Mapping Dark Matter in Galaxy Clusters:

From Weak Galaxy-Galaxy Lensing to Cluster Lensing

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Plan

Constraining Galaxy Scale Dark Matter Halos: Galaxy-Galaxy Lensing

- A very weak lensing regime ($\kappa \simeq \gamma \simeq 0$) - Numerical simulations: feasibility ?
  $\Rightarrow$ A maximum likelihood method allows to constrain mass and extent of galactic dark matter halos
- Results on a homogeneous sample of 5 galaxy clusters at $z \sim 0.2$
  $\Rightarrow$ Halos in high density environments are more compact compared to halos around field galaxies of equivalent luminosity (Tidal stripping)
- Comparaison with N-body hydrodynamical numerical simulations

Constraining Cluster Scale Dark Matter Halos: Strong & Weak Cluster Lensing in Abell 1689

- Strong lensing from HST-ACS data + extensive spectroscopy (VLT - KECK)
  $\Rightarrow$ Constraints on the inner mass profile
- Wide field Weak lensing from CFH12K
  $\Rightarrow$ Constraints on larger scales
- Small field Weak lensing from an HST mosaic
  $\Rightarrow$ Does A 1689 has a large (> 20) concentration parameter ?

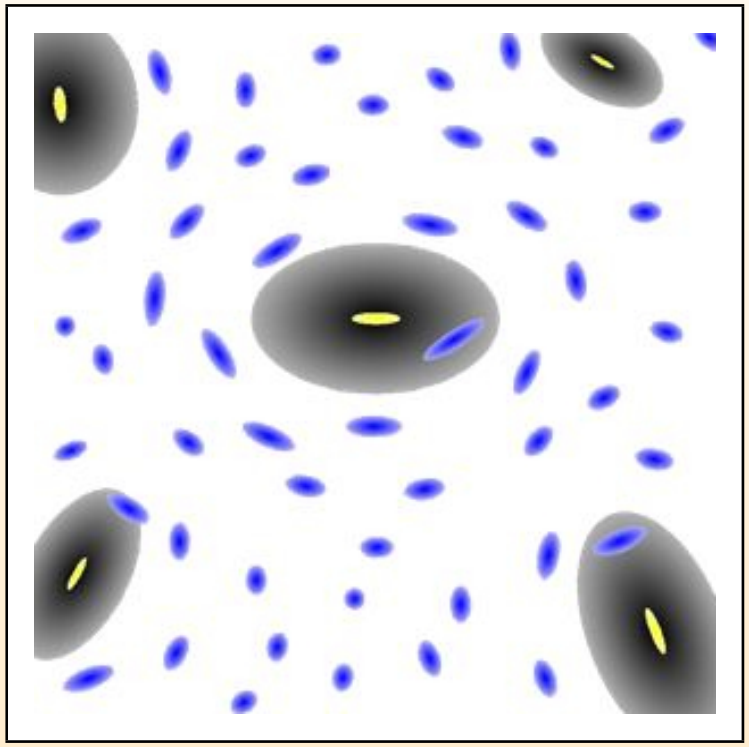
Cluster Galaxies Halos Properties

Influence of the environment ?

Galaxy-Galaxy Lensing: Deformation of background galaxies by foreground galaxies

$\Rightarrow$ Constraints on the foreground cluster galaxies

- One pair, $< \gamma > \sim 0.007$
- Noise $\sim$ 0.2/0.3
- A *Statistical* approach is needed
- Constraints averaged on a galaxy population



Analyse of simulated data sets for different observational configurations:
A Maximum Likelihood Analysis (Schneider & Rix, 1997) is well adapted: allow to constrain the mass and extent of galactic dark matter halos (Limousin, Kneib & Natarajan, 2005 - MNRAS)

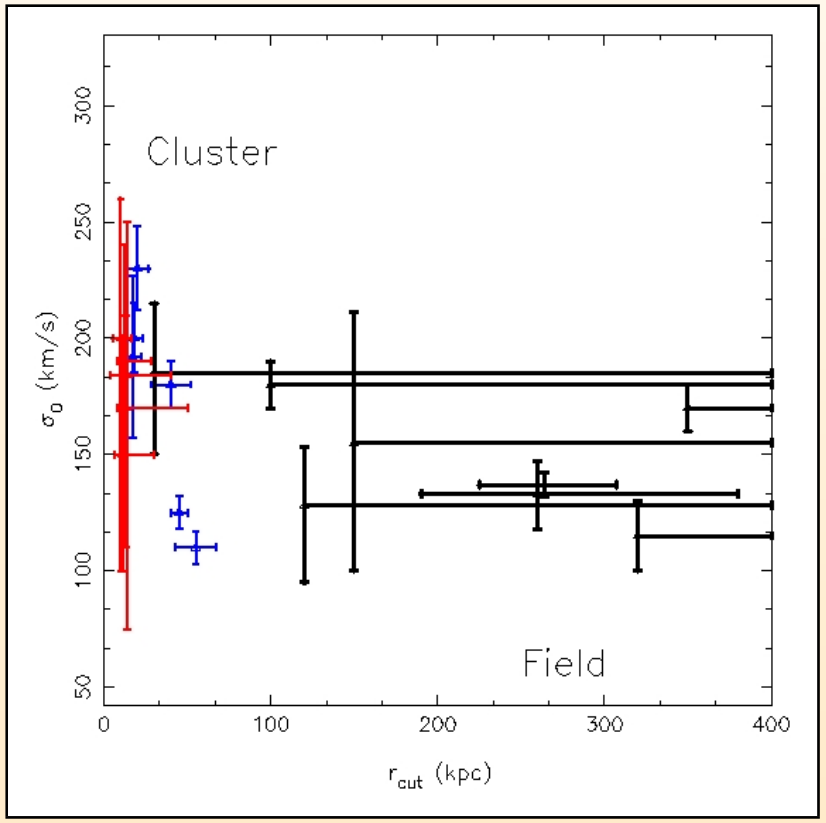
Truncation of Galaxy Dark Matter Halos in Clusters

An homogeneous sample of 5 massive galaxy clusters at $z \sim 0.2$

3 bands imaging from CFH12K $\rightarrow$ galaxy catalog:

(SEXTRACTOR, IM2SHAPE, HYPERZ)

- RED: Truncated Cluster Galaxy Halos (Limousin et al., 2007a - A&A)
- $r_{\rm cut} < 50$ kpc
- BLACK: Field: $r_{\rm cut} > 200$ kpc (see talk by Henk Hoekstra)
- Tidal Stripping
- BLUE: (Natarajan et al., 1998, 2002a,b) (HST) (see also Halkola et al., 2007 from Strong Lensing)



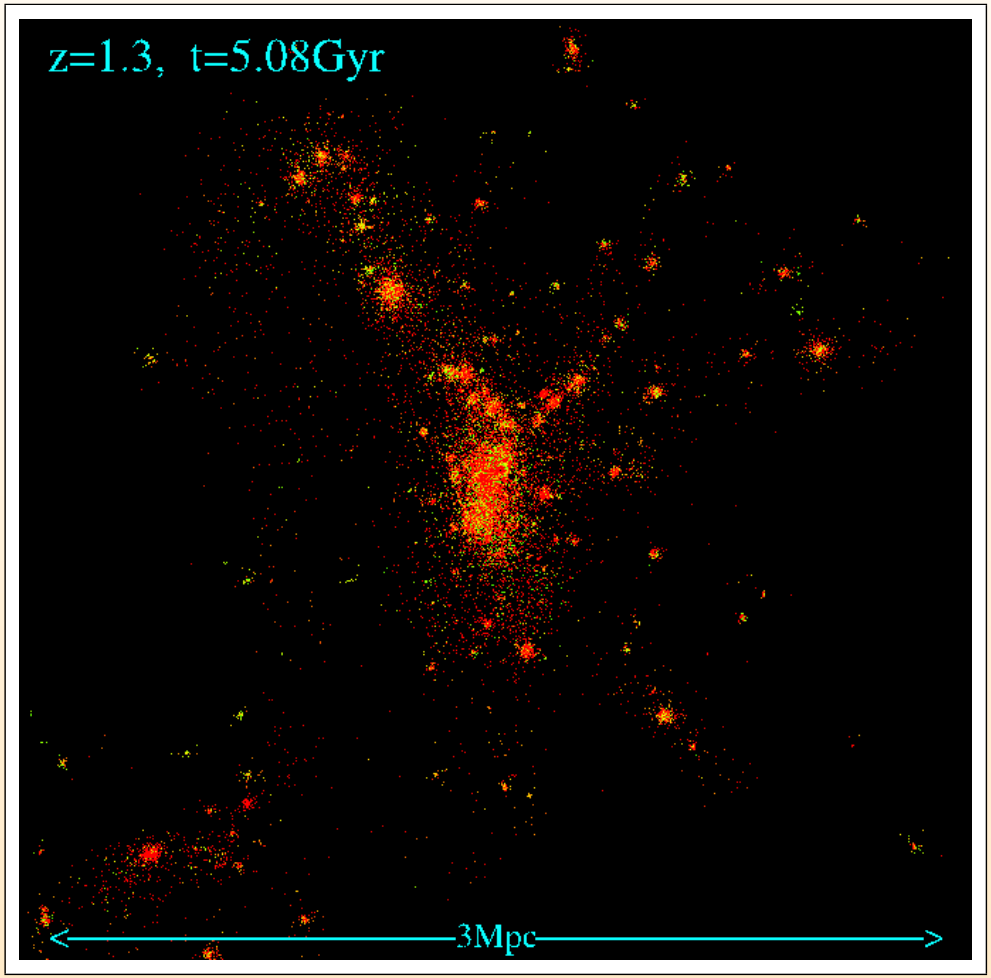
Galaxy-galaxy lensing: how does the environment shape dak matter halos

Comparison with Numerical Simulations

N-body/hydrodynamical (TREESPH) simulations within ΛCDM framework

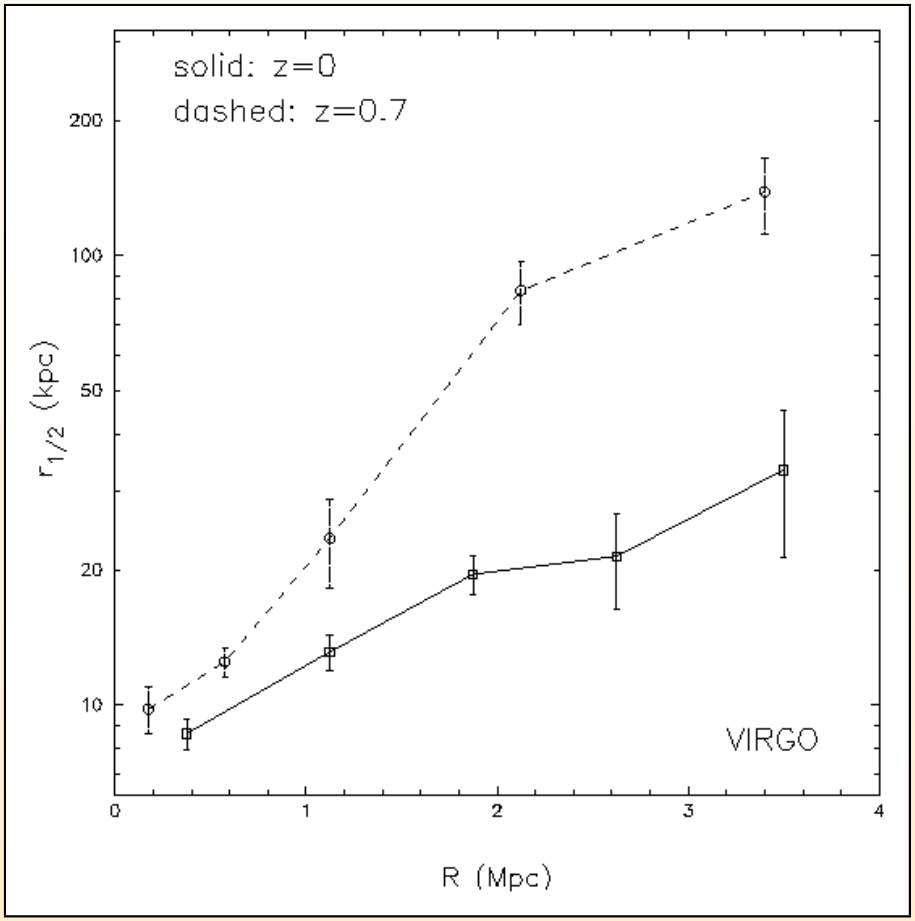
Jesper Sommer-Larsen et al.

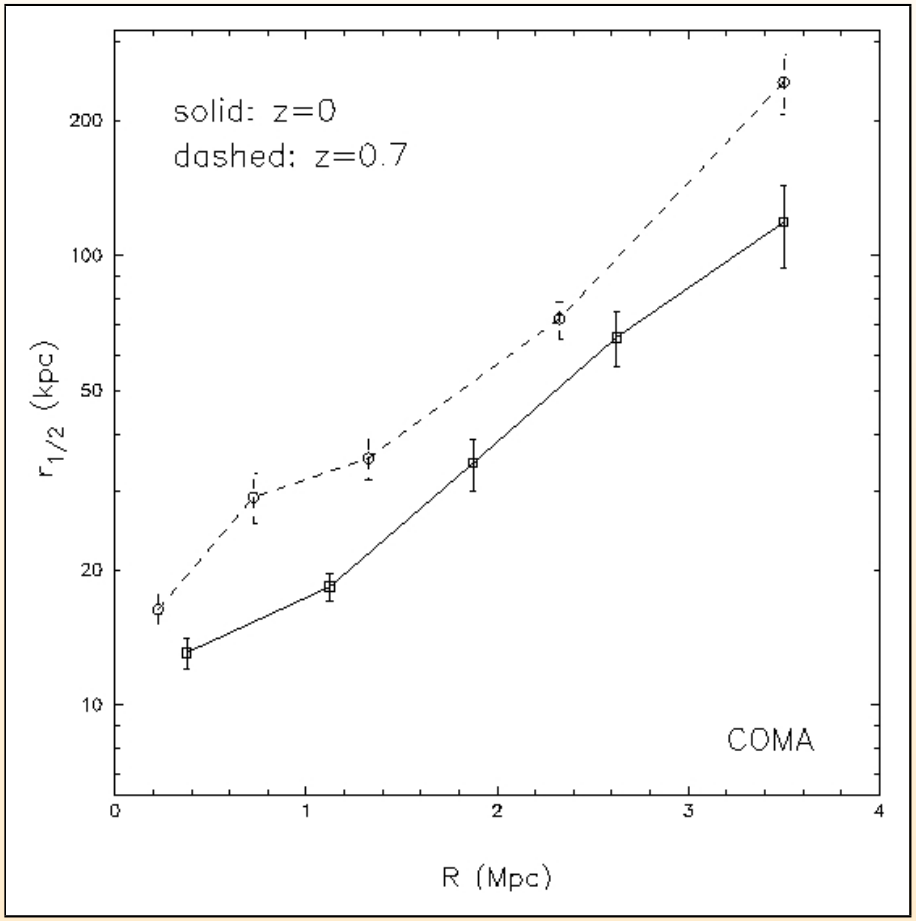
- Two Simulated Clusters: COMA, 6 keV and VIRGO, 3 keV
- Metallicity dependent radiative cooling
- Star formation for different IMF
- energy feedback
- chemical evolution (non instantaneous recycling of gas and heavy elements)
- meta-galactic UV field
- thermal conduction in the ICM



Comparison with Numerical Simulations

Are these simulated galaxies tidally stripped ?

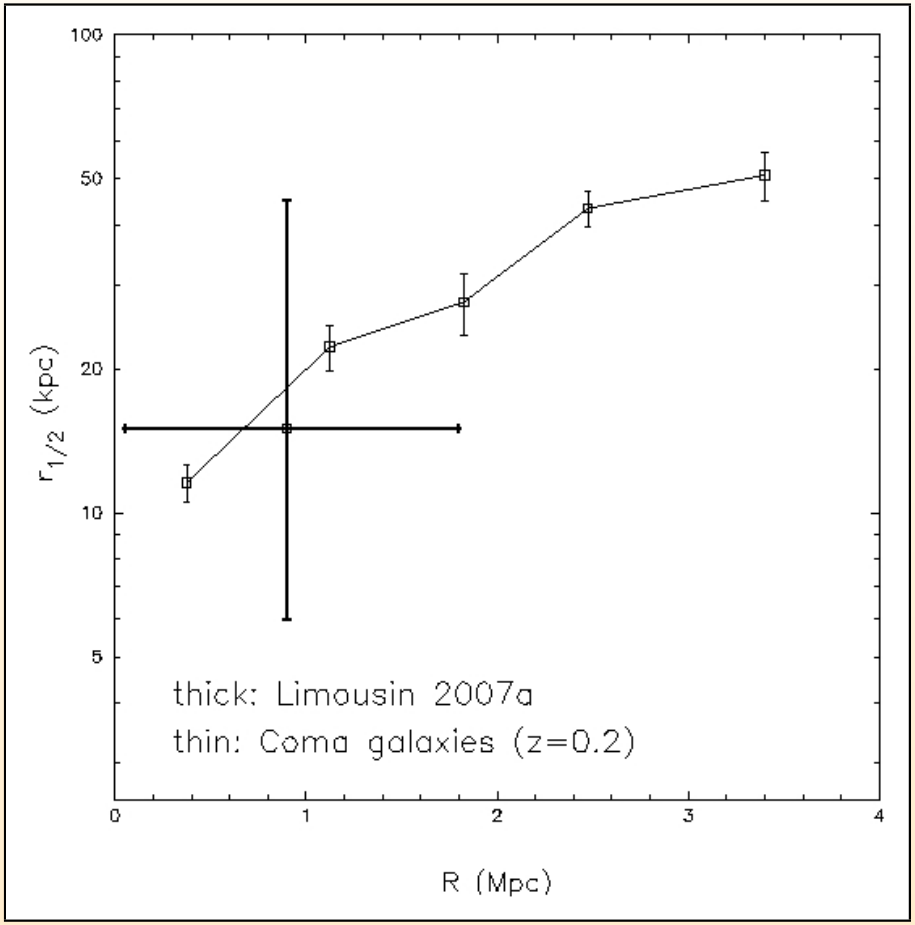


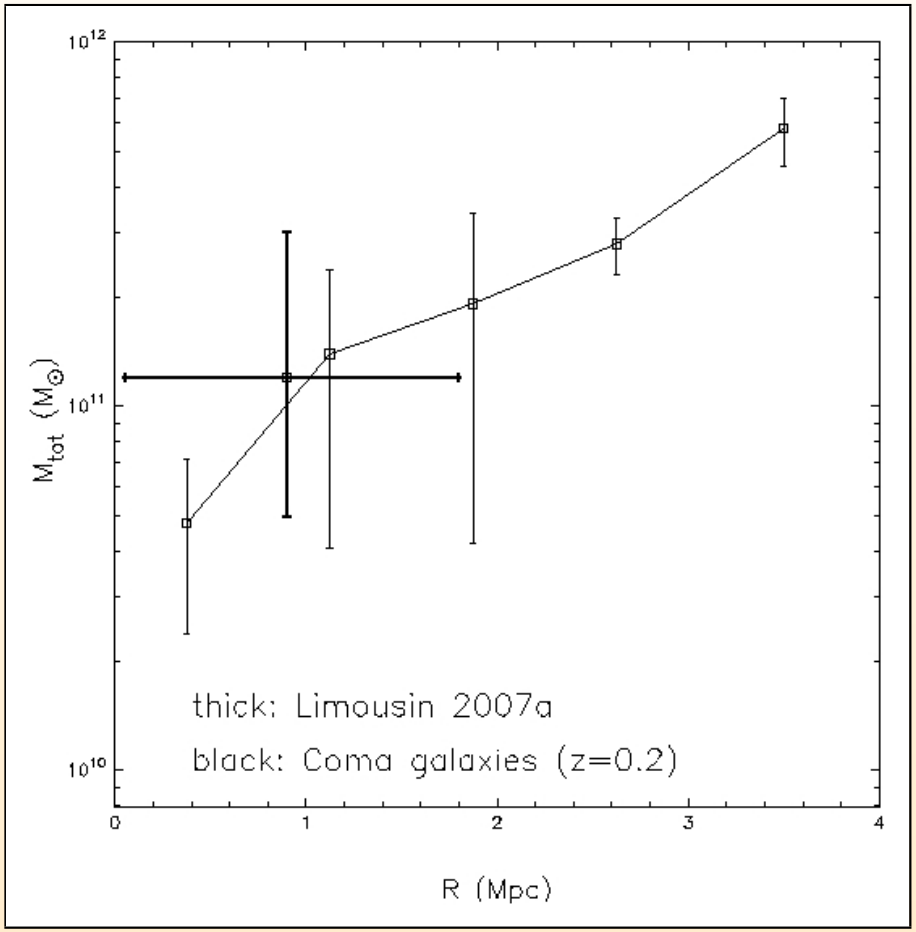


Yes, and the trend is already well defined at high redshift

Comparison with Numerical Simulations

Comparison to galaxy-galaxy lensing results ?



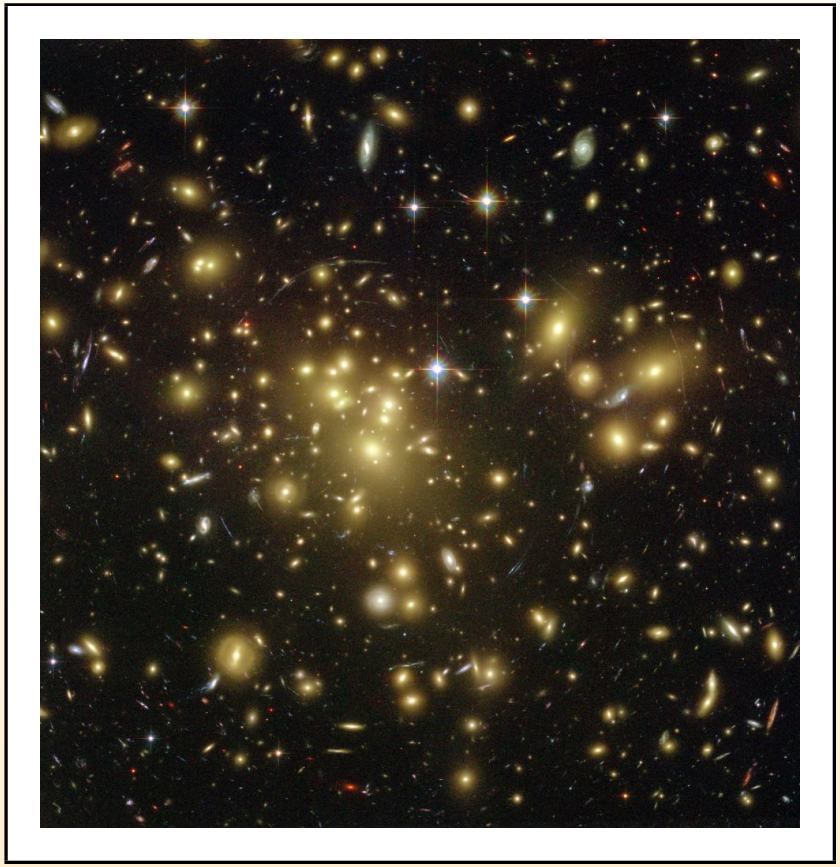


Qualitative agreement $\Rightarrow$ DUNE - SNAP

Limousin, Sommer-Larsen, Natarajan & Milvang-Jensen - Submitted

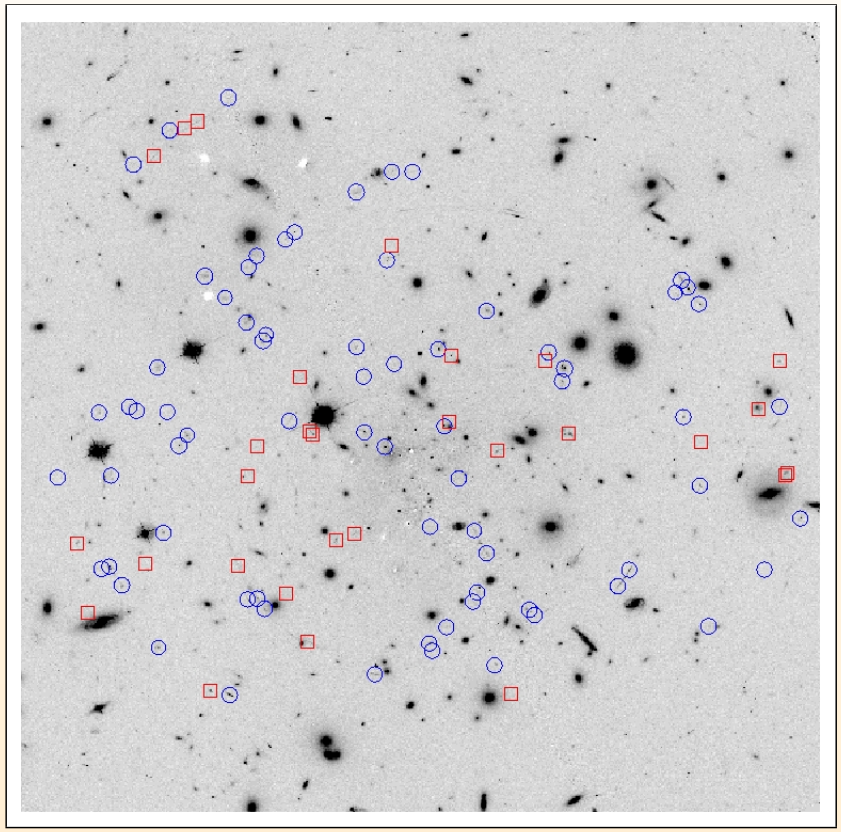
Strong Lensing in the Core of Abell 1689 (Limousin et al., 2007b)

- Deep HST/ACS Observations
  (Broadhurst et al., 2005; Halkola et al., 2006)
- $>$ 34 background sources strongly lensed:
  $>$ 100 images



Strong Lensing in the Core of Abell 1689 (Limousin et al., 2007b)

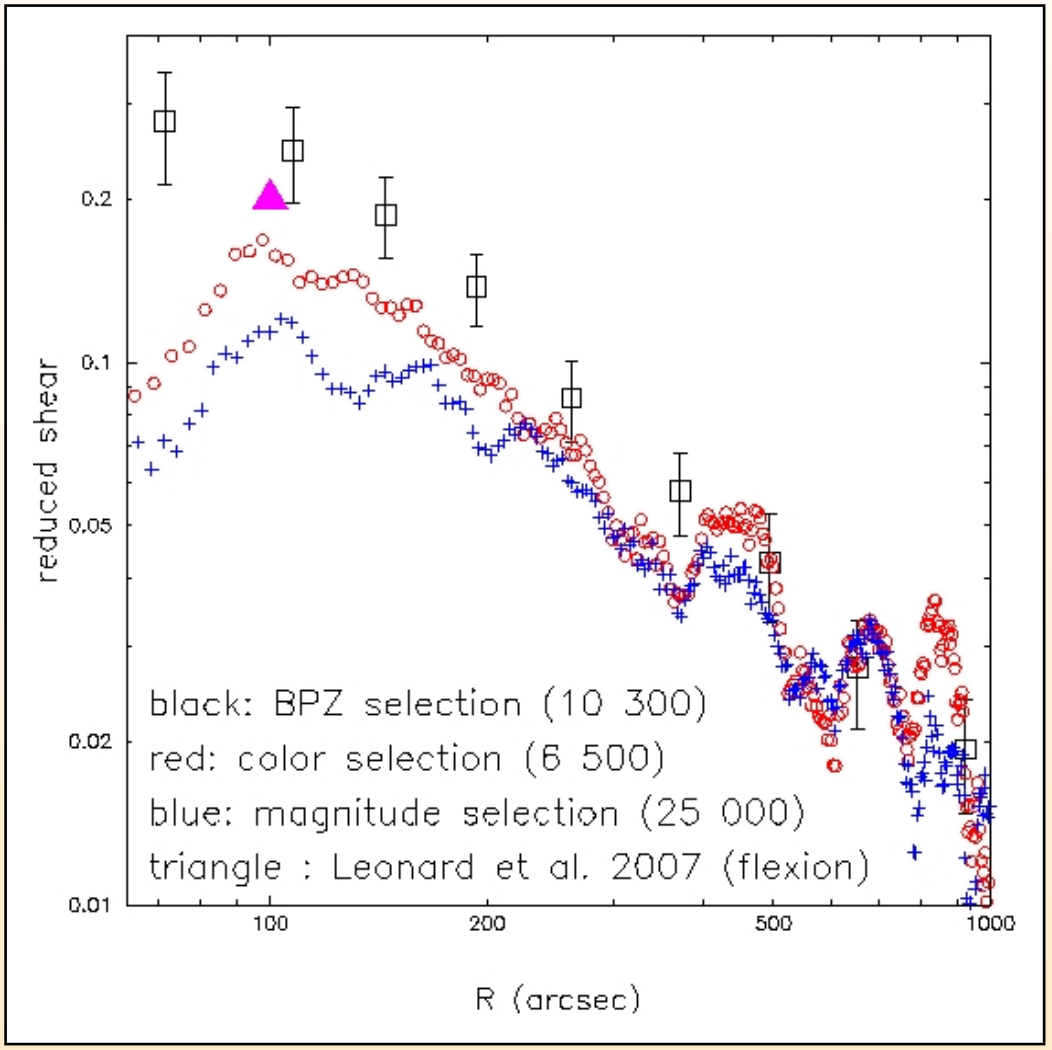
- Deep HST/ACS Observations
  (Broadhurst et al., 2005; Halkola et al., 2006)
- 34 background sources strongly lensed:
  $>$ 100 images
- Spectroscopic confirmation for 24 systems
  (Richard et al., 2007)
- Parametric mass reconstruction
  MCMC thechniques (Jullo et al., Submitted)
- Central mass distribution well constrained



Along the critical lines, amplification $\sim$ 20-50
Gravitational Telescope:
$z \sim 8 - 10$ candidates (Stark et al., 2007)

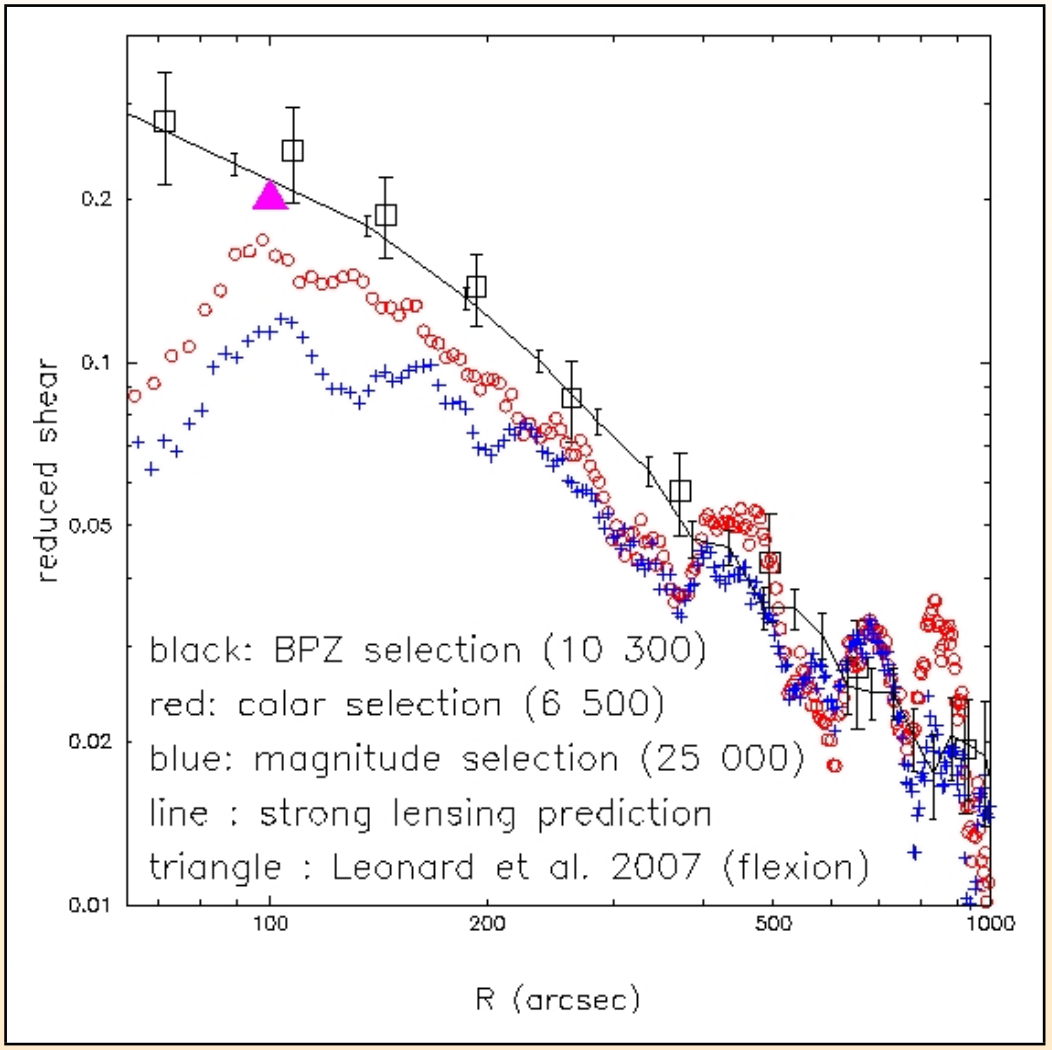
Weak Lensing $\Rightarrow$ large scale properties (Limousin et al., 2007b)

- Wide Field multi-color data
  CFH12K (Czoske et al., 2002)
- Bayesian Photometric Redshifts (BPZ)
- Who has been lensed ?!?
- Background galaxies selection is cruciale
- But M_{200} reliable (Bardeau et al., 2007)
- Lensing in the flexion regime (ACS)
  (Leonard et al. 2007) $\longrightarrow$ $g(100'') \sim 0.2$



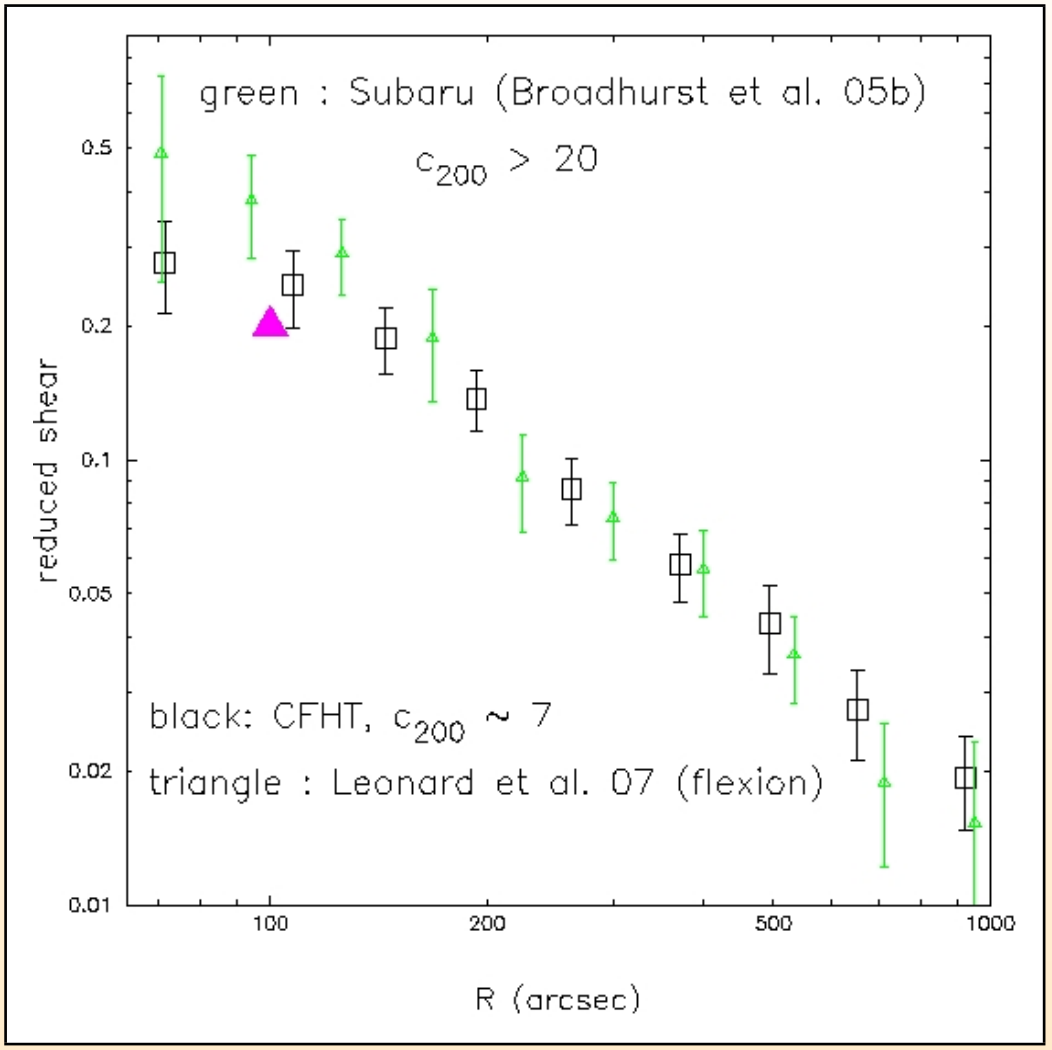
Weak Lensing: agree with Strong Lensing

- Wide Field multi-color data CFH12K (Czoske et al., 2002)
- Bayesian Photometric Redshifts (BPZ)
- Background galaxies selection is cruciale
- Strong and Weak lensing agree ($c_{200} \sim 7$)
- c_{200} High but Compatible with ΛCDM (Neto et al. 2007): possible but rare



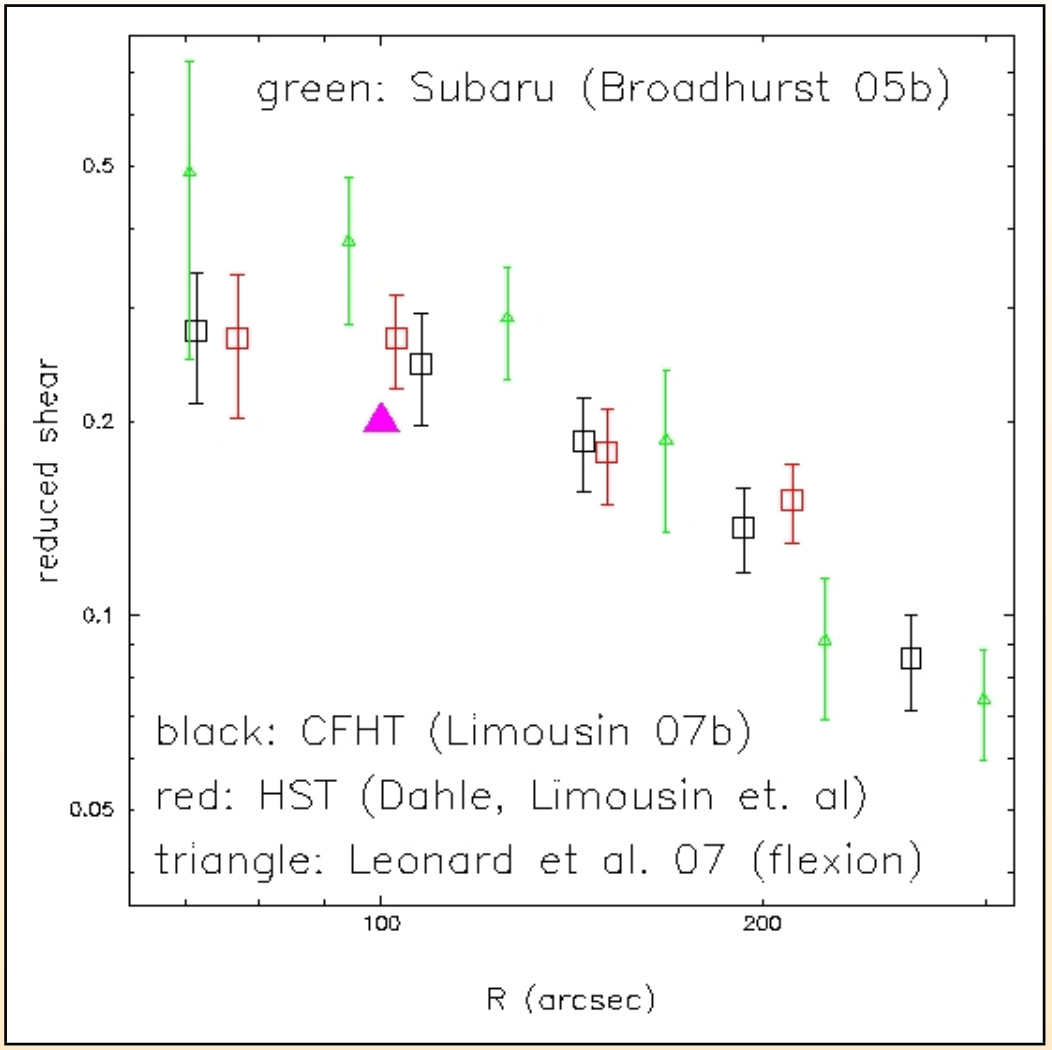
Weak Lensing: Subaru data (Broadhurst et al., 2005b)

- Weak Lensing from SUBARU:
  $c_{200} > 20$
- Weak lensing from CFHT:
  $c_{200} \sim 7$
- Lensing in the flexion regime:
  (Leonard et al. 2007) $\longrightarrow$ $g(100'') \sim 0.2$



Weak Lensing: $c_{200} < 10$ or $c_{200} > 20$? (Dahle, Limousin et al., in prep.)

- HST mosaic: (16 pointings, ~ 1 Mpc) (IMCAT)
- CFHT: Wide Field multi-colour (IM2SHAPE + BPZ)
- SUBARU: Wide Field multi-colour (IMCAT)
- $\rightarrow$ $c_{200} < 10$

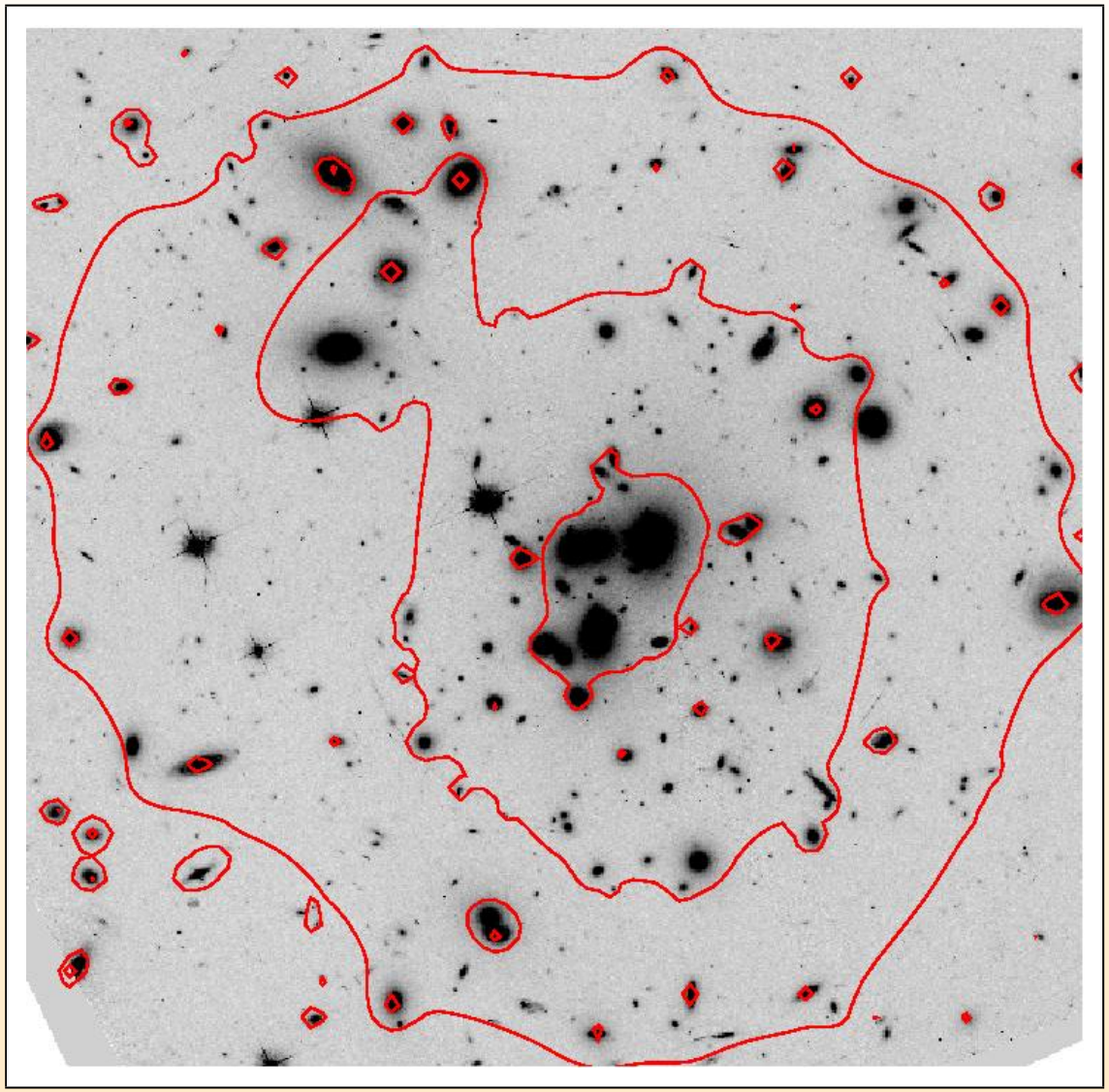


Conclusions

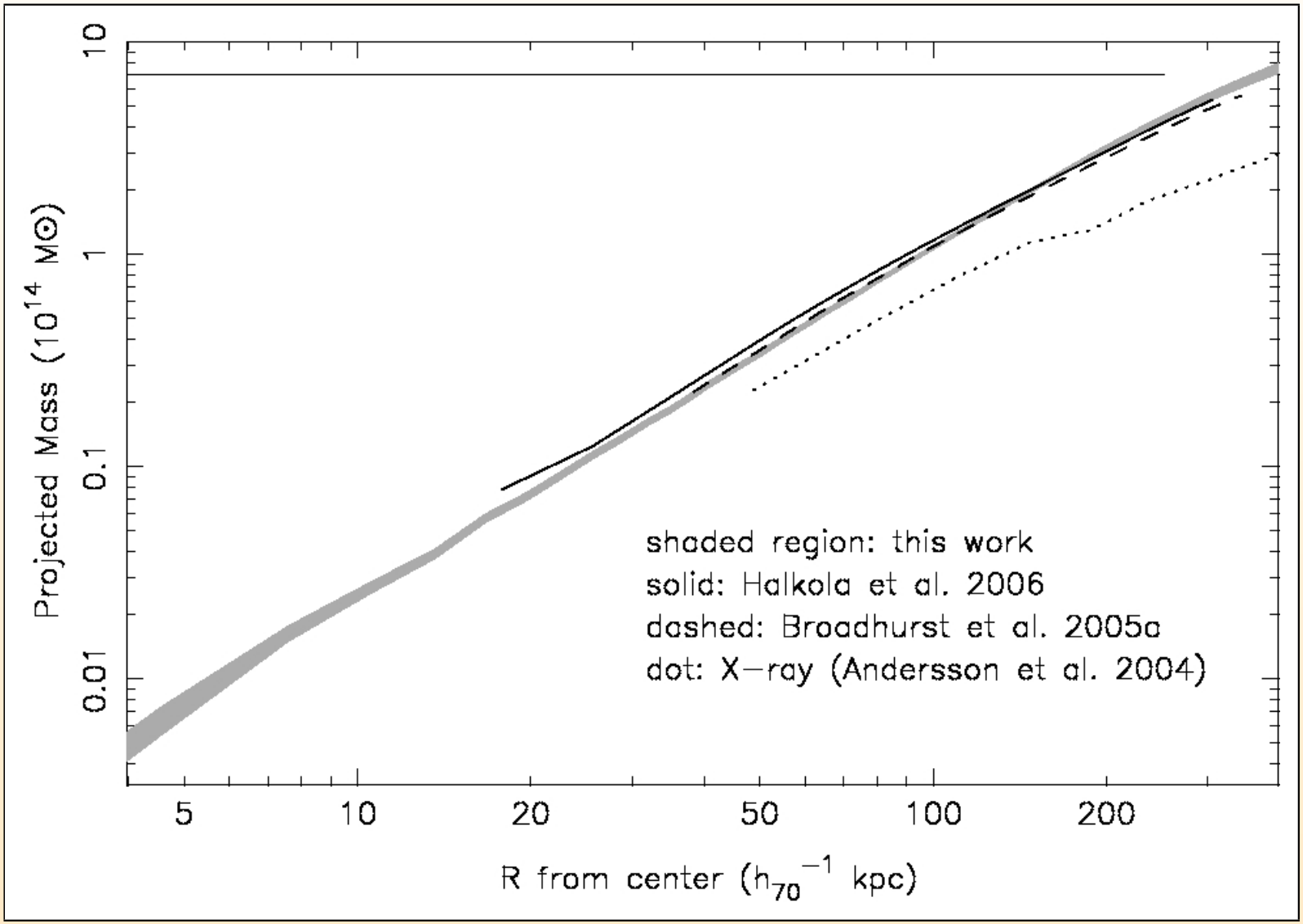
Different Regimes of Lensing can be Combined to Map Dark Matter Distribution on Different Scales

- Weak Galaxy-Galaxy Lensing $\longrightarrow$ galaxy scale halos
  - A Sample of 5 Massive Clusters
  - Truncated Dark Matter Halos: Tidal Stripping
  - Agreement with Simulations
- Strong Cluster Lensing $\longrightarrow$ Cluster Core
- Weak Cluster Lensing $\longrightarrow$ Whole Cluster: from R_e to the Outskirts
  - Application on Abell 1689: HST, Spectro (VLT - KECK), Wide Field (CFHT)
  - Strong and Weak Regimes Agree (Background selection)
  - $c_{200} \sim 7$: compatible with ΛCDM Simulations
  - M_{200} as inferred from Weak Lensing not biaised by contamination

A1689: Mass Map



A1689: Mass Profiles



Inverse Method: Maximum Likelihood

Consider one image i and associated lenses j:

$$a_i(\sigma_0, r) = \sum_{\substack{z_j < z_i \\ d(i,j) < R_{\max}}} a_{ij}$$

Computing $a_i(\sigma_0, r)$ and observing ε_i^{obs} :

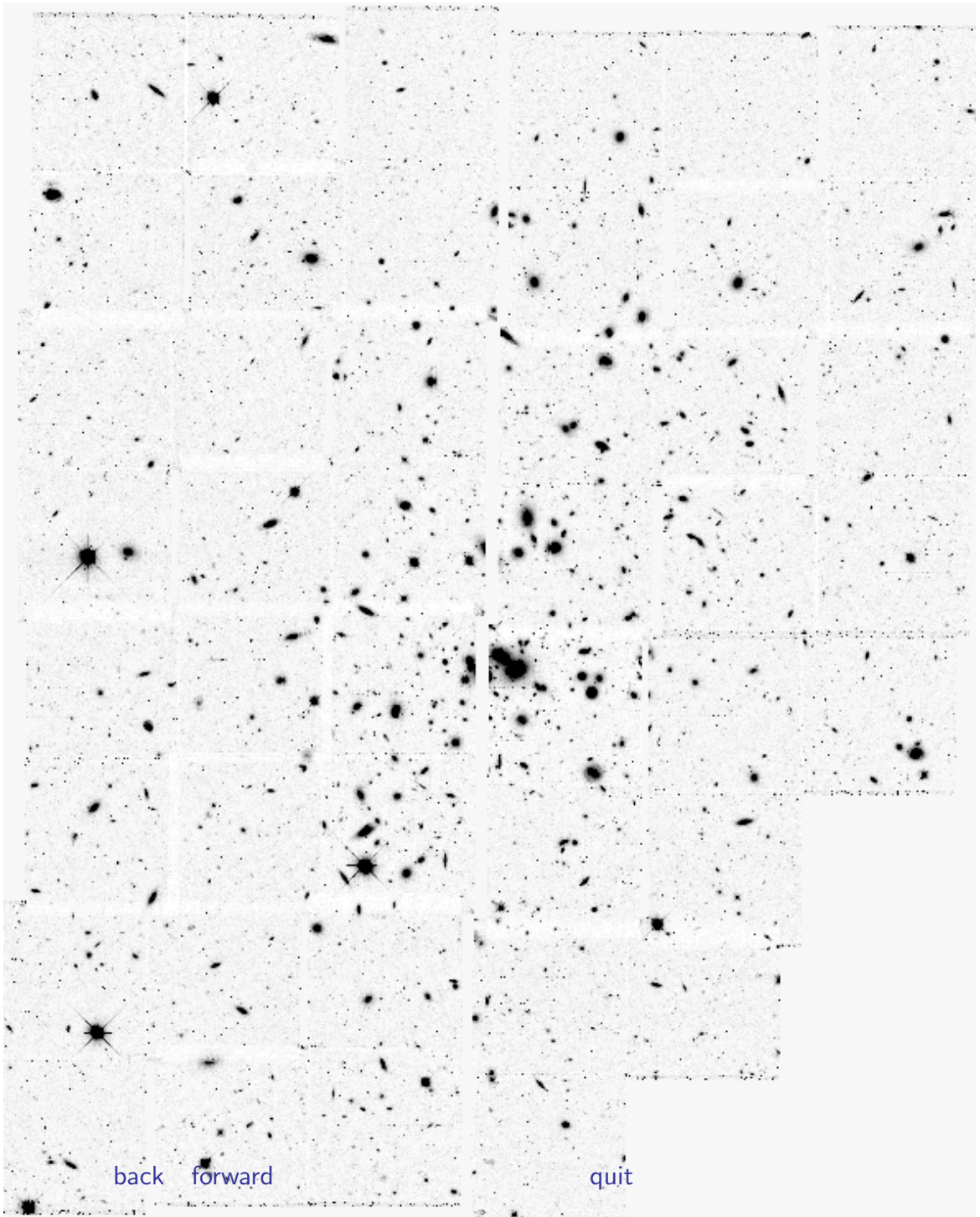
$$\varepsilon_i^s = F(\varepsilon_i^{obs}, a_i(\sigma_0, r)) = \varepsilon_i^s(\sigma_0, r)$$

Intrisic Ellipticity Distribution:
$\Rightarrow$ We assign a likelihood to the parameters (σ_0, r) :

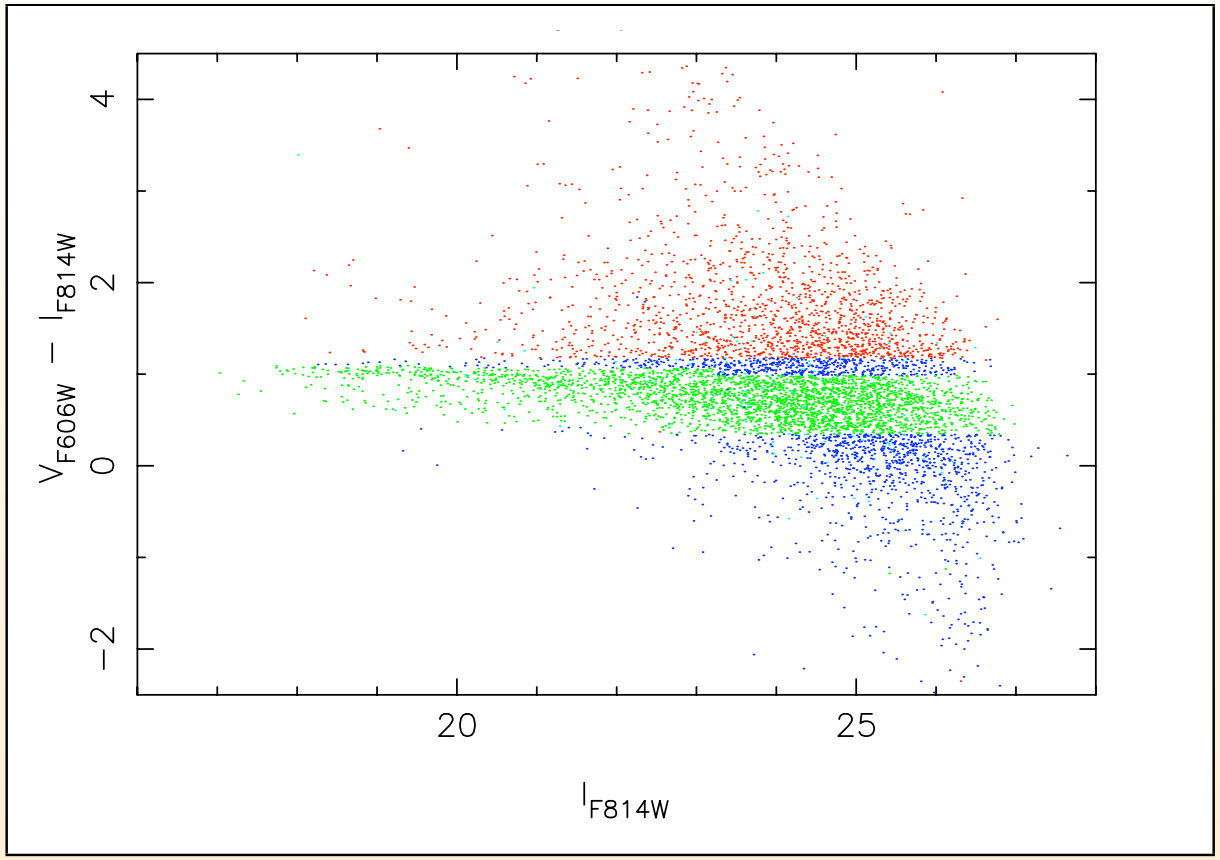
$$\mathcal{P}^s(\varepsilon^s) = \frac{1}{2\pi\sigma} e^{\frac{-\varepsilon^{s2}}{2\sigma^2}}, \quad \sigma \simeq 0.2$$

Likelihood Fonction: $\mathcal{L} = \prod_i \mathcal{P}^s(\varepsilon_i^s) = \mathcal{L}(\sigma_0, r)$

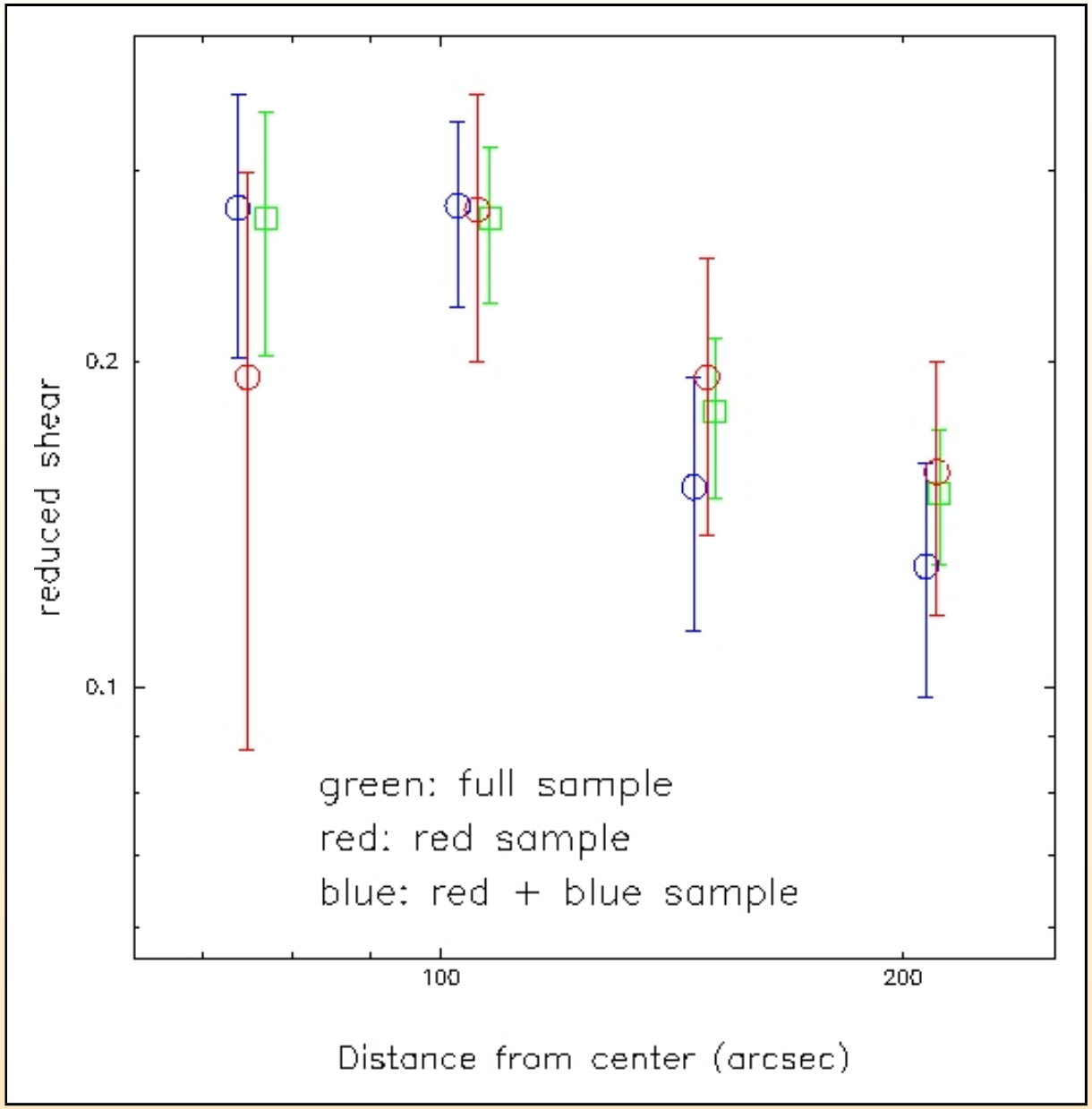
HST Mosaic



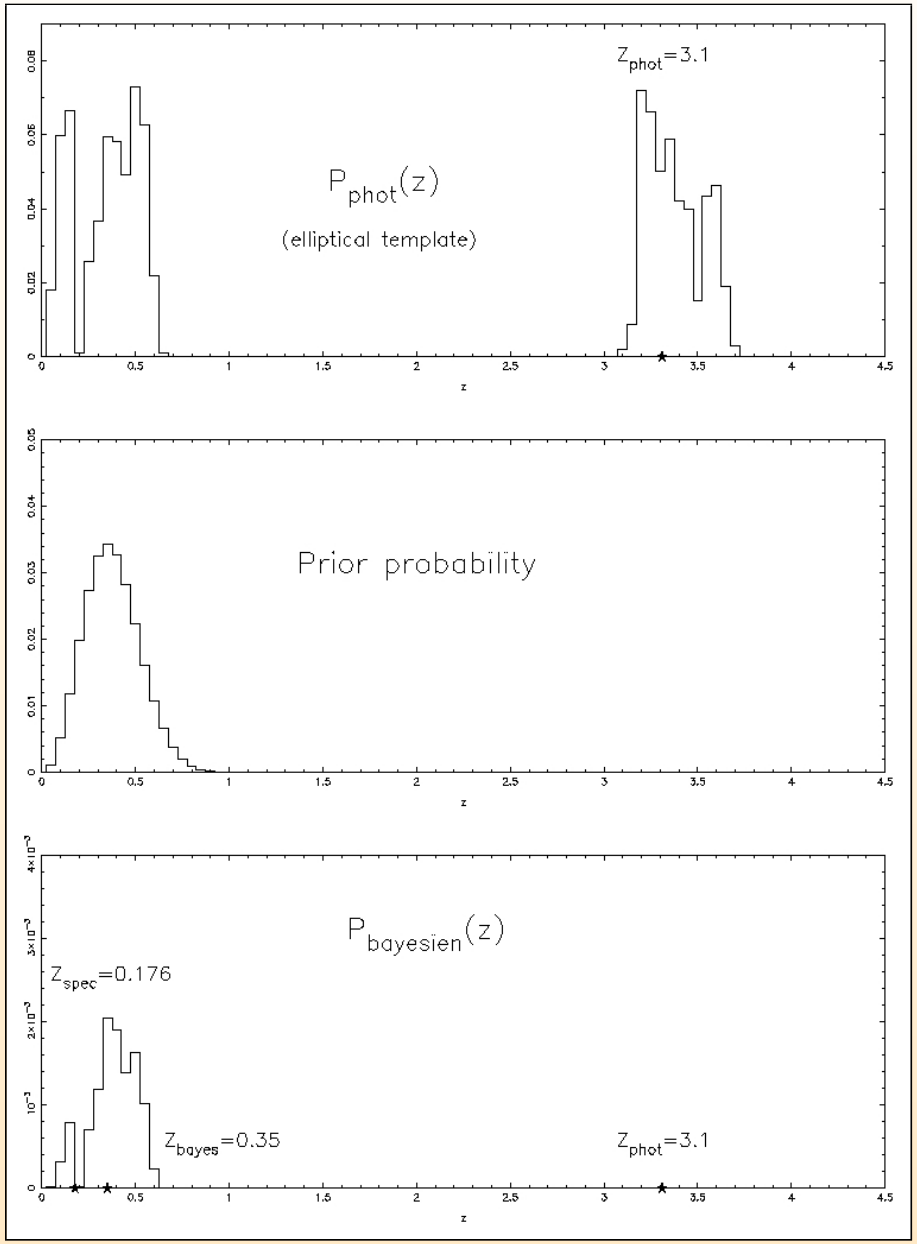
Color Magnitude Diagram



Three Samples



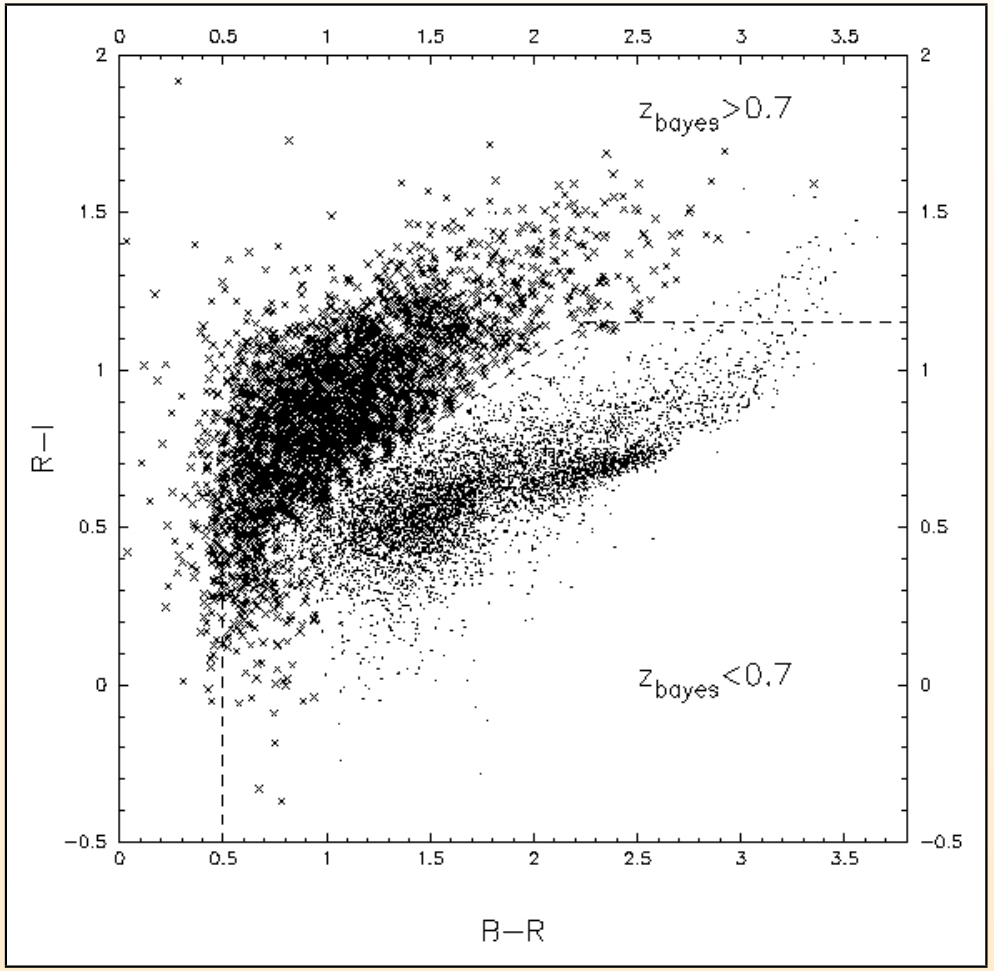
Bayesian Photometric Redshifts



(Benitez, 1999)

- Elliptical:
  $z_{\rm spec} = 0.176$ (B,R,I)
- HYPERZ $\longrightarrow$ $z_{\rm phot} = 3.1$
- Prior:
  $P(z|m)$ (LF)
- $z_{\rm bayes} = 0.35$

Bayesian Photometric Redshifts: Validity ?



Comparison to DEEP2 survey

Background Population Selection

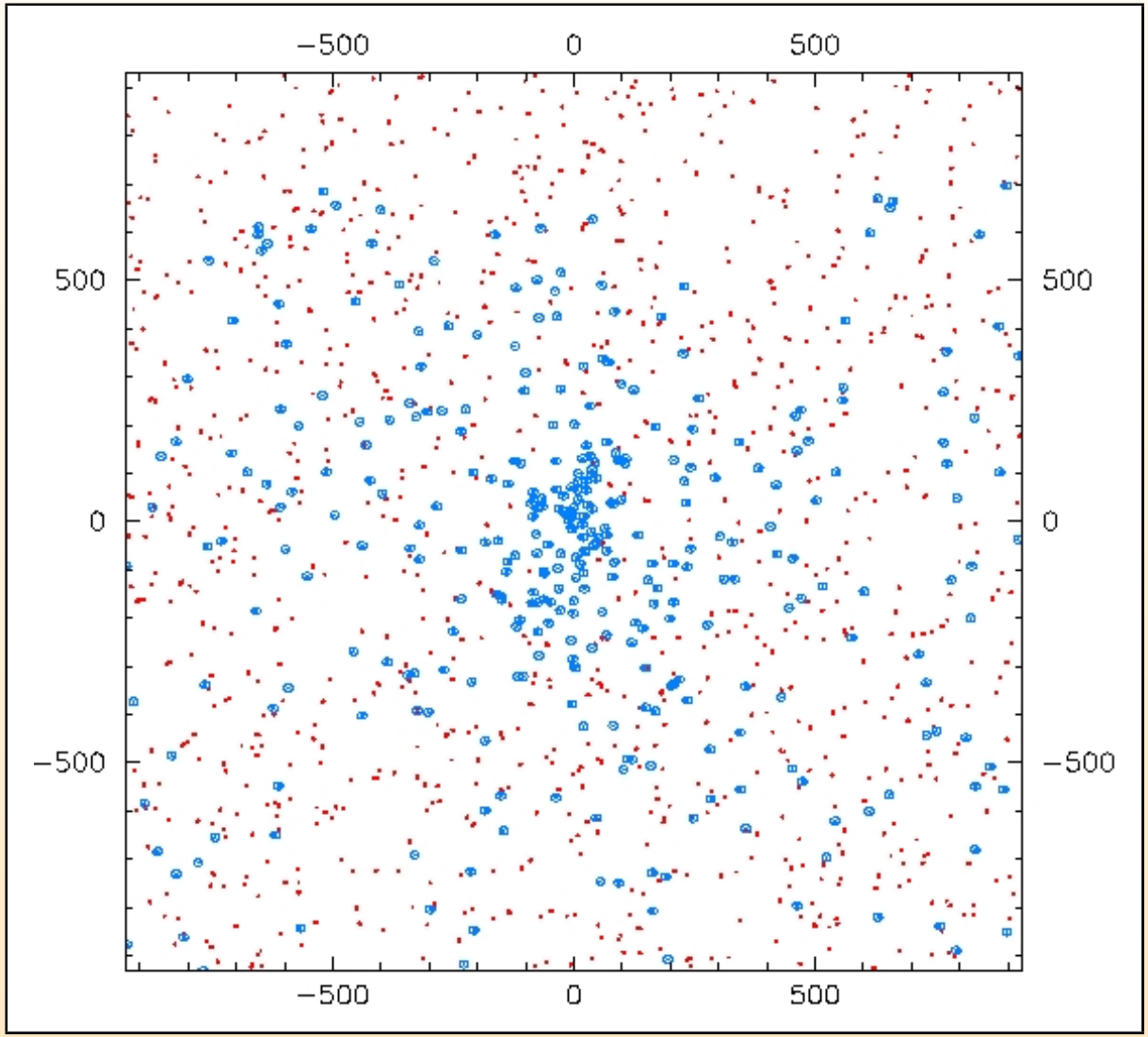
$$\mathrm{BPZ} \rightarrow P_{\mathrm{bayes}}$$

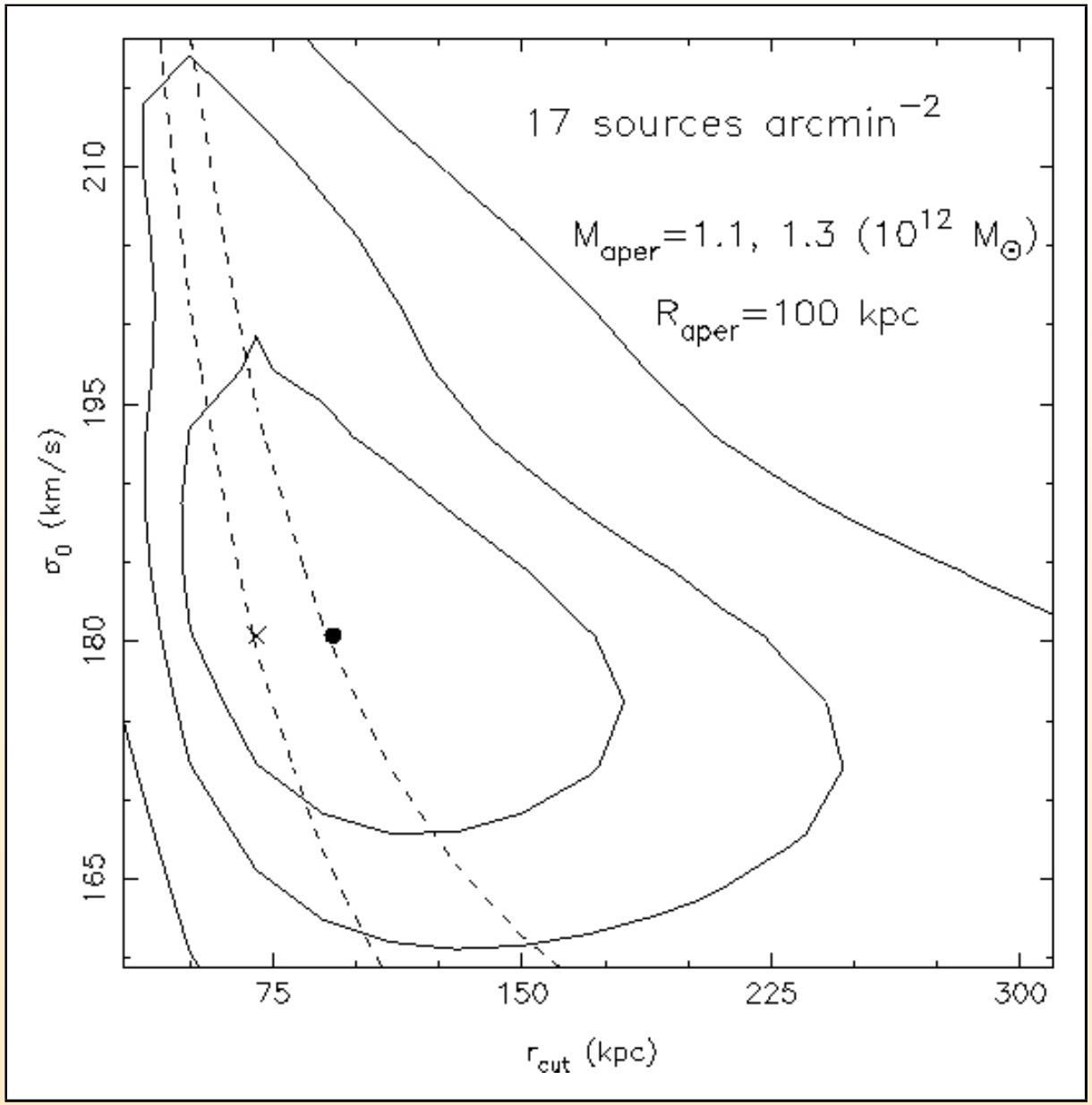
$$\chi_z = \frac{1}{\mathrm{N}} \int_z^{+\infty} P_{\mathrm{bayes}}(z')dz'$$

Tunning on a spectroscopic sub-sample:

$\chi_{0.4} > 60 \rightarrow$ Cluster Galaxies are rejected (4% contamination)

Galaxy-Galaxy Lensing: Simulations




17 sources arcmin^{-2}
M_{aper}=1.1, 1.3 (10^{12} $M_\odot$)
R_{aper}=100 kpc
σ_0 (km/s)
210
195
180
165
75
150
225
300
r_{cut} (kpc)

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