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Fig. 1

Figure 1: Fig. 1

Abstract

Full Text

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ASTRONOMY

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RADIO-INTERFERENCE PHENOMENA CAUSED BY THE IONOSPHERE OF THE MOON

(Presented by Academician V. A. Ambartsumian on 6 IX 1957)

During some solar eclipses an increase in the total radio emission of the Sun was noticed before the beginning and at the end of the eclipse. In (^{1,2}) an attempt was made to explain this phenomenon by the refraction of radio waves in the lunar ionosphere and, on the basis of the observed increase in radio emission (sometimes reaching 10–15%), to estimate the density of the Moon’s atmosphere.

Along with the refraction of radio waves in the lunar atmosphere (ionosphere), under certain conditions some phenomena of an interference character should be observed, caused by the fact that two radio rays emerging from some element of the surface of the Sun reach the observer by two different paths: one directly, the other through the ionosphere of the Moon. In this case, depending on the value of the ratio of the difference in the optical paths of the two rays to the wavelength, either an amplification of the received signal or its weakening will occur. Correspondingly, an increase of the radio emission will be obtained in the first case and a decrease in the second. A quantitative analysis of the phenomenon described, whose optical analogue may be Lloyd’ s interferometer, leads to a number of interesting results, on which we should like to dwell.

Fig. 1

Let a coherent source A, situated on the surface of the Sun* (Fig. 1), emit two beams of radio waves, one of which, AT, is directed straight to the observer on the Earth, T, while the other, ALT, is also directed toward the Earth, but after passing through the atmosphere of the Moon undergoes refraction in its ionosphere. In Fig. 1, φ_0 denotes the “angle of refraction” –the maximum

Fig. 2

Figure 2: Fig. 2

deflection of the ray as it passes through the base of the Moon' s ionosphere (for details see (^{1,2})). The magnitude of φ_0 is the greater, the greater the electron concentration of the ionosphere and the longer the wave.

Owing to the rarefaction of the Moon's ionosphere, the optical path of the second ray may be taken equal to its geometrical path, and for the path difference of the first and second rays one may simply write $\Delta s = ALT - AT$. If D denotes the distance from the Earth to the Moon, it is not difficult to find for the determination of the maximum path difference Δs_0

$$\Delta s_0 = \frac{1}{2} D \varphi_0^2. \qquad (1)$$

For the remaining rays the condition $0 \leq \varphi \leq \varphi_0$ holds, and therefore Δs will be bounded— is between zero and ΔS_0. Calculation by (1) gave the following values of ΔS_0 for various values of the refraction angle ($D = 3.8 \cdot 10^{10}$ cm). As can be seen, the maximum optical path difference ΔS_0 increases with increasing refraction angle φ_0, and already at $\varphi_0 > 1'$ it exceeds several times the limiting wavelength at which the Sun still gives sufficiently strong radio emission.

φ_0	$0'.1$	$0'.2$	$0'.5$	$1'$	$2'$	$3'$	$5'$	$8'$
ΔS_0, m	0.16	0.65	4.05	16	65	147	407	1040

At large refraction angles ($\varphi > 1'$) the phase differences of the oscillations arriving at the point T, being different, will be distributed uniformly in the interval 0—360°. As a result, the intensities of the radiation from the individual points will add, and consequently we cannot observe an interference pattern. At small refraction angles ($\varphi < 1'$) one may expect, especially in the meter-wave range, the formation of an interference pattern; however, observing this pattern will be difficult—the period of the oscillation is of the order of 0.01—0.1 sec., and the amplitude is of the order of 0.1% of the intensity of the total radio emission of the uneclipsed Sun.

Fig. 2

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* Here and below, by the surface of the Sun is meant that layer in the atmosphere of the Sun from which radio waves of the wavelength under consideration may originate.

Thus, the total radio emission of the Sun can practically not produce an interference pattern either at large or at small refraction angles.

The matter is different when local and, in particular, point sources of solar radio emission are considered. As is known, the radio-emitting capacity of these objects, which sometimes have very small dimensions, is often comparable with the total radio emission of the Sun, amounting at times to several tens of percent of it. The interference of these sources can be detected. Since the dimensions and radio-emitting capacity of the individual sources differ from one another, the general interference pattern will more likely resemble irregular fluctuations of the radiation than regular sinusoidal oscillations.

Let us suppose that, at a given phase of the eclipse, on the uneclipsed part of the surface there are k point sources with an average radiation intensity in the wavelength under consideration equal to $\overline{I}_\lambda$. If I_λ^0 is the intensity of the total radio emission of the uneclipsed part, then $I_\lambda^{(1)} = I_\lambda^0 + k\overline{I}_\lambda$ will be the full intensity of that same part (the mean level). Let, further, in a narrow arc-shaped strip of width ψ near the limb of the Moon there be a group,

consisting of n point sources (out of the total number k). If, for the wave under consideration, the condition $\psi < \varphi_0$ is satisfied, then the radiation from these sources will arrive at the point T both directly from the Sun and through the ionosphere of the Moon, and will interfere at this point. Under the assumption that all n sources in the strip ψ are distributed, for example, uniformly, we shall have, for the intensity of the radio radiation arriving at the point T,

$$I_\lambda^{(2)} = I_\lambda^0 + k\bar{I}_\lambda + \bar{I}_\lambda \delta_\lambda(n,\psi), \tag{2}$$

where

$$\delta_\lambda(n,\psi) = \sum_{i=0}^{n-1} \cos \frac{\pi}{2} \frac{D\psi^2}{\lambda} \left(1 - \frac{i}{\lambda}\right)^2 . \tag{3}$$

For a given combination of ψ, λ, and n, the factor $\delta_\lambda(n,\psi)$ in (2) may be either positive or negative. In the first case the intensity is above the mean level ($I_\lambda^{(2)} > I_\lambda^{(1)}$), and in the second case ($I_\lambda^{(2)} < I_\lambda^{(1)}$). However, as concrete calculations show, for large values of n ($n \gtrsim 8$) the factor $\delta_\lambda(n,\psi)$ (let us call it the "interference term") is only positive. Figure 2 gives the curves $\delta_\lambda(n,\psi)$ as a function of ψ for some n. These curves are similar for different wavelengths; they differ from one another only by the scale along the ψ-axis. The quantity characteristic for these curves, $a_0 = (8\lambda/D)^{1/2}$, has the following values for some wavelengths:

λ, cm	3	10	50	100	150	300	450	600
a_0	$0'.09$	$0'.16$	$0'.35$	$0'.50$	$0'.61$	$0'.86$	$1'.08$	$1'.20$

For large values of n, as is evident from Fig. 2, the interference term on the average increases as ψ decreases. This means that the narrower the region near the limb of the Moon in which a given number of sources n is concentrated and for which interference plays a role, the greater will be the increase in radio emission. Similarly, the greater the number of sources n located in a narrow strip of the solar disk whose radiation undergoes refraction in the lunar ionosphere, the greater will be the increase. At the next instant the indicated n sources will be occulted by the Moon. Therefore a sharp increase in radio emission will be followed by a sharp decrease. Considerable oscillations (fluctuations) of the radio emission result. The maxima of these fluctuations arise as a result of refraction, and the minima as a result of the occultation of sources of radio emission by the Moon. Such a natural amplification of fluctuations was very often observed during certain solar eclipses and was sometimes incorrectly attributed to the measuring apparatus.

A strip on the surface of the Sun of unit width and containing n point sources will, in projection, have an angular width in the central region of the solar disk considerably greater than when this strip is at the edge of the disk. In other words, the angle ψ within which the given group of n sources is concentrated will gradually decrease in going from the center to the edge of the disk. But, as follows from Fig. 2, with decreasing ψ (for large n) the increase in radio emission also grows, i.e., the fluctuations are amplified. This result is also confirmed by observational data. Thus, for example, a strong amplification of fluctuations at the first and fourth contacts, reaching 30–40% of the normal (uneclipsed) radio emission of the Sun, was established at the wavelength $\lambda = 1.5$ m during the total solar eclipse of 20 V 1947 (^{3}). An amplification of fluctuations by 7% before the eclipse and by 15% after the eclipse was also found at the wavelength $\lambda = 10.7$ cm during the partial eclipse of 23 XI 1946 (^{4}). In both cases they considerably exceed instrumental fluctuations. It should be noted that both observations were carried out in an epoch of maximum solar activity; in May 1947 the maximum number of sunspots was observed.

over the ten-year period (1940–1950) (^{7}). On these days many flares, prominences, eruptions, bright H_α-flocculi, H_α-fibers, etc. (^{5},^{6}) were observed on the Sun. Meanwhile, it is known that all these formations are associated with sources of radio emission.

Judging from the curve of the variation of the intensity of radio emission at wavelength $\lambda = 1.5$ m (^{3}), the duration of the "fluctuation bursts" of radio emission before and after the eclipse was of the order of 2–3 min. The relative displacement of the Moon during this time is $0'.4$—$0'.6$. This is the width of the region in which the point sources of radio emission must be concentrated.

Comparing Fig. 2 with Table 2, we find, approximately, that, for example, at $n \sim 20$, ψ should be of the order of $0'.2$—$0'.3$, which is in good agreement with the estimate given above.

In more exact calculations one should also take into account the circumstance that, when n sources are uniformly distributed within a strip on the surface of the Sun, their visible distribution will not be uniform. The intensity of radio emission in this case is also determined by relation (2), but $\delta_\lambda(n, \psi)$ now has a different form:

$$\delta_\lambda(n, \psi) = \sum_{i=1}^{n-1} \cos \frac{\pi}{2} \frac{D\psi^2}{\lambda} \left(1 - \frac{i}{n}\right)^4 . \qquad (4)$$

Allowance for the indicated effect shows that one and the same degree of fluctuation is attained in this case at a considerably larger value of ψ than in the case (3).

It is interesting to note that the theoretical amplification of fluctuations in going from the center of the disk to its edge occurs not gradually, but rather sharply, almost stepwise, and at the very edge of the disk. However, taking account of the absorption of radio waves emerging from the edge of the disk in the solar atmosphere should lead to some reduction of this contrast.

Thus, the refraction and interference of radio waves, due to the ionosphere of the Moon, and coming from point sources on the Sun, lead to an amplification of the fluctuations of radio emission before and after an eclipse. For the same source intensity, the fluctuations are amplified as its angular dimensions decrease; fluctuations from extended sources are less strong. The magnitude of the fluctuations at different wavelengths is different, but on average it increases with increasing wavelength. The study of these fluctuations, in turn, will make it possible to estimate the dimensions and power of the point sources of the Sun' s radio emission.

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[1] G. A. Gurzadyan, *Radio Astrophysics*, Yerevan, 1956, p. 245.
[2] G. A. Gurzadyan, *Izv. AN ArmSSR*, Ser. Phys.-Math. Sci., **10**, 59 (1957).
[3] S. E. Khaikin, B. M. Chikhachev, *DAN*, **58**, 1923 (1947).
[4] A. Covington, *Nature*, **159**, 405 (1947).
[5] Tr. Pulkovo Main Astr. Obs., Ser. 2, **65** (1949).
[6] *Quart. Bull. Solar Activity*, No. 69-76 (1947).
[7] J. L. Thomsen, *Southern Stars*, **14**, No. 9 (1950).