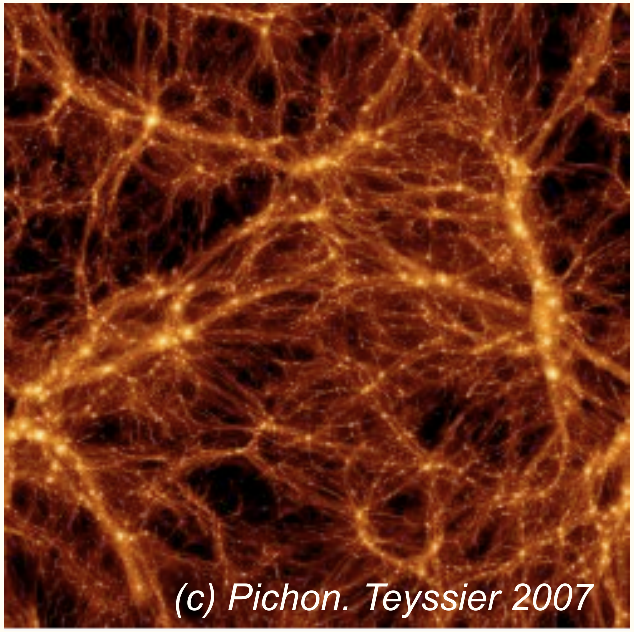
Galaxy Clusters

M.Arnaud (CEA-Sap Saclay France)

The Cosmic Web, hot baryons and clusters

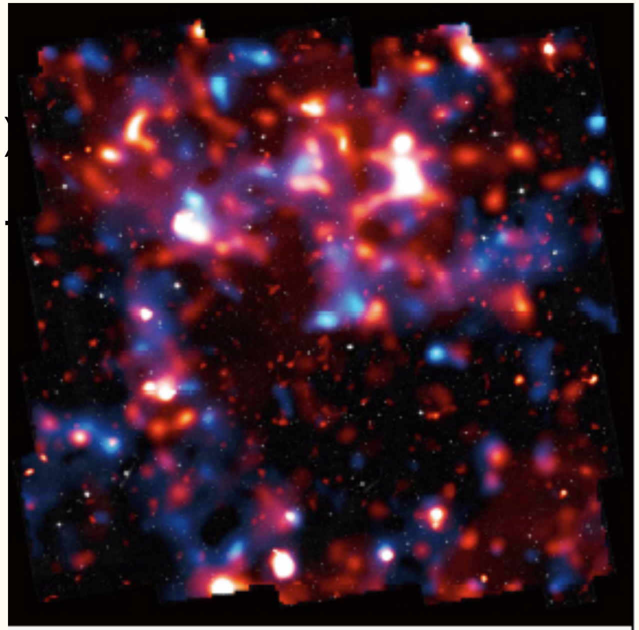


COSMOS Field:1.6 deg^2

1000 h (HST) 400 h (XMM)

ESO-VLT, CFHT, Subaru …

3D maps of
- total amount of matter
  5/6 dark matter (lensing)
- cold baryonic matter
  (opt+IR)
- hot matter XMM-Newton



R. Massey et al., 2007, Nature

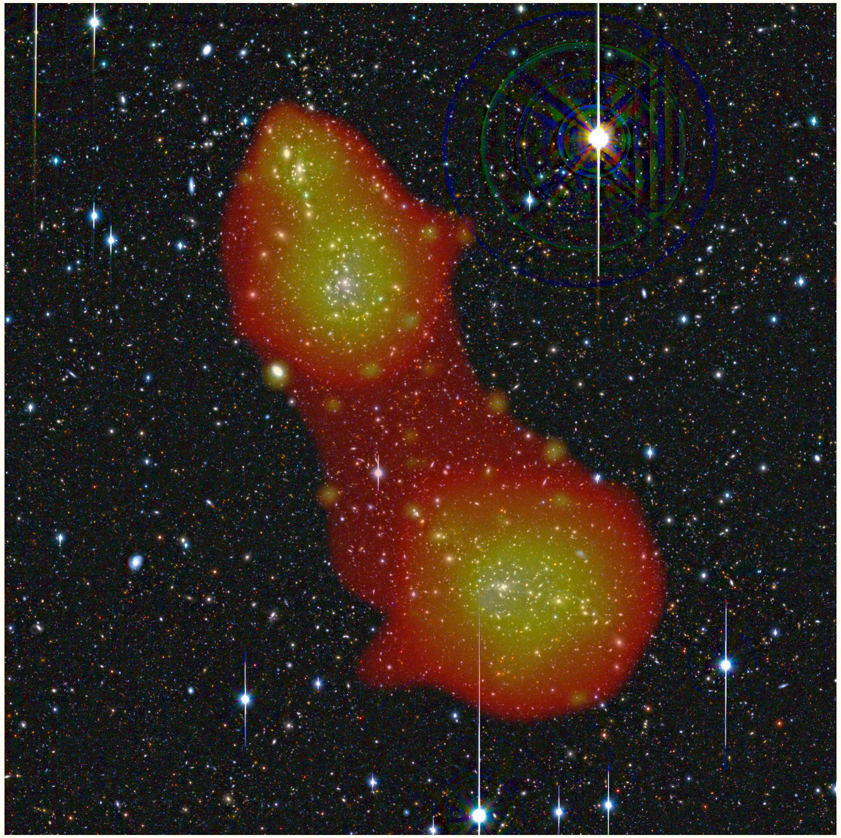
⇒ Loose network of filaments, growing over time

⇒ Normal matter accumulates along the densest concentrations of dark matter.

⇒ Consistent with predictions of gravitationally induced structure formation

⇒ hot diffuse baryons: groups at crossing of filaments; no evolution up to z=1.3
(Finoguenov et al, 07)

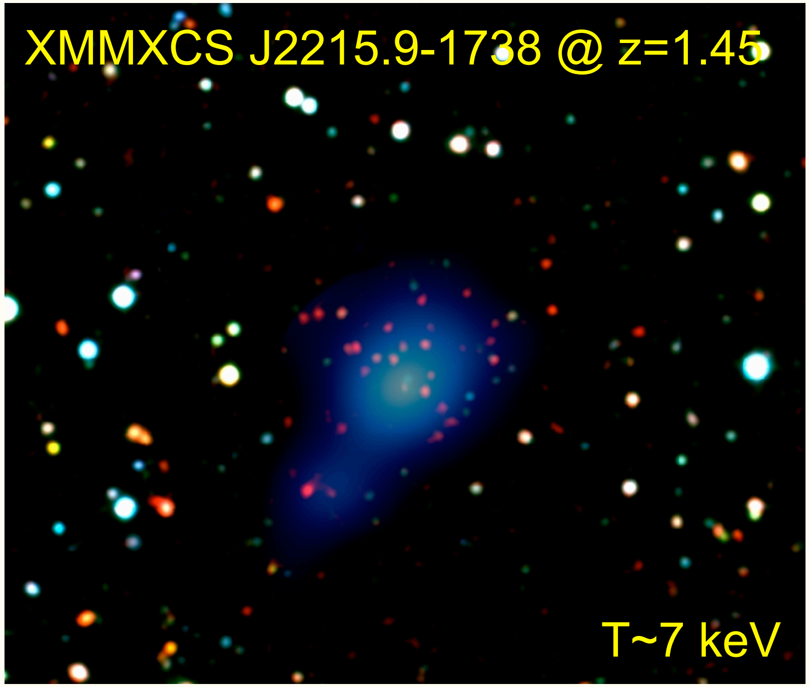
Clusters and filaments



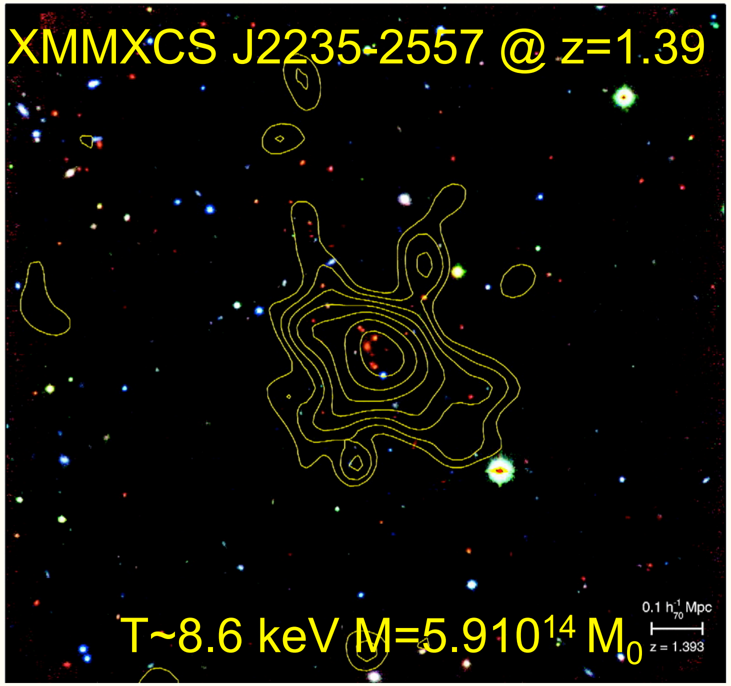
Werner et al, 2008

Detection of hot gas in the filament
connecting
the clusters of galaxies
Abell 222 and Abell 223

Clusters in the early (1/3 age) Universe



Stanford et al, 06



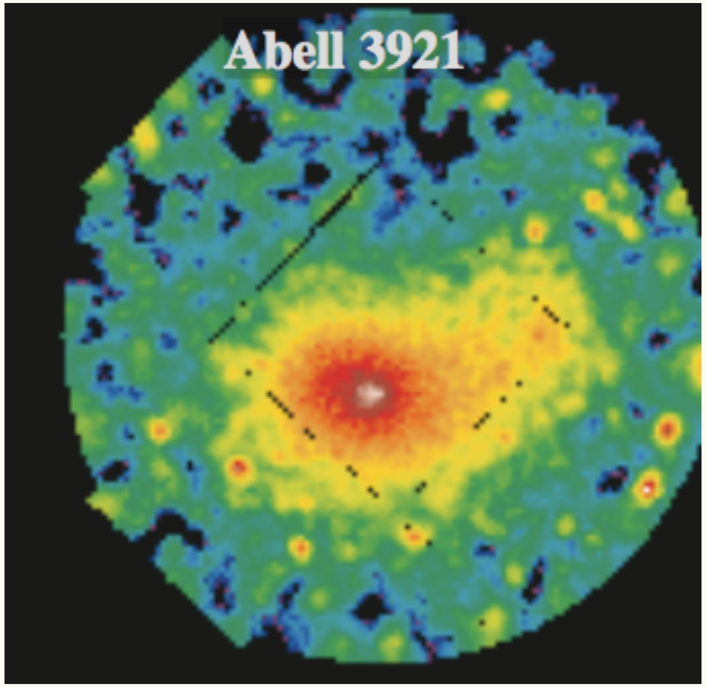
Mullis et al, 04; Rosati et al, 09

The most distant confirmed cluster

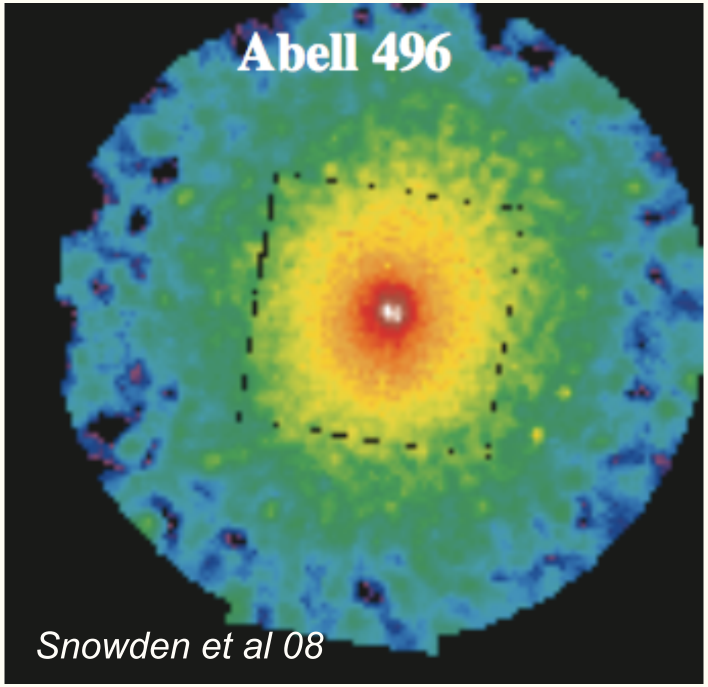
The most massive @ z>1

More with XCS on cosmology with N(M,z) …

A variety of (evolving) clusters



Dynamically young objects



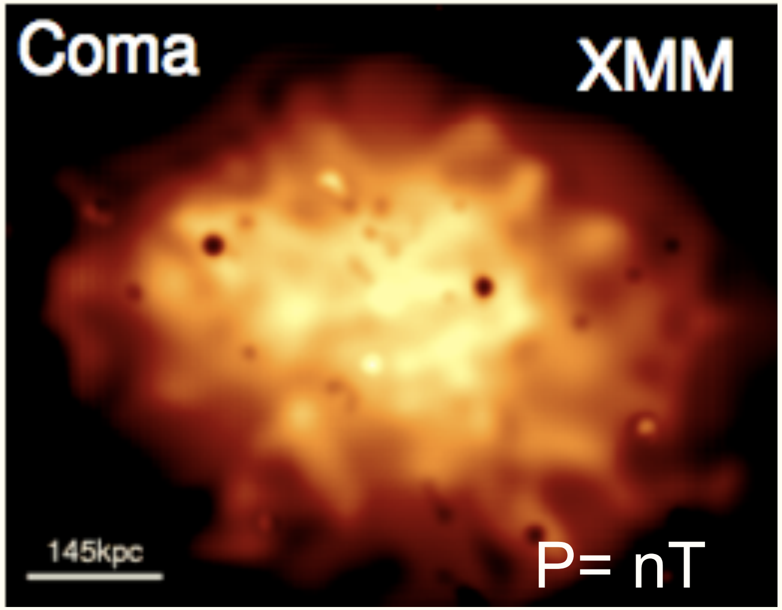
Relaxed clusters

Precise XMM-Newton spatially resolved spectroscopy ⇒ n(r), T(r)

⇒ new insight on physics of cluster formation

Physics of mergers

Bohringer& Werner, 09

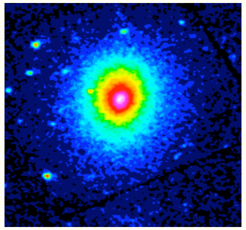


Schuecker et al, 04

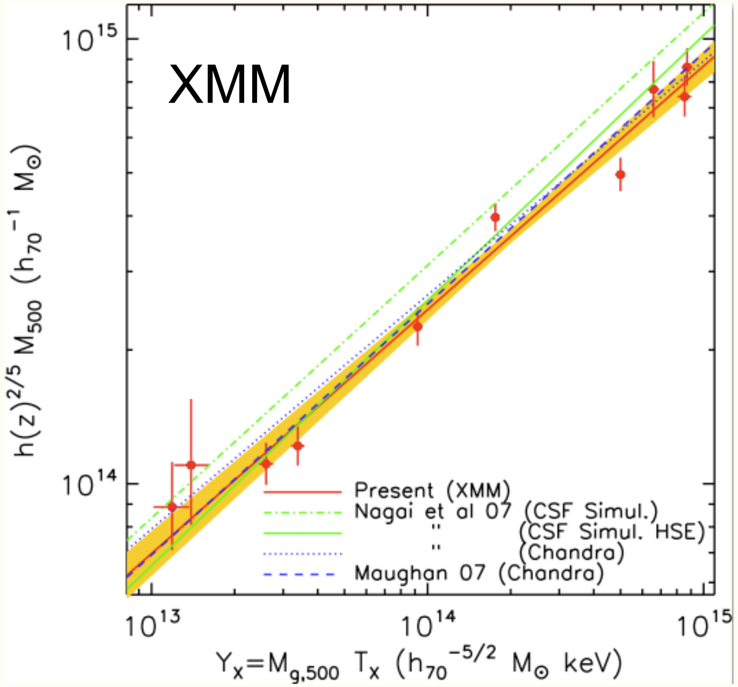
Turbulence induced by merger events

Synergy with radio (LOFAR) and HE (Fermi, CTA..) NT emission

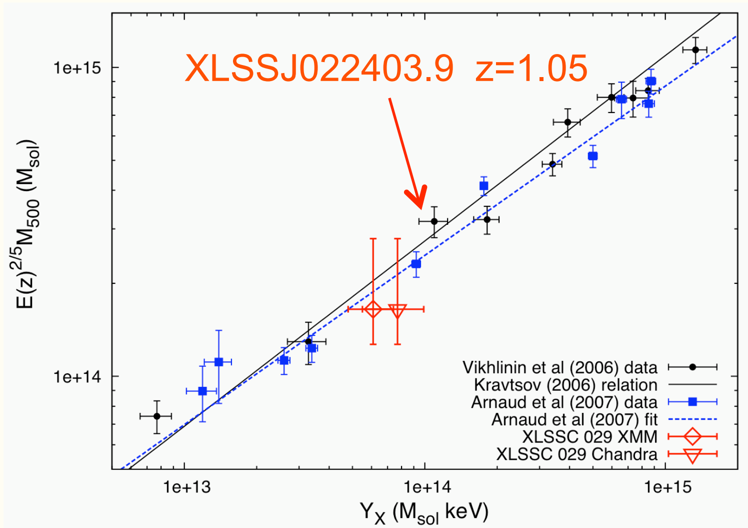
Weighting clusters



$$M(r) = -\frac{kT}{G\mu m_p}\left[\frac{d\ln n_e}{d\ln r} + \frac{d\ln T}{d\ln r}\right]$$



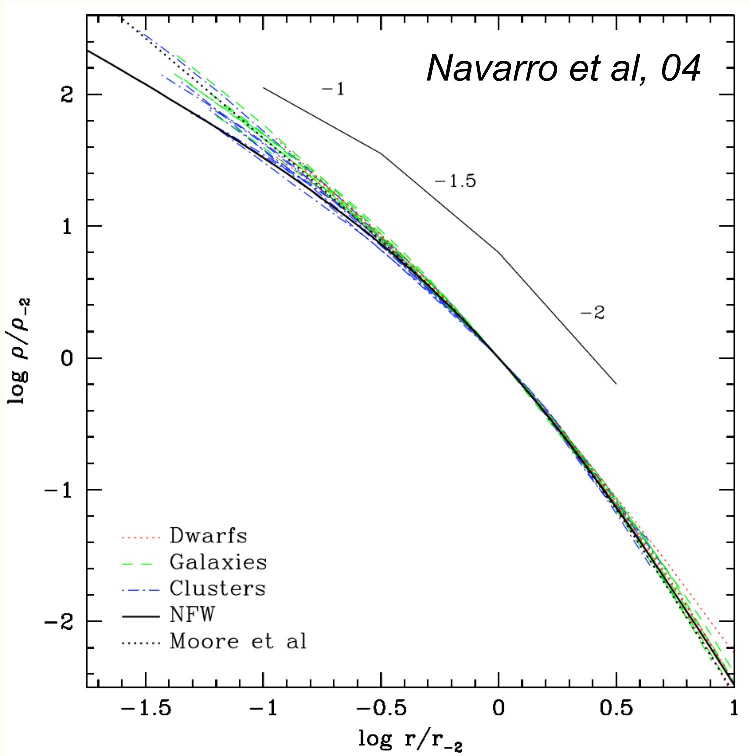
Arnaud et, 07



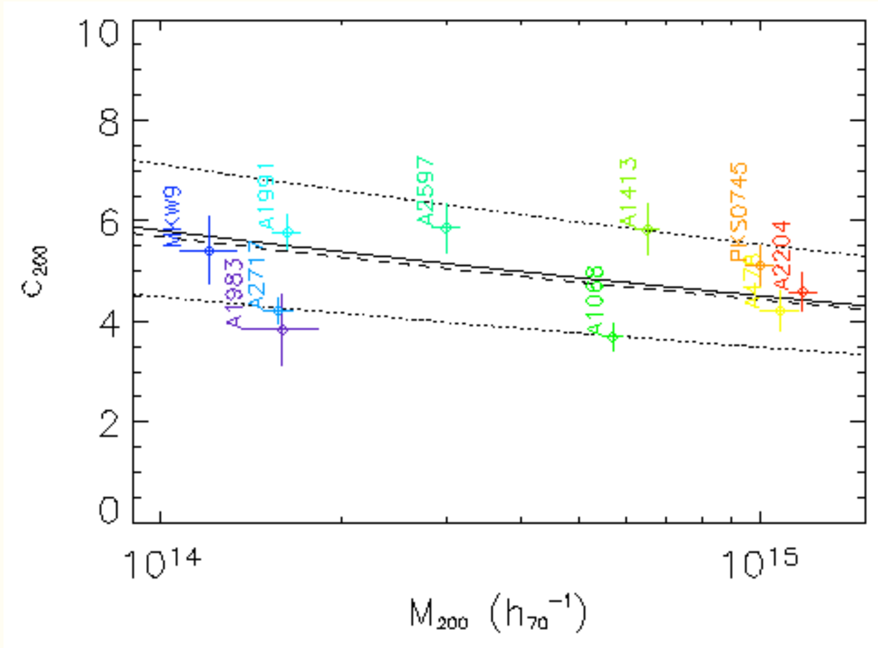
Maughan et al, 08
See also Kotov & Vikhlinin, 07

Precise converging calibration of the *local* mass-proxy relation with likely standard evolution up to high z

Dark matter distribution



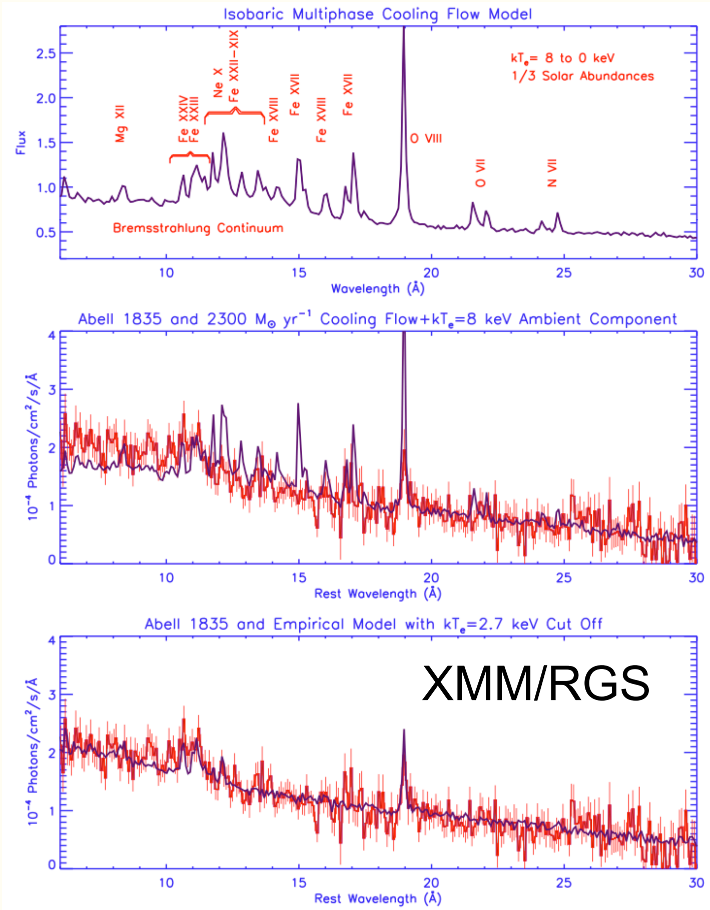
ΛCDM simulations of structure formation:
Universal $\rho/\rho_c(z)$ cuspy profiles



Pointecouteau et al, 05
See also Vikhlinin et al, 06; Buote et al, 07

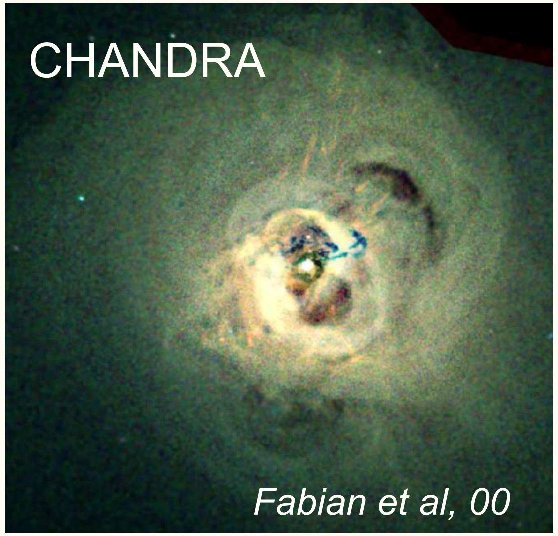
Universal profile shape as expected from simulations
DM collapse well understood

New vision of Cooling Cores



Peterson et al, 01

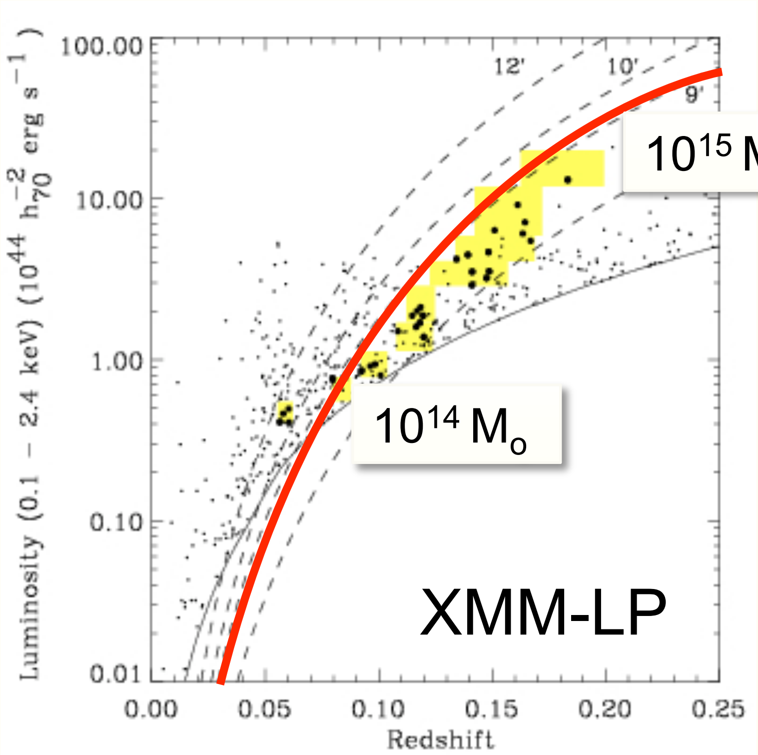
Cooling not as expected



AGN regulates cooling

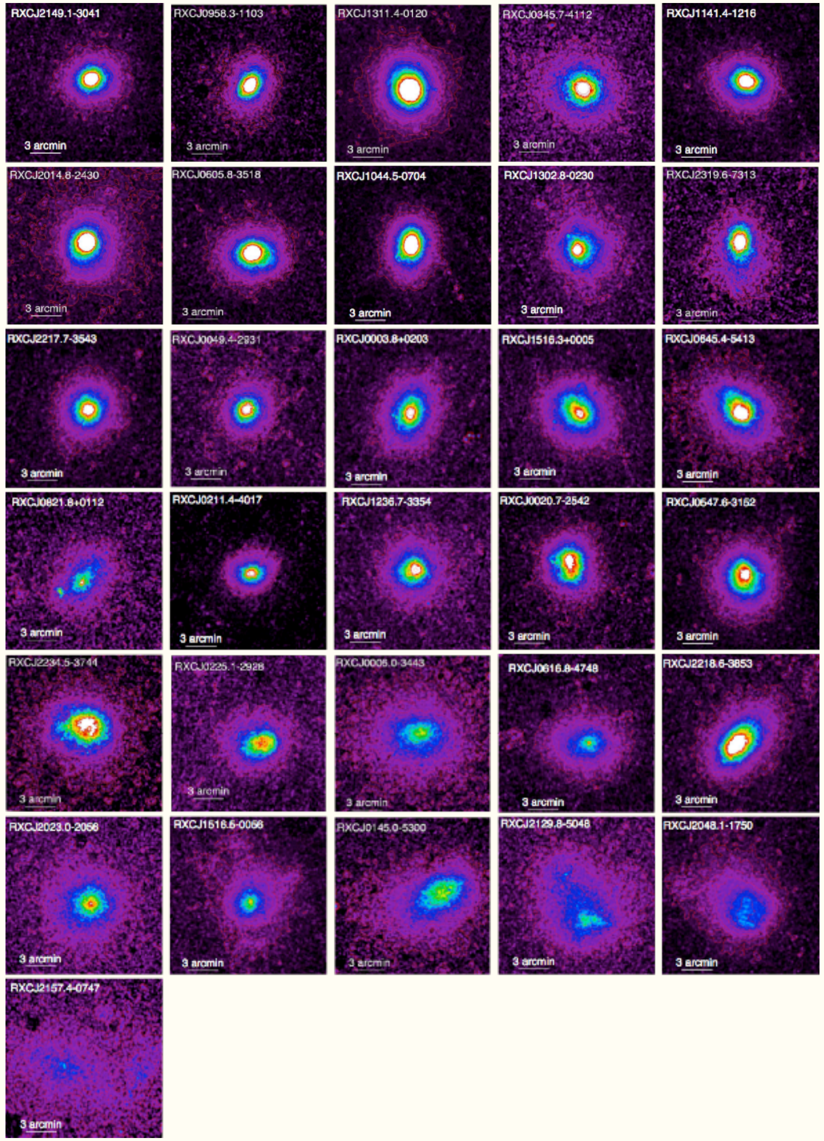
Specific gas physics
cooling non-gravitational heating
in center & at large scale
not well understood

Statistical properties



Böhringer et al 2007

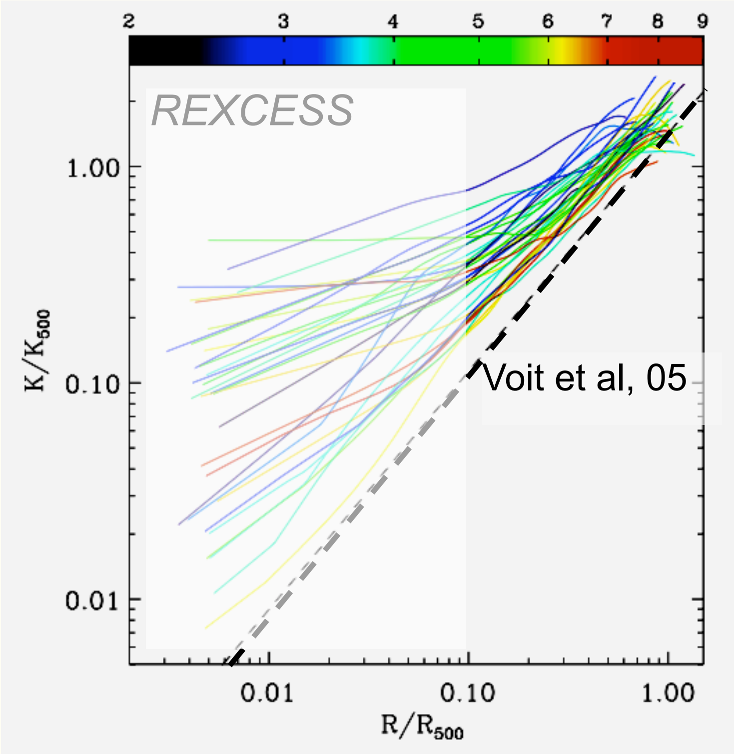
from REXCESS
representative cluster sample

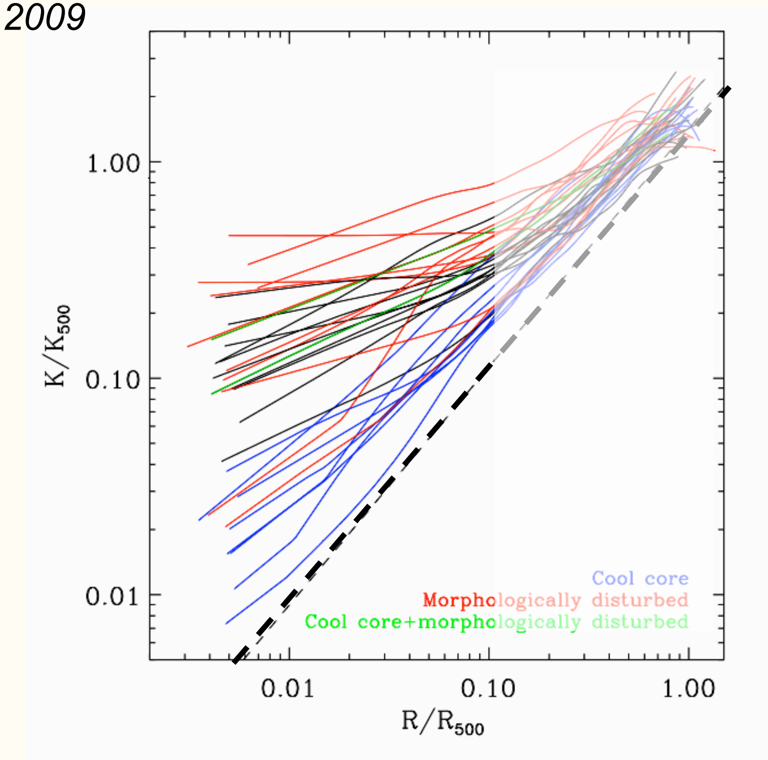


Entropy and thermo-dynamical history

$K=T/n^{2/3}$

Pratt et al 2009





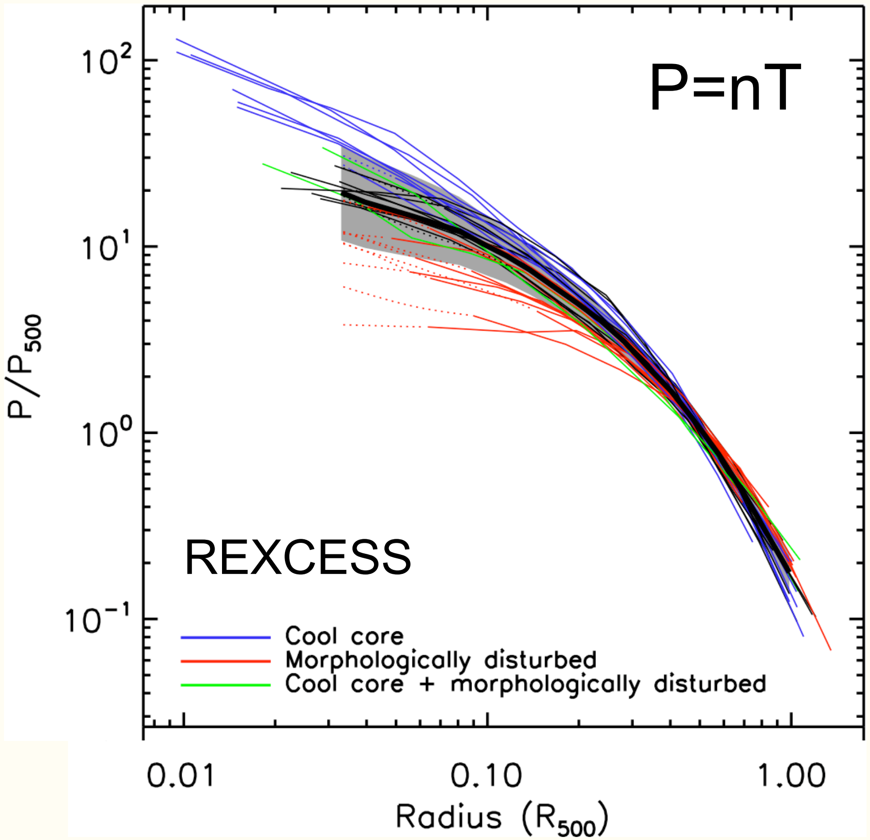
Entropy excess due to non-grav processes
Increase with decreasing mass
Less pronounced towards outskirt

Increased dispersion in the core due to non-grav processes

and

dynamical history

Pressure profiles



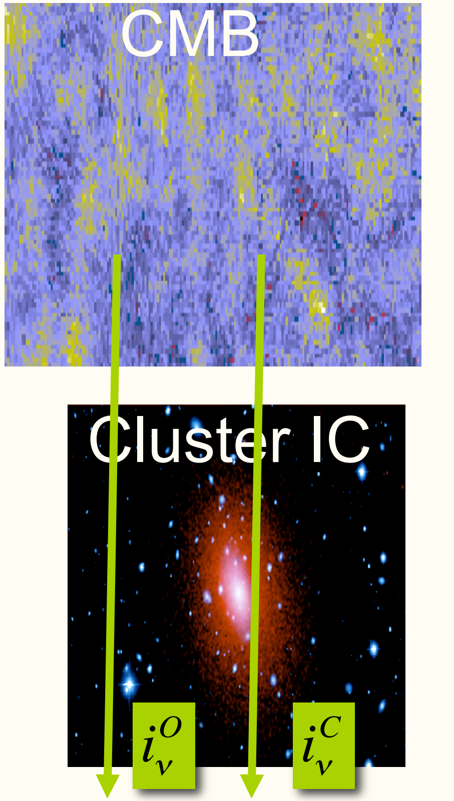
Arnaud et al 2009

Much lower dispersion
Pressure less (little) affected by non-grav processes
and
dynamical history

⇒universal pressure profile

Pressure scaled by $P_{500} \equiv M^{2/3}$

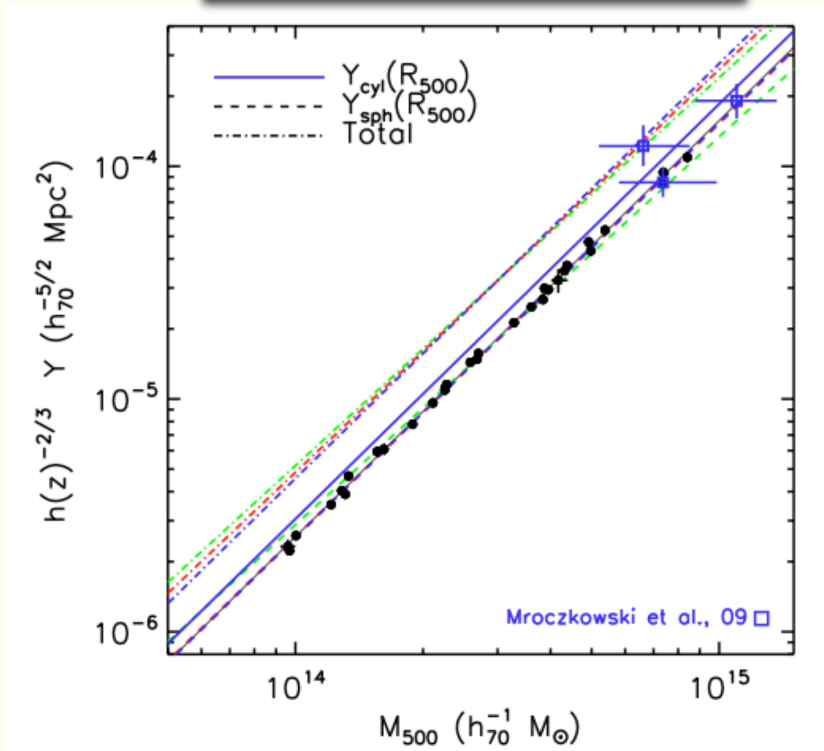
Pressure and Sunayev-Zel'dovich effect



$$\Delta i_\nu \ \alpha \ y \ \alpha \int_{los} n_e T dl$$

no $(1+z)^4$ dimming

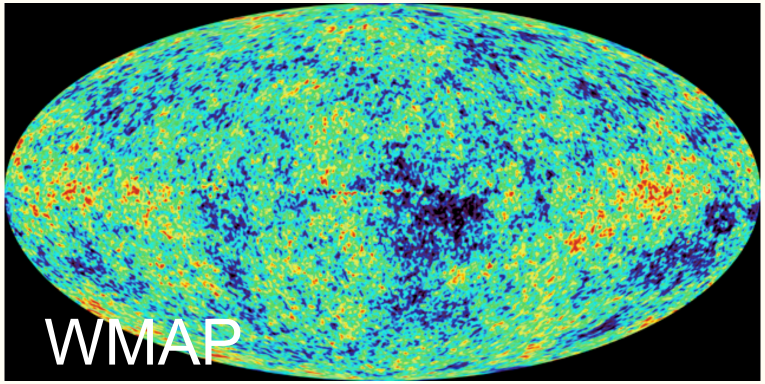
$$Y \ D_A^2 = \int_{amas} y \, d\Omega \ \alpha \int P \, dV$$

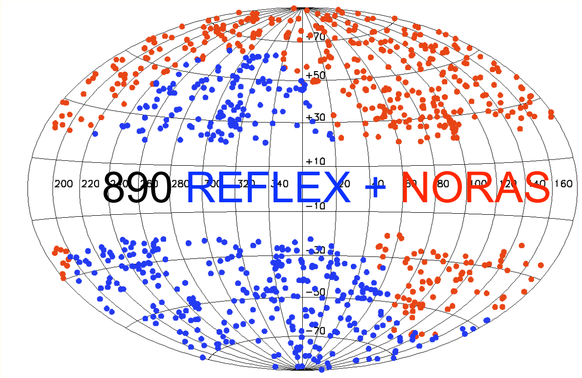


Arnaud et al 2009

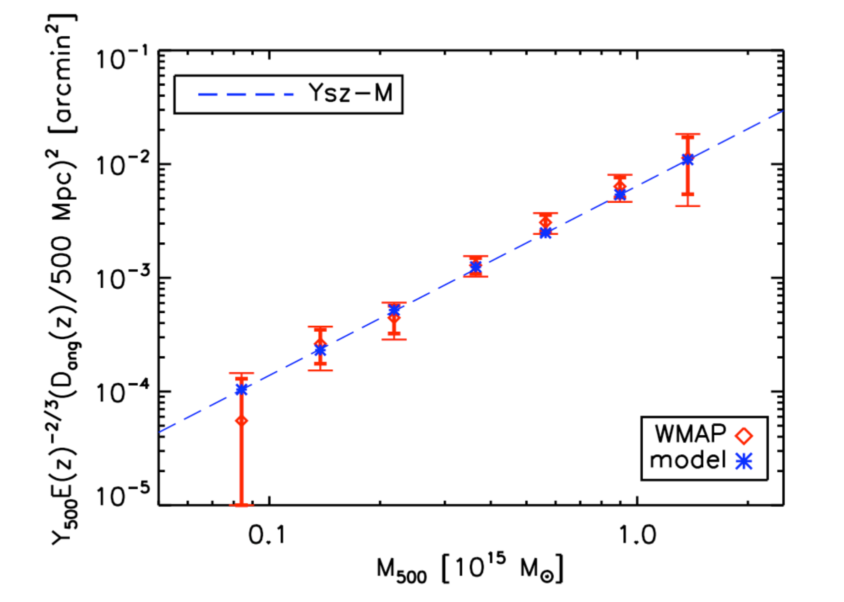
Y closely related to the mass
Y_{SZ}-M prediction
from REXCESS universal profile

Y_{SZ}- M from WMAP



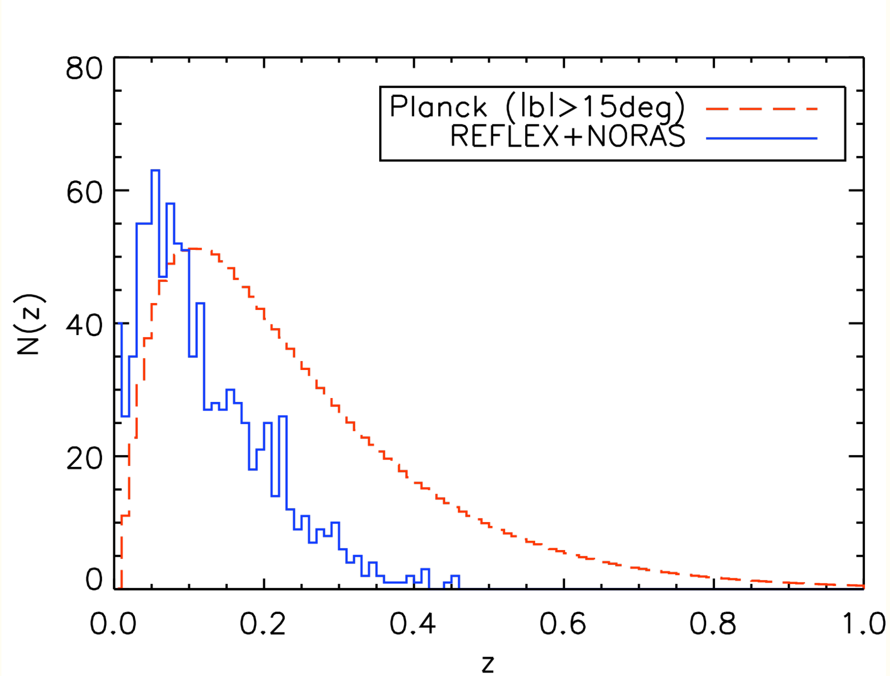


Melin et al to be subm.



Direct SZ data from WMAP in good agreement with XMM predictions

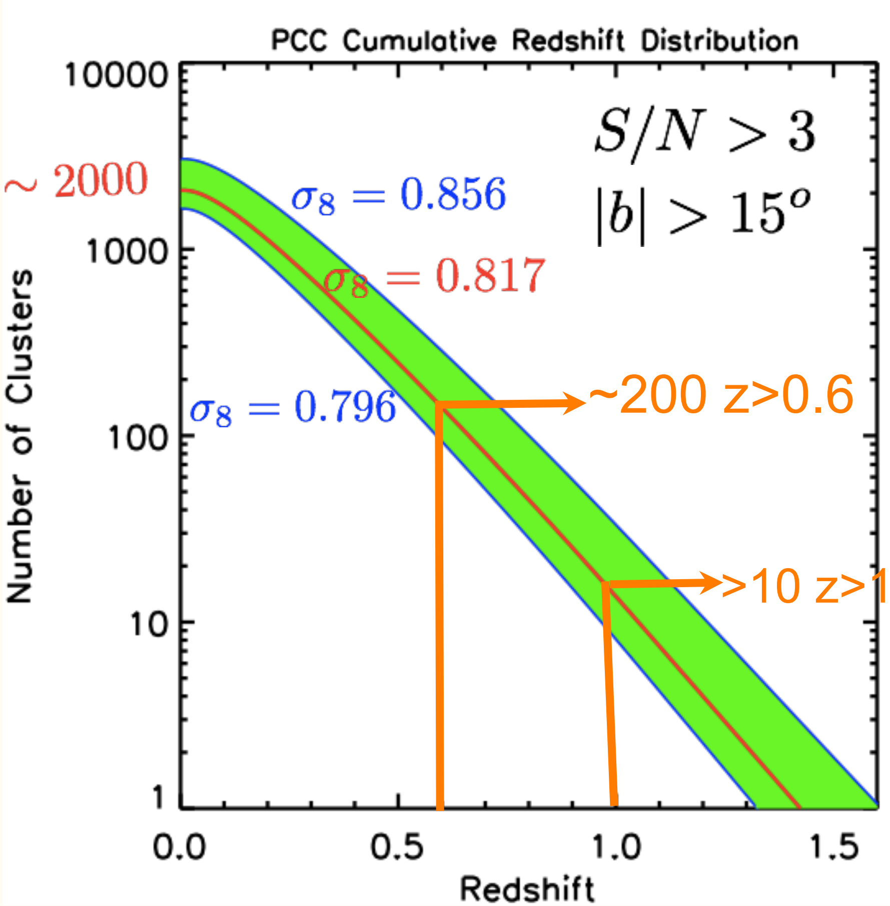
Planck SZ All-sky survey



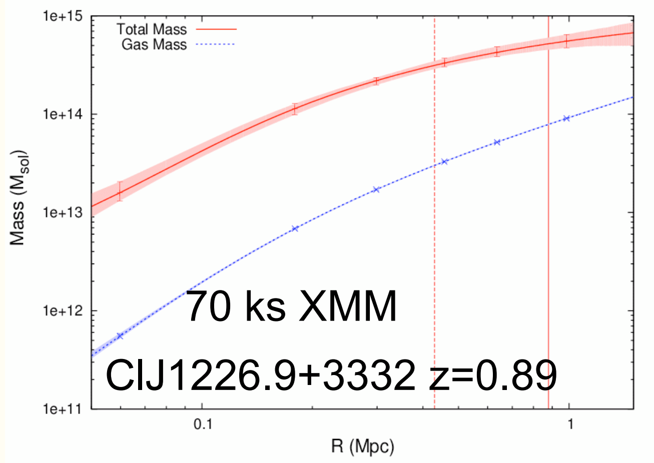
Courtesy of A. Chamballu & J.Bartlett;
See also Bartlett et al, AN, 08

Gain of SZ surveying
Close to mass selected survey
Efficient at high z

Planck & XMM-Newton



Maughan et al., 2007



All hot, luminous systems

⇒ ~50-fold increase in sample size of massive clusters

⇒ with XMM follow-up:
- ⇒ evolution of c(M) at high M
- ⇒ cosmo from $f_{gas}(z)$, N(Y[M],z)

CONCLUSION

- new instrument (RGS) ⇒new (unexpected) vision of cluster

- high throuput spatially resolved spectroscopy (EPIC)
  ⇒much clearer view of complex cluster formation physics

- importance of large samples, deep observations
  e.g deep RGS on center; low mass and/or high z clusters

- new discovery space open in distant universe from SZ surveys