Postdoc Fellowships for non-EU researchers

Final Report

Name	Sumana Nandi
Selection	2012
Host institution	Ghent University
Supervisor	Prof. Dr. Maarten Baes
Period covered by this report	from 01/11/2013 to 30/04/2015
Title	A multi-wavelength follow-up of Double-Double Radio Galaxies (DDRGs)

1. Objectives of the Fellowship (1/2 page)

The main objective of this Fellowship was a detailed and systematic study of so-called “double-double radio galaxies" (DDRGs). DDRGs can be characterized by two or more pairs of synchrotron emitting lobes, driven by same central active galactic nucleus (AGN). In most cases, the inner double is edge-brightened Fanaroff-Riley type II while the diffused outer lobes lack bright hot spots. The existence of such peculiar sources is extremely important to test models of the evolution of AGN, as they provide vital evidence for multiple nuclear activity. At present only 40 DDRGs are known in the literature (for references see Saikia & Jamrozy 2009; Nandi & Saikia 2012). A large sample of rejuvenated radio galaxies provides important clues to the duration and duty cycle of the AGN jet activity. Additionally, a large sample can probe the exact mechanism of formation of DDRGs. In the proposed project, we mainly concentrated on the detail study of a statistical sample of DDRGs using a multi-wavelength approach.

Since the outer diffused lobes from an earlier cycle of activity are likely to have a steep radio spectrum, low-frequency radio observations should help to identify such features. We proposed to perform low-frequency radio observations for this sample to confirm their renewed jet activity. We also planned to carry out a spectral ageing analysis, which is an important tool to reveal the age of the inner and outer lobes. This information helps us to constrain the time scales of recurrent AGN activity.

The exact condition for a AGN to restart its second phase is not well understood. The recurrent jet activity could be triggered due to galaxy mergers or refueling of large gas cloud in the central engine. Through a systematic study of optical host galaxy properties of a large sample it is possible to propose a conclusive argument regarding the formation of DDRGs.

2. Methodology in a nutshell (1/2/ page)

The methodology of the project consists of three phases. In the first phase, a suitable sample of sources is selected, based on existing large catalogues. In the second phase, the necessary radio and optical data are collected for these sources. Here we used a combination of existing archival data, and new data that we managed to collect through observing proposals on internationally competitive telescopes. The final step consisted of a detailed analysis and modelling of the data. Below we provide some more details on each of these three steps.

Sample selection: From the FIRST (Faint Images of the Radio Sky at Twenty cm; Becker, White & Helfand 1995) survey, Proctor (2011) has classified 242 sources as DDRGs. This large sample served as the starting sample for our study. After a careful study of each individual object from this sample at both radio wavelengths (i.e. a study of the morphology at 20 cm) and optical wavelengths (i.e. a by-eye study of the optical morphology), we have identified only 23 sources which we believe to be promising DDRG candidates.

Data collection: In light of our objectives we started a low-frequency radio observation campaign of all 23 DDRG candidates in our initial sample. We proposed 610 MHz continuum observations with the Giant Metrewave Radio Telescope (GMRT cycle 23, Proposal code 23-056, Principal Investigator: S. Nandi and GMRT cycle 26, Proposal code 26-030, Principal Investigator: S. Nandi). After confirmation of second epoch of activity we also proposed (GMRT cycle 28, Proposal code 28-044, Principal Investigator: S. Nandi) for further observations at lower frequencies (325 MHz and 150 MHz) for few samples. Concerning the optical data, we made use of the Sloan Digital Sky Survey (SDSS) Data Release 12 (DR12), which contained optical spectra for the majority of the sources. For the remaining sources, typically the weakest sources from the sample, we requested optical spectroscopy using the Nordic Optical Telescope. Unfortunately, this observing proposal was not granted telescope time.

Analysis and modelling: The data reduction of the GMRT data was performed using the standard radio interferometry techniques. We note that this is a very time-consuming task that requires frequent manual interaction (contrary to e.g. optical or infrared data reduction that can be done almost semi-automatically). After the reduction of the data, we combined the GMRT data with the existing FIRST radio data and the optical spectroscopy data in order to probe several unanswered question about the variation of spectral indices of the outer and inner lobes, their central AGN activity, host galaxy properties and the nature of the surrounding medium governing the jets' propagation. More details are given in Section 3.

3. Results (6-8 pages)

3.1 Introduction

Galaxies as we observe them in the Universe come in many sizes and shapes. They are not just combinations of stars bound by gravity, but complex systems of dust, gas, stellar remnants and dark matter. A very interesting property of a galaxy is its nucleus, which is not only the geometrical center around which the stars of the galaxy orbit, but a whole system on its own in which many different physical processes occur. Active galactic nuclei (AGNs) are nuclei that are observed to produce a very high luminosity by themselves (sometimes as much as thousands times the luminosity of a typical galaxy) in a very small volume. Galaxies hosting an AGN are called active galaxies.

Many different types of AGNs have been identified, including Seyfert galaxies, blazars, quasars, etc. There might possibly be a model in which all these different classes with all their different properties can neatly be unified, depending only on one or a few known parameters. The so-called AGN unification model was proposed about 30 years ago, and has been tested in many different ways in the past three decades. The essence of the models is a central accreting supermassive black hole, surrounded by an optically thick dusty torus. The result is that, depending on the angle we look at the object, very different behaviour is shown. Figure 1 shows an illustration of this unified model.

AGN emission goes from lower energy radio waves all the way up to the high energetic γ-ray ranges. A lot can be said about the observed spectra in the far infrared up to the very high-energy waves. However, the lower energy ranges of radio emission are much more rich and complex than the former and in the context of this thesis much more important. AGNs with complex and spatially resolved radio emission are called radio galaxies. They have been intensely studied since various decades, and they also form the topic of the research done in the frame of this project. In particular, our research focuses on so-called double-double

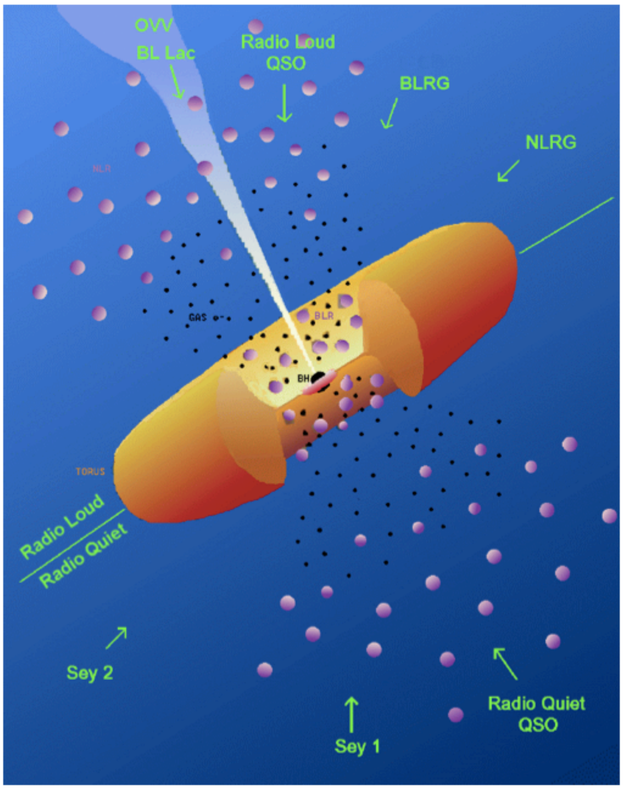

Figure 1: Illustration of the unified model of AGNs. The central of the AGN is an accreting supermassive black hole, which is surrounded by an accretion disc and an obscuring torus. Depending on the intrinsic luminosity of the source, the viewing angle, and the presence of radio jets, a different AGN type is observed. Figure from Urry and Padovani (1995).

radio galaxies, i.e. AGNs with two distinct pairs of radio lobes, which indicates the presence of (at least) two distinct episodes of AGN activity.

3.2. Discovery of a red quasar with recurrent activity

In most of the cases double–double radio sources are associated with galaxies but it is also possible for a quasar to appear as a radio source exhibiting episodic activity. However, the number of double–double radio quasars (DDRQs) reported so far is very limited (Jamrozy et al. 2009), and it is important to identify more of these to make the physical scenario of this class statistically robust. J0935+0204 (4C02.27), located at the redshift of 0.65, is one promising DDRQ reported by Jamrozy et al. (2009). It has a blue-continuum-dominated spectrum, with projected linear sizes of 70 and 470 kpc for the inner and outer radio lobes, respectively. Although in optical surveys the widely popular "Color selection technique" already identified a large number of quasars having blue-continuum-dominated spectra, recent studies found huge dust accumulation around many new similar objects, which make them optically redder (Urrutia et al. 2009). These red quasars are usually believed to represent an early stage of AGN evolution, which is going through a merging process, leading to the presence of large amounts of gas and dust (Glikman et al. 2012).

From our sample of 23 DDRGs we identified a new double-double radio quasar, DDRQ, J0746+4526, which exhibits two cycles of episodic activity. The full-resolution radio images (Figure 2) of J0746+4526 obtained from FIRST at 1400 MHz and that from GMRT at 607 MHz, show that there have been two episodes of activity. The diffuse north-western outer lobe is imaged better at the lower-frequency GMRT image. The spectral indices between 607 and 1400 MHz for the north-western and south-eastern outer lobes are 1.62 ± 0.13 and 1.18 ± 0.13, respectively. The corresponding two-point spectral indices for the north-western and south-eastern inner components are 0.93 ± 0.13 and 1.00 ± 0.13, respectively.

The outer doubles of this DDRQ appear reasonably well aligned with the inner ones and are collinear with the parent optical host galaxy. The radio core has not been detected at either frequency. The projected linear size between the outer radio lobes is ~630 kpc whereas the separation between two inner lobes is ~95 kpc.

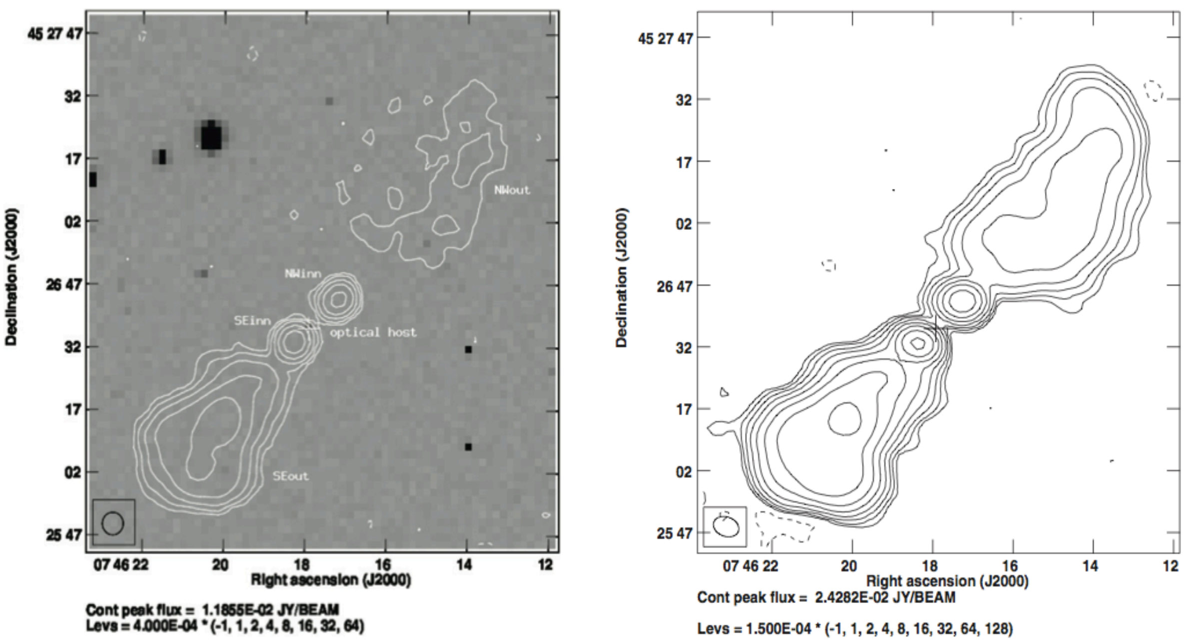

Figure 2: Left panel: the FIRST image at 1400 MHz overlaid on the optical field from the Sloan Digital Sky Survey. The optical host and both the outer and inner doubles are marked in the same image. Right panel: the GMRT image at 607 MHz. The + sign represents the host position.

The outer lobes are highly asymmetric in intensity and do not show any evidence of hot spots at the ends of the lobes. The flux density ratio of the outer components at 1400 MHz is 4.96, while for the inner lobes it is 1.18, with the south-eastern component being brighter in both cases. The log luminosities at an emitted frequency of 1400 MHz for the inner and outer doubles are 25.41 and 26.17 W/Hz, respectively (Nandi & Saikia 2012).

"Reverberation Mapping" (RM) or "Echo Mapping" has proven to be a viable technique to measure the location of the line emitting clouds and the BH mass (Blandford & McKee 1982; Peterson 1993). A major drawback with RM is that for a single system it requires a long-term monitoring program to measure the time gap between the continuum and the broad line variability. To measure the BH mass of this DDRQ we follow the indirect technique of the virial single-epoch method, which is an approximation of the RM method (Kaspi et al. 2005; Chand et al. 2010; Joshi et al. 2011; Kuzmicz & Jamrozy 2012). It exploits the empirical power-law correlation between the size of the BLR and the AGN continuum luminosity, as expected from photoionization model predictions (Bentz et al. 2006). We have used the empirical relation of Vestergaard & Osmer (2009) to calculate the SMBH mass of our DDRQ based on the broad component of the Mg II line. The FWHM of the broad component, obtained from the fitting, is 35.22 ± 0.1 Å. This corresponds to a BH mass of about 0.82 billion solar masses. This value is about one order smaller than the BH mass estimated for J0935+0204.

The BH masses of giant and small-sized radio quasars, measured from Mg II emission lines, typically fall in the range between 0.16 and 1.22 billion solar masses, and 0.1 and 2.03 billion solar masses, respectively (Kuzmicz & Jamrozy 2012). For J0746+4526, the BH mass estimated using the Mg II line is smaller than that of J0935+0204. However, their accretion rates are comparable. Although Kuzmicz & Jamrozy (2012) suggested that larger mass BHs are associated with smaller accretion rates, this does not persist for all types

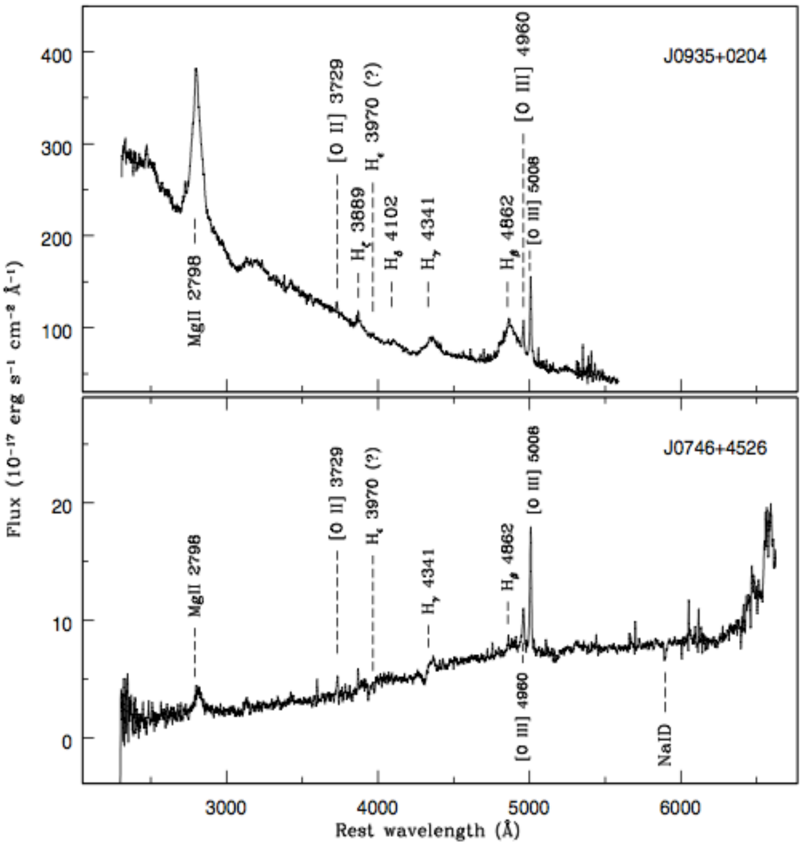

Figure 3: SDSS spectra of J0935+0204 (upper panel) and J0746+4526 (lower panel). For both spectra, the wavelengths were corrected for the redshifts of the galaxies, while the fluxes were measured after performing the corrections due to corresponding redshifts and galactic extinctions. Several spectral lines have been marked in both spectra.

of quasars (e.g., J2335−0927, J1623+3419, J1433+3209). Hence, it appears that the BH mass and accretion rates of these DDRQs are quite similar to other quasars.

Another important difference between the two DDRQs is the shape of the optical spectrum (Figure 2). The optical spectrum of J0935+0204 shows a blue-continuum-dominated spectrum, similar to most quasars, whereas that of J0746+4526 shows evidence of more extinction and obscuration, similar to that of red quasars. Significant populations of obscured red quasars have been reported in recent studies (e.g., Urrutia et al. 2009; Glikman et al. 2012). These findings demonstrate that some different mechanism rather than the orientation of the torus is possibly responsible for large obscuration. In particular, the large extinction in red quasars is probably related to significant dust extinction in the host galaxies. The fact that out of the two known DDRQs one is a red quasar is an interesting result. As large dust extinction is often related to massive starbursts and galaxy merging, it suggests that galaxy merging can trigger not only powerful AGN activity (Heckman et al. 1986; Wilson & Colbert 1995; Sanchez & Gonzalez-Serrano 2002) but also the interruption and restarting of jet formation. In other words, this result plausibly supports the merger-driven scenario for DDRG formation (Liu et al. 2003). In order to test whether this mechanism is the main scenario for DDRG formation, a larger sample of DDRGs needs to be investigated and compared with the global AGN population.

All these results were published in Nandi et al. (2014, ApJ, 789, 16).

3.3. Confirmation of recurrent activity in new samples

Using the FIRST survey data (2003 April release, 811,117 entries) Proctor (2011) initially classified 242 radio sources as possible double-double radio galaxies (DDRGs). Further investigation of this sample along with optical data from the SDSS and DSS catalogues reduced the sample to only 23 sources as promising-candidates of DDRGs (Nandi & Saikia 2012). Though early studies indicated that large linear sizes are characteristic of most of the known DDRGs (Saikia & Kulkarni 1994; Saikia & Jamrozy 2009), these 23 objects have shown jet interruption often occur in smaller sources as well. To get an overall statistical overview on the range of time scales of episodic activity, variation of spectral indices for the inner and outer doubles, we started a GMRT low frequency observational campaign for this sample.

We proposed 610 MHz continuum observations with the Giant Metrewave Radio Telescope (GMRT cycle 23, Proposal code 23-056, Principal Investigator: S. Nandi and GMRT cycle 26, Proposal code 26-030, Principal Investigator: S. Nandi) to image these objects as well as to estimate the variation of spectral indices of the outer and inner lobes. After confirmation of second epoch of activity we also proposed (GMRT cycle 28, Proposal code 28-044, Principal Investigator: S. Nandi) for further observations at lower frequencies (325 MHz and 150 MHz) for few samples. It needs to be stressed that the GMRT is a state-of-the-art radio interferometer in which the observing time is earned using a very strong international competition; the fact that our observing proposals were so successful is already a strong success.

In addition to the radio properties, we also investigate the nearby galactic environment in which these DDRGs are located. Several studies have been found that powerful radio-loud AGNs reside in rich groups and clusters (Donoso et al. 2010). It has been already shown that that nearby environment has a substantial influence of formation and evolution of radio sources. By examining the nearby medium of these DDRGs it is possible to correlate the repeated jet activity with richness of the environments.

We used SDSS DR12 data to explore the nearby galactic environment of our sample. Using a cone search with a radius of about 6 times the size of each DDRG size, keeping the host at the centre for each source, we identified all nearby galaxies. In the radio image we also marked all the galaxies that are located all within a recession velocity between 2500 km/s of the host galaxy. These choices are similar to those adopted in previous studies (Pirya et al. 2012, Mao et al. 2010).

For DDRGs, the outer older lobes from prior AGN activity are aged significantly due to the long synchrotron radiative life times of electrons. On the other hand, the inner components of DDRGs are identified with regions with highly accelerated electrons. Therefore, a difference in spectral indices is expected between outer lobes and inner components. A spectral index analysis is therefore a useful tool to confirm the second epoch of activity.

These low-frequency observations reveal more diffused emission for the outer lobes for most of the sources. The GMRT full-resolution 610 MHz images of few sample DDRGs are presented in figures 3 and 4. Using both 610 MHz and FIRST total intensity maps we estimated the spectral index for inner and outer lobes of each sources. In most of the cases we find steeper integrated radio spectral index for the outer double than the inner ones. This implies at least two distinct epochs of jet activity for each source. We have also studied the fields of sources based on spectroscopic redshifts of nearby galaxies. We find the most over-dense field for the DDRG J1158+2621, which is located in the galaxy cluster Abell 1425. For rest of the cases, except J1326+1924, we find relatively low concentration of galaxies around the location of the optical host. For the last mentioned source we did not find any nearby galaxy.

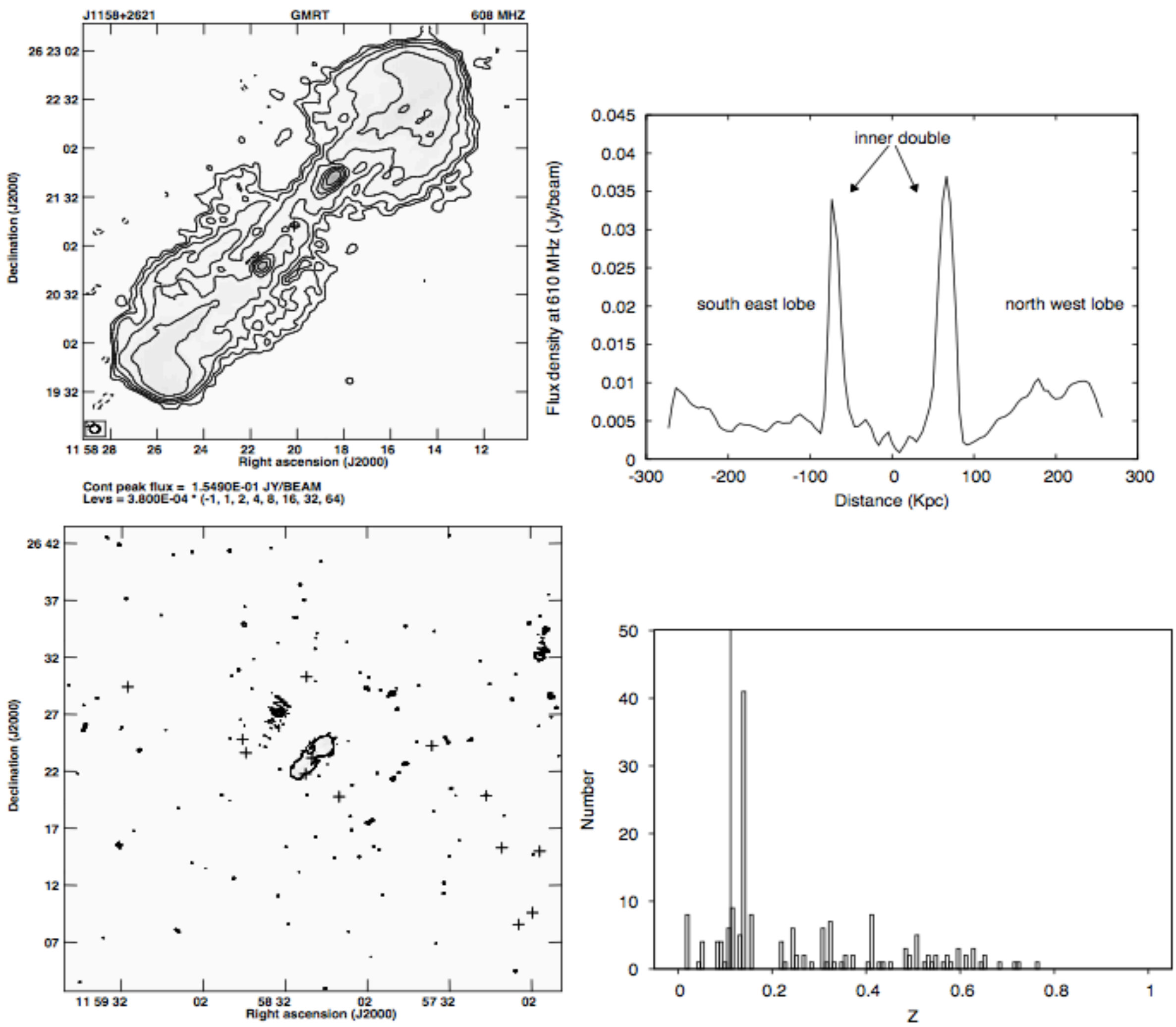

Figure 4: The GMRT image of DDRG J1158+2621 at 610 MHz is shown in upper left panel. The one-dimensional flux distribution of J1158+2621 on the 610 MHz map is given in upper right panel. The position of all optical objects (denoted by + sign) within ±2500 km/s is shown lower left panel. Lower right panel represents the redshift distribution of galaxies with a bin size ΔZ = 0.008. The vertical line gives the redshift of the central host.

The observations, data reduction, the analysis of the radio images and the study of the environment are currently being described in a paper to be submitted soon (Nandi et al., in prep.).

3.4. A misaligned DDRG J1328+2752

To date, nearly 20 DDRGs have been well studied. In the vast majority of the cases, the outer double lobe appears reasonably aligned with the inner one and the time-lapse between the two subsequent jet eruptions varies from one hundred thousand to hundred million years (Saikia & Jamrozy 2009). A change in the direction of the new restarted jets is not common phenomenon for these DDRGs.

There are few examples of DDRGs that show a change of the orientation of the inner and outer lobes, which indicates a change of the jet axes. These misaligned DDRGs represent the inconstancy of AGN jet direction, and it has been suggested that the reorientation is caused by a precession of the AGN or even a flip of the axis. The change in direction of new jet may happen because of the influence of a nearby galaxy or due to a binary black hole merger (Saripalli et al. 2013). On the other hand, the most extensively discussed model of formation of DDRGs is the merger of supermassive black holes. The interruption and subsequent restart of the active phase of an AGN in DDRGs may be triggered by a galaxy merger (Liu et al. 2003, Nandi et al. 2014). So, more discoveries of such examples will provide a reliable statistical overview on the occurrence rate of orientations of the black hole axes, their time-scales and the conditions under which this phenomenon takes place. Moreover these sources also support mergers as a possible mechanism responsible for triggering

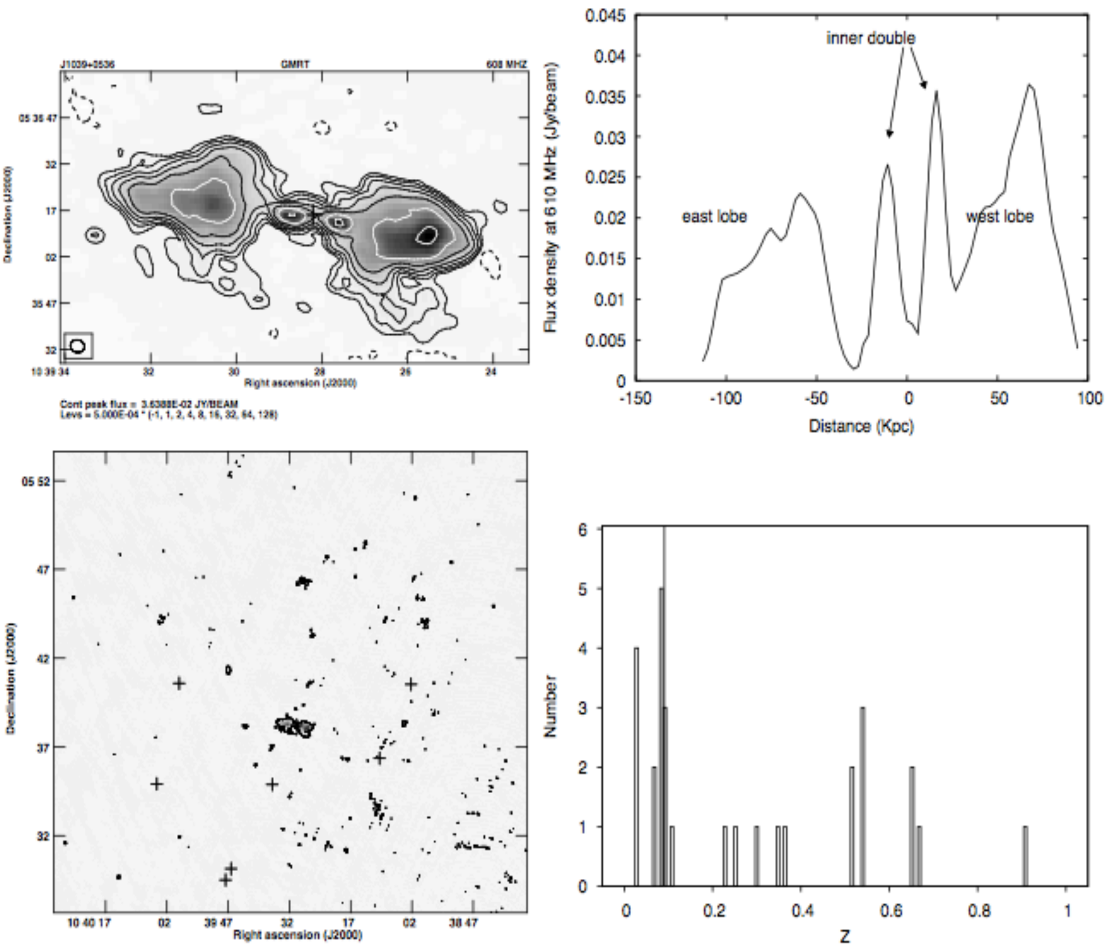

Figure 5: Same as Figure 4, but now for the DDRG J1039+0536.

the second, younger, activity.

From our radio sample of DDRGs studied using GMRT and FIRST, J1328+2752 turned out to be a misaligned DDRG. In our GMRT 610 MHz image, a weak core component at the position of the optical host has been detected. In the case of the FIRST image, the core is more prominent. At both frequencies, the outer lobes are well-defined, and a simple analysis shows that the inner double is completely misaligned with the outer lobes by an angle of ~30 degrees (see Figure 6).

To estimate the spectral indices of each component, the total intensity maps at 610 and 1400 MHz are convolved in to a uniform resolution. From these convolved maps the flux densities at two frequencies have been estimated over similar areas. The spectral indices for outer north-west and south-east lobes are 1.56 ± 0.10 and 1.59 ± 0.13 respectively. For inner west and east lobes the spectral index are 1.44 ± 0.10 and 0.82 ± 0.10 respectively. On the other hand, the optical host of J1328+2752 is identified with double-peaked [O III] λλ4959, 5007 narrow emission lines, which are explained as a possible merging of two supermassive black holes (Liu et al. 2010). This strongly supports the hypothesis that major merger is responsible for triggering the second nuclear activity with a jet-flip. These misaligned DDRGs are potential examples that provide a excellent opportunity to examine the time scales and conditions under which the perturbations to the black hole axes takes place. So, a spectral ageing analysis for this source is necessary to estimate the time span between two epochs of activity.

Our GMRT 610 MHz observation and FIRST archival data prominently detected its misaligned radio structure. However, data only at these two frequencies are insufficient to determine time scales under which the axes change. We further proposed (proposal code 22_044) to observe this source from GMRT at 150 MHz and 325 MHz to determine the radio spectra over a wide frequency range. We get 16 hrs observation time for this proposal. In parallel to the proposed GMRT observations, we will propose to observe J1328+2752 with JVLA at C-band. To make the morphological description of J1328+2752 as complete as possible we will combine this new data with existing GMRT 610 MHz and FIRST data. The combination of FIRST, GMRT and VLA data will also help us to determine the radio spectra over a wide frequency range

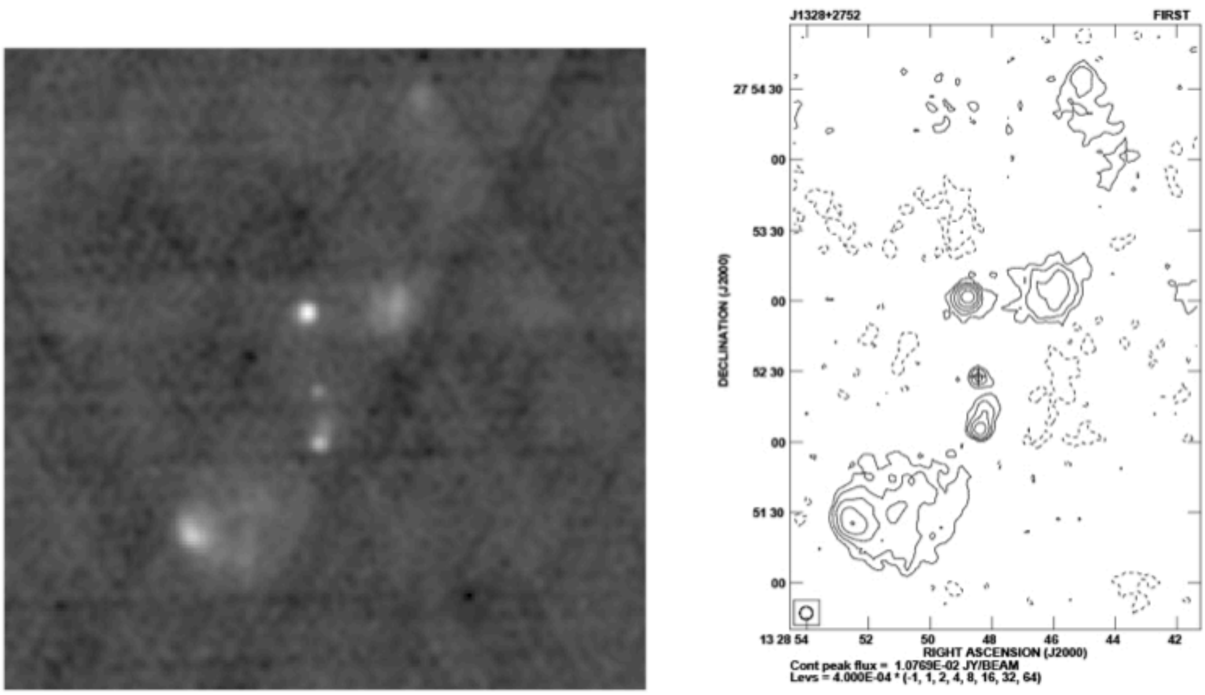

Figure 6: The mislagned double-double radio galaxy J1328+2752. The left panels shows the FIRST image at 1400 MHz, where the misalignment can clearly be spotted. The right panel shows a contour plot of our GMRT observations, which shows the same obvious misalignment.

and to estimate the time scale of jet eruption cycle as well as ages of the outer and inner doubles from both spectral and dynamical ageing calculations.

4. Perspectives for future collaboration between units (1 page)

The Fellowship has opened many possibilities for future collaboration. The subject of the project itself is of significant interest of both parties, and there are still many options to extend the topic of this Fellowship. Aryabhatta Research Institute of Observational Sciences (ARIES) and other institutes/ universities from India are actively involved with this project. For the research work done so far, we have used mostly the unique Indian facility for radio astronomical research, GMRT. But we plan to extend this research using other facilities worldwide. We have already (unfortunately unsuccessful so far) applied for optical spectroscopy of the least luminous DDRGs in the sample using the Nordic Optical Telescope, and will continue this effort. We will also be applying for JVLA and LOFAR time to obtain complementary high and low frequency data in upcoming cycles. Similarly to investigate the host galaxy properties of the DDRGs optical observations from upcoming 3.6 m class telescope in ARIES as well as ESO facilities will be used. In this regard, we are also interested to continue our pre-existing collaborations with different Indian Astronomical Institutes. The study and analysis of DDRGs that was the focus of this project is still ongoing, and we expect that this research line will result in more publications and observing proposals in the near future.

At the same time, this project can be regarded as a starting point for a broader collaboration between both parties. The UGent astronomy group has an active radio research profile, mainly focusing on the study of the interstellar medium and the dark matter in nearby galaxies. For this research, spectral line observations in the radio domain are required, and the UGent group is a common user of the most advanced radio interferometers, such as the Very Large Array in New Mexico and the Australia Telescope Compact Array in Australia. Sumana Nandi has so far focused her research on continuum radio observations, and during her Fellowship in Belgium she has learned the power of spectral line observations and the specialised techniques that are needed to reduce the data. Her specific expertise and working experience with the GMRT (the largest radio interferometer in the world) and the scientific expertise of the UGent team on spectroscopic radio observations opens an entire new window for future collaboration. Several possible collaborations have already been discussed, amongst others a HI survey of a number of nearby edge-on spiral galaxies for which the UGent group has a specific interest, and extremely deep spectroscopic and continuum observations to maps the star formation and gas content of nearby galaxies.

Finally, it is our hope that this project offers more perspectives than just an extended collaboration between the parties already involved. It actually fits in the frame of a much wider collaboration between Belgium and India in the field of astronomy. In November 2009, Belspo signed an agreement with the Aryabhatta Research Institute of Observational Sciences (ARIES) on the cooperation for the construction of a 3.6 metre optical telescope at Devasthal, Asia's largest optical telescope. In return of this financial investment from Belspo, Belgian astronomers will receive 7% of the observing time. The telescope was originally expected to have first light early 2013, and the first instrument will be an optical imager and low-resolution spectrograph. Ideally, this new facility would have been used in the frame of the current project. The construction of the 3.6m telescope has been delayed, however, such that it was too late for use in the frame of the present project. It is close to first light at the moment, and given that we have now strengthened our ties with our Indian partners, we are now in an ideal position to make the best possible use of our joint expertise.

It is our hope that it will stimulate the entire Belgian astronomical community to make the best possible use of the Devasthal 3.6 m telescope.

5. Valorisation/Diffusion (including Publications, Conferences, Seminars, Missions abroad...

Publications

Discovery of a Red Quasar with Recurrent Activity
Nandi S., Roy R., Saikia D. J., Singh M., Chandola H. C., Baes M., Joshi R., Gentile G., Patgiri M.
The Astrophysical Journal, 789, 16 (2014)

Confirmation of recurrent activity of 23 candidates using FIRST and 610 MHz GMRT data
Nandi S., et al.,
Monthly Notices of the Royal Astronomical Society, to be submitted

Teaching

Supervisor of a master student at Ghent University
Wietse Heremans: Periodic activity in radio galaxies
Master of Physics and Astronomy, 2014-2015

Conferences and Seminars

Cosmic Magnetic Field Conference, Cracow (Poland), 20-24 October 2014
Contributed talk: "A radio study of misaligned double-double radio galaxies".

Astronomical Observatory of the Jagiellonian University, 28 October 2014
Seminar: "Episodic activity of a red quasar".

69th Dutch Astronomy Conference, Noordwijkerhout (Netherlands), 19-21 May 2014
Contributed talk: "Confirmation of episodic activity in radio galaxies using GMRT and FIRST data"

6. Skills/Added value transferred to home institution abroad (1/2 page)

During the Fellowship, Sumana Nandi has learned a variety of skills that were completely new to her and that she can transfer to her home institute. The most important ones are

- **Optical data analysis.** The UGent group has a strong expertise and tradition in the analysis and interpretation of optical data (both imaging and spectroscopy), whereas the expertise of Sumana Nandi was mainly in the radio domain. During her fellowship she learned how to reduce and analyse optical data, a skill that is extremely important now that Asia's largest optical telescope is about to get first light.
- **Spectroscopic radio data reduction.** As indicated in Section 4, the UGent astronomy group has a strong expertise in spectroscopic radio data, whereas Sumana Nandi has so far focused her research on continuum radio observations. In the 18 months of her Fellowship in Belgium she has learned the power of spectral line observations and the specialised techniques that are needed to reduce the data.
- **Radiative transfer and the physics of interstellar dust.** Apart from radio galaxies, the interstellar medium is the main research topic in the UGent astronomy group. Throughout her research stay and especially during the SKIRT days, Sumana has learned much about the physics of dust and was introduced to working with the UGent SKIRT radiative transfer code.
- **General research and teaching skills.** By working in a multi-topic and international research team, Sumana has learned a number of research skills (meetings, presentations,…) that will be of general use at her home institute. In the past year, she supervised a master thesis student, which is also a skill/expertise that will be beneficial for her future career.