

*From Young to Restarted:
The Largest Sample of Peaked-Spectrum Sources from
LoTSS DR3*

Anupama Mohanan

Supervisors : *Pratik Dabhade & Katarzyna Małek*

Collaborators : *D. J. Saikia & H.J.A. Rottgering*

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NARODOWE CENTRUM
BADAŃ JĄDROWYCH
ŚWIERK

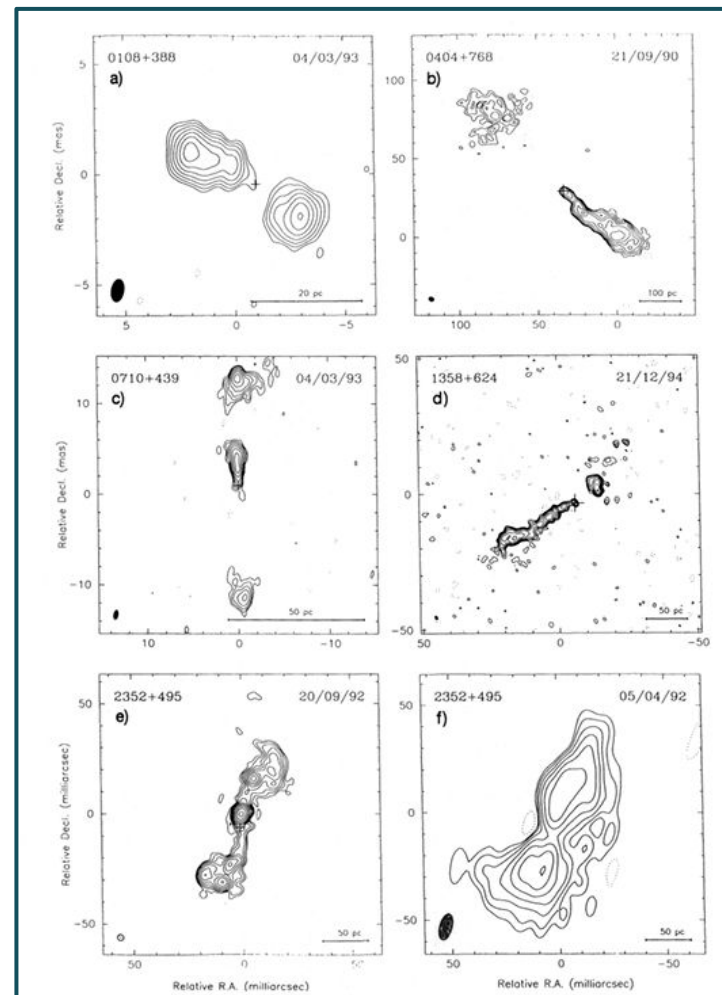
Outline

- *Compact and Peaked-Spectrum Radio Sources*
- *Search for extended emissions in PS sources (restarted activity)*
- *Towards a Robust PS Census in LoTSS DR3*
- *Current Status and Future Work*

Compact (Small) Radio Sources

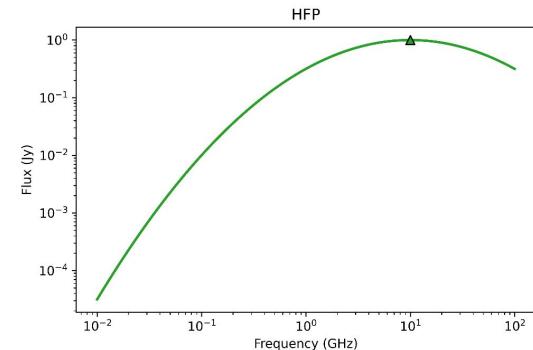
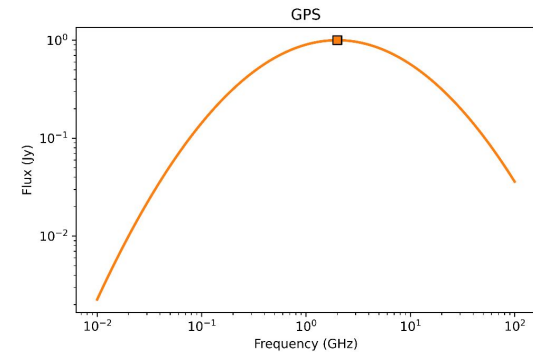
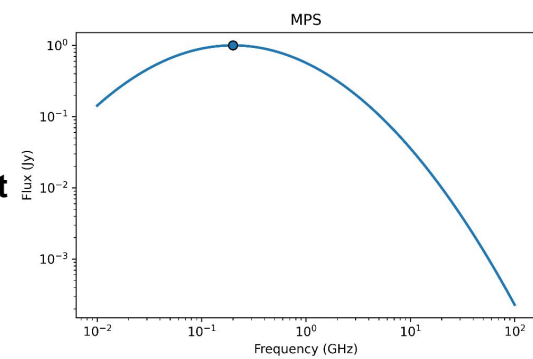
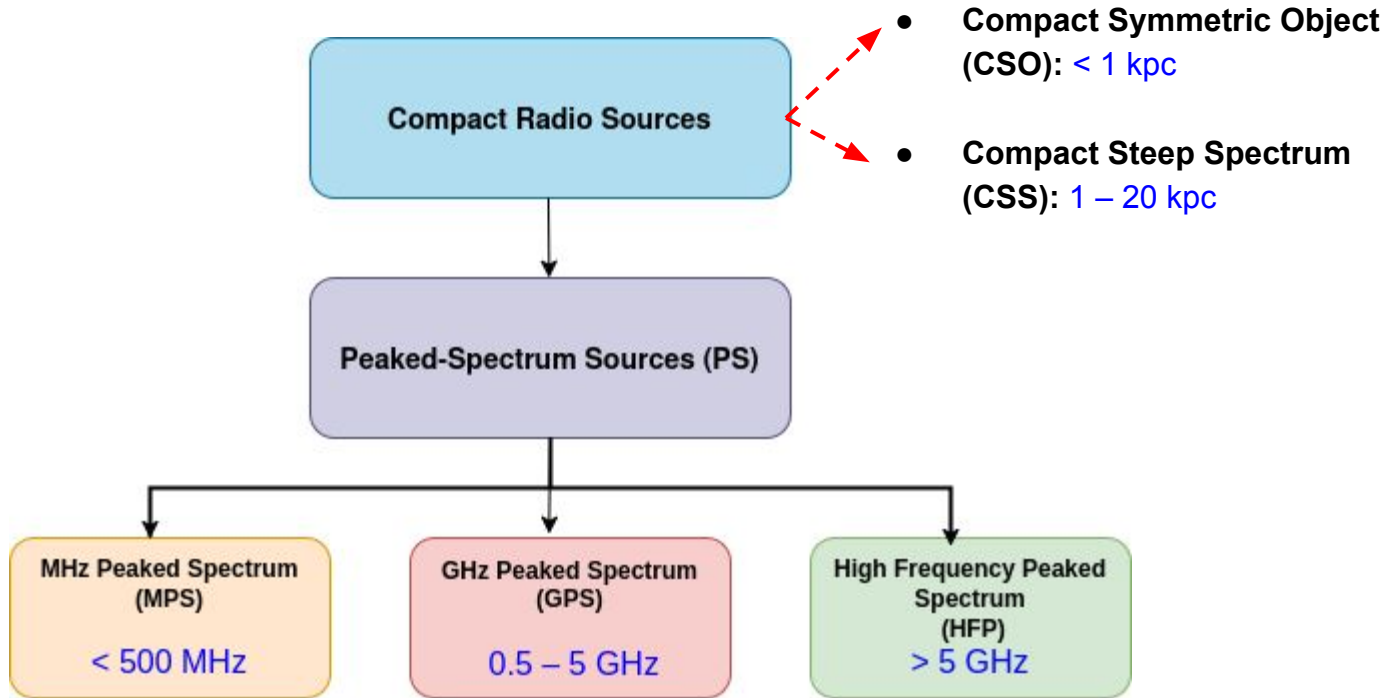
- They typically have linear sizes < 20 kpc.
- High-resolution observations often reveal double-lobed or compact symmetric structures on parsec to sub-kiloparsec scales.
- Currently considered to represent the early stages of large radio galaxies.

([Fanti et al. 1995](#); [Readhead et al. 1996](#); [Snellen et al. 2000](#))



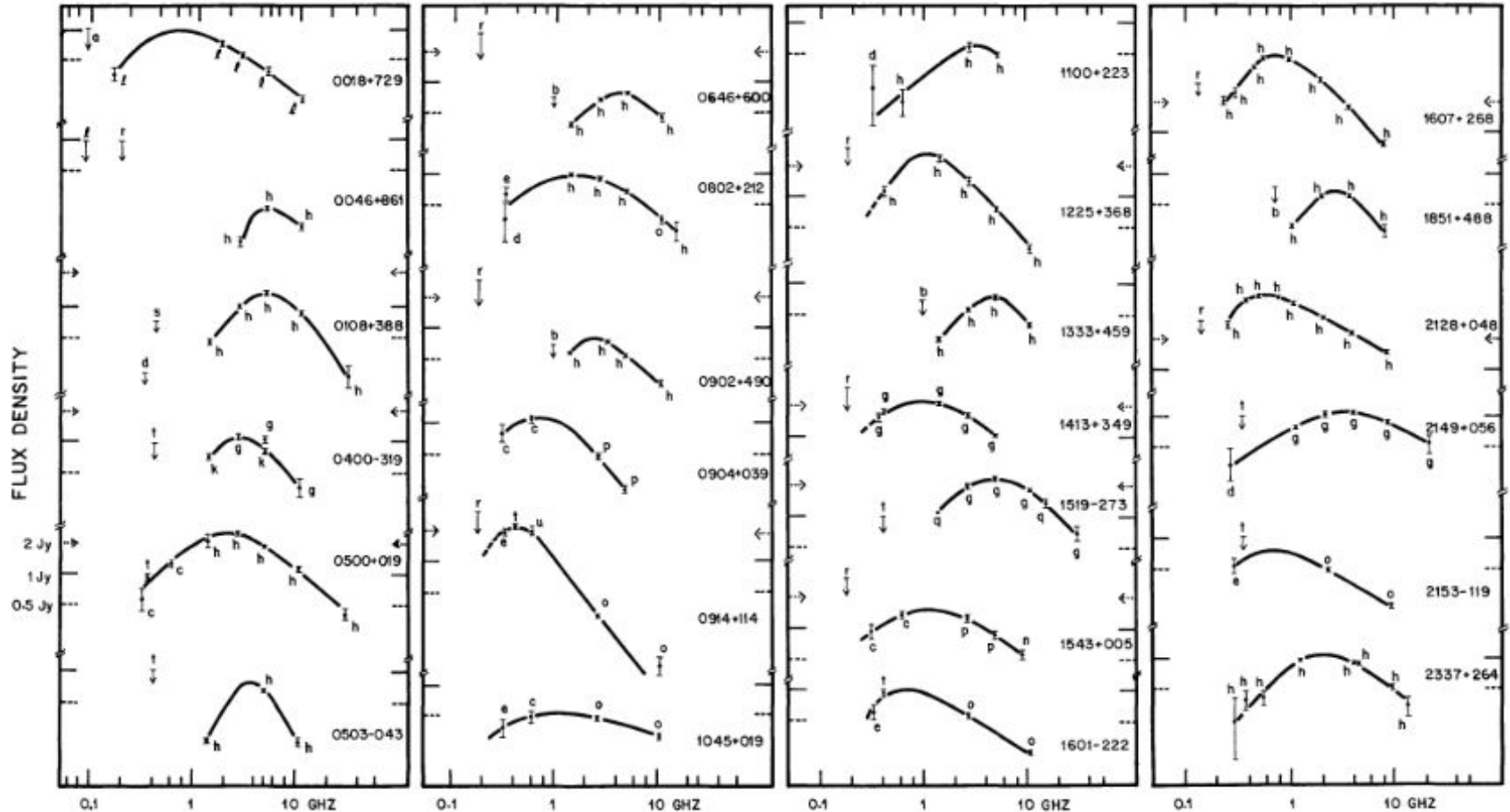
[Readhead et al. \(1996\)](#)

Nomenclature for Compact Radio Sources



Examples of peaked radio spectra

Gopal-Krishna et al.(1983)



Physical Origin of the Peaked Radio Spectrum

CENTRAL AGN

RADIO GENERATING REGION

SHOCKED MEDIUM

IONIZED GAS (HII REGION)

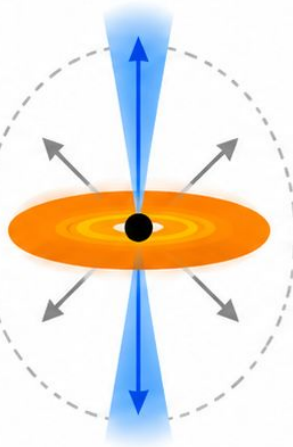
OBSERVER

(core / jet / lobes)

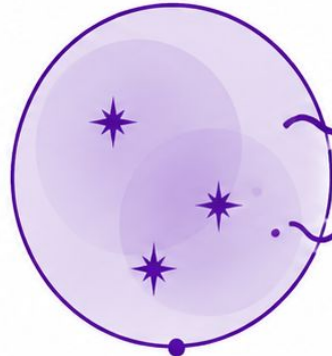
(internal absorber)

(external absorber)

(on Earth)

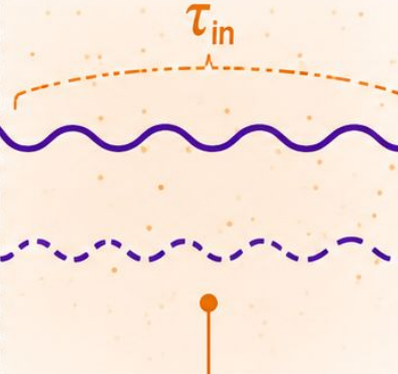


**Engine: accretion
disk + jets**



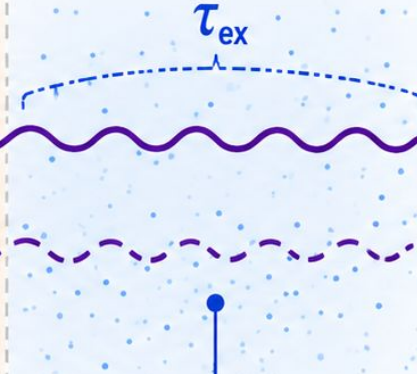
Synchrotron emission

Relativistic electrons
produce synchrotron
radiation.



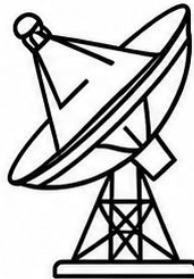
Internal absorption

Synchrotron Self-Absorption (SSA)
and/or internal Free-Free
Absorption (FFA).



External absorption

Free-Free Absorption (FFA)
by ionized gas in the
surrounding environment.



-  High-frequency
(optically thin)
→ escapes
-  Low-frequency
(optically thick)
→ absorbed

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.

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Jet-gas interactions



magnetic fields + ionized gas



cold neutral gas

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.
- AGN feedback.

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

Why are PS Sources Important?

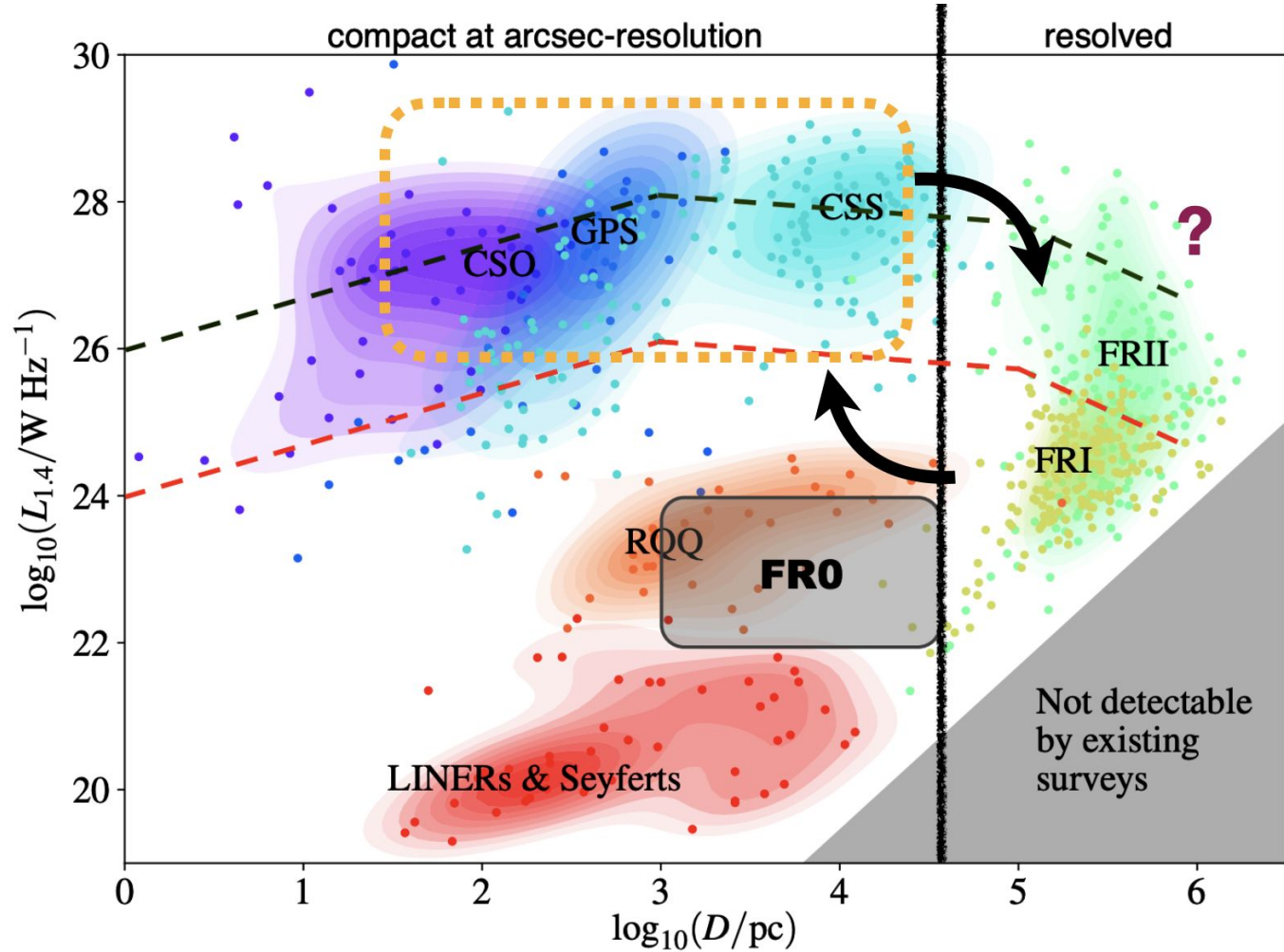
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- Bright, symmetric radio structures at small scales.
- Trace **NLR & ISM** through: Faraday rotation / depolarization, HI absorption and Interaction with emission-line gas.
- AGN feedback.

2. Key to Radio Galaxy Evolution

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

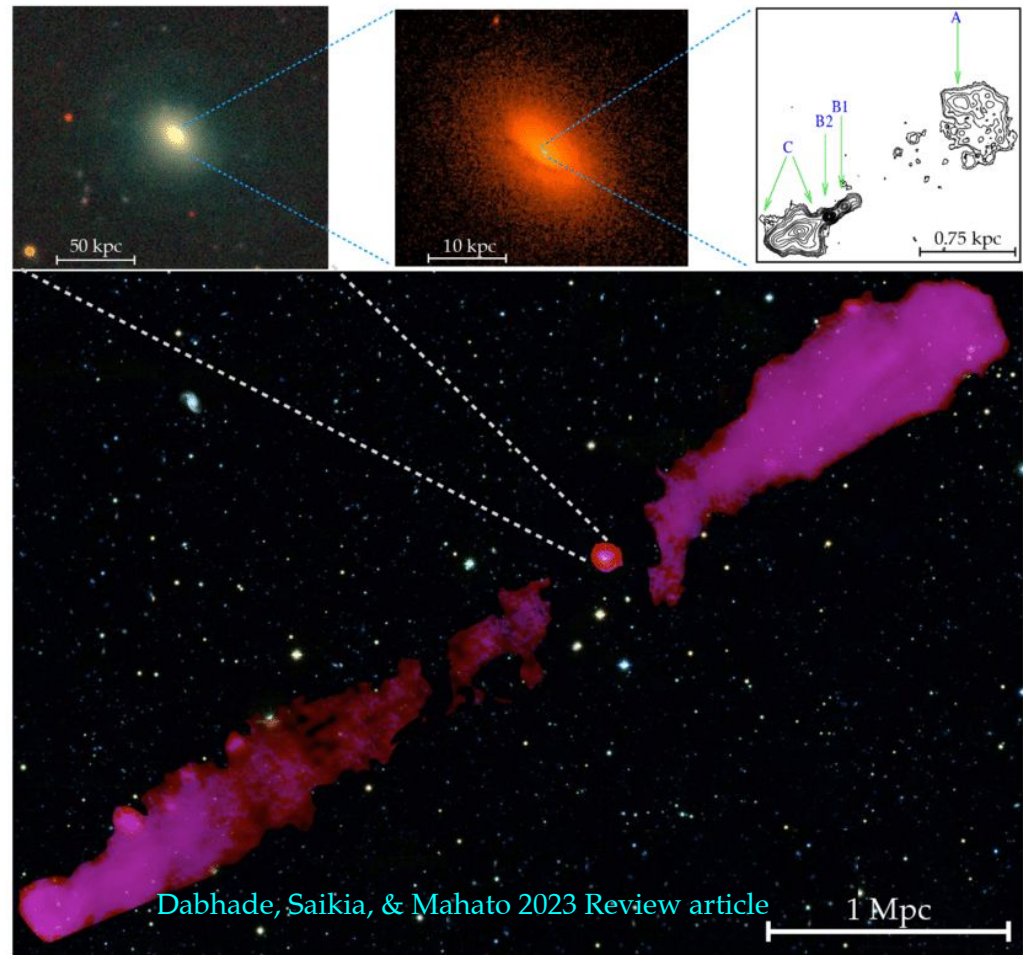
(O'Dea, Christopher P. ;Baum, Stefi A., *Astronomical Journal*, January 1997)



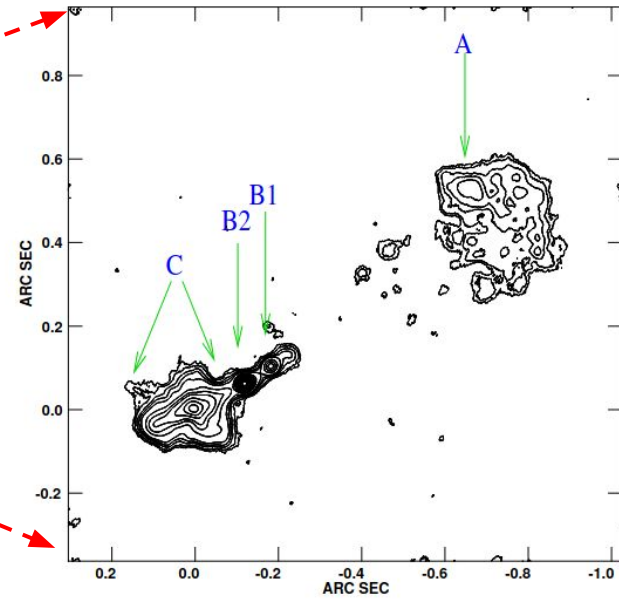
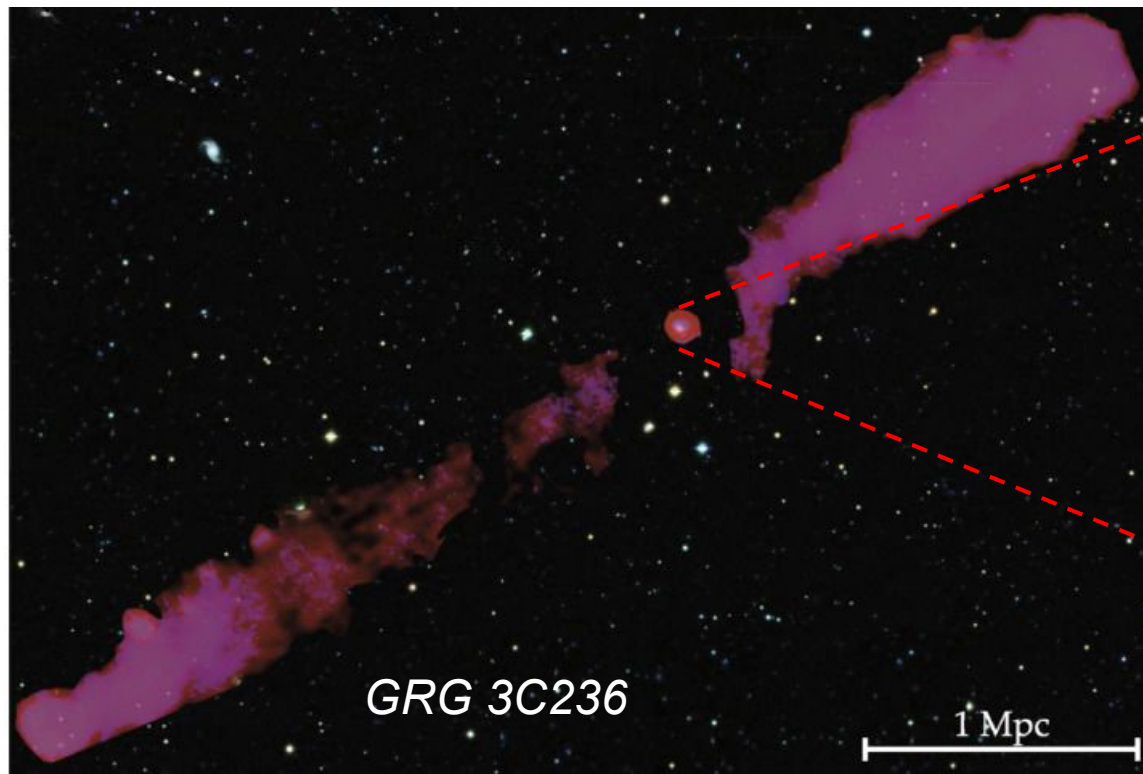
Adapted from [Baldi 2023, A&A Rv](#)

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

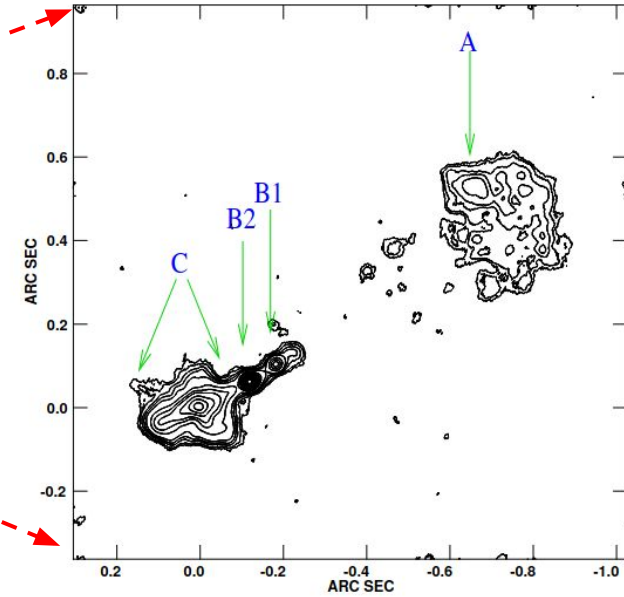
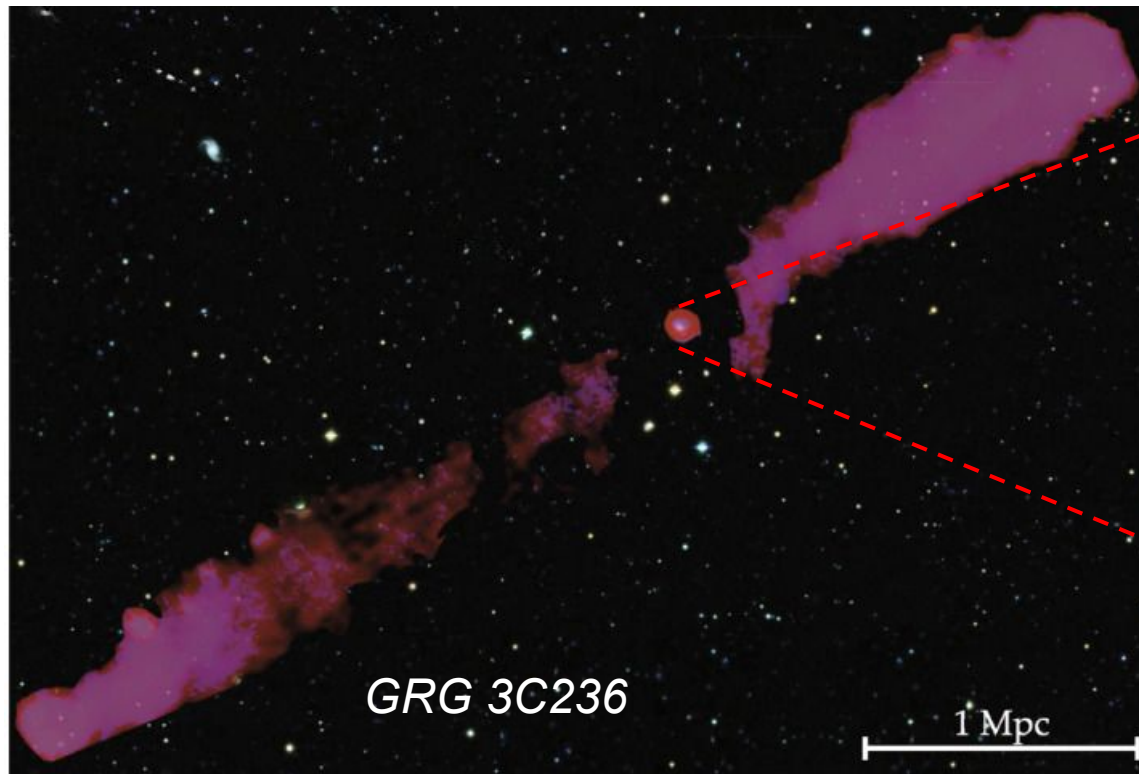


Multi-wavelength images of GRG 3C236 on various scales 12



Schilizzi et al. 2001

Dabhade, Saikia, & Mahato 2023 Review article

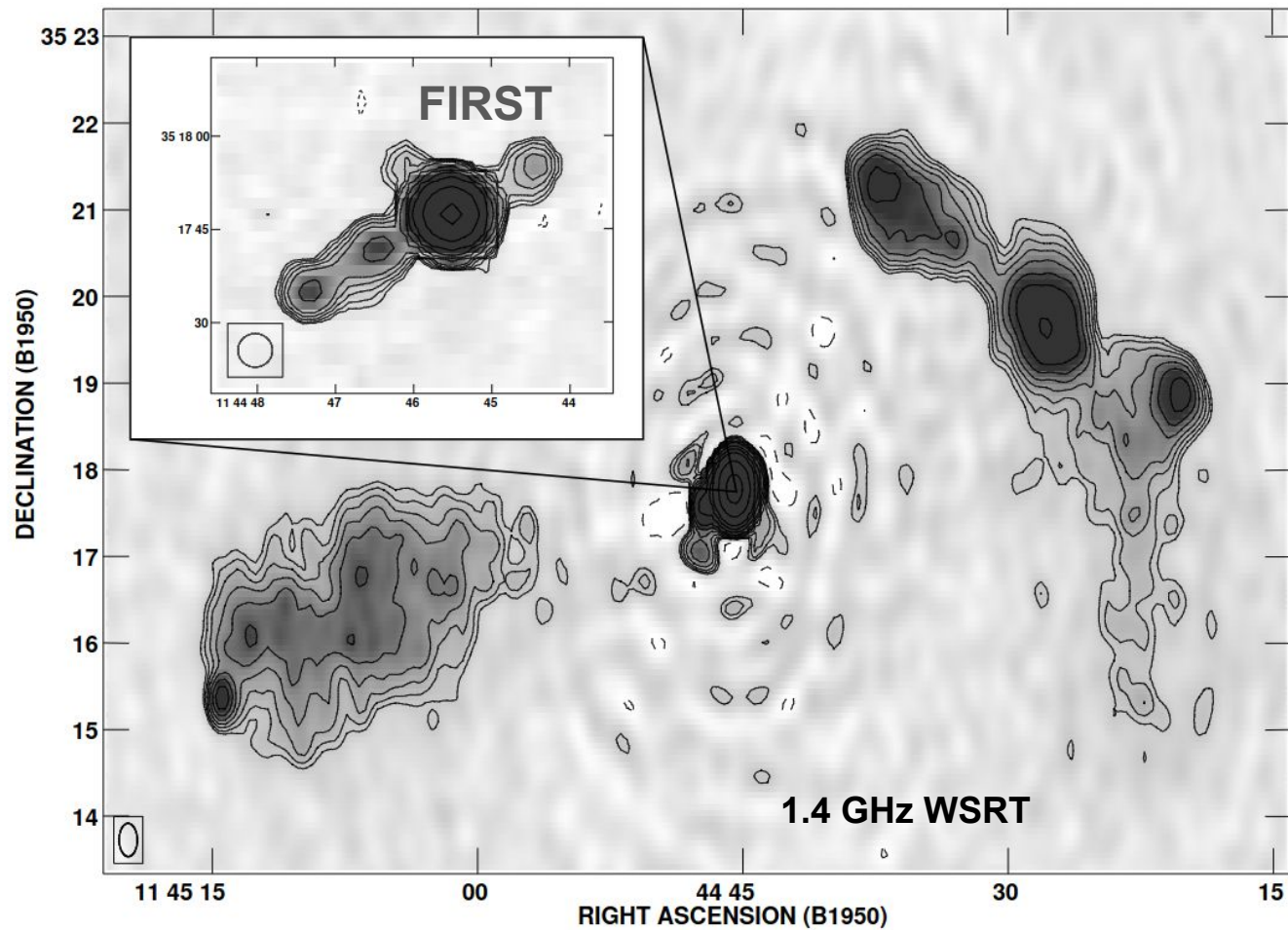


Schilizzi et al. 2001

Dabhade, Saikia, & Mahato 2023 Review article

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

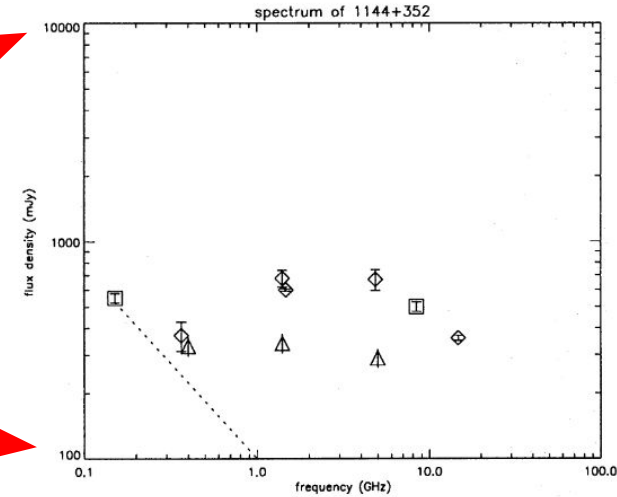
B1144+352



Variability can temporarily mimic a peaked-spectrum shape

LoTSS DR3 144 MHz
~ 1.2 Mpc GRG

B1144+352



Snellen et al. 1995

Variable, BL Lac or beamed AGN

Motivation and 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.*
- *Well-known examples include **0108+38890** (Baum et al. 1990), **B1144+352** (Schoenmakers et al. 1999), **1345+125** (Stanghellini et al. 2005) and **J1245+676** (Marecki et al. 2003)*
- *Past wide-area radio surveys lacked surface-brightness sensitivity and resolution to detect “compact core + relic emission”.*
- *LOFAR enables the detection of faint, diffuse radio structures*

PS Samples from literature

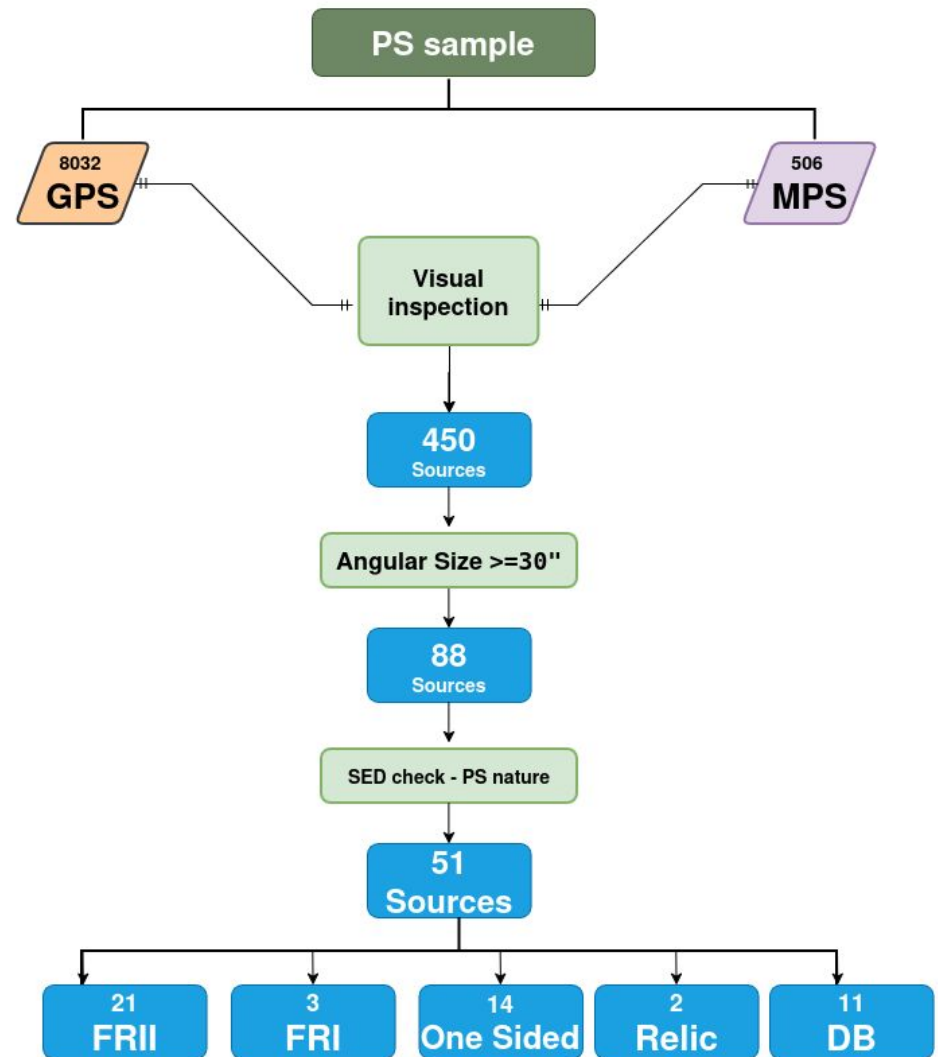
- *PS sources have been studied for more than four decades.*
- *Around 7000 PS sources known till date (GPS; Gopal-Krishna et al. 1983; Spoelstra et al. 1985; O'Dea 1998 etc., MPS; Coppejans et al. 2015, 2016, Callingham et al.2017 etc.)*
- *Heterogeneous and defined using different selection criteria and surveys,*
- ***Ballieux et al. (2024)** provided the first large, homogeneously selected PS catalogue.*

Ballieux et al. (2024): Parent Catalogue

- *Largest uniformly selected PS catalogue available at the time (**506 MPS and 8032 GPS**)*
- *27 % of the northern sky*
- *Built using **LoLSS DR1, LoTSS DR2, NVSS and VLASS***

Methodology

From data collection to analysis.....



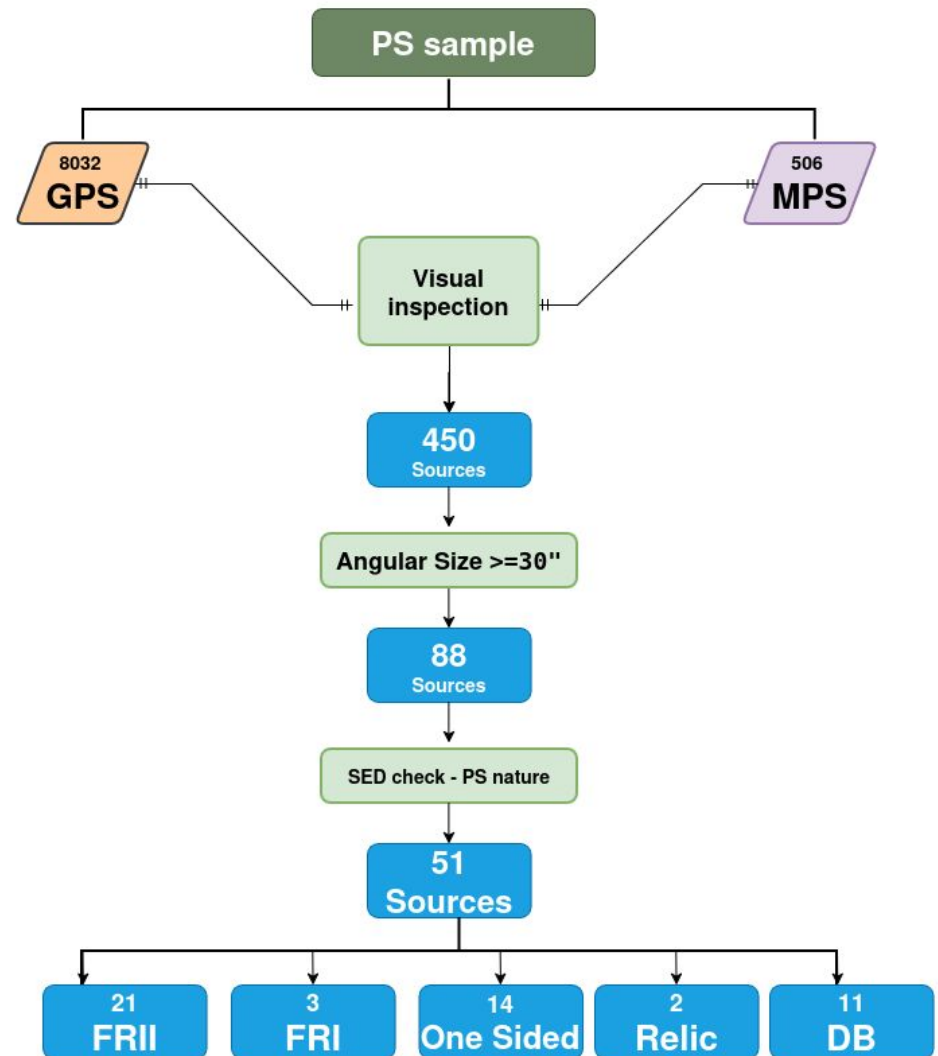
A.Mohanan et.al in preparation

Methodology

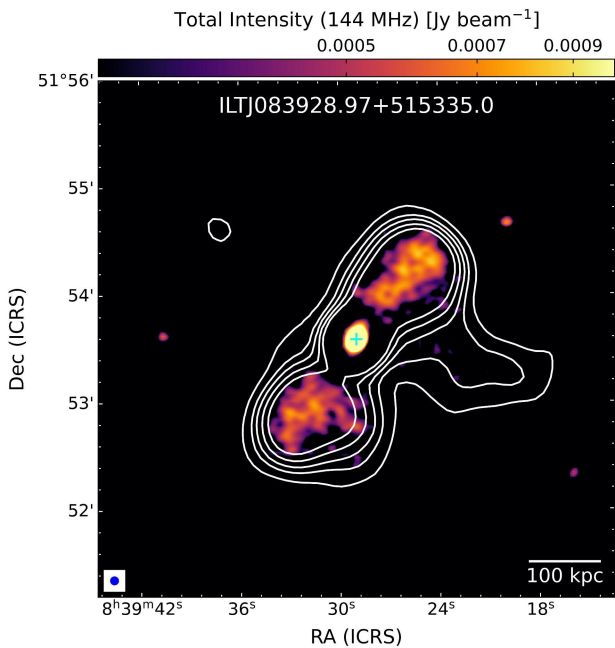
From data collection to analysis.....

- 22 GRGs (> 700 kpc)
- 14 sources with archival VLBI

A.Mohanan et.al in preparation

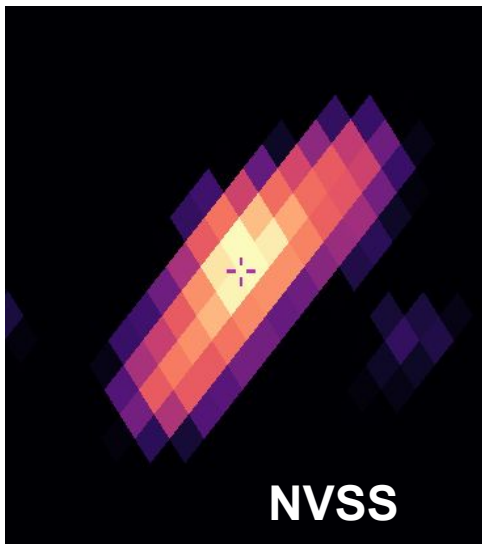
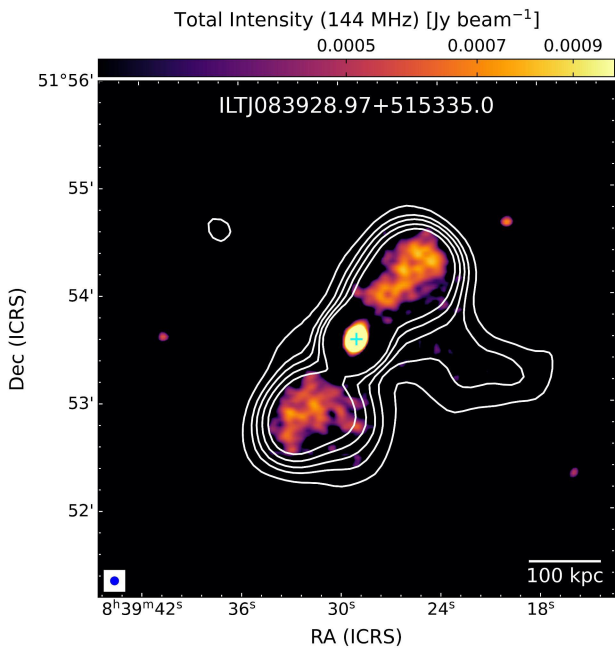


A GPS Misclassification Caused by NVSS Flux Contamination



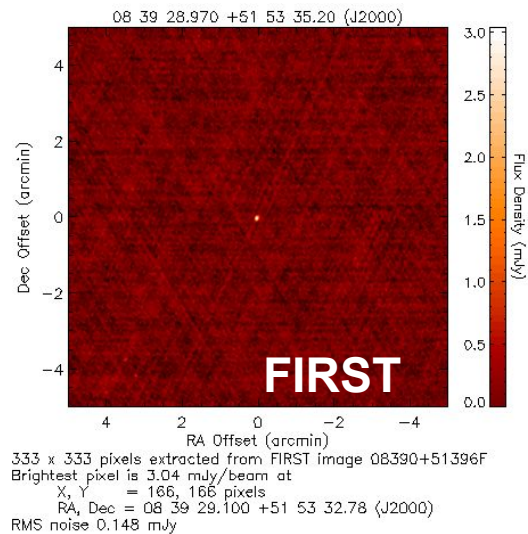
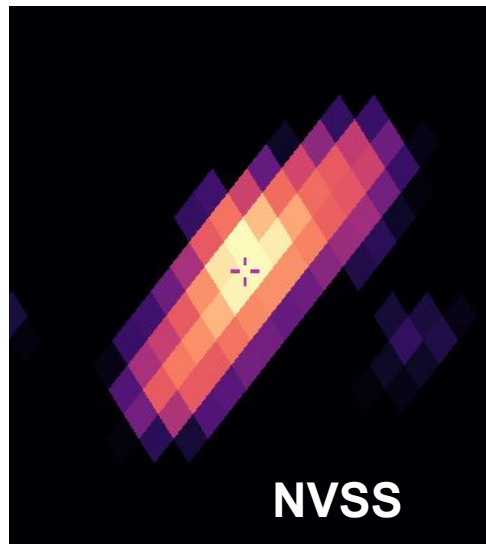
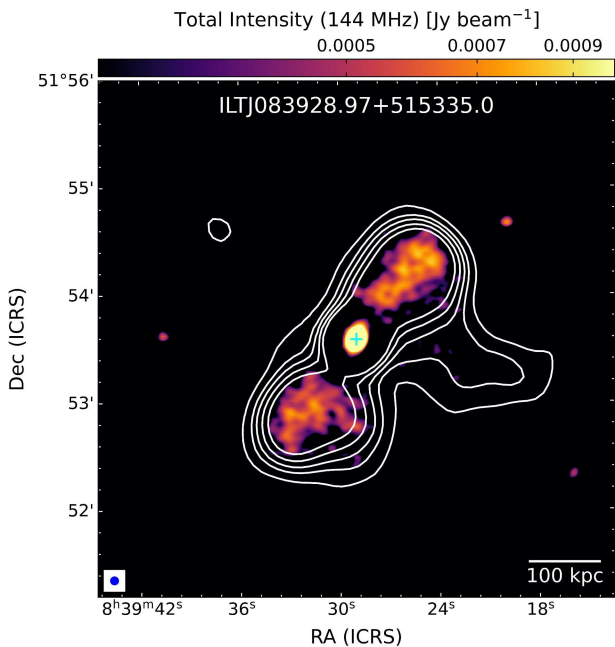
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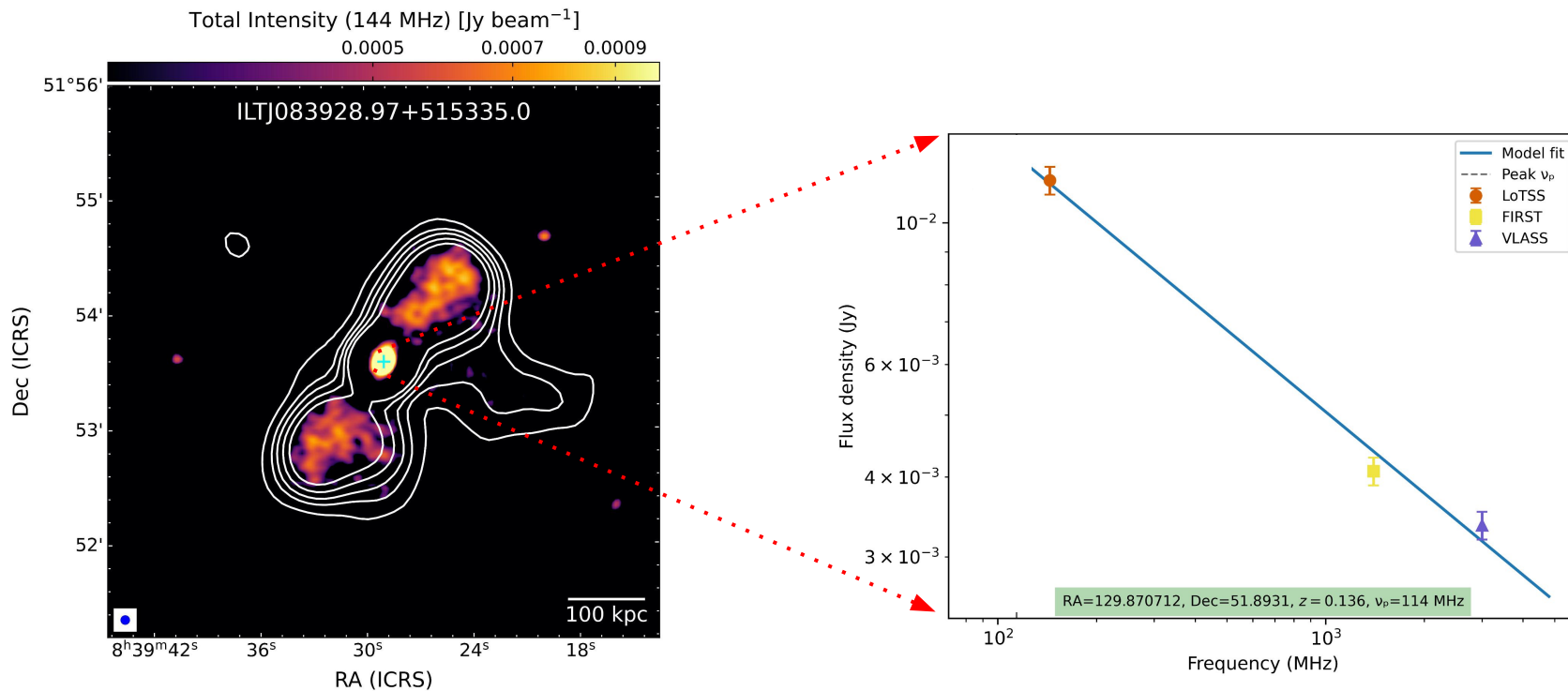
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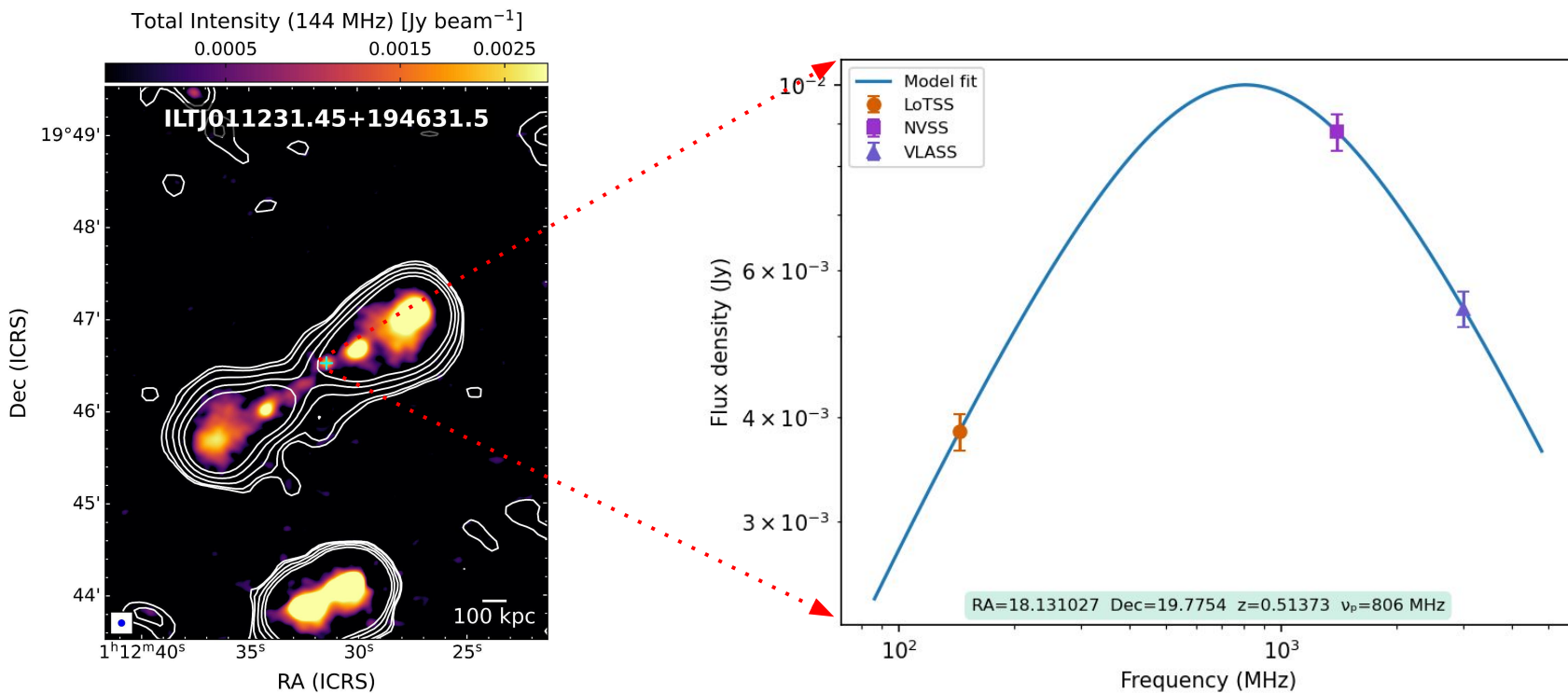
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A.Mohanan et.al in preparation

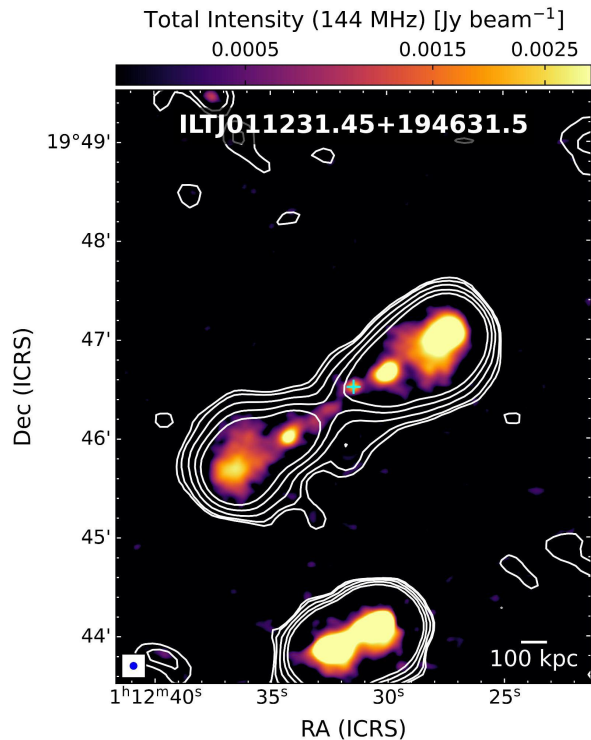
Challenges in Identifying Genuine Peaked-Spectrum Sources

A Re-examination of Peaked-Spectrum Candidates from Ballieux et al. (2024)

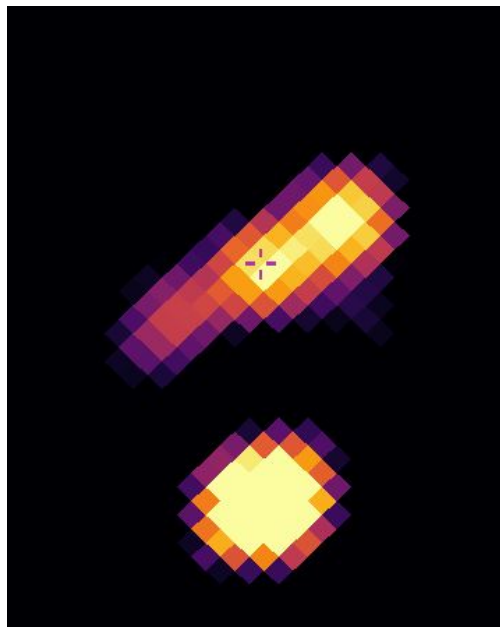


Challenges in Identifying Genuine Peaked-Spectrum Sources

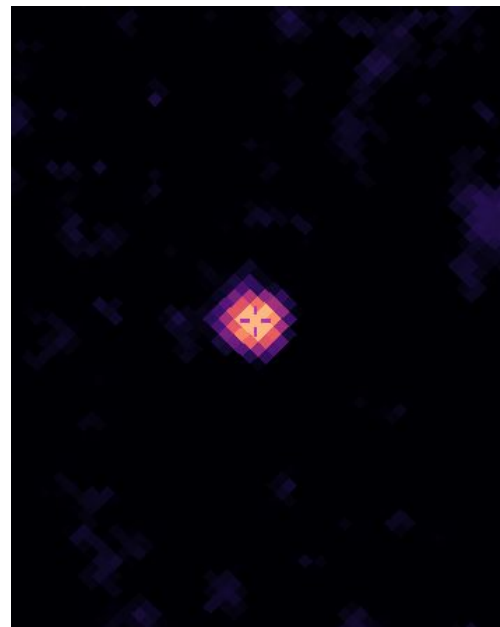
A Re-examination of Peaked-Spectrum Candidates from Ballieux et al. (2024)



LoTSS (6'')



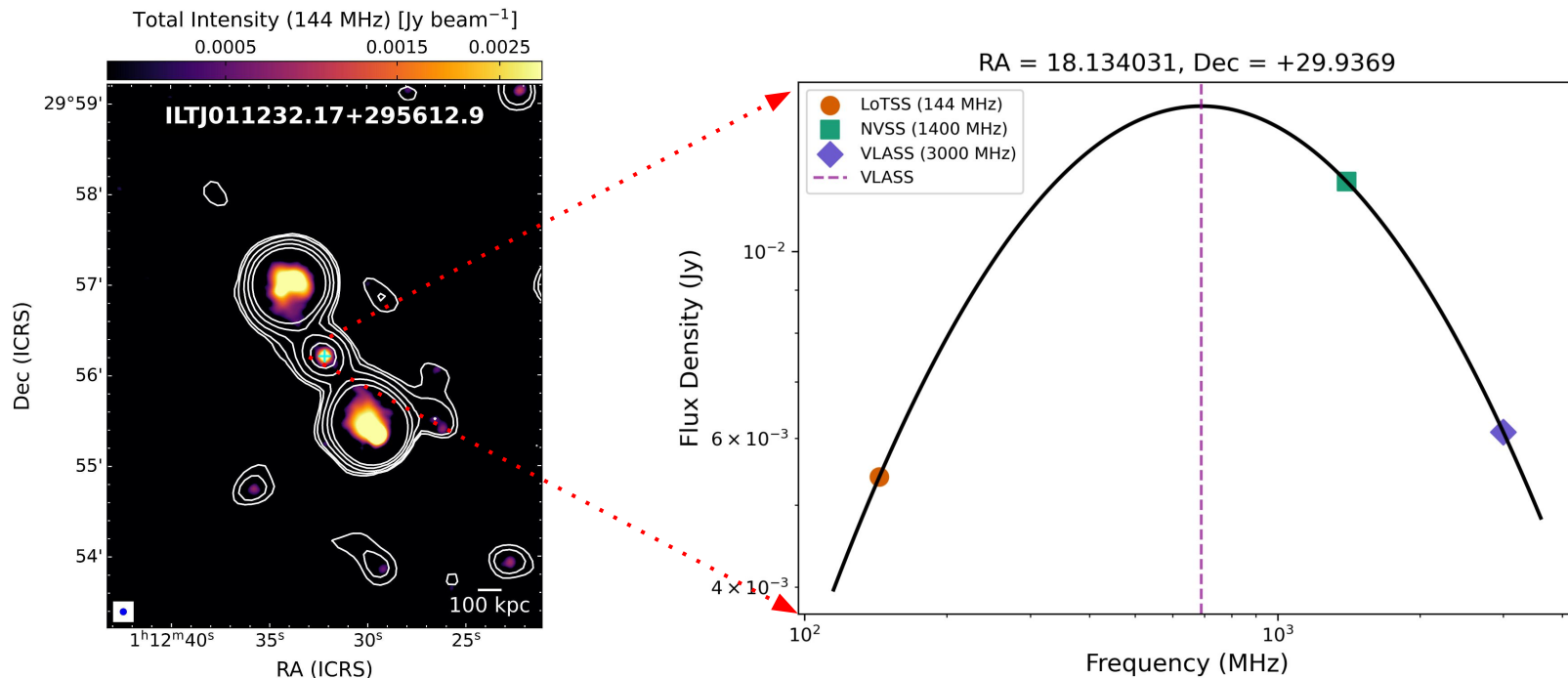
NVSS (45'')



VLASS (2.5'')

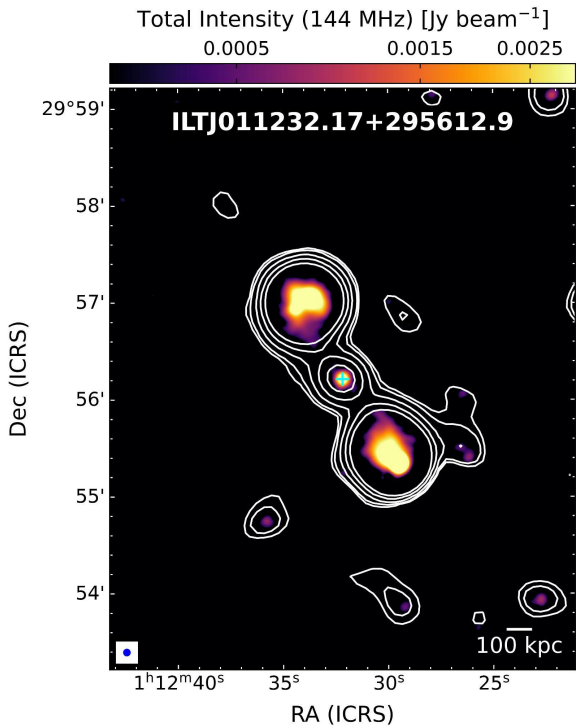
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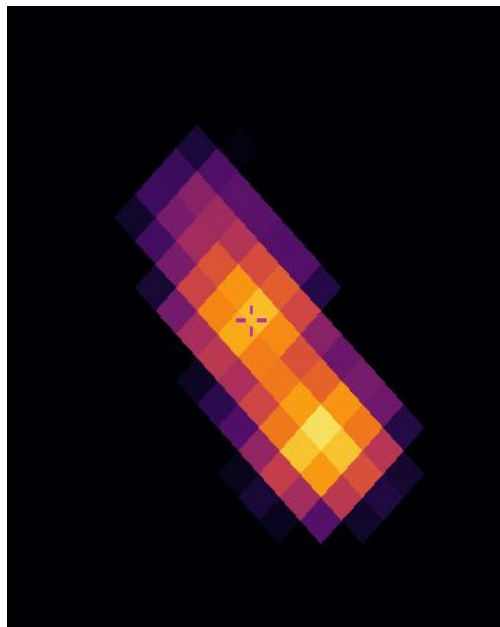


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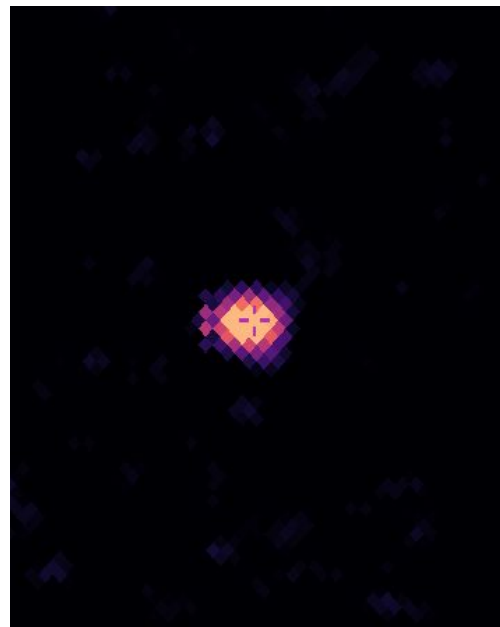
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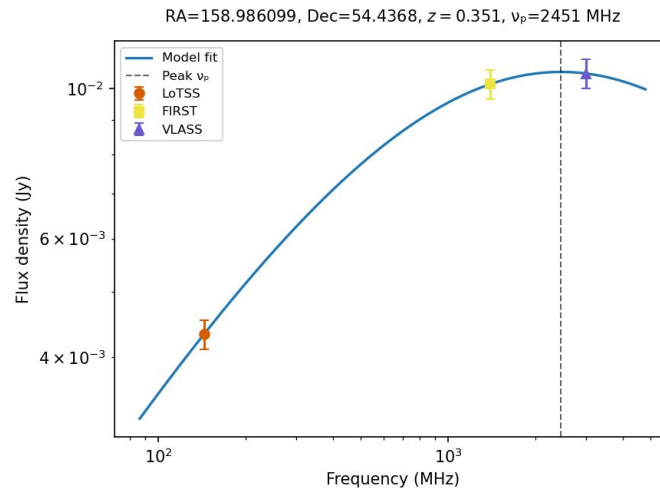
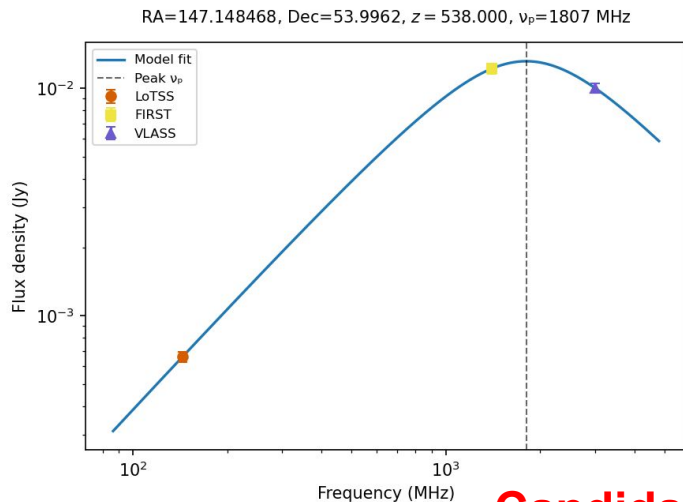
LoTSS (6'')



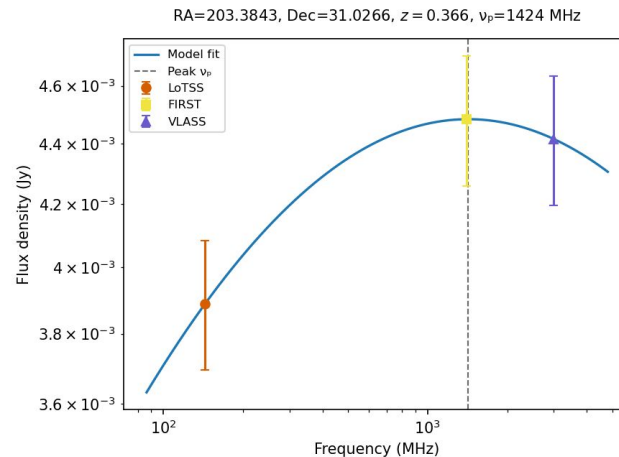
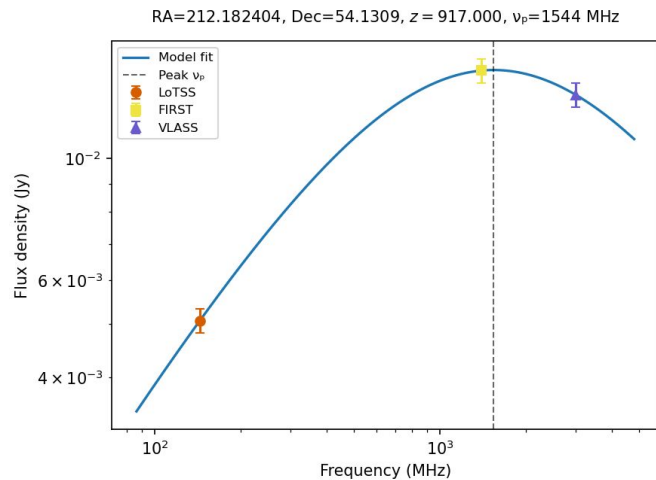
NVSS (45'')



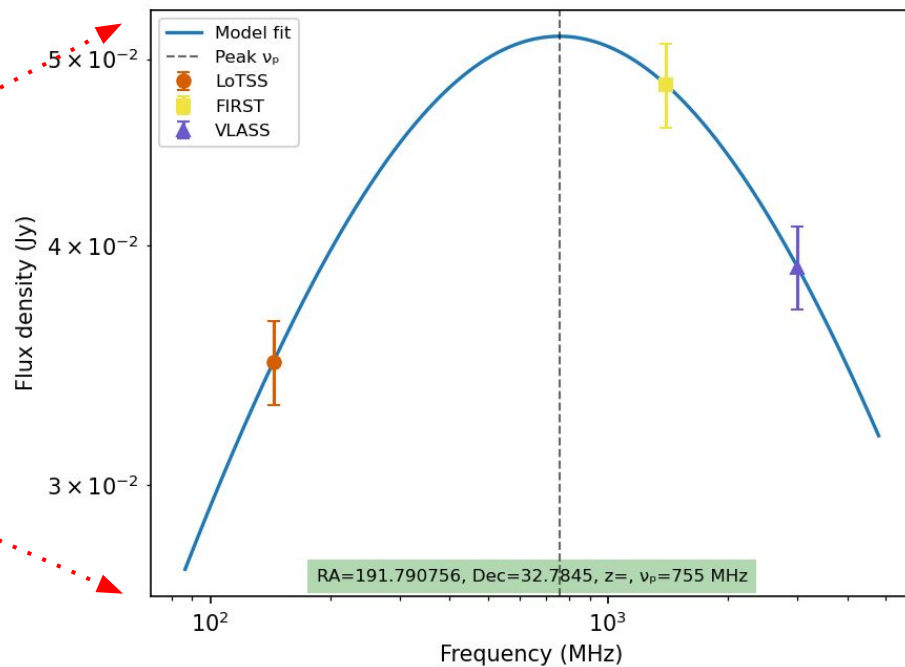
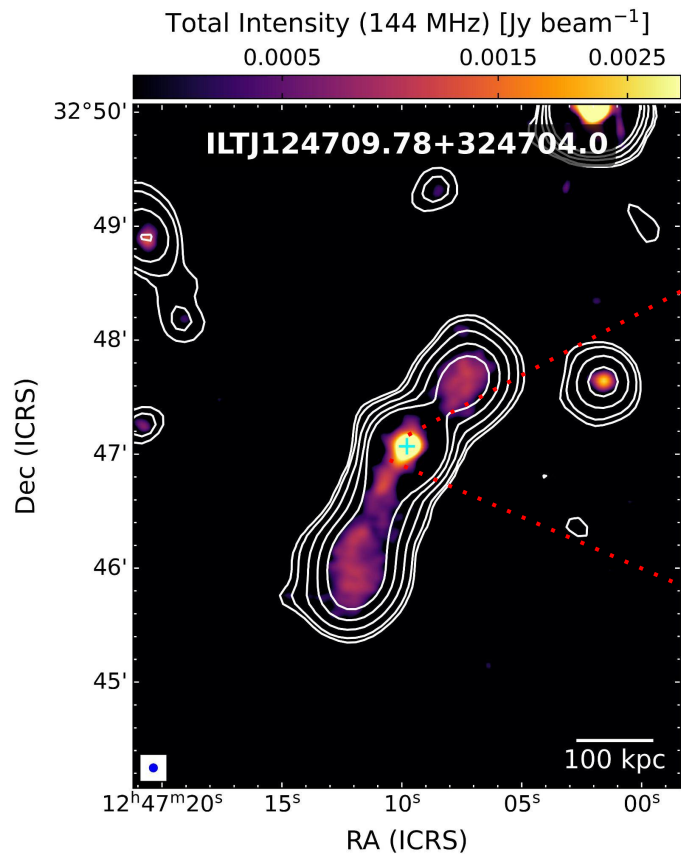
VLASS (2.5'')

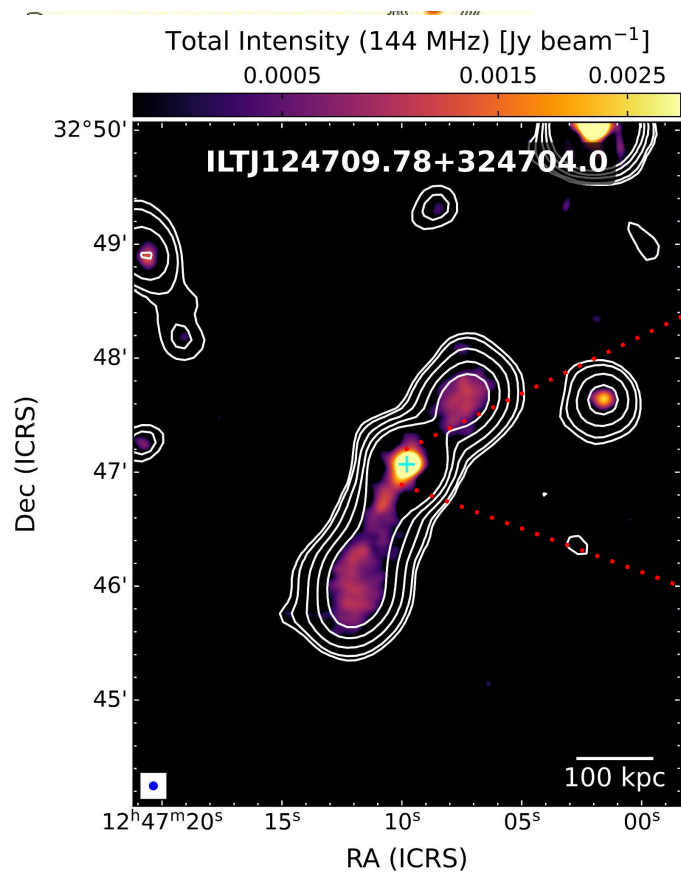


Candidate GPS Sources (GPS*)

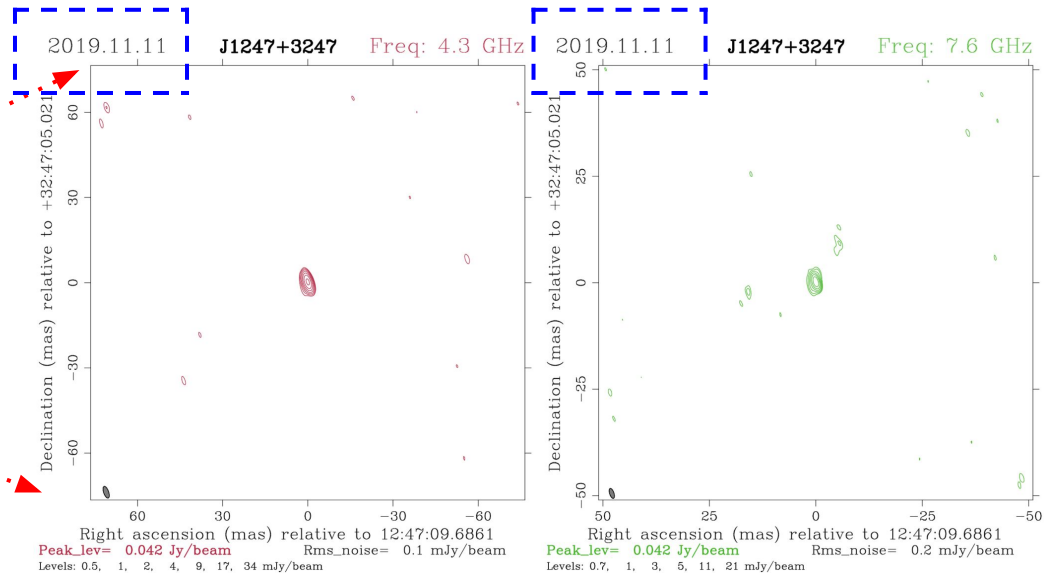


Sometimes a convex spectrum does not tell the full story



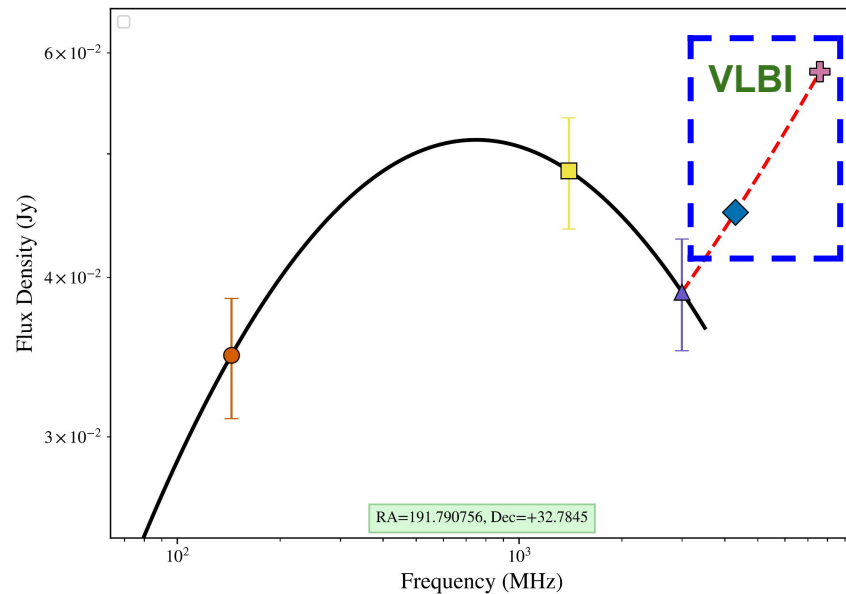
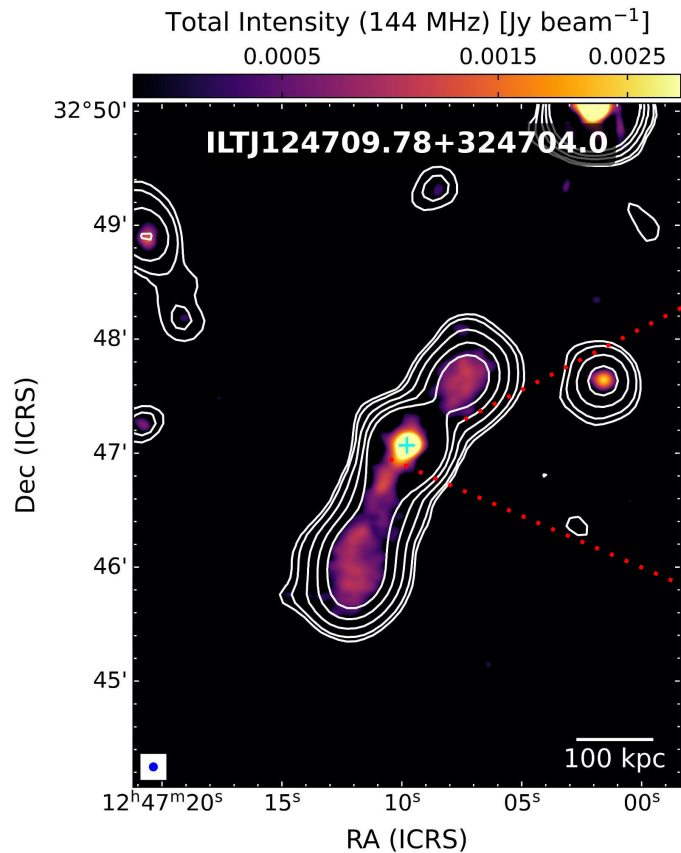


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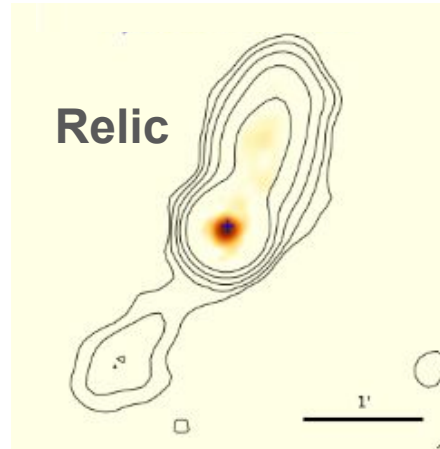
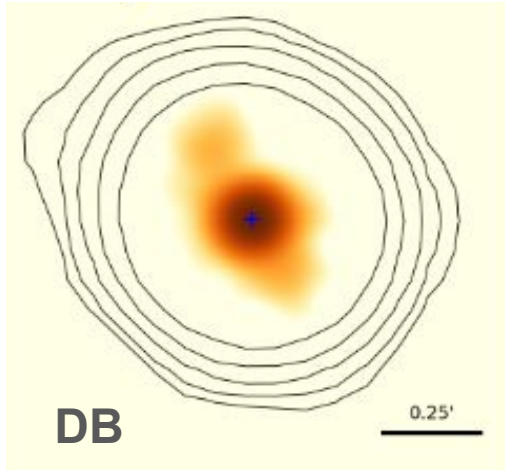
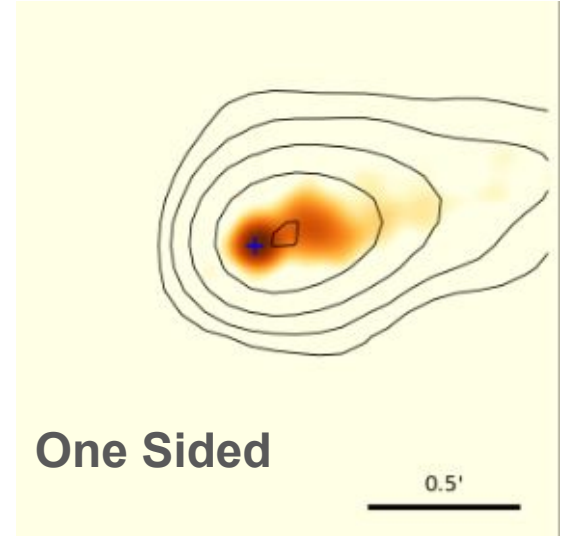
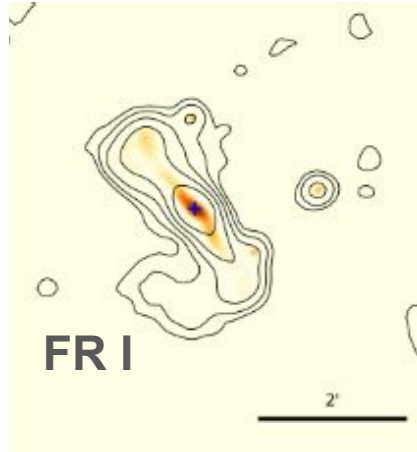
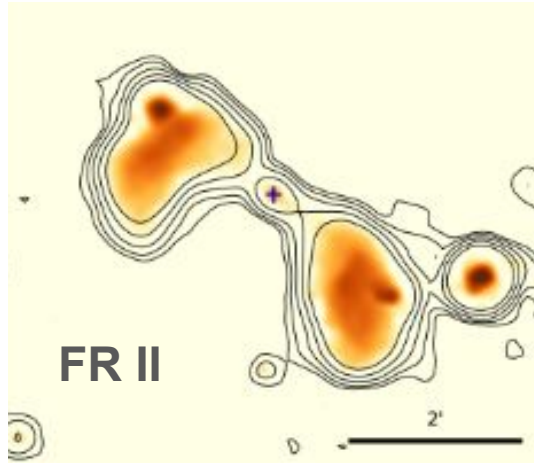
Credits: Astrogeo VLBI FITS image database

Sometimes a convex spectrum does not tell the full story



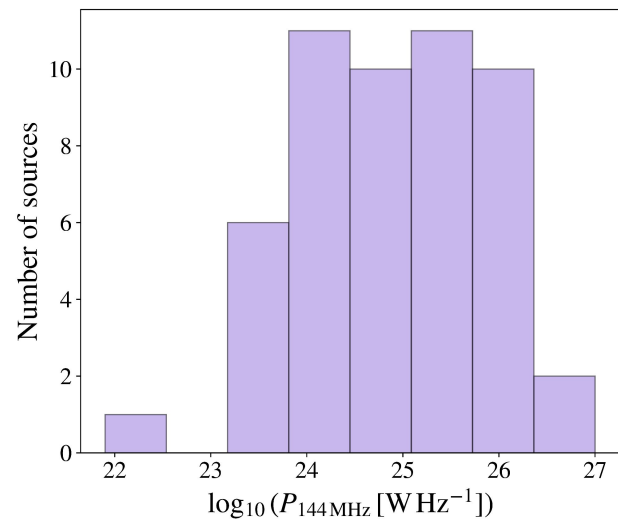
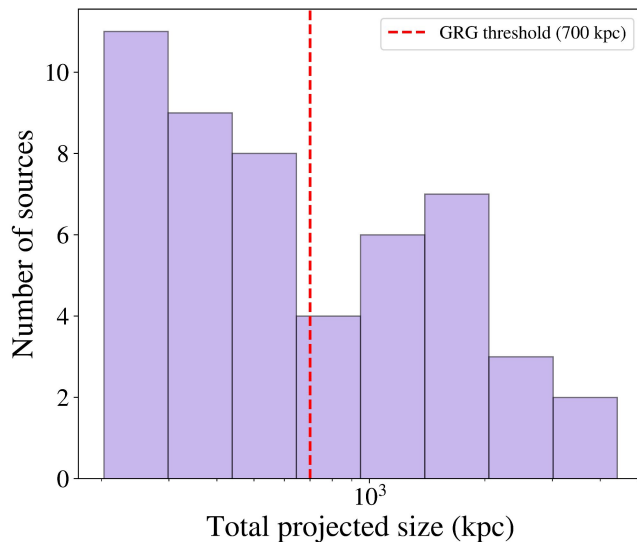
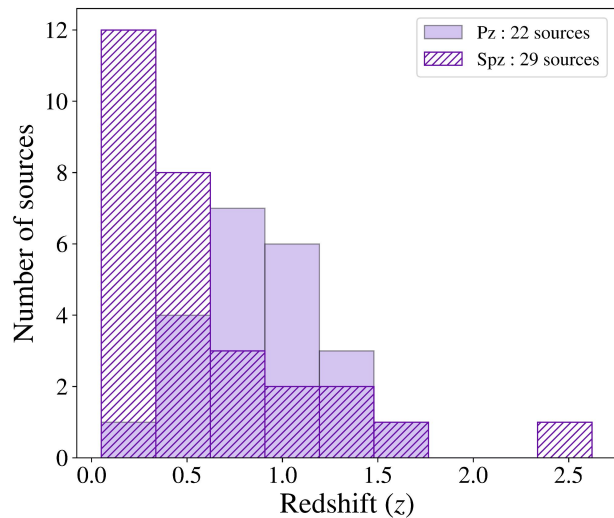
Variable AGN Mimicking a Peaked-Spectrum Source

Morphological Classifications of extended structures around PS core



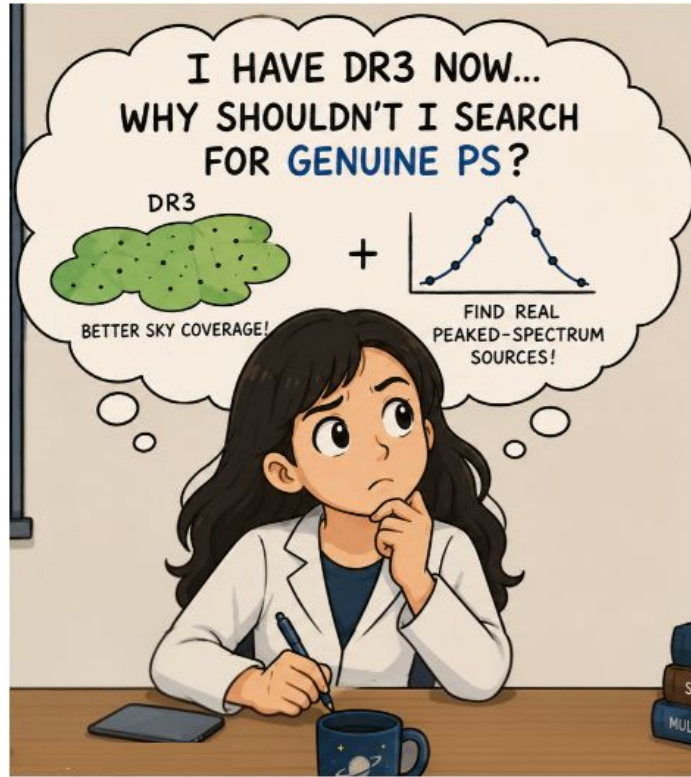
A.Mohanan et.al in preparation

Properties of the 51 PS Sources Associated with Extended Radio Emission



A.Mohanan et.al in preparation

Not all candidate PS sources are genuinely peaked !

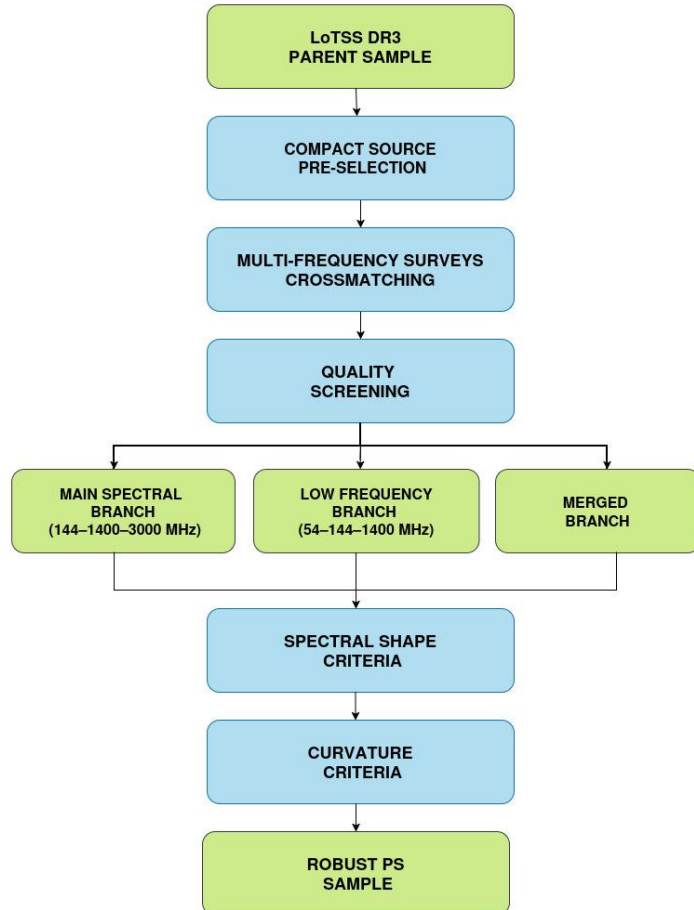


From Lessons Learned to a Stronger, Cleaner DR3 PS Sample

So what can we do with a larger DR3 PS sample?

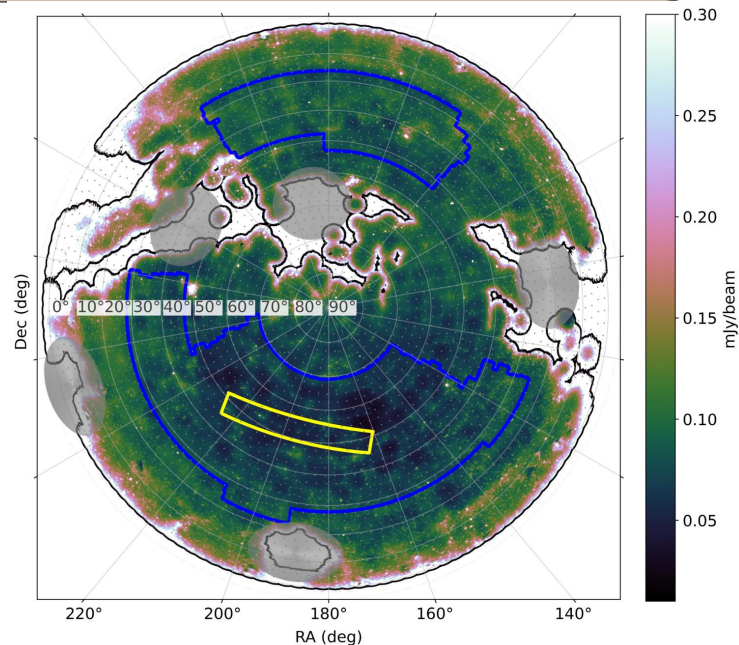
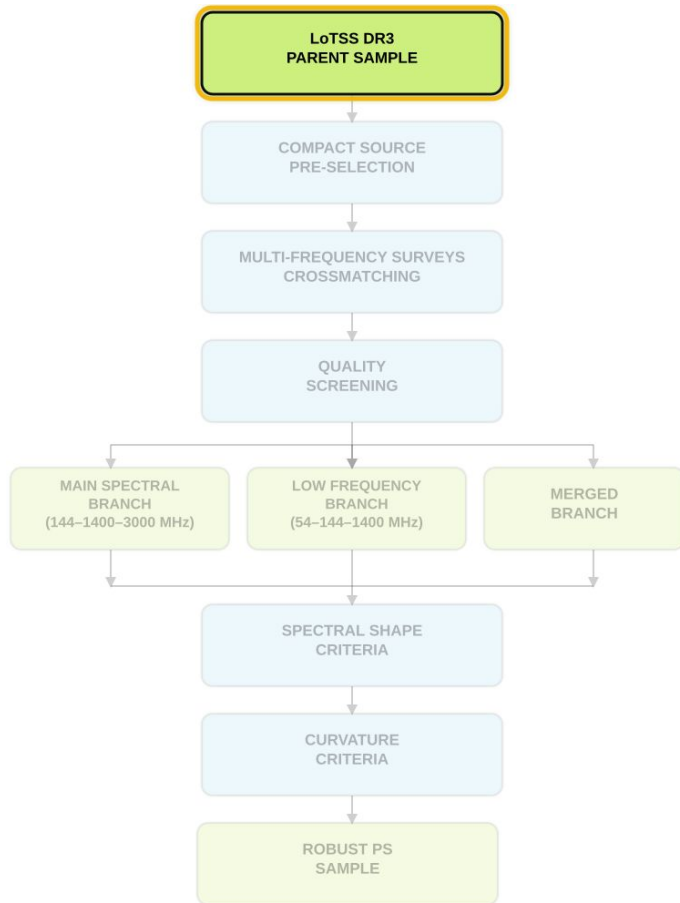
- Potential evolutionary sample: PS sources are often interpreted as **young, recently triggered, frustrated, or intermittent** radio AGN.
- A large sample can test how common these phases are in the radio-loud AGN population.
- Improved demographic studies (Host galaxy properties)
- Enables to study the source density of PS objects
- Better duty cycle studies.

Framework for Selecting Peaked-Spectrum Radio Sources from LoTSS DR3



A.Mohanan et.al in preparation

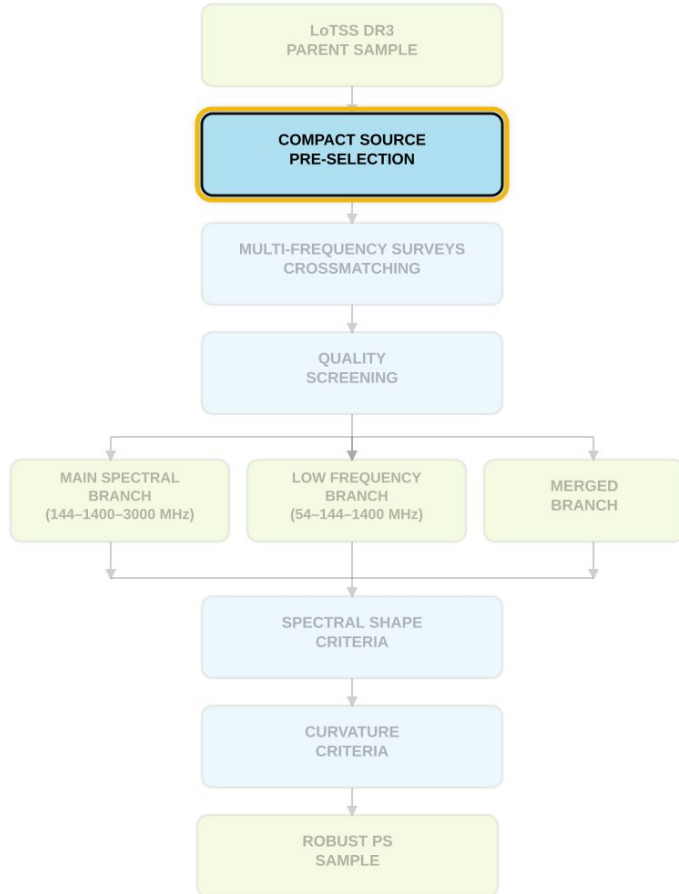
Framework for Selecting Peaked-Spectrum Radio Sources from LoTSS DR3



- ❖ 88% of the northern sky
- ❖ 13.7 million radio sources
- ❖ 16.9 million Gaussian components
- ❖ Resolution: 6"
- ❖ Median sensitivity: 92 $\mu\text{Jy beam}^{-1}$

Shimwell et al. (2026)

Framework for Selecting Peaked-Spectrum Radio Sources from LoTSS DR3

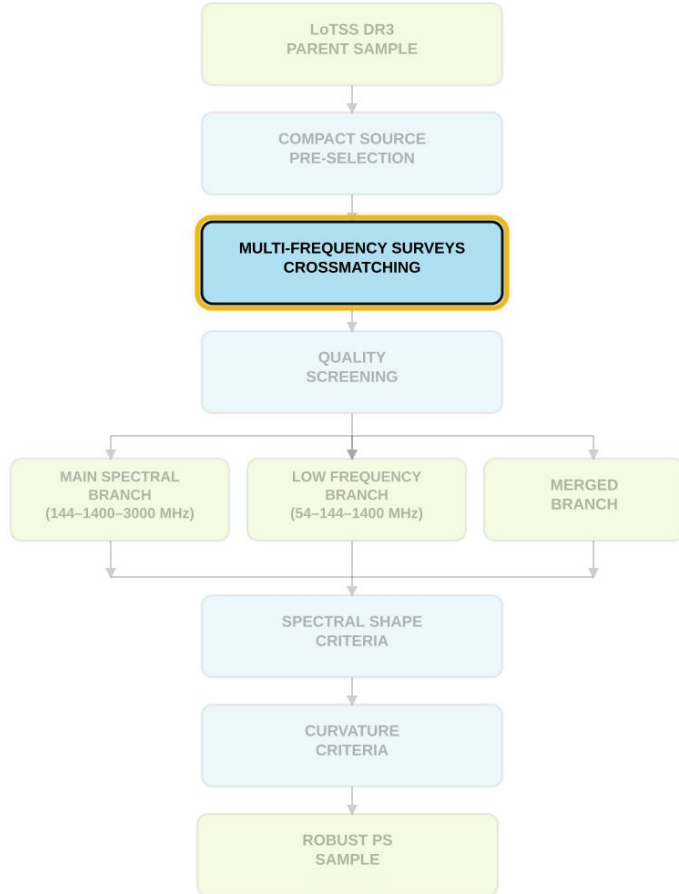


❖ *Selected sources classified as single-component compact objects*

❖ *Subtract known PS sources*

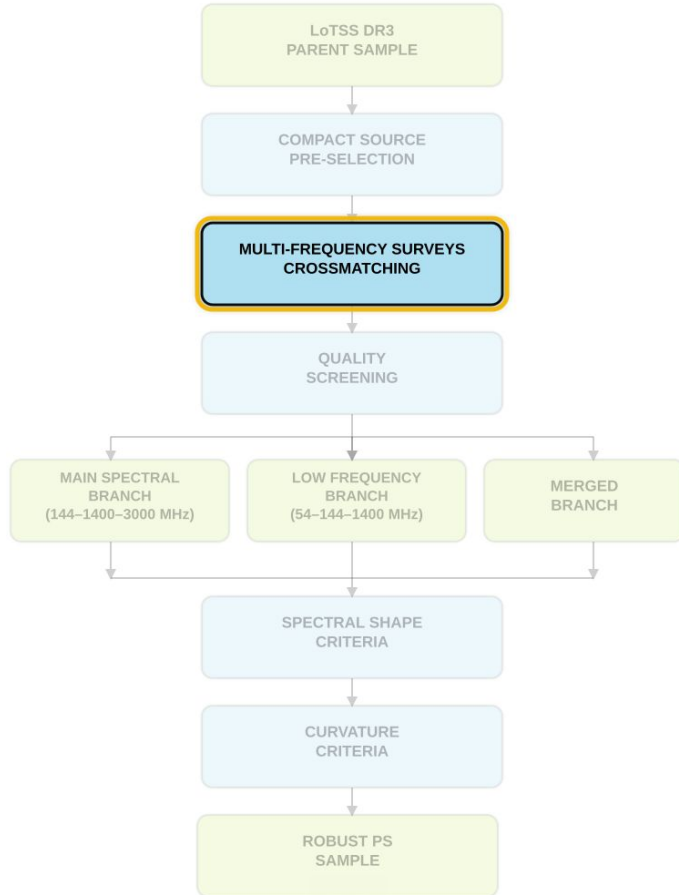
A.Mohanan et.al in preparation

Framework for Selecting Peaked-Spectrum Radio Sources from LoTSS DR3



Survey	Frequency
LoLSS	54 MHz
LoTSS DR3	144 MHz
FIRST	1.4 GHz
APERTIF	1.3 GHz
VCLASS	3 GHz

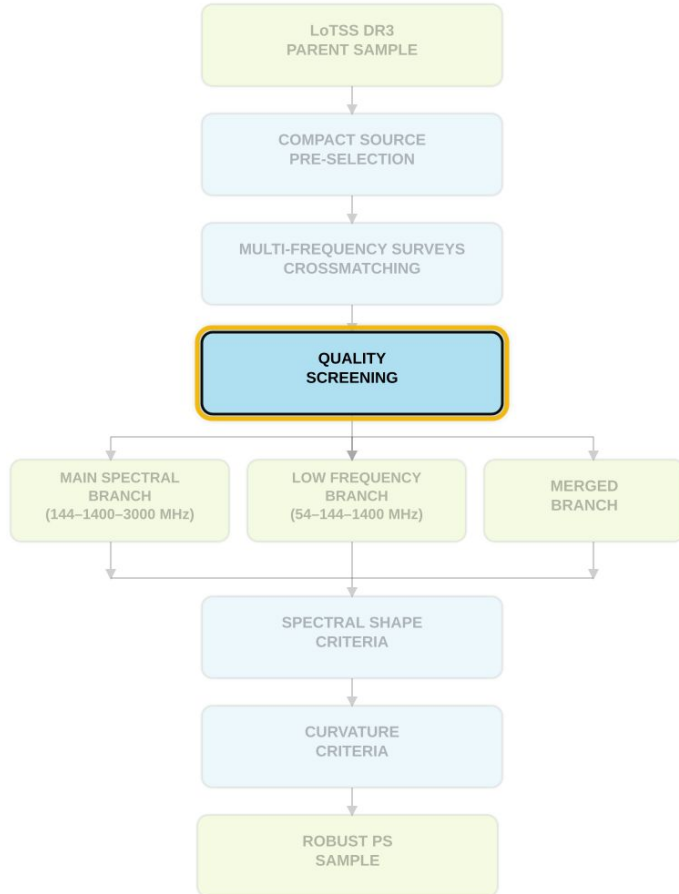
Framework for Selecting Peaked-Spectrum Radio Sources from LoTSS DR3



Survey	Frequency
LoLSS	54 MHz
LoTSS DR3	144 MHz
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- *Spectral Index computation*

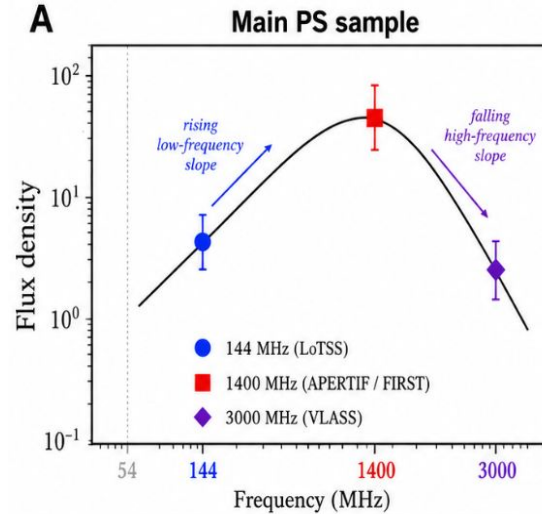
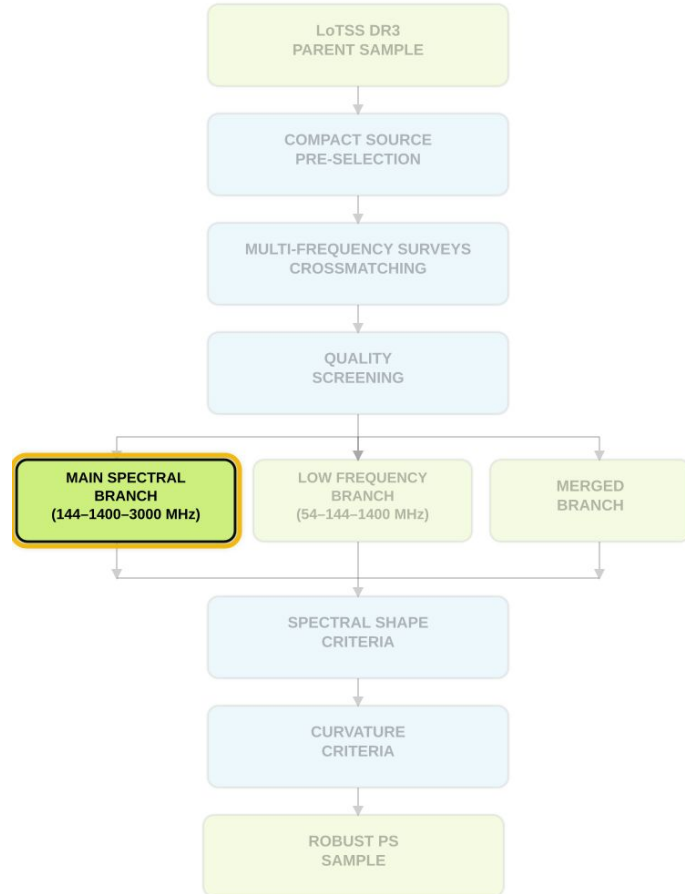
Framework for Selecting Peaked-Spectrum Radio Sources from LoTSS DR3



- *Removed sources flagged as duplicates*
- *Removed probable sidelobes/artifacts*

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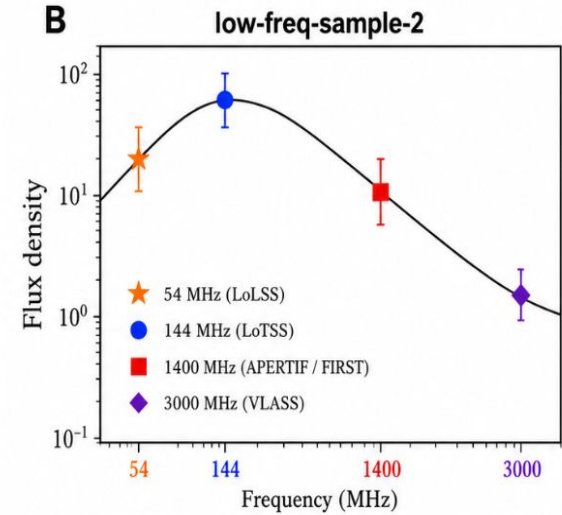
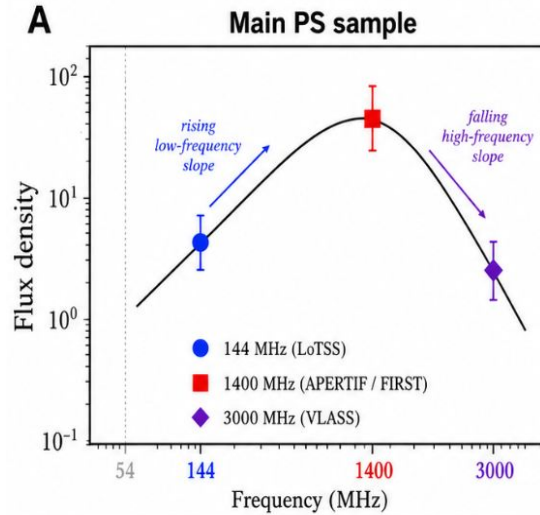
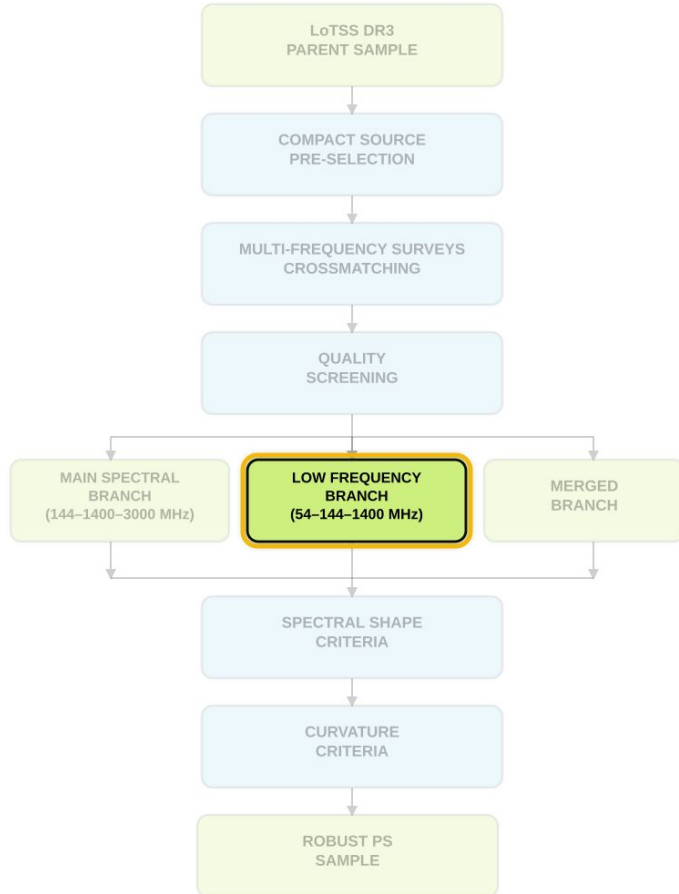
Framework for Selecting Peaked-Spectrum Radio Sources from LoTSS DR3



**LoTSS-APERTIF-VLASS
&
LoTSS-FIRST-VLASS**

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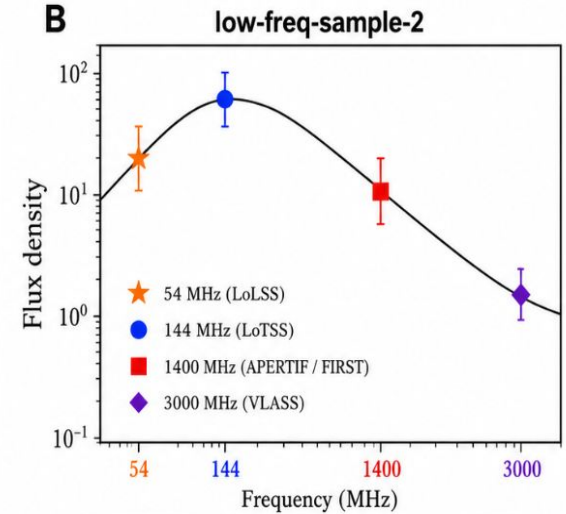
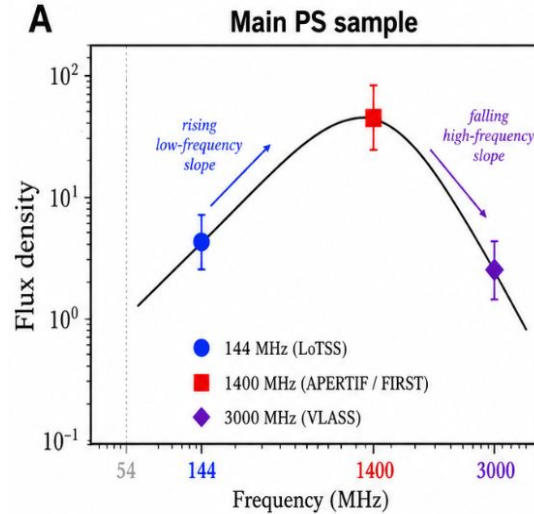
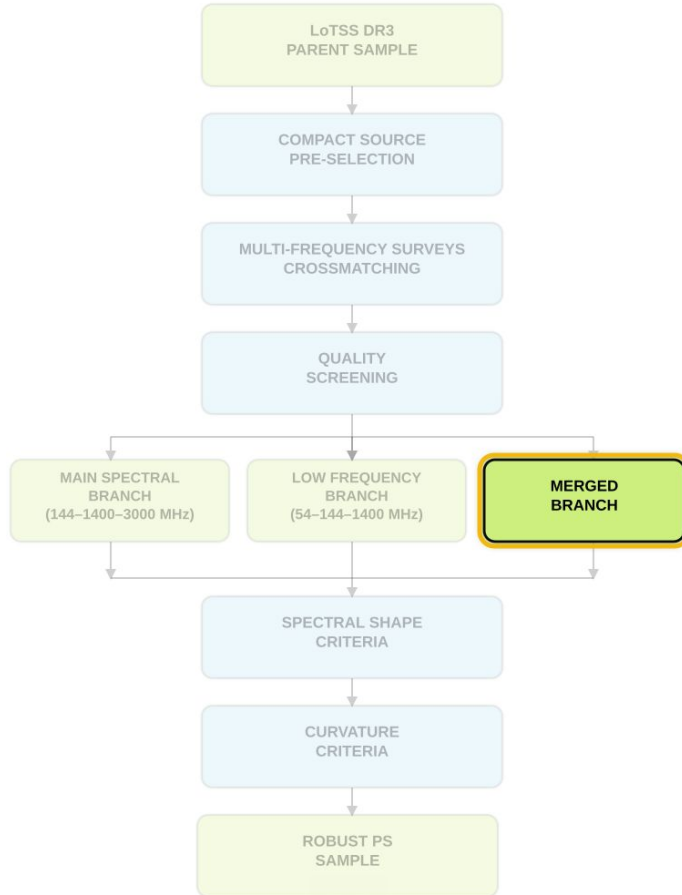
Framework for Selecting Peaked-Spectrum Radio Sources from LoTSS DR3



**LoLSS-LoTSS-APERTIF-VLASS
&
LoLSS-LoTSS-FIRST-VLASS**

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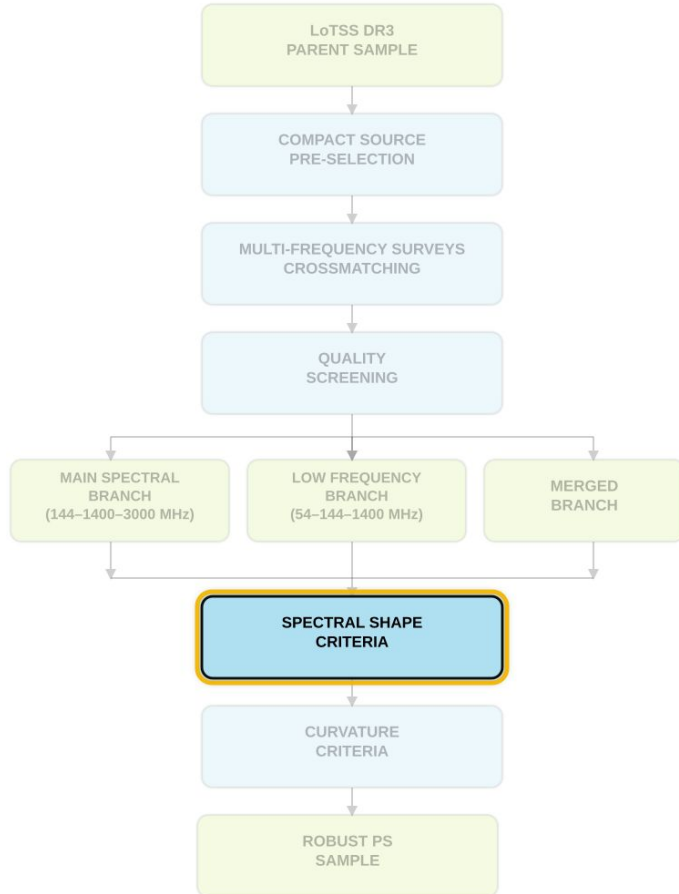
Framework for Selecting Peaked-Spectrum Radio Sources from LoTSS DR3



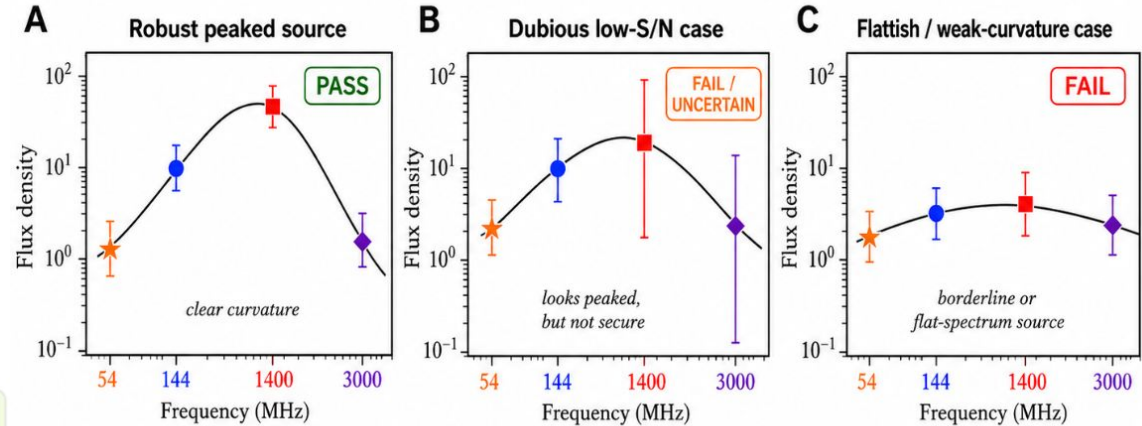
$$PS_{\text{total}} = PS_{\text{main}} + PS_{\text{low freq}} - PS_{\text{common}}$$

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Framework for Selecting Peaked-Spectrum Radio Sources from LoTSS DR3



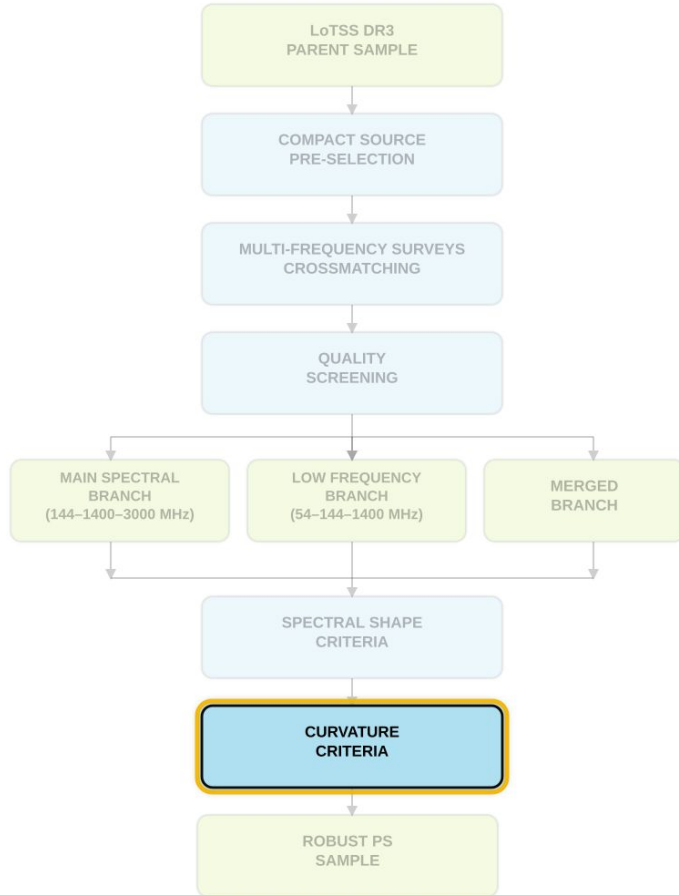
Why curvature and S/N criteria matter



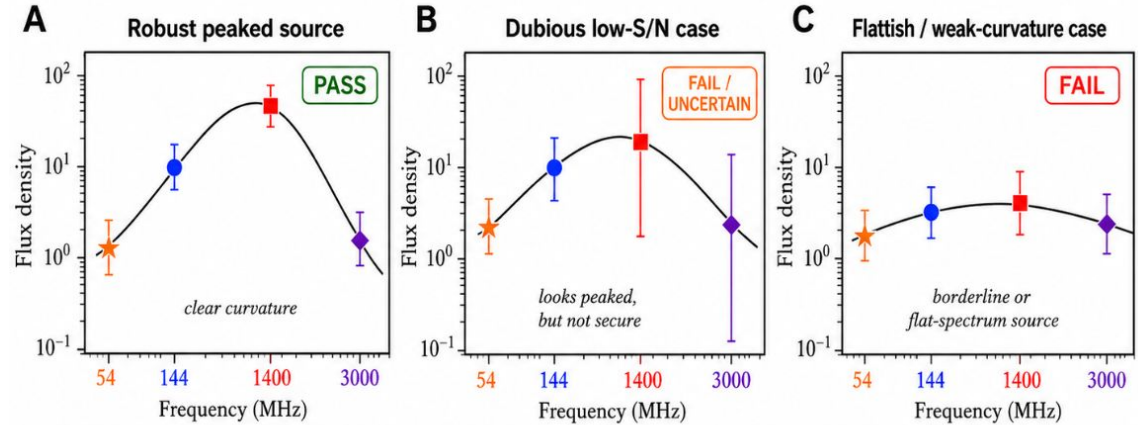
Retained $S/N \geq 5$ in all surveys

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Framework for Selecting Peaked-Spectrum Radio Sources from LoTSS DR3

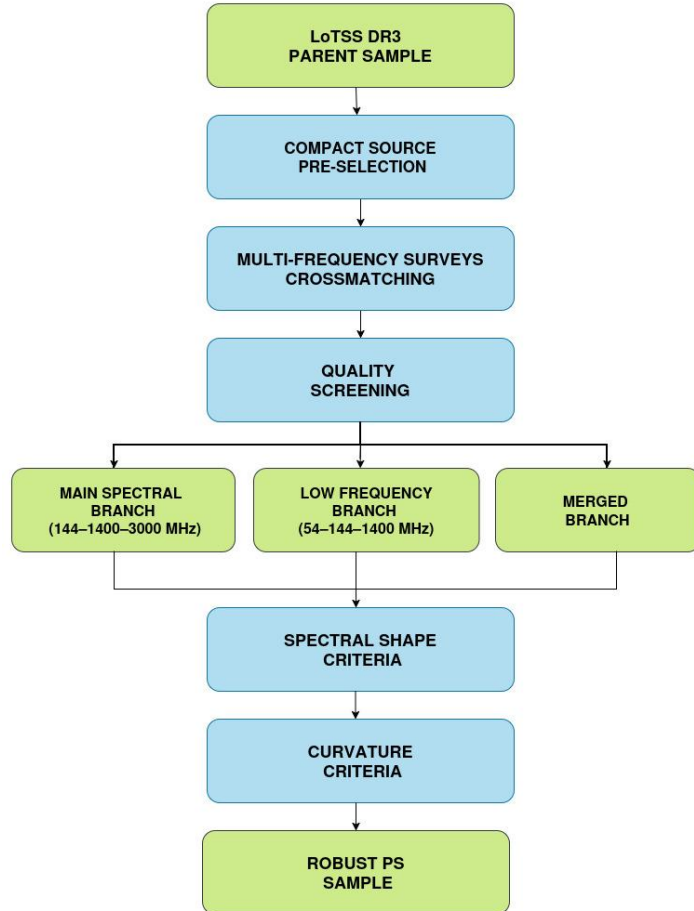


Why curvature and S/N criteria matter

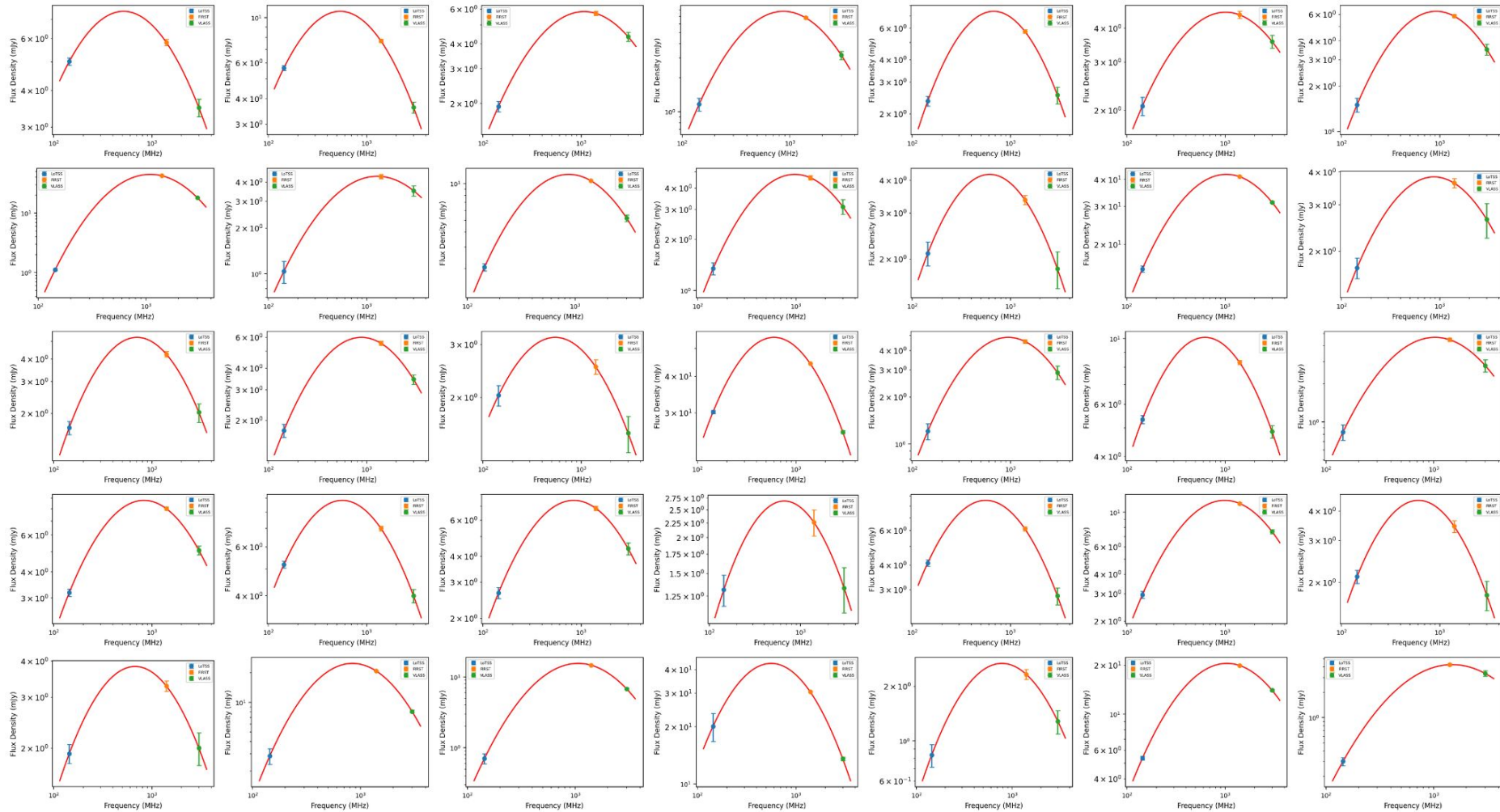


$$\Delta\alpha = \alpha_{\text{low}} - \alpha_{\text{high}}$$

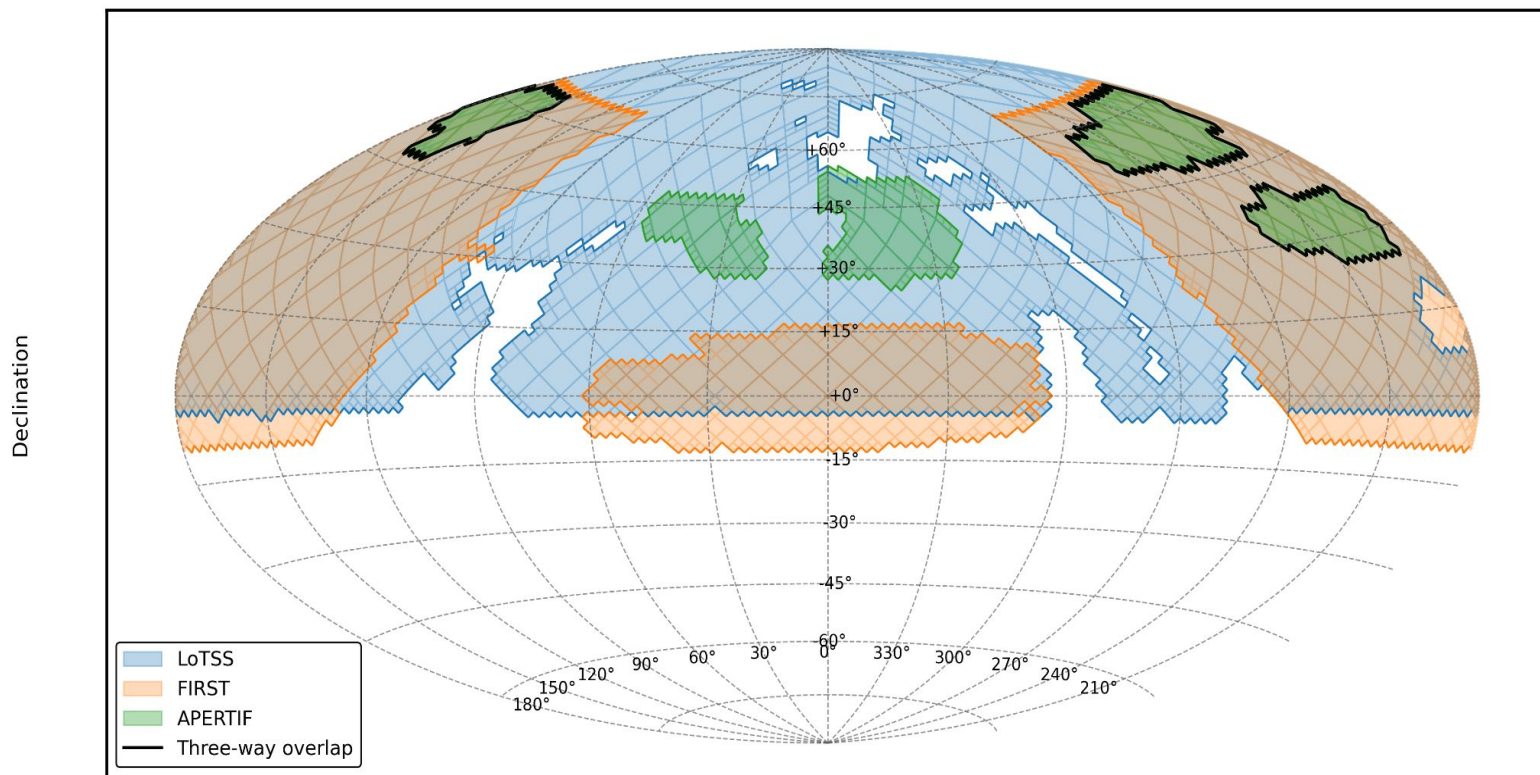
Framework for Selecting Peaked-Spectrum Radio Sources from LoTSS DR3



~12,000 PS Sources



Survey Coverage and Effective Search Area



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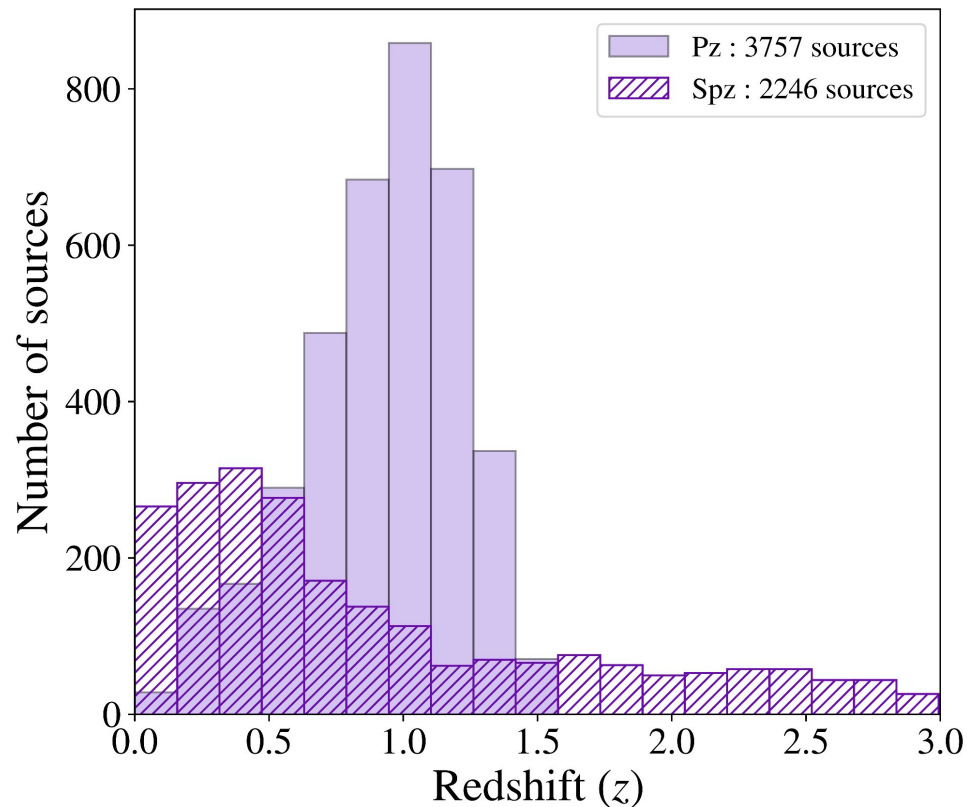
Our PS sample is drawn from $\sim 9,800 \text{ deg}^2$ ($\sim 50\%$ of LoTSS DR3)

Comparison with the PS catalogue of Ballieux et.al 2024

- Ballieux et al. (2024) catalogue: 8032 GPS + 506 MPS = **8538** PS sources
- Applied our PS selection criteria on LoTSS DR2 sky area.
- **5936** sources identified

Preliminary Results

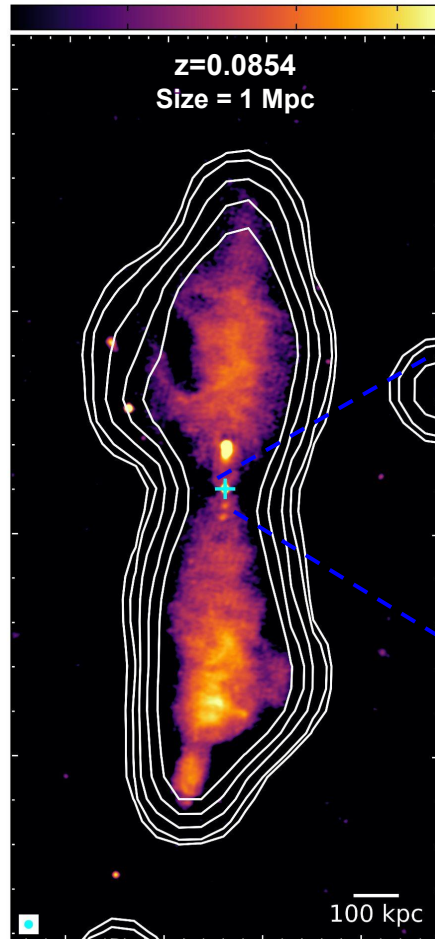
Redshift Distribution of PS from DR3



Redshifts for about 50% of the sample

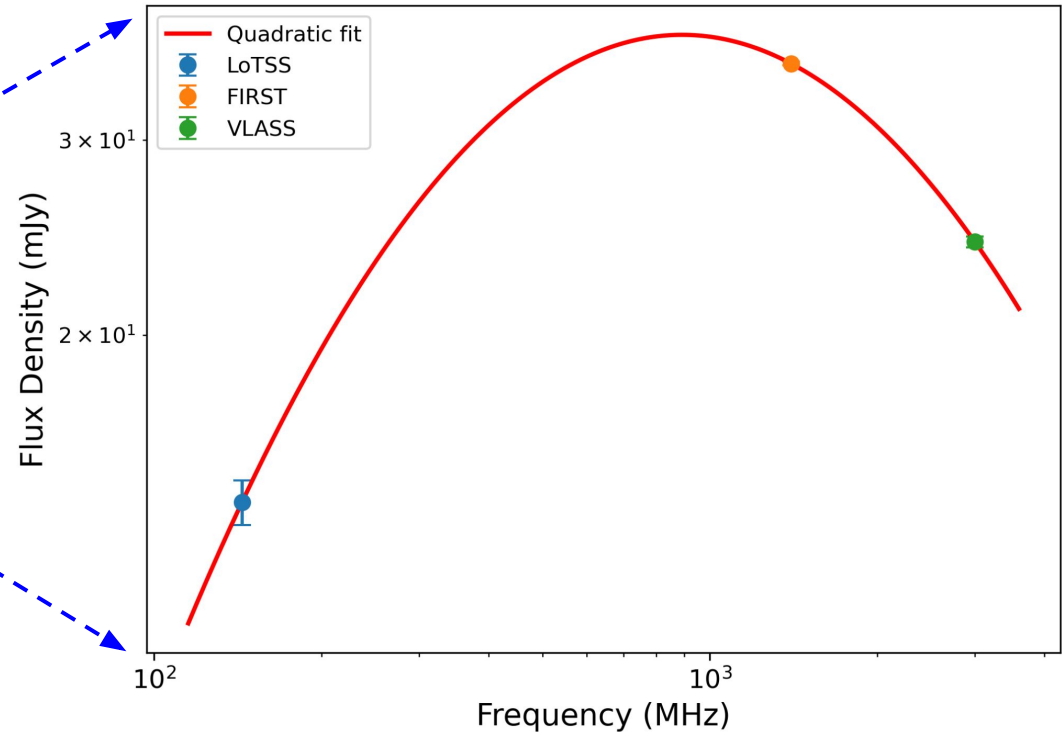
- *SDSS*
- *HETDEX*
- *DESI*
- *COSMOS*
- *Quia compilation etc.*

Total Intensity (144 MHz) [Jy beam^{-1}]
0.0005 0.0015 0.0025



Preliminary Results

Giant with a GPS core !



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Ongoing and Future Work

- *Identification of extended lobes and diffuse relic structures.*
- *Estimate host galaxy properties and compare with control samples.*
- *Higher resolution radio mapping of PS core.*
- *Constrain duty cycle.*

Conclusions

- *Identified 51 candidate restarted radio galaxies from LoTSS DR2.*
- *Large PS population from LoTSS DR3 (~12k) ; Strong sample for population statistics.*
- *Redshifts for about 50% of the PS sample from DR3.*
- *Potential evolutionary sample - not all PS sources need to be young.*
- *Significant fraction of our PS sample from DR3 has been found to have associated extended emission around the core.*

...Thank you...