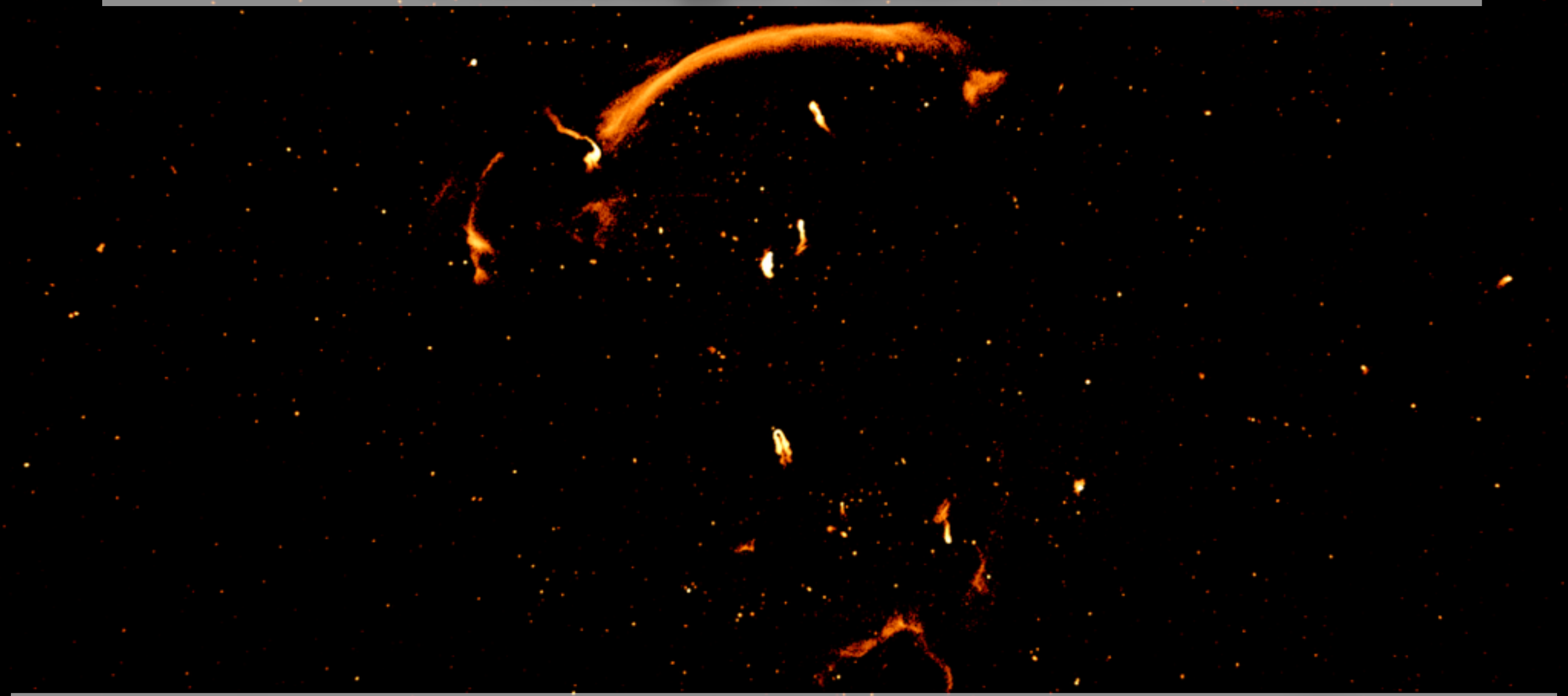
# Deep in the (un)known: the Sausage Cluster

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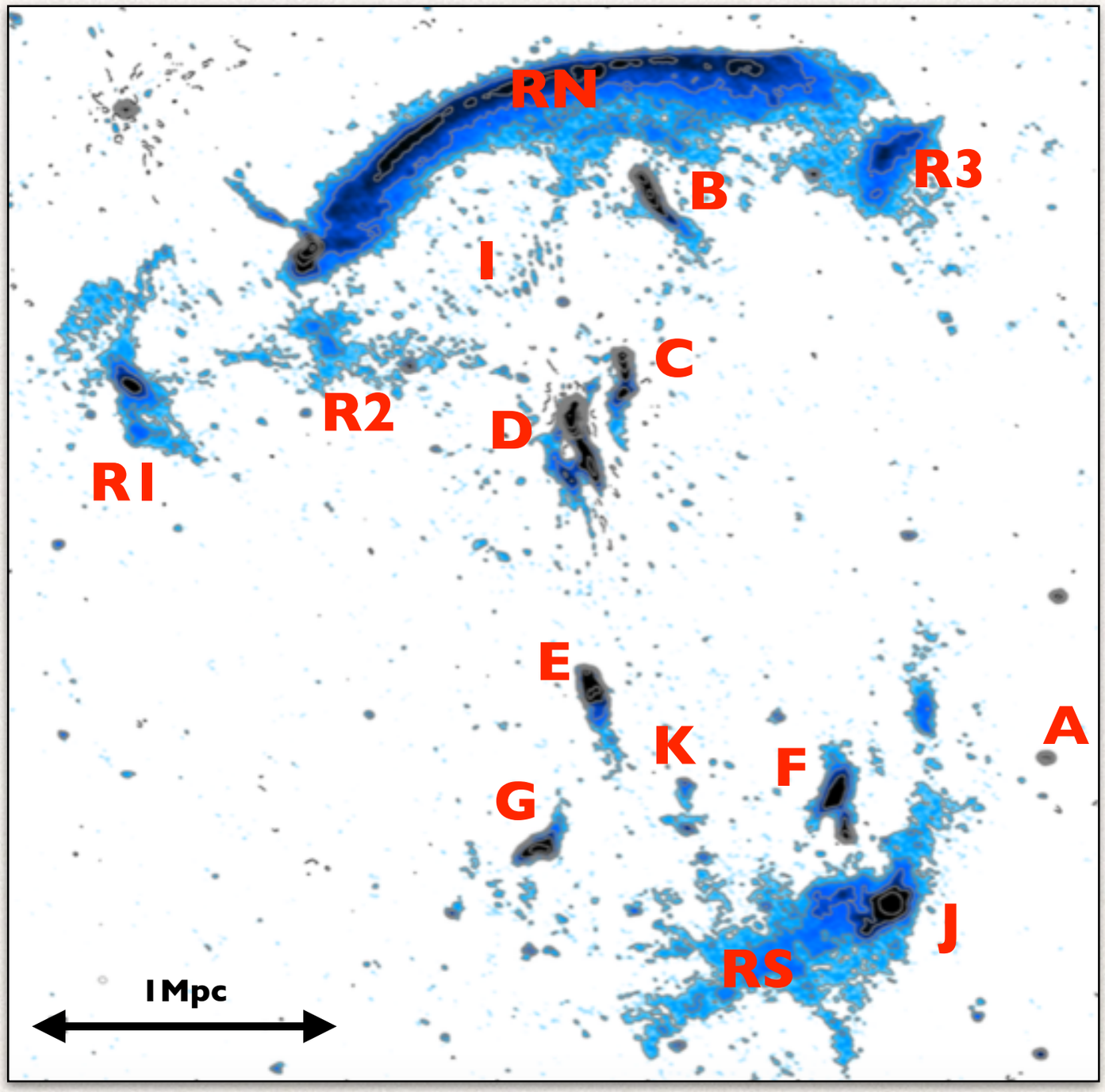
Collaborators: Reinout van Weeren, Huub Röttgering, Duy Hoang, Tim Shimwell, William Forman, Christine Jones



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

# CIZA J2242.8+5301

(a.k.a "Sausage")




LOFAR 145MHz, Hoang+ submit.

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

## HOANG+ SUBMITTED:

- ☑ noise up to 140 $\mu$Jy/beam (full resolution)
- ☑ $\mathcal{M}_{RN} \approx 2.7$, $\mathcal{M}_{RI} \approx 2.5$ (in according to X-ray obs.)
- ☑ $\alpha_{halo} \approx -1.06$

# CIZA J2242.8+5301

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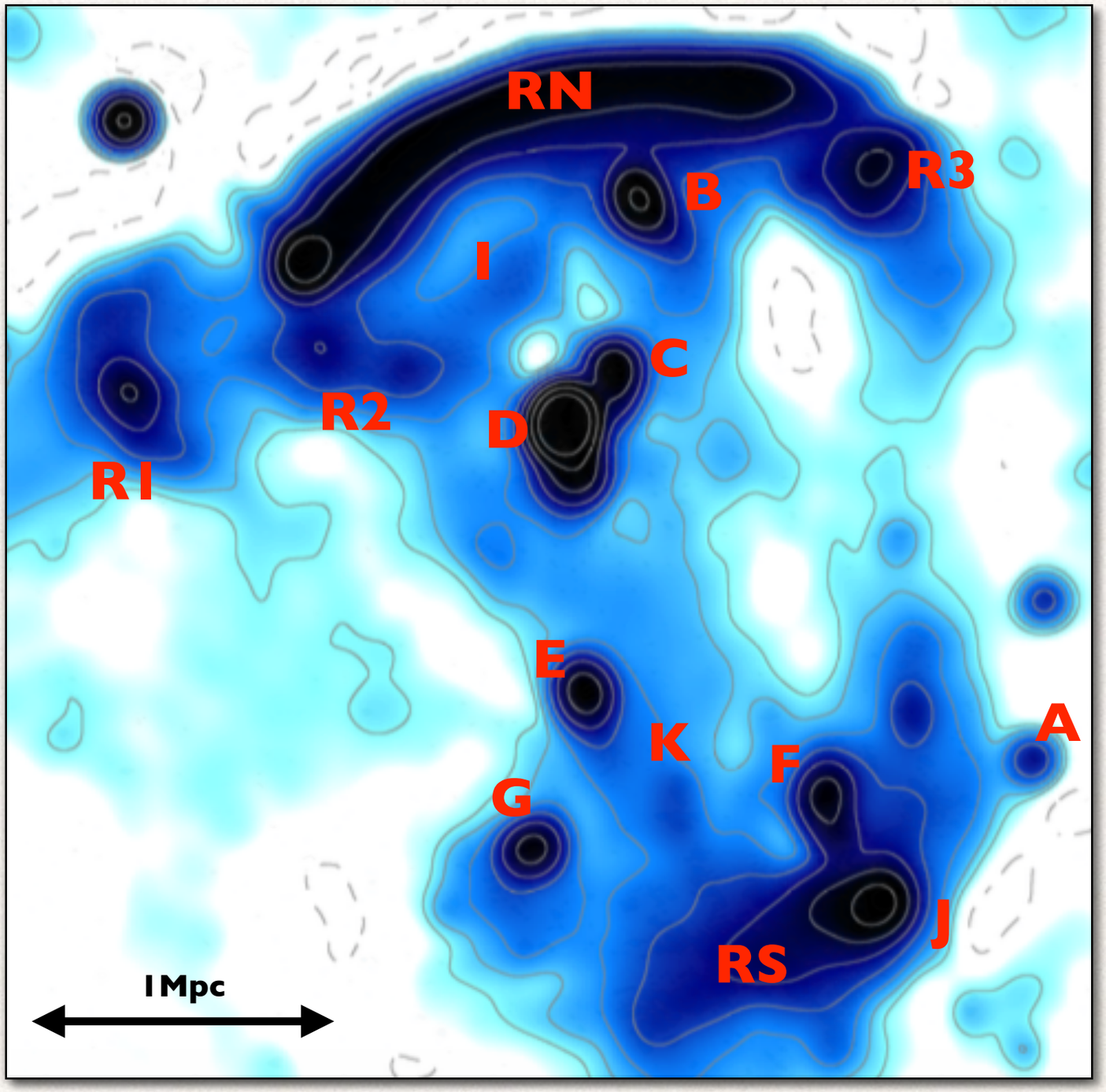


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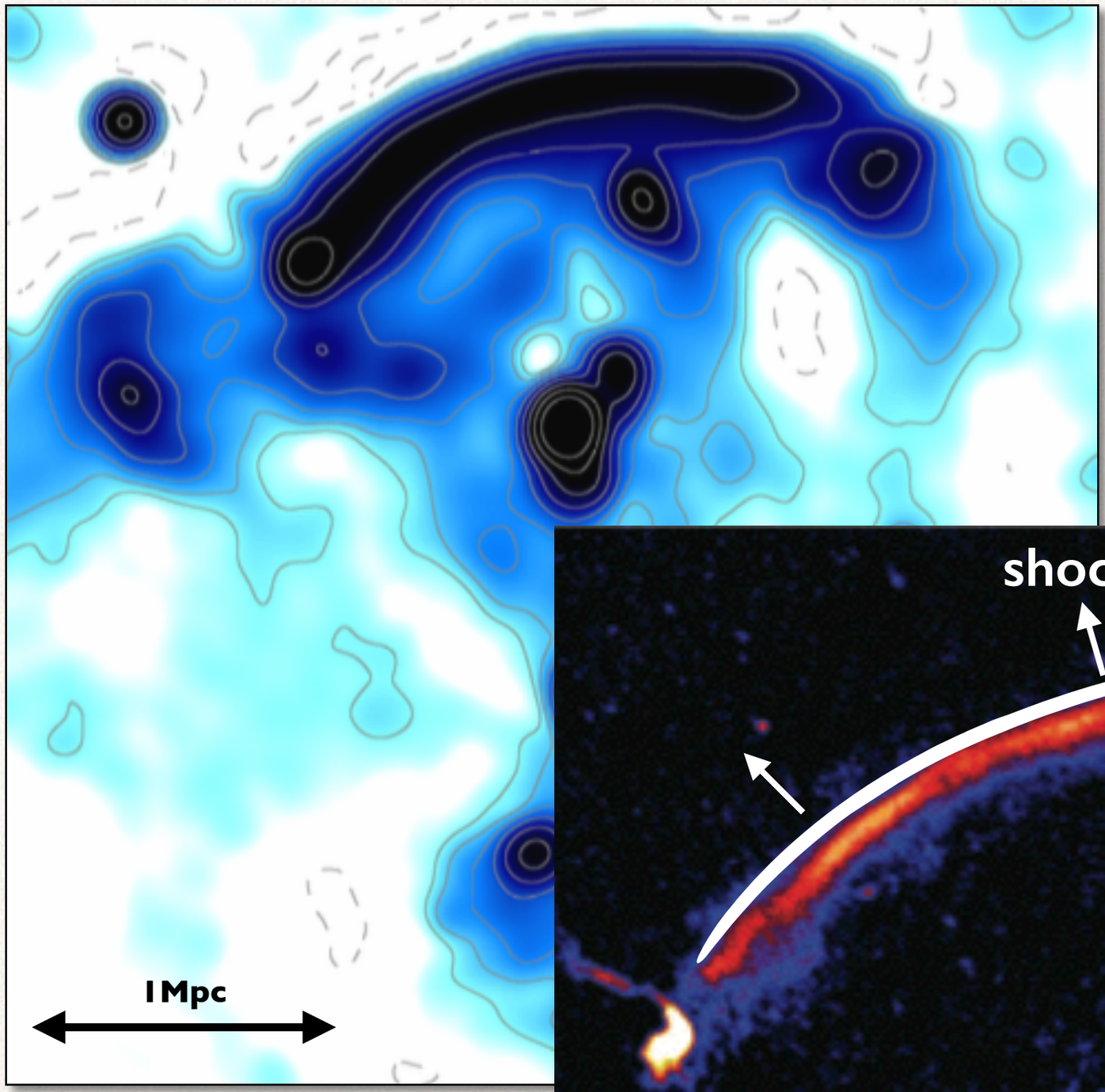
# LOFAR: CIZA J2242.8+5301

**(a.k.a "Sausage")**

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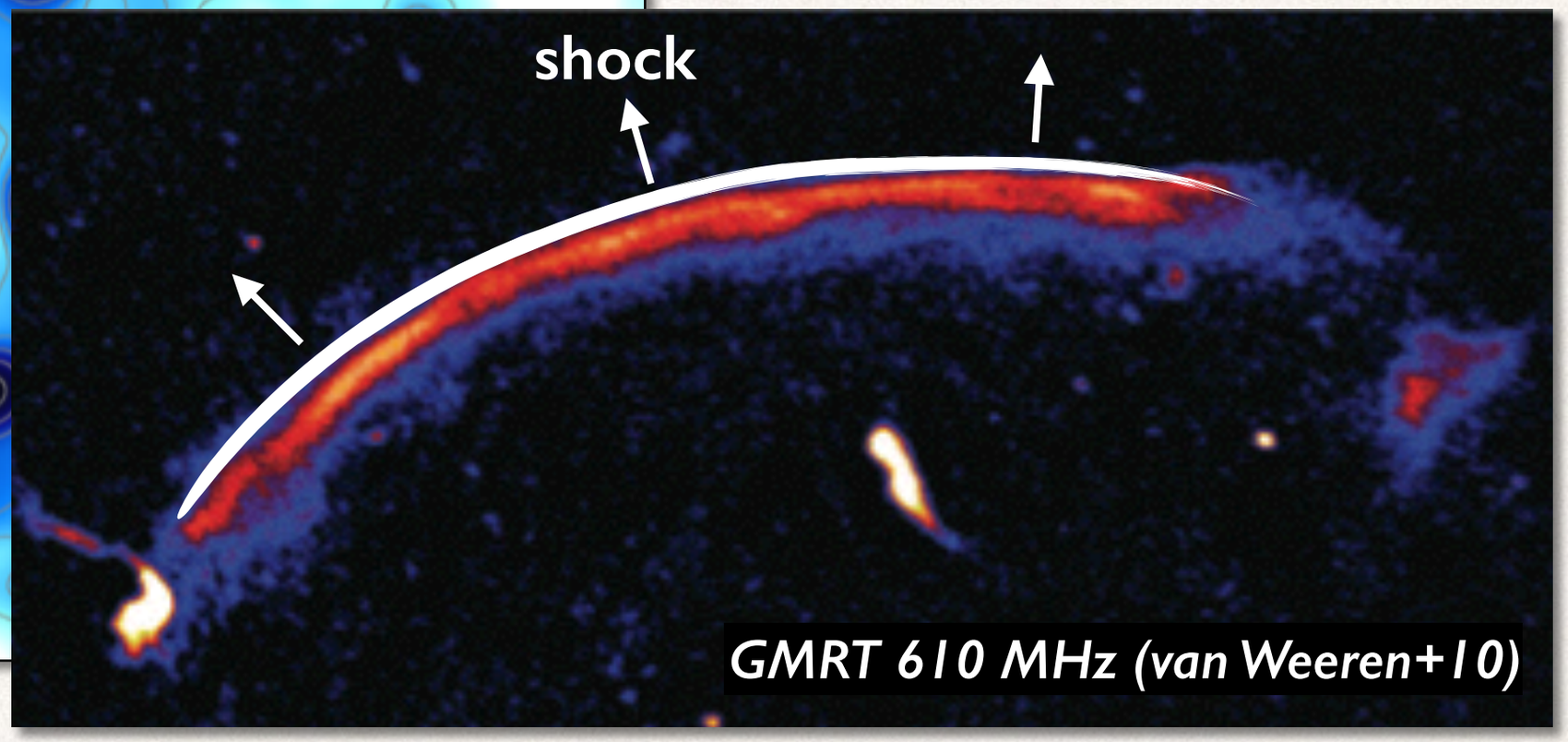
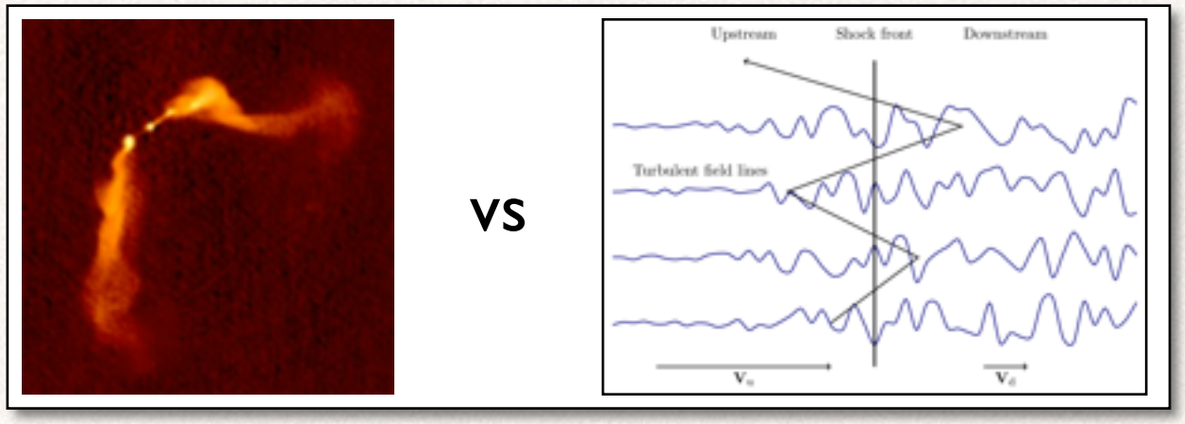
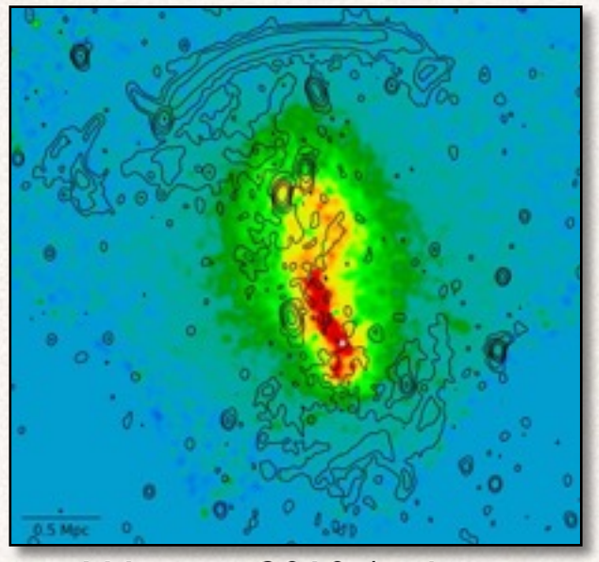


# OPEN QUESTIONS

- How are the particles (re-)accelerated ?

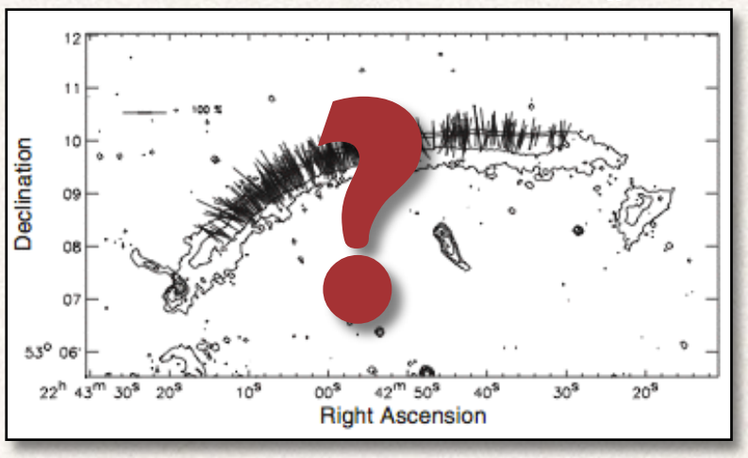



- What is the connection between the non-thermal plasma (radio) and the thermal hot gas (X-ray) ?



van Weeren+2010 (radio contours)
Ogrean+2014 (X-ray colors)

- What are the relic polarization characteristic at high resolution ?




van Weeren+2010

# OPEN QUESTIONS

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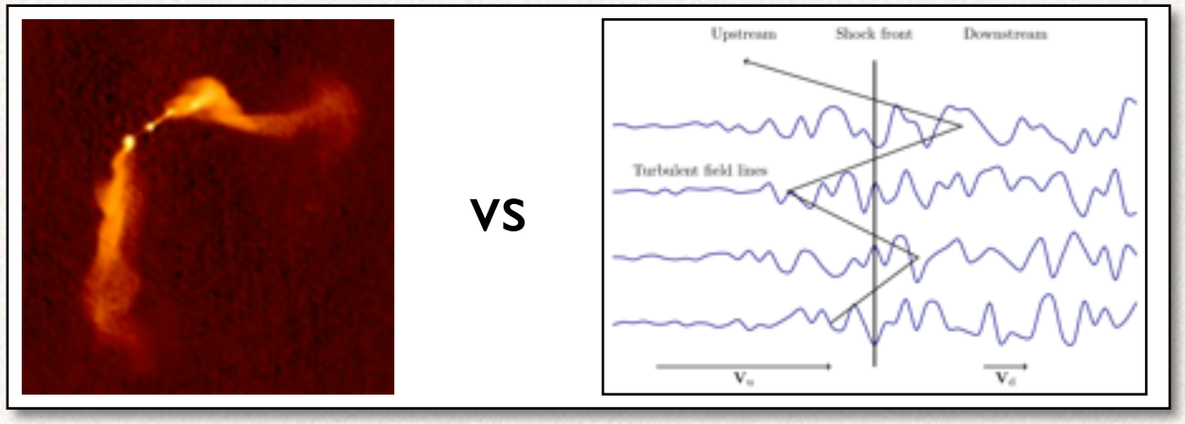


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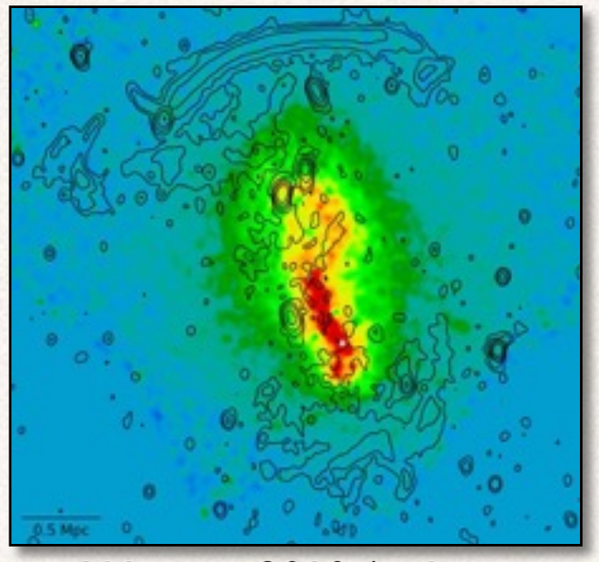

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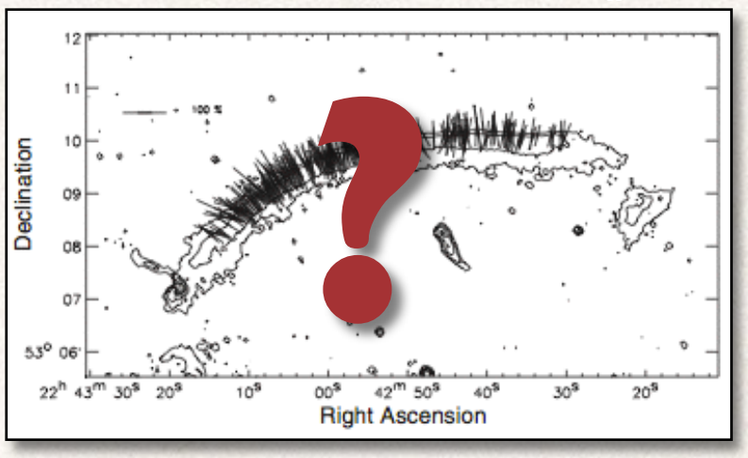



van Weeren+2010

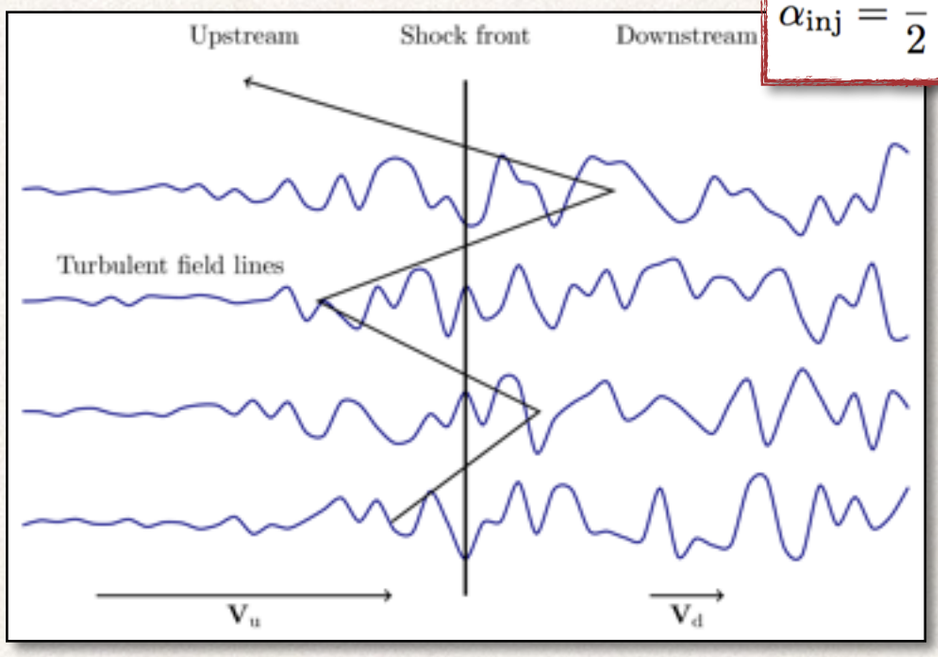
# Origin of the radiating electrons

## SHOCK ACCELERATION

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

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

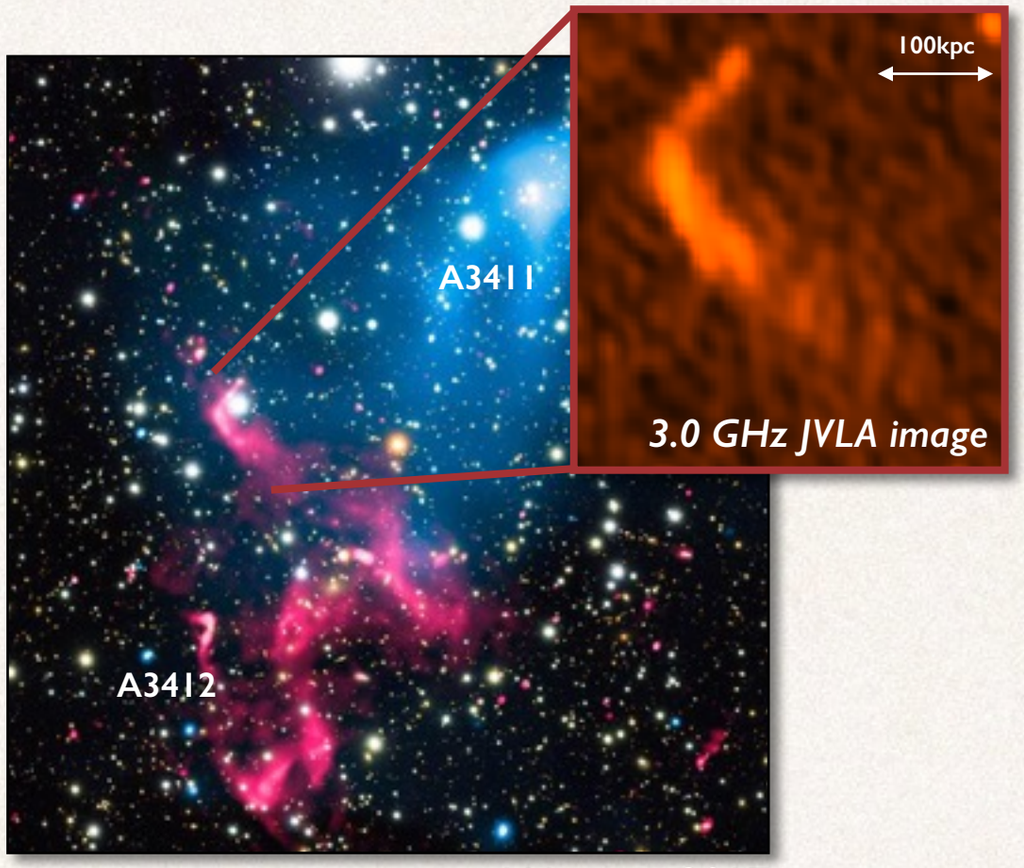
$$\alpha_{\rm inj} = \frac{1}{2} - \frac{\mathcal{M}^2+1}{\mathcal{M}^2-1}$$




## RE-ACCELERATION

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

- Old plasma re-accelerated by a shock
- Morphological connection between radio galaxies and relics

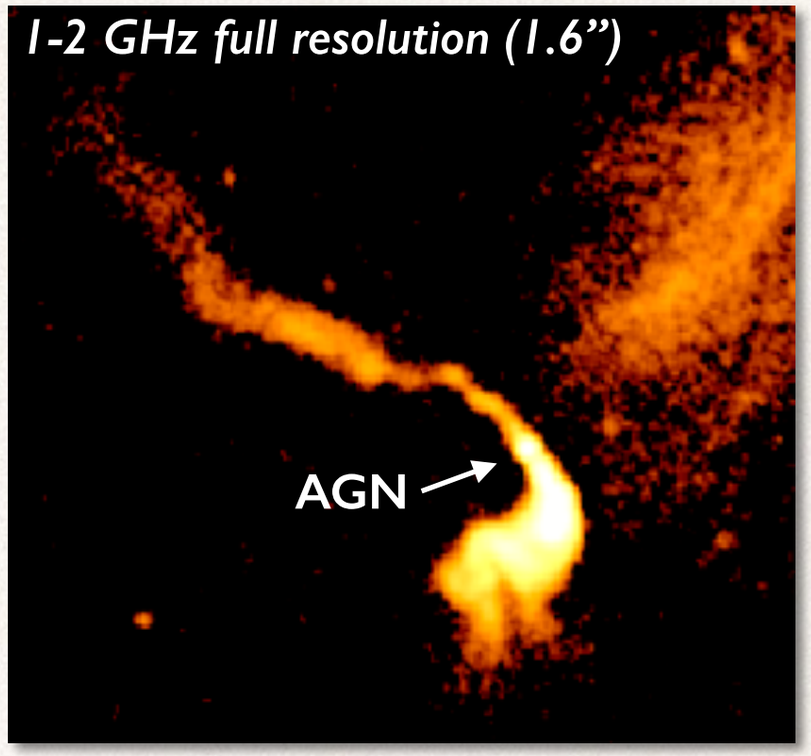


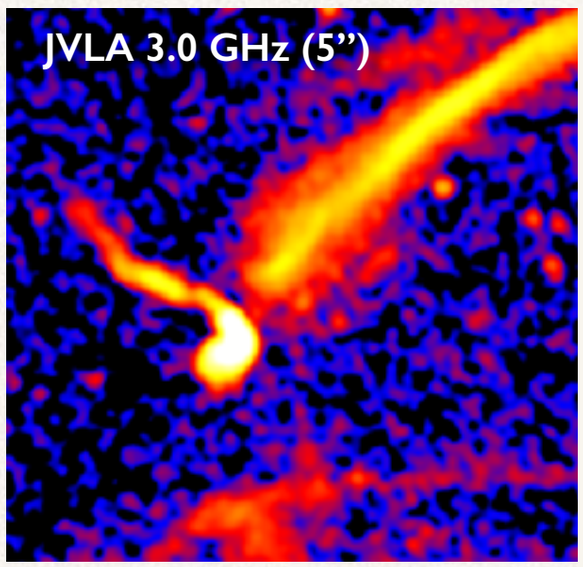

van Weeren+2017

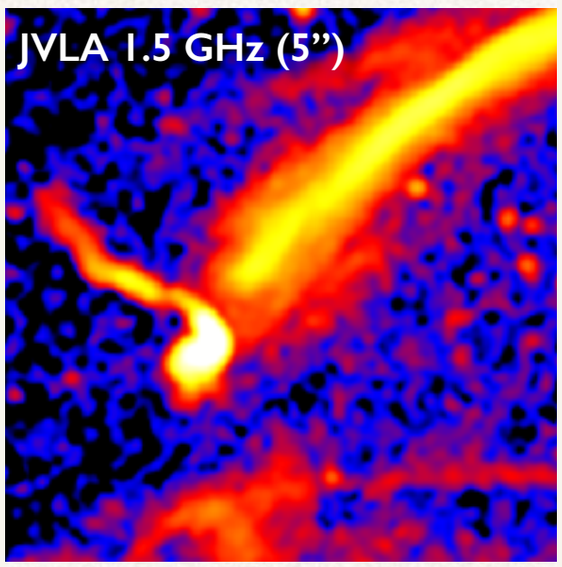
# CIZA J2242.8+5301

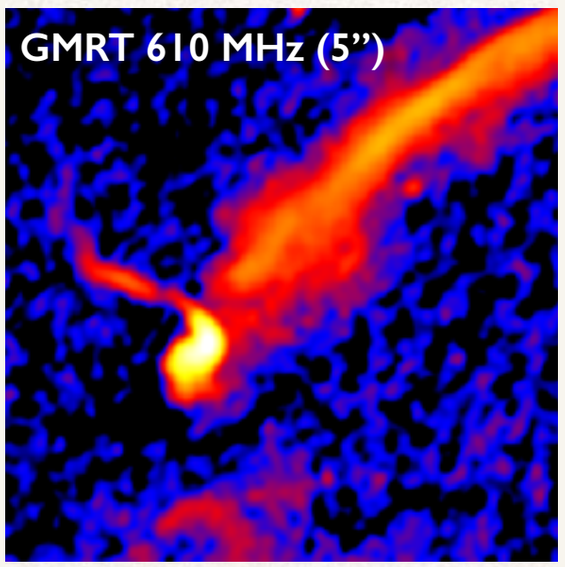
## New Deep L- and S-band JVLA observations (1-4 GHz)

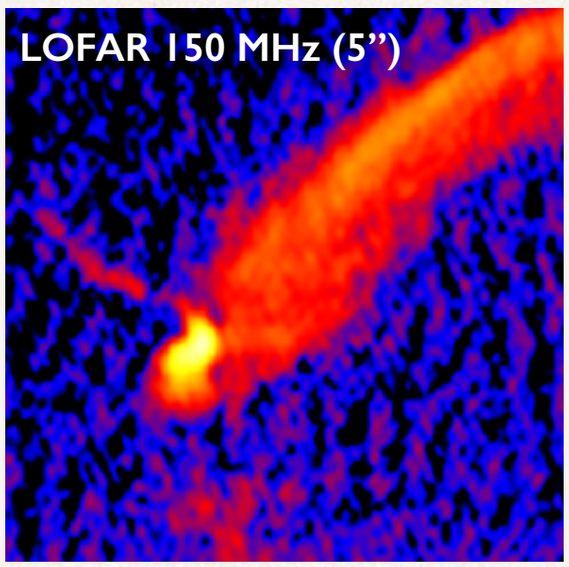
- high (1.6” / 0.8”) and low resolution images
- spectral index and curvature maps (JVLA, GMRT, LOFAR)
- test for the DSA mechanism
- polarization study across the relics



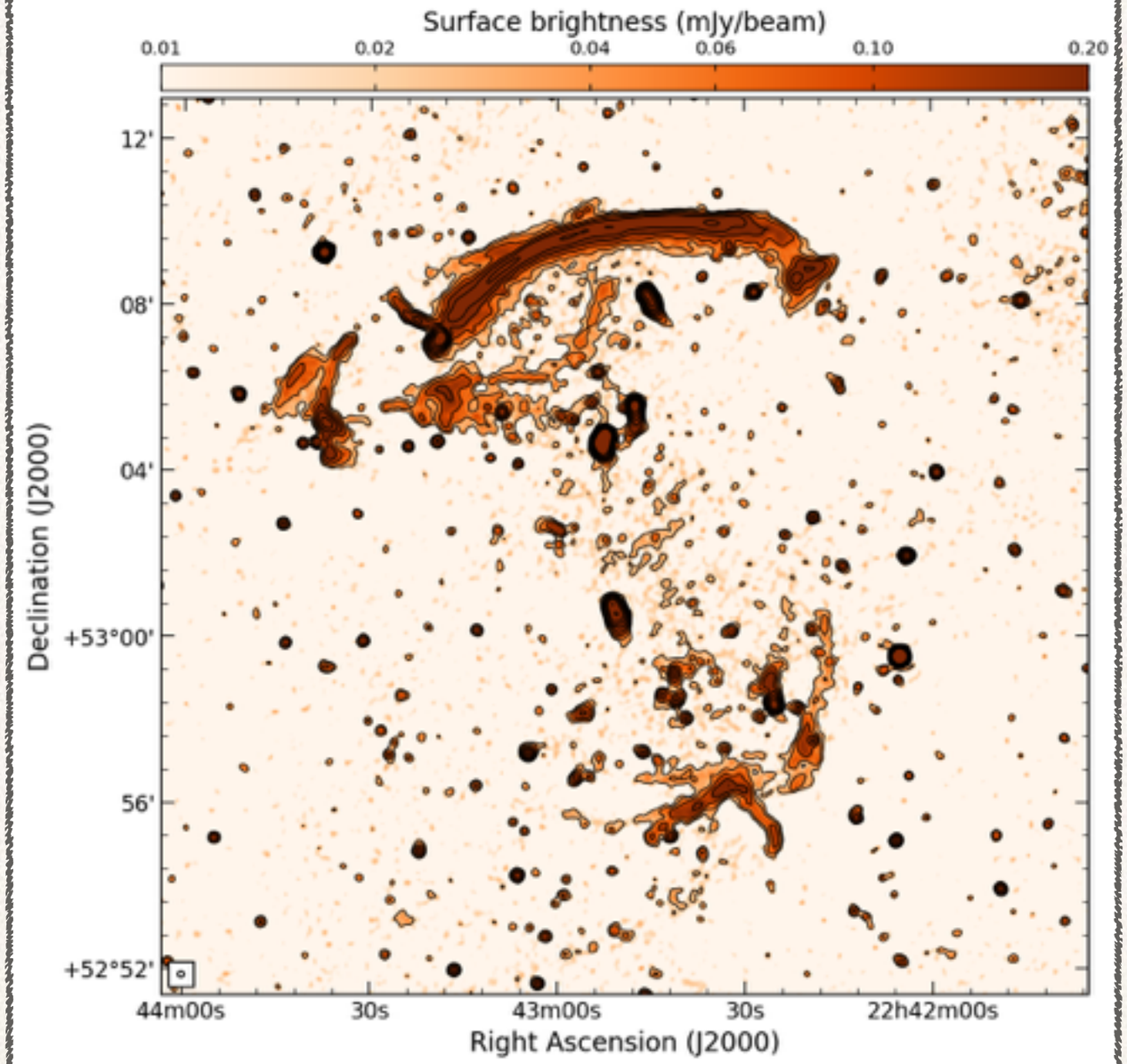



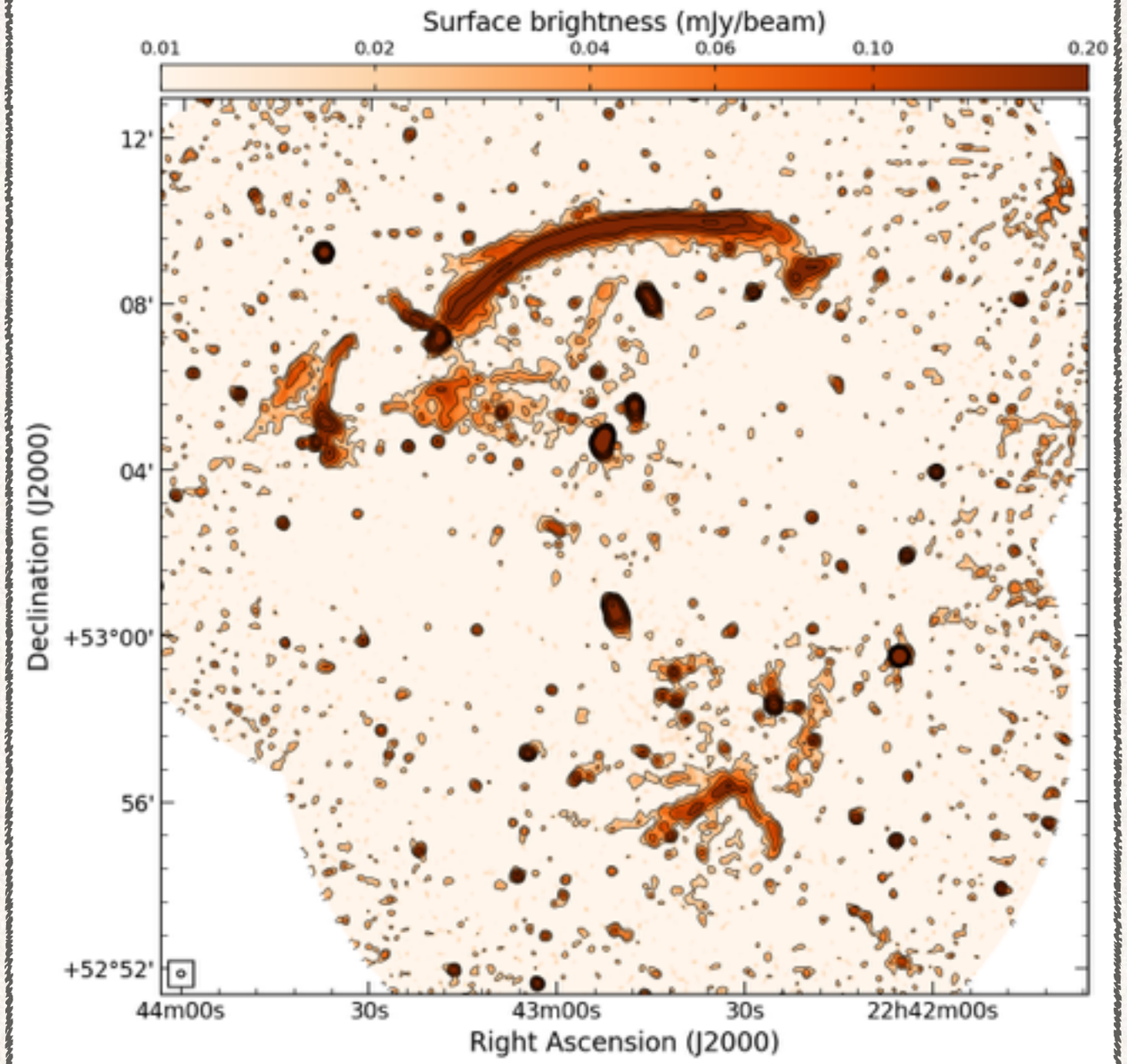



# CIZA J2242.8+5301

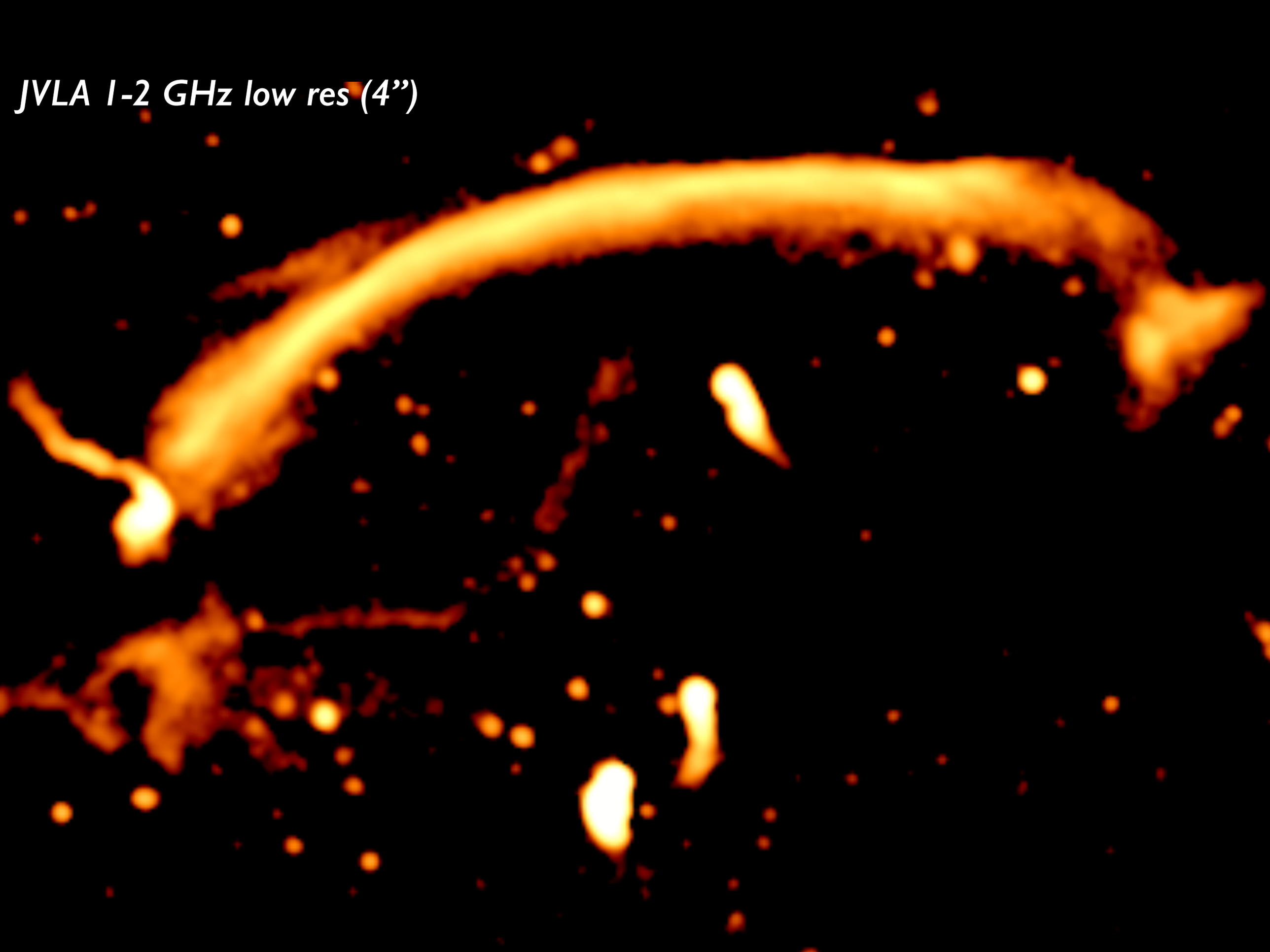
## L-band (10” res)




## S-band (10” res)



*JVLA 1-2 GHz low res (4")*

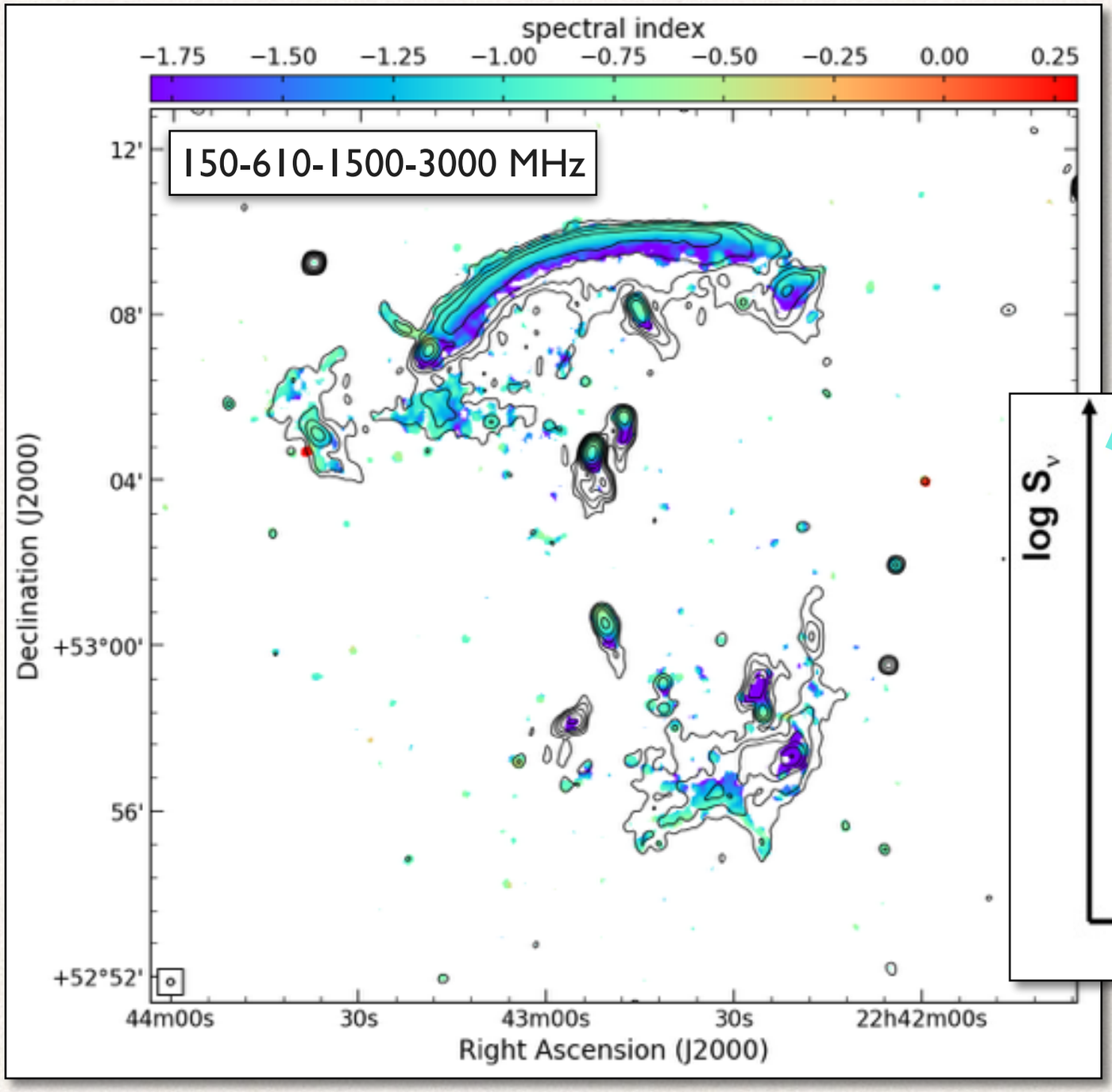


*JVLA 1-2 GHz full res (1.6")*

*noise ≈ 4 $\mu$Jy/beam*

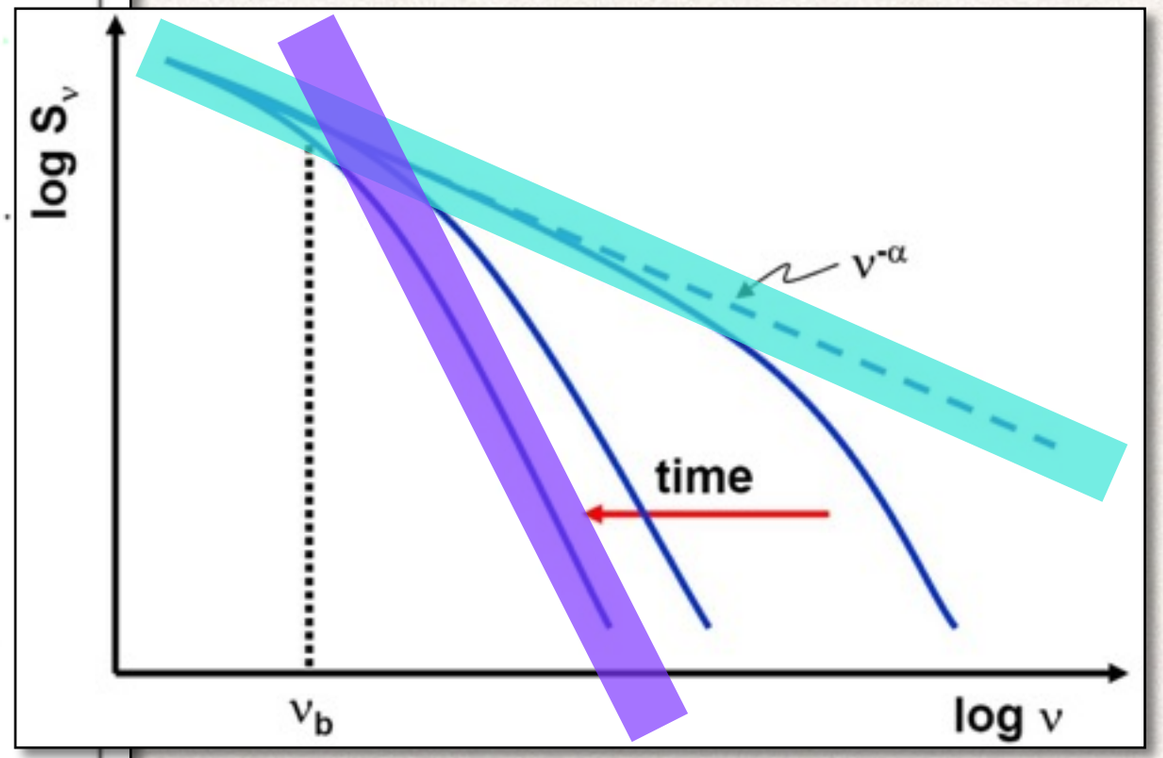
# Spectral Index analysis

LOFAR-GMRT-JVLA (10” res)



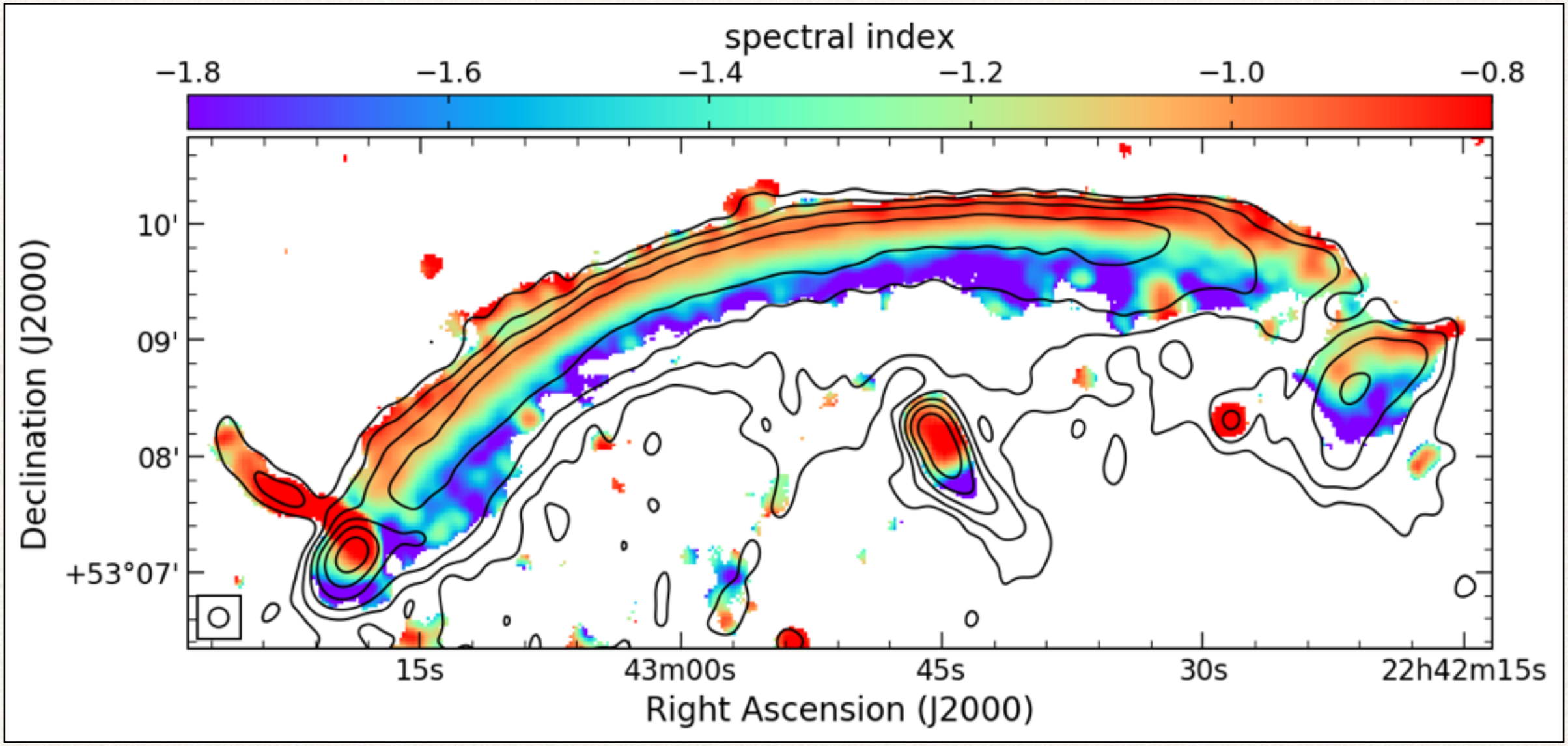

Contours: LOFAR 150 MHz

## PARTICLES AGING



# Spectral Index analysis

## NORTHERN RELIC

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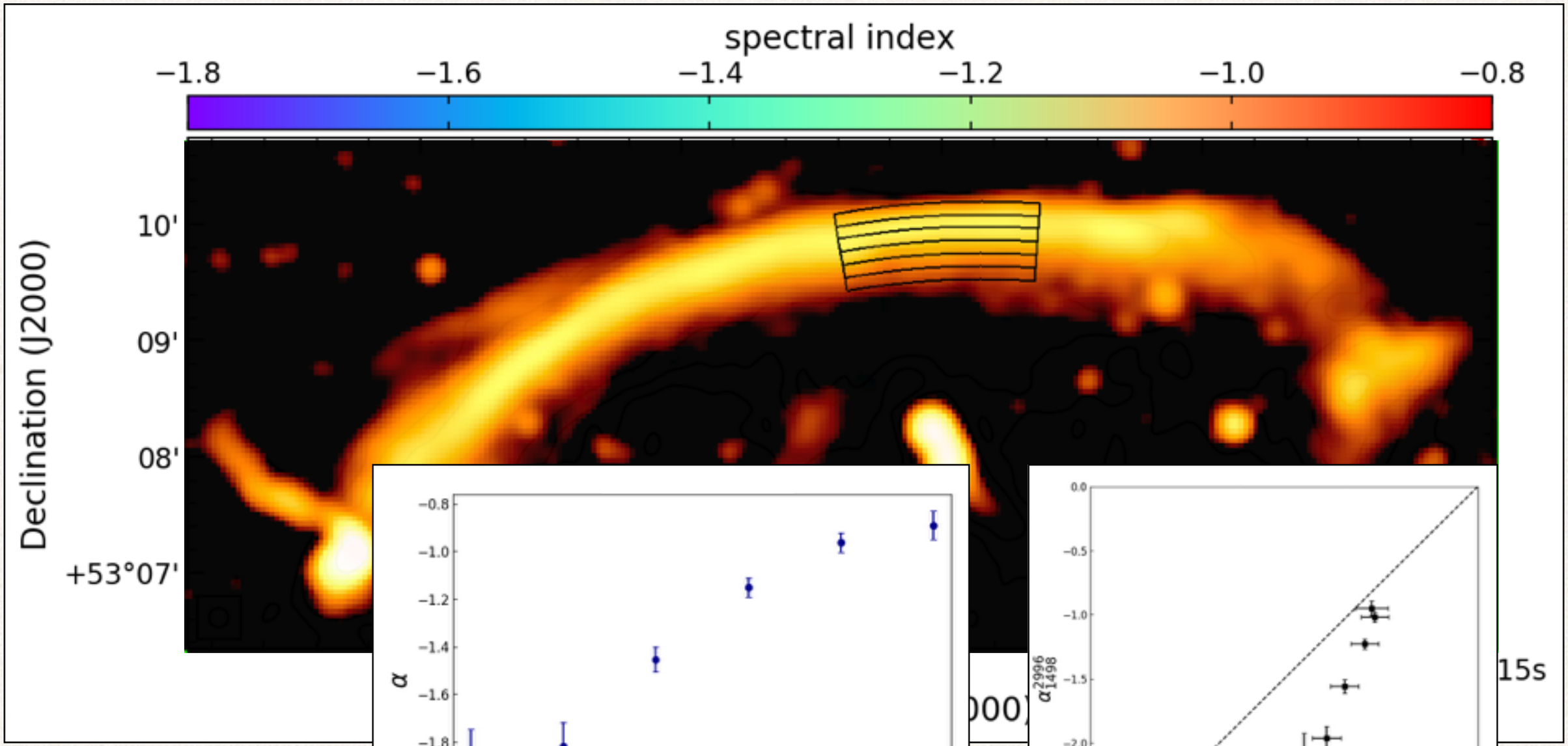

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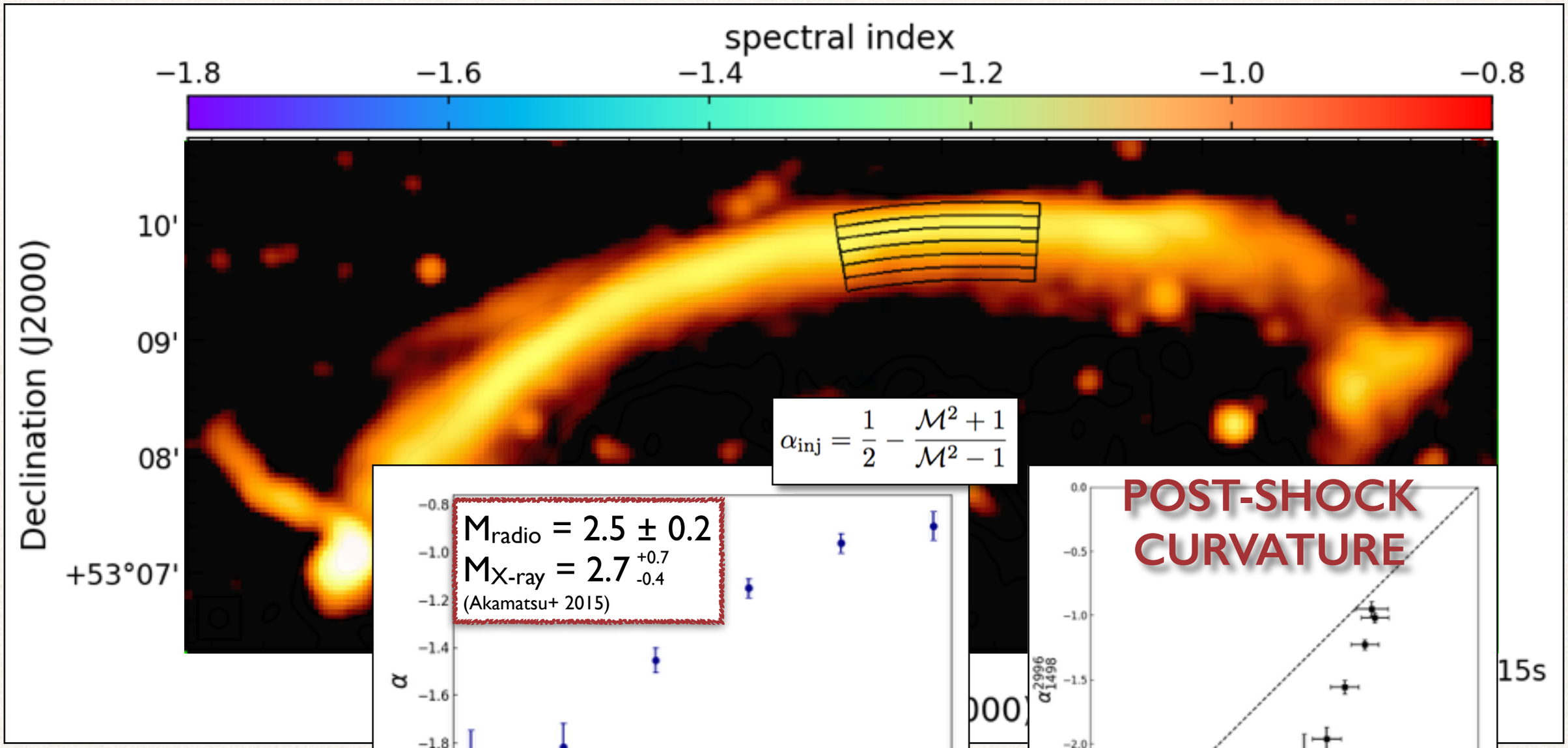
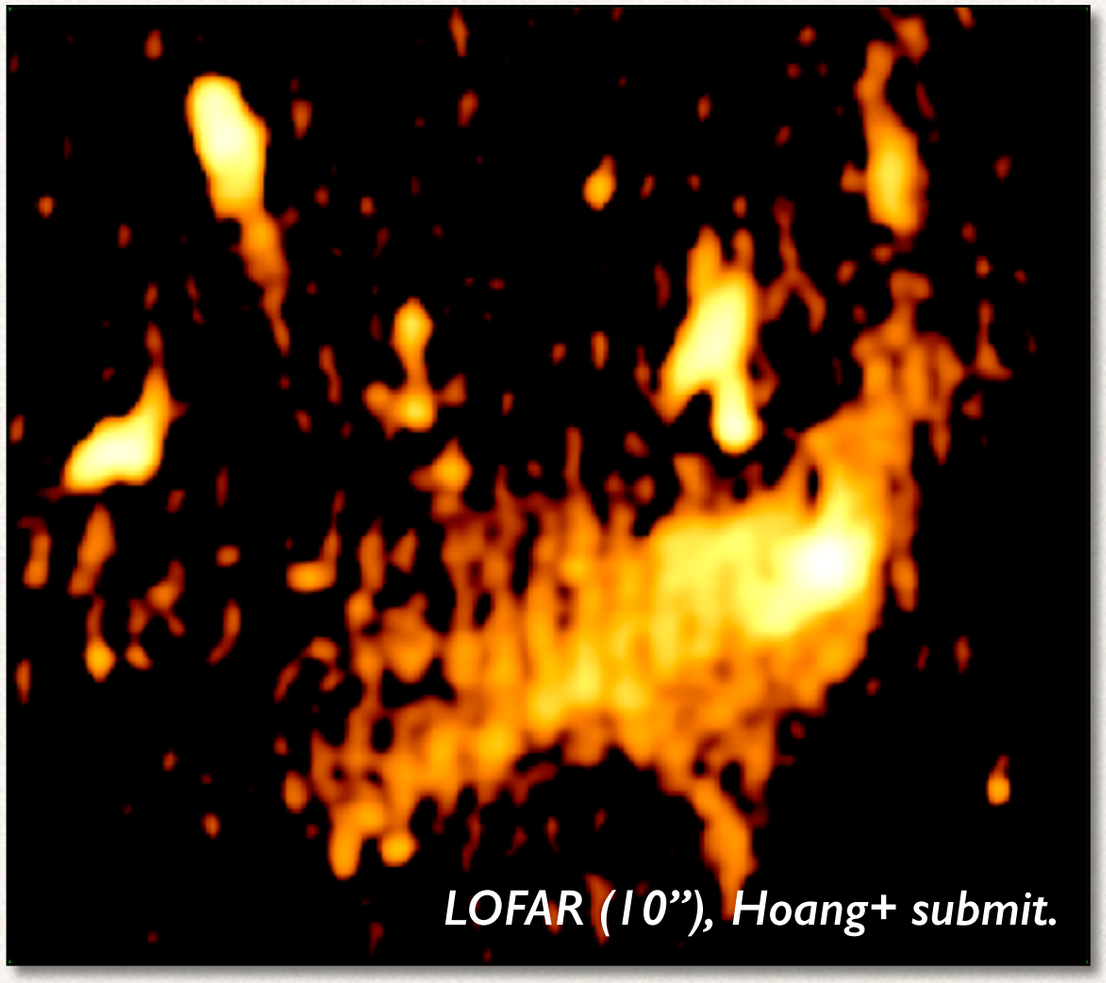



in agreement with literature works (e.g. Stroe+13,+16; Hoang+ submitt.)

# Spectral Index analysis

## SOUTHERN RELIC



# Spectral Index analysis

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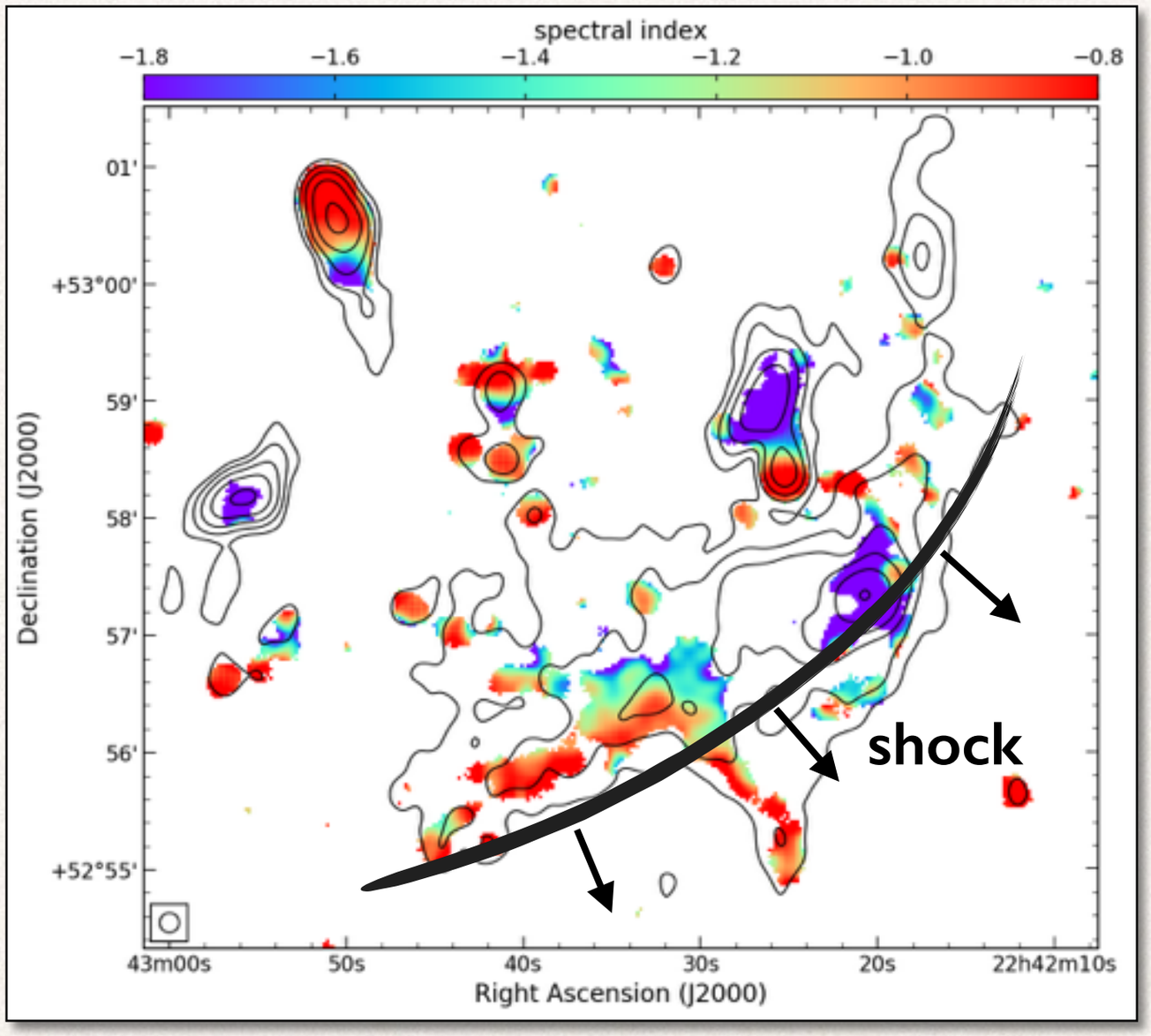


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# Spectral Index analysis

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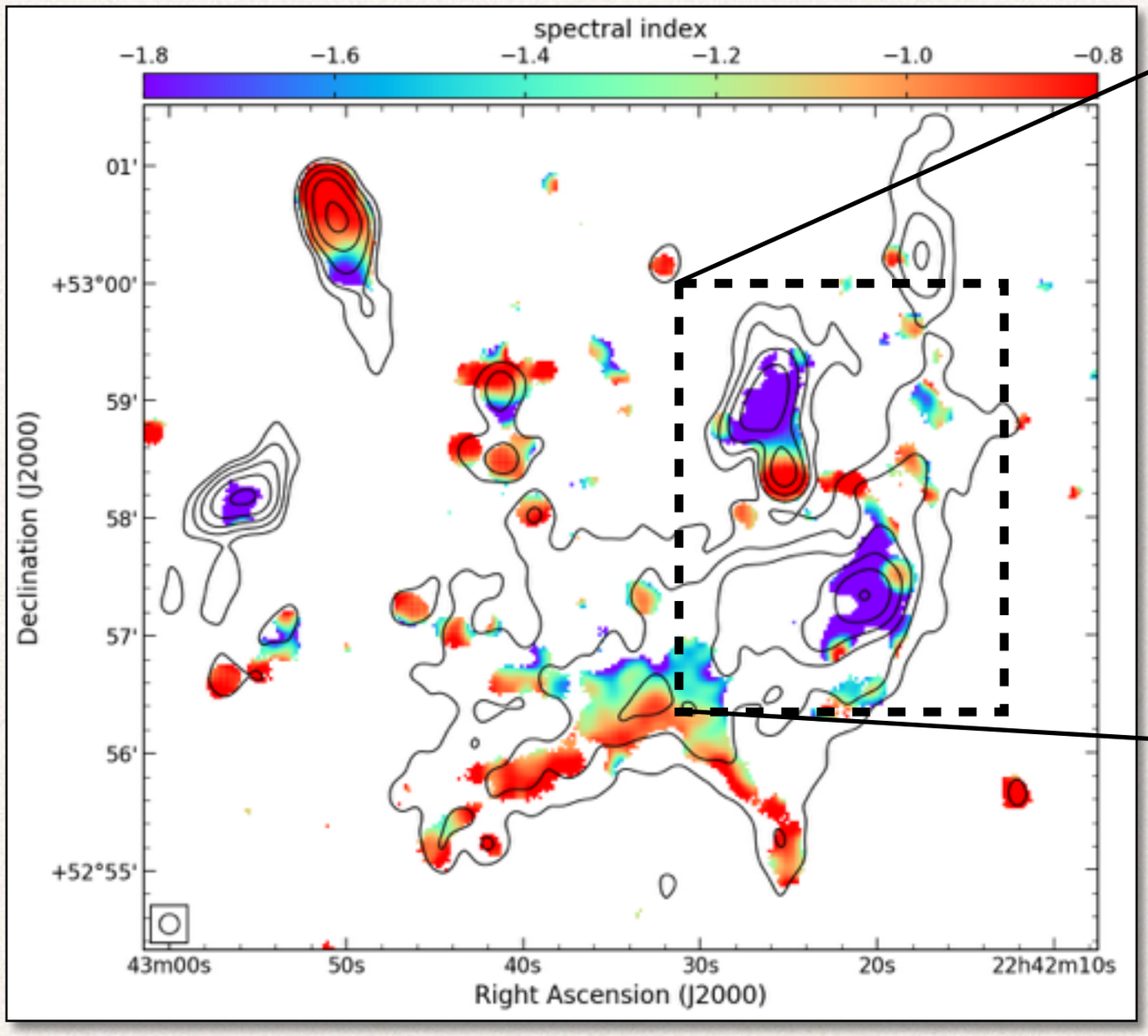
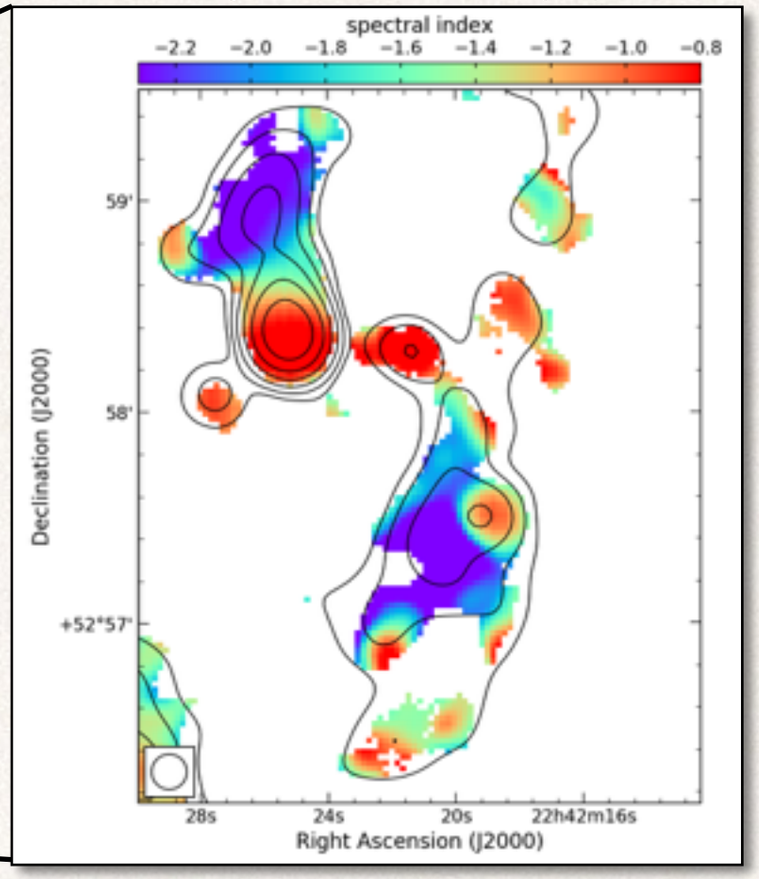



Contours: LOFAR 150 MHz

Contours: JVLA 1.5 GHz (4")



# Spectral Index analysis

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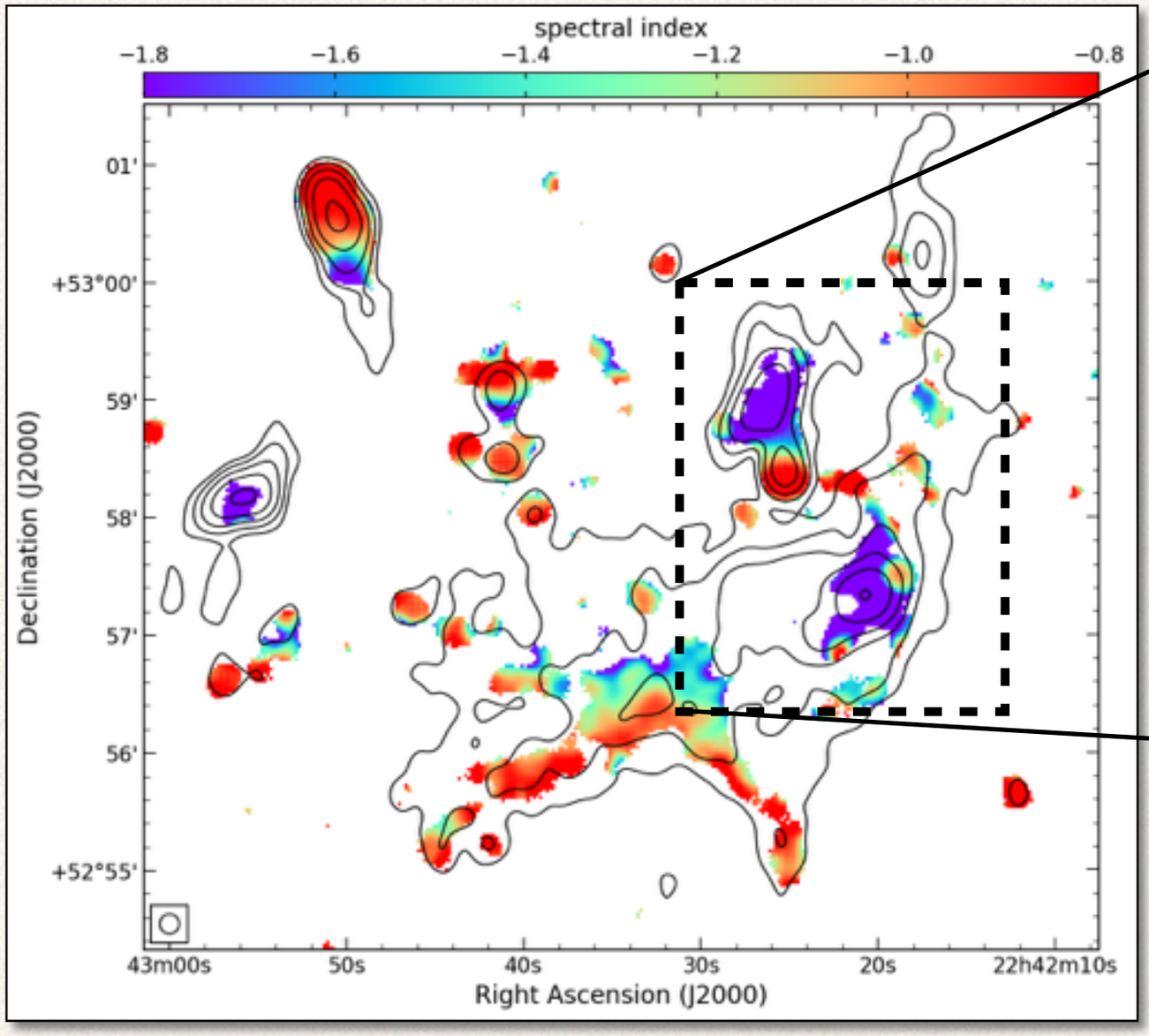


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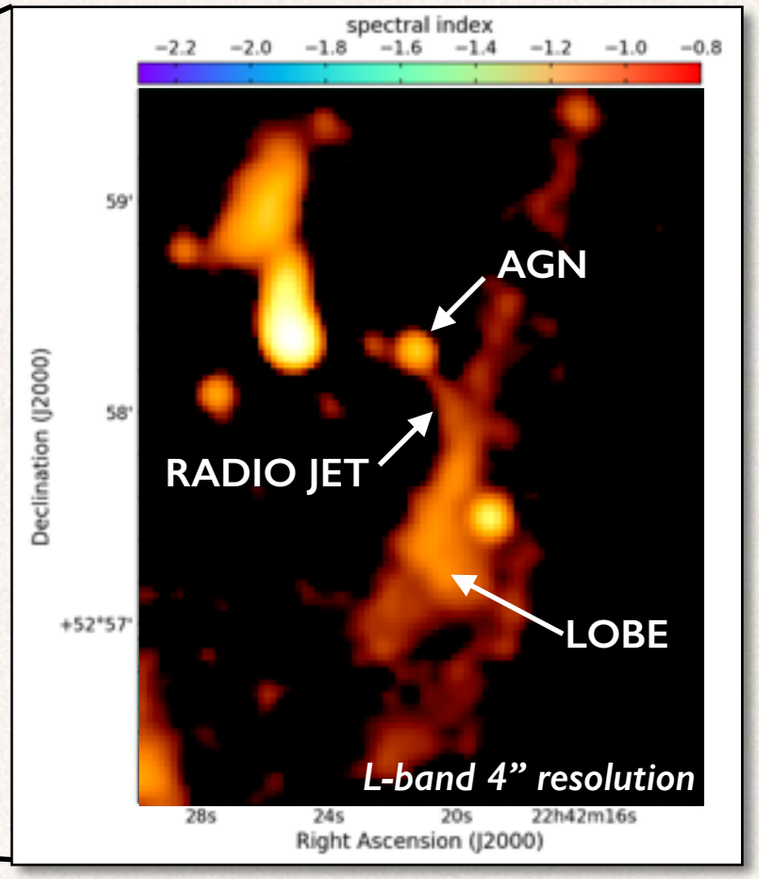

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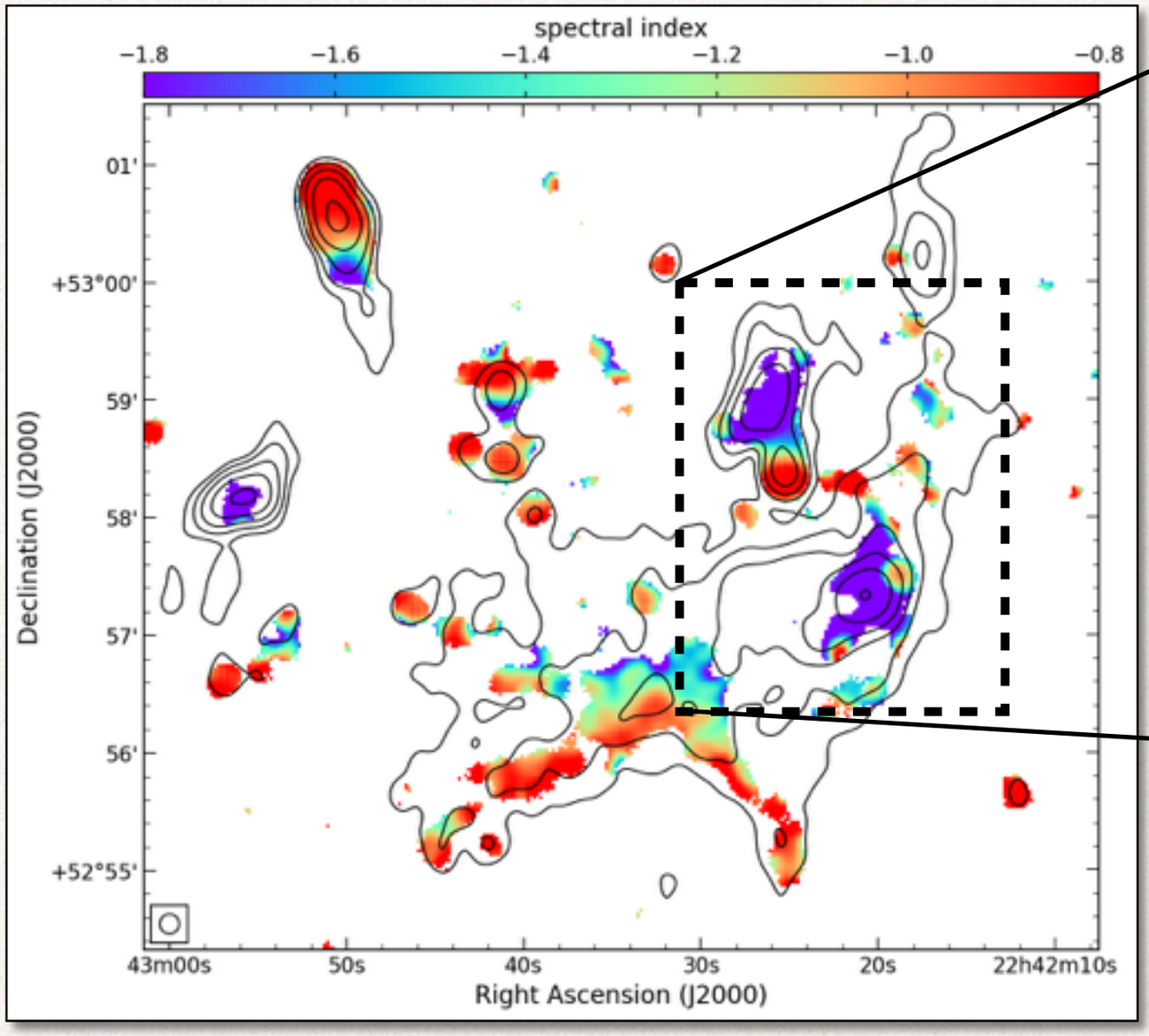


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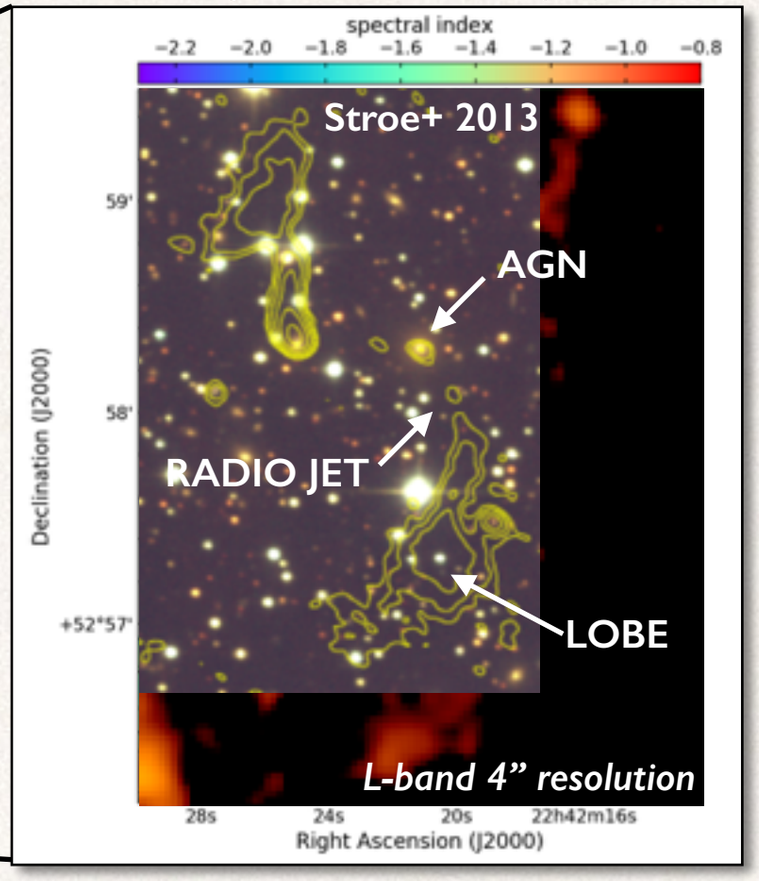

# Spectral Index analysis

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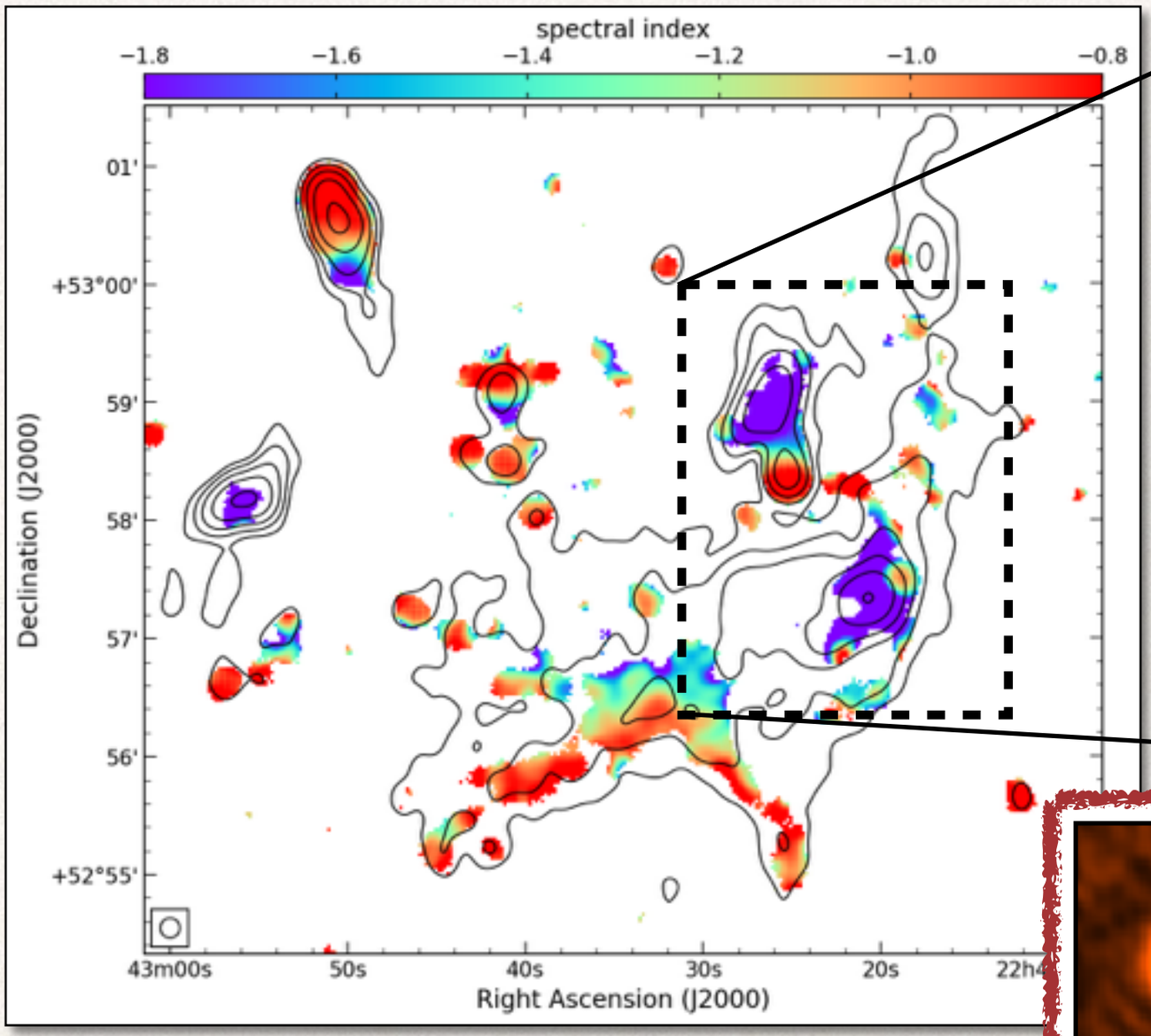


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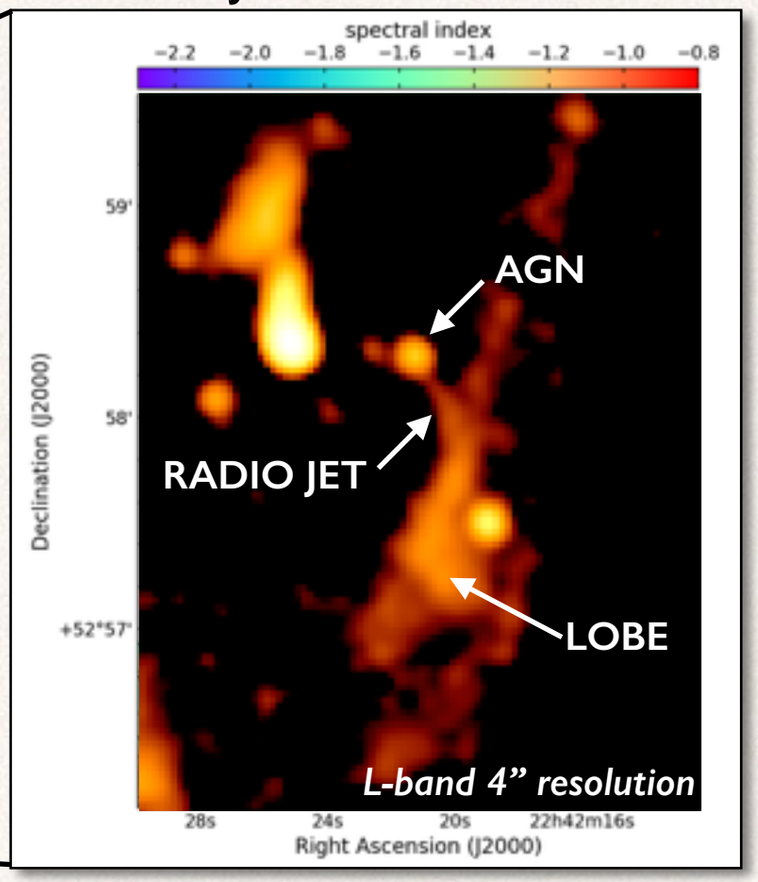
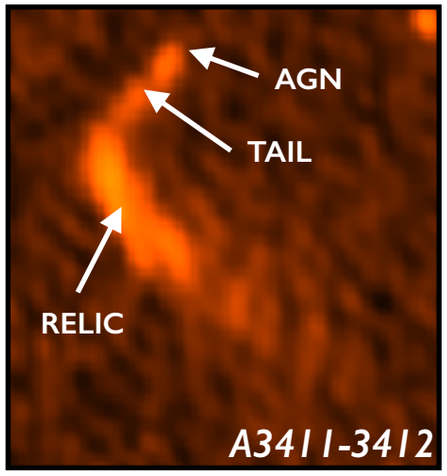
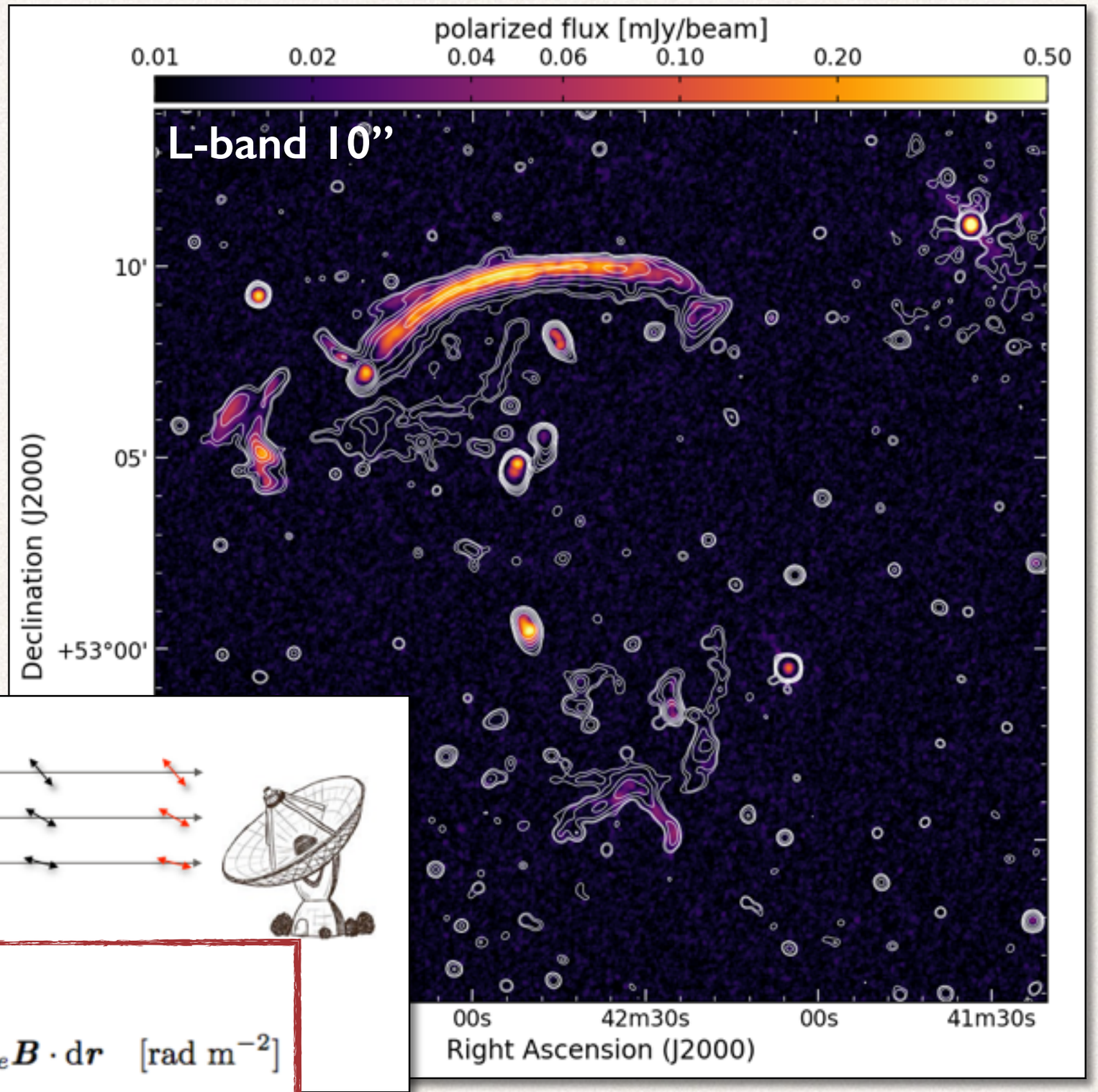
Contours: JVLA 1.5 GHz



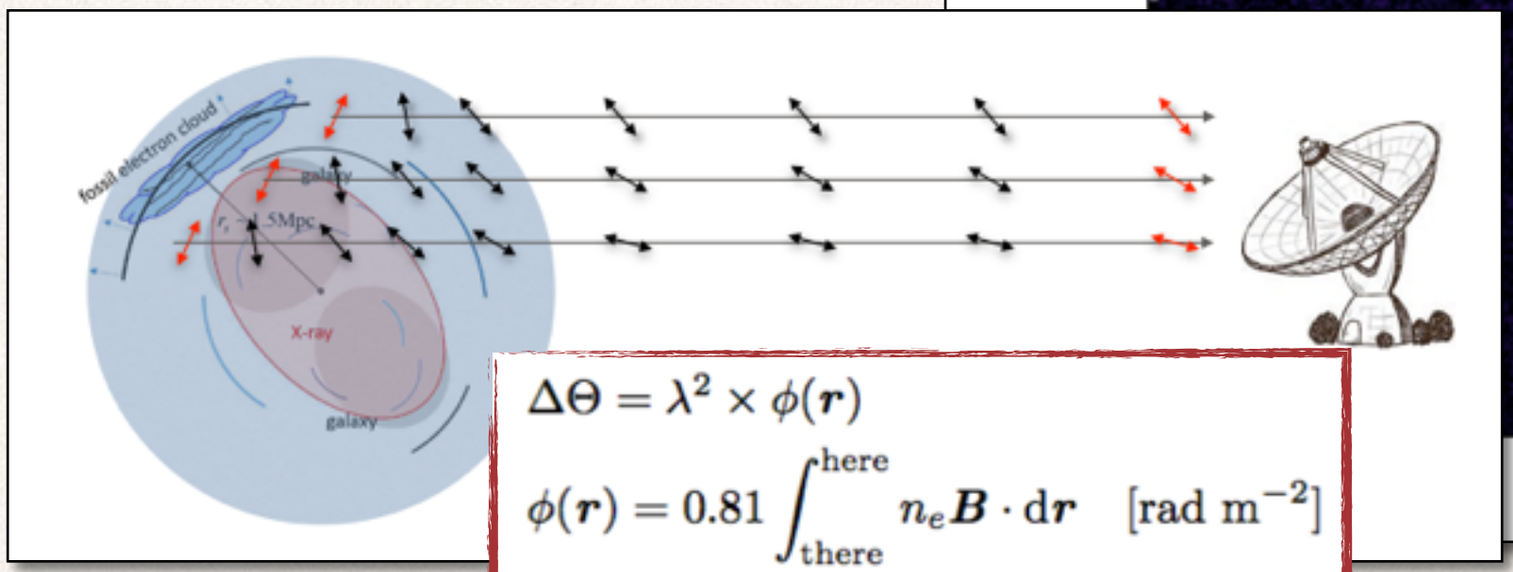




Possible connection between a tail and the relic as for A3411-3412 ?

# JVLA: Polarization




## FARADAY ROTATION

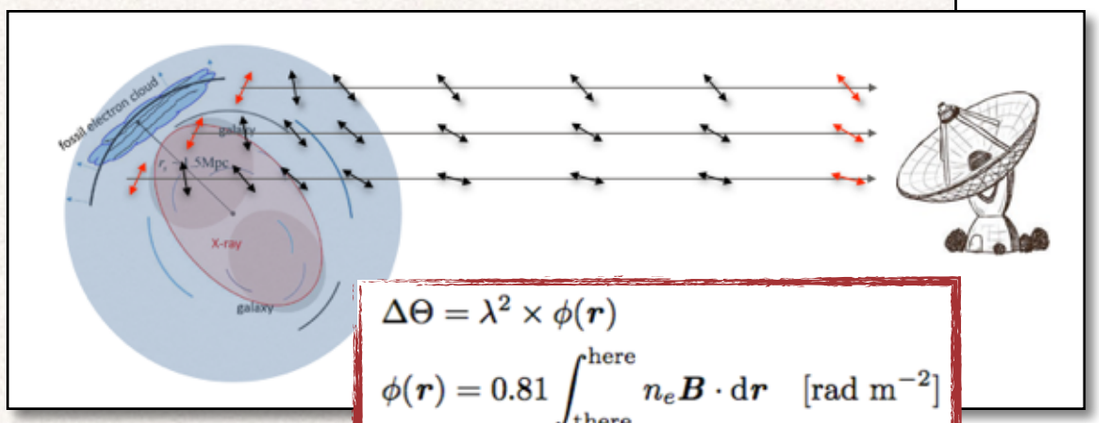



$$\Delta\Theta = \lambda^2 \times \phi(\boldsymbol{r})$$

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

Contours: JVLA 1.5 GHz (10”)

# JVLA: Polarization

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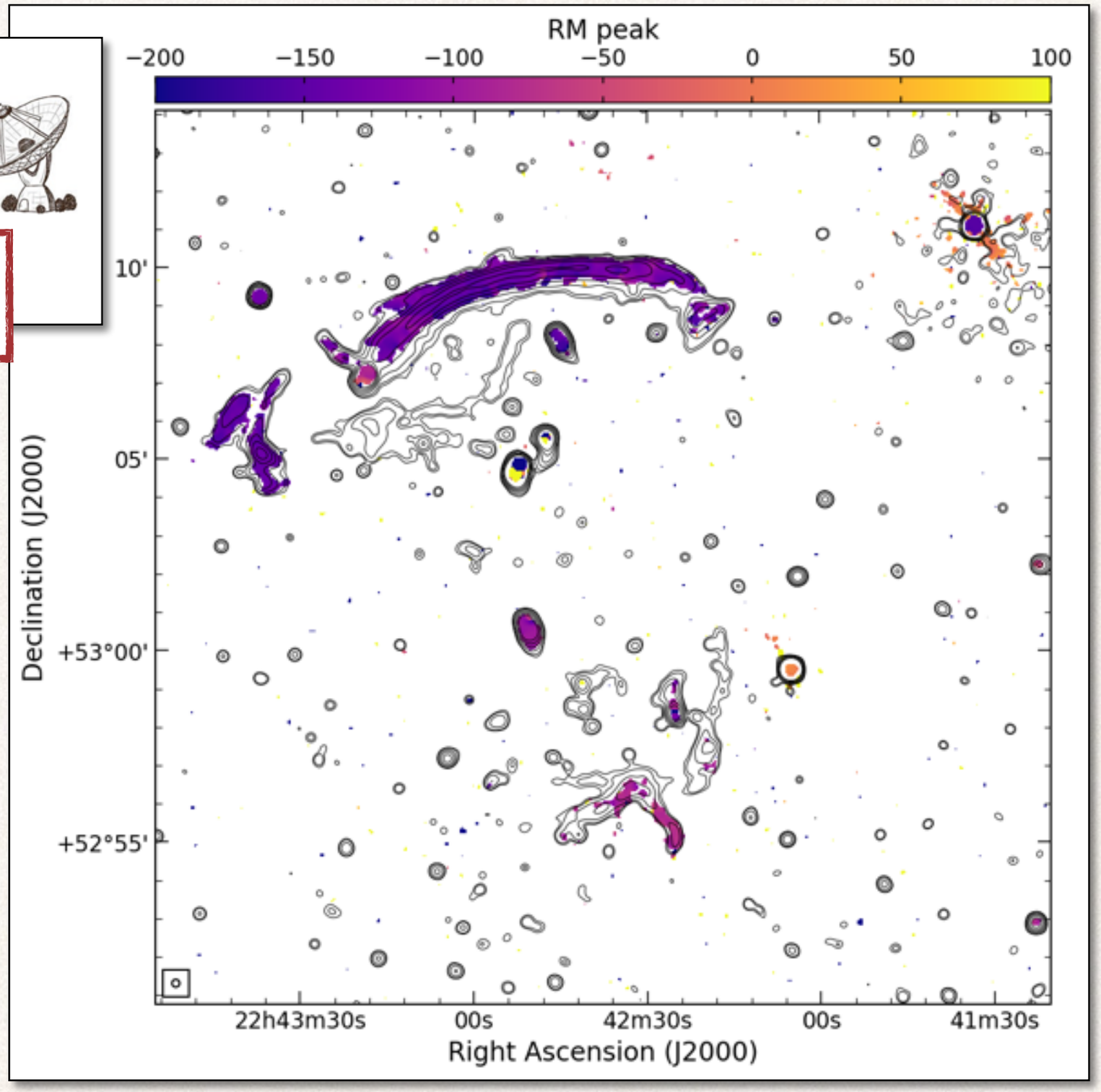
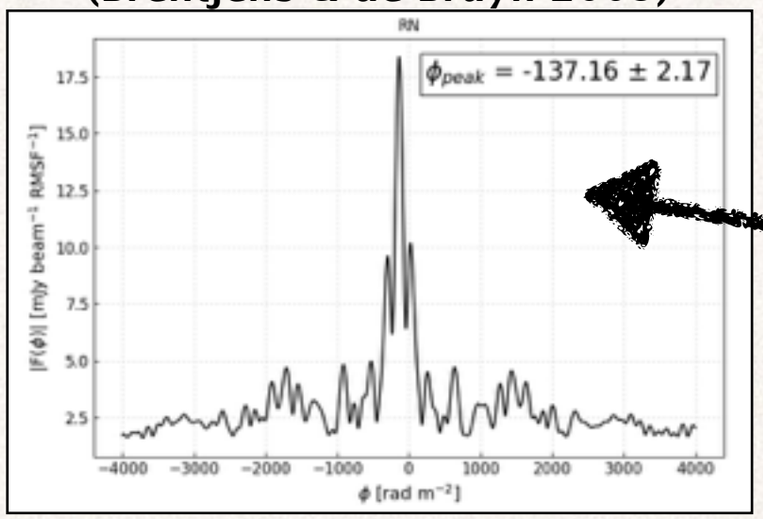
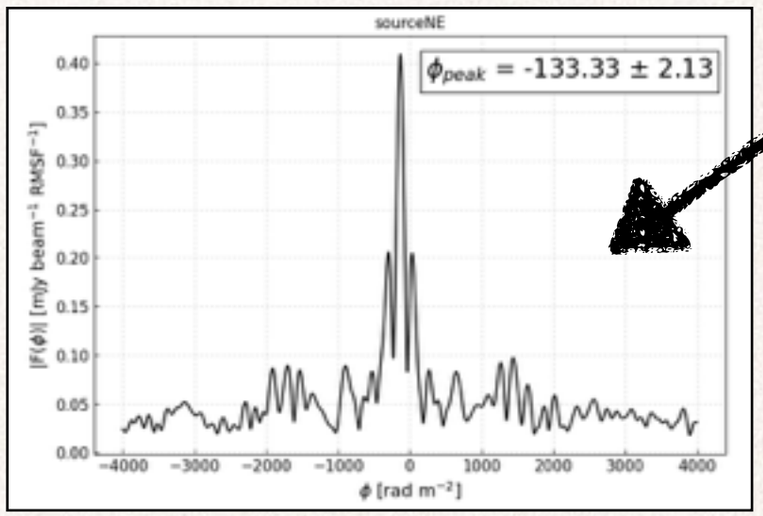


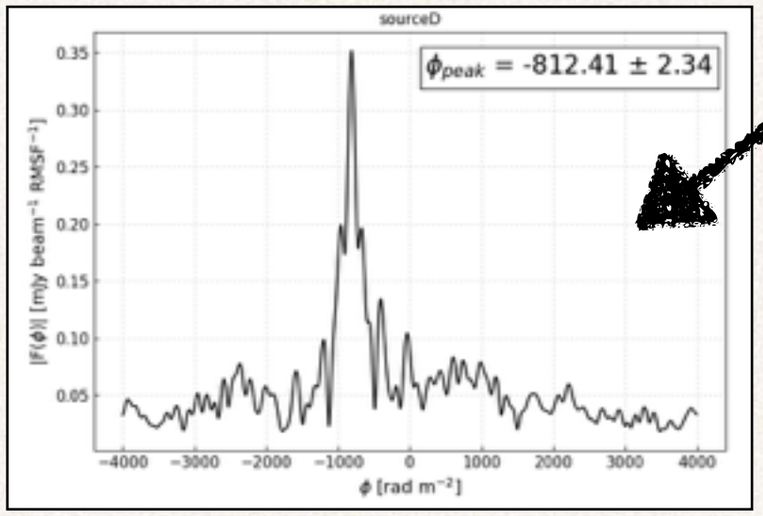

Contours: JVLA 1.5 GHz (10")

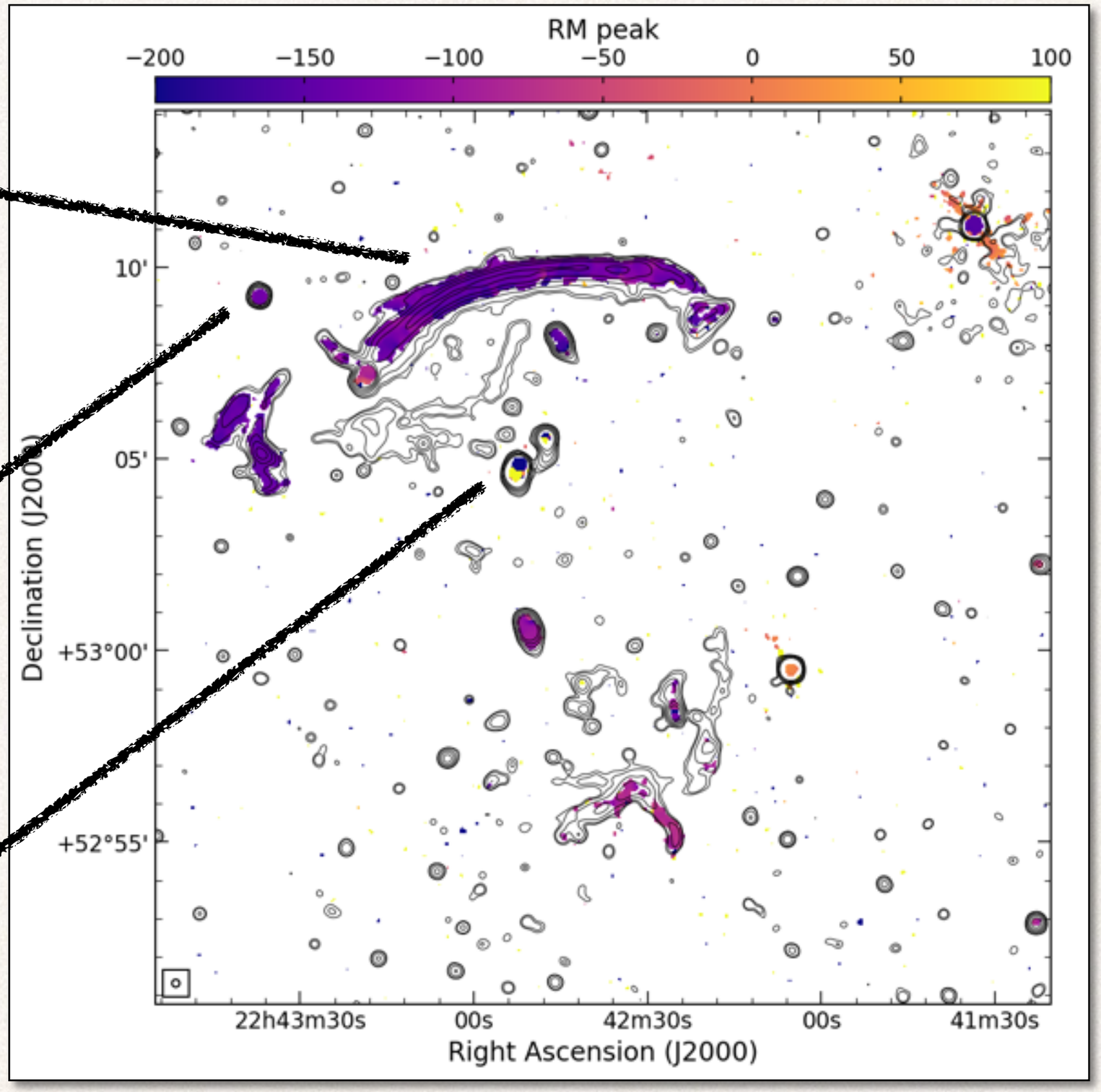
# JVLA: Polarization

**RM-Synthesis**
**(Brentjens & de Bruyn 2005)**



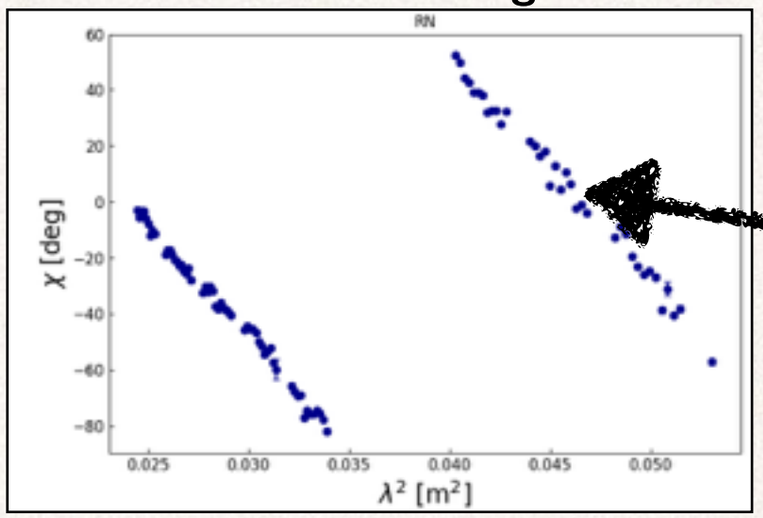



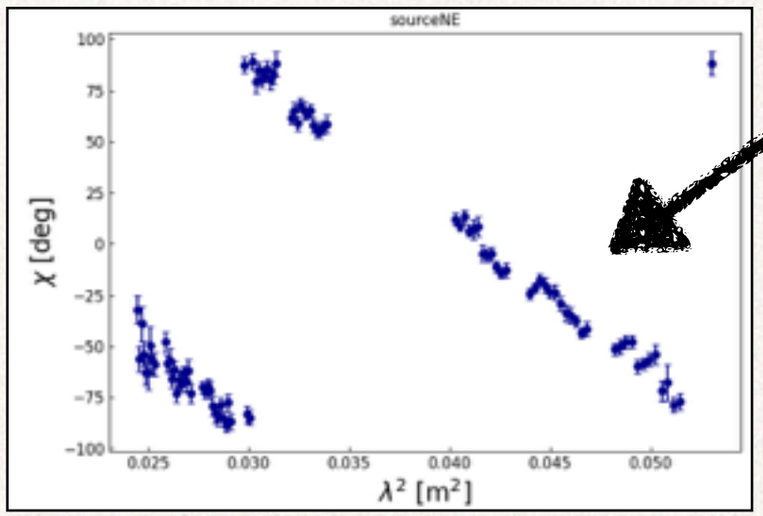



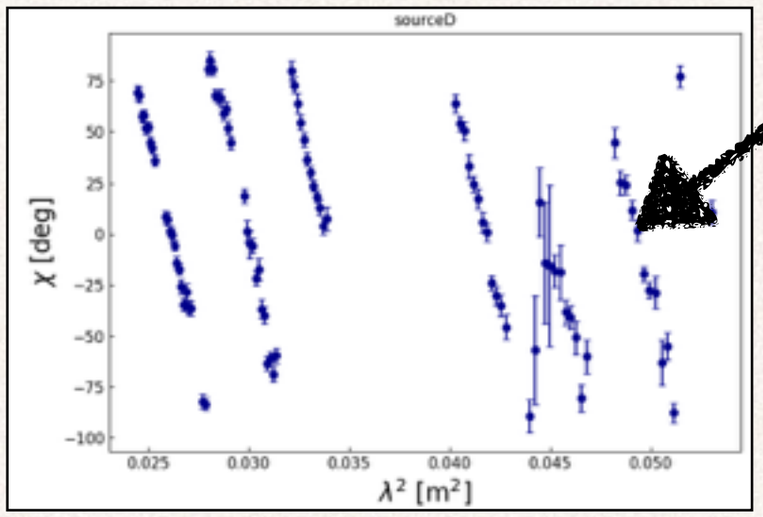

Contours: JVLA 1.5 GHz (10")

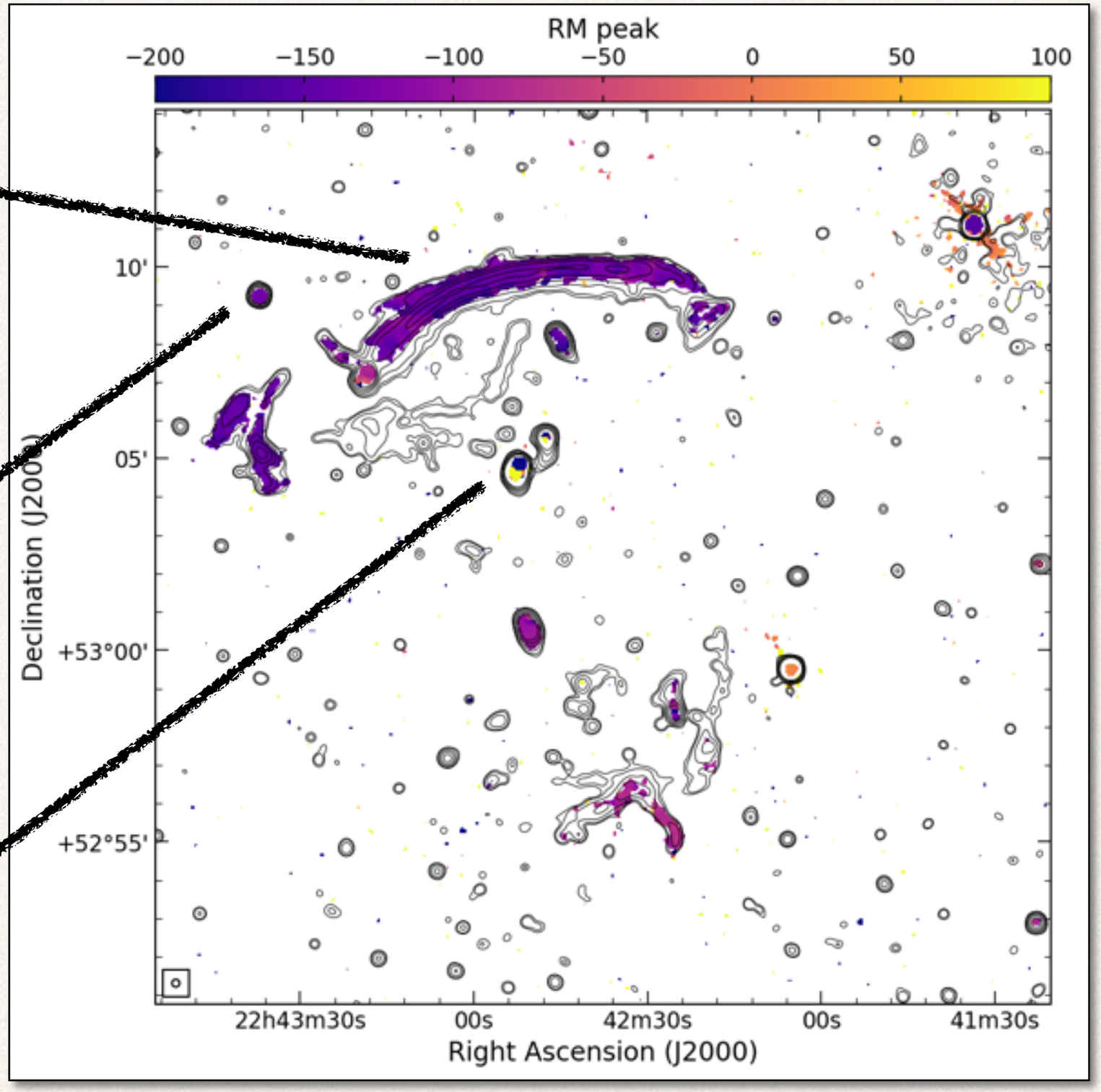
# JVLA: Polarization

**Polarization angle**



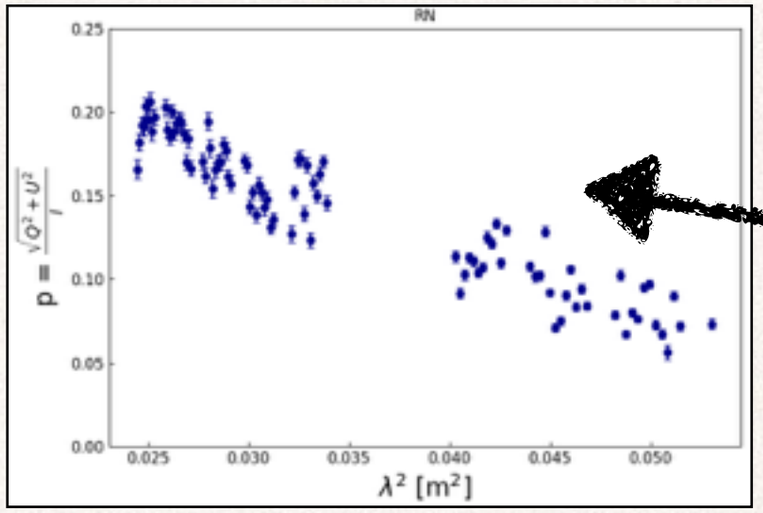



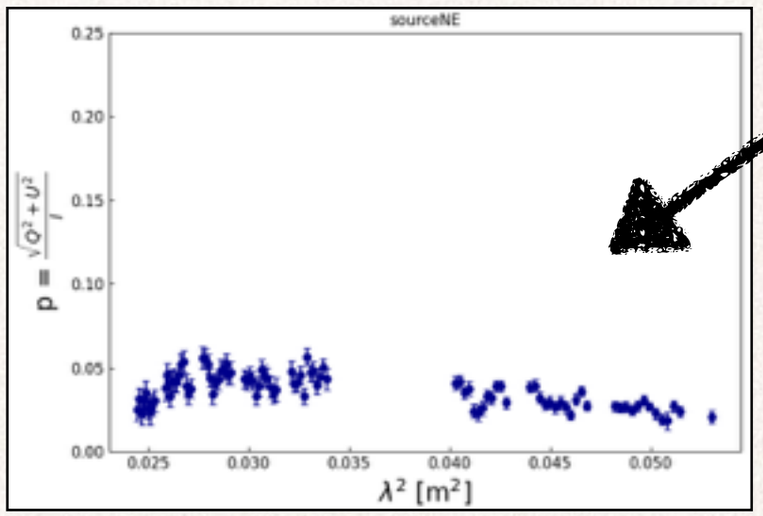



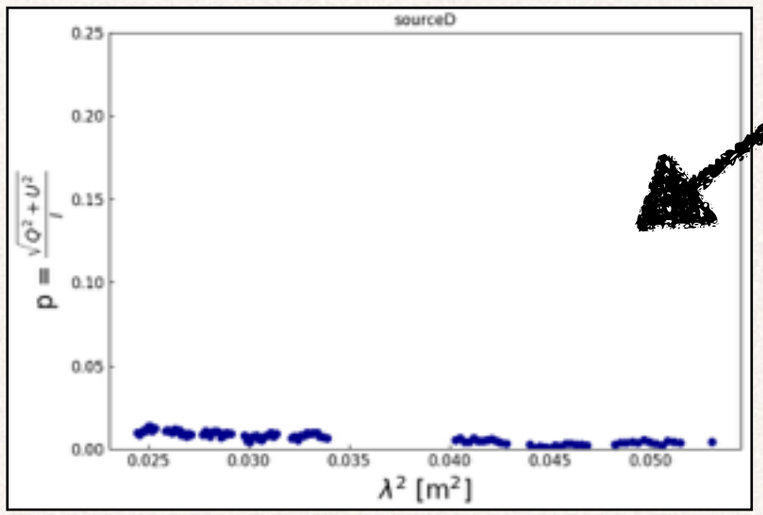

Contours: JVLA 1.5 GHz (10")

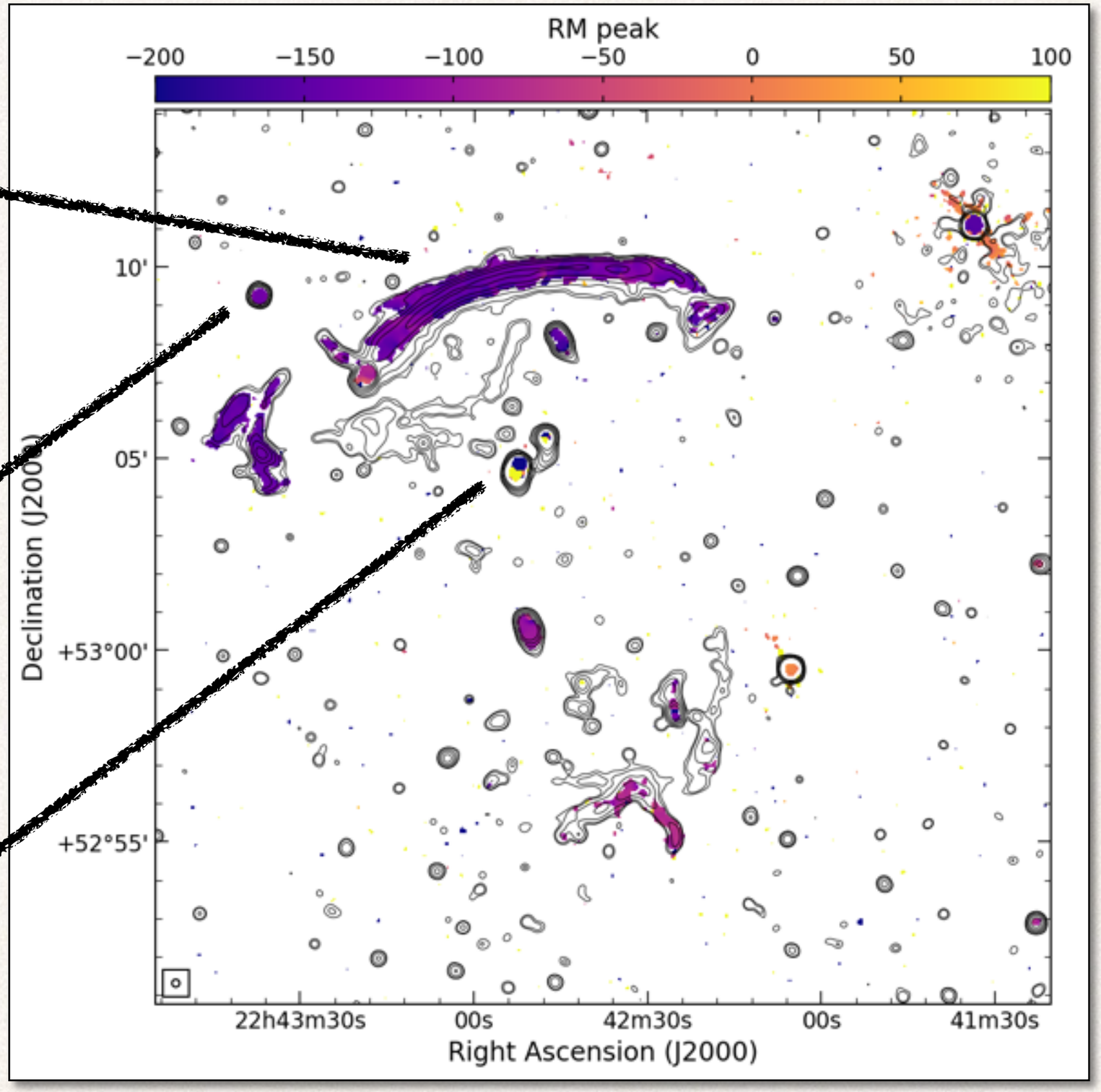
# JVLA: Polarization

**Polarization fraction**




Contours: JVLA 1.5 GHz (10")

# SUMMARY

- Ultra-deep JVLA images of CIZA J2242.8+5301 in combination with ultra-deep LOFAR (Hoang+) and GMRT observations
  - ☑ Confirmation of spectral curvature >> spectral aging in the shock downstream region
  - ☑ Possible connection between a radio tail and the southern relic >> hints for re-acceleration mechanism
  - ☐ RS ? Halo ? Other tails ?
- First polarization study in wide band by means of RM-Synthesis
  - ☑ RN and R1 located in the cluster outskirts
  - ☑ RN polarization fraction drops quickly (from 20% to few %)
  - ☐ Add S-band JVLA
- ☐ Increase the resolution (down to 2.5”)

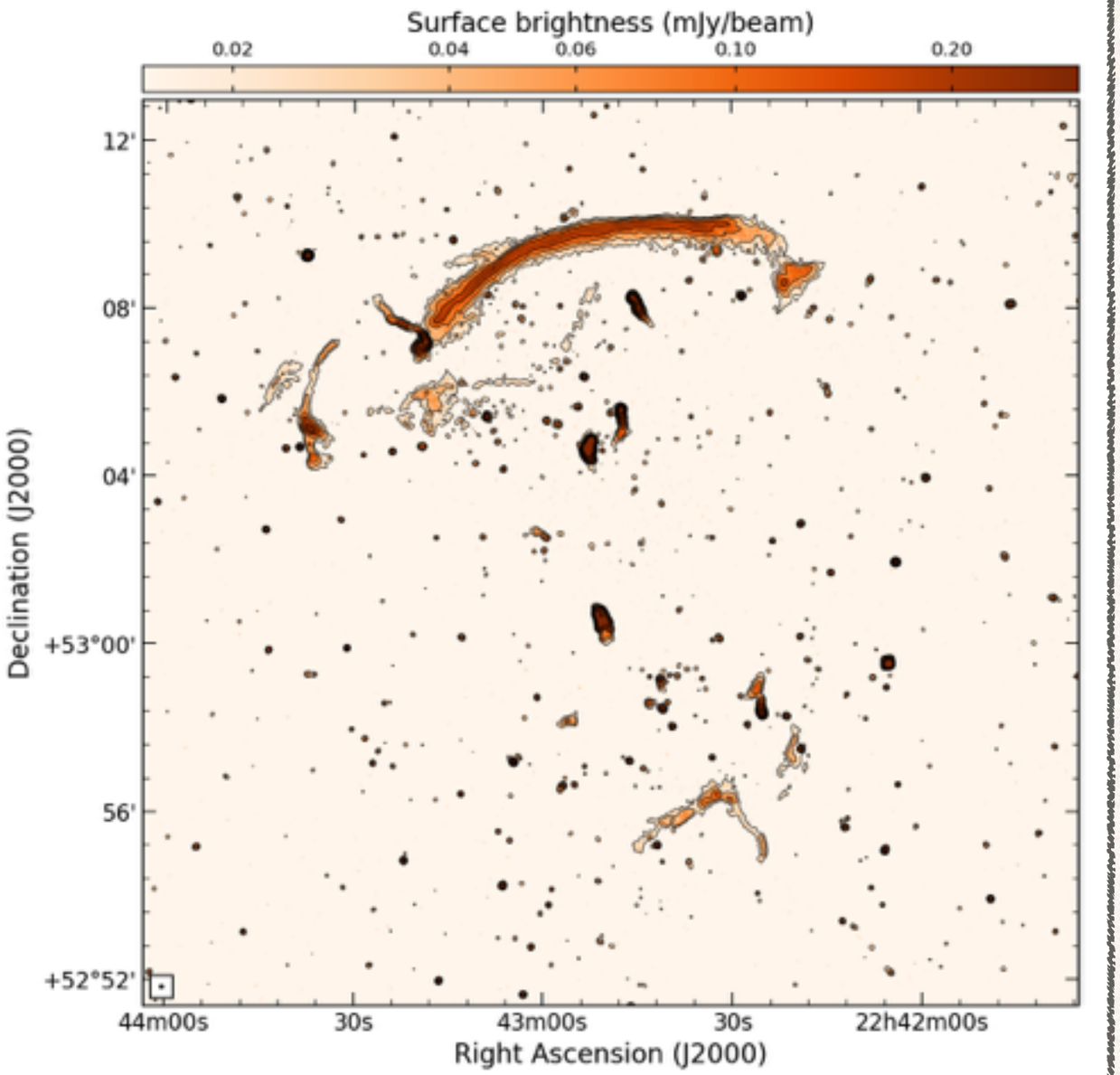
# Thank you

# BACKUP SLIDES

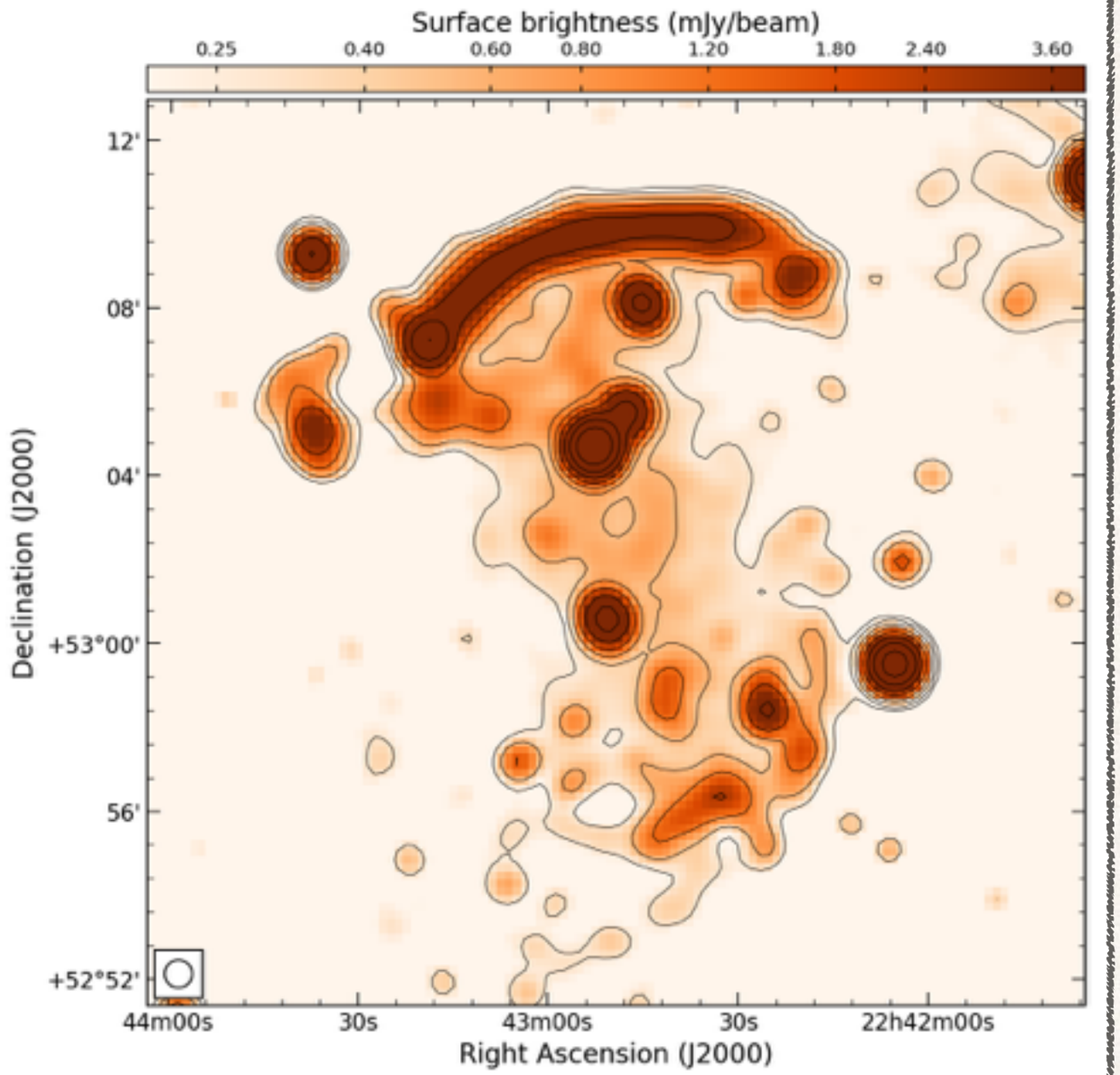
# CIZA J2242.8+5301

(a.k.a “Sausage”)

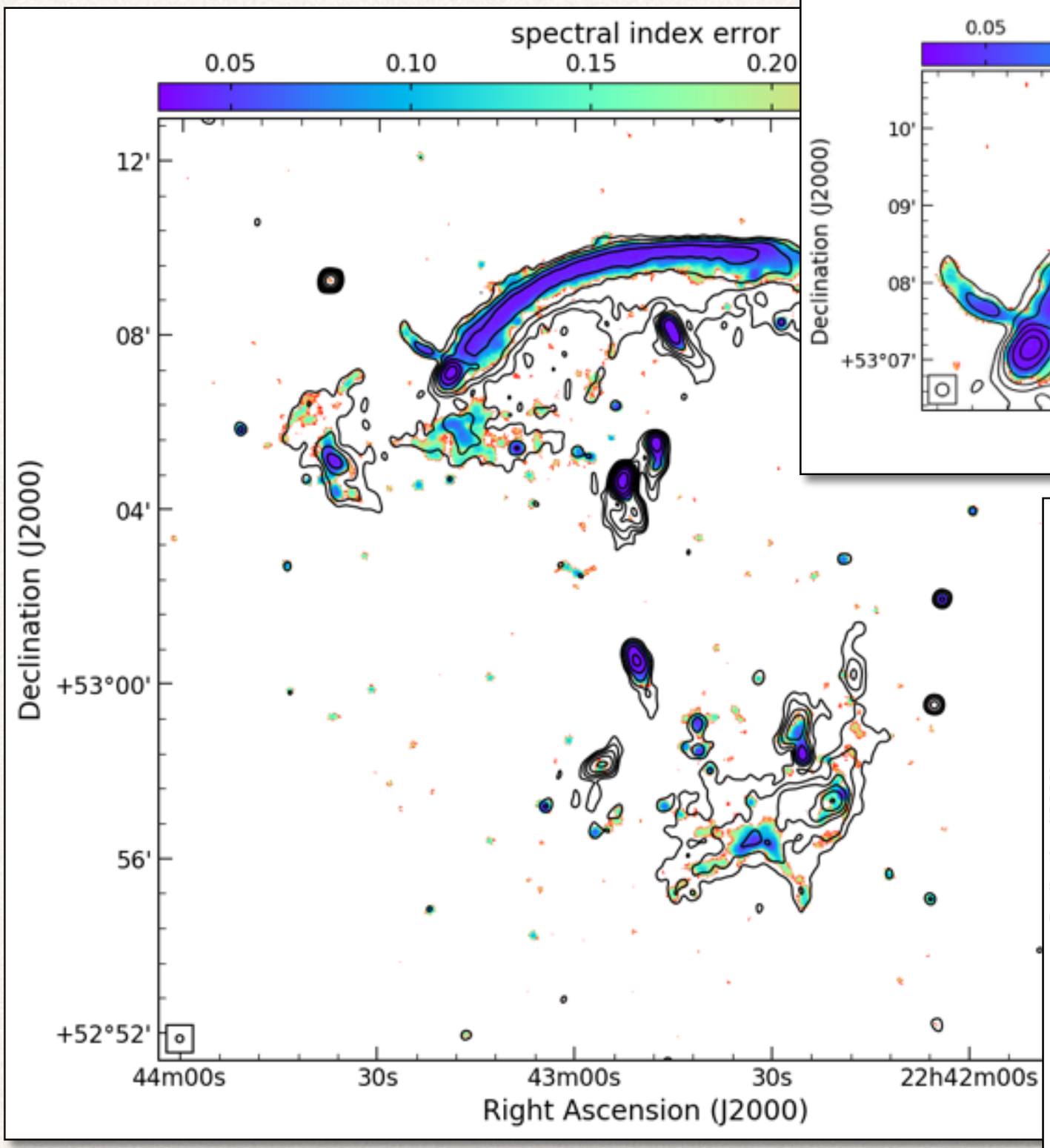
## L-band (5” res)

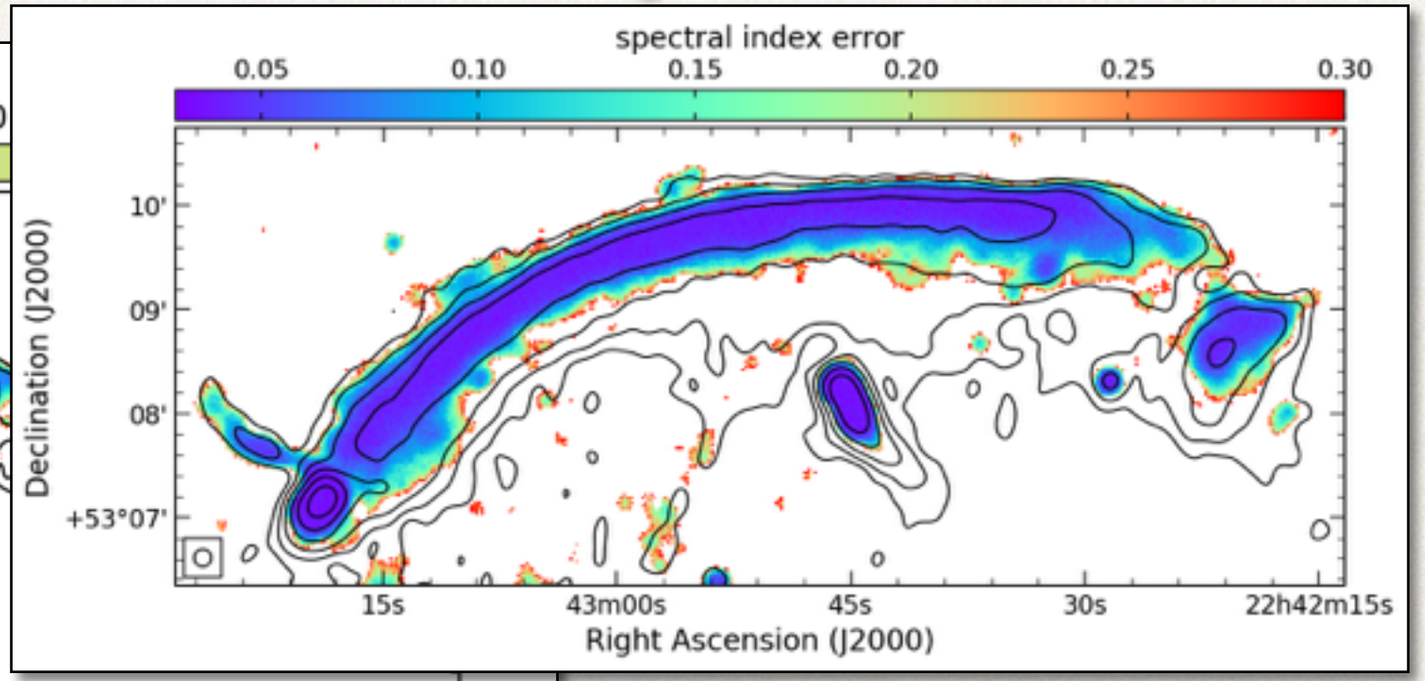


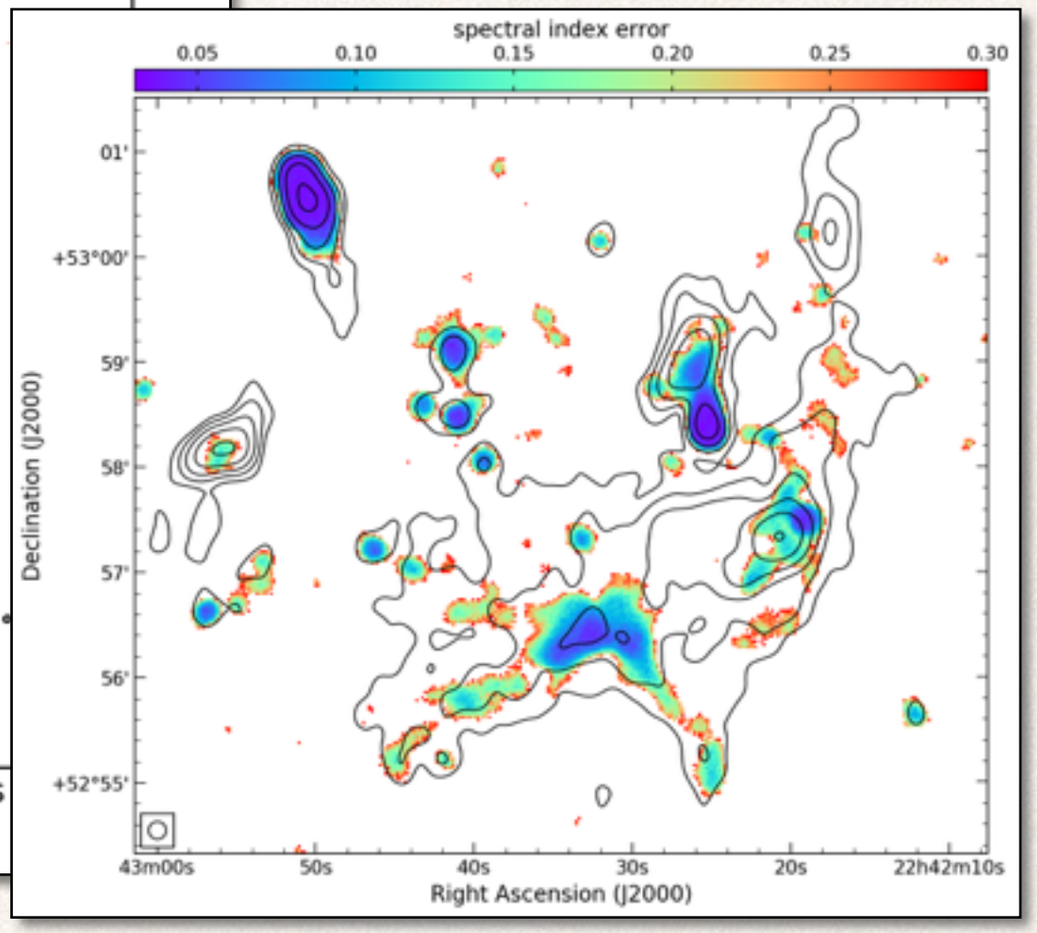

## L-band (45” res)



# Spectral Index analysis

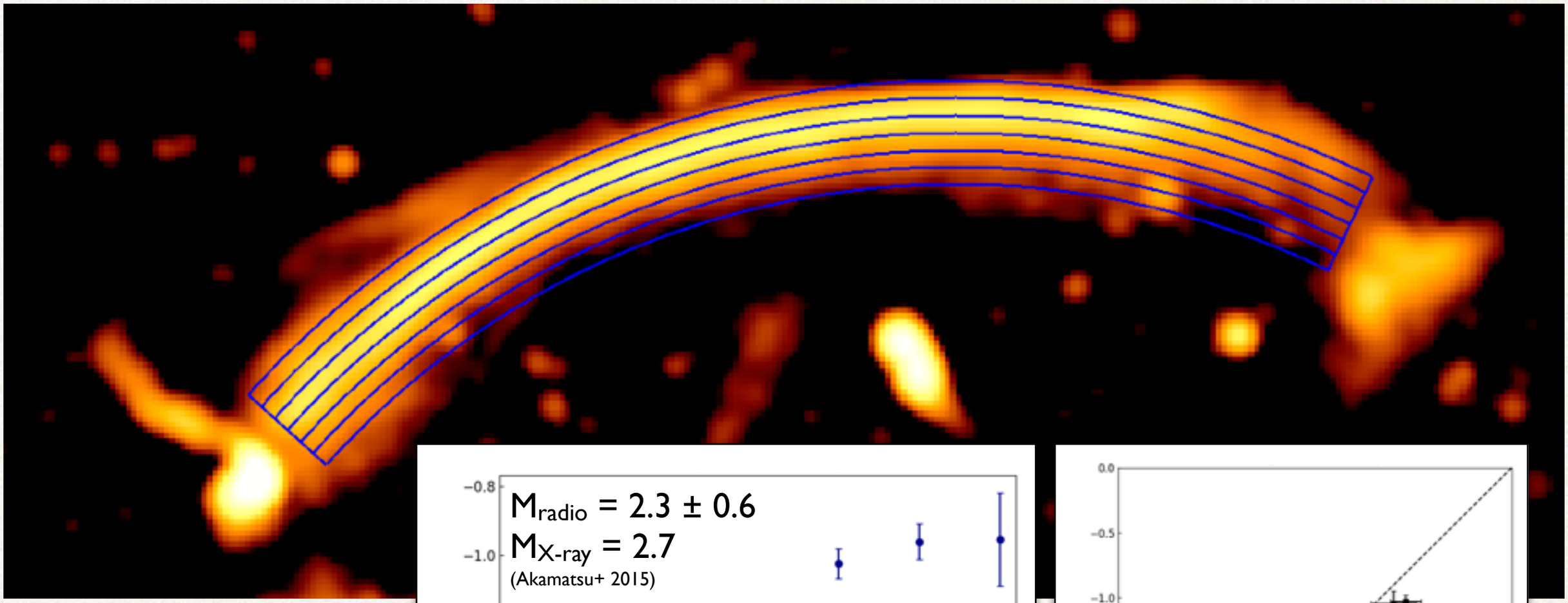


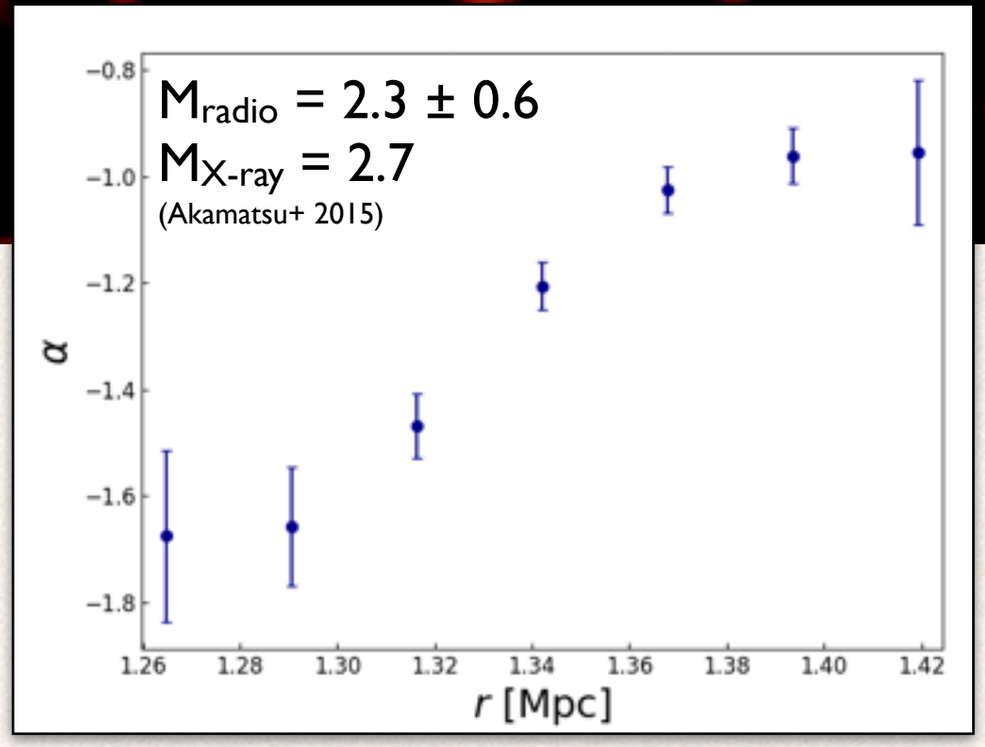



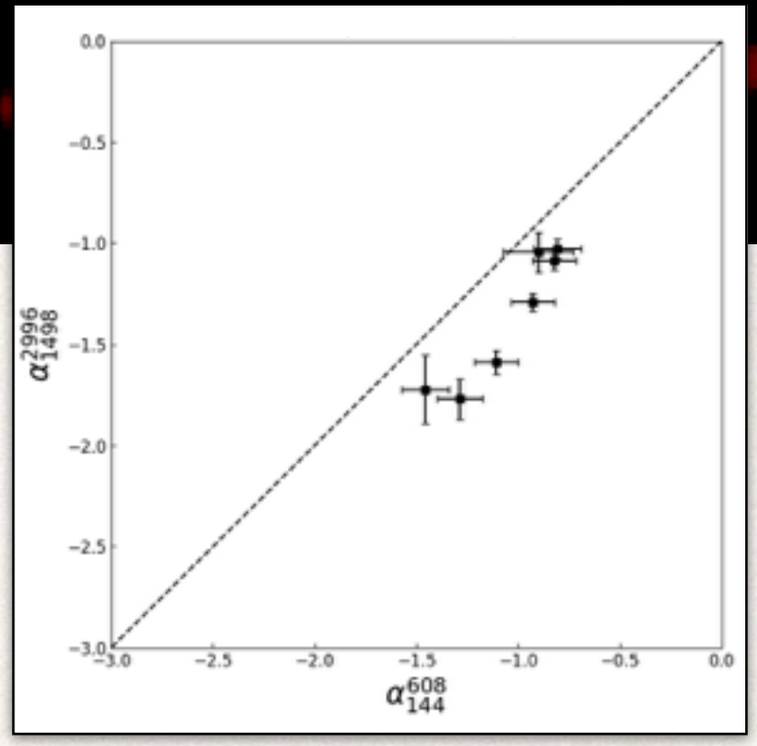



# Spectral Index analysis

## NORTHERN RELIC





# Polarization