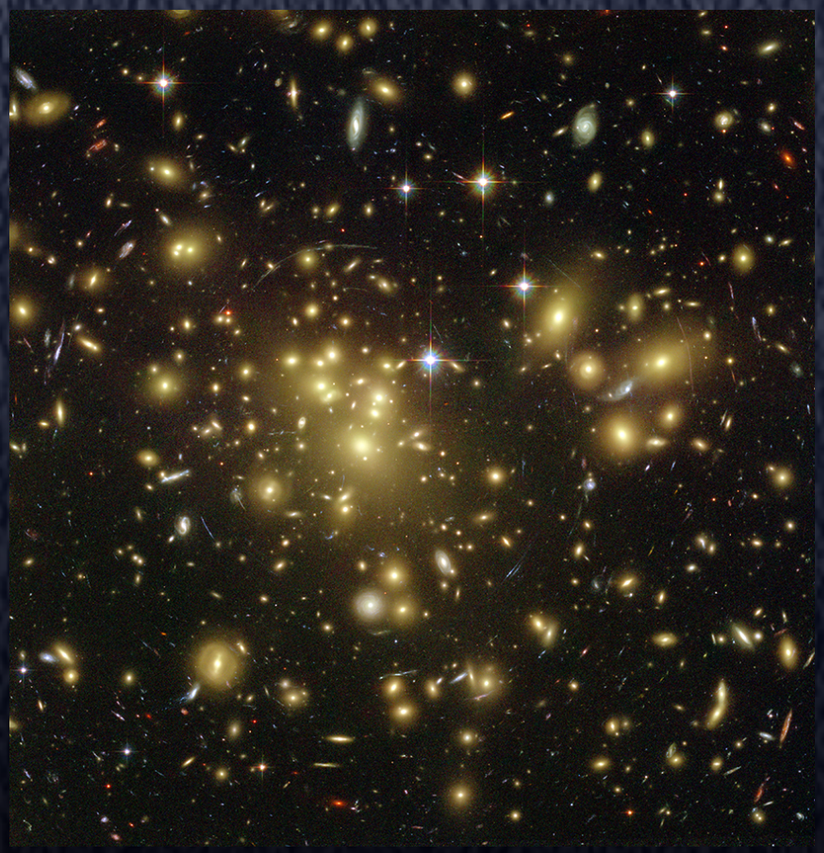
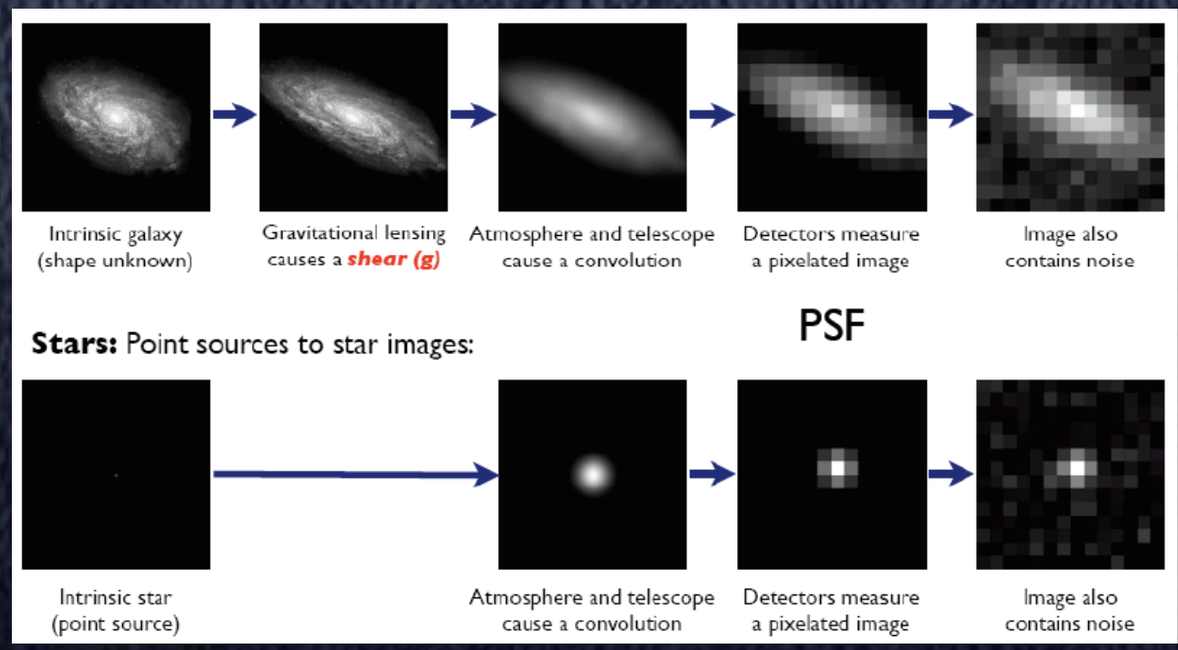
Quantifying substructure in Galaxy Clusters with X-ray and Gravitational Lensing Measurements.

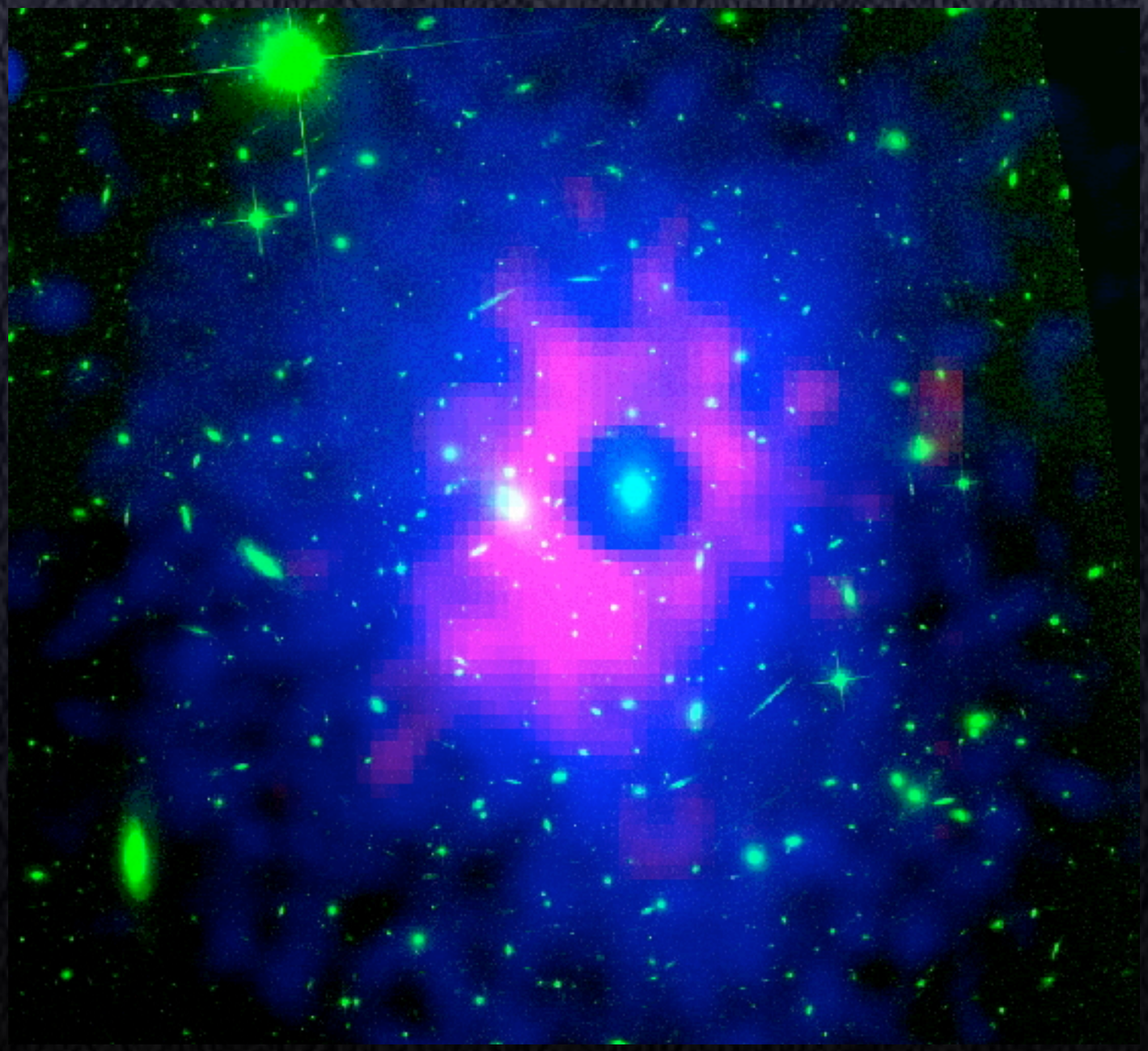




Sanghamitra Deb

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

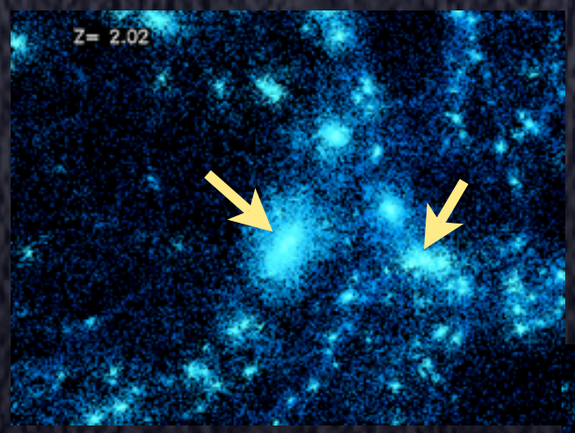
gas: Xray observations

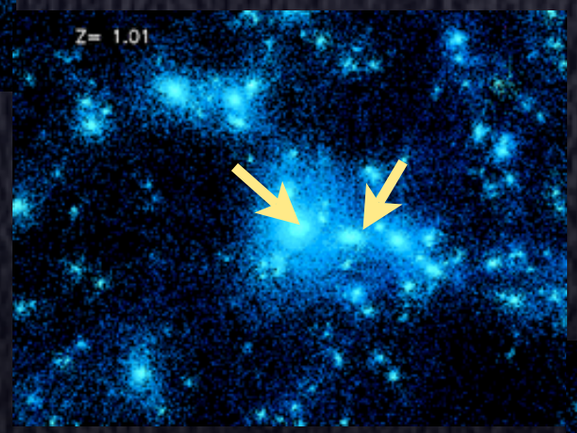
gas: Sunyaev Zeldovich Effect

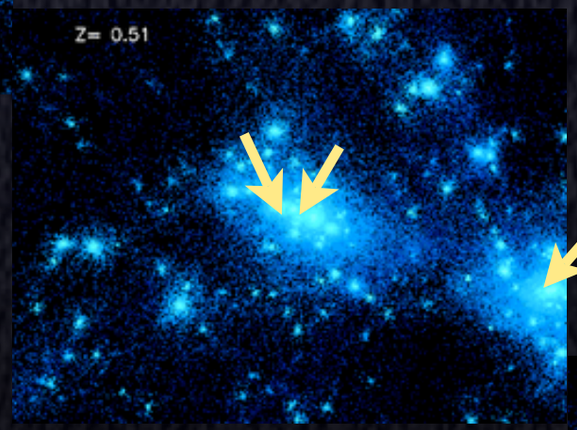
Galaxy Cluster RXJ1347-1145

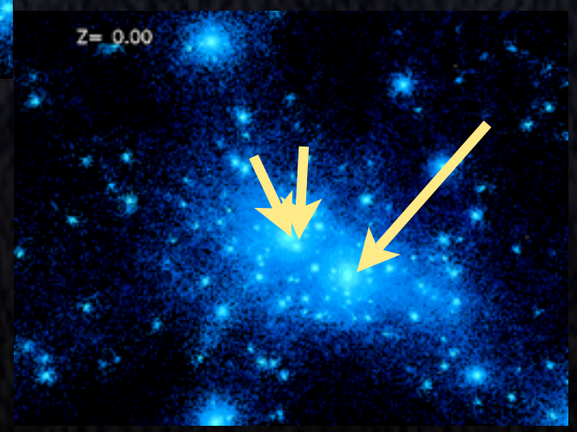
http://chile1.physics.upenn.edu/gbtpublic/

Substructure: Elliptical Halos





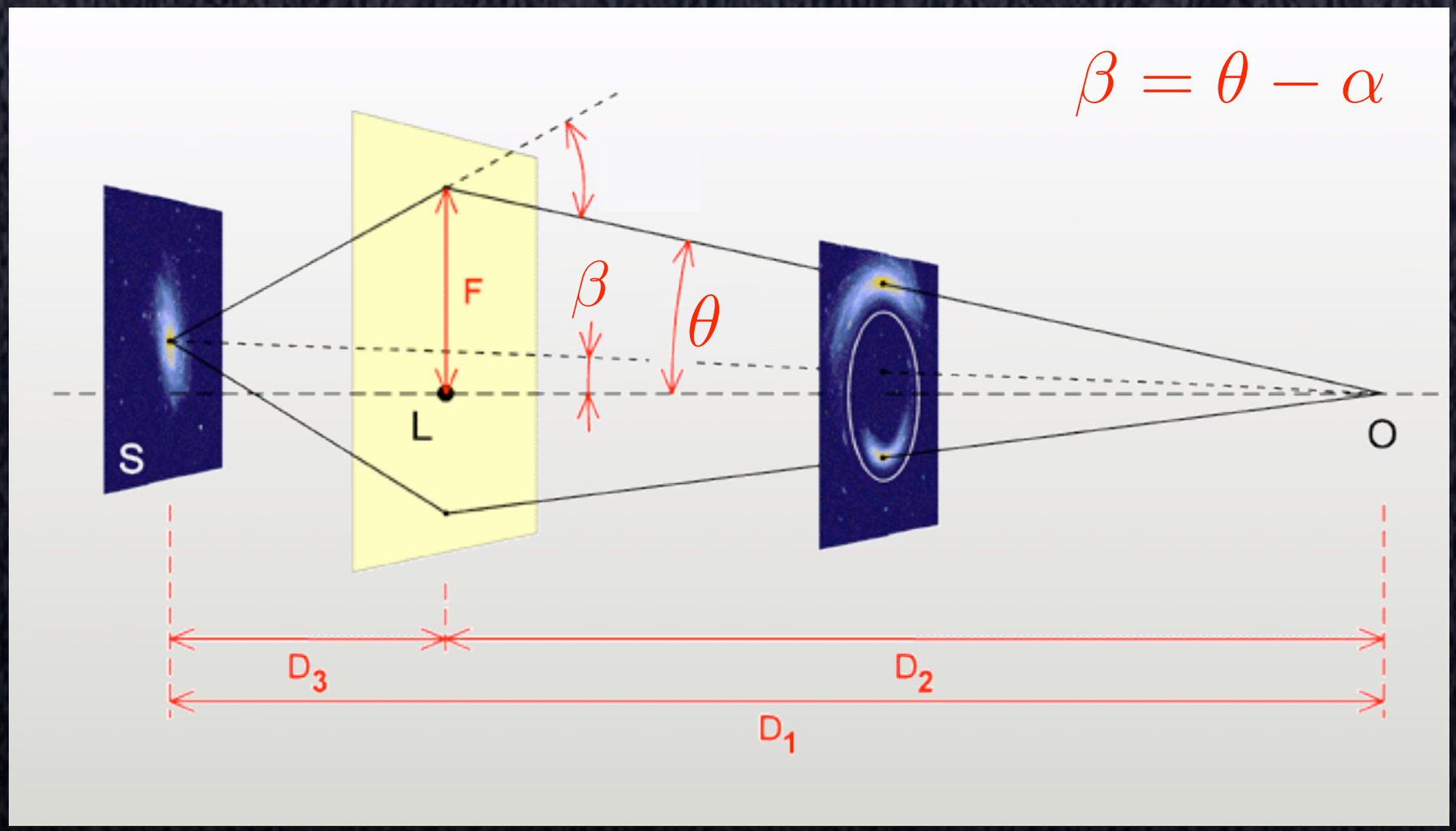




What is the distribution of cluster ellipticity?

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

Gravitational Lensing



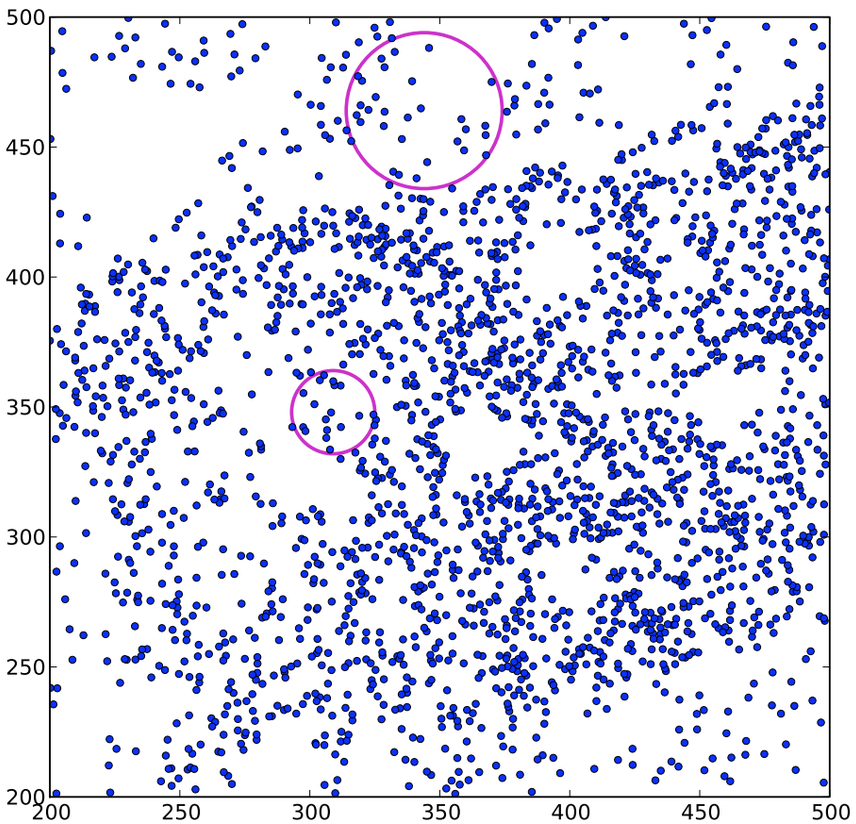
Dimension less surface mass density

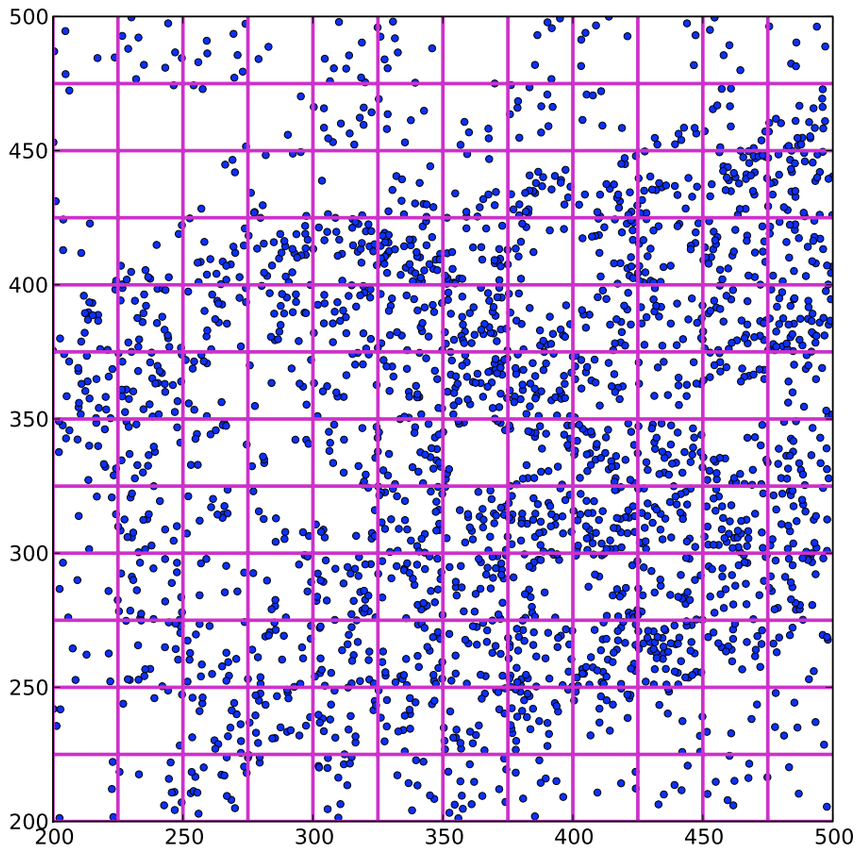
$$\kappa = \frac{\Sigma}{\Sigma_{cr}}$$

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

Particle Based Lensing

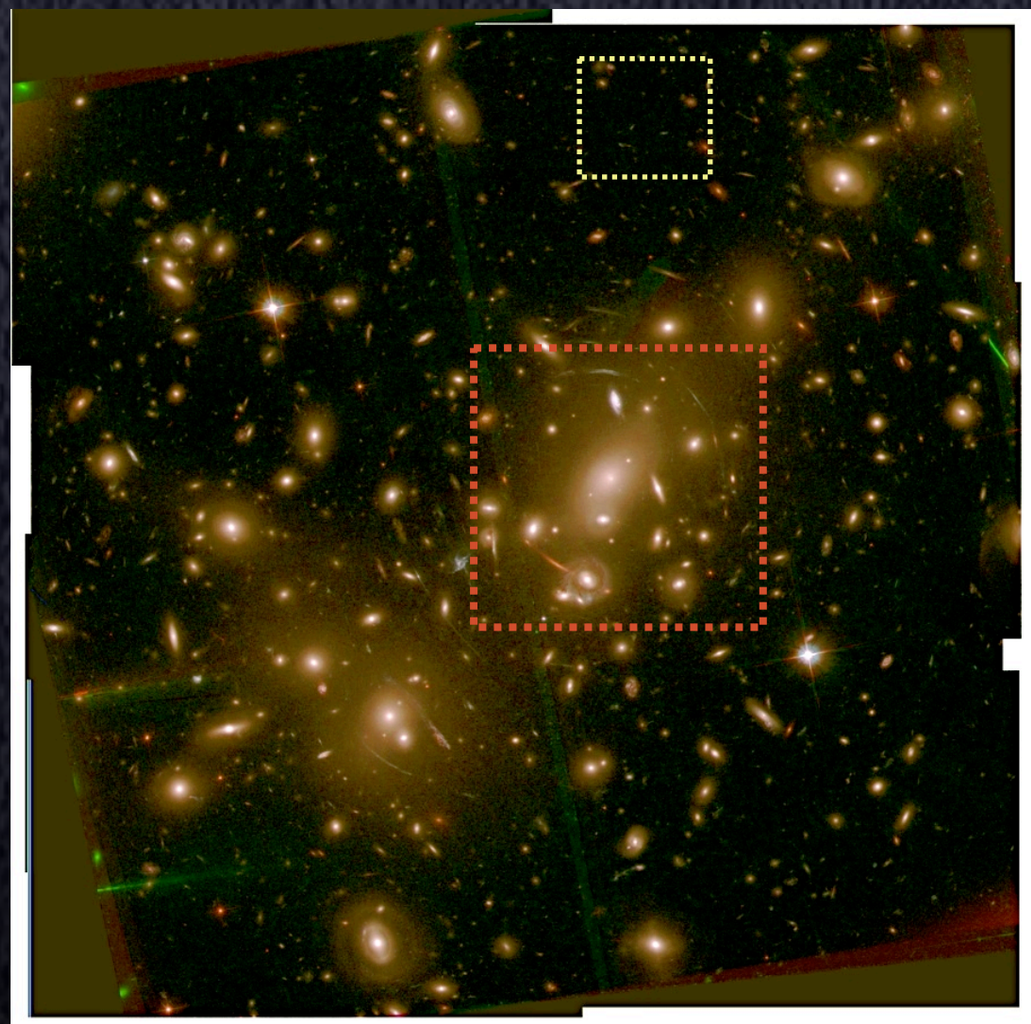
Particles-> lensed image positions



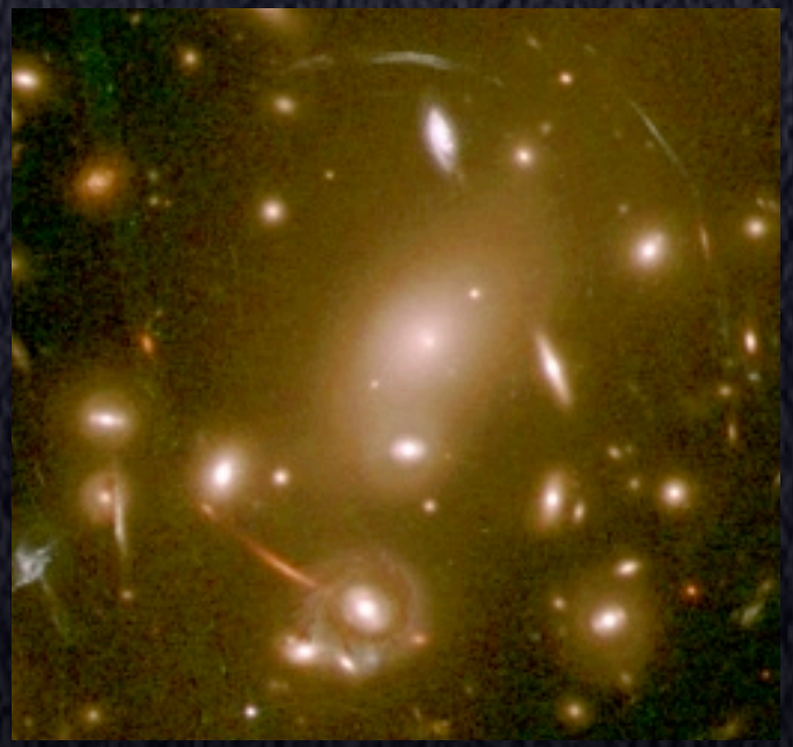


- Variable Resolution with the same complexity as finite differencing on a regular grid.
- No empty grid cells.

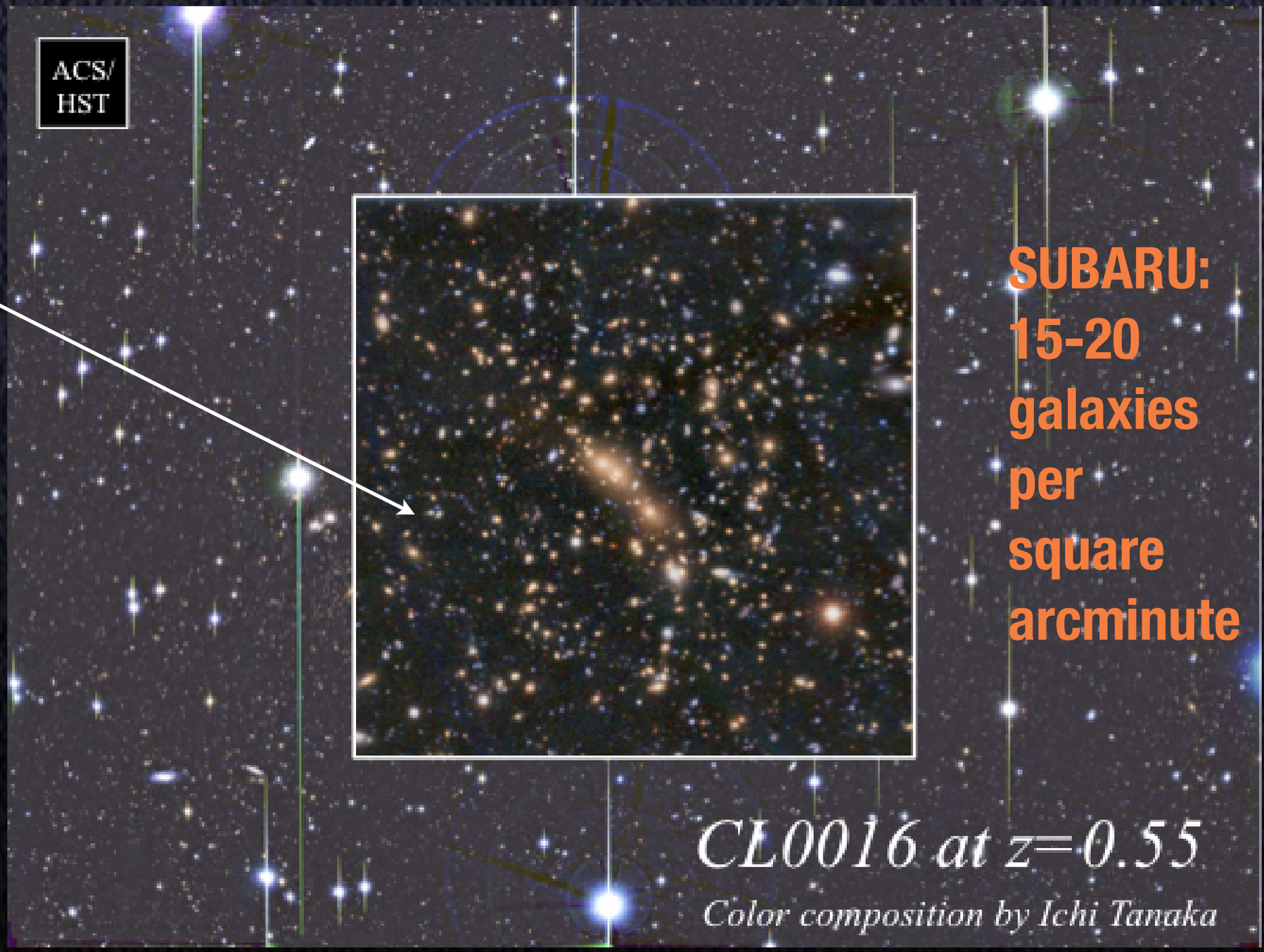
Strong+Weak Lensing: Challenges



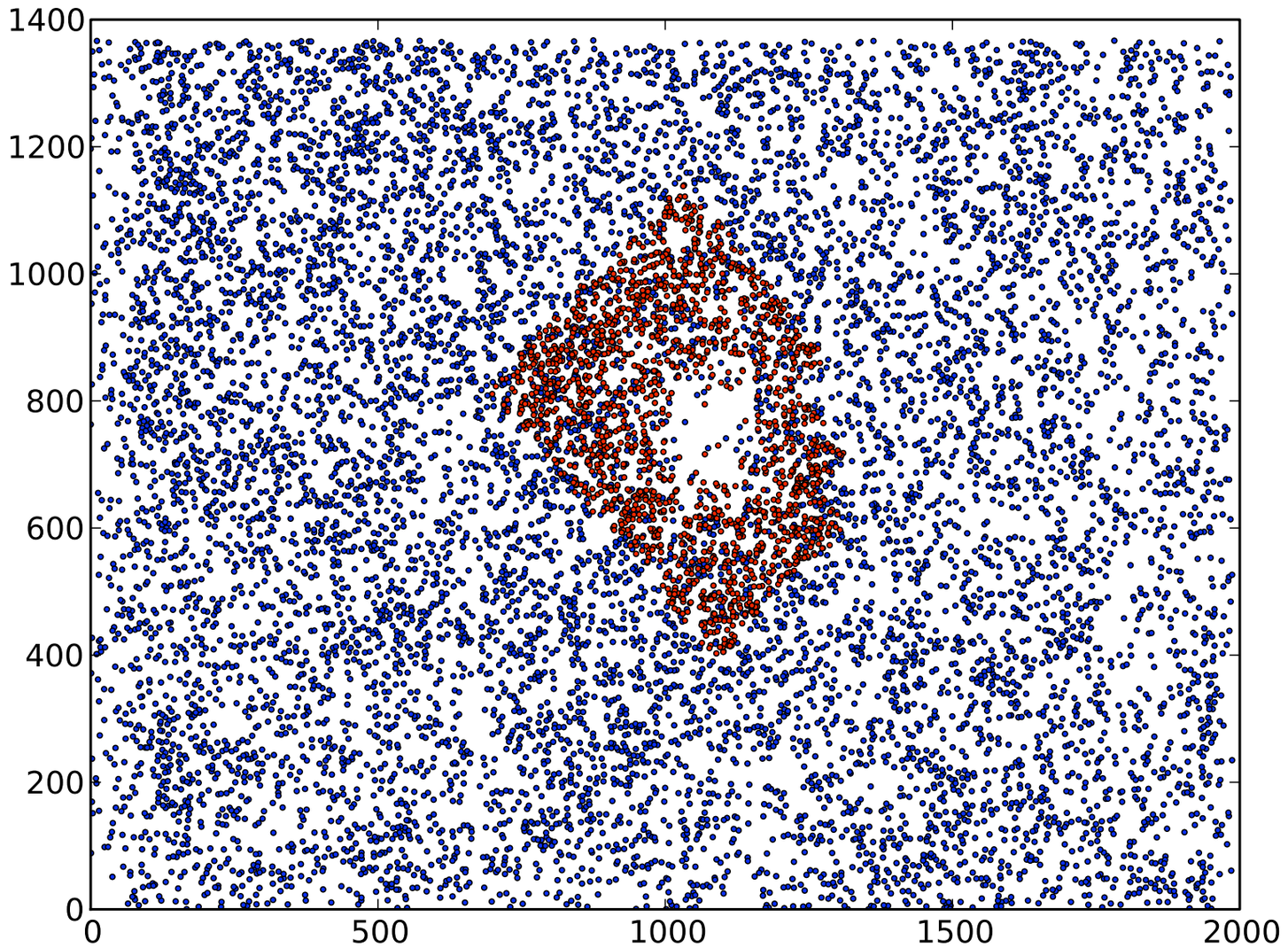
HST/ACS image of Abell 2218 (Sánchez et al. 2006)



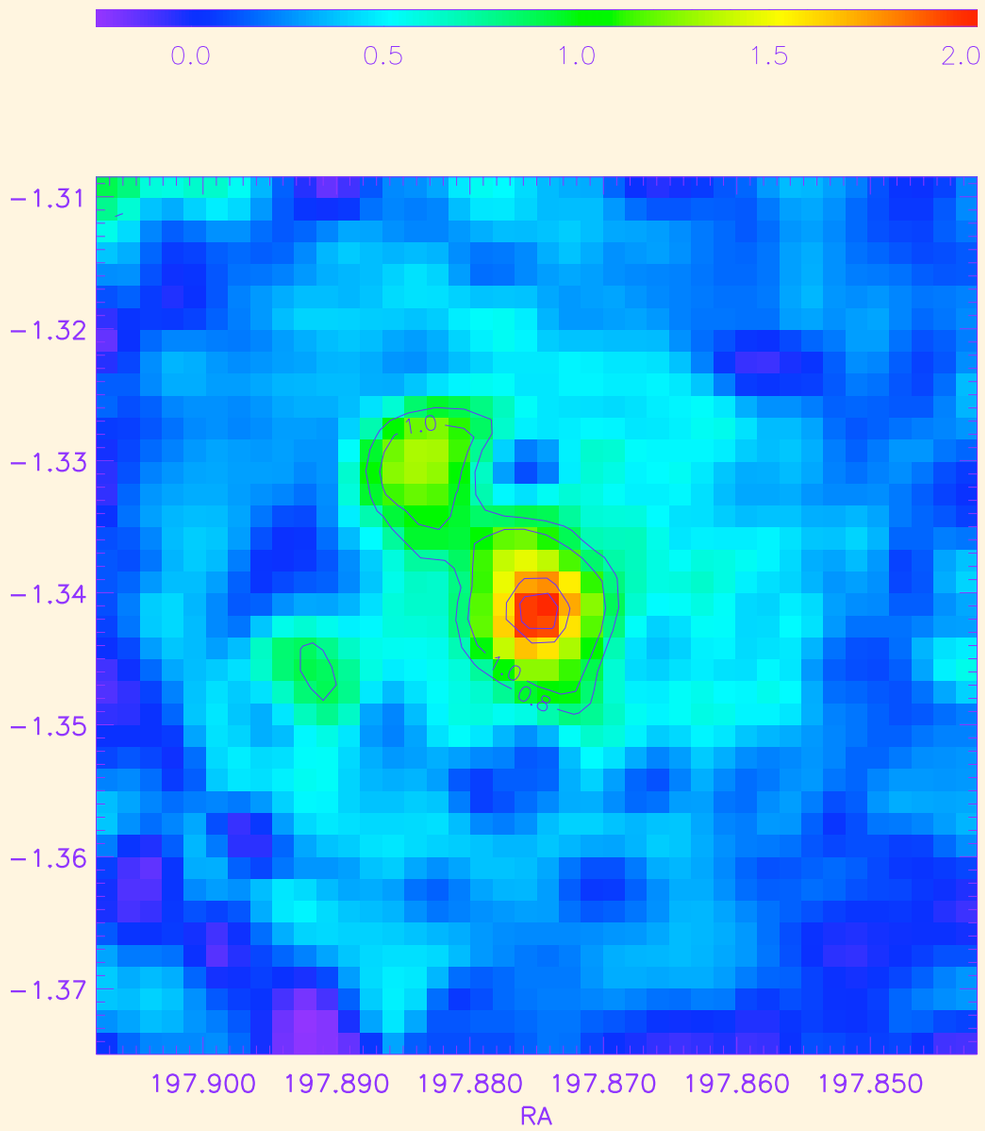
Heterogeneous Datasets

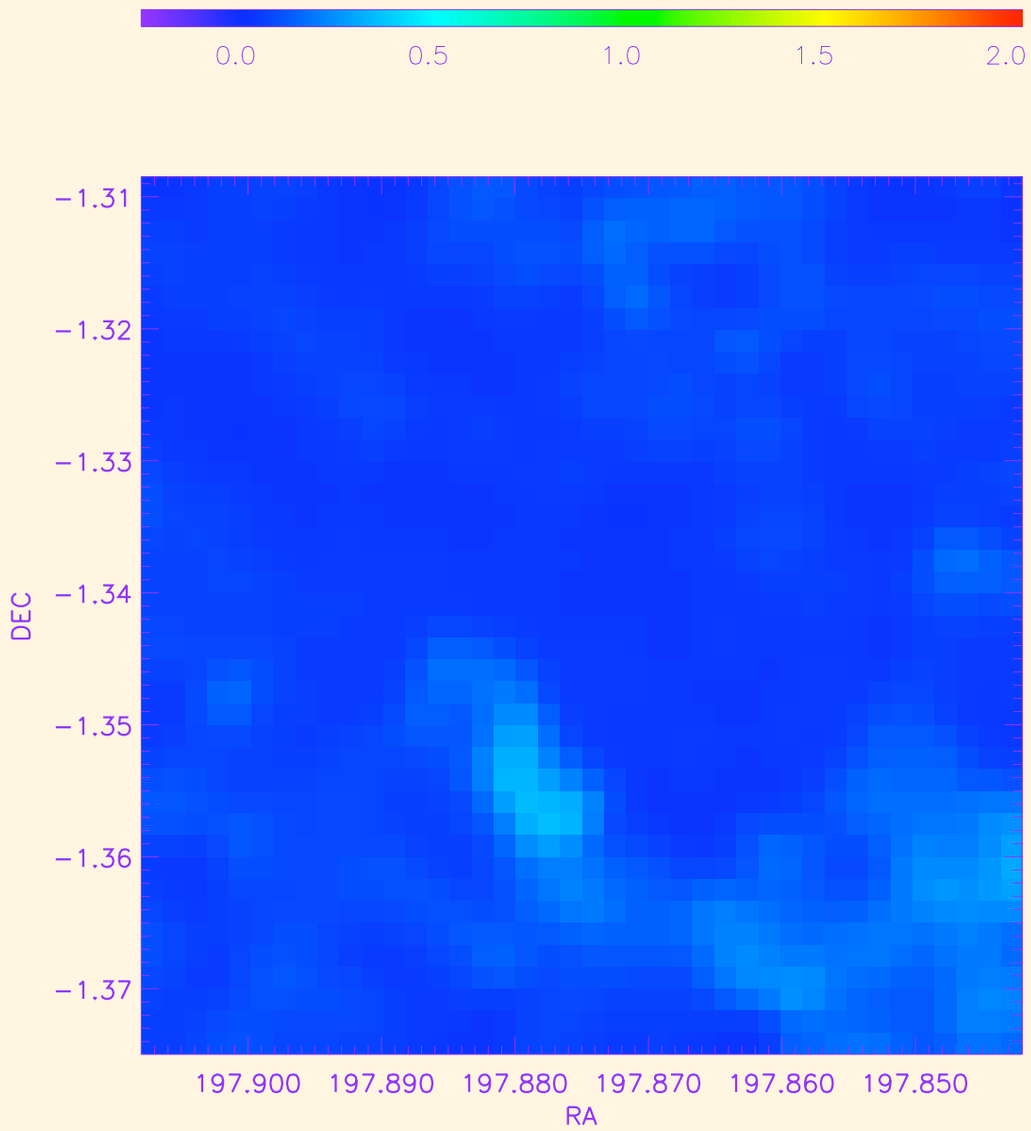


A1689: ACS+SUBARU

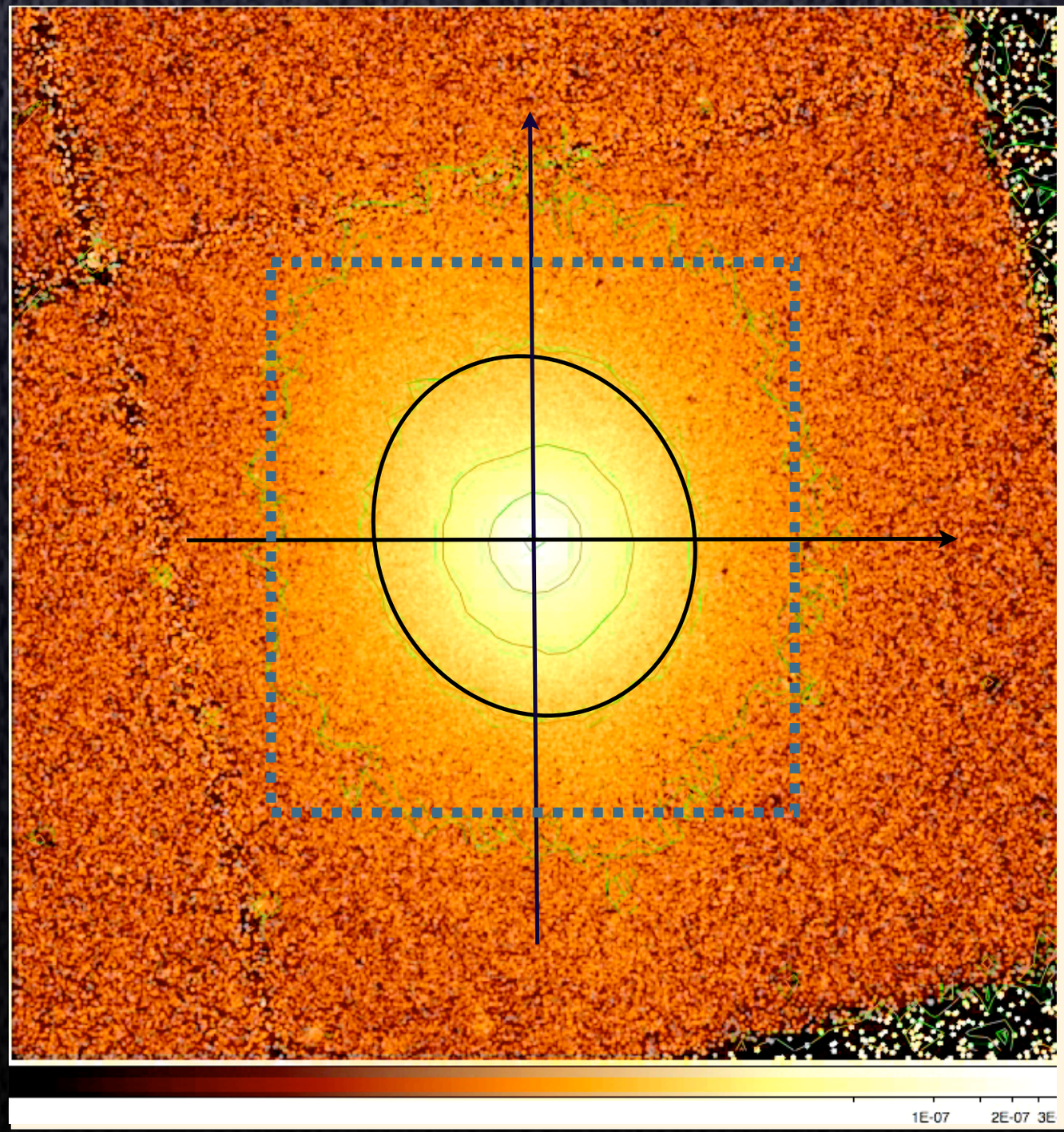


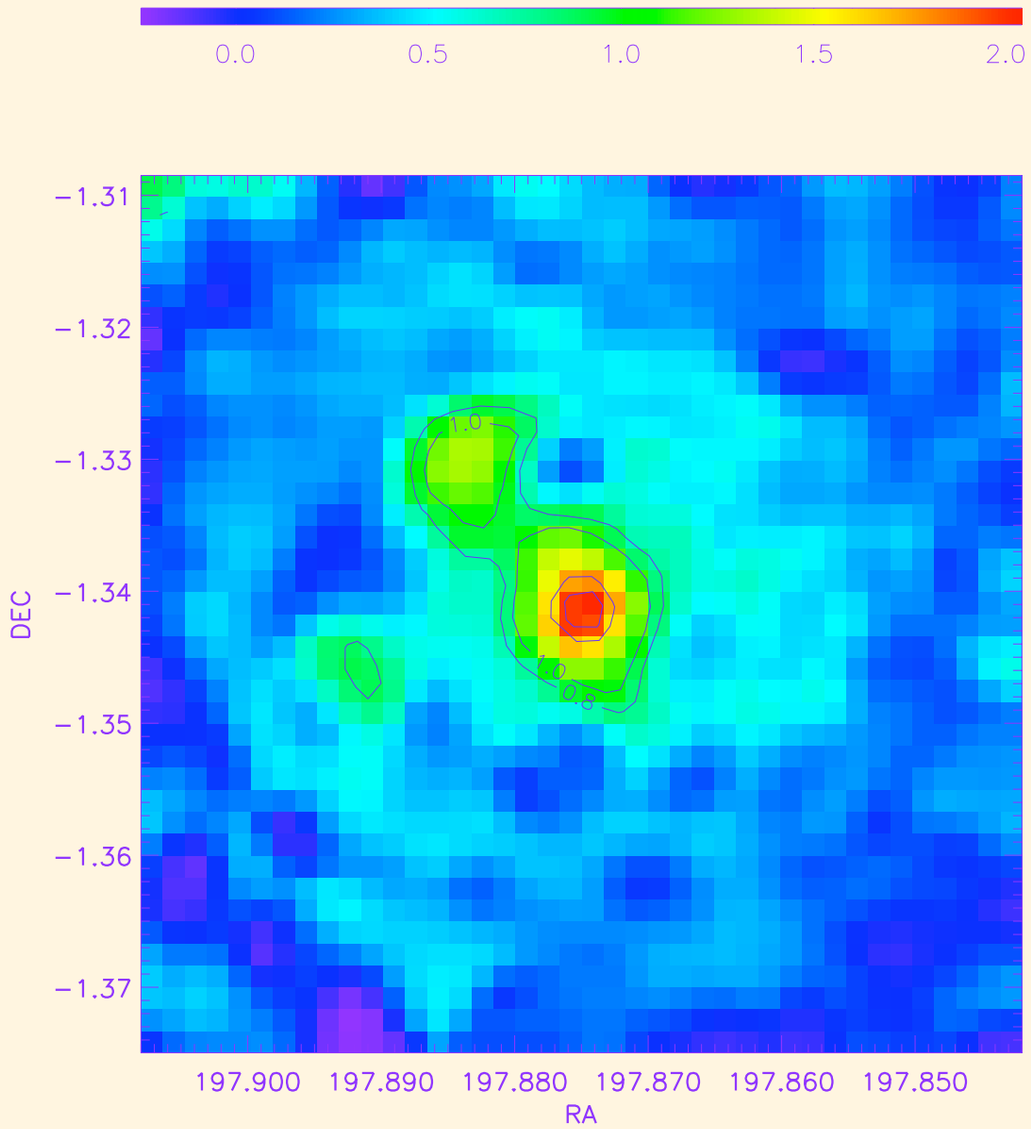
Mass Map


0.0
0.5
1.0
1.5
2.0
−1.31
−1.32
−1.33
−1.34
−1.35
−1.36
−1.37
DEC
1.0
1.0
0.8
197.900
197.890
197.880
197.870
197.860
197.850
RA


0.0
0.5
1.0
1.5
2.0
−1.31
−1.32
−1.33
−1.34
−1.35
−1.36
−1.37
DEC
197.900
197.890
197.880
197.870
197.860
197.850
RA

X-ray vs S+W Lensing





Power Ratios

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

$$a_m(r) = \int_{r'<r} \Sigma(\vec{r'}) \left(r'\right)^m \cos(m\phi') d^2\vec{r'},$$

$$b_m(r) = \int_{r'<r} \Sigma(\vec{r'}) \left(r'\right)^m \sin(m\phi') d^2\vec{r'}.$$

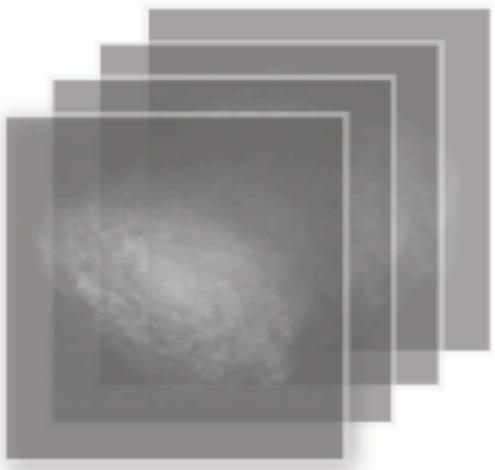
$$P_0 = [a_0 ln(R)]^2,$$

$$P_m = \frac{1}{2m^2 r^{2m}} \left(a_m^2 + b_m^2\right).$$

Power	X-ray	Lensing
P_2/P_0	$(6.68 \pm 0.27) \times 10^{-06}$	$(1.6 \pm 0.25) \times 10^{-5}$
P_3/P_0	$(3.71 \pm 1.12) \times 10^{-07}$	$(0.9 \pm 0.14) \times 10^{-5}$
P_4/P_0	$(6.42 \pm 2.65) \times 10^{-08}$	$(8.6 \pm 0.3) \times 10^{-5}$

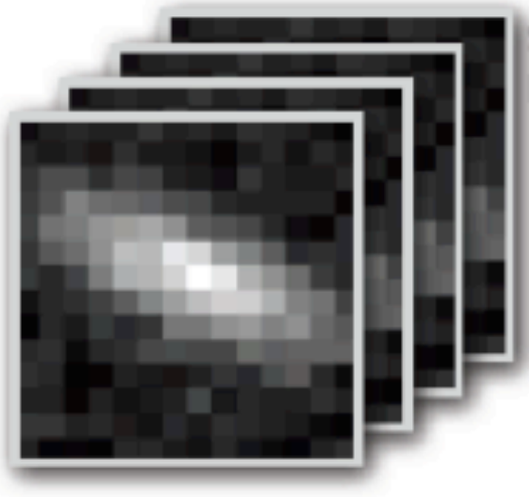
Recovering the Shear

The Inverse Problem:
Measured images to *shear*

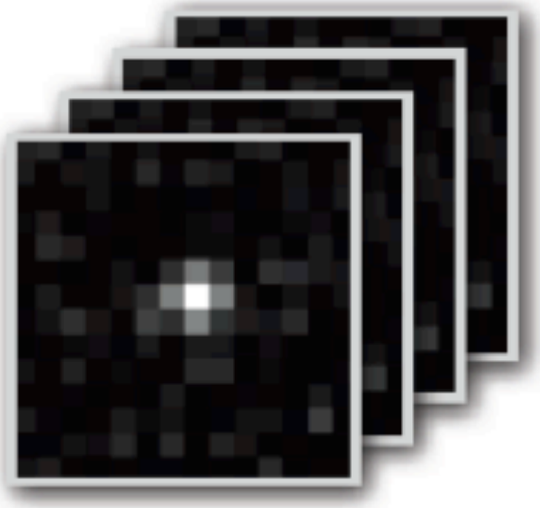


intrinsic galaxy shapes can be inferred, but are not used beyond shear estimation

Shear Field



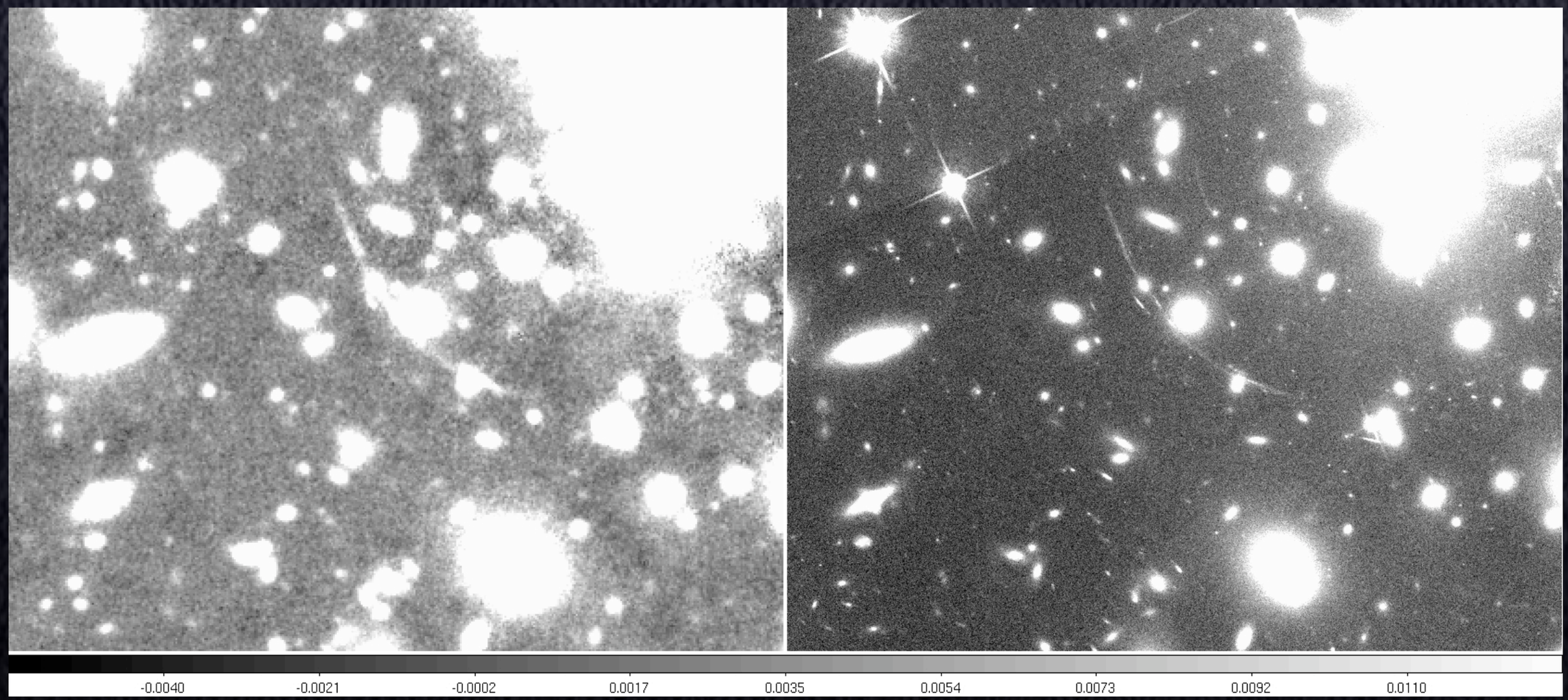
Set of galaxy images.
Each contains:
- noise
- pixelisation
- convolution
- ***shear***
- intrinsic shape



Set of star images.
Each contains:
- noise
- pixelisation
- convolution

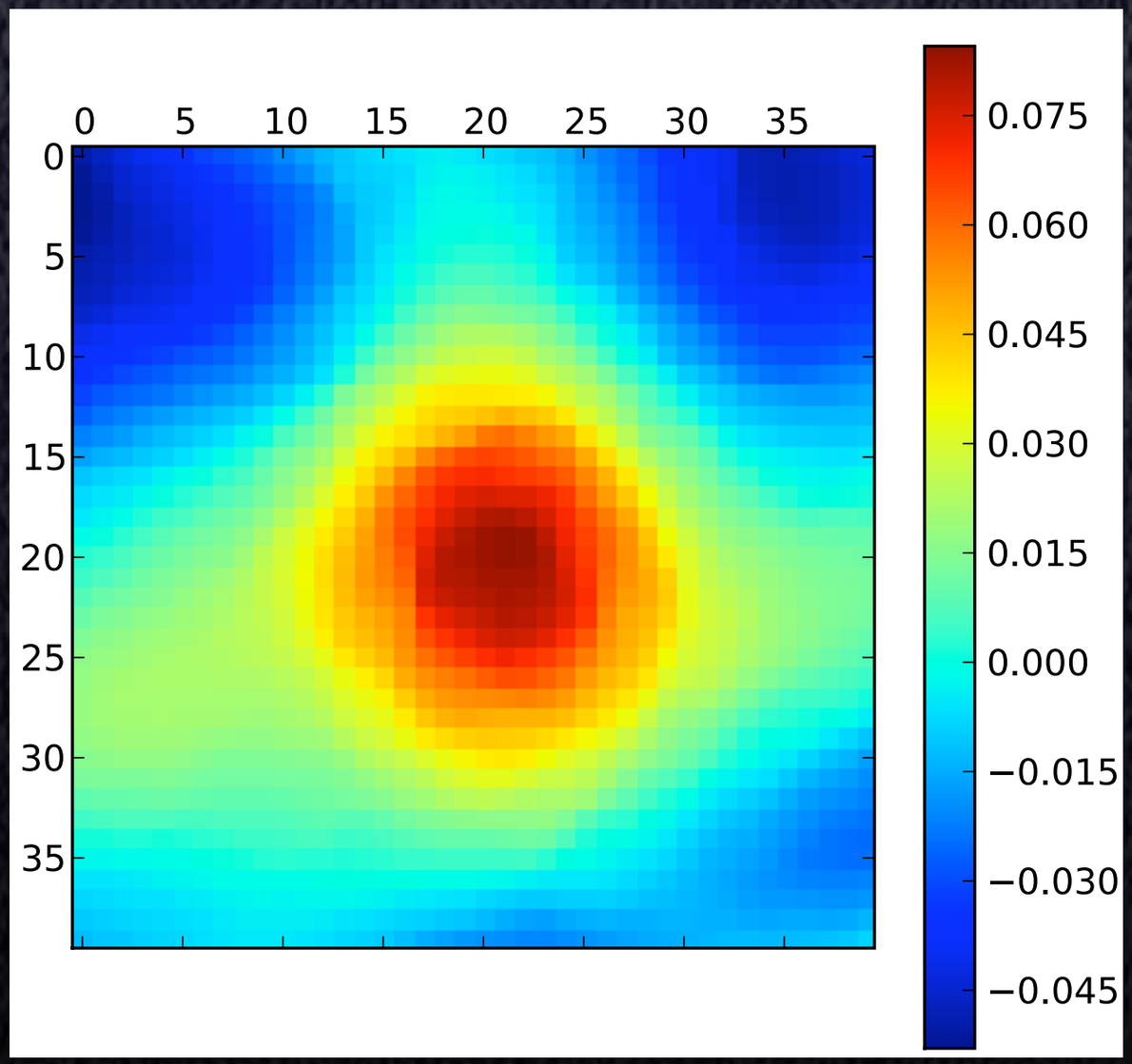
Catherine Heymans

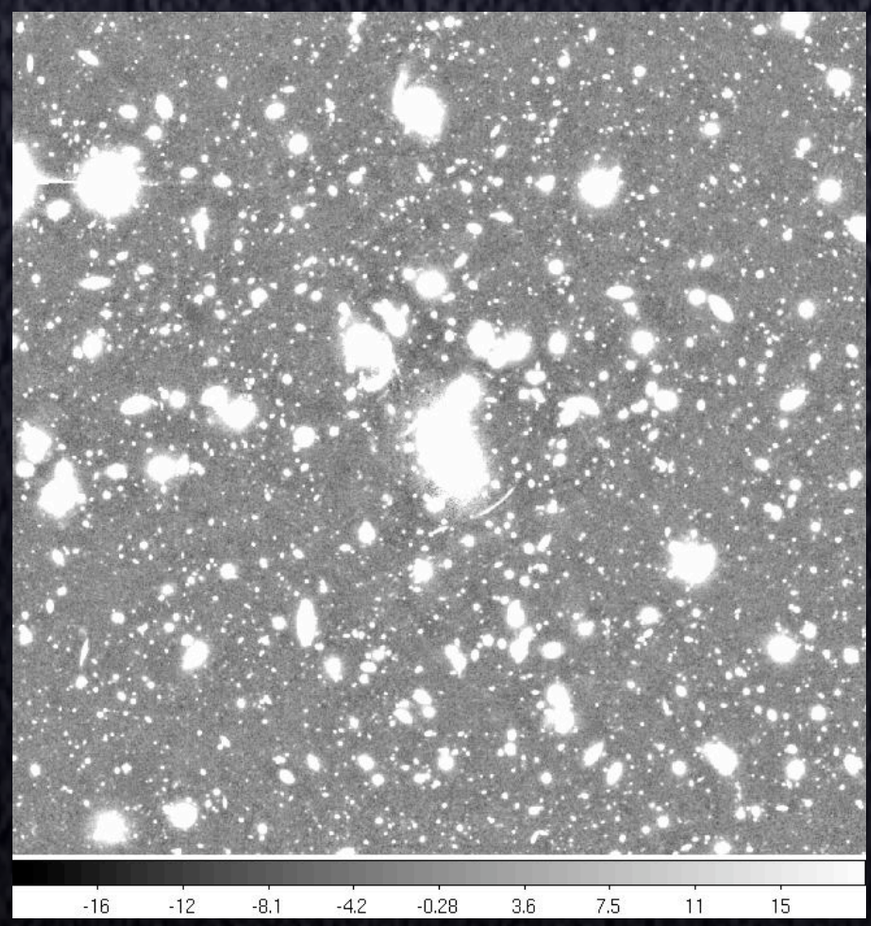
Comparison of Space vs Ground: A1689



Current Research

A2219: Optical vs Lensing mass reconstruction

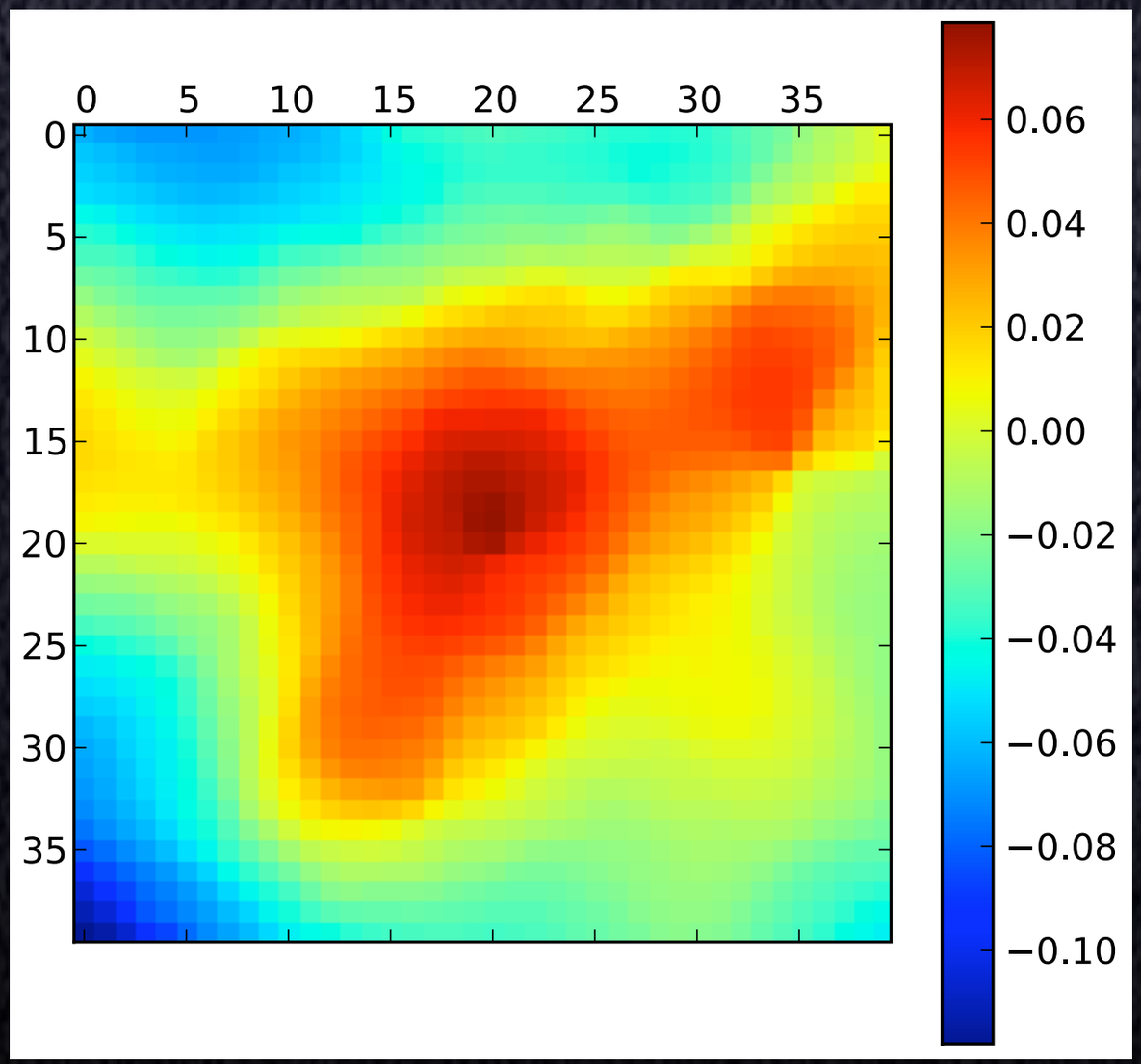




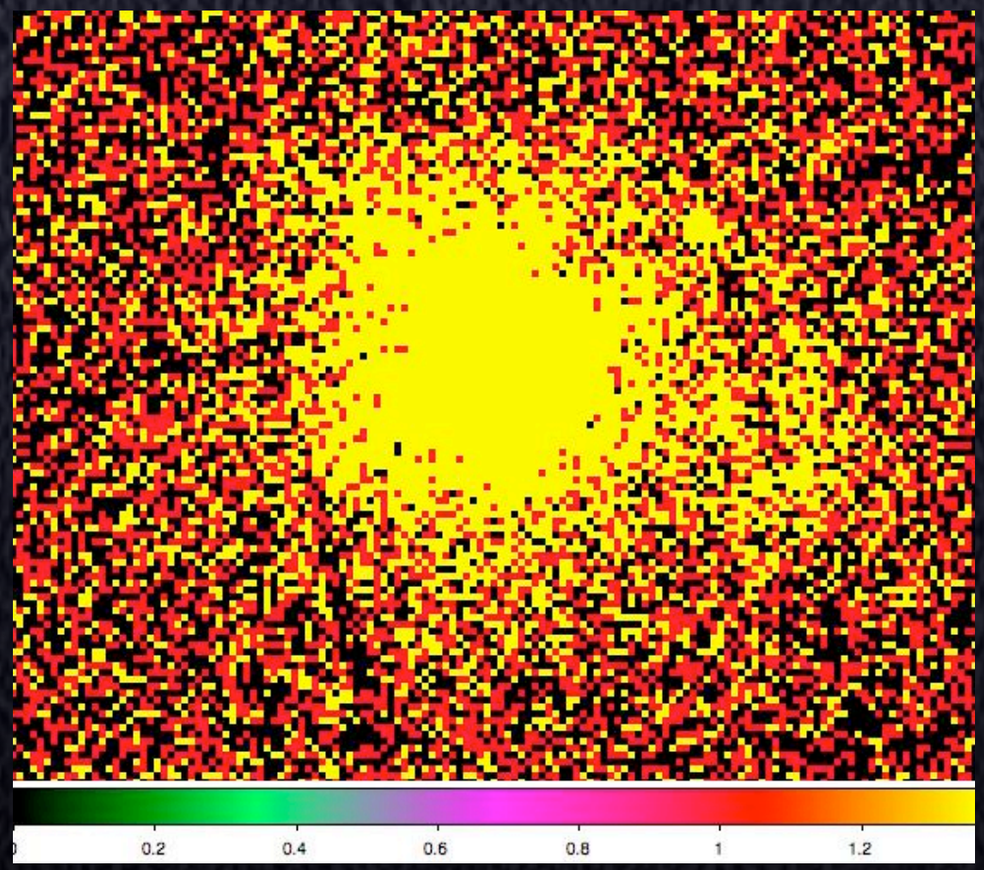
PRELIMINARY

Current Research

A2261: X-ray vs Lensing mass reconstruction



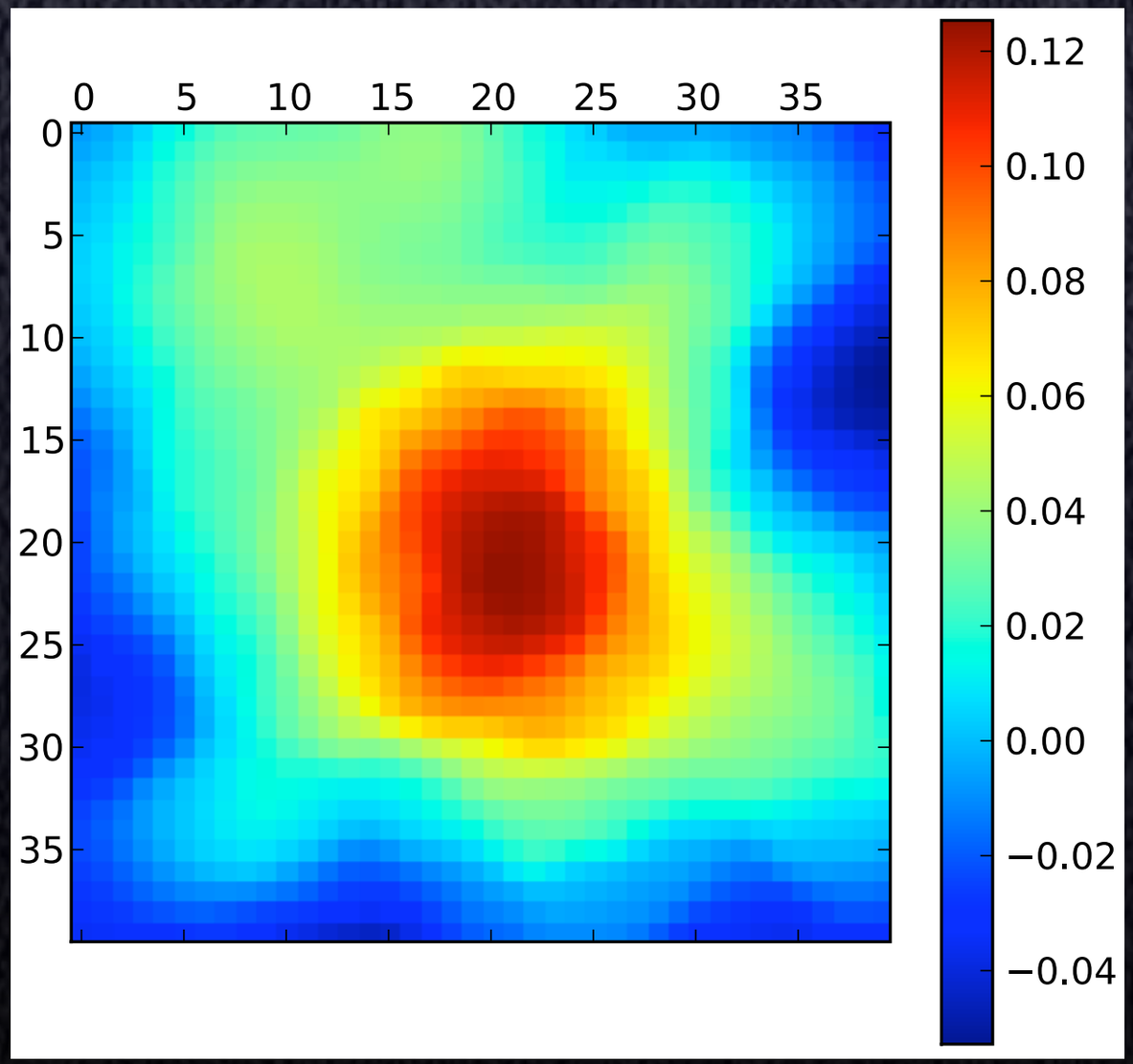
XMM Newton



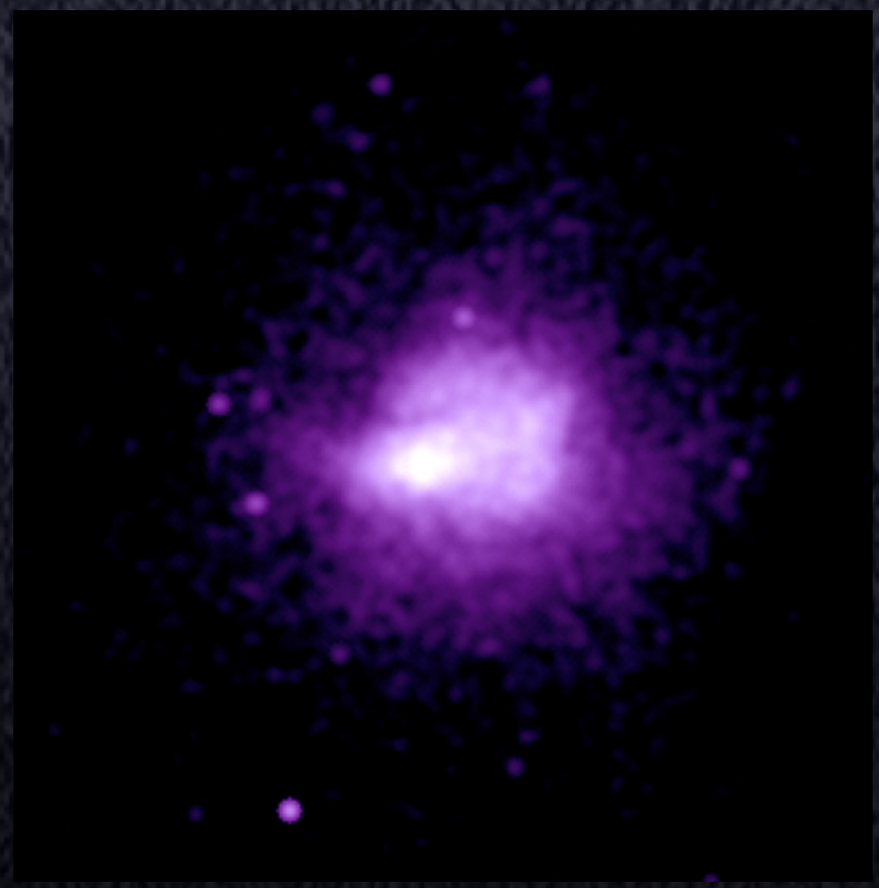
PRELIMINARY

Current Research

A1914: X-ray vs Lensing mass reconstruction



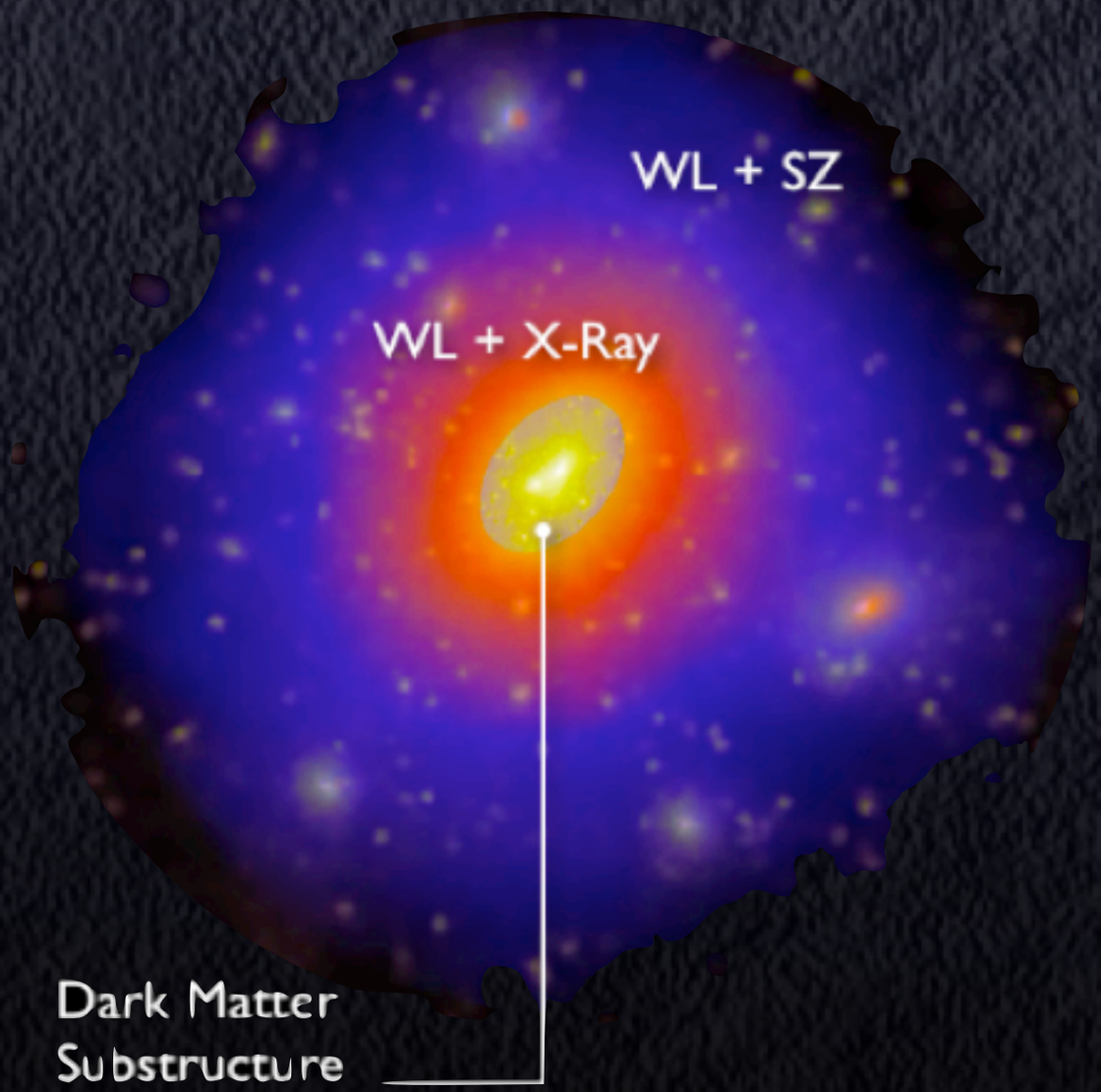
Chandra data



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

PRELIMINARY

Multiwavelength analysis



Multiwavelength shape analysis of galaxy clusters for the current sample of 20 clusters.

X-ray data: Chandra & XMM archival data
SZ data: Future plans of writing CARMA proposals with Dr. Morandi for some of these clusters.

Clusters are being discovered as we speak with SZ experiments like ACT/SPT. Lensing observations of these clusters will also increase this data set.