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Large sample of DDRGs from LoFAR surveys and their spectral nature

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One of the most striking evidence of recurrent activity in AGN is the existence of double-double radio galaxies (DDRGs). These consist of two pairs of radio lobes, usually along a similar jet axis. DDRGs tend to have FR-II morphology, with the outer pairs of lobes which are from an earlier cycle of activity being more diffuse and extended while the more recent pairs of lobes display hotspots. If the time scale of the restarting is large or if the large-scale environment is quite inhomogeneous then we also find the offset in the two pairs of lobes with respect to each other. DDRGs allow us to constrain the duty cycle of the AGN activity, where the source morphology and the information from the radio spectra can help us to reconstruct the history of the episodic activity. The existence of these sources poses several interesting questions related to the triggering and fueling mechanism of the central black hole, the time cycle of AGN activity, the evolution of radio galaxies and feedback processes from AGN. In order to understand the growth and evolution of radio galaxies, studies of remnant and restarted radio galaxies (e.g. DDRGs) are of vital importance, where low-frequency telescopes like LOFAR are playing a crucial role in identifying relatively elusive populations. Surveys with LOFAR provide excellent sensitivity to diffuse and spectrally steep plasma, which is prevalent in both remnant and restarted radio sources.

By 2016, only about 300 giant radio sources (end-to-end radio size > 0.7 Mpc) were known and were thought to be very rare. However, today, the total tally is about 3300 sources of which nearly 2500 were discovered using LOFAR surveys at 150 MHz. In contrast, as per the last compilation of DDRGs in 2017, only about 70 such sources were known in the literature and that number has not drastically increased as expected. This is mainly due to a lack of dedicated systematic searches through the LOFAR surveys. In order to advance the above-mentioned studies, we need to compile a statistically large sample of DDRGs and study with other phases of radio galaxies like the remnant. Identification of DDRGs mainly depends on radio morphology and automating that task has been proven to be difficult, although significant development is underway in employing techniques of machine learning for it. Hence, currently, the most reliable way is to carry out a manual visual inspection (although very tedious). However, it is very difficult to cover ~5700 sq deg of LOTSS DR2 sky manually. It is interesting to note that a significant

fraction of the known DDRGs are giant sizes (>0.7 Mpc). Therefore, in order to optimise our search for DDRGs, we use the known giant radio sources list from LOTSS DR2 of nearly 2500 sources to look for the signature of double-double radio morphology. As a result, we were able to reliably identify nearly 50 new DDRGs. A significant fraction of these newly identified DDRGs is undetected in other high-frequency surveys like NVSS, highlighting the steep spectral nature of the sources and the importance of LOTSS surveys. Interestingly, we also, found a radio source with three episodes of jet activity (triple-double radio galaxy or TDRG), making it only the fourth such known so far.

Based on our own compilation of DDRGs from literature to date, we found nearly 60 DDRGs in LOTSS DR2 sky coverage. Hence, for the first time, we are able to characterise the low-frequency radio properties of a large sample (~100) of DDRGs. Using our newly identified DDRGs and the DDRGs from literature covered in LOTSS DR2 sky area, we have made a sub-sample of sources to study their radio spectral properties. For this, in addition to the LOTSS DR2 data, we have used ancillary radio data from higher frequency surveys like Apertif-WSRT, NVSS, and FIRST and thereby probing the spectral nature over a wide range of frequencies. Hence, for the first time using relatively a large sample, we were able to show a clear and systematic difference in the spectral index in the inner and outer lobes of DDRGs. This allows us to constrain the duty of the cycle of these objects. The unprecedented sensitivities achieved by the LOTSS survey at 150 MHz, unveiled many peculiar morphological traits associated with these sources, which we have attempted to characterise and explain. We aim to explain our methods and results via an oral contribution at the LOFAR family meeting (2023).