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High sensitivity EVN+Areribo observations of nearby dual AGN Mrk 463

Sravani Vaddi[a,*]

[a] *Arecibo Observatory,*
Arecibo, Puerto Rico, USA

E-mail: sravani.vaddi@gmail.com

We report results of the VLBI observations carried out using EVN+Arecibo at 18 cm with the aim to study the pc-scale emission of dual AGN. Mrk 463 is one of the nearby brightest dual AGN in which the east and west nuclei are optically separated by 4 kpc. The radio properties of the Mrk 463E match with those obtained by [1] almost two decades ago. We report the radio detection of the Mrk 463W at 6 σ level and confirm the presence of an AGN core.

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*Speaker

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1. Introduction

Studies of dual active galactic nuclei (DAGN) play an important role in our understanding of the formation and growth of the final supermassive black hole (SBH) through merger-driven AGN models. Their demographics are helpful in obtaining constraints on the frequency of galaxy mergers. While it is difficult to directly detect binary SBHs, hints on their presence and evolution have been estimated by exploring a comparatively easily observable kpc-scale separated DAGN. A variety of signatures have been used to search for DAGN such as the presence of double peak in the optical emission lines [2], studies of recoiling black holes [3], S or X-shape radio jet structures [4, 5], optical variability [6], and dips in the light curves of stellar tidal disruption events [7]. It is widely known that galaxy major mergers bring in a large reservoir of gas that can serve as fuel for star formation and/or can lead to enhanced accretion on to the central SBHs thereby triggering nuclear activity on one or both the SBHs [8]. However, the conditions in which this process occurs is poorly understood. VLBI studies of a large number of DAGN are useful to understand the evolution of one nucleus in the presence of a nearby active nucleus. We observed a sample of four DAGN at 18 cm using European VLBI network. Of the four, two DAGNs were observed using EVN and legacy 305 m Arecibo telescope to benefit from its higher sensitivity and detect the weaker companion. We report here the observations of one of the DAGN Mrk 463, which is the nearest and brightest of the DAGN in our sample.

2. EVN+Ar radio VLBI observations

Mrk 463 was observed at 1.6 GHz using the EVN+Ar VLBI network (project ID: EV022) on 12-June-2020. This project was the last successful VLBI observation performed using the upgraded VLBI recording system at the Arecibo observatory. The total on-source observing time was 177 minutes. The source was observed in multi-phase center correlation technique thereby making full use of the wide primary beam. In this technique multiple datasets, each with different phase center located within the primary beam, can be produced in a single correlator pass. The primary phase center of the observations point to the eastern nucleus Mrk 463E and a second phase center, centered at Mrk 463W was generated in the correlation phase. Phase referencing was not performed since it is a bright source. J0927+3902 was used as the fringe-finder. The antennas available for this observation are Jodrell (UK), Westerbork (Neterlands), Effelsberg (Germany), Onsala (Sweden), Svetloe (Russia), Irbene (Latvia) , Arecibo (Arecibo), and Pickmere (UK). The data was recorded at a rate of 1024 Mbps with dual polarization, eight subbands per polarization and 16 MHz bandwidth per subband. The correlation was performed at the EVN software correlator of the Joint Institute for VLBI in Europe (JIVE). The correlator output data was grouped into two multiple-source FITS-IDI files. Each file has one target and all the calibrators, and averaged with an integration time of 2 seconds and 32 channels per intermediate frequency channel (IF). Calibration of this dataset was done using the AIPS software and following the usual VLBI calibration steps for the EVN [1]. An interactive self-calibration was performed on Mrk463E since it has a high signal-to-noise level. The peak of the component and its position is measured from the map using TVMAXFIT task in AIPS. The total flux density and the RMS noise is measured using TVSTAT. The component size

[1]https://www.evlbi.org/evn-data-reduction-guide

is obtained from 2D Gaussian fits using the task JMFIT. Phase only self-calibration was performed on Mrk 463E. Since the western nucleus is weak, self-calibration was not attempted.

3. Results and Conclusions

Mrk 463 is a nearby 237 Mpc DAGN with the two nucleus Mrk 463E and Mrk 463W oriented along E-W direction and separated by about 4 kpc [9]. Figure 1 shows the Sloan Digital Sky Survey (SDSS) data release 10 [10] *ugriz* color composite image of Mrk 463. Mrk 463E, the eastern nucleus, is the brighter of the two nuclei and is classified as a Seyfert type 2 based on the optical line ratios[11]. The western nucleus Mrk 463W is classified as a composite of LINER and star forming system [12]. Deep optical images show tidal tails indicative of merger between two spiral galaxies [11]. The near-IR data shows that the flux density of Mrk 463E dominates that of Mrk 463W with increasing wavelengths. The near IR emission in the eastern nucleus is predominantly from dust while in the western nucleus it is from starlight with weak dust emission.

Figure 2 shows the EVN maps of Mrk 463E and Mrk 463W and Table 1 lists its radio properties.

In Mrk 463E, the 20 cm A array VLA data taken in the year 1987 shows a radio emission consisting of a core, a northern, and southern component at 4" (4 kpc) and 18" (18 kpc) respectively from the core [12]. The radio structure is linear extending in the north-south direction that also coincides with the [OIII] emission[1]. High resolution VLBI data resolved the core into four distinct components that align in the same direction as the large-scale structure. Two components form the inner core-jet structure, while the third and fourth components are spaced at 0.3” (0.3 kpc) and 1.2” (1.2 kpc) respectively from the core [1] with the farthest component being the weakest. The new EVN observations reported here match the inner core-jet structure earlier detected by [1] while the weaker components are resolved out and are not detected. The central parsec-scale core-jet structure is seen in Mrk 463E. The extent of the central core-jet structure is ~ 50 mas. The total flux density is 75.2 mJy which is ~ 23% of the total flux of the arcsec-scale structure. Jet speed is estimated from the jet to counter-jet brightness ratio (R_J). Using the peak flux density of the core-jet component and the noise at the counter-jet direction, $R_J = 44$. Assuming the jet structural parameter $p = 3.0$ (continuous jet with spectral index α=-1;[13]), the jet speed required to produce the observed R_J is 0.66c. The brightness temperature is computed using $T_B = 1.8 \times 10^9 (1+z)(\frac{S_\nu}{mJy})(\frac{\nu}{GHz})^{-2}(\frac{\theta_1\theta_2}{mas^2})^{-1} K$ [14]. Here, S_ν is the core flux density at frequency ν, θ_1 and θ_2 are the FWHMs of the fitted elliptical Gaussian components along the major and minor axes measured in mas, and z is the redshift. The brightness temperature thus estimated using S_ν = 56.32 mJy and core size of 33×23 is 5.5×10^7 K.

It is for the first time that the western nucleus has been detected on VLBI scales. We obtained a 6 σ detection with a peak flux density of 1.23 mJy/beam where the convolved beam size is 66.4×14.9 mas. The radio image shows an an extended emission that appears to be elongated in NE-SW direction although wen note that the restoring beam also has a similar orientation. The length of this extended structure measured using TVSTAT is about 0.1±0.05 arcsec which translates to 105±157 pc using the scale value of 1.05 kpc/arcsec. The total flux density is 3.97±0.6 mJy which is same as the arcsec-scale flux density measured by [12] indicating that the radio emission originates entirely from a compact core. Further, the measured brightness temperature of Mrk 463W is 2.96

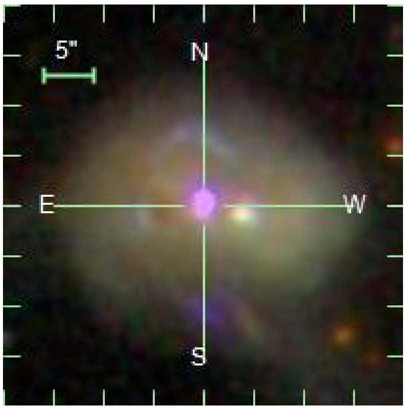

Figure 1: SDSS DR10 [10] *ugriz* color composite image of Mrk 463. Two nuclei are clearly visible. The eastern and western nucleus are identified as Mrk 463E and Mrk 463W respectively.

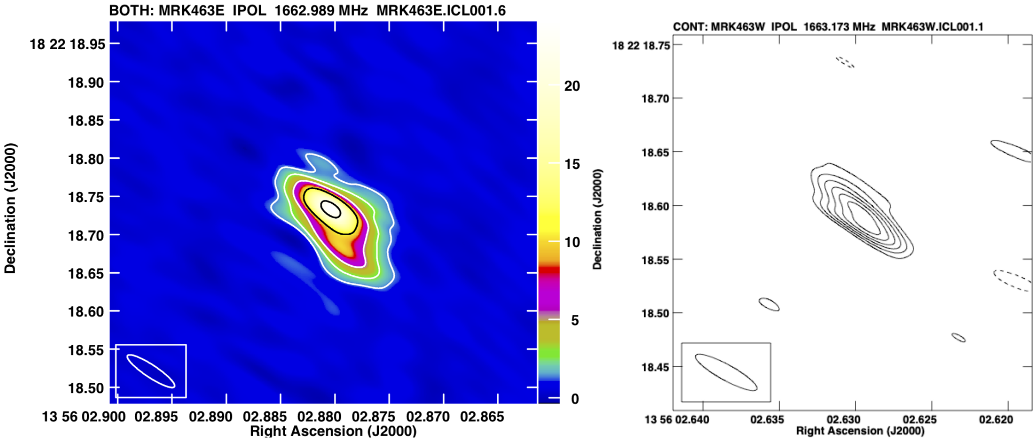

Figure 2: Left: EVN 18 cm VLBI flux density map of Mrk 463E. The convolved beam size is 75×16 mas. The contours are drawn at -5.6, 5.6, 11.25, 22.5, and 90 per cent of the peak flux density of 24 mJy beam^{-1}. Right: EVN 18 cm contour plot of Mrk 463W. The convolved beam size is 66.4×14.9 mas. The contours are drawn at -40, 40, 50, 60, 70, 80, and 90 per cent of the peak flux density of 1.27 mJy beam^{-1}

$\times\ 10^6$ K which undoubtedly confirms the radio emission dominated by non-thermal synchrotron process and thus the western nucleus is an AGN with pc-scale radio emission [15].

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Name	Component	Separation (arcsec)	S_{total} (mJy)	S_{peak} (mJy)	σ (mJy/beam)	Size (mas)
Mrk 463E	core	0	56.32±2.4	23.86	0.18	33×23
	jet	0.063	25.67±1.6	10.02	0.18	
Mrk463W	core	3.57	3.97±0.6	1.27	0.19	65×15

Table 1: Radio properties of Mrk 463 observed using EVN+Arecibo at 18 cm.

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