Study of Large-Scale Radio Structures associated with Spiral Galaxies

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Almost all known powerful extragalactic radio sources, named radio galaxies, are hosted by elliptical (or lenticular) galaxies. However, few examples of strong radio galaxies associated with spiral galaxies have been found in the recent years. In the very centre of a parent galaxy the active galactic nucleus (AGN) can be found. AGN is a small-size, rare formation composed of a supermassive black hole (SMBH; with masses exceeding 10 million Solar masses) surrounded by matter forming an accretion disk, a dusty torus and a corona - heated to millions of degrees and, in some cases, jets of relativistic plasma. These energetic, collimated outflows sometimes blown into huge lobes have their origin near the SMBH and are characterized by a wide range of observed sizes (from dozens of kiloparsecs up to a few megaparsecs). A very important aspect in the study of AGNs is to answer the question why only few powerful, large-scale radio sources are associated with spiral galaxies. Here we present these unique objects with particular interest in radio galaxy B0313−192 which is located in Abell 428 galaxy cluster.

1 Introduction

Radio galaxies are observed at large angles (from 45° up to 90°) to the line of sight and they are usually classified as Fanaroff-Riley radio sources, divided into two types: Fanaroff-Riley I (FR I) and Fanaroff-Riley II (FR II; Fanaroff & Riley 1974). The radio brightness of FR I objects decreases with the distance from their centers, while for more powerful FR II – radio brightness increases outwards and the diffuse lobes are characterized by prominent hot spots at the edges.

The evolution of radio galaxies depends a lot on the conditions in the surrounding intergalactic medium (IGM), i.e. it is strongly determined by the efficiency of the energy transport/dissipation through the jets. Jets of FR Is are less energetic and decelerate quickly in the vicinity of the parent galaxy. Velocities of FR IIs' jets remain relativistic almost throughout the whole length of the outflow (Fanaroff & Riley 1974).

2 Extended radio lobes associated with spiral hosts

There are six known spiral galaxies associated with large double-lobe radio structure. They are named: B0313−192 (Mao et al. 2015; Ledlow et al. 1998), Speca (Hota et al. 2011), J2345−0449 (Bagchi et al. 2014), J1649+2635 (Mao et al. 2015), MCG+07-47-10 (Mulcahy et al. 2016), J0836+0532 (Singh et al. 2015). Four of them are classified as FR II (Mao et al. 2015).

Large-scale radio structures associated with spiral galaxies usually reach up to several hundred kpc in size. There are, however, two sources with much bigger lobes:

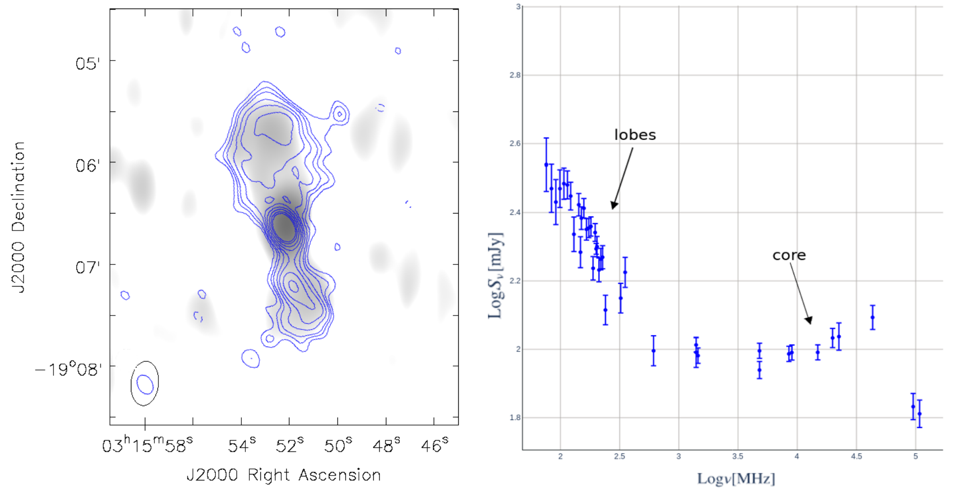

Fig. 1: Left panel: radio galaxy B0313-192: grey-scale map is based on the VLA observations in the 220-480 MHz range. Contour map has been created using GMRT observations at 320 MHz. Contour levels are (-3, 3, 5, 7, 10, 15, 30) $\times$ 0.16 mJy beam^{-1}. Right panel: radio spectrum of B0313-192. The points represent flux density of the total structure in the frequency range from 76 MHz to 108 GHz.

the radio source J2345$-$0449 located on $z = 0.0755$ (Bagchi et al. 2014) possesses $\sim$ 1.6 Mpc–long lobes, and Speca located on $z = 0.137$ with $\sim$ 1.4 Mpc–long lobes (Hota et al. 2011). In addition, the double-double lobed structure of these two sources appears to be due to the episodic activity of their central AGN (one AGN per source). Their external lobes reveal earlier cycle of activity, while recent activity manifests in the form of a pair of new inner jets/lobes (see e.g. Saikia & Jamrozy 2009).

Recent studies of large-scale radio structure associated with spiral galaxies, outline some characteristic features common for such sources, namely: enormous SMBHs in their centres reaching up to 10^9 M$_\odot$ (J2345$-$0449; Bagchi et al. 2014) and high rotation velocities of the planar galactic disk: 400-500 km s^{-1} (Bagchi et al. 2014). These particular spirals are also extremely bright with continuous star forming activity in their galactic disks (Bagchi et al. 2014).

Concerning the formation of these both FR type radio-loud AGNs, the position of a jet relative to the host galaxy disk plane plays a crucial role - in too dense interstellar medium it will not expand far from the central engine and will lose its collimation quickly around the optical host. This could be one of the reasons why we only know a few sources of this type. Also, the origin of such massive black holes in these spirals is quite surprising, since the most massive black holes occur in old, giant elliptical galaxies. Probably, these particular galaxies passed through mergers with other objects (Bagchi et al. 2014).

3 Double-lobed radio source B0313-192: the first confirmed radio galaxy with a spiral host

This interesting source reveals double-lobe radio morphology (Keel et al. 2006) but it is also unique due to the fact that this is the first confirmed double-lobed radio object hosting spiral galaxy (Ledlow et al. 1998). The total radio structure of B0313-192 is about 360 kpc wide (with the angular scale of $1.29\,\mathrm{kpc\,arcsec}^-1$) composed of one-sided nuclear jet, one-sided large-scale radio jet emerging from the central region and extended radio emission forming diffuse radio lobes. It has been classified as a powerful ($\log L_{1.4\mathrm{GHz}} = 23.95\,[\mathrm{W\,Hz}^{-1}]$) FR I radio source (Ledlow et al. 2001).

The optical host of B0313-192 turns out to be a classic edge-on disk galaxy. Optical and near-IR observations of dust lane and stellar disk indicate that this galaxy is observed within 0.5° to the line of sight (Keel et al. 2006). The SMBH in its center has a mass of $8 \times 10^8\,\mathrm{M}_\odot$ (Ledlow et al. 2001) and the object is extremely bright (m_K = 12.7mag, Skrutskie et al. 2006), even after neglecting star-forming regions.

We analyze archival and dedicated radio observations, Fig.1 left panel, to create broadband radio spectra for each structure of the B0313-192: radio nucleus, jets and diffuse lobes. The right panel of Fig.1 shows the continuum spectrum for the total structure of B0313-192 in the range from 76 MHz to 108 GHz. We plan to perform dynamic modeling analysis to learn more about the object's physics and the external environment, e.g. the density of the intergalactic medium, the jet's power and the source's lifetime (see e.g. Machalski et al. 2008). This will allow us to determine more accurately the conditions under which such radio structures may form in spiral galaxies. What is more, we may be able to answer the question why only few galaxies of this type have been discovered so far.

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References

Bagchi, J., et al., *ApJ* **788**, 1538 (2014)

Fanaroff, B. L., Riley, J., *MNRAS* **166**, 1 (1974)

Hota, A., et al., *MNRAS* **417**, L36 (2011)

Keel, W. C., White, I., Raymond E., Owen, F. N., Ledlow, M. J., *AJ* **132**, 2233 (2006)

Ledlow, M. J., Owen, F. N., Keel, W. C., *ApJ* **495**, 227 (1998)

Ledlow, M. J., Owen, F. N., Yun, M. S., Hill, J. M., *ApJ* **552**, 120 (2001)

Machalski, J., Kozieł-Wierzbowska, D., Jamrozy, M., Saikia, D. J., *ApJ* **679** (2008)

Mao, M. Y., et al., *MNRAS* **446**, 4176 (2015)

Mulcahy, D. D., et al., *A&A* **595**, L8 (2016)

Saikia, D. J., Jamrozy, M., BASI **37**, 63 (2009)

Singh, V., et al., *MNRAS* **454**, 1556 (2015)

Skrutskie, M. F., et al., *AJ* **131**, 2, 1163 (2006)