Multi-frequency mapping and analysis of the largest giant radio galaxies

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This talk is dedicated to all my teachers and mentors

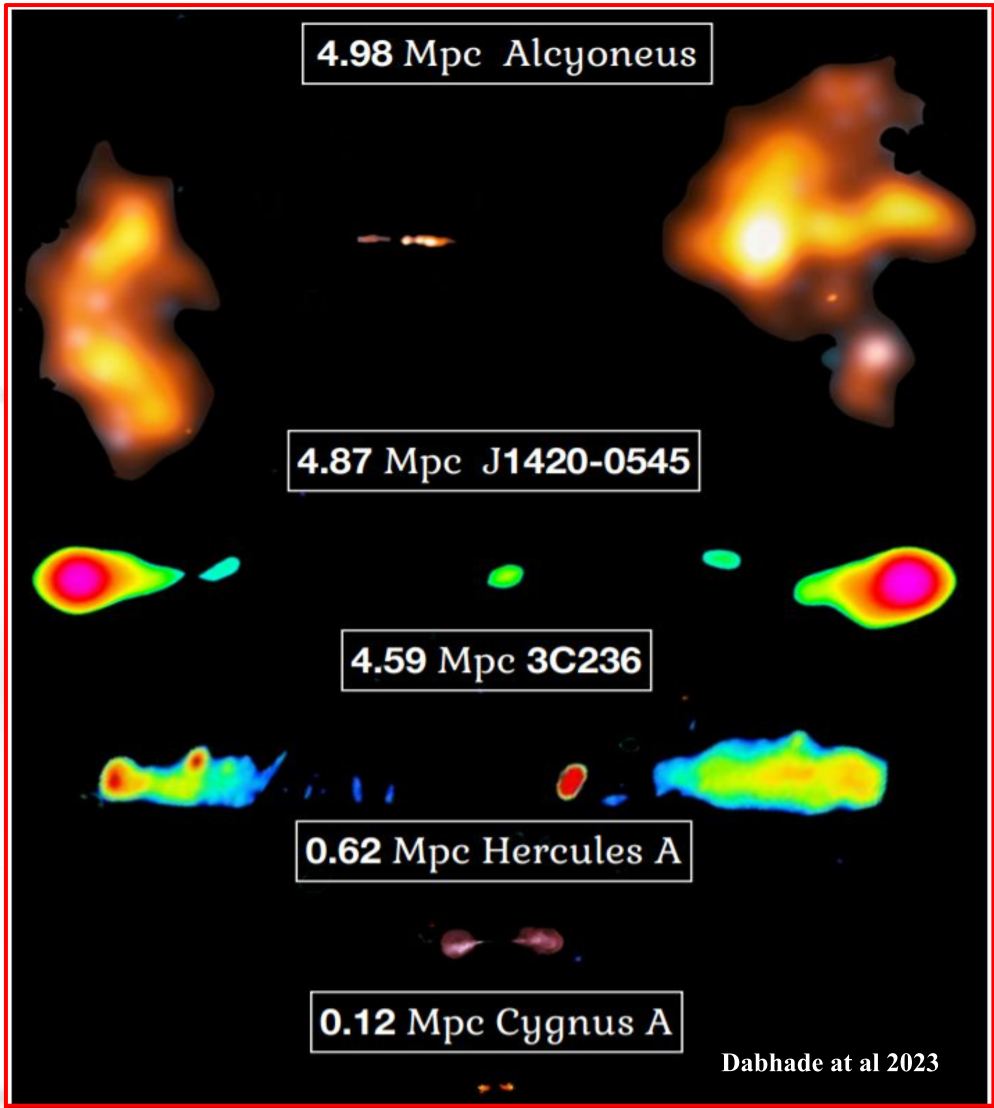
LOFAR Family Meeting 2024, Leiden

GRGs: The story so far we know

Giant Radio galaxies (GRG)

- Radio Galaxy (RG) **> 700 kpc** → GRG.
- Largest known GRG ~ **5Mpc**
- **Millions of RGs** have been discovered since the first discovered RG. But only a few percent of these are GRGs.

- Scale comparison of **Cygnus A** and **Hercules A**, RGs with 3 largest Radio galaxies.
- **Alcyoneus, J1420-0545, 3C236**



Size of Milky Way galaxy 0.03 Mpc

Wide area low-frequency sky survey

Initial GRGs found in

- NVSS (1400 MHz), SUMSS (843 MHz), WENSS (325 MHz) ~ **500 GRGs**

  GRGs are difficult to detect because of their
  Highly extended angular size
  Low surface brightness (of their lobes)
  Steep radio spectrum (due to radiative losses)

This allows new generation deep low frequency surveys to discover more and more GRGs.

- LoTSS (144 MHz), EMU (888 MHz), RACS (888 MHz)

  - LoTSS-DR1 (206 GRGs)
  - LoTSS-DR2 (2050 GRGs)
  - LoTSS Deep Field (281 GRGs)
  - LoTSS DR + ML (~10,000 GRGs)

⇒ **~12,500**

Number of GRGs discovered till now roughly around ~14,000

GRGs beyond 2Mpc

Only ~7-10 % GRGs are larger than 2Mpc

GRG Density

Catalog	Area deg^2	GRG < 2Mpc Density	GRG > 2Mpc Density
LoTSS DR-1	424	0.6	0.02
LoTSS DR-2	5700	0.4	0.06
LoTSS Deep Field	95	2.9	0.21
LoTSS ML	5700	1.8	-

Why some giants are exceptionally large ?

The possible physical explanations for the exceptional sizes of GRGs could be:

1. The growth of GRGs is favoured in **low-dense environment.**
2. The AGNs of GRGs are extremely powerful,
   hence they could have **efficient and collimated relativistic jets.**
3. Or GRGs are late stage evolution of RGs, **ancient RGs.**

The formation is solely not depends on only one factor but combination those.

GRG Sample & Basic Properties

Selection criteria

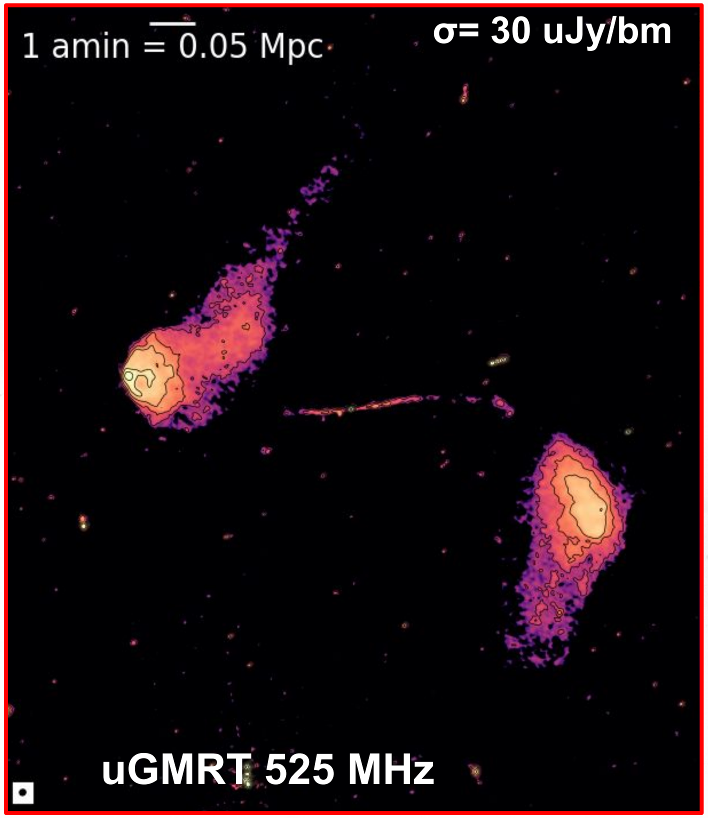
We selected a small sample of bright and extreme-sized GRGs (> 2Mpc)
From Kuzmicz & Jamrozy (2018)+ Dabhade et al. (2020a)+ (2020b) ~ **1000 GRGs (Expand it)**

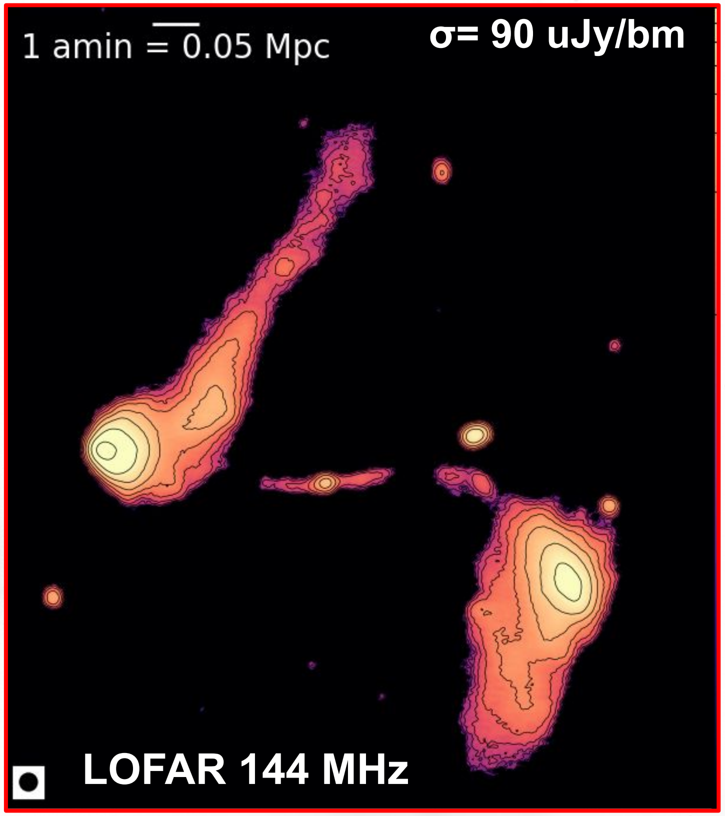
Property	**Condition**	**Possible reason**
Projected linear size	> 2Mpc	The largest GRGs
RG (Type)	FR II	For dynamical modelling
Total integrated flux	$\gtrsim$ 0.25 Jy	Bright enough to detect in wide range of frequency
Redshift	$\lesssim$ 0.6	Spectroscopic redshift
Total radio power(W/Hz)	$\gtrsim 10^{25}$	FRIIs in the FR division
Declination	-55° and 90°	To observe simultaneously in low and high frequencies like **JVLA**, **uGMRT**, and **LOFAR**

Out of 1000 GRGs 12 GRGs meet our criteria and we again discarded 4 GRGs due to lack of data

Final: only 8 targets (7GRG, 1 GRQ). Aim to perform spectral and dynamical aging.

Importance of spectroscopic redshift





PhotoZ= 0.24, proj. linear size= 2.8 Mpc
Spec Z= 0.0489, proj. linear size= 0.7 Mpc

Discovery of 100 kpc narrow curved twin jet in S-shaped GRG.

For more details check out, Sethi et al 2024 ApJ accepted

Sample

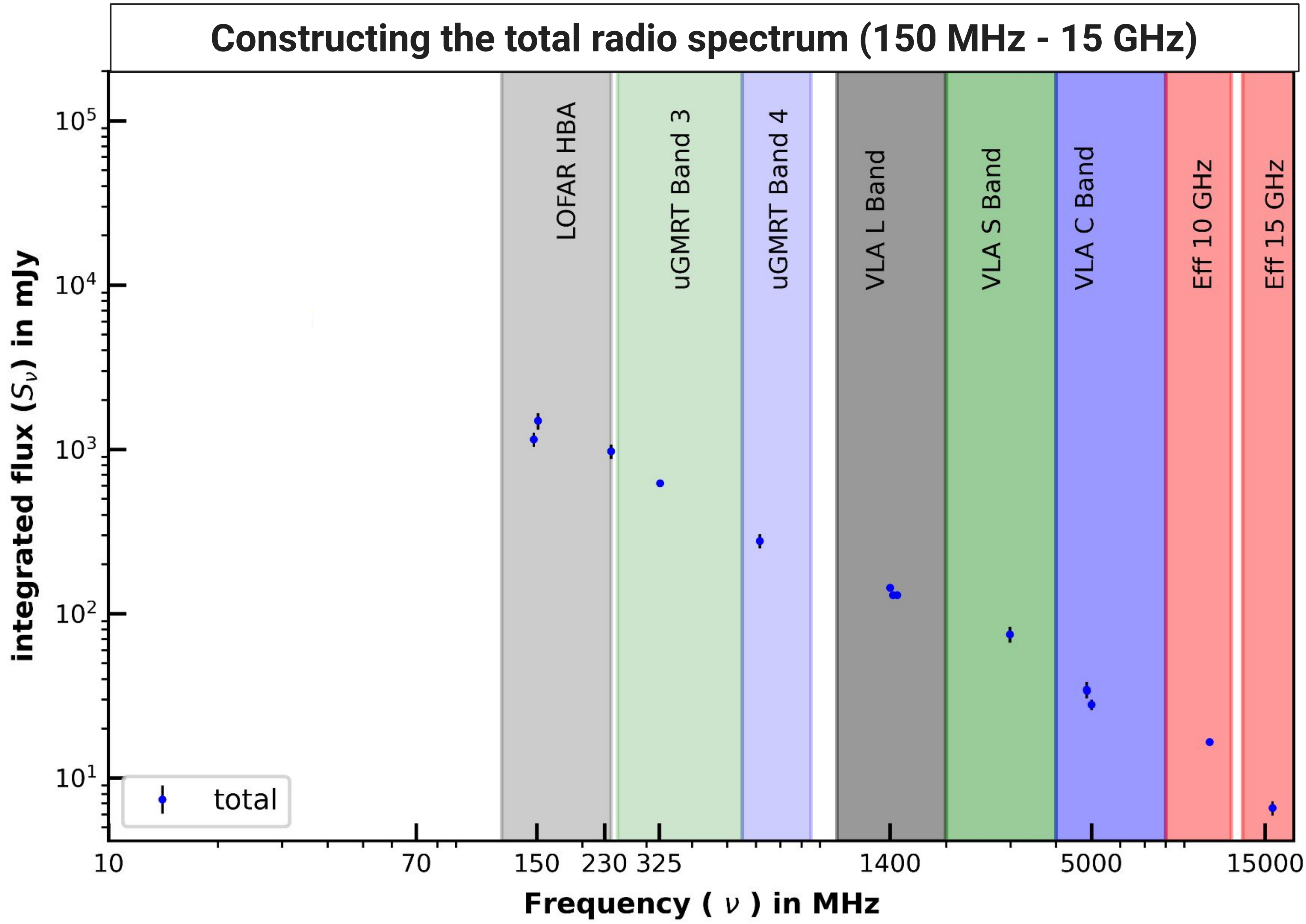
Name	Spec.z	Angular Size (amin)	Proj. Linear (Mpc)	S1400 MHz mJy	P150 MHz (10^25) W/Hz	Axial Ratio
GRG1	0.0953	19.50	**2.14**	484.8	5	5
GRG2	0.5380	7.00	**2.63**	238.8	124	12
GRG3	0.0800	25.20	**2.36**	915.9	10	16
GRQ4	0.6337	4.90	**2.07**	1134.0	771	7
GRG5	0.2060	10.90	**2.28**	446.8	26	9
GRG6	0.3670	7.00	**2.21**	239.6	78	8
GRG7	0.1457	18.30	**2.89**	395.4	10	9
GRG8	0.2550	11.70	**2.87**	274.0	23	18

Dedicated observations data (2020 - 22, PI - Sagar Sethi)

7 Telescope proposals LoFAR (21hr), uGMRT (47hr), JVLA (7hr)

Telescope/ID	Band	Frequency Cov.	Target	Mosaicing
LOFAR	HBA	120-240 MHz	SGRG	
LOFAR	HBA	120-240 MHz	GRG9	
uGMRT	band 3	300 - 500 MHz	GRG3	Yes
	band 4	550 - 750 MHz	GRG3	Yes
	band 4	550 - 750 MHz	GRG4	
	band 3	300 - 500 MHz	GRG4	
	band 4	550 - 750 MHz	GRG7	
uGMRT	band 3	300 - 500 MHz	GRG6	
	band 4	550 - 750 MHz	GRG6	
	band 3	300 - 500 MHz	GRG8	
	band 4	550 - 750 MHz	GRG8	
uGMRT	band 2	120-250 MHz	GRG8	
	band 2	120-250 MHz	GRG3	
	band 4	550 - 750 MHz	GRG5	
VLA D-conf	C band	4-8 GHz	GRG7	Yes
VLA C-conf	C band	4-8 GHz	GRG3	Yes
	S band	2-4 GHz	GRG8	Yes
	C band	4-8 GHz	GRG3	Yes
	S band	2-4 GHz	GRG8	Yes

Dedicated observation + archival data



Ageing Analysis

Ageing analysis

Spectral age:

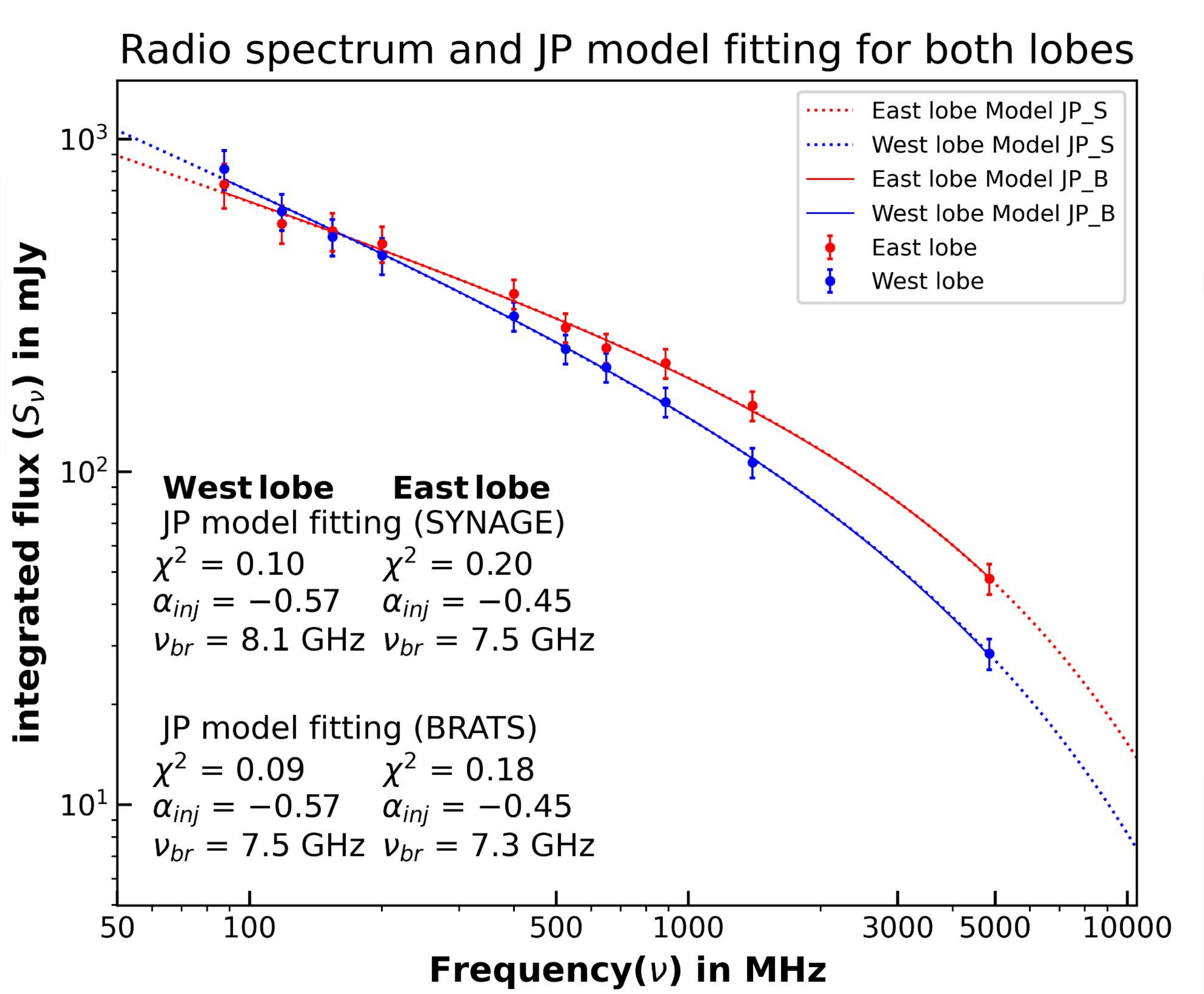
- Considering **synchrotron, adiabatic and IC scattering of CMB losses**
- Can be calculated from **broad band radio spectrum**.
- Required **alpha**$_{\mathbf{inj}}$ and the characteristic **break frequency (**$\boldsymbol{\nu}_{\mathbf{break}}$**)**
- We can obtain **spectral age** using **SYNAGE/BRATS** package.
- Steepening of the spectrum at frequencies higher than ν_{break} not entirely due to aging of plasma may be due to →**Dynamical age**.

Dynamical age:

- Considering **magnetic field structure and evolution**, **mixing of electron plasma, jet power, density of the IGM, with all losses.**
- Can be calculated by considering **self-similar of RG** model (KDA model).
- Required few **observable parameters**.
- We can obtain **dynamical age** using **DYNAGE/RAiSEHD** package.
- We can also obtain **jet power** and **IGM density**.

Ageing analysis of largest bright radio galaxies: Preliminary results

Spectral age fitting one of the GRG in our sample

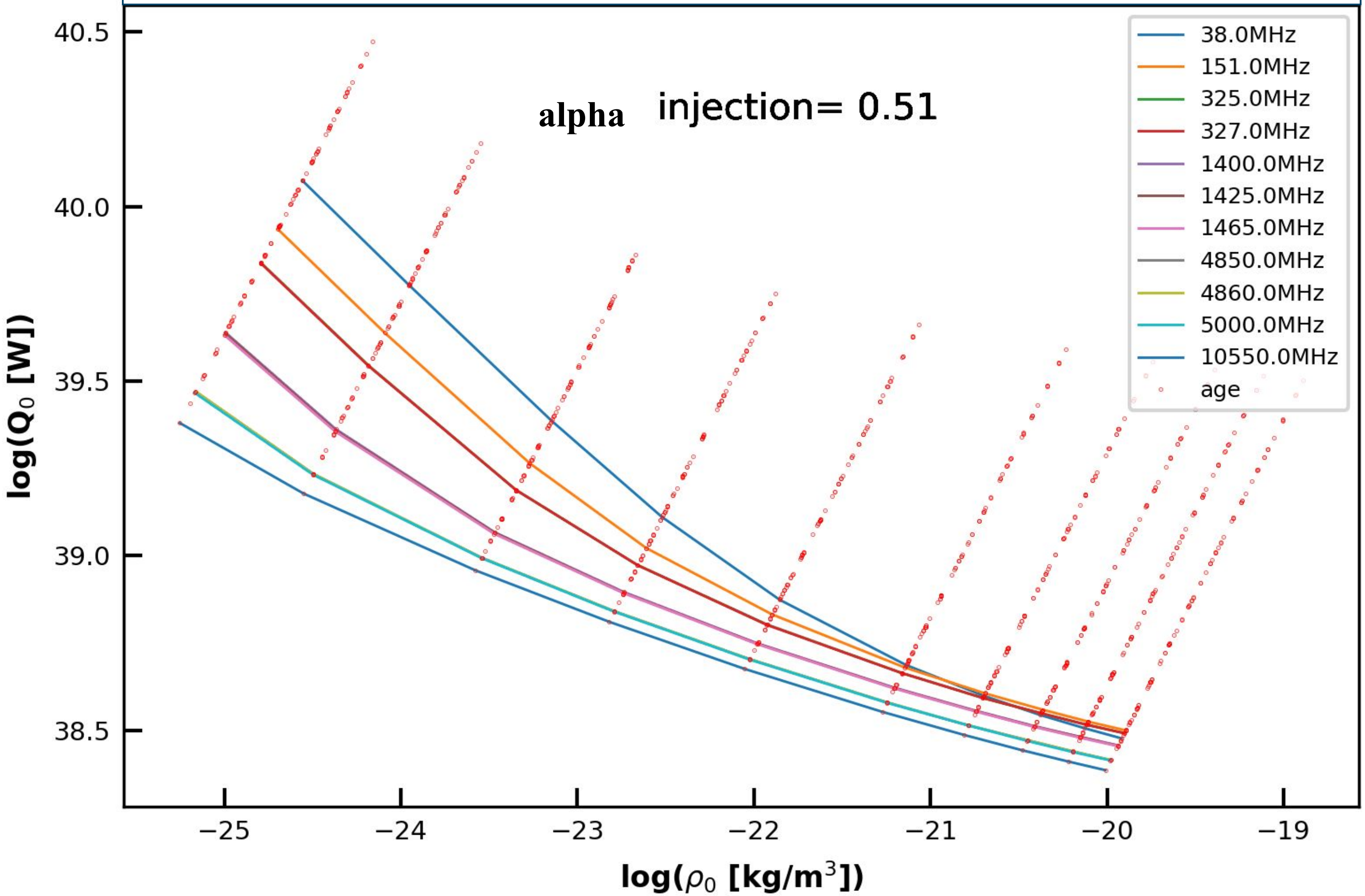


Its total integrated spectral age fitting.

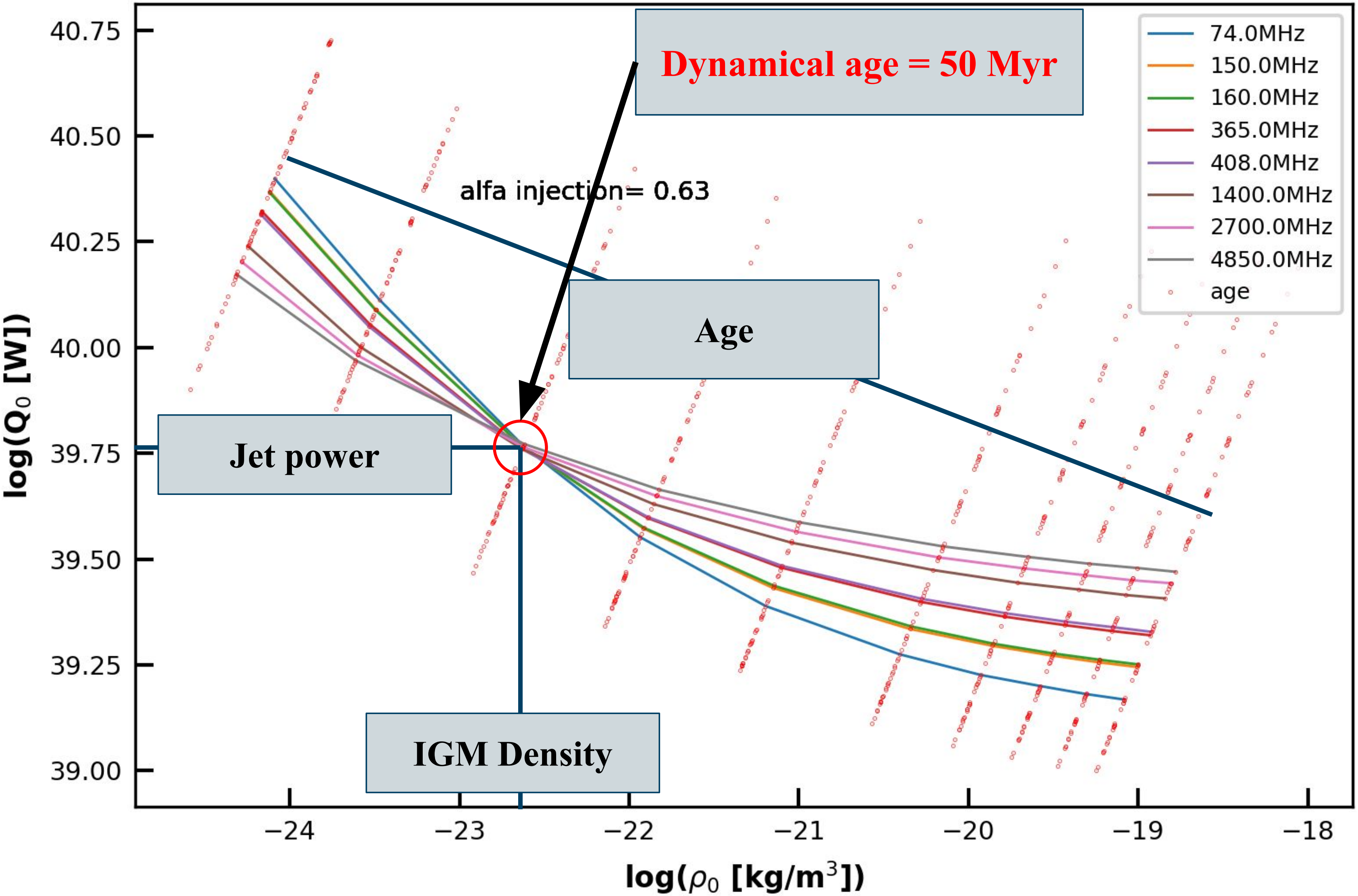
We will follow up with BRATS modelling with multiscale resolved spectral age analysis.

Dynamical age modelling using DYNAGE (KDA model)

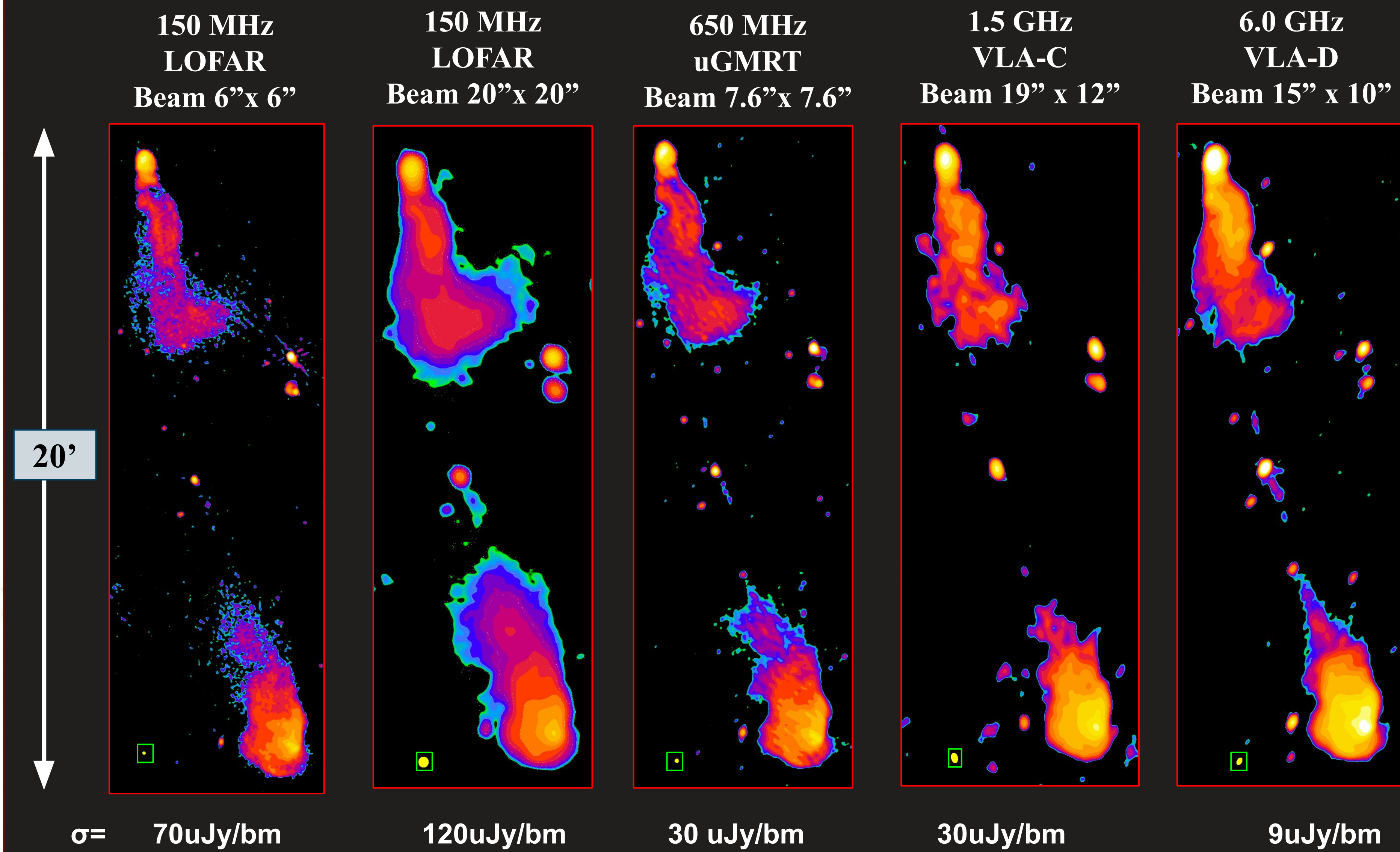
Another GRG as example for Dynamical model



Age, Jet power, IGM density from KDA analysis



Age (Myr) = 10, 20, 50, 100, 200, 400, 600, 800, 1000, 1200



Multi-frequency radio continuum maps of this 2.9 Mpc GRG from our dedicated LOFAR, uGMRT and VLA observations.

Future Work

- Ageing analysis of 8 GRGs (> 2Mpc) with 150 MHz- 10-15 GHz
- Spectral age: Integrated, multi-scale, multi frequency (BRATS, SYNAGE)
- Dynamical age: Comparison between KDA and Analytical model (DYNAGE, RAiSEHD). Here we used KDA model for dynamical age analysis. We will follow up with analytical modelling with RAiSEHD pacakage.
- Hotspots: Multi-scale, multi frequency analysis
- Explore other parameters with high resolution radio images.

Thank you and stay tuned

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