STUDY OF RECURRENT ACTIVITY IN RADIO SOURCES

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Supervisors : *Pratik Dabhade & Katarzyna Małek*
Collaborators : *D. J. Saikia & H.J.A. Rottgering*

NARODOWE CENTRUM BADAŃ JĄDROWYCH ŚWIERK

Graduate Physics Seminar 2025

Supervisors : ***Pratik Dabhade & Katarzyna Małek***

Outline….

- Radio Astronomy
- Active Galactic Nuclei
- Radio Galaxies
- Peaked Spectrum Sources

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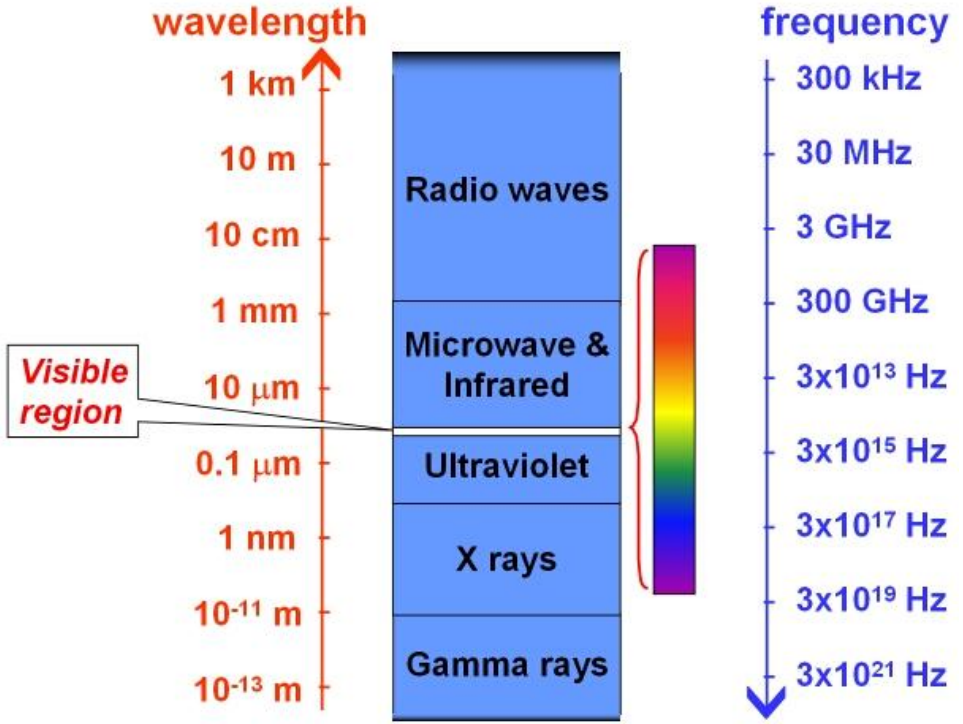
- Radio Astronomy
- Active Galactic Nuclei
- Radio Galaxies
- Peaked Spectrum Sources

- Motivation
- Aim of the study
- Methodology & Analysis
- Preliminary results
- Summary & Future perspective

An Introduction to Radio Astronomy

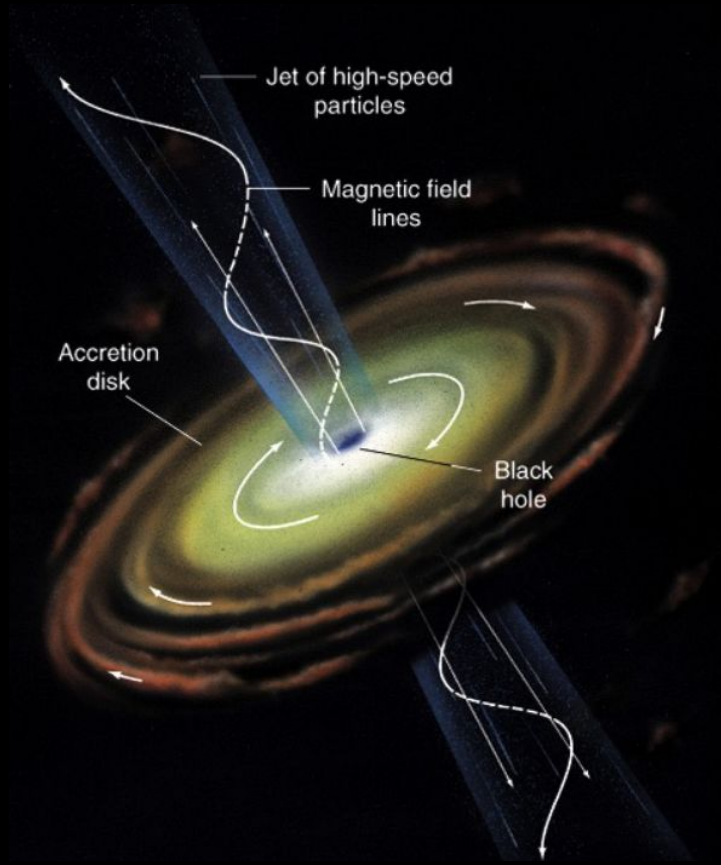
- *Study of natural radio emission from celestial sources.*
- *Longer wavelength : From about 1 mm (10^{-3} m) to 10^{4} m*
- *Radio wavelengths are unobscured by dust.*
- *Sensitive to low-energy electrons - detects aged plasma and relic emission.*
- *Traces H (21-cm line)*



Active Galactic Nuclei

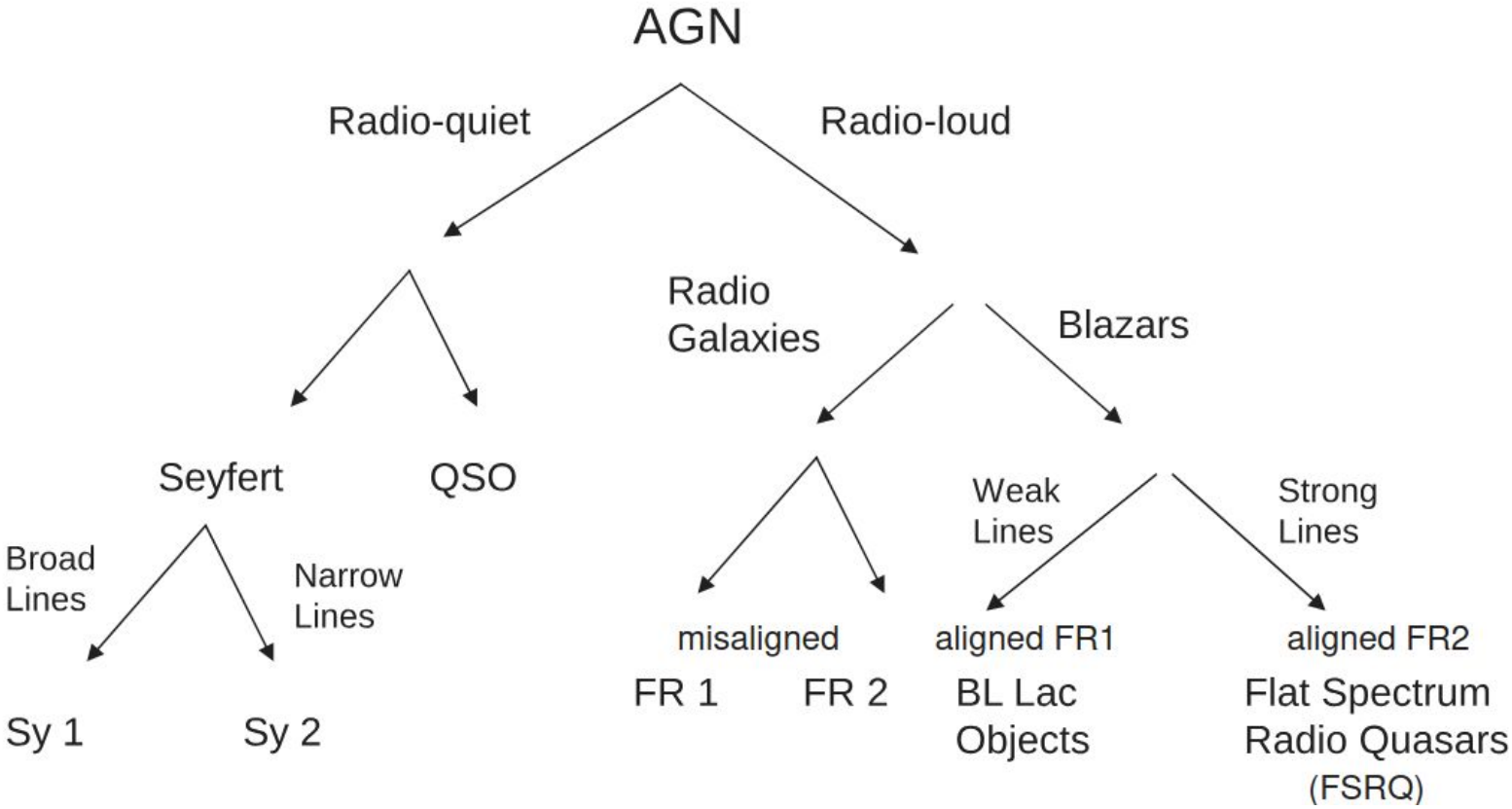
Powered by SMBH accretion

- Powerful sources of radiation which exist in the centre of all galaxies where accretion onto a supermassive black hole releases significant gravitational energy .
- Galaxies which host an AGN are known as **Active galaxies.**
- AGN are not always active - the **active phase is short** in a galaxy's lifetime.
- Jets are thought to come from twisting of magnetic field in the inner part of accretion disk.



Francis Halzen (2021)

AGN Classification



Charles Dennison Dermer, Berrie Giebels (2016)

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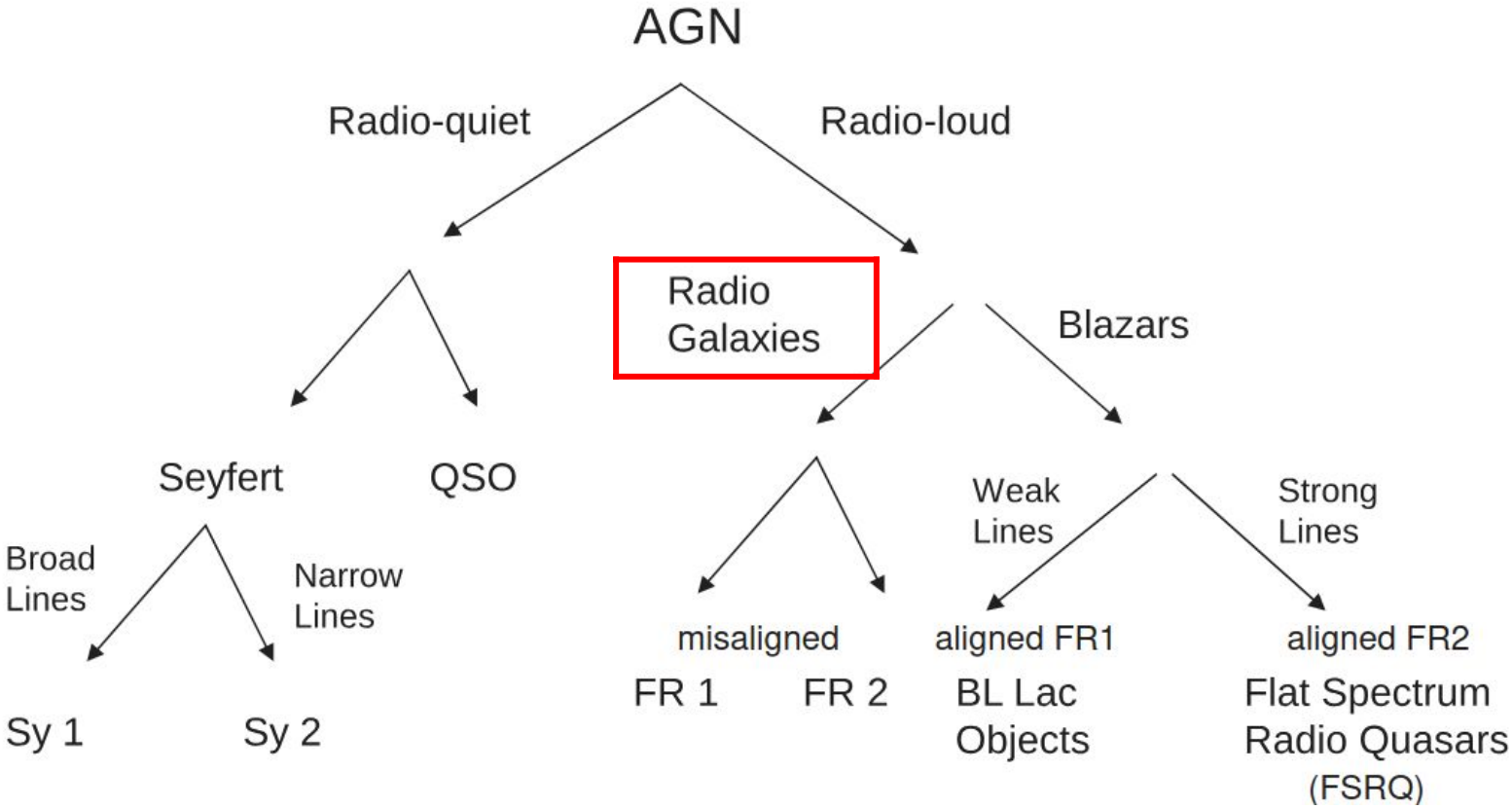
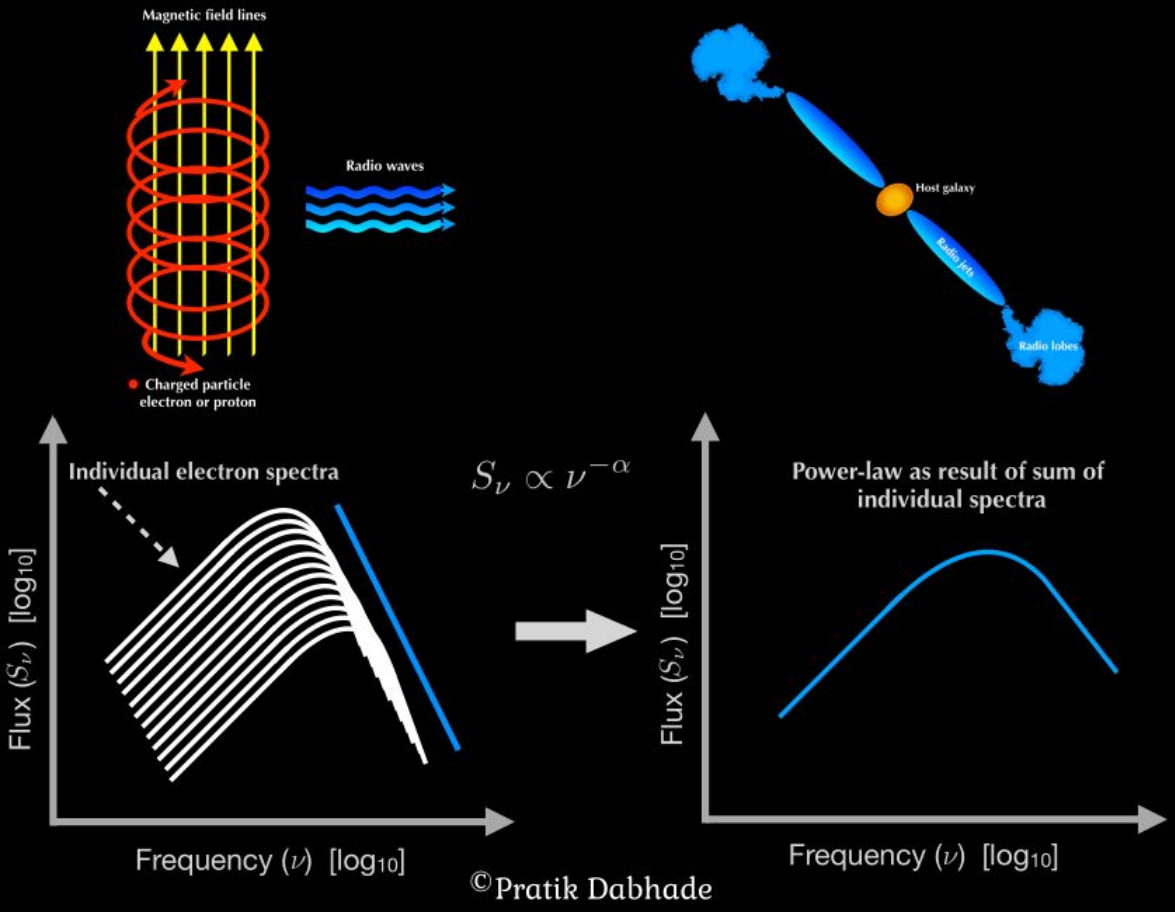


Charles Dennison Dermer, Berrie Giebels (2016)

What Causes Radio Emission in Galaxies ?

1. Synchrotron Emission



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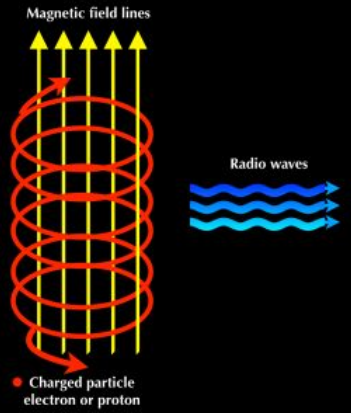
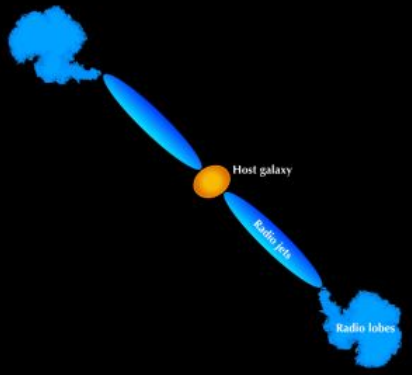
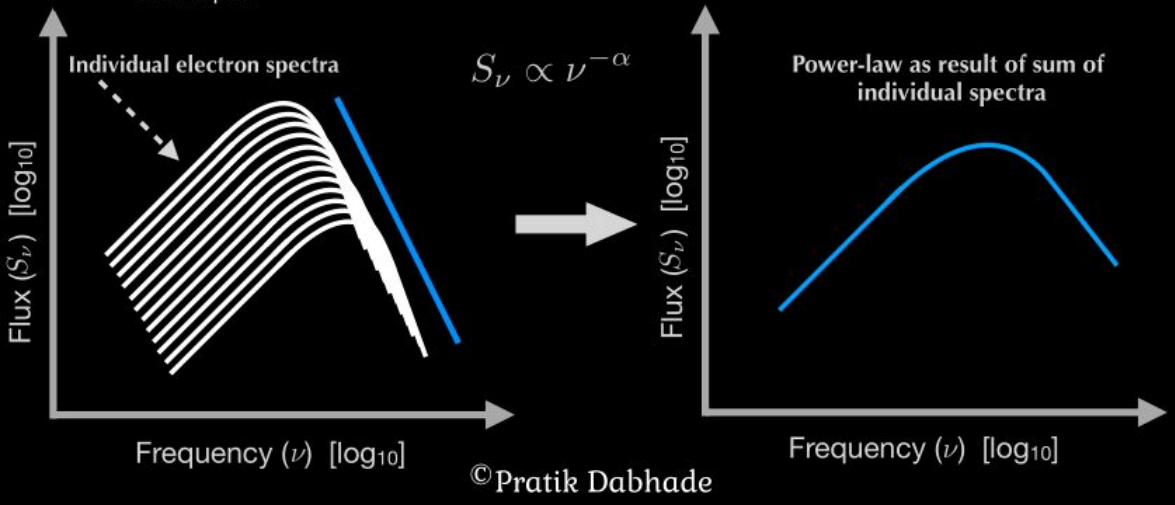
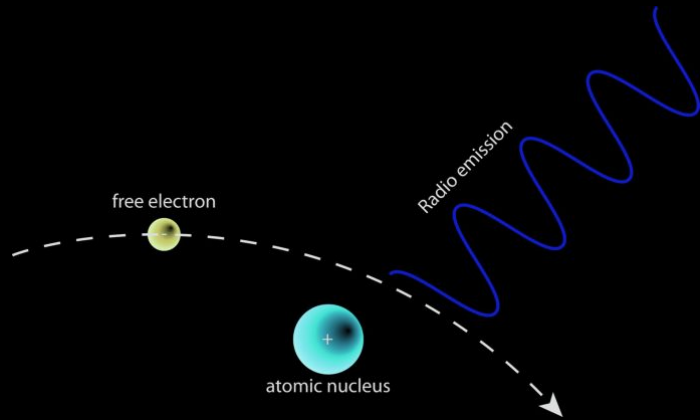






2. Free-Free Emission

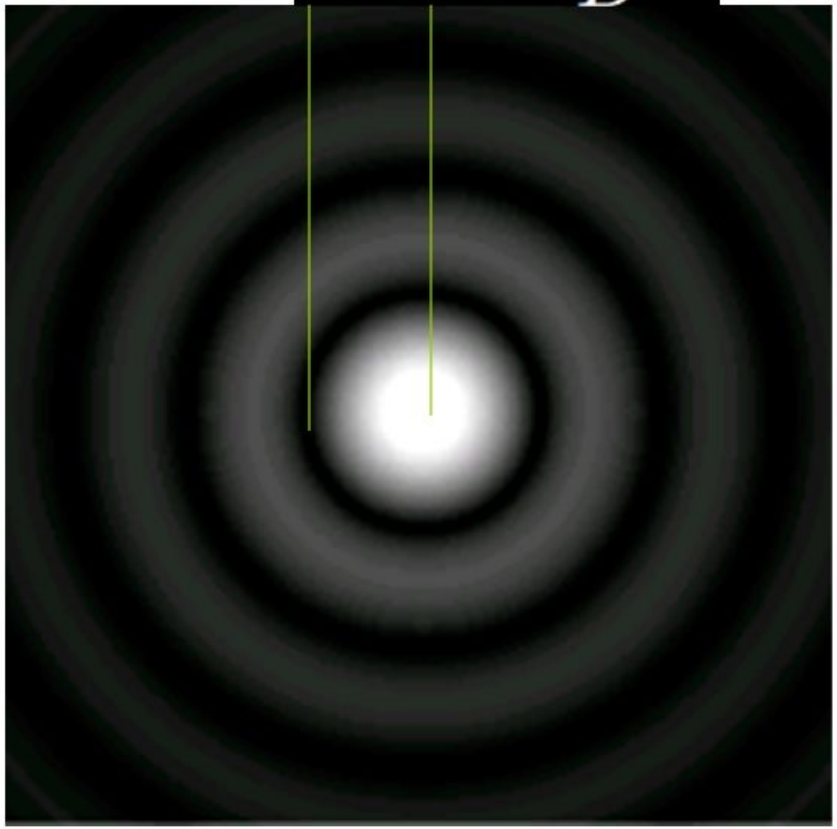
Thermal Bremsstrahlung



Observing the Radio Sky

Dwingeloo Radio Observatory

Resolution $\Delta\theta \approx \frac{1.22\lambda}{D}$



Radio Interferometry

VLA (Credit: Alex Savello)

Radio Interferometry

$\theta \sim \lambda / B$

VLA (Credit: Alex Savello)

VLBI is interferometry on a global scale…..

EUROPEAN VLBI NETWORK

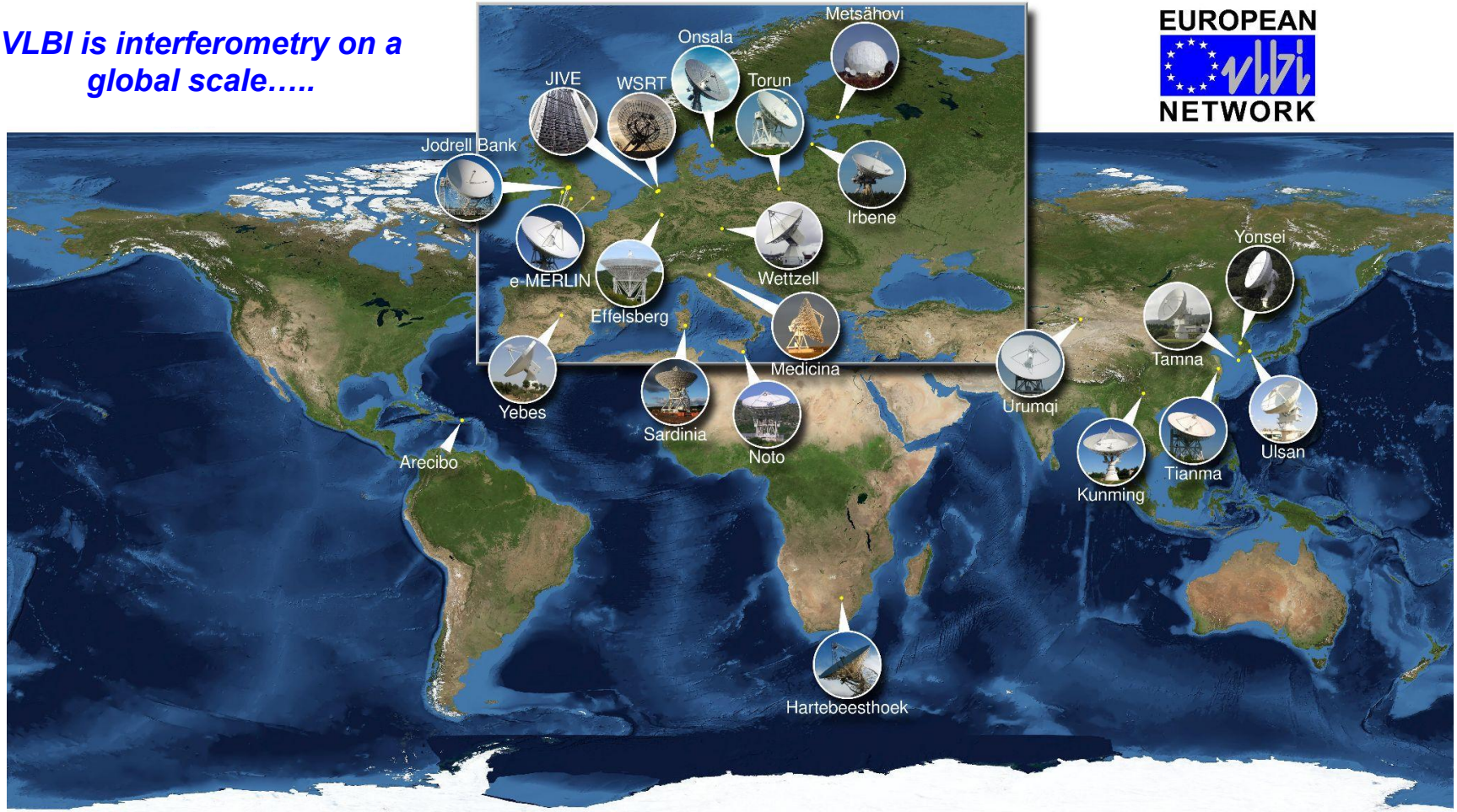


Image by Paul Boven (boven@jive.eu). Satellite image: Blue Marble Next Generation, courtesy of Nasa Visible Earth (visibleearth.nasa.gov).

Radio Galaxies

- A subclass of active galactic nuclei (AGN).

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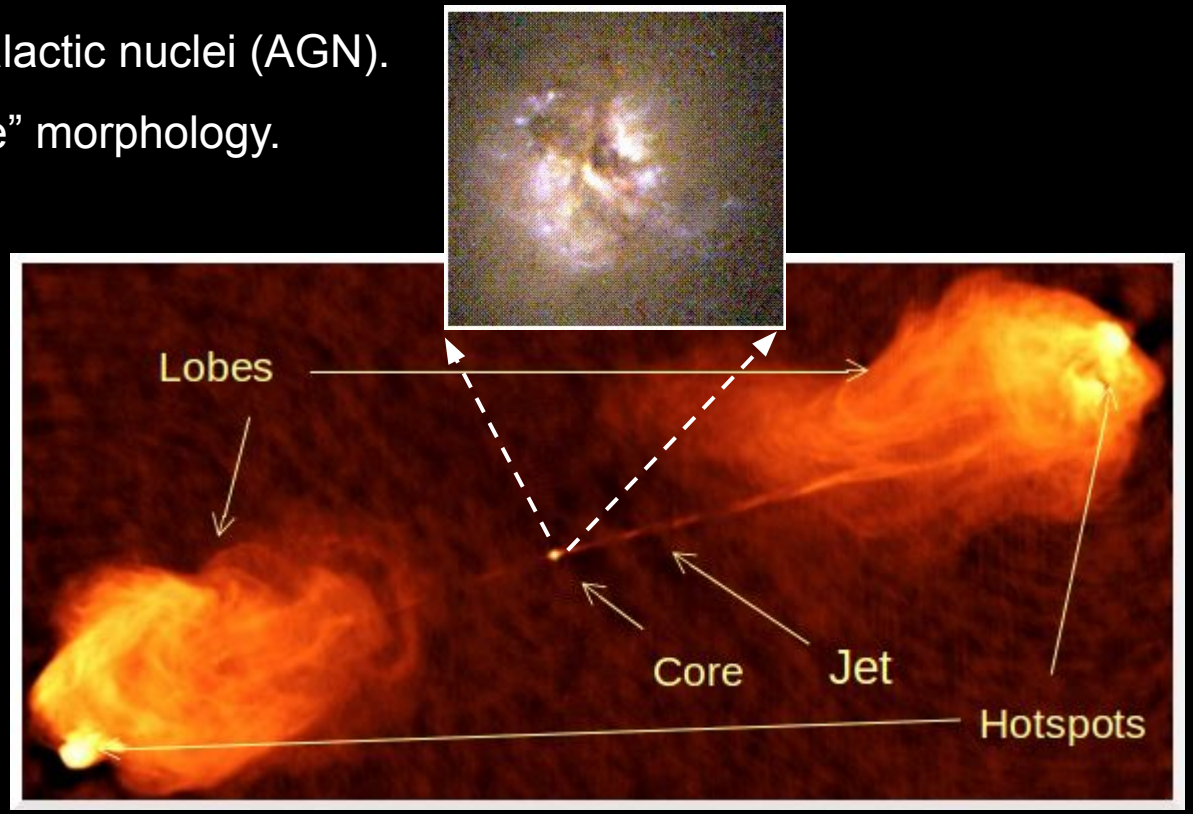
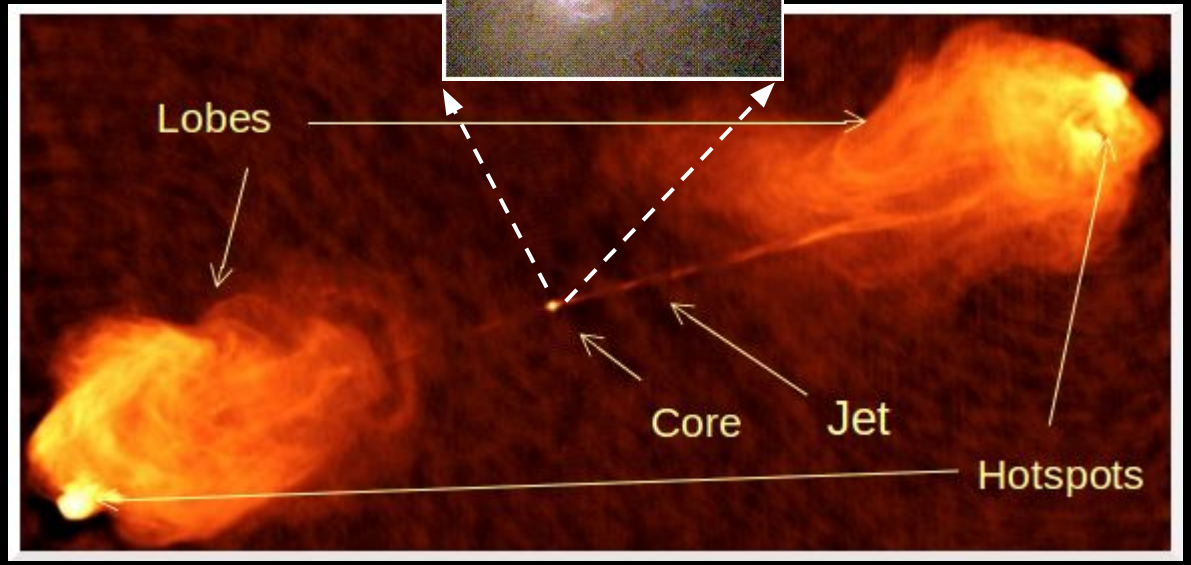
- Display a “core-jet-lobe” morphology.



Radio Galaxies

- A subclass of active galactic nuclei (AGN).
- Display a “core-jet-lobe” morphology.
- Sizes from pc to Mpc.



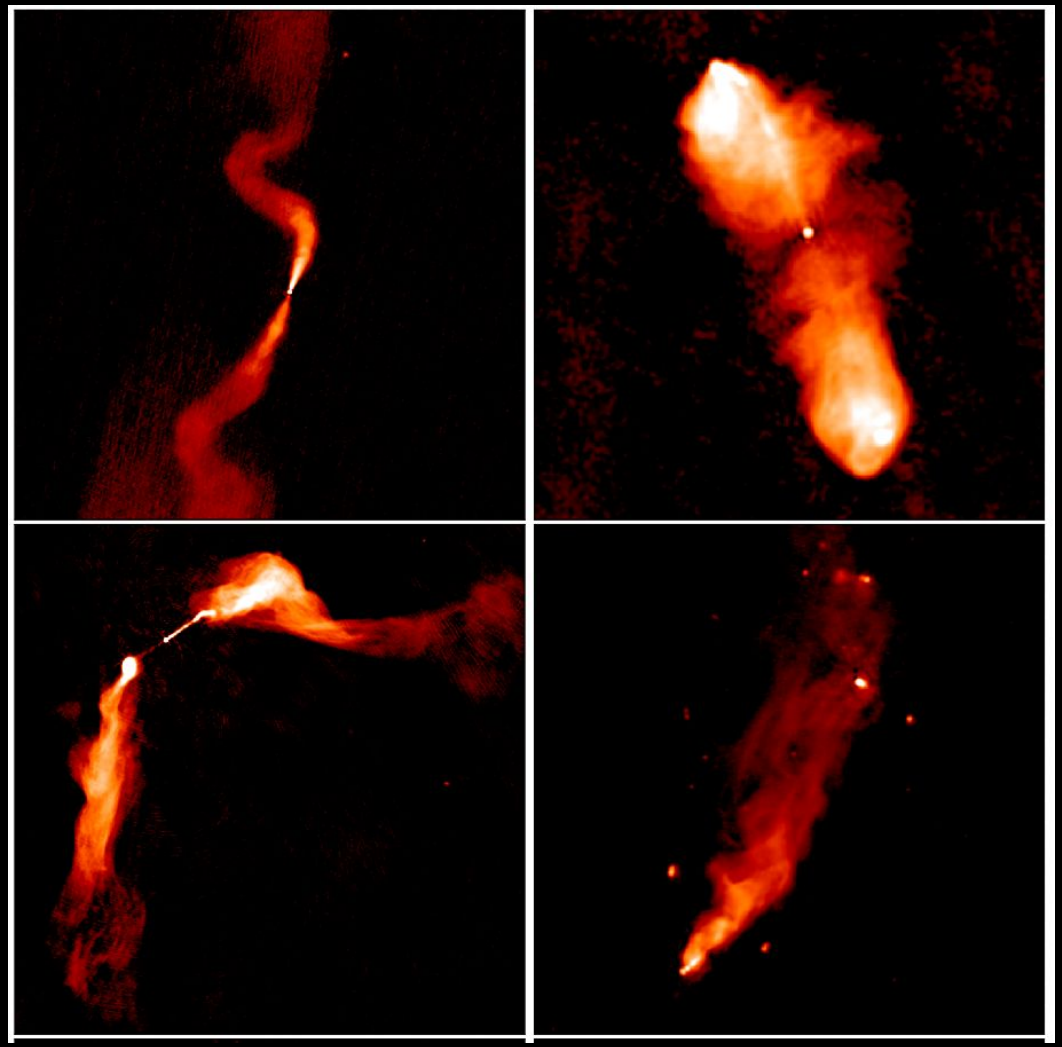
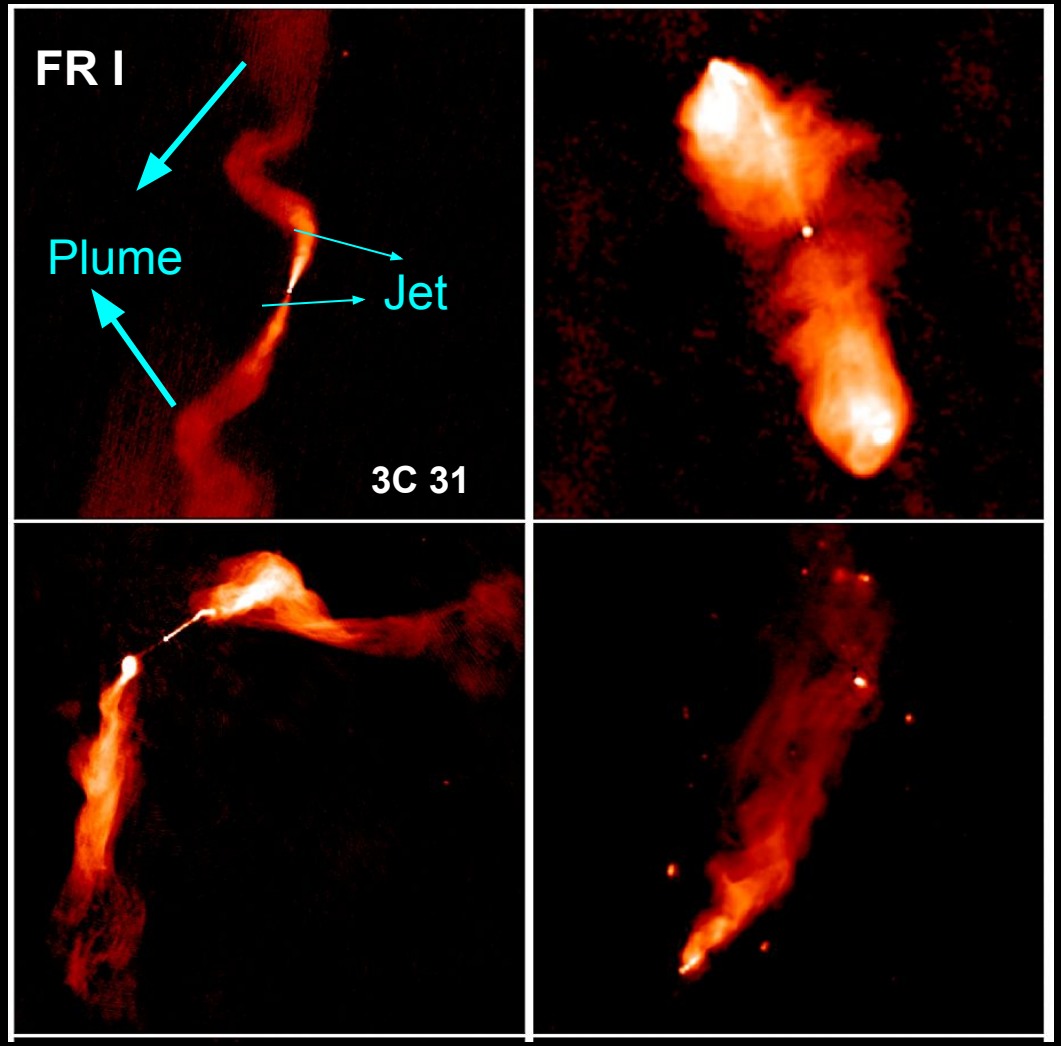


Image modified from Hardcastle+2020



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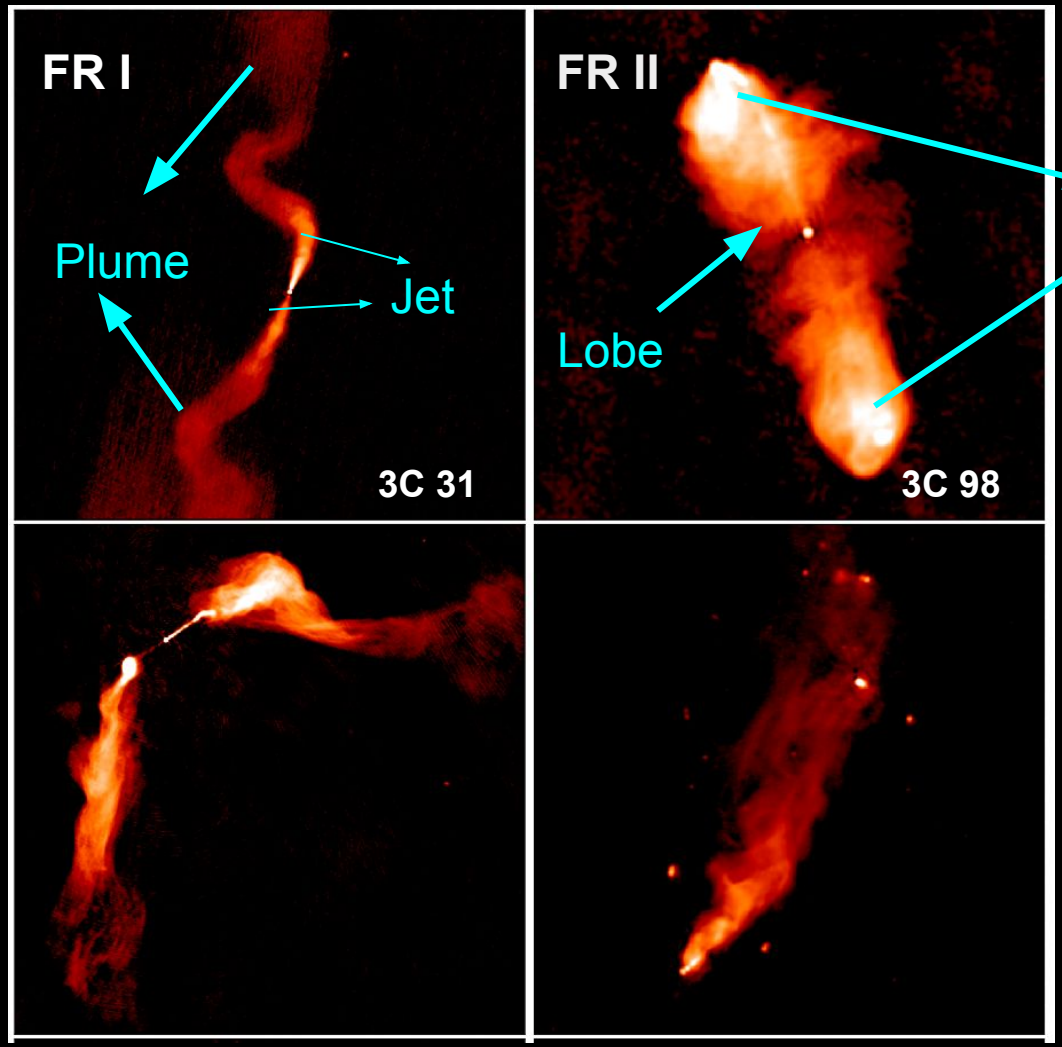

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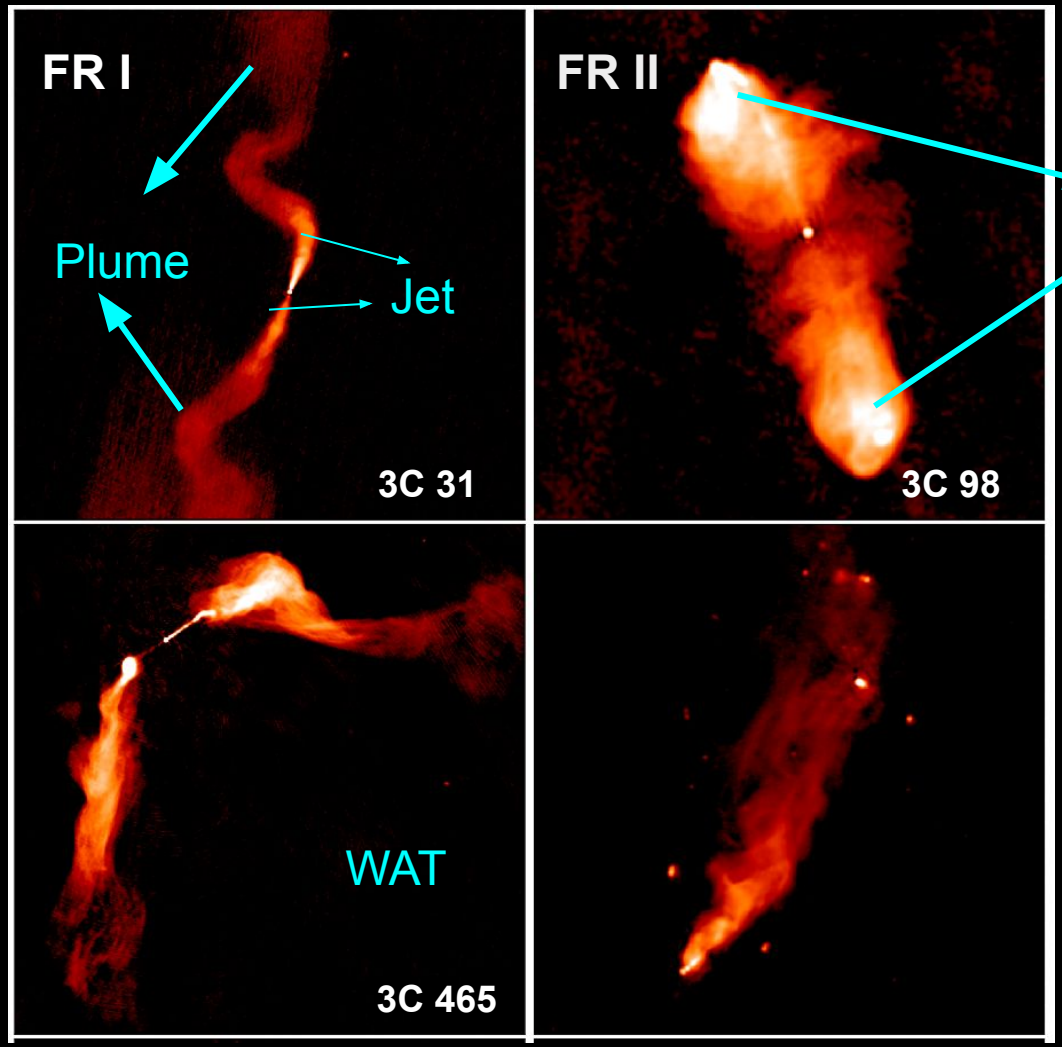

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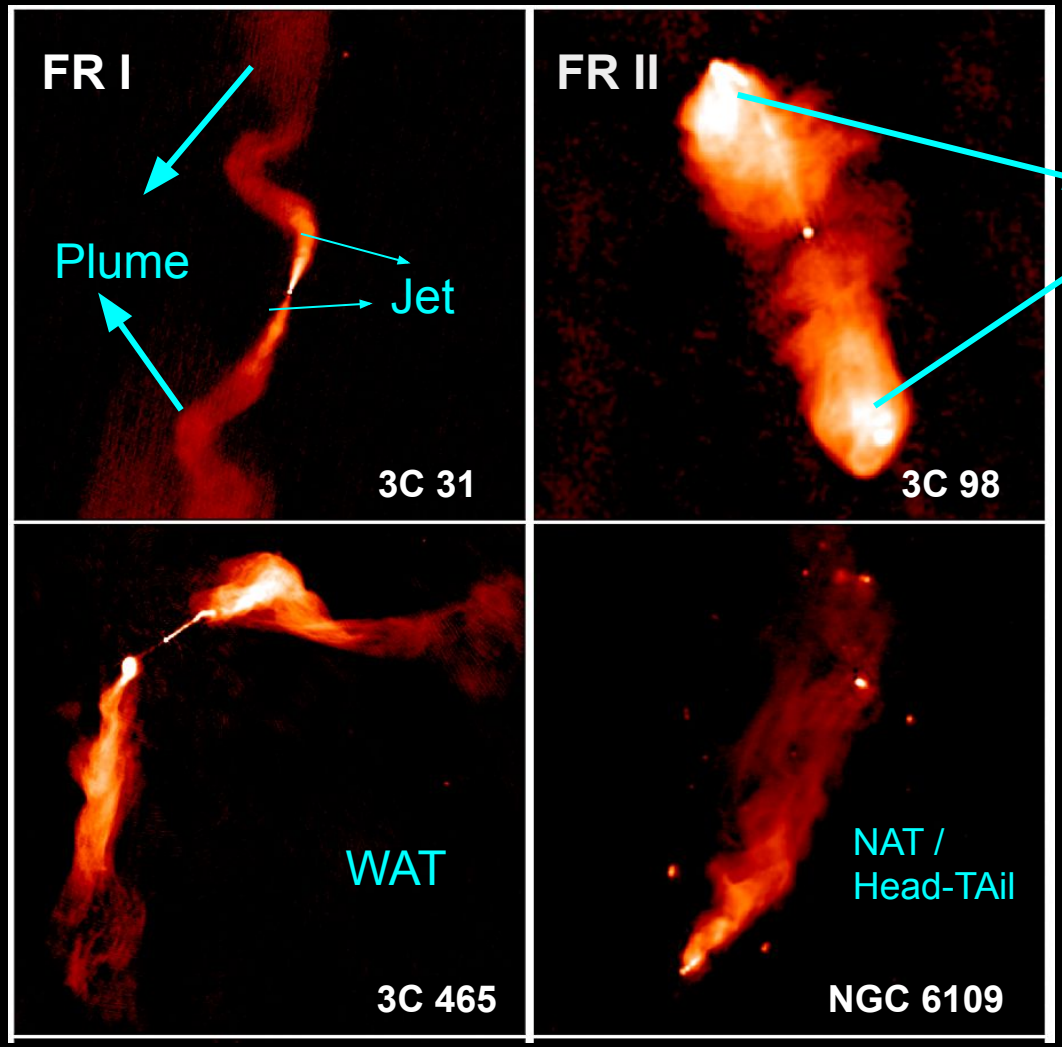

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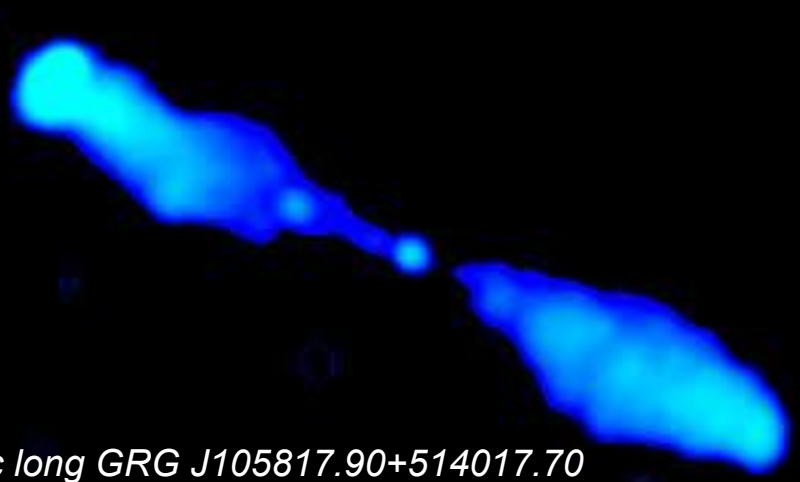
Giant Radio Galaxy (GRG)

- One of the largest astrophysical sources in the Universe with an overall projected linear size of **0.7 Mpc** or more
- GRGs are considered to be the endpoint of radio galaxy evolution.
- Largest known GRG - 7 Mpc.



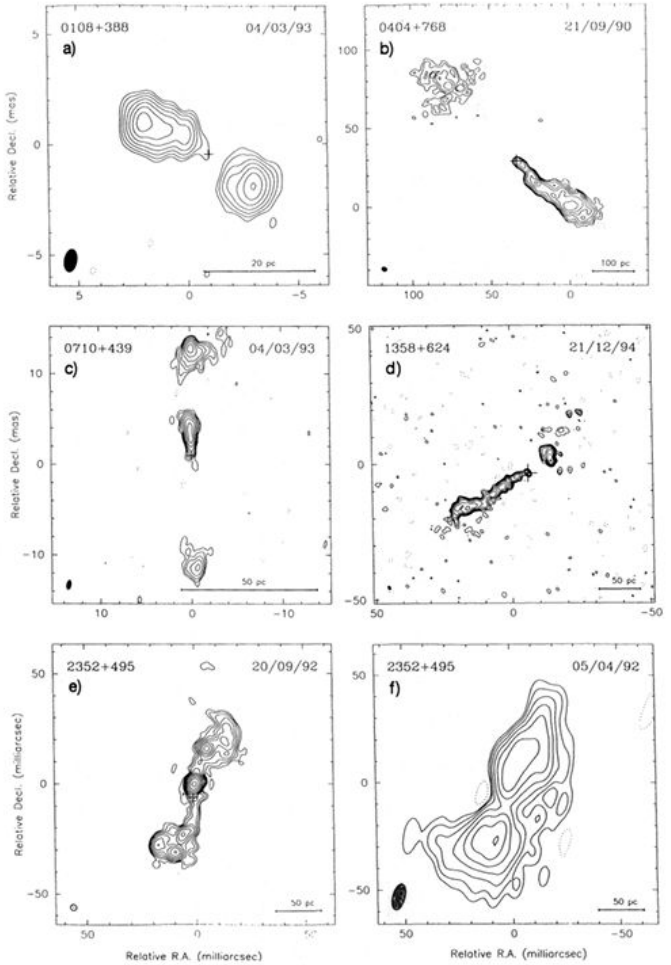
1.86 Mpc long GRG J105817.90+514017.70
Dabhade et al.2020

Compact (Small) Radio Sources

- Radio source characterised by a classical double structure on the 100 parsec (pc) scale.

- Considered as the early stages of the large radio sources.

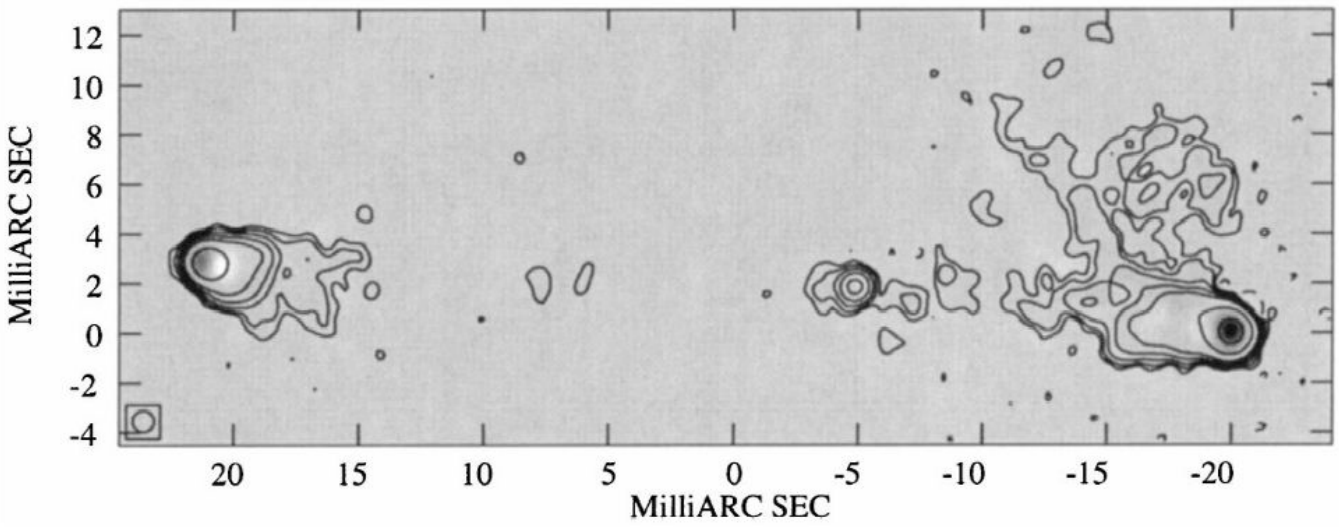
Sources that I am interested in !



Readhead et al. (1996)

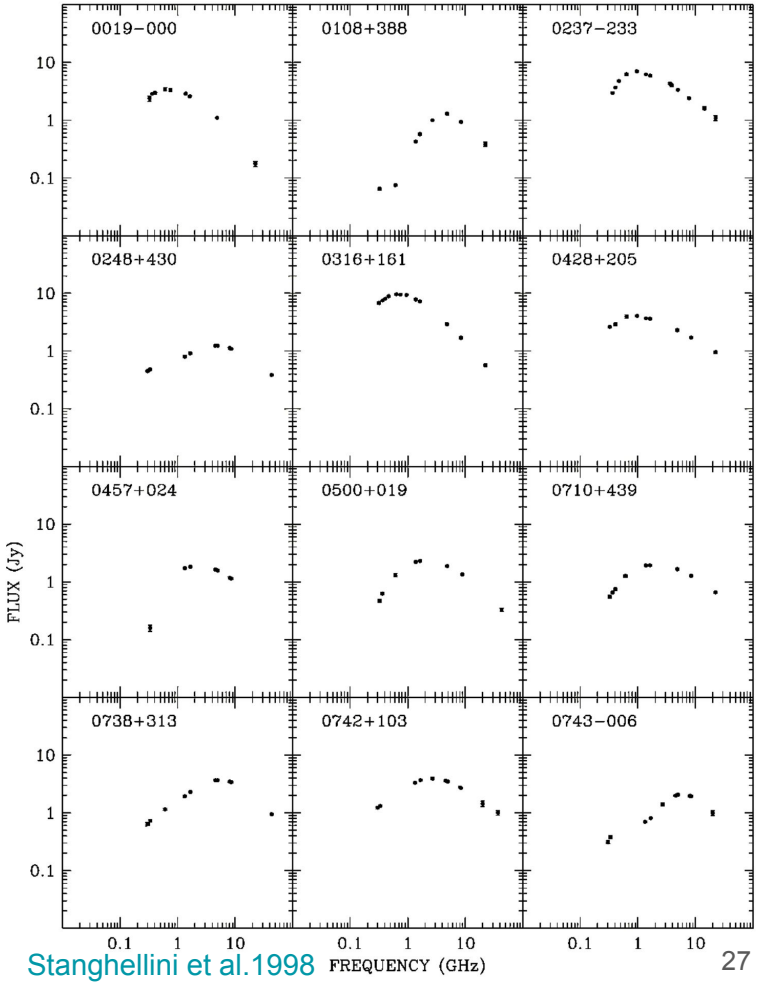
How do we know they are young ?

- A direct test is to measure hotspot expansion using multi-epoch VLBI observations and derive the kinematic age.
- For eg., source 1943+546 shows a hotspot separation velocity of 0.42c and an inferred age of 1000 years based on proper motions.
- Both dynamical and radiative arguments suggest that the ages of these sources lie in the range $10^2 - 10^5$ yr.



(Polatidis et al. 1999)

Nomenclature for Compact Radio Sources



Stanghellini et al.1998

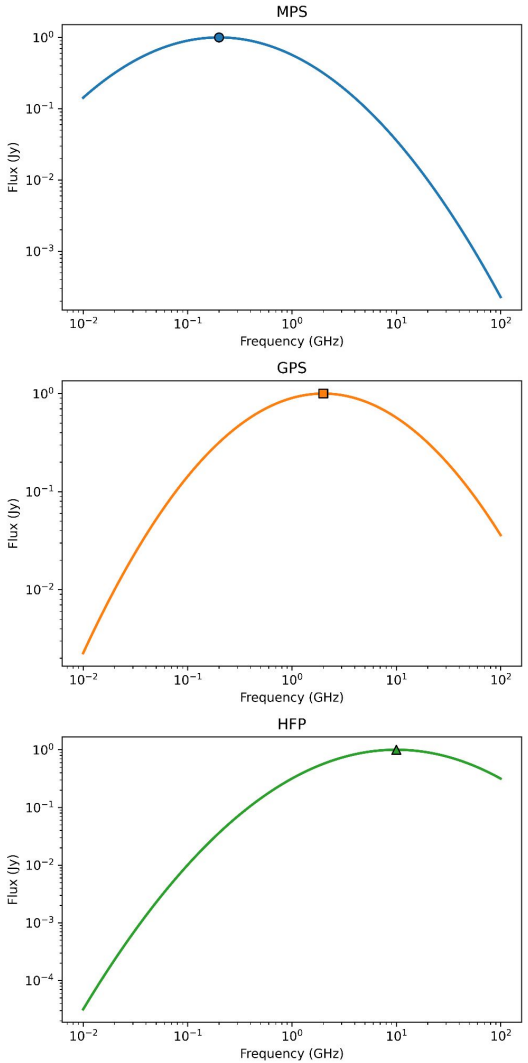
Nomenclature for Compact Radio Sources

Radio Spectrum (peak frequency):

- **MHz Peaked Spectrum (MPS):** < 500 MHz
- **GHz Peaked Spectrum (GPS):** 0.5 – 5 GHz
- **High Frequency Peaked Spectrum (HFP):** > 5 GHz

By Radio Source Size :

- **Compact Symmetric Object (CSO):** < 1 kpc
- **Compact Steep Spectrum (CSS):** 500 pc – 20 kpc



Nomenclature for Compact Radio Sources

Peaked Spectrum (PS) → Sizes < 500 pc

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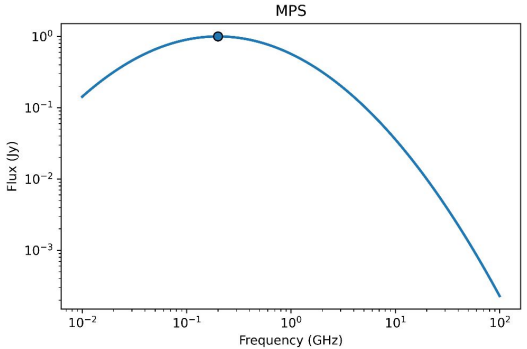
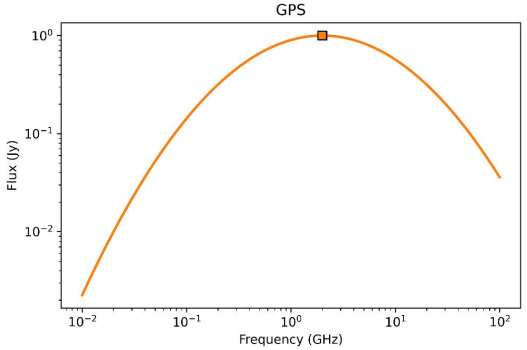
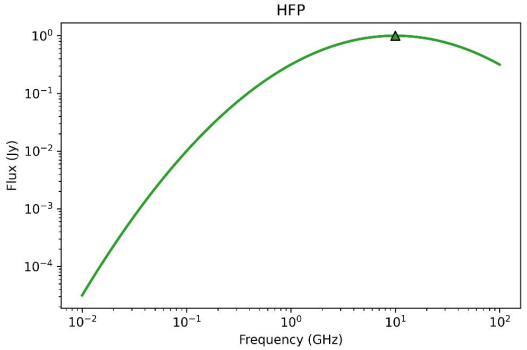
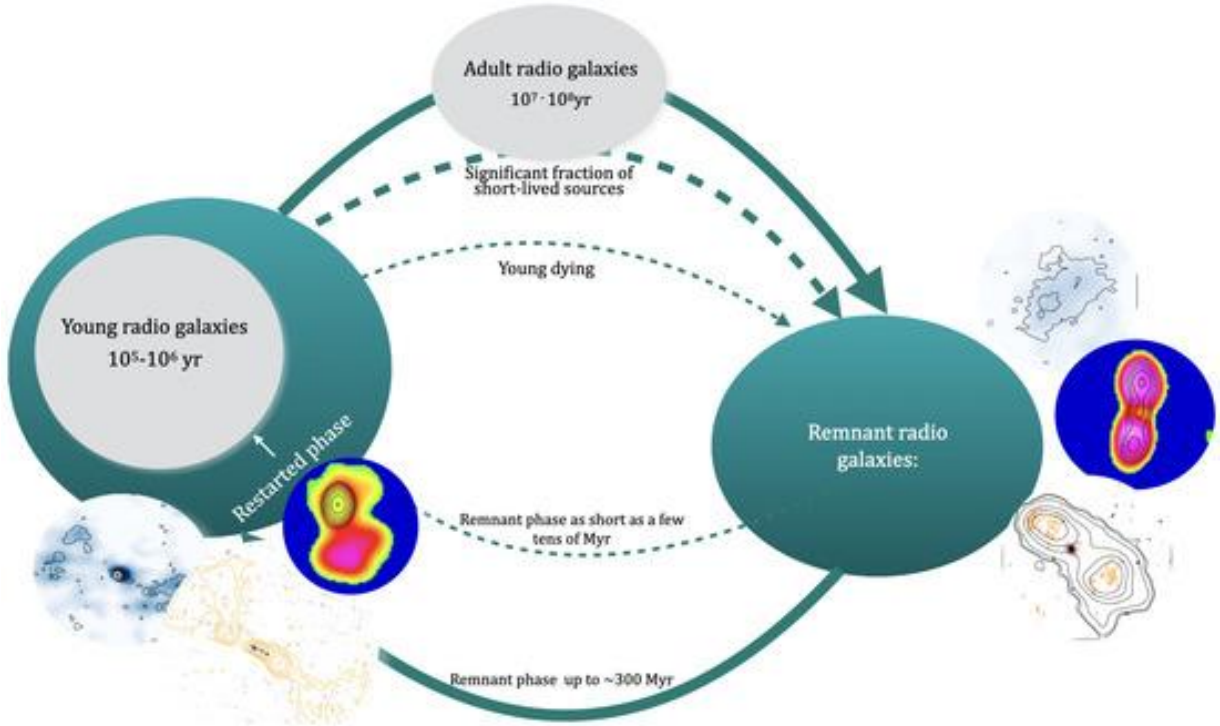




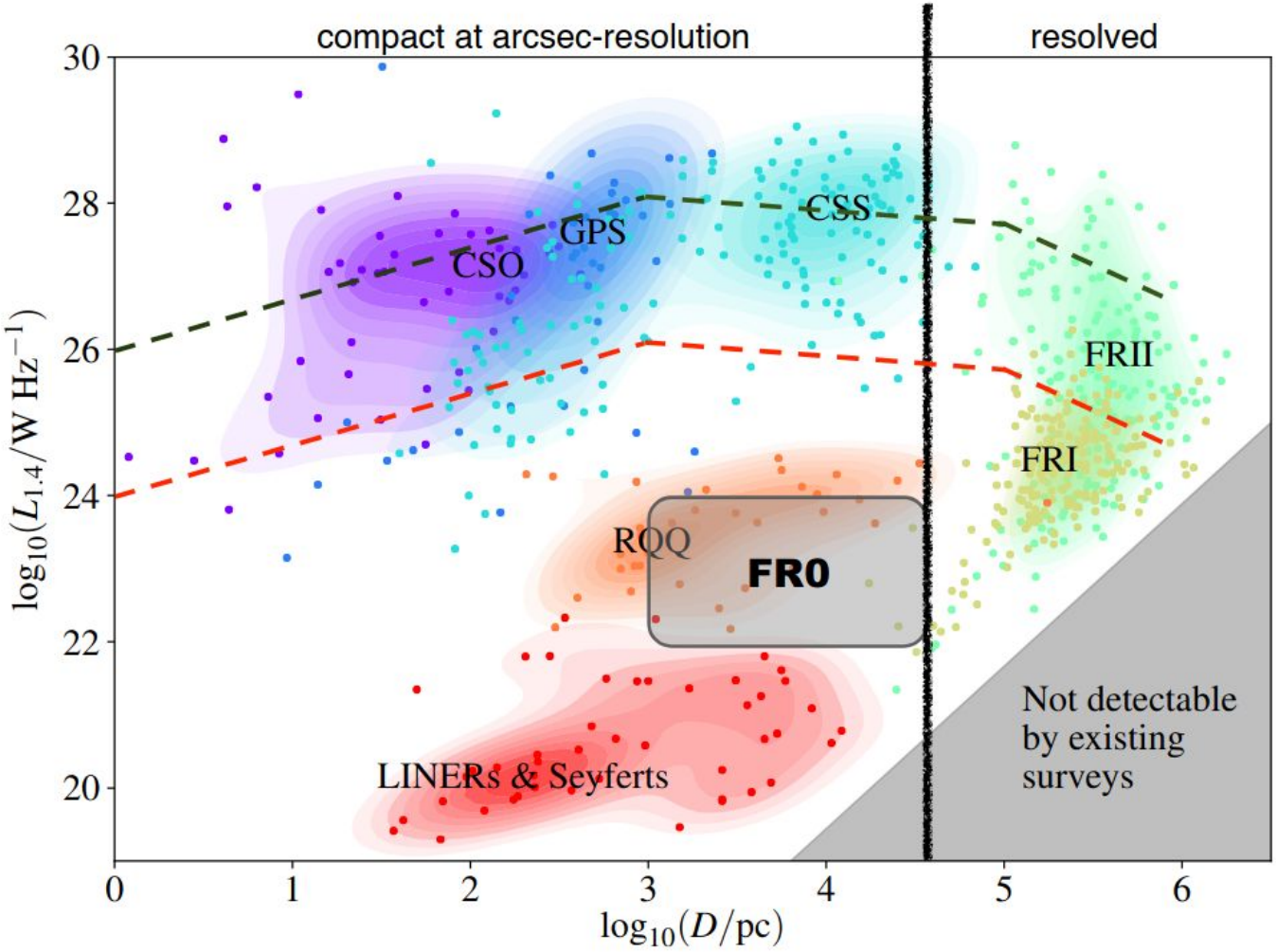


Life-cycle of radio galaxies

- *Exhibit a life cycle with alternating phases of activity and quiescence.*
- *Different phases of evolution-* ***young,evolved,dying (remnant) and restarted sources.***
- *Identified using spectral properties and in some cases morphology.*

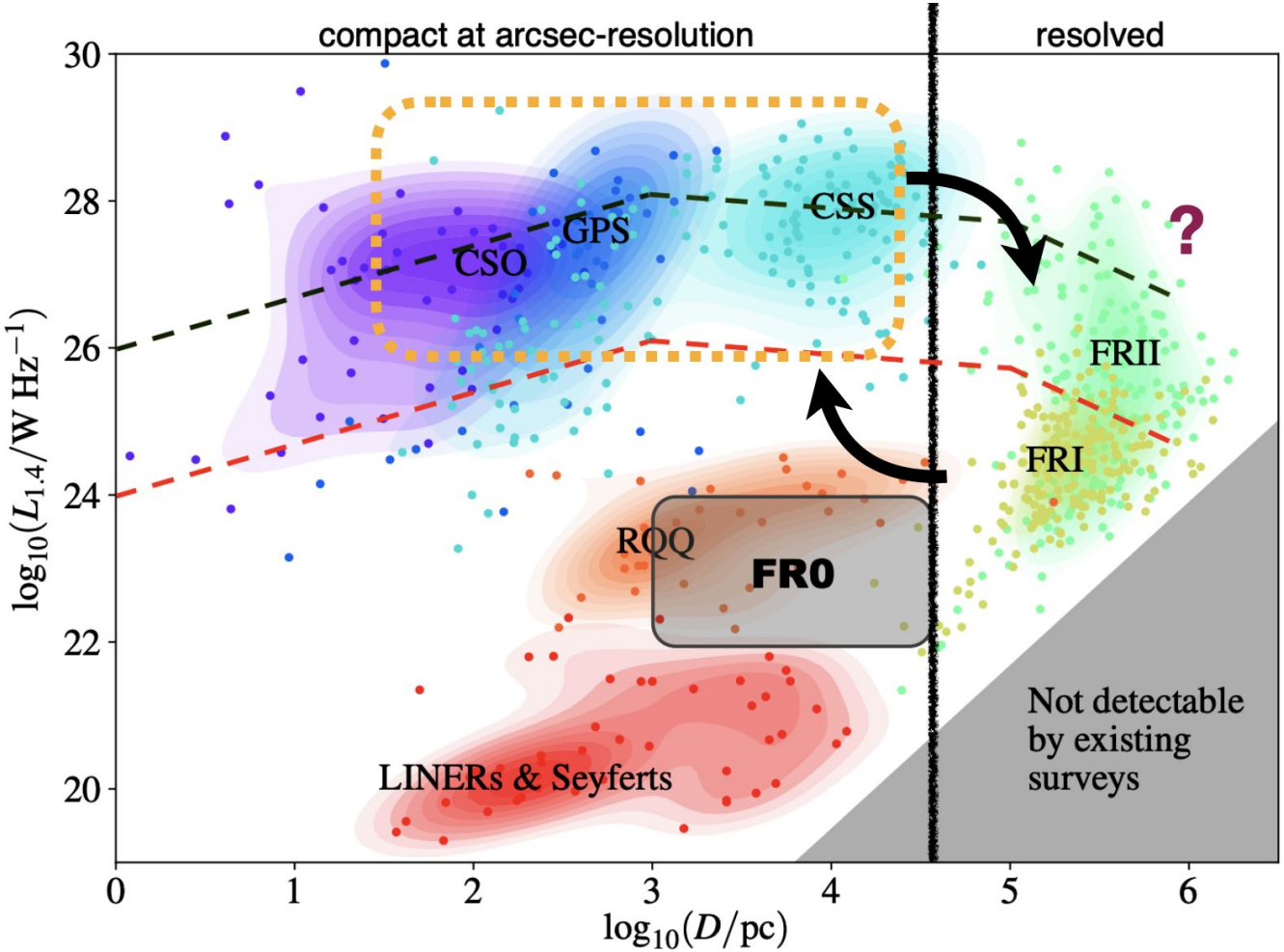


Raffaella Morganti(2024)



- **CSO: 10-100 pc**
- PS : < 500 pc
- **CSS:** 500 pc – 20 kpc

Baldi 2023, A&A Rv



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Adapted from *Baldi 2023, A&A Rv*

Why are PS Sources Important?

1. **Probes of the Host Galaxy**

- Bright, symmetric radio structures at small scales.
- Trace **NLR** & **ISM** through: Faraday rotation / depolarization, HI absorption and Interaction with emission-line gas.

(O'Dea, Christopher P. ;Baum, Stefi A.,*Astronomical Journal, January 1997)*

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magnetic fields + ionized gas

Jet–gas interactions

cold neutral gas

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2. **Key to Radio Galaxy Evolution**

- Represent very young radio galaxies (ages ~10^3–10^5 yr), often precursors of CSS and FR I/II sources.
- Offer insight into radio source origin & growth.

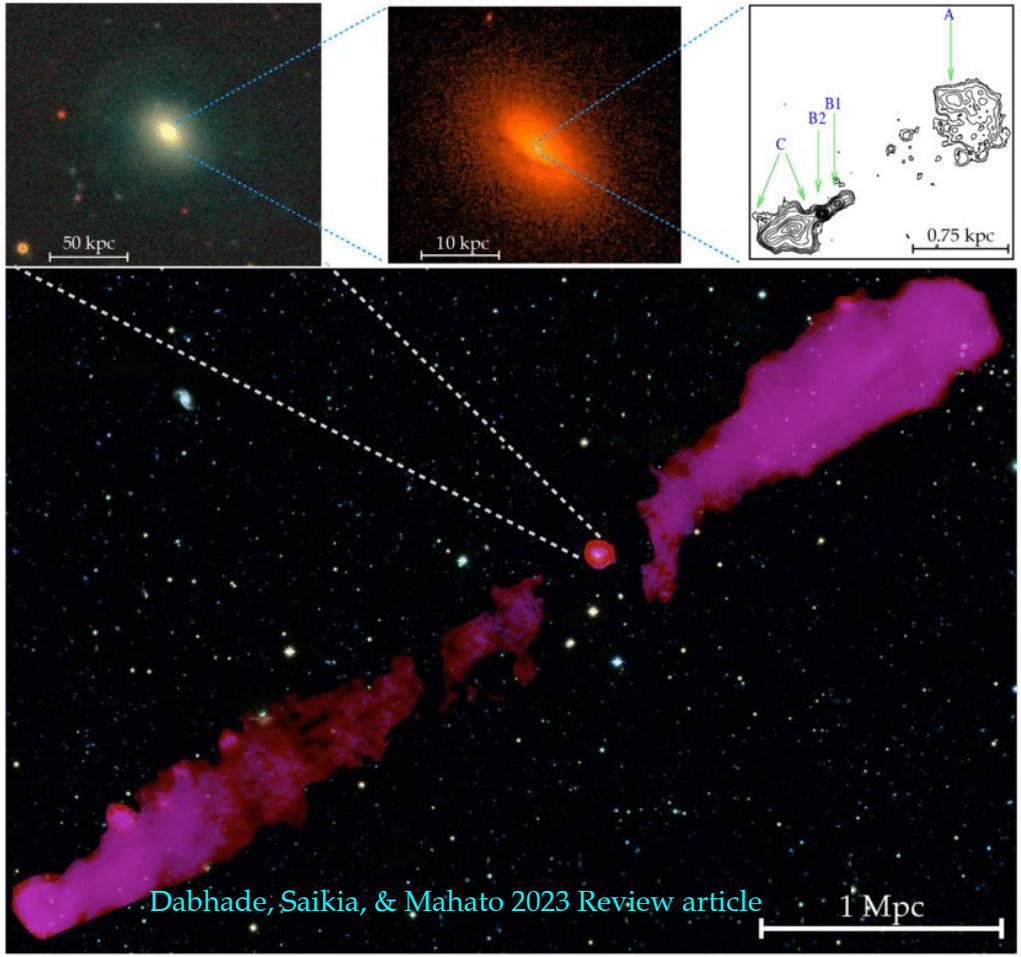
(O'Dea, Christopher P. ;Baum, Stefi A.,*Astronomical Journal, January 1997)*

What Can We Learn by Studying Peaked Spectrum Sources?

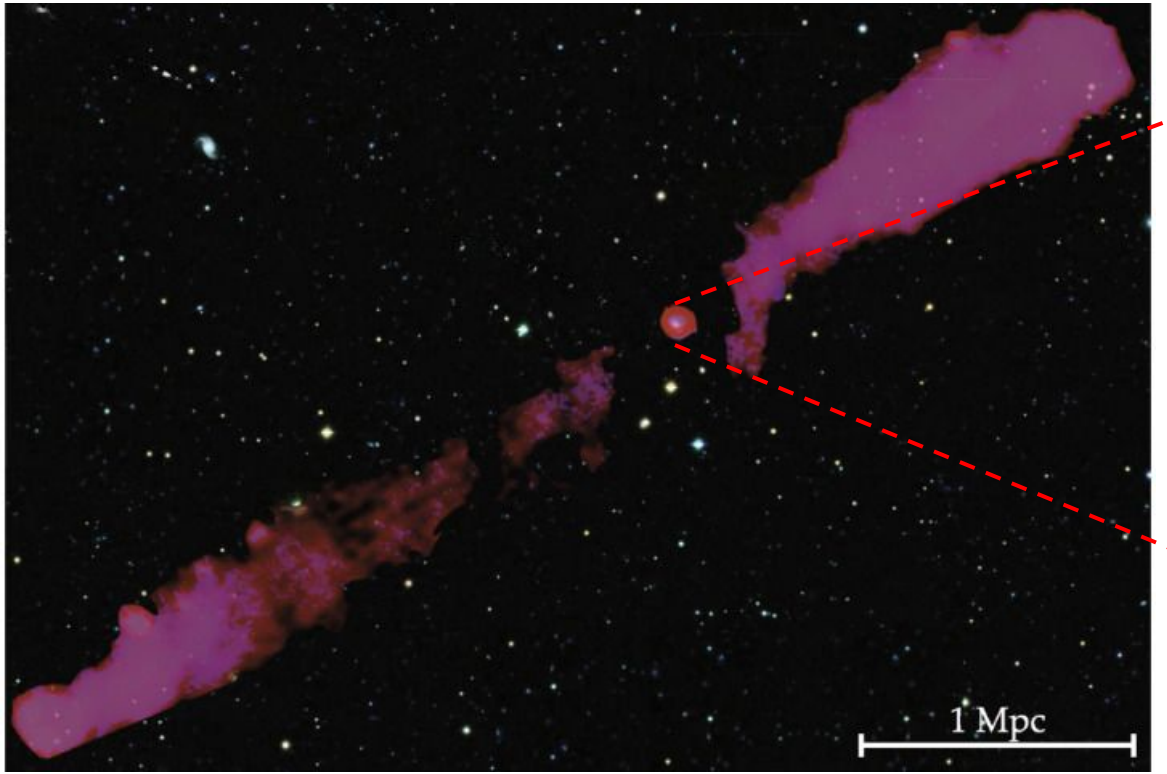
- How, when, and where are radio galaxies "born", and what do their early years look like?
- How long do radio galaxies remain in their active phase(s)?
- How does feedback operate in the circumgalactic environment?
- How do jets begin, and what does their early phase look like?
- Do high-power and low-power sources follow the same birth and evolutionary pathways?
- How does nuclear activity and kinetic outflow impact galaxy evolution?
- Do these characteristics change with redshift?

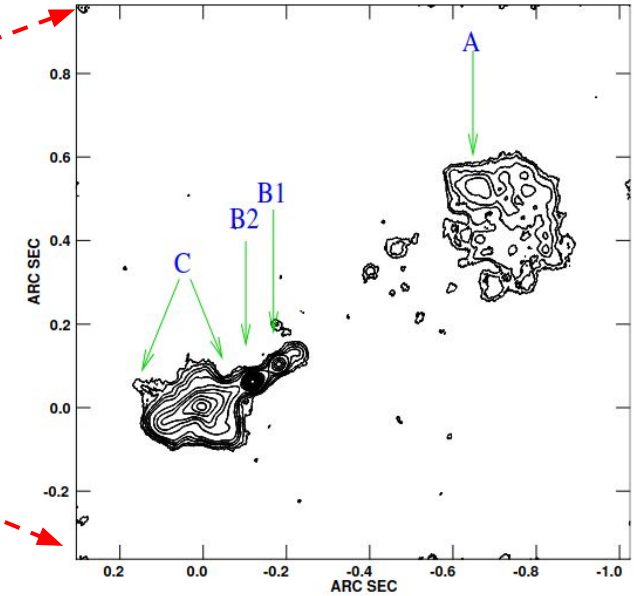
From pc to Mpc scale emission

VLBI reveals compact doubles within kpc-scale cocoons, indicating PS sources may evolve into FR I/II radio galaxies



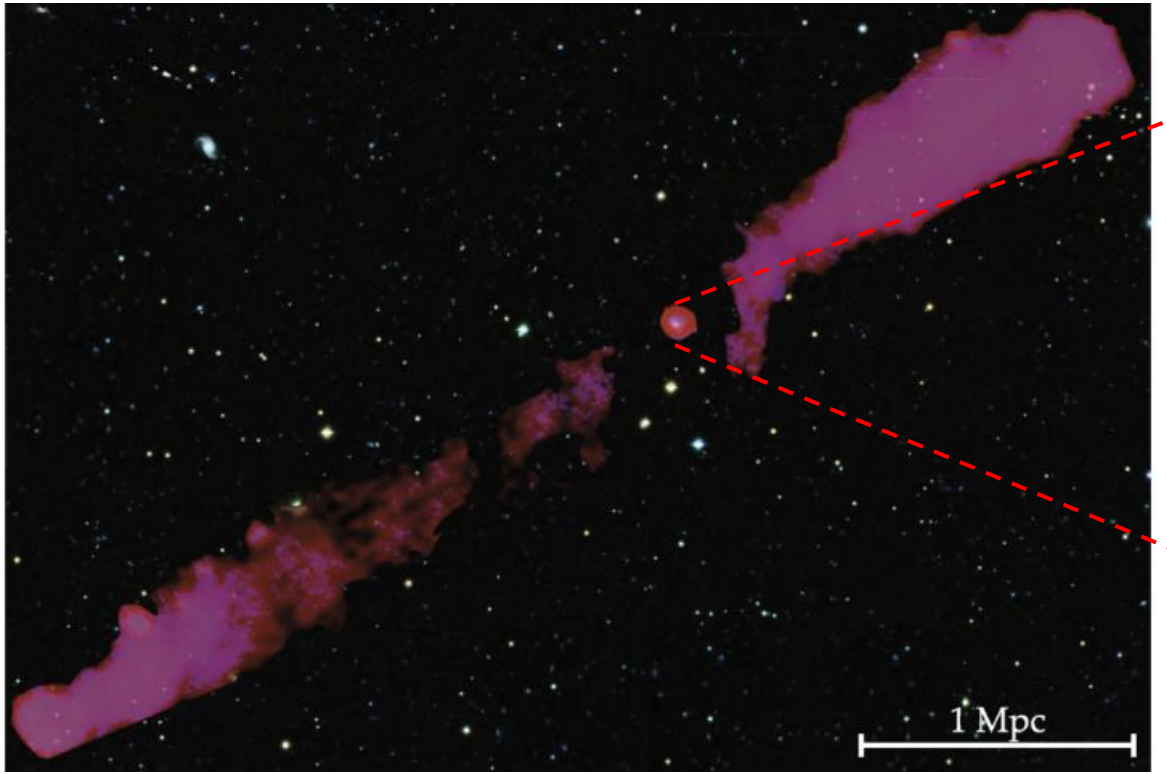
Multi-wavelength images of GRG 3C236 on various scales

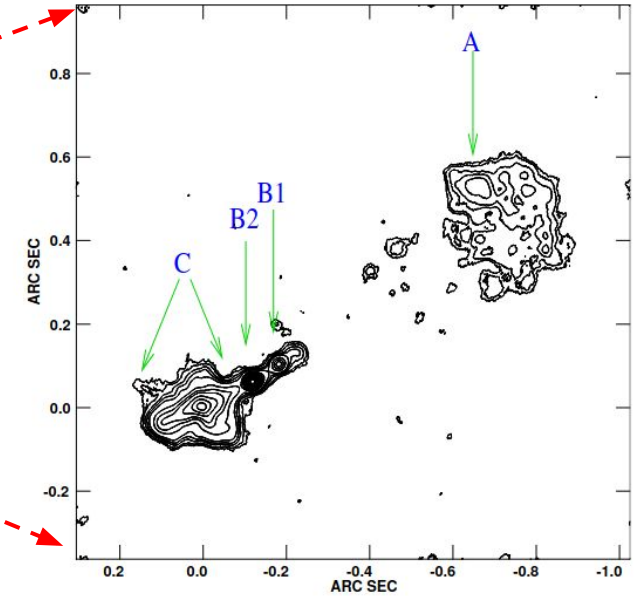




Schilizzi et al. 2001

Dabhade, Saikia, & Mahato 2023 Review article





Schilizzi et al. 2001

Dabhade, Saikia, & Mahato 2023 Review article

Whether this growth is typical or PS activity instead consists of short bursts separated by long quiescent periods ?

Project 1:

Aim of the study…..

- AGN activity is episodic, shaping the lifecycle of radio galaxies.
- Only a few PS AGN have been found within older faint cocoons ➡ duty cycle remains unclear.
- Past wide-area radio surveys lacked surface-brightness sensitivity and resolution to detect “compact core + relic emission”.
- Recent low-frequency interferometry enables detection of faint, diffuse emission.

A.Mohanan, Dabhade, Malek et al.
(in preparation)

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Understand the duty cycle of these radio galaxies by investigating the presence of kpc scale radio emission (e.g., relic, low–surface-brightness emission).

A.Mohanan, Dabhade, Malek et al.
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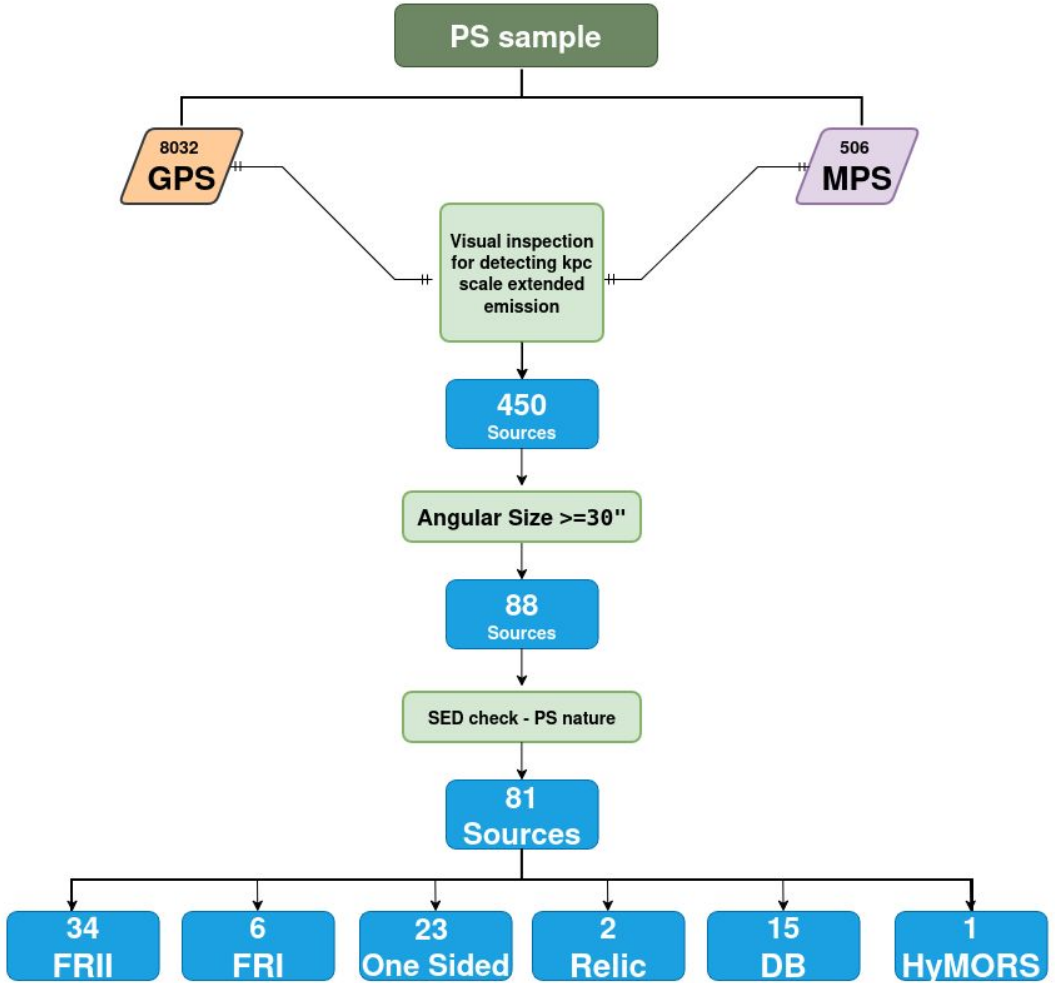
Methodology

From data collection to analysis…..



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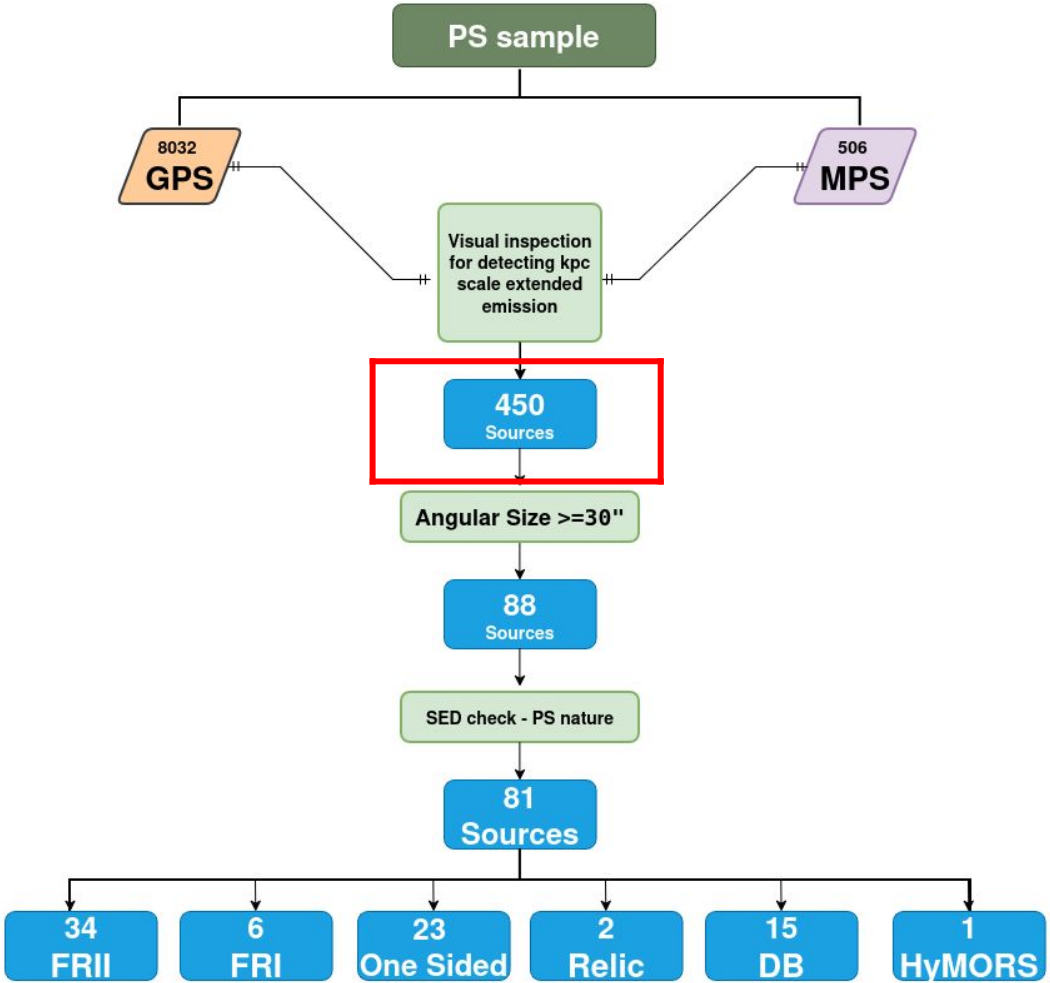

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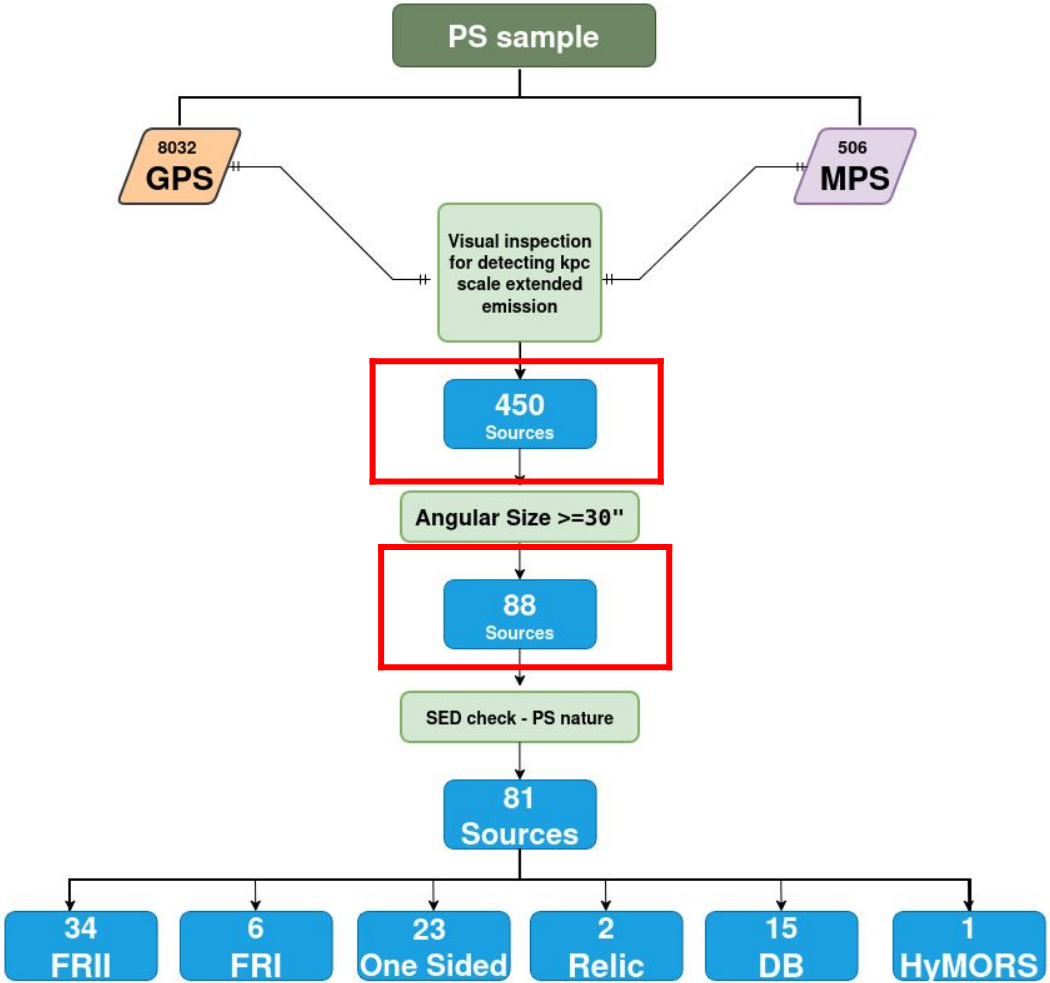

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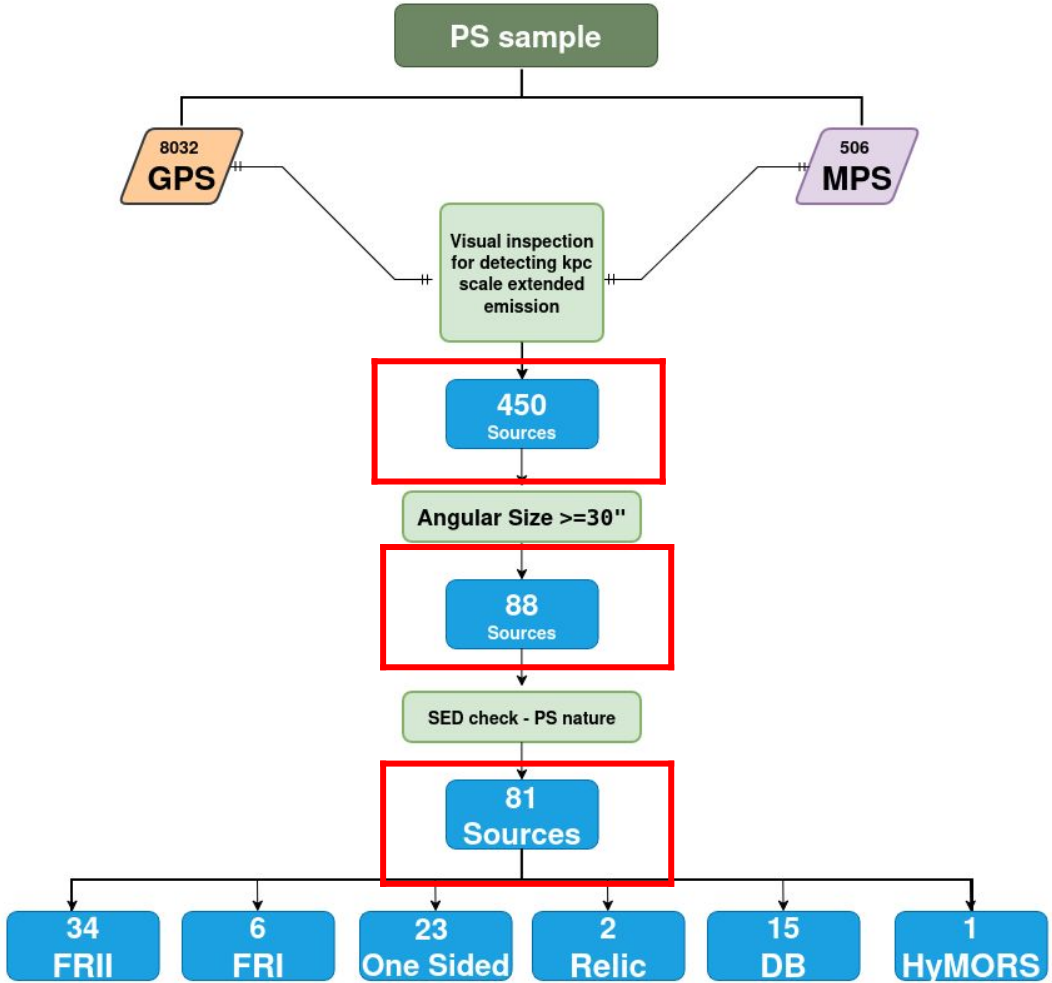

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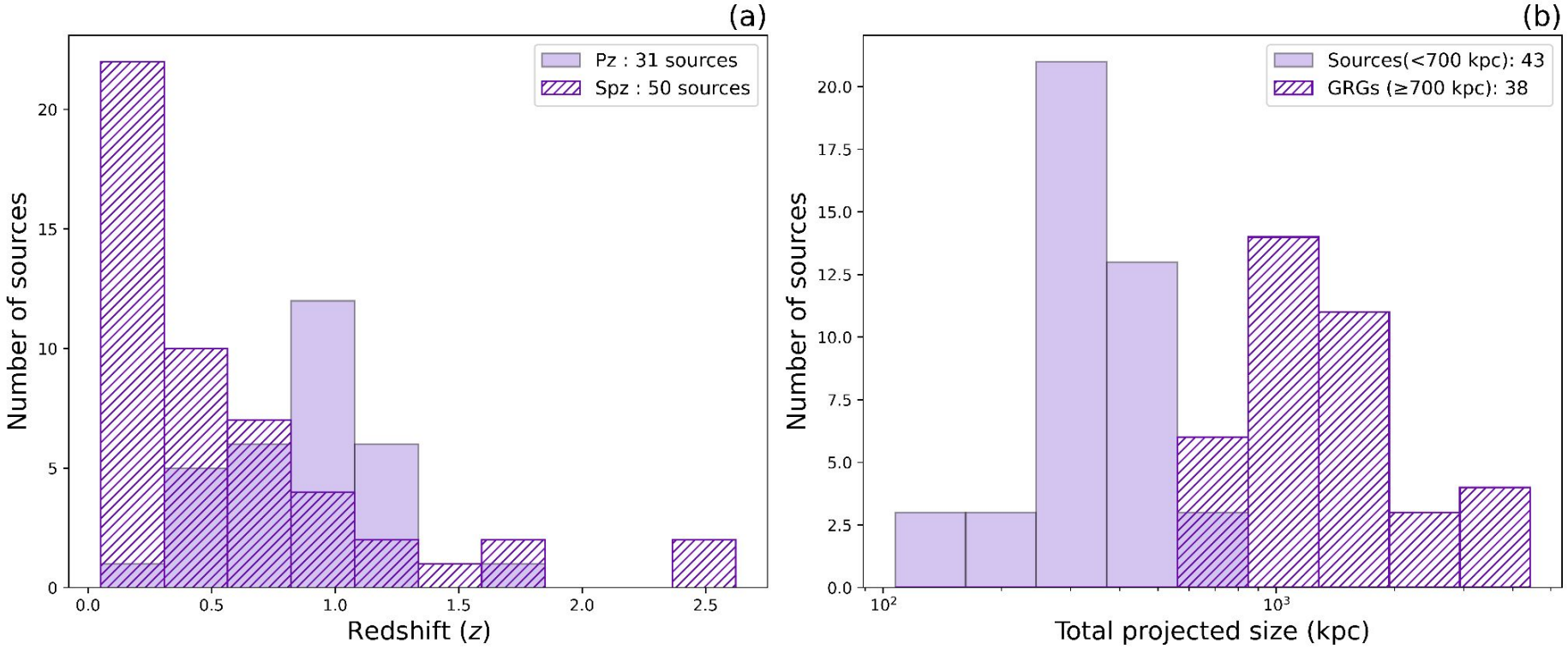

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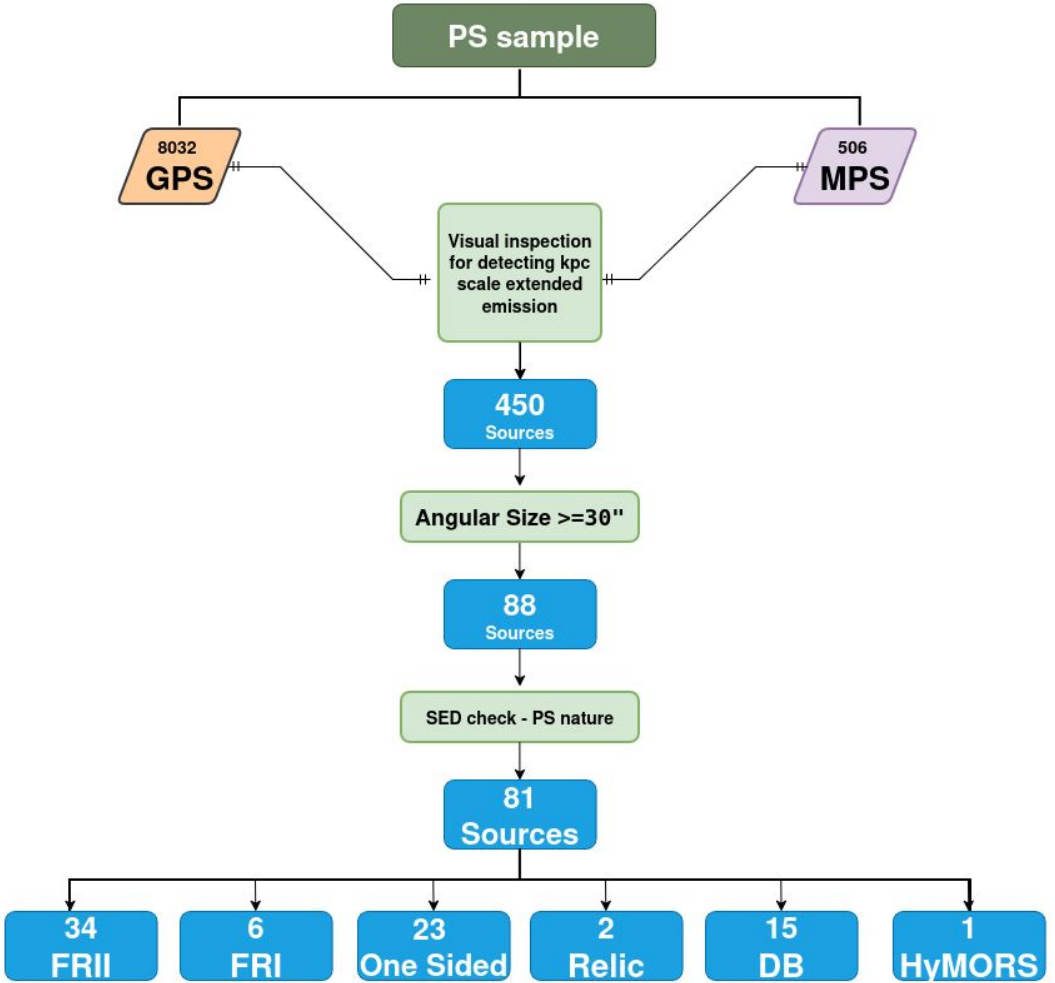
38 GRGs (Sizes>0.7 Mpc)



A.Mohanan, Dabhade, Malek et al. (in preparation)

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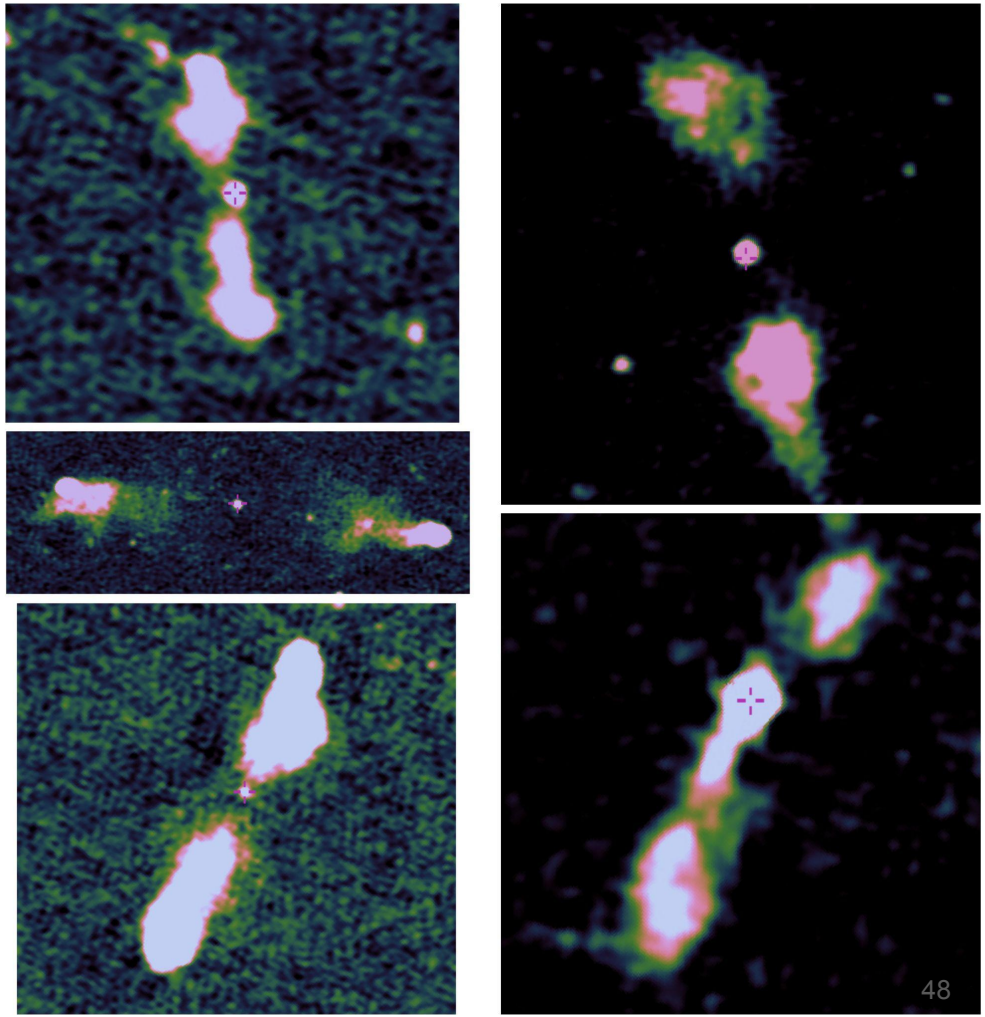
(Sizes>0.7 Mpc)

Observational confirmation that compact sources can evolve through multiple duty cycles.

A.Mohanan, Dabhade, Malek et al.
(in preparation)



LoTSS 144 MHz image at 6”

Methodology

From data collection to analysis…..

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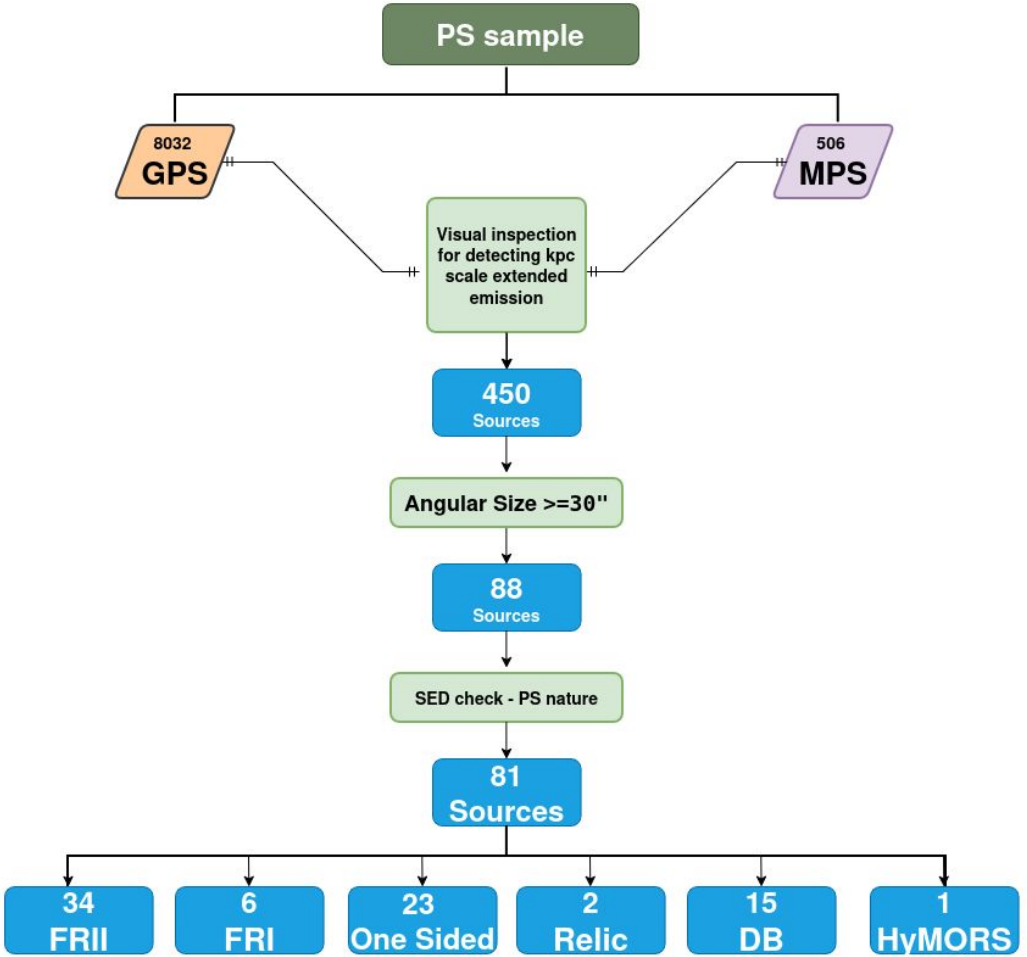
11 NEW GRGs !



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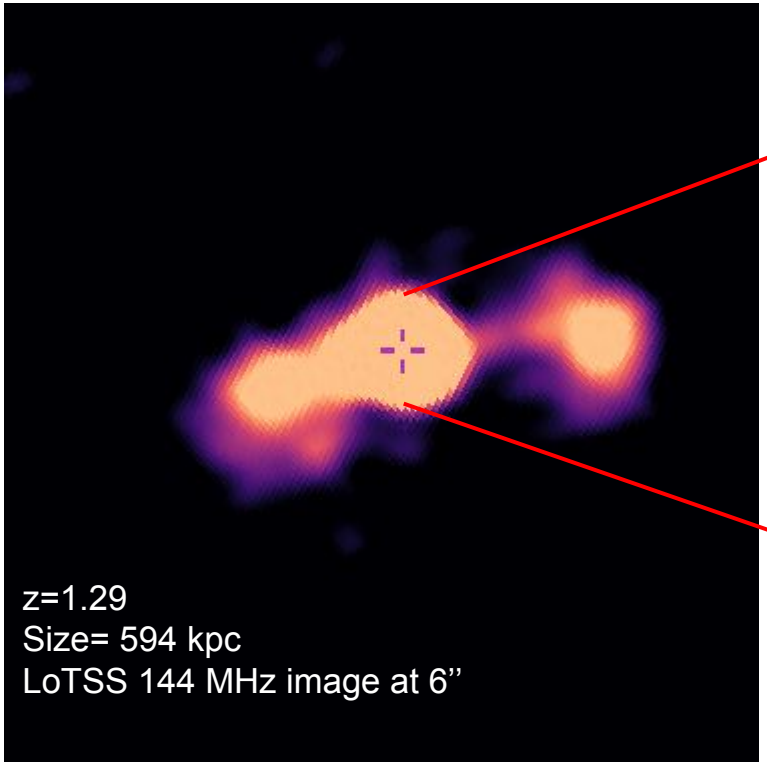
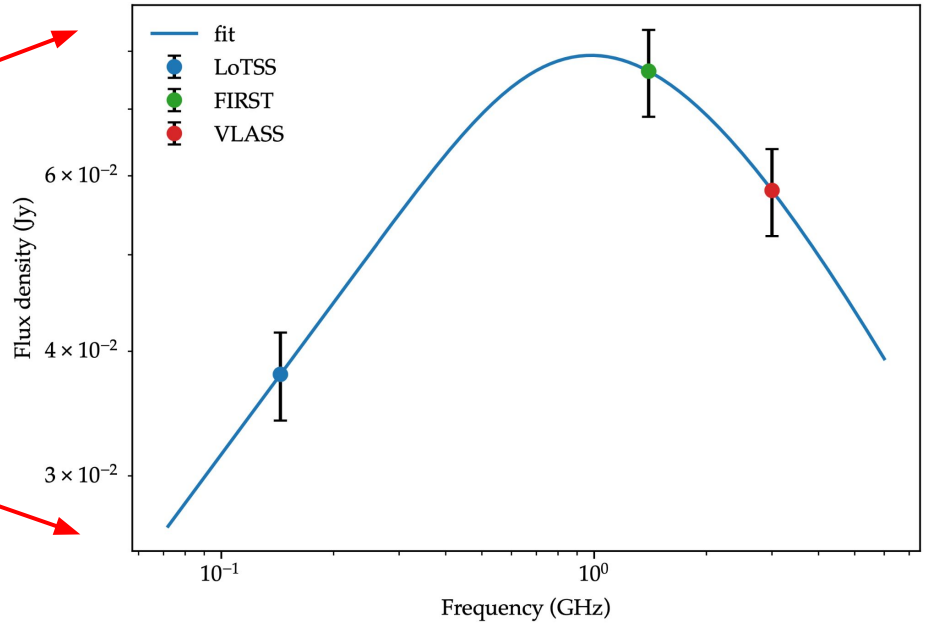
Few examples….

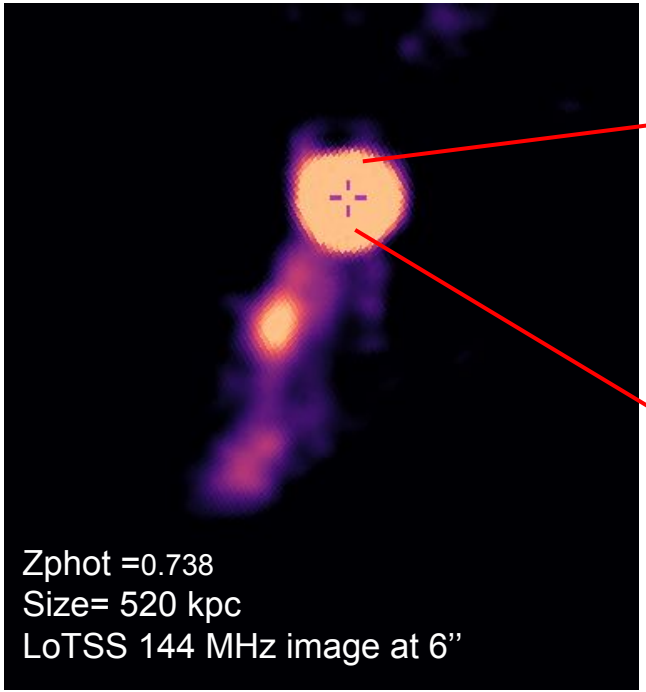


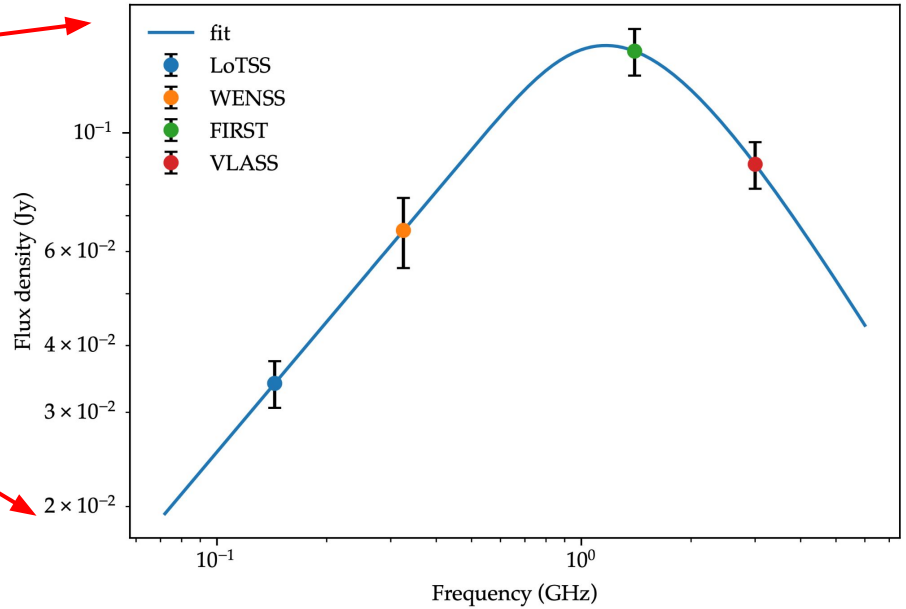


Diffuse emission both sides

A.Mohanan, Dabhade, Malek et al. (in preparation)

Few examples….





A.Mohanan, Dabhade, Malek et al. (in preparation)

One sided emission

Summary ….

- *Using LoFAR surveys data we have identified PS sources with diffuse emission extending ≥ 50 kpc beyond their unresolved cores.*
- *Some of these PS sources reside inside giant radio galaxies that already span megaparsec scales.*
- *Relic/extended emission around PS sources provide unambiguous evidence of restarted activity.*

Future Work….

- *Proposal for telescope time (EVN, e-MERLIN) for a large sample of sources.*
- *Methods and framework here scale directly to deeper LOFAR 2.0 and future SKA-Low/Mid surveys, opening a new window for uncovering the full evolutionary history of radio-loud AGN.*

…….Thank You……