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A study of the lobes of the radio galaxy Hydra A using MeerKAT observations

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Hydra A is a radio galaxy located at the center of the galaxy cluster Abell 780. It hosts a pair of 100 kpc scale radio lobes that have been inflated by one of the most powerful outbursts known to date. In a previous conference proceedings, we presented images of Hydra A based on a single observational epoch; here, we present the results from the entire observation of Hydra A with MeerKAT from which we identify a new tail-like structure extending from the southern lobe. We found that the spectral index in this region is significantly softer than the spectral index of the outer lobes. By combining our observations with two low-frequency VLA observations, we found the overall spectrum for the outer lobes of Hydra A shows a steepening with increasing frequency. We found that the Kardashev-Pacholczyk model for spectral aging adequately describes the overall spectrum.

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1. Introduction

Hydra A is a type I Fanaroff-Riley (FRI) radio galaxy [1] located at the center of the galaxy cluster Abell 780 at a redshift of $z = 0.054$. Previous observations show that Hydra A consists of a bright central source [2], two jets, two inner radio lobes, and two outer radio lobes [3]. The electron population in the radio lobes experiences energy losses due to synchrotron radiation and inverse Compton scattering. In the presence of a magnetic field greater than a few μG, synchrotron radiation is the dominant mechanism for radiative losses. Spectral aging [4,5,6] is the process whereby the radio spectrum steepens due to the radiation of energy by the electrons. The radiative cooling of the electrons results in a time evolution of the spectrum. The giant lobes of Hydra A have previously been detected using the Very Large Array (VLA) radio telescope at 74 MHz, 327 MHz and 1415 MHz [2]. These observations also reveal a structure extending beyond the southern outer jet. The spectral index map between 74 and 330 MHz shows a softening of the spectral index in this extended region.

In this paper, we report on the preliminary results obtained from the spectral and morphological analysis that we performed on MeerKAT observations of Hydra A between 900 and 1525 MHz.

2. Observations and Analysis

For this study, Hydra A was observed on 30 May 2019 using 60 antennas of the MeerKAT radio telescope(Proposal ID: SCI-20190418-PA-01; PI: Prokhorov). The observations were made in the L-band configuration (856-1712 MHz) with 4096 channels of ~209 kHz per channel. The data was accumulated in four observation epochs of 30 minutes each. A standard flux and bandpass calibrator was observed for 10 minutes and a phase calibrator for 80 seconds every 15 minutes during the observation. For the data reduction we used the Containerised Automated Radio Astronomy Calibration (CARACal) pipeline [7]. The CARACal pipeline is an open source radio reduction pipeline that employs a number of data reduction packages in the Python environment. During the flagging process, two antennas were flagged as well as all the known radio frequency interference (RFI) channels, any other RFI were flagged using the tricolour[1] autoflagger. Flagging was performed once before cross-calibration and once after, before the self-calibration process. The final image at 1000 MHz (Figure 1) has a restoring beam size of 20×12 arcsecs^2, a 5σ noise level of ~ 6 mJy/beam and a peak flux of 11.76 Jy/beam. We derived the fluxes from the radio maps at four frequencies to obtain the spectral index for the different regions of Hydra A.

[1] https://github.com/ratt-ru/tricolour

3. Results

We examined the spatial morphology of Hydra A at 1000 MHz (Figure 1) and identified a pair of bright inner lobes and a pair of diffuse outer lobes. We reported and detailed these findings in a previous conference proceedings (in press)[8], in which we presented the results from a single observational epoch. Here, we report the detection of a tail-like structure at a frequency of 1000 MHz in the entire data set. This structure has only been seen previously at frequencies not exceeding 330 MHz. The morphology of this tail could be due to the motion of the radio galaxy through the cluster or due to the viewing angle of the lobes.

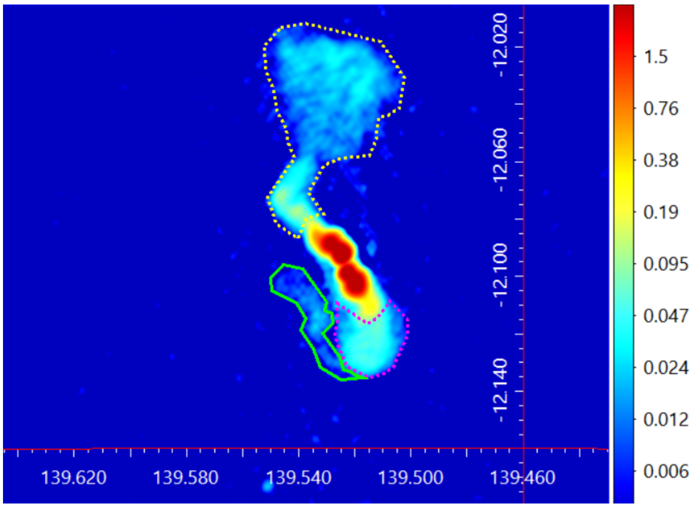

Figure 1: Radio map of Hydra A at 1000 MHz shown in equatorial coordinates of right ascension (deg) and declination (deg.). The colour bar represents the radio intensity in units of Jy/beam.

For a study of the spectral behaviour of Hydra A, we computed the radio fluxes for the outer lobes and the tail region at 1000 MHz, 1100 MHz, 1330 MHz and 1485 MHz. The regions defined as the outer lobes are indicated by the dashed yellow and magenta lines and the tail is shown by the thick solid green line in Figure 1. We found that the overall spectrum for the outer lobes in the MeerKAT frequency range is well described by a steep power law with a spectral index of 2.02 with a statistical error of 0.03. We combined our observations with the available two low-frequency observations at 74 MHz and 327 MHz [2, 9]. Extrapolating the power law derived from the MeerKAT frequency range to the 74 MHz data point yields a significantly higher flux than the measured flux of ~221 ± 30 Jy. This provides strong evidence for the presence of a spectral break that is most likely produced due to spectral aging. We found that the spectral index for the tail region is significantly softer than the spectral index of the outer lobes and exhibits a spectral index of 2.89 with a statistical error of 0.20. This softening of the spectral index can be seen in the extended region of the VLA spectral index map between 330 and 74 MHz. The softer spectral index suggests that this region of the galaxy contains electrons that have undergone the most spectral aging and is the oldest region of the galaxy.

By modelling the spectral steepening in the outer lobes, we have found that for values for the age and magnetic field strength of 35 million years and 18 μG, respectively, the overall spectrum is sufficiently well reproduced using the Kardashev-Pacholczyk model [4, 5] for spectral aging (see Figure 2). For a more refined and accurate fitting procedure, we refer the reader to a future paper, currently in preparation.

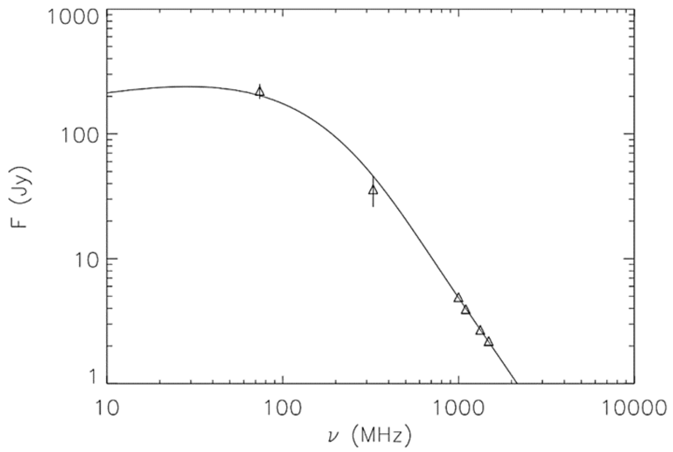

Figure 2: An illustrative model for the overall radio spectrum of the outer lobes of Hydra A.

4. Conclusion

We analyzed the entire observation of Hydra A made using the MeerKAT radio telescope. We performed a spatial analysis of the outer lobes and found a tail-like structure extending from the southern lobe. We found that the spectral index in this tail-like region is much softer than in the outer lobes pointing to more extensive spectral aging. A joint analysis with the MeerKAT data and the previous low-frequency VLA observations reveals the presence of a spectral break. We showed that the Kardashev-Pacholczyk model for spectral aging provides an adequate description for the observed spectrum of the outer lobes.

Acknowledgements

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