A study of irregular radio galaxies from the VLA FIRST survey

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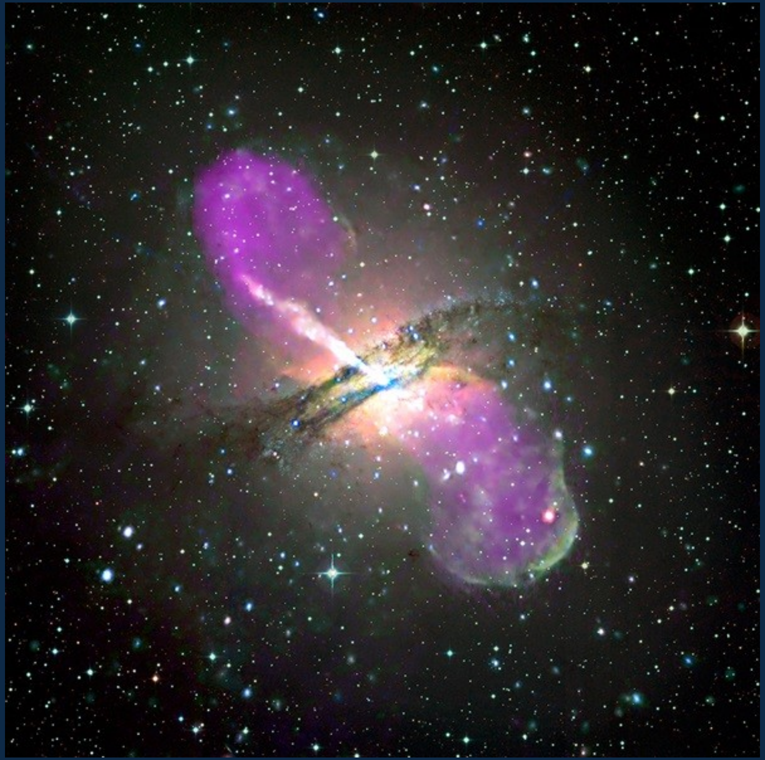
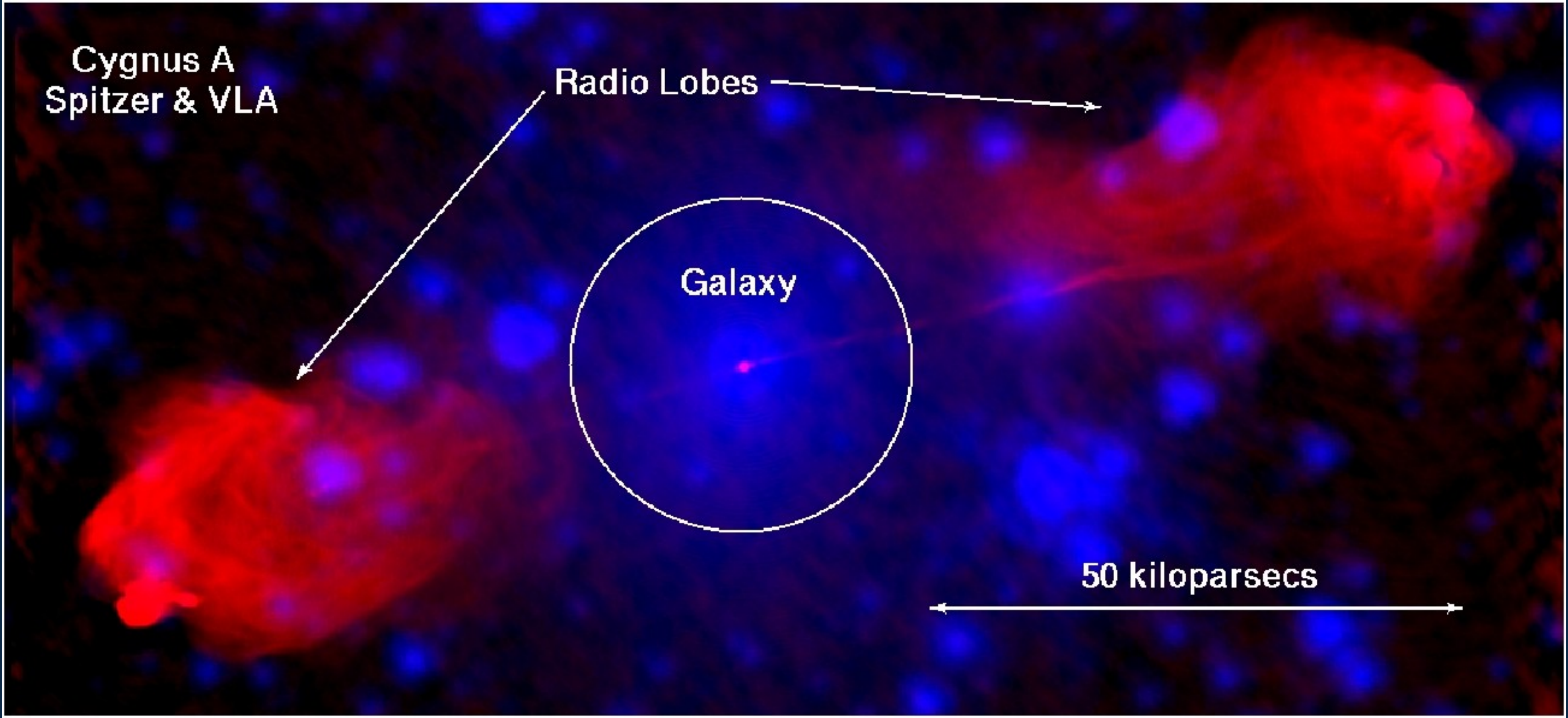
Tianlai Collaboration Meeting, 24th July, Hangzhou, China

Why observe in the radio?



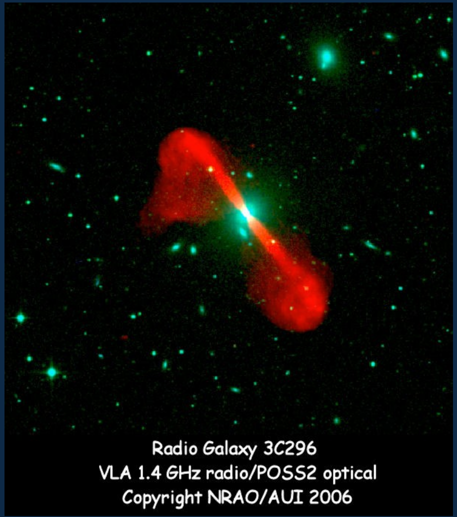
Optical (left) and Radio (right) Images of Centaurus A. Image credit: ESO

A typical radio galaxy

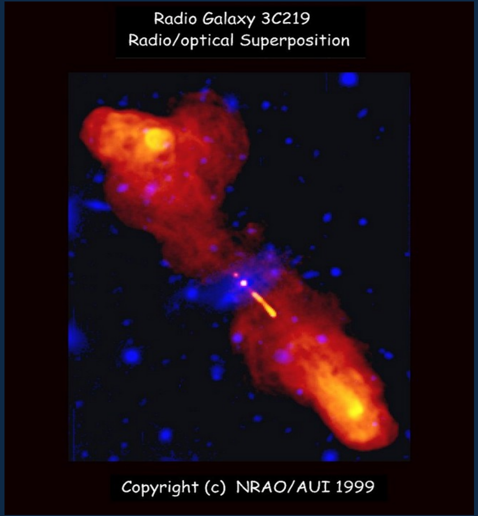


Redshift (z): 0.056, Luminosity- 10^41 to 10^46 erg/s in the frequency range of 10 MHz to 100 GHz. Image credit: Spitzer (Optical) and VLA (Radio)

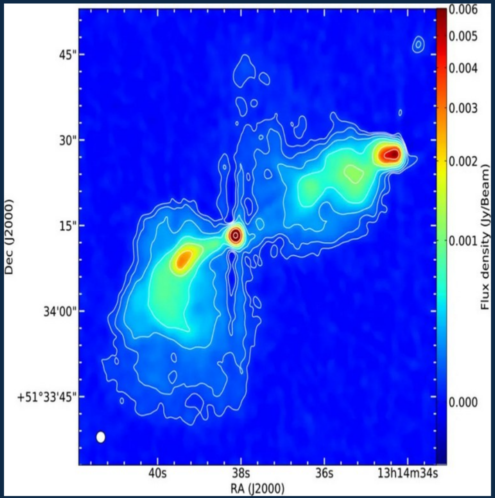
Regular radio galaxies



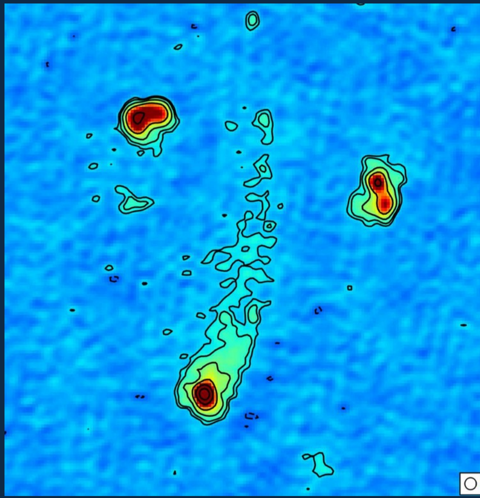
FR-I



FR-II



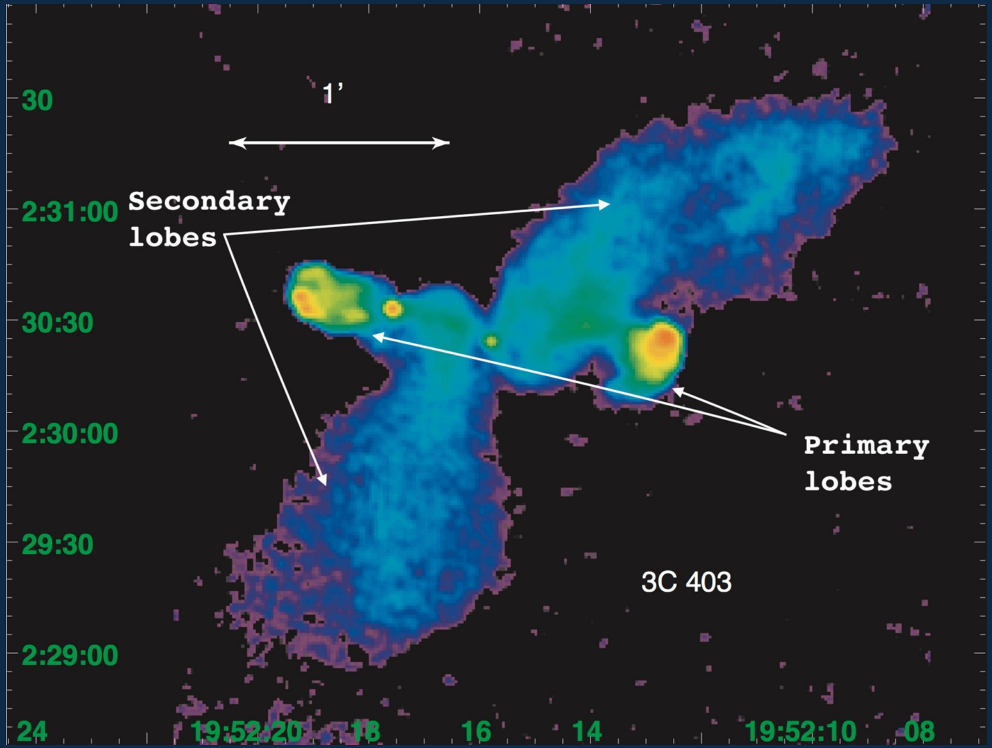
HyMORS



FR-0

- FR-I: Less luminous and edge darken than centre.
- FR-II: Luminous and edge brighten than centre.
- HyMORS: One side FR-I and another side FR-II.
- FR-0: Not able to produce relativistic jets, early stage of FR-I.

Winged radio galaxy: 3C 403



This is a well-known winged radio galaxy 3C 403 (Courtesy: seramarkoff.com).

Proposed Origins of the Winged Radio Sources

- **Backflow of Plasma**- formed by jet material that is supposed to be released by the hotspots and then streams back toward the host galaxy. Lateral expansion of the surrounding medium along the minor axis.

- **Black Hole Merger** - When a relatively smaller black hole coalesces with a larger one through a galaxy merger process, the spin axis of the larger black hole undergoes a sudden change.

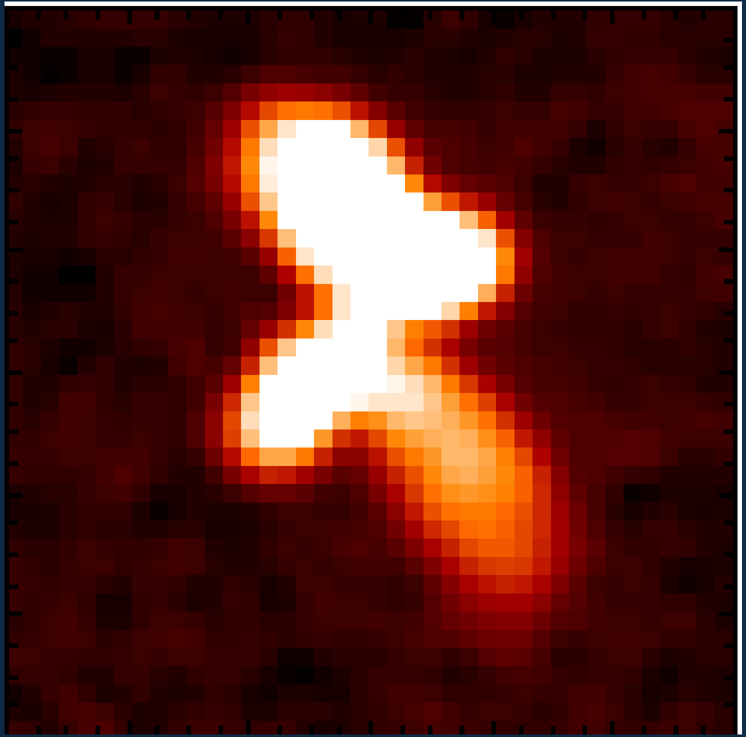
- **Precession of Jets** - a rapid realignment of the central supermassive black hole-accretion disk system.

- **Twin AGNs** - The two pairs of jets are believed to be ejected from two unresolved AGNs in different directions.

- **Buoyancy** - Buoyant forces can be the reason for the bending of the lobes and thus affect the overall radio morphology.

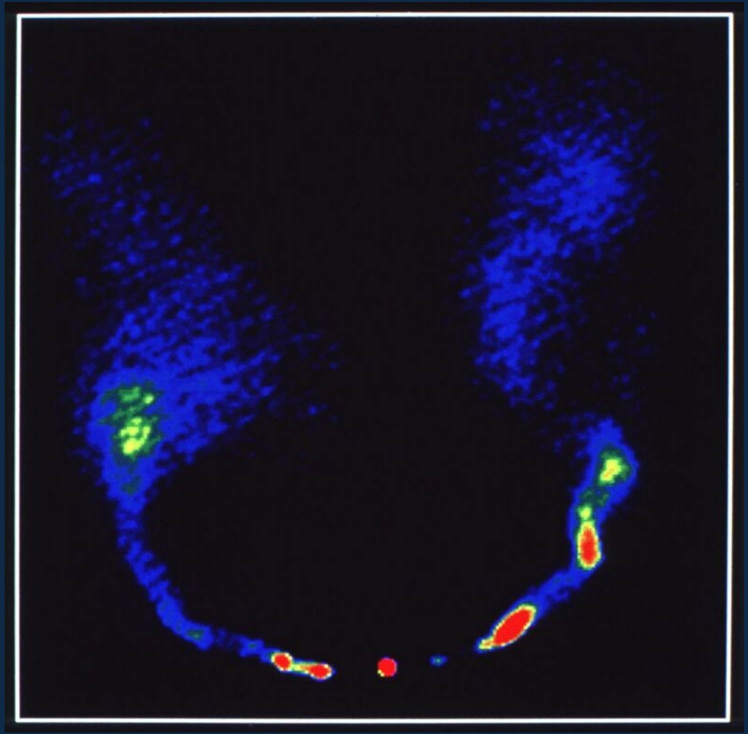
- **Jet-Shell Interaction** - Wings of the XRGs arise when the jets are disrupted by the shells.

Classification of ‘wing’ radio galaxy



Left: Radio image of a X-shape Radio Galaxy (XRG). Right: Radio image of a Z-shape Radio Galaxy (ZRG).

Bent-tail radio galaxies: NGC 1265



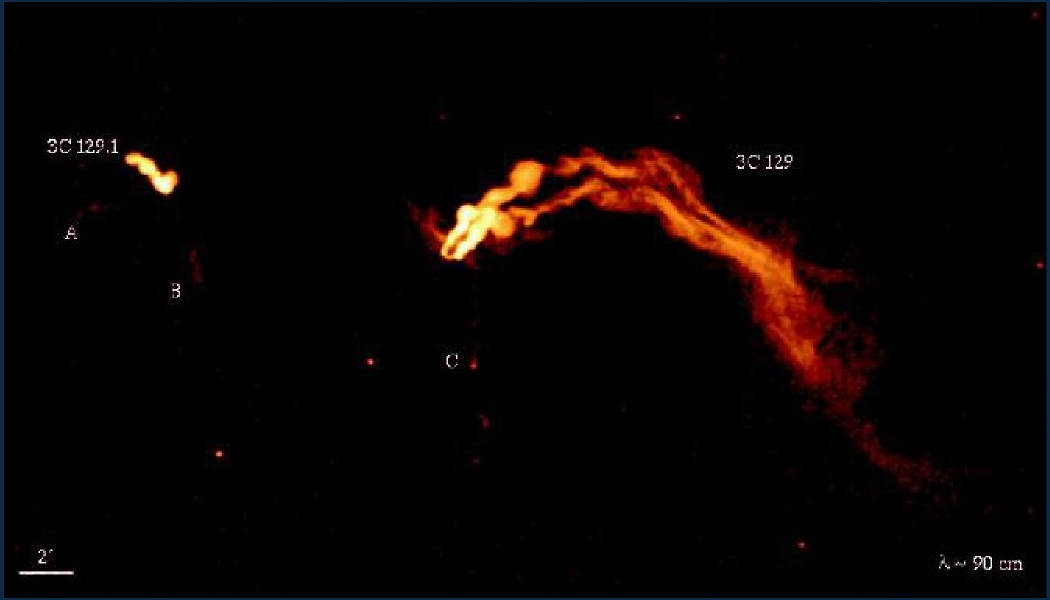
NGC 1265: showing the basic bent morphology that is typical of Bent-tail source. Highest radio intensity shown in red. Image credit: Pearson Education, Inc

Reason of bending of jets

Bending of radio tails results from motion of the host galaxy through the intracluster medium (ICM), cluster-environments, as well as projection effects through ram pressure striping.

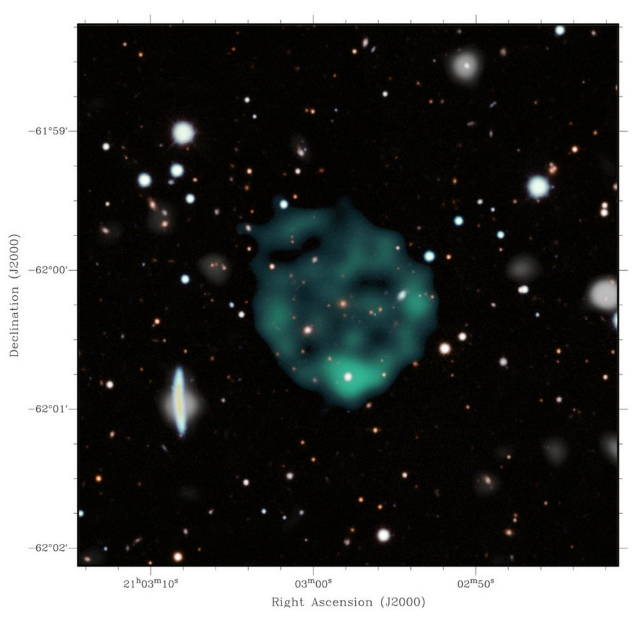
When these sources move through the ICM with sufficient velocities, the jets are bend in the same direction due to the action of ram pressure. This 'ram-pressure' model was first proposed by Begelman et al. (1979). When the material density of the radio jets is less than the density of the surrounding medium, the buoyancy force comes into action. It pushes the lobes to the regions of ICM where the density of the jet is equal to that of the surrounding medium as a result jets are bends.

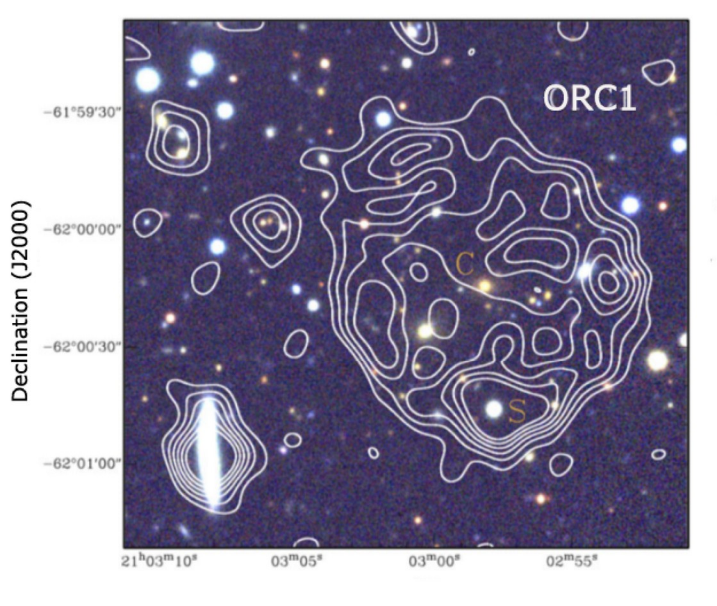
Classification of Bent-tail radio galaxy



Left: Radio image of a Wide angle tail (WAT) sources. Right: Radio image of a Narrow angle tail (NAT) sources. Angle between the jets is greater than 90 degree for WAT and less than 90 degree for NAT.

Odd Radio Circles (ORCs)

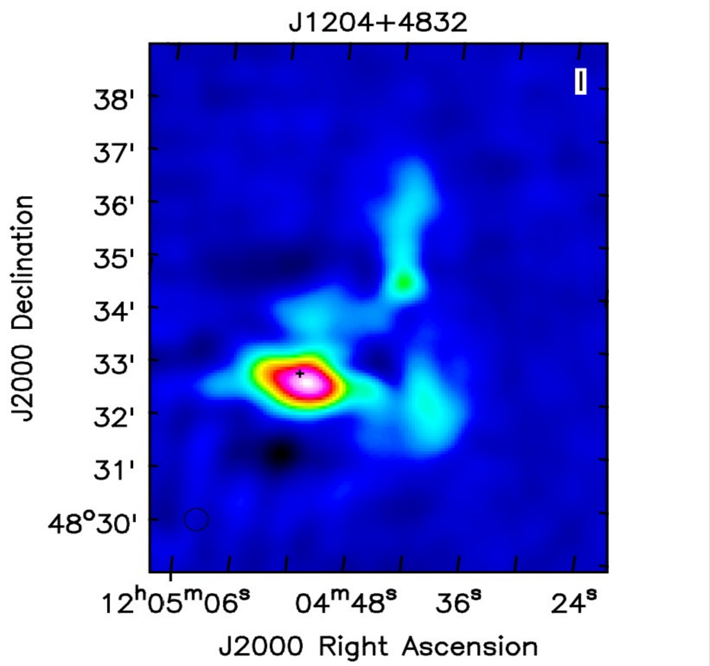




- Spherical shock wave from the central galaxy
- A double-lobed radio active galactic nucleus (AGN) seen endon
- The result of interactions between galaxies

Left:The ASKAP radio image of ORC J2103-6200, adapted from Norris et al, . The resolution is 11 arcsec, and the rms sensitivity is 25 μJy/beam. Redshift 0.551. Right: The contours overlaid onto a DES optical image

Peculiar Radio Morphology



Radio image of a peculiar source J1204+4832.

- The radio morphology of a source depends on the jet structure and alignment. The jets ejected from the central core are not necessarily equal, interaction between the jets to the ICM or intergalactic medium (IGM).

- A galaxy goes through a certain number of phases during its evolution. In each phase, the structure or the morphology of the galaxy changes. Since peculiar sources are different from known structures, thus, it may indicate a special phase or phase transition in their evolution.

- The phenomena like galaxy merger, change in axes of the spin orientation, the effect of bouncy, back-flow of plasma, and ram pressure due to the relatively high-speed motion maybe sum up to give rise to such interesting morphology.

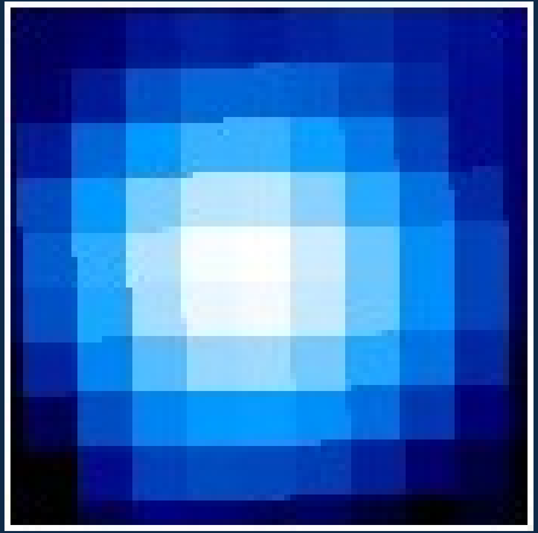
Very Large Array (VLA) Faint Images of the Radio Sky at Twenty-cm (FIRST) survey

- Location- New Mexico
- Operated by- National Radio Astronomy Observatory (NRAO)
- Number of antennas: 28 (27 active and 1 spare)
- Dish size: 25 meters
- Configuration- VLA B-configuration
- Survey Frequency- 1.4 GHz

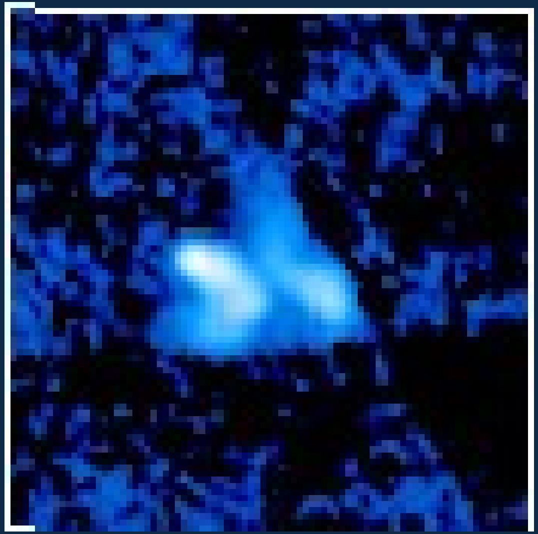
An aerial view of the Very Large Array and its ‘Y-shaped’ arrangement (Courtesy: NRAO).

Why VLA FIRST?

- Sky Coverage- 10,575 square degrees at 1.4 GHz(~25% of the whole sky, 80% of the north and 20% of the south galactic cap)
- Resolution- 5″ (9 times better than NVSS)
- Mean rms (σ)- 0.15 mJy

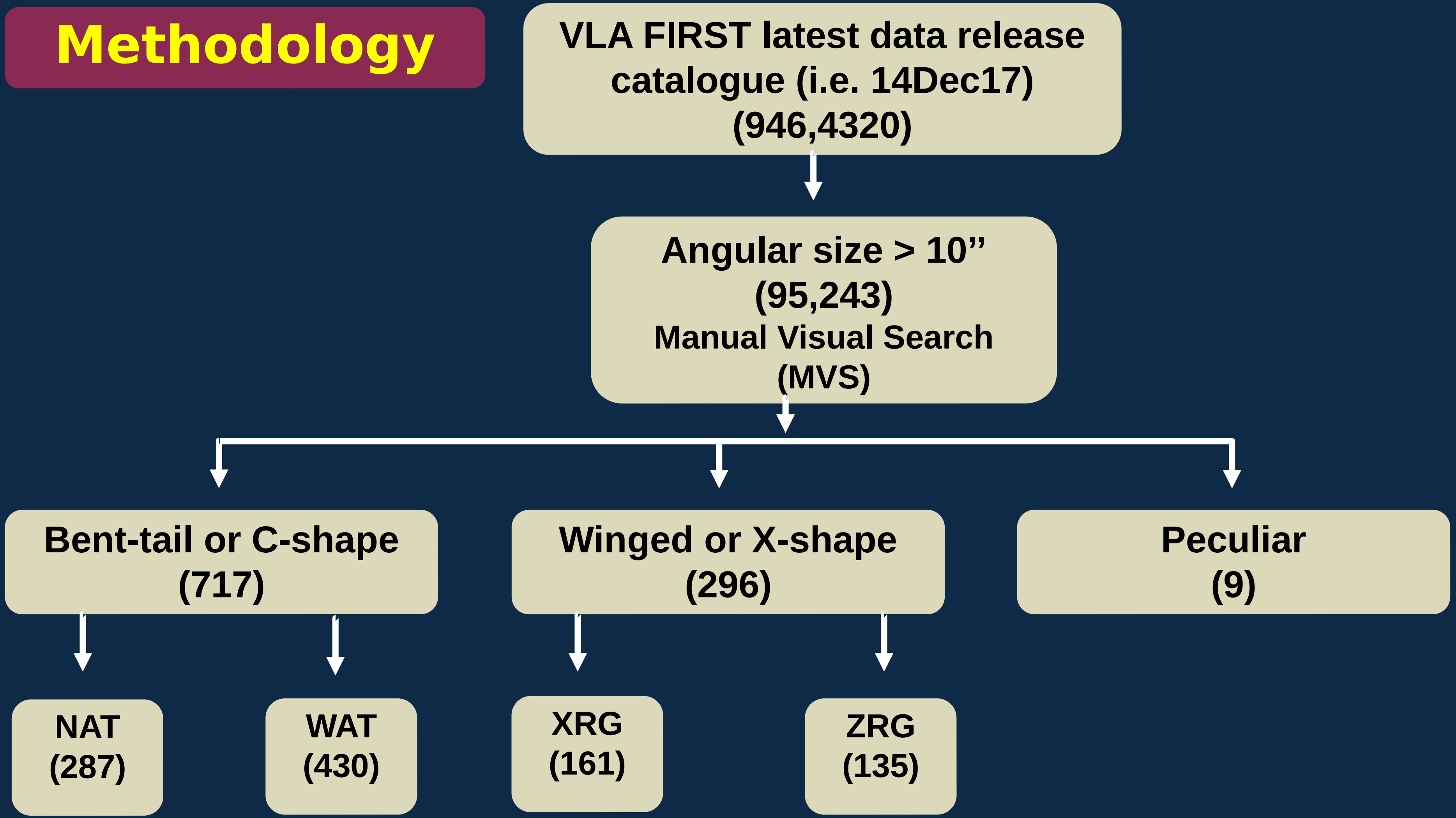


This is a 256×256 pixels radio image of J1054+5521 from NVSS.



This is a 256×256 pixels radio image of J1054+5521 from VLA FIRST.

Methodology



Sample tables of irregular sources from VLA FIRST

THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 251:9 (15pp), 2020 November — Bera et al.

Table 1
Candidate X-shaped Radio Sources

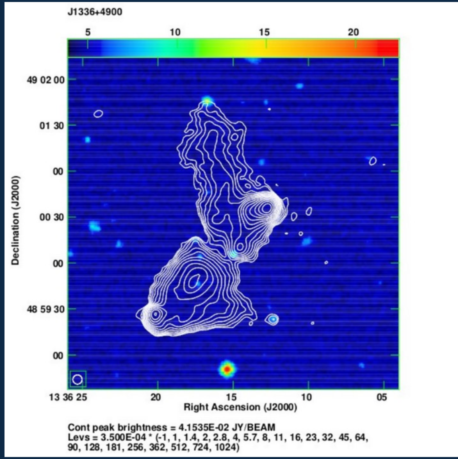
Catalog Number	Name	R.A. (J2000.0)	Decl. (J2000.0)	Ref.	Redshift (z)	F_{1400} (mJy)	F_{150} (mJy)	α_{150}^{1400}	Linear Size (kpc)	L (erg s^{-1}) ($\times 10^{42}$)	Other Catalogs
25	J0747 + 2202	07 47 36.74	+22 02 15.9	SDSS	0.46	44	301	−0.86	606	4.65	1
26	J0748 + 2324	07 48 45.10	+23 24 45.8	SDSS	0.19	515	3238	−0.82	260	33.87	…
27	J0749 + 2007	07 49 19.08	+20 07 53.7	SDSS	0.37	139	960	−0.86	518	1.94	1, 2, 10, 12
28	J0750 + 1144	07 50 25.95	+11 44 52.0	SDSS	0.96	289	1846	−0.83	1512	172.51	15
29	J0758 + 4406	07 58 08.43	+44 06 17.0	EE	…	31	68	−0.35	…	…	1

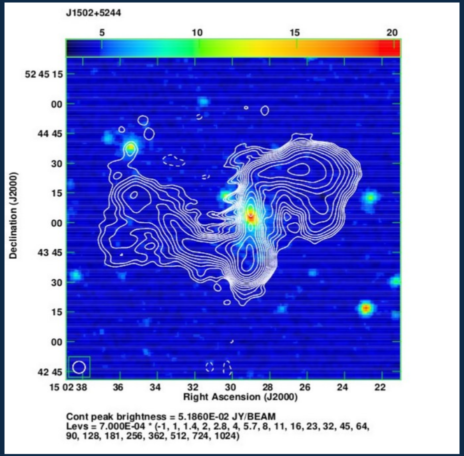
THE ASTROPHYSICAL JOURNAL SUPPLEMENT SERIES, 259:31 (9pp), 2022 April — Sasmal et al.

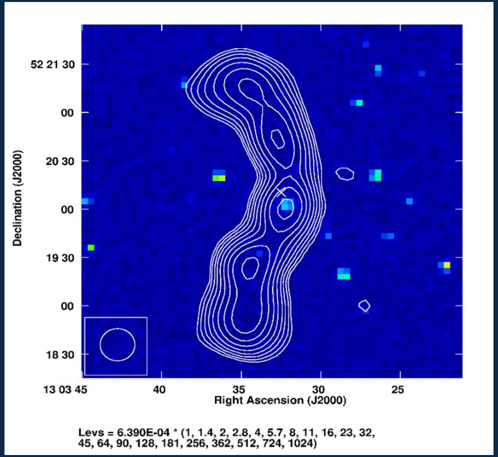
Table 2
Candidate Narrow-angle Tail Radio Sources

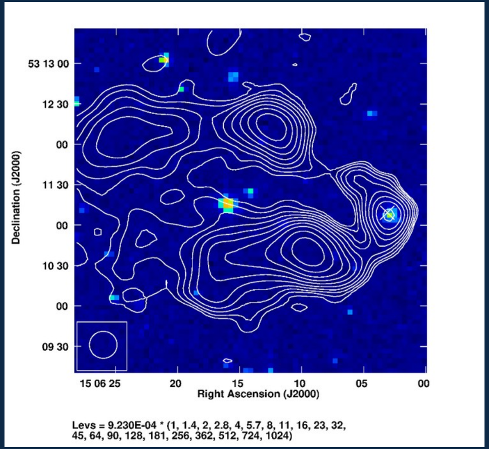
Catalog Number	Name	R.A. (J2000.0)	Decl. (J2000.0)	Ref.	Redshift (z)	F_{1400} (mJy)	F_{150} (mJy)	α_{150}^{1400}	L (erg s^{-1}) ($\times 10^{43}$)	FR Type (I/II)	Other Catalogs
1	J0012–0607	00 12 48.62	−06 07 03.1	2MASX	0.20[a]	66	…	…	…	II	15
2	J0017+0827	00 17 37.70	+08 27 52.9	EE	…	55	…	…	…	I	…
3	J0020+0004	00 20 14.18	+00 04 48.0	EE	…	170	457	−0.44	…	I	16
4	J0023+0717	00 23 46.06	+07 17 55.5	2MASX	0.25[a]	74	…	…	…	I	1, 2, 10
5[c]	J0041–0925	00 41 49.95	−09 25 48.6	GALEX	…	35	…	…	…	II	…
6	J0047+1034	00 47 11.24	+10 34 58.2	2MASS	…	24	…	…	…	…	…
7	J0054+0302	00 54 43.83	+03 02 10.5	SDSS	0.41[a]	18	192	−1.06	1.58	…	1
8	J0056–0119	00 56 30.55	−01 19 19.9	EE	…	162	…	…	…	…	…
9[a,c]	J0056–0120	00 56 02.70	−01 20 03.5	CGCG	0.04[a]	370	…	…	…	II	8, 11, 14, 16
10	J0111+1141	01 11 40.13	+11 41 34.1	EE	…	13	…	…	…	II	…

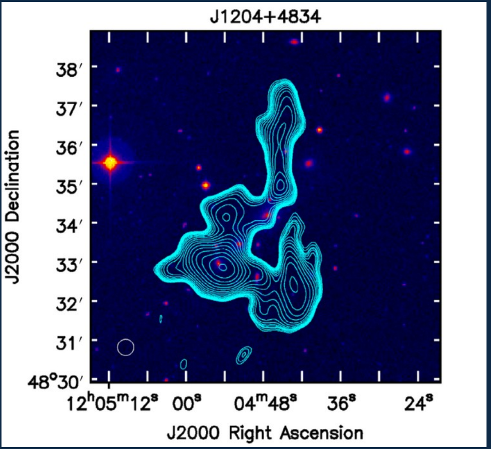
Sample images of winged, BT and peculiar from VLA FIRST



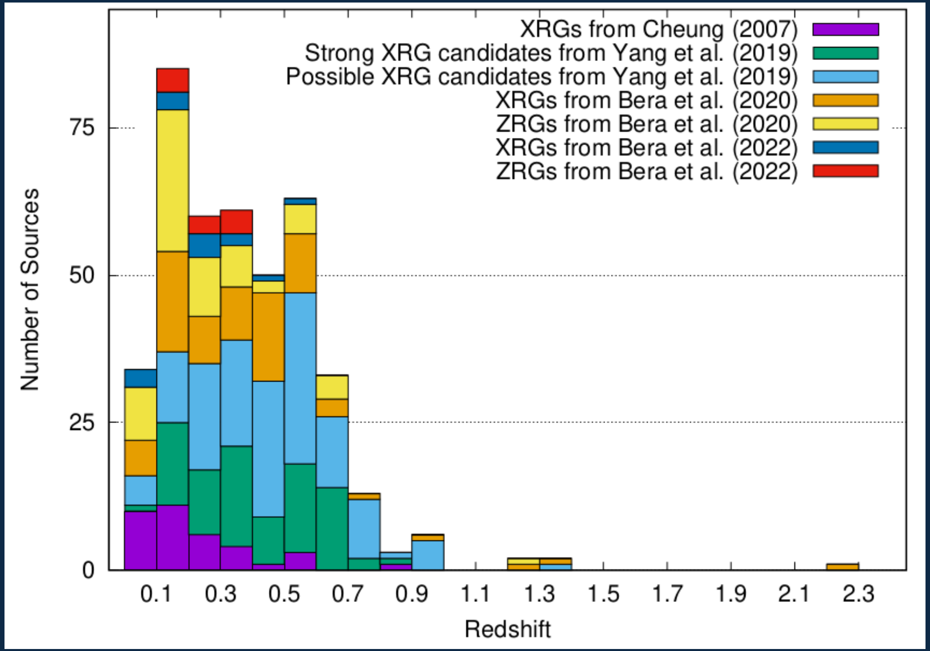


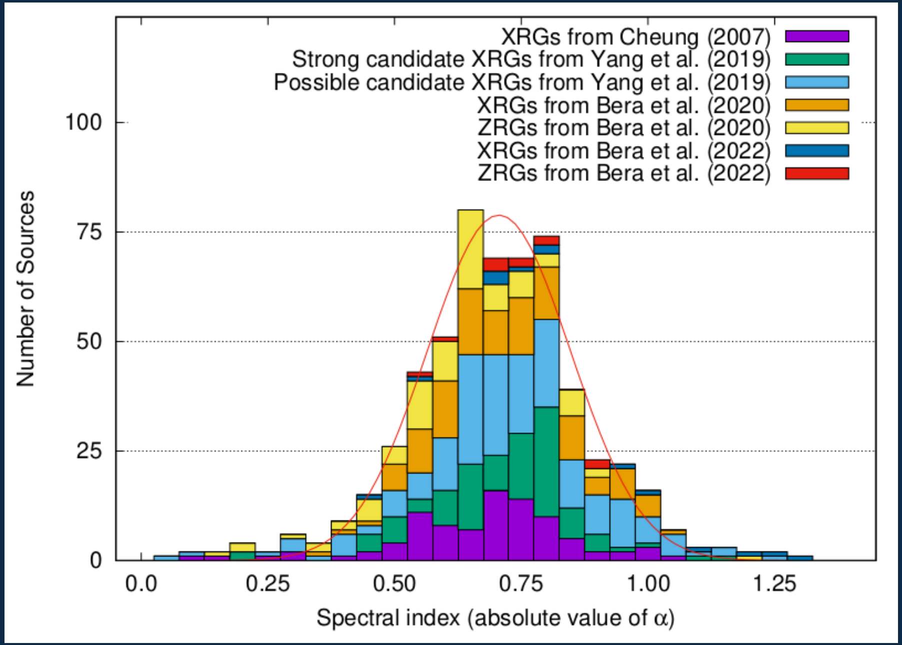






Redshift and Spectral Index distribution





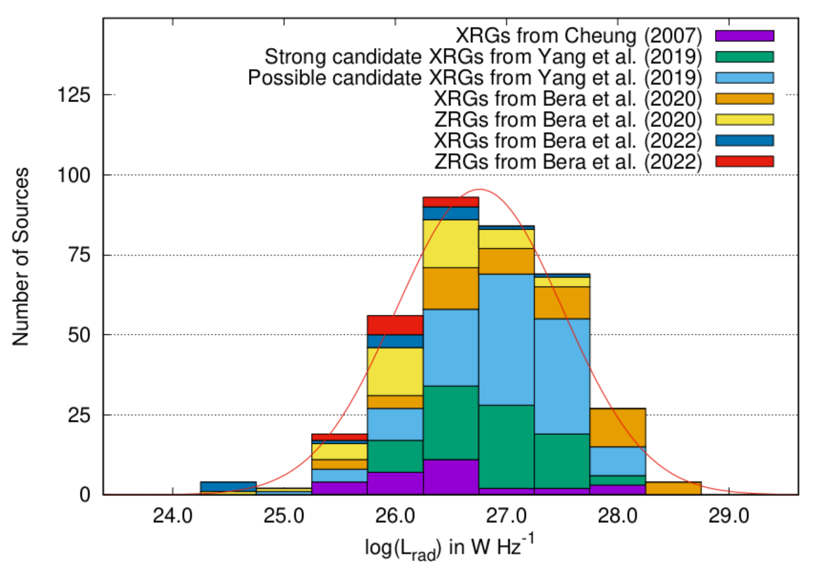
- 93% of sources have *Z <0.70*
- *70% have 0 < Z < 0.5*
- Highest *Z* = 2.24 for XRG J1124+*4325*

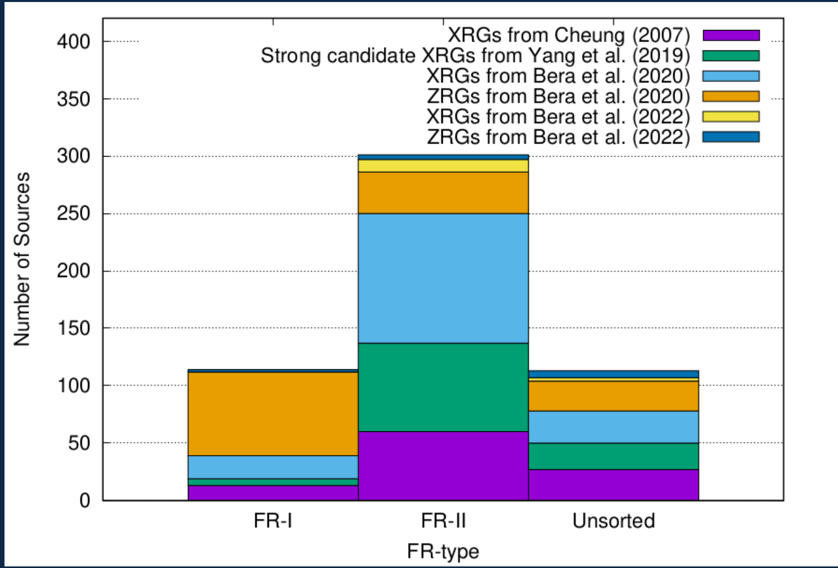
- 60% of sources have spectral index in the range –0.60 to –0.80.

- global mean −0.7, in the range of typical radio galaxy

- 91% of source have steep spectrum, means not relic source, relatively young source

Lumonosity and FR-dichotomy distribution





- Mean luminosity (log scale) is 26.77 W Hz^{-1}
- 80% of sources have luminosity in between the range $10^{26} - 10^{28}$ W Hz^{-1}

- 73% sources show FR-II characteristics
- Supports the theory that, this class of sources preferentially found in FR-II type of galaxies (Leahy & Parma 1992; Dennett-Thorpe et al. 2002)

Summary of my work

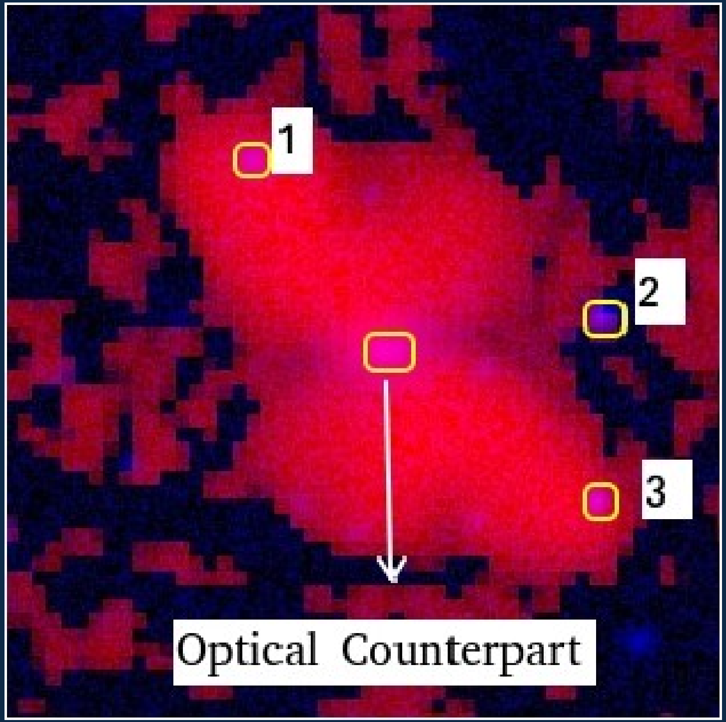
- Reported a total of 717 BT sources from FIRST survey, largest BT catalogue till date. 430 WATs and 287 NATs.

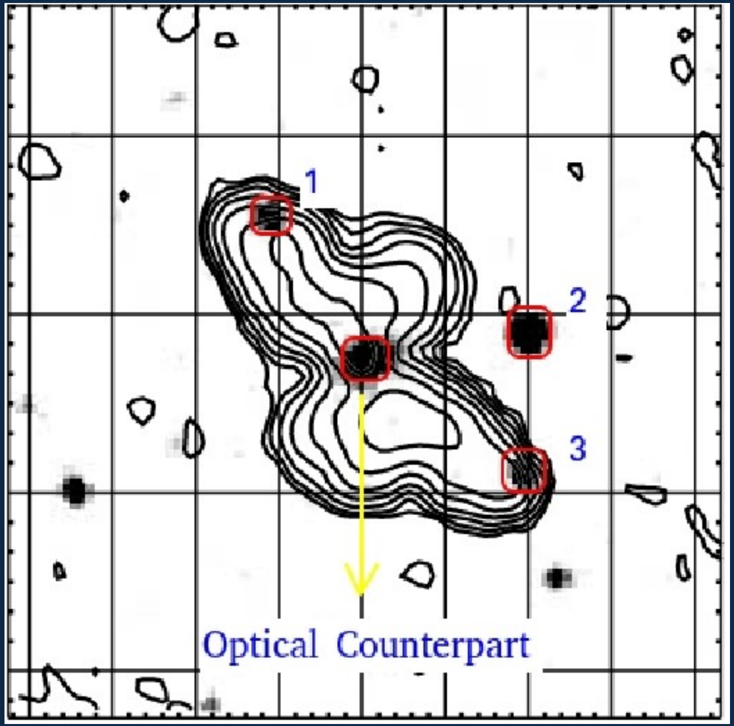
- Reported a total of 296 ‘winged’ from FIRST survey , largest ‘winged’ catalogue till date. 161 XRGs and 135 ZRGs.

- Reported a total of 9 peculiar sources from FIRST and first time reported.

Thank You

Identification of Optical Counterpart





The left panel shows the colour radio image overlaid on the optical image when the right panel shows the contour radio image for the same source overlaid on the optical image and using NED and SDSS DR12.

List of publications

A. Journal Articles

1. *Miscellaneous Radio Galaxies from LOFAR survey*
Sasmal, T. K., Bera, S., & Mondal, S., 2022, AN, 343(8),

2. *A New Catalog of Head-Tail Radio Galaxies from the VLA FIRST Survey*
Sasmal, T. K., Bera, S., Pal, S., & Mondal, S., 2022, ApJS, 259(2), 31

3 *"Winged" Radio Sources from the LOFAR Two-meter Sky Survey First Data Release (LoTSS DR1)*
Bera, S., Sasmal, T. K., Patra, D., & Mondal, S., 2022, ApJS, 260(1), 7

4. *FIRST Winged Radio Galaxies with X and Z Symmetry*
Bera, S., Pal, S., Sasmal, T. K., & Mondal, S., 2020, ApJS, 251(1), 9

5. *A Catalog of Bent-Tail Radio Galaxies from LoTSS DR1 and their Correlation with Associated Clusters*
Sasmal, T. K., Bera, S., & Mondal, S., 2023, MNRAS

6. *A FIRST look on the Miscellaneous Radio Galaxies*
Bera, S., Sasmal, T. K., Mondal, S., et al. (2023), Submited AJ

B. Conference Proceedings

1. *Discovery of Four Miscellaneous Radio Galaxies from LoTSS DR1*
Sasmal, T. K., Bera, S., Pal, S., & Mondal, S. (2020). In Journal of physics conference series (Vol. 1579, p. 012021)

2. *MRG: The Miscellaneous Radio Galaxies from the FIRST Survey*
Bera, S., Pal, S., Sasmal, T. K., Mondal, S., & Patra, D. (2020), In Journal of physics conference series (Vol. 1579, p. 012023)