Shocking News from Galaxy Clusters

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MERGING CLUSTER COLLABORATION

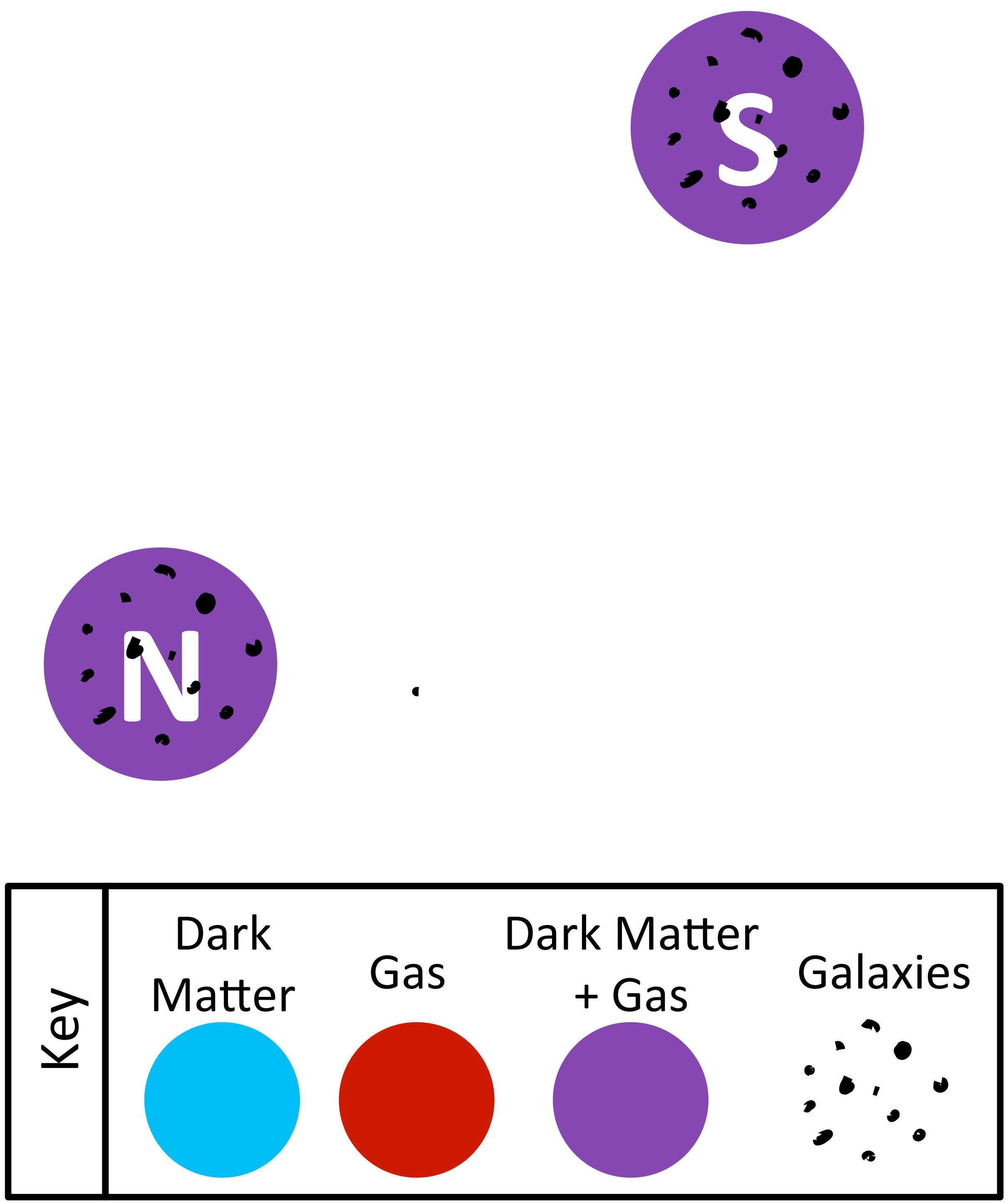
What can mergers between galaxy clusters teach us about:

1. Particle acceleration (and generation of B fields)?

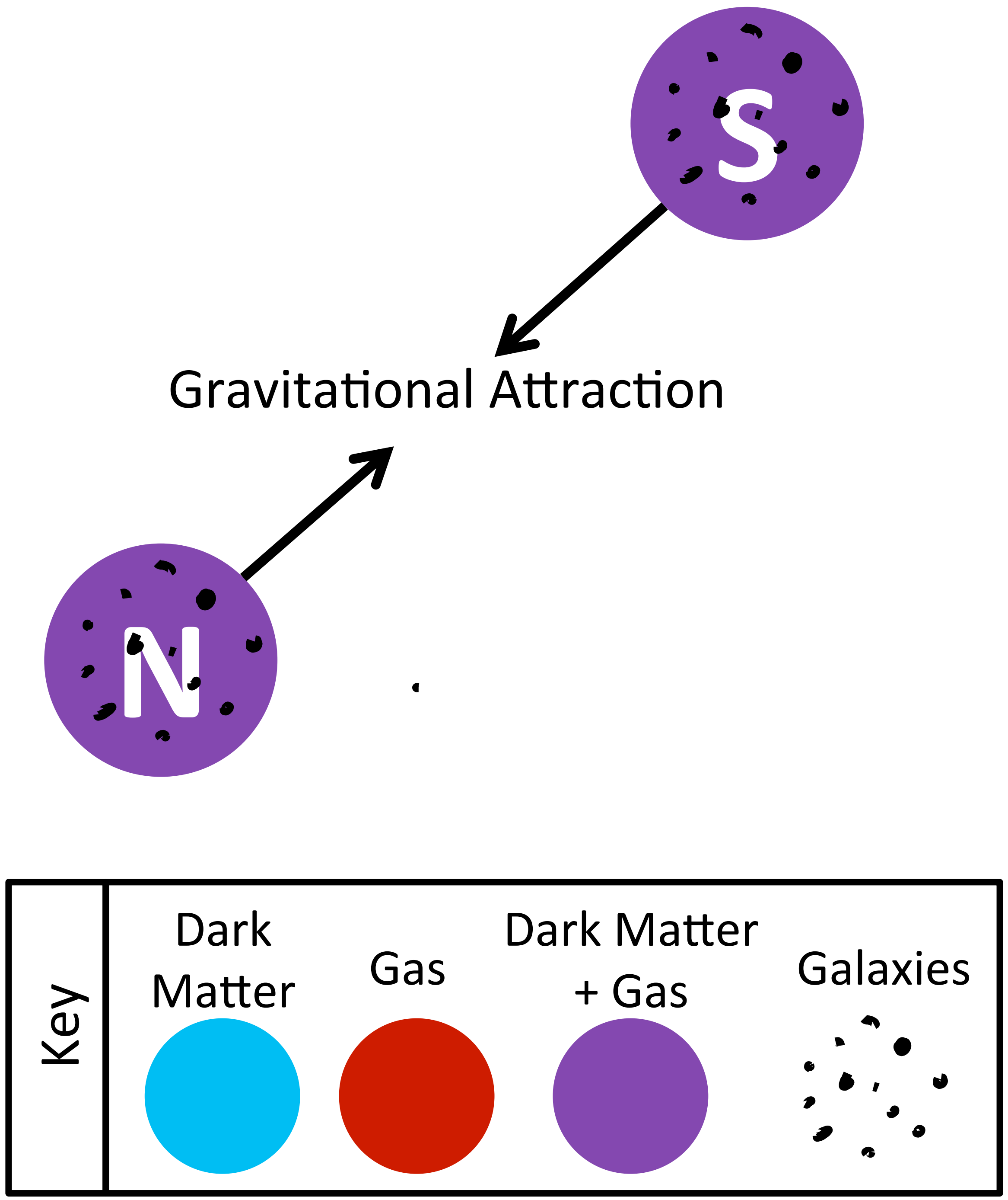
2. The nature of Dark Matter?

3. Galaxy Evolution?

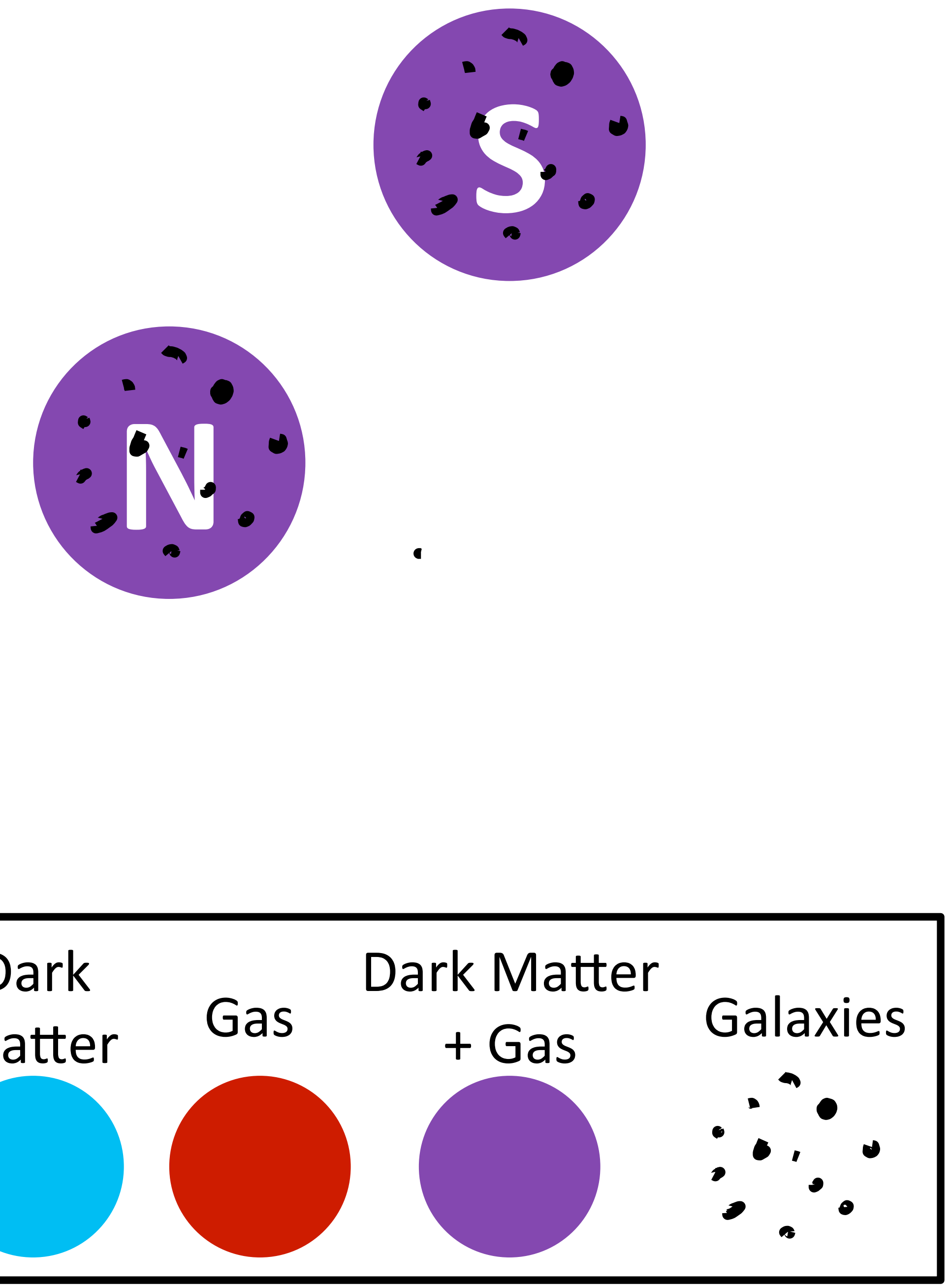
Merger Scenario



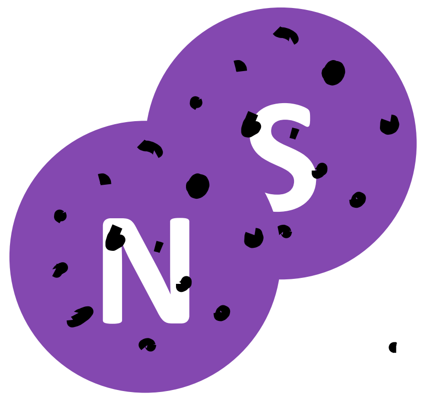
Merger Scenario

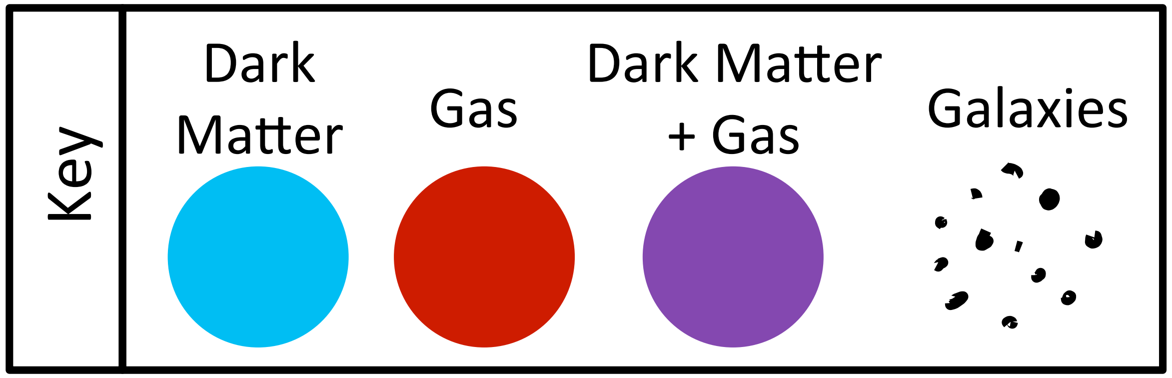


Merger Scenario

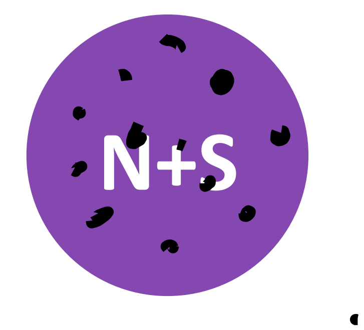


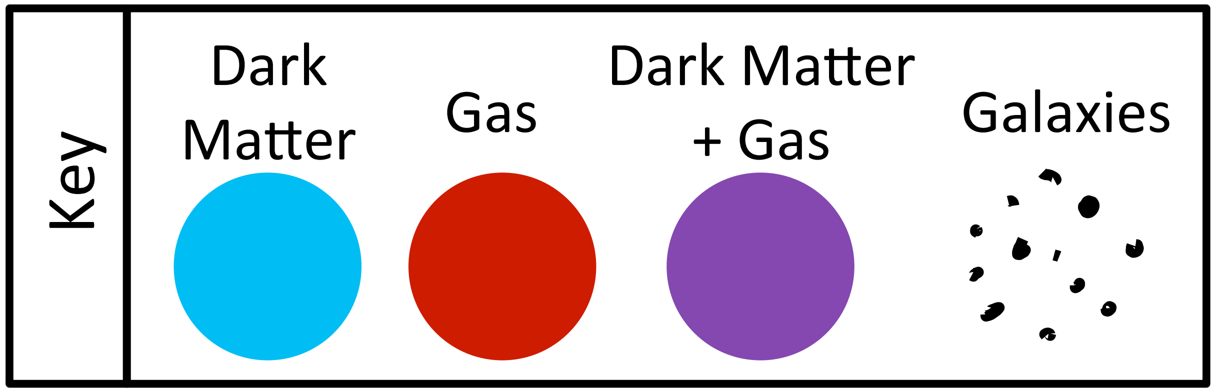
Merger Scenario



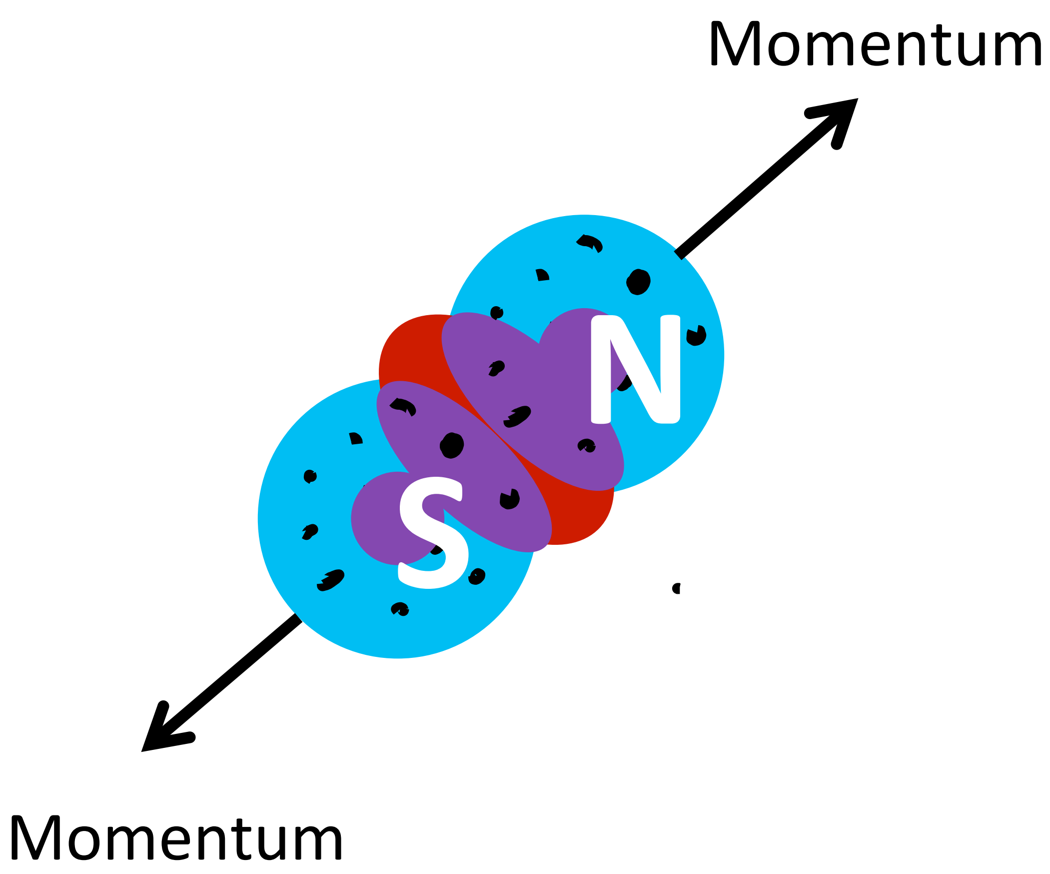


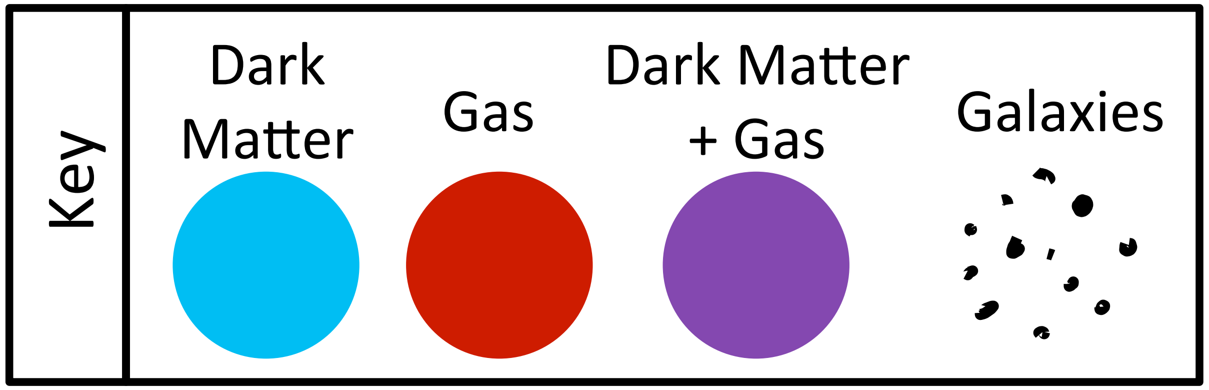
Merger Scenario



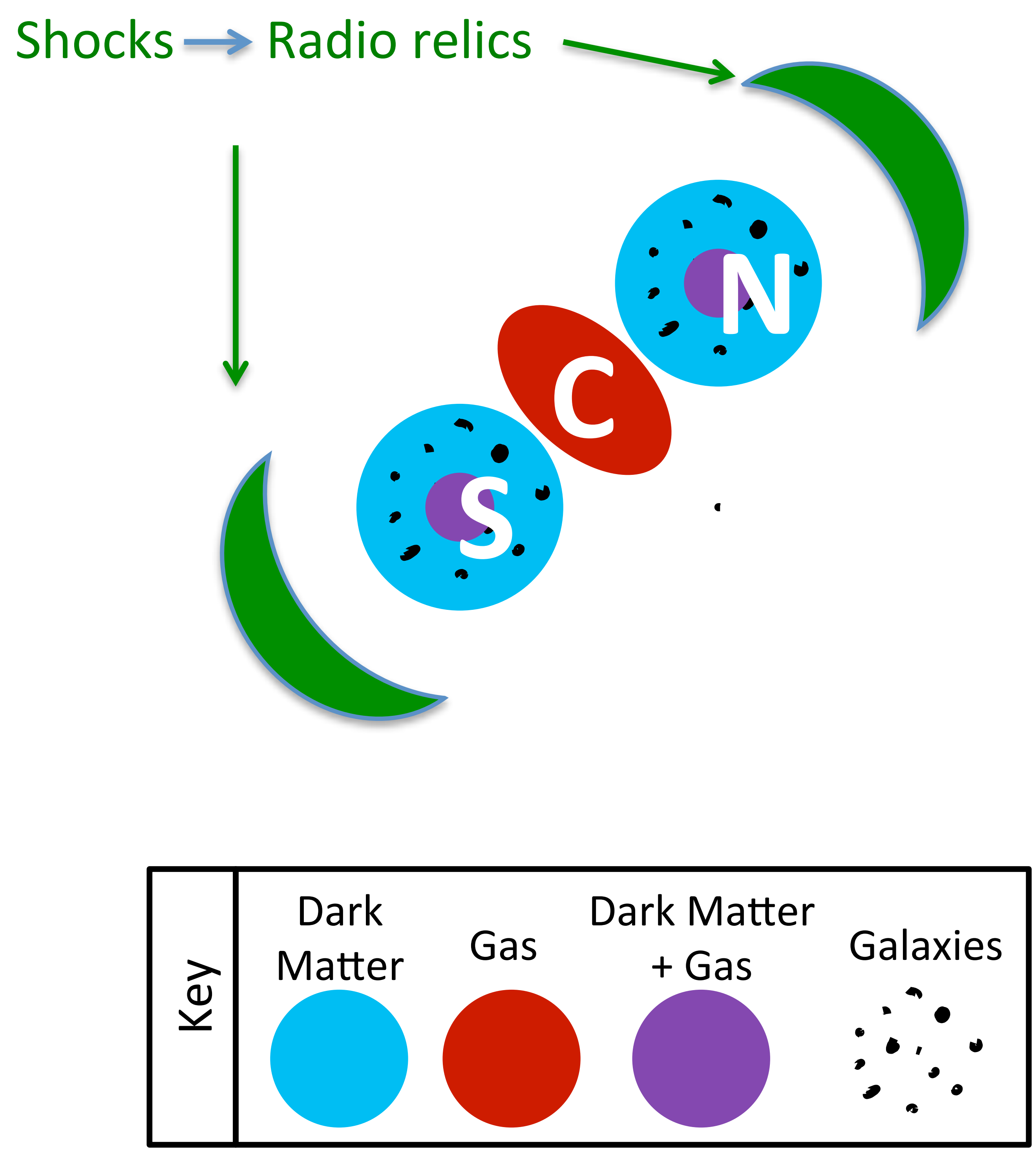


Merger Scenario

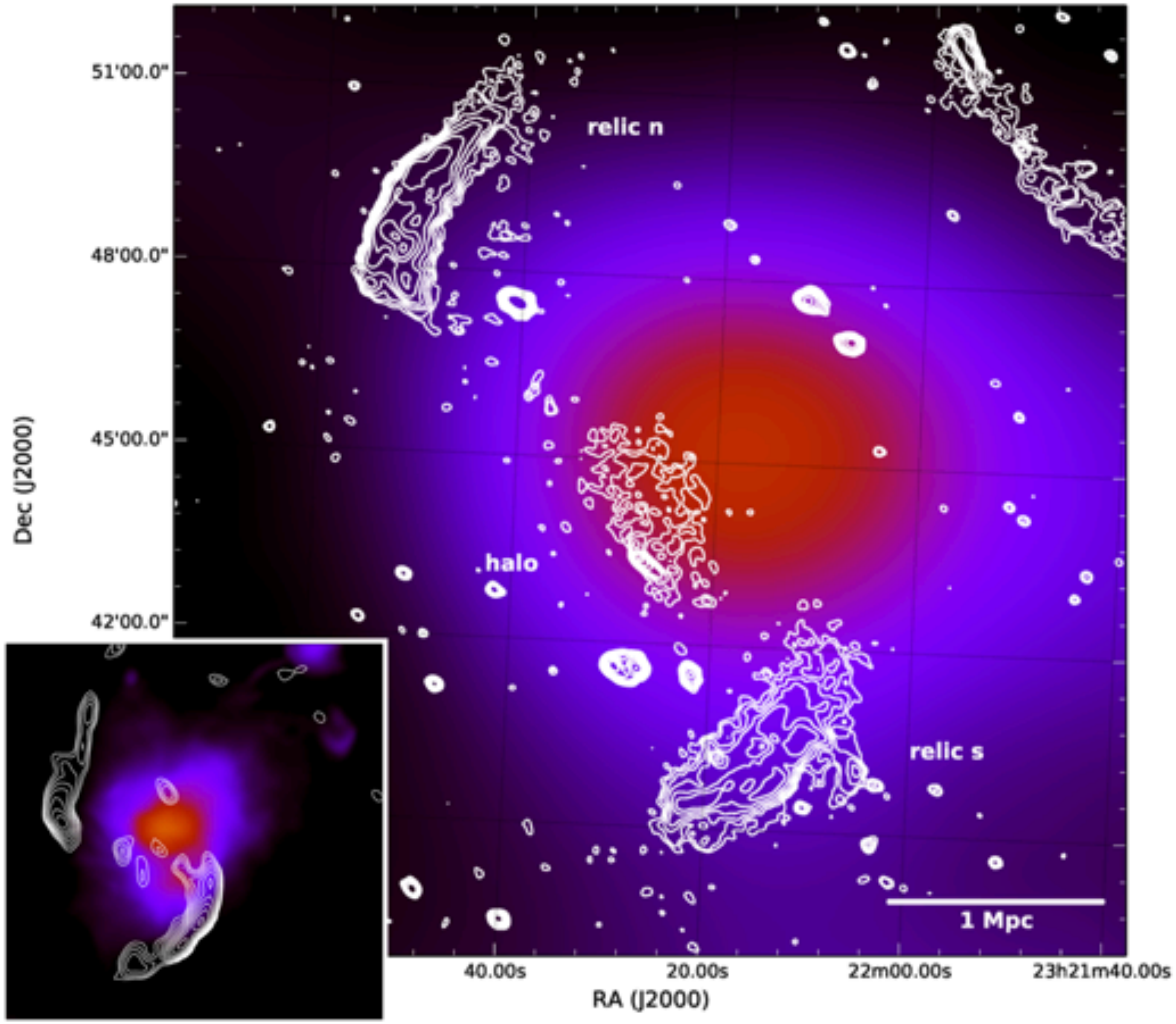




Merger Scenario



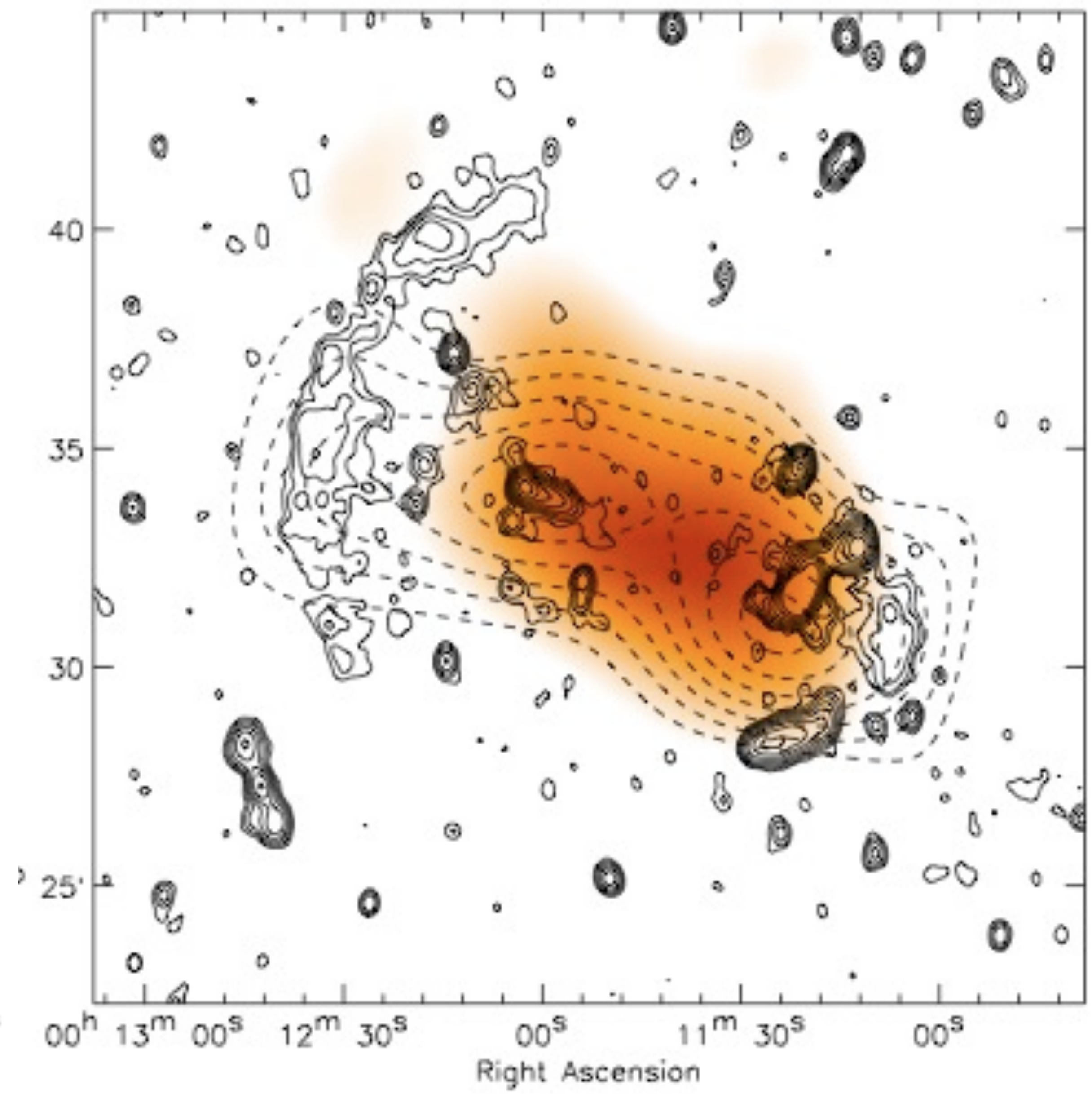
What are radio relics?



PSZ1 G108.18-11.53

colour: X-ray
contours: radio

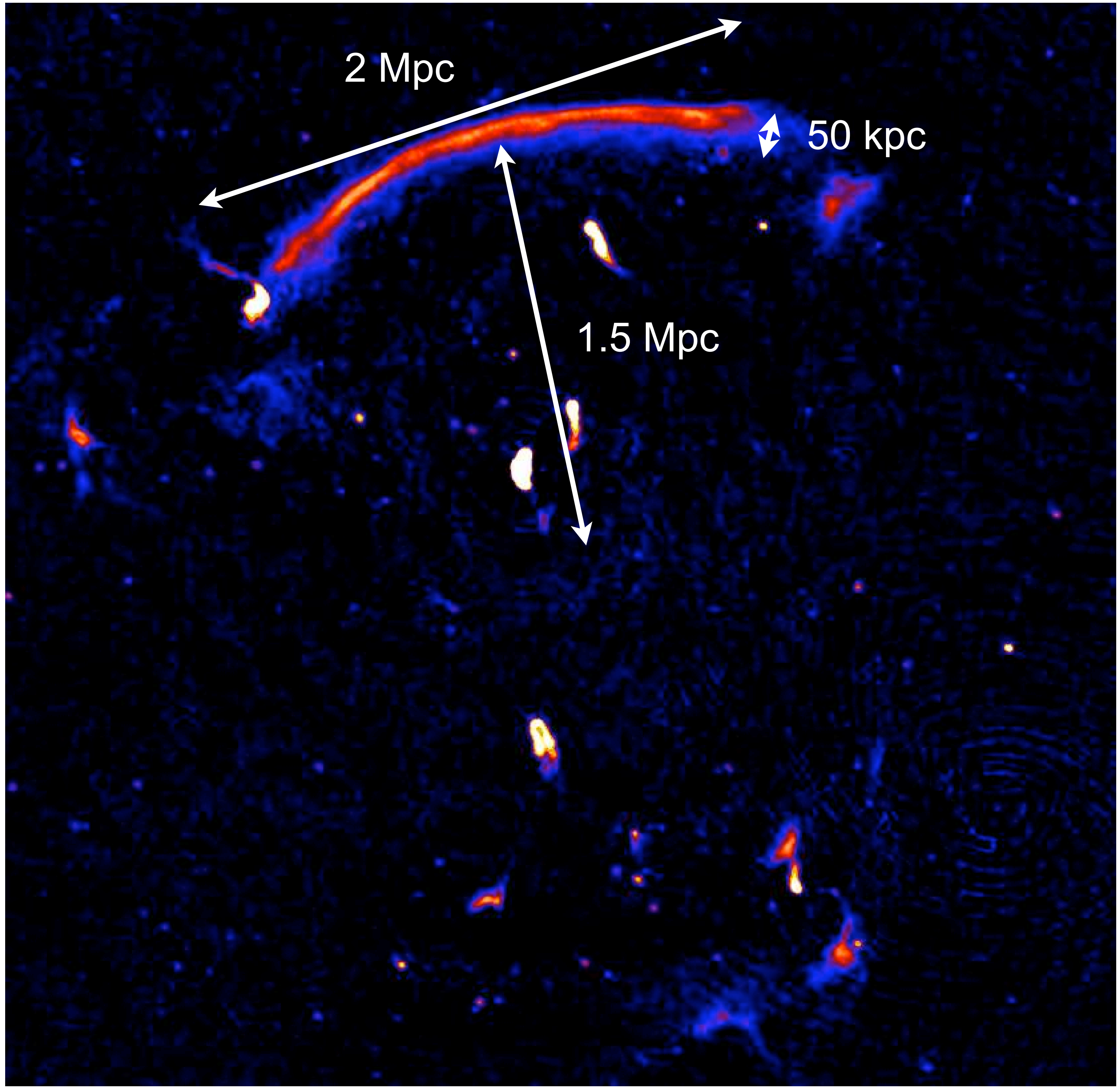
De Gasperin 14



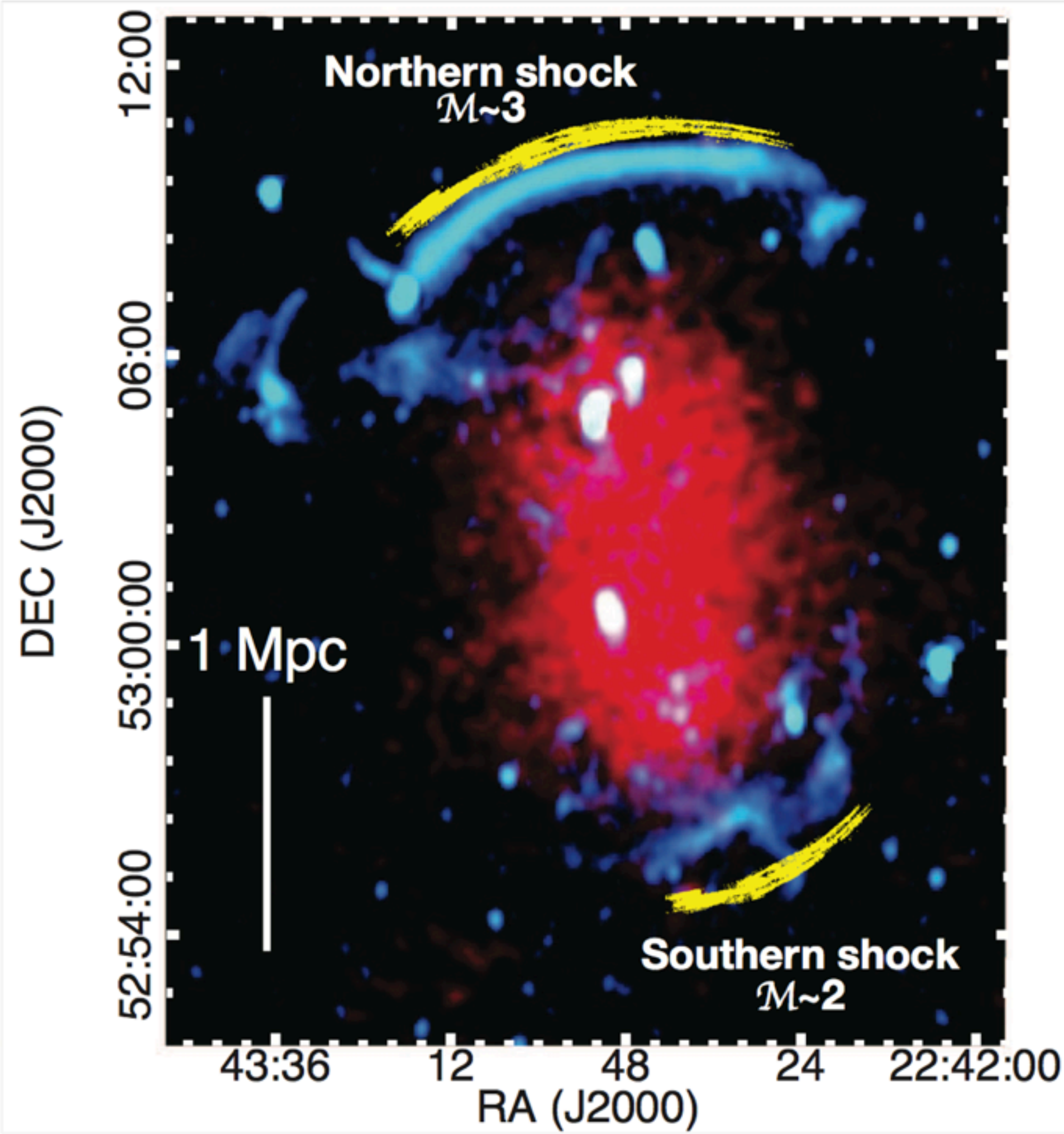
ZwCl 0008.8+5215
van Weeren et al. 11

The sausage: CIZA J2242.8+5301

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

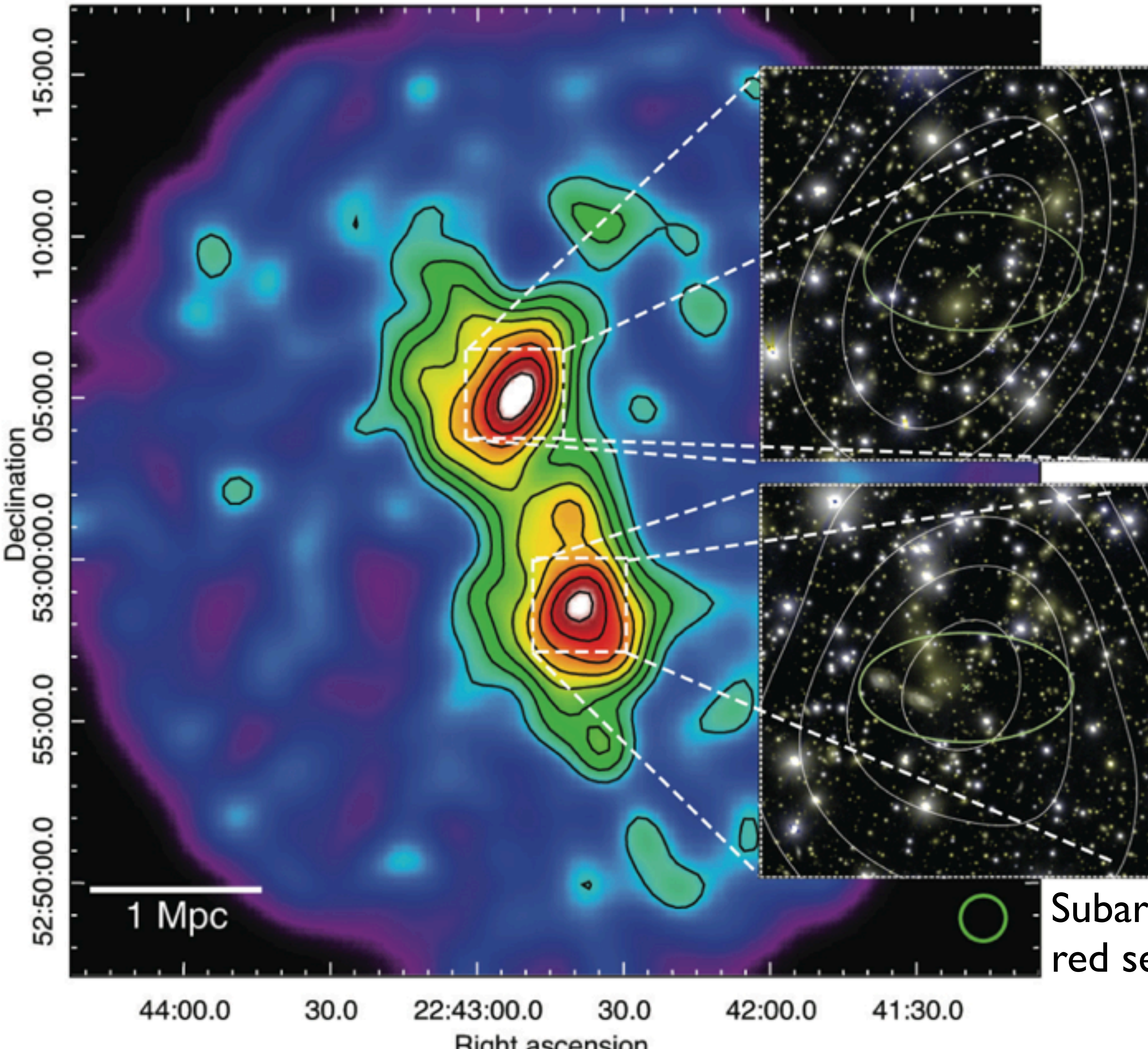


GMRT 610 MHz, resolution of 4.8 arcsec×3.9 arcsec.
total on source time 9 hrs, bandwidth of 32 MHz.



Akamatsu, van Weeren, Kawahara, Röttgering, MB, Hoeft, Sobral, Ogrean, Kaastra 2014

Smoothed galaxy luminosity density map of CIZA



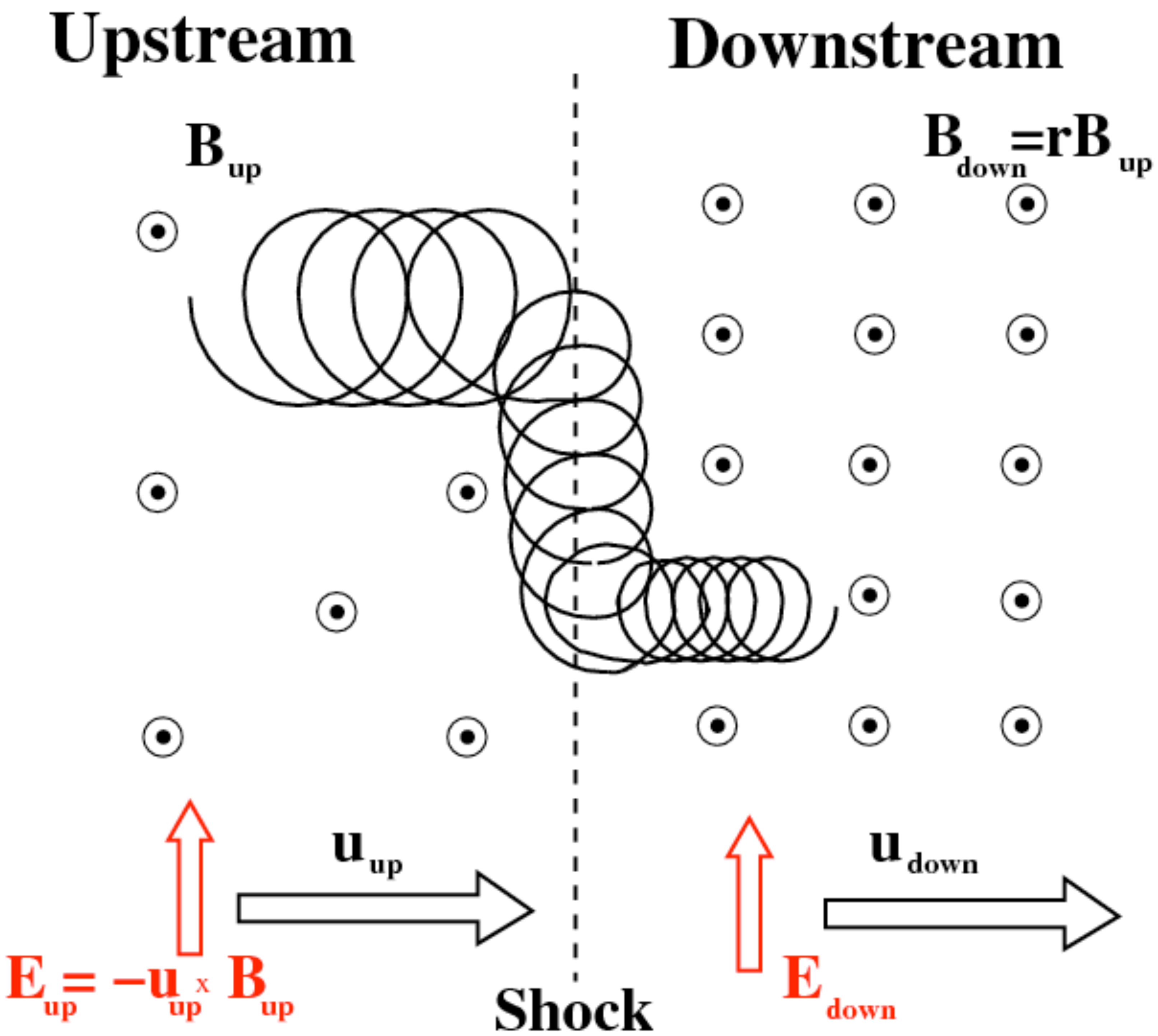
Subaru data
red sequence selection

Dawson et al. 2014

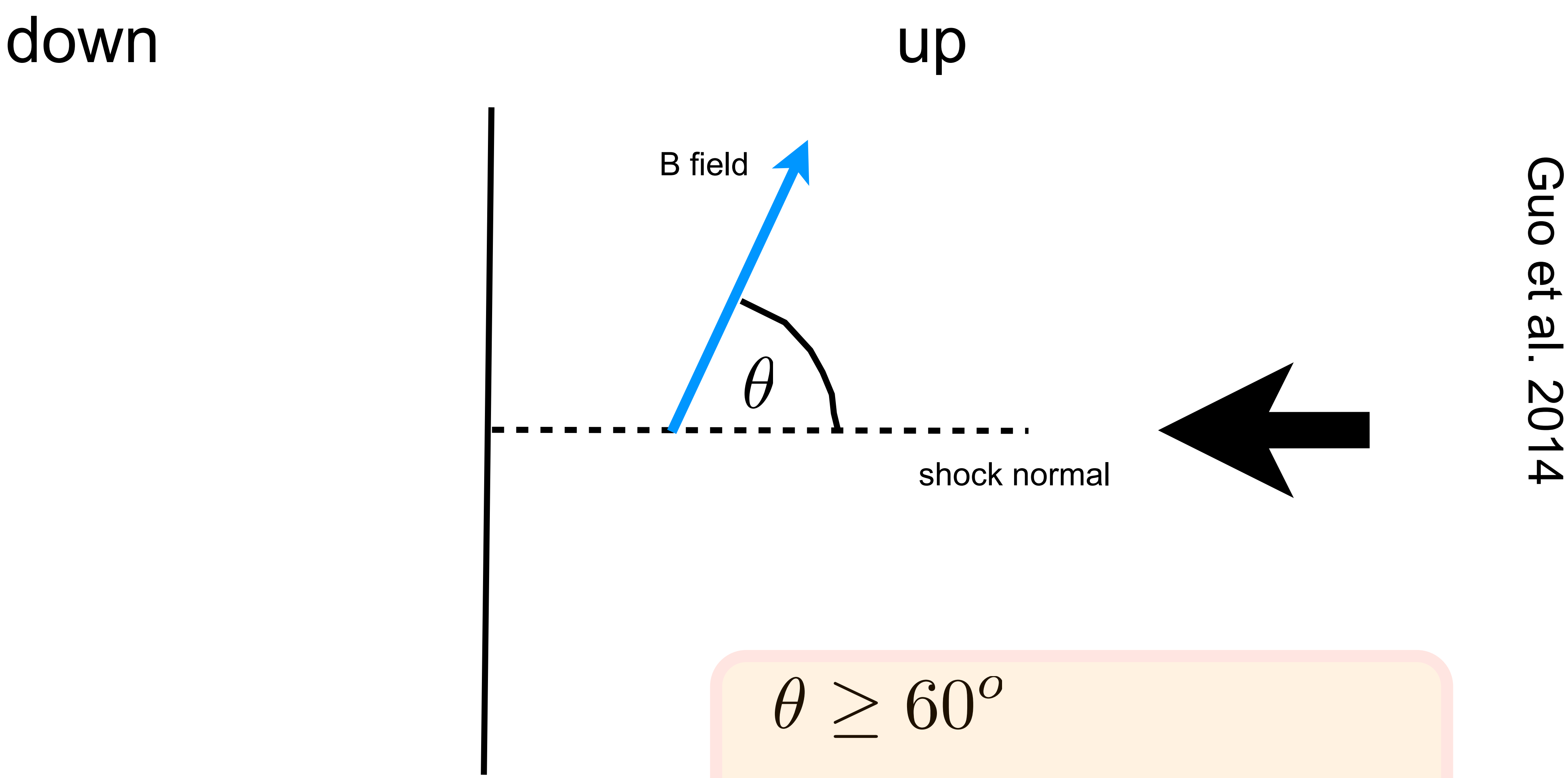
1

Problem #1: Efficient electron acceleration at low Mach numbers

Shock-Drift Acceleration



Shock-Drift Acceleration



Need:

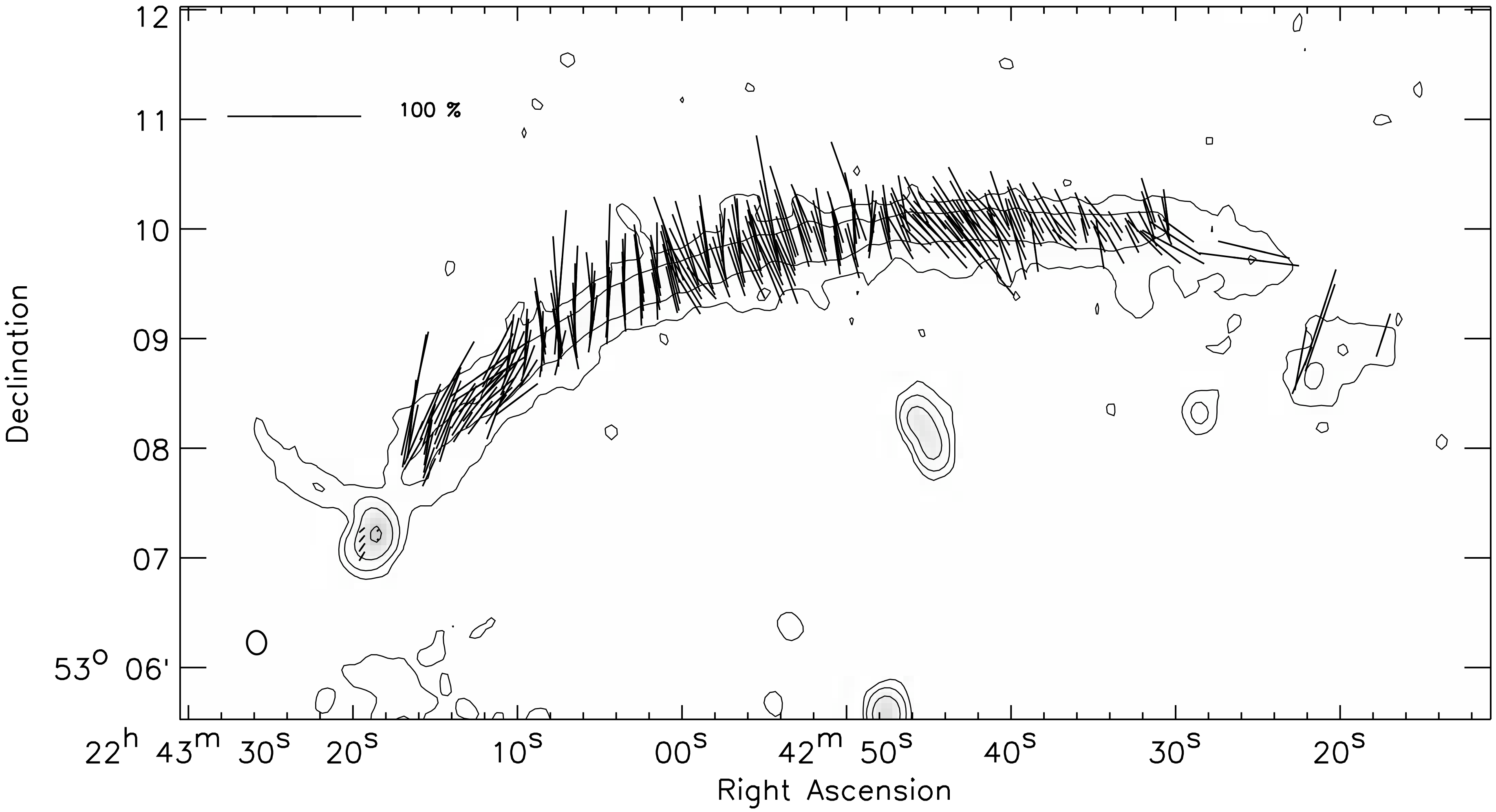
$$\theta \geq 60^o$$

$$M_s \leq 6$$

$$\beta \geq 20$$

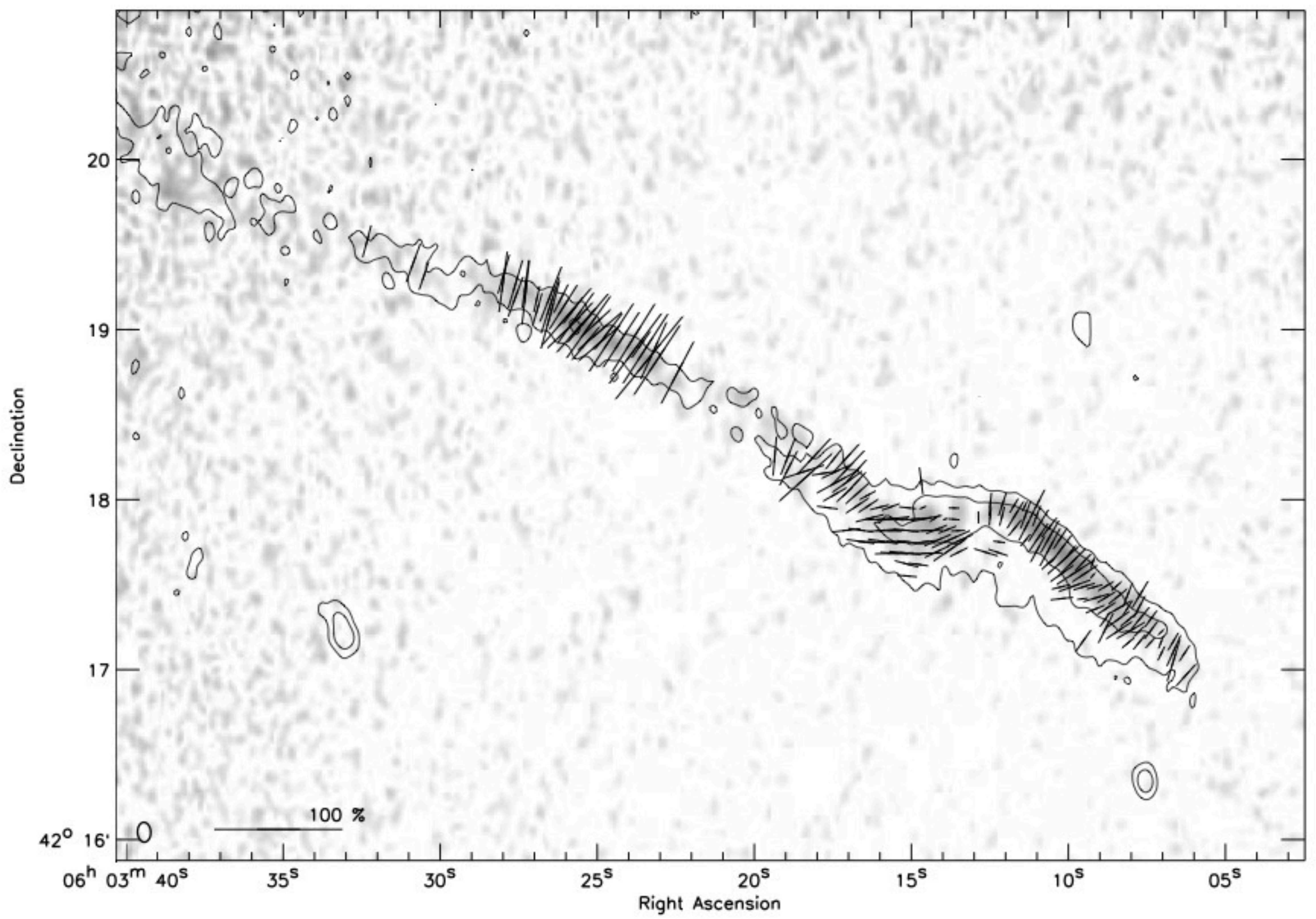
$$10^6 K \leq T_e \leq 10^9 K$$

E-vectors



polarisation @ 2.2 GHz: 50 %

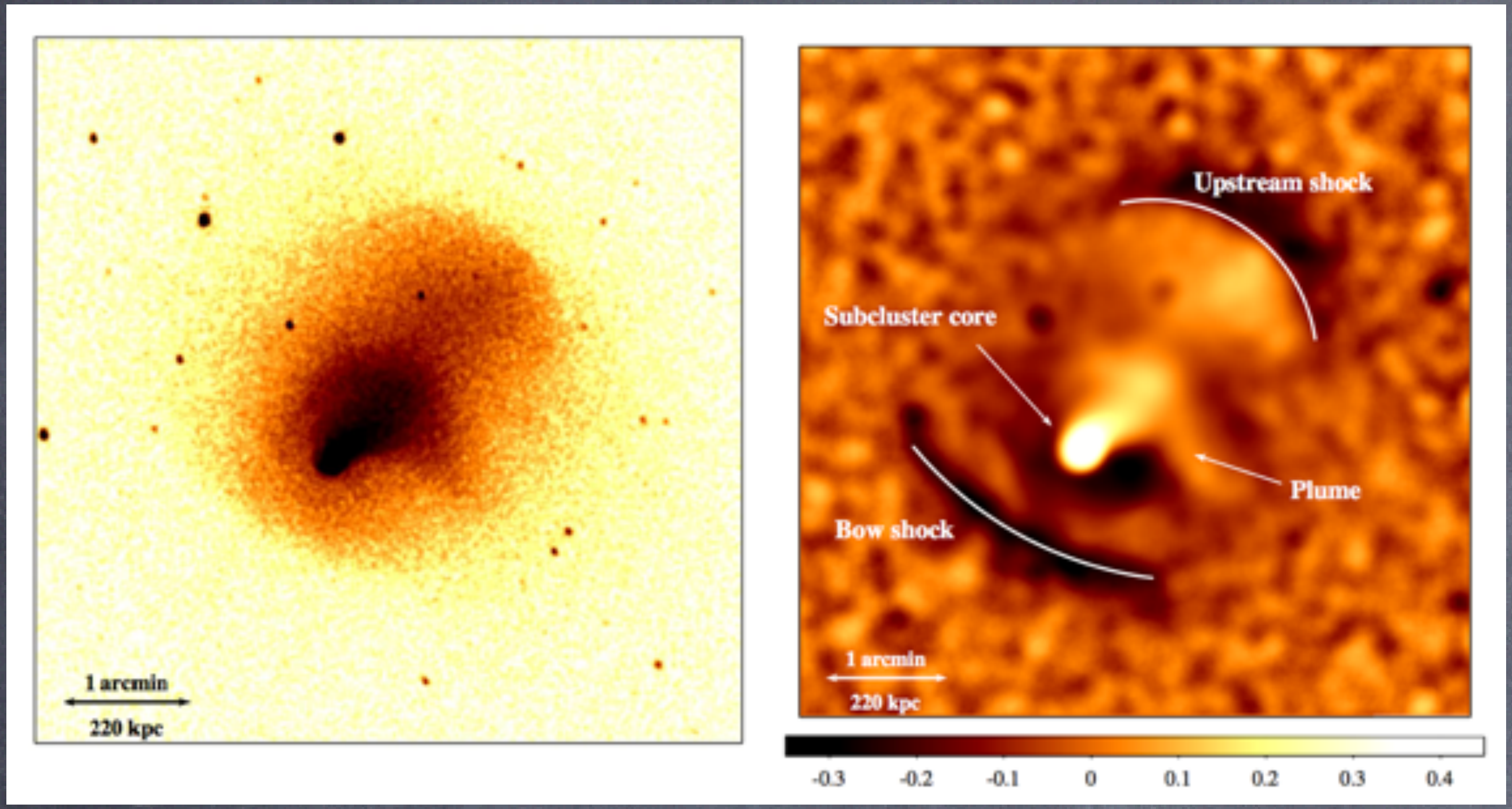
and why is it so smooth?



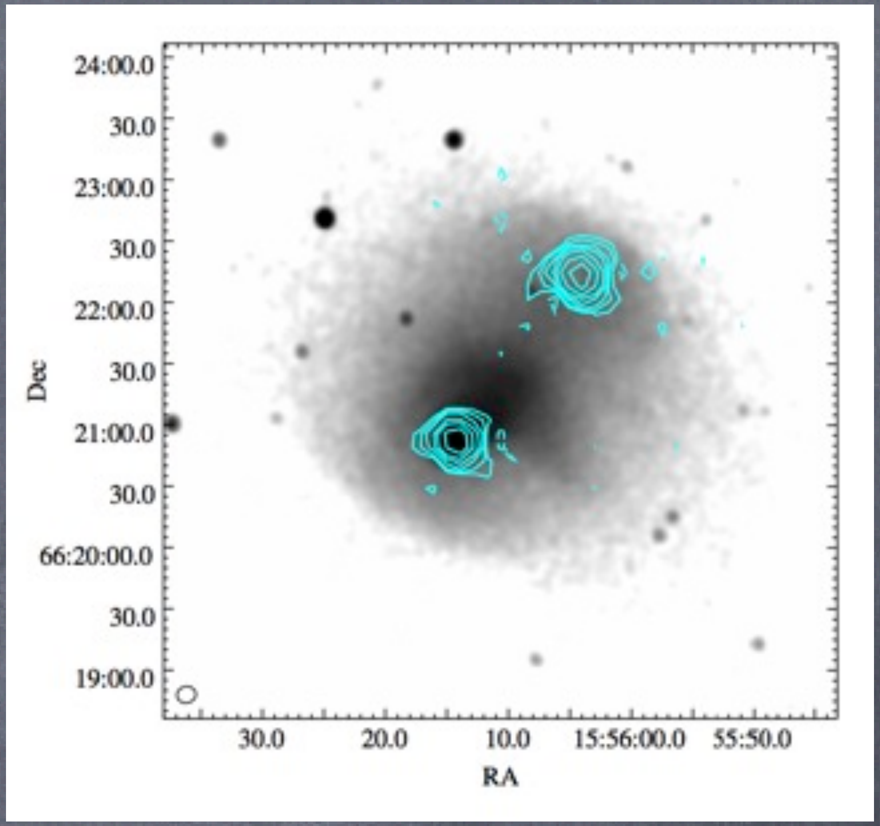
Declination
20
19
18
17
42° 16'
100 %
06h 03m 40s
35s
30s
25s
20s
15s
10s
05s
Right Ascension

Still some questions...

Abell 2146 puzzle



Chandra 0.3-7.0 keV, Russell et al. 2011



GMRT 325 MHz

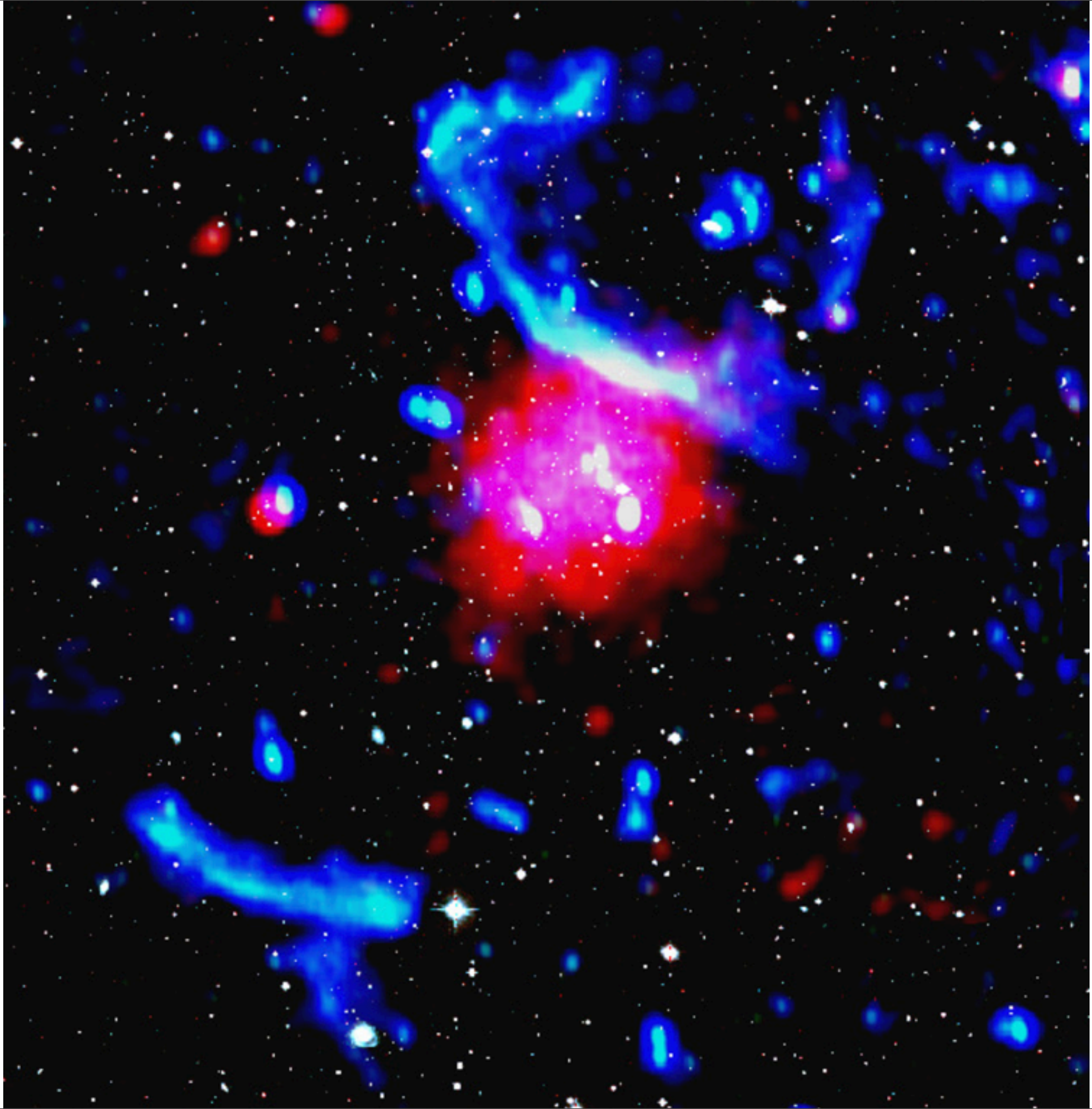
Mach numbers:

M = 2.1 +/- 0.2

M = 1.6 +/- 0.1

Why do we not observe radio emission from these shocks?

Slide from Reinout



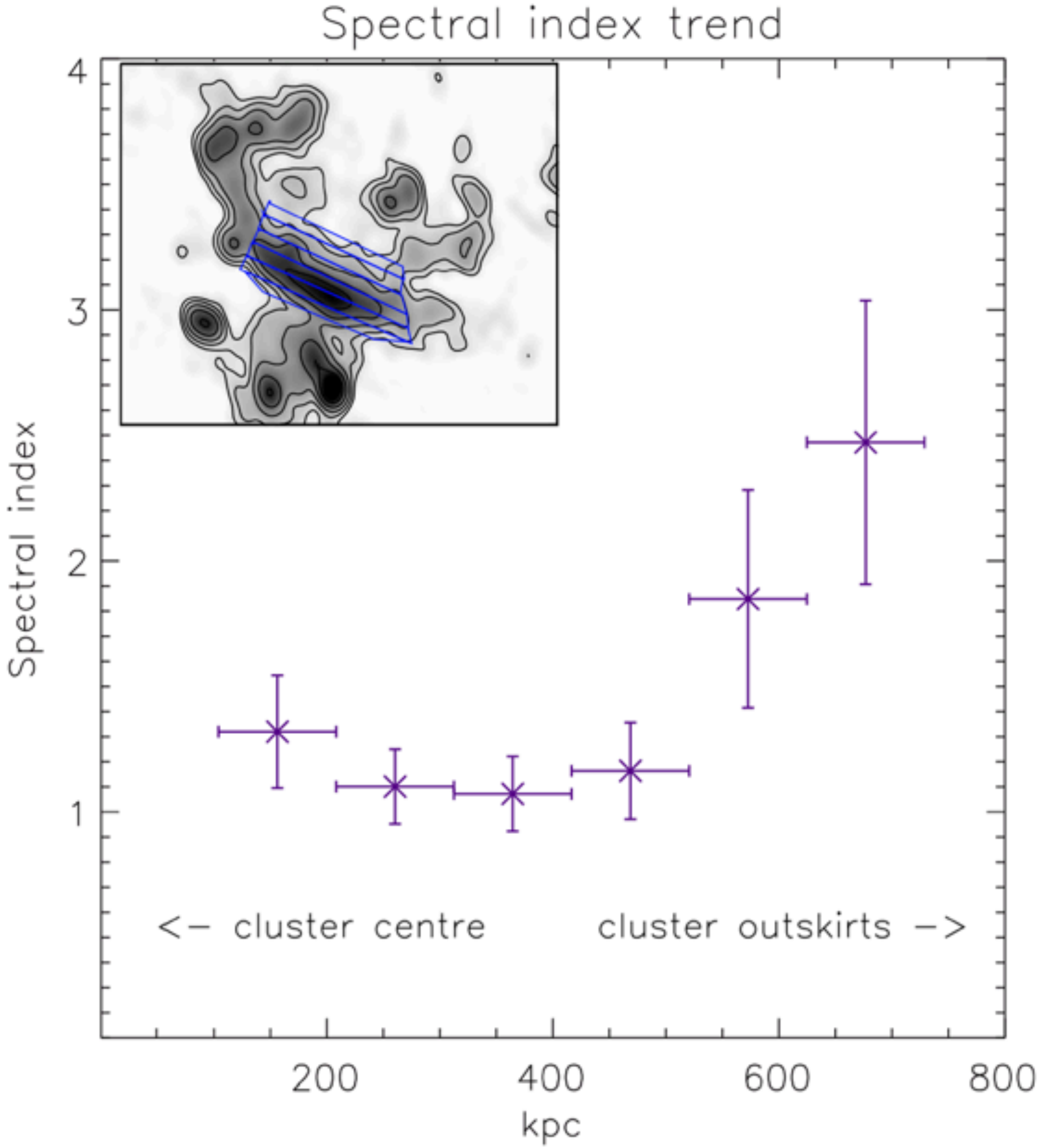
PLCKG287.0 +32.9

Connection AGN relic?

red: XMM
blue: 325 MHz

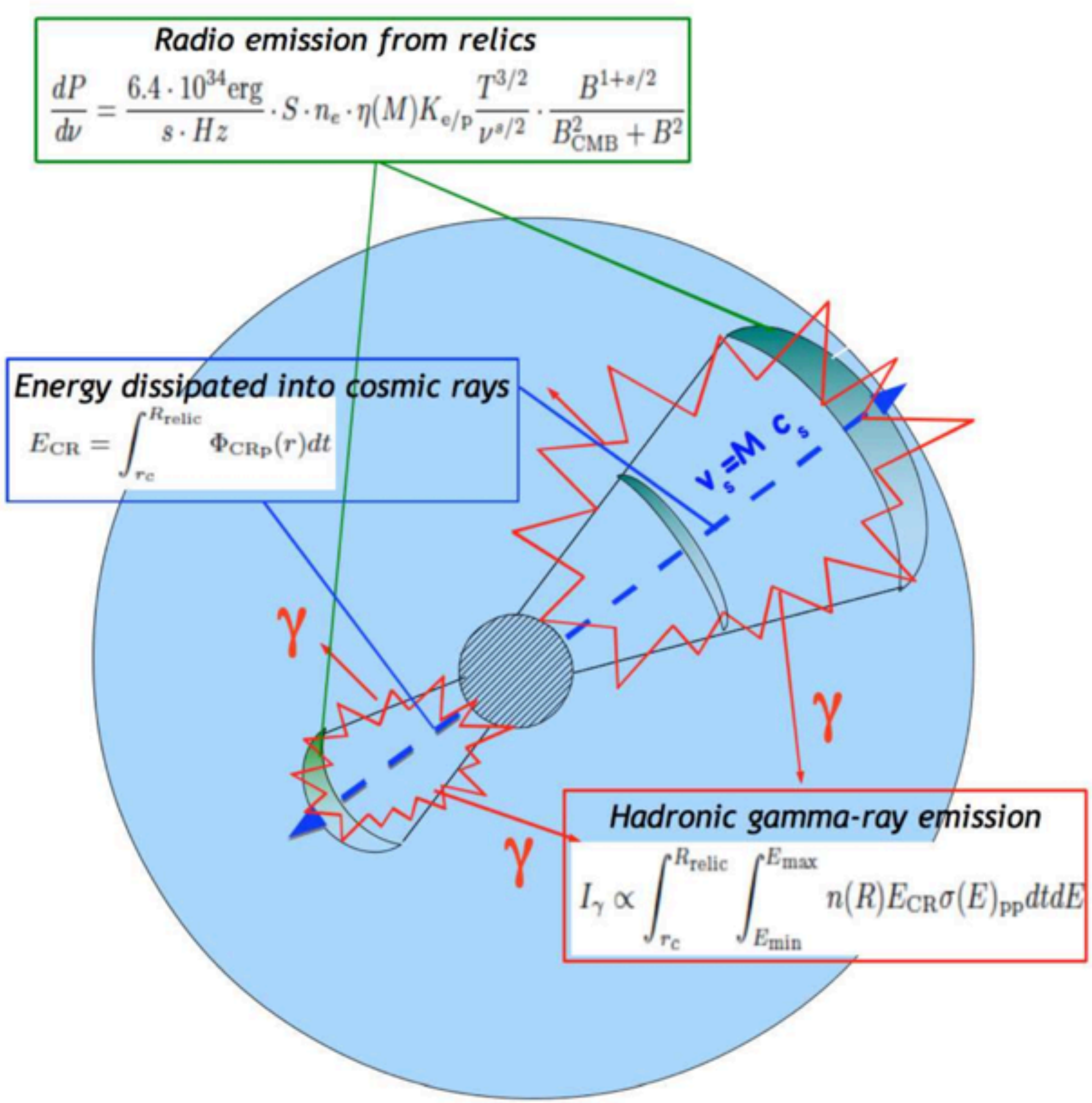
Bonafede et al 2014

PLCKG287.0 +32.9

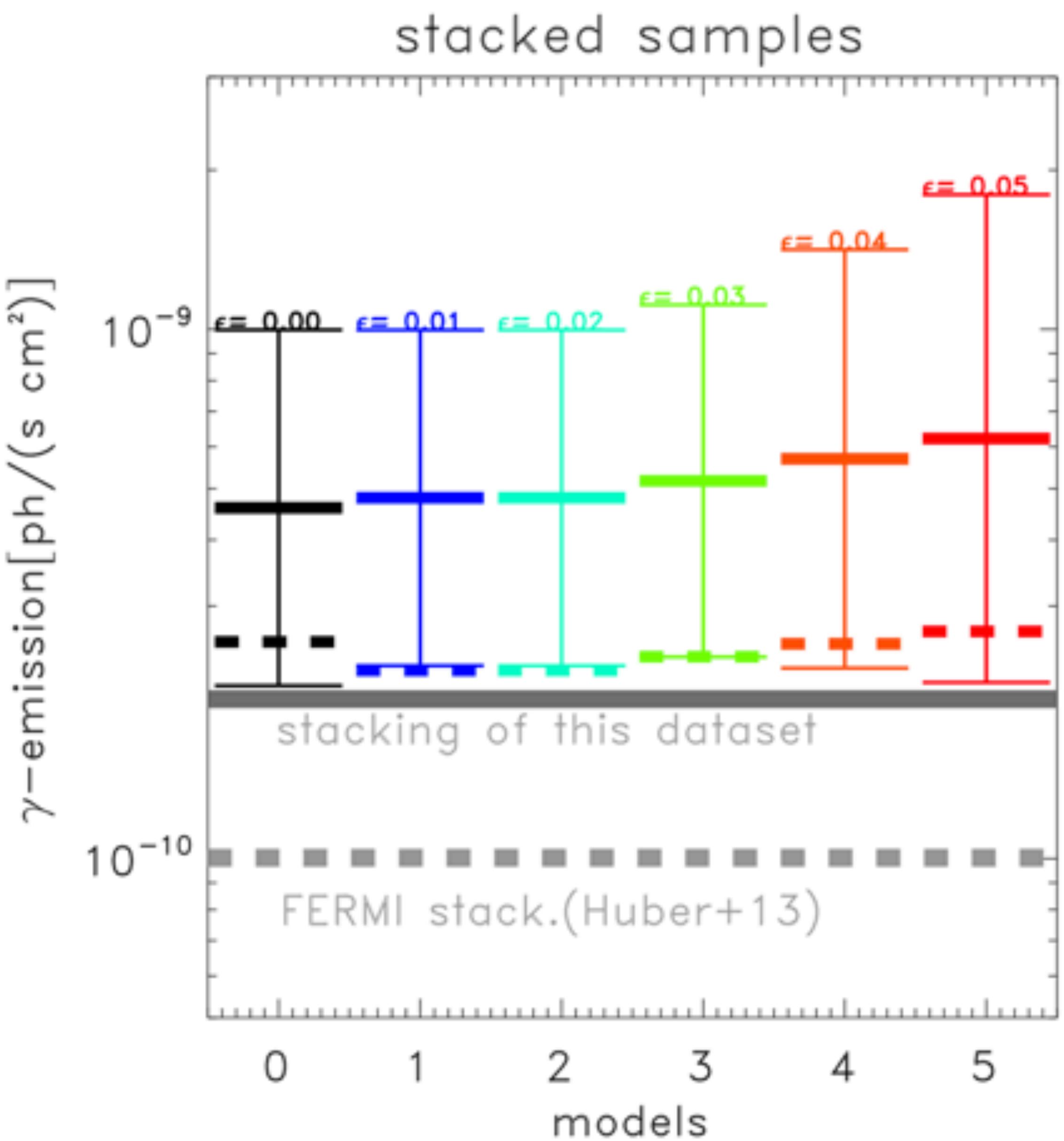


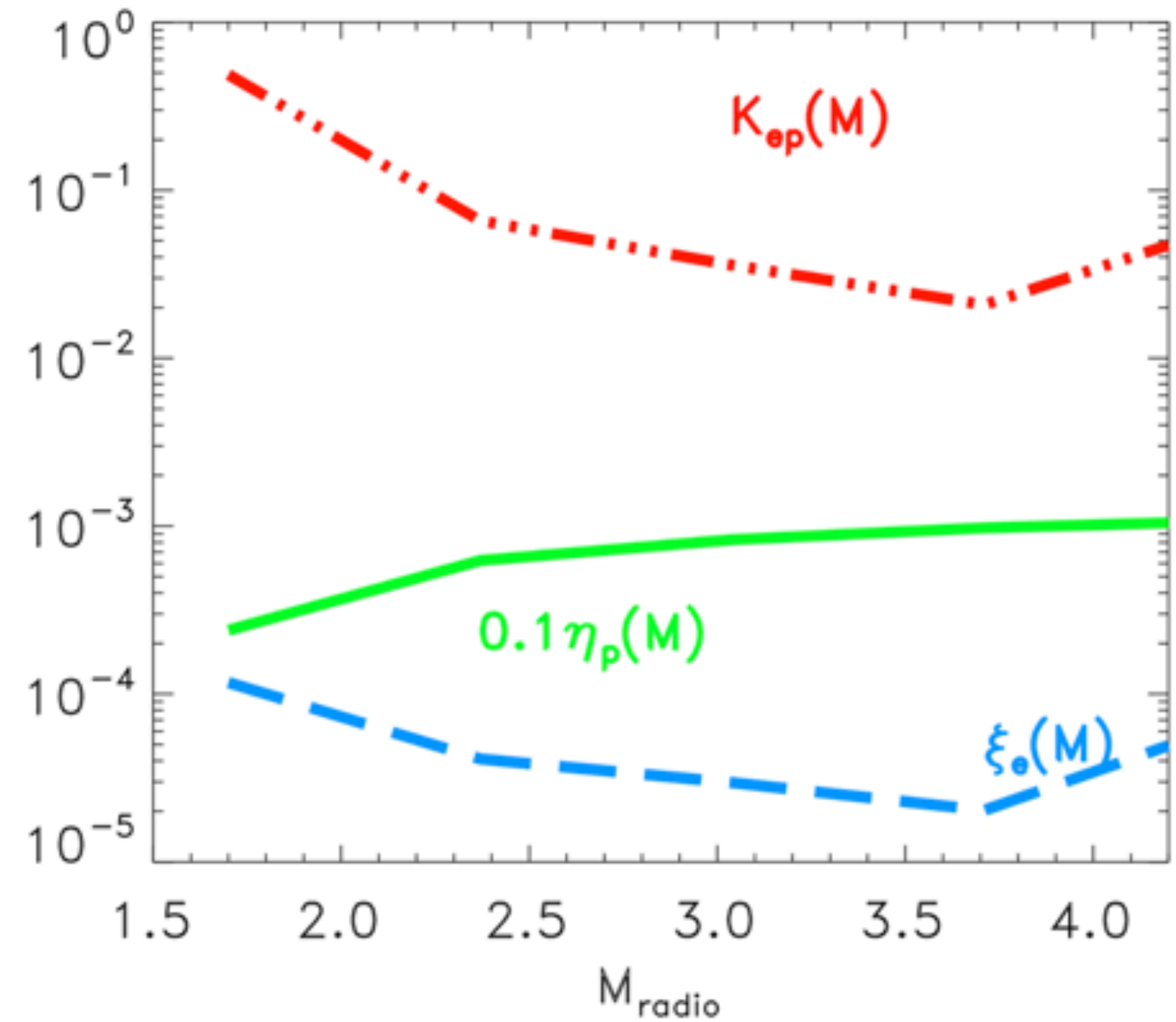
Problem #2: Where are the protons?

Where are the protons?



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





Vazza, Eckert & Brüggen (in prep.)

Figure 8. Acceleration efficiency of CR-protons (green, rescaled by a factor $\times 10$ down) and CR-electrons (blue), and electron to proton acceleration ratio (red) allowed by our combined radio and γ-ray comparison with observations. In this case, we assumed a fixed magnetic field of $B = 2\mu G$ for all relics.

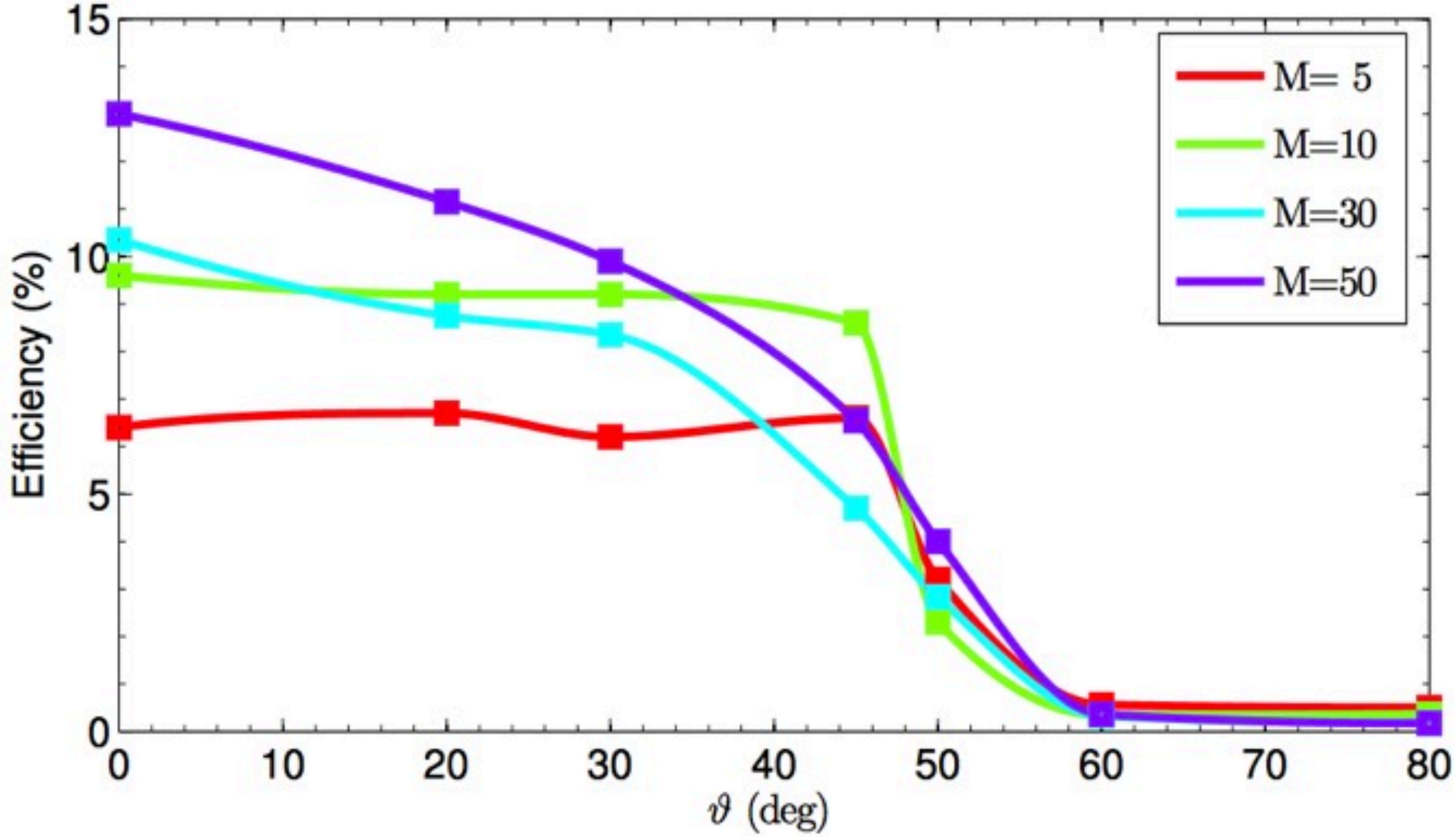


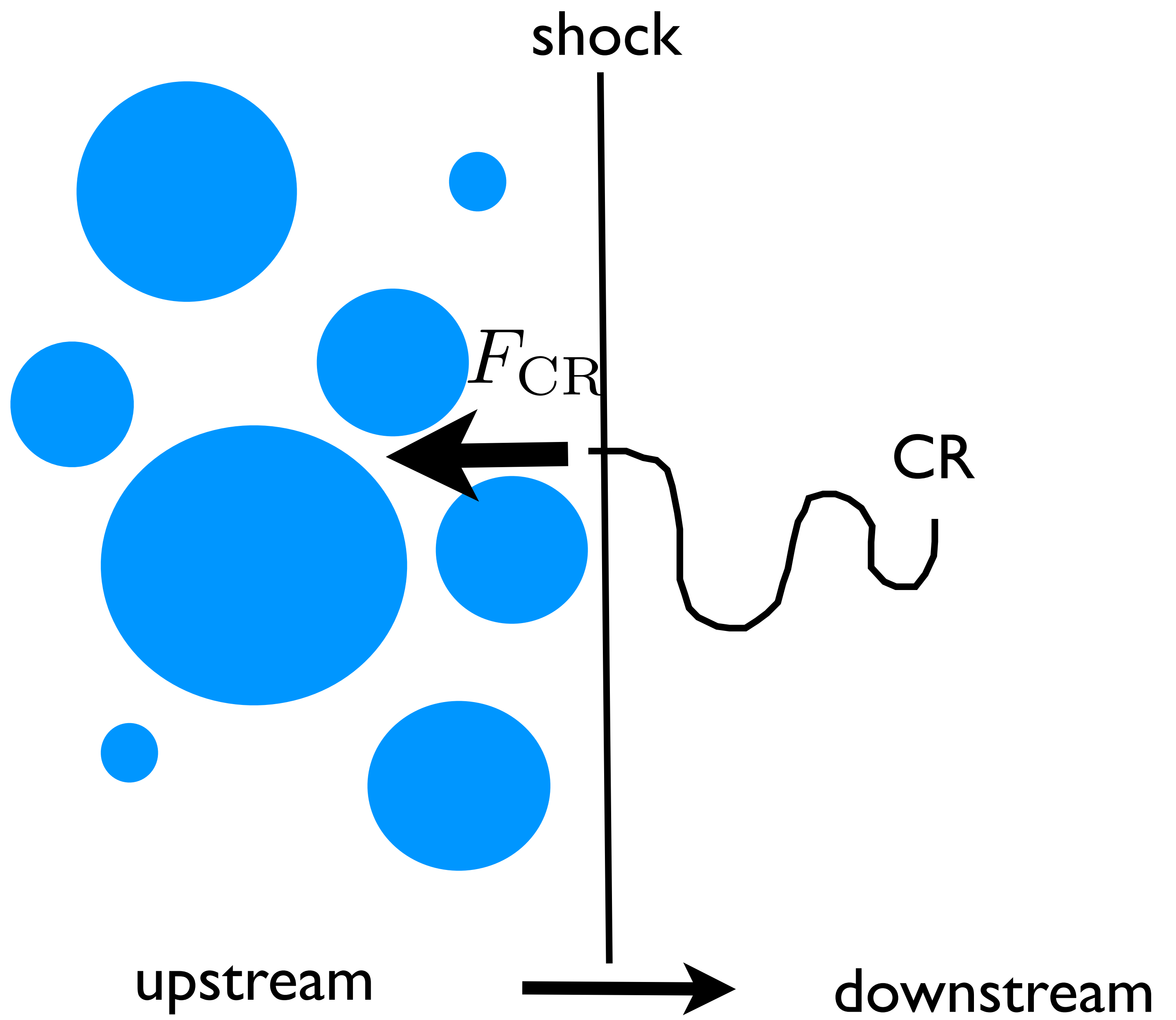
Figure 3. Acceleration efficiency, defined as the fraction of the post-shock energy density in particles with $E \geq 10E_{sh}$, at $t = 200\omega_c^{-1}$, for several shock inclinations and Mach numbers. There is a very significant drop in the acceleration efficiency for $\vartheta \gtrsim 45°$, and the largest efficiency is achieved for fast, parallel shocks. *A color version is available in the online journal.*

Caprioli et al. 2014

Problem #3: Where does the B field come from?

Magnetic field amplification by cosmic rays

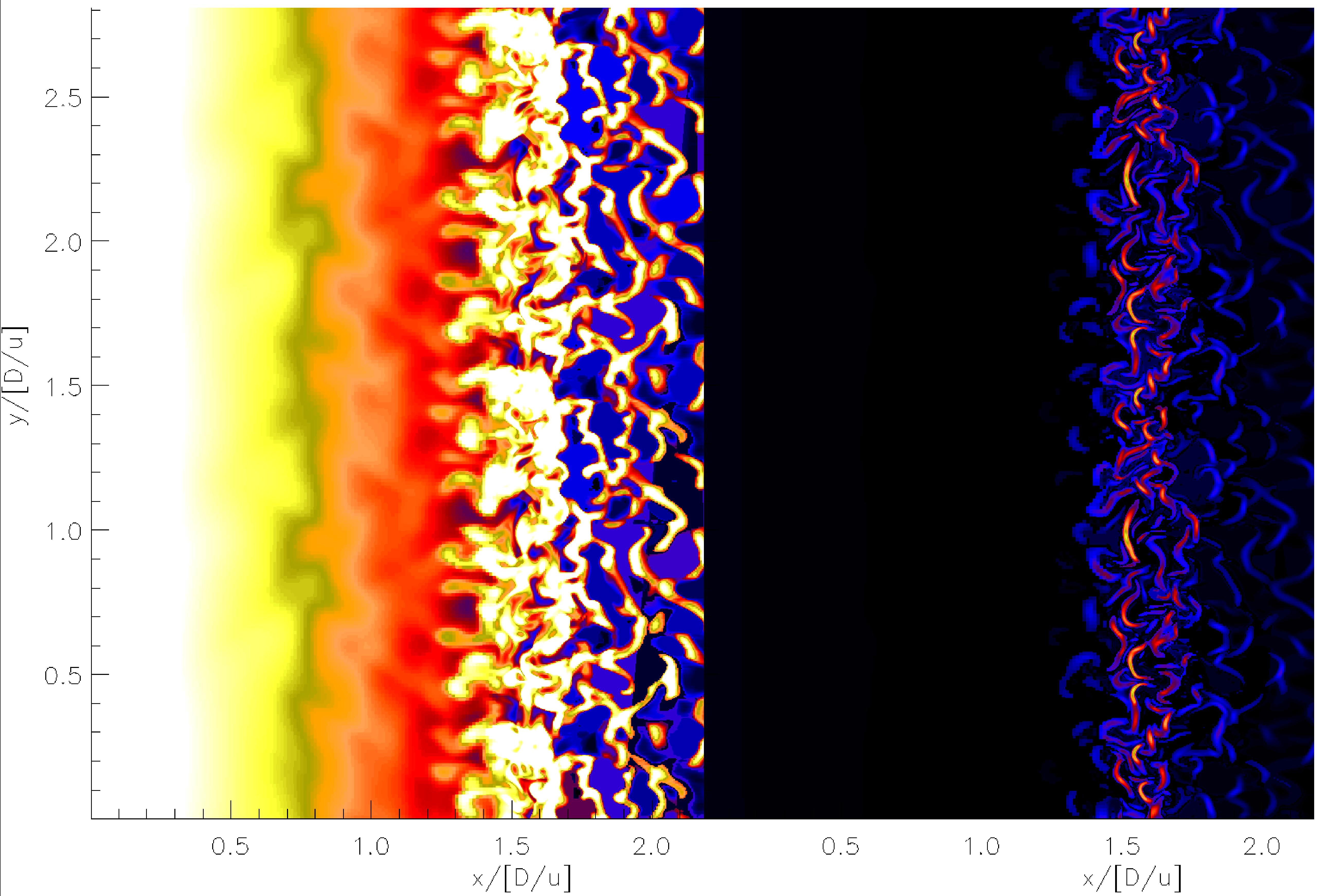
density fluctuations



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

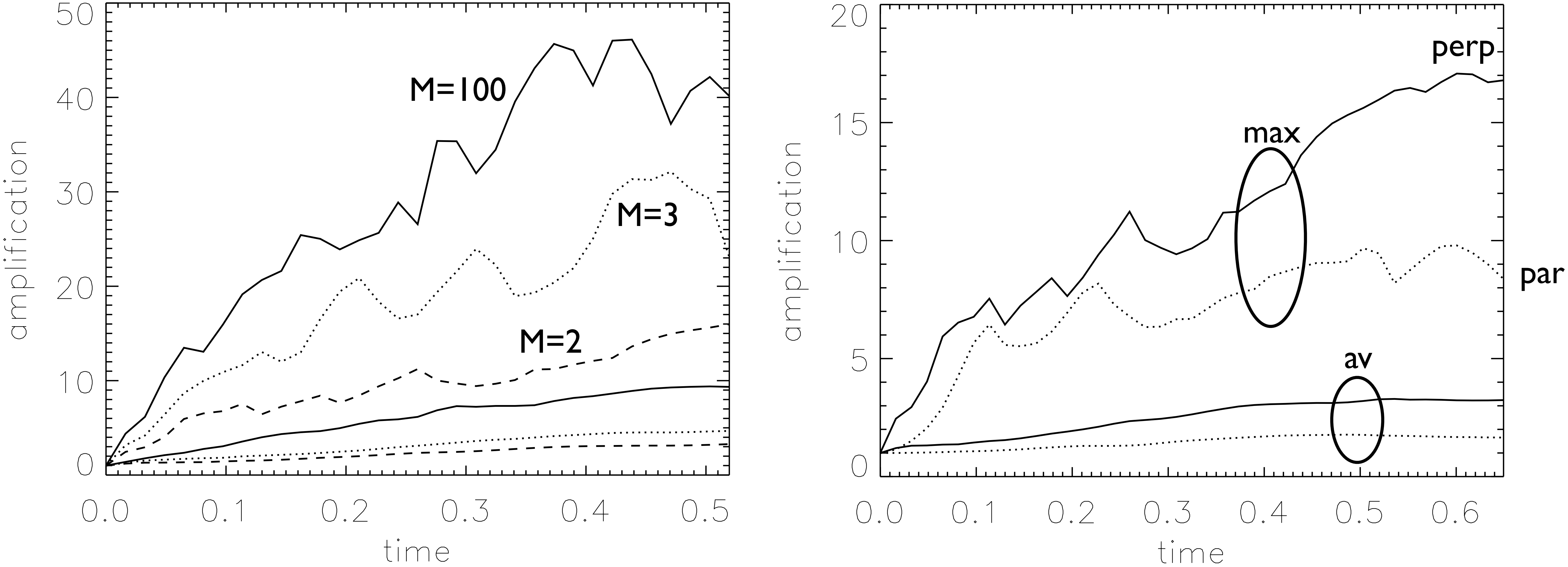
Density fluctuations → acceleration fluctuations → density fluctuations

Cosmic-ray driven turbulence



Brüggen 2013

Magnetic field amplification



can be probed with Faraday rotation...

Brüggen 2013

B field

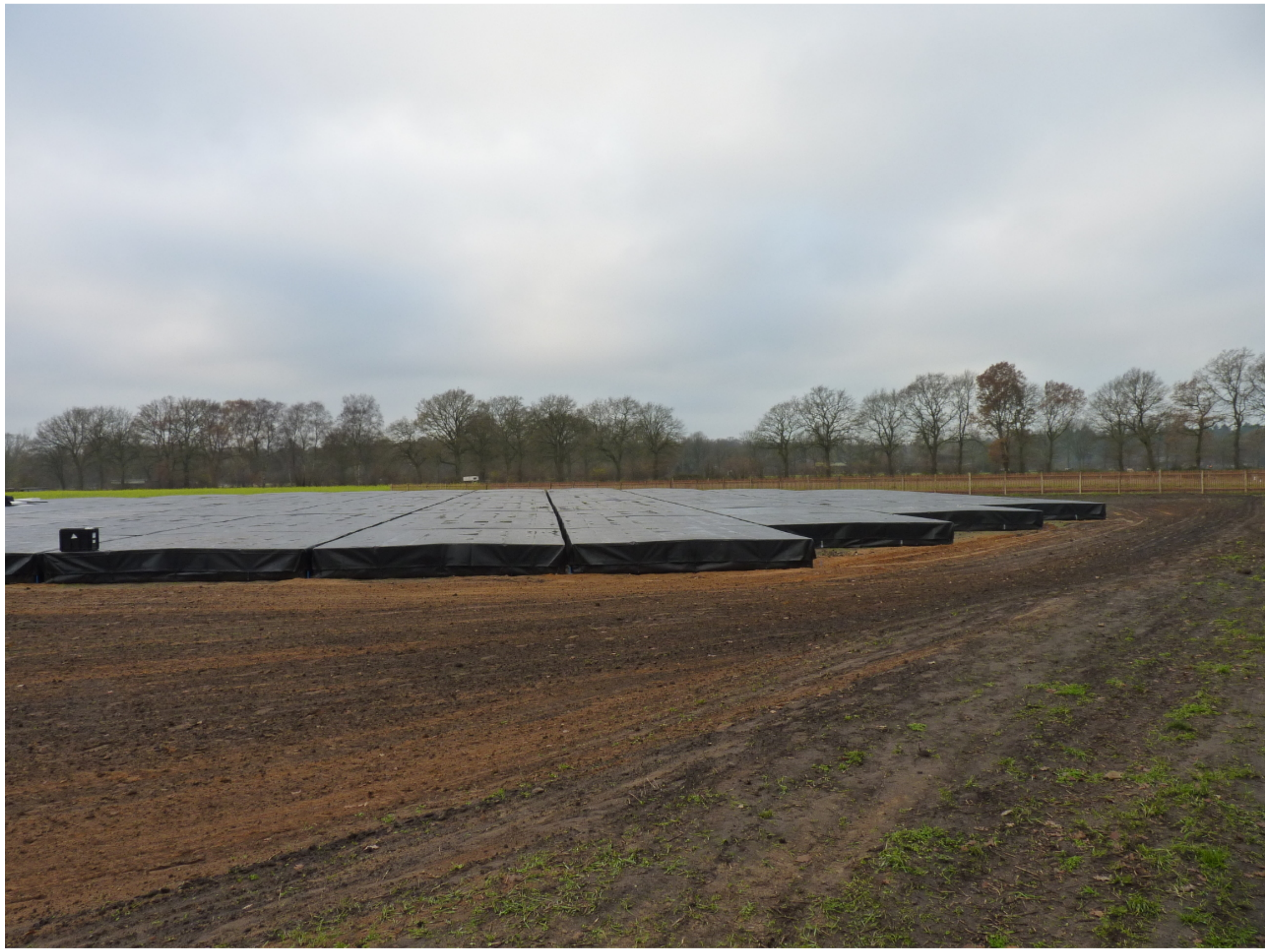
shock

many shocks
of different M

strong shocks
align fields and
amplify

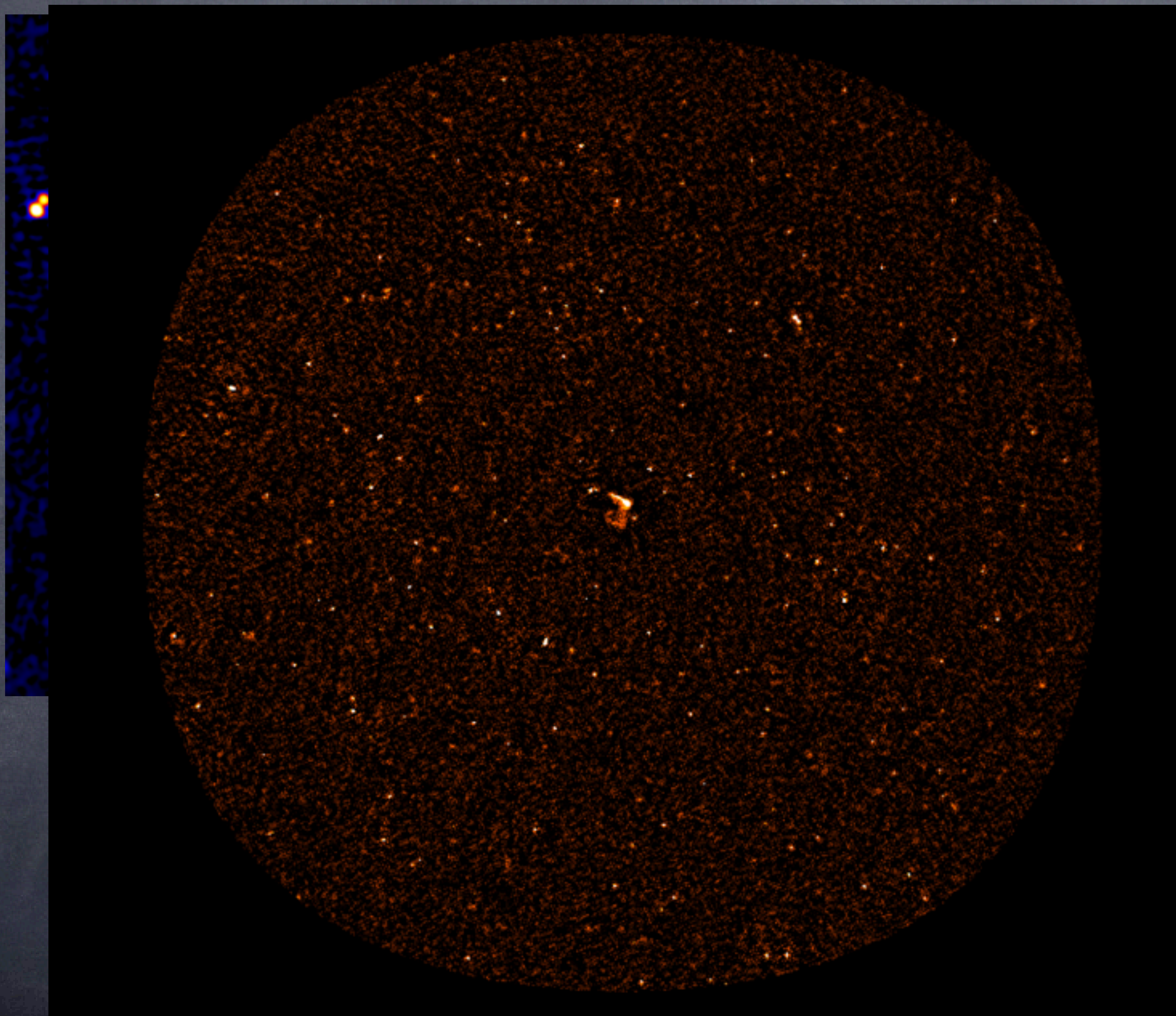
strong shocks
also dominate
radio emission(?)

Hamburg LOFAR station just completed



https://lofar.physik.uni-bielefeld.de//

LOFAR



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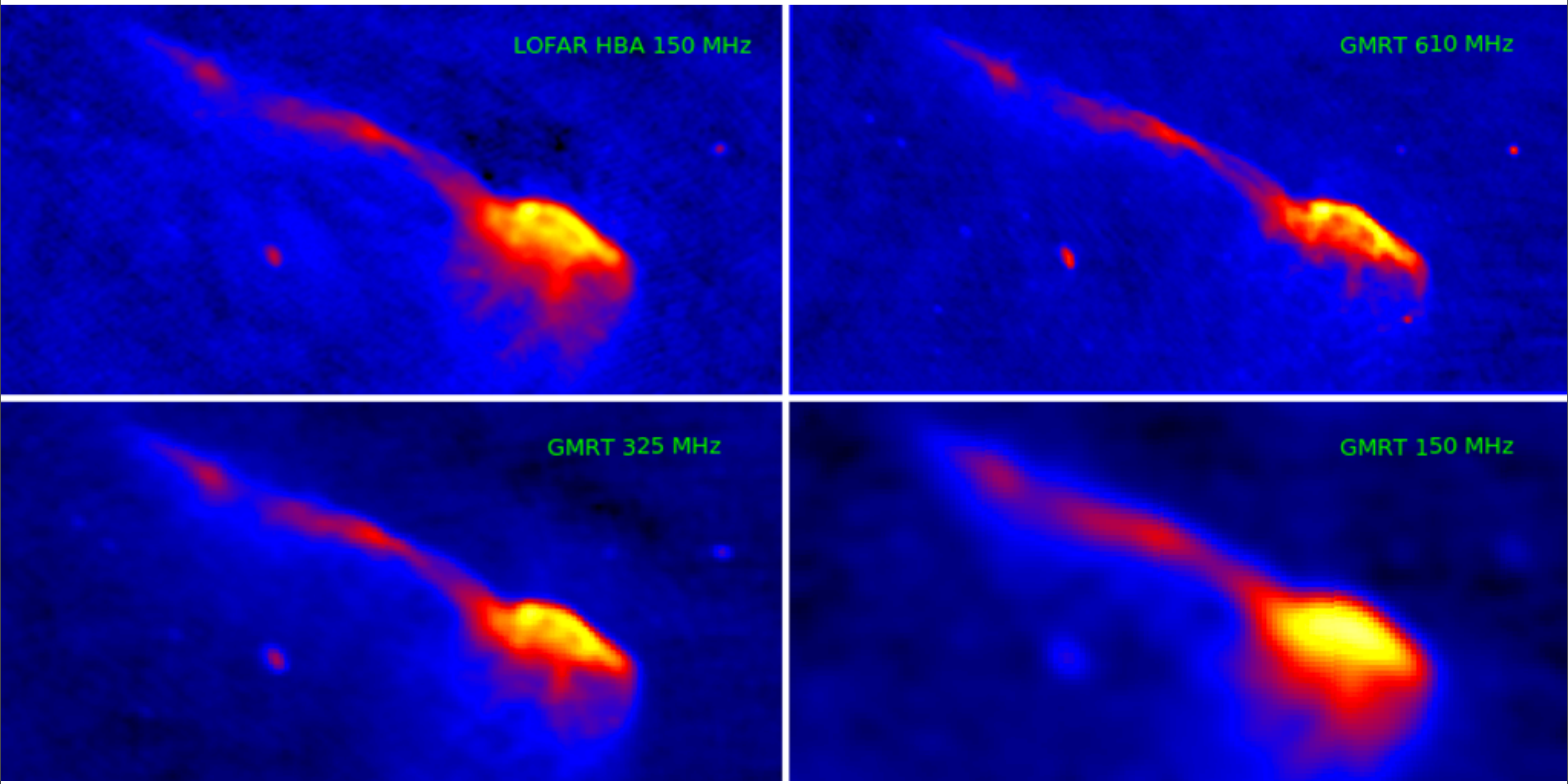
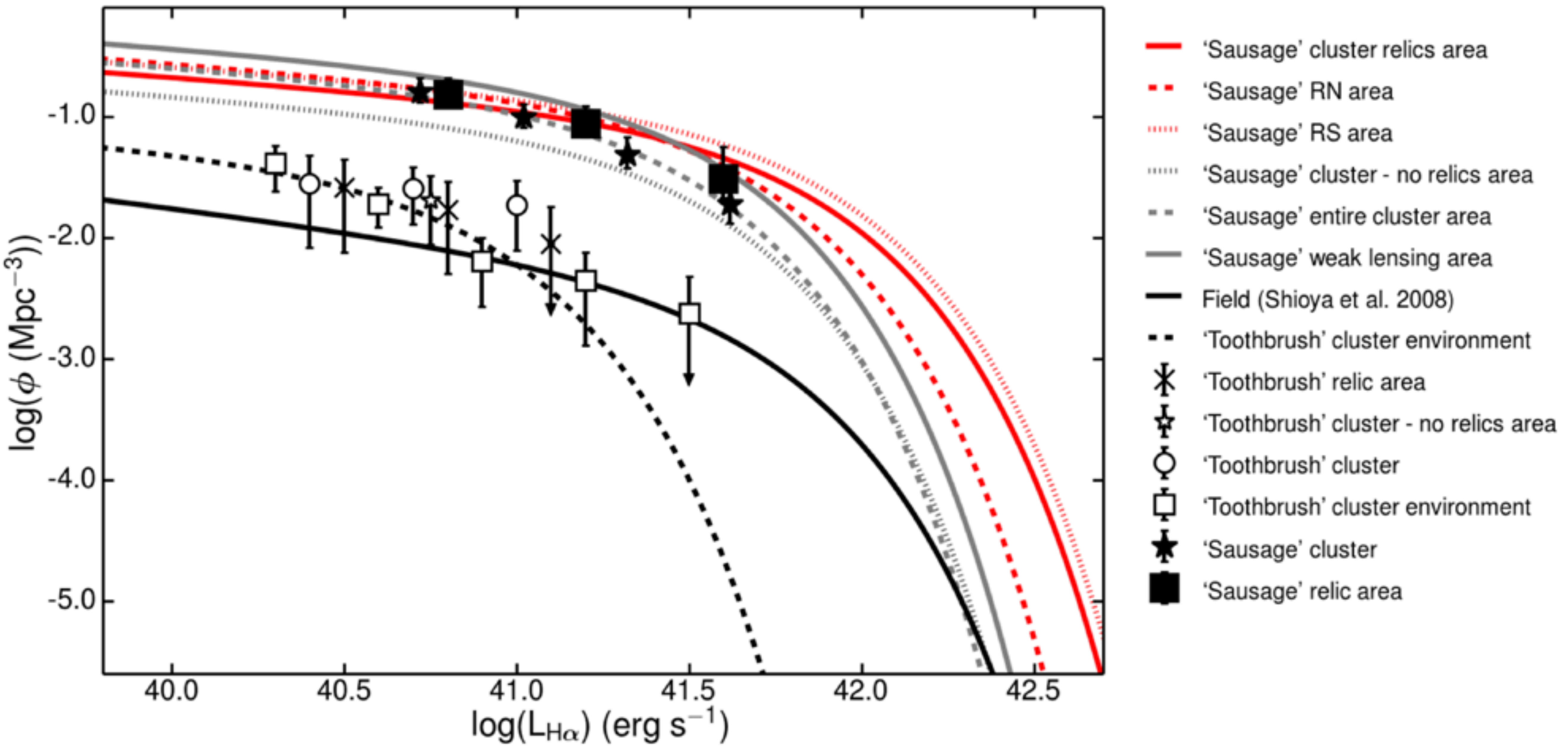
Slide from Reinout



van Weeren et al in prep

H alpha Luminosity Function



Stroe, Sobral, Dawson, Jee, Hoekstra, Brüggen, et al. 2014

Conclusions

- Relativistic plasma is great for finding shocks in cluster outskirts and learn about B-fields
- Some cluster shocks show relics, some do not.
- Relics show best evidence to date for shock acceleration at low M
- Efficient electron acceleration at low-M shocks at high beta via SDA
- Why are there no gamma rays detected?
- Look for offset between DM and galaxy centroid - SIDM?
- Star formation increased behind shock in CIZA 2242 but not in toothbrush
- First LOFAR observations of relics are becoming available

Thank you!