Giada Pignataro
PhD student
Università di Bologna

Probing diffuse emission in radio bridges between galaxy clusters

LOFAR FAMILY MEETING 2023

June 14th 2023 **Olsztyn, Poland**

Supervisors:
Annalisa Bonafede
Gianni Bernardi
and others

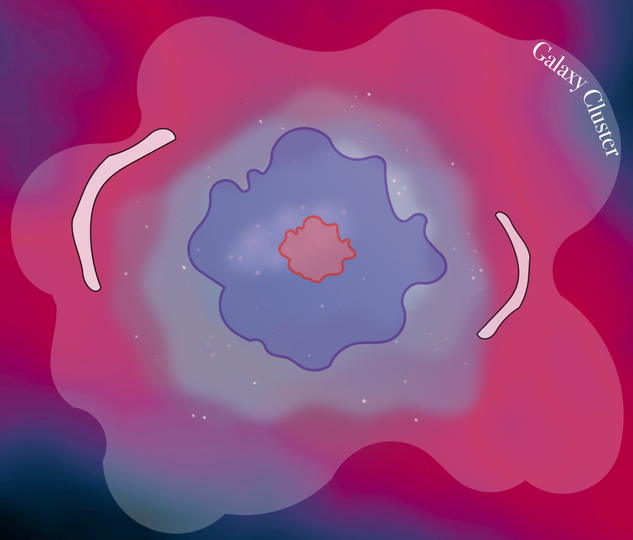
Diffuse non-thermal radio emission on large-scale

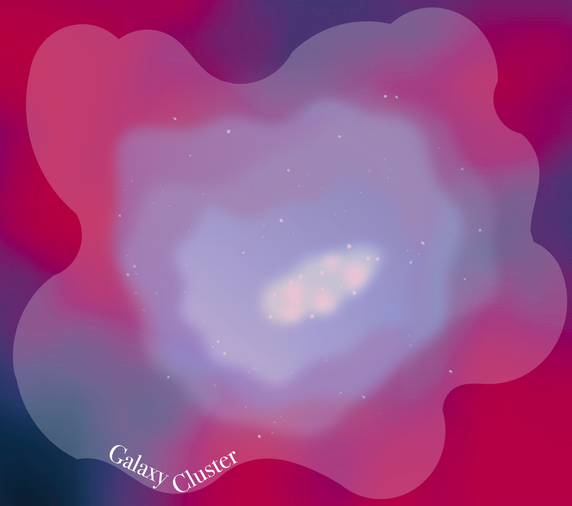
Three main classes found in galaxy clusters:

- ✦ Giant radio halos
- ✦ Mini halos
- ✦ Radio relics

Steep synchrotron spectra* !

$$1 < \alpha < 1.4$$





See e.g.
Van Weeren et al. 2019
Vazza et al. 2019
Brunetti & Vazza 2020

$* S \propto \nu^{-\alpha}$

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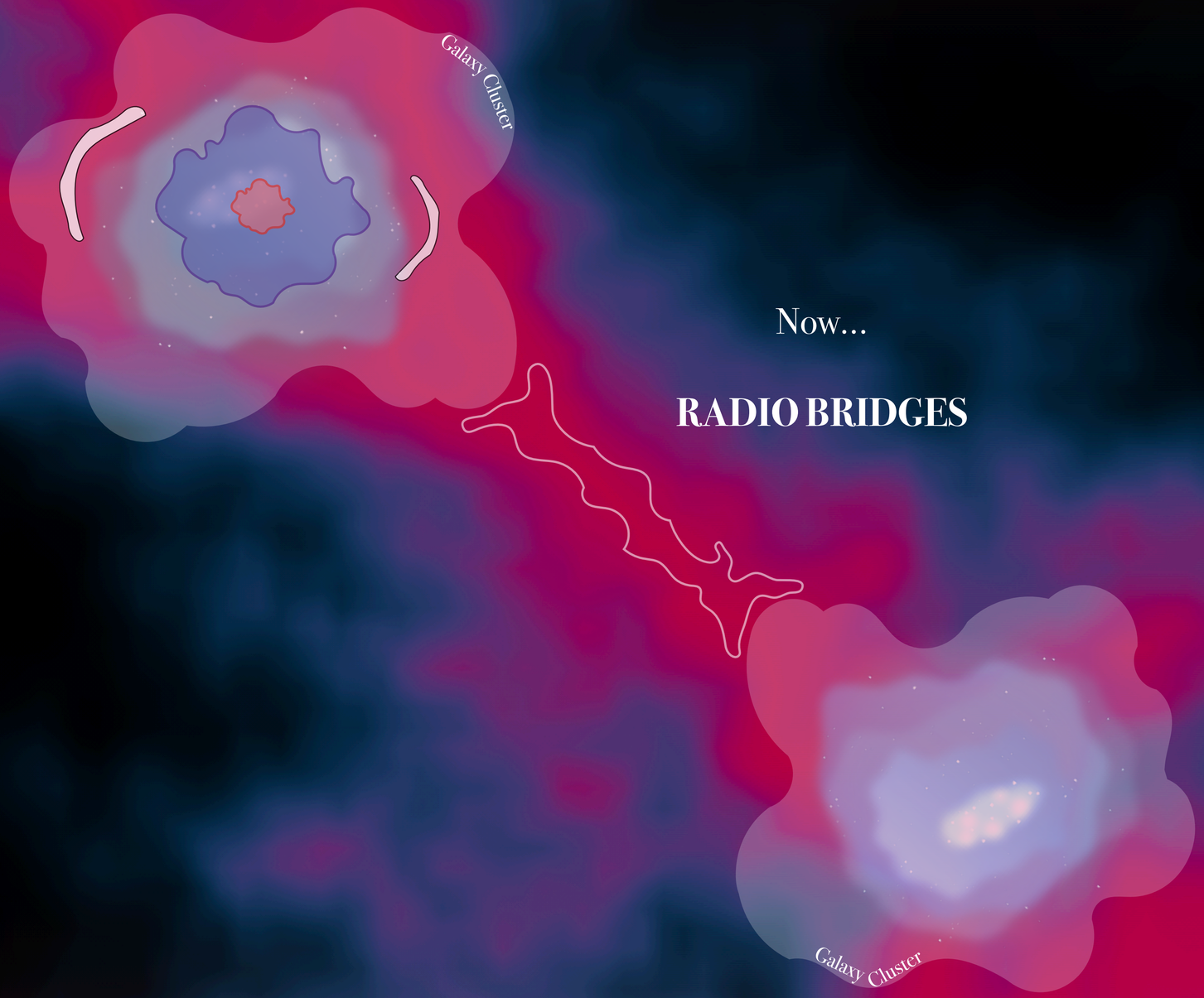

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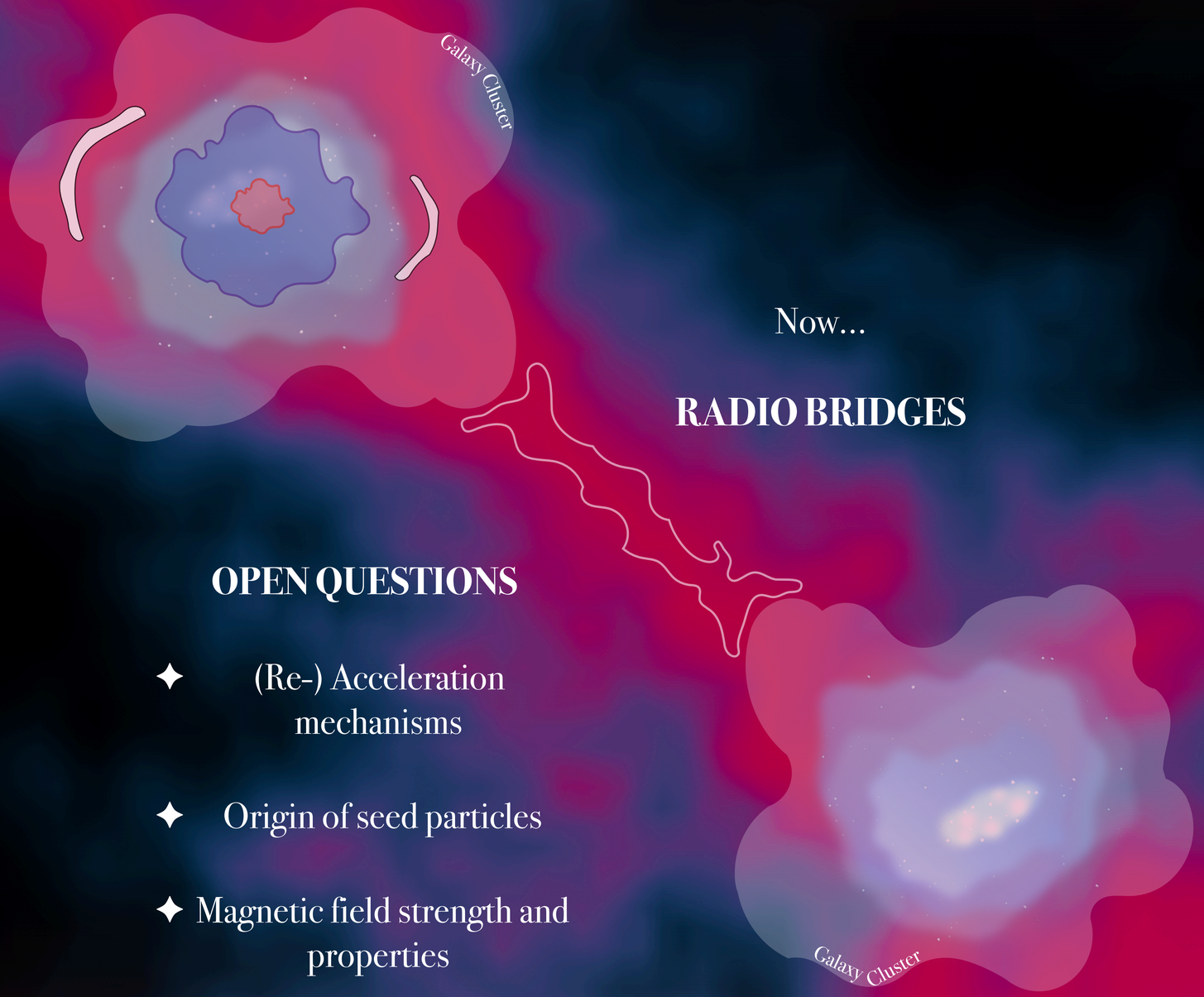

Now...

RADIO BRIDGES

OPEN QUESTIONS

- ✦ (Re-) Acceleration mechanisms
- ✦ Origin of seed particles
- ✦ Magnetic field strength and properties

MODELS

- ✦ Diffusive shock (Fermi I) acceleration (DSA) ?

↓

Spectra* with spectral index

$\alpha \sim 1.2 - 1.3$

- ✦ Turbulence acceleration (Fermi II) of electrons ?

↓

Fossil electrons released by past activity of AGNs and star-forming galaxies

Spectra with steep spectral index

$\alpha > 1.5$

See e.g.
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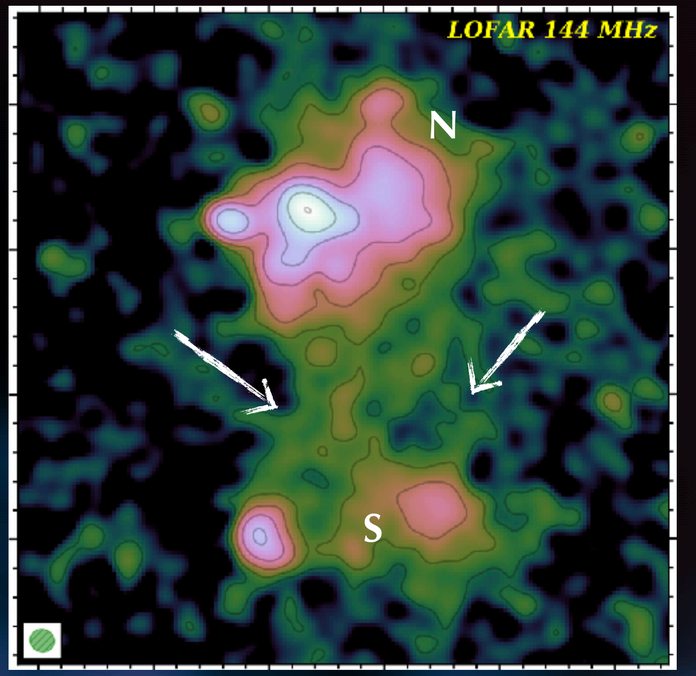
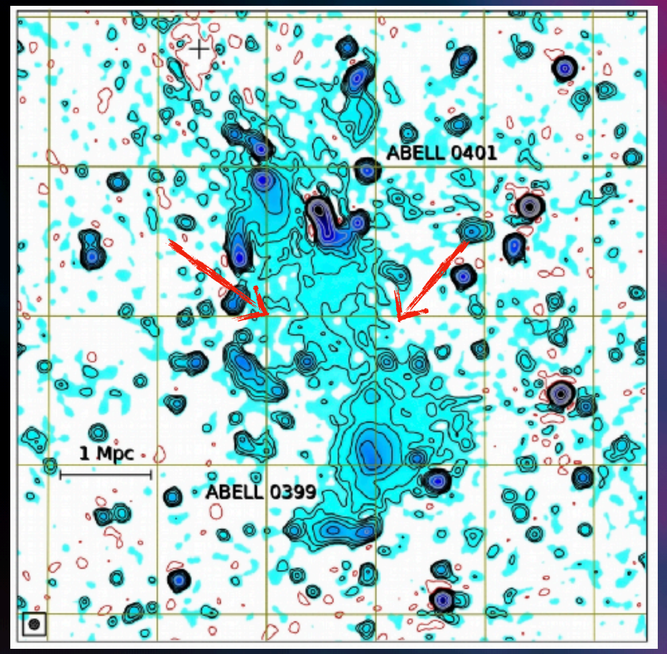
$* S \propto \nu^{-\alpha}$

Radio bridges so far…

Galaxy Cluster

ABELL 1758 N - S
Botteon et al. 2020
z~0.28
$M > 10^{15} M_{\odot}$
D~2Mpc





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Govoni et al. 2019
z~0.07
$M > 5 * 10^{14} M_{\odot}$
D~3Mpc

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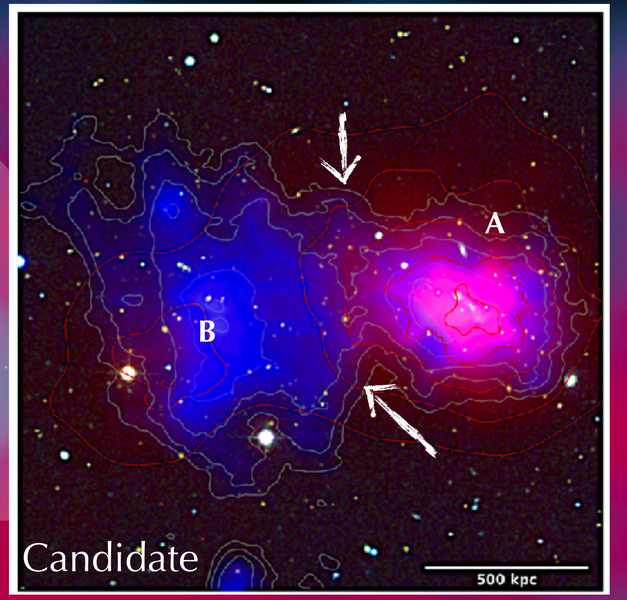

ABELL 1430 A - B
Hoeft et al. 2021
z~0.36
$M \sim 7 * 10^{14} M_{\odot}$

Radio bridges so far…

We need **MULTIFREQUENCY** studies!

Characterisation of spectral properties &

brightness distribution

+

More samples for statistical assessment

Galaxy Cluster

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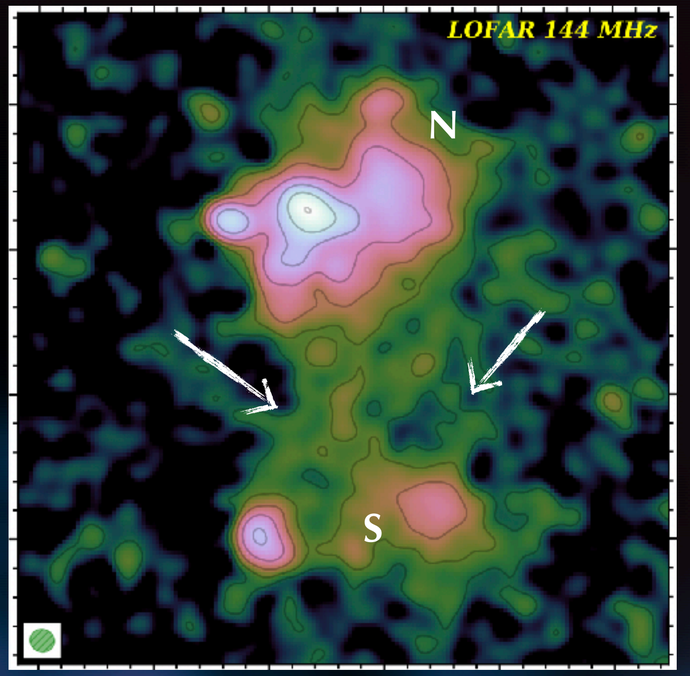

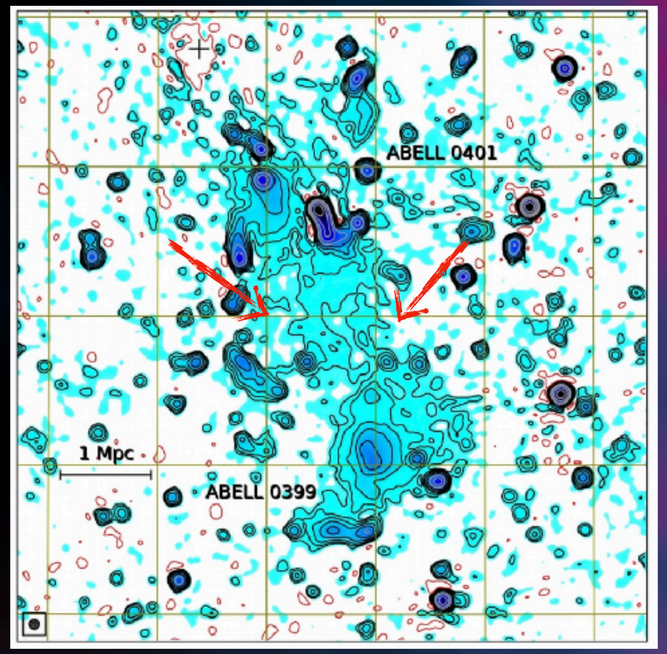

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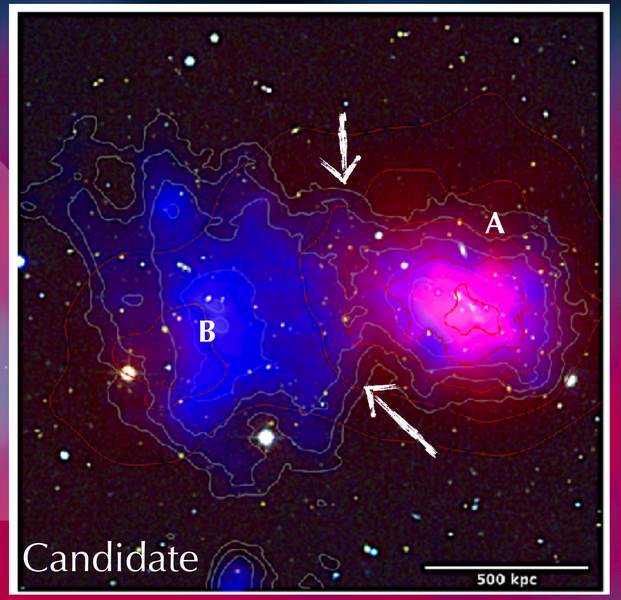

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uGMRT + LOFAR data analysis

A399-A401

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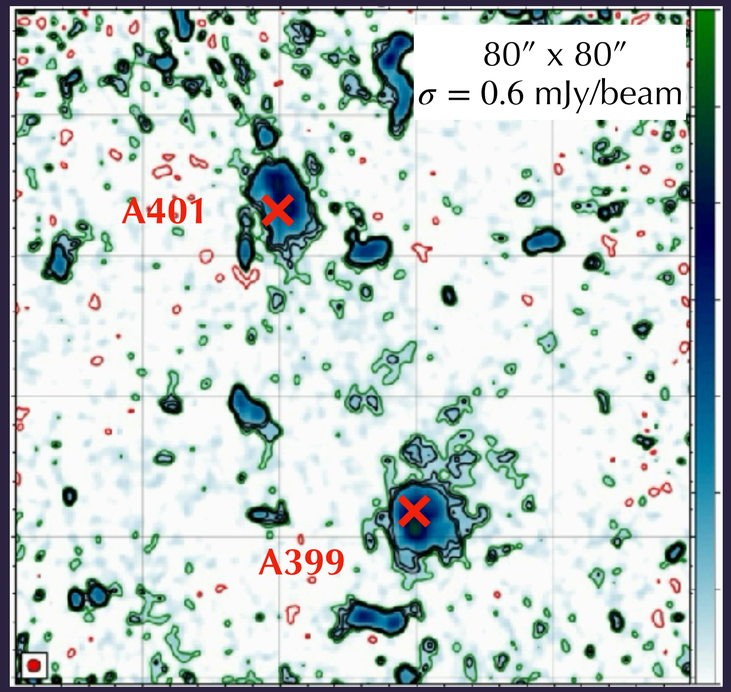
13° dec

uGMRT band3 **250-500MHz**

Pignataro et al., submitted

10 **hrs** on source time

Two pointings - linear mosaic

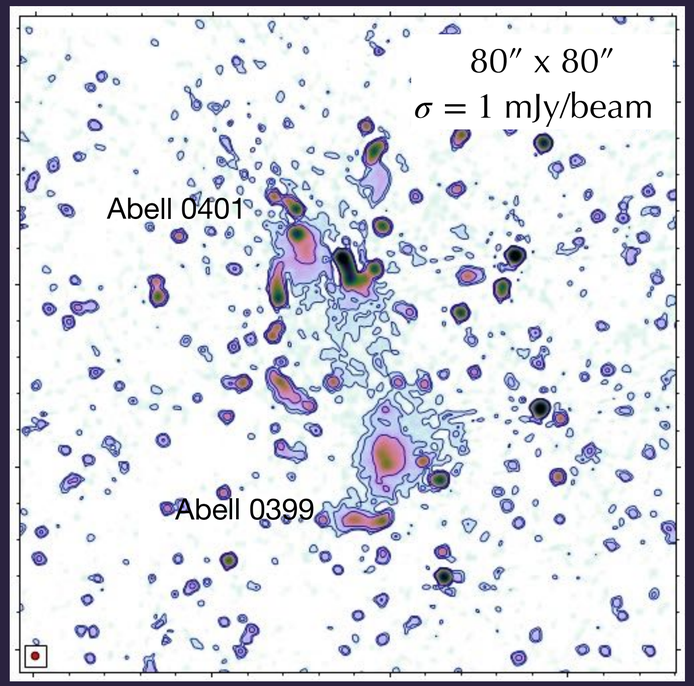


LOFAR HBA at **140 MHz**

Govoni et al. 2019

10 **hrs** on source time

3-σ detection of radio bridge



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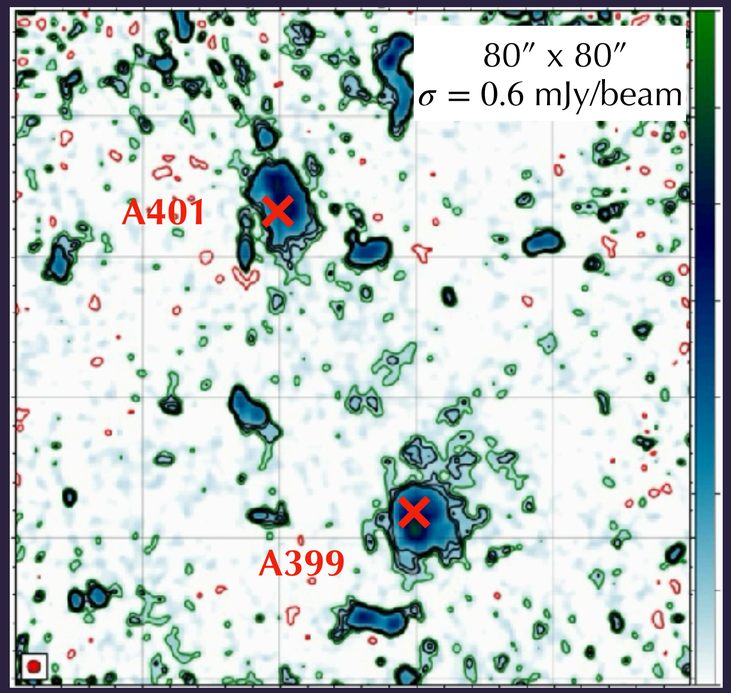

No diffuse emission from radio bridge detected @400MHZ

Define a **new procedure** to place limits on the spectrum and radio emission of radio bridges

INJECTION METHOD

e.g. Venturi et al. 2008,
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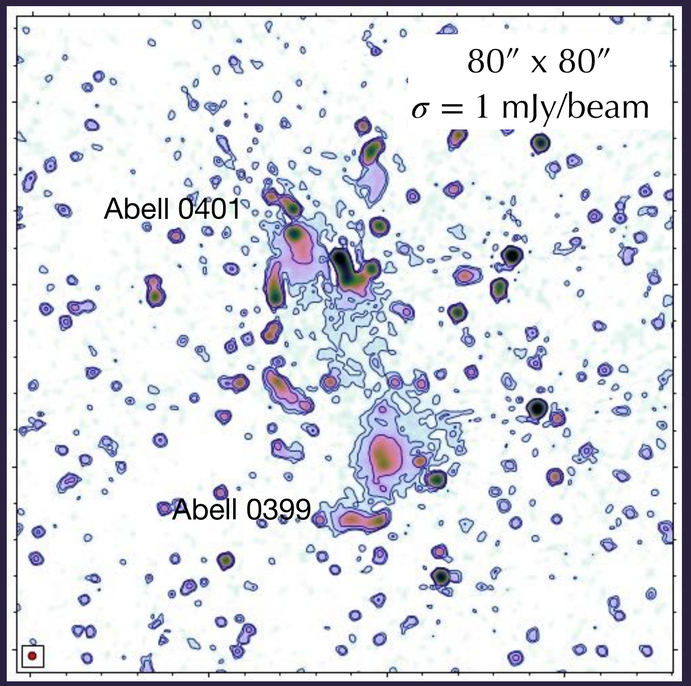

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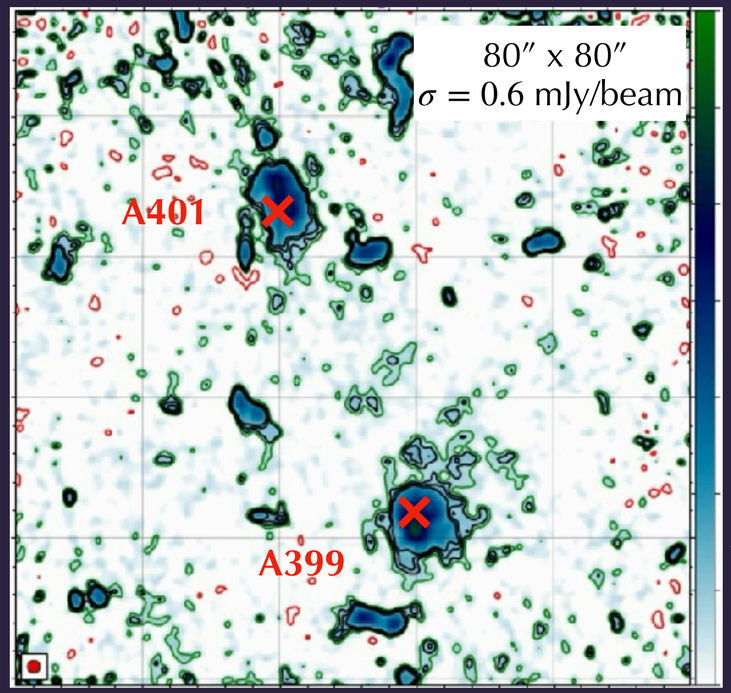

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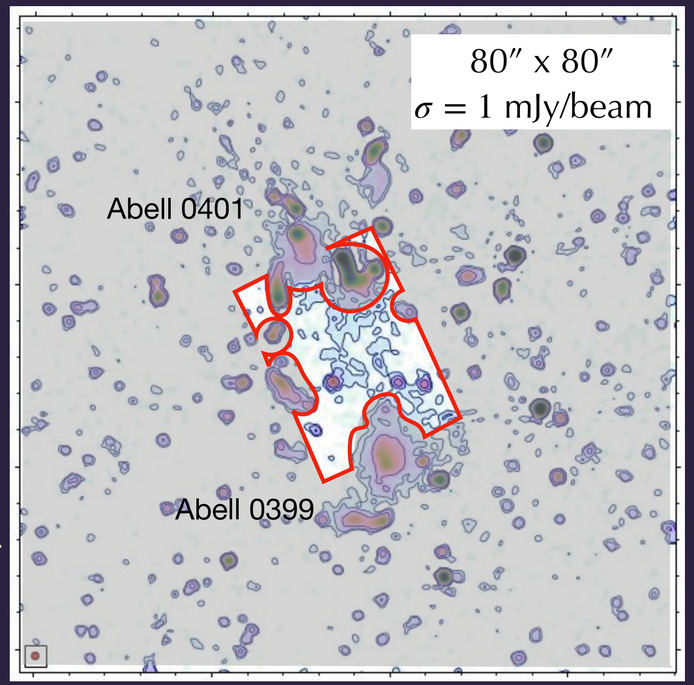

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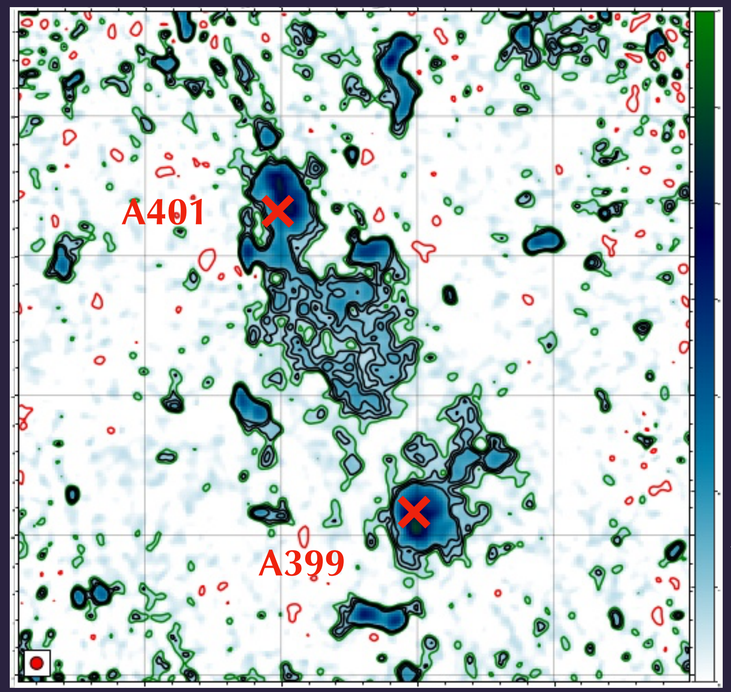

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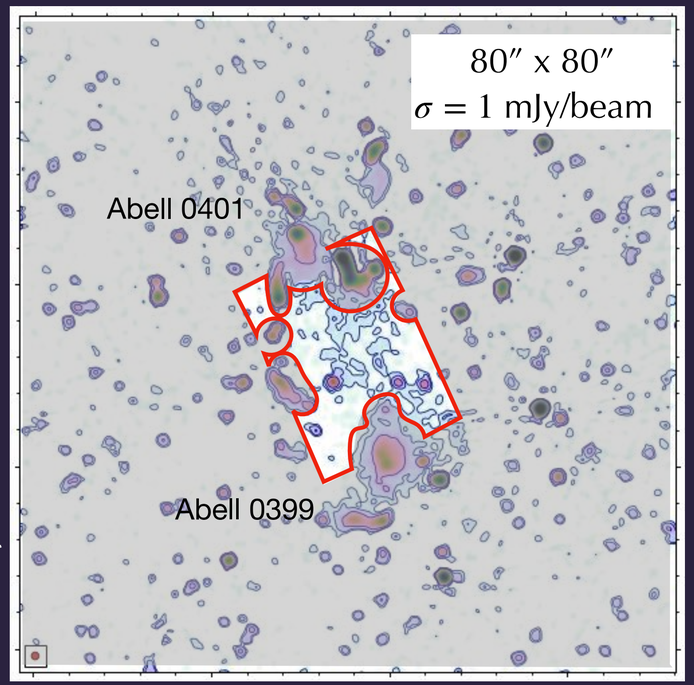

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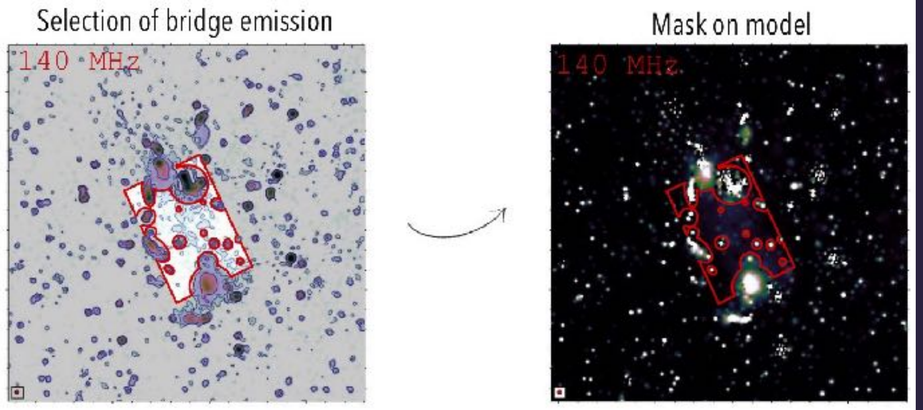
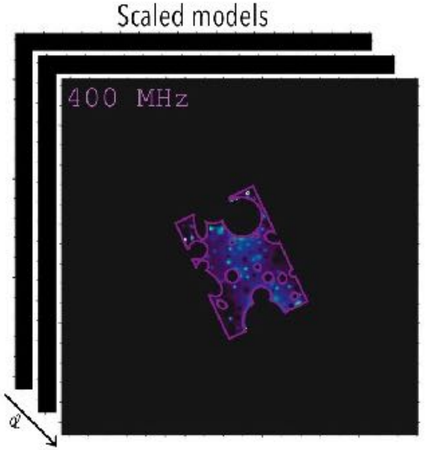




Extrapolation of bridge model at uGMRT frequency with different spectral indexes

$$S_{inj}(\alpha) = S_{LOFAR}\left(\frac{\nu_{GMRT}}{\nu_{LOFAR}}\right)^{-\alpha}$$

+

uGMRT primary beam attenuation

INJECTED DATA =

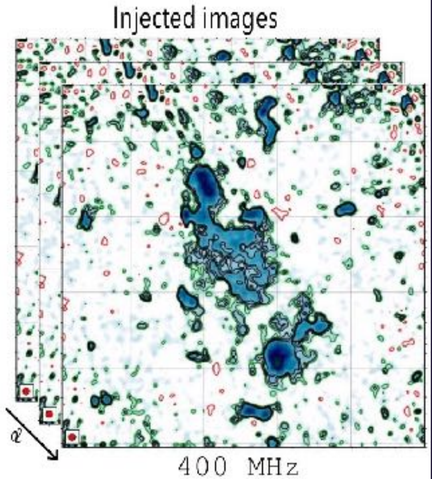
DATA + MODEL DATA

+

linear mosaicking

+

imaging



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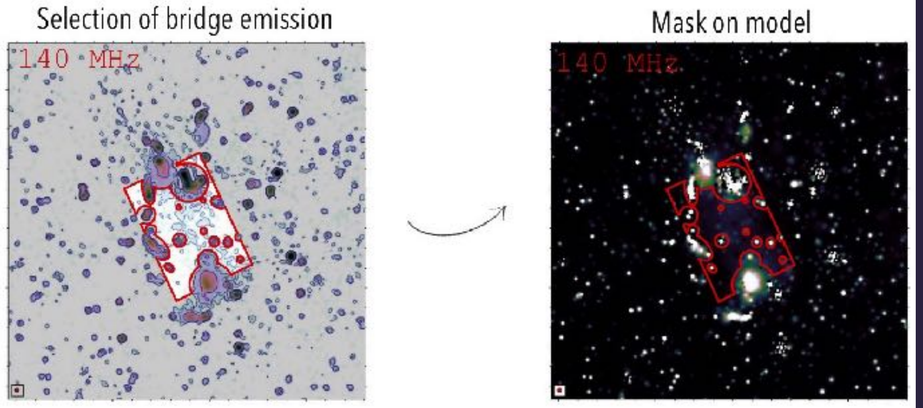

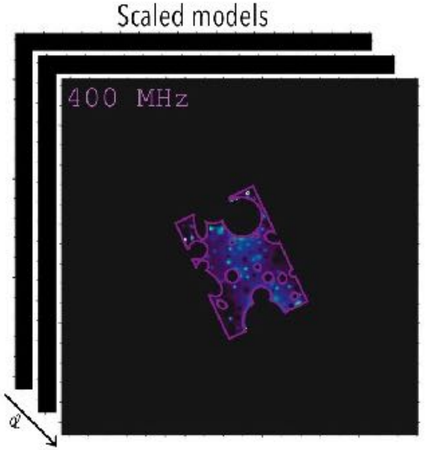

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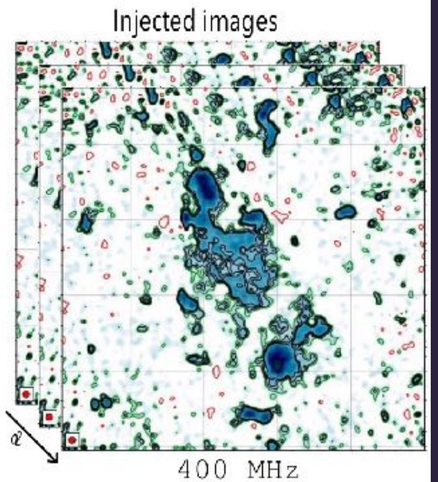

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$$R(\alpha) = \frac{S_{inj}(\alpha)}{S_0}$$

uGMRT + LOFAR data analysis

Pignataro et al., submitted

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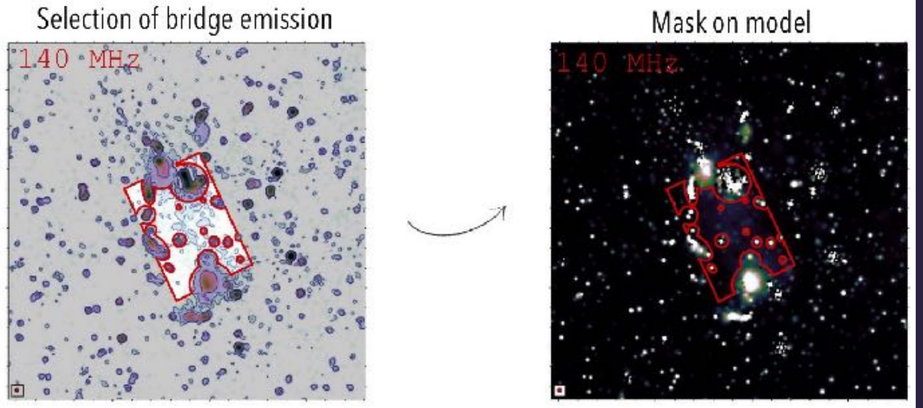

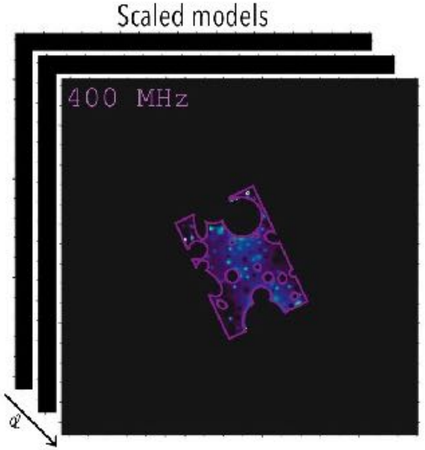

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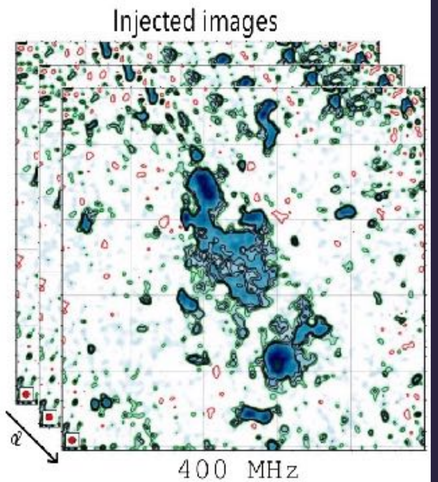

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uGMRT + LOFAR data analysis

Pignataro et al., submitted

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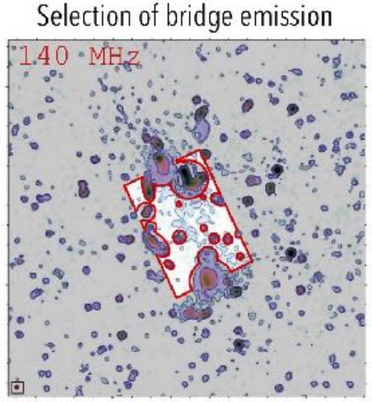

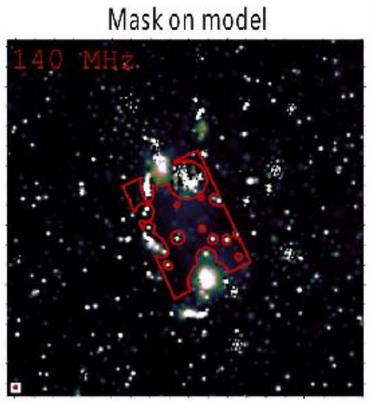

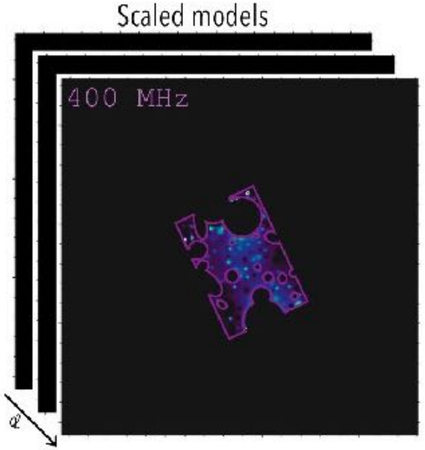

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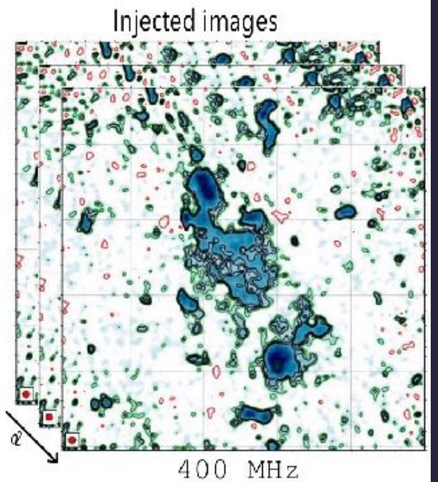

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- Lower limit on bridge spectral index at **95% confidence level**

$$\alpha > 1.9$$

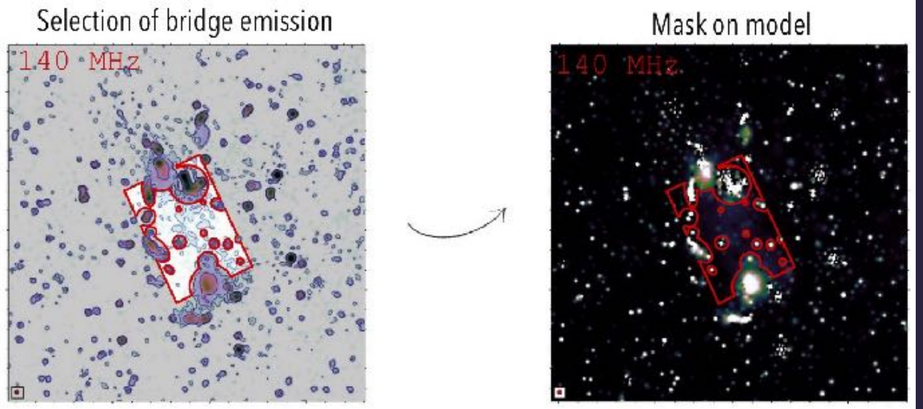
Ultra-steep spectrum between 140 and 400 MHz

uGMRT + LOFAR data analysis

Pignataro et al., submitted

A399-A401

INJECTION METHOD



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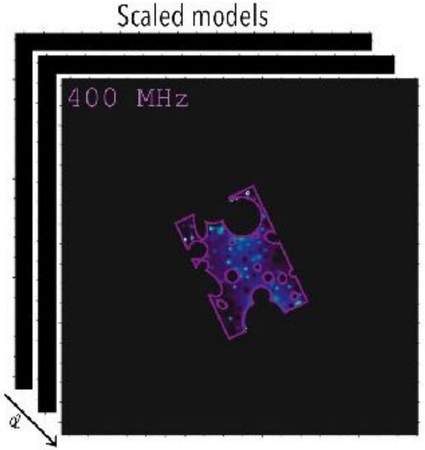

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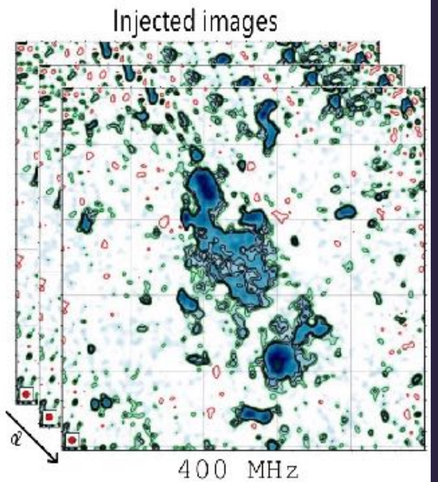

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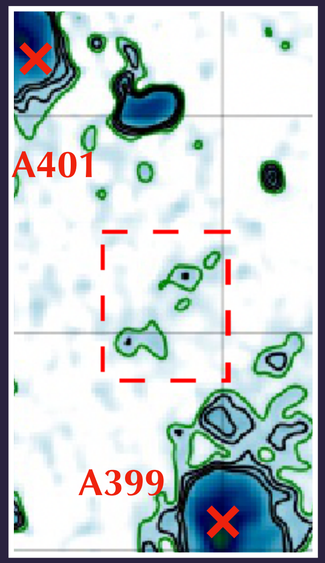
Ultra-steep spectrum between 140 and 400 MHz

- Bridge-patch spectral index

$$\alpha_{140}^{400} = 1.1 \pm 0.2$$



LOFAR LBA data analysis

WORK IN PROGRESS

A399-A401

MULTIFREQUENCY study!

✓ LOFAR HBA

✓ uGMRT

&

... LOFAR LBA

18 hours LBA observation at central frequency of **60MHz**

Calibration strategy:

Library for Low Frequencies (**LiLF**)*

To solve for systematic effects (also low-dec target)

Promising preliminary results from pipeline!

With DD-cal we aim to reach a

rms noise < 1mJy/beam

(beam:50”x50”)

Direction Independent Errors (DIE) calibration ✓

Direction Dependent Errors (DDE) calibration

*De Gasperin et al. 2018, 2019, 2020

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LOFAR LBA data analysis

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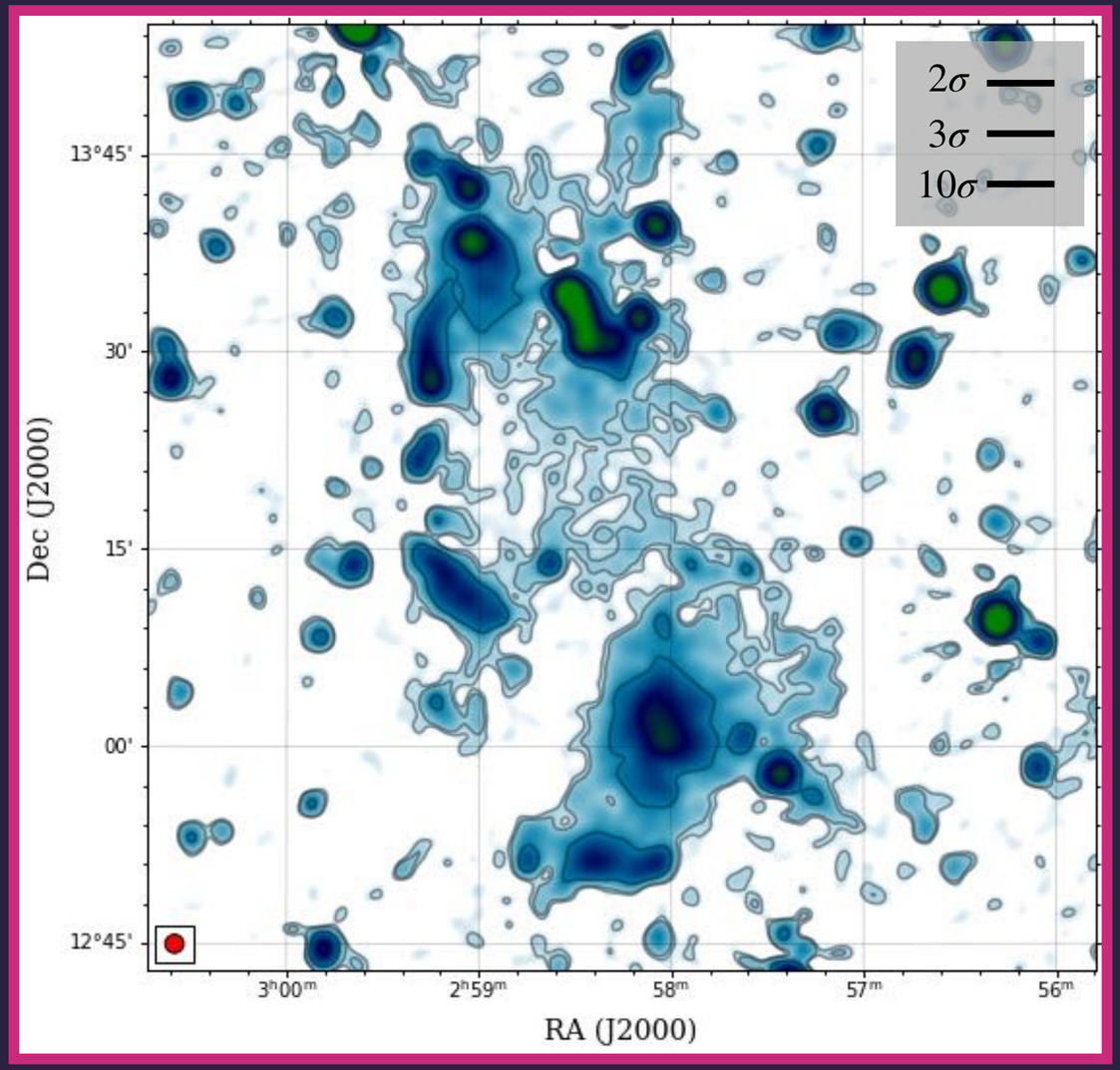
LBA



Preliminary results from direction-independent calibration only

85″ x 85″

$\sigma_{rms}^{LBA} \sim 5mJy/beam$

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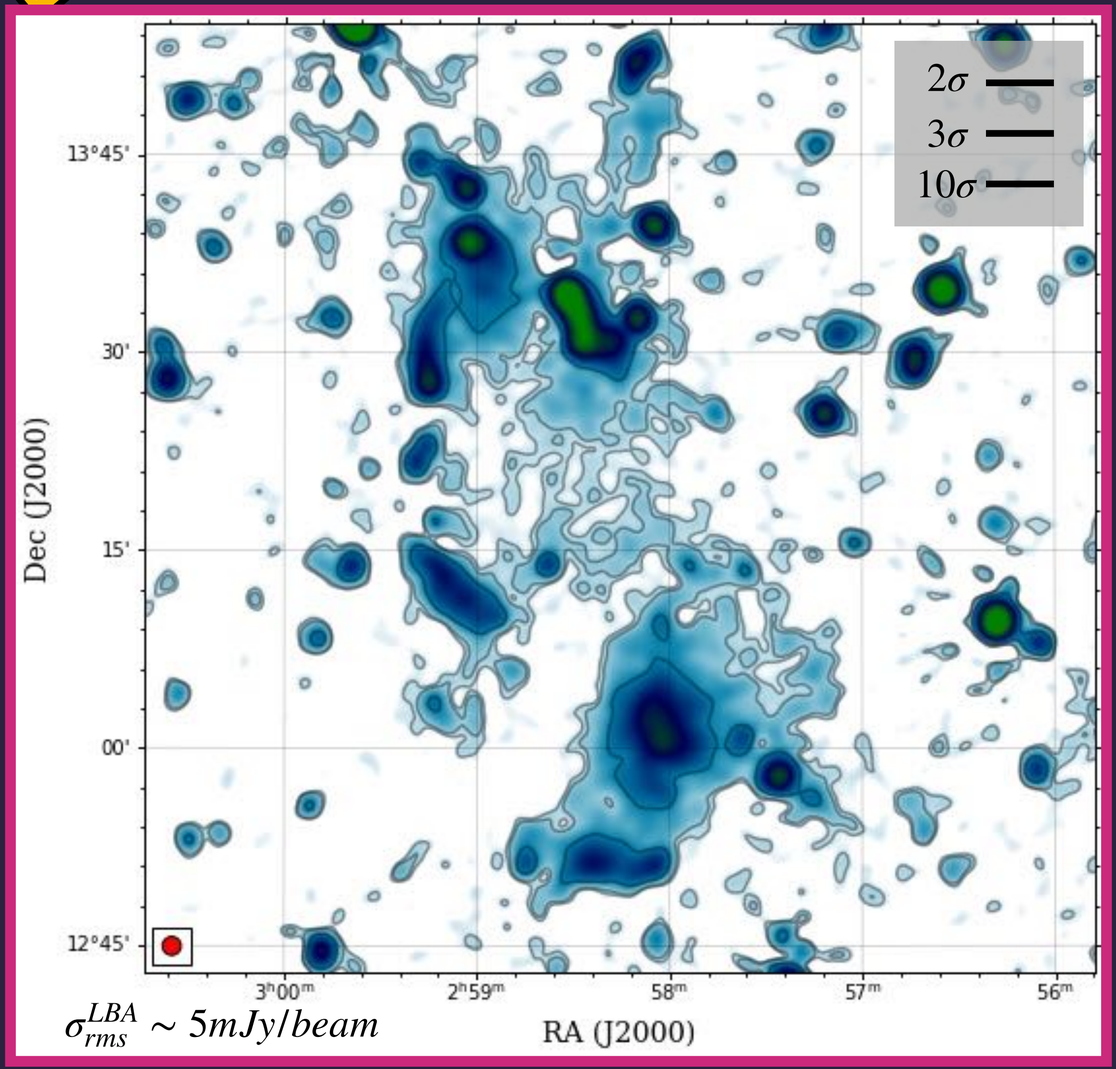
LBA



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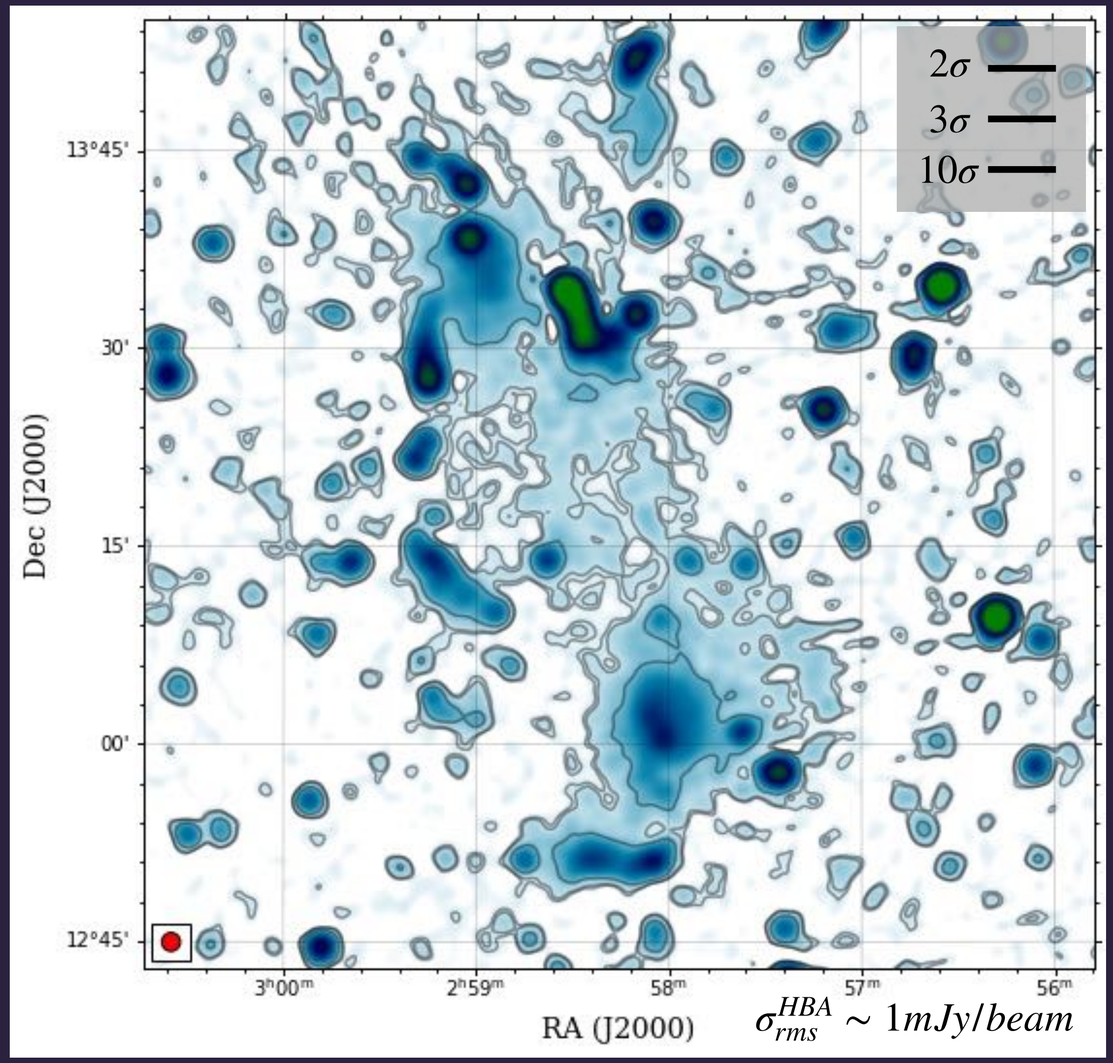
85″ x 85″

HBA (Govoni et al. 2019)



$\sigma_{rms}^{HBA} \sim 1 mJy/beam$

We can determine a first estimate of the **bridge spectral index using HBA and LBA data**

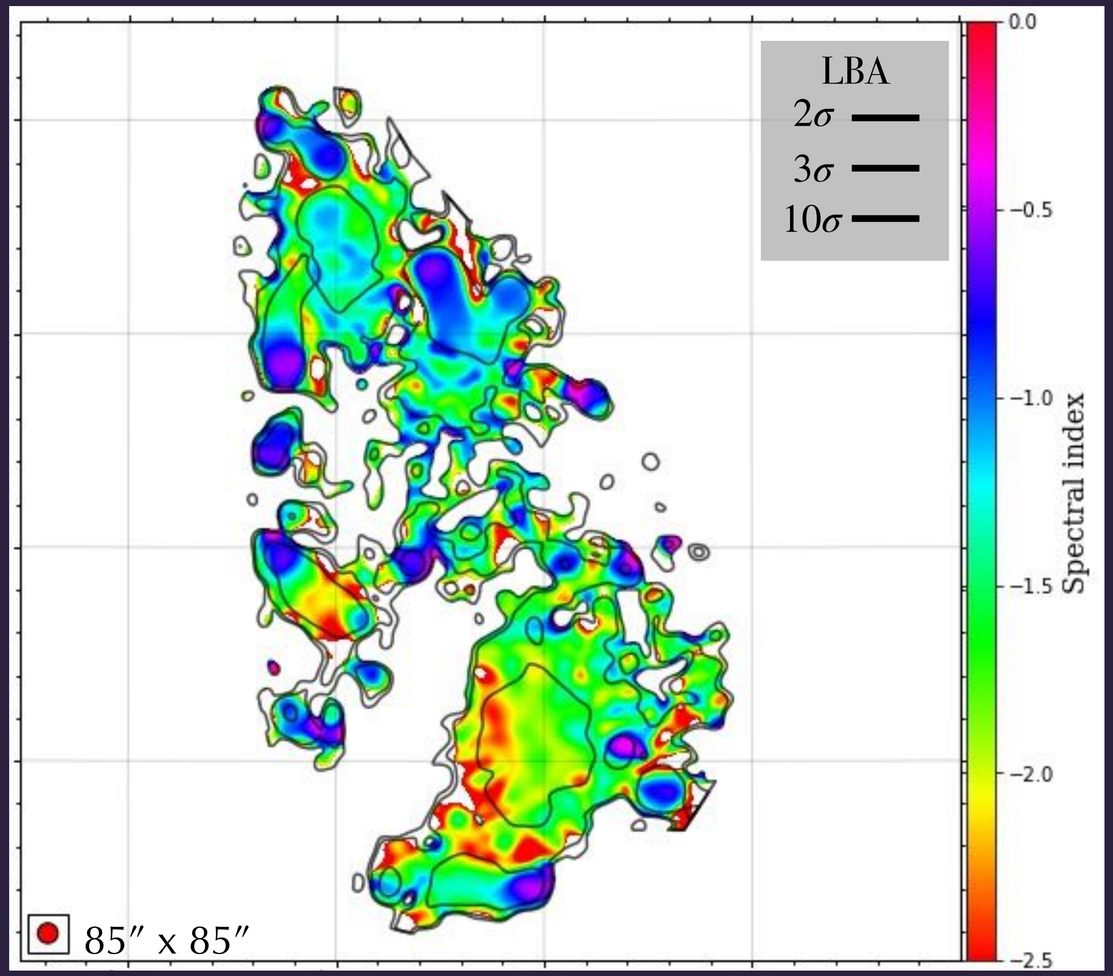
WORK IN PROGRESS

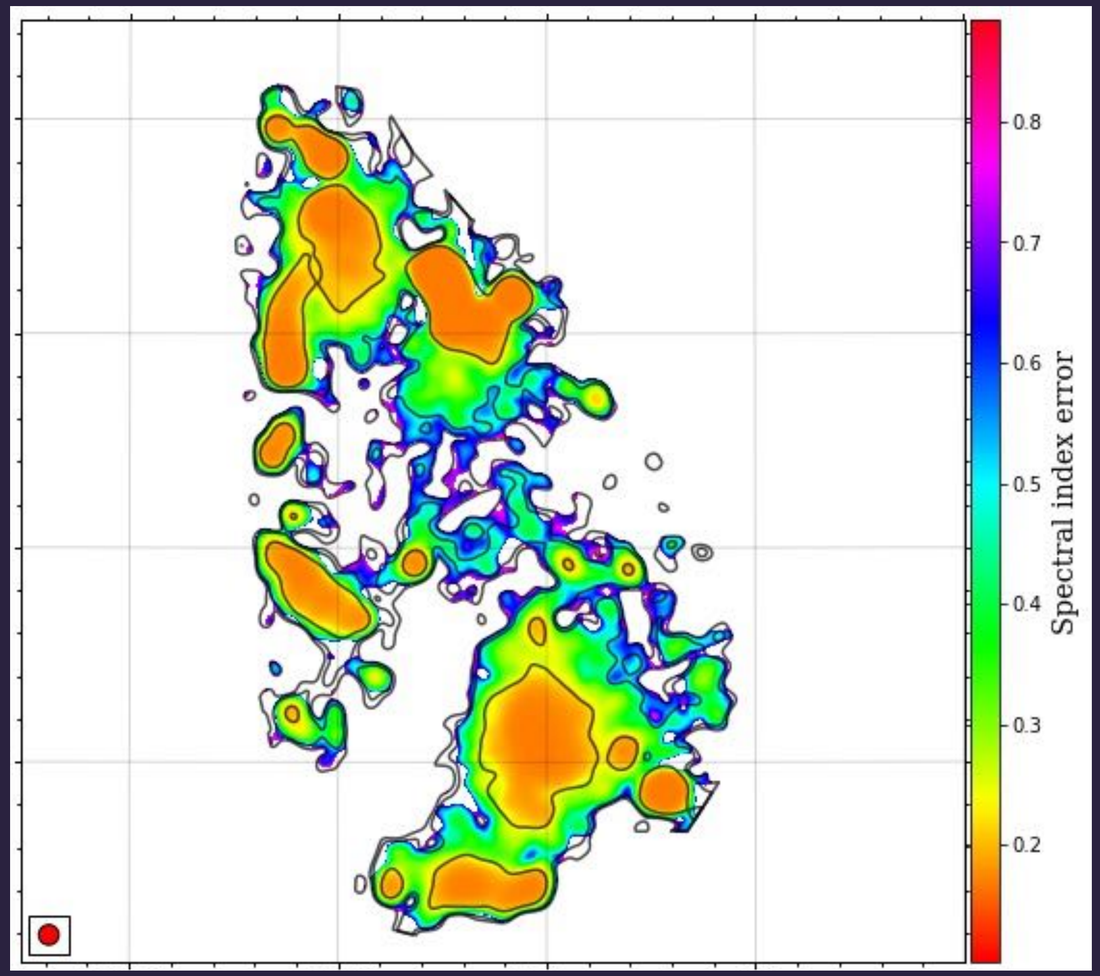
LOFAR LBA data analysis

A399-A401

BRIDGE SPECTRAL INDEX

Preliminary results between **60 MHz and 140 MHz**





$* S \propto \nu^{\alpha}$

WORK IN PROGRESS

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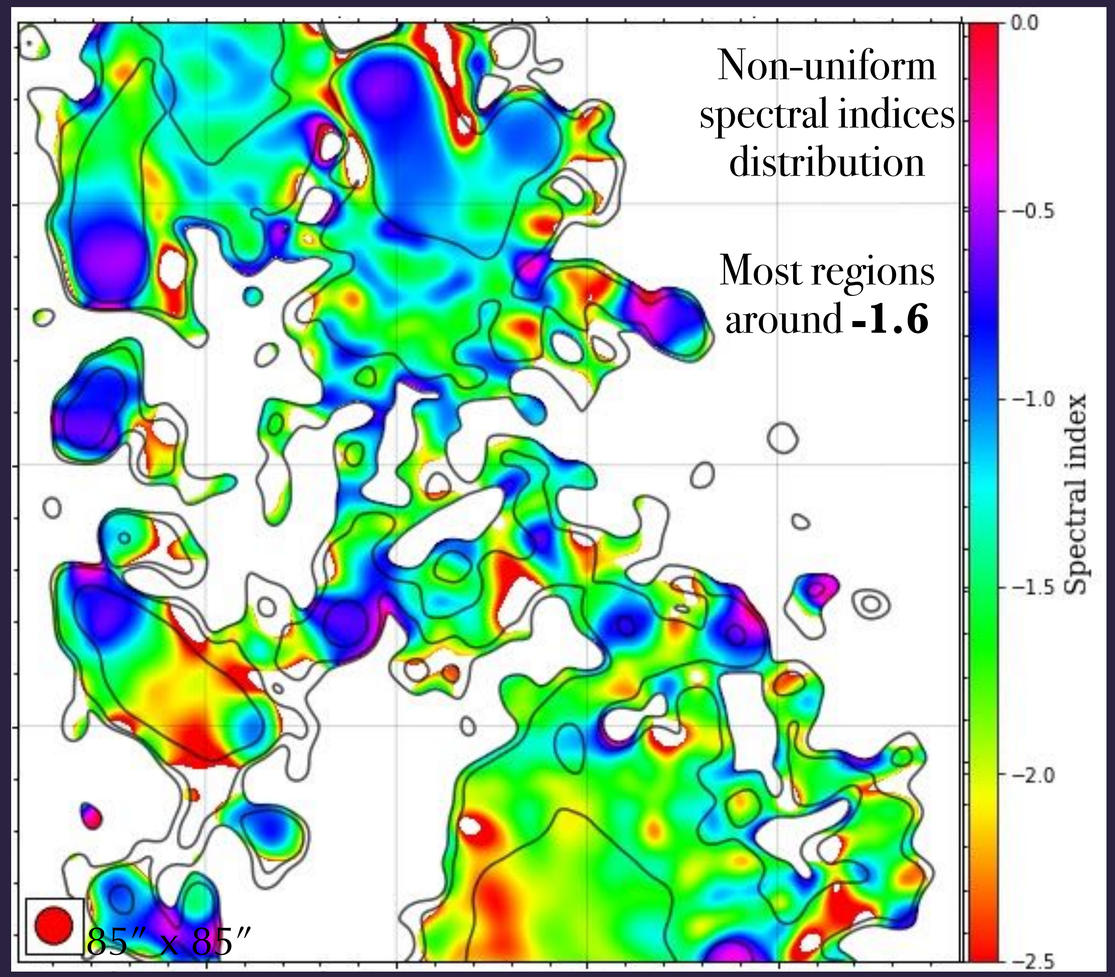

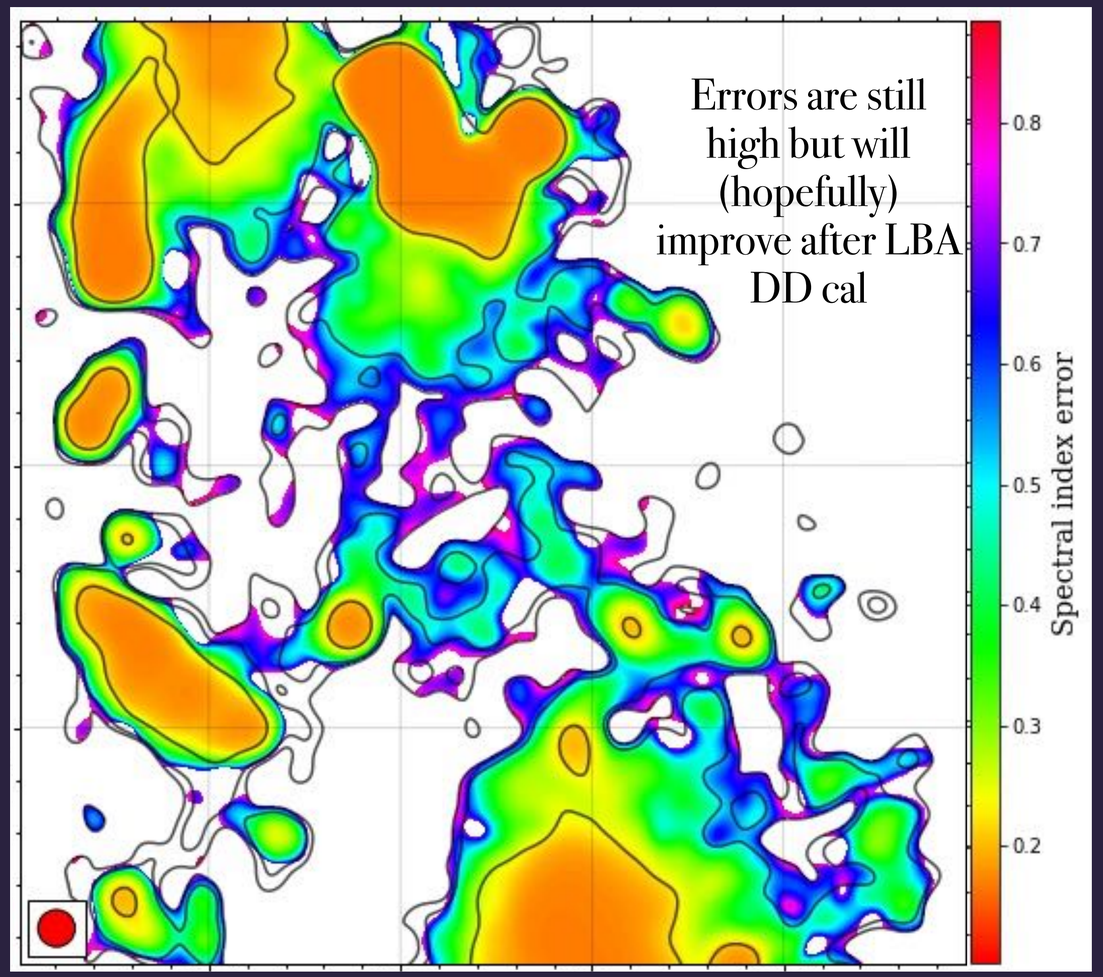

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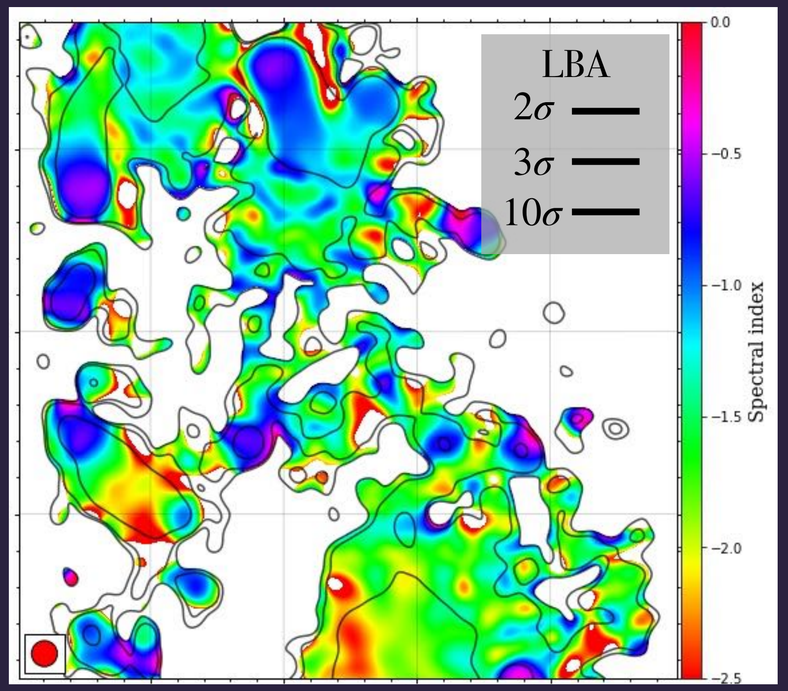

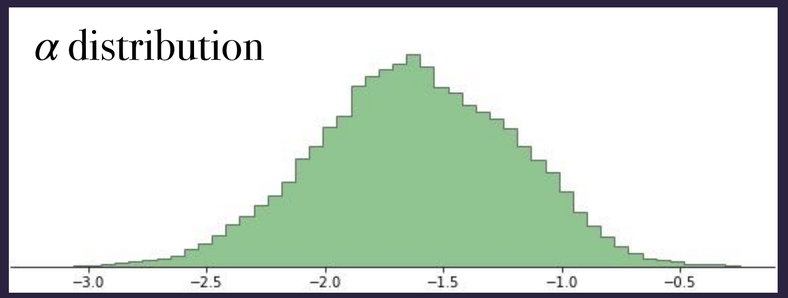

- Masking compact-sources and radio-halos, the integrated spectral index over the bridge area is

$S_{60} = 1.2 \pm 0.1$ Jy

$$\langle \alpha \rangle_{60}^{140} = -1.6 \pm 0.2$$

$S_{140} = 320 \pm 30$ mJy

WORK IN PROGRESS

LOFAR LBA data analysis

A399-A401

BRIDGE SPECTRAL INDEX

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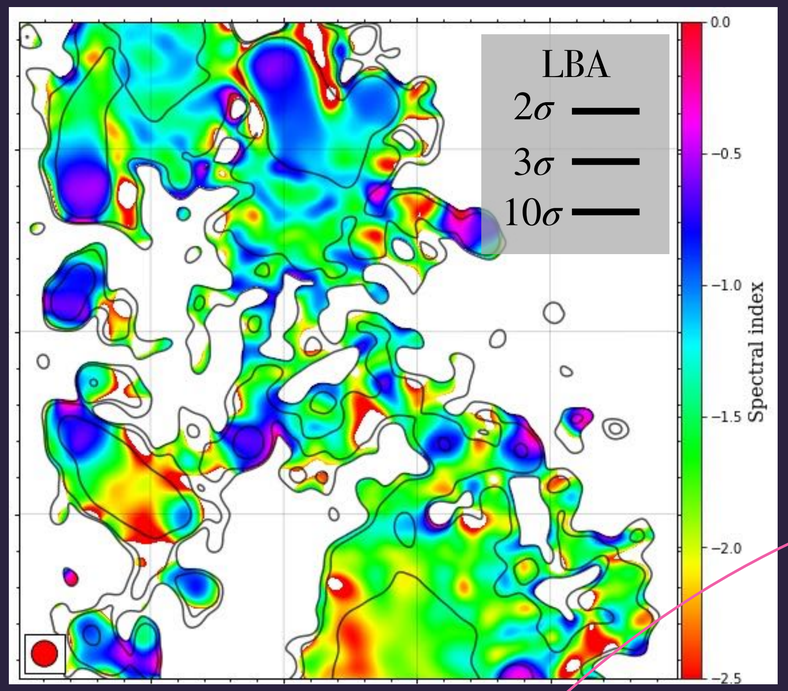

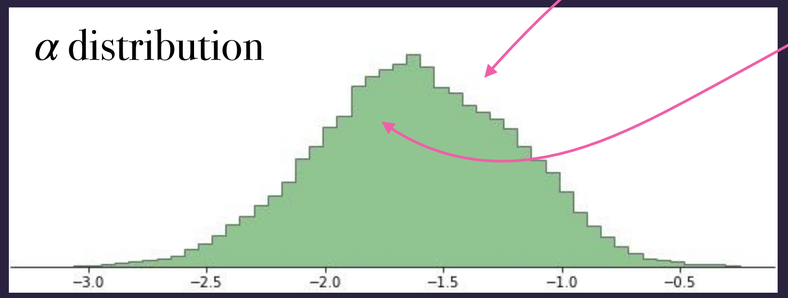

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- The distribution of spectral index values over the bridge region is not uniform

Mostly regions with $-1.6 \lesssim \alpha \lesssim -1.3$ (green)

But also steeper regions with $-2.0 \lesssim \alpha \lesssim -1.8$ (yellow)

Disfavours shock acceleration models for these regions

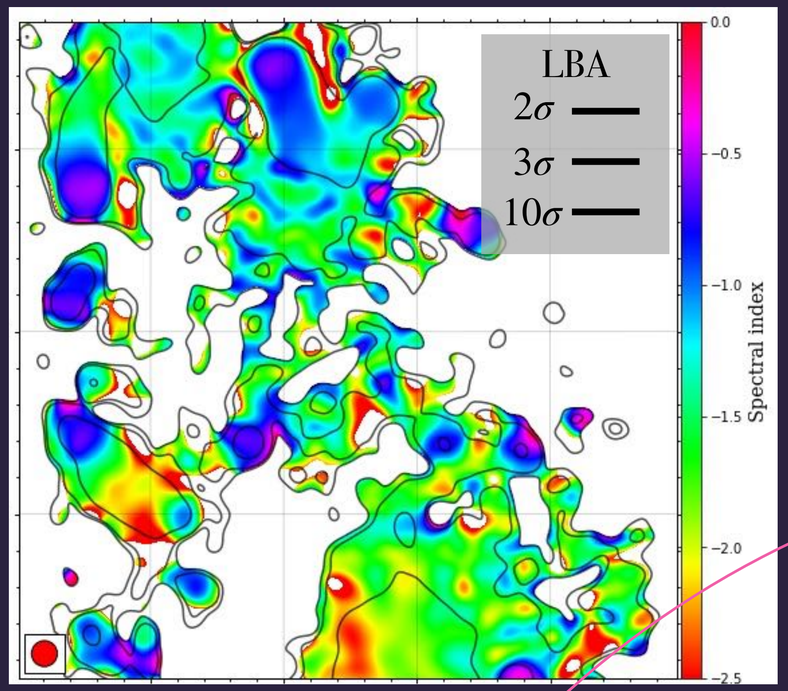
WORK IN PROGRESS

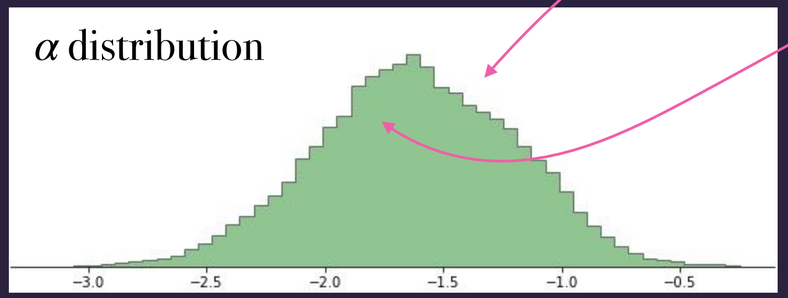
LOFAR LBA data analysis

A399-A401

BRIDGE SPECTRAL INDEX

Preliminary results between **60 MHz and 140 MHz**





- Masking compact-sources and radio-halos, the integrated spectral index over the bridge area is

$S_{60} = 1.2 \pm 0.1$ Jy $\quad \langle\alpha\rangle_{60}^{140} = -1.6 \pm 0.2 \quad S_{140} = 320 \pm 30$ mJy

- The distribution of spectral index values over the bridge region is not uniform
  - Mostly regions with $-1.6 \lesssim \alpha \lesssim -1.3$ (green)
  - But also steeper regions with $-2.0 \lesssim \alpha \lesssim -1.8$ (yellow)
  - Disfavours shock acceleration models for these regions
- Improvements to be made next:
  - DD calibration of LBA data
  - Subtraction of compact sources

Future & conclusions

uGMRT/LOFAR

Lower limit on A399-A401 bridge spectral index

$\alpha > 1.9$

Bridge-patch spectral index

$\alpha_{140}^{400} = 1.1 \pm 0.2$

RESULTS

New procedure to derive limits on the bridges emission that can be applied to **more systems in future observations**

LOFAR LBA

Preliminary results spectral index between 140 and 60 MHz

$\langle \alpha \rangle_{60}^{140} = 1.6 \pm 0.2$

NEXT

Final analysis of the spectral index of the radio bridge in A399-A401

DD calibration of **LOFAR LBA** data @60MHz

Compare with theoretical models

Explore **SUPERCLUSTERS OF GALAXIES** with **LoTSS**

Search for pairs/triplets

Statistical assessment on radio bridges

Thank you for your attention