Insights into cosmic magnetic fields from radio relic observations at metre wavelengths

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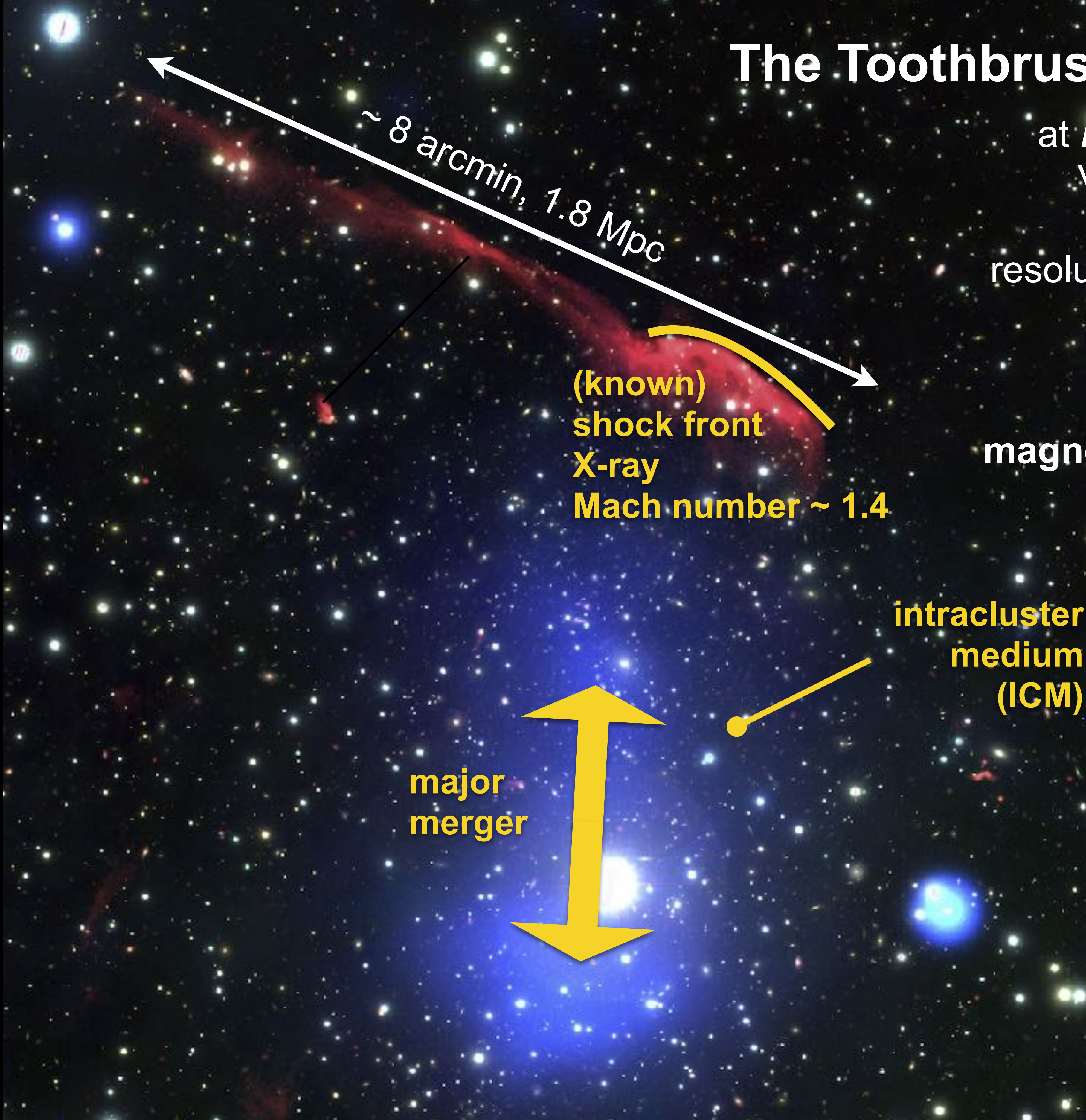
in collaboration with
K. Rajpurohit, M. Kierdorf, R. van Weeren, D. Wittor, R. Beck, F. Vazza et al.

mainly based on
Rajpurohit+ 18, Rajpurohit in prep., Kierdorf+ 17

The Toothbrush radio relic



at ***L-band*** frequency
VLA ABCD config

resolution ~ 1.8 arcsec
rms noise ~ 6 μJy

manifestation of magnetic fields in ICM

Rajpurohit+ 2018

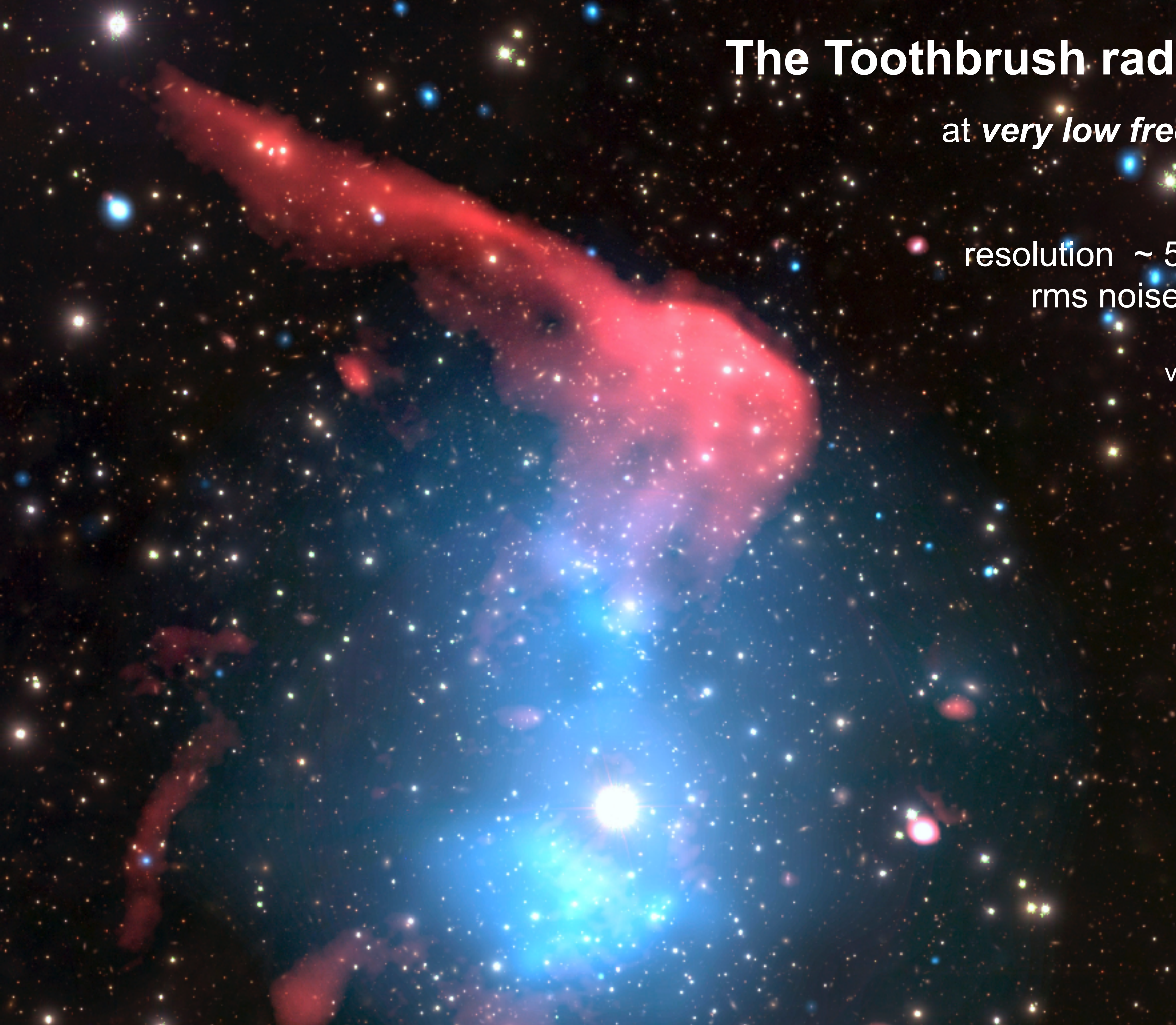
white: optical
blue: X-ray
red: radio

The Toothbrush radio relic

at ***very low frequencies***
LOFAR

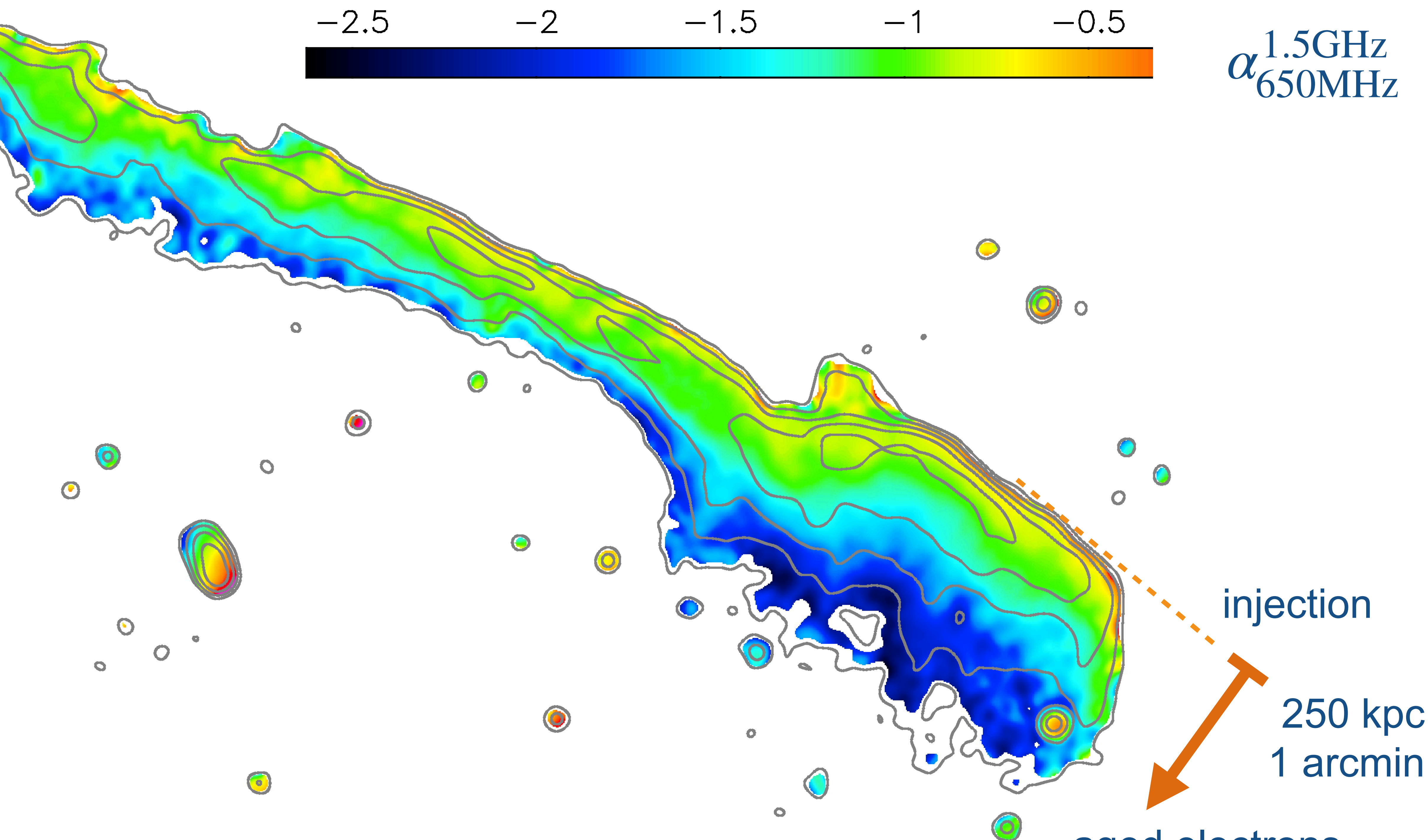
resolution ~ 5.0 arcsec
rms noise ~ 60 μJy

van Weeren+
2016



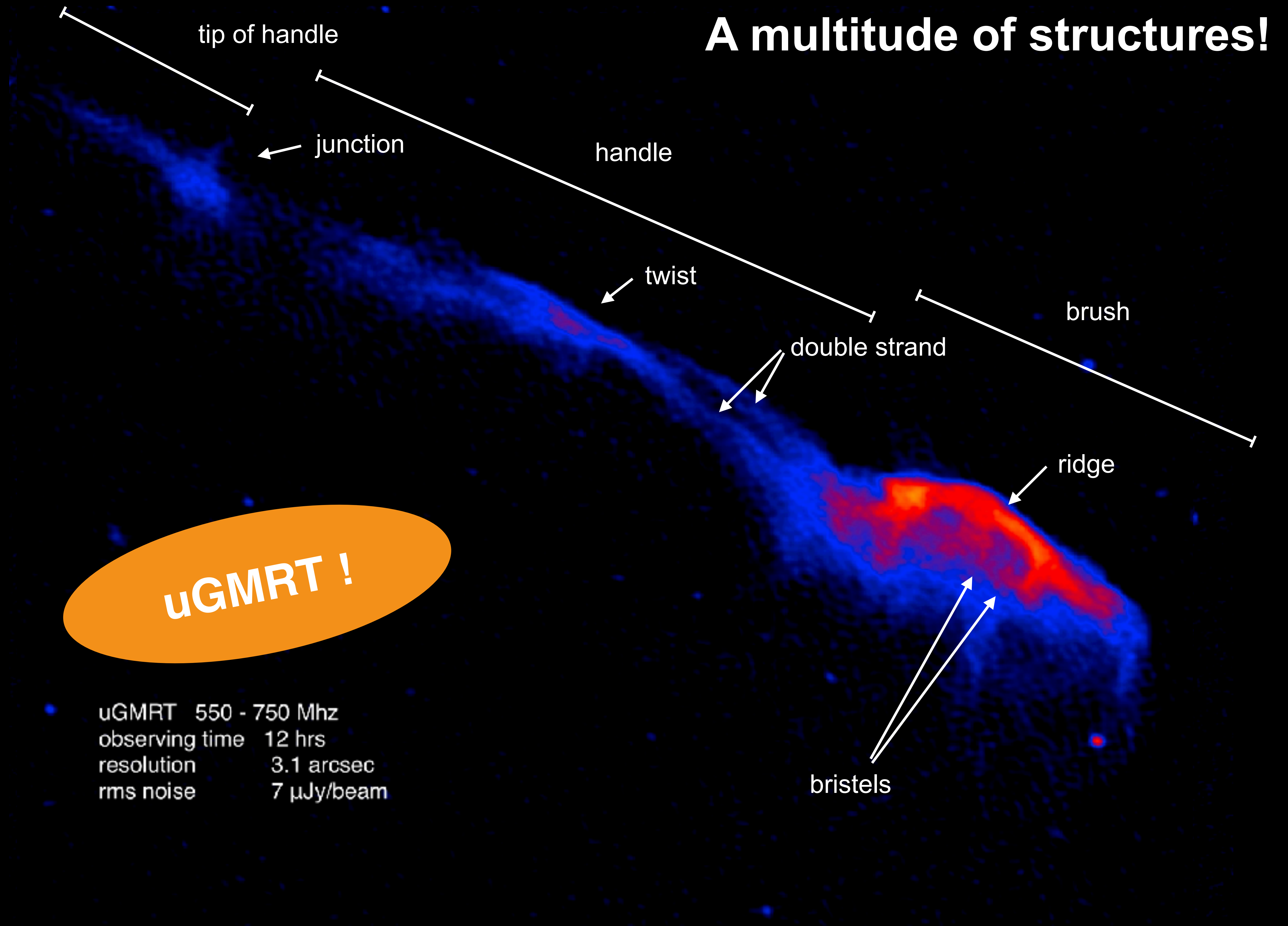
white: optical
blue: X-ray
red: radio

Spectral index reveals electron ageing



resolution: 5.5 arcsec

A multitude of structures!

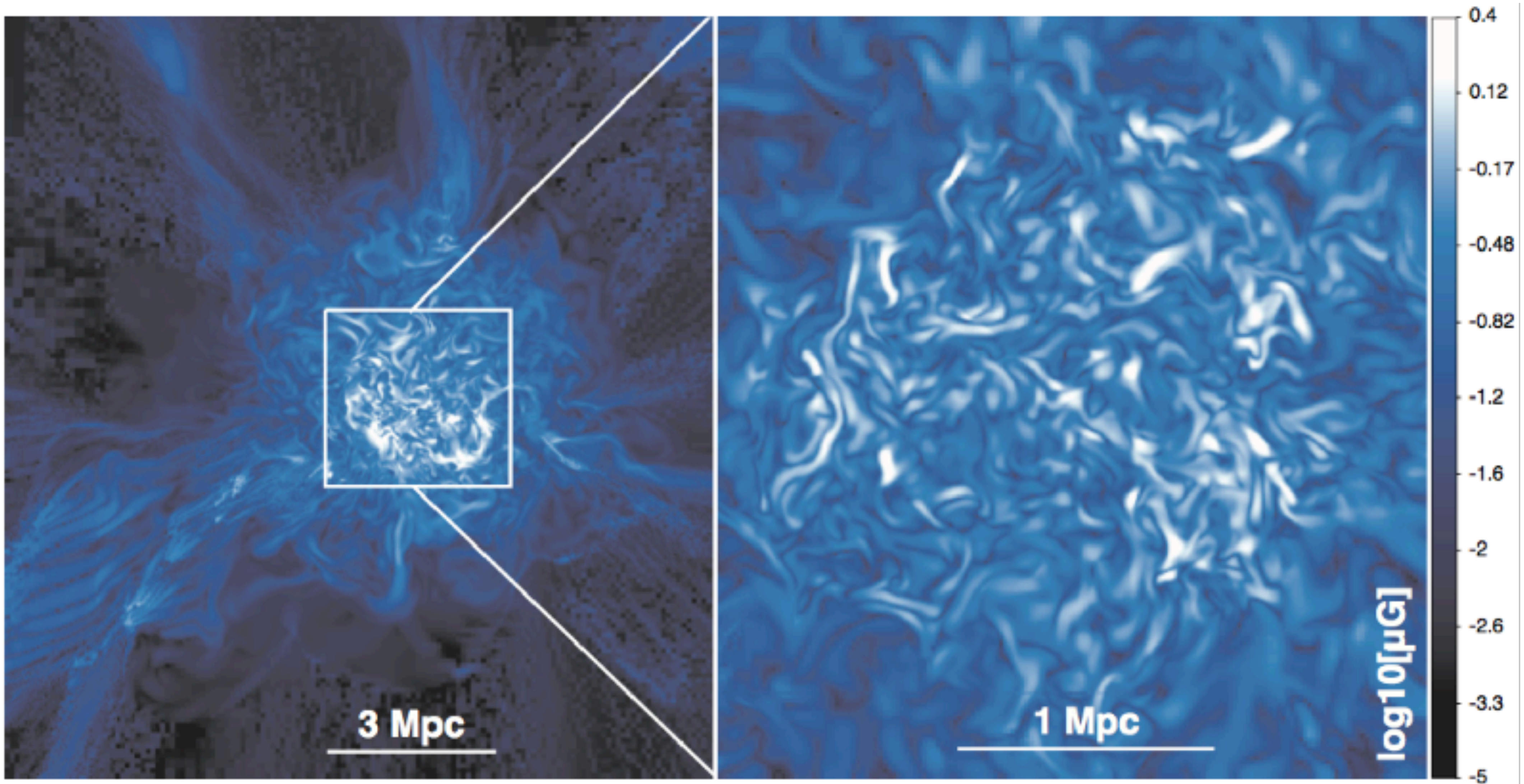


Substructure of Toothbrush relic
Origin is unknown!

Possibility A

filaments reveal **magnetic field structure**
similar to a cut through a puffy pastry

puffy pastry
something like samosa …



Vazza+ 2018

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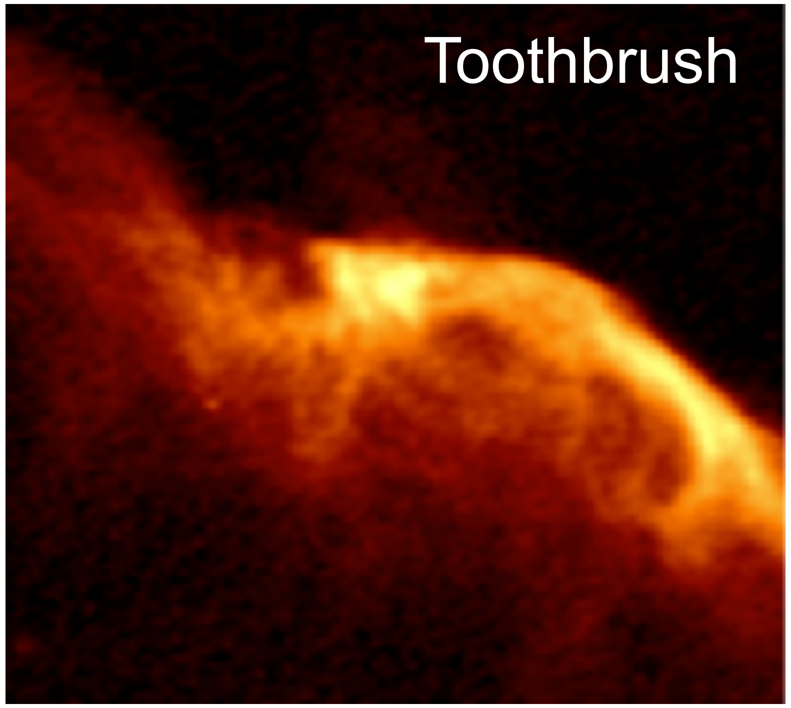
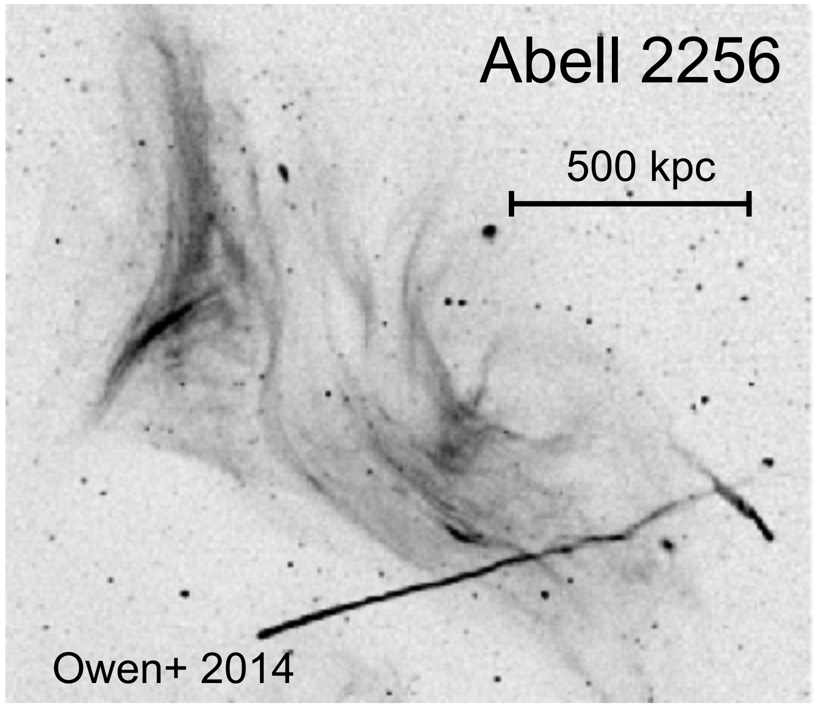


a relic (very likely) seen edge on



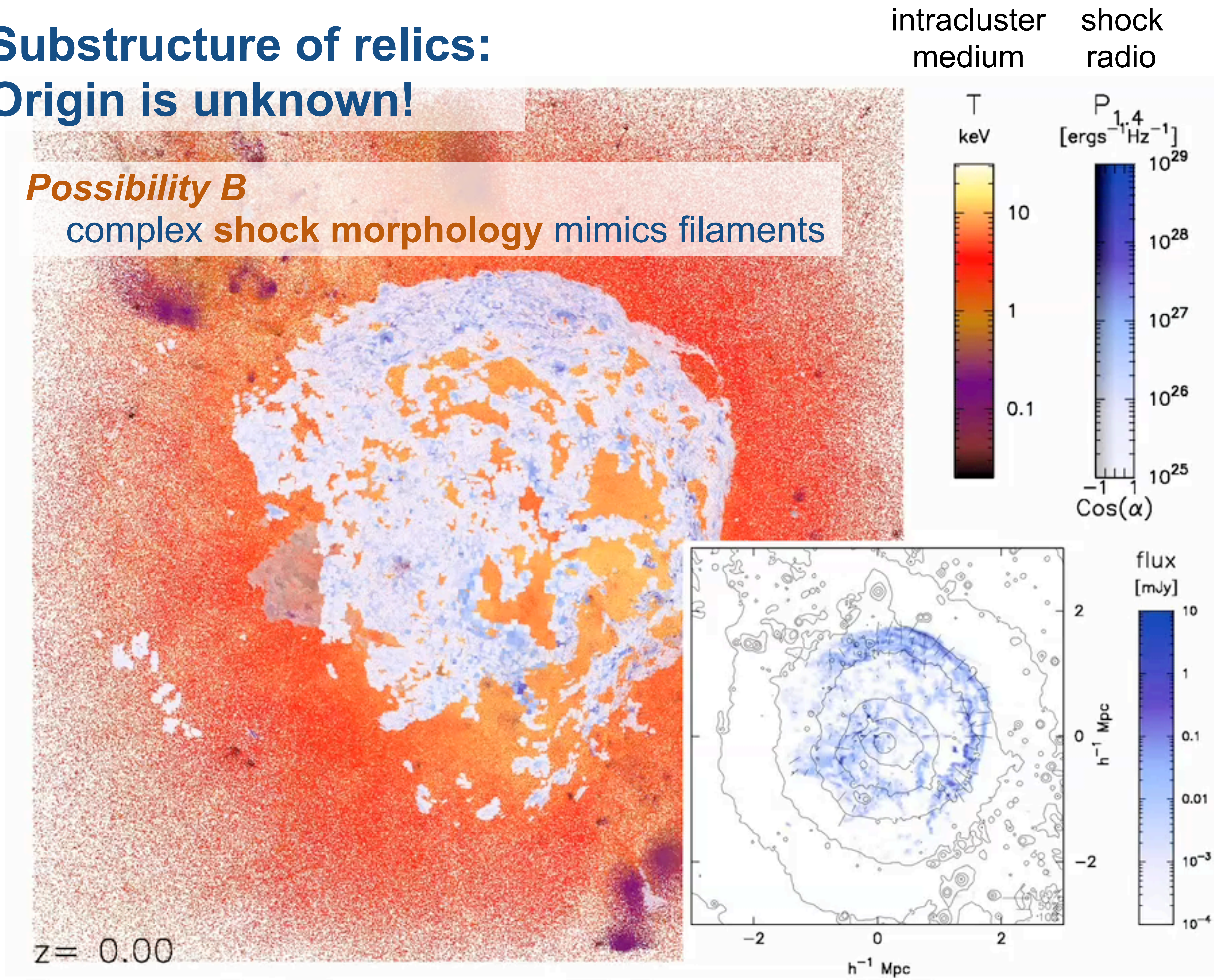
(very likely) a relic is seen face on

Does the filaments in the two clusters have the same origin?

Substructure of relics: Origin is unknown!

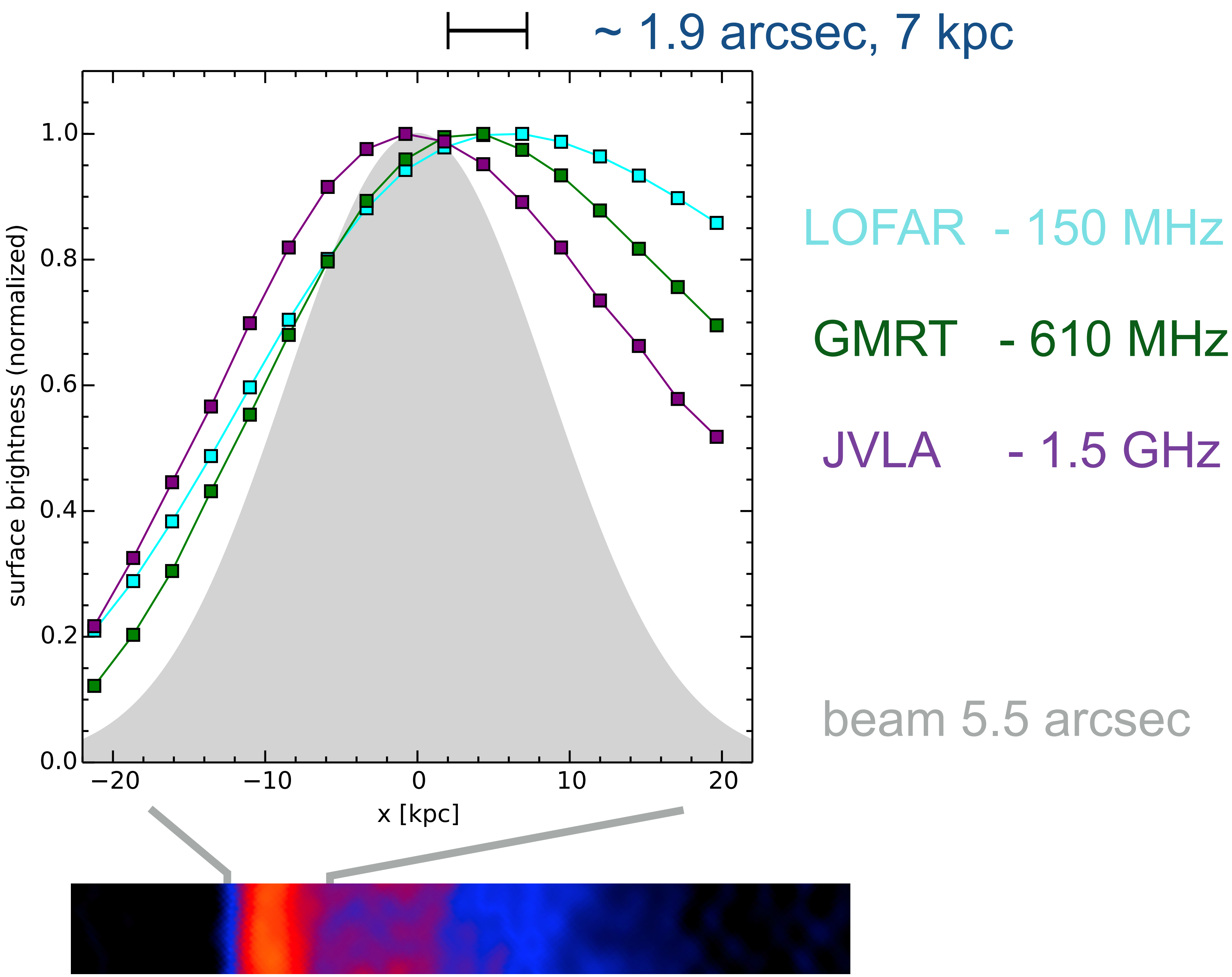
Possibility B

complex **shock morphology** mimics filaments



Ridge is asymmetric and peak shifts with frequency

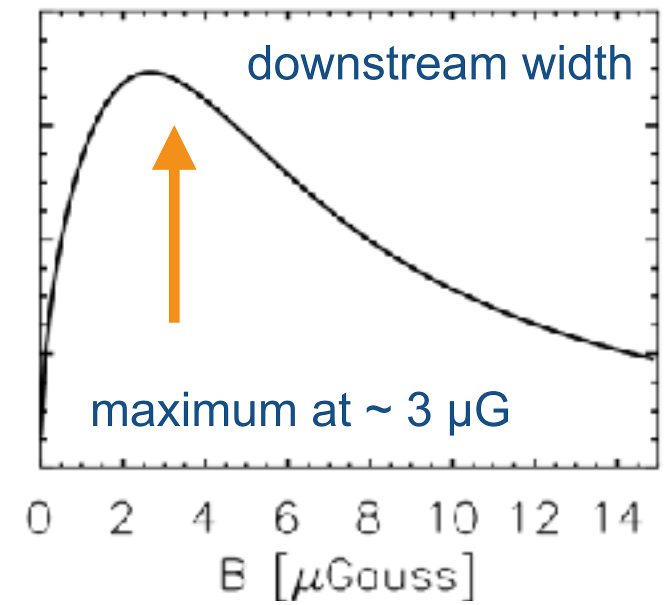
downstream profile changes with frequency
consistent with ***shock injection + downstream cooling*** scenario

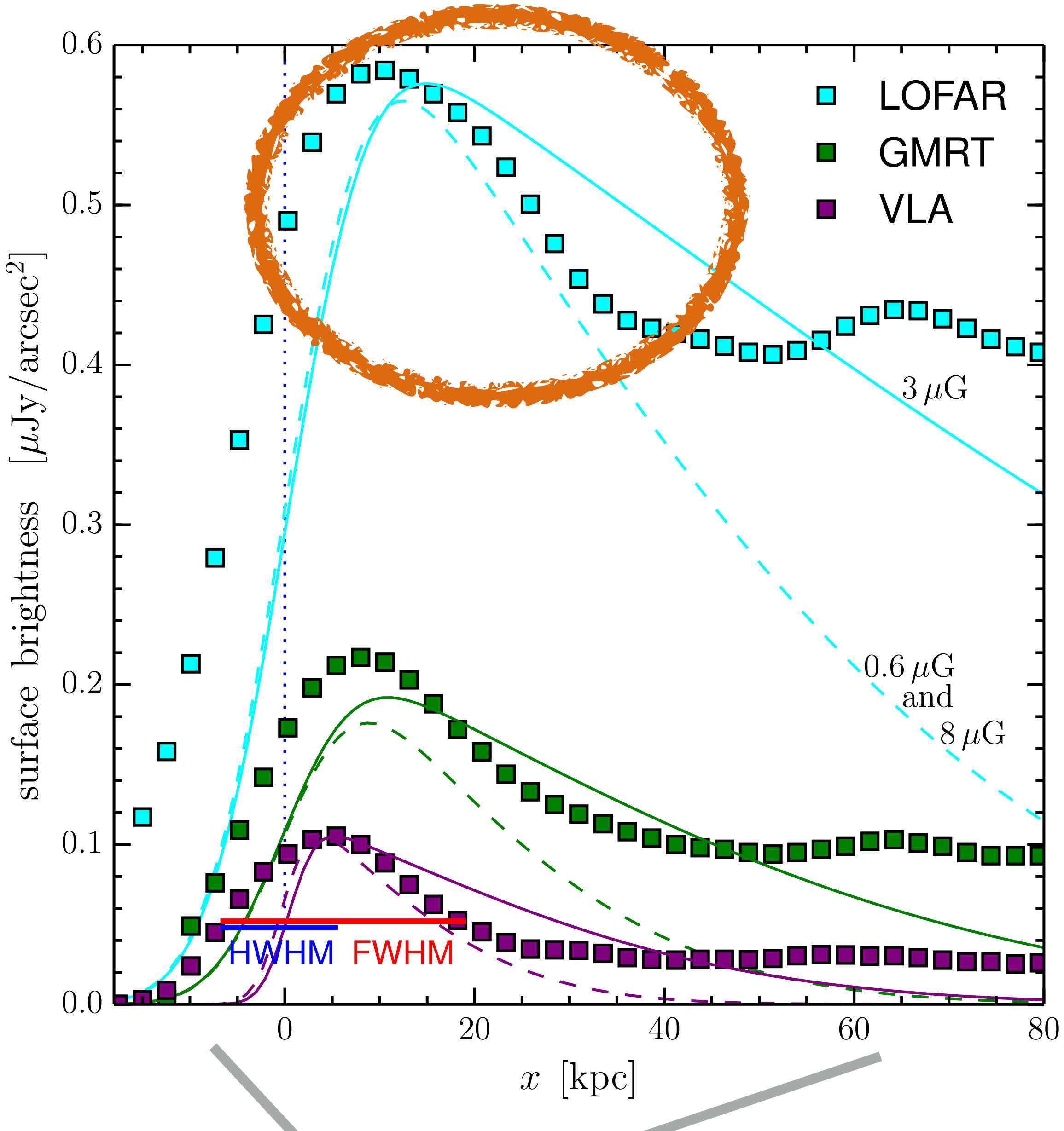


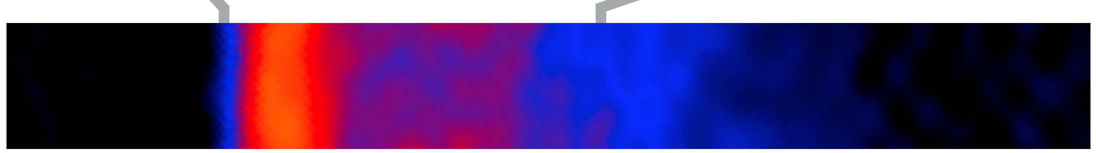
Narrowness of the ridge

disfavours: $B \sim 0.8 \ldots 5 \mu G$

impossible to match width and downstream slope





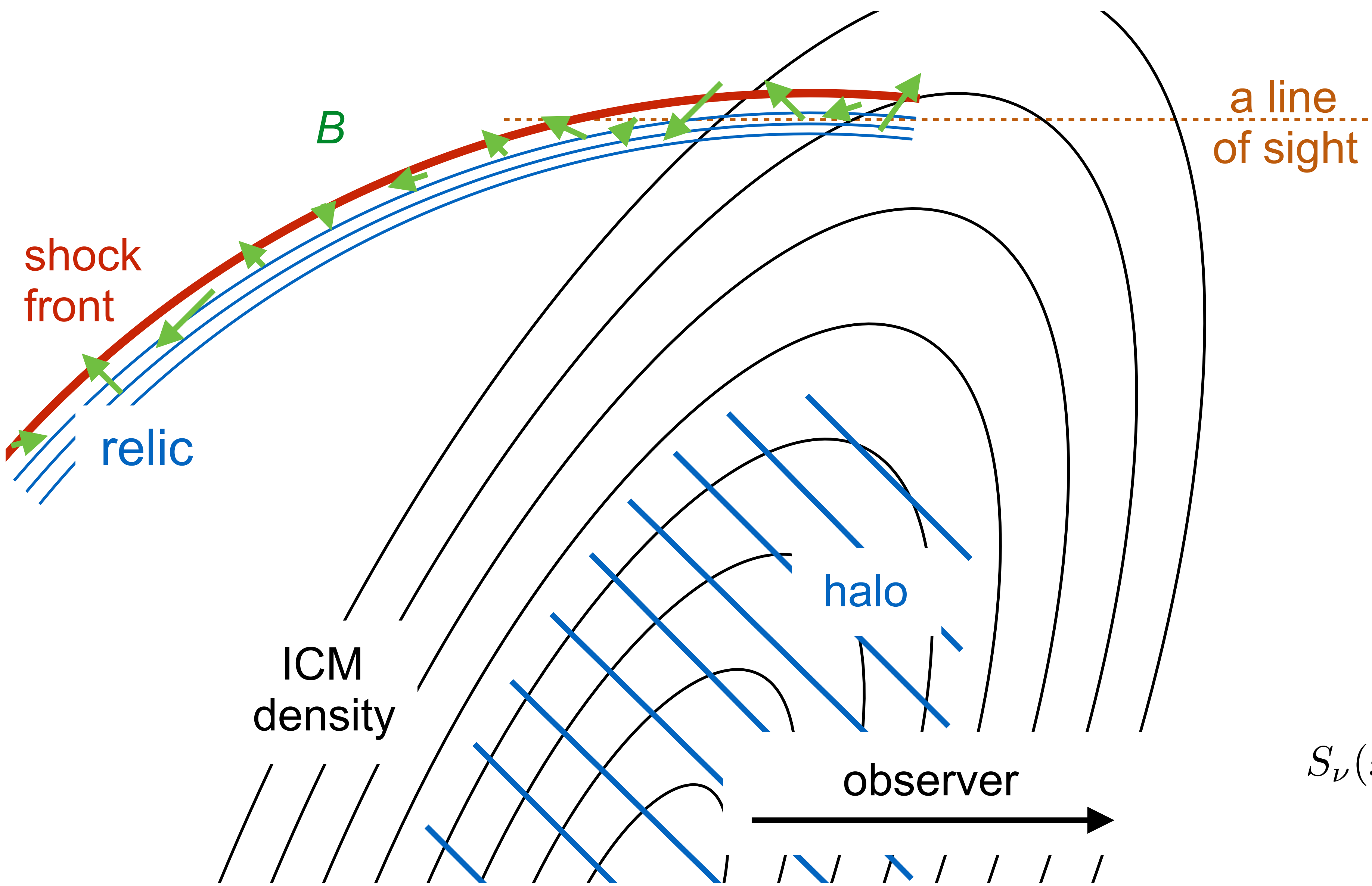


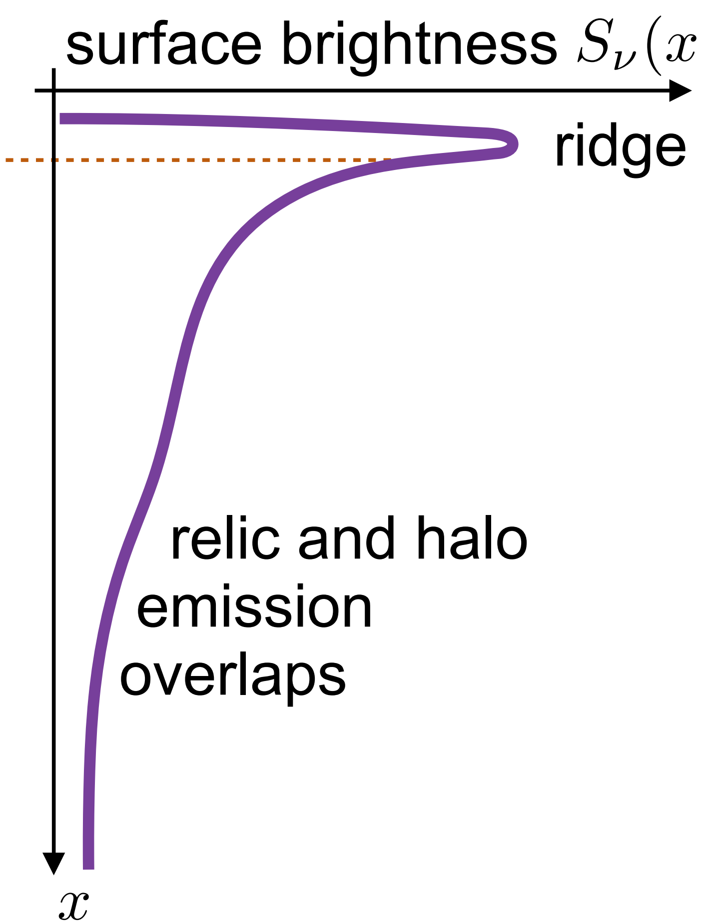
Mach number of model

$\mathscr{M} = 3.1$

From an idealised model to a more realistic scenario

Part 1: *projection* of the shock front



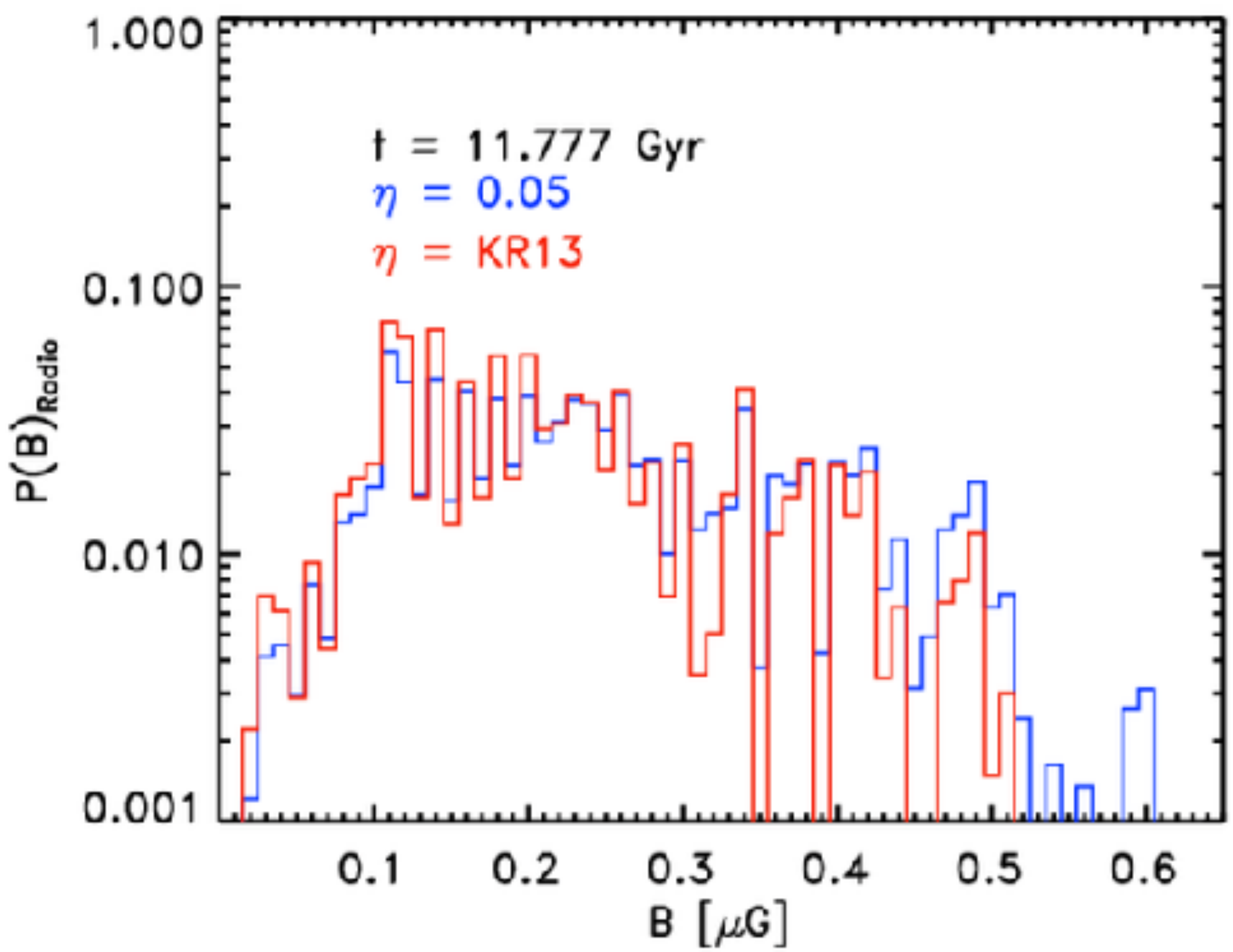


$$S_\nu(x) = \int \mathrm{d}x' \, W(x') \, S_{\nu,\mathrm{av}}(x - x')$$

encodes shock geometry and luminosity is unkown

From an idealised model to a more realistic scenario

Part 2: scatter of ***magnetic field*** strengths

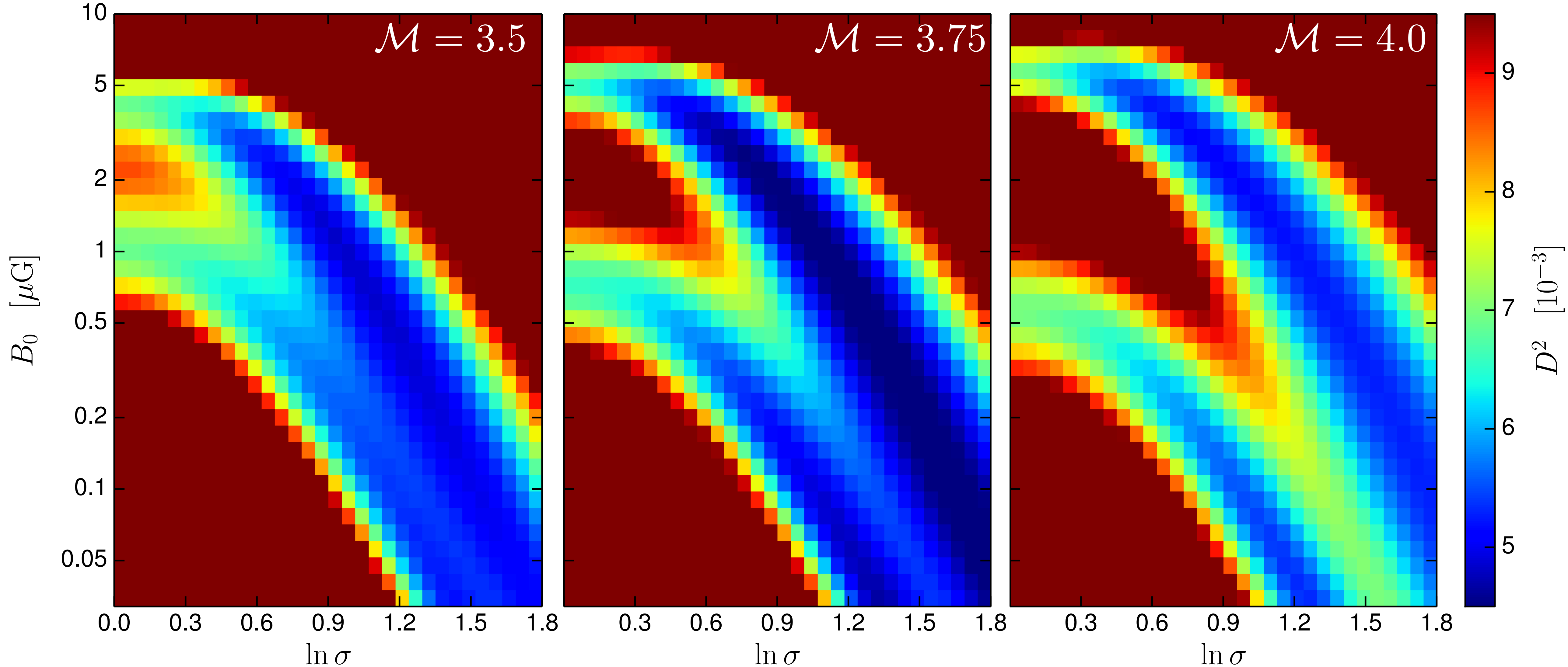


D. Wittor

→ motivates ***toy model***: lognormal distribution

$$h(B; B_0, \sigma)\,\mathrm{d}B = \frac{1}{\sqrt{2\pi}\sigma B}\,\exp\left\{-\frac{\ln(B/B_0)}{2\sigma^2}\right\}\,\mathrm{d}B$$

Low magnetic field with scatter preferred



good match between model and data

poor match

best match for *M* ~ 3.75

ICM depolarises emission

Kierdorf+ 2017

RM fluctuations cause depolarisation

a relation between
fractional polarisation p and RM

$$\frac{p_2}{p_1} = \exp\{-2\sigma_{\rm RM}^2(\lambda_2^4 - \lambda_1^4)\}$$

Turbulent depolarisation

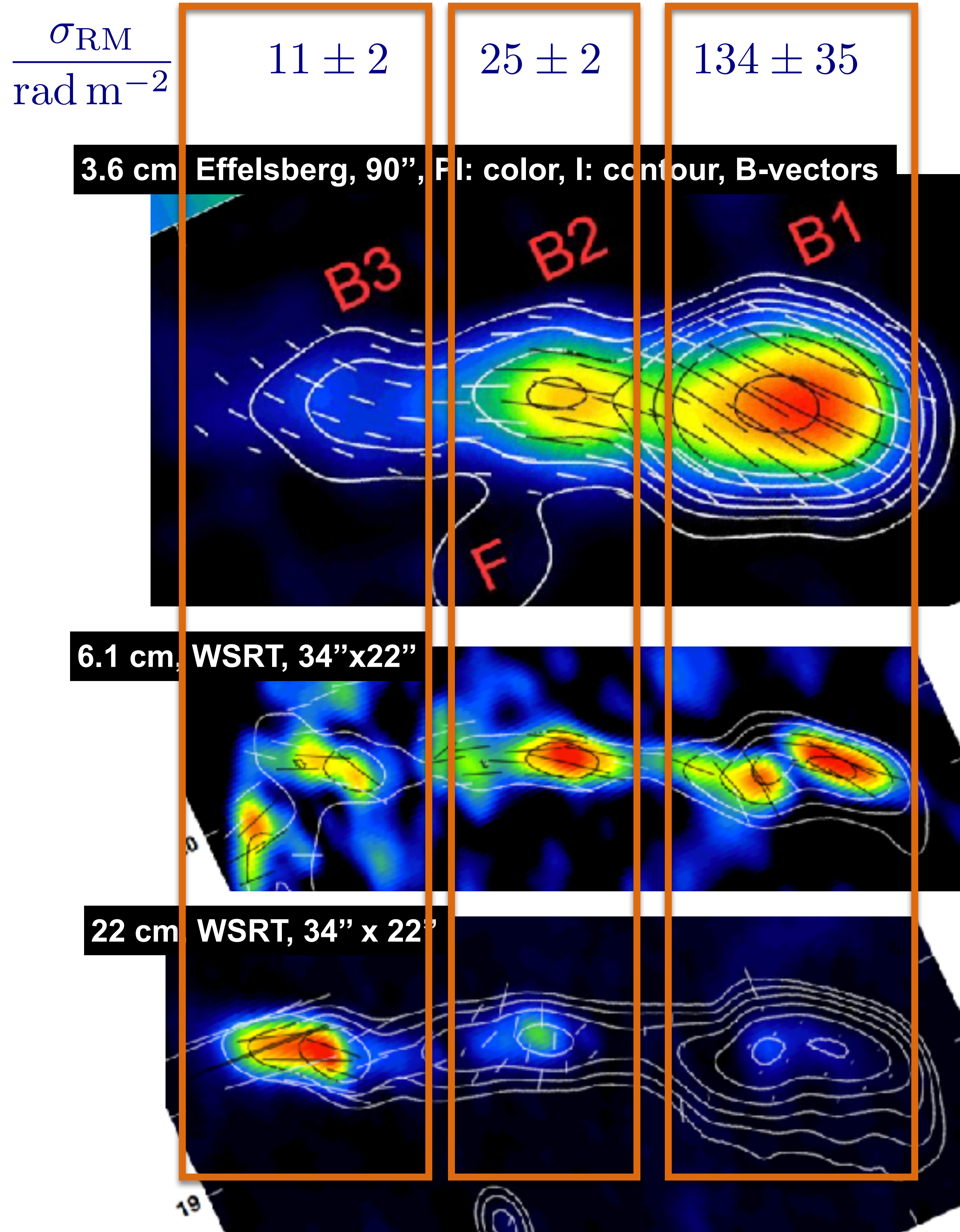
$$\sigma_{\rm RM} \sim n_{\rm e}\, B_{\rm turb}\, (Ll)^{0.5}$$

L: length l.o.s. through medium
l: correlation length

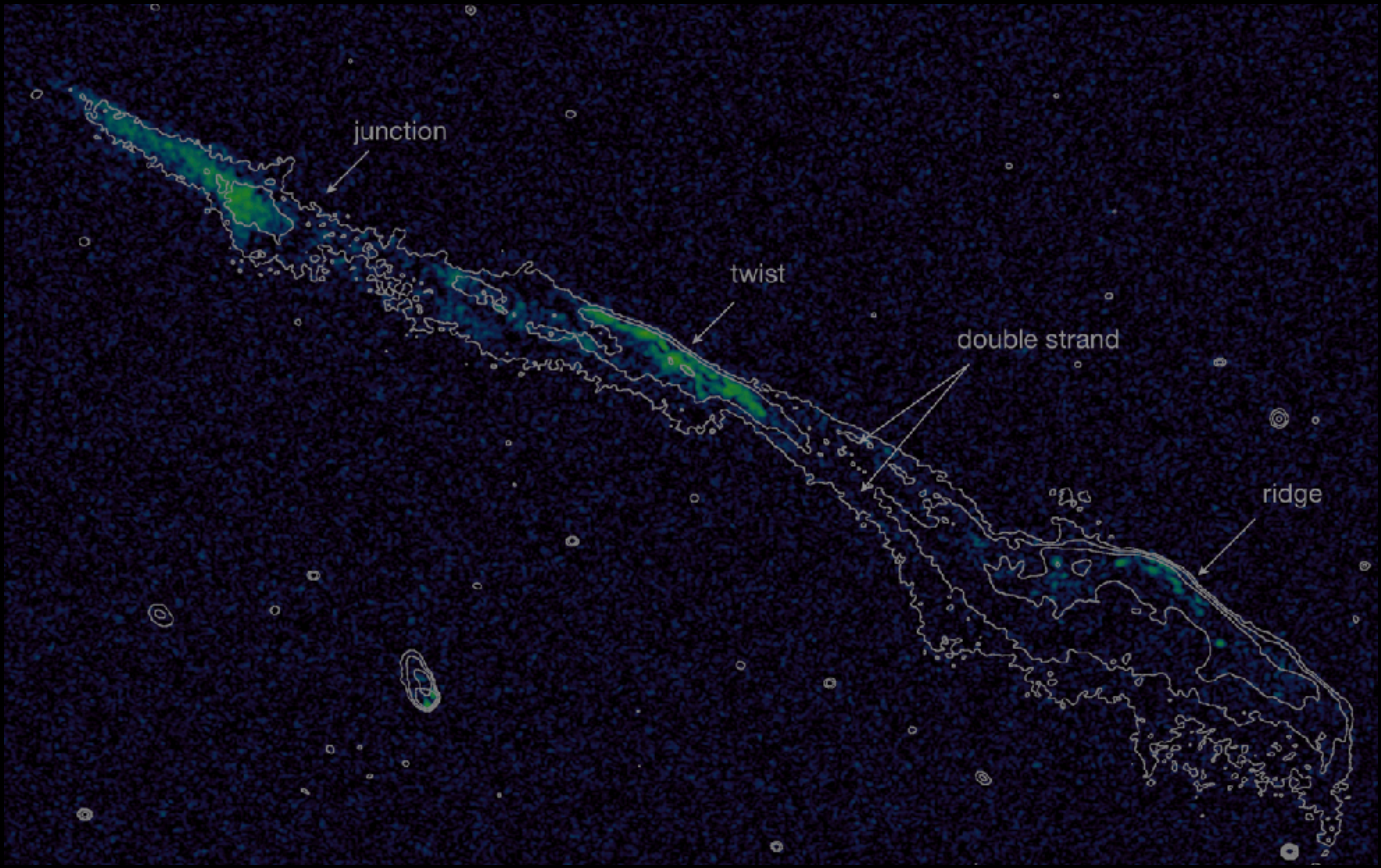
[Sokoloff+ 1998]

e.g. for ‘brush’-region (B1) consistent
with typical ICM values

$$10^{-3}\,{\rm cm}^{-3},\;\; 1\,\mu{\rm G},\;\; 1.5\ {\rm Mpc},\;\; 10\,{\rm kpc}$$



Polarised intensity in L-band



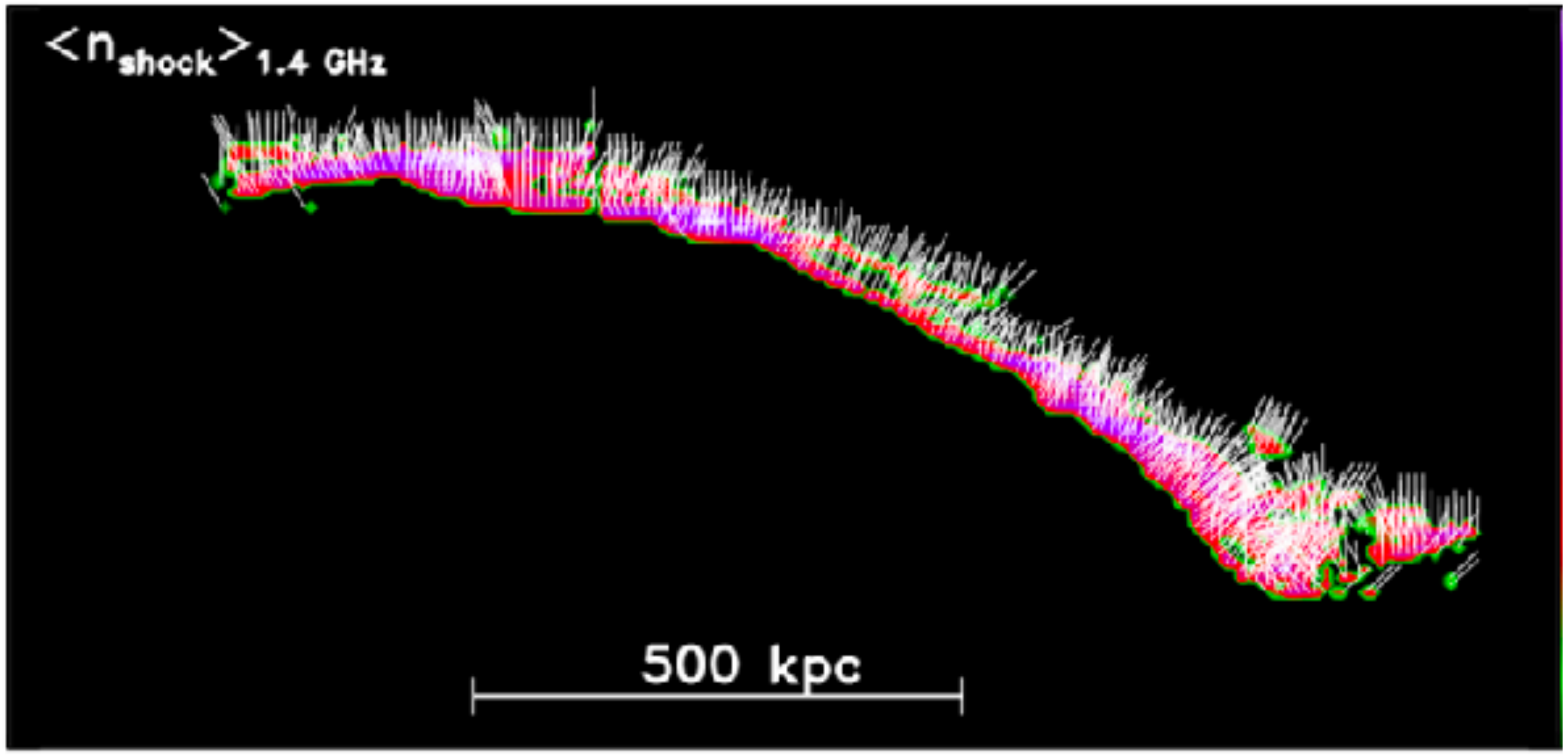
Rajpurohit+ in prep.

What is the intrinsic polarisation of radio emission?

Wittor+ subm

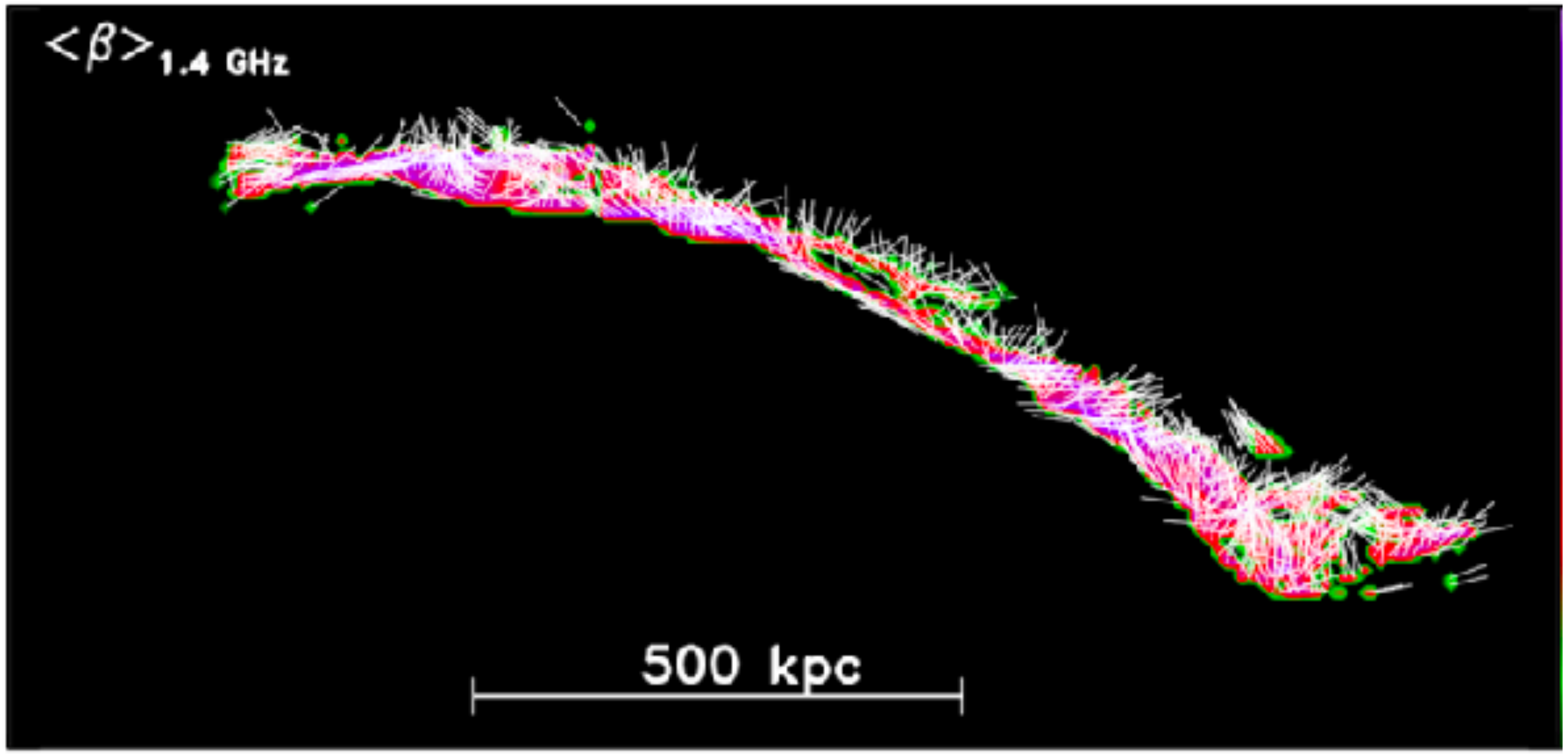
Shock normal

quite perpendicular to shock

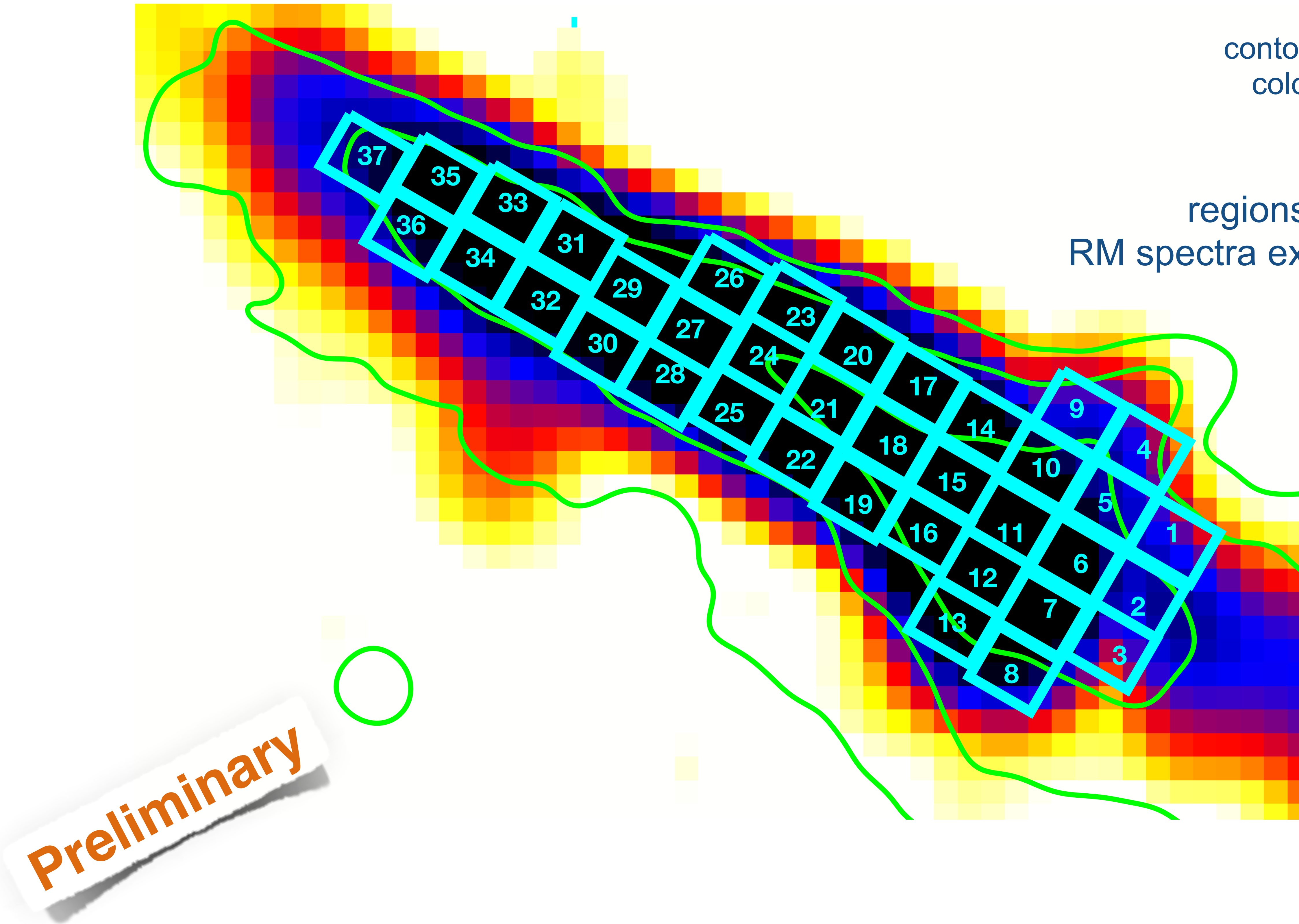


Magnetic field

large scatter



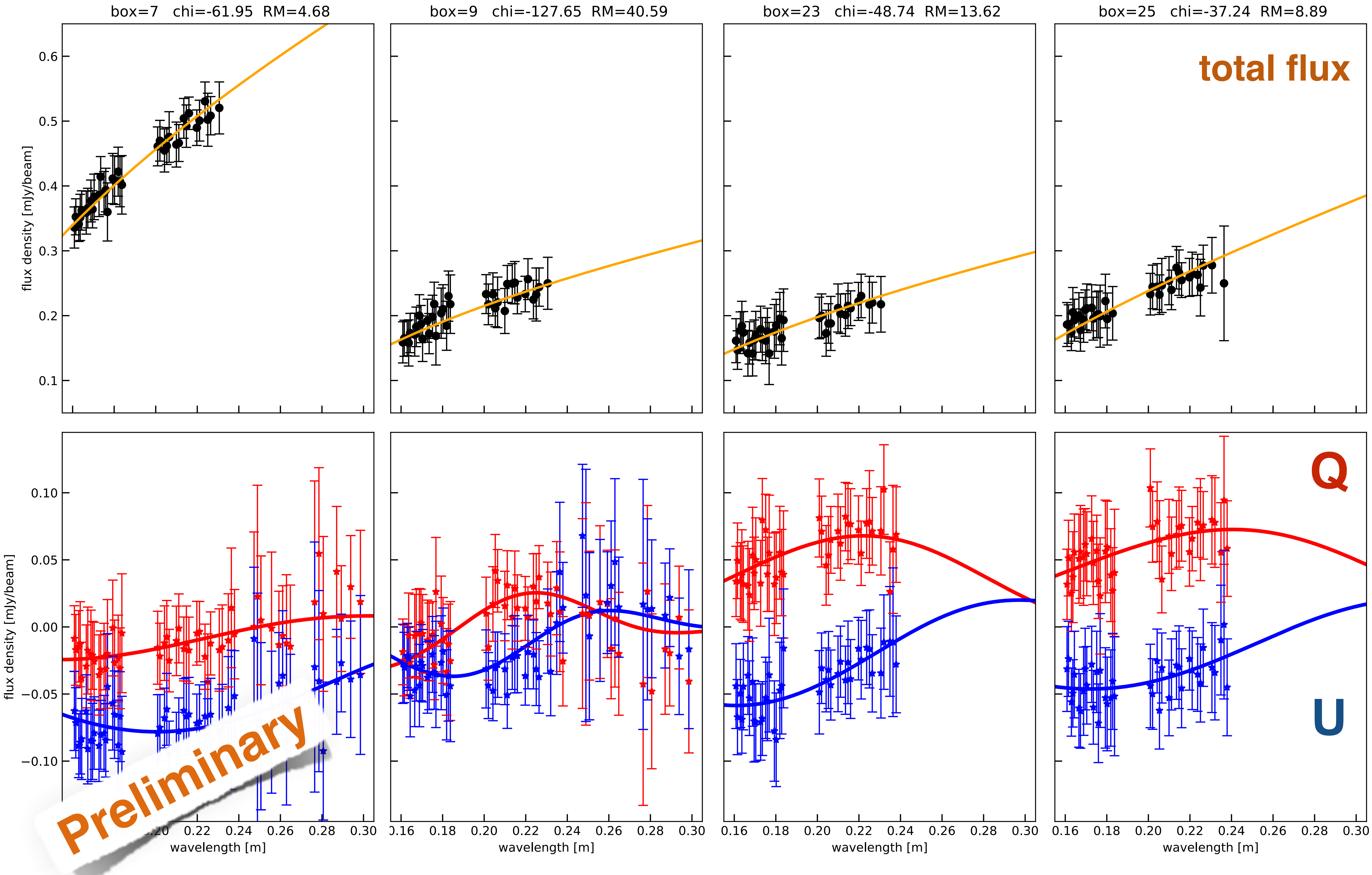
Selecting regions for QU fitting
'tip of handle'-region only



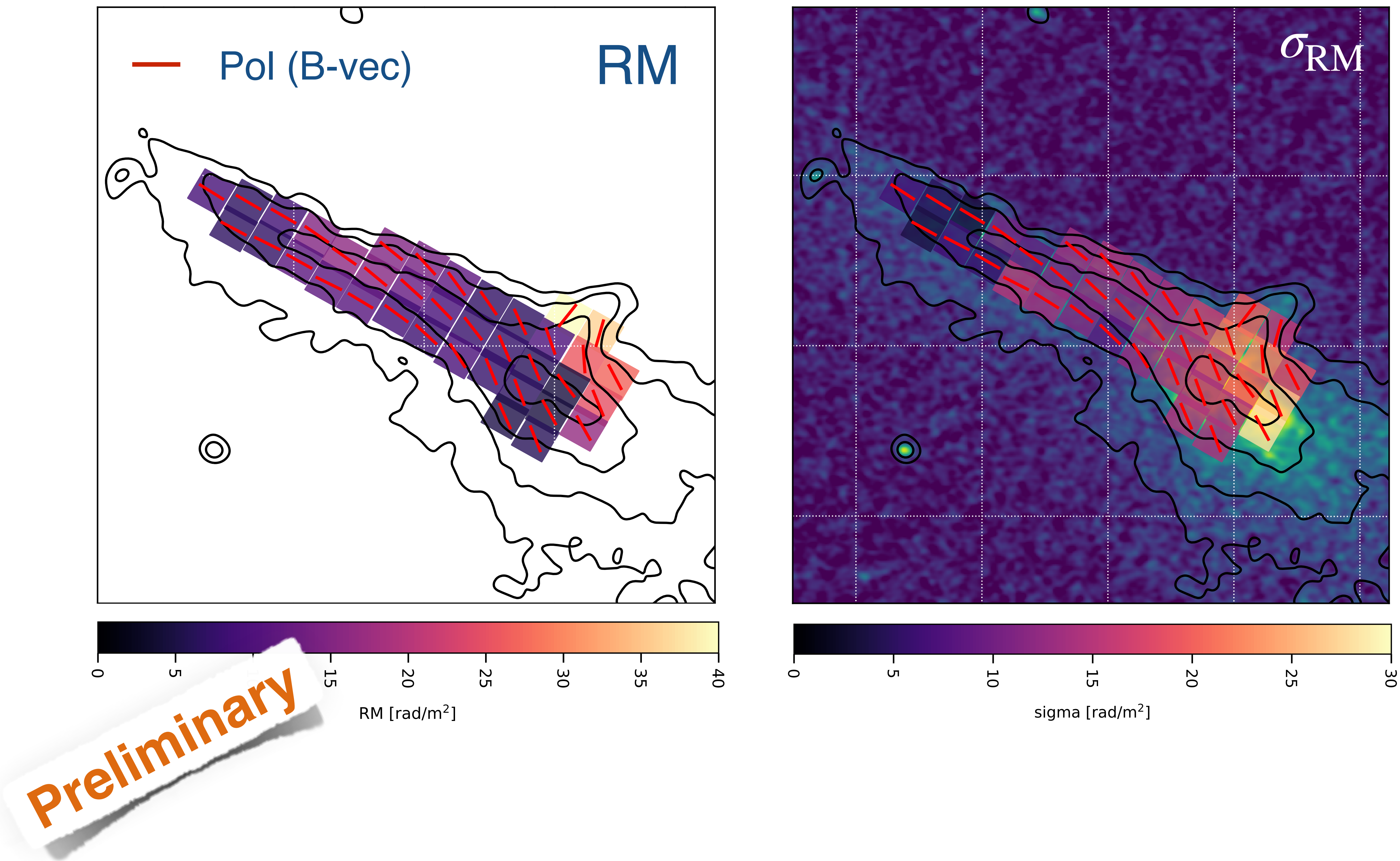
contour: TP 5''
color: PI 12''

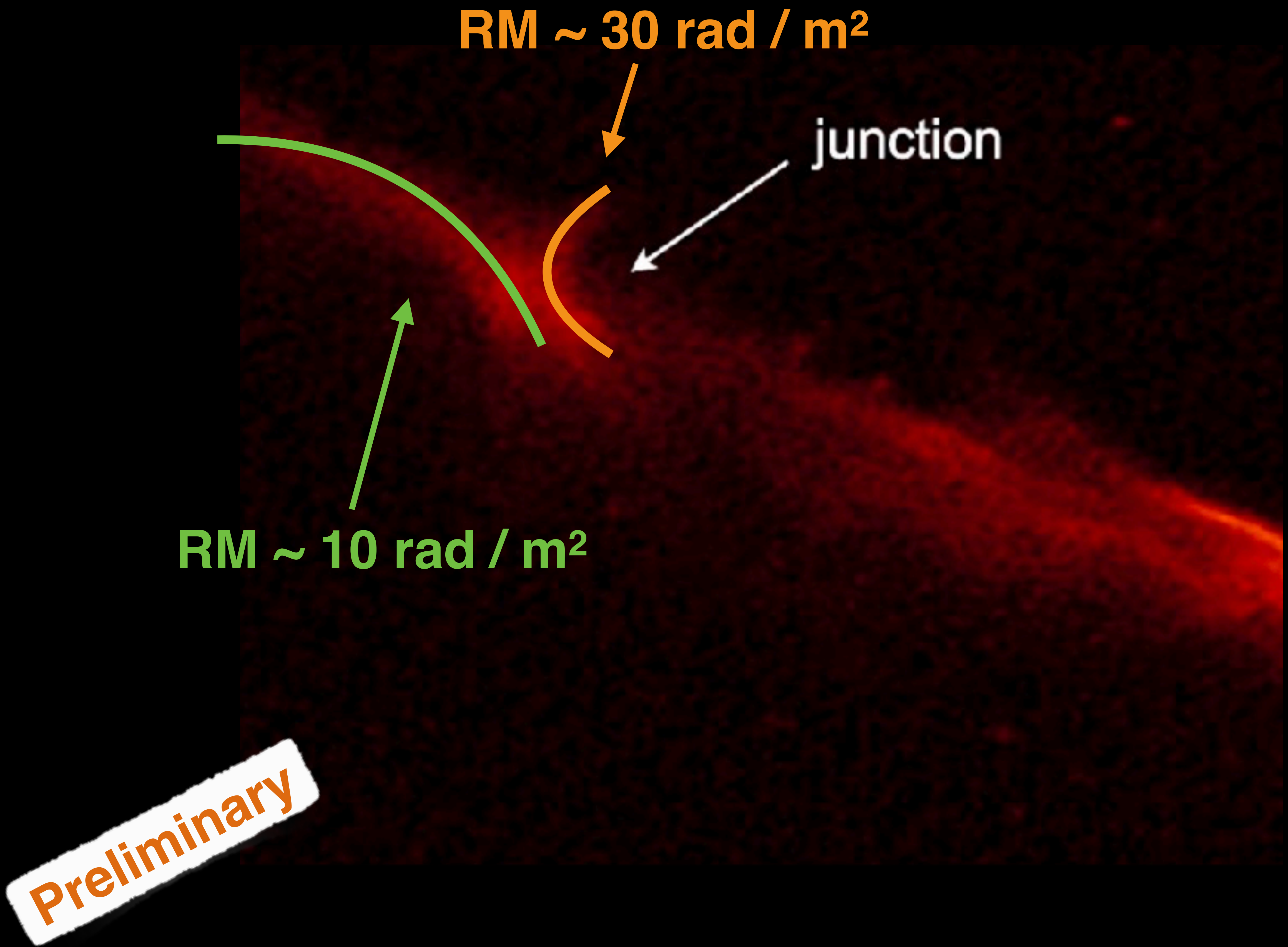
boxes:
regions where
RM spectra extracted

QU fitting in small box regions



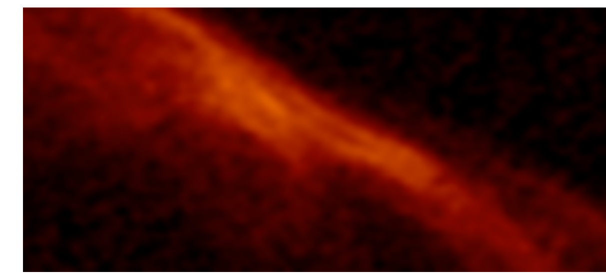
Polarisation (B-vector) well aligned with shock



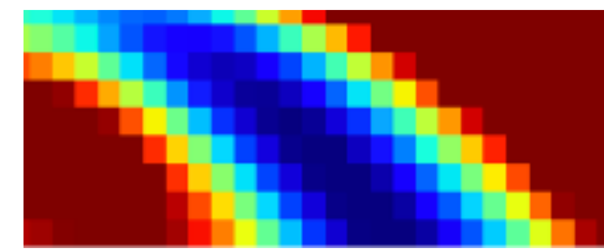

RM ~ 30 rad / m²
junction
RM ~ 10 rad / m²
Preliminary

Summary

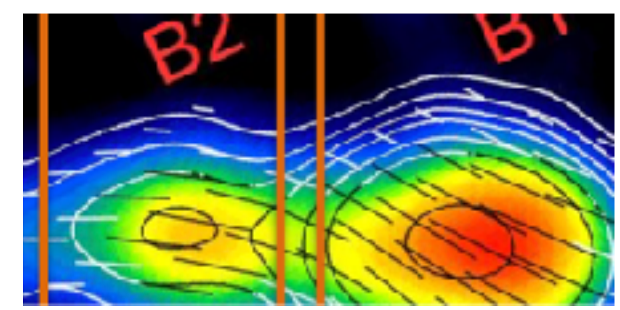
- high resolution reveals **filamentary structure** of emission



- the ridge profile suggests:
  - **high B** (>5μG) is **unlikely**
  - in the emission region the **strength of B scatters** significantly



- large scale depolarisation gradient indicates **handle region is behind ICM**



- Small box QU-fitting:
  - Polarisation (B-vec) **well aligned with shock**
  - shock structures are at **different Rotation Measure depths**