PROCEEDINGS OF SCIENCE

Flux densities and spectral indices of Relaxed Double radio galaxy 3C 84

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Here we study the flux densities distribution at 1380, 4908 and 15365 MHz, as well as the radio spectral index of 3C 84, a Double Radio source Associated with Galactic Nucleus (DRAGN). 3C 84 is the dominant giant elliptical galaxy in the Perseus cluster, and thus very interesting for our research. This famous radio galaxy Perseus A has Relaxed Double classification because it has the large halo, with the lack of its compact structure. We show its structure (using 2D and 3D flux density plot). Besides, we calculated the radio spectral index, which we then used to investigate the nature and mechanisms of its radiation. The obtained values of spectral indices indicated that the northern hotspot is dominated by synchrotron radiation, while in southern hotspot there are thermal and non-thermal radiations, depending on the studied frequency pairs.

11th International Conference of the Balkan Physical Union (BPU11),
28 August - 1 September 2022
Belgrade, Serbia

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PoS(BPU11)043

1. Introduction

The active galactic nuclei (AGNs) are emitting the most radiation from galaxies [1], and in case of radio galaxies, a lot of their radiation is emitted at radio wavelengths. Radio galaxy contains in its center AGN, a pair of collimated jets of relativistic particles, and jets contain a pair of lobes at their ends. They were discovered by Carl Seyfert in 1943 [2]. Only around 10-15 % of Galactic Nuclei are active [3]. More details about this radiation coming from vicinity of supermassive black holes (SMBH) see in [4]. Radio galaxies according to difference in their spectra have different optical-to-radio flux ratios and can be classified as radio-loud and radio-quiet AGNs. The Double Radio Sources Associated with Galactic Nuclei (DRAGNs) are manifested as double radio sources produced by outflows (jets) that are launched by processes in AGN. As the environs of a galaxy are not a perfect vacuum the jets push their way through surrounding external media and form the ”classical” double-lobed structures. The main characteristics of DRAGNs are synchrotron radiation, jets and lobes. Also, DRAGNs are characterized by bright hotspots near the end of each lobe [1].

Based on the degree of correlation between the high and low surface brightness in the lobes of extragalactic radio sources with their radio luminosity, it is possible to give a classification scheme [5]. This classification given by the Fanaroff and Riley divided radio galaxies in FR I and FR II type, i.e. separated low power and high power radio galaxies, respectively. Radio spectral properties of radio galaxies is very important feature, that is why a number of radio galaxies were discussed in papers [6–8] and references therein.

The 3C 84 is the famous radio galaxy Perseus A, the dominant giant elliptical galaxy in the Perseus cluster. Its cross-identifications are: NGC 1275; Perseus A; UGC 02669; MRK 1505; MRK 9013. It can be said that its radio structure is complicated and therefore it is particularly difficult to image well. In paper [9] the authors propose and discuss the detected jet precession. Also, in [10] it is explained that the subparsec-scale radio structure is dominated by slow-moving features in both the eastern and western lanes of the jet, as well as that the jet appears to be accelerated.

Here, we study the flux distribution of 3C 84 DRAGN as well as the radio spectral index in some characteristic points. The paper is organized in the following way: in Section 2 we describe the observational data and our method that we used for calculation of radio spectral index. In Section 3 we present and discuss the flux distribution and spectral index of 3C 84 DRAGN. At the end of this section we point out the main conclusions in our study.

2. Data and method

In our study we used publicly available data and images of the source at different frequencies, as well as Leahy's atlas of double radio-sources (containing data and some very useful information). The radio source 3C 84 was listed in the Third Cambridge Catalogue of Radio Sources, where the number after 3C indicates its position in the dataset.

Observational data that we used are given in FITS (short for Flexible Image Transport System) format. This is the standard data format and by structure it consists of one or more sets of a Header and Data Units (called HDUs). In our case we used a two dimensional radio image and other data, where each coordinate corresponds to a value for flux density. Using these available flux data we show its distribution and obtain spectral indices. For details regarding this type of data, see: https://www.loc.gov/preservation/digital/formats/fdd/fdd000317.shtml.

The observations were carried out using "The Very Large Array" (VLA) and "The Very Long Baseline Array" (VLBA) radio telescopes, both operated by the National Radio Astronomy Observatory (NRAO). VLA is located in New Mexico, USA, and from 2012 it is named "Karl G. Jansky VLA", while VLBA is located in several US states and can measure the position and distance of radio sources extremely well due to its high precision observations.

It is useful here to notice that we use the calibrated data, i.e. the data and images after they are processed using analysis techniques and programs like `CLEAN` algorithm (see [11] and references therein). Particularly, regarding the resolution of the processed data used here, the lowest one of $4''$ is at 1380 MHz, while those at 4908 and 15365 MHz are much higher: 0.06 mas and 0.1 mas, respectively.

The observed data for 3C 84 radio source have been taken from Leahy's Atlas of DRAGNs [12]:

- J. P. Leahy, A. H. Bridle, R. G. Strom, An Atlas of DRAGNs (2013): http://www.jb.man.ac.uk/atlas/.

The atlas contains the basic information concerning the closest 85 of these DRAGNs (radio galaxies and related objects) from the 3CRR sample of Laing, Riley & Longair (1983) [13].

Also, the FITS files for each selected source (at different frequencies) can be found through the NASA/IPAC Extragalactic Database (NED). Database site:

- NASA/IPAC Extragalactic Database: http://ned.ipac.caltech.edu/.

The method that we used for calculation of radio spectral index we developed for the main Galactic Loops [14–19], but we extend the same method to extragalactic radio sources [20, 21]. As the objects from Leahy's Atlas are observed with much better resolution, this extension of our previous method to much smaller objects was possible.

2.1 Radio spectral index

In radio sources, the flux density S_ν dependence on frequency ν, is characterized with the power-law relation:

$$S_\nu \propto \nu^{-\alpha}, \tag{1}$$

where α is called the 'spectral index'. It is easily obtainable by measuring the flux density at different frequencies and taking the negative slope of the above relation, i.e. it is negative value of coefficient of the line:

$$\log S_\nu = \log K - \alpha \log \nu, \tag{2}$$

with K being constant, and then α resulting in:

$$\alpha = -\frac{\log\left(\frac{S_{\nu_1}}{S_{\nu_2}}\right)}{\log\left(\frac{\nu_1}{\nu_2}\right)}. \tag{3}$$

The spectral index can be used to classify radio sources and understand the origin of radio emission. More specifically, if $\alpha > 0.1$ the emission is non-thermal (synchrotron) in origin, meaning it does not depend on the temperature of the source, and for $\alpha < 0$ it is thermal (depends only on the temperature of the source) in origin.

3. Results and conclusions

Observations with the RadioAstron space telescope have shown that there are the core shifts in the jets, and that its position may become frequency dependent. Also, there are strong indications for a precession of the 3C 84 jet. Therefore, the radio spectral index maps are usually calculated after image alignment.

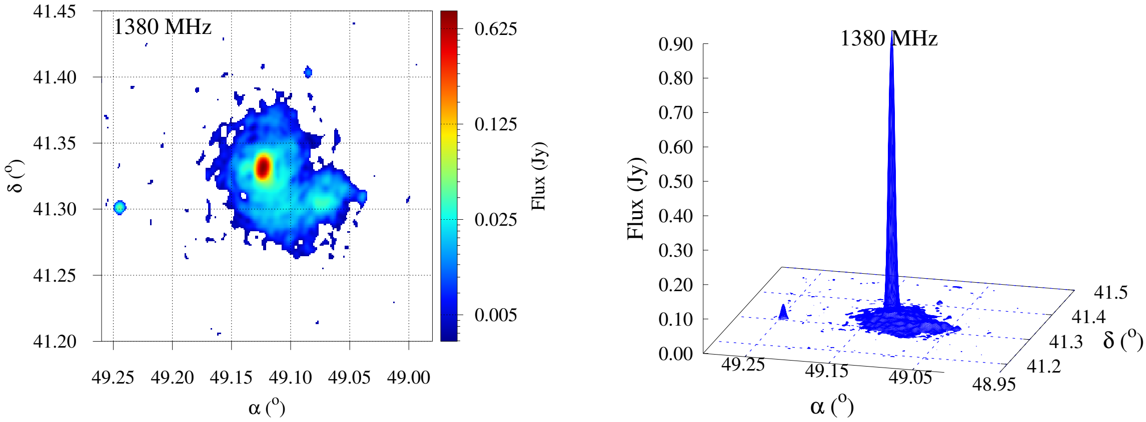

Figure 1: The flux density 2D plot (left) and 3D plot (right) for 3C 84 at 1380 MHz.

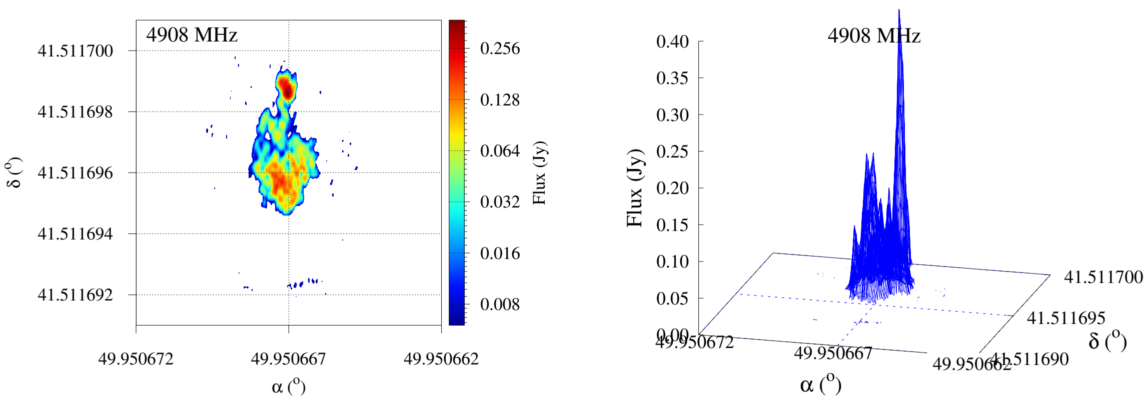

Figure 2: The same as 1, but for 4908 MHz.

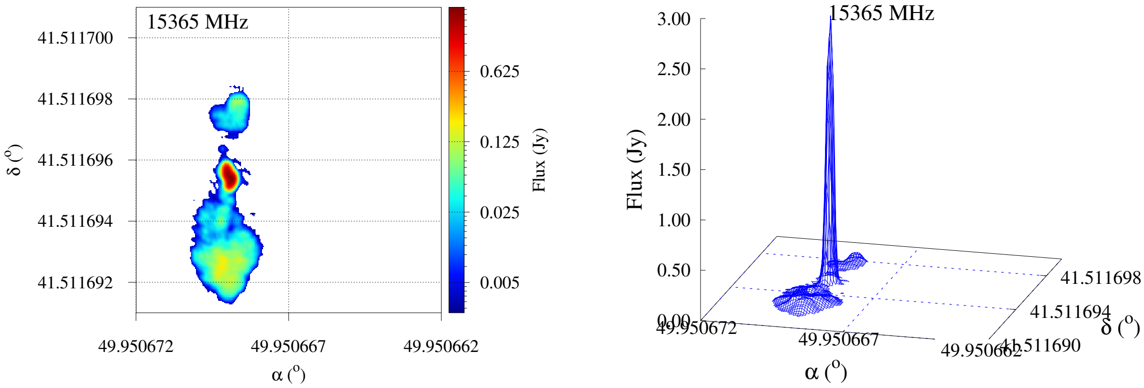

Figure 3: The same as 1, but for 15365 MHz.

In Figs. 1 – 3 we show the positions in equatorial RA and DEC coordinates (α, δ) and the distributions of flux density (in the form of 2D, as well as of 3D plot) of 3C 84 at the following three frequencies:

- ν_1 = 1380 MHz (22 cm) – obs. date 1984,
- ν_2 = 4908 MHz (6 cm) – obs. date 1998,
- ν_3 = 15365 MHz (2 cm) – obs. date 1995.

The observational data that we used for ν_1 = 1380 MHz are reduced to epoch B1950, while the observational data for ν_2 = 4908 MHz and ν_3 = 15365 MHz are reduced to epoch J2000 and for that reason they are more similar. If we take a look at the RA and DEC coordinates, we can say that the core shift is really noticeable. Therefore, in order to calculate the spectral indices between two frequencies (at some characteristic points), it was necessary to make the figures alignment. We calculated spectral indices of the northern and southern hotspots, between each pair of the three frequences, and obtained the following results:

- northern hotspot: $\alpha_{12} = 0.64$, $\alpha_{13} = 0.92$, $\alpha_{23} = 1.23$;
- southern hotspot: $\alpha_{12} = -1.42, \alpha_{13} = -0.72, \alpha_{23} = 0.06$.

We found that the non-thermal (synchrotron) radiation dominates in the northern hotspot of the studied source. However, the southern hotspot is dominated by a thermal emission when taking into account two frequency pairs $\nu_1 - \nu_2$ and $\nu_1 - \nu_3$ (due to negative value of α_{12} and α_{13}). It should be emphasized here that α_{23} is positive, meaning non-thermal radiation. Therefore, in the southern hotspot the thermal and non-thermal radiations may be present simultaneously, depending on the studied frequency pairs.

We obtained the flux density of 3C 84 at 1380, 4908 and 15365 MHz. As can be noticed from displayed figures, at the very center is an extremely bright flat-spectrum core. The lack of compact structure in the halo gives this object its Relaxed Double classification. We also provided the spectral index values for northern and southern hotspots derived from three pairs of frequencies. The results of this study will be helpful for understanding the evolutionary process of the 3C 84 radio source.

Acknowledgment. This work is supported by Ministry of Science, Technological Development and Innovations of the Republic of Serbia. PJ wishes to acknowledge the support by this Ministry through the project contract No. 451-03-68/2022-14/200002.

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