# 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 IN MULTIWAVELENGHT APPROACHES

5% galaxies OPTICAL, IR $\sigma_v$=500-1300 km/s

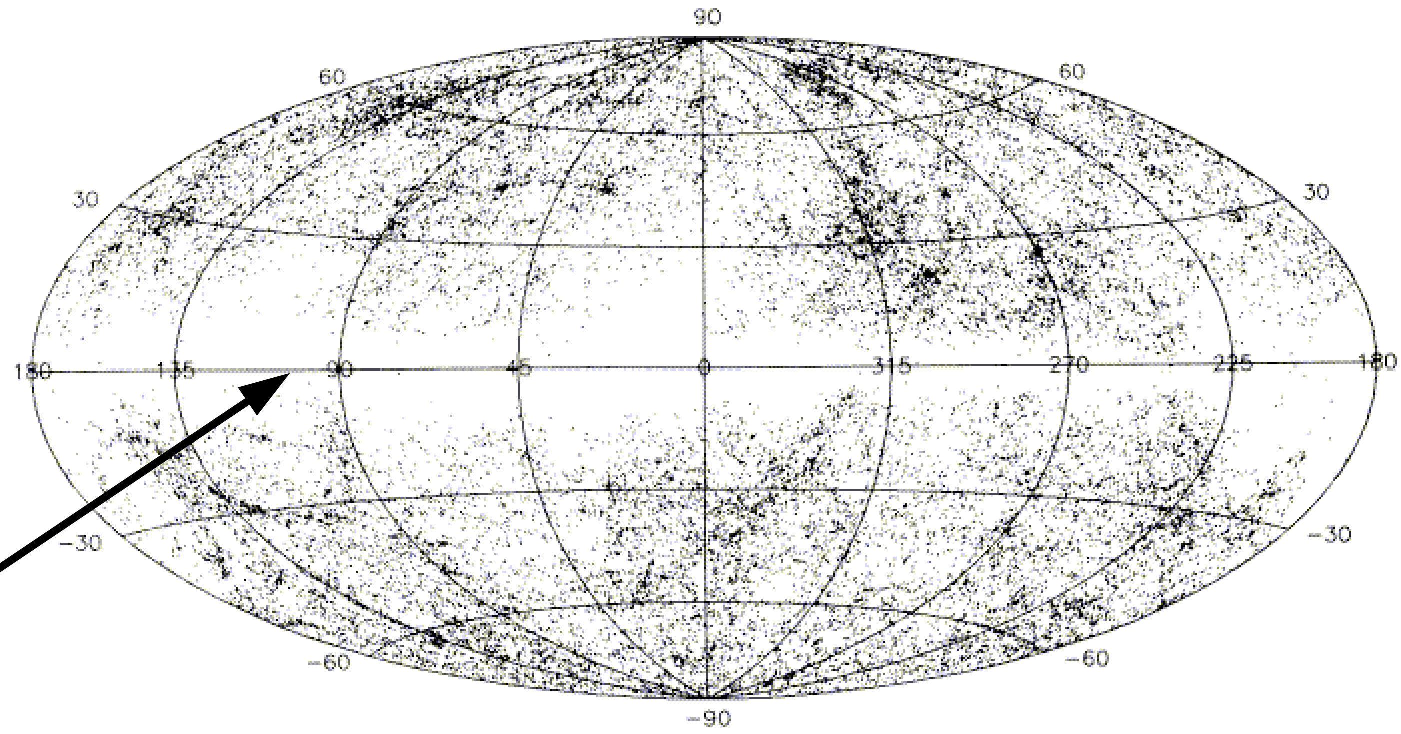
80% Dark Matter DM GRAVITATIONAL LENSING

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, correspondind to the plane of 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

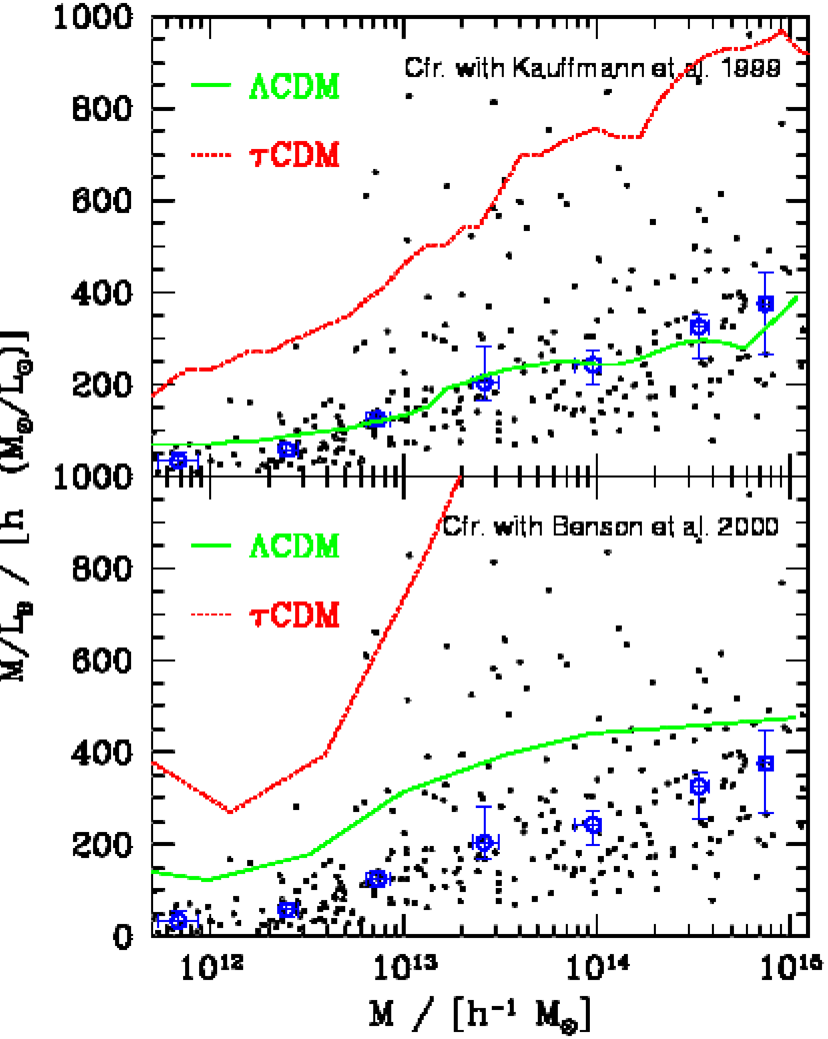
Collisional+collisionless matter
Cluster mergers as energetic events
Non thermal X-ray components
Magnetic fields

**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

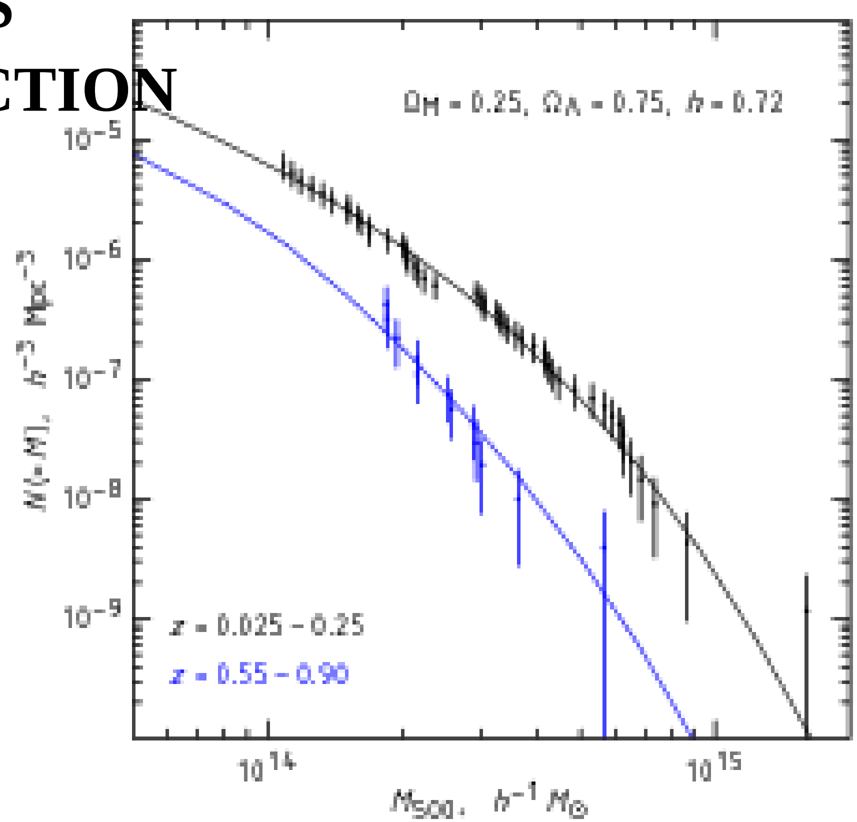



$M/L_{Bj} \sim 250\ h\ (M/L)_{\odot}$

Mass increases
faster than luminosity:

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

**MASS FUNCTION**



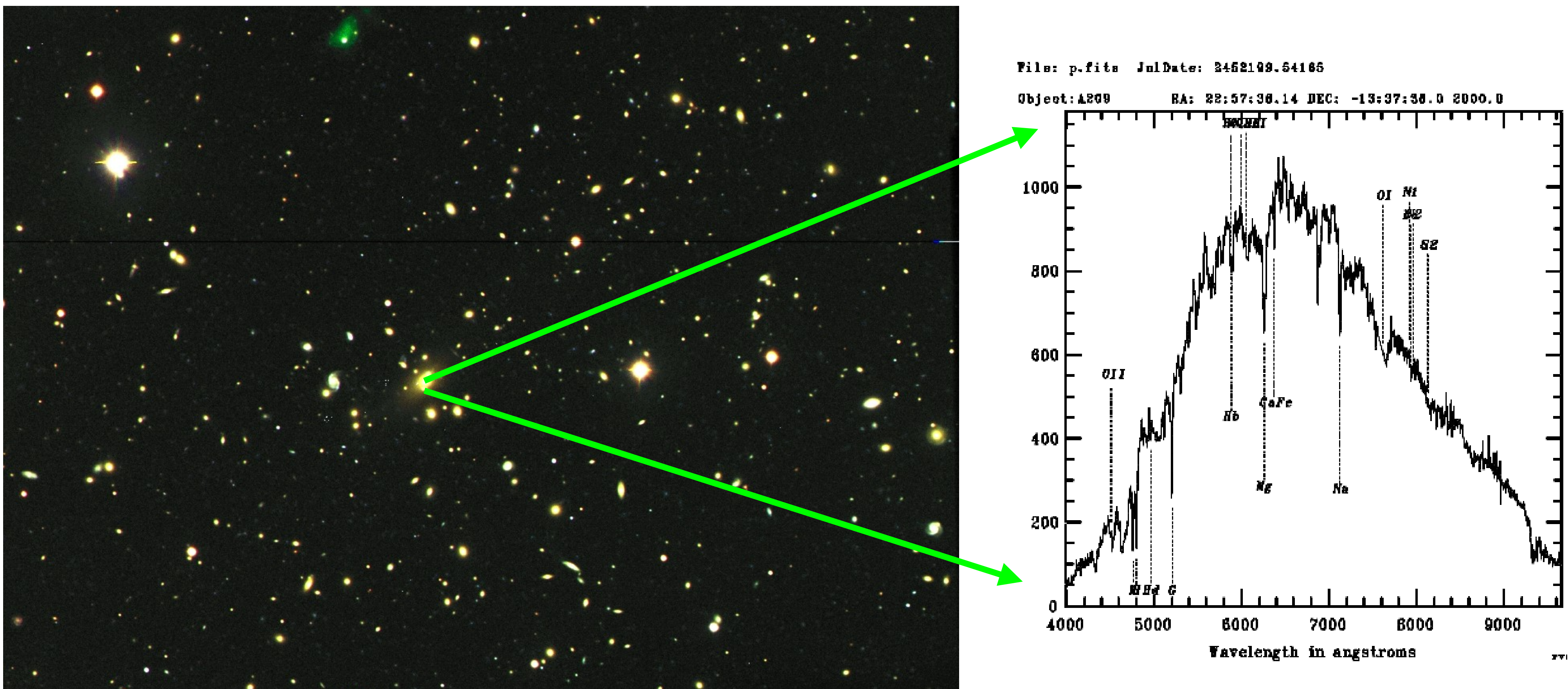

Giodini+14 Space Sci.Rev.

# 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.

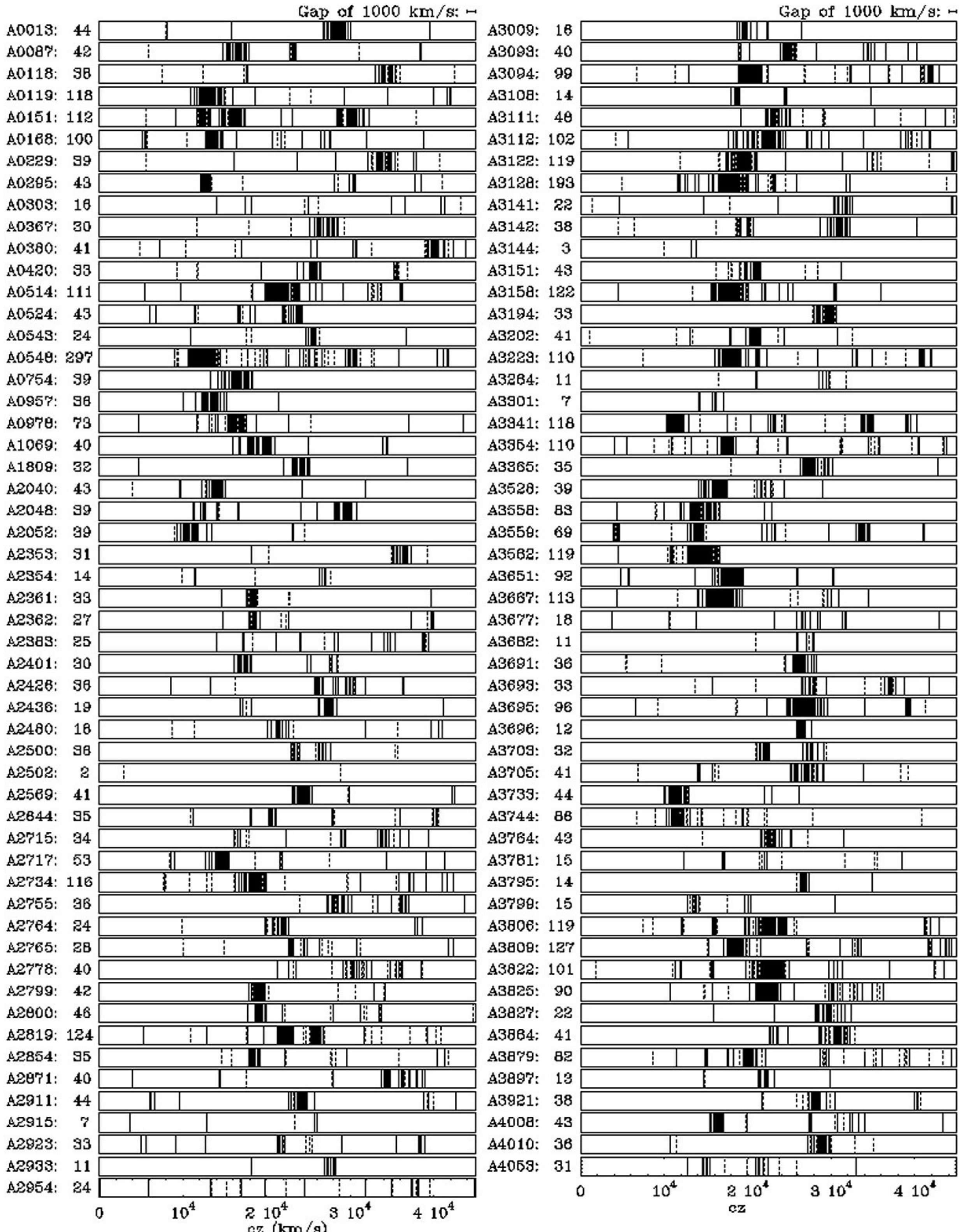
$1+z = \lambda obs/\lambda em$; <cz> gives distance and individual cz the internal cluster kinematics.

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

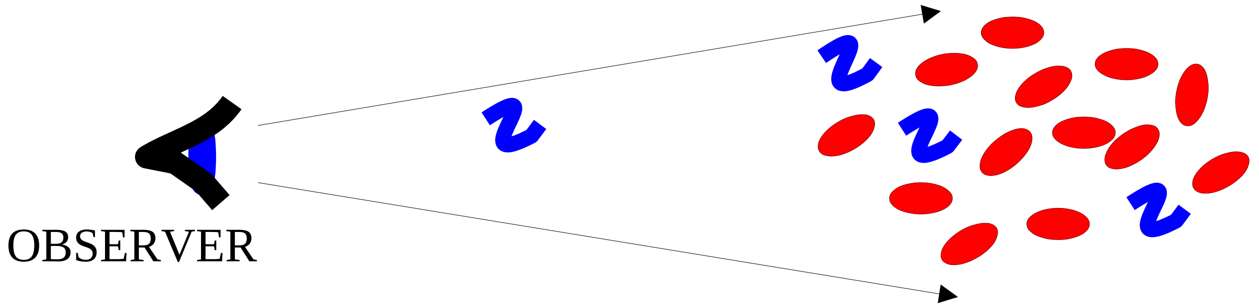


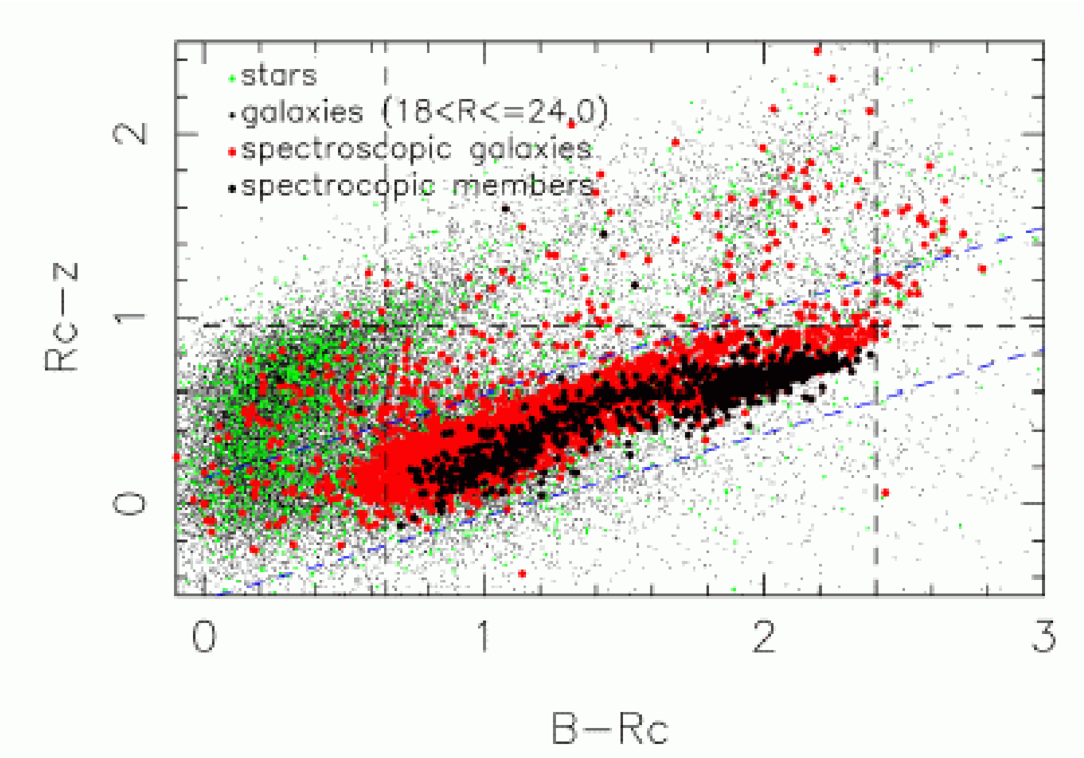
ENACS
CLUSTERS
Redshifts
Per cluster

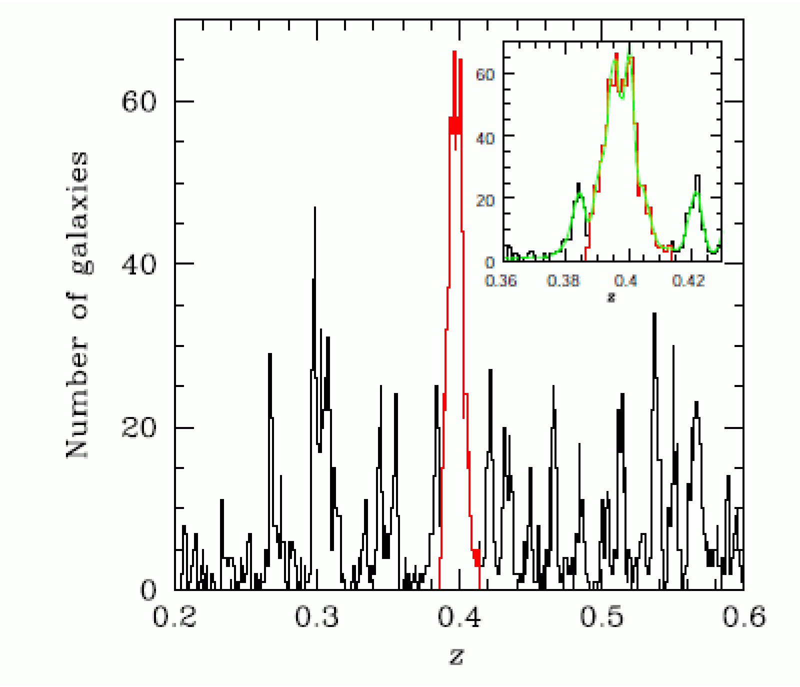
Credit:ESO



# 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:**

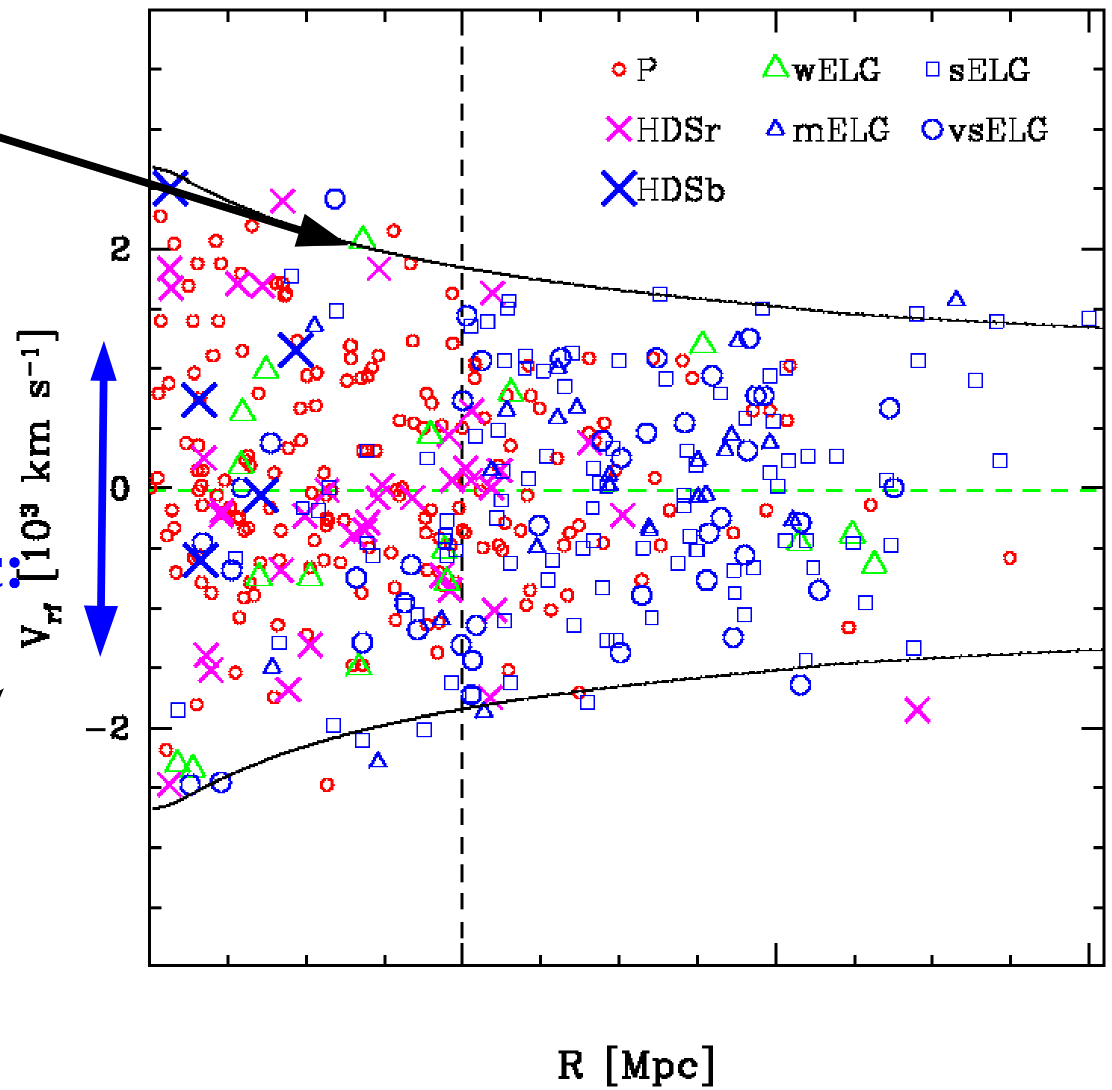
**$M \propto \sigma_v^2$**

**(virial theorem)**

**For the R200 radius**

**$R_{200} \propto \sigma_v$**

**$M_{200} \propto \sigma_v^3$**




V rest frame=(cz-<cz>)/(1+z)

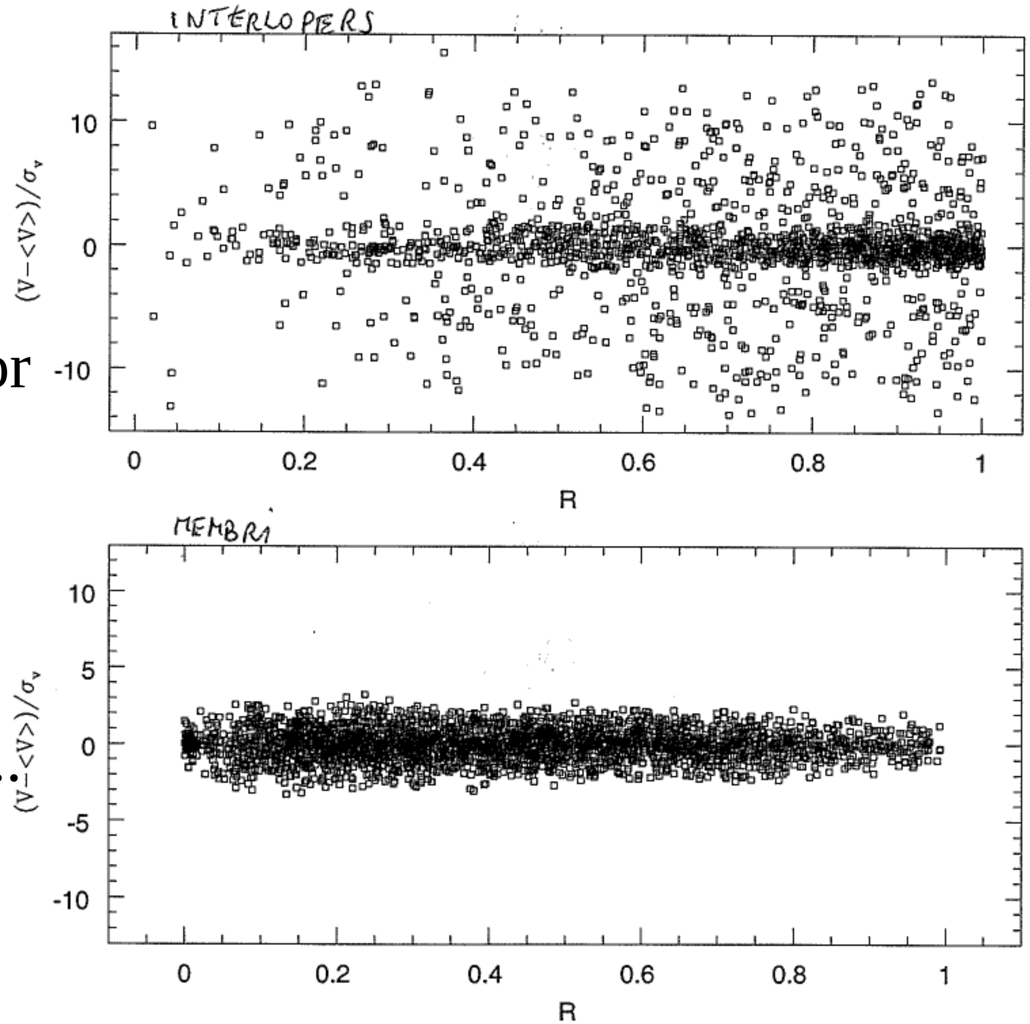
To reject non-member galaxies
= “interlopers”
is not so easy....

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**

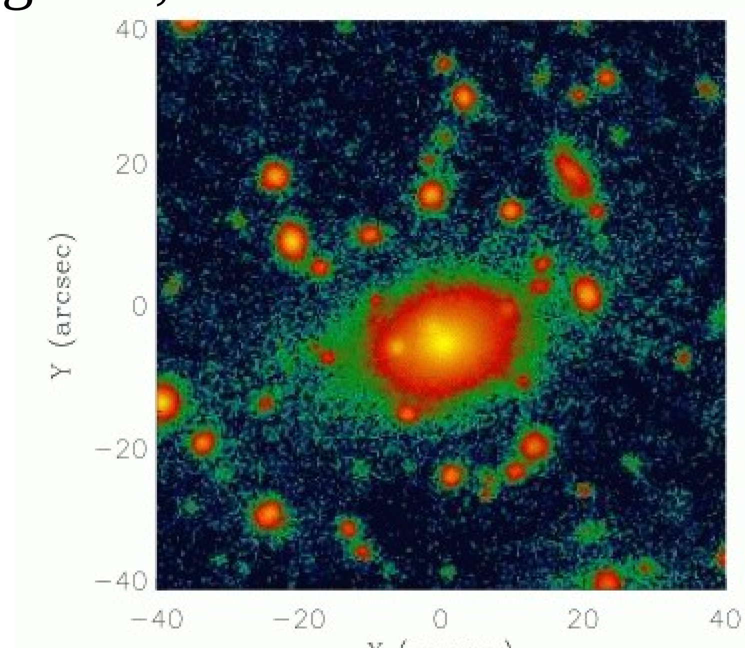
**FOssil Groups Origin**

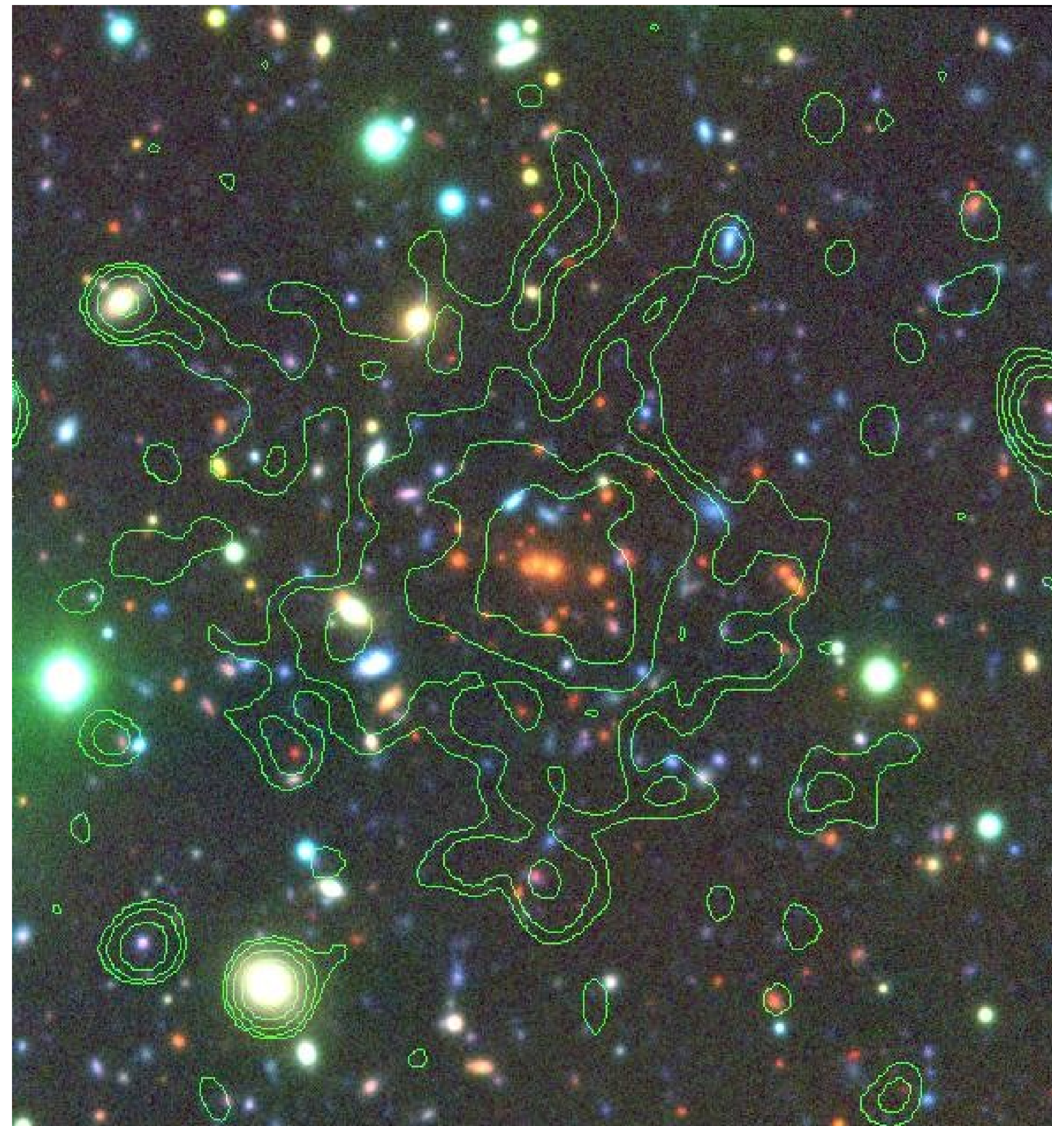
**With a very bright central galaxy.**

ITP Project with

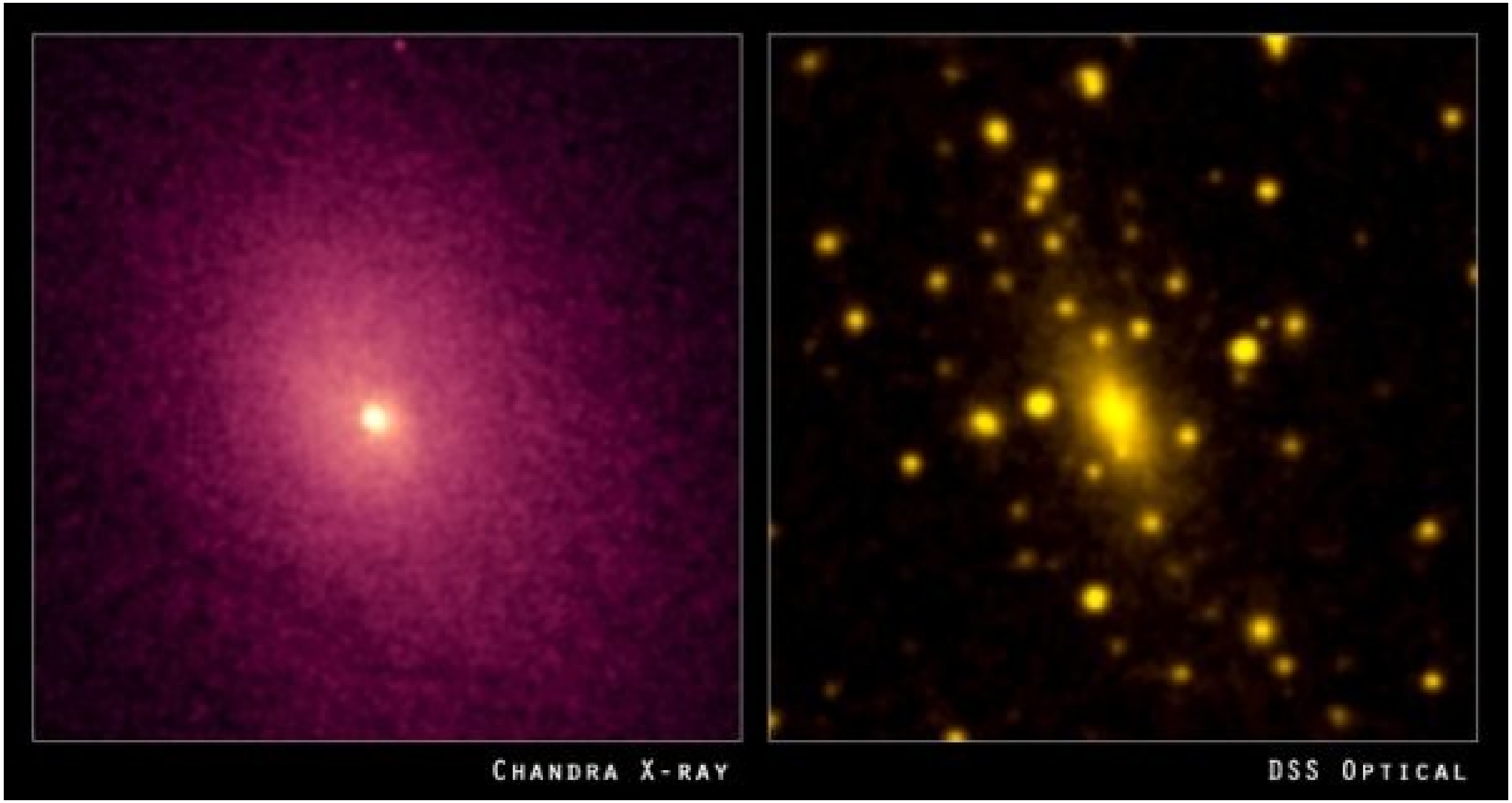
A.Aguerri – IAC Canary Is.

Aguerri, Girardi +12 A&A



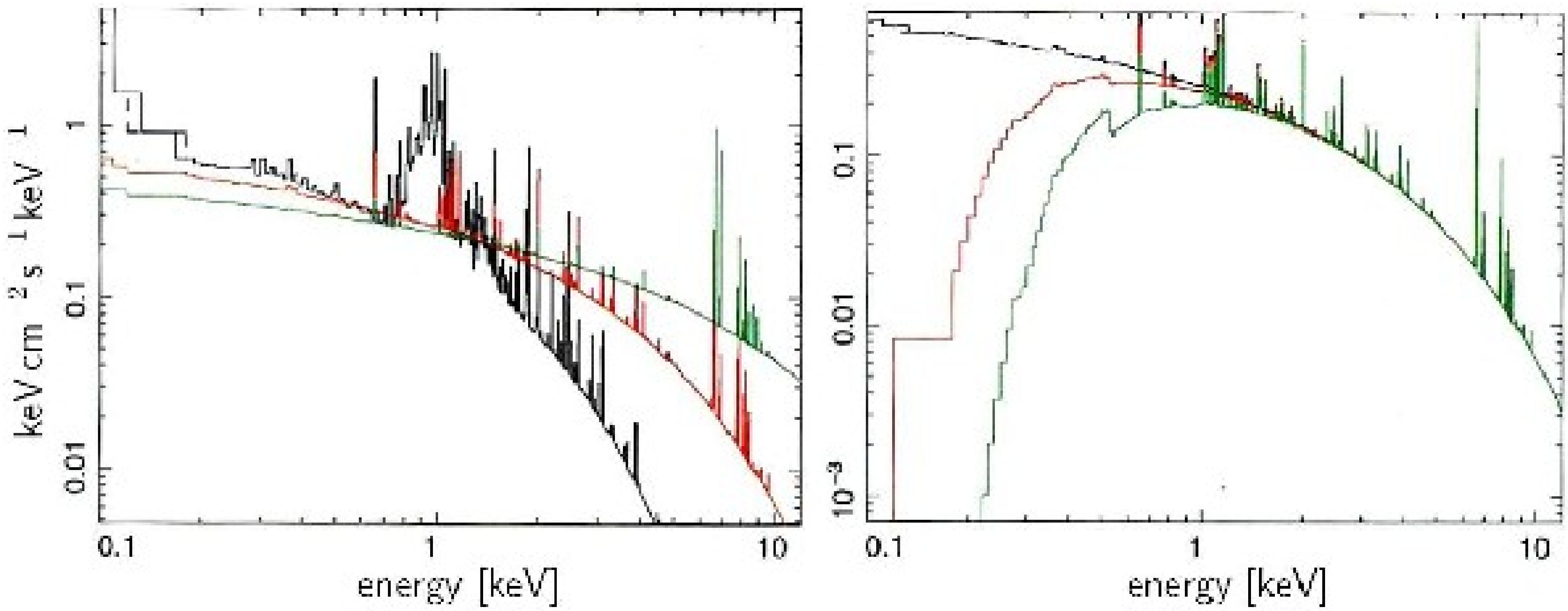



X-ray from hot intracluster medium (ICM)
Abell 2029, X and optical view




Credit: Chandra

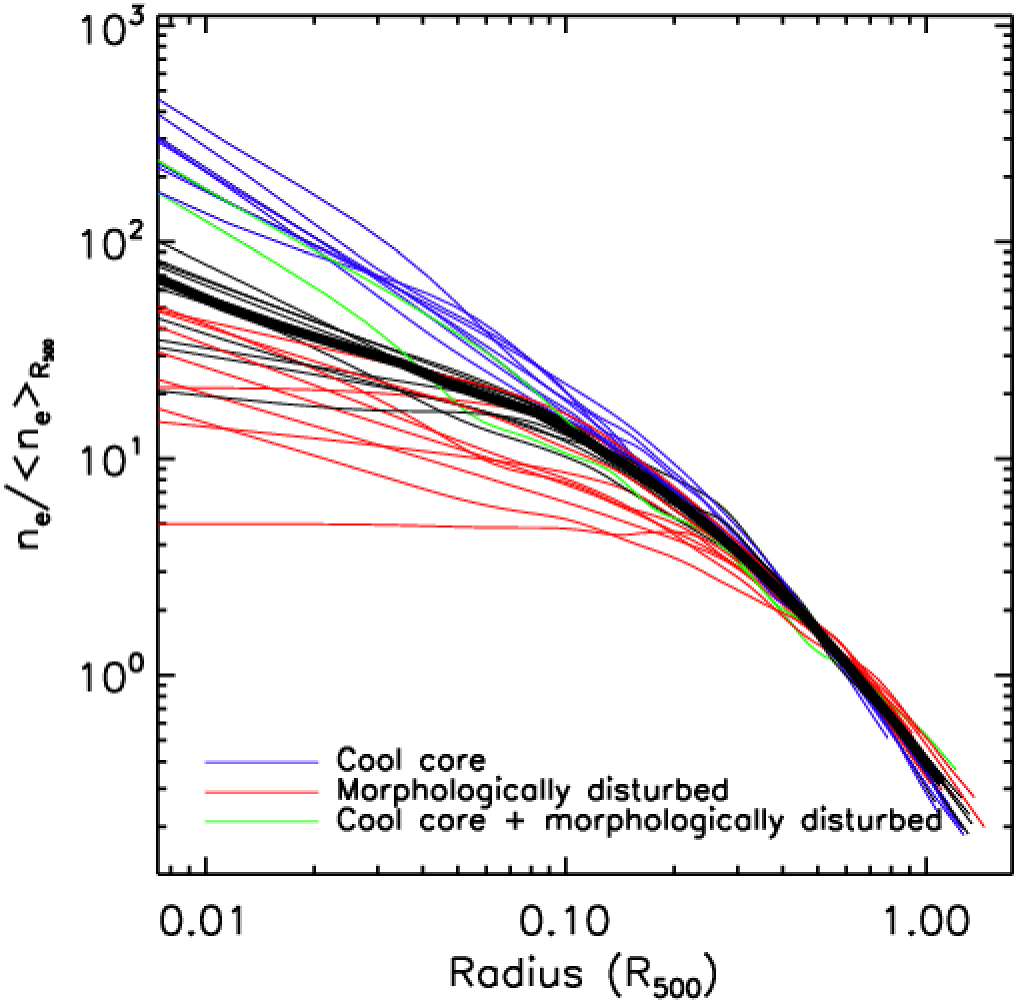
Credit to: http://inspirehep.net/record/787471/plots

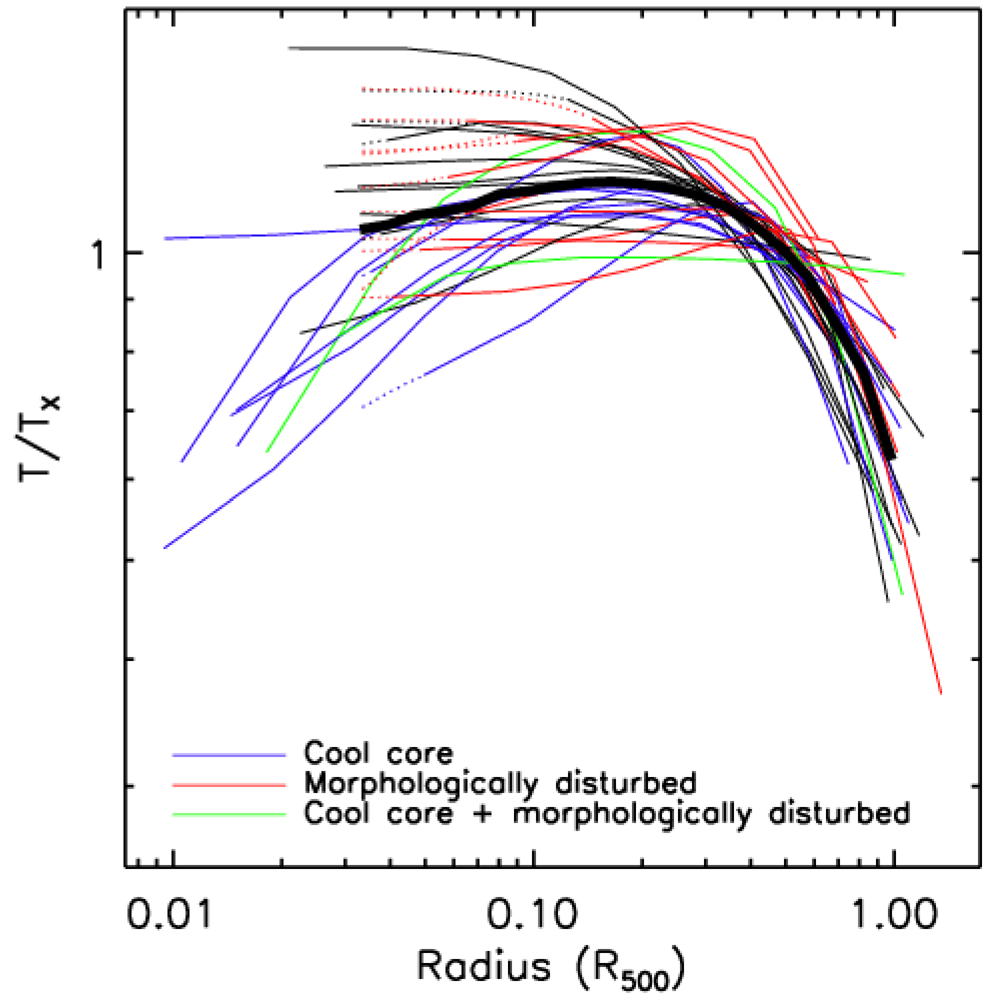



X-ray emission of the ICM. {\em Left:} Unabsorbed ICM model spectra of the bremsstrahlung continuum and line emission for plasmas with 0.4 solar metallicity and temperatures of 1\,keV (black), 3\,keV (red), and 9\,keV (green). {\em Right:} Absorbed model spectra of T=3\,keV observed through galactic 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.

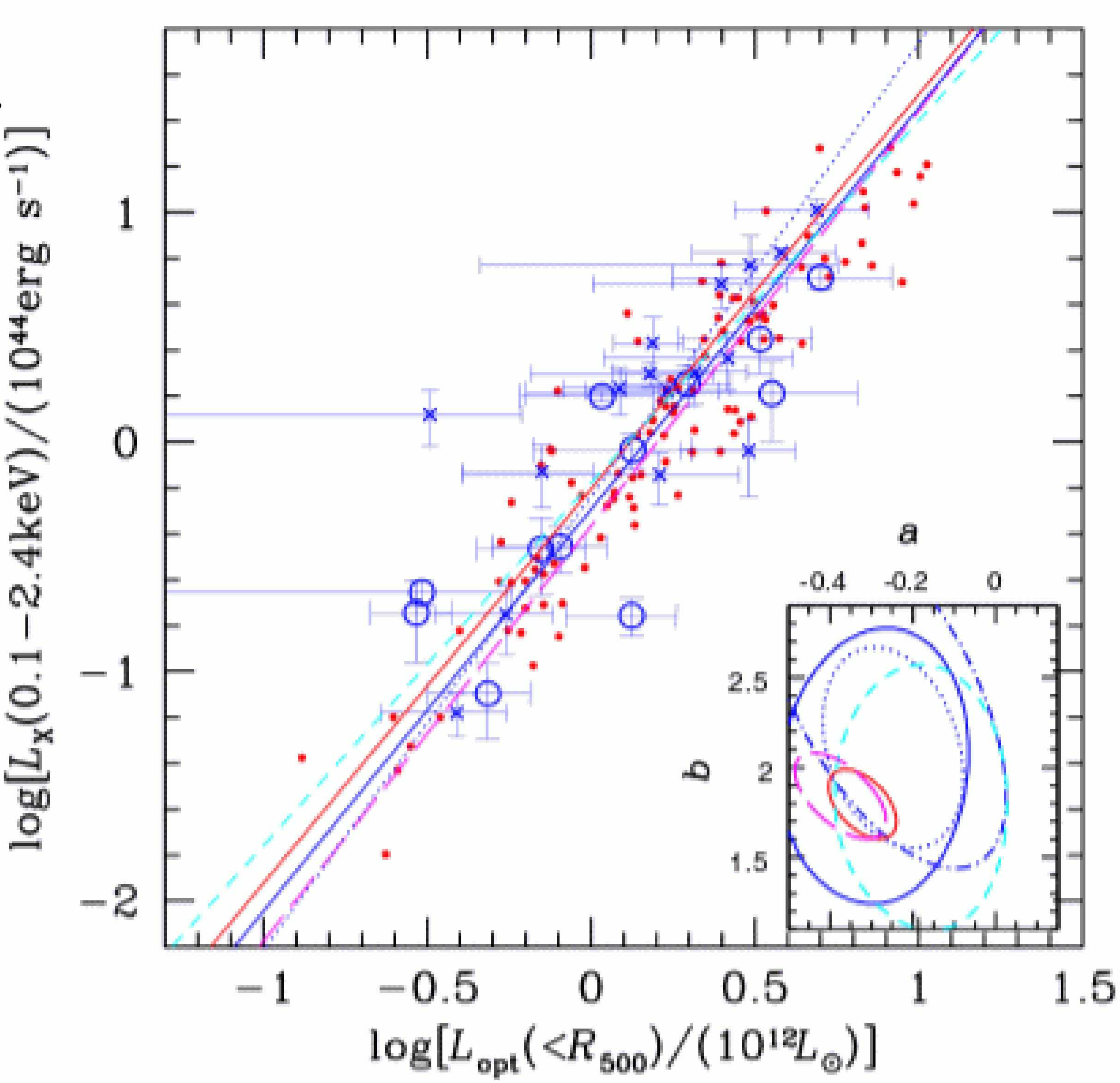


**Comparison between Loptical and Lxray.**

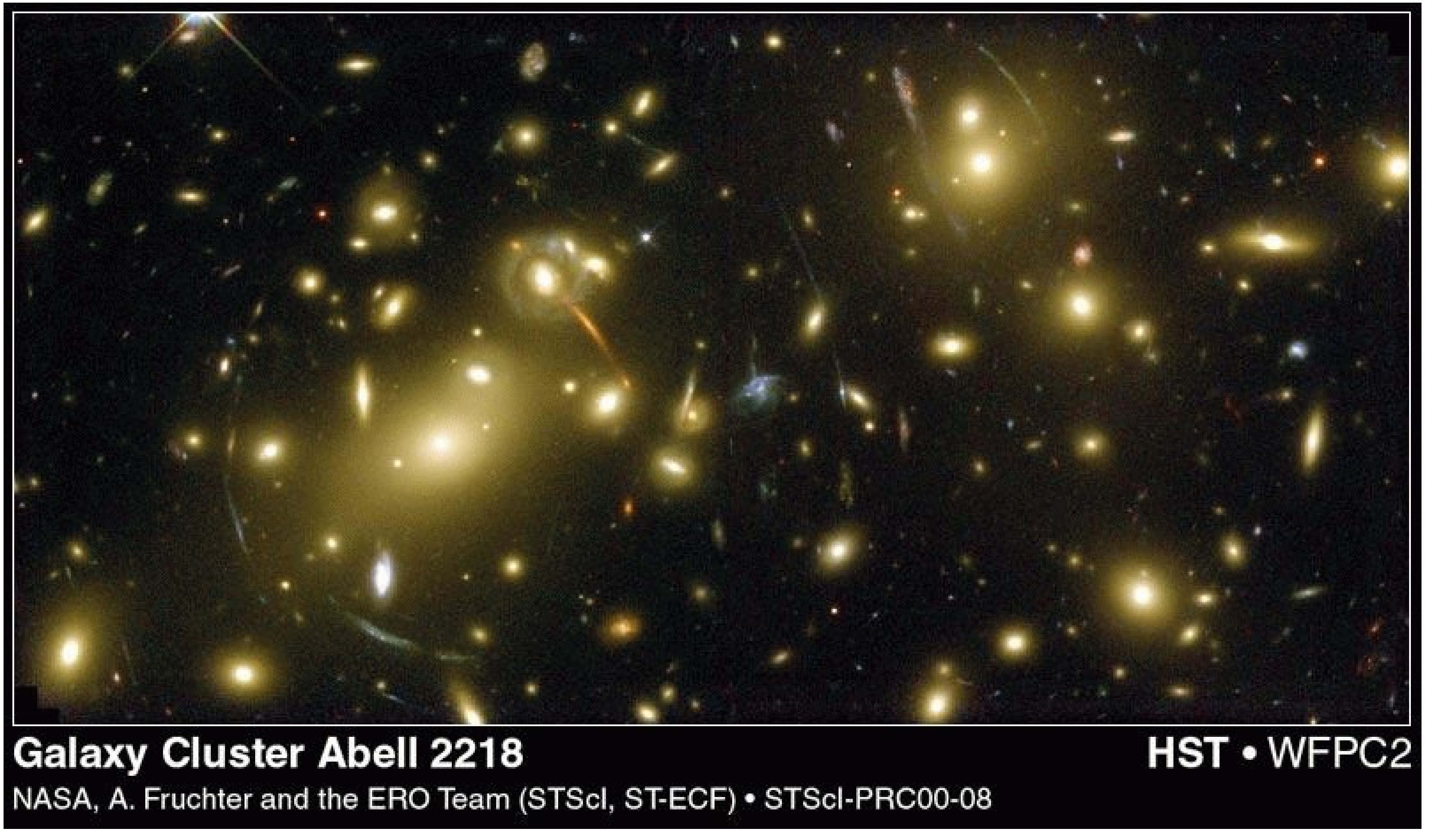
Both are good mass proxies.

Clusters and fossil groups.




Girardi+14 A&A

Gravitational lensing effect.



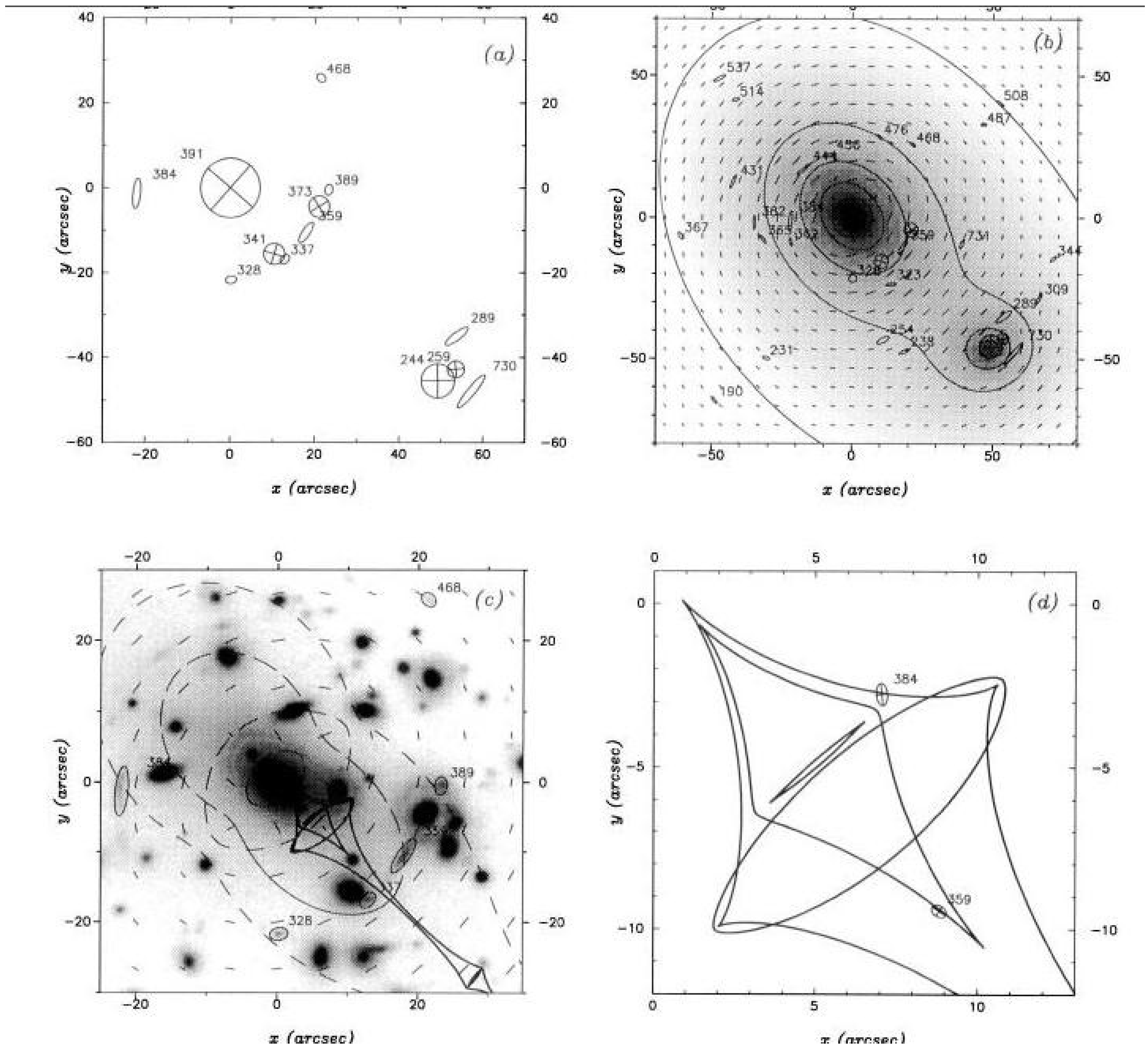

Credit: NASA HST     cluster at z sim 0.2

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.**

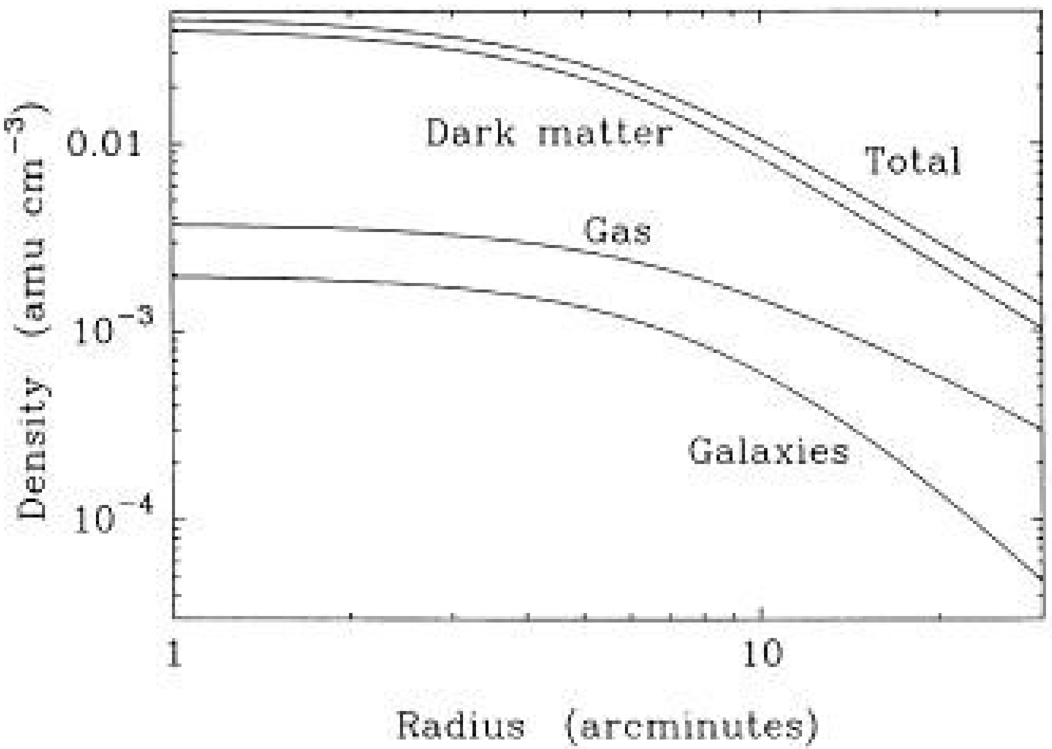
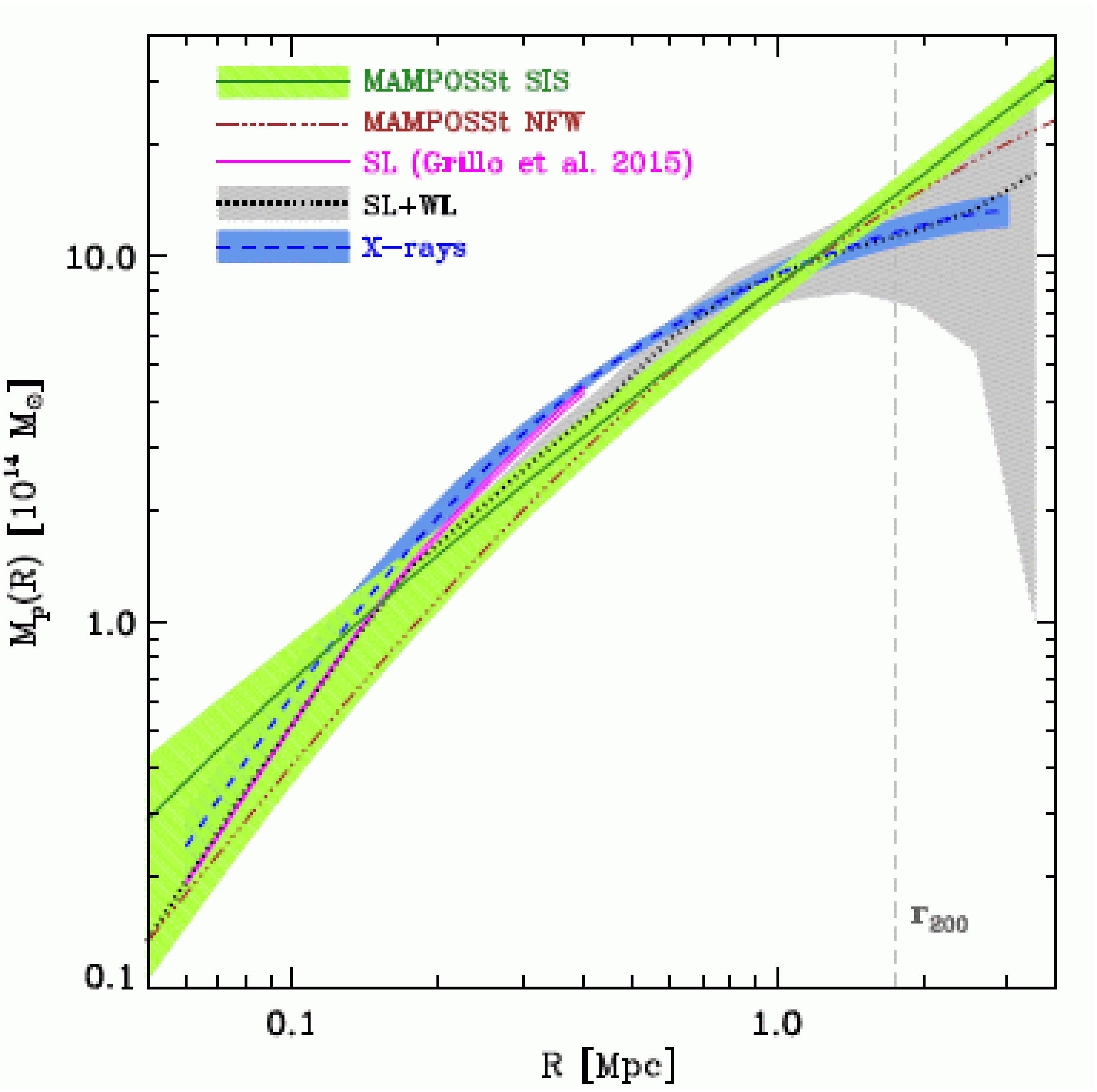



**Figure 9.** Density profile of the major contributors to the mass of the cluster. The gravitating and gas mass profiles are derived in the present work, and the galaxy mass density is from the data of Kent & Gunn (1982) assuming $M/L_V = 5(M_\odot/L_\odot)$.

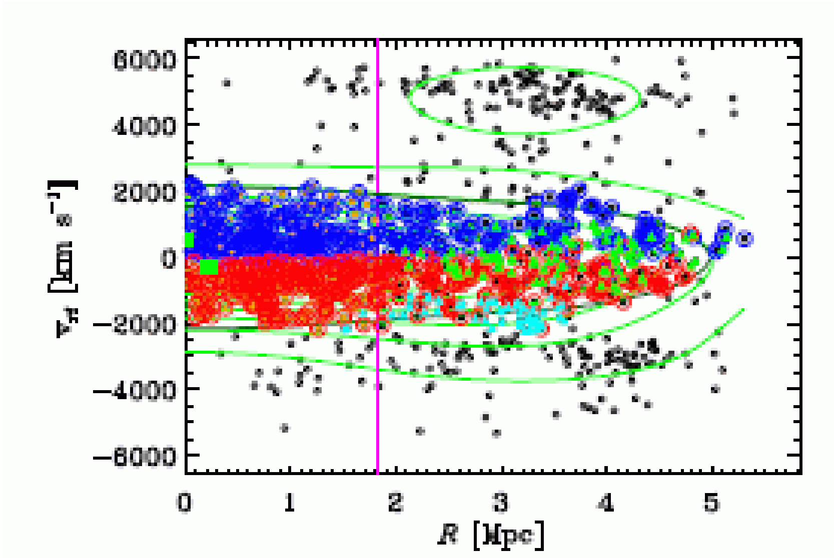
Credit: Watt et al. 1992 MNRAS

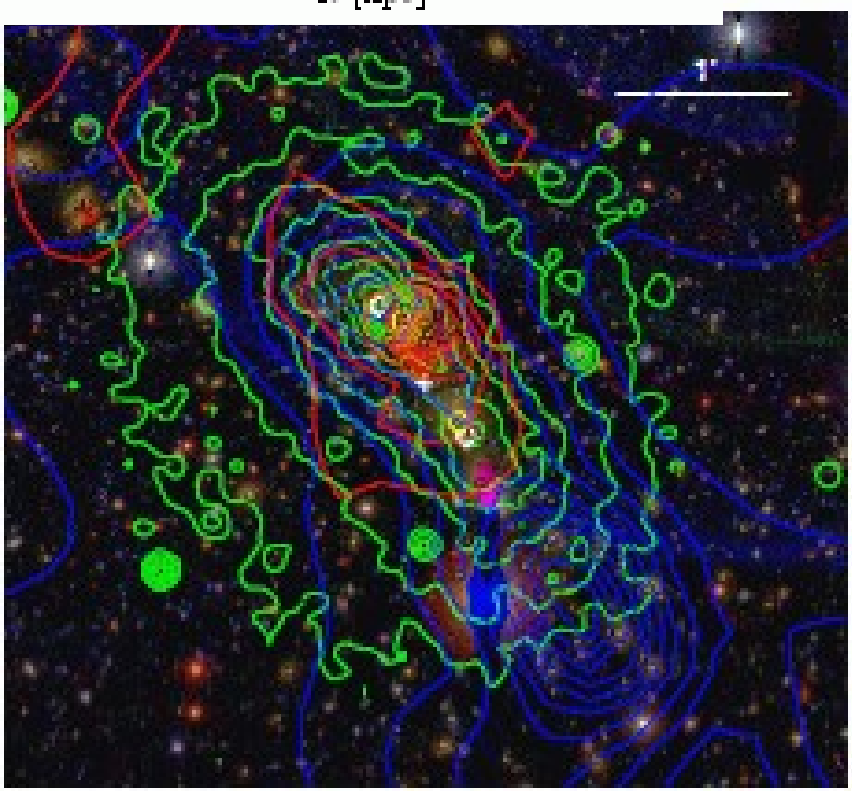
Comparison
between mass estimates
from different bands.
MAMPOSSt by Mamon
And Biviano uses galaxy
Kinematics.
Balestra et al 2015
(**Sartoris**)

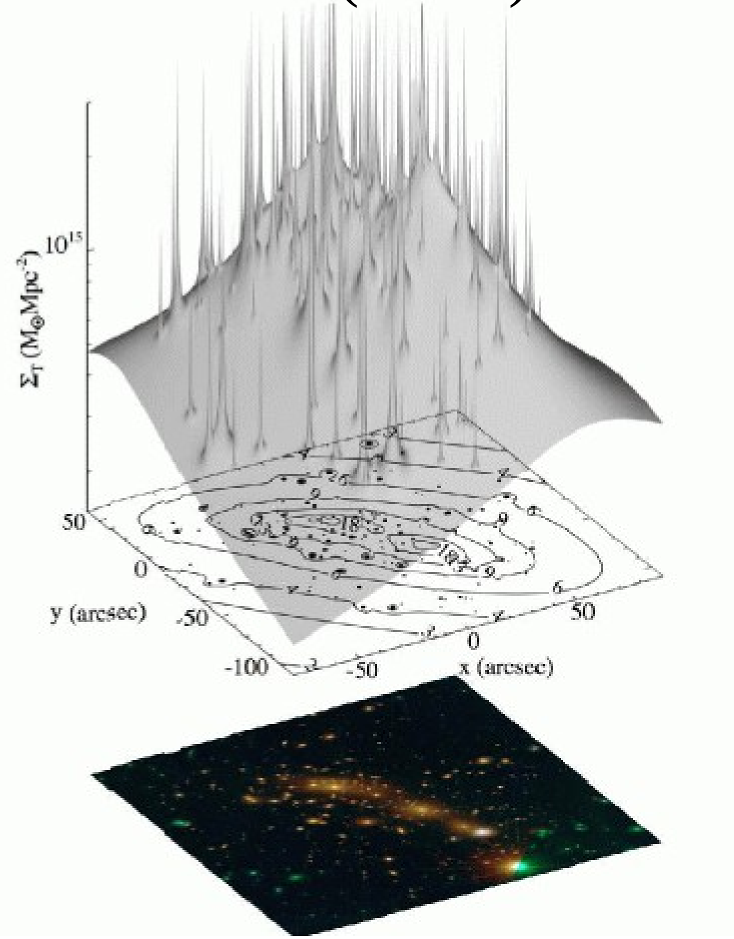


The cluster MACSJ0416 (CLASH HST+VLT data).
Substructure.

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)