Study of Solar Wind Transients Using IPS

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Abstract. Interplanetary scintillation (IPS) observations made using the Nagoya University 4 station IPS system in Japan and the Ooty Radio Telescope in India show that both the solar wind velocities and the relative scintillation indices (g - values) are enhanced during the passage of solar wind transients. We have identified a number of these events and tried to trace their origin back to the Sun. In all the cases under discussion, type II radio bursts associated with solar flares were reported by ground radio observatories, which estimated high shock velocities. Based on the time of arrival of the events, it appears that these coronal type II's were the sources of the interplanetary disturbances(IPD's) observed by IPS. While, it is not possible to state that there were no CME's present during these events, it may be equally premature to conclude that no coronal type II bursts can produce interplanetary shocks, as has been stated by (1).

INTRODUCTION

We use IPS data from the multi-station IPS system of Nagoya University, Toyokawa, Japan and the large Ooty radio telescope in India, both operating at 327 MHz. Both systems provide estimates of daily solar wind velocities and for more recent observations, scintillation enhancement factor, g. The g-value is defined as the ratio of scintillation index of any source at any elongation to that of the average index of the same source at the same elongation. For a quiet solar wind, therfore, the g-value will be around unity.

OBSERVATIONS

We have specifically looked at a number of energetic proton flares with accompanying type II/IV radio bursts and find that a significant percentage of them leave their signatures in the IP medium in the form of increased velocities and often with enhanced scintillation. We describe several of these events below.

June 1991 Events

TABLE 1. Flare Timings and Shock Speeds.

date	flare pk UT	lat./long.	sh. spd. * kms^{-1}	burst type
June 1	15:20[a]	N25 E90	1400	II/IV
June 4	03:52[a]	N30 E44		IV
June 6	01:08[a]	N33 E44	1400	II/IV
June 9	01:43[b]	N34 E04	2000	II/IV
June 11	02:09[a]	N31 W17	1200	II/IV
June 15	08:21[a]	N33 W69	2500	II/IV

Notes: In the second col. the superscript 'a' refers to Class X12 flares and 'b', class X10 flares. In col. 4, the * refers to values of coronal shock speeds estimated from Type II radio burst observation.

The most energetic solar flares of the solar cycle 22 took place in June 1991. Table 1 shows the five X12 class and one X10 class flares (2), from June 1 to June 15, 1991. IPS of compact radio sources is observed by the multi-station system daily in different heliographic latitudes and longitudes at various elongations (distances in AU) from the Sun. Out of the six flares in Table 1, IPD's were detected corresponding to five (no data were recorded on June

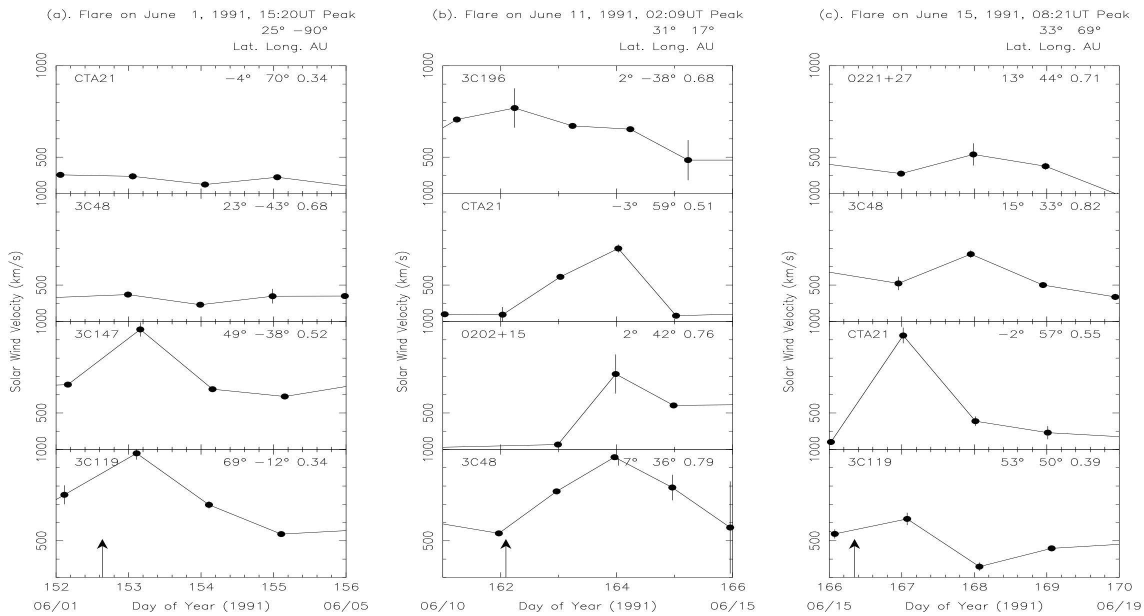

FIGURE 1. a,b,c show velocities for the l-o-s to four radio sources,respectively, on June 1, June 11 and June 15, 1991 that show higher values on one day compared to earlier dates (see text). The inset gives the l-o-s values of heliographic latitudes and longitudes and the distance from Sun in AU.

4).

Figures 1 (a), (b) and (c) show how the velocities measured by various radio sources increase in the case of the flares on June 1, 11, and 15 for which shock estimates are shown in Table 1. The abscissa shows the day of the year 1991 and the ordinate gives the velocity for each radio source as a daily measurement. On the right hand top corner of the figure, the heliographic latitudes and longitudes and the distance from Sun in AU of the line of sight (l-o-s) to the radio sources at the time of observation is given. The arrows at the bottom of the figures along the abscissa indicate the peak time of the flare.

We have made estimates of the time it takes for the IPD to travel from Sun to the l-o-s (transit time) for all the three events using the flare peak as a time-marker. These show reasonable agreement with the measured velocities. As an example, we take the case of the flare of June 15 for which there are two sources that observed the disturbances closer to the Sun ($\sim 0.47 \pm 0.08$)AU and two of them appear to detect the same disturbances about 20 hrs later on the same day at a distance of ($\sim 0.76 \pm 0.05$)AU. The transit time estimate from the Sun to the l-o-s gives the average speed as 1400 km s^{-1} for the first set and 900 km s^{-1} for the second set. Considering that the shock estimate is 2500 km s^{-1} at the origin, as shown in Table 1, it appears to decelerate rapidly to merge with the ambient solar wind by the time it reaches 1 AU. It is known both from observation and MHD simulation that faster the initial coronal shock speed, the greater the deceleration rate (3) (4). It is of interest to note that in each of the above cases, velocities derived from transit time estimates and the measured IPS velocities caused by the passing IPD's show reasonable agreement.

May 7-8, 1992 events

The SESC, Boulder, reported solar events on May 7 and 8, 1992 from NOAA region 7154. The first flare on May 7 at S23E48 was accompanied by a type II shock at 0643UT. The second flare on May 8 was also from the same region at 1546 UT at S26E10. For both these events a shock-time-of-arrival (STOA) model (5) was used to predict the propagation of IPD in the IP medium. Two IPD's were observed by the Ooty Radio Telescope as well as by the Cambridge array. The detailed analysis and modelling are described in (6). Good consistency was seen between the g-maps of Cambridge and Ooty. A recent re-look at the Toyokawa IPS data also shows the passage of the IPD very clearly (Figure 2). The transit times from the Sun to the l-o-s to radio source 3C138 at 0.54 AU and thence to the source 3C161 at 0.83 AU

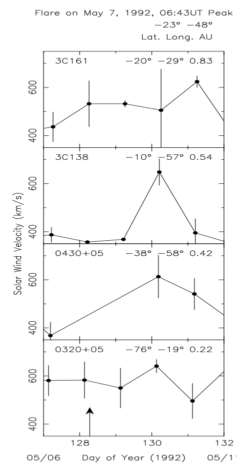

FIGURE 2. Velocities for four sources that show higher values on May 9, 1992 compared to earlier dates. The inset captions are same as Figure 1. Note the passage of the shock at 0.83 AU on May 10.

show that it is a relatively slow moving disturbance which, hence, decelerates at a slower rate.

Oct.-Nov. 1992 events

In this case too, real time STOA predictions were made for the two solar X-class flares that took place on Oct.30, 1992 and Nov.2, 1992. The extensive observations made by the Ooty Radio Telescope following the STOA prediction and their analysis are described in (7). Archival data from Toyokawa show that the IPD's were observed by the multi-station system in Japan also. A recent re-analysis of the Ooty data is shown in Figure 3. The large number of sources that show enhanced velocities enable one to follow the propagation of the disturbances from Oct. 31 to Nov.1 and from Nov.2 to Nov.3. A re-analysis by (8) shows that occurrence of CME's associated with the event cannot be ruled out, since Ulysses records two CME's which could be related to the IPD's. Hence in this particular event a multiplicity of factors are involved.

October 20, 1995 event

A proton flare $>$ 20 Mev was observed on the Sun on Oct.20, 1995 peaking at 06:00 UT in the AR 7912 at S09W55. Both type II and type IV emissions were recorded at Hiraiso, Culgoora and other radio observatories. Estimated shock speed was $\sim$ 1200 km/s. This has been described recently in (9).

Figure 4 shows the velocities in the l-o-s to four sources that have higher values on October 21 compared to the earlier dates. They are located around 60° in longitude and, latitudes spanning $-26°$ to

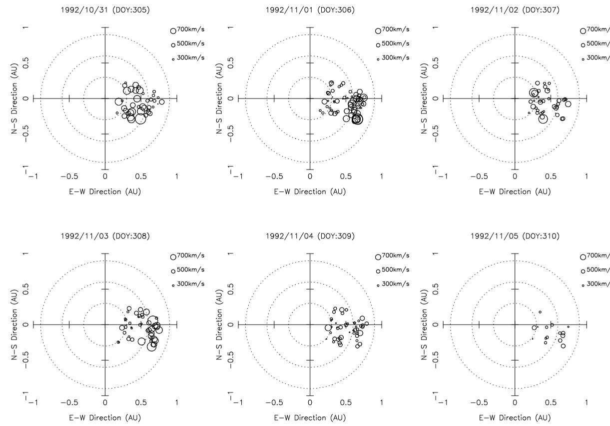

FIGURE 3. Maps of velocity enhancements for the Oct.-Nov. 1992 events(See text).

$+14°$. A control source 1245 - 19 at a similar longitude, but high south latitude does not show any change. The transit time between the flare initiation on Oct. 20 and the observed increase in velocity on all the sources is $\sim$ 19 hours, which gives an average speed of travel for the IPD $\sim$ 1050 km/s to cover a distance of $\sim$ 0.48 AU, indicating deceleration during its passage. It is also interesting that two of the compact sources located at $\sim$ 0.85 AU, which were observed at $\sim$ 23 hours UT on Oct. 21 show similar increase in velocities compared to the earlier values. This may mean that the shock took another 22 hrs. to cover 0.37 AU and therefore had an average velocity of $\sim$ 700 km/s. This agrees well with the IPS velocity measured for these sources.

An examination of the H α and sunspot maps indicate that the flare was associated with the western AR 7912. Coronal hole data indicate that there were only two high latitude ($> 50°$) CH's and none in the vicinity of the flare. There are no CME's recorded by Mauna Loa Solar Observatory on that day.

SUMMARY AND DISCUSSIONS

In a detailed study of the associations between CME's and metric type II bursts, Sheeley *et al.* (1984) (10) showed that (i) type II's without CME's were associated with short lived X - ray events, but not with IP shocks and (ii) type II's with CME's were associated with LDE's and IP shocks. They interpreted the above results to mean that the former type die within the corona, whereas the latter will propagate as shocks into the interplanetary medium. Gopalswamy *et al.* (1998) (1), have also argued that 'the coronal and IP shocks are two different populations and are of independent origin'. It is very interesting that the solar event described above on

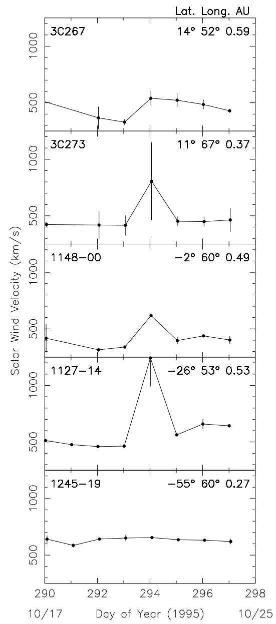

FIGURE 4. Velocities for four sources that show higher values on October 21 compared to earlier dates. The inset gives the line-of-sight values of heliographic latitudes and longitudes and the distance from Sun in AU. Note that the control source 1245-19 at a high south latitude does not show any change.

Oct 20, 1995 is one of the events included in Table 1 of (1), wherein they do not detect any IP shock by the WAVE instrument operating below 14 MHz.

However, from the large number of cases shown above, except for the October 1992 event, the origin of the IPD's appear to be closely related to flare associated type II shocks. The clear association during the solar maximum and solar minimum may indicate that the propagation of type II shocks takes place during all phases of the solar cycle.

As stated by Ananthakrishnan *et al.* (1999), the fact that the WAVE instrument did not detect the interplanetary shock cannot be taken as a proof for the absence of such shocks. Either the cone angle of the shock may not be very wide (cf.Figure 4) or, the location of the WIND spacecraft, the l-o-s to the IPS sources and the equatorial streamer belt could be of such a geometry that the shock may be dampened considerably in the dense streamer belt so that the WAVE instrument does not detect the shock, whereas the l-o-s passes through the high latitude solar wind enabling the IPS observation to detect the shock.

CONCLUSIONS

It seems clearly premature to conclude that coronal type II burst associated shocks do not travel far from the Sun (1). Based on the IPS observations described above, it appears that at least the fast and energetic flare associated type II shocks do produce easily detectable IPD's in the distance range 0.2-0.9 AU on a one-to-one basis. Even a simple STOA model is able to predict the approximate location and time of arrival of the resulting IPS disturbance. Except in one case, there were no clear evidences for the presence of CME's in these events. However, IPS also detects IPD's related to CME's, which may or may not be associated with flares, erupting coronal holes and magnetic clouds. Much work remains to be done to elucidate the various interconnections, for which the ground based IPS observations could be a powerful tool.

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