

A. Bolton (U. Hawai'i IfA), L. Koopmans (Kapteyn), T. Treu (UCSB), R. Gavazzi (IAP Paris), L. Moustakas (JPL/Caltech), S. Burles (MIT)

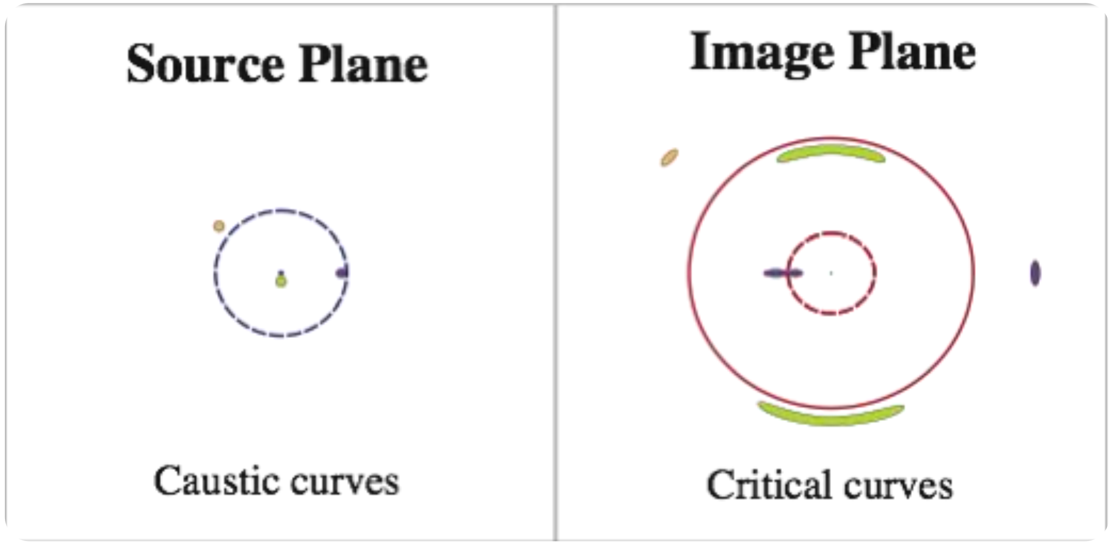
Image credit: A. Bolton, for the SLACS team and NASA/ESA

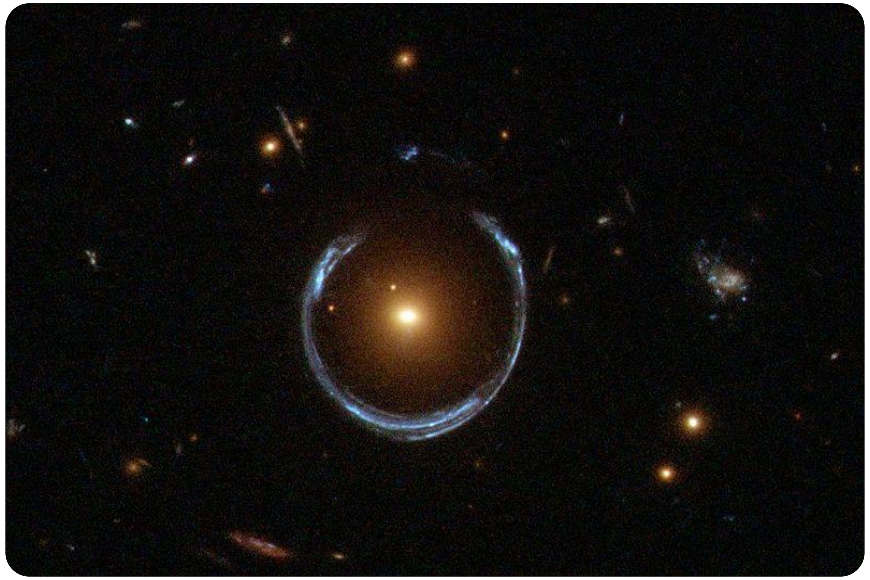
GRAVITATIONAL LENSING

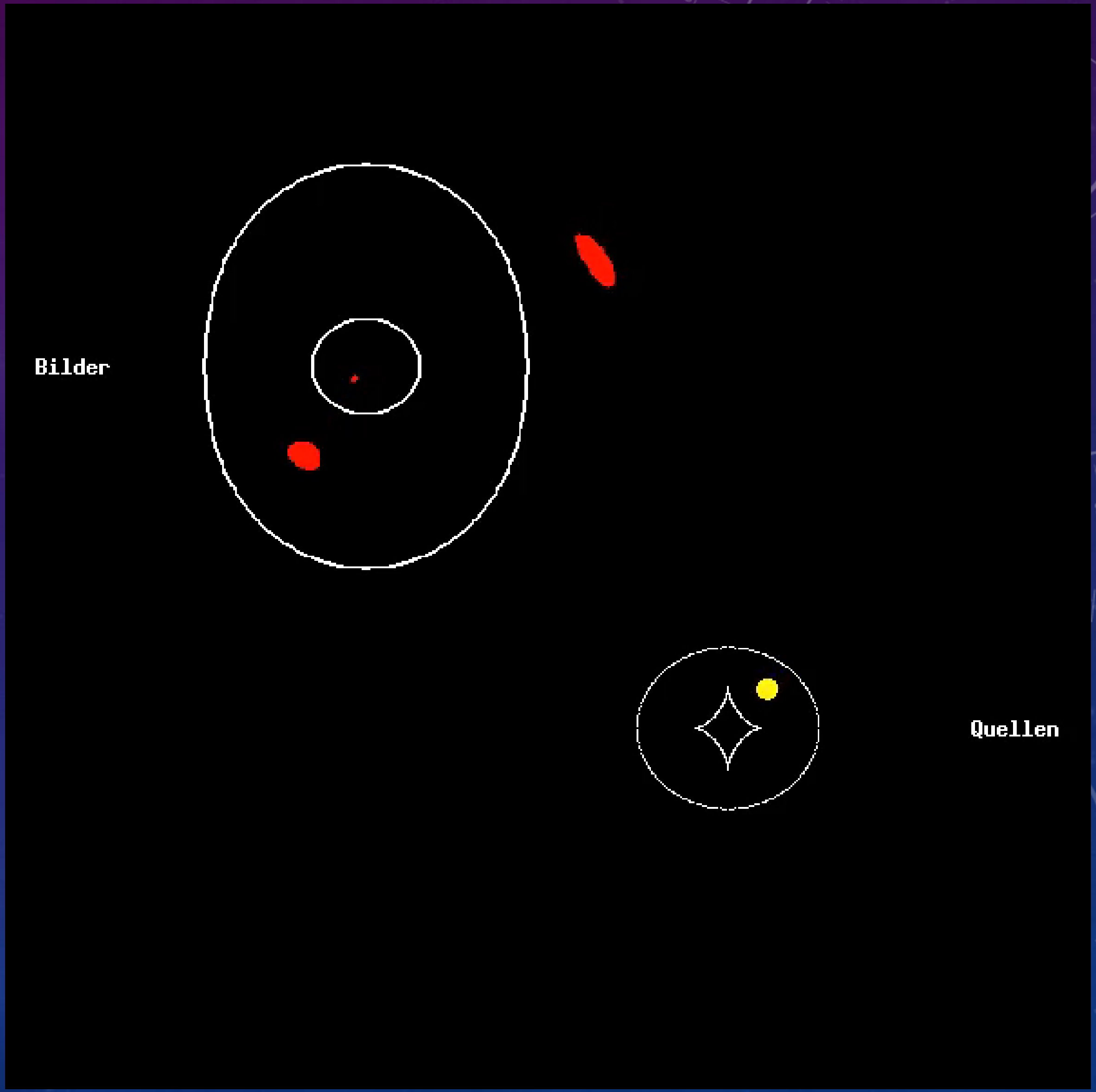




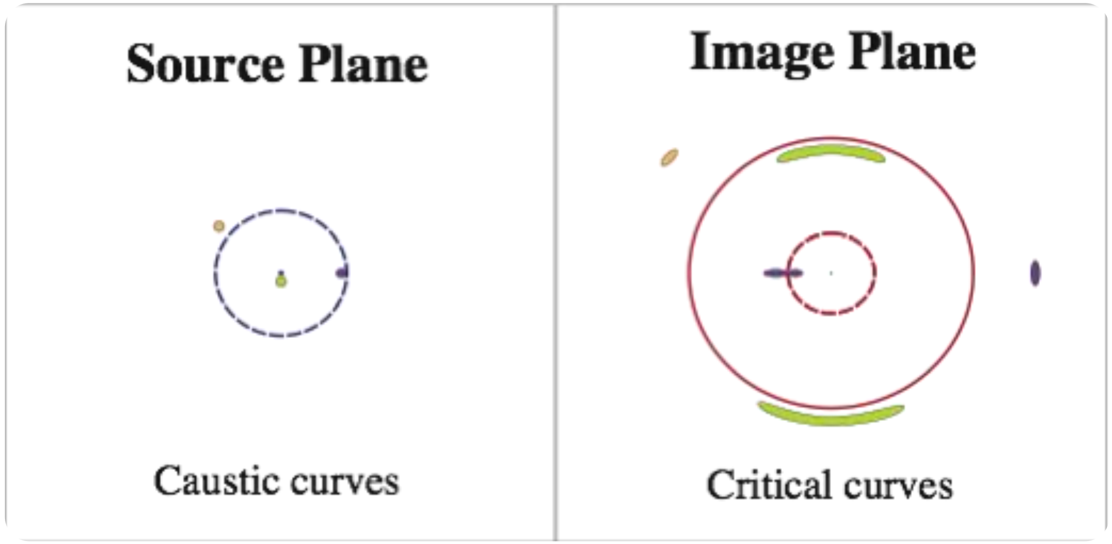
GRAVITATIONAL LENSING

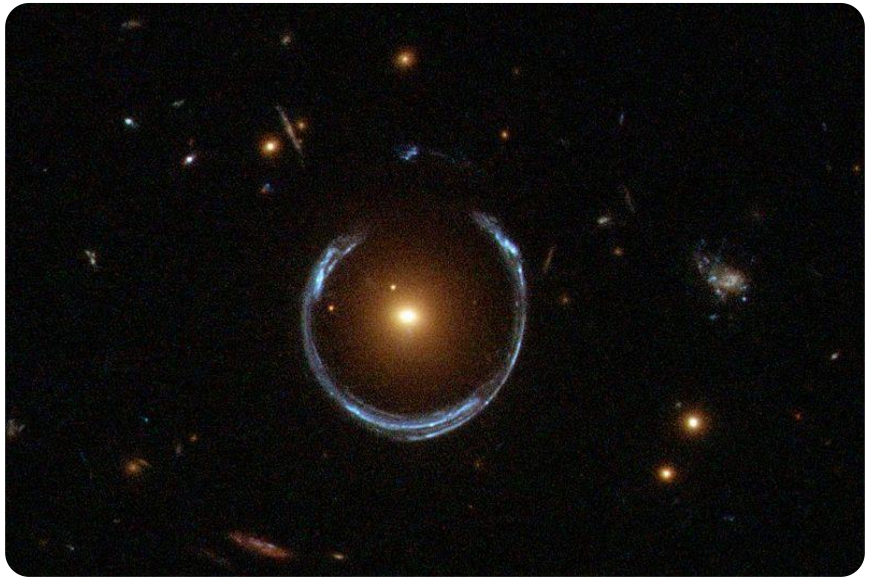


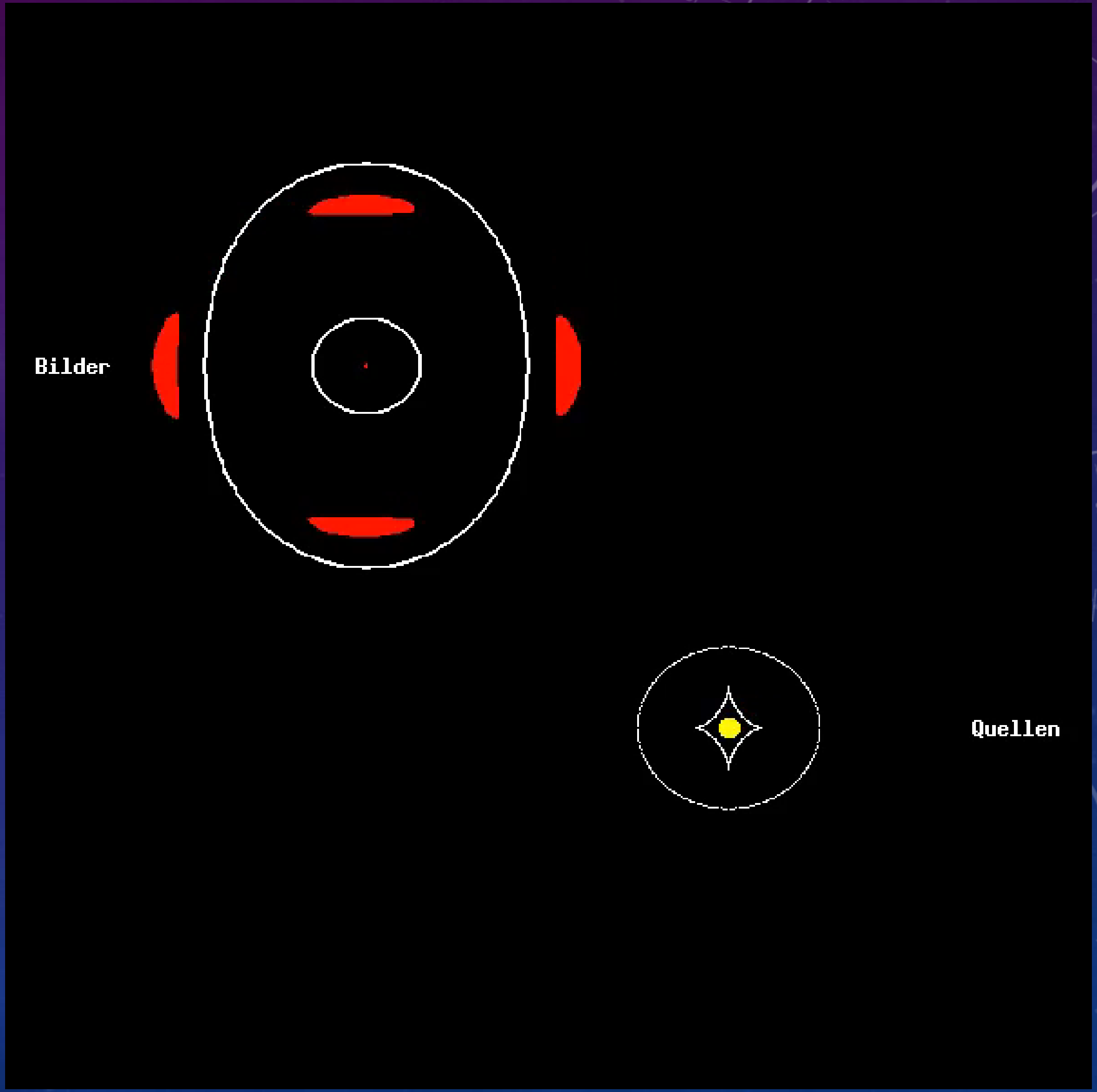




GRAVITATIONAL LENSING

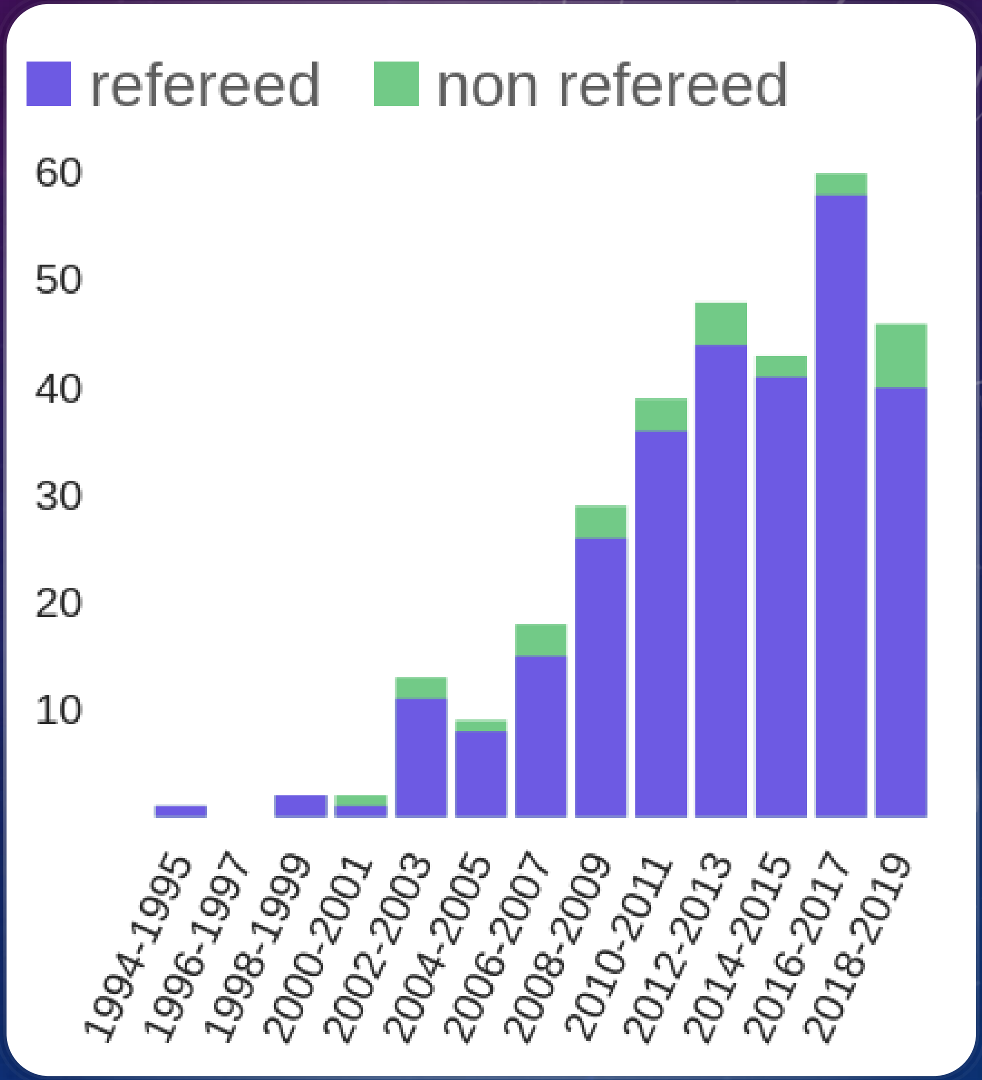






LENSTOOL: INFORMATIONS

- Gravitational lensing simulation program
- Created by J.P. Kneib (1993)
- Public, open source, multi developers
- French collaboration : Toulouse, Marseille, Lyon
- Used by about 10 research teams around the world

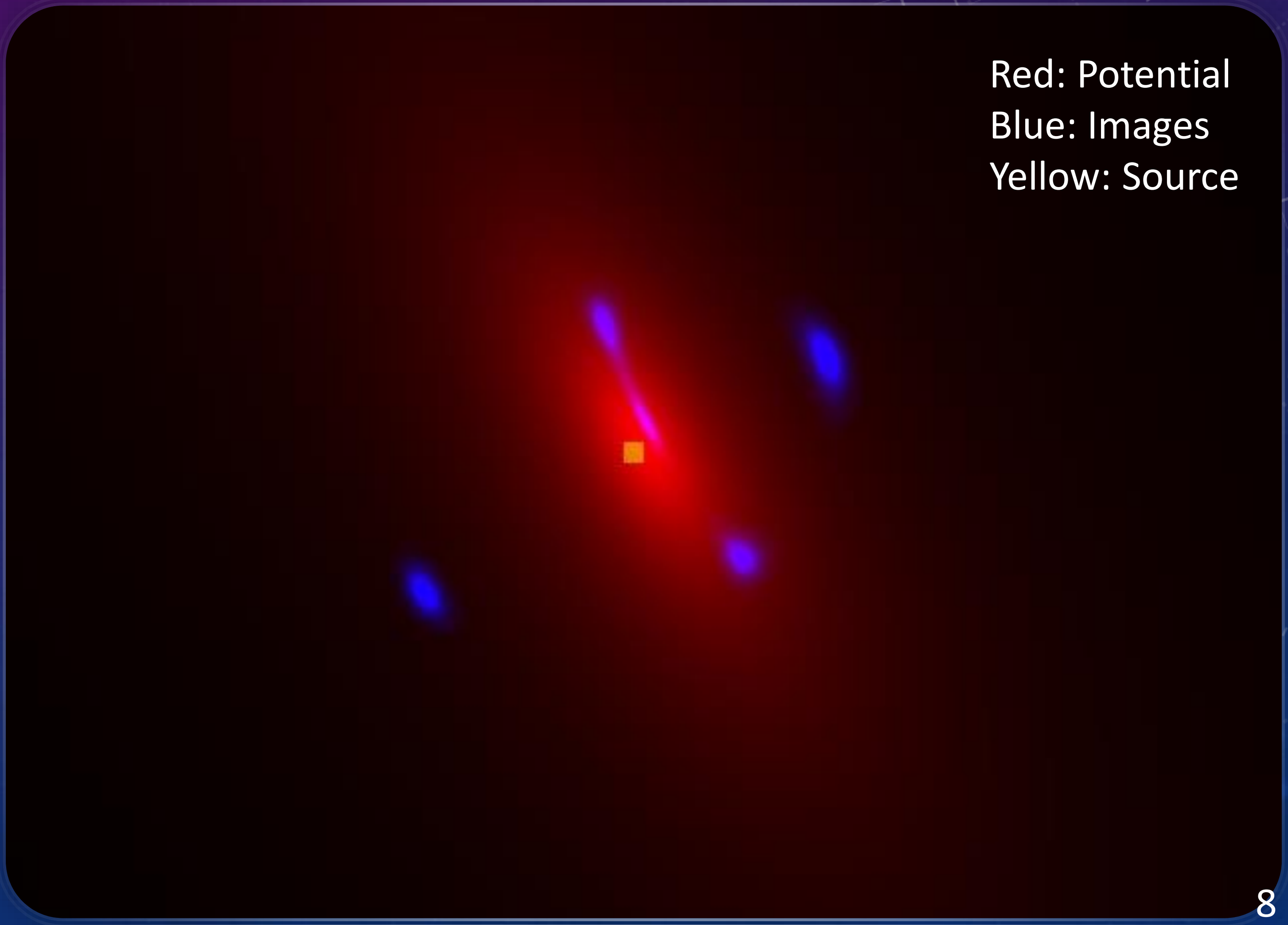


LENSTOOL: RUNNING

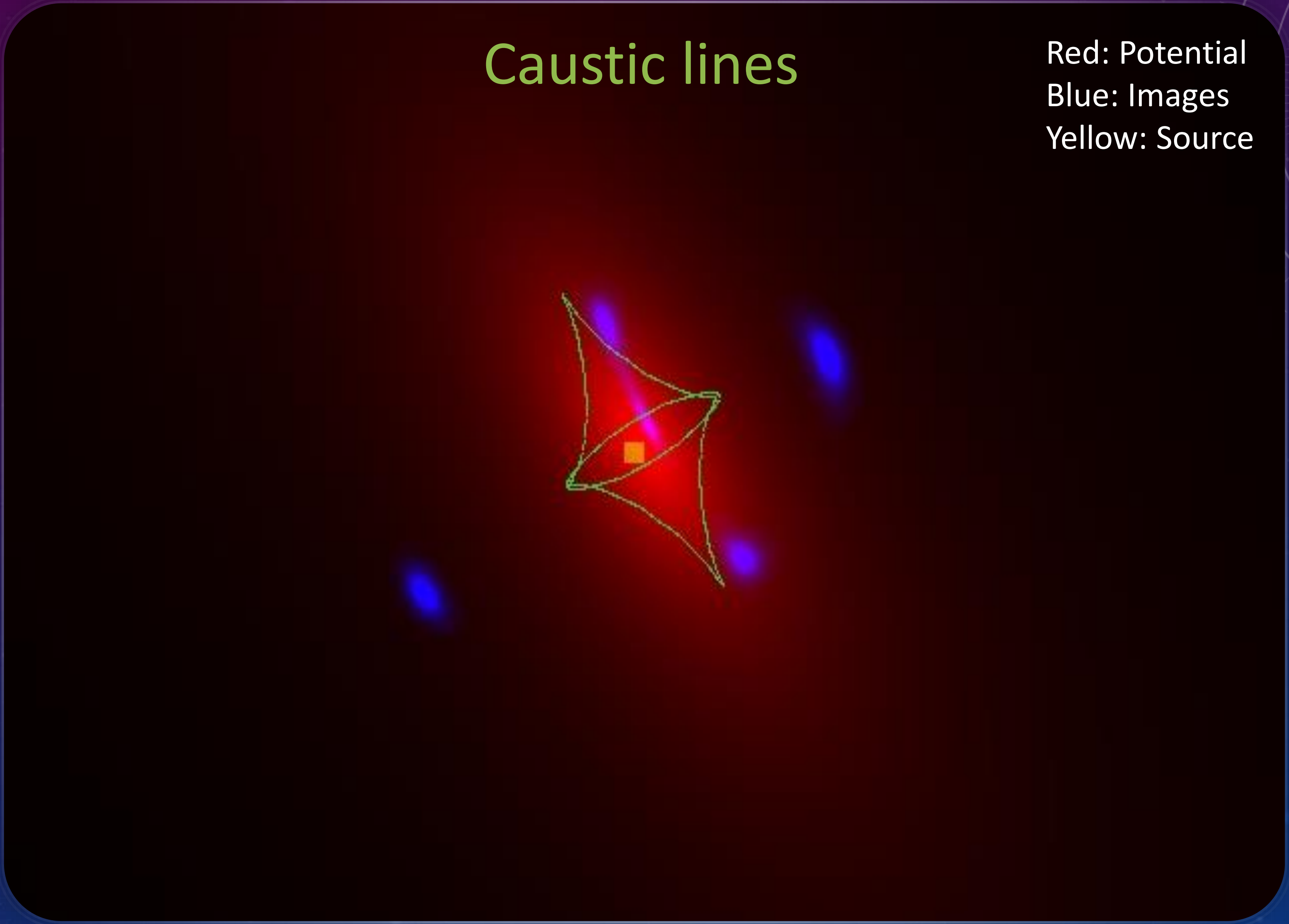
INPUT : source / image positions
+ lens parameters

```
runmode
        reference      3 133.69 -1.36
        image      0 image_wcs.cat
        end
grille
        nombre        100
        polaire       0
        nlentille     1
        end
potentiel O1
        profil         81
        x_centre       0.0
        y_centre       0.0
        ellipticite       0.65
        angle_pos         120.0
        core_radius_kpc       16.11
        cut_radius_kpc      1343.23
        v_disp      800.0
        z_lens      0.4000
        end
```

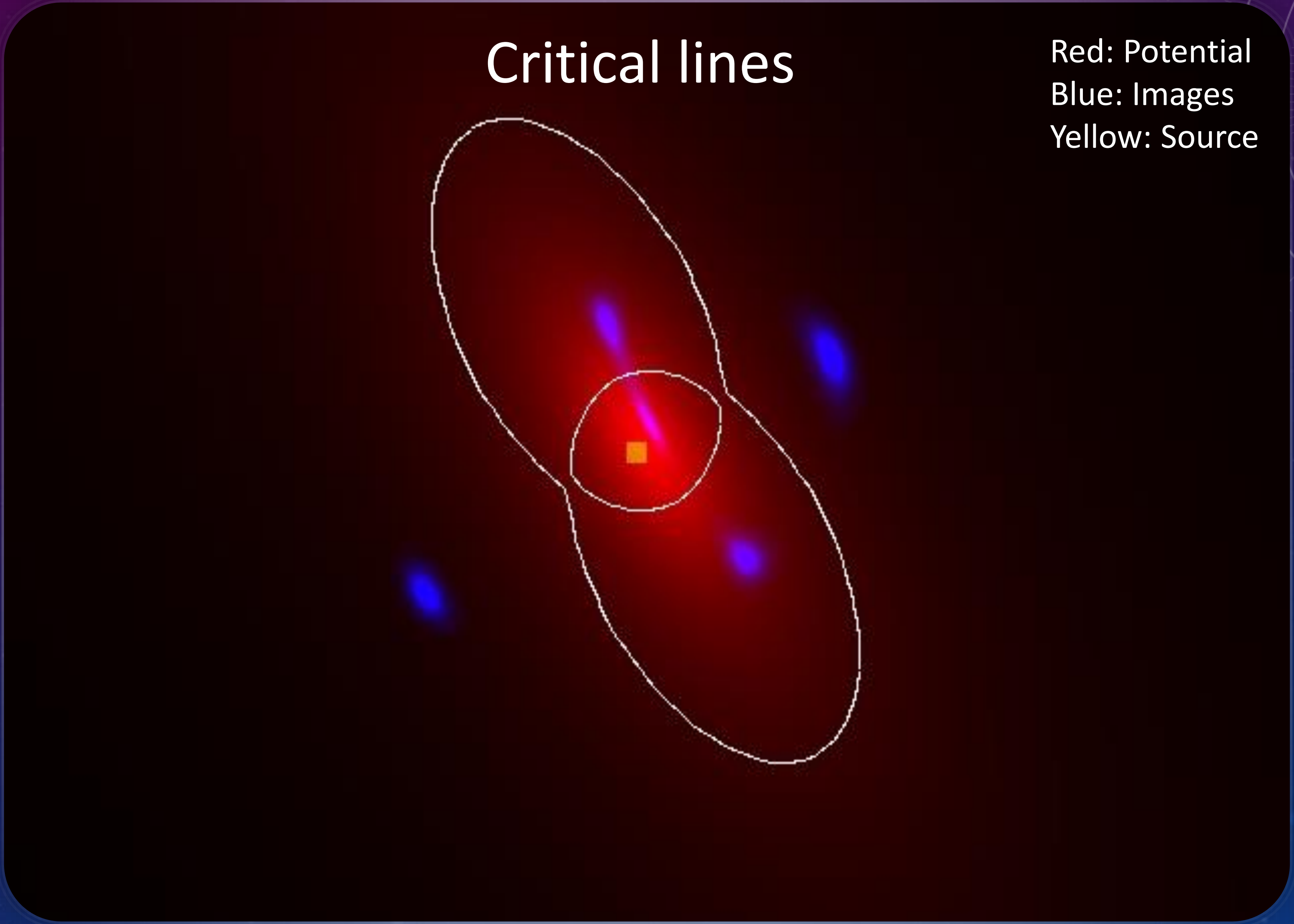
OUTPUT : All images and source(s) positions



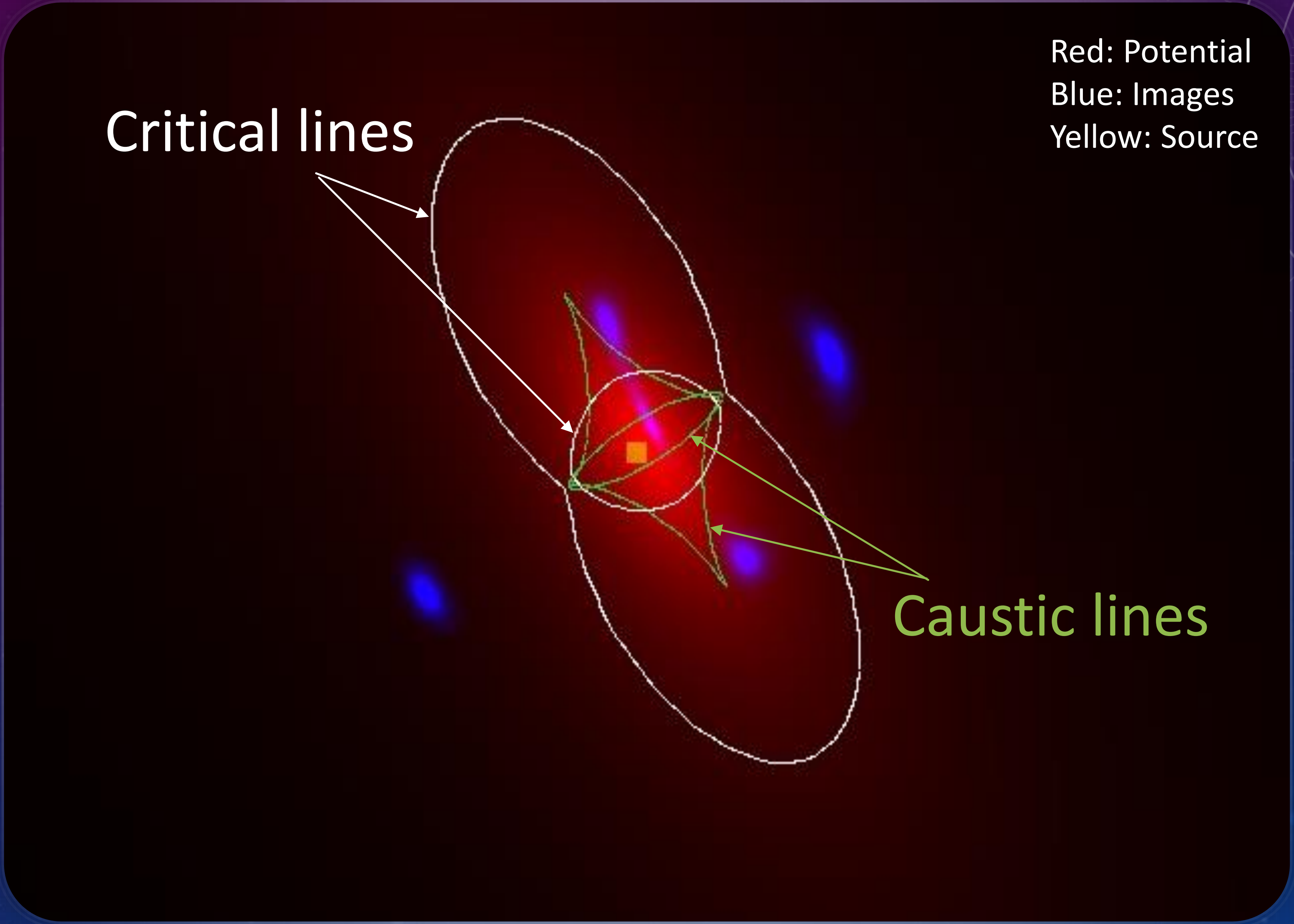
LENSTOOL: MODEL



LENSTOOL: MODEL



LENSTOOL: MODEL

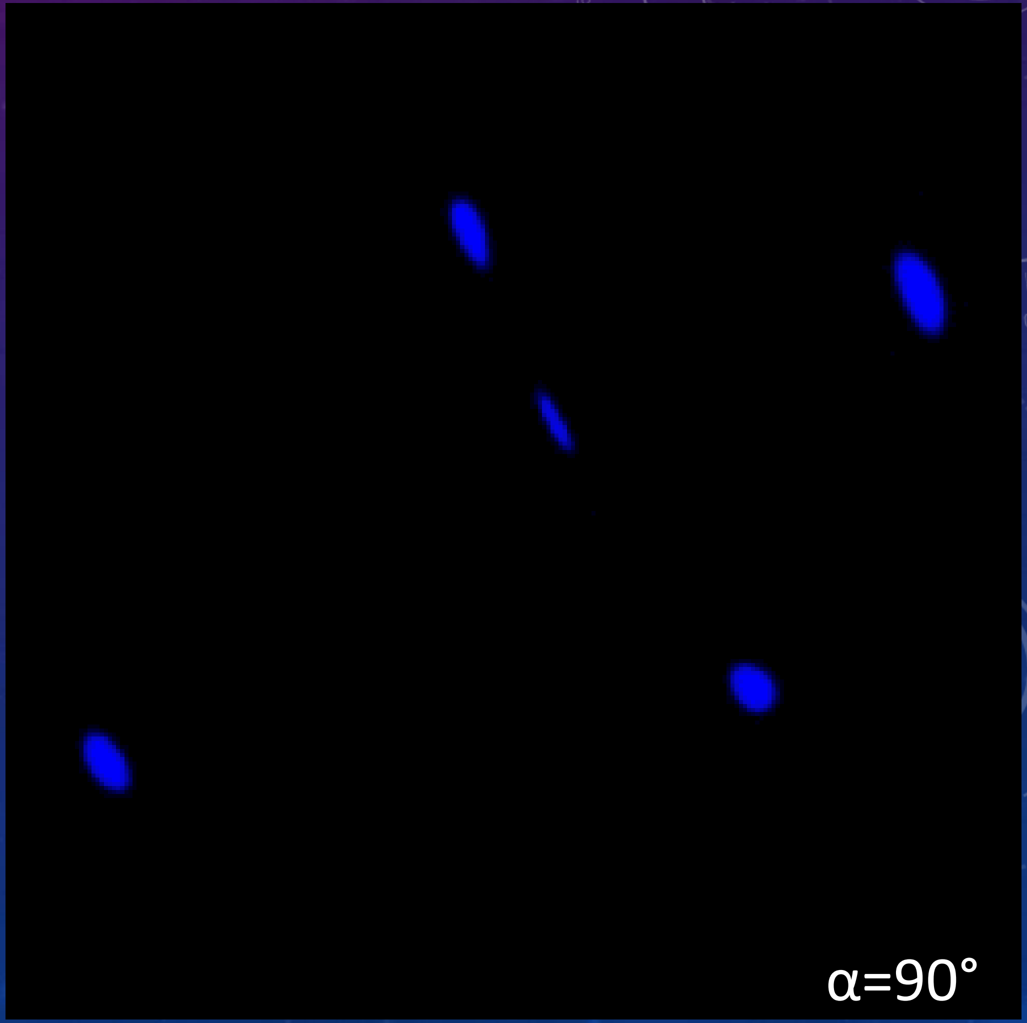


LENSTOOL: SHEAR

- Environment effects create a deformation on images
- Modelisation by a shear in the image
- The Shear is described by a strength γ and an angle α

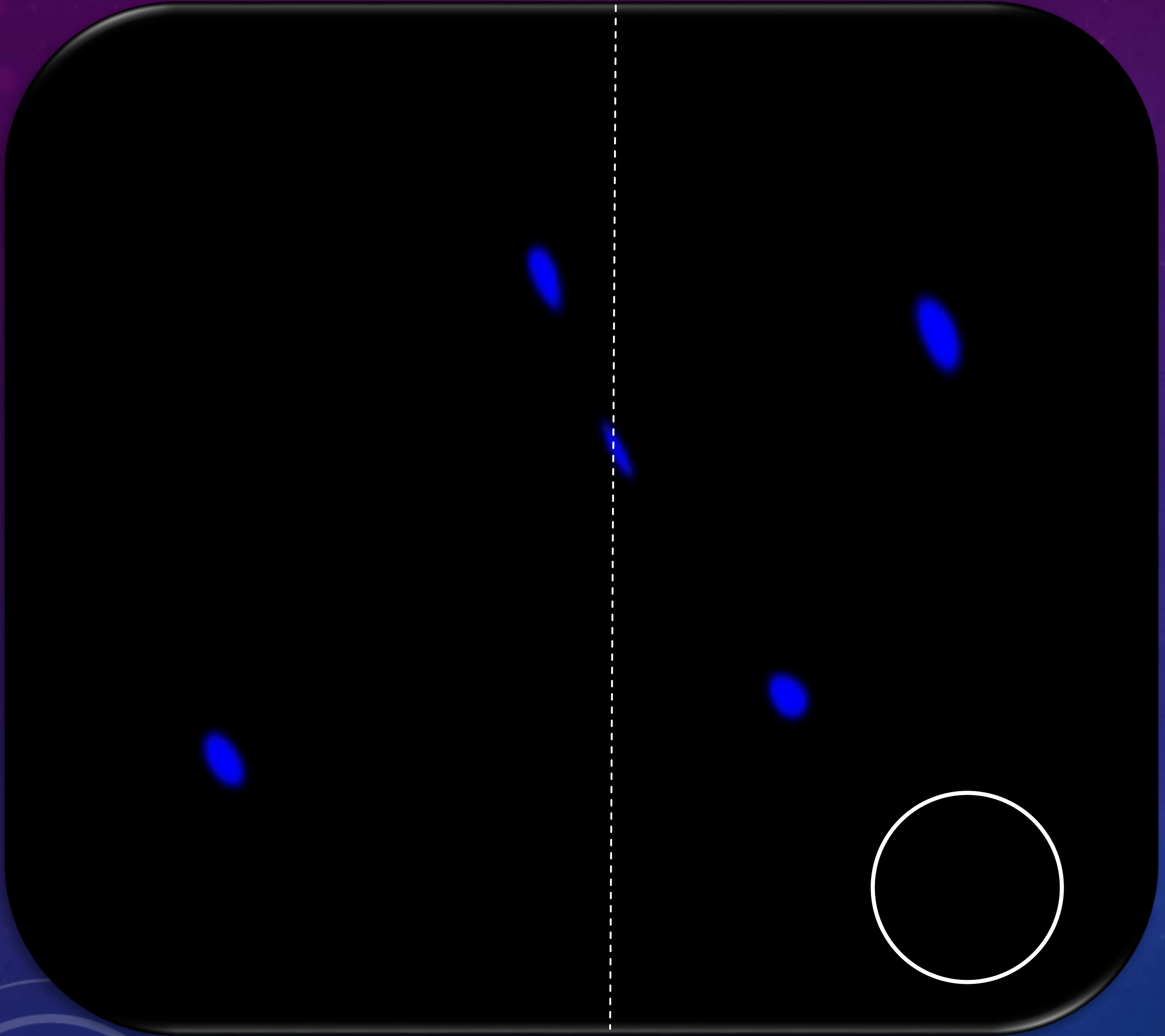
Objective ⇨ Find the images with no shear

Model + vertical
shear strength up to γ=0.2

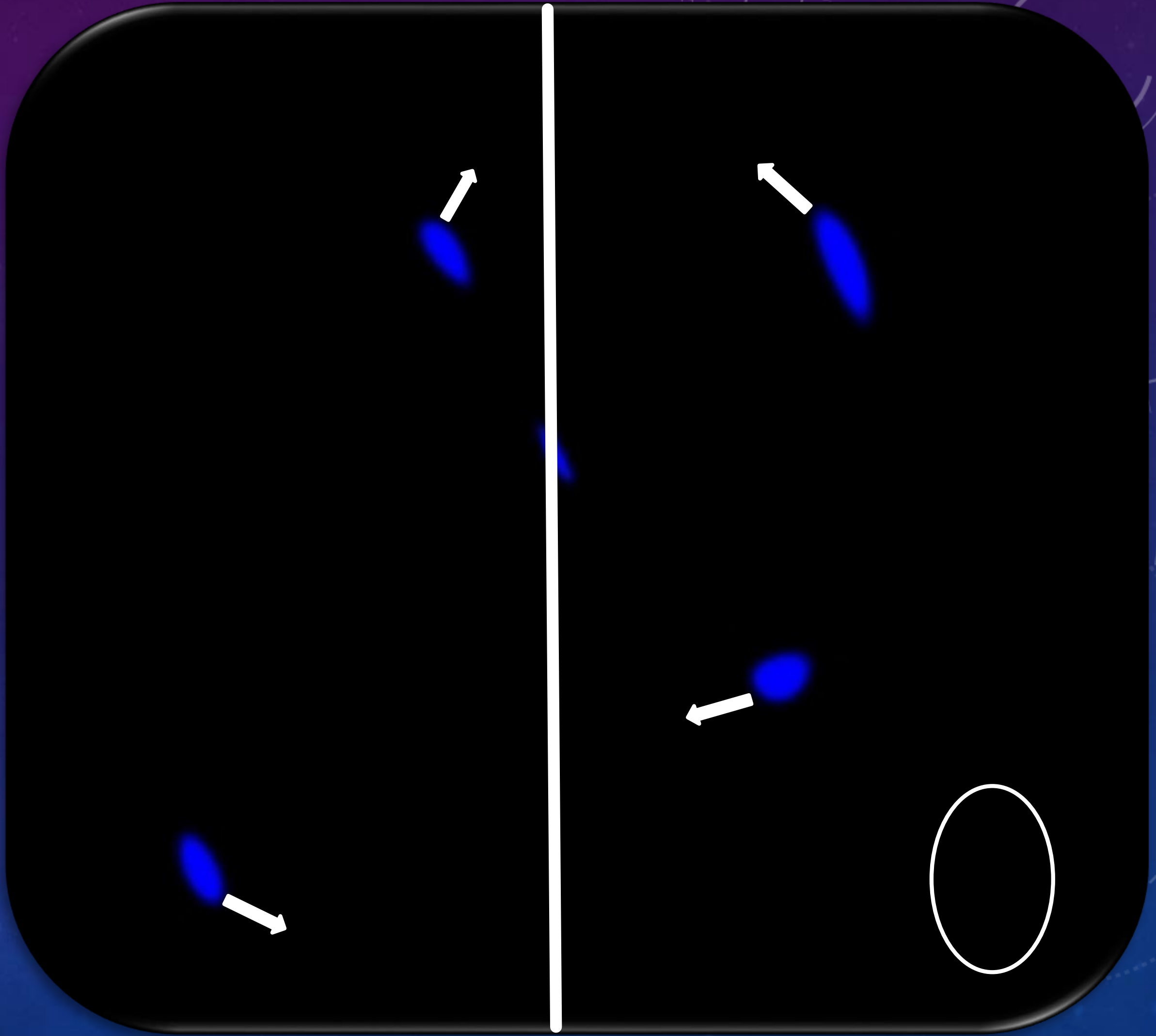


LENSTOOL: SHEAR EFFECT

α=90°



No Shear

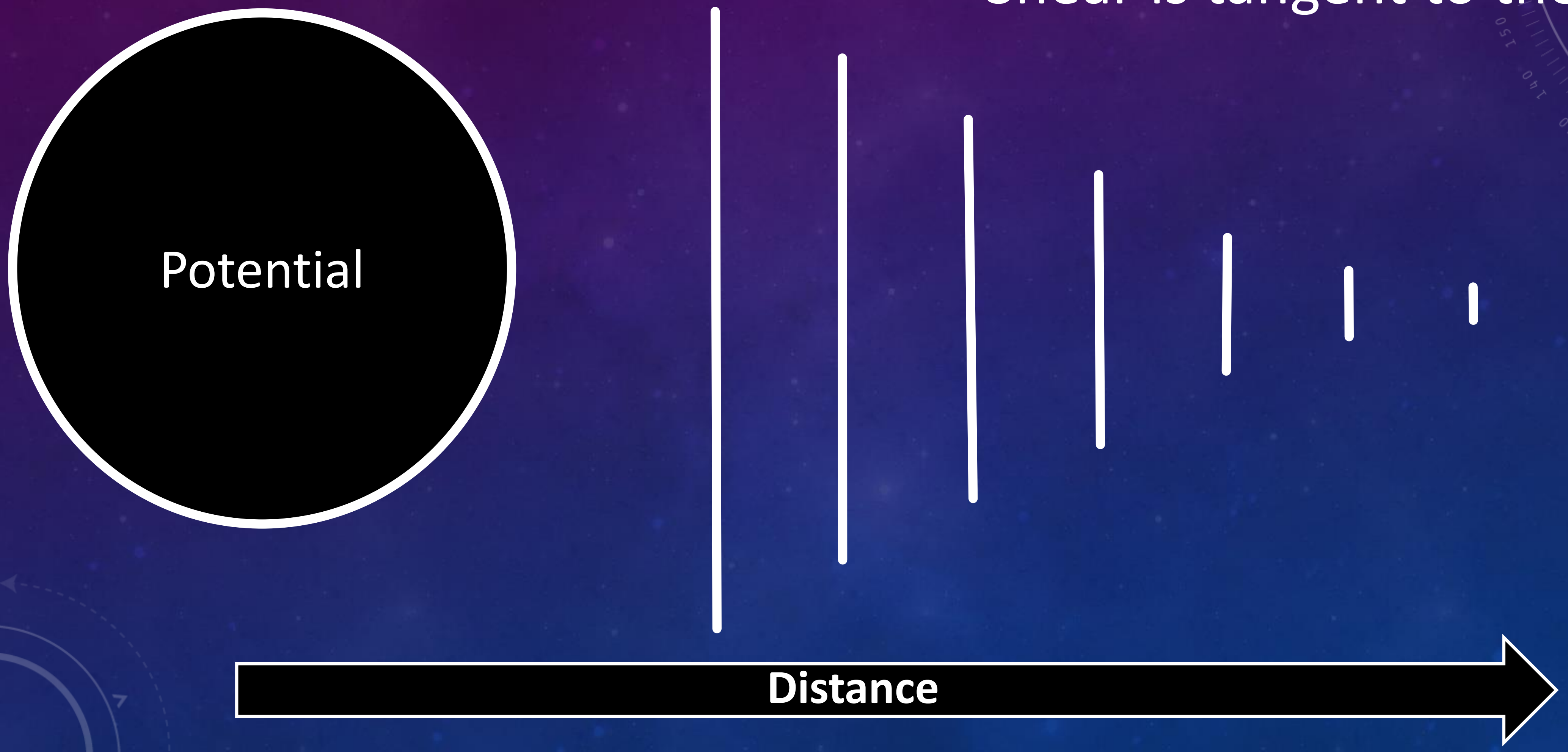


Shear $\gamma = 0,2$

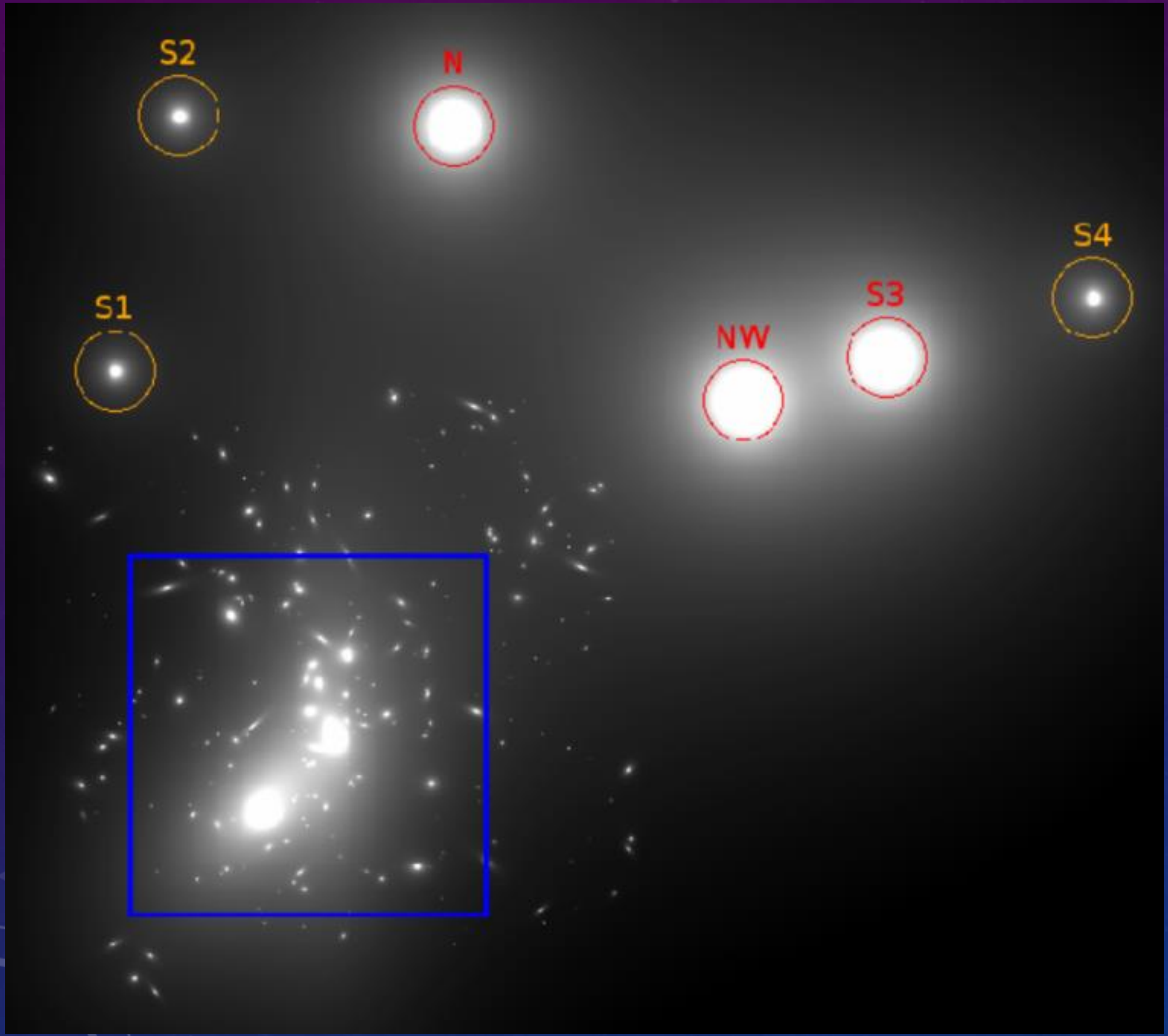
LENSTOOL: SHEAR EFFECT

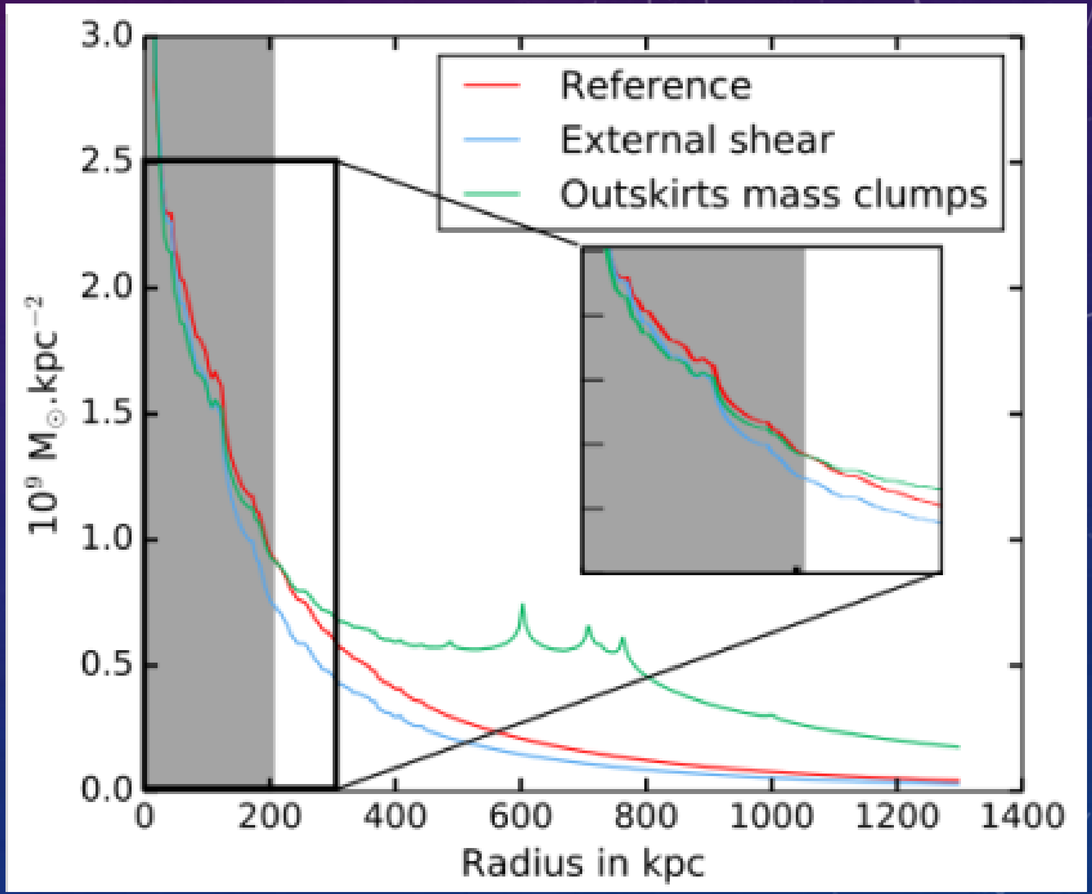
γ decrease with the distance

Shear is tangent to the potential



LENSTOOL: SCIENTIFIC INTEREST





G. Mahler et al 2018

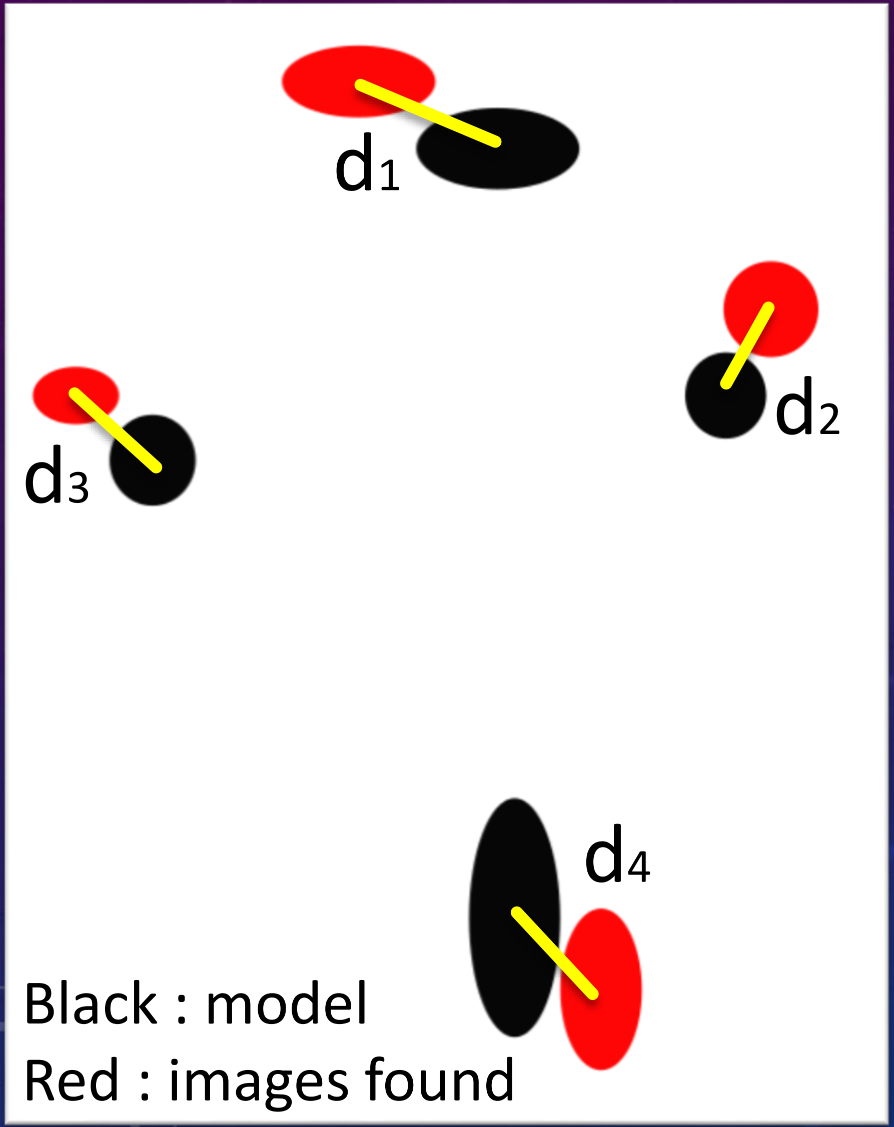
LENSTOOL: POTENTIAL OPTIMISATION

```
potentiel 1
        profil     81
        x_centre     0.0
        y_centre     0.0
        ellipticite     0.65
        angle_pos     120.
        core_radius  3.0
        cut_radius  250.0
        v_disp     800.
        z_lens     0.4
        end
limit 1
        x_centre        0 -100.0  100.0 0.01
        y_centre        0 -1.0  1.0 0.01
        ellipticite     1 0.1  0.75 0.01
        angle_pos       1 0. 180.0 0.1
        core_radius     0 0.1 4. 0.1
        cut_radius      0  50. 500. 0.1
        v_disp          0 200. 1000.  0.1
        end
```

- Prior : uniform, gaussian
- Limit : min, max
- Iteration step, deviation 1σ

Find images for each case and compute χ^2

LENSTOOL: χ^2 CALCULATION



$$\chi^2 = \left(\frac{d_1}{\epsilon}\right)^2 + \left(\frac{d_2}{\epsilon}\right)^2 + \left(\frac{d_3}{\epsilon}\right)^2 + \left(\frac{d_4}{\epsilon}\right)^2$$

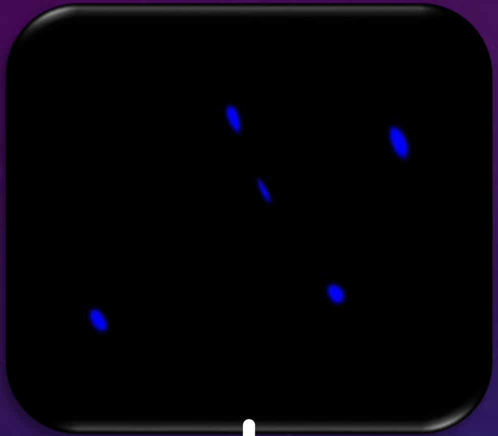
D_i : separation distance in arcsec

ε : astrometric errors (0.1'')

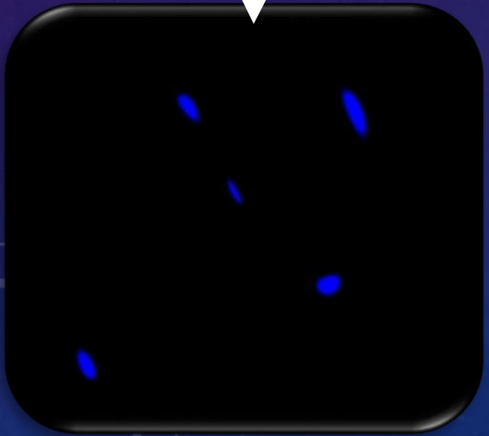
LENSTOOL: TEST PROCEDURE

INPUT

Images with shear



γ = 0



γ = 0,2

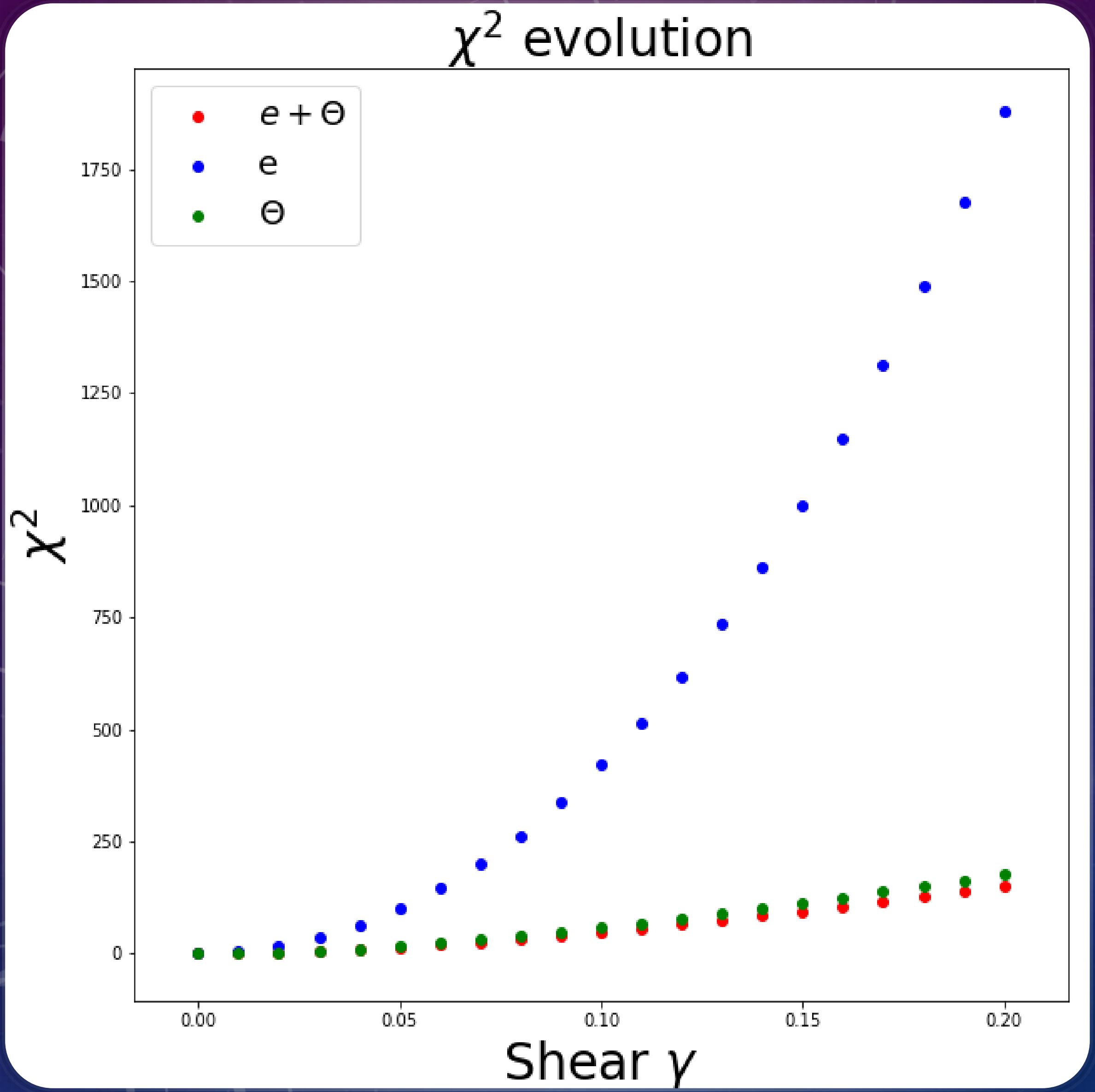
OPTIMIZATION

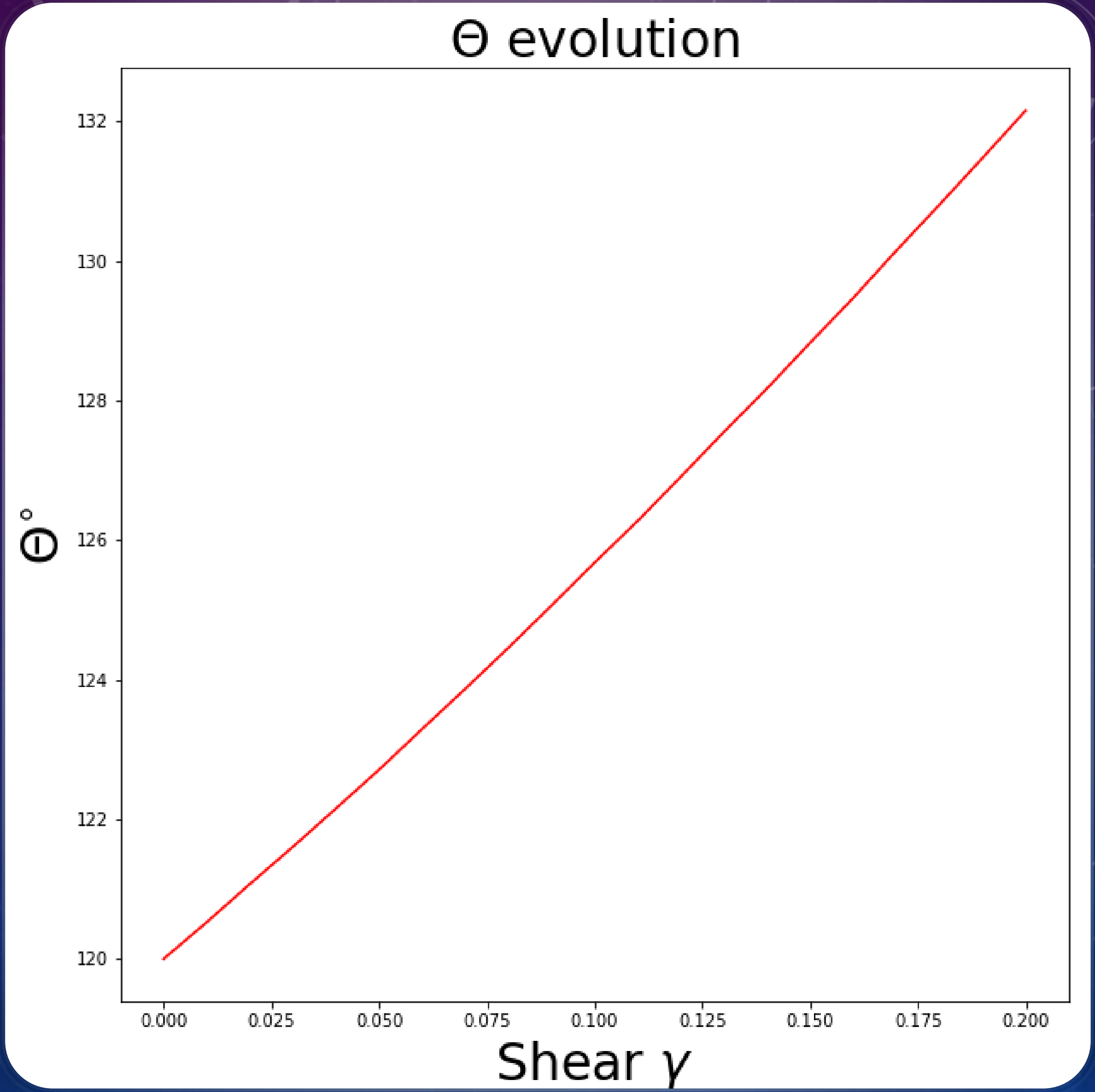
- 1 potential optimizing Θ,ellipticity,...
- 2 potentials :
  1 fixed potential
  1 spherical potential
  optimizing: x, σ, y...

OUTPUT

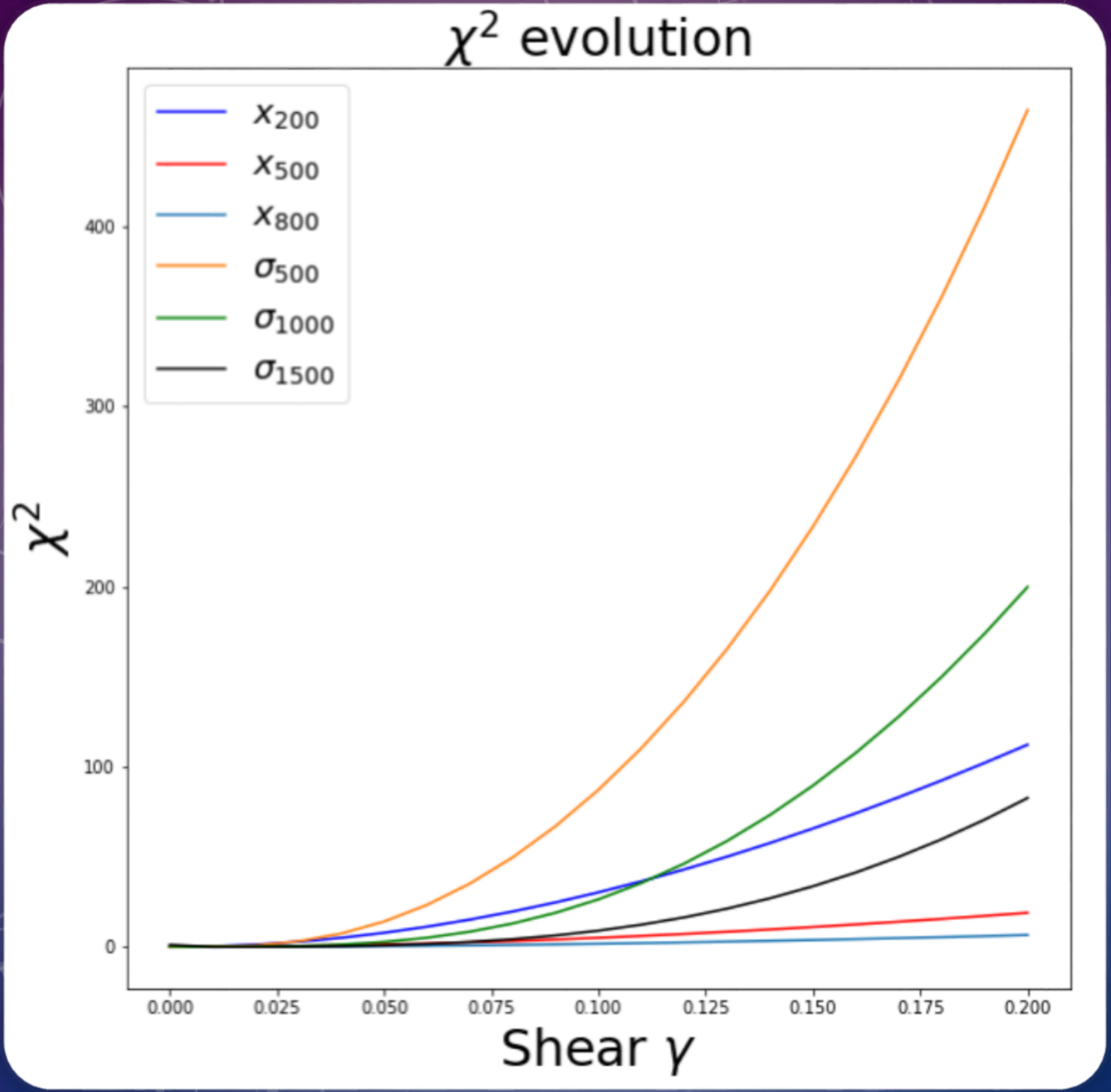
Best model minimizing χ^2

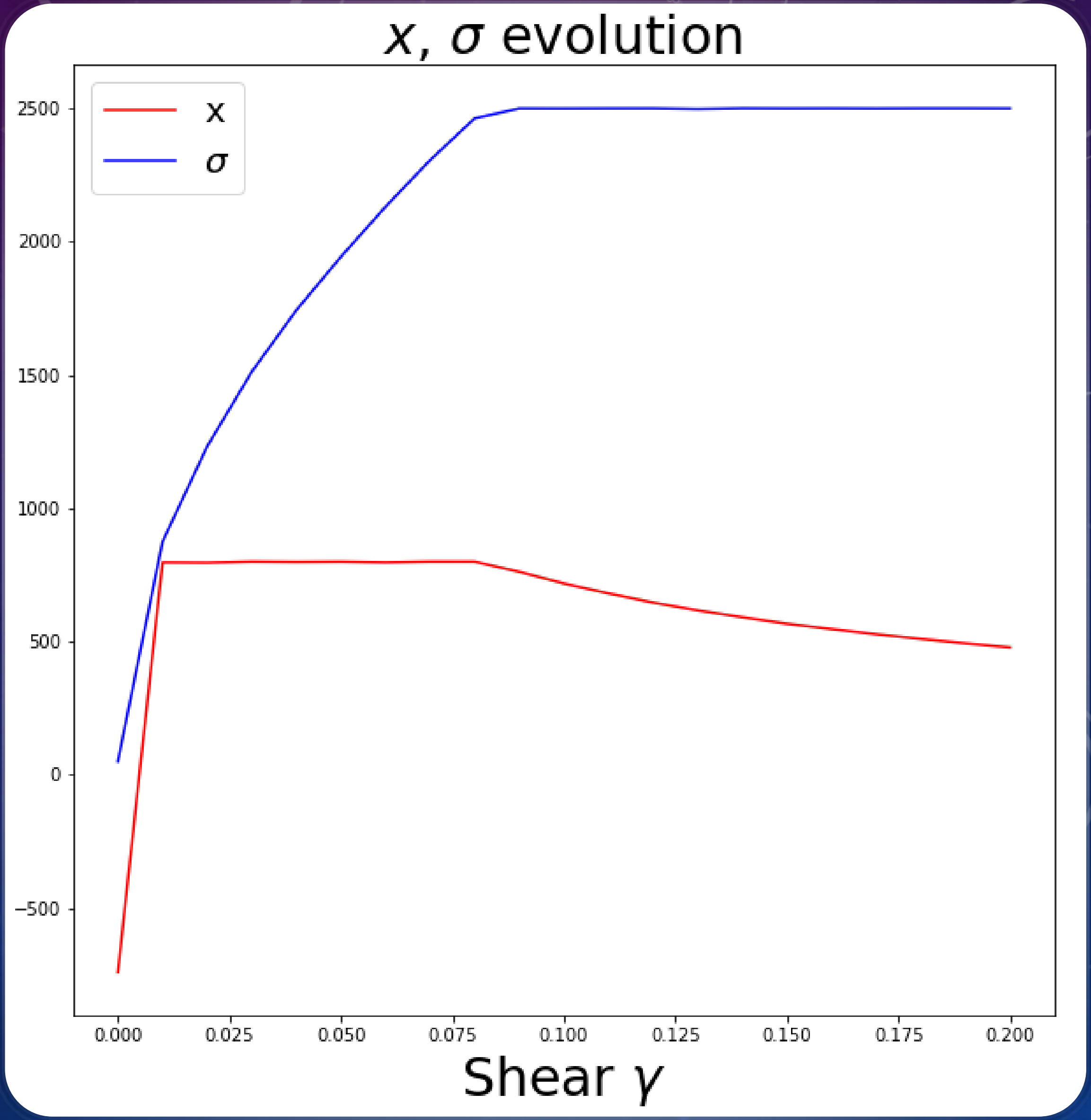
LENSTOOL: RESULTS FOR 1 POTENTIAL



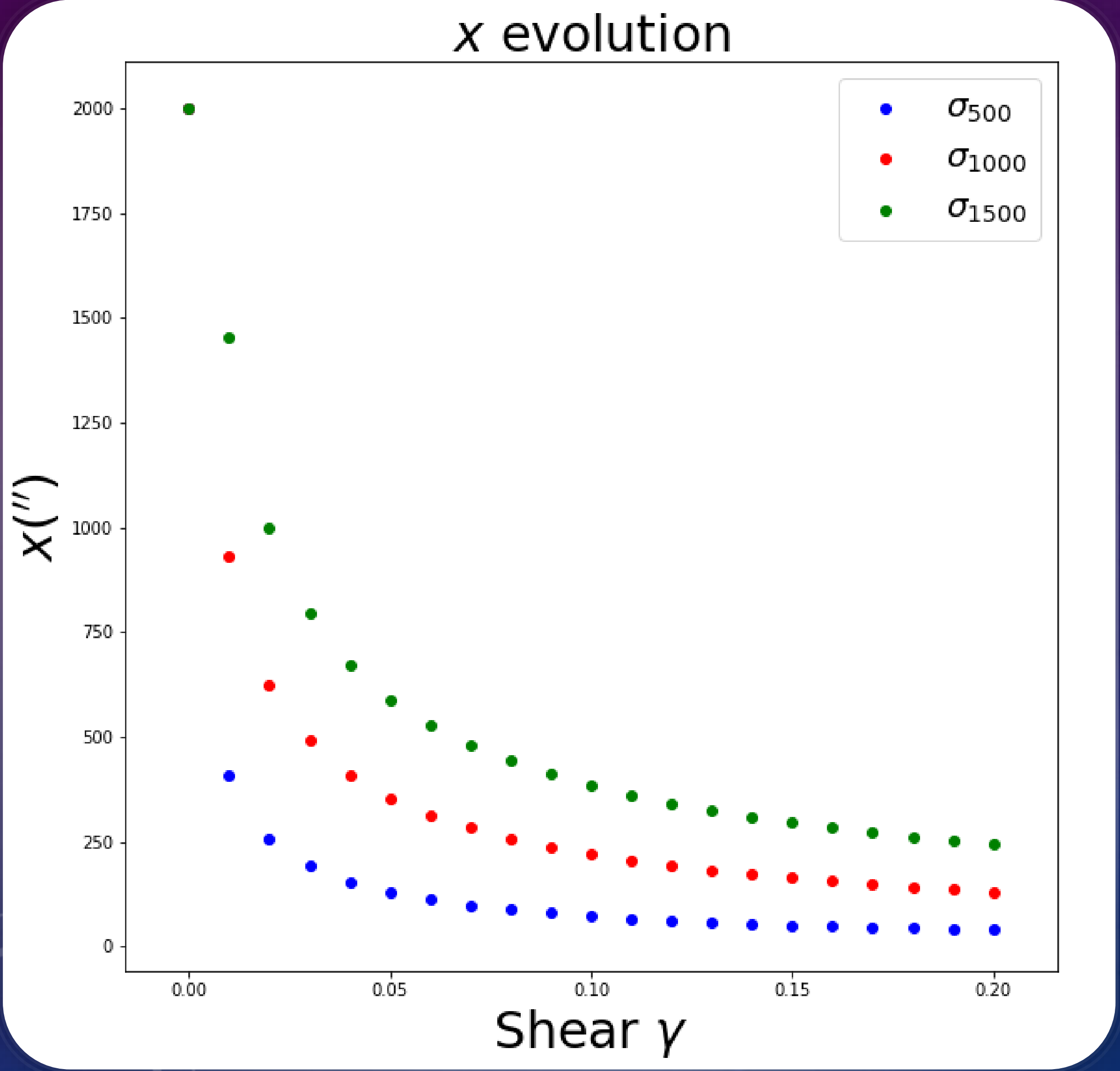


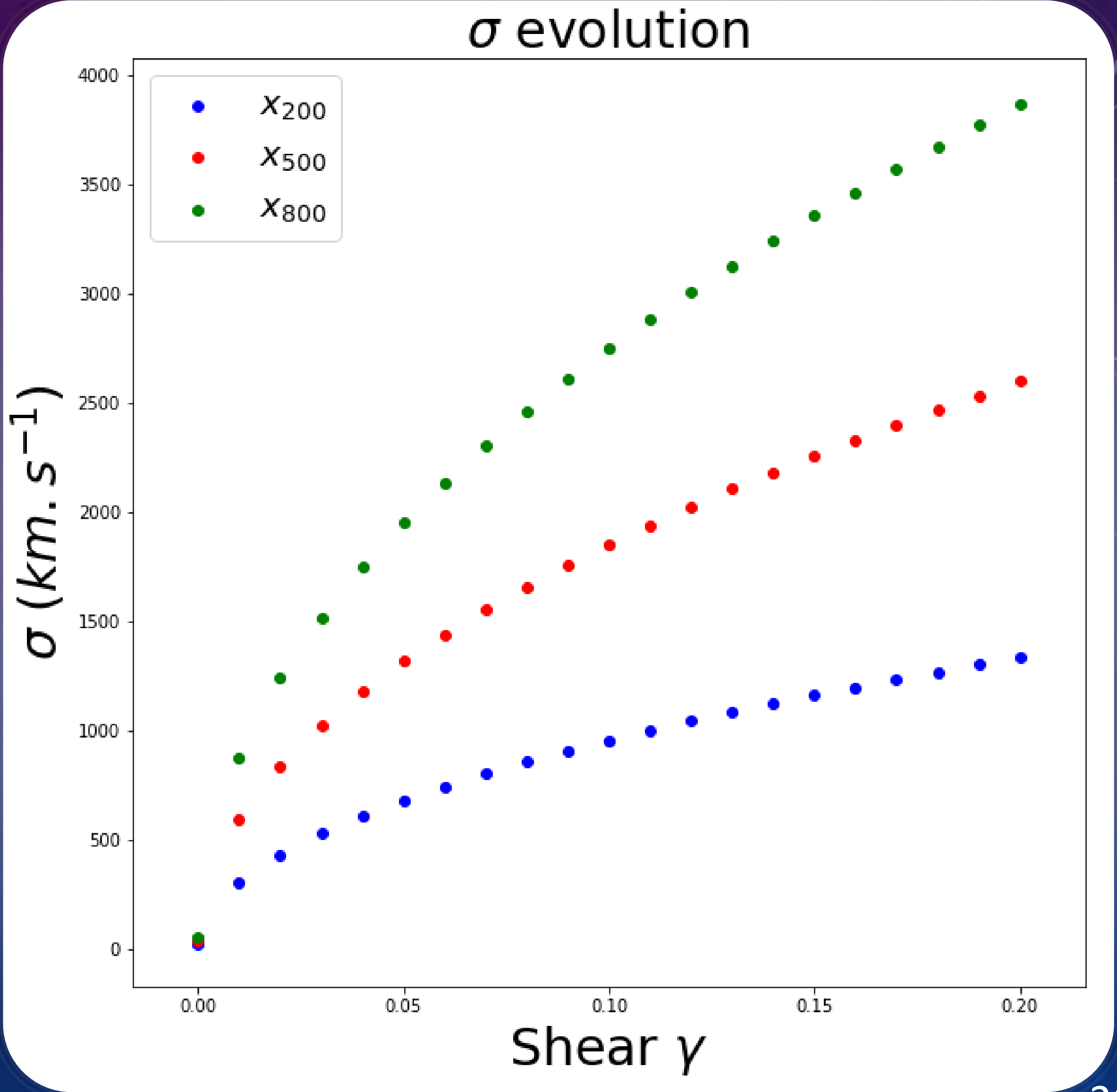
LENSTOOL: RESULTS FOR 2 POTENTIALS





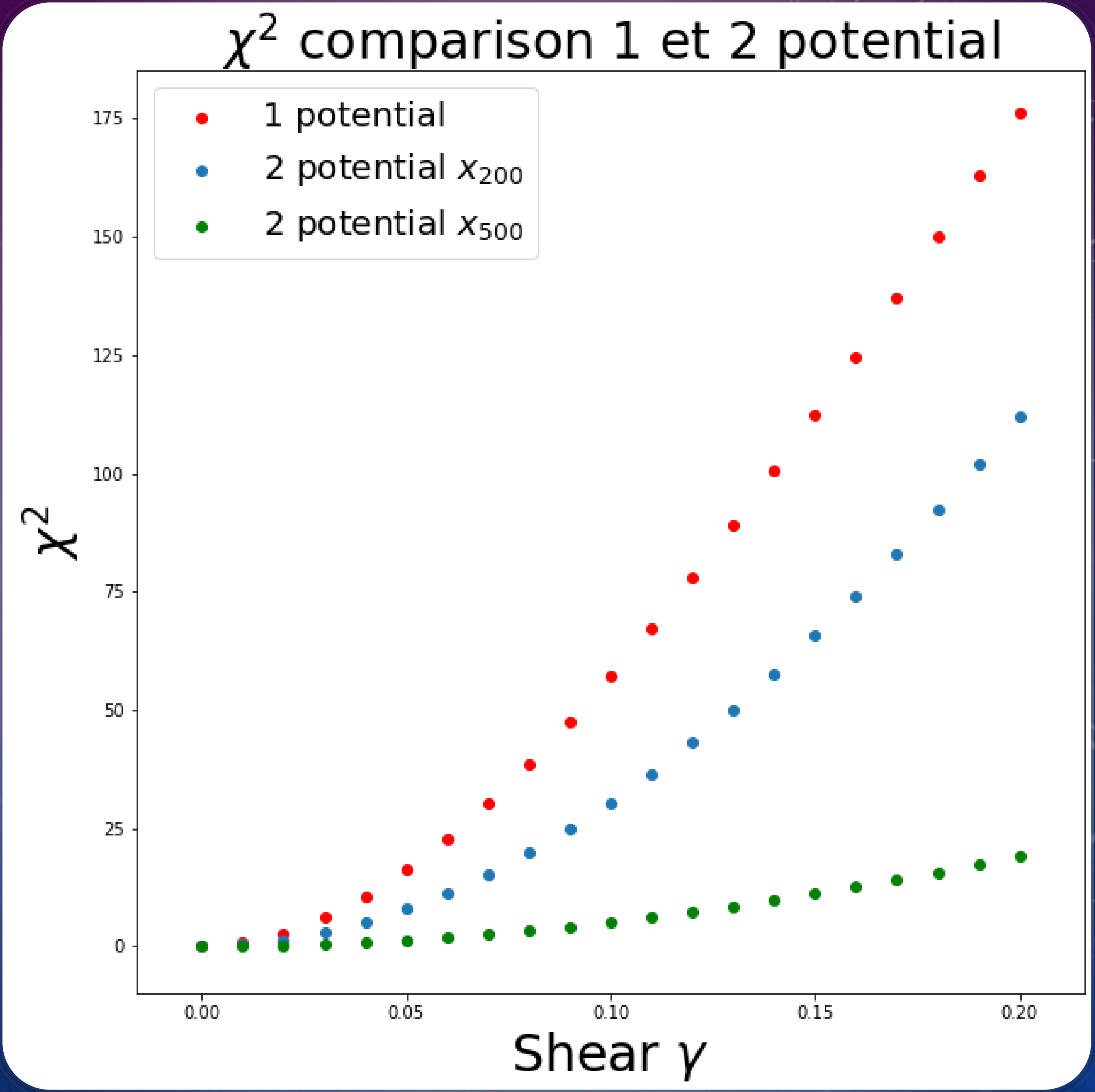
LENSTOOL: RESULTS FOR 2 POTENTIALS



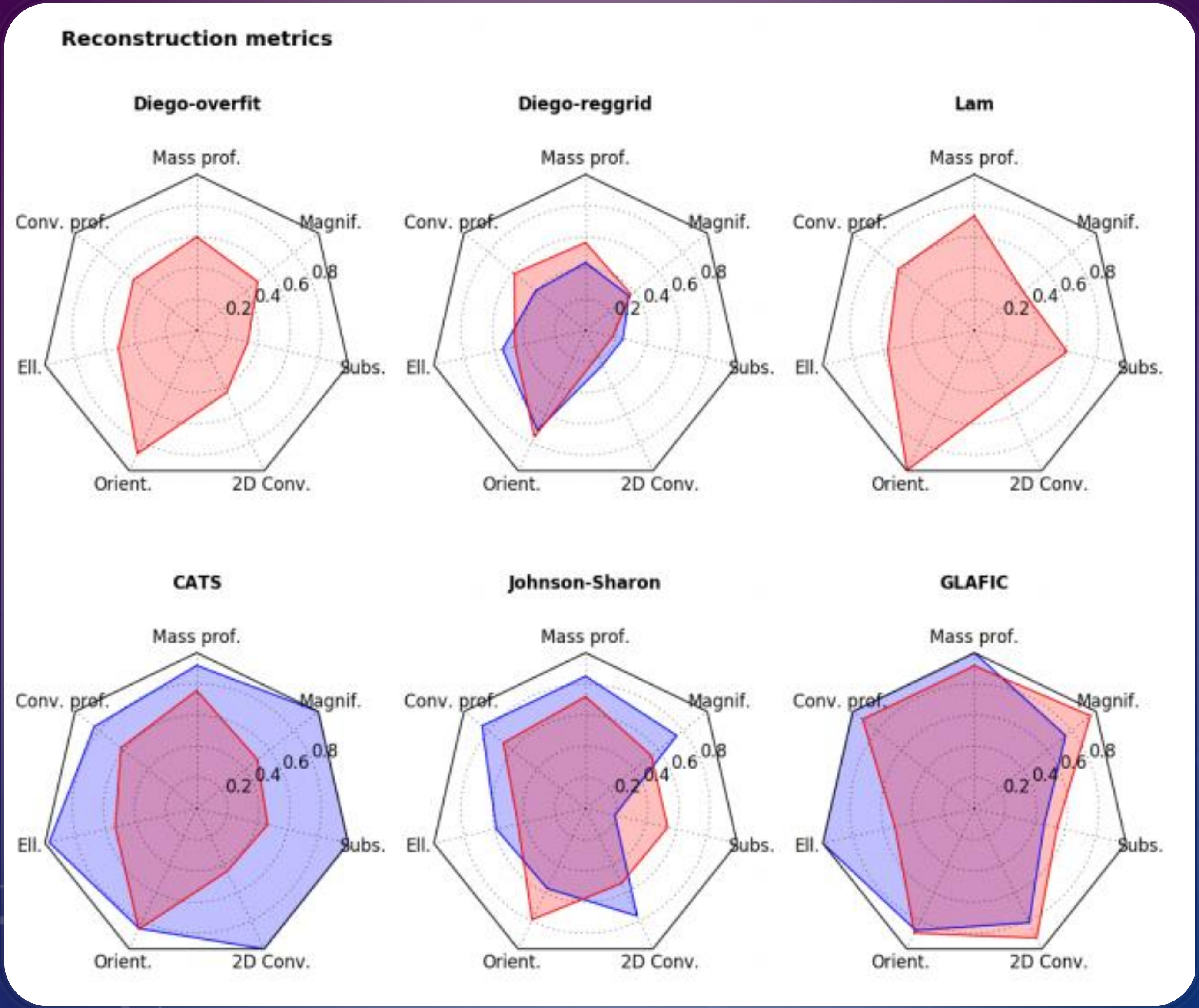


LENSTOOL: RESULTS

- Better results with 2 potentials
- Model is harder to reproduce with increasing shear



LENSTOOL: CURRENT LIMIT + OTHER MODELS



Red : SPH model
Blue : Semi-analytical model

CATS uses LENSTOOL

Meneghetti et al 2017

CONCLUSION

- Shear is important to understand the environment effect
- Good reproduction of images with shear when including a 2nd spherical potential
- Considering mass environment what would be the effect on the images ?

- Install C program with svn and compile with all libraries/dependencies
- Understand and use a scientific program
- Understand overall behaviour of the optimisation process for parametric model
- Data Analysis with python
- Visualisation with DS9

Thank you !