

Shocks in galaxy clusters or Always trouble with relics

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Georgiana Ogrean (HH->CfA)

Huub Röttgering (Leiden)

Franco Vazza (HH)

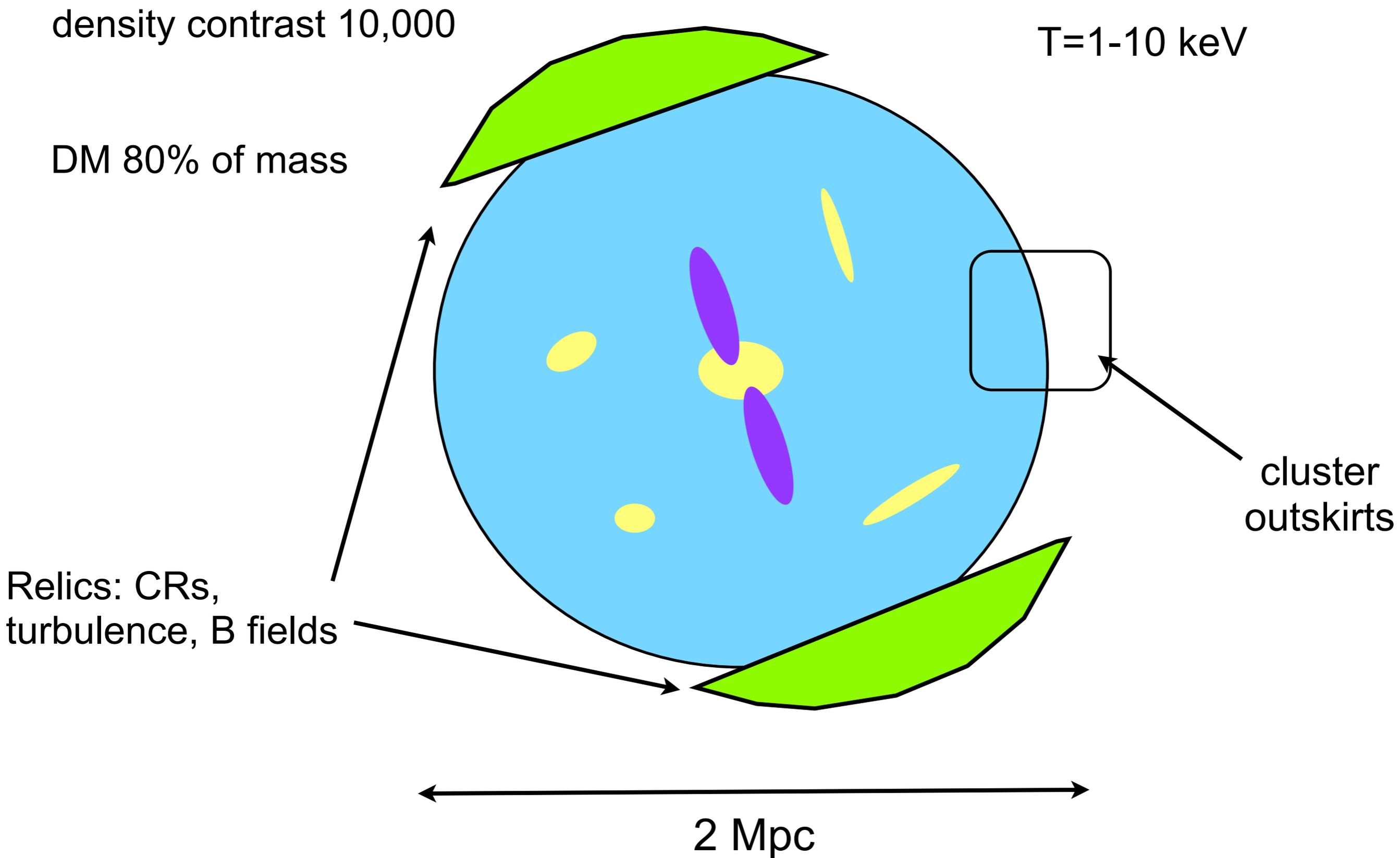
Annalisa Bonafede (HH)

Andra Stroe (Leiden)

Aurora Simionescu (somewhere)

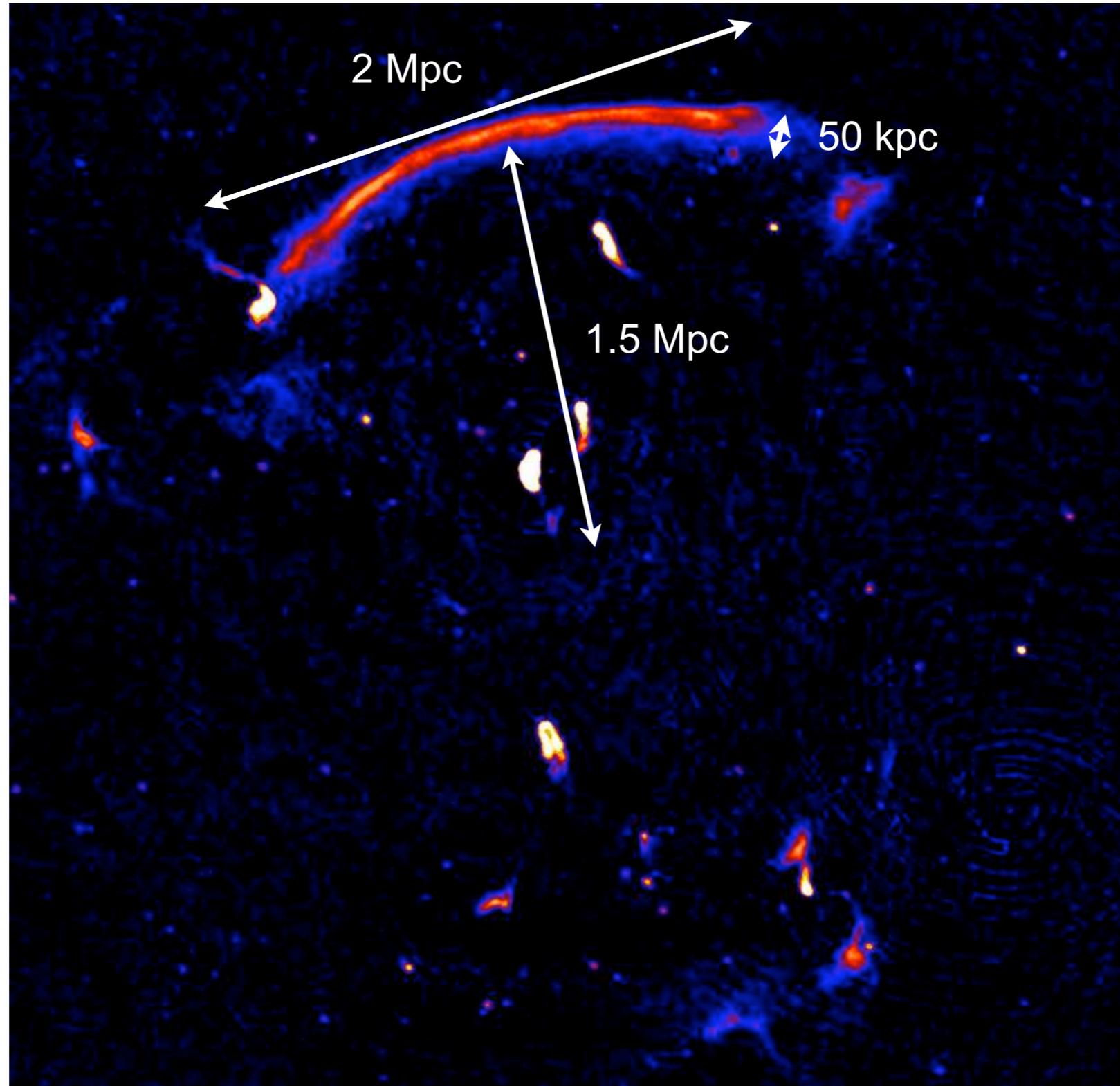
Will Dawson (Livermore)

Anatomy of a galaxy cluster

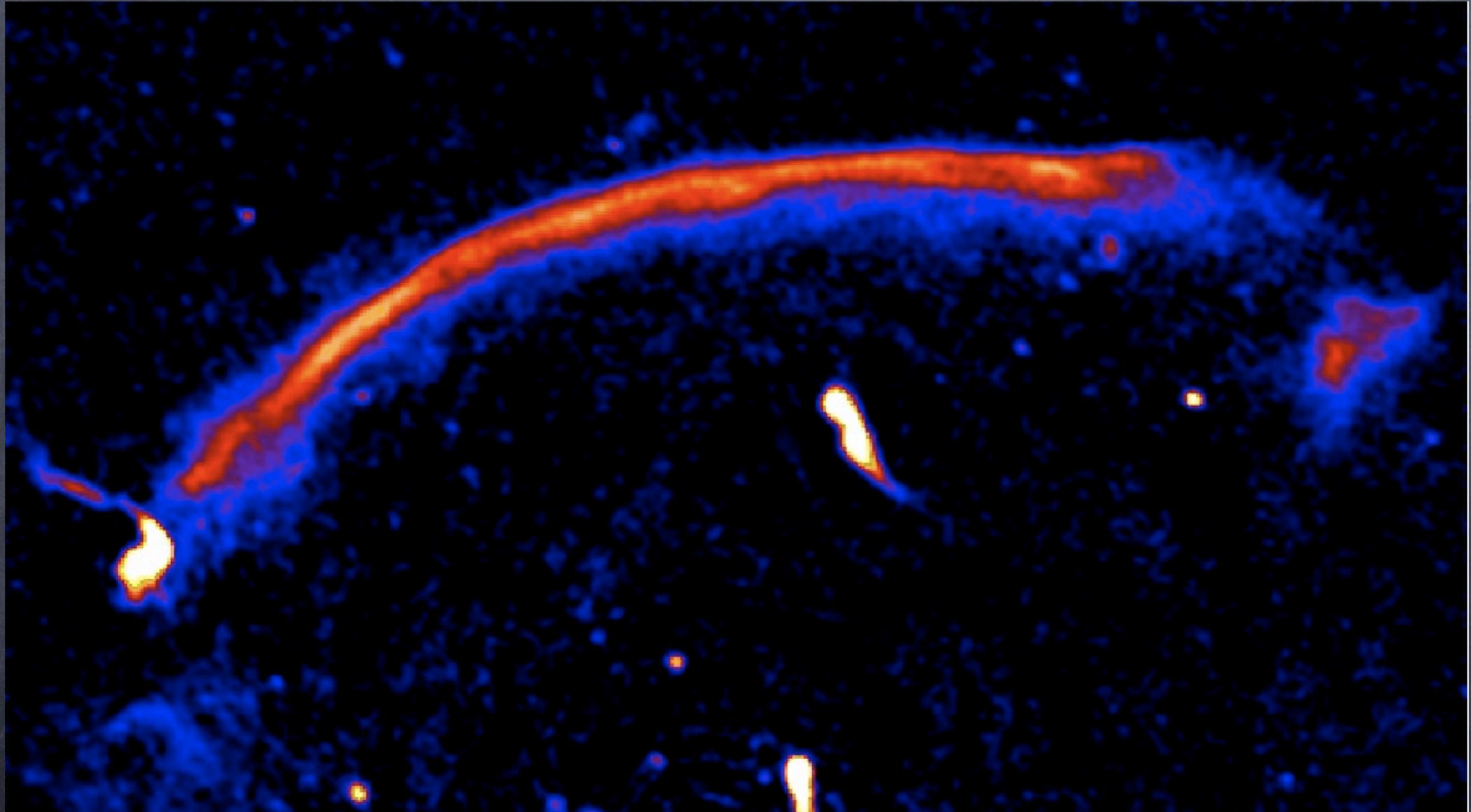


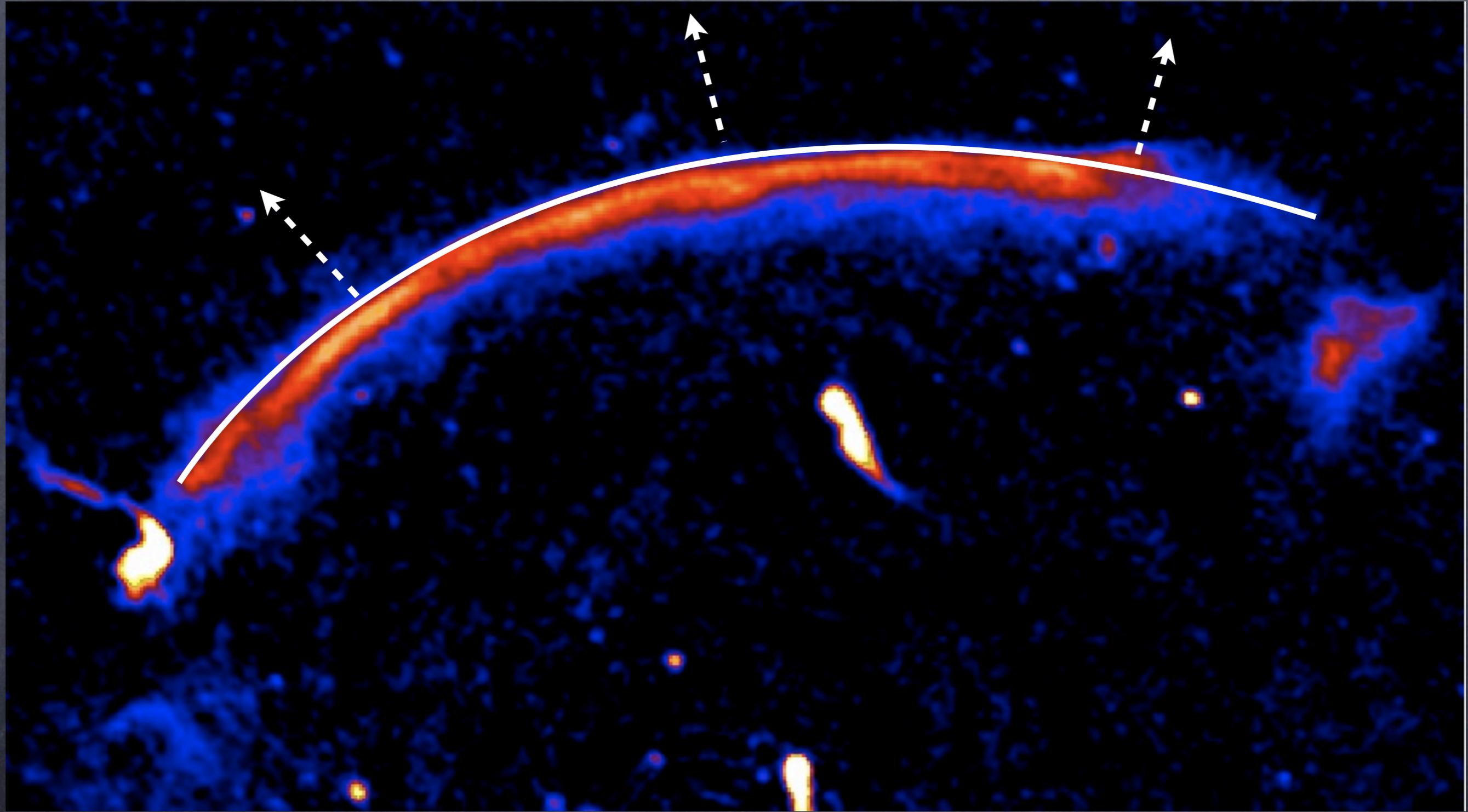
The sausage: CIZA J2242.8+5301

van Weeren, Röttgering, Brüggen, Hoeft, Science, 330, 347 (2010)



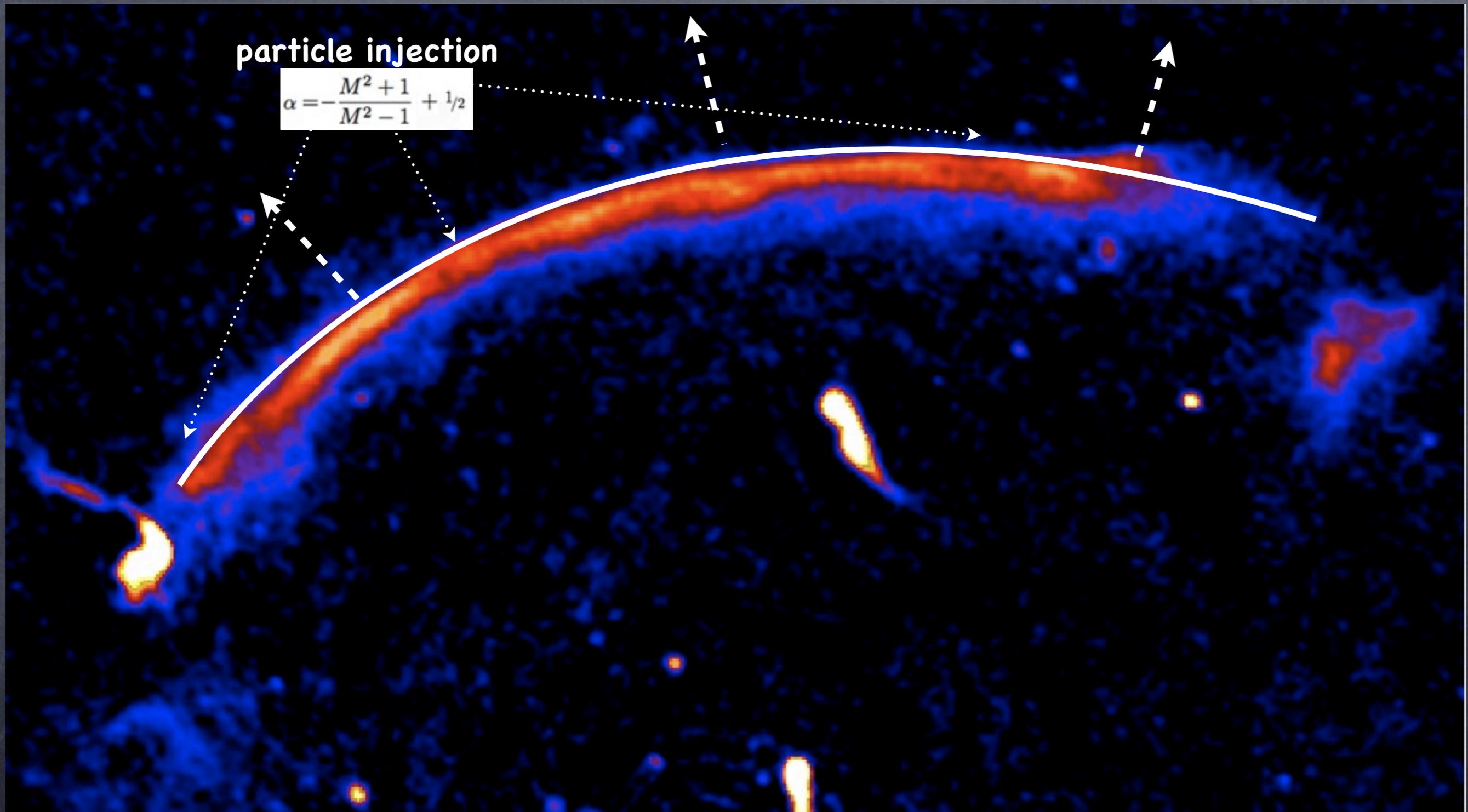
GMRT 610 MHz, resolution of $4.8 \text{ arcsec} \times 3.9 \text{ arcsec}$.
total on source time 9 hrs, bandwidth of 32 MHz.





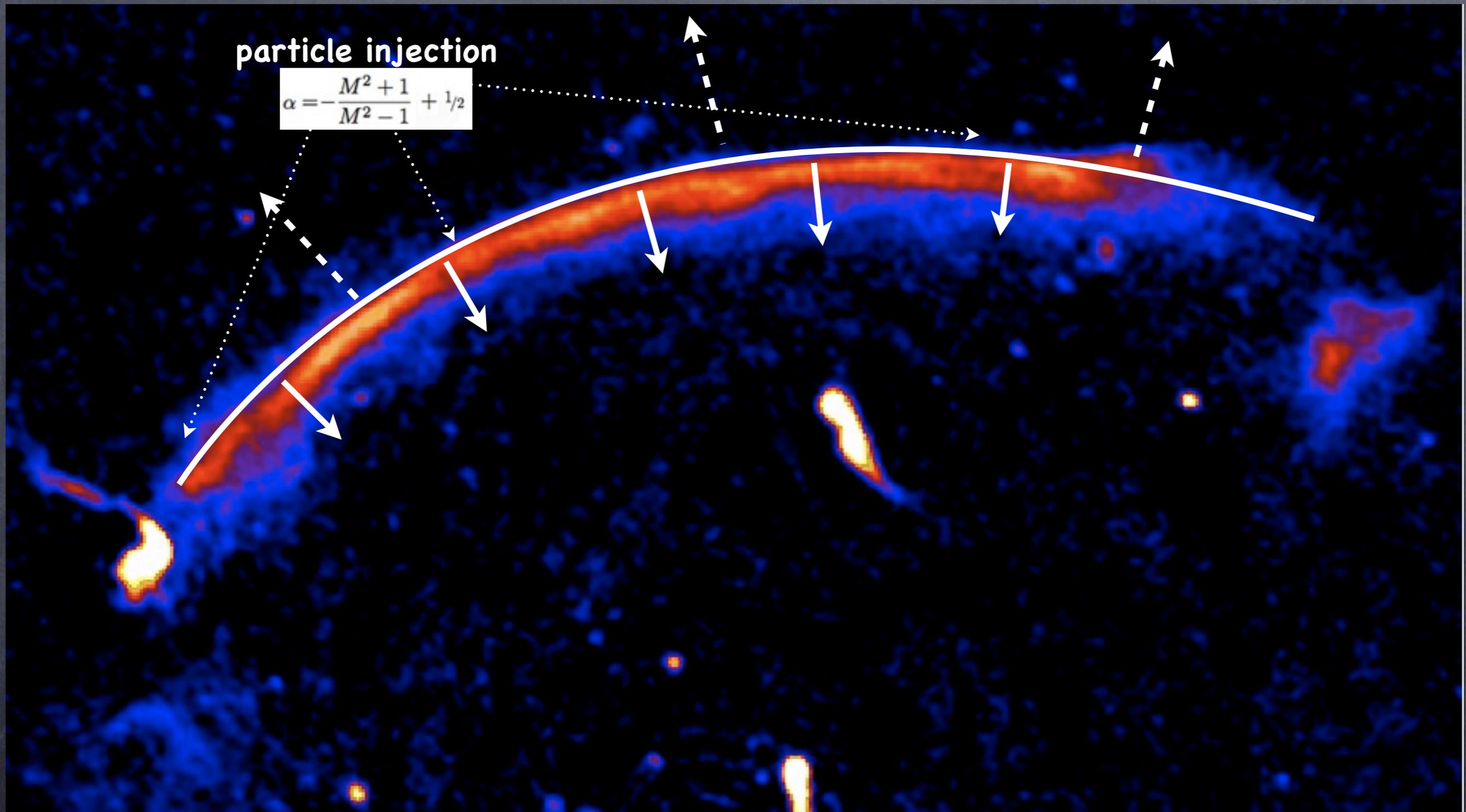
particle injection

$$\alpha = -\frac{M^2 + 1}{M^2 - 1} + 1/2$$



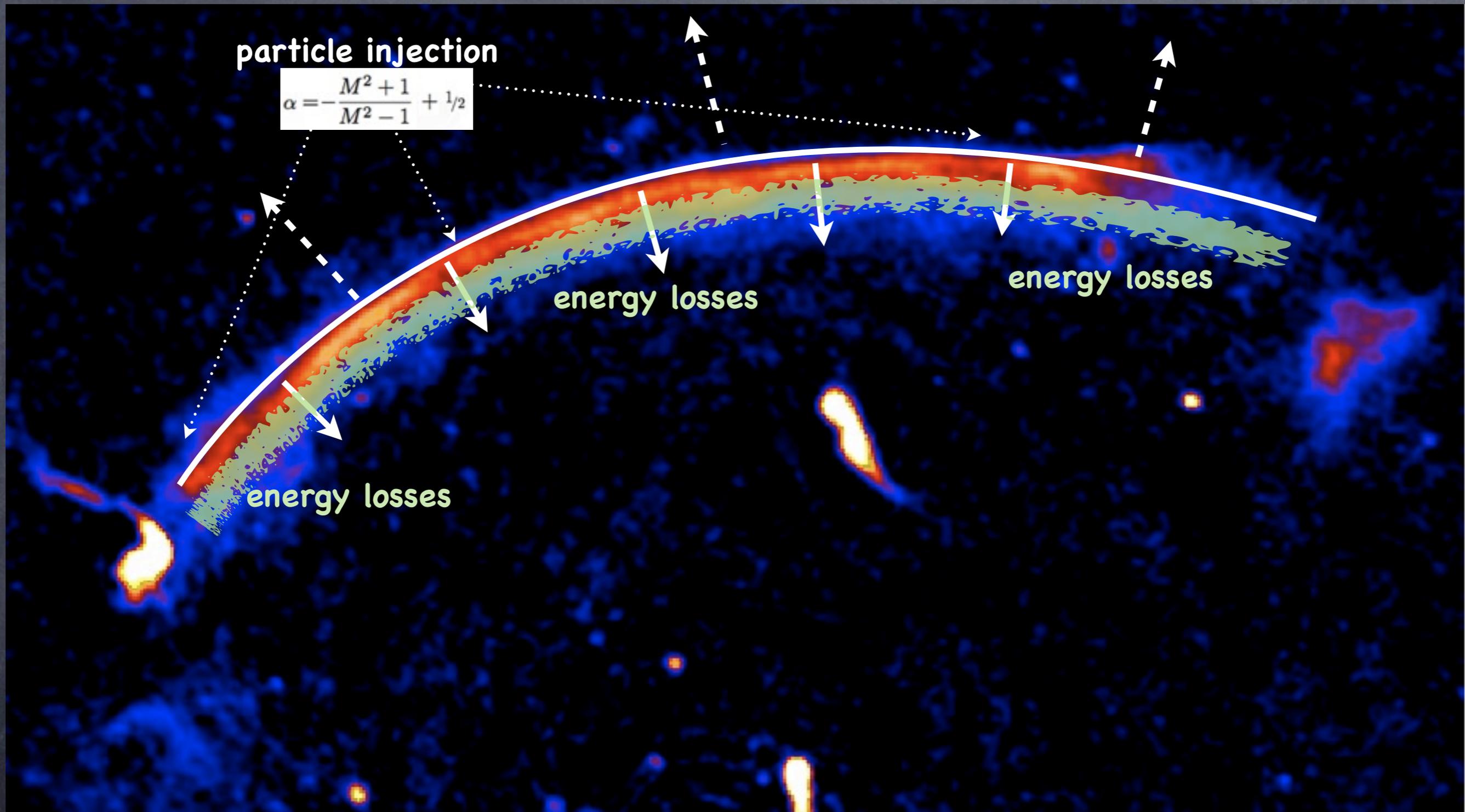
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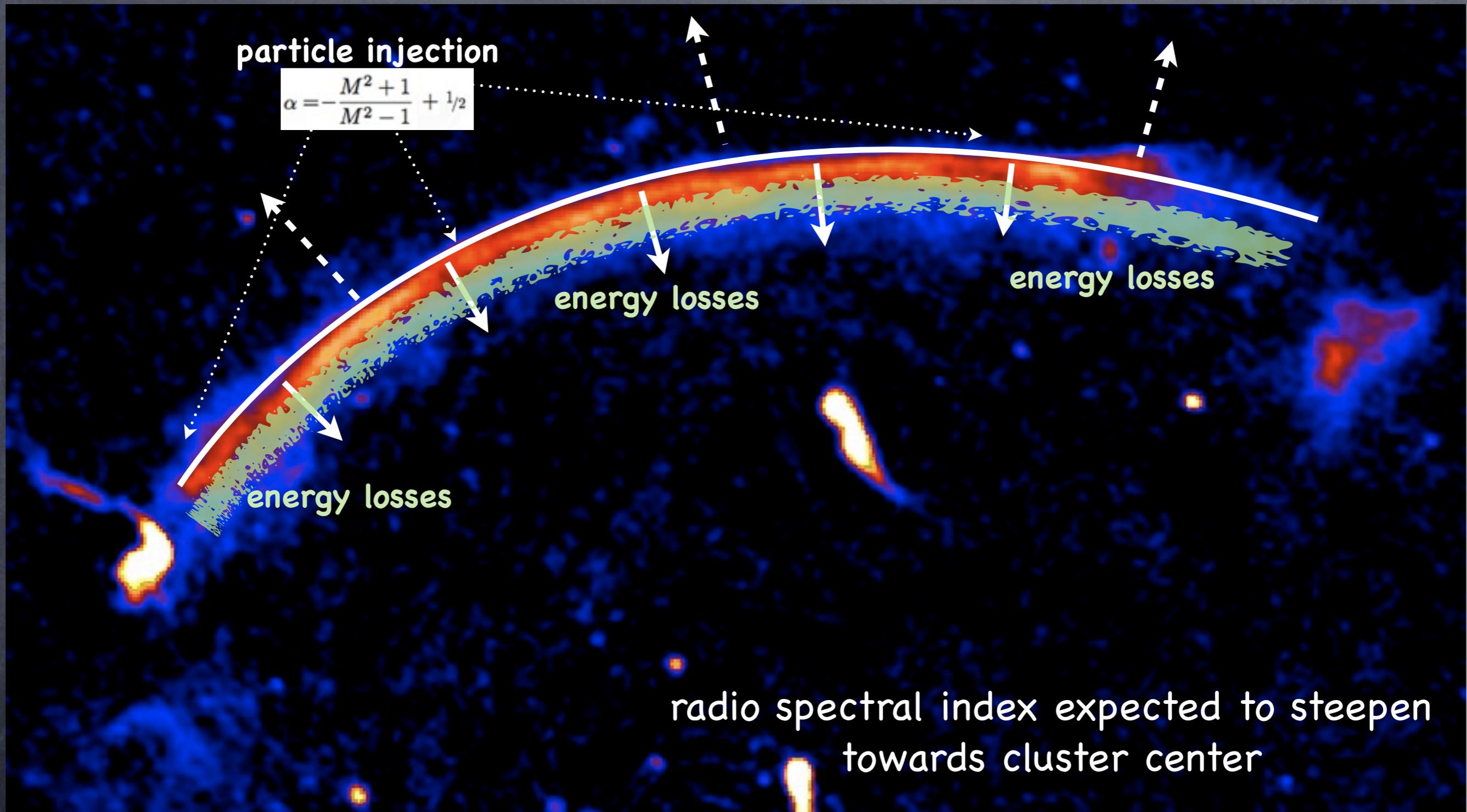
energy losses

energy losses

energy losses

particle injection

$$\alpha = -\frac{M^2 + 1}{M^2 - 1} + 1/2$$



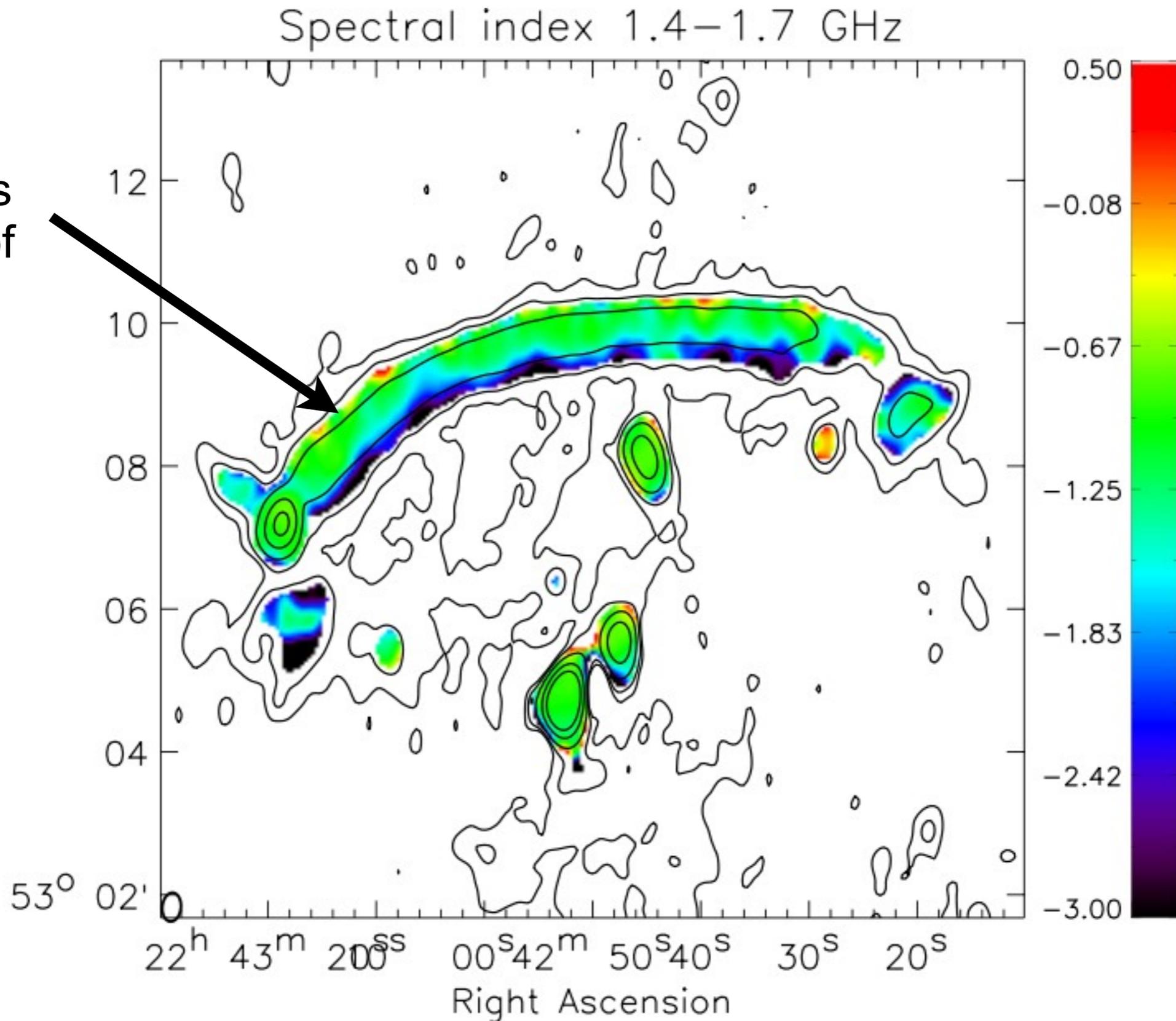
energy losses

energy losses

energy losses

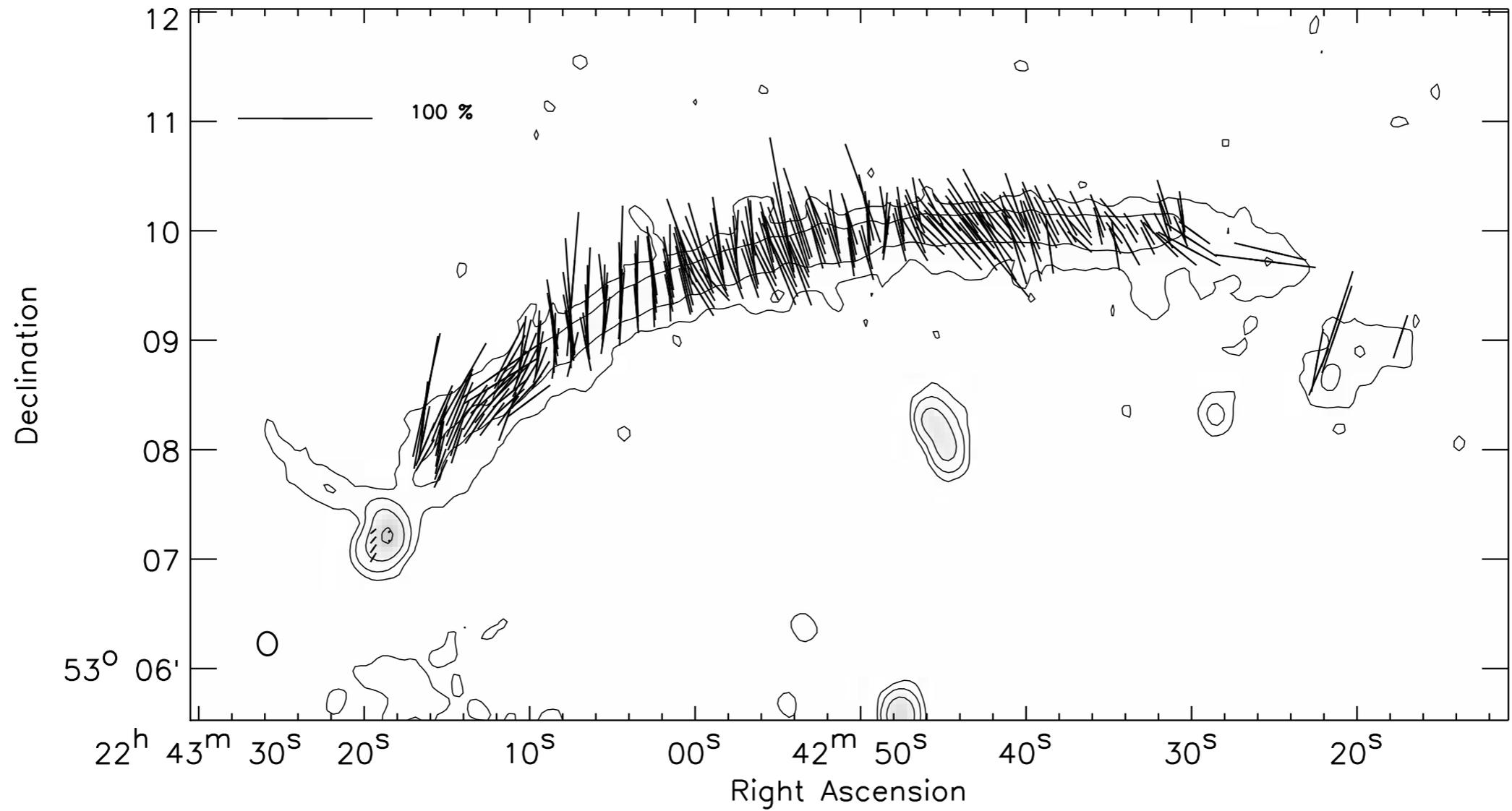
radio spectral index expected to steepen
towards cluster center

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

Polarisation



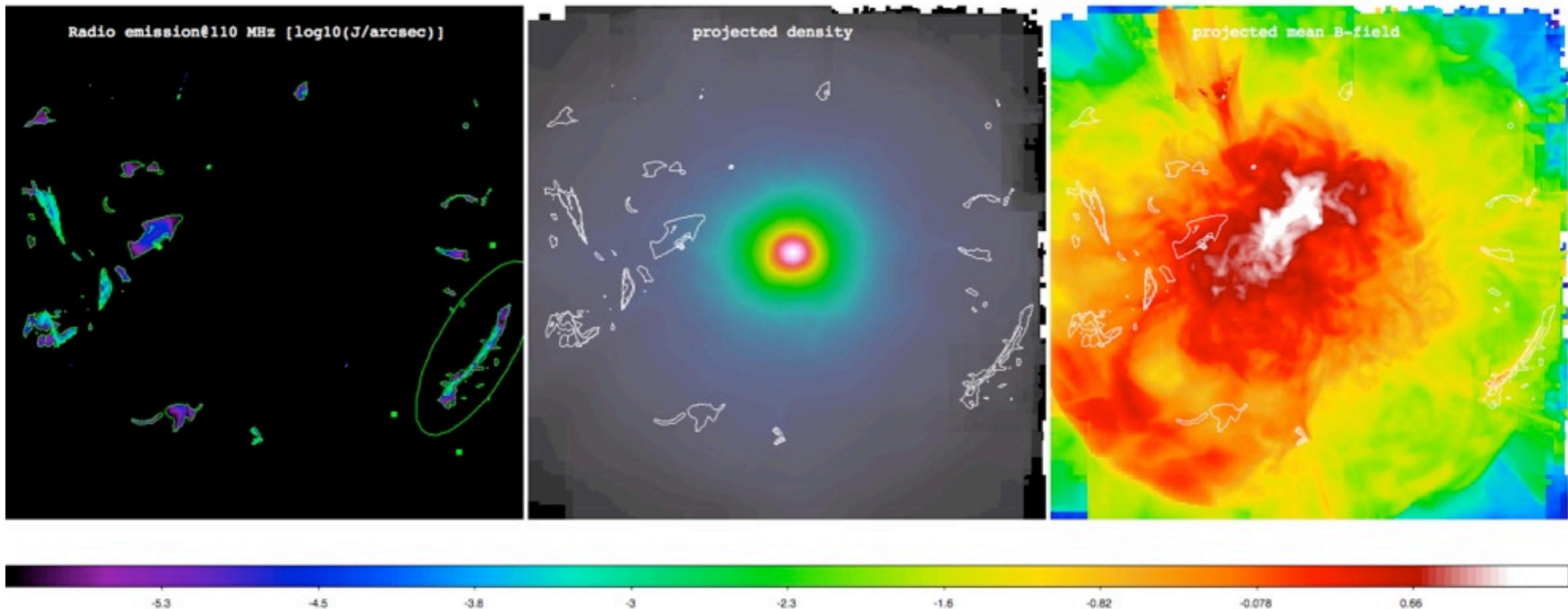
So are magnetic fields aligned with merger shocks?

Sam (Skillman et al. 2013) says no.

New set of unigrid ENZO MHD simulations:

probably right.

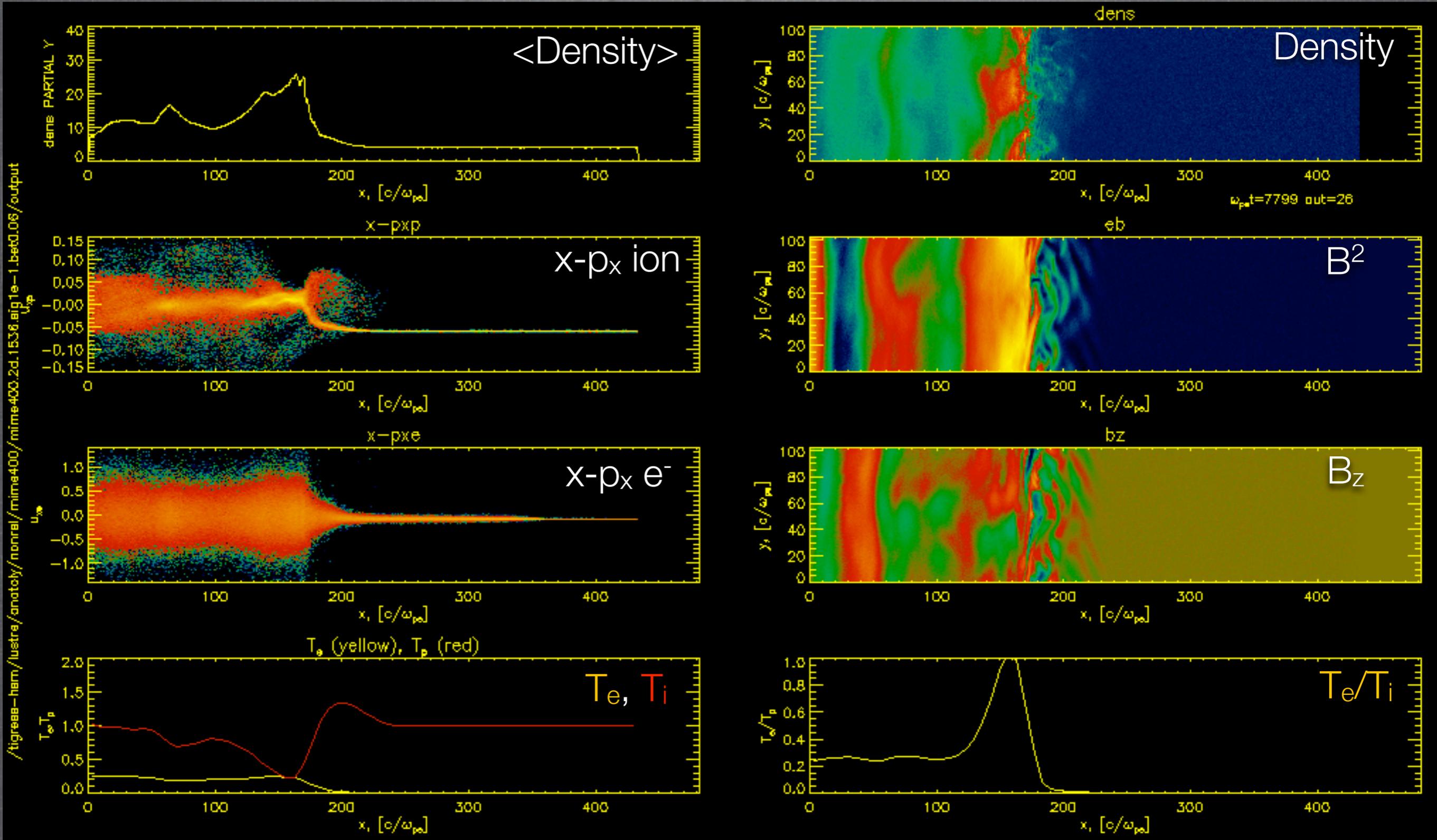
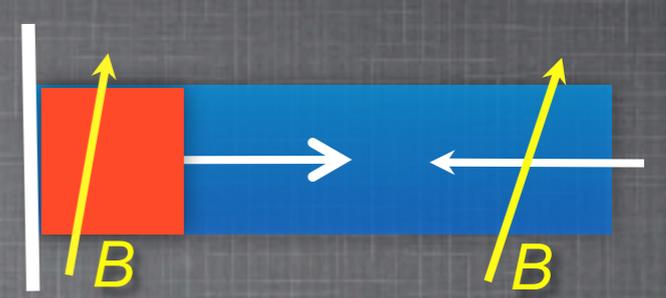
So maybe only merger shocks with quasi-perp fields produce relics?



Spitkovsky et al., Riquelme et al.

Nonrelativistic shocks: shock structure

$m_i/m_e=400$, $v=18,000\text{km/s}$, $\text{Ma}=5$, quasi-perp 75° inclination



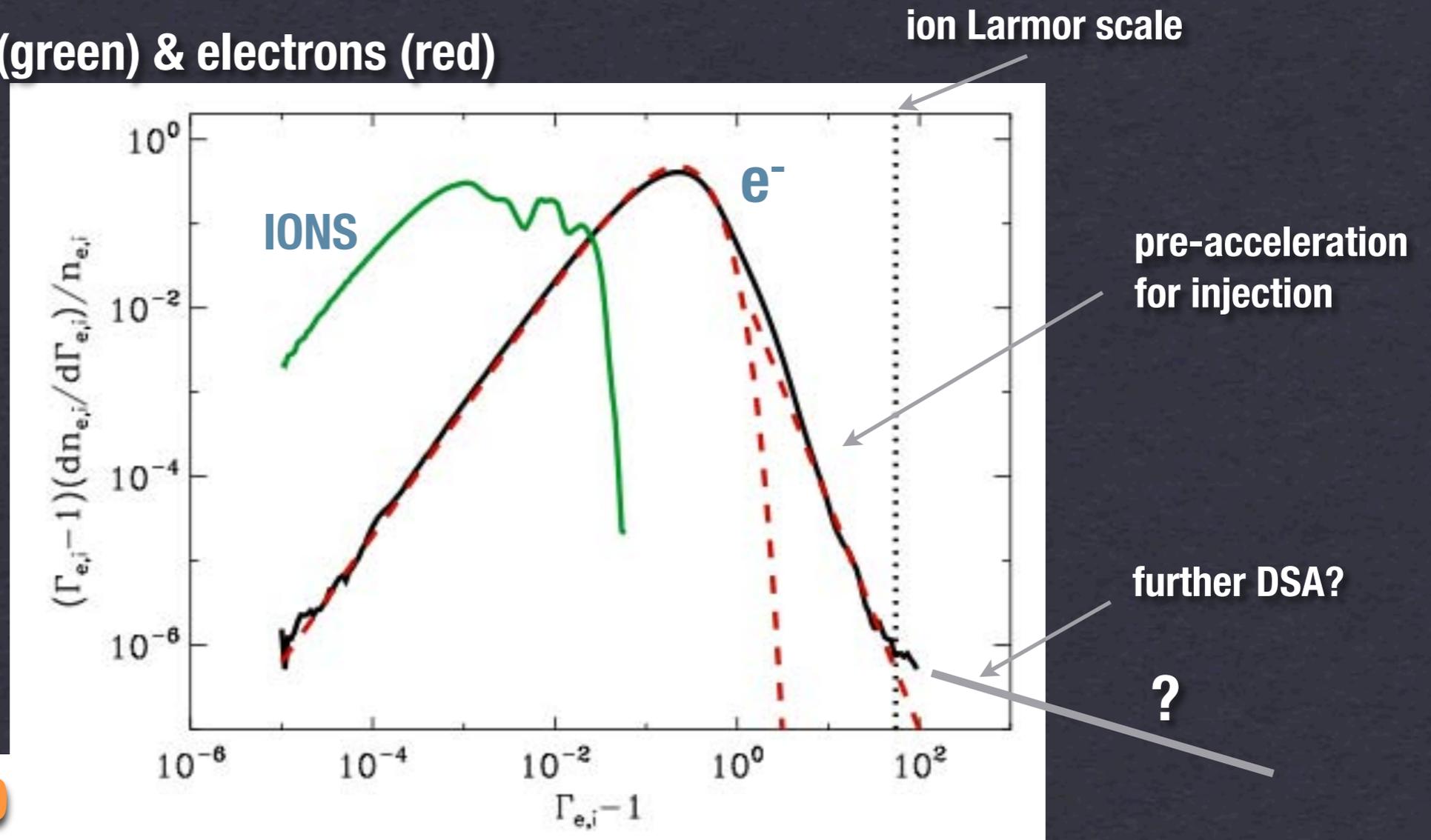
Shock foot, ramp, overshoot, returning ions, electron heating, whistler(?) waves.

Parameter dependence

Spectrum of ions (green) & electrons (red)

Ma=7

$m_i/m_e=400$



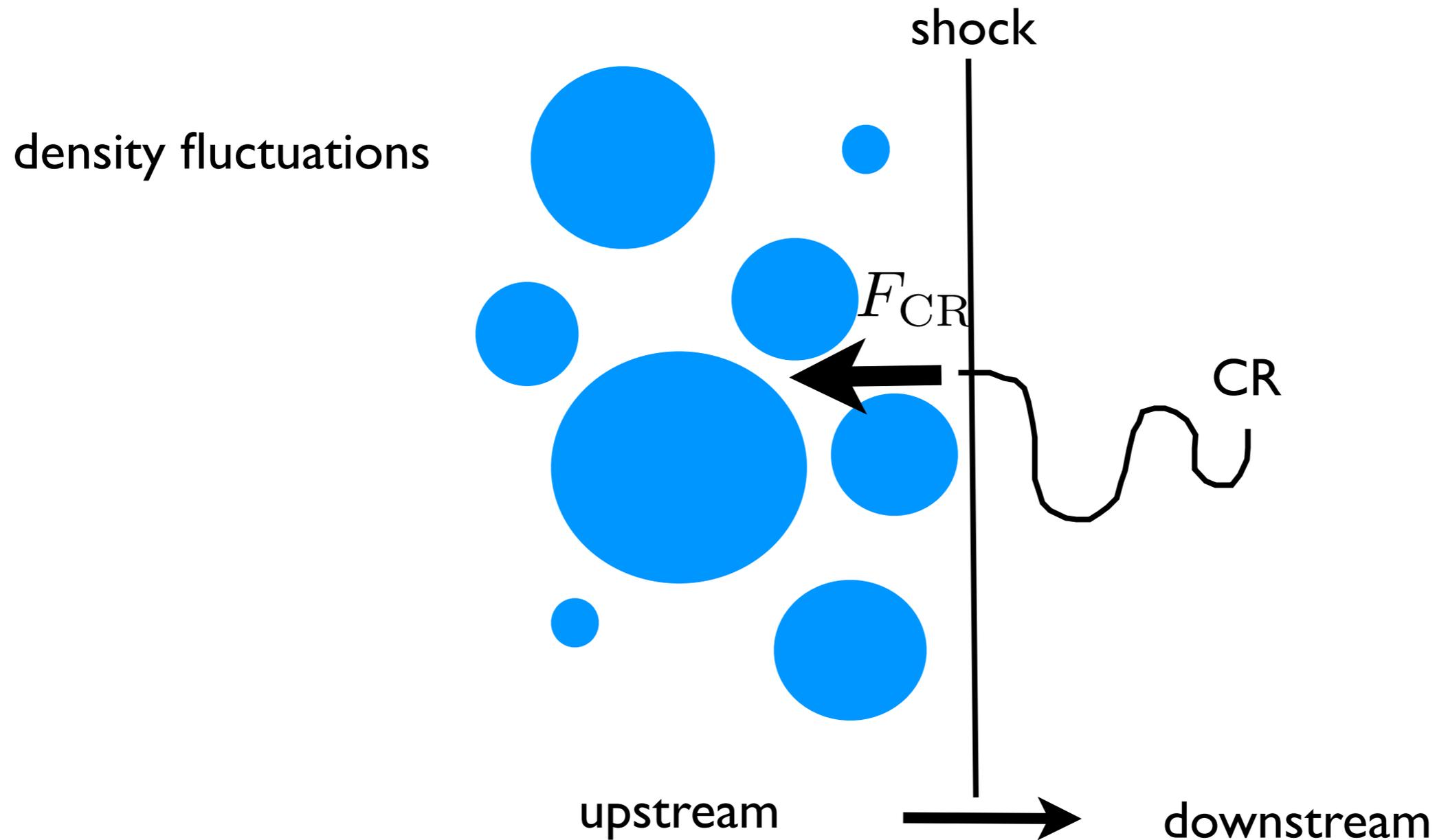
Riquelme & AS, '11

Electron injection needs:

Quasi-perpendicular shocks, $45^\circ < \theta_{Bn} < 90^\circ$

Lower Alfvénic Mach numbers (to create whistlers): $M_A < (m_i/m_e)^{1/2}$

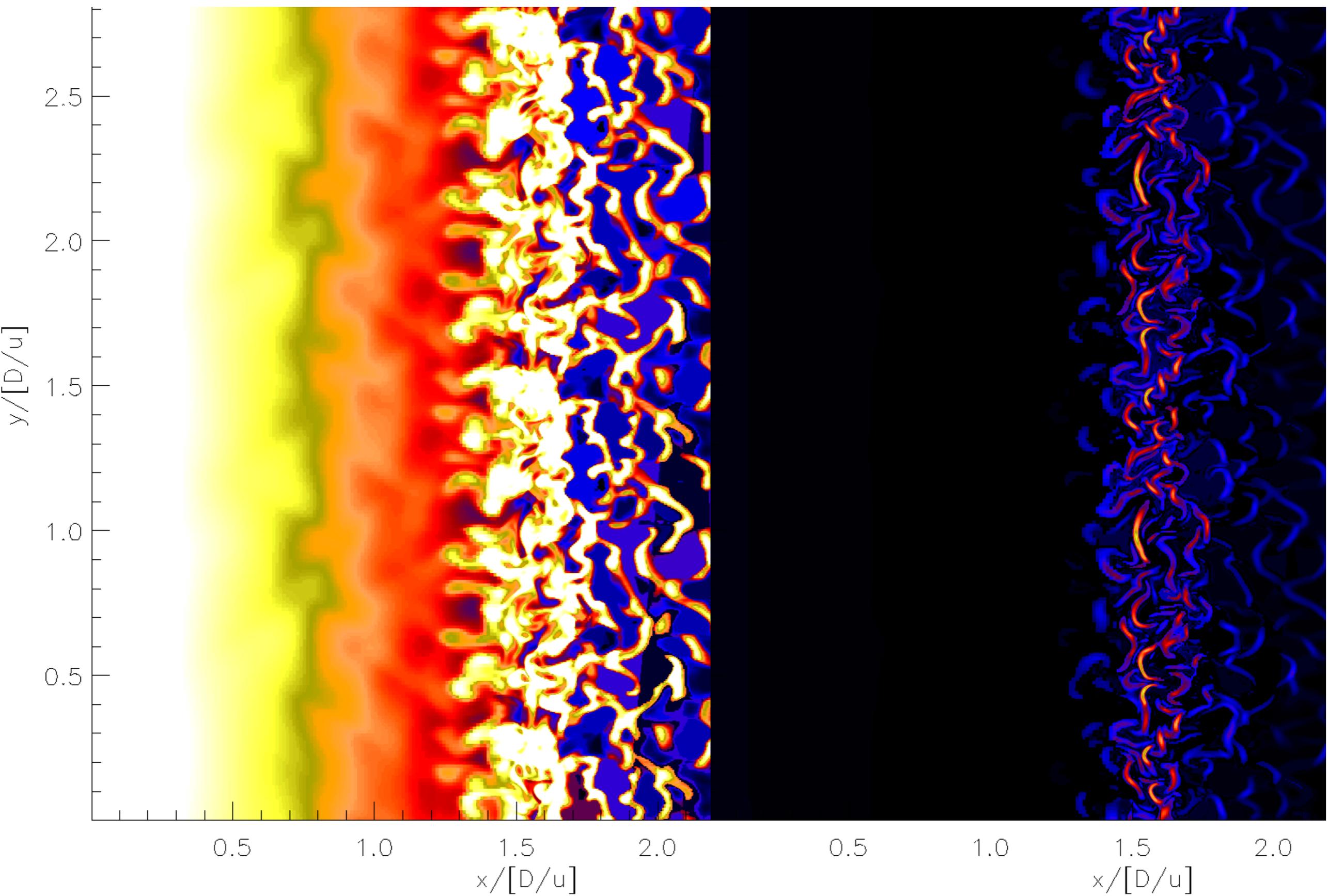
Magnetic field amplification by cosmic rays



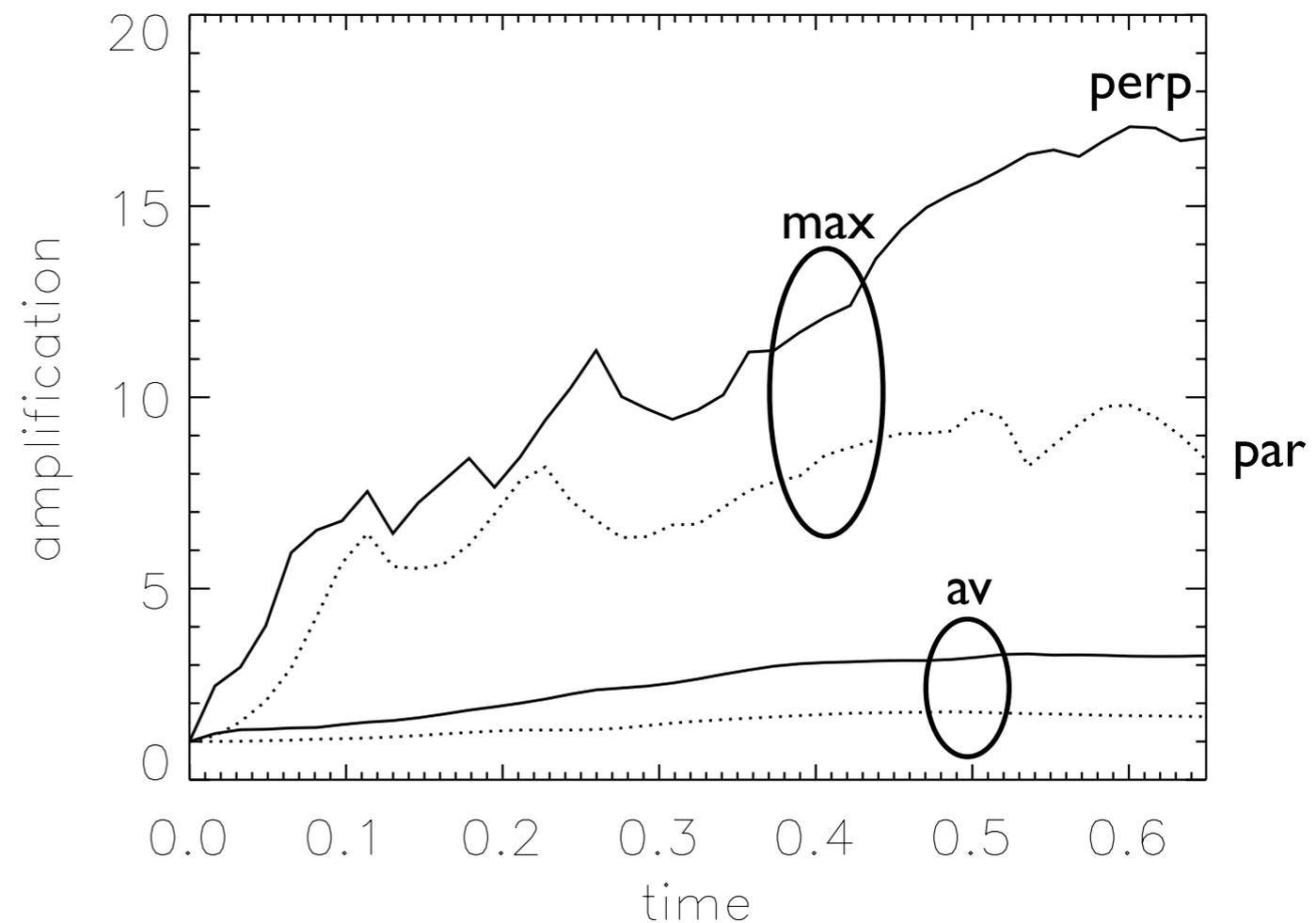
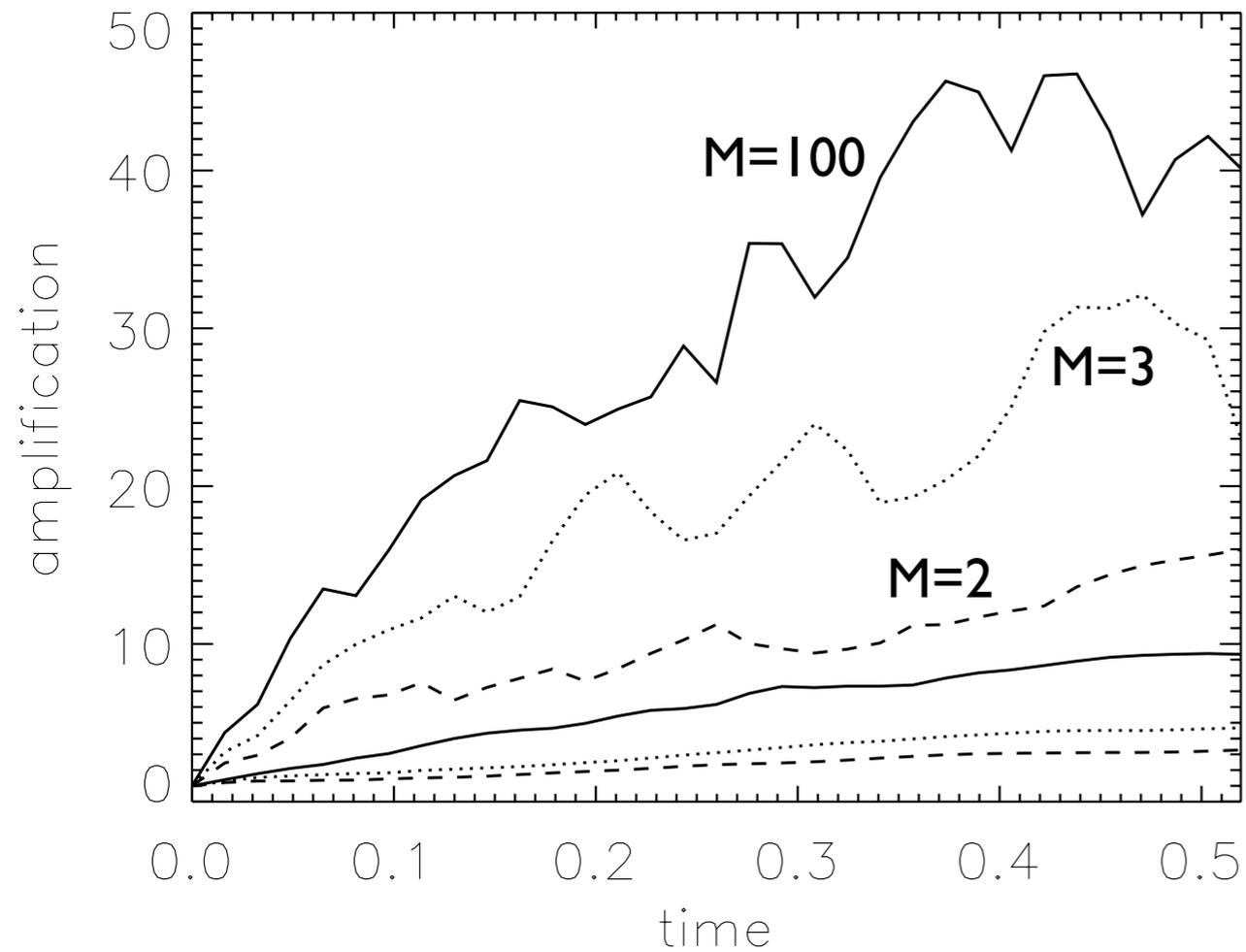
precursor exerts a force on the upstream plasma not proportional to gas density

Density fluctuations \rightarrow acceleration fluctuations \rightarrow density fluctuations

Cosmic-ray driven turbulence

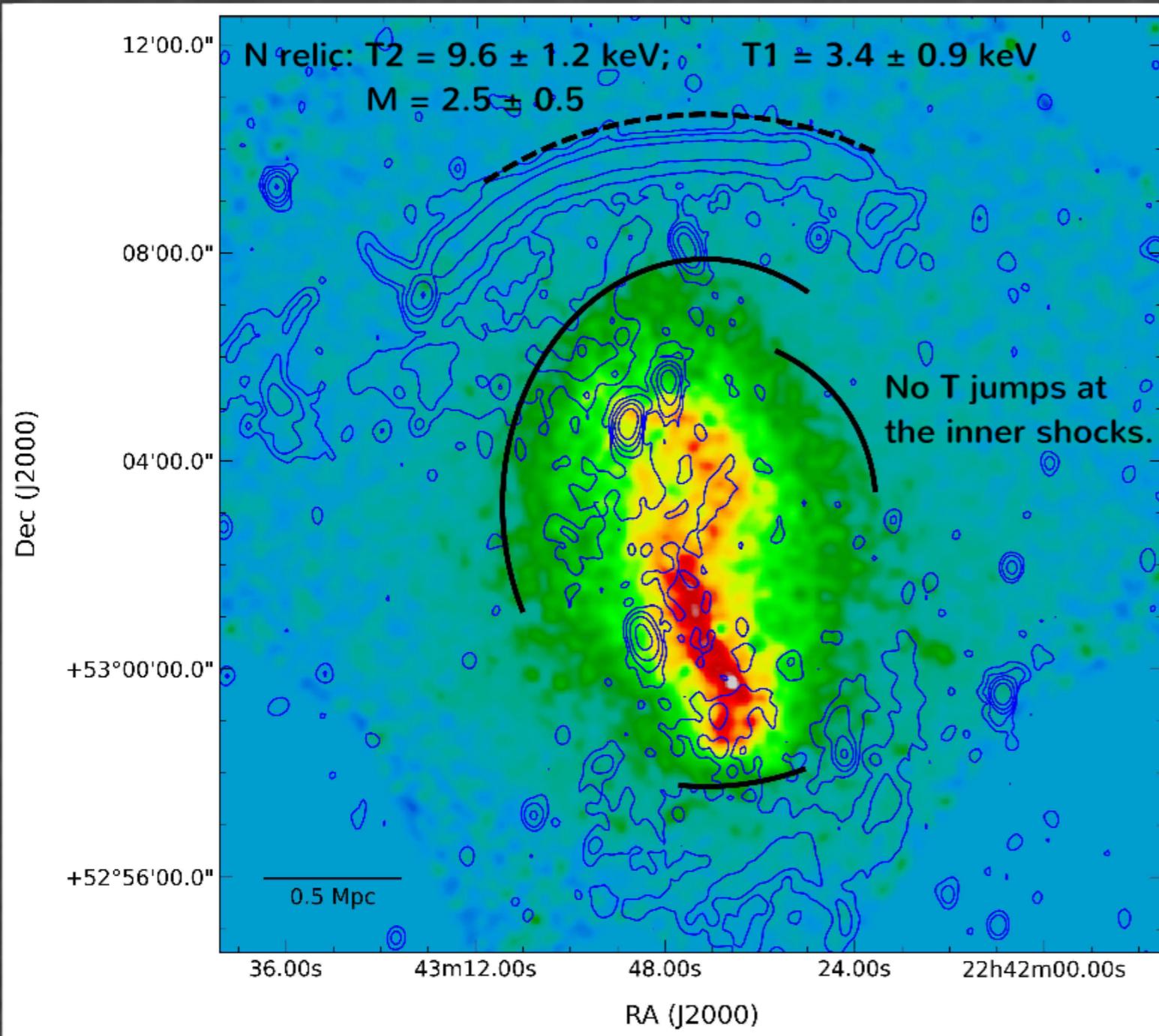


Magnetic field amplification



can be probed with Faraday rotation...

Brüggem 2013



ClZA J2242.8+5301

$z = 0.19$

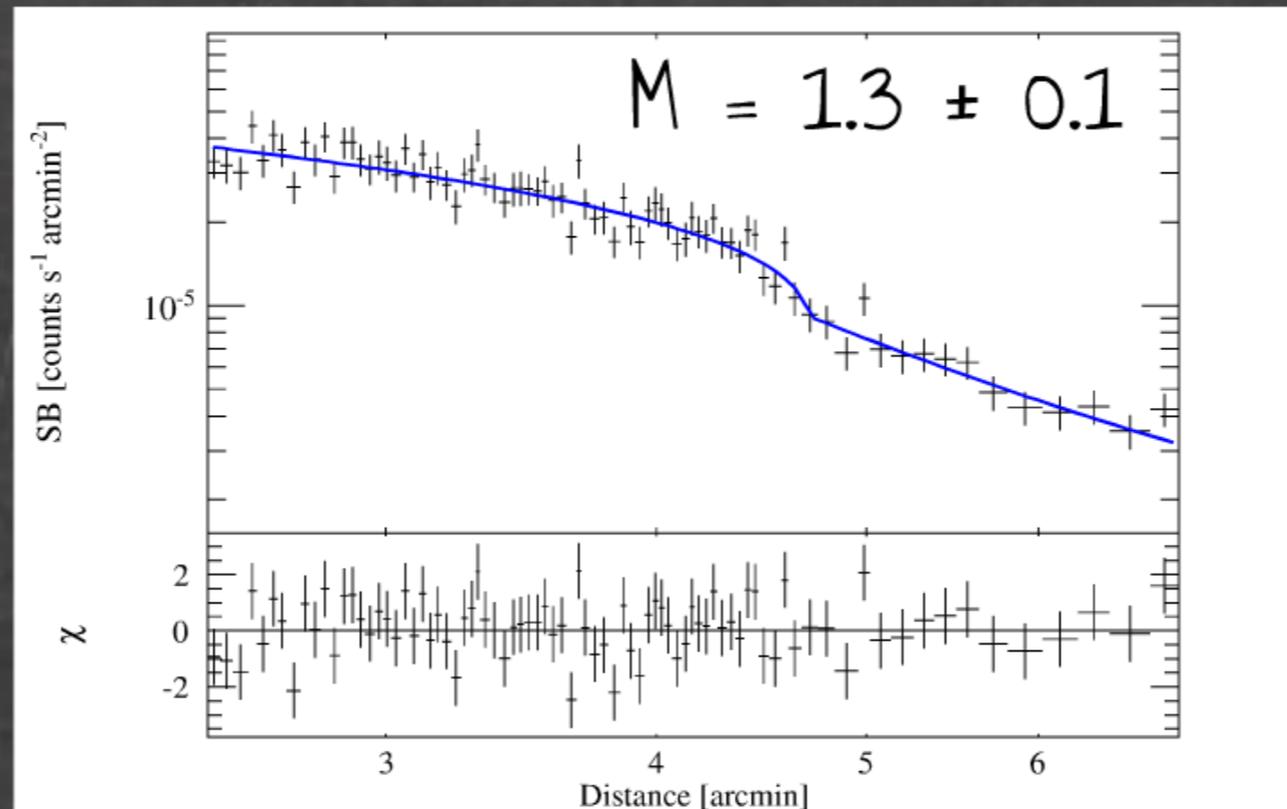
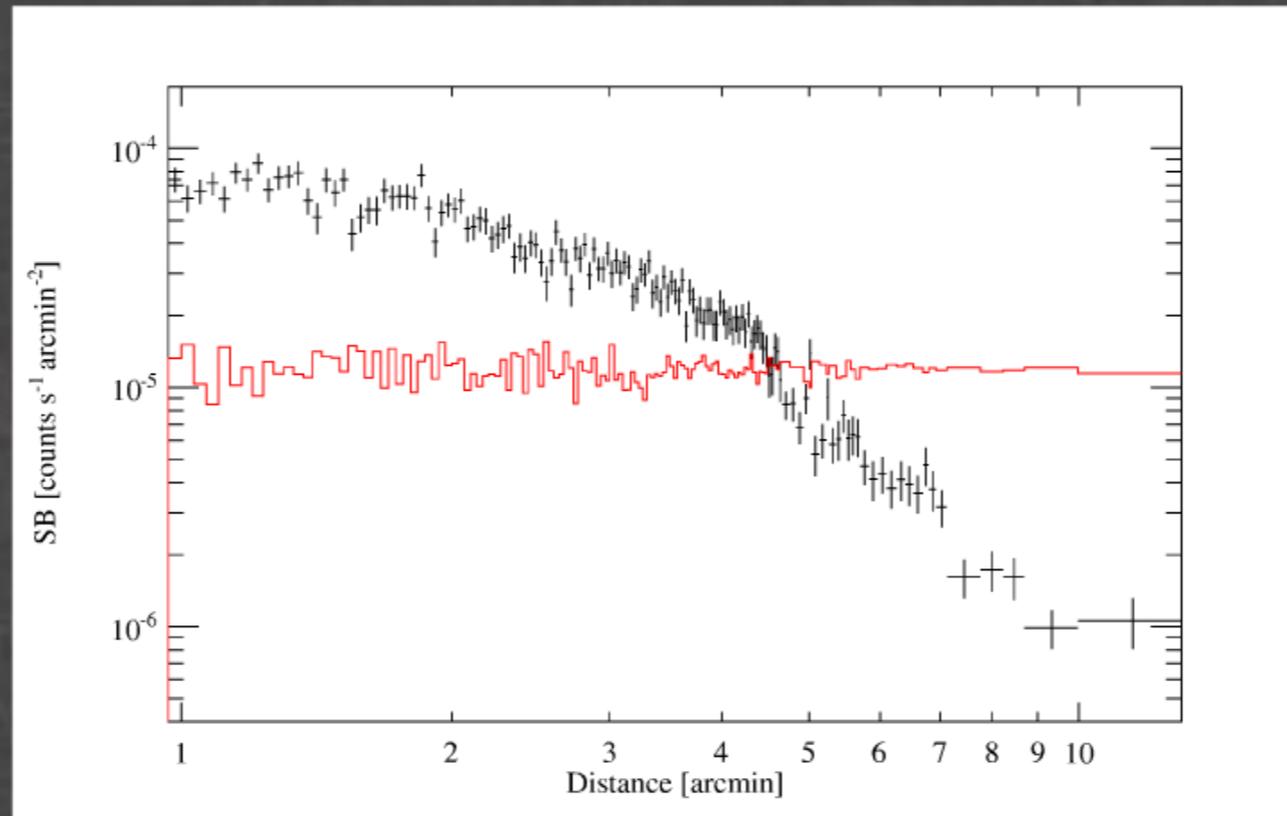
Chandra (Ogorean+ '13)

WSRT (van Weeren+ '10)

200 ks Chandra time

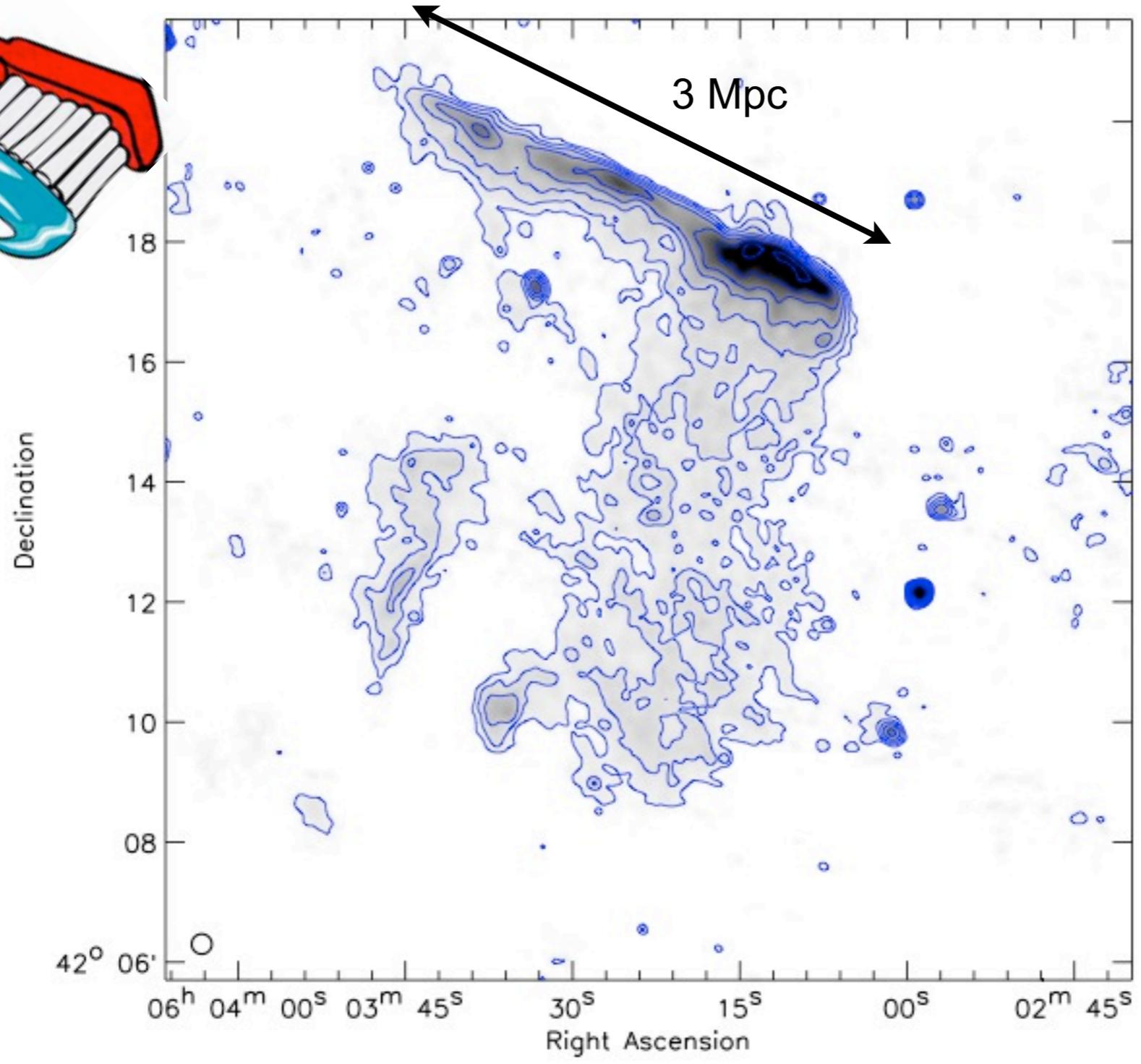
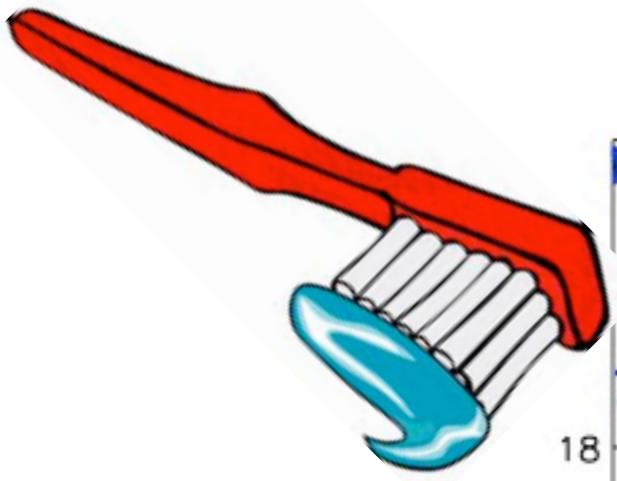
Pl: Ogorean

N profile



Slide from Georgiana

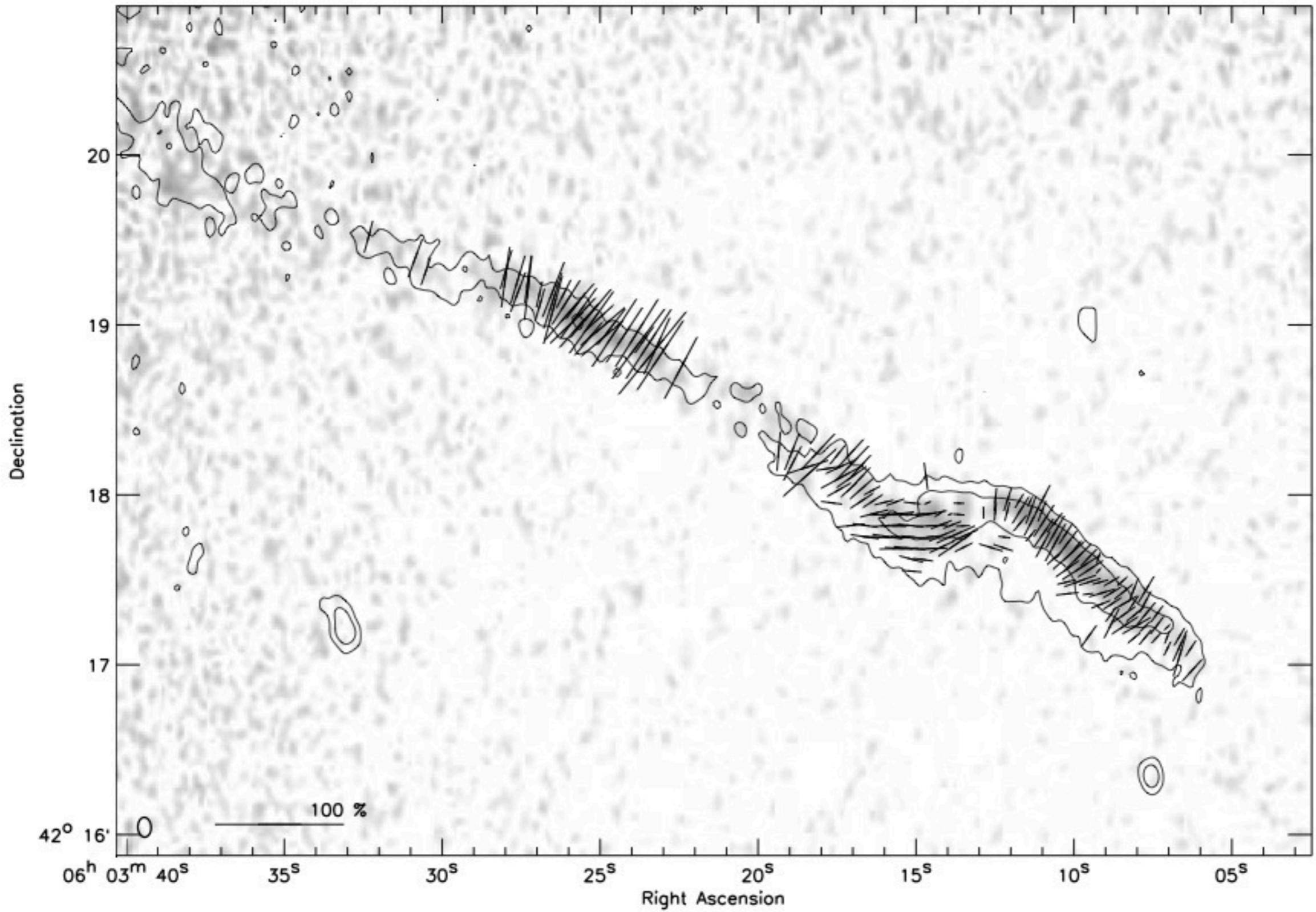
1RXS J0603.3+4213



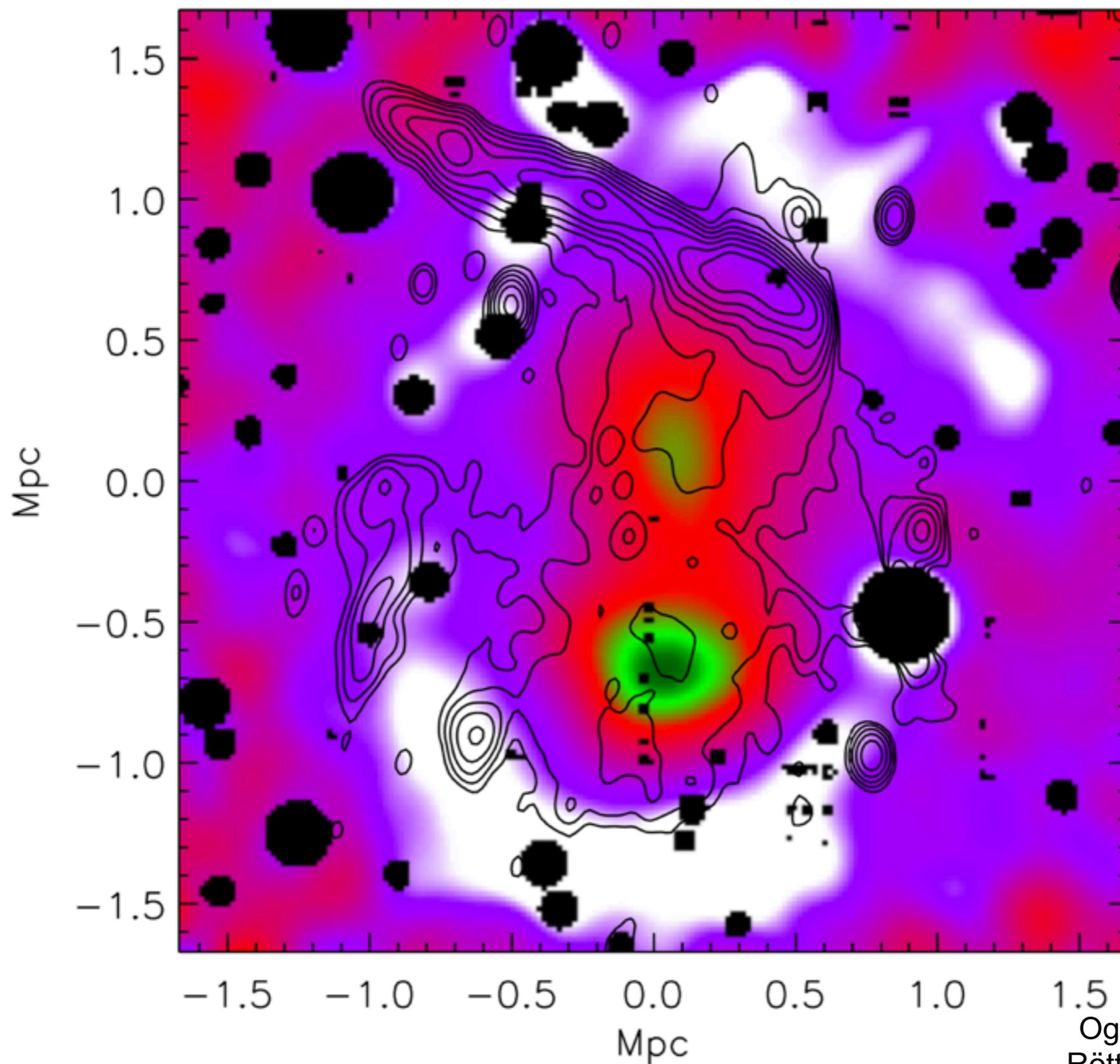
largest relic known
to date

$z=0.25$

610 MHz GMRT map

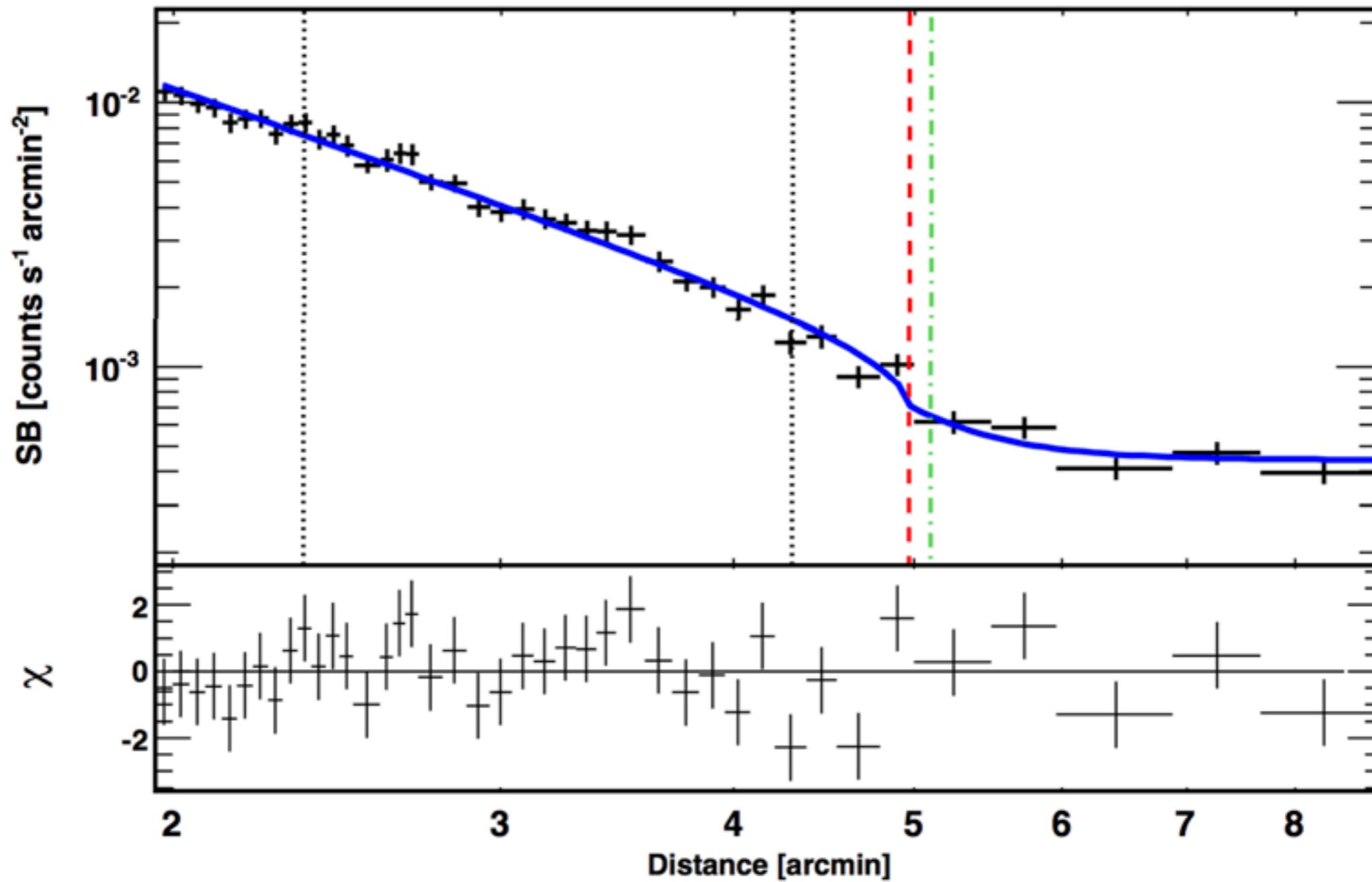


XMM unsharp-masked



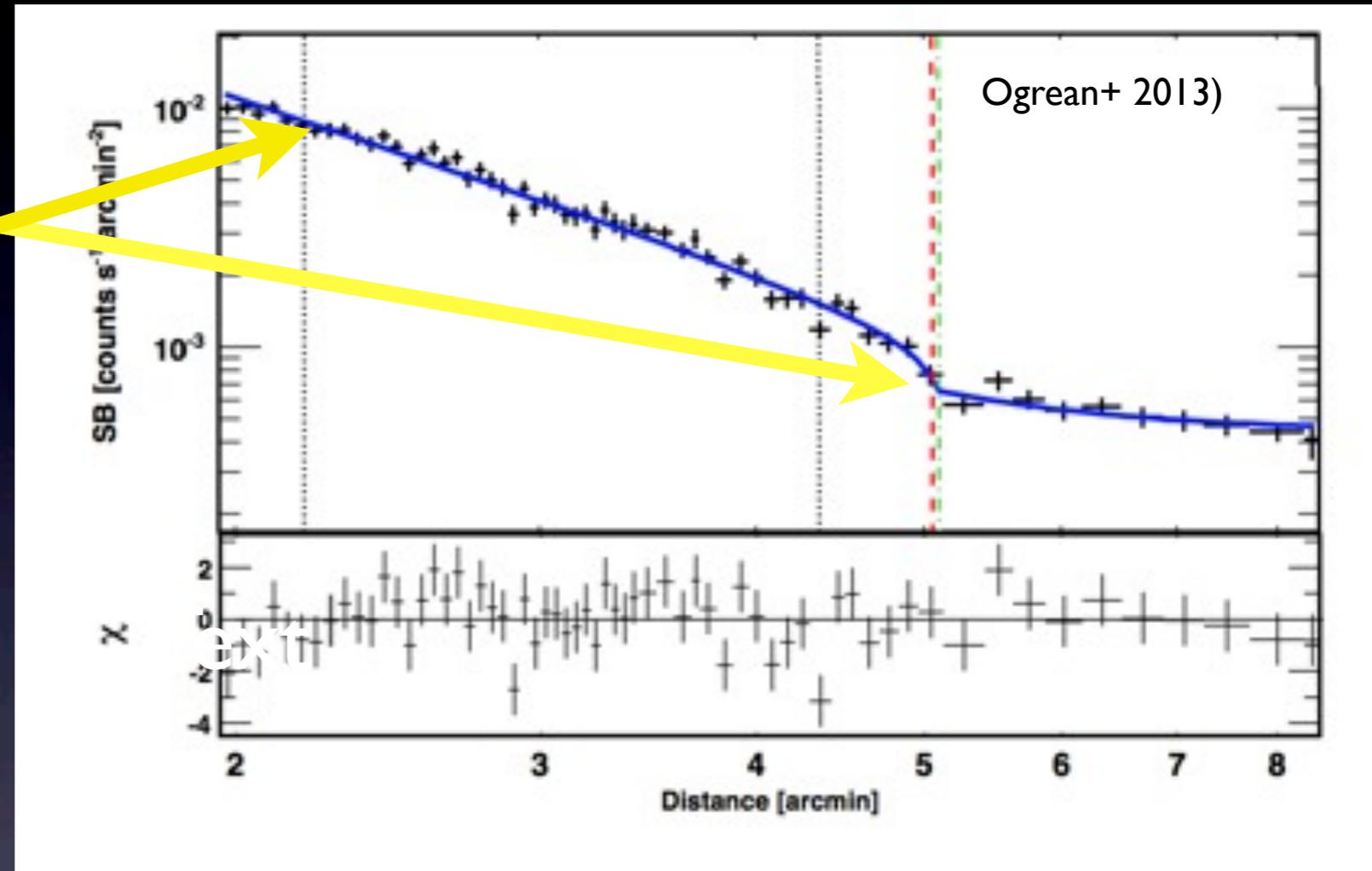
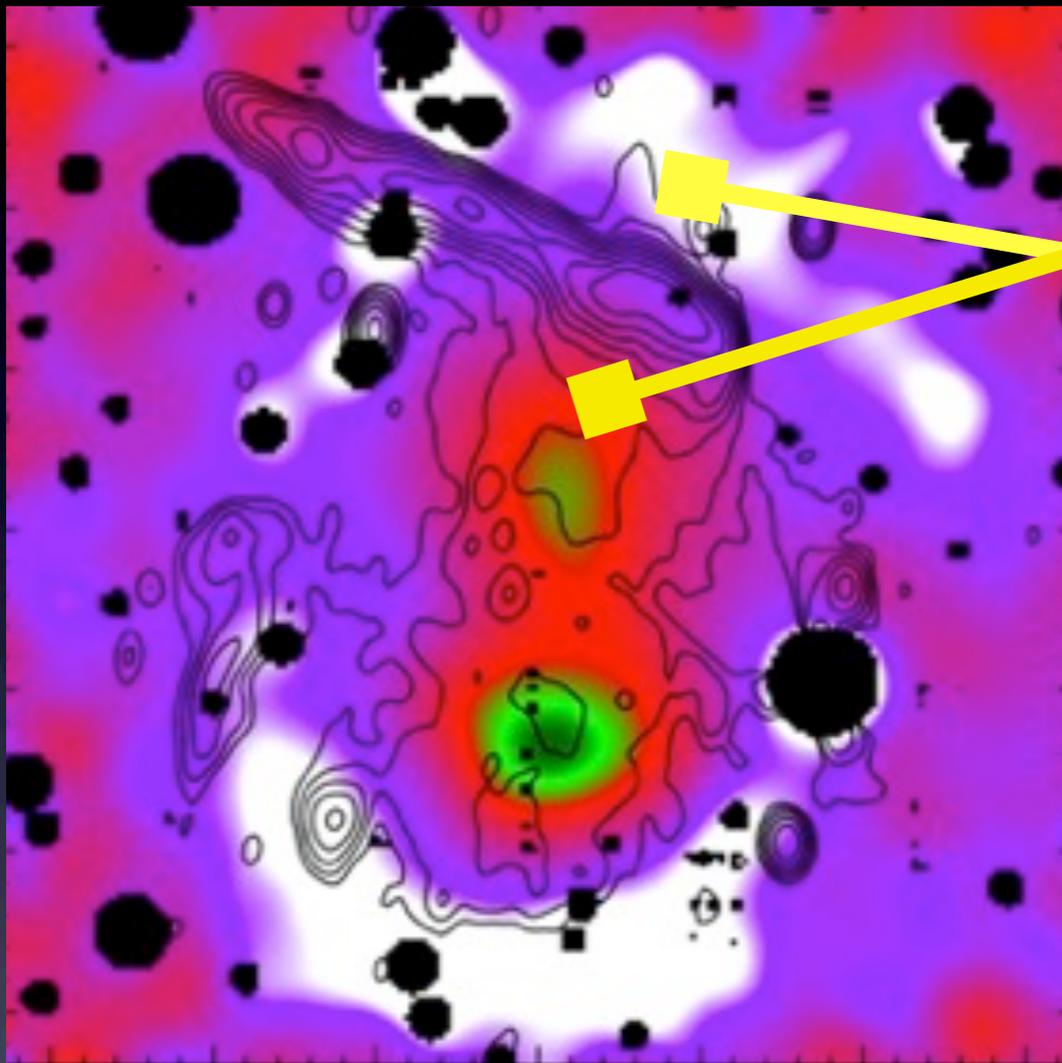
Ogreaan, Brüggan, van Weeren,
Röttgering, Hoeft, Croston 2013

Surface brightness profile along N



radio - X-ray shock inconsistencies?

Ogreaan et al. 2013

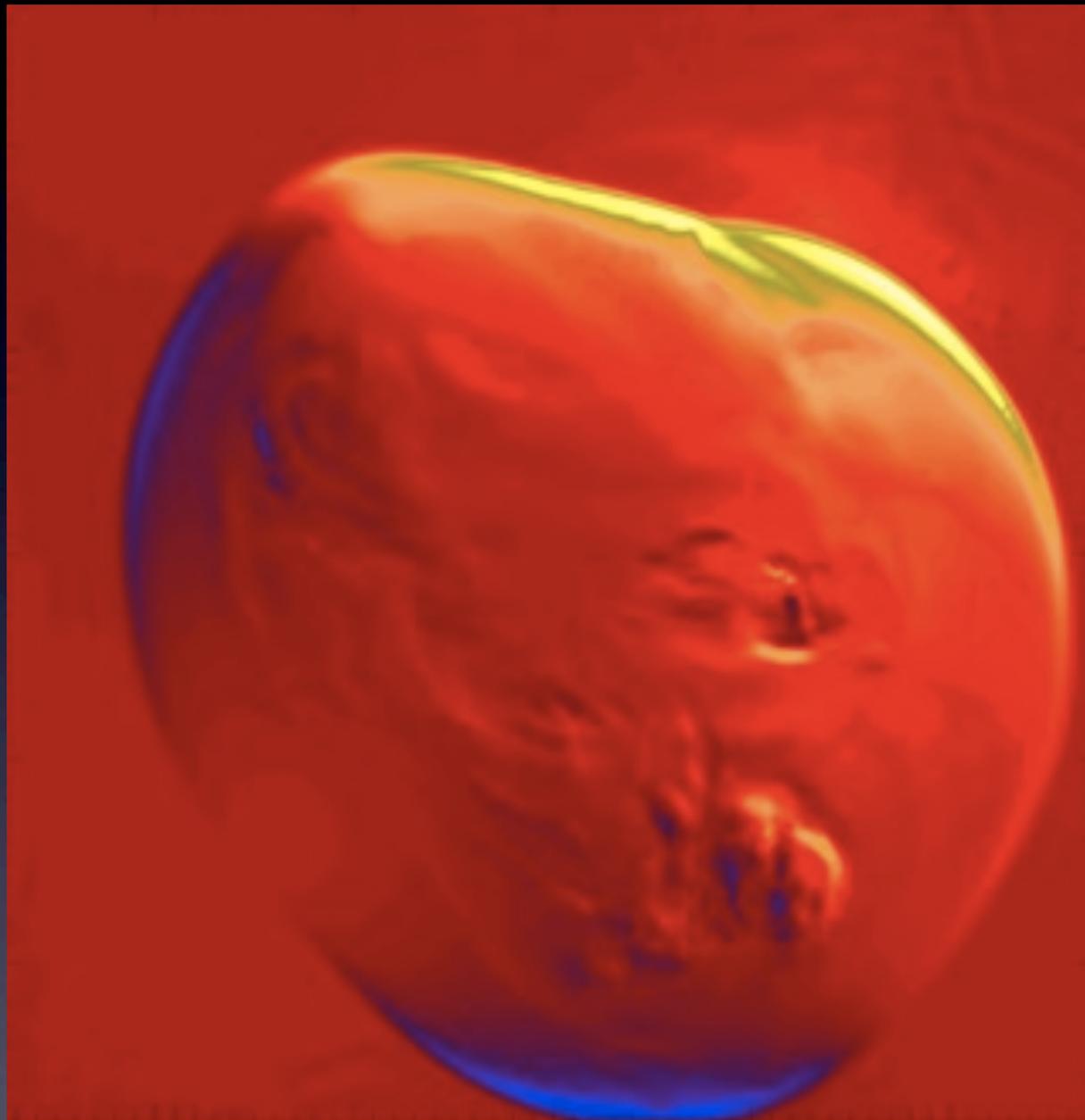


Unsharpened XMM (+ radio) image

- at the Toothbrush, indications that
- the shock $M < 2$, inconsistent with radio Mach number
- the “shock front” is, offset from the radio emission

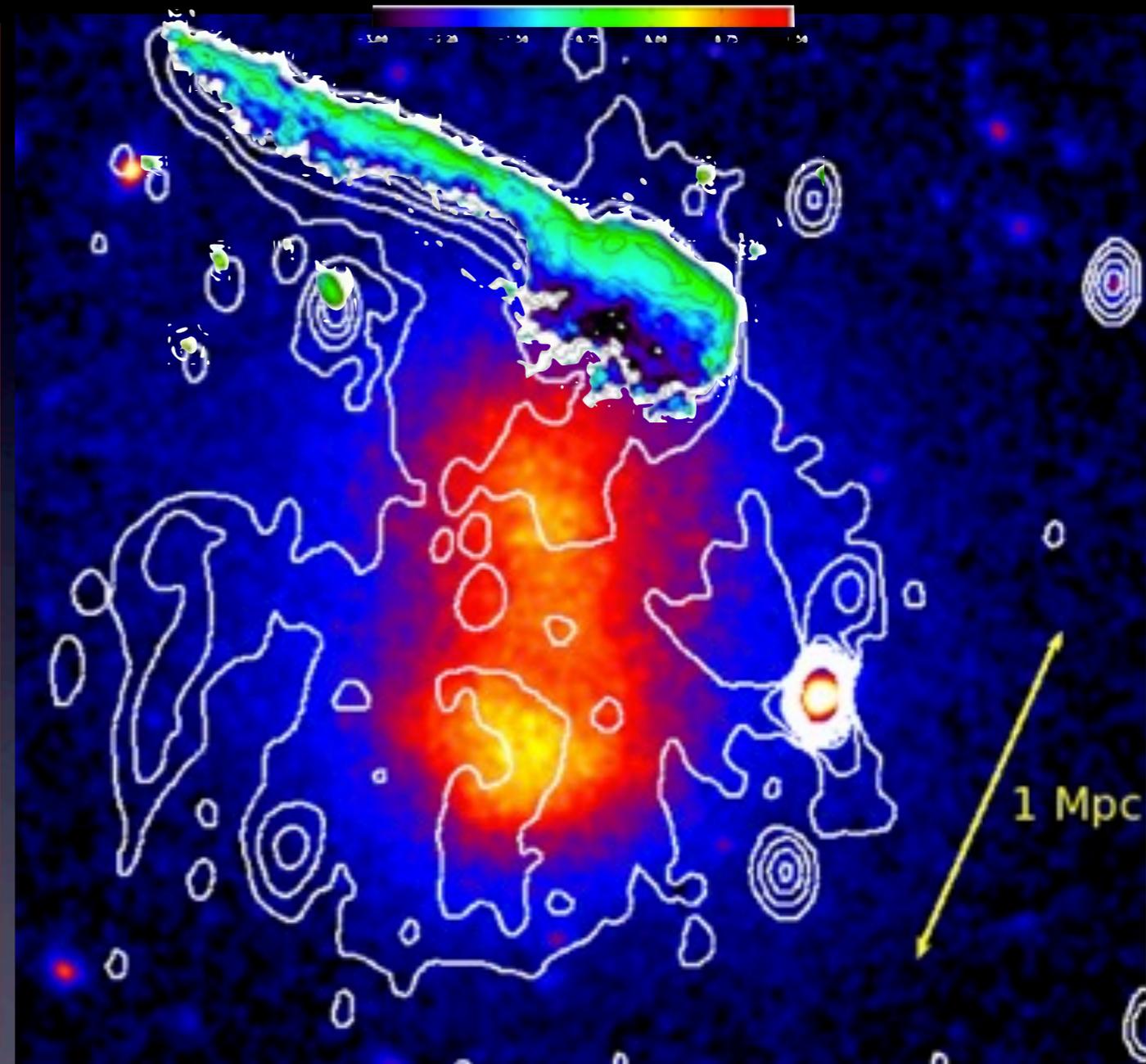
A triple merger might work

Bruggen, van Weeren, HR, 2012



Simulation:

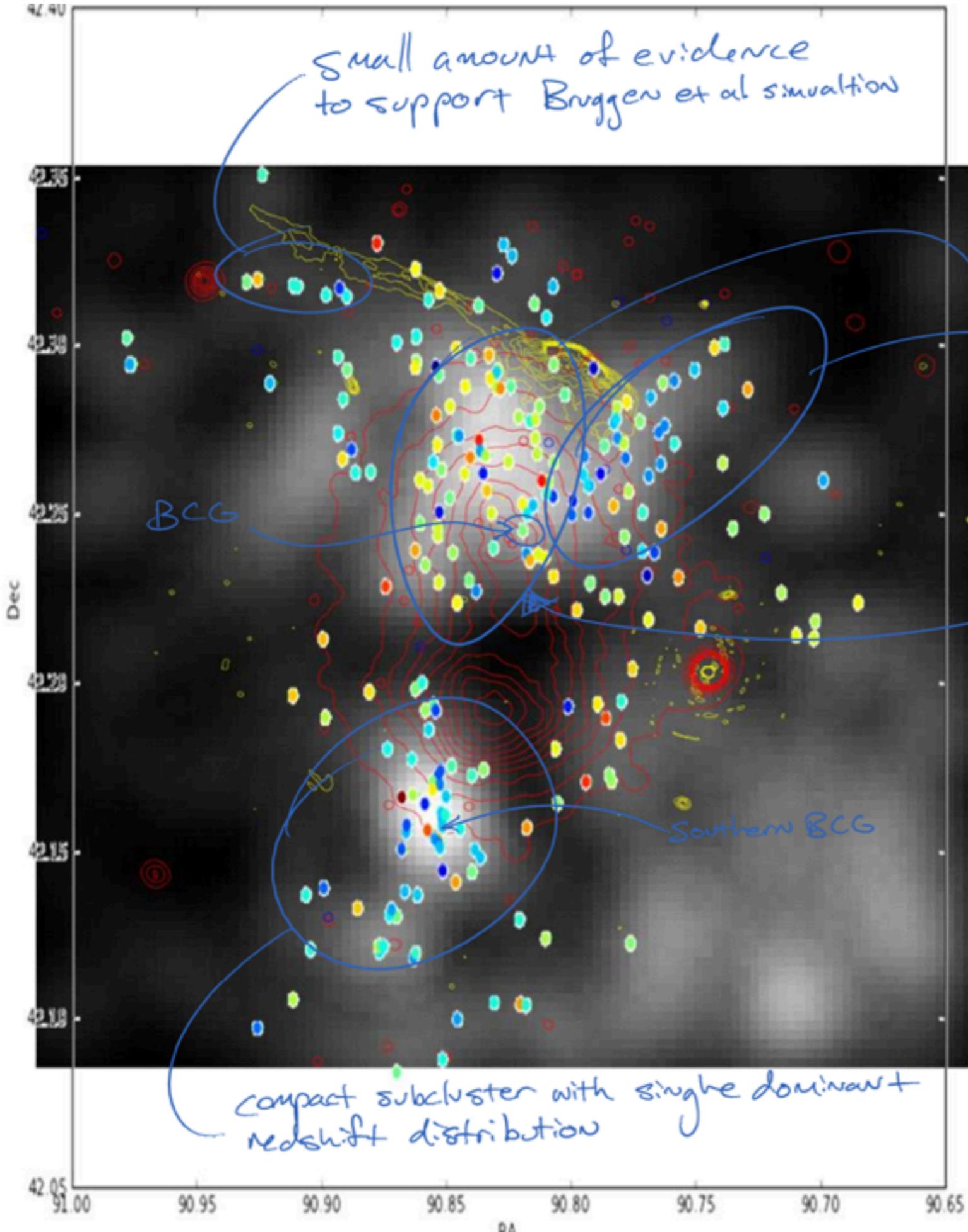
Projection of energy dissipated at the shock (at 3.5 Gyrs).



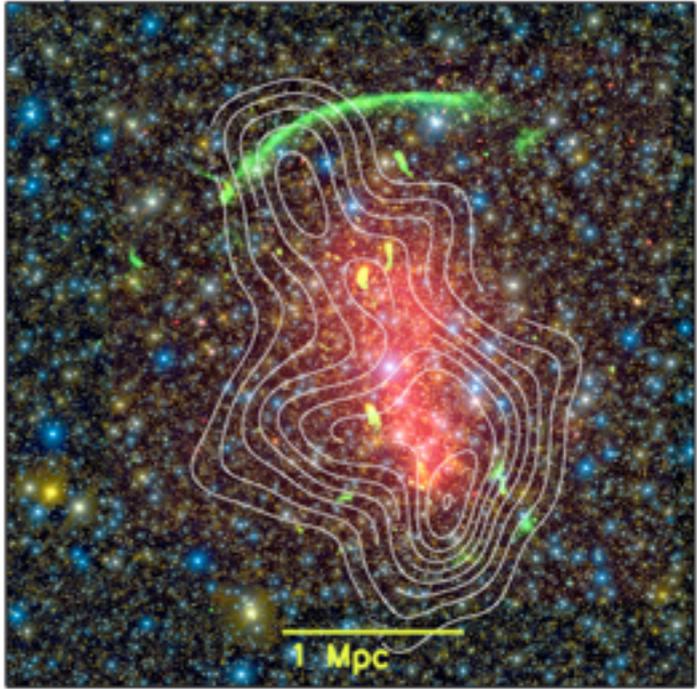
Observations:

X-ray+radio (total intensity plus spectral index at shock)

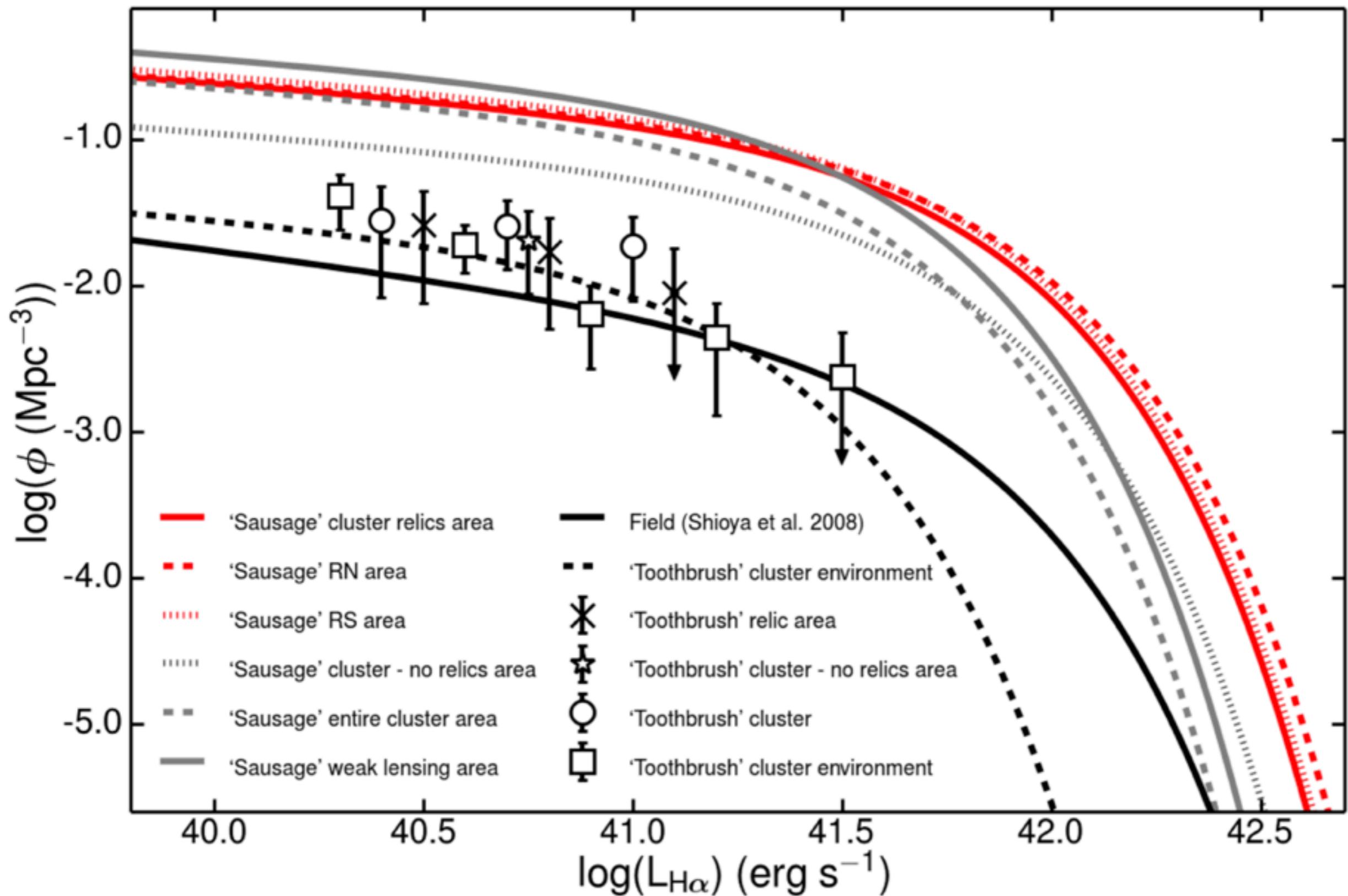
Keck-DEIMOS spectroscopy of the Toothbrush

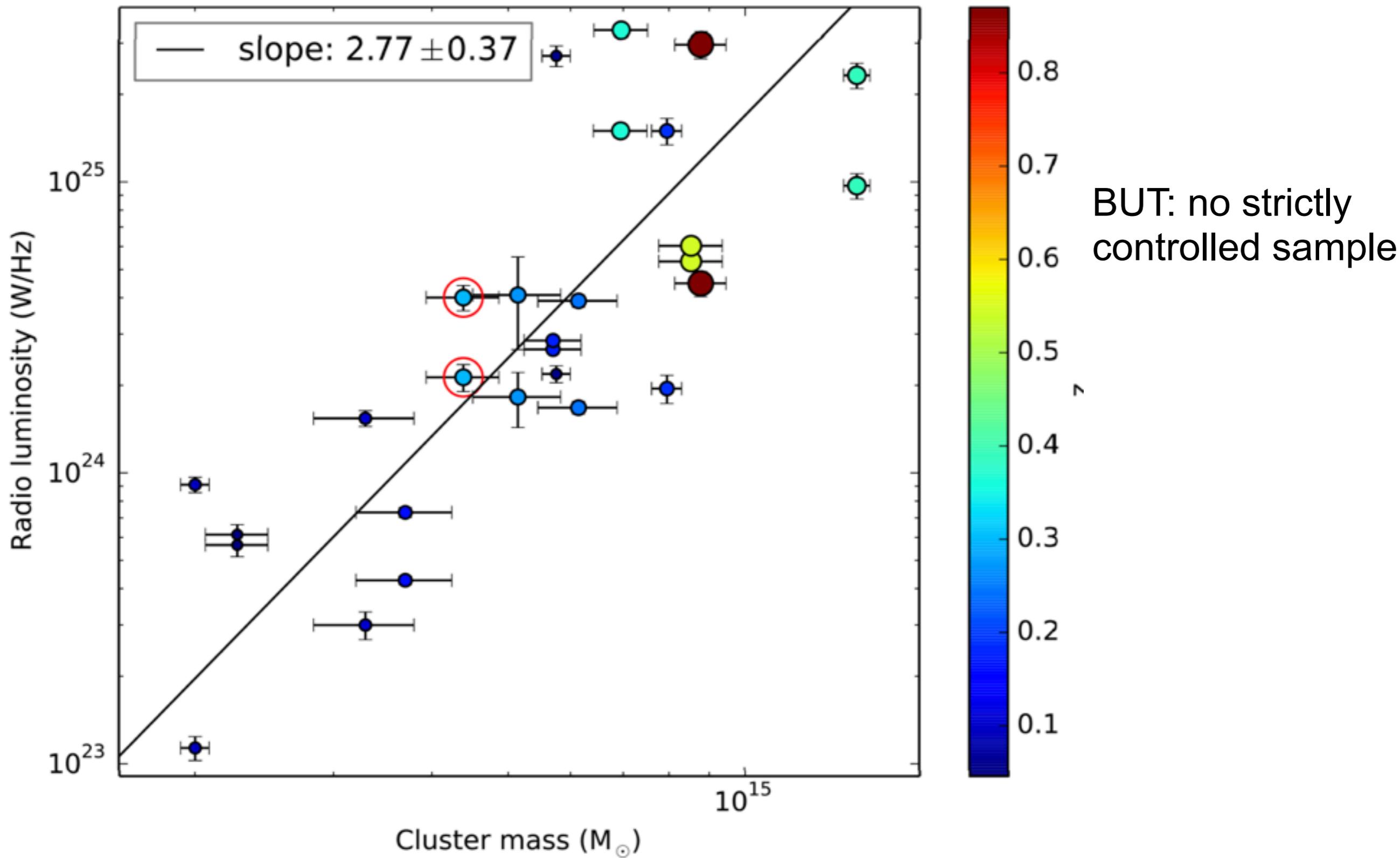


Based on X-ray + radio
I would say that this
redshift concentration
is most likely the one
associated with the
major merger



What about the galaxies in the merging clusters?

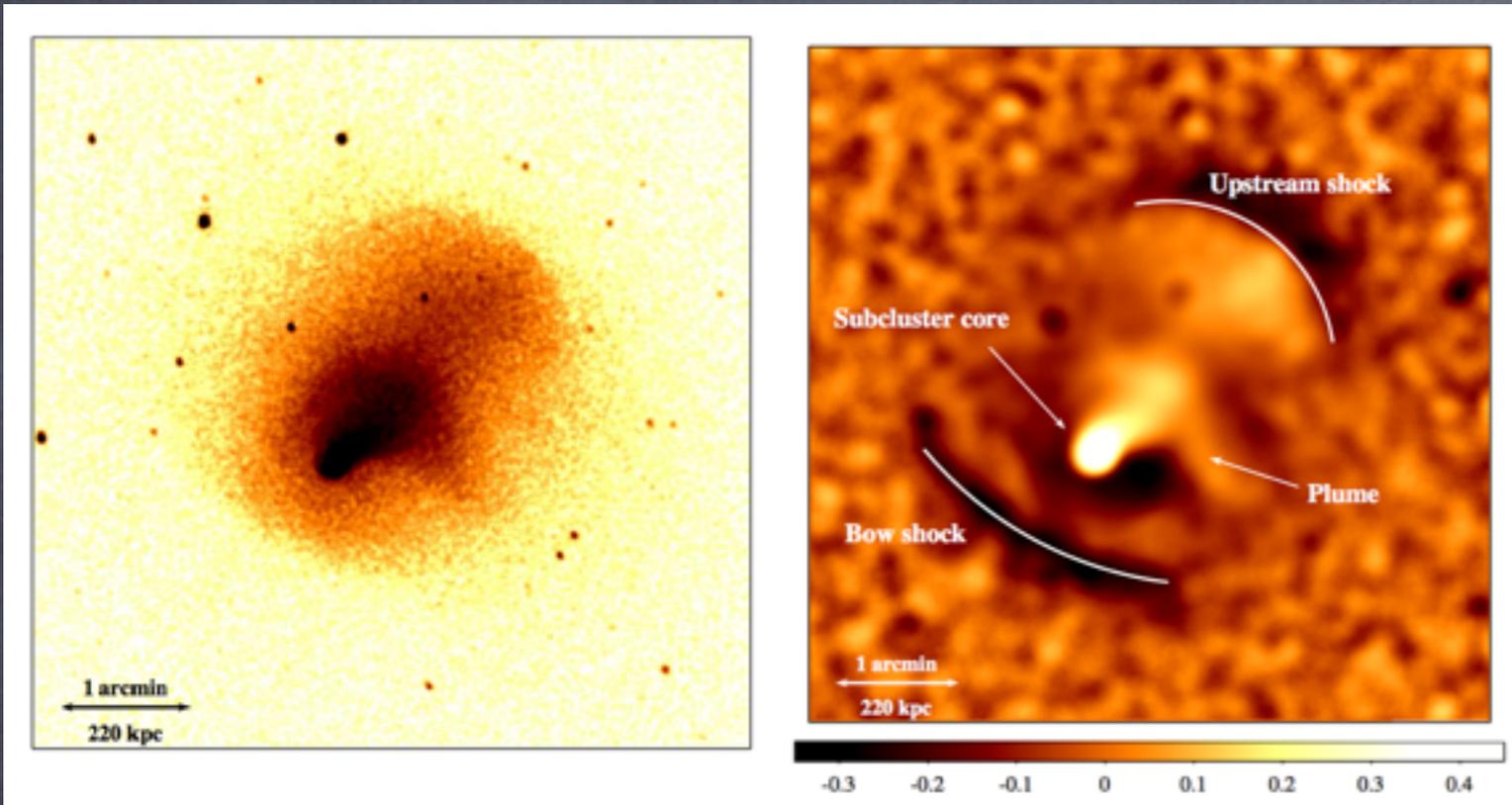




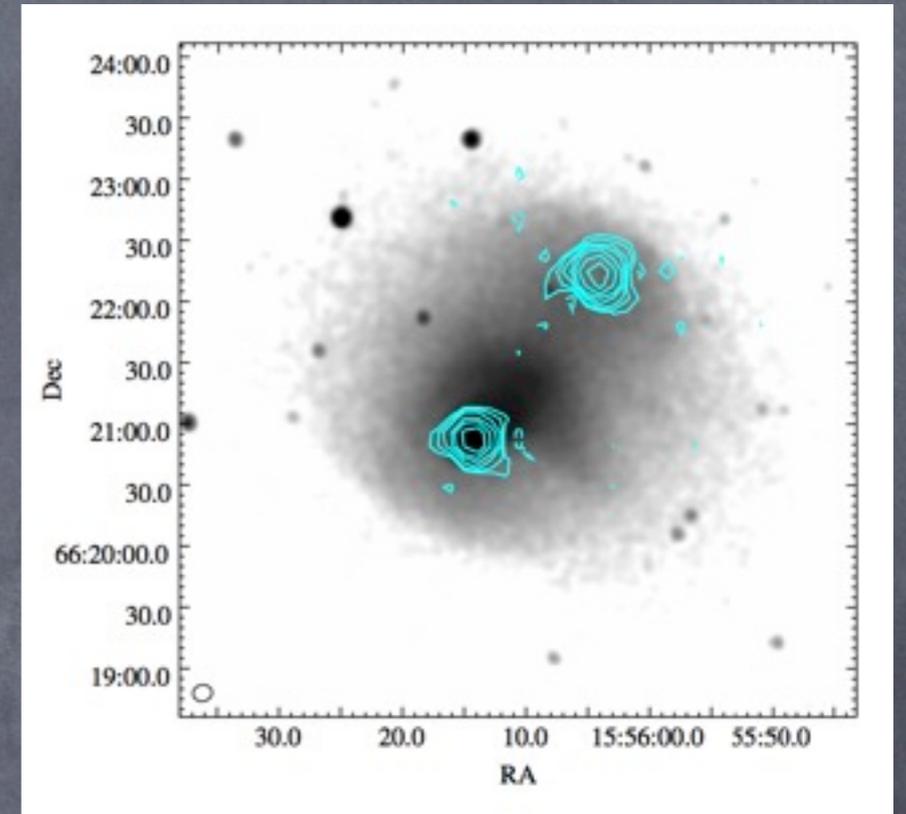
(a) Double radio relic systems

de Gasperin, van Weeren, MB, Vazza, Bonafede, Intema (just out)

Abell 2146 puzzle



Chandra 0.3–7.0 keV, Russell et al. 2011



GMRT 325 MHz

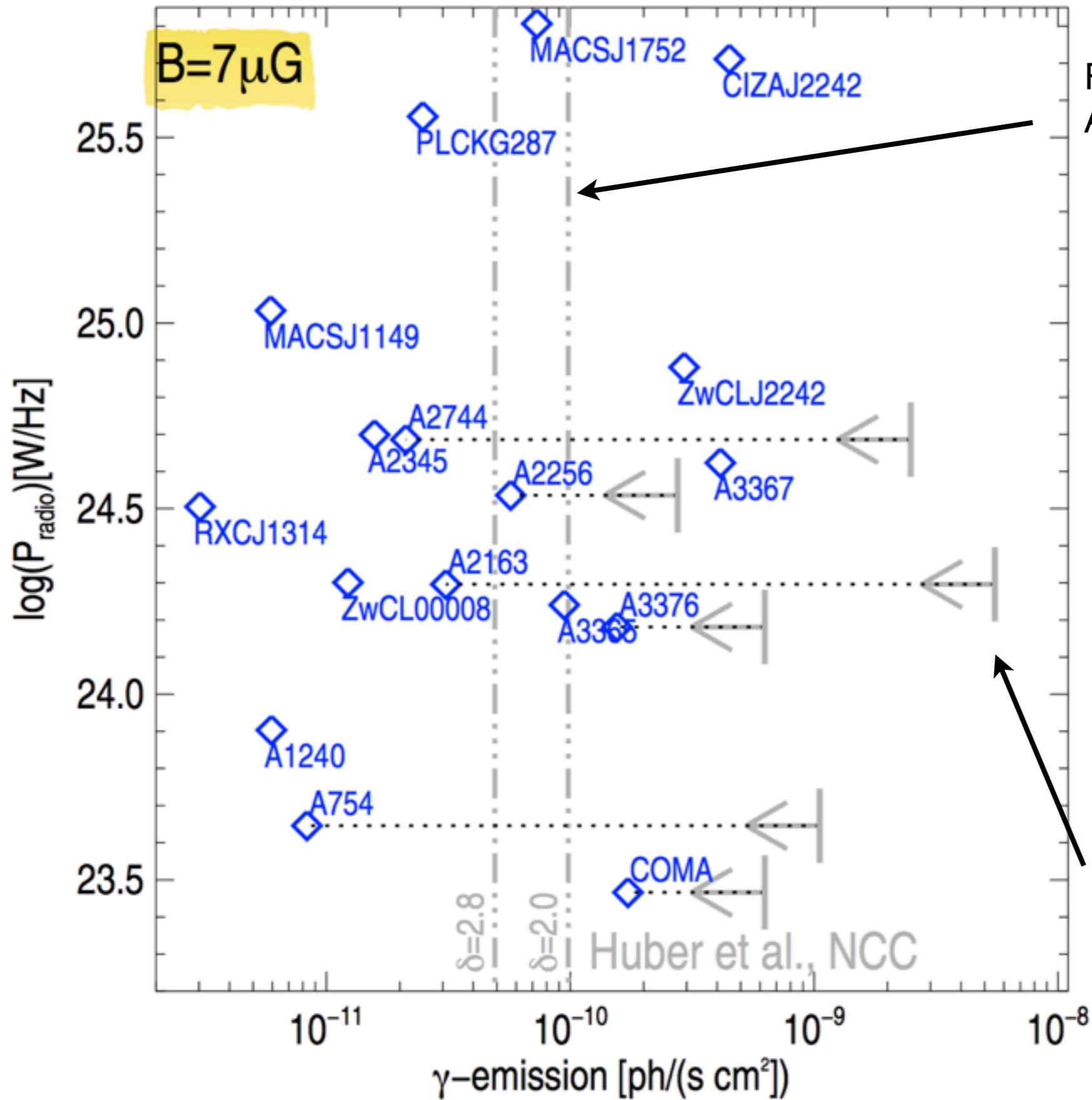
Mach numbers:

$$M = 2.1 \pm 0.2$$

$$M = 1.6 \pm 0.1$$

Why do we not observe radio emission from these shocks?

Where are the protons?



Fermi-upper limits (stacked)
Ackermann et al (2013)

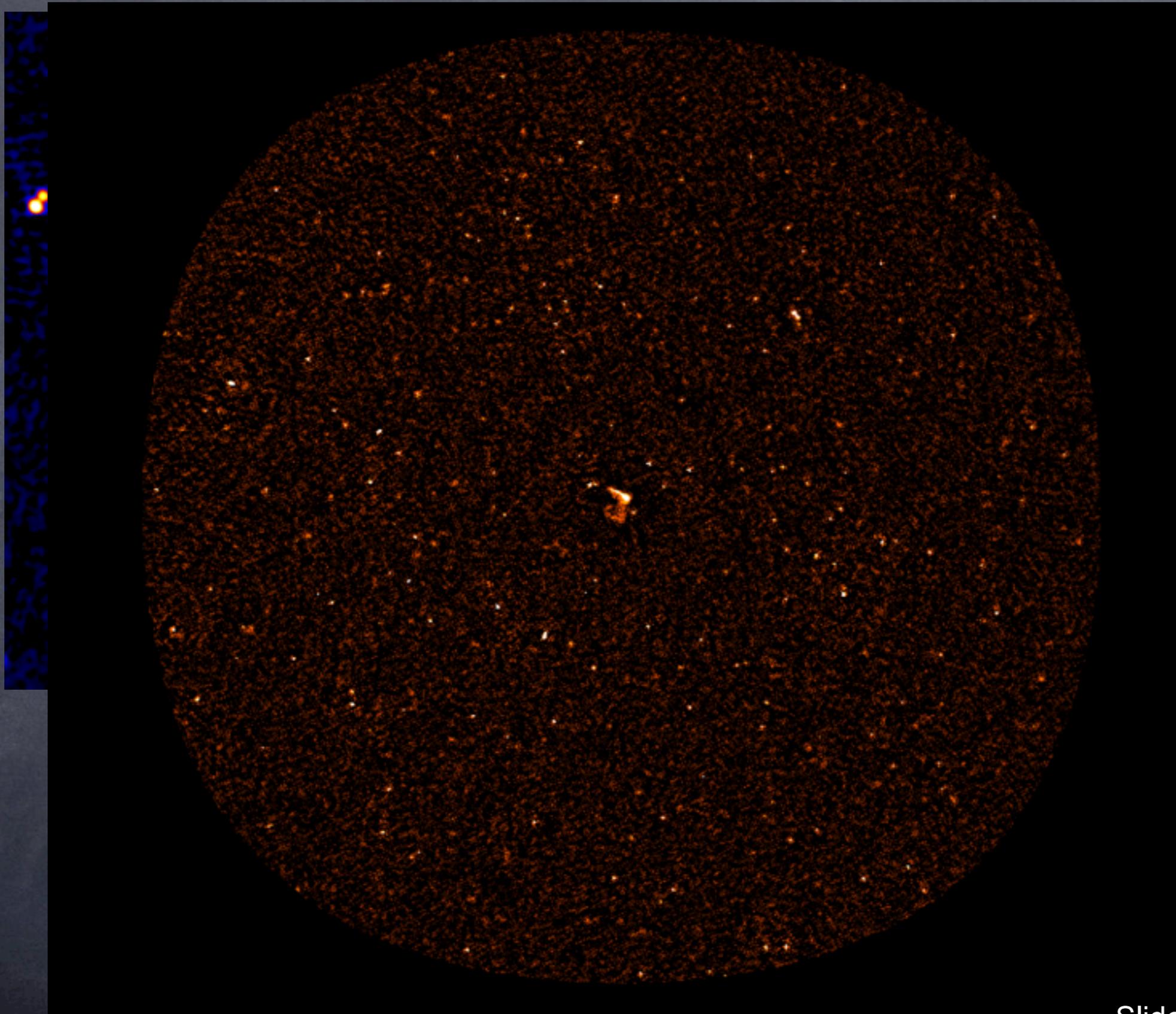
Vazza & Brügger (2013)

Fermi-upper limits

Huber et al., NCC



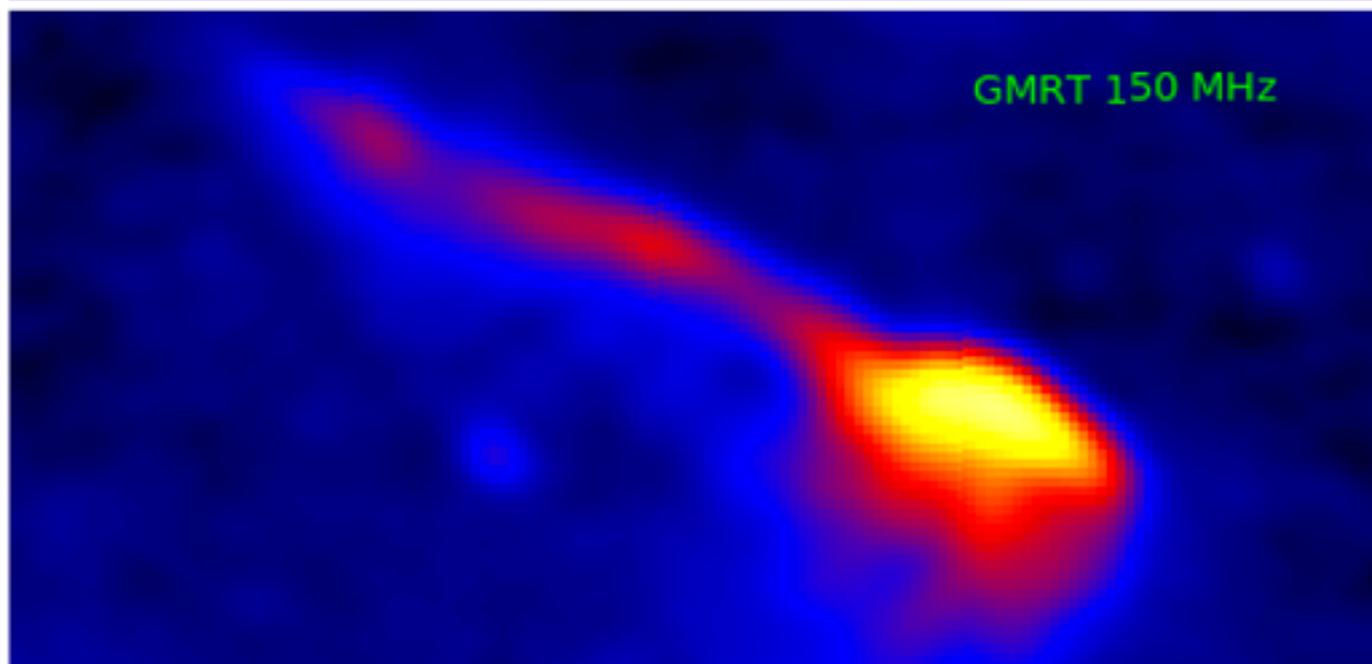
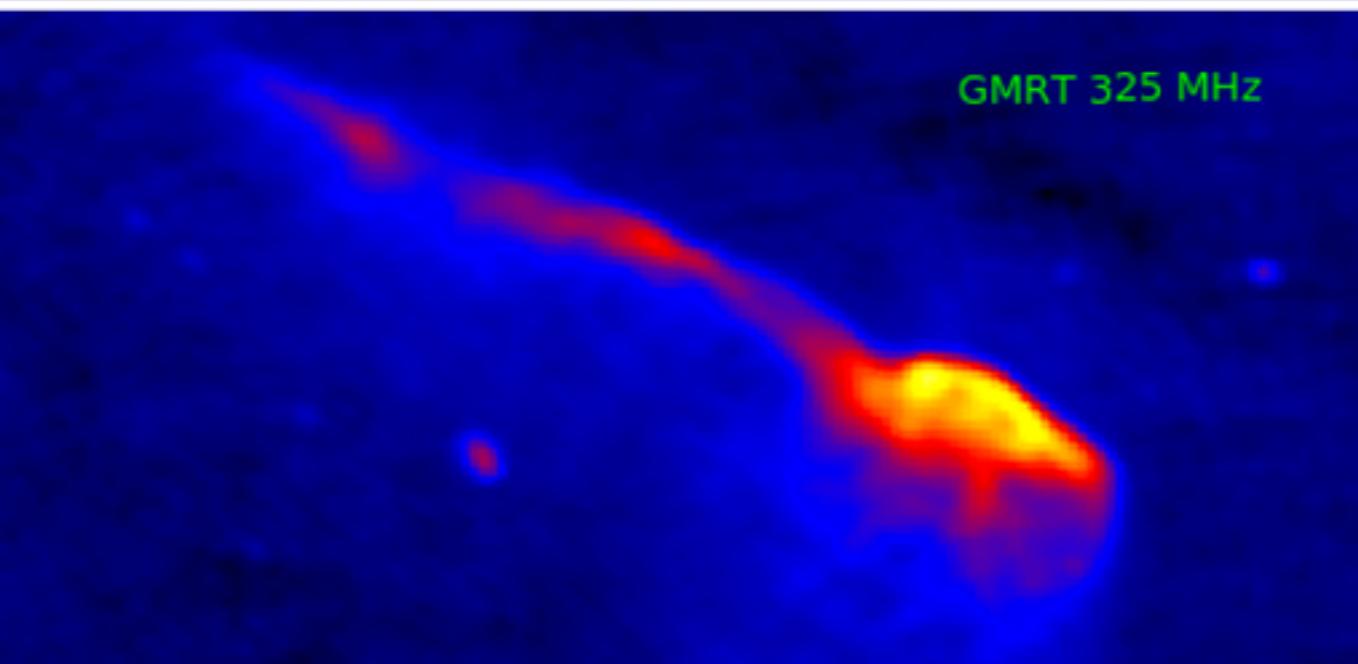
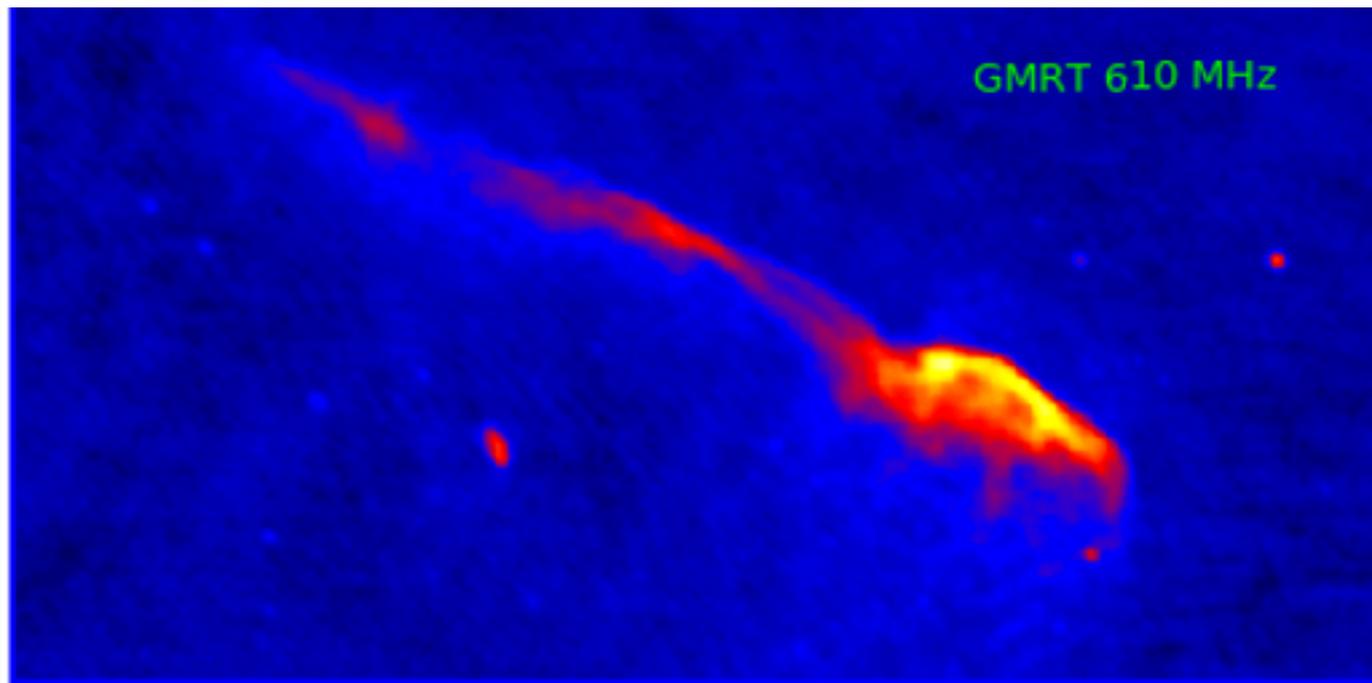
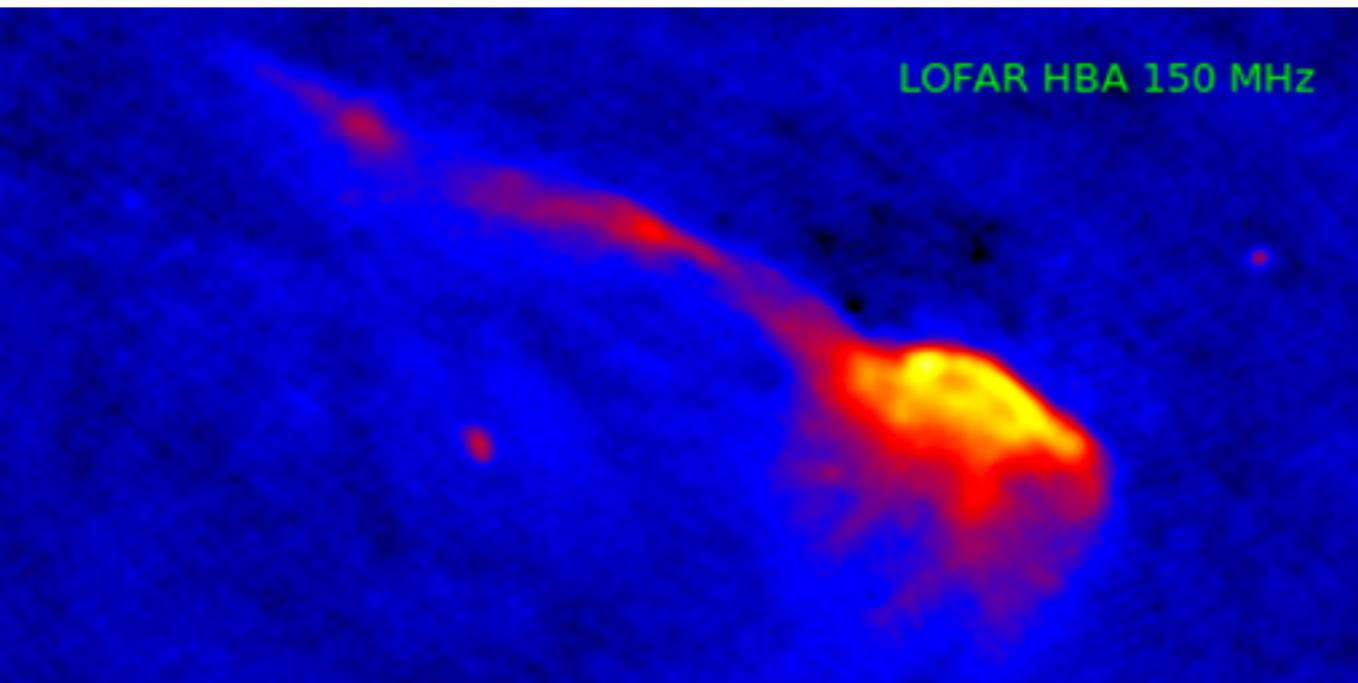
LOFAR



able

Slide from Reinout

LOFAR observations of the sausage



Take-home messages

1. In some merging clusters, no radio emission at weak shocks is found
2. The shock front is not always co-located with the relic
3. Some relic spectra are too shallow for DSA
4. In some cases X-ray and radio-inferred Mach numbers do not match
5. Relic power scales strongly with cluster mass
6. Just behind clusters, H α emission might be boosted
7. No gamma-rays detected

Thank you!