The image plane approach to cosmic telescopes

Masamune Oguri
(University of Tokyo)

Collaborators (alphabetical): Masafumi Ishigaki, Ryota Kawamata, Yoshiaki Ono, Masami Ouchi, Kazuhiro Shimasaku

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Oguri PASJ **62**(2010)1017

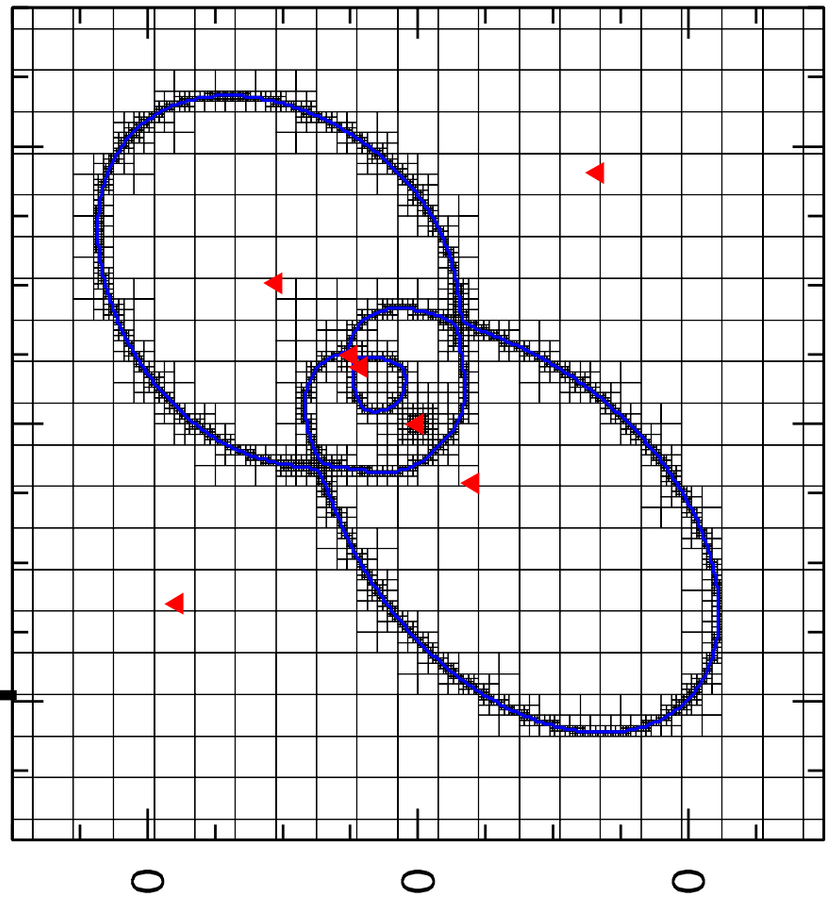
Mass modeling with *glafic*

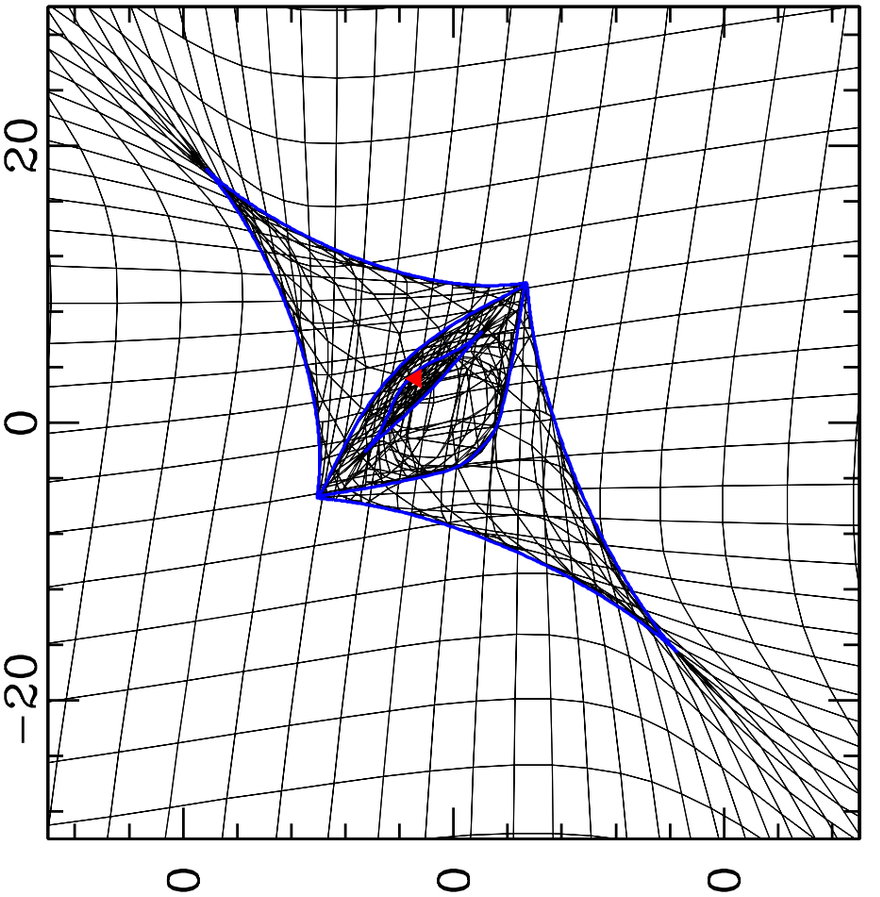
- publicly available strong lens modeling code
  (http://www.slac.stanford.edu/~oguri/glafic/)
- parametric mass modeling with a variety of lens potentials (NFW, SIE, Hernquist, perturbations, ...)
- can handle both point and extended sources
- efficient algorithms to solve lens equation and optimize model parameters

image plane ($\vec{\theta}_i$)

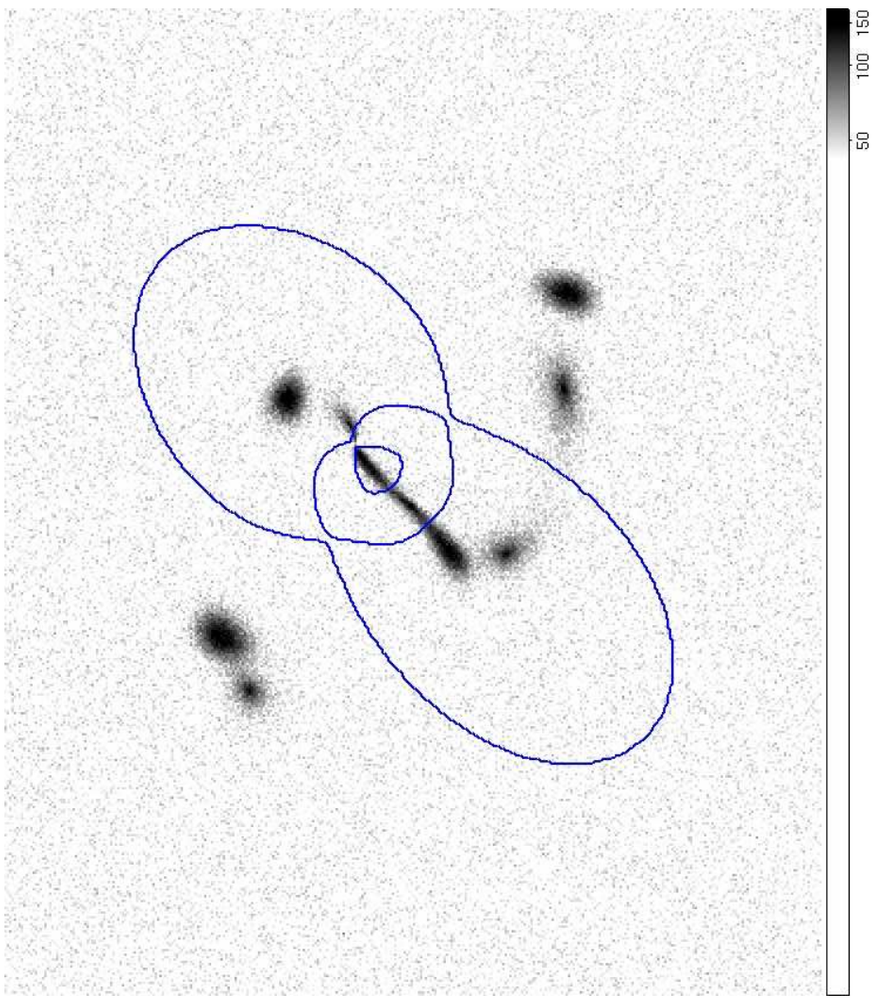
source plane ($\vec{\beta}_i$)

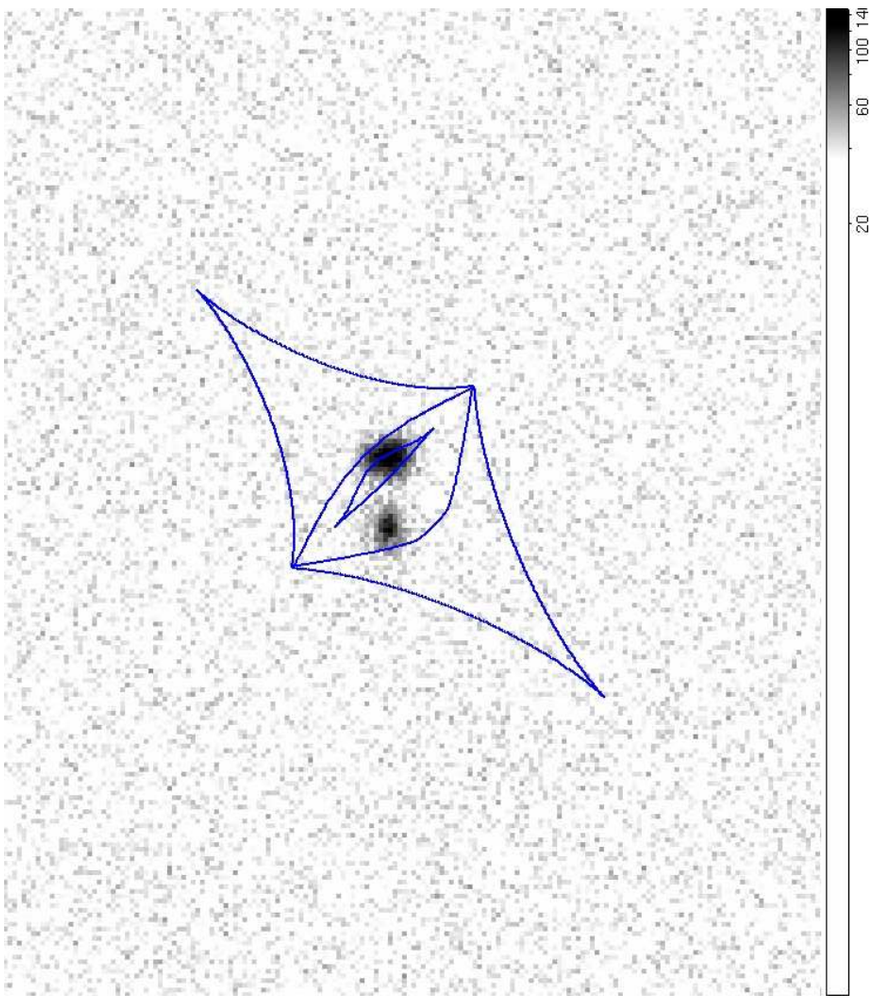
point source





extended source

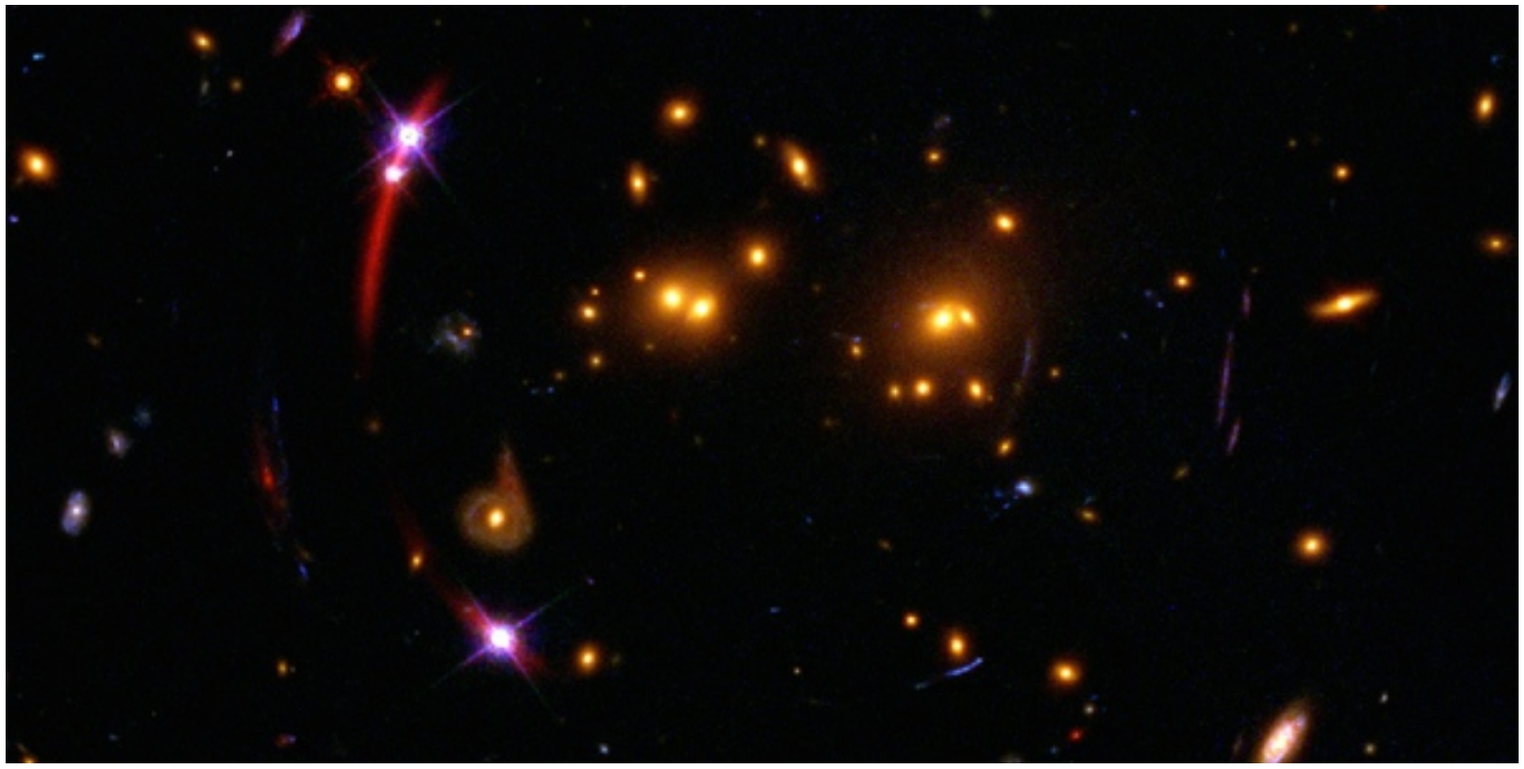




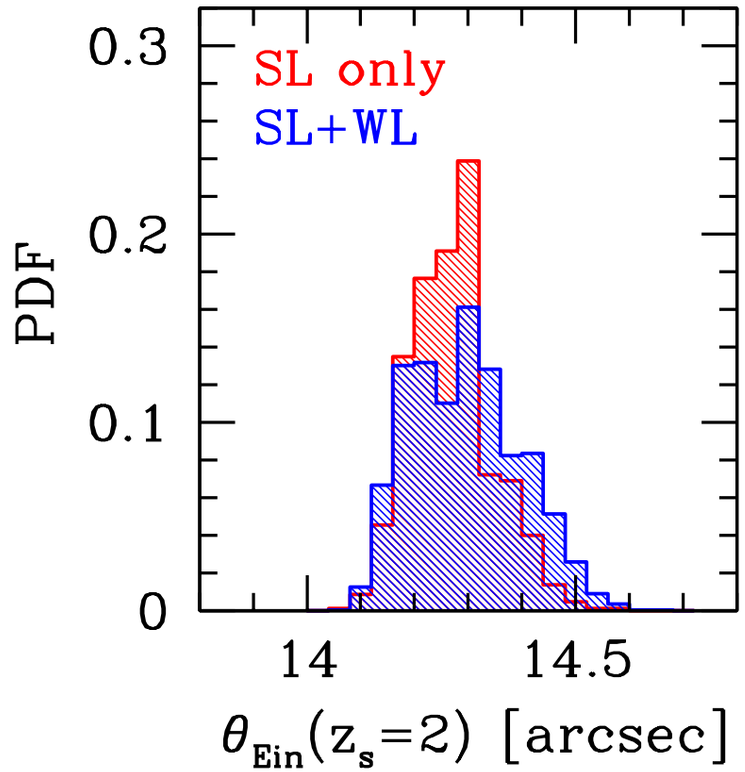
Recent *glafic* update: mapprior

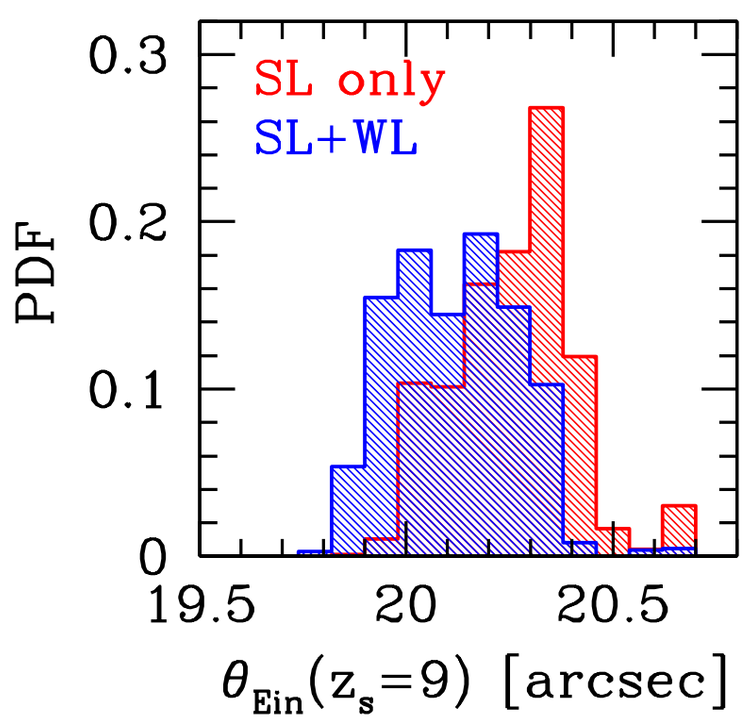
- now one can include constraints on various lensing quantities (e.g., μ, κ, γ_1, γ_2, ...) at arbitrary position on the sky
- this allows one to add magnification constraints from SNIa (Rodney et al. 2015) and (reduced) shear constraints from weak lensing

An example from SDSS J1029+2623



Oguri et al. (2013)





- 27 multiple images at z~2
- HST weak lensing constraints added (20" grid, 89 positions)

Cluster as a cosmic telescope

- two competing effects from lensing magnification
  - detection of intrinsically faint galaxies
  - decrease of the survey volume

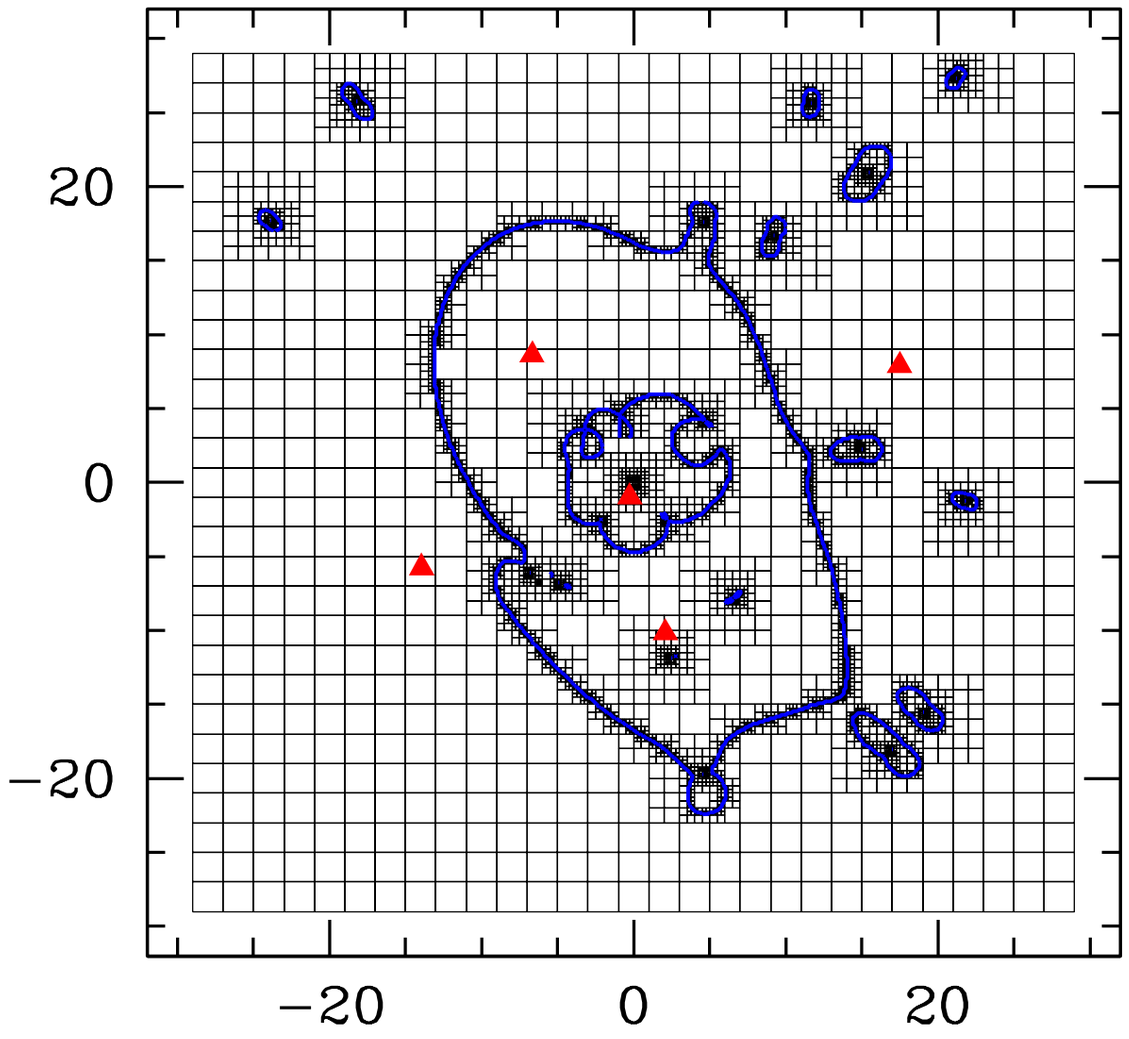
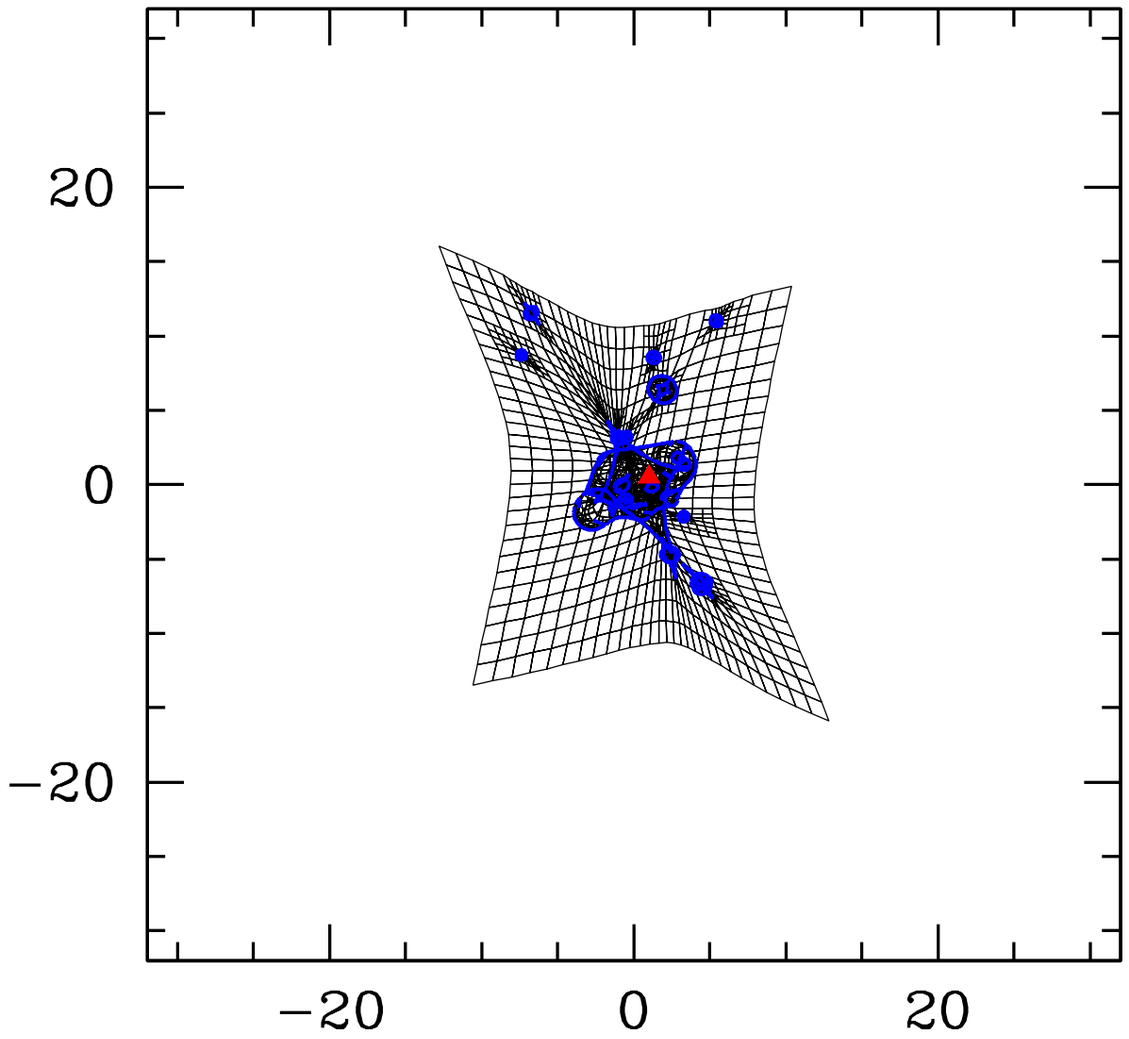


image plane

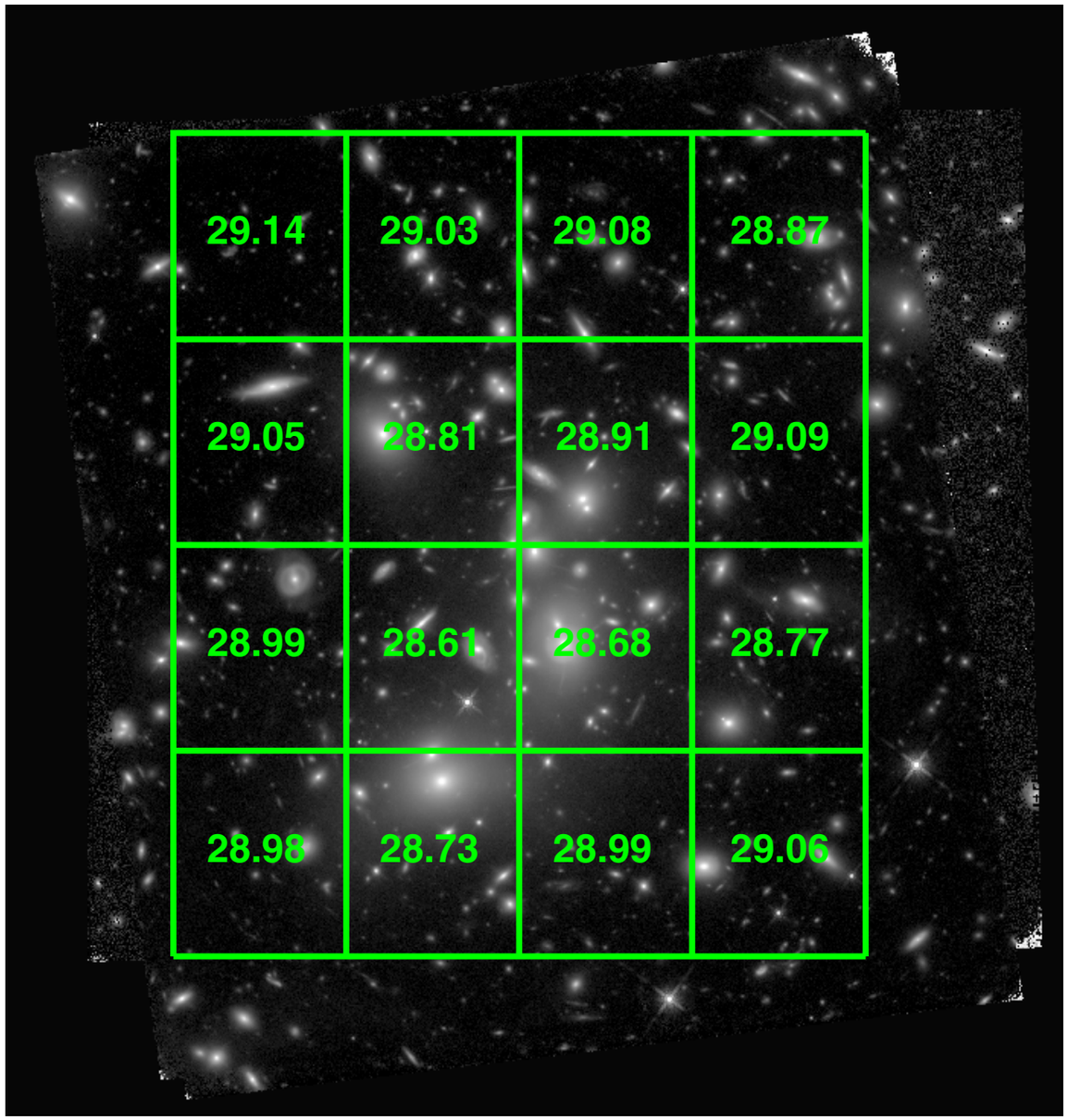


source plane

Luminosity function?

- traditional (?) approach: source plane approach
  - derive un-lensed mags for all high-z galaxies
  - compute magnification-corrected volume
  - estimate luminosity function
- some difficulties

Non-uniform survey depth



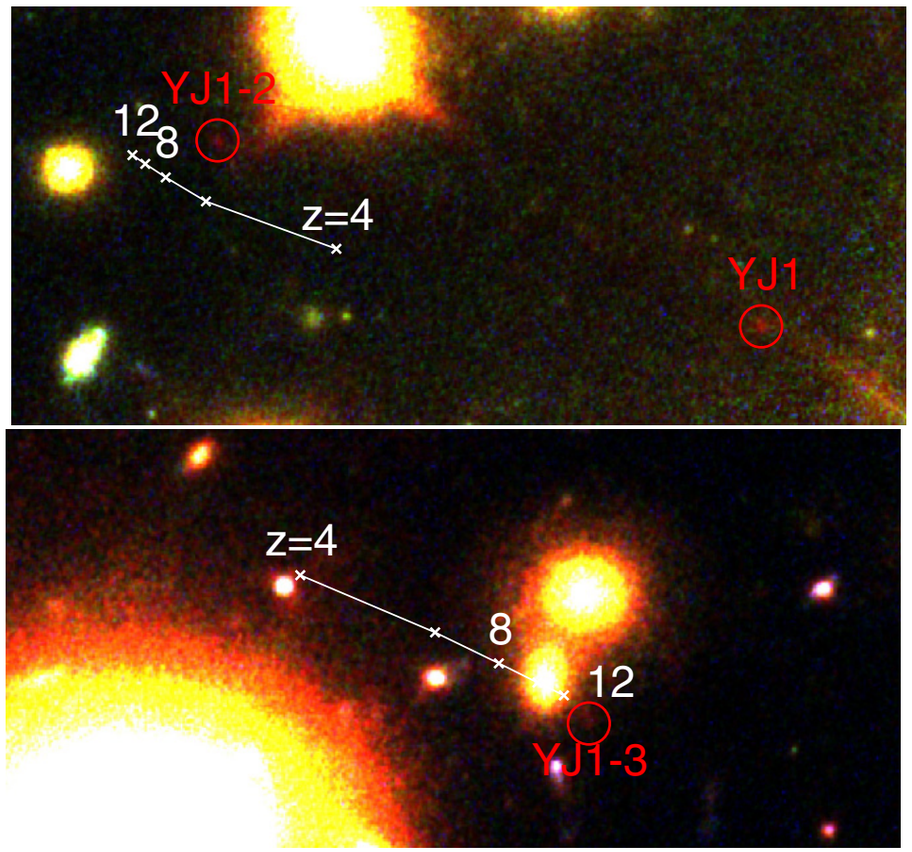
Ishigaki et al. (2015)

- in a cluster field limiting mags are non-uniform due to ICL etc.
- also limiting mags and magnifications must be correlated

Complex lensing effect

- high-z galaxies are not point sources but extended
- selection function depends on not only magnification but also shear, spatial variation of magnification, ... (see, e.g., Oesch et al. 2015)
- also at high magnifications model error is very large, making the estimate of unlensed magnification inaccurate

Image multiplicity



Ishigaki et al. (2015)
[see also Zitrin et al. 2014]

- high-z galaxies can often be multiply imaged
- sometimes it's not clear whether candidate multiple images are real or not
  (e.g., Kawamata et al. in prep.)
- not all multiple images are detected (above mag limit)

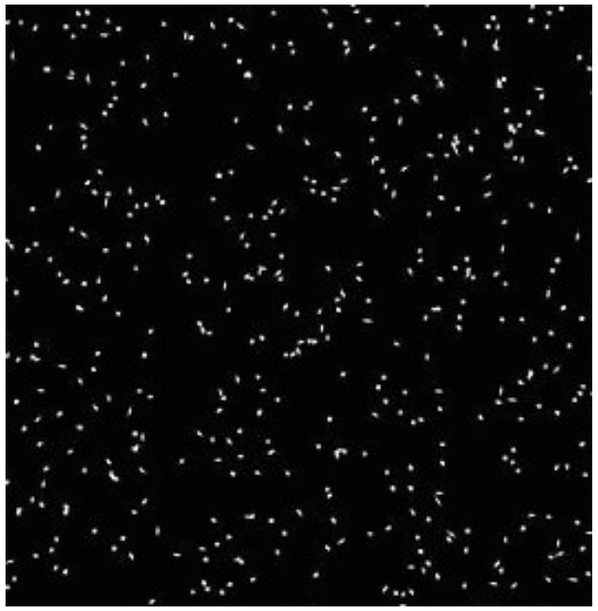
Ishigaki et al. ApJ **799**(2015)12

Our approach: Image plane approach

- compare number counts of galaxies in the image plane
- full Monte Carlo simulations including all lensing selection effects to predict observed number counts for each input LF model

Ishigaki et al. ApJ **799**(2015)12

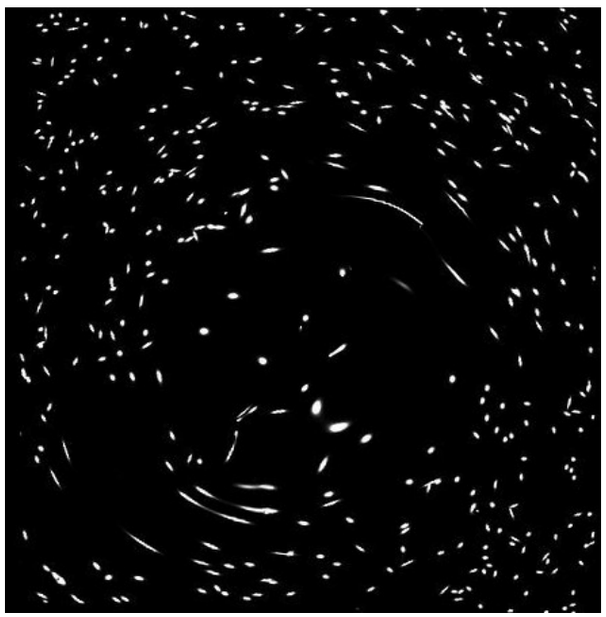
Our approach: Image plane approach



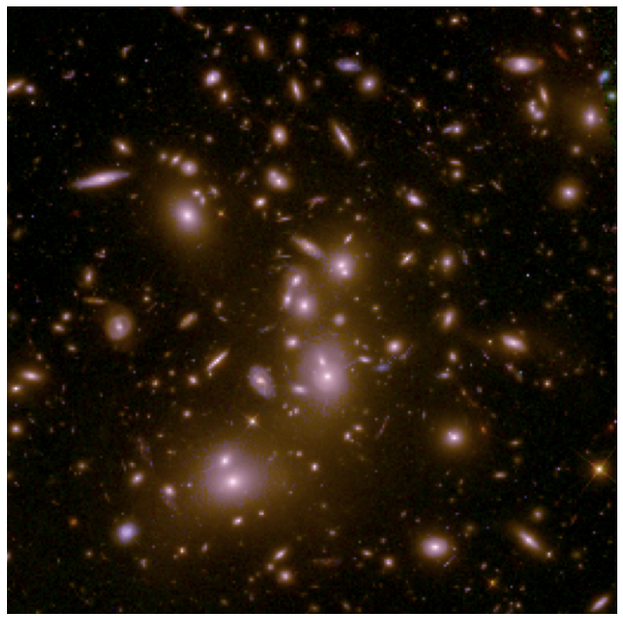
Schechter param
(Φ*, M*,α)

populate
galaxies

lensing
effect w/ glafic



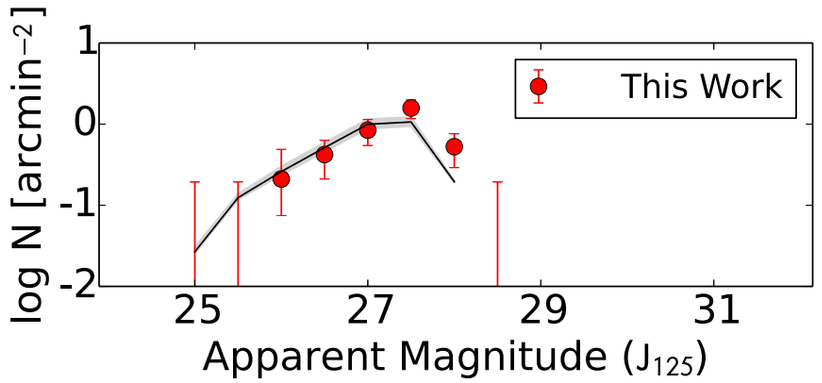
add to
HFF
image



mock
observation

Number count
(N vs m_{obs})

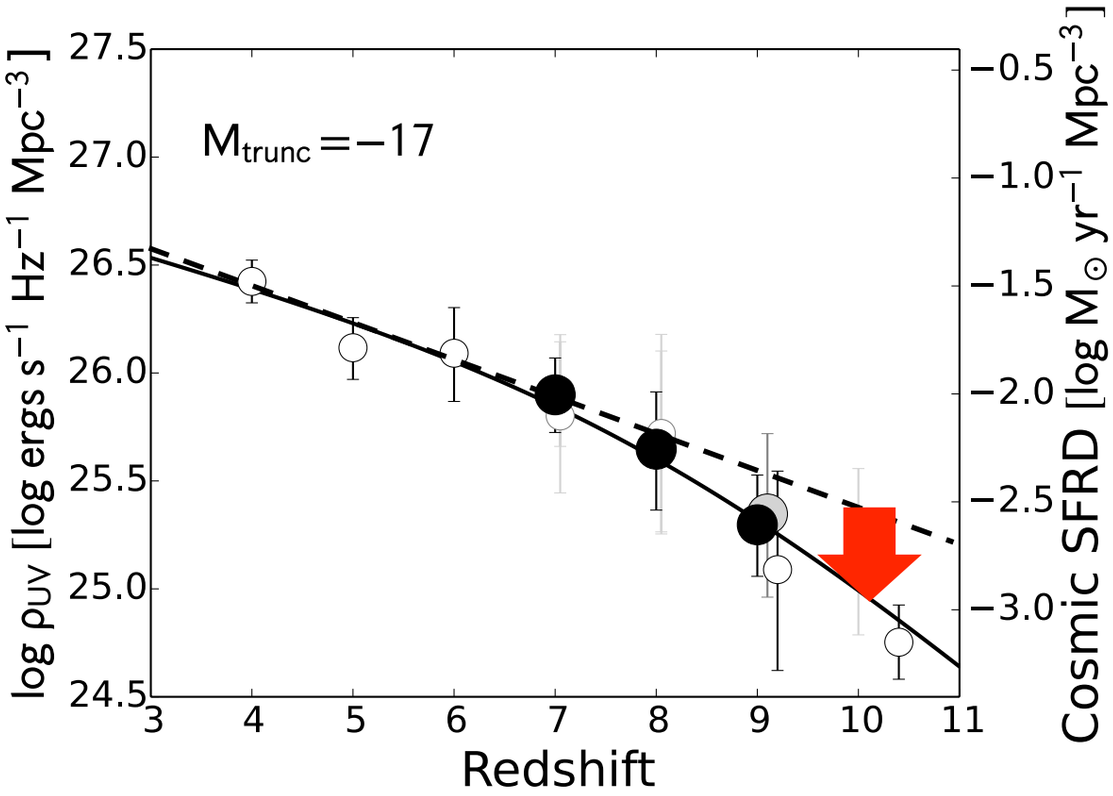
fitting to observed
number counts
→ best-fit param

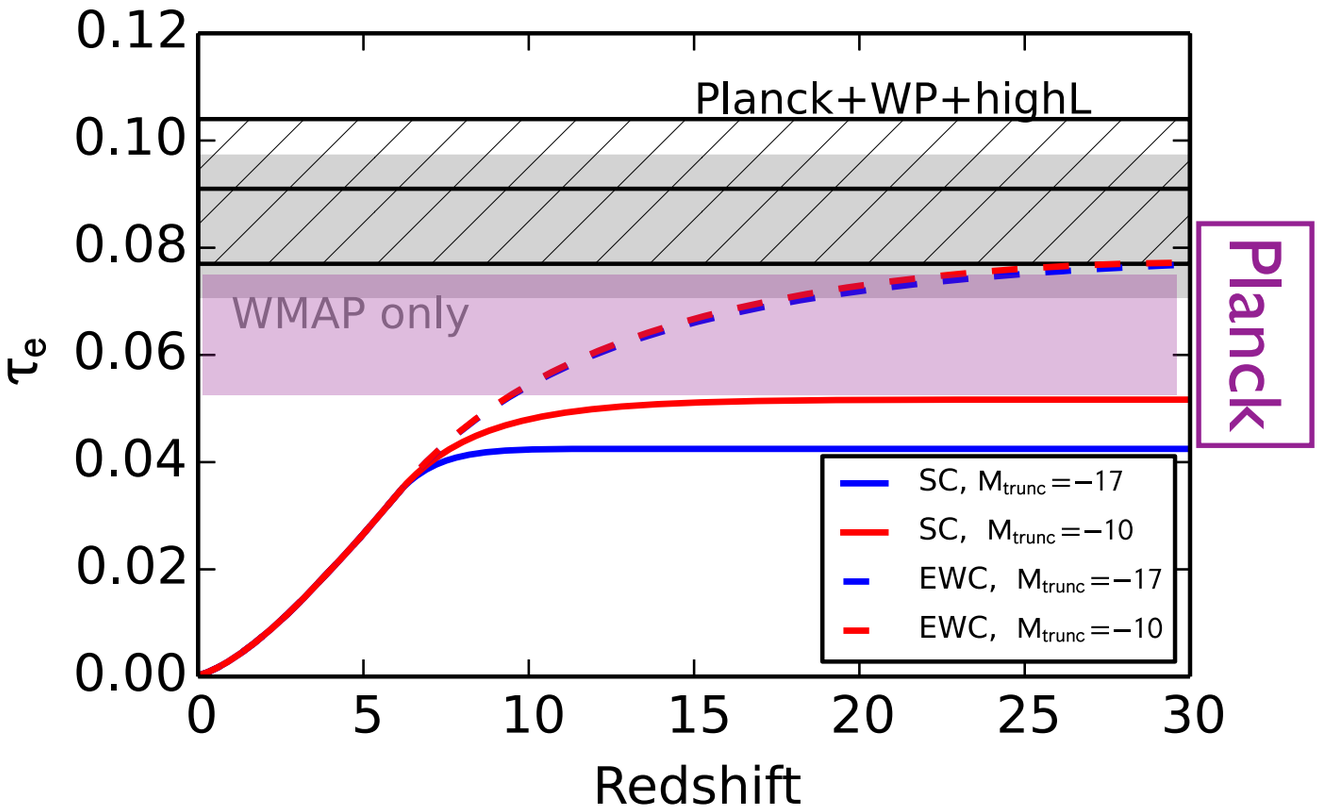


complex lensing/selection effects fully included!

Ishigaki et al. ApJ **799**(2015)12

Implication for cosmic reionization





- confirm rapid decrease of ρ_{UV} at z>8
- in tension with large τ from WMAP, but tension decreased in Planck

Kawamata et al. ApJ **804**(2015)103

Image plane approach to galaxy size

- traditional approach has been to measure galaxy sizes by fitting normal (unlensed) Sersic profile to lensed galaxy image and then correct for magnification

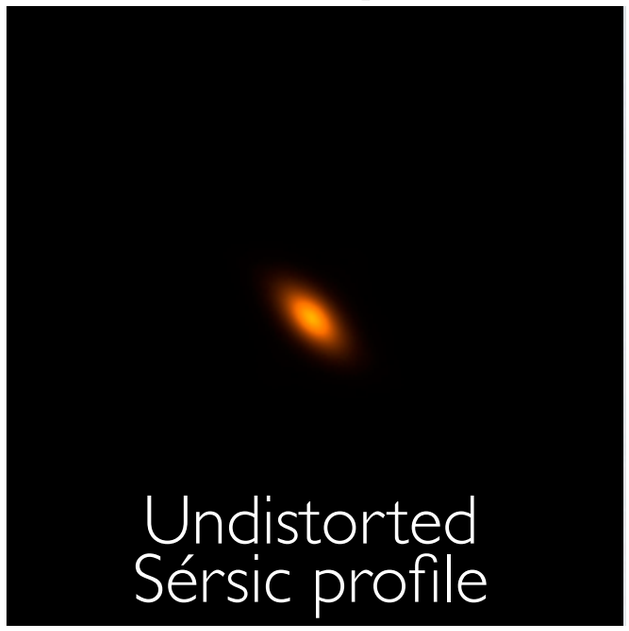
- we directly fit lensed and distorted Sersic profile to observed galaxy image

Kawamata et al. ApJ **804**(2015)103

Image plane approach to galaxy size

Sersic param
(M, re, e, PA)

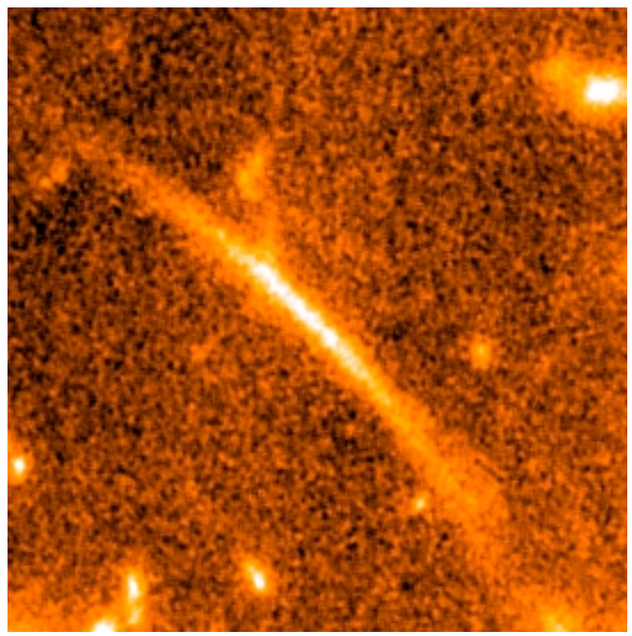
source plane



lens effect
w/ glafic

image plane

image
fitting

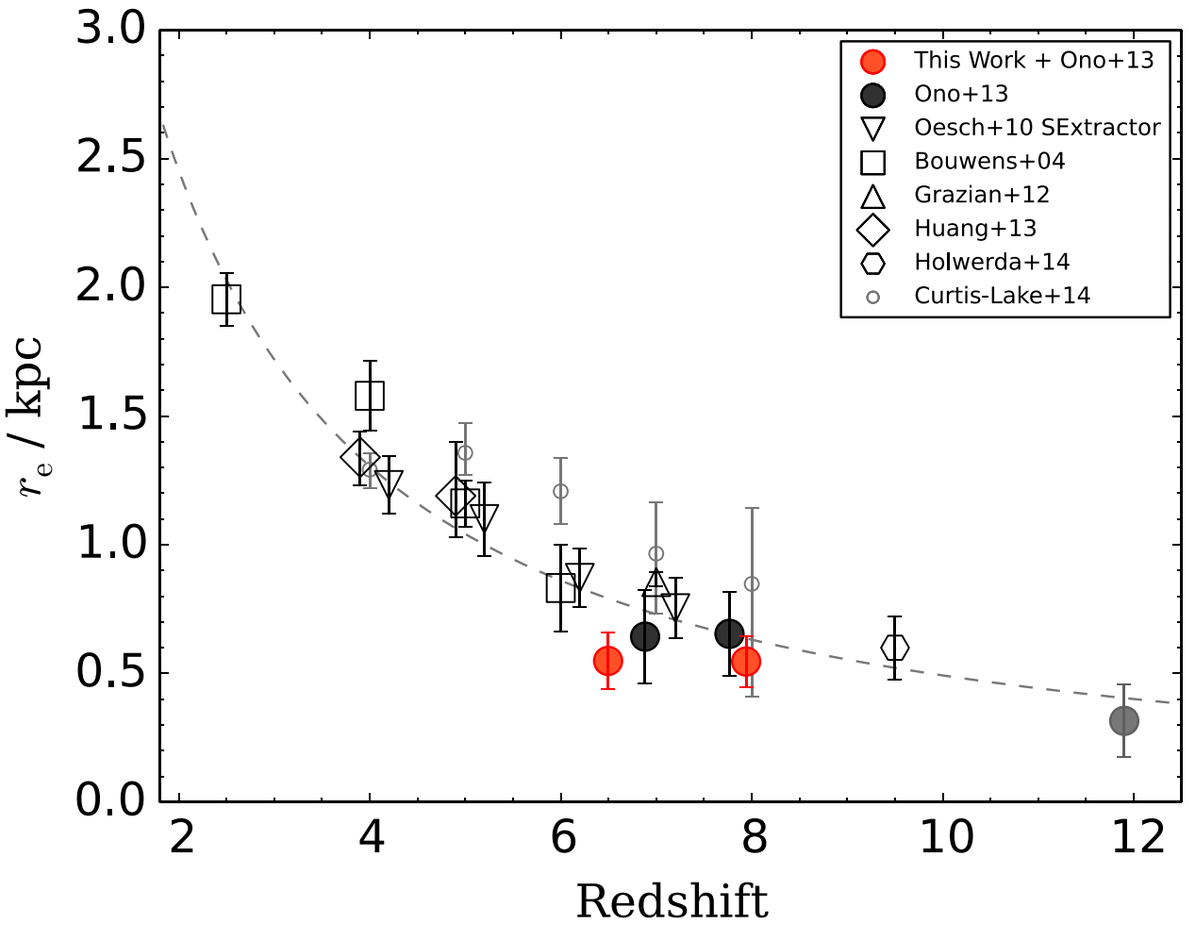


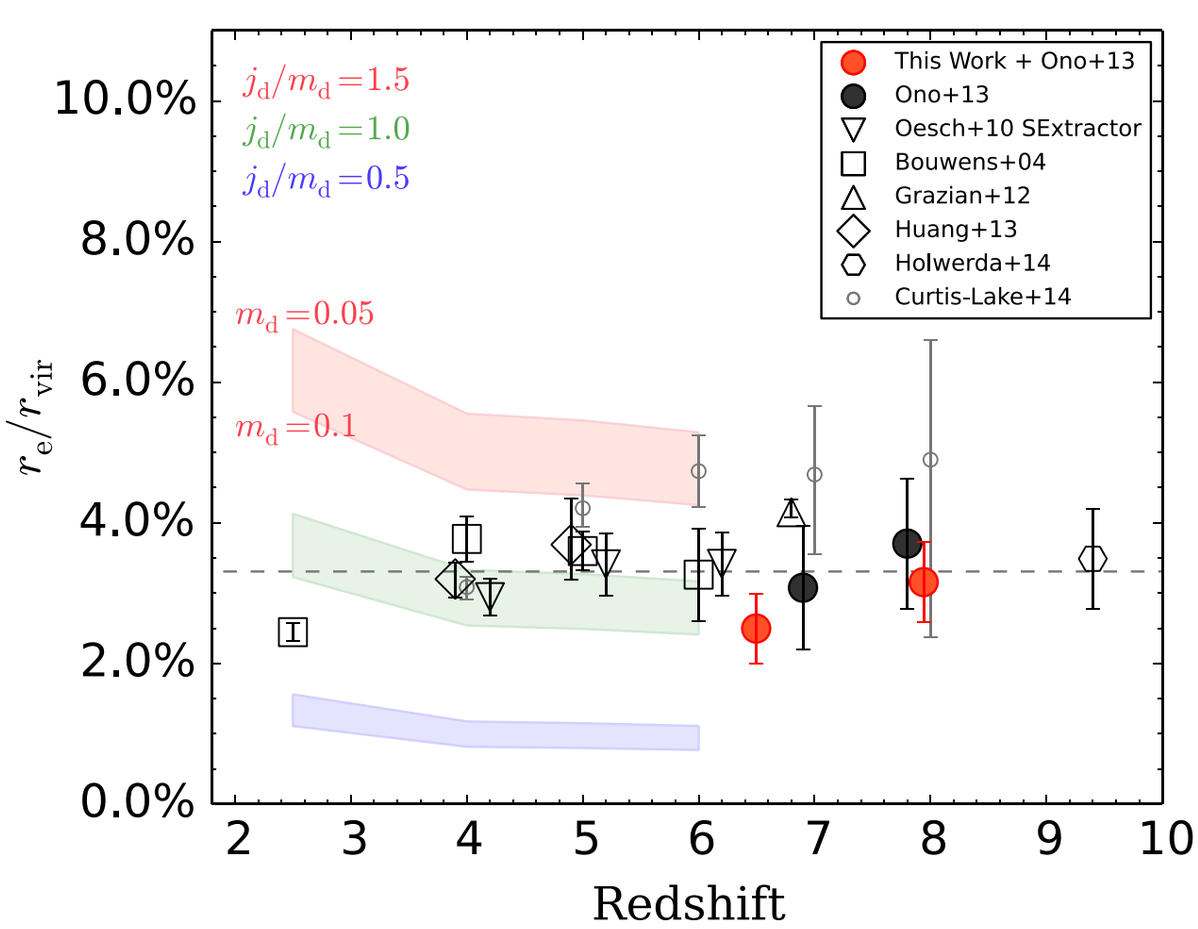
galaxy in
HFF image

best-fit
parameters

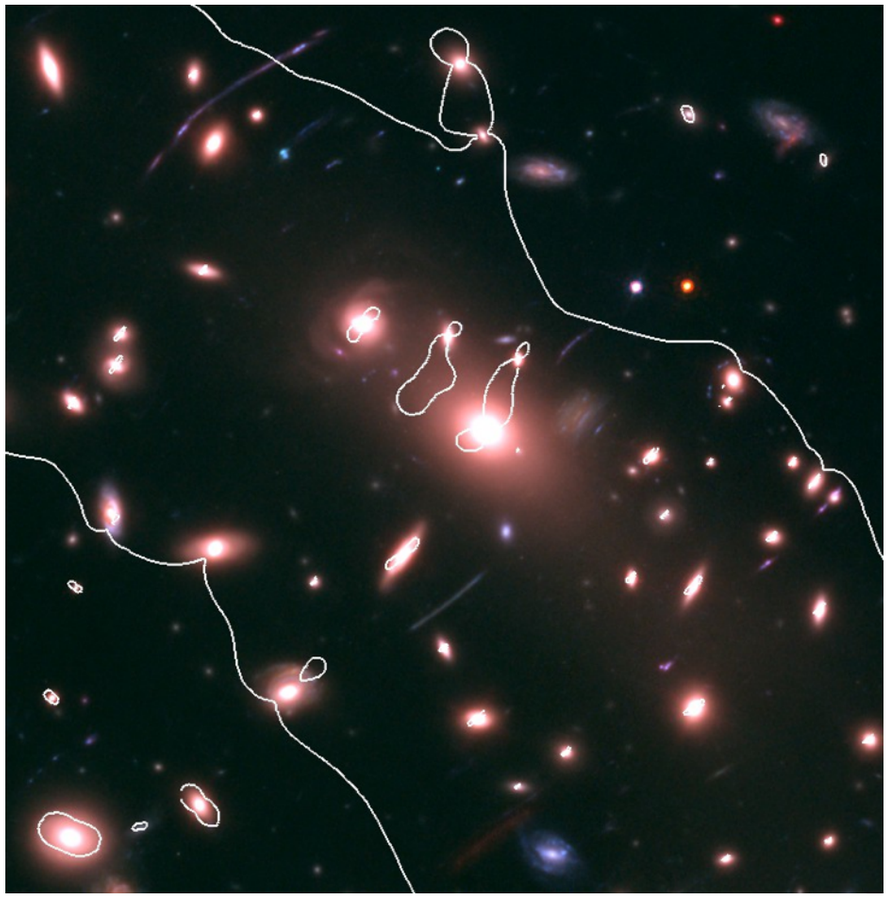
Kawamata et al. ApJ **804**(2015)103

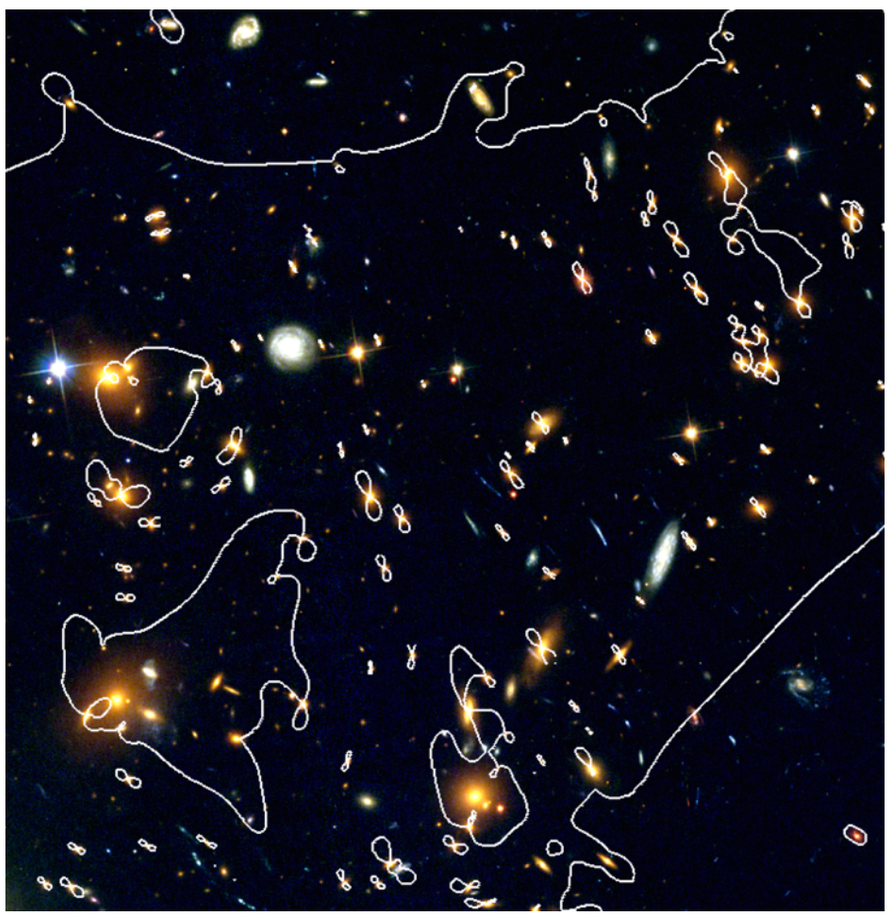
Evolution of galaxy sizes

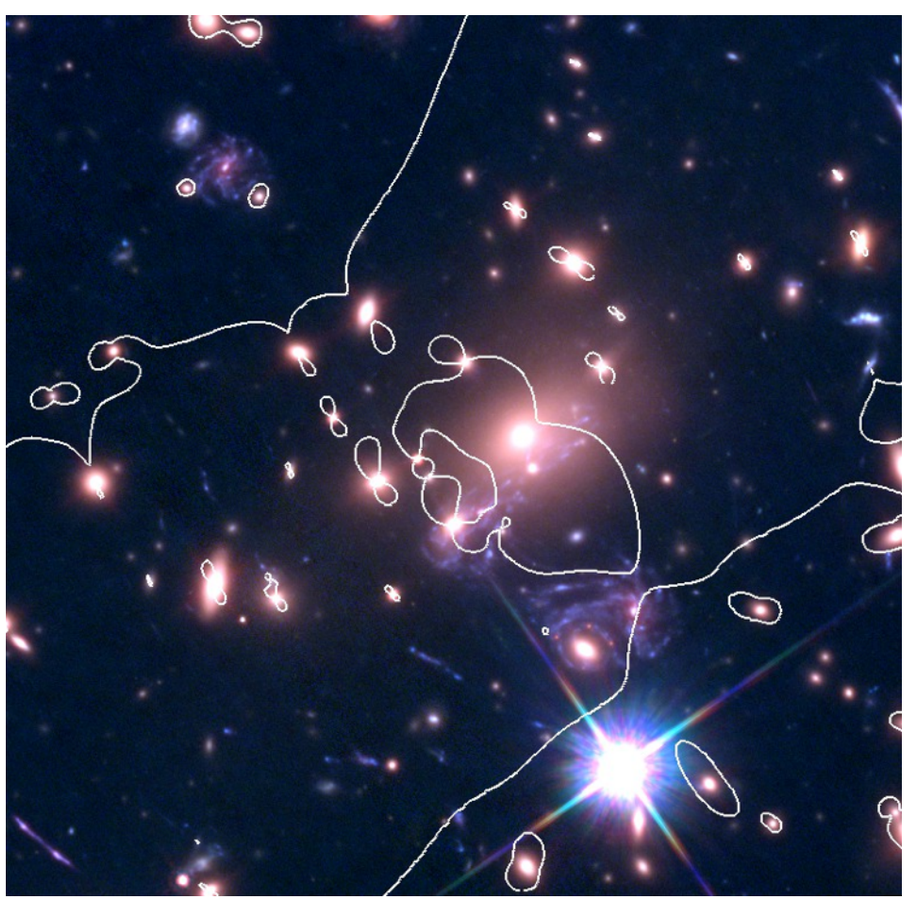




- galaxy sizes evolve with $\propto(1+z)^{-1.24}$
- ratio of galaxy size to virial radius of host halo is almost constant (~3.3%) over wide z range
  [host halo mass from abundance matching]



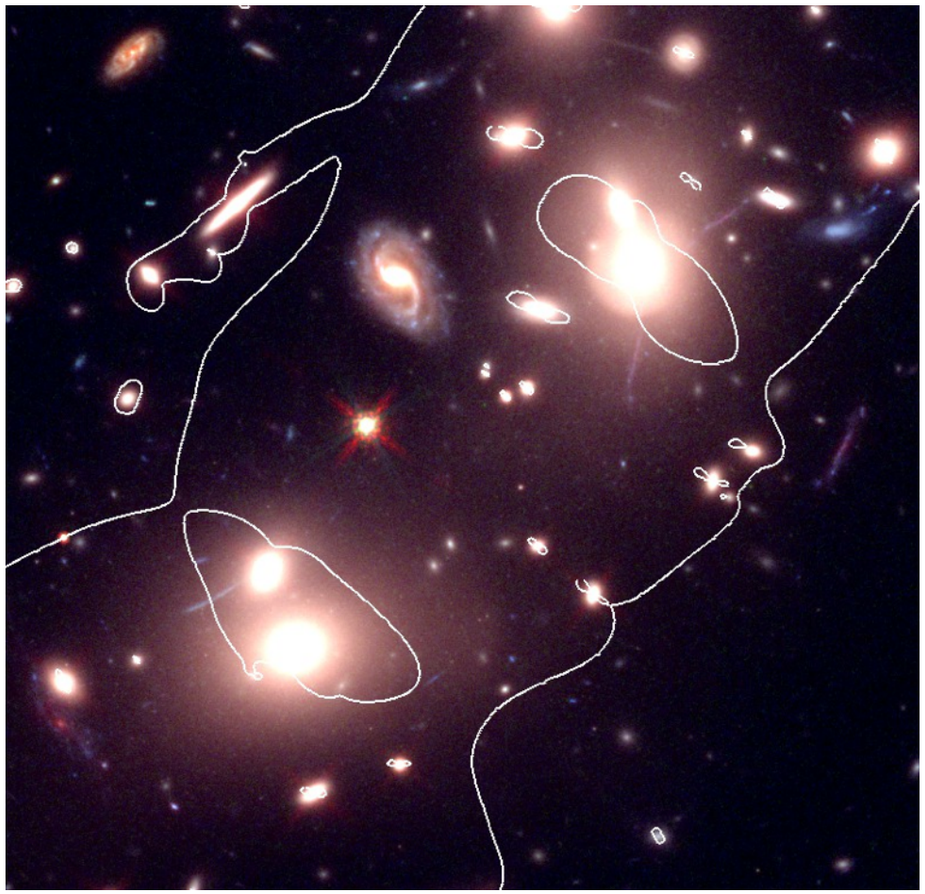


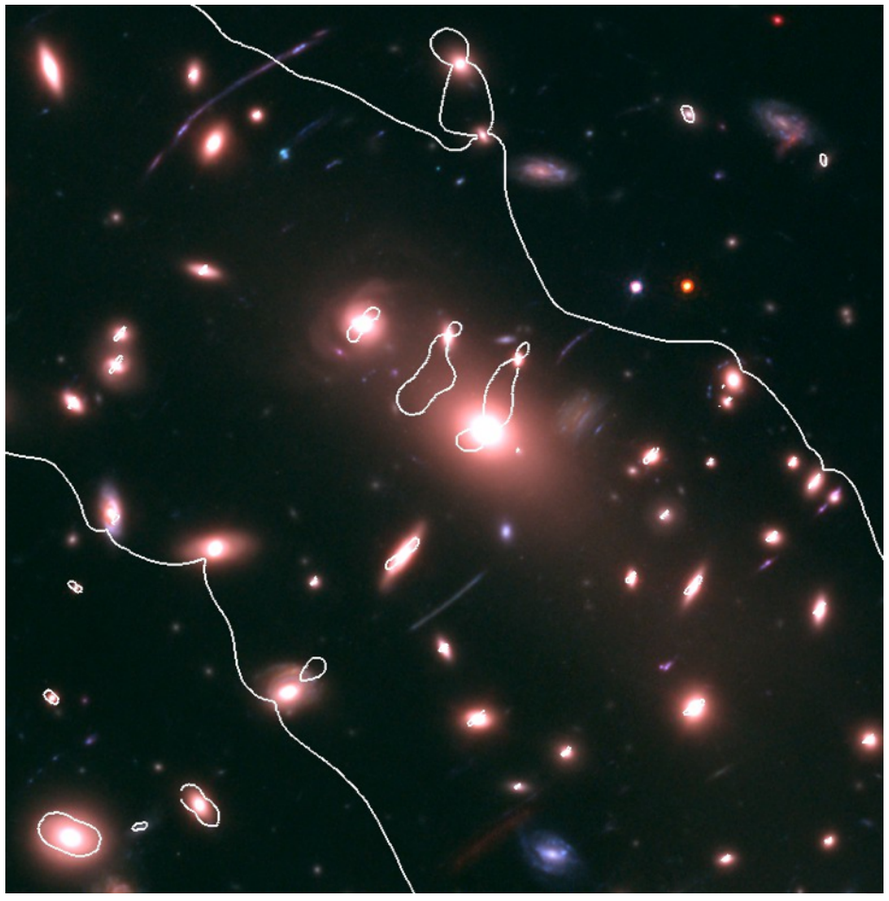


Current status: mass modeling of 4 clusters are ongoing

accuracy: image position RMS ≲ 0.4”

(Kawamata et al. in prep)





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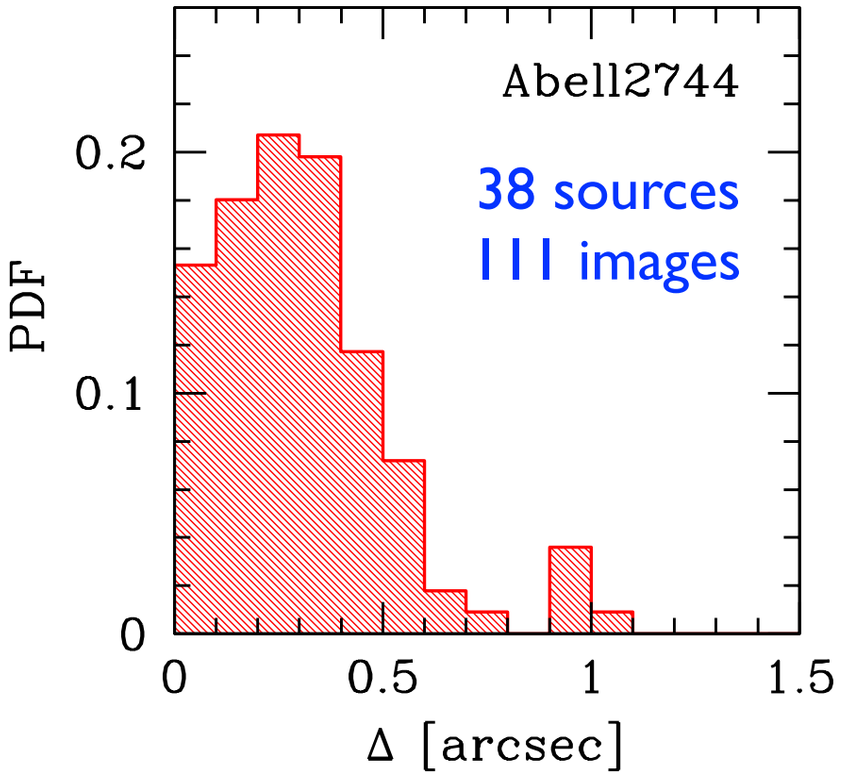

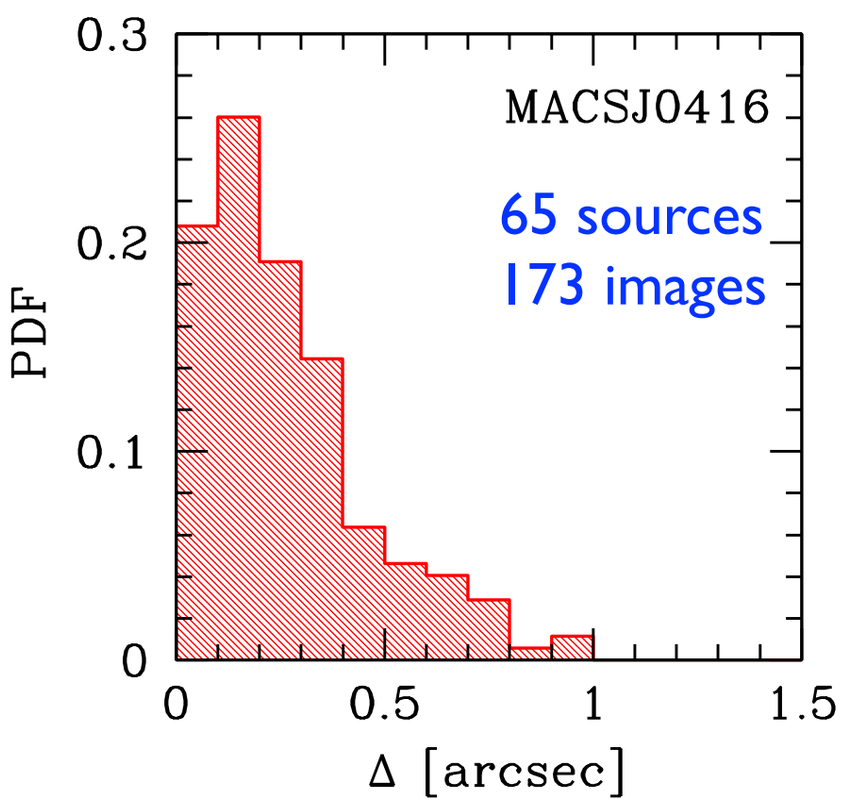

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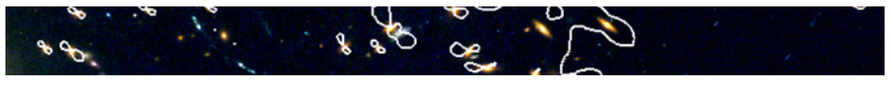

Summary

- image plane approach offers a robust route to extract high-z info from cosmic telescopes
- the publicly available software *glafic* provides useful tools for this
- interesting results on reionization and galaxy sizes (from the analysis of A2744 only!)
- analysis of more HFF clusters ongoing