Galaxy-galaxy lensing constraints on field and cluster halos

Priya Natarajan
Yale University

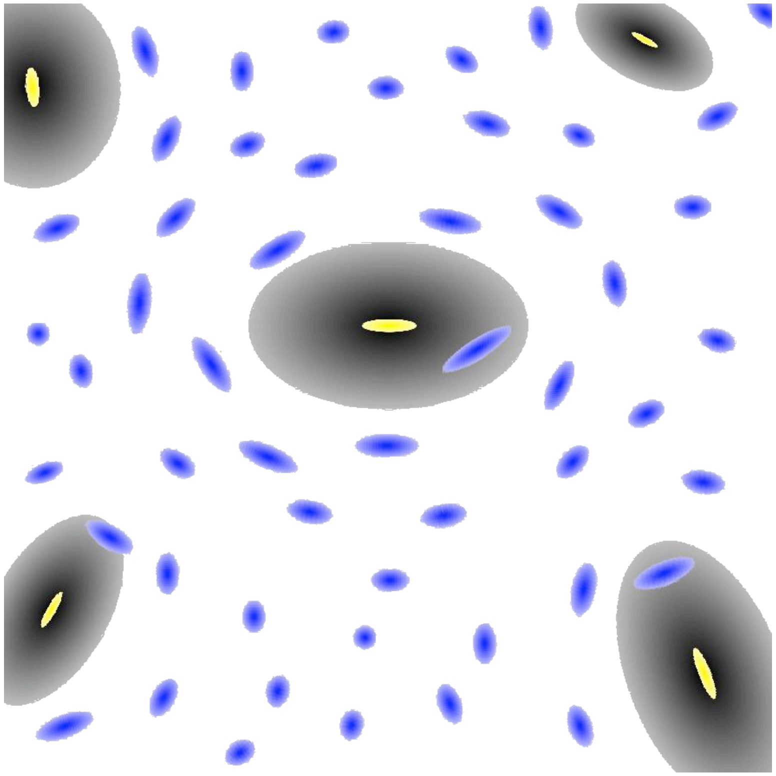
Collaborators: Jean-Paul Kneib, Ian Smail, Richard Ellis, Gabriella de Lucia, Volker Springel, Marceau Limousin Tommaso Treu, Sean Moran

Talk Outline

- Galaxy-galaxy lensing in the field
  - masses of halos
  - flattening of halos
  - galaxy-mass correlation
  - bias
- Galaxy-galaxy lensing in clusters
  - masses of subhalos
  - mass function of substructure
  - tidal stripping
  - constraints on the nature of dark matter
  - constrains on mass assembly of clusters

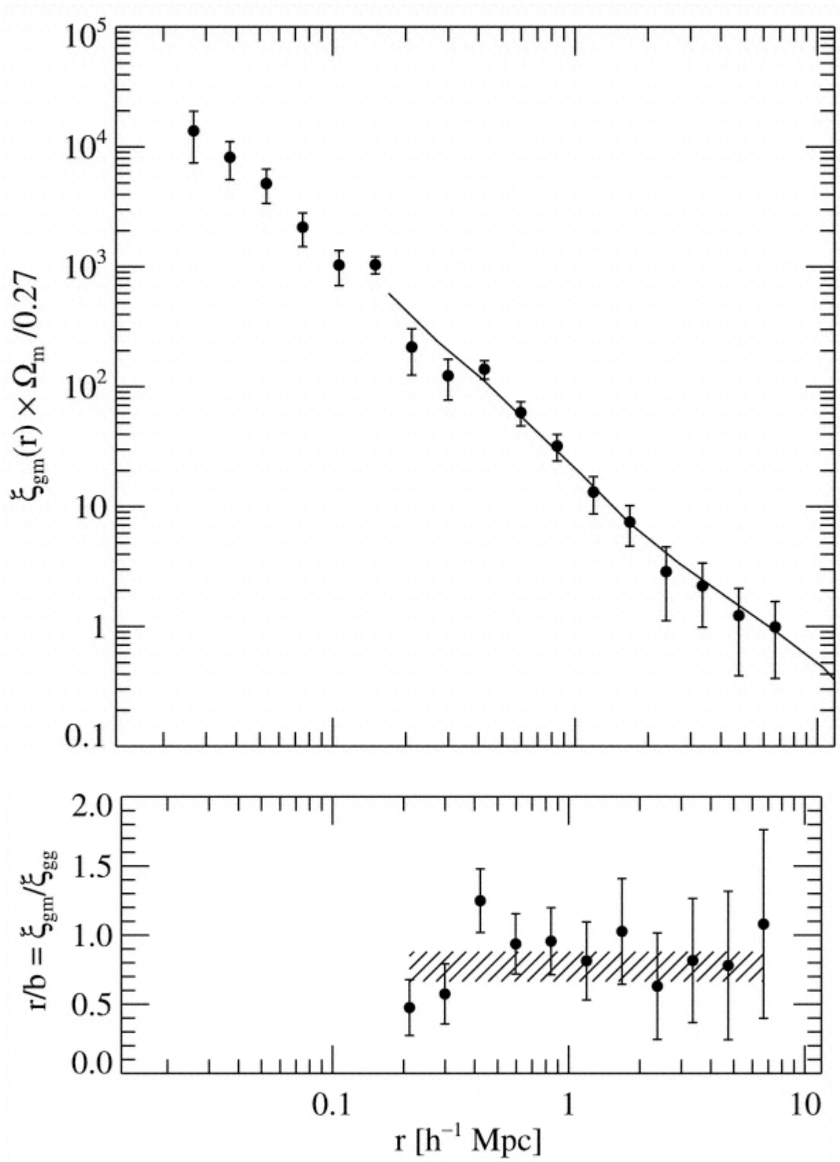
Insights into cluster assembly, testing structure formation in the LCDM paradigm

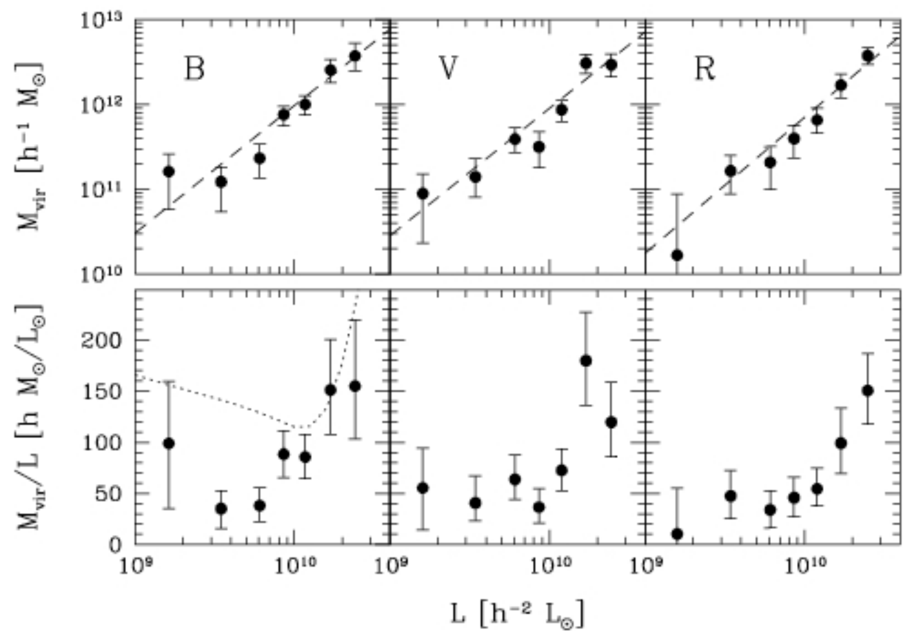
Galaxy-galaxy lensing



Tyson et al. (1990); Brainerd, Blandford & Smail (1996)

Galaxy mass correlation function, biasing

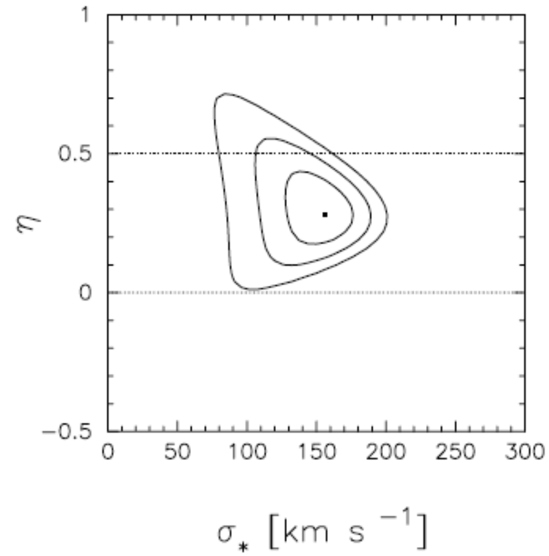


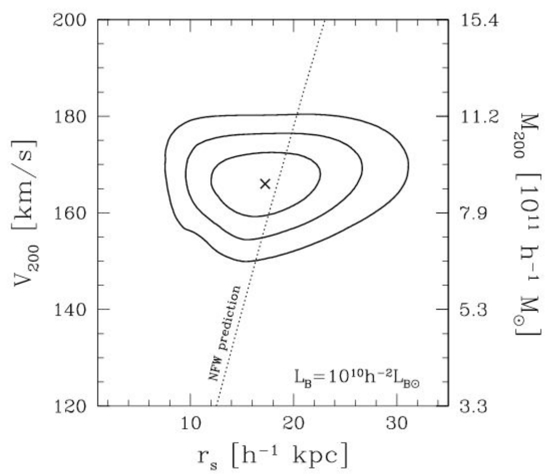


Sheldon et al. (2004); Guzik & Seljak (2002); Hoekstra et al. (2005) CFHT-LS, using photometric redshift catalog from Hsieh et al. (2005)

Relation between mass and light, halo mass, and flattening

Results from maximum likelihood analysis: direct comparison with results from numerical simulations.





M/L α $L^{-0.5}$ (model SIS)

$$\frac{\sigma_V}{\sigma_*} = \left(\frac{L}{L_*}\right)^\eta$$

Halos are aligned with the light

Spherical halos excluded at 99.5%

Good agreement with LCDM

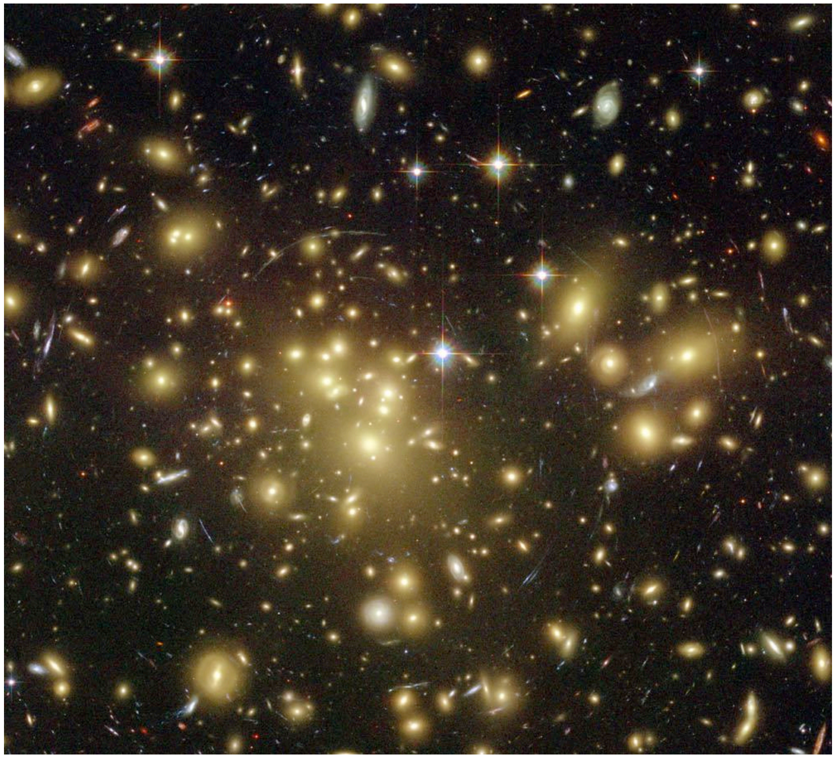
RCS,SDSS, CFHT-LS, COMBO-17

Kleinheinrich et al. (2006); Guzik & Seljak (2000); PN & Refregier (2000); Hoekstra et al. (2005), Mandelbaum et al. (2006)

Strong lensing

multiple images, highly distorted and magnified arcs

- Projected surface mass density within the beam $\Sigma(r) > \Sigma_{crit}$
- Mass enclosed within the arc is tightly constrained



Weak lensing

coherent distortion in the shapes of background galaxies

- Shear field used to construct mass map

Kaiser & Squires (1993)

Mapping DM in Clusters

- Composition: ~1 % of mass in galaxies, ~10 % of mass is hot gas, rest is DM
- Interesting questions: detailed spatial distribution of DM, subhalos

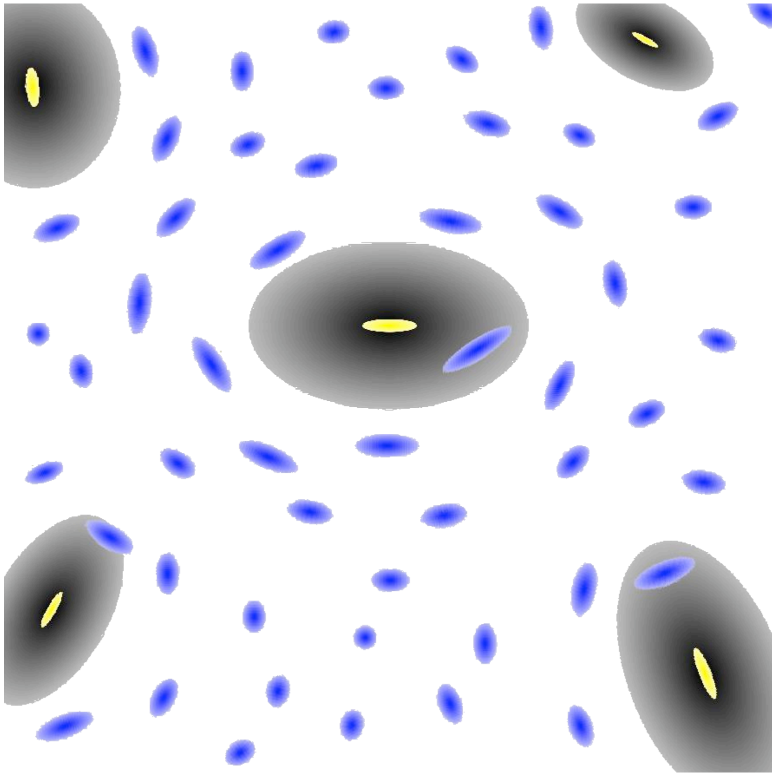
Mass modeling

- Identify all arcs, identify multiple images e.g. LensTool Kneib et al. (1993), LensInvert PN (2003)
- Model cluster mass as a smooth 'isothermal' ellipse (parametric model), parameters: velocity dispersion, ellipticity, truncation radius
- Add perturbations to model effect of cluster sub-halos

Galaxy halo properties

- Truncation radii, mass, velocity dispersion, total M/L ratios
- Mass function, radial distribution of DM
- Implications of the spatial distribution for the nature of dark matter

Galaxy-galaxy lensing in clusters



DM potential of the cluster = ‘smooth’ component + clumps

Associate clumps with bright early-type spectroscopically confirmed cluster members and use positions, magnitudes and redshifts of multiple images (strong lensing features), and the shapes of background galaxies (weak lensing) to partition the total mass

PN & Kneib (1996); Geiger & Schneider (1997); PN et al. (1998,2002; 2005,2006)

Mass modeling

- Identify all arcs, identify multiple images, measure redshifts
- Inputs to LensInvert
- Model cluster mass as a smooth ’pseudo-isothermal' ellipse with a parametric model

parameters: velocity dispersion, ellipticity, core radius, truncation radius, Faber-Jackson index

$$\sigma_* \alpha \; L^{\eta} \qquad\qquad \sigma_* \propto \sigma_{DM}$$

- Add perturbations to model the effect of dark sub-halos associated with cluster galaxies

Non-parametric version: Diego et al. (2005), Bradac et al, (2005); Abdelsalam et al. (1998)

Analysis of local distortions

Maximum likelihood method

Maximize log L for a given set of model parameters

$$\tau_{S_j} = \tau_{obsj} - \Sigma_i^{N_{clusgal}} \gamma_{p_i} - \gamma_c$$

$$L(\sigma_0^*, r_t) = \Pi_j^{Ngal} P(\tau_s)$$

$$L(r_c, \alpha) = \Pi_j^{Ngal} P(\tau_s)$$

Subhalo properties

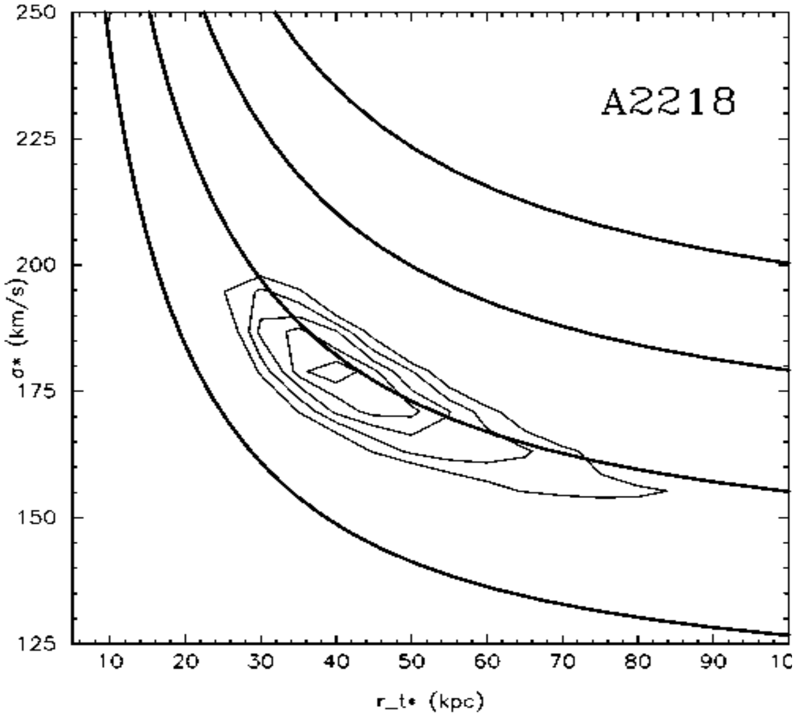
truncation radii, mass, velocity dispersion, M/L ratios
mass function, radial distribution $M \propto \sigma^2 r_t$

PN & Kneib (1997); Geiger & Schneider (1998)

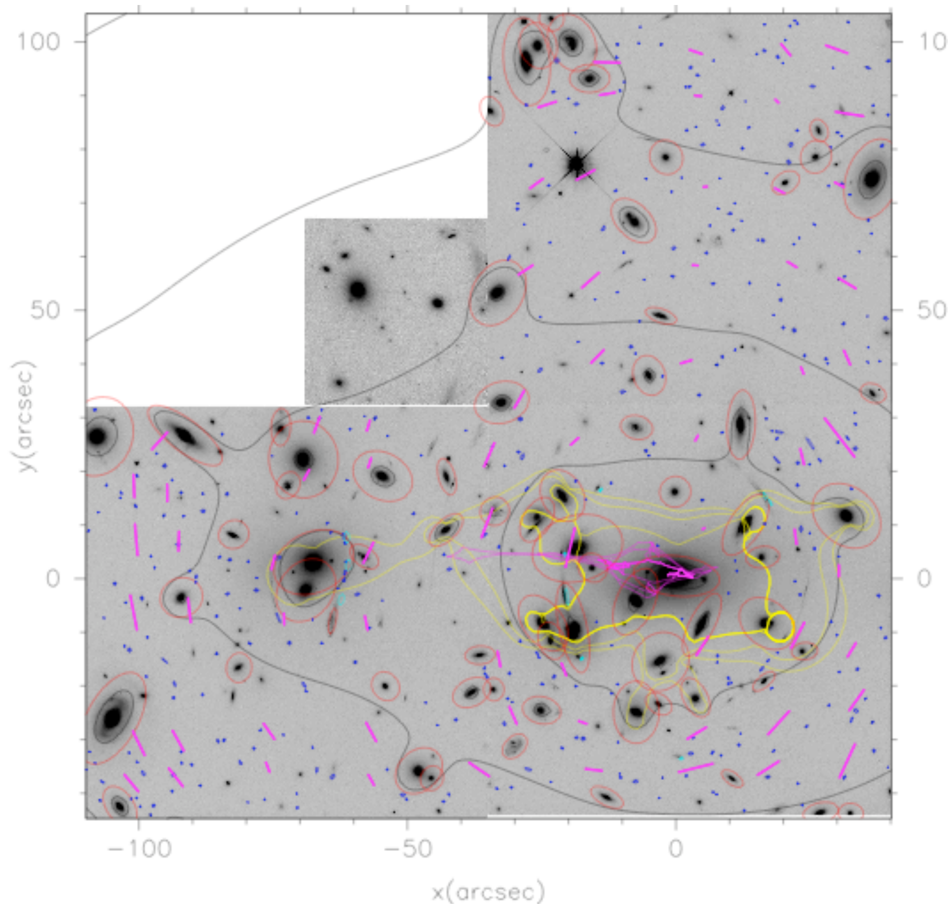
Results of maximum-likelihood analysis

galaxy halos in clusters less extended, less massive than equivalent L field galaxies

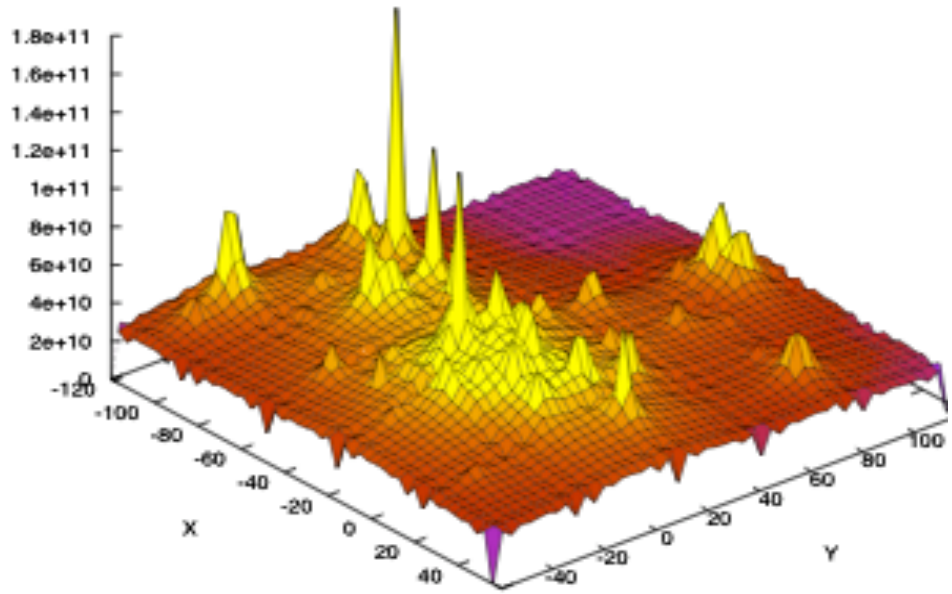
central velocity dispersion of typical sub-halo



Tidal radius of typical sub-halo



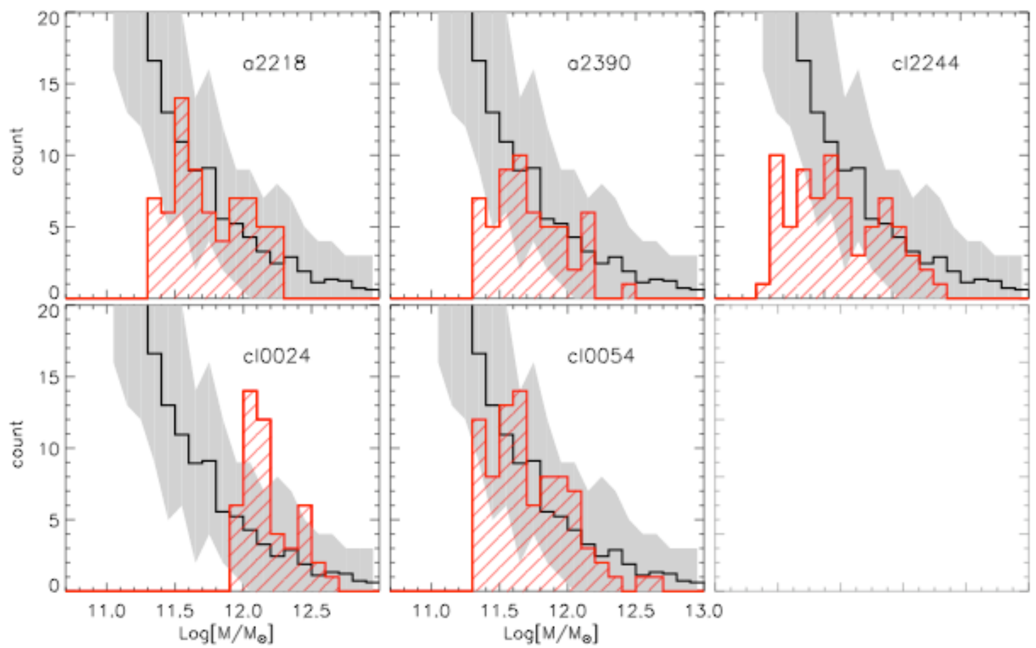
The dark matter clump distribution in A2218



PN et al., 2004, 2005

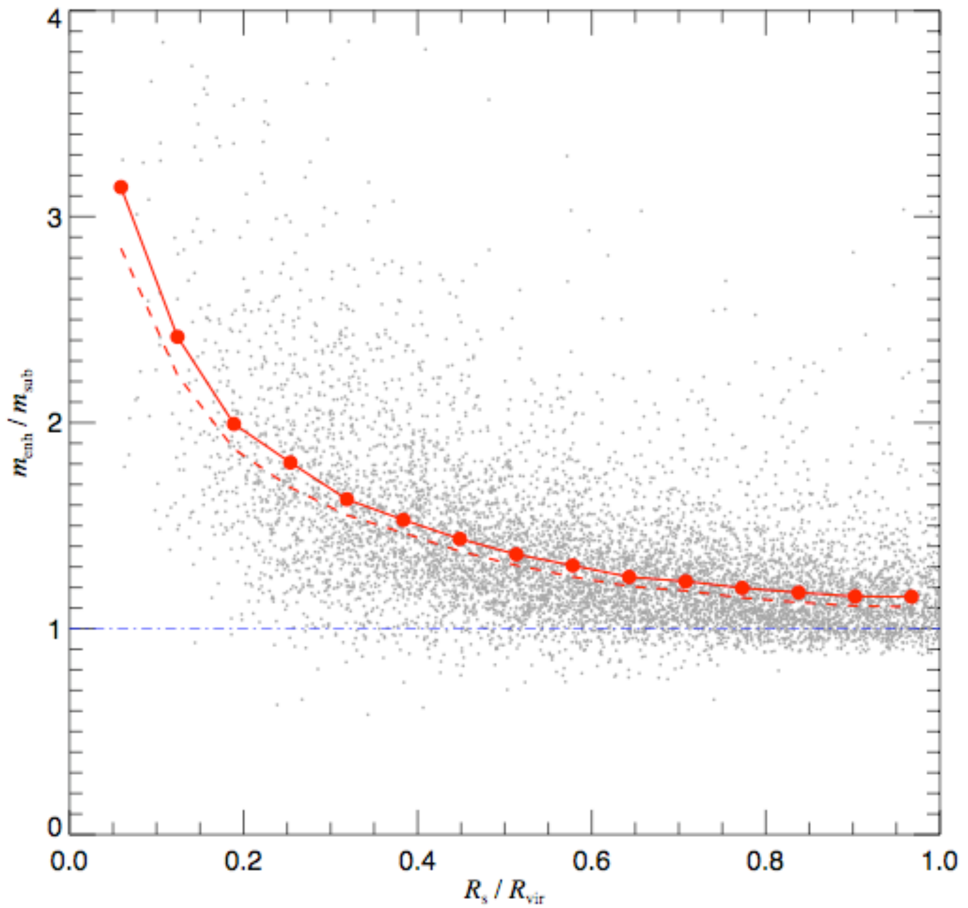
Comparison with clusters in the Millenium Run

The sub-halo mass function



PN, De Lucia & Springel, '06

Defining subhalos (bound subhalos?, mass enhancement?)

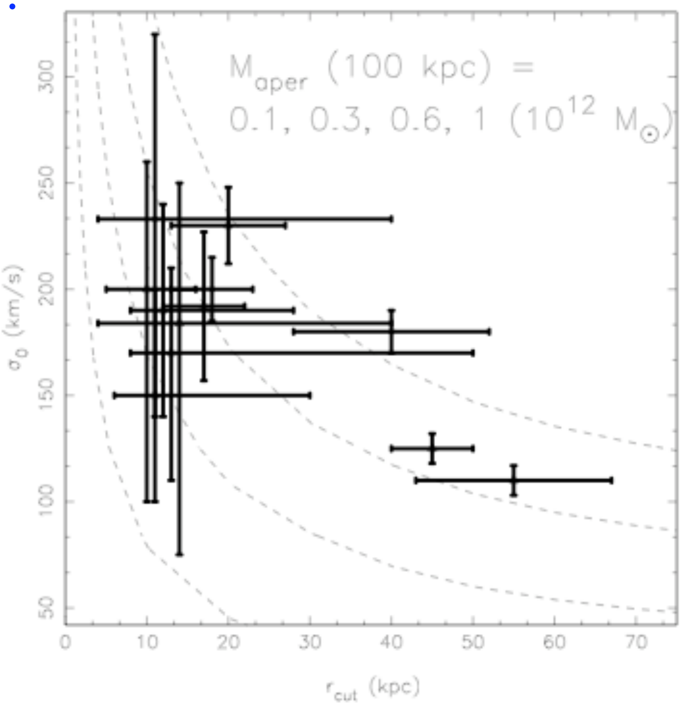


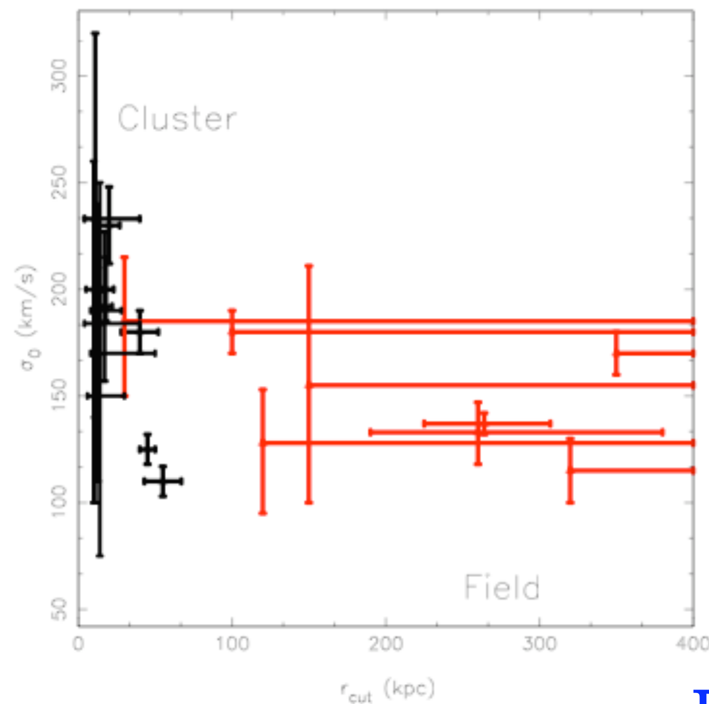
systematically under-estimate masses in the centers of clusters

Galaxy-galaxy lensing in the field and clusters

Central velocity dispersion (in km/s)

Cluster





r_cut (in kpc)

r_cut (in kpc)

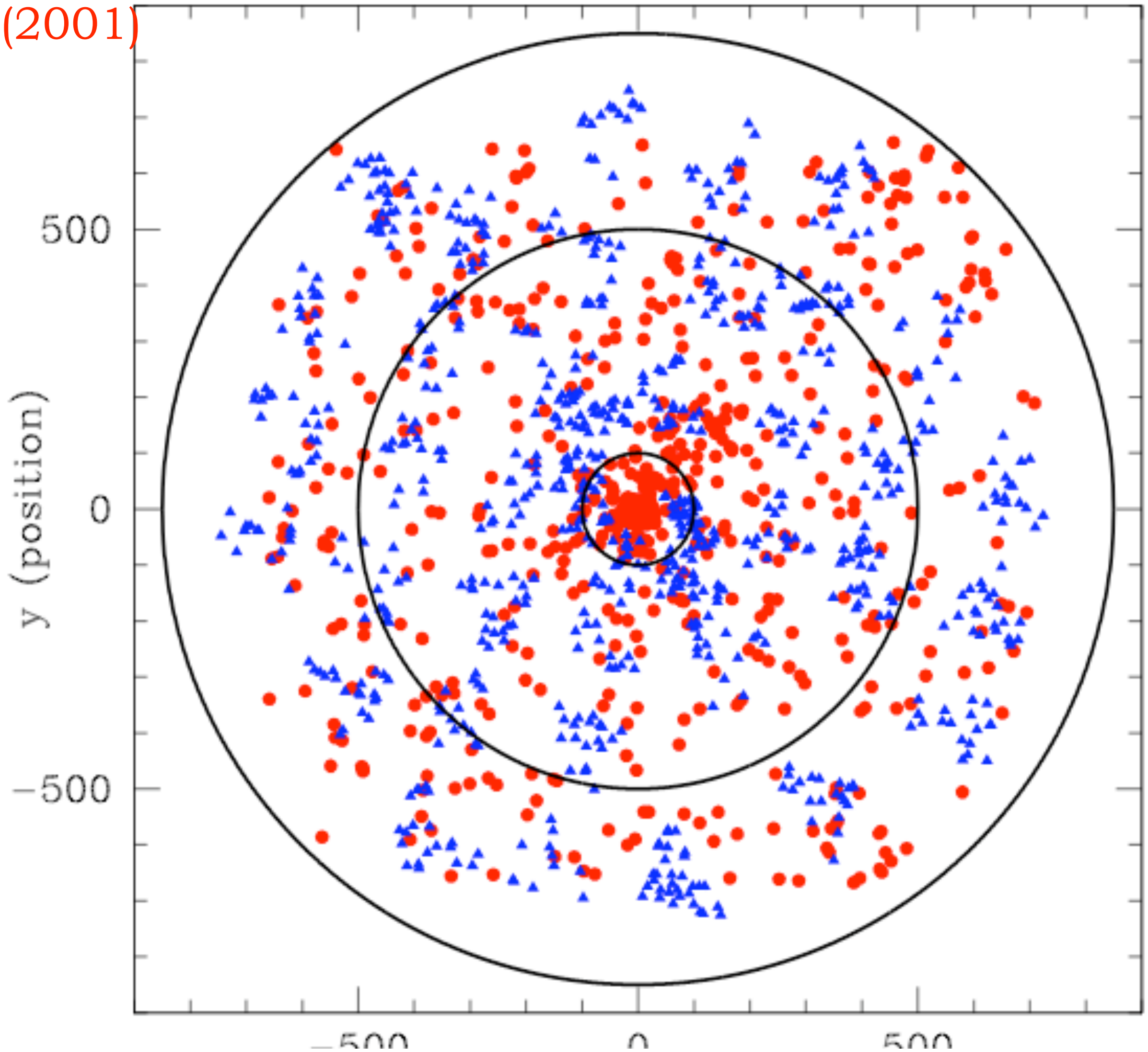
Field

Limousin et al. (2005; 2006)

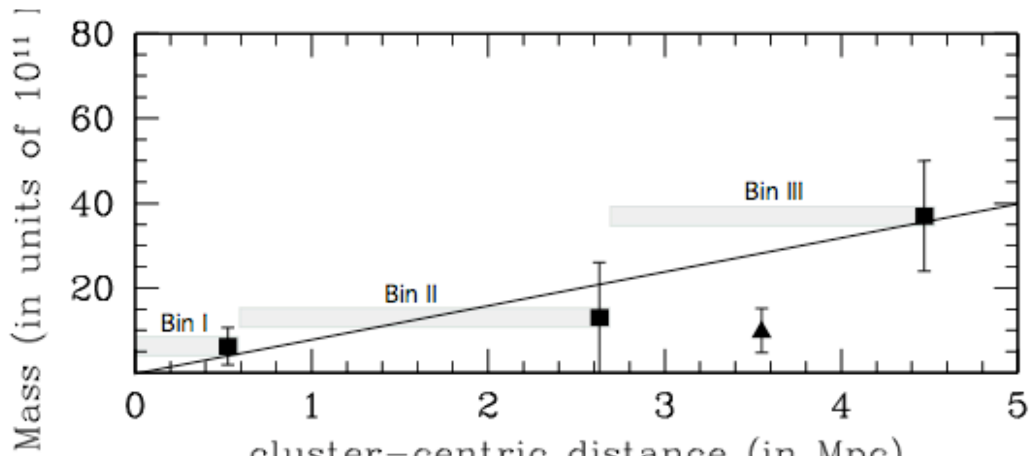
PN et al., Gavazzi et al. (2004); see poster by Halkola et al. [A1689]

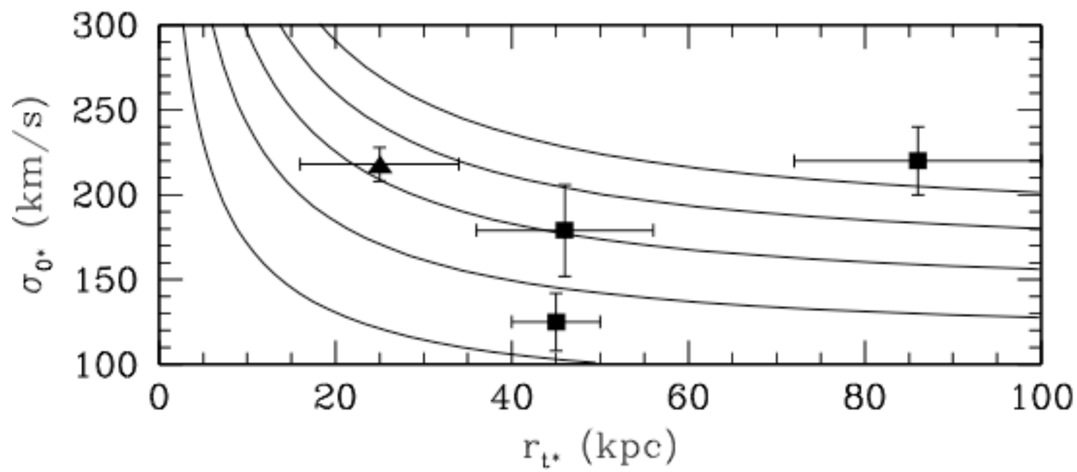
Cl0024+16 (z = 0.39) extending analysis to 5 Mpc

Treu et al. Kneib et al. (2003)
Czoske et al. (2001)



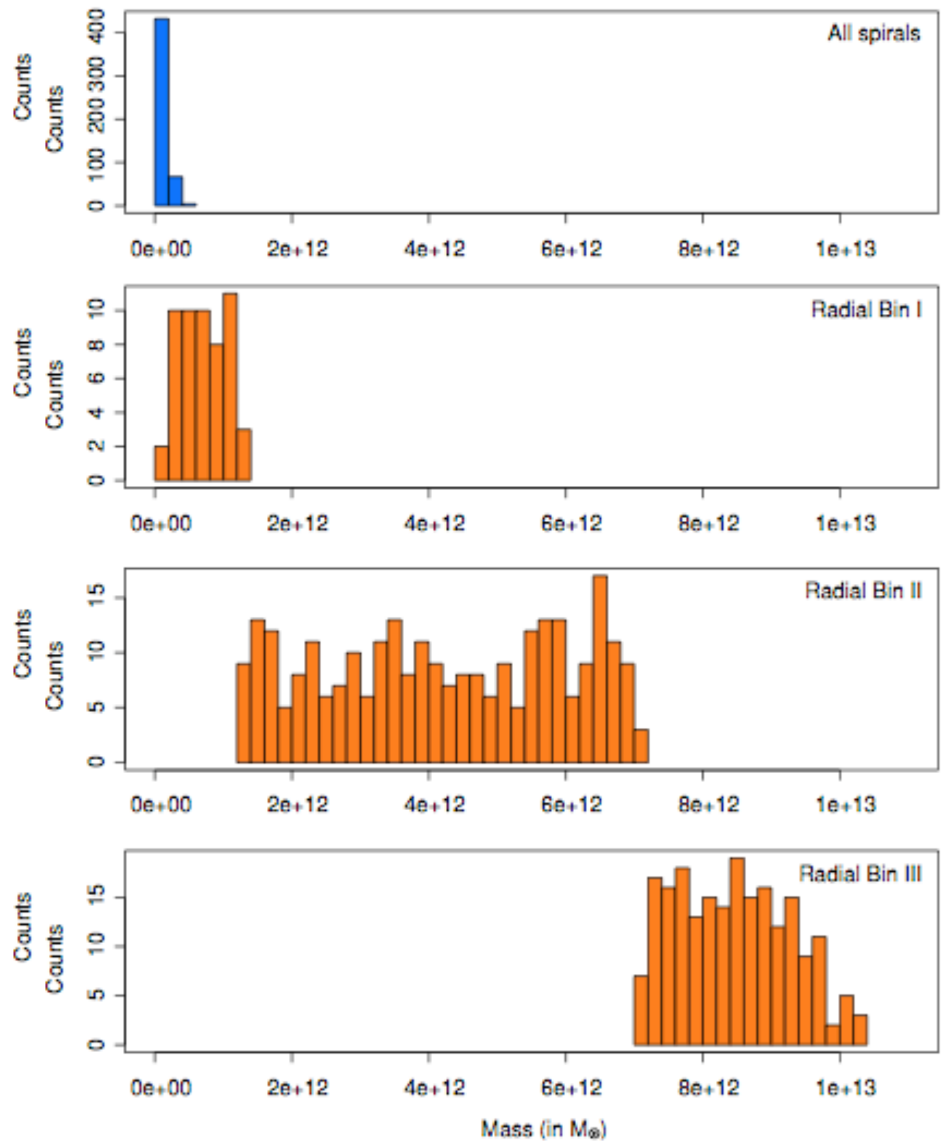
Results of the g-g lensing analysis



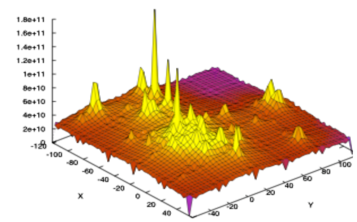


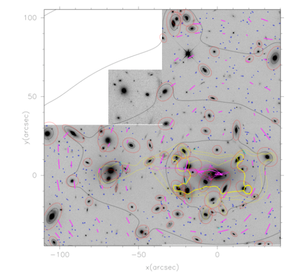
$$R_{\rm tidal} \propto \left(\frac{\sigma_{\rm gal}}{\sigma_{\rm cluster}}\right) r_t$$

Detect presence of infalling groups

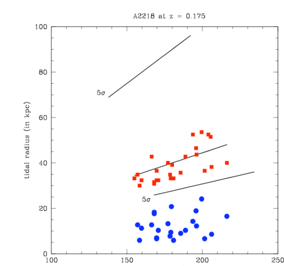


Conclusions

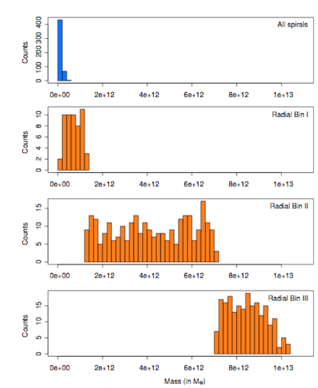




- 10 - 15% of cluster dark matter is in subhalos with M >10 ^{11} solar masses.
- Both the smooth component and subhalos are well traced by light



- Mass function of substructure in clusters is in good agreement with Lambda CDM predictions in contrast to galaxy scales



- Current lensing data rules out fluid dark matter models and is consistent with collisionless dark matter
- Studies of the mass function in radial bins consistent with tidal stripping of DM halos and suggests cluster assembly from infalling groups