A STUDY OF INTERPLANETARY SCINTILLATION AT 327 MHz

by

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S Y N O P S I S

When radio waves pass through the interplanetary medium they are scattered by irregularities in the density of the interplanetary plasma. One of the manifestations of this scattering is interplanetary scintillation (IPS), which is the fluctuation of the apparent intensity of compact radio sources when the line of sight to the source approaches the Sun. The study of IPS has yielded considerable information on the properties of the solar wind and on the small scale structure of radio sources. This thesis is concerned with the observations and analysis of IPS at 327 MHz, using the Ooty Radio Telescope.

In chapter II we review the various theoretical results used in interpreting the observations. The thin screen model is examined in some detail and the various approximations that are commonly used, are derived. The effect of an evolving pattern in the screen is also considered and it is shown that for strong scattering, the random velocities estimated from the observed intensity pattern on the ground can be considerably larger than what is present in the interplanetary medium.

In chapter III we describe the observations and the calculation of the scintillation indices and the power spectra. In Chapter IV we interpret the observations and estimate the r.m.s. phase fluctuation and the scale size of the irregularities. While there is good agreement between our estimates of the r.m.s. phase fluctuation and those of other workers, our scale sizes differ considerably from the scale sizes reported by the Cambridge group. We attribute this discrepancy to the correction they make for the finite diameter of the scintillating source and to the model on which the correction is based. Our observations, which do not require any correction, show that between 0.25 A.U. and 0.7 A.U. from the Sun, the scale size is roughly constant and it does not increase linearly with distance, as has been suggested earlier. The turnover of the scintillation index close to the Sun is also discussed and it is shown that the broadening of the power spectrum close to the Sun is not compatible with the source size explanation for the turnover.

Our attempts to measure the velocity of the solar wind from single station observations by calculating the Bessel transform of the intensity fluctuations, are described in chapter V. For most of the observations the Fresnel filter pattern was not seen and so the velocity could not be estimated. The possible reasons for our not seeing the Fresnel pattern are discussed.

In chapter VI we estimate the angular diameters of the nine sources we have observed and compare them with the results of other measurements.

In the last chapter we summarise our results and point out the various outstanding problems in IPS. We also discuss the ways in which some of these problems could be resolved.

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Statement required under 0.770

No part of the work presented in this thesis has been submitted previously for any degree or diploma or other academic award in the Bombay University or any other University or body.

Statement required under 0.771

This thesis presents new observations of Interplanetary Scintillations at 327 MHz. Our observations show that the size of the small scale irregularities does not increase linearly with distance from the Sun, as has been suggested earlier by other workers. It is important to establish the scale size of the irregularities and its variation with distance from the Sun, since these quantities throw light on the origin of the small scale structure of the solar wind. Further, the estimated diameters of the scintillating sources depend sensitively on the assumed scale size of the irregularities. We have proposed an improved description of the small scale structure in the solar wind and have used it to estimate the diameters of the observed sources. The observations and most of the interpretation presented in this thesis are original. References are given in appropriate places whenever use has been made of the work of other people.

The observations were made in collaboration with Mr. S. Ananthakrishnan and Mr. S.M. Bhandari. However, most of the analysis and interpretation were done by me.

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List of Publications

1. Lunar Occultation Observations of 25 Radio Sources made with Ooty Radio Telescope: List 1.
G. Swarup, V.K. Kapahi, N.V.G. Sarma, Gopal-Krishna, M.N. Joshi and A.P. Rao.
Astrophysical Letters, 9, p.53 (1971).

2. Diameter of PKS 1514-24 (Ap. Lib)
S. Ananthakrishnan, A. Pramesh Rao and S.M. Bhandari
Nature Physical Science 235, p.167 (1972).

3. Accurate Position of PSR 1749-28 from Lunar Occultation
A. Pramesh Rao and S. Krishnamohan
Nature Physical Science, 238, p.67 (1972).

4. Observations of Interplanetary Scintillations at 327 MHz
A. Pramesh Rao, S.M. Bhandari and S. Ananthakrishnan
Australian Journal of Physics, 27, p.105 (1974).

5. Structure of 194 Southern Declination Radio Sources from Interplanetary Scintillations
S.M. Bhandari, S. Ananthakrishnan and A. Pramesh Rao
Australian Journal of Physics, 27, p.121 (1974).

6. Occultation of Radio Source PKS 2025-15 by Comet Kohoutek (1973 f)
S. Ananthakrishnan, S.M. Bhandari and A. Pramesh Rao
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CHAPTER 1

INTRODUCTION

Radio waves propagating through the interplanetary (IP) medium are scattered by irregularities in the plasma density. Two consequences of this scattering are the angular broadening of radio sources and the fluctuations in the intensity of compact radio sources when they are seen through the IP medium. The present thesis describes a study of the latter phenomenon, which is called Interplanetary Scintillations (IPS), and the estimation of some of the properties of the small scale structure in the solar wind.

The idea of investigating the solar corona by studying its effects on radio waves propagating through it, was first suggested by Vitkevitch (1952) and by Machin and Smith (1952). At that time it was known from optical observations that the solar corona was made up of ionised gases whose density was such that the plasma frequency was in the radio frequency range. Since radio waves cannot propagate in regions where the plasma frequency is higher than the radio frequency, the size of the occulting disc of the Sun is essentially the distance at which the two frequencies are equal, and it varies with frequency, being larger at lower frequencies. It was suggested by the above authors that by studying the occultation of the Crab nebula by the Sun and by measuring the size of the occultation disc of the Sun, it should be possible to estimate the plasma density in the solar corona. Observations of the Crab during the occultation were made using radio interferometers, by Machin and Smith (1952) and by Hewish (1955) and they found that long before the source got occulted, the observed visibility of the source decreased and this decrease was roughly independent of frequency.

The observations were interpreted by Hewish as due to the angular broadening of the Crab nebula caused by the scattering of the radio waves by the density irregularities in the coronal plasma. The observed angular broadening depends on a, the scale size of the density irregularities and on ϕ_0, the root mean square (r.m.s) phase fluctuation imposed by the medium on the incident wave front. If $\phi_0 \ll 1$, the angle of scattering is equal to $\lambda / 2\pi a$ where λ is the wavelength at which the observation is made. However, if $\phi_0 \gg 1$, the angle of scattering, and hence the observed angular size is equal to $\lambda \phi_0 / 2\pi a$. Since ϕ_0 is proportional to λ, by studying the dependence of the angular broadening on wavelength, Hewish (1955) concluded that the scattering was strong i.e. $\phi_0 \gg 1$, and so, from the observed angular broadening one could not measure the absolute value of a and ϕ_0, but could estimate only their ratio. Since then angular broadening has been measured by a number of observers at various frequencies and it has been established that the angular broadening decreases with distance from the Sun as a power law with index in the range 1.5 to 2.5. However these observations could not give useful estimates of the parameters of the IP medium since they gave only the ratio of a to ϕ_0.

The absolute determination of a and ϕ_0 has been possible only after the discovery, in Cambridge in 1962, that compact radio sources show marked intensity fluctuations when the line of sight to the source comes close to the Sun. The study of this phenomenon, which is called Interplanetary Scintillation (IPS), has yielded a wealth of information on the small scale density irregularities in the IP medium. IPS is another manifestation of the scattering of radio waves in the IP medium. It arises when the scattered radiations interfere with each other producing a randomly varying intensity pattern on the ground. Since the IP medium moves away from the Sun with a velocity of about 400 km s^{-1} forming what has been called the solar wind, the intensity pattern on the ground also moves with a similar velocity, with the result that the intensity at any point on the ground varies rapidly with time.

Both single station observations and multi station observations of IPS have been made. In single station observations the variations of the intensity of the source with time are recorded and the time scale of the fluctuations and its strength, as measured by the scintillation index, are estimated. From the observed time scales, the scale size of the intensity fluctuations on the ground can be deduced only if one knows the velocity of the pattern on the ground. For most single station observations this velocity has to be assumed. In multi station observations this assumption is not required since the velocity of the pattern is also measured. In these observations the intensity is simultaneously measured at three points on the ground which are separated by about a hundred kilometers or so. By measuring the delay in the arrival times of the fluctuations and from the known distances between the stations, the velocity of the pattern on the ground can be deduced. The relation between the observed velocity on the ground and the solar wind velocity is fairly straight forward and there is general agreement between the various observations. The solar wind velocity is found to be roughly radial and independent of distance from the Sun in the range 0.3 A.U. to 1.0 A.U. In this range the velocity has a value between 350 and 450 km s^{-1}. There is some evidence that closer than 0.2 A.U. from the Sun the velocity of the solar wind decreases.

To estimate ϕ_0 and a one has to compare the observed scintillation index and scale size on the ground with the theoretical predictions. Useful theoretical results can be derived only in the weak scattering regime where $\phi_0 \ll 1$. ϕ_0 increases as the line of sight to the source approaches the Sun and thus at any frequency, there is a lower limit on the distance from the Sun for which useful estimates of the properties of the medium can be got. At large distances from the Sun the scintillations are too weak to be observed in the presence of the receiver noise. The largest distance from the Sun at which observations can be made is determined mainly by the system temperature and by the intensity of the source. Thus at any frequency we can estimate the properties of only that part of the IP medium that lies between these two limits. Since ϕ_0 is inversely proportional to the observing frequency, the properties of the IP medium at different distances from the Sun can be estimated by studying IPS at different frequencies. However, combining the observations at different frequencies and forming an overall picture of the IP medium is not very easy since the observations at different frequencies are generally made by different observers using different instruments and methods of analysis. While there is reasonably good agreement between the estimates of ϕ_0 at various frequencies, the situation regarding the scale size of the irregularities is not very satisfactory. The observed scale size of the intensity fluctuations on the ground depends on both the scale size in the medium and on the angular diameter of the scintillating source. Since neither of these quantities are known, from the observed scale sizes one has to make a self consistent model for both the structure of the source and the scale size of the irregularities. Thus the estimates of the scale sizes are not unambiguous and the agreement between the different observations is not very good.

In this thesis we present new single station IPS observations at 327 MHz and estimate ϕ_0 and a for distances from the Sun in the range 0.25 A.U. to 0.7 A.U. We show that the effect of source size on the observed scale sizes is negligible for our estimates in this range. Between 0.25 and 0.7 A.U. the scale size is observed to be nearly independent of distance from the Sun which is in contrast to the earlier results which indicated that the scale size increased approximately linearly with distance from the Sun. The discrepancy seems mainly due to the corrections made by earlier workers for the effect of the source size.

The first part of this thesis will be devoted to the theory of the phenomenon. After a brief discussion of wave propagation in a randomly inhomogeneous medium we will examine in some detail the thin phase screen model for IPS. Using a unified treatment we will derive a number of results which have earlier been derived by different workers using different approaches. In the second part of the thesis we will describe the observations and the analysis of the data. In chapter 4 we give our interpretation of our data and combine the available observations to form an overall picture of the IP medium. In chapter 5 we present our measurements of the Bessel transforms of the intensity fluctuations, using which we have tried to estimate the velocity of the solar wind using our single station observations. The angular structures of the sources we have studied are estimated in the next chapter while in the last chapter we summarise our conclusions and discuss their implications.