Catalogue with visual morphological classifications of 32,616 radio objects with galactic hosts

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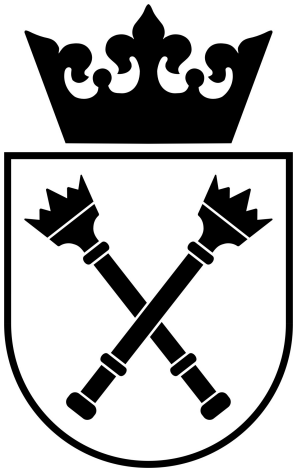
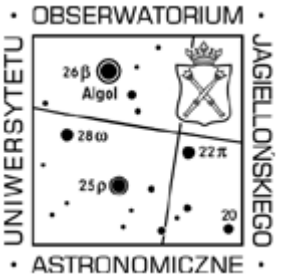




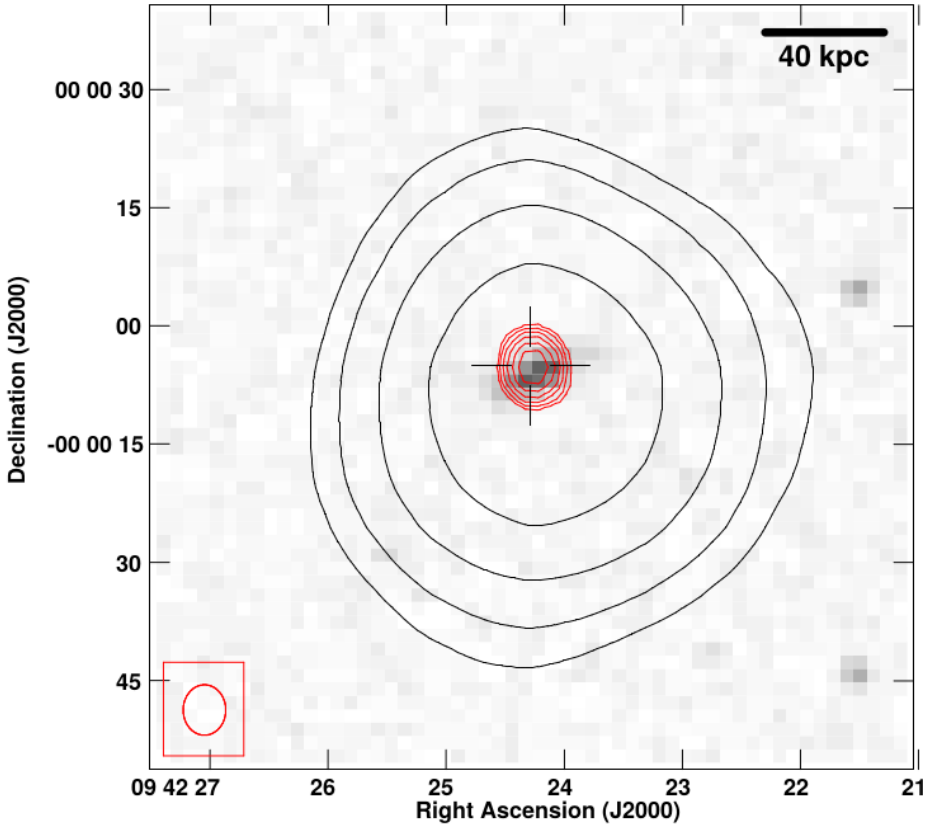
This support is being provided by the Development in Africa with Radio Astronomy (DARA) project funded by the UK's Newton Fund.

Abstract

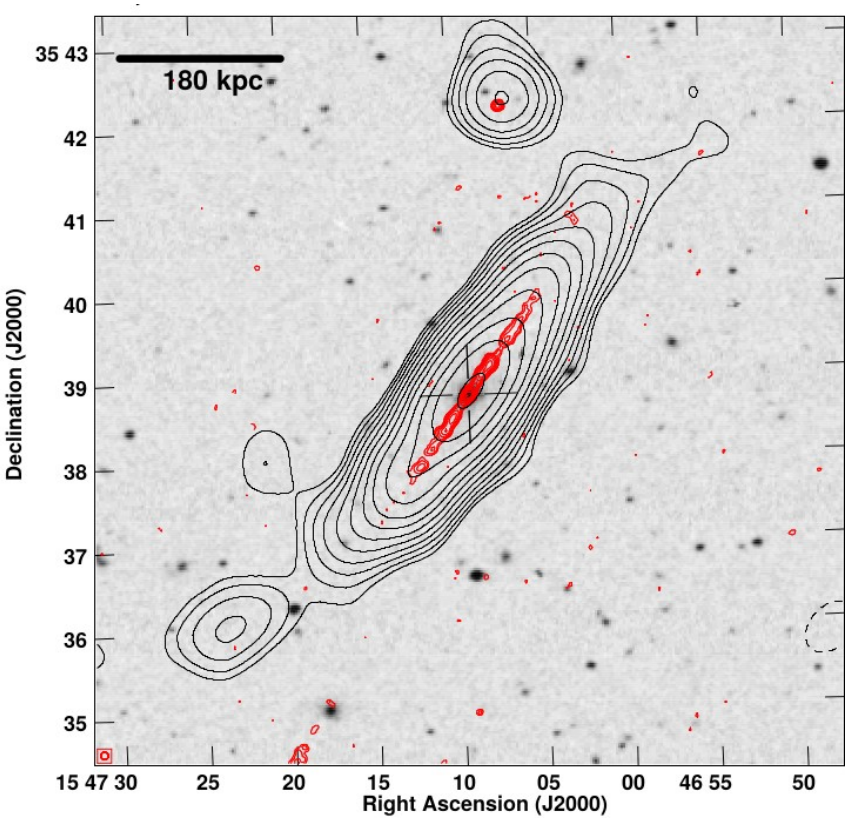
We present the catalogue of Radio Objects associated with Galaxies having Unresolved or Extended morphologies (ROGUE I), which is the **largest handmade** catalogue of visually classified radio objects and optical galaxies. It was created by cross-matching galaxies from the Sloan Digital Sky Survey Data Release 7 (SDSS DR 7; Abazajian et al. 2009) as well as radio sources from the First Images of Radio Sky at Twenty Centimetre (FIRST; Becker et al. 1995) and the National Radio Astronomical Observatory VLA Sky Survey (NVSS; Condon et al. 1998) catalogues. ROGUE I contains 32,616 galaxies with a FIRST core within 3 arcsec of the optical position. All the objects possess good quality optical spectra with the signal-to-noise ratio >10 and spectroscopic redshifts up to 0.6. The radio morphology classification was performed by visual examination of the FIRST and NVSS contour maps overlaid on a Digitized Sky Survey (DSS) image, while for the classification of an optical morphology the 120 arcsec snapshots from the SDSS database were used.

Introduction

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

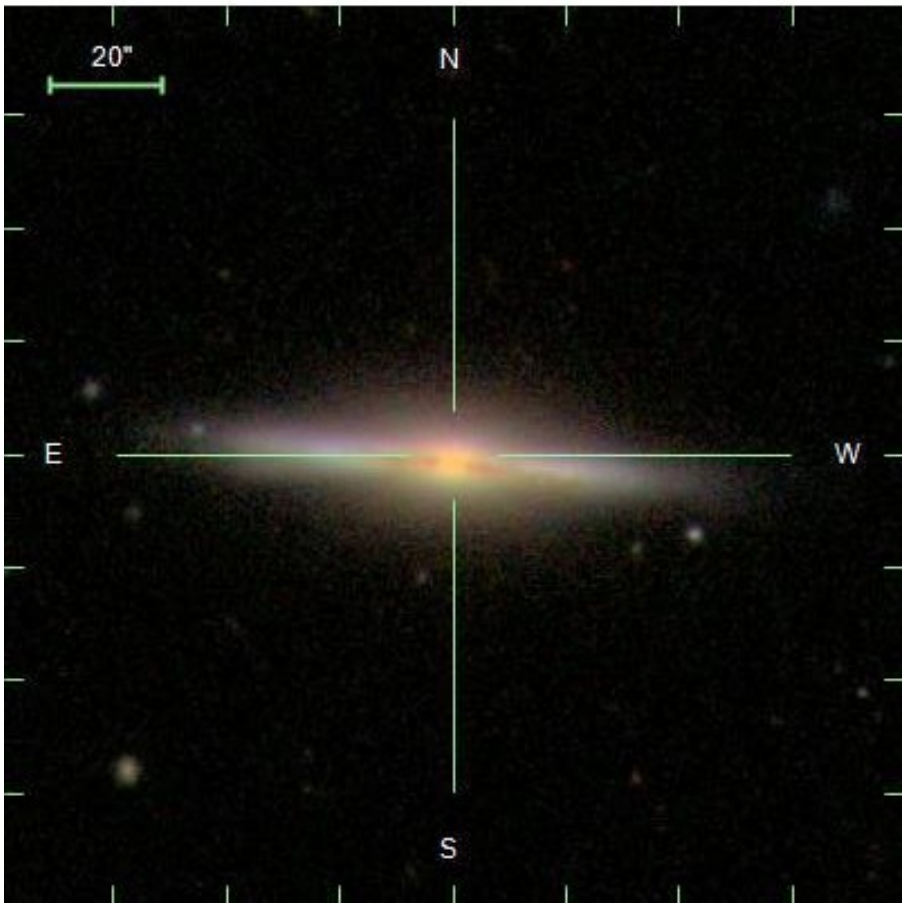
ROGUE I provides the **largest** sample of spectroscopically selected radio galaxies to date, covering ~30% of the entire sky. It contains sources with:

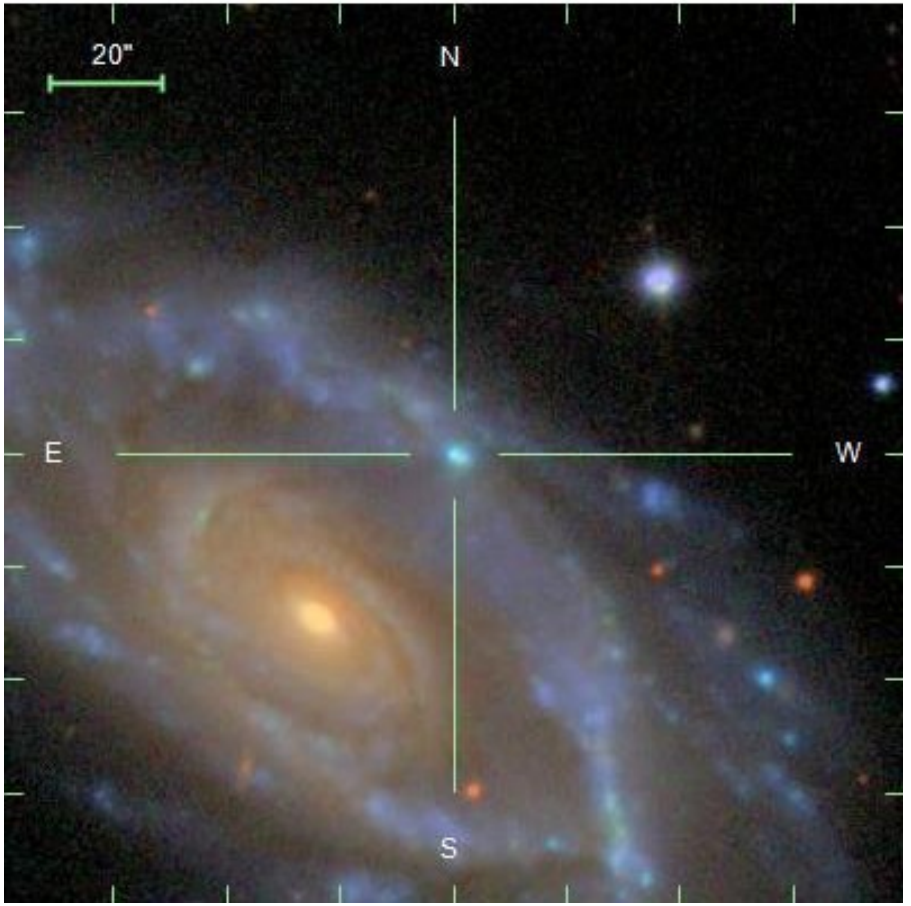
1. spectroscopic redshift (z);
2. good quality optical spectrum from SDSS to study properties of host galaxy;
3. FIRST and/or NVSS fluxes of radio cores and extended radio structures;
4. sub-mJy flux level corresponding to 3σ radio source detection provided by FIRST;
5. radio and optical morphological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

Methodology

First, we generated a list of objects as a result of cross-matching the optical positions of SDSS galaxies with the radio positions of FIRST sources, allowing for an error of 3 arcsec. Subsequently, we prepared the SDSS images as well as the DSS - FIRST/NVSS overlay maps with angular sizes corresponding to 1 Mpc linear size at the source distance, centered at the host galaxy position. This allowed us to perform the morphological classification of all objects from our sample including large sources such as the giant radio sources. The classical (Fanaroff et al. 1974) classification scheme was used to classify extended sources, where sources brighter at the edges are classified as FR II and sources with the brightest part located close to the center are classified as FR I. Hybrid sources (Gopal-Krishna et al., 2003) with mixed FR I/FR II morphology were also separated. Moreover, sources with complex morphology, such as: Z-shaped (lobes forming Z or S shape structure), X-shaped (two inclined pairs of lobes), double-double (two collinear pairs of lobes), WAB (bent structure, angle between lobes >90°) and NAB (bent structure, angle between lobes <90°), head-tail (bright core connected to one-sided tail-like emission), halo (diffuse emission around a core), and star-forming region sources.

The optical host galaxies were classified using the standard Hubble classification scheme. Moreover, we included into our scheme additional morphological classes like distorted, ring, and merging galaxies as well as a describtion of details of the morphological types such as presence of bar or signs of interactions. Also objects where the SDSS spectrum concerns a star-forming region or a part outside the nucleus of a galaxy were distinguished.





Results

The main results of our visual classifications are as follows:

→ Single-detection and multiple one-sided radio sources constitute ~92%, while clearly extended radio sources ~8% in ROGUE I.

→ Among clearly extended sources, ~73% are FR I, FR 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 entire extended sample.

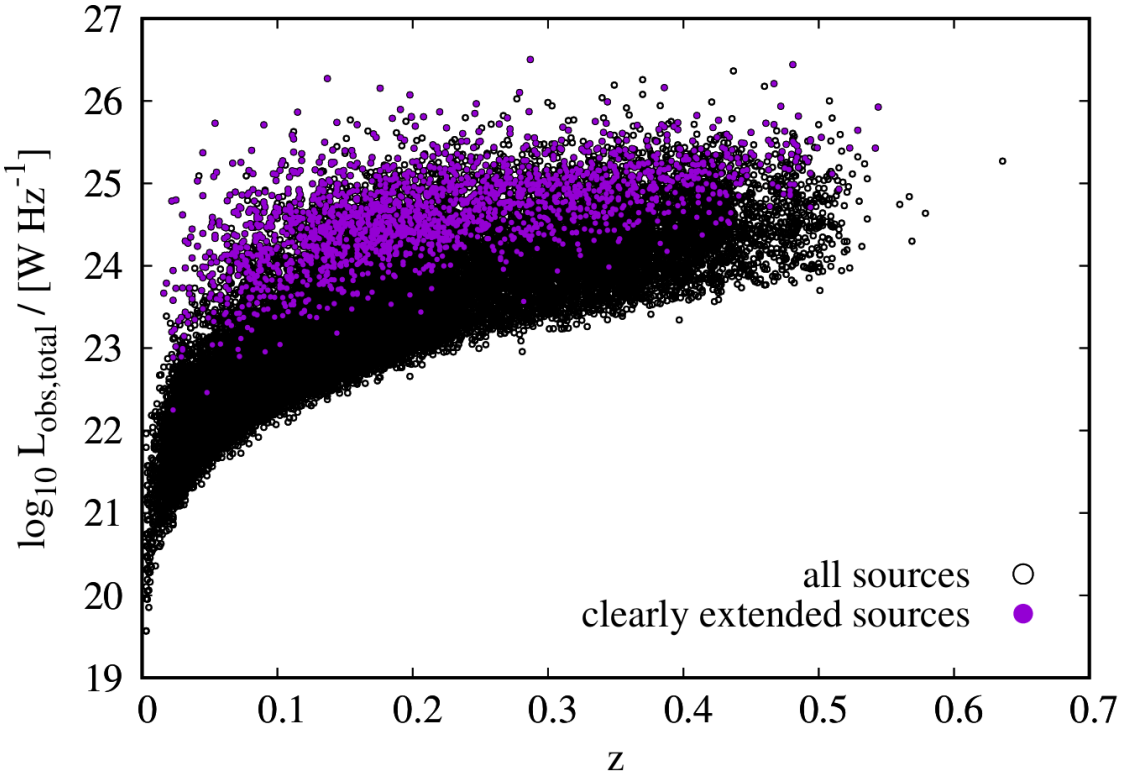
→ We have classified much bigger samples of FR Is and FR IIs (427 and 884, respectively, including both secure and possible assignments), than presented in Capetti et al., 2017 due to higher *z* range and lower radio detection thresholds in our study.

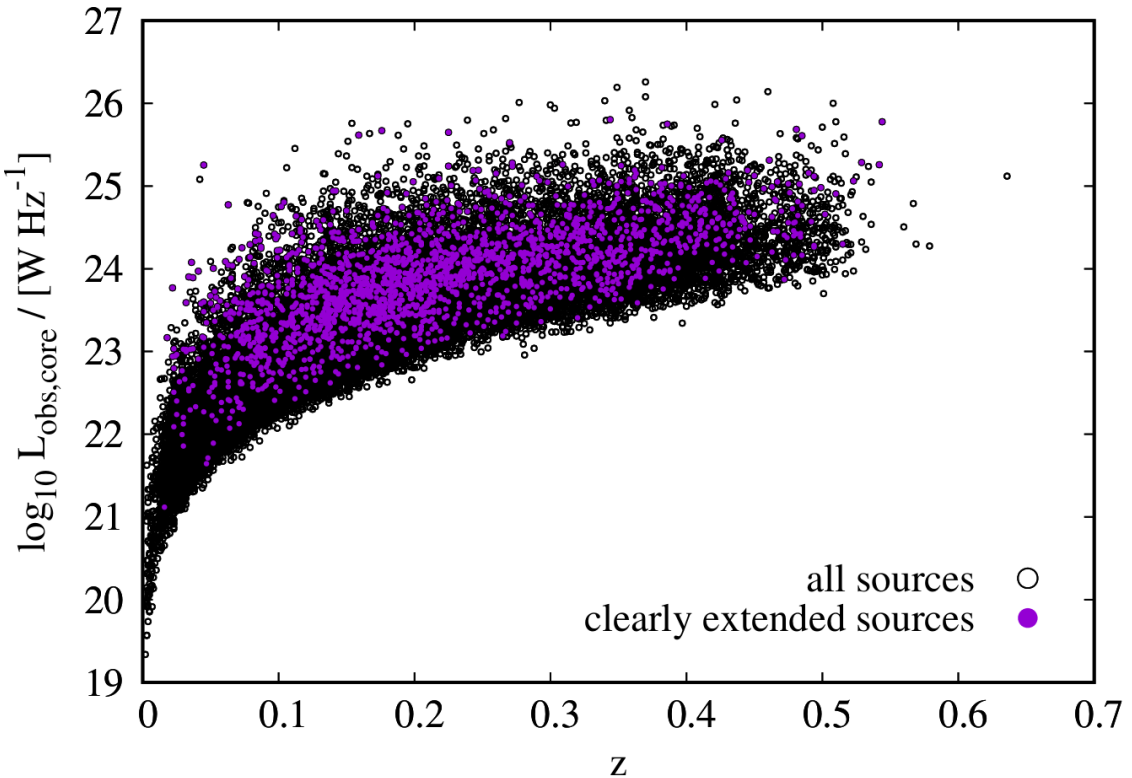
→ Most of FR IIs in ROGUE I have low radio luminosities comparable to luminosities of FR Is.

→ 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 82 giant radio sources (56 new and 26 from the sample of Kuzmicz et al. 2018) among 2,059 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.



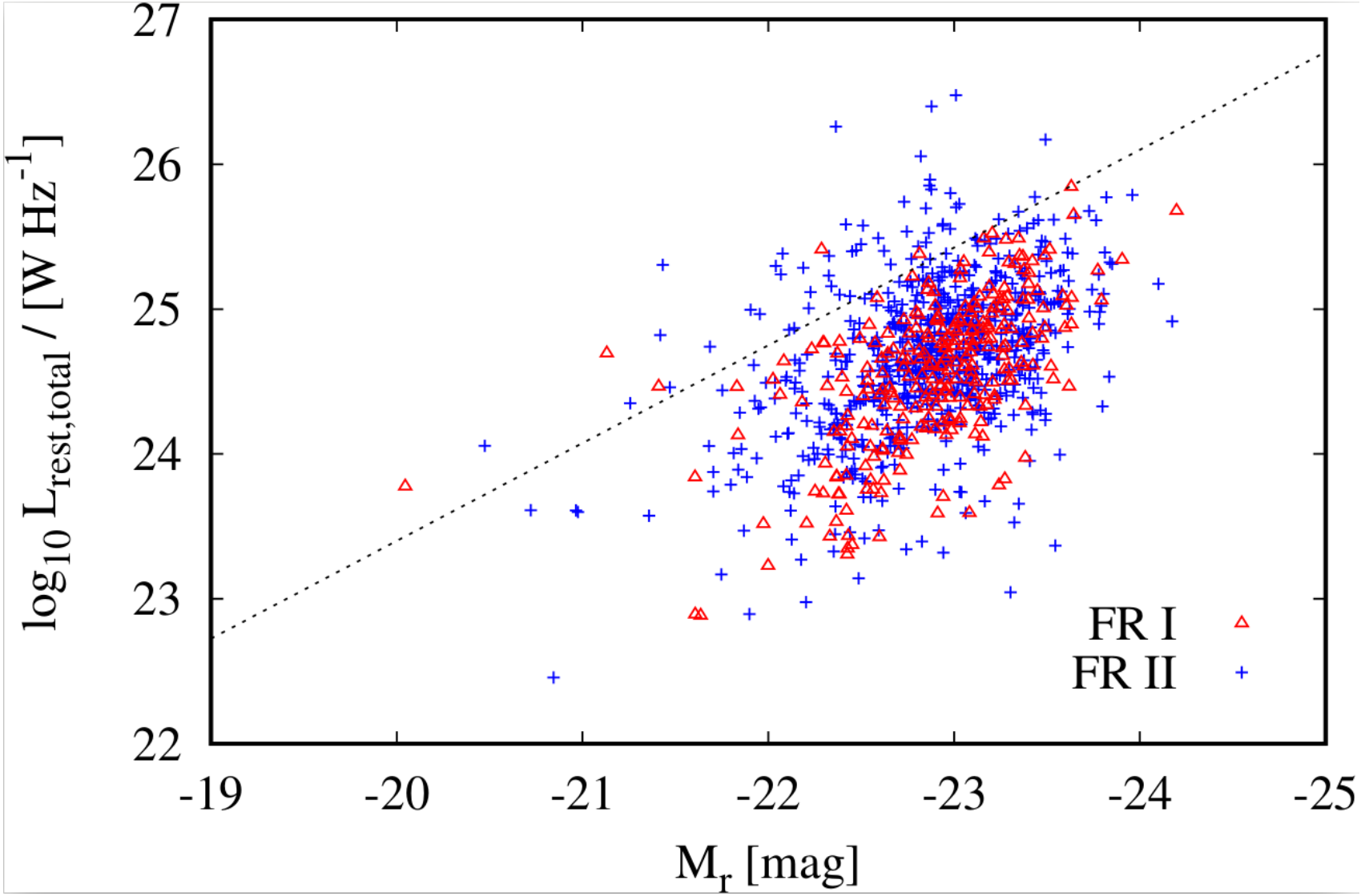


→ The distribution of $L_{obs,total}$ shows the detection threshold of FIRST. Clearly extended radio sources are shifted with respect to the whole population of the ROGUE I sources.

→ An offset of the clearly extended sources in relation to all sources in the core radio luminosity distribution is due to the fact that at low luminosities the lobes of extended radio structures cannot be detected by FIRST as the low-luminosity extended emission is resolved out due to lack of short baselines in snap-shot FIRST survey and only the core is detected.

Ledlow-Owen diagram

most of FR IIs are found below the original division line in the Ledlow–Owen diagram



→ 269 FR Is
→ 723 FR IIs

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 galaxies without FIRST cores.

Acknowledgments

DKW acknowledges the support of Polish National Science Centre (NCN) grant via 2016/21/B/ST9/01620. AG acknowledges the full support of NCN via 2018/29/B/ST9/02298. NZ work is supported by the NCN through the grant DEC-2014/15/N/ST9/05171.

References

→ Abazajian et al. 2009, ApJS, 182, 543
→ Becker et al. 1995, ApJ, 450, 559
→ Capetti et al., 2017a, A&A, 598, A49
→ Capetti et al., 2017b, A&A, 601, A81
→ Condon et al. 1998, AJ, 115, 1693
→ Fanaroff et al. 1974, MNRAS, 167, 31
→ Gopal-Krishna et al. 2003, A&A, 363, 507
→ Kuzmicz et al. 2018, ApJS, 238, 3
→ Ledlow & Owen, 1996, AJ, 112, 9