Shocking news from cluster outskirts
or
Always trouble with relics

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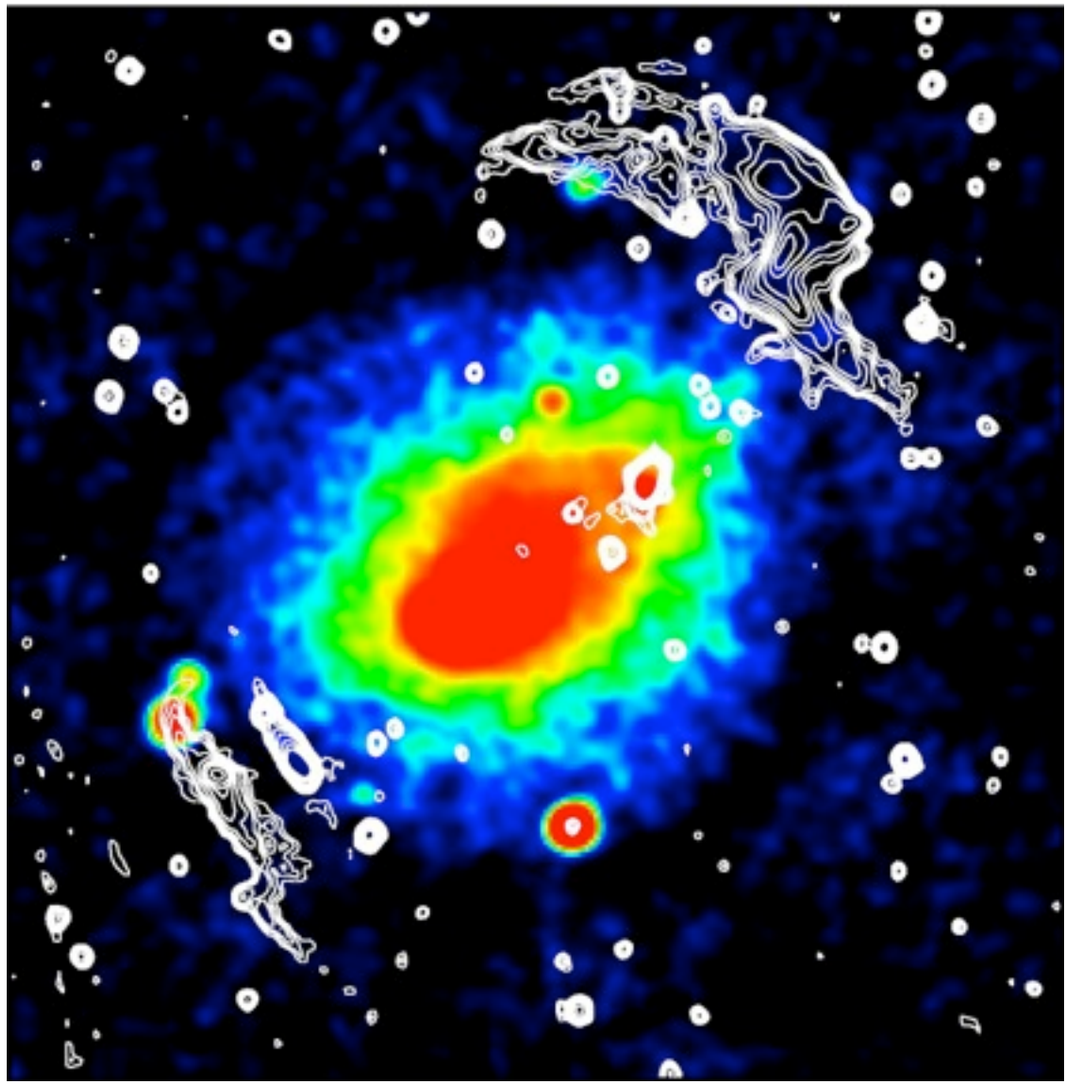
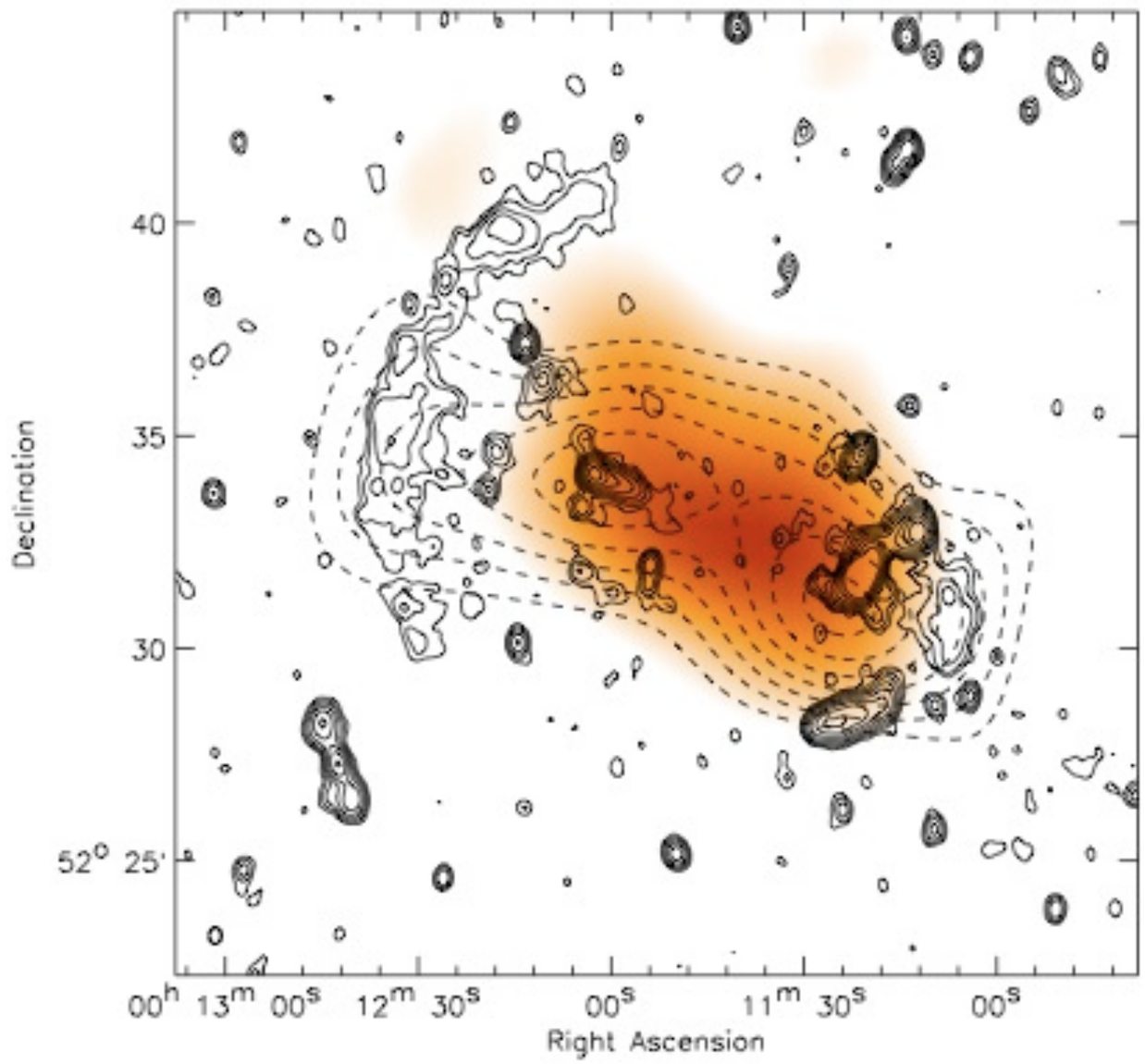
What are radio relics?



Abell 3667

colour: X-ray
contours: radio

Röttgering 97

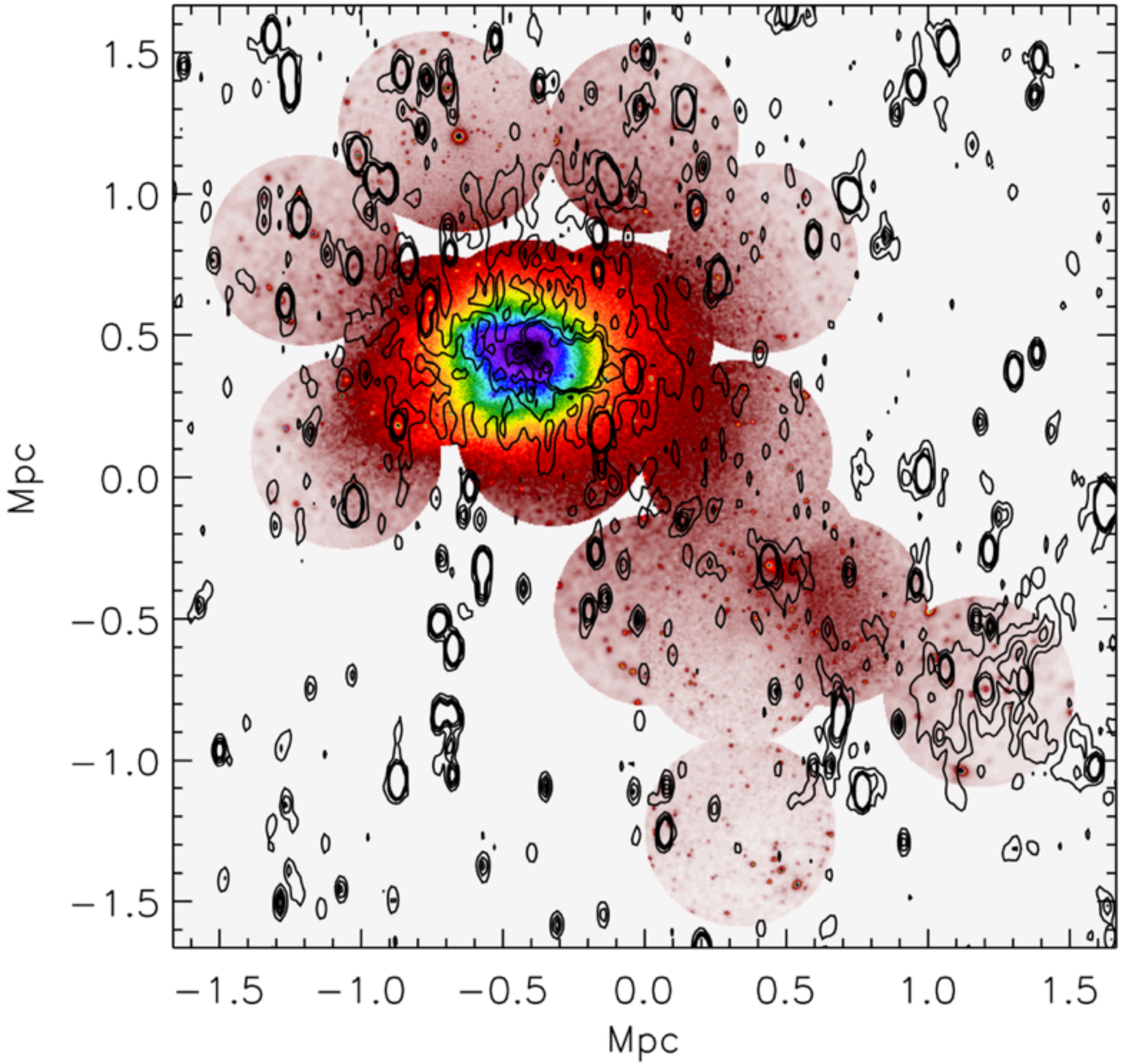


ZwCl 0008.8+5215
van Weeren et al. 11

Why bother ?

- In galaxies cosmic rays constitute 1/3 of the energy density: CR crucial in galaxy formation (Springel et al. 2006)
- Origin of ultra-high energy cosmic rays?
- The low-frequency radio sky is dominated by these diffuse sources: unique tracer of ongoing structure formation
- Tracer of IGM magnetic fields
- Contribution to foreground of polarised CMB?

But so far only about 30 relics are known. Difficult to find


1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Mpc
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
Mpc

Coma Cluster

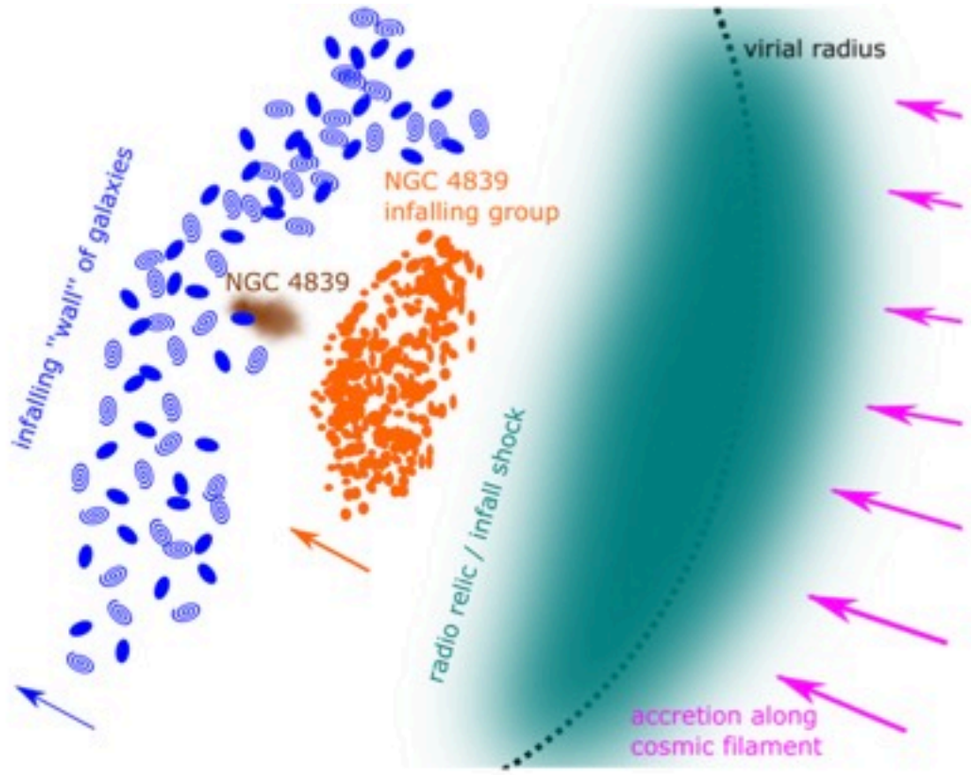


Figure 6. Cartoon of the dynamics around the Coma relic region. **The shock front does not move significantly over the synchrotron time of the cosmic ray electrons.** The figure is not to scale.

XMM: M=2 shock

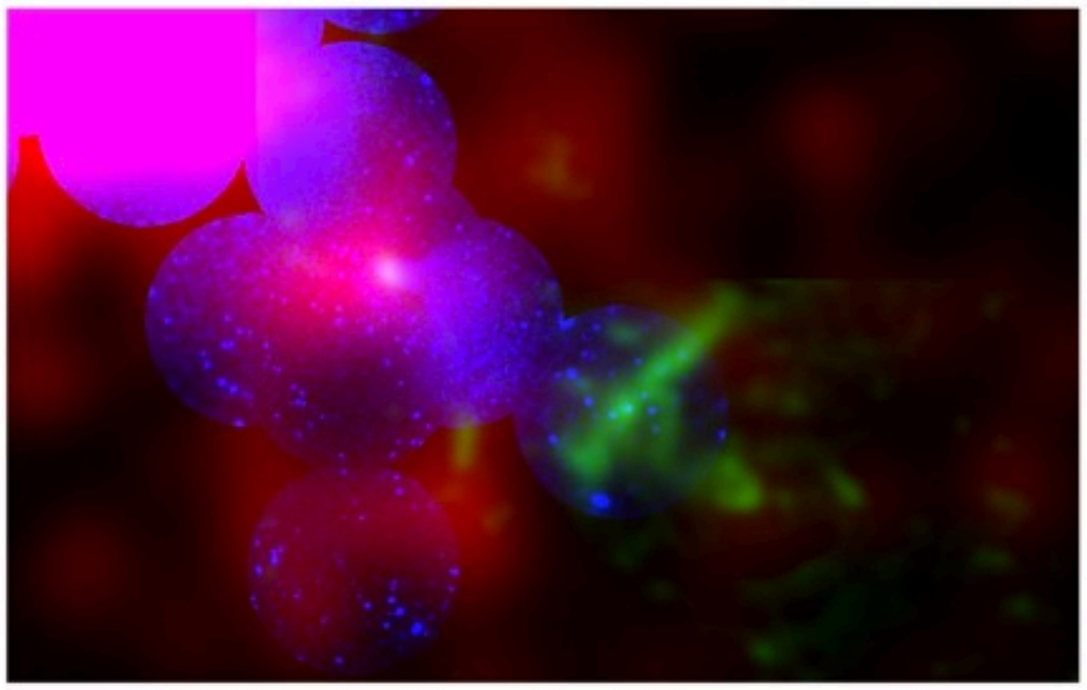
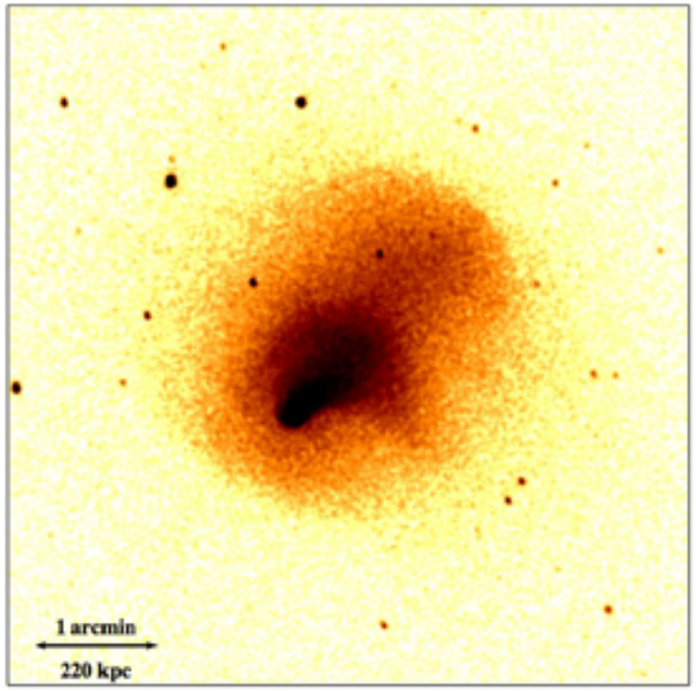
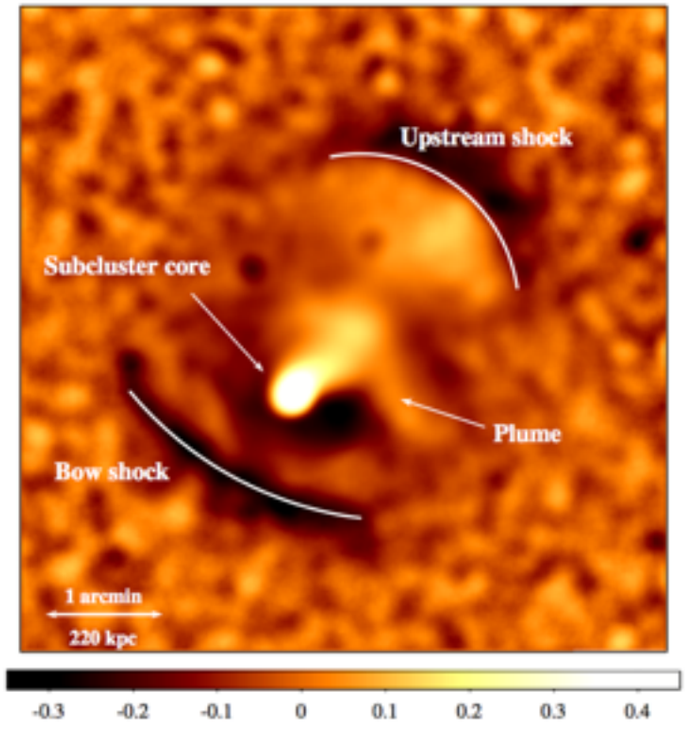


Figure 7. Optical/radio/X-ray (red/green/blue) overlay showing the region of the Coma relic. The composite image contains

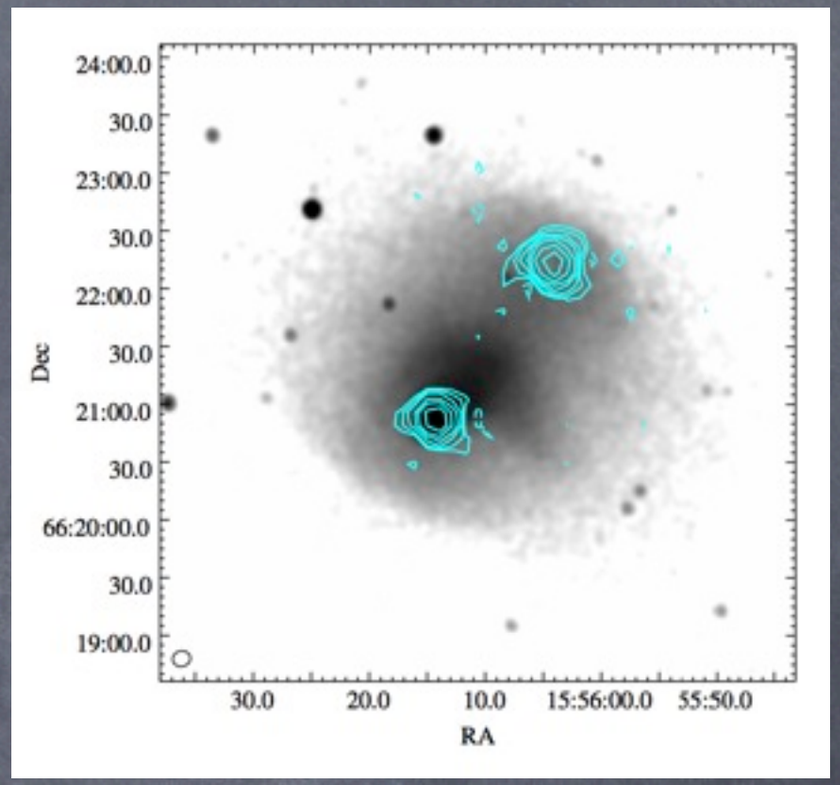
Ogrean & Brüggen 2013

Abell 2146 puzzle





Chandra 0.3-7.0 keV, Russell et al. 2011



GMRT 325 MHz

Mach numbers:

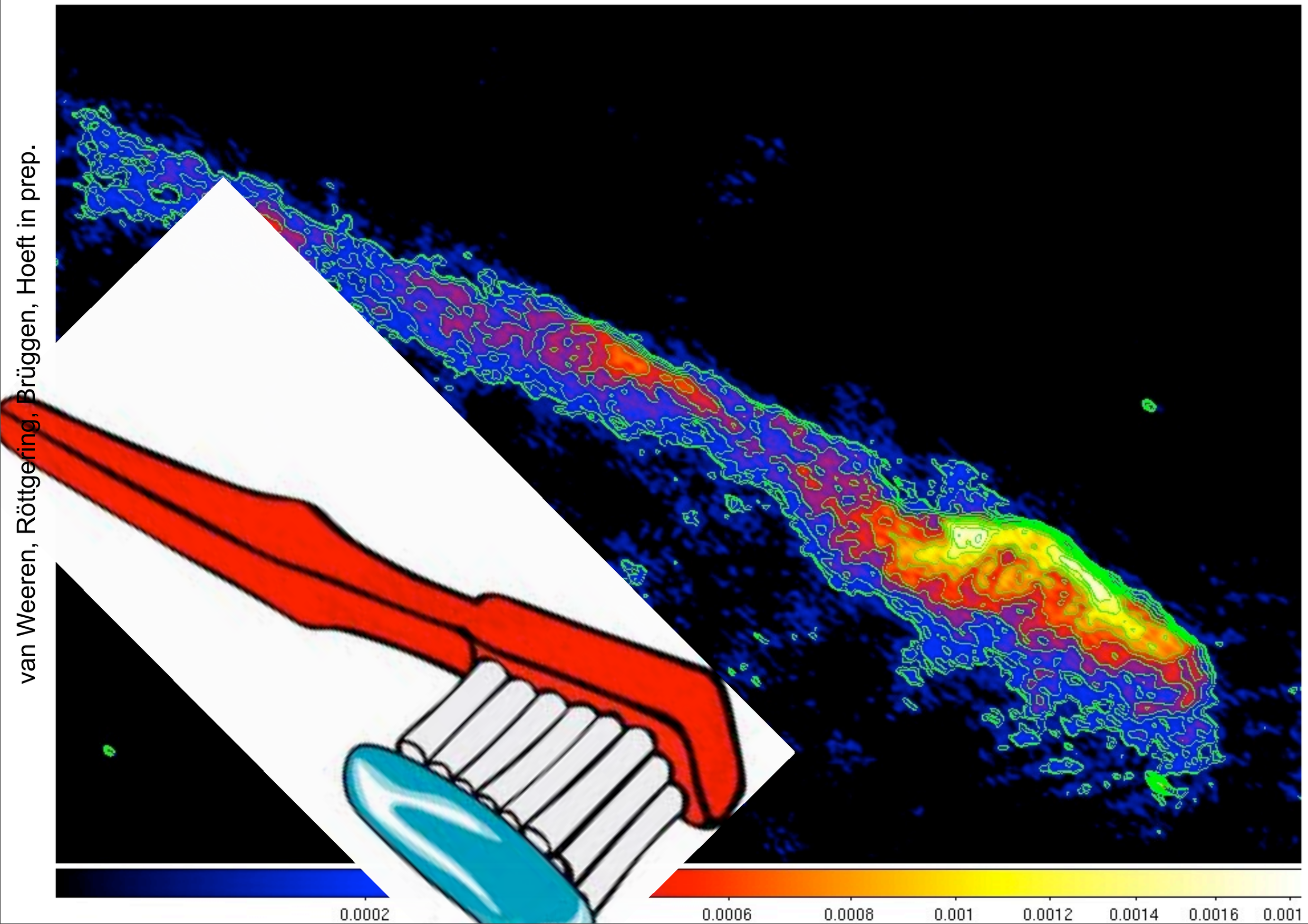
M = 2.1 +/- 0.2

M = 1.6 +/- 0.1

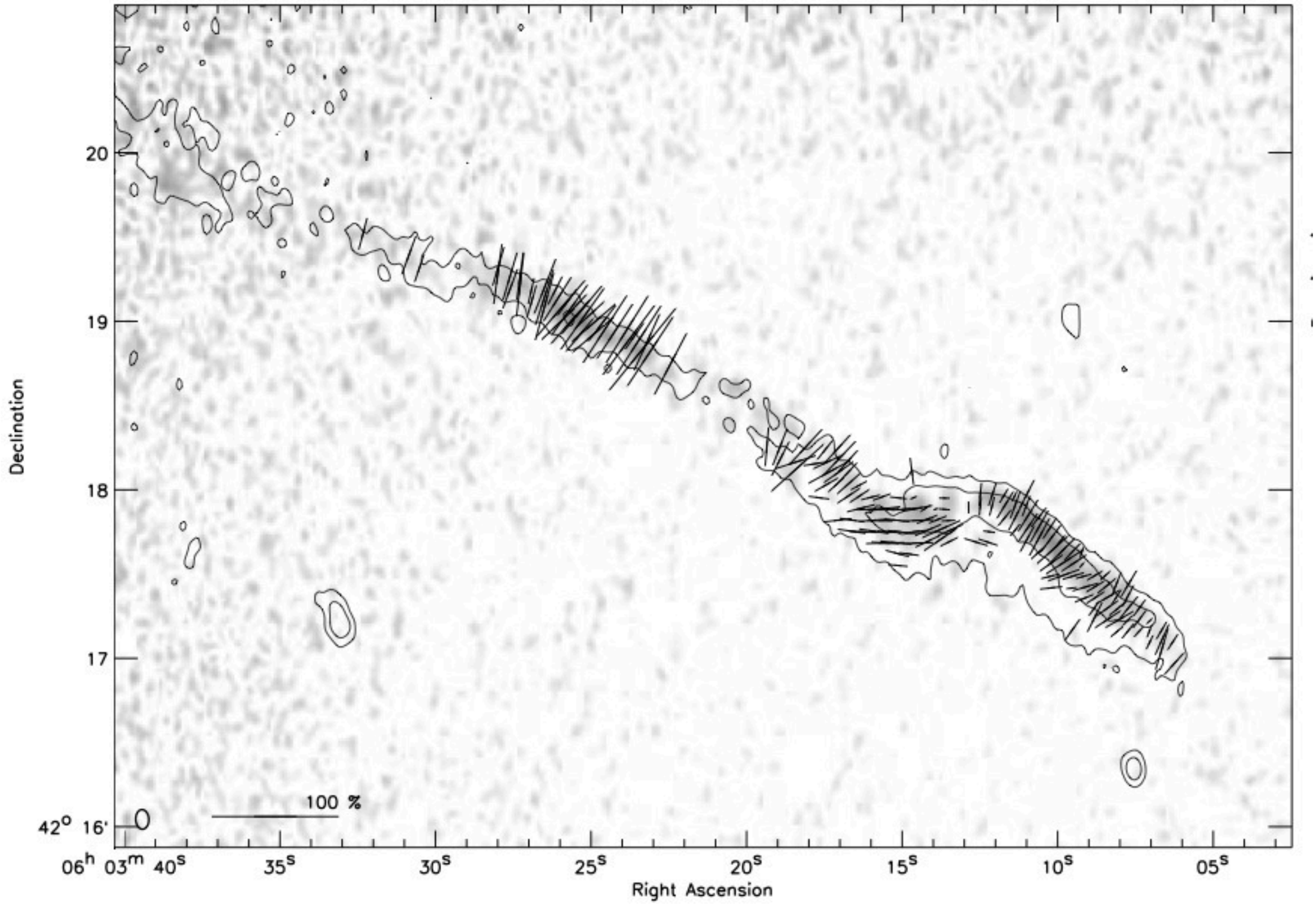
Why do we not observe radio emission from these shocks?

Slide from Reinout

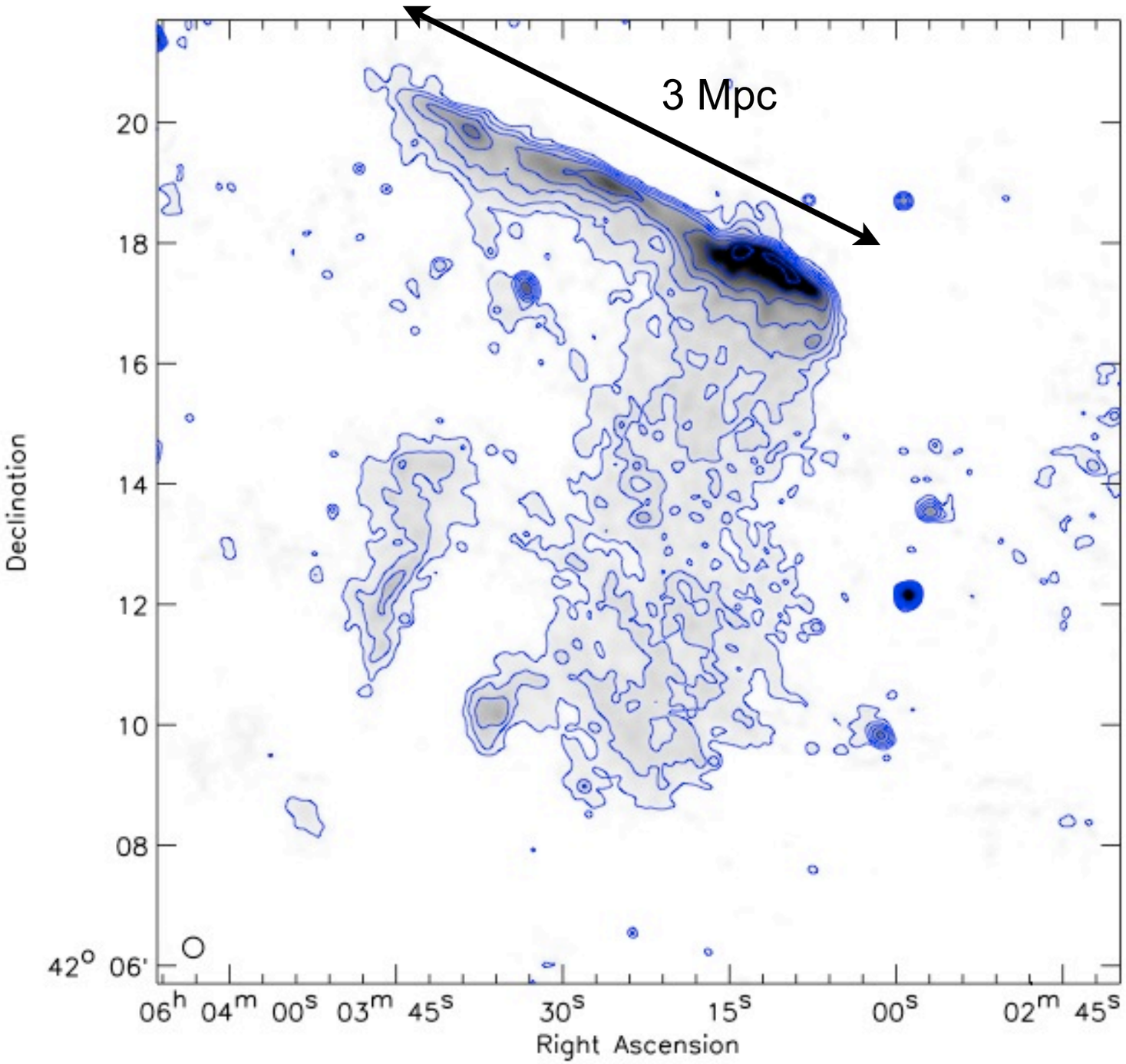
The toothbrush: **1RXS J0603.3+4213**



van Weeren, Röttgering, Brüggen, Hoeft in prep.


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

1RXS J0603.3+4213

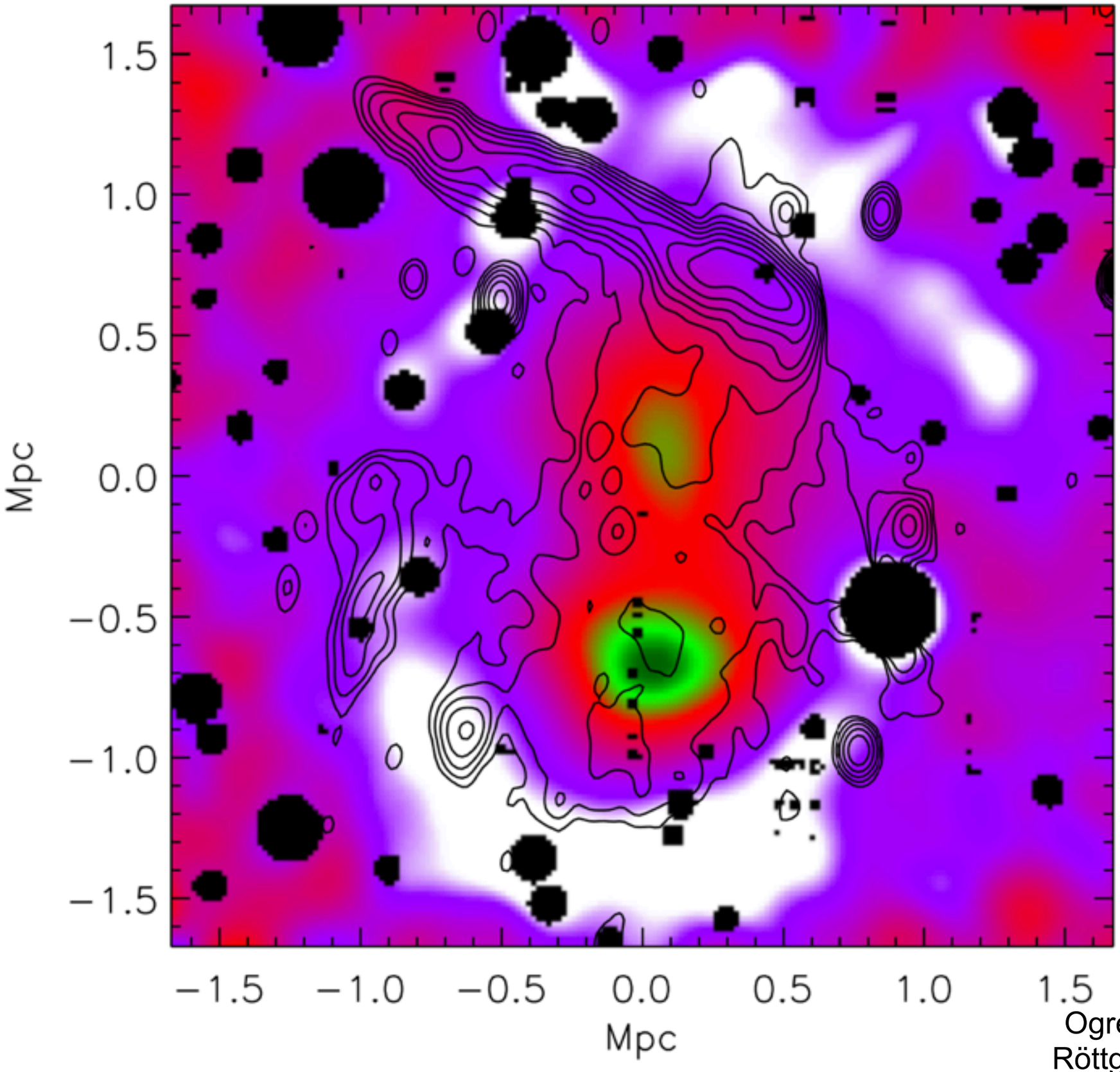


largest relic known to date

z=0.25

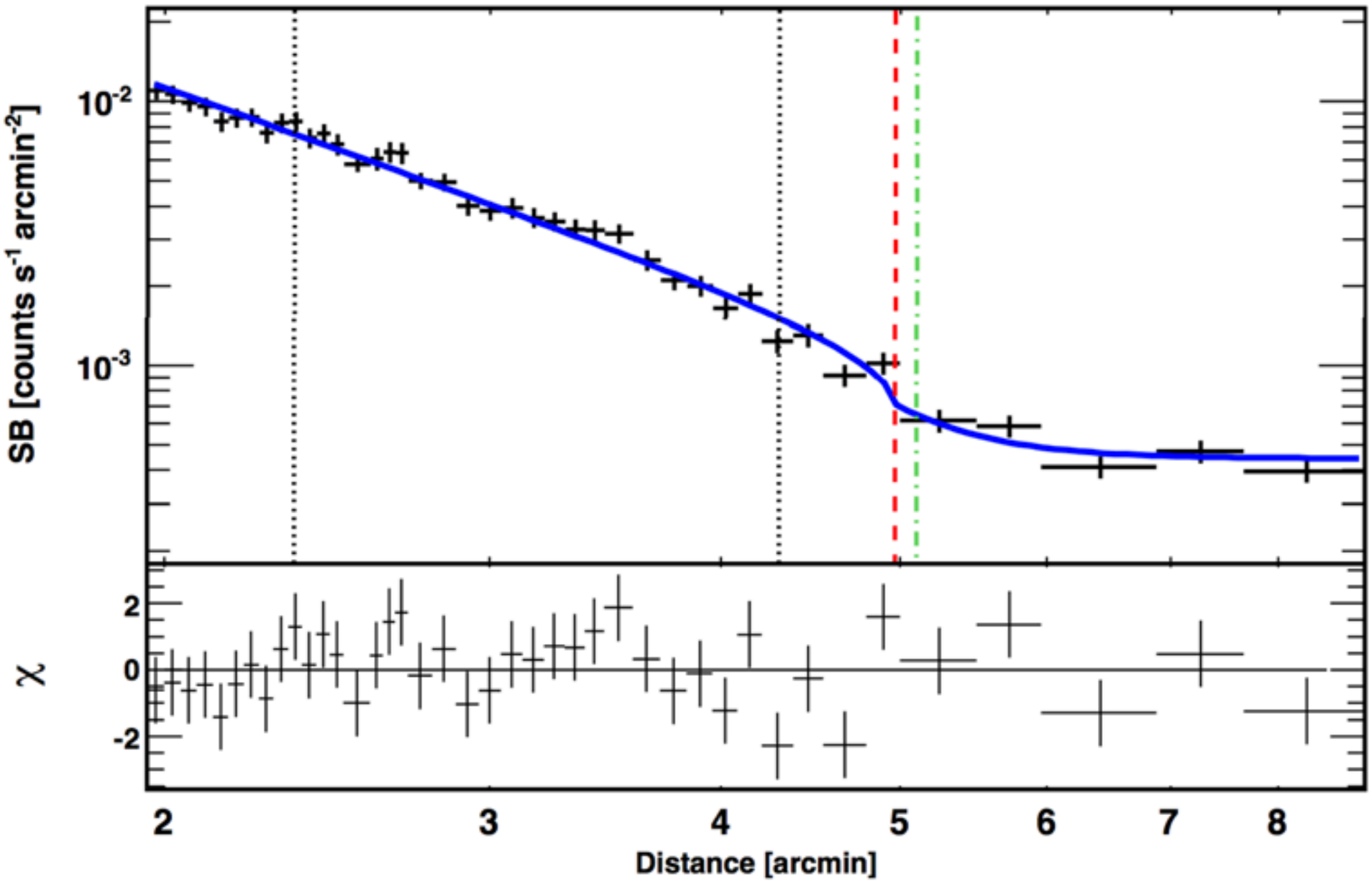
610 MHz GMRT map

XMM unsharp-masked



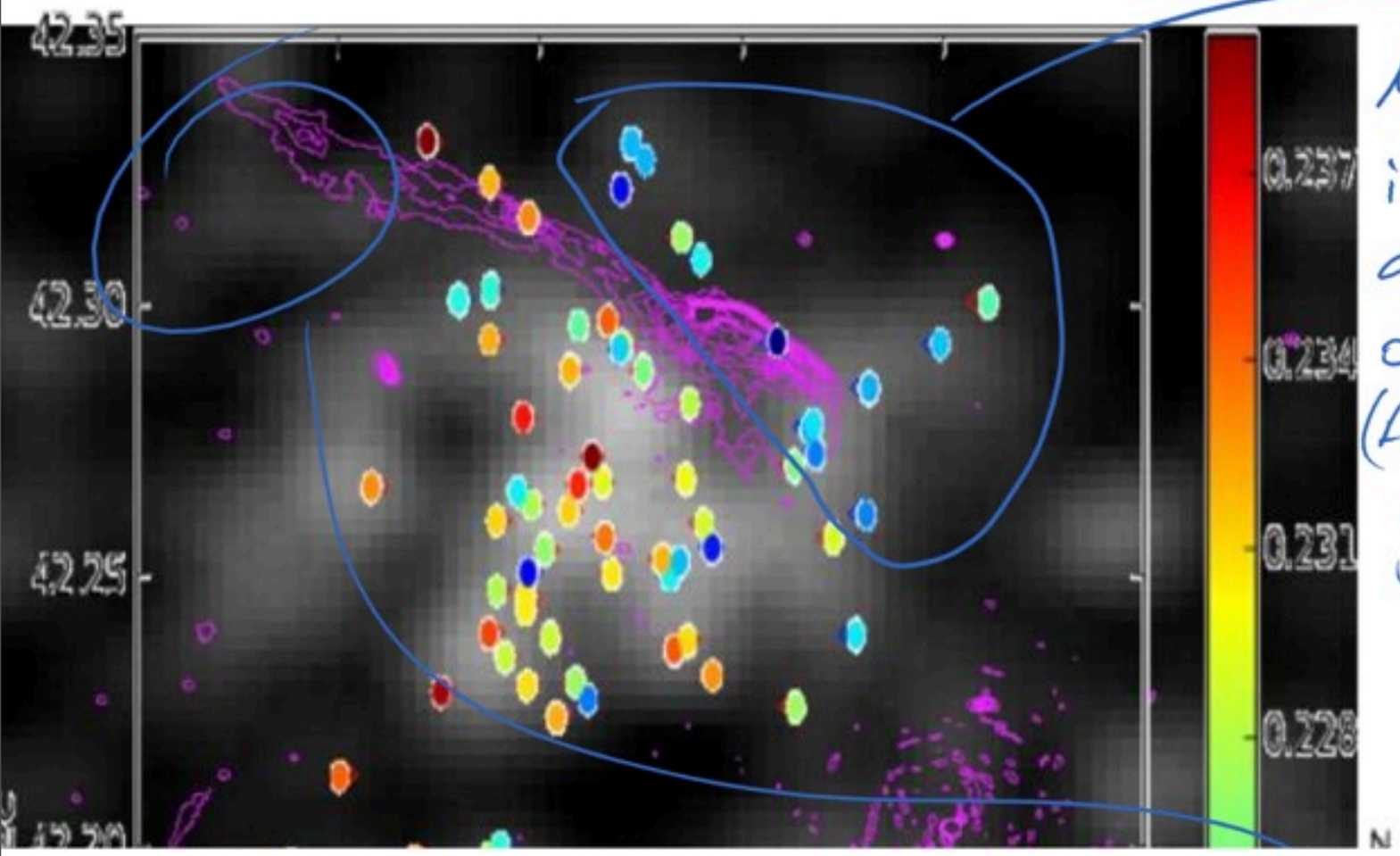
Ogrean, Brüggen,van Weeren,
Röttgering, Hoeft, Croston 2013

Surface brightness profile along N



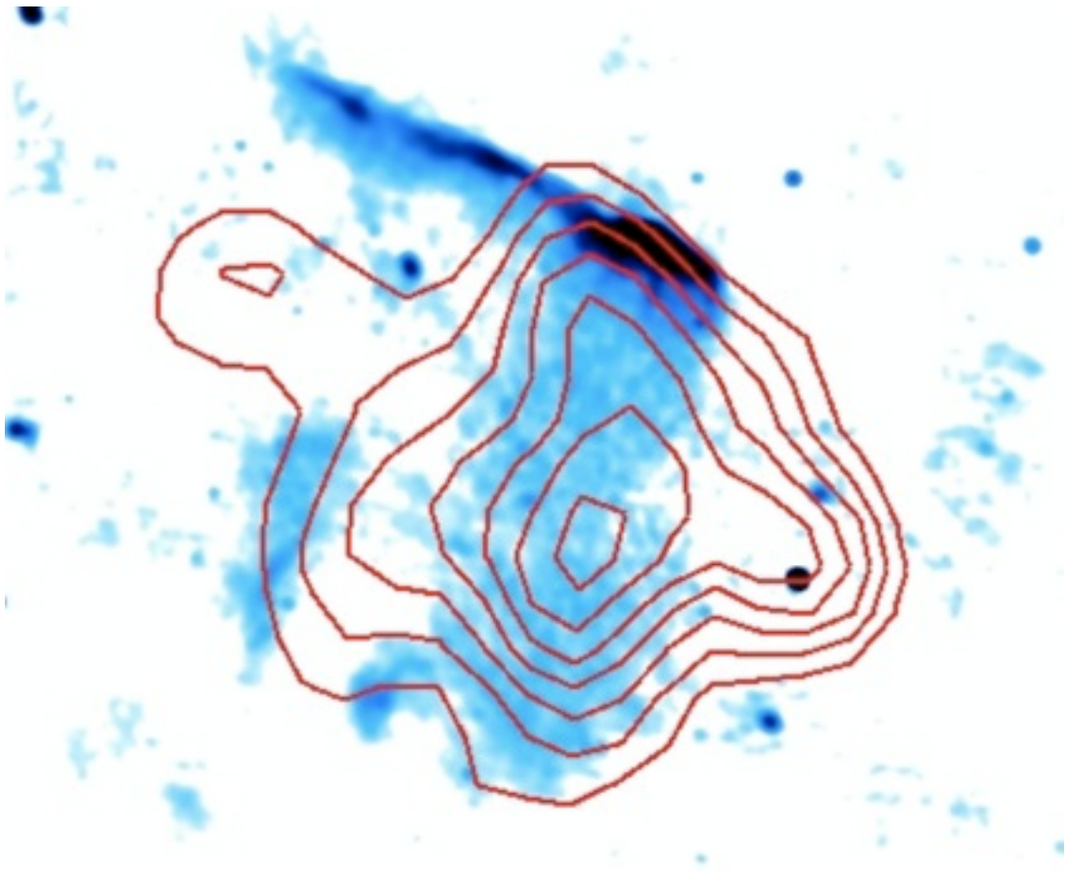
Ogrean, Brüggen,van Weeren,
Röttgering, Hoeft, Croston 2013

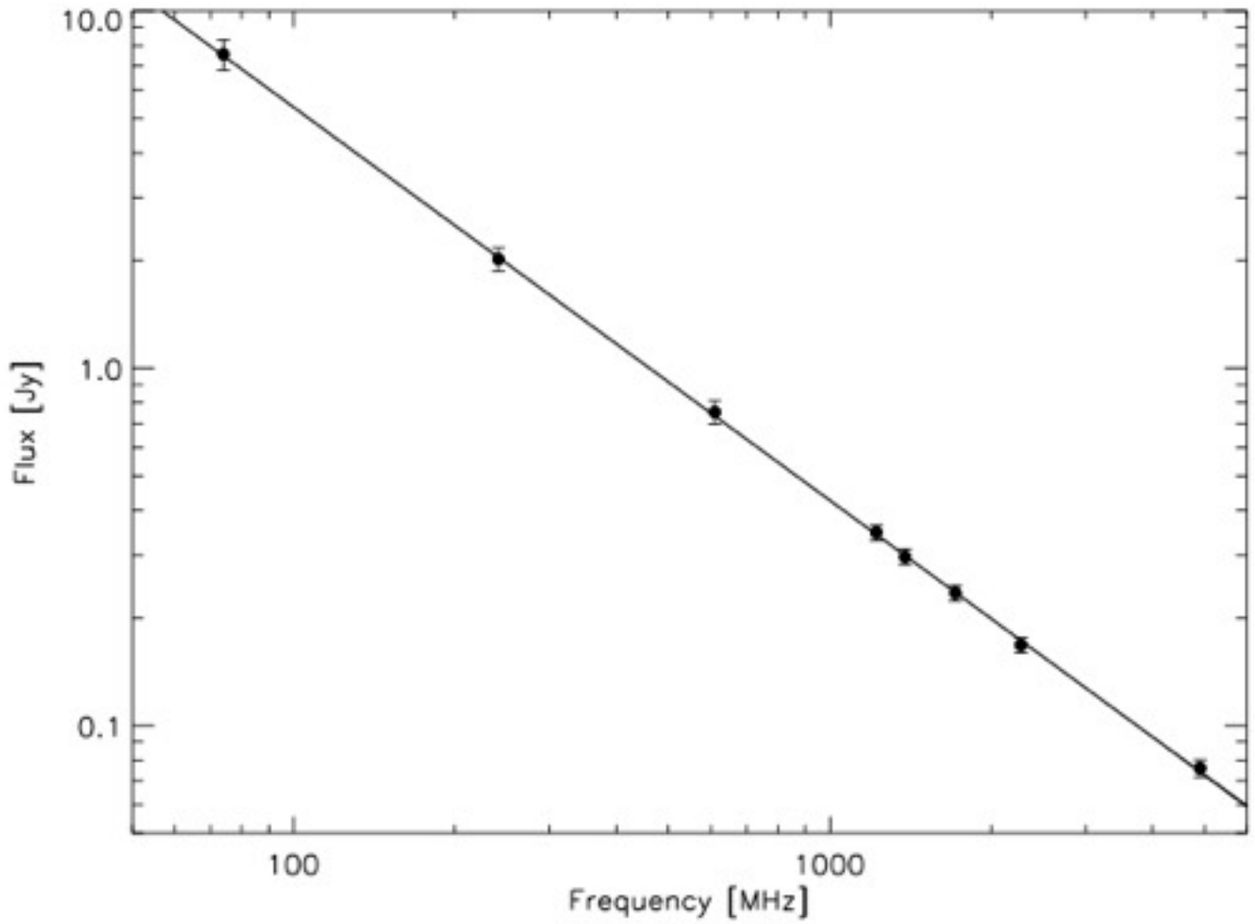
Keck-DEIMOS spectroscopy of the Toothbrush



Many of the bluer galaxies in the Northern subcluster are actually located ahead of the radio relic.
(About ½ of northern "blue" galaxies).

Some more puzzles



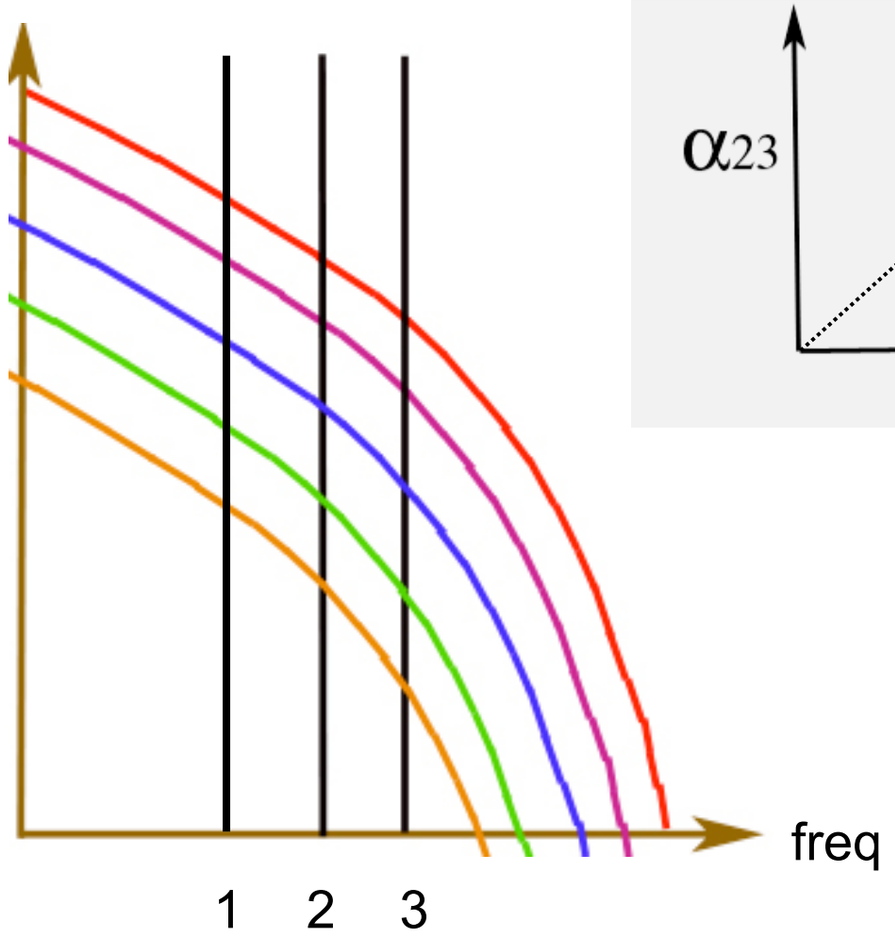


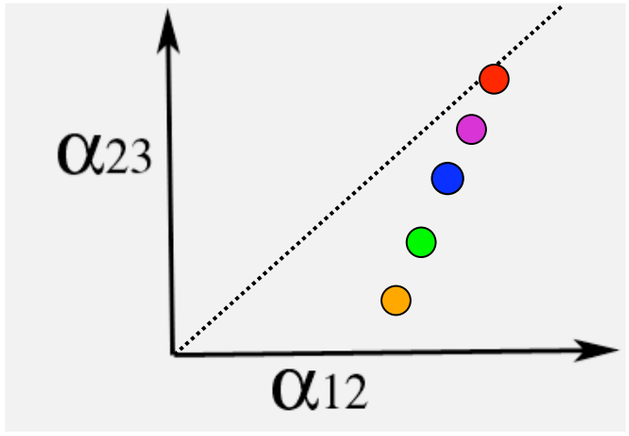
ROSAT

74 MHz - 4.9 GHz spectrum is a perfect power-law (alpha = -1.1 +/- 0.03)

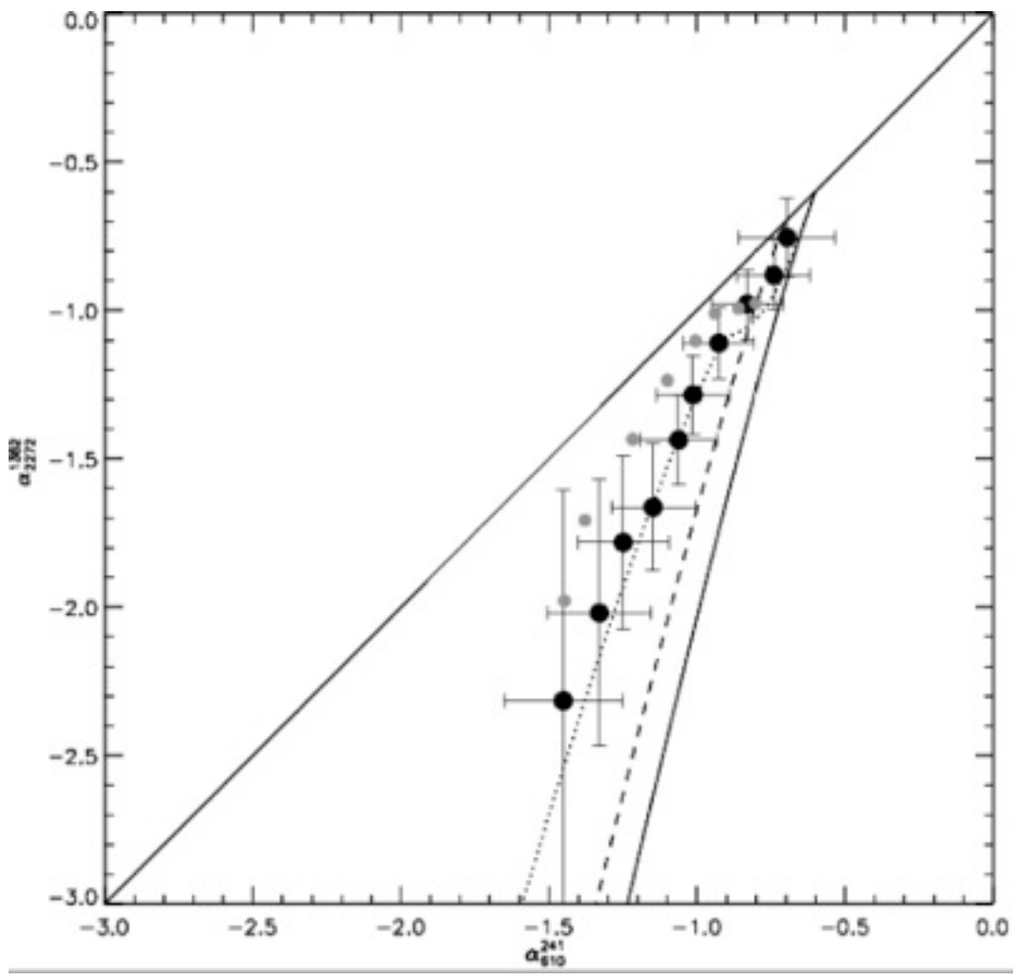
What does the relic really consist of?

- in reality things are more complicated
- not pure ageing
- mixture of populations
- PLUS extra steep spectrum component only visible at 50cm, 200cm



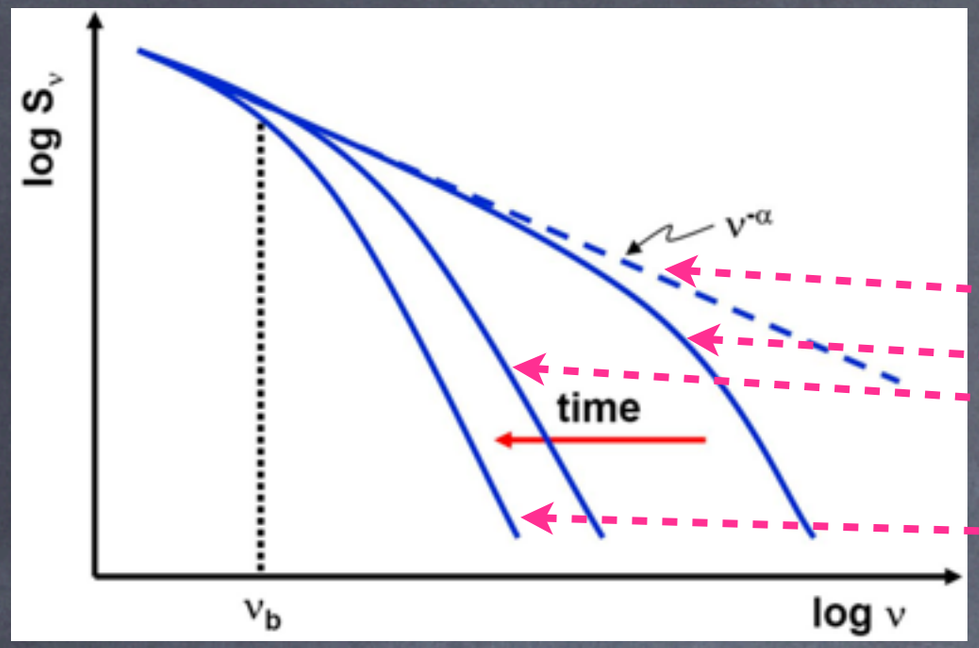


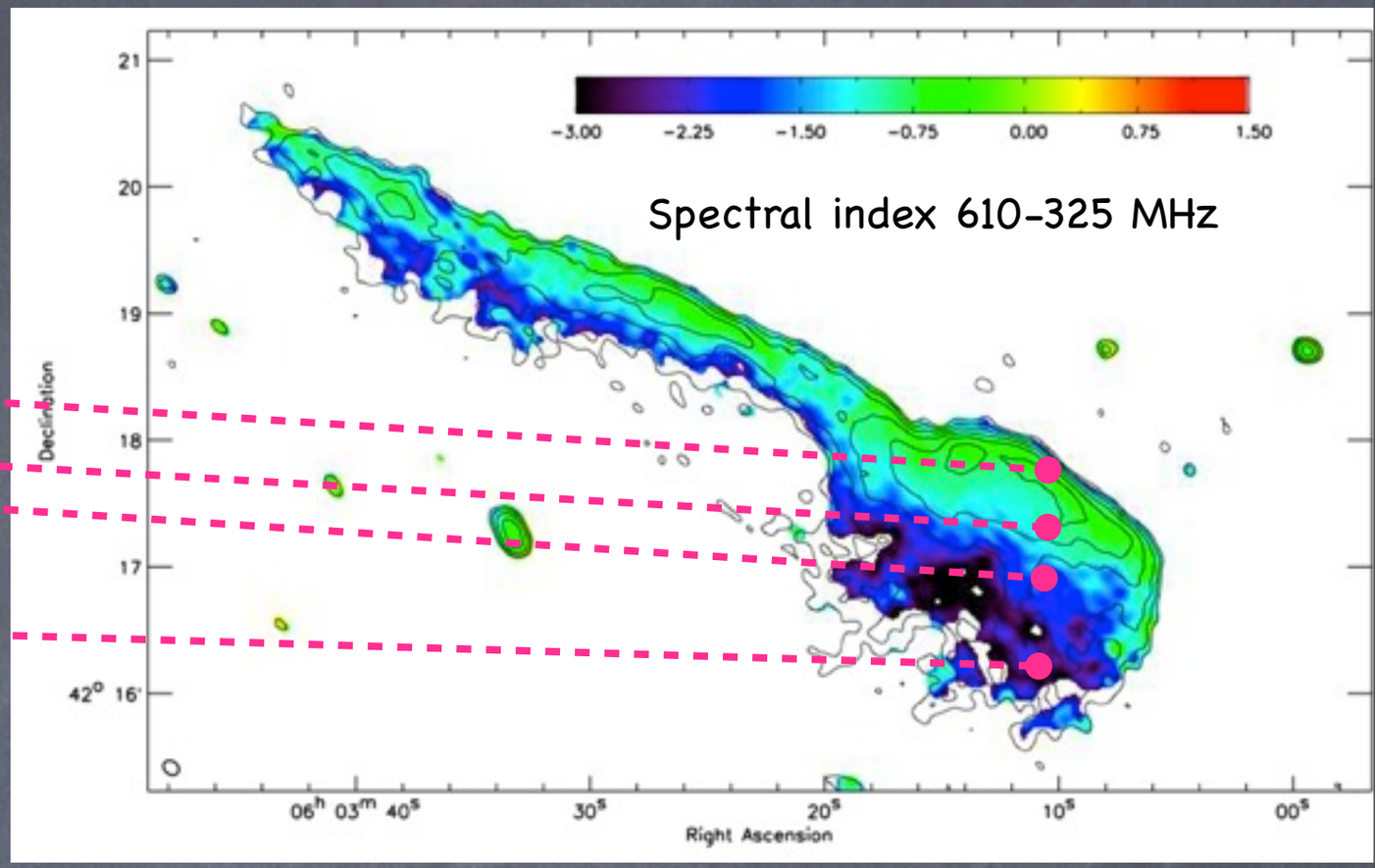
van Weeren et al. 2012



mix of spectral ages

1RXS 0603.3+4214





1. Spectral index gradient ✔

2. Power-law spectrum at relic's outer edge where acceleration takes place ? ✔

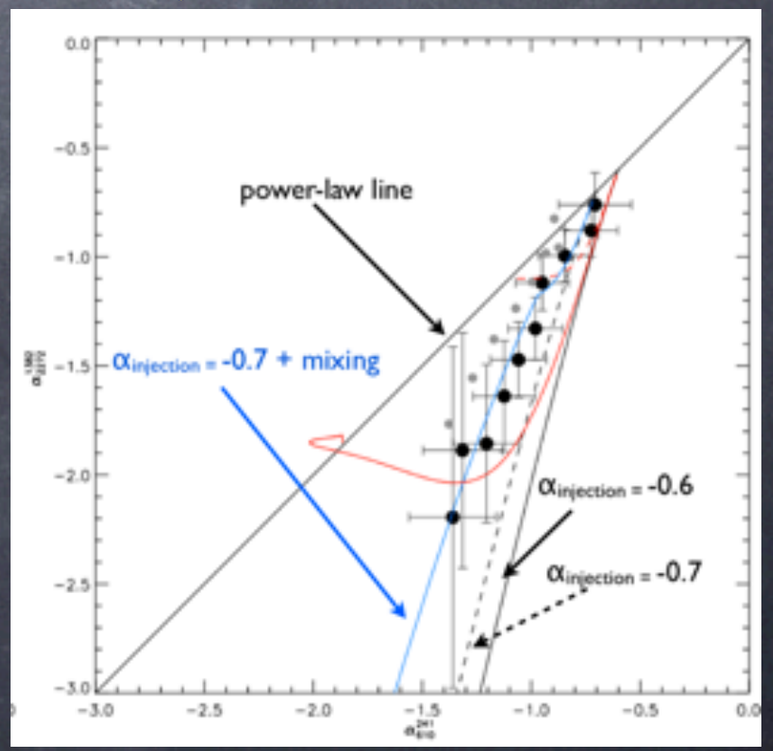
3. Curved spectra in the post-shock region due to energy losses ? ✔

8 flux measurements between 150 MHz and 2.1 GHz

extra information: 'flux normalization' of radio spectra with respect to the location of the break frequency

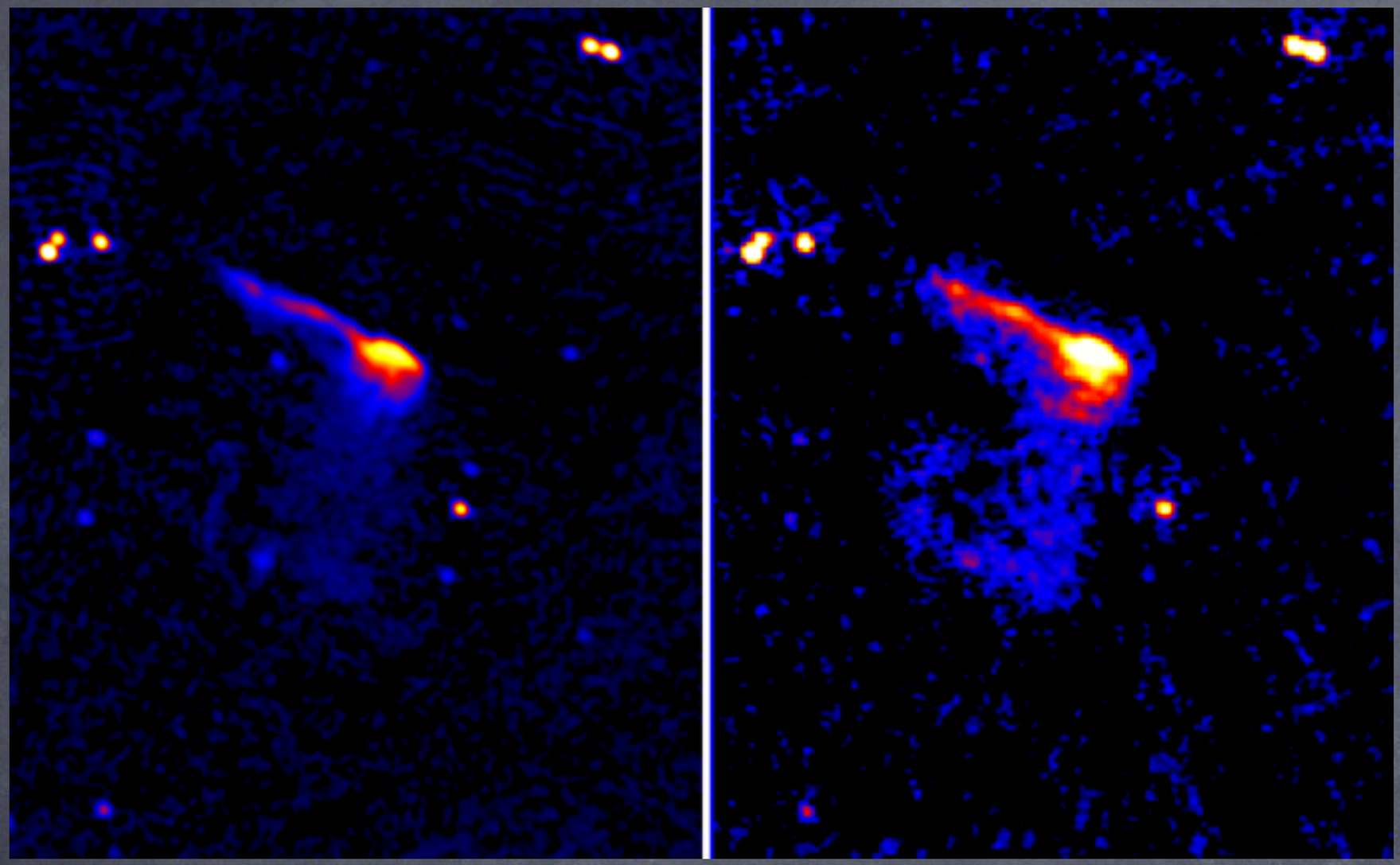
spectral shape change due to:

- B-field changes ? ✖ ?
- spectral ageing ? ✔



van Weeren+ 2012

LOFAR

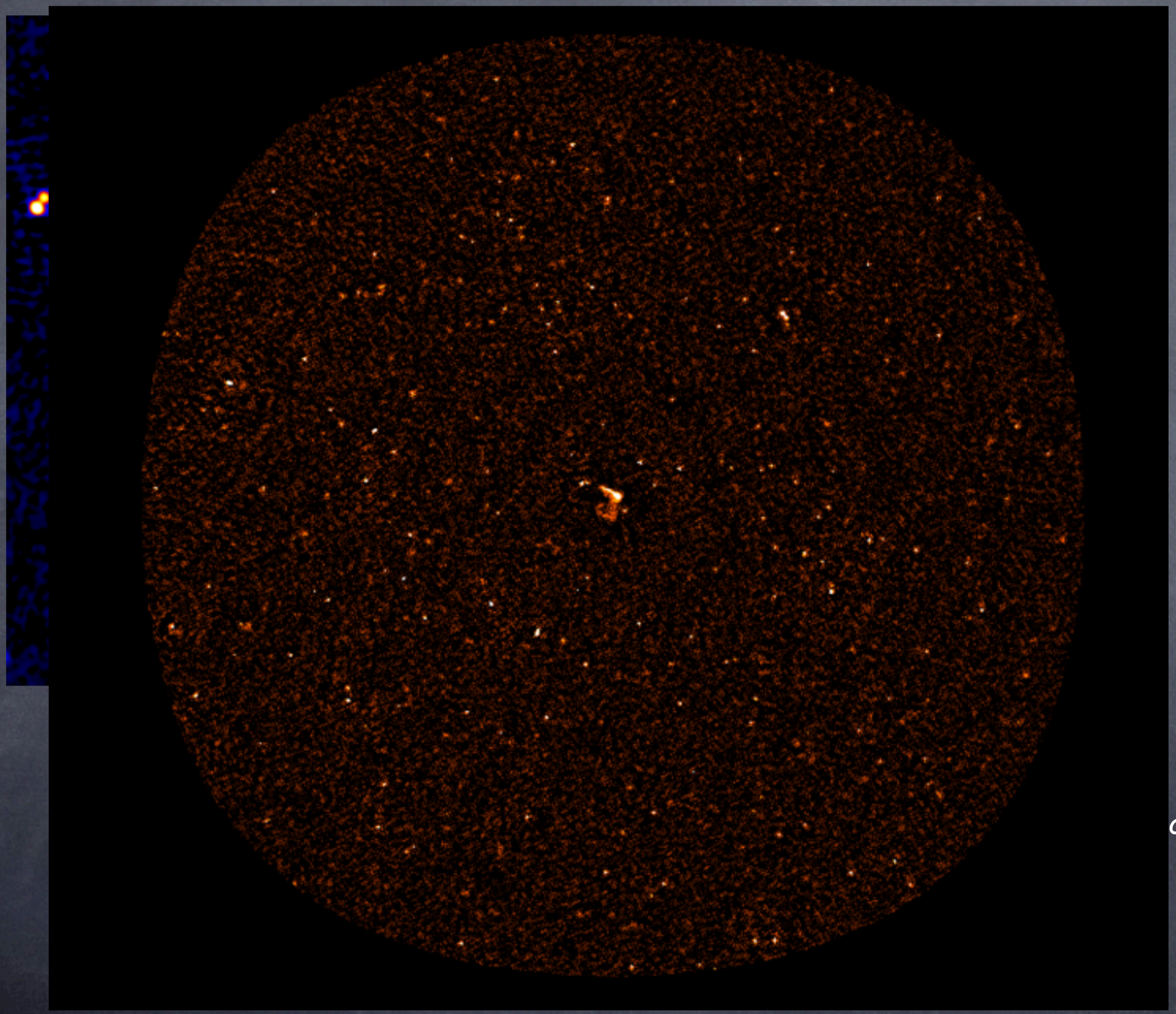


10 hrs GMRT @ 150 MHz

10 hrs LOFAR @150 MHz
- 0.3 % of the data
- 1/4 of the resolution available

Slide from Reinout

LOFAR



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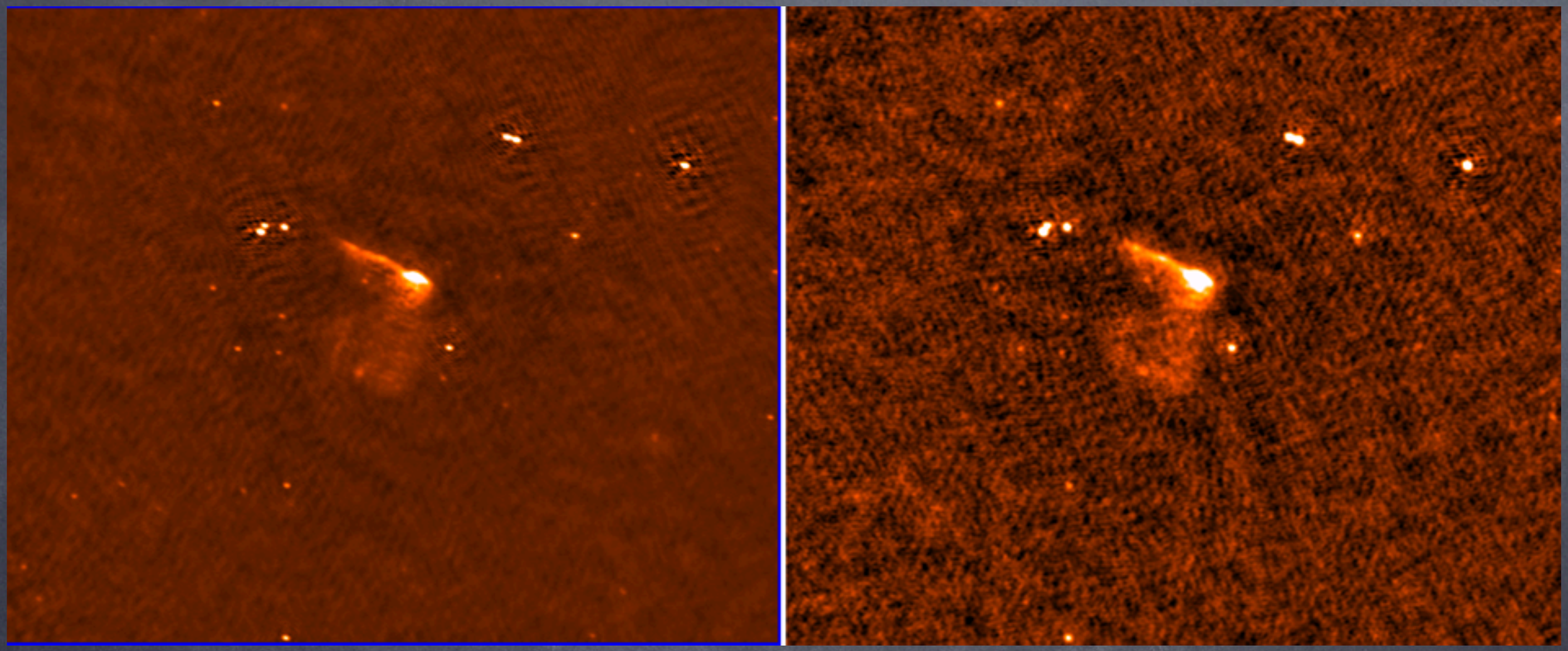
Slide from Reinout

LOFAR

Toothbrush cluster



10 hrs LOFAR @150 MHz
- 3 % of the data,
- 1/4 of the resolution available

10 hrs LOFAR @150 MHz
- 0.5 % of the data,
- 1/4 of the resolution available

Work in progress.....

Slide from Reinout

Conclusions

• Relativistic plasma is great for finding shocks in cluster outskirts and learn about B-fields

•Some cluster shocks show relics, some do not. (???)

• Some newly detected sources show best evidence to date for diffusive shock acceleration

• How can shock acceleration work at such low-M shocks?

• Shock in Toothbrush relic is 200 kpc offset from relic (???)

• First LOFAR observations of relics are becoming available