銀河団の非熱的成分に関する諸問題
Non-Thermal Components in Clusters of Galaxies

滝沢元和（山形大），
板花まどか(山形大)、赤松弘規(SRON)、河原創(東京大） 他

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「銀河団の物理」ワークショップ
＠東京理科大・神楽坂キャンパス

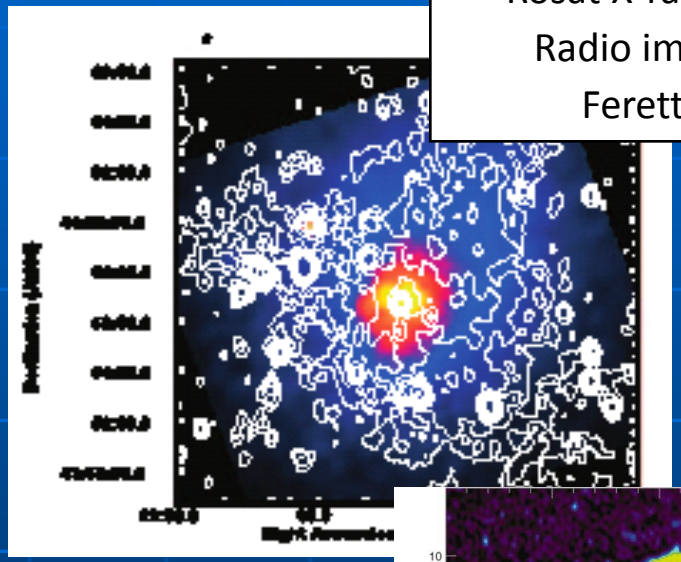
Cosmic Ray Electrons: Radio Halos / Relics

Non-thermal radio emission from merging clusters of galaxies

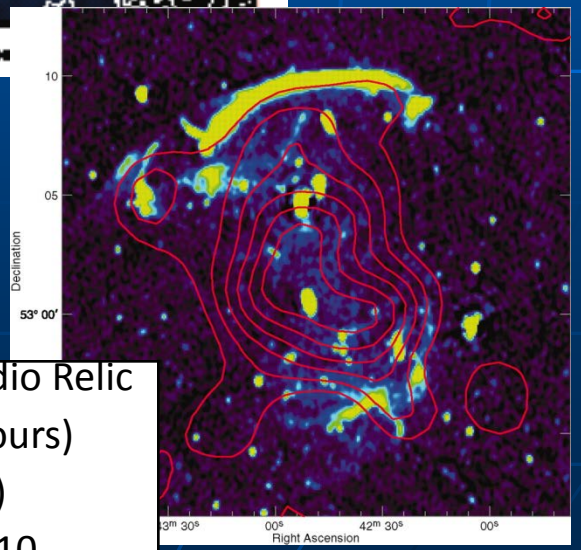
synchrotron radio

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

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

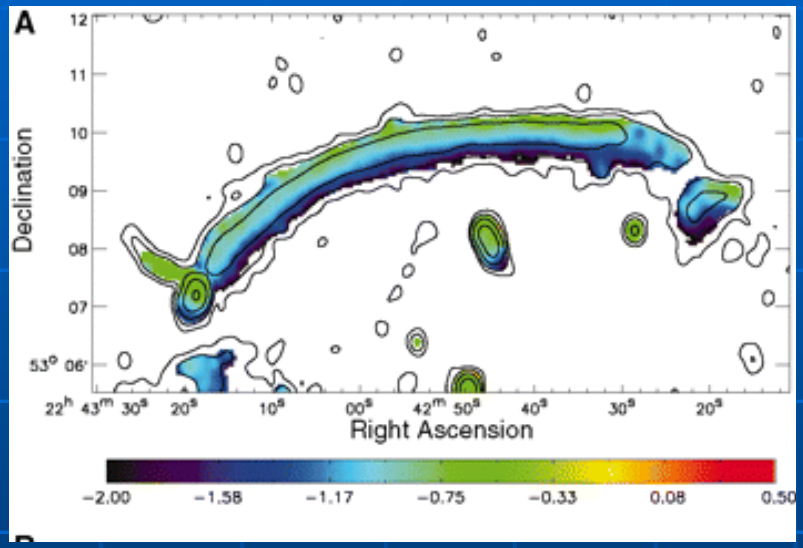


Abell 2319 with Radio Halo
Rosat X-ray image (colors)
Radio image (contours)
Feretti et al. 1997



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



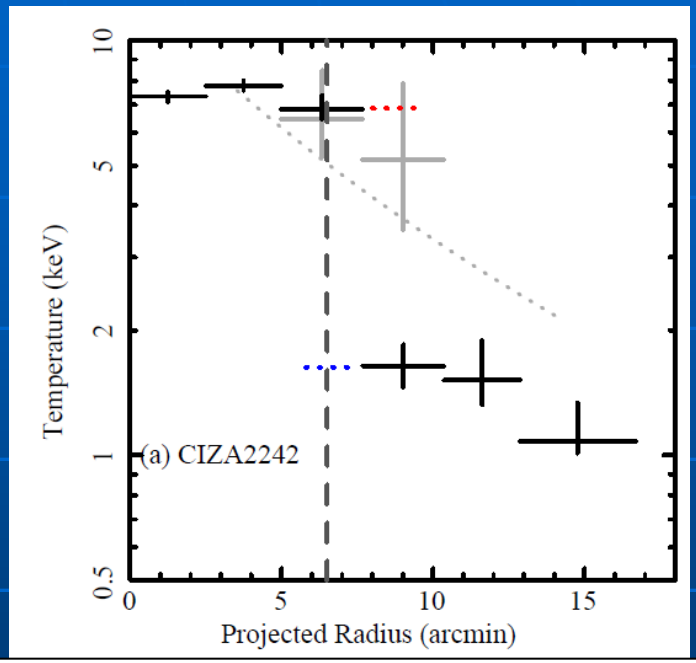
Radio Spectral index map

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

From a (simple) diffusive shock accerelation model,

--->

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



Temperature Profile across the Shock with RH relation

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

Radio Relics: Mach Number Discrepancy?

- According to figure 8 in Akamatsu&Kawahara (2013), M_X and M_{radio} seem to be consistent with each other.

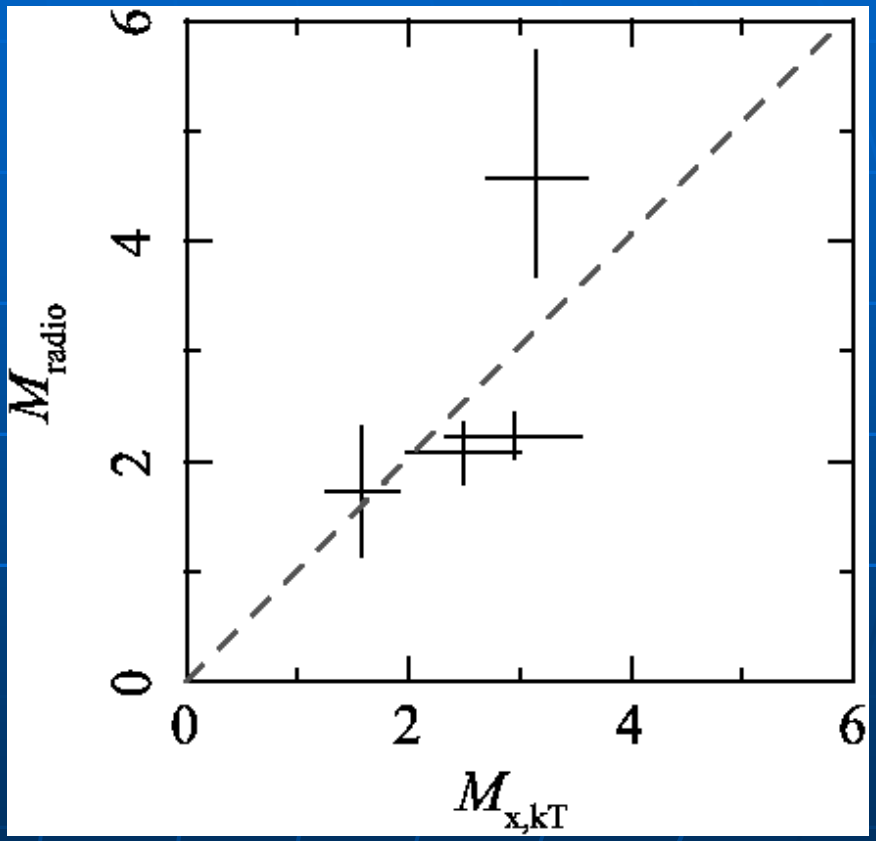


Figure 8 in Akamatsu&Kawahara (2013)

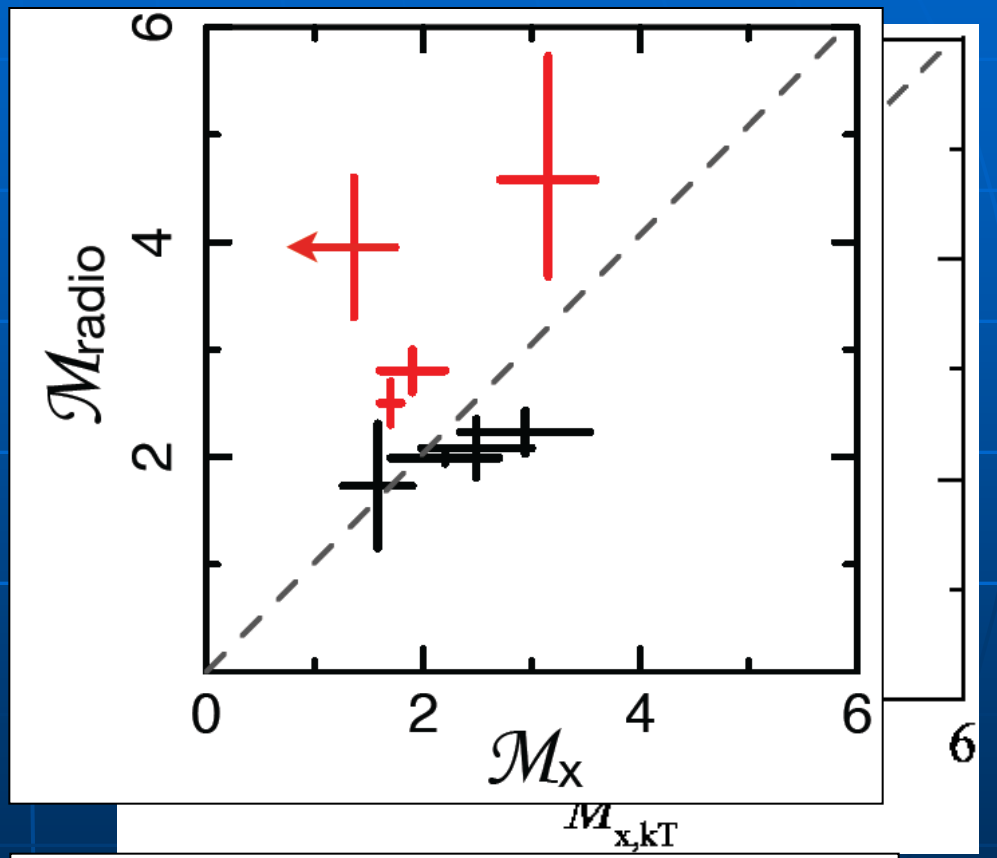
Radio Relics: Mach Number Discrepancy?

- According to figure 8 in Akamatsu&Kawahara (2013), M_X and M_{radio} seem to be consistent with each other.
- For the sample where the injection spectrum is clearly resolved, we begin to see a hint of the discrepancy .

---> re-acceleration??

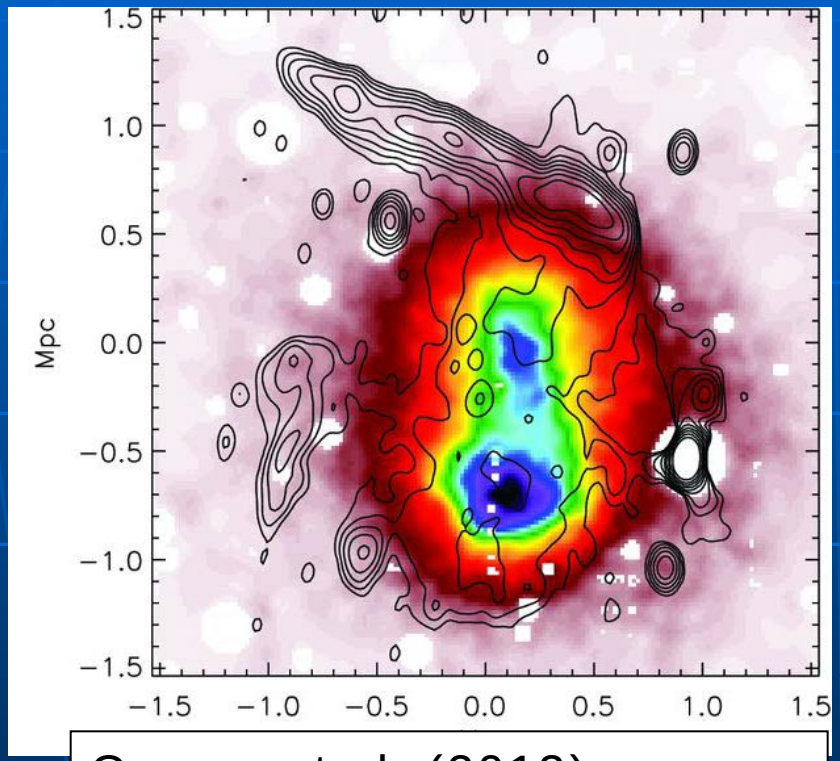
non-linear effect??

others ???



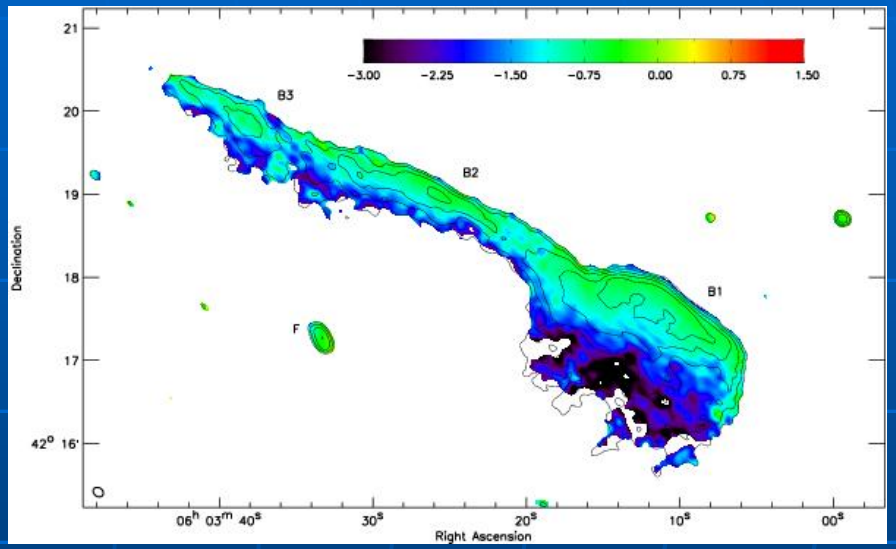
131228 (preliminary) version of Figure 8 in Akamatsu&Kawahara (2013)
red: injection spectrum
black: integrated spectrum

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



Ogrean et al. (2013)

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



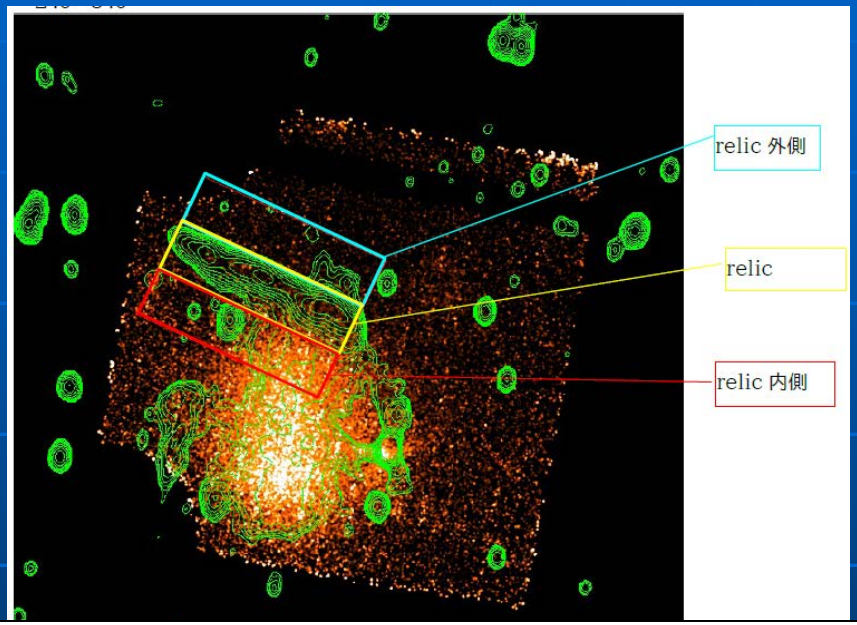
Radio spectral index map (van Weeren et al. 2012)

α_{inj}=0.6−0.7

−−−>

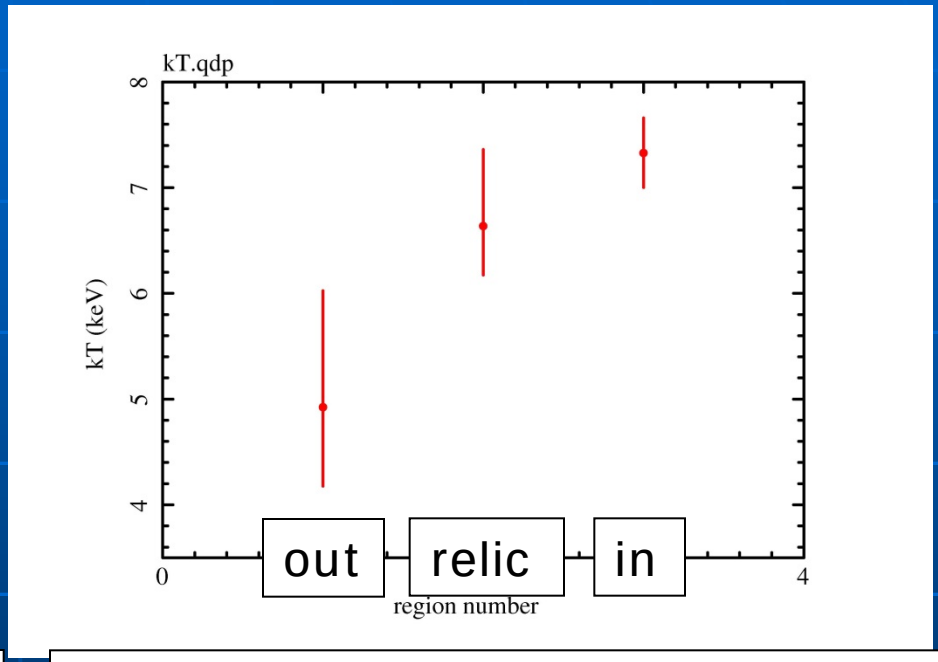
M_{radio}=3.3−4.6

1RXS J0603: Suzaku Results (Preliminary)



Suzaku image (120ksec) with radio contours

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



Temperature profile across the relic (statistical errors only)

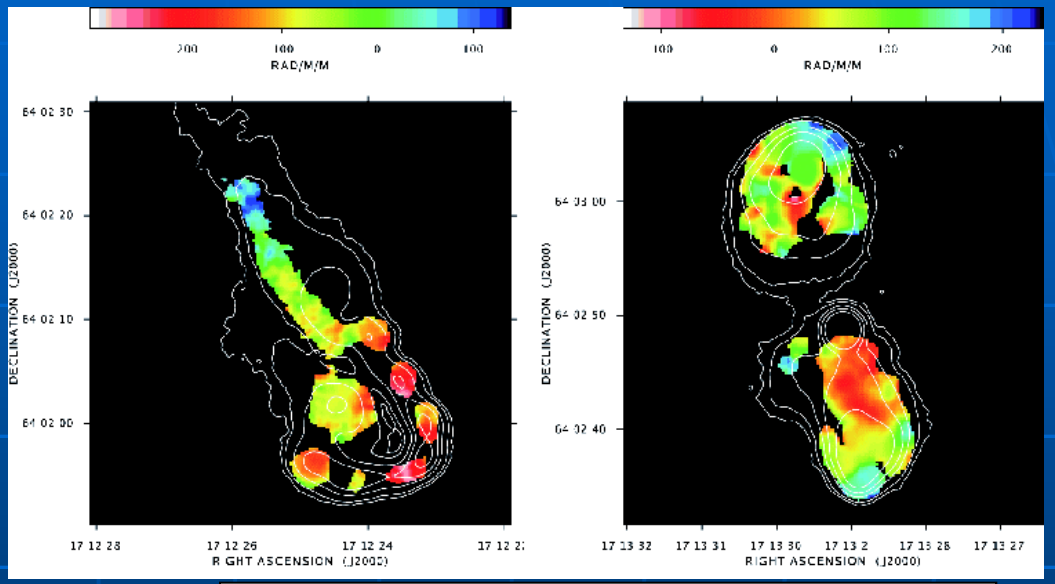
No significant temperature jump
From the best fit values, $M_X = 1.36$
(tentative) upper limit: $M_X < 1.74$
(cf. $M_{radio} = 3.3\text{-}4.6$)

Magnetic Field : Faraday Rotation

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

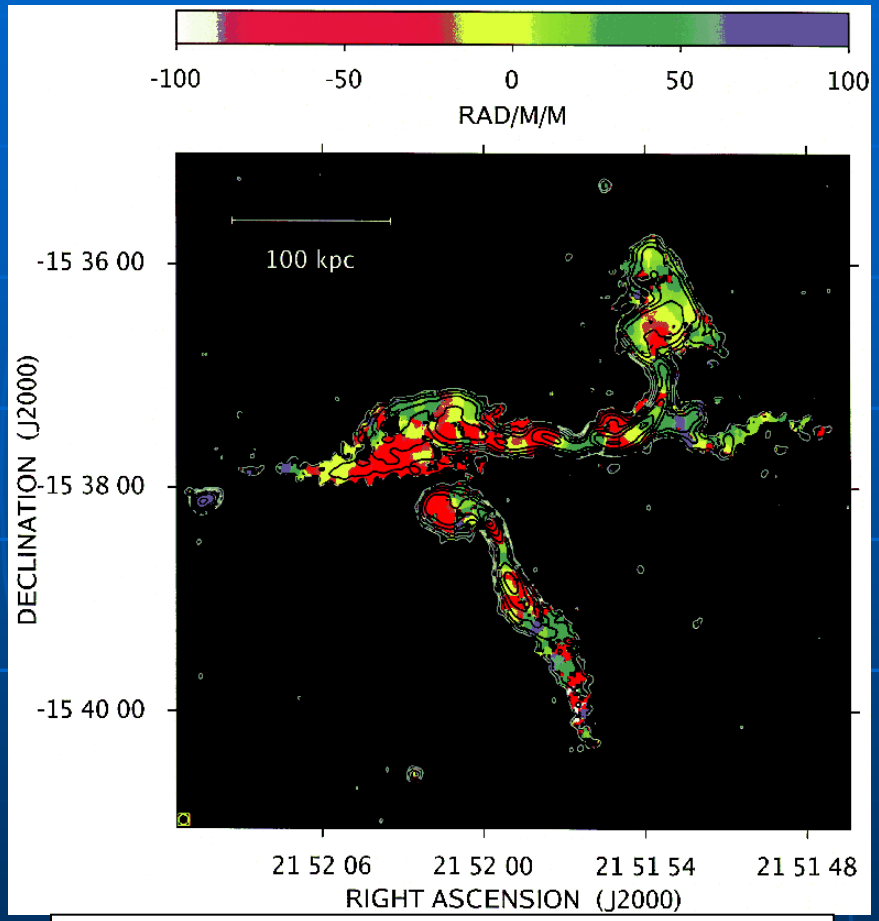
$$\Delta\theta = \frac{2\pi e^3}{m^2 c^2 \omega^2} \int_0^d n B_{\parallel} \, ds.$$

- 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

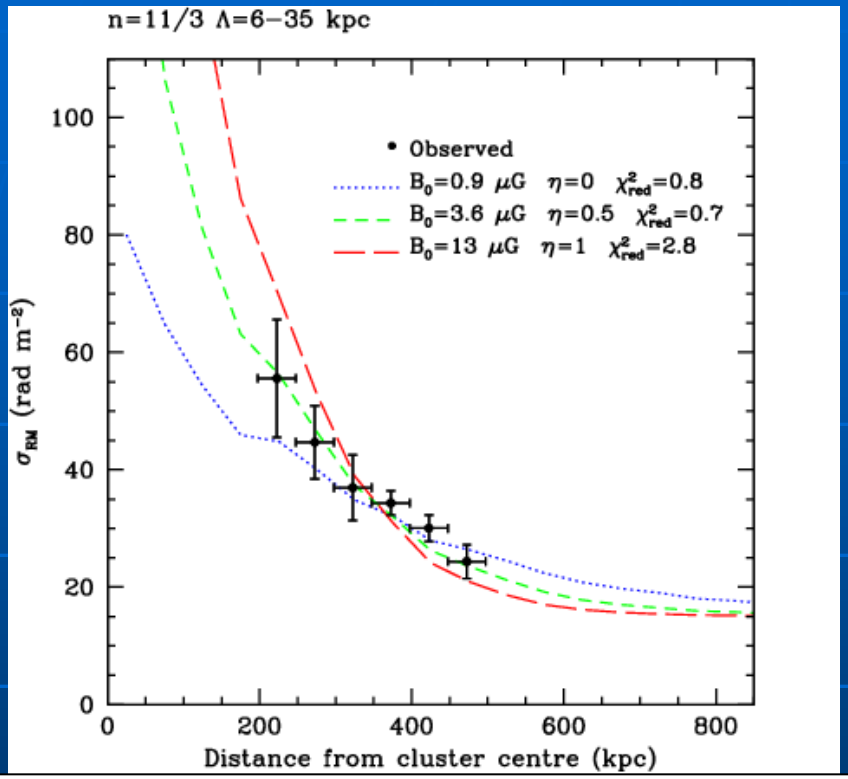
Case of Abell 2382



RM images of PKS 2149-158 A etc (Guidetti et al. 2008)

- Simulated RM images with model magnetic field are compared with the observed data.
- Random Gaussian
- $|B_k|^2 \propto k^{-n}$
- $\langle B \rangle (r) \propto [n_e(r)]^{\eta}$
- Consistent with n=11/3 (Kolmogorov)
- But, many parameters,,,

Degeneracy of Model Parameters

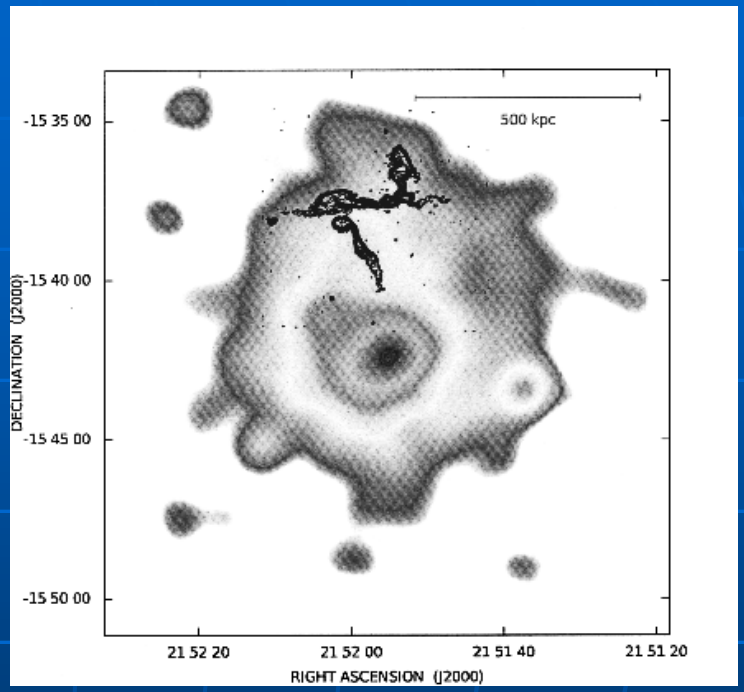


Radial profile of σ_RM

$\langle B \rangle(r) = \langle B_0 \rangle [n_e(r)/n_0]^{\eta}$

$\langle B_0 \rangle$ and η are degenerated.

(Guidetti et al. 2008)



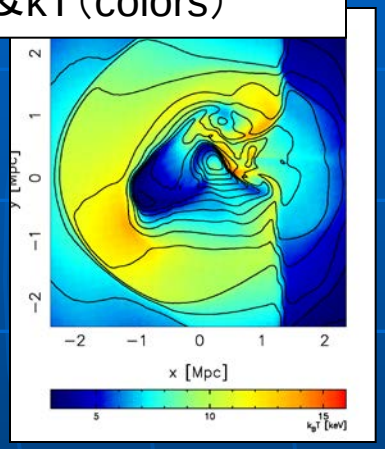
Rosat PSPC image and Radio image

RM can be measured only in the limited regions where the polarized sources exist.

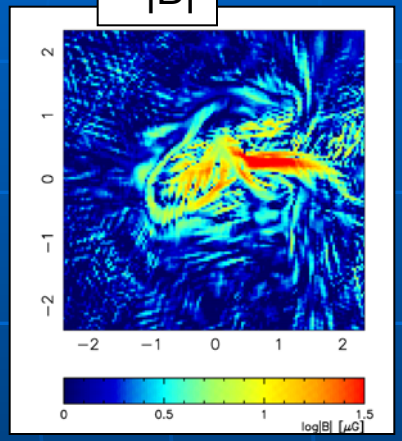
Coherent structures:

They should be taken into account as well as the random component ?

density（contours）
&kT（colors）



|B|



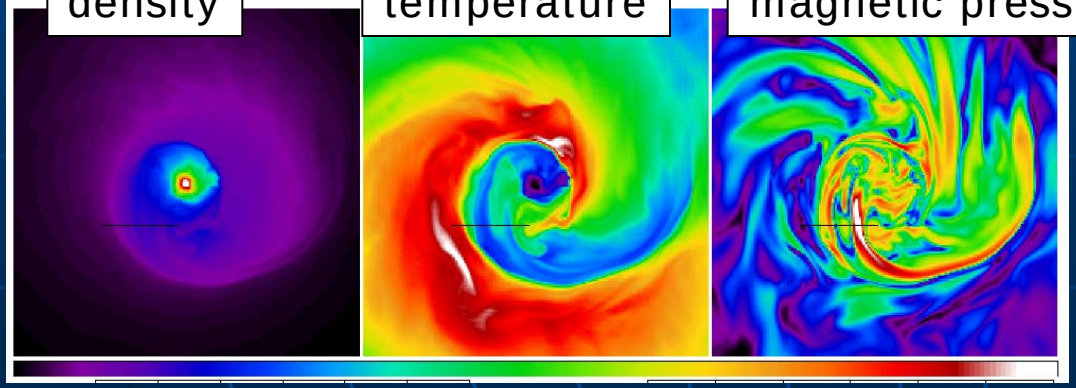
- Low temperature region surrounded by the magnetic field
- Ordered magnetic field structure behind the small subclump

(MHD simulations of cluster merger, Takizawa 2008)

density

temperature

magnetic pressure

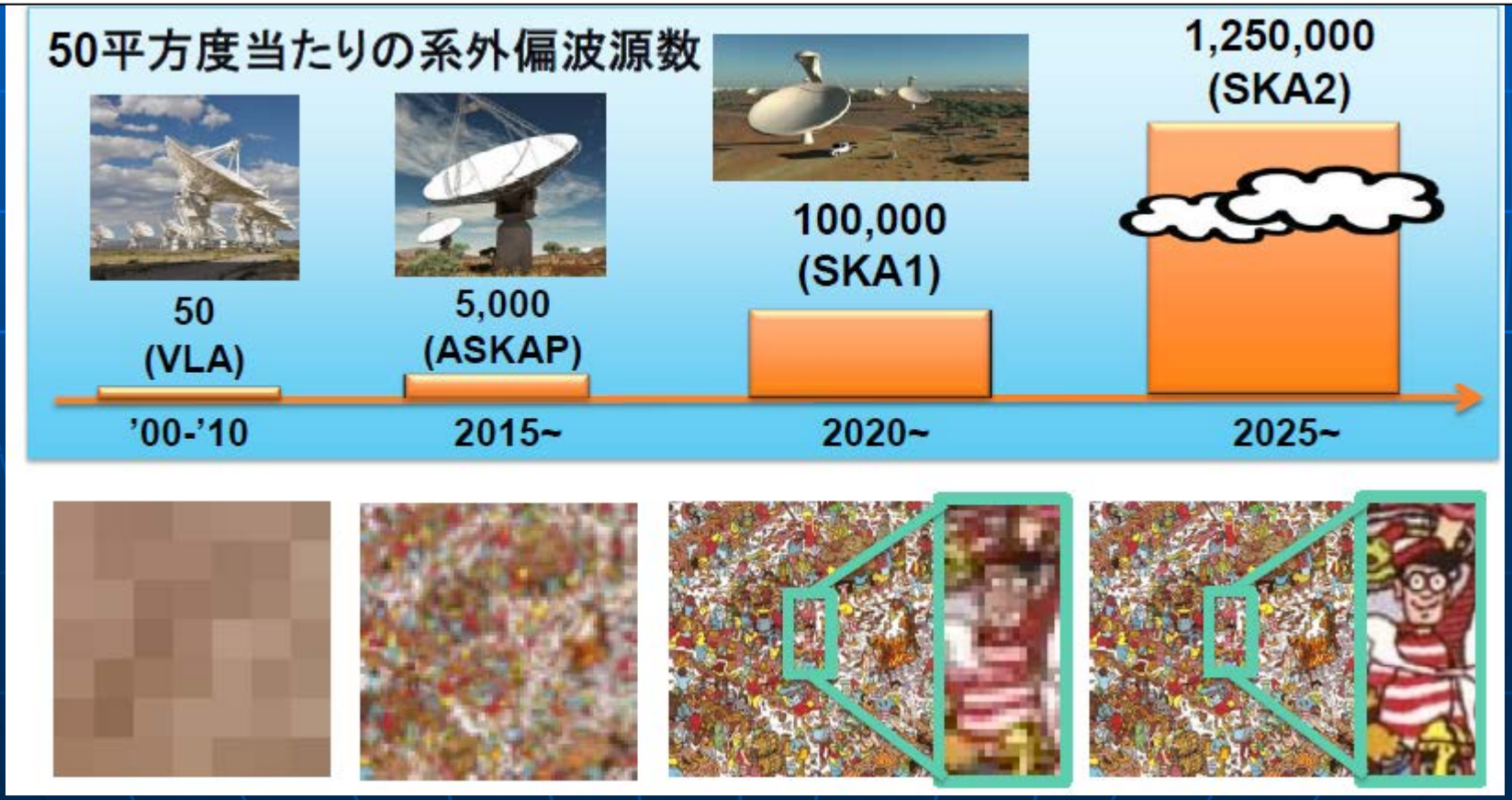


MHD simulations of sloshing-type cold fronts

ZuHone et al (2011)

More polalized sources in the future !!!

Numbers of extragalactic polalized radio sources per 50 square degrees
(from Akahori-san's presentation file)



X-ray and Radio

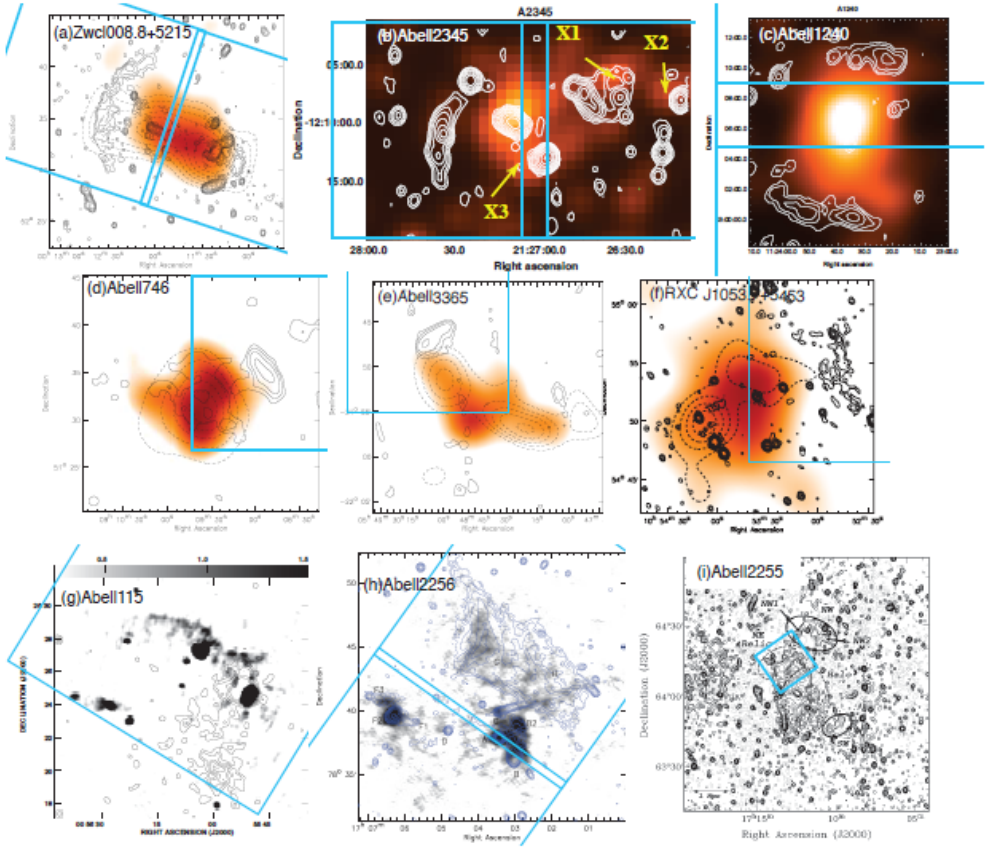
- Particle acceleration processes are likely related with magnetized plasma motion.

  shocks or magetic turbulence or ???

- Information about “gas motion”, “high energy particles”, and “magnetic fields” is necessary.
- Combinations of X-ray and Radio (cm--m) observations are crucial.

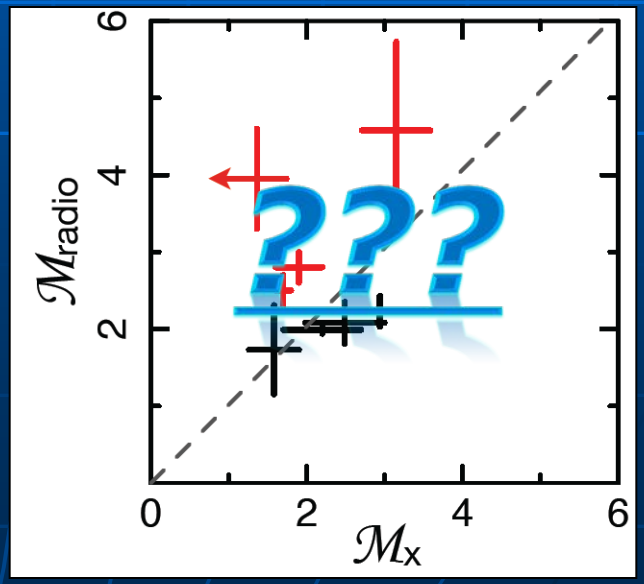
Exploring Energetics at the Largest Shock Structure in the Universe

(applying Suzaku AO9 key project, PI : Akamatsu)



12 radio relics
(with reliable radio data and active radio people)

1143 ksec



Summary

- Radio relics are probably related with shocks, but the Mach numbers derived with two independent methods (M_x, M_{radio}) are often inconsistent with each other.

- Magnetic field modeling with FRM has some problems (parameter degeneracy, coherent structures, etc).

- Number of extragalactic polarized sources will increase drastically in the future (ASKAP, SKA).

- Combinations of X-ray and radio (cm--m) observations are crucial.

  --->applying Suzaku AO9 key project (PI: Akamatsu)