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IPS OBSERVATIONS OF FLARE-GENERATED INTERPLANETARY SHOCK WAVES DURING THE SECOND STIP INTERVAL (MARCH 15-MAY 15, 1976)

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Abstract

Dynamical characteristics for interplanetary shock waves are investigated from observations using solar, IPS and geomagnetic data during the second STIP interval (March - May 1976). In the case of the shock wave generated by the solar flare at 08 UT on March 23, 1976, the shock velocity, V_s, is seen to be proportional to the heliocentric distance, R, as follows:

$$V_s \propto R^{-0.4},$$

which suggests a blast-like deceleration.

The trajectory for the shock wave generated by the solar flare at 21 UT on April 30, 1976 indicates a piston-driven character to about 0.4 AU. In the cource of further expansion, this shock wave was strongly decelerated. The shock velocity is expresses by a formula:

$$V_s \propto R^{-0.8} \quad (R \gtrsim 0.4 \text{ AU}),$$

which suggests a strong deceleration of the piston.

1. Introduction

Two special intervals for studies of solar-terrestrial events had been chosen by members of Study of Travelling Interplanetary Phenomena (STIP) Project during the 18th planary meeting of COSPAR held in Varna, Bulgaria in 1975. In the cource of the first STIP interval (September-October 1975), no outstanding solar-terrestrial event was reported. On the other hand, the solar activity was rather high during the second STIP interval (March 15 - May 15, 1976), and at least three pronounced events were reported. Collected data reports on the events during the second STIP interval have been published from WDC-A for Solar-Terrestrial Physics (H.E. Coffey and J.A. Mackinnon, eds.). In this report, the flare-generated interplanetary shock waves which were detected by IPS (interplanetary scintillation) observations at 69 MHZ during the second STIP interval are discussed.

2. Events of March 23 – April 1, 1976

The active region of McMath #14143 showed flare activity in the solar east limb on March 23, 1976. Associated Type II and Type IV radio bursts were reported at 0841 UT (IZMIRAN, Moscow). Sudden commencement of gemagnetic storm (SSC) occurred at 0233 UT on March 26. Figure 1 shows a geometry of lines of sight to scintillating radio sources of 3C48 and 3C144 on March 23, 1976. The closest approach to the sun was approximately 0.6 AU on the line of sight to 3C48. In the case of 3C144, the closest approach was about 1 AU from the sun.

Daily solar wind speeds and IPS levels (variances of intensity fluctuations normalized by galactic background noise level) which were obtained by IPS observations of 3C48 and 3C144 are shown in Figure 2. Simultaneous increase of both solar wind speed and IPS level, which is considered to indicate the existence of disturbed post-shock plasma on the line of sight (e.g., Kakinuma and Watanabe, 1976), is clearly seen in Figure 2 on March 26. Observed turbulent and high speed solar wind is attributed to the shock wave generated by the solar flare on March 23, 1976. This shock wave was also detected by the IPS observations of 3C48 on March 25.

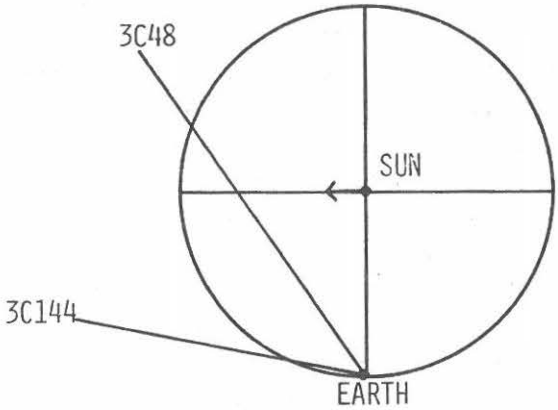

Figure 1. A geometry of the lines of sight to 3C48 and 3C144 on March 23, 1976 projected on the ecliptic plane. The longitude of flare normal on March 23 is also shown by an arrow.

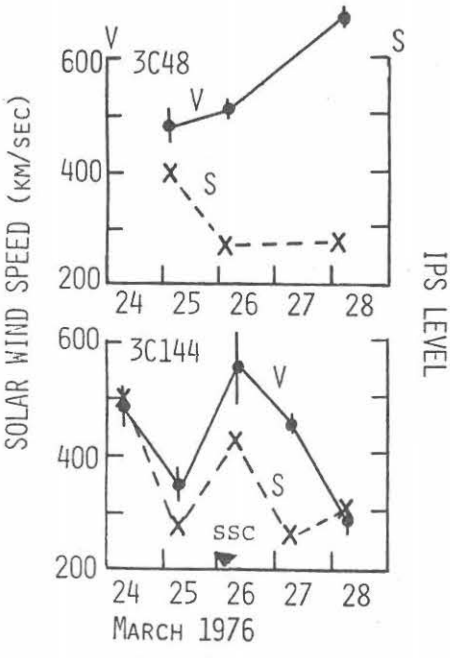

Figure 2. Solar wind speeds, V's, and IPS levels, S's, obtained by IPS observations of 3C48 and 3C144. The IPS level is the 'variance' of intensity fluctuations normalized by the galactic background noise level (arbitrary unit).

With the combination of Type II radio observations, IPS observations of disturbed post-shock plasma, in-situ measurements of shock waves, and SSC's, we obtaine a shock's trajectory under the assumption of spherical shock expansion (e.g., Dryer, et al., 1975) in following way.

First, we estimate the average velocity, V_{avg}, of the shock wave which is determined by heliocentric distance of the shock or disturbed region devided by the lapse time after the relevant flare onset. Estimated average velocity is plotted as a function of one-half the heliocentric distance. In the case of IPS observations, the position of the disturbed post-shock region is located at the point of the closest approach to the sun on the line of sight to observing radio source. We can determine the shock velocity, V_s, as a power-law function of a heliocentric distance, R, fitting a straight line to the points on the log-log plot. The average velocities which are estimated from IPS observations have an ambiguity because each radio source is observed every 24 hours.

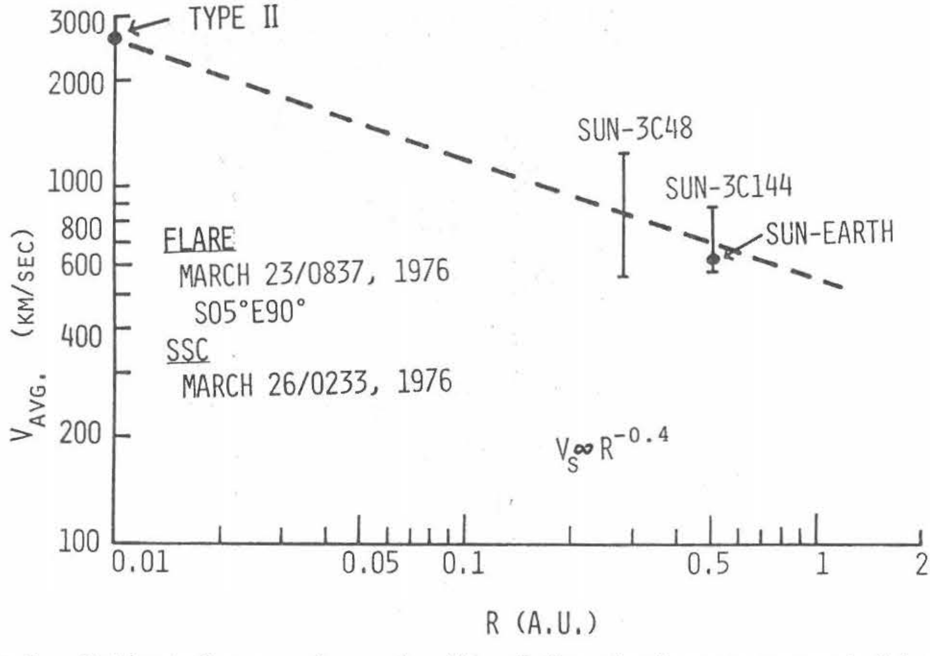

Figure 3. Estimated power-law velocity of the shock wave generated by the solar flare on March 23, 1976. Spherical shock expansion is assumed. The drift velocity of the Type II radio burst is given by Pintér (1977).

The average velocities of the shock wave generated by the solar flare on March 23, 1976 at various heliocentric distances are shown in Figure 3. The shock velocity at about 0.01 AU based on the drift of the Type II radio burst (Pintér, 1977) is also plotted. It is seen in Figure 3 that all plotted data can be fitted by a line which is expressed by a formula:

$$V_s \propto R^{-0.4}. \tag{1}$$

The solar flare accompanied by Type II and Type IV radio bursts were also reported on March 28, 1976. Associated SSC was commenced on April 1. In this case, however, we cannot find unambiguous evidence of the flare-generated shock wave from IPS observations of 3C48 and 3C144.

3. Events of April 30 – May 2, 1976

A solar flare accompanied by Type II and Type IV radio bursts occurred in the active region of McMath #14179 (return of #14143) on April 30, 1976 at 47° west of the central meridian. The Type II burst was reported at 2107 UT (Harvard). Related SSC was observed at 1828 UT on May 2, 1976. The geometry of the line of sight to 3C144 on April 30 is shown in Figure 4. The heliocentric distance of the closest approach on the line of sight was approximately 0.7 AU. Observed solar wind speeds and IPS levels are plotted in Figure 5.

Unusual increase in IPS level accompanied by increase in solar wind speed up to 800 km/sec was detected by the IPS observation of 3C144 on May 2 at about 10 hours before the onset of SSC. This increase is attributed to the shock wave generated by the solar flare on April 30. Using the same method as given in the previous section, we examine the dynamical behavior of this shock wave. Average shock velocities and drift velocity of the Type II burst (Pintér, 1977) are plotted in Figure 6. In this case, it is difficult to draw the shock trajectory only by the plotted data because the average velocity from the sun to the line of sight to 3C144 is considerably ambiguous.

Watanabe (1977) proposed a method to estimate the dynamical characteristics for the turbulent post-shock plasma on the basis of

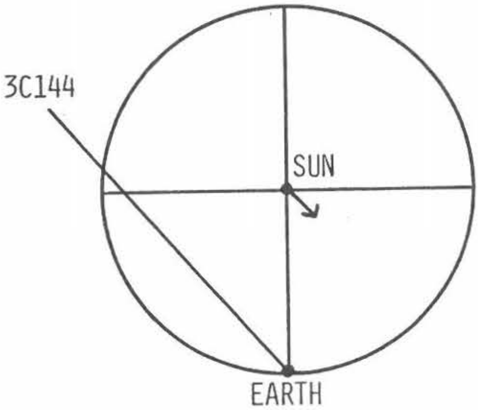

Figure 4. A geometry of the line of sight to 3C144 on April 30, 1976. The longitude of the flare normal on April 30 is indicated by an arrow.

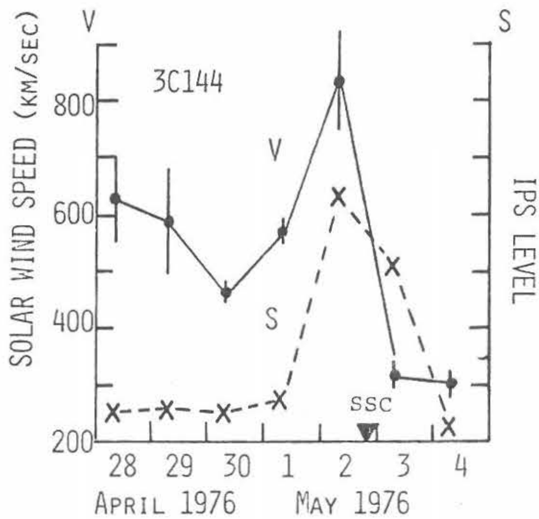

Figure 5. Solar wind speeds and IPS levels obtained by the IPS observations of 3C144 during April 28 - May 4, 1976. The unit of IPS level is arbitrary.

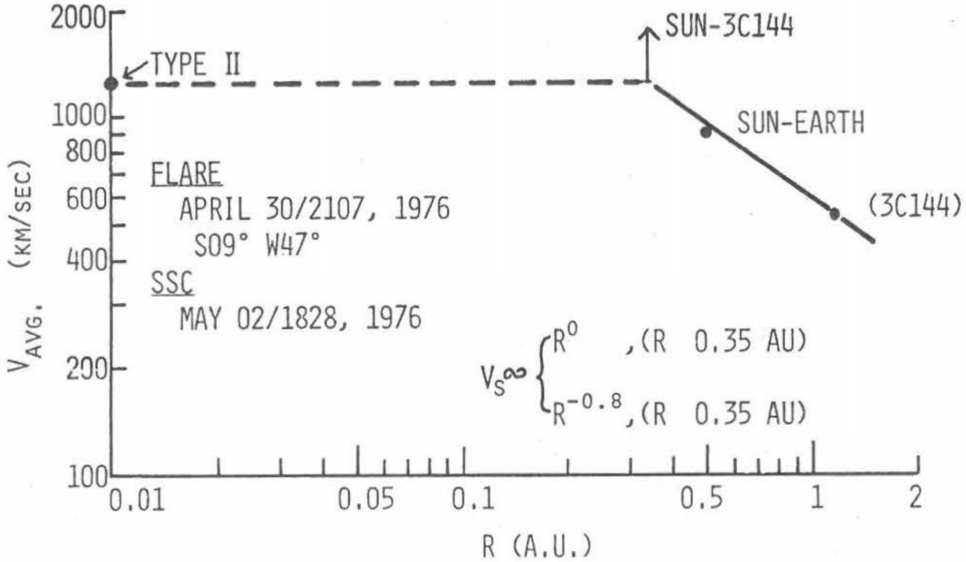

Figure 6. Estimated power-law velocity of the shock wave from the solar flare on April 30, 1976. The drift velocity of the Type II radio burst is given by Pinter (1977). Solid line represents the deceleration of the disturbed post-shock plasma which is given by Eq. (2). Spherical shock expansion is assumed.

IPS observations. When the disturbed post-shock plasma exists on the line of sight during, at least, succesive two days, we can estimate a power-law function of expanding velocity through the comparison between a suitable model and IPS observations. In the case of the shock wave generated by the solar flare on April 30, 1976, the disturbed post-shock plasma still existed on the line of sight to 3C144 on May 3 because the IPS level of 3C144 on May 3 was similar to that on May 2. Observed low speed on May 3 is explained by a combination of following two effects; (1) projection of radial flow vector, and (2) deceleration of flow speed with heliocentric distance if we assume the spherical expansion. According to the method given by Watanabe (1977), the IPS observations of 3C144 during May 2 - 3, 1976 are explained by the spherical shock wave whose expanding speed is expressed by the formula:

$$V_s \text{ (km/sec)} = 1200 \ (\ r - 0.35 \ )^{-0.8}, \tag{2}$$

where r is the heliocentric distance in AU ($r \gtrsim 0.35$). The shock trajectory given by Eq. (2) is shown in Figure 6. It is seen that estimated velocity of the disturbed post-shock plasma at r = 0.35 AU (1200 km/sec) is very similar to that of the drift speed of the relevant Type II burst (1250 km/sec) which has been given by Pintér (1977). This means that the shock wave, which was produced by the solar flare on April 30, 1976, expanded with approximately constant velocity of 1200 km/sec from the sun to about 0.4 AU and that the expanding velocity was strongly decelerated in further expansion beyond 0.4 AU.

4. Concluding Remarks

As shown in Figure 3, the shock wave generated by the solar flare on March 23, 1976 was continuously decelerated throughout its journey from the sun to about 1 AU. Estimated power-law index of deceleration (0.4) is very similar to that of a theoretical blast wave (0.5) propagating in the normal solar wind (e.g., Parker, 1963).

The solar flare on April 30, 1976 is considered to have produced the shock wave of a driven-type because, as shown in Figure 6, the deceleration of this shock wave was very small during its propagation from the sun to about 0.4 AU. It is also suggested that strong deceleration which was observed in the course of further expansion beyond 0.4 AU from the sun means the deceleration of the piston.

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