Subaru Weak-Lensing Results of Galaxy Clusters

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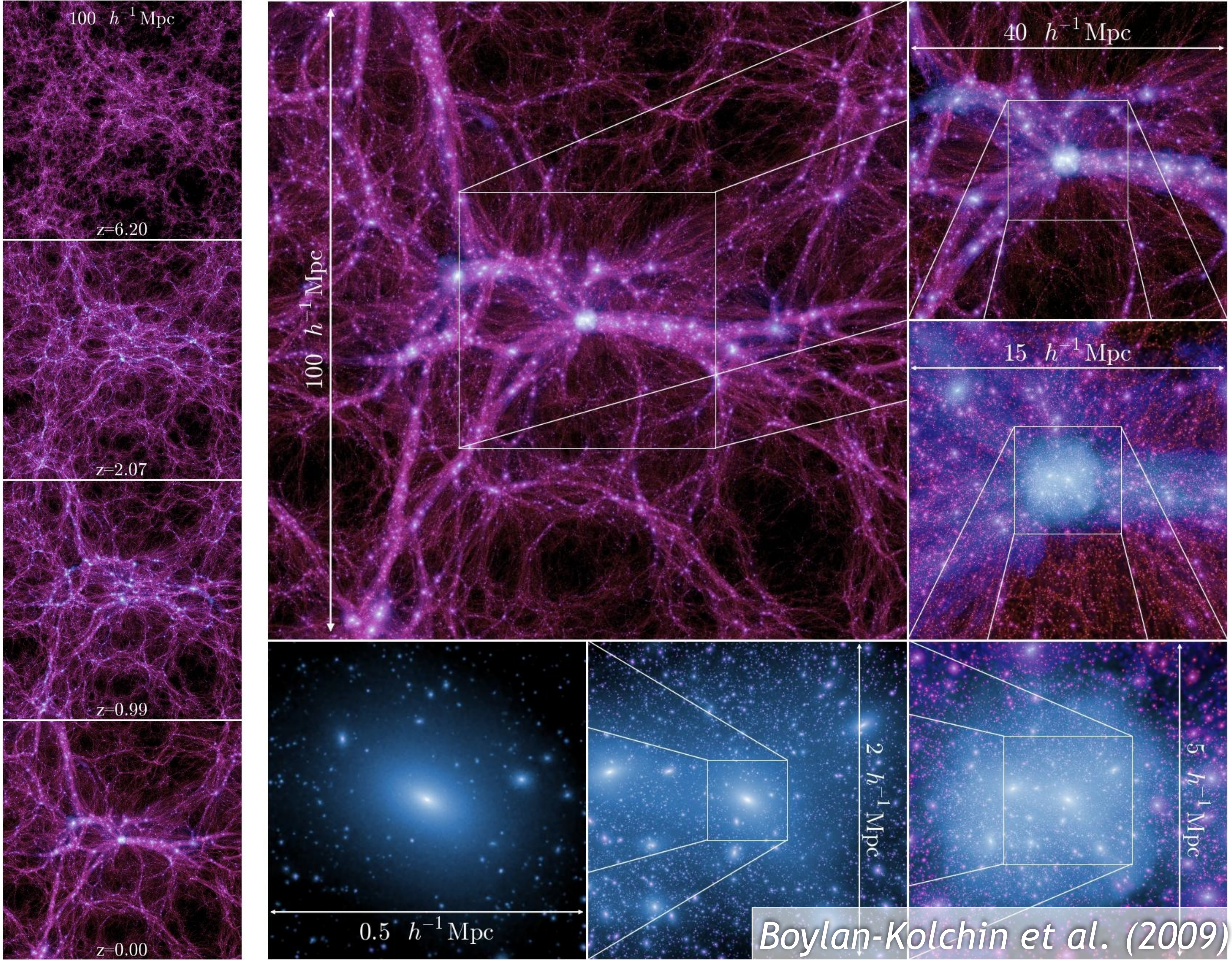
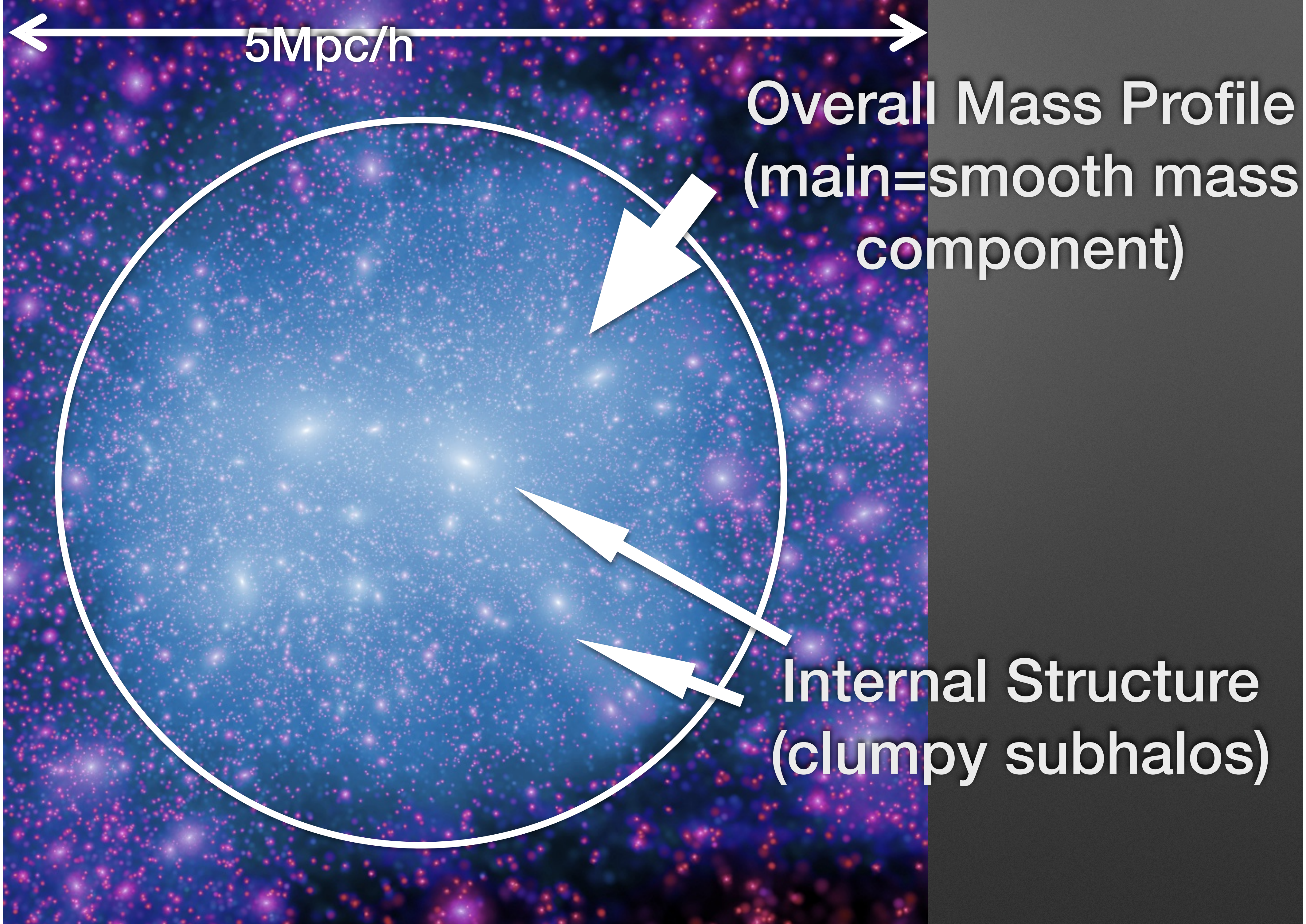
2014/Jan/22

in a collaboration with

Futamase, T., Kajisawa, M., Smith, G. P.,Takada, M., Umetsu, K., and LoCuSS project



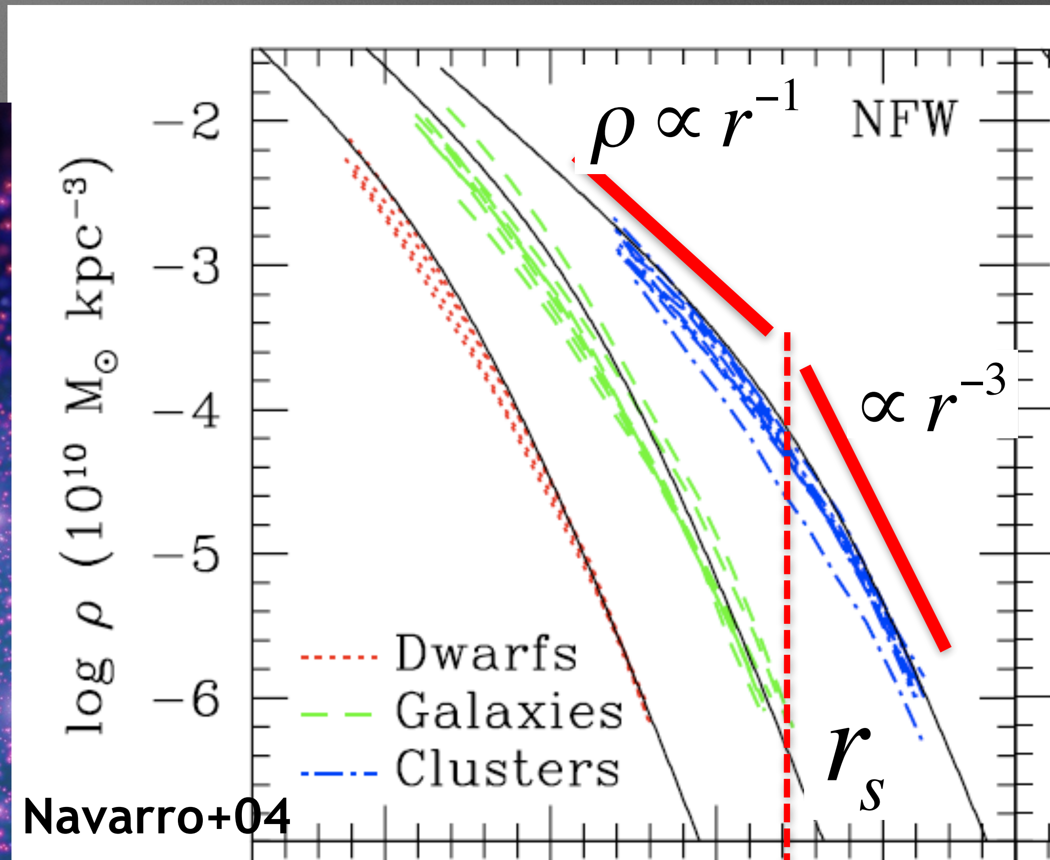
Boylan-Kolchin et al. (2009)



Boylan-Kolchin+09

Universal Mass Profile

Simulation-based predictions: the appearance of a characteristic, universal density profile (Navarro, Frenk & White 96, 97; NFW profile)

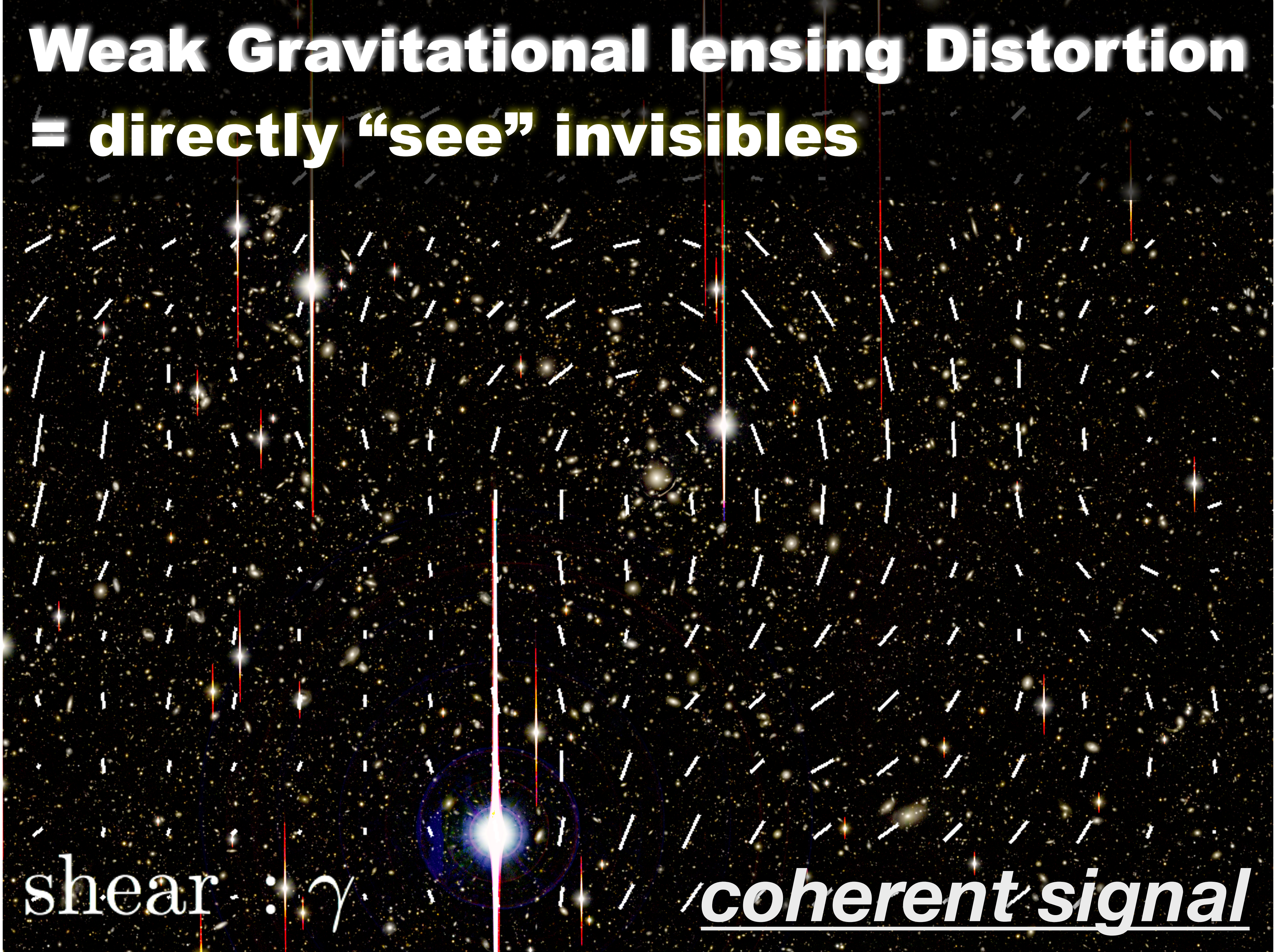


$$\rho_{\mathrm{NFW}}(r) = \frac{\rho_s}{(r/r_s)(1+r/r_s)^2}$$

M_{vir} Cluster Mass

$c_{\mathrm{vir}} = r_{\mathrm{vir}}/r_s$ Concentration parameter

Weak Gravitational lensing Distortion
= directly “see” invisibles



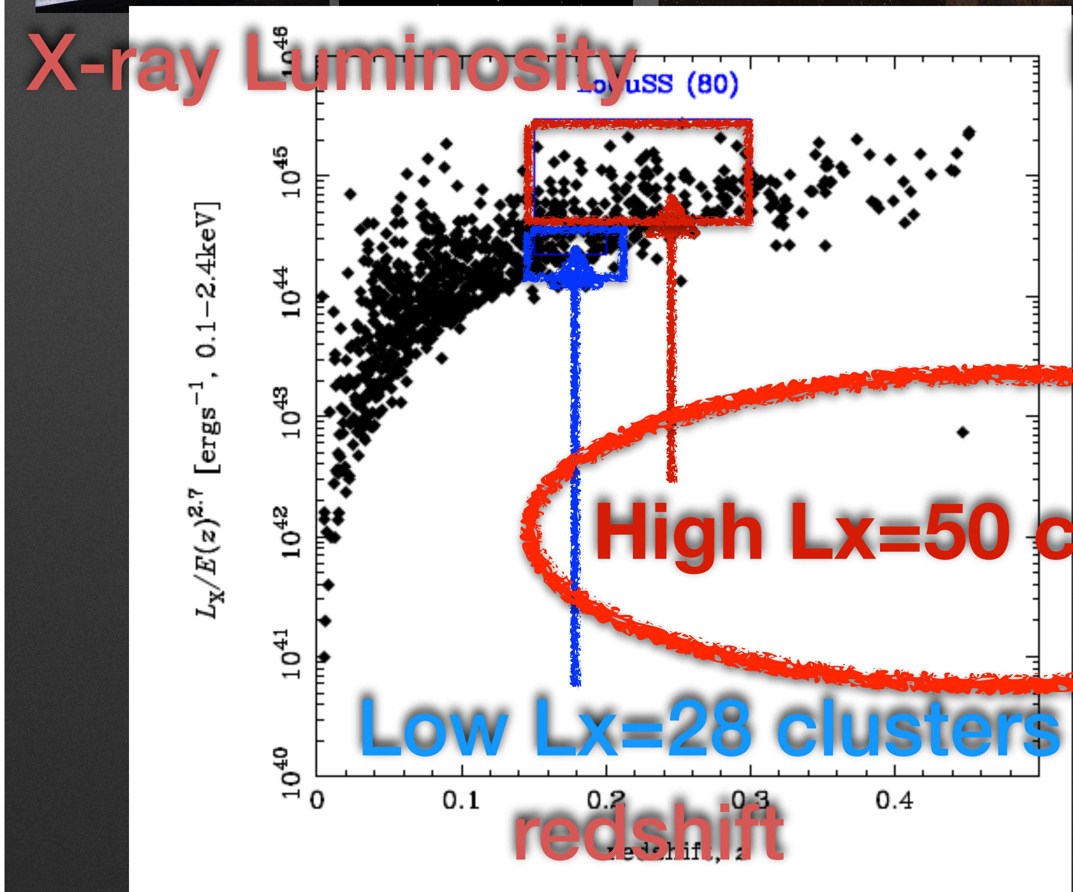
Question

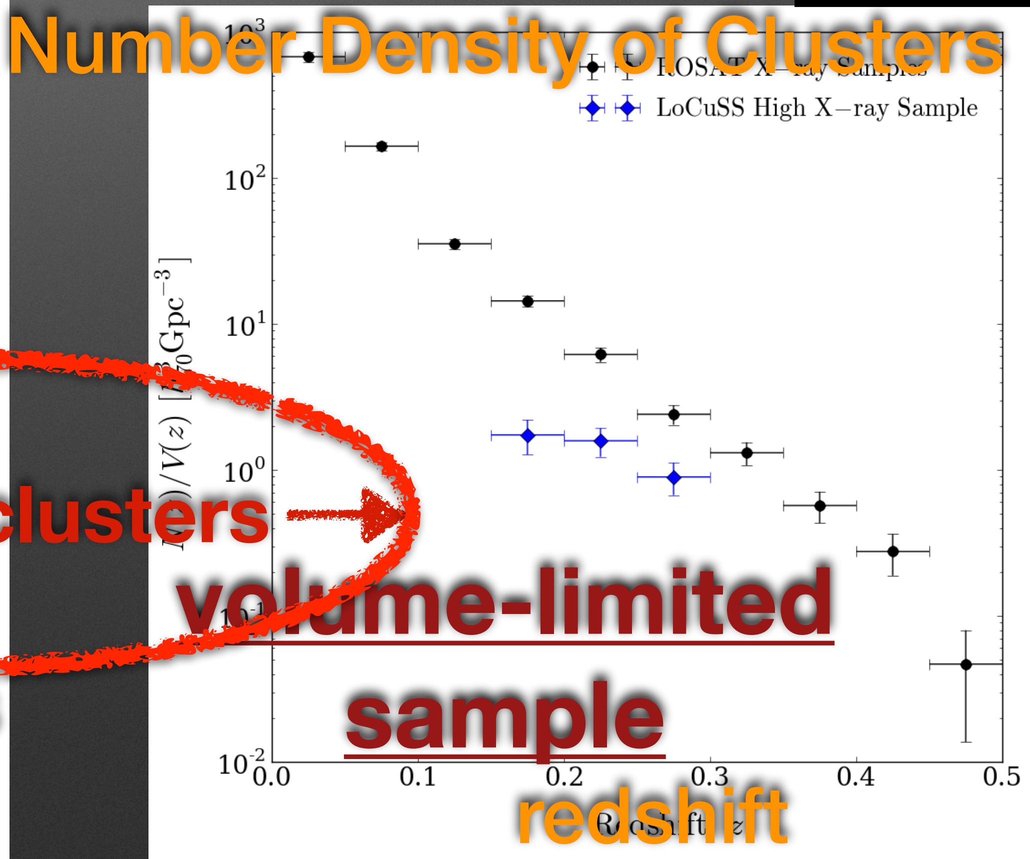
An average mass profile for clusters

1. Sample Definition.
2. Method.

LoCuSS (local Cluster Substructure Survey)

multi-wavelength survey for ~ 80 clusters at z = 0.15-0.3,
unbiasedly selected from X-ray luminosity

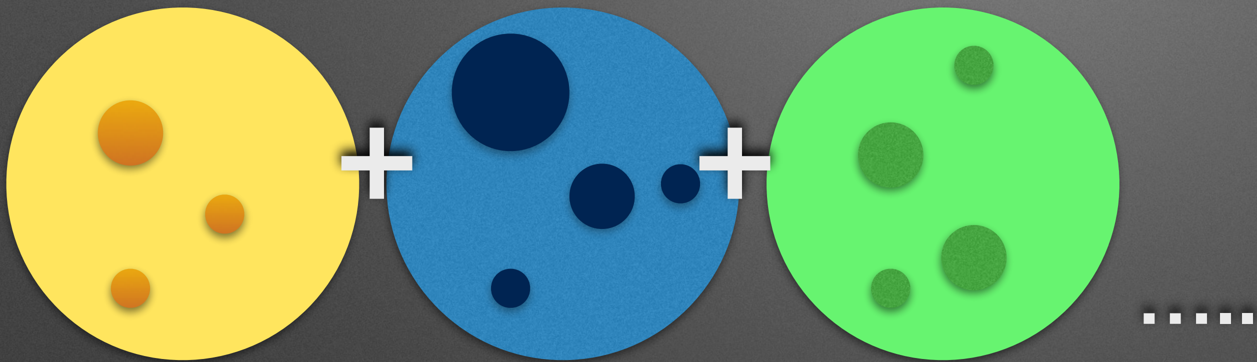




Stacked Weak-lensing analysis for *50 clusters*

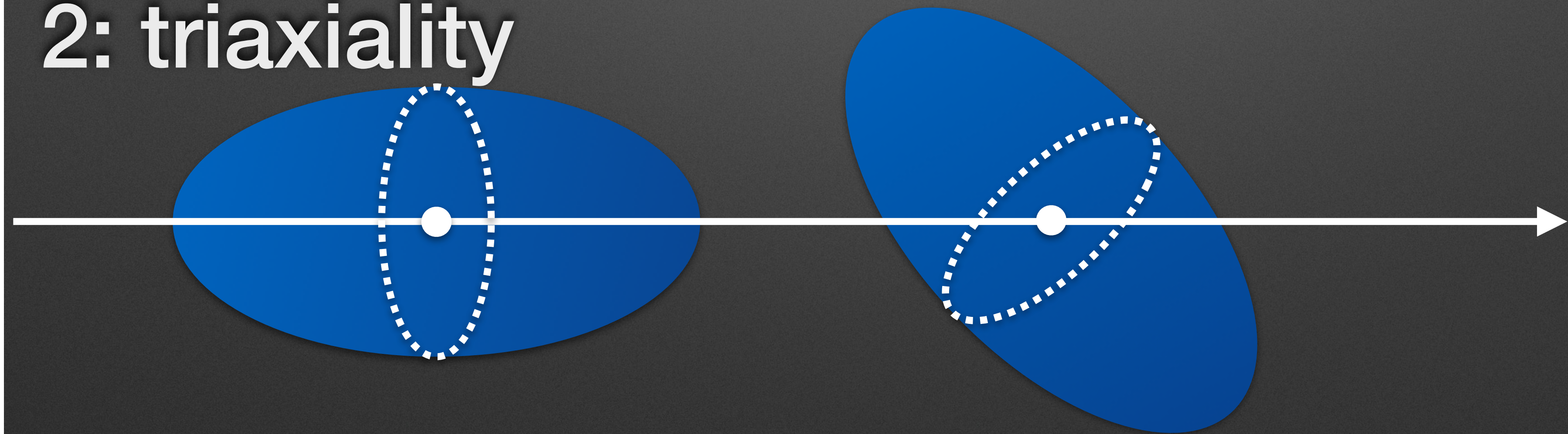
Less sensitive to

1: subhalos

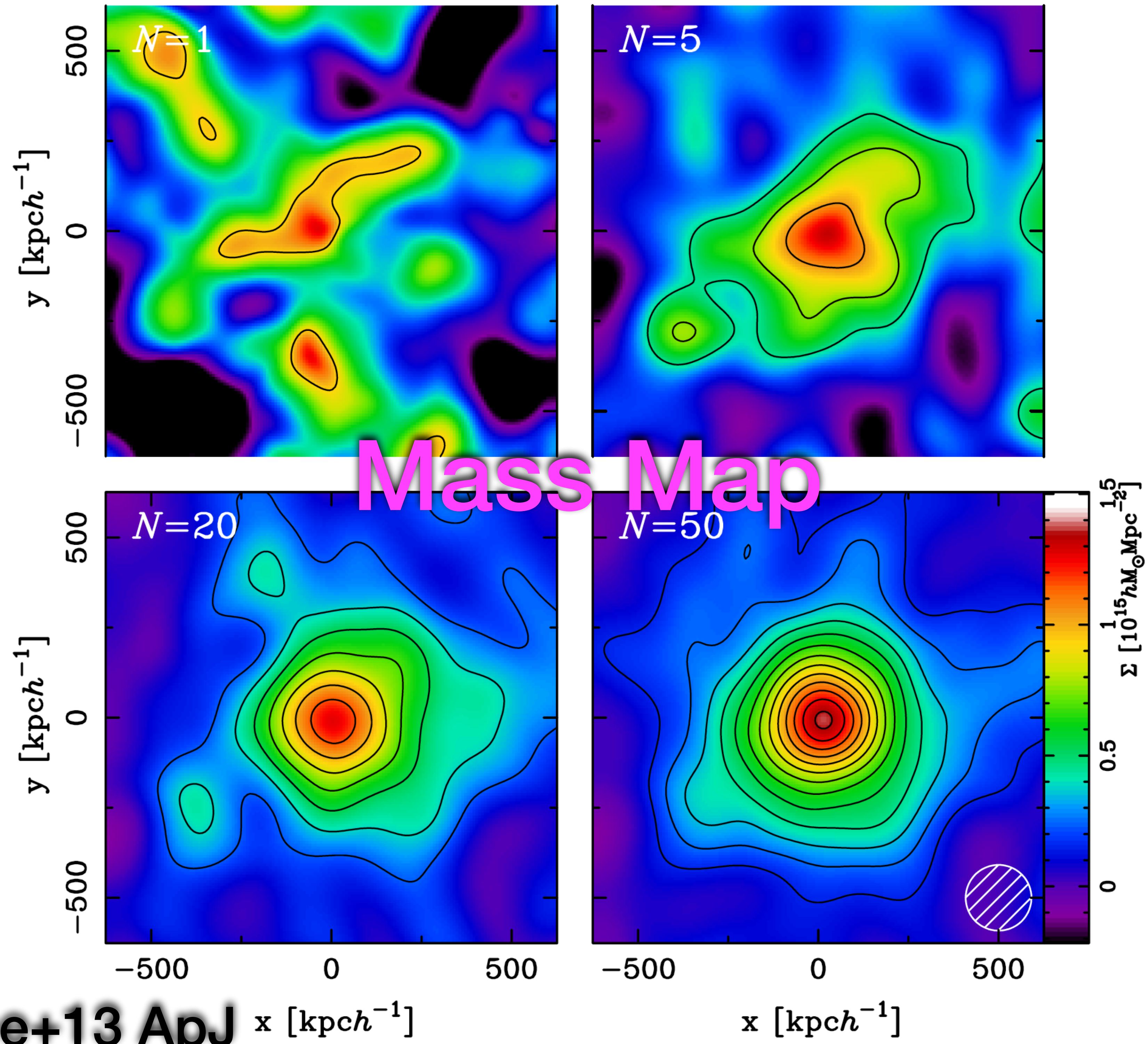


$$\gamma = \bar{\kappa}(< \theta) - \kappa(\theta)$$

2: triaxiality



Powerful to unveil an average mass distribution for statistically well-defined, unbiased sample of clusters.


Mass Map
N=1
N=5
N=20
N=50
y [kpch^{-1}]
x [kpch^{-1}]
500
0
−500
Σ [10^{15}hM$_\odot$Mpc^{-2}]
0
0.5
1
1.5

Okabe+13 ApJ

Control systematics

small statistical errors

$$\frac{30\ \%}{\sqrt{50}} \sim 4\ \%$$

Number of clusters

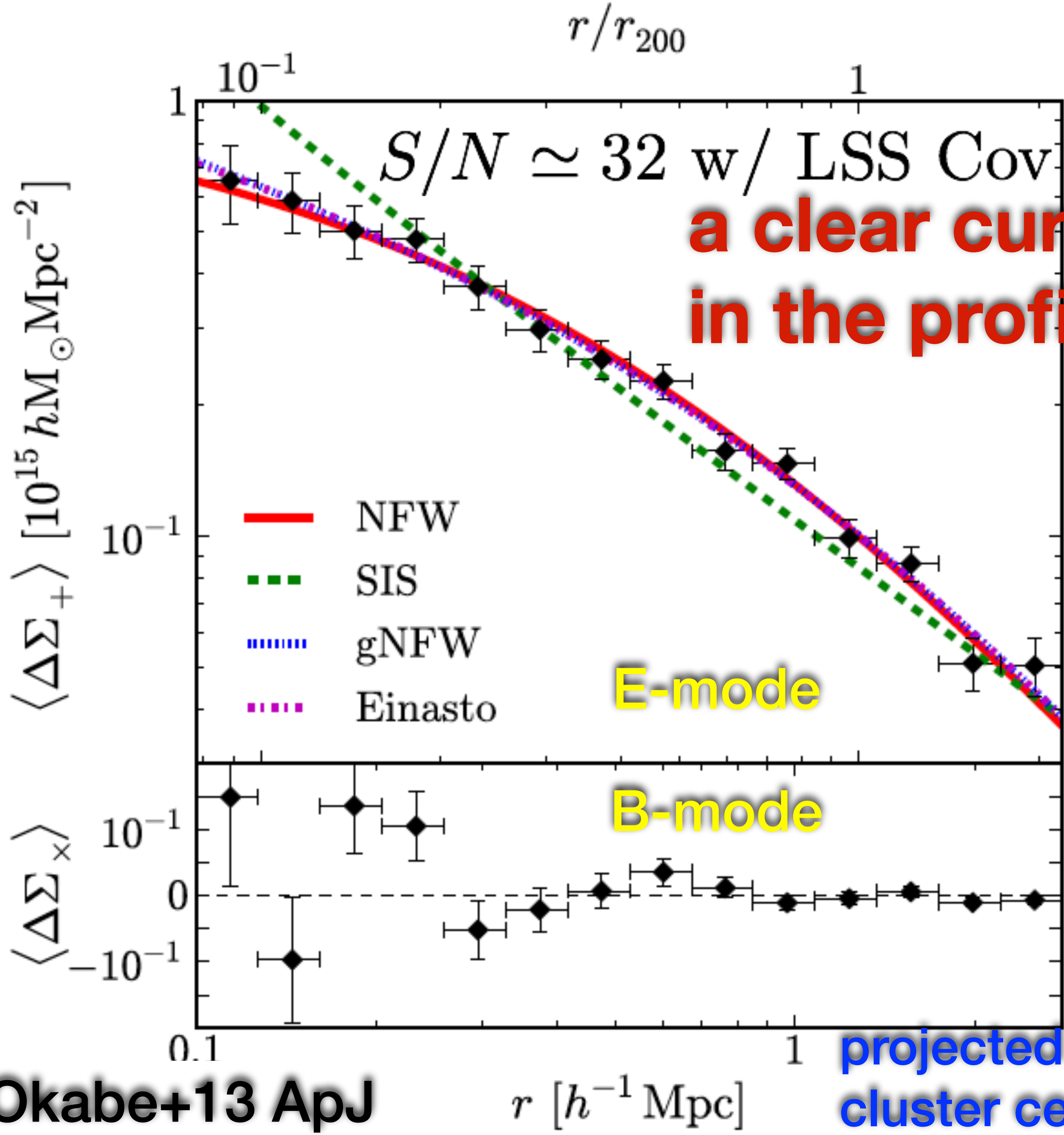
Need to control systematics down to a few %

Main Systematic Error

Contamination of member galaxies in background source catalog

~50 % underestimated, at maximum

We developed a new simple method to quantitatively control the contamination level (1%)



a clear curvature in the profile

SIS model (singular isothermal model)

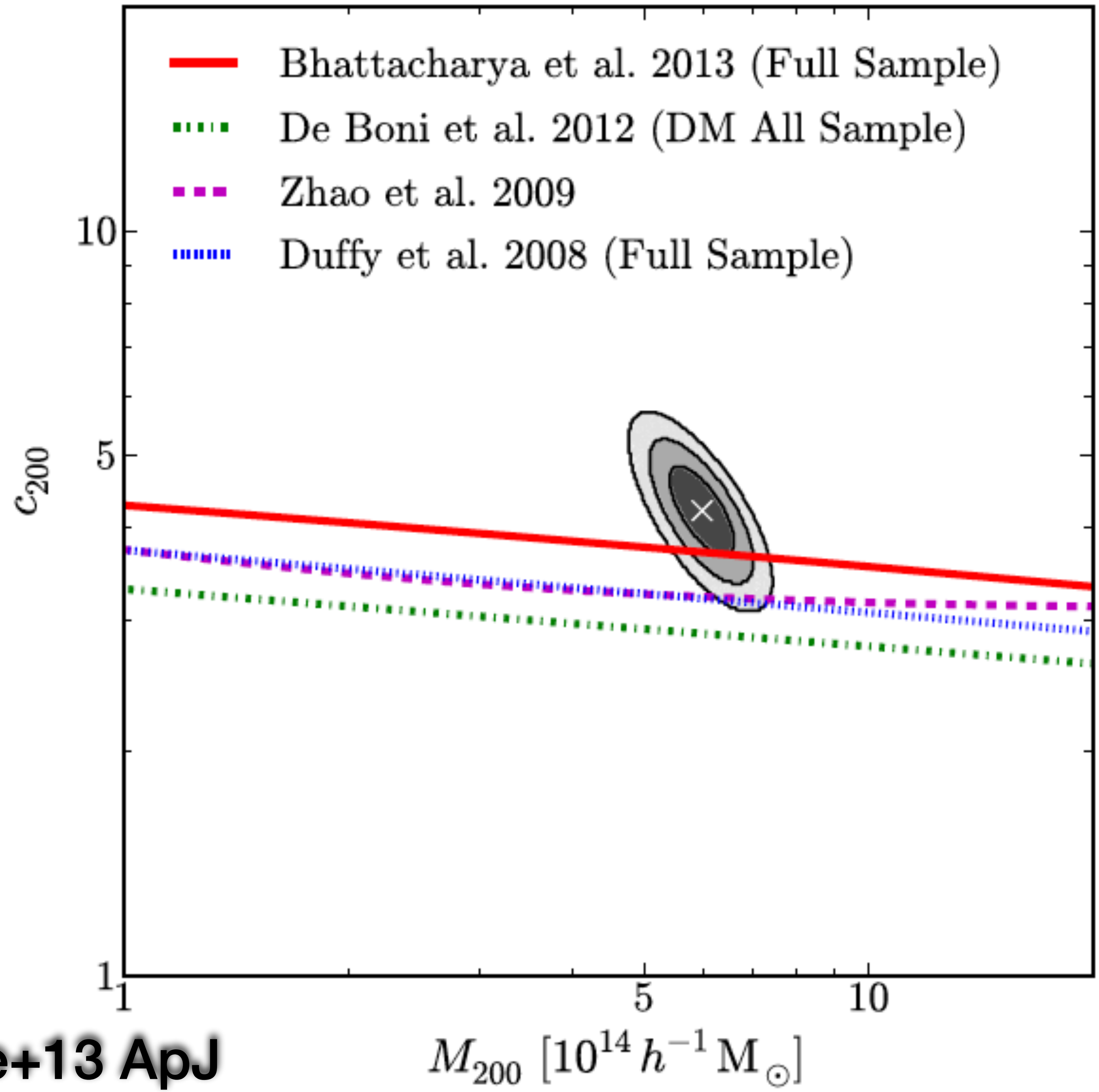
$$\rho_{\mathrm{SIS}} \propto r^{-2}$$

NFW model

$$\rho_{\mathrm{NFW}}(r) = \frac{\rho_s}{(r/r_s)(1+r/r_s)^2}$$

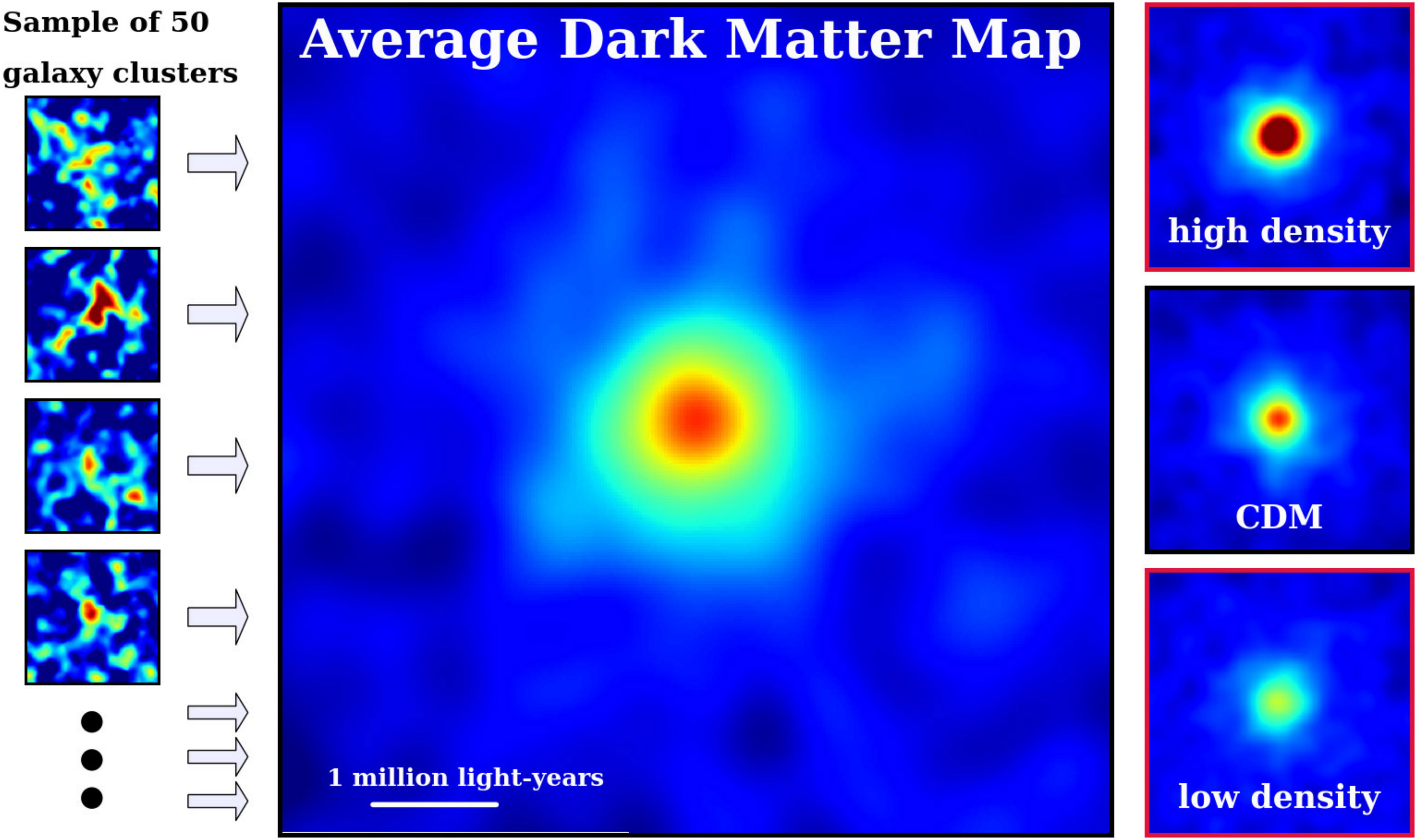
projected distance from cluster centers.

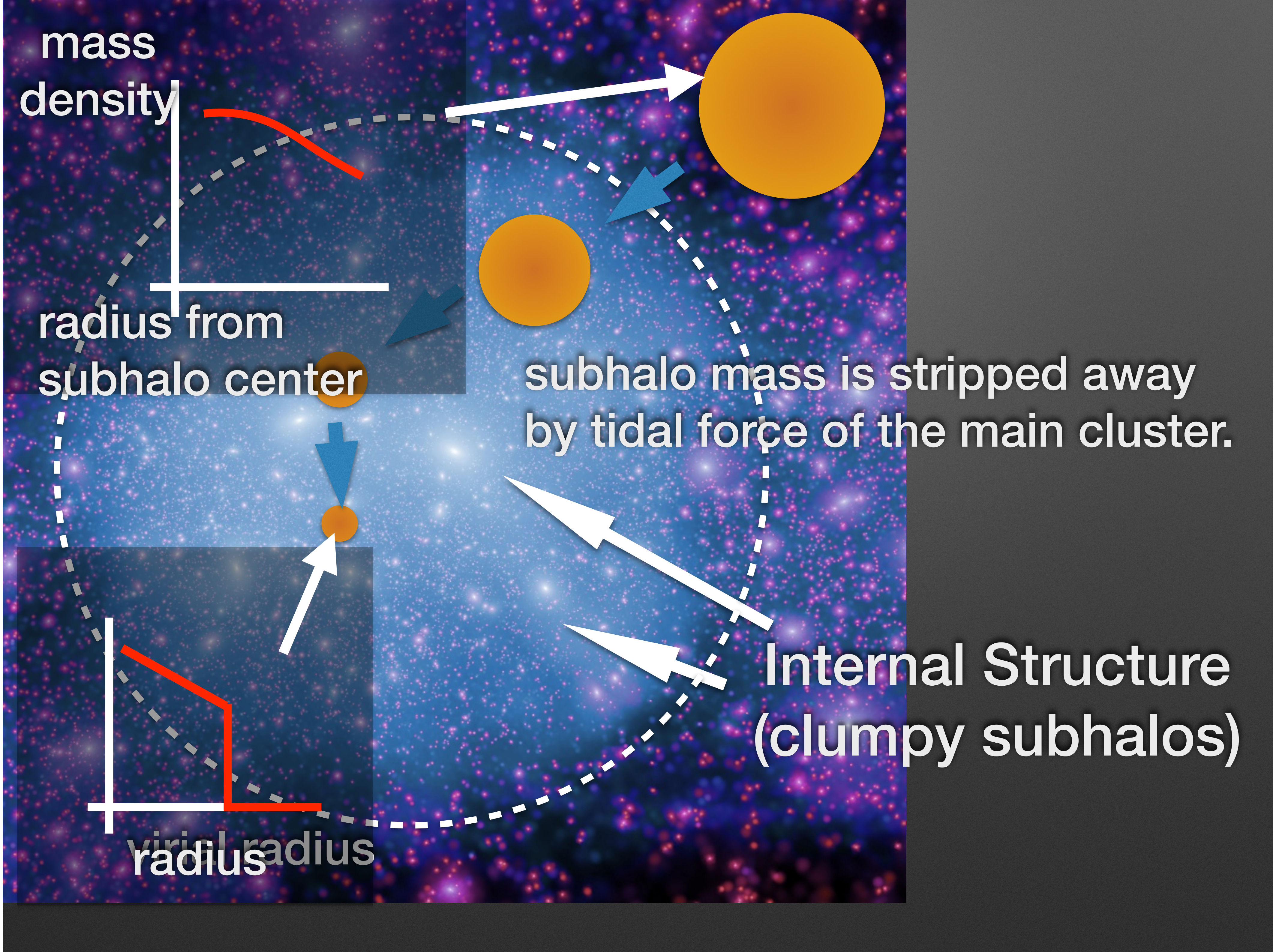
Okabe+13 ApJ



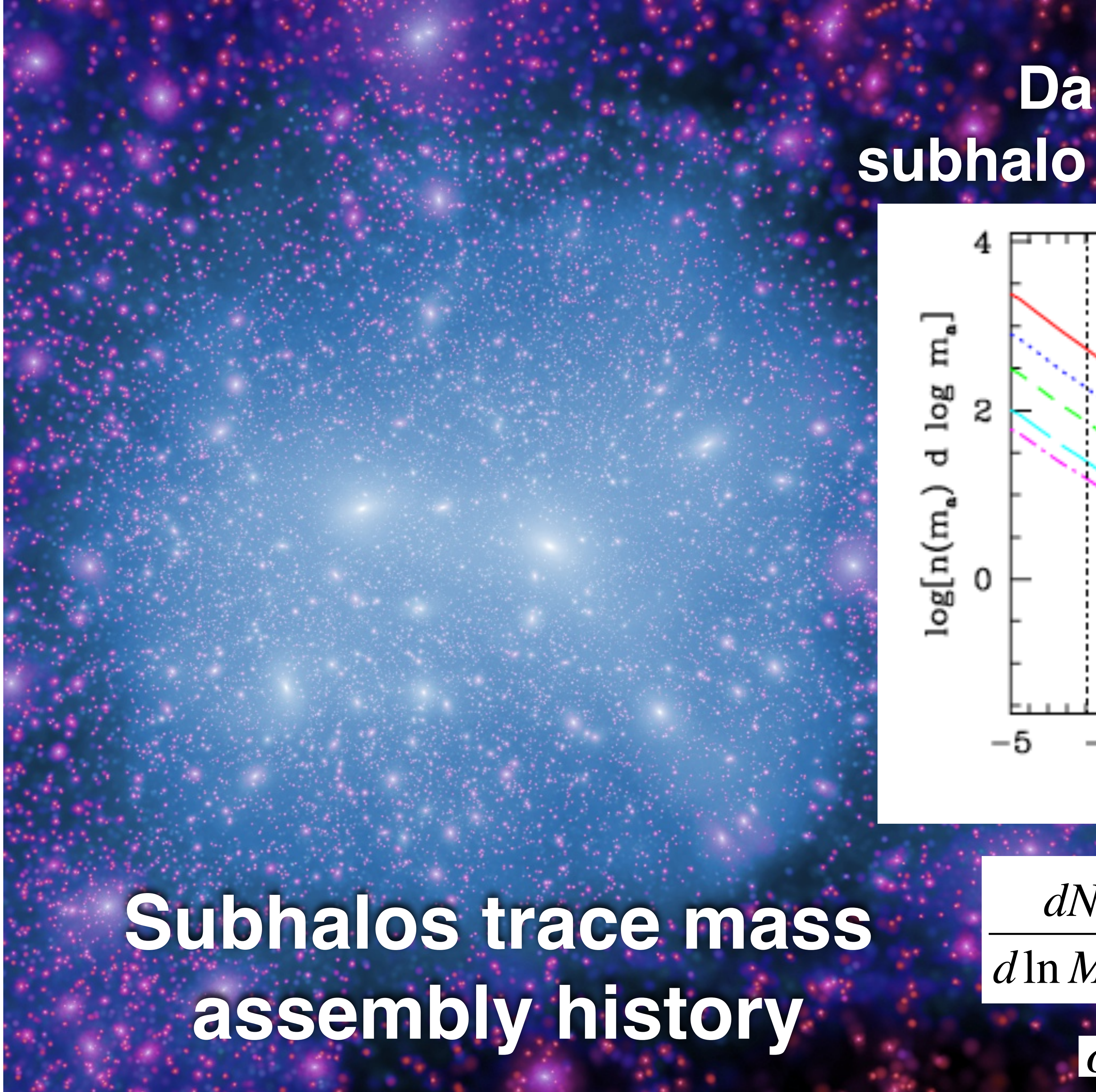
Bhattacharya et al. 2013 (Full Sample)
De Boni et al. 2012 (DM All Sample)
Zhao et al. 2009
Duffy et al. 2008 (Full Sample)
10
5
1
c_{200}
1
5
10
M_{200} [$10^{14}\,h^{-1}\,\mathrm{M}_\odot$]

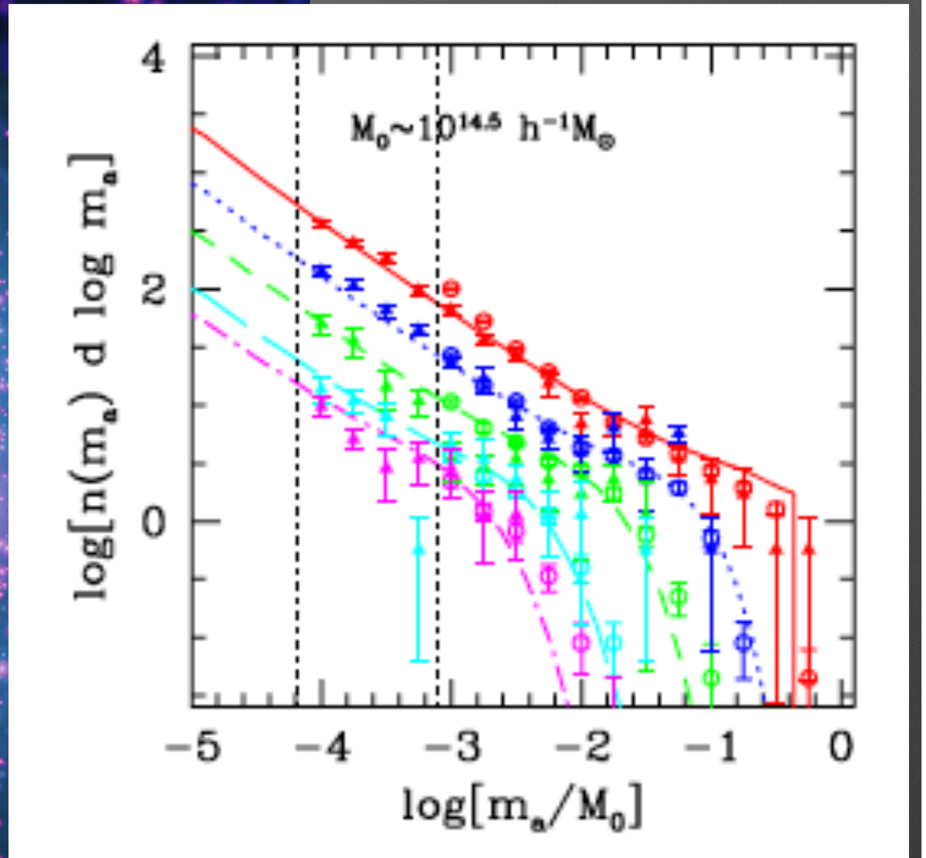
Okabe+13 ApJ


Sample of 50
galaxy clusters
Average Dark Matter Map
1 million light-years
high density
CDM
low density


mass
density
radius from
subhalo center
subhalo mass is stripped away
by tidal force of the main cluster.
Internal Structure
(clumpy subhalos)
virial radius
radius

Dark matter subhalo mass function





$$\frac{dN}{d\ln M_{\rm sub}} \propto \left(\frac{M_{\rm sub}}{M_{\rm vir}}\right)^{-\alpha}$$

$$\alpha \sim 0.9 - 1.0$$

Subhalos trace mass assembly history

Motivation : Subhalo Properties

1: Statistical properties of subhalos (e.g. mass function) make a stringiest test of CDM predictions on scales of less than several Mpc.

2: galaxy - dark matter connection.

3: Difficult to infer subhalos’ masses from galaxies, because assumptions on mass distribution extending beyond galaxies is required.

4: Weak gravitational lensing analysis is a direct route to measure subhalo masses.

z~0.2

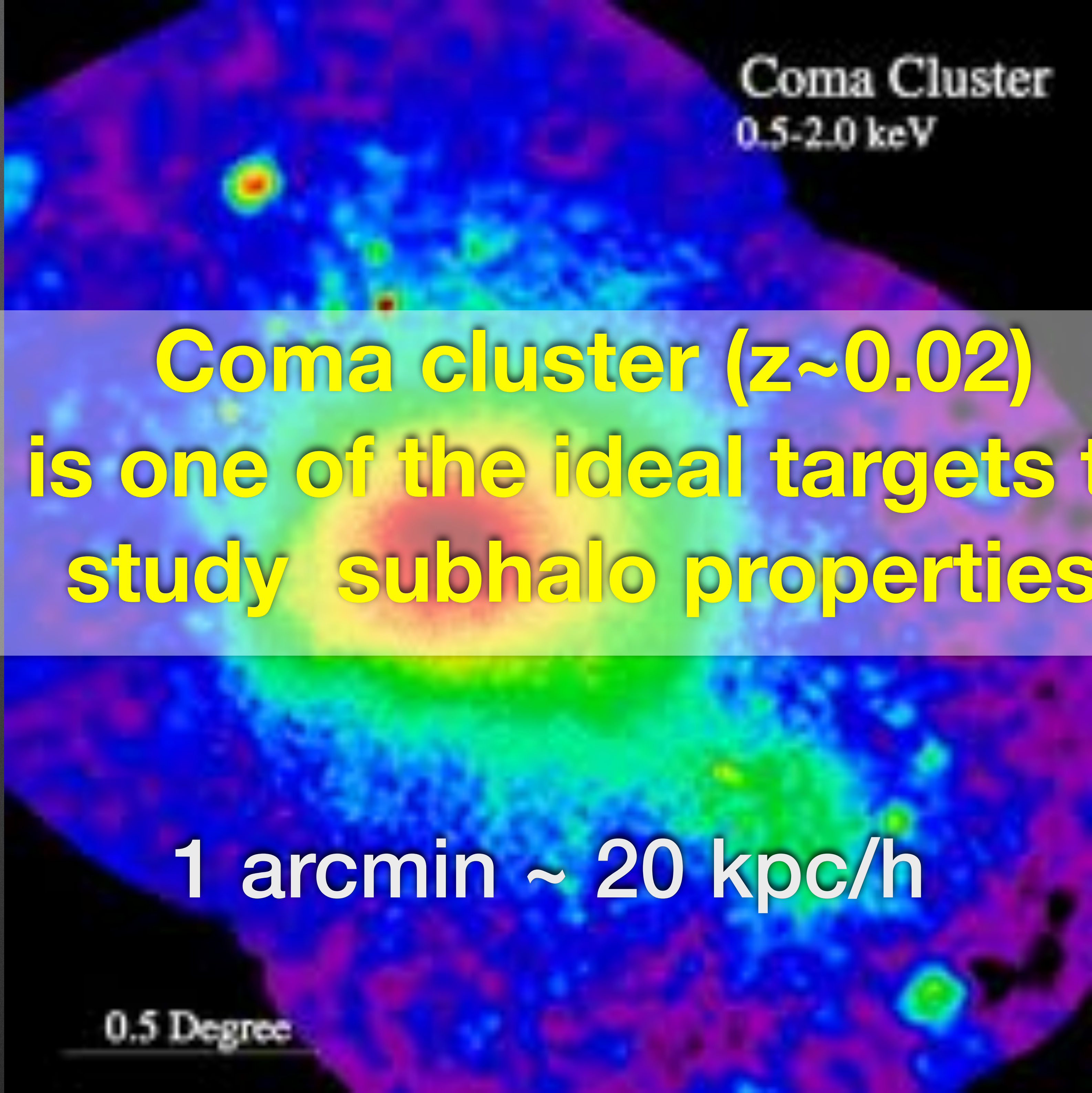
z~0.02

7 times larger

subhalo size :

e.g. 30 kpc/h ~ 0.2 arcmin

Apparent size of very nearby clusters is large enough to resolve less massive subhalos.

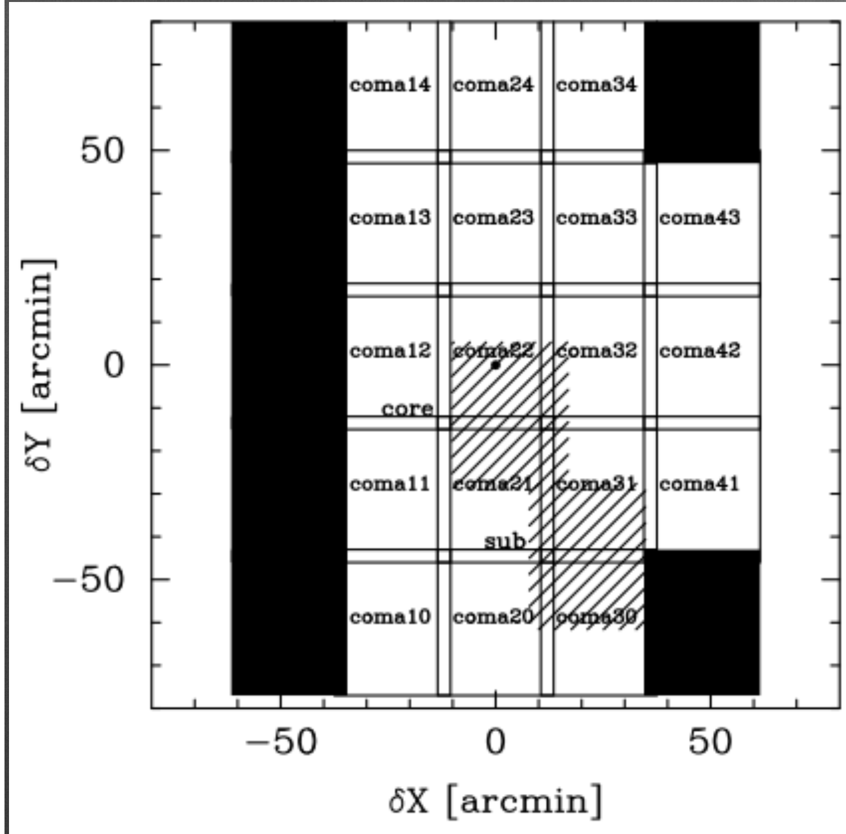


Coma cluster (z~0.02) is one of the ideal targets to study subhalo properties.

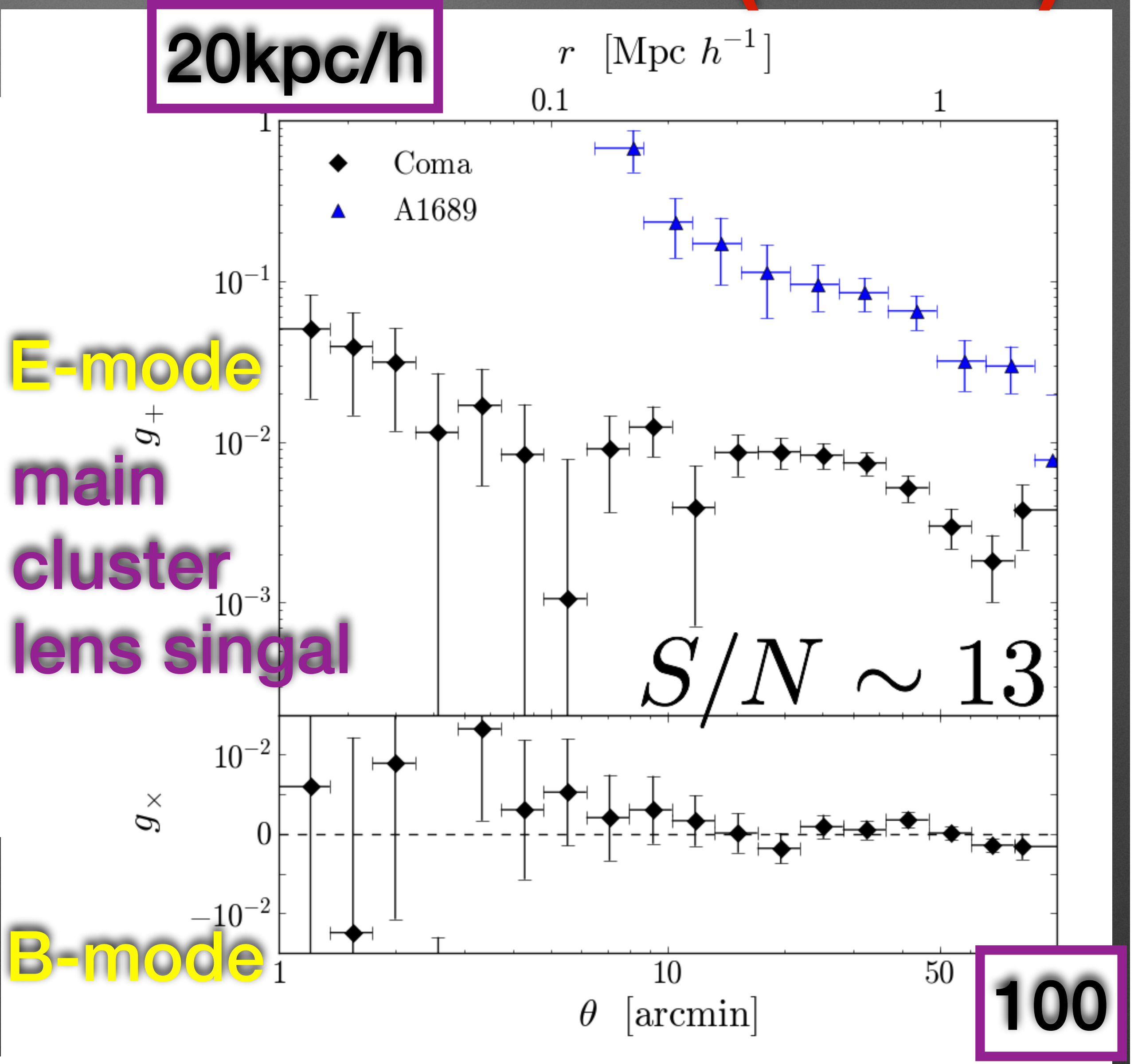
1 arcmin ~ 20 kpc/h

Subhalo Survey for Coma cluster (z~0.02)

Okabe+arXiv:1304.2399



4 sqdeg / 18 pointings

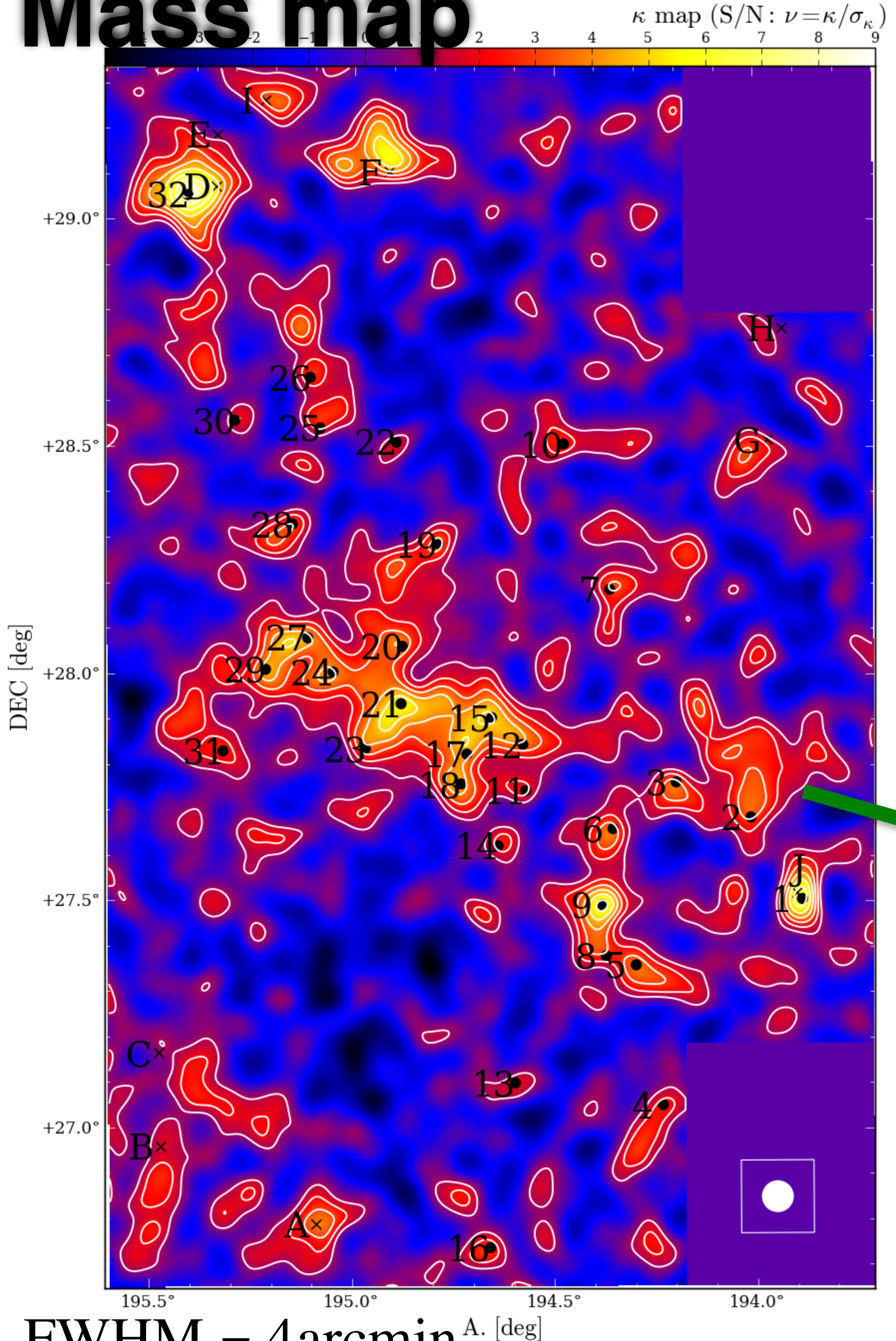


$N_{\rm bkg} \approx 6\times10^5$ (20 - 60 times higher than those at z ~ 0.2)

(e.g. stacked lensing of 50 clusters $N_{\rm bkg} \approx 2\times10^5$)

$n_{\rm bkg} \approx 40$ [arcmin^{-2}](2 - 8 times higher)

Mass map



FWHM = 4arcmin

Properties

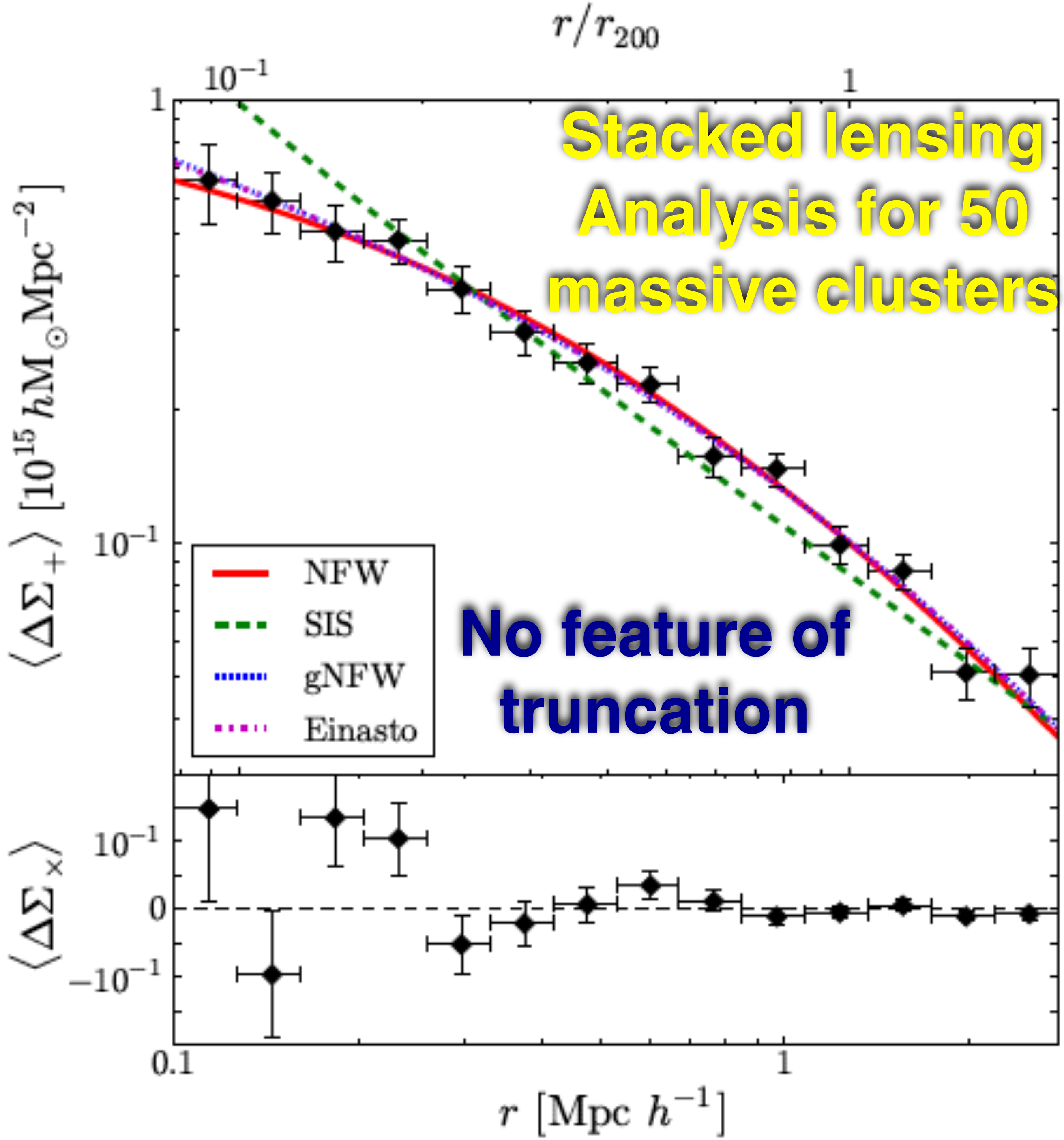
1. Subhalos are anisotropically distributed.
2. Associated with well-known optical groups
3. Elongation of mass distribution is parallel to well-known LSS direction

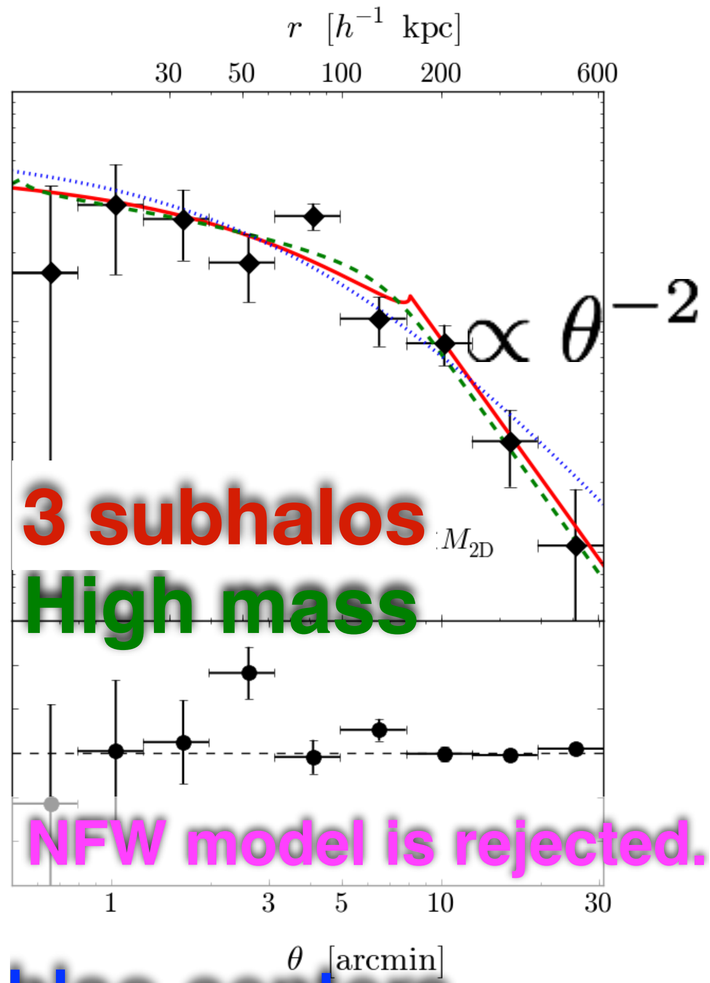
LSS direction

Integer number :
32 cluster subhalos

Alphabet :
10 Known backgrounds

Stacked Lensing Analysis :



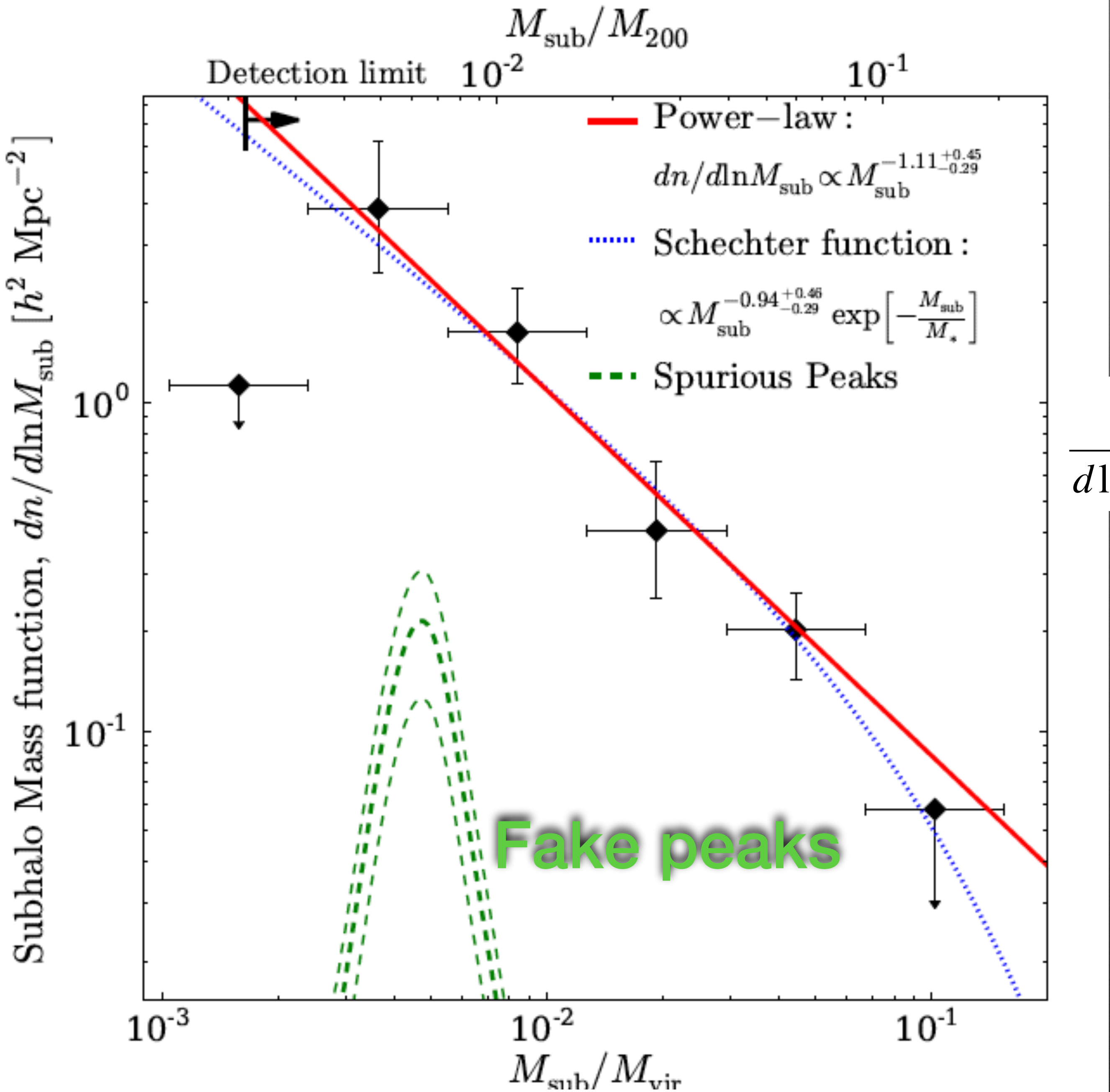


hlao centers

eature.

$$\rho_{\mathrm{TNFW}} = \begin{cases} \rho_{\mathrm{NFW}} \ (r < r_t) \\ 0 \ (r > r_t) \end{cases}$$

Subhalo mass function



$$\frac{dN}{d\ln M_{sub}} \propto \left(\frac{M_{sub}}{M_{vir}}\right)^{-1.11^{+0.45}_{-0.29}}$$

$$\frac{dN}{d\ln M_{sub}} \propto \left(\frac{M_{sub}}{M_{vir}}\right)^{-0.94^{+0.46}_{-0.29}} \mathrm{Exp}\left[-\frac{M_{sub}}{M_*}\right]$$

Consistent with CDM predictions : slope ~0.9-1

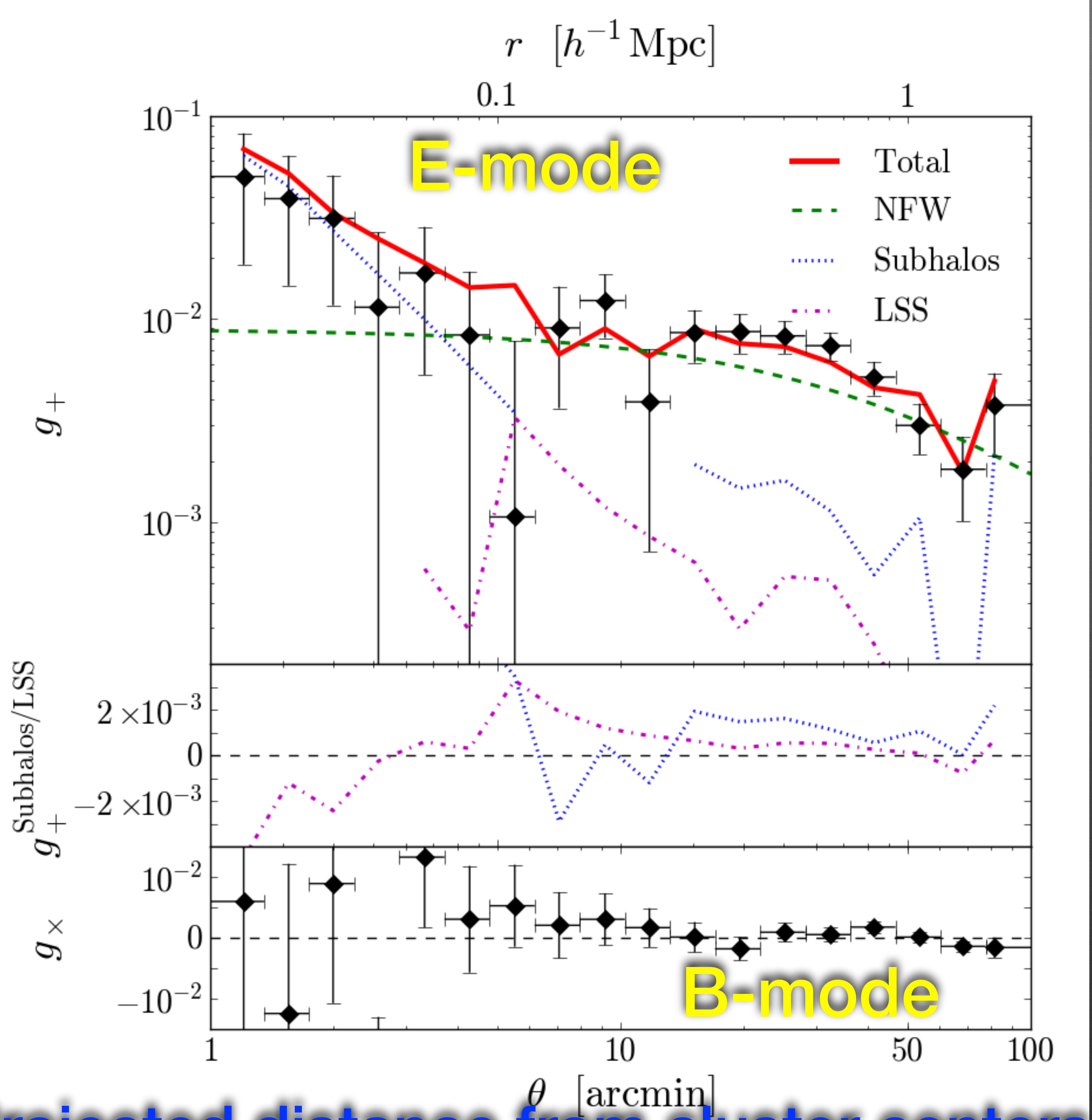
Two orders of magnitude in mass

Lens Signal of the Main Cluster

Total : $S/N \sim 13.3$

Subhalos : $S/N \sim 4.4$

LSS : $S/N \sim 1.3$



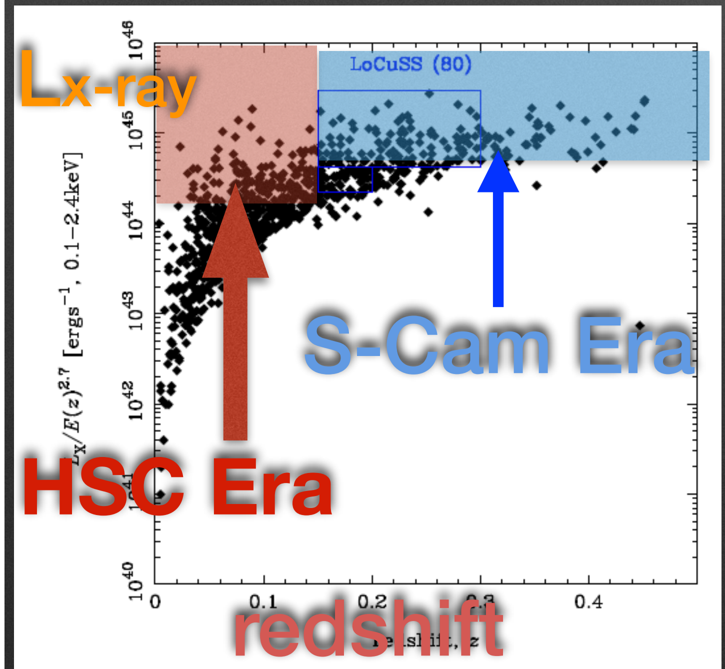
Projected distance from cluster centers.

Observed tangential profile is well-described by three mass components of smoothed component (NFW), subhalo lensing, and LSS lensing model.

Summary

1. Precise mass measurement for the volume-limited sample of 50 clusters at z~0.2 shows that NFW model is preferable for cluster mass distribution, and a correlation between the halo concentration and mass is in a good agreement with CDM prediction.

2. WL analysis of the very nearby, Coma, cluster (z~0.02), enables us to resolve less massive subhalos and directly measure these masses.



1)Truncated NFW model is preferable to subhalo mass models.

2)Slope of subhalo mass function is consistent with CDM prediction.

3) Opens up a frontier of cluster WL analysis (very nearby clusters)