Plasma Properties of Driver Gas Following Interplanetary Shocks Observed by ISEE-3

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Abstract

Plasma fluid parameters calculated from solar wind and magnetic field data obtained on ISEE 3 were studied to determine the characteristic properties of driver gas following a select subset of interplanetary shocks. Of 54 shocks observed from August 1978 to February 1980, 9 contained a well defined driver gas that was clearly identifiable by a discontinuous decrease in the average proton temperature across a discontinuity which we assume is tangential. While helium enhancements were present somewhere downstream of the shock in all 9 of these events, only about half of them contained simultaneous changes in the two quantities. Often the He/H ratio changed over a period of minutes. Simultaneous with the drop in proton temperature the helium and electron temperature decreased abruptly. In some cases the proton temperature depression was accompanied by a moderate increase in magnetic field magnitude with an unusually low variance, by a small decrease in the variance of the bulk velocity, and by an increase in the ratio of parallel to perpendicular temperature. The cold driver gas usually displayed a bi-directional flow of suprathermal solar wind electrons at higher energies (>137 eV).

1. Introduction

Interplanetary shocks have been observed throughout that part of the heliosphere sampled by space probes during the last two decades. These shocks were generally formed either by high speed streams which steepen with increasing radial distance into forward-reverse shock pairs at their leading edges [Hundhausen and Gosling, 1976; Smith and Wolf, 1976], or by transient events at the sun which expel coronal material to drive forward shocks [see e.g. Hundhausen, 1972]. Shocks produced by transient events in the corona can also form forward-reverse shock pairs but usually outside of 1 AU. The characteristics of the plasma behind this latter type shock have been studied extensively. The "driver gas" for these shocks is usually identified by one or more of the following anomalous solar wind conditions: He abundance enhancements [Bame et al., 1968; Hirshberg et al., 1972; Borrini et al., 1982], proton temperature depressions [Gosling et al., 1973], electron temperature depressions [Montgomery et al., 1974], high magnetic field strength [Hirshberg and Colburn, 1969; Schatten and Schatten, 1972; Burlaga and King, 1979] with low variance [Pudovkin et al., 1979], unusual heavy ion ionization states [Bame et al. 1979; Fenimore 1980; Schwenn et al., 1980; Gosling et al., 1980; Zwickl et al., 1982], and bidirectional streaming of both solar wind electrons [Montgomery et al., 1974; Temmy and Vaisberg, 1979; Bame et al., 1981] and energetic protons [Palmer et al., 1978; Kutchko et al., 1982].

The most commonly used characteristics in determining the presence of driver gas behind interplanetary shocks are He abundance enhancements and proton temperature depressions. However, these plasma signatures are observed after less than half of all shocks [Schwenn et al. 1980; Borrini et al., 1982], and when present can show a very complex pattern [Ogilvie and Burlaga, 1974; Bame et al., 1979].

Plasma fluid parameters calculated from solar wind data together with magnetic field data obtained with instrumentation on ISEE 3 have been studied to determine the characteristic properties of driver gas following a select subset of interplanetary shocks. Of 54 shocks observed from August 1978 to February 1980, 9 were followed by well defined driver gas that is clearly identifiable by a discontinuous decrease in the average proton temperature. This decrease is accompanied by an abrupt change in the magnetic field strength in 7 and possibly 8 of the 9 events and when taken together with the observed discontinuous changes in other plasma parameters implies the presence of a tangential discontinuity at the interface between the shocked ambient plasma and driver gas. In this paper the plasma properties of the driver gas from the 9 events are examined with a view toward characterizing the complexity of the most well defined events.

2. Characteristic Properties of Driver Gas

The subset of 9 events in this study were selected only on the basis of a well defined discontinuous decrease in proton temperature following a shock. Constraints were not placed on any other property of the assumed driver gas. Characteristic properties of the plasma following these 9 events are shown in Table 1. The identification of a He/H increase following a shock was not restricted just to plasma within the lowest temperature region. The first three properties are those most often used to identify the presence of driver gas in this select subset. Helium abundance increases and T_e decreases are present in all but one case, indicating both properties are commonly present in driver gas. Bi-directional streaming of plasma electrons is often but not always seen (Table 1). The thin proton density enhancement, located near the discontinuity separating the shocked plasma from the driver, is the least reliable indicator of driver gas and is probably not a general feature. The next three quantities in Table 1 have not been discussed previously and all three (a bulk speed increase, a decrease in the RMS deviation of V, σ_V, and an increase in the parallel to perpendicular proton temperature ratio) are usually present. The last two quantities in the table indicate the nature of the magnetic field magnitude (increase) at the interface between the shocked plasma and the low temperature driver gas and RMS deviation ,σ_B, decrease within the temperature depressed phase of the driver gas. The significance of a decrease in σ_B is hard to determine in cases where large macroscopic variations in B are taking place.

Table 1
ISEE-3
Characteristic Properties of Driver Gas

Characteristic	Nov 12 1978	Dec 14 1978	Feb 21 1979	Mar 9 1979	Mar 22 1979	Apr 1 1979	Apr 5 1979	Apr 24 1979	May 29 1979
1. T_p decrease	Y	Y	Y	Y	Y	Y	Y	Y	Y
2. He/H increase	Y	Y	Y	Y	Y	Y	Y	Y	Y
3. T_e decrease	Y	Y	Y	Y	Y	-	Y	Y	Y
4. Bi-directional streaming	Y	-	?	Y	Y	-	Y	Y	Y
5. Density spike	?	Y	Y	Y	?	-	-	-	Y
6. V increase	Y	-	-	Y	Y	-	Y	Y	Y
7. σ_V decrease	Y	Y	Y	Y	Y	-	Y	Y	Y
8. $T_\parallel/T_\perp$	Y	-	-	Y	Y	Y	Y	Y	Y
9. $\|B\|$ increase	Y	?	Y	Y	Y	Y	Y	-	Y
10. σ_B decrease	Y	?	-	Y	Y	-	Y	Y	Y

Y = yes ? = uncertain - = not present

3. Temporal variability of driver gas

The time history of several solar wind parameters together with the strength of the interplanetary magnetic field are shown in Figure 1 for the shock occurring on 21 February 1979. The dashed line (~1515 UT) indicates the onset of the discontinuous drop in proton temperature and marks the location of the discontinuity which we assume is tangential. Simultaneous with this drop in proton temperature, the proton density increases, the He/H ratio increases, and the electron temperature decreases (not shown). While the magnetic field magnitude increases at this time, it is difficult to determine if this increase is due to the presence of the driver gas or is just another of the many variations in the field.

The plasma flow after the 21 February shock is a near classical example of what the solar wind parameters (T_p, T_e, He/H) would look like in the ideal case: all parameters change simultanously at the onset of the driver gas. However, such events are rare, only 3 of the special subset of 9 events show similar characteristics.

In general the He/H abundance ratio enhancement can occur at any time after the onset of the discontinuous drop in temperature. The most interesting example of the He/H abundance variation is found in the 22 March 1979 event shown in Figure 2. Here, the He/H abundance is enhanced before, depressed during, and enhanced after the low temperature region. Several other interesting features are also present in Figure 2. The magnitude of the magnetic field increases simultaneously with the decrease in proton temperature

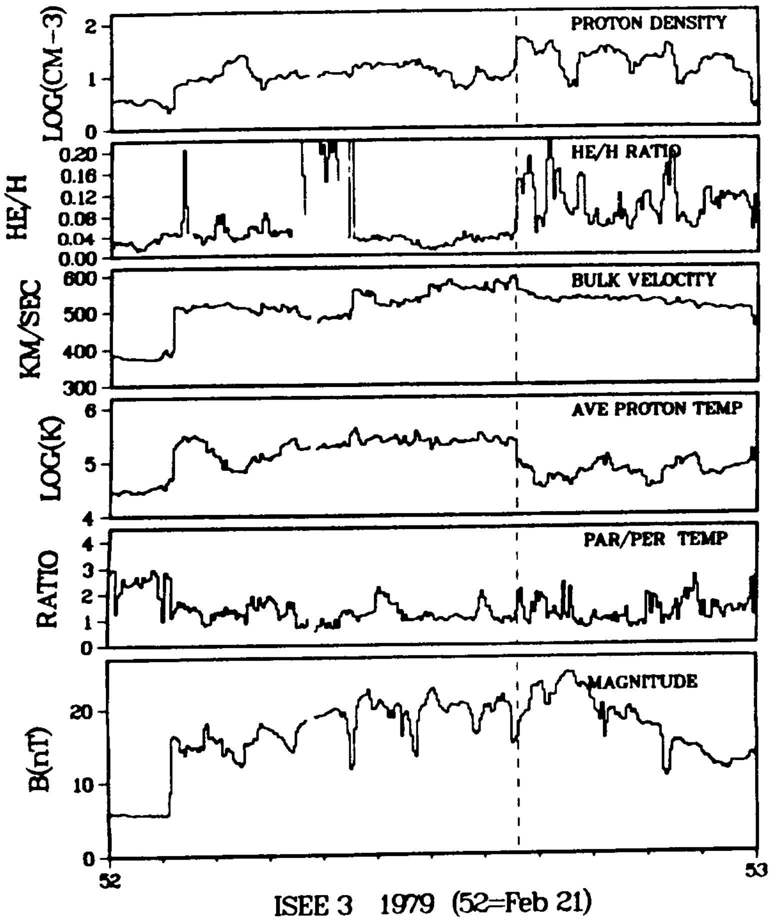

Figure 1. Time history of selected solar wind parameters for shock occurring on 21 February 1979. The dashed line at 1515 UT indicates the onset of a discontinuous drop in proton temperature.

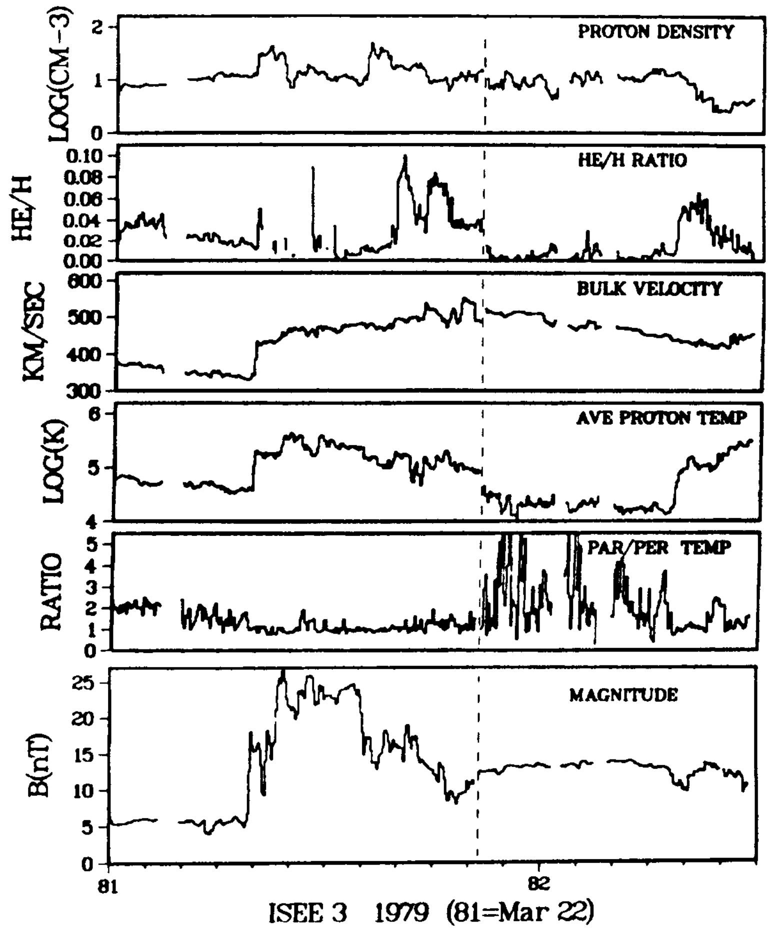

Figure 2. Time history of selected solar wind parameters for shock occurring on 22 March 1979. An unusual feature in this event is the simultaneous drop in the He/H ratio at the on-set of the discontinuous drop in proton temperature.

and remains high with a reduced RMS deviation throughout the low temperature region. During the same time interval the ratio of the parallel to perpendicular proton temperature increased to relatively high levels. However, a significant part, though not all, of the increase is due to the difficulty of making accurate measurement of the two components at low temperature.

4. Discussion

Many of the parameters shown in Table 1 and Figures 1 and 2 have been examined previously. The most often studied parameter, the He/H ratio, has long been held to be the best indicator of the presence of driver gas behind a shock [Hirshberg et al., 1972]. The present study indicates that He/H increases [Bame et al., 1979] can occur anywhere with respect to the boundaries of the low temperature regions. They usually have rise and decay times on the order of minutes, a time much shorter than the overall duration of the He enhancement. Such would not be the case if the He/H increases were a necessary and sufficient identifier of cold driver gas. In the case of the He/H increase occurring prior to the T_p decrease in the 22 March 1979 event shown in Figure 2, we believe the enhanced He plasma was ejected from the corona ahead of the discontinuity, and as such is simply an extended signature of the transient disturbance which later produced the shock.

This study confirms and extends recent work concerning the nature of the magnetic field during the passage of driver gas. Borrini et al. (1982), in a statistical survey of 103 forward shocks, showed that, on the average, driver gas containing enhanced He/H ratios also exhibited increased magnetic field strength. Earlier Pudovkin et al. (1979) had indicated that the RMS deviation of the magnetic field often decreases during the passage of driver gas. These two characteristics are clearly seen in the 22 March 1979 event shown in Figure 2 and their frequency of occurrence in clearly identified cold driver gas can be determined from the data in Table 1.

The signature of the magnetic field parameters in driver gas suggests a similar examination be made of the bulk flow velocity and its RMS deviation. These parameters, shown in Table 1, indicate that while the solar wind bulk velocity often increases at the onset of the driver gas, the RMS deviation, averaged over a 10 minute interval, usually decreases slightly. Thus, the plasma data and the magnetic field data indicate that cold driver gas contains lower than normal levels of low frequency wave activity.

A schematic model illustrating a possible geometry for plasma driving an interplanetary shock is shown in Figure 3 (based on Figure 10 from Bame et al., 1979). Many of the characteristic properties of driver gas listed in Table 1 are illustrated in the figure. Of particular note in Figure 3 is the uneven distribution of helium enriched plasma and the smooth closed magnetic field lines. The geometry of our model differs considerably from that presented by Pudovkin et al. (1979). Our model suggests that it is possible to observe the shock without detecting driver gas, and when driver gas is observed the He enhancement may occur early or late or the He enhancement may occur in several distinct regions. These characteristics, which are observed in the data, are not shown in their model [Pudovkin et al., 1979].

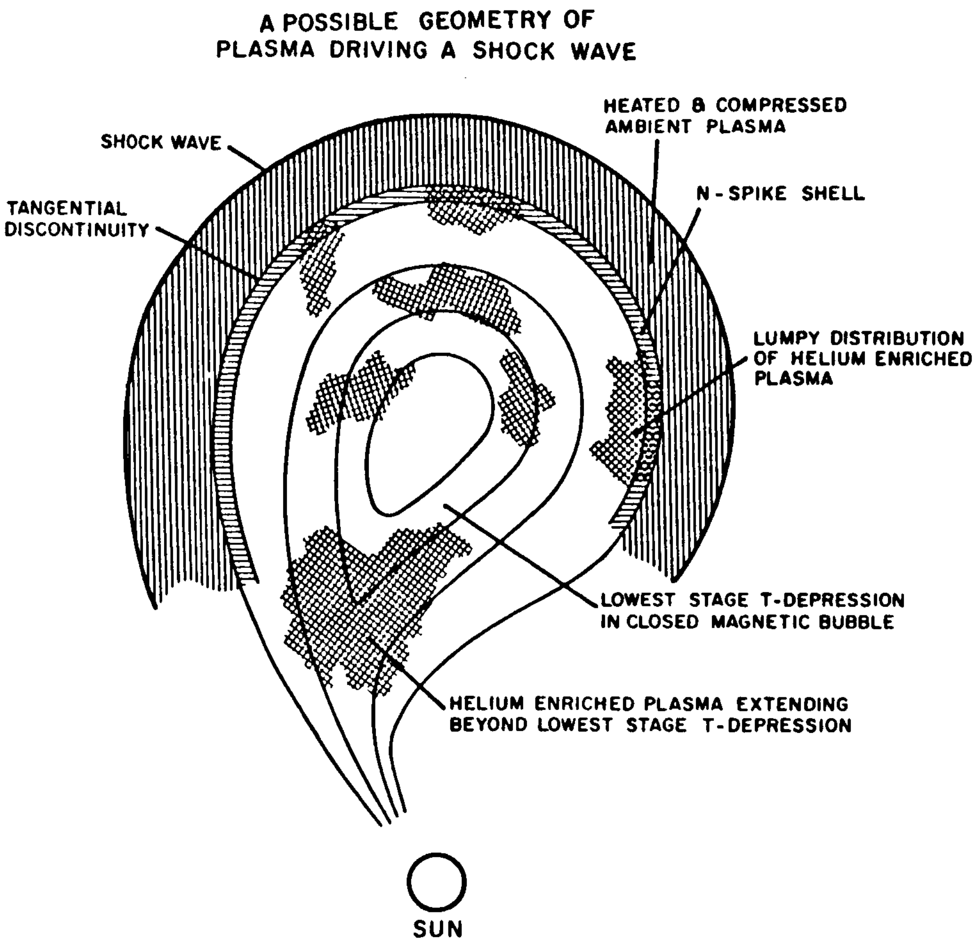

Figure 3. Schematic model illustrating a possible geometry for plasma driving an interplanetary shock (based on Figure 10 from Bame et al., 1979).

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