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R. P. LEPPING

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R. P. Lepping

Laboratory for Extraterrestrial Physics
NASA-Goddard Space Flight Center
Greenbelt, Maryland 20771

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Abstract

The interplanetary shock speed and surface normal for the July 8, 1966 shock in the vicinity of the earth have been accurately estimated and shown to be in serious disagreement with previously estimated values. The shock speed was 570 ± 20 km/sec and the normal had a direction given by $\theta_{SE} = -38^\circ \pm 7^\circ$ and $\phi_{SE} = 166^\circ \pm 7^\circ$. These values yielded the most consistent picture of the event where the following constraints were put on the estimation: (1) the MHD shock conservation equations (excluding the normal momentum and energy equations) had to be satisfied and (2) the time-of-sighting restriction for the shock passage between Explorers 28 and 33, both in interplanetary space, had to be fulfilled. Vela 3A, which was in the magnetosheath at the time of its shock sighting, observed the shock 3.0 $\pm$2.1 min. later than might be expected from the simple model of a shock front remaining plane and constant in both speed and (normal) direction after interaction with the bow shock. The lower end of this range (1 min.) is not inconsistent with the delay time obtained by Lepping and Chao (1971) in studying the January 11, 1968 traveling shock-bow shock interaction. Hence, the traveling shock probably experienced a rapid slowing-down and significant distortion from a plane shape in the sunward region of the earth's magnetosheath.

Introduction

The actual shapes of shock surfaces in interplanetary space have an obvious bearing upon models of the propagation of shocks caused by solar events. These models in turn influence explanations of the solar source of such shocks and yield knowledge of the detailed characteristics of the interplanetary medium. The July 8, 1966 shock (Van Allen, 1966; Van Allen and Ness, 1967, Ness and Taylor, 1968; and Lazarus and Binsack, 1968) in the vicinity of the earth has been estimated by Greenstadt et al. (1970) to have an interplanetary normal which is inclined 65-70° below the ecliptic plane at solar ecliptic longitude 165°. They made this estimate using a three-spacecraft kinematic method. This direction is in the correct octant for a shock induced by a solar flare located at heliographic coordinates 34°N, 48°W and occurring at 0022 UT on July 7. If the severe inclination of this estimated normal is correct, it would provide important quantitative information regarding the possible shapes of such shock surfaces in interplanetary space (e.g. Hirshberg, 1968; Hundhausen, 1971: and Schatten and Schatten, 1971).

It is the principal purpose of this study to obtain two estimates of the July 8 interplanetary shock normal in the vicinity of the earth by using two semi-independent methods, each considered to be of approximately equal accuracy.

Methods

The estimated normals from these two methods must be, on the one hand, consistent, within the error due to fluctuations in the data, with a least-squares best fit of interplanetary magnetic field and plasma data (from Explorer 33) to a six-equation subset of the Rankine-Hugoniot equations. This method described by Lepping and Argentiero (1971) will be referred to as Method 1. On the other hand, these estimates must be consistent with the times of observation of the shock by two spacecraft in interplanetary space; this requirement is the essence of Method 2.

We now describe Method 2 in detail. As a by-product of Method 1 the shock speed V_S and the magnetic field difference $\Delta\vec{B}(\equiv \vec{B}_2-\vec{B}_1)$ across the shock are obtained.

The components of the best-fit plasma and field quantities (including densities as one-component vectors) can be examined from the point of view of their estimated errors normalized by the magnitudes of their associated vectors. The source of the errors is primarily the natural fluctuations in the original data over the analysis interval as measured by RMS deviations. When these normalized errors are compared against each other, those for the field quantities are usually distinctly smaller than those for the plasma quantities; this is in fact the case for the July 8 shock (Table 1). Also field differences across the shock are expected to have, in general, smaller errors than the fields themselves because any original measurement-bias would tend to cancel. Hence, $\Delta\vec{B}$ is probably the most accurately determined quantity from the best-fit analysis. Then for known $\Delta\vec{B}$, V_S, $\vec{R}$ and τ (where $\vec{R}$ is the displacement vector between any two interplanetary spacecraft and τ the time delay between shock sightings for the two spacecraft) the shock normal is estimated by the following scheme:

$$\Delta\vec{B} \cdot \vec{n} = 0 \tag{1}$$

$$\vec{R} \cdot \vec{n} = \tau V_s \tag{2}$$

$$|\vec{n}| = 1, \tag{3}$$

where the single Rankine-Hugoniot equation (1) is used and where constant $\vec{n}$ and V_s over the region of interest is assumed. For the second spacecraft Explorer 28 (IMP 3) was used. Plasma data was not available from this spacecraft so Method 1 could not be applied in its case. Since $|\vec{R}|/|\vec{\tau}|$ ($\gtrsim$16,000 km/sec) for Explorers 28 and 33 is so much larger than characteristic interplanetary shock speeds, $\vec{n}$ depends only very weakly on the value of V_s through the constraint imposed by equation (2). Hence, Methods 1 and 2 are coupled essentially only by $\Delta\vec{B}$, believed to be the most accurately determined quantity in the analysis. If the two methods give normals which agree within a reasonably small error cone angle, then the necessary self-consistency is accomplished.

Vela 3A, which was used by Greenstadt et al. in their estimation of the interplanetary normal together with the above-mentioned two spacecraft, was located in the magnetosheath at the time of its shock sighting and therefore, we believe, disqualified to supply data for Method 2. It is not sufficient to say that Vela 3A was "close to" the boundary of the bow shock and therefore almost in interplanetary space, because the traveling shock will slow down severely just after its encounter with the bow shock giving a large relative time-delay error (Dryer et al., 1967 and Lepping and Chao, 1971); this implies a large normal direction error in Method 2. Also, as pointed out by Burlaga (1971), the three spacecraft were all close to the ecliptic plane, and therefore the component of the normal perpendicular to the ecliptic plane is the one least accurately determined by the Greenstadt et al. three-spacecraft method. In this study we use the solar ecliptic $\hat{R}$-$\hat{T}$-$\hat{N}$ coordinate system for representing both physical quantities and spacecraft positions. This system is defined such that $\hat{R}$ is in the ecliptic plane radially away from the sun, $\hat{N}$ is normal to the ecliptic and "Northward", and $\hat{T} = \hat{N} \times \hat{R}$, which is tangential to the earth's velocity about the sun. Using Method 2 we notice that even though $\vec{R}\,(=(31.9, 96.6, 3.4)R_E)$ is nearly in the ecliptic plane, $\Delta\vec{B}(=(-1.9, 7.6, -4.8)\gamma)$, calculated via the least squares best-fit Method 1, is about 31° below it.

In applying Method 1 it turned out to be important that only a rather short interval of data, taken near the shock, be used. There is always a certain measure of unavoidable arbitrariness in choosing the proper interval to be used in a least-squares shock analysis, but this arbitrariness is significantly decreased by the evaluation of an associated quality index. This index is defined as the square root of the ratio of the total number of points of all shock parameters used in the analysis to the standard sigma-weighted least-squares loss function at convergence (Lepping and Argentiero, 1971). This index is usually greater than unity for characteristic interplanetary shocks provided reasonable sigma-weights are employed. For the July 8 shock the short analysis interval yielded an index of 1.2 whereas longer intervals gave distinctly lower values, usually below unity. After some necessary trial and error, the analysis (short) interval chosen as most reasonable was:

Magnetic field data near the shock	5 points (6.5 min.) before shock. 6 points (7.1 min.) after shock.
Plasma data near the shock	Average of first 2 points (at 22.2 and 16.7 min., respectively) before shock, excluding a spurious point occurring just before the shock (including the spurious point caused a drop in the quality index to the unacceptably low value of 0.86). First single point (10.5 min.) after shock.

The magnetic field data indicated significant directional changes about seven minutes before and after the shock jump as listed above; this, in the final analysis, determined the field data interval. The plasma data that was used, guided by the quality index, turned out to be simply the closest reasonable values to the shock jump.

Since there were no plasma data within the analysis intervals determined by the magnetic field data (except for the single spurious point just before the jump), use of such data requires justification that the plasma points that were available, were still characteristic of the "true" values, before and after the shock, within estimated errors. As Table 1 shows, the plasma data was weighted in the analysis by rather large sigma-weights, which were based on RMS deviations in the data over ± 30 mins from the shock jump. The magnetic field data, in turn, was weighted with relatively smaller sigma-weights based on the ± 7 mins intervals from the jump. The (95% certainty) error cone angle which is estimated for the resulting normal, and given below, will depend on <u>all</u> of these sigma-weights, and it will be an optimum estimate based in part on the relatively large estimates of the plasma sigma-weights. The important assumption made here then is that the sigma-weights put on the plasma quantities are characteristic of the fluctuations close to the shock, i.e., over the interval for which there is no plasma data ($\approx \pm 11$ mins), as they are for the ± 30 mins interval.

The best-fit analysis was repeated ten times using the same (short interval) input data in each case except for a change in each one of the five plasma parameters, which was successively replaced by either its extreme maximum or minimum value based on the average $\pm\sigma$. In no case did the normal deviate by more than 3° from the best-fit normal based strictly on the average plasma values given in Table 1 as input. Also in no case did a field component change by even as much as 0.1γ. Even though this indicates, in this case, a weak dependence of the resulting normal on the plasma parameters, the influence of these parameters is still significant as the small error cone angle (11°) and high quality index indicate.

Table 1 gives the best-fit results of Method 1. The best-fit magnetic fields, before and after the shock, expressed in solar ecliptic θ and ϕ ($B = (F, \theta_{SE}, \phi_{SE})$) were

$\vec{B}_1 = (12.6\gamma, -6.4^\circ, 312.1^\circ)$ and

$\vec{B}_2 = (20.7\gamma, -17.4^\circ, 301.4^\circ)$, respectively. These may be compared with those of Van Allen and Ness (1967) which were

$\vec{B}_1(\text{V.A.N}) = (12.2\gamma, -10^\circ, 310^\circ)$ and

$\vec{B}_2(\text{V.A.N}) = (20.8\gamma, -18^\circ, 300^\circ)$, where these estimates were derived from straightforward 13 min. averages. From the point of view of accurately estimating shock normals from magnetic field data a significant difference occurs only for the pre-shock parameters θ_{SE}; otherwise the agreement is rather good. The difference is principally due to the difference in the length of the analysis intervals used and partly on the influence of the plasma data on the present estimates.

TABLE 1

July 8, 1966 Explorer 33 Shock Parameters

Parameter		Average Value	Estimated Sigma	Best Fit Value
B_{1R}	(γ)	-8.3	0.70	-8.4
B_{1T}		9.2	0.70	9.3
B_{1N}		-1.2	0.75	-1.4
B_{2R}		-10.4	0.83	-10.3
B_{2T}		17.0	0.57	16.9
B_{2N}		-6.3	0.75	-6.2
W_R *	(km/sec.)	69.6	30.0	55.C
W_T		-2.9	25.0	20.7
W_N		-38.4	20.0	-56.6
N_1	(#/cm^3)	5.3	0.49	5.1
N_2		8.0	0.78	8.4
n_R		0.83		0.85
n_T		-0.14		-0.13
n_N		-0.54		-0.52

*$\vec{W}$ is the difference velocity ($\vec{V}_2$ - $\vec{V}_1$) across the shock.

The two-point average of the preshock plasma velocity in an inertial coordinate system at rest with respect to the sun was $\langle \vec{V}_1 \rangle$ = (419, -3, -33) km/sec. Using this and the best fit plasma and normal values from Table 1 in the mass conservation equation yields an estimate for the shock speed V_s = 570±20 km/sec in the same inertial system. Then the component of the shock velocity in the ecliptic plane, based on Method 1's normal is, 490±17 km/sec, which is in close agreement with the estimate of this quantity by Sugiura et al. (1968); using a different approach they arrived at a value of 500 km/sec. The error is due principally to the uncertainty in the magnitude of $\langle \vec{V}_1 \rangle$ (±15 km/sec). Since Explorer 28 recorded the shock onset time and uncertainty interval to be 2105:54±24 UT (Taylor, 1969) and since the Explorer 33 onset time was 2105:40.5 (+3.5/-4.5) UT (Greenstadt et al., 1970), the delay time $\tau (\equiv t_{28}-t_{33})$ between the two spacecraft ranged between -14 and +42 sec. Hence, τV_s in (2) is somewhere between -1.3 R_E and +3.9 R_E, where the worst-case value of V_s (590 km/sec) was used. We employ Method 2 twice, once each for τV_s equal to these two extreme values. Table 2 lists the results of these calculations as well as the results of the estimates of other investigators for

TABLE 2

Estimated Normals for the July 8, 1966 Shock

Investigator(s)	Method	$\vec{n} = (n_R, n_T, n_N)$	θ_{SE}, ϕ_{SE}
Van Allen and Ness (1967)	Coplanarity Theorem using Explorer 33 average magnetic fields, GSFC experiment	0.89, +0.03, -0.45	$-27^\circ \pm 5^\circ$, $182^\circ \pm 5^\circ$
Ness and Taylor (1968	Magnetic Field data from each spacecraft (Explorer 28, Explorer 33 respectively) using $\Delta\vec{B}\cdot\vec{n}=0$ and delay-time coordination.	0.90, -0.33, +0.28 0.65, -0.20, -0.73	16°, 160° -47°, 163°
Taylor (1969)	Coplanarity Theorem using Explorer 28 average magnetic fields, then assuming $\theta_{SE} = 0^\circ$	0.85, -0.34, +0.41 0.93, -0.37, 0.00	24°, 158° 0°, 158°
Greenstadt et al. (1970)	Three spacecraft method	0.33, -0.09, -0.94	-70°, 165°
Greenstadt et al. (1970)	Coplanarity Theorem using average magnetic fields. Ames experiment, Explorer 33	0.78, -0.17, -0.60	-37°, 168°
Burlaga (1971)	Greenstadt et al. $\Delta\vec{B}$ field values, their shock surface intersection with the ecliptic, and using $\Delta\vec{B}\cdot\vec{n} = 0$.	0.74, -0.21, -0.64	-40°, 164°
Lepping	Method 1	0.85, -0.13, -0.52	-31°, 171°
Lepping	Method 2 $\begin{cases}\tau V_s = -1.3\ R_E \\ \tau V_s = 3.9\ R_E\end{cases}$	0.72, -0.23, -0.65 0.77, -0.19, -0.61	-41°, 162° -38°, 166°

comparisons. The two normals obtained from Method 2 differ by less than 4°. Obviously the small difference between the results of Methods 1 and 2 is due to the inaccuracy in $\Delta\vec{B}$. The (95% certainty) error cone angle associated with Method 1 was 11°. The angles between the normal obtained from Method 1 and the two normals from Method 2 were 11° ($\tau V_s = -1.3\ R_E$) and 5° ($\tau V_s = 3.9\ R_E$), respectively. Therefore, the two methods agree to within 11° with approximately a 95% certainty. The averages of θ_{SE} and ϕ_{SE} for these three normals are

$$< \theta_{SE} > = -37.7^\circ \text{ and } < \phi_{SE} > = 166.3^\circ,$$

which fall between the angles obtained by Greenstadt et al., <u>using only the coplanarity theorem and straightforward average magnetic field values</u>, and the angles obtained by Burlaga. <u>Taylor's</u> (1969) assumption that $\theta_{SE} = 0^\circ$ was not applicable in this case--also there was a very large uncertainty in the Explorer 28 B_{2N} component in any case.

Since the error cone angle associated with Method 2 is estimated under worse case assumptions concerning the $\Delta\vec{B}$ error to be also 11°, the average normal given by $<\hat{n}> = (<\theta_{SE}>, <\phi_{SE}>)$ has an estimated error angle of about 7°. The Alfvén Mach numbers, based on the best-fit magnetic field components along the shock normal $<\hat{n}>$, were 3.0 ± 1.0 (preshock) and 2.7 ± 1.1 (postshock). These are somewhat lower than typical values for interplanetary shocks (~ 5) <u>Hundhausen</u>, 1970).

Further Results and Discussion

Using (2) again with $\vec{R}$ ($\equiv \Delta\vec{R}_V$) now representing the displacement vector between Explorer 33 and Vela 3A, τ_V the related time delay, and V_s equal to 570 km/sec, enables us to determine the time Vela would have seen the shock had the spacecraft been in interplanetary space during the shock transit. Where $\Delta\vec{R}_V$ ($= \vec{R}_{33}-\vec{R}_V$) was (39, 61, 13) R_E we find that τ_V is 130 sec. Then the "expected" time of sighting at Vela, "t_V" ($\equiv t_{33}-\tau_V$) is 2103:30. The actual Vela sighting took place at t_V=2106:32 $\pm$1 according to Greenstadt et al. The difference between actual and "expected" times, 3.0 mins. $\pm\ \Delta\tau_V$, where $\Delta\tau_V$ is the uncertainty in the estimate of τ_V, represents the delay experienced by the traveling shock (T.S) due to the T.S.-bow shock interaction. The quantity $\Delta\tau_V$ is 2.1 mins. for a 7° uncertainty in $<\hat{n}>$, and the lower end of the range 3.0 $\pm$2.1 min is a reasonable value for such an interaction delay time (Lepping and Chao, 1971). The normal $\hat{n}_V$ =(0.70, -0.25, -0.67) (θ_{SE}= -42°, ϕ_{SE} = 160°) would, in fact, give such a result. The other end of the range, 5.1 min., is obtained from $\hat{n}'_V$ = (0.84, -0.11, -0.53) (θ_{SE} = - 32°, ϕ_{SE} = 173°). If the interaction delay time is indeed close to one minute, then $\hat{n}_V$ might represent a refinement of $<\hat{n}>$($\pm 7^\circ$) but such a conclusion is too speculative without detailed knowledge of at least where Vela 3A was with respect to the bow shock. Notice however, that $\hat{n}_V$ lies very close to the normal derived by Method 2 for τV_s = -1.3 ($\approx 2^\circ$ difference).

The instantaneous shock speed in the vicinity of the earth was estimated by Van Allen and Ness (1967) to be 890$\pm$40 km/sec which is probably 1-1/2 times too large. Our estimate of 570 ± 20 km/sec satisfies a consistent picture as described above, and furthermore is very much in line with all of the most accurately determined shock speeds listed by Hundhausen (1970). The Van Allen and Ness estimate of V_s was based on the assumptions that (a) the shock front was orthogonal to the radius vector to the sun (i.e., the $\hat{R}$-direction at the earth's location), (b) the onset time of the terrestrial sudden commencement (2102.2 UT) corresponded to the passage of the shock front past the center of the earth, and (c) the nearby moon had no significant effect. Assumption (c) is probably a good one and was implicitly used in this work. Assumption (a) is not acceptable since such calculations using time delays between "spacecraft" (earth and Explorer 33) are usually sensitive to the true direction of $\vec{n}$, and $\hat{R}$ and $\langle \hat{n} \rangle$ were 40° from each other in this case. However, if a more accurately determined normal such as $\langle \hat{n} \rangle = (-37.7^\circ, 166.3^\circ)$ had been used, too low a value of V_s (≈ 380 km/sec) would have resulted. Using $\hat{n}_v$ yields a still lower value (210 km/sec). This inconsistency is not surprising since assumption (b) is a weak one in light of the fact that the signals arriving earliest at the earth, which are initiated at the outer boundary of the magnetosphere $R=R_M$, propagate downward with characteristic speeds usually higher than the interplanetary shock speed and take about 1-1/2 min. for $R_M = 10\ R_E$ (Sugiura, 1965); these start as hydromagnetic waves and then degenerate into ordinary electromagnetic emissions below the ionosphere. Adding to this the fact that the traveling shock will slow down as it interacts with the bow shock makes assumption (b) difficult to accept.

The average shock speed from the sun to the earth, for the solar flare occurring at 0022 UT on July 7, was determined by Van Allen and Ness to be 950 km/sec with about a 1% uncertainty. As is commonly the case this is considerably higher than the instantaneous speed at 1 AU (Hundhausen, 1970).

Ness and Taylor (1968), using their estimate of the shock normal ($\theta_{SE} = 16^{\circ}$, $\phi_{SE} = 160^{\circ}$) derived from the magnetic field data of Explorer 28 and the near simultaneity of the shock onset at Explorers 28 and 33, calculated an upper limit on V_s. Their estimate of this limit was based on the assumption that the onset time of the SSC at earth occurred (shortly) after the arrival of the shock at the bow shock. For the time delay (210 sec) and associated displacement vector in our equation (2) they used those quantities for Explorer 28 and the shock-shock interaction point. They point out that the propagation velocities through the magnetosphere and magnetosheath are significantly different from those in interplanetary space, and imply that a limit on V_s is all that may be obtained without use of plasma data. The upper bound turned out to be 710 $\pm$50 km/sec. If a more accurate normal such as $<\hat{n}>$ is used in this model, essentially the same value (720 km/sec) is obtained. However, a normal mid-way between $<\hat{n}>$ and the Ness and Taylor normal yields a bound of 110 km/sec in this model, making their result somewhat fortuitous. For an accurate normal this sort of model should yield a reasonable but conservative upper bound on V_s for the type of magnitude of the time delay encountered here.

Instead of estimating V_s as these authors do, we "reverse" the calculation and proceed as we did for Vela where now the earth replaces

Vela in the calculation. The resulting time is an "expected" time that the earth would have seen the shock had its environment not "interfered" with the traveling shock. Using V_s = 570 km/sec, $<\hat{n}>$, and R_{e-33} = (29.3, 59.9, -2.3) R_E the effective delay time is seen to be τ_{e-33} = 2.3 min. This, of course, assumes that V_s and $\vec{n}$ are constant between the earth and Explorer 33. Although crude this is a more realistic assumption than assuming these quantities constant in the magnetosheath in front of the earth where most of the slowing down of the traveling shock takes place. Hence, the "expected" onset time at earth is 2103.4 UT (because the onset time at Explorer 33 was 2105.7). Since the SSC at earth occurred at 2102.2, the time difference (t_D) of +1.2 min. between "expected" and actual onset times represents a net speed-up of the overall signal, regardless of its nature, as received at the earth. Sugiura et al. (1968) have shown, in fact, for the July 8 event that the magnetospheric propagation of the magnetic field toward the tail is indeed faster than the propagation of the interplanetary shock just outside the bow shock, even if it is assumed that V_s = 700 km/sec. They used the magnetic field data of OGO 3 which was located at (10.1, -10.3, 11.6) R_E. They also point out that a 60 sec. transit time from the magnetopause to the earth along the earliest-signal-path is not unreasonable for this event.

Using this 60 sec. transit time let us estimate t_D from theoretical considerations. It is clear that, according to our model,

$$t_D = t_{SH} - (t_{MS} + t_M), \qquad (4)$$

where t_{SH} is the time the shock would travel from the bow shock to the earth ($\approx 15\ R_E$) at 570 km/sec unimpeded, t_{MS} is the minimum hydromagnetic wave travel time of 60 sec. through the magnetosphere ($\approx 12\ R_E$), and t_M is the magnetosheath shock travel time where the shock velocity will be assumed equal to ≈ 400 km/sec in this region ($\approx 3\ R_E$). Hence, $t_{SH} \approx 2.8$ min., $t_M \approx 0.8$ min., and therefore $t_D \approx 1.0$ min., which compares reasonably well with $t_D = 1.2$ min. above. Again there is considerable uncertainty associated with t_D-observational and t_D-theoretical, but either value cautions against modeling the true t_D as zero.

Concluding Remarks

The most accurately estimated interplanetary normal for the July 8 shock in the vicinity of the earth is indeed rather severely inclined with respect to the ecliptic plane. But an inclination of $\theta_{SE} \approx -38^\circ$ is more consistent with a reasonable overall picture then the value of $\theta_{SE} = -70^\circ$ as obtained by Greenstadt et al. The -70° inclination would not allow a satisfactory fitting of the shock data to the conservation equations because this direction for the normal lies outside the 11° error cone whose axis is along $\langle\hat{n}\rangle$ (or $\vec{n}$ from Method 1). The use of plasma data from Explorer 33 enabled us to estimate the shock speed to be 570 ± 20 km/sec, significantly lower than the Ness and Taylor upper limit of 710 ± 50 km/sec. The onset time of signals at Vela and the earth aided in more fully understanding the shock interaction event: apparently the traveling shock experienced a rapid slowing-down and distortion from a plane shape as it impinged on the earth's bow shock. This sort of interaction, in the case of the January 11, 1968 shock, has been studied by Lepping and Chao (1971) and earlier, in its general considerations, by Dryer et al. (1967). The qualitative view developed here is in essential agreement with these previous investigations.

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References

Burlaga, L. F., Hydromagnetic Waves and Discontinuities in the Solar Wind, NASA-X-692-71-95, March 1971. To appear in Space Sci. Rev.

Dryer, M., D. L. Merritt, and P. M. Aronson, Interaction of a Plasma Cloud with the Earth's Magnetosphere, J. Geophys. Res., 72, 2955, June 1967.

Greenstadt, E. W., I. M. Green, G. T. Inouye, and C. P. Sonett, The Oblique Shock of the Proton Flare of 7 July 1966, Planet. Space Sci., 18, 333, 1970.

Hirshberg, J., The Transport of Flare Plasma from the Sun to the Earth, Planet. Space Sci., 16, 309, 1968.

Hundhausen, A. J., Composition and Dynamics of the Solar Wind Plasma, Rev. Geophys. and Space Physics, 8, 729, 1970.

Hundhausen, A. J., Interplanetary Shock Waves and the Structure of Solar Wind Disturbances, Proc. of the Conference on Solar Wind (in press), Asilomar Conference Grounds, Pacific Grove, Calif., 1971.

Lazarus, A. J. and J. H. Binsack, Observations of the Interplanetary Plasma (associated with the July 7, 1966 Flare), Annals of IQSY, 3, 378, 1968.

Lepping, R. P. and P. D. Argentiero, Single Spacecraft Method of Estimating Shock Normals, J. Geophys. Res., 76, 4349, July 1971.

Lepping, R. P. and J. K. Chao, Multiple Spacecraft Observations of an Interplanetary Shock Bow Shock Interaction, to be published, 1971.

Ness, N. F. and H. E. Taylor, Observations of the Interplanetary Magnetic Fields, July 4-12, 1966, Annals of IQSY, 3, 366, 1968.

Schatten, K. H., and J. E. Schatten, Magnetic Field Structure in Solar Wind Disturbances, to be published, 1971.

Sugiura, M., Propagation of Hydromagnetic Waves in the Magnetosphere, Radio Sci, J. Res., NBS Part D, 69-D, 1133, 1965.

Sugiura, M., T. L. Skillman, B. G. Ledley, and J. P. Heppner Propagation of the Sudden Commencement of July 8, 1966 to the Magnetotail, J. Geophys. Res., 73, 6699, November 1968.

Taylor, H. E., Sudden Commencement Associated Discontinuities in the Interplanetary Magnetic Field Observed by IMP-3, Solar Phys, 6, 320, 1969.

Van Allen, J. A., Low Energy Solar Particle Observations, paper presented at American Astronomical Society Special Meeting on Solar Astronomy, October 3-5, 1966, Boulder, Colorado.

Van Allen, J. A., and N. F. Ness, Observed Particle Effects of an Interplanetary Shock Wave on July 8, 1966, J. Geophys. Res., 72, 935, February 1967.