GALAXY CLUSTERS

A few hundreds of luminous galaxies

Typical size R~ >1Mpc

Very X-ray luminous Lx=1.0E43-1.0E45 erg/sec

Most massive quasi-virialized systems M=1.0E14-1.0E15 Msun

MULTICOMPONENT SYSTEMS

STUDIED THROUGH MULTIWAVELENGHT APPROACHES

5% galaxies OPTICAL, IR σ_v=500-1300 km/s

80% Dark Matter DM GRAVITATIONAL LENSING

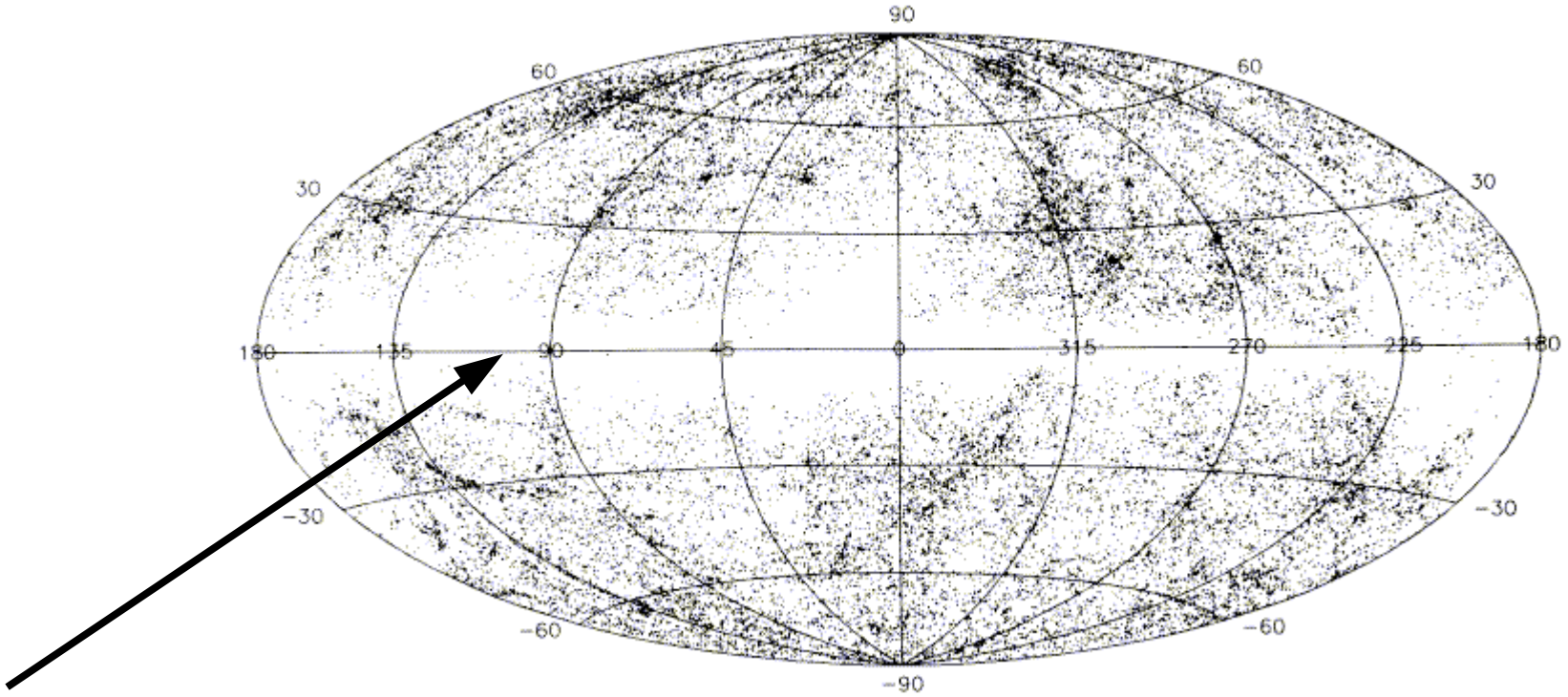
15% hot (Tx=2-10 keV, 1.0E8 K)

low density gas (1.0E-3 atoms/cm^3)

X-RAY emitting through bremsstrahlung mechanism

Cluster distribution in the sky

Abell catalog – Aitoff projection



Zone of avoidance, corresponding to the plane of the disk of our Galaxy

WHY STUDY GALAXY CLUSTERS?

Exceptional visibility at high z
Peaks in the matter distribution
Reliable mass estimates
Typical mix of baryonic and DM

COSMOLOGY

Mass function
M/L ratios
Correlation function

High galaxy density
Sample of galaxies at = distance
Mixing of different galaxy types
Interplay between gas & galaxies

LABORATORIES FOR GALAXIES

Gals formation & evolution
Environmental effects

Collisional+collisionless matter
Cluster mergers as energetic events
Non thermal X-ray components
Magnetic fields

STUDY OF RARE PHENOMENA

NATURE OF DM

Mass-to-Light Ratio of Clusters

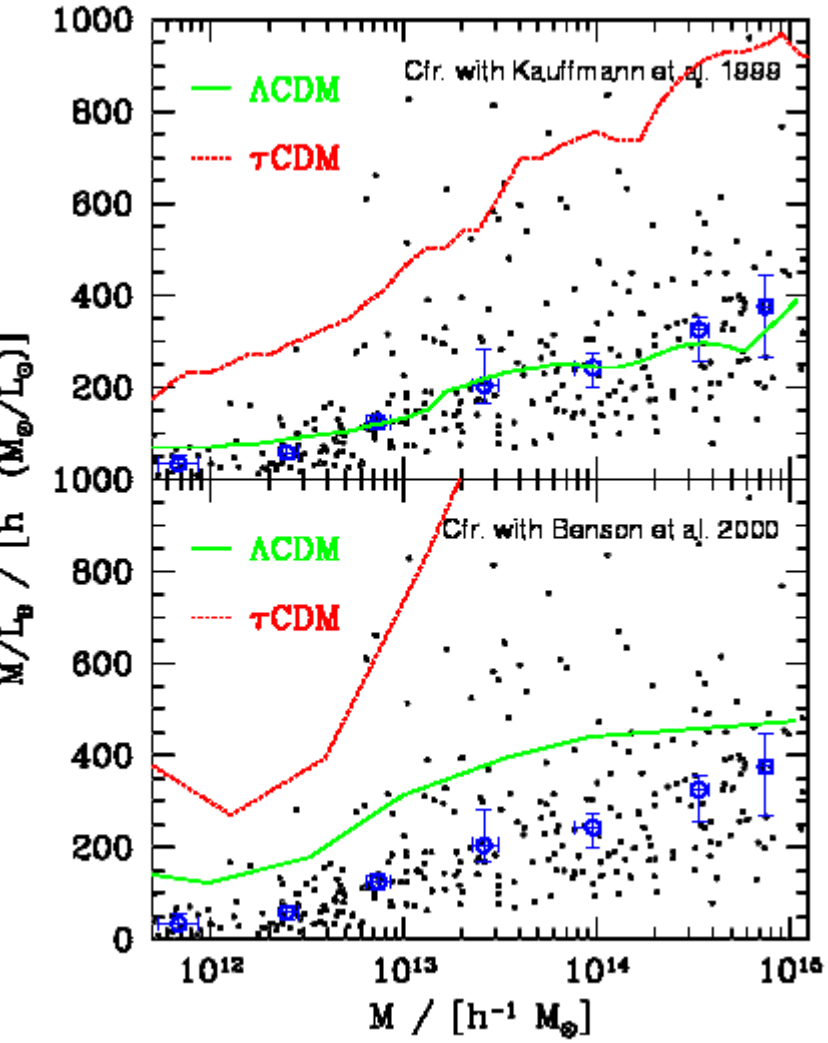
MG et al. 2000, ApJ, 530, 62

MG et al. 2002, ApJ,569,720

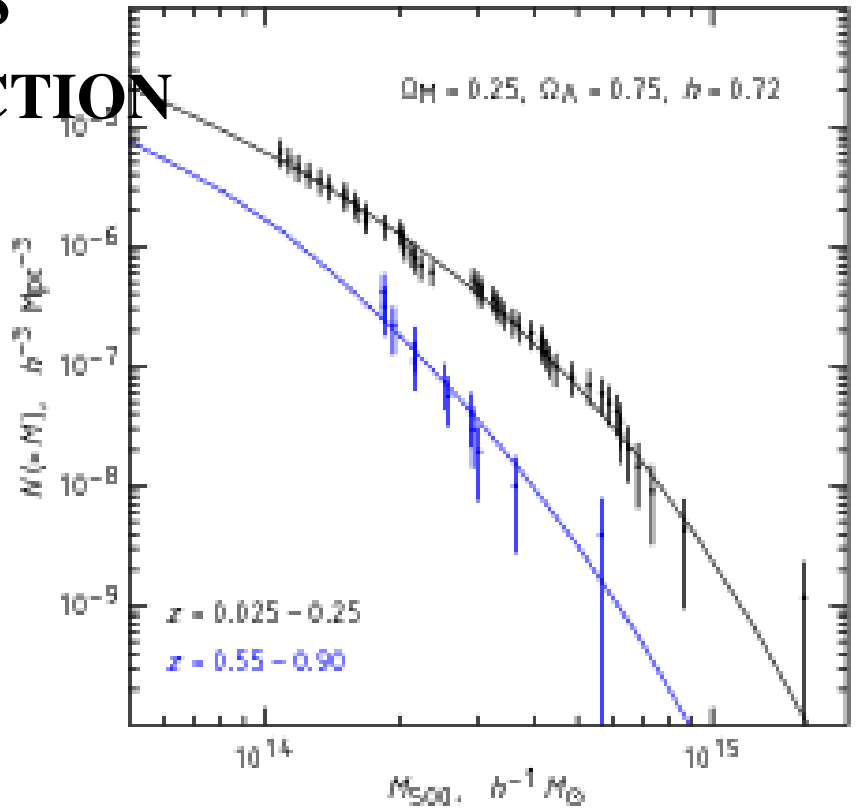
$M/L_{Bj} \sim 250\ h\ (M/L)_{\odot}$

Mass increases faster than luminosity:

$M \propto L_{Bj}^{1.2\text{-}1.3}$



MASS FUNCTION



Giodini+14 Space Sci.Rev.

Main information:

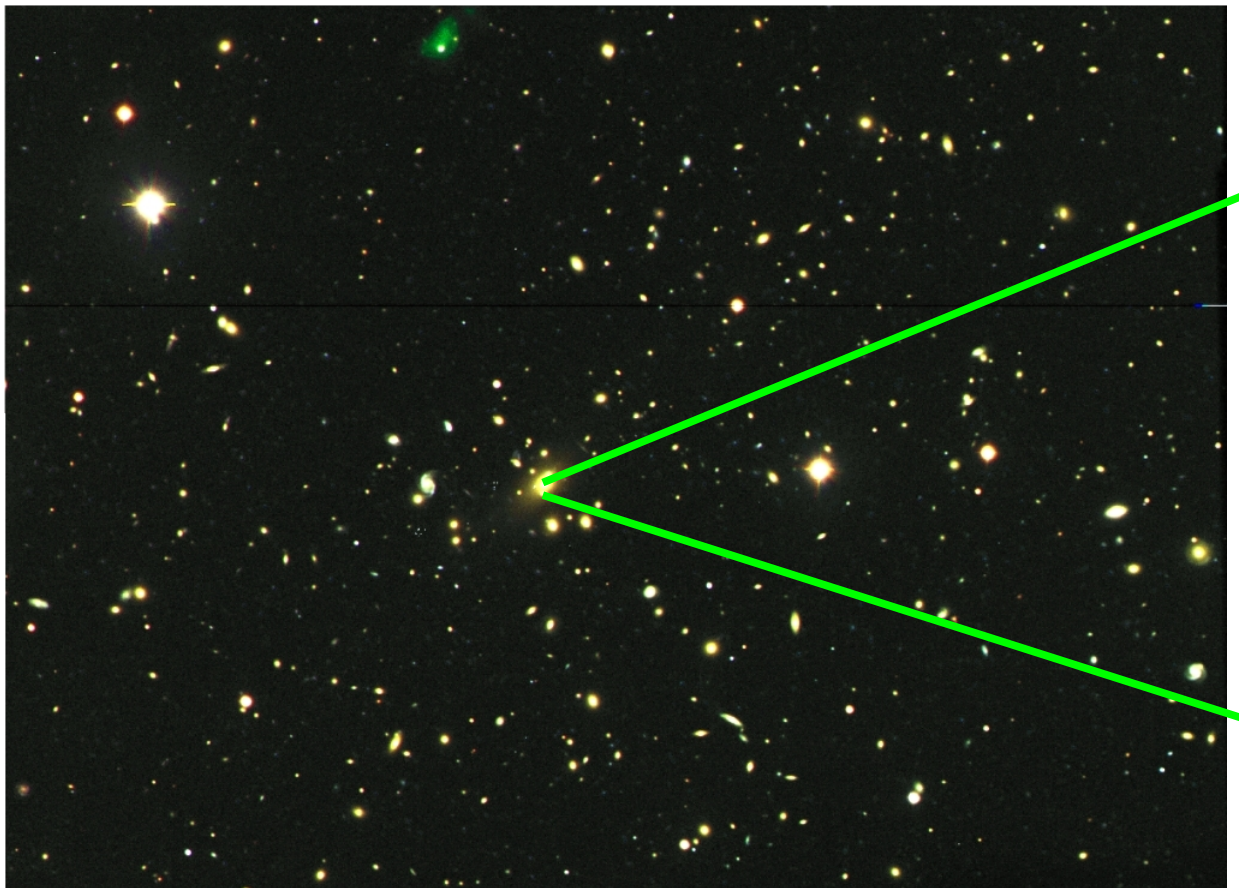
galaxy positions and line -of-sight velocities v=cz

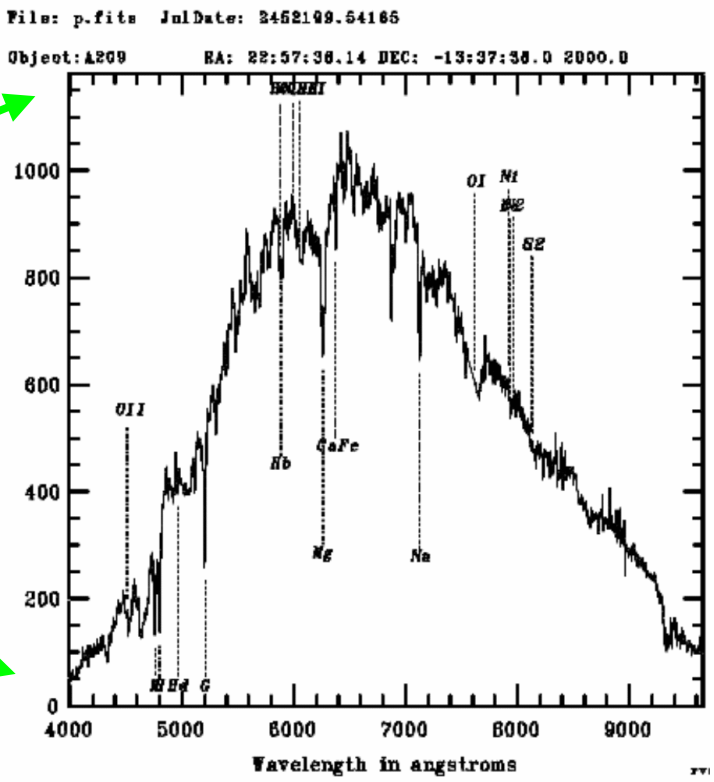
+color, morphology, spectral type

Redshift z: the Doppler shift for objects receding from the Earth. Because of the expansion of the Universe, objects with high redshift are far away.

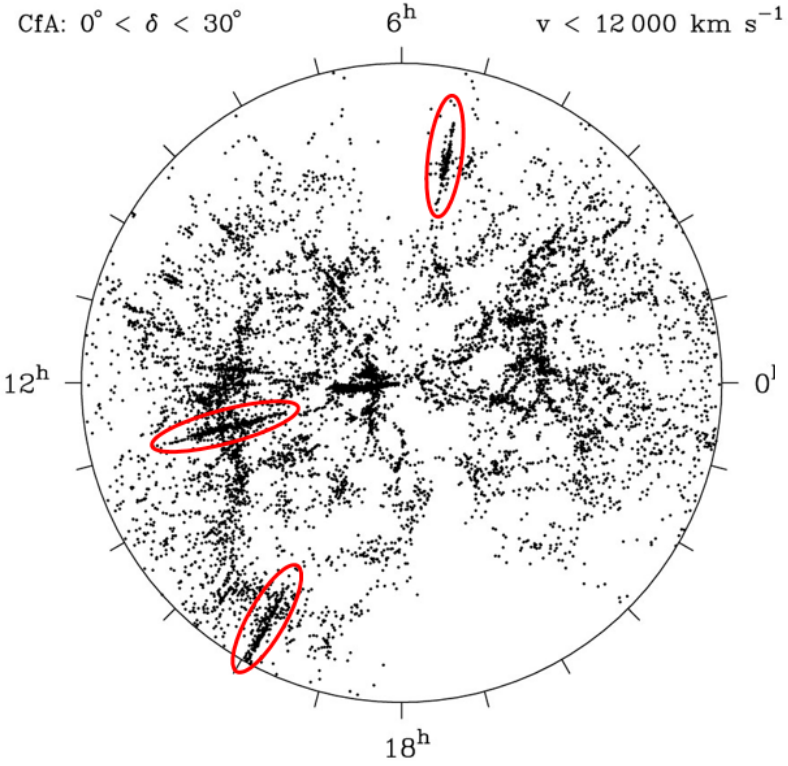
$1+z = \lambda obs/\lambda em$; <cz> gives distance and individual cz the internal cluster kinematics.

A209 ESO NTT photometry+multi object spectroscopy (Mercurio,MG, et al. 2003)





FINGERS OF GOD



Credit: CfA and
https://i.stack.imgur.com/6Qekg.png

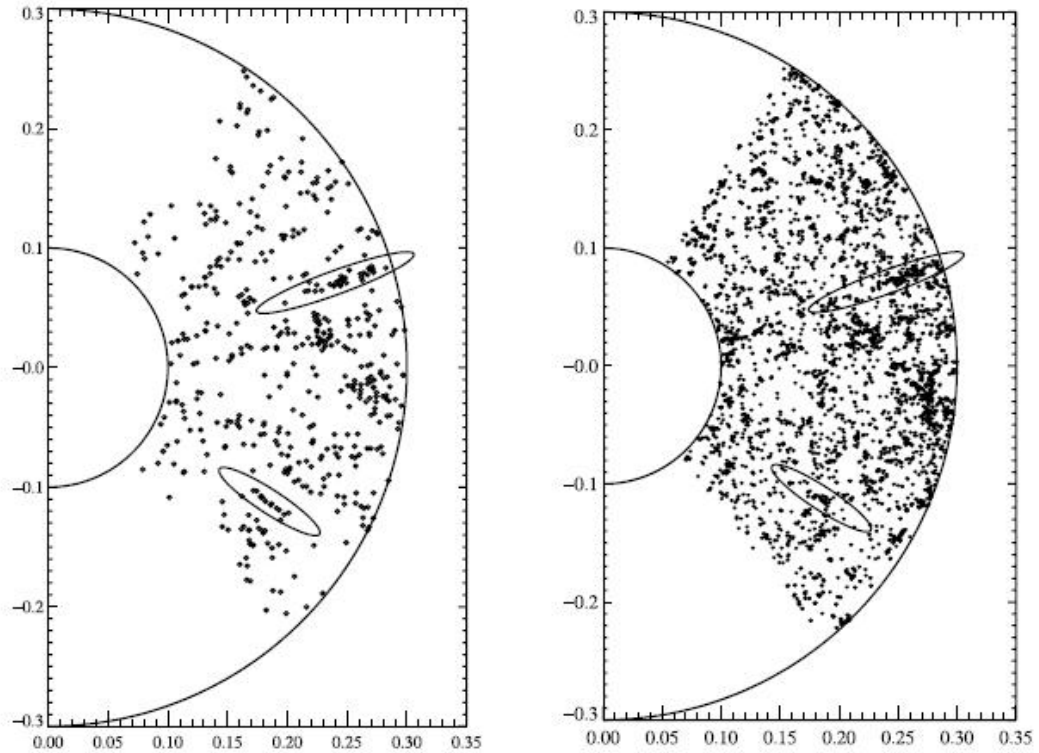
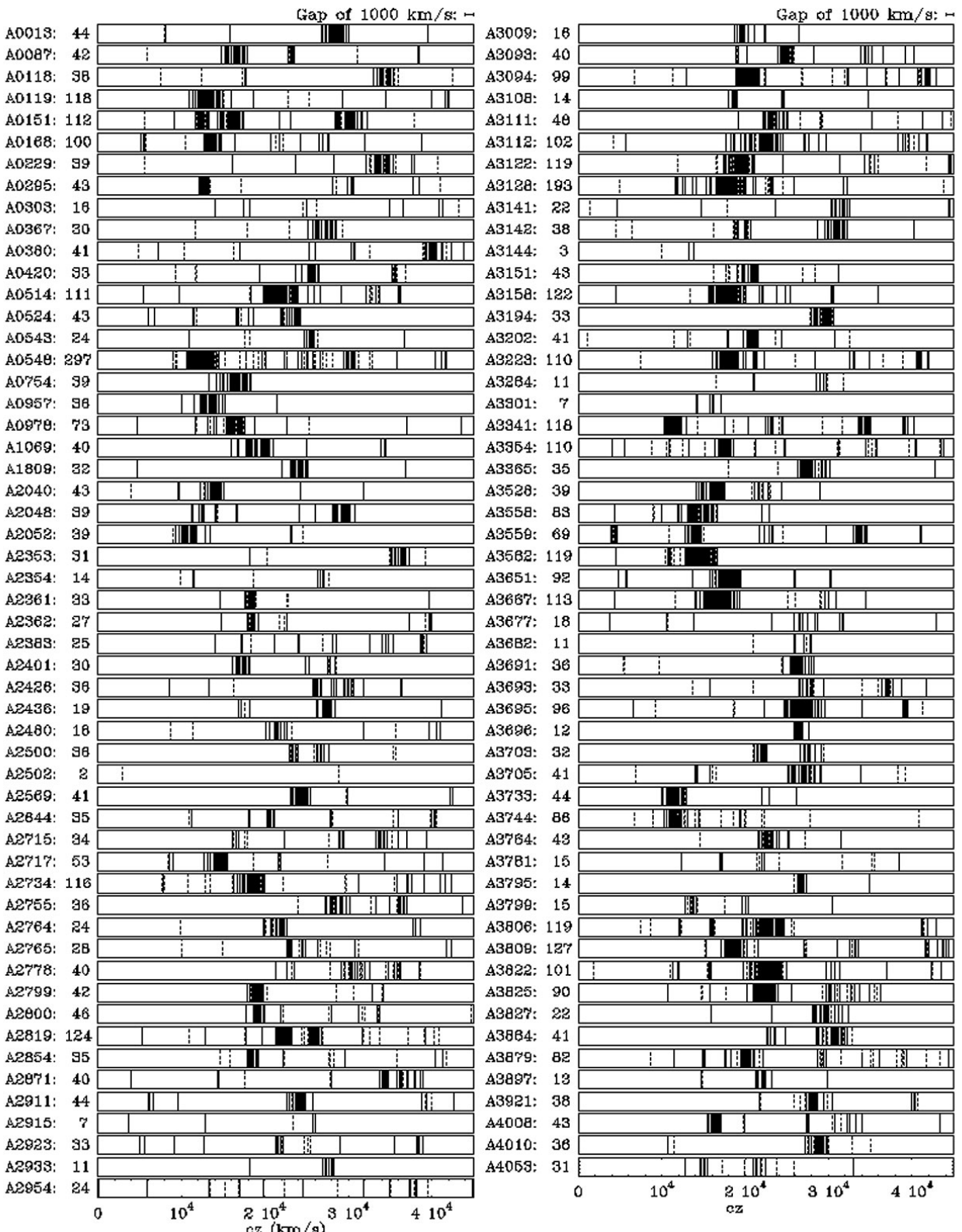


FIG. 5.—SDSS data in the region of the SDSS southern equatorial stripe, with $-1.25° \leq$ decl. $\leq 1.25°$ and with R.A. $< 100°$ or R.A. $> 300°$. The left panel shows the locations in right ascension and photometric redshift of the maxBCG cluster centers. The right panel shows the right ascension and spectroscopic redshift of SDSS luminous red galaxies (LRGs). This slice contains 492 clusters, about 3.5% of the total catalog. Circles drawn at $z = 0.1$ and 0.3 show the boundaries of the maxBCG catalog redshift range. The approximately volume-limited nature of the cluster catalog is apparent. There are several features that look like "fingers of God." These are partly generated by the ± 0.01 uncertainties in the photometric redshifts. Their appearance is exaggerated when they enhance real features in the galaxy distribution, as in the two examples outlined by the ellipses added to both panels.

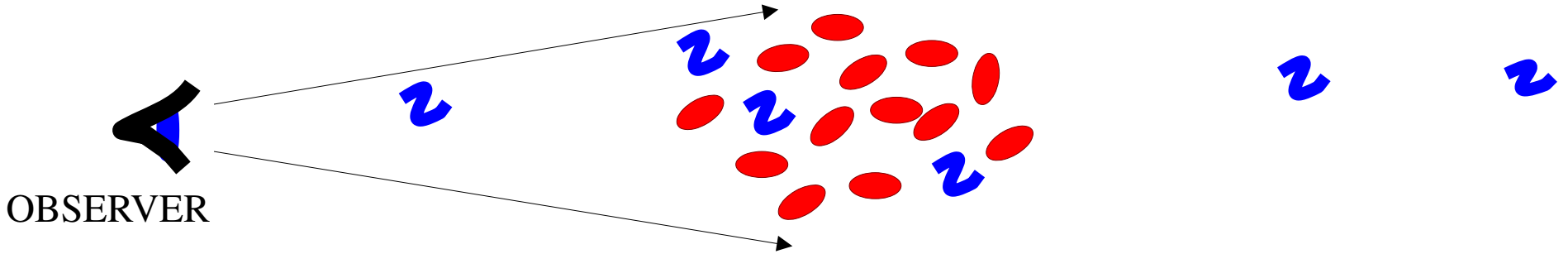
Credit: MaxBCG Catalog
Koester et al. 2007,
The Astrophysical Journal, 660, 239

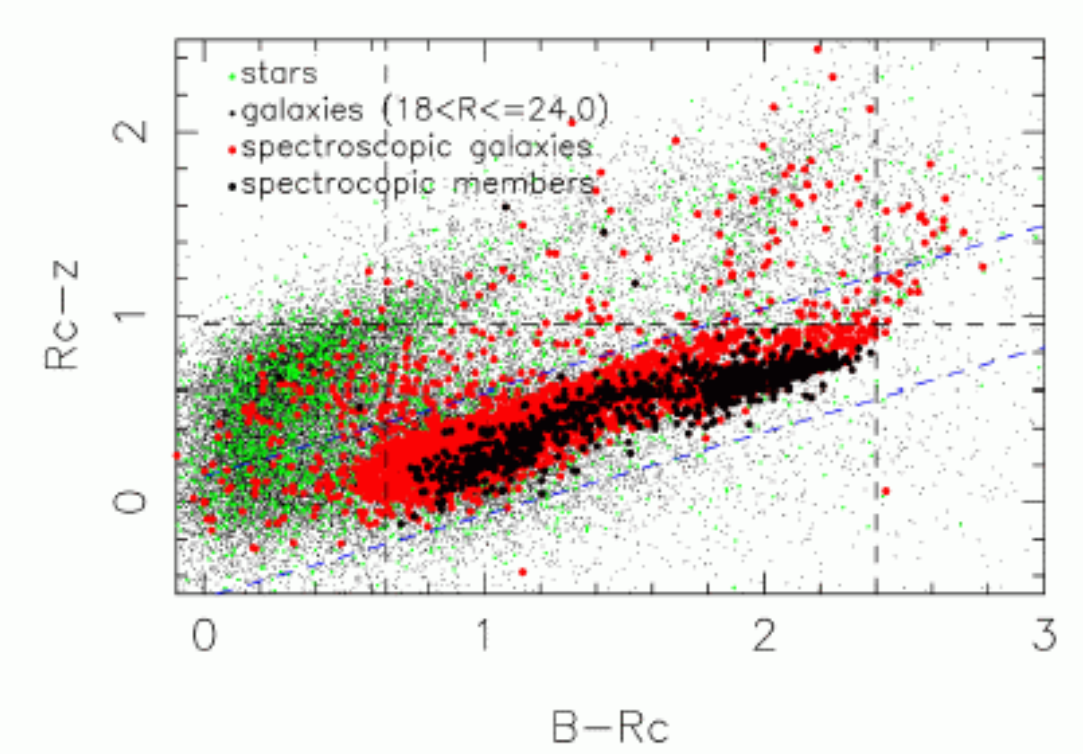
ENACS
CLUSTERS
Redshifts
Per cluster

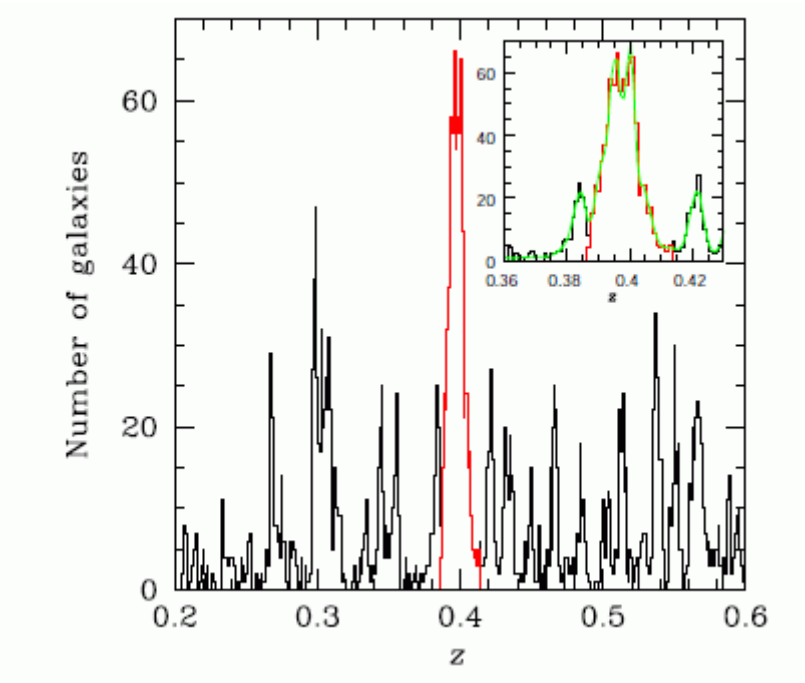
Credit:ESO



Selection of Cluster Members







Data from **CLASH-VLT** (PI P.Rosati) for MACSJ0416

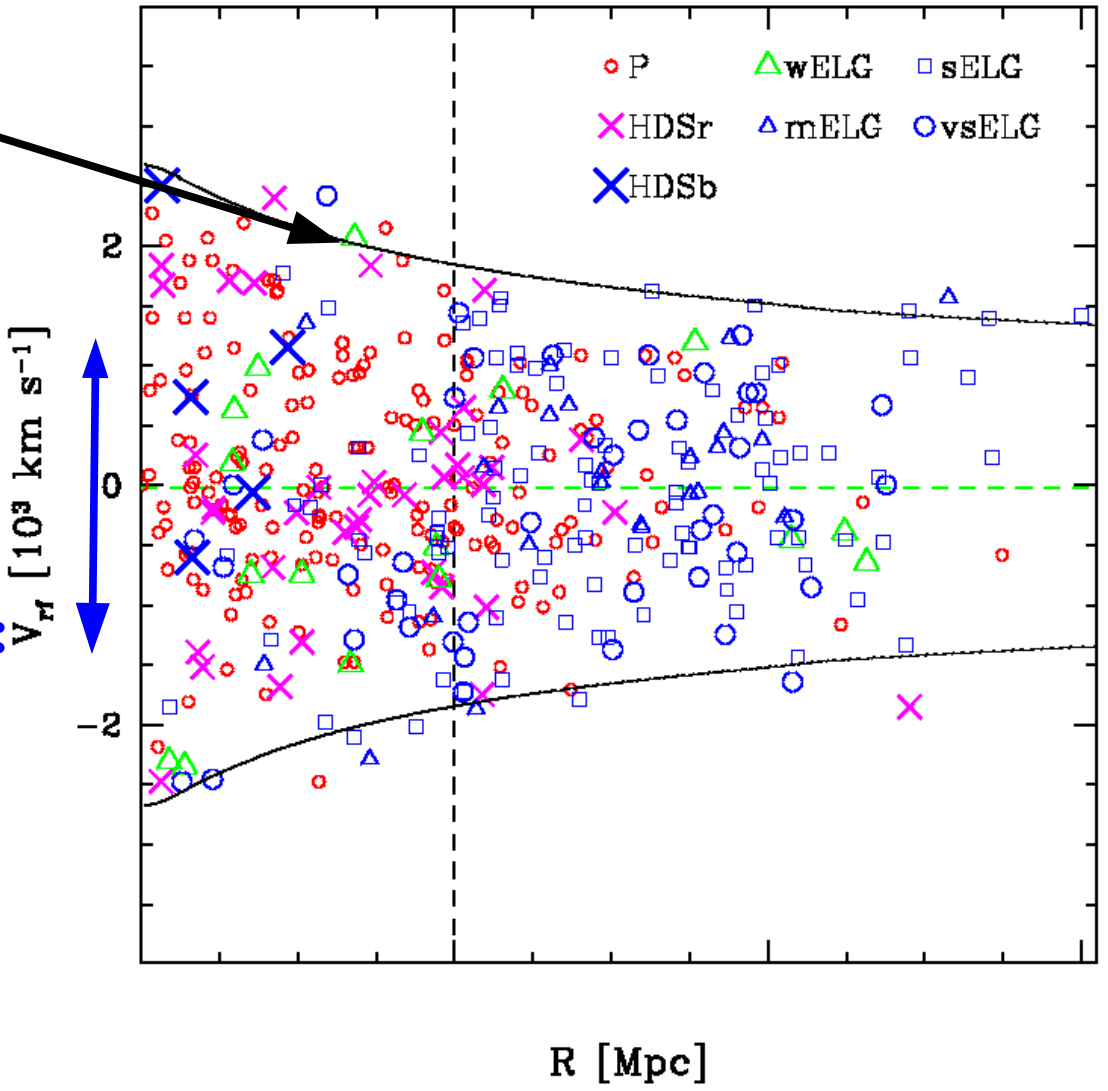
Spectra from VIMOS VLT@ESO, imaging from Suprime Cam @Subaru + HST

Balestra, Mercurio, Sartoris, Girardi,..Nonino...Biviano

Projected phase space of galaxies of MACS1206 at z=0.4 (CLASH-VLT)

Escape velocity - lines.

Velocity dispersion
of galaxy population
is a good proxy
of cluster mass.
For a physical radius in Mpc:
$M \propto \sigma_v^2$
(virial theorem)
For the R200 radius
$R_{200} \propto \sigma_v$
$M_{200} \propto \sigma_v^3$



$V_{rest\ frame}=(cz-\langle cz\rangle)/(1+z)$

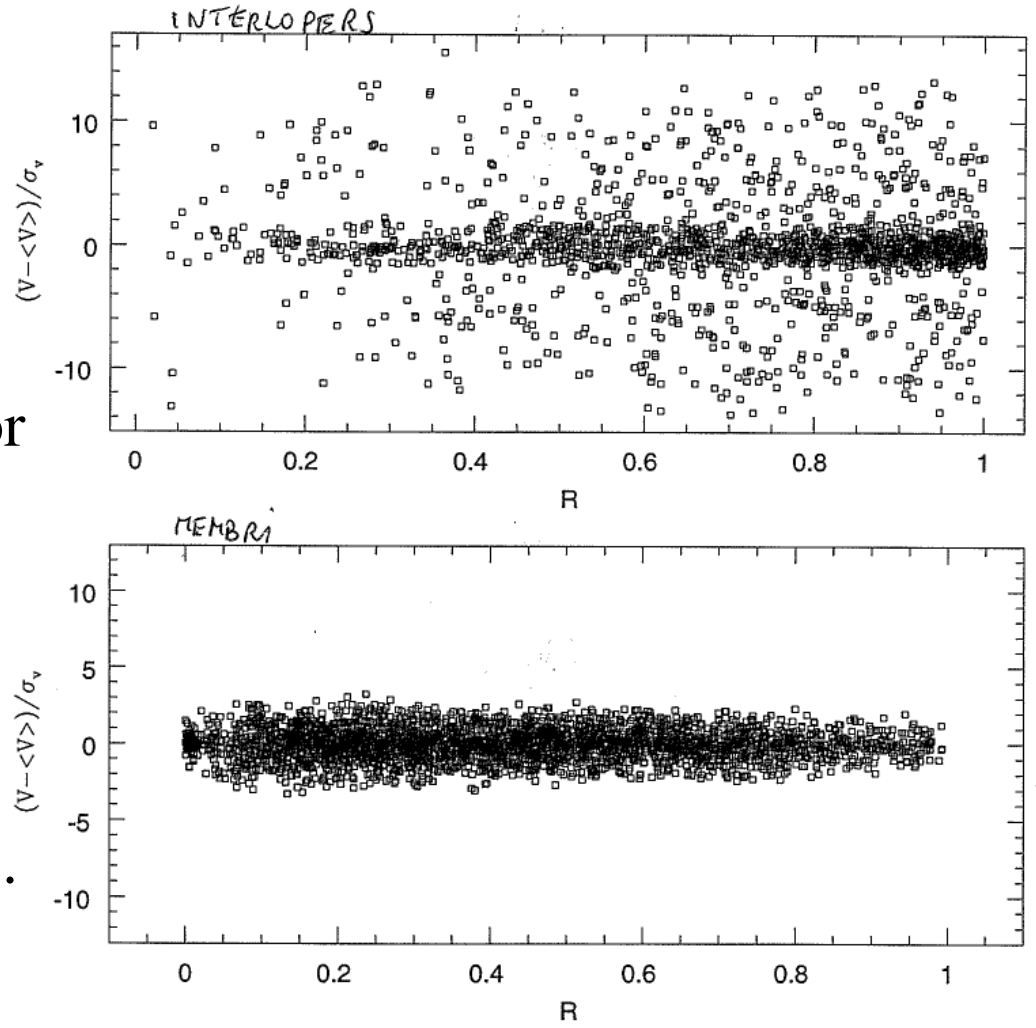
To reject non-member galaxies
= “interlopers”
is not so easy....

Here only DM N-body (2007!)

But observed galxies have color and red galaxies are much more contrasted onto the sky...
Maybe better results when using with **new simulations** where “galaxies” are available..

GIRARDI ET AL. IN PREP. 2007

ANALISI DI SIMULAZIONI N-BODY (BORGANI ET AL.)



Study of distant clusters

at z=0.8,1.2,1.4 (Rosati & co. clusters)

RXJ0152-13; RDCS1252-29;XMM2235

FOGO

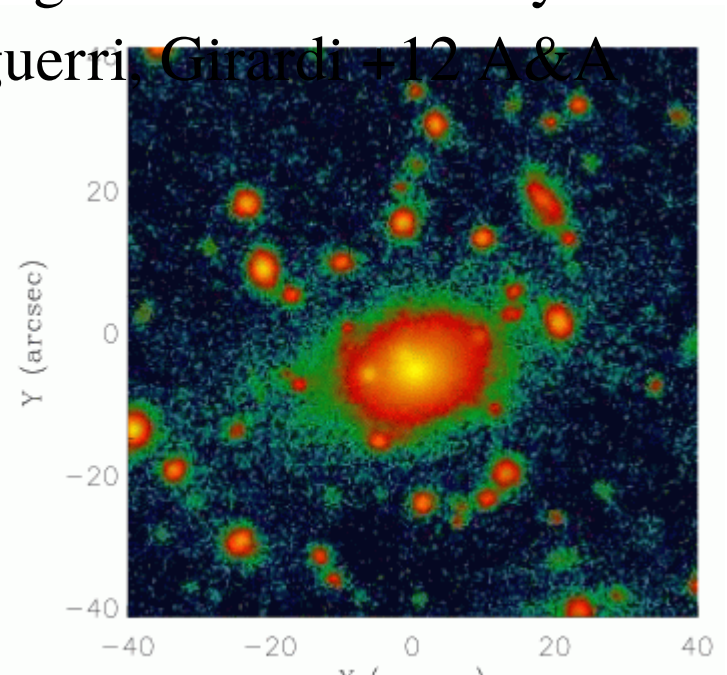
FOssil Groups Origin

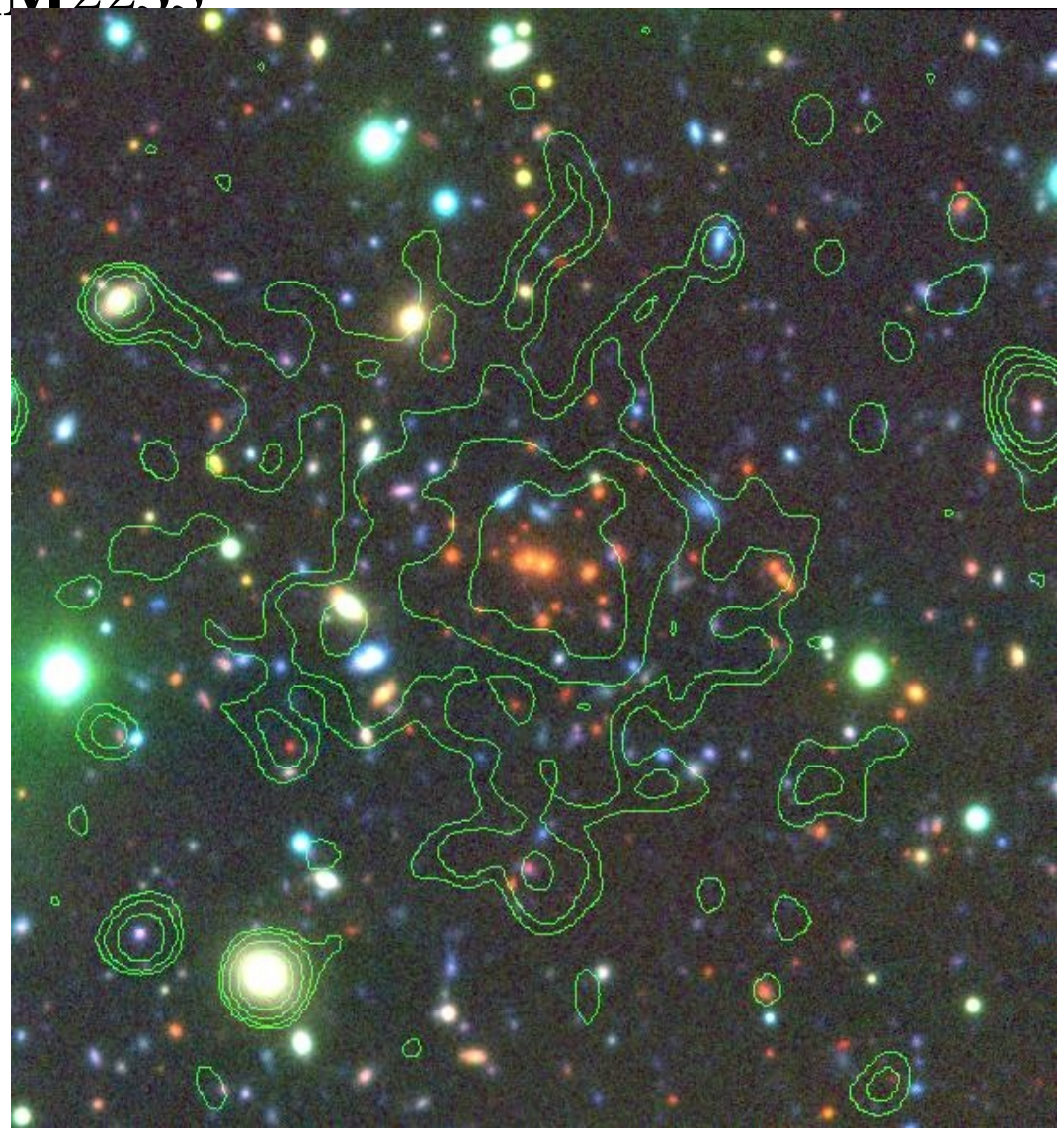
With a very bright central galaxy.

ITP Project with

A.Aguerri – IAC Canary Is.

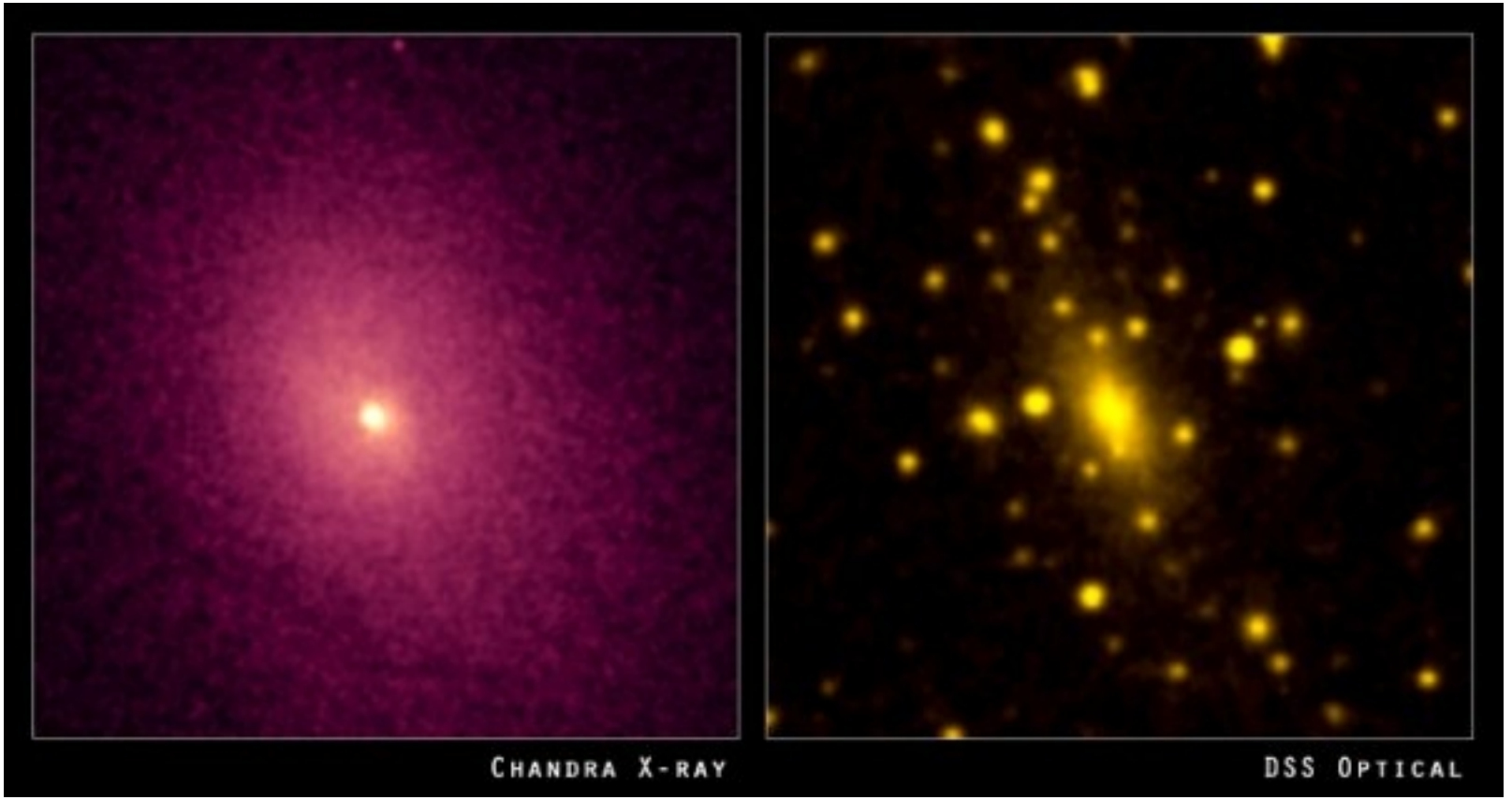
Aguerri, Girardi +12 A&A





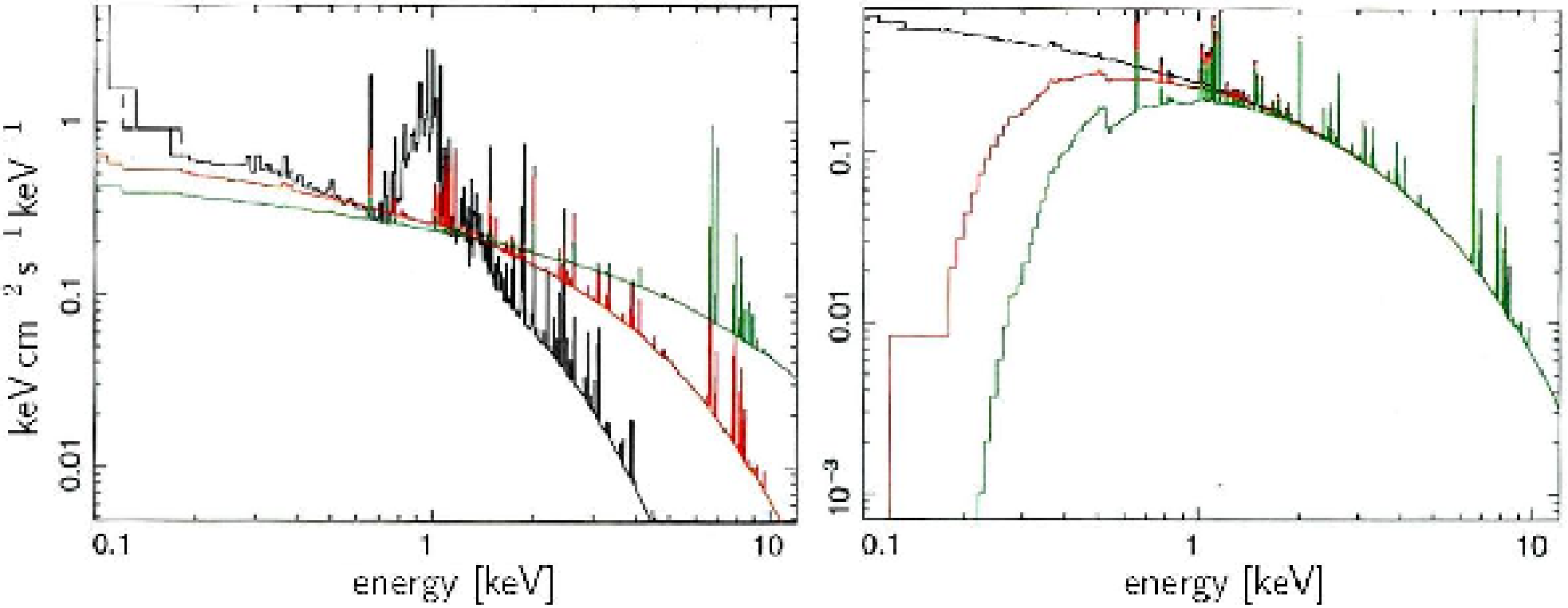
X-ray from hot intracluster medium (ICM)

Abell 2029, X and optical view



Credit: Chandra

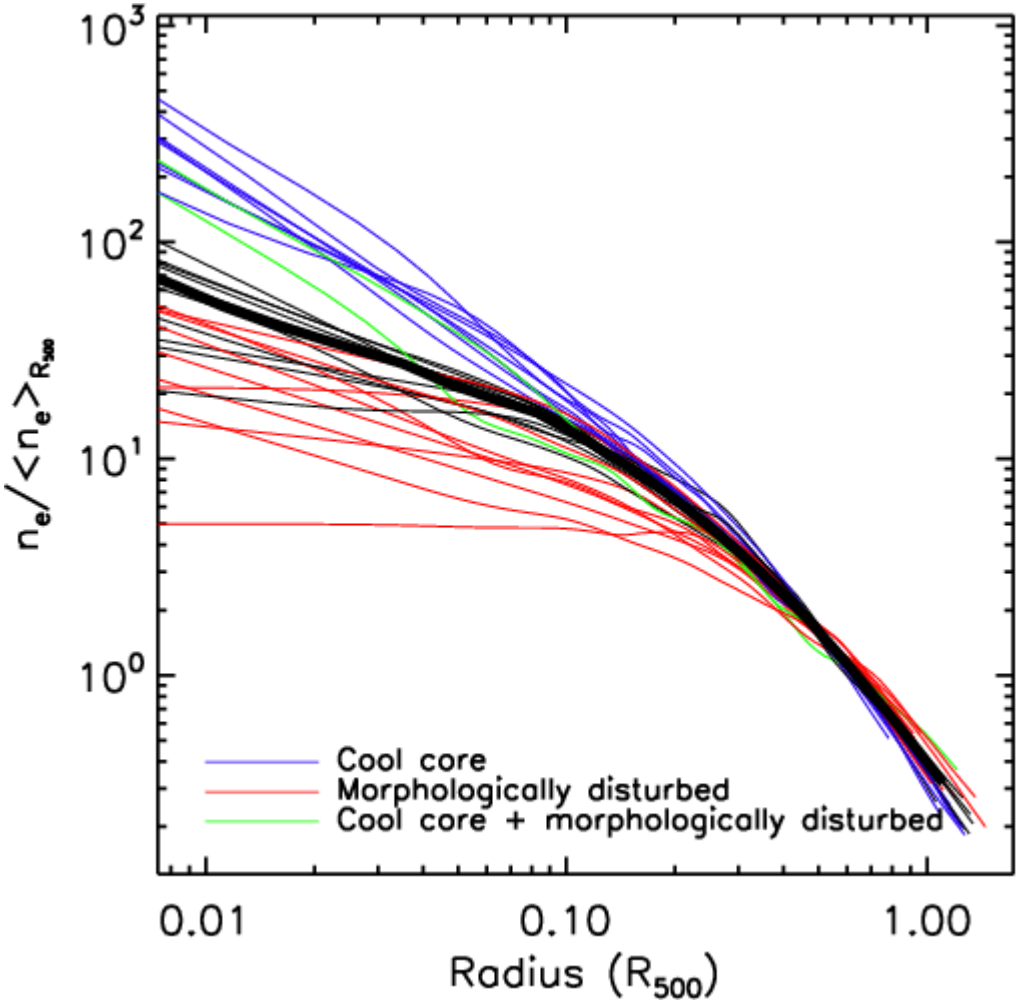
Credit to: http://inspirehep.net/record/787471/plots

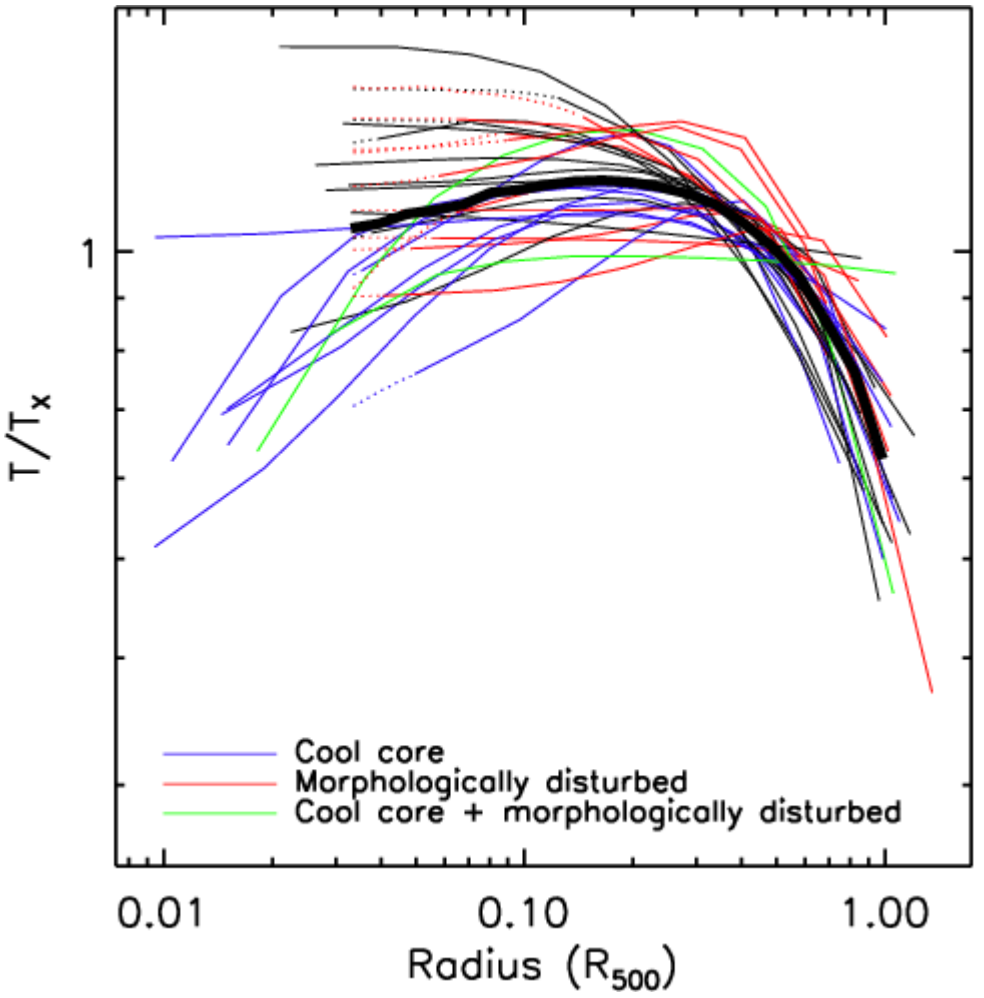


X-ray emission of the ICM. {\em Left:} Unabsorbed ICM model spectra of the bremsstrahlung continuum and line emission for plasmas with 0.4 solar metallicity and temperatures of 1\,keV (black), 3\,keV (red), and 9\,keV (green). {\em Right:} Absorbed model spectra of T=3\,keV observed through galactic hydrogen columns of 1021\,cm−2 (green), 3×1020\,cm−2 (red), and for the unabsorbed case (black).Plots from Schneider \cite*{Schneider2006a}.

Credit: Arnaud et al. REXCESS

Cool core vs non cool core clusters.

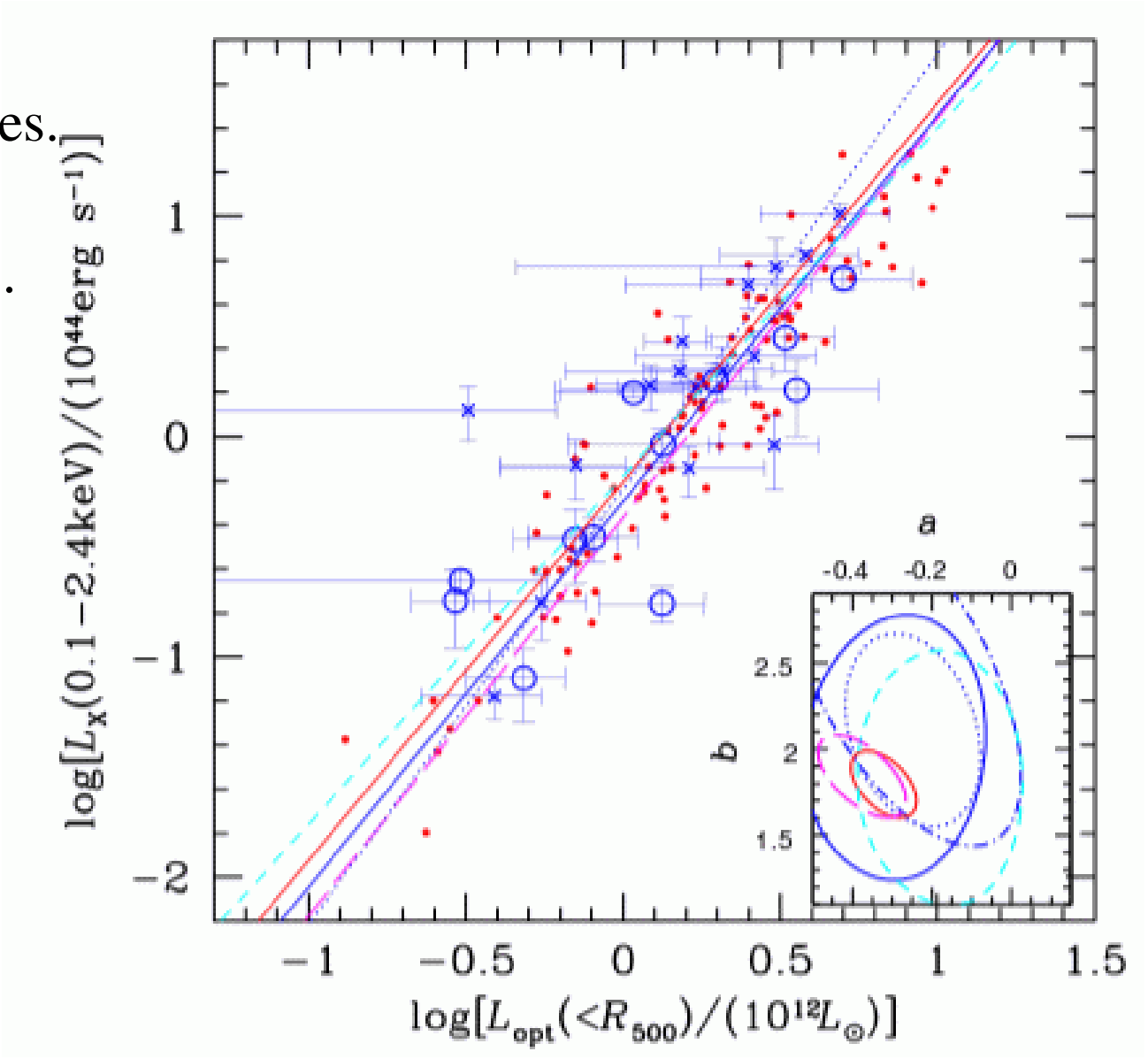




Comparison between Loptical and Lxray.

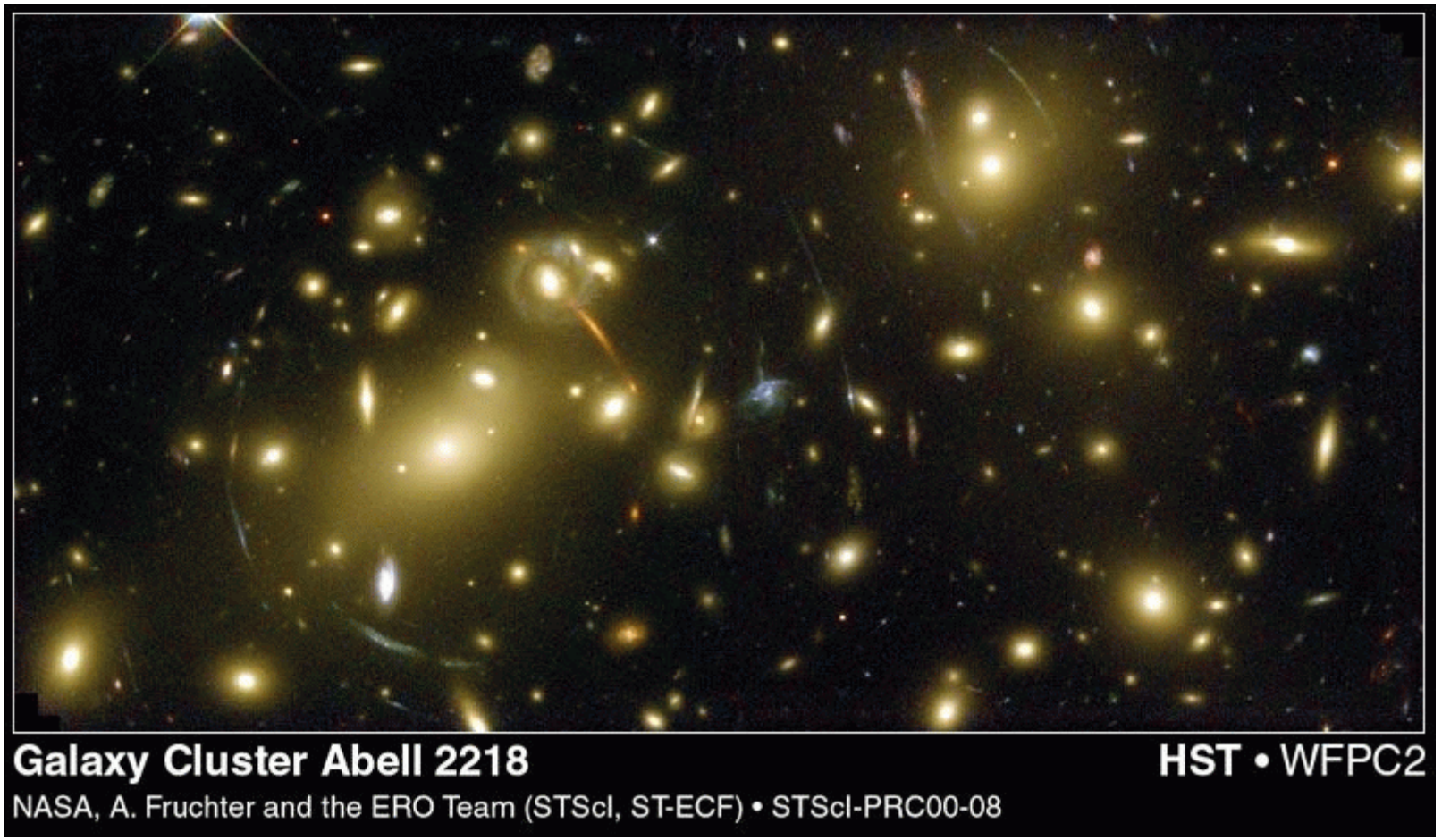
Both are good mass proxies.

Clusters and fossil groups.



Girardi+14 A&A

Gravitational lensing effect.



Credit: NASA HST cluster at z sim 0.2

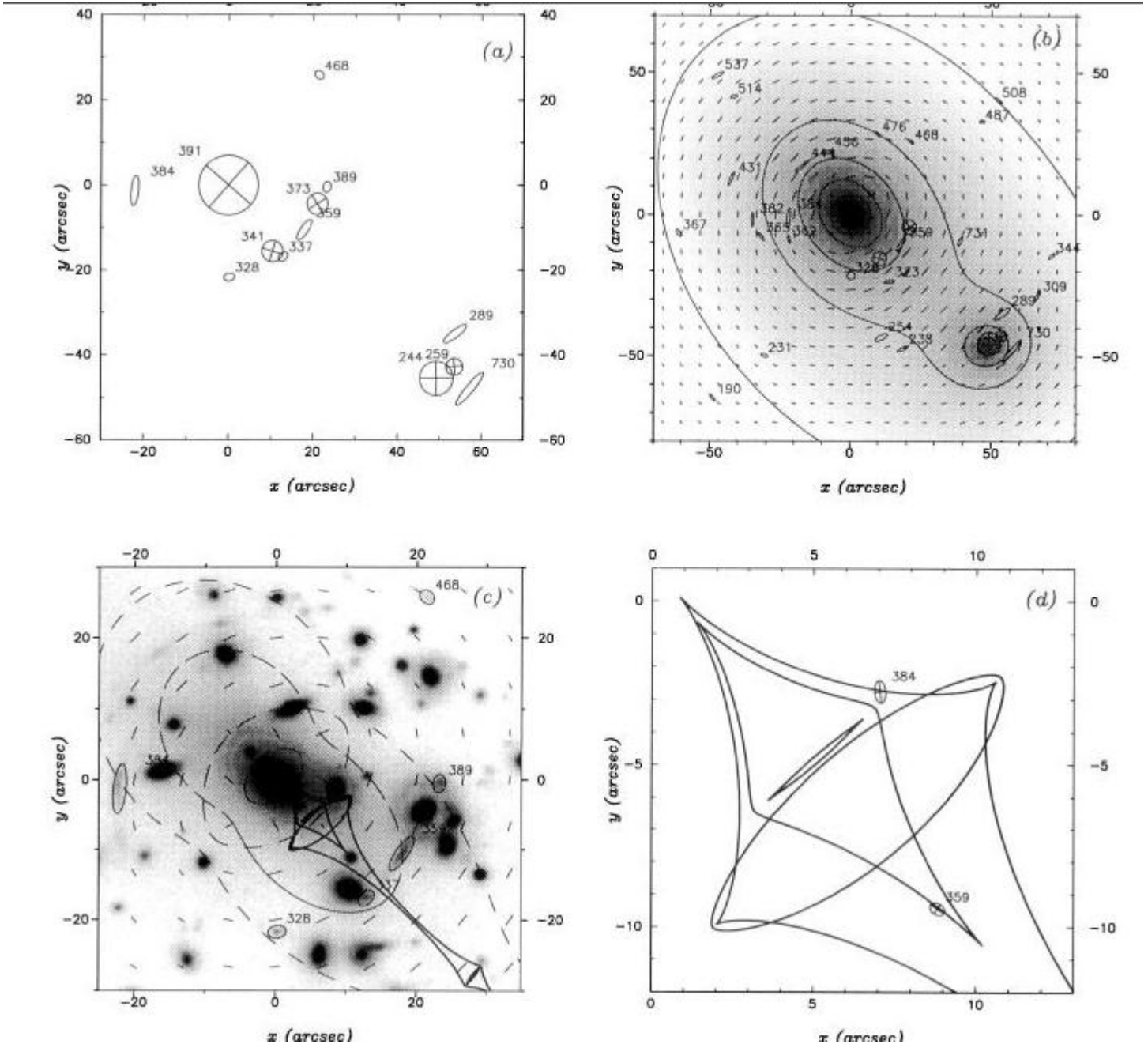
Credit: NASA HST MACSJ1206- CLASH DATA

cluster at z sim 0.4

MASS IS CONNECTED TO GALAXY LIGHT

Credit: Kneib+ 1995 A&A

A2218
Galaxies
vs
mass reconstruction
From
strong gravitational
Lensing (SGL).



Mass follows light hypothesis

….Galaxy light or galaxy number

Profiles of galaxy number, ICM density, DM density.

Gas distribution is less peaked.

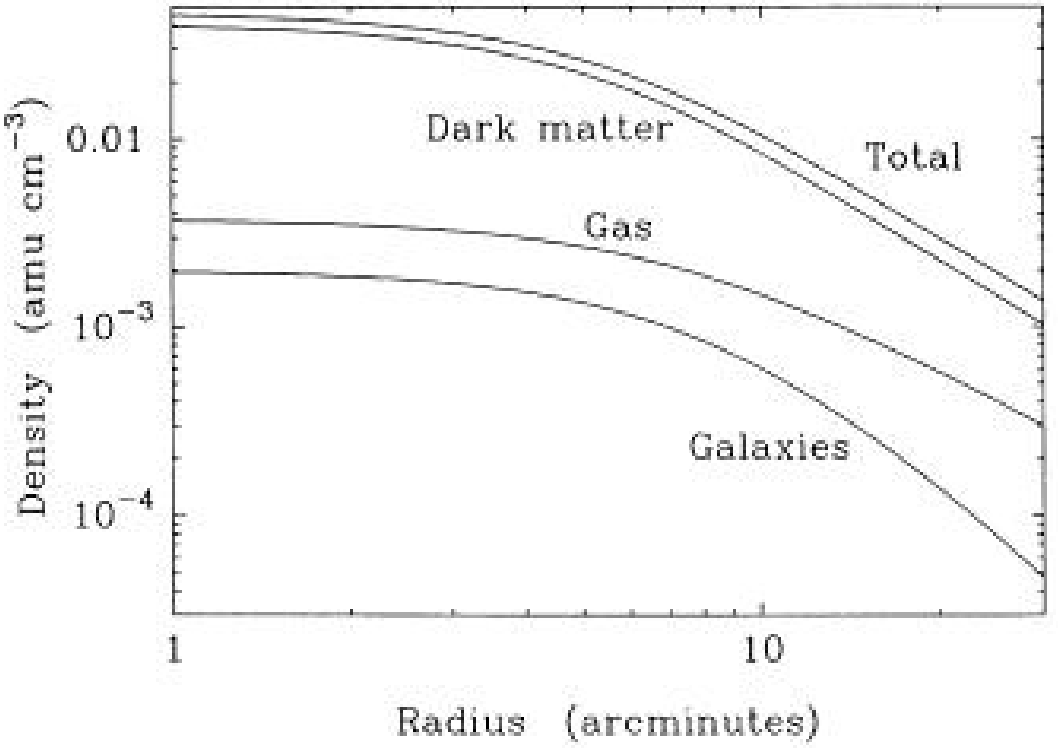
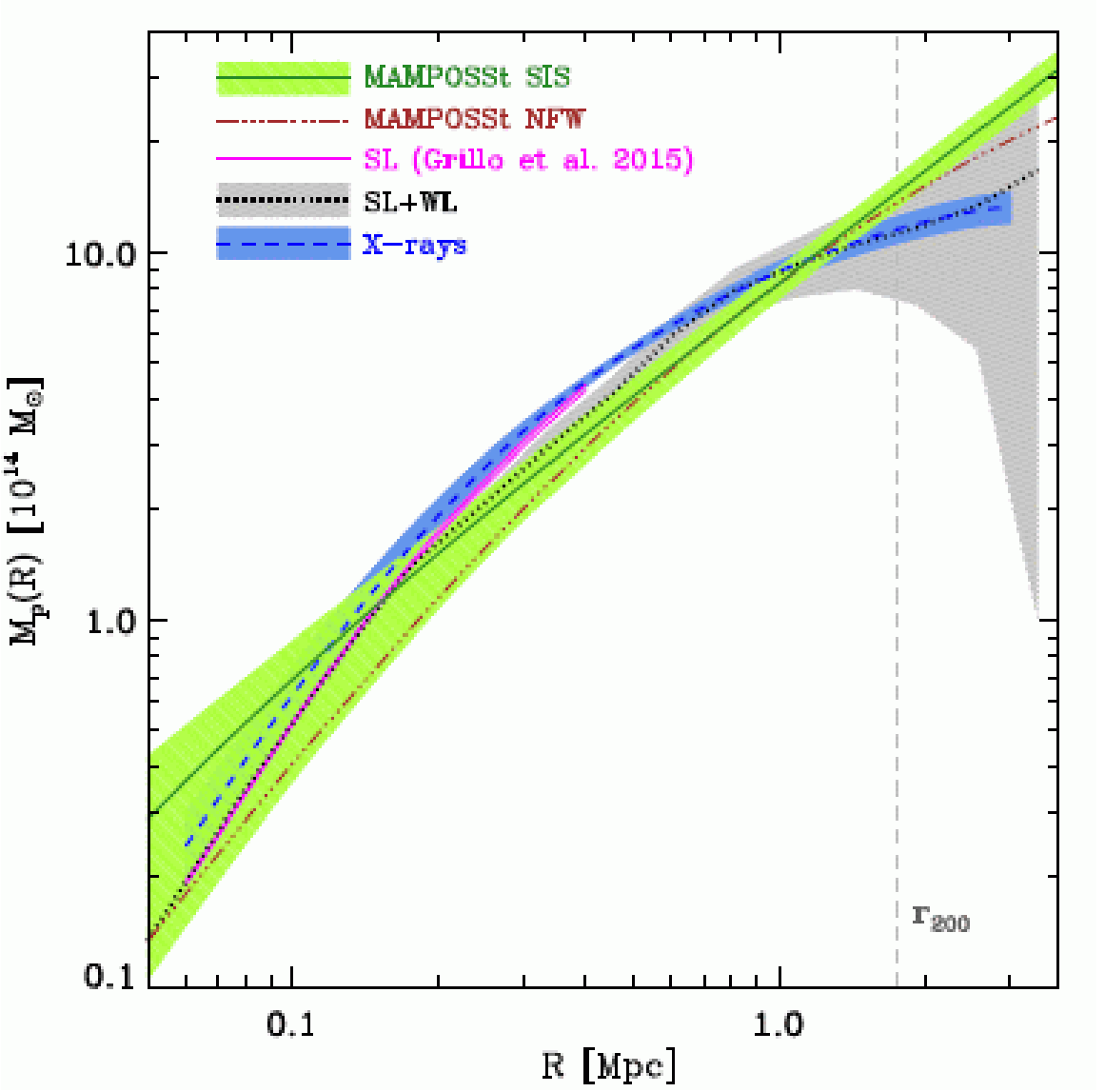


Figure 9. Density profile of the major contributors to the mass of the cluster. The gravitating and gas mass profiles are derived in the present work, and the galaxy mass density is from the data of Kent & Gunn (1982) assuming $M/L_V = 5(M_\odot/L_\odot)$.

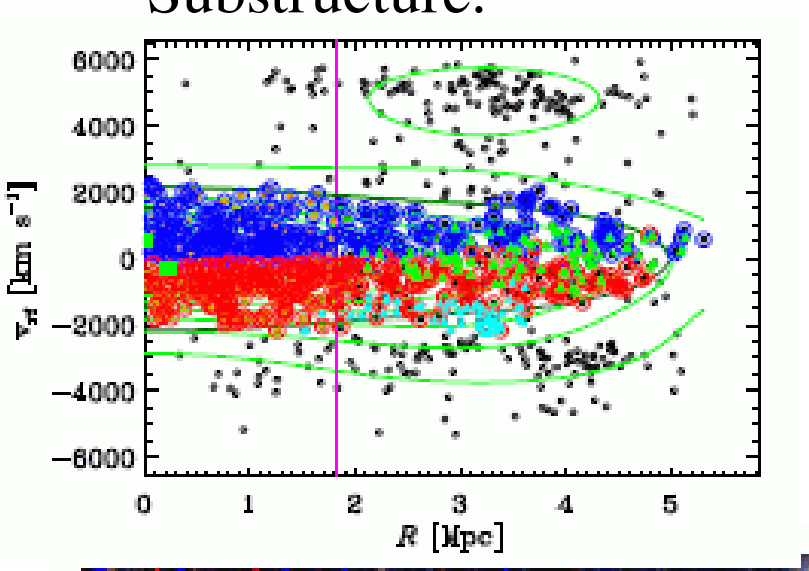
Credit: Watt et al. 1992 MNRAS

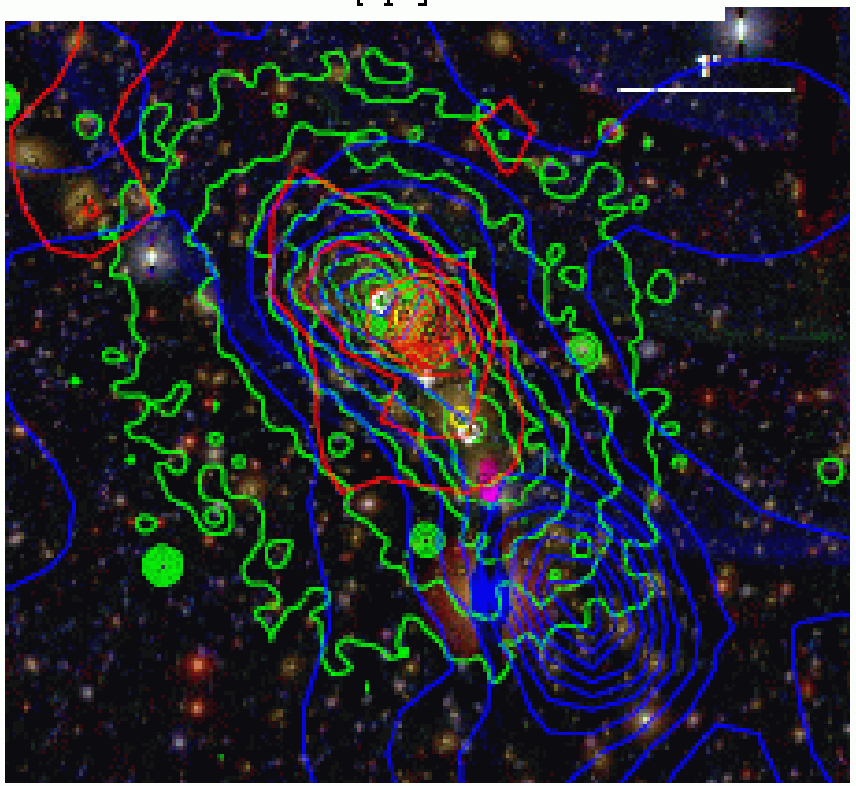
Comparison
between mass estimates
from different bands.
MAMPOSSt by Mamon
And Biviano uses galaxy
Kinematics.
Balestra et al 2015
(one of the
CLASH-VLT clusters)



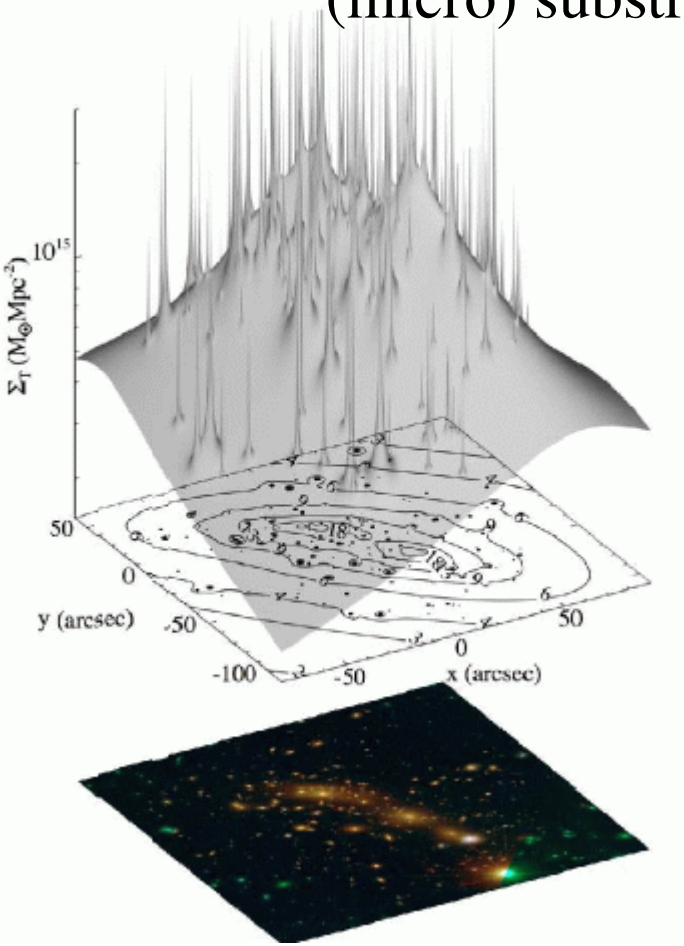
The cluster MACSJ0416 (CLASH HST+VLT data).

Substructure.





Reconstruction of (micro) substructure



Credit to Grillo et al. 2015, ApJ

CLASH-VLT collab.

Balestra, Mercurio, Sartoris, Girardi,...Nonino...2015 subm. ApJS

PECULIAR CASES: CLUSTER MERGERS

Credit: Chandra – Clowe BULLETT CLUSTER →DM PROOF

SHOWING THE DECOUPLING OF COLLISIONAL (ICM) VS NON-COLLISIONAL MATTER (DM and gals)