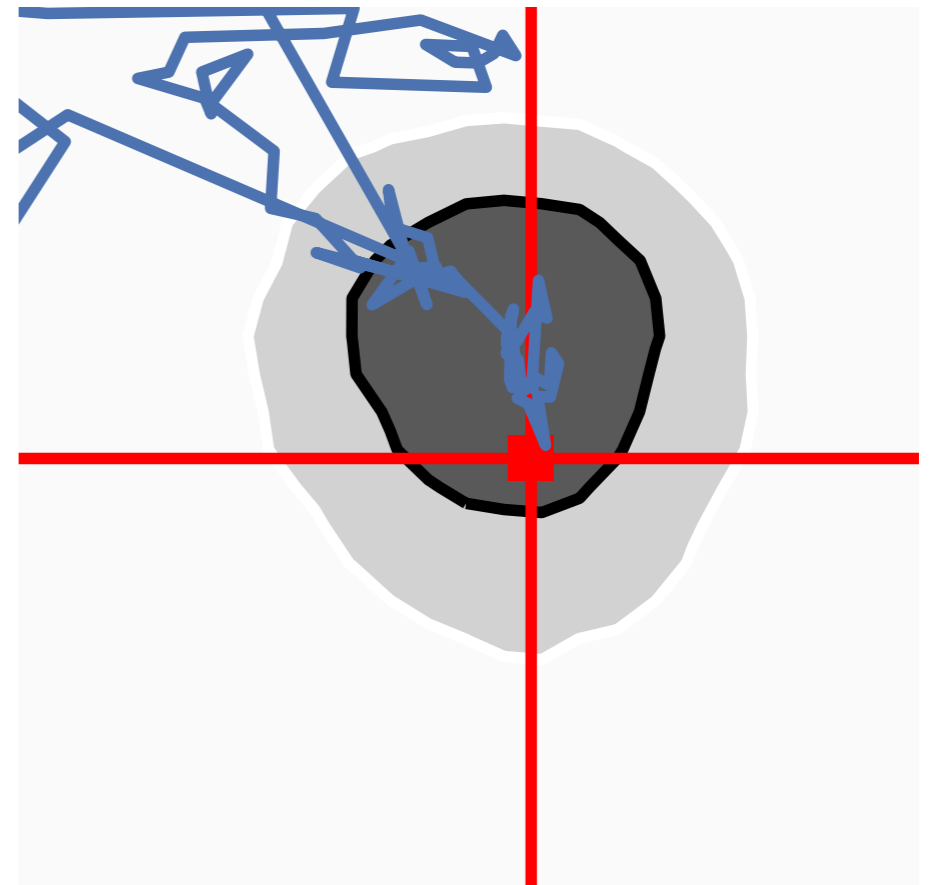
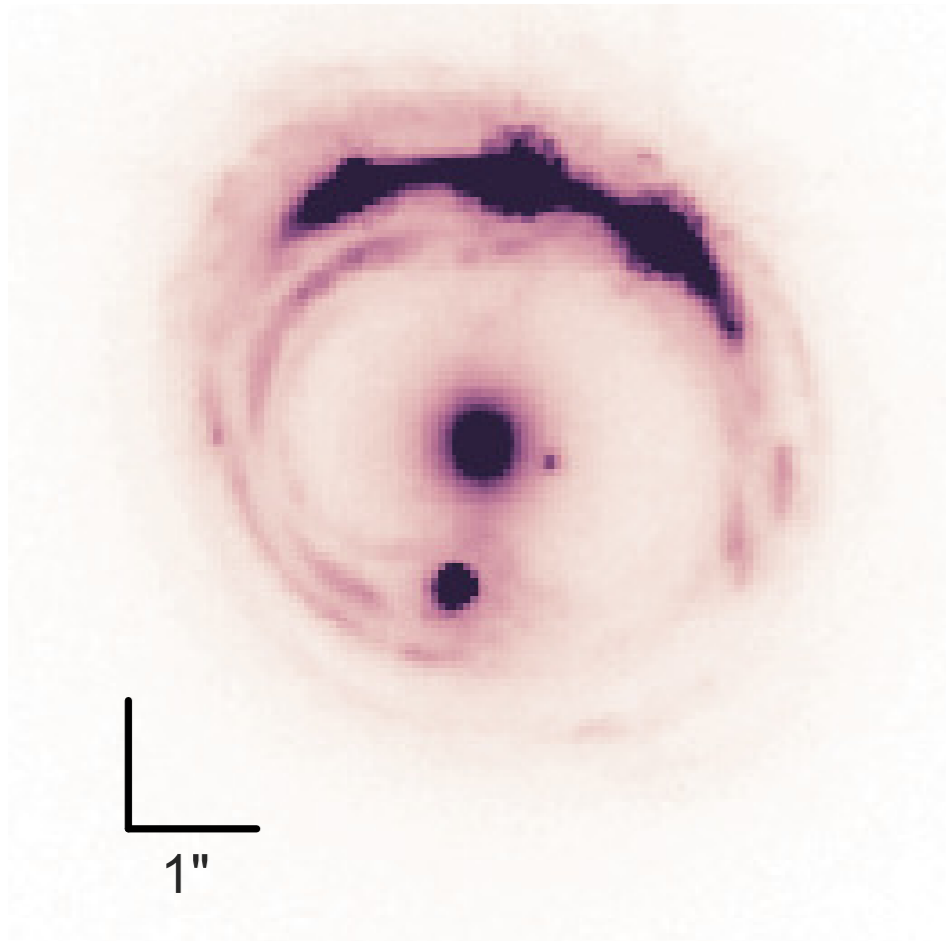


Strong lens modelling @ETH



Simon Birrer
with Adam Amara & Alexandre Refregier
and ETH Software Lab

Strong Lensing

- continuous mapping of source to image plane
- multiple image positions

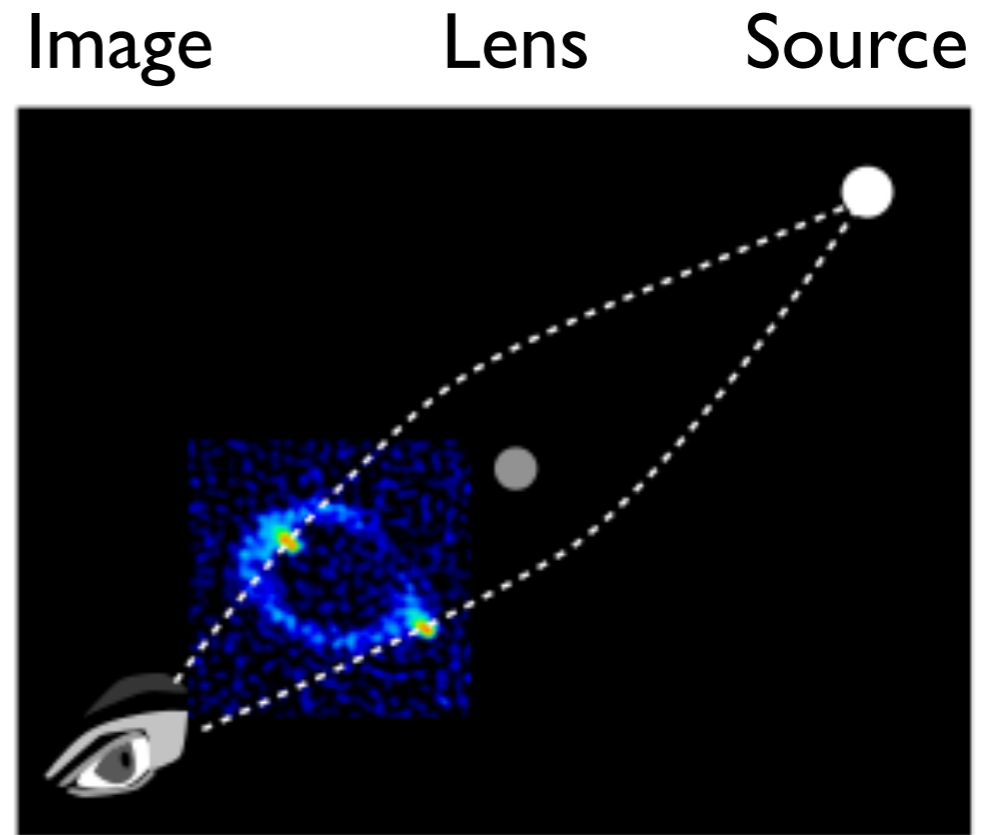


image credit: Simple Nature, Benjamin Crowell

Change in... brightness → linear ...response
mapping → non-linear to pixel values

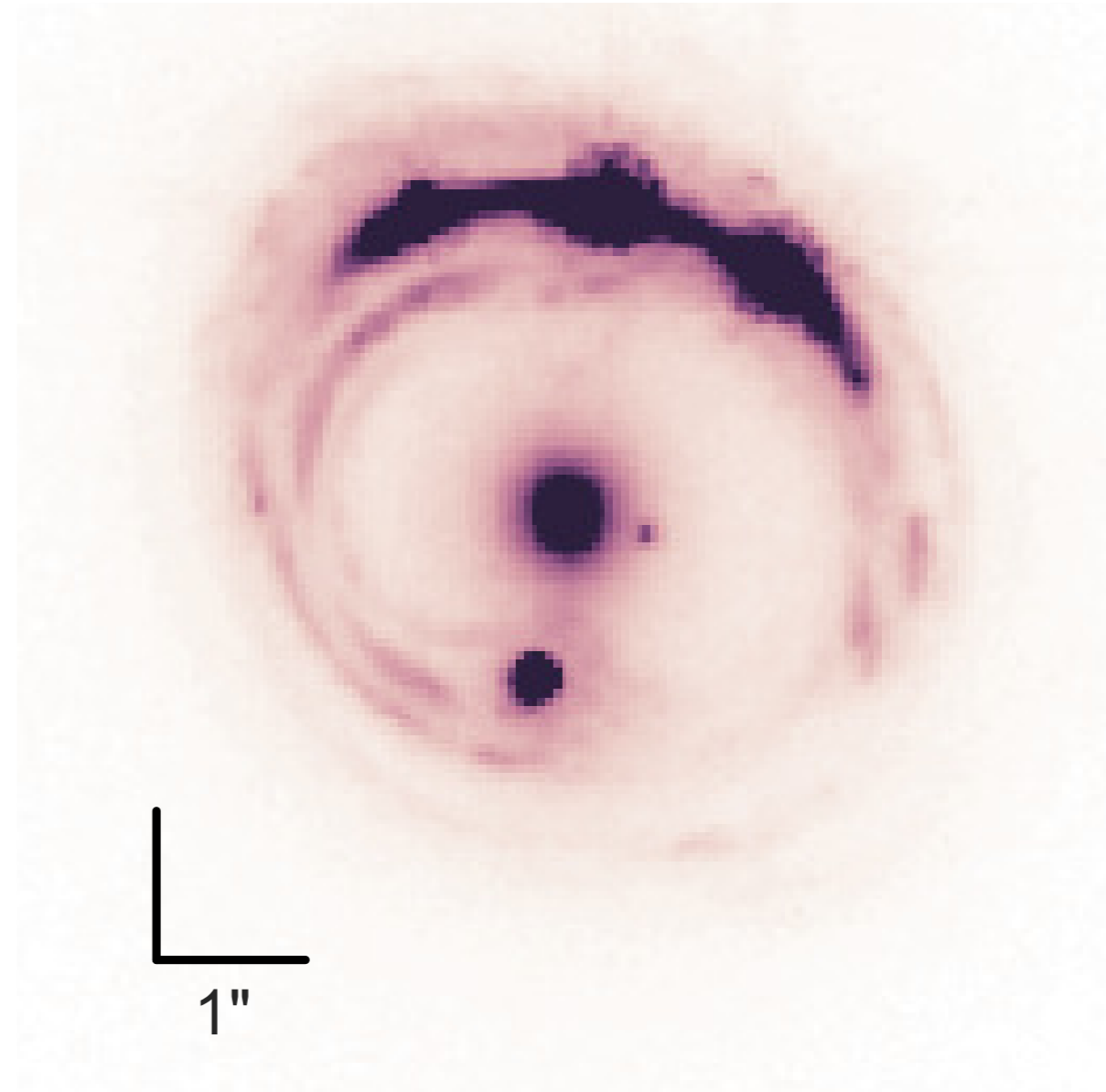
Lens modelling

To be modelled:

- lens mass (light deflection)
- lens light
- point source
- extended source
- PSF

Challenges:

- more than 30 non-linear parameters
- several hundred linear parameters
- many local minima (not under control)
- marginalisation over linear parameters
- Hubble PSF is complex
- Known and unknown degeneracies



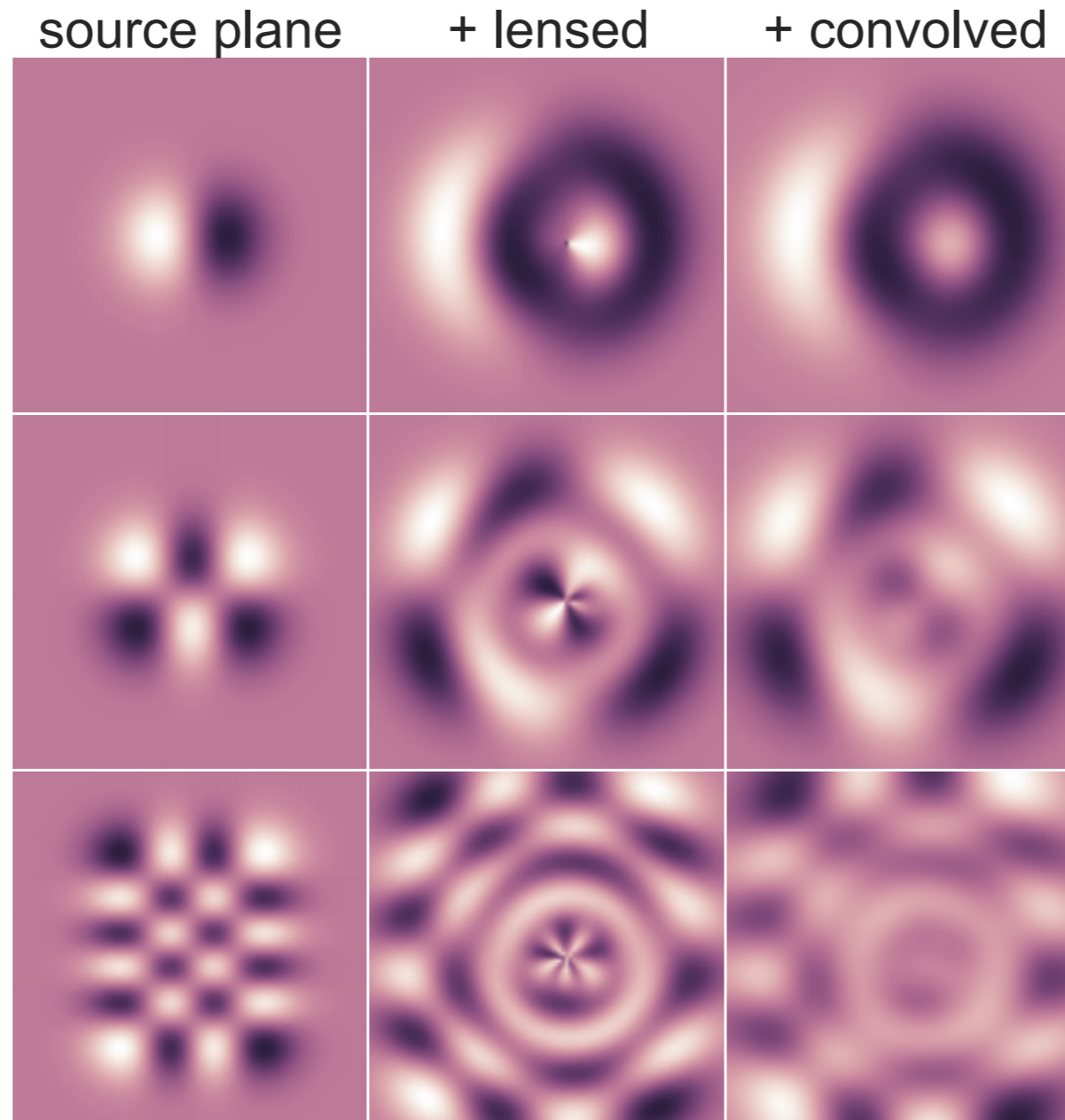
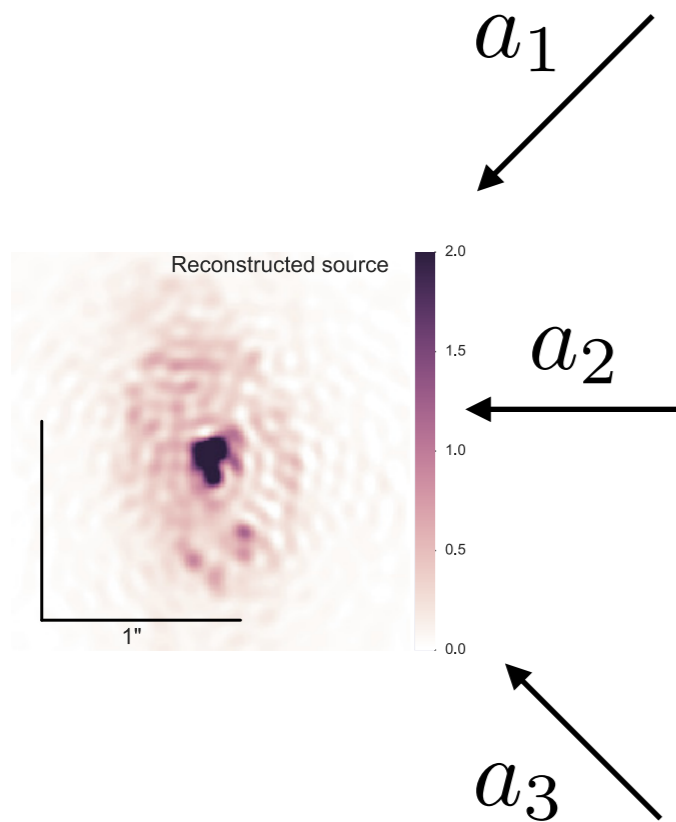
HST ACS F814W image of RXJ1131-1231

Sluse+ 2003

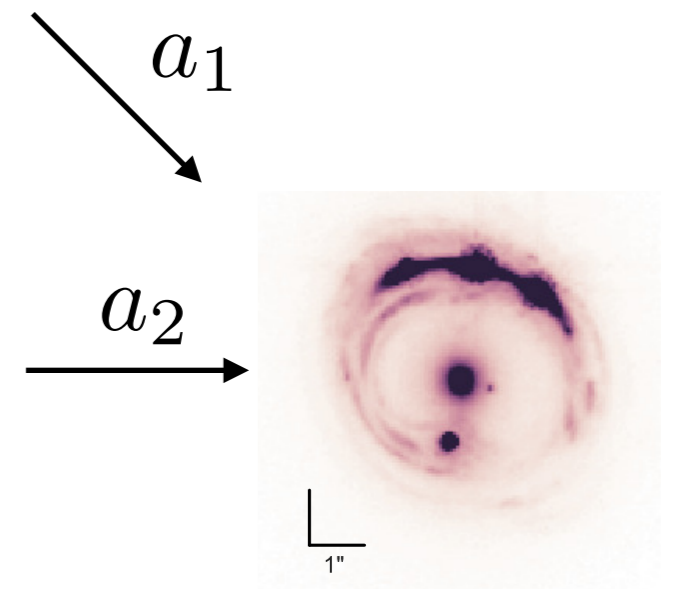
Suyu+ 2013

Source reconstruction technique (linear)

Basis set:
Shapelets

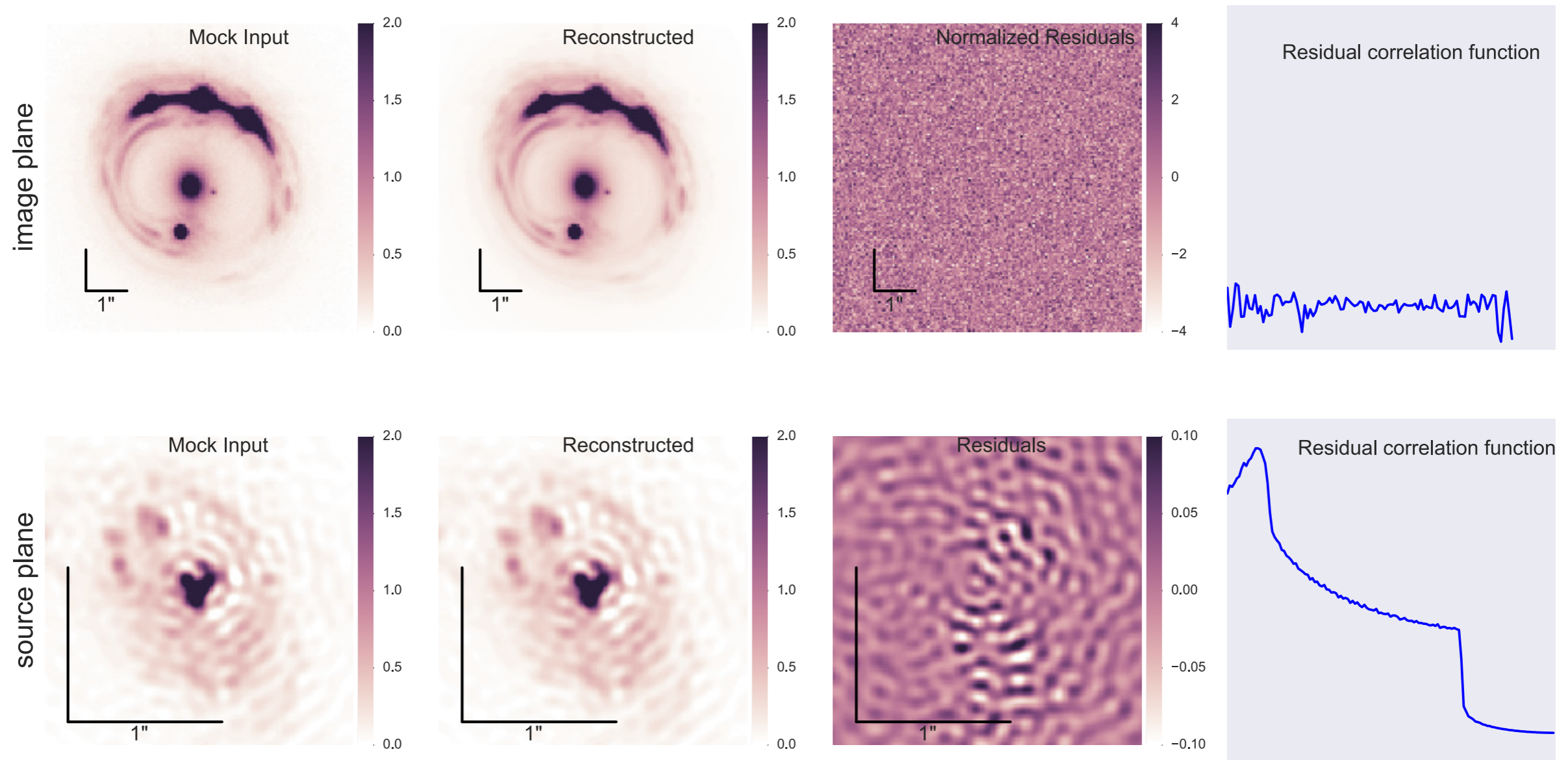


weighted linear
least square



Shapelets: Refregier 2003
Method: Birrer+ 2015

Source reconstruction technique: example



Performance for 1333 basis functions: 10s on 1 CPU

Lens model parameters (non-linear)

Non-linear parameters are expensive!

What is the minimal number of parameters and the functional form to match the data?

- SIS, SPEP, SPEMD, NFW profiles
- sub-clumps (yet another profile)
- External Shear
- Smooth perturbations
- ...

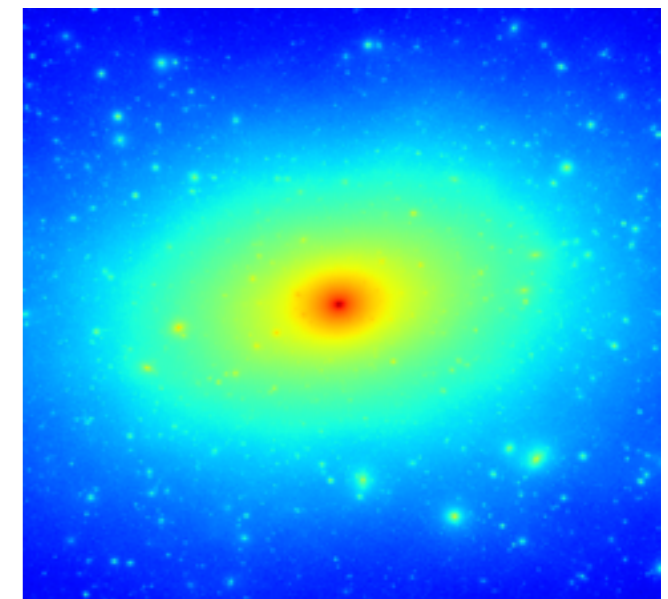
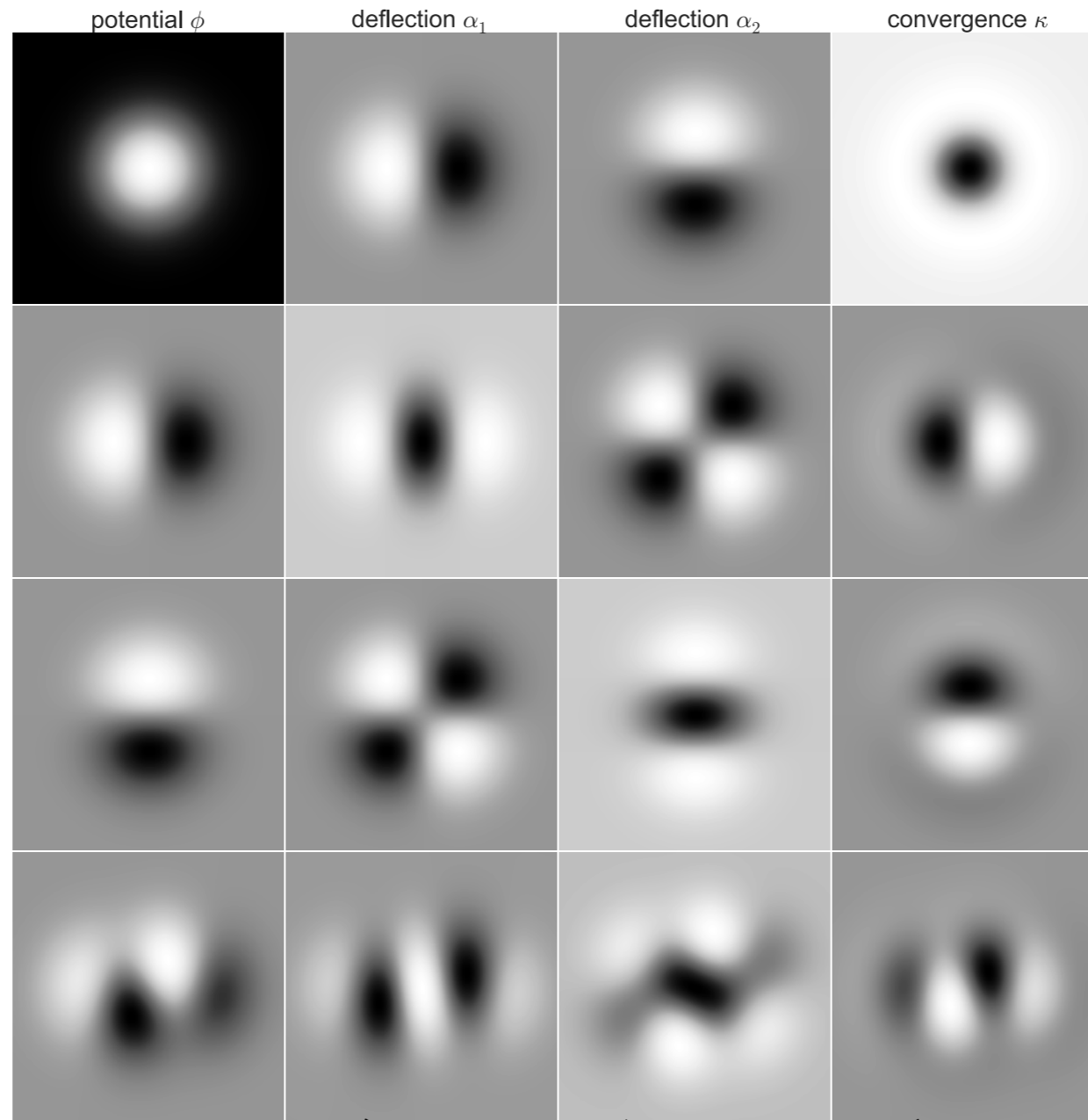


image from ViaLactea

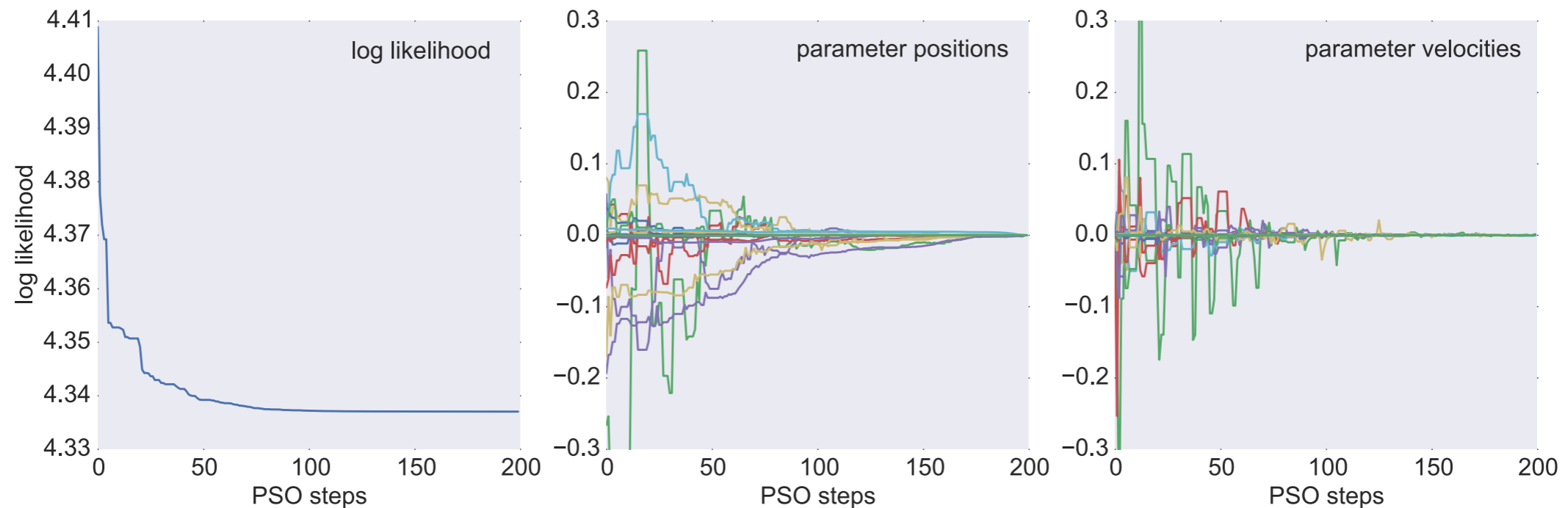
Lens model perturbations (smooth component)



Analytic relations

Shapelets: Refregier 2003
Method: Birrer+ 2015

Convergence technique: Particle Swarm Optimization (PSO)

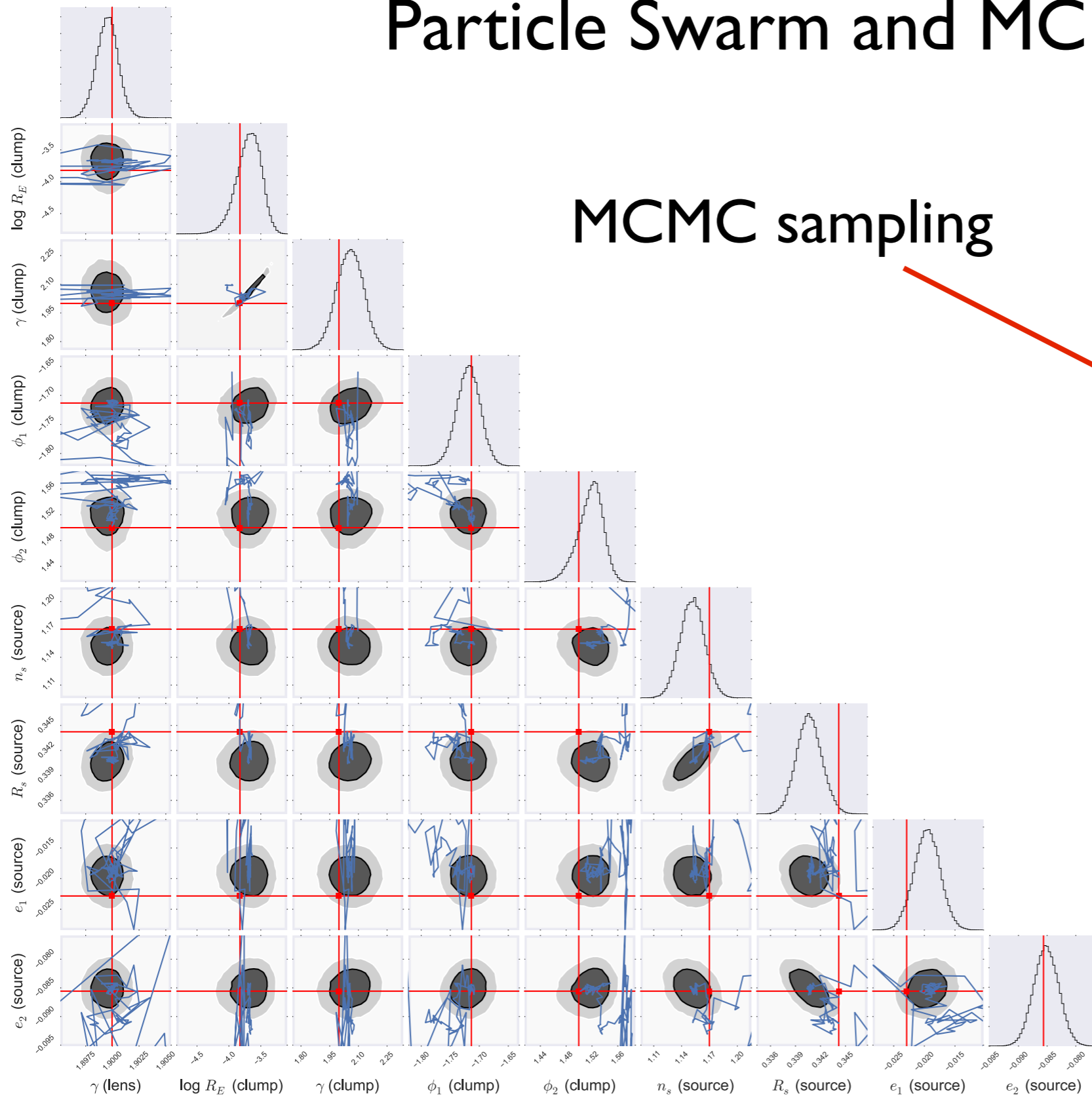


Tricks:

- re-parameterisation along degeneracy axes
- analytic marginalisation over linear parameters
- reduce the effective number of parameters with constraints (i.e. bright point source positions)
- Use of Particle Swarm Optimisation (PSO)

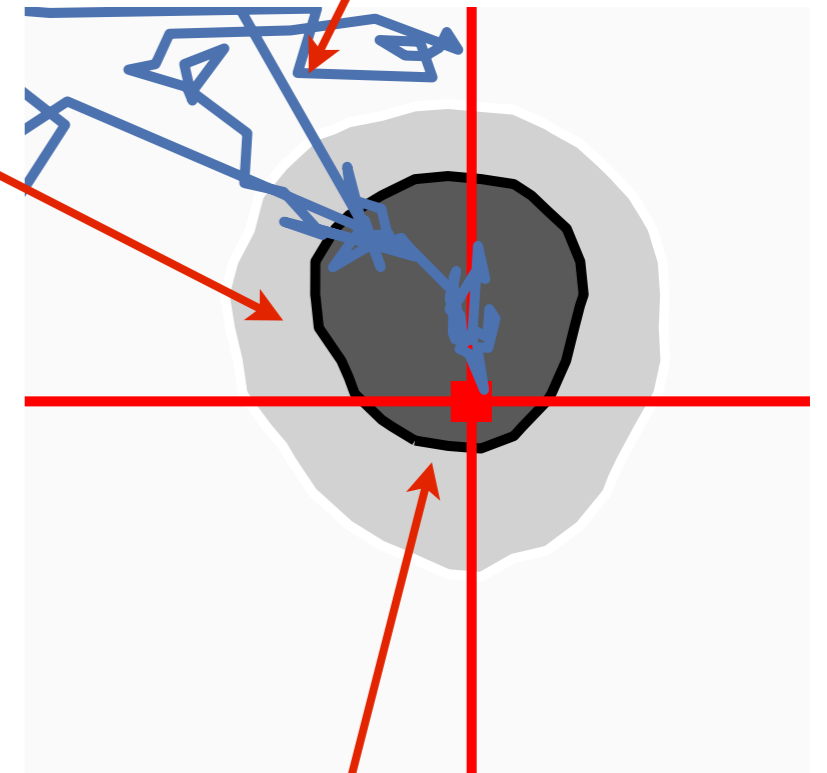
Attention: This is only about finding the minima!

Particle Swarm and MCMC combined



MCMC sampling

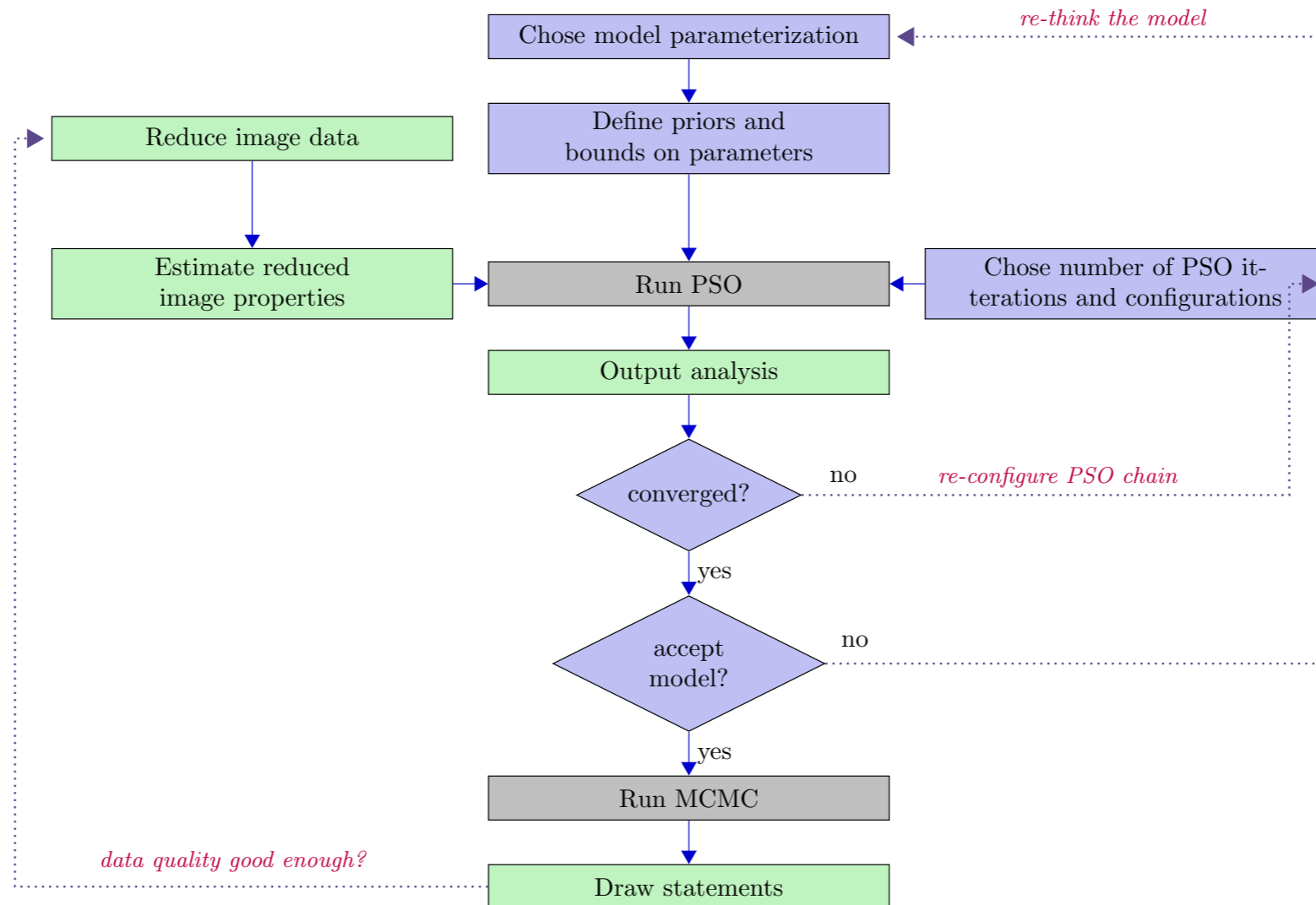
PSO walking



truth

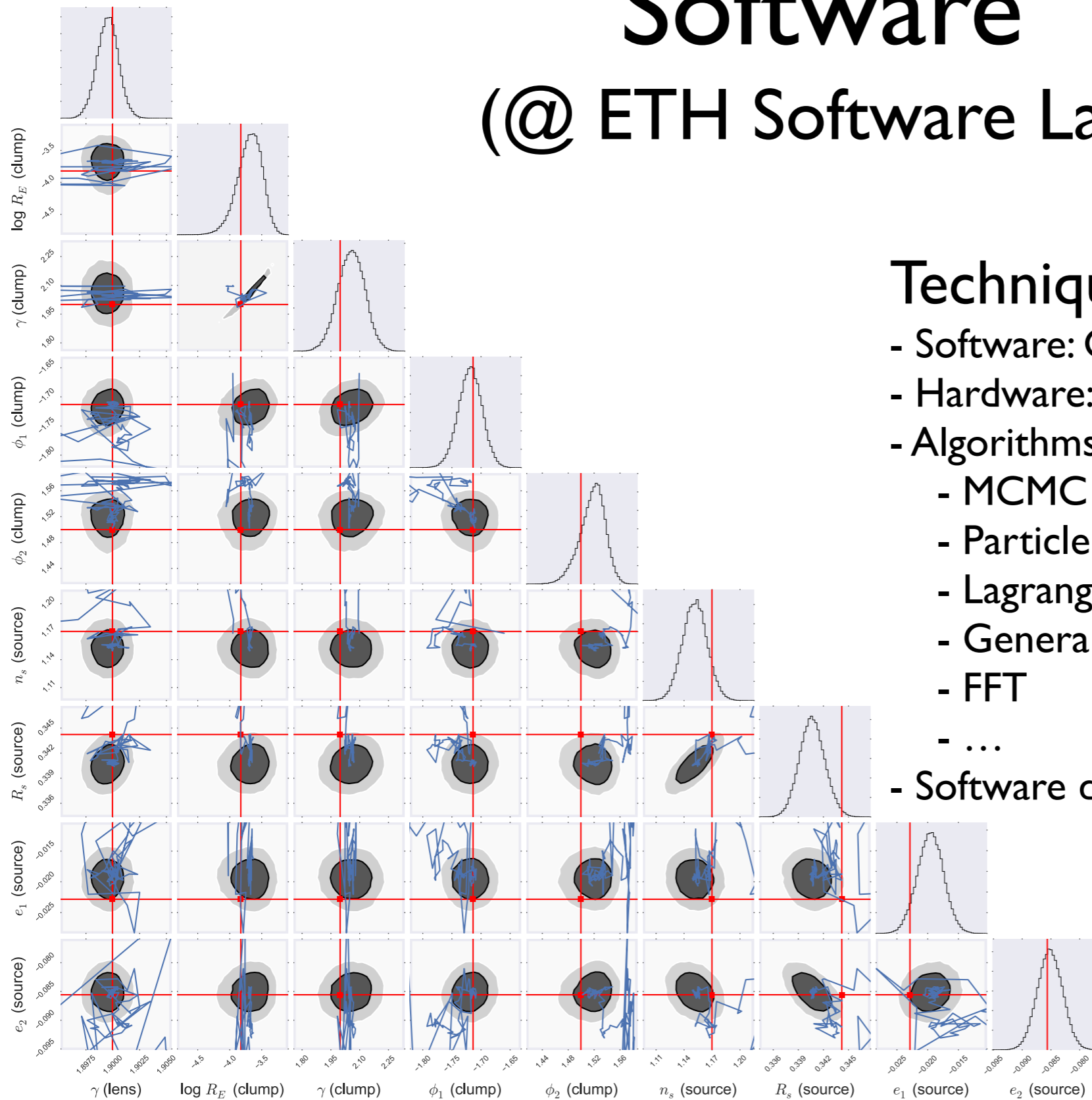
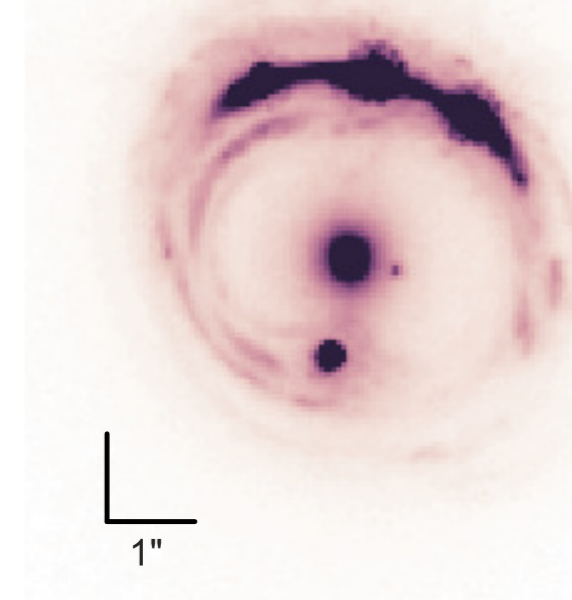
Akeret, Seehars+ 2013
Birrer+ 2015, in prep

Overview on framework



- minimise human wall time per lens system
- split convergence and inference
- transparent setting
- focus on software design (@ ETH Software Lab)

Software (@ ETH Software Lab)

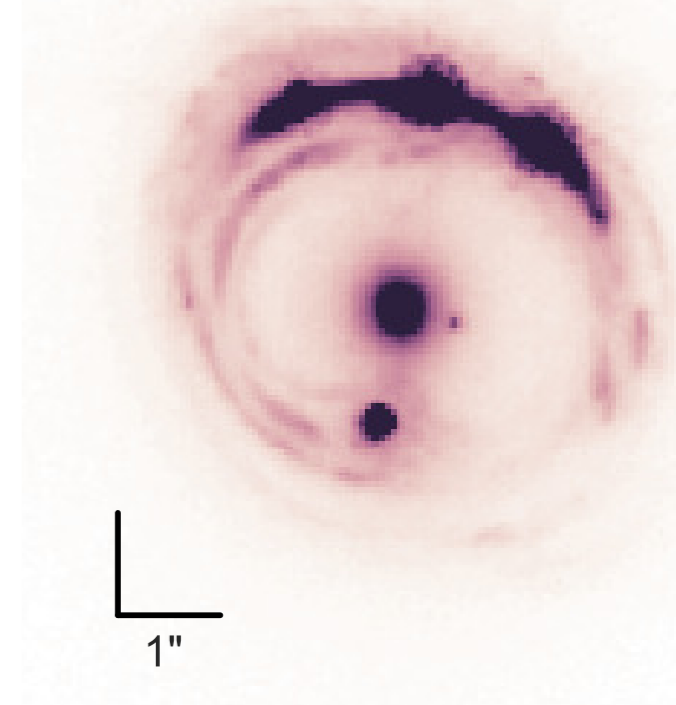
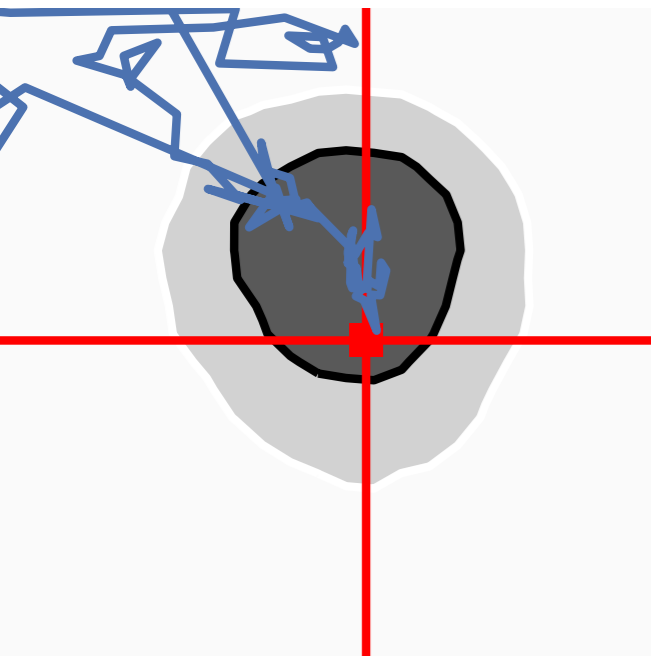


Techniques:

- Software: CosmoHammer, Ufig, Hope,...
- Hardware: Clusters (Monch, Brutus)
- Algorithms:
 - MCMC
 - Particle Swarm Optimization
 - Lagrange multiplier/ optimal control
 - Generalized Least Square methods
 - FFT
 - ...
- Software design, Python with speed-up

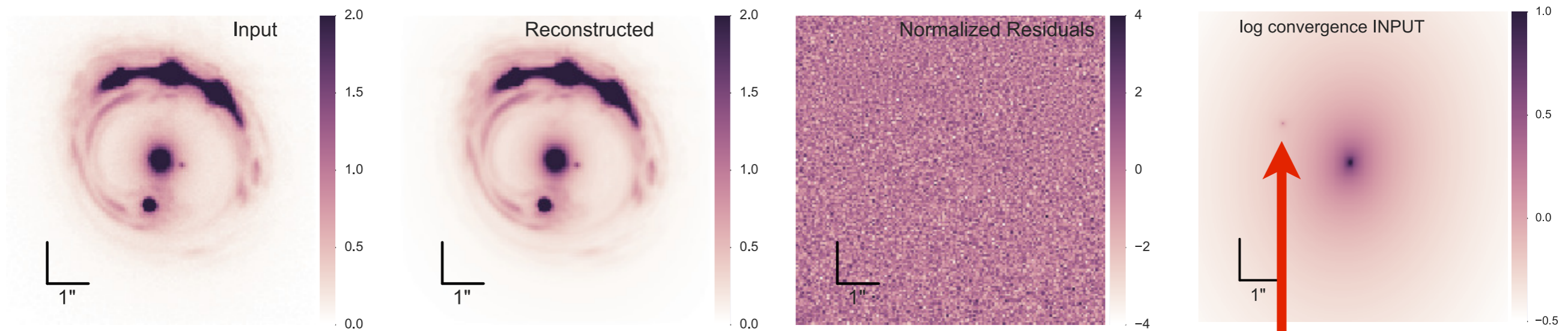
Akeret, Seehars+ 2013
 Bergé+, 2013
 Akeret, Gamper+, 2014
 Birrer+ 2015, submitted

Summary

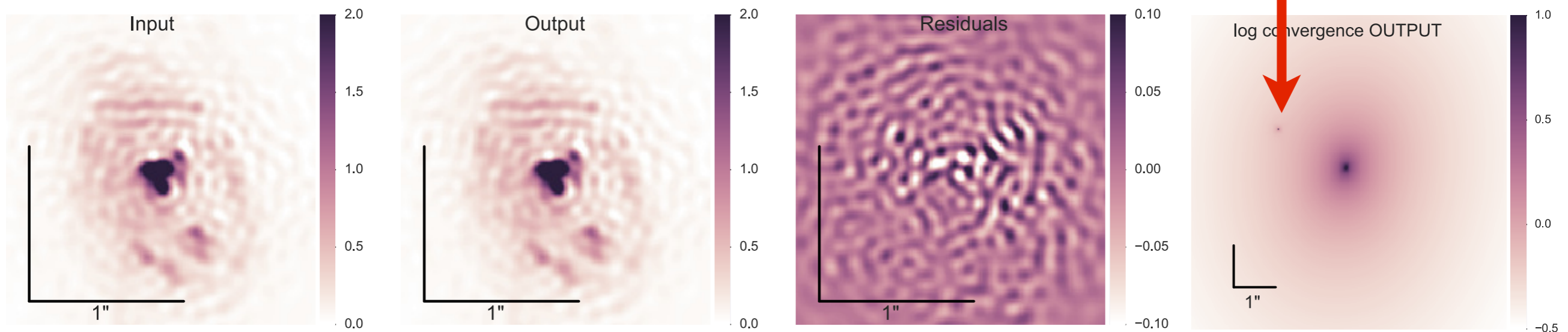


- Multipurpose framework
- Fast modelling of many lens systems
- We want to contribute to DES/STRIDES/...
- Birrer+ 2015, submitted (today on the arXiv)
- Happy to collaborate with you!

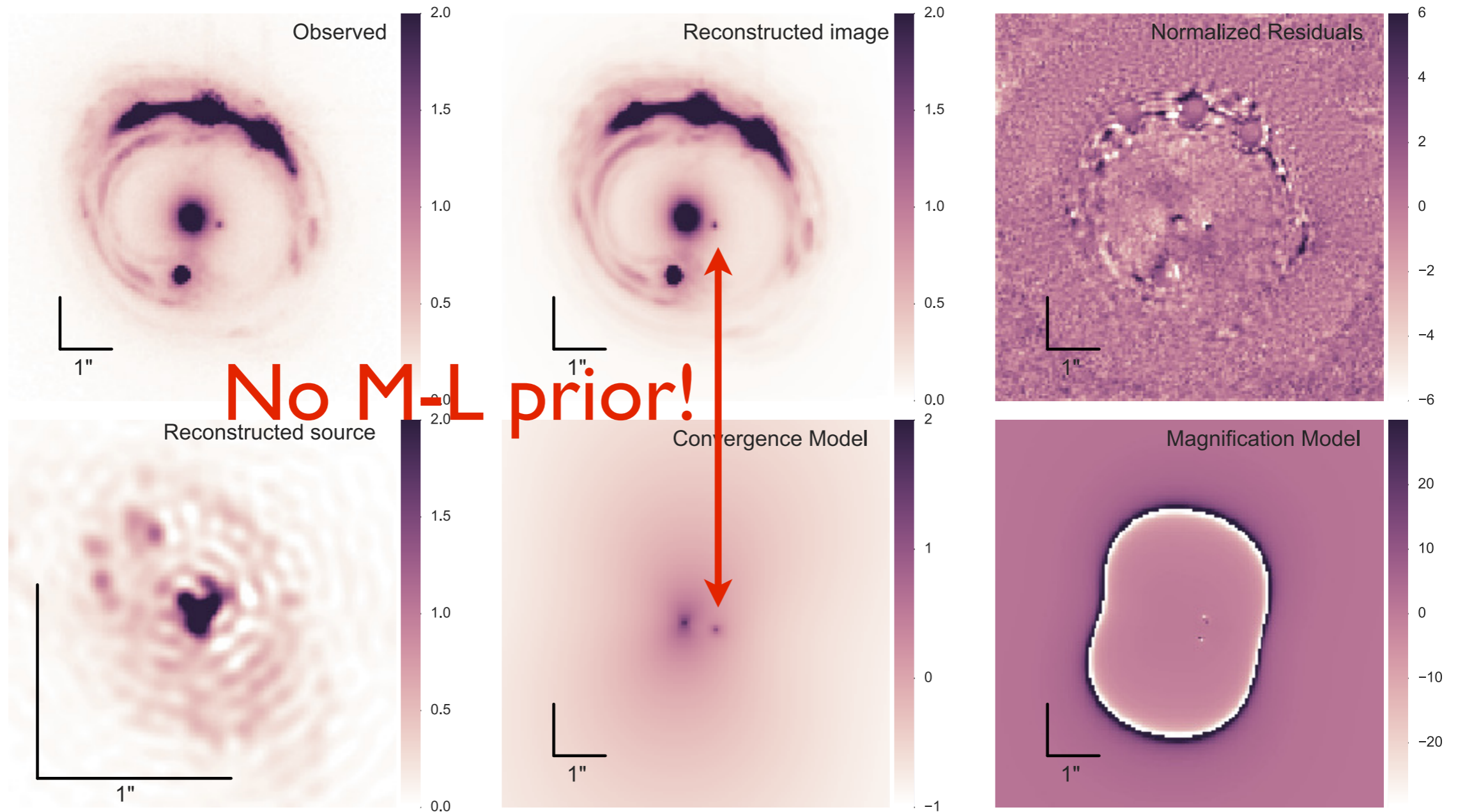
Sub-clump positioned in the arc of $10^8 M_{\odot}$



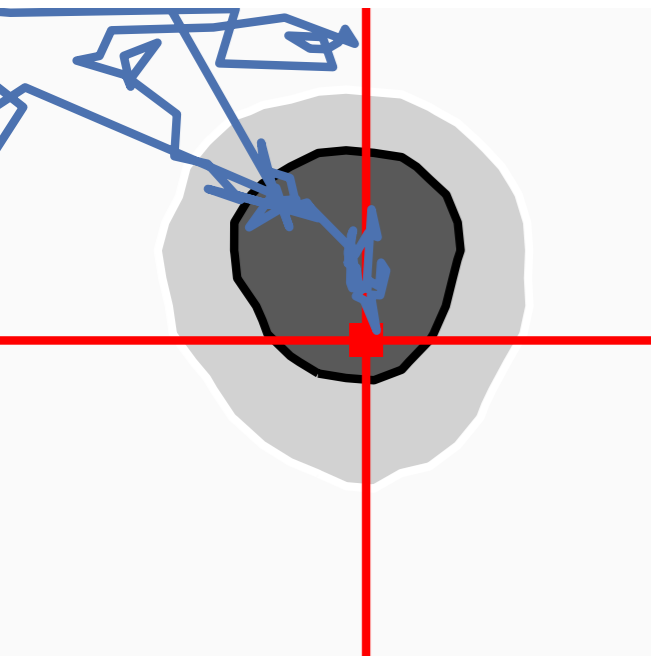
We are sensitive and we find it!



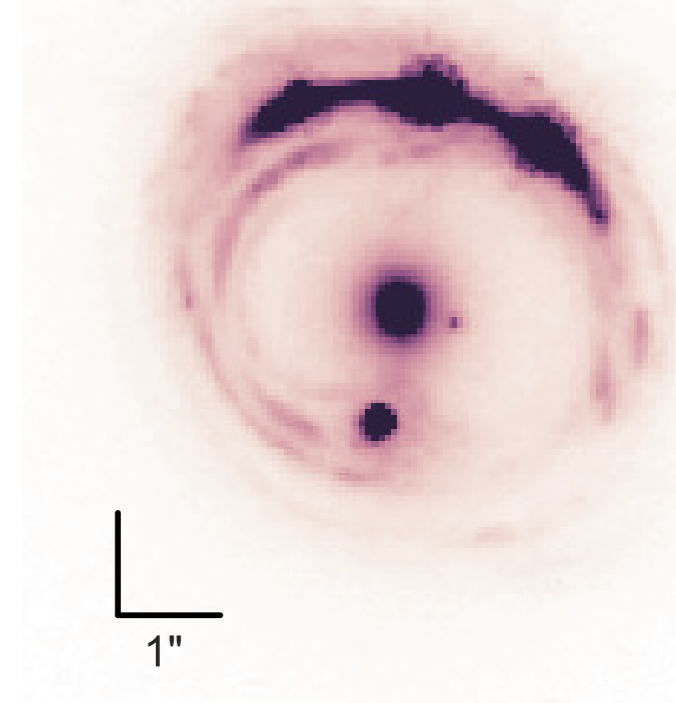
Application to data: RXJ1131-1231



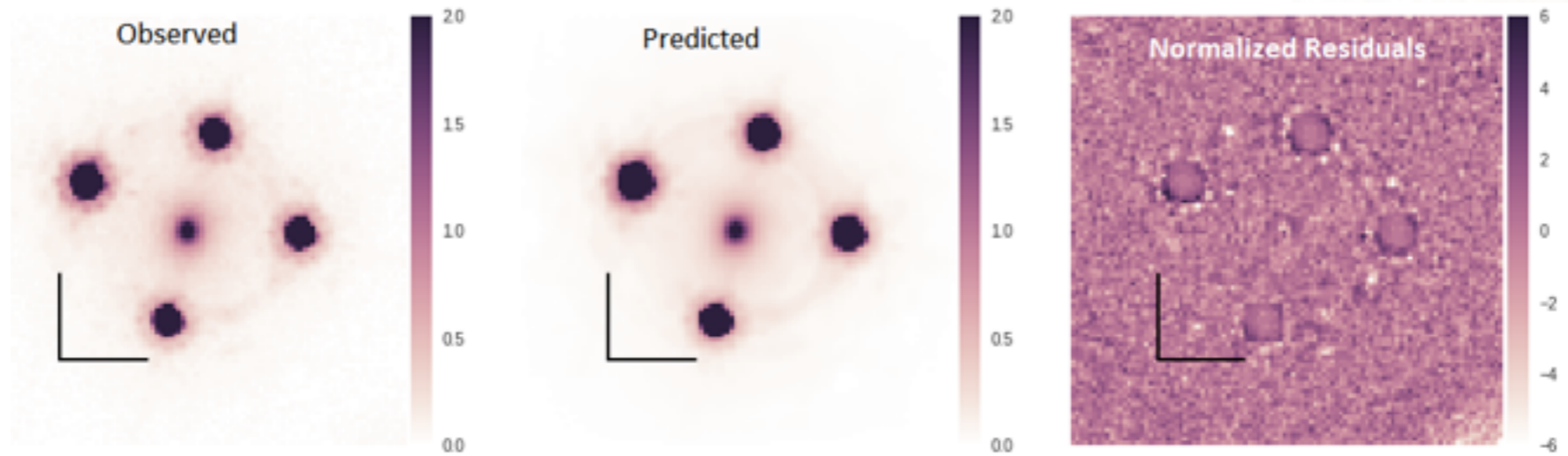
e.g modelled by Suyu+ 2013
discovered by Sluse+ 2003



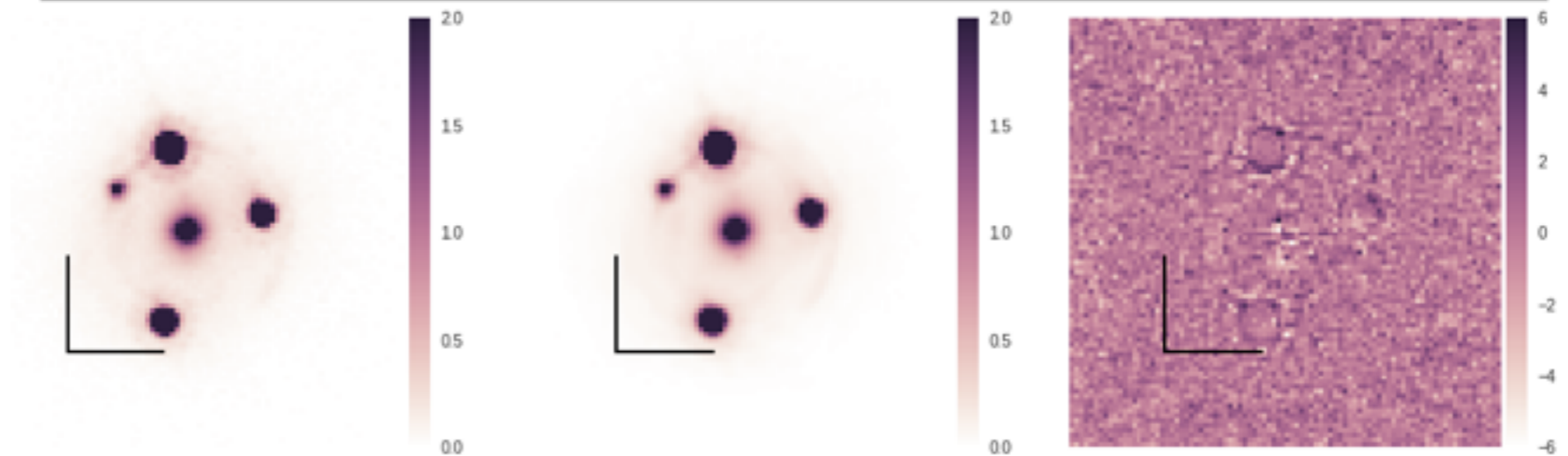
Supplementary material: Example of other systems



HE0435-1223

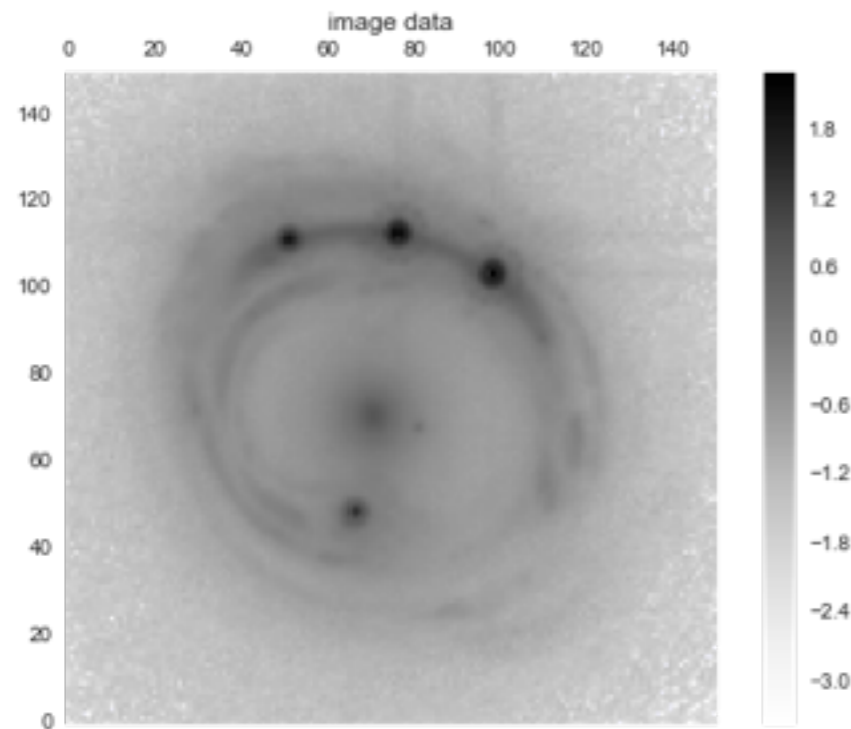


SDSS0924-0219



Credit: Kevin Fusshoeller, semester project (about two days per system)

F814W



Supplementary material: Multiband analysis

F555W

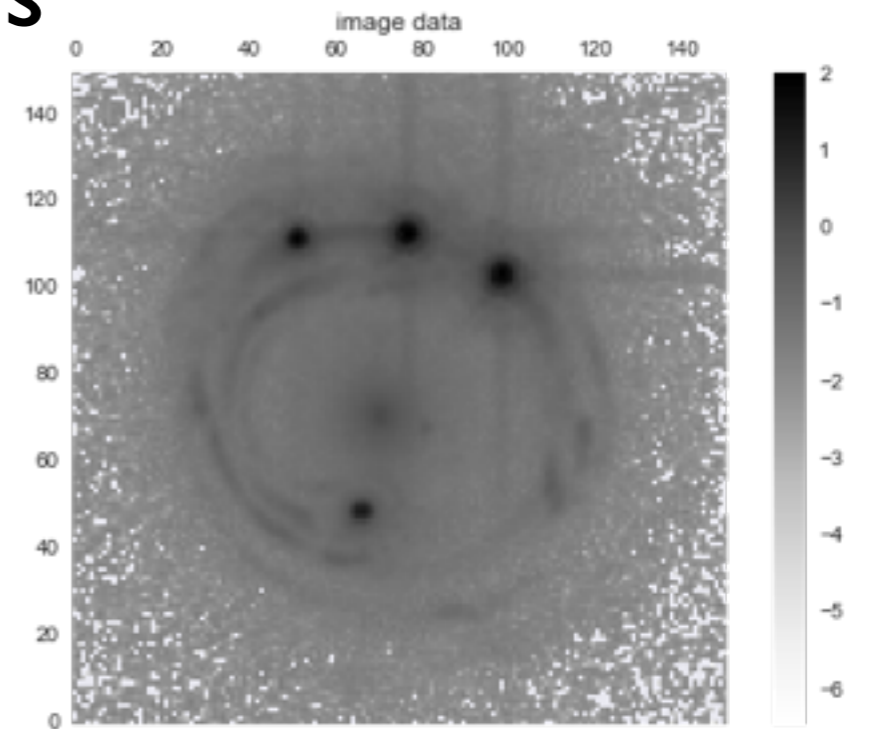
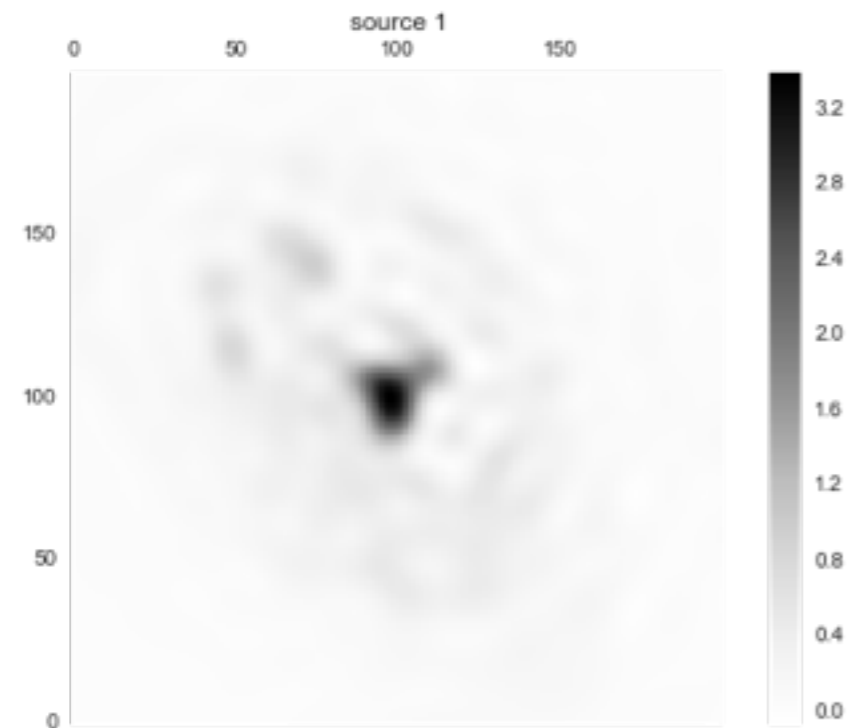


image
(data)



source
(reconstructed)

