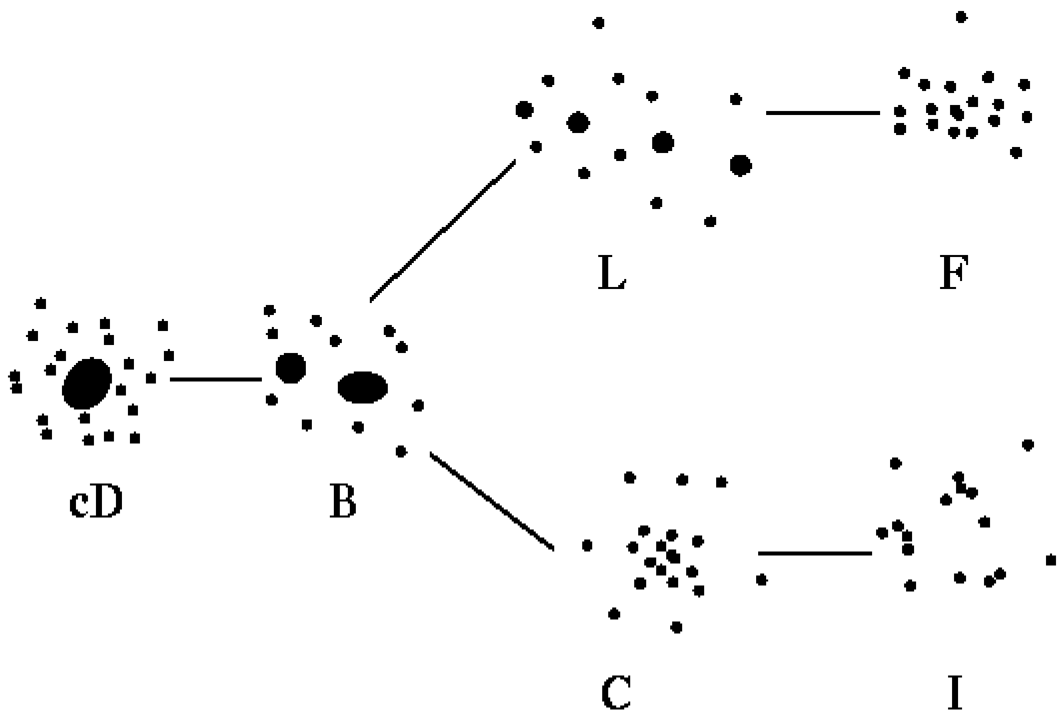
GALAXY CLUSTER
FORMATION, MORPHOLOGY, SUBSTRUCTURE, MERGER

MORPHOLOGY

ROOD-SASTRY CLASSIFICATION based on the brightest galaxies
Clusters with cD central Dominant galaxy),
Binary clusters,
Linear,
Flat,
Core,
Irregular



CLUSTER FORMATION

Lynden-Bell (1967). Theory of the “Violent Relaxation”.
The variation of energy of a galaxy depends only on the variation of the global potential (see Binney & Tremaine text, too).

dE/dt ~dPhi/dt Phi=global cluster potential

→ we expect velocity equipartition among galaxies
And Maxwellian distribution of velocities (Gaussian in 1D, i.e. line-of-sight).

In the case galaxies and gas form the cluster simultaneously, we expect density energy equipartition between galaxies and gas, e.g. Sarazin (1986).

$$\beta_{spec}=\sigma_v^2/(kT\ \mu\ m_p)=1$$

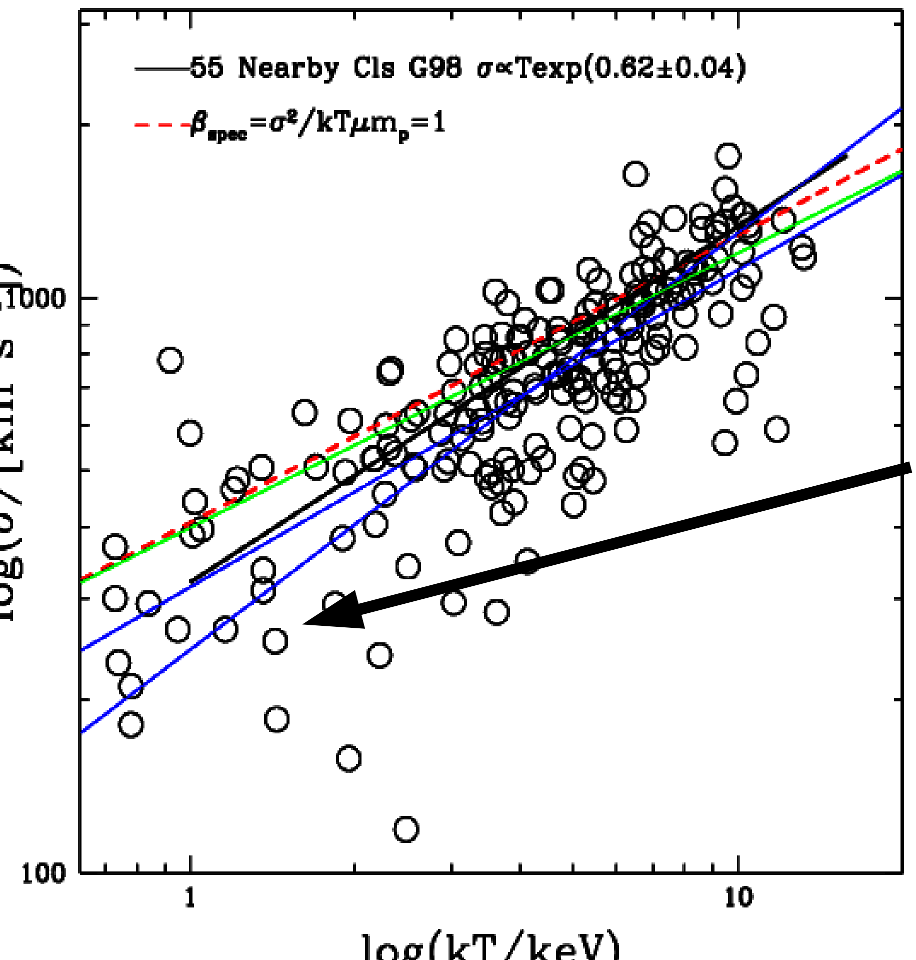
Old data → beta_spec>1...now ~1

Velocity Dispersion and X-ray Temperature
β_spec VALUE

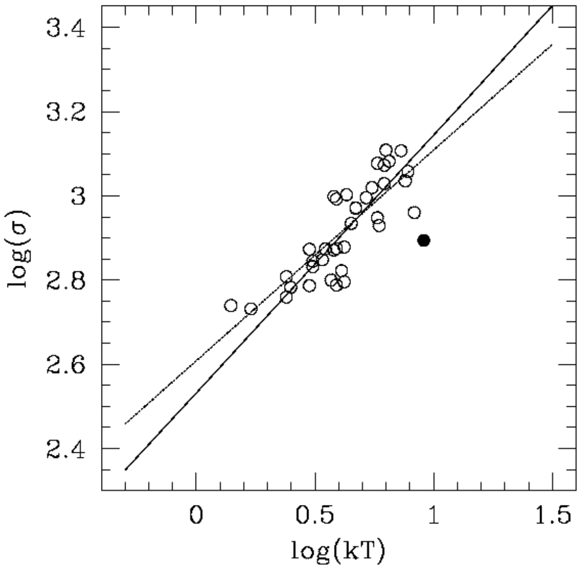
σ_v and Tx give the measures of the energy per unit mass of two different cluster components (galaxies and gas)

β_spec=σ_v*σ_v/[kT/(molec-weight*proton-mass)]

Model of gals/ICM specific energy equipartition β_spec=1



Some new data in 2009



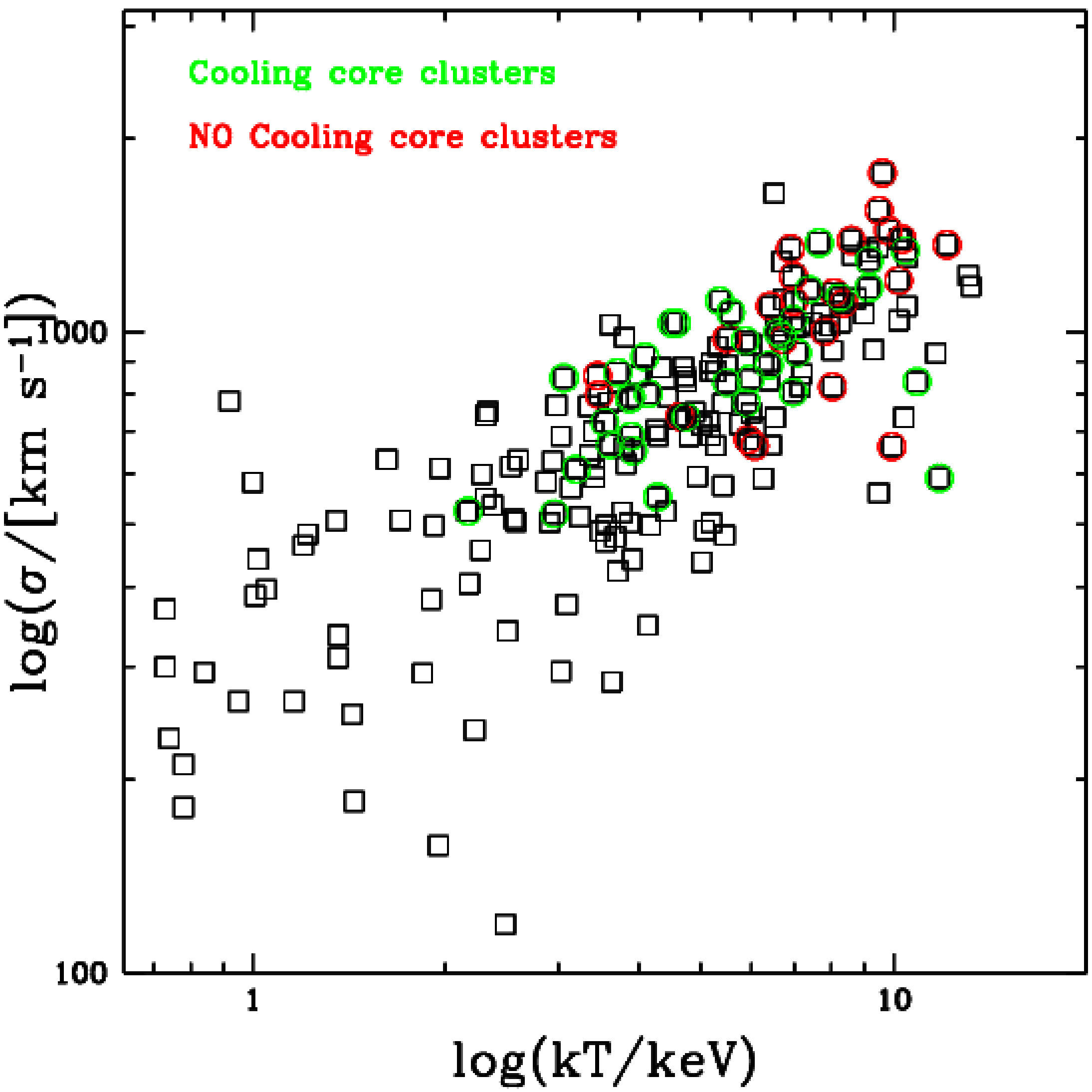
MG+1996,1998

Dynam. friction slows down group gals?

extra-heating model for gas e.g. gal. winds?

NEED TO BE RE-ANALYZED!

Clusters far from dynamical equilibrium deviate from σ_v-Tx Relation? No!



Using cooling times by
Allen & Fabian 98;Peres et al. 98

61 Cls with a cool core

~RELAXED CLUSTERS

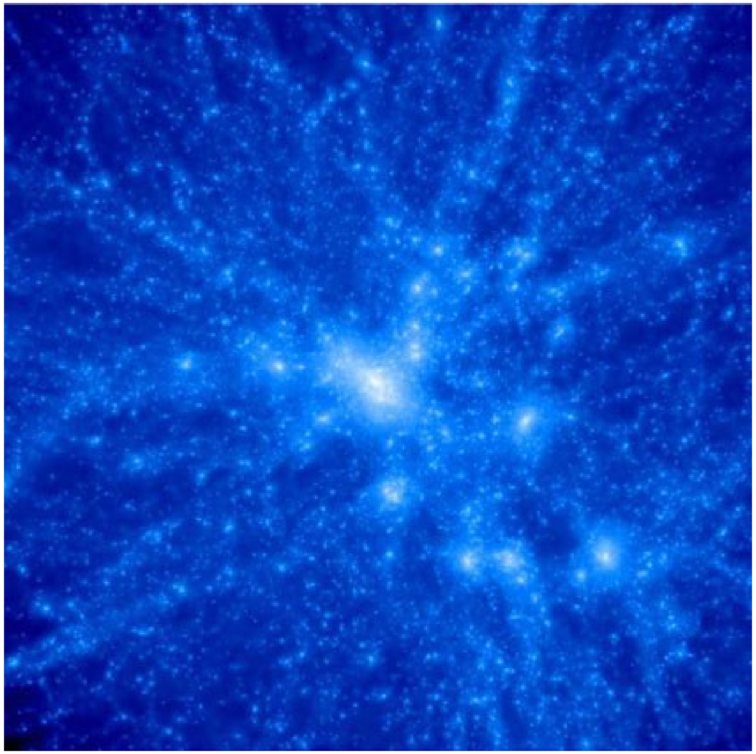
24 Cls without a cool core

NON RELAX. CLUSTERS

Distributions are different at the 95%

NON RELAXED CLUSTERS HAVE LARGER σ_v AND Tx.

Within hierarchical cosmological scenario, clusters
Are though to form through the merger of smaller systems, likely at the intersection of the large scale structure (LSS).



Kravtov & Borgani 2012
A&A Annual Review 12

Cluster merger is an ongoing process, with a lot of observational evidence in both local and distant Universe.
A connected feature is the presence of SUBSTRUCTURE.

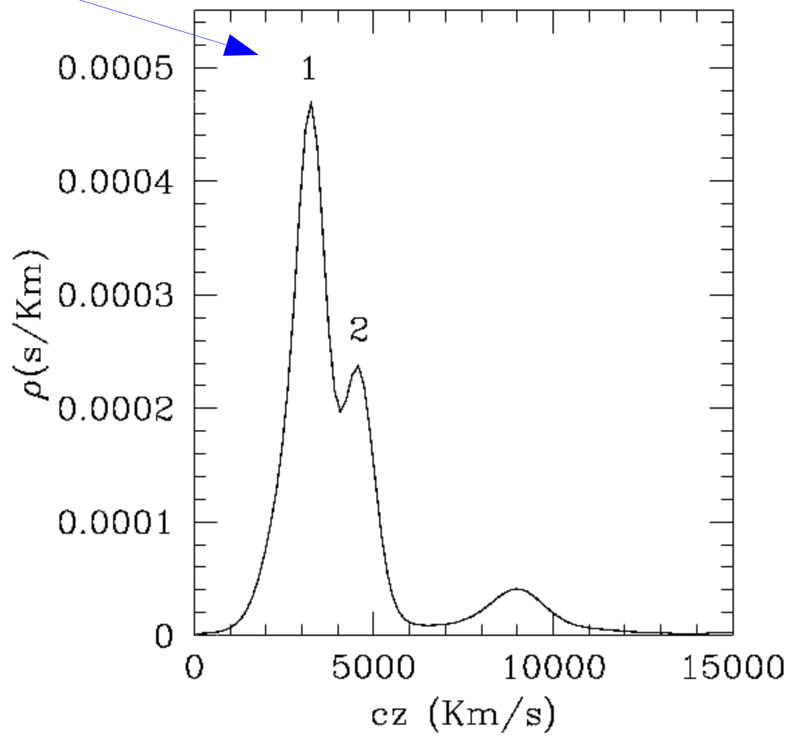
OPTICAL STUDIES FROM GALAXIES >50%
of clusters show substructure
(small substructure ~10% of the total mass)
Major substructure (=major merger) only in 10% of clusters.

Methods of detection:
1D in the velocity space
2D gals density onto the sky
3D correlation between position and velocity

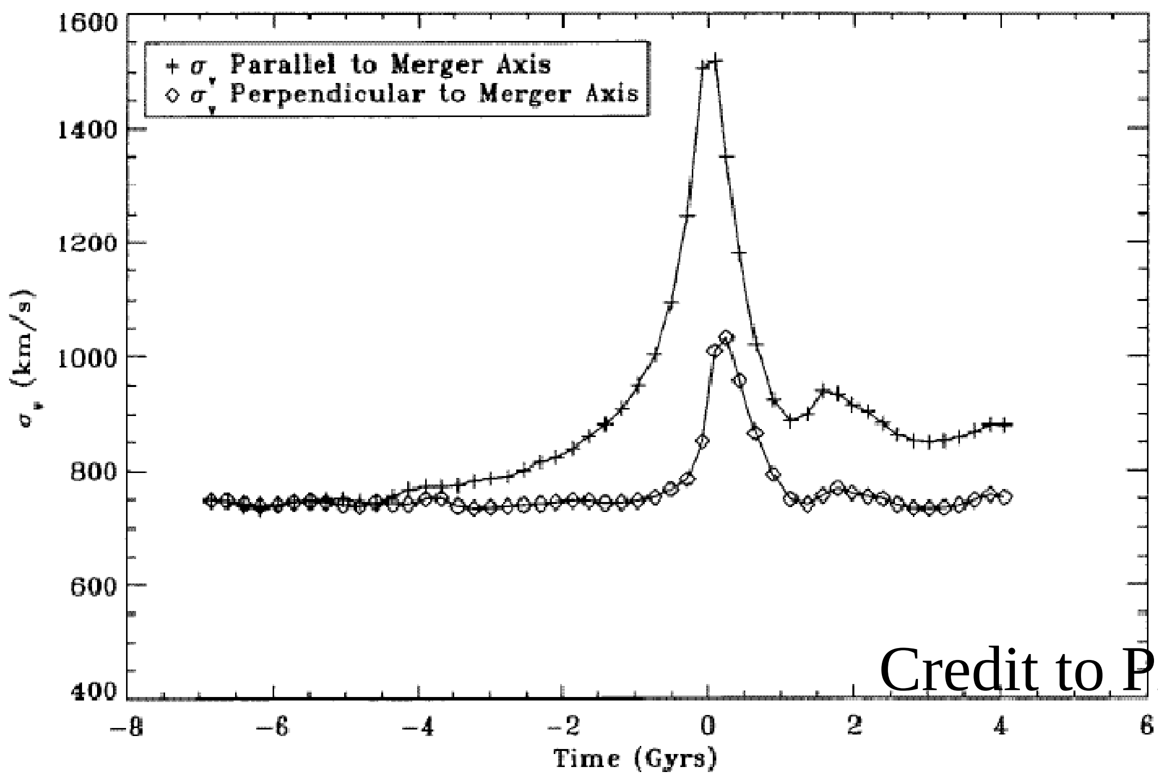
SUBSTRUCTURE MAY BE:
*cluster mergers,
*subsystems with system already relaxed (remnant),
*bound group that will merge,
*unbound group, projected onto the cluster.

Since the violent relaxation theory → Gaussian 1D velocity distribution
1D – tests often based on Gaussian.
This is instead the result for a non-parametric adaptive method of galaxy density.

A 10% OF CLUSTERS ARE FAR FROM DYNAMICAL EQUILIBRIUM → MASS ESTIMATE VARIES BY A FACTOR 2



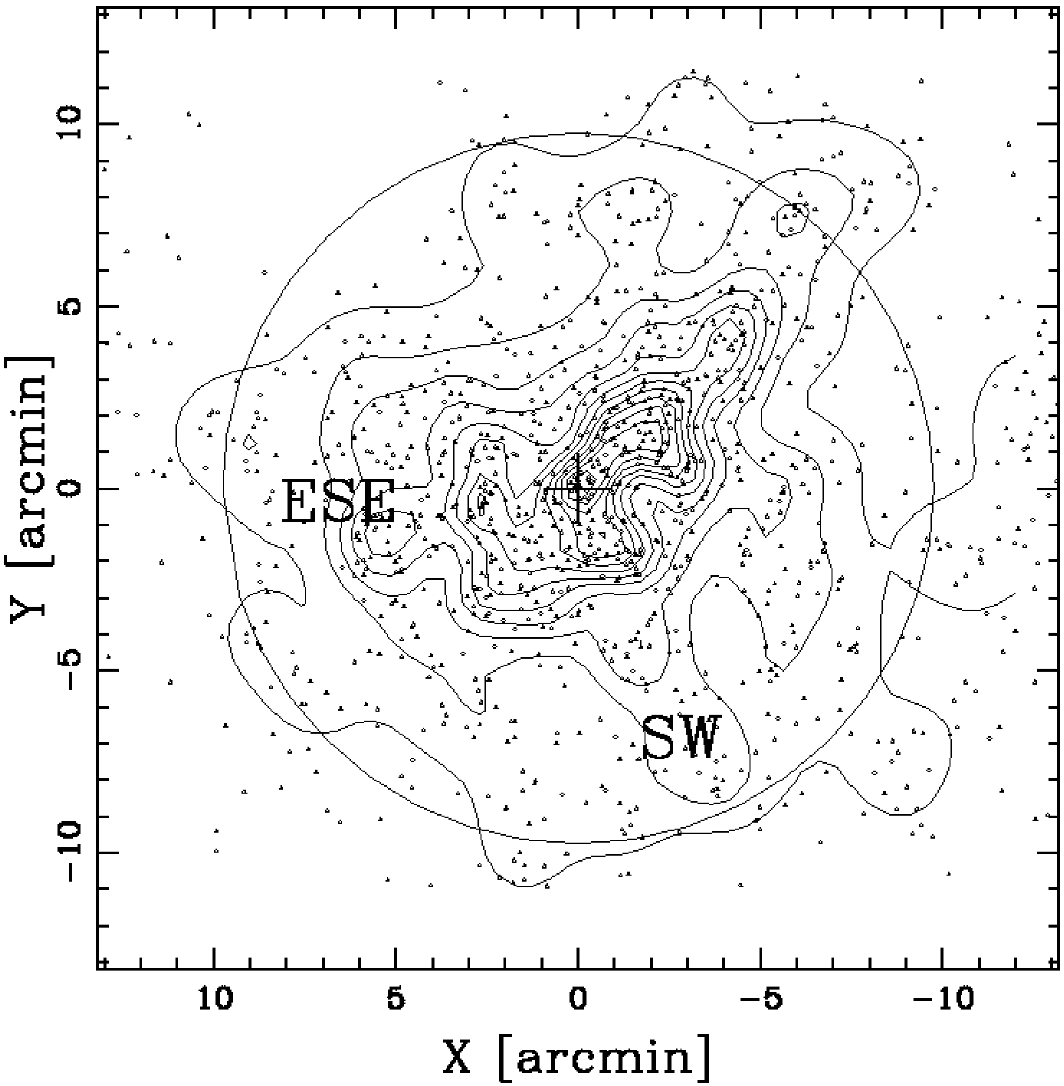
σv estimate increases during the merger!

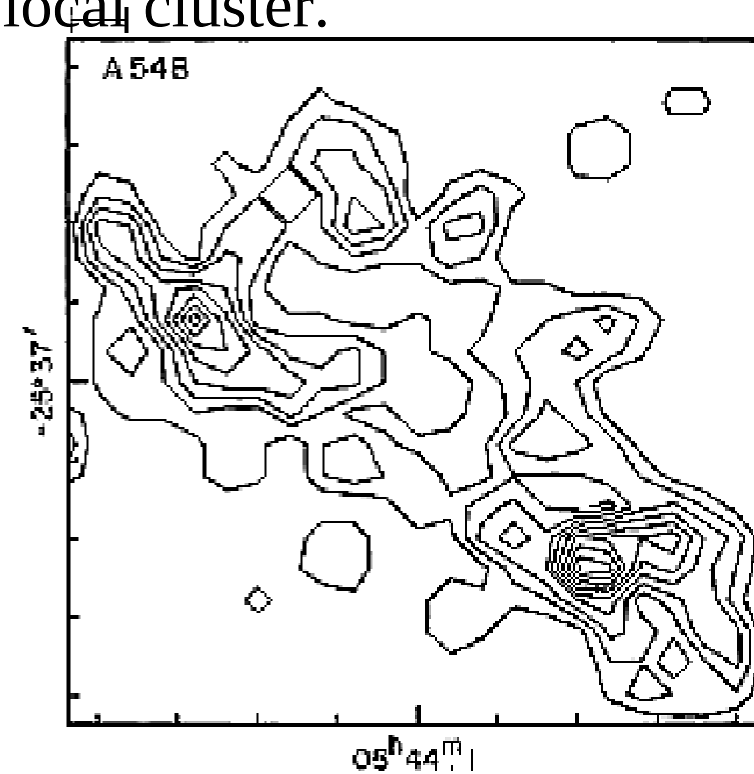


Credit to Pinkney 1996

2D analysis.
Galaxy density isocontours.

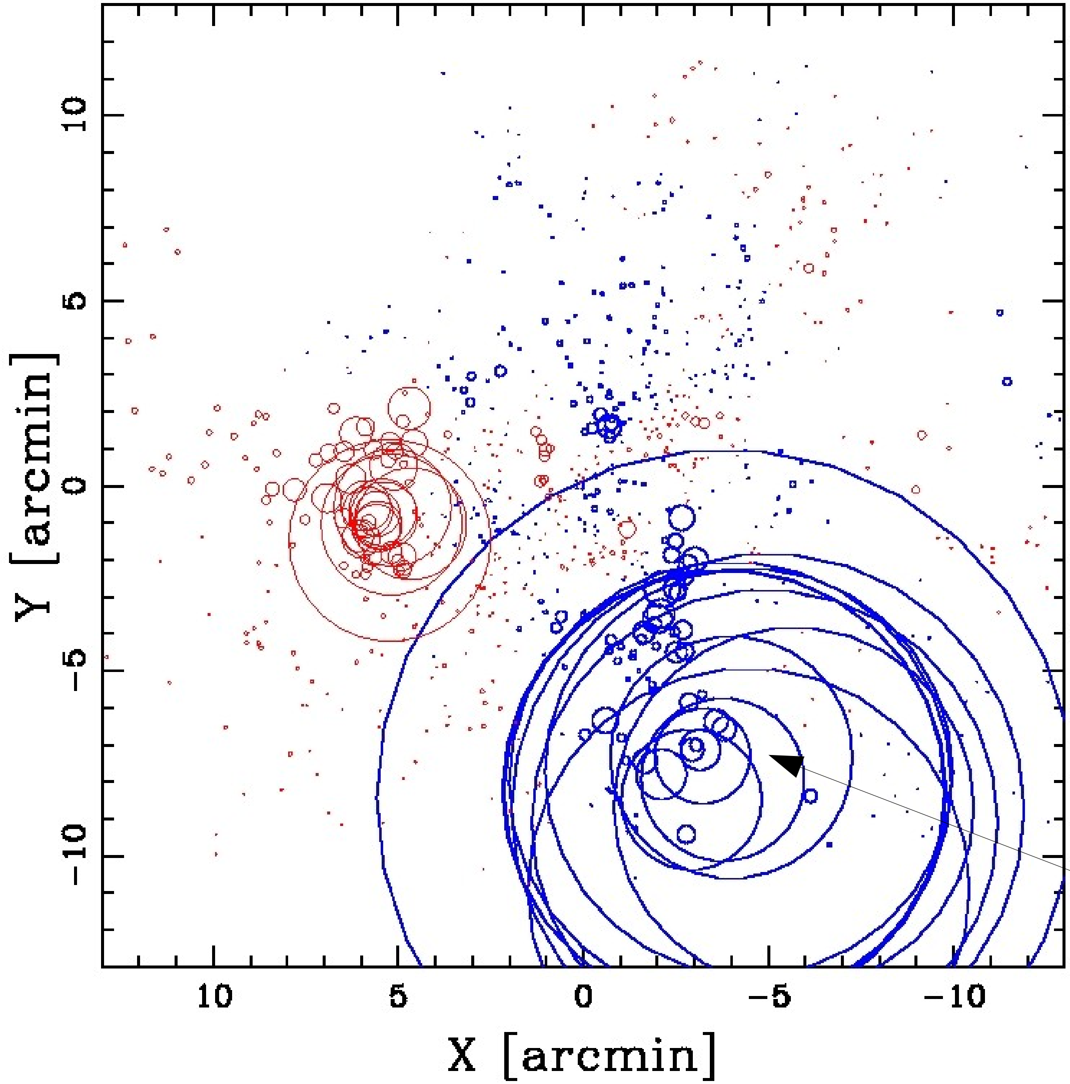
Geller 1982.
For a local cluster.

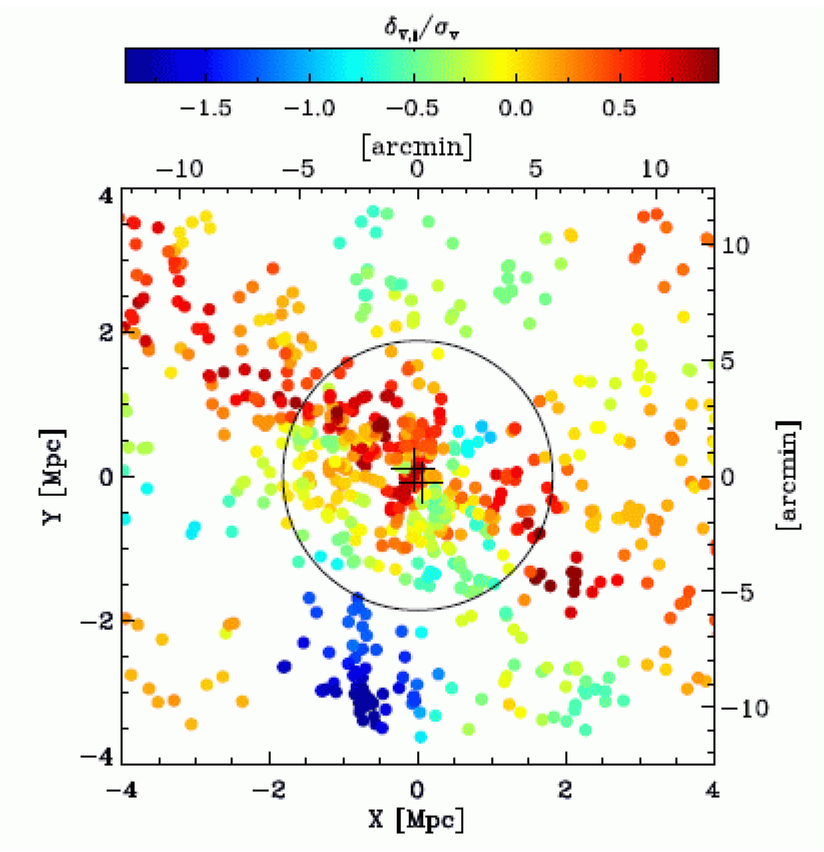




Ongoing work on Abell 209
CLASH-VLT data for >1000 gals
At z=0.2. 1116 cluster gals.
PI Piero Rosati.
In TS, MG,A.Biviano,M.Nonino,
+others and postdocs

CLASH-VLT data MACS J0416 at z=0.4
And Abell 209 at z=0.2
3D-analysis. Dessler-Schectman test
For departure of the local mean velocity
From global mean velocity.



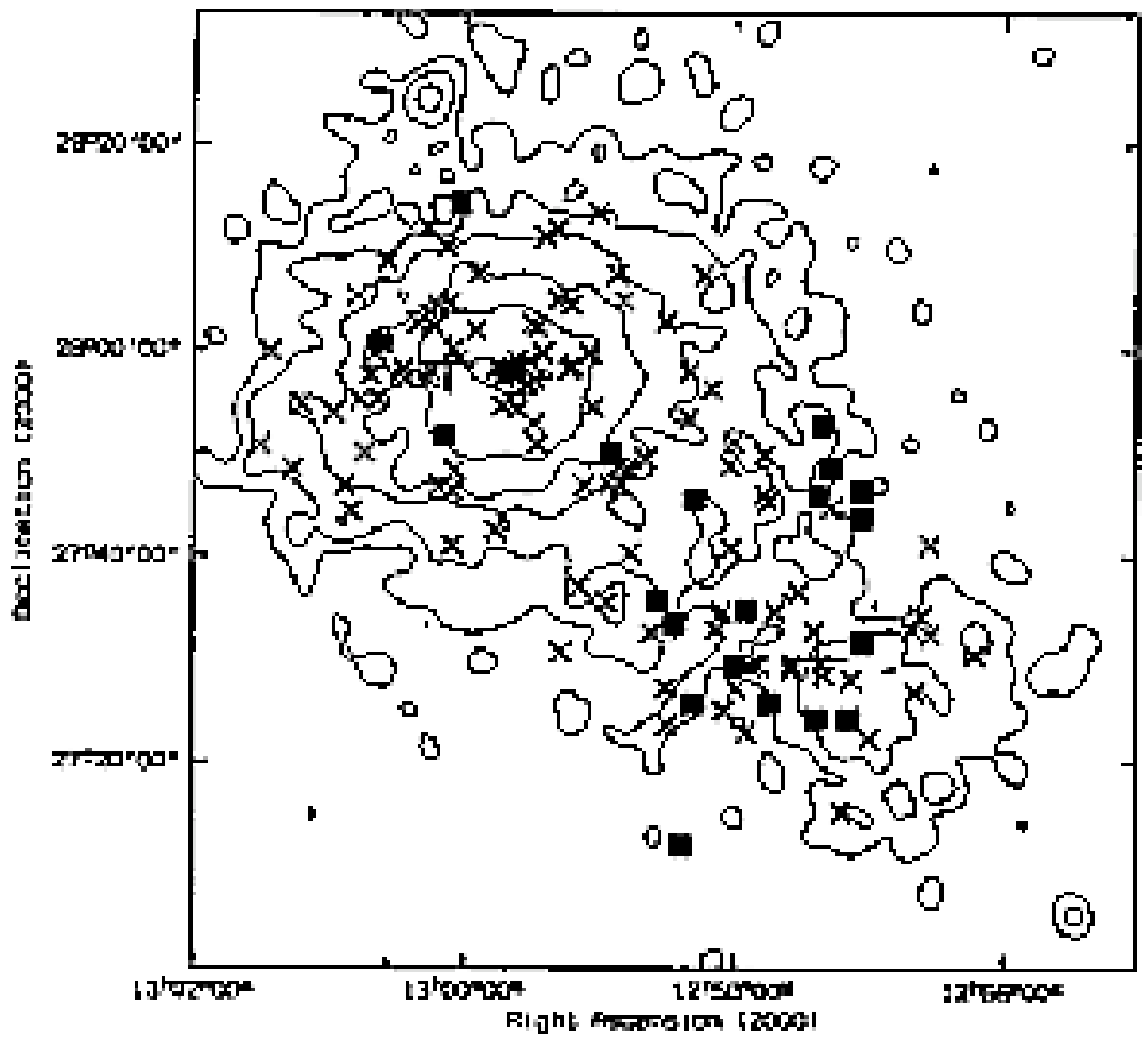


Statistical sign. through
Montecarlo simulations.

Low mean velocity

Cluster mergers can stop or enhance the star formation in galaxies.
Debate in the literature.

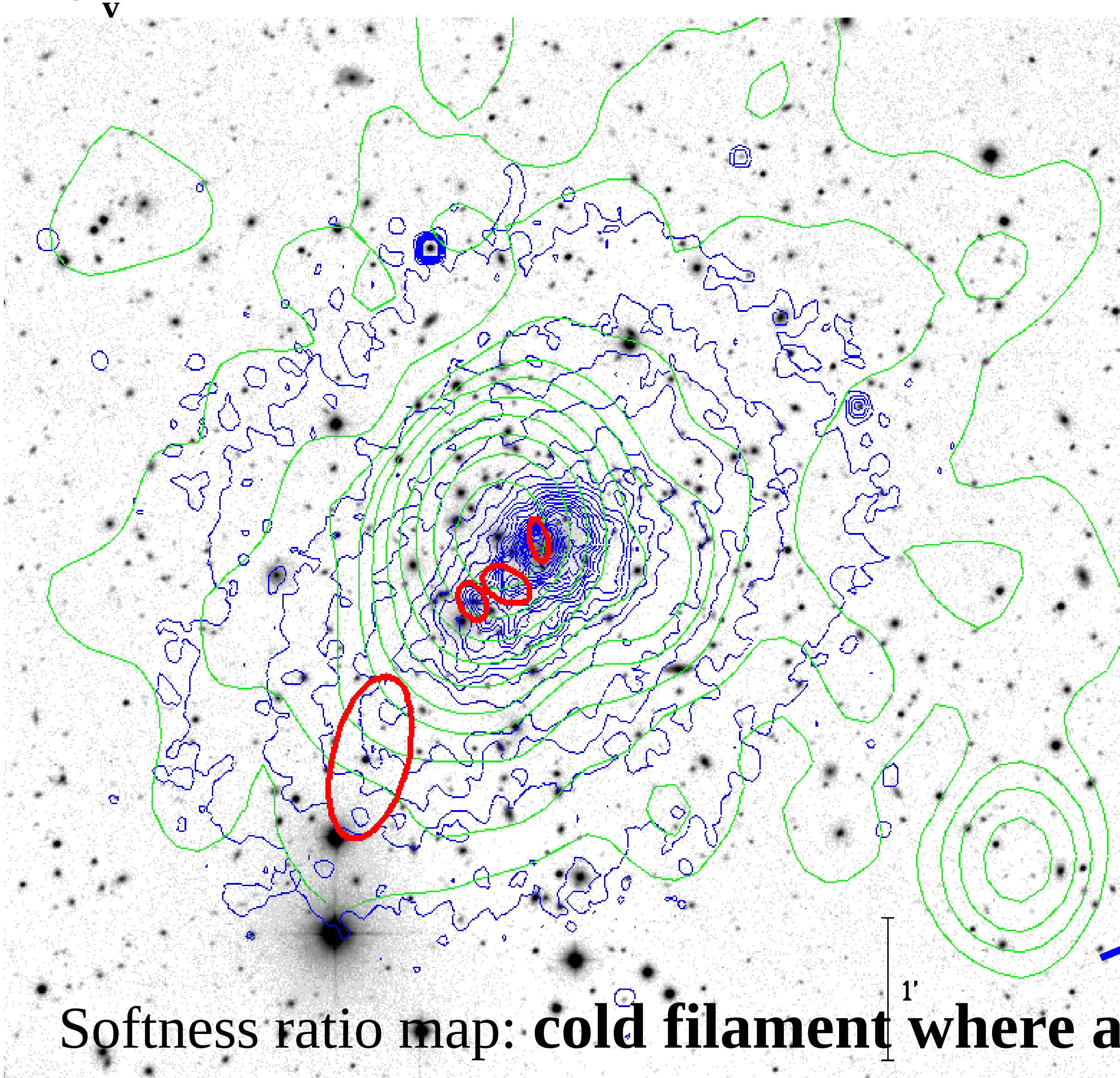
Caldwell+1993   Post Starbust (PSB) galaxies and cluster mergers

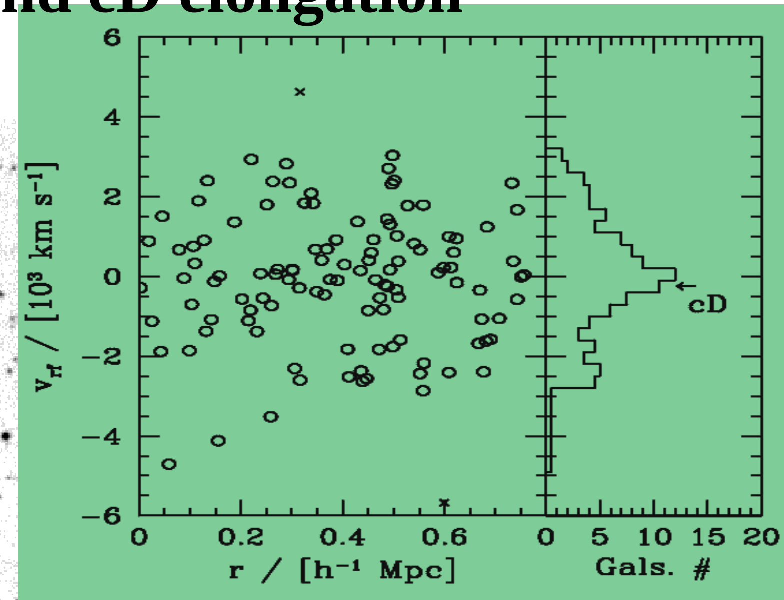


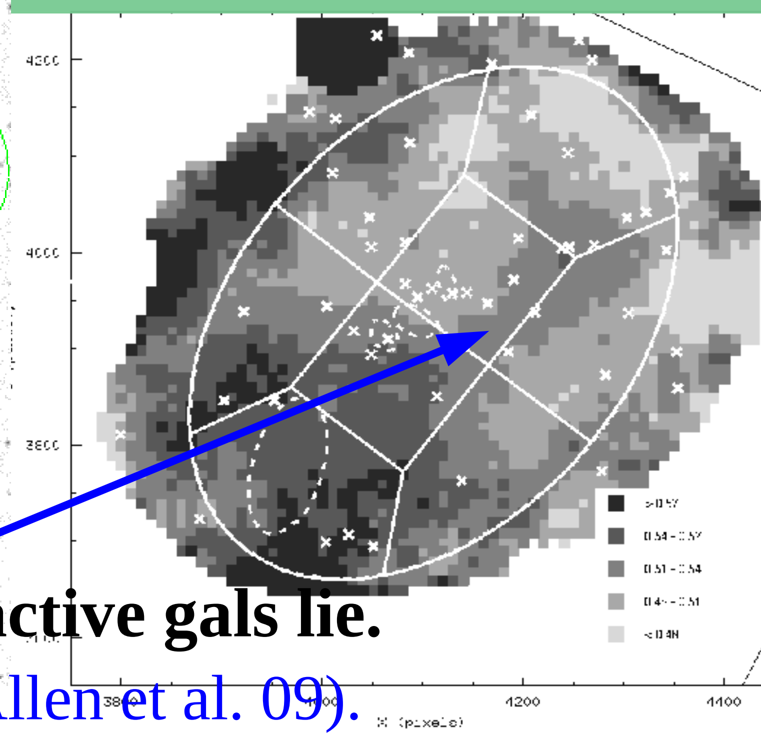
A2219, z ~ 0.22
Radio halo

(Boschin, MG, Barrena, et al. 2004, AA, 416, 839)
TNG/Dolores +CFHT multiobject spectroscopy
SE-NW cluster and cD elongation

σ_v~1400 kms-1



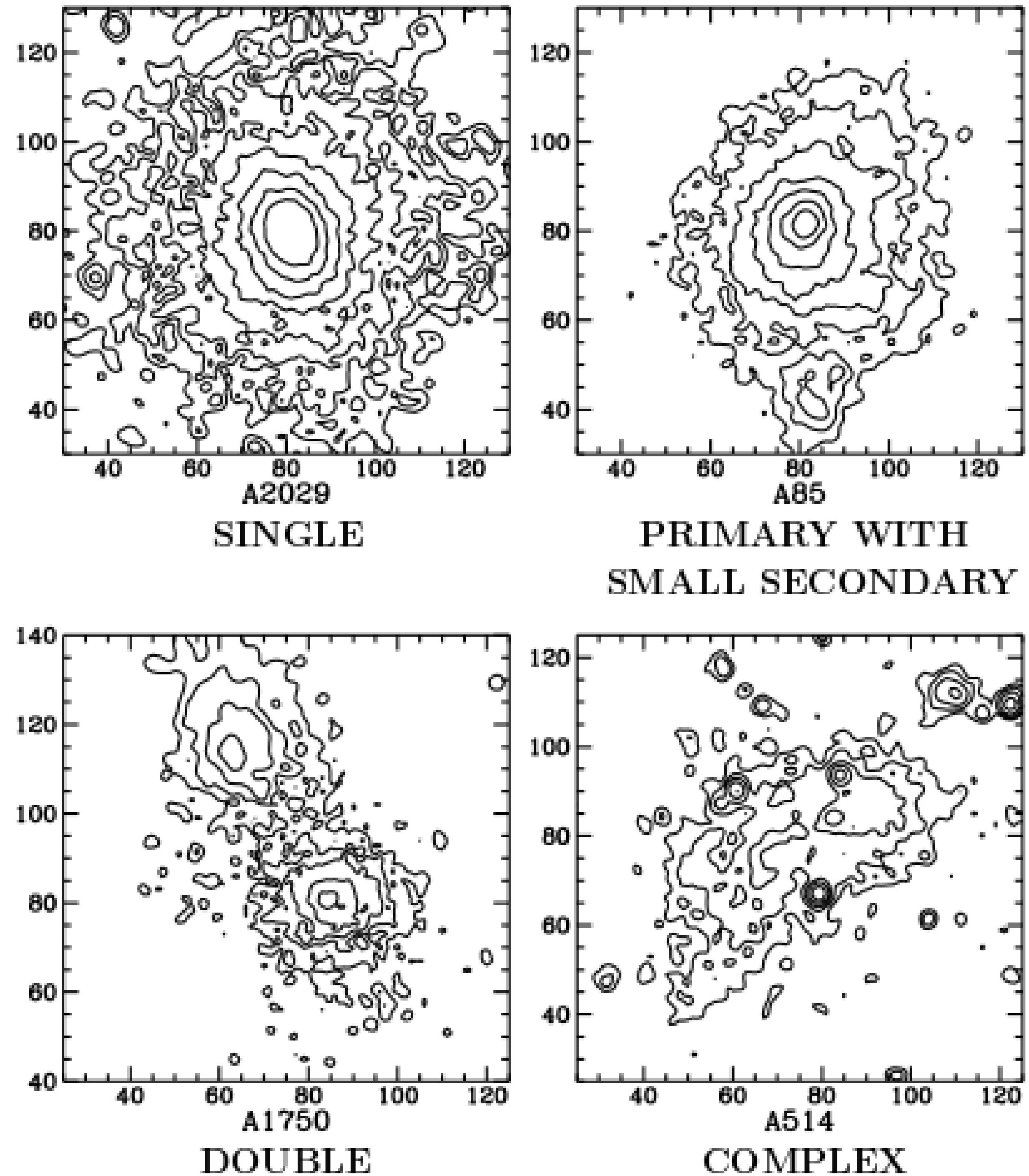




Softness ratio map: **cold filament where active gals lie.**

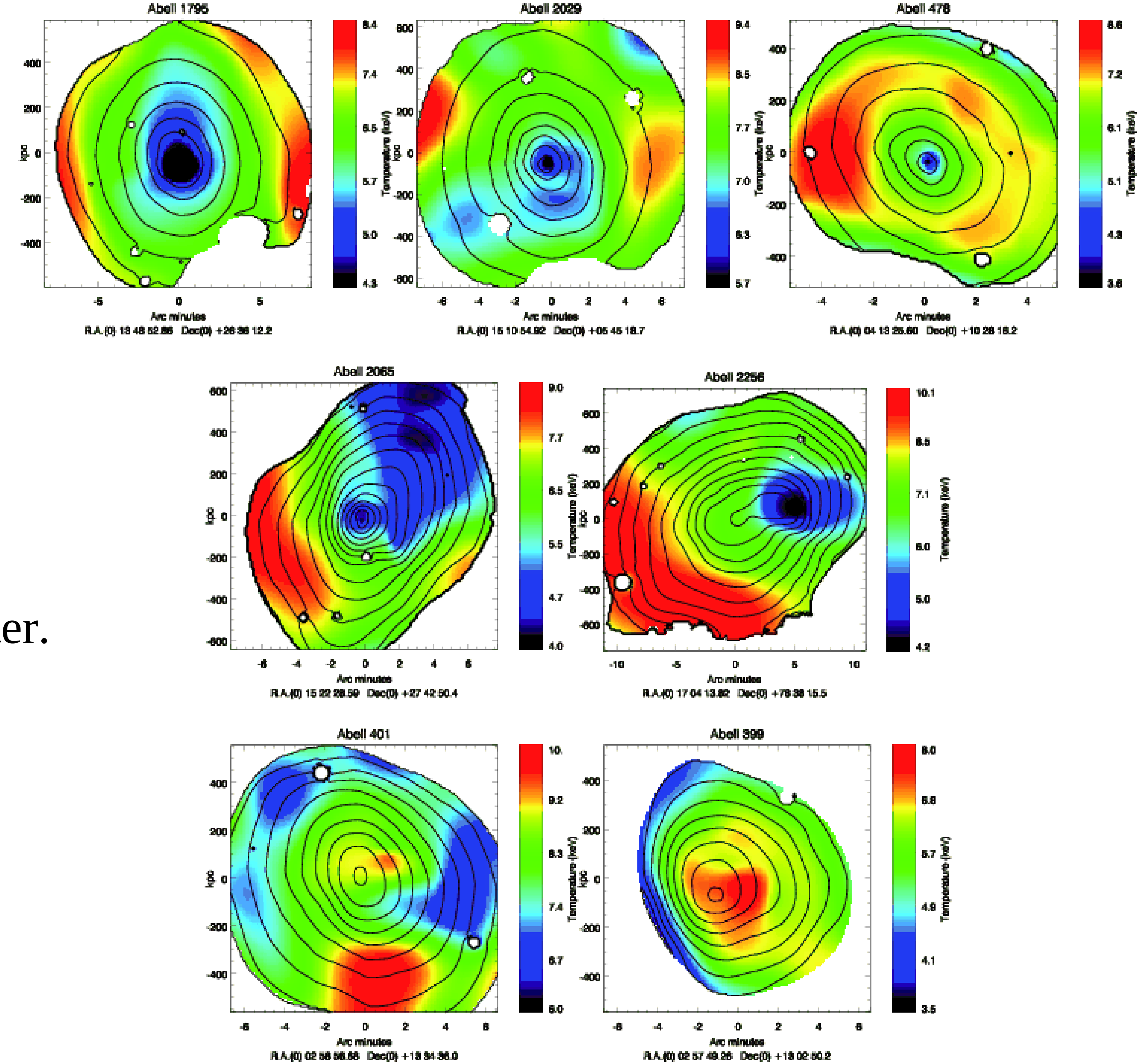
Recent discover of a cold front (Million & Allen et al. 09).

X-ray morphology
Forman 1984
Rosat data.
Surface brightness
contours.



Temperature
maps overlaid
To brightness
Isocontours.
Bourdin and
Mazzotta 2008.

A cool core
is a sign
of a relaxed cluster.



Buote 2002. A scenario for cluster evolution.

Now
Cool core
Not cooling flows.

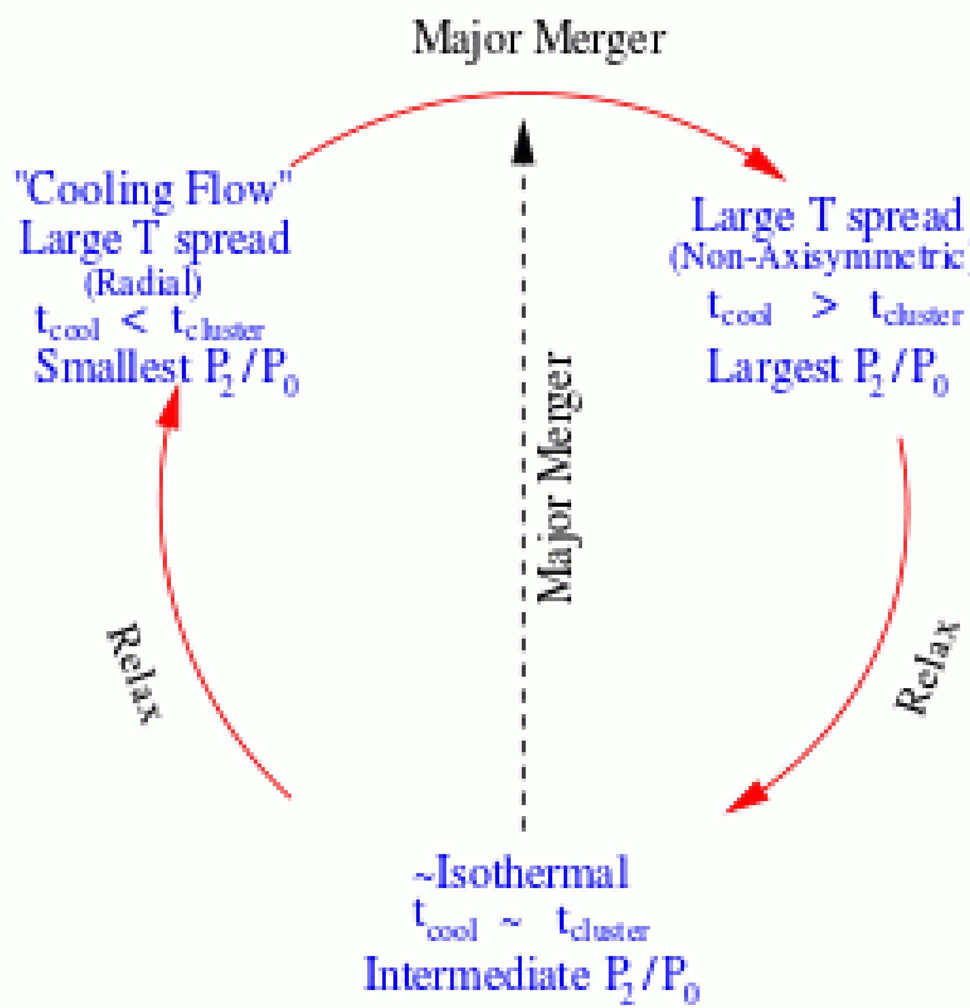


Figure 1.17. A possible description of the evolution of the X-ray temperature structure and image morphology during the formation and evolution of a cluster.