X線と電波で探る
銀河団電波レリックの粒子加速過程

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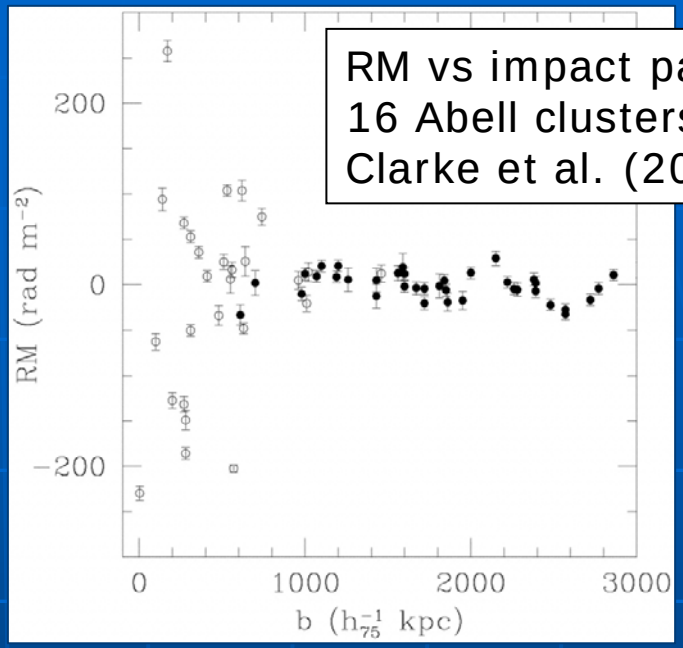
@国立天文台三鷹

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

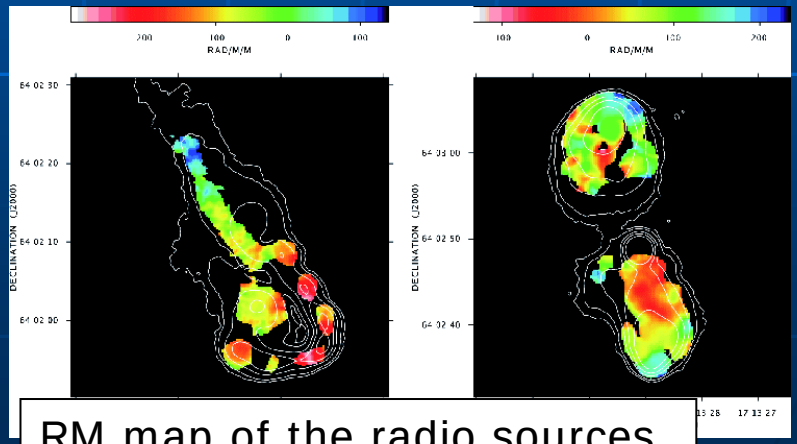
- Polarized plains of linear polarized radio wave rotate when propagating through the magnetized plasma.

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

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



RM vs impact paameter for 16 Abell clusters
Clarke et al. (2001)



RM map of the radio sources in Abell 2255
Govoni et al. (2006)

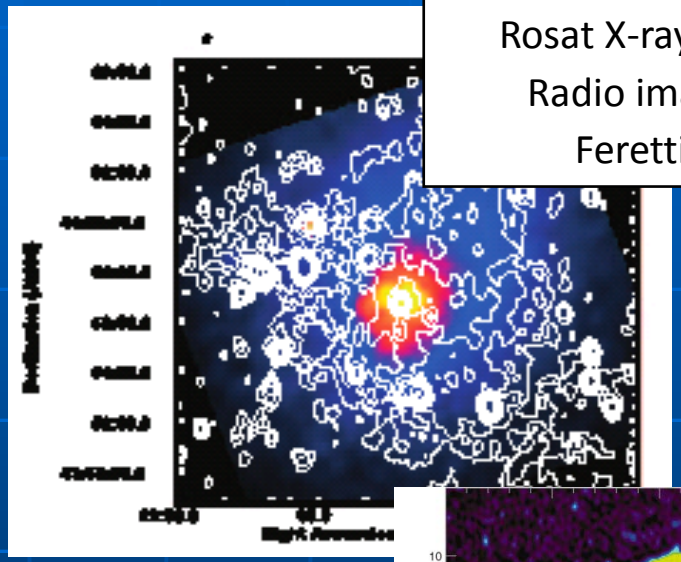
Observational Evidence of Intracluster Magnetic Field (2): Radio Halos / Relics

Some merging clusters have non-thermal diffuse radio emission

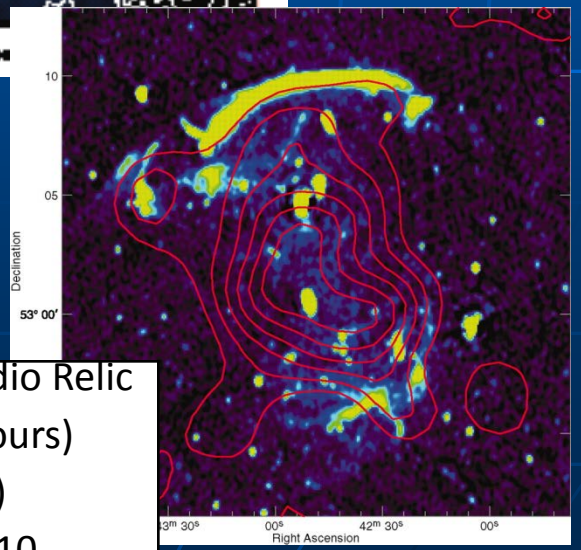
synchrotron radio

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

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

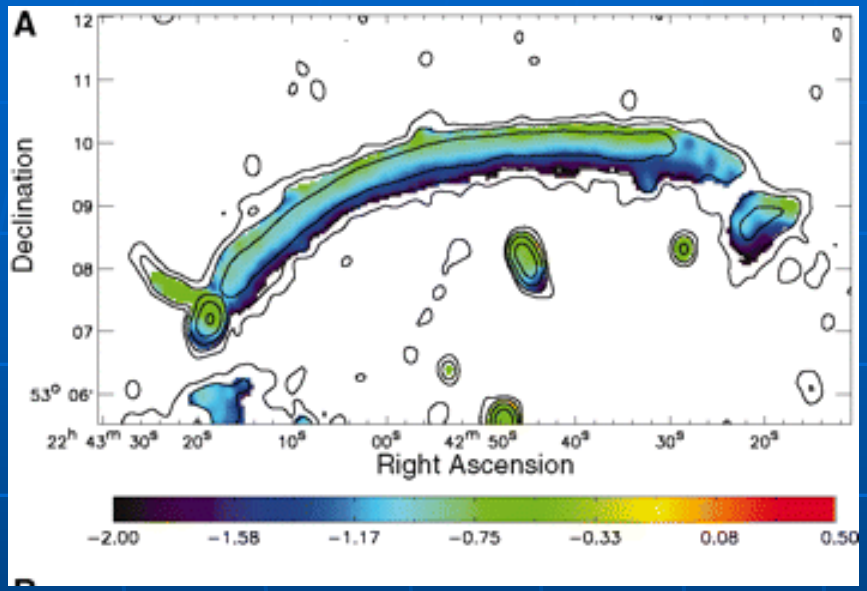


Abell 2319 with Radio Halo
Rosat X-ray image (colors)
Radio image (contours)
Feretti et al. 1997



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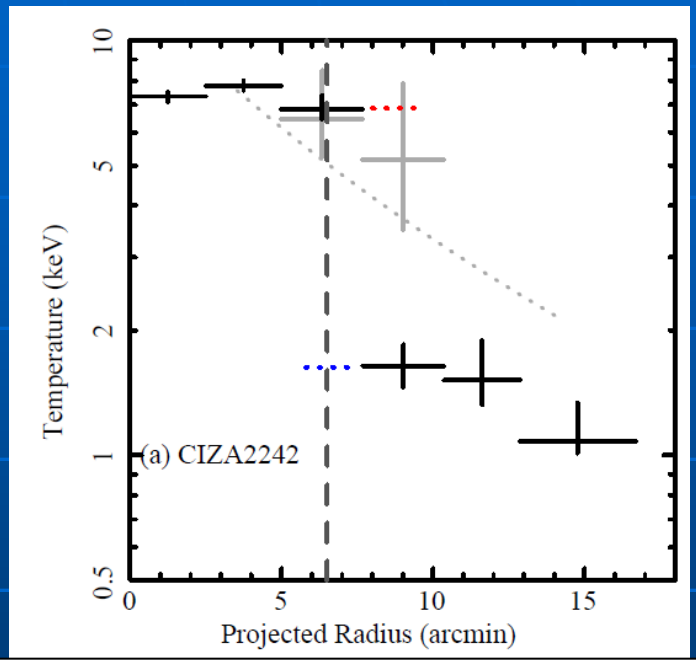
$\alpha = (M^2+1)/(M^2-1)-1/2$



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

With the RH relation

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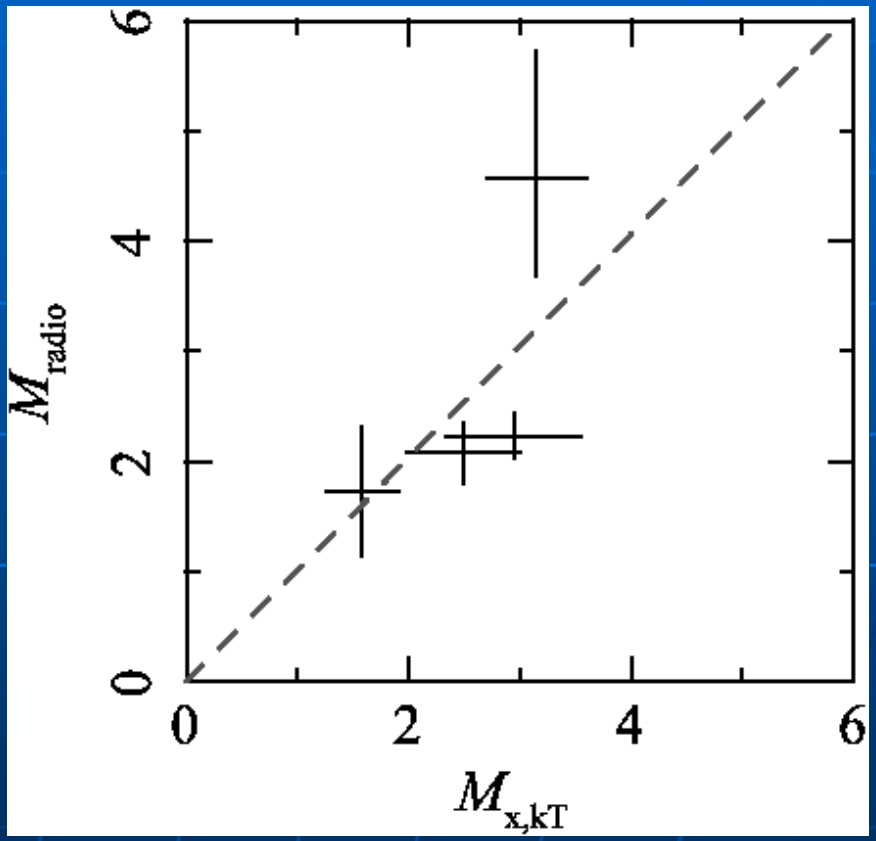
$T_{post}/T_{pre} = (5M^4+14M^2-3)/(16M^2)$

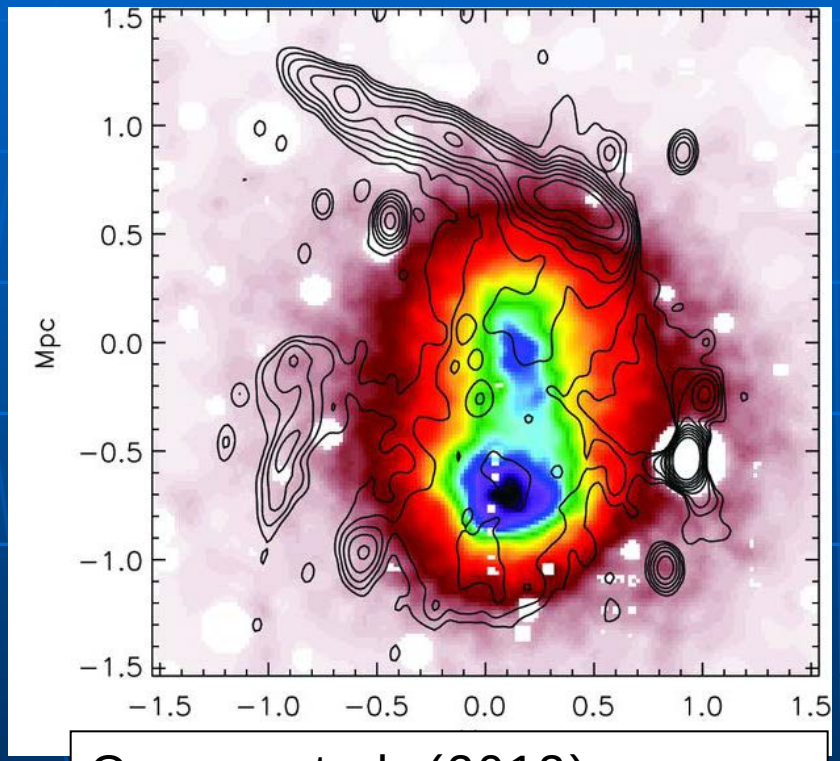
Radio Relics: Mach Number Discrepancy???

- 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.



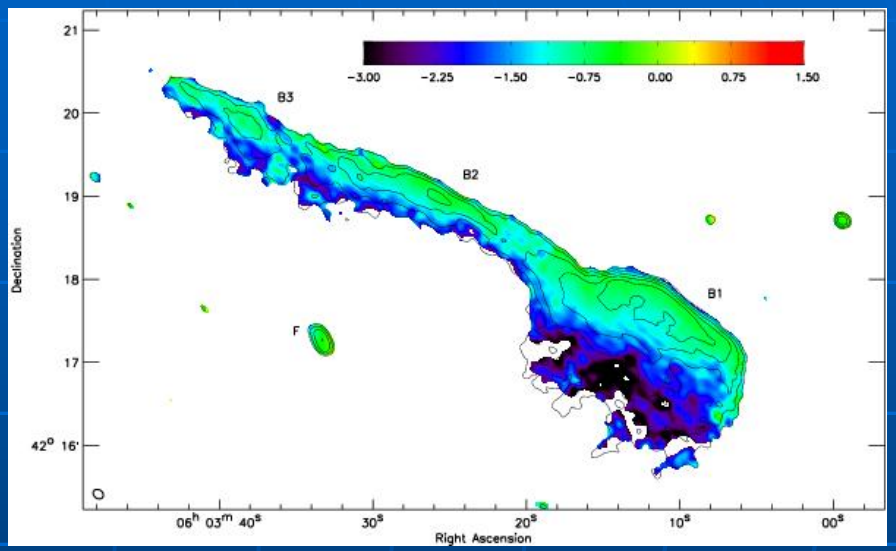
Akamatsu&Kawahara (2013)

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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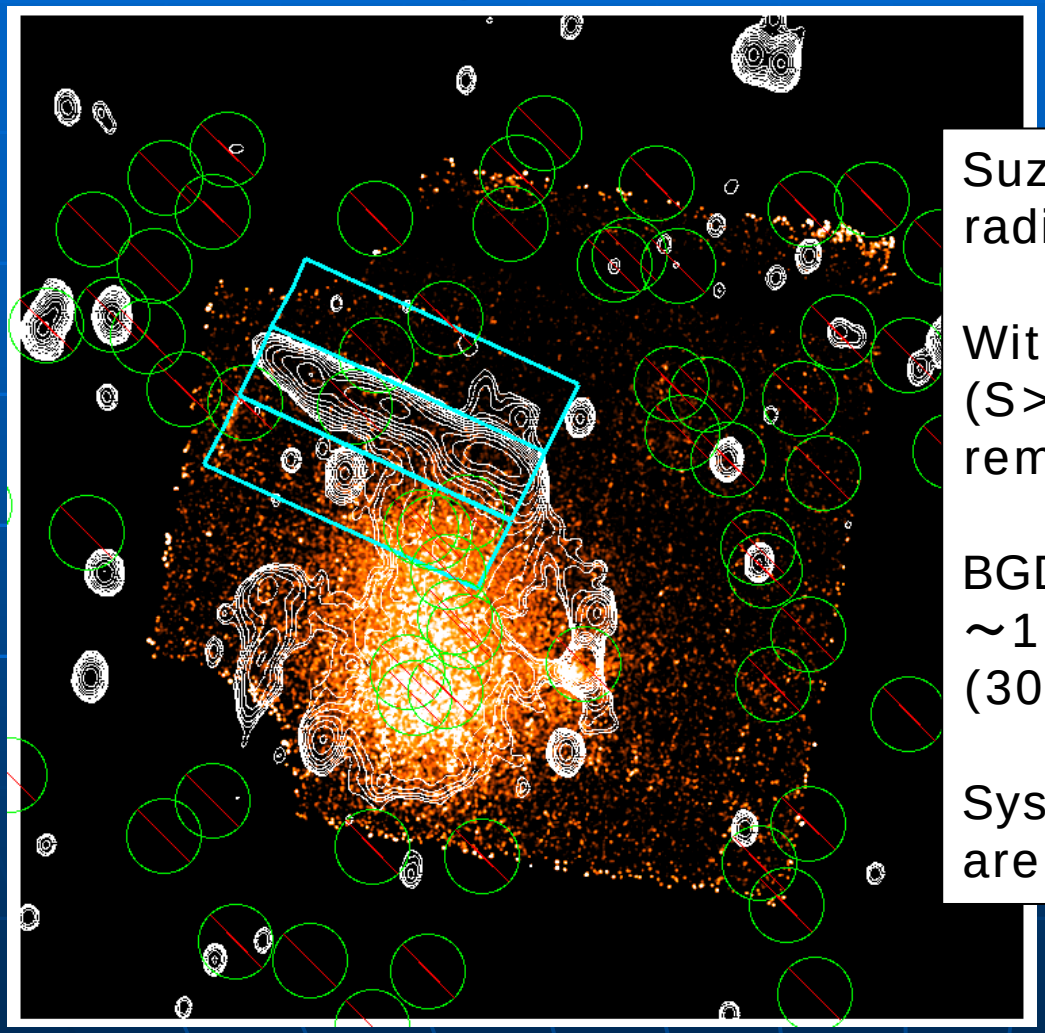
M_{radio}=3.3−4.6

1RXS J0603: Suzaku Results

(Itahana, Takizawa et al. in prep.)



Suzaku image (120ksec) with radio contours

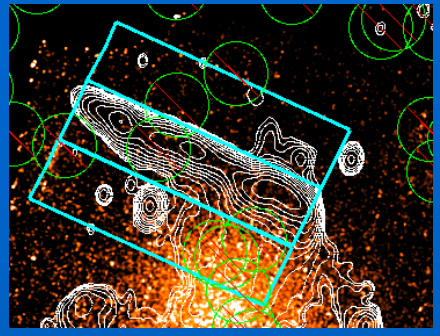
With XMM data, point sources ($S > 1.0 \times 10^{14}$ erg/cm^2/s) are removed (green circles).

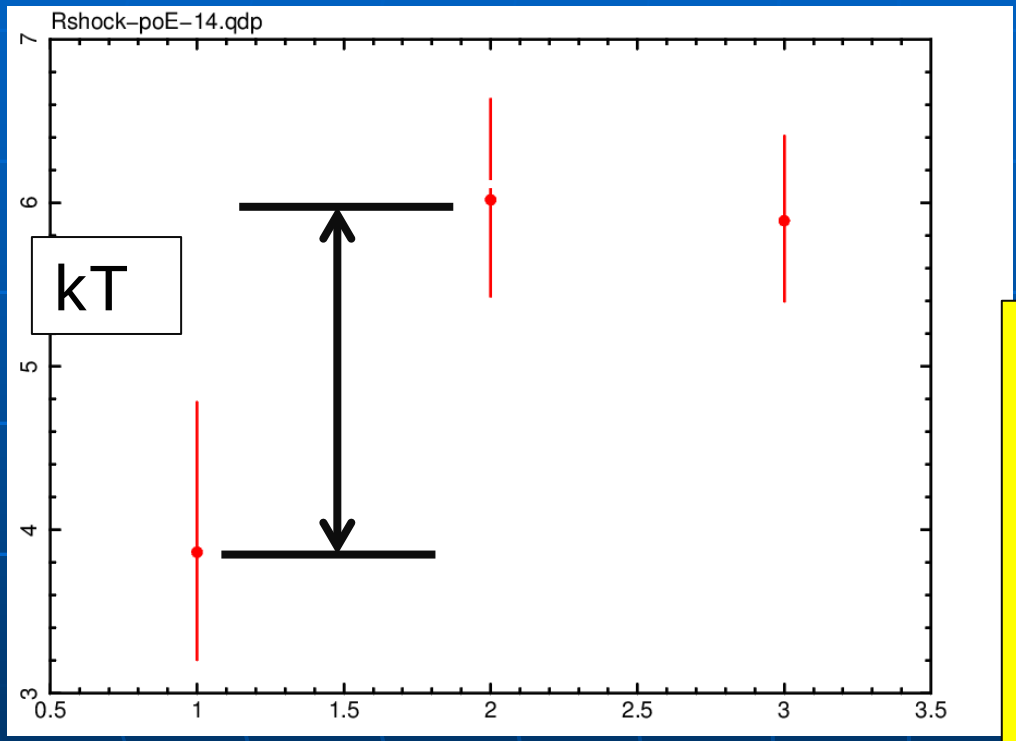
BGD model is estimated from the ~1 deg offset region data (30ksec).

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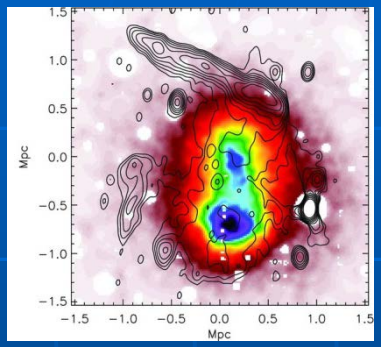
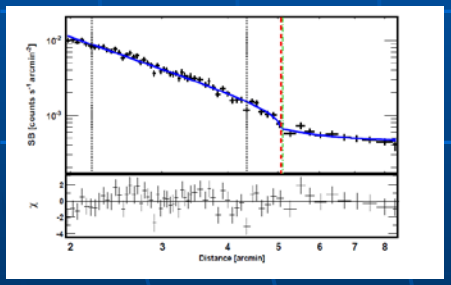
This suggests that a simple diffusive shock acceleration model is not valid at least for this object.

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

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

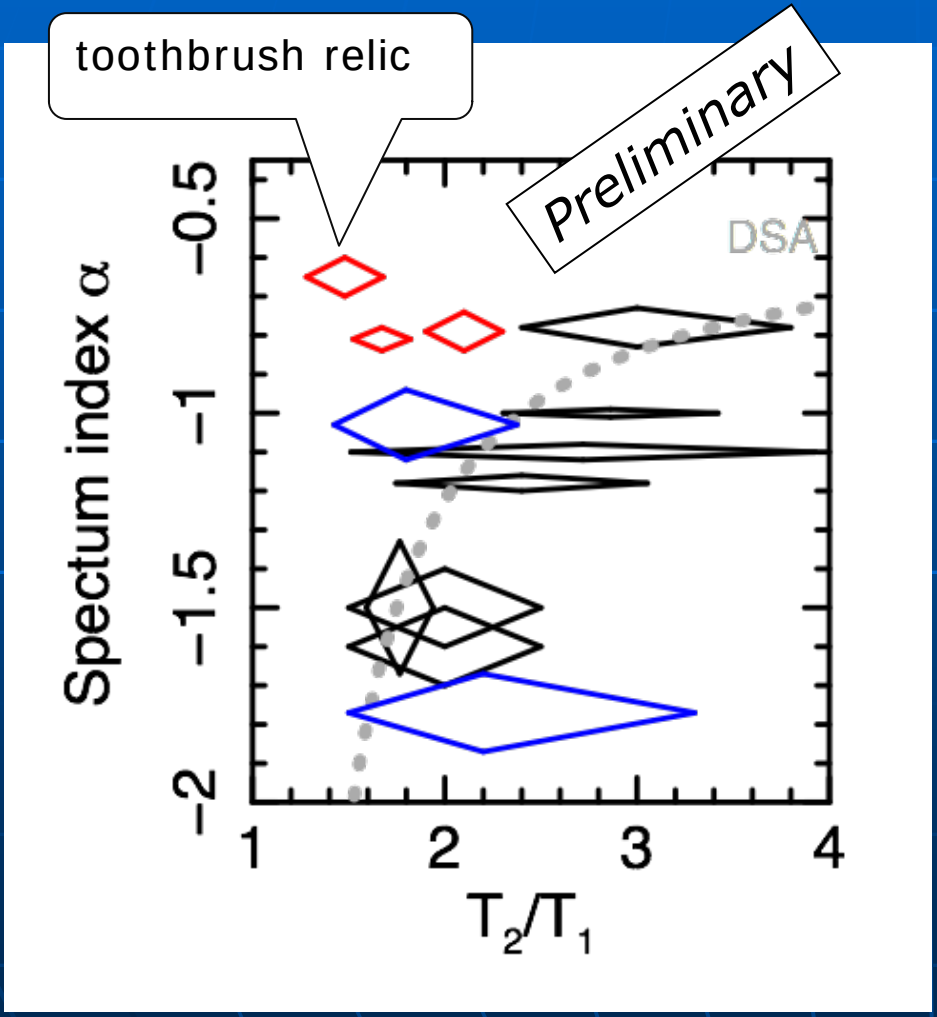
Comparison with XMM results





- 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 ?

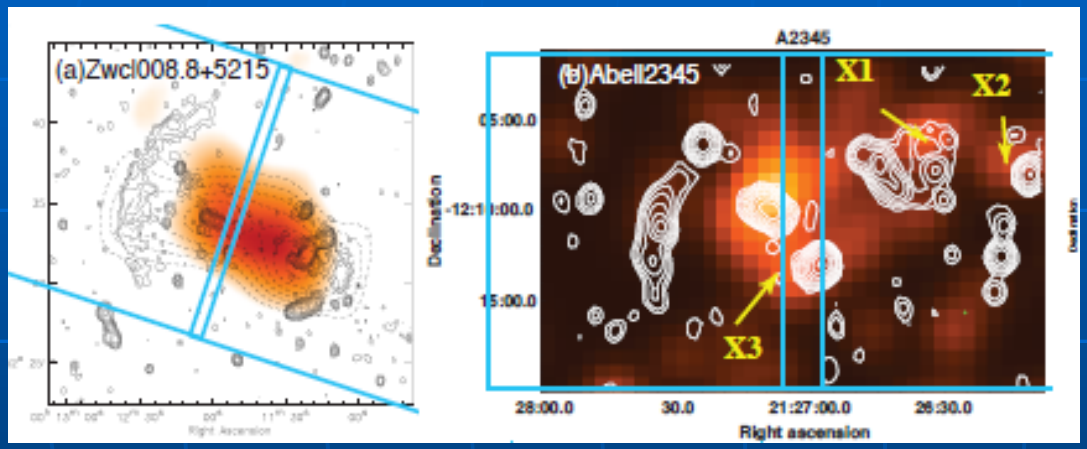
  Non-linear acceleration?

  re-acceleration?

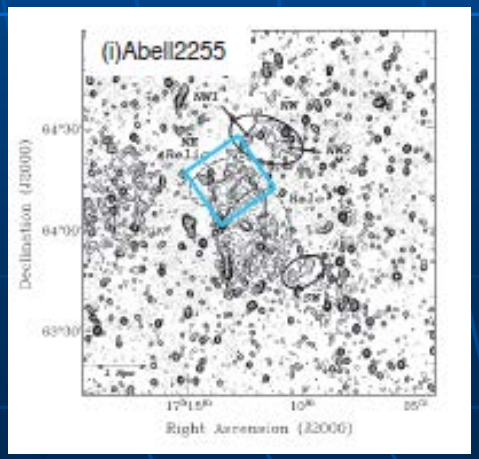
  complicated dynamical history?

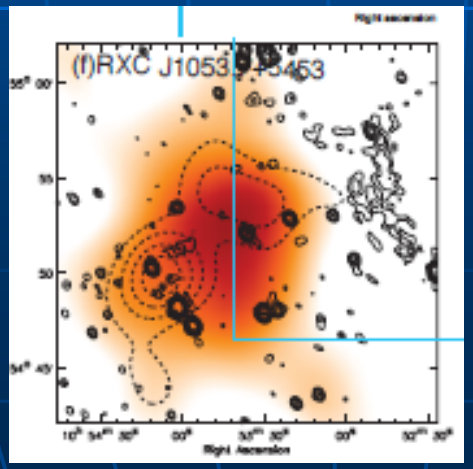
Exploring Energetics at the Largest Shock Structure in the Universe

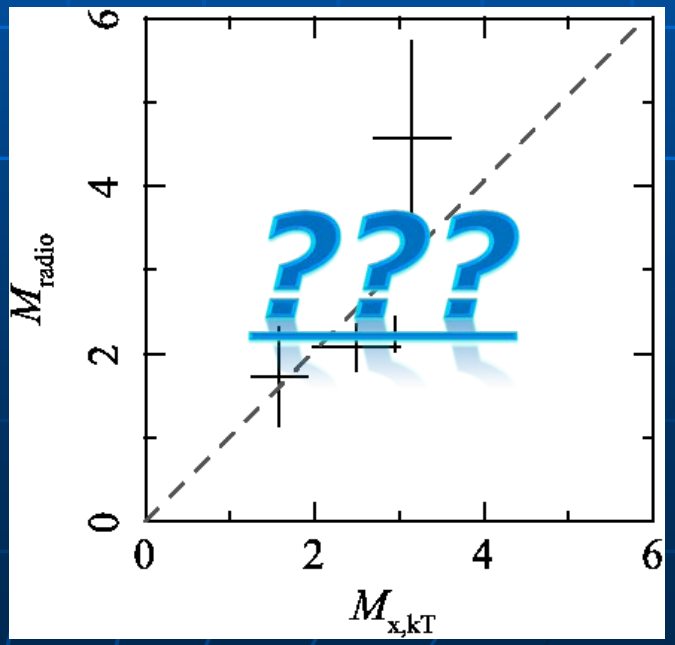
(approved as Suzaku AO9 key project, PI : Akamatsu@SRON)



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.