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INTERPLANETARY FLICKERING OF RADIO SOURCES AND ITS USE IN ASTROPHYSICS

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To study the nature of astrophysical objects it is important to know the dimensions of the radio-emitting region; it is also very important to know the dependence of the source dimension on the length λ of the emitted wave.

An investigation of the angular dimensions of radio sources and of the distribution of their radio brightness is limited by the resolution θ_0 of the radiotelescopes, which is determined by the width of their directivity pattern:

$$\theta_0=\frac{\lambda}{d}; \qquad (1)$$

here d is the base of the receiver (dimension of the antenna or distance between the separated antennas). In modern radiotelescopes (such as the cruciform radiotelescope of FIAN (Academy of Sciences Physics Institute)), $d \sim 1$ km and at meter wavelengths $\theta_0 \sim 3'$—$20'$. This accuracy is insufficient to localize objects with angular dimensions smaller than 20′, or to investigate the fine structure of extended radio sources.

A method for obtaining much higher resolution was proposed in 1950[1]. It is based on observing cosmic radio emission diffracted by the moon. When diffraction by the edge of the moon's disc is used, the resolution is determined by the distance between the maxima of the diffraction pattern on earth, which coincides with the dimension $L=\sqrt{\lambda R}$ of the first Fresnel zone and by the distance $R \sim 400{,}000$ km between the moon and the earth*:

$$\theta_0=\frac{L}{R}=\sqrt{\frac{\lambda}{R}}. \qquad (2)$$

When $\lambda = 3$ m we have $\theta_0 \sim 20''$, i.e., the resolution is one order of magnitude higher than that of radiotelescopes. In principle a second part of the same diffraction pattern, located on the same straight line with the

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*To estimate L we can use, in accord with the definition of the Fresnel zone, the relation $\sqrt{R^2+L^2}-R \sim \lambda$. This yields $L=\sqrt{\lambda R} \sim 30$ km at $\lambda = 3$ m.

source and the center of the moon*, could yield a resolution $\theta_0 \sim 0.2''$, i.e., higher by two orders of magnitude. The latter method is not used in practice, however, because of the distortion of the diffraction pattern by the roughness of the lunar surface, which is comparable with the scale L, and by the need of having the source in line with the center of the moon during the time of observation. Measurements made recently during the eclipse of the radio source 3C 273[2] and of the Crab nebula[3] by the moon have yielded interesting information on the structure and distribution of the radio brightness of these objects.

The discovery in 1963 of astrophysical objects of a special type, called quasars, with angular dimensions $\lesssim 1'$, has again raised the question of obtaining a much higher resolution.

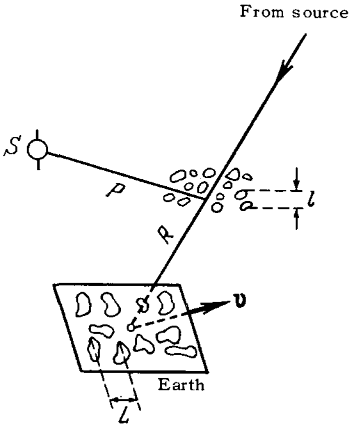
At present much promise is offered by a method based on observation of the "flicker" of radio stars. The idea of this method was first advanced in 1956[4] and was considered in detail in 1958 in [5]. The principle of this method consists in the following. If a thin layer containing statistical inhomogeneities of electron density with characteristic dimension l is located between a point source of radio waves and the earth, then the waves passing through this layer are diffracted. The entire diffraction pattern is produced at a "focal" distance $l/4\,\Phi_{sc}$ from the inhomogeneity layer, where Φ_{sc} is the characteristic angle of scattering of the radio waves by the inhomogeneities. If the dimension of the inhomogeneities is much larger than the wavelength (~ 1 m), as is the case under the conditions of the solar corona, then the conditions of geometrical optics are well satisfied, and therefore the scattering action of the inhomogeneity layer reduces to a distortion of the phase of the wave $\Delta\psi$. If $|\Delta\psi| \ll 1$, then the scale of the diffraction pattern in the plane of observation is $L \sim l$, but if $|\Delta\psi| \gg 1$, then L depends on the ratio of the dimension of the inhomogeneity (l) to the dimension of the first Fresnel zone ($\sqrt{\lambda R}$). When $l < \sqrt{\lambda R}$ we have $L \sim l$,† and when $l > \sqrt{\lambda R}$ this small-scale pattern is superimposed on the large-scale pattern, which has a characteristic dimension l. The presence of the latter is connected with the focusing action of the inhomogeneities, which occurs when $l \gg \sqrt{\lambda R}$ (see [5]).

Everything stated above pertains to a point source. With increasing angular dimension θ_s of the source, the diffraction pattern begins to smear out when

$$\theta_s \sim \frac{l}{R}, \tag{3}$$

where R is the distance from the earth to the layer containing the inhomogeneities. This makes it possible to observe sources with $\theta_s < l/R$ by determining the presence of flicker. When the inhomogeneities move with velocity v relative to the earth (see the figure), the diffraction pattern moves over the earth with the same velocity, and this leads to fluctuations of the intensity of radio emission at the point of observation ("flicker") with a period

$$\tau = \frac{L}{v}. \tag{4}$$



In 1964 Hewish, Scott, and Wills observed several radio-emission sources at a wavelength $\lambda = 1.7$ m, some of which had strongly pronounced fluctuations or radio emission with period $\tau \sim 1$–2 sec. Similar observations were made somewhat later at the Radioastronomy Station of FIAN on the 3C 48 source at a wavelength 3.5 m[8]. The observed flicker had a period ~ 3 sec. In 1965, fluctuations of radio emission from the Crab nebula were observed at $\lambda = 7.9$ m[9] with an approximate characteristic period of several seconds. In these observations the depth of modulation of intensity had a well pronounced annual variation. It decreased as the source approached the sun and disappeared completely when the source passed near the sun.

Since the oscillations of radio emission intensity observed in [7-9] have a period τ amounting approximately to several seconds, they cannot be due to the changes of the intensity of the sources themselves, inasmuch as τ is much smaller than the time of propagation of the light through the source. Rejecting like-

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*In this case the scale L of the diffraction pattern is given by

$$\sqrt{R^2+(r+L)^2}-\sqrt{R^2+r^2} \sim \lambda$$

(r = 1740 km is the radius of the moon). Hence $L \sim R\lambda/r \sim 350$ m at $\lambda = 3$ m.

†To understand the origin of the scale $L \sim l/|\Delta\psi|$, let us imagine that the layer with inhomogeneities is displaced in its own plane through a distance l. Then the phase distortion of the rays passing through a fixed point of observation will vary in the range from $-|\Delta\psi|$ to $|\Delta\psi|$. Since a change in phase by $\Delta\psi \sim 1$ corresponds to a passage from the minimum to the maximum of the diffraction pattern (or vice versa), we see that displacement of the latter through a distance l is accompanied by an alternation of $\sim |\Delta\psi|$ bands, thus giving rise to the indicated value of the scale.

wise an ionospheric origin of the observed flicker*, the authors of [5-7] reach the conclusion that the observed flicker of the radio sources is due to diffraction of radiowaves by inhomogeneities of the supercorona of the sun, which move with the same velocity as the solar wind, which in turn reaches, in accord with Parker's theory[1], about 300 km/sec over a distance $\sim 100\,R_\odot$. The parameters of the inhomogeneities of the supercorona of the sun, which are estimated from data on the scattering of radio waves, are in good agreement with relations (3) and (4) and with the corresponding scales of the diffraction pattern.

A study of the properties of the supercorona of the sun by the method of "beaming through" to distances $\sim 60\,R_\odot$ from the sun[10,11] and extrapolation of the results of these observations to larger distances allows us to estimate the minimum line-of-sight distance to the sun, p_{min}, at which a source with specified angular dimension ($\sim 1''$) satisfies the condition (3), i.e., the minimum line-of-sight distance to the sun at which flicker will be observed.

Estimates show that the flicker of radio sources in the meter band should occur at $p_{min} \sim 100\,R_\odot$, which agrees with the observations of[7,8]. The increase in the apparent dimensions of the source Φ_{sc}, observed by the "beaming through" method, at which the following relation is satisfied[6]

$$\Phi_{sc} > l/R, \tag{5}$$

allows us to estimate the upper limit of the scale l. According to estimates[10], $l \lesssim 5000\,\text{km}$ at $p = 60\,R_\odot$. Knowledge of l makes it possible in turn to estimate the upper limit of the angular dimensions of the radio source, at which observation of the flicker is possible, and which depends on p. [7]

Thus, the small angular dimensions of radio sources, which are not amenable to direct measurements, can be obtained indirectly, from the appearance and disappearance of flicker in the intensity of the radio emission. Observation of the flicker also allows us to investigate the fine structure of extensive objects. Thus, for example, in the Crab nebula it became possible to observe a powerful compact radio source with angular dimensions $\sim 0.1''$ [9]. On the other hand, observation of radio flicker in conjunction with direct measurement of the velocity of the solar wind makes it possible to study the structure of the sun's supercorona $l = l(p)$ at such large distances from the sun ($p \gtrsim 100\,R_\odot$) which were hitherto inaccessible to other radioastronomical methods. It must be noted that the region of the solar supercorona $p \sim 100\,R_\odot$ has hitherto been inaccessible to regular observations. Observation of radio flicker makes it possible in principle to carry out regular observations of the supercorona at a distance $\sim 100\,R_\odot$ and to trace the variation of $\tau = \tau(p)$ for different phases of the solar activity.

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*If the flicker were to be of ionospheric origin, then in accordance with condition (3) it would be necessary to ascribe to the inhomogeneities such a small dimension (~ 10 km) that the scattering of radio waves by such inhomogeneities should lead to visible angular dimensions $\gtrsim 10°$, which is absurd.

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