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ANGULAR STRUCTURE OF THE RADIO GALAXY 3C239 IN THE DECAMETER RANGE

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ABSTRACT. We present the results of the observation of the radio galaxy 3C239 with the URAN interferometers at the decameter wavelengths. According to our study, the source in this range consists of two components that coincide in position and size with the lobes of the radio galaxy observed at the decimeter wavelengths, and a compact component corresponding to one of its hot spots. Another hot spot is not detected due to its low flux density at decameter wavelengths. In addition, an extended region of radiation with low surface brightness was detected, which surrounds the source lobes. The size of this halo is 28 arcsec, and its emission at the frequency of 25 MHz is about 20% of the total flux of the radio galaxy. A possible view of spectra of the radio source components and their variation in the range from decameter to decimeter wavelengths are determined. It is noted that in contrast to the high-frequency structure of 3C239, where radiation of the compact hot spots dominates, at decameter wavelengths about 90% of the radio galaxy flux is provided by more extended components — the source lobes and the halo.

Keywords: radio source, interferometer, decameter range, brightness distribution, decameter model.

АНОТАЦІЯ. Наведено результати спостереження радіогалактики 3C239 інтерферометрами УРАН на декаметрових довжинах хвиль. Згідно з дослідженням, джерело в цьому діапазоні складається з двох компонентів, які збігаються за положенням і розміром з пелюстками радіогалактики, що спостерігаються на дециметрових хвилях, та компактного компонента, що відповідає одній з її гарячих плям. Інша гаряча пляма не виявлена через низьку густину потоку. Крім того, була виявлена протягнена область випромінювання з низькою поверхневою яскравістю, яка охоплює пелюстки джерела. Розмір цього гало становить 28 кутових секунд, а його випромінювання на частоті 25 МГц становить близько 20% від загального потоку радіогалактики. Визначено можливий вигляд спектрів компонентів радіоджерела та їх змінювання в діапазоні від декаметрових до дециметрових хвиль. Відзначається, що на відміну від високочастотної структури 3C239, де домінує випромінювання компактних гарячих плям, на декаметрових хвилях близько 90% потоку радіогалактики забезпечується більш протягненими компонентами — пелюстками джерела і гало.

Ключові слова: радіоджерело, інтерферометр, декаметровий діапазон, розподіл яскравості, декаметрова модель.

1. Introduction

Studies of extragalactic radio sources with the URAN radio interferometers have shown that their structure in the decameter range differs markedly from images obtained at the decimeter and centimeter wavelength. The difference between the spectral indices of the emission of compact and extended source components, as well as the distortion of their "linear" spectra, caused, for example, by synchrotron self-absorption in hot spots at low frequencies and/or by synchrotron losses in extended lobes at high frequencies, leads to a significant change in the source brightness distribution at the decameter wavelengths compared to the shorter ones. An increase in the angular dimensions of components of the radio sources with frequency decreasing was also found.

The most intriguing feature found at decameter wavelengths is extended, low surface brightness halos with steep spectra that are larger than the full dimensions of the sources seen at shorter wavelengths (Megn et al., 2001, Megn et al., 2006). These components are found mainly in radio-loud quasars and rarely in radio galaxies, although the difference between these two types of extragalactic radio sources is only in the orientation of their axis relative to the line of sight to an observer. Because almost all radio galaxies that we observed with the URAN were extended sources with a small redshift, while the quasars were more compact and distant objects, it was interesting to study the compact radio galaxy 3C239, located in a distant cluster of galaxies with redshift $z = 1.781$.

This source was observed in a wide frequency range, from tens of megahertz to tens of gigahertz, but the maps have been obtained only at frequencies above 1.4 GHz using MERLIN radio interferometers and the VLA aperture synthesis system (Best et al., 1997, Liu et al., 1992).

At this frequencies, the radio galaxy is the FRII-type object with angular dimensions of about 15″. It consists of two elongated lobes (southwestern and northeastern) with hot spots in them. The total flux of the northeastern lobe and its hot spot exceeds the total radiation of the southwestern lobe with the hot spot located in it by more than 3 times.

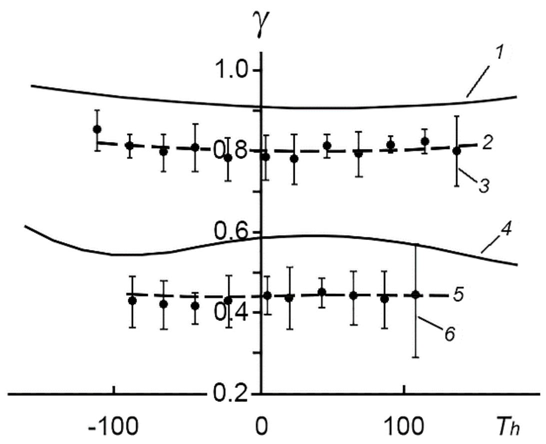

Figure 1: Normalized visibility modulus at the frequency of 25 MHz for the URAN-1*:* 1 – the high-frequency model, 2 – the decameter model, 3 – experimental data; the URAN-2: 4 – the high-frequency model, 5 – the decameter model, 6 – experimental data

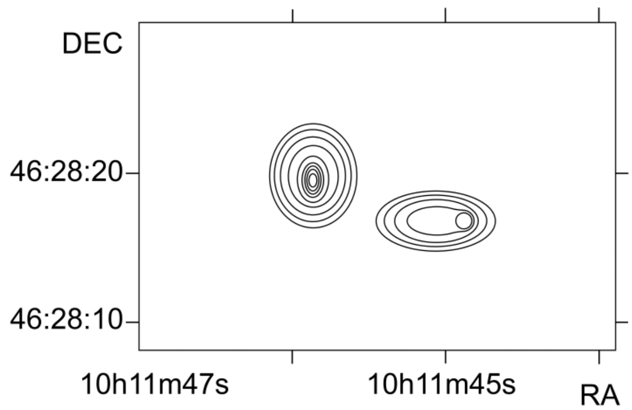

Figure 2: The model fitted to the 1.4 GHz map of 3C239

2. Observations and data reduction

Observations of the radio galaxy were carried out with the URAN interferometer network (Megn et al., 1997) at the frequencies of 20 and 25 MHz. The signals of the north-south antenna of the UTR-2 radio telescope were multiplied with the signals of four URAN antennas to form interferometer responses at different baselines. The observations of 3C239 were carried out at hour angles of ±120 minutes relative to the moment of crossing the meridian by the source with a scan duration of 20 minutes. The total amount of observations is about 20 days. The amplitudes of interferometer response obtained in the scans at a given hour angle were averaged over all observation days to find dependencies of the visibility function modulus versus the hour angle at four baselines and two frequencies.

An example of the experimental values of normalized visibility amplitudes and their errors measured with the URAN-1 and URAN-2 interferometers are shown in Fig. 1 by symbols *3* and *6*.

The dependences of the complex values of the visibility function, measured at different baselines, as is known, represent the Fourier transform of the source brightness distribution. If the coverage of the spatial frequency plane is sufficiently complete, the brightness distribution can be easily determined using the inverse Fourier transform. This approach is not acceptable with a small number of baselines and significant phase distortions typical for studies with the URAN at decameter wavelengths. So alternative method of model fitting with respect to the visibility function amplitudes is used to restore radio images of sources (Megn et al., 2001). According to this method, real source brightness distribution is represented by the model with a limited number of elliptical components with arbitrary orientated axes and a Gaussian radio brightness distribution. Then we calculate the model response for the URAN interferometers and change the parameters of the model (size, flux, and relative position of its components) attempting to minimize the difference between the calculated values and experimental dependences of the visibility modulus.

To achieve the best results of the fitting procedure, it is very important to select a good initial model. For this purpose, we choose a map of the studied radio source made in a range as close to the decameter as possible. This map should has a resolution no worse than that of the URAN's longest baseline and good reproduction of low spatial frequencies, to which the URAN-1 interferometer with the shortest baseline is sensitive. This map is transformed into the simplest model using the model fitting procedure described above. However, in this case, the calculated responses from the map are used instead of the experimental data. In this study, we used the digital map of 3C239 from the MERLIN archive, obtained at the frequency of 1420 MHz with the resolution of 0″.39×0″.34.

In the process of the map transformation into a model, individual structural elements – hot spots and lobes of the radio source were identified and their relative position, normalized flux, and angular size in the Gaussian approximation were determined. The general view of this model is shown in Fig. 2 and its parameters are in Table. 1.

The dependences of the visibility modulus on the hour angle calculated for this model are very close to the dependencies obtained for the map of the 3C239. Therefore, the resulting model describes well the real radio brightness distribution visible on the map. However, these dependencies, shown in Fig. 1 by lines *1* and *4* for the URAN-1 and URAN-2 interferometers, differ noticeably from the observational data at decameter wavelengths. It means that the angular structure of the source changes with frequency decreasing.

Table 1: High frequency model of 3C239

N	α,"	δ,"	S/S_0	θ,"	*a/b*	ψ,°
HS_{NE}	4,9	1,46	0,49	0,7	2	0
L_{NE}	4,9	1,7	0,28	2,8	1,2	0
HS_{SW}	-5,4	-1,4	0,08	0,46	1	0
L_{SW}	-3,3	-1,4	0,15	2,7	2	90

Note: *HS* – a hot spot; *L* – a lobe; α, δ – coordinates relative to the center of the source; S/S_0 – relative flux density; θ – angular size at half intensity; *a/b* – ratio of the axes of the elliptical component; ψ – position angle.

This “high frequency” model was extrapolated to low frequencies using all available information about the spectral characteristics of its components and taking into account the scattering in the interstellar medium that increases the dimensions of the most compact components of the source at decameters. The scattering angle calculated using formula (49) of (Shyshov, 2001) is equal to 0.86″ at 25 MHz and 1.4″ at 20 MHz The model with the parameters extrapolated in a such manner was used as the initial model in the fitting procedure with URAN’s data to search for the brightness distribution of 3C239 at decameter wavelengths.

3. Results

An analysis of the spectra of the source components showed that the radiation of the southwestern hot spot is too weak to detect with the URAN interferometers, so the initial model becomes a three-component one. During the model fitting of the angular structure of the source, it was assumed that the position and orientation of the components of the initial model do not change at decameter waves, and their sizes in this range are increased due to scattering in the interstellar plasma. It was found that any change in the free parameters of this model cannot provide a satisfactory agreement between the calculated values and experimental visibilities. An acceptable result can only be achieved by adding an extended detail to the model, similar to those found in previously studied quasars. Thus, the most probable decameter source model consists of four components. In addition to the new region of extended radiation, it contains two lobes with the same shape and relative position as those at high frequencies and a compact hot spot in the northeast lobe. The dimensions of the last three components are slightly enlarged. The ratio of their fluxes has changed significantly. Whereas at high frequencies the northeastern hot spot provides about half of the radiation of the radio galaxy, in the decameter range its radiation is only 14% of the total source flux, and the main part of the flux is emitted by more extended source lobes. A new extended component with an angular diameter of about 30" supplies more than 20% of the source flux.

The parameters of the resulting decameter model at frequencies of 20 and 25 MHz are given in Table. 2.

The hour angle dependences calculated for the low-frequency model are shown in Fig. 1 by dashed lines *2* and *5* for the URAN-1 and URAN-2 interferometers. A general view of the model brightness distribution at decameter waves, together with MERLIN's map at a frequency of 1420 MHz, is shown in Fig. 3. Errors in determining the parameters of the model are estimated to be 15%.

The fluxes of the parts of the radio galaxy obtained during the fittings at high and low frequencies made it possible to determine component spectra in a wide frequency range.

Table 2: The model at frequencies of 20 and 25 MHz

N	α,"	δ,"	S/S_0	θ_{25},"	θ_{20},"	a/b	ψ,°
HS_{NE}	4,9	1,46	0,14	1,1	1,6	2	0
L_{NE}	4,9	1,7	0,48	2,9	3,1	1,2	0
L_{SW}	-3,3	-1,4	0,16	2,8	3	2	90
G	0	0	0.22	28	29	1	0

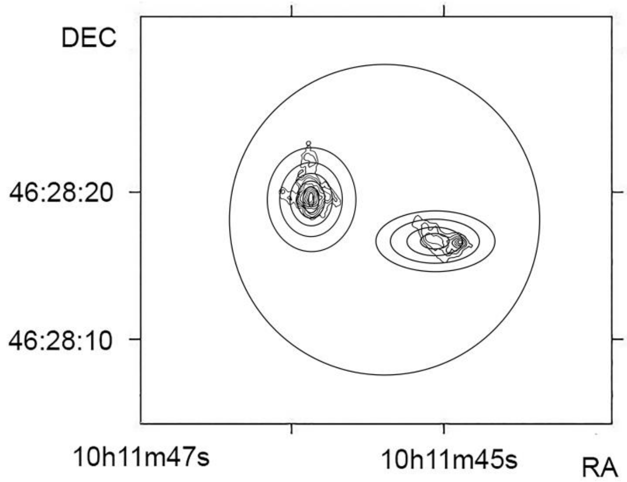

Figure 3: Model of 3C239 in the decameter range with the high-frequency map in the background

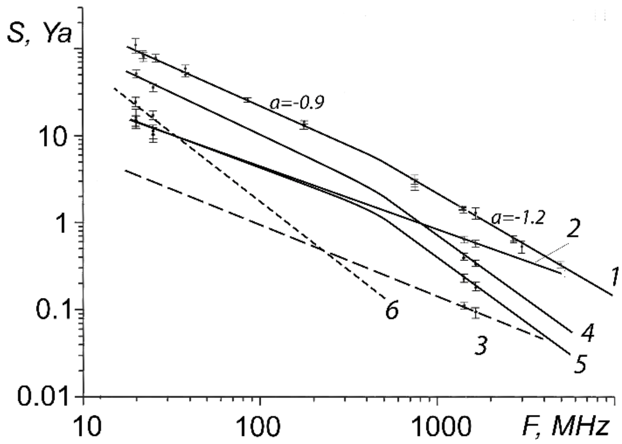

Figure 4: Spectral dependencies of 3C239

In Fig. 4. line *1* shows the total spectrum of 3C239, the spectrum of the northeastern hot spot is shown by lines *2*, the spectra of the lobes are shown by lines *4* and *5*, and the radiation of the extended halo is shown by *6*.

The decameter radiation of the southwestern hot spot is below the threshold of sensitivity of the URAN interferometers, and supposed spectrum of the component is shown by dashed line 3.

The values of the total flux density of the source at different frequencies are taken from NED (NASA/IPAC Extragalactic Database) with scale corrections according to (Baars et al., 1977). Data at the frequencies of 20 and 25 MHz were obtained in this work.

Linear approximations of the total spectrum are fitted by the least mean squares method separately at frequencies from 20 to 450 MHz and at frequencies above 450 MHz. Since the radiation of the southwestern hot spot is below the sensitivity threshold of URAN interferometers, its supposed spectrum is shown in Fig. 4 by dashed line 3.

Changes in the spectral index of the total radiation of a radio galaxy in the region of hundreds of megahertz arise from the peculiarity of the spectra of its lobes. Assuming that these features are associated with synchrotron radiation losses in these components, one can determine the synchrotron age of radio sources using formula 2 from (Murgia et al. 1999). With a break frequency of 450 MHz and a magnetic field in the lobes given in (Liu et al., 1992), it is approximately 5 My.

4. Conclusion

The angular structure of the radio galaxy 3C239 in the decameter wavelength range has been studied, and the source brightness distribution model consisting of four components has been determined in this work. We determined that:

1. Two lobes and one of the hot spots visible in high-frequency maps of the radio galaxy are detected in the decameter range.

2. The dimensions and position of these components have not changed remarkably with decreasing frequency, but the ratio of their fluxes has changed significantly. At the decameter wavelengths, the radiation of the lobes predominates, while in the decimeter range hot spots are brighter.

3. An extended halo with a low surface brightness was found, which provides about 20% of the total radio source flux in the decameter range. This component was not observed at shorter wavelengths due to its steep spectrum.

4. A break in the spectrum of the source lobes caused by synchrotron losses was detected, which made it possible to determine the age of the radio galaxy.

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