A spectacular view of the Toothbrush: filaments and inhomogeneous magnetic fields

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Thüringer Landessternwarte Tautenburg

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The Broad Impact of Low Frequency Observing
Bologna, June 21, 2017

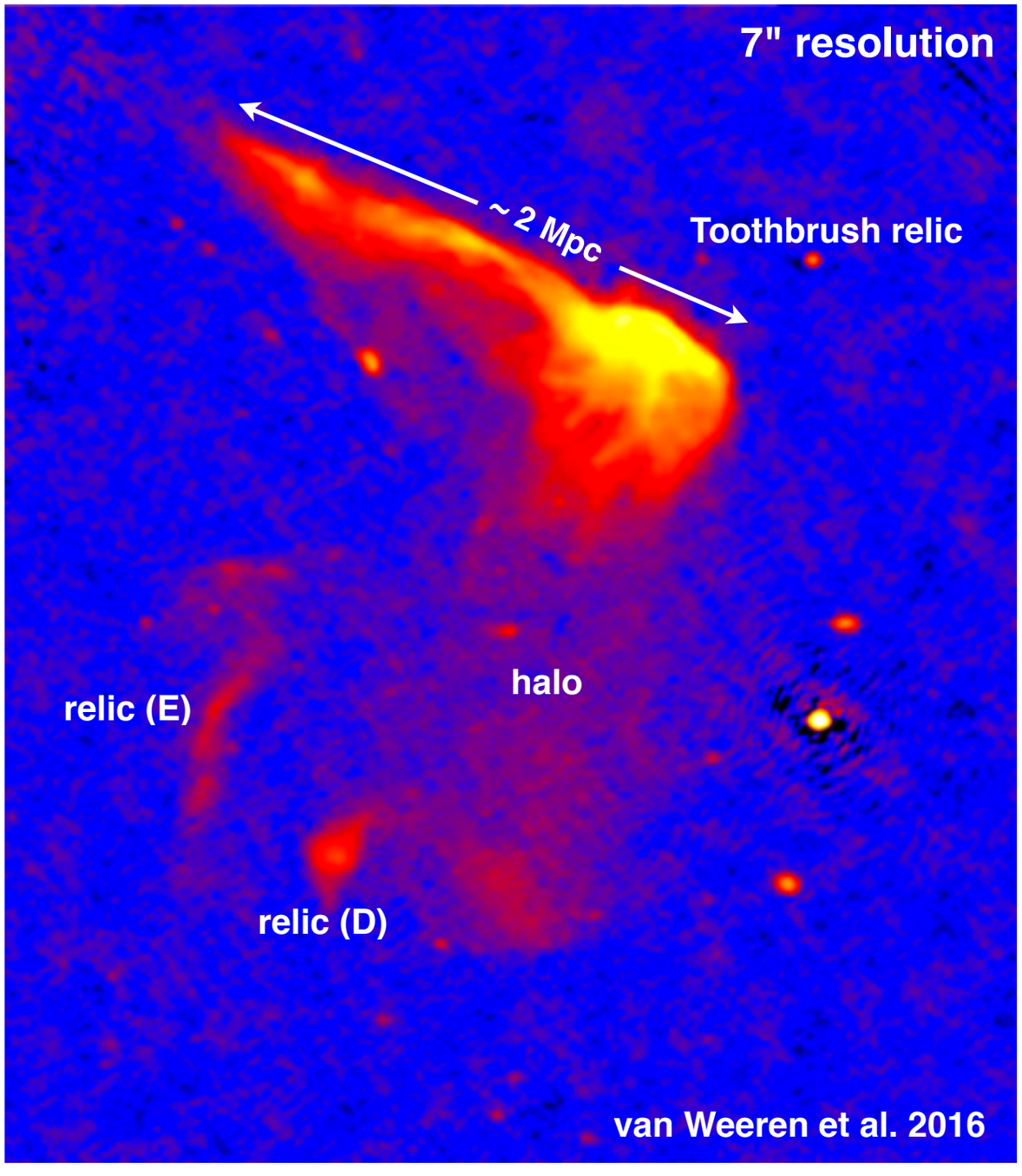
Large scale diffuse radio emission in 1RX J0603.3+4214

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

- **Toothbrush relic:**
  - steep spectrum, **$\alpha = -1.15 \pm 0.01$**

Mach number (M) ~ 3.78

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



LOFAR image (150 MHz)

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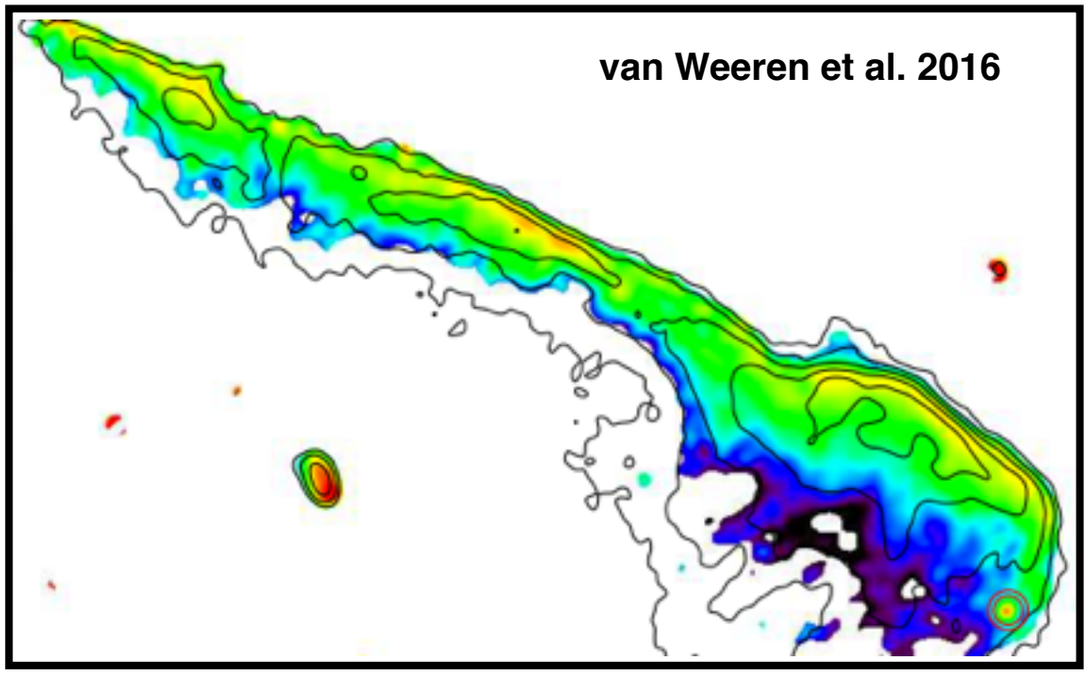

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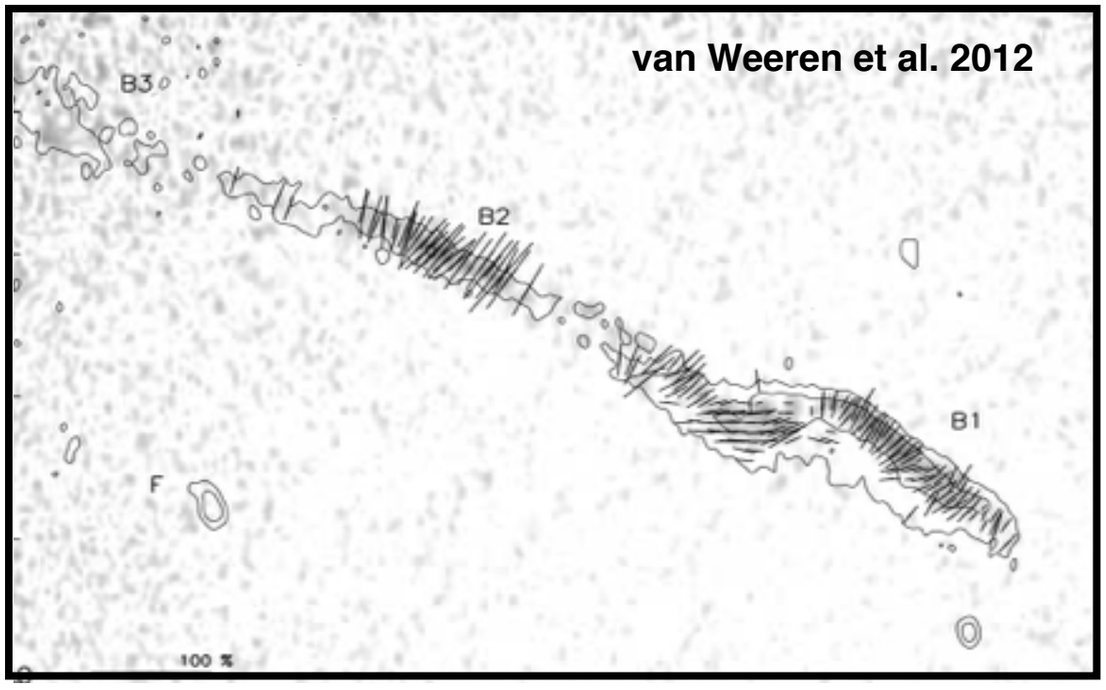
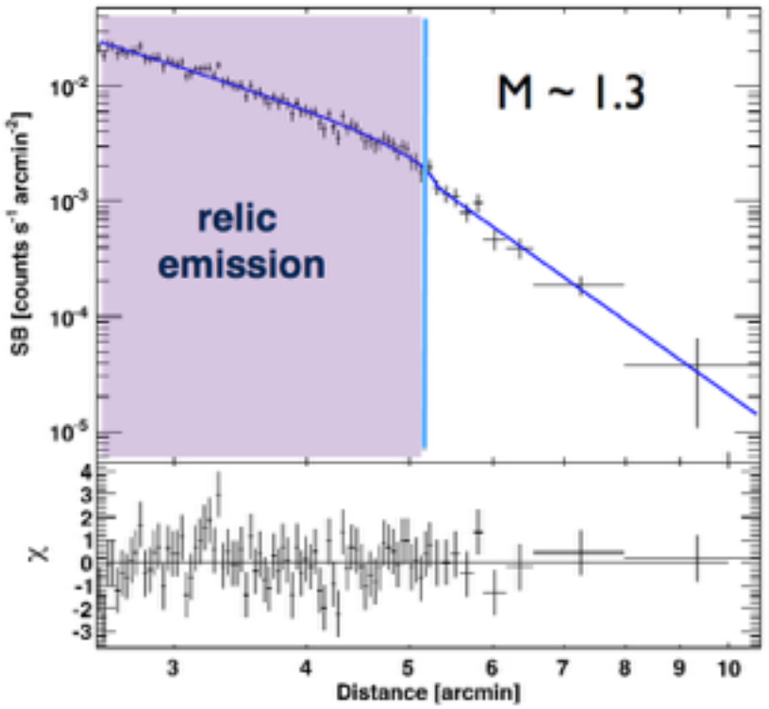
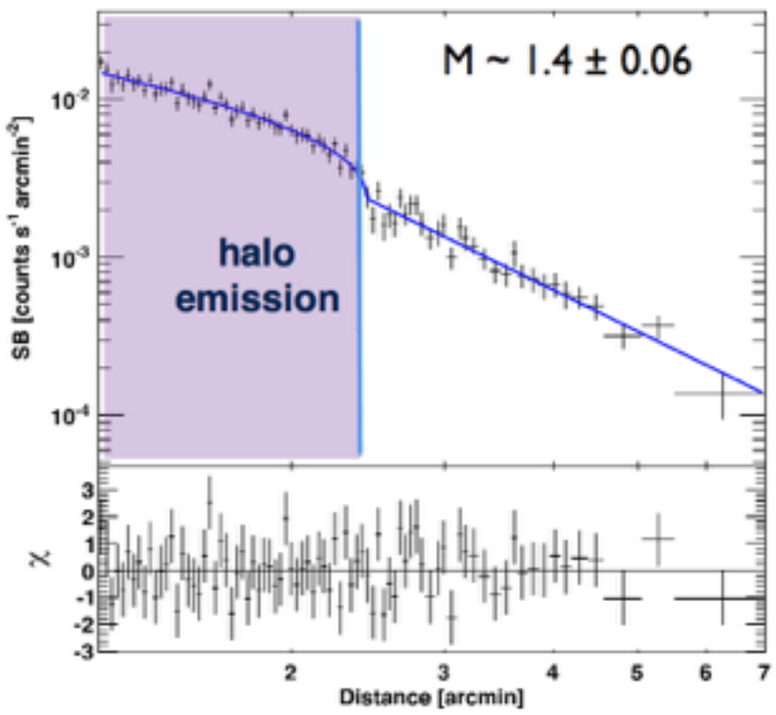
Low frequency spectral index map (150 - 610 MHz)



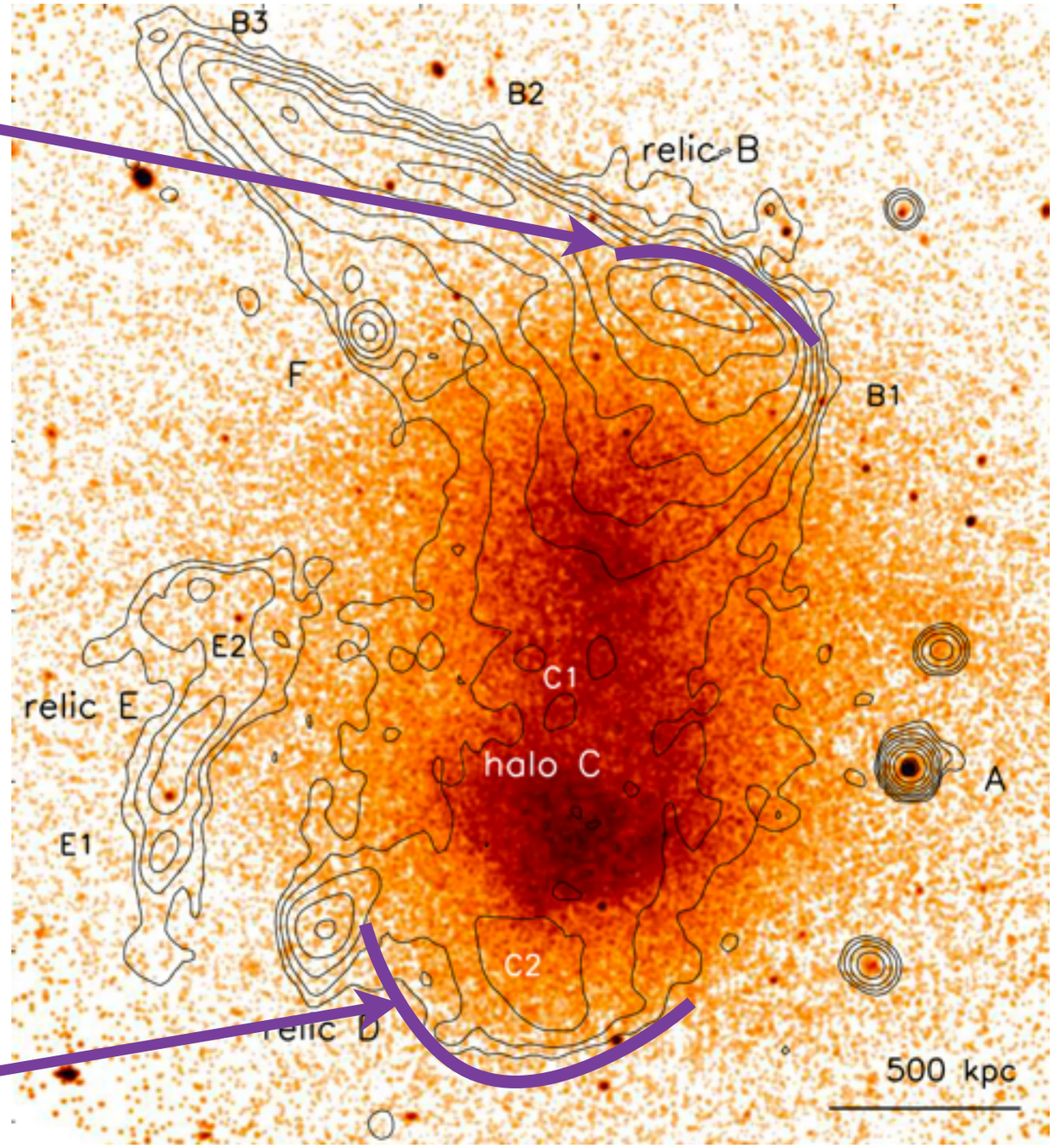
E-vectors distribution at 4.9 GHz

X-ray analysis: weak shock at northern edge





van Weeren et al. 2016



Chandra X-ray image

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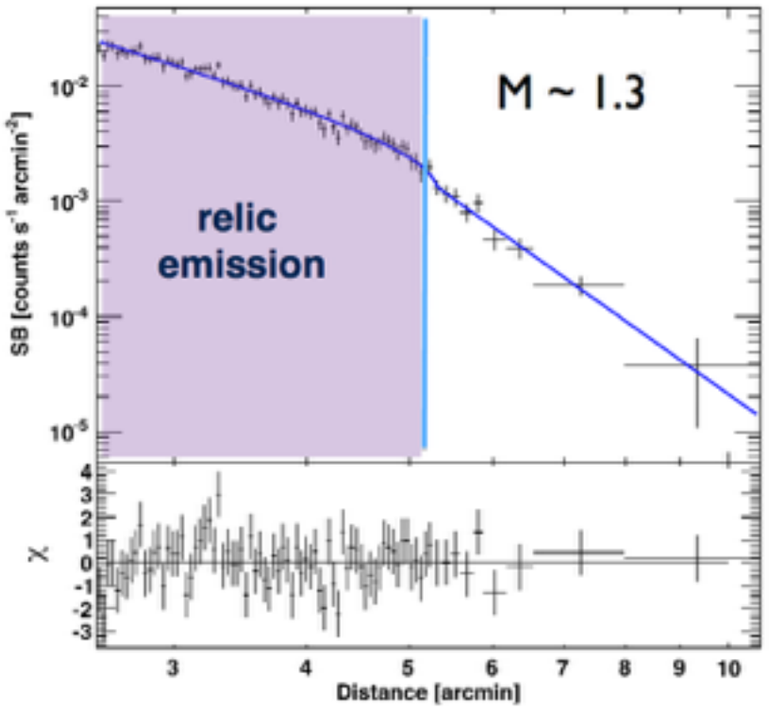
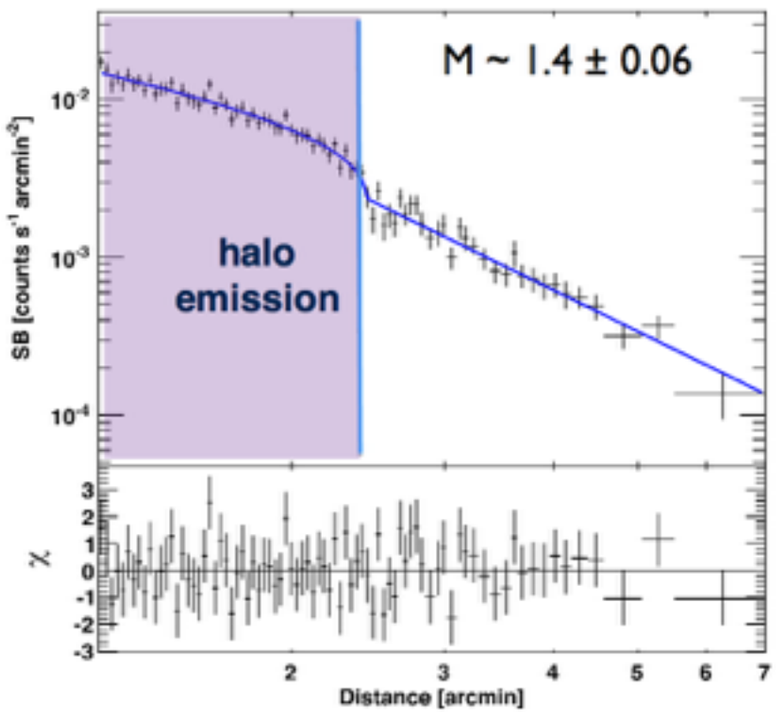


$M_{x\text{-}ray}$ ~1.3 but M_{radio} ~3.78



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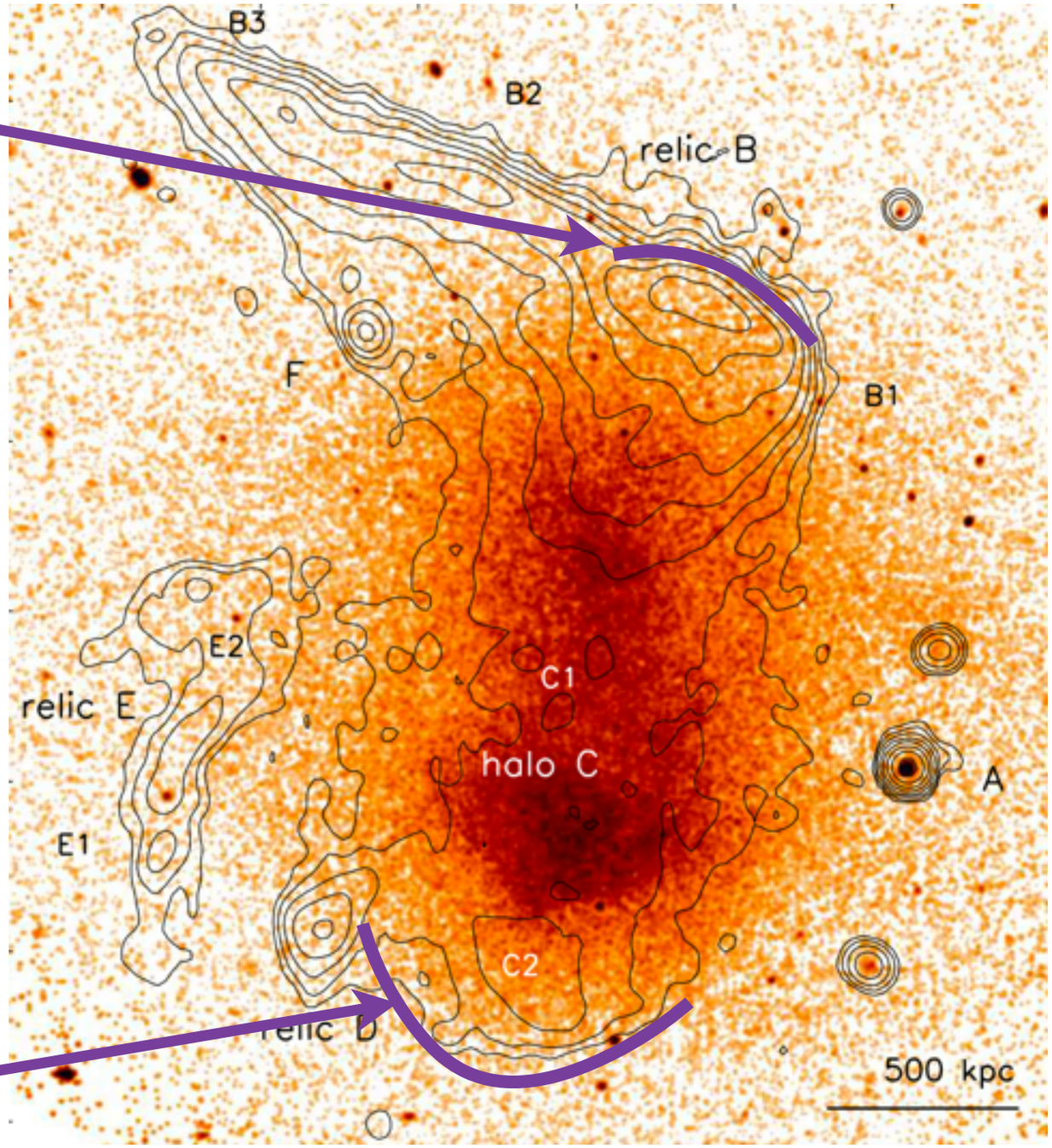
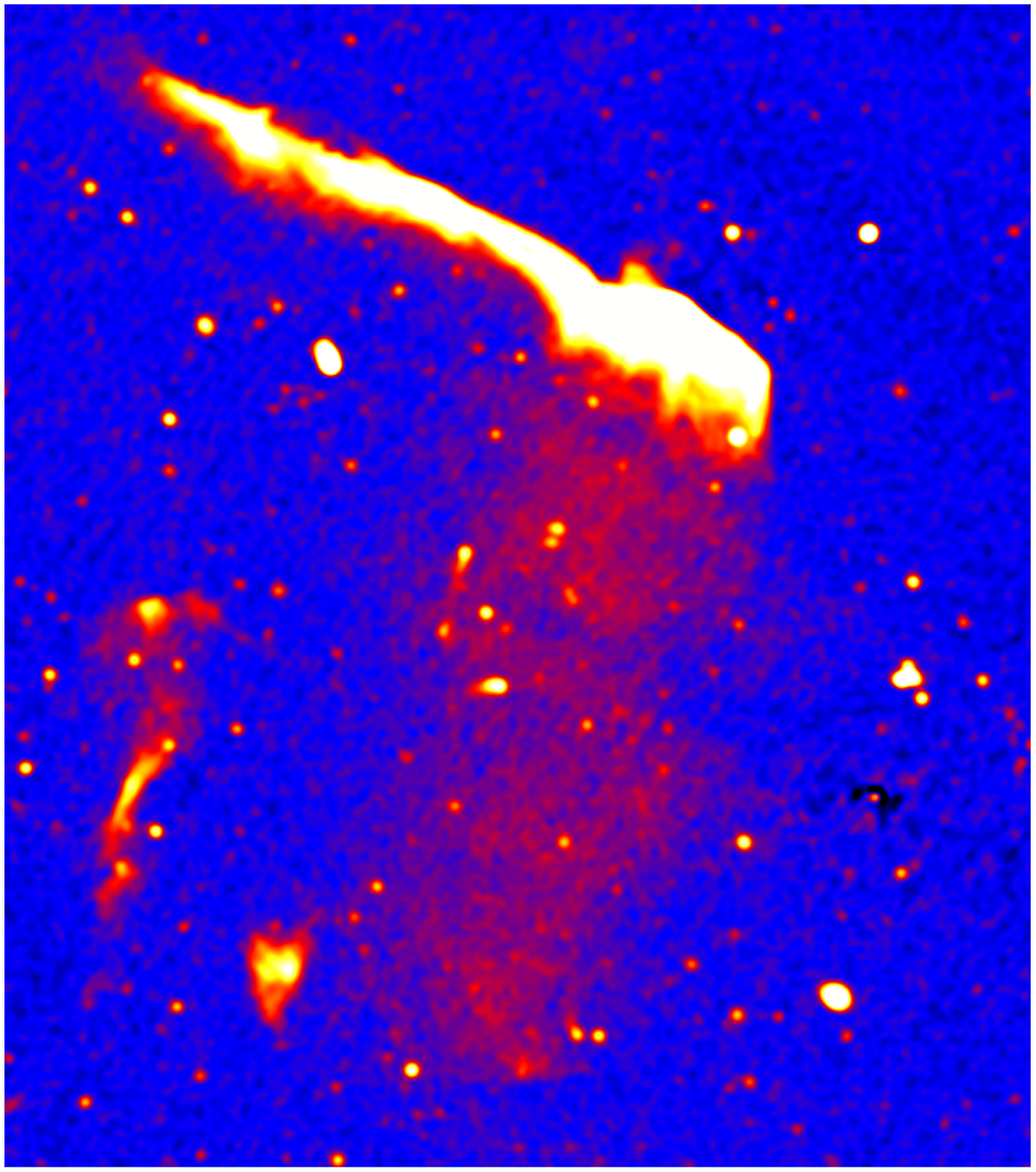


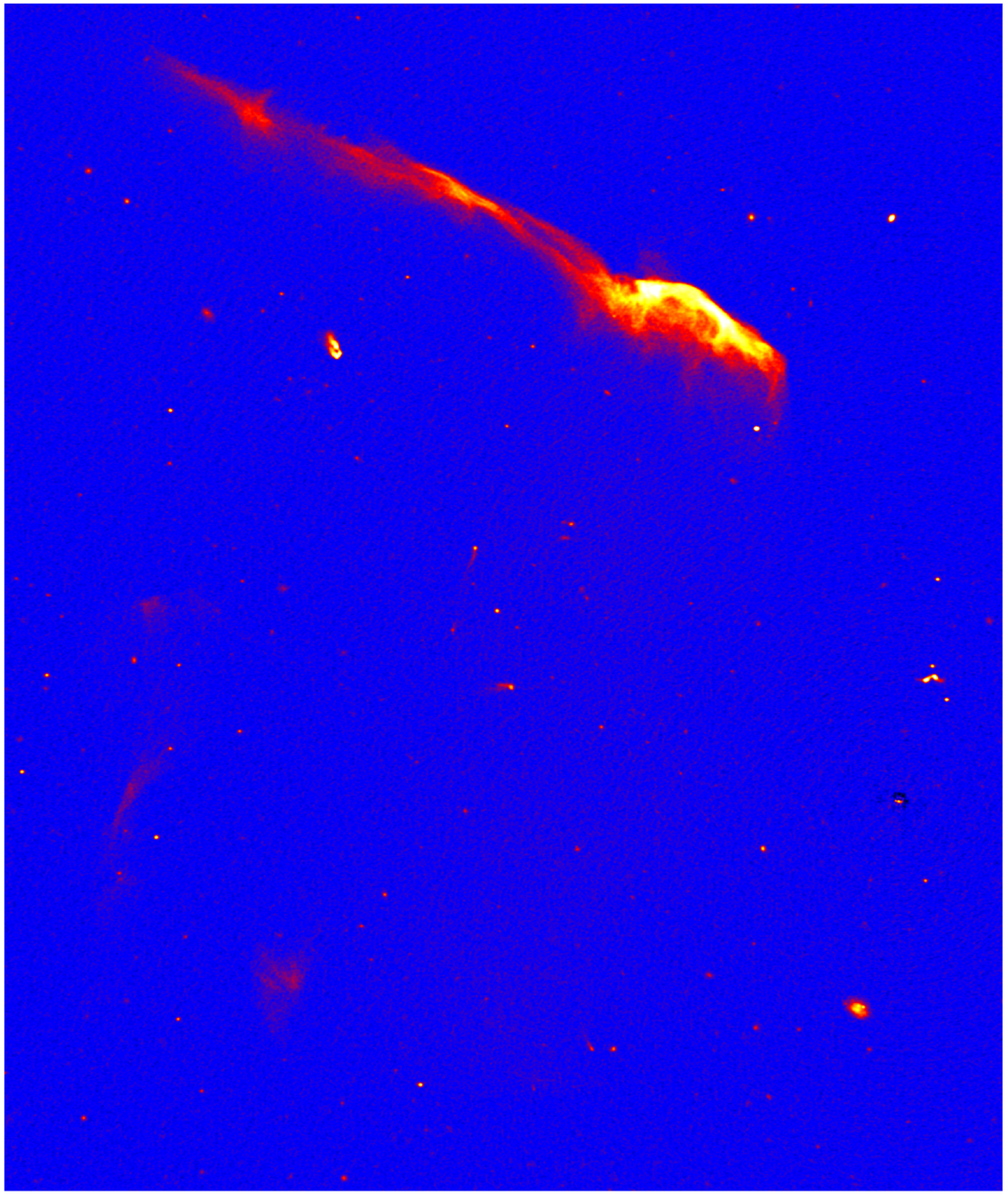
Chandra X-ray image

JVLA combined A+B+C+D array images

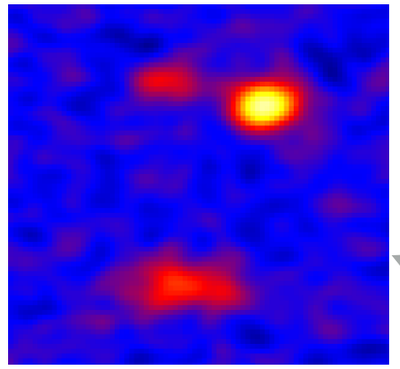
7" resolution, rms=9 μJy, frequency=1.5 GHz

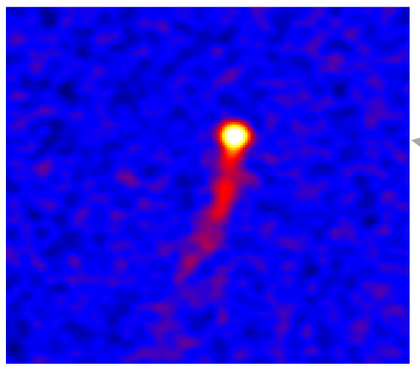


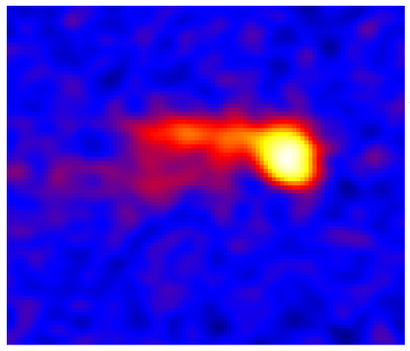
3" resolution, rms=6 μJy, frequency=1.5 GHz

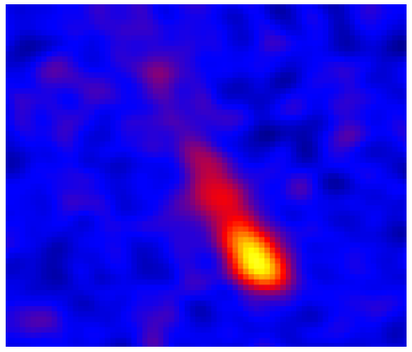


Detection of several head-tail radio galaxies

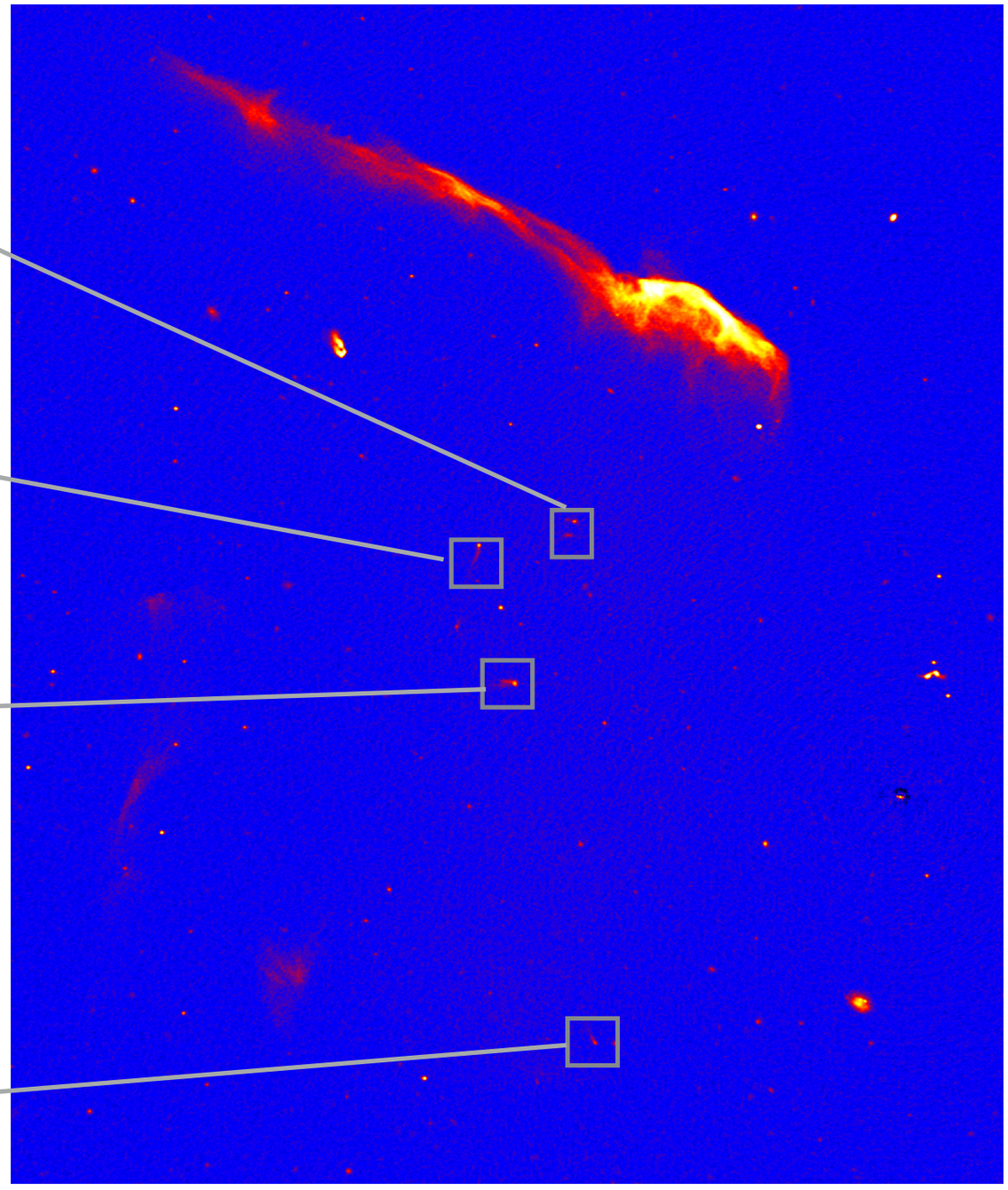








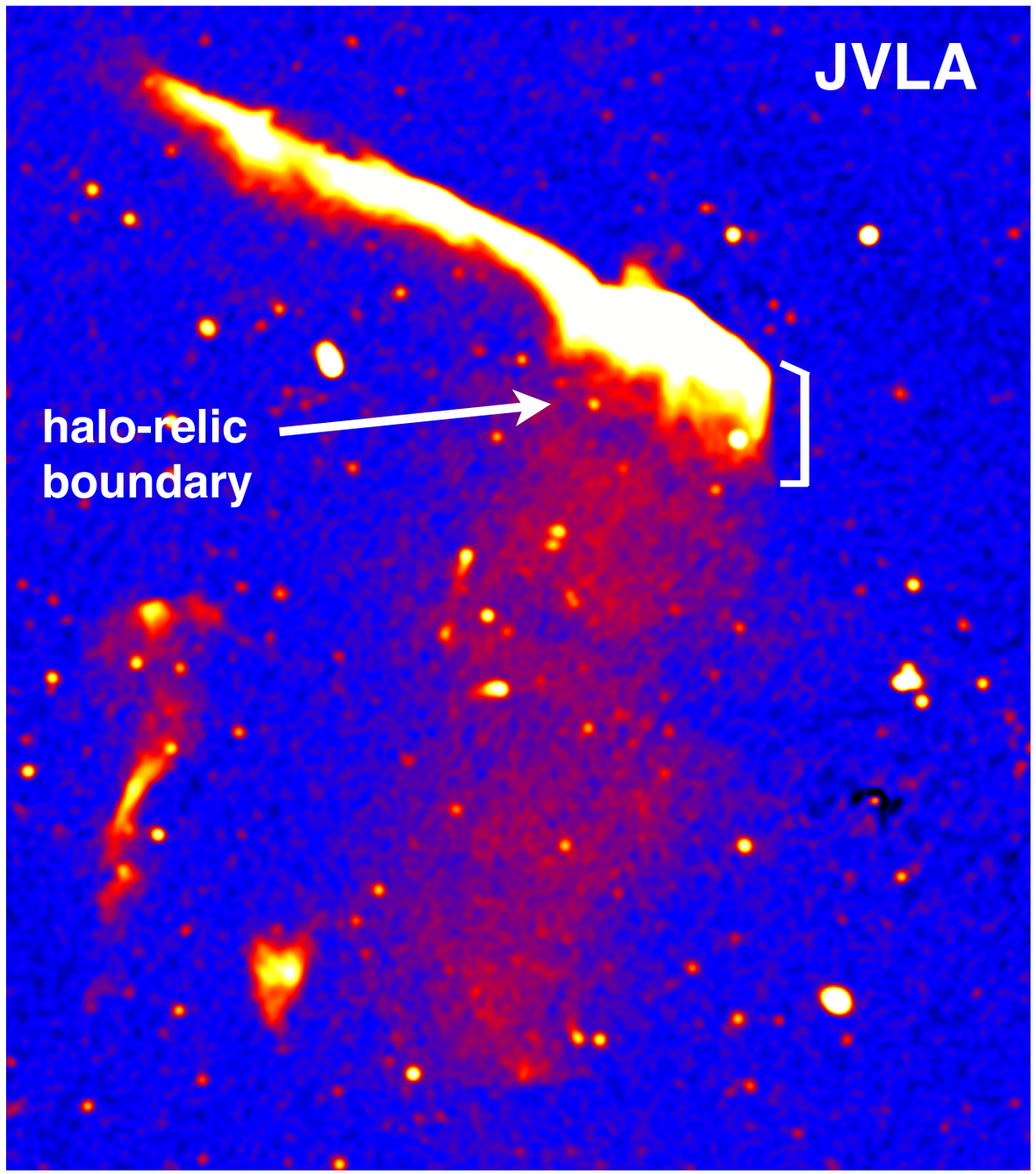
3" resolution, rms=6 μJy, frequency=1.5 GHz



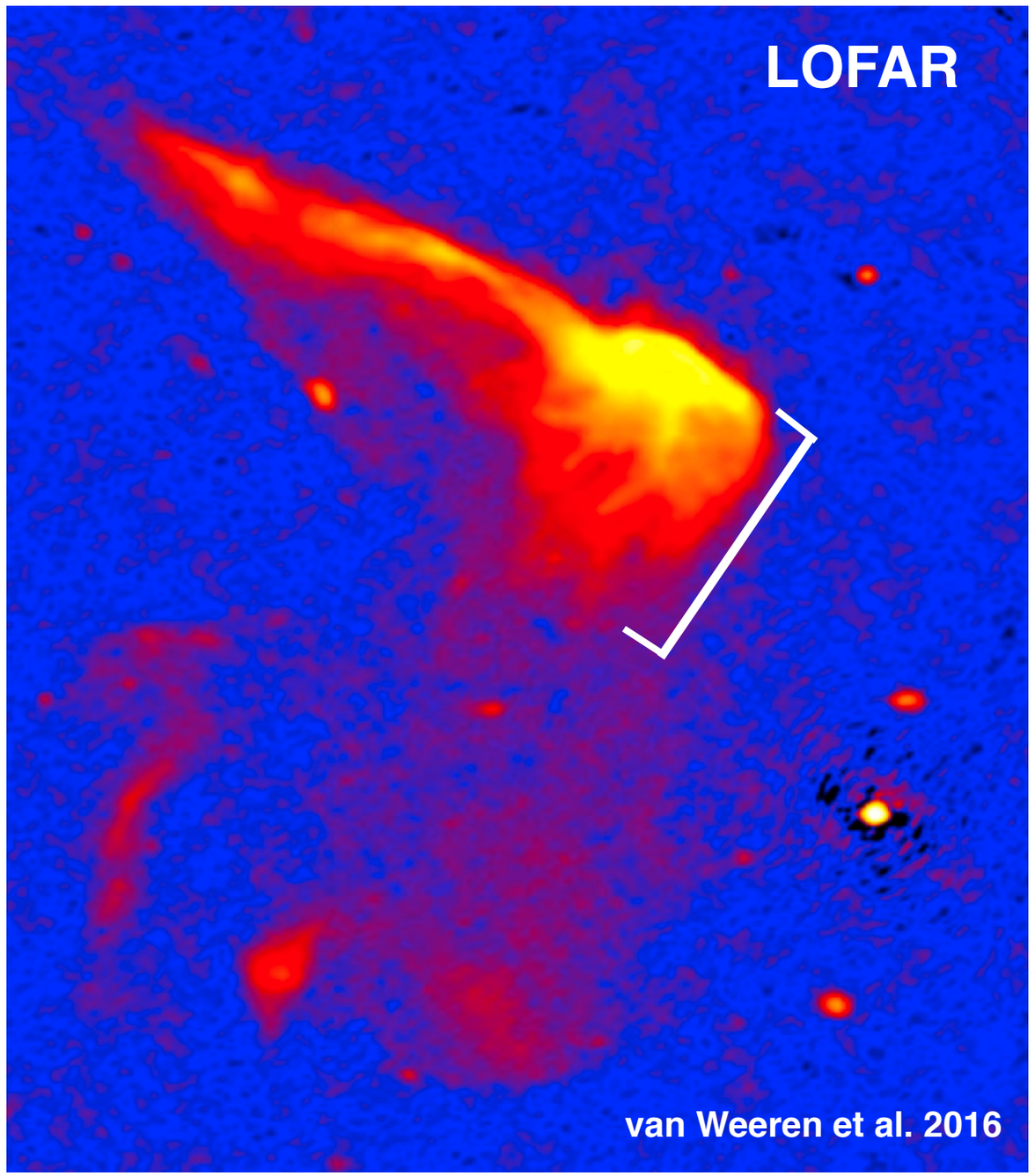
32 discrete sources within halo boundary

Comparison: Brush is extended at 150 MHz

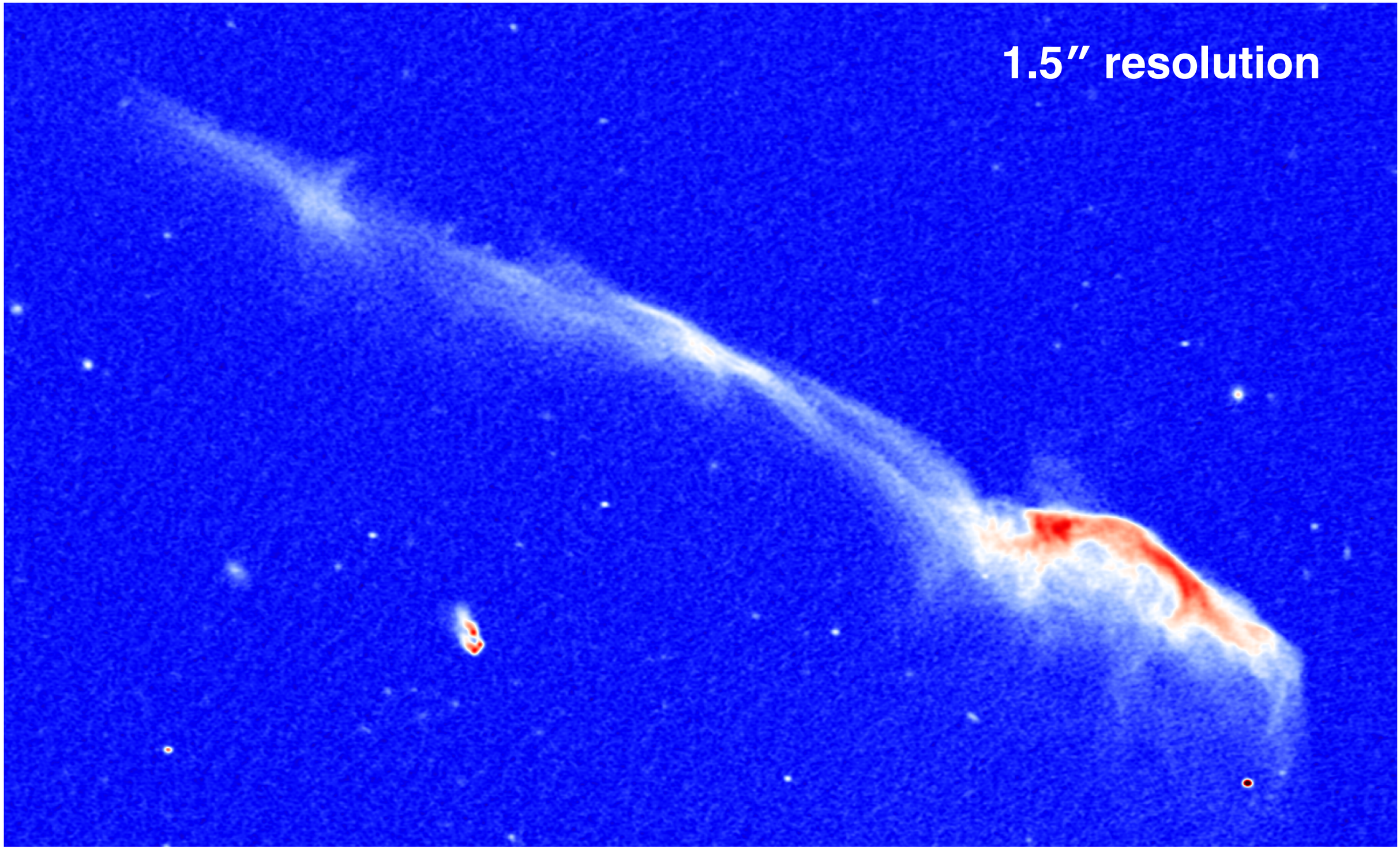
7" resolution, rms=9 μJy, frequency=1.5 GHz



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



Toothbrush: enigmatic filamentary structures



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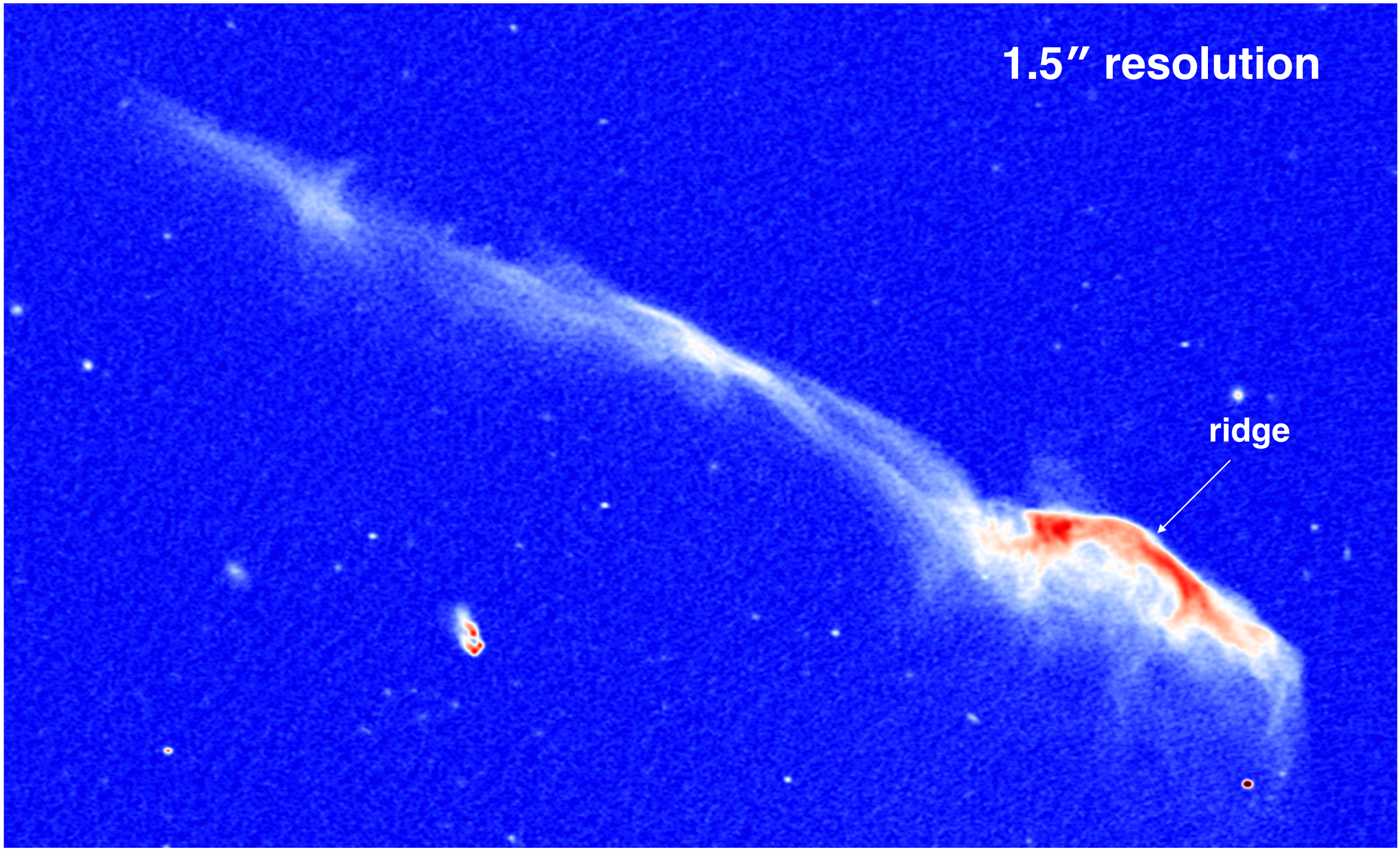

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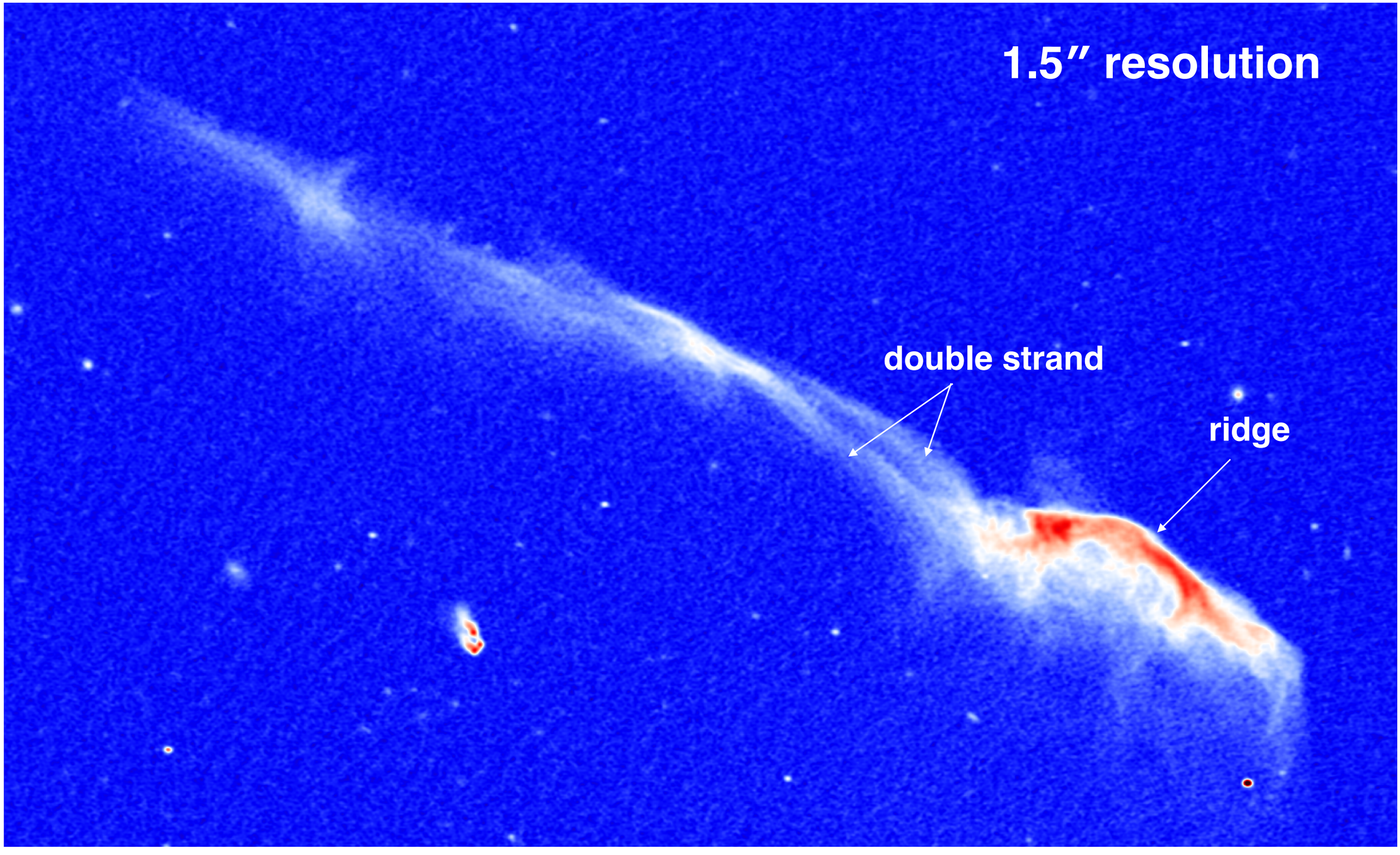

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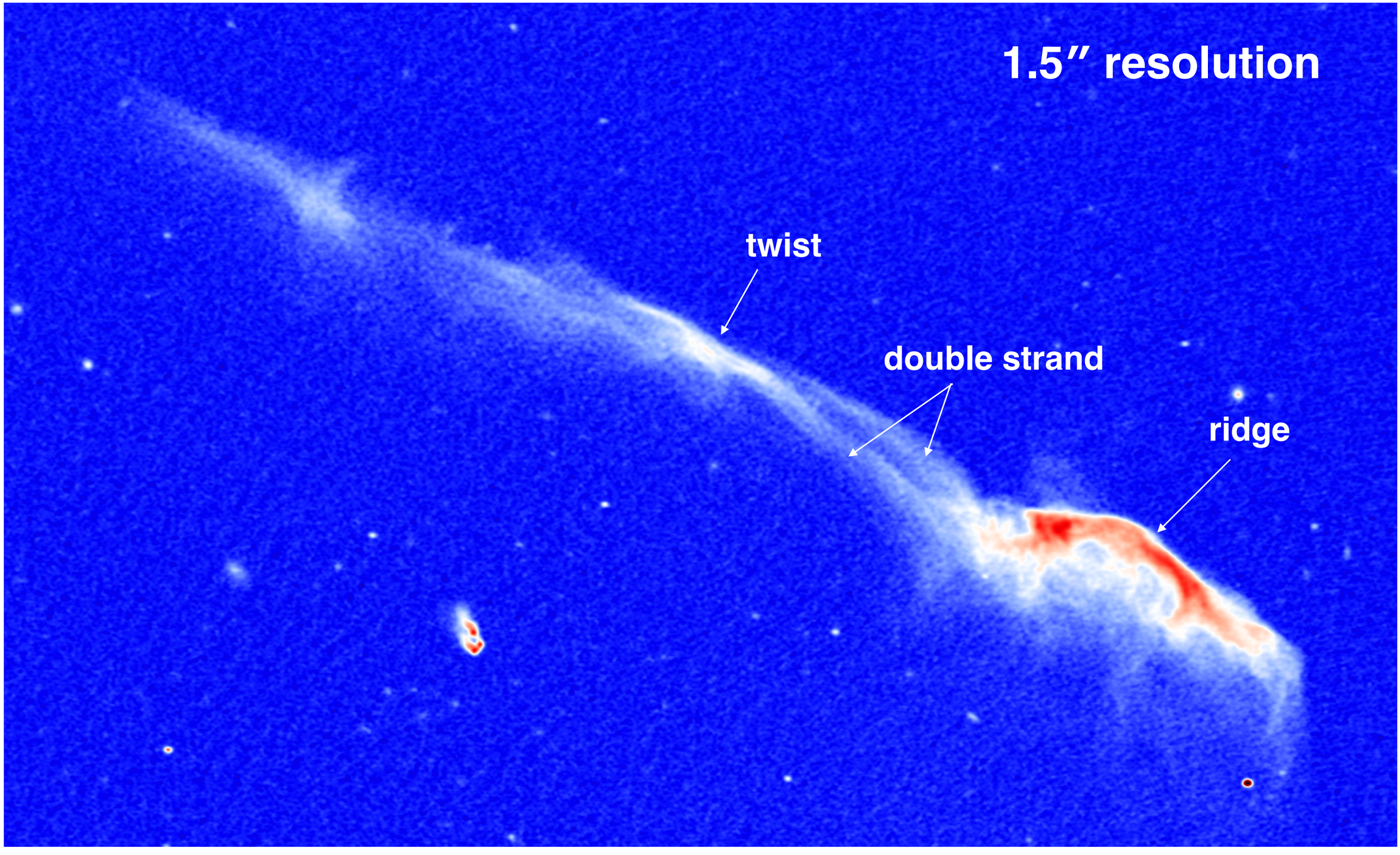

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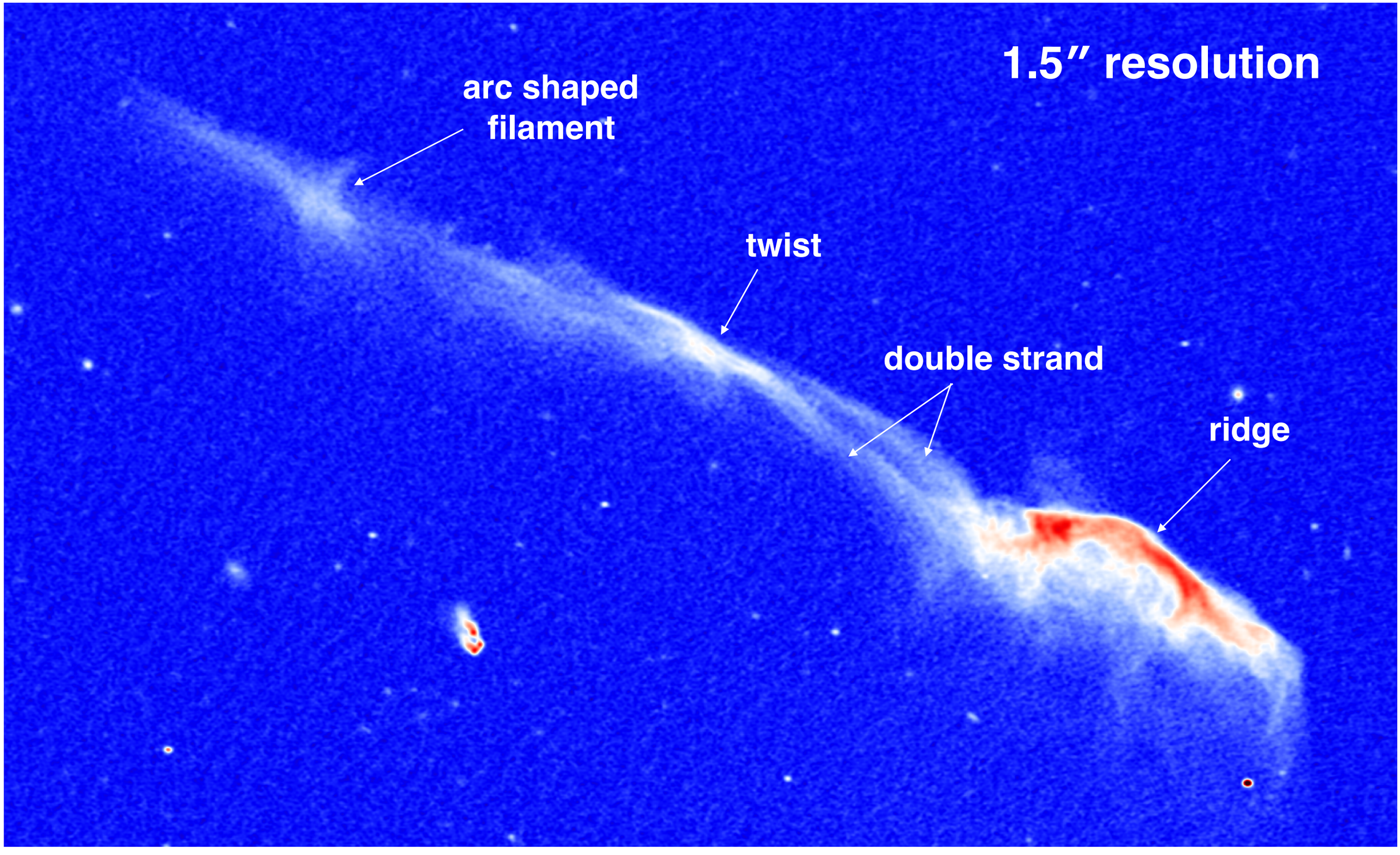
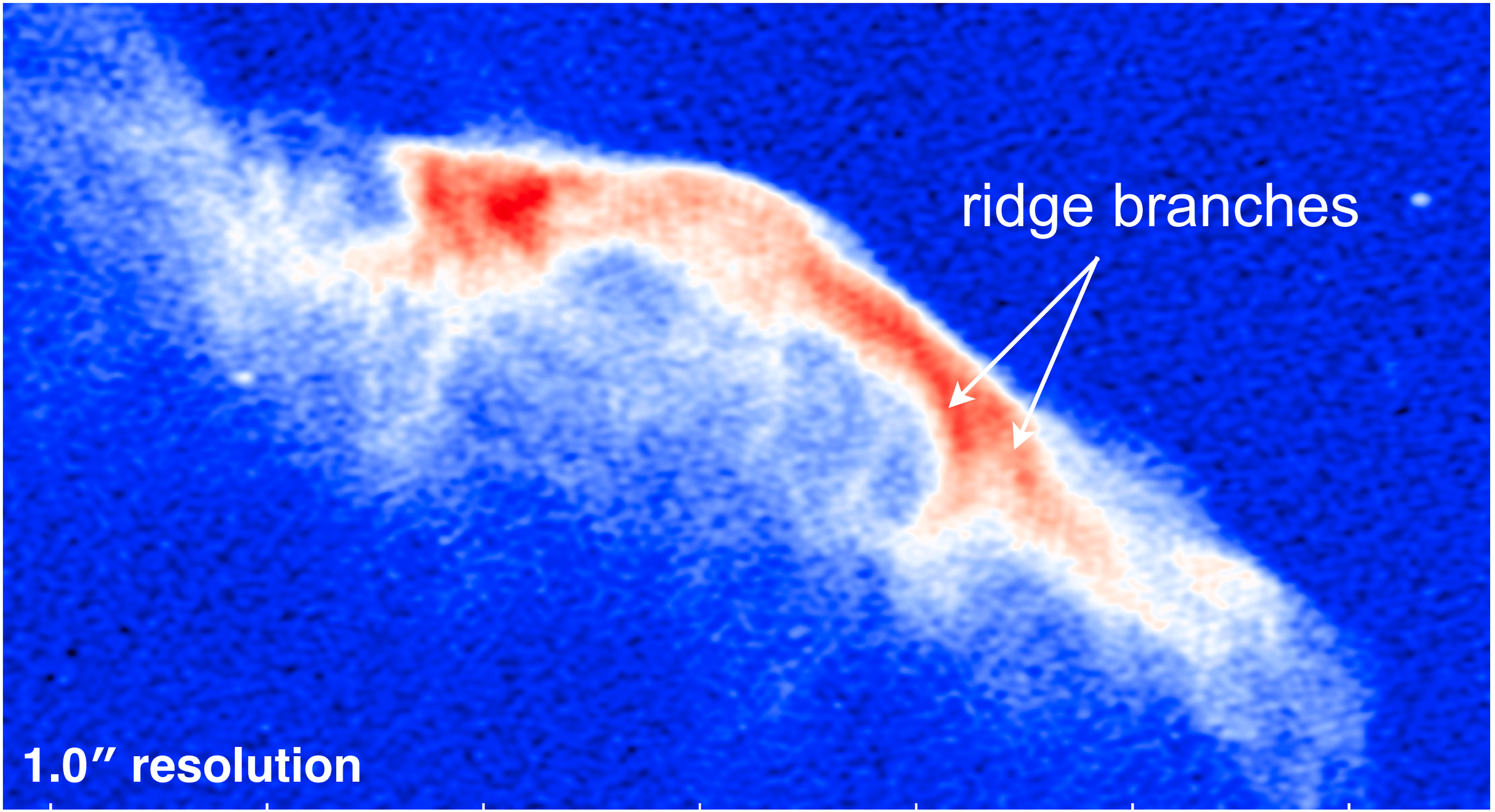


Ridge branches into two parts



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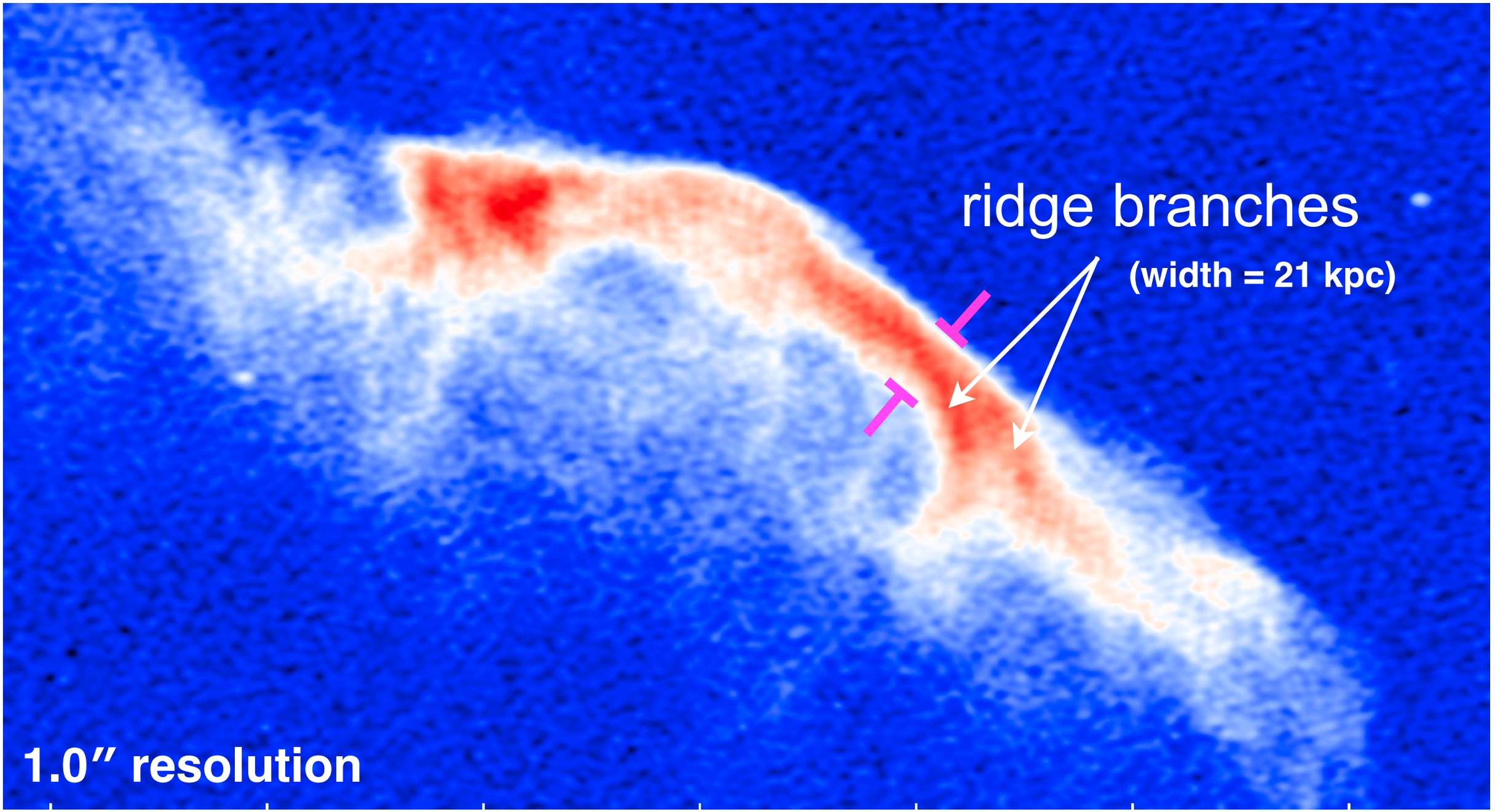
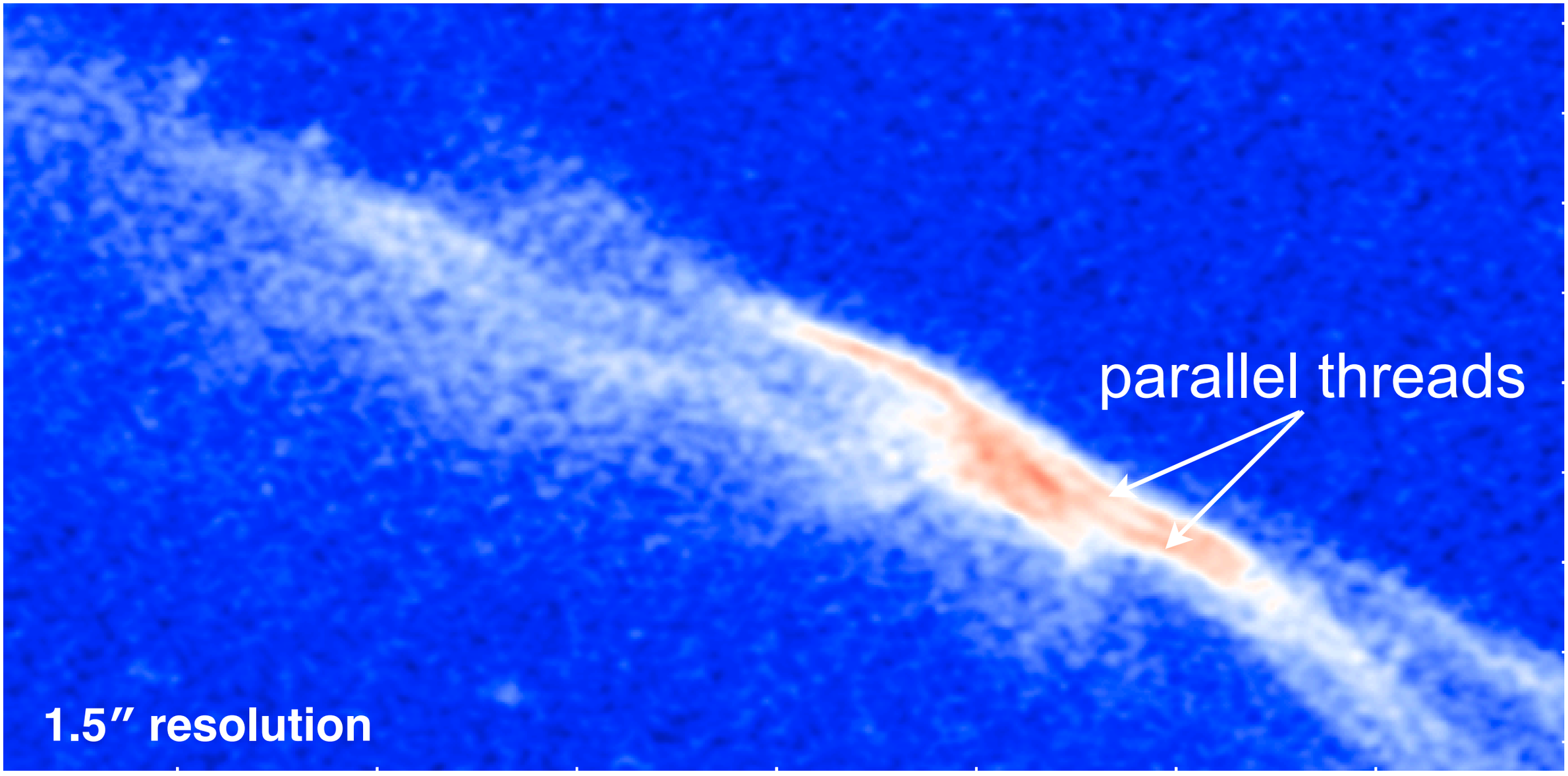
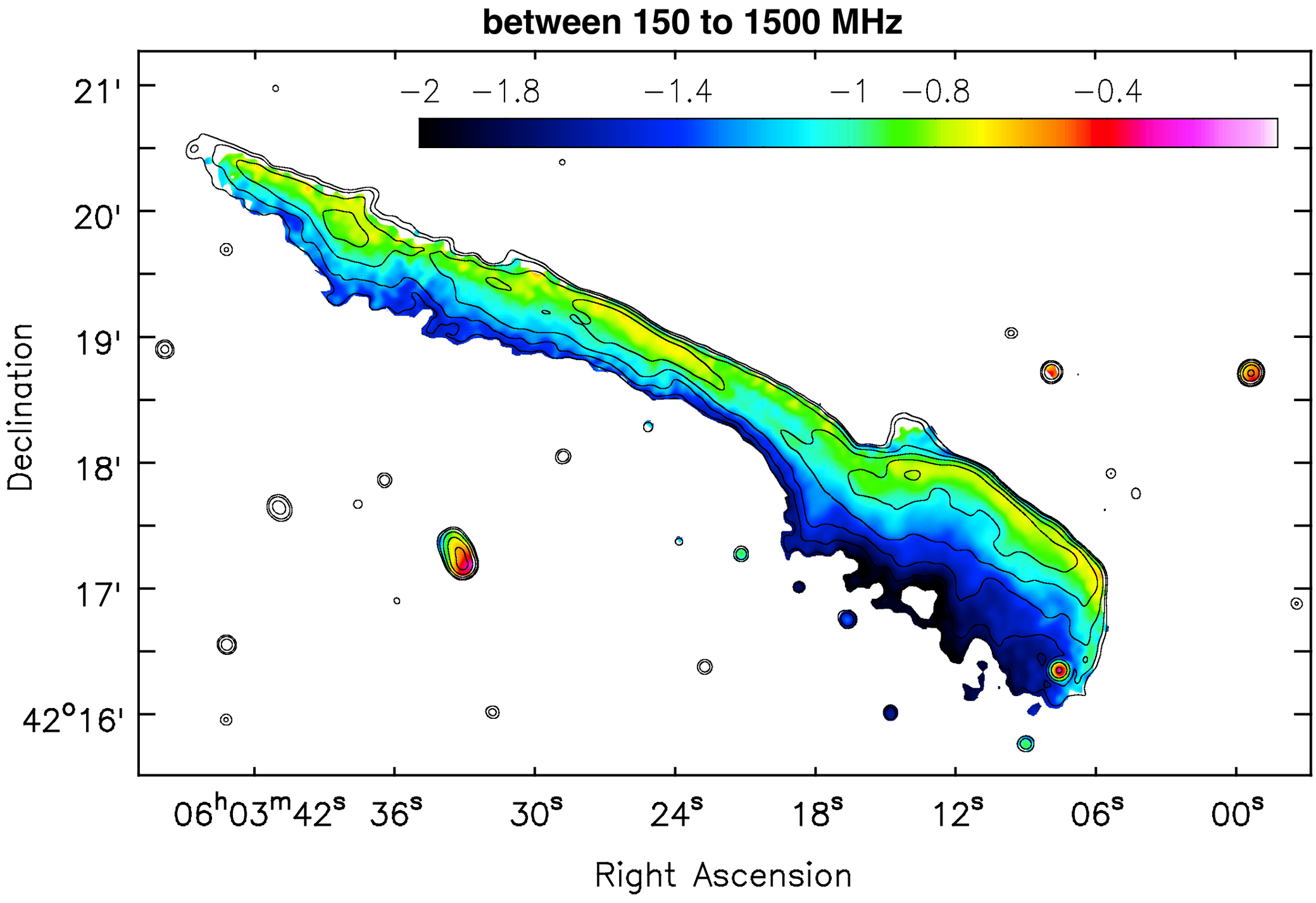


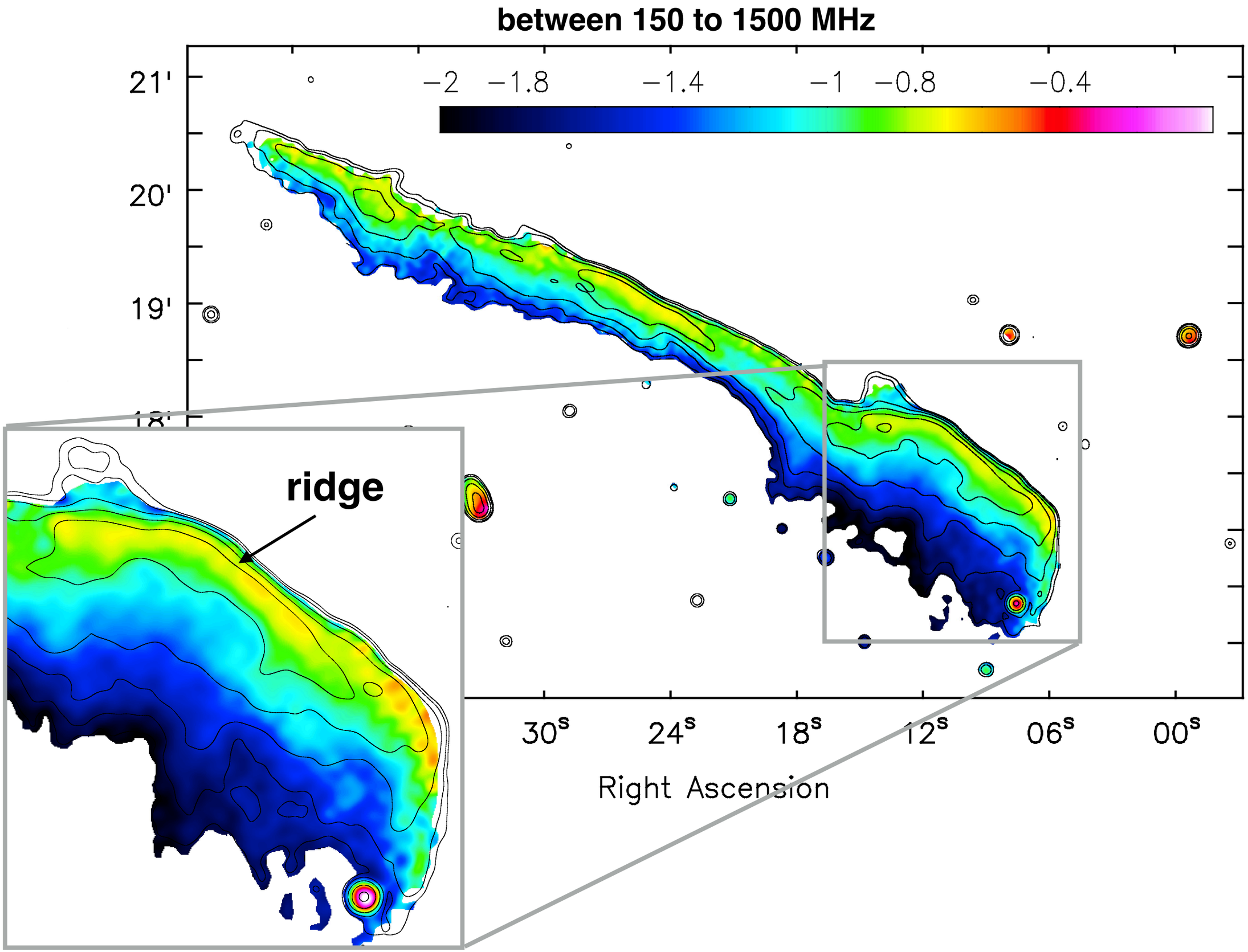
Two filaments separated by 5 kpc



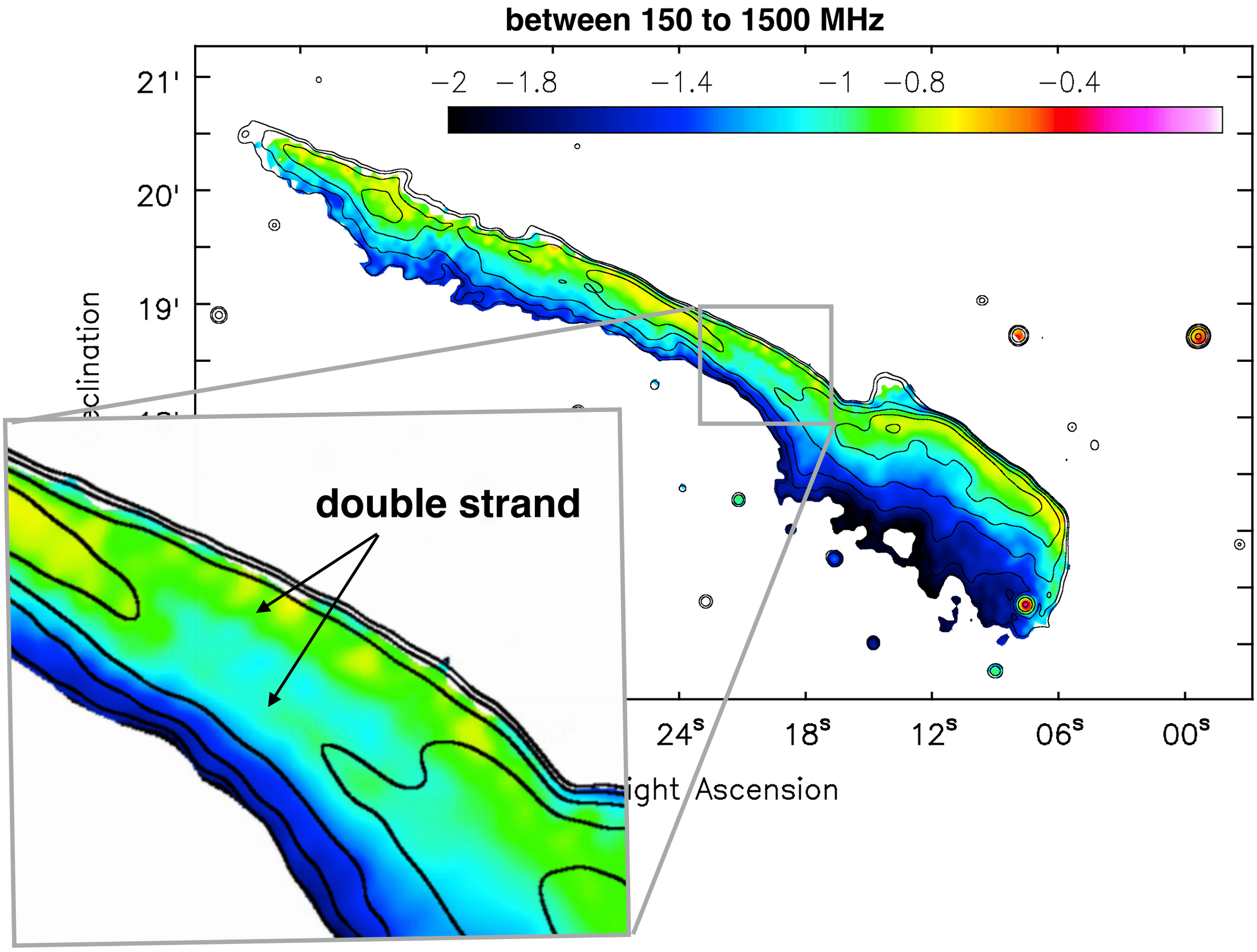
Spectral index at northern edge - 0.70 < α < -0.75



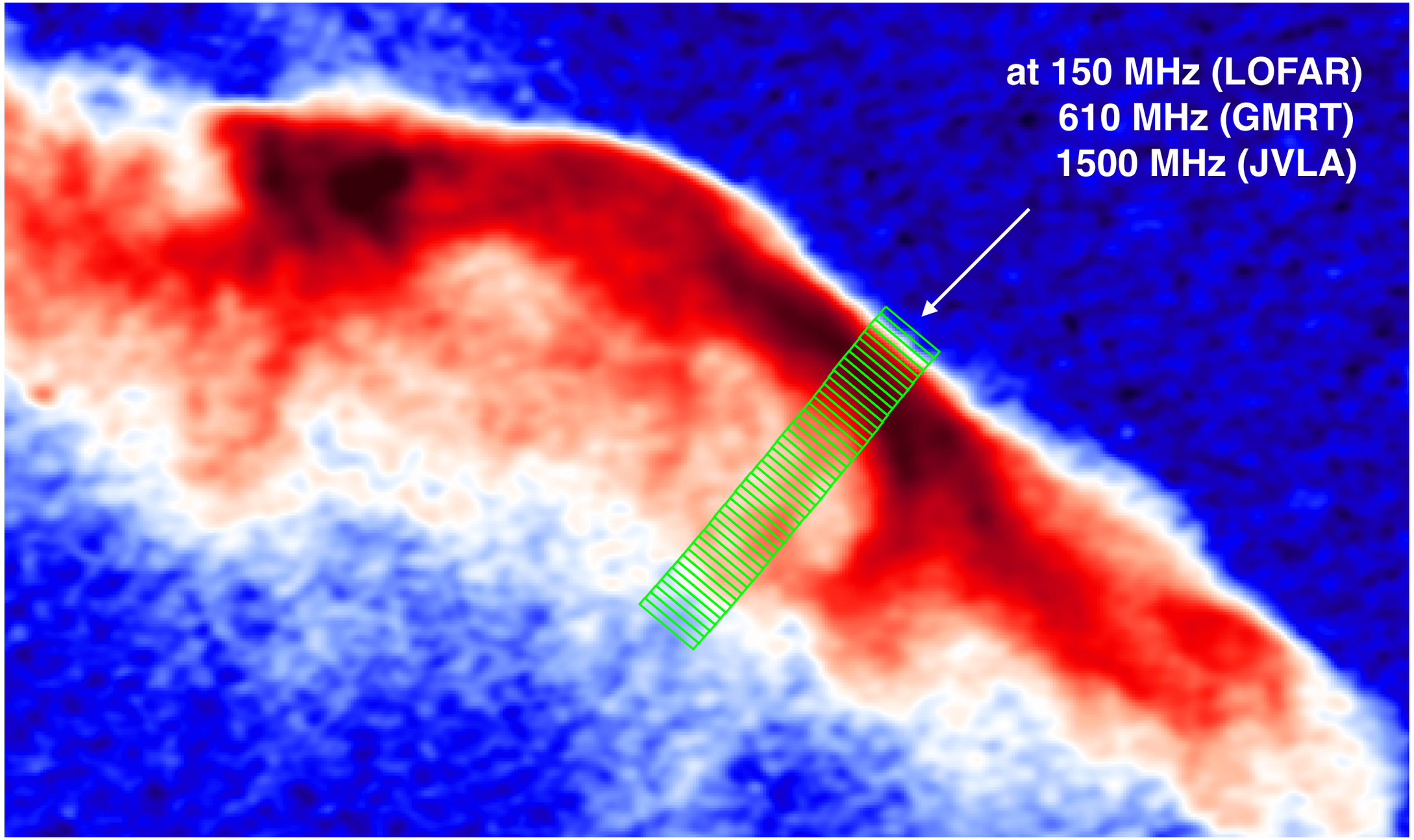
Spectrum steepens within the ridge



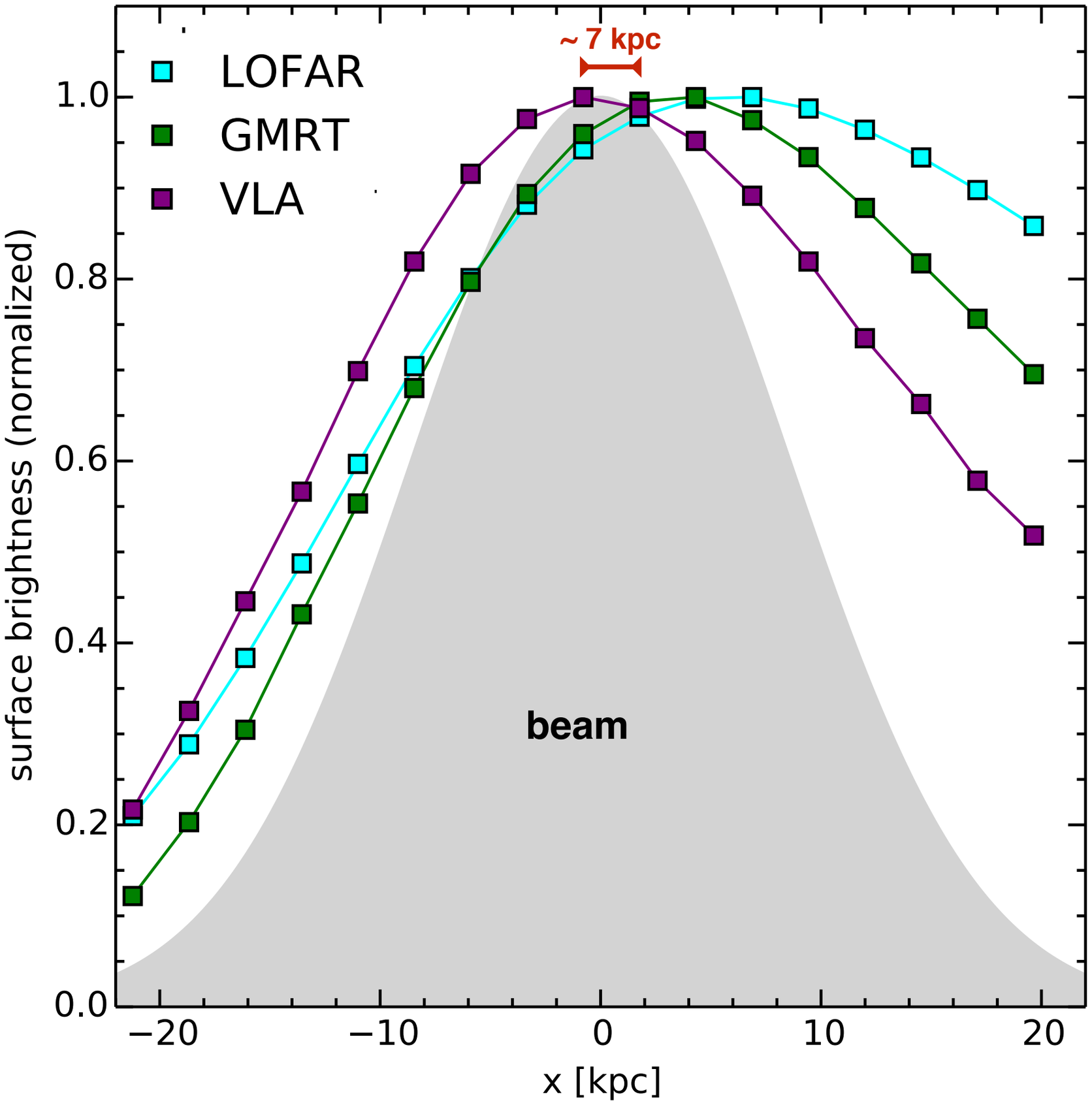
Spectral index across the double strand varies



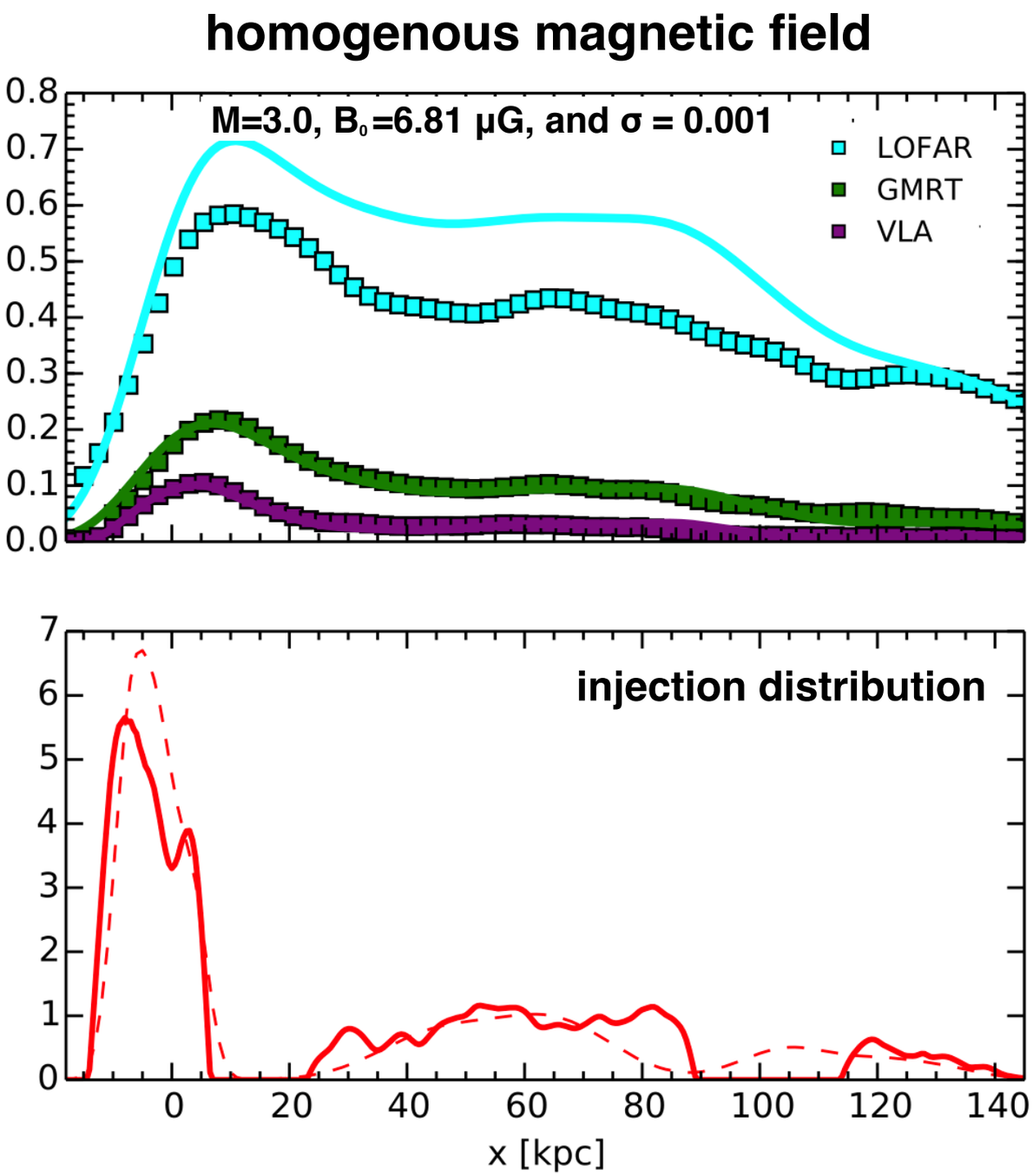
Detailed investigation of the ridge



Ridge position shifts with frequency



Surface brightness distribution:



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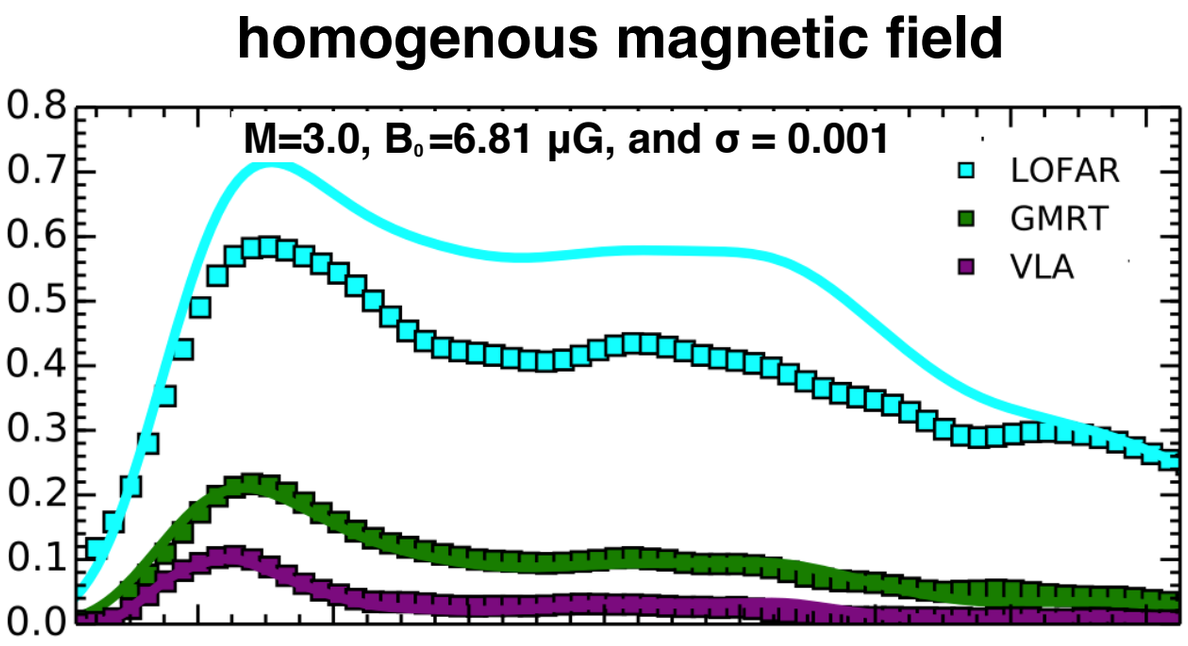
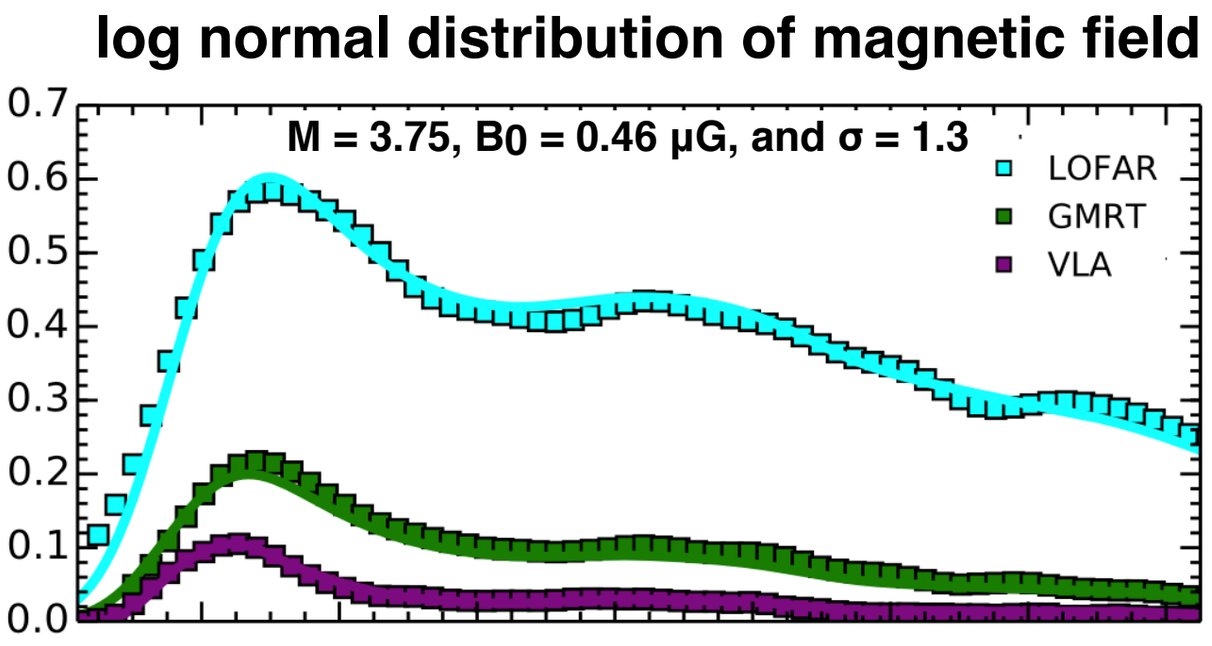
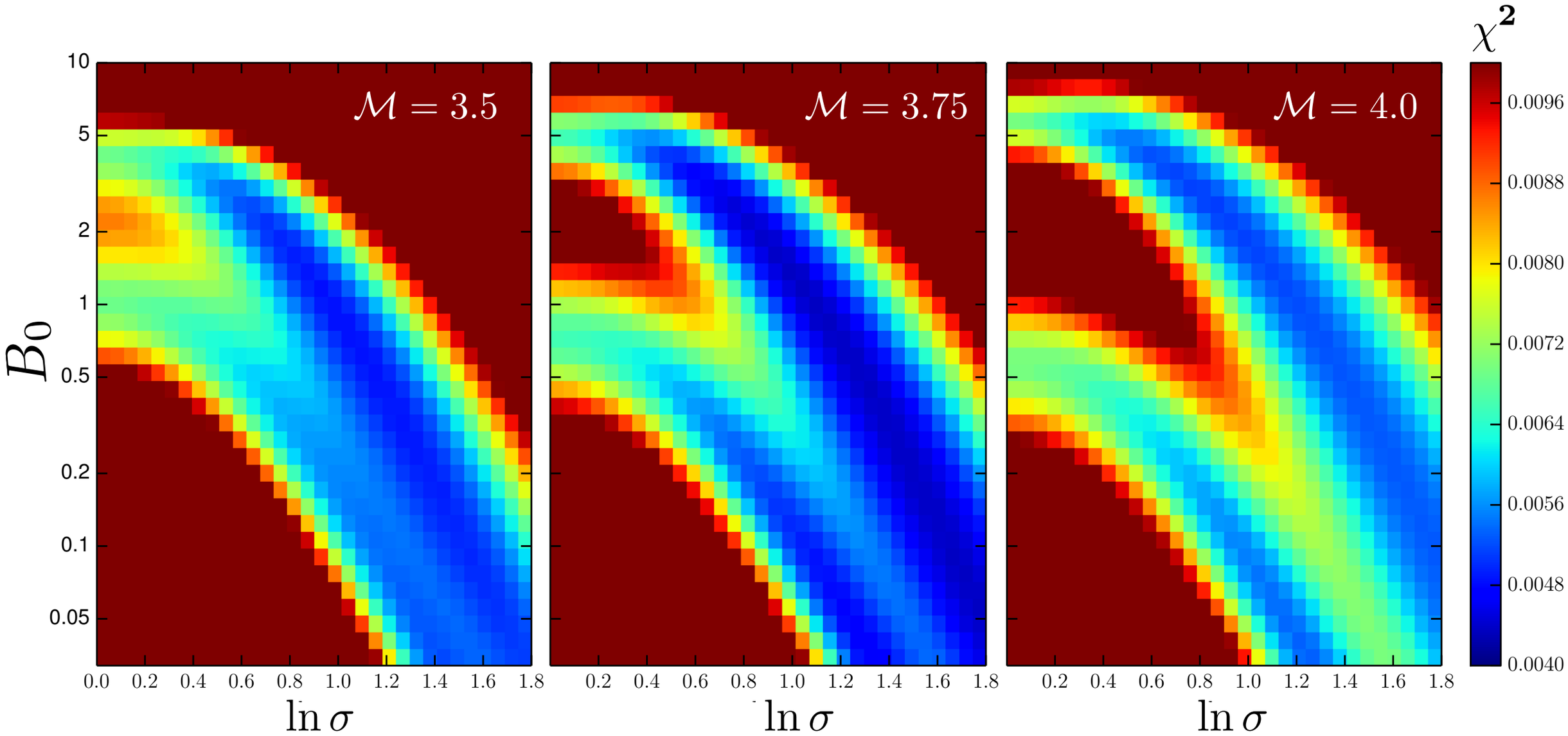




Best fit: $\mathrm{B_0} \leq 5\mu\mathrm{G}, \sigma \geq 0.7$ and Mach number = 3.75



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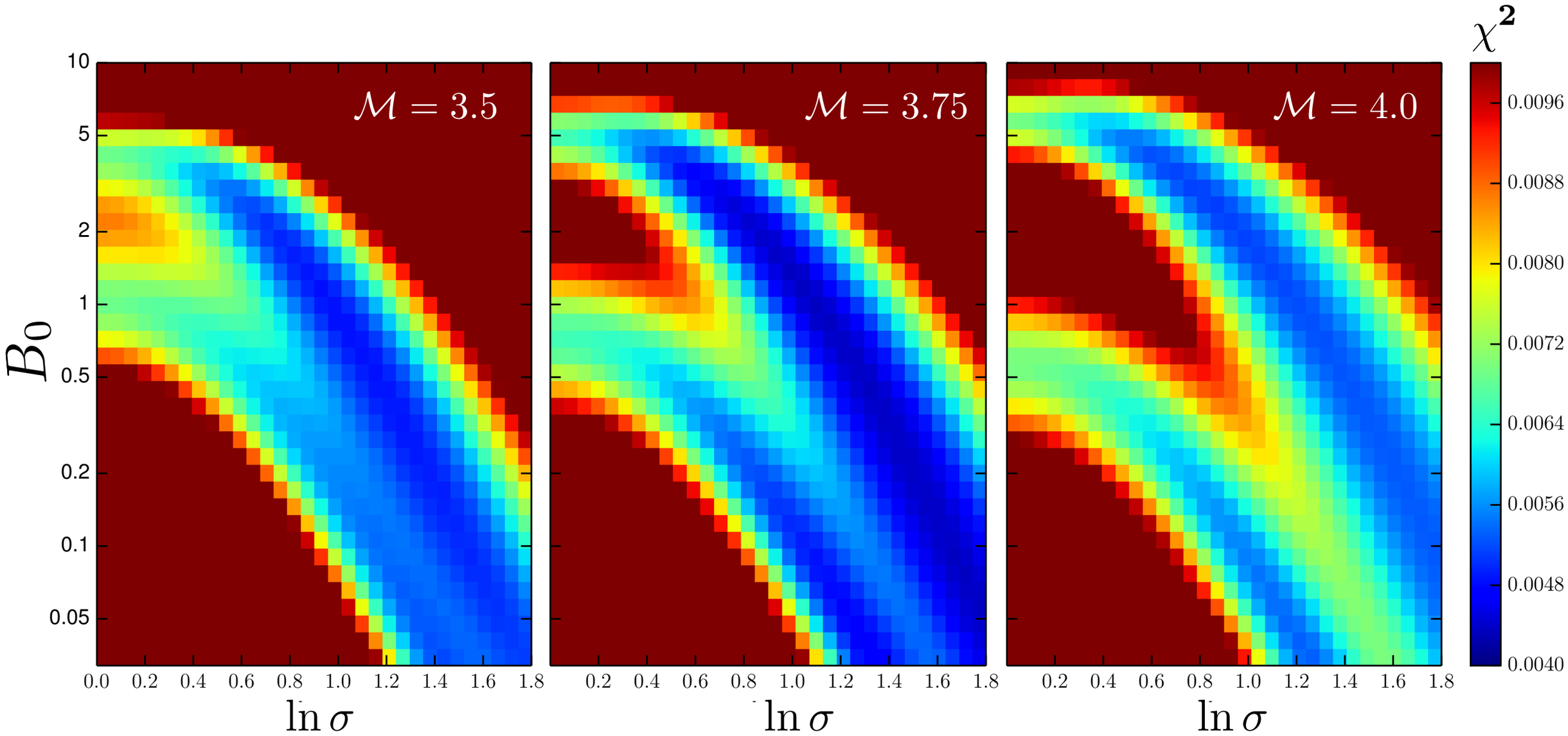
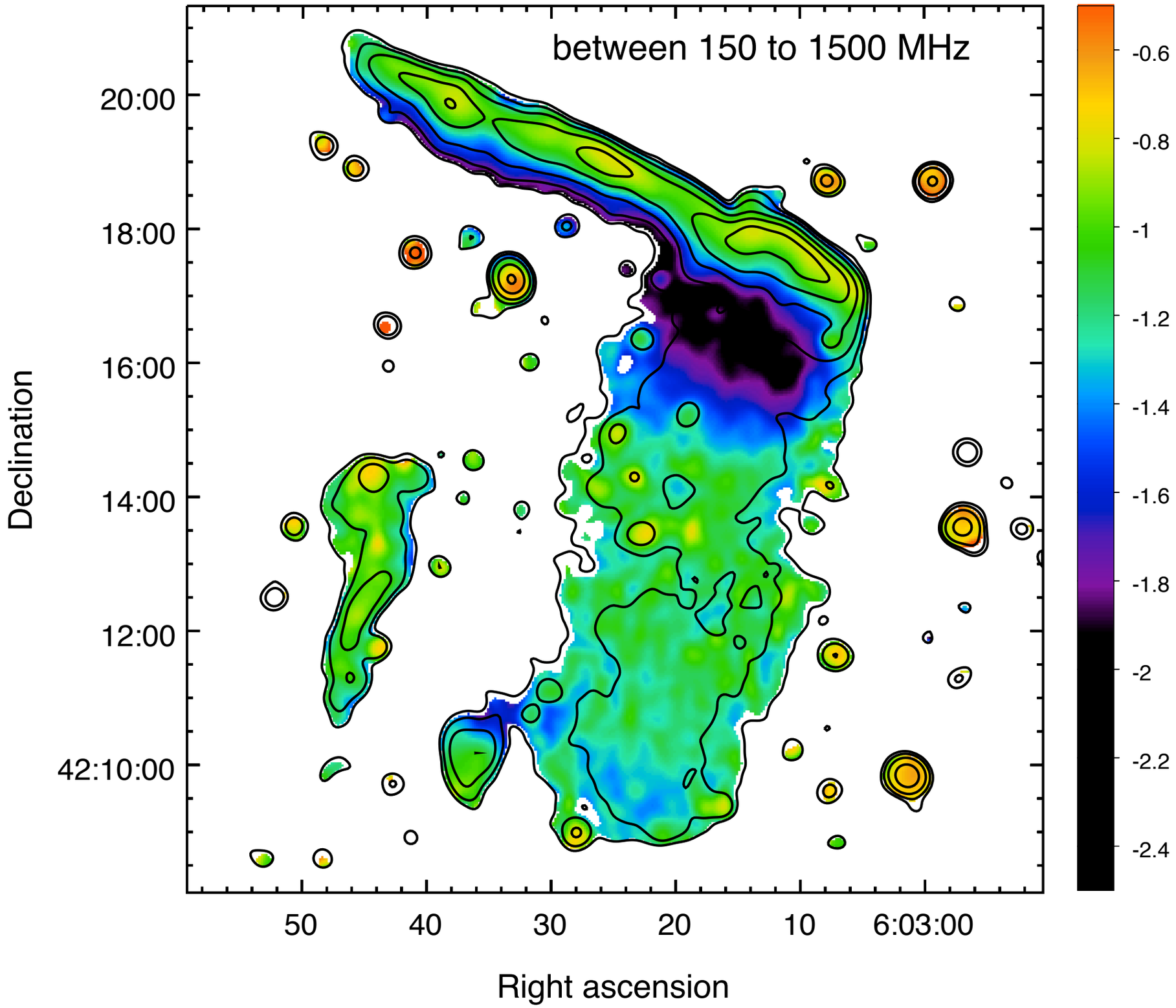
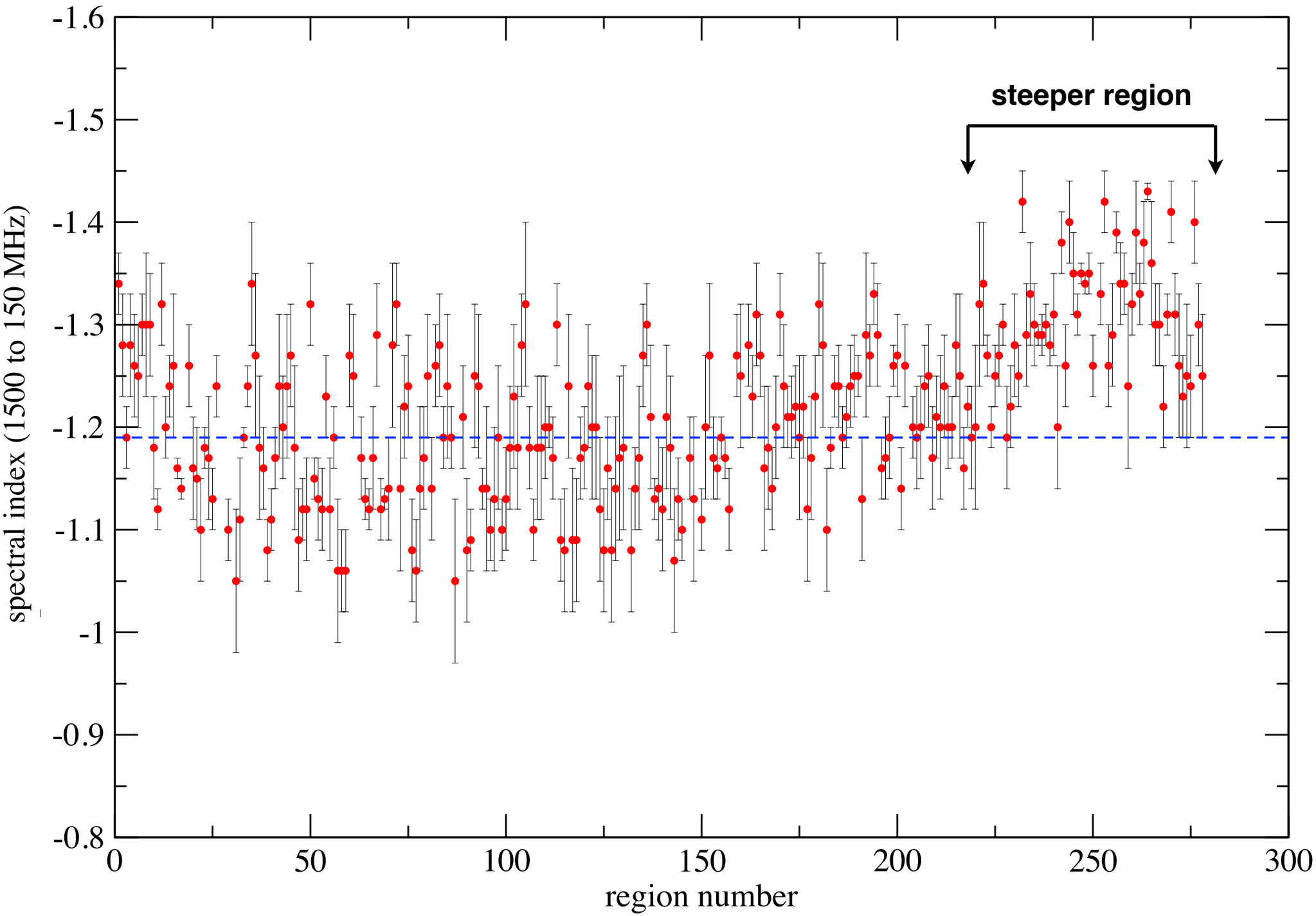


model ruled out field strength above 5 μG

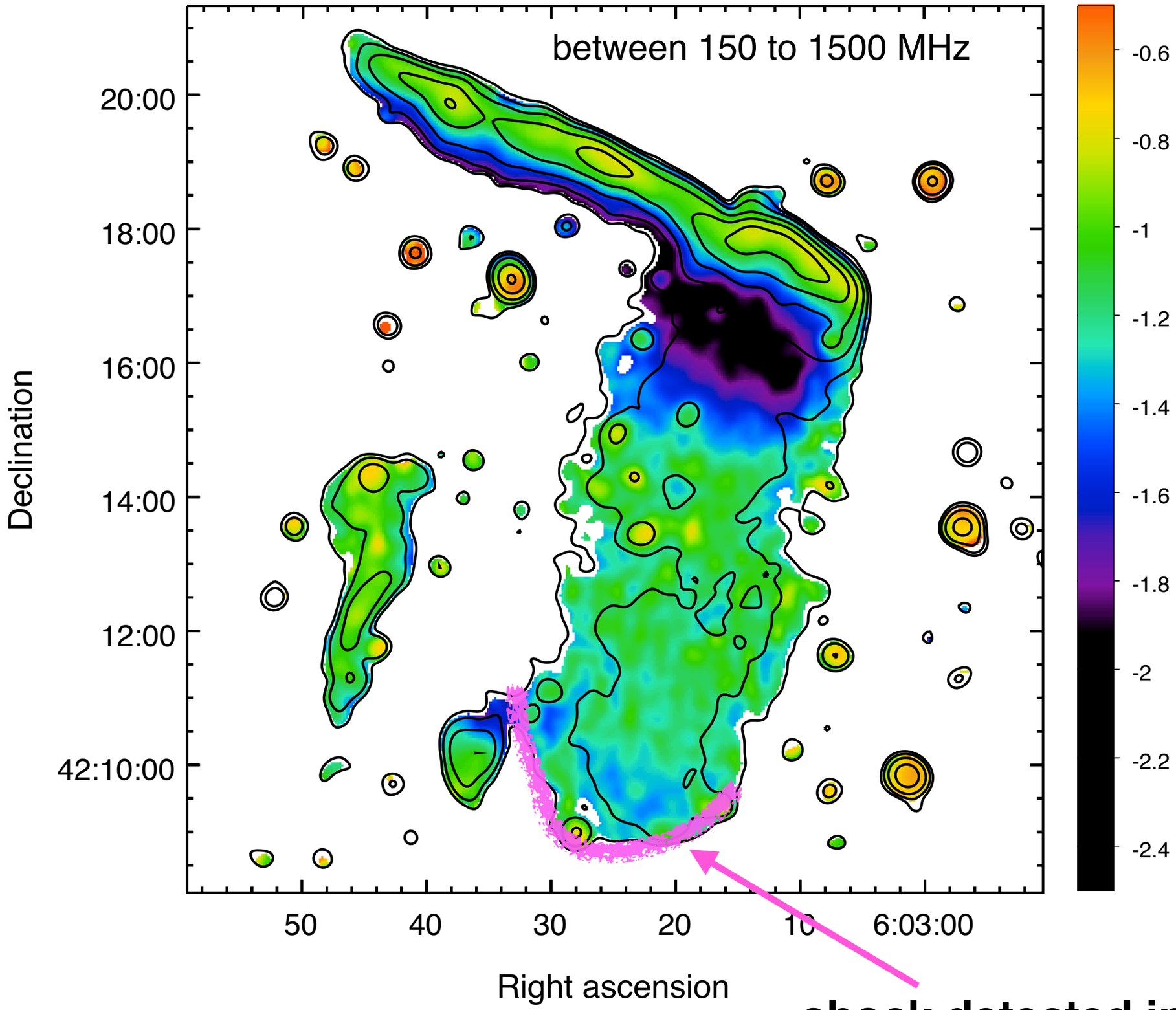
Halo: remarkable uniform spectral index



Halo: steep spectrum southern region

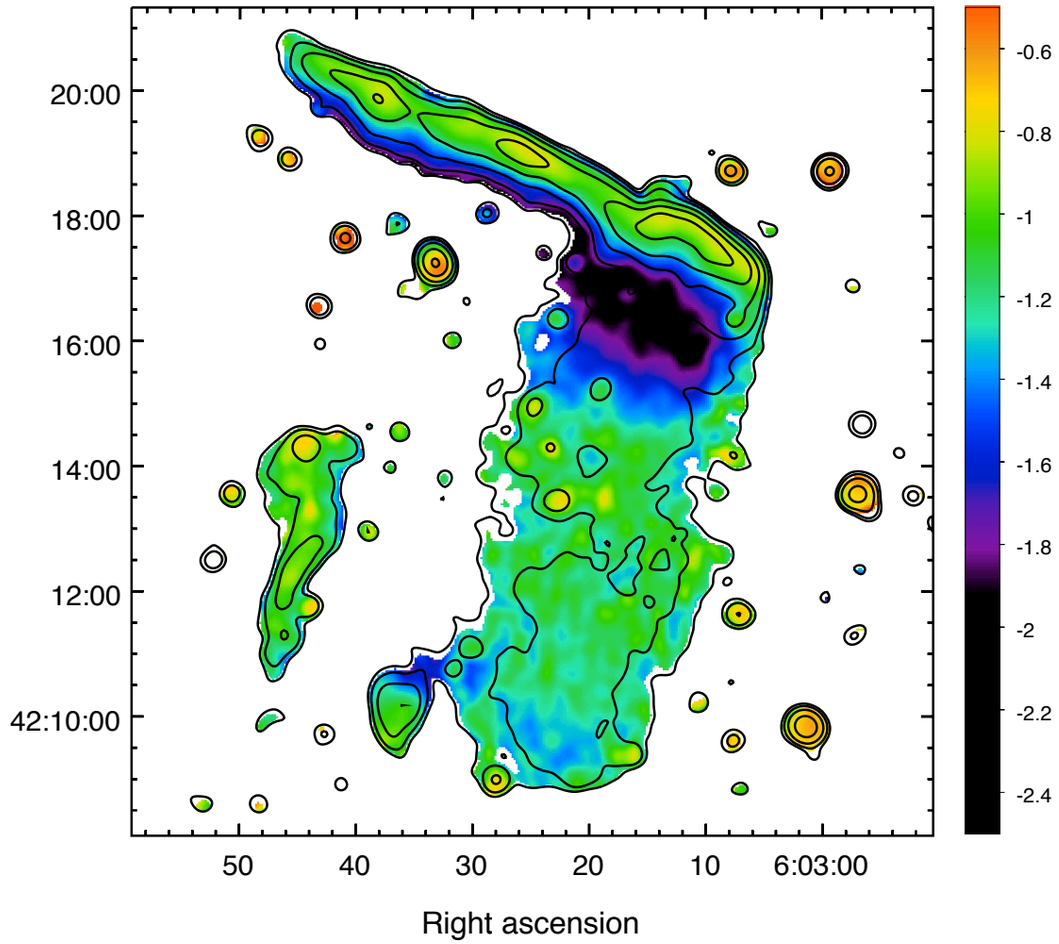


Halo southern most part: a fainter relic !

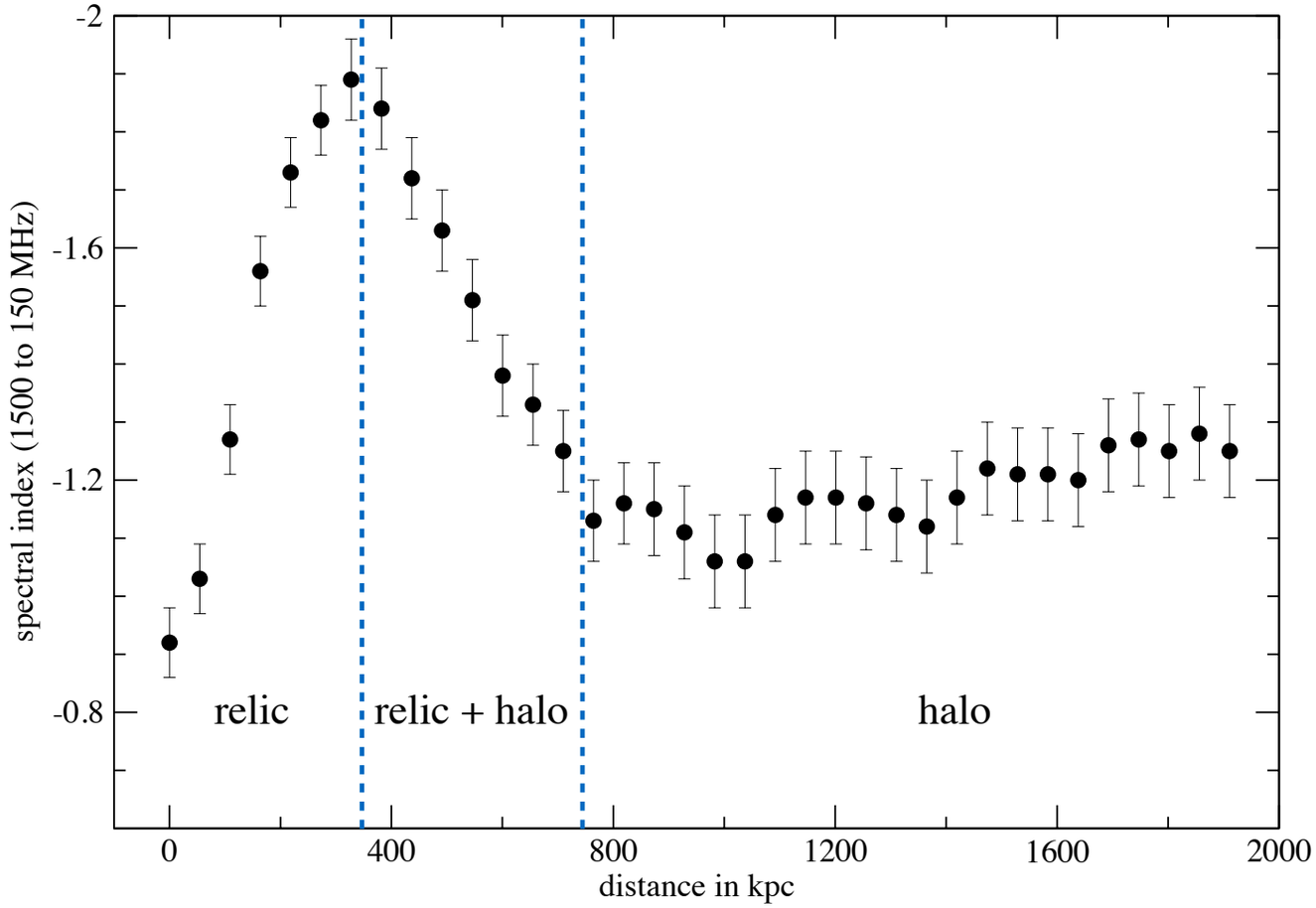


Relic and halo connection ?

JVLA contours



van Weeren et al. 2016 — gradual flattening is due to the re-acceleration by turbulence of “aged” electrons downstream of the relic



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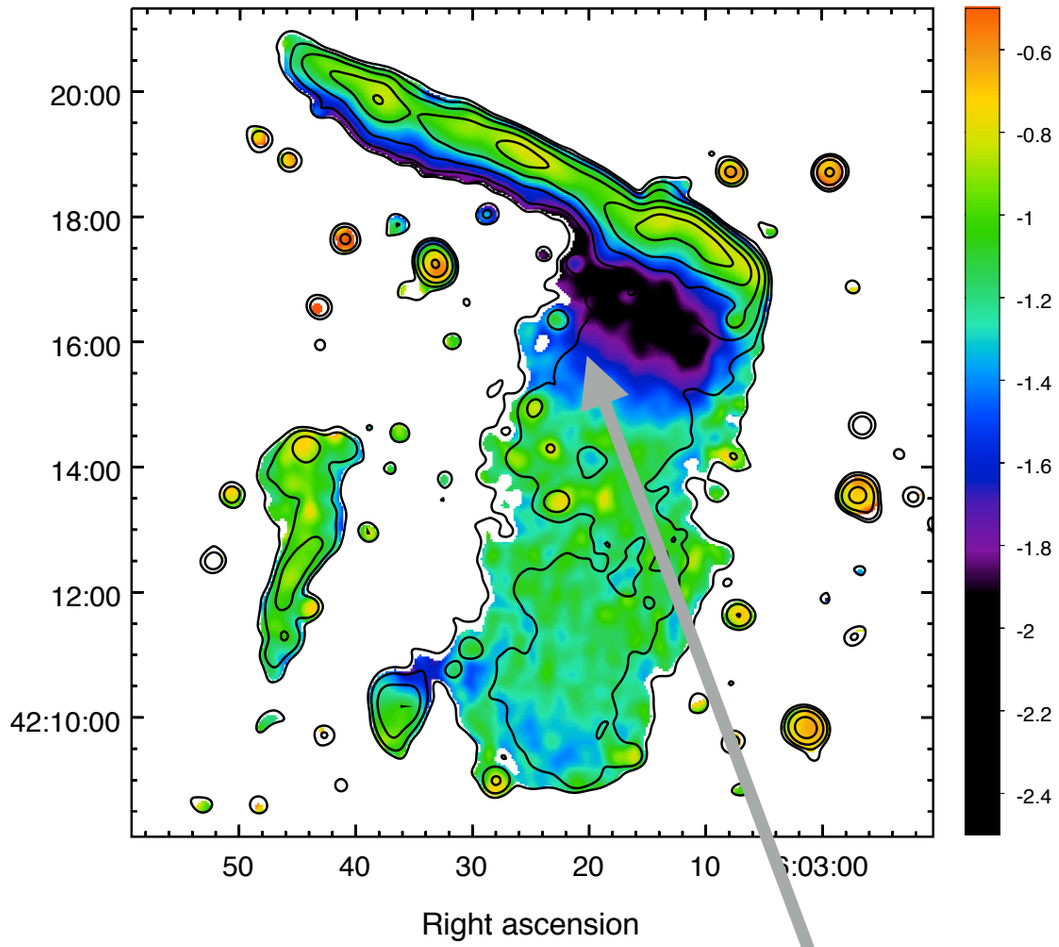

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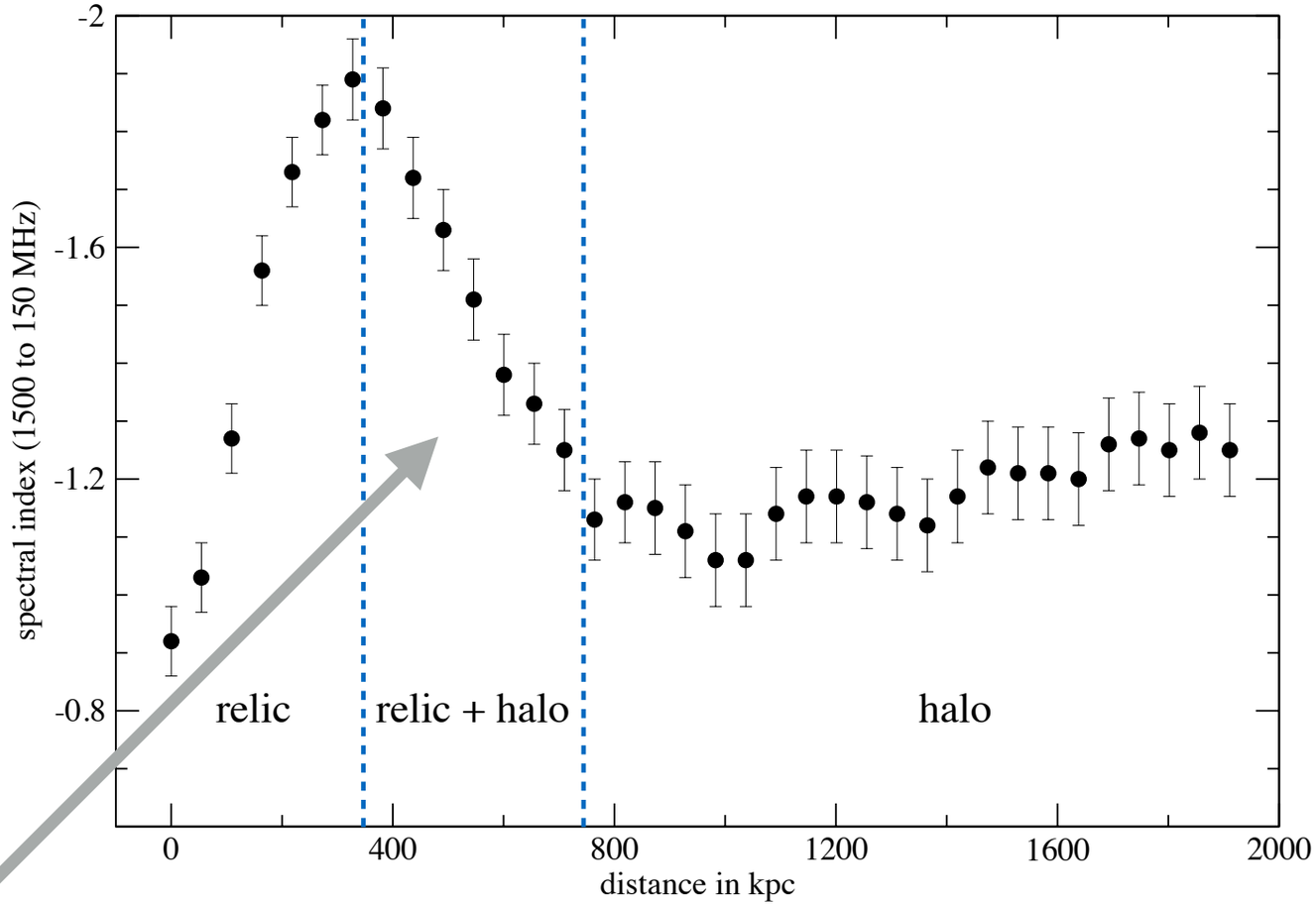
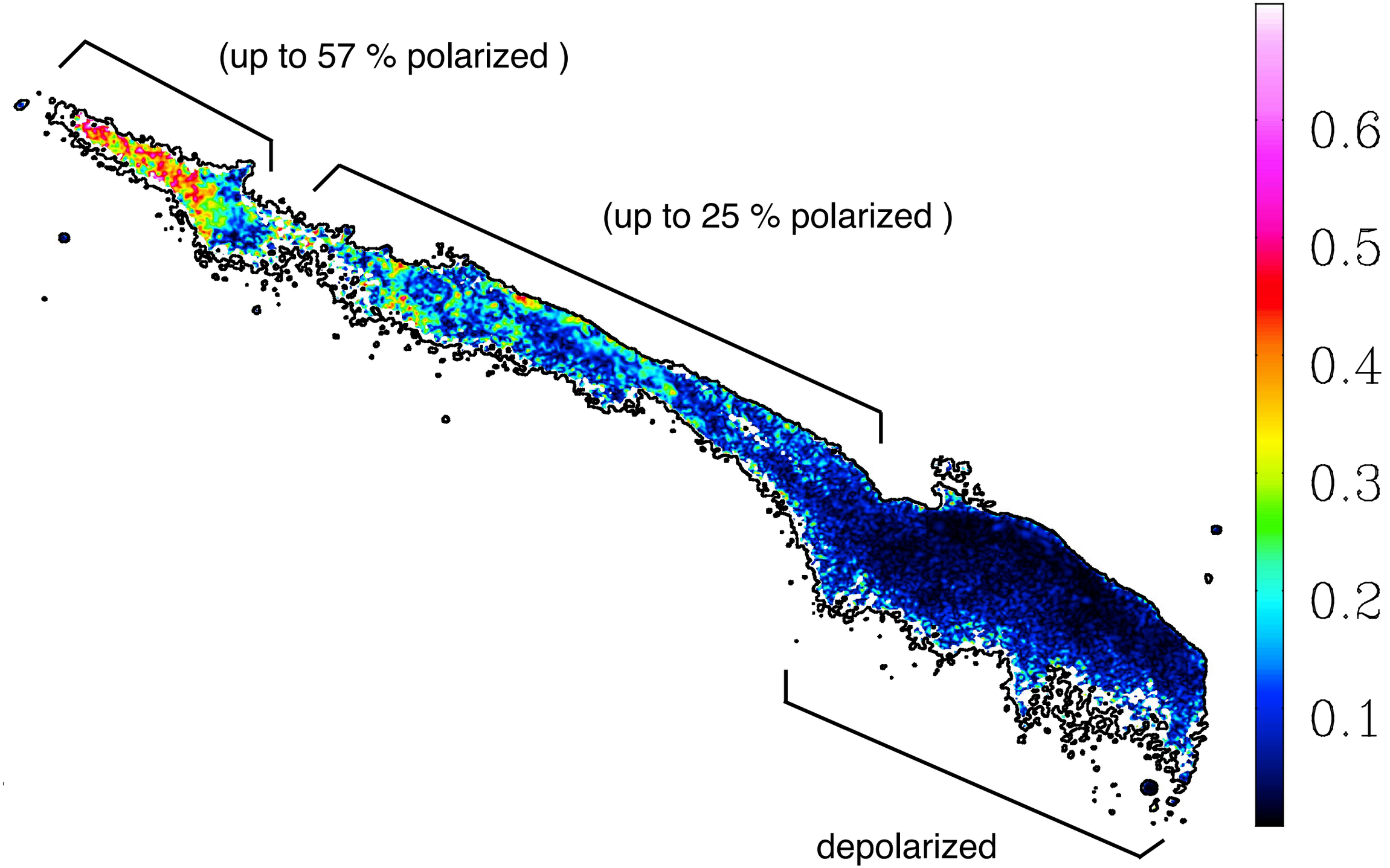


flattening is due to projection of halo and relic emission

Degree of polarization: brush depolarized at 1.5 GHz



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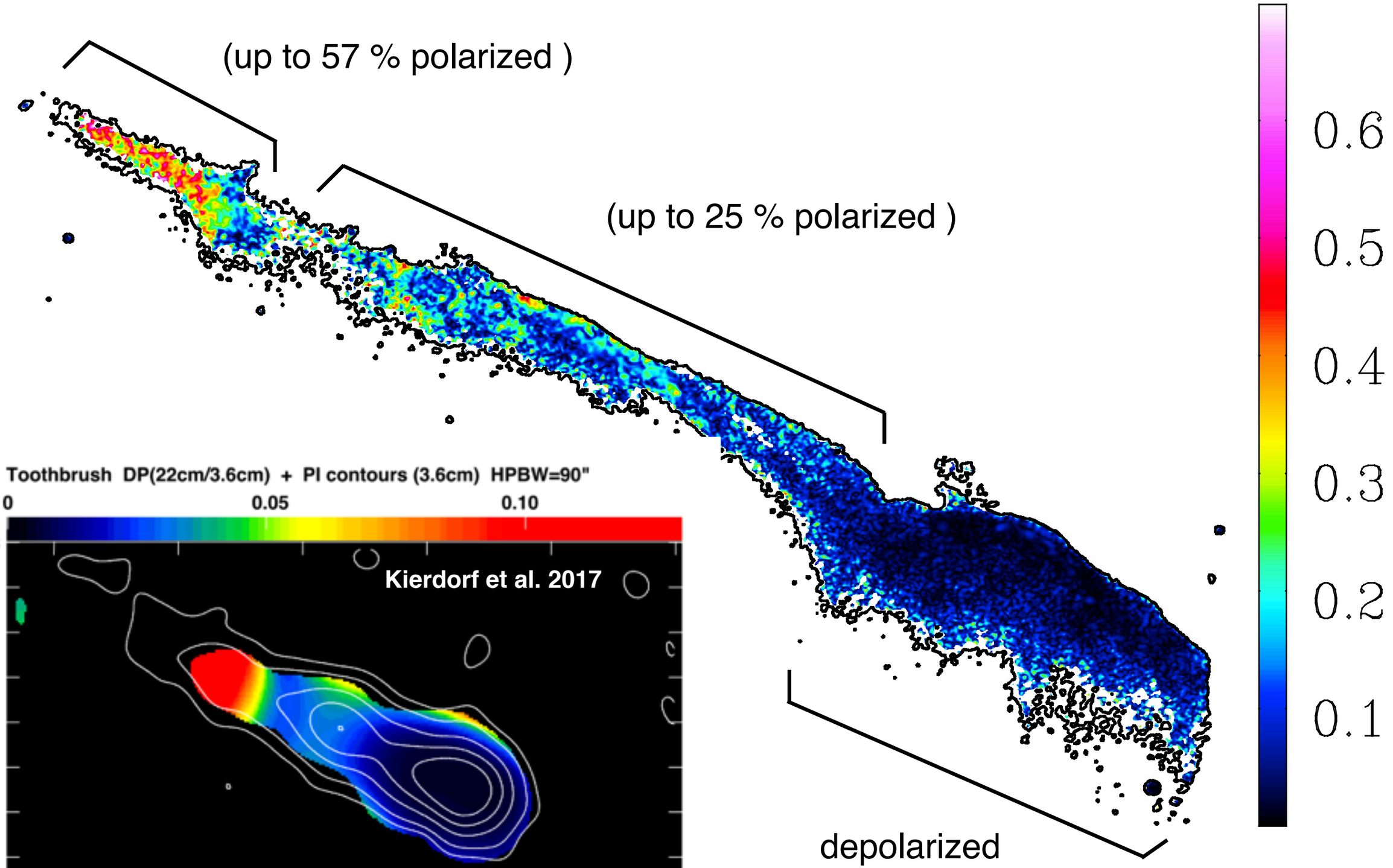
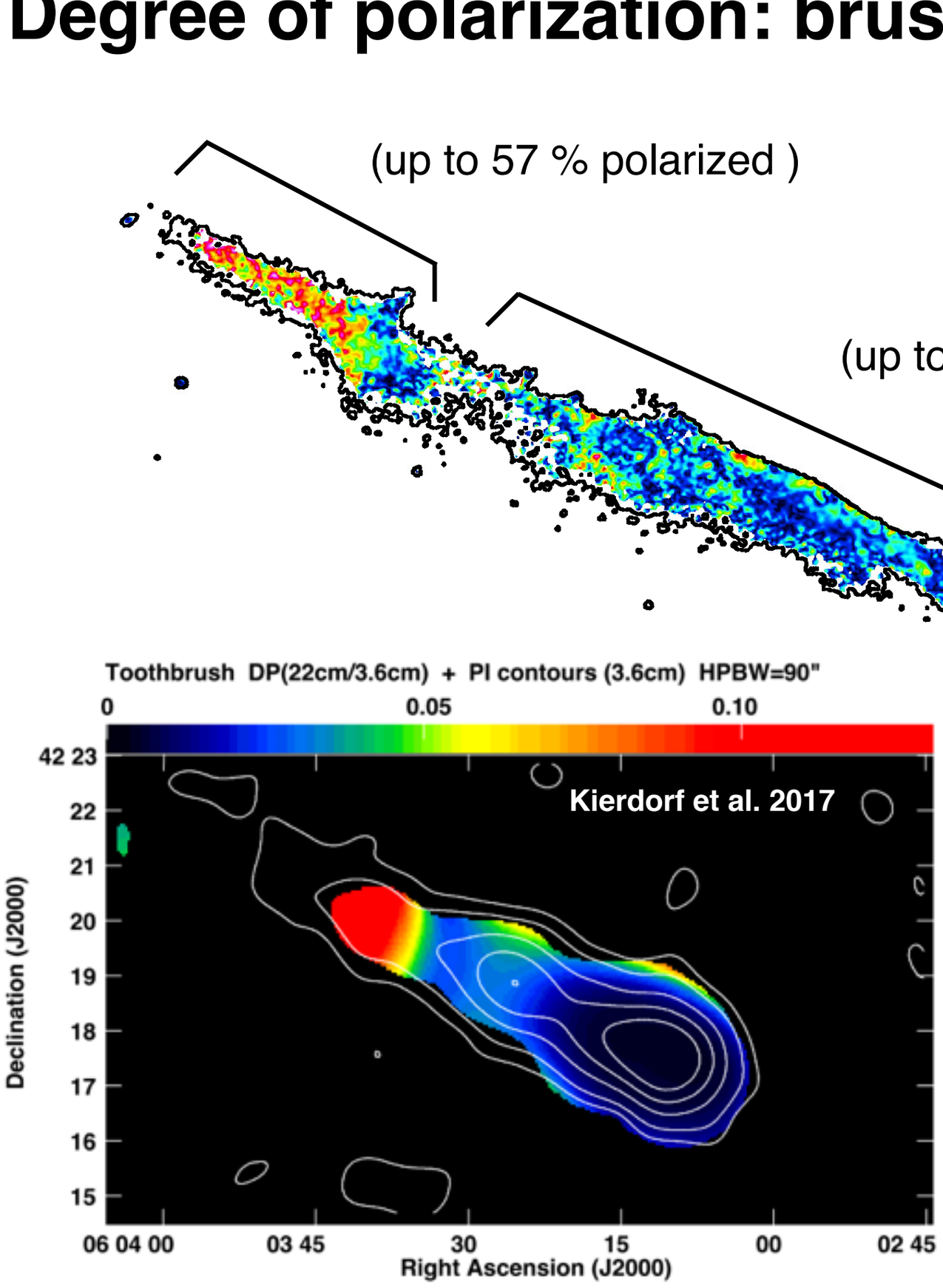
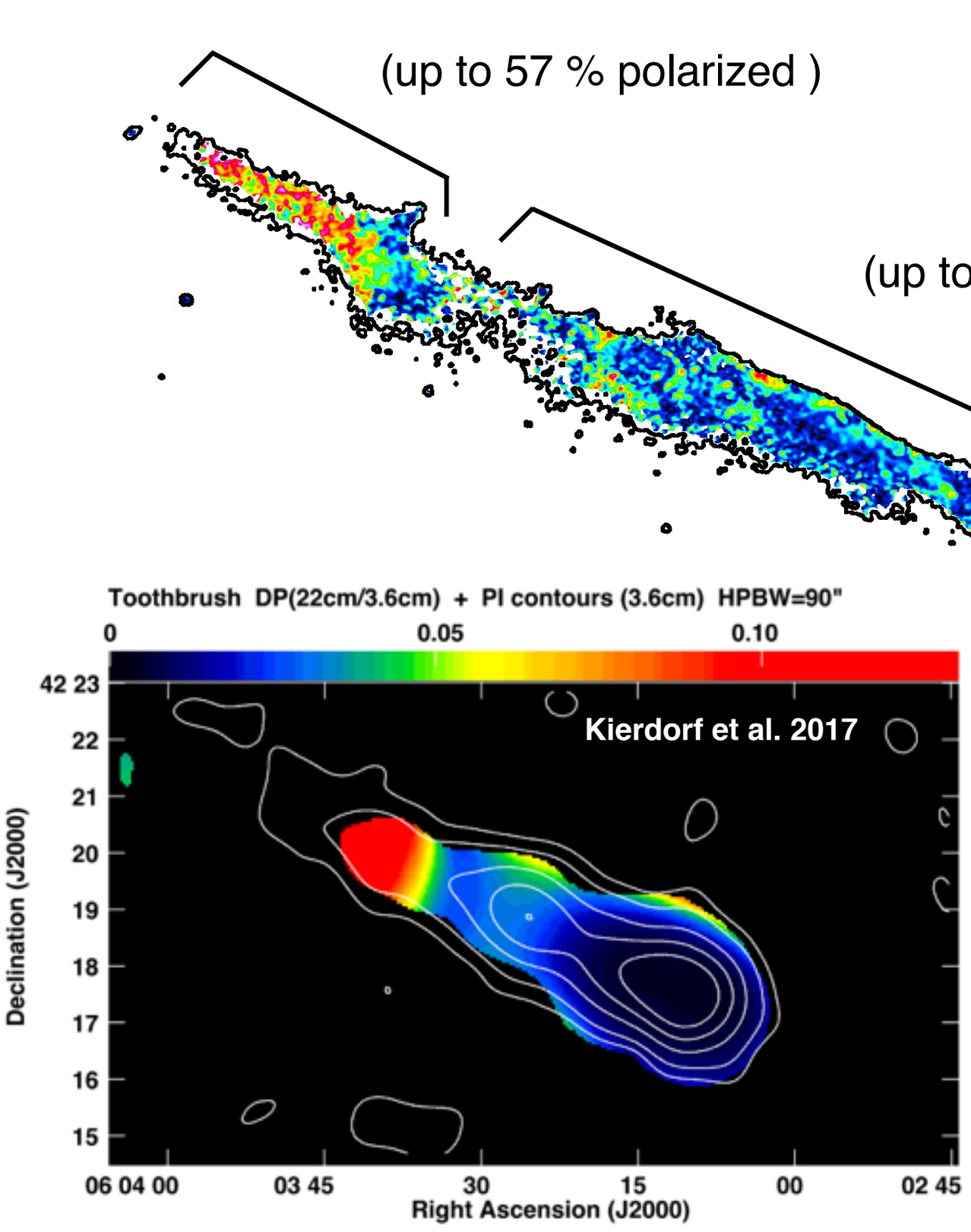
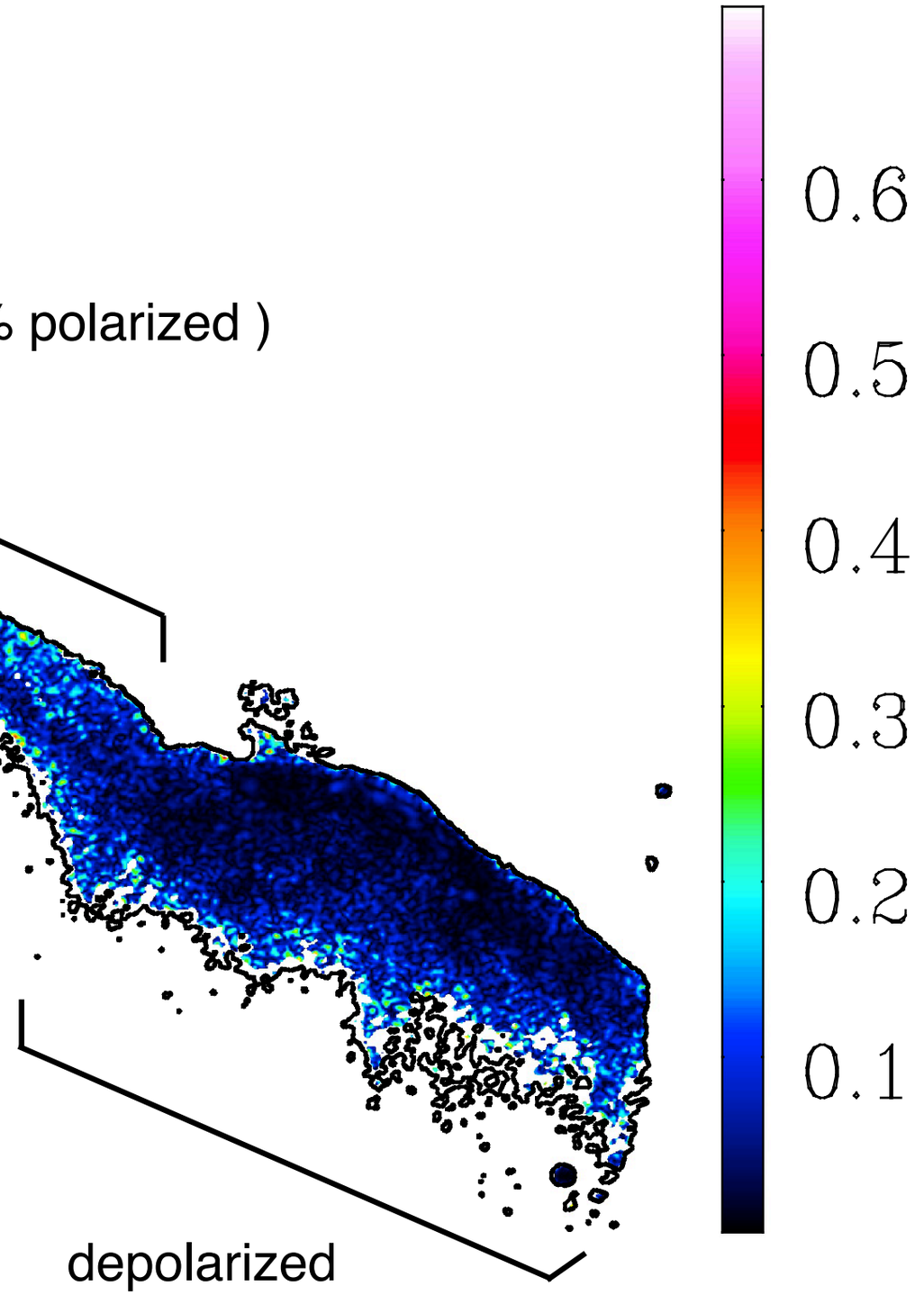




Depolarization between 1.38GHz and 8.35GHz (color)

Degree of polarization: brush depolarized at 1.5 GHz

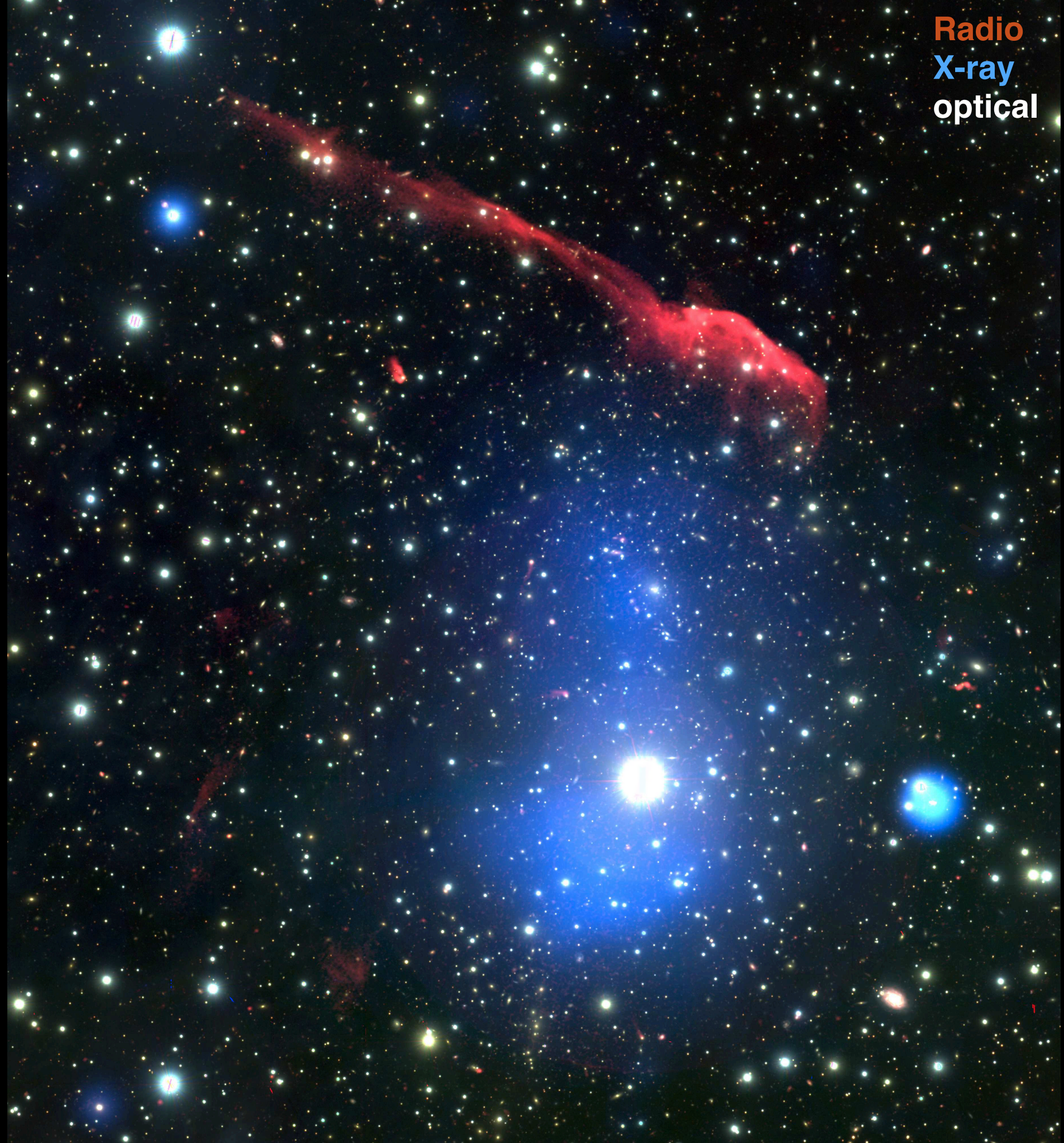




relic is behind the cluster

Summary

- Toothbrush is made up of filamentary structures
- Ridge peak shift with frequency, indicating intrinsic shape of the emission is frequency dependent
- Lognormal B distribution allows to approximate profiles significantly better
- Best fit: Mach ~ 3.75, $B_0 < 5$ μG, $\sigma > 0.7$
- Southern part of the halo is steeper and flattens again at the edge
- Brush depolarized at 1.5 GHz


Radio
X-ray
optical