Deep in the (un)known: the Sausage Cluster

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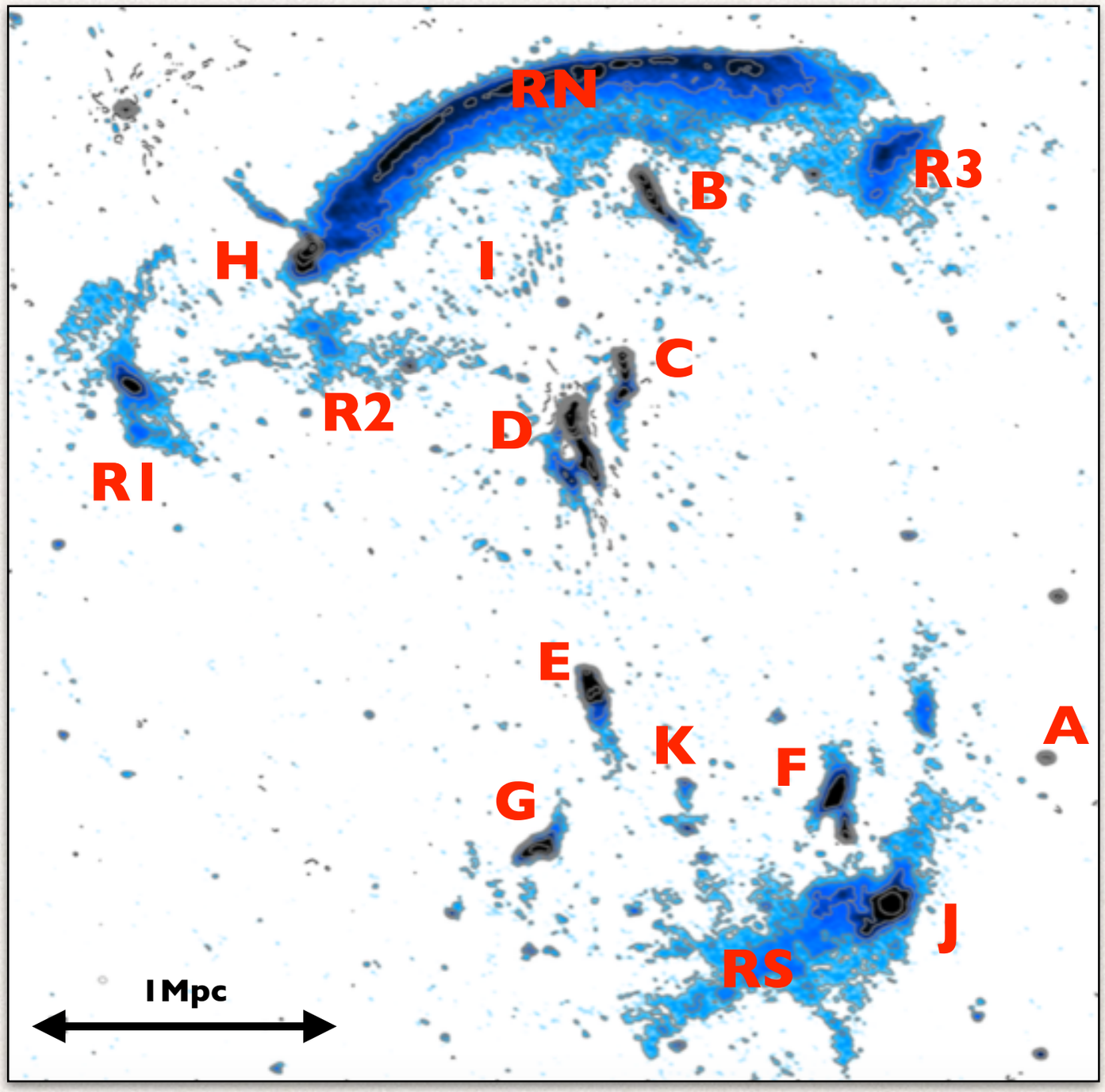
Diffuse Synchrotron Emission in Cluster of Galaxies: What is next? — Leiden, 23/10/2017

CIZA J2242.8+5301

(a.k.a "Sausage")



LOFAR 145 MHz, Hoang+17

- $z \approx 0.19$
- radio relic (N) length ~ 2 Mpc
- radio relic (N) width ~ 50 kpc
- additional southern (relic) and central (halo) diffuse emission
- symmetric configuration

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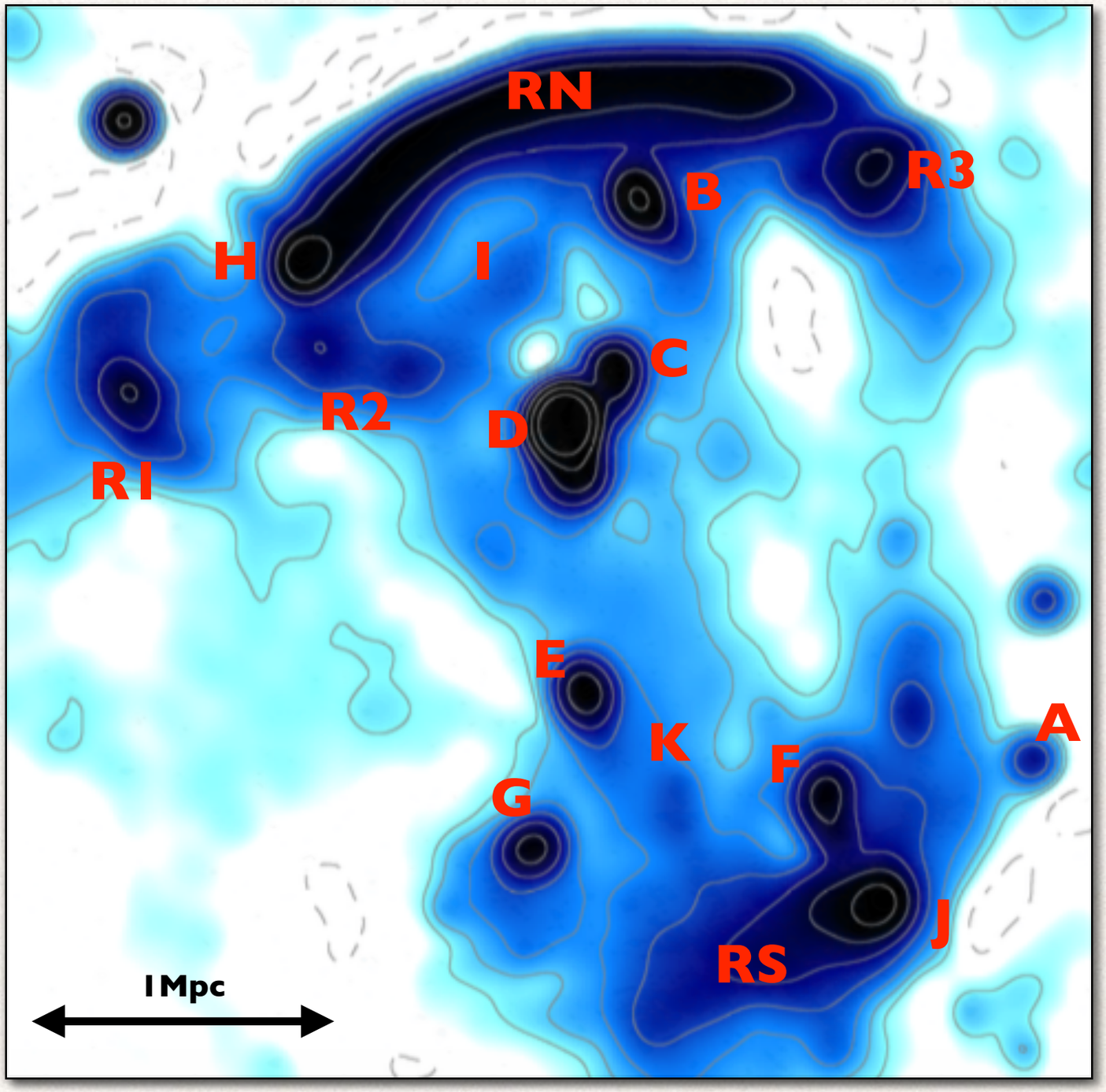

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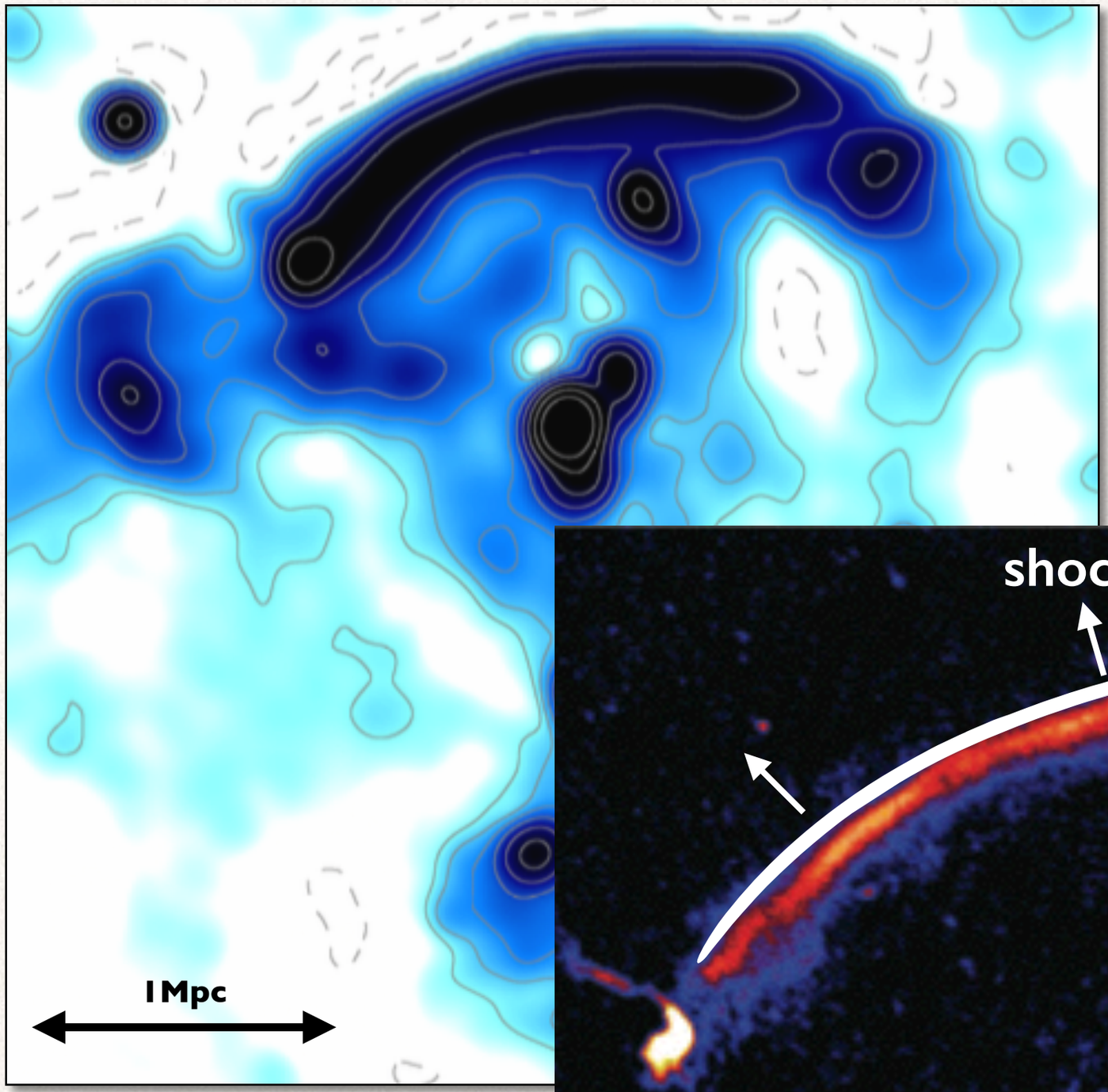

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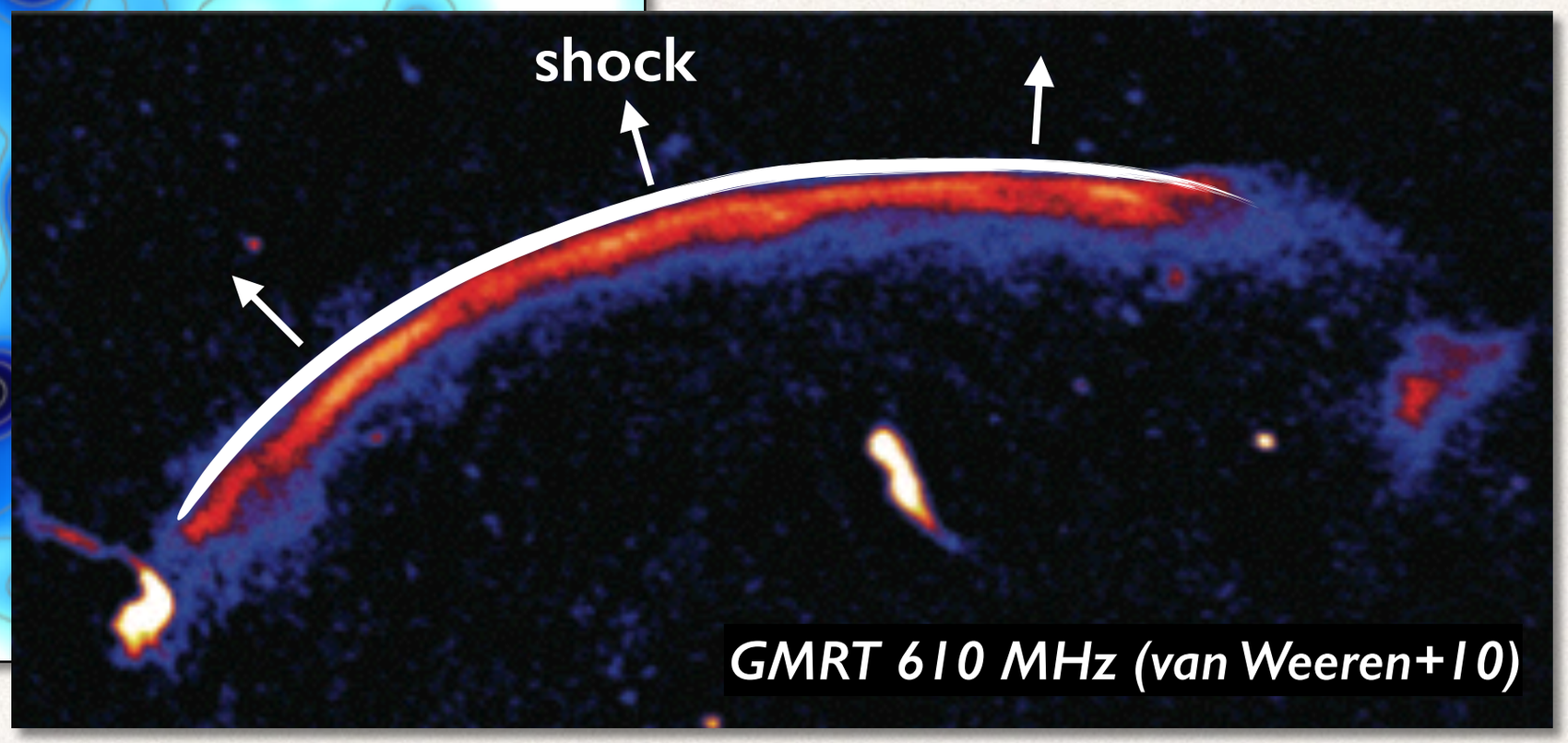
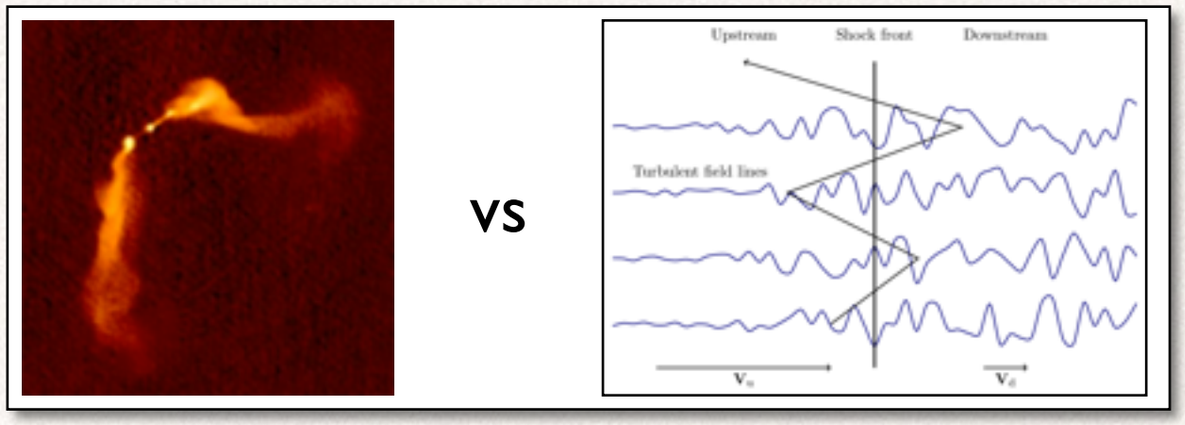


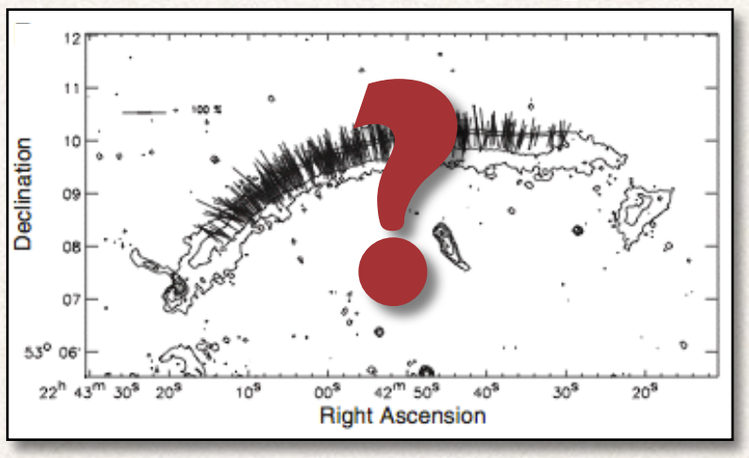
OPEN QUESTIONS

- How are the particles (re-)accelerated ?

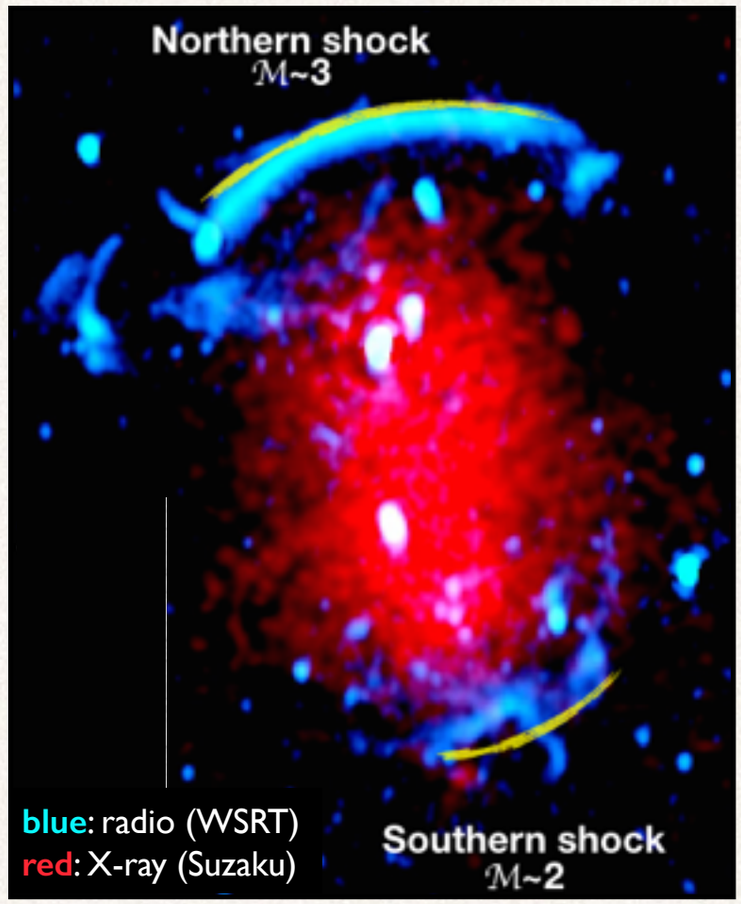


- What is the connection between the non-thermal plasma (radio) and the thermal hot gas (X-ray) ?

- What are the relic polarization characteristics at high resolution ?



van Weeren+10



Akamatsu+15

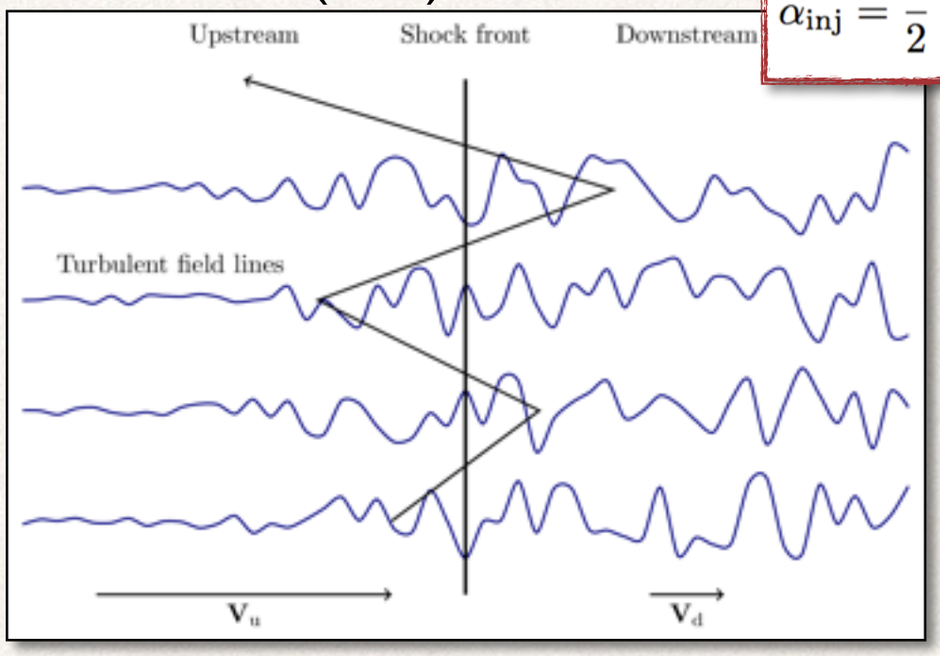
Origin of the radiating electrons

SHOCK ACCELERATION

(e.g. Ensslin et al. 1998, Blandford & Ostriker 1978)

- Particles from the thermal pool accelerated by multiple crossing of a shock front (first order Fermi: DSA)
- Relation between the radio spectral index (α) and the Mach number ($\mathcal{M}$)

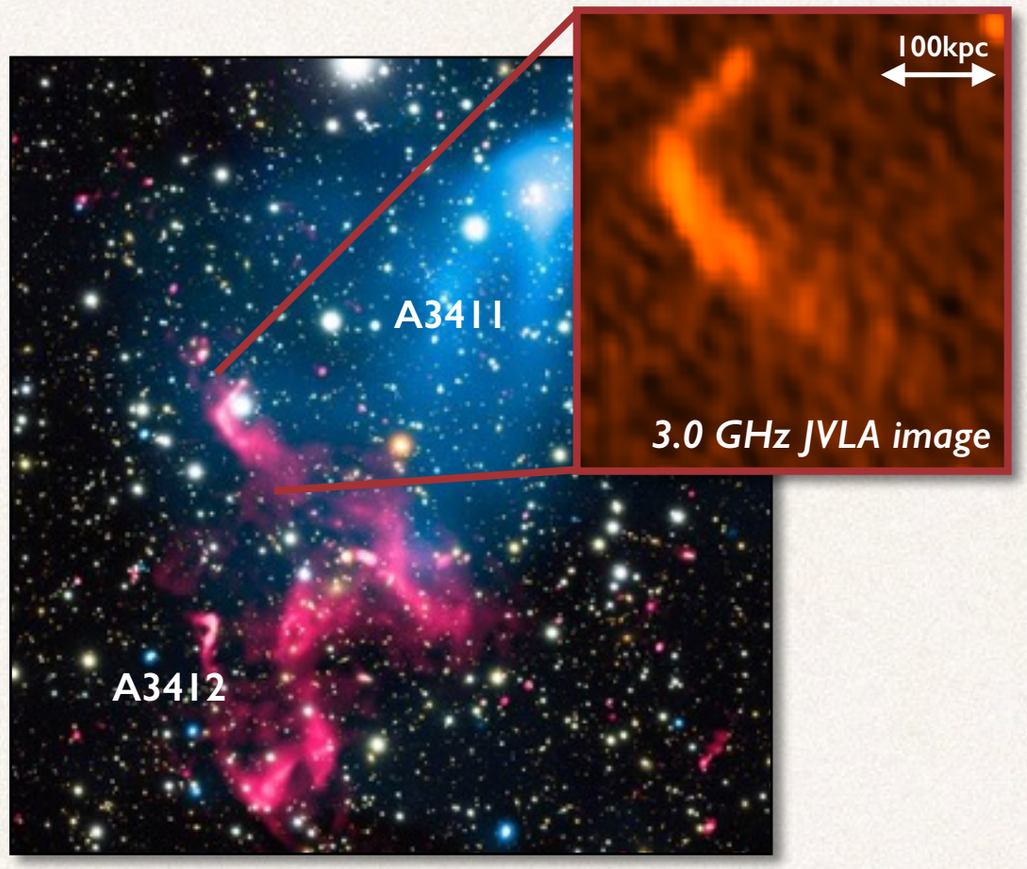
$$\alpha_{\rm inj} = \frac{1}{2} - \frac{\mathcal{M}^2+1}{\mathcal{M}^2-1}$$



RE-ACCELERATION

(e.g. Markevitch+2005, Kang & Ryu+2016)

- Old plasma re-accelerated by the crossing shock wave
- Morphological connection between radio galaxies and relics



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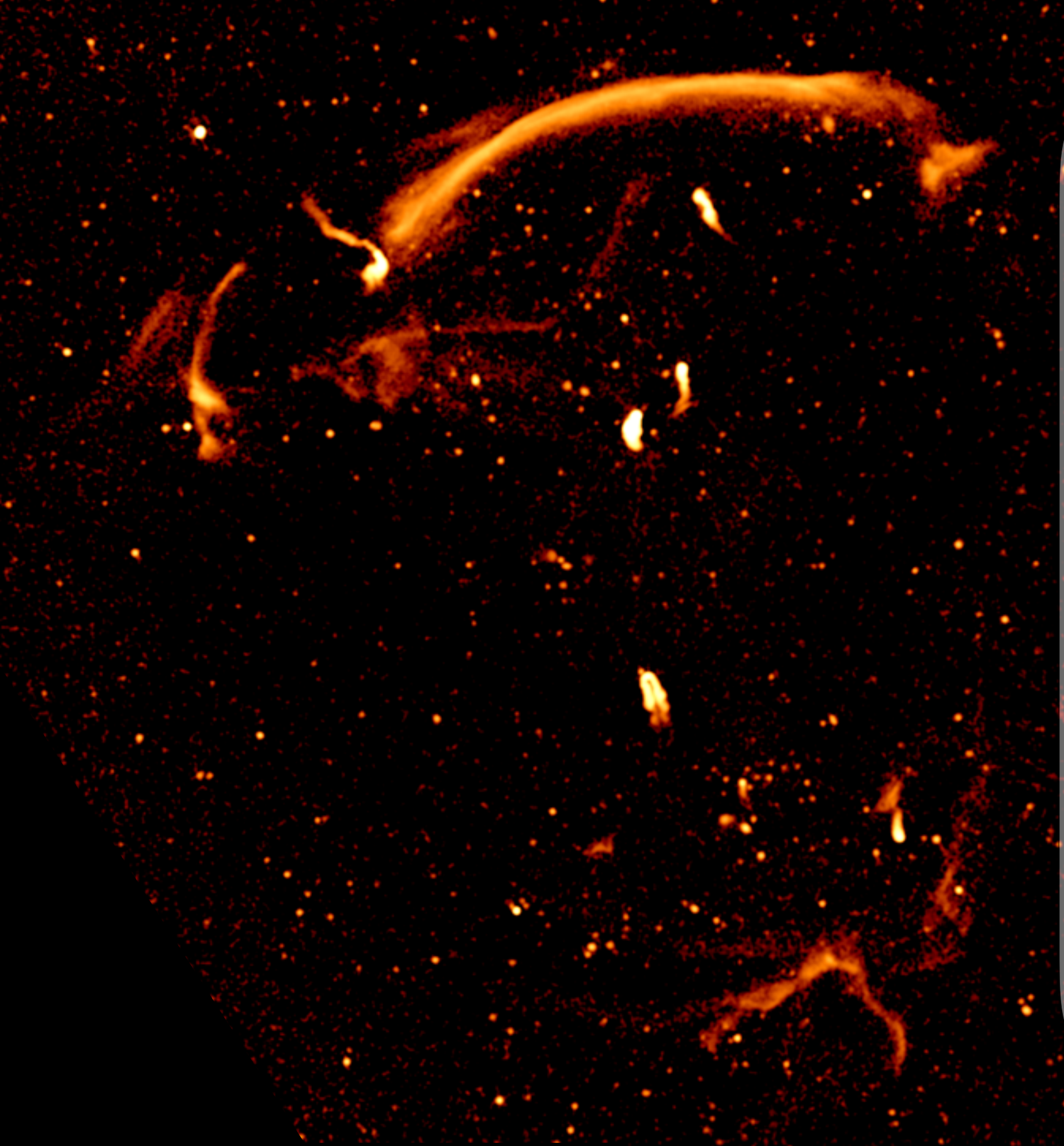

JVLA 1-4 GHz (2.5” resolution)

New Deep L- and S-band JVLA observations (1-4 GHz)

- high (1.6” / 0.8”) and low resolution images;
- spectral index and curvature maps (JVLA, GMRT, LOFAR);
- test for the DSA mechanism;
- polarization study across the relics.

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JVLA 1-4 GHz (10” resolution)

RELICS

HALO

RELICS

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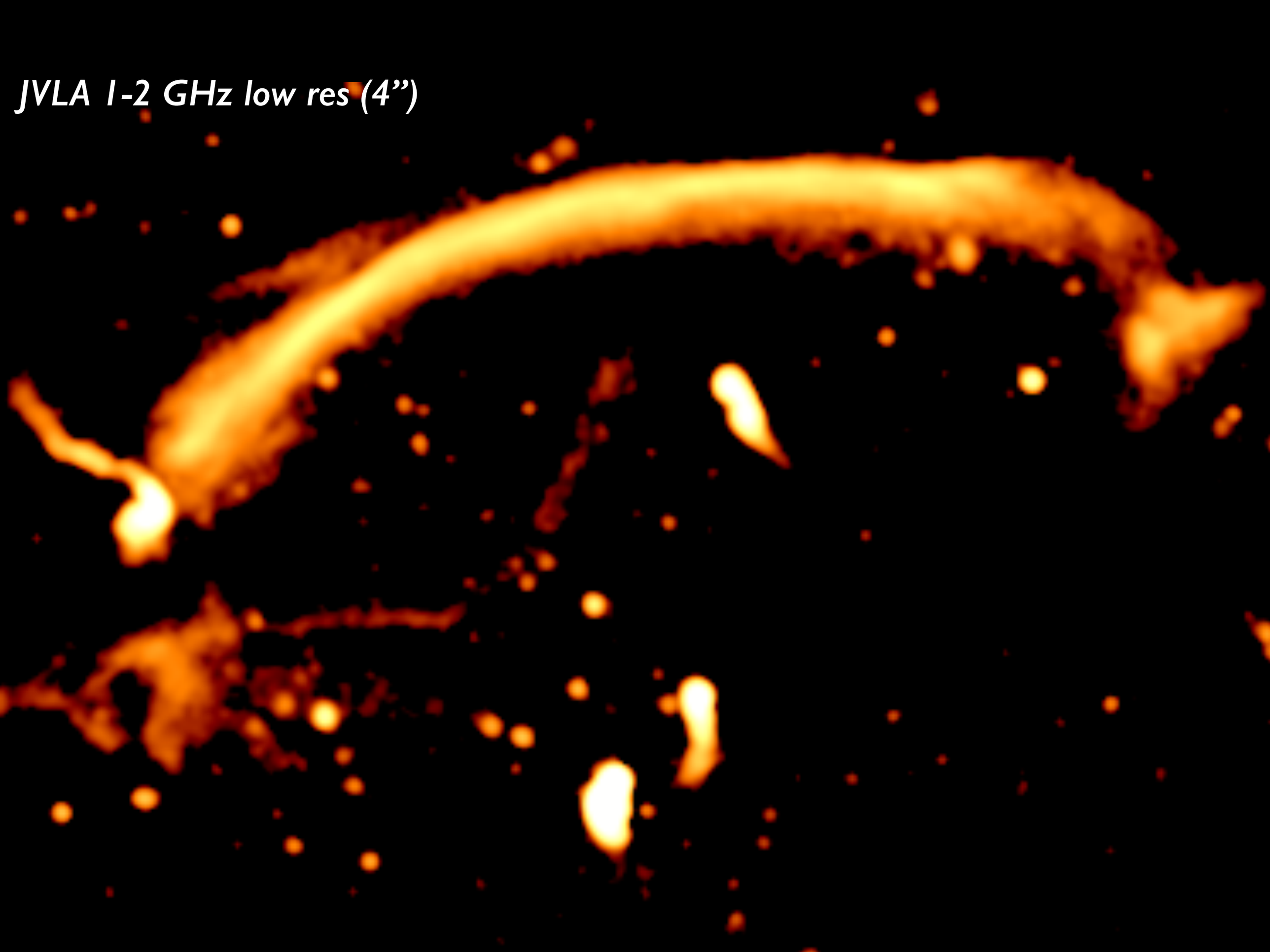
JVLA 1-2 GHz low res (4")



JVLA 1-2 GHz full res (1.6")

noise ≈ 4 μJy/beam

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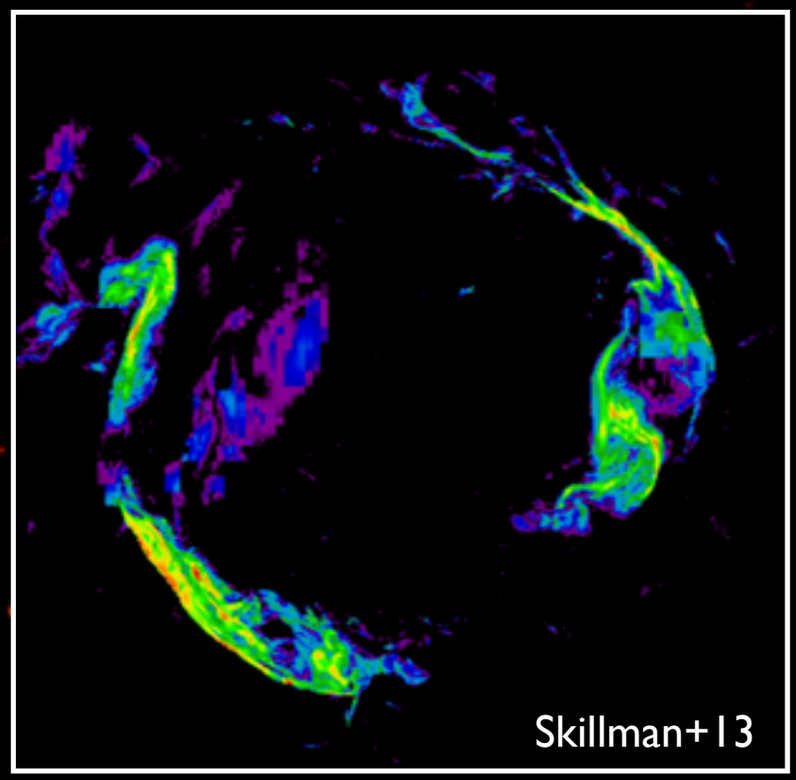
FROM SIMULATIONS



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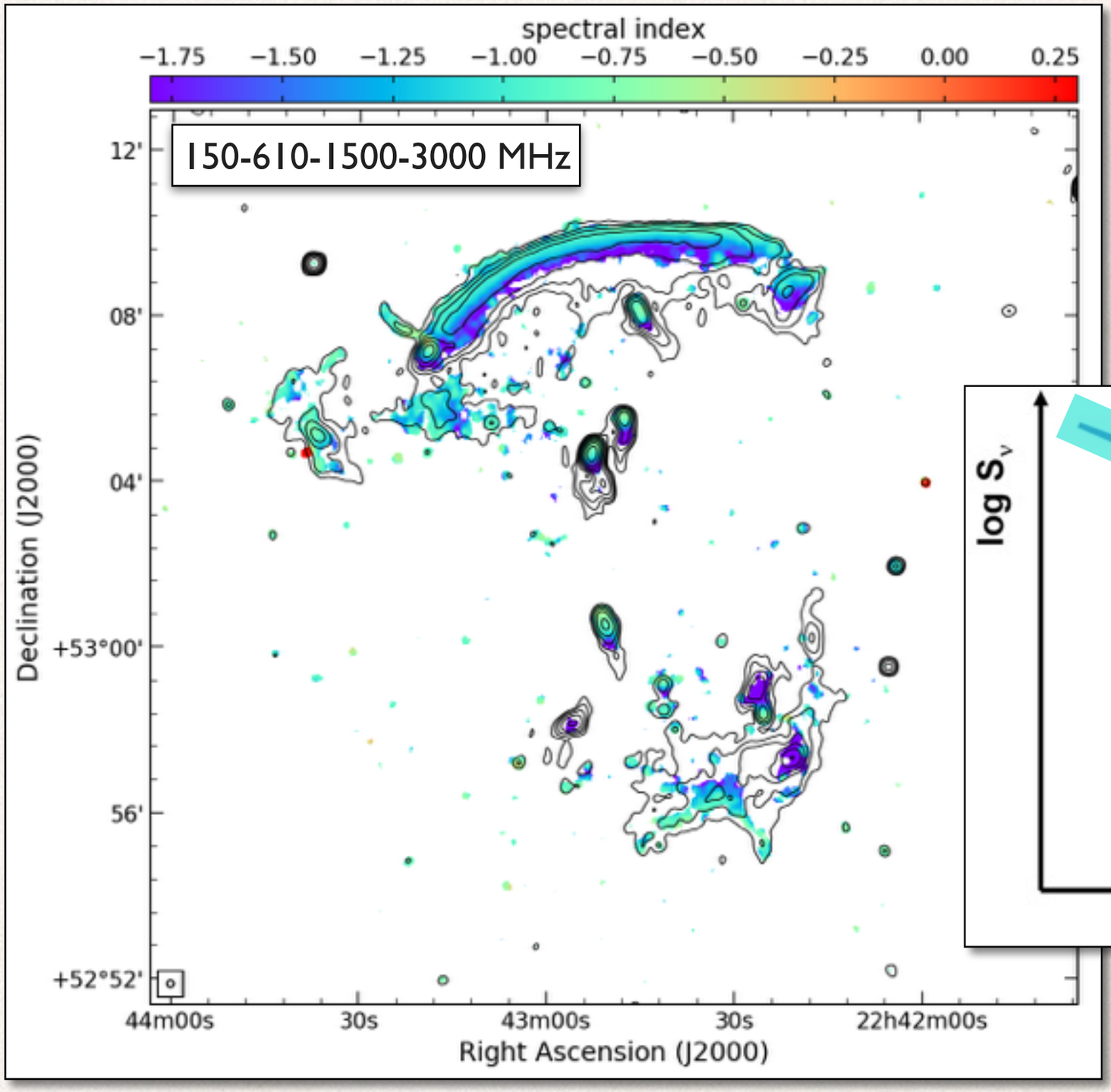
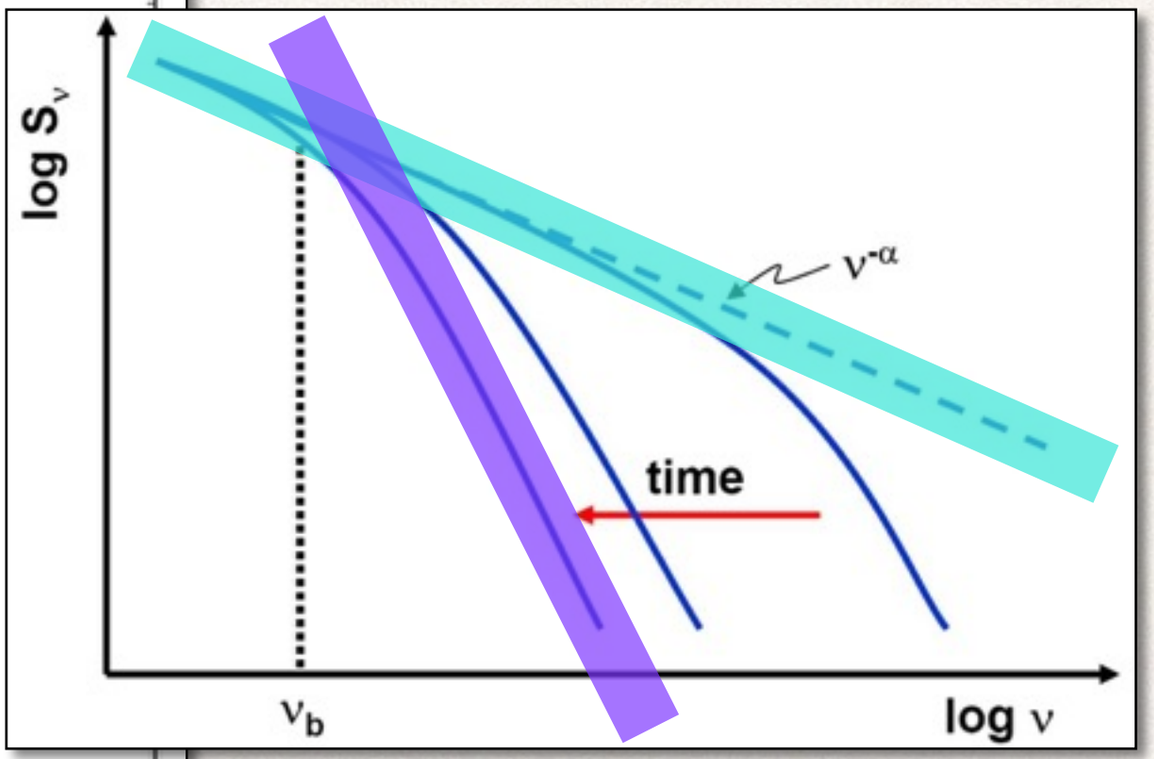
Spectral Index analysis

LOFAR-GMRT-JVLA (10” res)



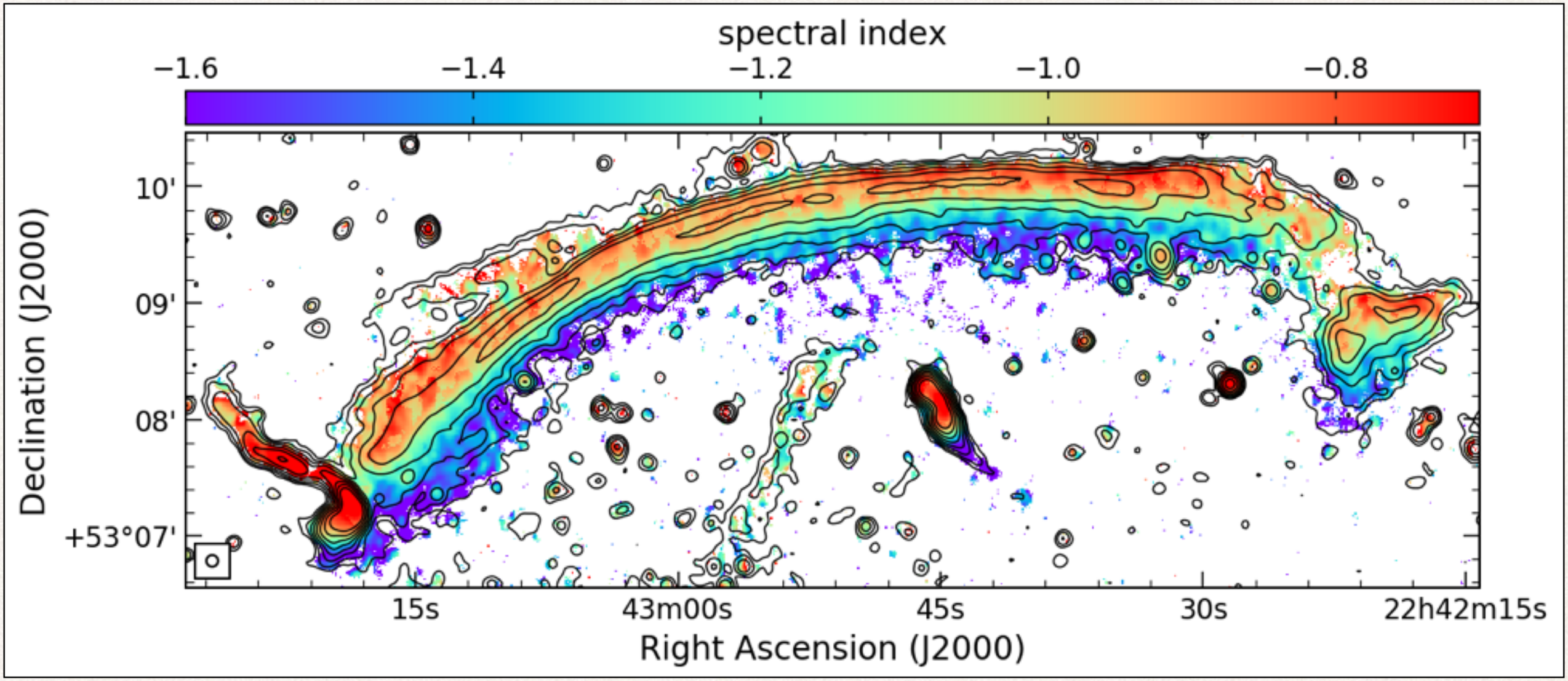
PARTICLES AGING



Contours: LOFAR 150 MHz

Spectral Index analysis

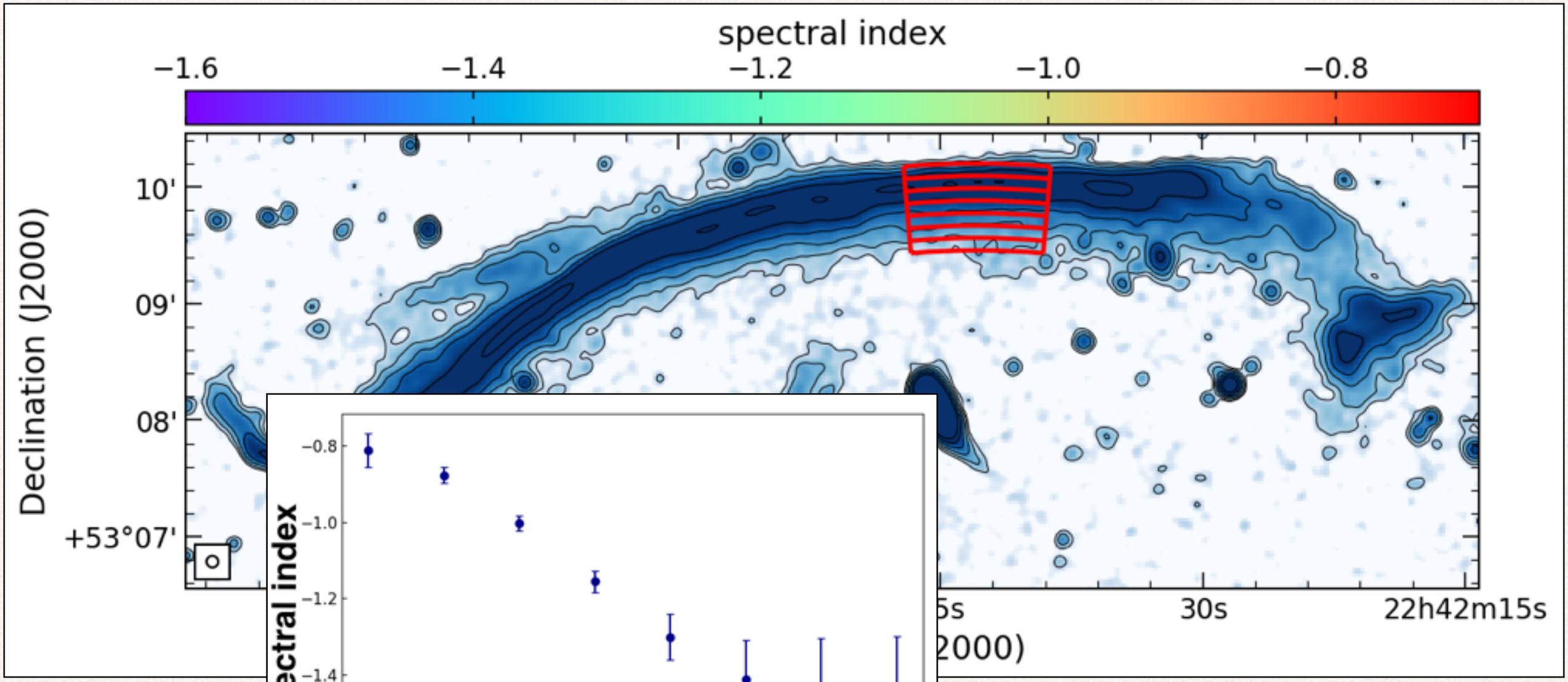
NORTHERN RELIC

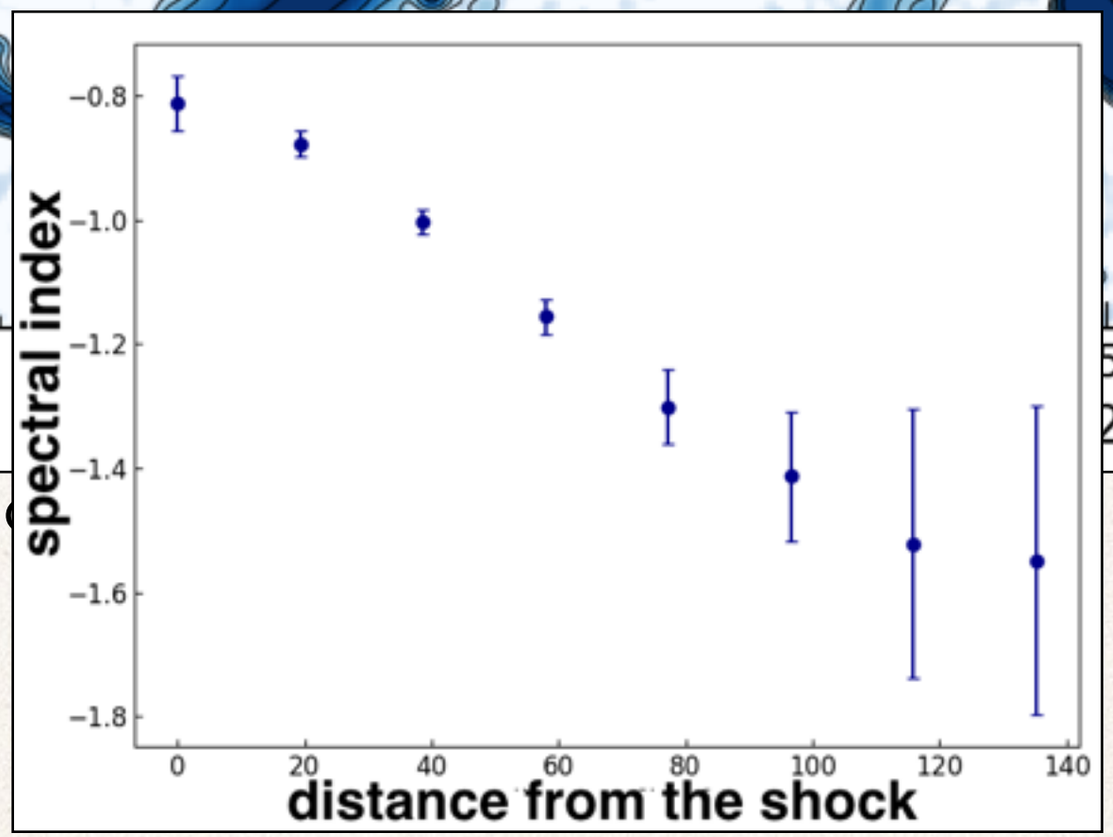


Contours: JVLA 1-4 GHz (5” res)

Spectral Index analysis

NORTHERN RELIC





Contours: JVLA 1-4 (

Spectral Index analysis

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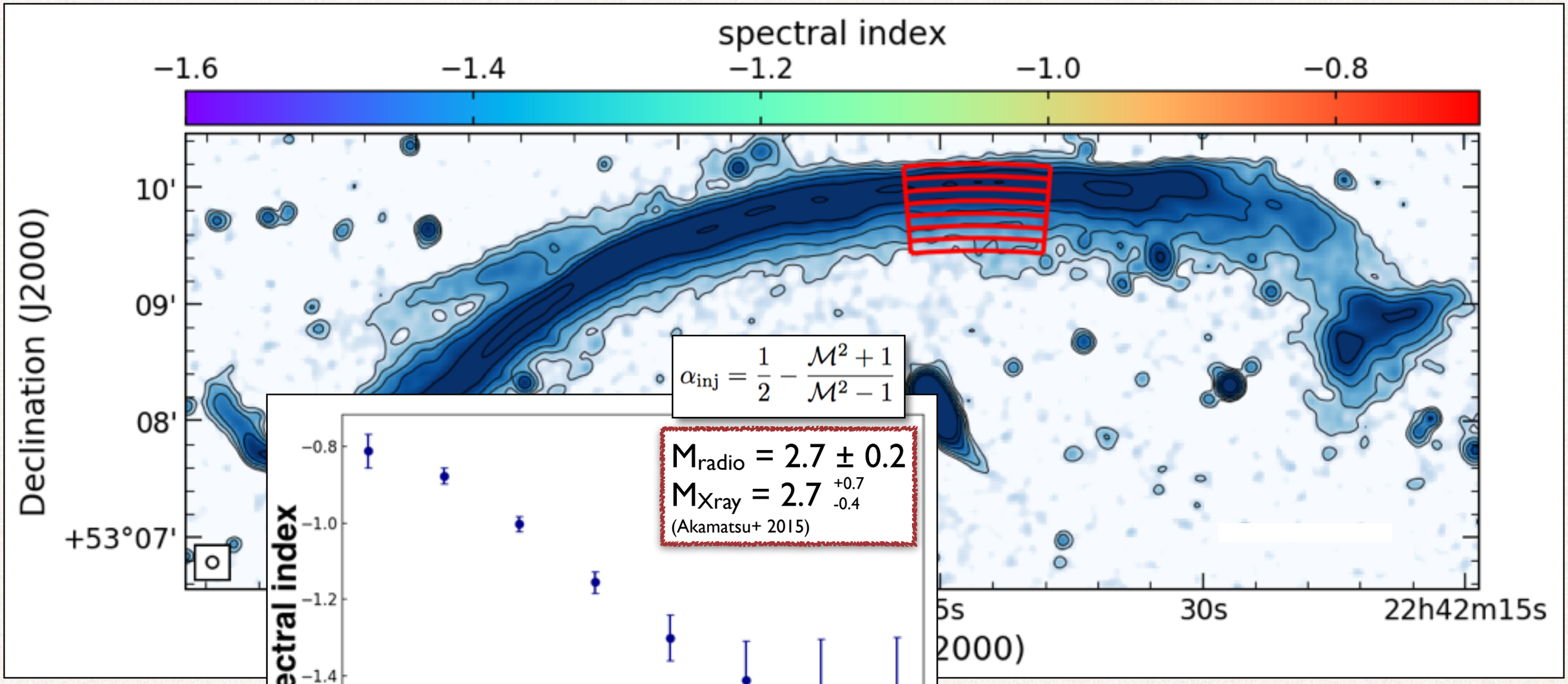

Contours: JVLA 1-4 (

in agreement with literature works (e.g. Stroe+13,+16; Hoang+17)

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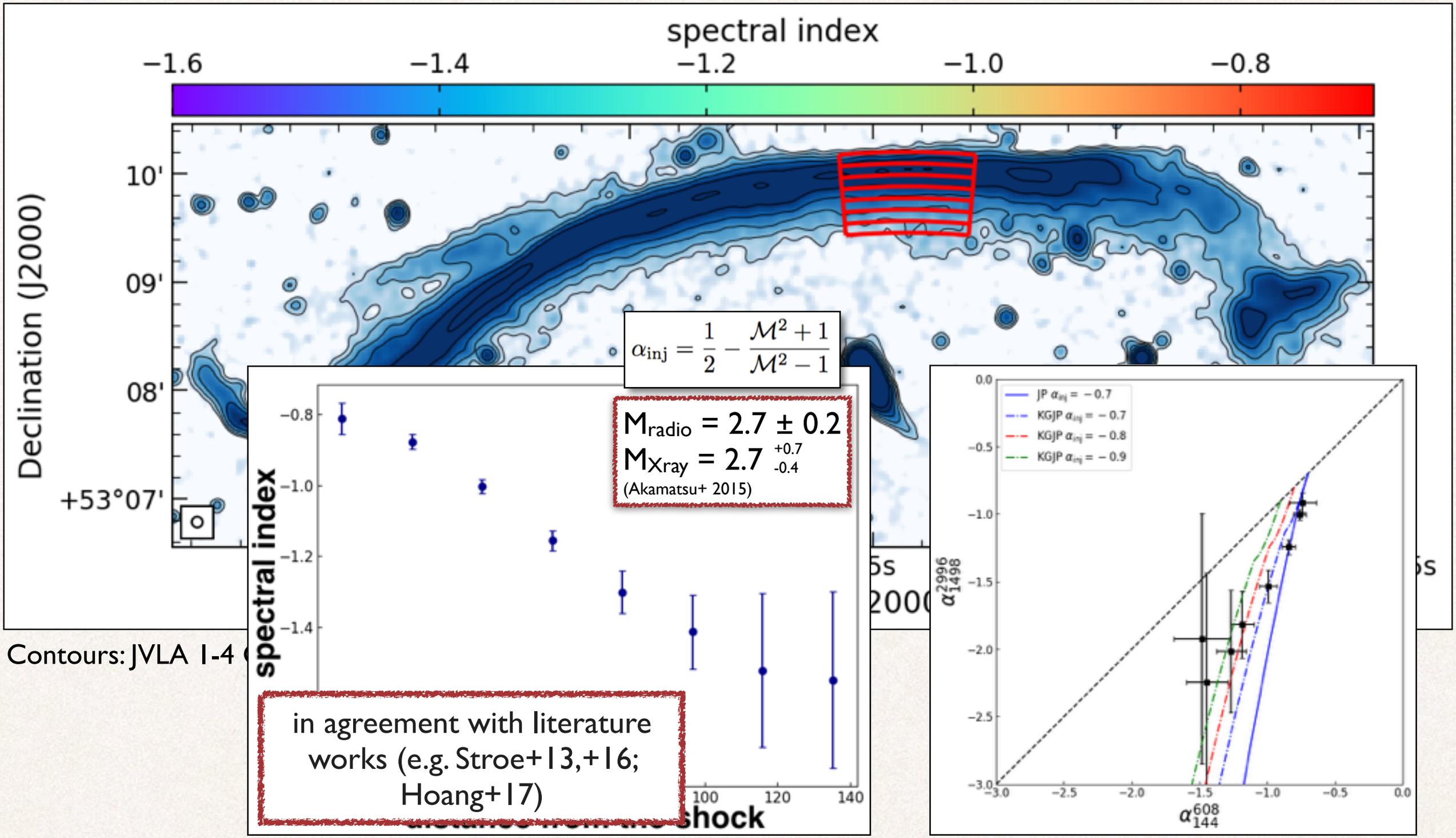

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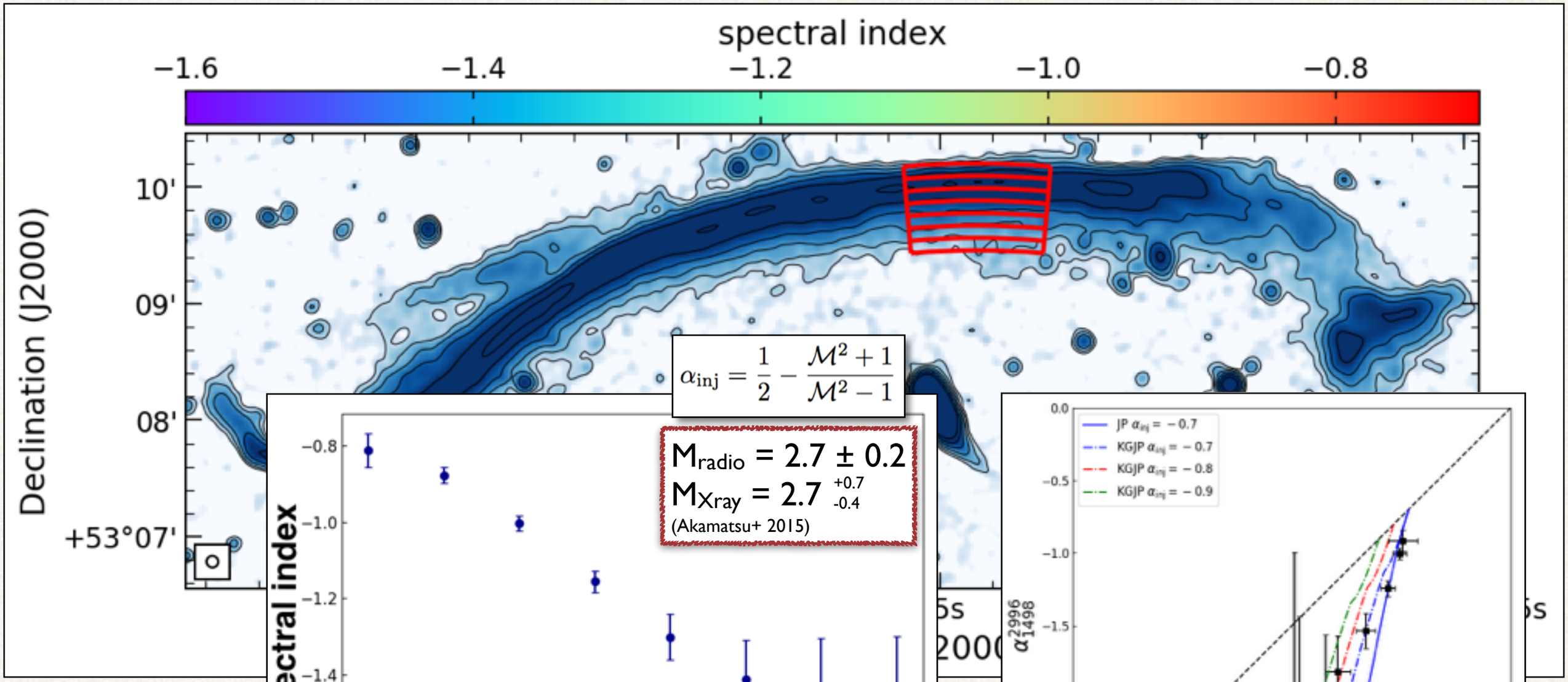
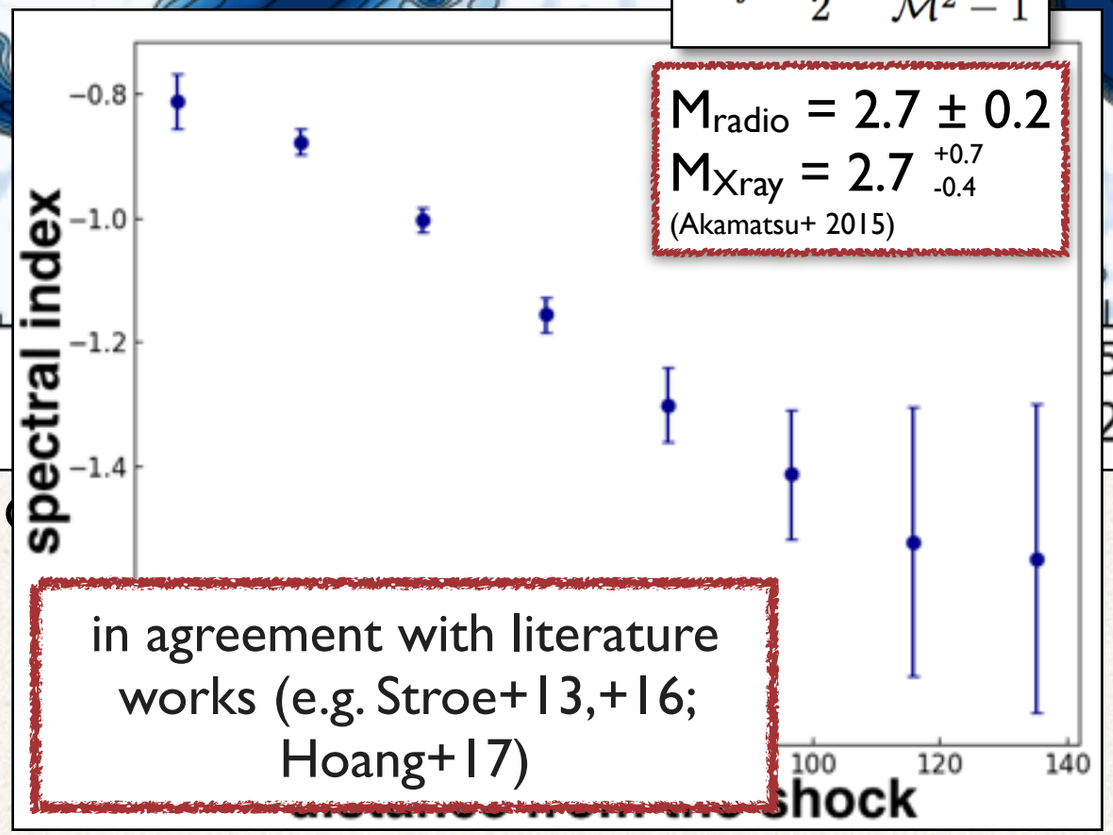


$$\alpha_{\rm inj} = \frac{1}{2} - \frac{\mathcal{M}^2+1}{\mathcal{M}^2-1}$$

$M_{radio} = 2.7 \pm 0.2$

$M_{Xray} = 2.7\ ^{+0.7}_{-0.4}$

(Akamatsu+ 2015)



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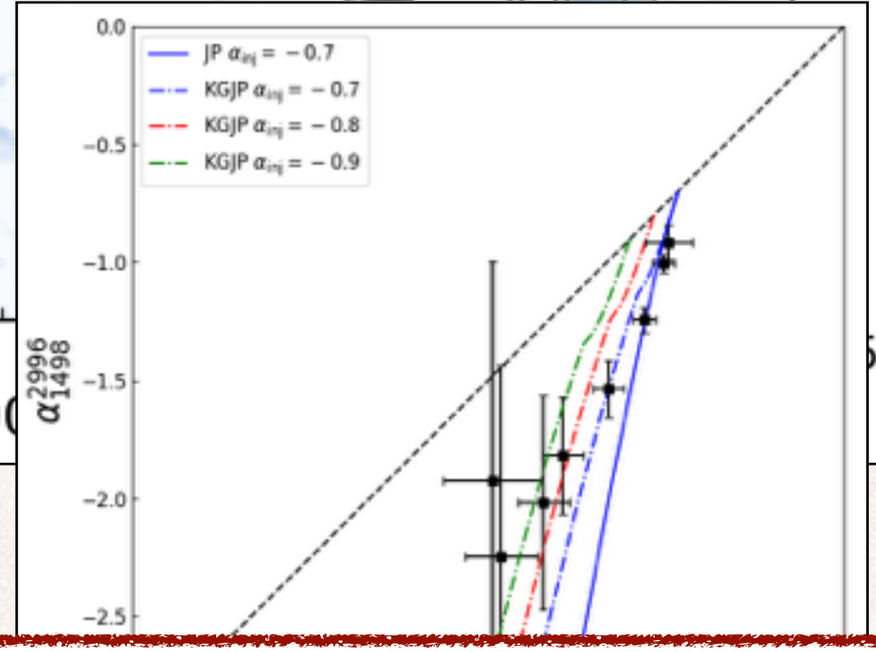

CURVATURE IN ALL THE RELIC ANNULI

Contours: JVLA 1-4

Spectral Index analysis

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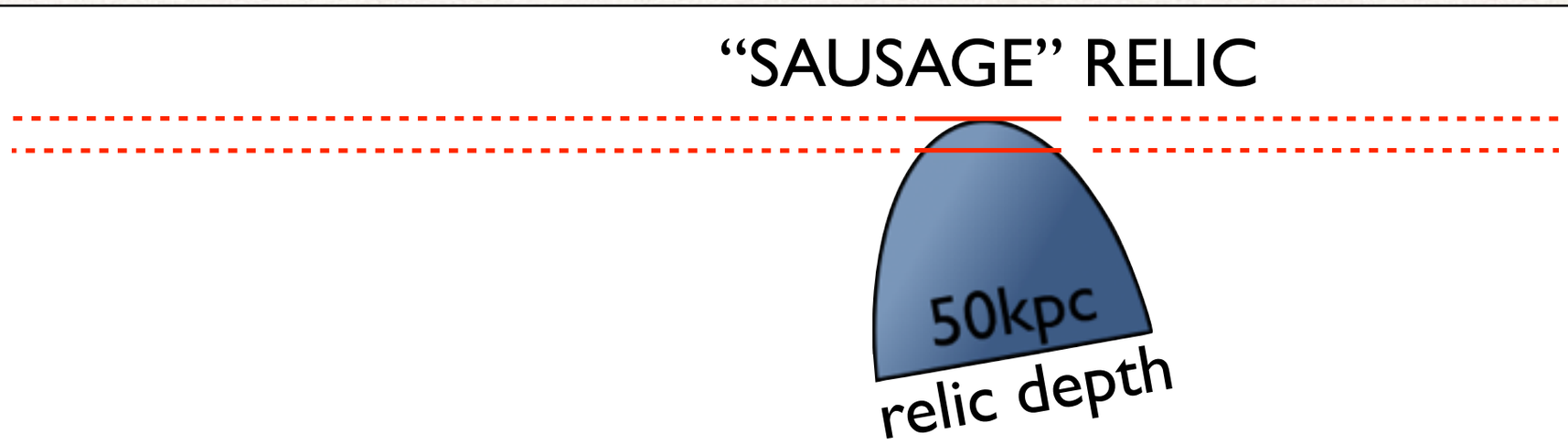

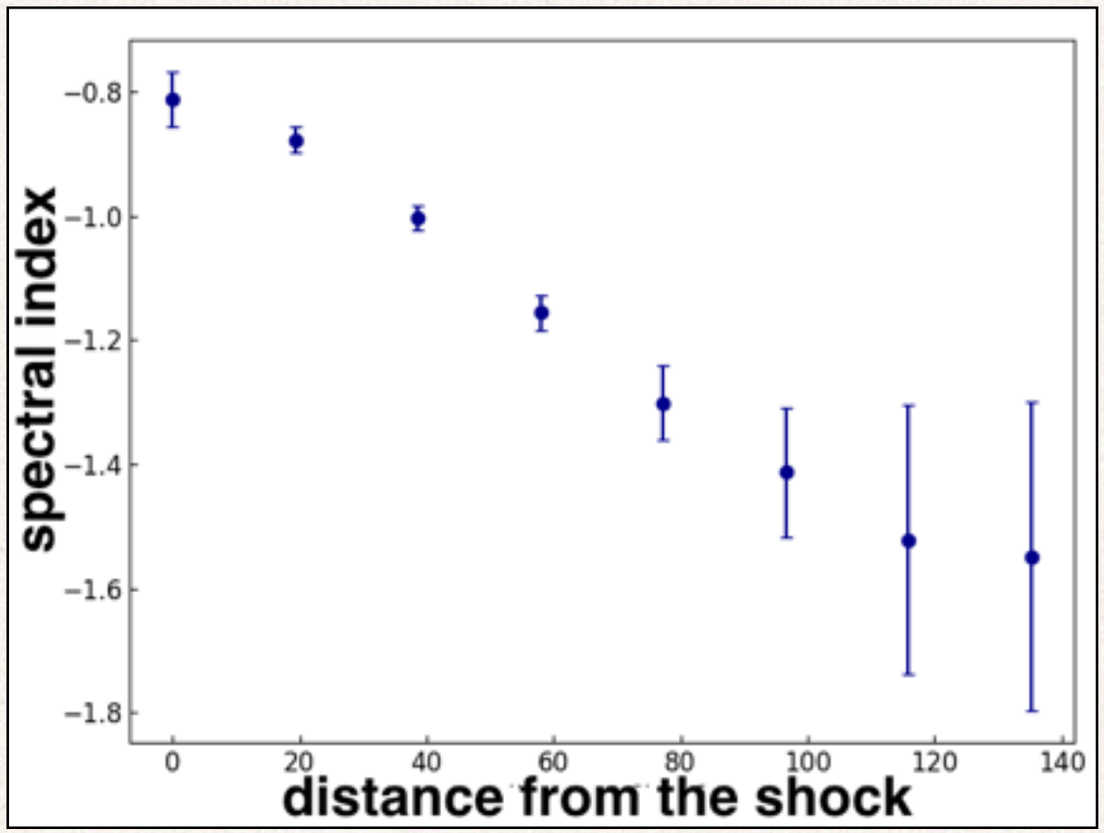

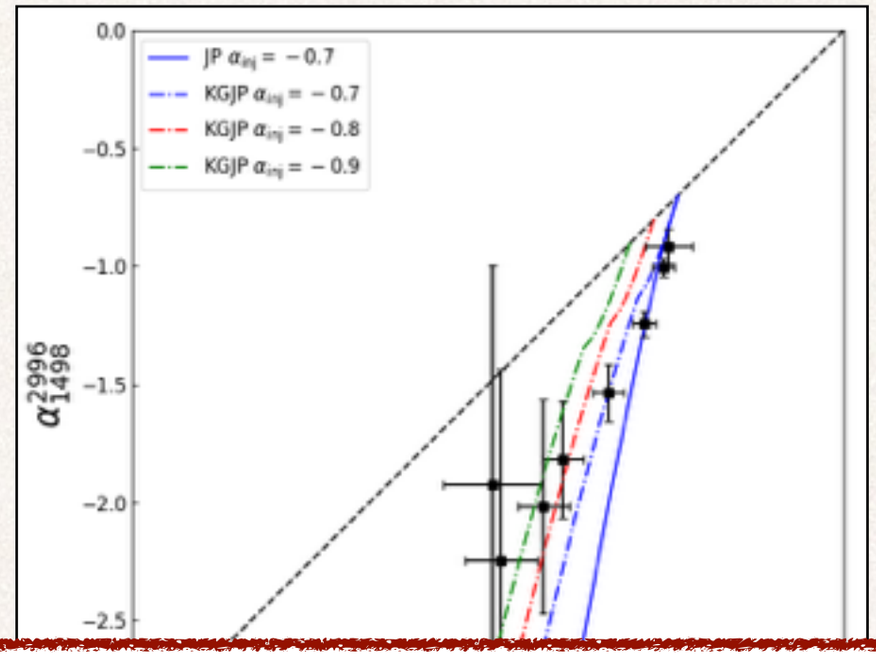

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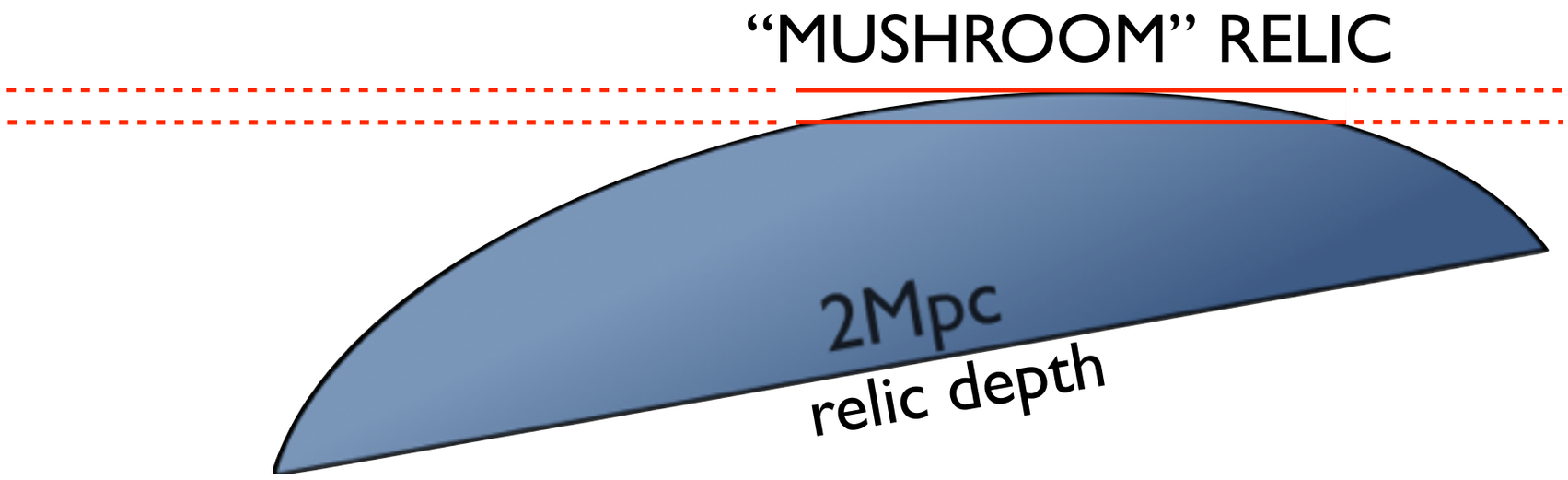

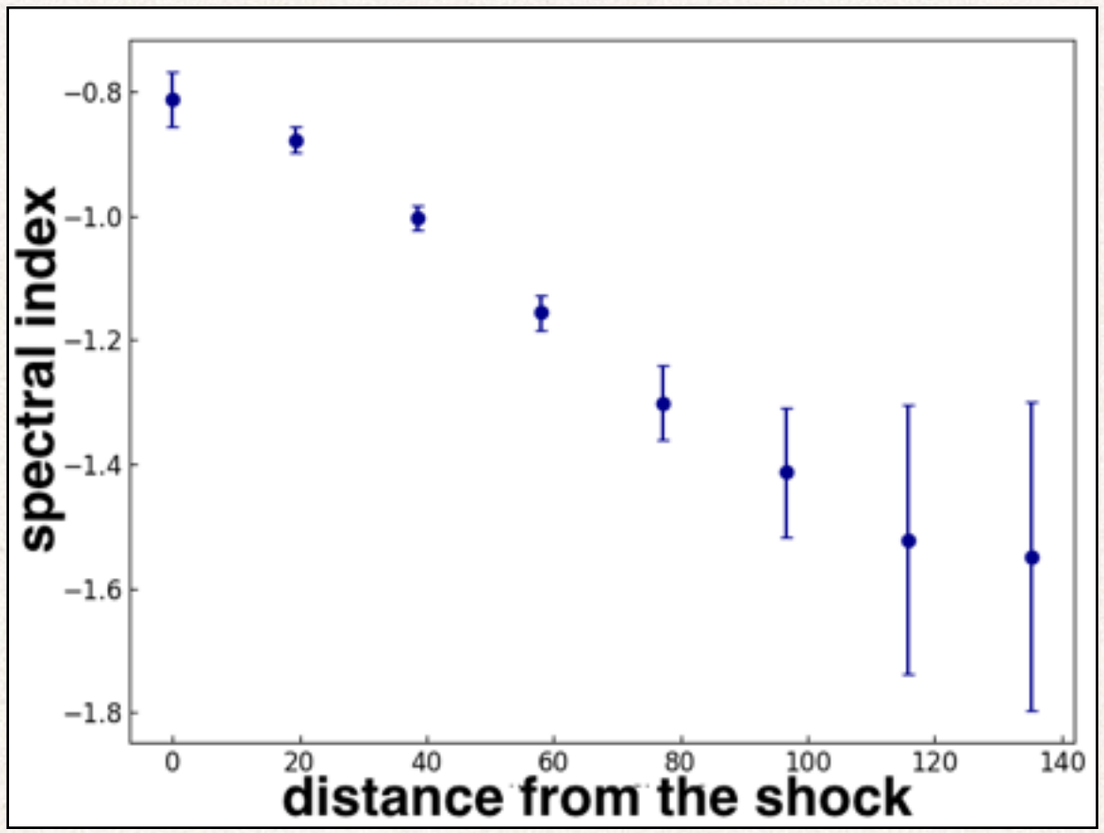

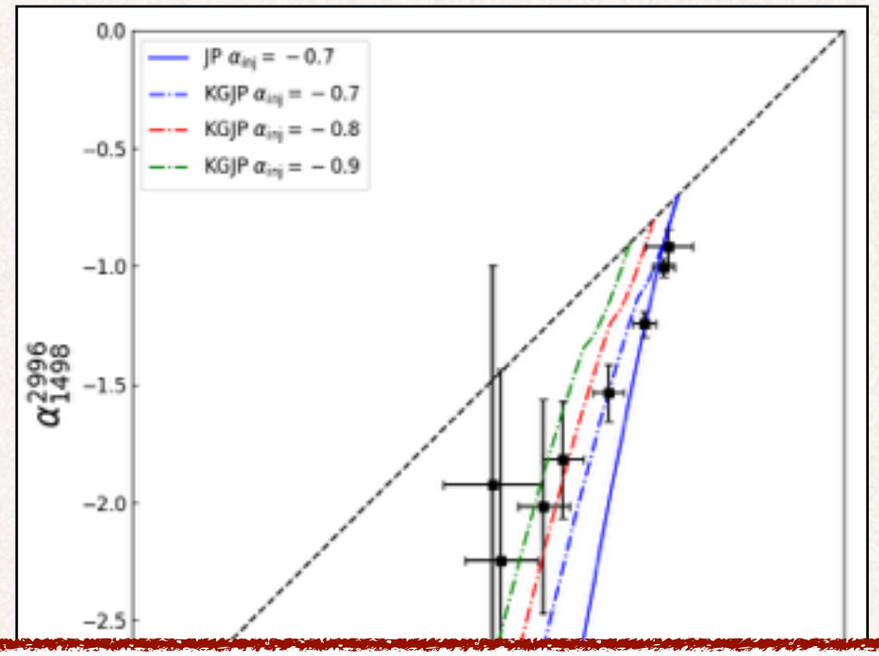

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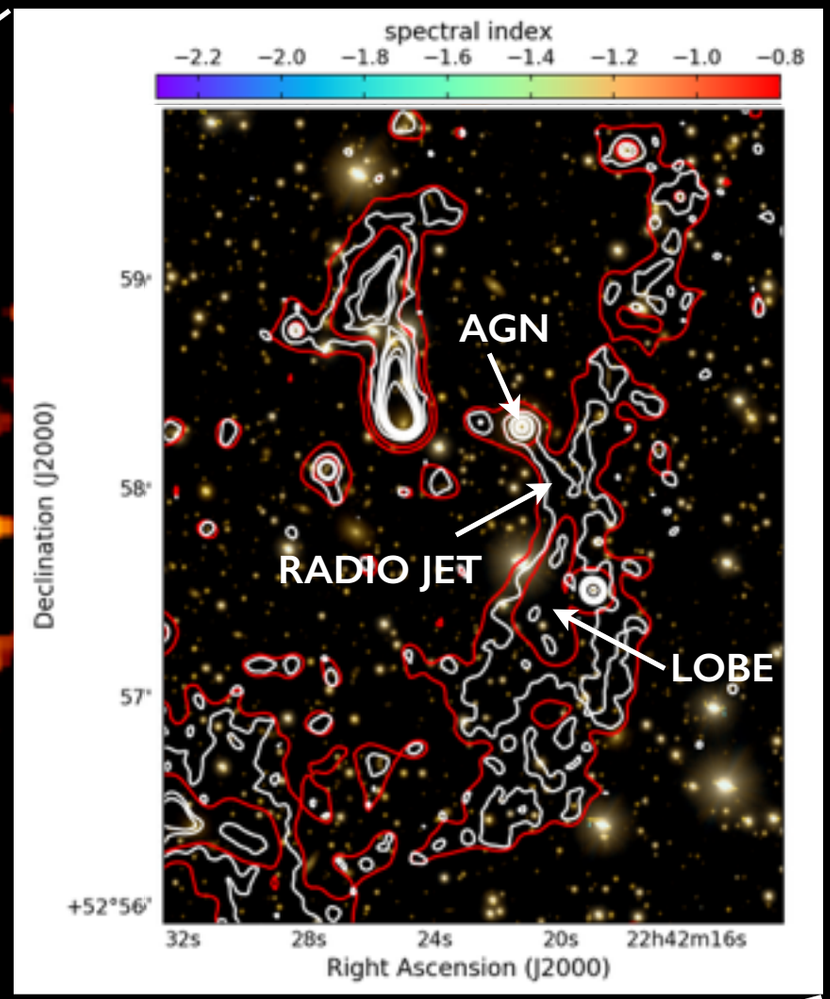

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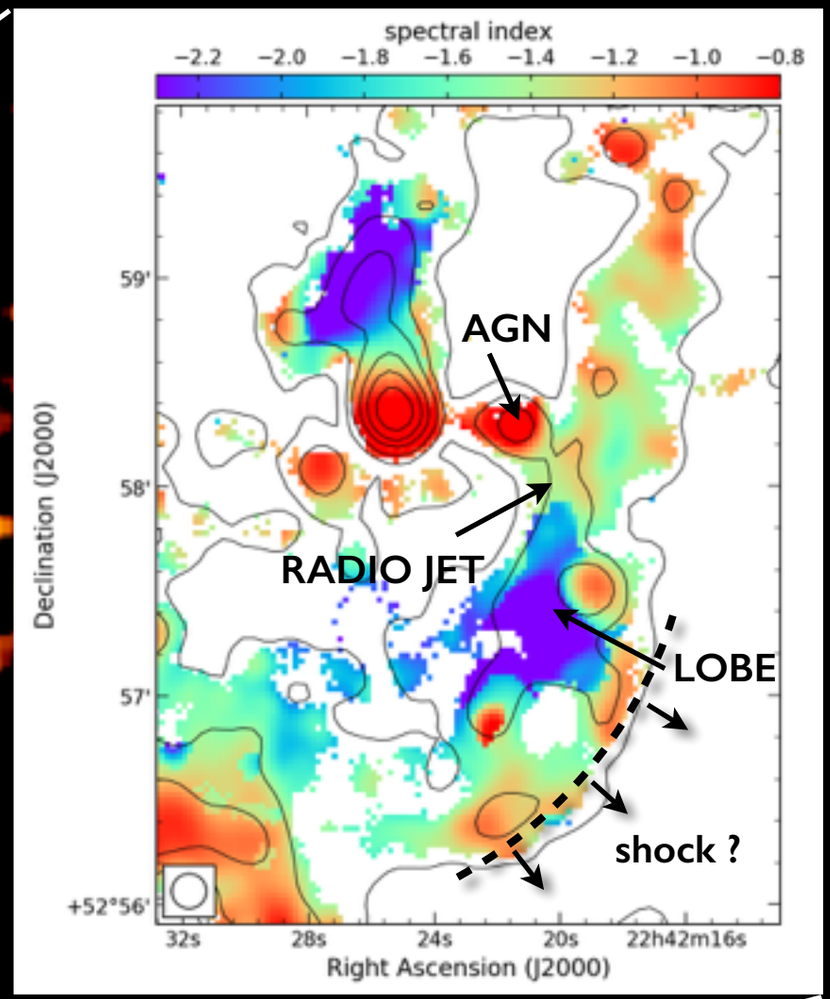

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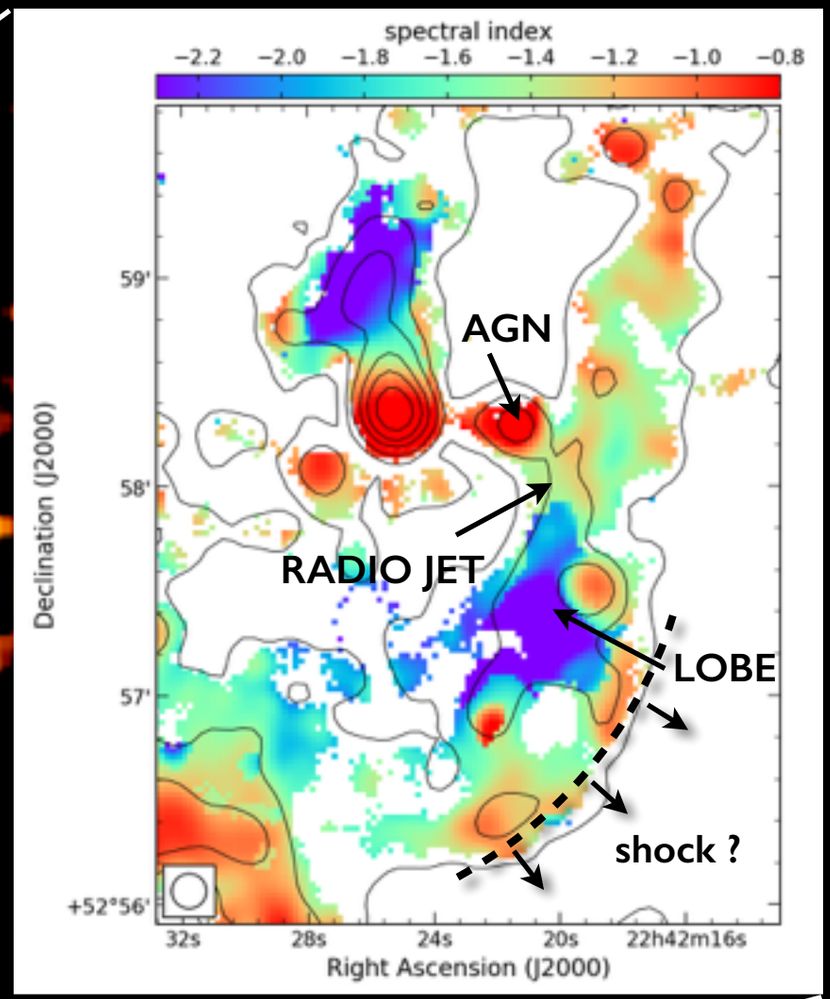

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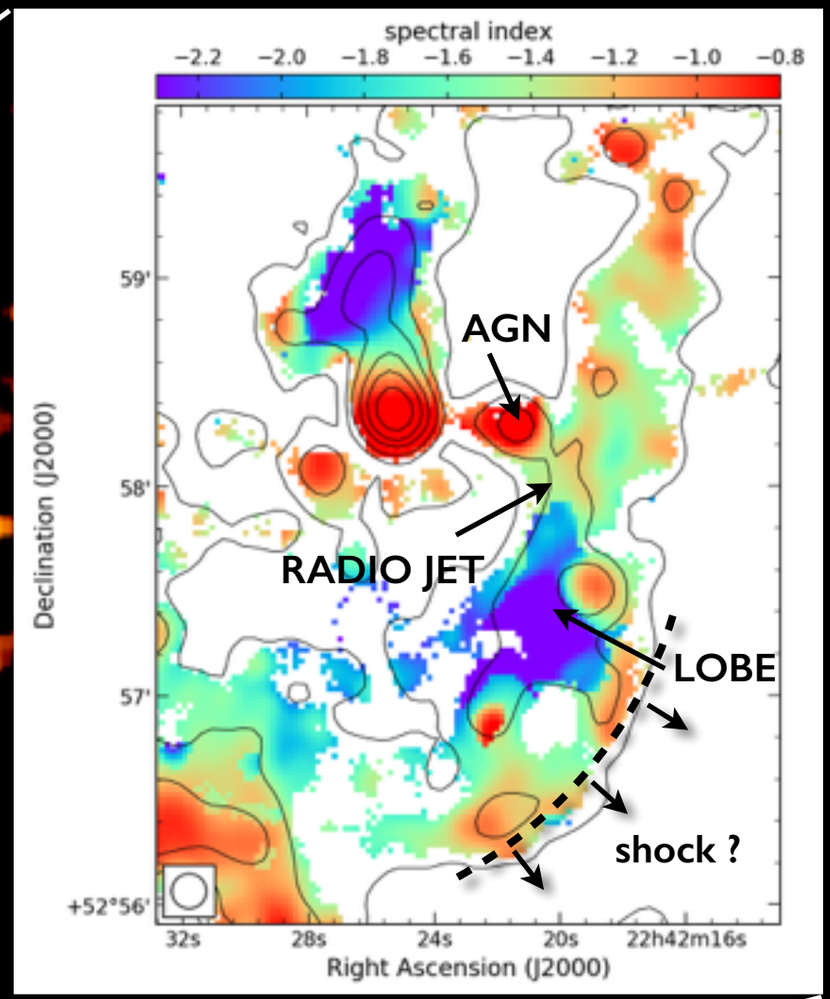

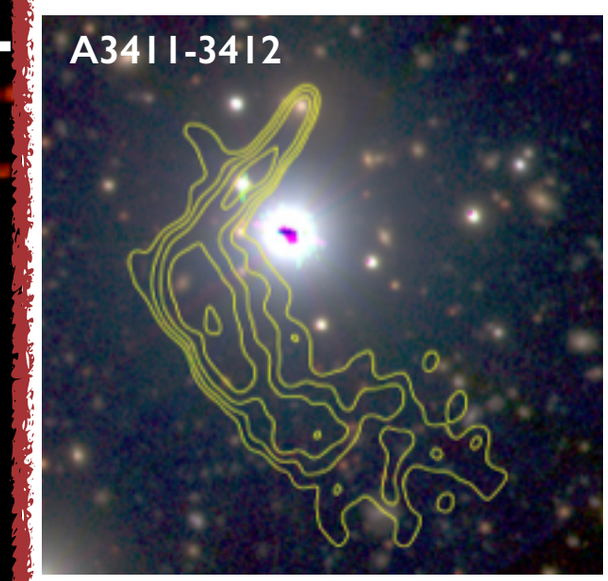

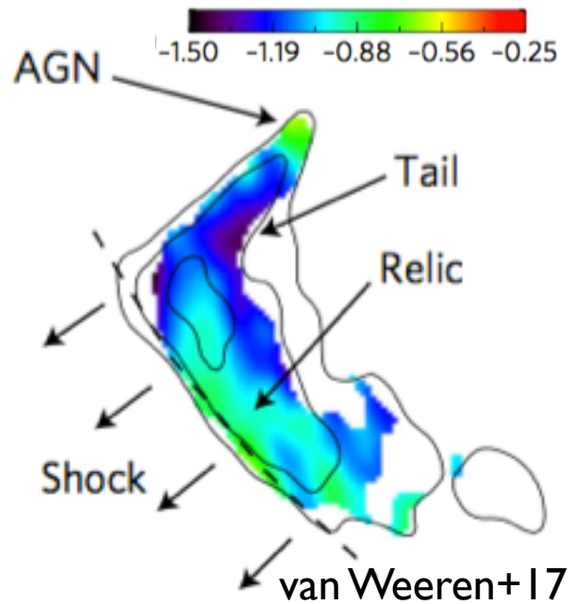

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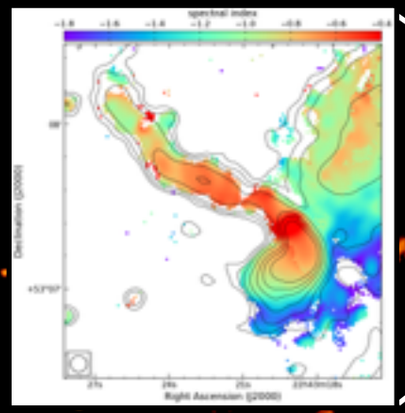
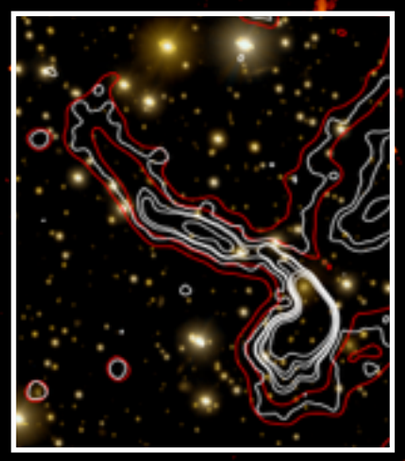
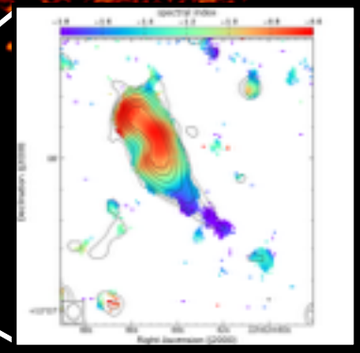
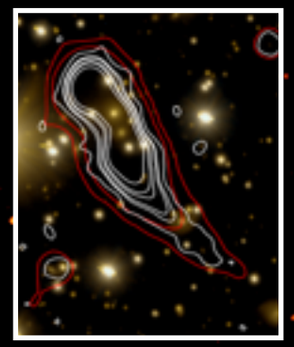
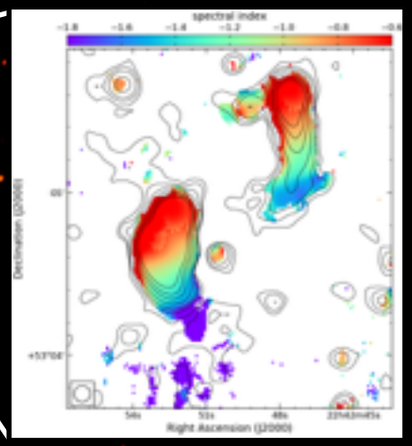
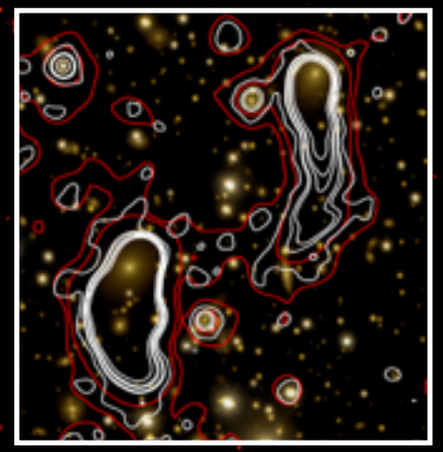


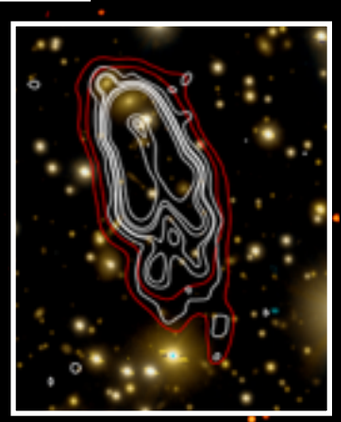


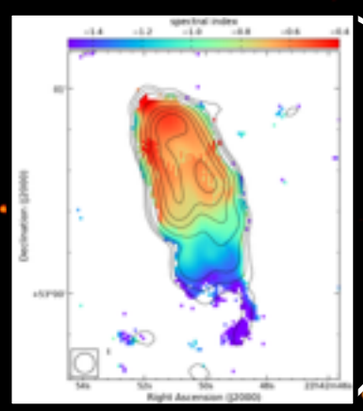


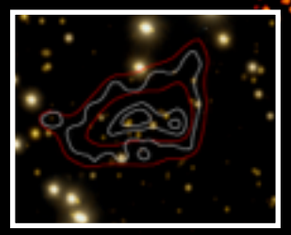


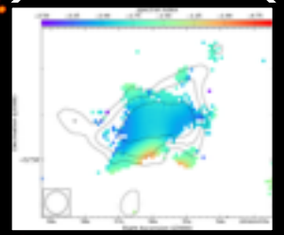


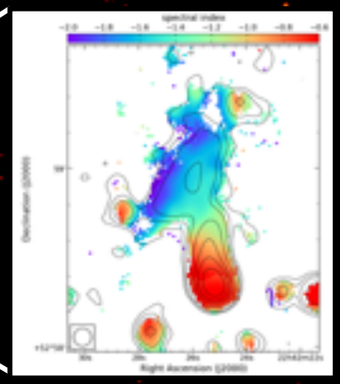


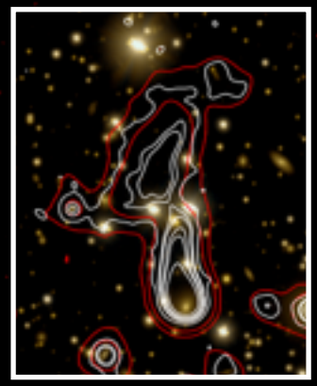












SUMMARY

- Ultra-deep JVLA images of CIZA J2242.8+5301 in combination with ultra-deep LOFAR (Hoang+17) and GMRT (van Weeren+10) observations

  ➡ Spectral curvature at cluster shock >> spectral aging in the downstream region **and at shock front**

  ❗ radio maps might not catch properly the shock front

  ➡ Possible connection between a radio tail and the southern relic >> hints for re-acceleration mechanism

  ❗ waiting for better X-ray observations…

  ➡ Tailed radio galaxies can be important for the cluster diffuse synchrotron emission

  ➡ Halos ?

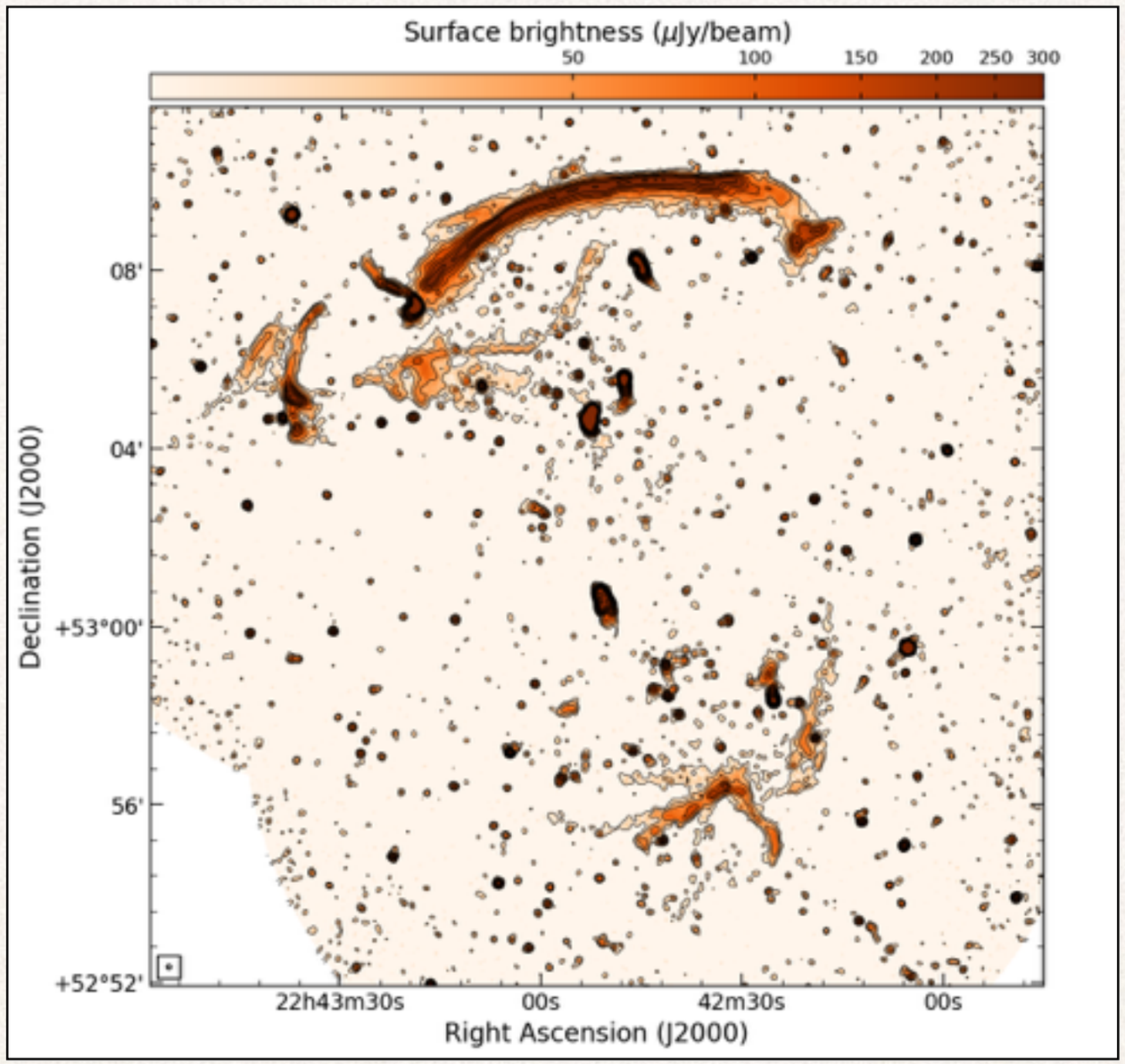
Thank you

BACKUP SLIDES

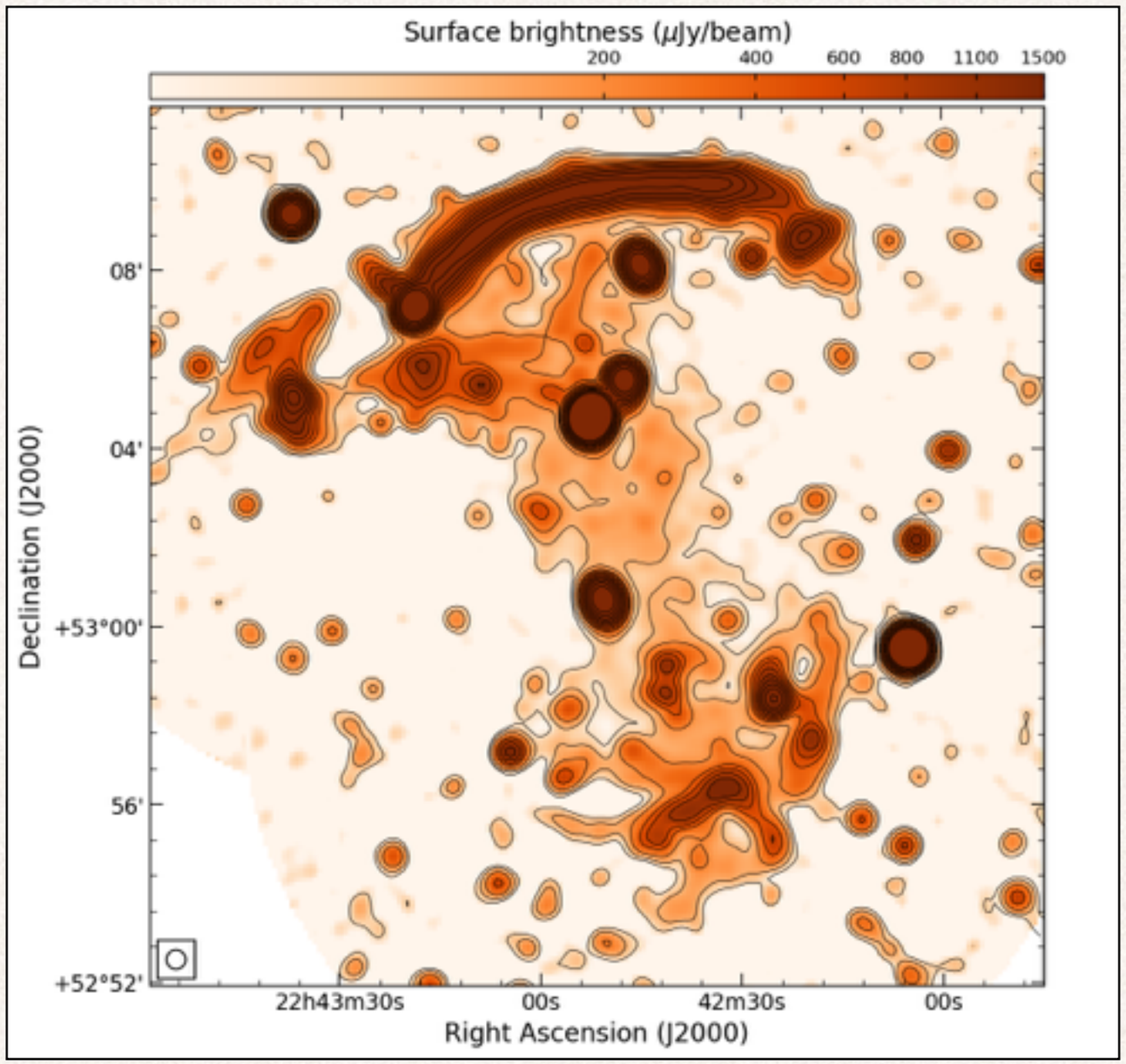
CIZA J2242.8+5301

(a.k.a "Sausage")

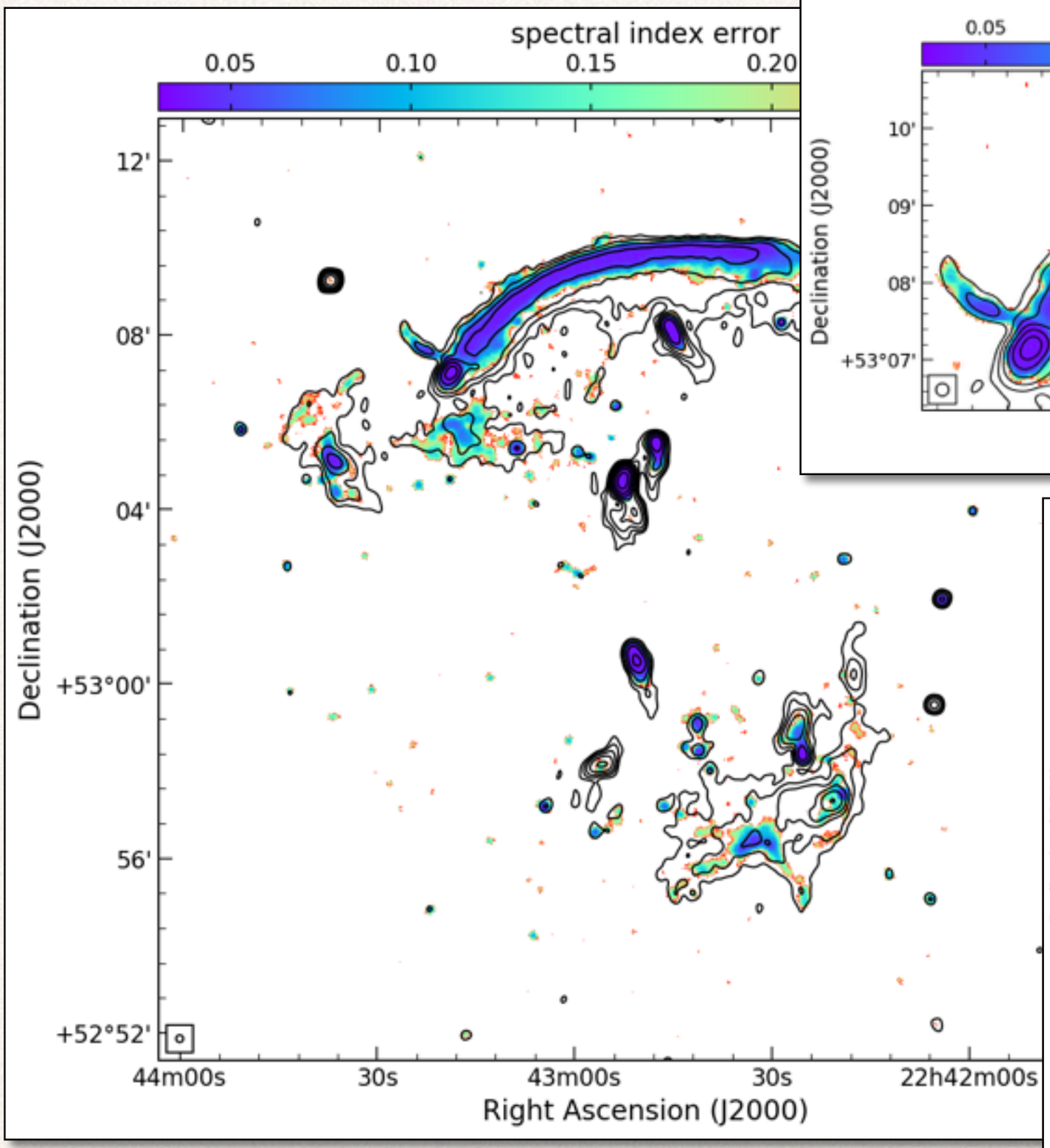
5" resolution

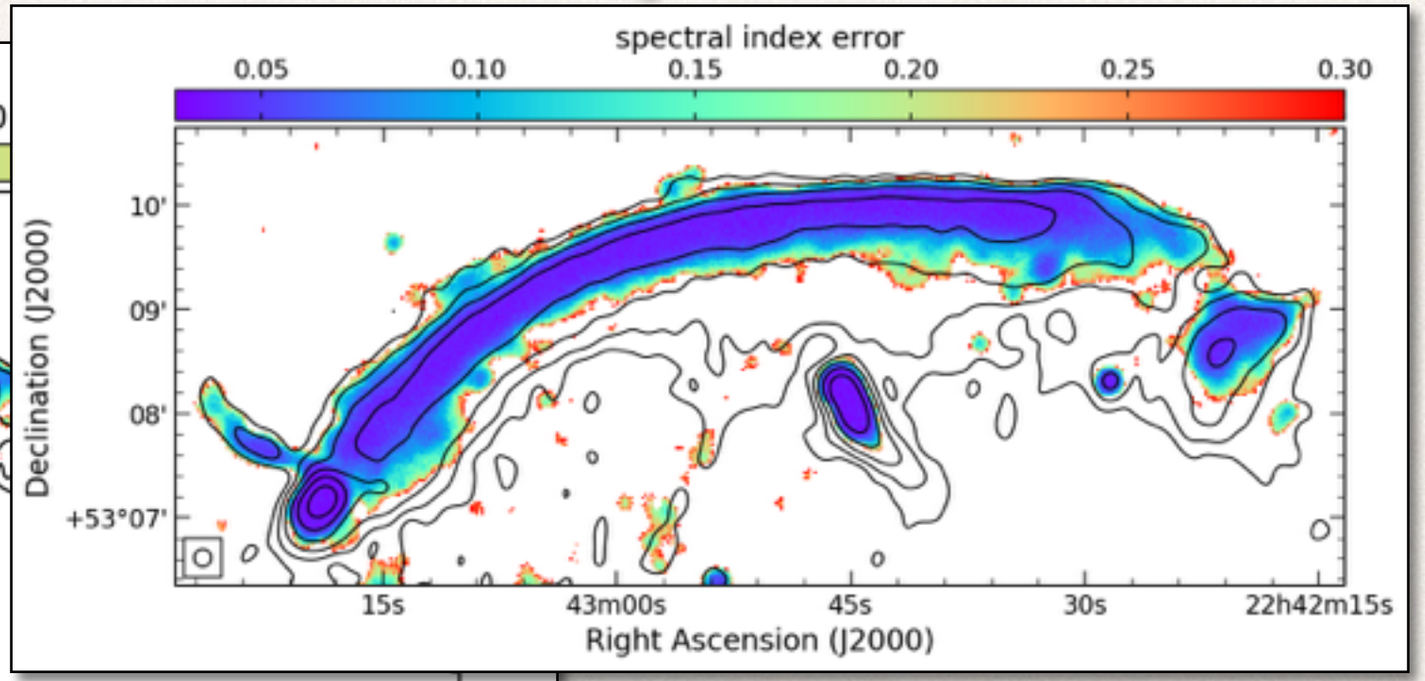


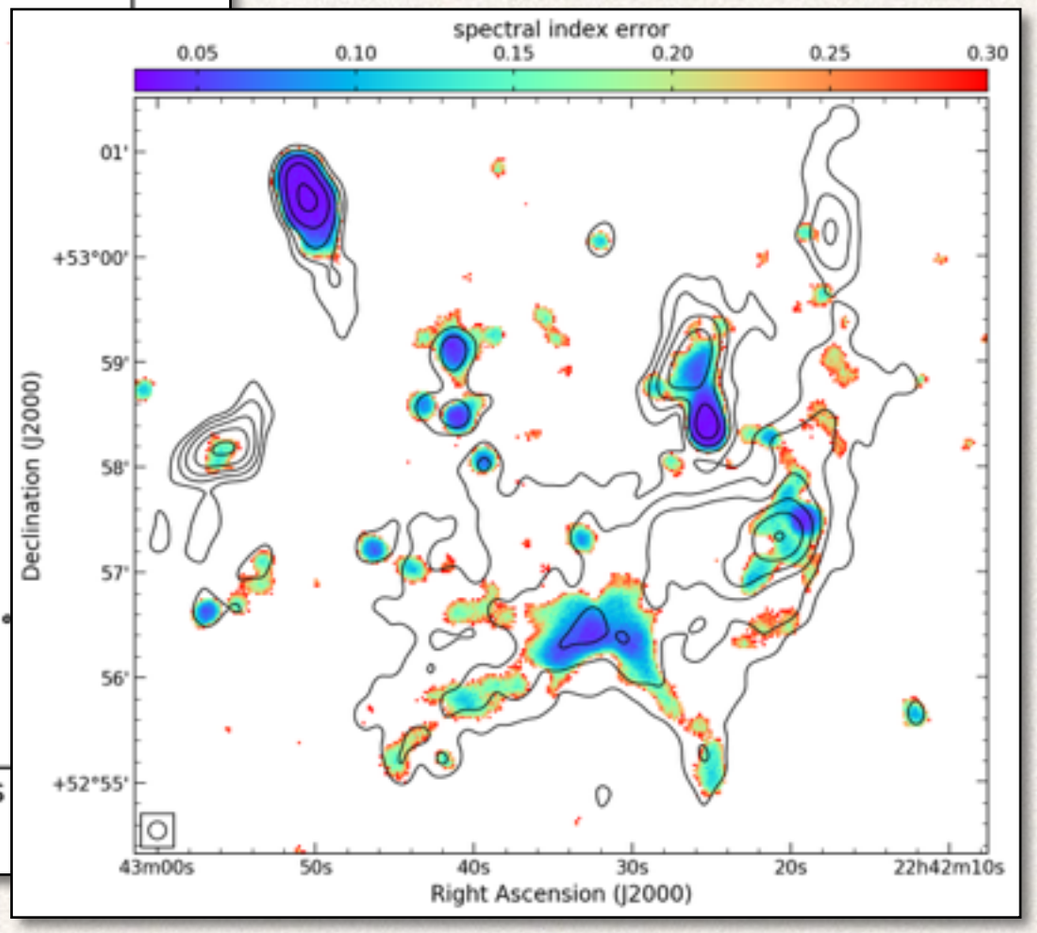
25" resolution



Spectral Index analysis

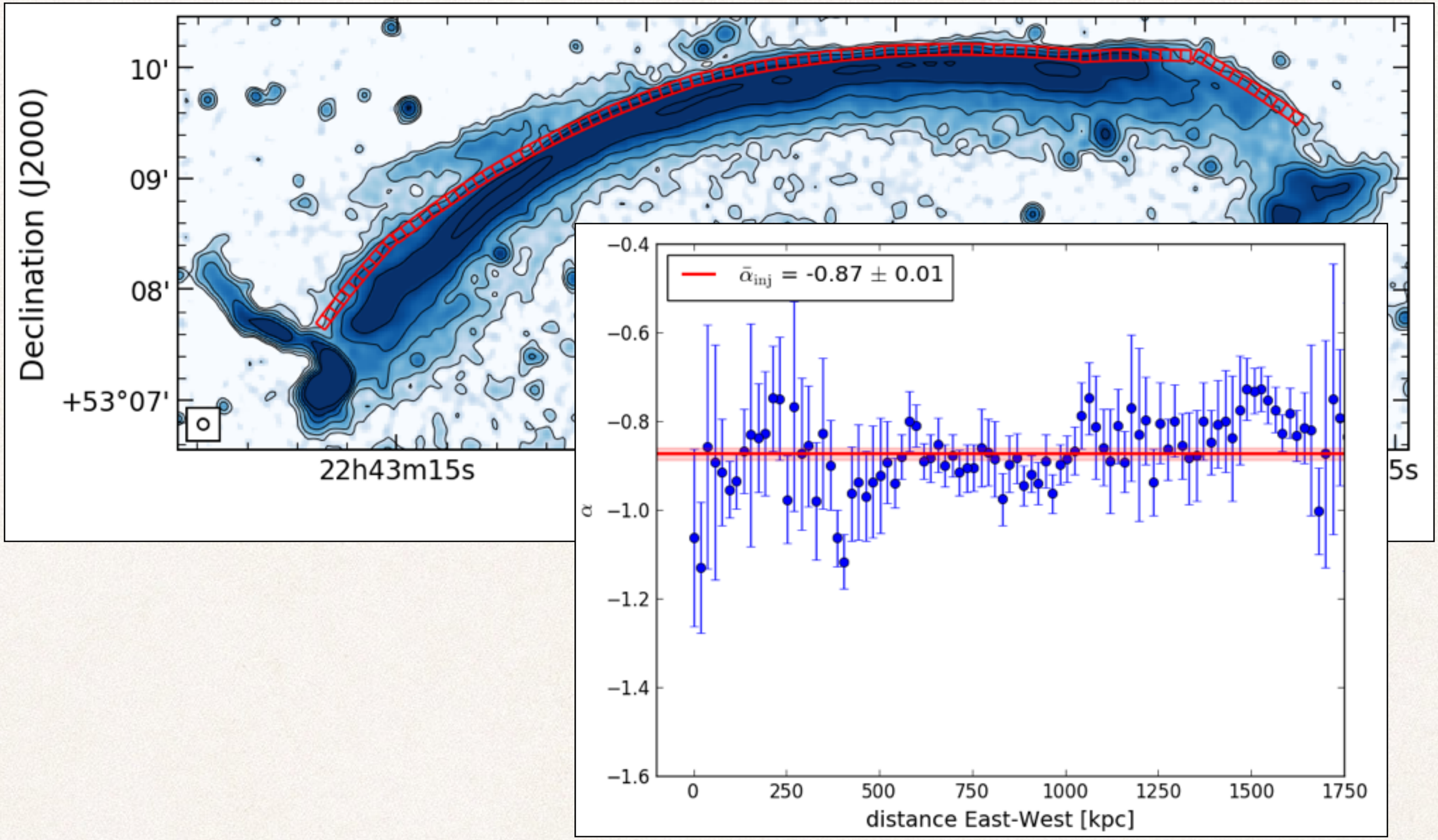






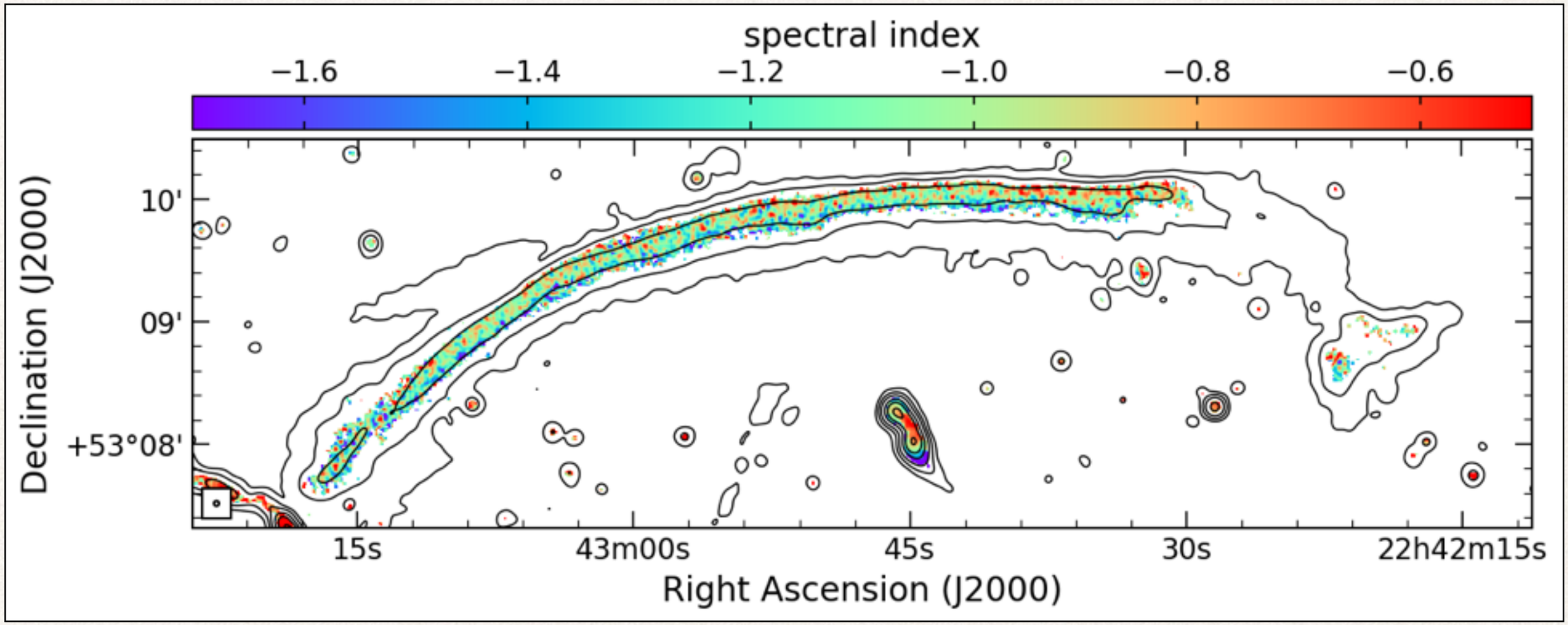
Spectral Index analysis

NORTHERN RELIC



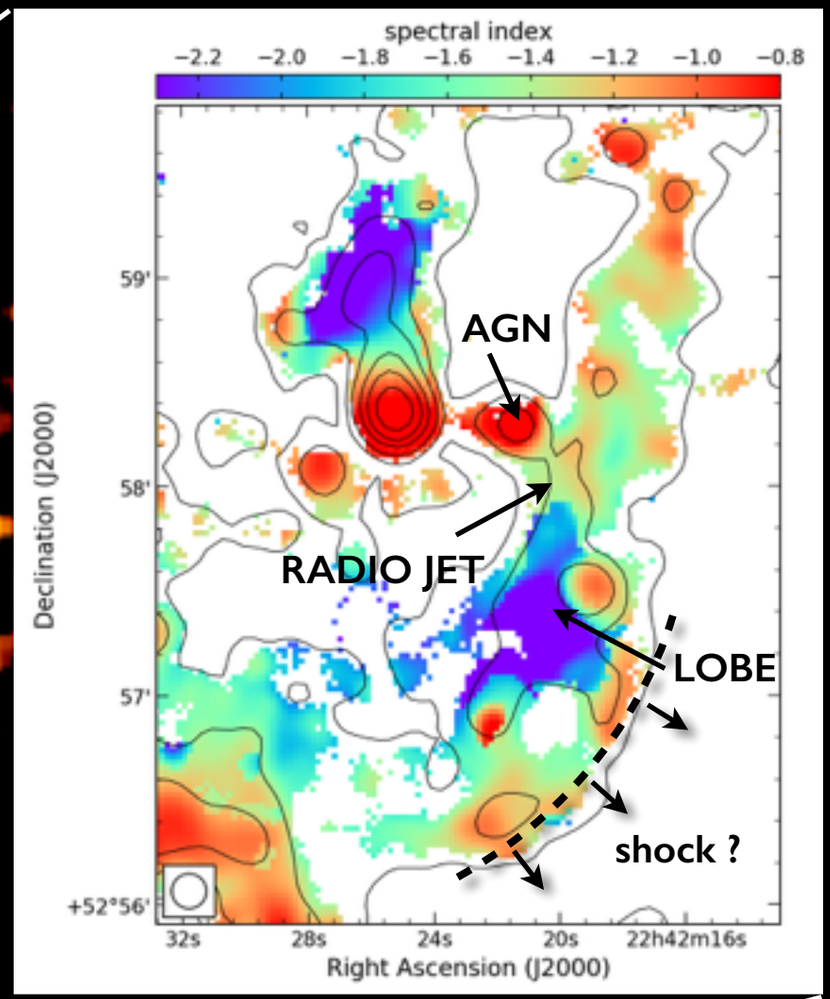
Spectral Index analysis

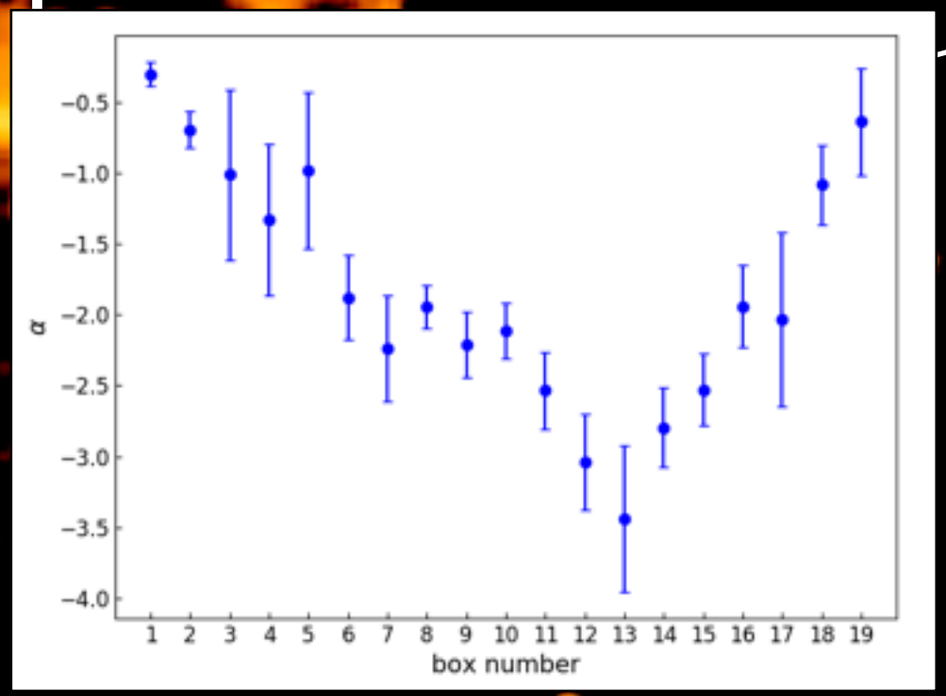
NORTHERN RELIC

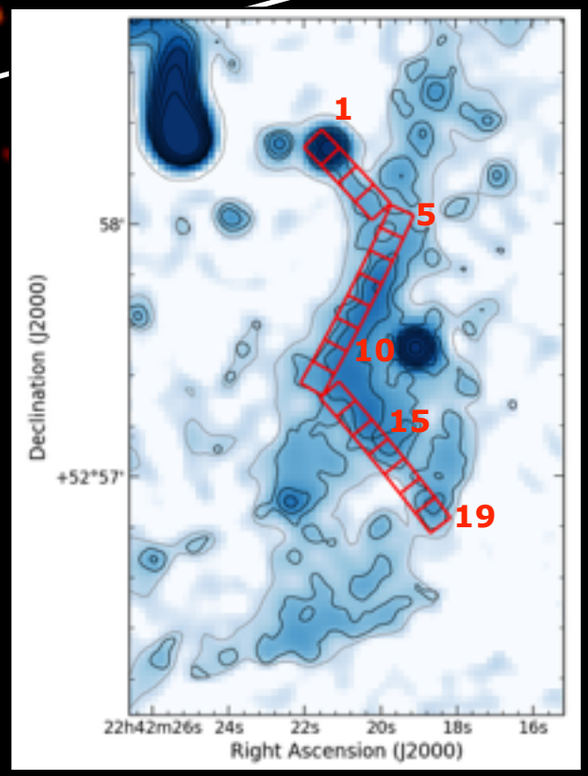


Contours: JVLA 1-4 GHz (2.5” res)

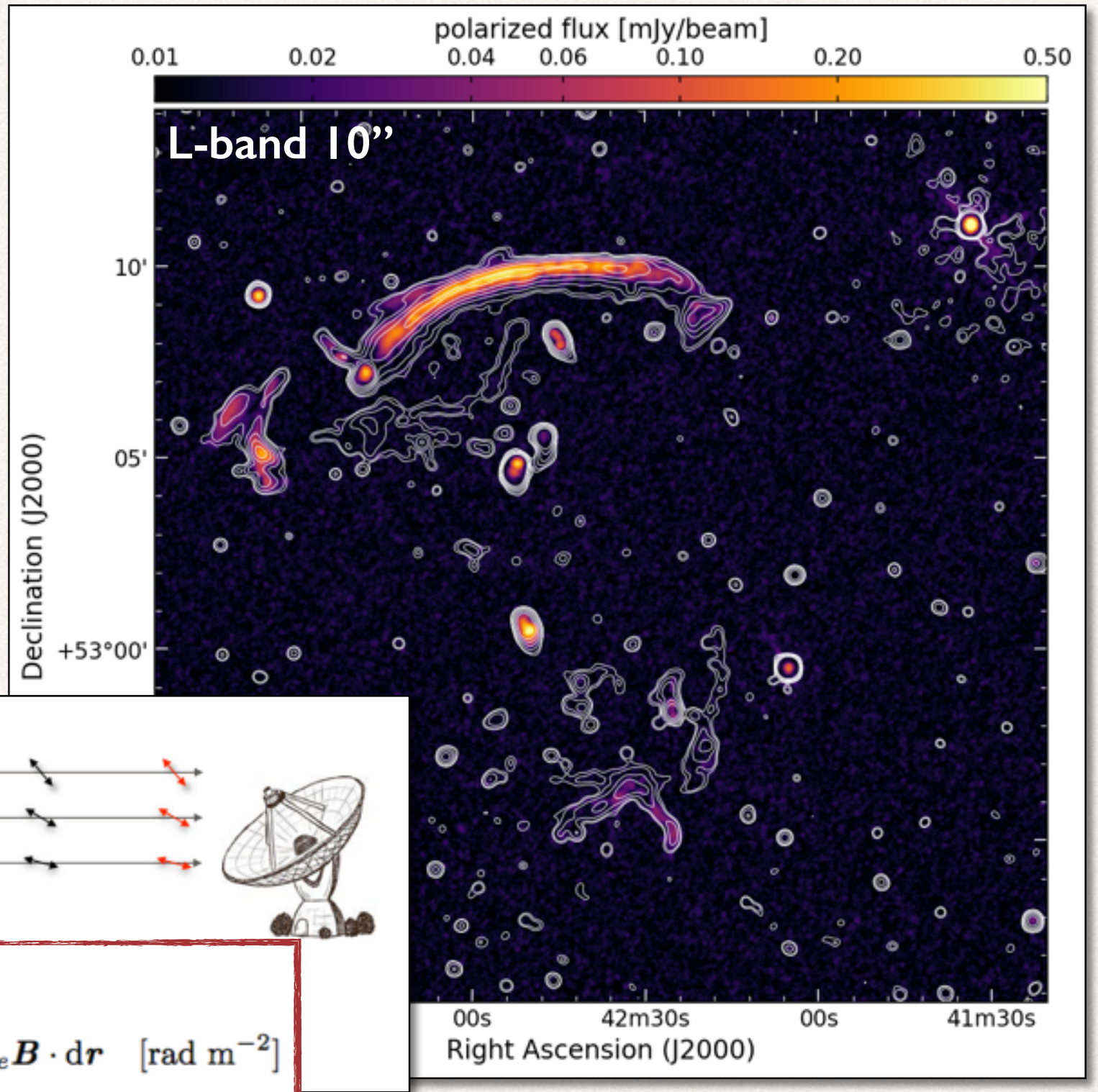
JVLA 1-4 GHz low res (6")



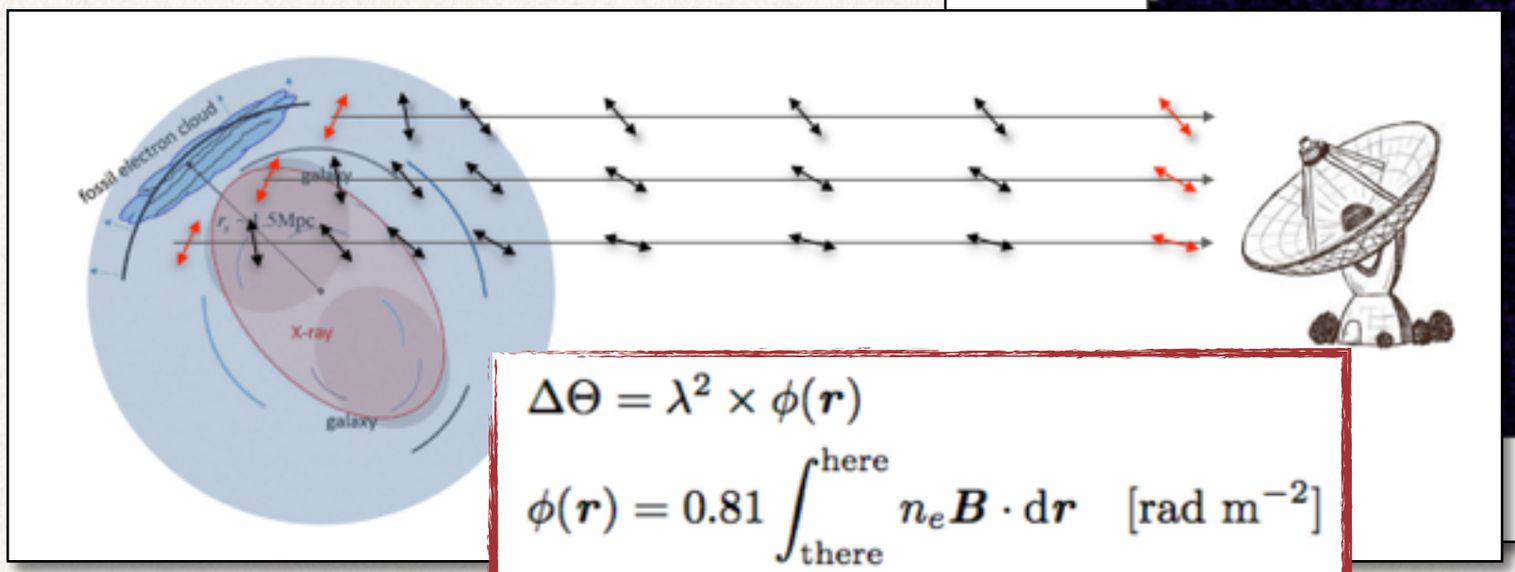




Polarization



FARADAY ROTATION



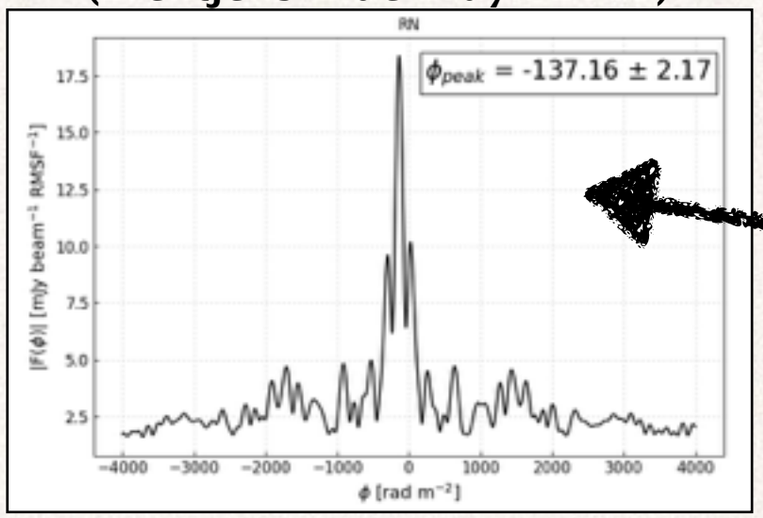
$$\Delta\Theta = \lambda^2 \times \phi(\boldsymbol{r})$$

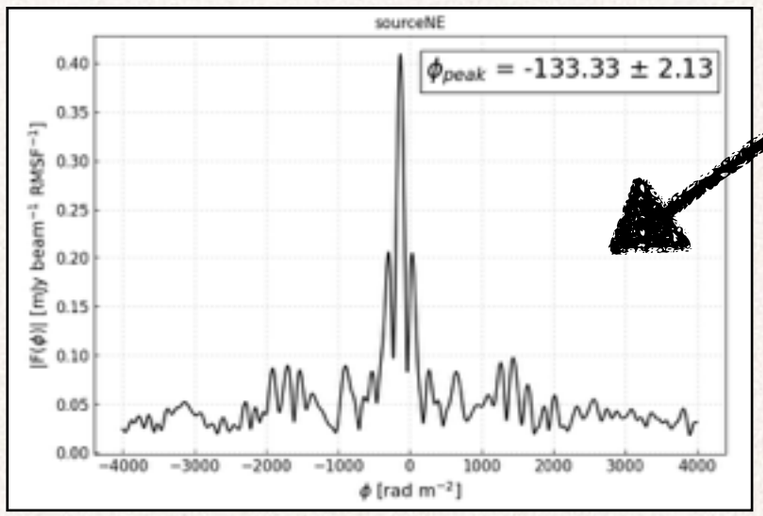
$$\phi(\boldsymbol{r}) = 0.81 \int_{\text{there}}^{\text{here}} n_e \boldsymbol{B} \cdot \mathrm{d}\boldsymbol{r} \quad [\text{rad m}^{-2}]$$

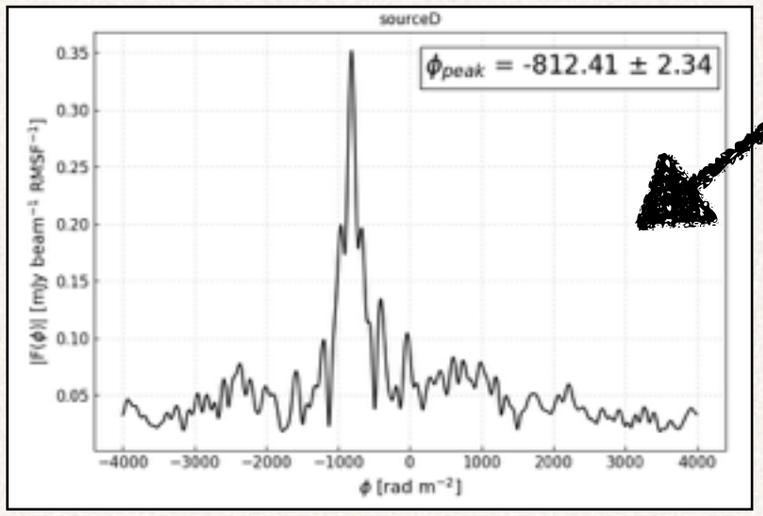
Contours: JVLA 1.5 GHz (10”)

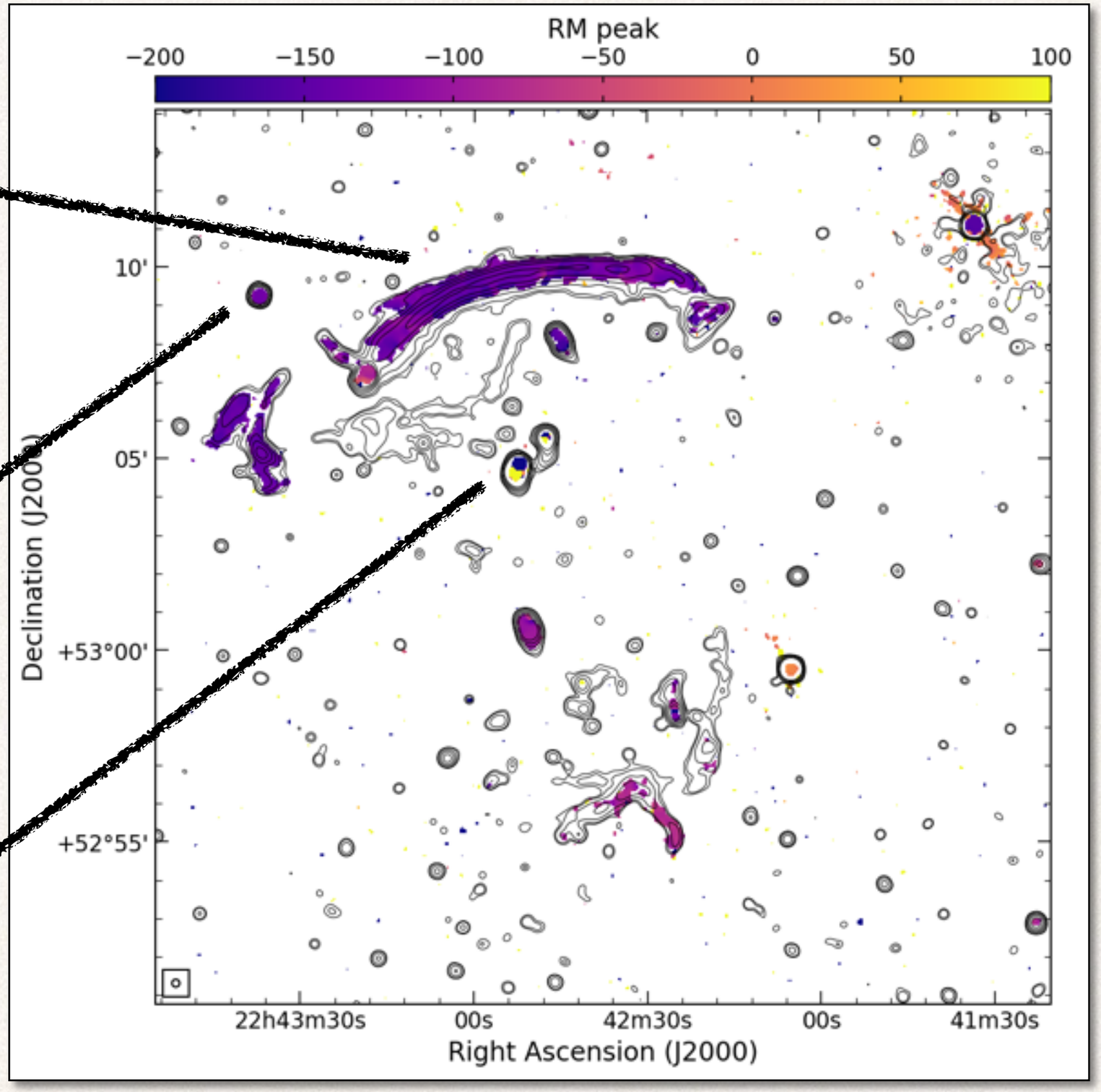
Polarization

RM-Synthesis
(Brentjens & de Bruyn 2005)





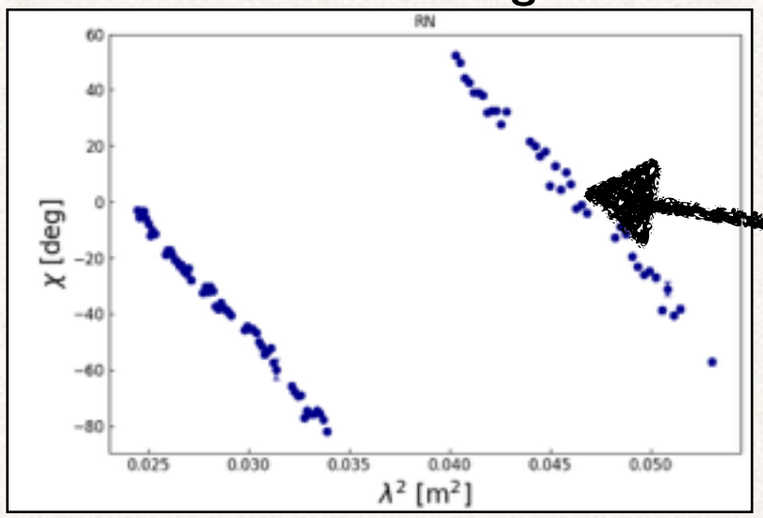


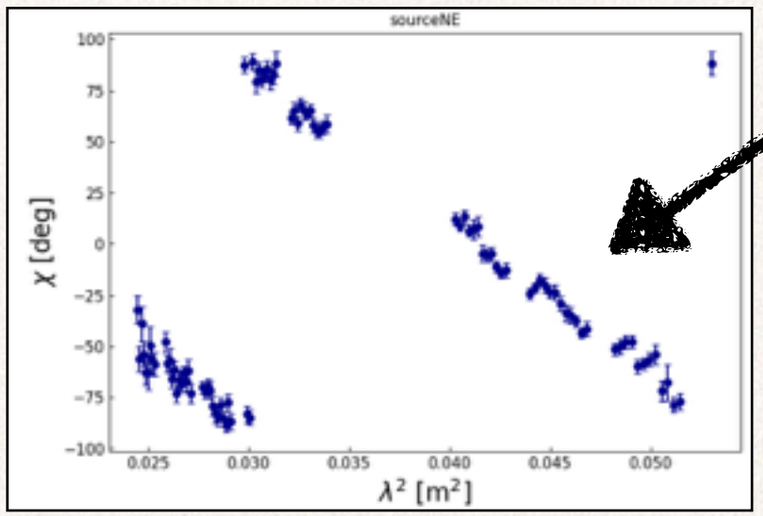


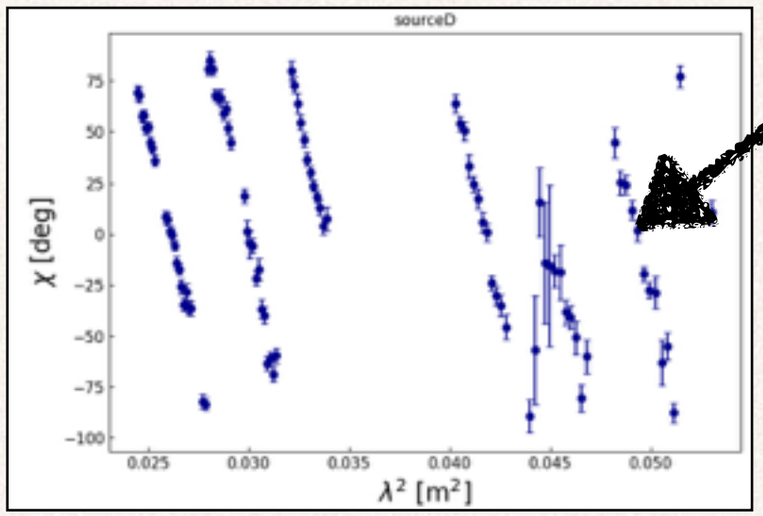
Contours: JVLA 1.5 GHz (10")

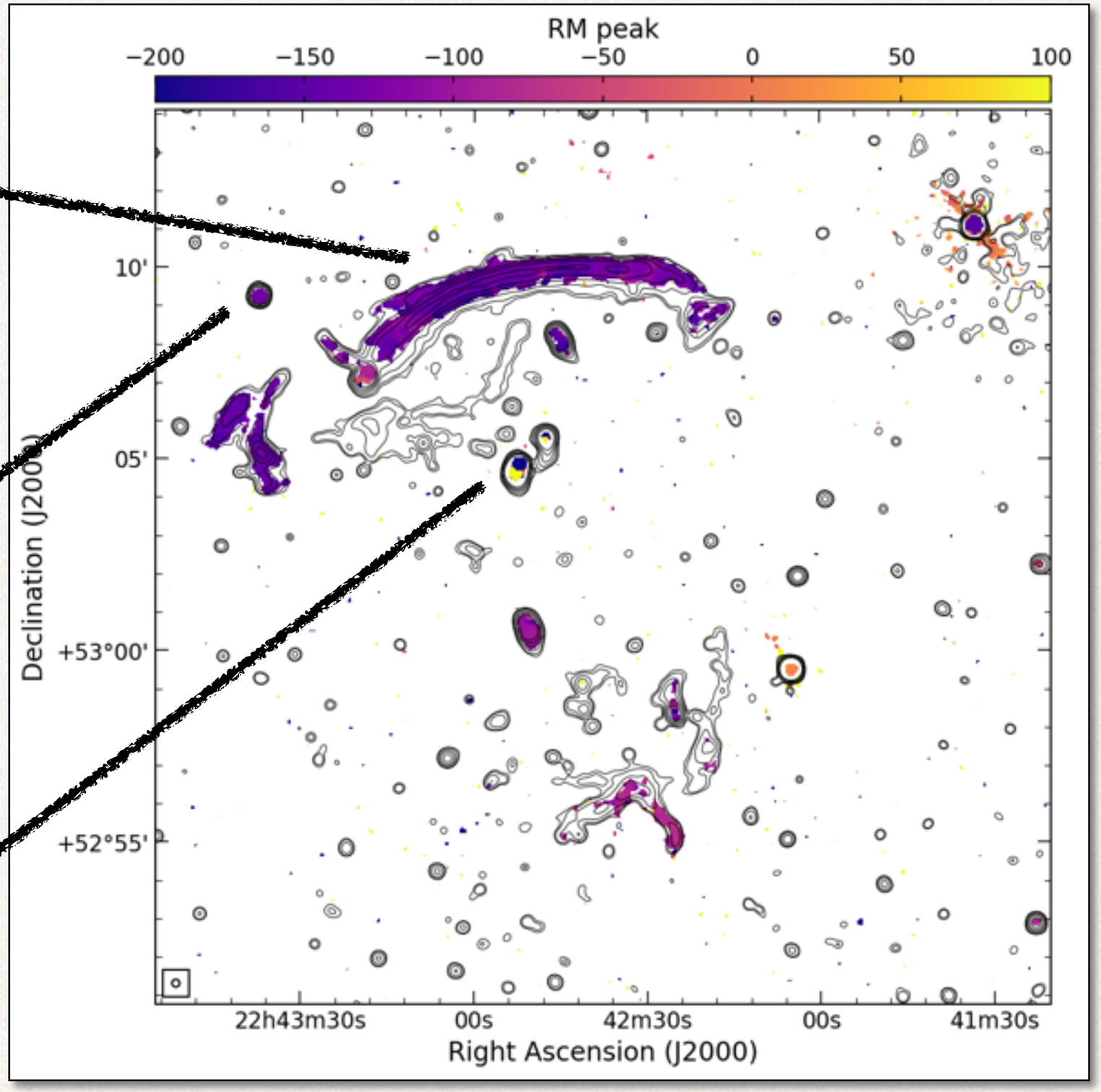
Polarization

Polarization angle





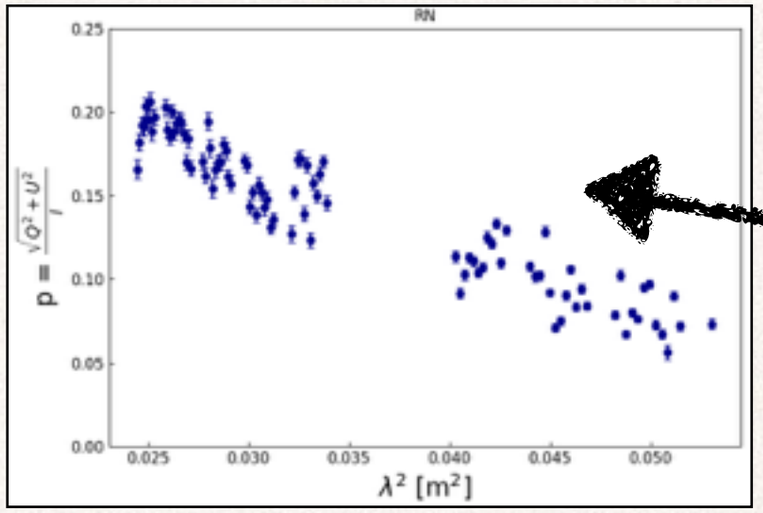


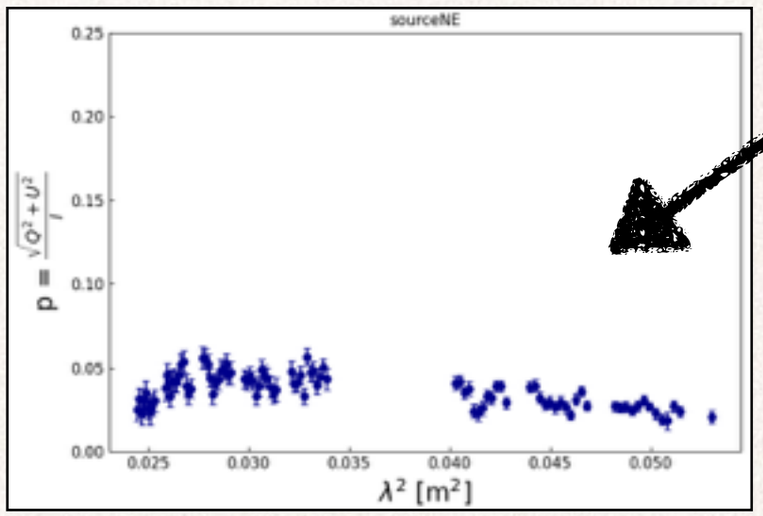


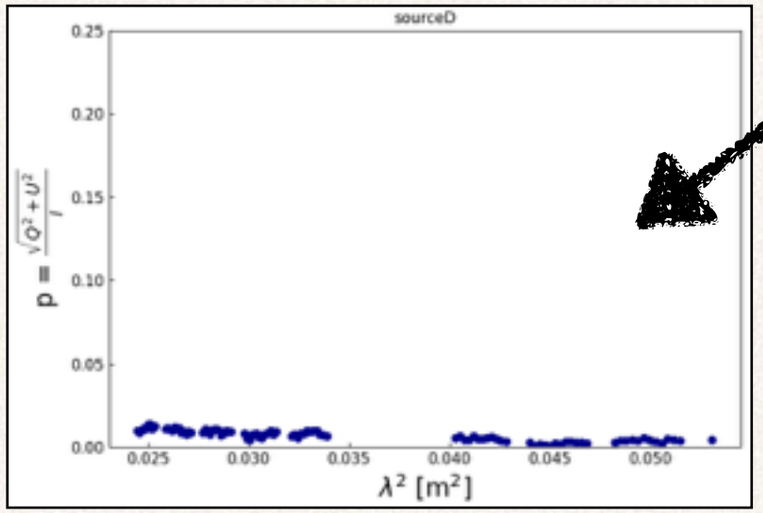
Contours: JVLA 1.5 GHz (10")

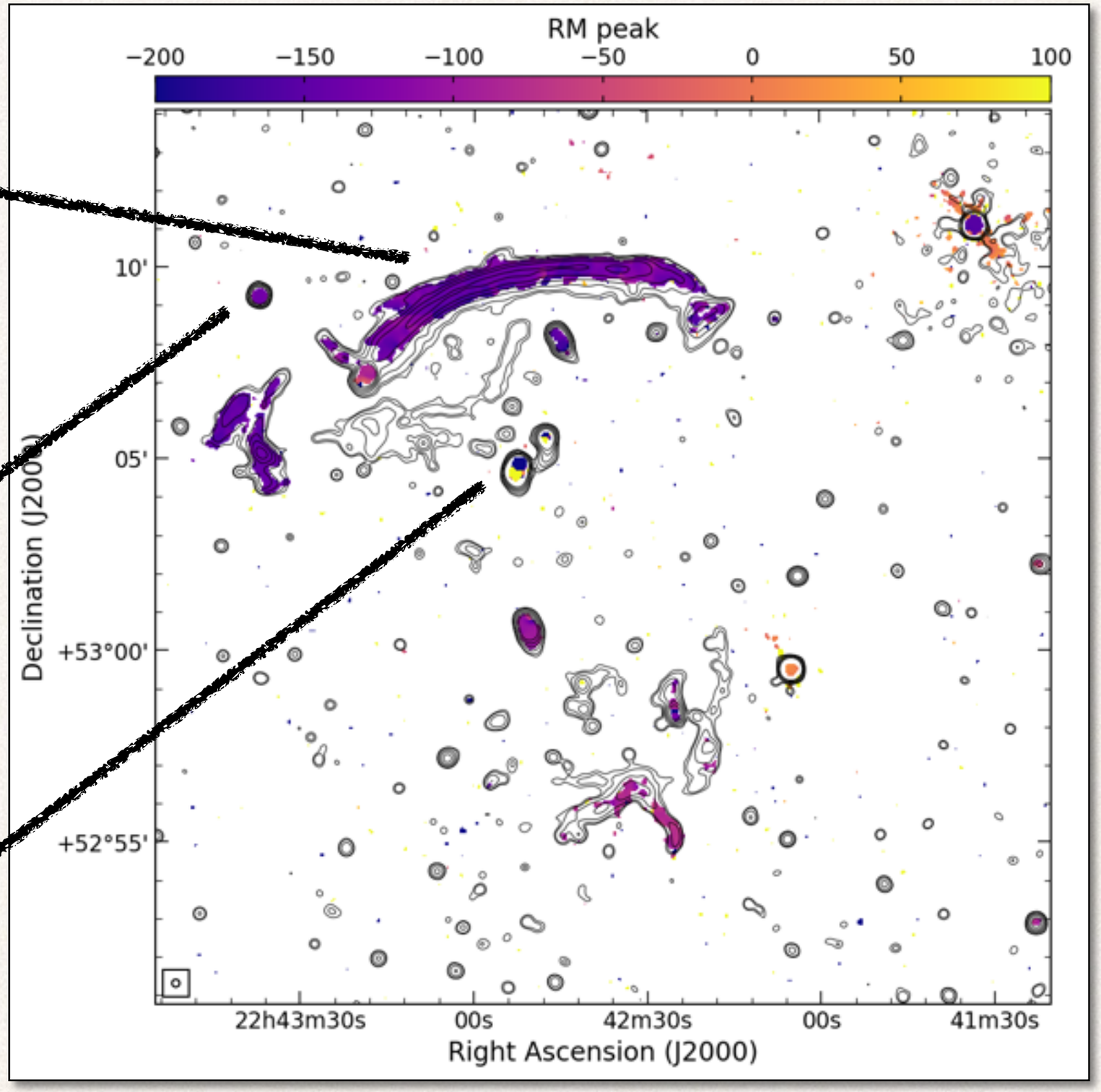
Polarization

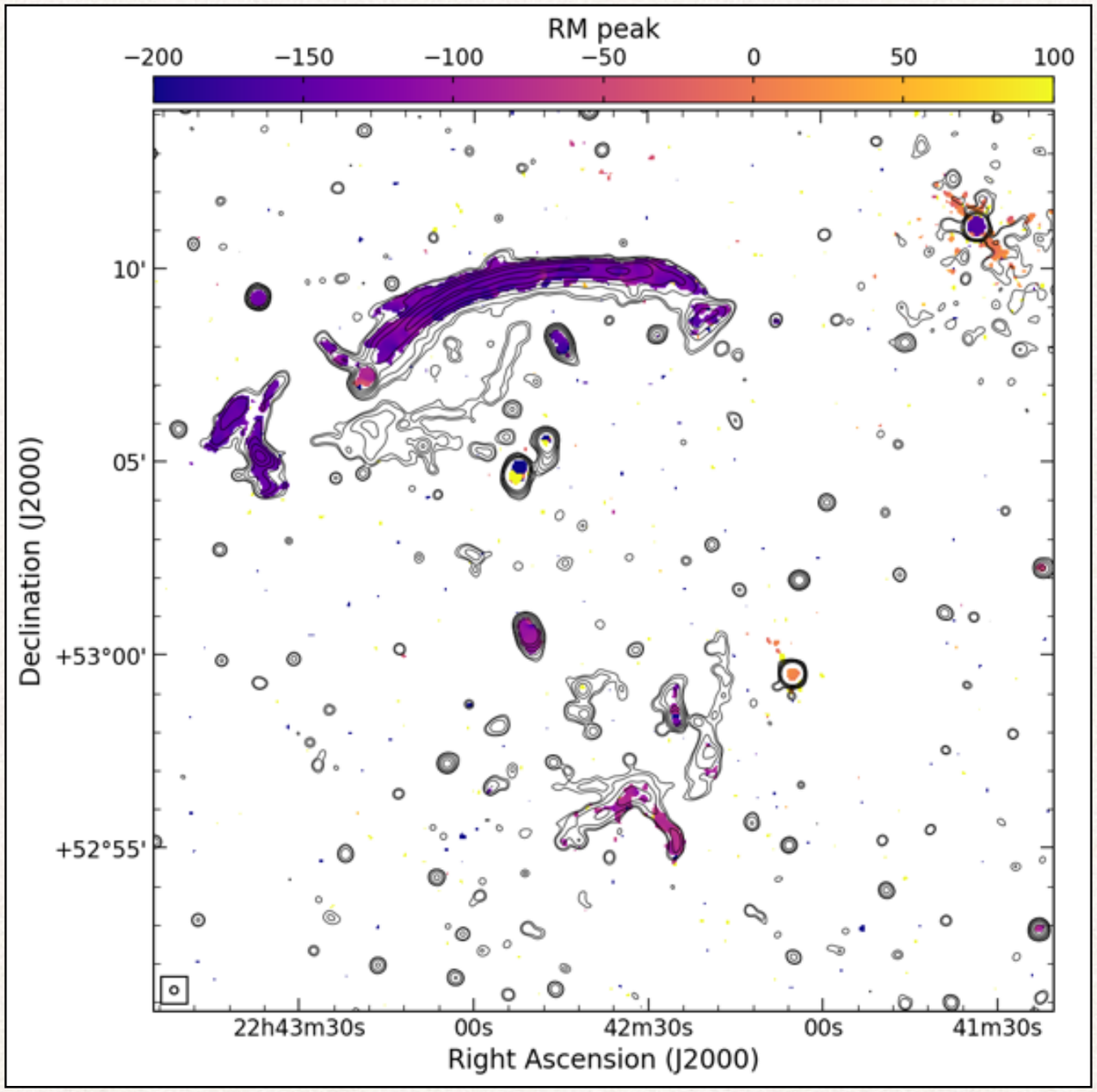
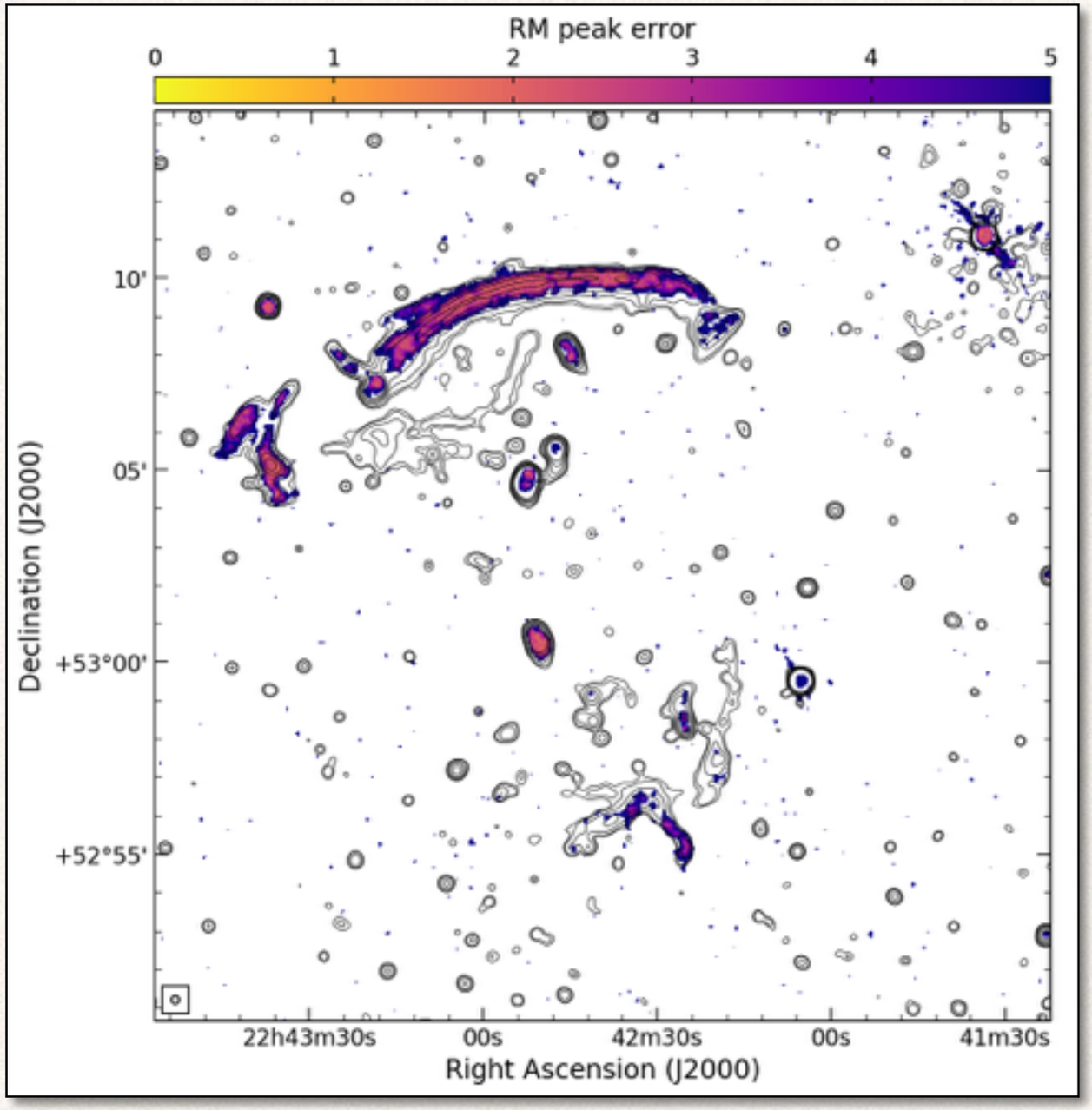
Polarization fraction









Contours: JVLA 1.5 GHz (10")

Polarization