Deep L-band VLA observations of the Toothbrush cluster

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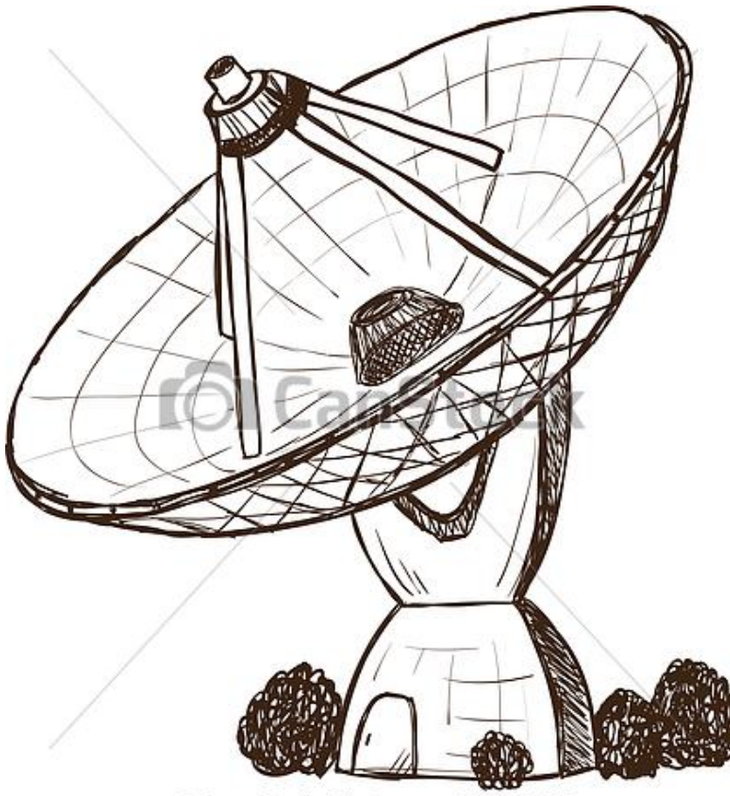
Why we study galaxy clusters in radio

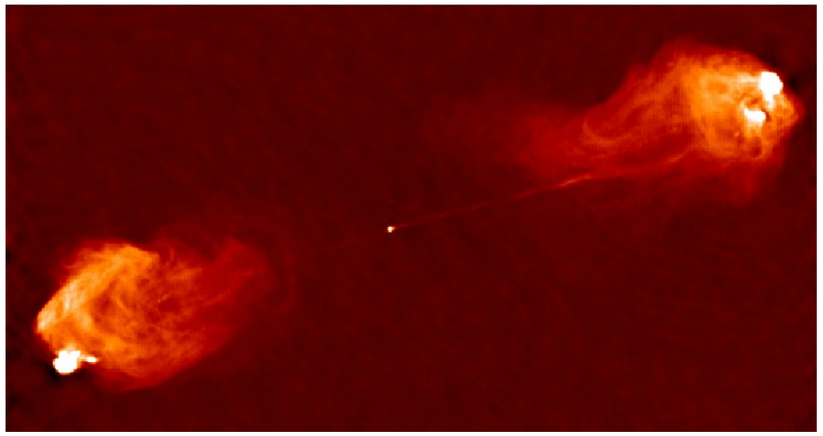
- Galaxy clusters (GCs) grow by mergers
- These mergers create shocks in the intracluster medium (ICM)
- Shocks have a profound impact :
  - heat up the X-ray
  - compress/amplify magnetic fields
  - accelerate particles

- Non-thermal component: fraction of GCs produce **diffused synchrotron emission** on clusters scale
  - physics of shocks & turbulence
  - particle acceleration mechanisms
  - magnetic fields in the ICM



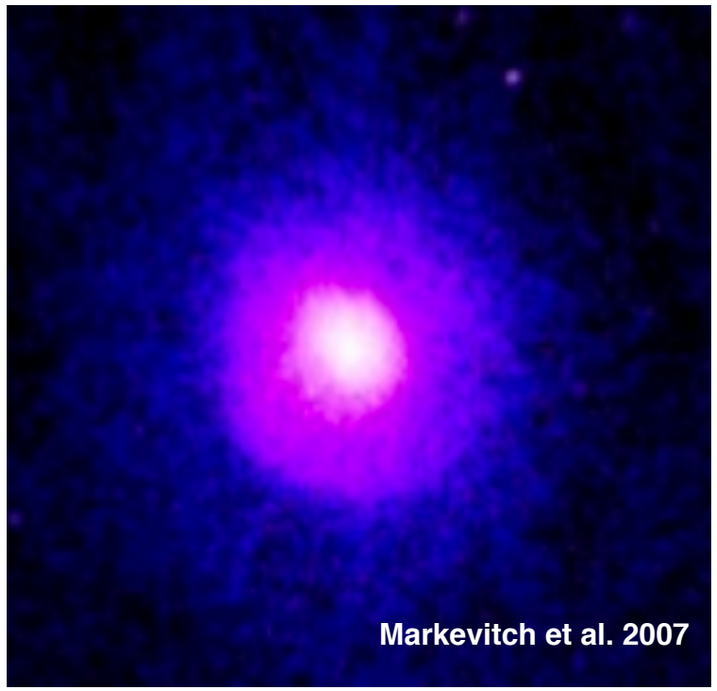
Radio emission from galaxy clusters

- **Radio halos**
- **Radio relics**
- **Radio mini halos**
- **AGN**



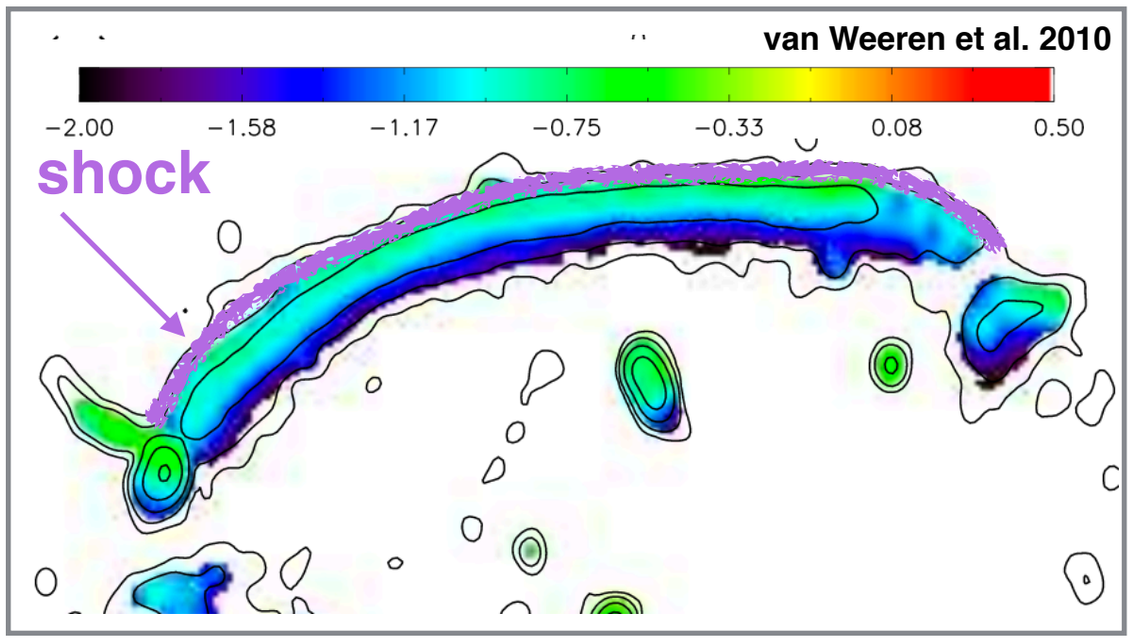
merging cluster

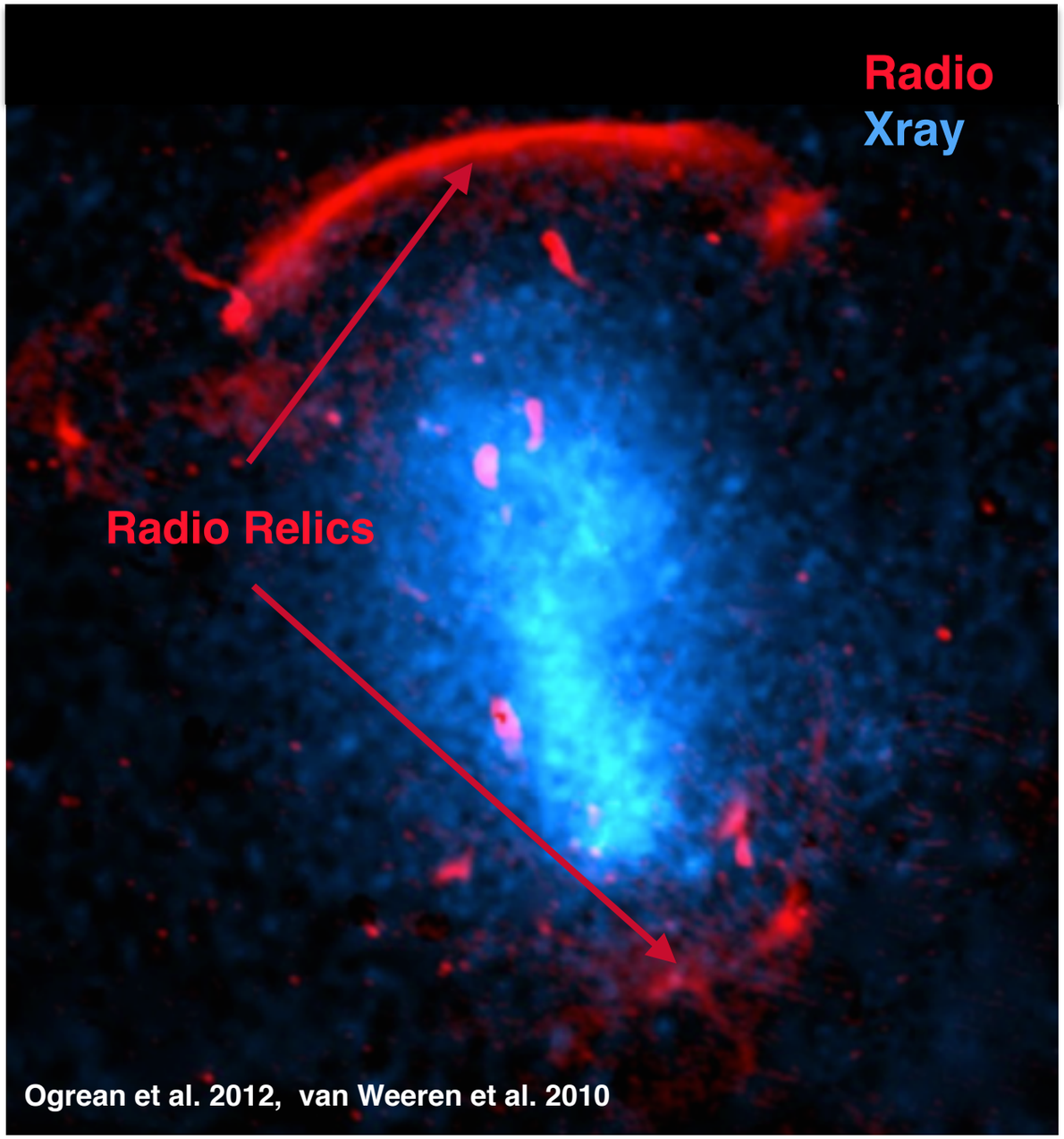
relaxed cluster



Radio relics: emission traces shocks

- found at cluster outskirts
- elongated morphology
- traces shock
- shows spectral index gradient
- strongly polarized (10~60%)





CIZA J2242.8+5301

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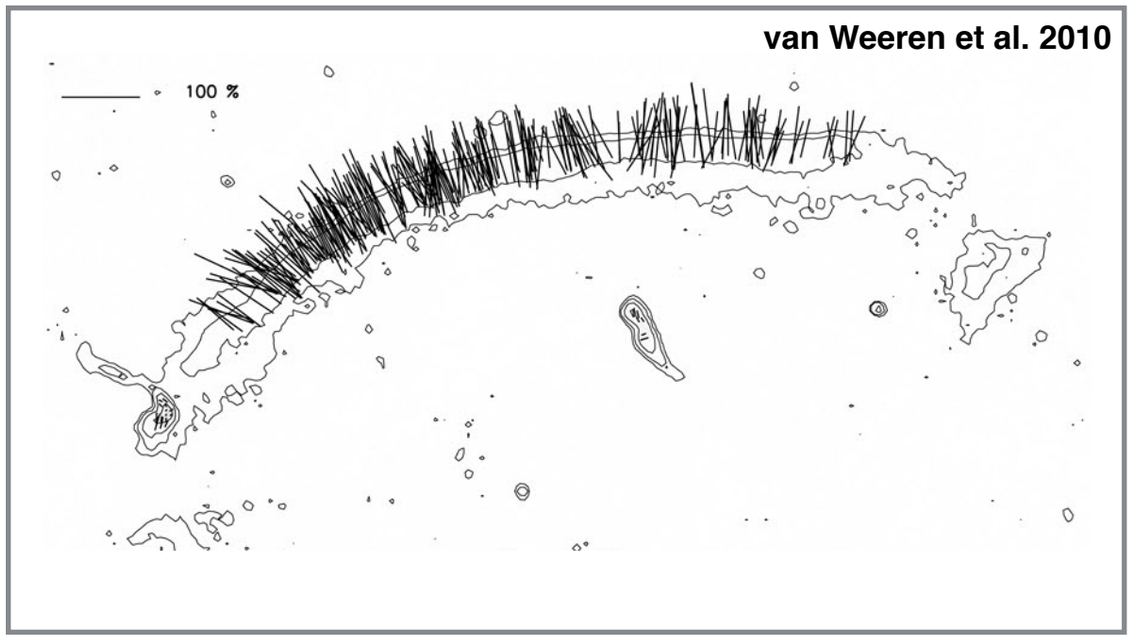
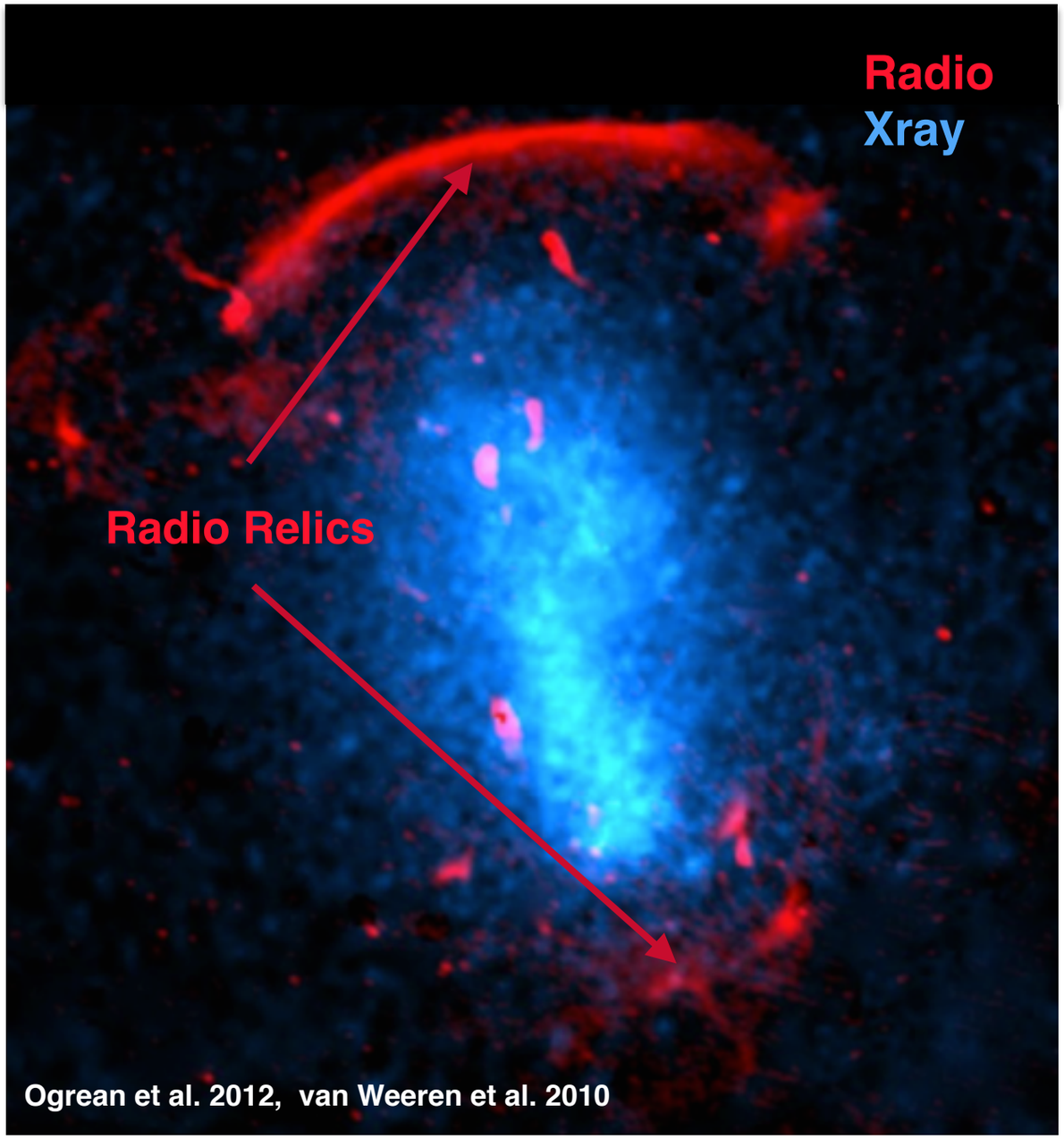




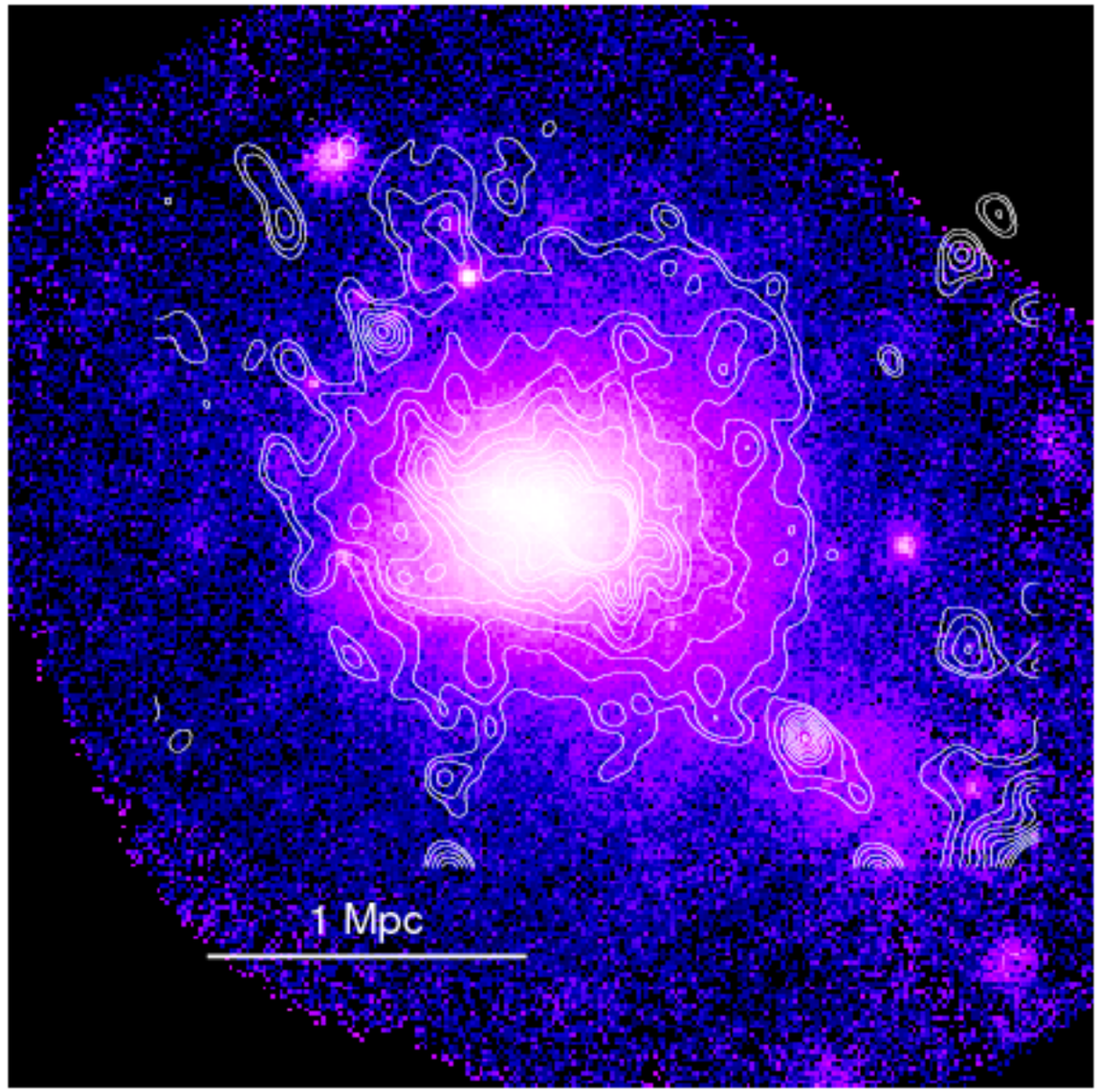
CIZA J2242.8+5301

Radio halos: similar in morphology to X-ray

- centrally located
- radio emission follows X ray emission
- unpolarized
- origin of radiating electrons:

1. **Turbulent re-acceleration model**
2. **Hadronic models**

Markevitch 2010

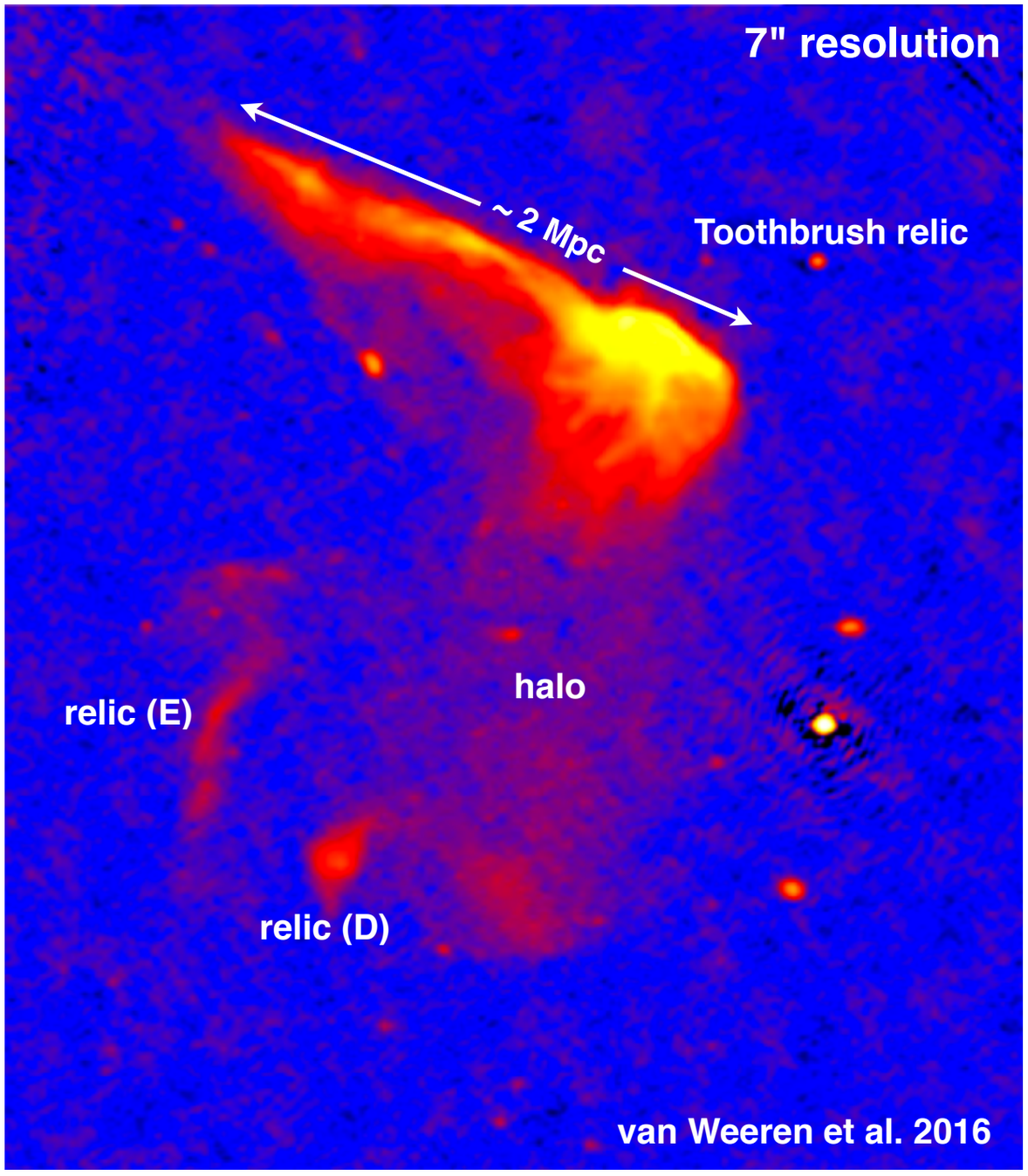


Abell 520

Large scale diffuse radio emission in 1RX J0603.3+4214

- **Radio observations by van Weeren +2012 :**
  - cluster host ~ 2 Mpc relic
  - additional fainter relics and halo
  - z = 0.225

- **Toothbrush relic:**
  - clear spectral index gradient towards cluster centre
  - strongly polarized (up to 60%) at 4.9 GHz



LOFAR image (150 MHz)

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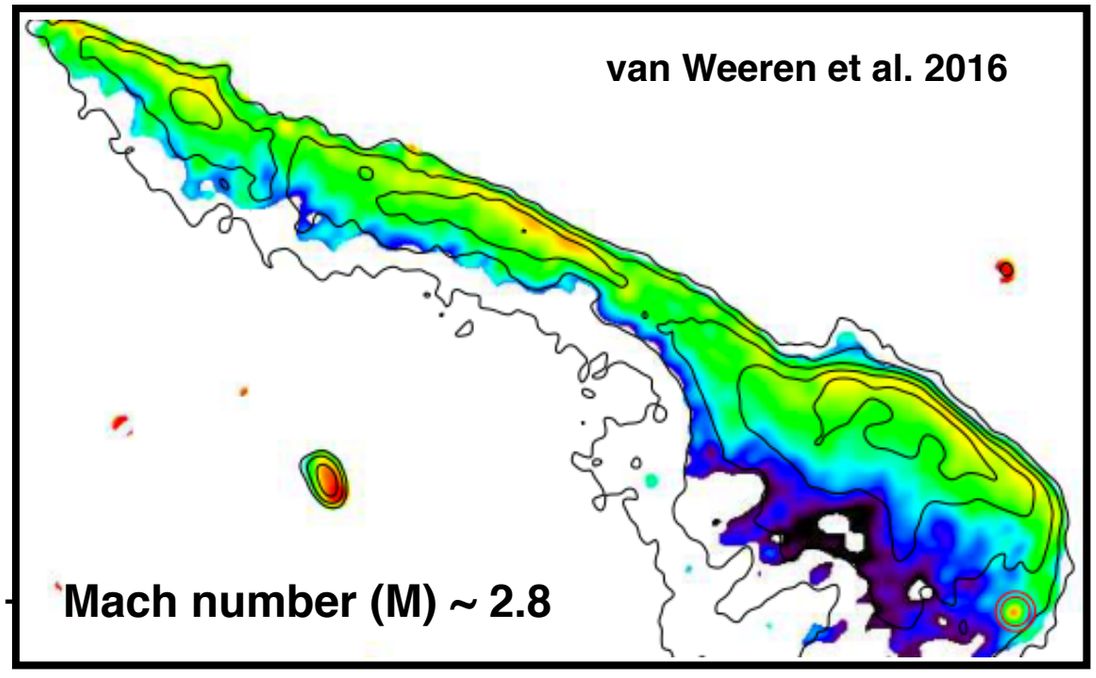

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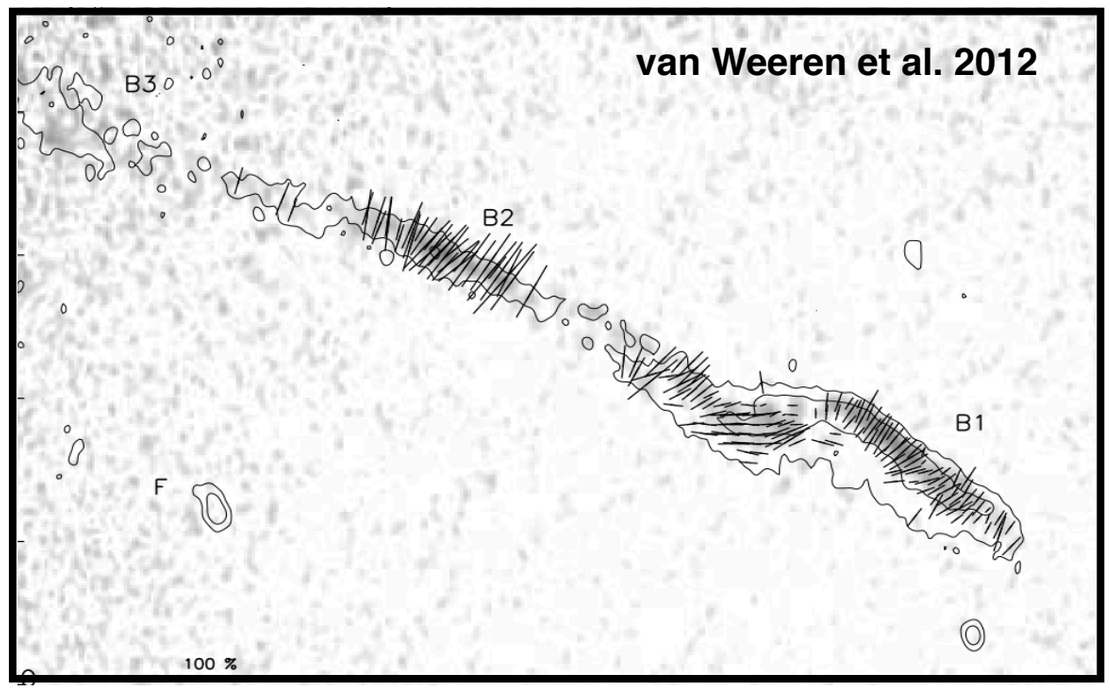
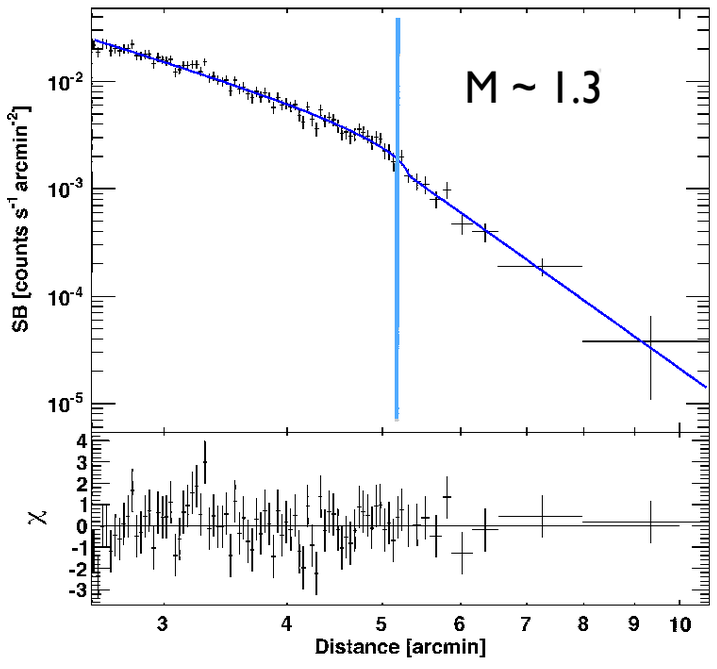
Low frequency spectral index map (150 - 610 MHz)

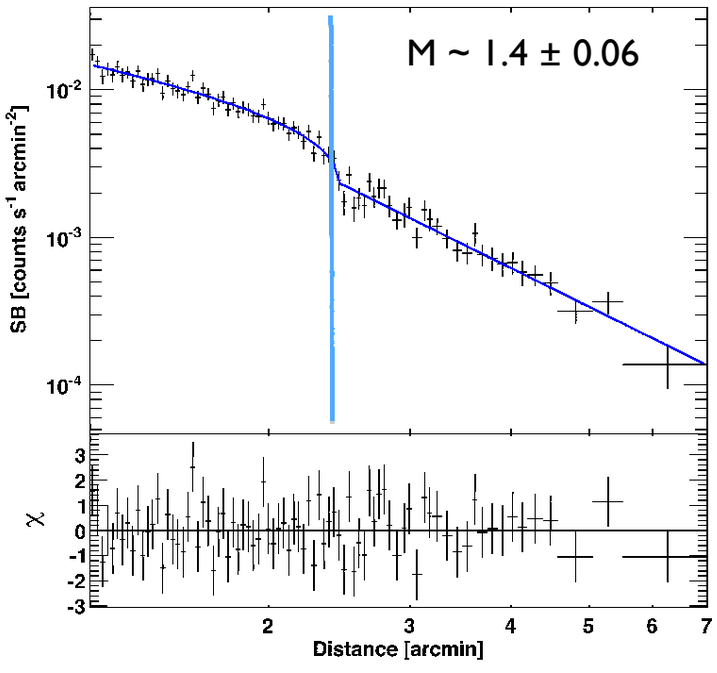


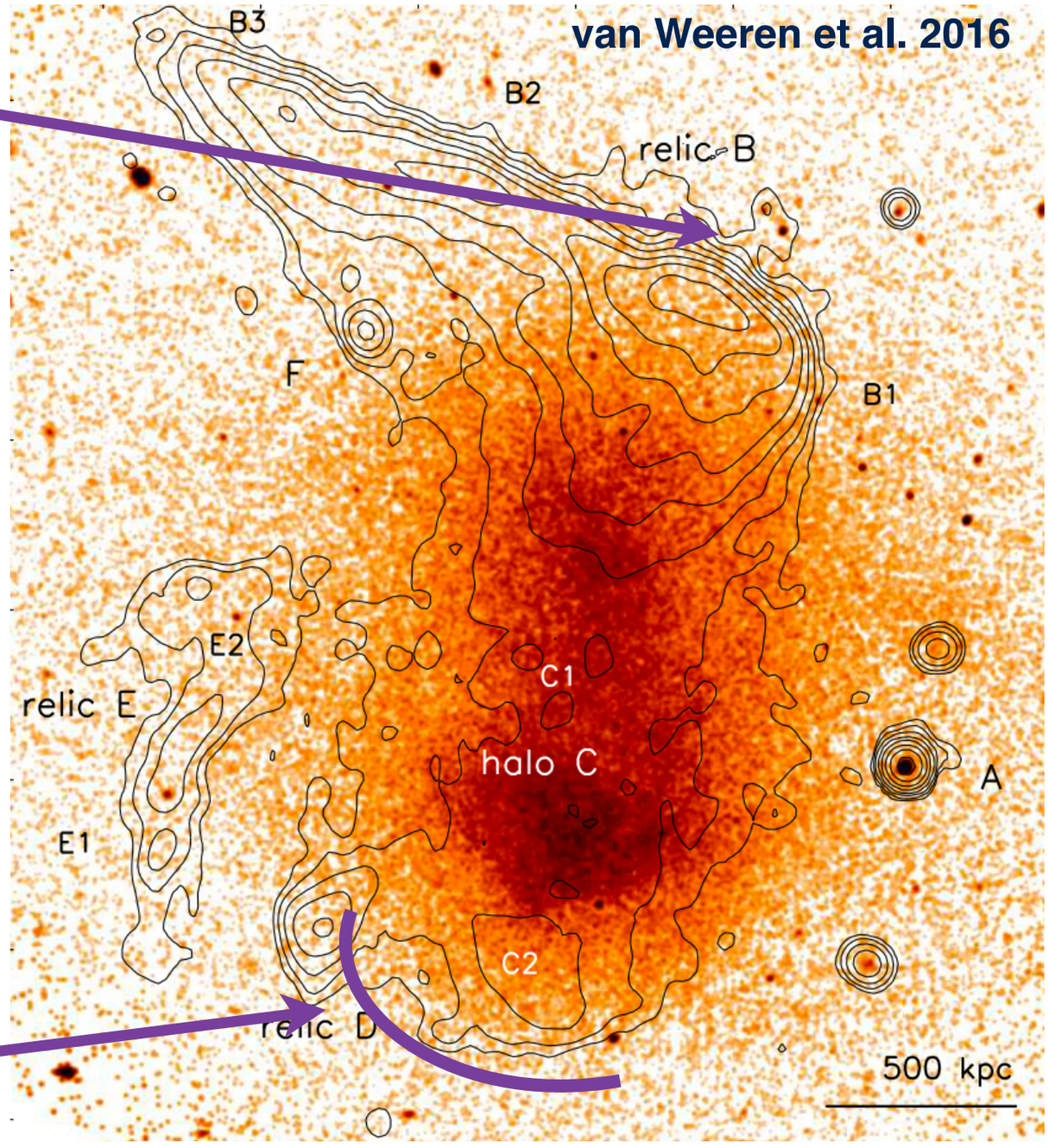
E-vectors distribution at 4.9 GHz

Chandra observations: weak shock at B1



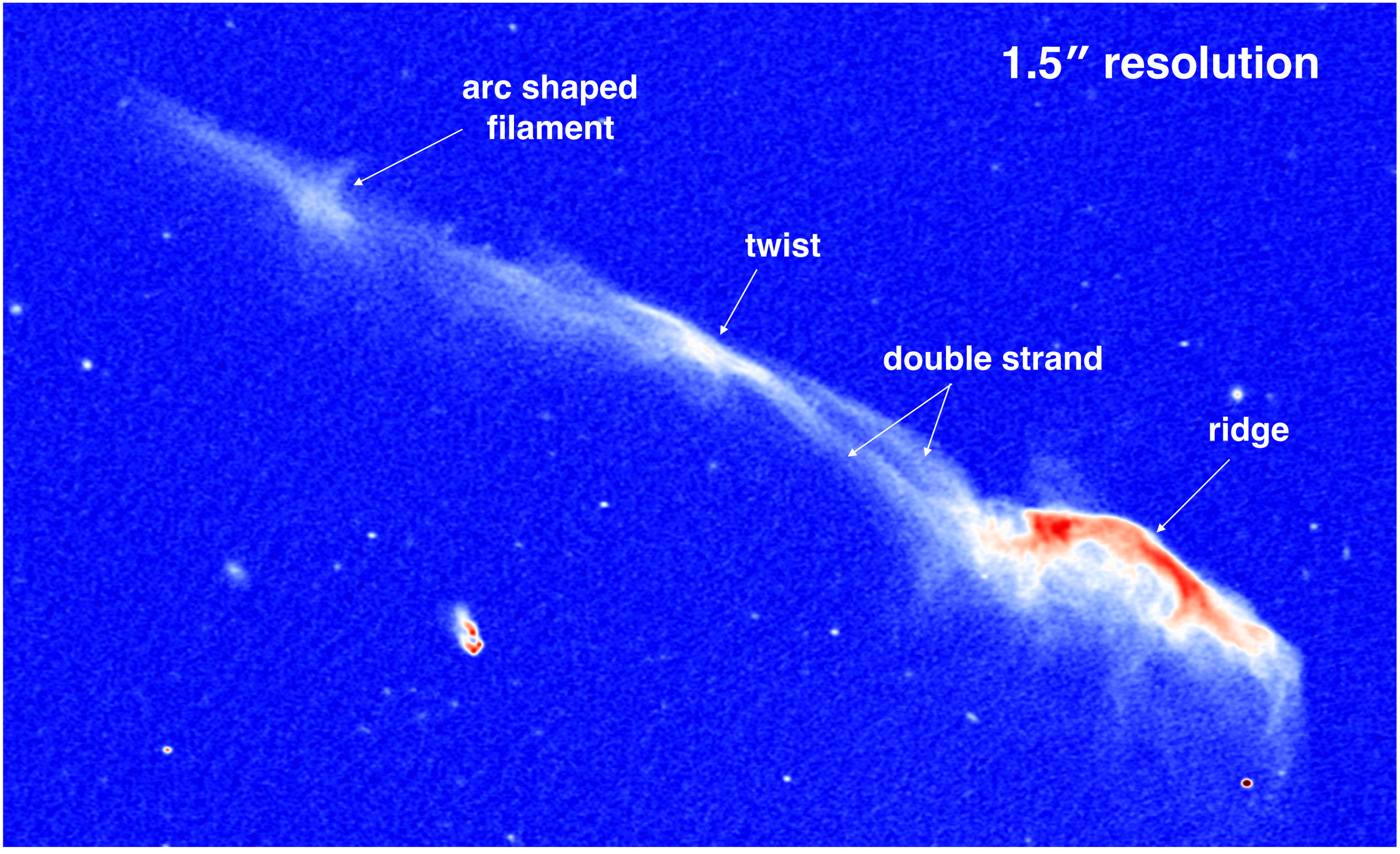
$M_{X\text{-}ray} \sim 1.3 \neq M_{radio} \sim 2.8$



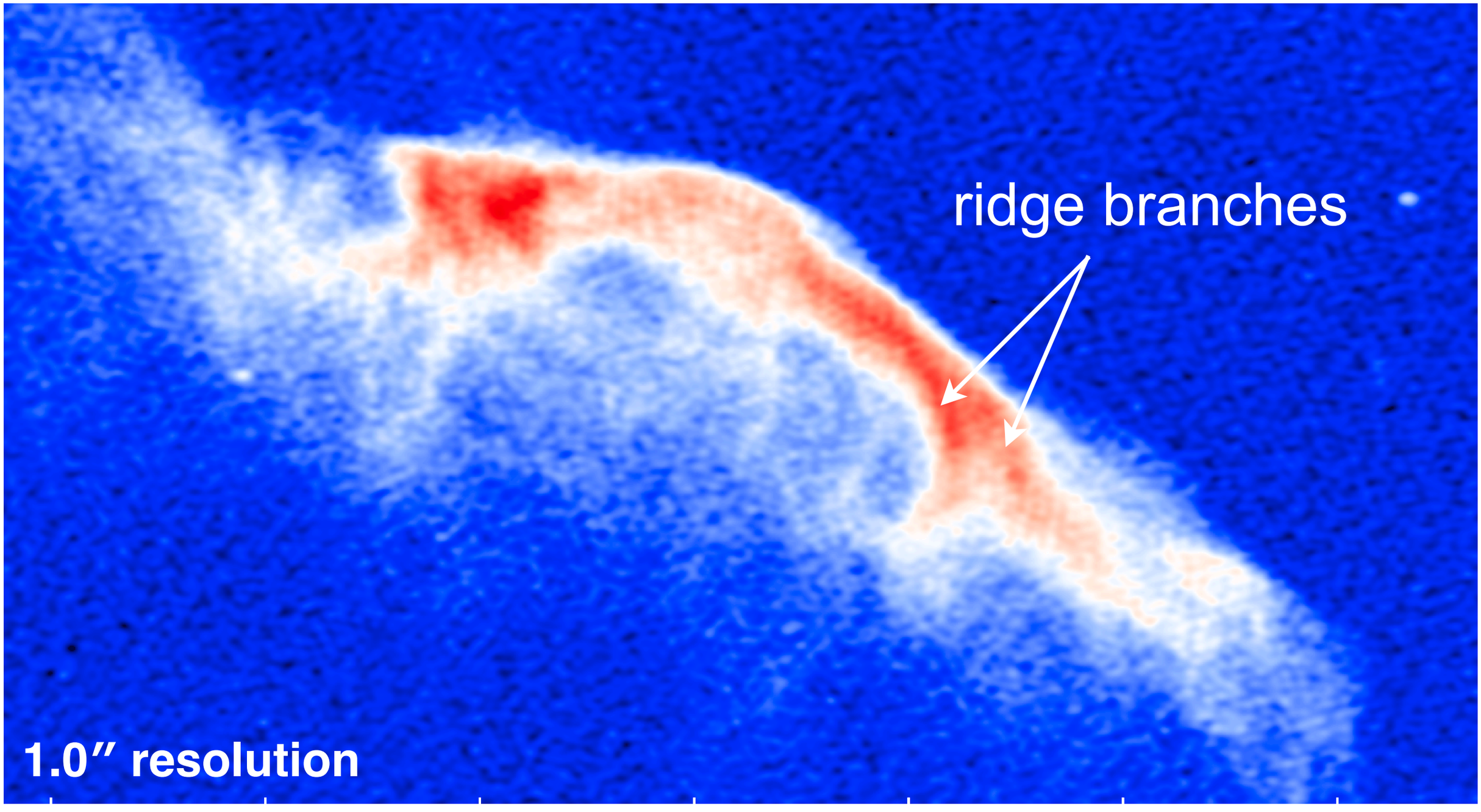


Chandra X-ray image (+radio contours)

Toothbrush: enigmatic filamentary structures



Ridge branches into two parts



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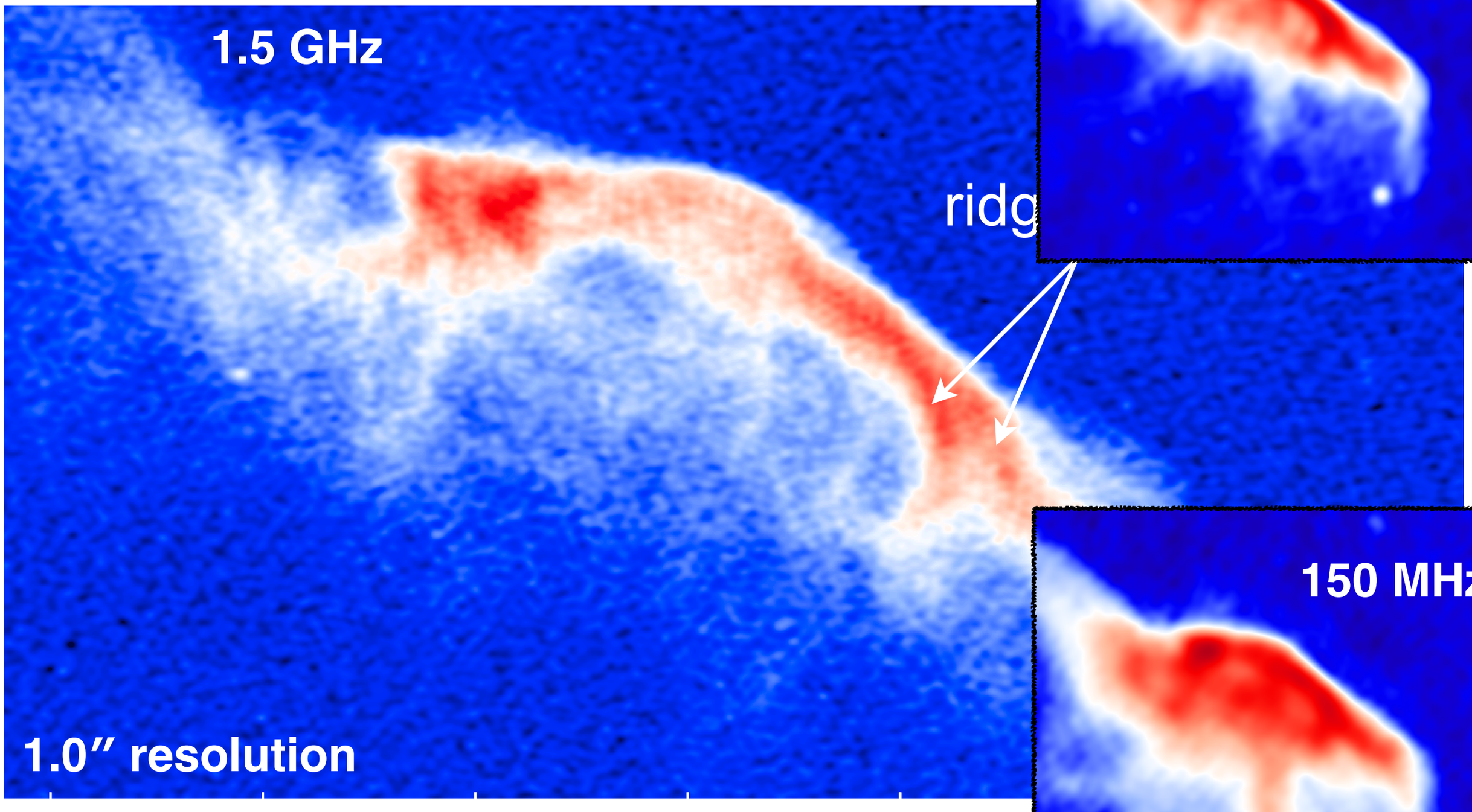
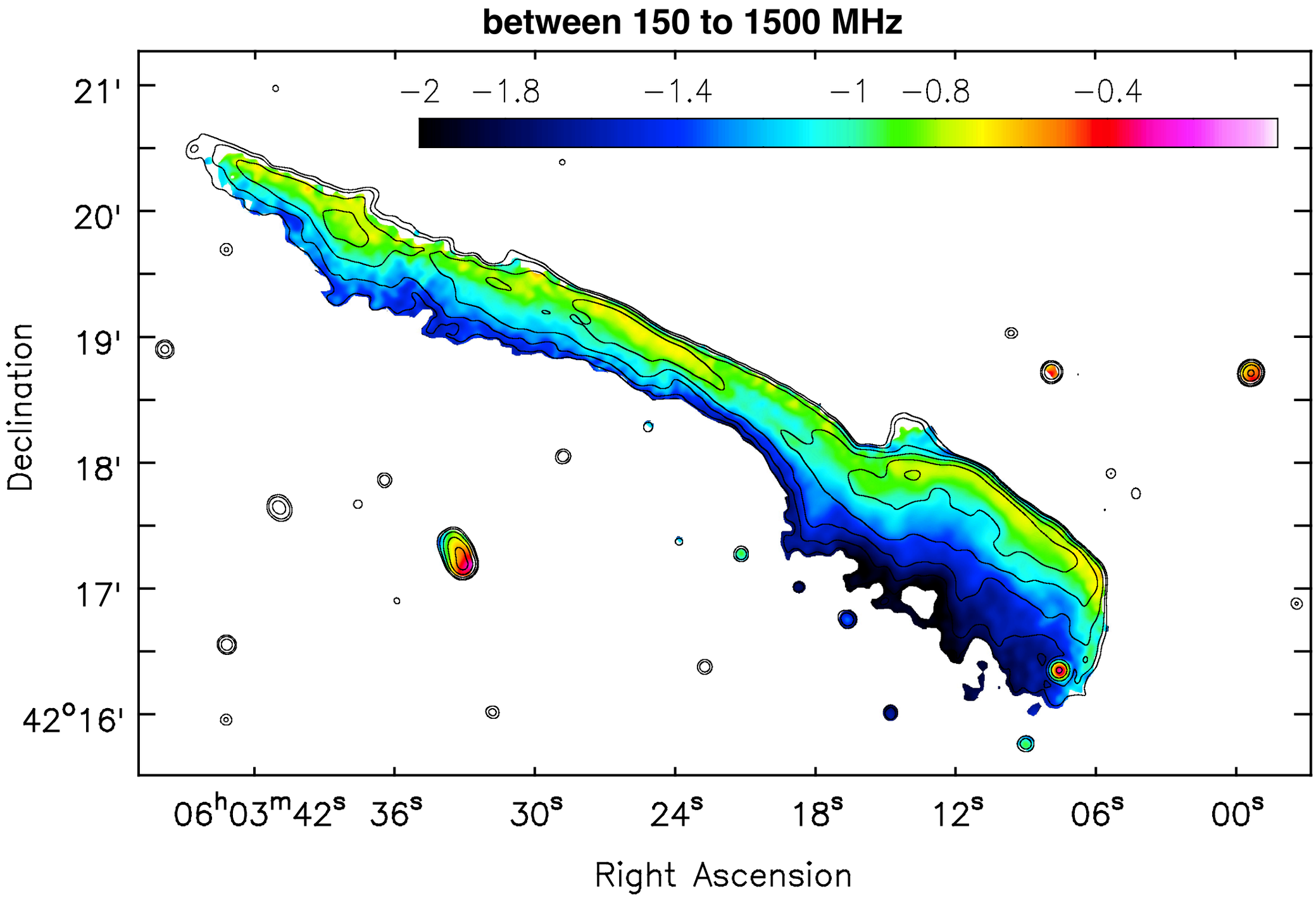
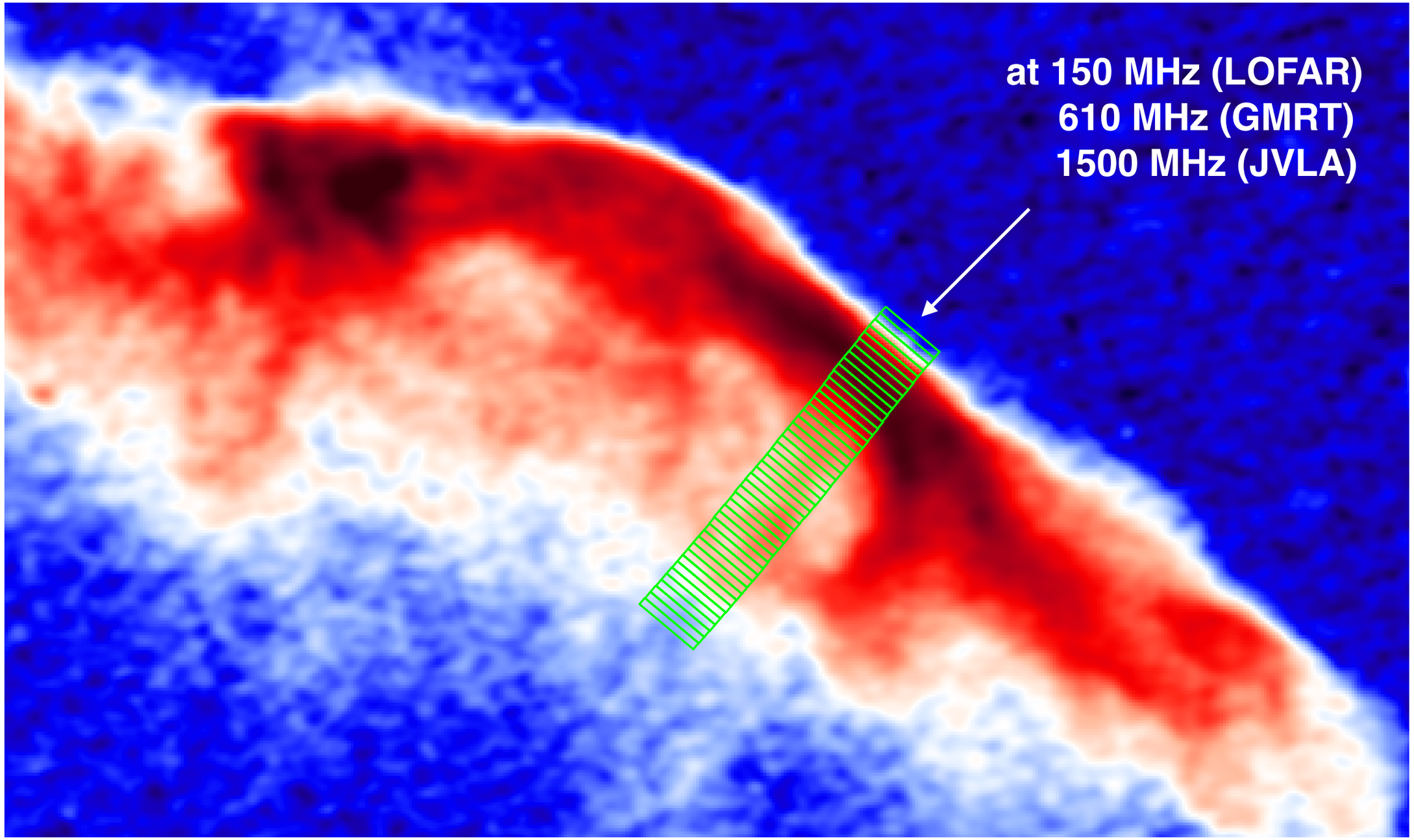


Spectral index at northern edge - 0.70 < α < -0.75

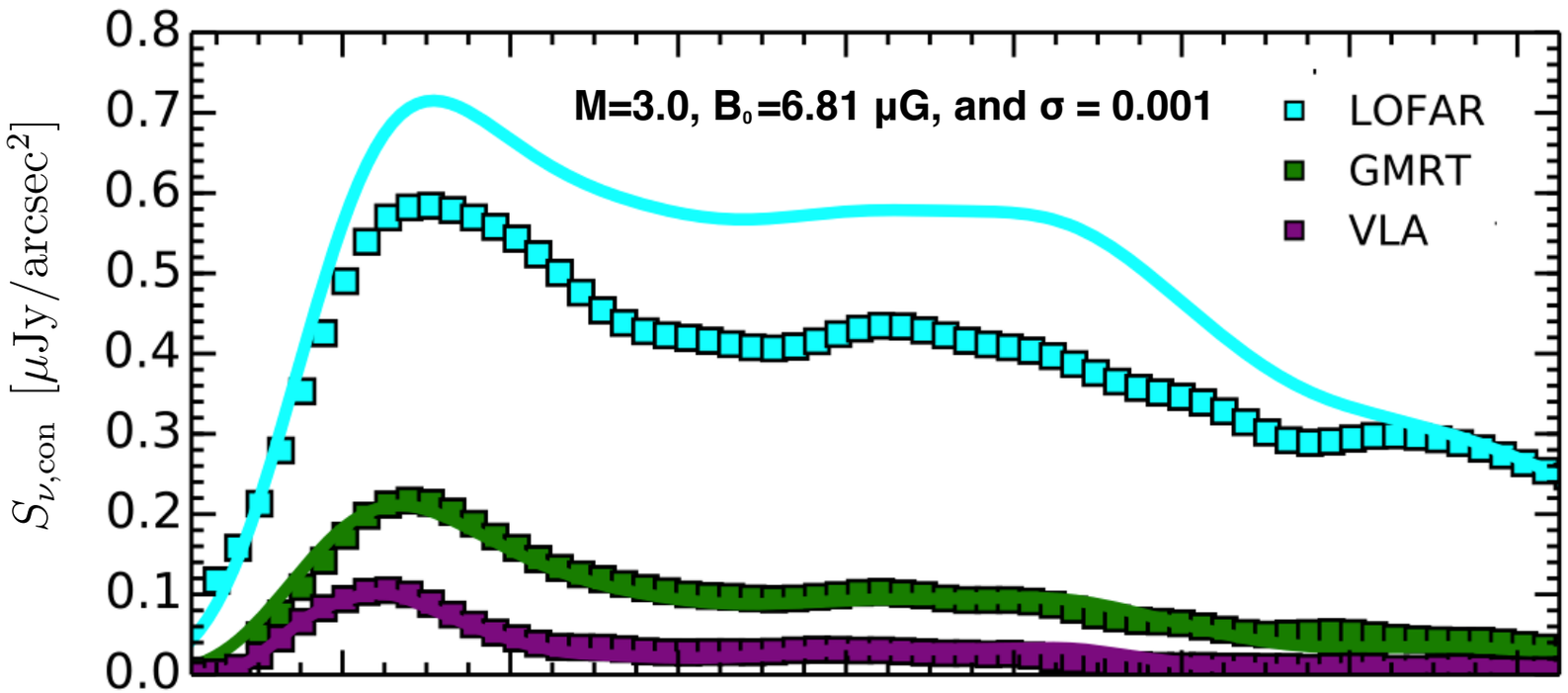


- Mach number obtained from the integrated spectrum is **M ~ 3.78**

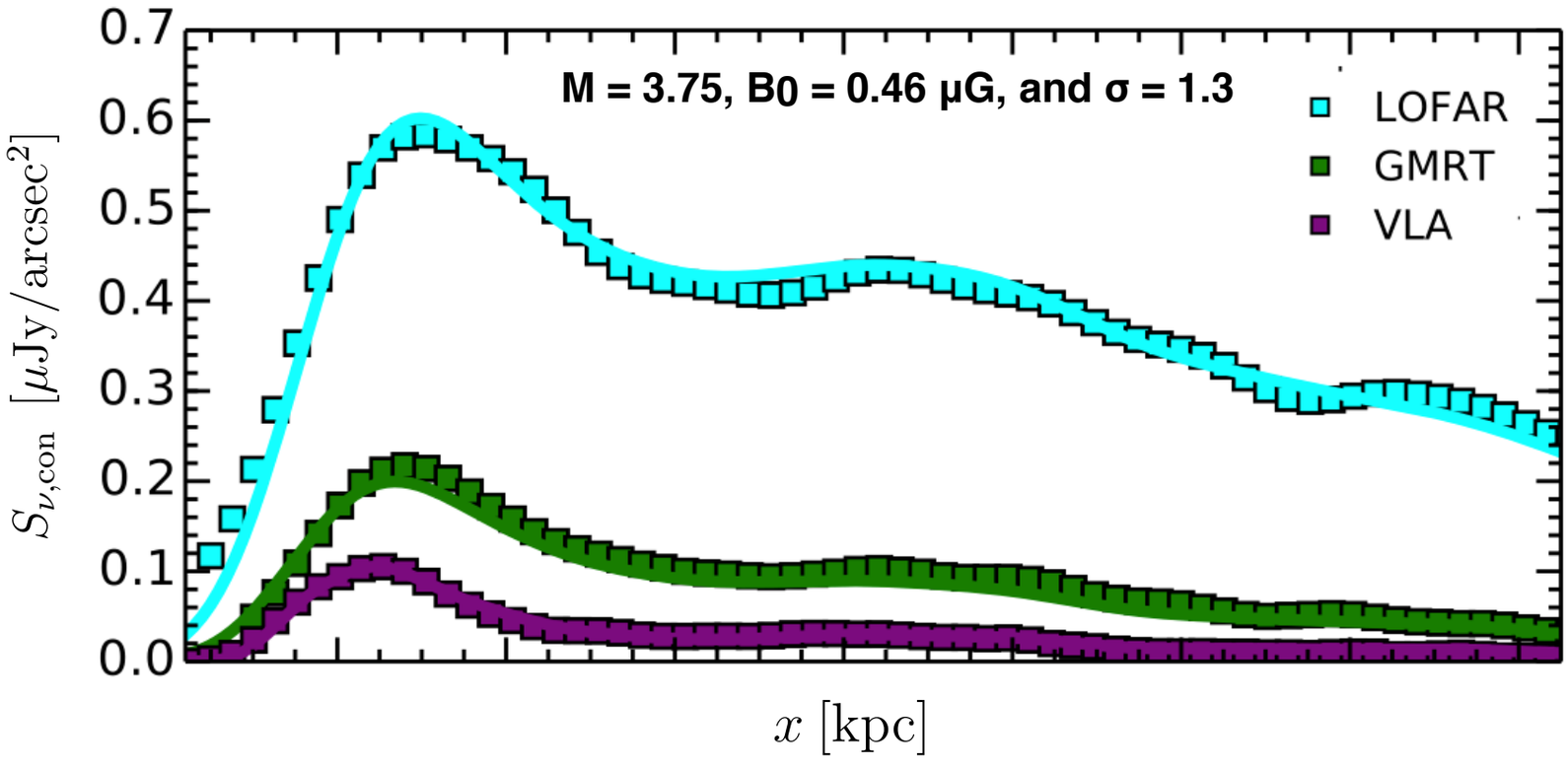
Detailed investigation of the ridge



Surface brightness distribution:

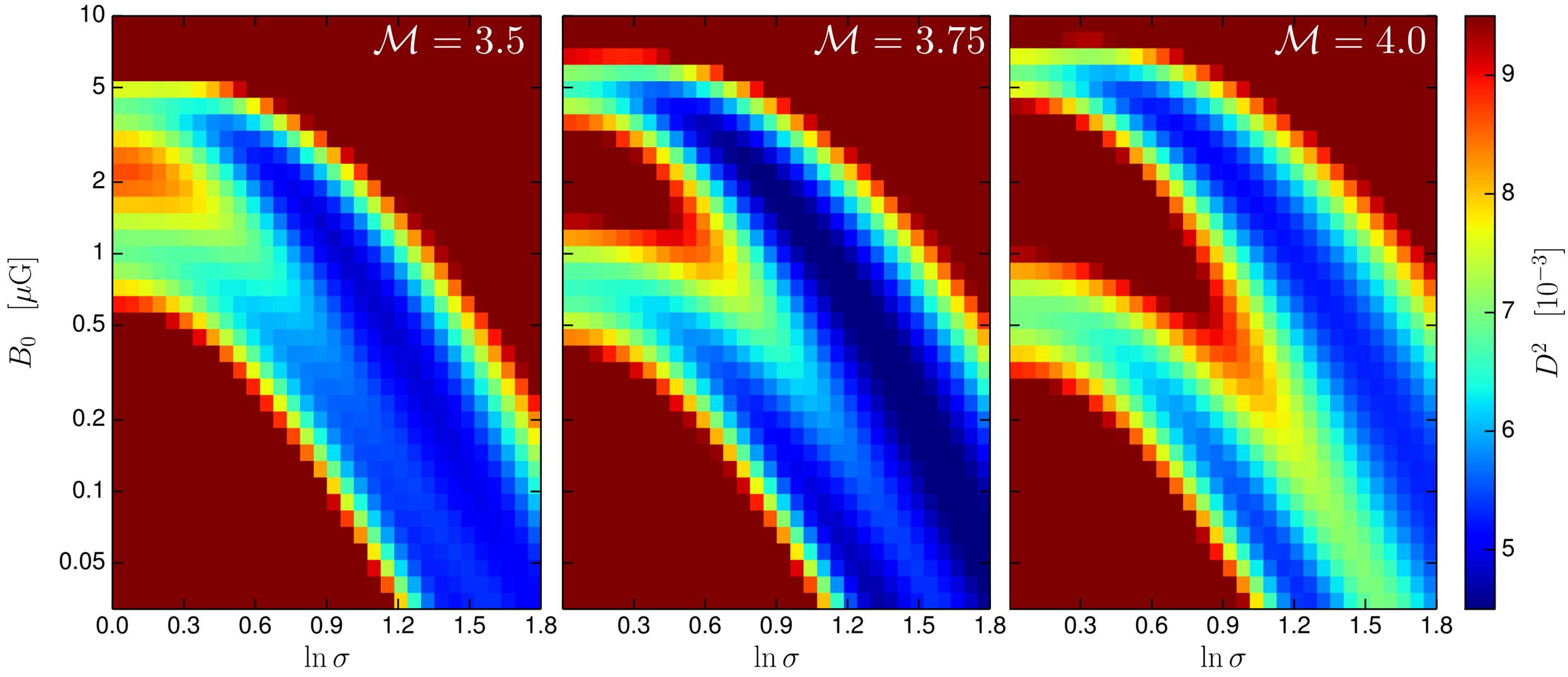


homogenous magnetic field



log normal distribution of magnetic field

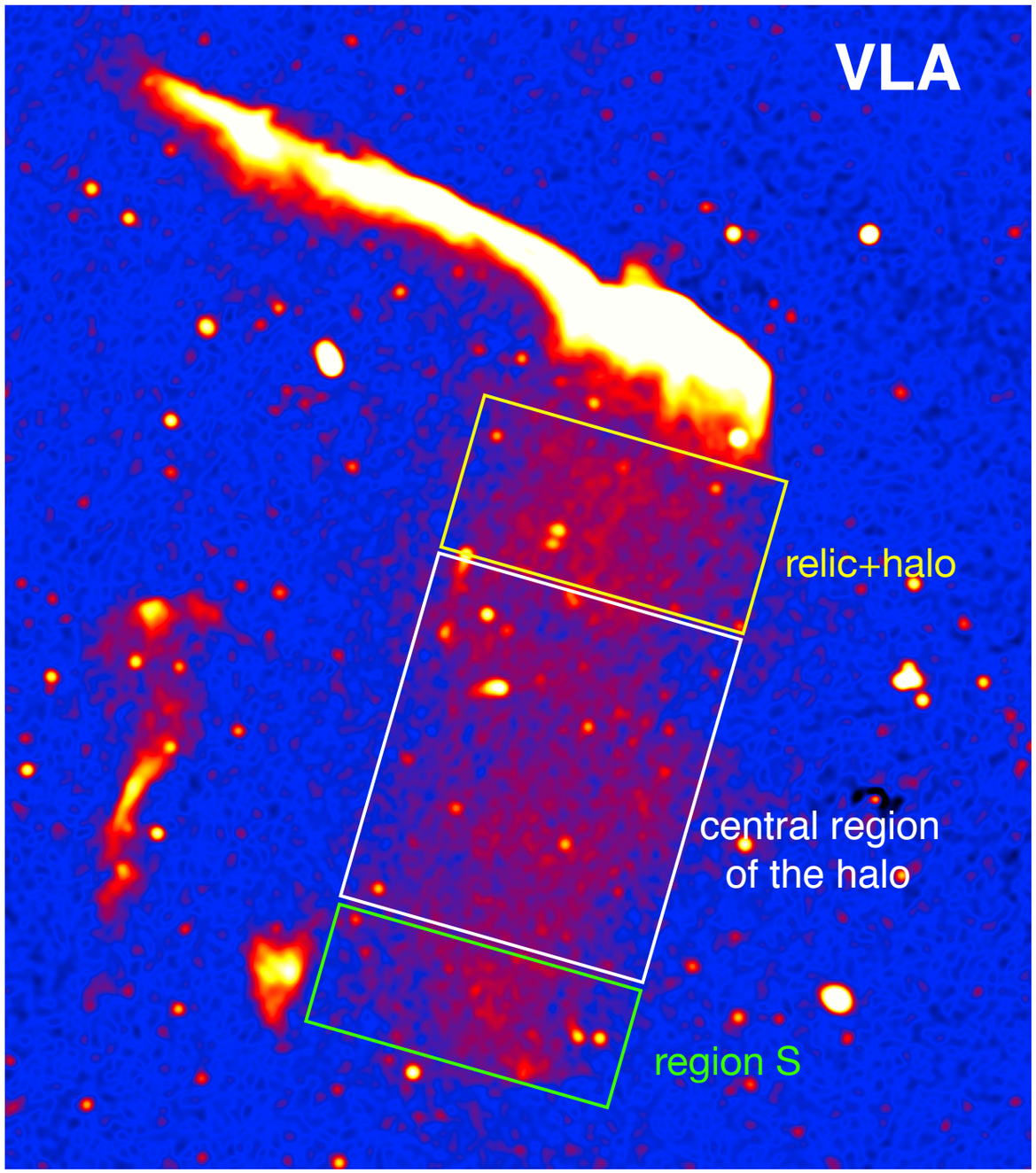
Best fit: $\mathbf{B_0 \leq 5\mu G, \sigma \geq 0.7}$ and Mach number = 3.75



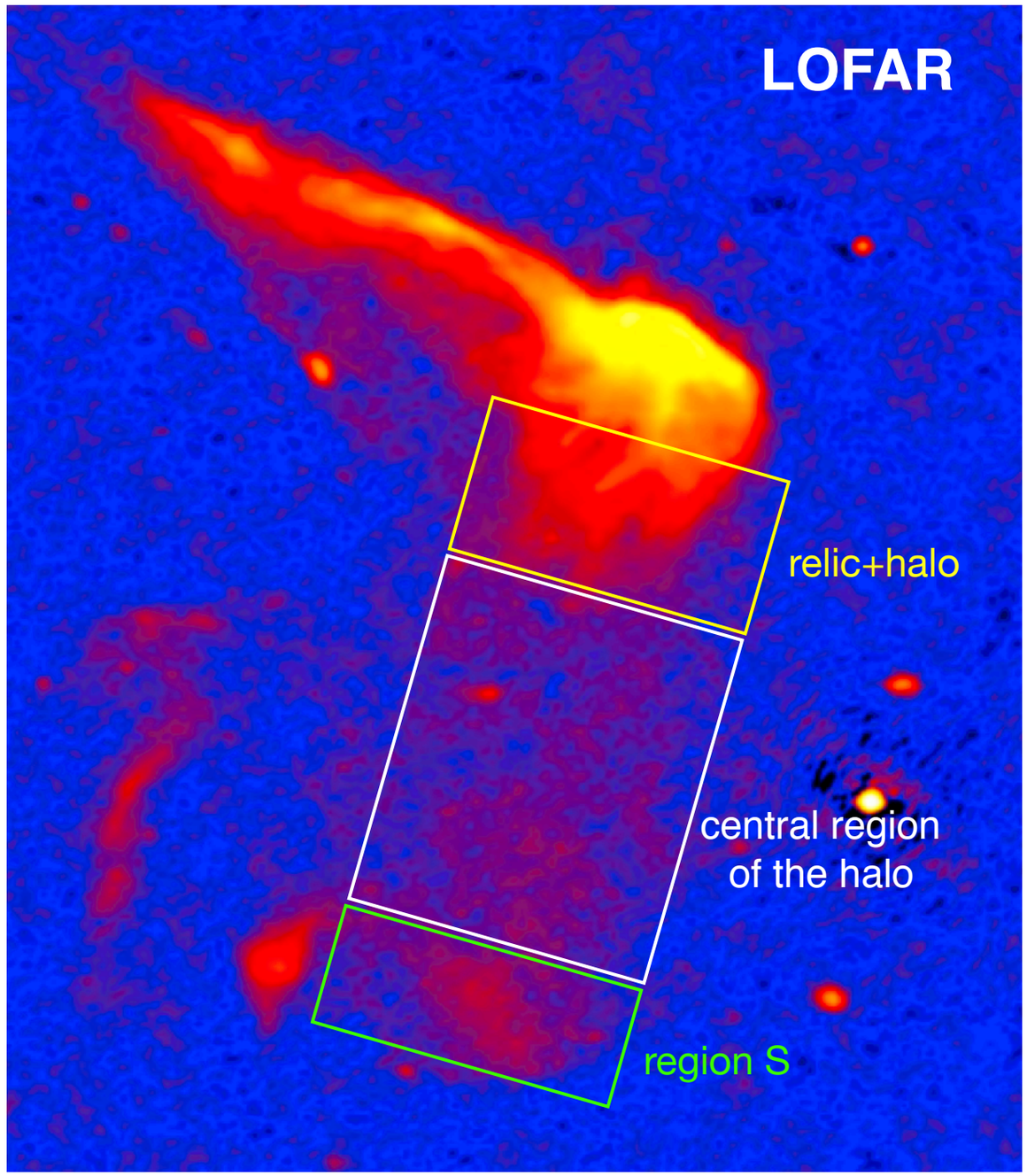
model ruled out field strength above 5 μG

Comparison of the halo

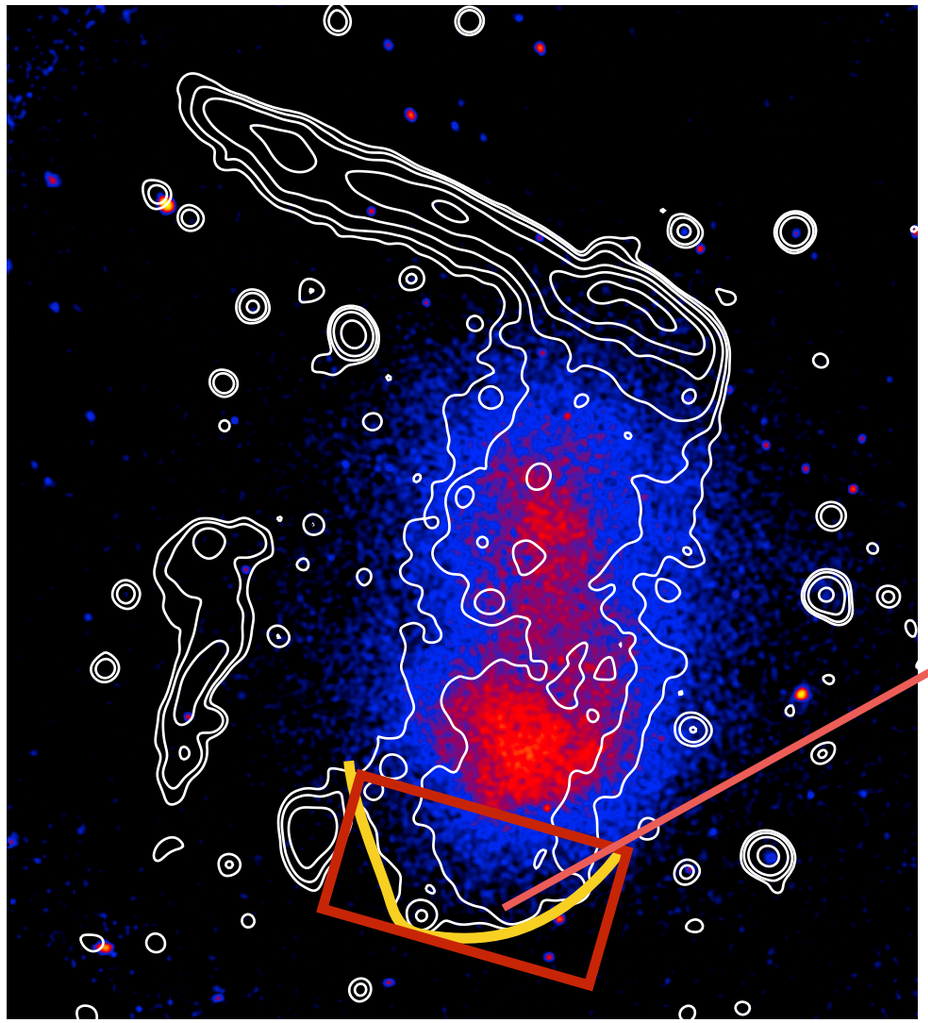
7" resolution, rms=9 μJy, frequency=1.5 GHz

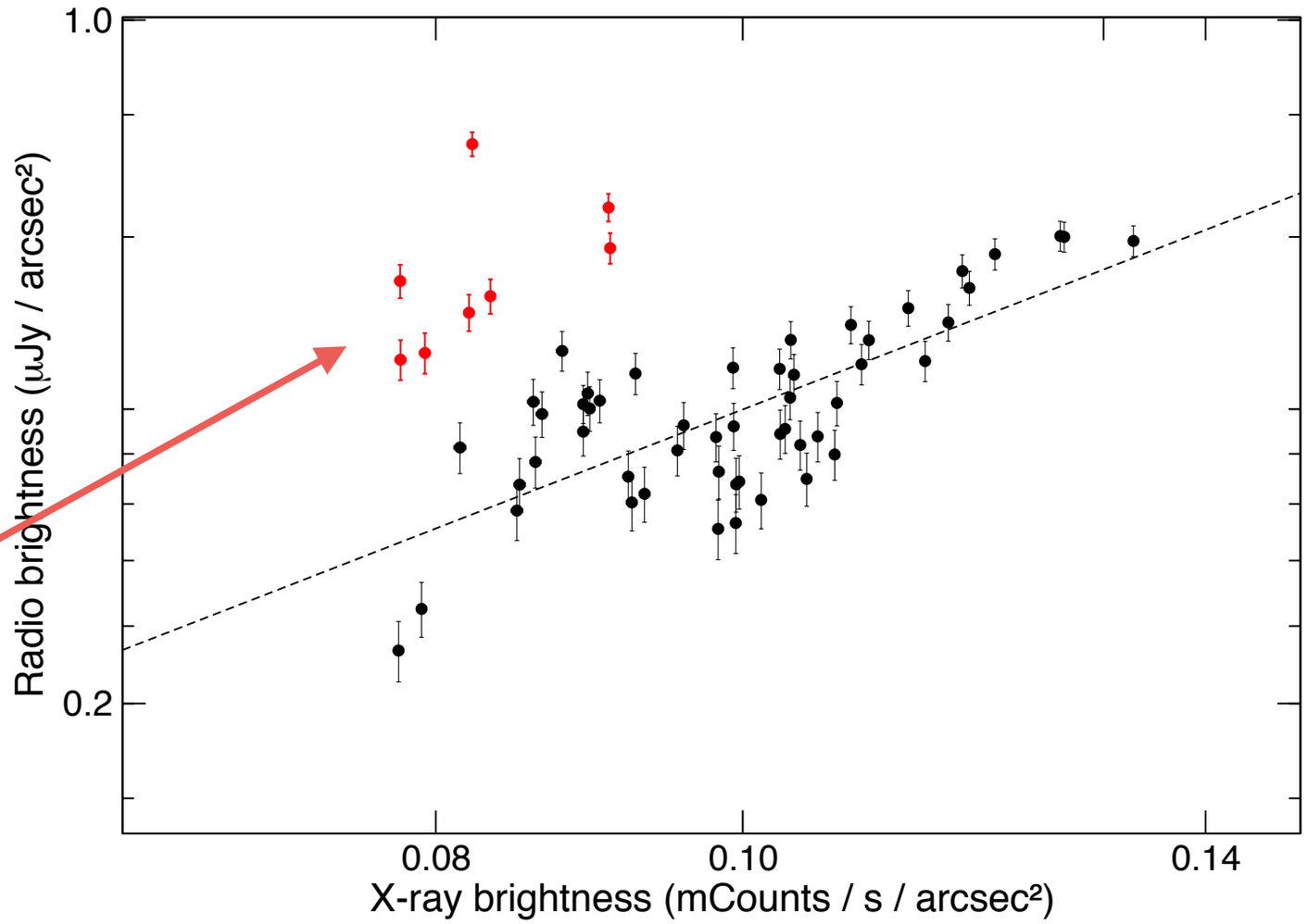


7" resolution, rms=93 μJy, frequency=150 MHz

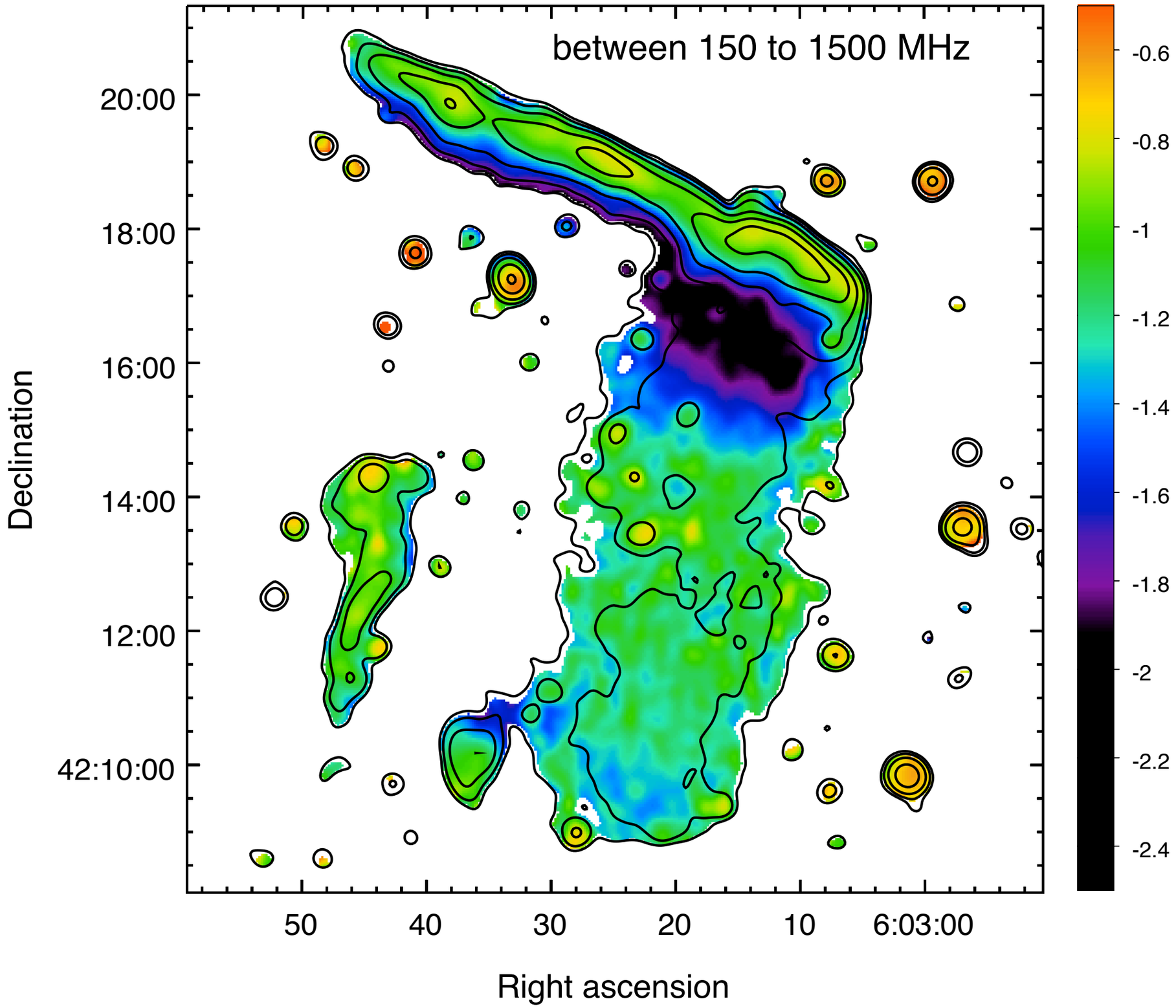


Halo: radio brightness correlates well with X-ray brightness

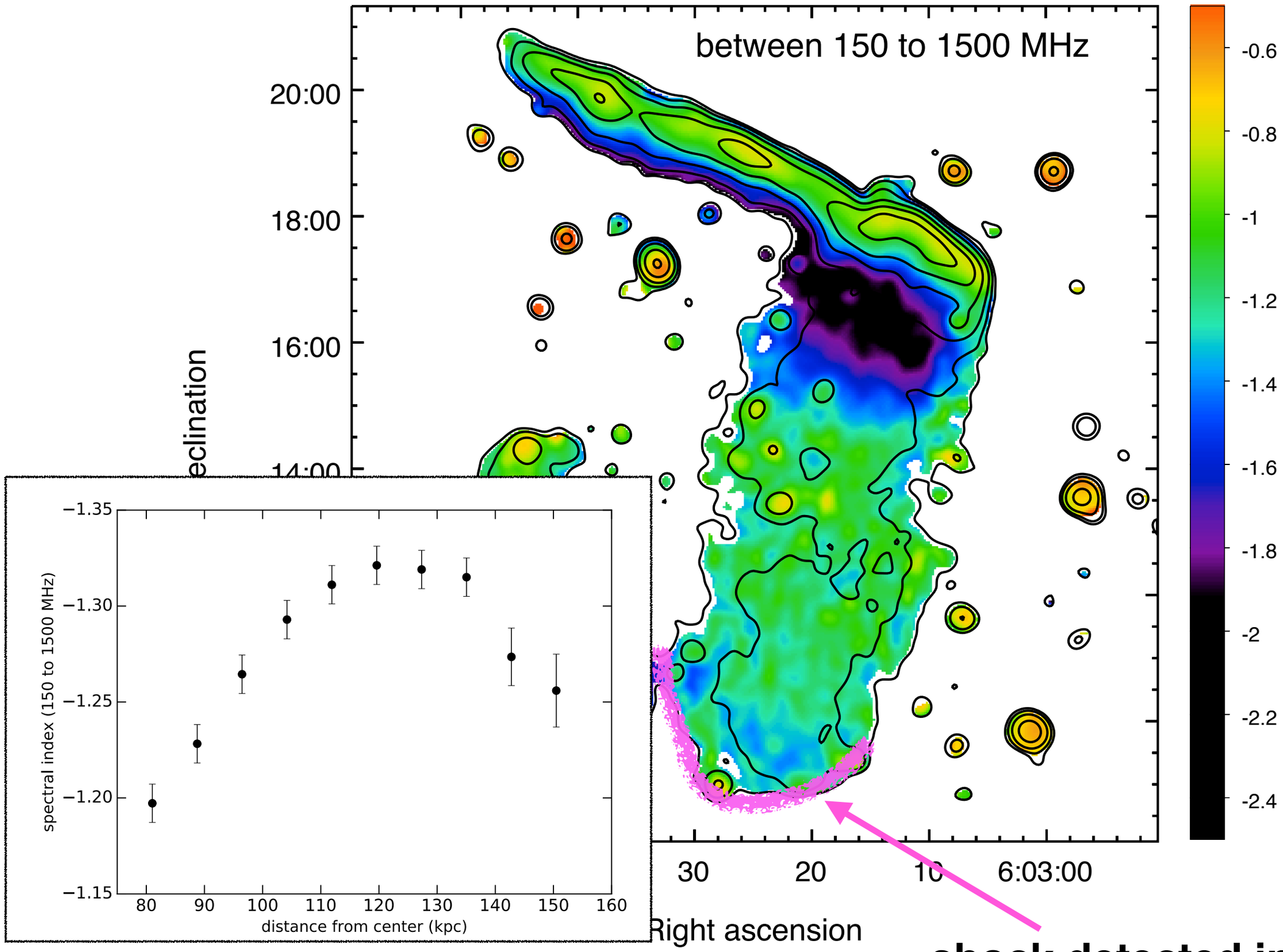




Halo: average spectral index map of -1.16± 0.5

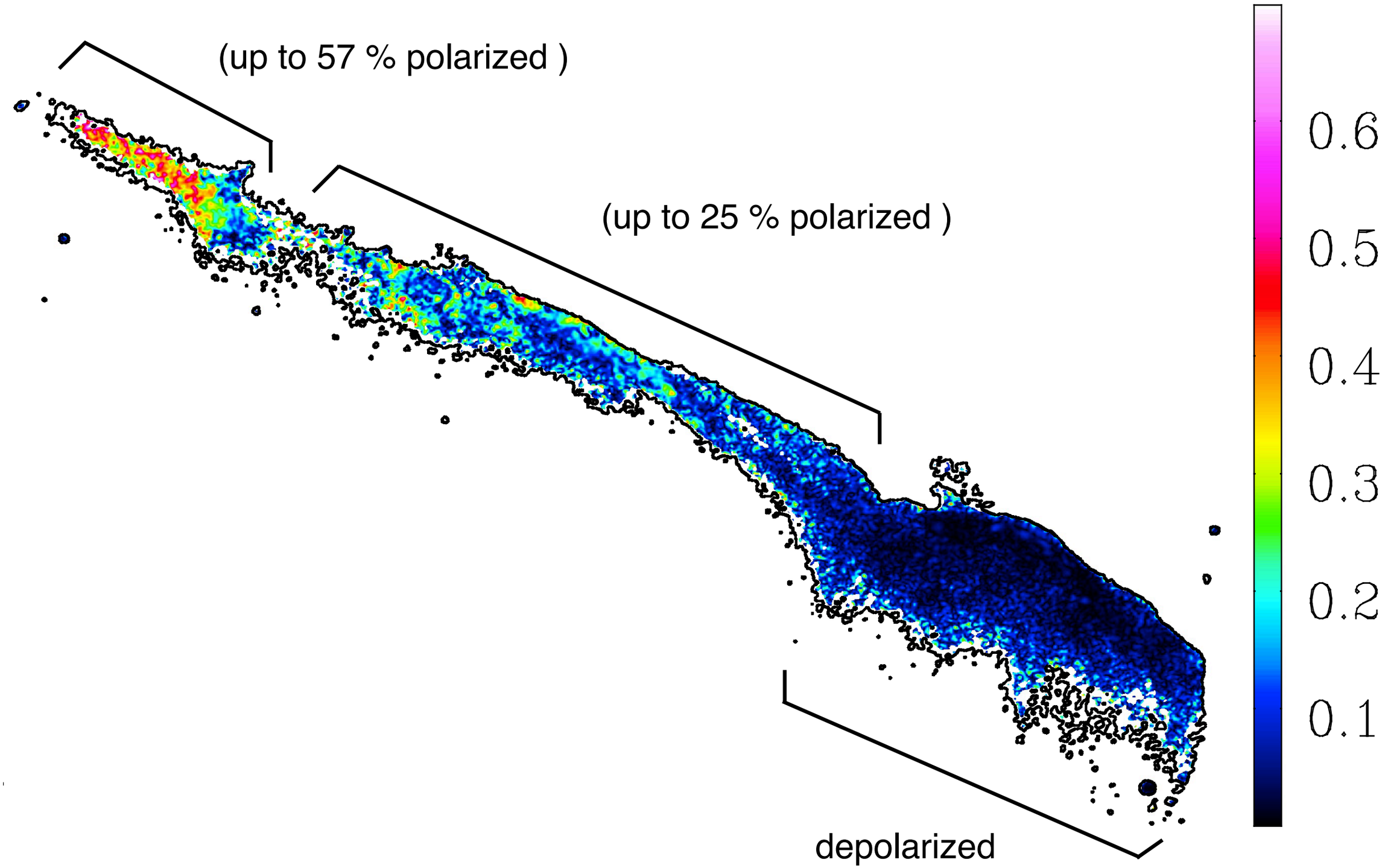


Halo southern most part: a fainter relic !

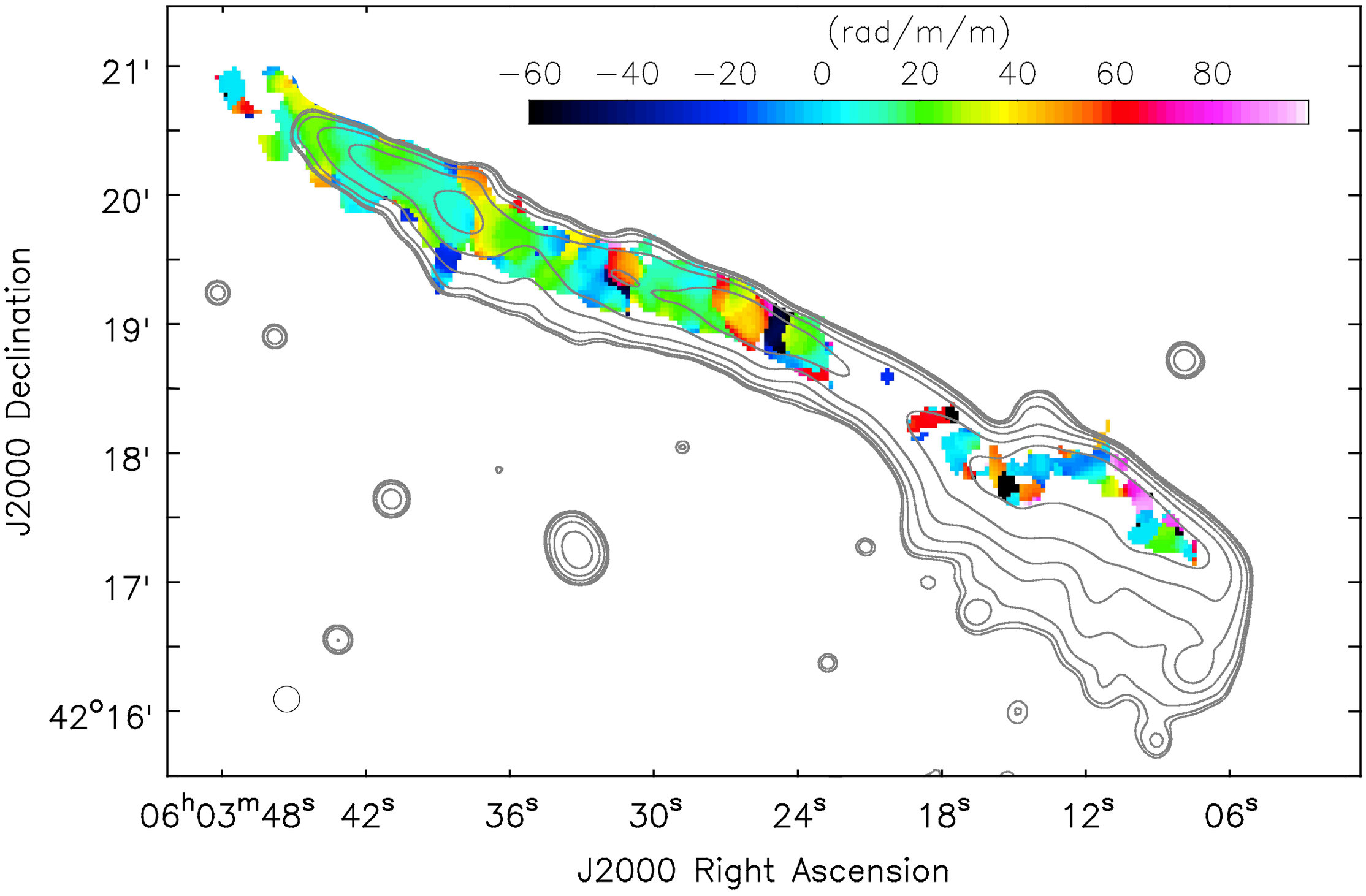


shock detected in Chandra

Degree of polarization: brush depolarized at 1.5 GHz

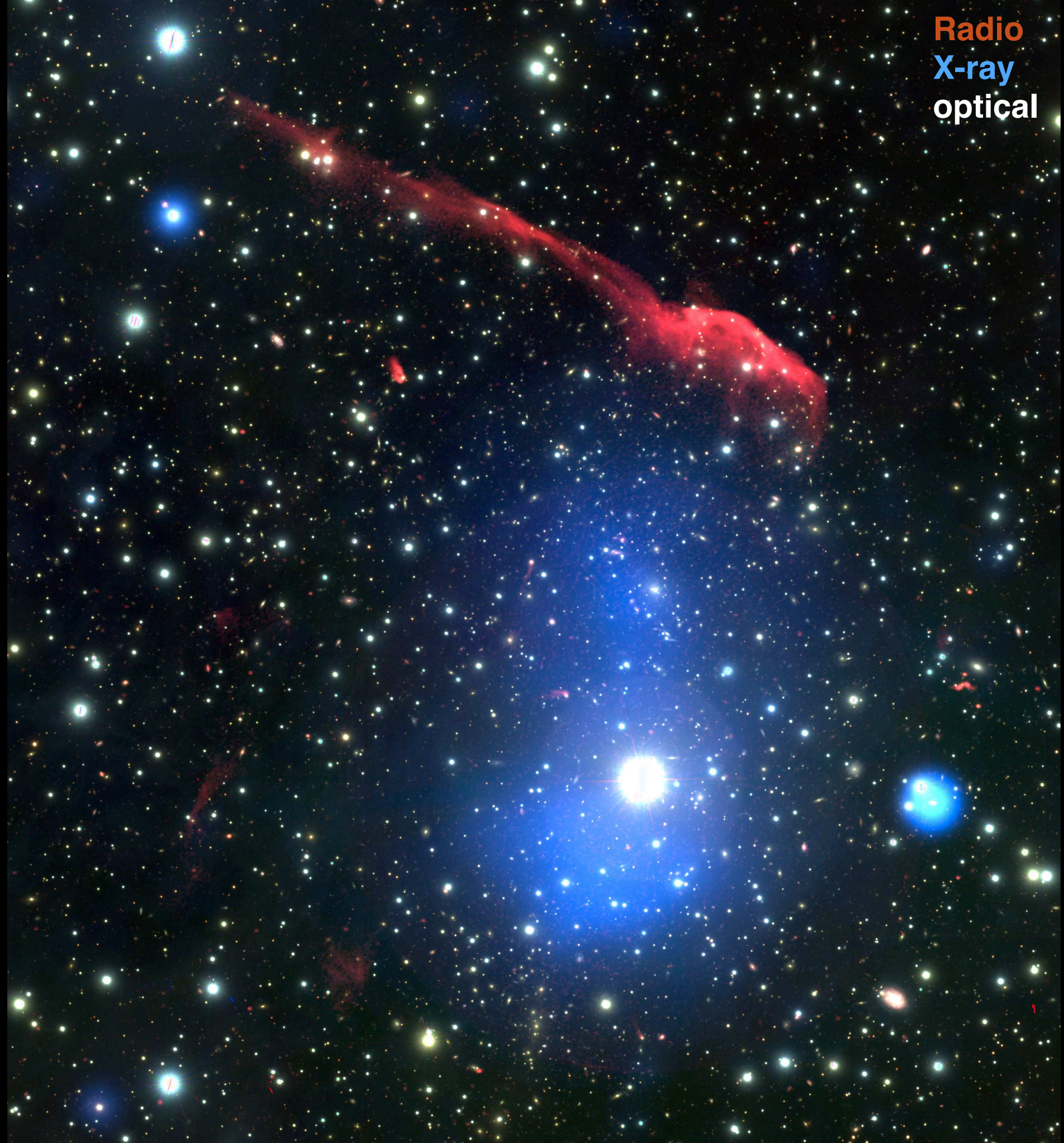


Strong RM gradient across B2 and B3 region



Summary

- Toothbrush is made up of filamentary structures
- Lognormal B-field distribution allows to approximate profiles significantly better
- Best fit: Mach ~ 3.75, $B_0 < 5$ μG, $\sigma > 0.7$
- Radio brightness correlates well with the X-ray brightness in the central region of the halo.
- Southern part of the halo shows a spectral index gradient and possibly related to a shock front.
- Brush depolarized at 1.5 GHz, strong RM variations across B2 and B1 region.


Radio
X-ray
optical