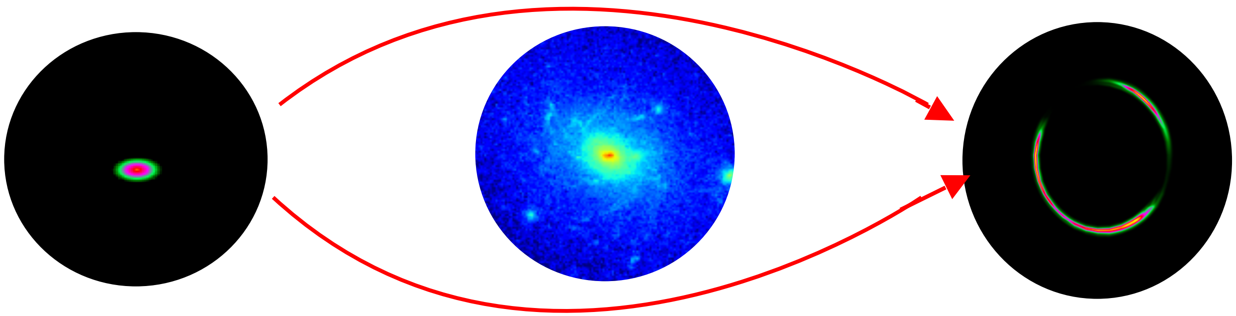
SEAGLE I & II : Constraining galaxy evolution scenarios from Strong lens simulations with EAGLE



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In collaboration with
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Prof. Joop Schaye (Leiden Observatory, co-supervisor)
Prof. R. Benton Metcalf (University of Bologna)
Dr. Crescenzo Tortora (RUG)
Dr. Mathhieu Schaller (Durham University)
Dr. Nicholas Tessore (Jodrell Bank Observatory)
Dr. Robert Crain (Liverpool John Moores University)
Dr. Georgios Vernardos (RUG)
Dr. Fabio Bellagamba (University of Bologna)

How many strong lenses do we need and why ?

I. If we want to achieve 1% error on mass slopes we require 50+ lenses per parameter-voxel (e.g. **Barnabe et al. 2011**).

II. If we want to reach 0.1% in the mass fraction in substructure needs 50+ lens system with extended images (e.g.**Vegetti & Koopmans 2009**)

Probing a wide range of masses, environments and galaxy types requires $\mathbf{10^{(4\text{-}5)}}$ lenses to beat sample variance, noise & biases.

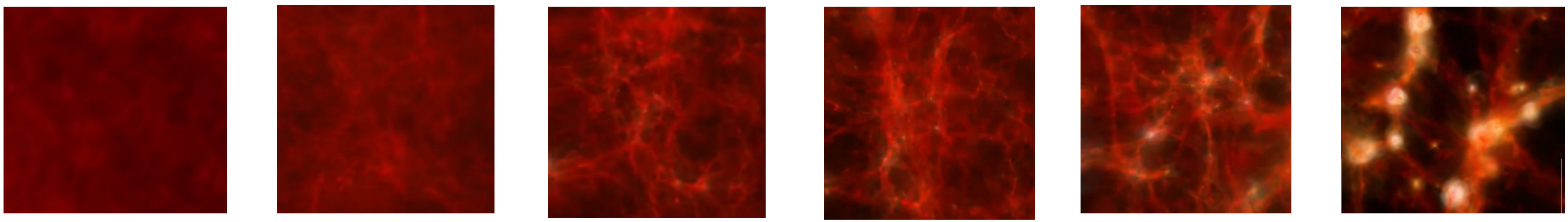
Why do I want to simulate so many strong lenses ?

1. Galaxy structure and evolution as function of mass, redshift and type: DM & Stellar mass profiles.

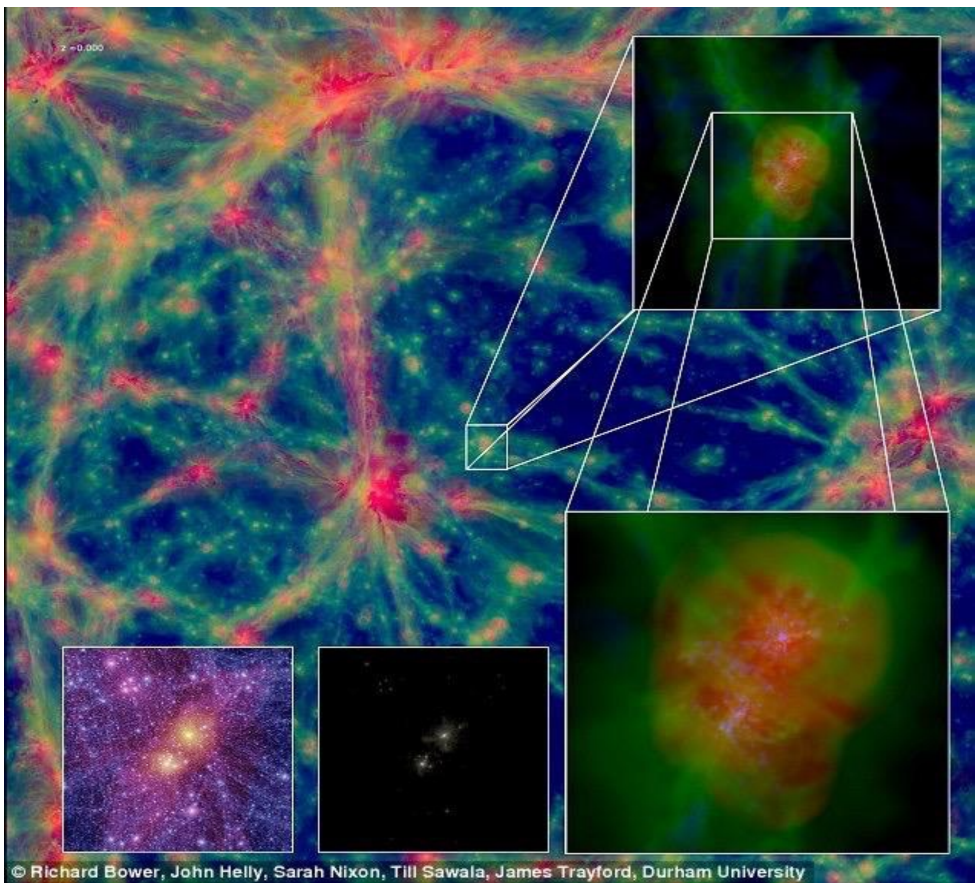
2. Setting constraints on galaxy evolution scenarios by simulating real strong lenses from model variations of EAGLE.

3. To predict future Lenses from KiDs, Euclid and SKA.

Evolution and Assembly of GaLaxies and their Environments (EAGLE)



z = 12.9 | z = 10.4 | z = 5.0 | z = 3.8 | z = 2.6 | z = 0.0



100x100x20 cMpc slice of Ref-L100N1504 at z = 0.0

EAGLE: A suit of hydrodynamical simulations

ΛCDM universe (13 Formation scenarios)

Cosmological parameters from Planck 2013

Simulation box sizes : 100, 50, 25, 12, cMpc

Maximum # particles : 1504^3

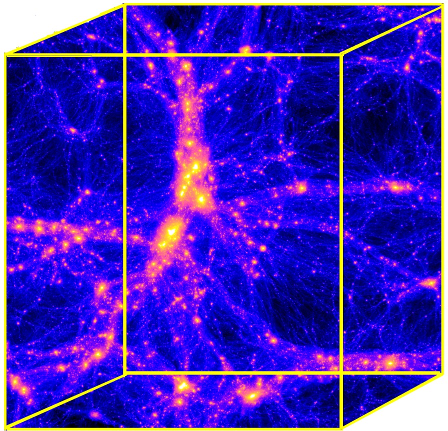
Matter content : Gas, Star, Dark Matter, BHs

Maximum mass resol. : $2.26*10^5$ $M_{sun}(m_g)$
$1.21*10^6$ M_{sun} (m_{dm})

Major improvement:
Feedback from Stars & AGN

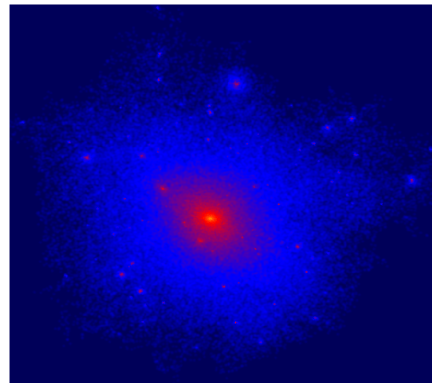
Image courtesy: Durham University & Schaye et al.

The Pipeline : Simulations & Modelling of Mock Strong Lenses



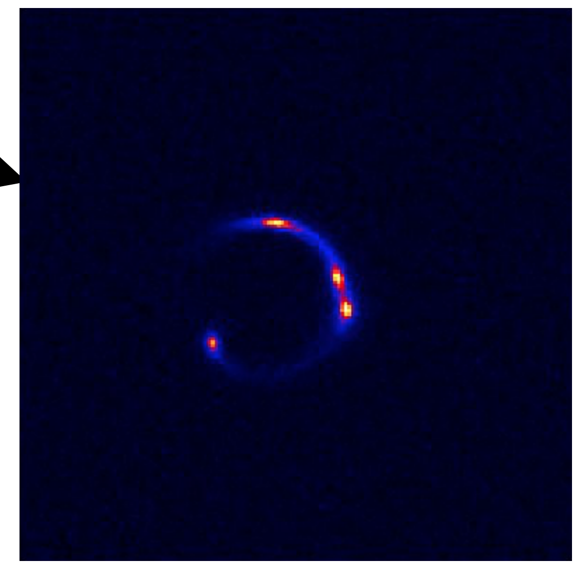
EAGLE

Subfind / FOF



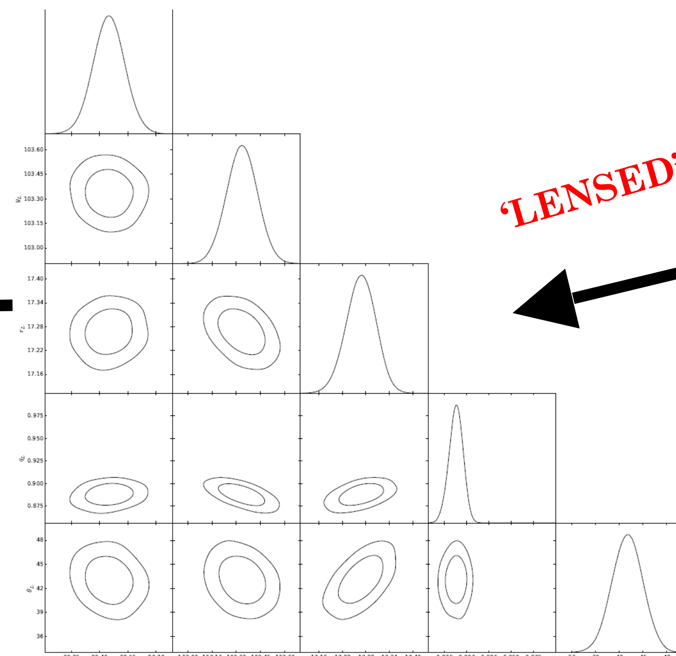
Lensing Galaxy

'GLAMER'[1]



Lens

'LENSED'[2]



Modelled Parameters of Lens

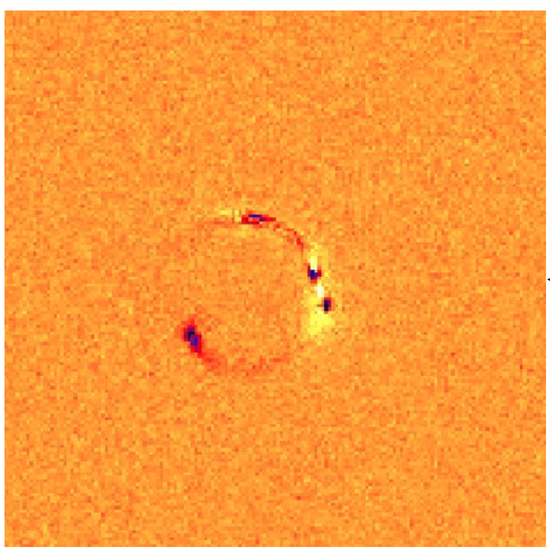
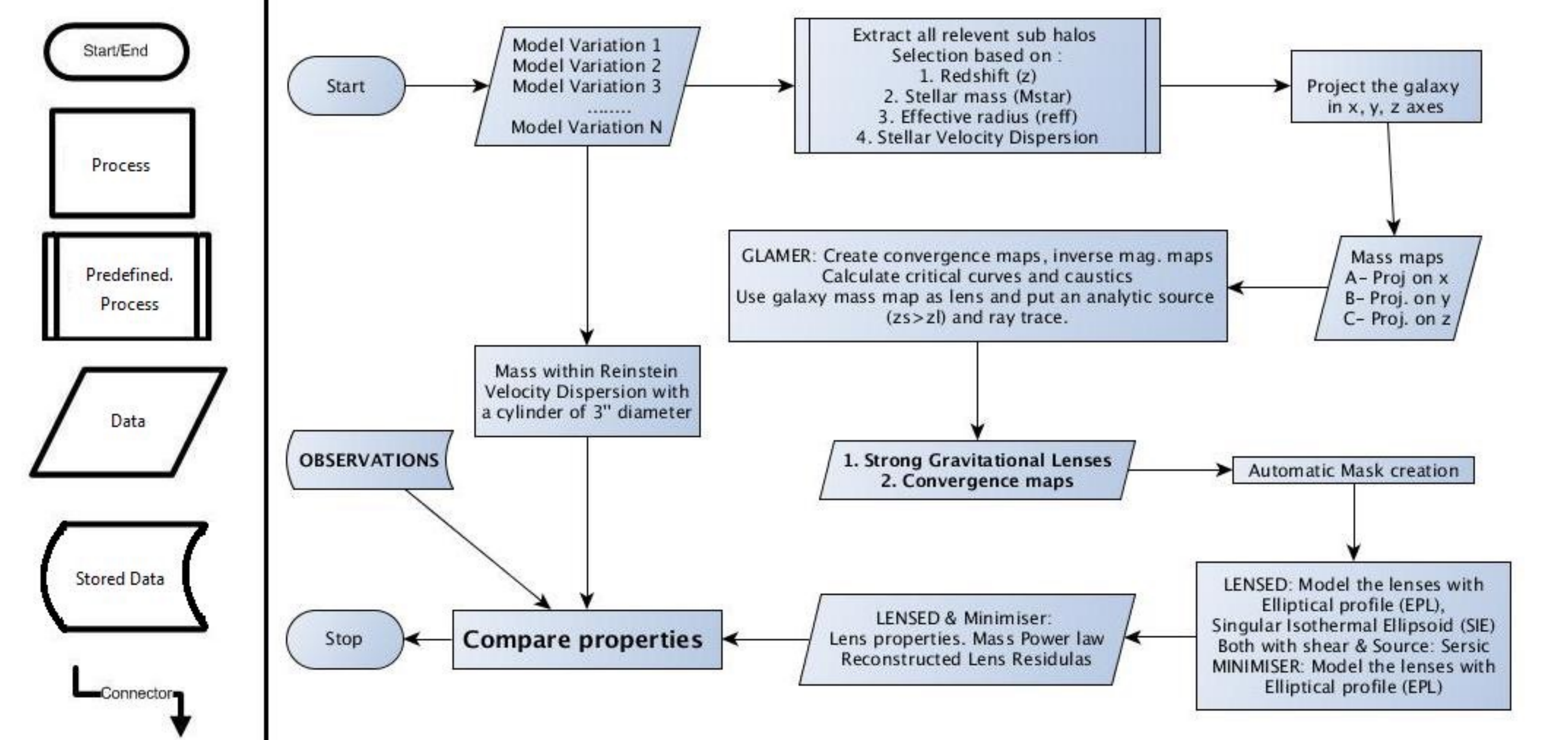


Image Residual

(Mock - Reconstructed)

1 http://glenco.github.io/glamer/

2 http://glenco.github.io/lensed/



Flow Chart Diagram of the Pipeline (SEAGLE I : Mukherjee+ 17 in prep)

LENSED (Tessore+ 2016)

- performs forward parametric modelling of strong lenses
- necessary calculations on a modern graphics processing unit (GPU)
- applied to subsample of the SLACS lenses

GLAMER (Metcalf+14, Petkova+ 14)

- incorporates adaptive mesh refinement
- read in mass maps and use them as lens planes.
- lensing quantities are calculated by FFT and interpolated from the grid

Which Early Type Galaxies to select ?

On what properties the selection should be made to reduce bias between real & simulated lenses ?

We use **Stellar Mass**, **Stellar Vel. Disp.** and **Effective Radii** from observations and then focus on the DM halos they live in compared to those derived from lens modelling.

Which type of Sources to use ?

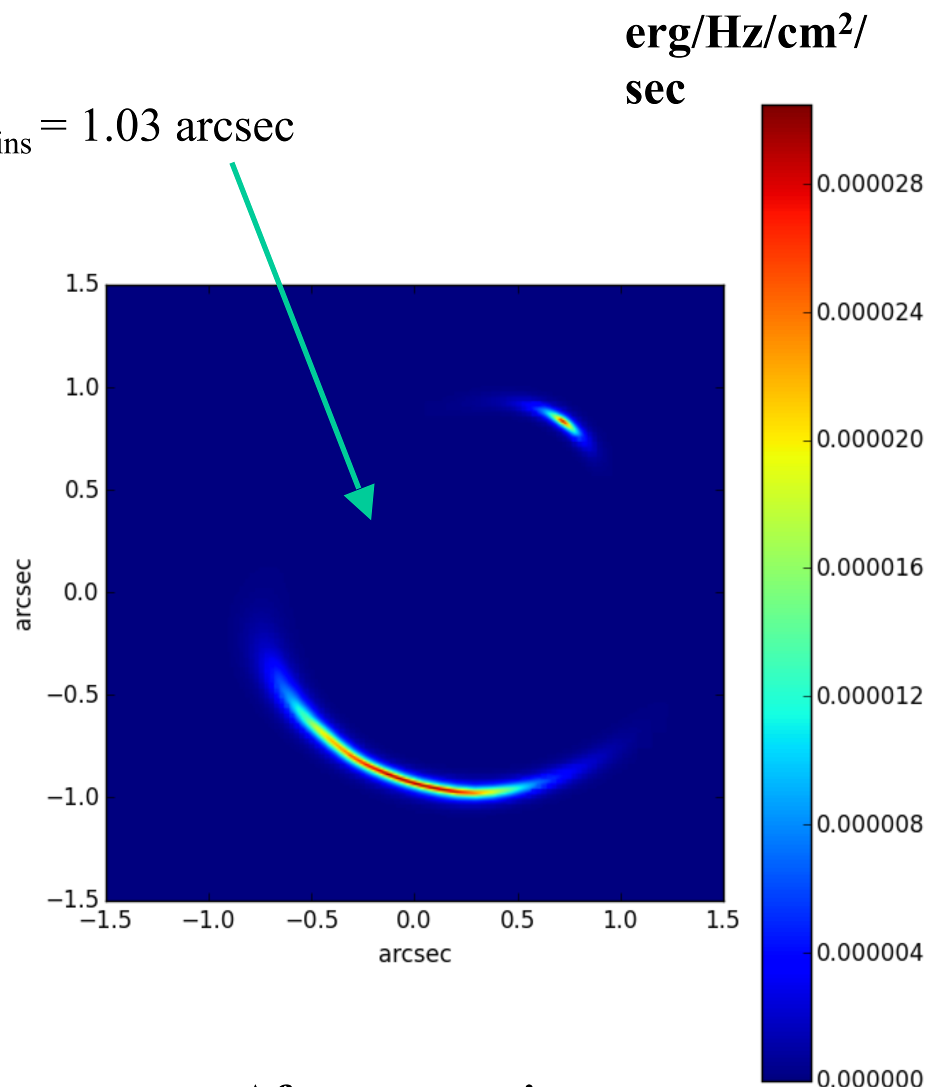
Which analytical sources best mimic Observed sources ?

We use **Sersic***, **Shapelets** and **Overzier** as sources.

Does the purpose and results from lensing analysis of galaxy not strongly dependent on the source type

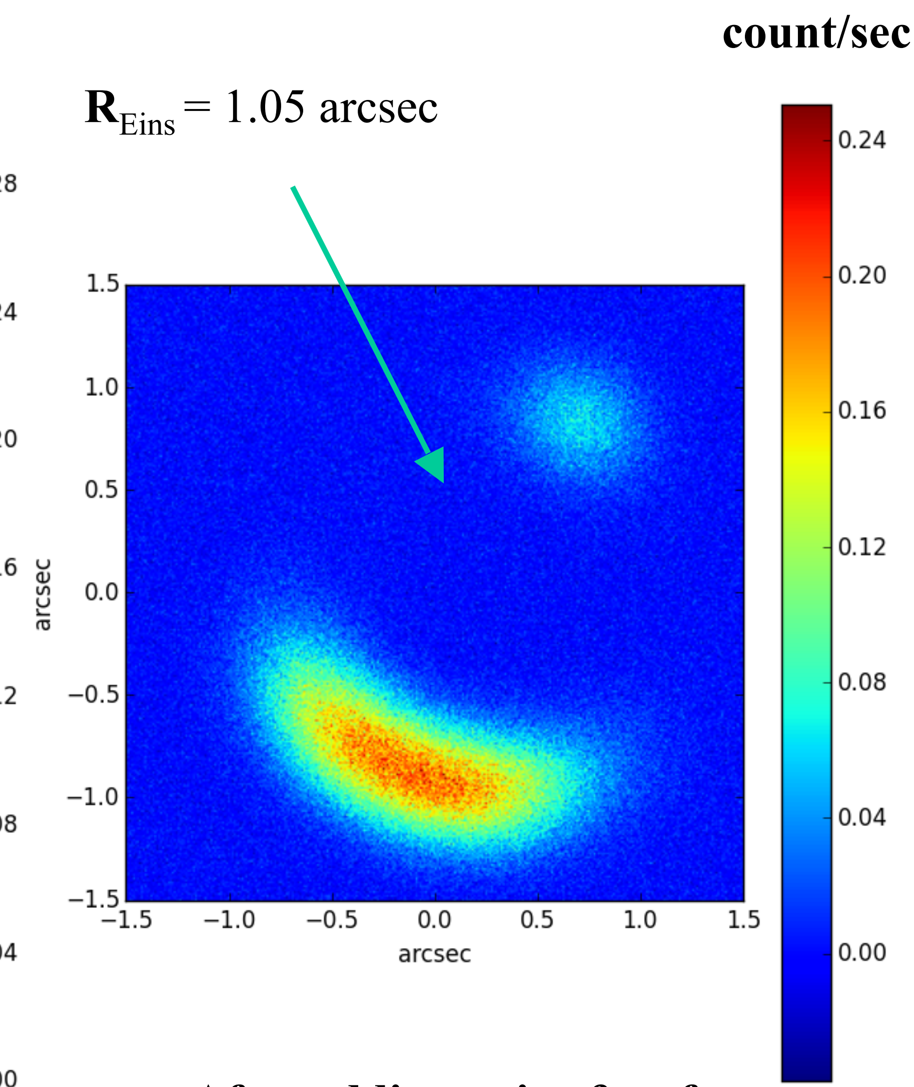
Do we get back reasonable quantities ?

R_{Eins} = 1.03 arcsec



After ray tracing

R_{Eins} = 1.05 arcsec



After adding noise & psf

$M_* = 4.8 \times 10^{10}\ M_{sun}$, $z_{source} = 1.0$, $z_{lens} = 0.366$, Source- Sersic

Some Strong Lenses from Sloan Lens ACS (SLACS) Survey

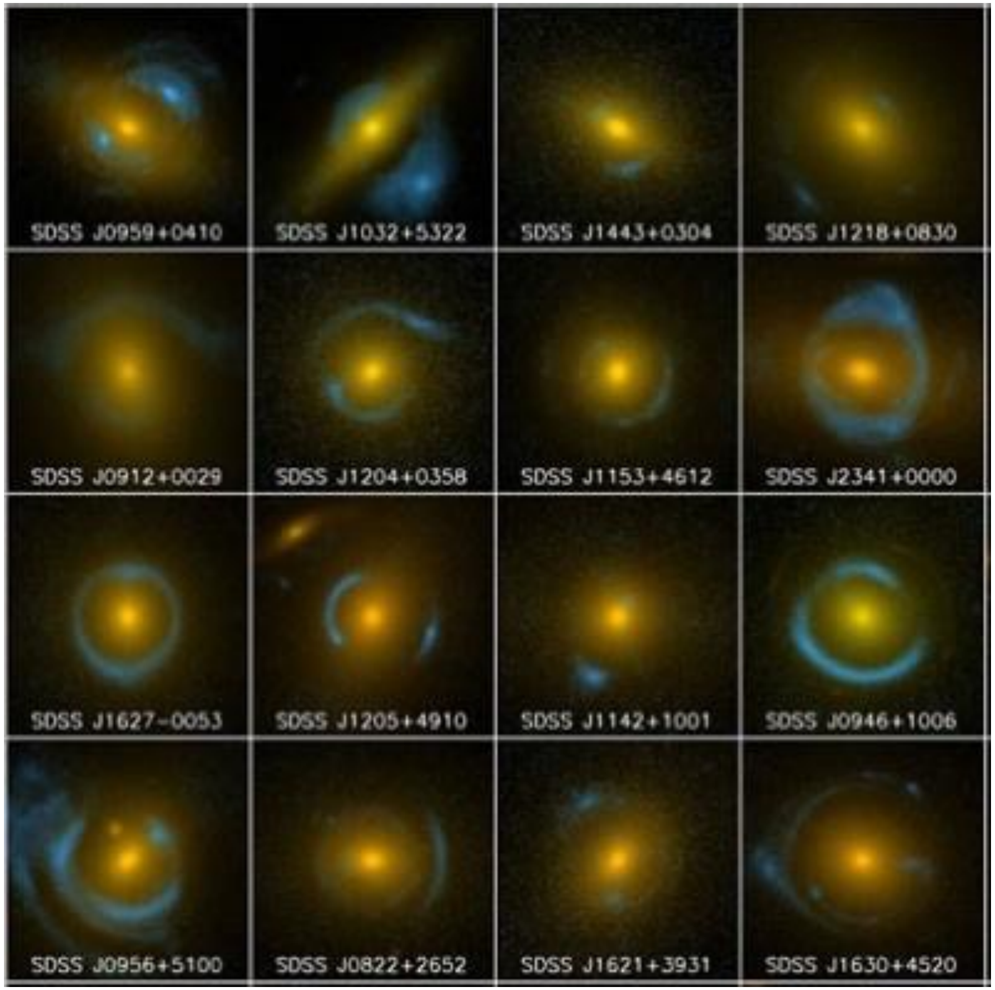
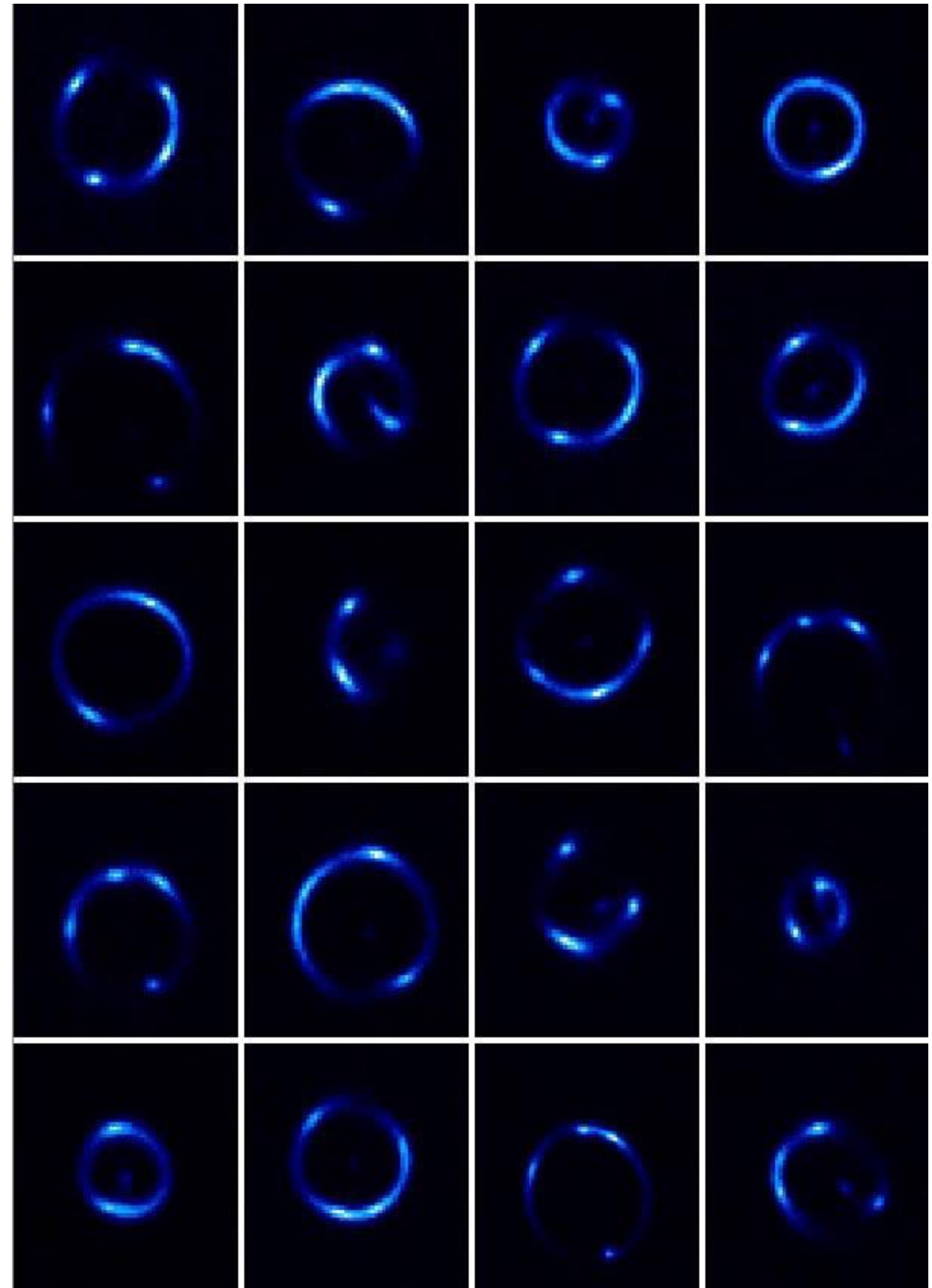


Image: A. Bolton (UH/IfA) for SLACS and NASA/ESA.

Comparison of observables such as Stellar Mass, Velocity dispersion, etc with SLACS Lenses, will put constraints on the galaxy formation scenarios of EAGLE

Some Strong lenses from EAGLE (REFERENCE) 50 cMpc, z =0.271



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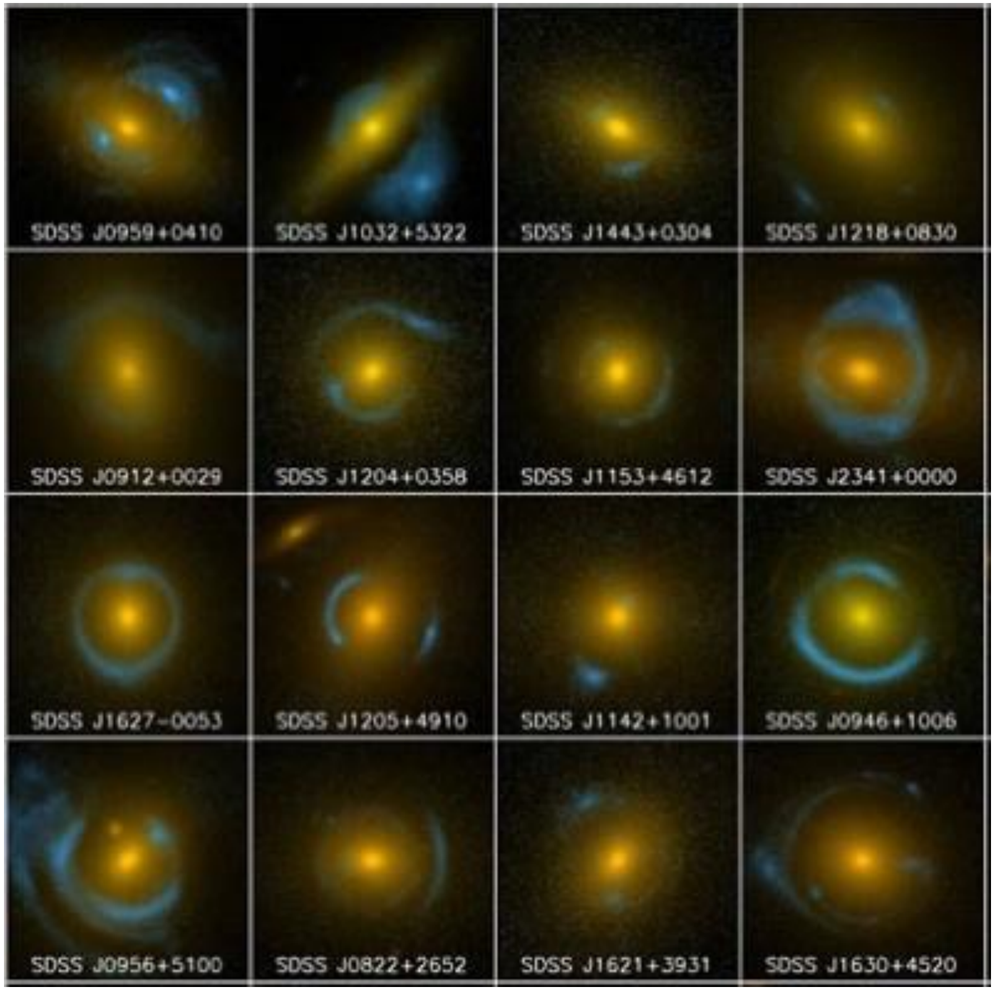

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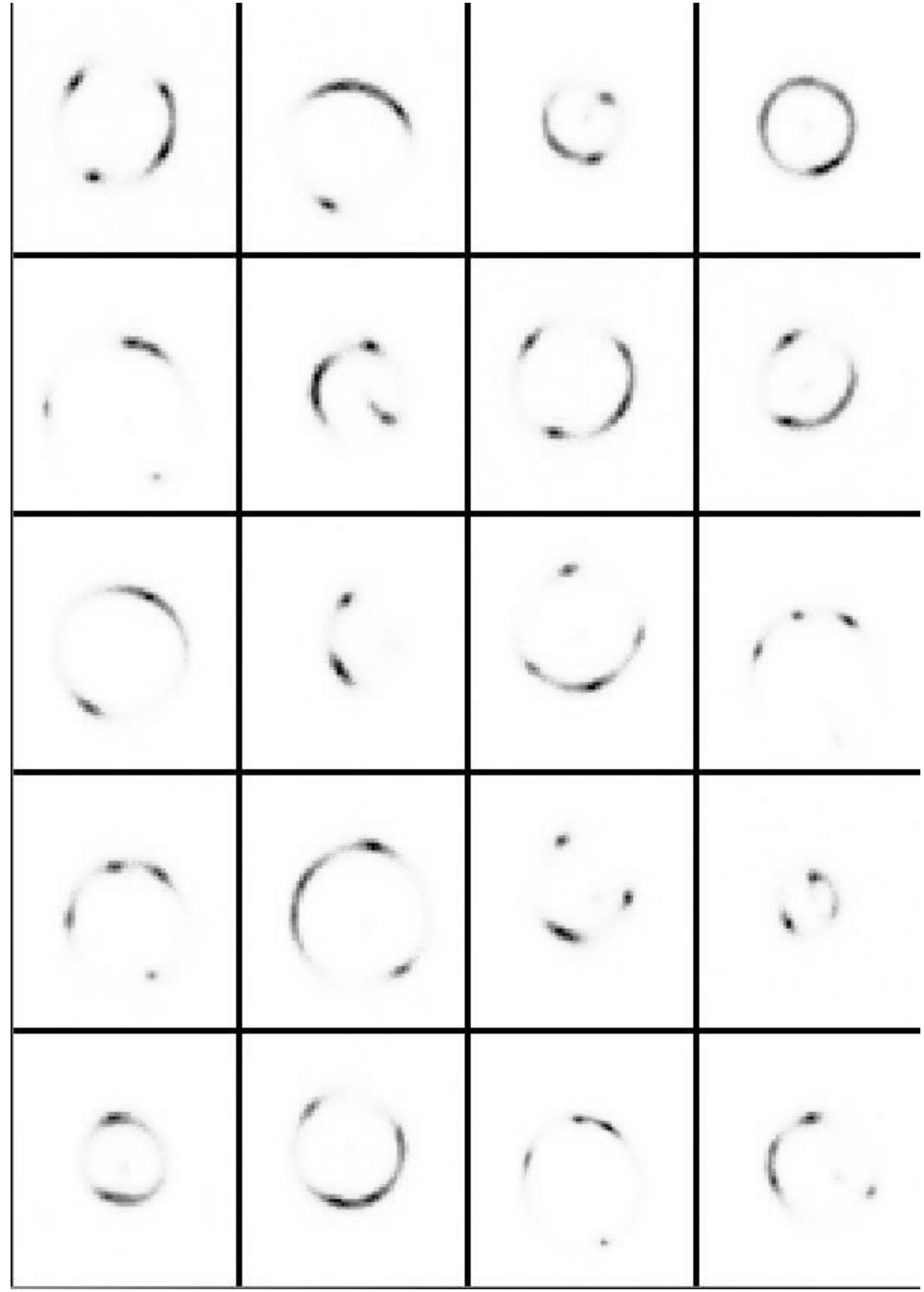

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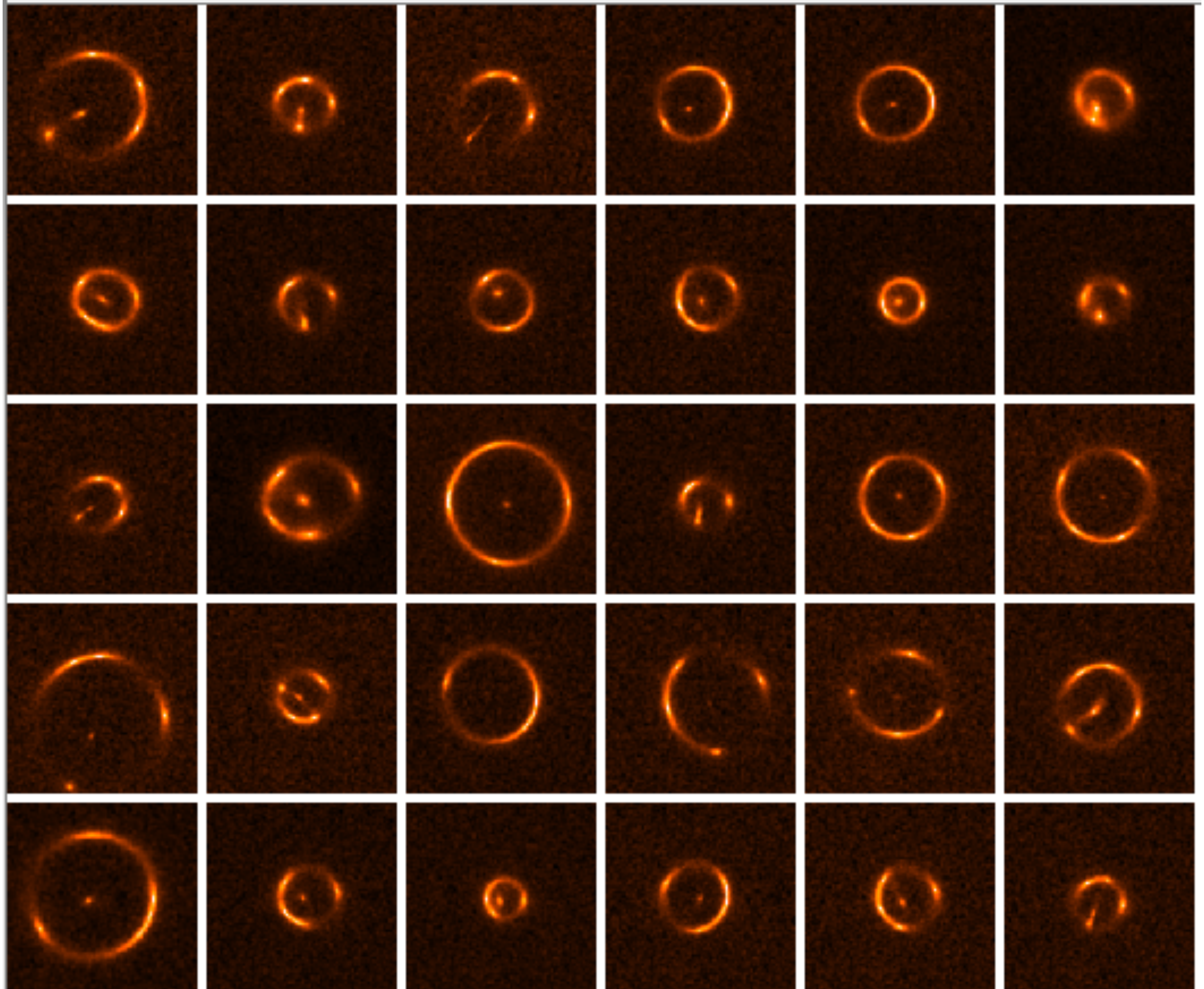
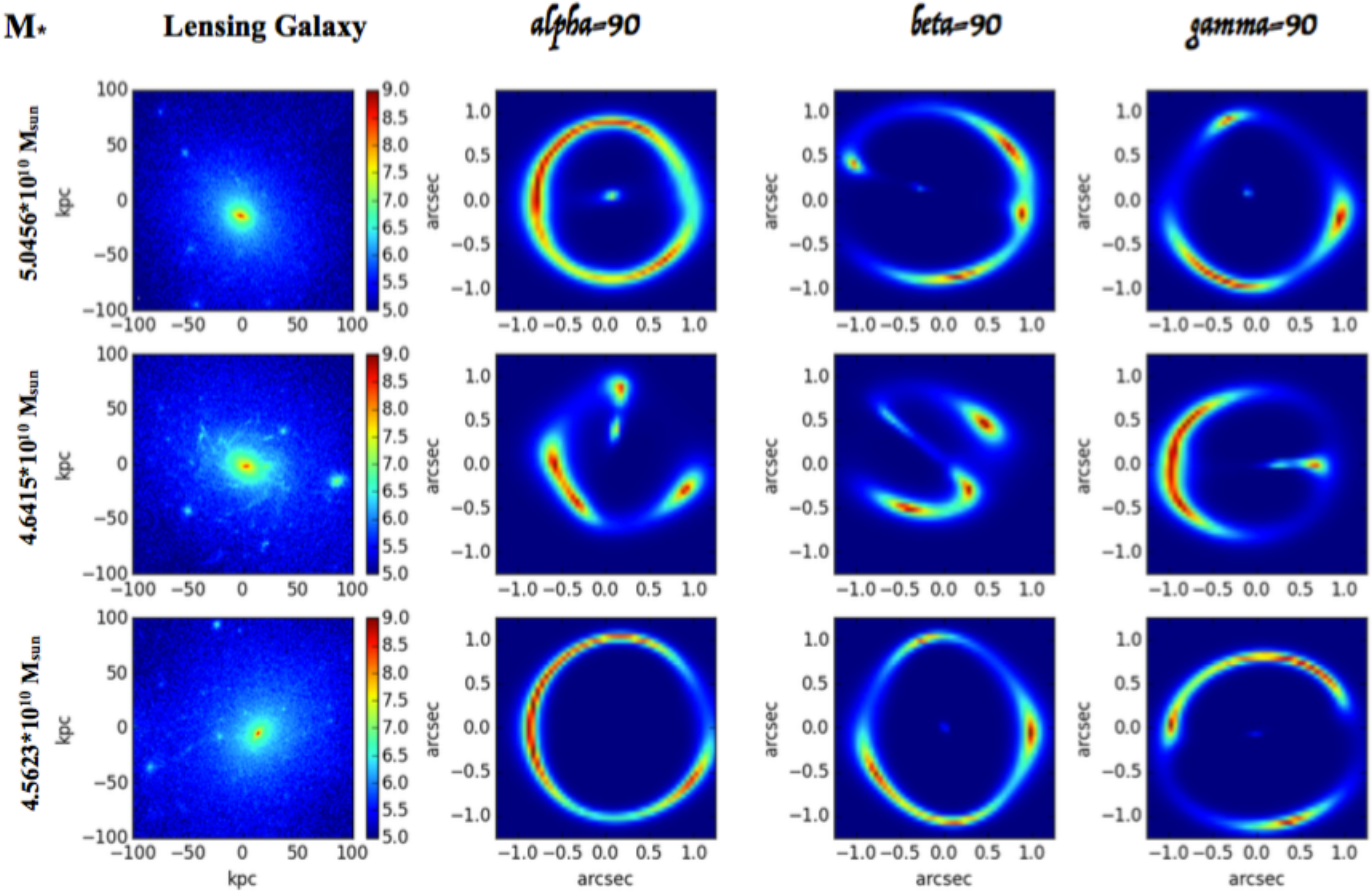


Some Strong lenses from EAGLE (FB Const) 50 cMpc, z =0.101

Mock Strong Lenses created from Projected Mass density maps. Source position close to optic axis within diamond caustics

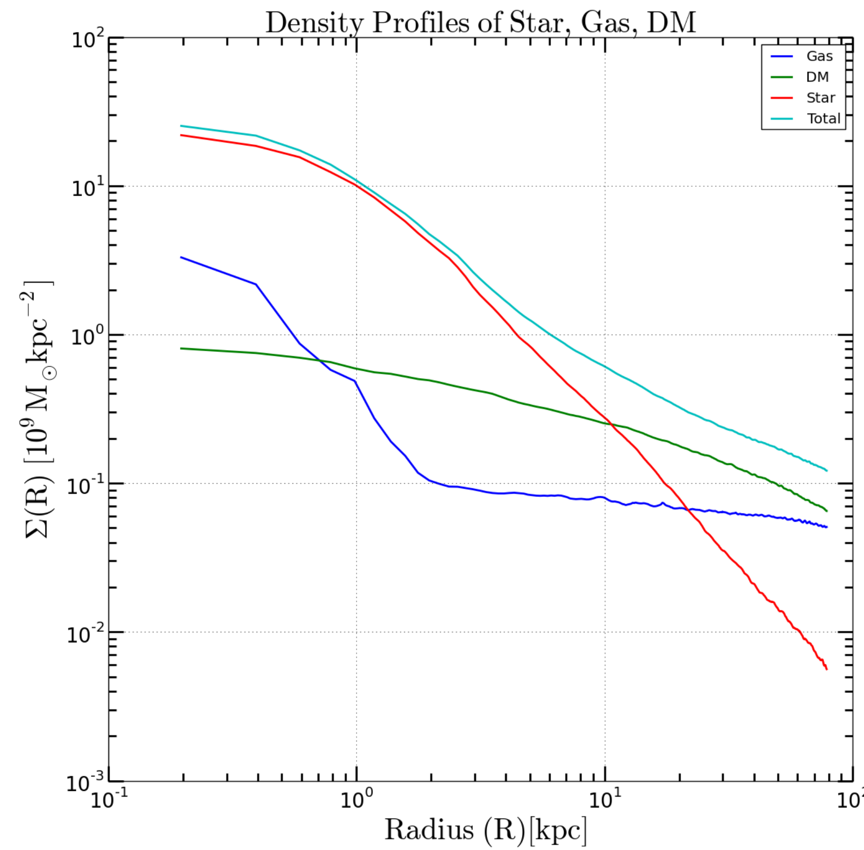


Source: Sersic, zlens = 0.271, zsource = 0.6, sim.box = 50cMpc (REF)

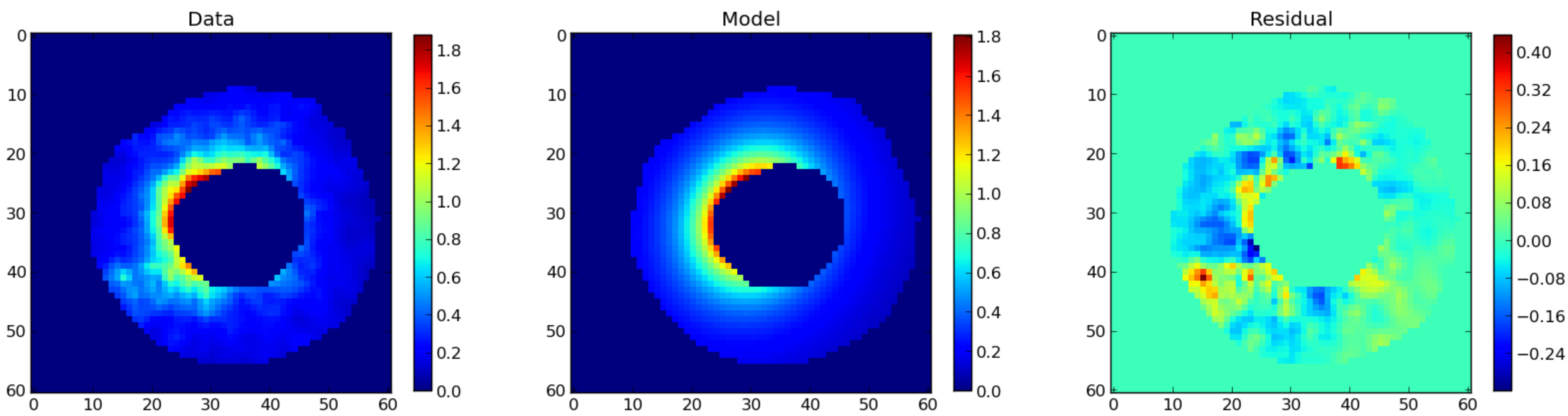
SCENARIOUS

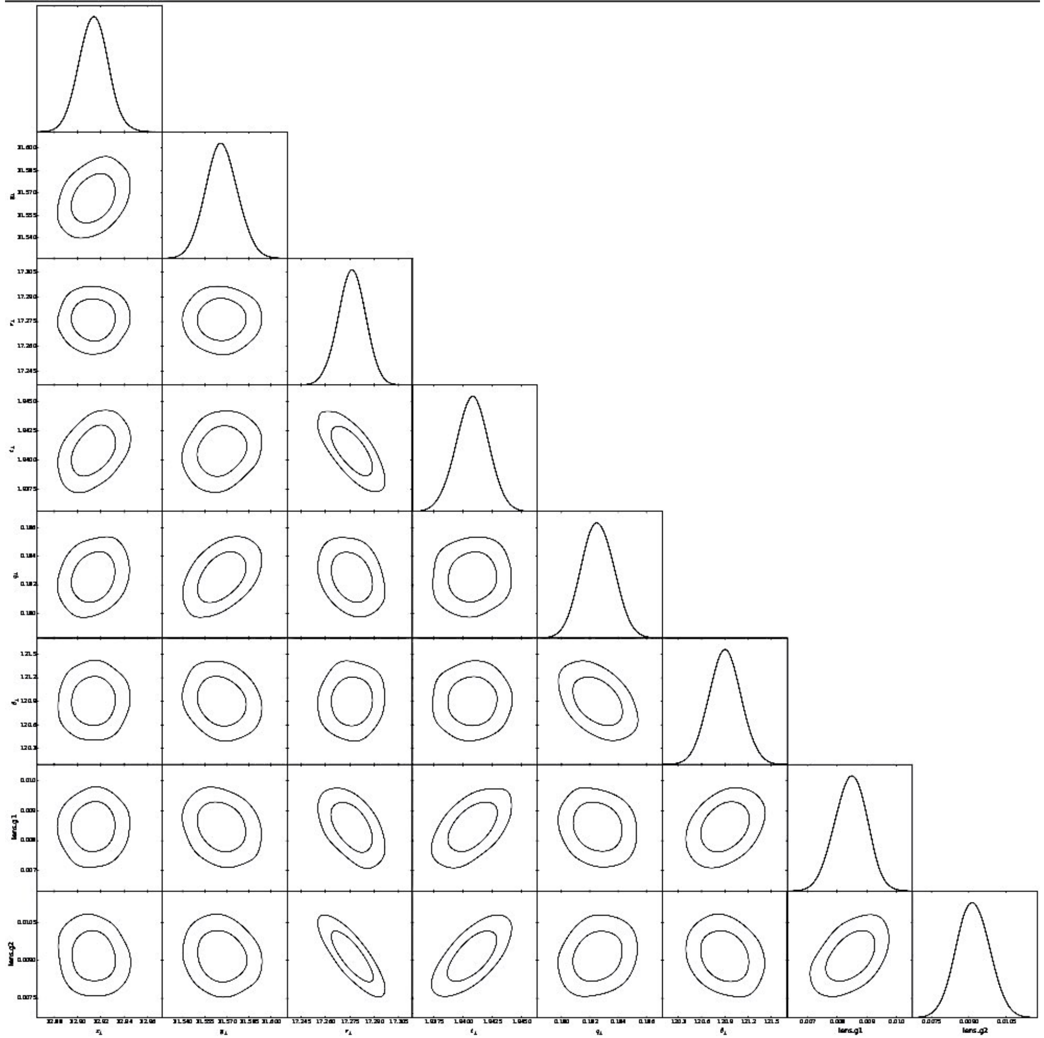
Identifier	Side length (cMpc)	N
Calibrated models		
FBconst	50	752
FBσ	50	752
FBZ	50	752
Ref (FBZρ)	50	752
Ref variations		
eos1	25	376
eos5/3	25	376
FixedSfThresh	25	376
WeakFB	25	376
StrongFB	25	376
ViscLo	50	752
ViscHi	50	752
AGNdT8	50	752
AGNdT9	50	752

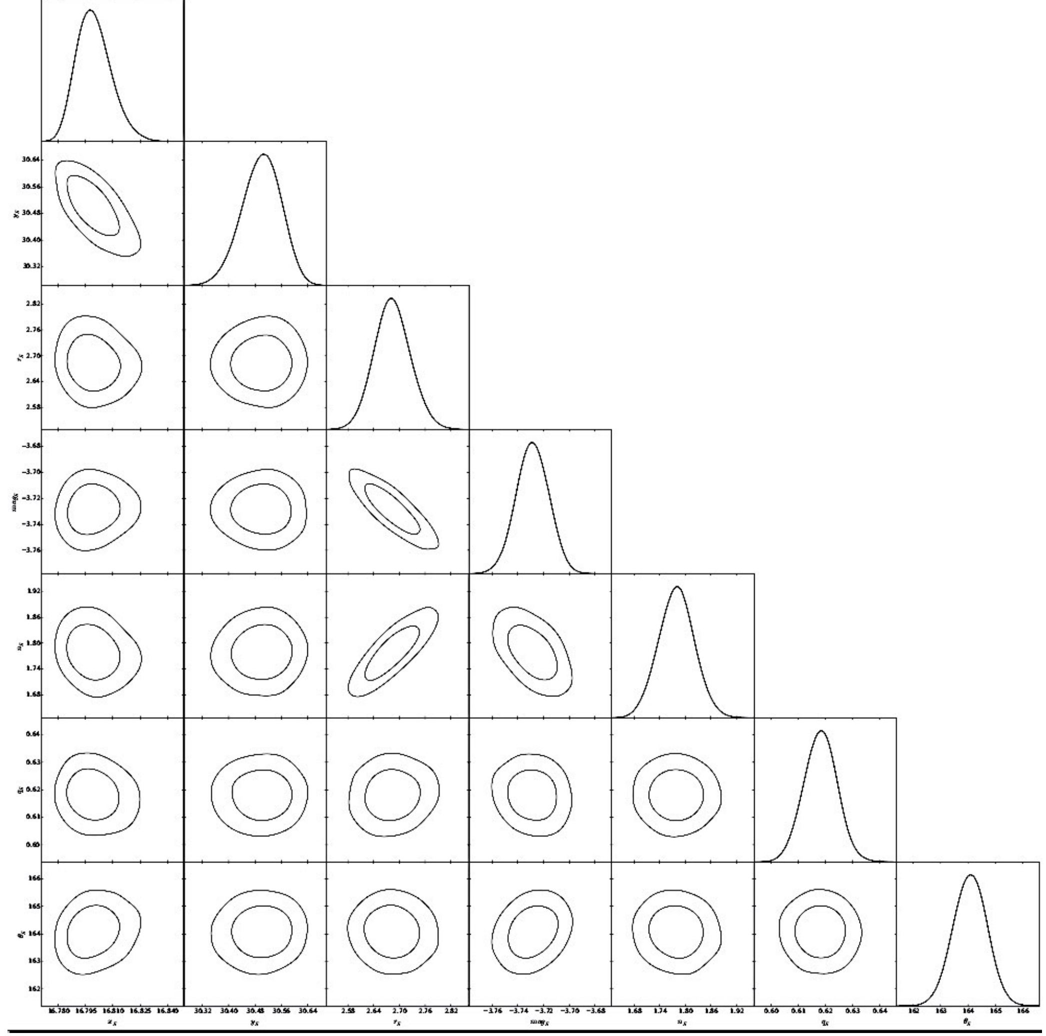
Surface Mass Density profiles of each of the lensing galaxies and their projections



Minimiser: Fitting Convergence maps with EPL model ==> Residuals







Lens Parameters

Lens Position (x_L,y_L)

Einstein radius (r_L)

Axis ratio (q_L)

Density Slope (t_L)*

Shear vector x (γ_1)

Shear vector y (γ_2)

Position Angle(θ_L)

LENSED

Tessore+ 2016

* EPL

Source Parameters

Source Position (x_s,y_s)

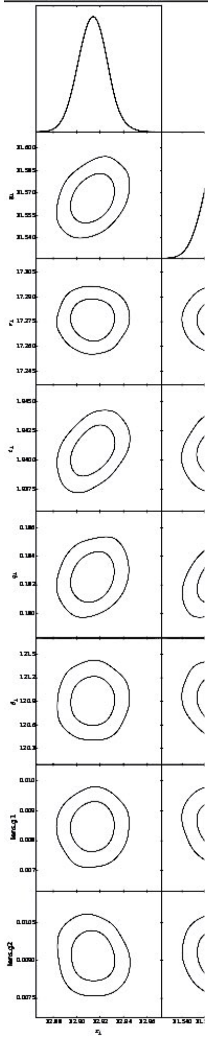
Effective radius (r_s)

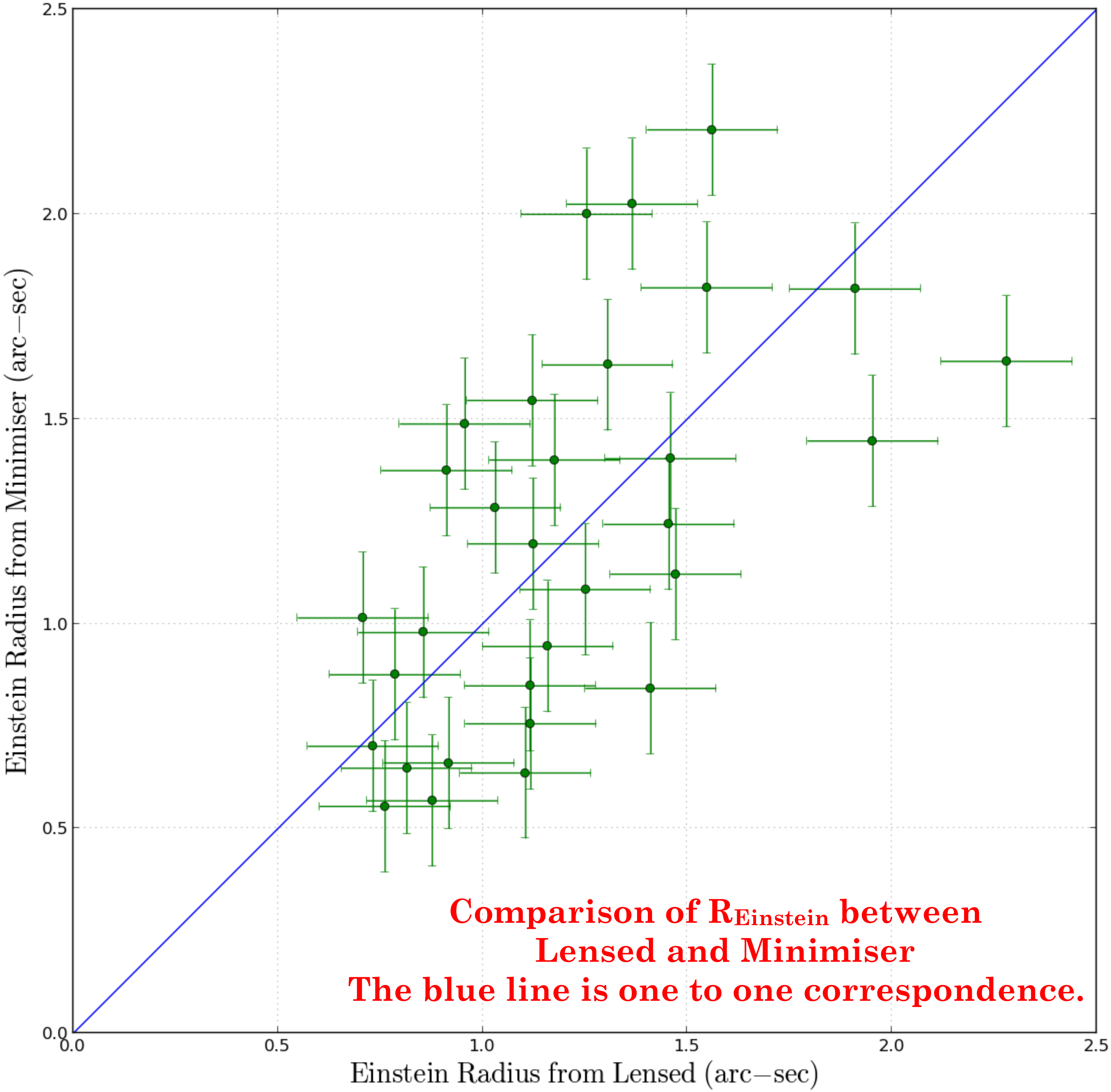
Axis ratio (q_s)

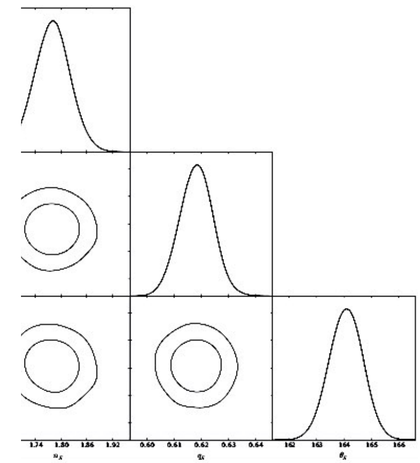
Source magnitude (mag_s)

Source index (n_s)

Position Angle(θ_s)







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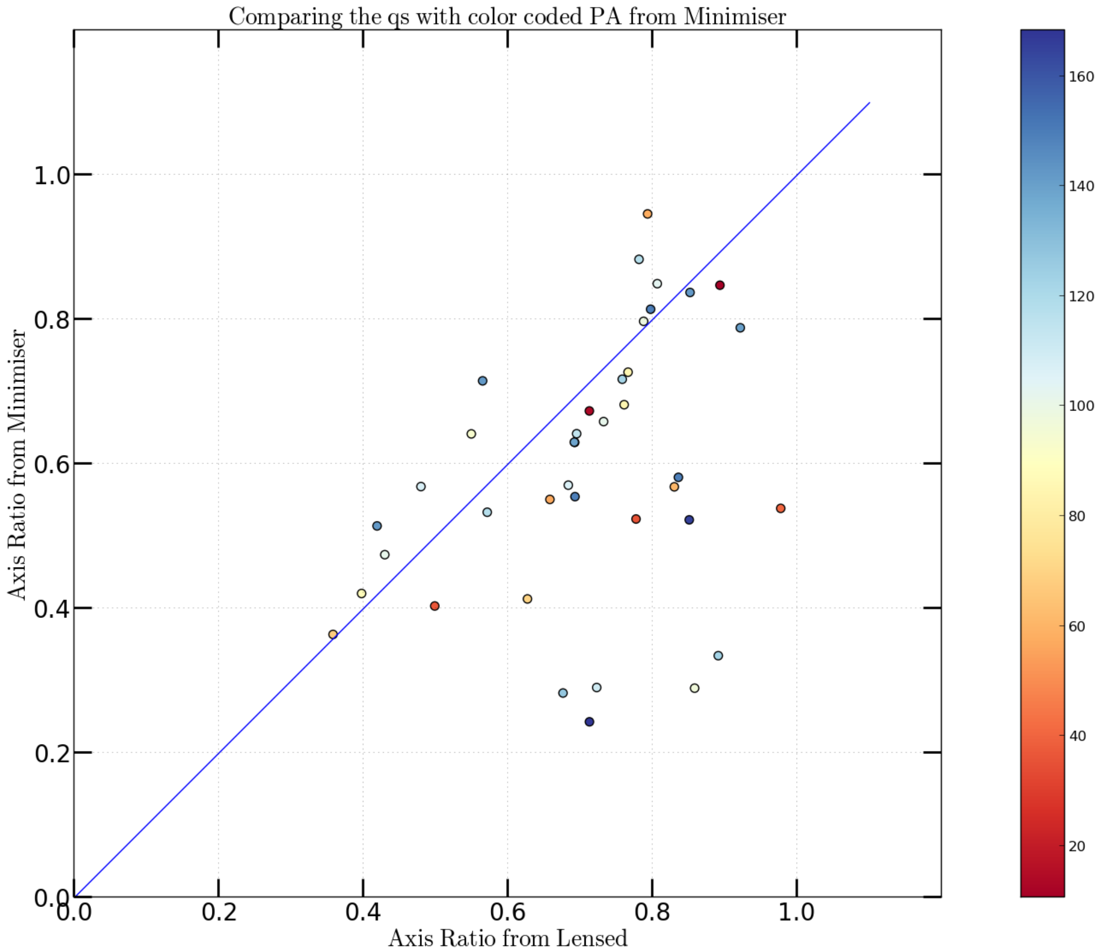
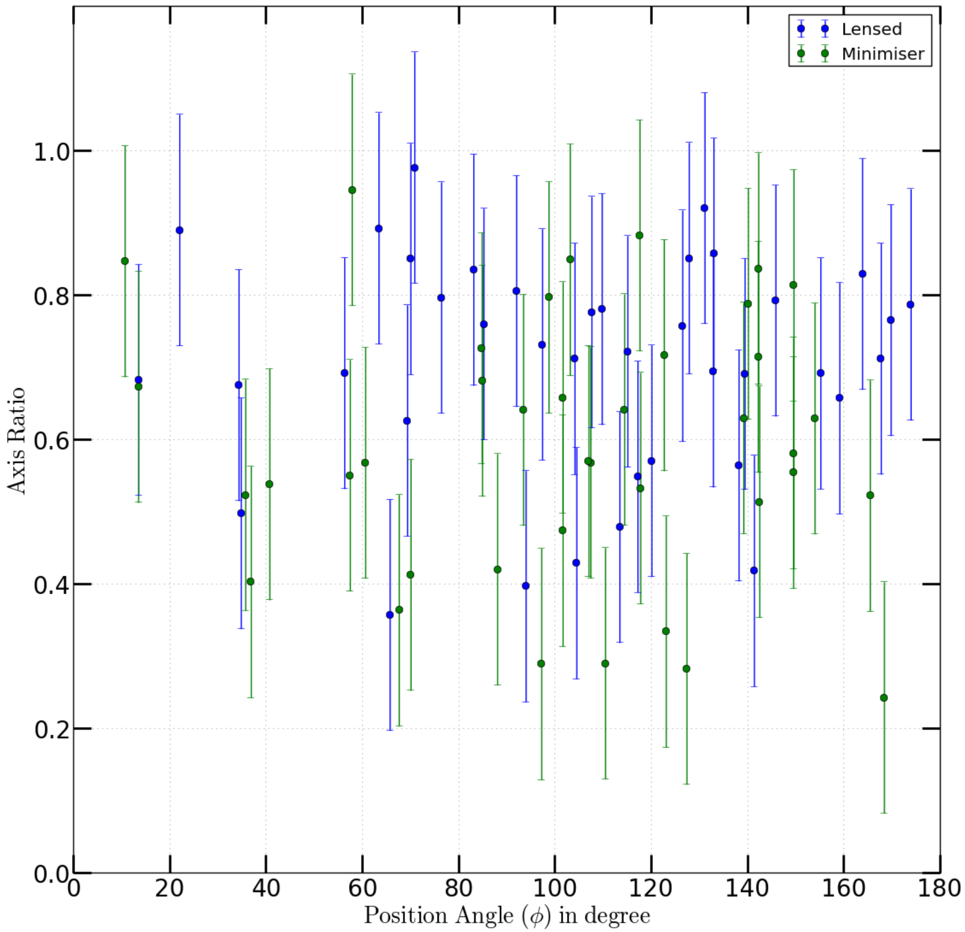
Position Angle(θ_L) SIE

eters
(x_s, y_s)
$s)$
(mag$_s$)

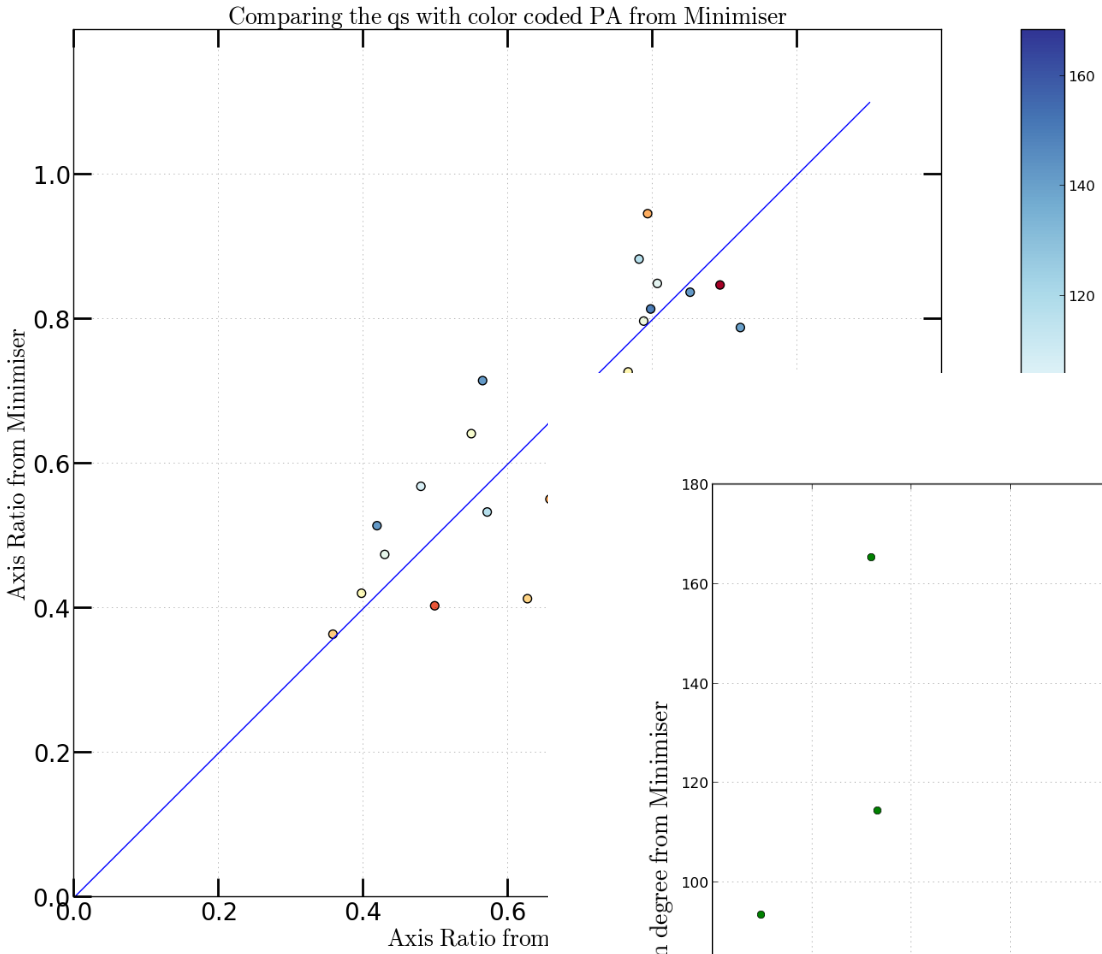


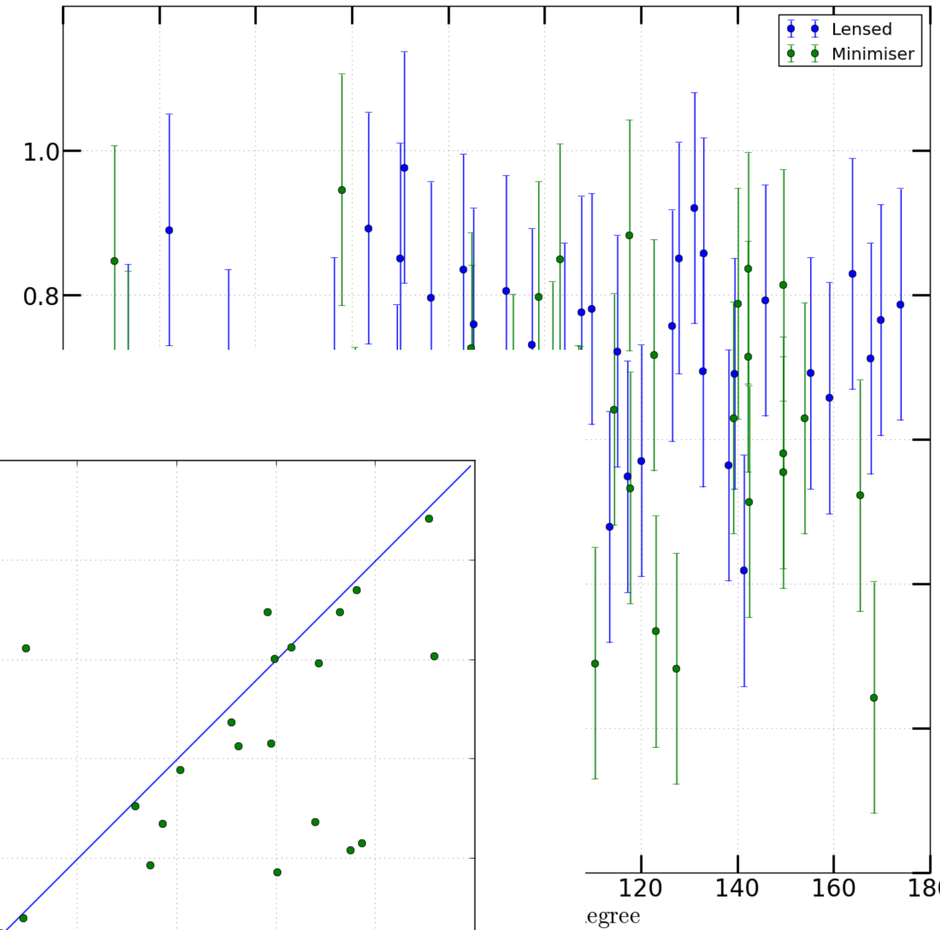
Axis Ratio Comparison

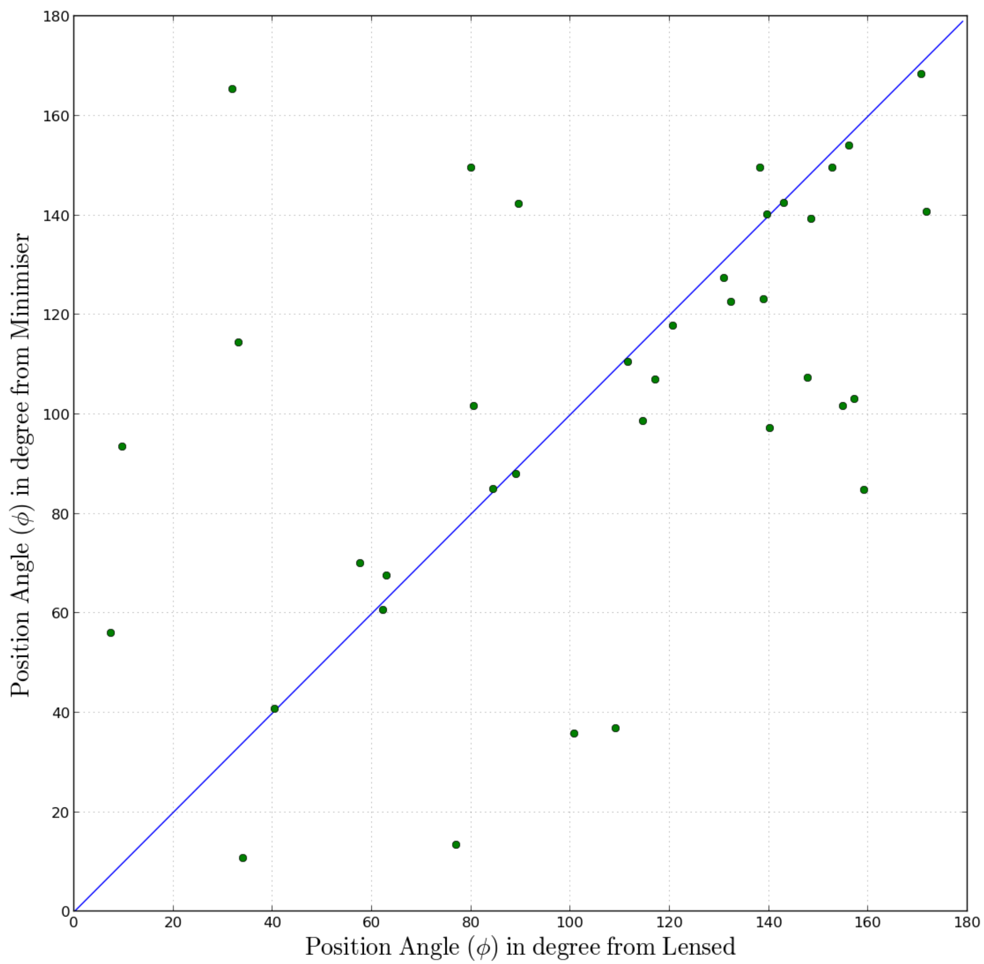


Axis Ratio vs PA comparison

SEAGLE II: *Mukherjee+ 17 in prep.*







Axis Ratio Co

comparison

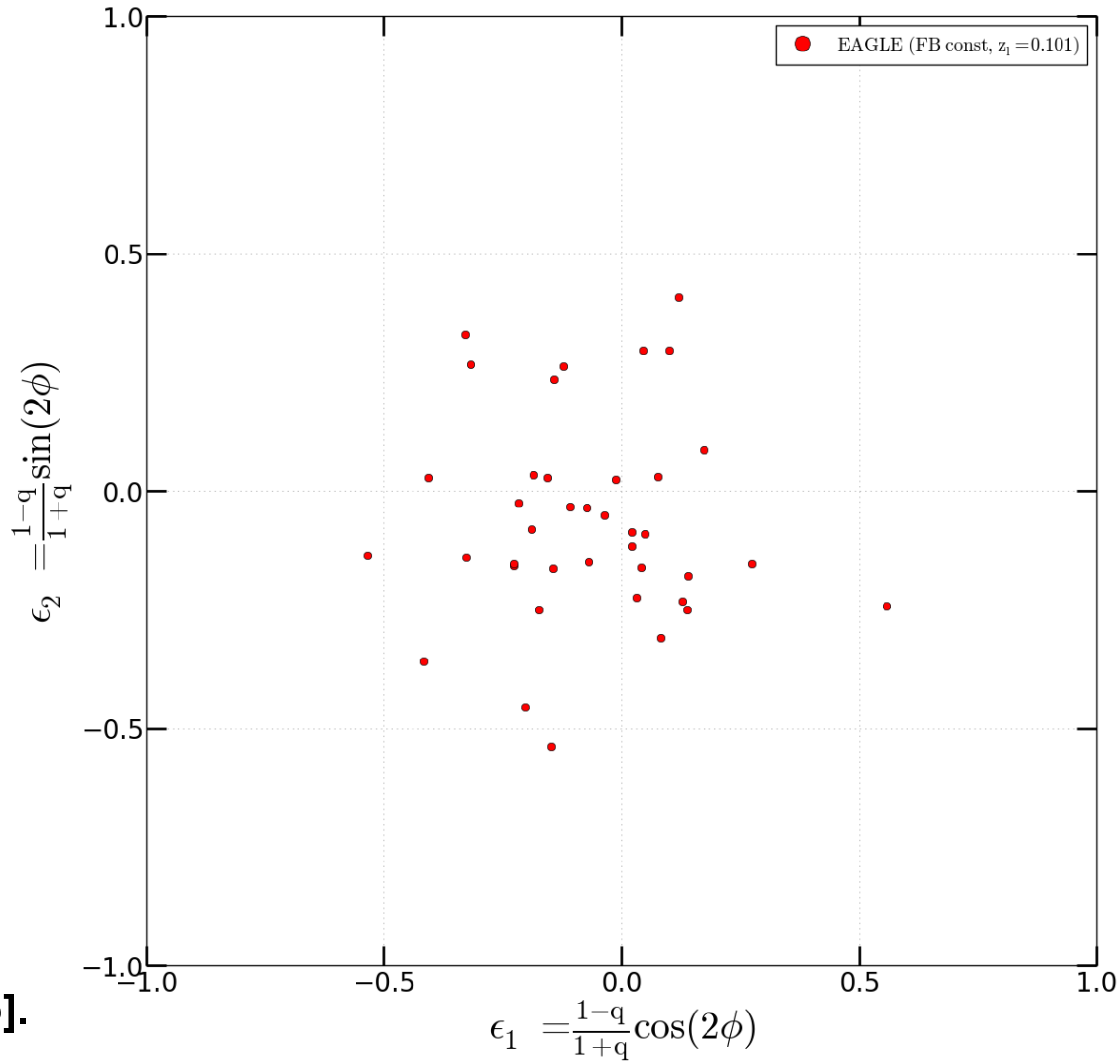
SEAGLE II: *Mukherjee+ 17 in prep*

‘Conspiracy’ between axis ratio (q) and position angle (Φ)

The PA near 170deg could also be -10deg (the ambiguity of +-180 degree due to the symmetry of the lens)

Now if the lens is round, or with some shear, an ambiguity of +-90 degrees is possible.

e.g., the kappa could be slightly prolate and in lensing its slightly oblate due to a change in ellipticity with radius; this would lead to a +-90 degree flip in PA.



The complex number:

$$\epsilon = (1-q)/(1+q) \exp(-2 i PA)$$

or in vector notation:

$$[\epsilon_1, \epsilon_2] = (1-q)/(1+q) [\mathrm{Cos}(2 PA), \mathrm{Sin}(2 PA)].$$

ϵ - space: 2D space where very round lenses will have a small value of ϵ i.e., (q~1) and they will be close in this space regardless of the PA.
For q << 1 abs(ϵ) will get larger and the PA should be more in agreement.

So in this complex space the agreement depends on the distance in a combined space of ‘q’ and ‘PA’.

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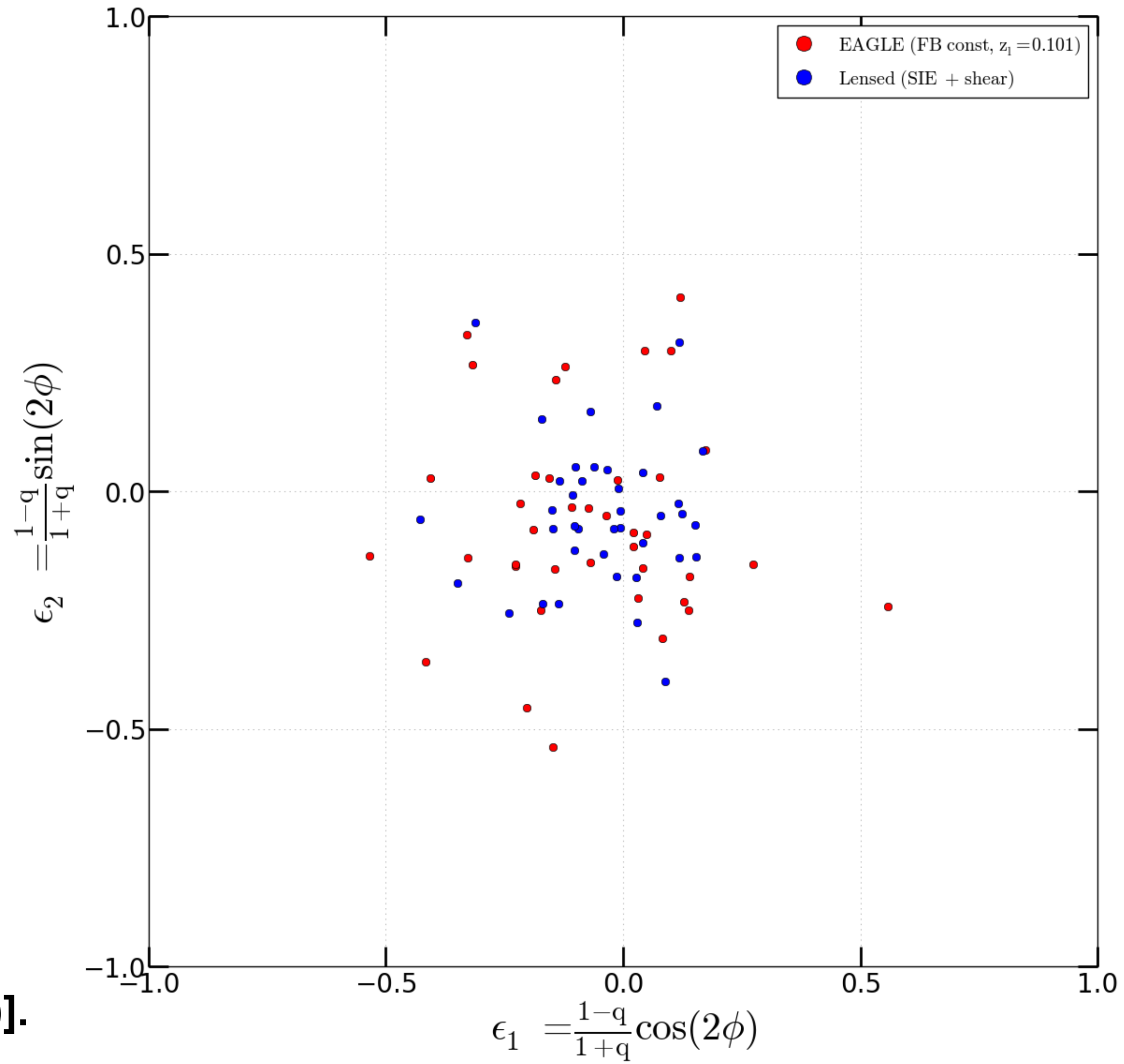

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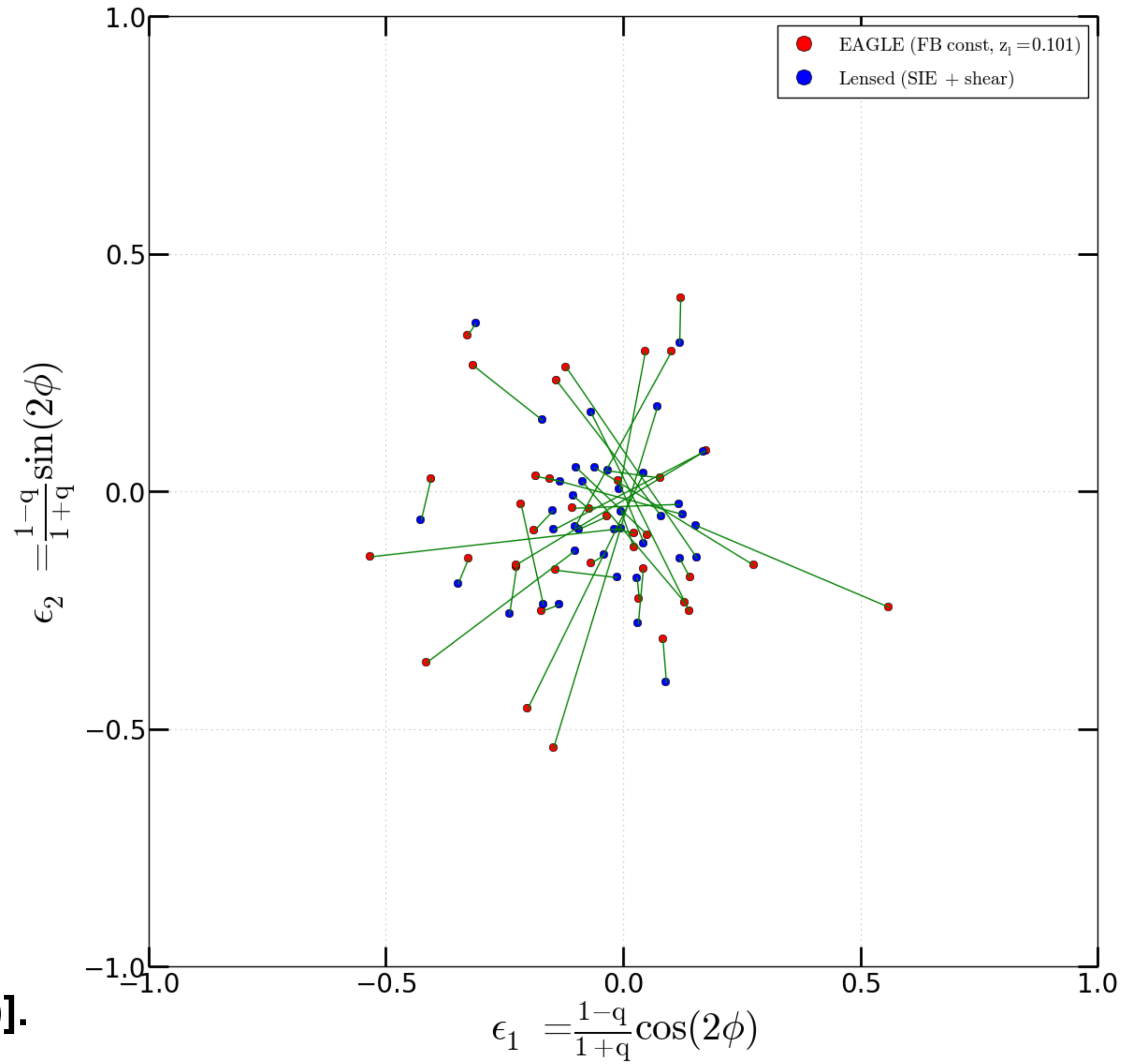

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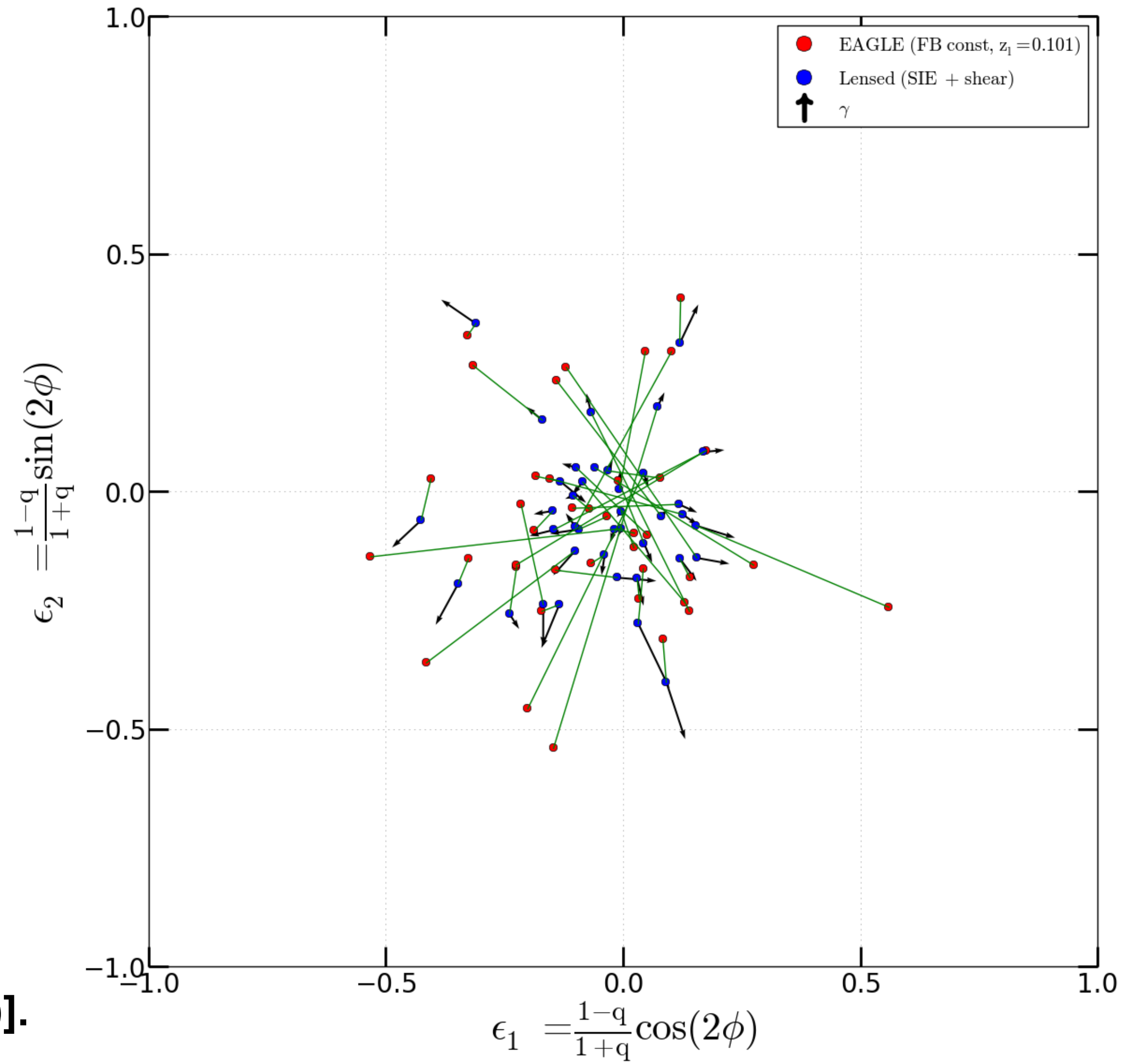

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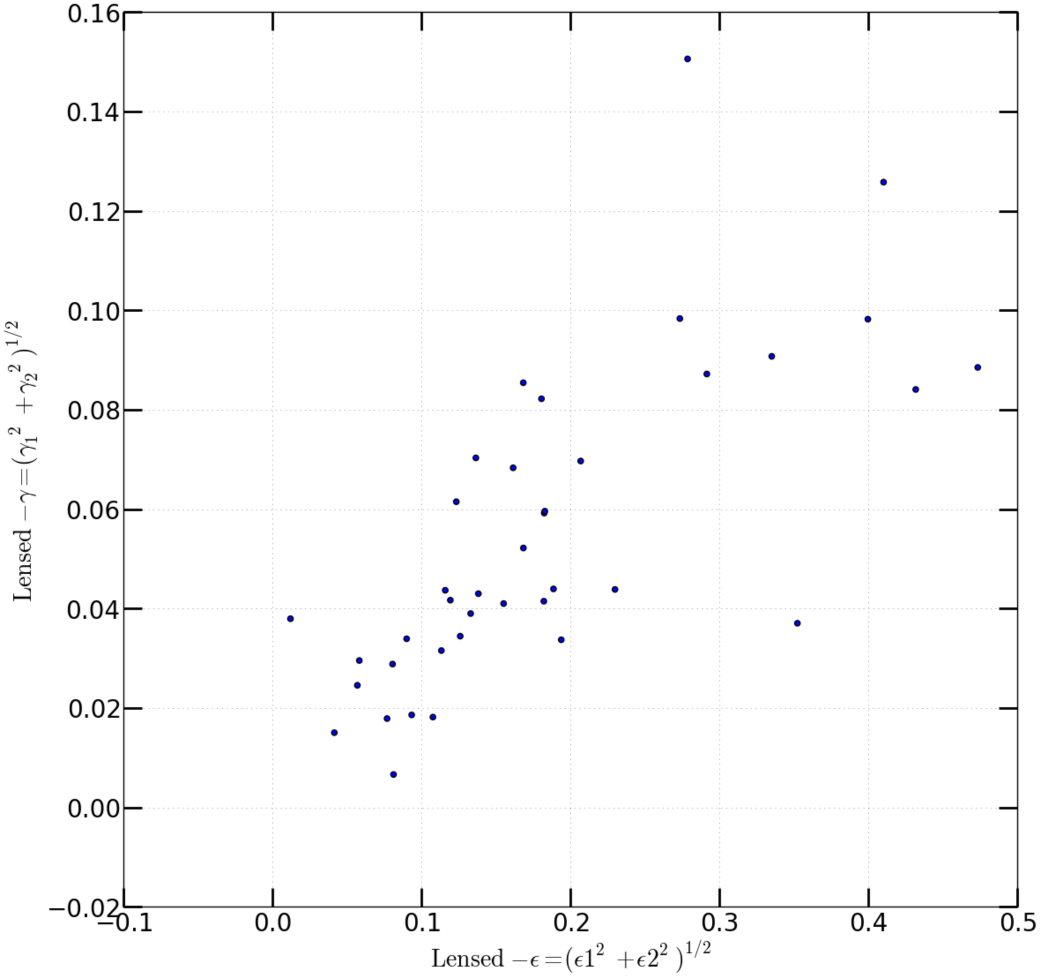
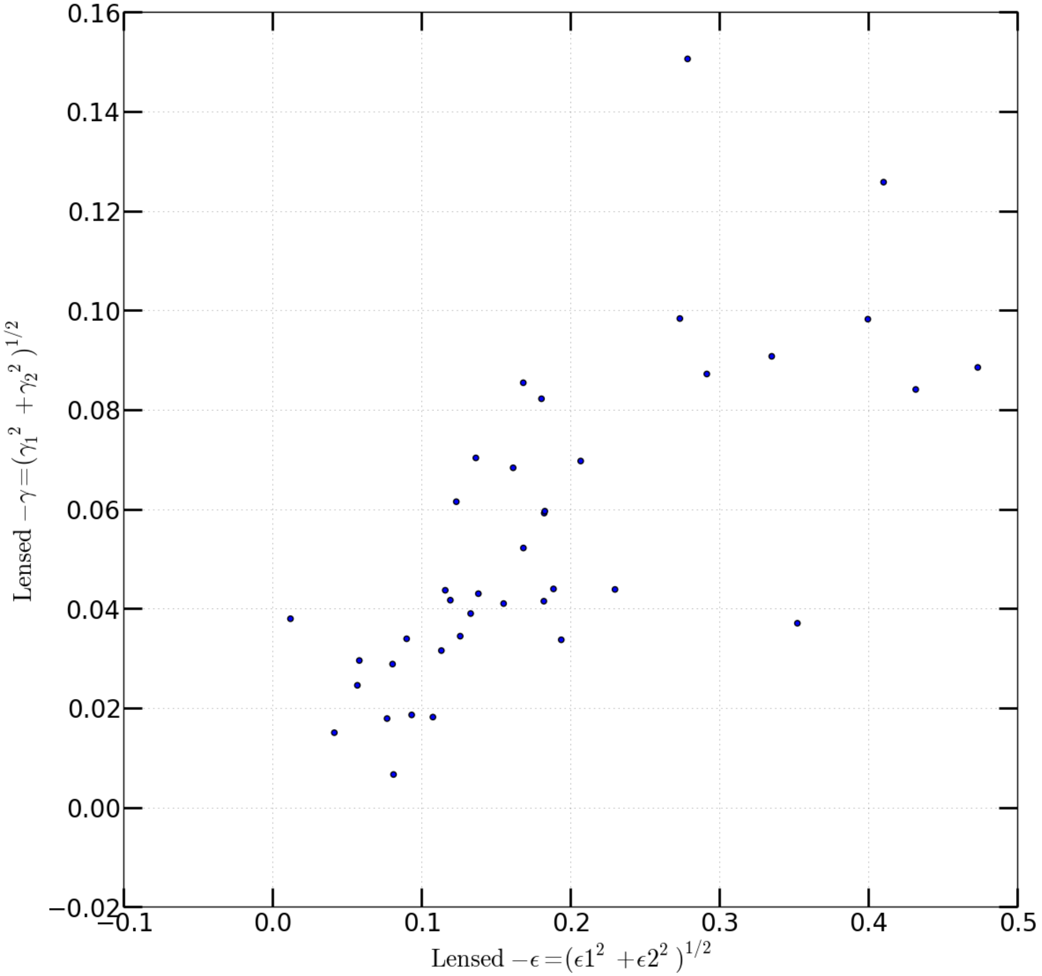
SEAGLE II: *Mukherjee+ 17 in prep.*



Comparison between
Shear and coupled q & Φ of Lensed

SEAGLE II: *Mukherjee+ 17 in prep.*



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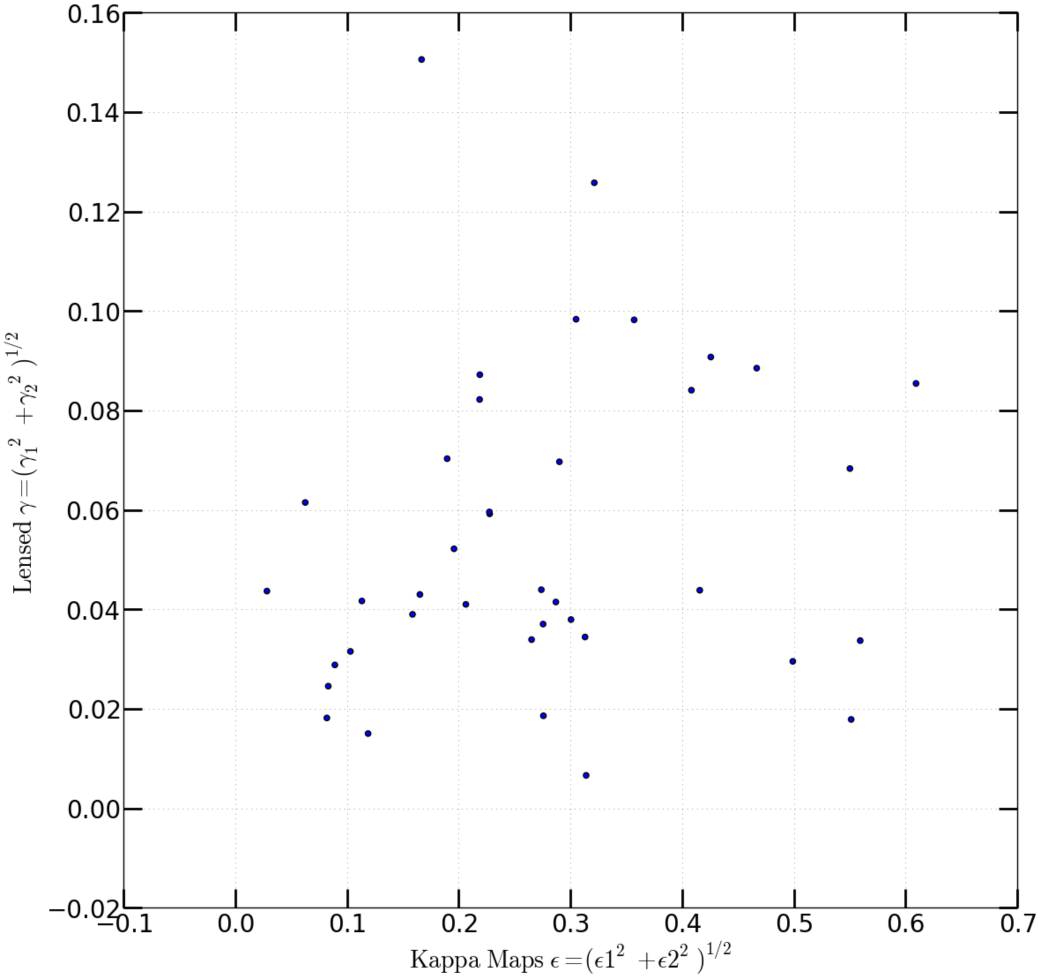
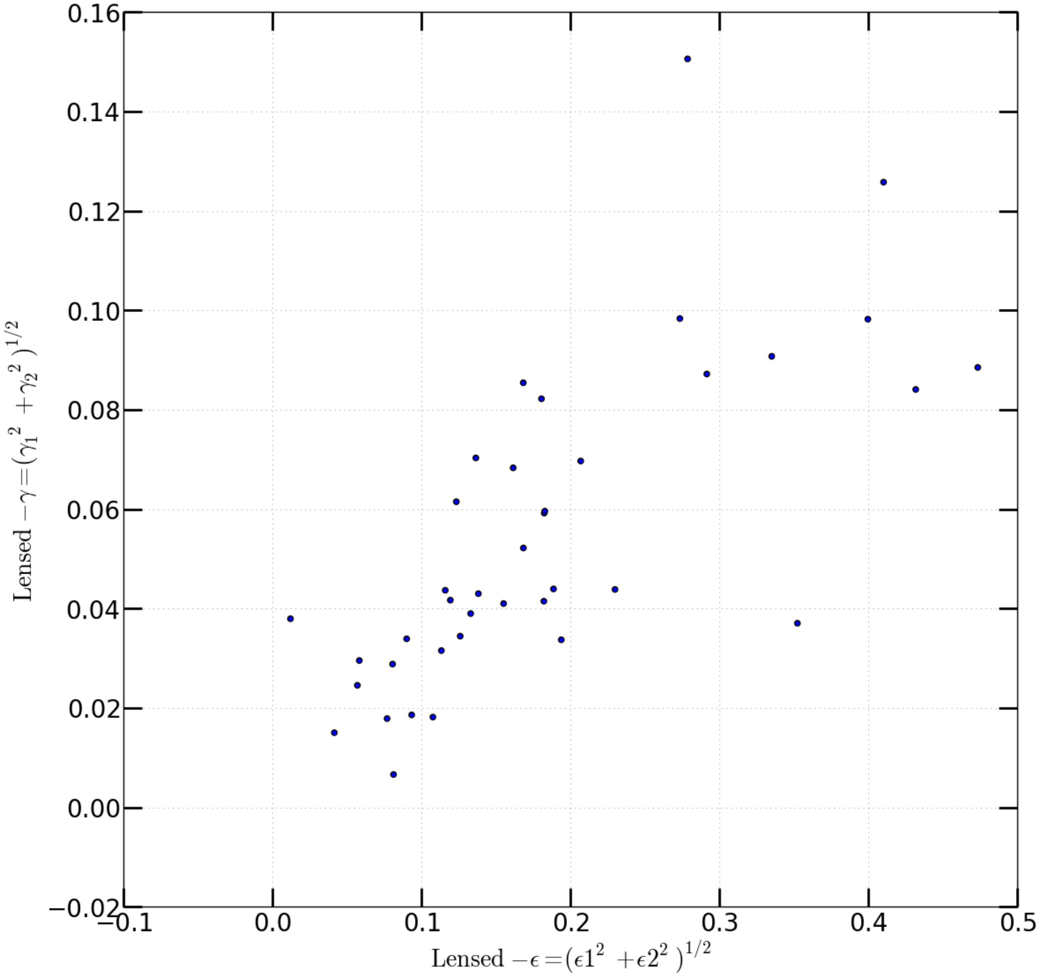


Comparison between
Shear of Lensed and coupled q & Φ of Kappa maps

SEAGLE II: *Mukherjee+ 17 in prep.*



Comparison between
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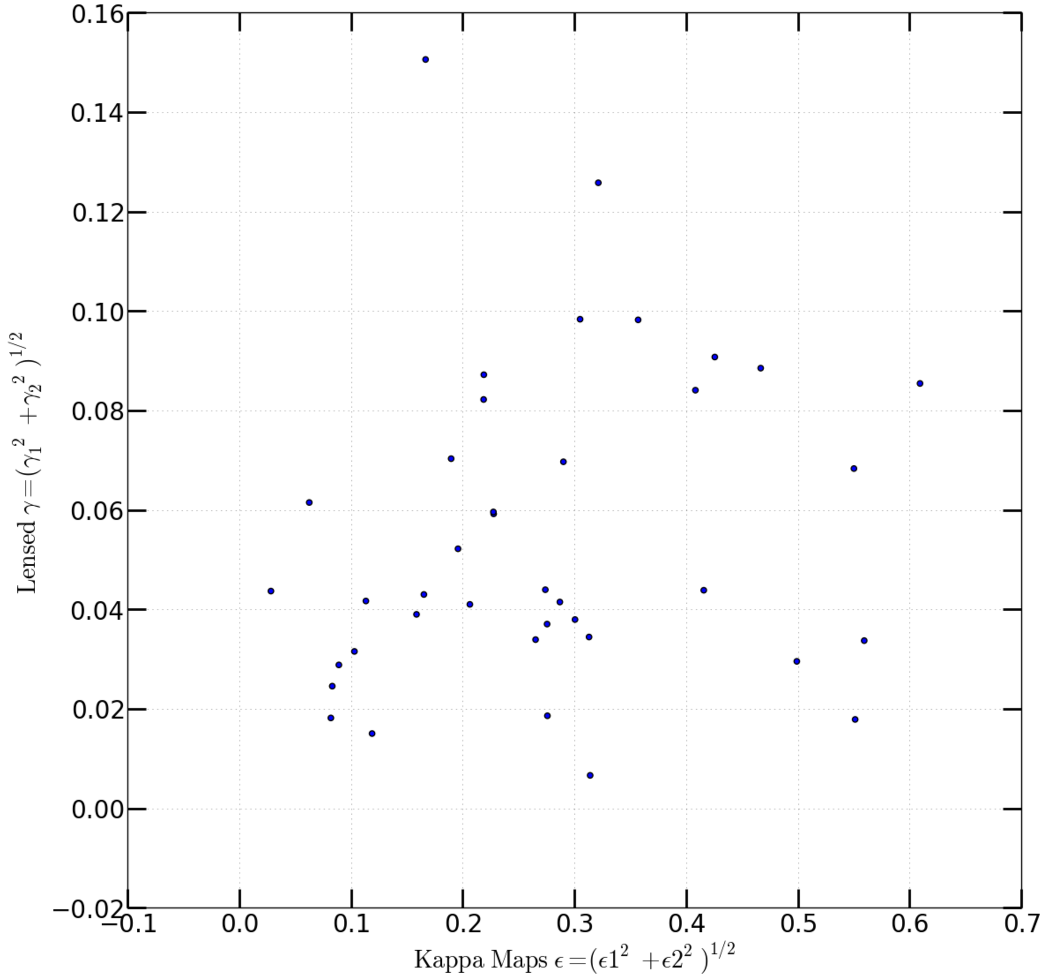


Comparison between
Shear of Lensed and coupled q & Φ of Kappa maps

Conclusion: A correlation exists between Shear (γ) and coupled q & Φ in complex space

For a tighter constrain on the correlation we need :

(i) shear, axis ratio and PA params of more modelled lens

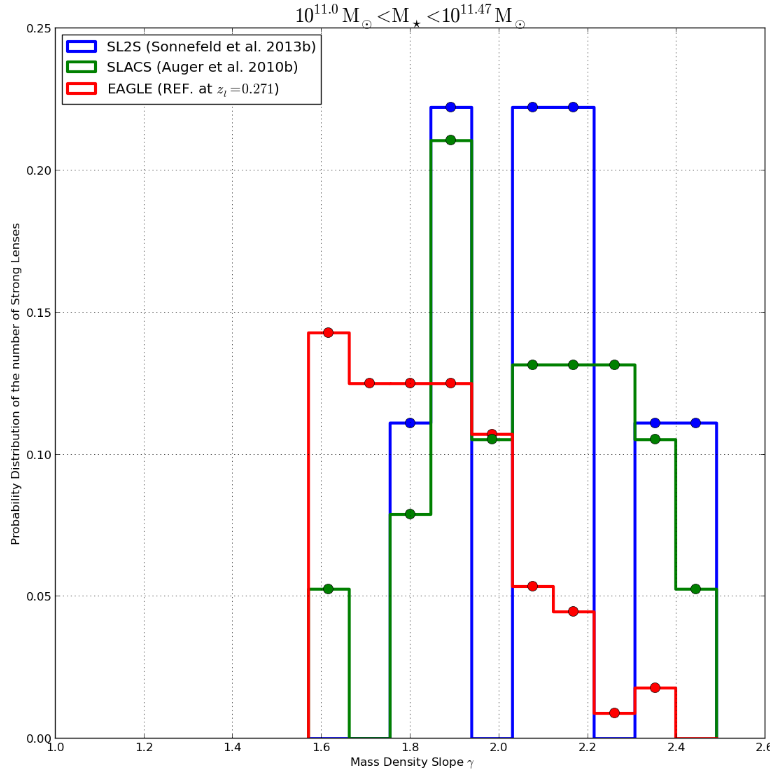
(ii) lenses made from different galaxy formation scenarios

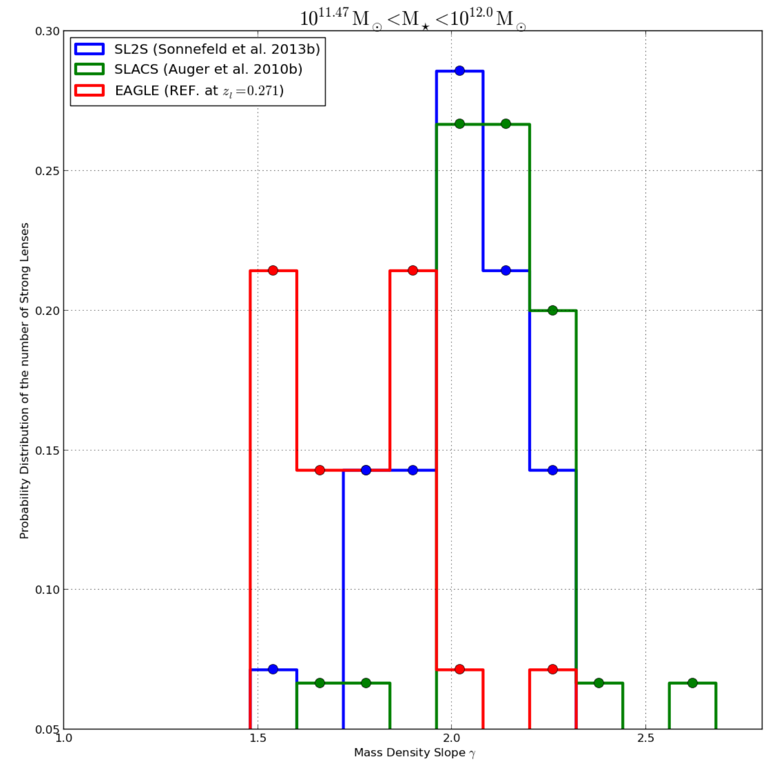
SEAGLE II: *Mukherjee+ 17 in prep.*

REFERENCE 50cMpc
z_l=0.271

A mass density and metallicity dependent scaling variable of the efficiency of star formation feedback

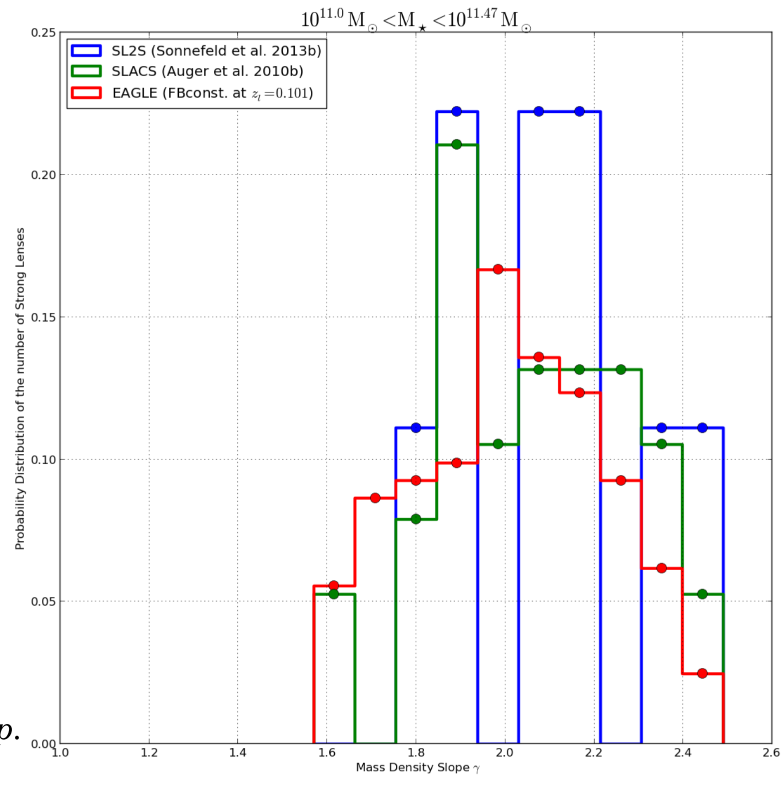
i.e. FB(Zρ)

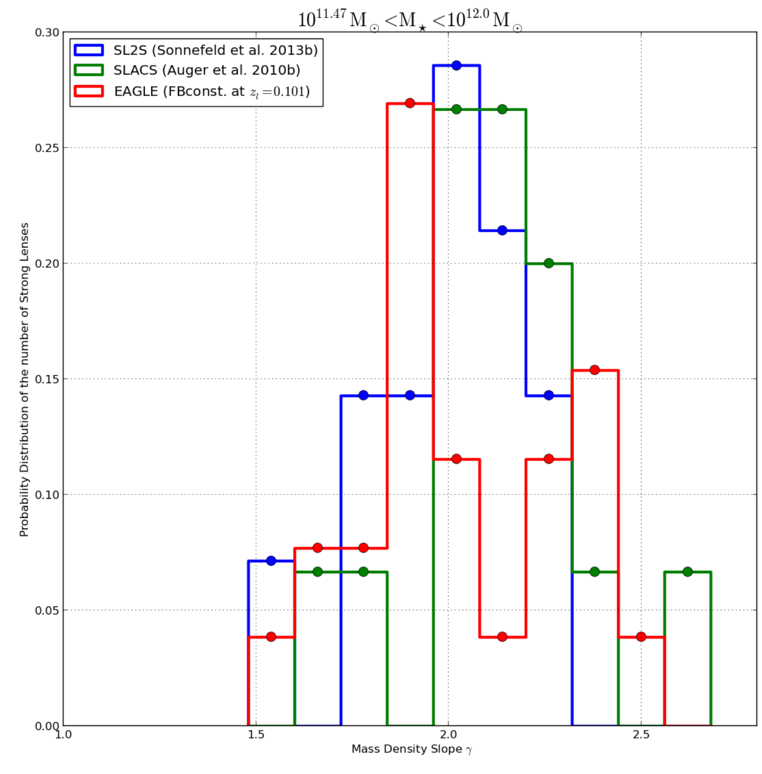




FB constant 50cMpc
z_l=0.101

The scaling variable of the efficiency of star formation feedback (f_{th}) = 1





SEAGLE II: *Mukherjee+ 17 in prep.*

Summary

1. An automatic pipeline for **creating & modelling** mock lenses with a high resolution hydrodynamic simulations, EAGLE, mimicking observational surveys and analysing them similar to real lenses. (**SEAGLE I**).

2. We quantify the effect(s) of projection/orientation of galaxies and compare properties of simulated mock strong lenses with SLACS & SL2S Lenses (**SEAGLE I &II**).

3. Applying the pipeline to different boxes and variety of galaxy formation scenarios (*Crain et al. 2015*) and source profiles to constrain the galaxy-formation mechanisms. (**SEAGLE II**).

Future Work

1. Mass Power-spectrum analysis on simulated Strong Lenses (with Saikat, **SEAGLE III**) in progress.

2. Comparison with observed Strong Lenses (with Dorota, **SEAGLE IV & V**).

Take home message

Simulation of realistic mock Strong Lenses is a very promising tool to probe galaxy evolution