Radio relics in clusters of galaxies

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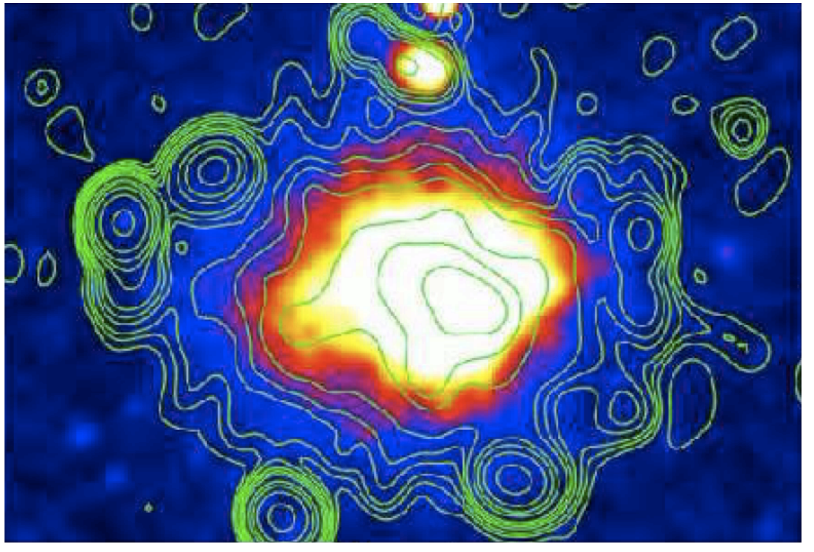
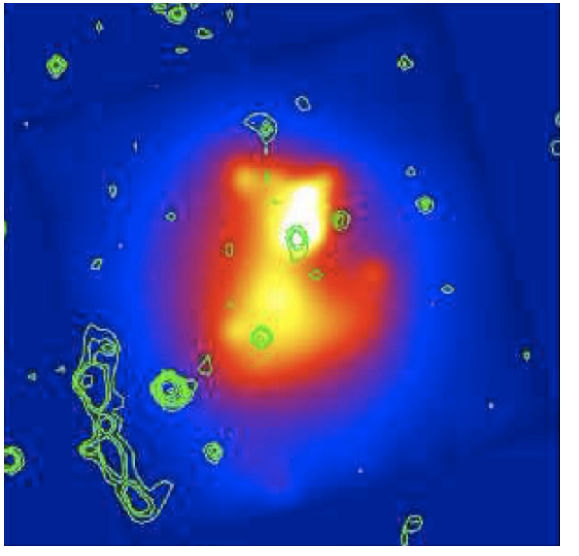
Thüringer Landessternwarte Tautenburg

Diffuse radio emission in galaxy clusters



Abell 2163



Abell 521

Color: X-ray Contours: radio [Ferrari 08]

Radio halo

Morphology similar to X-ray

Centered on cluster

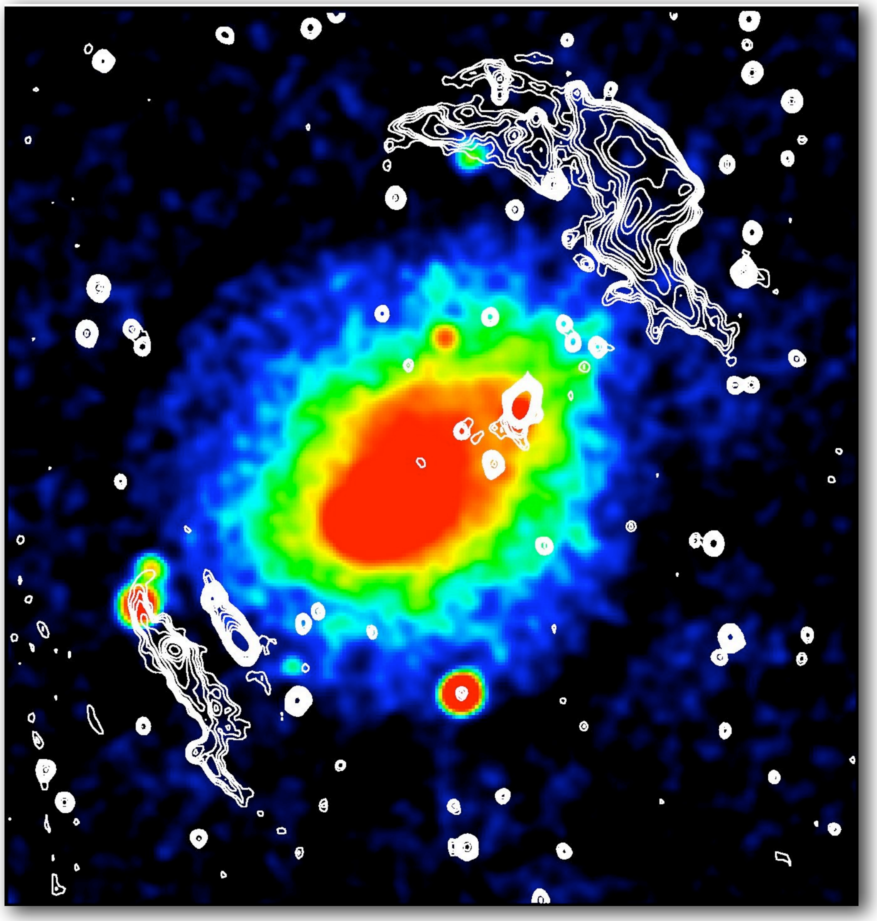
Radio relic

Elongated

At cluster periphery

The definition of 'radio relic'

- extended (about 1Mpc) diffuse emission at the periphery of galaxy clusters
- no optical counterpart
- irregular morphology
- merging cluster



Abell 3667

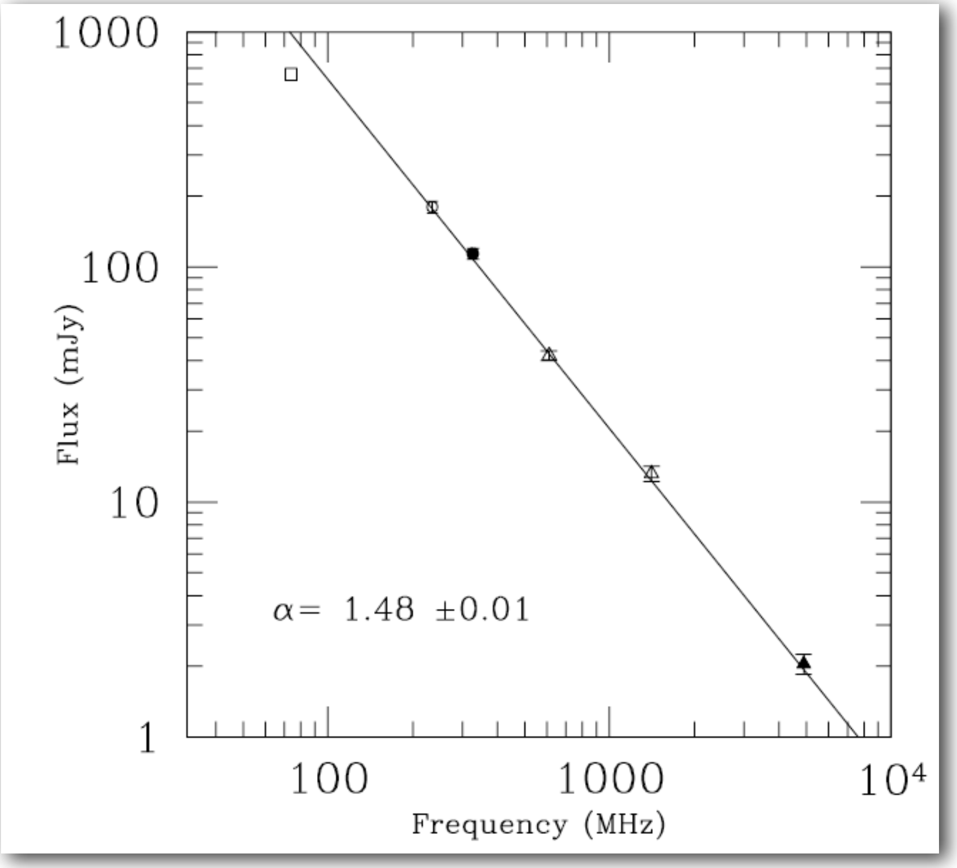
Color: X-ray

Contours: radio

[Roettgering et al. 97]

The overall radio spectrum

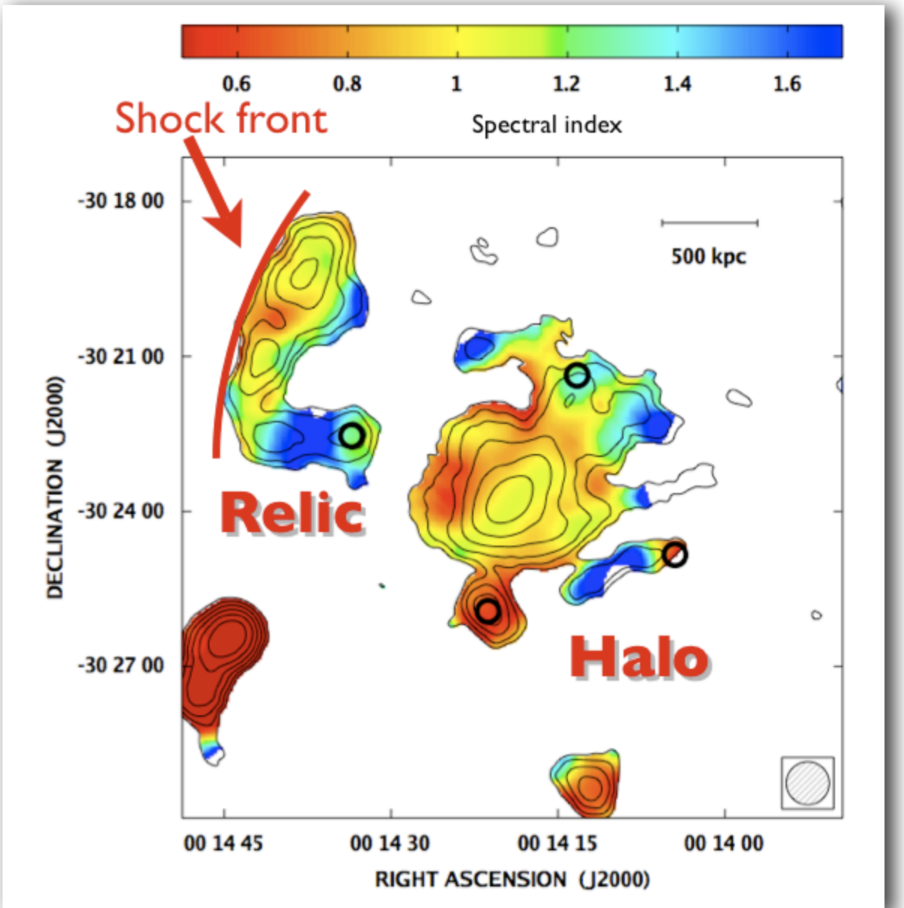
- perfect power-law in radio spectrum
- fits very well to predictions of `simple' diffusive shock acceleration theory (plus synchrotron cooling)
- Mach number ~ 2.3



Abell 521
[Giacintucci et al. 08]

Spectral index map - aging

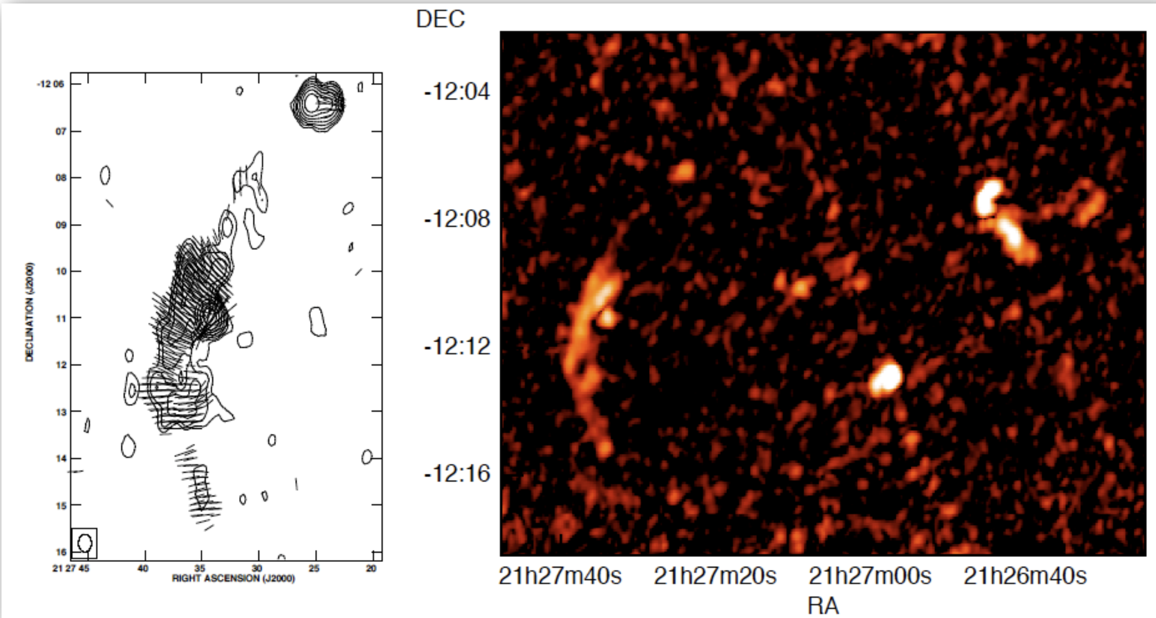
- systematic trend perpendicular to the long extend of the relic
- indicates motion of the shock front and aging of electrons



Abell 2744
[Orrù et al. 04]

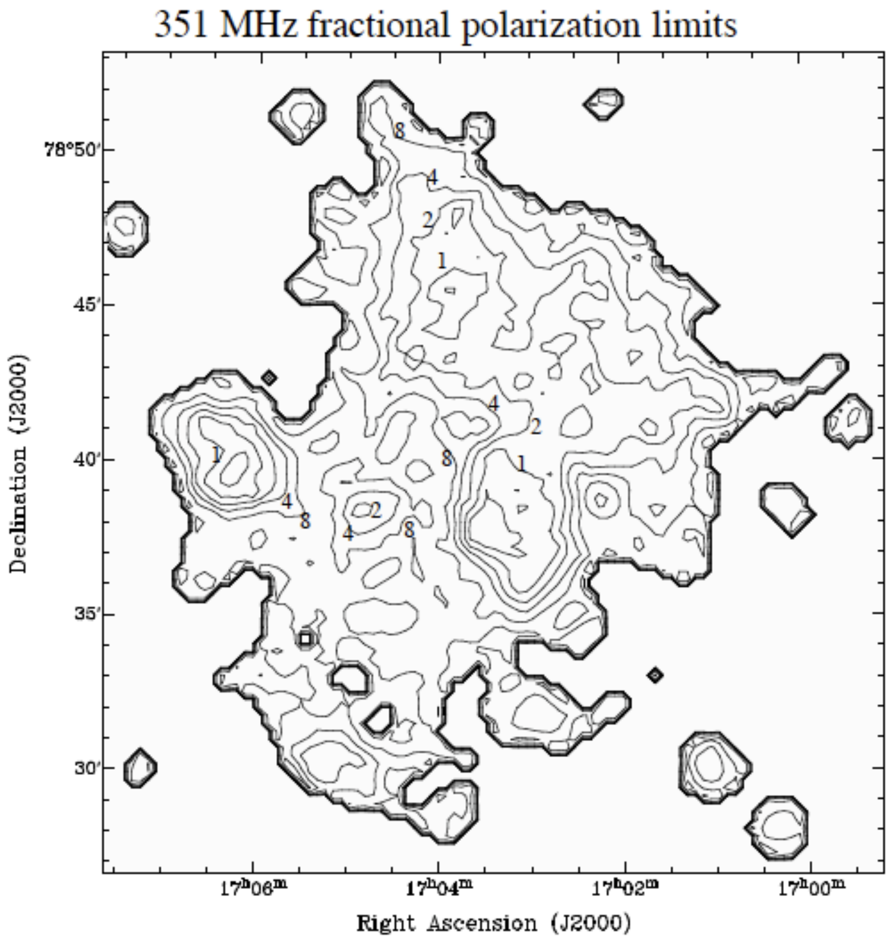
Polarization of the diffuse emission

- for A2345: average polarization 22%
  maximal polarization 50%
- other example Abell 786: average polarization 53%
  [Harris et al. 93]



Abell 2345
VLA 1.4 GHz
Color: polarized emission
[Bonafede et al. 2009]

Depolarization



Abell 2256

WSRT 351 MHz

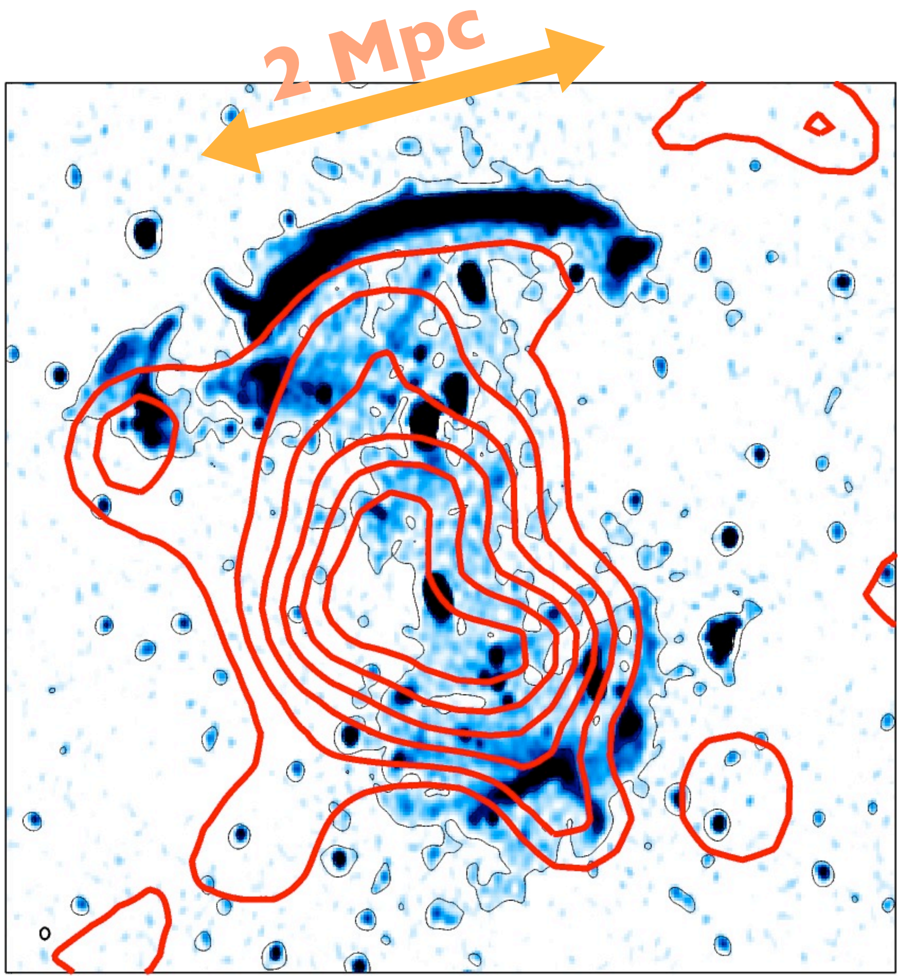
[Brentjens 2008]

Estimates for the magnetic field strength

	Abell 3667 NW relic
Rotation measure of background sources	3-5 μG [Johnston-Hollitt 04]
Inverse Compton emission would directly measure the electron density $$\frac{F^{\mathrm{sync}}}{F^{\mathrm{IC}}} = \frac{U_{\mathrm{B}}}{U_{\mathrm{CMB}}}$$	> 1.6 μG Suzaku 10-40 keV upper limit [Nakazawa et al. 08]
Equipartition	2 μG

Yet another radio relic: 'The sausage'

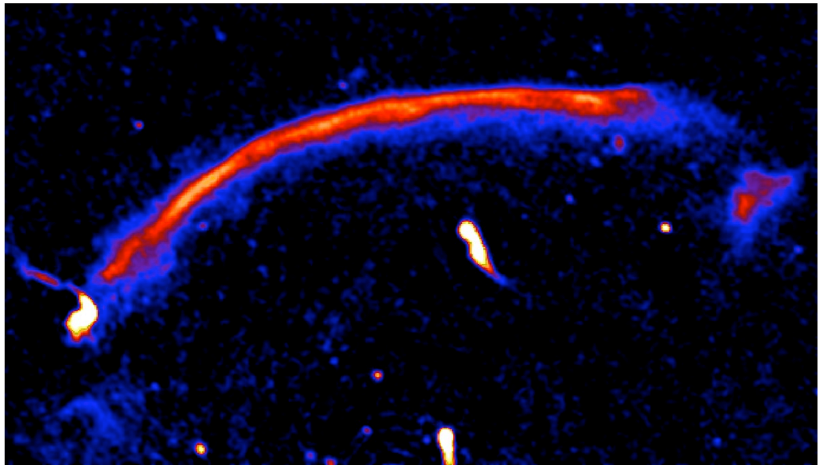
- WSRT @ 1.4 GHz
- $P_{1.4}$ = 1.4 x 10^{25} W/Hz
- L_X = 6.8 x 10^{44} erg/s (ROSAT)



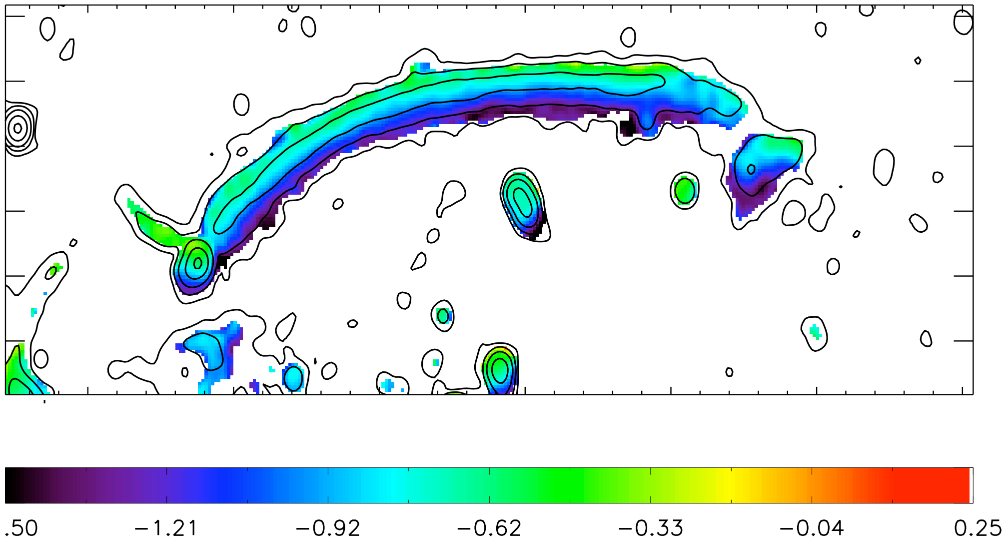
[van Weeren et al. subm.]

Spectral index gradient

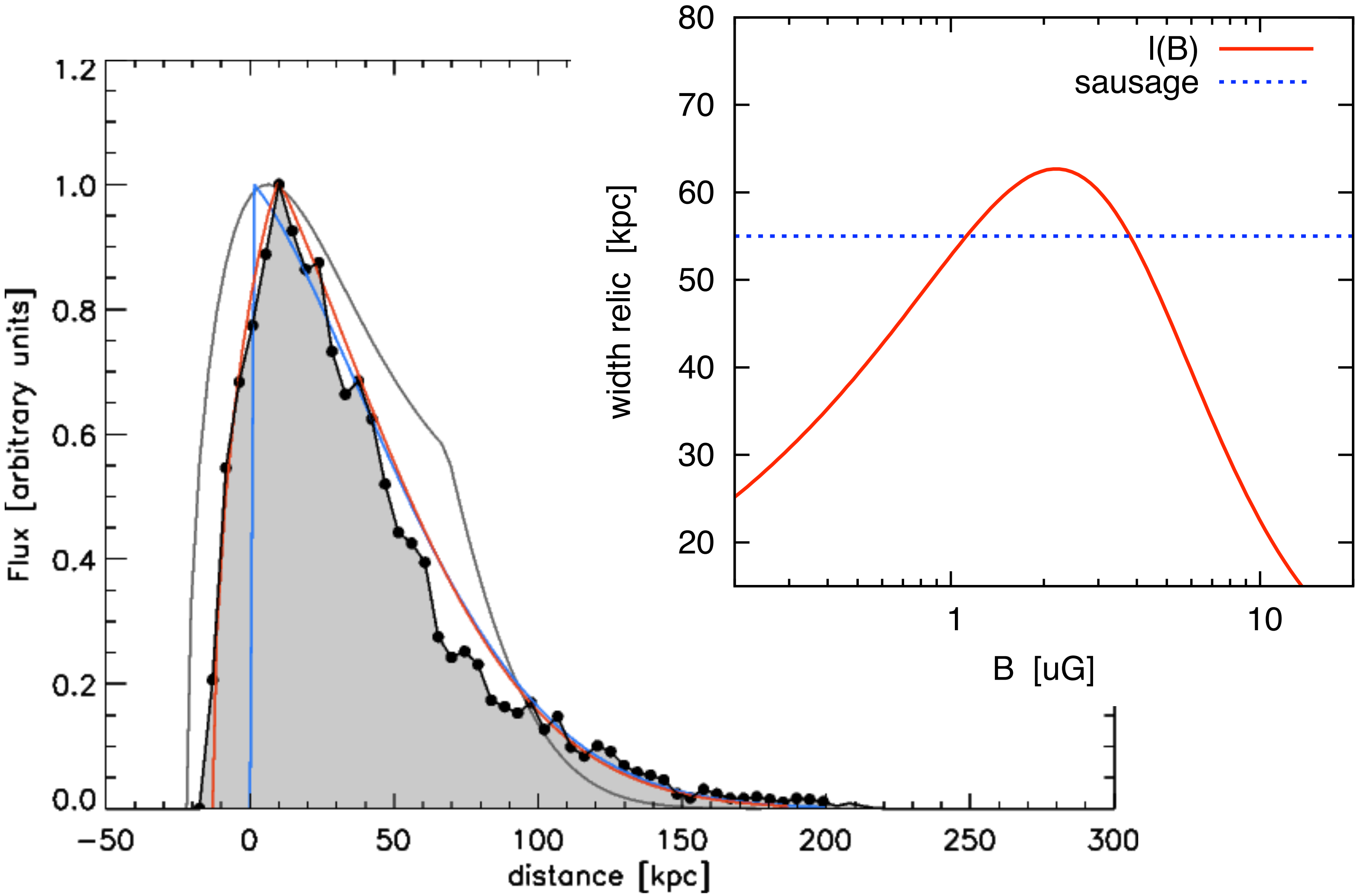
- GMRT @ 610 MHz
  resol $\sim 5''$



- Spectral index



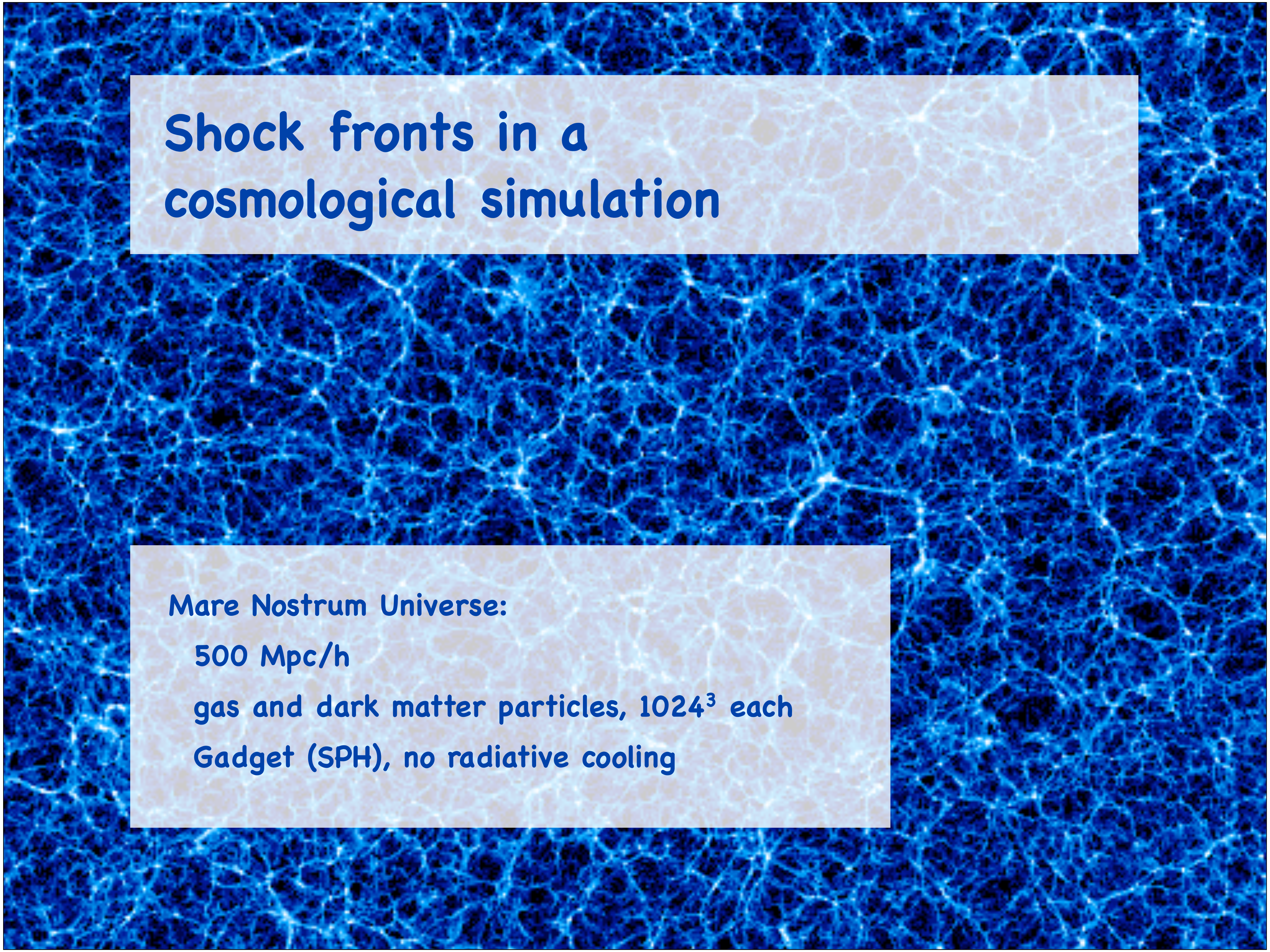
Deconvolved relic profile



Origin of radio relics

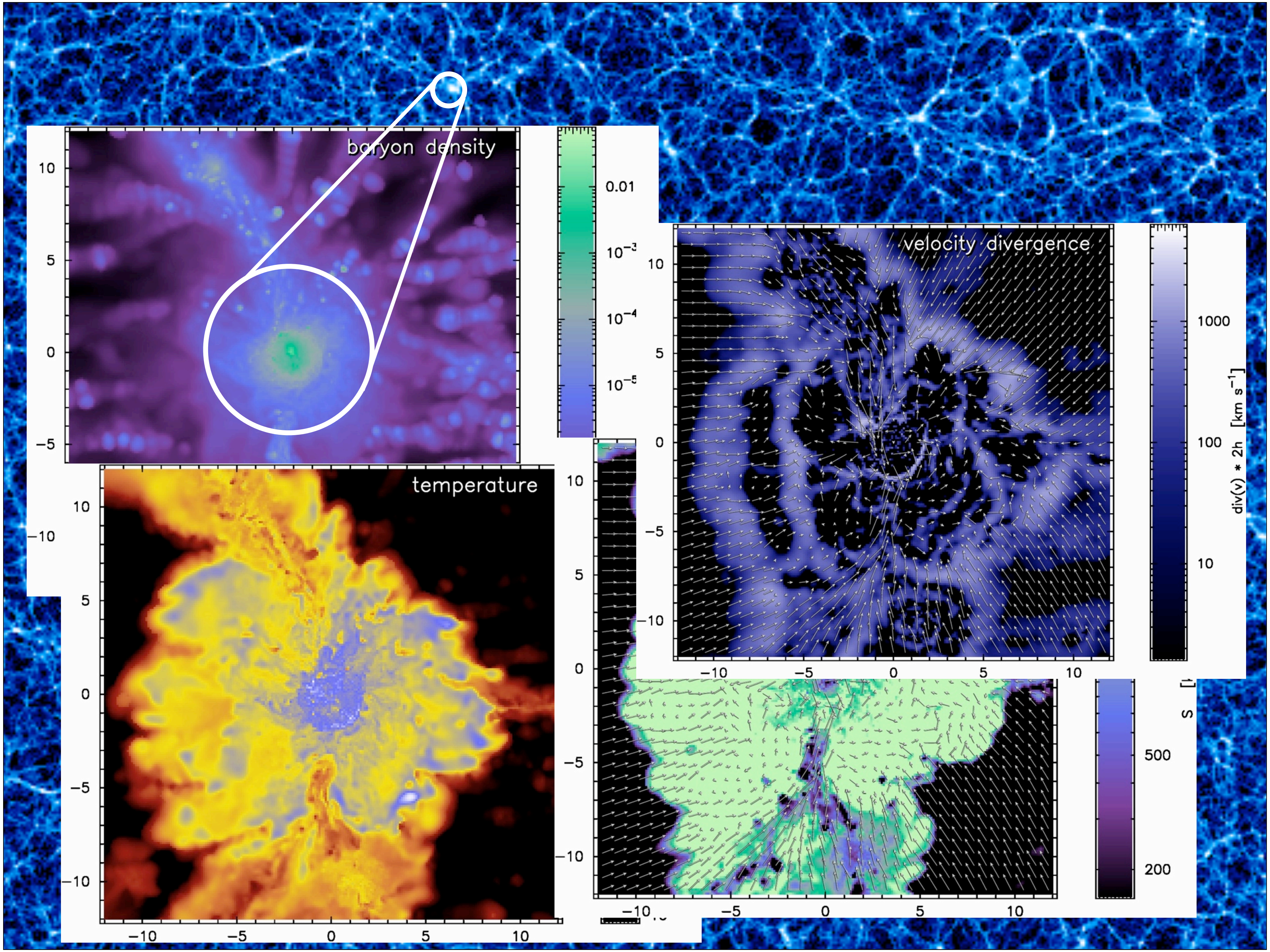
- diffusive shock acceleration produces non-thermal electrons at the shock front with a slope close to -2 (energy)
- energetic electrons are advected downstream with the thermal plasma and cool by synchrotron and IC losses
- magnetic fields in the emission region are at least about a few μG
- main field component parallel to long axis of relics, resulting polarization is up to 60%

Shock fronts in a cosmological simulation



Mare Nostrum Universe:

- 500 Mpc/h
- gas and dark matter particles, 1024^3 each
- Gadget (SPH), no radiative cooling

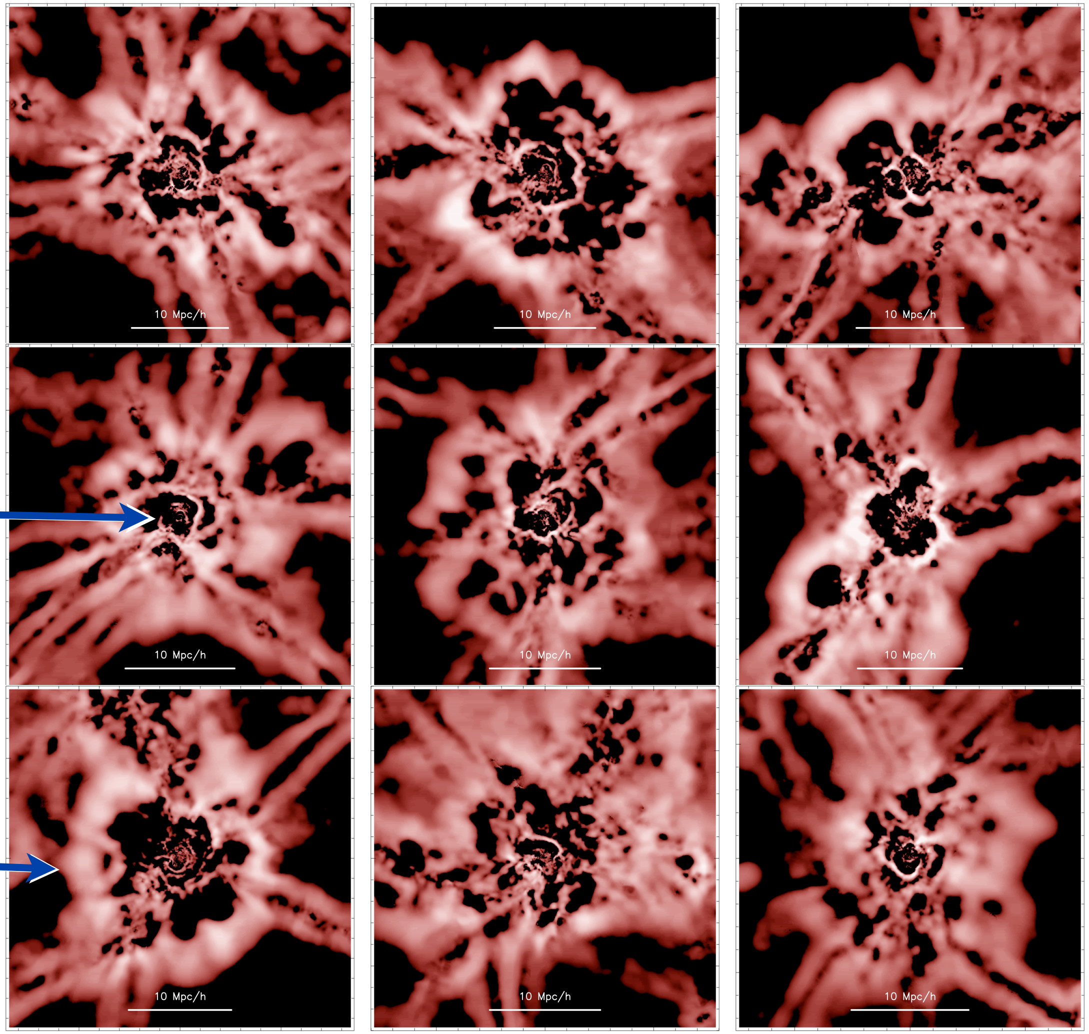


baryon density
0.01
10^{-3}
10^{-4}
10^{-5}
temperature
velocity divergence
1000
100
10
div(v) * 2h [km s^{-1}]
500
200

All clusters show shock multiple fronts!

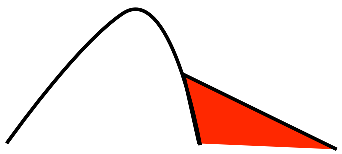
Merger shock

Accretion shock



How to compute the radio emission?

- Identify shock fronts
- Determine Mach number, downstream ρ, T, and B
- Assumption about acceleration efficiency ξ:
  fraction of dissipated energy into
  electrons supra-thermal $\sim$ 1%



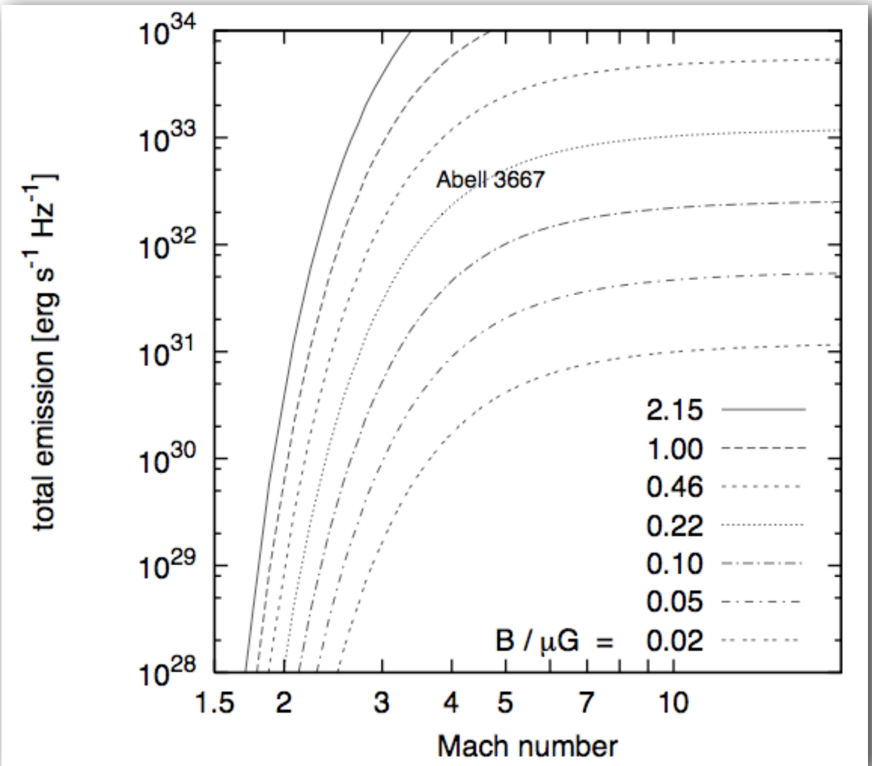
- Integrate over downstream advection and cooling

-> radio emission per shock area

$$\frac{\mathrm{d}P(\nu_{\mathrm{obs}})}{\mathrm{d}\nu} = 6.4\times 10^{34}\,\frac{\mathrm{erg}}{\mathrm{s\,Hz}}\,\frac{A}{\mathrm{Mpc}^2}\,\frac{n_{\mathrm{e}}}{10^{-4}\mathrm{cm}^{-3}}\,\frac{\xi_{\mathrm{e}}}{0.05}\left(\frac{\nu_{\mathrm{obs}}}{1.4\,\mathrm{GHz}}\right)^{-\frac{s}{2}} \times\left(\frac{T_{\mathrm{d}}}{7\,\mathrm{keV}}\right)^{\frac{3}{2}}\frac{\left(\frac{B}{\mu\mathrm{G}}\right)^{1+\frac{s}{2}}}{\left(\frac{B_{\mathrm{CMB}}}{\mu\mathrm{G}}\right)^2+\left(\frac{B}{\mu\mathrm{G}}\right)^2}\,\Psi(\mathcal{M},T)$$

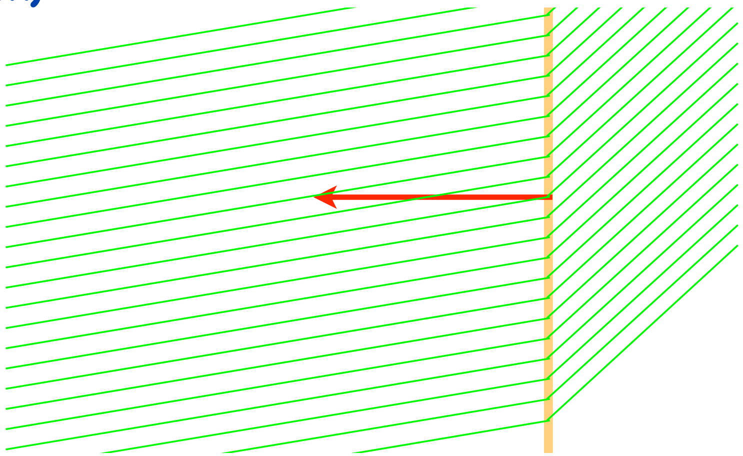
The emission model

- ψ(M) rises steeply between 2-4



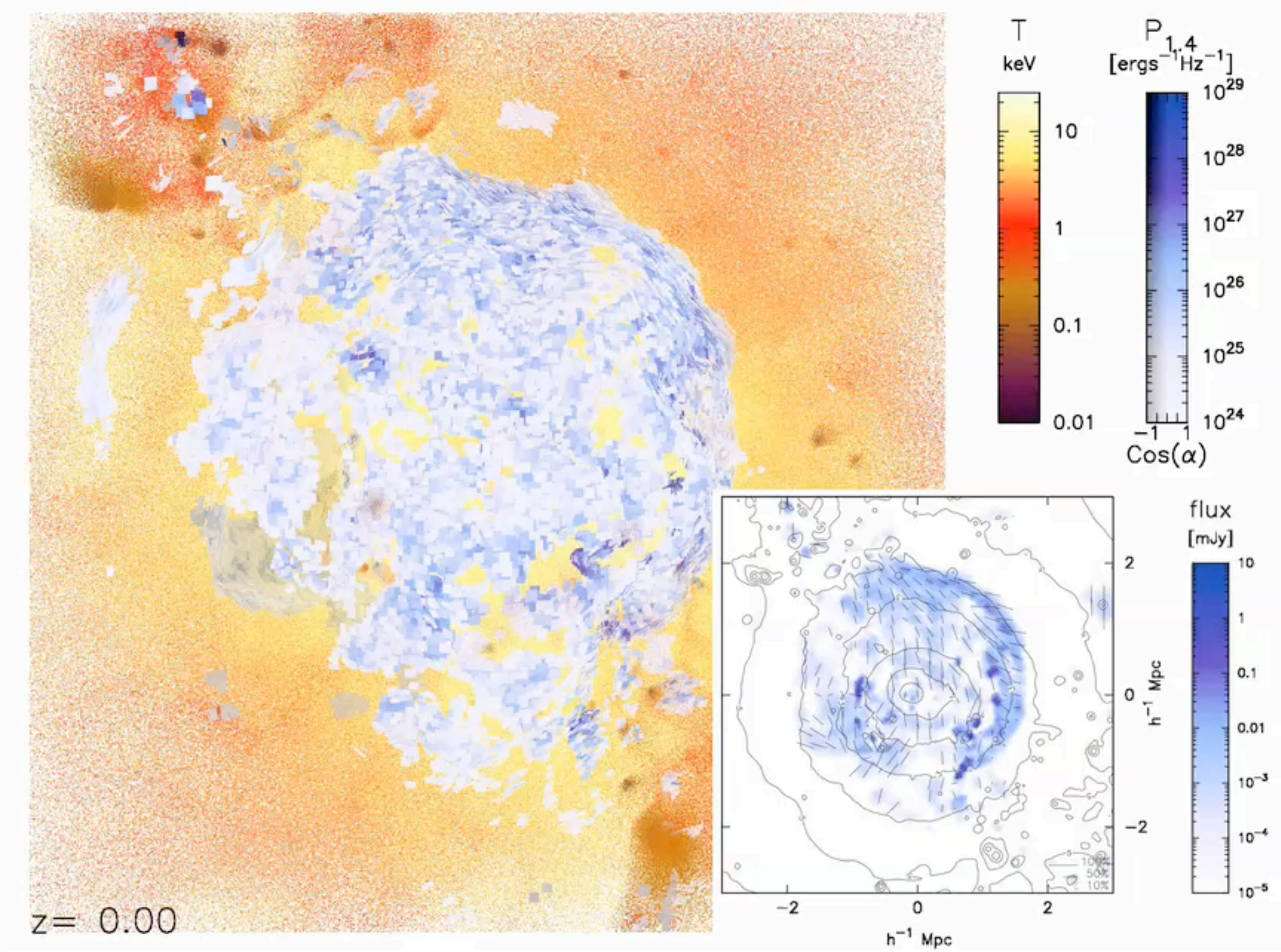
Model for the polarization

- downstream B direction according jump conditions (fast shock)



- randomly tangled magnetic field upstream

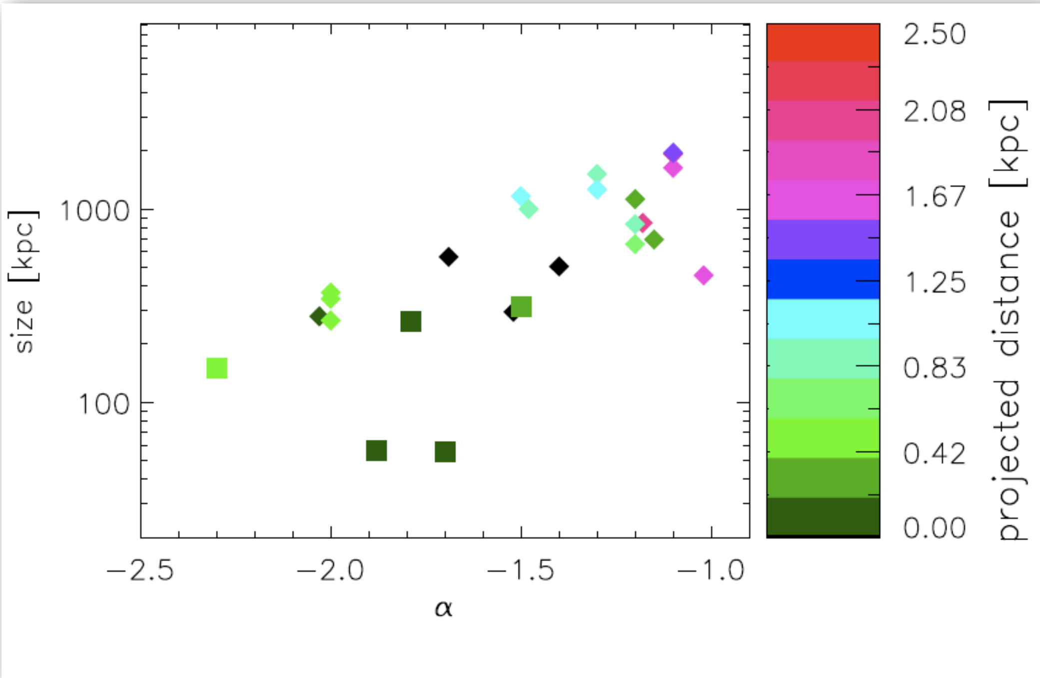
[Burn 66, Enßlin et al 98]



z= 0.00
T
keV
10
1
0.1
0.01
$P_{1.4}$ [ergs^{-1}Hz^{-1}]
10^{29}
10^{28}
10^{27}
10^{26}
10^{25}
10^{24}
−1 1
Cos(α)
flux
[mJy]
10
1
0.1
0.01
10^{-3}
10^{-4}
10^{-5}
2
0
−2
h^{-1} Mpc
−2 0 2
h^{-1} Mpc

Statistics of radio relics

- about 25 relics are known (only!)
- size $\propto$ distance
- correlation between luminosity and slope



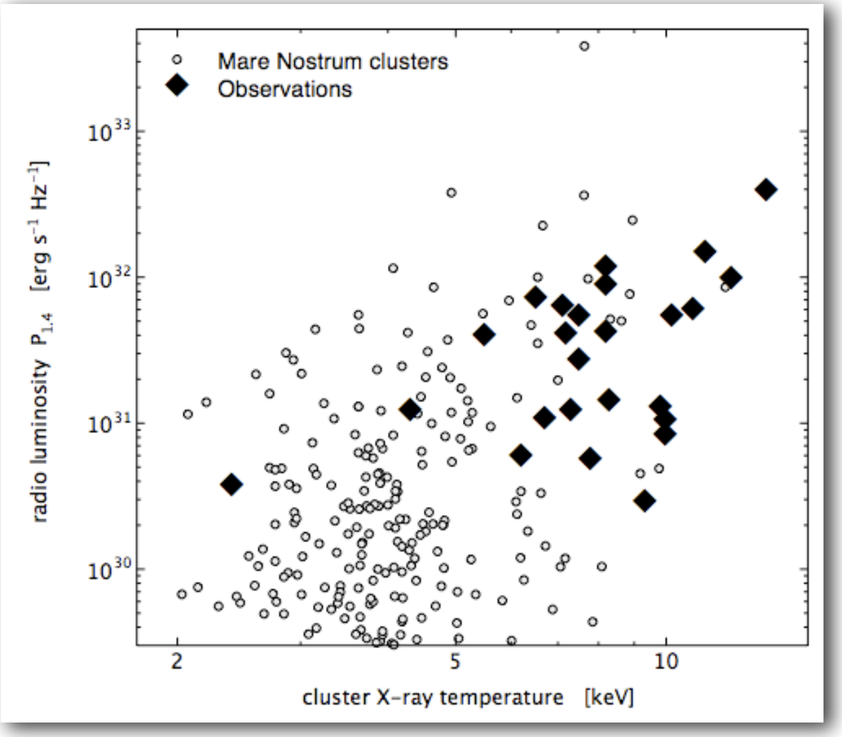
[van Weeren et al. 2009]

X-ray — radio correlation

or: 'populate' shock fronts with radio emission

Assumptions:

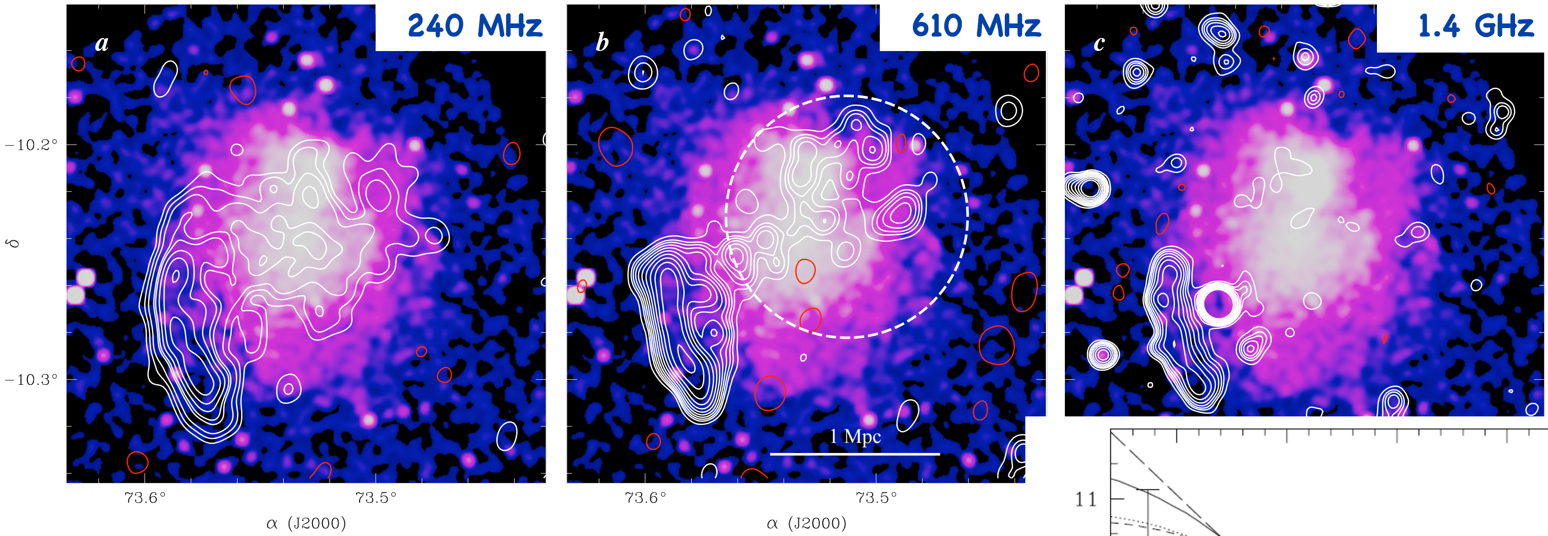
- $B \propto n^{2/3}$,
  alternative: B self-generated by shocks?
- acceleration efficiency of 10^{-3},
  alternative: Mach number depended efficiency?

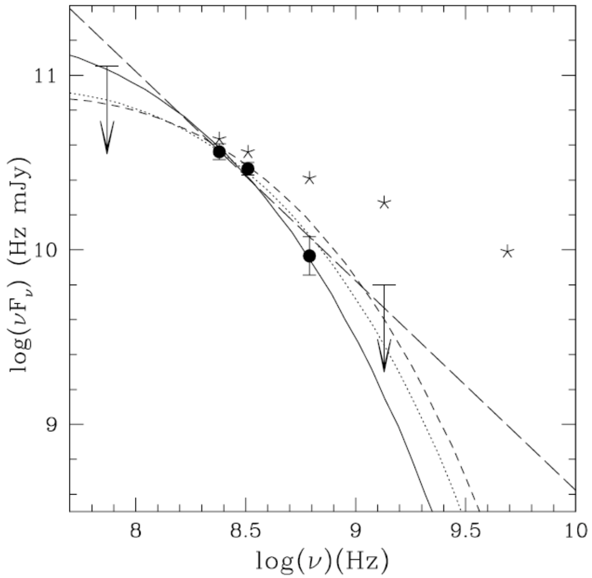



LOFAR
30 - 80
& 120 - 240 MHz
aperture
synthesis array
core, remote and
international stations
Nordsee
Ostsee
Atlantik
© Spektrum der Wissenschaft
Emde-Grafik

Low frequency observations

(The only possibility to find some objects ...)



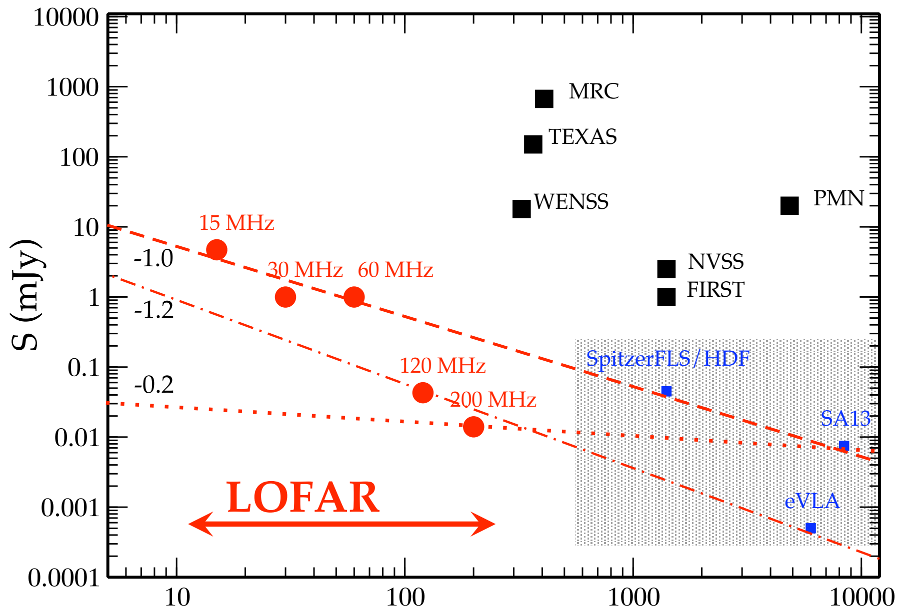


Ultra steep radio halo in Abell 521

[Brunetti et al. 2007]

Sensitivity and resolution of Lofar

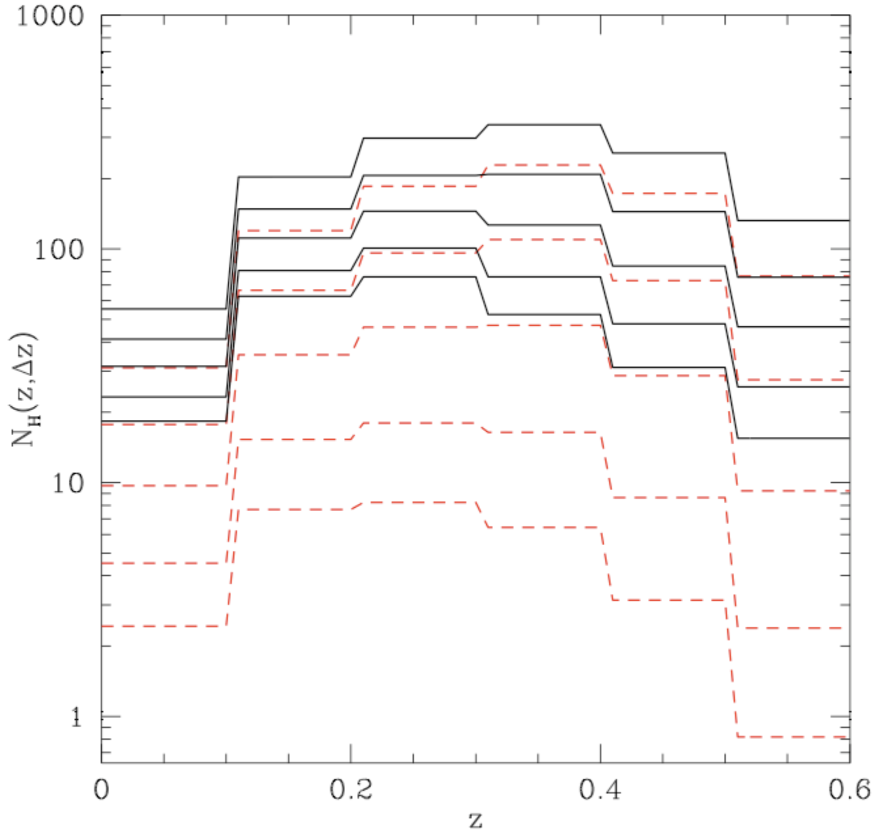
Freq. (MHz)	λ (m)	Resolution L = 80 km (arcsec)
15	20.0	41.3
30	10.0	20.6
45	6.67	13.8
60	5.00	10.3
75	4.00	8.25
120	2.50	5.16
150	2.00	4.13
180	1.67	3.44
210	1.43	2.95
240	1.25	2.58



[Roettgering 06]

Expected number counts for radio halos with LOFAR

Number counts for all sky survey with 120 MHz



[Cassano et al. 2010]

The case against DSA

- Not found in the termination shock

- Flat spectrum SN remnants

- Where are the protons?

Issues to investigate with LOFAR and SKA

Find more sources

needed: high sensitivity (at low frequencies)

Spectra

needed: cover 10 MHz to 10 GHz, spatially resolved

Polarization

needed: Pol + RM maps (probably only possible above ~ 1 GHz)

Why?

Structure and origin of cosmic magnetic fields

Particle acceleration at shock fronts

Physics of ICM and IGM (spectra of turbulence, mircrophysics, ..)