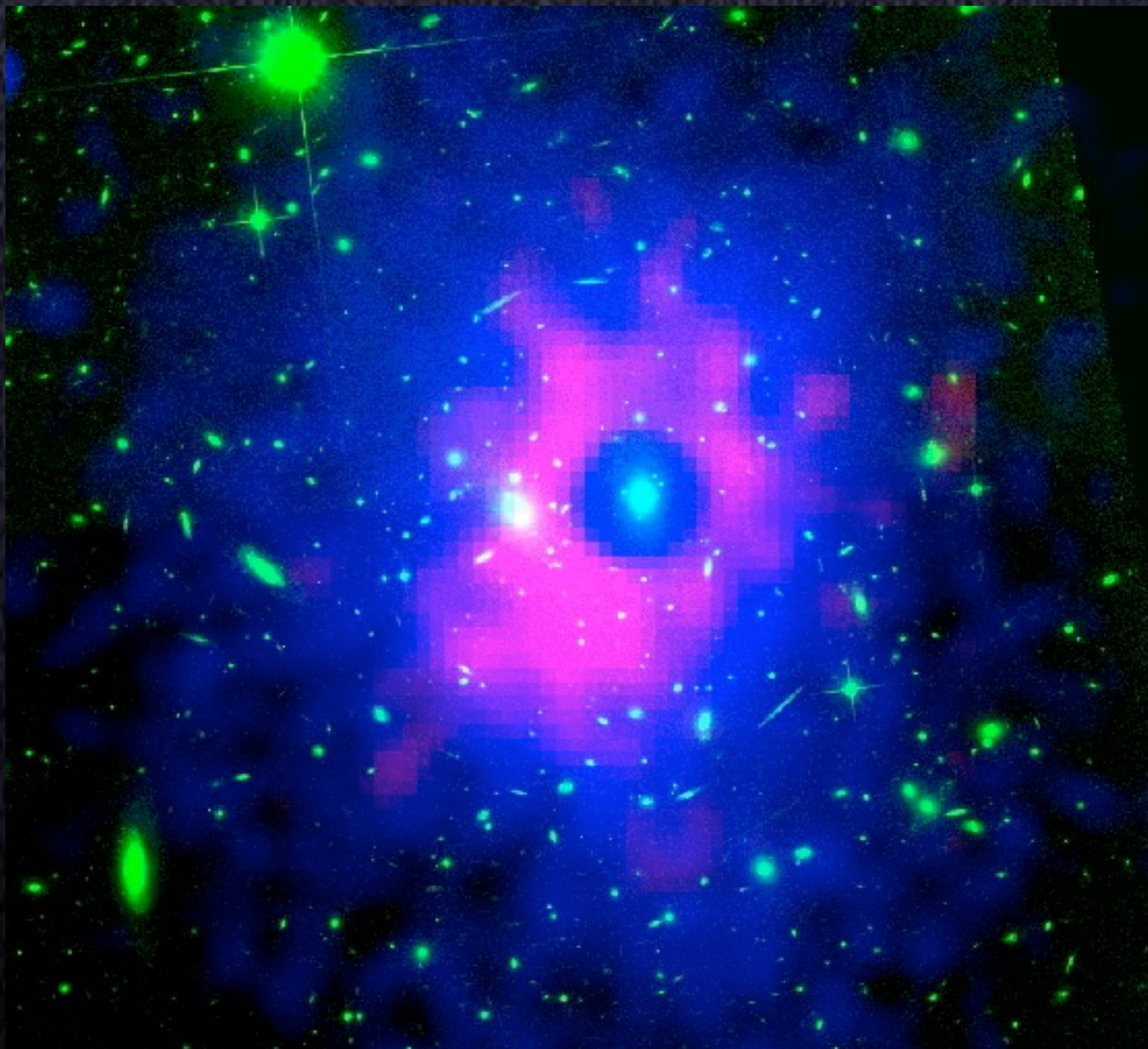
Probing Cluster Masses with Gravitational Lensing

Sanghamitra Deb
ANL

Collaborators: Prof. David M. Goldberg (Drexel University), Prof. Kristian Pedersen (DARK, Copenhagen), Dr. Andrea Morandi (DARK, Copenhagen & Univ. of Tel Aviv.), Dr. Marceau Limousin (LAM Marseille), Dr. Hakon Dahle (Univ. of Oslo), Dr. Signe Riemer-Sørensen (DARK, Copenhagen), Dr. Catherine Heymans (University of Edinburgh, IfA Royal Observatory), Dr. Reiko Nakajima (UC Berkeley), Dr. Rachel Mandelbaum (Princeton University), Prof. Gary Bernstein (University of Pennsylvania)

Observing Clusters



galaxies: HST, optical observations

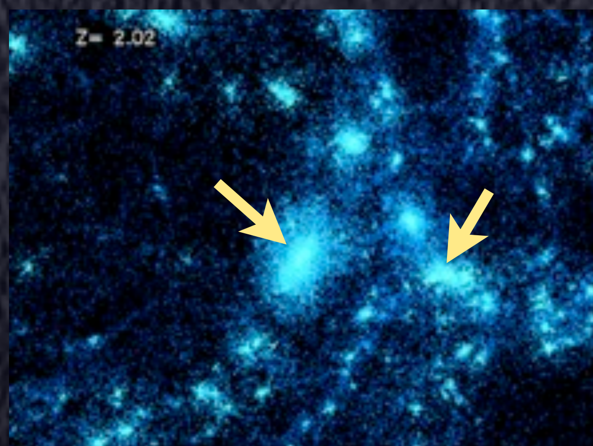
gas: Xray observations

gas: Sunyaev Zeldovich Effect

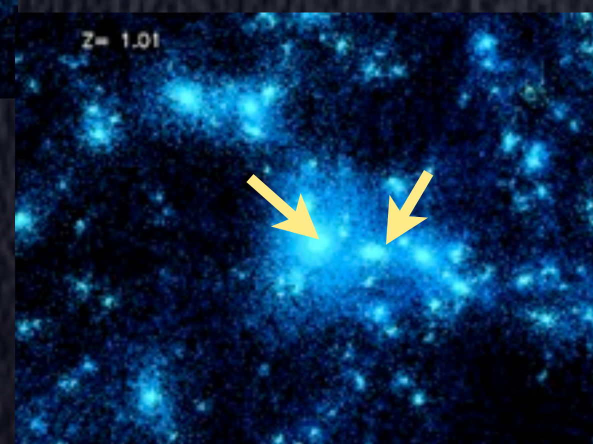
Galaxy Cluster RXJ1347-1145

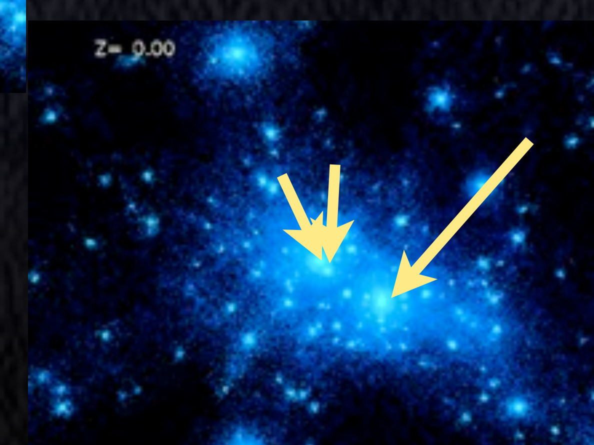
http://chile1.physics.upenn.edu/gbtpublic/

Substructure: Elliptical Halos



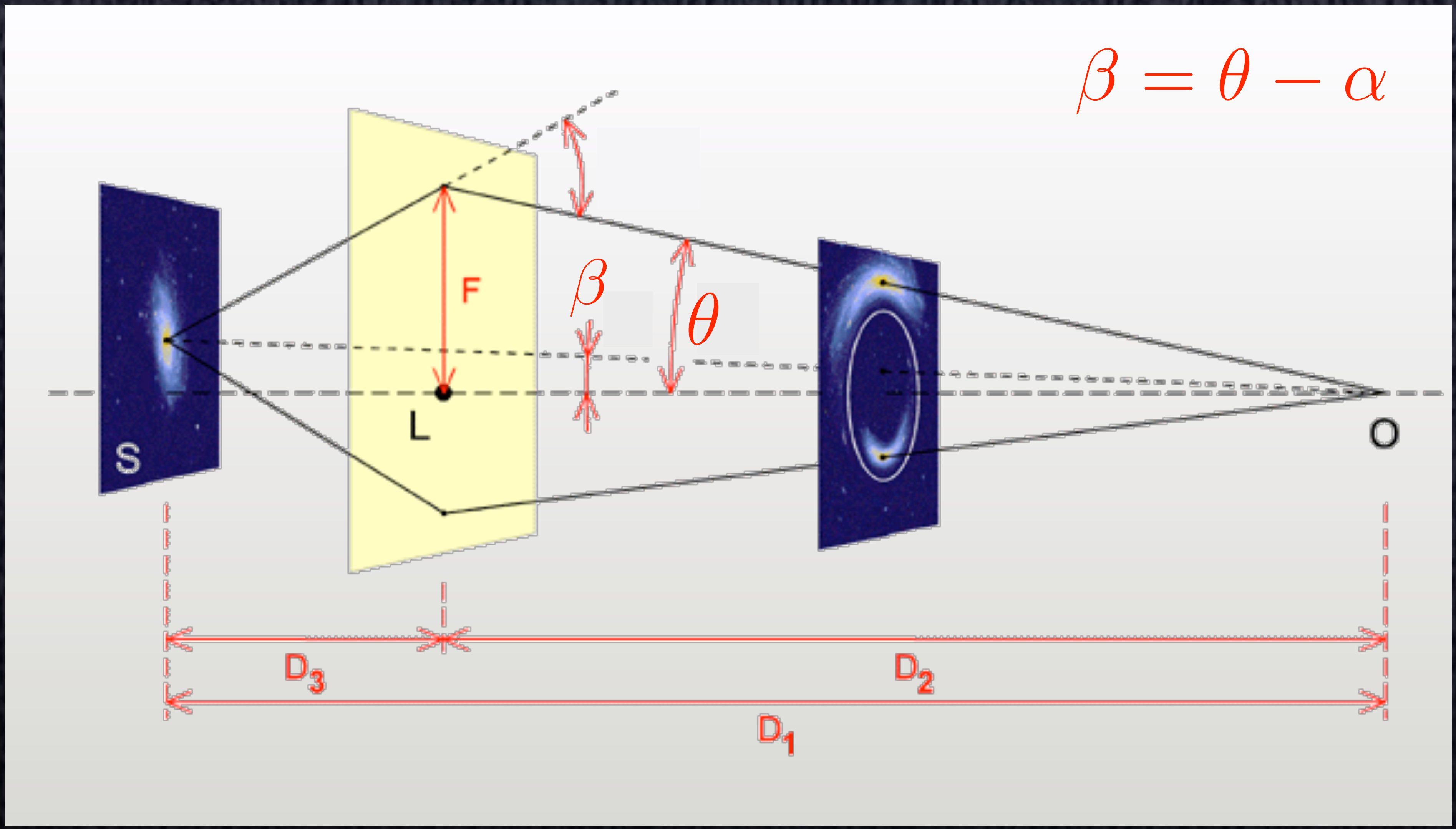
What is the distribution of cluster ellipticity?





How does the distribution and alignment vary with redshift & mass?

Gravitational Lensing



Dimension less surface mass density

$$\kappa = \frac{\Sigma}{\Sigma_{cr}}$$

Gravitational Lensing is co-ordinate transformation between the foreground (θ), and background positions(β)

Shape Distortions

$$\kappa = (\psi_{,11}+\psi_{,22})/2$$

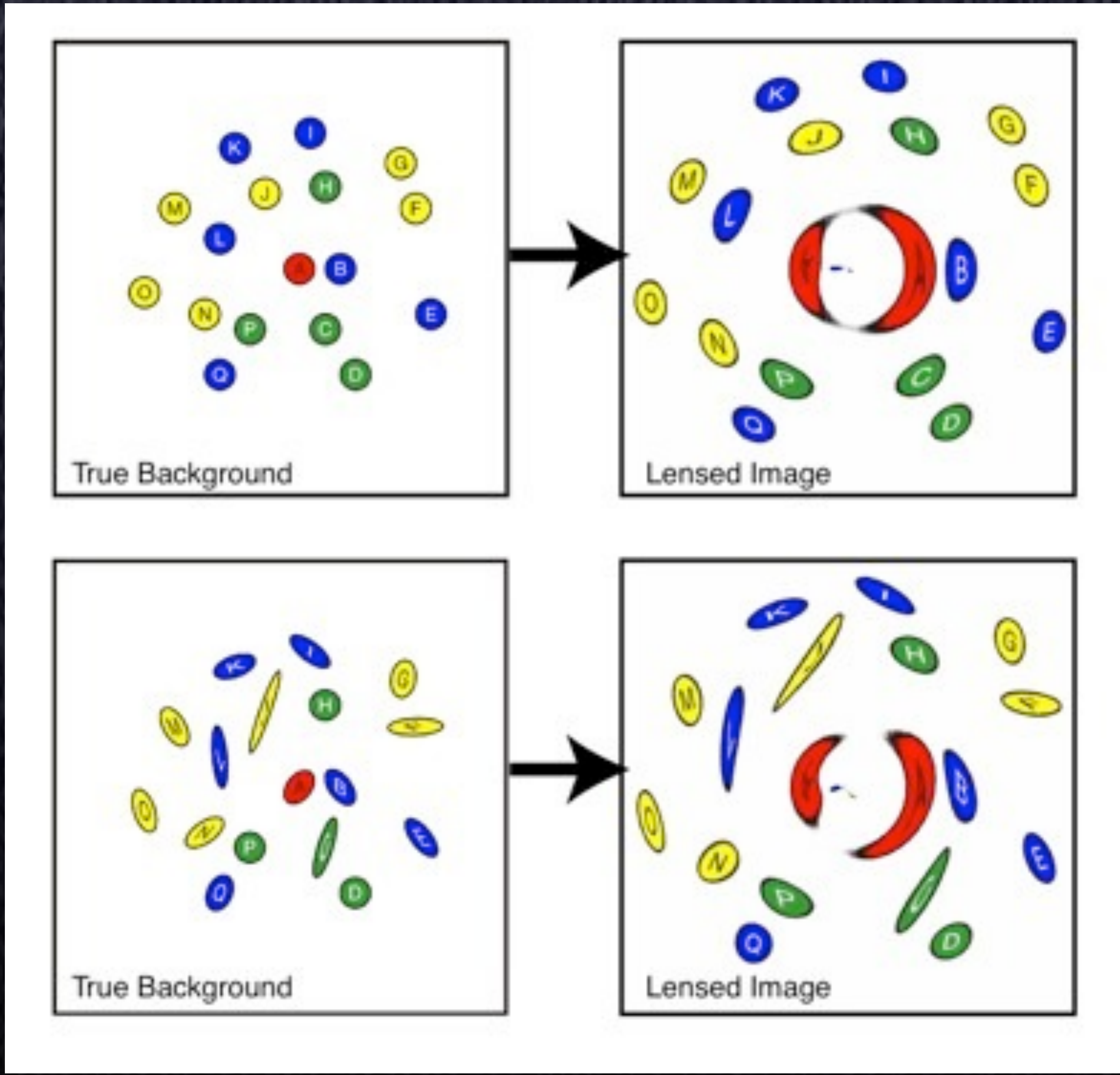
$$\gamma_1 = (\psi_{,11}-\psi_{,22})/2$$

$$\gamma_2 = \psi_{,12}$$

Distortion Observables are Measured Ellipticities.

For semi-strong regime: $g = \gamma/(1-\kappa)$

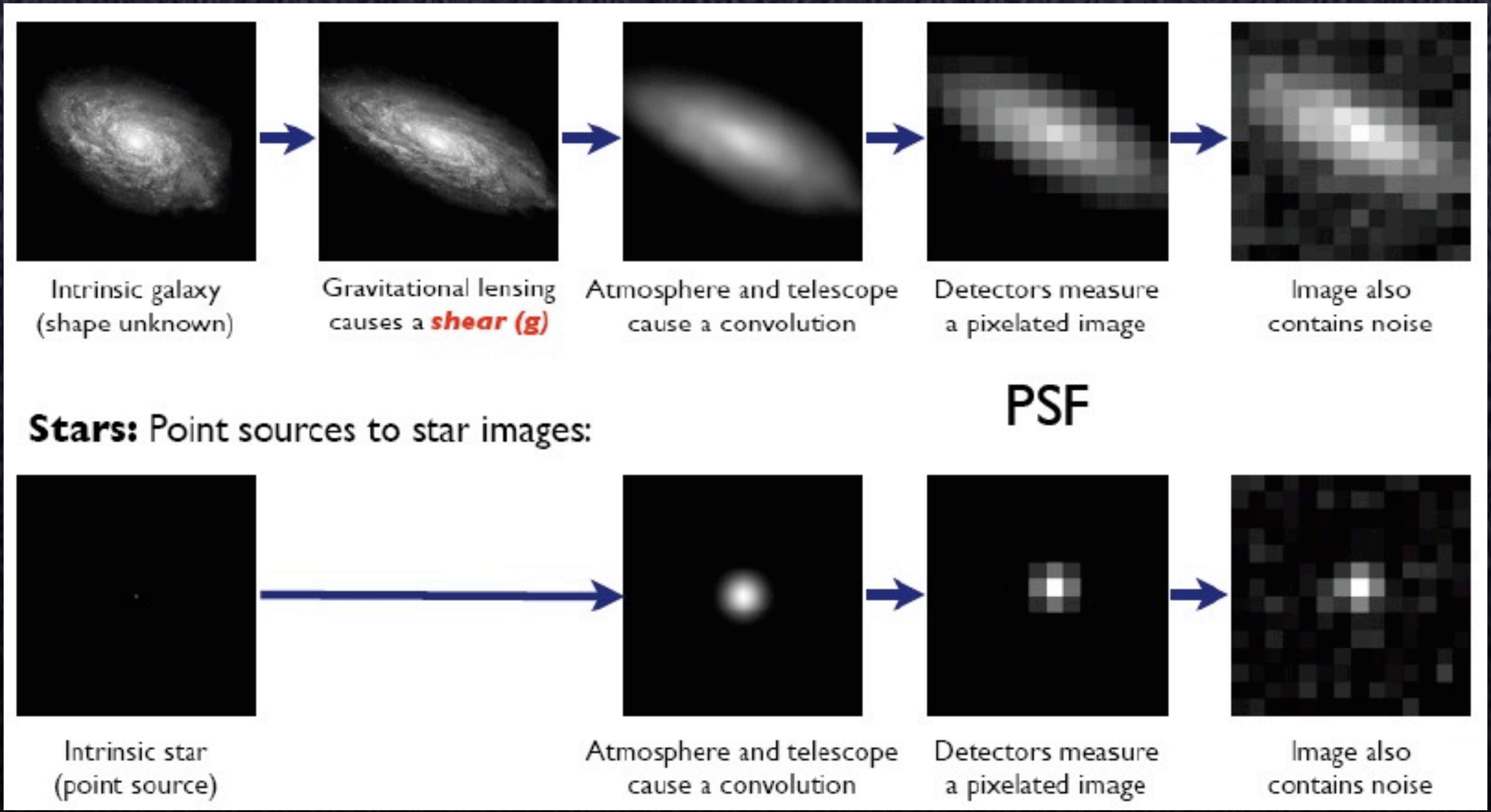
Weak Lensing



Williamson et al. 2007.

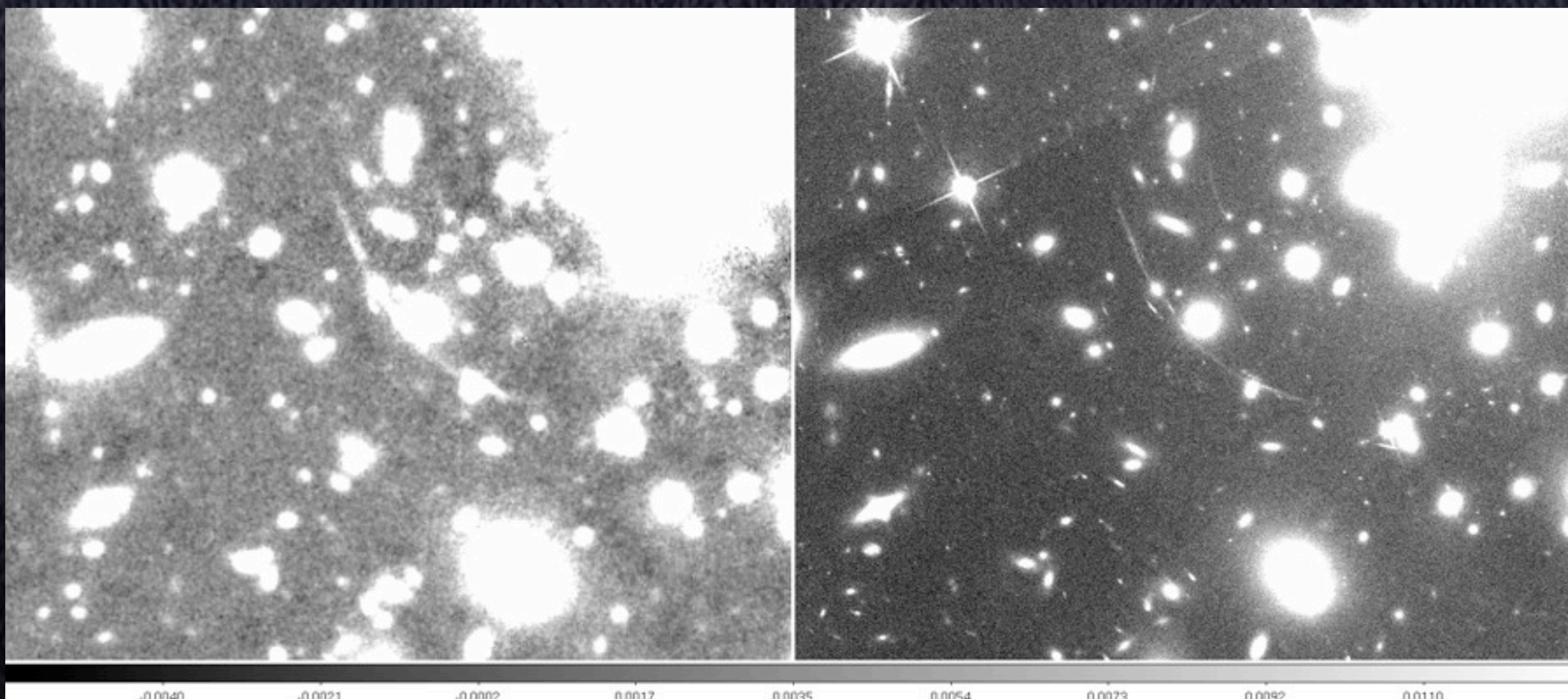
Weak lensing is a statistical measure of the distortion of background galaxies due to the intervening mass.

The shear signal

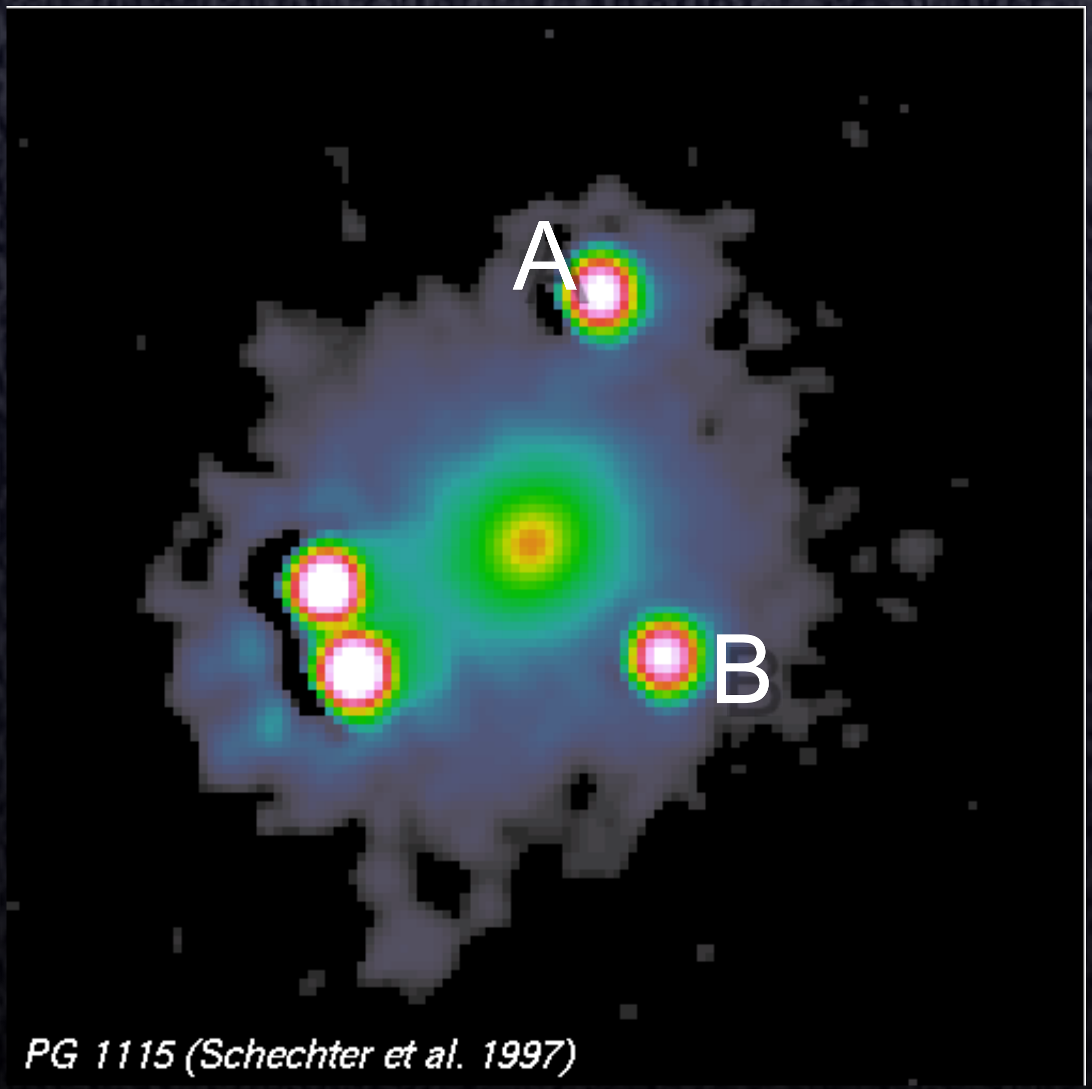


Catherine Heymans

Comparison of Space vs Ground: A1689



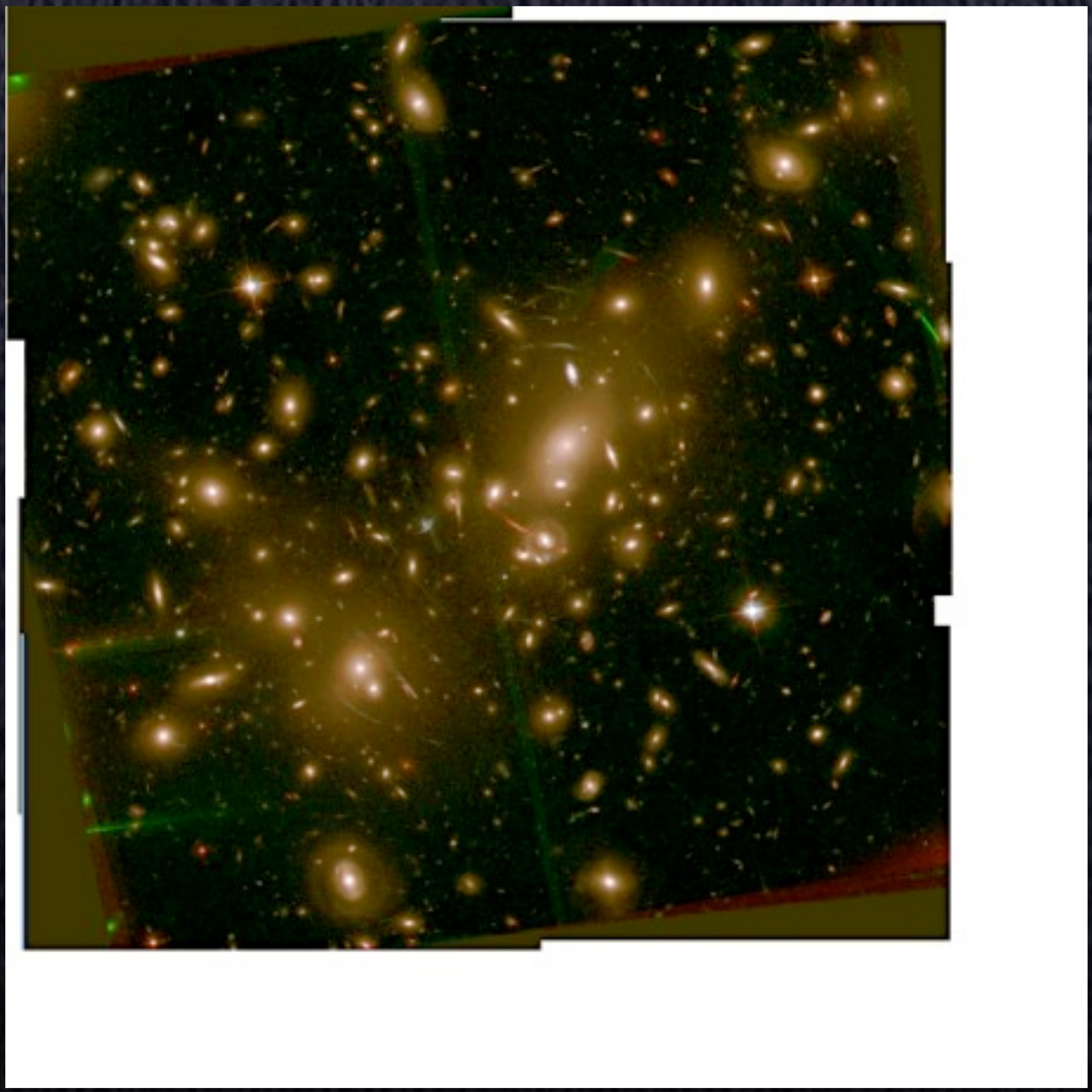
Strong Lensing



$$\alpha_i = \psi_{,i}$$

$$\alpha_A - \alpha_B = \theta_A - \theta_B$$

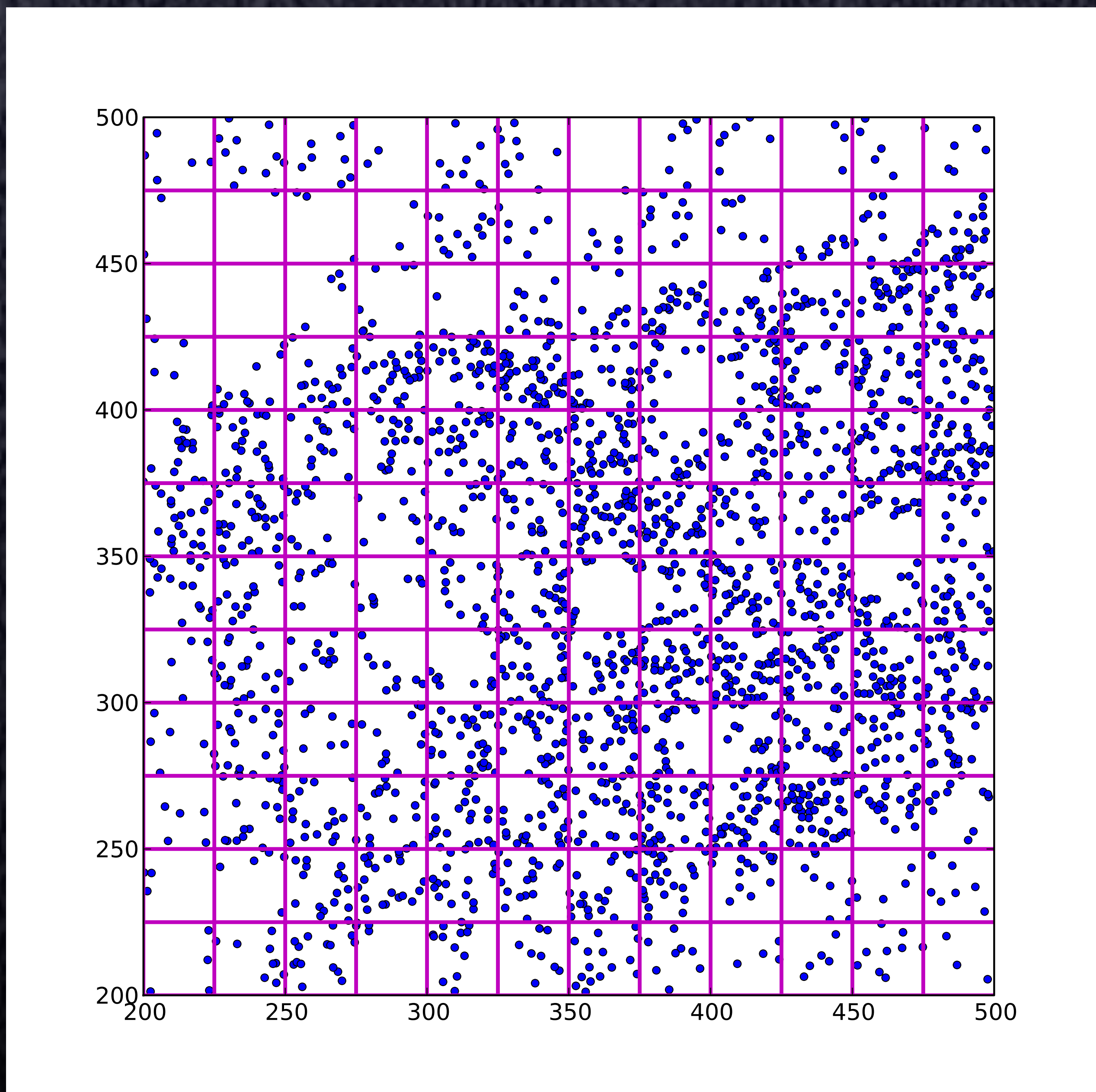
Parametric technique



Assumption: Light traces mass

- Place galaxy sized halos at the location of Cluster Members.
- Have one or more dark matter halos with free parameters that are fit from data.

Grid Based Lensing



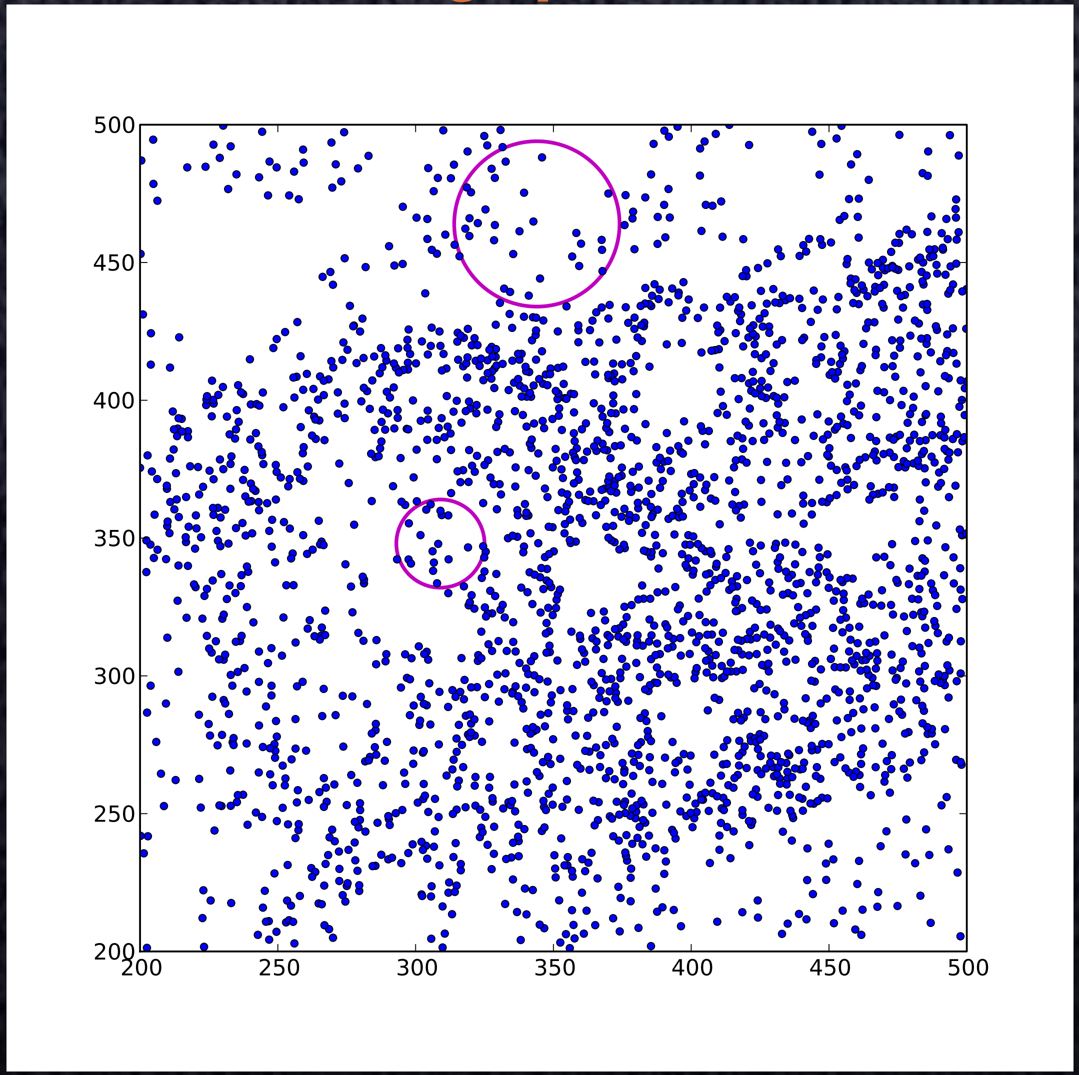
$\exp \Big|$

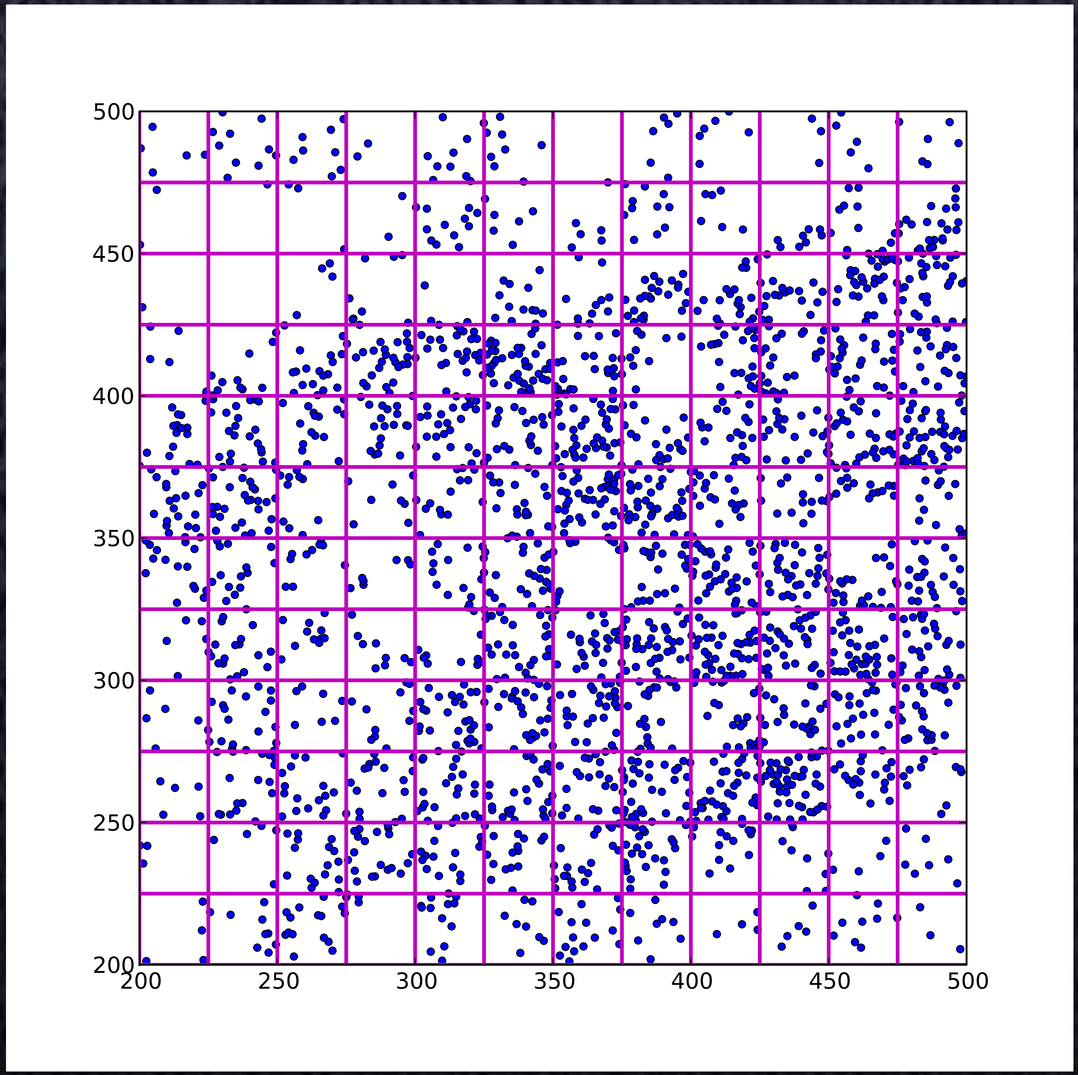
Convolution

$\sum$

Particle Based Lensing

Particles-> lensed image positions



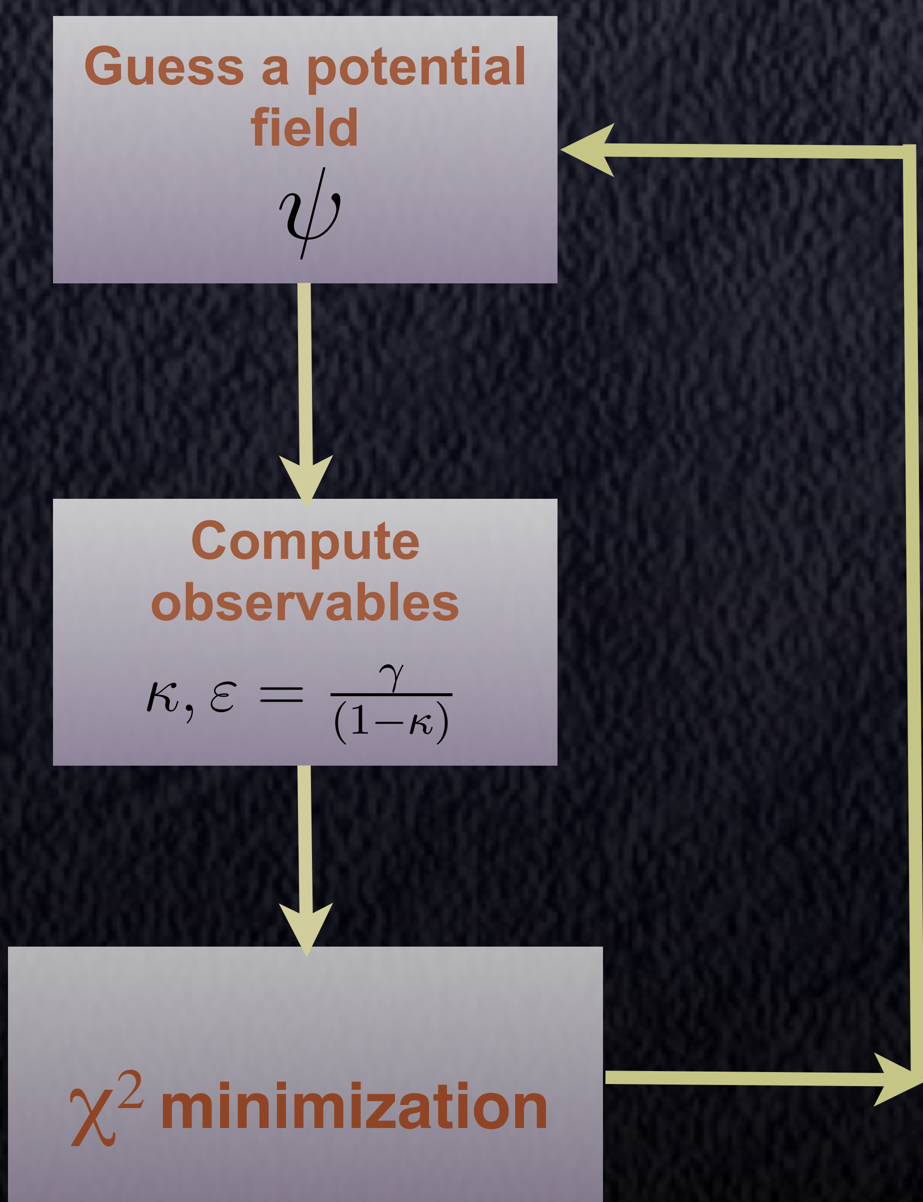


- Variable Resolution with the same complexity as finite differencing on a regular grid.
- No empty grid cells.

Reconstruction Procedure

Keep Iterating ...

$$\chi^2_{\rm weak} = \sum_i \frac{\left[\varepsilon_i - \frac{\gamma_i}{(1-\kappa_i)}\right]^2}{\sigma_i^2}$$

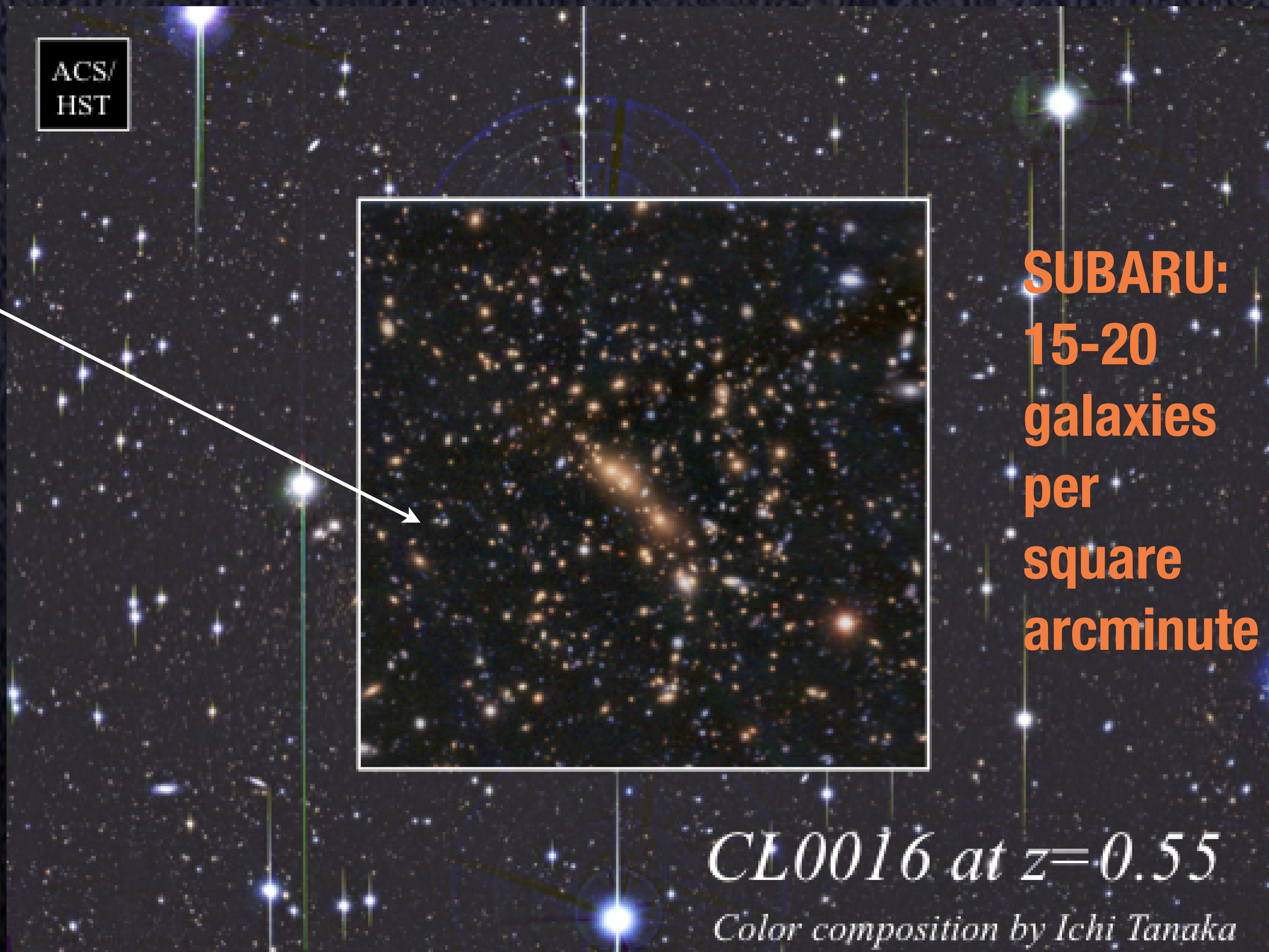


In case of weak lensing, a $\chi^2_{\rm w}$ like this will fit best to noisy data

Smoothing the ellipticity field before minimization and using the full covariance matrix in the the minimization

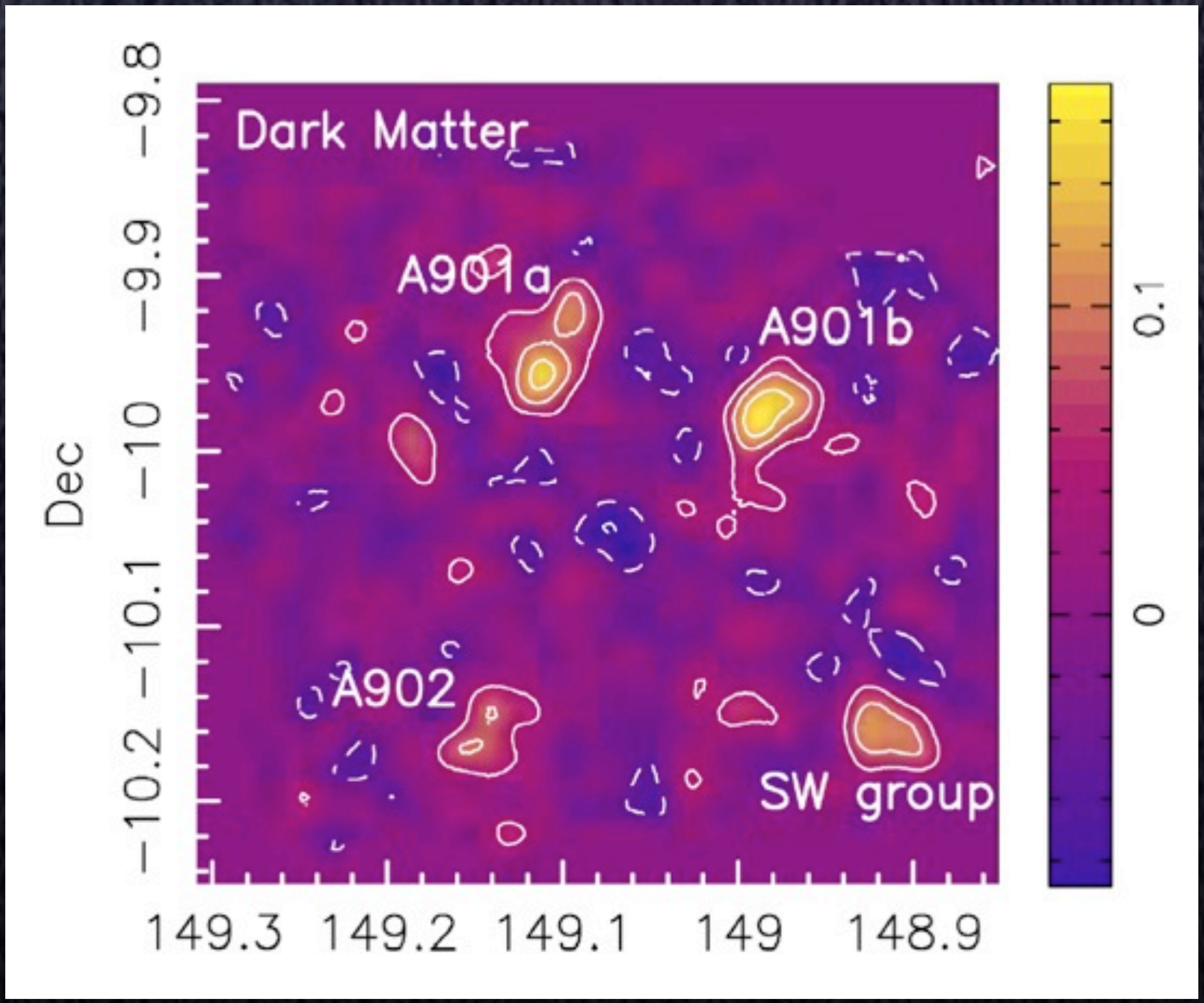
Heterogeneous Datasets

HST: 50-60 galaxies per square arcminute



SUBARU: 15-20 galaxies per square arcminute

Abell 901/902

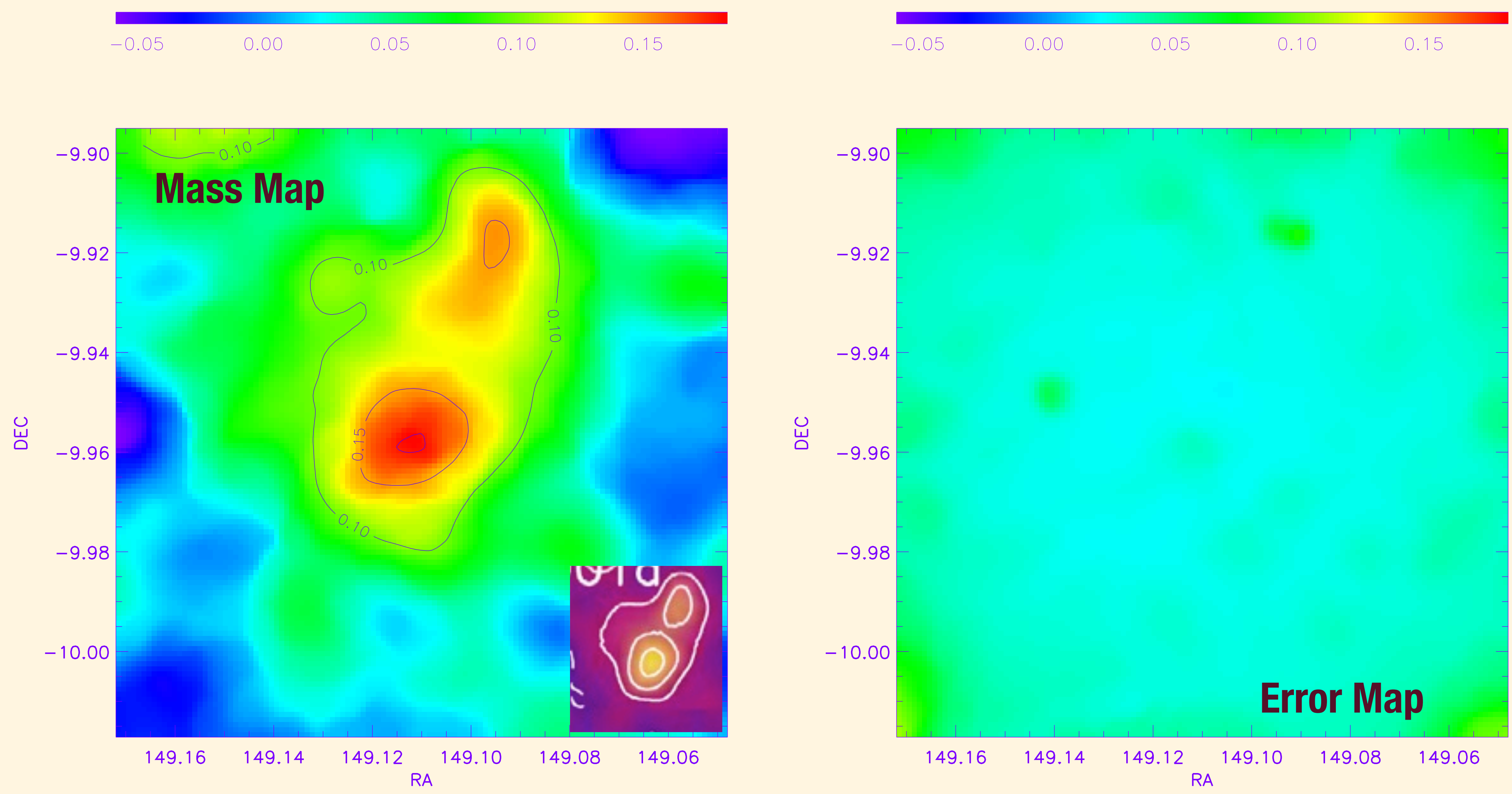


0.5 degree^2 fov
STAGES HST survey
60,000 background images.

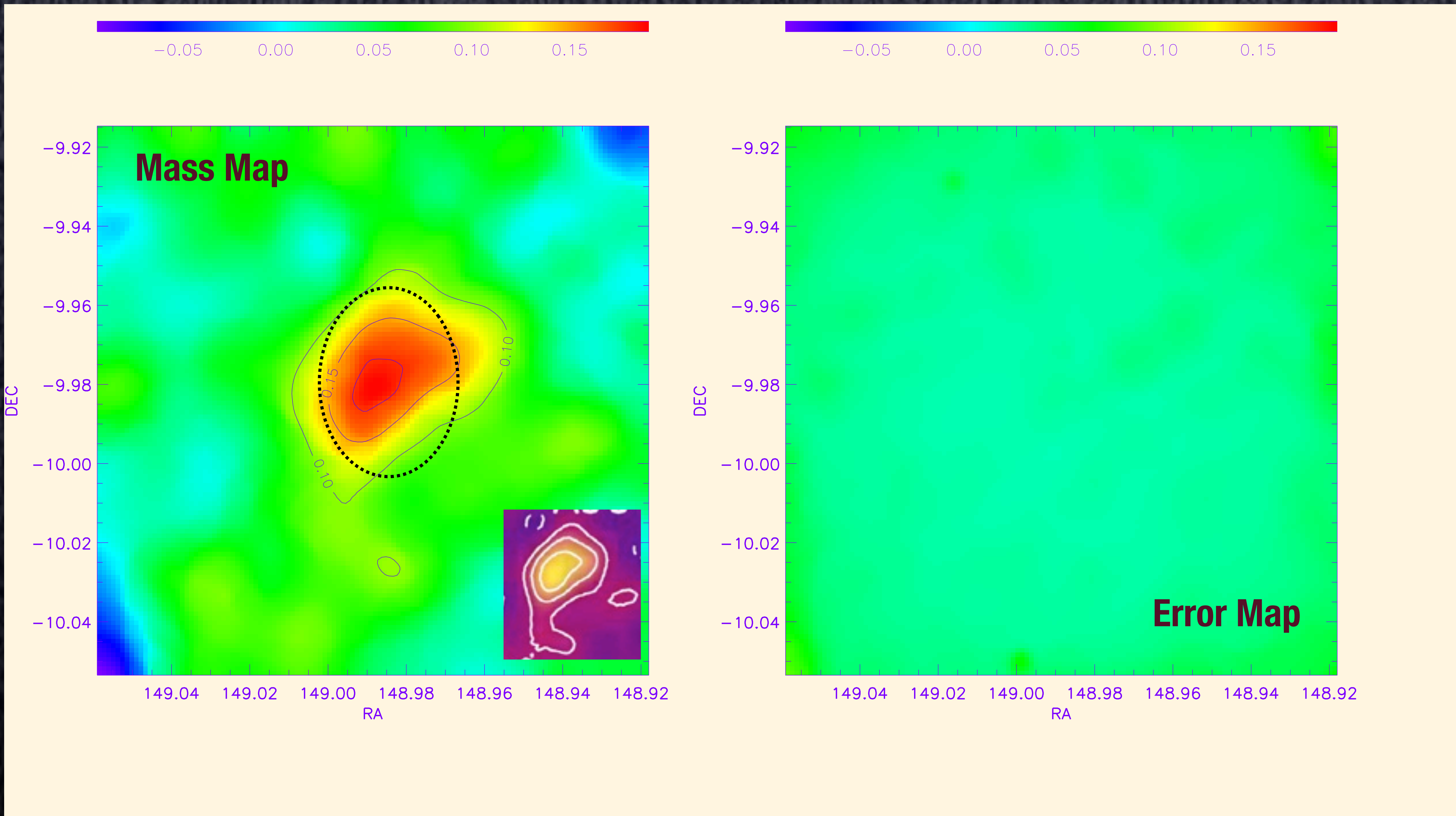
Heymans et. al. 2008.

A901a

From Deb et al. 2009



A901b

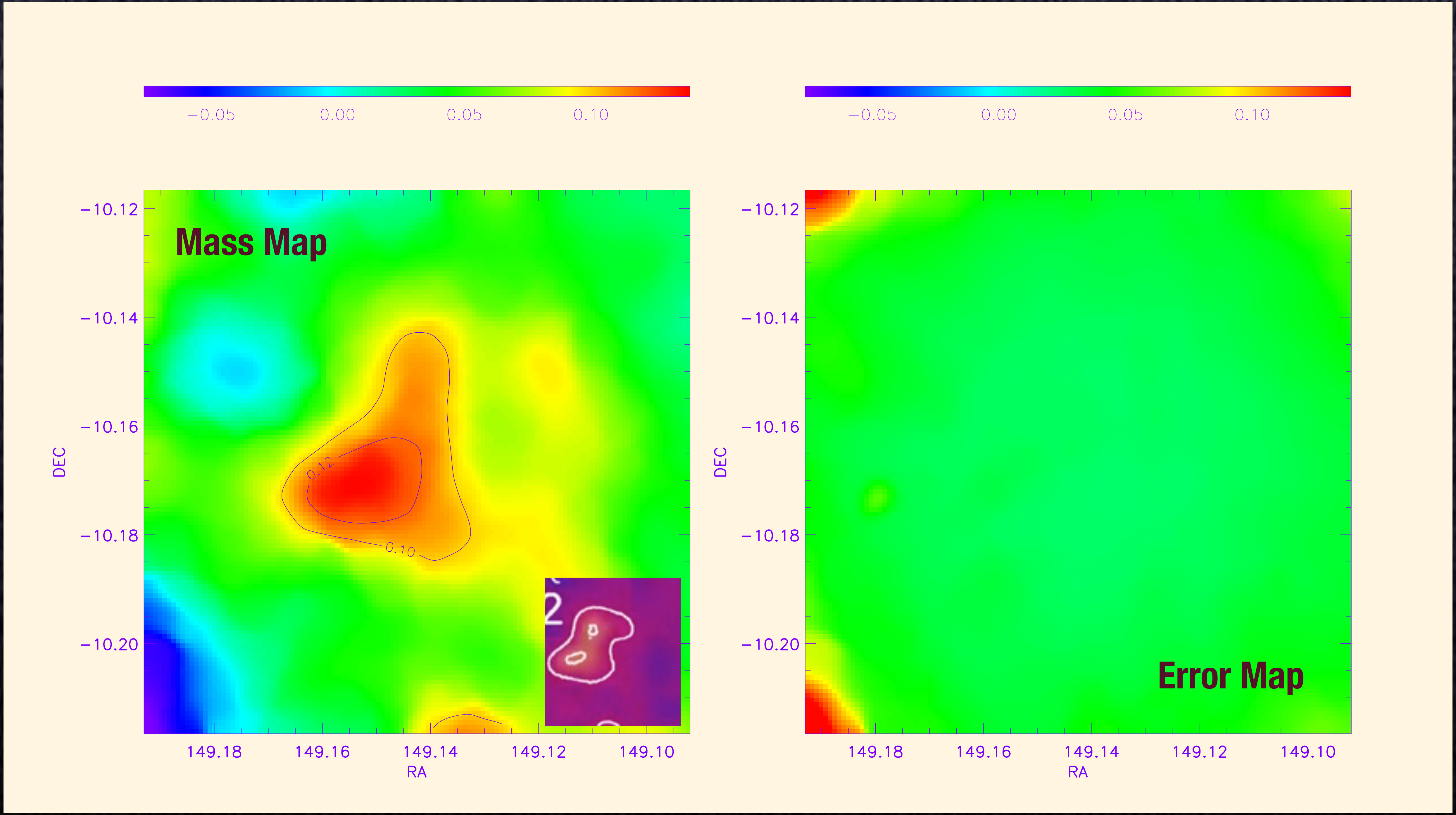


From Deb et al. 2009

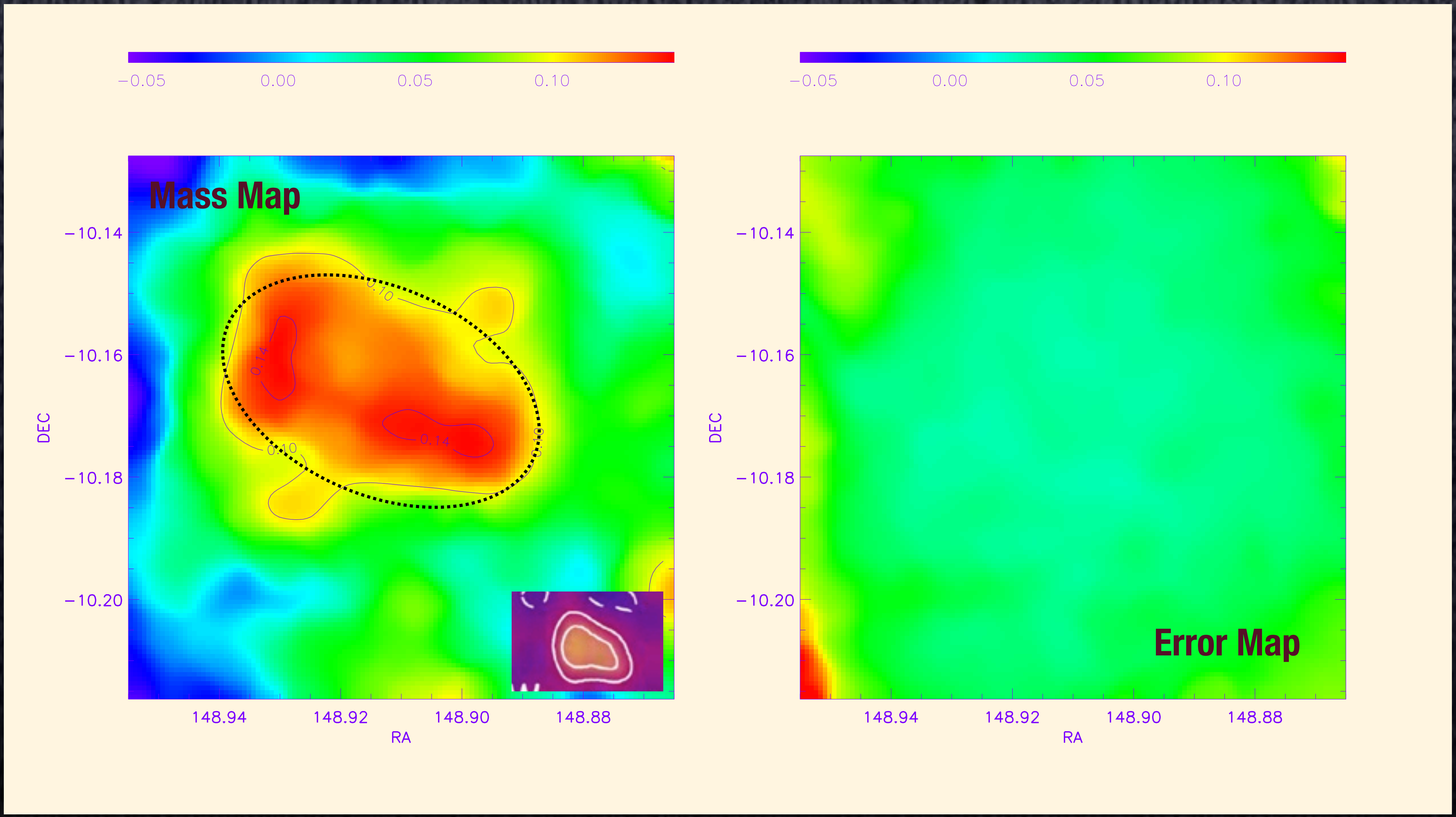
	Axis Ratio	Position angle
Non-Parametric:	$0.37^{+0.1}_{-0.1}$	$91.4^{+8.2}_{-8.2}$
Parametric:	$0.437^{+0.1}_{-0.087}$	$90.0^{+2.25}_{-2.25}$

A902

From Deb et al. 2009



Southwest Group

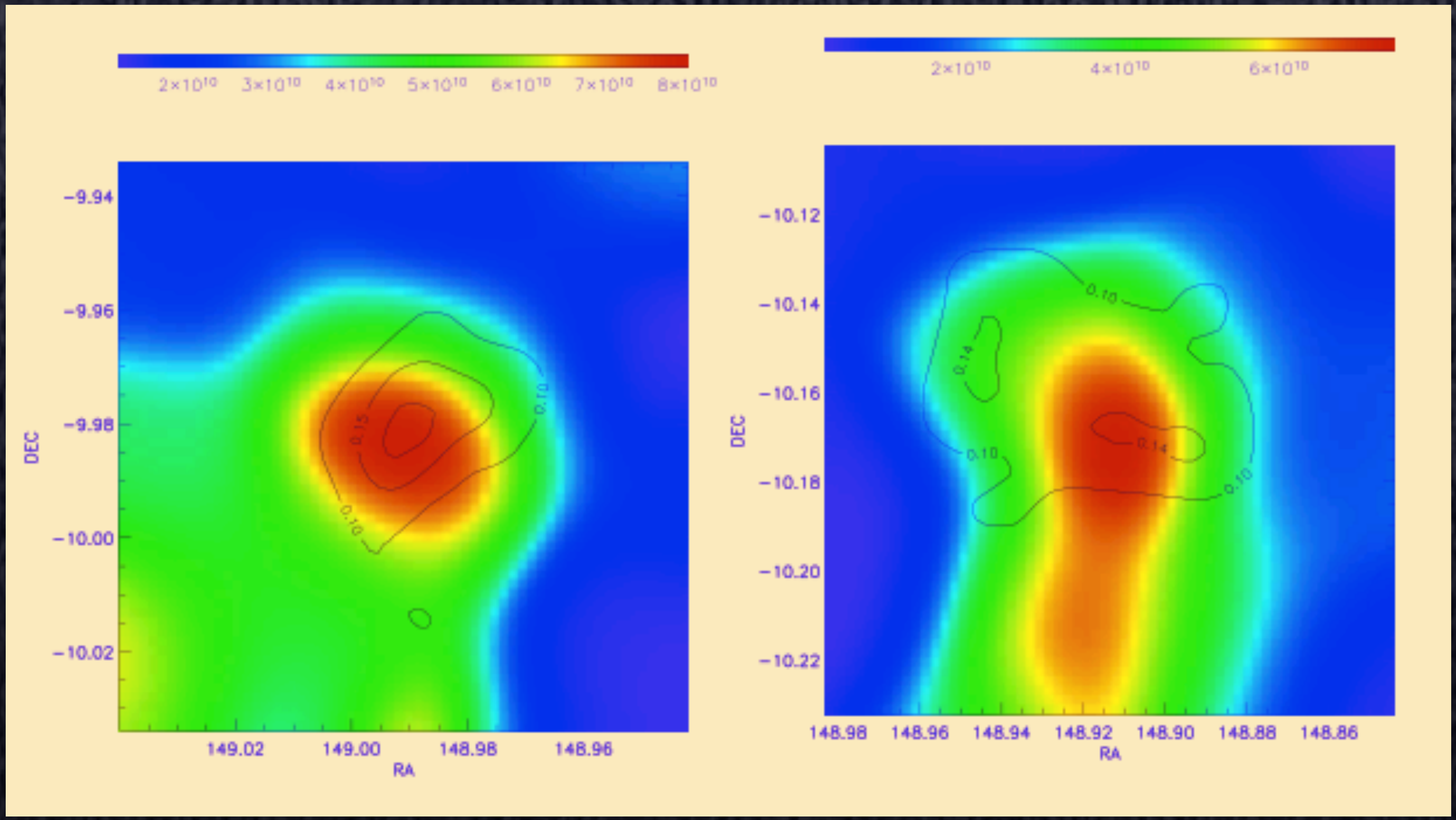


From Deb et al. 2009

	Axis Ratio	Position angle
Non-Parametric:	$0.54^{+0.08}_{-0.09}$	$120.0^{+4.8}_{-4.8}$
Parametric:	$0.42^{+0.18}_{-0.12}$	$180.0^{+7.73}_{-5.15}$

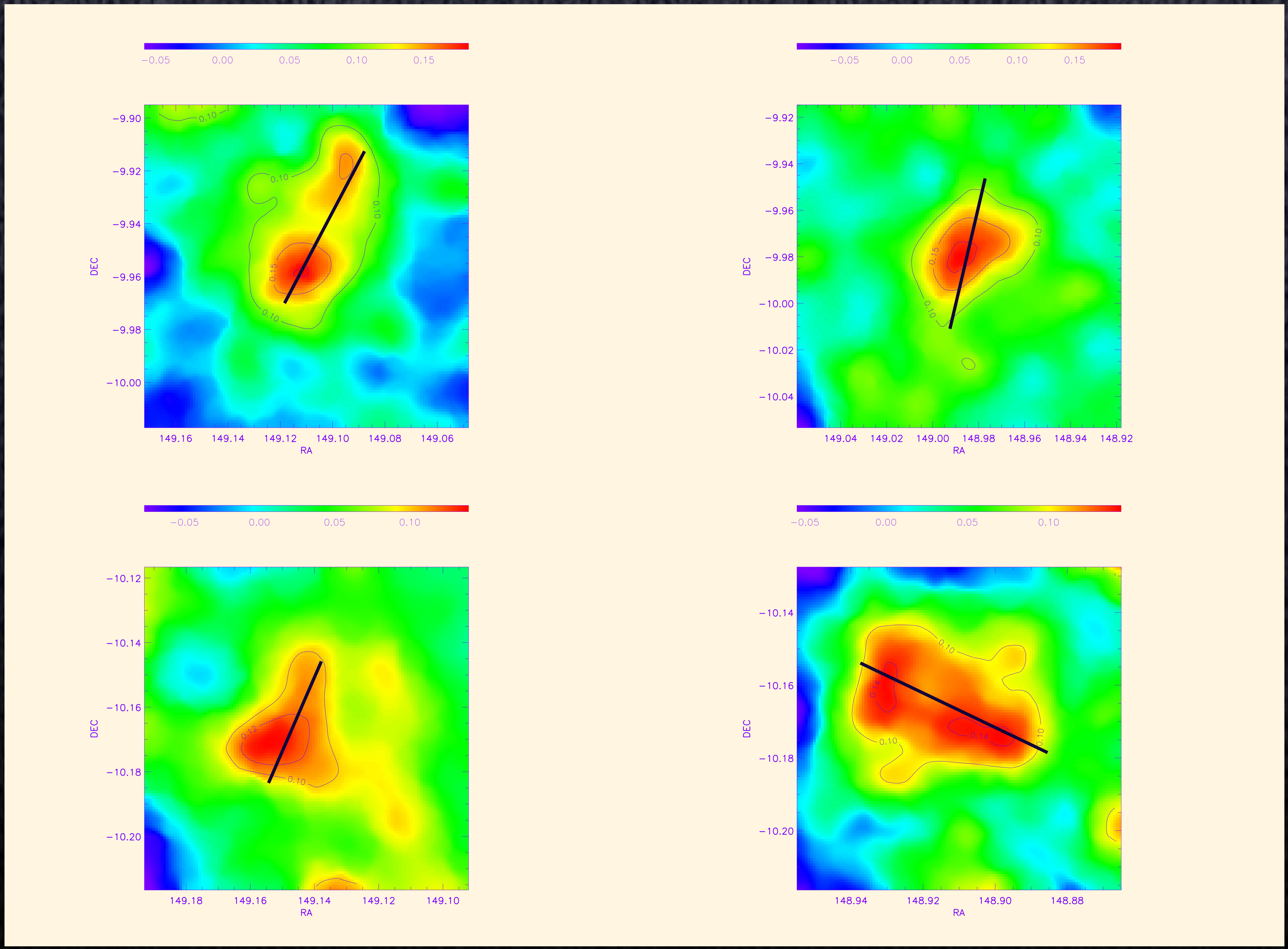
Dark Matter vs Light

From Deb et al. 2009



Alignment

From Deb et al. 2009



Reconstruction Methods

Parametric:

Strong Lensing

GRAVLENS - Keeton et al., 2001
LENSTOOL - Jullo et al., 2007

Galaxy-Galaxy Lensing

Natarajan et al. 2005

Hybrid

LENSTOOL - Jullo et al., 2009

Non-Parametric

Strong Lensing

Jullo & Kneib 2009,
LENSPERFECT -Coe et al, 2008,2010 (Mesh Free)

Weak Lensing

Kaiser 1995, Seitz & Schneider 1995-2001

Strong+Weak Lensing

Finite Differencing Based

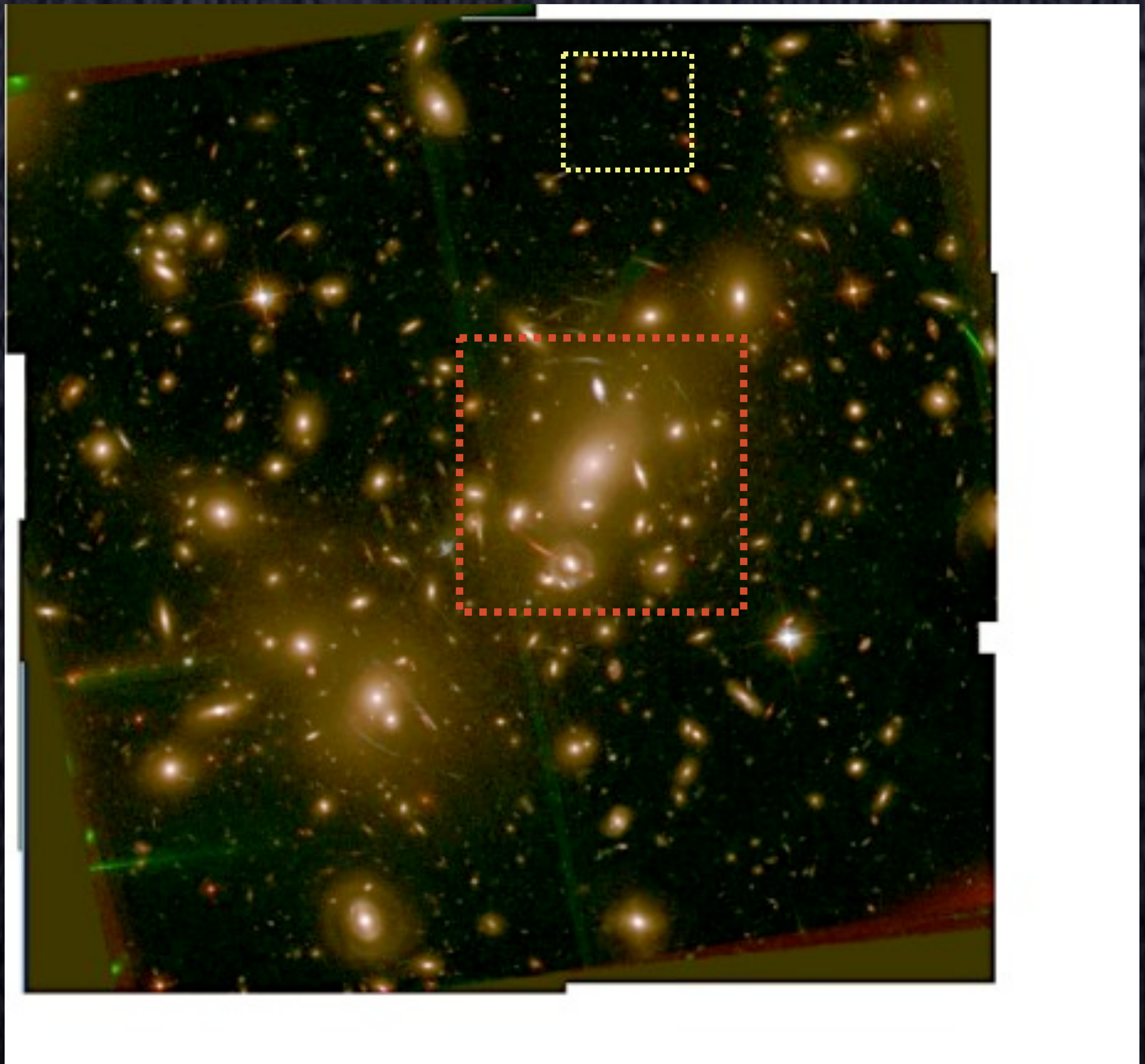
Bradac et al. 2004,
(ADAPTIVE) - Diego et al. , Cacciato et al.
Merten et al., Saha et. al. Pixelens
and more ....

Mesh-Free Technique

Particle Based Lensing (PBL)

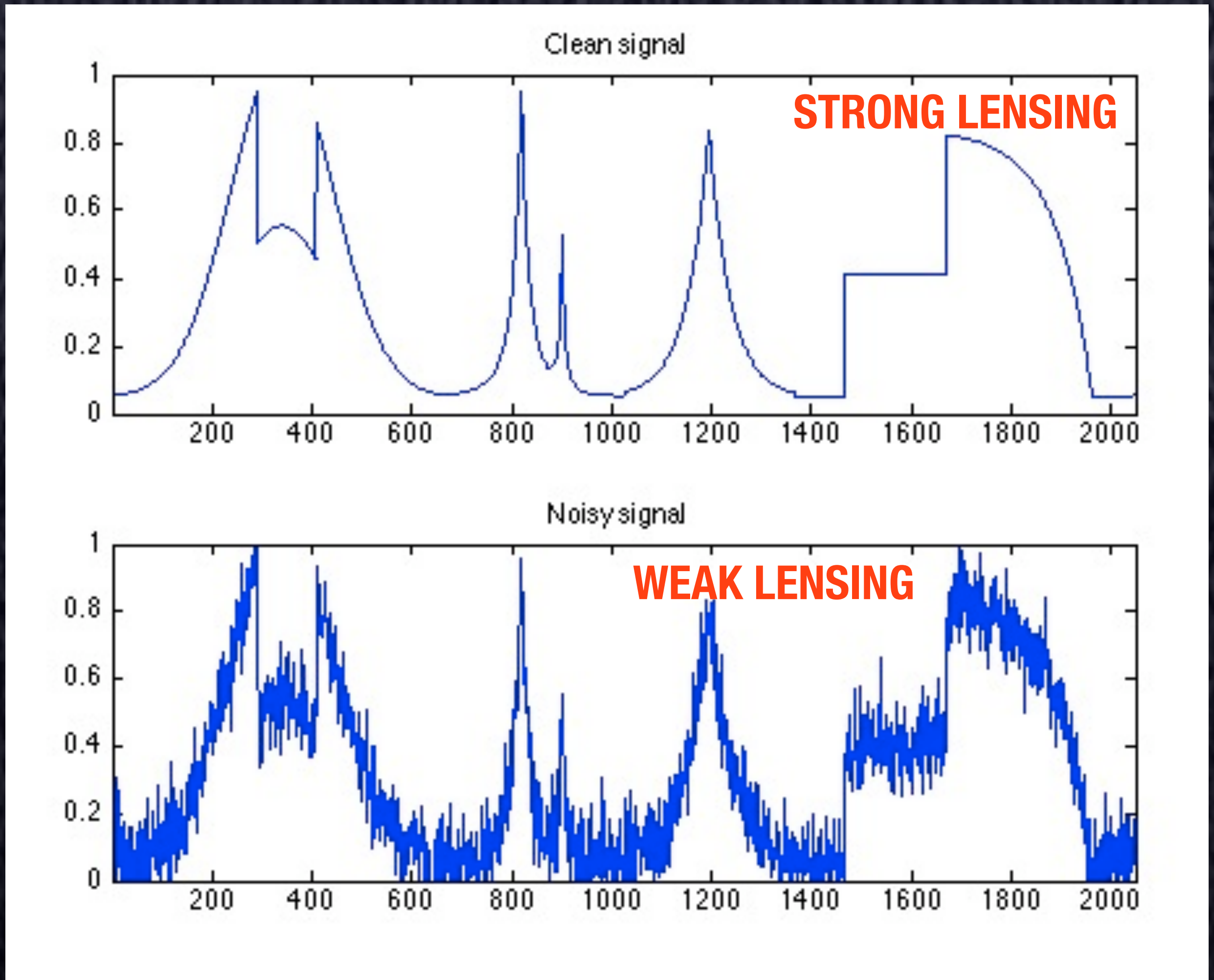
Deb et al. ,2008, 2009

Strong+Weak Lensing: Challenges



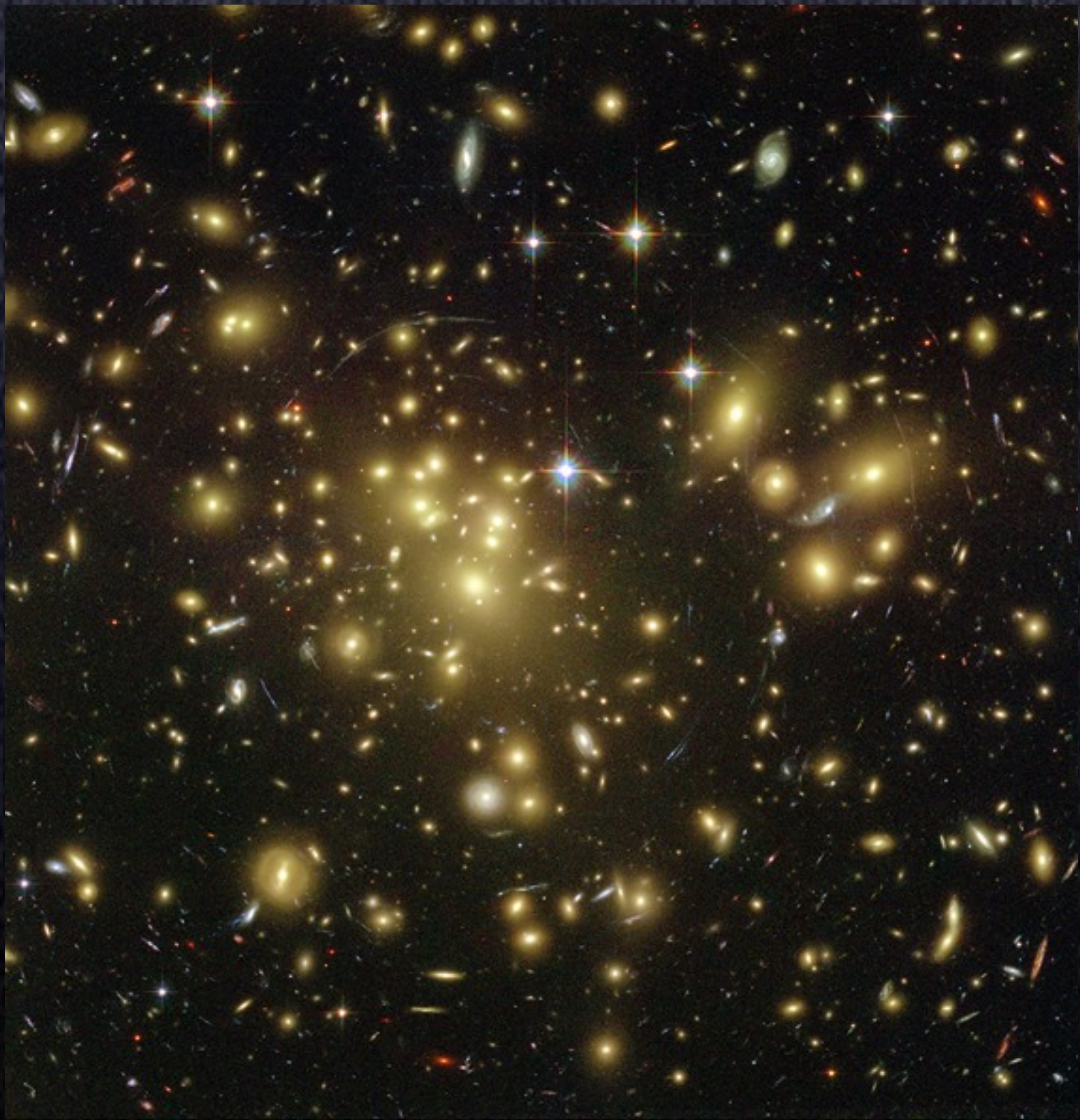
HST/ACS image of Abell 2218 (Sánchez et al. 2006)

Strong+Weak Lensing



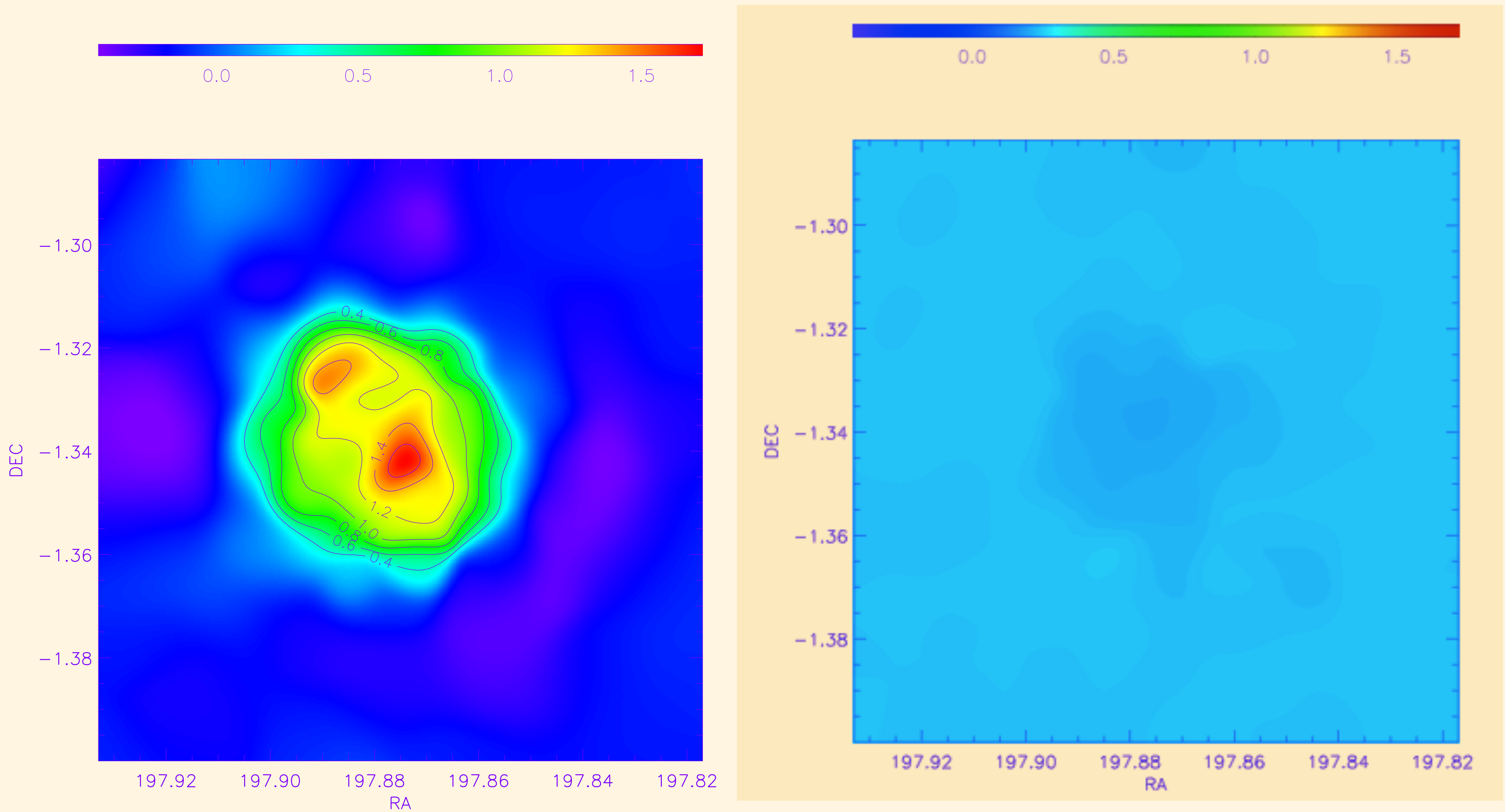
+

A1689

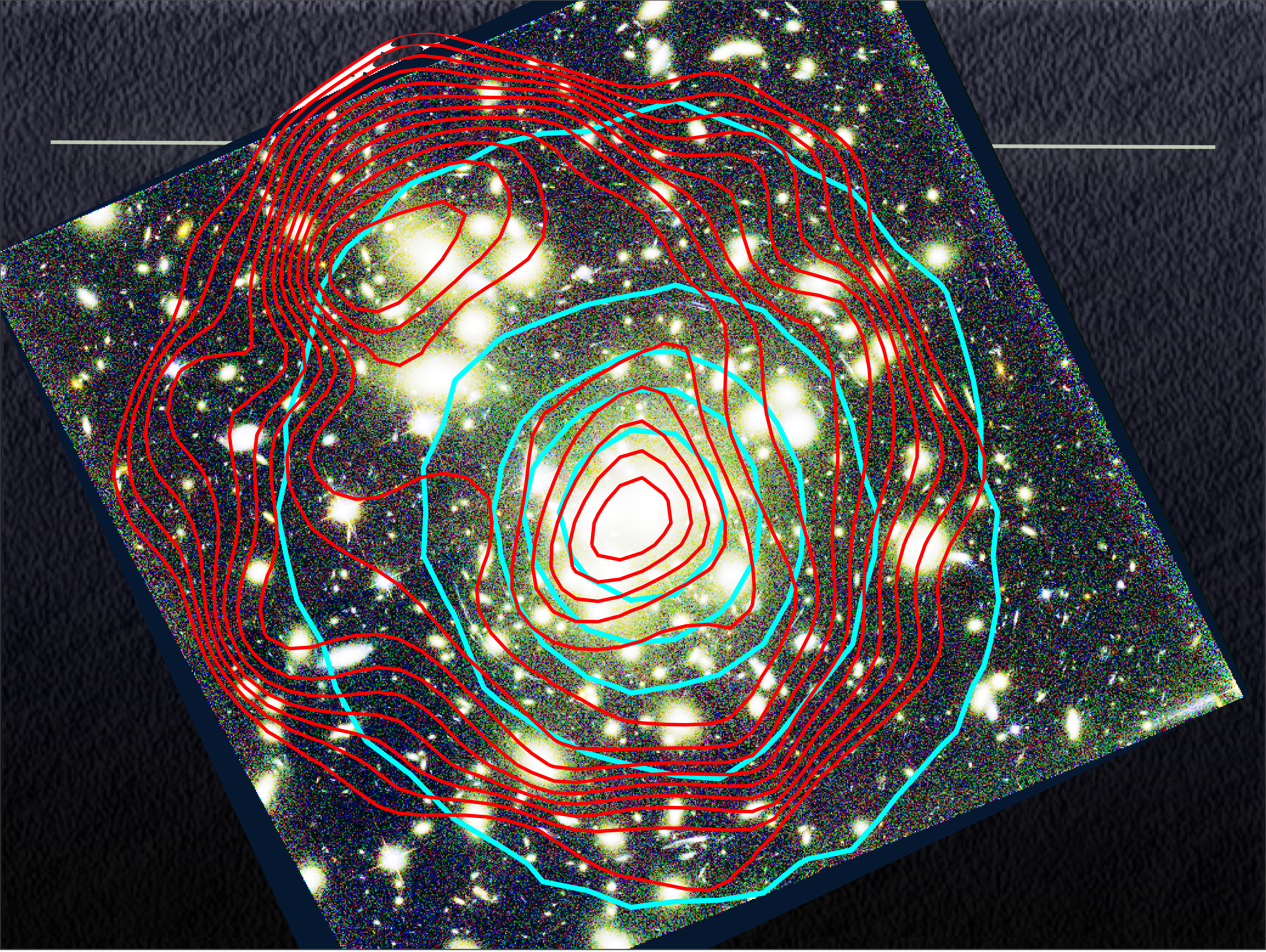


http://chandra.harvard.edu/photo/2008/a1689/

Mass Map

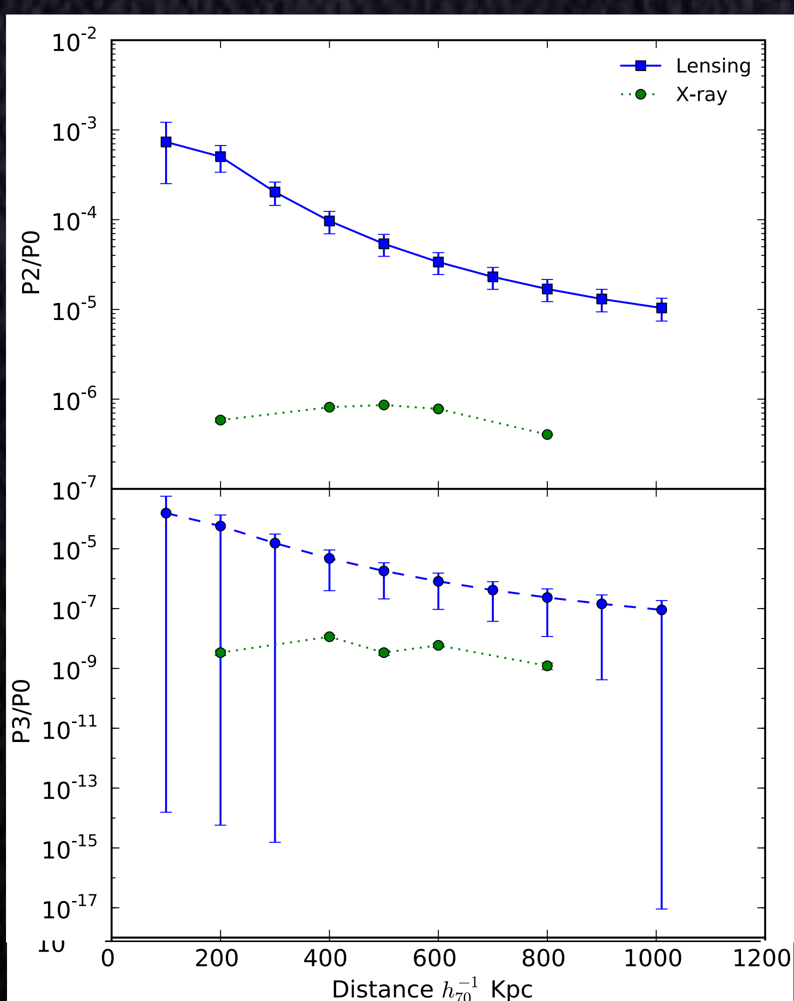


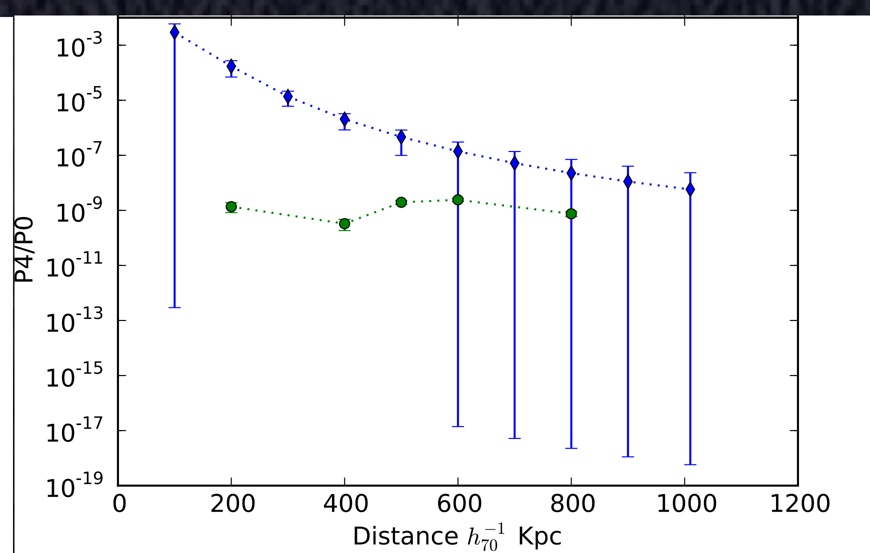
Error Map



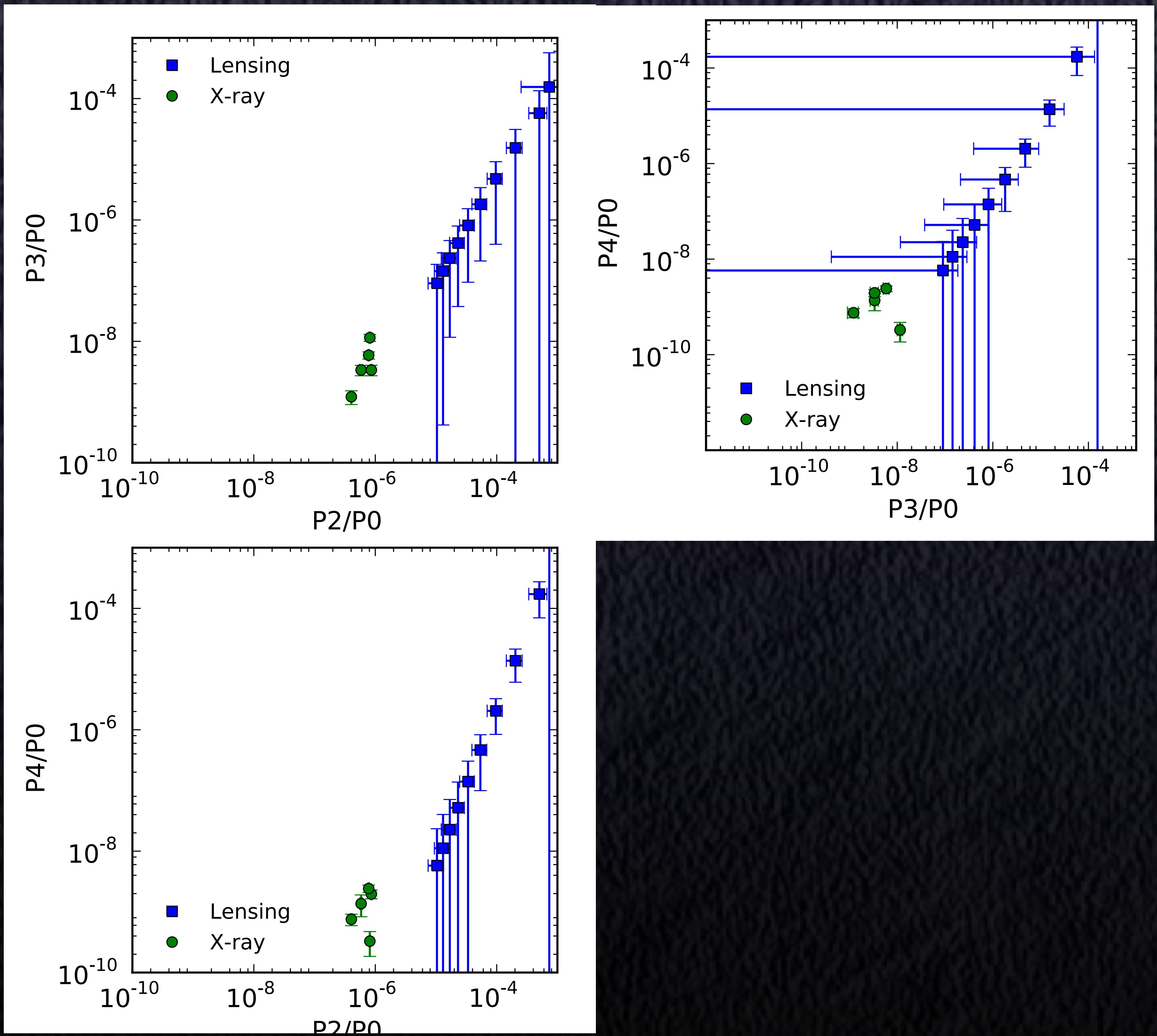
Power Ratios

Moments of the mass distribution characterize the morphology and substructure in dark matter distribution.



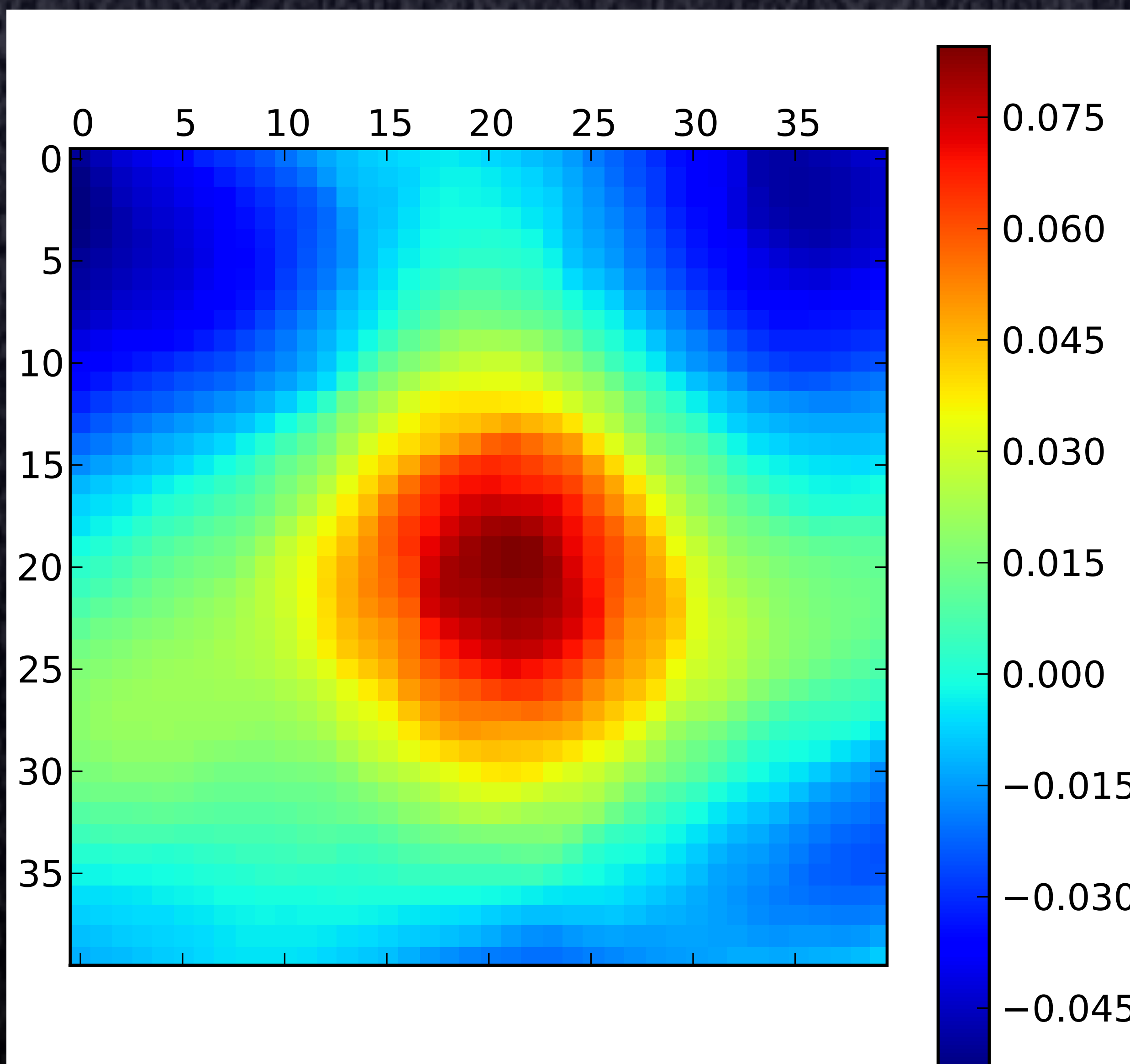


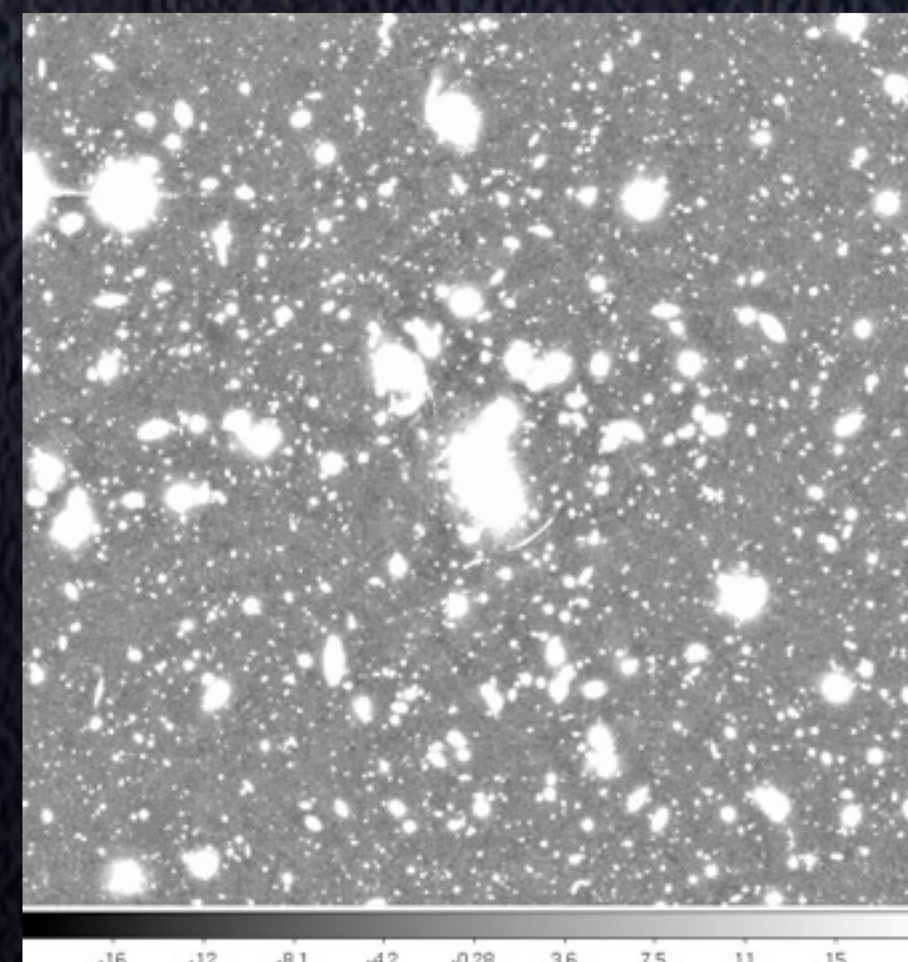
Cross-Correlations



Current Research

A2219: Optical vs Lensing mass reconstruction

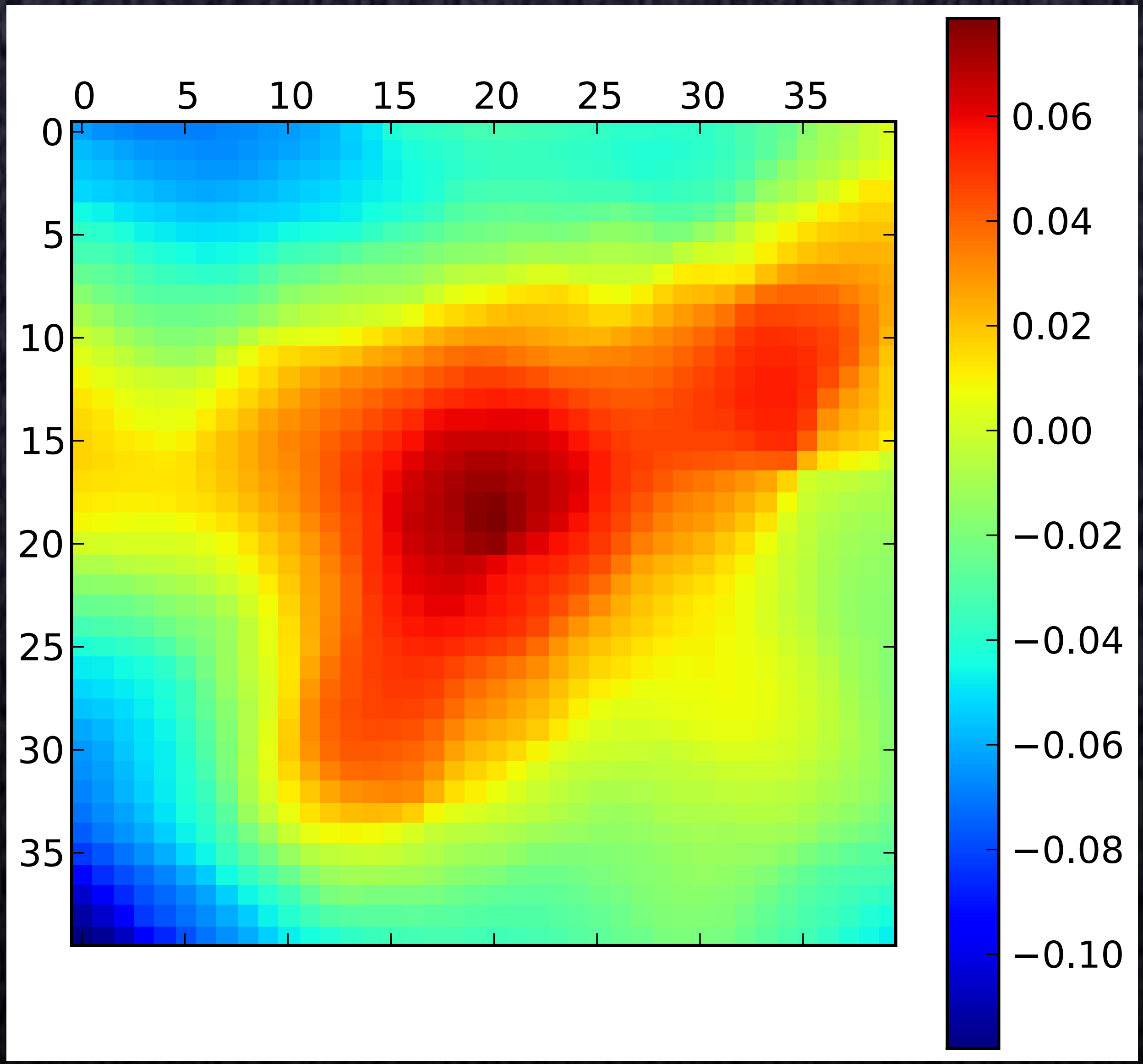




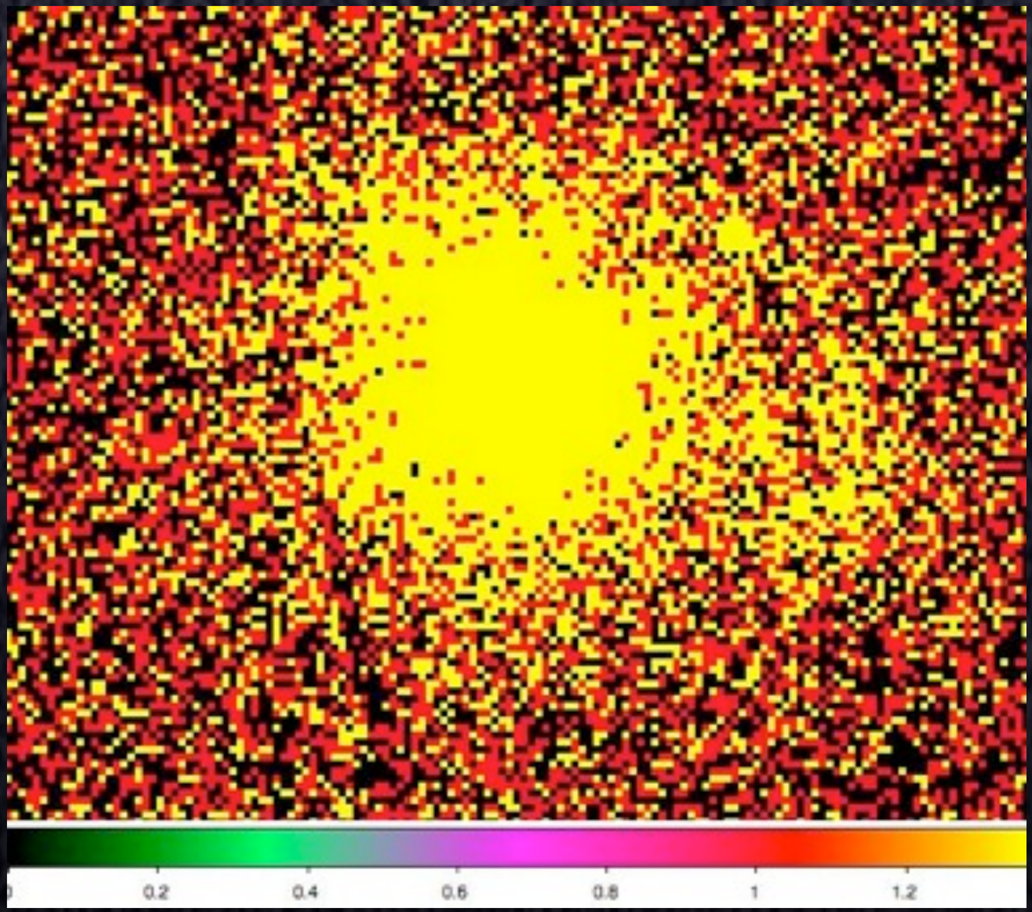
PRELIMINARY

Current Research

A2261: X-ray vs Lensing mass reconstruction



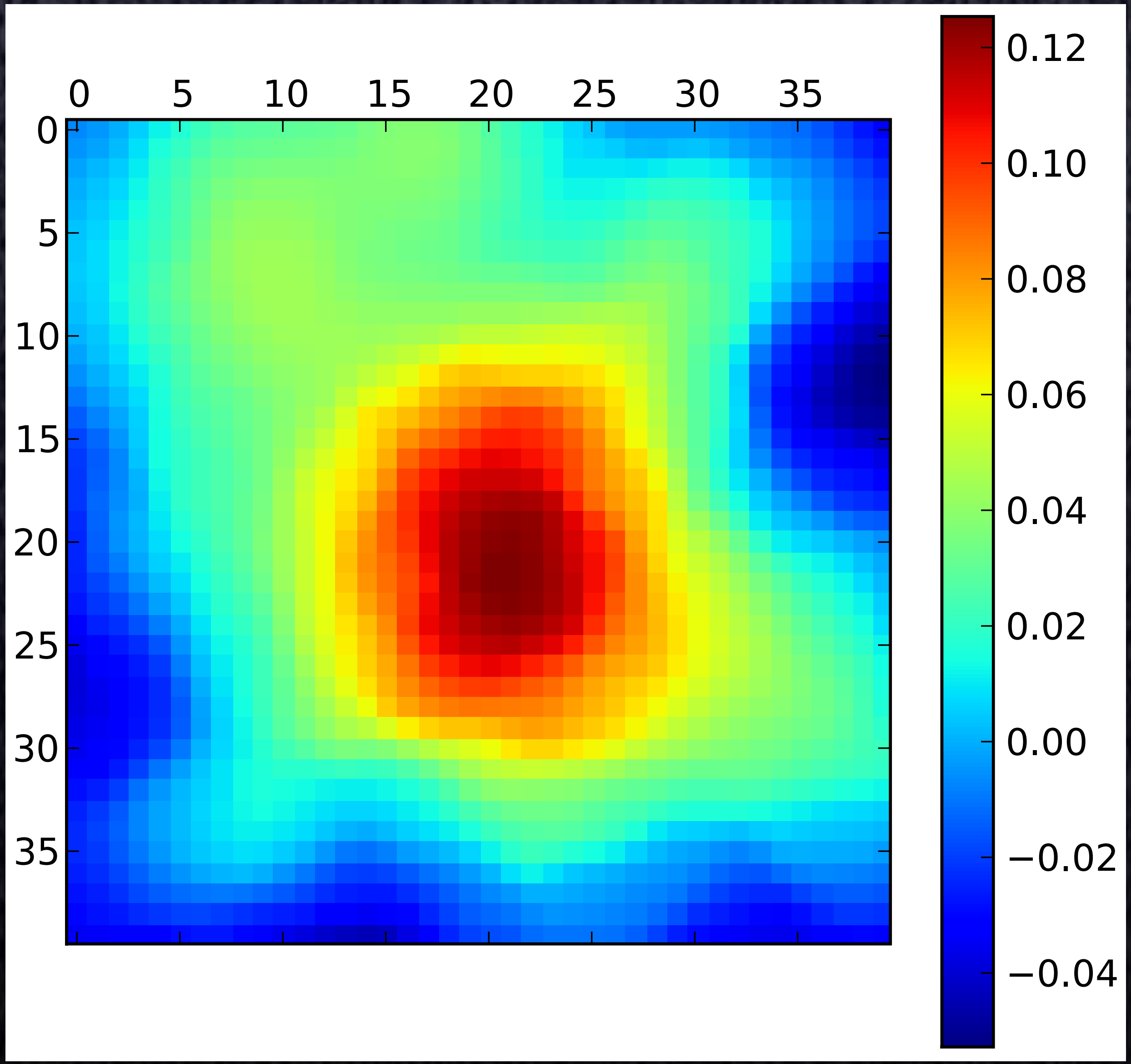
XMM Newton



PRELIMINARY

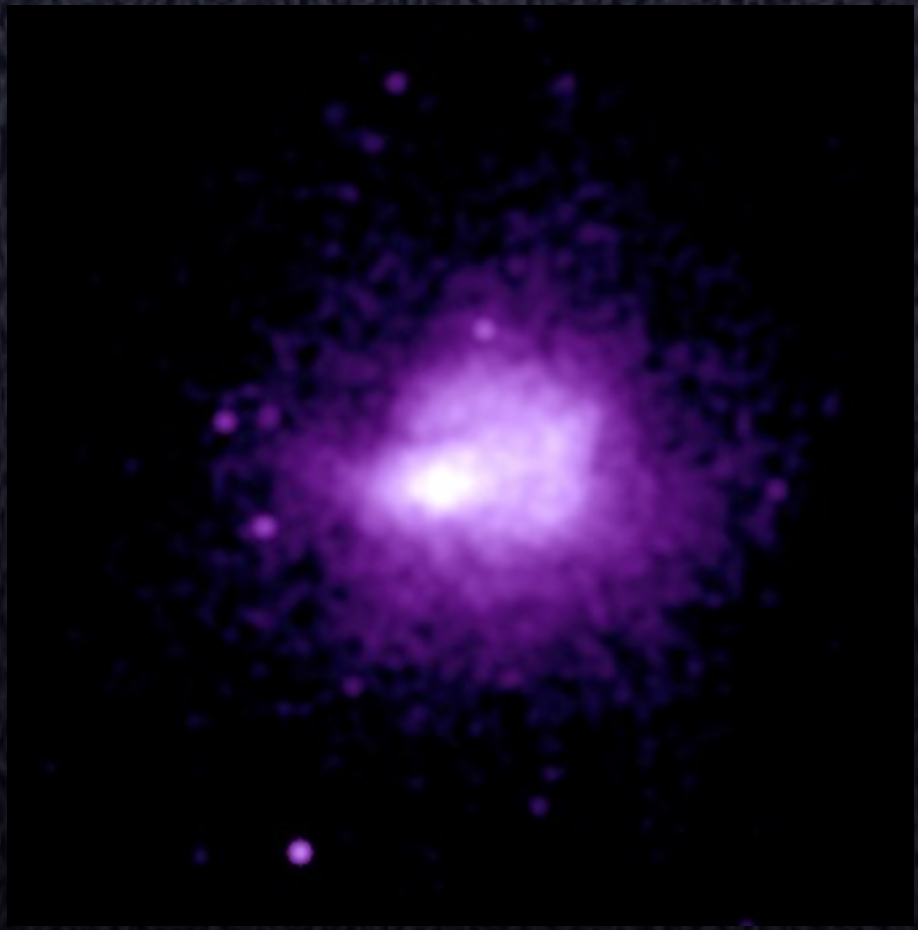
Current Research

A1914: X-ray vs Lensing mass reconstruction



PRELIMINARY

Chandra data



http://chandra.harvard.edu/photo/2006/clusters/

Summary

METHOD

Developed a non-parametric mass reconstruction technique "Particle Based Lensing" (PBL).
PBL is applied to compute mass maps of variable resolution and signal-to-noise.

RESULTS

- The ellipticity for the light distribution is smaller than the ellipticity of the dark matter distribution for A901b and the Southwest Group.
- A901a, A901b and A902 have strong alignment whereas the Southwest group is not aligned with the rest of the peaks.
- The gas distribution of A1689 is smoother than the dark matter distribution.

Future Research

Mutiwavelength analysis for a sample of 20 Supermassive Clusters.