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Abstract

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FEATURES OF THE SPECTRA OF SOURCES OF COSMIC RADIO EMISSION IN THE DECAMETER WAVELENGTH RANGE

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Because of the high level of interference and the absence of effective instruments, the spectra of cosmic discrete radio-emission sources at frequencies below 30 MHz have been reliably studied in relatively few cases ($^{1-9}$).

In the present work we give the results of measurements of the spectra of 55 radio sources in the range from 25 to 12.6 MHz, carried out from October 1966 to June 1967 on a new broadband radio telescope with electrical beam steering (^{7}).

1. The measurements were carried out simultaneously at five frequencies: 12.6; 14.7; 16.7; 20 and 25 MHz. The principal results are given in Table 1, where, for the indicated frequencies, the radio-emission flux densities S are given in units of 10^{-24} W/m$^2 \cdot$ Hz, and the resulting measurement error ΔS is given in percent. Also given here are the spectral indices α_{HF} for frequencies above 38 MHz, determined by Kellermann (^{8}), and α_{LF}, determined from the data of our measurements.

The table gives data only for 38 sources for which the number of reliable measurements at each frequency was not less than 5-10; the spectra of the remaining sources are considered preliminary. For the sources 3C144, 3C274, and NRA 0416, in addition to those given in the table, flux densities were measured at the frequency 10 MHz. Their values in units of 10^{-24} W/m$^2 \cdot$ Hz are 66; 90 and 12.7, respectively. The error of these measurements is 30%.

2. Analysis of the data obtained shows that, unlike at higher frequencies, in the frequency range under study there are substantial deviations of the spectral dependence of flux density from the universal power law for the synchrotron mechanism of emission, $S \sim f^{-\alpha_{\mathrm{HF}}}$. According to the character of this dependence in the decameter range, all radio sources can be divided into four groups. The first and second groups include sources

whose spectra obey a power law with spectral index α_{LF}, equal to α_{HF} (linear on a logarithmic scale), and spectra with negative curvature.

Examples of such spectra are shown in Fig. 1A, where, along with our results, the results of measurements by Williams (^{10}), FIAN USSR (^{11}), and also works ($^{1-6,9}$) are plotted. Linear spectral dependences are fairly widespread and occur in not less than 30-40% of cases, the spectral indices usually lying within the limits $0.67 < \alpha < 1.7$.

The decrease, with decreasing frequency, of the spectral density relative to the linear dependence has been considered in detail in the literature and, as is known, without excluding synchrotron (magnetobremsstrahlung) radiation, can be explained by several mechanisms—absorption in clouds of ionized hydrogen HII, reabsorption, or a refractive index in the source of less than 1 (^{12}). It should be noted that, as the measurements carried out show, such a form of spectral dependence with a clearly expressed radiation maximum in the frequency interval 12.6-30 MHz is observed comparatively rarely—only in 4 cases (3C123, 3C157, 3C405, 3C461).

Table 1*

Source	12.6 MHz S	12.6 MHz ΔS	14.7 MHz S	14.7 MHz ΔS	16.7 MHz S	16.7 MHz ΔS	20 MHz S	20 MHz ΔS	25 MHz S	25 MHz ΔS	α_HF	α_LF	α′_LF
3C10	10,8	52	9,5	26	9,6	27	9,0	22			0,67	0,67	
3C47	5,9	34	5,1	32	3,2	19	2,9	17	2,1	17	0,89	1,71	
3C66	6,8	31	4,3	28	3,3	23	2,5	20			0,71	1,6	4,0
3C84	19,0	13	16,7	13	15,5	14	10,8	13	10,5	13	0,7	1,5	1,70
3C98	8,8	24	4,8	23	4,2	19	3,9	17	2,6	20	0,74	1,4	2,4
3C111	6,0	15	5,3	14	4,7	15	4,1	14	4,6	14	0,74		
3C123	12,8	14	10,9	14	8,8	14	10,8	15	11	16	0,74		
3C134	10,1	14	9,8	15	7,0	16	6,0	14	5,7	14	0,99		
3C144	53	29	53	15	38,3	14	31,7	14	34,2	14	0,26	0,74	1,3
3C171	3,1	25	1,8	22	1,6	20	1,6	20			0,95		
3C175	4,0	24	4,3	19	2,8	17	2,2	16			0,97		
3C196	4,5	17	3,7	14	3,1	14	3,1	14	3,1	14	0,73	0,73	
3C196.1	4,6	30	3,7	28	3,7	21	2,9	22			1,0	1,0	
3C208	3,9	46	3,1	39	2,4	33	2,3	30	2,0	31	0,81	0,81	
3C218	39	16	30	15	30	14	21,5	15			0,93	0,93	
3C219	4,4	16	4	14	2,9	14	2,2	16			0,80	0,80	
3C227	5,7	18	3,7	16	3,7	16	3,2	16			0,82		
3C234	6,8	18	5,6	16	3,1	15	3,3	15			0,85	1,6	3,4
3C252	2,8	57	2,1	38	1,8	25	1,7	24			1,08	1,08	
3C254	1,95	46	2,1	30	1,4	20	1,3	22	1,1	18	0,93	0,93	
3C264	14,4	41	5,3	22	3,8	17	3,1	16			0,78	2,2	2,5
3C265					3,0	18	1,9	17	1,7	43	0,92	0,92	
3C273					5,8	37	6,7	28	8,6	43	0,40	0,74	

Source	12.6 MHz S	12.6 MHz ΔS	14.7 MHz S	14.7 MHz ΔS	16.7 MHz S	16.7 MHz ΔS	20 MHz S	20 MHz ΔS	25 MHz S	25 MHz ΔS	α_HF	α_LF	α'_LF
3C274	91	14	87,5	14	77	14	60,5	14	52	14	0,82	0,82	
3C295	2,9	28	1,9	20	1,5	19	1,1	18	1,6	16	0,58		
3C310	8,2	15	6,4	18	4,9	14	4,4	16	4,1	16	1,0	1,0	
3C313					2,7	41	3,0	23			0,87		
3C327	11	25	7,4	21	5,3	16	5,4	15			0,85	2,1	4,3
3C338	7,9	18	5,4	19	3,4	15	2,5	15	2,6	14	1,17		
3C348	63,5	14	60	14	42	14	36,5	14	23	13	0,97	0,97	
3C353	19,0	17	16,7	17	15,5	13	10,9	13	11,3	13	0,70	0,70	
3C380					4,7	19	3,3	20			0,77	0,77	
3C382			4,2	38	3,3	34	2,2	24			0,69	1,9	2,8
3C405	319	15	317	15	266	14	270	14	315	14	0,8		
3C461	585	14	650	14	600	14	650	14	580	14	0,77		
4C58.27					2,3	53	1,5	47	1,8	44	1,15	1,15	
4C38.39					1,5	16	1,1	17			1,55	1,55	
NRA 0416	6,9	32	5,2	33	3,6	28	2,9	19	3,0	17	1,68	1,68	

* The source names are given in accordance with the 3C and 4C catalogues [15].

Significantly more often (in approximately 40% of cases), spectra of the third group were observed. These spectra are characterized by a deviation from a linear dependence toward a faster increase, as the frequency decreases, than for $f^{-\alpha_{\mathrm{HF}}}$. In this case the spectrum, naturally, can be characterized only conditionally by a power-law dependence with two spectral indices, α_{HF} and α_{LF}, determined at high ($f > 30$ MHz) and lower frequencies ($12.5 < f < 30$ MHz). Examples of such spectra are given in Fig. 1B.

The fourth group, which makes up 15-20%, should include sources with a more complex, nonmonotonic character of the spectral dependence (for example, 3C171, 3C295, 3C338); moreover, for an accurate description of these spectra, more detailed measurements are required than in the preceding cases, both in the decameter and in the meter ranges.

It should be noted that we measured the flux densities of each source independently, since relative measurements with respect to 3C461 would have had a large error because of the nonstationarity of its flux. For 3C461 in Fig. 1A two spectra are presented—one from measurements of 1961-1962 and the spring period of 1967 (b), and the second on the basis of autumn-winter measurements of 1966 (a). As follows from the figure, although the qualitative form of the spectrum remains unchanged, the spectral flux densities differ by up to a factor of 1.5. Let us note that, on the basis of numerous measurements of 3C461 carried out at decameter wavelengths [2,3,5,13], it may be concluded that, instead of the monotonic decrease of the radiation by 2% per year following from theory

Fig. 1. Spectra of radio sources

Figure 1: Fig. 1. Spectra of radio sources

^{14}, there are substantial irregular changes without a noticeable tendency toward decline.

3. The more rapid increase of spectral density with decreasing frequency in the decameter range, found for many sources, than at high frequencies had not previously been considered in the literature, with the exception of three sources: 3C66, 3C84, 3C166 (^{2},^{6}).

It is characteristic that, apart from Taurus A ($\alpha_{\text{hf}} = 0.26$; $\alpha_{\text{lf}} = 0.73$), for all these sources α_{lf} varies within wide limits, $1 < \alpha_{\text{lf}} < 2.5$, whereas α_{hf} lies in the range $0.7 \div 0.9$.

Fig. 1. *a* and *b* –data of the present work; *c* –data ($^{1-6,\ 9-11}$). Arrows with the index S indicate the scale for the source spectrum.

At present, only for one of these sources–3C144–has a low-frequency component with small angular dimensions ($\varphi \simeq 0.2''$) been found, and its spectrum has been measured directly at frequencies $26 \div 100$ MHz (^{15},^{16}). It is characterized by a large spectral index $\alpha \simeq 1.2 \div 1.4$ (^{15},^{16}). Taking into account that the spectrum measured by us is determined by the total radiation of the main source and the low-frequency component, and assuming that the spectrum of the main source remains linear with spectral index $\alpha_{\text{hf}} = 0.26$ down to 10 MHz, one can determine the spectrum of the component. This spectrum is shown in Fig. 1b. The spectral index of the component in the range $10 \div 81.5$ MHz is $\alpha'_{\text{lf}} = 1.3$*.

* Here and in Table 1, α'_{lf} is the spectral index of the low-frequency spectrum found as the difference between the resulting spectrum and the spectrum of a hypothetical source having a linear spectrum with $\alpha = \alpha_{\text{hf}}$.

Since the spectrum determined in this way agrees well with direct measurements of the spectrum of the low-frequency component at frequencies of 38 and 81.5 MHz (^{15,16}), the cause of the deviation of the spectrum of Taurus A from a linear one may be regarded as established.

The preservation of the linearity of the spectrum of the low-frequency component of Taurus A down to 10 MHz indicates the absence of reabsorption in it. Taking into account the small angular dimensions of the component, the absence of reabsorption cannot be explained within the framework of an incoherent synchrotron mechanism. It is possible that the radiation of this component is associated with the coherent synchrotron mechanism proposed by V. V. Zheleznyakov (^{17}). Assuming the frequency at which the flux density reaches a maximum to be 10 MHz, we find that the coherent mechanism proves effective for acceptable parameters of the electron concentration of the plasma and of the relativistic electrons, $1 \div 6$ el/cm^3, magnetic-field strength $H_\perp \approx 0.05 \div 0.2$ oersted, electron temperature $(0.4 \div 2) \cdot 10^5$ °K, and $E_0/mc^2 = 20 \div 30$.

However, for the other sources listed in Table 1 with spectral characteristics of types III and IV, it is not possible to explain the experimentally observed spectrum by synchrotron radiation, negative reabsorption, or other known mechanisms. If, by analogy with 3C144, one assumes that a faster-than-linear increase of the spectral density with decreasing frequency is associated with components of the sources having small angular dimensions, one might expect such sources to have increased flux variability in comparison, for example, with sources of types I and II. For this purpose, for all observed sources a measure of flux variability was determined, which was estimated by the quantity σ (in decibels), defined as

$$\sigma = \left[\sum_{i=1}^{n}(\lg S_i - \overline{\lg S})^2/(n-1)\right]^{1/2}, \qquad \overline{\lg S} = \sum_{i=1}^{n} \lg S_i/n,$$

where n is the number of independent measurements of the source at the given frequency. Although several elevated values of σ are observed for Taurus A (from 1.81 to 2.27), as an analysis of the experimental data showed, the above assumption is nevertheless not confirmed, since at all frequencies the maximum values of σ correspond to sources with a linear spectrum. For sources of all types the value of σ lies within the limits $0.6 \div 2.6$ dB, with a maximum near 1.2—1.8 dB, and there is no clear dependence of the probability distribution of σ on the type of spectral characteristic of the source. Thus, in measurements from the surface of the Earth, no increase in fluctuations is observed for sources with a spectral index large at decameter wavelengths.

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