Particle Acceleration Processes in Galaxy Cluster Radio Relics Investigated through X-ray and Radio Observations

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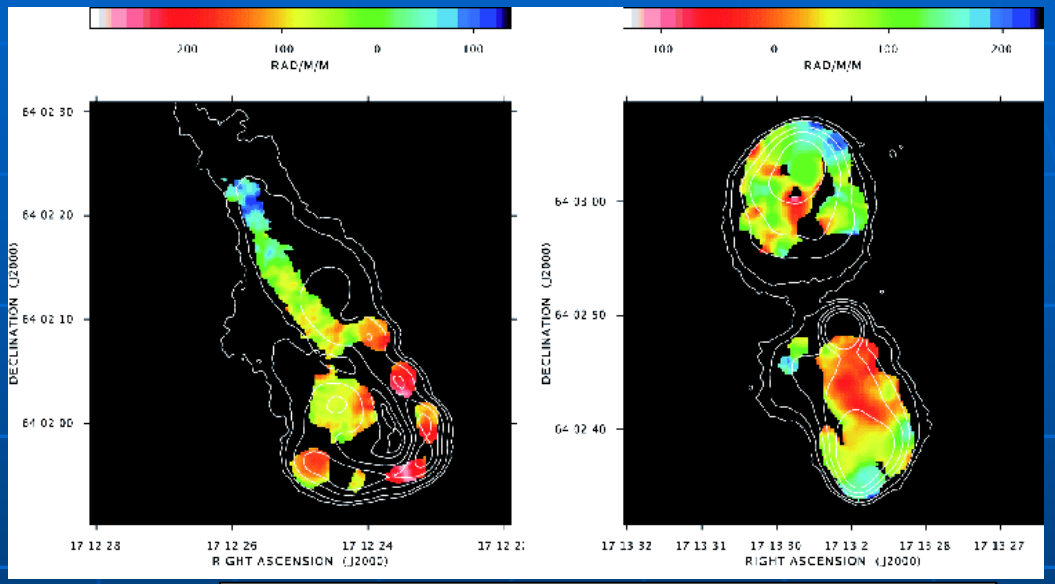
Observational Evidence of Intracluster Magnetic Field (1): Faraday Rotation

- Polarized plains of linear polarized radio wave rotate when propagating through the magnetized plasma.

$$\Delta\theta = \frac{2\pi e^3}{m^2 c^2 \omega^2} \int_0^d n B_{\parallel} ds.$$

- Polarized radio sources observations in and behind clusters suggest random magnetic field structures.



Faraday rotation measure map of the radio sources in Abell 2255
Color: FRM
Contour: radio
Govoni et al. (2006)

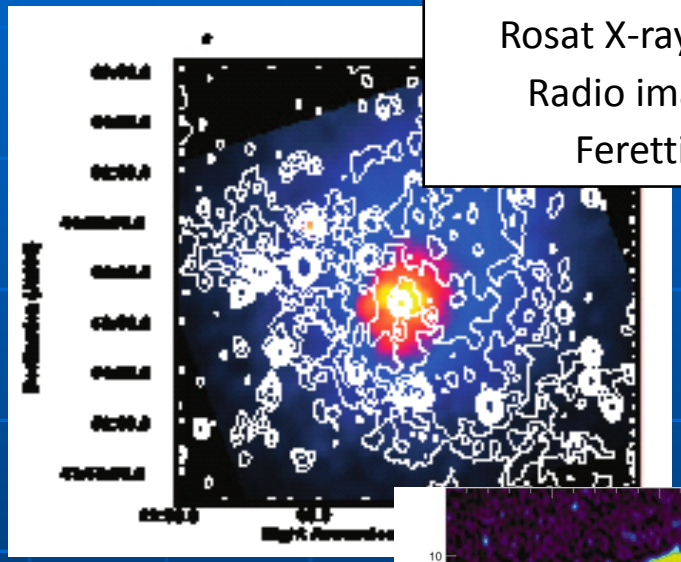
Observational Evidence of Intracluster Magnetic Field (2): Radio Halos / Relics

Some merging clusters have non-thermal diffuse radio emission

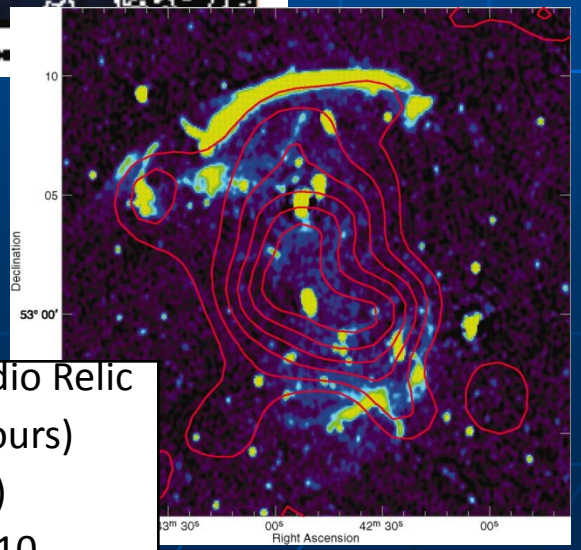
synchrotron radio

$\gamma \sim 10^4$ electrons + 0.1-10μG B

Hard X-ray will be emitted through Inverse compton with CMB

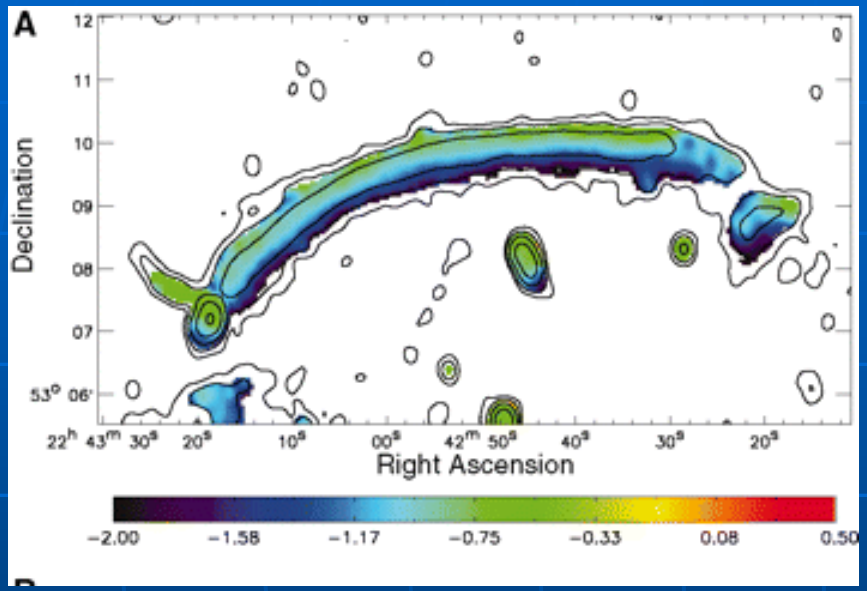


Abell 2319 with Radio Halo
Rosat X-ray image (colors)
Radio image (contours)
Feretti et al. 1997



CIZA J2242.8+5301 with Radio Relic
Rosat X-ray image (contours)
Radio image (colors)
Van Weeren et al. 2010

Mach Number Estimation of Shocks at Radio Relics : Two Methods



Radio Spectral index map of the relic in CIZA J2242.8+5301 (Van Weeren et al. 2010)

$F_\nu \propto \nu^{-\alpha}$ --> $N(E_e) \propto E_e^{-(2\alpha+1)}$

With a (simple) diffusive shock accerelation model,

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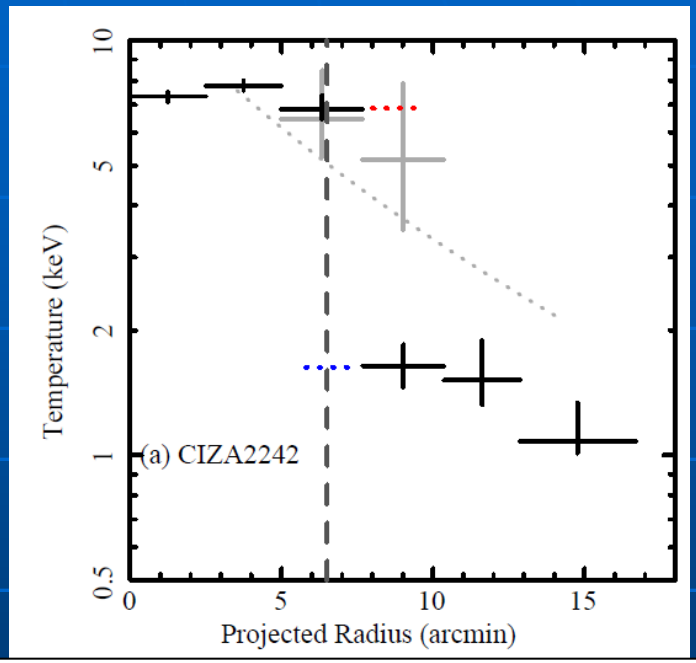
$\alpha = (M^2+1)/(M^2-1)-1/2$



Temperature Profile across the relic in CIZA J2242.8+5301 (Akamatsu & Kawahara 2013)

With the RH relation

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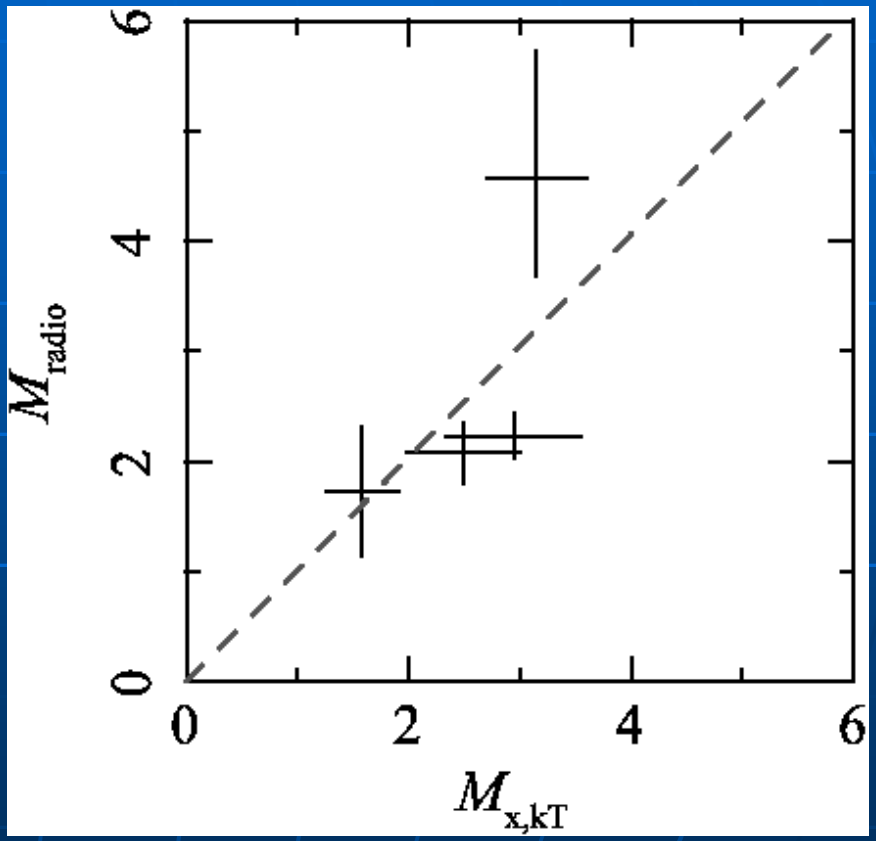
$T_{post}/T_{pre} = (5M^4+14M^2-3)/(16M^2)$

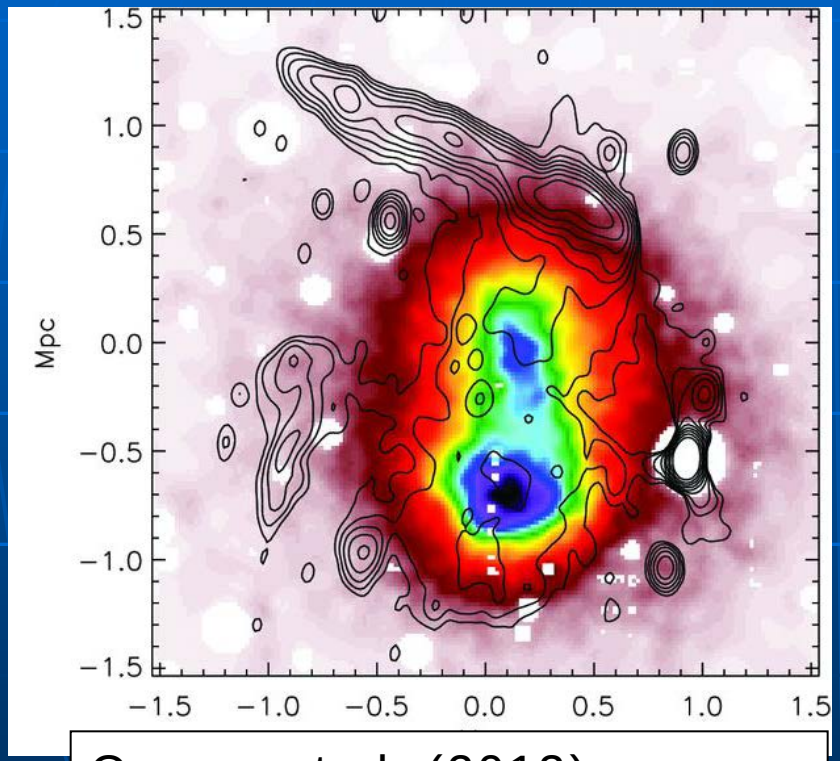
Radio Relics: Mach Number Discrepancy?

- Akamatsu&Kawahara (2013) suggests that M_X and M_{radio} seem to be consistent with each other.
- However, sample size is obviously too small to say something definite.



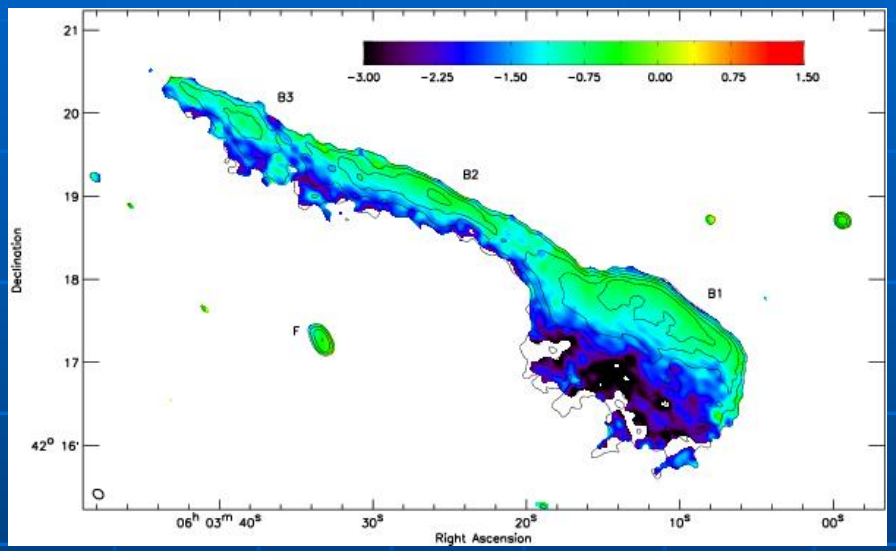
Akamatsu&Kawahara (2013)

1RXS J0603.3+4214 with "toothbrush-relic"



Ogrean et al. (2013)

Colors: X-ray(XMM)
Contours: radio(WSRT)



Radio spectral index map (van Weeren et al. 2012)

α_{inj}=0.6−0.7

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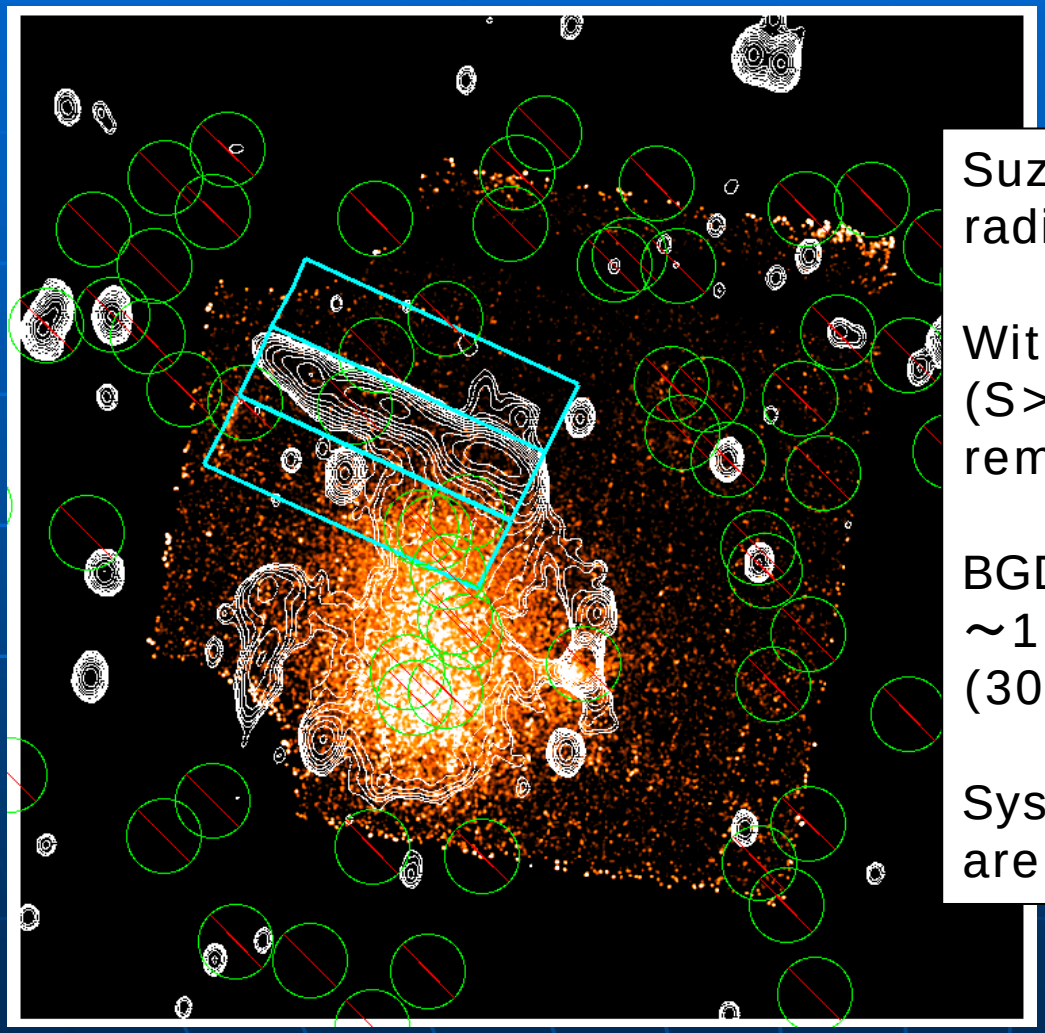
M_{radio}=3.3−4.6

1RXS J0603: Suzaku Results

(Itahana, Takizawa et al. in prep.)



Suzaku image (120ksec) with radio contours

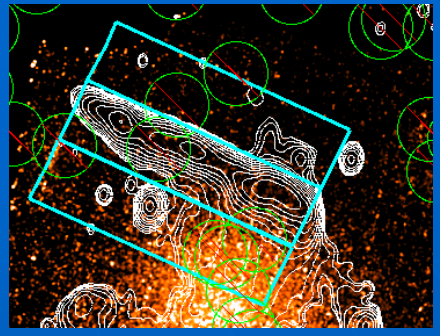
With XMM data, point sources ($S > 1.0 \times 10^{14}$ erg/cm^2/s) are removed (green circles).

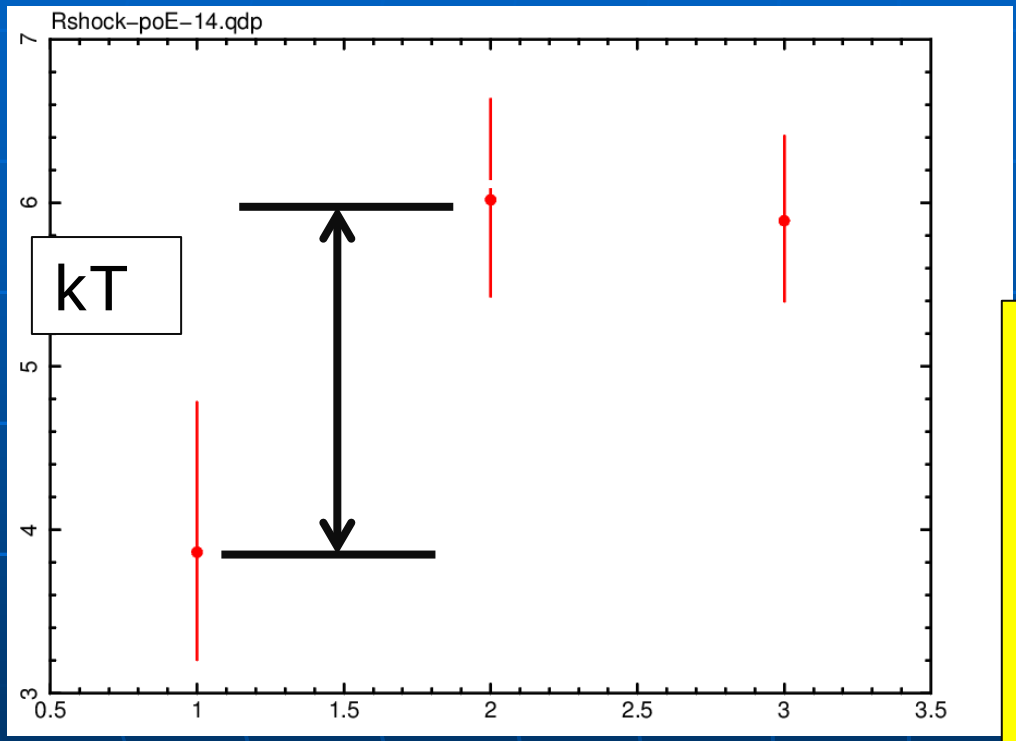
BGD model is estimated from the ~1 deg offset region data (30ksec).

Systematic errors of NXB and CXB are properly considered.

Mach number discrepancy in the toothbrush relic

(Itahana, Takizawa, et al. in prep.)





$$M_{radio} = 3.3 \sim 4.5$$

$$M_X = 1.55^{+0.29}_{-0.25}\ (1\sigma)$$

Considering both statistical and systematic errors, we have ~5 σ level discrepancy between M_X and M_{radio}.

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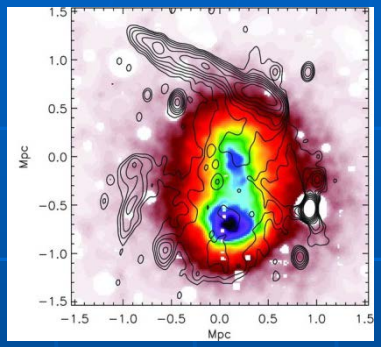
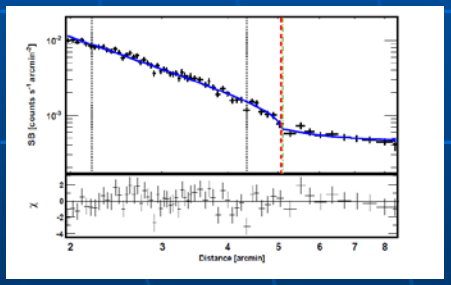
This suggests that a simple diffusive shock acceleration model is not valid at least for this object.

$$M_X = 1.55^{+0.38+0.27+0.10}_{-0.28-0.27-0.15}$$

with Statistical, CXB systematical, and NXB systematical errors
(90% confidence level)

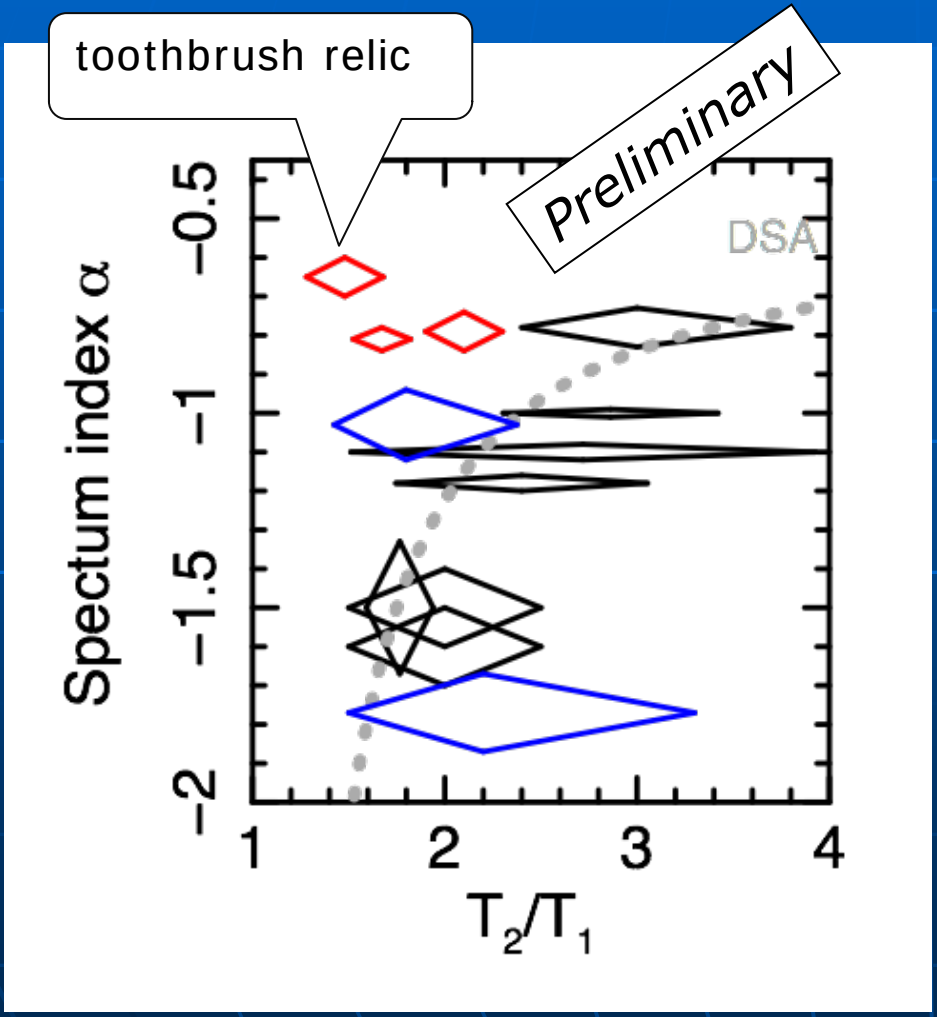
Comparison with XMM results





- Ogrean et al. (2013) obtained a similar Mach number for the toothbrush relic with XMM data.
- Their results are based on X-ray surface brightness distribution analysis, which is much more severely affected by line-of-sight projection effects and, in principle, some assumptions are necessary for 3D density distribution.
- Our results are more robust and model-independent.

Is a simple diffusive shock accelerarion model valid ?



- Number of observed relic is increasing.
- Some can be explained well by a simple DSA model, but others are not.
- Are other parameters needed ?

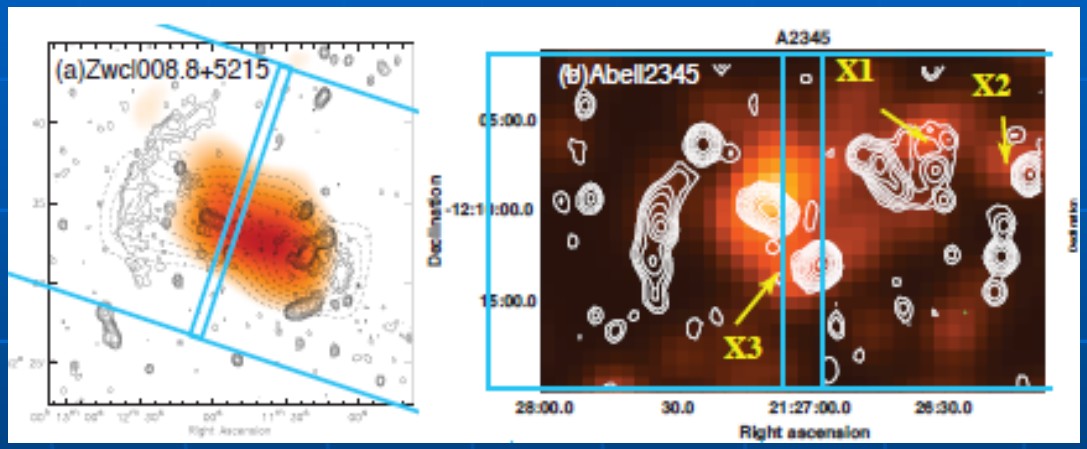
  Non-linear acceleration?

  re-acceleration?

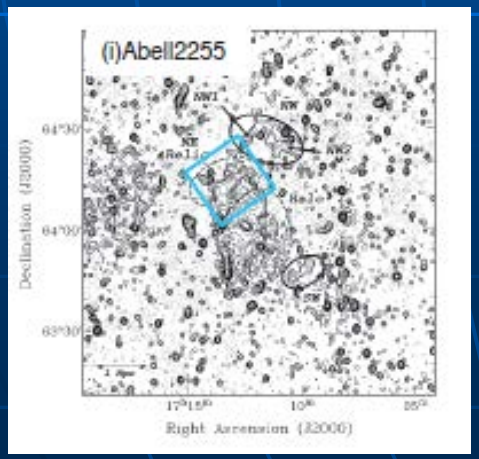
  complicated dynamical history?

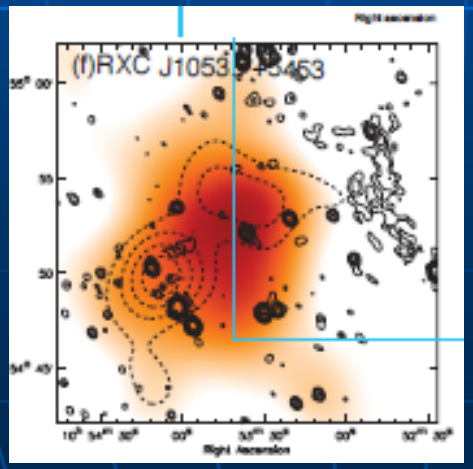
Exploring Energetics at the Largest Shock Structure in the Universe

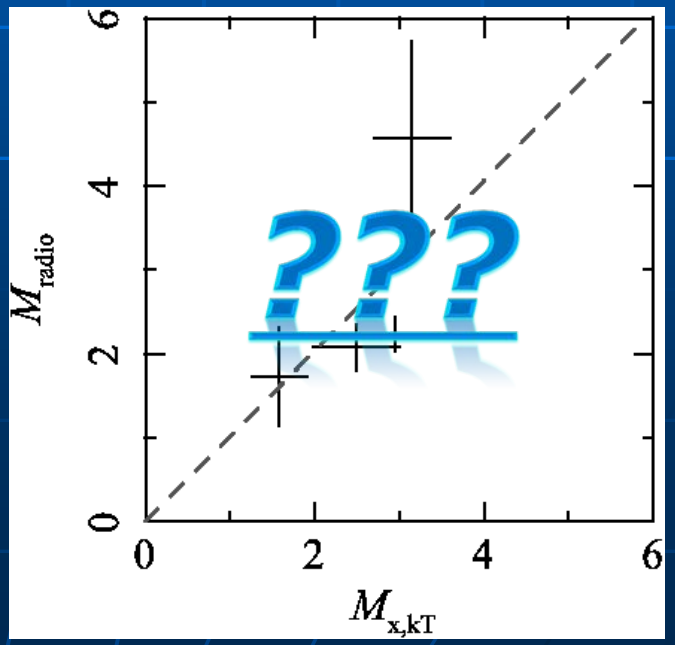
(approved as Suzaku AO9 key project, PI : Akamatsu@SRON)



5 radio relics
(with reliable radio data and active radio people)
～500 ksec







Summary

- Faraday rotation measure and radio halos/relics observations indicate the existence of the magnetic field in the intracluster space.
- Radio relics are most likely related with shocks.
- Crucial information about particle acceleration processes of relatively low Mach number shocks can be obtained with combination of radio and X-ray observations of radio relics.
- A simple diffusive sock acceleration model seems to be not valid at least in some relics, which suggests the existence of other parameters.