High precision cluster lensing modeling

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and the CATS team

Questions?

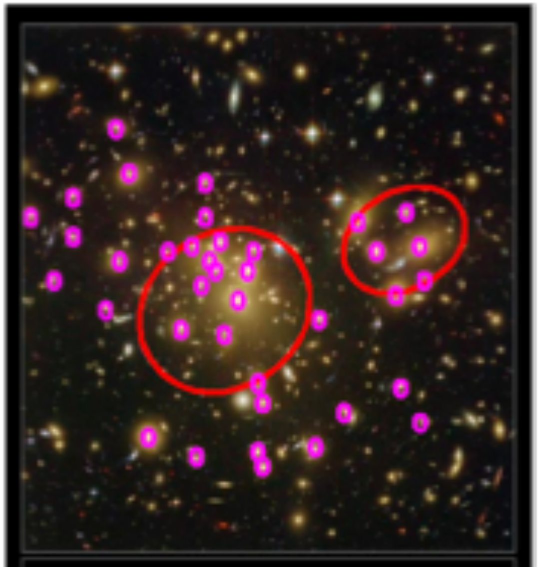
- What is the modeling precision needed for which accuracy on a particular science topic?

- Is the modeling precision proportional to the number of multiple images to fit?

Strong lensing modeling strategies

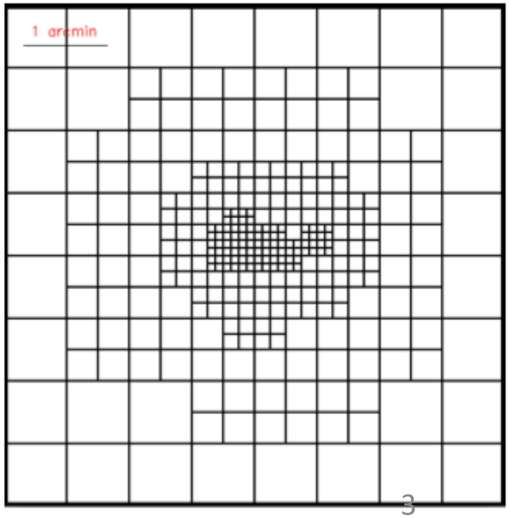
1) Observationally motivated models

- Decomposition into halos
- Good fit with few constraints
- Direct test of N-body derived models with evidence model ranking



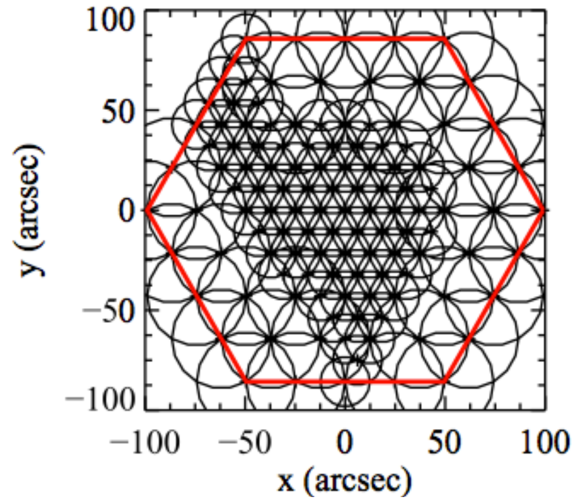
2) Free-form models

- Decomposition into RBF *"pixels"*
- Better fit with lots of constraints
- Good at
  - Detecting substructures
  - Testing Light Traces Mass assumption



Multiscale RBF model

Jullo et al. 2009, 2014



Linearized weak lensing equations

$$\mathbf{e} = \mathrm{M}_{\gamma\nu}\, \mathbf{v} + \mathbf{n}$$

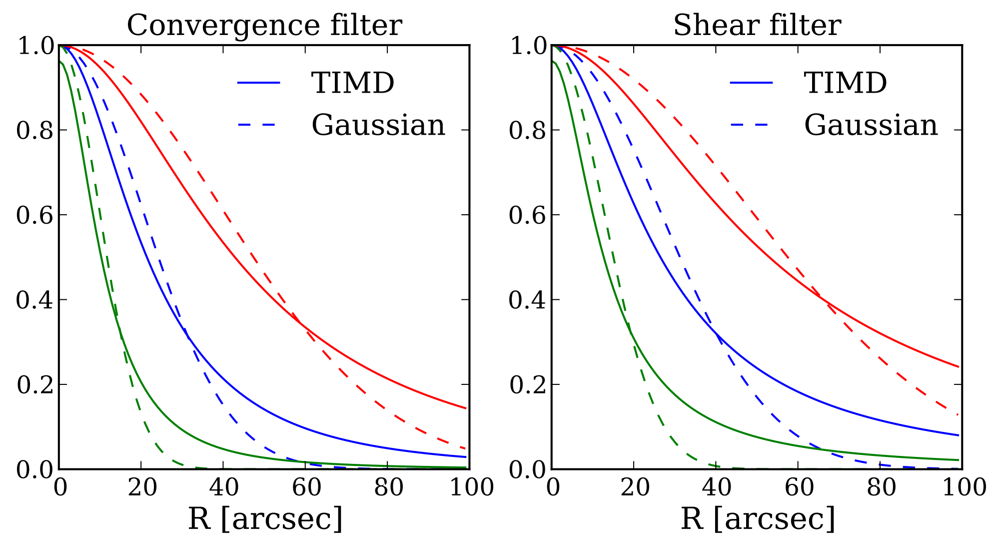
With data $\mathbf{e} = [\mathbf{e_1}, \mathbf{e_2}]$ and unknown $\mathbf{v} = [\nu_1, \ldots, \nu_N]$

$$\mathrm{M}_{ij} = \mathrm{D}_{\mathrm{LSi}} / \mathrm{D}_{\mathrm{OSi}}\, f_j(|\,\theta_i - \theta_j\,|)$$

f_j functions are derivatives of the TIMD potential (circular PIEMD)

Here the convergence is:

$$f(R,s,t) = \frac{1}{2G}\frac{t}{t-s}\left(\frac{1}{\sqrt{s^2+R^2}} - \frac{1}{\sqrt{t^2+R^2}}\right)$$

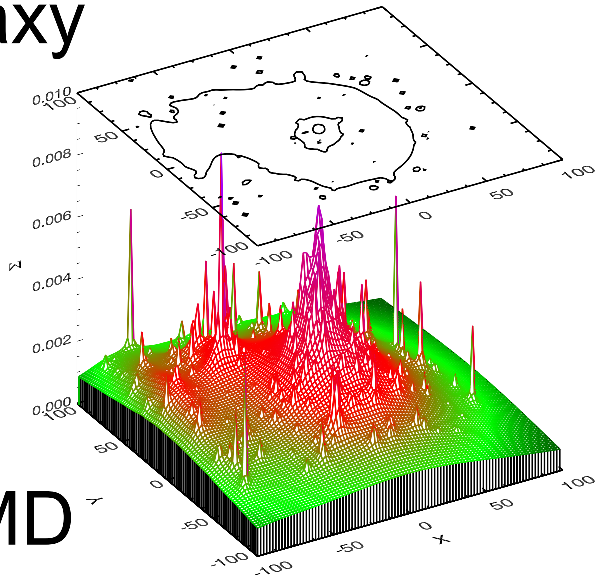


The RBFs density can be matched to the light distribution

Galaxy scale components model

Kneib et al 1996

- Large scale cluster component+galaxy halo components (stars+DM):



$$\phi_{tot} = \phi_{cluster} + \Sigma_i \phi^i_{halos}$$

- Need to scale the galaxy halo components, for example for a PIEMD mass distribution:

$$\sigma = \sigma_* (\frac{L}{L_*})^{1/4} \quad r_{cut} = r^*_{cut} (\frac{L}{L_*})^{\eta}$$

- Hence: $\frac{M}{L} \propto L^{\eta - 1/2}$ $\quad \eta = 1/2$ Constant M/L

$\eta = 0.8$ FP scaling

See also Mila's poster

New modeling of the Cluster Members

Brimioulle et al. 2013

- CM modeled with NFW profiles and scaling relation:

$$\left(\frac{M}{M^*}\right) = \left(\frac{L}{L^*}\right)^{\eta_M}$$

- Best fit for SDSS red galaxies $L^* = 1.6\ 10^{10}\ h^{-2}\ L_{r,sun}$
- $\eta_{M200} = 1.05 \pm 0.12$ and $M^*_{200} = 18.6 \pm 0.8\ 10^{11}\ h^{-1}$ Msun

- Best fit of the simulated cluster with $L^* = 1.2\ 10^{10}\ h^{-2}\ L_{K,sun}$
- $\eta_{M200} = 0.54 \pm 0.16$ and $M^*_{200} = 4.1 \pm 0.3\ 10^{11}\ h^{-1}$ Msun

Errors due to galaxies modeling

D'Aloisio & Natarajan 2010

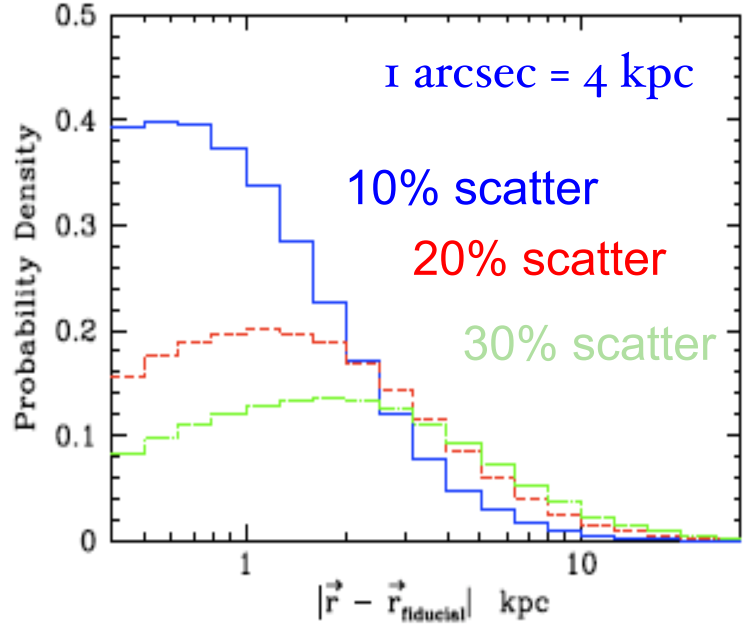
PIEMD
parameters
20% scatter

$$\begin{cases} \sigma_0 = \sigma_0^\star \left(\dfrac{L}{L^\star}\right)^{1/4}, \\ r_{\rm core} = r_{\rm core}^\star \left(\dfrac{L}{L^\star}\right)^{1/2}, \\ r_{\rm cut} = r_{\rm cut}^\star \left(\dfrac{L}{L^\star}\right)^{\alpha}. \end{cases}$$

The total mass of a subhalo scales then as:

$$M = (\pi/G)(\sigma_0^\star)^2 r_{\rm cut}^\star (L/L^\star)^{1/2+\alpha},$$

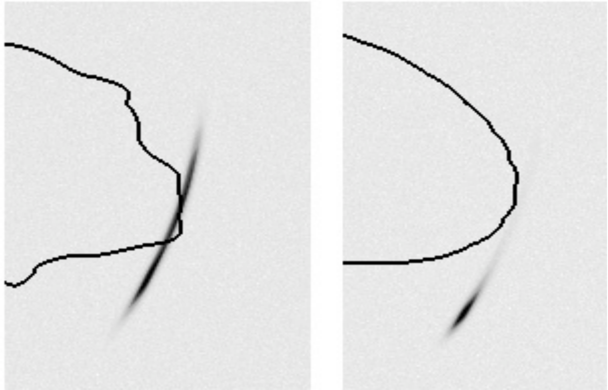
Jullo+07



- For A1689
- Scatter in the scaling relations ~ 1"

– > Scatter for each image

– > Images are weighted in χ^2 INDIVIDUALLY



Meneghetti+07

Errors due to deflections by LOS structures

D'Aloisio & Natarajan 2010

Cosmography with cluster strong lenses 7

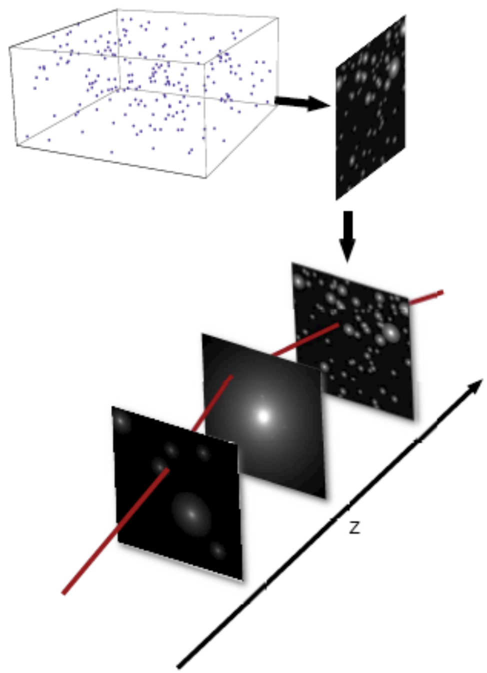
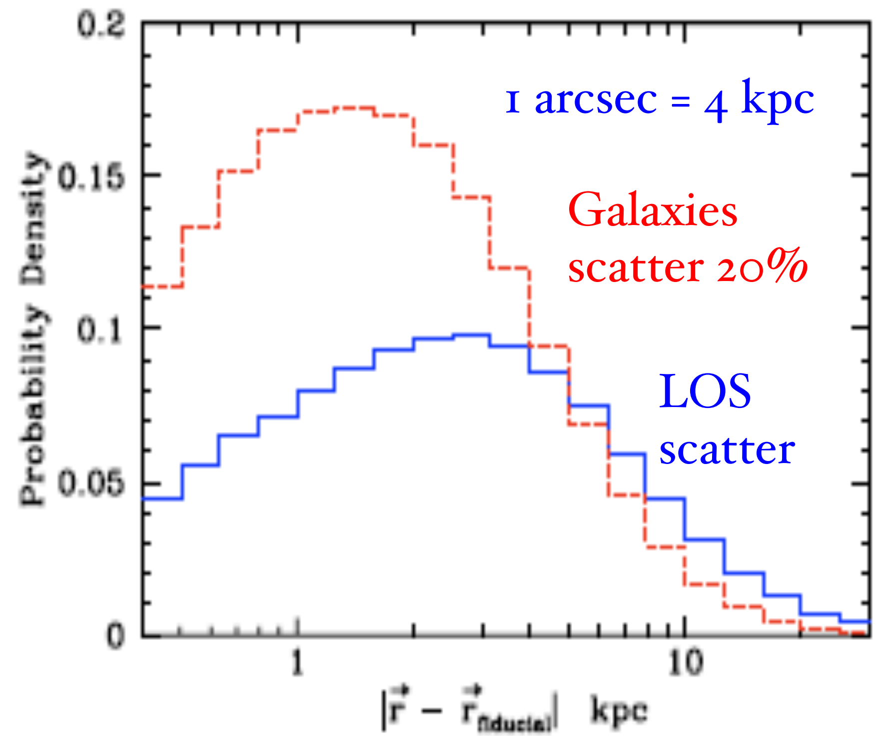


Figure 5. Schematic diagram illustrating the creation of lensplanes to quantify the effects of LOS halos. A rectangular slice of the Millenium Simula-



See also the talk by A. D'Aloisio

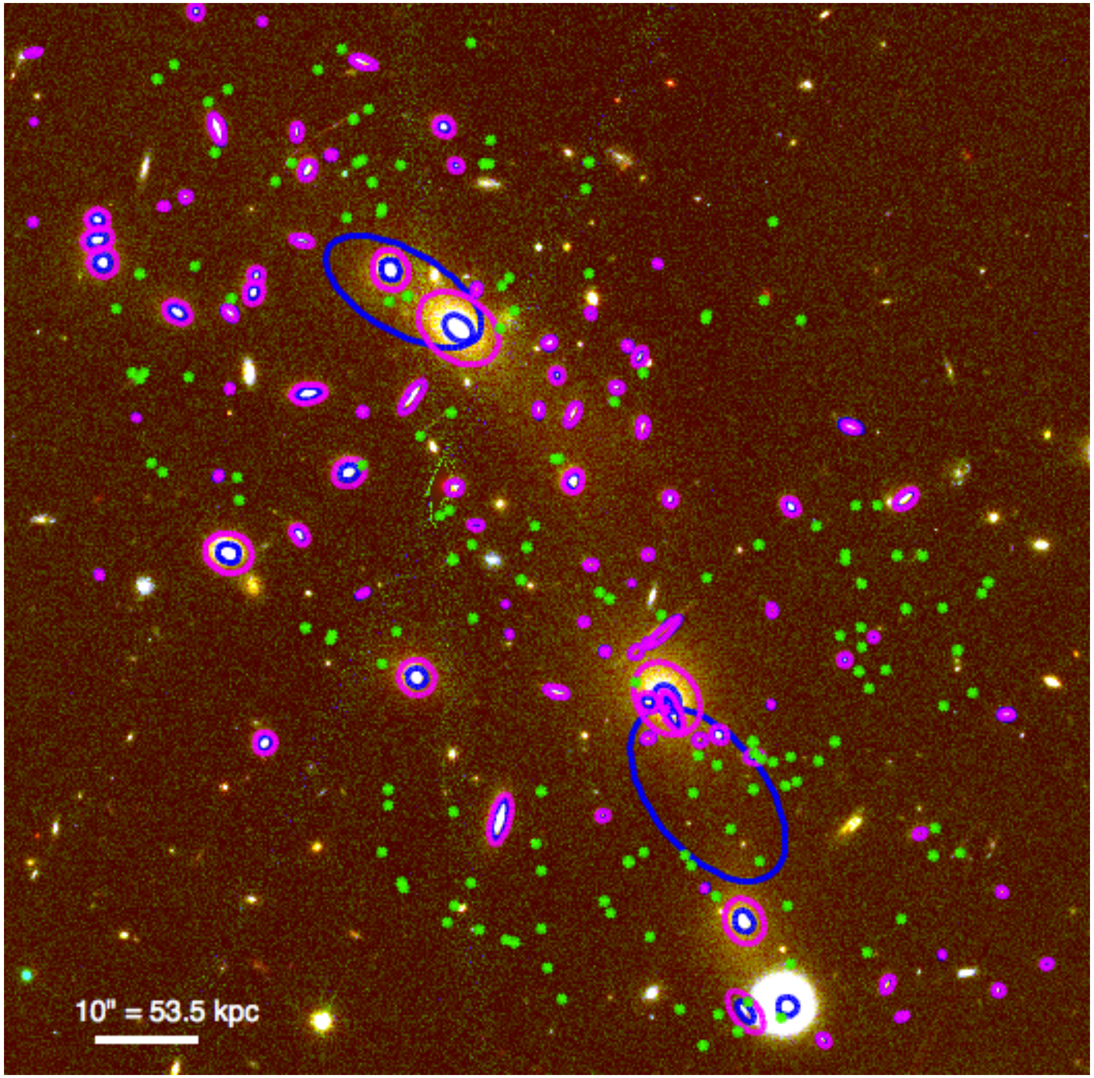
For A1689

•1" of scatter due to structures in the lens plane & along L.O.S.

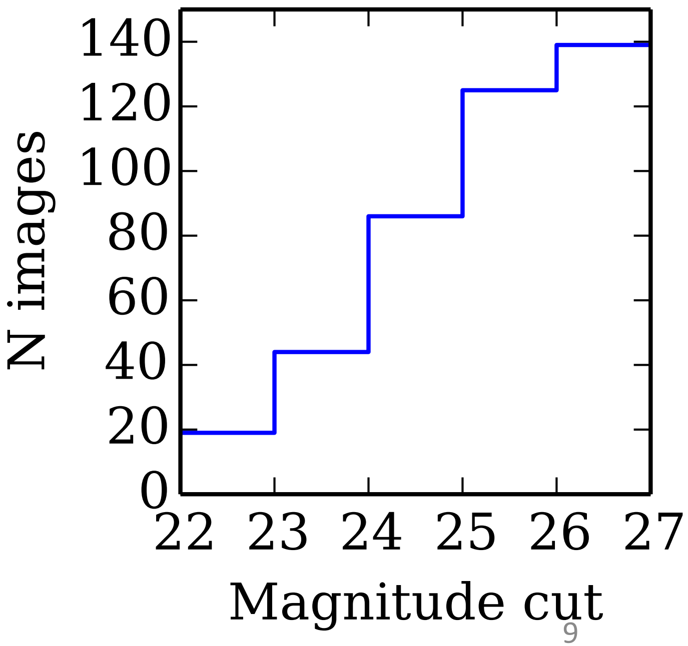
Correlated LOS (infalling subclusters, filaments)

Uncorrelated LOS (primary contribution to the errors)

MACS J0416.1-2403

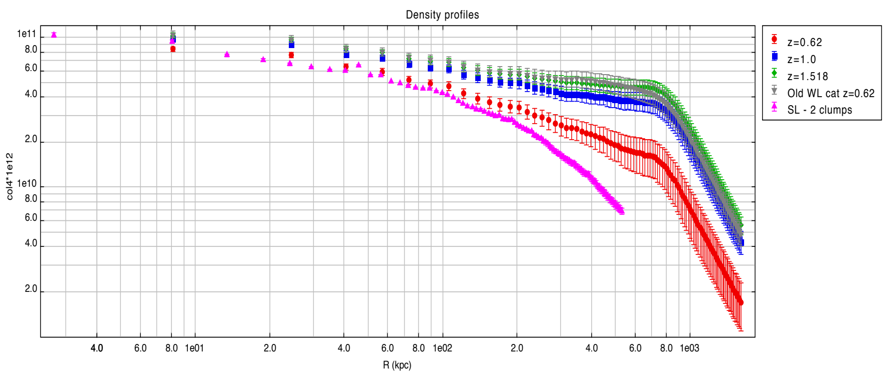


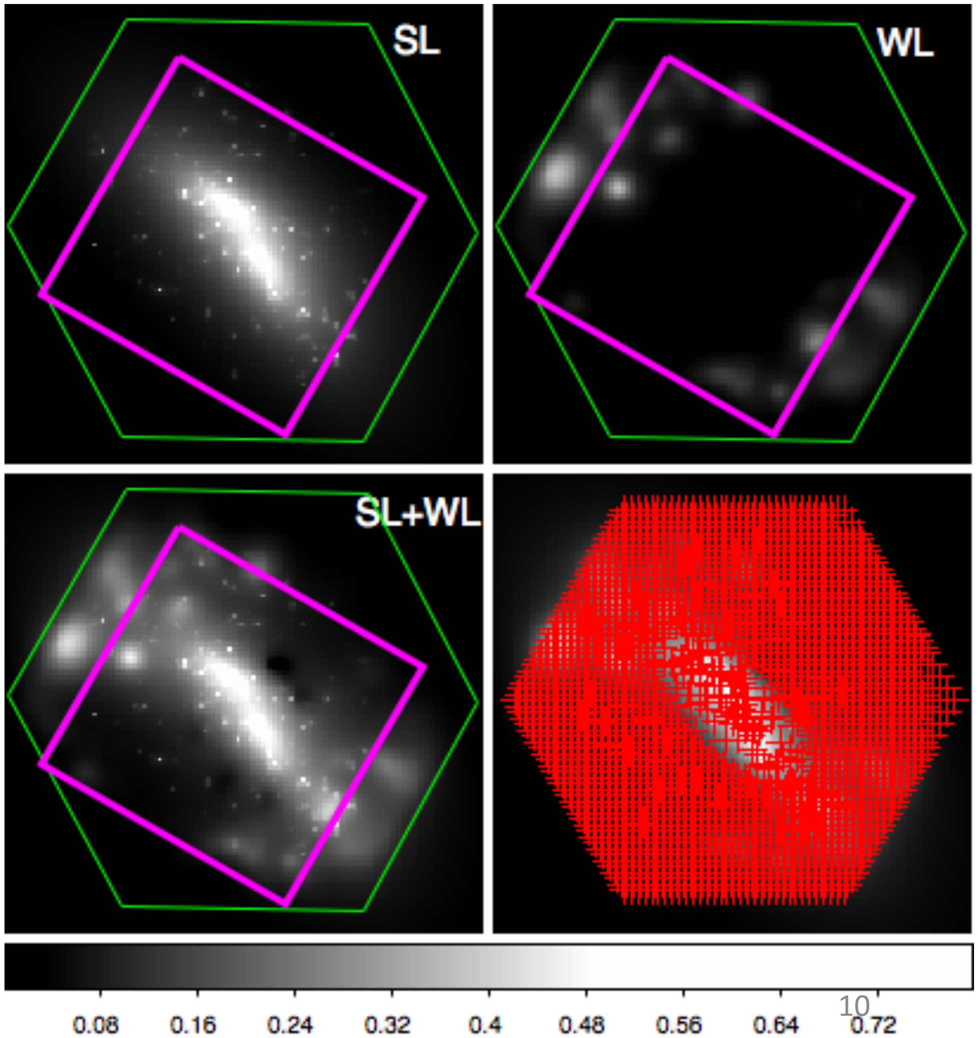
- 148 image constraints
- 57 systems
- 10 spec z
- 97 cluster members



Mixed *parametric* and free-form reconstruction to detect substructures

Joint SL+WL fit for grid-based model doesn't work yet





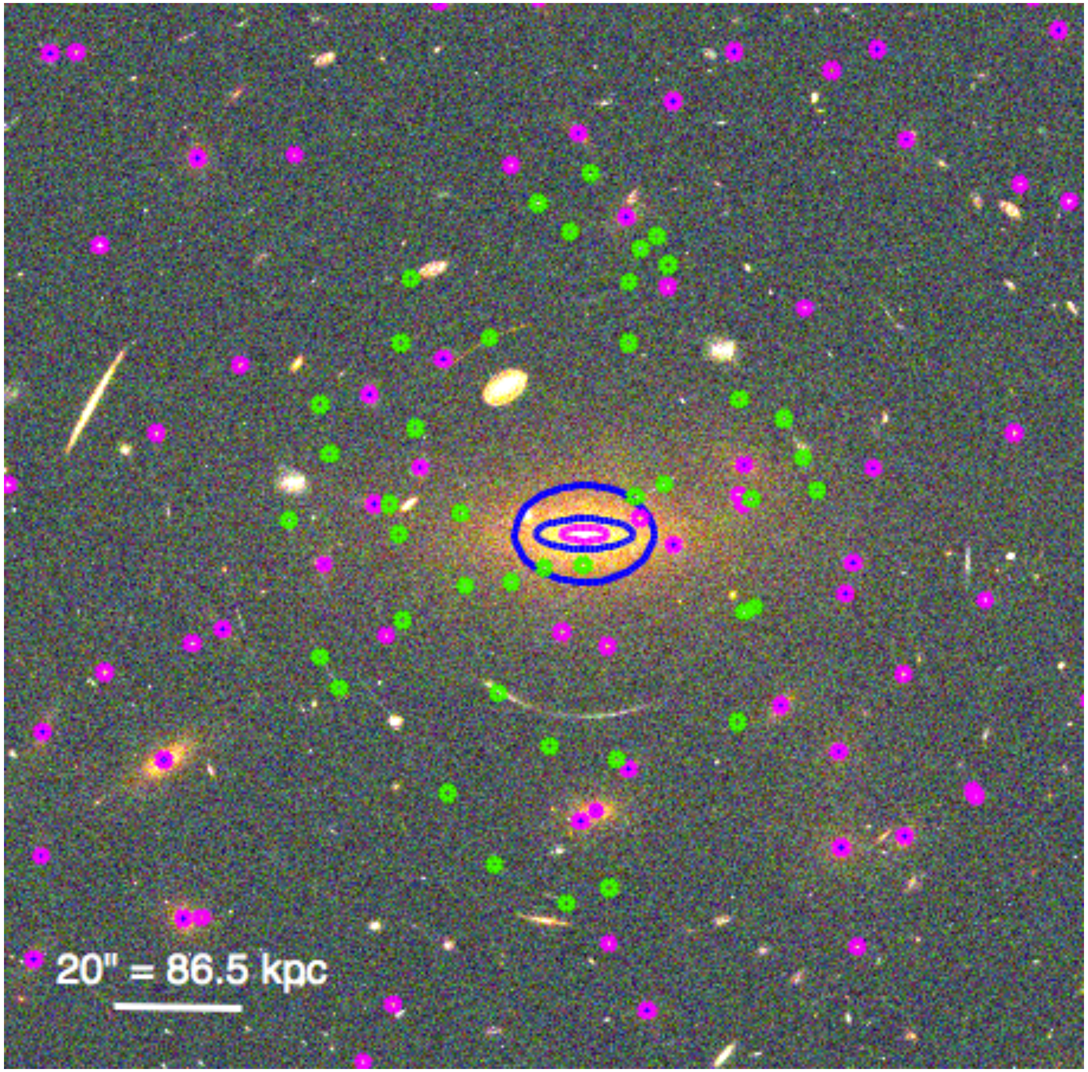
➔ Need to figure out SL and WL relative weights

Alternative, 2 step optimization

– Reconstruction with SL data
– WL reconstruction with prior parametric model

Impact of modeling technique

Strong lensing BLF Simulated cluster



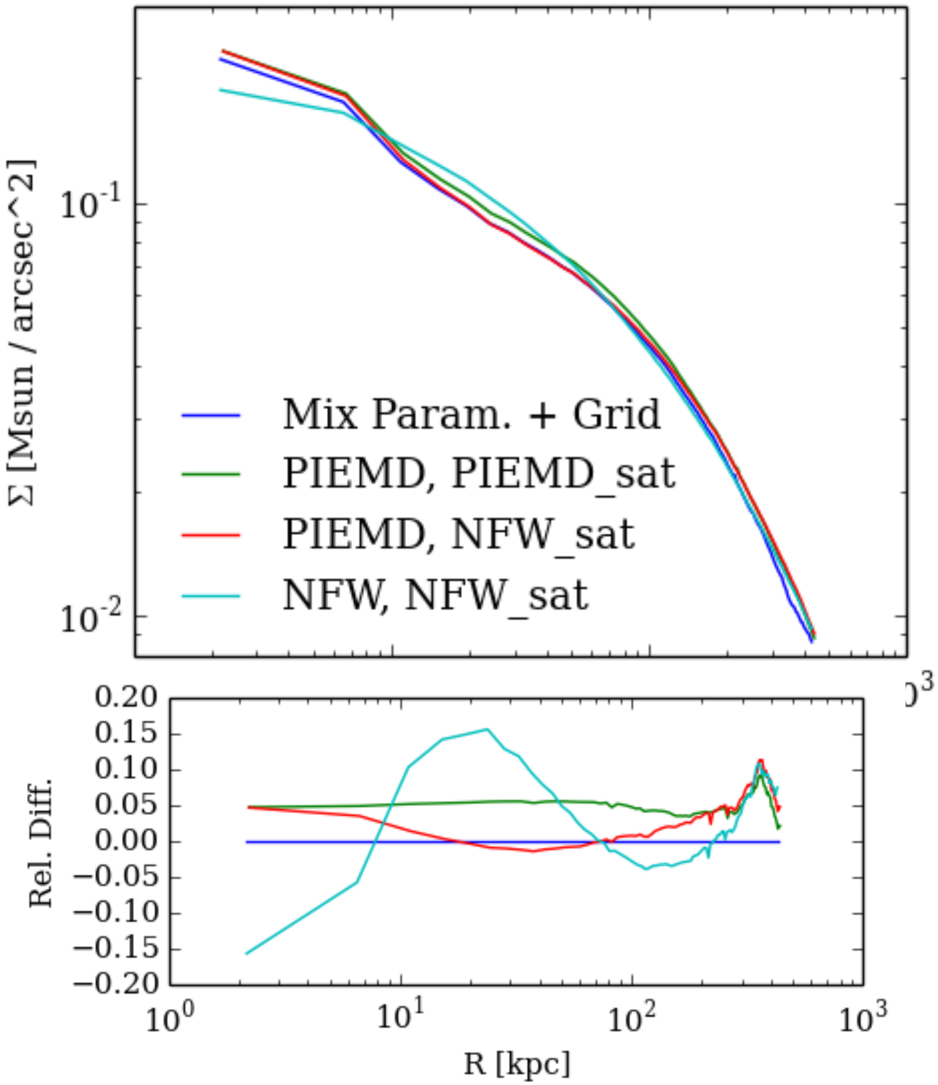
44 image constraints

126 Cluster Members

Optimized potential

- Cluster @ z = 0.288
- N-body-SAM simulation
- Skylens Ray tracing (Meneghetti et al. 2008)
- Simulated arcs from observed LF

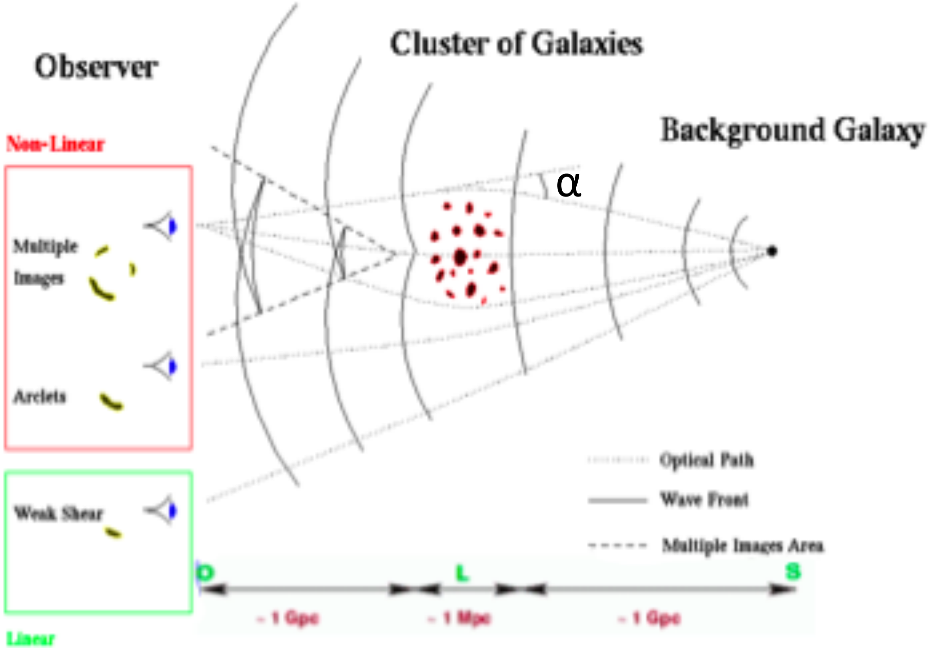
Density profiles Comparison

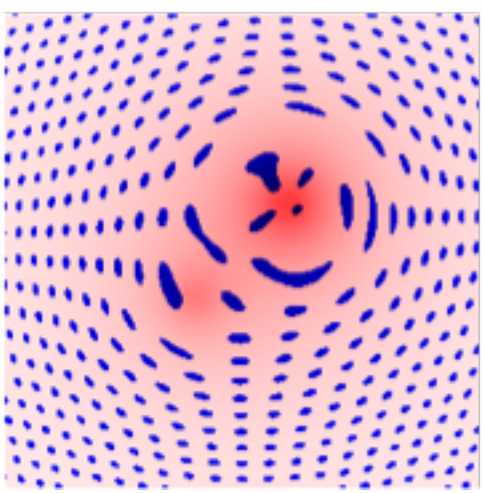


Model description	Best Chi2 (src)	Log (E)	RMSI
Mixed Param+Grid	50	-128	0.81
PIEMD, PIEMD sat	109	8.61	0.57
PIEMD, NFW sat	120	5.11	0.67
NFW, NFW sat	872	-326	1.25

Impact of missing data

Cosmography Methodology



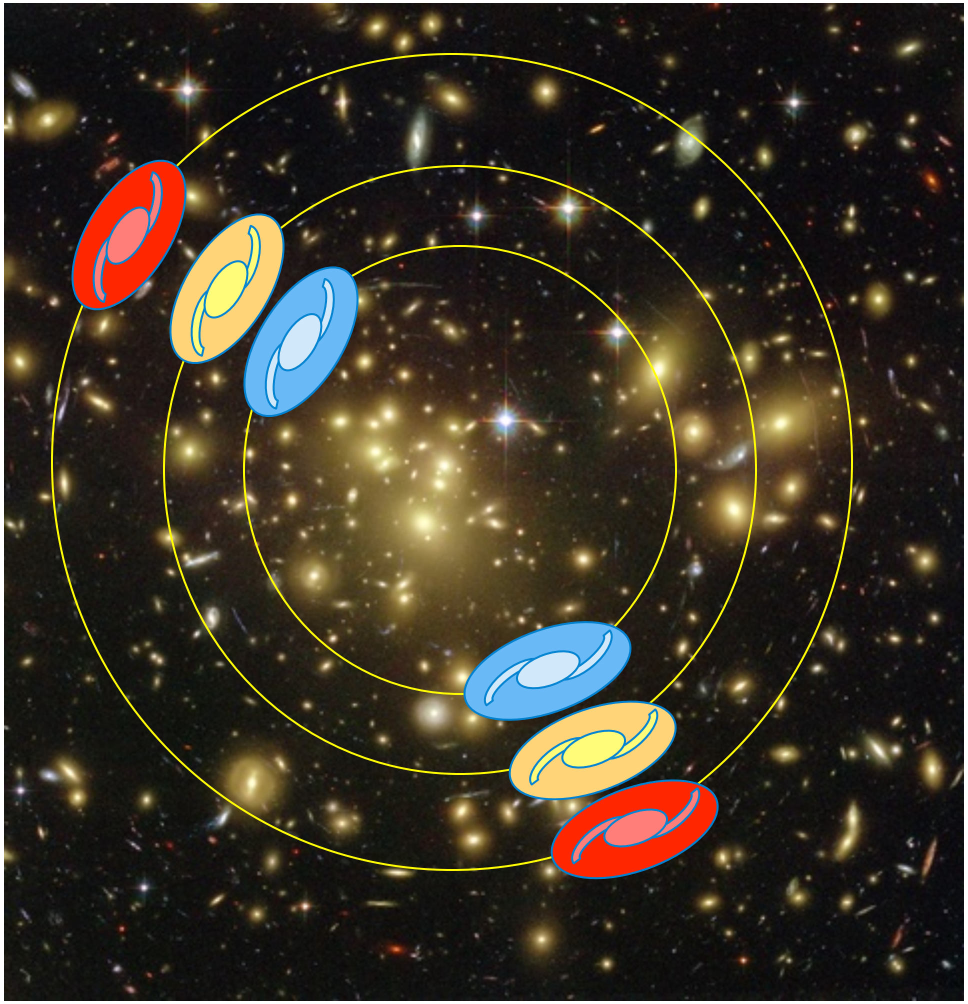


$$\alpha = \frac{D_{LS}}{D_{OS}} \nabla \varphi(\theta_I)$$

Cosmology

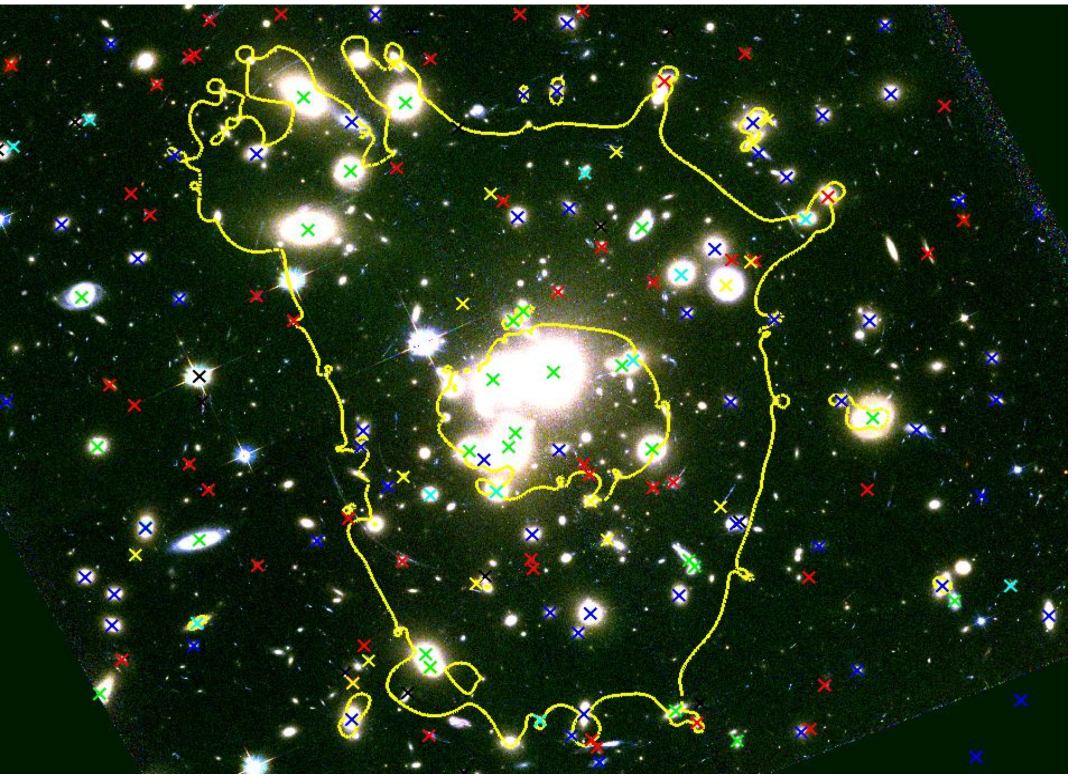
mass

Scaling with Cosmology or Mass??

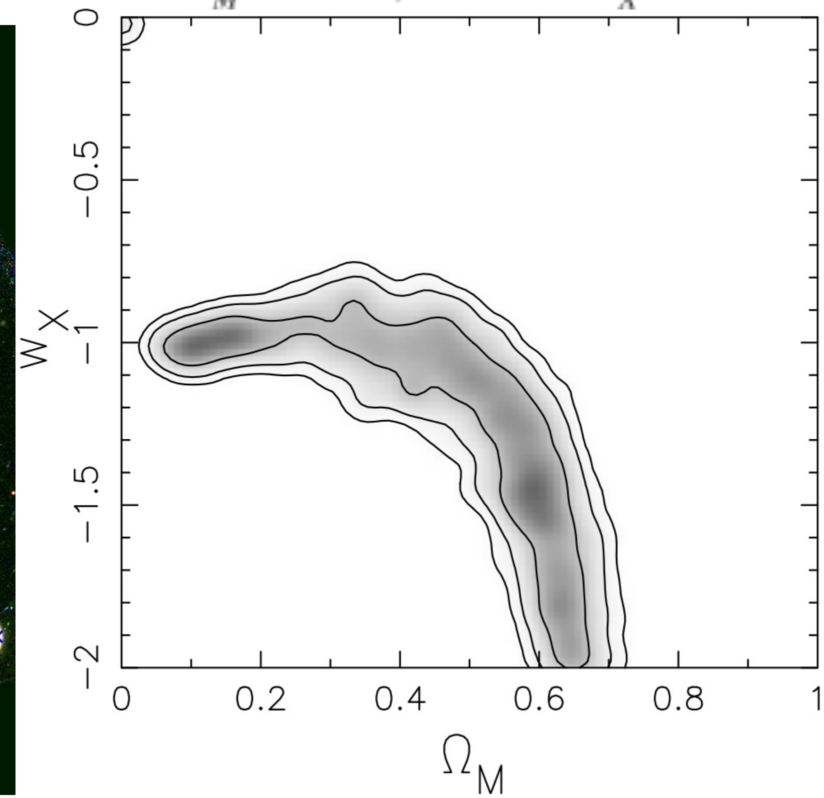


Cosmography with Abell 1689

Mass model with 3 PIEMD potentials; 58 cluster galaxies
Bayesian optimization: 32 constraints, 21 free parameters;
RMS = 0.6 arcsec; 28 multiple images from 12 sources with spec z, flat Universe prior

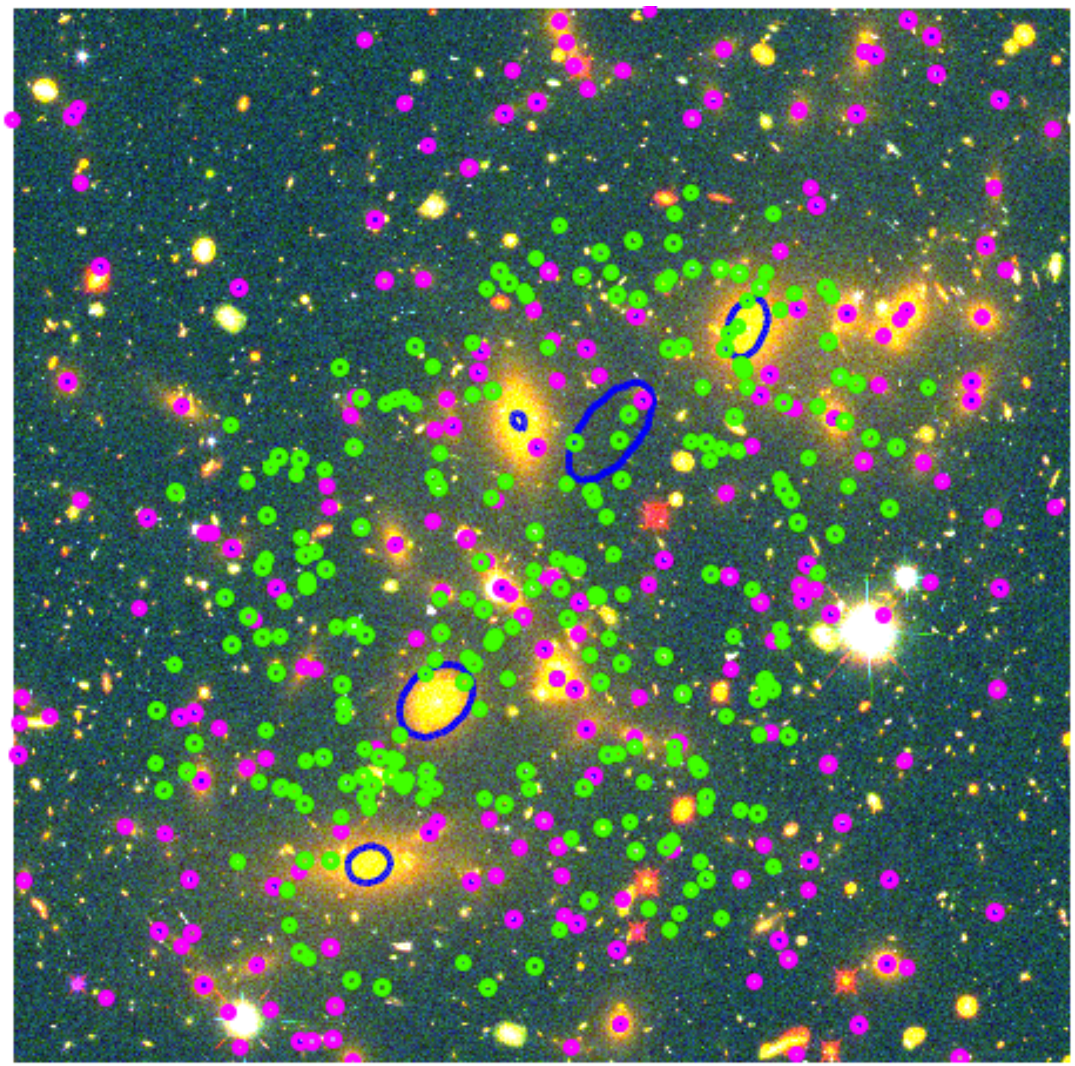


$0.1 \le \Omega_M \le 0.58; -1.57 \le w_X \le -0.85$

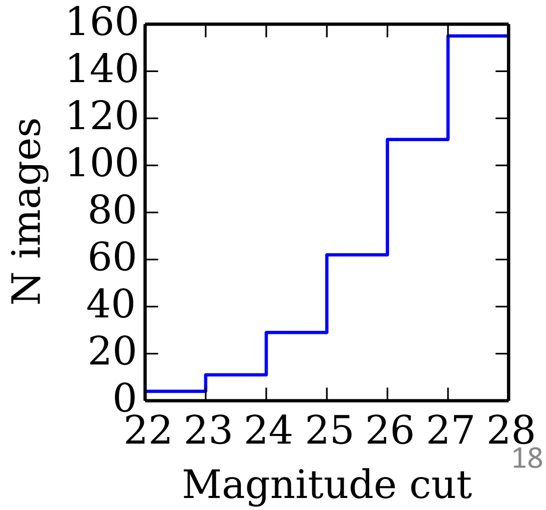


Jullo et al. (Science, August 2010, 329, 924)

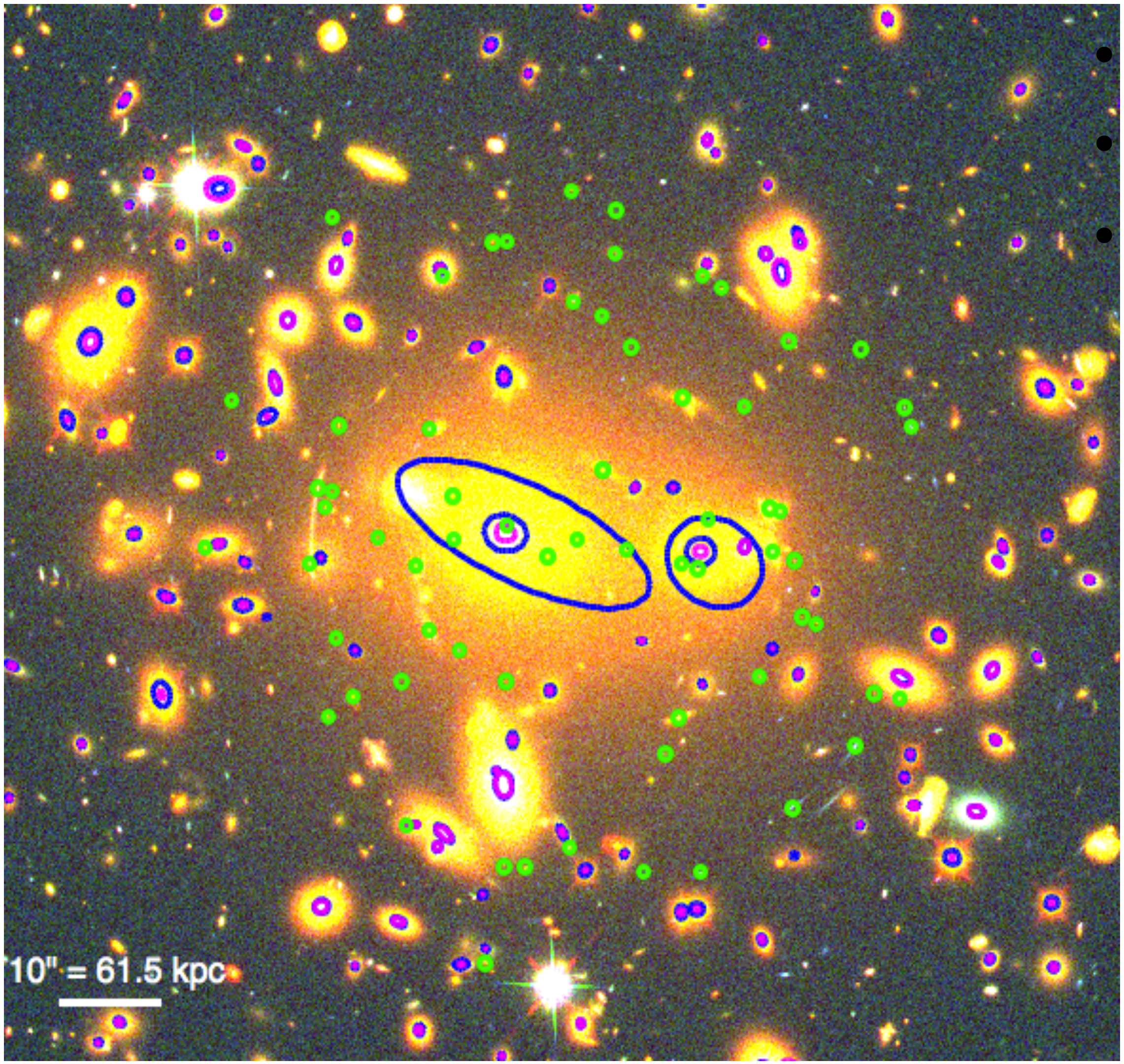
Ares Cluster



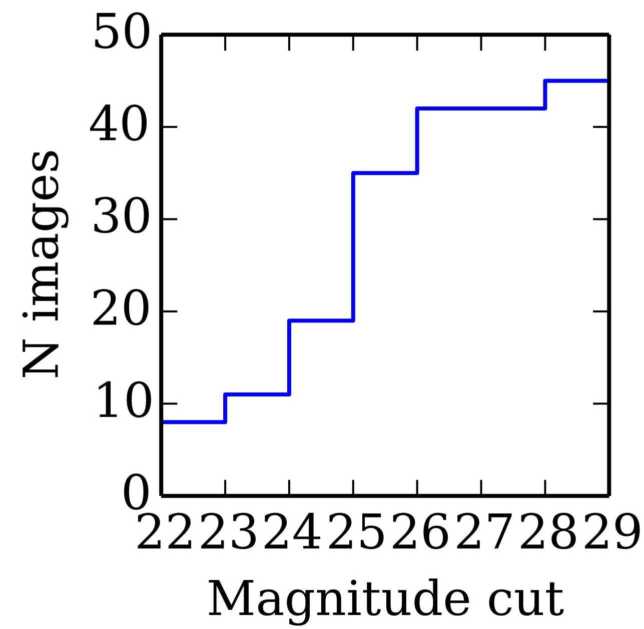
- 242 image constraints
- 122 systems
- 200 CM with magK<22



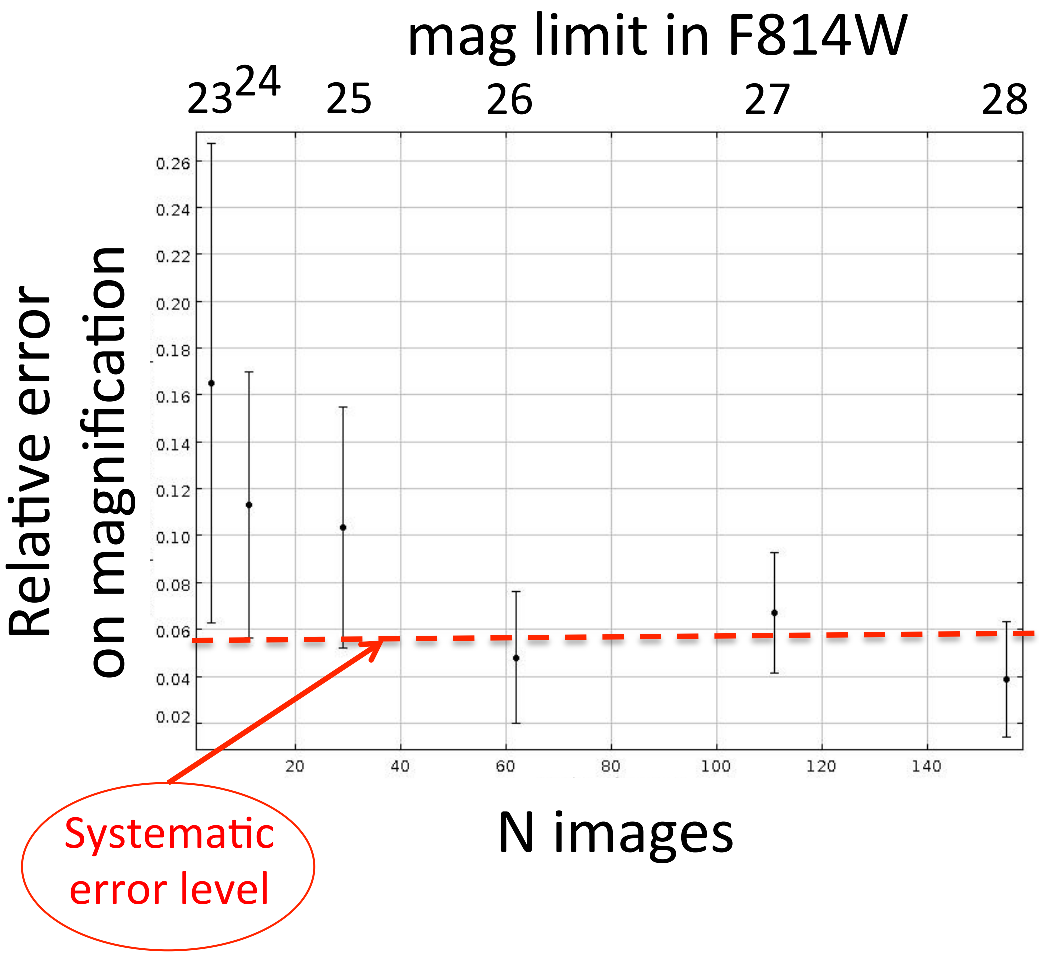
Hera Cluster



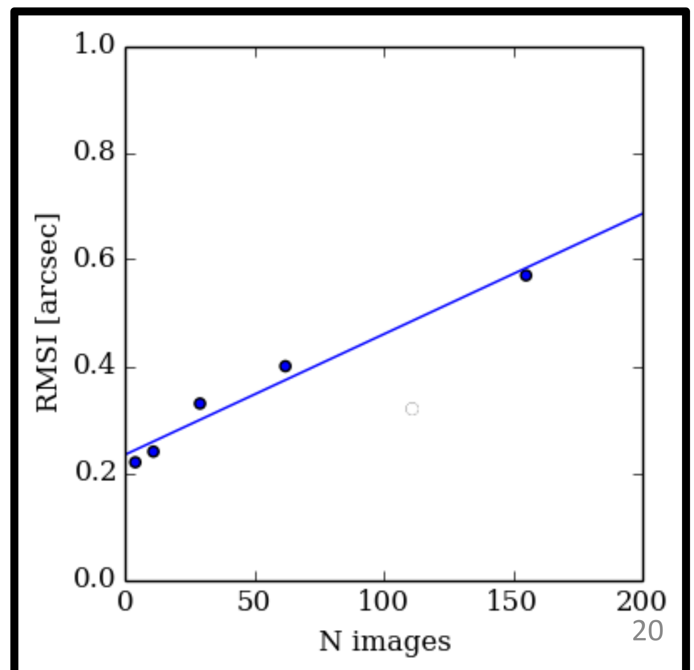
- 65 image constraints
- 19 systems
- 343 CM magK < 24



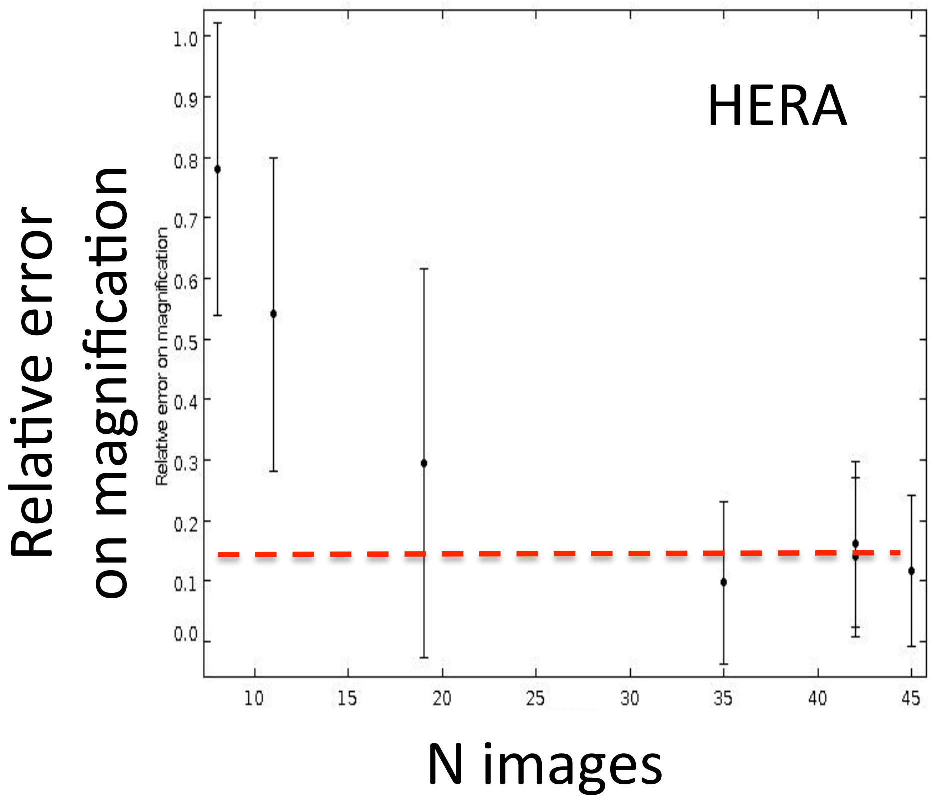
Errors on magnification

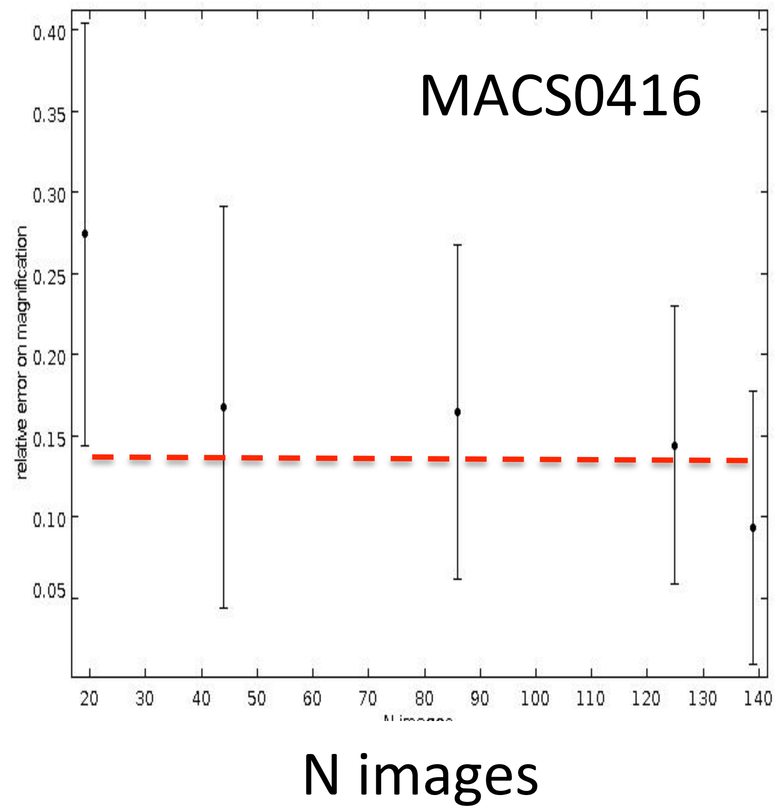


- In our model of ARES, we improve on statistical errors until Nimg < 50
- Systematic errors dominate at Nimg > 50

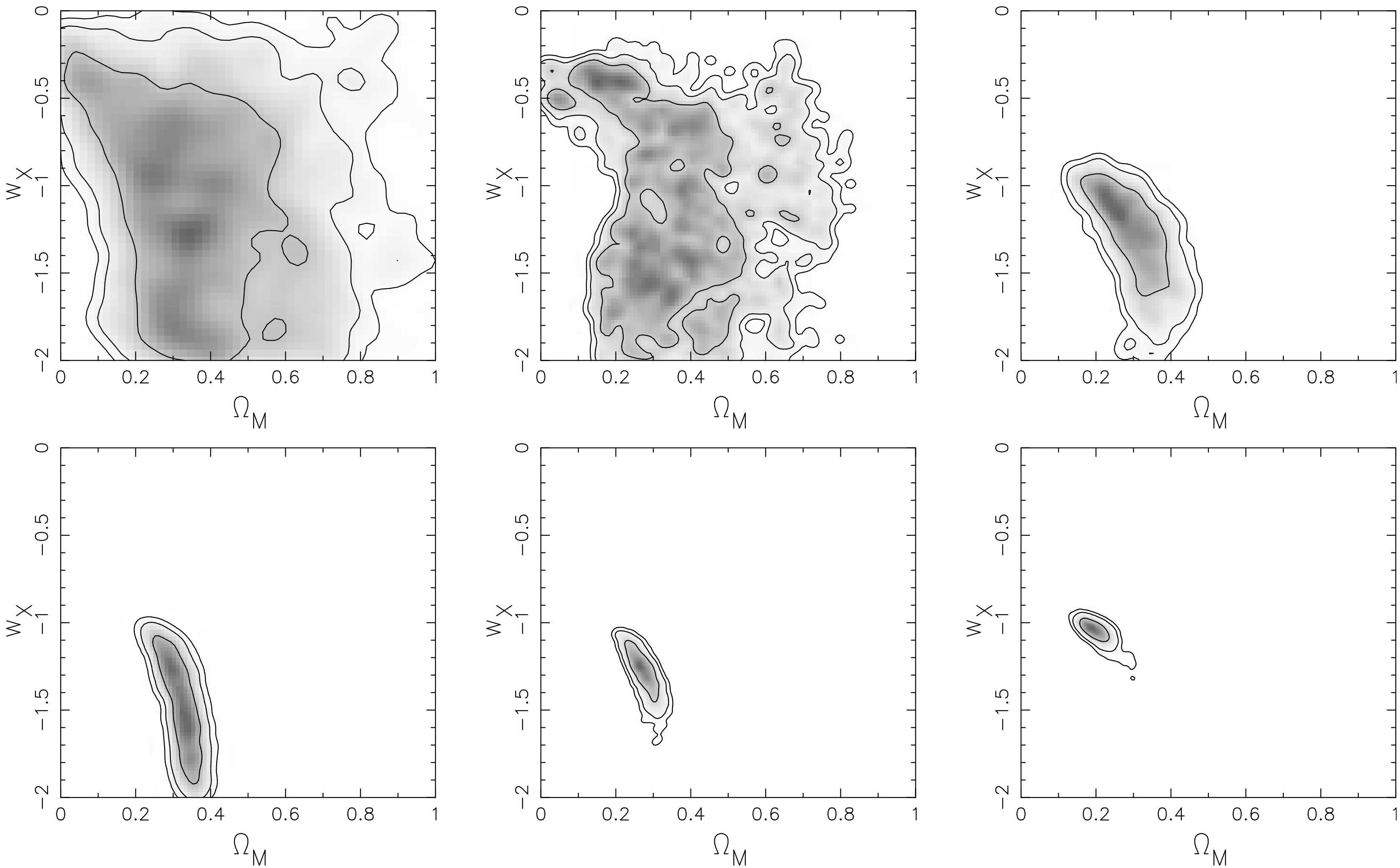


Errors on magnification, Cont.

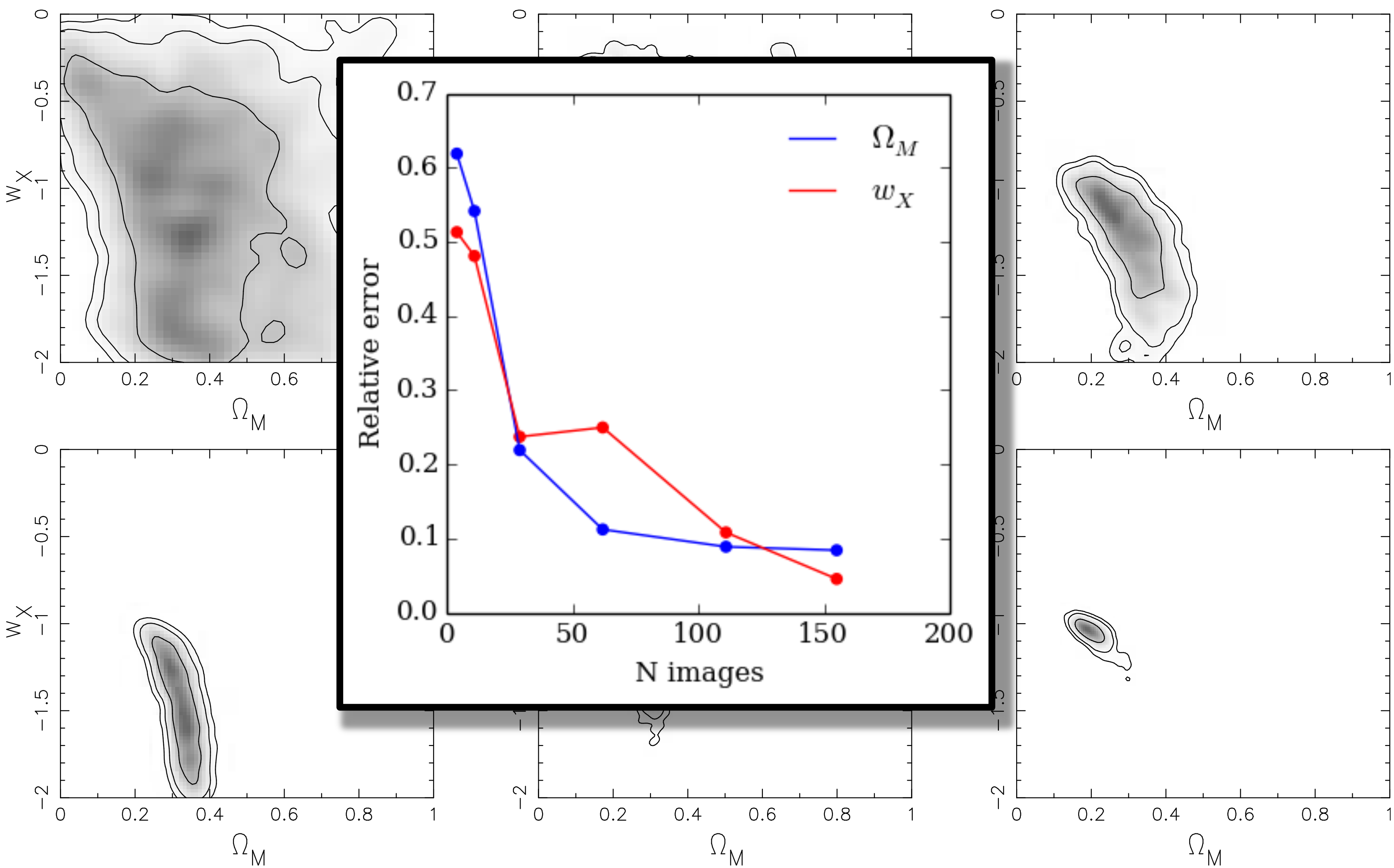




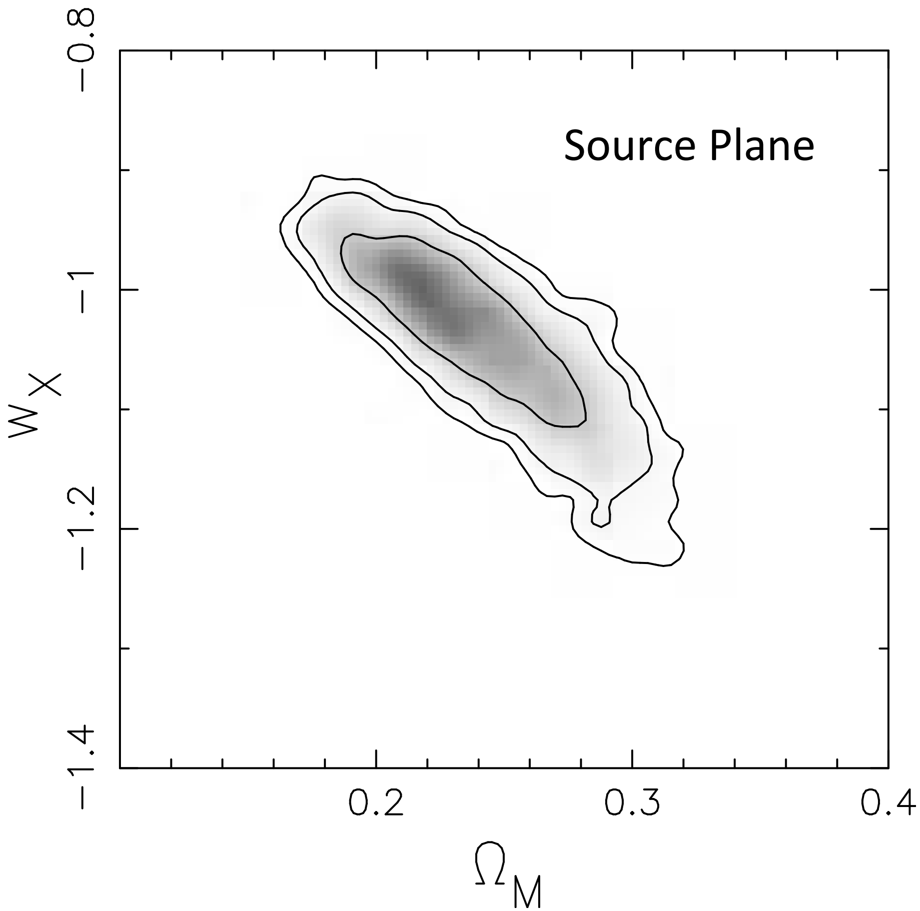
Errors on cosmological parameters in ARES

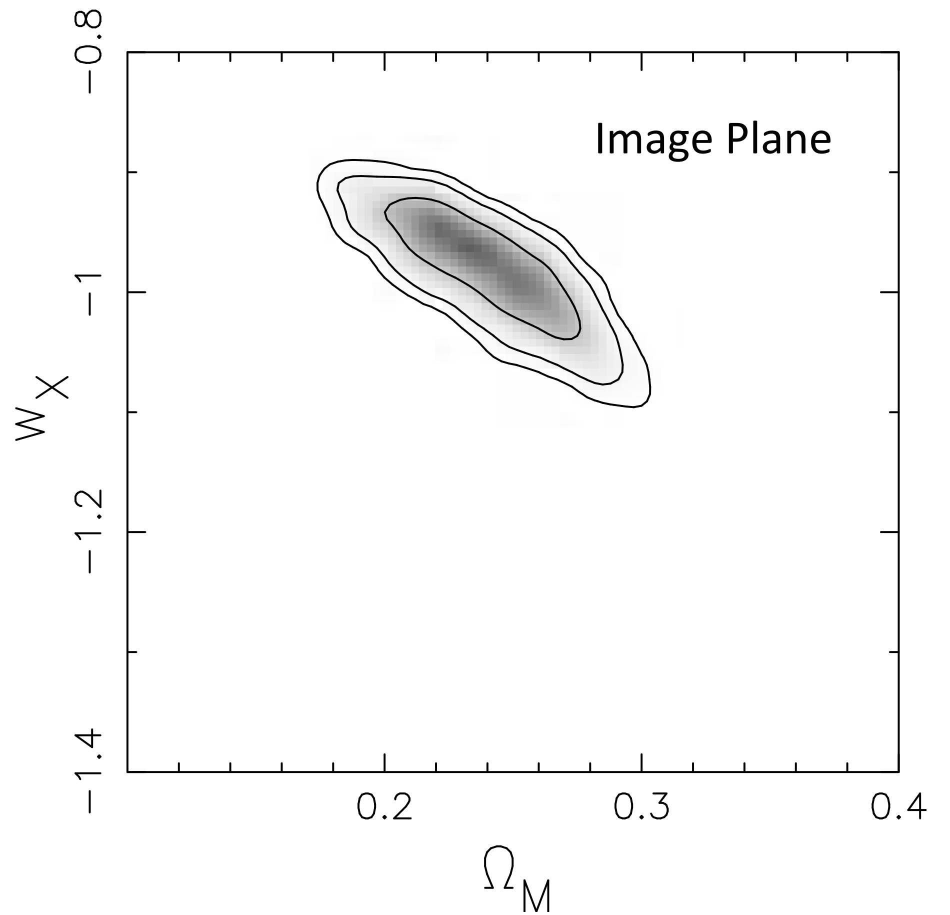


Errors on cosmological parameters in ARES



Source vs Image plane



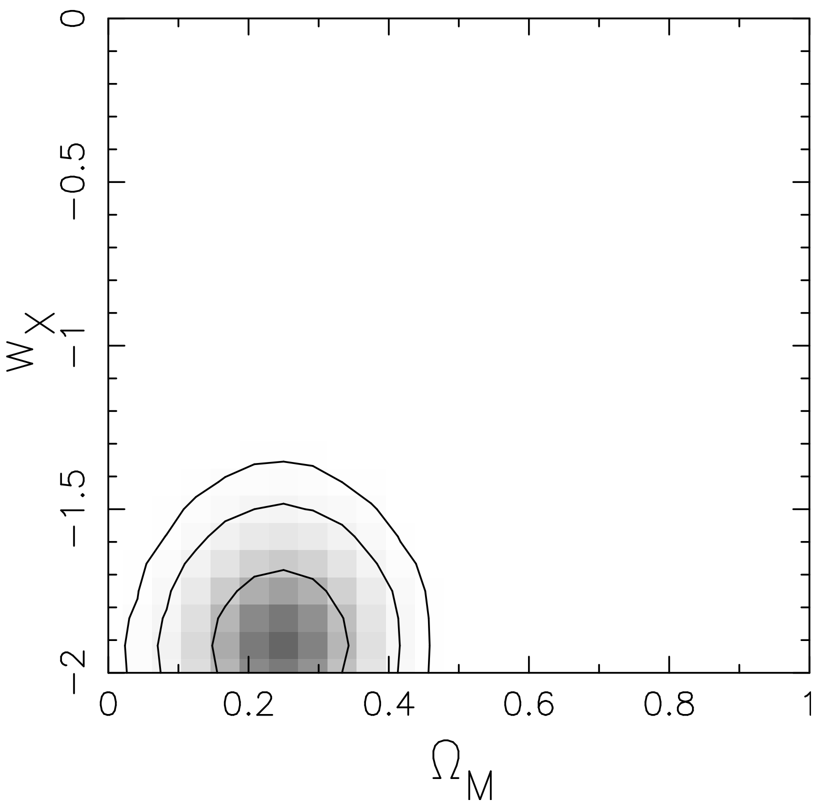


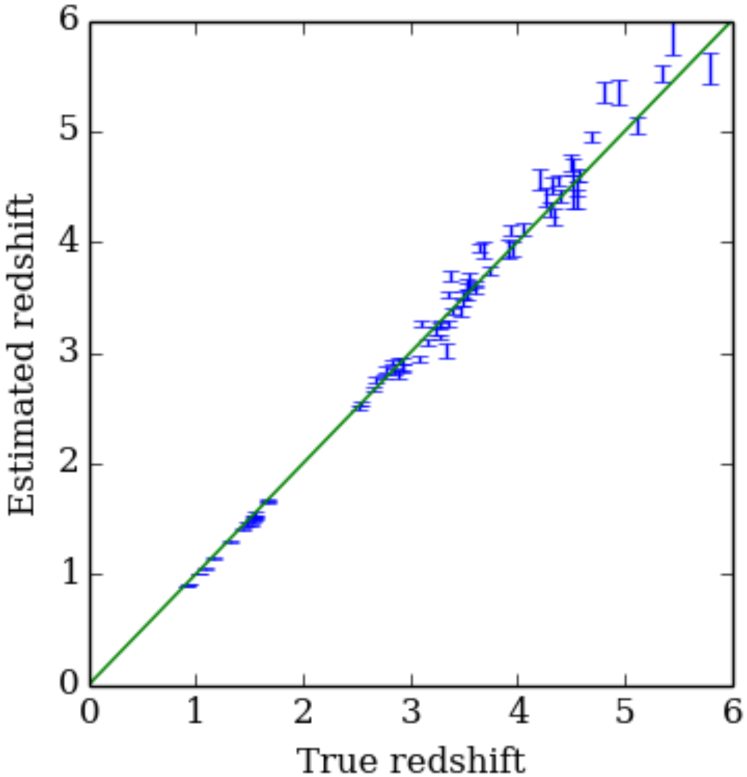
- Optimization with 242 image constraints
- Same errors in the χ^2 for all the images

➢ Image plane and source plane results are consistent

Impact of photometric redshifts

ARES simulation with 2/3 of the redshifts considered as zphot with $\sigma_z / (1 + z) = 0.02$





Conclusion

- We propose a new mixed "*parametric*" and free-form model to detect substructures in the outskirt of MACS0416
  - Good fit to the data but not justified in terms of Evidence
  - Not necessarily better in terms of RMSI
- Error bars saturate after Nimg > 50 ➔ models get dominated by systematic errors
- There is a lot of room for modeling improvement
- We not necessarily need more simulated clusters, but more informations the existing ones (ex: v_disp of galaxies, 3D distribution, 3D cluster shape, etc)