

INTERPLANETARY SCINTILLATION AND ITS RELATION TO THE ANGULAR STRUCTURE OF RADIO SOURCES

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(Received 1966 March 21)

Summary

The recent discovery of interplanetary scintillation has provided a new technique for deriving information about the angular structure of radio sources in the range $0''.1-1''$. A full account is given of the theory of the method and its practical application. The possibilities of the technique are illustrated by some typical observations at a frequency of 178 Mc/s.

1. Introduction. It has recently been discovered that radio sources possessing angular diameters less than about $1''$ exhibit rapid fluctuations of intensity when observed within 90° of the Sun. A consideration of the diffraction phenomena which arise from the passage of radiation through a medium containing random inhomogeneities of refractive index indicates that the fluctuations are readily accounted for by diffraction of this kind and it can be shown that the diffracting region is situated far beyond the magnetosphere. The effect has therefore become known as interplanetary scintillation (1, 2) and it is a further manifestation of the irregularities of plasma density whose presence has already been revealed, at distances somewhat closer to the Sun, by the angular scattering of radiation from the Crab nebula and other radio sources (3).

Study of the diffraction patterns caused by interplanetary irregularities provides a valuable technique for further investigation of the interplanetary medium and preliminary measurements have already shown that irregularities of electron density, with a typical scale of a few hundred kilometres and moving outwards under the action of a solar wind, are a permanent feature of the interplanetary medium to distances of, at least, the Earth's orbit (4).

The degree to which a radio source exhibits interplanetary scintillation is dependent upon its angular structure and the phenomenon provides a new method for the measurement of angular diameters in the range $0''.1-1''$. It may be applied to any source which is detectable with a sufficiently large signal/noise ratio and the method is thus likely to be particularly important for sources of low flux density which lie beyond the limits of detectability of long base-line interferometers. In addition, unlike interferometric methods, the scintillation technique lends itself naturally to measurements at low frequencies and should be particularly useful in the study of the variation of spectral index across a source.

It is the purpose of this paper to discuss fully the application of interplanetary scintillation to the measurement of radio source diameters. It will be shown how the variation of scintillation as a radio source approaches the Sun may be treated quantitatively and how the changing diffraction parameters provide a system of increasing angular resolution as the separation of the source and the Sun

decreases. The method is illustrated with reference to some typical observations of a few radio sources at a frequency of 178 Mc/s, but the application of the method to a larger quantity of observational material at this frequency will be described in another paper.

2. *The relation between scintillation and source dimensions*

2.1. *Diffraction by phase-changing irregularities.* The diffraction effects which occur when radiation traverses an extended medium containing randomly distributed phase-changing irregularities have been treated theoretically by many authors (see, for example, the reviews by Chernov (5) and Tatarski (6)). The problem is straightforward when the scattering is 'weak' i.e. the total phase modulation imposed upon the wavefront is smaller than one radian. In this case the diffracted energy is small compared to the energy which remains in the unscattered wave and multiple scattering may be ignored. The physical situation is readily visualized by considering, for example, a thin layer of such a medium in which it is supposed that the irregular phase-variations have some characteristic length l . It may be shown that fluctuations of wave-amplitude in the resulting diffraction pattern develop progressively with increasing distance from the layer for distances less than l^2/λ where λ is the wave-length; this region may be called the Fresnel region. At greater distances any point in the diffraction pattern is receiving scattered waves from many irregularities at once and this may be called the Fraunhofer region. In the Fraunhofer region the variations of amplitude have a Rice distribution and show no further increase with distance from the layer; the diffraction pattern has a constant scale which is the same as that of the phase-variations initially imposed upon the wave. The diffraction pattern for an extended medium is readily derived by superposing the patterns from each component layer and it is seen that the (small) amplitude variations increase in magnitude progressively as a wave travels into an extended medium.

In the more general case, when the phase deviations imposed by the medium are larger than one radian, multiple scattering has to be taken into account and the problem has not yet been fully solved. Progress has been made (7, 8) but it appears that a solution put forward by Chernov is in error (9, 10). The broad distinction between the Fraunhofer and Fresnel regions remains but in the Fraunhofer region the amplitude variations (no longer small) now have a Rayleigh distribution. An important difference as compared with the weak scattering case is that the scale of the diffraction pattern in the Fraunhofer region is less than l and is of the order $l/\Delta\phi\sqrt{2}$ where $\Delta\phi$ is the total r.m.s. phase deviation imposed upon the wave as it traverses the medium (7). Thus the characteristic scale of the diffraction pattern decreases progressively as a wave travels further into an irregular medium while the average magnitude of the fluctuations does not change. The decreasing scale is, of course, related to the increasing range of angles into which the radiation is scattered as it propagates through the medium.

2.2. *The scintillation problem.* Consider the diffraction pattern, in an x, y plane perpendicular to the direction of incidence, caused by an extended diffracting medium situated between the source and the x, y plane. An ideal point source of unit intensity located at great distance from the x, y plane, so that the diffracting region is illuminated by plane waves, will give rise to an intensity distribution $I(x, y)$. We define the diffraction pattern to be the function $f(x, y)$

where $f(x, y) = (I - \langle I \rangle) / \langle I \rangle$, averages being taken across the x, y plane. It is convenient also to define a scintillation index S where

$$S = \langle f(x, y)^2 \rangle^{1/2}.$$

The magnitude of S will depend upon the properties of the irregular medium and may vary from a value of unity, corresponding to the Fraunhofer region in the case of strong scattering, to zero when no fluctuations exist.

An extended source, which may be represented by an intensity distribution $p(\theta, \phi)$, where $\iint p(\theta, \phi) d\theta d\phi = 1$, will give rise to a pattern $g(x, y)$ having a scintillation index $\langle g(x, y)^2 \rangle^{1/2}$ which is generally smaller than the scintillation index for a point source. We now define another useful quantity, the scintillation visibility V , where

$$V = \frac{\langle g(x, y)^2 \rangle^{1/2}}{\langle f(x, y)^2 \rangle^{1/2}}.$$

It is also important to consider the scale of the diffraction patterns and these may be represented by the auto-correlation functions

$$\rho_f(\zeta, \eta) = \langle f(x, y)f(x + \zeta, y + \eta) \rangle$$

and

$$\rho_g(\zeta, \eta) = \langle g(x, y)g(x + \zeta, y + \eta) \rangle.$$

The general problem is to find how V and $\rho_g(\zeta, \eta)$ are related to the angular structure $p(\theta, \phi)$ of the source when the statistical properties of the irregular diffracting medium are given. In what follows it will be necessary to consider the Fourier transforms of certain quantities and so we write

$$f(x, y) \Leftrightarrow F(s_1, s_2) \quad \text{to denote the Fourier pair}$$

$$f(x, y) = \iint F(s_1, s_2) \exp \{2\pi i (s_1 x + s_2 y)\} ds_1 ds_2$$

$$F(s_1, s_2) = \iint f(x, y) \exp \{-2\pi i (s_1 x + s_2 y)\} dx dy.$$

$$\begin{aligned} \text{Similarly we have } g(x, y) &\Leftrightarrow G(s_1, s_2) \\ \text{and } p'(\zeta, \eta) &\Leftrightarrow P(s_1, s_2). \end{aligned}$$

2.3. Scattering irregularities confined to a thin layer. It is simplest to consider, initially, that the random phase-changes occur within a thin layer situated at a definite distance L above the x, y plane as shown in Fig. 1. It will also be assumed, as in the case of practical interest, that all angles are small. If a point source at P produces a diffraction pattern $f(x, y)$ in the x, y plane, then the same source displaced by angles θ, ϕ at P_2 will produce a similar pattern shifted by distances $L\theta$ and $L\phi$. The diffraction pattern for an extended source $p(\theta, \phi)$ is therefore given by

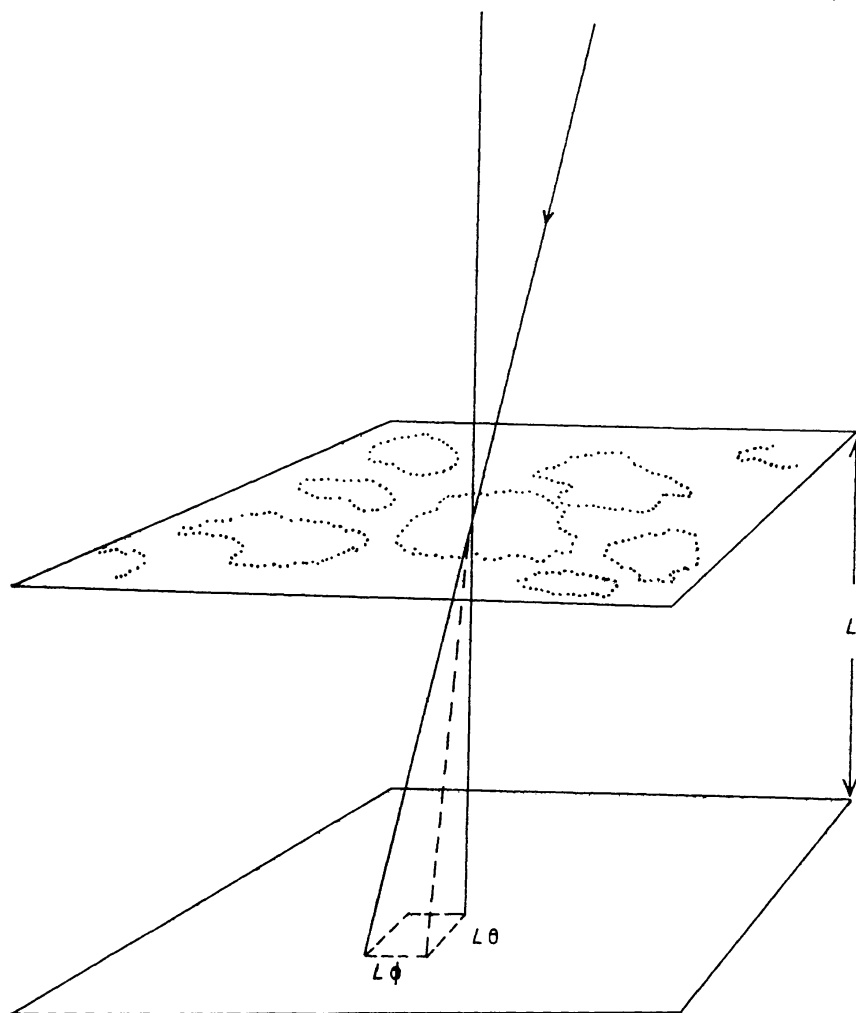
$$g(x, y) = \iint p(\theta, \phi) f(x - L\theta, y - L\phi) d\theta d\phi.$$

Introducing new variables $\zeta = L\theta, \eta = L\phi$ we have

$$g(x, y) = \frac{1}{L^2} \iint p(\zeta/L, \eta/L) f(x - \zeta, y - \eta) d\zeta d\eta$$

and if

$$p'(\zeta, \eta) = \frac{1}{L^2} p(\zeta/L, \eta/L)$$

FIG. 1. *Geometry of thin layer diffraction.*

it is apparent that the integration represents the convolution of $p'(\zeta, \eta)$ and $f(x, y)$. Application of the convolution theorem yields the result

$$G(s_1, s_2) = P(s_1, s_2)F(s_1, s_2)$$

where the transform relations are as defined in the previous section. Now the scale of the diffraction pattern $g(x, y)$ may be expressed in terms of the auto-correlation function $\rho_g(\zeta, \eta)$ where

$$\begin{aligned} \rho_g(\zeta, \eta) &\Leftrightarrow [G(s_1, s_2)]^2 \\ &\Leftrightarrow [P(s_1, s_2)F(s_1, s_2)]^2. \end{aligned} \quad (1)$$

This expression is convenient for studying the effect of the varying angular structure of a source upon the scale of the diffraction pattern. In order to determine the scintillation visibility (V) we note that, from Parseval's theorem,

$$\begin{aligned} \langle [f(x, y)]^2 \rangle &\propto \iint [f(x, y)]^2 dx dy \\ &\propto \iint [F(s_1, s_2)]^2 ds_1 ds_2 \end{aligned}$$

and similarly for $g(x, y)$.

Thus

$$V^2 = \langle [g(x, y)]^2 \rangle / \langle [f(x, y)]^2 \rangle \\ = \frac{\iint [P(s_1, s_2)F(s_1, s_2)]^2 ds_1 ds_2}{\iint [F(s_1, s_2)]^2 ds_1 ds_2}.$$

This expression affords a convenient means of studying how the scintillation visibility is modified by the angular structure of a source. Detailed calculations for particular source models using expressions (1) and (2) will be discussed in the following section.

3. *Scintillation for different source models.* In this section use is made of the relations (1) and (2) derived above in order to ascertain quantitatively how V and ρ_g depend upon the angular structure of different model sources. It is assumed that the diffracting irregularities are confined to a thin layer and that $\rho_f(\zeta, \eta)$ is circularly symmetrical and of the form $\rho_f(\zeta, \eta) = \exp\{-(\zeta^2 + \eta^2)/\zeta_0^2\}$. For a circular Gaussian source whose intensity distribution may be written

$$p(\theta, \phi) = (1/\pi\theta_0^2) \exp\{-(\theta^2 + \phi^2)/\theta_0^2\} \quad \text{we have} \\ p'(\zeta, \eta) = (1/\pi L^2\theta_0^2) \exp\{-(\zeta^2 + \eta^2)/L^2\theta_0^2\} \\ \Leftrightarrow \exp\{-\pi^2 L^2\theta_0^2(s_1^2 + s_2^2)\}.$$

Now

$$\rho_f(\zeta, \eta) = \exp\{-(\zeta^2 + \eta^2)/\zeta_0^2\} \Leftrightarrow \pi\zeta_0^2 \exp\{-\pi^2\zeta_0^2(s_1^2 + s_2^2)\}$$

and substituting in relation (2) gives

$$V^2 = \frac{\iint \exp\{-2\pi^2 L^2\theta_0^2(s_1^2 + s_2^2)\} \exp\{-\pi^2\zeta_0^2(s_1^2 + s_2^2)\} ds_1 ds_2}{\exp\{-\pi^2\zeta_0^2(s_1^2 + s_2^2)\} ds_1 ds_2} \\ = [1 + 2(L\theta_0/\zeta_0)^2]^{-1}.$$

Employing relation (1) we may also derive

$$\rho_g(\zeta, \eta) = \exp\{-(\zeta^2 + \eta^2)/(\zeta_0^2 + 2L^2\theta_0^2)\}$$

where for convenience the auto-correlation function has been normalized to unity when $\zeta = \eta = 0$.

This shows that the scale of the diffraction pattern is increased by a factor $(1 + 2L^2\theta_0^2/\zeta_0^2)^{1/2}$. The increase represents the blurring of fine structure in the diffraction pattern which is associated with the decrease of scintillation visibility.

Similar calculations have been carried out for other idealized source models and the results are summarized in Table I.

Curves of V as in functions of the parameters $(\zeta_0/L\theta_0)$ are plotted in Fig. 2 for the models listed in the Table I. It can be seen that for simple models such as (a), (b), and (c), there is little difference between the shapes of the visibility curves. A source whose extent in one dimension exceeds that in another gives a visibility curve much the same as a symmetrical source of intermediate diameter

TABLE I

<i>Model</i>	V^2	<i>Normalized</i> $\rho_\theta(\zeta, \eta)$
(a) Symmetrical Gaussian.		
$p(\theta, \phi) = \frac{1}{\pi\theta_0^2} \exp\left(-\frac{\theta^2 + \phi^2}{\theta_0^2}\right)$	$\left[1 + 2\left(\frac{L\theta_0}{\zeta_0}\right)^2\right]^{-1}$	$\exp\left(-\frac{\zeta^2 + \eta^2}{\zeta_0^2 + 2(L\theta_0)^2}\right)$
(b) Extended Gaussian.		
$p(\theta, \phi) = \frac{1}{\pi\theta_0\phi_0} \exp\left(-\left[\frac{\theta^2}{\theta_0^2} + \frac{\phi^2}{\phi_0^2}\right]\right)$	$\left[1 + 2\left(\frac{L\theta_0}{\zeta_0}\right)^2\right]^{-\frac{1}{2}} \left[1 + 2\left(\frac{L\phi_0}{\zeta_0}\right)^2\right]^{-\frac{1}{2}}$	$\exp\left(-\left[\frac{\zeta^2}{\zeta_0^2 + 2(L\theta_0)^2} + \frac{\eta^2}{\zeta_0^2 + 2(L\phi_0)^2}\right]\right)$
(c) Double 'point' source.		
$p(\theta, \phi) = \frac{1}{2}\delta\left(\frac{\theta_0}{2} + \frac{\theta}{2}\right) + \frac{1}{2}\delta\left(-\frac{\theta_0}{2}\right)$	$\frac{1}{2} \left[1 + \exp\left(-\frac{L^2\theta_0^2}{\zeta_0^2}\right)\right]$	$\left\{\frac{1}{2} \exp\left(-\frac{\zeta^2}{\zeta_0^2}\right) + \frac{1}{2} \left[\exp\left\{-\frac{(\zeta - L\theta)^2}{\zeta_0^2}\right\} + \exp\left\{-\frac{(\zeta + L\theta)^2}{\zeta_0^2}\right\}\right] \exp\left(\frac{-\eta^2}{\zeta_0^2}\right)\right\}$ $\times 2 \left[1 + \exp\left(-\frac{L^2\theta_0^2}{\zeta_0^2}\right)\right]^{-1}$
(d) Core-halo source		
Core of intensity I_1	$\frac{I_1}{(I_1 + I_2)} \frac{1}{\pi\theta_0^2} 2 \exp\left(-\frac{\theta^2 + \phi^2}{\theta_0^2}\right) \frac{I_1^2}{(I_1 + I_2)^3} \left[1 + 2\left(\frac{L\theta_0}{\zeta_0}\right)^2\right]^{-1}$	$\exp\left(-\frac{\zeta^2 + \eta^2}{\zeta_0^2 + 2(L\theta_0)^2}\right)$
Halo of intensity I_1		
radius $\gg \zeta_0/L$		

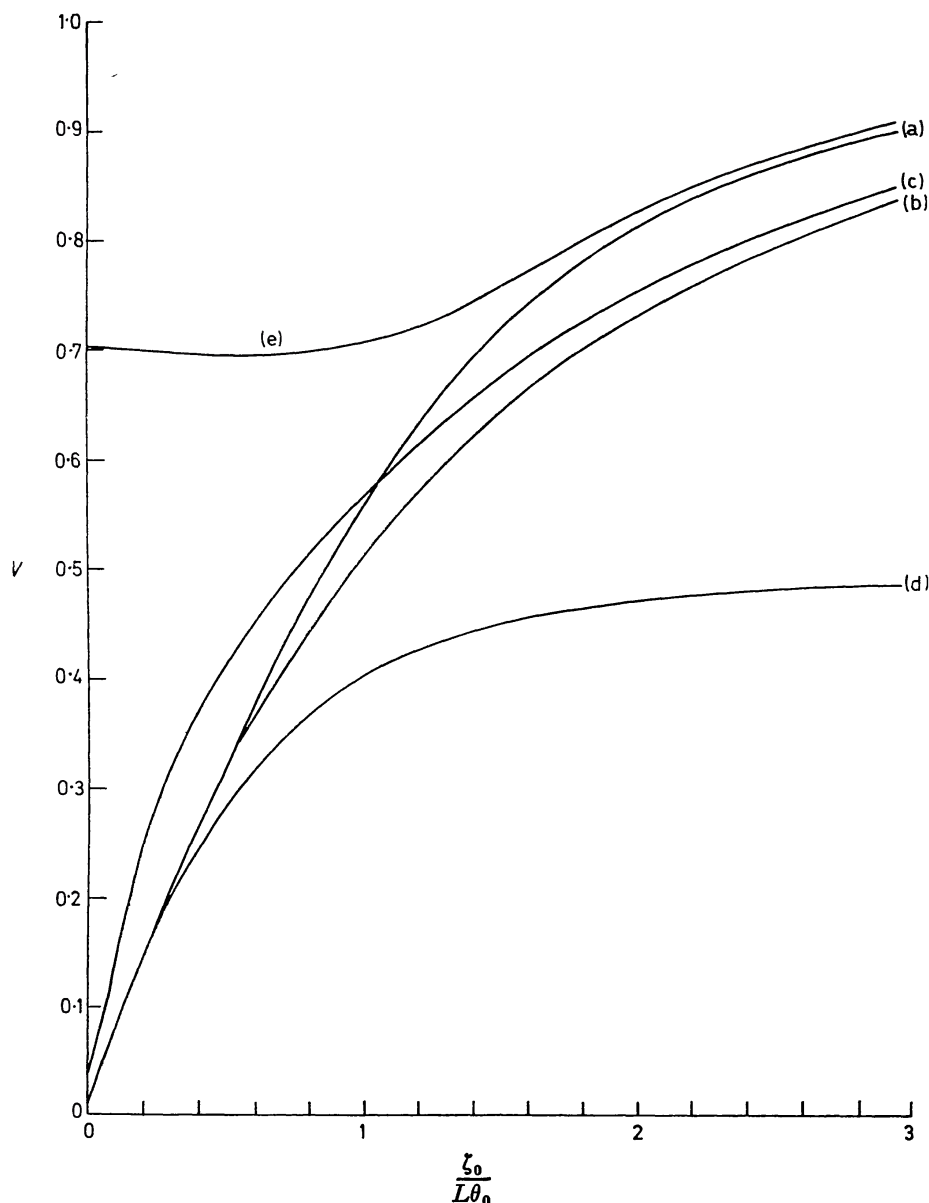


FIG. 2. $V(\xi_0/L\theta_0)$ for idealized source models. (a), Symmetric Gaussian: radius (to $1/e$) θ_0 ; (b), Extended Gaussian: semi-axes (to $1/e$) $2\theta_0$, $\frac{1}{2}\theta_0$; (c), Line source: semi-axes $2\theta_0$, 0; (d), Core-halo source: 50% core, radius $\frac{1}{2}\theta_0$, 50% halo, radius $\gg \xi_0/L$; (e), Double point source: separation $2\theta_0$.

but it is important to notice that scintillation only occurs for a source which is sufficiently narrow in both dimensions; a negligible extent in one direction will not, by itself, give rise to scintillation. It should, however, be possible to distinguish sources of marked complexity, such as (d) and (e), by means of the characteristic nature of their visibility curves.

Further information may, in principle, be obtained from $\rho_g(\zeta, \eta)$ but the measurements are difficult since they demand simultaneous observations made with at least three spaced receivers. If such information were available, however, it should be possible to distinguish sources extended in one dimension from circularly symmetrical sources, while the double-peaked form of $\rho_g(\zeta, \eta)$ for a double source should be clearly recognisable (Fig. 3).

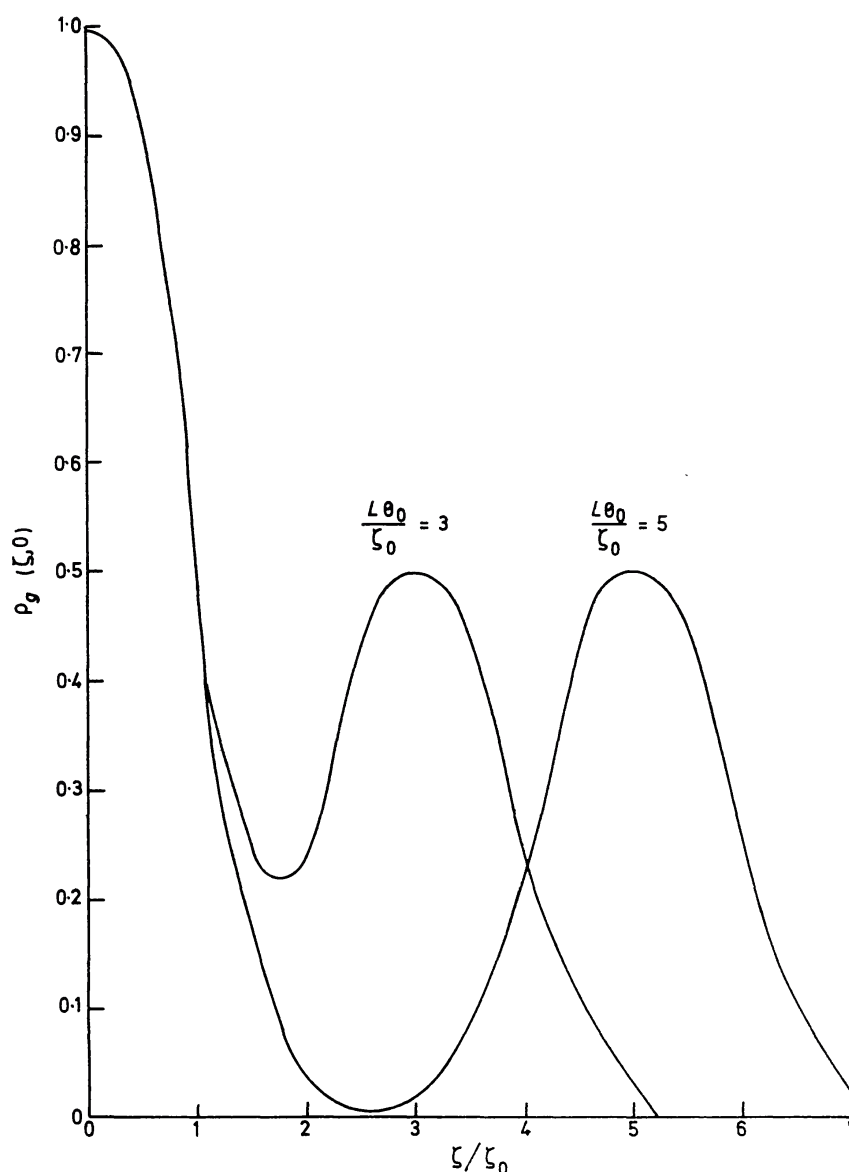


FIG. 3. $\rho_g(\zeta, 0)$ for double point source, separation θ_0 .

4. *Application of the scintillation method.* In order to make use of the theory described in the previous sections it is necessary to consider three additional topics. First, the interplanetary medium is extended and not a thin layer as treated in Section 2. Second, while it is now known that the medium constitutes a 'weak' scatterer for distances exceeding about 0.3 A.U. from the Sun at metre wavelengths (4) this is certainly not true for smaller distances and multiple scattering must therefore be taken into account. Finally, it is necessary to discuss the measurement of the relevant diffraction parameters which are required for the calculation of quantitative results. These points will now be considered in turn.

4.1. *Extended scattering medium.* It will be shown below that the finite extent of the scattering medium is only important at great distances from the Sun where multiple scattering can be ignored. A simple model is therefore

considered in which the scattering medium consists of N parallel layers, each layer being similar to that discussed in Section 2.3. It is assumed that each layer contains many irregularities so that there is no correlation from layer to layer. Suppose that the n th layer by itself produces a diffraction pattern $f_n(x, y)$ for an ideal point source and $g_n(x, y)$ for some extended source. Since multiple scattering may be ignored the resultant diffraction pattern is derived by superposing the patterns for each layer, giving $g(x, y) = \sum g_n(x, y)$. Now each component pattern has a phase which varies randomly from layer to layer and in summing the contributions intensities must be added whence

$$\langle [g(x, y)]^2 \rangle = \sum \langle [g_n(x, y)]^2 \rangle.$$

Thus

$$V^2 = \sum \langle [g_n(x, y)]^2 \rangle / \sum \langle [f_n(x, y)]^2 \rangle.$$

If each layer is statistically similar and the Fraunhofer condition applies (cf. Section 2.1) then

$$\sum \langle [f_n(x, y)]^2 \rangle = N \langle [f_n(x, y)]^2 \rangle$$

and

$$V^2 = \frac{1}{N} \sum V_n^2$$

where

$$V_n^2 = \langle [g_n(x, y)]^2 \rangle / \langle [f_n(x, y)]^2 \rangle.$$

This analysis shows that the scintillation visibility for an extended scattering medium is simply the r.m.s. of the values calculated for each component layer. If the Fraunhofer approximation were not valid it would be necessary to perform a weighted average, the most distant layers receiving the greatest weight.

It follows that a knowledge of the relation between V and L for a single layer leads immediately to the magnitude of V for an extended scattering region. To investigate the effect quantitatively it is convenient to suppose that the medium has a thickness D and is centred at distance L from the plane of observation. Curves of V as a function of $(L\theta_0/\zeta_0)$ have been computed for various values of the ratio D/L for a Gaussian source and are shown in Fig. 4. It may be seen that V is reduced somewhat more slowly when D is large, but the effect is small provided that $D/L < 1$.

Scattering by the interplanetary medium is known (3) to decrease with radial distance r according to a power law $(r/R_\odot)^{-1.6 \pm 0.2}$ so that this scattering region is effectively confined to the vicinity of the distance of closest approach of a line of sight to the Sun. For the interplanetary medium the fluctuations on 178 Mc/s are fully developed at distances greater than about 0.25 A.U., so that the Fraunhofer assumption in the preceding analysis will be valid except when a source is observed at large angles from the Sun. For sources observed within about 60° , then, it appears that a consideration of the finite extent of the scattering region makes only a negligible difference to the scintillation visibility.

4.2. Multiple scattering close to the Sun. From direct measurements of angular scattering using interferometric techniques and from observations of interplanetary scintillation it is known that multiple scattering becomes important for distances within about 0.3 A.U. from the Sun at a frequency of 178 Mc/s.

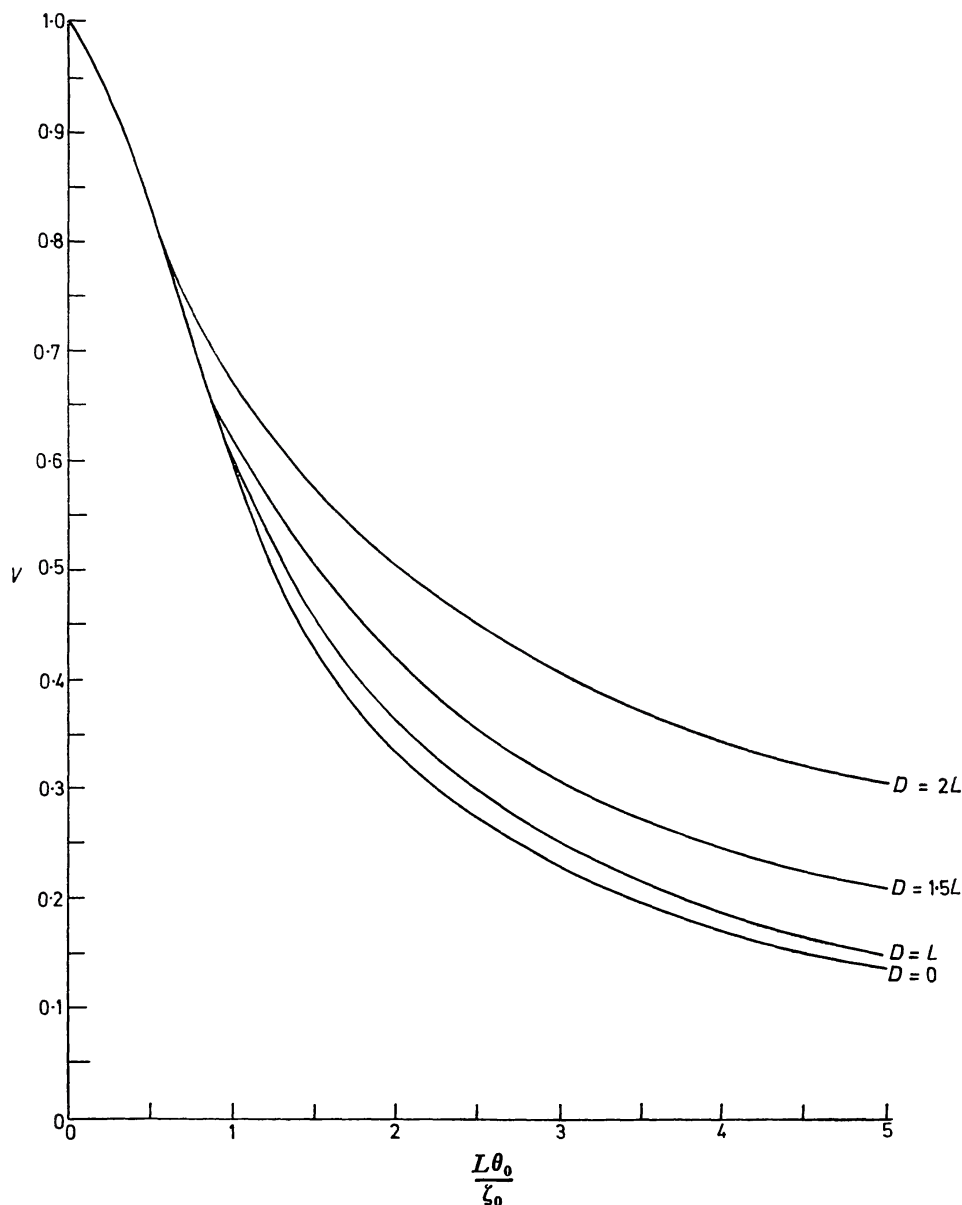


FIG. 4. $V(L\theta_0/\zeta_0)$ for extended medium and Gaussian source of radius $(\pi/e)\theta_0$.

At such close distances to the Sun the dominant scattering takes place over a small range of L and it is a good approximation to assume that scattering is confined to a thin layer. The analysis leading to expression (2) is consequently still valid and no difficulties arise from an incomplete theory of multiple scattering. Such difficulties would only be important for observations at a long wavelength where multiple scattering might occur at distances approaching 1 A.U. from the Sun.

4.3. *Estimation of the diffraction parameters.* A series of observations as a radio source approaches the Sun can be reduced to yield V as a function of ζ_0/L and a comparison of this curve with those computed for different models as shown in Fig. 2 provides information about the angular structure of the source when ζ_0 and L are known.

It is a simple matter to derive the scintillation index (S) directly from the records but to compute the corresponding values of V it is necessary to know the scintillation index for an ideal point source observed in the same positions, relative to the Sun, as the radio source under investigation. The diffracting properties of the interplanetary medium vary randomly from day to day (4) and they also show systematic variations during the solar cycle and with heliographic latitude (3). Any set of observations must make allowance for these variations by means of a suitable calibration technique. Sources of sufficiently small angular diameter for this purpose may be recognised since they must produce a scintillation index of unity sufficiently close to the Sun where the phase deviations imposed by the interplanetary medium are larger than one radian. The sources 3C 119, 3C 138 and 3C 237 appear to approach this ideal at 178 Mc/s and in Fig. 6 (a) is shown a set of contours (assuming an elliptical distribution) of constant scintillation index derived from observations of these sources. For the purposes of calculation it is convenient to use a co-ordinate system (p, θ) as shown in Fig. 5. The scintillation visibility for a source under investigation may thus be derived by dividing the observed scintillation index by a value read from the contour map.

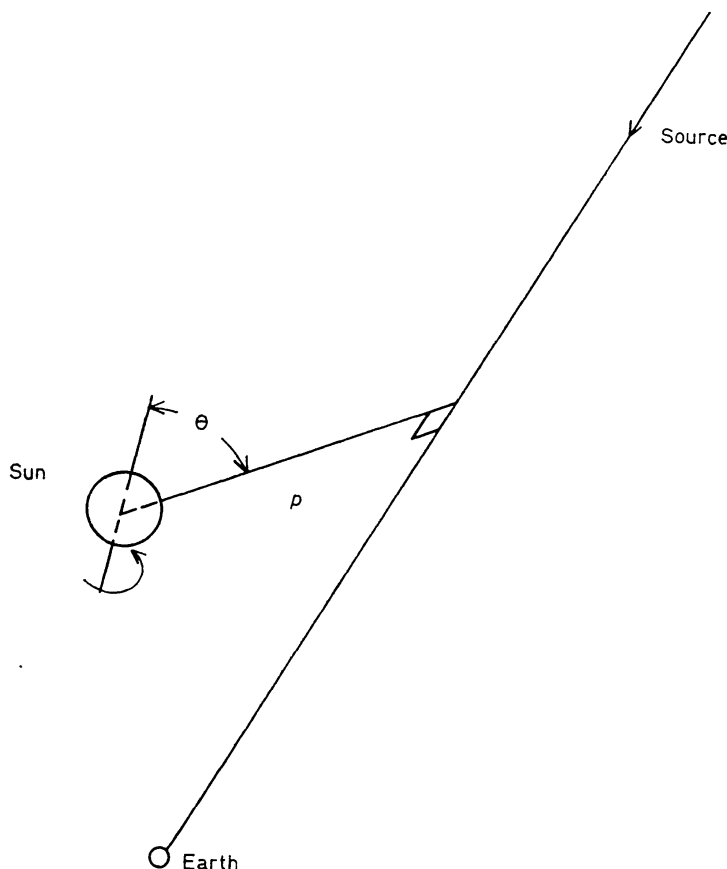
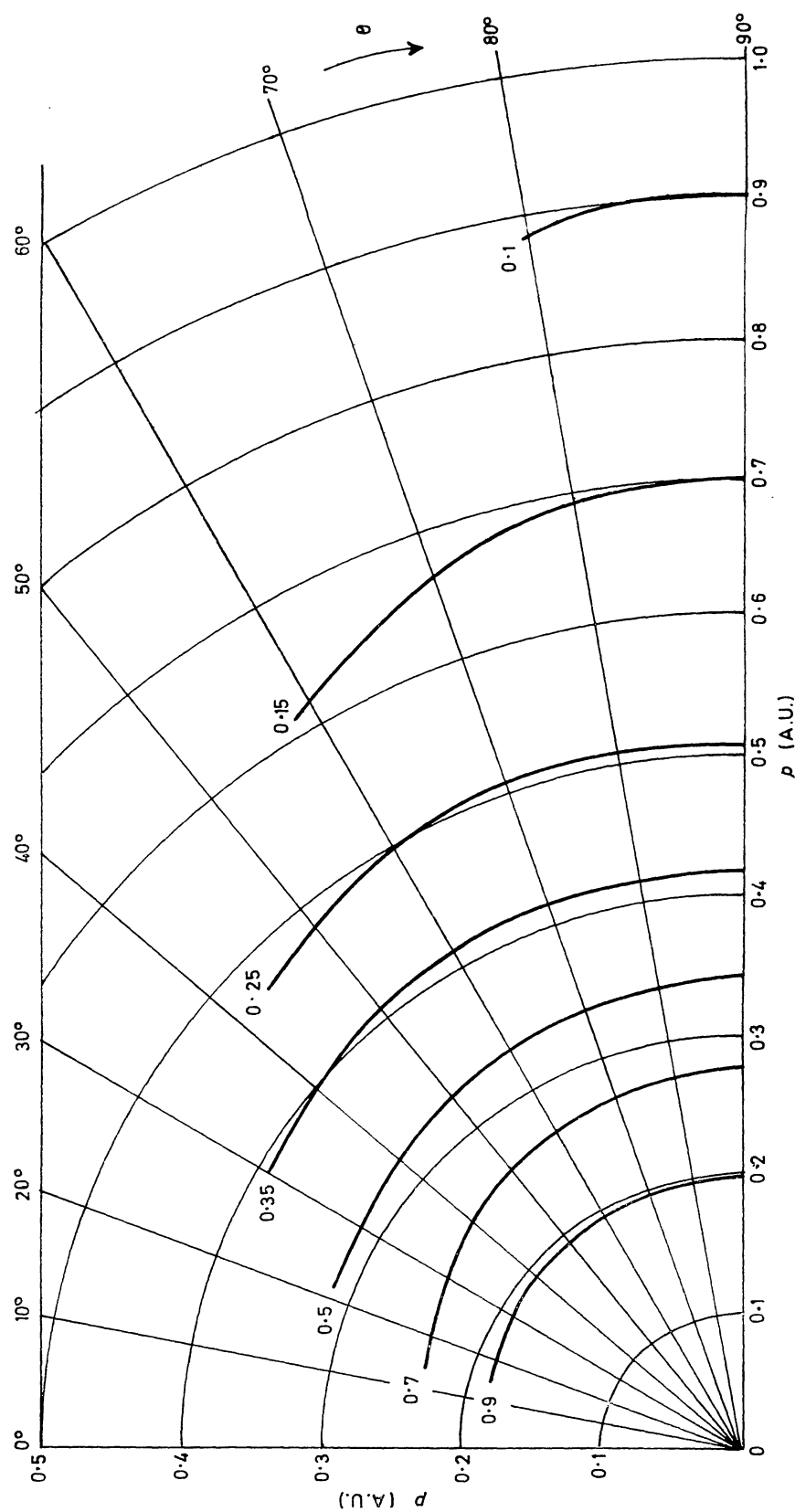
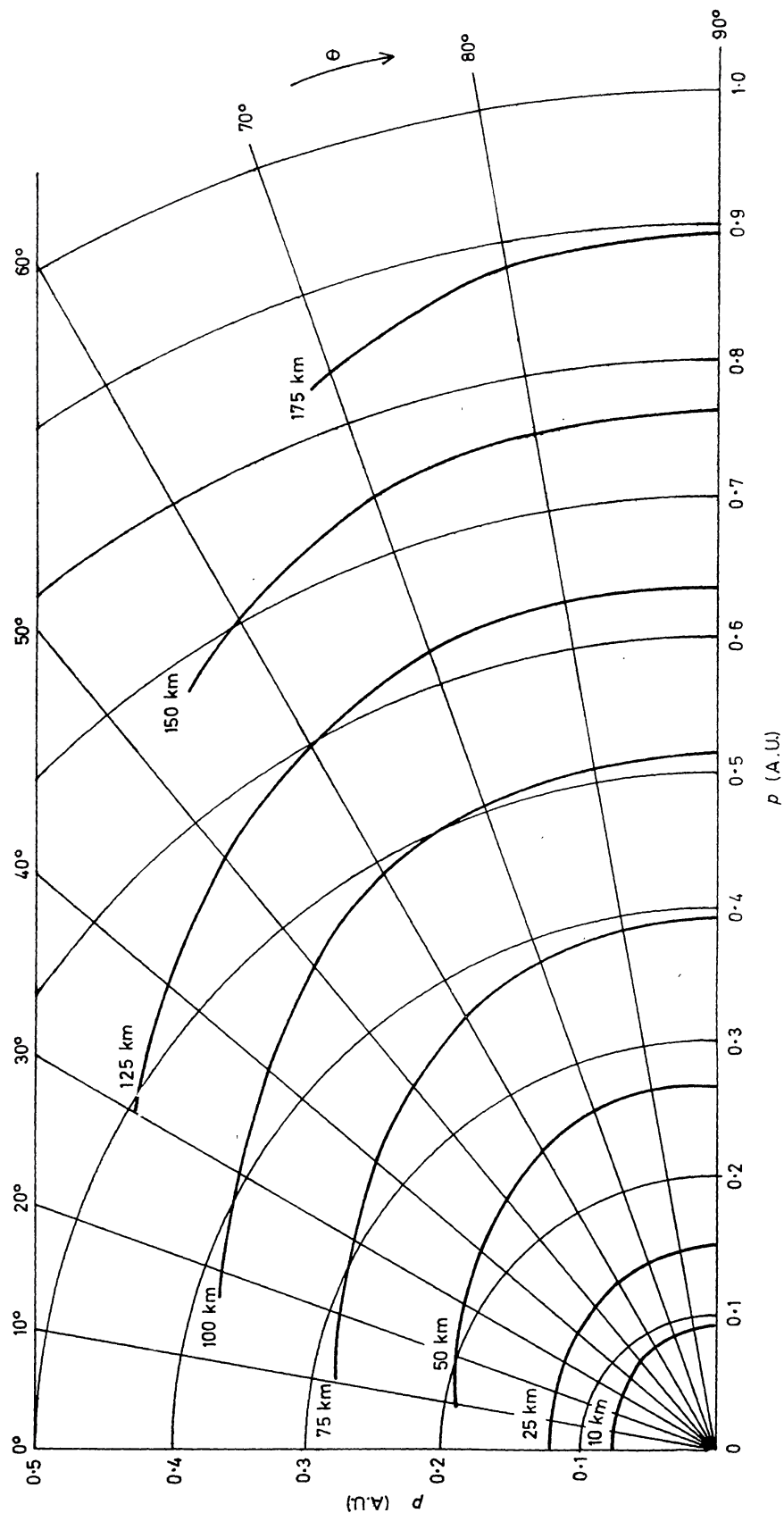


FIG. 5. Source co-ordinates.

To compute the desired curve of V as a function of ζ_0/L it is also necessary to possess a map of ζ_0 in the (p, θ) co-ordinate system. There are, in principle, two methods by which this parameter may be derived. The most direct method is to make observations of the diffraction pattern at different points on the ground

FIG. 6(a). Contour map of scintillation index S .

FIG. 6(b). Contour map of scale of pattern ζ_0 .

using a spaced-receiver technique. Some measurements on the source 3C 48 have already been made (4), but this source only yields values for $p > 0.4$ A.U. An alternative method is to make use of the extensive observations of scattering in the outer corona and the interplanetary medium which have been carried out with systems of increasing angular sensitivity since 1953. Such measurements provide the angular spectrum of the diffraction pattern and the well-known relationship between the auto-correlation function of the diffraction pattern and its angular power spectrum (11) enables ζ_0 to be derived. The most recent measurements, which cannot be discussed in detail here, were carried out during 1964 at 38 Mc/s and cover the range $0.1 < p < 0.6$ A.U. (12). A contour map of ζ_0 based on these measurements is shown in Fig. 6(b) and it is interesting to note that the values are in good agreement with the limited data so far obtained by direct observations of the diffraction pattern using spaced receivers. It should be noted that the decrease of ζ_0 for $p < 0.3$ A.U. is associated with the transition from weak to multiple scattering discussed above. The location of this region depends upon the wavelength, being further from the Sun at longer wavelengths, and it should be stressed that the diffraction parameters depicted in Fig. 6 are only relevant to the particular frequency 178 Mc/s.

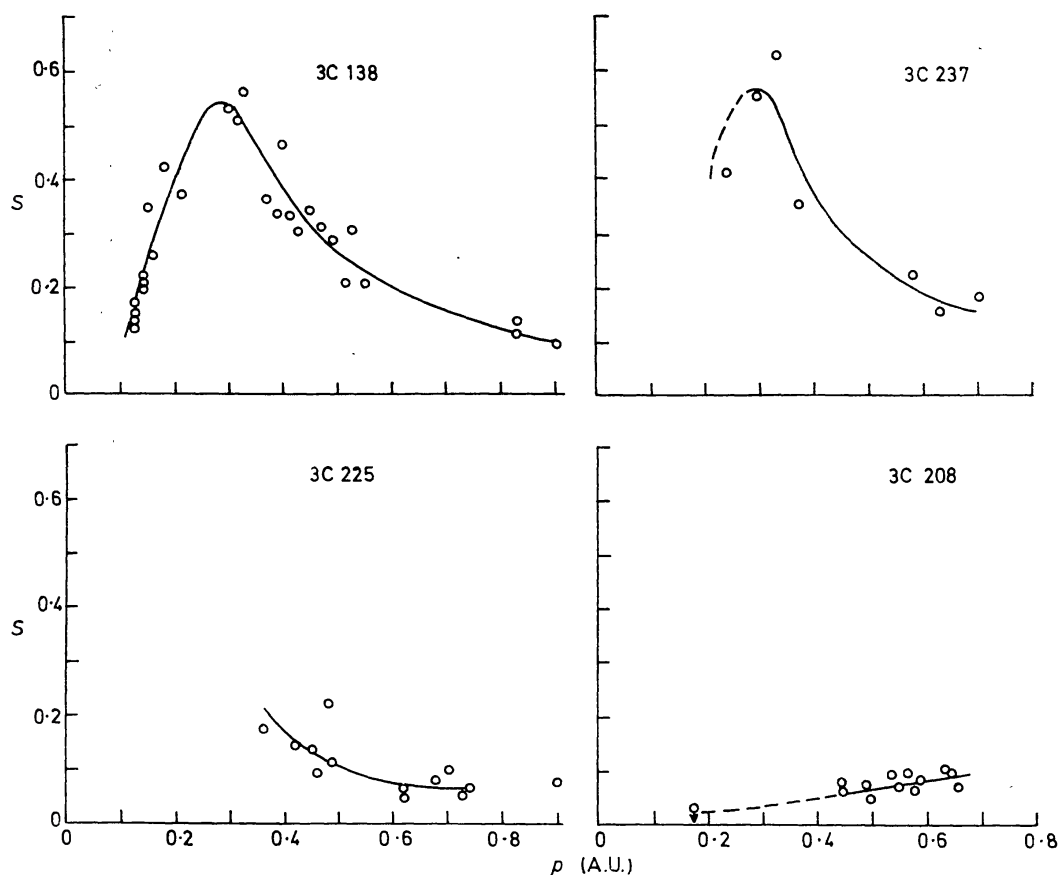


FIG. 7. Observed scintillation indices.

5. *Observational results.* As a radio source approaches the Sun it is therefore possible, making use of the two contour maps, to plot V as a function of ζ_0/L . Some typical results showing the observed scintillation index as a function of p are shown in Fig. 7. It appears that at least ten observations are needed to

average over the day to day variations. The smoothed curves drawn through the experimental points have been used to calculate V as a function of ζ_0/L and the corresponding curves are shown in Fig. 8. It is seen that the sources give noticeably different results and the estimated angular structure of the sources is shown in Table II together with results obtained from long base line interferometry (13, 14). As ζ_0 decreases the rate of fluctuation of intensity must increase if the irregularities are swept from the Sun by a solar wind. This means that a progressively smaller receiver time-constant is required if the scintillations are not to be blurred instrumentally. For this reason, it is not certain that the marked decrease of scintillation which occurred for the source 3C 138 when $p < 0.3$ A.U. represents a genuine resolution of the source.

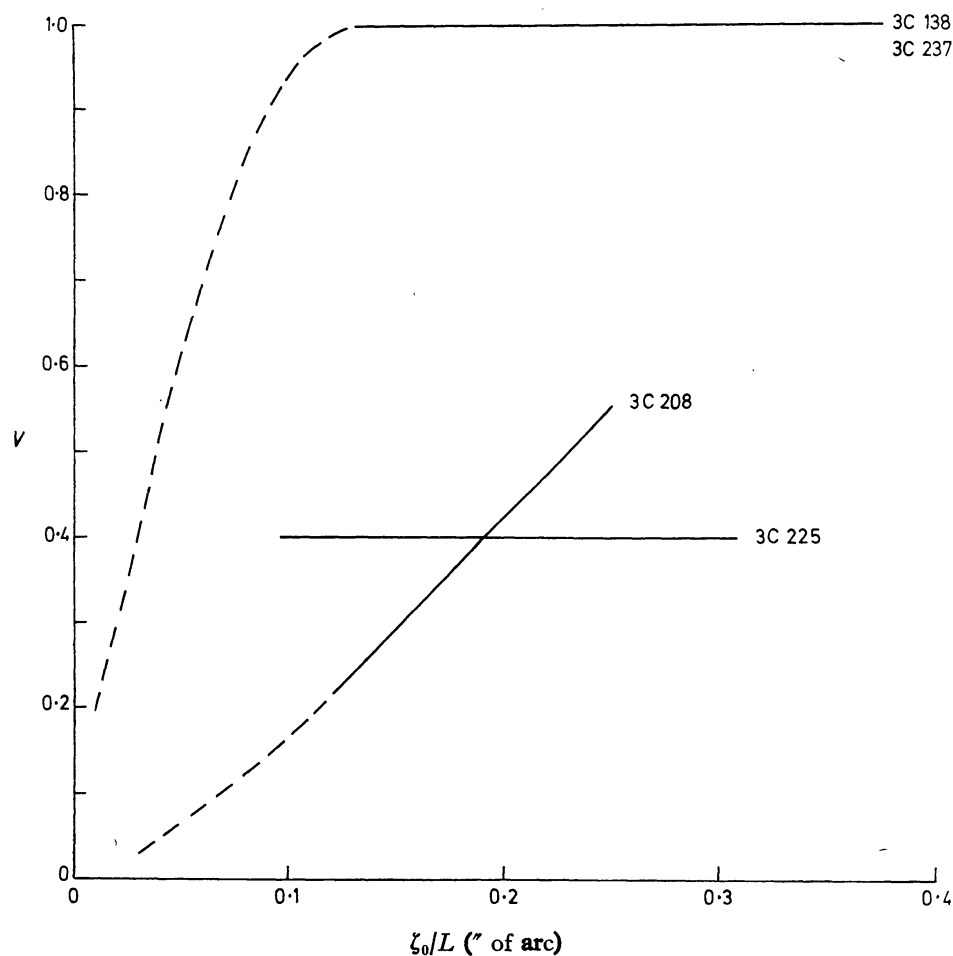


FIG. 8. *Derived visibility curves.*

For 3C 138, 225 and 237 there is no serious disagreement with the results obtained from long baseline interferometry, since these sources all give fringes when the resolving power is $0.4''$, and finer structure is by no means precluded. In particular there is good agreement as to the intensity of the small component in 3C 225. For 3C 208, however, there is strong evidence from interplanetary scintillation for the existence of an appreciable component $< 1''$, which does not agree with the interferometric measurements.

TABLE II

Source	Diameter	Comments	Long base line interferometry (references 13, 14)
3C 138	$\leq 0''.1$		High γ at 180 000 λ , small variation with hour angle (H.A.) Dimensions $\sim 0''.5$.
3C 237	$< 0''.2$		High γ at 180 000 λ , variations with H.A. Possibly double or elongated.
3C 208	$\sim 0''.5$	Interpreted as simple source. Since $V > 0.55$ has not been observed there could be some larger structure.	$\gamma = 0.2$ at 32 000 λ Dimensions $> 4''$. $\gamma = 0$ at 180 000 λ
3C 225	$40\% < 0''.2$ $60\% > 0''.6$	Interpreted as core-halo	$\gamma = 0.3$ up to 61 000 λ Fringes at some H.A.s at 180 000 λ . A component $\sim 0.6''$.

From the sample results shown above it is clear that interplanetary scintillation provides a valuable technique for studying the angular structure of radio sources. The application of the technique to observations of about eighty radio sources will be described in a further paper and a more detailed discussion will there be given of the derivation of the necessary diffraction parameters illustrated in Fig. 5.

Acknowledgment. One of us (L.T.L.) is indebted to S.R.C. for receipt of a maintenance grant.

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Cambridge:
1966 March.*

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