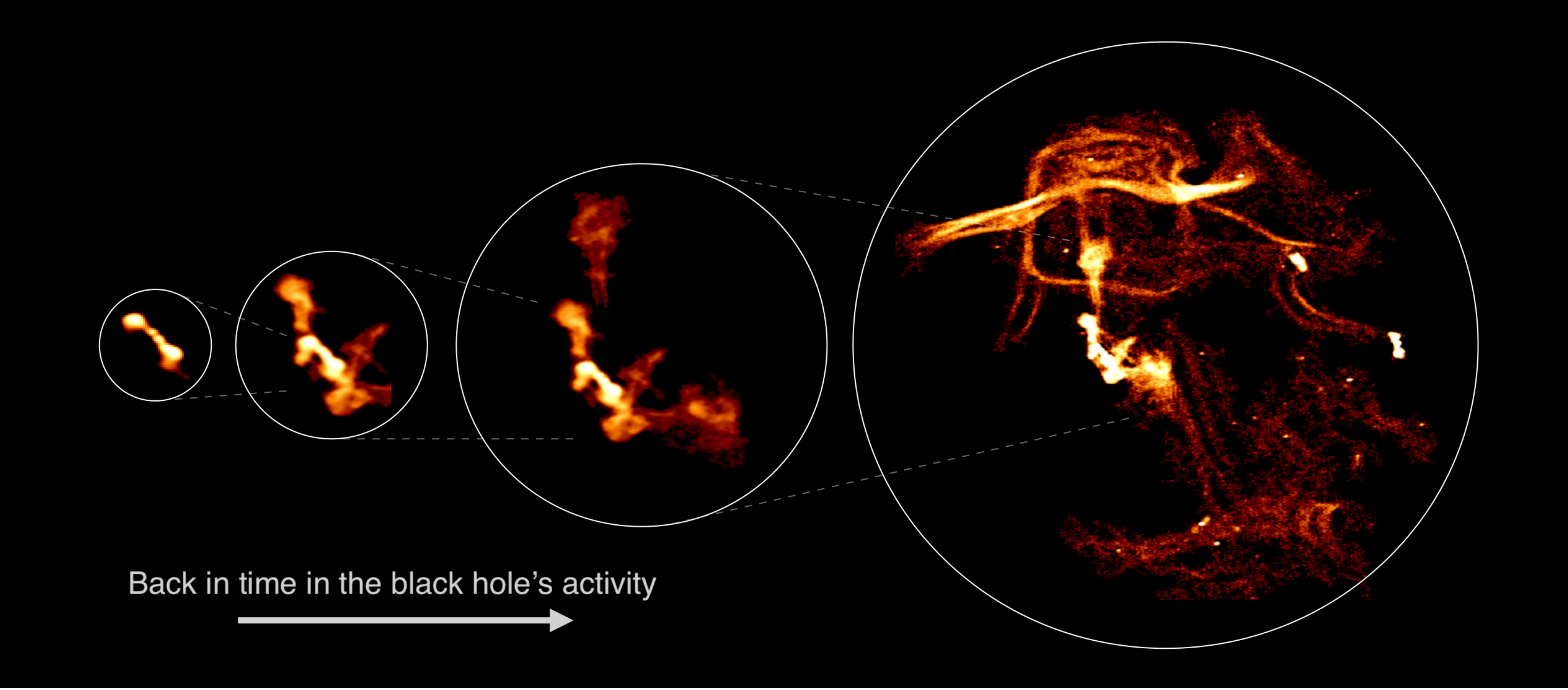



# Broad-band radio observations in the SKA era: the case of the galaxy group Nest200047

OAS-INAF

Marisa Brienza

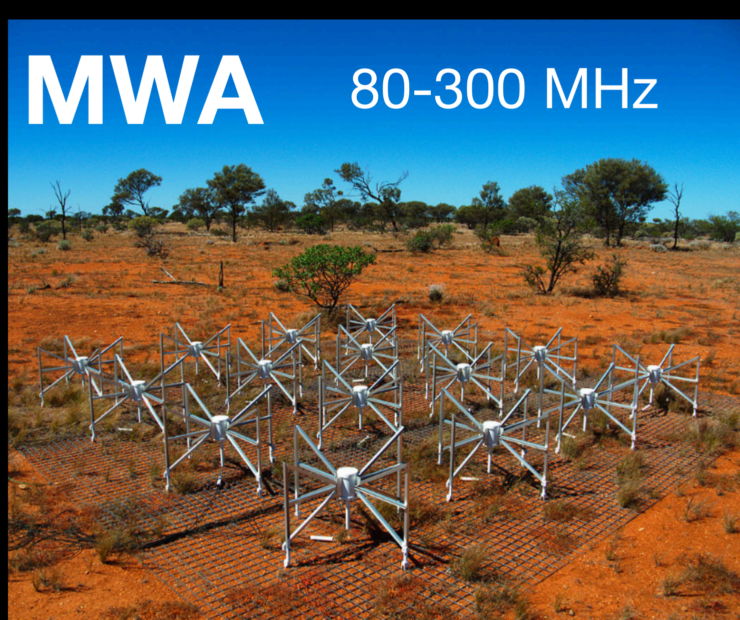
University of Bologna

**A. Bonafede, A. Botteon, G. Brunetti**, M. Brüggen, **A. Capetti**, E. Churazov, **F. De Gasperin**,
**F. Gastaldello, L. Lovisari**, K. Rajpurohit, A. Simionescu, **F. Vazza**
+ many others!

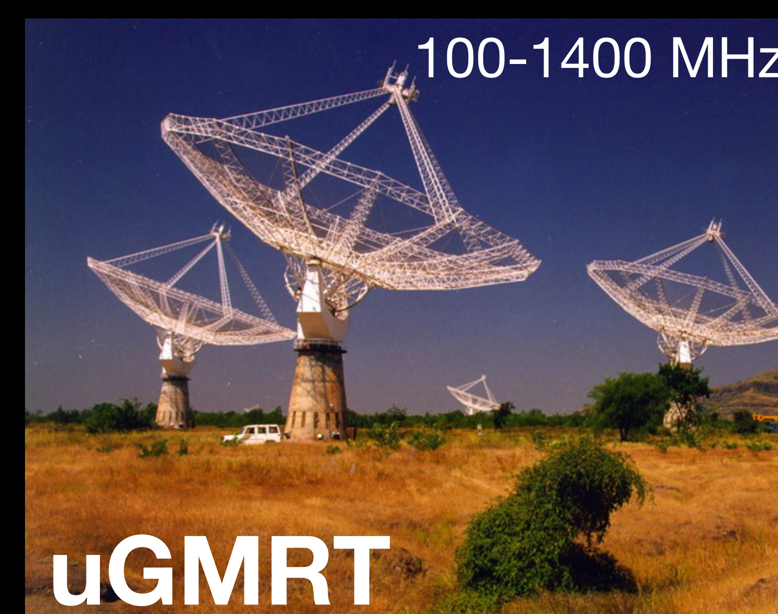



# Low radio frequencies (<1 GHz)

- High sensitivity (including to large-scale emission = short baselines)
- High spatial resolution (few arcsec)
- **MATCHED UV-PLANE**

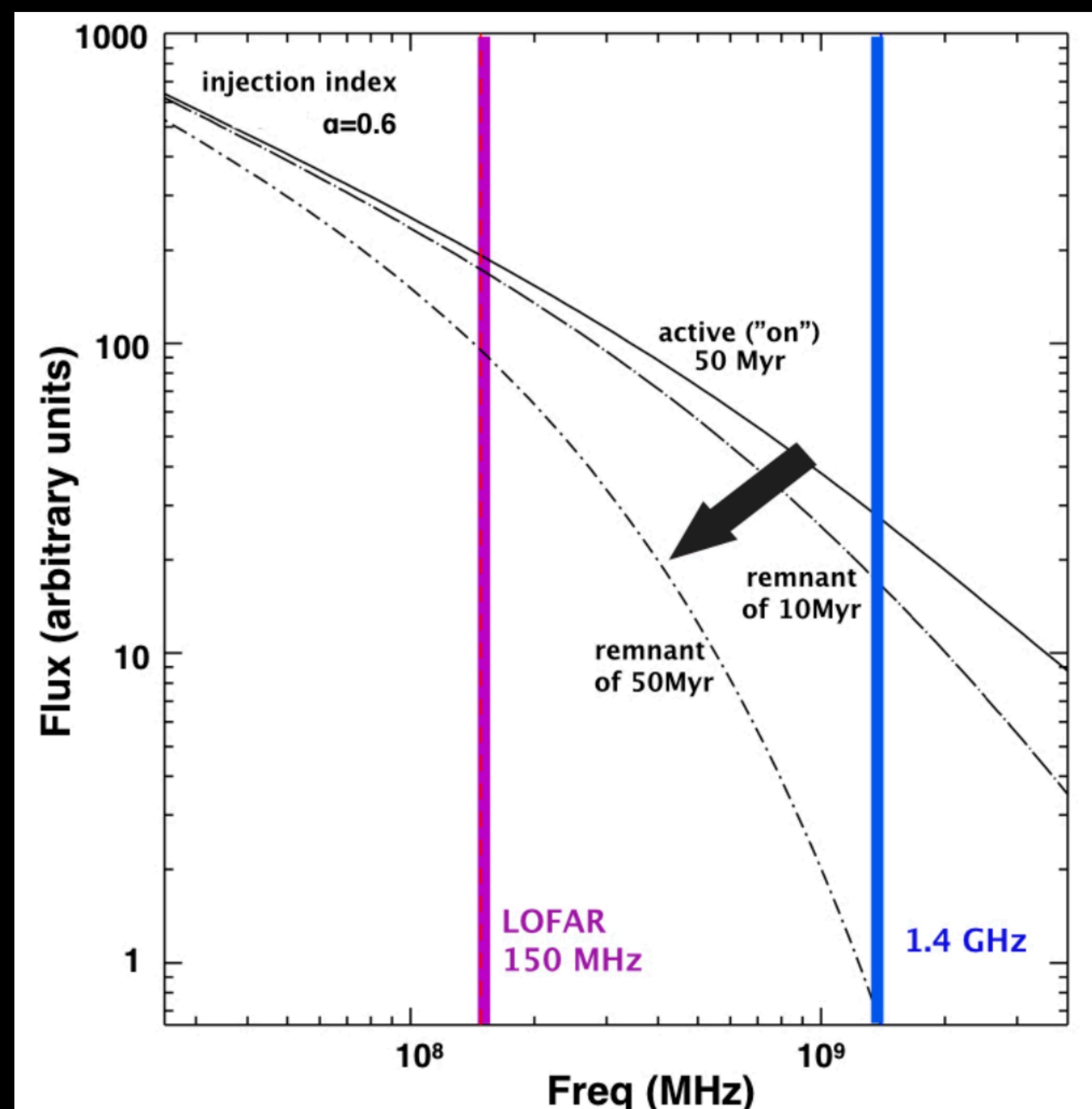







# Radio spectrum evolution

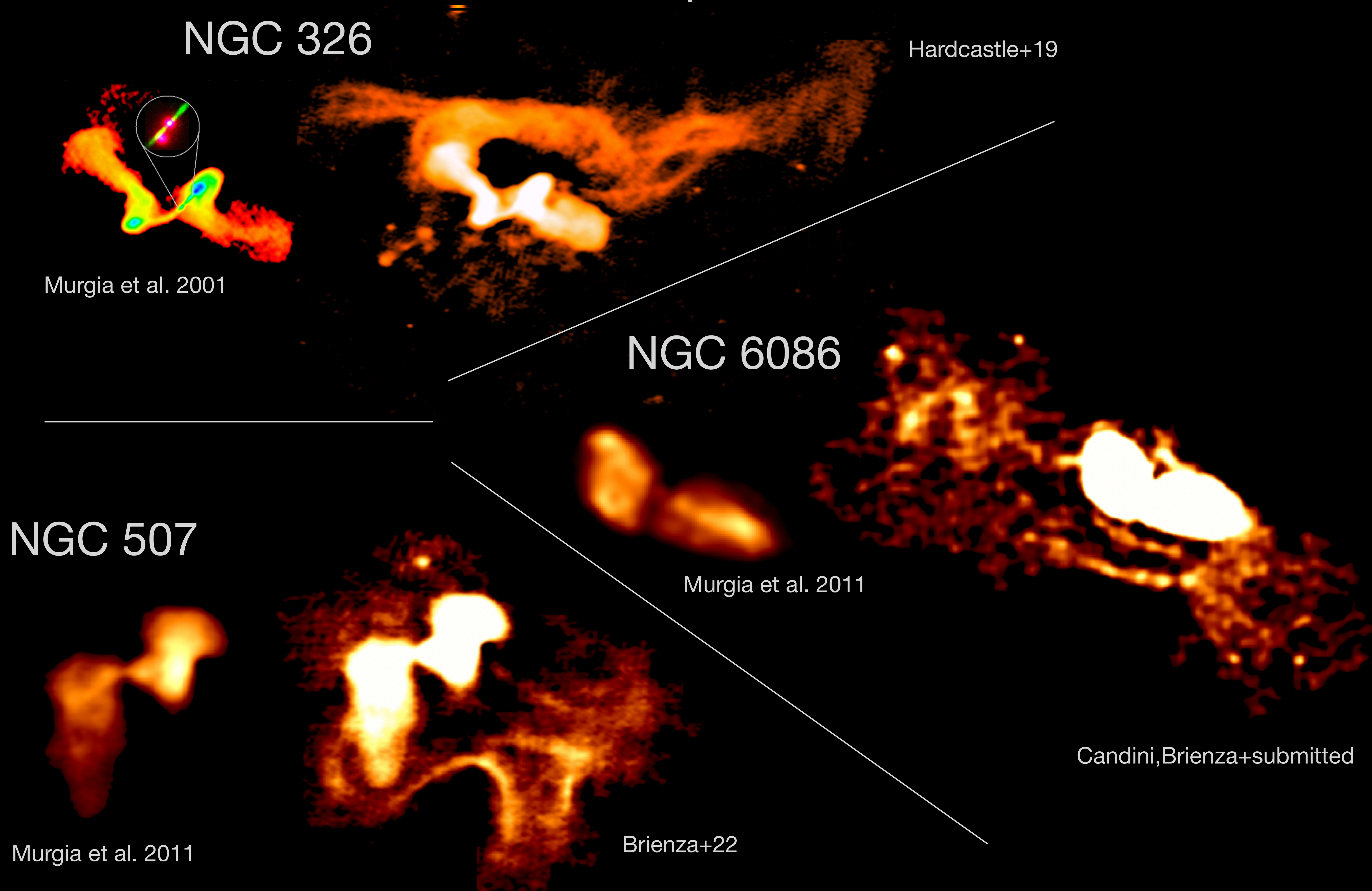
Low radio frequencies are best
to detect the oldest
populations of
emitting particles




**STEEPER=OLDER**

**FLATTER=YOUGER**

# Old AGN plasma



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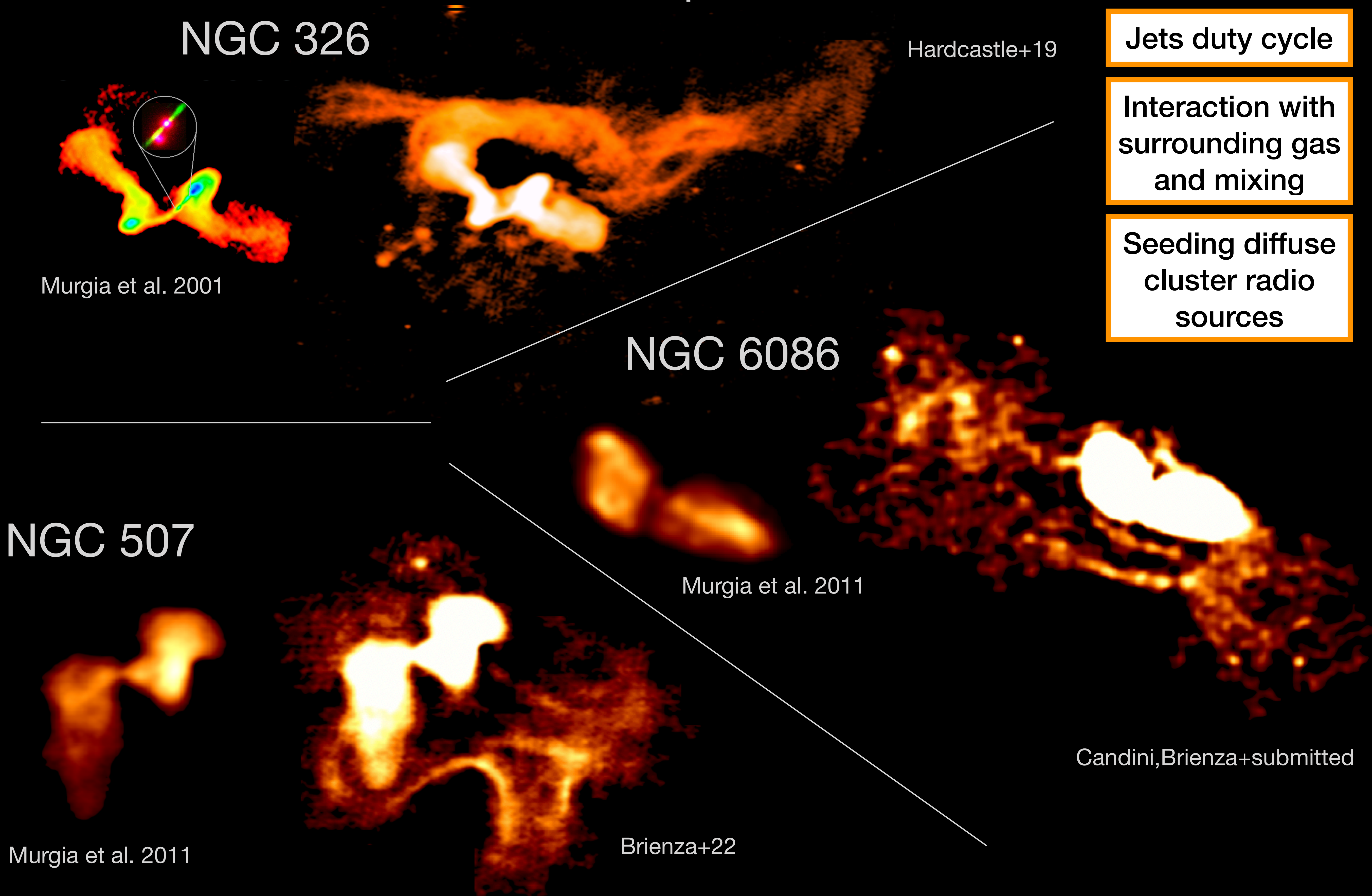
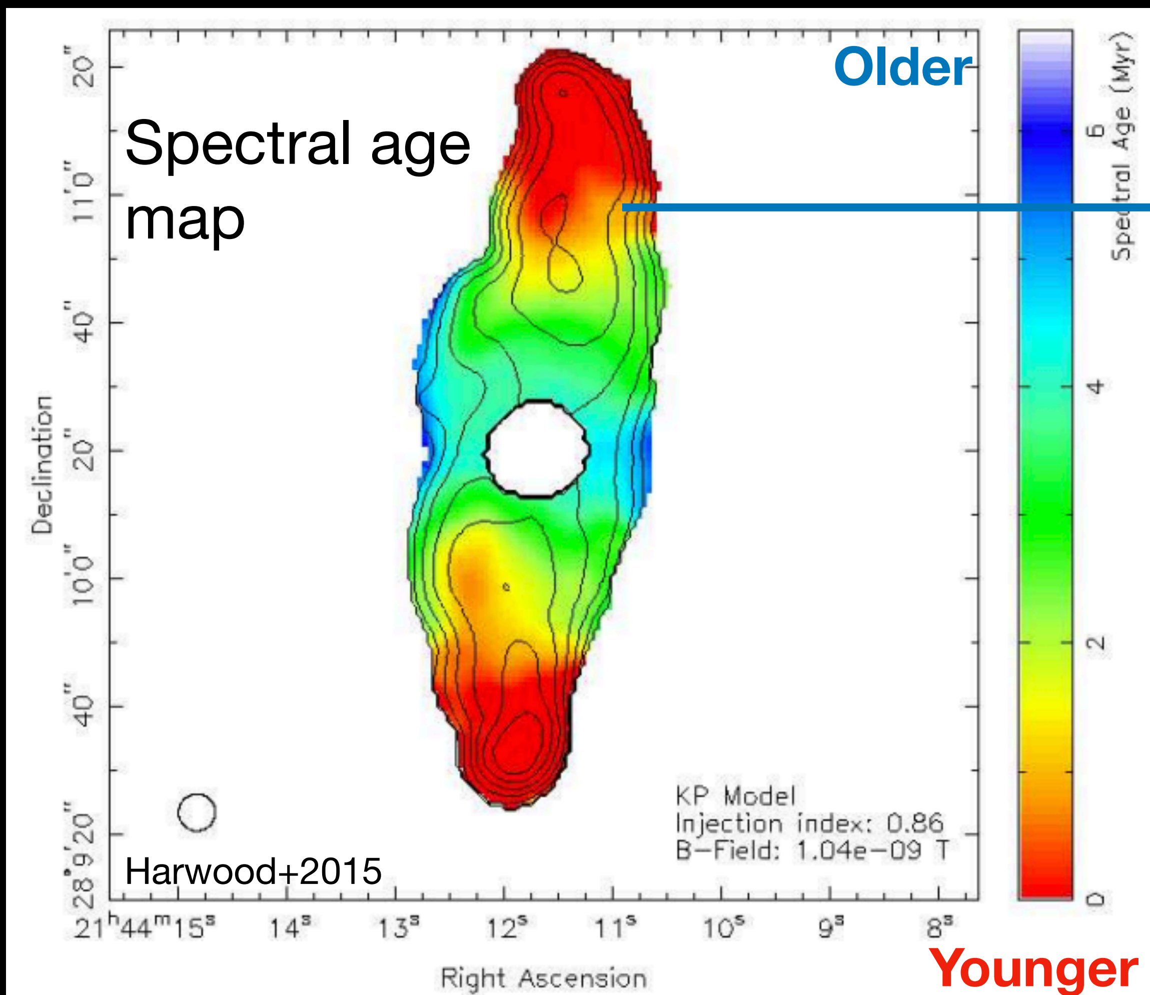
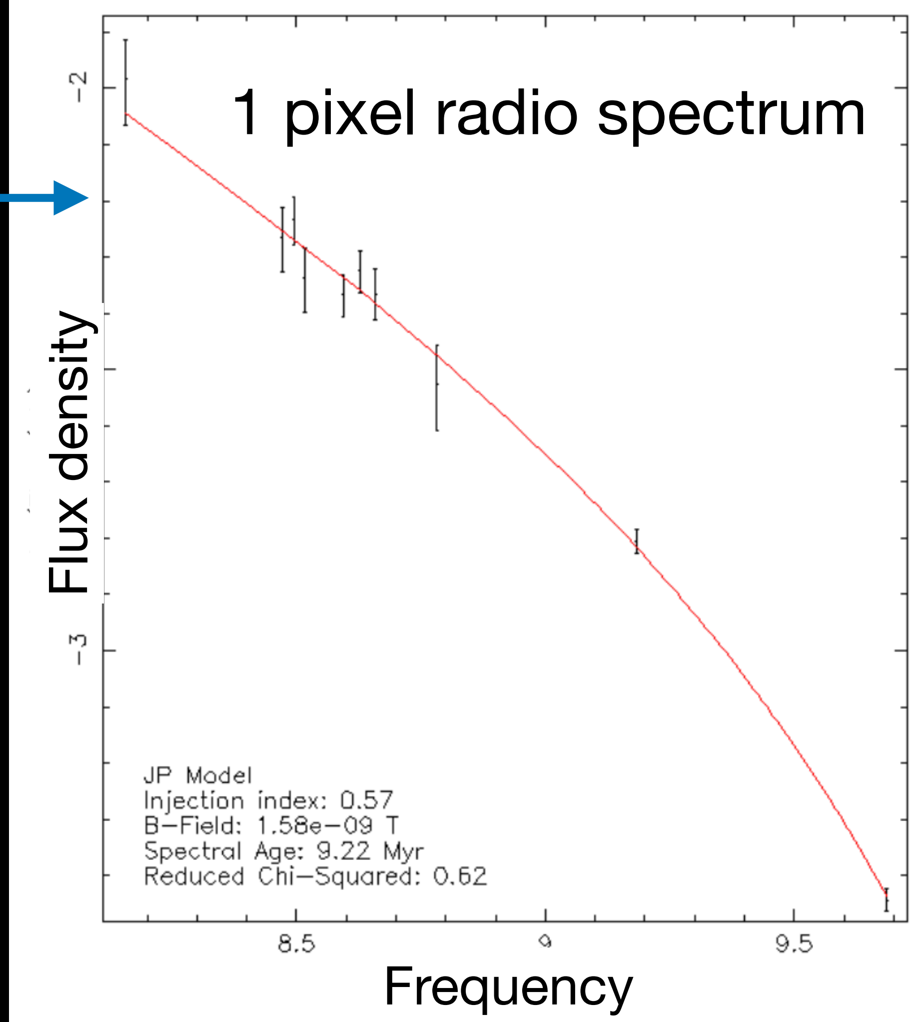


# Spectral curvature

Radiative age but also compression, reacceleration etc..




$$t_s = 1590 \frac{B_{eq}^{0.5}}{(B_{eq}^2 + B_{CMB}^2)\sqrt{\nu_b(1+z)}},$$

**Radiative evolution models**
**JP, KP, Tribble (Jaffe&Perola1974)**

B=magnetic field
v=break frequency

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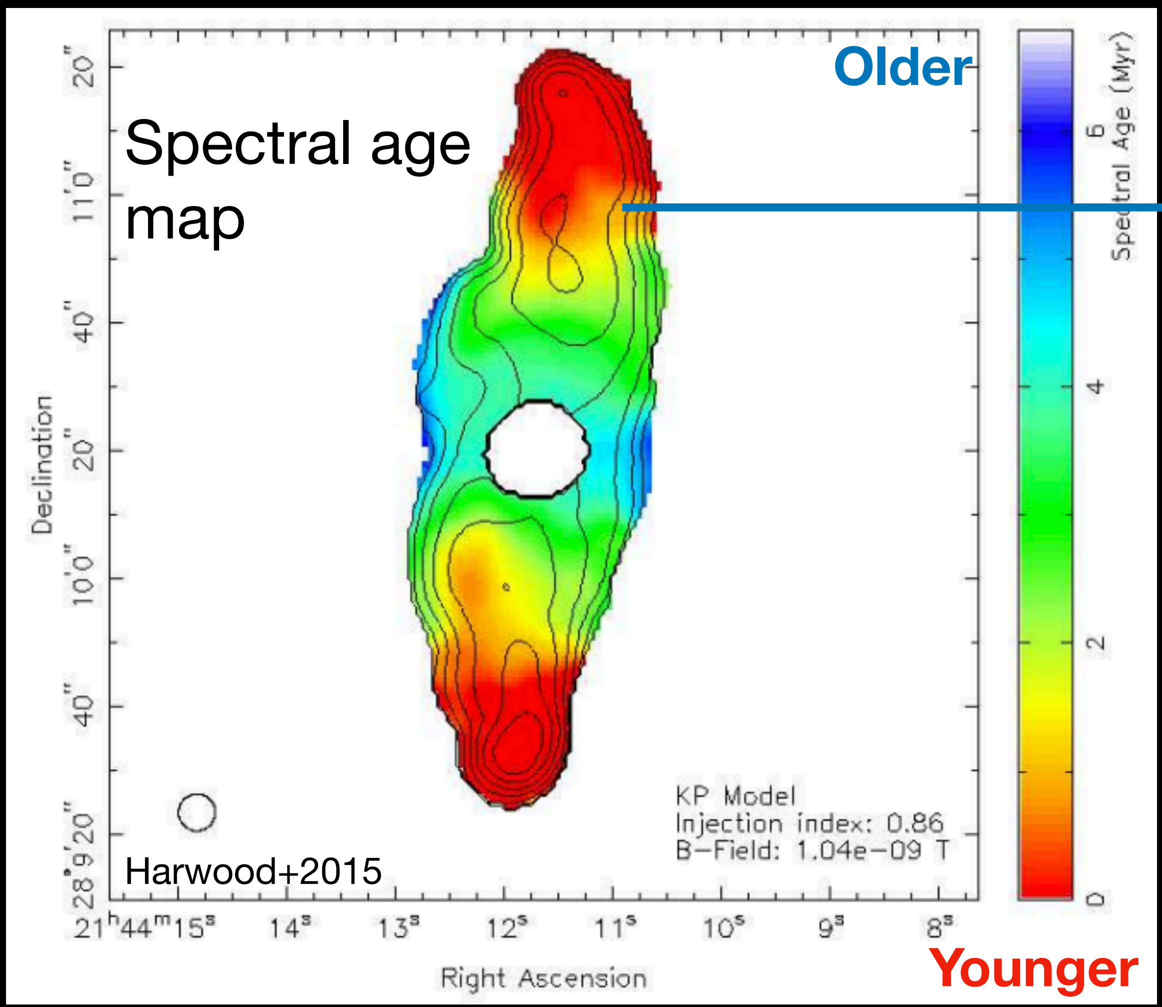
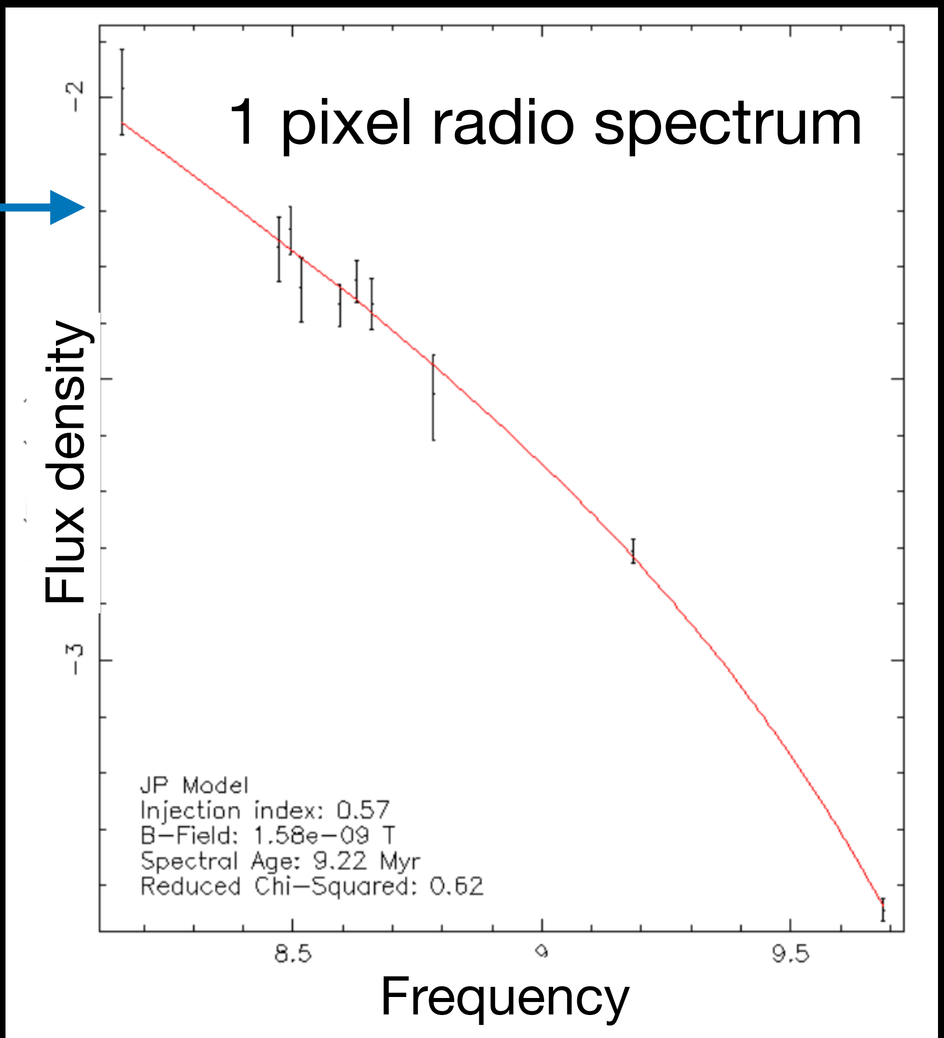
Radiative age but also compression, reacceleration etc..

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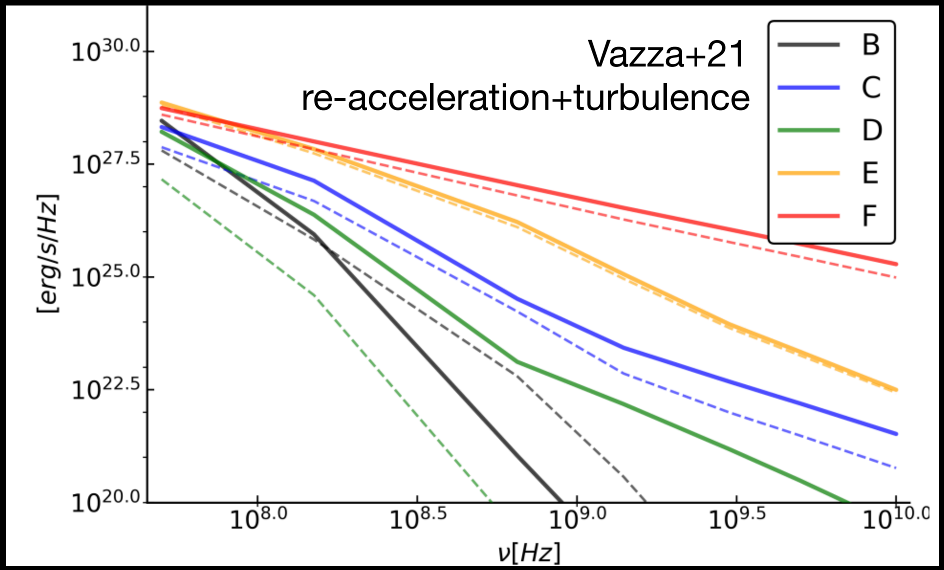



**Radiative evolution models**
**JP, KP, Tribble (Jaffe&Perola1974)**

B=magnetic field
v=break frequency

# The galaxy group Nest200047 (Brienza+ NatureAs 2021)

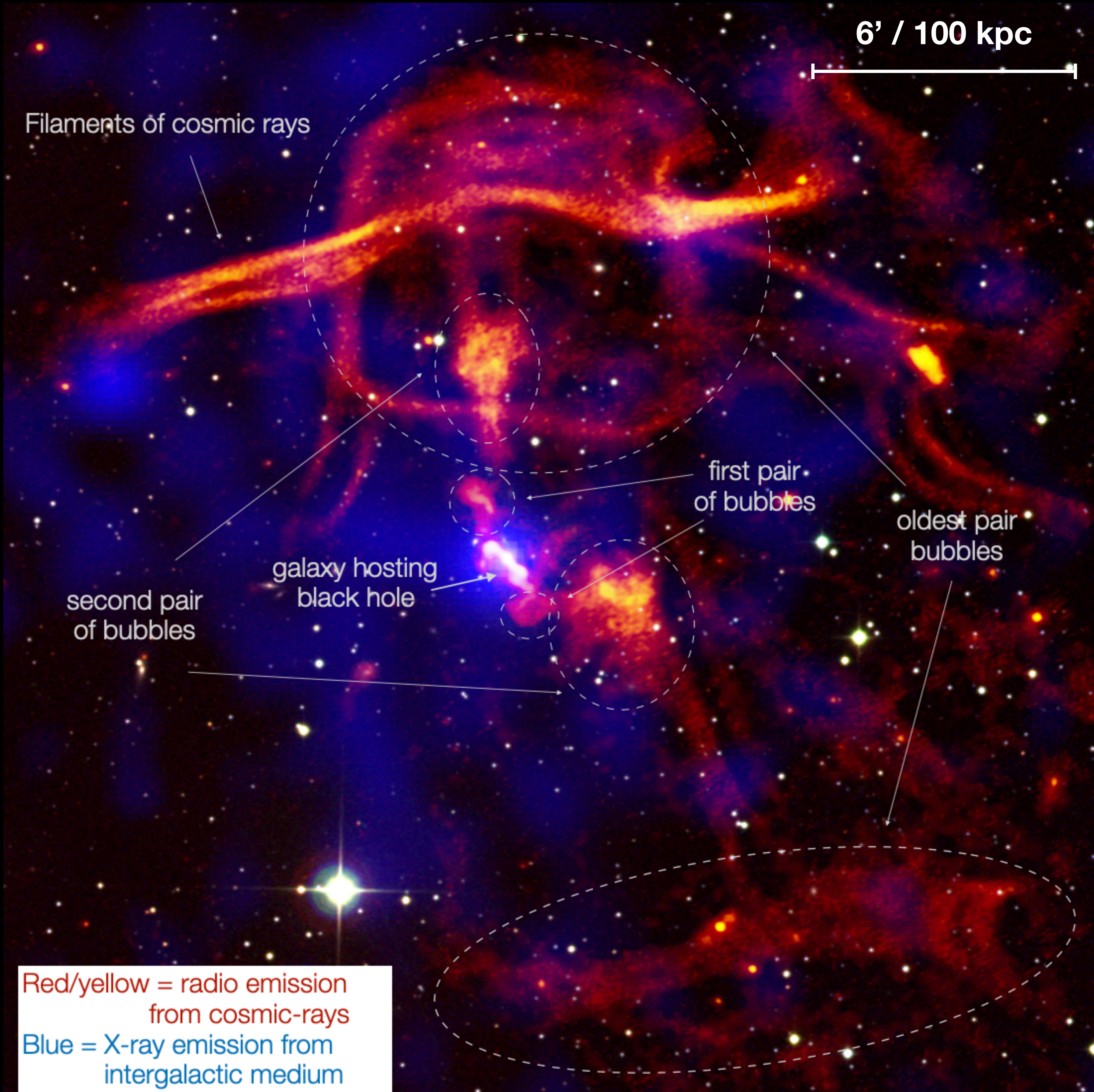
LOFAR 144 MHz
6” 0.2mJy/b
+
eROSITA 0.5-2.3 keV

**Nest200047**
z=0.018
galaxy group 17 galaxies
based on 2MASS (Tully+15)
sigma=421 km/s

Tx = 2 keV (eROSITA)
Mx =~3-7x$10^{13}$ $M_{sun}$

**FIRST RESULTS**

- **Age oldest bubbles ~300 Myr**
- **Bubble power compensates cooling IGrM**
- **Magnetic fields may prevent instabilities/complete mixing -> Alfven scale = 5-15 kpc = filaments width!**
- **Protons subdominant**



# The galaxy group Nest200047 (Brienza+ NatureAs 2021)

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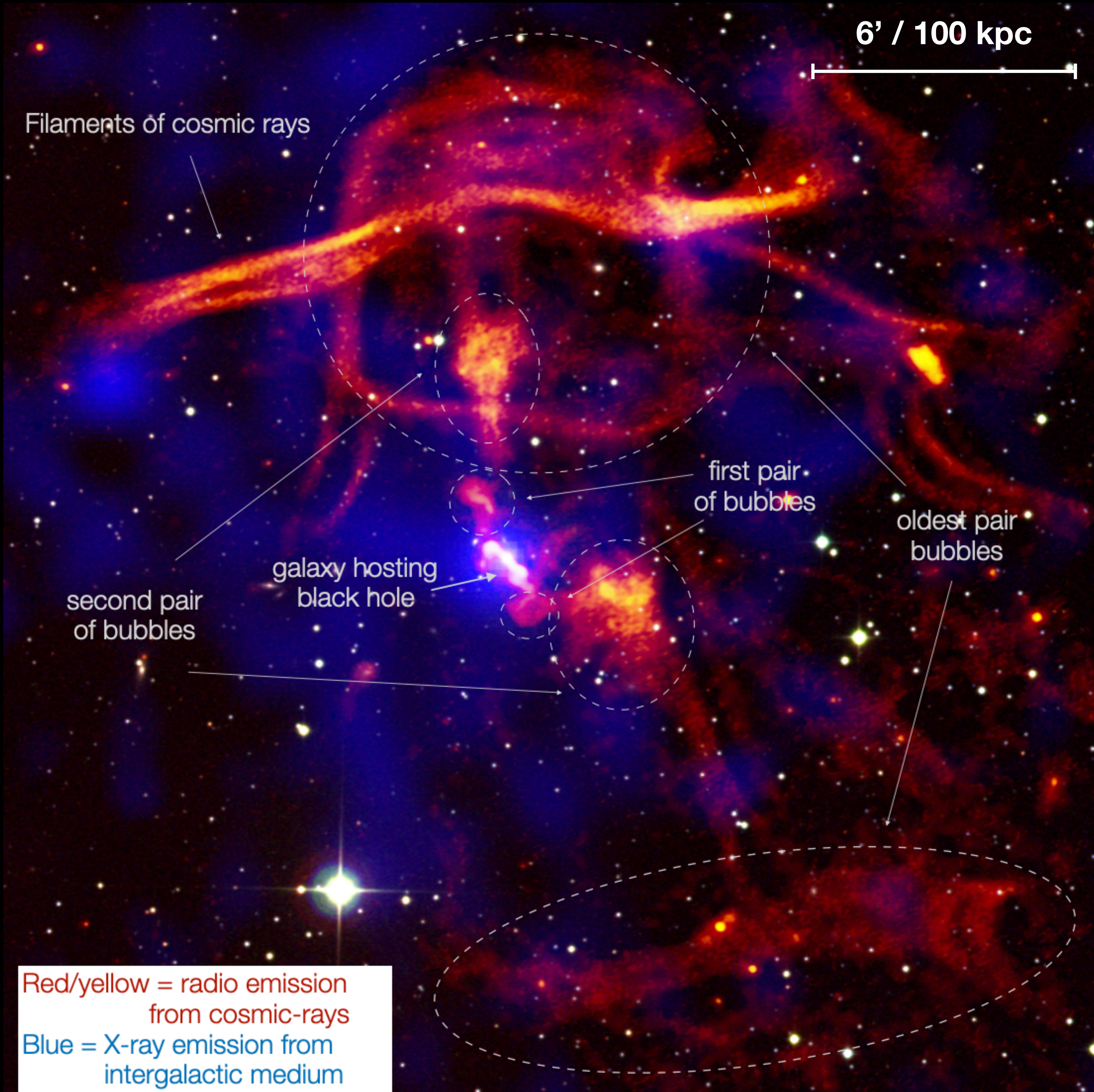
**MANY STILL OPEN QUESTIONS**

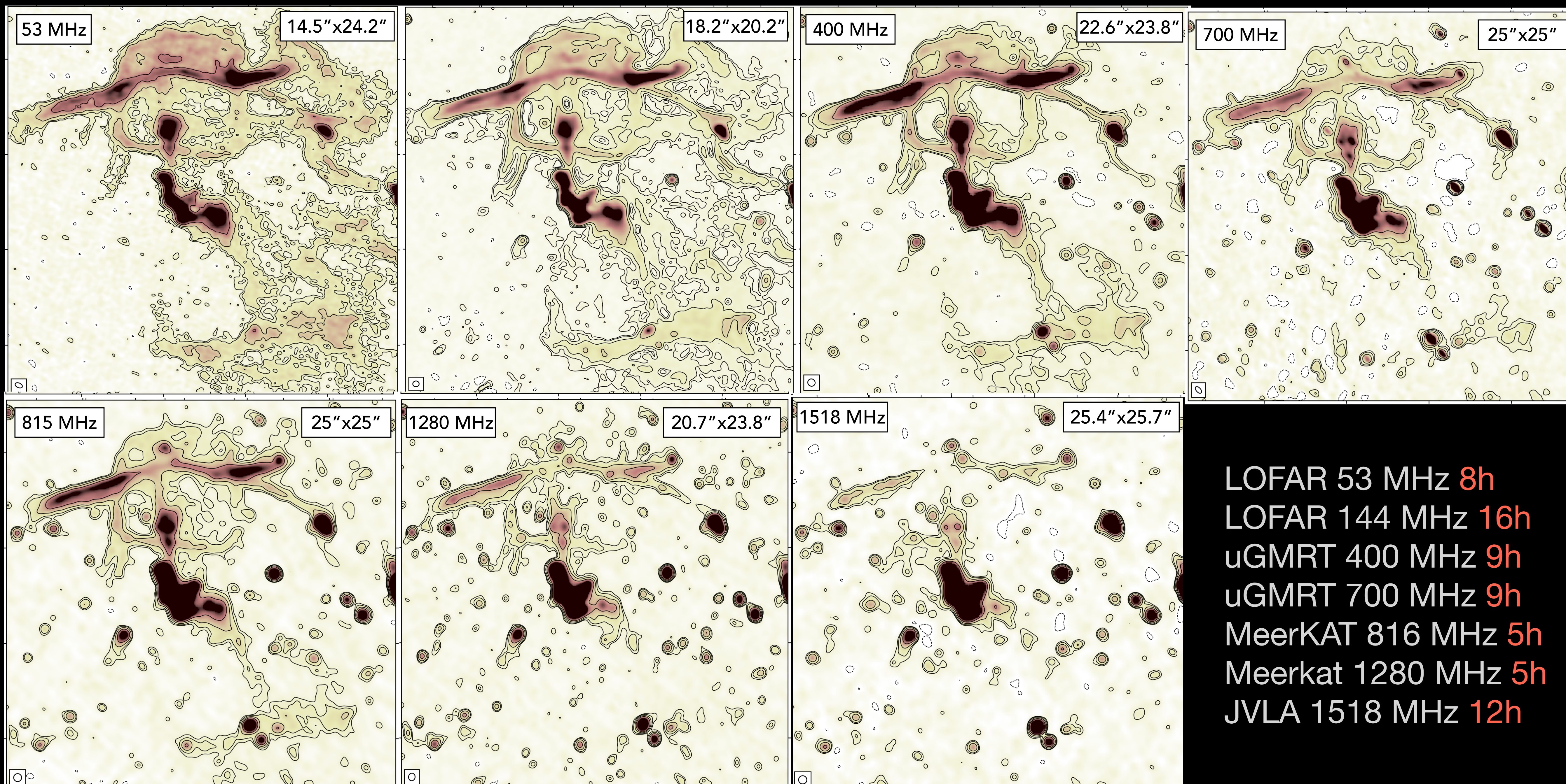
- How many episodes are there and what is the duty cycle?
- Is the plasma passively evolving?
- How are the filaments created and what are their spectral and magnetic properties?
- ....



# Multi-frequency observational campaign

**>60h** telescope time

Brienza+in prep

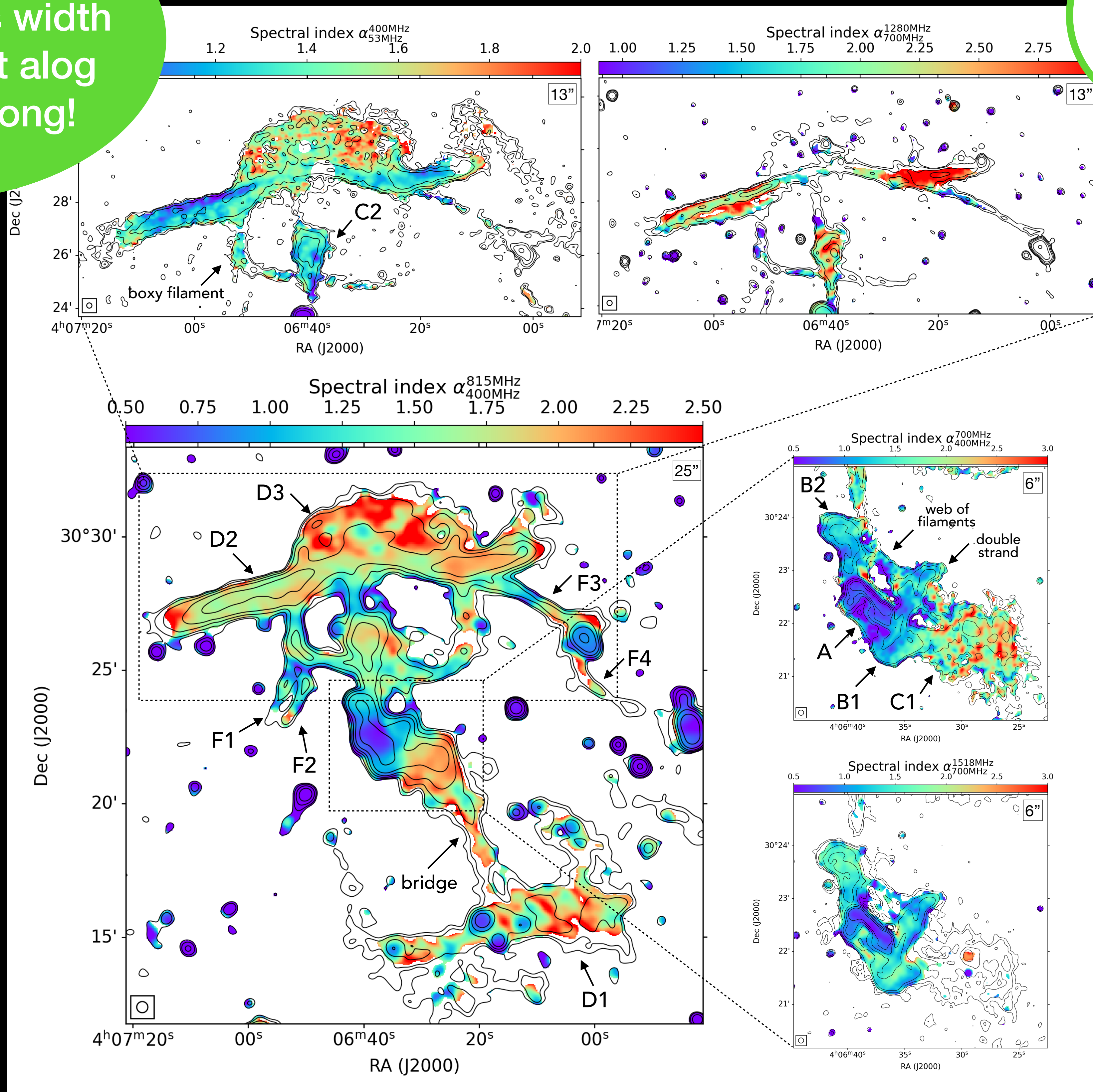



LOFAR 53 MHz 8h
LOFAR 144 MHz 16h
uGMRT 400 MHz 9h
uGMRT 700 MHz 9h
MeerKAT 816 MHz 5h
Meerkat 1280 MHz 5h
JVLA 1518 MHz 12h

# Spectral index maps

Spectral index gradient across width BUT ~constant alog filament 350 long!

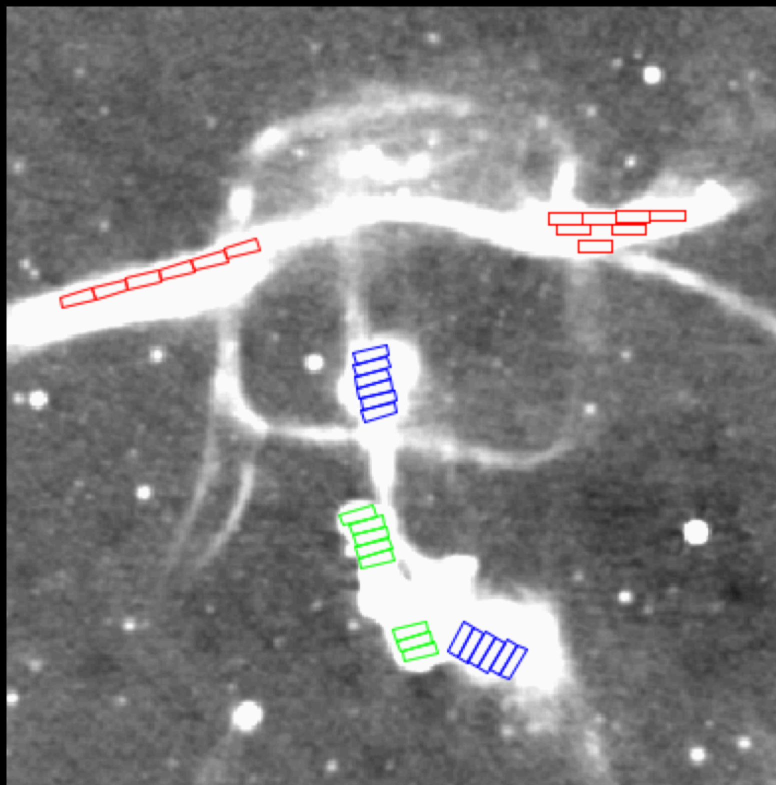
$S \propto \nu^{-\alpha}$

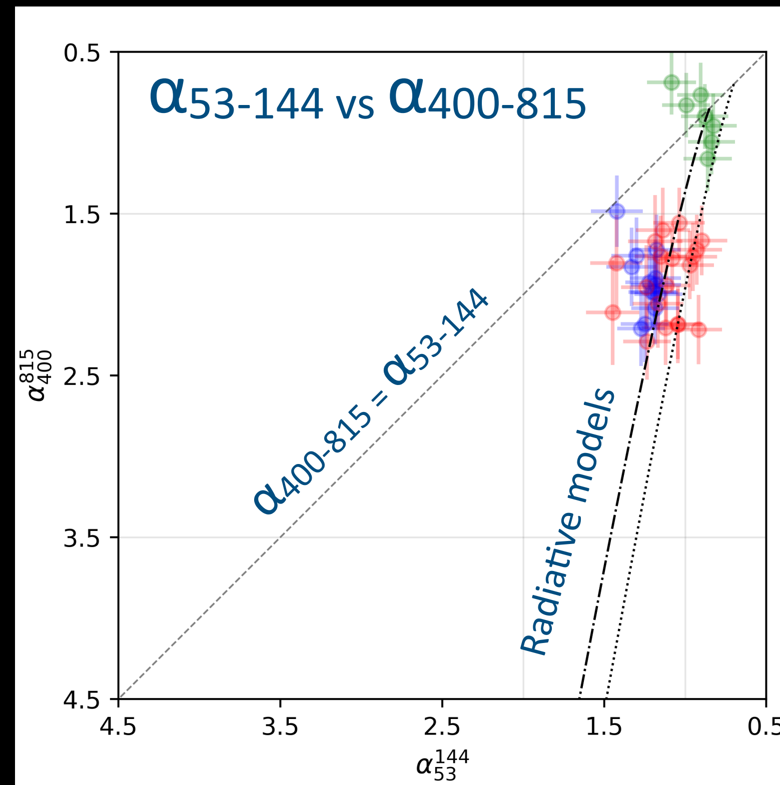


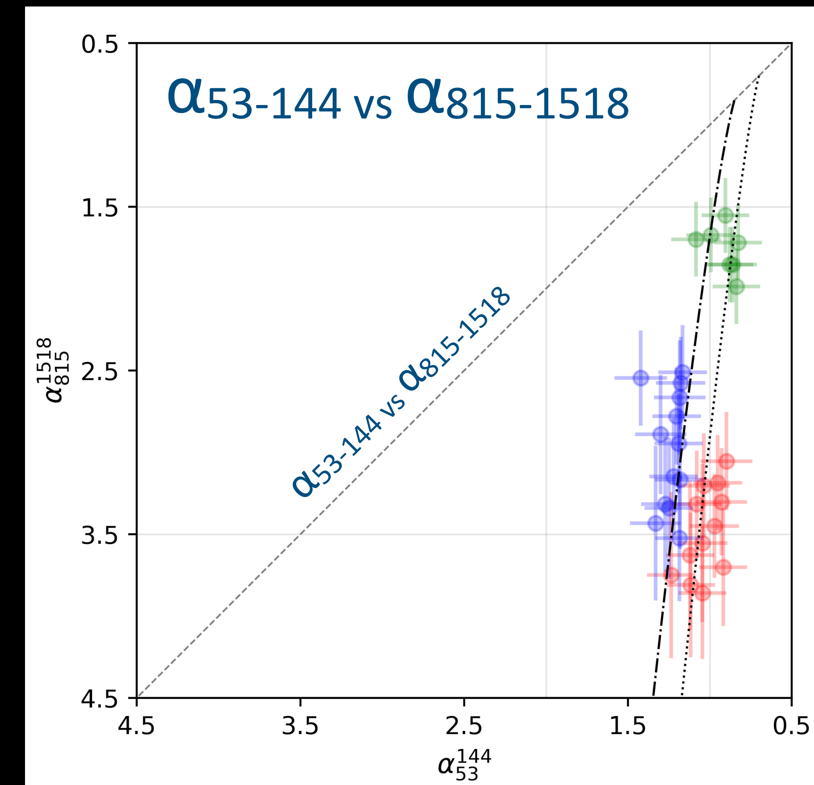

STEEPER=OLDER

FLATTER=YOUGER

# Color-color plots

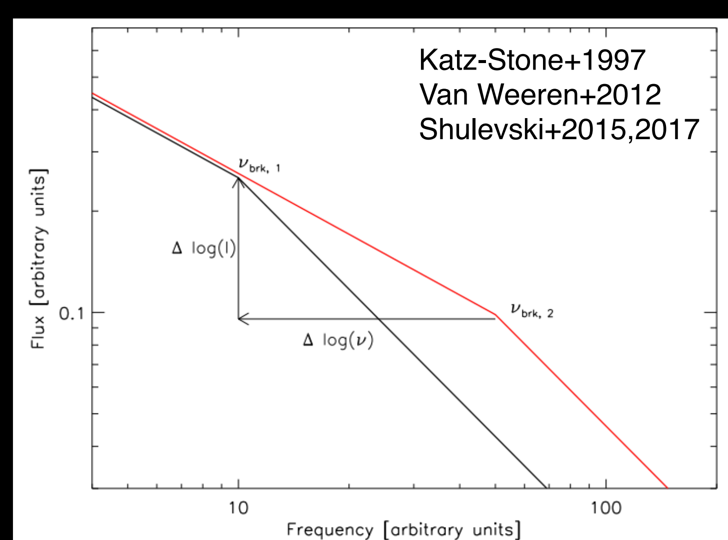


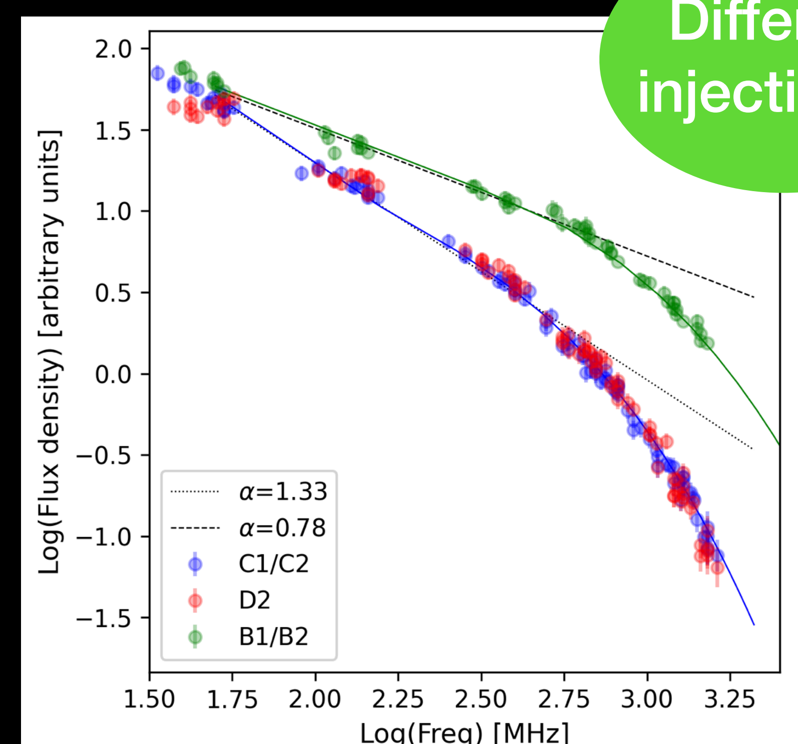



# Global spectrum

If different spectrum is only due to different energy losses and magnetic fields, one should be able to match the two spectra to a common 'global spectrum' by shifting one spectrum with respect to the other




Different injections?

# Data handling: Size

Include target and calibrators

Target only

| | Raw | Intermediate | Final | |
|---|---|---|---|---|
| LOFAR 53 MHz 8h | 1.5 TB | 6 TB | 15 GB | + ~30% imaging |
| LOFAR 144 MHz 16h | 5 TB | 8 TB | 10 GB | |
| uGMRT 400 MHz 9h | 500 GB | 1.5 TB | 1.8 GB | |
| uGMRT 700 MHz 9h | 500 GB | 1.5 TB | 1.8 GB | |
| MeerKAT 816 MHz 5h | 1.1 TB | 2 TB | 328 GB | |
| MeerKAT 1280 MHz 5h | 1.1 TB | 2 TB | 390 GB | |
| JVLA 1518 MHz 12h | 200 GB (88 GB (B array) + 70 GB (C array) + 40 GB (Darray) | 600 GB | 37 GB | |
| TOTAL INTENSITY ONLY! | ~10 TB | ~20 TB | 800 GB | ~1 TB |

Data column in MS

+corrected column
+model column
+averaging

NO BECKUP POSSIBLE!!!

# Data handling: Size

Averaging

Source subtraction

| | Raw | Intermediate | Final | |
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Note that source subtracted fits images have ~few tens of MB but full field images can be up to ~1.5 GB (LOFAR has a few deg field of view!)

PROBLEMATIC WITH STANDARD IMAGE VISUALIZATION TOOLS (CASAVIEWER, DS9) → CARTA

# Data handling: Retrieval

| | Raw | Download time (Bologna LOFAR CLUSTER) |
|---|---|---|
| LOFAR 53 MHz 8h | 1.5 TB | - |
| LOFAR 144 MHz 16h | 5 TB | - |
| uGMRT 400 MHz 9h | 500 GB | 24 h |
| uGMRT 700 MHz 9h | 500 GB | 24 h |
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Remember that depending on the instrument/ archive the data staging by the observatory can take up to a few weeks!

# Data handling: Processing - Software

## LOFAR

PREFACTOR + DDFPIPELINE + EXTRACTION

van Weeren+2016, 2020,
Williams+2016
de Gasperin+2019
Tasse+2014, 2015, 2018, 2021
Offringa+2010, 2012, 2014 ....

DDF
kMS
WSCLEAN
AOFLAGGER
+

## GMRT

SPAM

**Source Peeling and Atmospheric Modeling**

Intema+2009
Offringa+2010, 2012, 2014
+2007

+CASA+WSCLEAN

- Selfcal essential
- Direction Dependent Calib

## MeerKAT

CARACAL

Józsa et al. 2020

oxkat: Semi-automated imaging of MeerKAT observations

Heywood+

+CASA+WSCLEAN

## JVLA

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Offringa+2010, 2012, 2014
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007

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CHALLANGE = use specific software version and keep software up to date

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+

## GMRT

SPAM

Source Peeling and Atmospheric Modeling

Intema+2009
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2007

+CASA+WSCLEAN

~10 days each dataset (optimistic and if everything goes smoothly!)

## MeerKAT

CARACAL

Józsa et al. 2020

oxkat: Semi-automated imaging of MeerKAT observations

Heywood+

+CASA+WSCLEAN

## JVLA

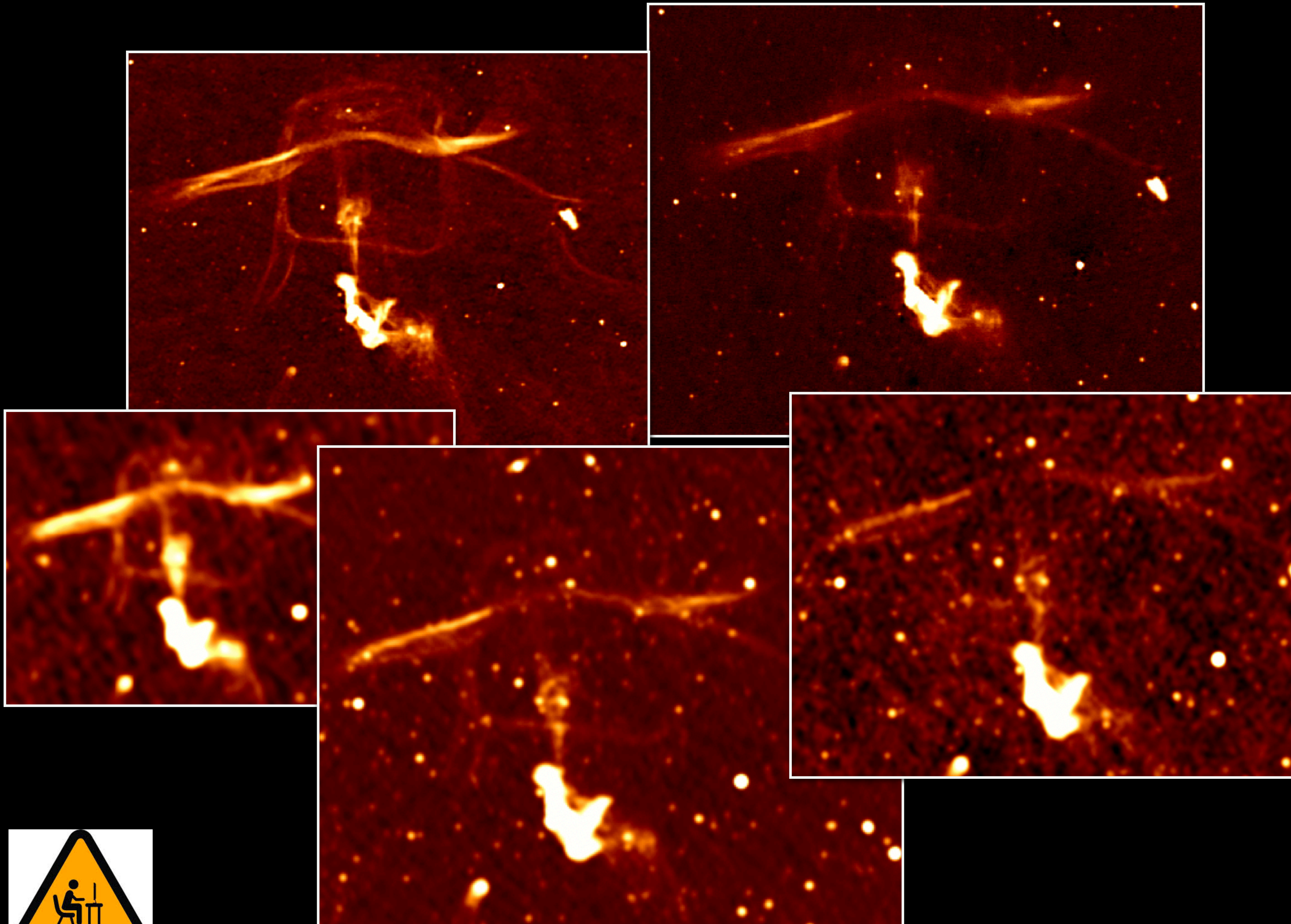
CASA

Offringa+2010, 2012, 2014
Mcmullin+2007

+AOFLAGGER +WSCLEAN

LOFAR CLUSTER in BOLOGNA
lofar8 node ->**500 GB RAM - 128 CPUs - 32TB disk space**

DATA IN LOCAL!

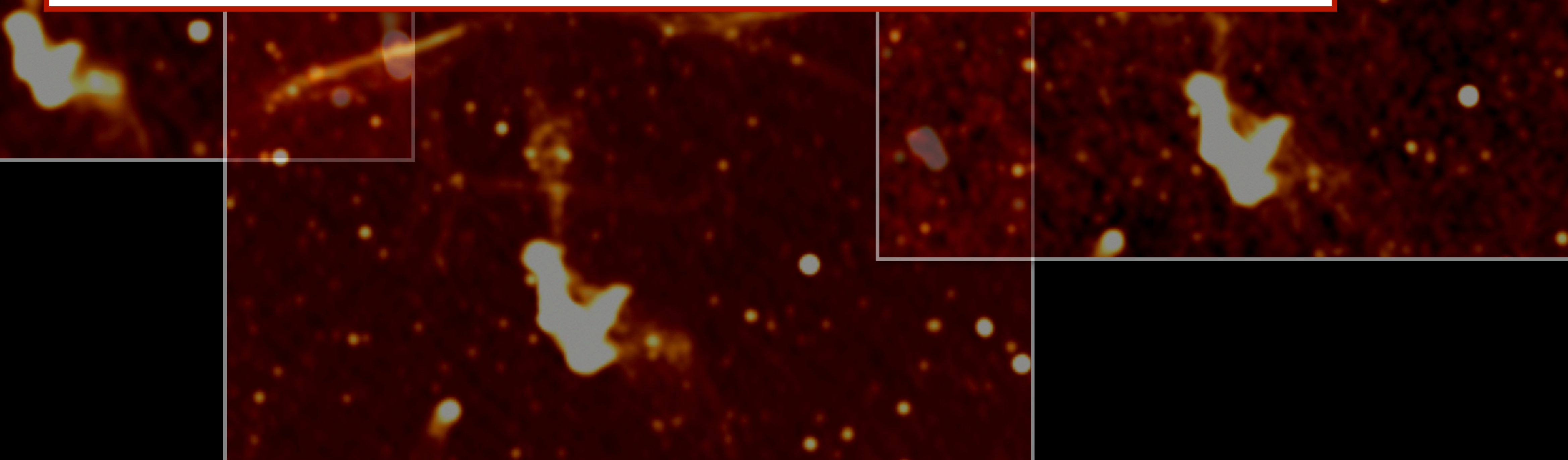


WORK IN PROGRESS

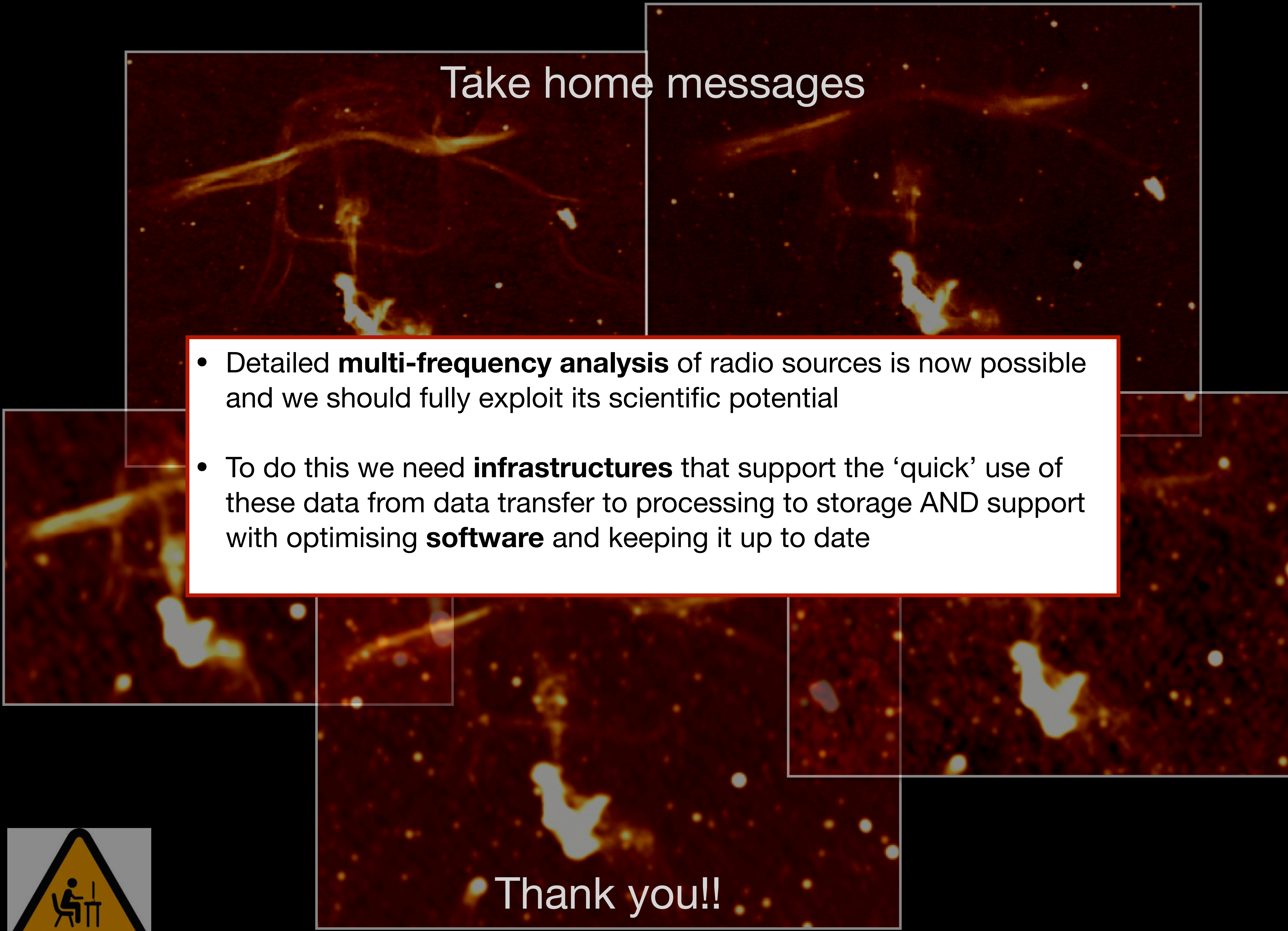
# Take home messages

- Detailed **multi-frequency analysis** of radio sources is now possible and we should fully exploit its scientific potential

- To do this we need **infrastructures** that support the ‘quick’ use of these data from data transfer to processing to storage AND support with optimising **software** and keeping it up to date



# Take home messages



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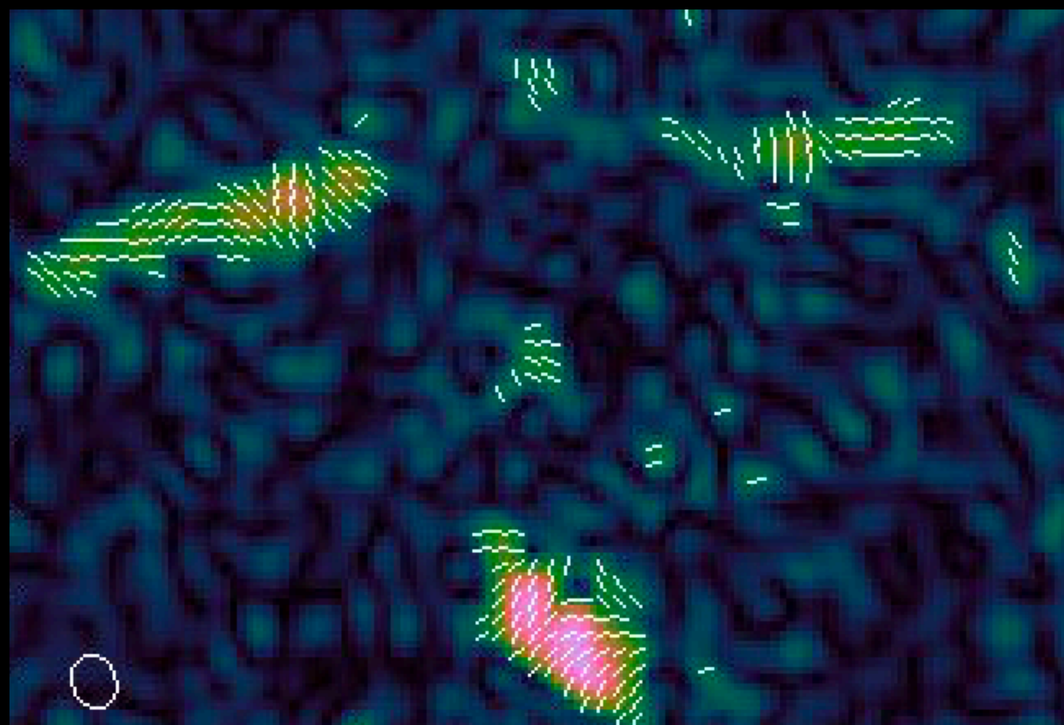
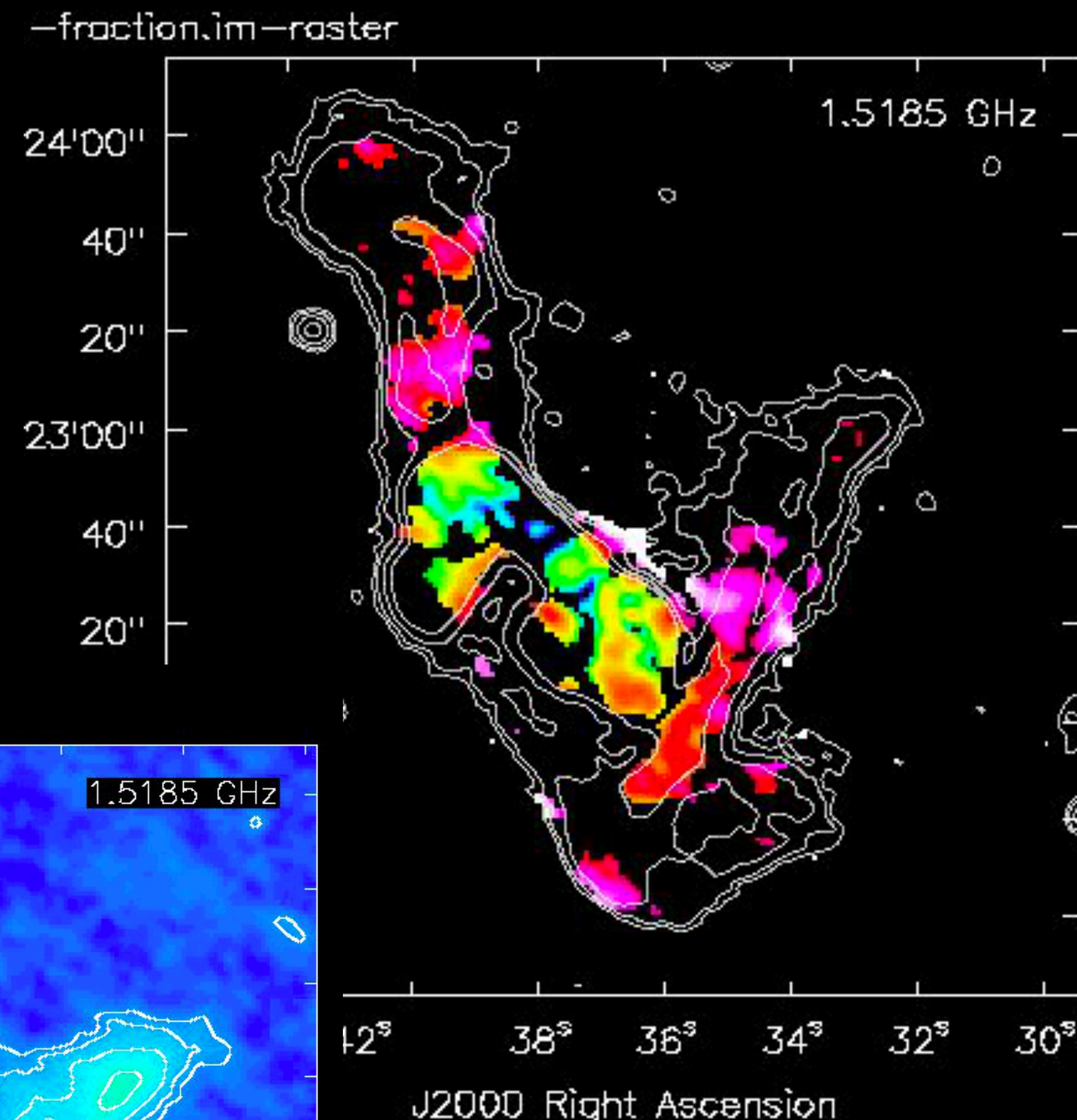
Thank you!!

# Polarisation





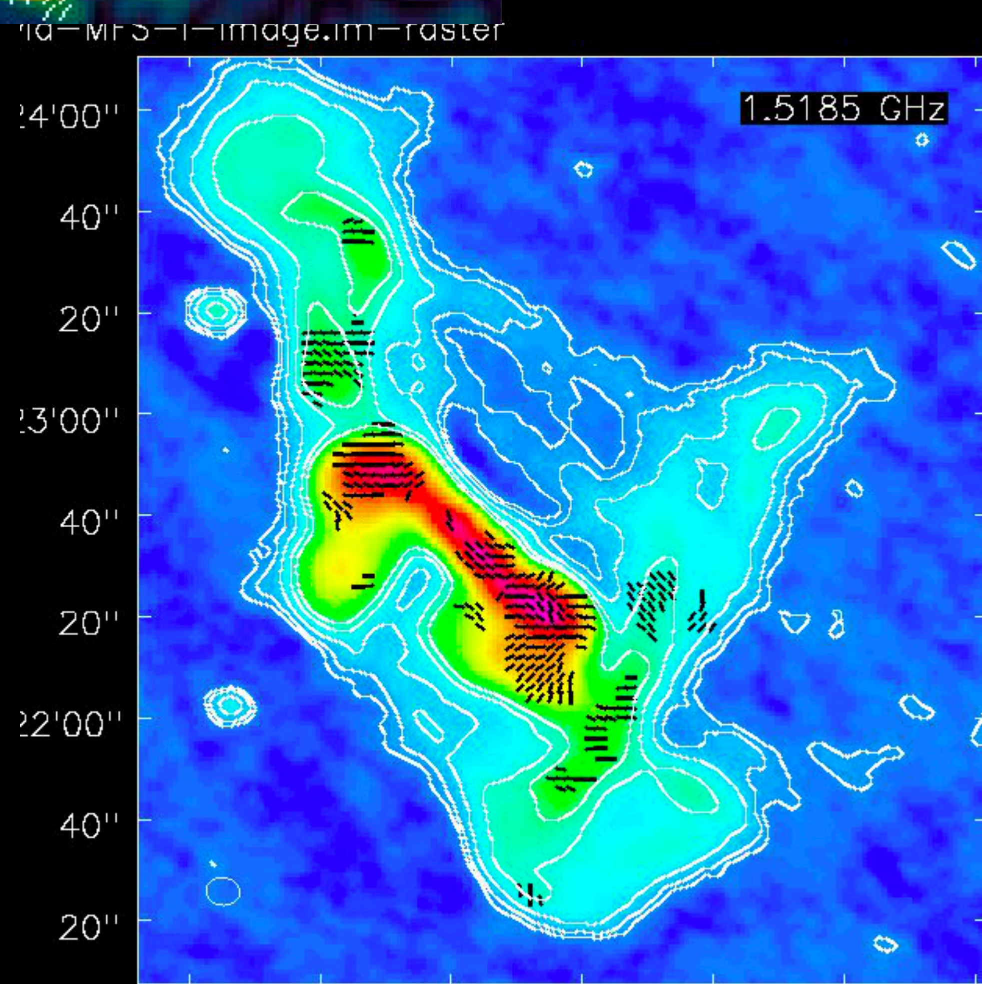



Table 1: Summary of the observations of Nest200047 used in this work.

| Telescope | Bandwidth | Central frequency | UVmin | TOS[1] | Integration time | Date |
|---|---|---|---|---|---|---|
| LOFAR[2] | 30-78 MHz | 53 MHz | $12\lambda$ | 8h | 1s | 17/04/2020 |
| LOFAR[2,3] | 120-168 MHz | 144 MHz | $32\lambda$ | 16h | 1s | 27/03/2020, 19/08/2020 |
| uGMRT | 300-500 MHz | 400 MHz | $100\lambda$ | 9.7h | 5.3s | 21/11/2020 |
| uGMRT | 550-950 MHz | 700 MHz | $200\lambda$ | 9.7h | 5.3s | 19/11/2020 |
| MeerKAT | 544-1087 MHz | 816 MHz | $50\lambda$ | 4.7h | 7s | 12/02/2022 |
| MeerKAT | 856-1711 MHz | 1284 MHz | $80\lambda$ | 4.4h | 7s | 25/01/2022 |
| VLA B array | 1000-2000 MHz | 1518 MHz | $700\lambda$ | 4.5h | 3s | 25/09/2021 |
| VLA C array | 1000-2000 MHz | 1518 MHz | $250\lambda$ | 3.3h | 3s | 27/06/2021 |
| VLA D array | 1000-2000 MHz | 1518 MHz | $180\lambda$ | 2h | 3s | 02/04/2021 |

[1]Time On Source; [2] Observations presented in Brienza et al. (2021); [3]Observations not centered on the target.

Table 2: Summary of the radio images of Nest200047 presented in this work (see Fig. 1, 3 and 1).

| Central frequency | Beam [arcsec×arcsec] | Weighting | UV-taper [arcsec] | RMS noise [$\mu$Jy/beam] |
|---|---|---|---|---|
| 53 MHz | 9.2×14.6 | Briggs -0.8 | - | 1500 |
| 53 MHz | 14.5×24.2 | Briggs -0.5 | 10 | 1500 |
| 144 MHz | 4.3×8.6 | Briggs -0.5 | - | 166 |
| 144 MHz | 10×10 | Briggs -0.5 | - | 230 |
| 144 MHz | 18.2×20.2 | Briggs -0.5 | - | 260 |
| 400 MHz | 4.8×5.8 | Briggs -0.5 | - | 30 |
| 400 MHz | 10.5×11.5 | Briggs 0 | 8 | 45 |
| 400 MHz | 22.6×23.8 | Briggs 0 | 20 | 100 |
| 700 MHz | 3.1×5.0 | Briggs 0 | - | 9 |
| 700 MHz | 10×10 | Briggs 0 | - | 27 |
| 700 MHz | 14.1×24.9[1] | Briggs 0 | 25 | 60 |
| 815 MHz | 6×13.6 | Briggs -0.8 | - | 25 |
| 815 MHz | 15×15 | Briggs -0.8 | - | 35 |
| 815 MHz | 9.2×21.6[1] | Briggs 0 | - | 50 |
| 1280 MHz | 4.1×9.4 | Briggs -0.5 | - | 7 |
| 1280 MHz | 5.4×12.4[2] | Briggs 0 | - | 8 |
| 1280 MHz | 20.7×23.8 | Briggs 0 | 15 | 22 |
| 1518 MHz | 3.4×4.3 | Briggs 0 | - | 8 |
| 1518 MHz | 12.8×13.5 | Briggs 0 | 12 | 7 |
| 1518 MHz | 25.4×25.7 | Briggs 0 | 25 | 20 |

[1] Smoothed to 25 arcsec; [2] Smoothed to 15 arcsec.