Nonthermal signature of cluster shock waves

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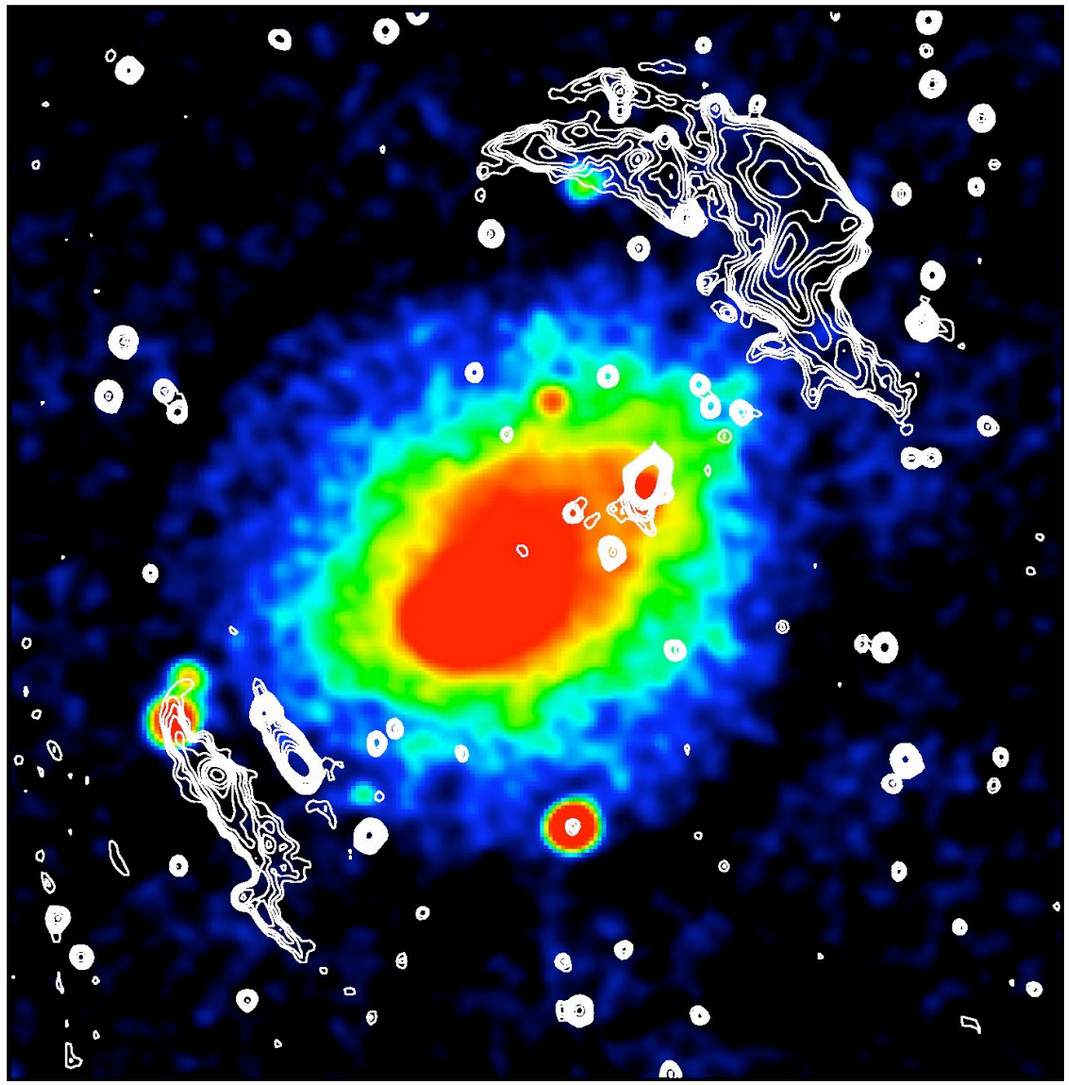
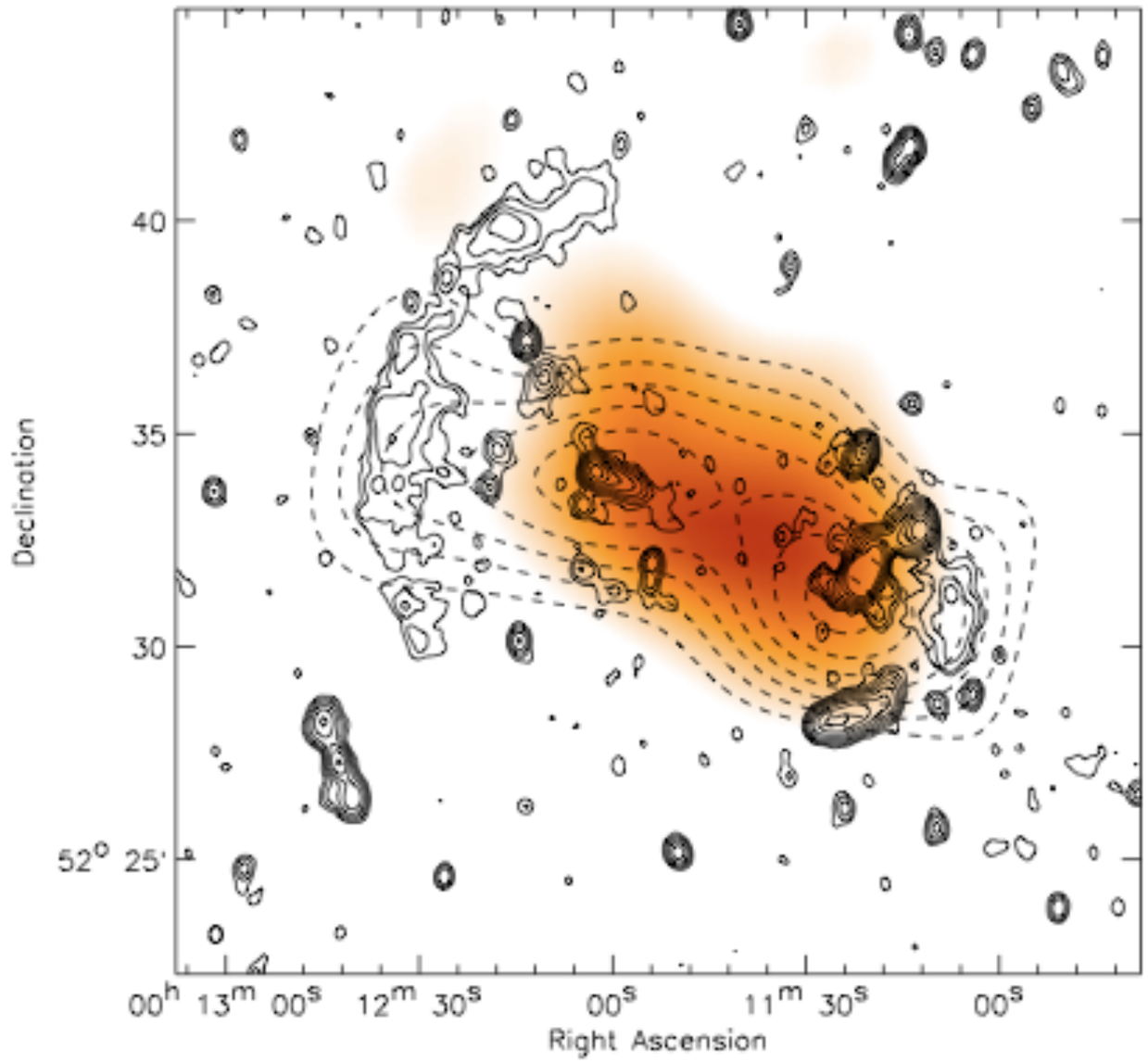
What are radio relics?



Abell 3667

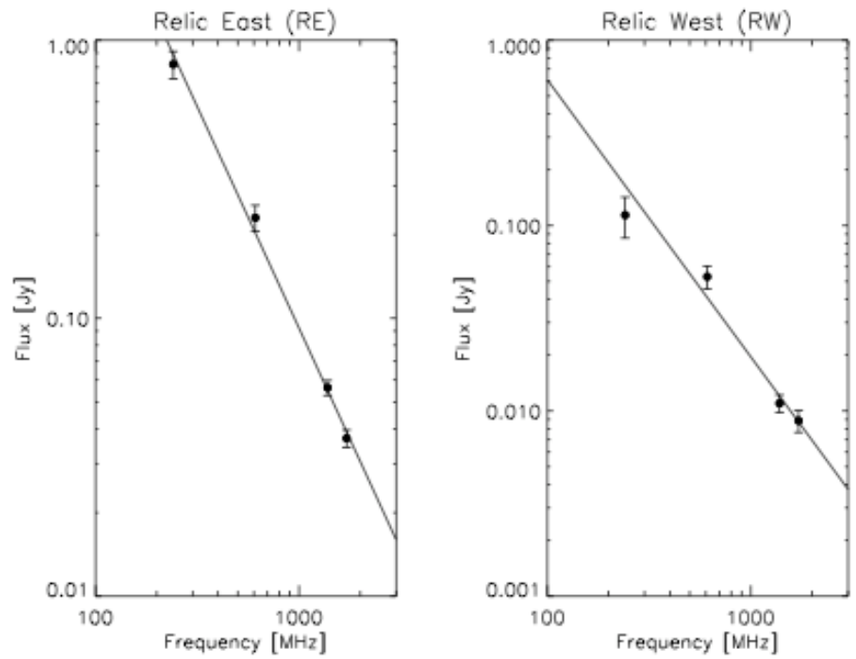
colour: X-ray
contours: radio

Röttgering 97



ZwCl 0008.8+5215
van Weeren et al. 11

Diffuse radio sources

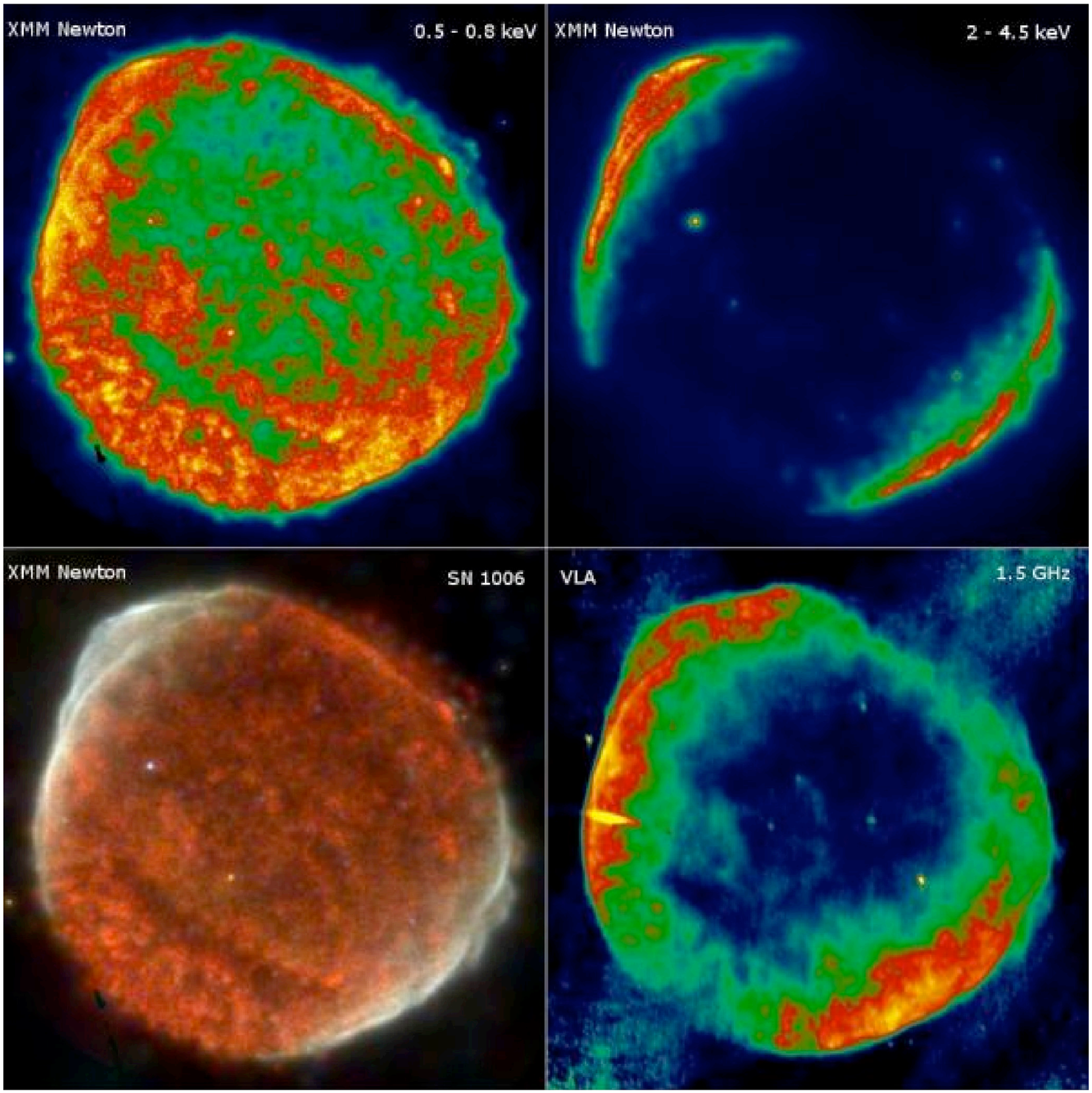


- have a low surface brightness
- have a steep spectrum
- are extended (1 Mpc) objects
- are not associated with any particular radio source
- halos lie in clusters and are not polarised
- relics lie at periphery of cluster and are polarised

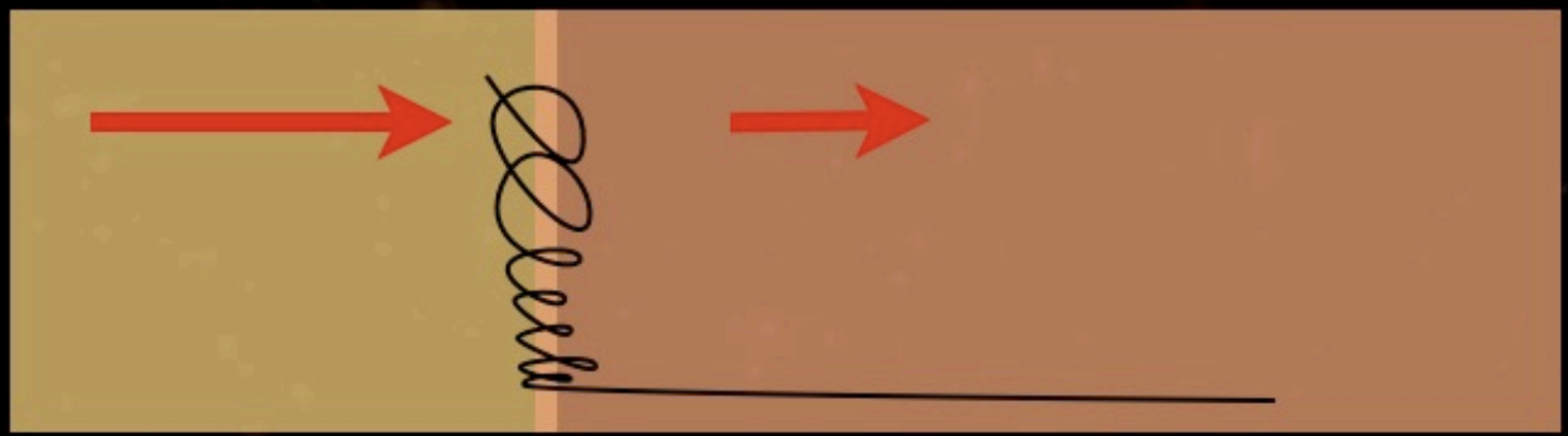
The radio emission is indicative of a non-thermal population of electrons.

Diffusive particle acceleration at cosmological shocks

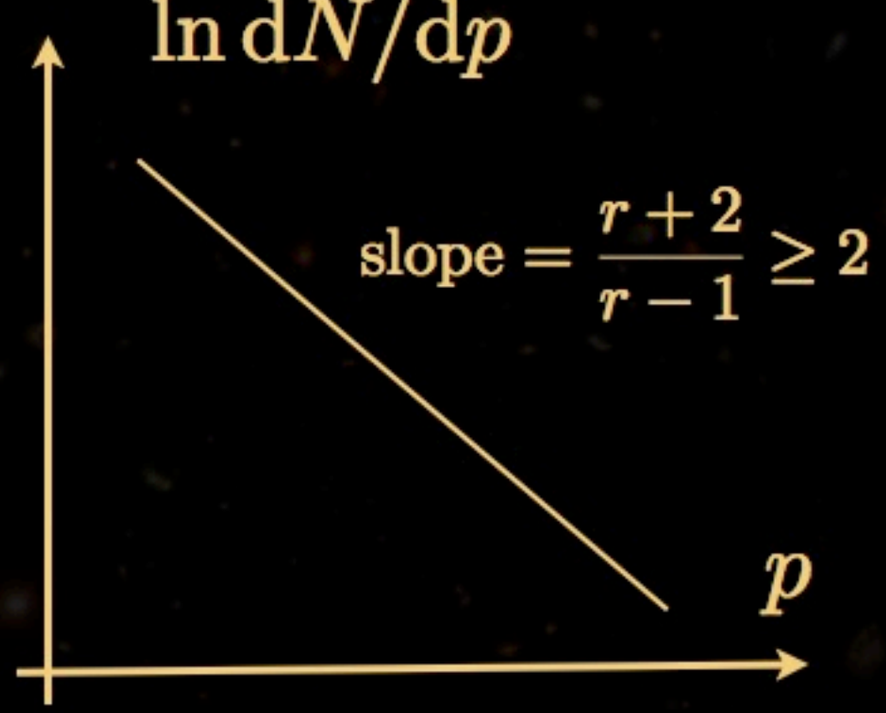
SN1006

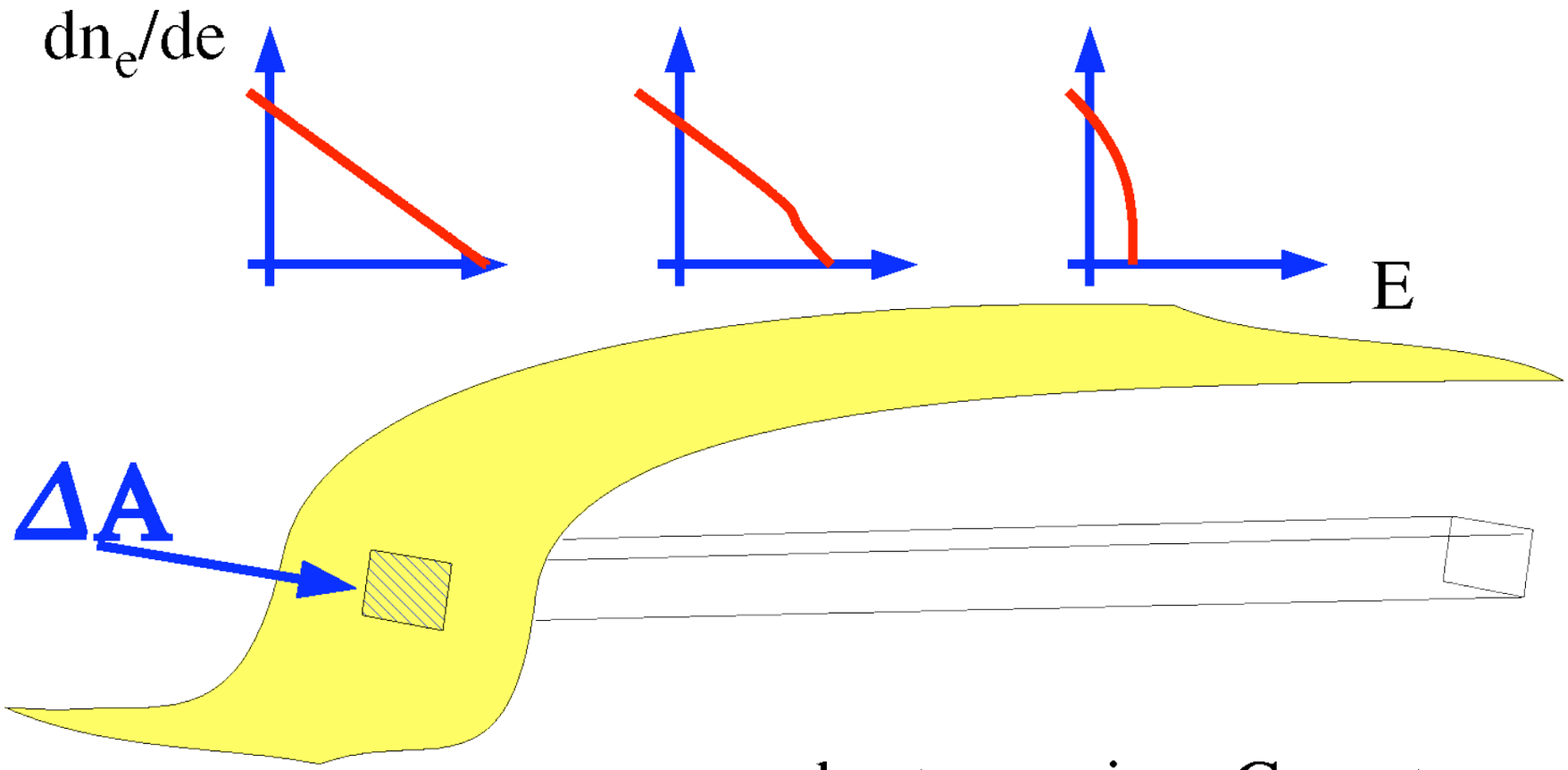

XMM Newton
0.5 - 0.8 keV
XMM Newton
2 - 4.5 keV
XMM Newton
SN 1006
VLA
1.5 GHz

Diffusive shock acceleration



- momentum gain in each cycle
- escape probability



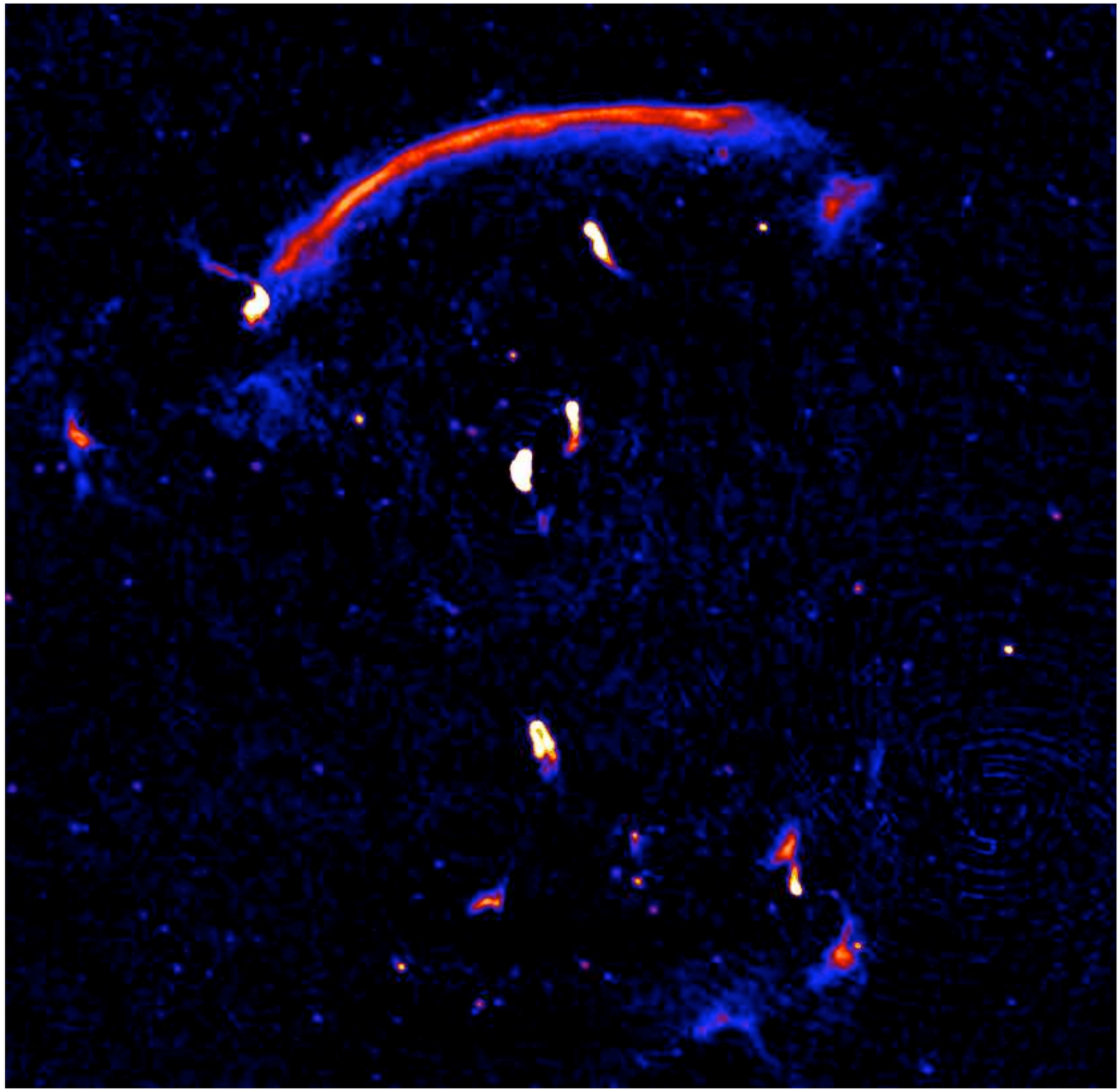


injection

synchrotron + inv. Compton cooling

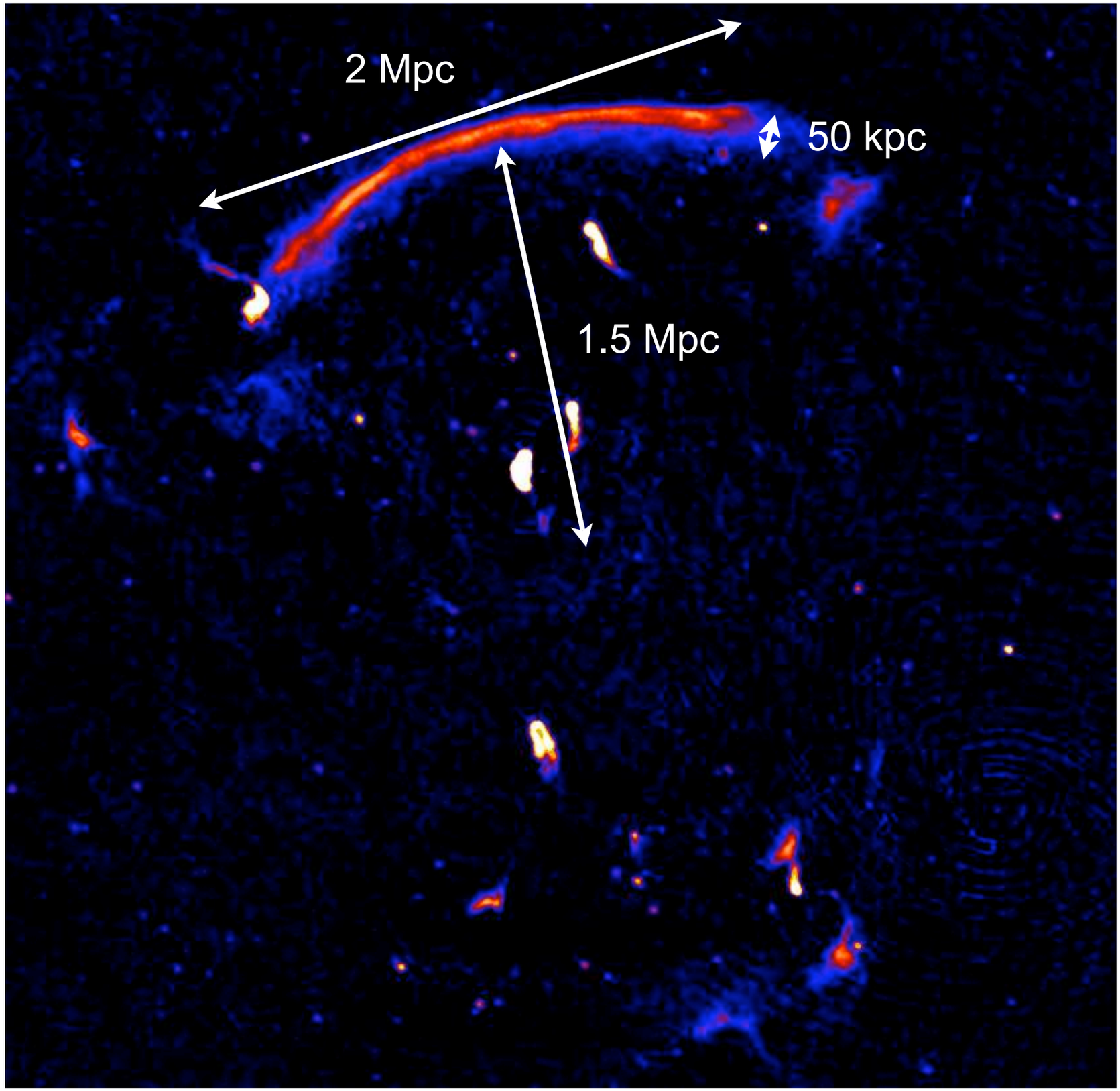
$$dp = -\frac{4}{3}\sigma_T \left\{u_B + u_{\rm CMB}\right\} - \frac{1}{3}\frac{1}{V}dV$$

The sausage: CIZA J2242.8+5301



GMRT 610 MHz, resolution of 4.8 arcsec×3.9 arcsec.
total on source time 9 hrs, bandwidth of 32 MHz.

The sausage: CIZA J2242.8+5301



GMRT 610 MHz, resolution of 4.8 arcsec×3.9 arcsec.
total on source time 9 hrs, bandwidth of 32 MHz.

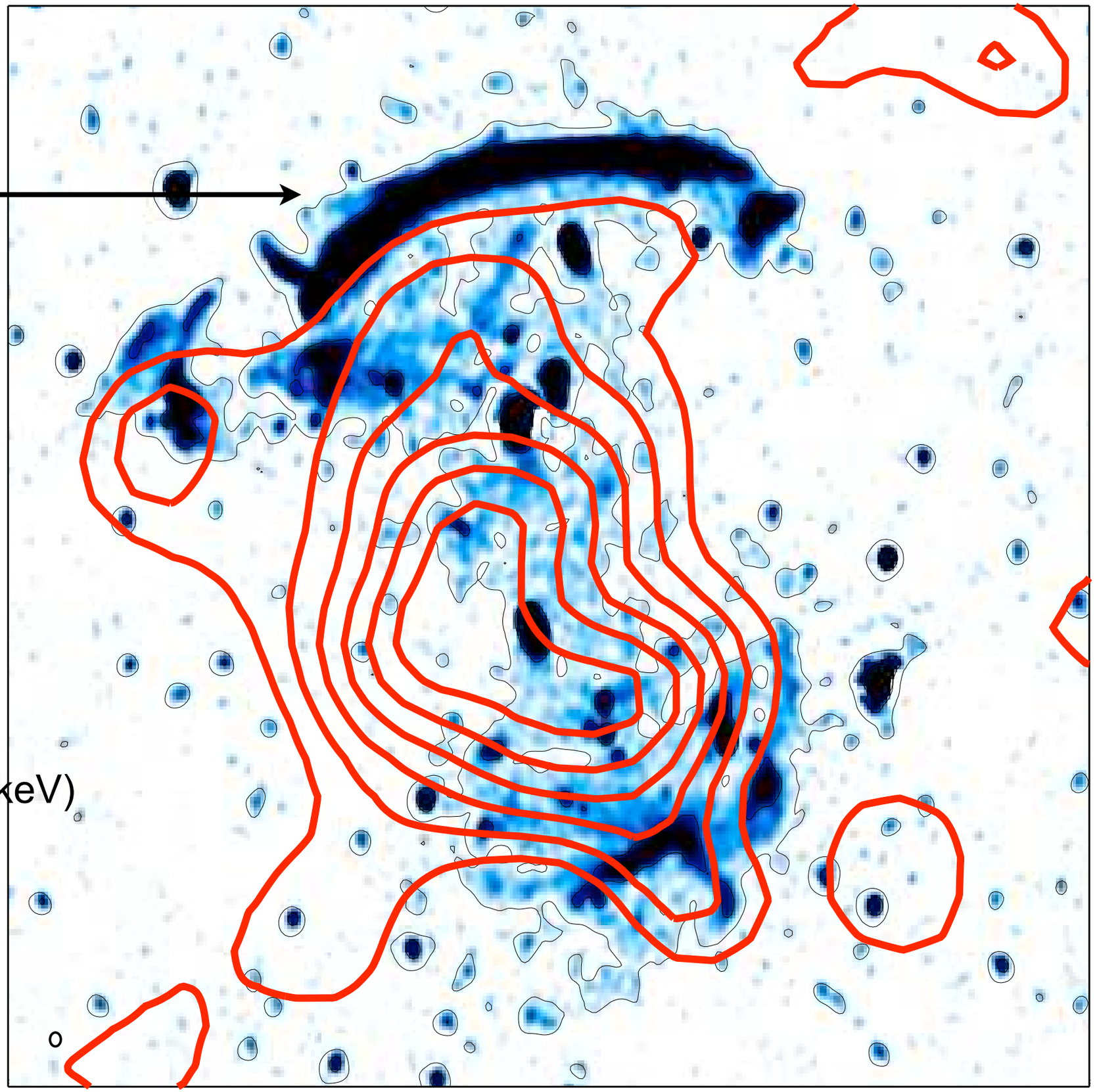
CIZA J2242.8+5301

WSRT + ROSAT

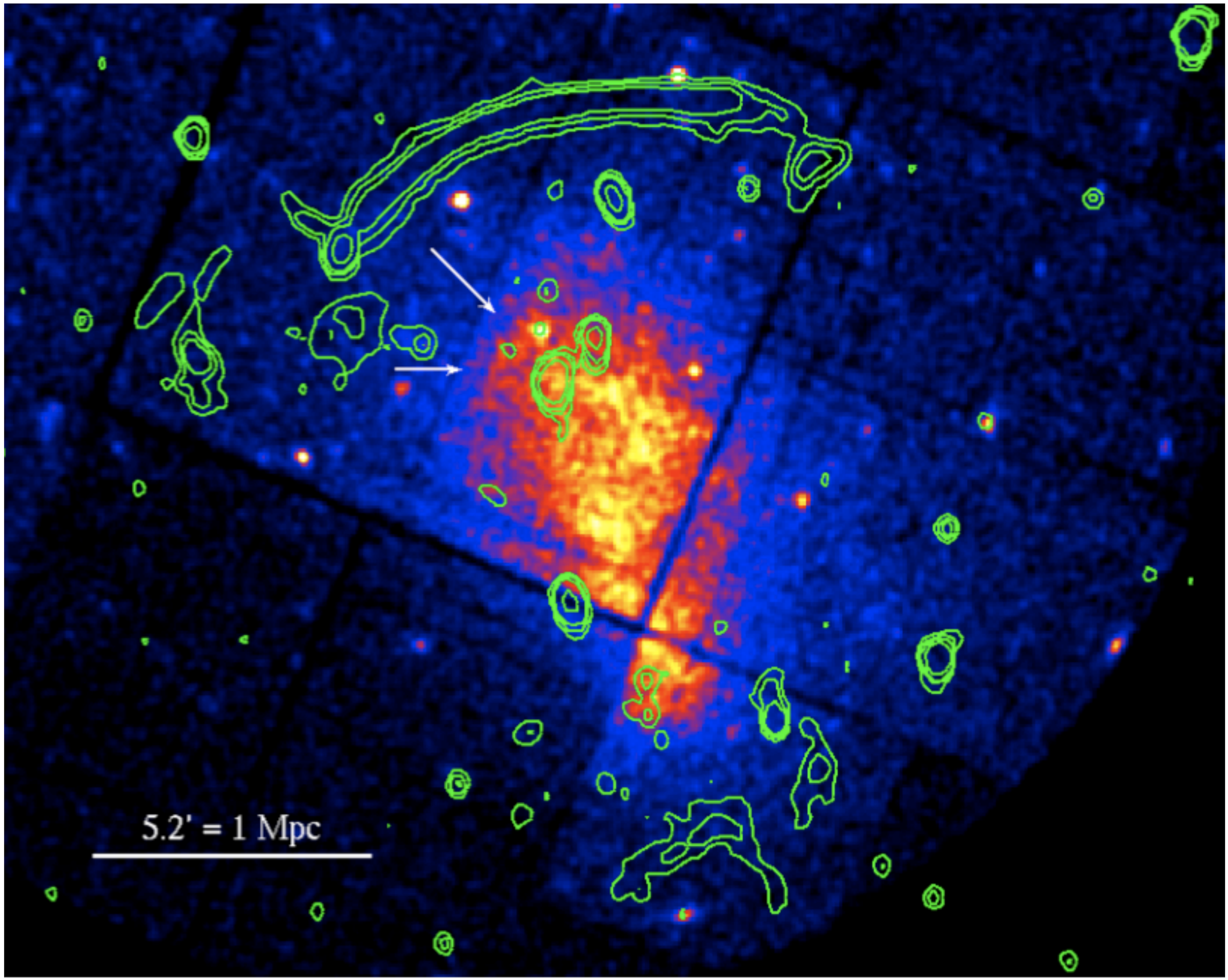
$$P_{1.4} = 1.4 \times 10^{25} \text{ W Hz}^{-1}$$

- binary merger
- T=9 keV
- z=0.19
- two relics edge-on
- halo forming
- equipartition 1.5-6μB

L_X = 6.8 10^{44} erg s^{-1}, (0.1-2.4 keV)

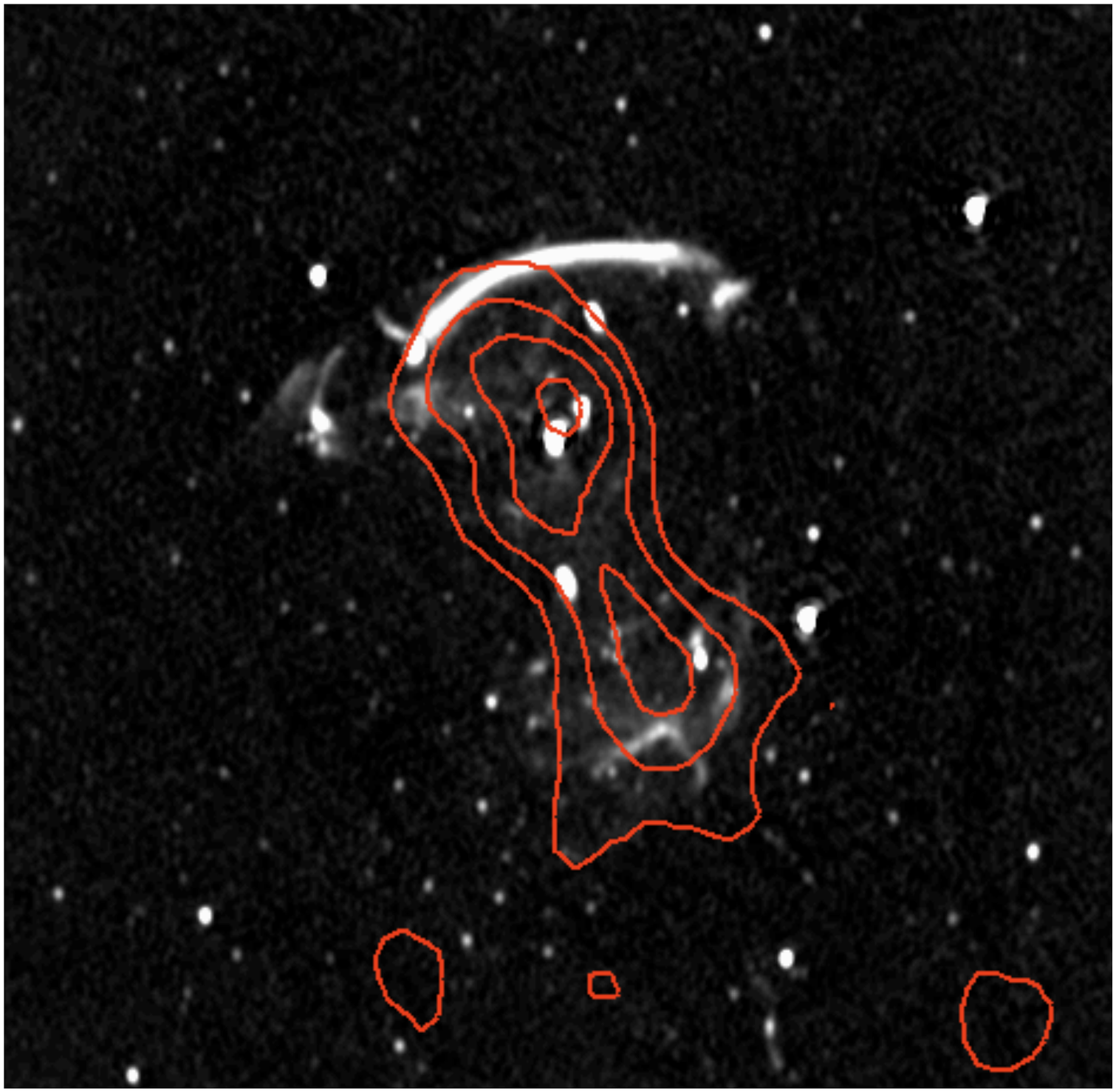


XMM+WSRT

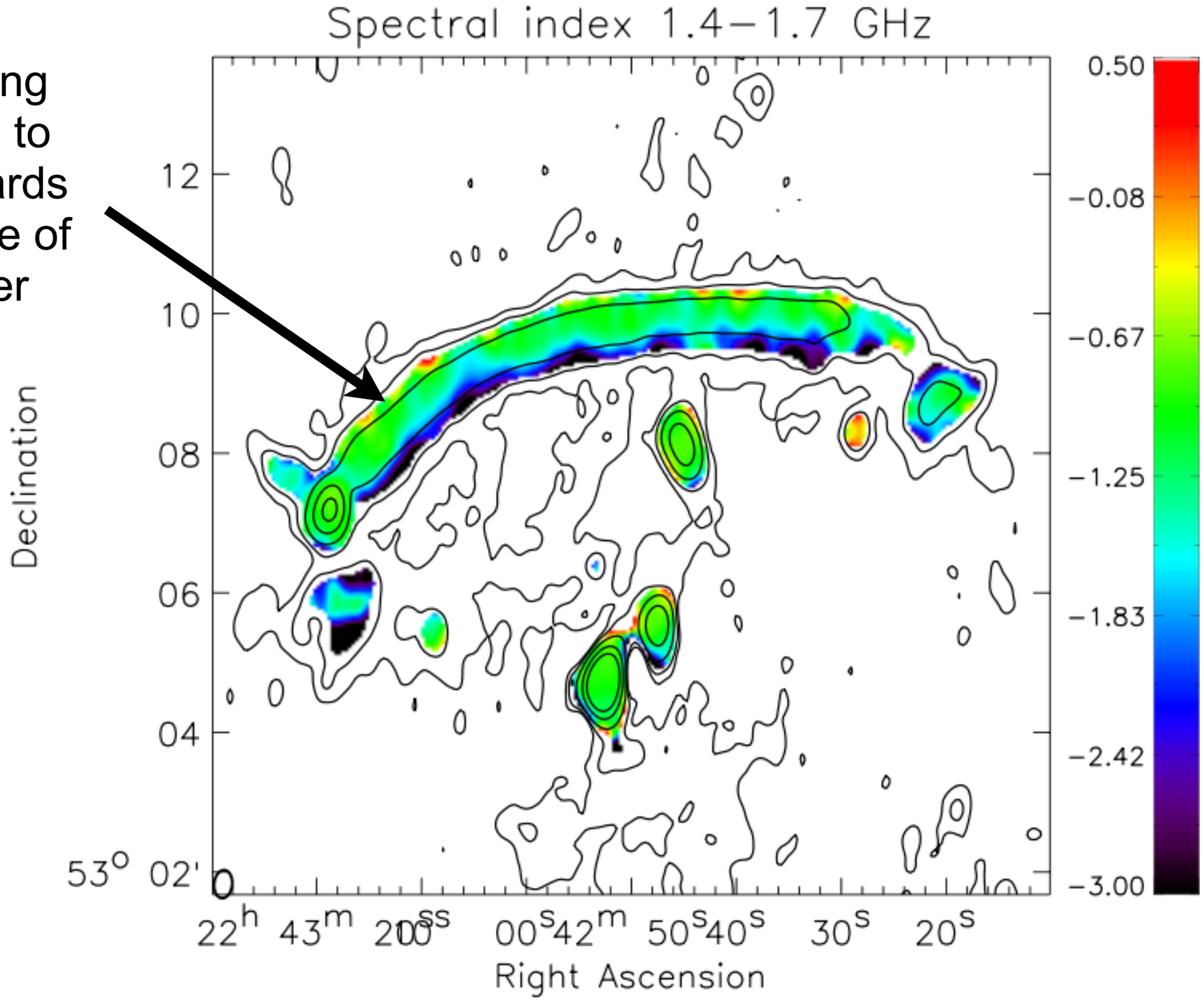


Ogrean, Brüggen, van Weeren, Röttgering, Simionescu (in prep.)

Galaxy iso-density map

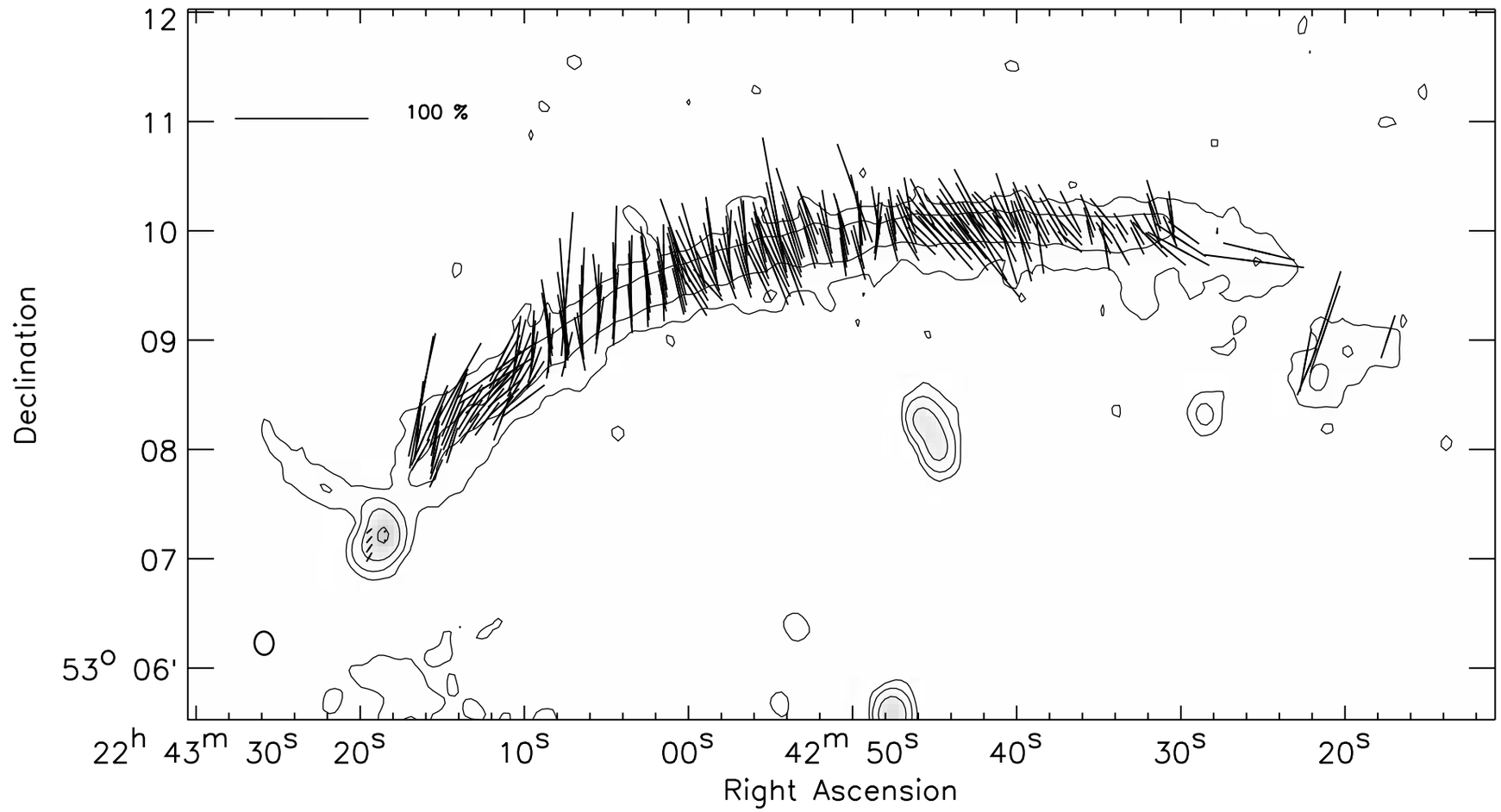


Steepening from -0.5 to -2.5 towards the centre of the cluster



spectral index for at the front of the relic is -0.6 ± 0.05. DSA gives a Mach number of 4.6

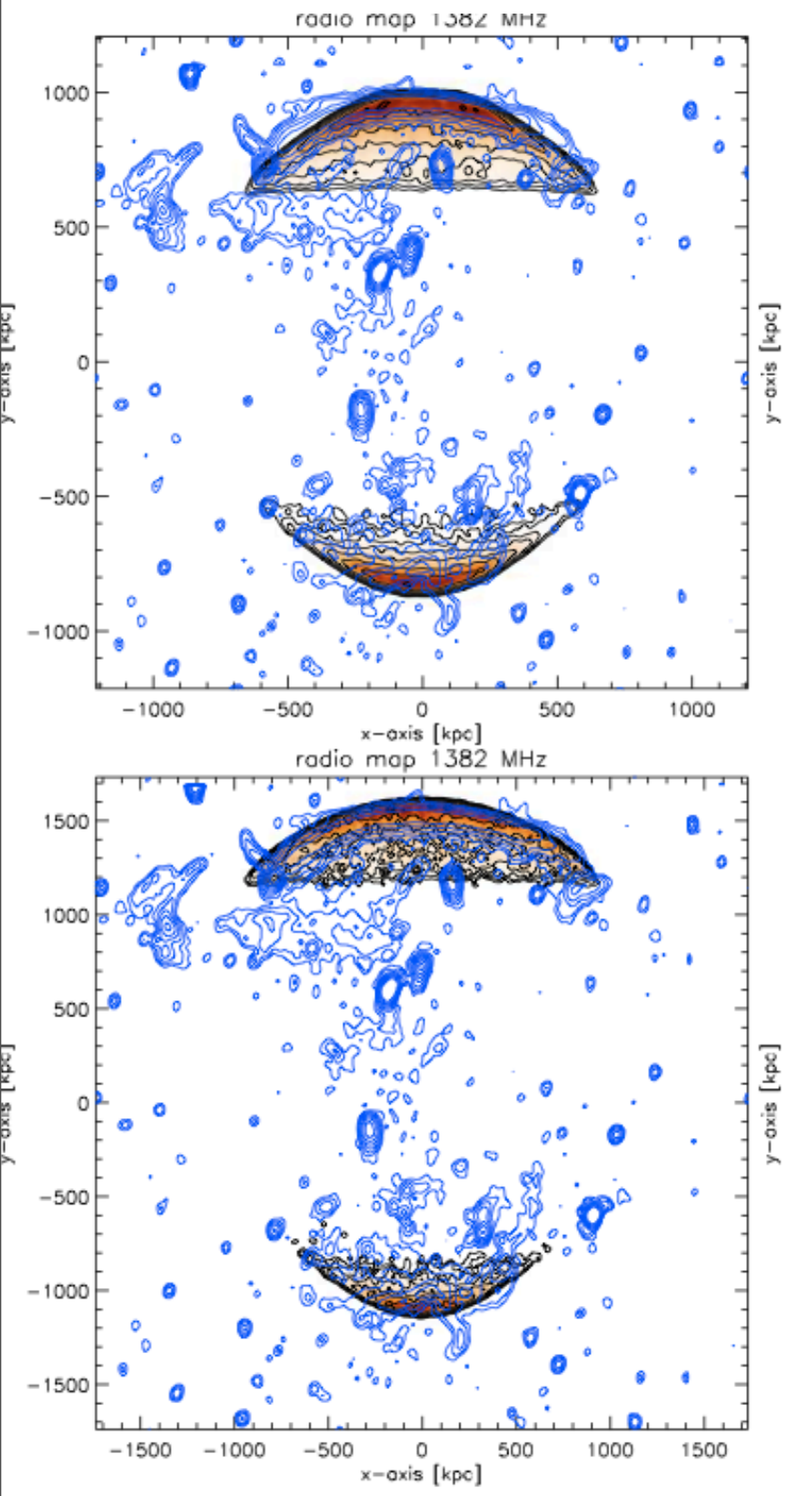
E-vectors

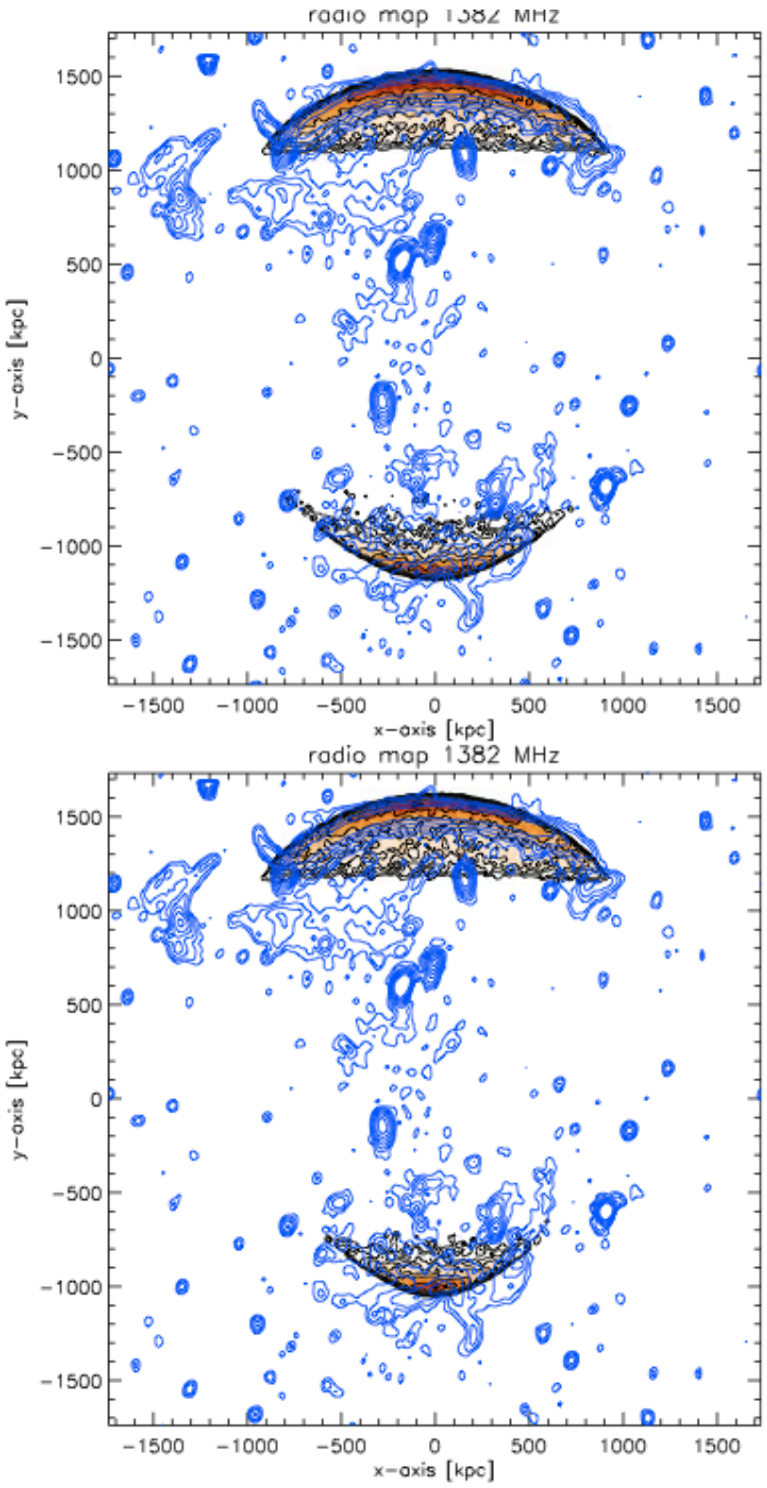


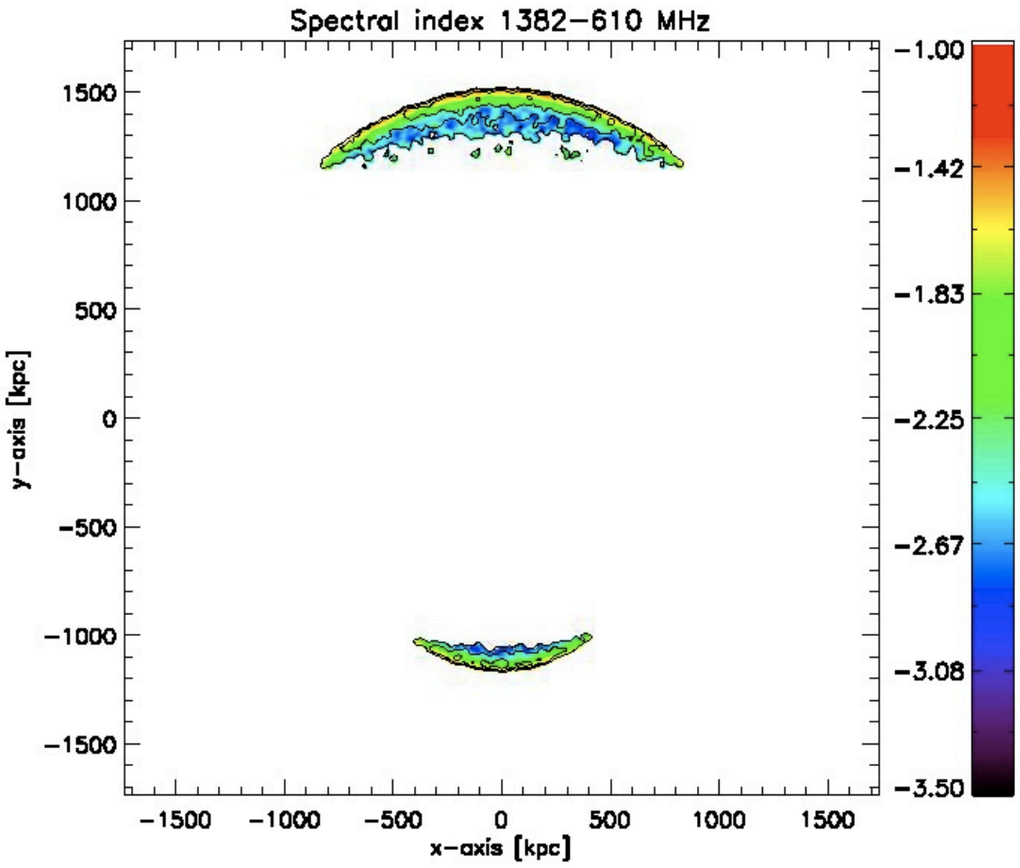
polarisation @ 2.2 GHz: 50 %

and why is it so smooth?

Simulations of the “Sausage”

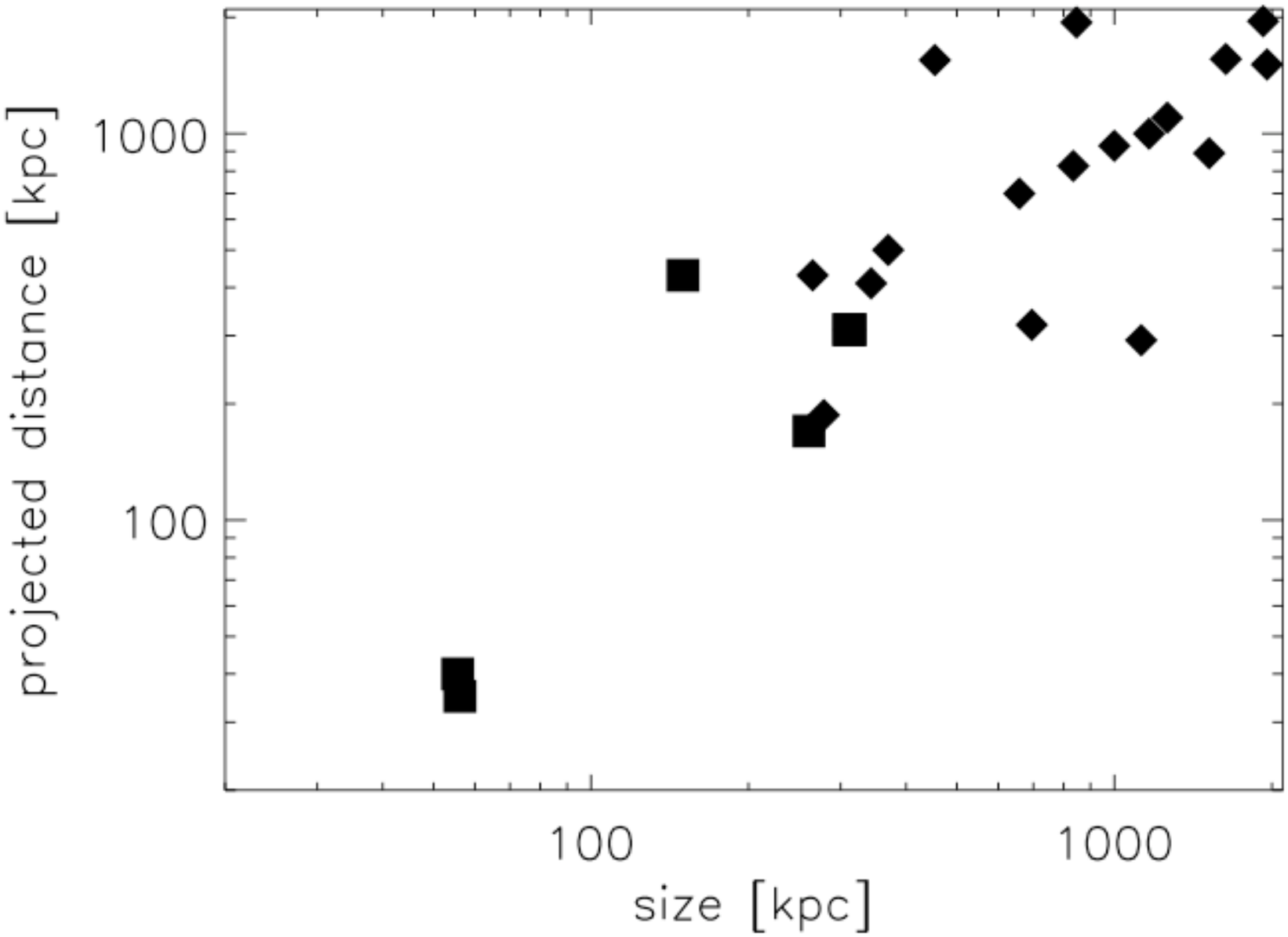




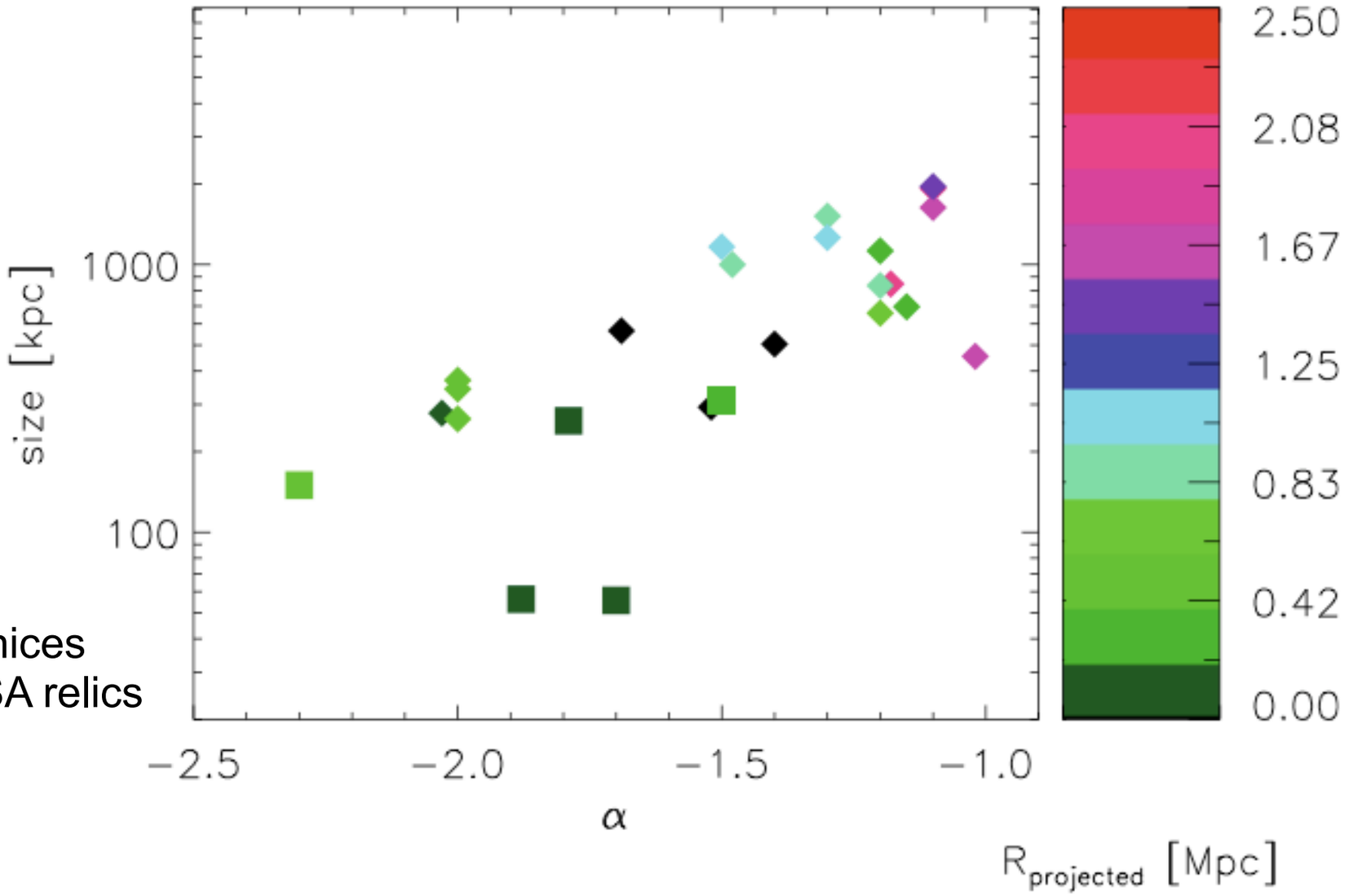


van Weeren & Brüggen (in prep.)

Size vs distance

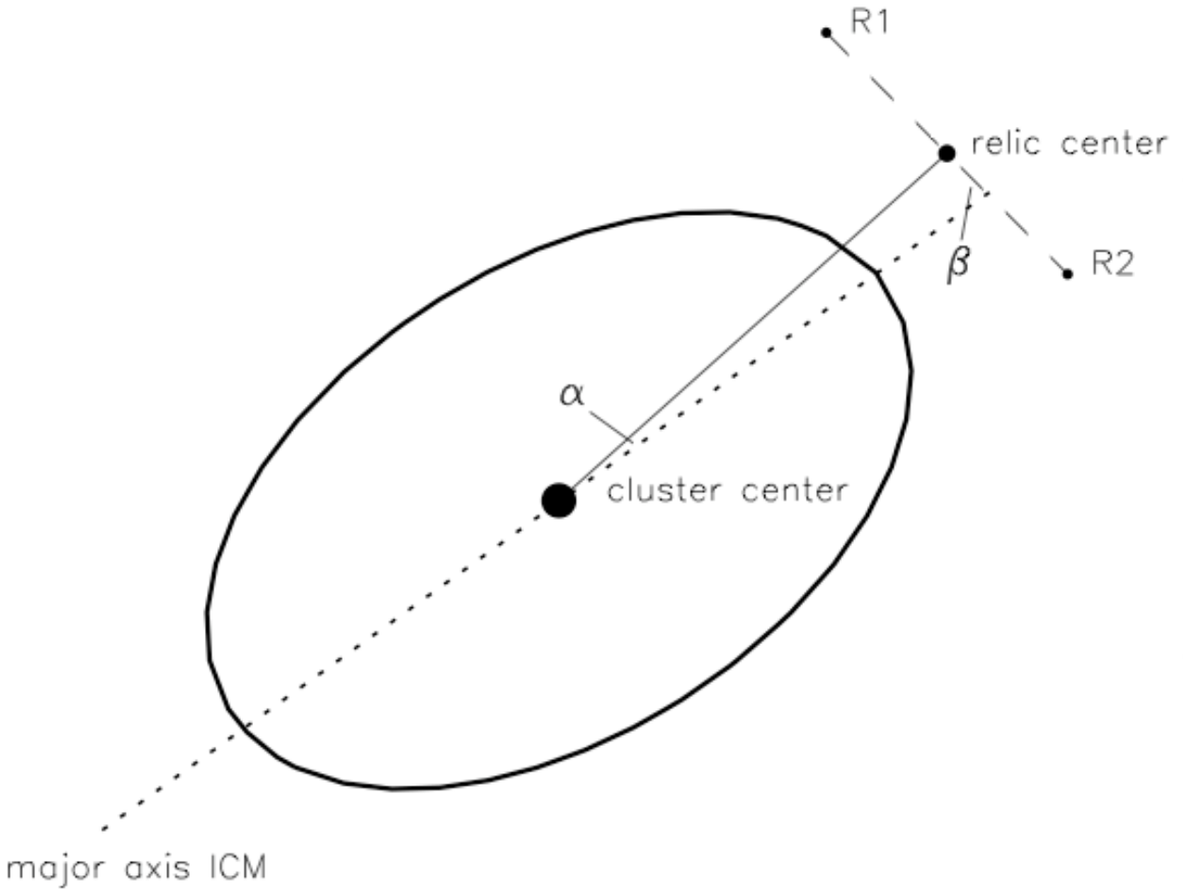


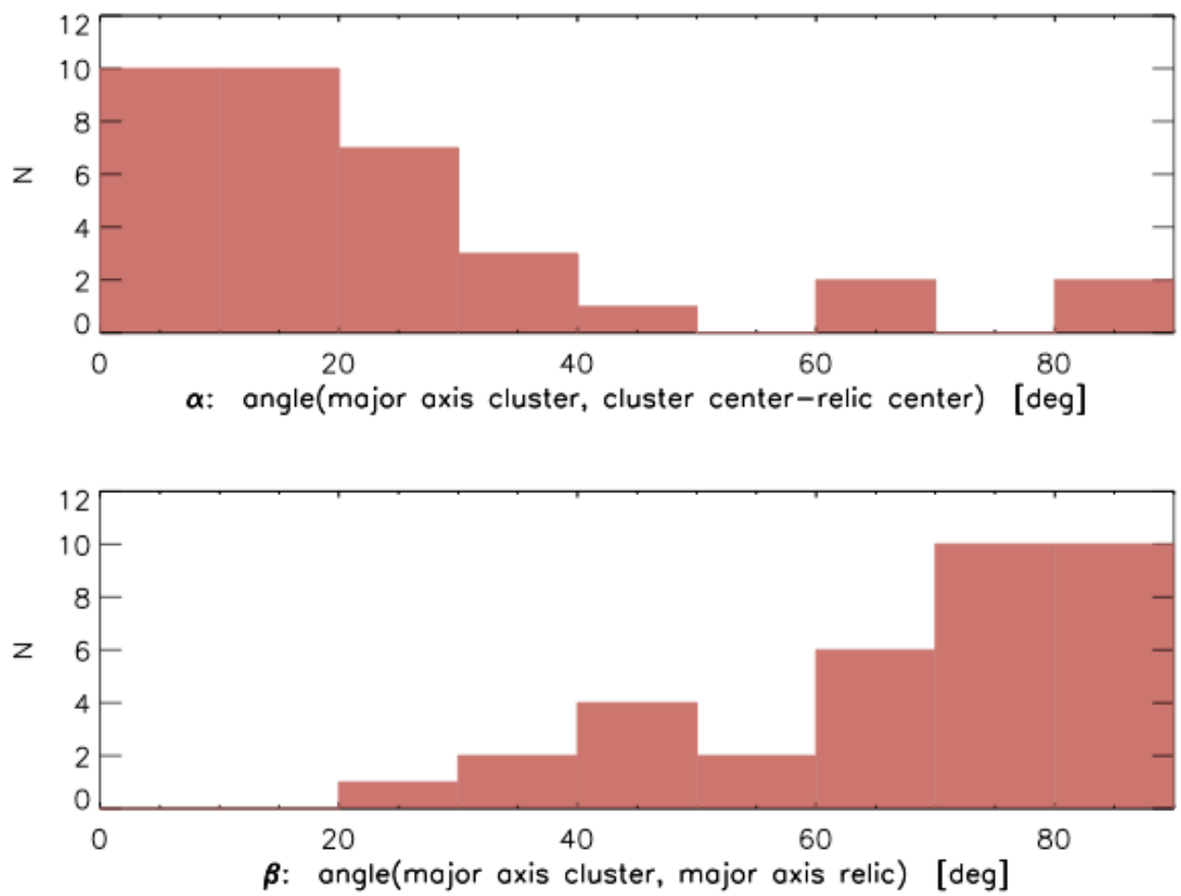
Size vs spectral index



square: phoenices
diamonds: DSA relics

smaller relics have steeper spectra: i) radio phoenices populate steep/small region
ii) larger shock waves occur in less dense environment,
higher Mach number
shallower spectra





van Weeren, Brüggen, Röttgering, Hoeft, Nuza, Intema (2011)

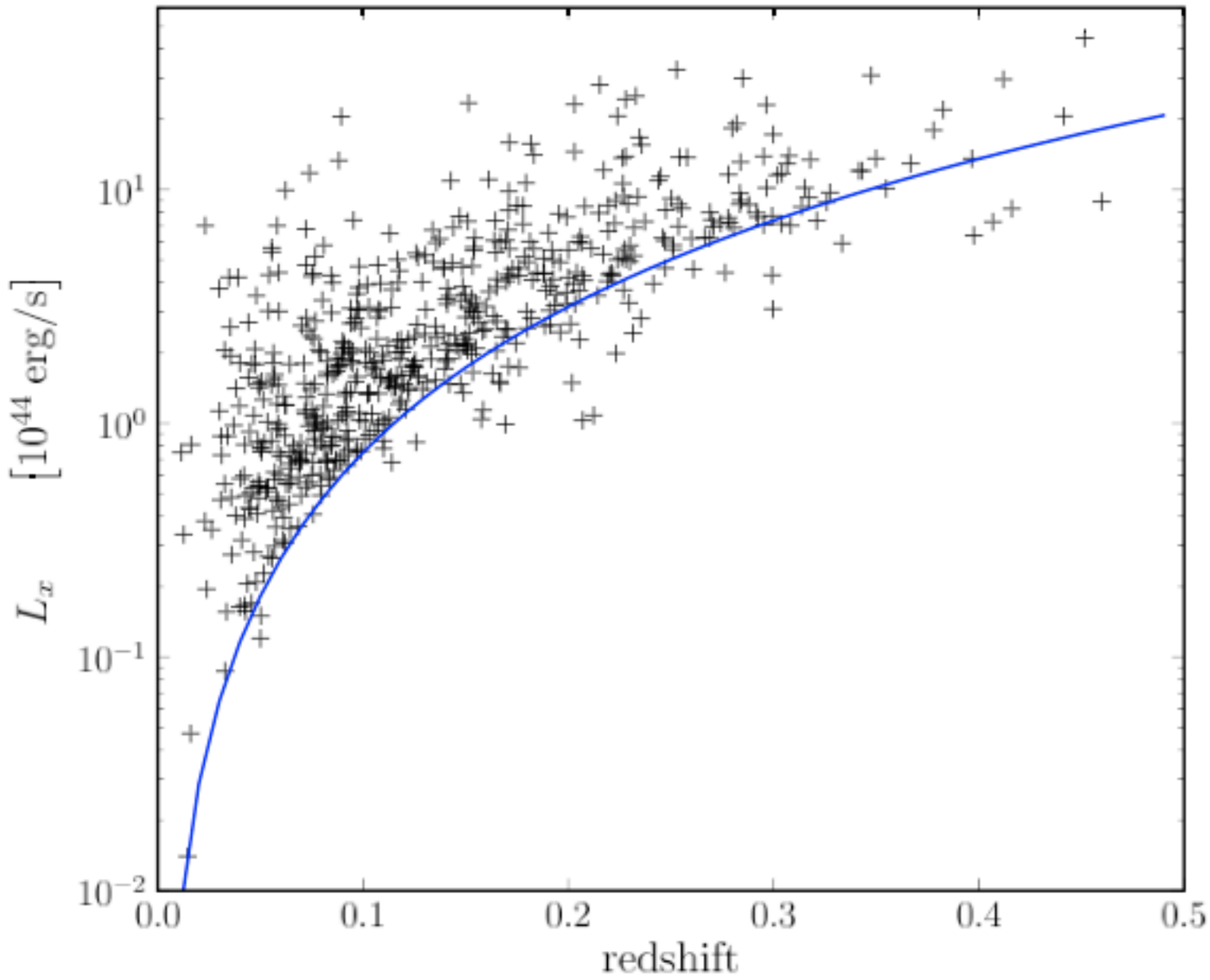
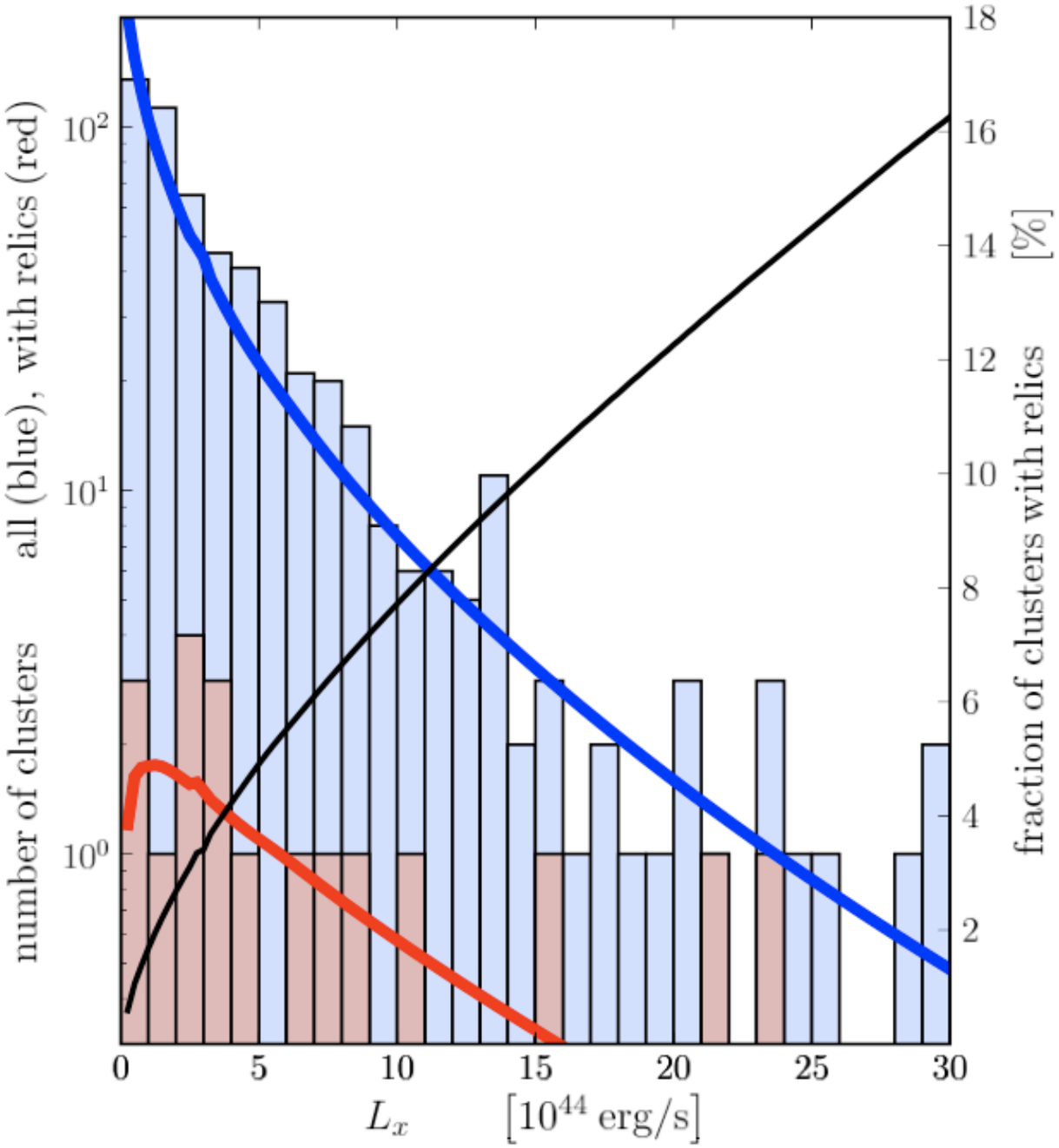


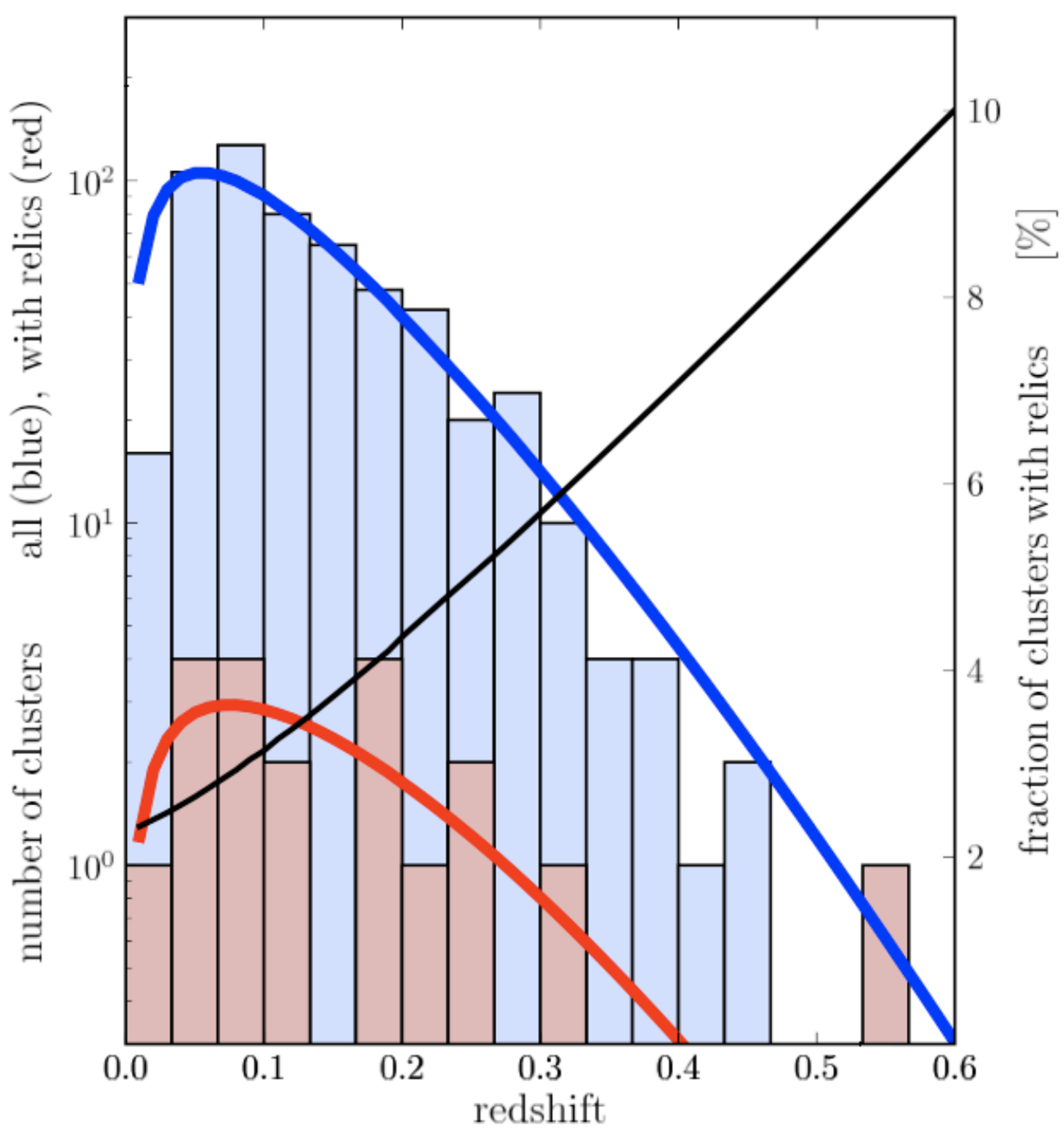
Fig. 20. L_X-redshift distribution for the NORAS and REFLEX surveys. The solid blue line is the flux cutoff of 3.3×10^{-12} erg s^{-1} cm^{-2} we use for selecting cluster to be compared the the relic cluster sample.

van Weeren, Brüggen, Röttgering, Hoeft, Nuza, Intema (2011)

X-ray luminosity distribution



redshift distribution

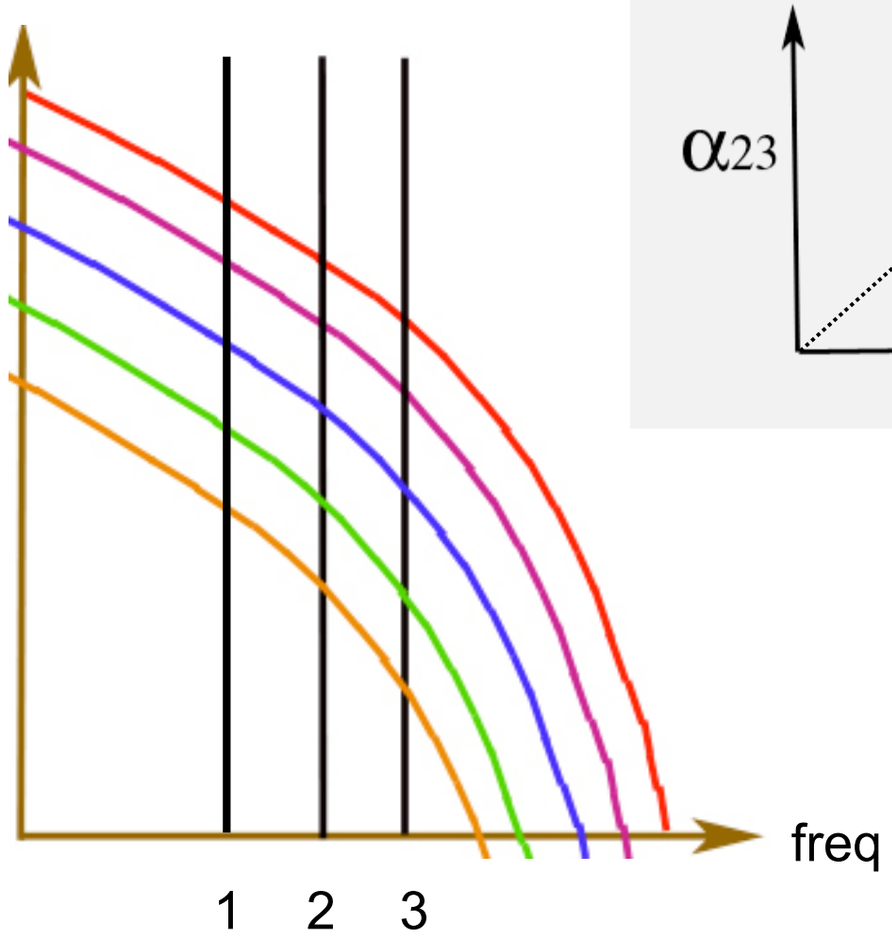


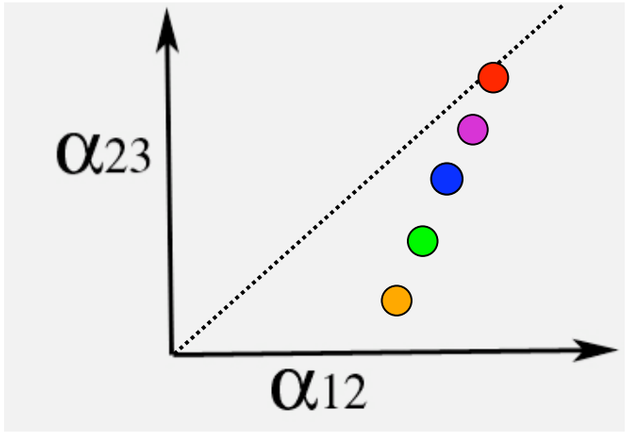
Blue histograms shows the NORAS/REFLEX sample, red the relic cluster sample. The solid blue line displays the predicted luminosity distributions from Nuza et al., while the solid red line is the prediction for cluster hosting relics in the simulation.
The fraction of cluster with relics is given by the **black solid line** (ratio of the blue and red lines).

van Weeren, Brüggen, Röttgering, Hoeft, Nuza, Intema (2011)

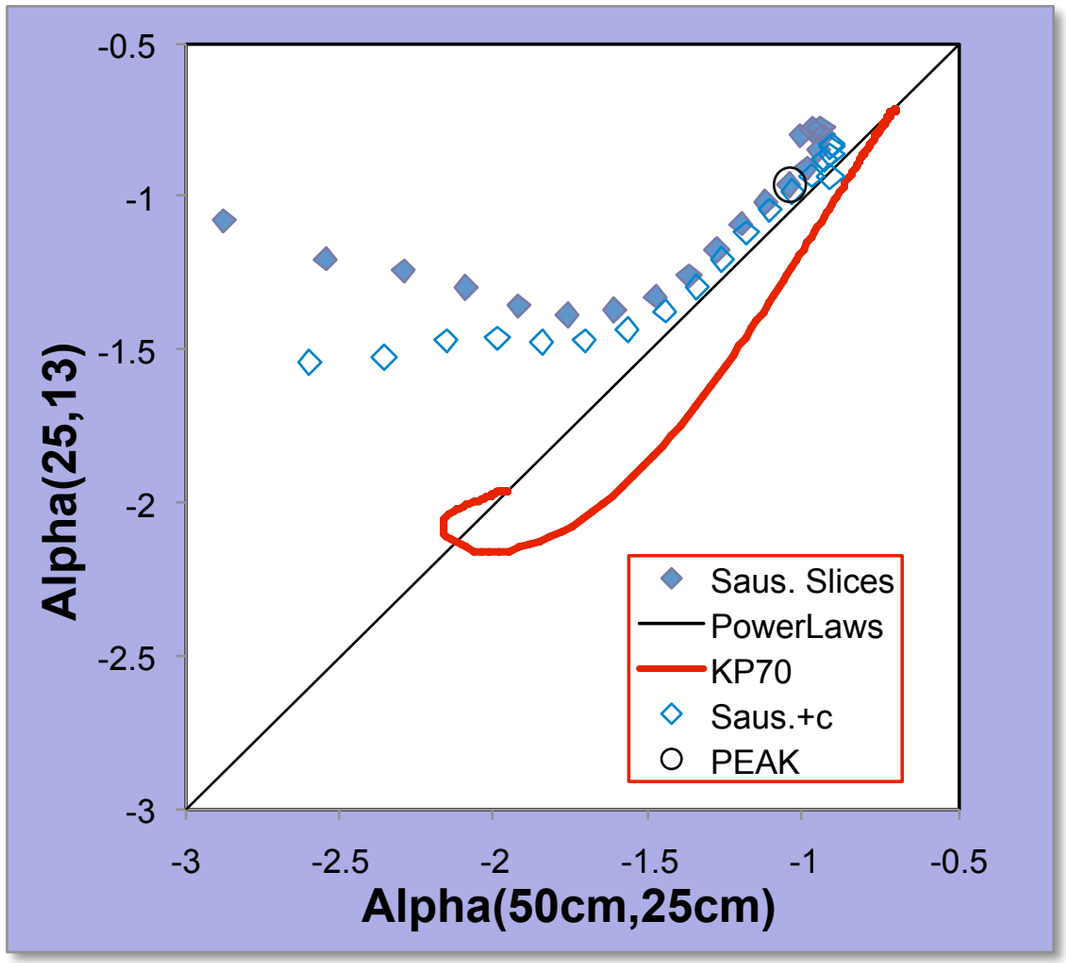
What does the relic really consist of?

- in reality things are more complicated
- not pure ageing
- mixture of populations
- PLUS extra steep spectrum component only visible at 50cm, 200cm





work in progress



slide by L. Rudnick

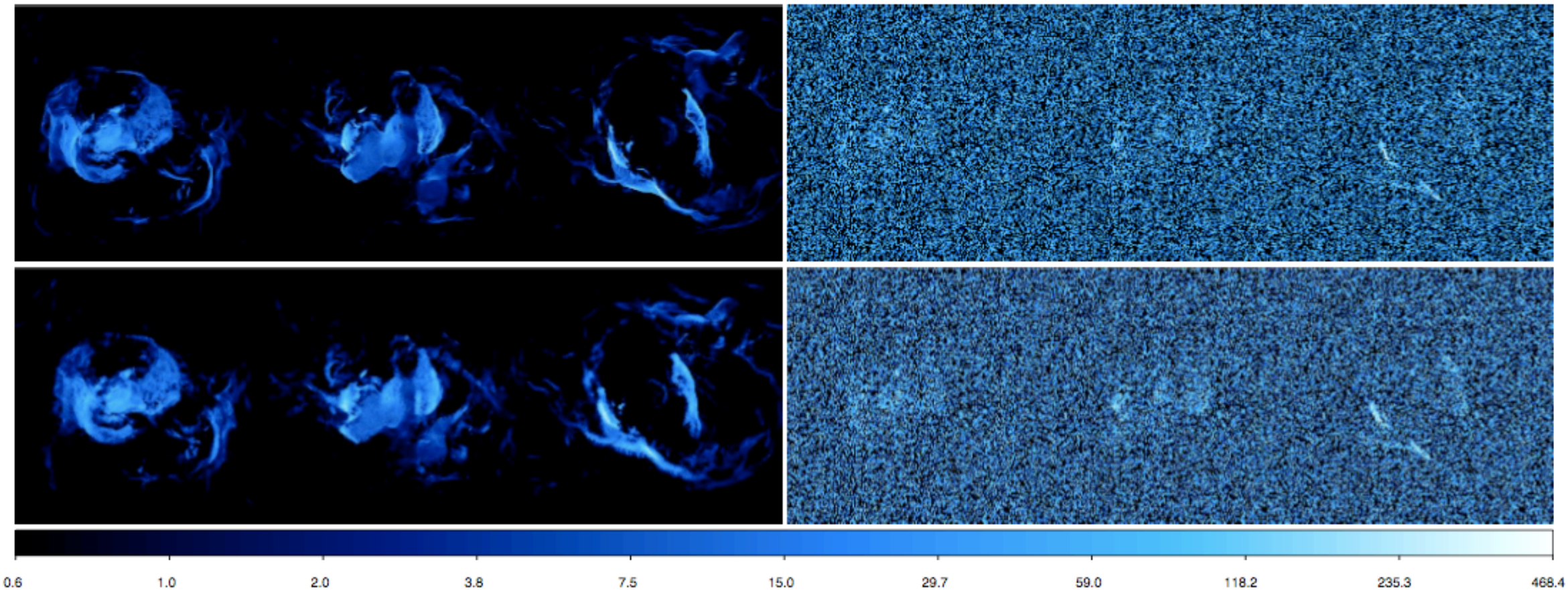
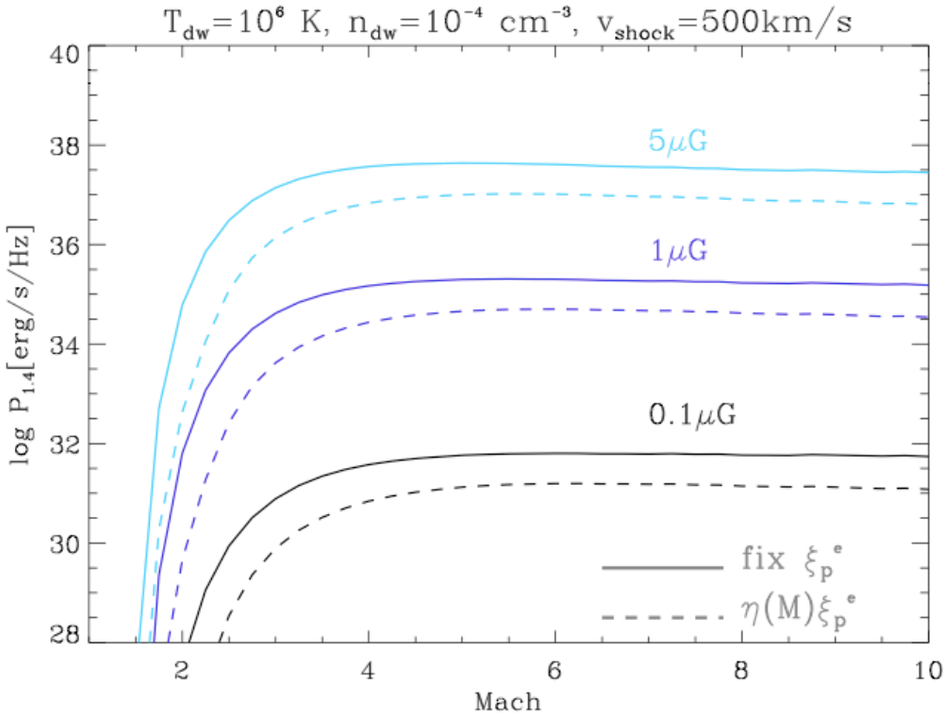


Fig. 15. Left panels: projected maps of radio emission (in μJ/beam) for the three projections of cluster E1 at the distance of z=0.05, with (top) and without (bottom) the effect of the broadening of the emission region. Right panels: shame as in the right panel, but with the addition of the Gaussian noise with $\sigma = 70\mu J$/beam. All maps assume $B = 7\mu G$ and $\xi_p^e = 0.1$.



work in progress

Gaussian noise, no secondary lobes from other sources in the beam

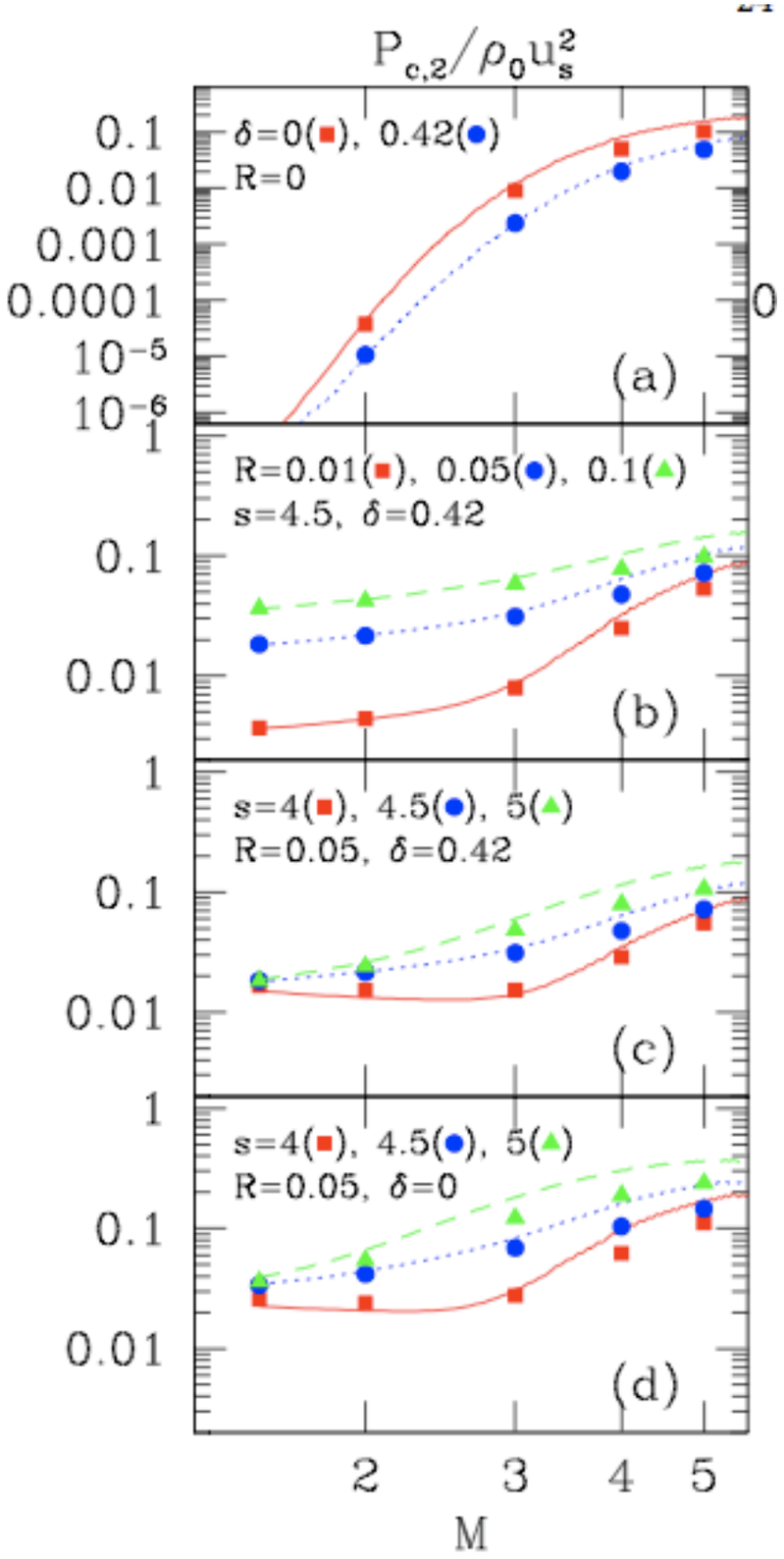
morphology, statistics and spectral properties can be reproduced well

power is 1-2 magnitudes too low

Vazza in prep.

Also see talk by Burns/Skillman
poster by O'Shea

Pre-acceleration...



Kang & Ryu 2011

What about turbulence?

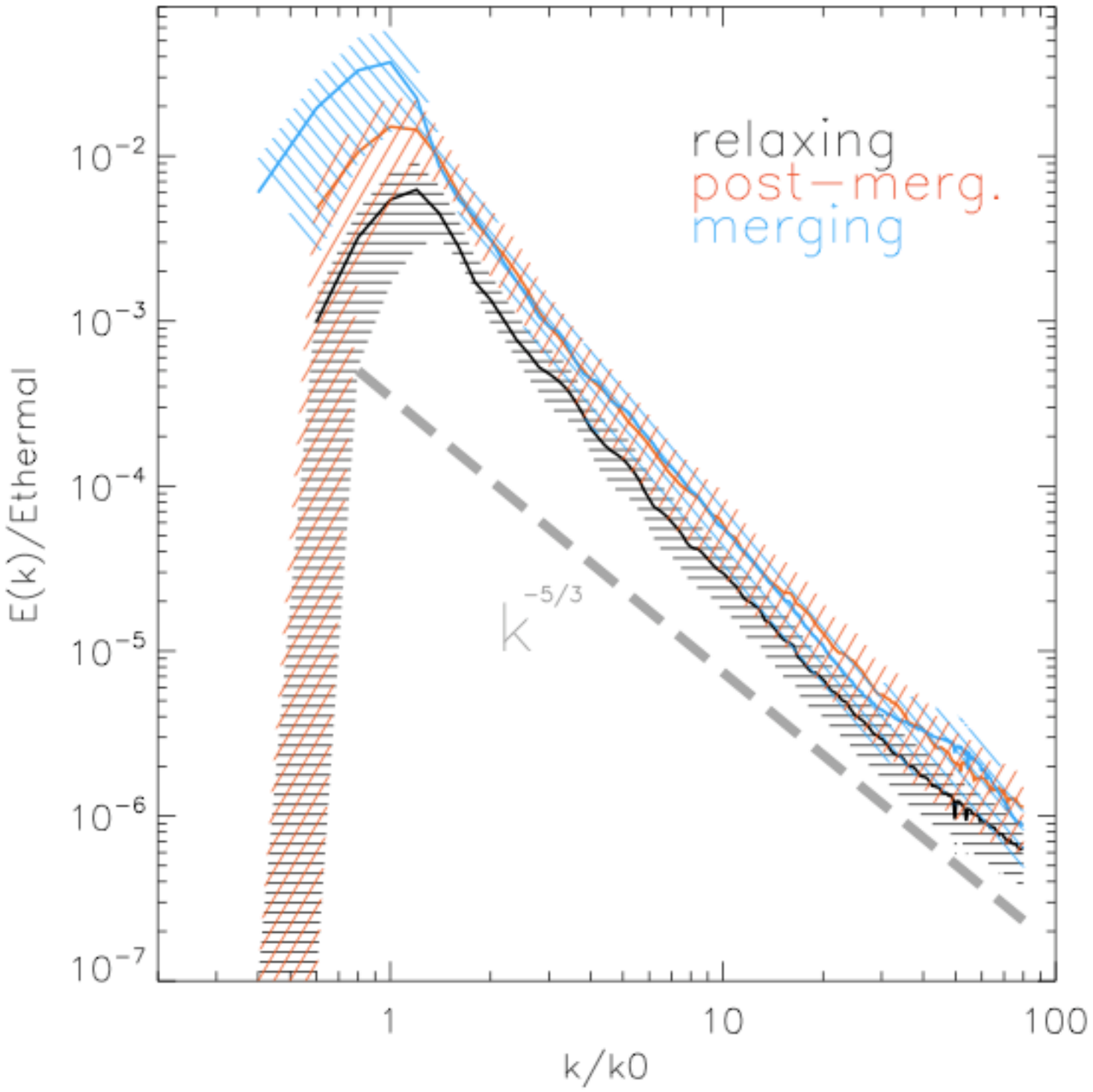


Fig. 7. Average power spectra of the 3–D velocity field for the different classes of galaxy clusters in our sample, at $z = 0$.

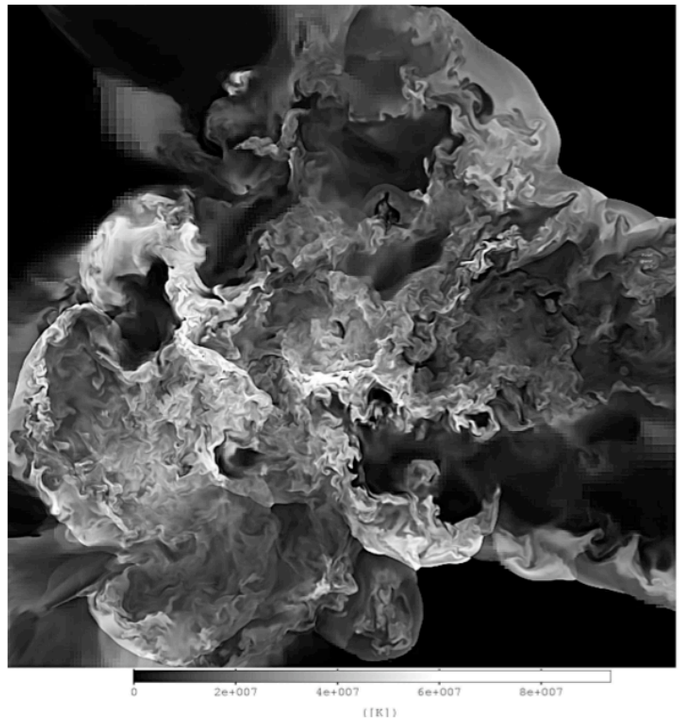
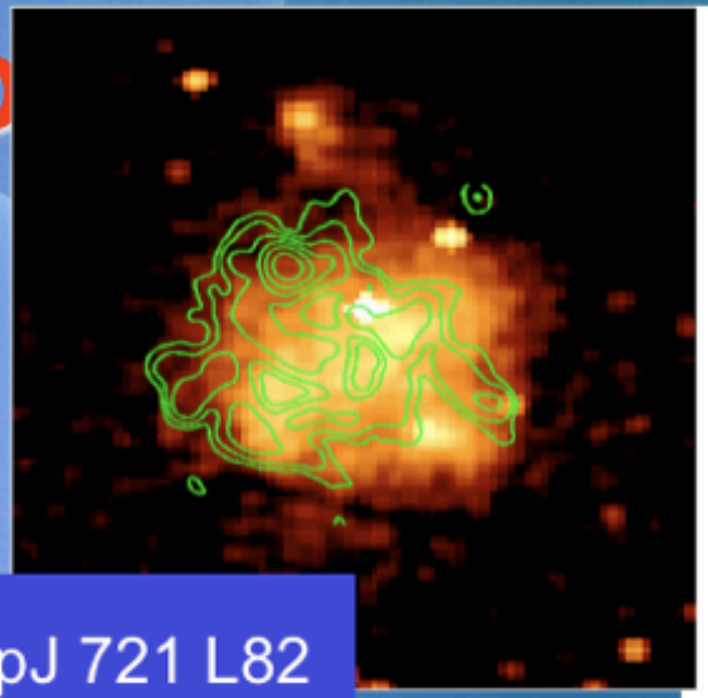


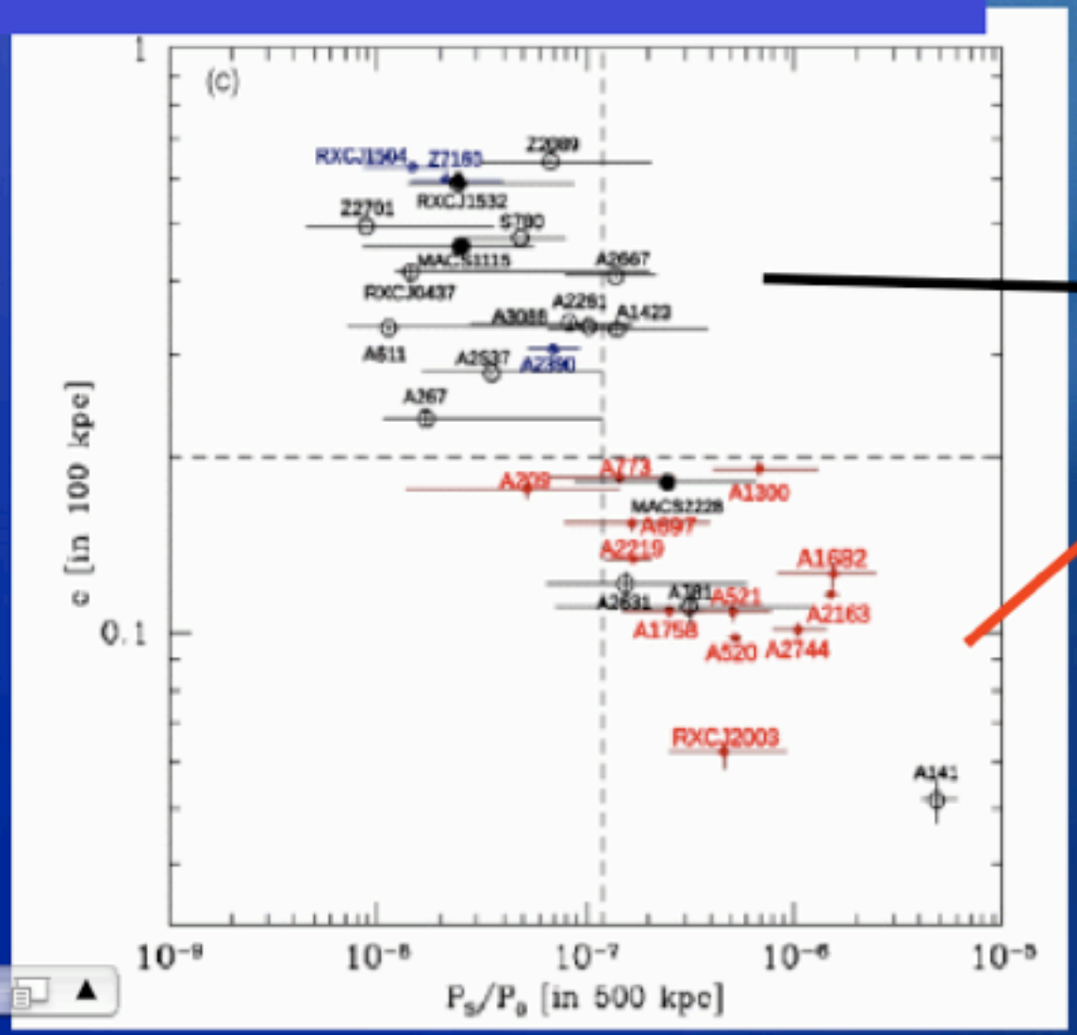
Fig. 1. 2-dimensional slice showing the gas temperature for the innermost region of galaxy cluster E1, during its main merger event ($z = 0.6$). The side of the slice is $8.8Mpc/h$ and the depth along the line of sight is $25kpc/h$.

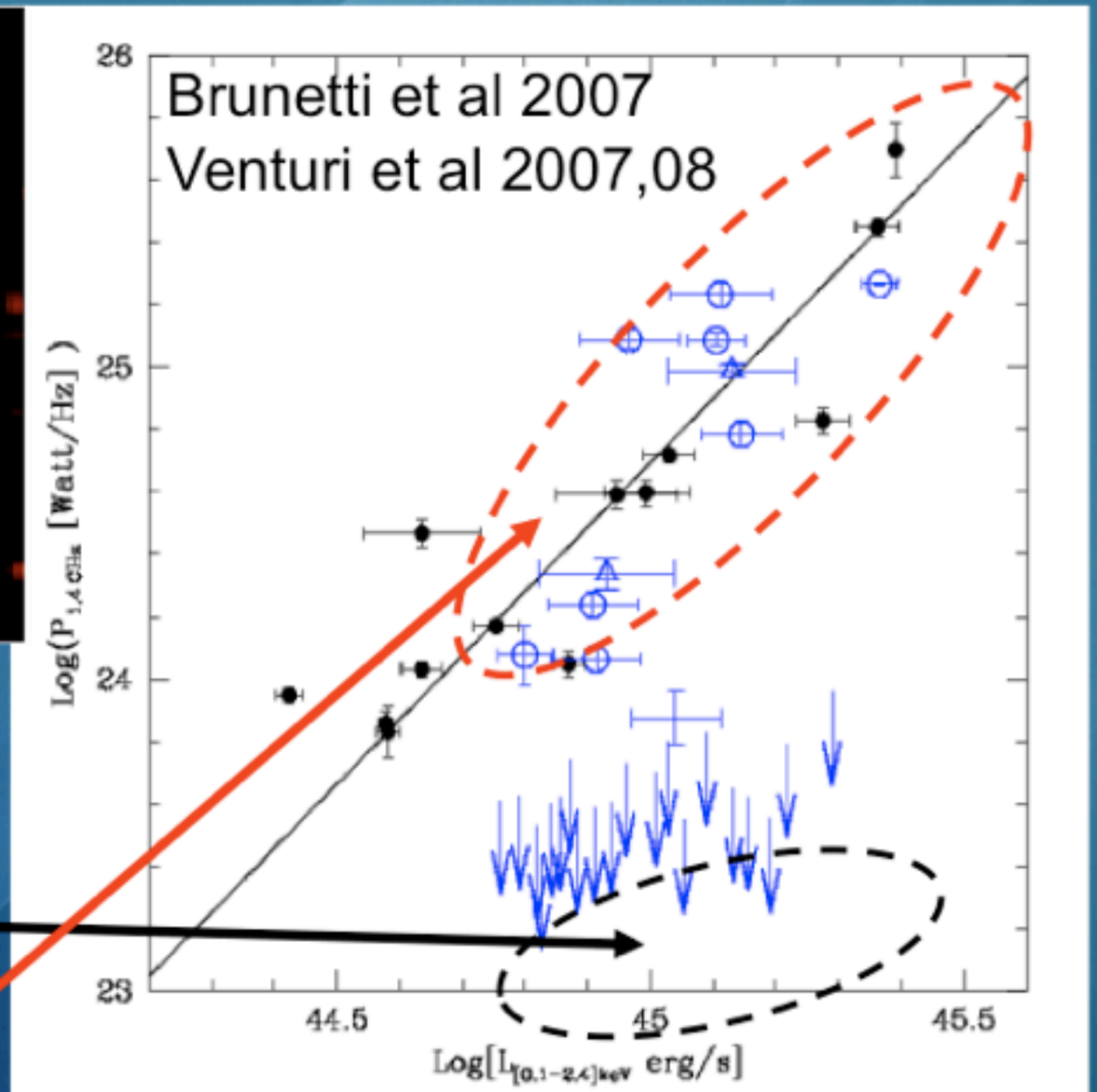
Vazza et al. (2010)

Cluster mergers - radio halos connectio

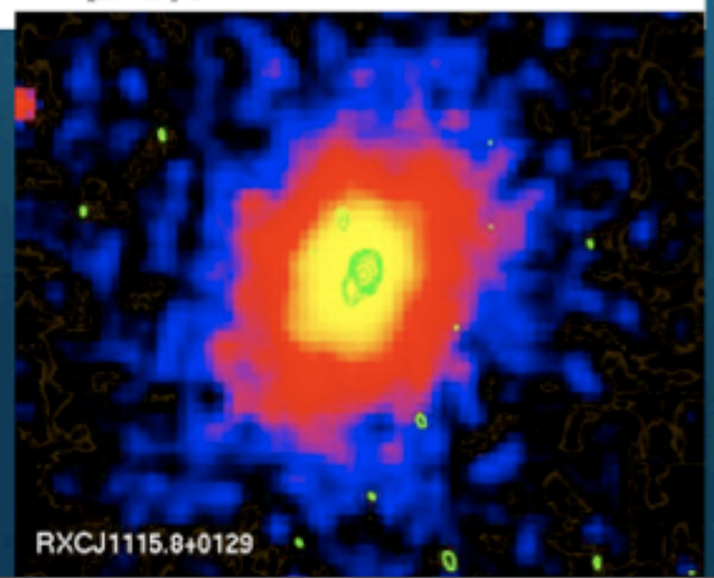


Cassano et al 2010 ApJ 721 L82

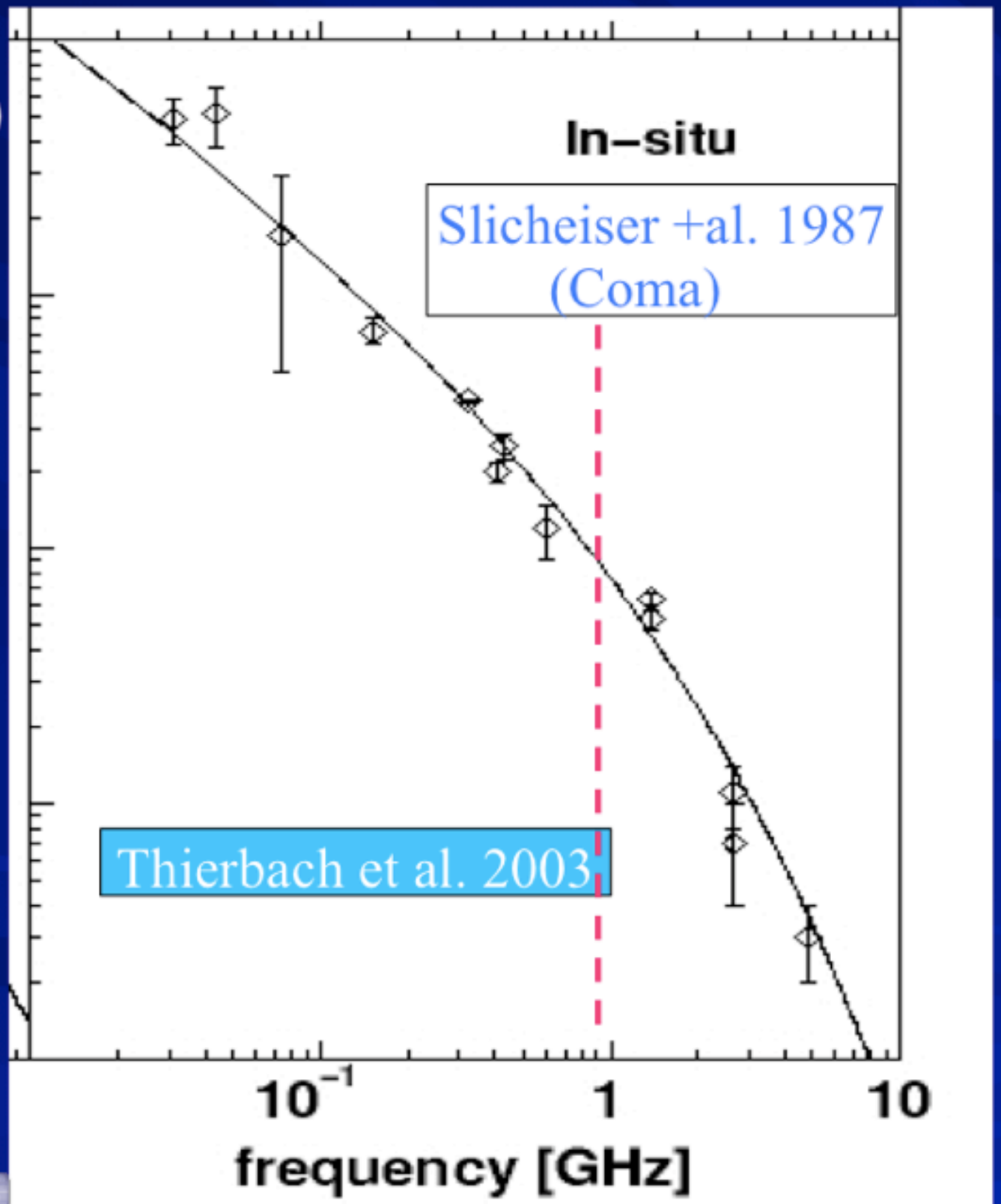




The radio bimodality has a correspondence in terms of dynamical segregation

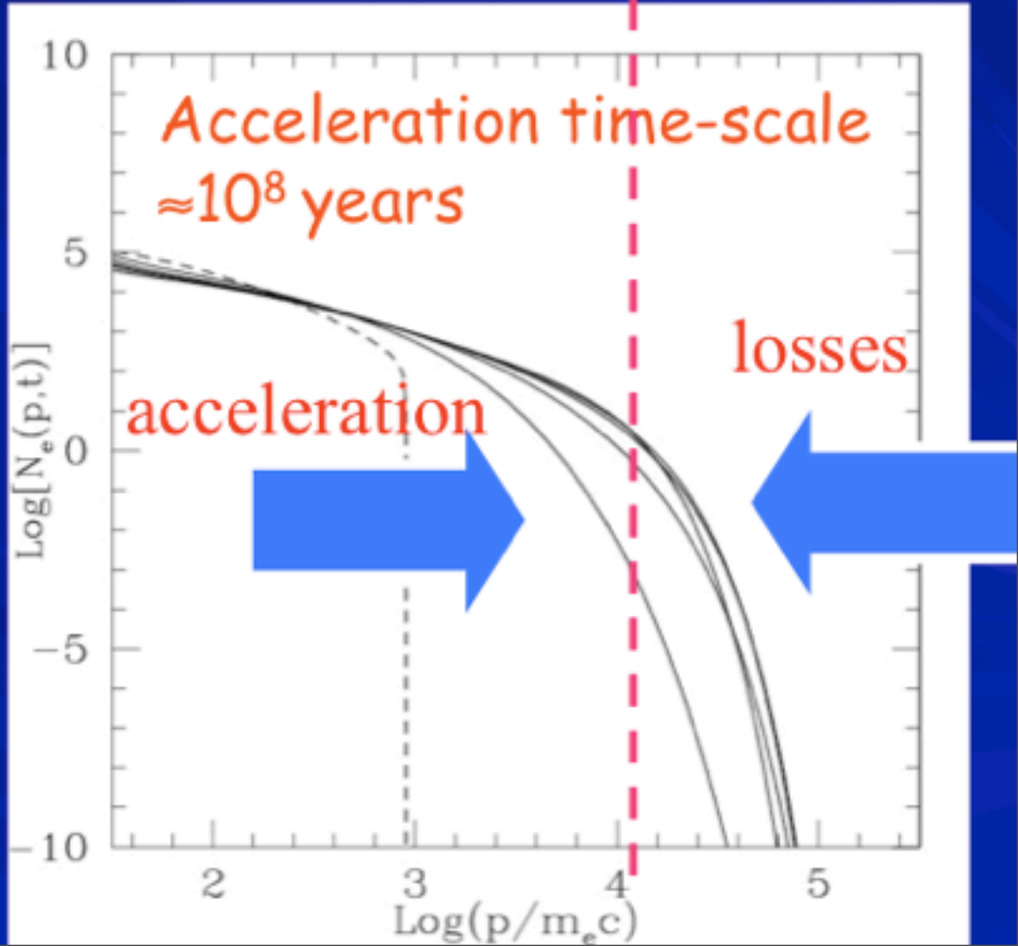


Radio Halos : are they generated by "inefficient" mechanism of CRe acceleration ?

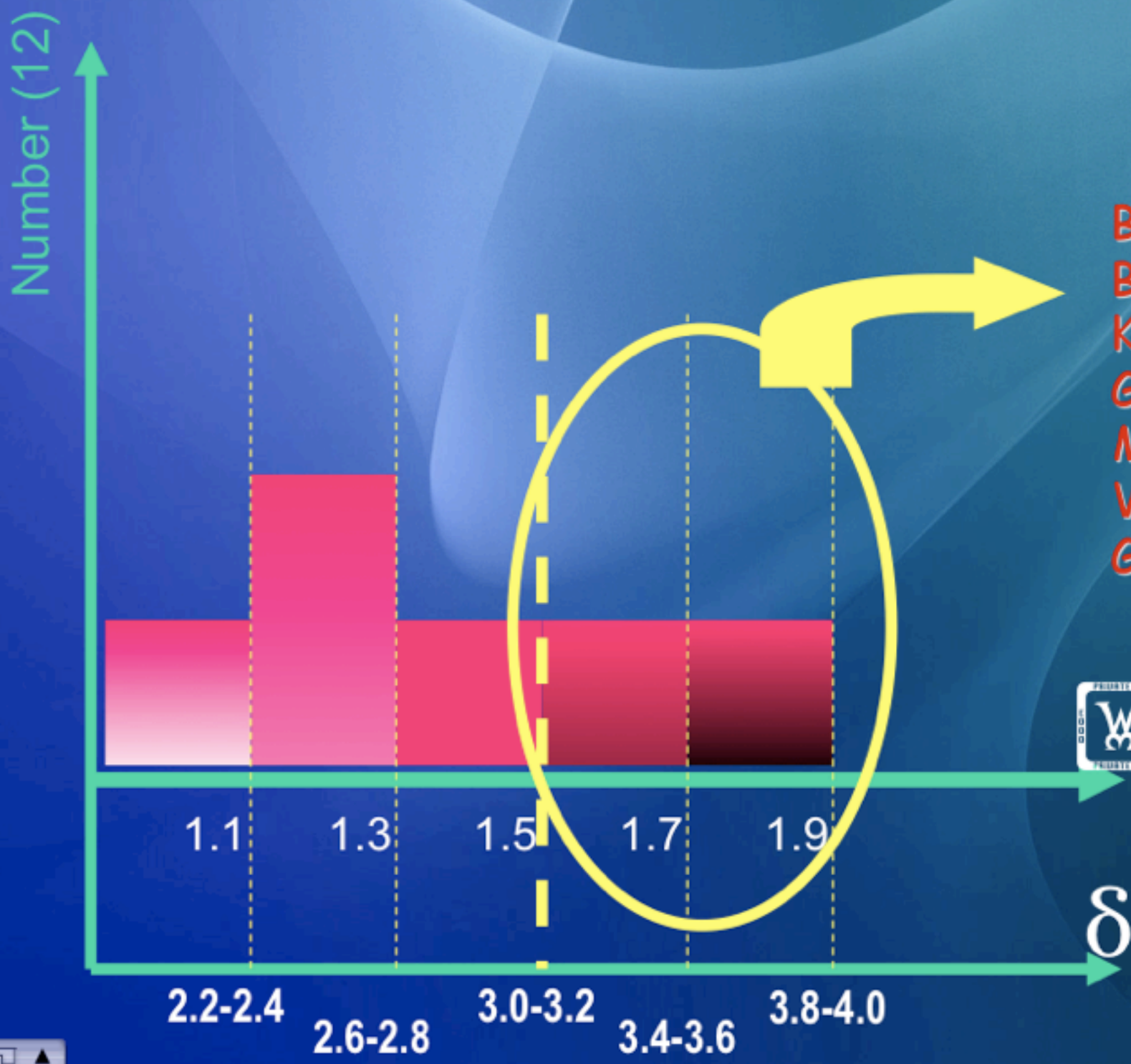


Evidence of break in the spectrum of the emitting electrons at energies of few GeV

Acceleration mechanism efficient !



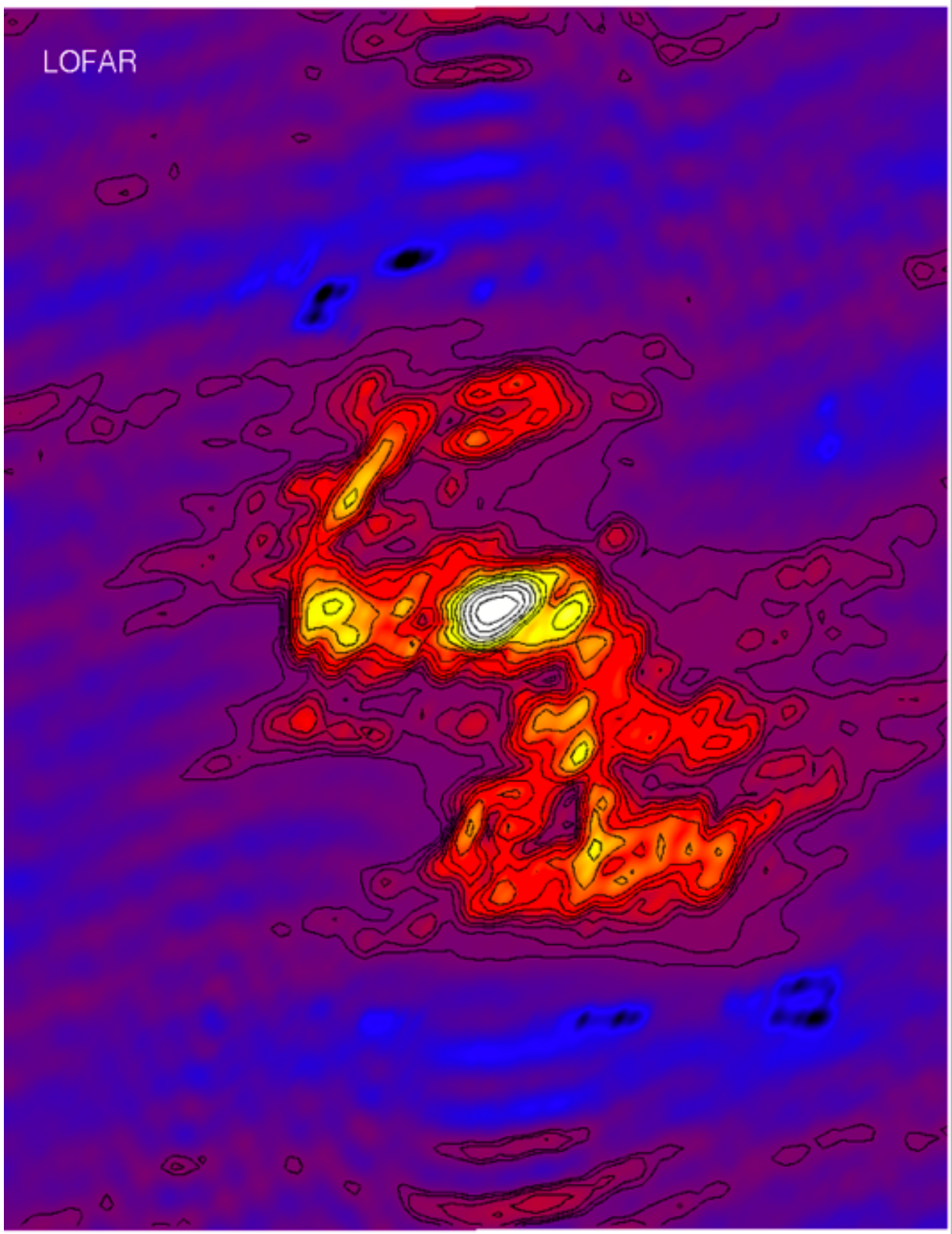
Observed spectra of radio halos : ruling out hadronic origin of the emitting electrons ?

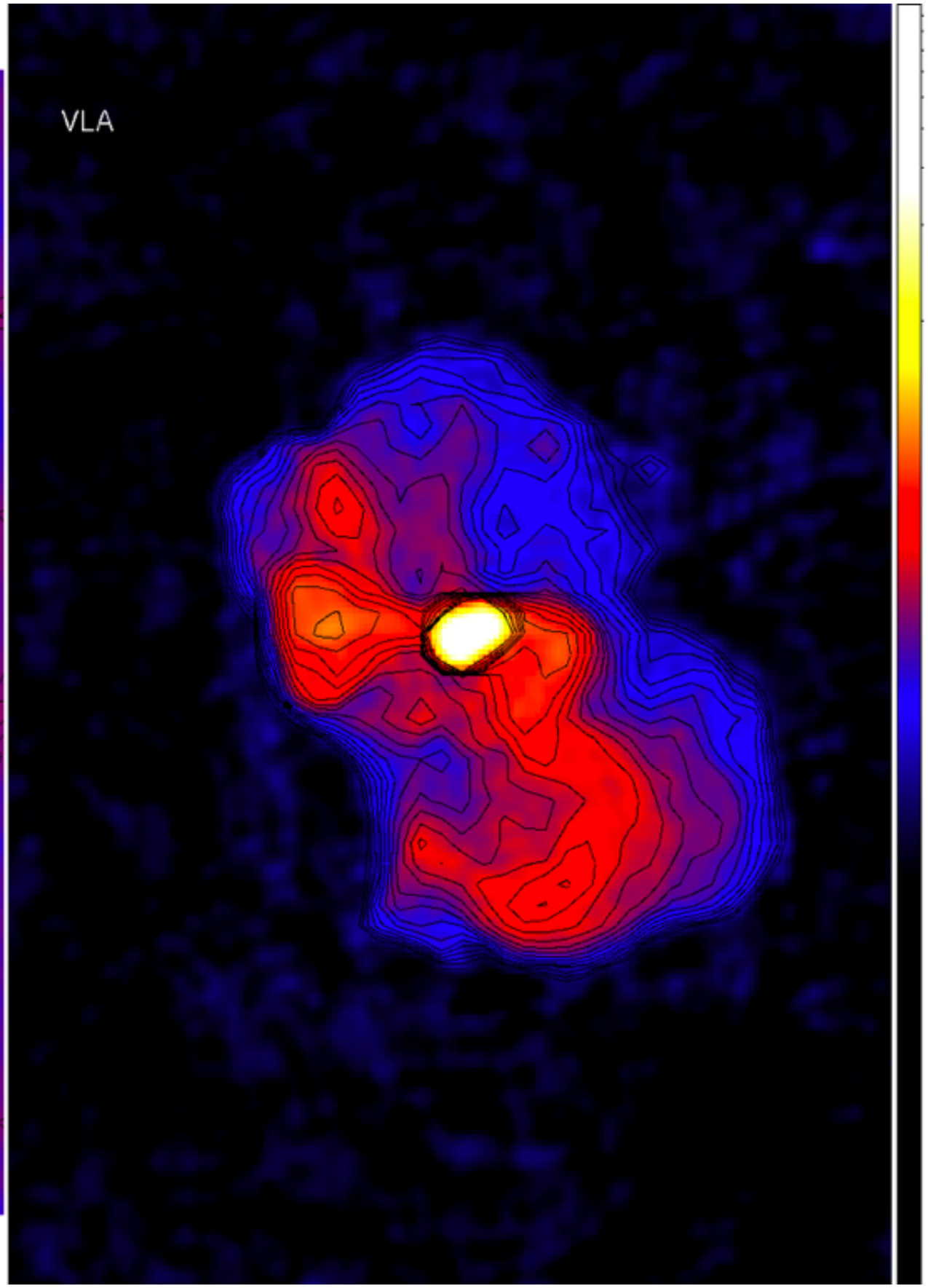


Brunetti et al 2008
Brentjens 2008
Kale & Dwarakanath 2009
Giovannini et al 2009
Macario et al 2010
Venturi 2011
GB, Venturi, Rudnick 2011...

$F(\nu)=K\,\nu^{-\delta}$

$N_{CR}(E)=k\,E^{-\delta}$


LOFAR


VLA
0.045
0.035
0.03
0.025
0.02
0.015
0.01
0.005

Conclusions

- We have significantly enlarged the sample of known radio relics and halos

- Some newly detected sources show best evidence to date for diffusive shock acceleration

- Standard shock acceleration has problems (pre-acceleration?)

- These objects probe plasma physics in unchartered territory of universe

- New questions: What produces magnetic fields so far out in the cluster?

- LOFAR is expected to find 100s of new diffuse radio sources