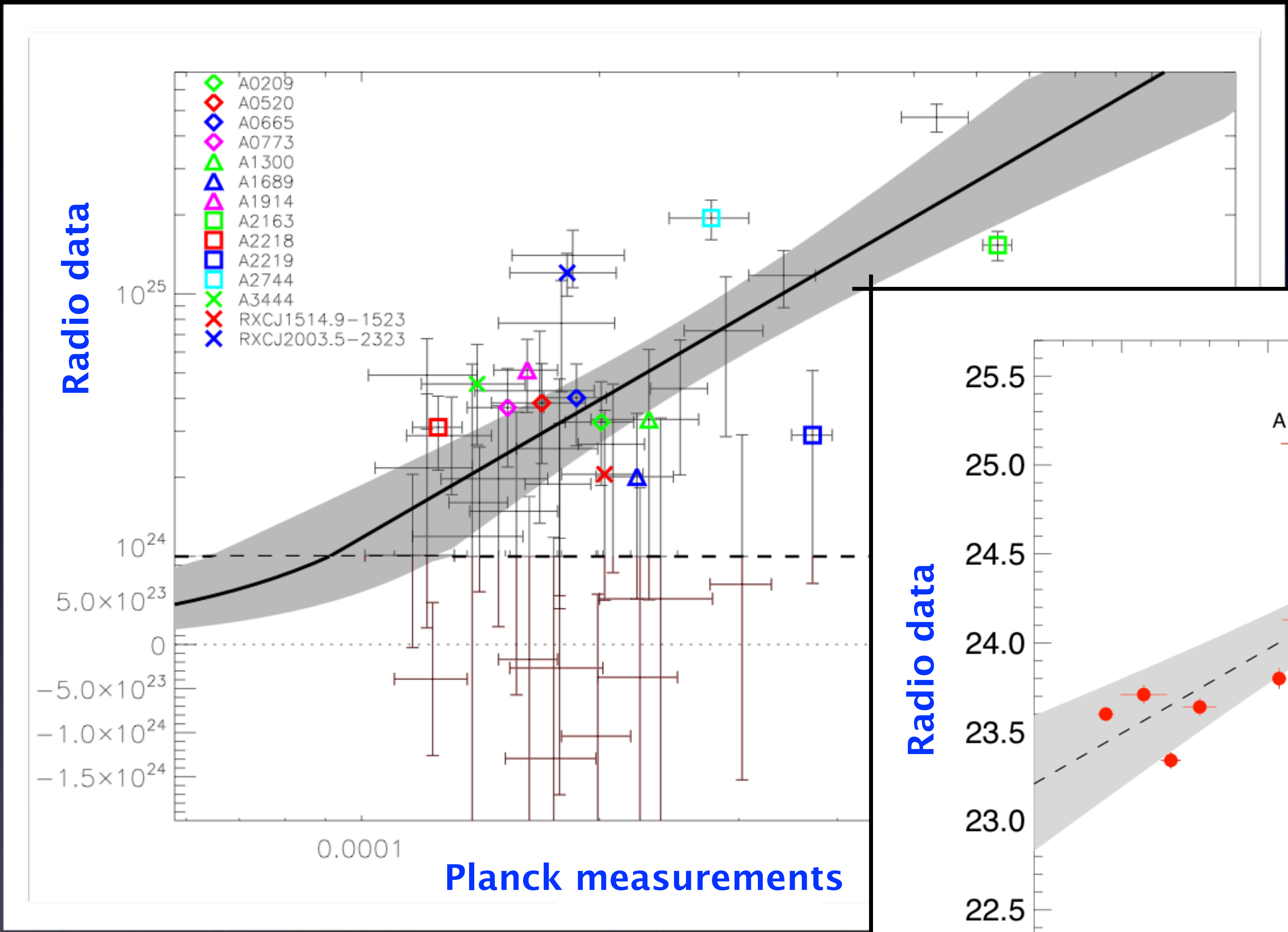
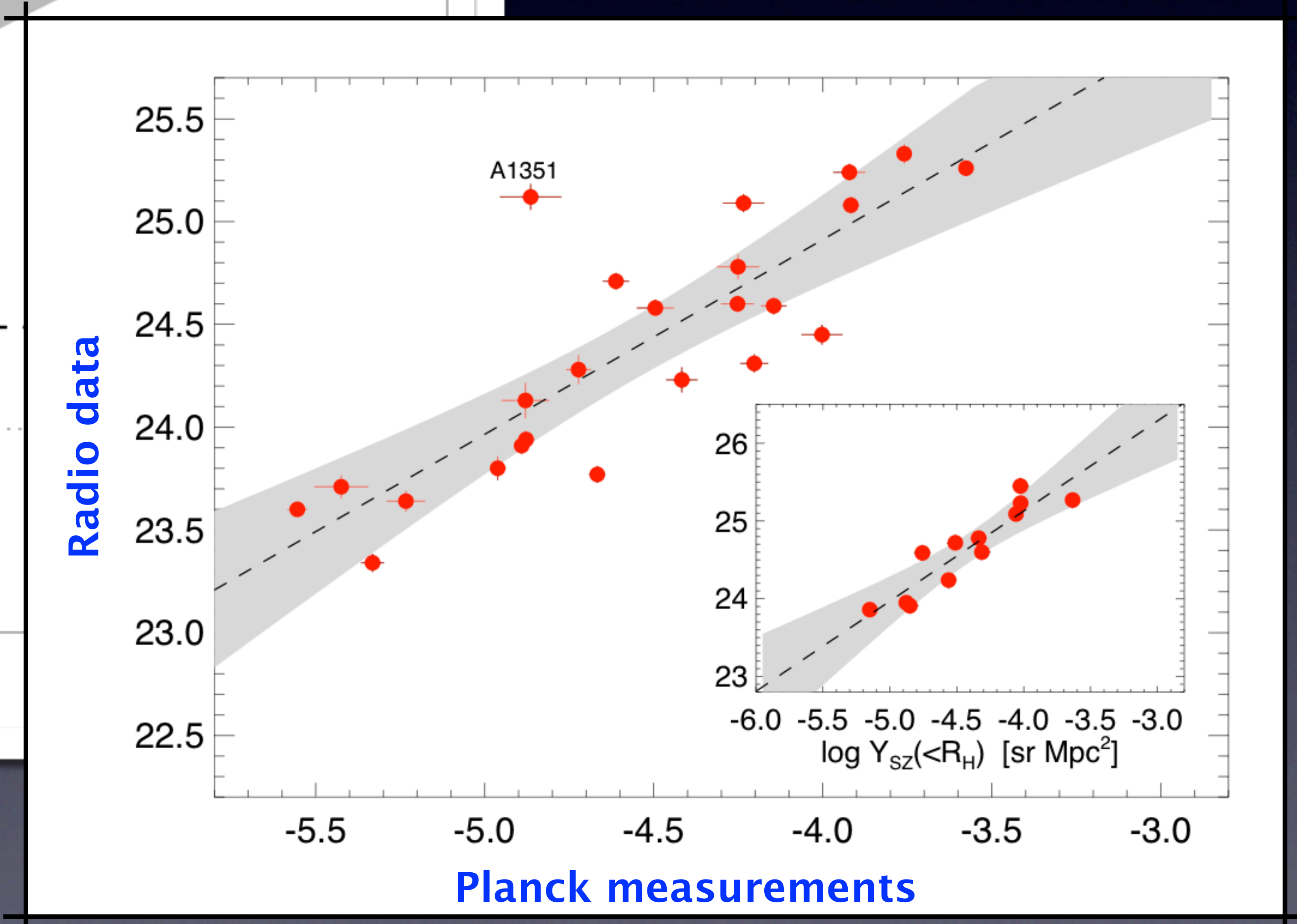
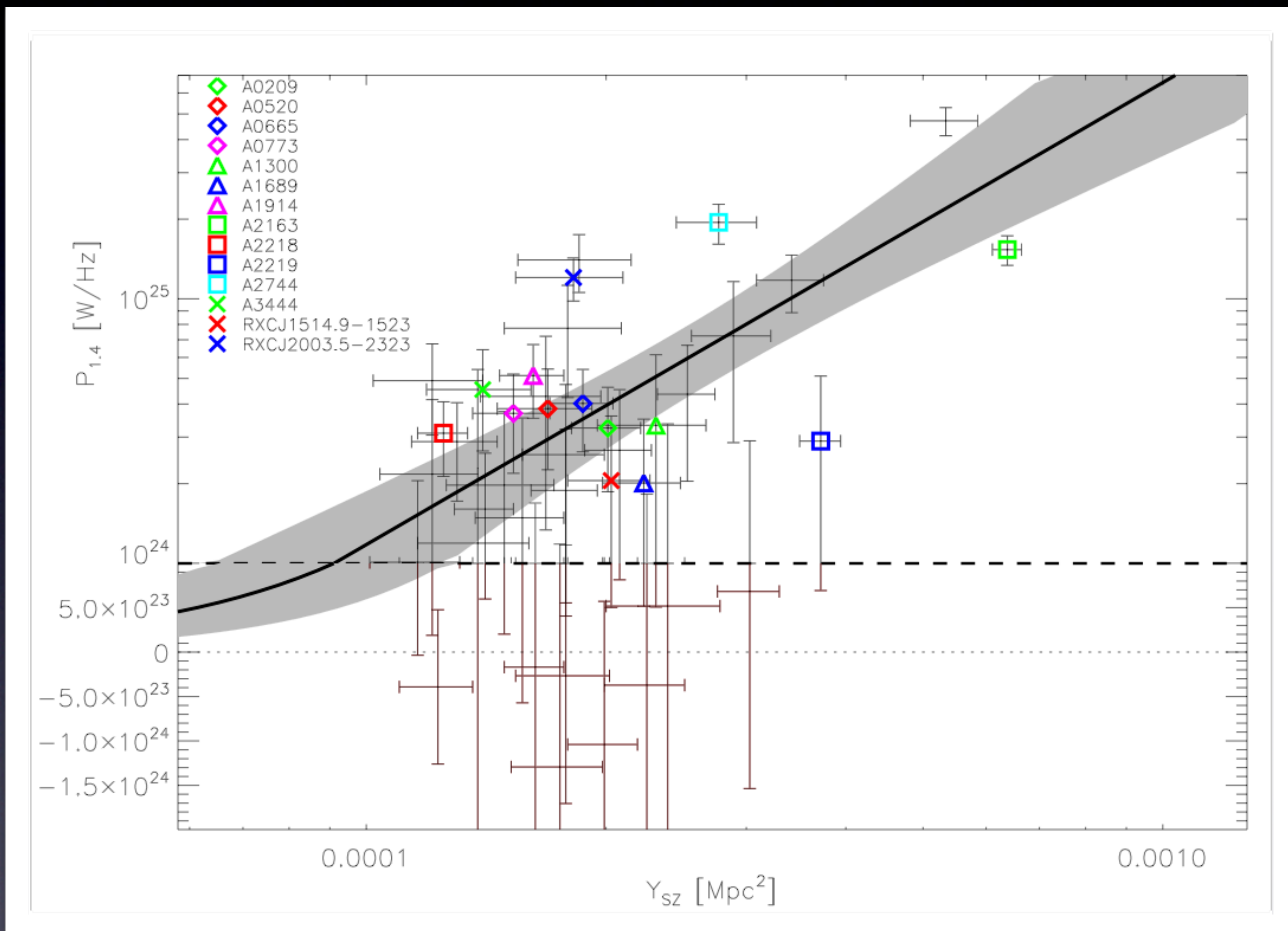
The role of *Planck* in understanding galaxy cluster radio halos





The role of *Planck* in understanding galaxy cluster radio halos



Kaustuv Basu

Martin W. Sommer

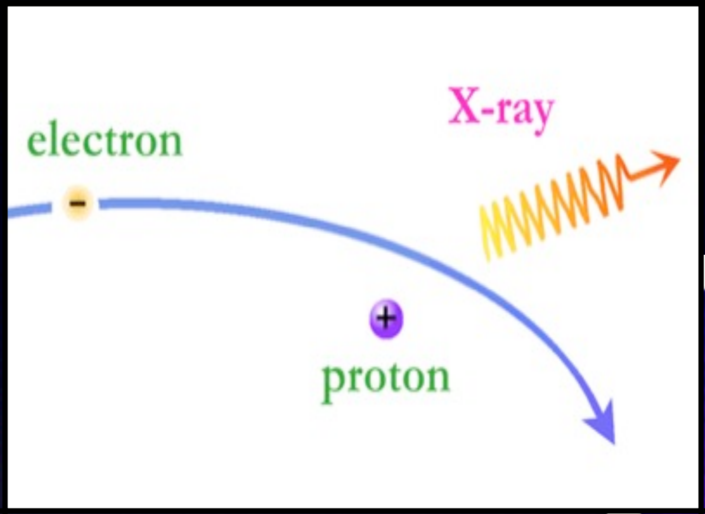
Argelander Institute for Astronomy, University of Bonn

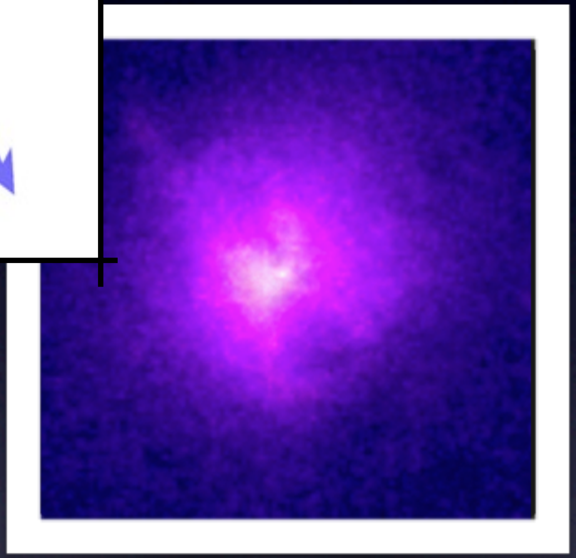
Outline of This Talk

- ☐ *Thermal and non-thermal emissions from galaxy clusters*
- ☐ *Radio halos: known properties and unknown puzzles*
- ☐ *The new radio-SZ correlation for radio halos*
- ☐ *Analysis of complete X-ray and SZ selected samples*
- ☐ *Understanding the selection difference, conclusions*

The Intra-Cluster Medium (ICM)

Thermal X-ray Emission

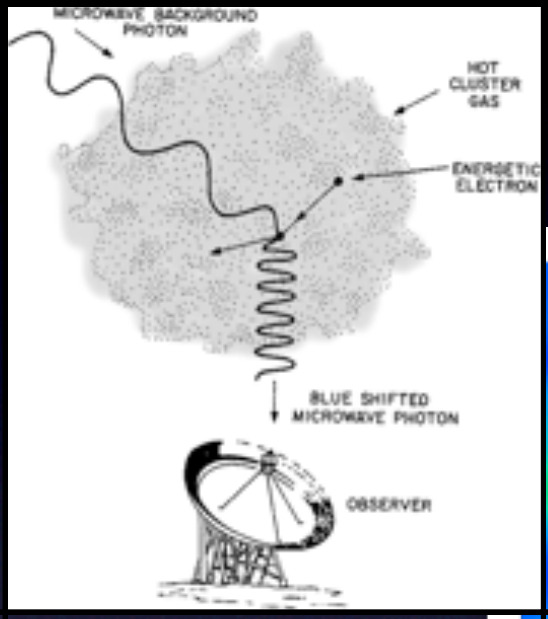


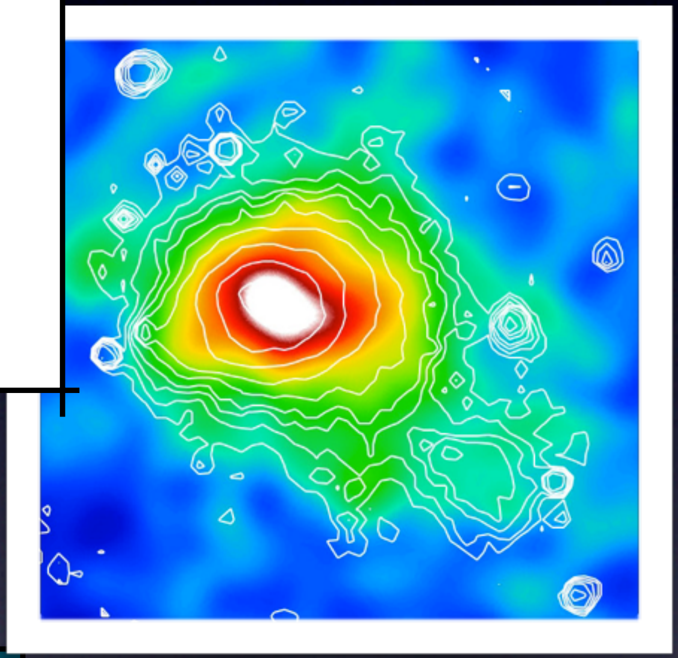


X-ray ~ $n_e^2\ \Lambda(T_e)$

The hot, ionized ICM emits in the X-rays due to thermal bremsstrahlung. X-ray surface brightness depends on the gas density squared, weakly varying with the gas temperature below ~2 keV band.

Sunyaev-Zel'dovich Effect

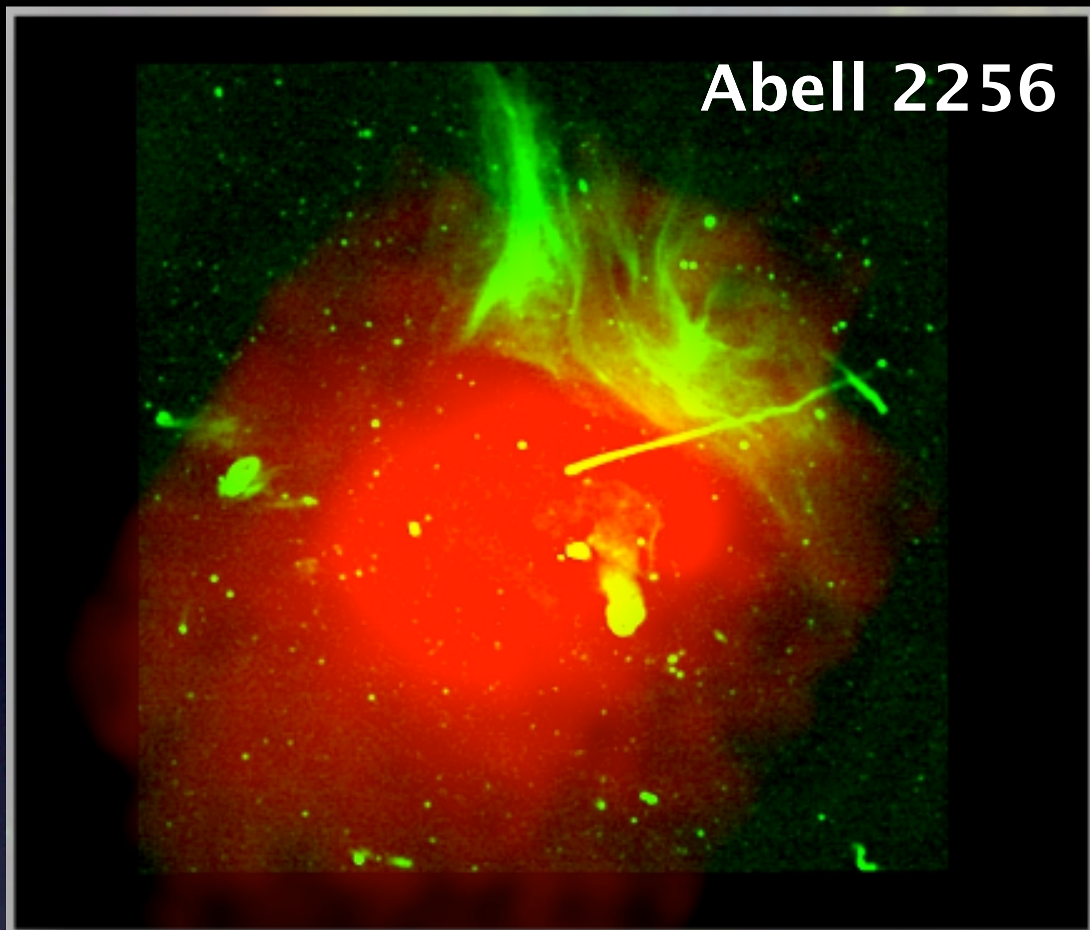




SZE ~ $n_e\ T_e$

The same electrons in the ICM causes (inverse) Compton scattering of the background CMB photons, known as the Sunyaev-Zel'dovich effect. Signal is proportional to the gas pressure.

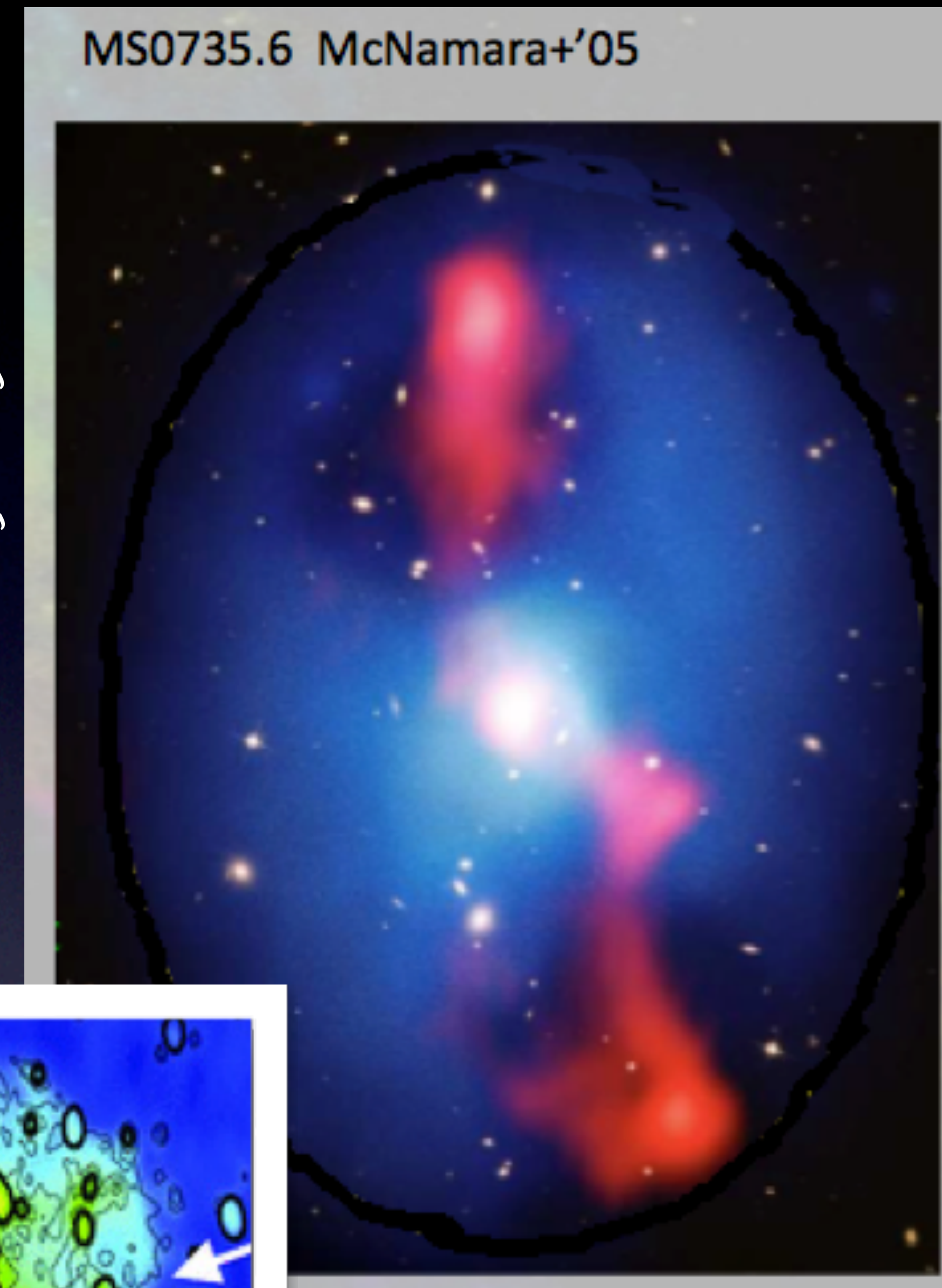
Non-Thermal ICM



Rudnick, Owen, Eliek et al.

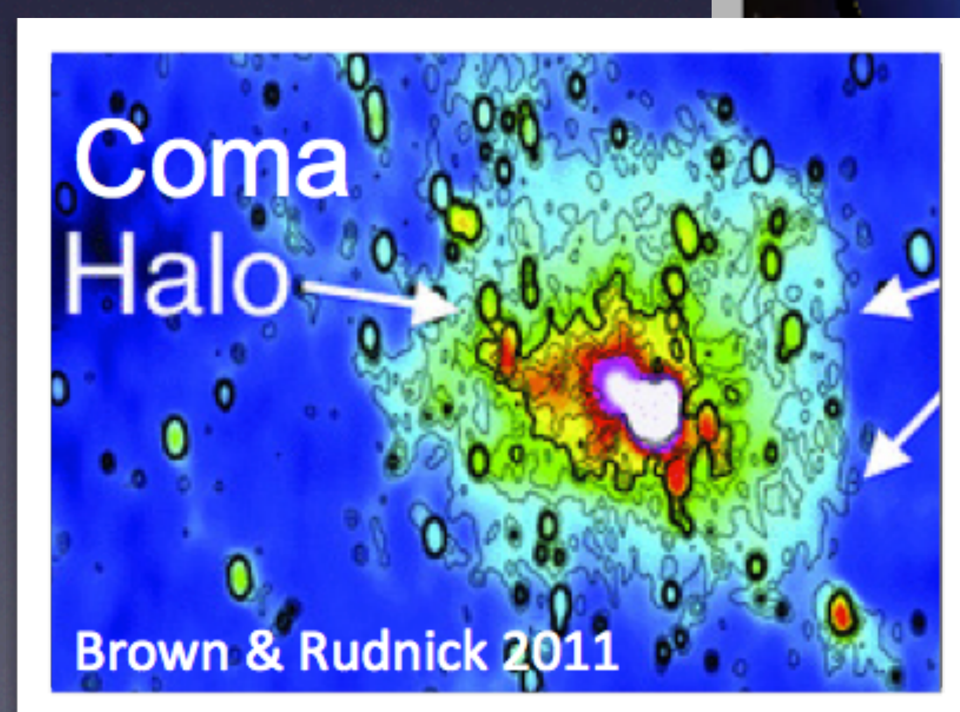
AGN related

Radio jets and lobes,
WAT sources,
plasma bubbles,
AGN relics
etc.



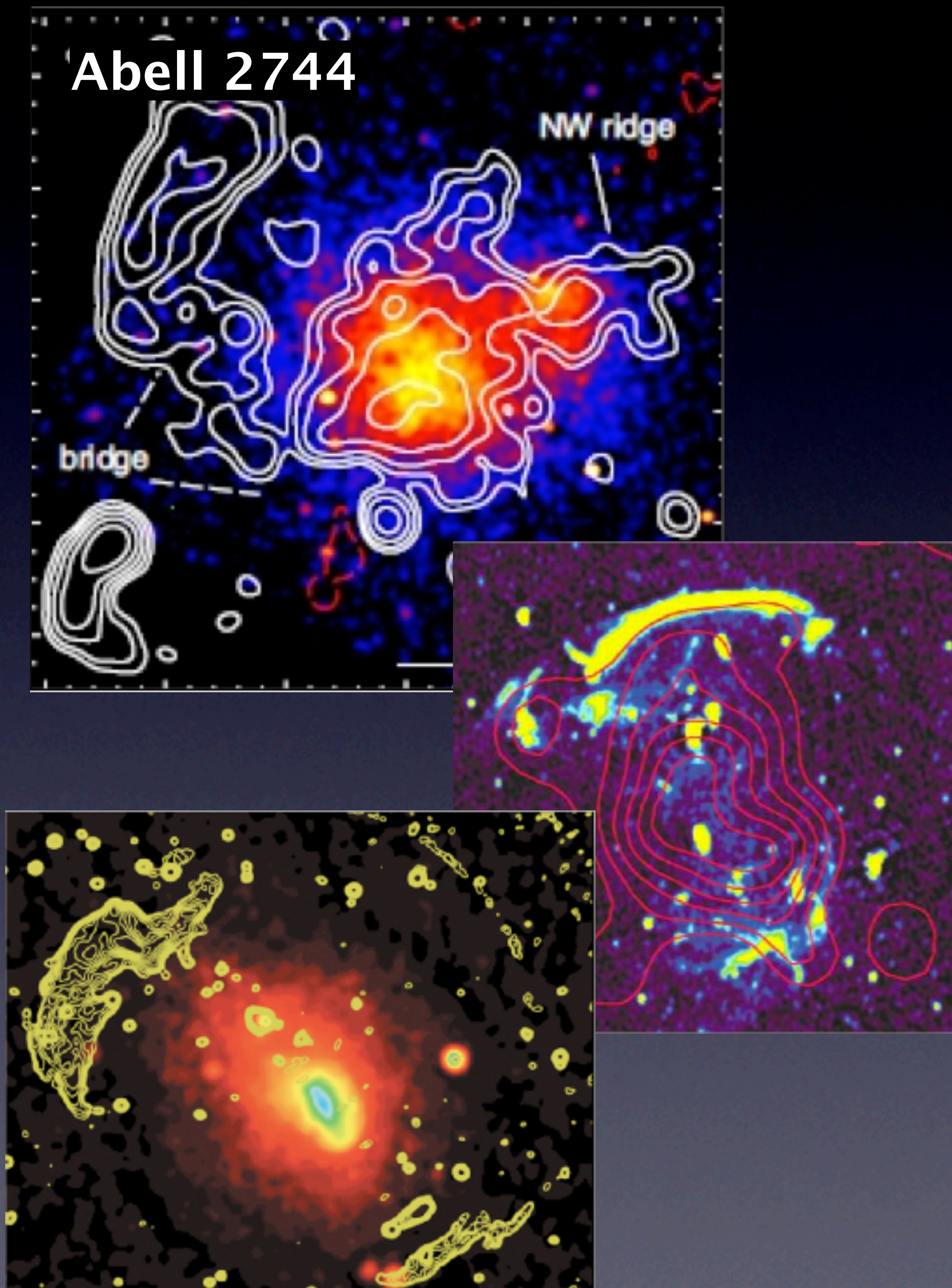
Diffuse radio emissions

Radio halos,
radio relics,
mini halos, radio gischt
radio phoenix etc.



Halos and relics are most common, likely relating to particle acceleration in shocks

Diffuse Radio Emission in Clusters



Radio Halos ($L_{1.4GHz} \sim 10^{24}$-10^{26} h_{70}^{-2} Watt/Hz)

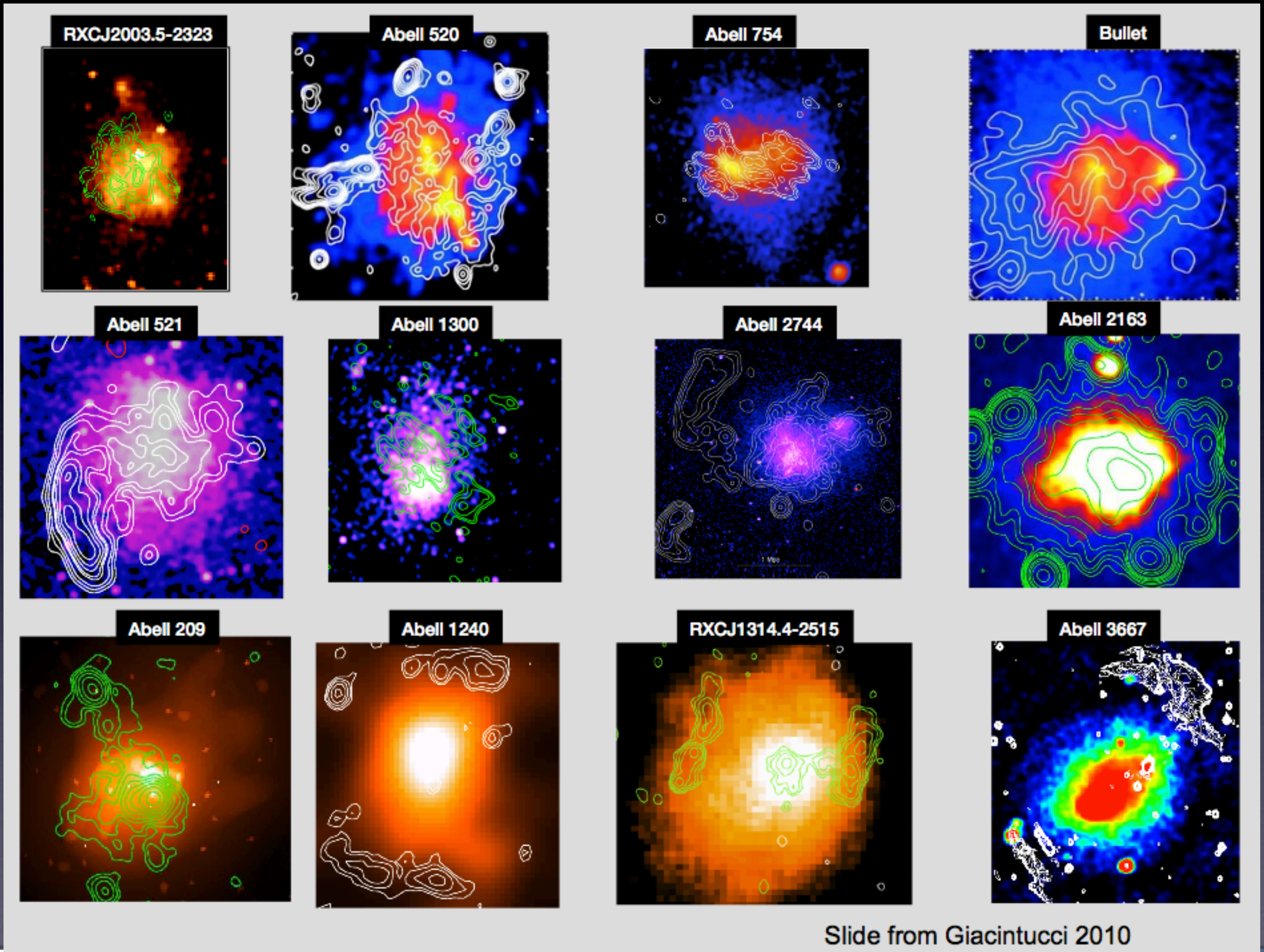
- steep spectrum sources ($\alpha \sim 1.1$-1.5)
- low surface brightness (μJy arcsec^{-2} at 1.4 GHz)
- at the cluster centre
- generally regular shape (mimic the X-ray morphology) (~Mpc size)

Radio Relics ($L_{1.4GHz} \sim 10^{23}$-10^{25} h_{70}^{-2} Watt/Hz)

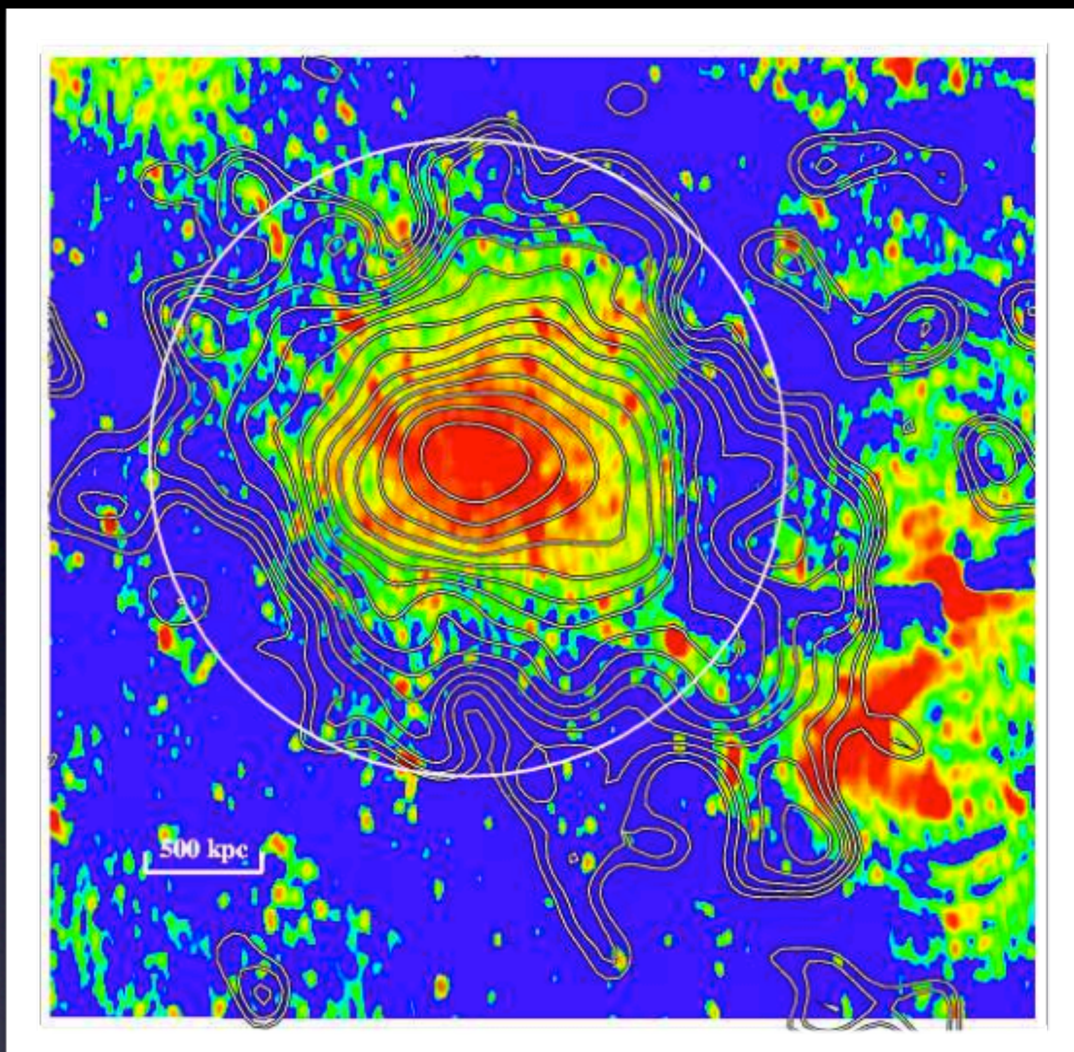
- steep spectrum sources ($\alpha \sim 1.1$-1.5)
- at the cluster outskirts
- elongated morphology + polarised

Slide from R. Cassano

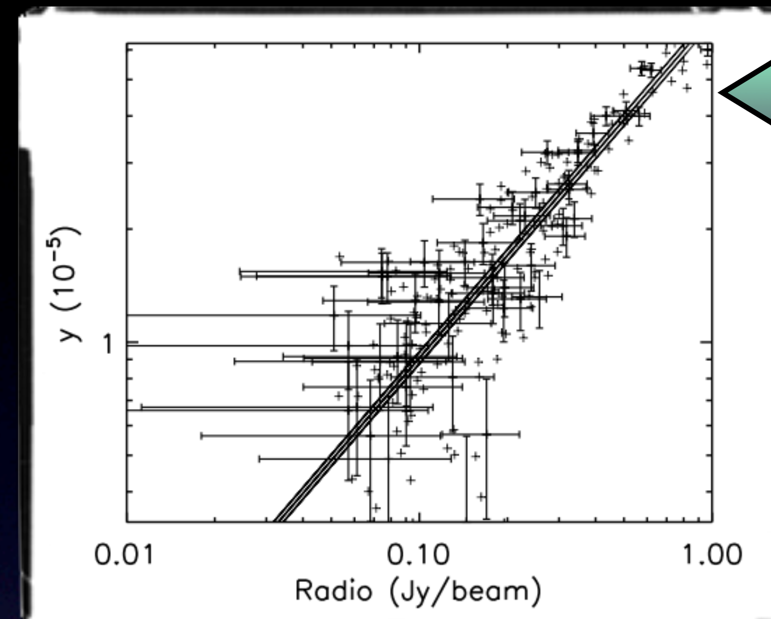
Diffuse Radio Emission in Clusters



Planck analysis of Coma radio halo



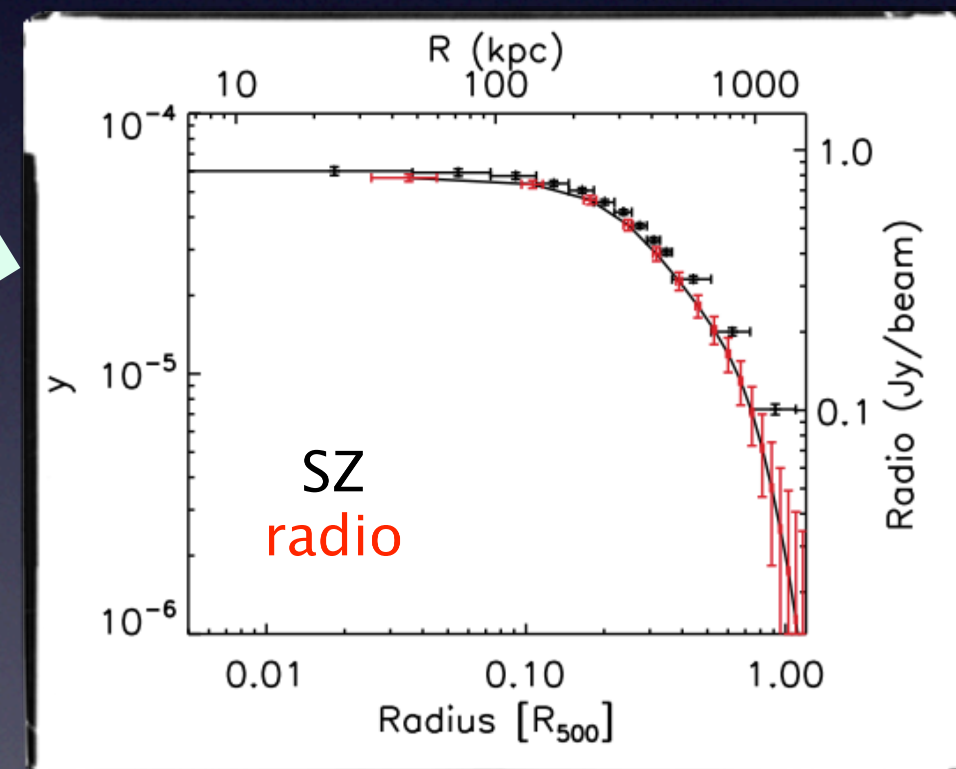
Planck *y*-map (color) and WENSS 352 MHz radio contours (Brown & Rudnick 2011)



Linear relation between SZ and radio at 352 MHz

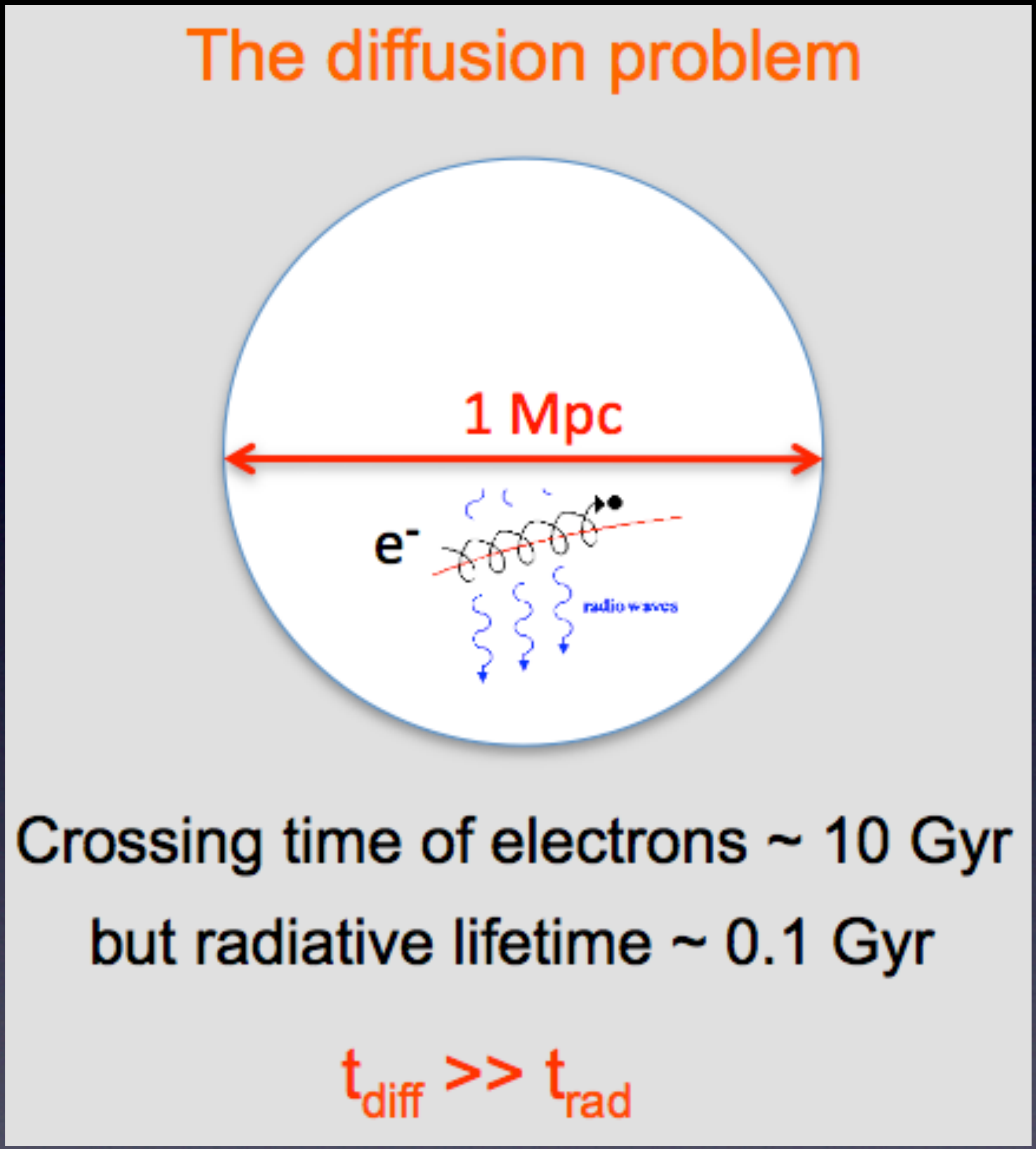
Consistent with what we found first (later in this talk)!

similarity of the profiles

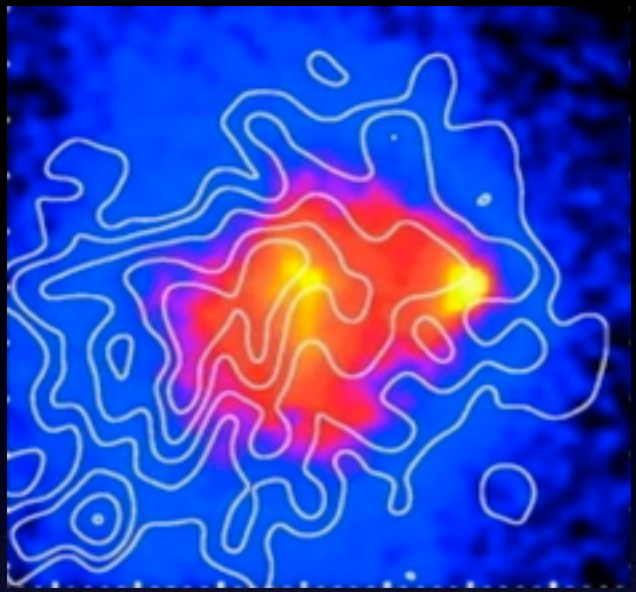


Planck Intermediate Results. X. *Physics of the hot gas in the Coma cluster*

The Puzzle of Radio Halo Origin



How to fill the ~1 Mpc volume with these radio emitting high-energy electrons?

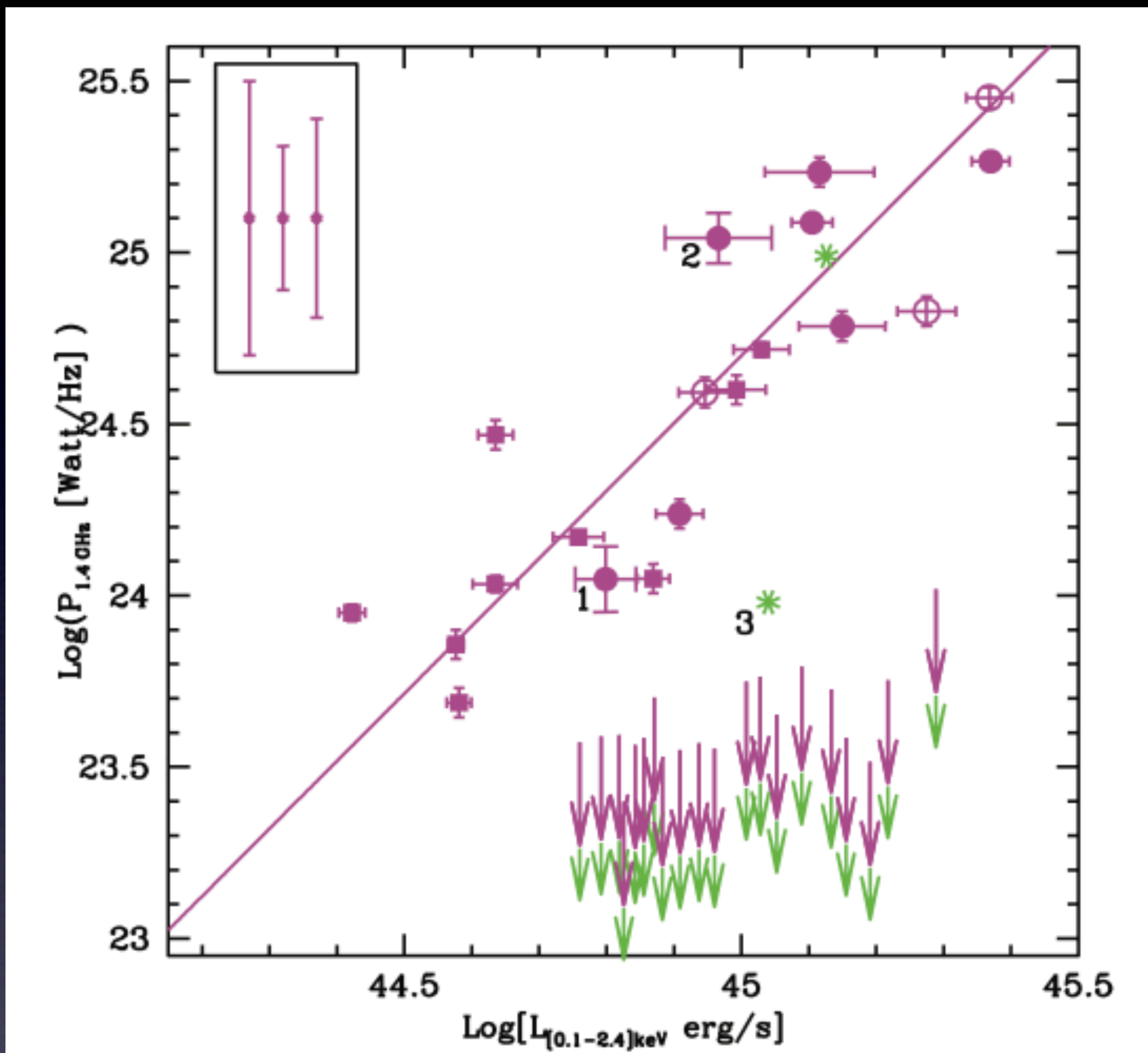


Radio halo in the Bullet cluster (Liang et al. 2000)

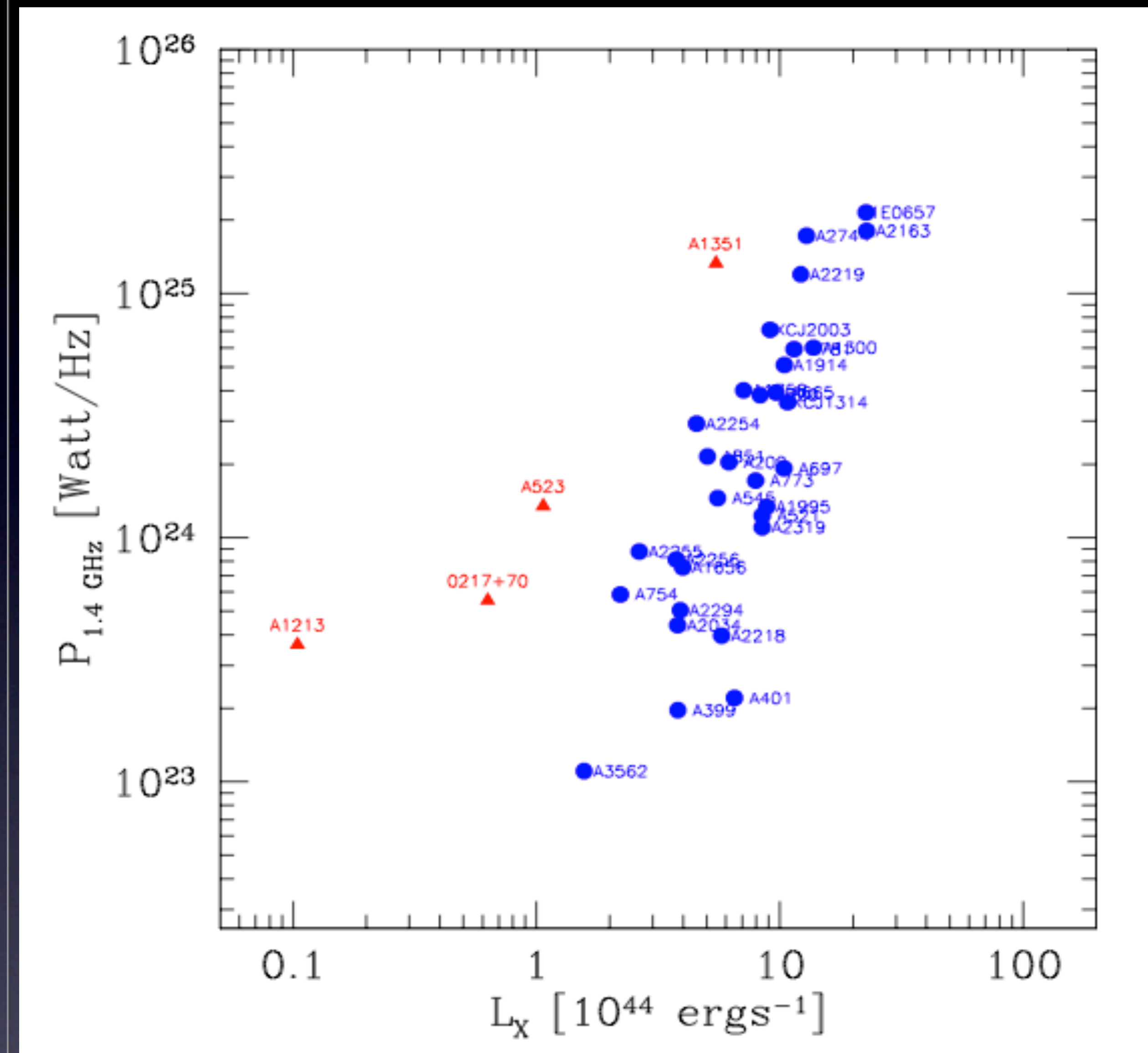
Primary models (or re-acceleration models): electrons are accelerated in shocks and/or turbulence induced by cluster mergers, via Fermi-I process

Secondary models: electrons are produced via collision between thermal ions and cosmic ray protons, the latter having significantly longer lifetimes

Radio - X-ray Correlation

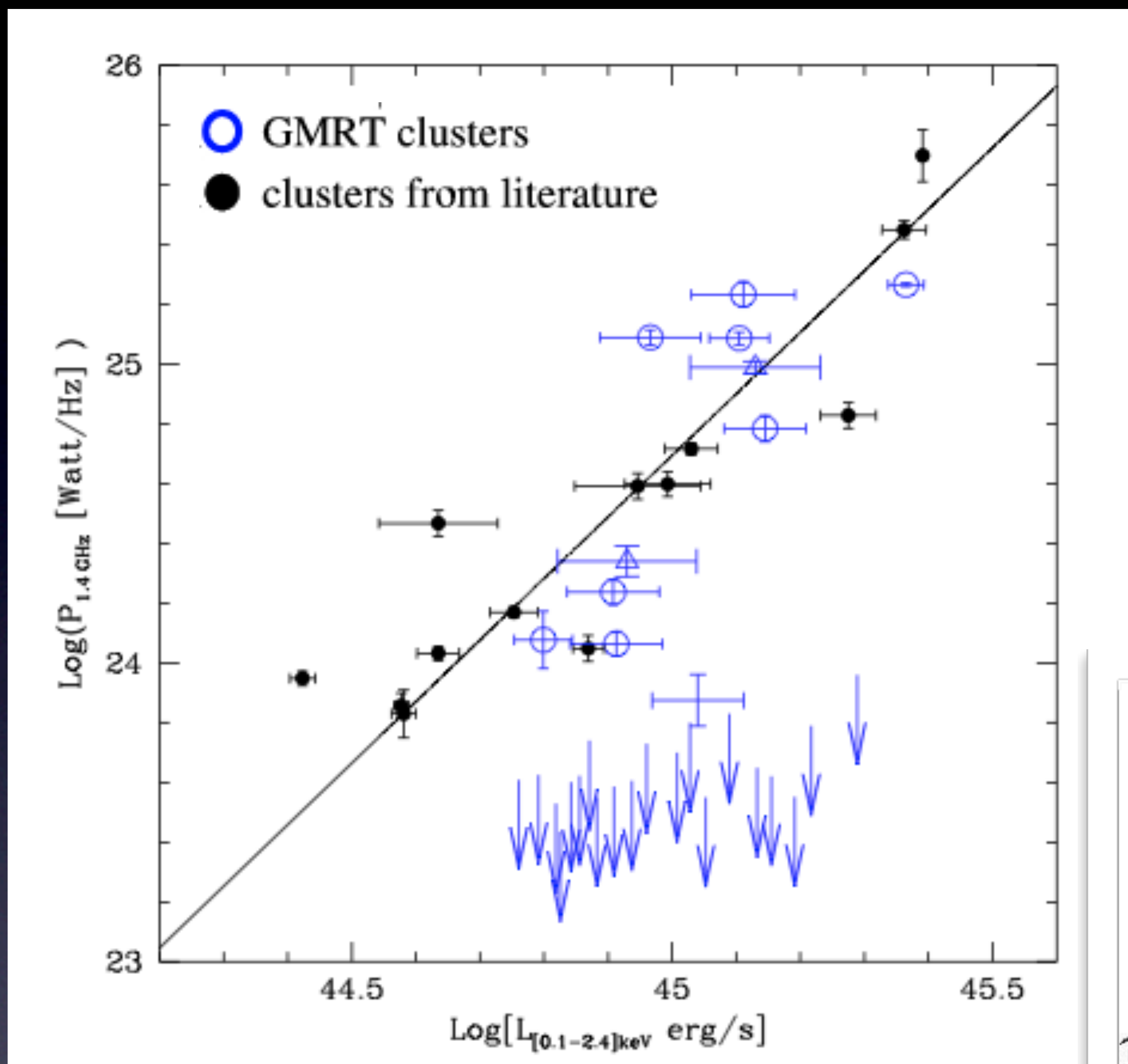


Brunetti et al. (2007)



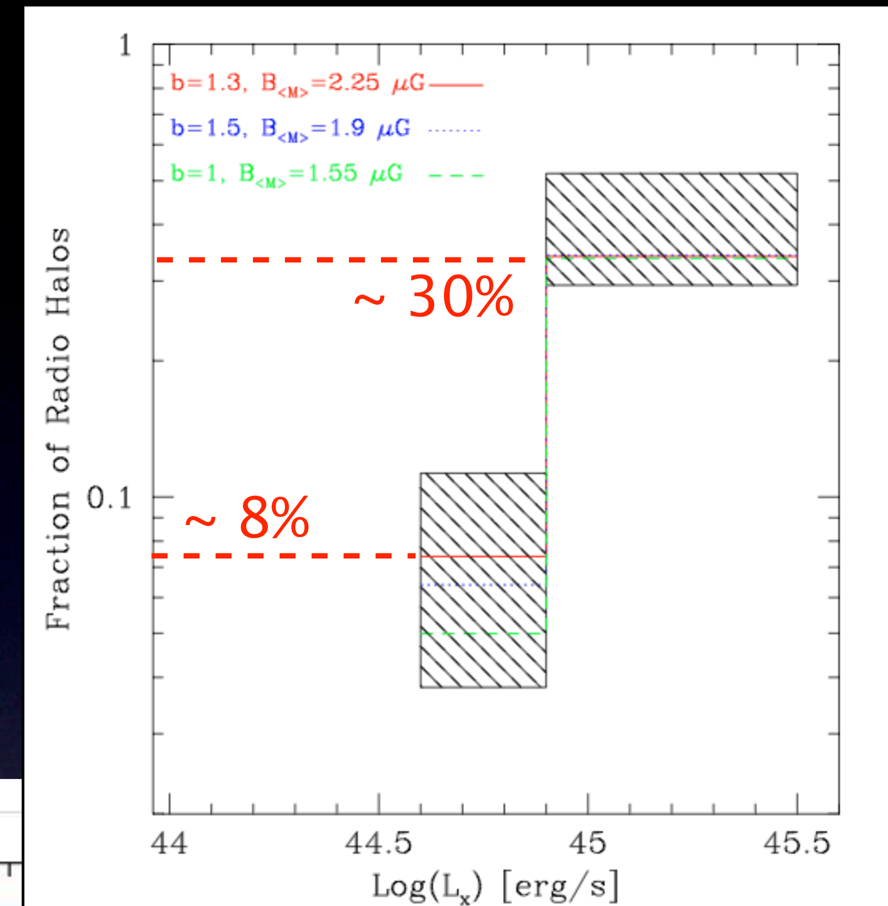
Giovannini et al. (2011)

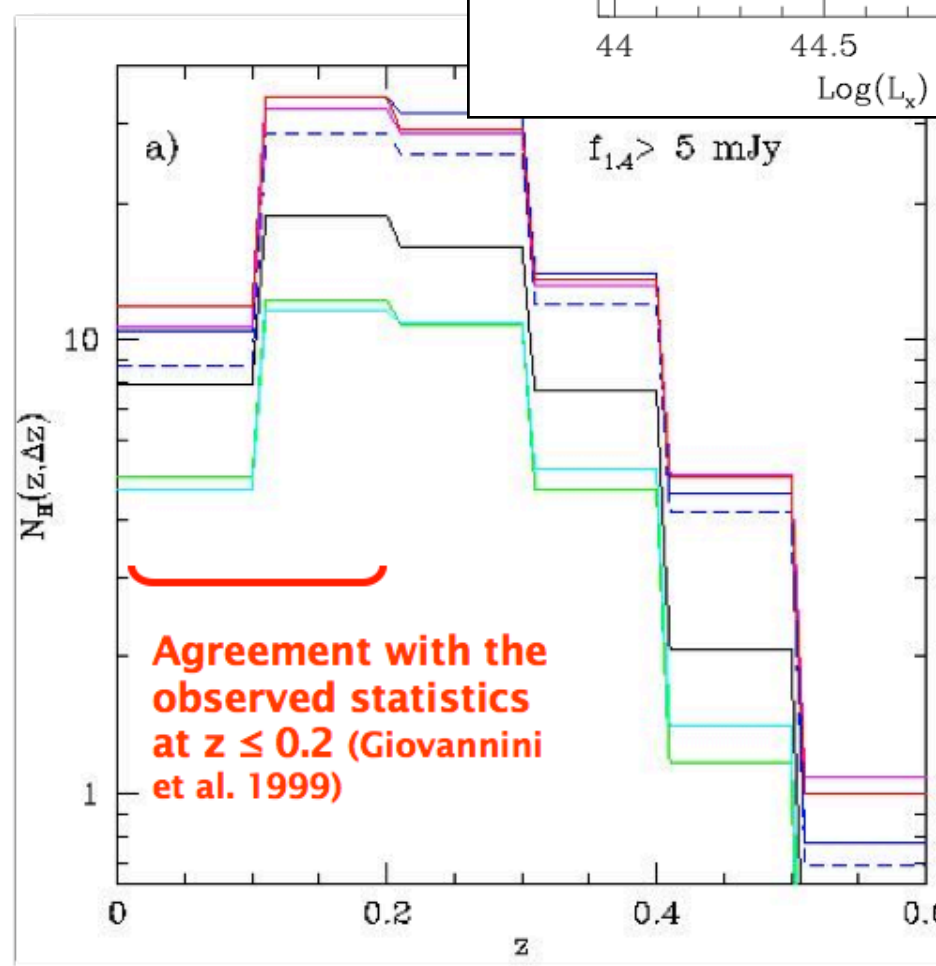
The “Rarity” of Radio Halos



GMRT radio halo survey (Venturi et al.)

Cassano et al. (2007)

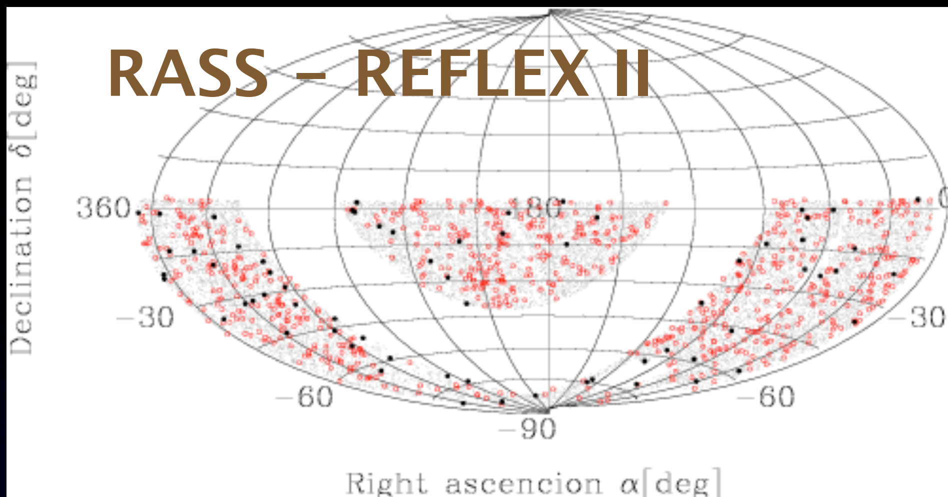




Cassano et al. (2010)

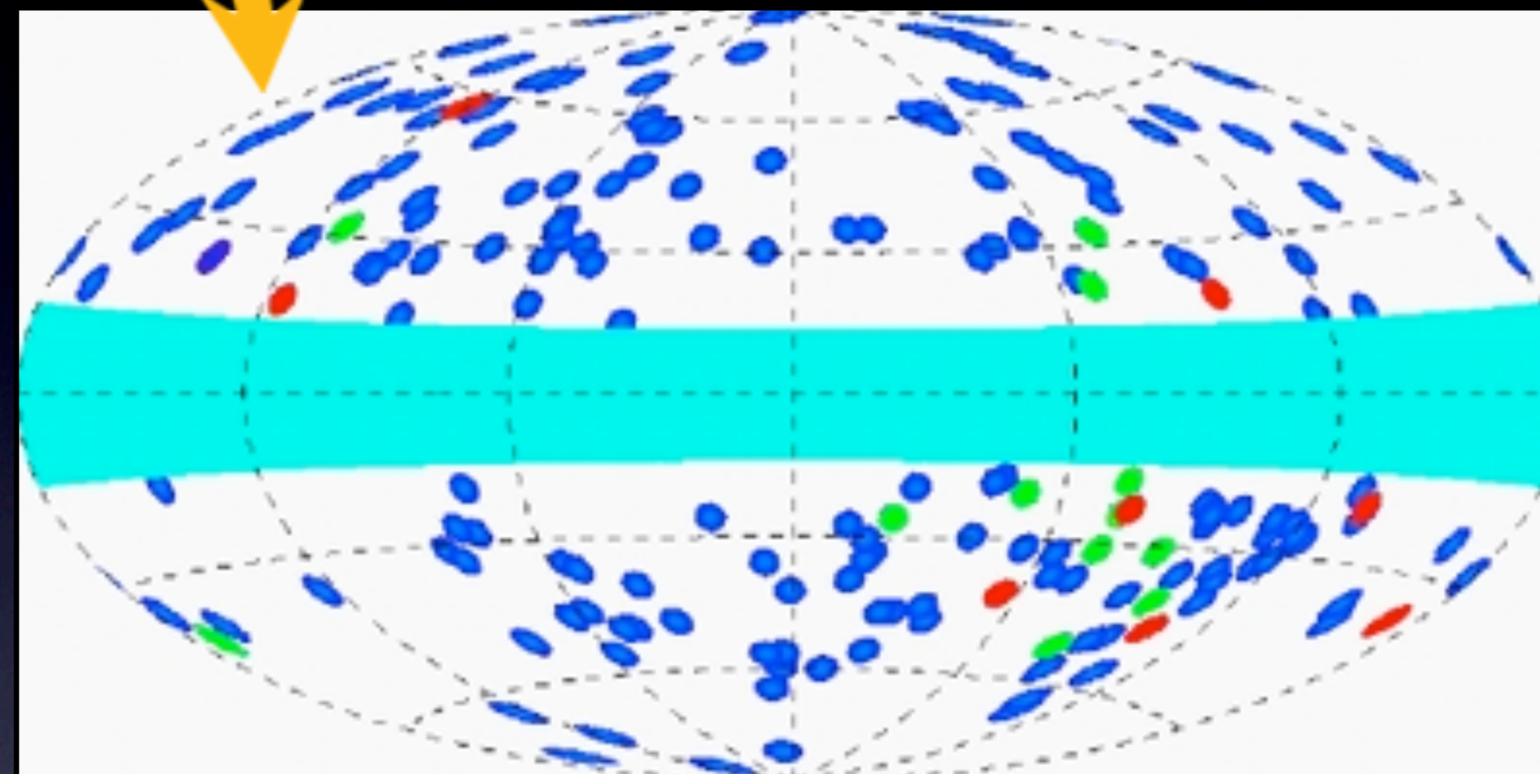
The low number of radio halos in X-ray selected clusters seem to support the primary (re-acceleration) model, and leads to a small predicted number of radio halos in the sky

Planck and the (E)SZ Catalog



ROSAT provided the first all-sky cluster catalog, selected in L_X

Planck ESZ clusters



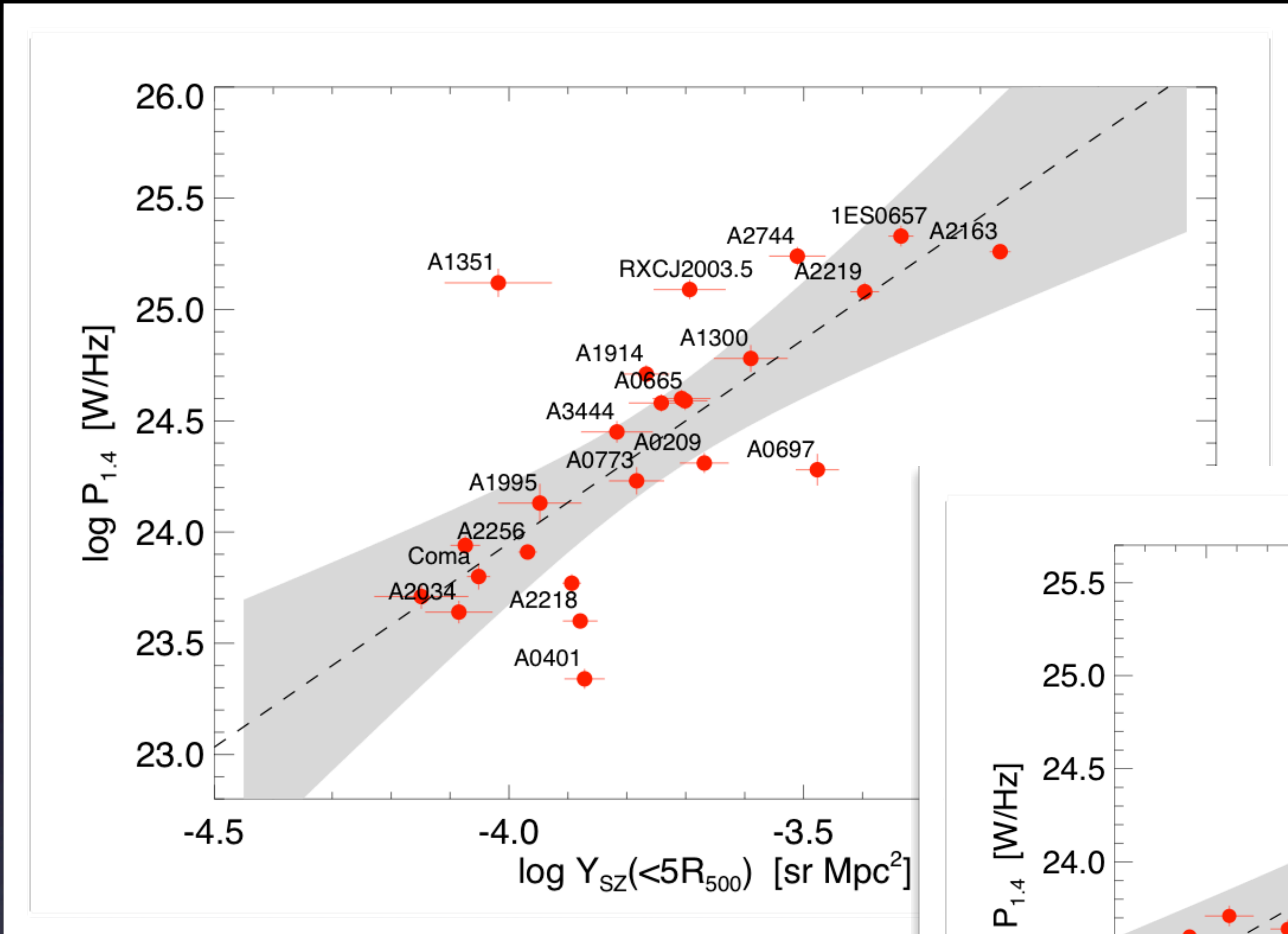
Planck provides the first all-sky SZ catalog, 20 years after ROSAT

Sample	No. of Clusters	of which Radio Halos	*Planck* Detects	of which Radio Halos
V08	26	6	9	5
B09⋆	44	21	20	16
R09	72	14	27	12

Samples: V08 = Venturi et al. 2008; B09 = Brunetti et al. 2009; R09 = Rudnick & Lemmerman 2009. ⋆ Not X-ray complete

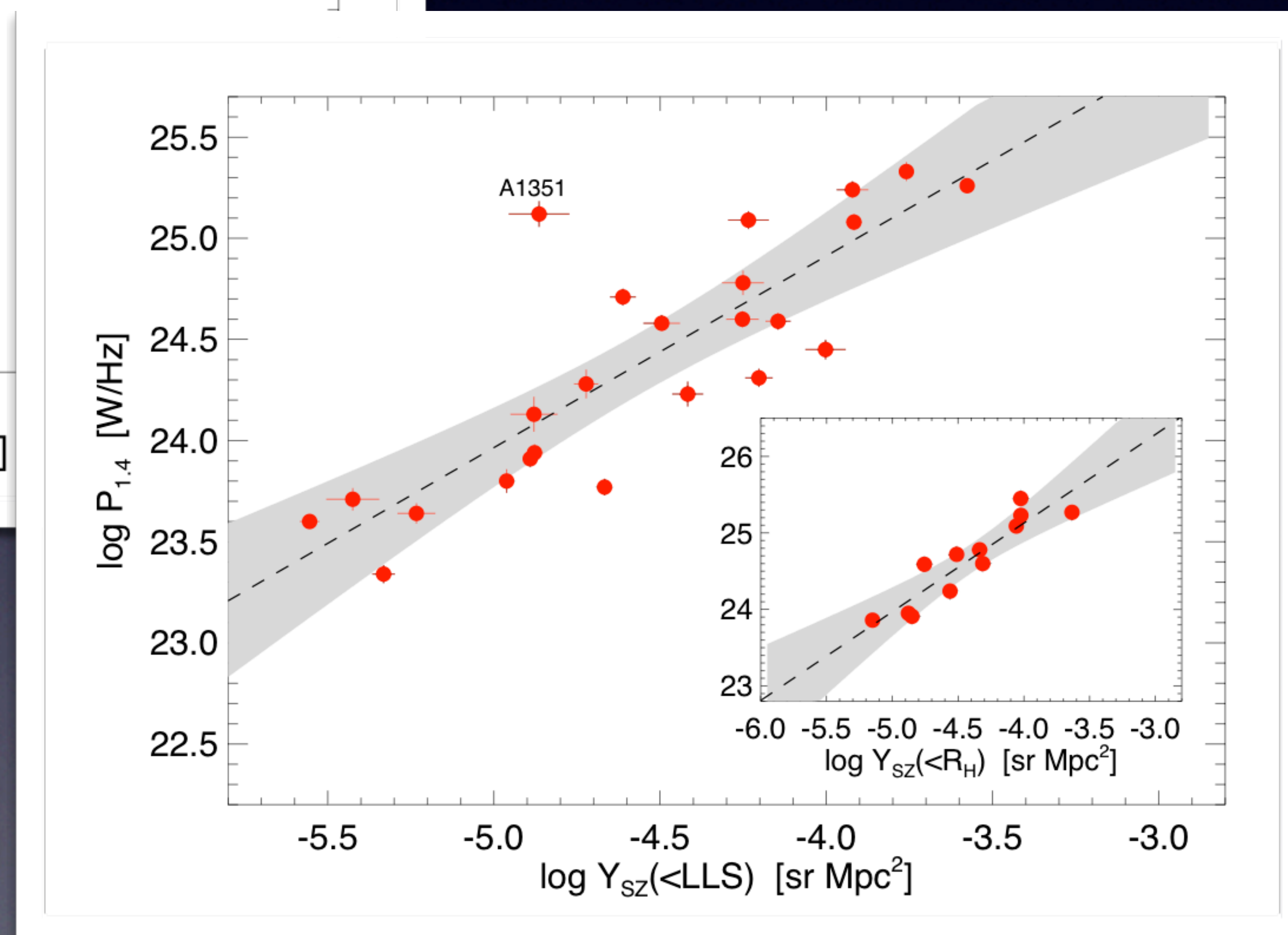
Cross-correlating all known radio halos in the literature with the Planck ESZ catalog

Radio - SZ Correlation



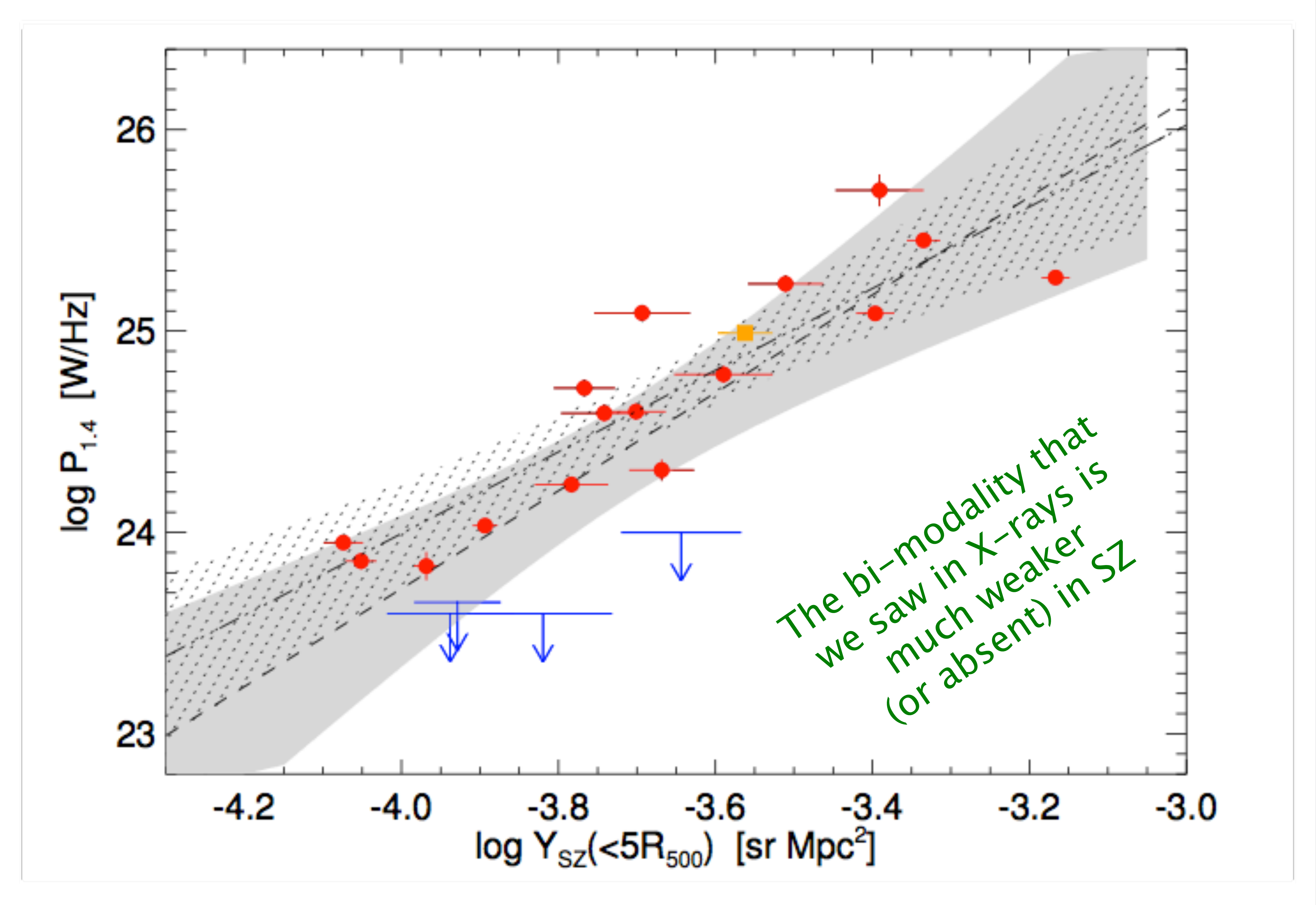
The cluster SZ signal and radio halo power are correlated (as expected from known X-ray correlation)

Basu (2012)



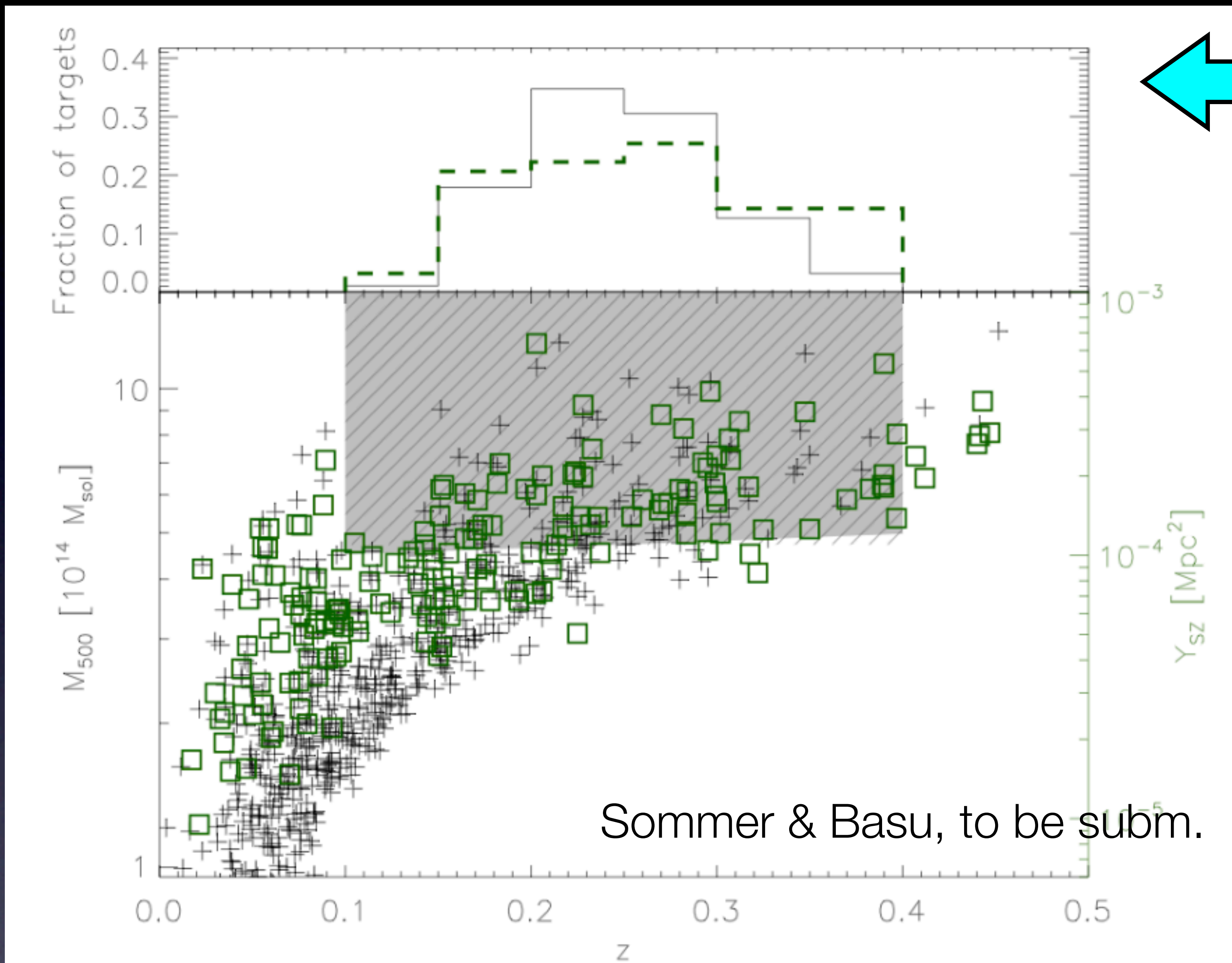
The correlation becomes stronger when the SZ signal is scaled to within the radio halo radius

A “Reduced” Bi-modality



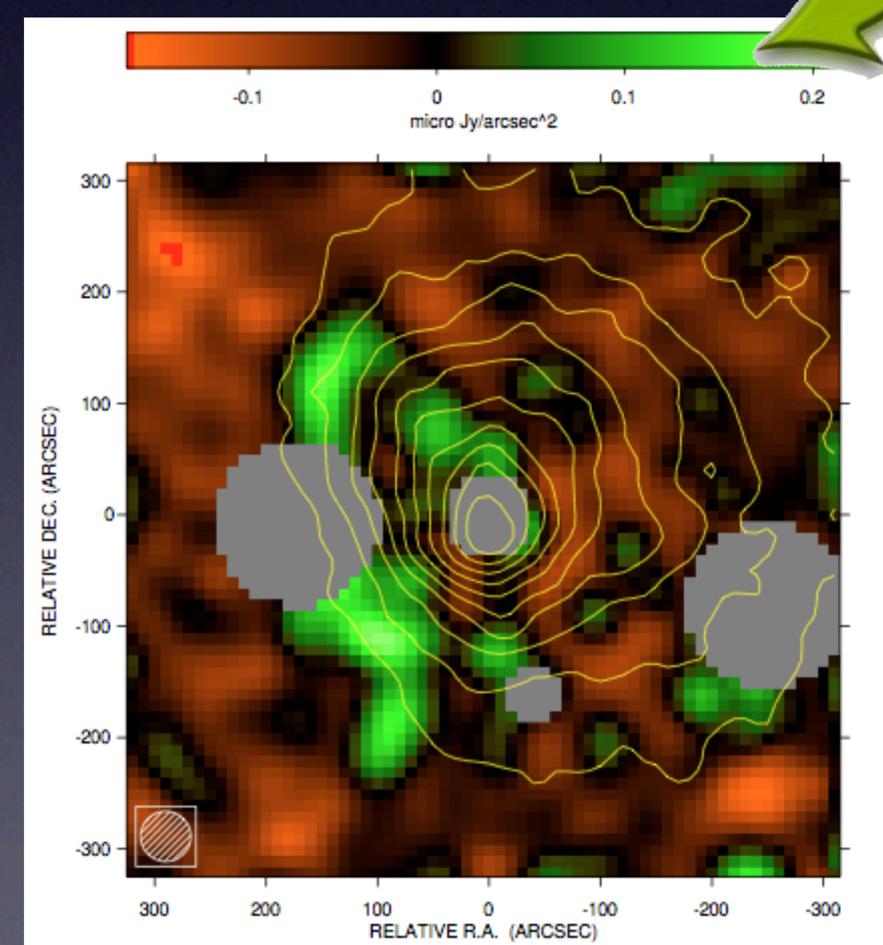
Basu (2012)

Testing Complete SZ + X-ray samples



We selected near-identical mass limited clusters samples in SZ and X-rays

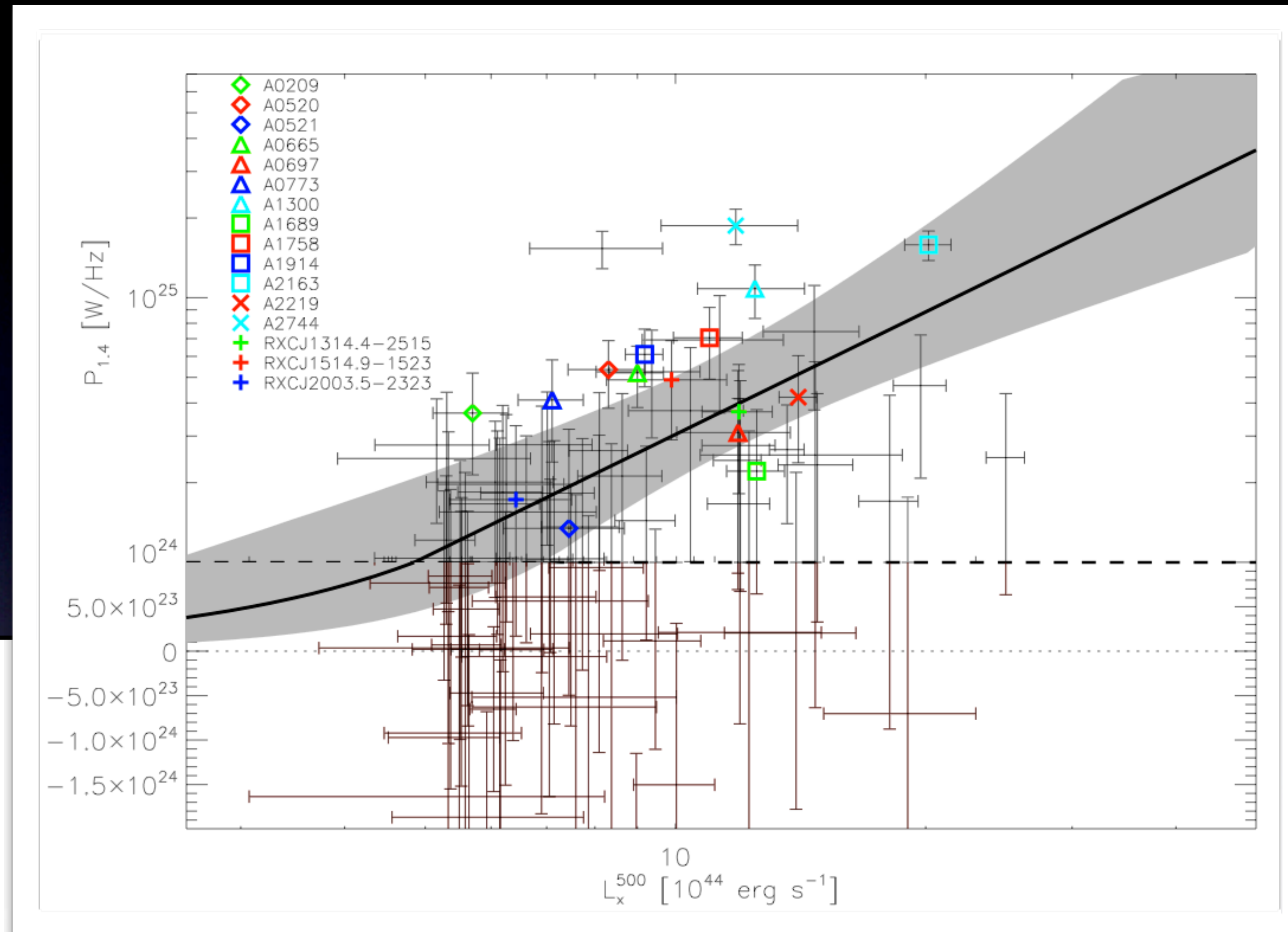
We then analyzed the corresponding NVSS 1.4 GHz sky maps for diffuse radio emission at the cluster centers



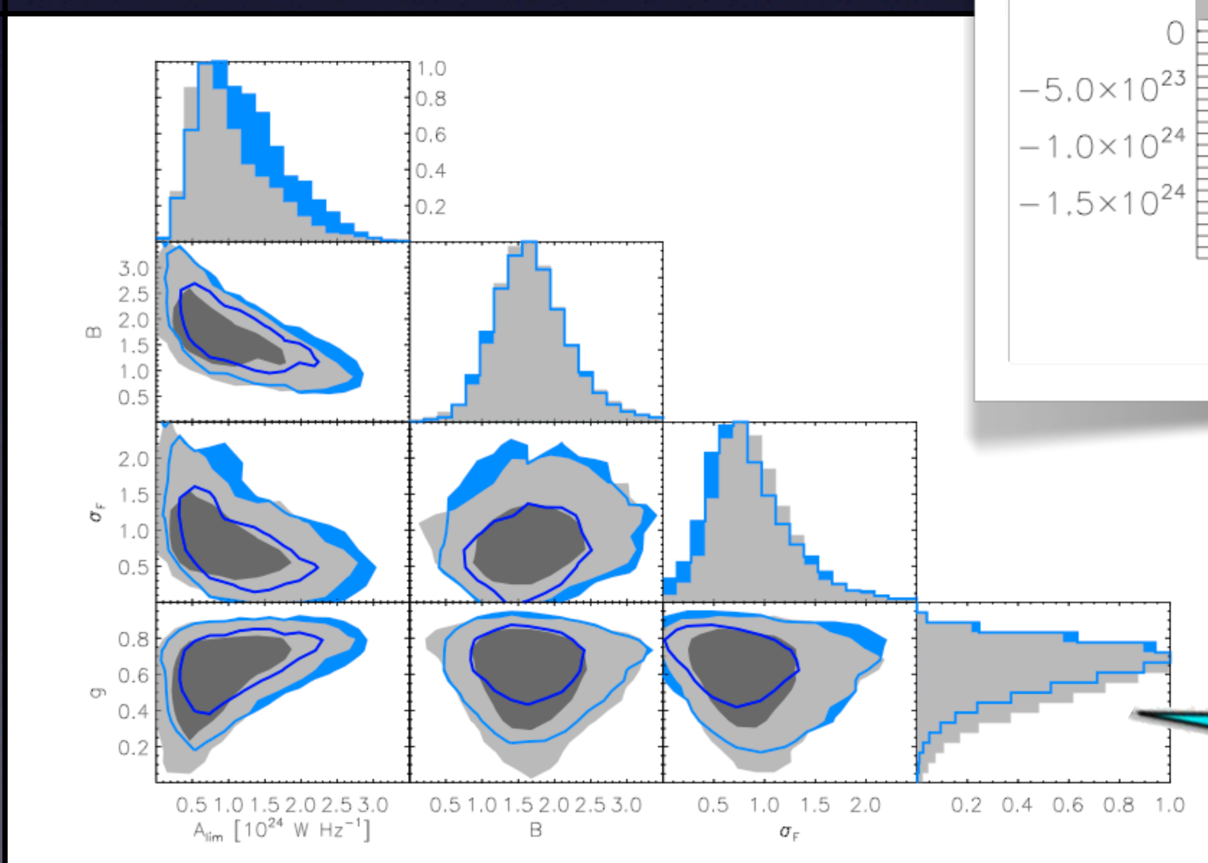
⭐ We developed a **regression method** that takes into account errors in both direction, intrinsic scatter, non-detections *and a dropout fraction* (i.e. zero population)

Results for X-ray Selection

Most of our cluster radio halos from NVSS are non-detections. We do not stack maps, but rather assign individual radio power to each cluster.



Sommer & Basu, to be subm.

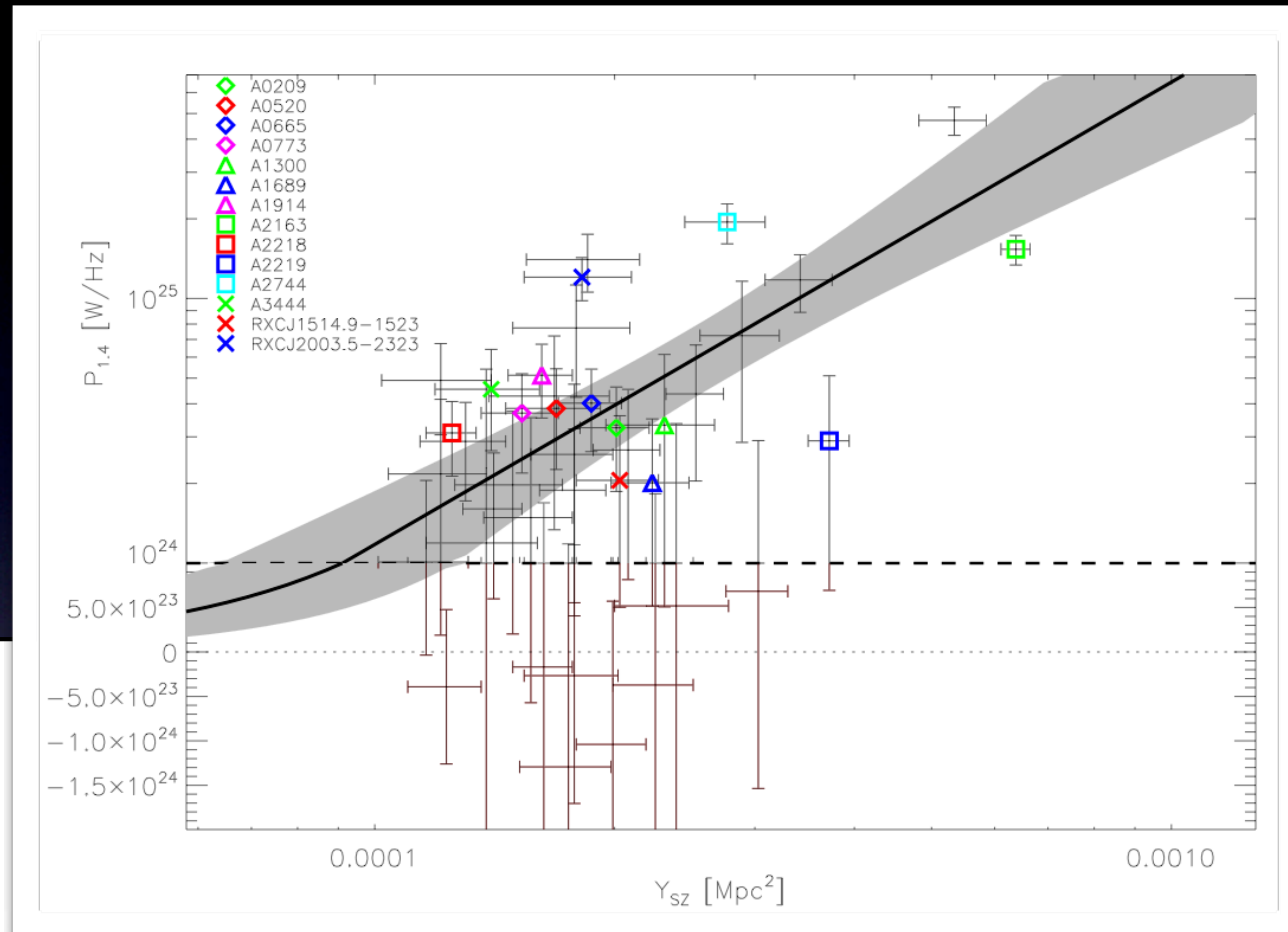


dropout 72 ± 20 %

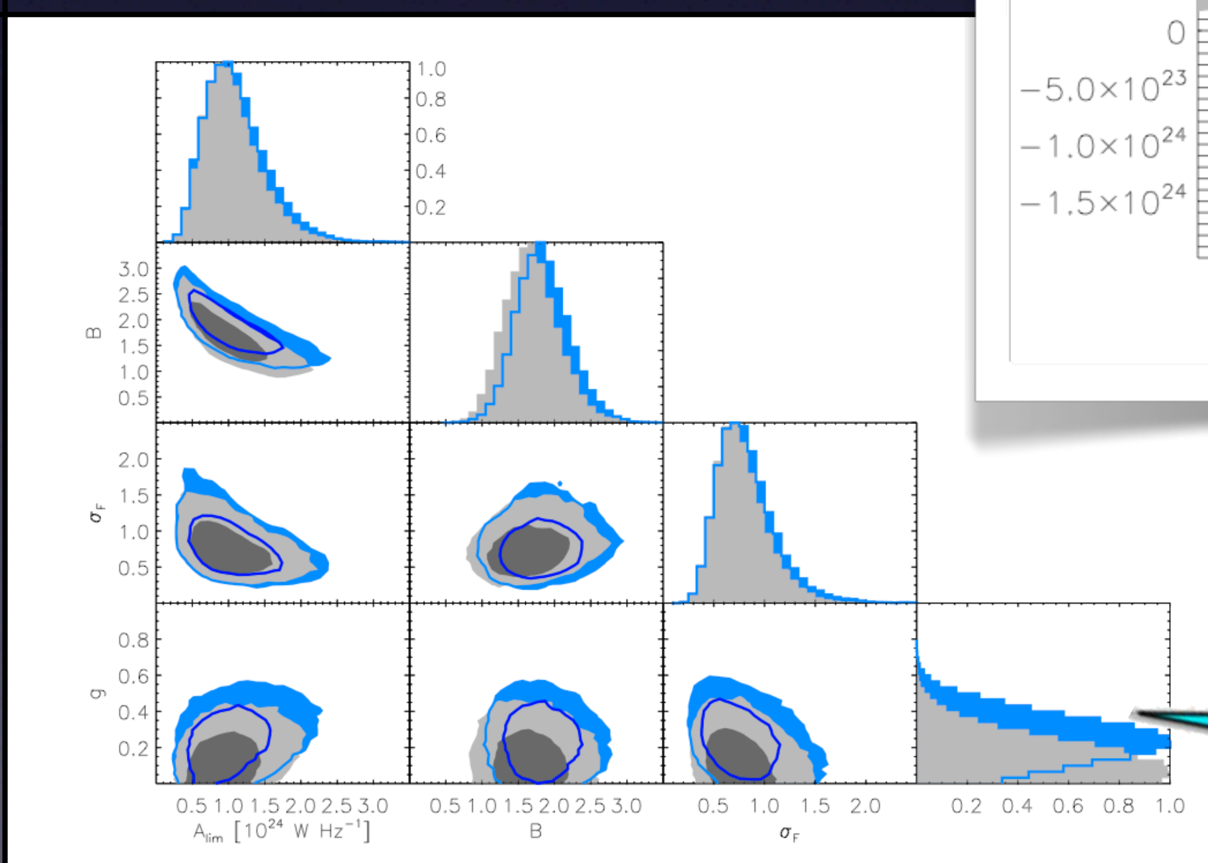
Results for *Planck* SZ Selection

We then fit simultaneously for an “on-correlation” population and a “zero” population using these data.

The zero-populations are strikingly different!

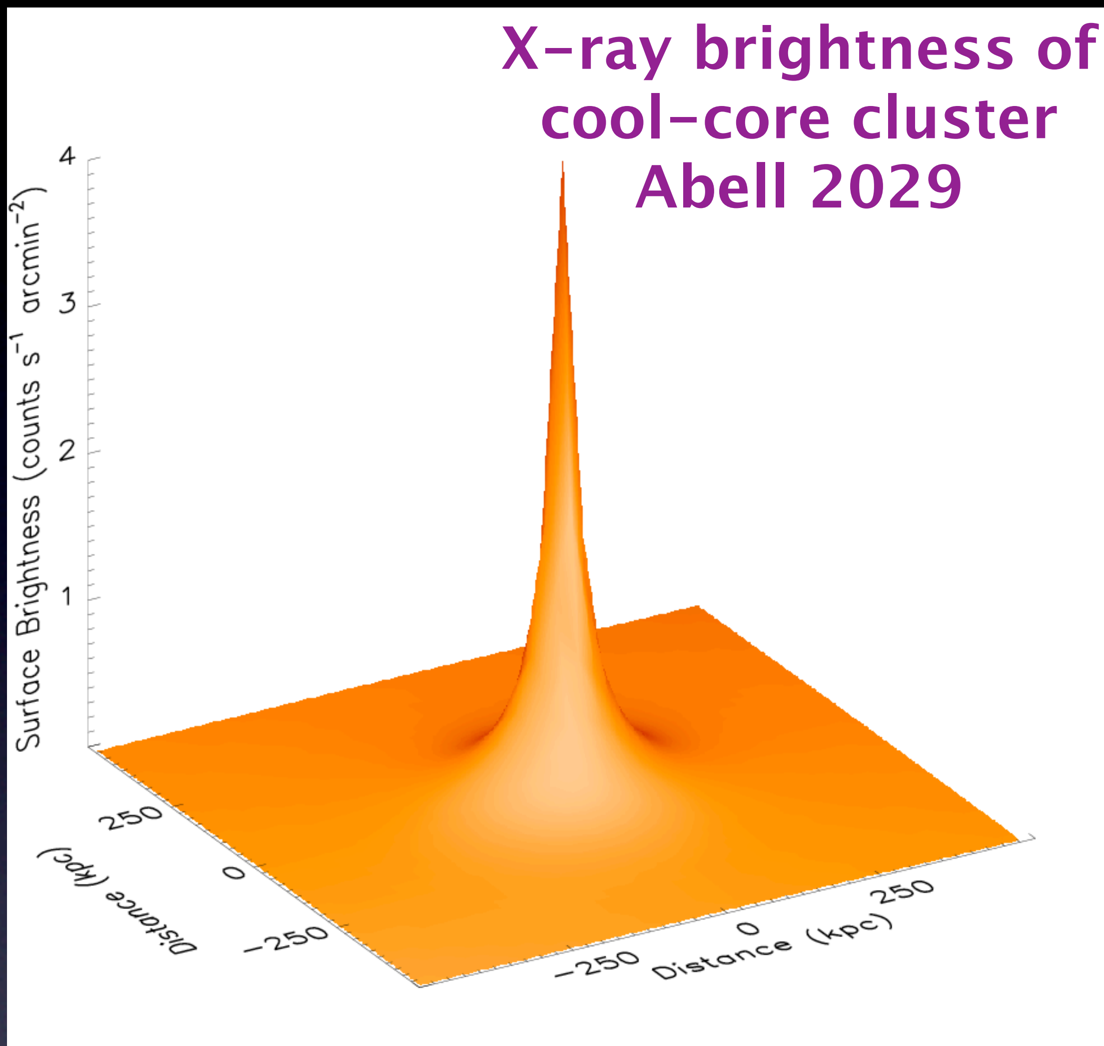


Sommer & Basu, to be subm.

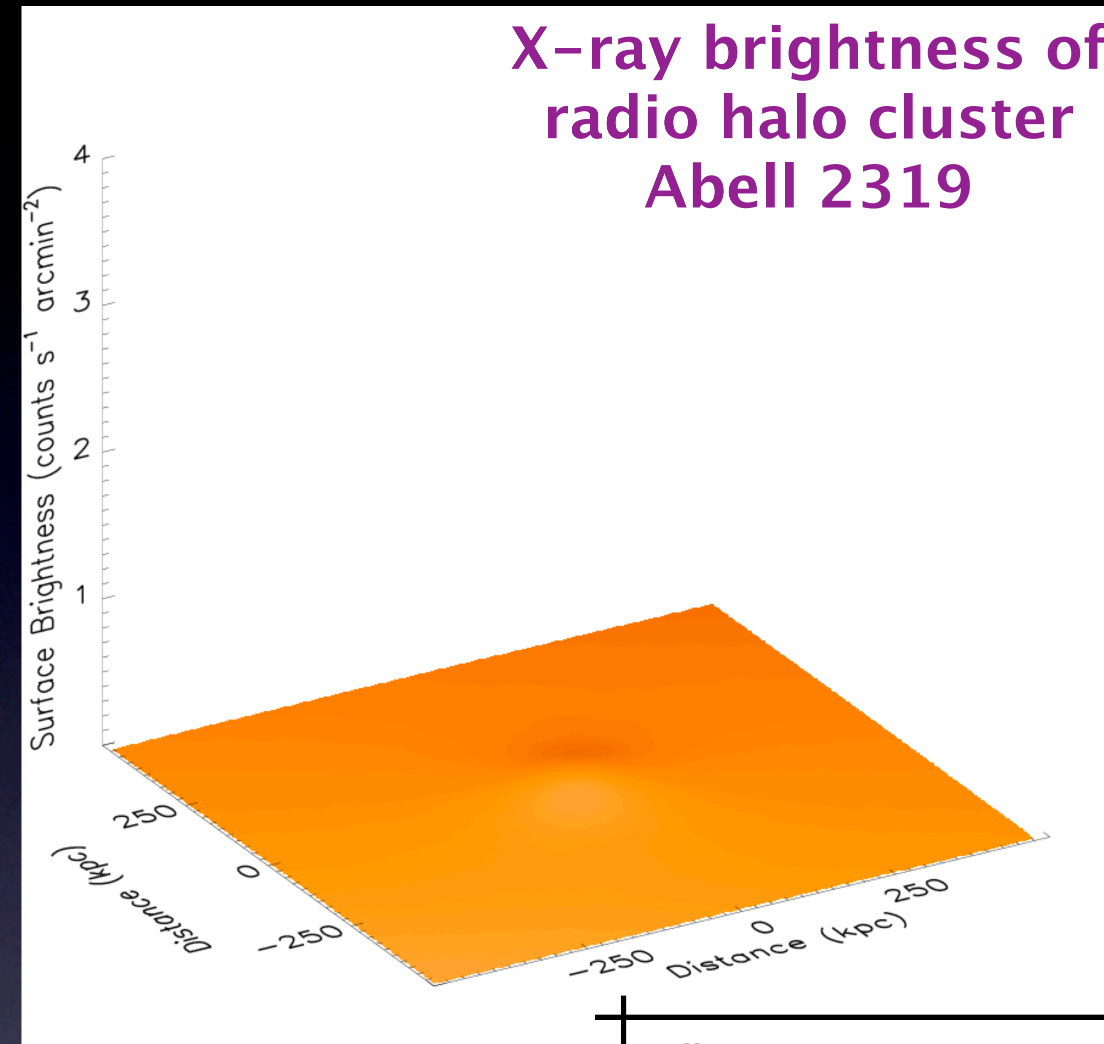


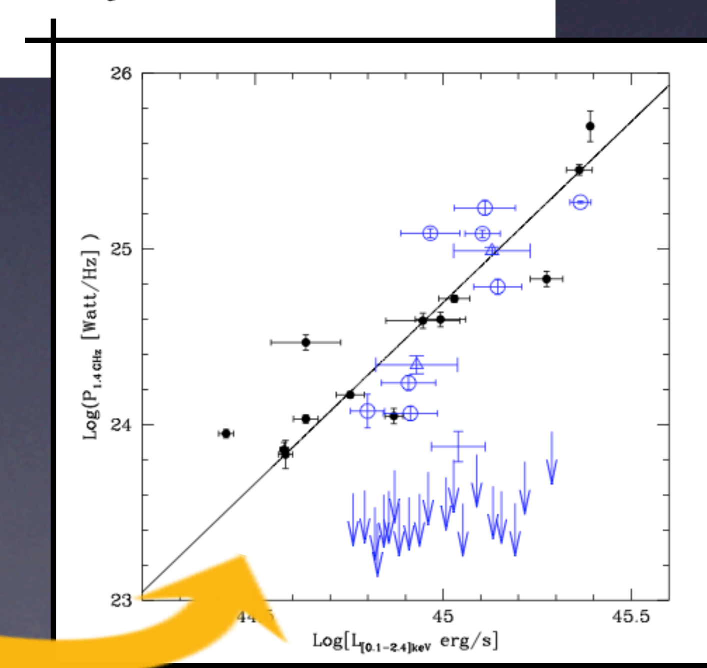
dropout
20 ± 18 %

What It Means? Cool-Core Clusters



Million & Allen (2009)



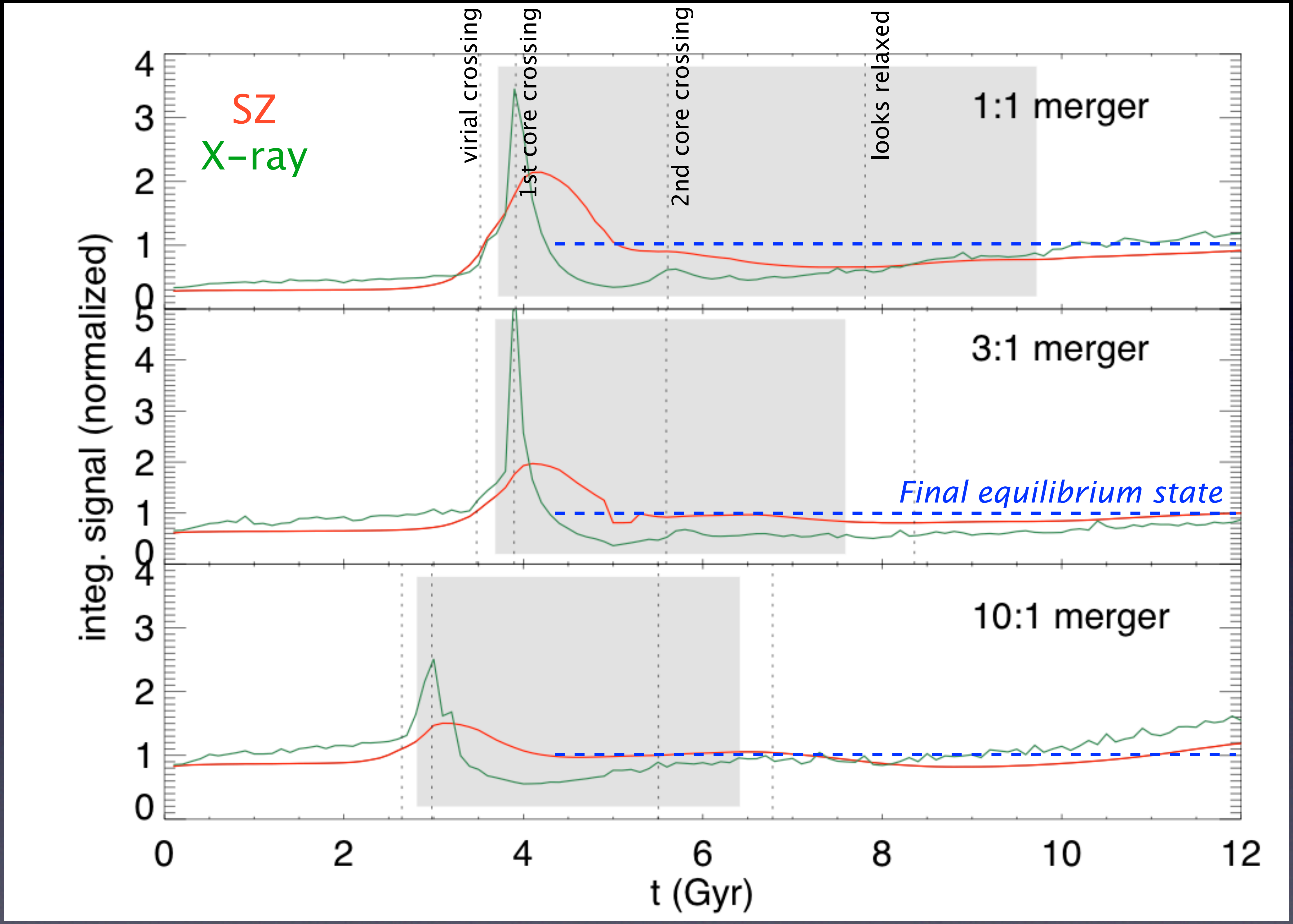


Relaxed, ***cool-core clusters*** are a minority, but they are over represented in X-ray flux limited samples

These systems generally do not host giant radio halos

➜ producing a bi-modal distribution in X-rays

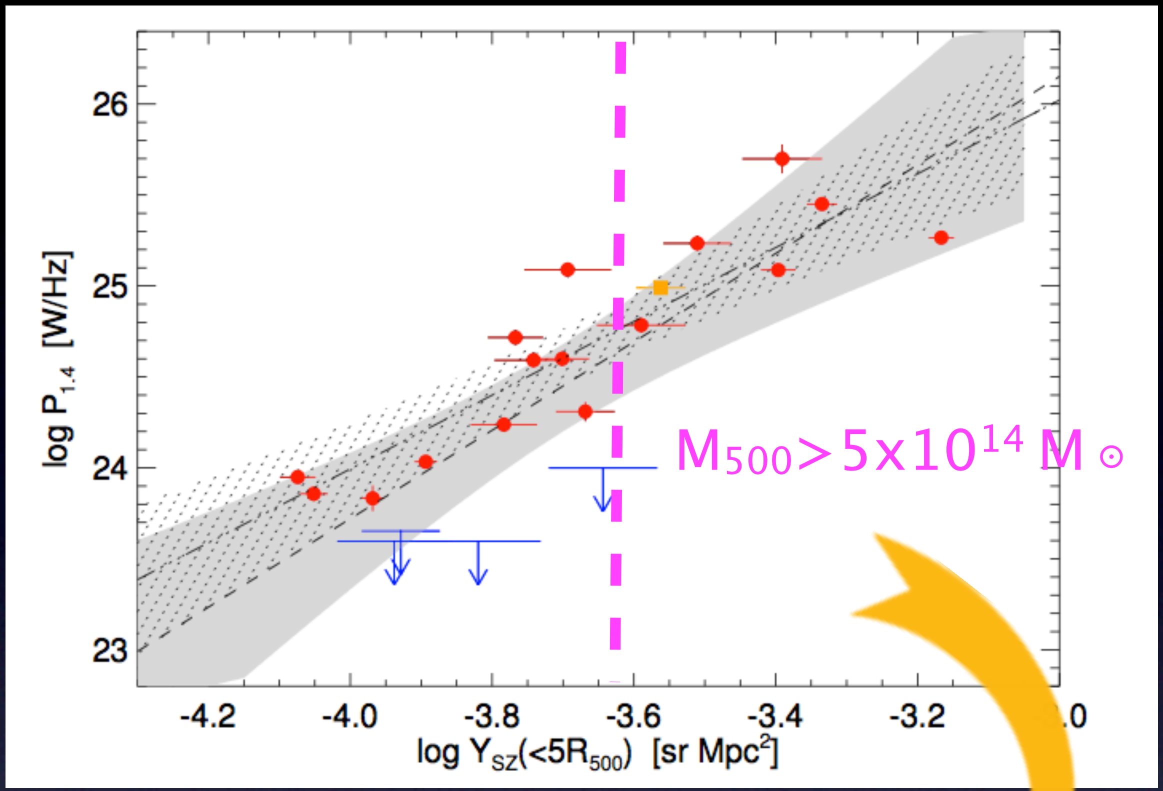
Merger Scenarios

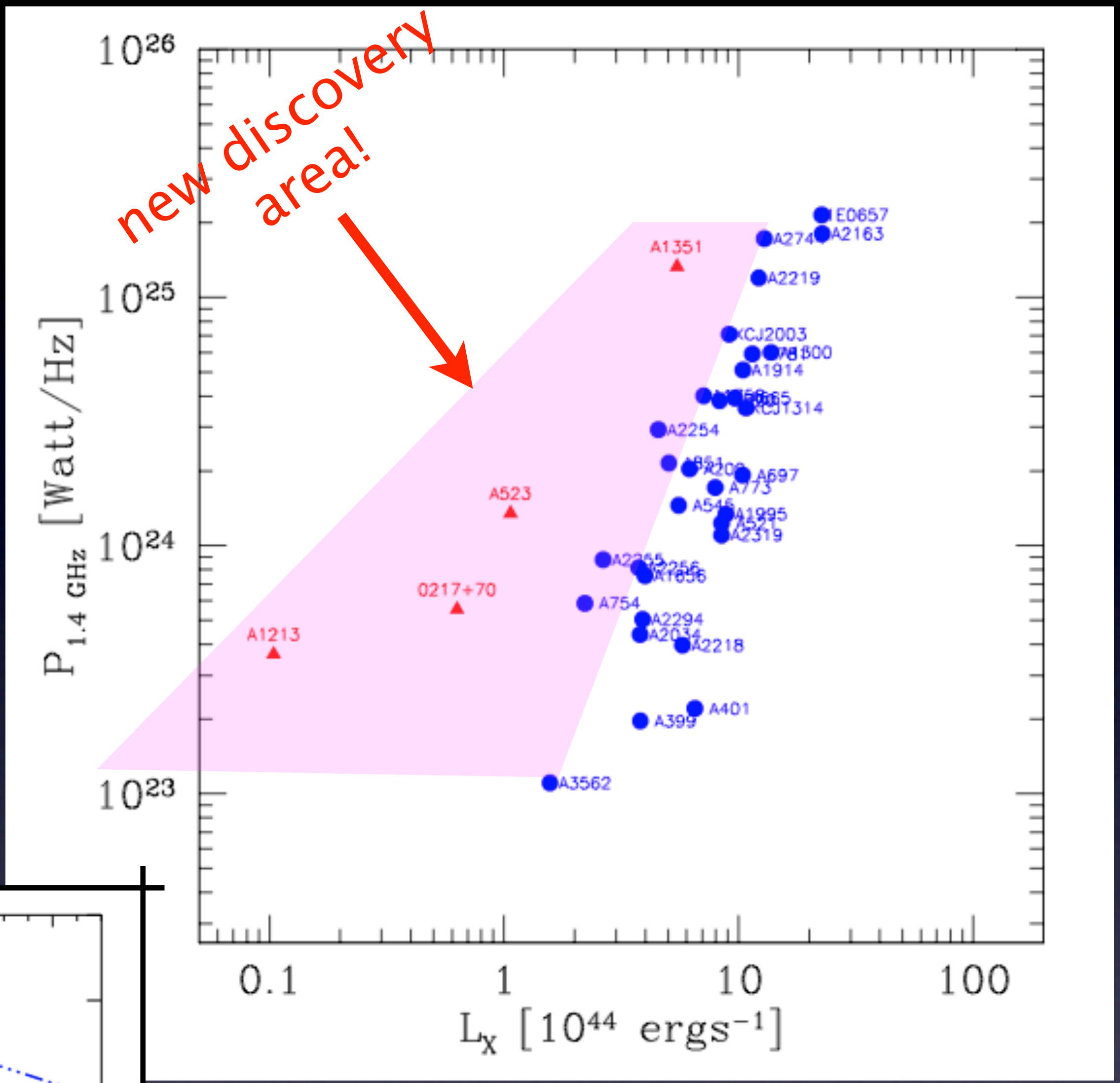


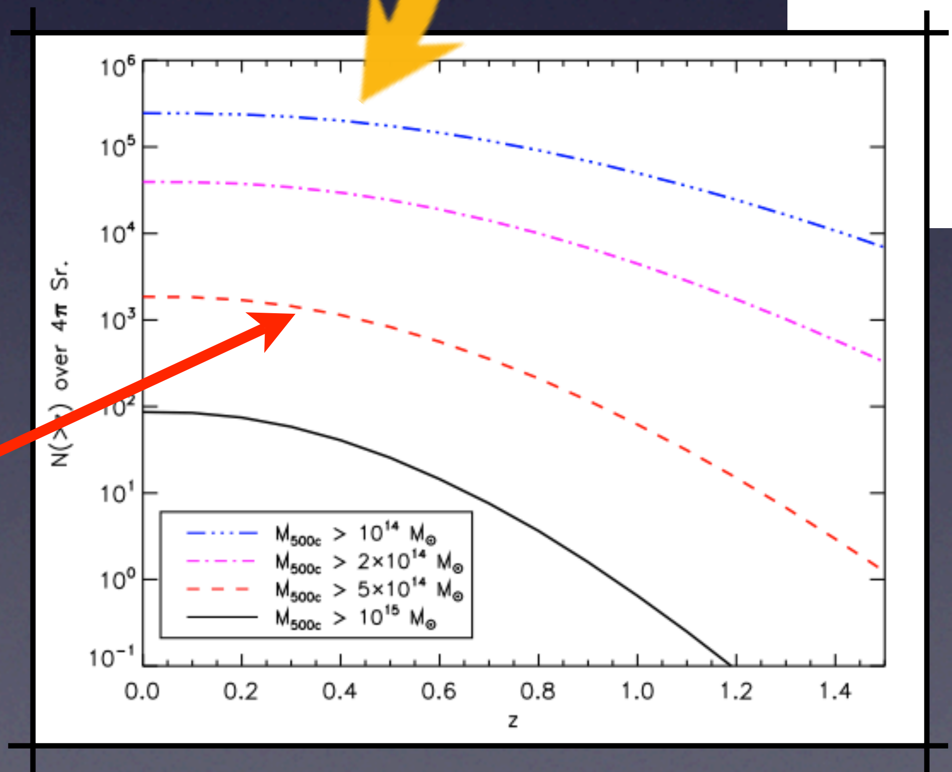
Sommer & Basu, to be subm.

N-body hydro simulation results from Poole et al. (2007)

Implications for Radio Halo Count







There are over 1000 clusters with M_{500} > 5×10^{14} $M_\odot$ in the sky!

We predict a *large number* of low X-ray luminosity clusters hosting radio halos, to be discovered by upcoming radio surveys like LOFAR and SKA_1

Conclusions

- **Radio halos:** Radio halos are ~Mpc scale diffuse radio synchrotron emissions whose origin and prevalence remain controversial. Correlating with X-ray luminosities in clusters reveal a distinct "bi-modal" division in the radio halo population.

- **What's new:** We have obtained the first radio-SZ correlation for galaxy cluster radio halos. Apart from a tight correlation, the "bi-modality" appears to be much weaker (or non-existent) in SZ. Further analysis with complete SZ and X-ray selected samples reinforce these initial results.

- **What we can expect:** The number of radio halos in the sky can be expected to undergo a major upward revision! All massive clusters appear to be hosting a radio halo, and their numbers should increase with redshift (increasing merger fraction). Great news for upcoming radio surveys like LOFAR and SKA[1].