Catalogue with visual morphological classifications of 32,616 radio objects associated with optical galaxies

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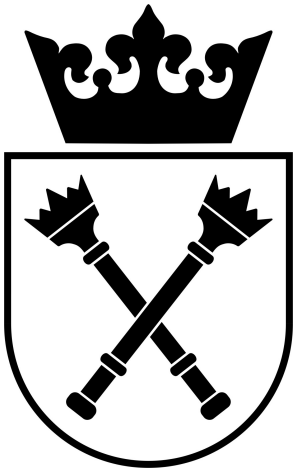

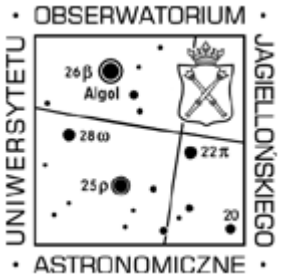

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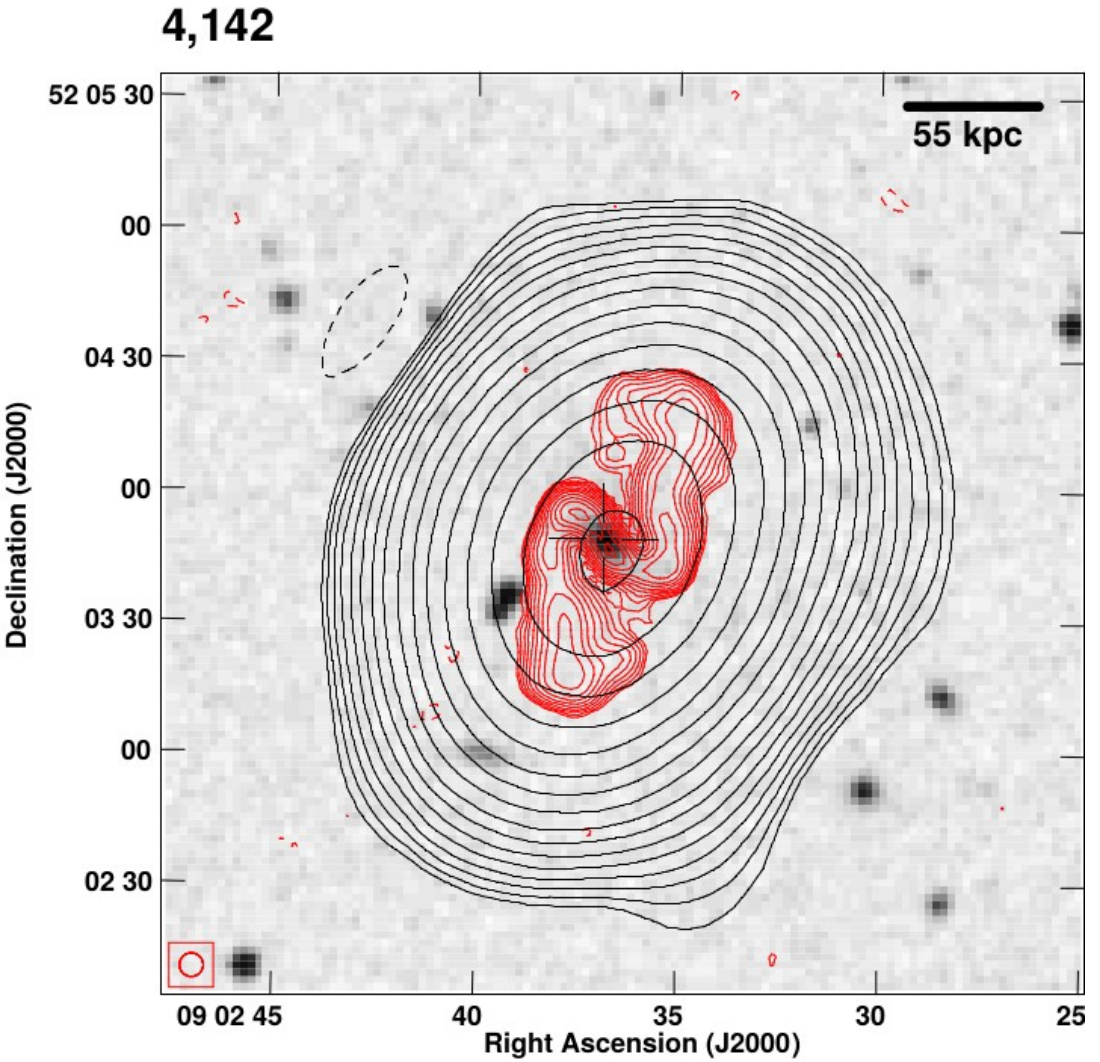


Existing similar catalogues of radio sources

1. **Lin et al. (2010)**:
→ Cross-matching SDSS DR6 with NVSS and FIRST
→ Total flux density at 1.4 GHz: $S > 3$ mJy
→ Redshift limit: $0.02 < z < 0.3$
→ Host galaxy more luminous than the characteristic magnitude M* in the galaxy luminosity function
→ Search radius (in NVSS): 3’
→ Catalogue contains ~10,500 objects, among which 1,040 have extended morphology

2. **Best & Heckman (2012)**:
→ Cross-matching SDSS DR7 with NVSS and FIRST
→ Total flux density at 1.4 GHz: $S > 5$ mJy
→ Division into star forming galaxies, high- and low-excitation galaxies ($z < 0.3$)
→ From 9,168 galaxies with $z < 0.3$: 2,187 LEGs, 216 HEGs
→ Catalogue contains 18,286 radio objects: ~15,000 AGNs and 3,000 SF galaxies

Existing similar catalogues of radio sources

3. **Van Velzen et al. (2015)**:

→ Catalogue of FR II radio sources
→ Based only on the FIRST catalogue
→ Automatic identification of double-lobed sources
→ Maximum size: 1', flux density limit ~12 mJy

Table 1. Cuts for a well-defined sample of FR II radio sources.

Cut	No. of sources left	Explanation
$d_{\max} = 1$ arcmin	115 889	Maximum angular separation of the lobes.
$S_\nu > 12$ mJy	59 192	Flux limit for a complete sample (applied to the sum of the integrated flux of the lobes).
$d_{\min} = 18$ arcsec	35 851	Minimum angular separation.
$f_{l/l} < 10$	30 021	Upper/lower limit on the ratio of the integrated flux of the lobes.
$F_i/F_p < 5$	24 973	Integrated flux over the core flux (applied to each lobe).

Radio Objects associated with Galaxies having Unresolved or Extended morphologies

- SDSS DR7 spectroscopically selected galaxies with good quality spectra from SDSS DR7: 662,531 galaxies
- FIRST (5” beam, 1 mJy completeness): 946,432 radio sources
- NVSS (45” beam, 2.5 mJy completeness): 1,773,483 radio sources

Visual inspection of maps for more than 600,000 objects!

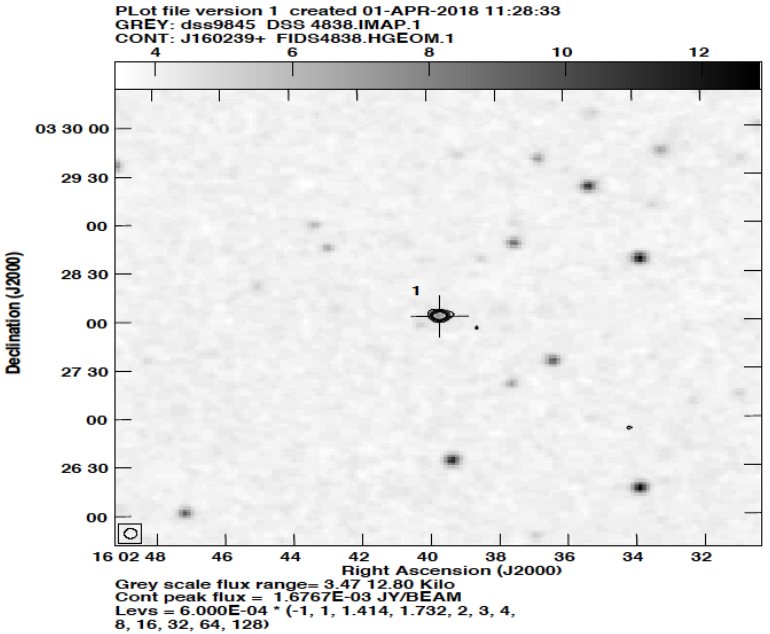
Selection procedure:

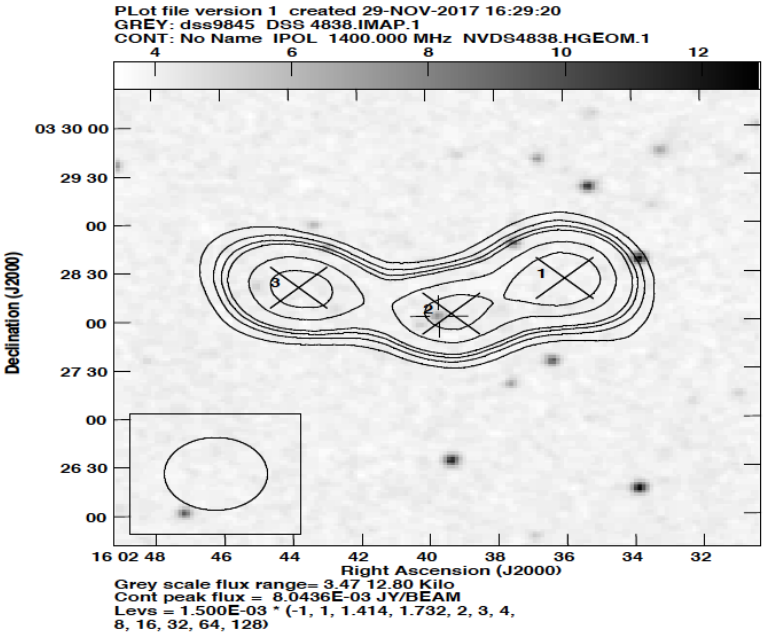
→ Matching position of SDSS galaxy with FIRST radio detection within 3”

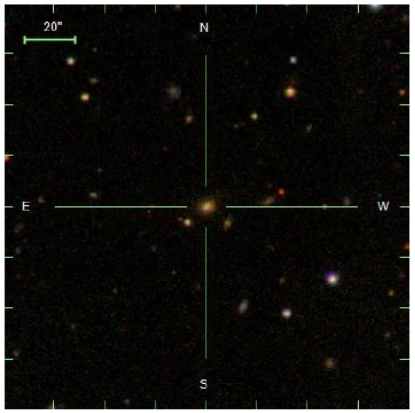
ROGUE I: A catalog of SDSS galaxies with FIRST cores → **32,616 objects**

→ Preparation of FIRST and NVSS radio maps overlaid on optical image
→ Visual identification and classification of radio structure and optical galaxy

ROGUE I catalogue - selection procedure



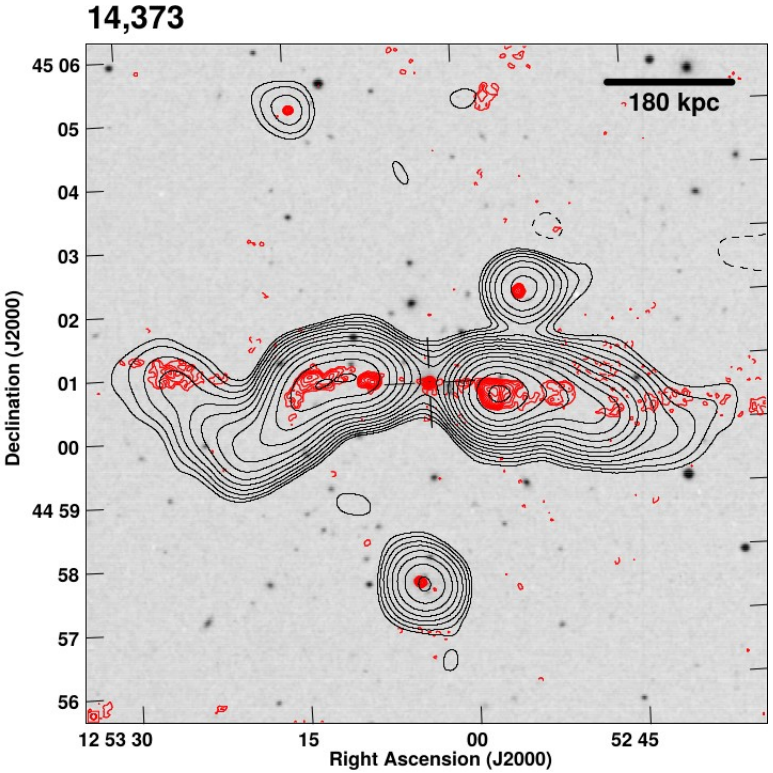




ROGUE I catalogue

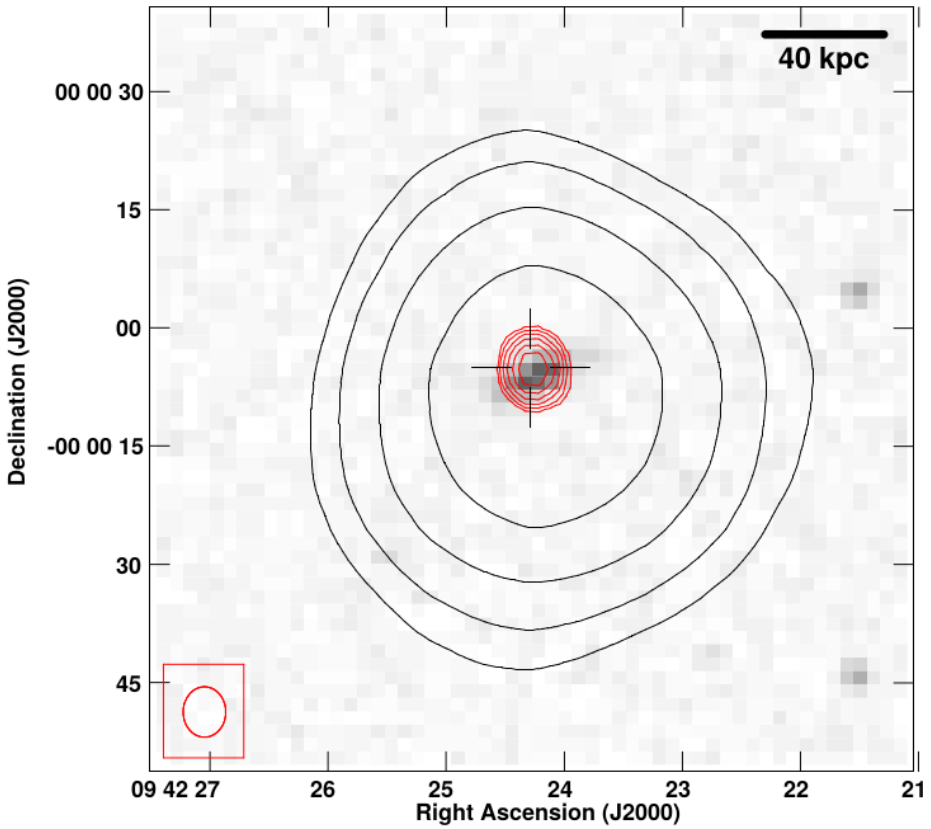
ROGUE I provides the **largest** sample of spectroscopically selected radio galaxies to date, covering ~30% of the entire sky:

1. spectroscopic redshift (z);
2. good quality optical spectrum from SDSS to study properties of host galaxy;
3. FIRST and/or NVSS fluxes of radio cores and extended radio structures;
4. sub-mJy flux level corresponding to 3 radio source detection provided by FIRST;
5. radio and optical morphological classifications of radio structures and optical host galaxies performed **visually**.

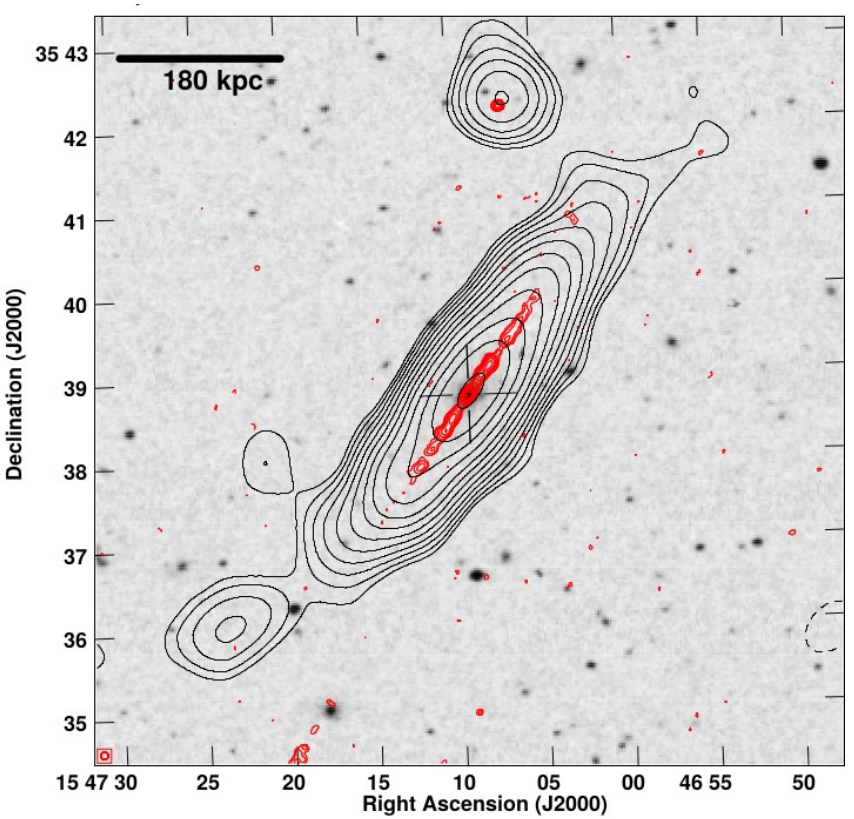


ROGUE I catalogue – morphological classification

The present study provides a catalogue of radio sources comprising:
→ **unresolved**, i.e. single detection identified with a radio core having compact morphology
→ **extended**, i.e. multiple detections identified with radio core and jets and lobes or single detection with elongated morphologies

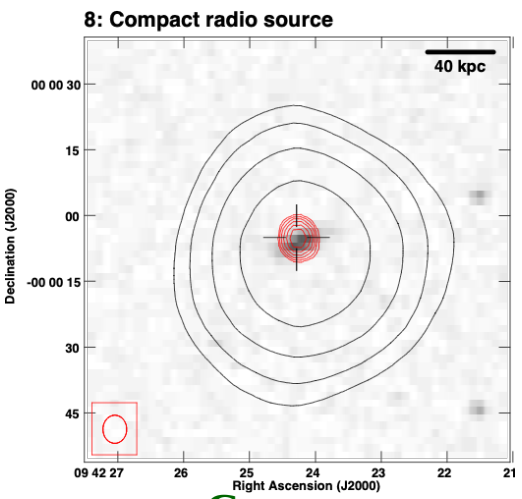


Unresolved, compact source

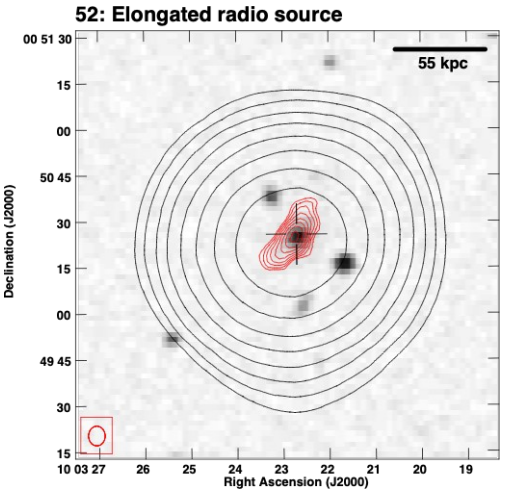


Extended, FR I type source

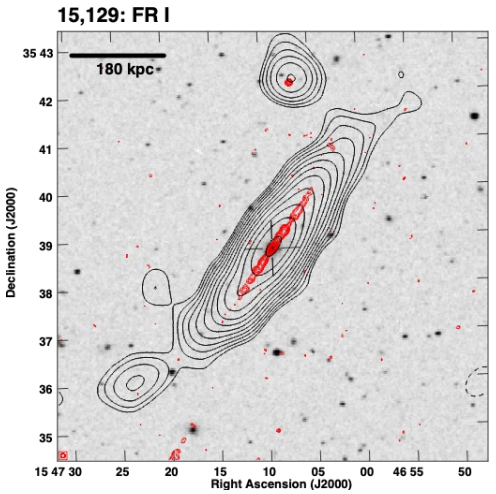
ROGUE I catalogue - morphological classification



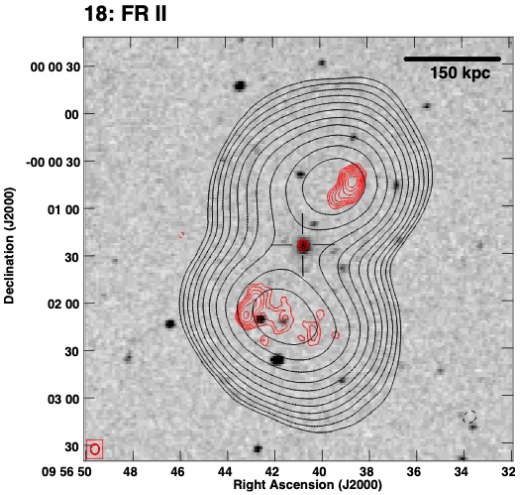
Compact



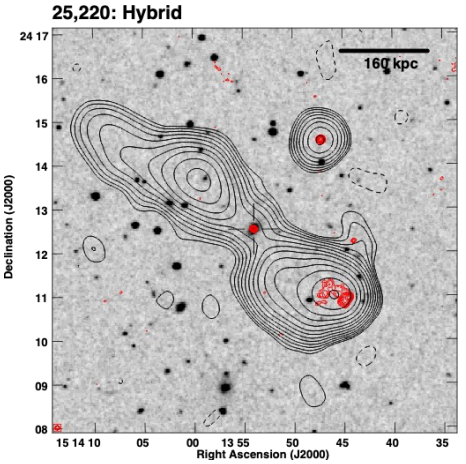
Elongated



FR I



FR II

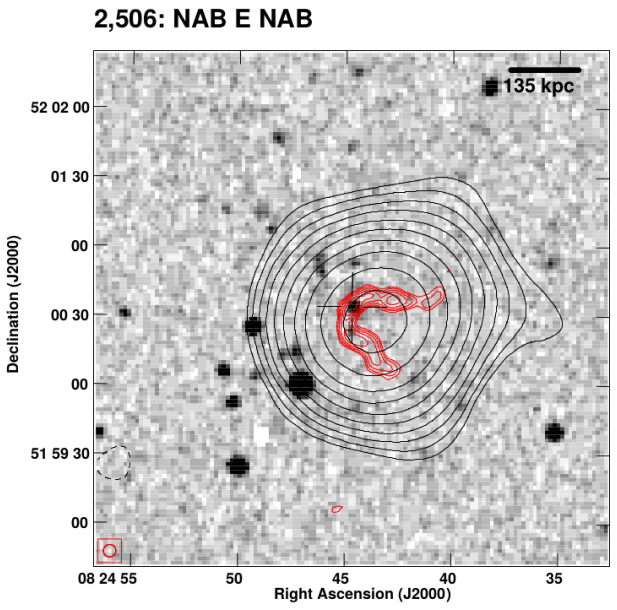


Hybrid

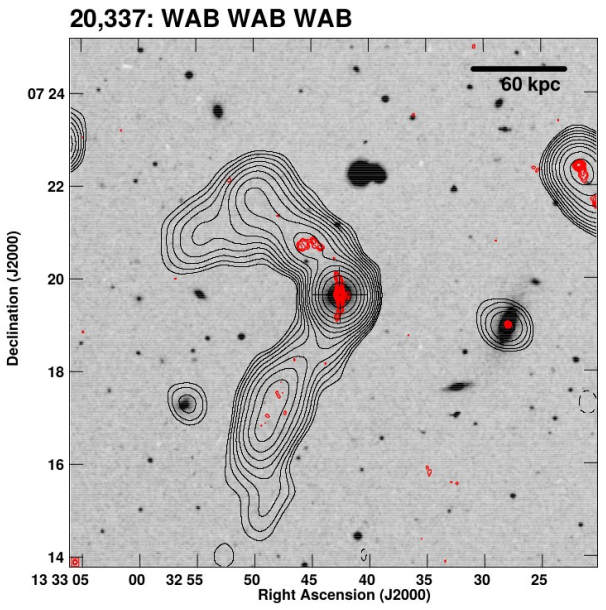
FIRST - red contours

NVSS - black contours

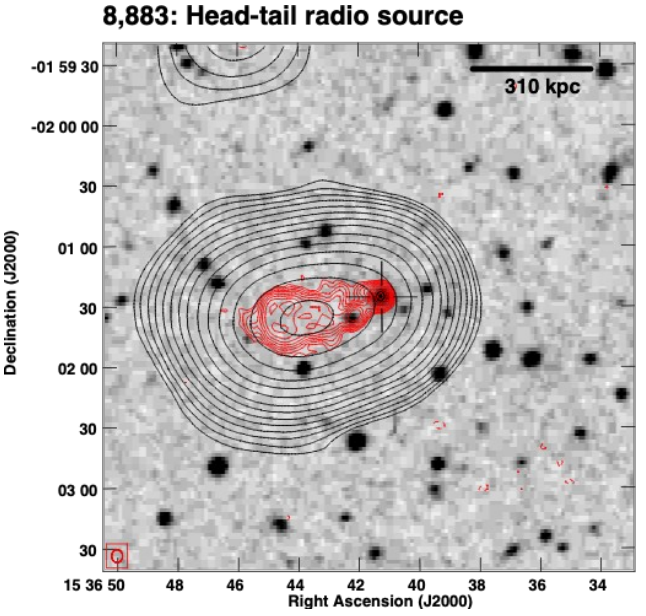
ROGUE I catalogue - morphological classification



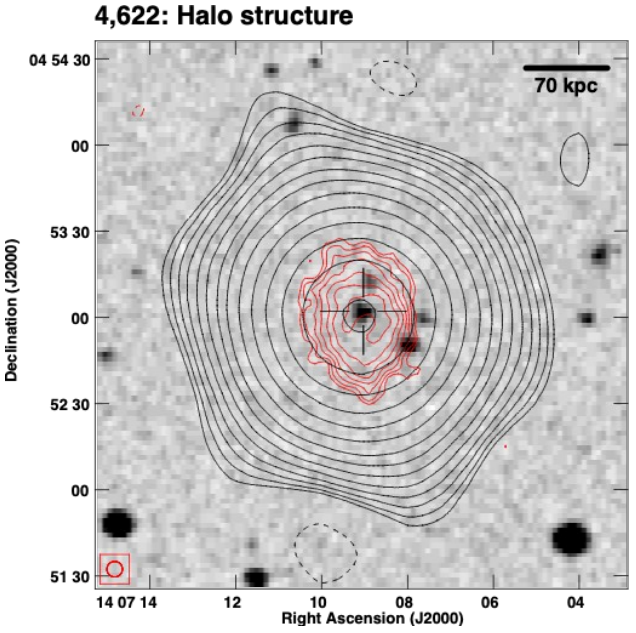
narrow-angle bent (NAB)



wide-angle bent (WAB)



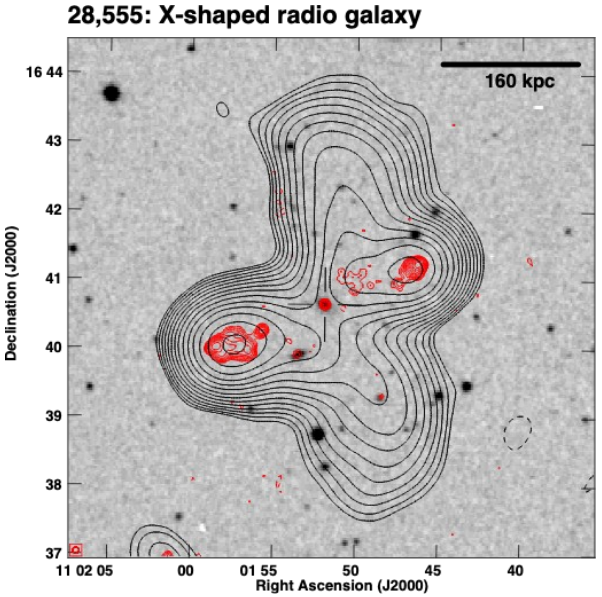
head-tail (HT)



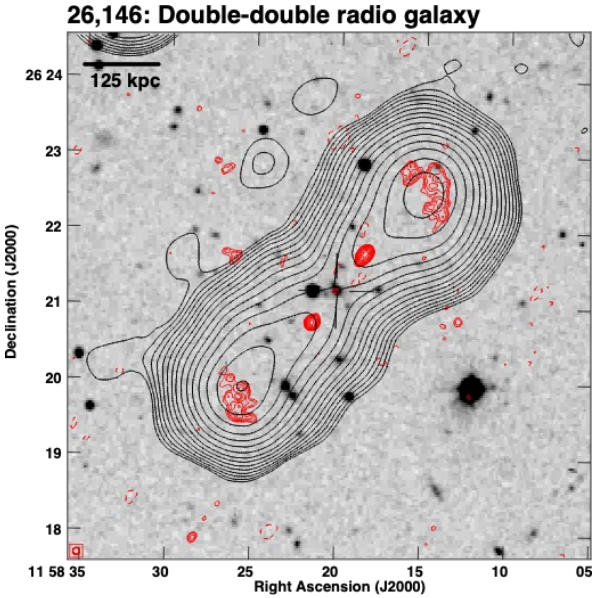
Halo

FIRST - red contours
NVSS - black contours

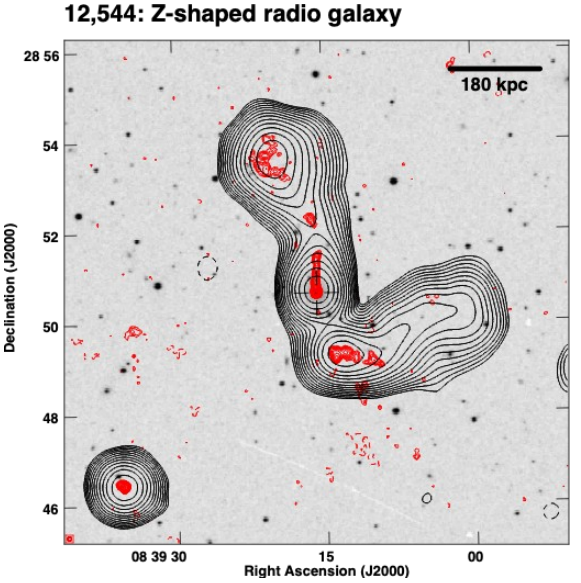
ROGUE I catalogue - morphological classification



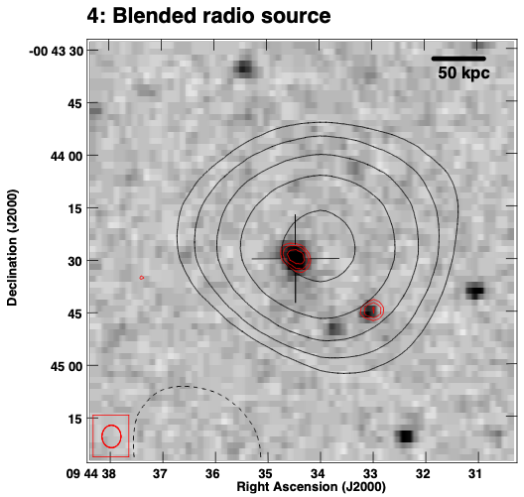
X-shaped



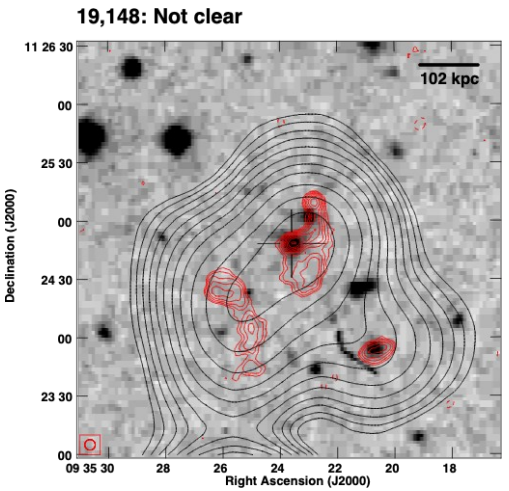
Double-double



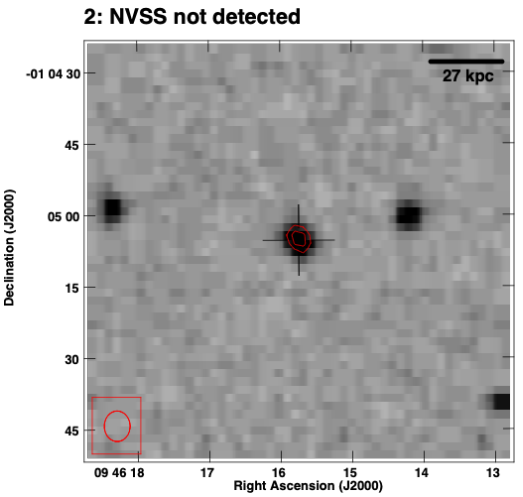
Z-shaped



Blended (NVSS)



Not clear

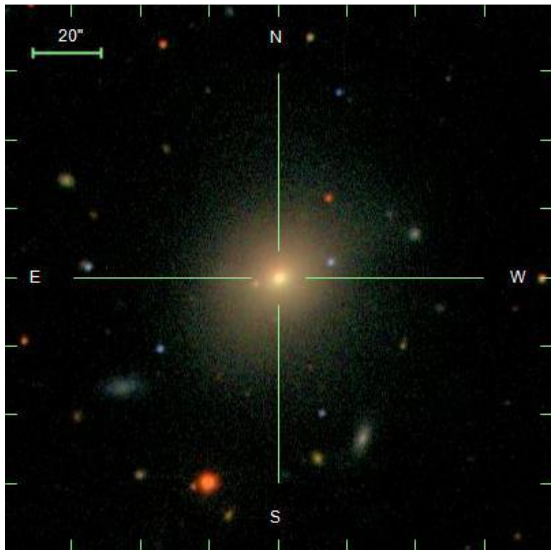


Not detected (NVSS)

FIRST - red contours NVSS - black contours

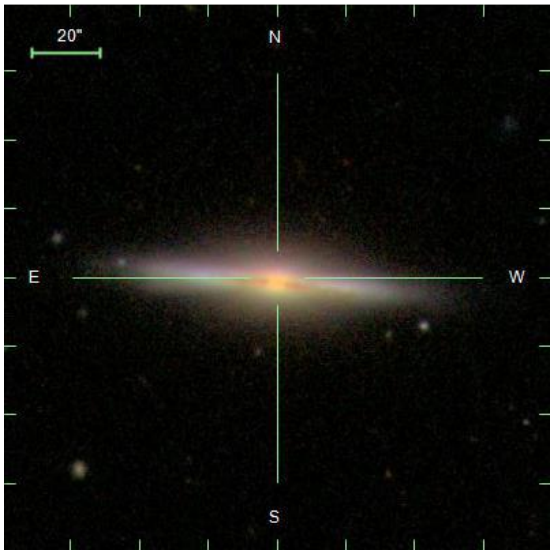
ROGUE I catalogue - morphological classification

173: E



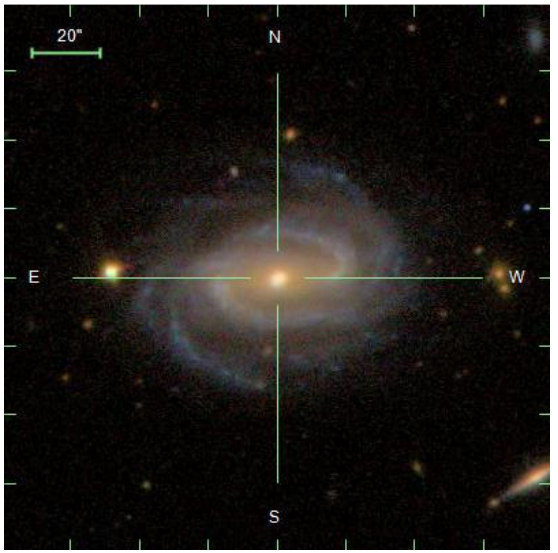
elliptical

13,314: L



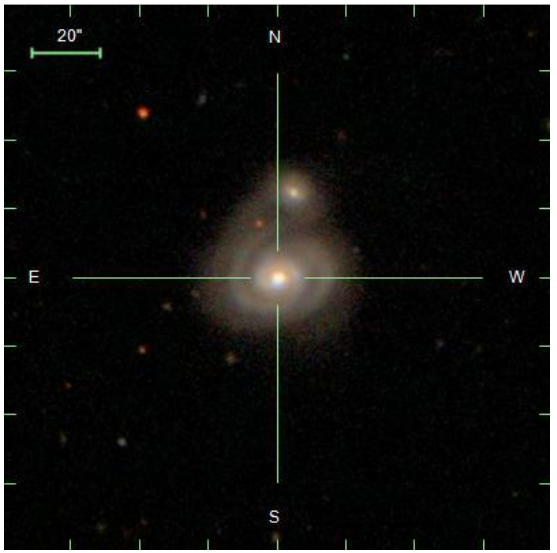
lenticular

29,176: S



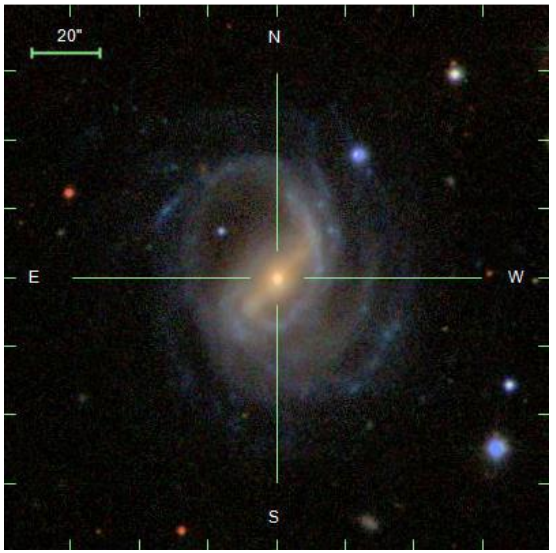
spiral

15,476: iS



interacting spiral

3,674: bS

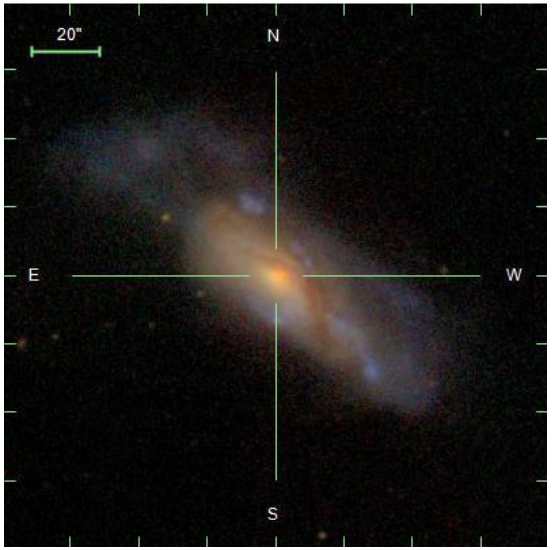


barred spiral

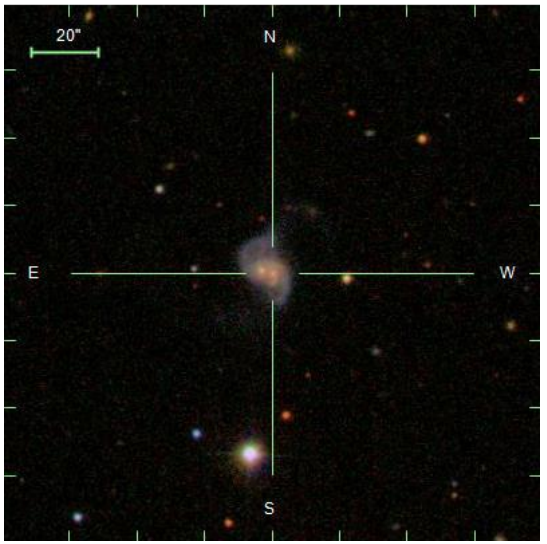
ROGUE I catalogue - morphological classification

distorted

10,663: D

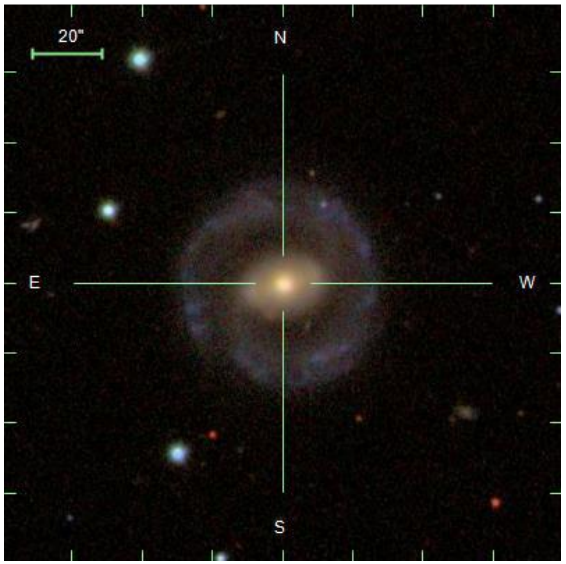


3,873: M



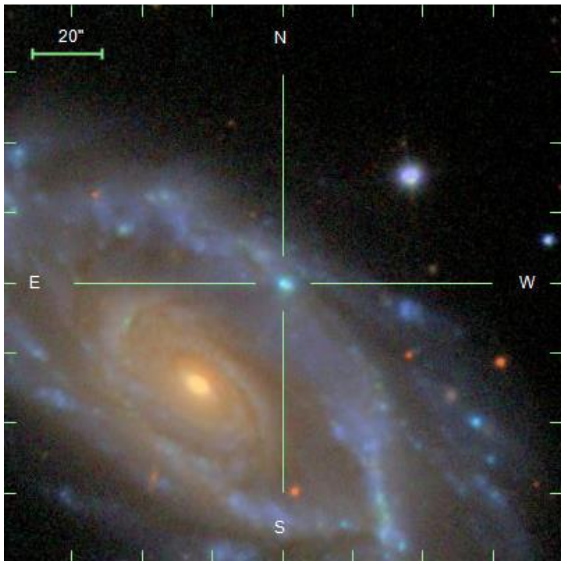
merger

24,874: R



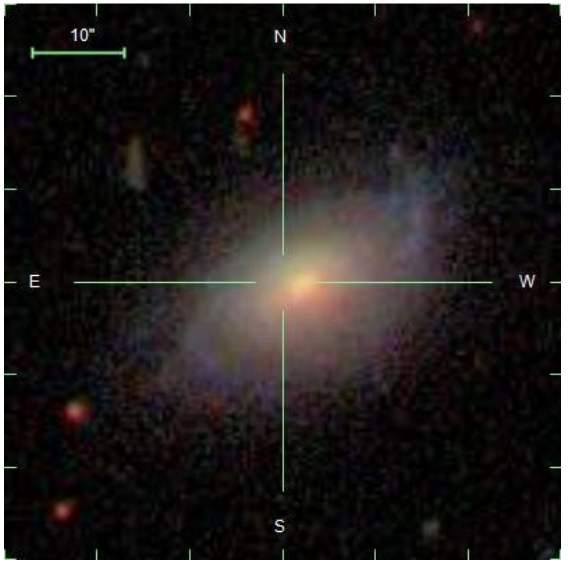
ring galaxy

28,750: SFR



star-forming region

2,024: O



off-center

ROGUE I catalogue: FR I / FR II separation?

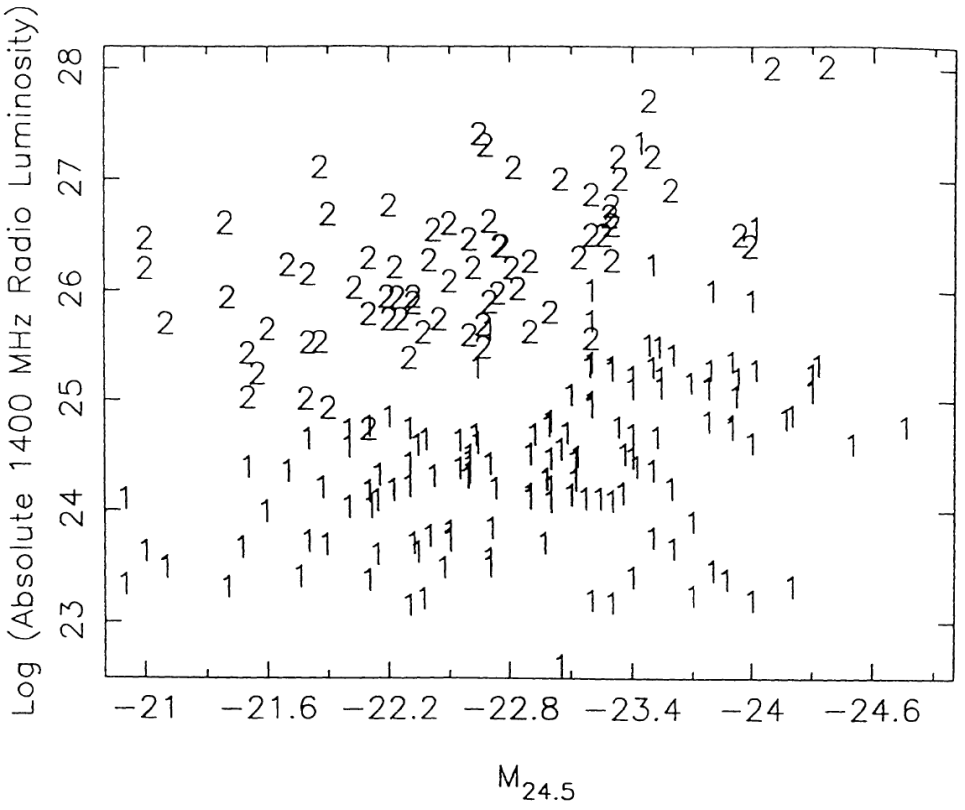
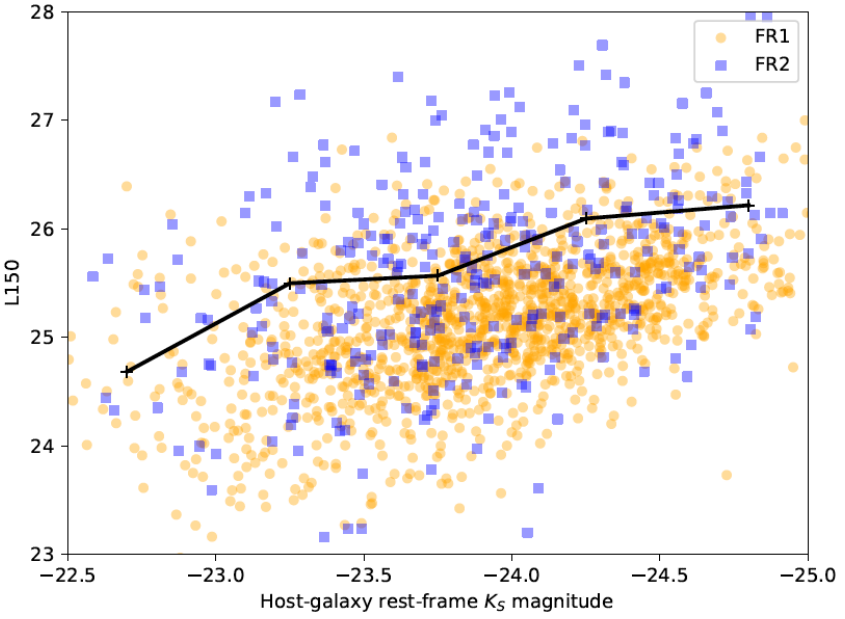
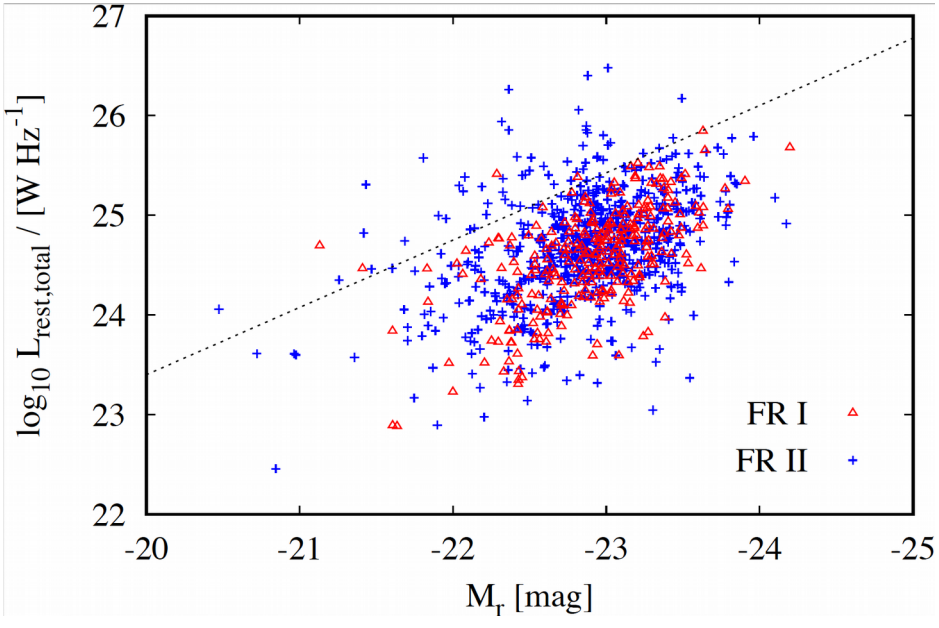


FIGURE I FR I's and II's versus radio and R-band optical luminosity. Radio units are W Hz^{-1}. The 1's and 2's refer to FR I's and FR II's, respectively.

Owen & Ledlow (1994)

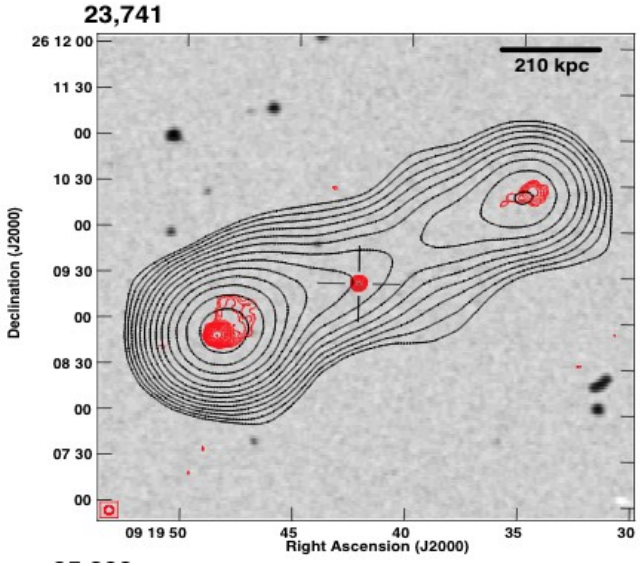


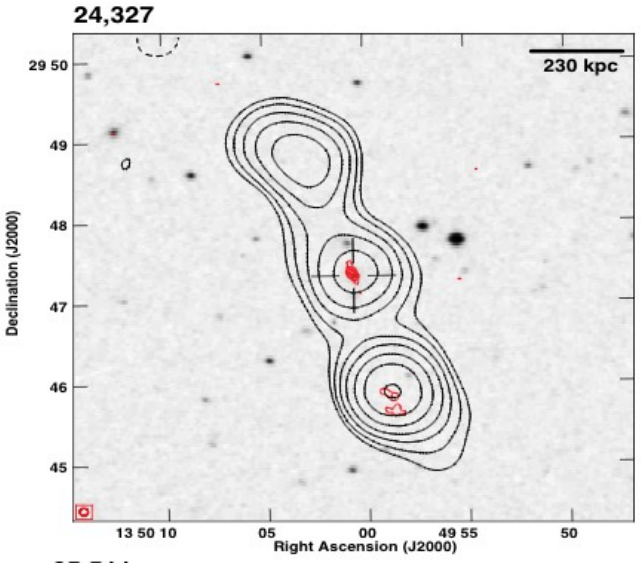
Mingo et.al (2019)

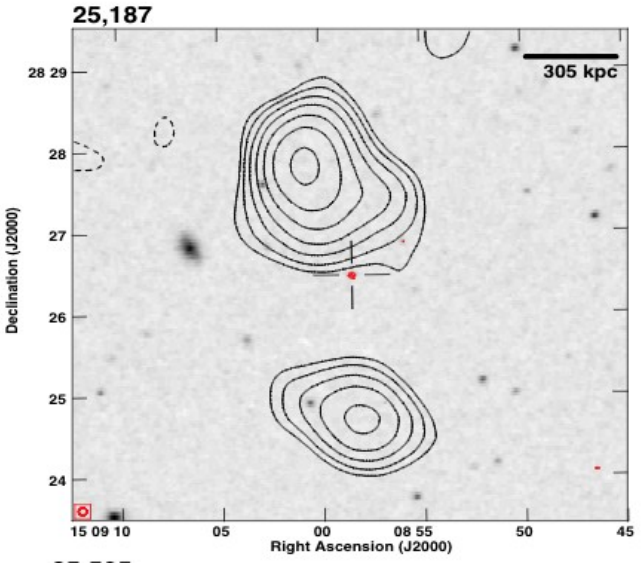


ROGUE I

ROGUE I catalogue: new discoveries

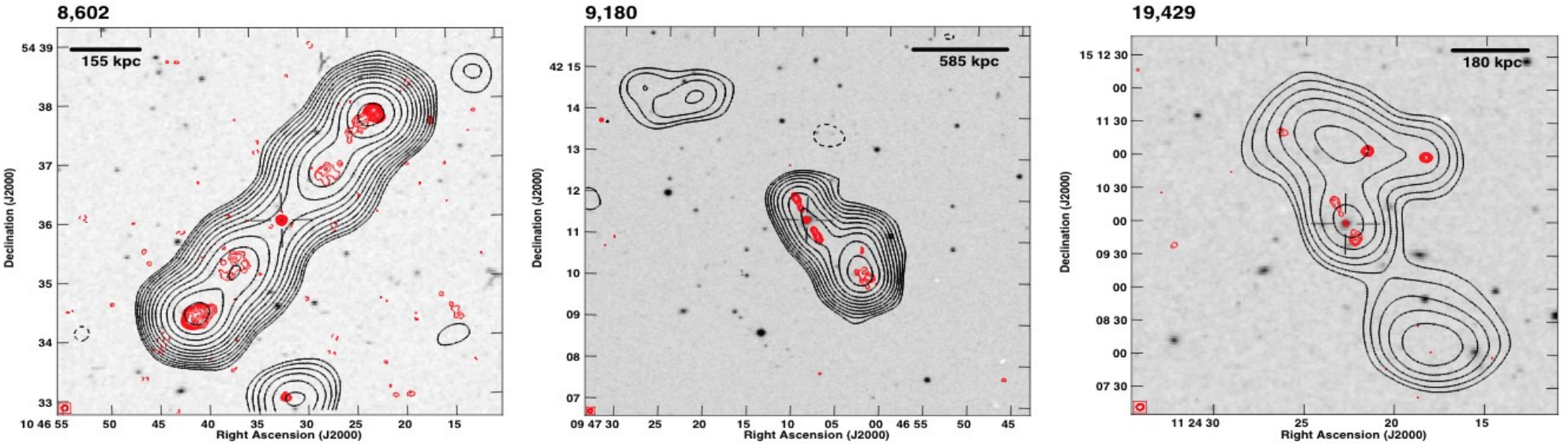






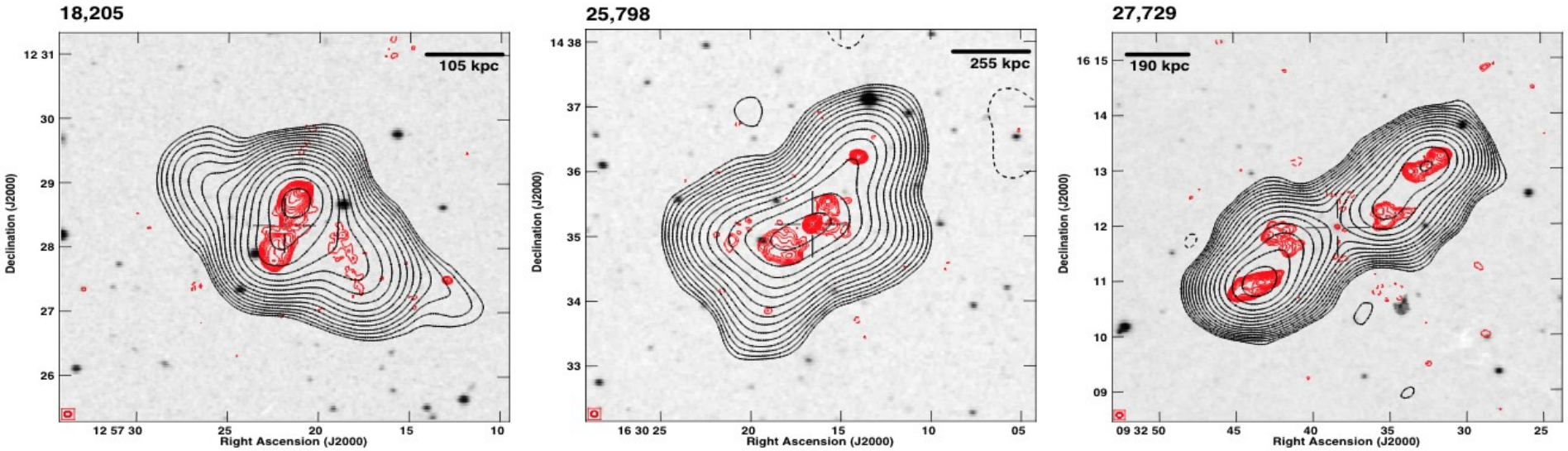
Identification of 83 giant and possible giant radio sources (sizes > 700kpc) from which 56 are newly discovered

ROGUE I catalogue: new discoveries



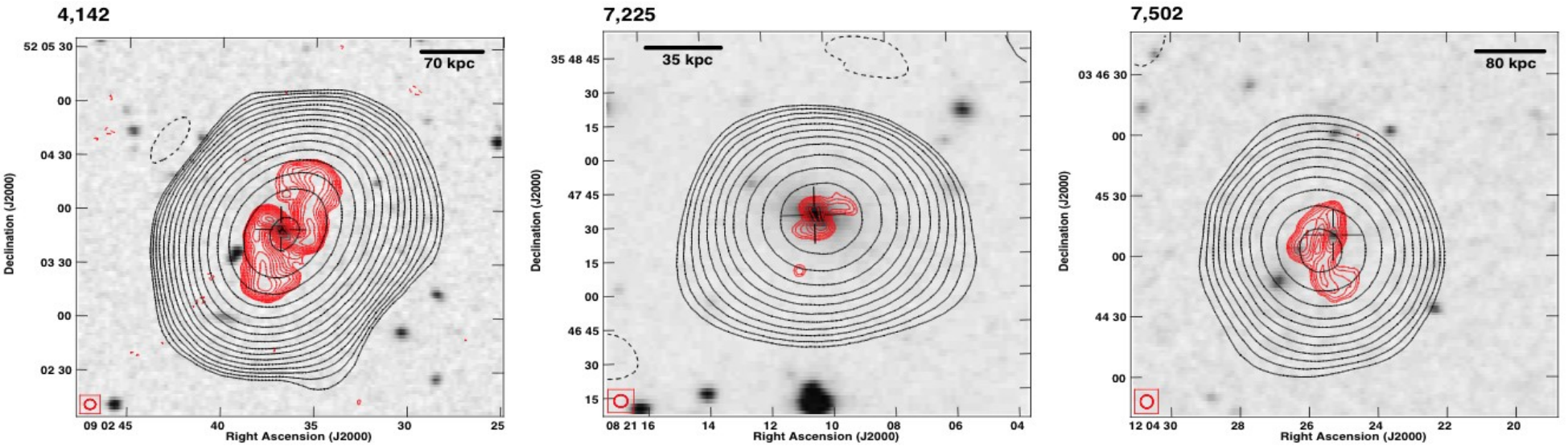
Double-double radio sources: 11

ROGUE I catalogue: new discoveries



X-shaped radio sources: 5

ROGUE I catalogue: new discoveries



Z-shaped radio sources: 25

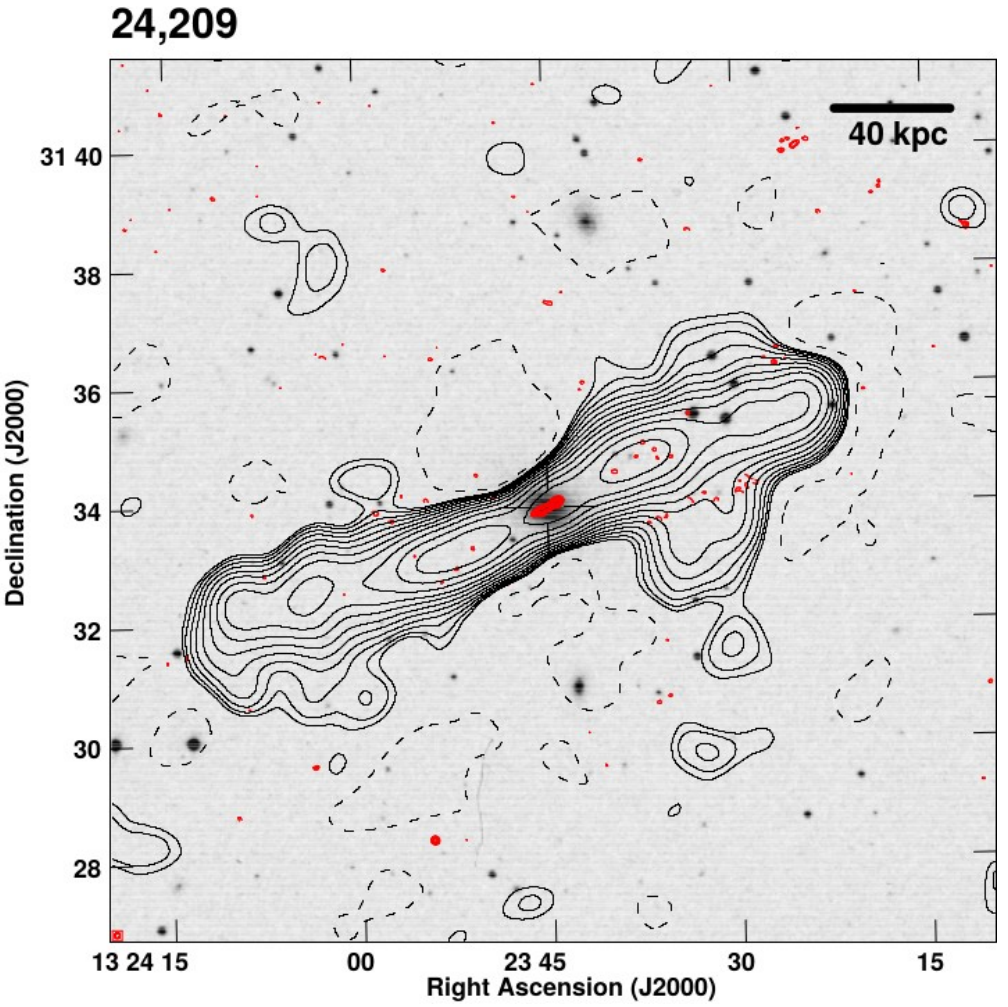
Summary

The main results of our visual classifications are as follows:

→ Single-detection radio sources constitute ~92%, while extended radio sources ~8% in ROGUE I.

→ Among multiple-detection sources, ~73% are FR I, II, and hybrid radio sources, bent (WAB, NAB, and head-tail) sources form ~23%, while sources with intermittent or reoriented jet activity (double-double, X-shaped, Z-shaped sources) are ~3% of of entire extended sample.

→ Most of FR IIs in ROGUE I have low radio luminosities comparable to luminosities of FR Is.



Summary

→ Our selection procedure allowed to discover or reclassify a significant number of objects as giant, double–double, X–shaped, and Z–shaped radio sources. We identify 83 giant radio sources (56 new and 27 from the sample of Kuźmicz et al. 2018) among ~2,000 extended radio sources in ROGUE I.

→ The optical host galaxies in ROGUE I have elliptical (~64%), spiral (~16%), distorted (~12%), and lenticular (~7%) morphologies; the remaining ~1% are ring galaxies and galaxy mergers.

Beside its substantial scientific value for the systematic and compound studies of radio sources, the presented sample can serve as a database for training automatic methods of identification and classification of optical galaxies and radio sources.

Further Directions

Optical galaxies without radio match are not included in ROGUE I. The remaining 629,815 galaxies from the SDSS sample might give rise to an extended radio emission without core, which will be searched for within the second catalogue, ROGUE II: A catalog of SDSS radio galaxies without FIRST cores.

Catalogue website: http://www.rogue.oa.uj.edu.pl/

Acknowledgments

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→ Van Velzen et al. 2015, MNRAS, 446, 2985