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RESULTS OF OBSERVATIONS OF THE SCATTERING OF RADIO WAVES BY THE ELECTRONIC INHOMOGENEITIES OF THE SOLAR CORONA

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I

A new method for the investigation of the solar corona, suggested by us (Vitkevitch, 1951) [1], consists of observing the radio source identified with the Crab nebula (NGC 1952; $\alpha = 05^h\ 31^m\ 40^s$, $\delta = 22^\circ\ 10'$) when it is covered by the solar corona. This occurs every year on 14–15 June.

Although the angular dimension of this source is smaller than the radio diameter of the sun, it is possible to resolve the radiation of the Crab nebula from the radiation of the sun with the aid of the interferometer method.

The first observations aimed at investigating the propagation of radio waves through the solar corona were carried out in 1951 at a wave-length of 4 metres by means of a sea interferometer. These observations did not give any positive results, as from 9 to 22 June the solar radiation was disturbed. These first observations showed, however, that during the time when the sun is quiet the interference picture of the Crab nebula might be seen quite clearly on the background of the sun.

Observations of 1952, confirmed by observations of 1953, showed that when the source of radio emission is covered by the solar corona the amplitude of the interferometer records from the source is appreciably decreased, even when the angular distance between the sun and the source is fairly large. The influence of the solar corona upon the propagation of radio waves of 3·5 metres begins to be perceptible at a distance of about $10\ R_\odot$. The influence of the corona at wave-lengths of 6 metres is perceptible at a distance of $15\ R_\odot$.

It was then suggested that the observed effect is caused by the scattering of radio waves by the electronic inhomogeneities of the outermost parts of the solar corona, which will be designated as the solar 'supercorona'.

Observations in 1954 by means of two interferometers made it possible to measure the angular dimension of the radio source and to establish how much this dimension increases when covered by the solar corona. The angular dimensions of the source may reach 18′ for 3·5 metre wave-lengths and 27′ for 5·8 metre waves (Vitkevitch, 1955) [2]. Thus it was confirmed that the observed effect is actually an effect of scattering by the electronic inhomogeneities of the solar corona. Analogous conclusions were also made by Hewish at the same time (1955) [3].

The results of our observations, and also Hewish's data, permit us to conclude that the 'supercorona' is, like the corona, somewhat asymmetric, its dimensions being somewhat larger towards the equator.

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Let us now apply the results obtained to some problems of solar radio emission. As the electronic inhomogeneities of the 'supercorona' surround the sun, the solar radio emission is determined not only by the character of the generation of the radio emission, but also by the 'supercorona' which influences the waves passing through it. The effect of scattering by the 'supercorona' affects the observed angular dimensions of individual local sources of radio emission, the distribution of the radio emission from the 'quiet' sun, and the duration of individual short periodic radio emission bursts (peaks).

A formula given by Chandrasekhar (1952) [4] may be applied in our calculations. This formula determines the root-mean-square value of the scattering angle ϕ_c in an inhomogeneous medium:

$$\phi_c = 2\sqrt[4]{\pi}\Delta n\, l^{-1/2}\sqrt{z} = \psi\sqrt{z}$$

where Δn is the root-mean-square deviation of the refractive index from unity, l is the dimension of the inhomogeneities and z the length of the path.

Writing for $z=0$: $\phi_c=\phi_0$, we have

$$\phi^2(z) = \phi_0^2 + \psi^2 z.$$

If Δn and l are slowly varying functions of z, we obtain

$$\phi^2(z) = \phi_0^2 + \int_0^z \psi^2(x)\, dx.$$

Applying this expression to the experimental data reported above, the following values of $\psi^2(r)$ were obtained, where r is the distance from the centre of the sun and the values of ϕ, ψ, and r are expressed in minutes of arc:

$$\lambda = 5{\cdot}8 \text{ metres; } \psi^2(r) = 7 - 0{\cdot}027r,$$
$$\lambda = 3{\cdot}5 \text{ metres; } \psi^2(r) = 5{\cdot}5 - 0{\cdot}033r.$$

These values of $\psi^2(r)$, obtained by us, refer to $r > 4R_\odot$, but in calculating the scattering effect on radio spots we extrapolated these expressions to smaller values of r.

It is seen that the values $\psi^2(r)$ increase with decreasing r. This is natural, as with the approach to the photosphere a greater influence of inhomogeneities upon the scattering of radio waves may be expected. Let us point out that the values $\psi^2(r)$ for different wave-lengths should satisfy the following relation:

$$\psi^2(r, \lambda_1) = \psi^2(r, \lambda_2)\,\frac{\lambda_1^4}{\lambda_2^4}.$$

In our case this relation is not fulfilled. The reason apparently is the observational errors. In the present paper we do not intend to obtain the real numerical data, and shall therefore examine the functions $\psi^2(r, \lambda)$ for two wave-lengths of 5·8 and 3·5 metres independently.

On the basis of the values of $\psi^2(r, \lambda)$ obtained above we may calculate the minimum dimensions of the radio spots caused by the scattering in the 'supercorona'. The results of these computations are tabulated in Table 1.

Table 1

	$\lambda = 3{\cdot}5$ metres		$\lambda = 5{\cdot}8$ metres	
	$\phi = 0°$	$\phi = 90°$	$\phi = 0°$	$\phi = 90°$
$r_2 = 25'$	18′	21′	25′	29′
$r_2 = 40'$	16′	21′	27′	29′

Here r_2 is the distance between the source generating the radio waves and the centre of the sun, ϕ is the angle between the direction towards the earth and the source of radio emission. It is seen that the minimum dimensions of the radio sources are 16′ to 21′ on the 3·5 metre waves and 25′ to 29′ on the 5·8 metre waves. The influence of scattering upon the dimensions of the radio-emission sources is thus very important.

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Let us pay attention now to some experimental results. The diameters of 'radio spots' obtained at the Crimean Station of the Physical Institute of the U.S.S.R. Academy of Sciences are the following: 7′.6 and 9′.8 on the

1·5 and 2 metre waves, respectively (data by Tchikhatchev), and 20′ on the 3·5 metre waves (Vitkevitch).

Let us attempt to compare these experimental results, supposing that the true dimensions of the source for two neighbouring wave-lengths are equal, and that the differences in the apparent dimensions are caused by scattering. Denoting by ϕ_n the measured angle of the observed radio spot, by ϕ_0 the proper dimensions of the radio source, and ϕ_p the angle of scattering, and assuming that the effect of scattering should be combined with the proper dimension by adding the squares, we obtain the following table:

Table 2

	Comparison of 1·5 and 2 metre waves		Comparison of 2 and 3·5 metre waves	
	1·5 metres	2 metres	2 metres	3·5 metres
ϕ_n	7′.6	9′.8	9′.8	20′
ϕ_o	5′.8	5′.8	7′.7	7′.7
ϕ_p	4′.4	7′.8	6′	18′

We see that for 1·5 and 2 metre waves the angular dimension of the radio spot equals 5′.8 and the scattering effect is of the same order. On 3·5 metre waves the effect of scattering equals 18′, which exceeds appreciably the dimensions of the source, equalling 7′.7. It is seen besides that there may be some increase of the dimension of the radio source with increasing wave-lengths.

One deviating observation may be mentioned. On 11 July 1955 a case was registered on 3·5 metres wave-length, when the dimension of the radio spot was much smaller than 20′. Consequently, either the 'supercorona' above the spot was much less intense during that day, or the source was located very far from the photosphere, which is less probable.

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The above calculations may be applied not only to local radio spots, but also to the radio emission of the 'quiet' sun.

Comparison of experimental data on the distribution of radio brightness with calculations based on a model solar corona, obtained from optical data, has shown considerable discrepancies up to the present. The radio diameter of the sun obtained experimentally for the metre wave-lengths is appreciably larger than that obtained theoretically. For instance, Machin (1951) [5], who compares the theoretical and experimental data of the distribution of solar radio brightness at 81·5 Mc./s., finds that theoretically the radiation must be absent for values $r > 2R_{\odot}$, while experimentally the fall of radiation takes place at distances of r exceeding $3R_{\odot}$. The divergence is considerable and equals 20′. A correction of this order of magnitude might be expected on account of the scattering of radio waves by the electronic inhomogeneities of the supercorona.

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REFERENCES

[1] Vitkevitch, V. V. *Dokl. Akad. Nauk U.S.S.R.* **77**, 585, no. 4, 1951.
[2] Vitkevitch, V. V. *Dokl. Akad. Nauk U.S.S.R.* **101**, 429, no. 3, 1955.
[3] Hewish, A. *Proc. Roy. Soc.* A, **228**, 238, 1955.
[4] Chandrasekhar, S. *M.N. R.A.S.* **112**, no. 5, 1952.
[5] Machin, K. E. *Nature*, **167**, 889–91, 1951.

Discussion

Owren: What are the linear dimensions of scattering elements?

Vitkevitch: There is not a unique answer. A possible combination of values is $l = 100$ km., $\Delta N_e = 1300$, at $R = 5R_{\odot}$; $\Delta N_e = 600$, at $R = 10R_{\odot}$; $\Delta N_e = 280$, at $R = 15_{\odot}$.

Hewish: Observations on the occultation of the radio star in Taurus have been carried out in Cambridge from 1950 onwards, but useful results were not obtained until 1952 owing to the enhanced radiation from sunspots. Detailed measurements made in 1953, using the large radio-telescope in addition to three interferometers of different spacing on 3·7 and 7·9 metres, were reported at the previous Jodrell Bank symposium two years ago. These showed that the apparent reduction of intensity, which could be detected to a distance of 20 solar radii, was caused by multiple scattering in the outer corona. By the application of a diffraction theory it was possible to make deductions about the scale and density of the coronal irregularities (Hewish, 1955) [1].

Similar observations carried out in 1954 and 1955 showed good agreement with the previous measurements, indicating that the irregularities are a permanent feature of the outer corona. In addition, the results have all shown a slight systematic asymmetry, the scattering being greater when the radio source recedes from the sun. Because the sun's axis is not exactly perpendicular to the path of the radio source this could be explained if the contours of constant scattering were ellipses, extended in the equatorial plane, having an axial ratio of about 0·6.

REFERENCE

[1] Hewish, A. *Proc. Roy. Soc.* A, **228**, 238, 1955.