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RESEARCH REPORT

THE RADIAL EVOLUTION OF ENHANCED SCINTILLATION REGIONS

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Abstract

Observations of scintillation index and solar wind velocity using a grid of sources at 327MHz, enable us to study the radial evolution of enhanced scintillation regions between 0.3-1.0 a.u. and at a large range of heliocentric latitudes.

Statistical analysis as well as the study of specific events during the declining phase of the solar cycle, show that enhanced scintillation regions associated with compressed plasma density due to the interaction between fast and slow solar wind flows, develop only beyond 0.5 a.u.

At distances less than 0.5 a.u., the scintillation index varies in a similar manner to the variations in plasma density as observed by space probes at the same distances from the Sun.

1. Introduction

The scintillation of radio sources due to small scale irregularities along lines of sight through the interplanetary medium provides a convenient, ground based, method of monitoring disturbances in interplanetary space. Much evidences now exist that enhancements of scintillation may be identified with regions of compressed plasma moving outward from the Sun in advance of high velocity zones. The compression regions usually occur between fast and slow solar wind stream or near the leading edges of spherical disturbances associated with a shock front at 1 a.u. (Houminer and Hewish, 1972; Kakinuma and Watanabe, 1976; Rickett, 1975; Tappin et al., 1984).

The study of the radial evolution of the compression regions is important for better understanding of the mechanisms involved in the formation of strong interplanetary shocks and stream-to-stream interaction regions. Also, the prediction of the arrival at the Earth of such disturbances is of great practical interest because they cause geomagnetic storms resulting in communication disruptions, failure of electrical power transmissions and may cause radiation hazards to astronauts.

Scintillation observations at VHF frequencies enables us to study large scale perturbations of plasma density only at distances larger than 0.6 a.u. from the Sun because of the onset of strong scattering at shorter distances (Readhead 1971). Since 1983, three station observations of interplanetary scintillation at 327 MHz have been carried out at Toyokawa, Fuji and Sugadaira (Kojima et al., 1982; Kakinuma and Kojima, 1984; Kojima and Kakinuma, 1986). The observations are mainly carried out for the purpose of monitoring the solar wind velocity but can also provide scintillation index data. These data can be used for studying the evolution of compression regions at distances between 0.3 - 1.0 a.u.

In this paper we present results of such a study based on observations during 1983-1985 at the declining phase of the solar cycle. During this period enhanced scintillation regions were mainly due to the interaction between fast and slow solar wind streams. Thus our results of the radial evolution of enhanced scintillation regions mainly describe this type of interactions.

2. The evolution of enhanced scintillation regions

Daily observations at 327 MHz of a grid of radio sources have been carried out since 1983 at three stations - Toyokawa, Fuji and Sugadaira. The frequency of observations allows probing the interplanetary medium close to the Sun at distances up to 0.25 a.u. (Kakinuma and Kojima, 1984). Scintillation index data can be used to determine the evolution of enhanced scintillation region as a function of distance from the Sun between 0.3 - 1.0 a.u.

Two approaches were adopted in this study. First, finding the distribution of scintillation index values at different radial distances, and second, examining certain events known to have produced shock fronts or stream-stream interaction regions.

Each radio source is being tracked for about 15 minutes each day and the scintillation index m is calculated from the observed spectrum of fluctuations: $m^2 = \int[P(\nu)-N(\nu)]d\nu$, where $P(\nu)$ is the power spectrum of the flux density fluctuations, $N(\nu)$ is the background spectrum and ν is the fluctuation frequency. Only relative scintillation indices are determined. To specify day to day perturbations about the mean, an enhancement factor g was defined as $g = m/\bar{m}$ where $\bar{m}$ is the average scintillation index for a given source at a particular radial distance.

In order to determine the statistical distribution of g values, three years of data from 1983-1985 were grouped at 0.1 a.u. intervals between 0.3-0.9 a.u. Only data obtained at heliographic latitudes between ± 25° were used in the analysis.

The results of the statistical analysis are shown in Figure 1. It can be clearly seen that between 0.3-0.5 a.u., the distributions of g^2 values are nearly symmetrical

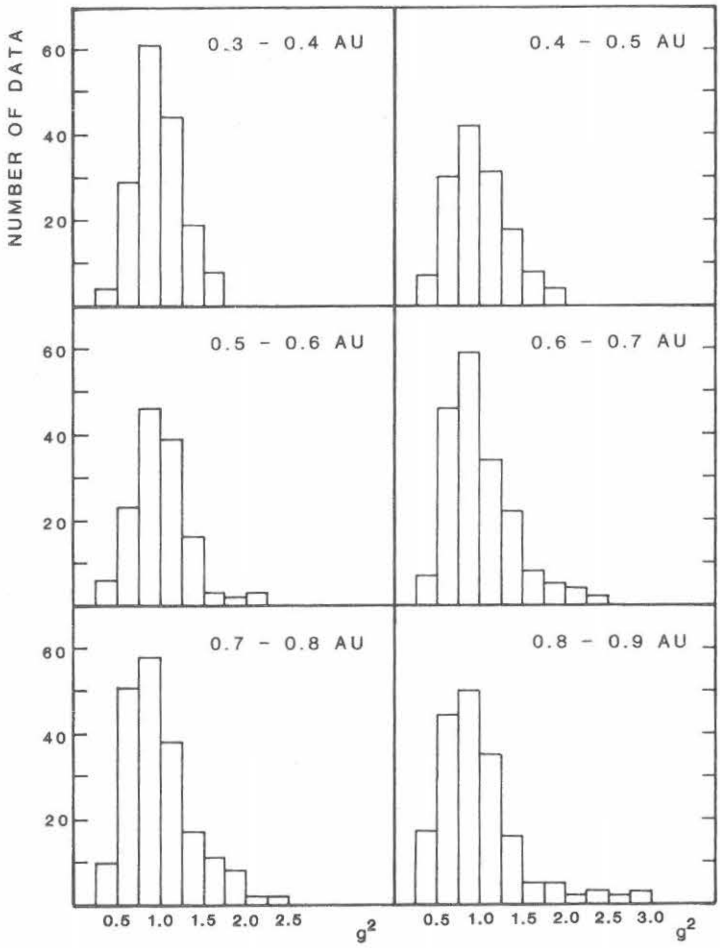

Fig. 1. Statistical distribution of g^2 values at 0.1 a.u. intervals between 0.3-0.9 a.u.

about the mean with values g <2.0. Beyond 0.6 a.u., there is a distinct tail of high g^2 values increasing progressively with distance from the Sun. At 0.8-0.9 a.u., values of $g^2>1.75$ occur for about 9% of the time. Thus the distributions in Figure 1 clearly show that large perturbations in scintillation index occur only beyond 0.6 a.u.

3. The radial dependence of corotating structures

High speed solar wind streams are often observed especially during the declining phase of the solar cycle (Hundhausen, 1979). The combined effect of corotation and the interaction of fast flows with slower flows ahead of them, generate a characteristic spiral pattern in which the leading boundary of the high speed stream is associated with a compression zone of enhanced density followed by lower density high-speed flows. This structure has been well observed by spacecraft at 1 a.u. and the temporal profiles of wind velocity and plasma density are in good agreement with fluid dynamical models (Pizzo, 1978, 1980, 1982).

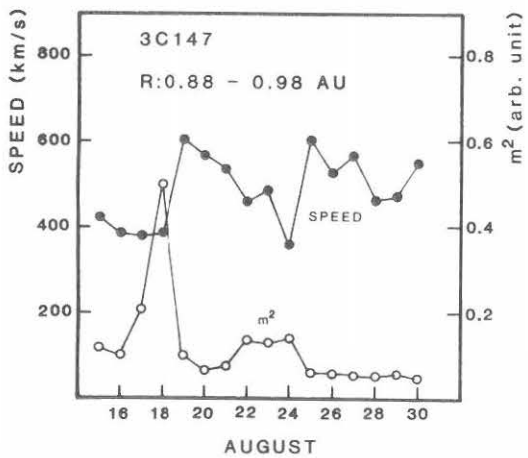

Fig. 2. Square of scintillation index m^2 (open circles) and solar wind speed (dots) obtained from observations of 3C147 during August 15-30, 1985.

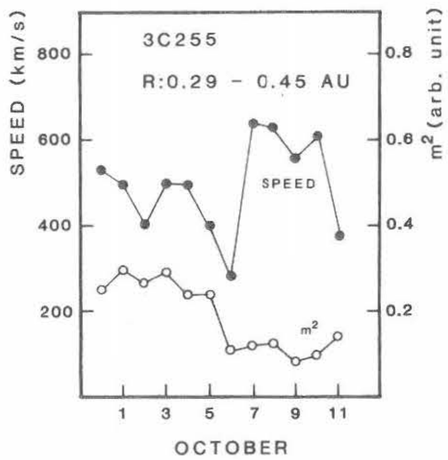

Fig. 3. Same as Figure 2 but obtained from observations of 3C255 during September 30 - October 11, 1985.

Scintillation index and solar wind velocity obtained from observations of 3C147 during August 15-30 in 1985, are presented in Figure 2. This shows an example of scintillation observations of the interaction region between high and low velocity flows at about 1 a.u. This interaction region was located at the leading edge of a northern high velocity flow at heliographic latitude 21^{o} and between longitudes 200^{o} and 240^{o} (refer to Figure 1 in the paper by Kojima et al. (this volume)). The point of closest approach to the Sun along the line of sight to 3C147 during the above period was between 0.88-0.98 a.u. One can clearly see in Figure 2, a large increase in scintillation index in front of the high-speed stream, corresponding to the compressed plasma density at the interaction region.

The temporal variations of velocity and scintillation index at radial distances <0.5 a.u., can be seen in Figure 3. The scintillation observations are of 3C225 having the point of closest approach along the line of sight at radial distances between 0.29-0.45 a.u. Figure 3 shows an interaction region observed at heliographic latitude -16^{o} and between Carrington longitudes $300^{o}$and 330^{o} (refer to Figure 1 in the paper by Kojima et al. (this volume)). It can be clearly seen that there is no compression region in front of the high velocity flow observed between 7 - 11 October 1985. The velocity and scintillation index vary in a similar manner but in opposite directions i.e., low scintillation at the time of high speeds and high scintillation at low speeds. This is very similar to the behaviour of plasma density and solar wind velocity observed by the Helios 1 and 2 space probes at the same radial distances (Burlaga, 1979).

The temporal variations of scintillation index shown in Figure 3 are consistent with the symmetrical distribution of scintillation indices shown in Figure 1 for radial distances less than 0.5 a.u. The temporal variations of scintillation index shown in Figure 2, are consistent with the distributions at radial distances larger than 0.6 a.u.

4. Conclusions

Observations of scintillation index and solar wind velocity using a grid of radio sources at 327 MHz, enable us to study the radial evolution of corotating interaction zones between 0.3 - 1.0 a.u. and at a large range of heliocentric latitudes.

The present study shows that compression regions due to the interaction between fast and slow solar wind flows, develop only beyond 0.5 a.u. At distances less than 0.5 a.u., the velocity and scintillation index vary in similar manner but in opposite directions, i.e., high velocities at time of low scintillation indices while low velocities at time of high scintillation indices.

The observed density and velocity by space probes at radial distances less than 0.5 a.u., show very similar behaviour to the scintillation index and velocity observed by interplanetary scintillation. This further proves the very good correlation between plasma density and scintillation index.

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