Bull. Astr. Soc. India (1998) **26**,225-229

Detection and tracking of IP disturbances using interplanetary scintillation

V. Balasubramanian[1], R. Srivatsan[1], P. Janardhan[2,3] and S. Ananthakrishnan[4]

[1] *Radio Astronomy Centre, TIFR, PO Box 8, Udhagamandalam (Ooty) 643 001, India*

[2] *Physical Research Laboratory, Ahmedabad 380 009, India*

[3] *Radioastronomisches Institut, Universitat Bonn D 53173, Bonn, Germany*

[4] *National Centre for Radio Astrophysics, TIFR, PO Box 3, Ganeshkhind, Pune 411 007, India*

Abstract. A well known method of probing large portions of the interplanetary medium (IPM) is by observations of interplanetary scintillations of a large number of spatially well-distributed compact extragalactic radio sources at meter wavelengths. For this purpose large dipole arrays operating as transit instruments are used. Such telescopes generally observe a source only once a day and detect IP disturbance (IPD) travelling outward from the sun by recording the enhancement of the scintillation indices in certain regions of IPM due to the IPD. The use of a steerable radio telescope with large collecting area, such as the Ooty Radio Telescope (ORT), enables not only the detection of scintillation enhancements due to travelling IPD but also the determination of the velocity of the disturbance. Based on such data one could select a set of appropriately located scintillating sources so that the set of lines of sight to these sources is used as a "picket fence" to intercept the oncoming disturbance. The concept was tested successfully on four occasions when the times of occurrence and the travel paths of the IPD were predicted in advance by a theoretical model of generation and propagation IPD driven by solar flares. The paper describes the method and its advantages and disadvantages when adopted for predicting geomagnetic disturbances triggered by solar transients.

Key words : solar wind - interplanetary transients - interplanetary scintillations

1. Introduction

Several techniques have been developed in the past four or five decades for observing the outermost parts of the solar atmosphere, namely the solar corona and the solar wind in the interplanetary medium (IPM). Such studies have yielded a wealth of data regarding the occurrence of disturbances in the sun-earth space environment and their association with discrete ejections of mass and energy from the sun. For a concise review of these techniques one may refer to Jackson (1991). Most of the techniques are applicable to study the IPM either close to the sun (at heliocentric distances $d < 30\ R_o$ where R_o = radius of the sun) or close to the earth ($d \sim 200\ R_o$). Interplanetary scintillation (IPS) of compact extragalactic radio sources in the only ground-based technique for remote sensing the IPM in the distance range 30 R_o to 200 R_o from the sun. The phenomenon of IPS arises when electron density irregularities in the solar wind plasma scatter radio waves coming from distant, compact radio sources and produce intensity fluctuations at ground-based radio telescopes used for observing the radio sources. IPS is highly sensitive to turbulence in the solar wind. When travelling IP transients cross the line of sight (LOS) from the earth to the source, they exhibit themselves as enhanced levels of scintillation; i.e. higher than expected scintillation index (m), where m is the ratio of the root-mean-square deviation of the signal intensity to the mean signal intensity. IPS responds to the properties of the solar wind plasma all along the line of sight to the source. However the medium at the part of the LOS which is closest to the sun dominates the effect owing to the fact that deviation in electron density of the solar wind is a strongly decreasing function of the distance from the sun.

2. *g* - maps and *v* - maps

The enhancements in scintillations due to IP disturbances are quantified by a parameter $g = \Delta S \sqrt{\Delta} S$ were ΔS is the scintillating flux for a source and $\overline{\Delta S}$ is the long term mean scintillating flux of the source. The observation of a large number of (about 900) spatially well-distributed sources enables the mapping of the activity in the IPM to the plane of the sky as *g - maps* (Gapper et al. 1982; Hewish et al. 1985; Hewish and Duffet-Smith, 1987). On such maps enhanced density regions in the IPM will show up as regions of $g > 1$ while depleted density will show up as regions with $g < 1$.

Disturbances in the IPM can be investigated by using velocity maps (*v - maps*) also (Manoharan et al. 1995; Janardhan et al. 1996). The most convenient method of determining the velocities of the IPM in a large number of spatially well-distributed directions is to use the single station technique of determining solar wind velocity by using a radio telescope with large collecting area (Manoharan and Ananthakrishnan 1990).

3. The Ooty IPS survey

The Ooty Radio Telescope (ORT) operating at 327 *MHz* was refurbished in 1991 (Selvanayagam et al. 1993) so that there was a large improvement in its sensitivity. It is possible now to obtain power spectra of IPS of compact radio sources that have a scintillating flux as low as 0.25*Jy* at 327 *MHz* with three minutes of data ($1 Jy = 10^{-26}\ Wm^{-2}$). An IPS survey was initiated in August 1992 (Balasubramanian et al. 1993) to detect compact radio sources in the 7 steradian of the sky visible to the ORT, in the declination range $-35° \leq \delta \leq 35°$.

About 5000 known radio sources were selected for this purpose from the catalogues of the

Molonglo and Texas radio source surveys which were conducted at 408 and 365 *MHz* respectively. For our IPS survey observations only those sources with $S_\nu \geq 1.5 Jy$ were chosen from the two catalogues ($\nu = 408$ or $365 MHz$). About 2100 of these sources were found to be exhibit IPS at $327 MHz$, and about 1050 of these were strong scintillators. For the strong scintillators, we could determine reliable estimates of the angular sizes of the scintillating components.

4. The picket fence method for detection and tracking of IP disturbances

The Ooty Radio Telescope (ORT) has a large collecting area and is readily steerable. The set of 2100 scintillating sources identified during the IPS survey at 327 *MHz* with the ORT are spatially well-distributed. Hence one could use the ORT to observe selected sets of sources at different elongations in rapid succession such that, in case travelling IP disturbance was detected by IPS observations while it crossed the line of sight to a particular source, it could be followed up immediately by observing other scintillators at larger solar elongations. In other words one could use the lines of sight to a set of spatially well-distributed compact radio sources as a rapidly movable 'picket fence' to monitor the progress of the travelling IP disturbance. The main advantages in using this techniques of detection and tracking of travelling IP disturbances by using ORT, over the *g-map* technique adopted with the Cambridge IPS array are as follows : The velocity of travelling IP disturbances can be determined readily from observation of the IPS source with the ORT, whereas the Cambridge *g-map* technique requires data on two successive days to determine the velocity of the IP disturbances i.e. *v-maps* of the interplanetary environment can be produced readily in addition to the *g-maps*, by using the IPS observations with ORT. Owing to the streerability of the ORT, the progress of the travelling IP disturbance can be monitored at much shorter intervals as compared with the minimum of 24-hour interval in the case of the IPS observations with the Cambridge radio telescope.

5. Observational validation of the picket-fence technique

The concept was tested successfully on four occasions even as the detection and selection of a spatially well-distributed sample of IPS sources were in progress during 1992. The method adopted to detect and follow up the travelling IP disturbances was somewhat different from the technique proposed in the previous section. In these tests cases a theoretical model, called the shock time of arrival model (STOA model) was used to predict the direction of propagation of IP transients. On the basis of this prediction in real time, scintillating sources in the appropriate directions were observed with the Ooty radio telescope so as to intercept the transients with the lines of sight to these sources. Inputs to the STOA model were the data from optical and radio observations of solar flares. For details on the STOA model one may refer to Smith and Dryer (1990, 1991).

On 7 May 1992 a two ribbon flare with associated eruptive filament occurred in the active region AR 7154 at S 23° E 48°. A type II radio burst associated with the flare was also recorded at 0643 UT, the velocity of the type II shock being 1300 kms^{-1}. Using these data as input the STOA model predicted the direction of propagation of the IP shock. On the basis of this prediction scintillating sources were selected in the relevant directions and were observed with the ORT. In the same active region AR 7154 another flare occurred on 8 May 1992 at S 26° E 10°. This information was also input to the STOA model and observations made with the ORT. The *g-maps* and υ-maps produced from the Ooty IPS data for observations from 7 to 10 May 1992 showed the passage of the two shocks across the lines of sight to the scintillating radio sources on 8 and 9 May 1992 (Manoharan et al. 1995).

A similar situation occurred a few months later with the start of a strong flare at 1659 UT on 30 October 1992 in AR 7321 at S 25° W 60°. It was accompanied by a strong type IV radio burst. The STOA model predicted the passage around 0530 UT on 31 October 1992, of a strong shock front west of the sun-earth line at an elongation of about 24°. The IPS observations with the ORT detected the shock front crossing the lines of sight to the scintillating sources at elongation of 35° at about 0615 UT on 31 October 1992. The υ*-maps* for 31 October 1992 and 1 November 1992 clearly showed the outward movement of the high velocity front from lower to higher elongations (Janardhan et al. 1996). The υ*-map* for 2 November 1992 showed that the conditions in the particular region of interest in the IP medium has returned to normalcy. However, the active region AR 7321 flared up again on 2 November 1992 at 0308 UT. IPS observations with ORT were planned on the basis of the predictions from the STOA model for this flare also. These observations resulted on the passage of the predicted IP disturbance on the υ*-map* of 3 November 1992 at elongation > 35°.

6. Discussion and conclusions

As the velocity of the propagating IP disturbance can be readily determined from the IPS observations with the ORT one can trace back the disturbances to locations on the surface of the sun. The uncertainties in determining the location of the causative events on the solar surface by such a back-projection method are somewhat large. Nevertheless, in the four instances described above the back-projected positions obtained by using the velocity information from IPS were found to agree well with the positions of the optically observed flares, the data on which were used as inputs to the STOA model. Such attempts to trace the observed IP transients back to the surface of the sun have been made earlier also, but with spatially sparse data (Rickett, 1975; Jackson, Rompolt and Svestka, 1988). With a large number of scintillating sources visible to a large, steerable radio telescope it is possible to sample the propagating front of an IP transient with good spatial resolution so that the precision in tracing back the source of the IP transient to the solar surface can be improved.

The IPS technique is very sensitive to turbulence in the IP medium and transients in velocities and density of the medium can be detected easily. However, it may become difficult to trace back the IP transients to their sources on the solar surface unambiguously using IPS data alone if there are several events taking place on the solar surface in a short interval of time. For example, the velocity of the IP transient from a temporally later event on the sun could be higher than the velocity of the transient due to an earlier event so as to overtake the first transient.

The IPS technique is not sensitive to the polarity of the magnetic field associated with the IP transient. Hence, although it is possible to predict from the IPS monitor observations whether a certain IP transient detected during the observations will intercept the earth or not, one cannot make precise predictions as to whether the transient will cause geomagnetic disturbances, by using the IPS data alone. Nonetheless, the IPS technique described here has the advantage that it can detect such transients when they are at considerable distance from the earth, several tens of hours before they reach the earth.

References

Balasubramanian V., Janardhan P., Ananthakrishnan S., Manoharan P.K., 1993 BASI, 21, 469.

Gapper G.R., Hewish A., Purvis A., Duffett-Smith P.J., 1982, Nature, 296,633.

Hewish A., Duffett-Smith P.J., 1987, Planetary Space Sci., 35 487.

Hewish A., Tappin S.J., Gapper G.R., 1985, Nature, 314,137.

Jackson B.V., 1991, Solar Wind Seven, Proc. 3rd COSPAR Colloquium, p.243.

Jackson B.V., Rompolt B., Svestka Z., 1988, Solar Phys., 115, 327.

Janardhan P., Balasubramanian V., Ananthakrishnan S., Dryer M., Bhatnagar A.McIntosh P.S., 1966, Solar Phys., 166, 379.

Manoharan P. K., Ananthakrishnan S., 1990, MNRAS, 244 691.

Manoharan P.K., Ananthakrishnan S., Dryer M., Detman T.R., Leinbach H., Kojima M.,Watanabe T., Kahn J., 1995, Solar Phys., 156,377.

Selvanayagam A.J., Praveenkumar A., Nandagopal D., Veluswamy T., 1993, IETE Technical Rev., 10, No.4, 333.

Smith Z., Dryer M., 1990, Solar Phys., 129, 387.

Smith Z., Dryer M., 1991, Solar Phys., 131,363.