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HELIUM, HYDROGEN, AND OXYGEN VELOCITIES OBSERVED ON ISEE-3

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ABSTRACT

The velocities of hydrogen, helium and oxygen ions over a full range of solar wind conditions have been recorded by the Ion Composition Instrument (ICI) and Los Alamos National Laboratory Plasma Instrument (LANLPI) aboard the ISEE-3 spacecraft between August 1978 and December 1979. Interspecie velocity differences were observed frequently. For solar wind velocities between 300 and 400 km s^{-1} the helium velocity exceeded the hydrogen velocity by 5 km s^{-1} on the average. For solar wind velocities between 400 and 500 km s^{-1} the average difference was 14 km s^{-1}, however no evidence was found for a non zero average velocity difference between helium and oxygen ions even at the higher velocities.

Velocity differences were examined in a number of streams and across a number of interplanetary shocks. Generally helium-hydrogen velocity differences are bounded by the Alfvén speed. Velocity differences show abrupt changes across interplanetary discontinuities, presumably tangential. The electrostatic potential change across a shock produces differences between the velocities of ions having different charges. The magnitude of the potential difference can be deduced from the changes in velocities and agrees satisfactorily with that calulated from the energy jump condition for a perpendicular hydromagnetic shock.

Introduction

The original identification of helium in the solar wind (Neugebauer and Snyder, 1966) was made by assuming that helium traveled at the same speed as the more abundant hydrogen, and that its state corresponded to that of a plasma in thermal equilibrium at the known temperature of the corona. The velocity of hydrogen in the solar wind can be accurately determined with electrostatic energy analyzers which measure energy per charge. To obtain the velocity of helium during periods of low to moderate kinetic temperatures from energy per charge measurements a velocity distribution function is usually assumed. During periods of high kinetic temperatures, for example after interplanetary shocks, the helium energy per charge distribution is partially overlapped by the hydrogen distribution and an accurate determination of the helium velocity distribution function is not possible. In this paper we present observations made in such a way that this limitation does not apply.

It has been observed that for much of the time helium and hydrogen move with the same velocity in the solar wind within a few percent (Robbins _et al_., 1970; Formisano _et al_., 1970; Ogilvie and Zwally, 1972; Bollea _et al_., 1972; Asbridge _et al_., 1976). Non-zero velocity difference $\bar{V}_{He} - \bar{V}_H$ is only possible along the magnetic field (Neugebauer, 1976), thus $\bar{V}_{He} - \bar{V}_H = \Delta\bar{V} = \pm\Delta V\hat{b}$ where ΔV is the scalar speed difference and $\hat{b}$ is a unit vector along the magnetic field. The sign depends upon whether ΔV is parallel or antiparallel to $\hat{b}$.

Speed differences in excess of a few percent are known (Formisano _et al_., 1970; Ogilvie, 1975, Asbridge _et al_., 1976) and have been observed to increase with solar wind speed (Hirshberg _et al_., 1974; Ogilvie, 1975; Asbridge _et al_., 1976). Observations on the Helios spacecraft (Marsch _et al_., 1982) have indicated that $\Delta\bar{V}$ at given $\bar{V}_H$ increases as one approaches the sun from 1 AU, usually remaining less than or equal to the Alfvén speed, V_A.

The relationships among the speed differences, helium temperatures and the presence of Coulomb collisions have been discussed by Neugebauer (1976) and by Neugebauer and Feldman (1979), respectively. At radial distances of up to 4 AU from the sun, non-zero values of ΔV persist at high V_H indicating that, once set up, the velocity differences can be quite stable, and that Coulomb collisions and wave-particle interactions are not completely effective mechanisms for equilibrating the velocities of the two ions (Goodrich et al., 1979).

The simultaneous presence of two interpenetrating streams with different velocities has been observed in the trailing edges of solar wind streams (Feldman et al., 1973; Asbridge et al., 1976). The relationship between this phenomenon and the interspecies speed differences, which are sometimes observed in the same regions, has not been fully elucidated; however, it has been suggested that observations of two independent streams with differing speeds and helium abundances could be misinterpreted to be a single stream with relative motion between the constituent ions. Additional velocity resolution does not resolve this ambiguity, although it makes the detection of double streams easier. In this study we have attempted to eliminate doubtful observations from consideration by deleting data showing double streams.

Early work with electrostatic analyzers during periods of low solar wind speed and kinetic temperature showed that the minor ions such as O^{+6} and O^{+7}, and Fe^{+7} to Fe^{+12} traveled at the same speed (Bame et al., 1968; 1970). More direct evidence has recently been obtained showing that O^{+6} and O^{+7} generally move at the velocity of helium rather than hydrogen (Schmidt et al., 1978; Ogilvie et al., 1980; Schmidt et al., 1980). In this paper we present observations of hydrogen, helium, and oxygen velocities over a wide range of solar wind conditions. Particular attention has been paid to velocity differences before, during and after shocks where an application of the jump conditions across the shock front gives calculated velocity differences in agreement with observations.

Instrumentation and Data Reduction

The main data used in this study were obtained by the Ion Composition Instrument (ICI) on the ISEE-3 spacecraft between August 1978 and December

1979. The ICI has been described previously (Coplan et al., 1978). The instrument mode used for this investigation consisted of a 25 point search, which required 75 seconds, of the helium velocity range from 300 to 620 km sec^{-1}. This was followed by a scan covering the (M/Q) range from 1.4 to 6.0 in 41 steps over the velocity range between 0.9 and 1.1 U_{max} where U_{max} is the velocity corresponding to the maximum helium flux observed during the search. A complete scan required 30 minutes with each M/Q - velocity step held for two spacecraft spin periods.

During each spacecraft rotation the instrument is sensitive only for the time that its field of view is within a 45° arc centered on the solar direction. The angular spread of ions in the solar wind increases with the kinetic temperature, but the ±22-1/2° observation angle is sufficient to allow the undistorted determination of the helium ion velocity distribution function over a range of velocity about the bulk velocity of at least three times the thermal velocity. The instrument has a background counting rate amounting to approximately 0.25 counts/spin, the result mainly of penetrating secondaries of cosmic ray particles. This background rate has been determined by a careful survey of the counts recorded by the instrument in parts of the M/Q-velocity space in which there are no solar wind ions. It is normally constant within statistical fluctuations and has a completely negligible effect upon the results of this investigation. Periods when large solar particle events are in progress, causing the background to become anomalously large, have been rejected. The spacecraft was in the interplanetary medium during the whole period with which this paper is concerned, most of the time in the halo orbit about the libration point between the Earth and the Sun.

The velocity of the i^{th} ion was obtained from a parabolic fit to the quantities C_{ij}/V_j^4, where C_{ij} is the number of counts of ion i at velocity channel j and V_j is the velocity corresponding to velocity channel j. A gaussian function was then adopted to represent the ion distribution functions and thus obtain approximate densities and kinetic temperatures. The helium ion is normally the overwhelmingly abundant ion with M/Q = 2.0. Oxygen ions, observed at M/Q = 2.67 ($^{16}O^{+6}$) are contaiminated to a small but variable extent by $^{14}N^{5+}$ due to the finite passband of the instrument.

However, this is not a major problem since this study is concerned with processes that depend upon the ionic masses and charges rather than upon their chemical nature.

Hydrogen ion velocities were obtained from the ISEE-3 data pool tape. These data are derived from observations by the Los Alamos National Laboratory plasma instrument (LANLPI) on ISEE-3 (Bame et al., 1978) by application of a simplified algorithim. In order to reduce scatter, 3 point running averages were formed with the time characterizing a given speed being the time at which the second component of the running average was taken. Comparisons are made between the hydrogen and helium speeds falling nearest in time. The time differences between measurements of the hydrogen and of minor ion distributions was always less than 150 sec.

The averaging process slightly smooths the data, and reduces the scatter in the vector velocity difference $\Delta\vec{V}$. It also has the effect of modifying interspecies velocity differences during periods of rapid change. This does not introduce significant errors in data interpretation except when the plasma is exceedingly turbulent or the velocities are changing over periods faster than our measurement time. The ICI requires 42 seconds to perform a velocity measurement for a minor ion, so that these measurements are of limited usefulness in very turbulent conditions. No smoothing is used with the helium and oxygen data.

Because the present work involves the comparison between LANLPI hydrogen velocities, obtained from the data pool tape with velocities of helium and oxygen ions obtained from measurements by the ICI on the same spacecraft, verification that the three point average hydrogen velocities (VDP) agree with those obtained using the full data reduction program at Los Alamos (VLP) has been carried out and is discussed in the Appendix. Agreement between the VDP and the VLP values is satisfactory above 450 km s^{-1} with a scatter of ±15 km s^{-1} (see Figure 9). For velocities below 450 km s^{-1}, there is a systematic difference which increases with decreasing velocity. The reason for this difference is discussed in the Appendix. For the data used in this study the average offset $\langle(VDP - VLP)\rangle$ is 8 km s^{-1} for velocities below 450 km s^{-1}. Comparison of a small number of helium velocities determined by ICI and LANLPI using the full data reduction programs show agreement to better than 1-2% with no observable systematic difference. Although the present paper deals primarily with velocity differences between minor solar wind ions, velocity differences between hydrogen and helium over an unrestricted range of temperatures will also be examined.

Results

Examination of the complete data set covering a wide range of solar wind conditions shows that $\Delta\bar{V}$ significantly exceeds 0.05 V_H about 12% of the time. To better examine the velocity dependence of $\Delta\bar{V}$, the data have been divided into two parts according to whether 300 km $s^{-1} \leq V_{He} \leq$ 400 km s^{-1} or 400 km $s^{-1} \leq V_{He} \leq$ 500 km s^{-1}. Histograms for these two velocity intervals are shown in Figures 1 and 2. In both of these histograms the independent variable is the dimensionless quantity $\Delta V/V_A$ with ΔV obtained from ICI helium velocities, and V_A from the LANLPI data pool hydrogen densities and 64 second averages of magnetic field observations from the ISEE-3 data pool tape (E. J. Smith, private communication). The sign for ΔV was chosen to be positive for $V_{He} > V_H$. The maximum of the histogram of Figure 1 corresponds to ΔV = -3 km s^{-1}. Correcting for the known offset of +8 km s^{-1} gives a value of 5 km s^{-1} in good agreement with the previous determination of Asbridge et al., 1976 of 6 km s^{-1} at V_H = 350 km s^{-1}. This agreement gives confidence that the measurements and data reduction procedures are correct.

The histogram of Figure 2 is based on measurements made during 81 days out of approximately 8 months in 1979 when the solar wind speed was between 400 and 500 km s^{-1}. The average value of $\Delta\bar{V}/V_A$ for these data is $\sim$ 0.5 with variations from -1.0 to 1.5. The corresponding average value of ΔV is 14 km s^{-1} in good agreement with the value of 13 km s^{-1} obtained at 450 km s^{-1} by Asbridge et al. (1976).

Figure 3 is a histogram of normalized velocity differences for helium and $^{16}O^{+6}$ for the same periods as in Figure 2. Though these data have not been corrected for the magnetic field direction there is no reason to believe that such a correction would change the basic shape of the histogram or the position of its maximum. There is no evidence in Figure 3 for a systematic velocity difference between helium and $^{16}C^{+6}$. To further substantiate this assertion we list in Table I averages for the velocities and their differences, derived for periods when V_{He} was approximately constant. The range of V_{He} is however much wider than that in Figure 3. Values of $< \Delta V >$ vary considerably as do the values of $< V_A >$ as a consequence of the highly variable nature of the interplanetary medium. Nevertheless, the values of $< \Delta V >$ in Table I are all statistically greater than zero while the values of $< V_O > - < V_{He} >$ are statistically equal to zero. Note that while $< \Delta V >$ increases with $< V_{He} >$, there is no indication that $< V_O > - < V_{He} >$ increases with $< V_{He} >$ over the range studied.

Observations in Streams

Studies of velocity differences between various ion species may be useful in clarifying the mechanism by which solar wind streams are accelerated in the experimentally inaccessible region inside a heliocentric radius of 0.3 AU. It is therefore important that studies of such differences not include data obtained during periods of double streams which might be confused with simple stream velocity differences (Asbridge et al., 1974). We have excluded periods in which the search data show more than a single extremum. The remaining data contain many periods of sustained velocity differences including several which are well removed from the trailing edges of streams.

Figures 4 and 5 show data for V_H and V_{He} for two different streams on March 17, 1979 and September 29, 1979. The September 29 data show a typical example of sustained velocity differences in a stream. During the entire passage of the high speed stream V_{He} is approximately 20 km s^{-1} greater than V_H. The observed velocity fluctuations are due in part to changes in the ambient magnetic field direction. The March 17 data, by contrast, show a short perod of high speed when V_H is greater than V_{He}, followed by a period of turbulence and then a period when V_{He} is greater than V_H. An examination of the heat flux direction during this period reveals an abrupt 180° change in flow direction starting at 0700 UT on March 17 followed by a second change at 1800 UT of the same day. Such a reversal indicates the presence of a large scale kink or reversal in the magnetic field (Asbridge et al., 1976). The latter part of the stream behaves in a normal manner, with a ΔV of the usual sign and magnitude. An interesting phenomenon is present in the tail of the September 29 stream. For the firsrt 18 hours of October 1 V_{He} remains nearly constant while V_H fluctuates widely. The magnetic field also shows large amplitude quasi-periodic fluctuations in direction during this period. Marsch et al., 1982, interpret a similar observation as being due to Alfvén wave motion confined to the hydrogen while the helium moves at constant velocity in the radial direction. The values of V_O are in better agreement with V_{He} than V_H for this period, but show larger fluctuations due in part to the larger measurement uncertainties. Abrupt changes in V_{He} at 1900 UT on September 30 and 0100 UT on October 1 appear to be associated with discontinuities in the magnetic field direction.

Two additional examples of high speed streams are shown in Figures 6 and 7. For the May 22 event shown in Figure 6 the interaction regions shows only small fluctuating differences between V_{He} and V_H while in the tail of the stream there is a stable though small difference. The absence of magnetic field data around 0500 UT on May 23 prevents us from determining whether there was also a magnetic field discontinuity at this time. The data of March 11 and 12 of Figure 7 show an unusual velocity signature in which a large velocity difference occurs. During the period from 0700 to 1500 UT on March 11 ΔV exceeded the Alfvén speed by $\sim$ 40%; after 1700 UT there was a change in the flow and the velocity difference decreased to $\sim$ 70% of V_A; the magnetic field was very quiet during this time. The period from 0600 UT on March 12 until the end of the trace again shows the "smooth helium, fluctuating hydrogen" flow pattern. The abrupt changes in hydrogen speed at about 1300 and 1800 UT on March 12, coincide with discontinuities (apparently tangential) in the magnetic field. We note that, looking at the hydrogen velocity alone, the increase starting at about 0300 UT on March 11 is hardly large enough to indicate the existence of a stream, however the clear change in V_{He} is characteristic of a high speed stream.

The definition of a tangential discontinuity does not restrict the velocity difference between the flows on either side of the discontinuity (Burlaga, 1971). However, plasma instability thresholds usually limit the velocity differences to a values less than V_A. The component of the magnetic field normal to the discontinuity is zero and one could expect to find situations in which the minor ions are streaming with different velocities along the field on either side of a tangential discontinuity.

Observations near Interplanetary Shocks

Figure 8 shows observations obtained on July 6 and 7, 1979, before and after the passage of a strong interplanetary shock at 1853 UT on July 6. This and other shocks discussed here were identified by E. J. Smith (private communication) from combined plasma and magnetic field data from ISEE-3 during 1978 and 1979. Before the July 6 shock, V_{He} exceeded V_H by 25 km s^{-1}. At the shock the difference changed sign and for about 8 hours V_H was greater than V_{He} by 30 km sec^{-1} before abruptly vanishing at 0300 UT on July 7. Before the shock V_{He} and V_O were about the same speed, but after the shock V_{He} was less than V_O.

The jump conditions across a shock in a two fluid plasma (electrons and protons) including the electrostatic potential ϕ have been discussed by Woods, 1969, and by Sanderson, 1976. For a perpendicular shock Woods derived the energy jump condition for the i^{th} ion of mass m_i and charge e to be

$$[1/2\, V_i^2 + \frac{5}{2}\frac{k_{T_i}}{m_i} - \frac{\delta k_{T_e}}{m_i} + \frac{e}{m_i}\phi] = 0, \qquad (1)$$

where V_i is the ion velocity in a frame in which the shock is at rest, and T_i, T_e and ϕ are the ion temperature, electron temperature and electric potential respectively. The parameter δ approaches zero in the collisionless conditions of the interplanetary medium, so that the term in T_e can be neglected. Taking the value of ϕ_1 to be zero, $\phi = \phi_2$ is the potential across the shock. Assuming that the shock takes place in the hydrogen plasma, and that the helium ions are test particles, ϕ can be calculated using the hydrogen plasma parameters measured by LANLPI, and $U = (n_{H1}V_{H1} - n_{H2}V_{H2})/(n_{H2} - n_{H1})$ for the shock speed, where V_{H1} and V_{H2} are the hydrogen velocities on either side of the shock and n_{H1} and n_{H2} are the respective hydrogen densities. In Table II we list the shock parameters and calculated values of ϕ for seven interplanetary shocks in 1978 and 1979. These quasi-perpendicular shocks were chosen because their normals lay near the radial direction ($0.8 \leq n_x \leq 1.0$). The positive values of ϕ indicate that the potential was greater on the downstream side of the shock than the upstream side. ϕ increases with shock strength as measured by the density ratio across the shock. The shocks on September 5, 1978 and November 30, 1979, have ϕ values which are small and density ratios of 1.7 and 2.2 respectively, contrasted with the density ratio of 3.2 for the shock of July 6, 1979. The average value of ϕ for the seven shocks is 108V. This is similar in magnitude to the results of two direct potential difference measurements made across the bow shock with the electric field instrument on ISEE-1 (Aggson, 1981), and to potential differences inferred from observations of the deceleration of protons just upstream of the magnetic field gradient at the bow shock (Neugebauer, 1970).

Since a helium ion is doubly charged, it undergoes a larger kinetic energy change in falling through a given potential difference than a hydrogen ion. In Table III, upper part, we have calculated, using observed helium velocities, the change in kinetic energy ΔE, undergone by a helium ion in crossing the five best observed shocks in our sample. We also show values of ΔE_2, changes in kinetic energy for a helium ion, but calculated using observed hydrogen velocities. The differences $\Delta E_1 - \Delta E_2$ are seen to agree reasonably well with the energy $2e\phi$ necessary to transport a doubly charged ion over a potential barrier of height ϕ. In the lower part of Table III we have performed a similar calculation for oxygen ions for two of the shocks for which we have adequate observations. The agreement is also satisfactory. This shows that the potential differences across shocks introduce changes in the velocities of minor ions. Thus interspecie velocity differences can be created or modified by the passage of shocks through the medium.

Conclusions

We find that ΔV tends to increase with the solar wind speed even though the fluctuations are large at any given value of the hydrogen velocity. Values of ΔV are generally less than V_A and at times when V_A is high the speed difference can reach 70-80 km s^{-1}. In high speed streams the velocity difference between hydrogen and the minor ions has been observed to persist for extended periods. These observations are in agreement with models of the solar wind in which Coulomb collisions play a major role in equalizing the velocities of all the ions at low speeds and high densities, but are much less efficient at high speeds when the density is low. The variation of interspecie speed differences at high speeds then becomes the result of a competition between accelerating forces tending increase the differences up to the Alfvén speed and Coulomb collisions acting to reduce them to zero.

There is a marked tendency for helium and oxygen ions to have the same velocities indicating that the acceleration of minor ion species probably involve waves carried by the proton component and does not depend in a sensitive manner on the M/Q ratio. It has been suggested by Marsch et al., 1982, that Alfvén waves, which are often regarded as the cause of the superacceleration of helium, affect the hydrogen streaming direction much more than that of helium. In this way the wave motion is borne by the major constituent of the solar wind and the minor ions react to it.

Although the $\Delta\bar{V}$ is usually positive there are frequent periods when this is reversed and we have observed negative values of $\Delta\bar{V}$ over a wide range of solar wind speeds. Marsch et al., 1982, have observed that the negative values of $\Delta\bar{V}$ at low speeds do not vary with heliocentric distance in contrast to the observed strong radial variation for $\Delta\bar{V}$ at high speeds. While some appparent interspecie velocity differences can be caused by the increase in helium abundance with increasing hydrogen velocity, not all differences can be attributed to this effect because they are often observed well away from interaction regions.

Finally, we observed that interplanetary shocks can establish and alter interspecie velocity differences. Since shocks are presumably more frequent, stronger, and cover larger angles close to the sun, they may be important in setting up speed differences. Applying the magnetohydrodynamic jump conditions, the electric potentials across several interplanetary shocks have been calculated. The values of these potentials are similar to previous measurements at the earth's bow shock and are large enough to cause interspecie velocity changes of the magnitude we have observed.

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FIGURE CAPTIONS

FIGURE 1 Histogram of the ratio of the scalar speed difference between helium and hydrogen, ΔV, to the Alfvén speed, V_A, for times when the helium speed was between 300 and 400 km s^{-1}. The period covered was June 19 to September 7, 1979. Positive values of the ratio correspond to $V_{He} > V_H$.

FIGURE 2 Histogram of the ratio of the scalar speed difference between helium and hydrogen, ΔV, to the Alfvén speed, V_A, for times when the helium speed was between 400 and 500 km sec^{-1}. The period covered was March 10 to November 2, 1979. Positive values of the ratio correspond to $V_{He} > V_H$.

FIGURE 3 Histogram of the ratio of the speed difference between oxygen and helium to the helium velocity for times when the helium speed was between 400 and 500 km s^{-1}. The period covered was March 10 to November 2, 1979.

FIGURE 4 Velocities for helium and hydrogen during a stream between September 29 and October 1, 1979. A short period of oxygen velocity measurements is shown on October 1.

FIGURE 5 Velocities for helium and hydrogen during a stream between March 17 and March 18, 1979.

FIGURE 6 Velocities for helium and hydrogen during a stream between May 21 and May 23, 1979.

FIGURE 7 Velocities for helium and hydrogen during a stream between March 10 and March 12, 1979.

FIGURE 8 Velocities for helium and hydrogen across a propagating interplanetary shock beginning on July 6, 1979. The shock is unusual in that the sign of the velocity difference between helium and hydrogen is reversed.

FIGURE 9 Comparison between the 3-element running average data pool hydrogen velocity VDP with the corresponding Los Alamos reduced velocity VLP from 300 to 600 km s^{-1}. The histograms divide the data into two velocity ranges and show the offset in the lower range.

Table I

Average Velocities

Period (year:day:UT)	$\langle V_{He} \rangle$	$\langle V_0 \rangle$	$\langle \Delta V \rangle$	$\langle V_A \rangle$	$\langle V_0 \rangle - \langle V_{He} \rangle$
79:43:2200 - 44:0800	326 ± 4 kms^{-1}	325 ± 5 kms^{-1}	+5 kms^{-1}	43 kms^{-1}	1 ± 6 kms^{-1}
79:47:1500 - 47:2300	351 ± 10	356 ± 14	+3	52	4 ± 17
79:43:0200 - 43:0700	399 ± 5	398 ± 6	-7	31	1 ± 8
79:69:2300 - 70:1000	443 ± 13	441 ± 15	15	58	2 ± 20
79:70:0300 - 70:0600	455 ± 3	461 ± 17	25	54	6 ± 17
79:69:1700 - 69:2000	500 ± 6	500 ± 24	40	51	9 ± 24
79:85:1900 - 85:2300	541 ± 20	536 ± 40	51	95	5 ± 40
79:49:0400 - 49:1700	544 ± 9	542 ± 17	26	42	2 ± 19
79:95:1400 - 95:1800	568 ± 17	558 ± 17	37	75	20 ± 24
79:48:1800 - 48:2100	585 ± 5	582 ± 9	39	57	3 ± 10

Table II

Shock Parameters

Date and Time	V_{H1}	V_{H2}	n_{H1}	n_{H2}	U^*	ϕ^{**}	V_{He1}	V_{He2}
Aug. 27, 1978 0210	310 ± 3 kms^{-1}	430 ± 5 kms^{-1}	$8 \pm .3$ cm^{-3}	$20 \pm .5$ cm^{-3}	510 kms^{-1}	106V	313 ± 4 kms^{-1}	409 ± 6 kms^{-1}
Sept. 5, 1978 1817	336 ± 2	370 ± 5	$8.2 \pm .3$	14 ± 1	418	13	339 ± 5	370 ± 6
Feb. 21, 1979 0218	386 ± 3	511 ± 3	$2.9 \pm .1$	$6.7 \pm .3$	618	174	394 ± 6	450 ± 7
Mar. 22, 1979 0748	344 ± 3	436 ± 4	$13.5 \pm .5$	30 ± 1	511	92	323 ± 4	409 ± 7
July 6, 1979 1853	466 ± 4	650 ± 10	$2.8 \pm .1$	$9 \pm .3$	733	261	491 ± 8	611 ± 10
Nov. 18, 1979 0139	395 ± 5	470 ± 5	$3.6 \pm .1$	$5.9 \pm .2$	587	94	406 ± 7	463 ± 8
Nov. 30, 1979 0649	294 ± 1	340 ± 5	66 ± 2	145 ± 4	372	18	---	---

*The uncertainty in U is estimated to be approximately 15%.

**The uncertainty in ϕ is estimated to be approximately 30% or $\pm$ 15 V , whichever is larger.

Table III

Helium				
Shock Date	ΔE_1	ΔE_2	$\Delta E_1 - \Delta E_2$	$2e\phi$
Aug. 27, 1978	672 eV	572 eV	100 ± 70 eV	212 ± 40 eV
Feb. 21, 1979	848	439	409 ± 100	348 ± 70
Mar. 22, 1979	510	414	96 ± 40	184 ± 30
Jul. 6, 1979	1288	873	415 ± 100	522 ± 110
Nov. 18, 1979	464	348	116 ± 50	188 ± 35
		Oxygen		$6e\phi$
Feb. 21, 1979	3392	2474	918 ± 150	1044 ± 200
Jul. 6, 1979	5152	3338	1814 ± 150	1566 ± 300

ORIGINAL PAGE IS OF POOR QUALITY

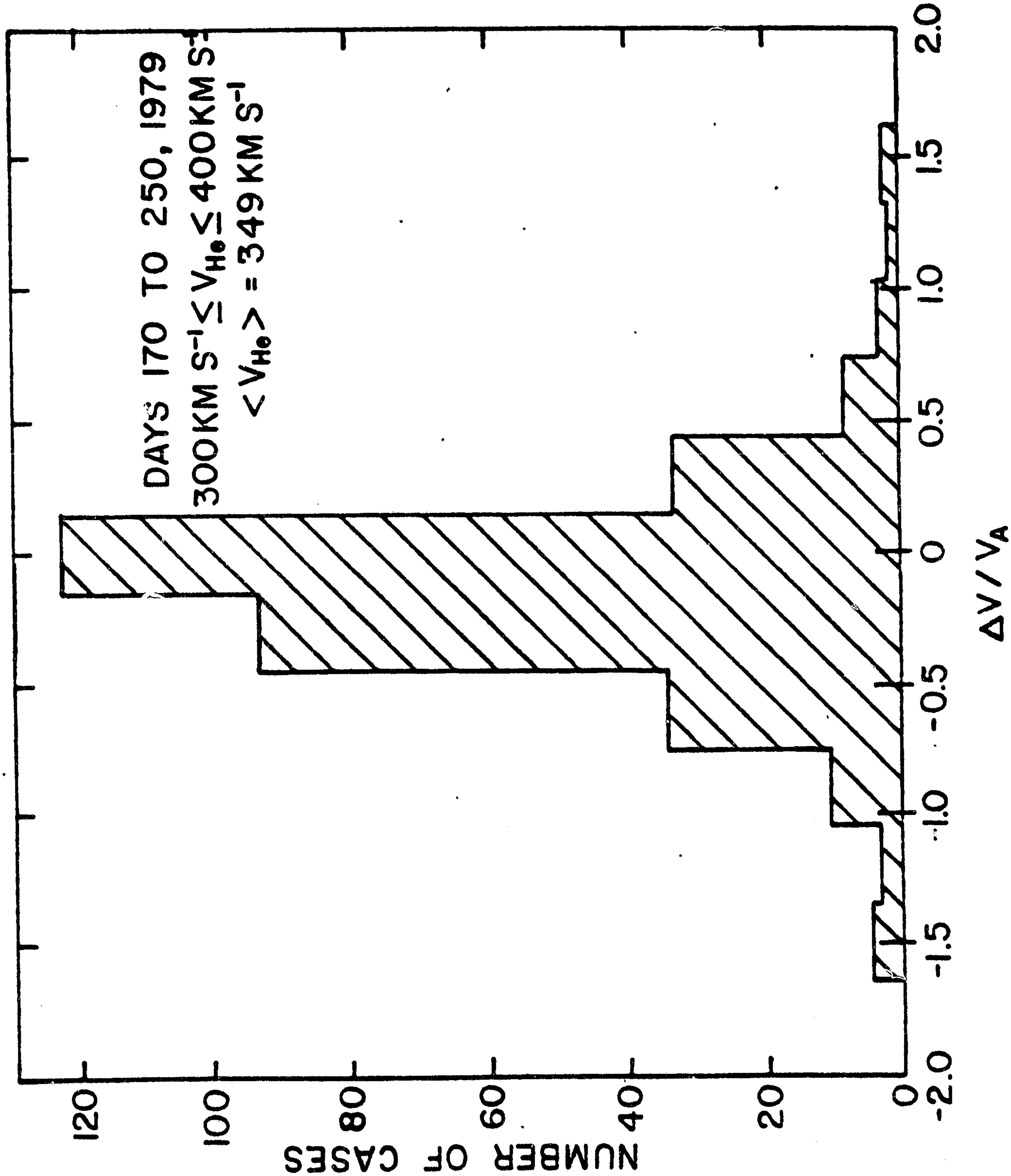
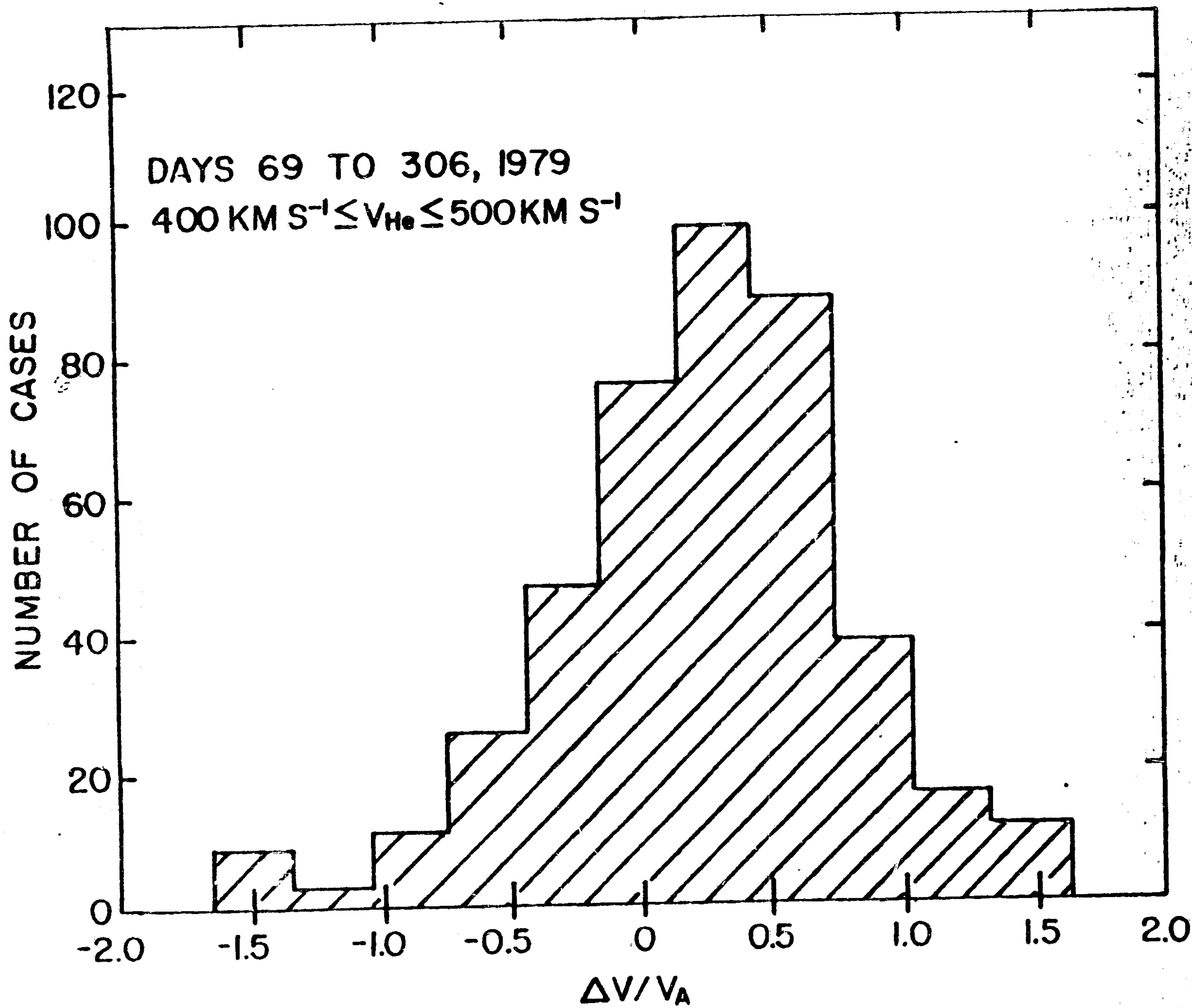


Figure 1



DAYS 69 TO 306, 1979
400 KM S⁻¹ ≤ V_He ≤ 500 KM S⁻¹
NUMBER OF CASES
0
20
40
60
80
100
120
-2.0
-1.5
-1.0
-0.5
0
0.5
1.0
1.5
2.0
ΔV/V_A

Figure 2

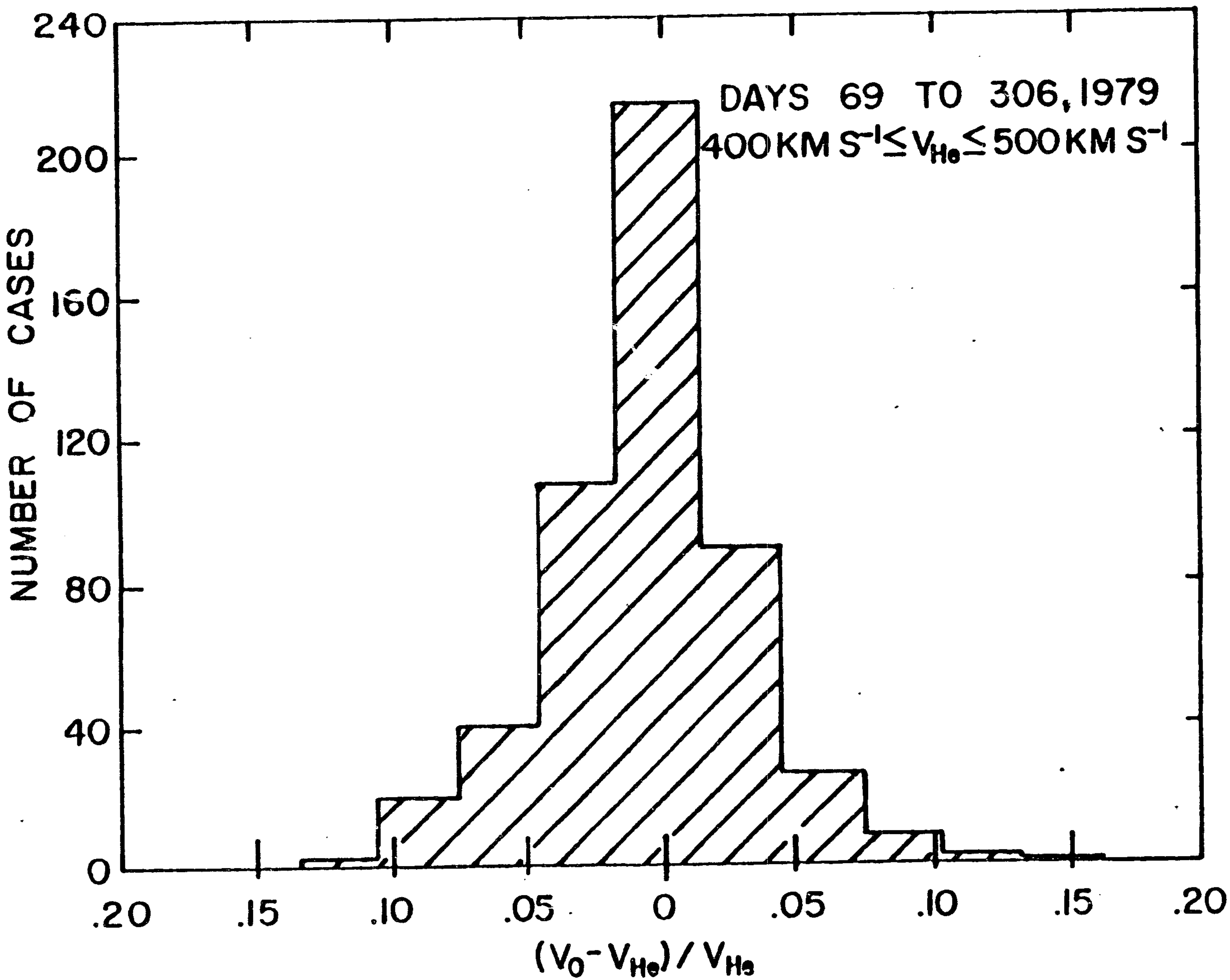

DAYS 69 TO 306, 1979
400 KM S-1 ≤ VHe ≤ 500 KM S-1
NUMBER OF CASES
240
200
160
120
80
40
0
.20
.15
.10
.05
0
.05
.10
.15
.20
(V0 - VHe) / VHe

Figure 3

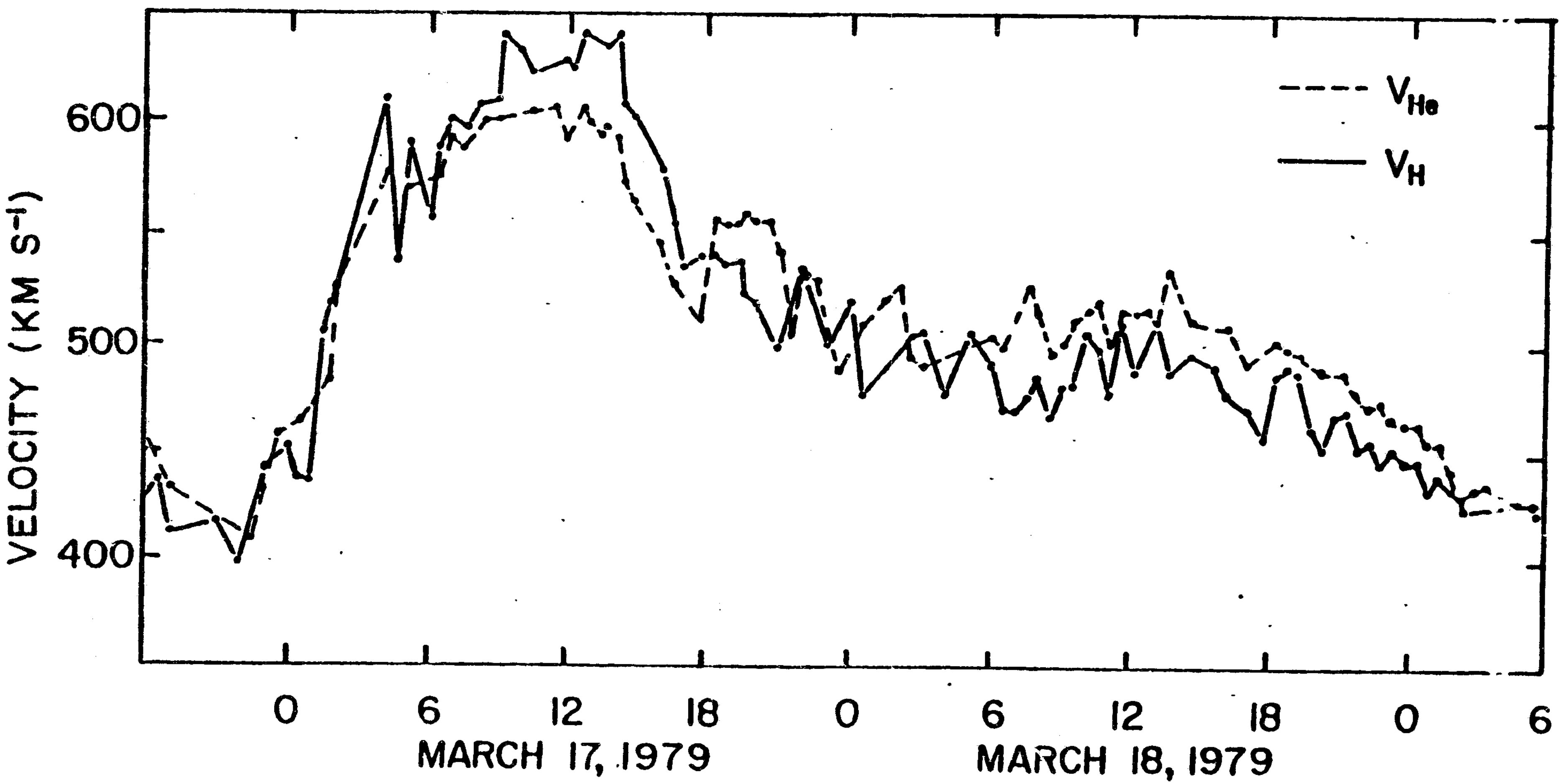
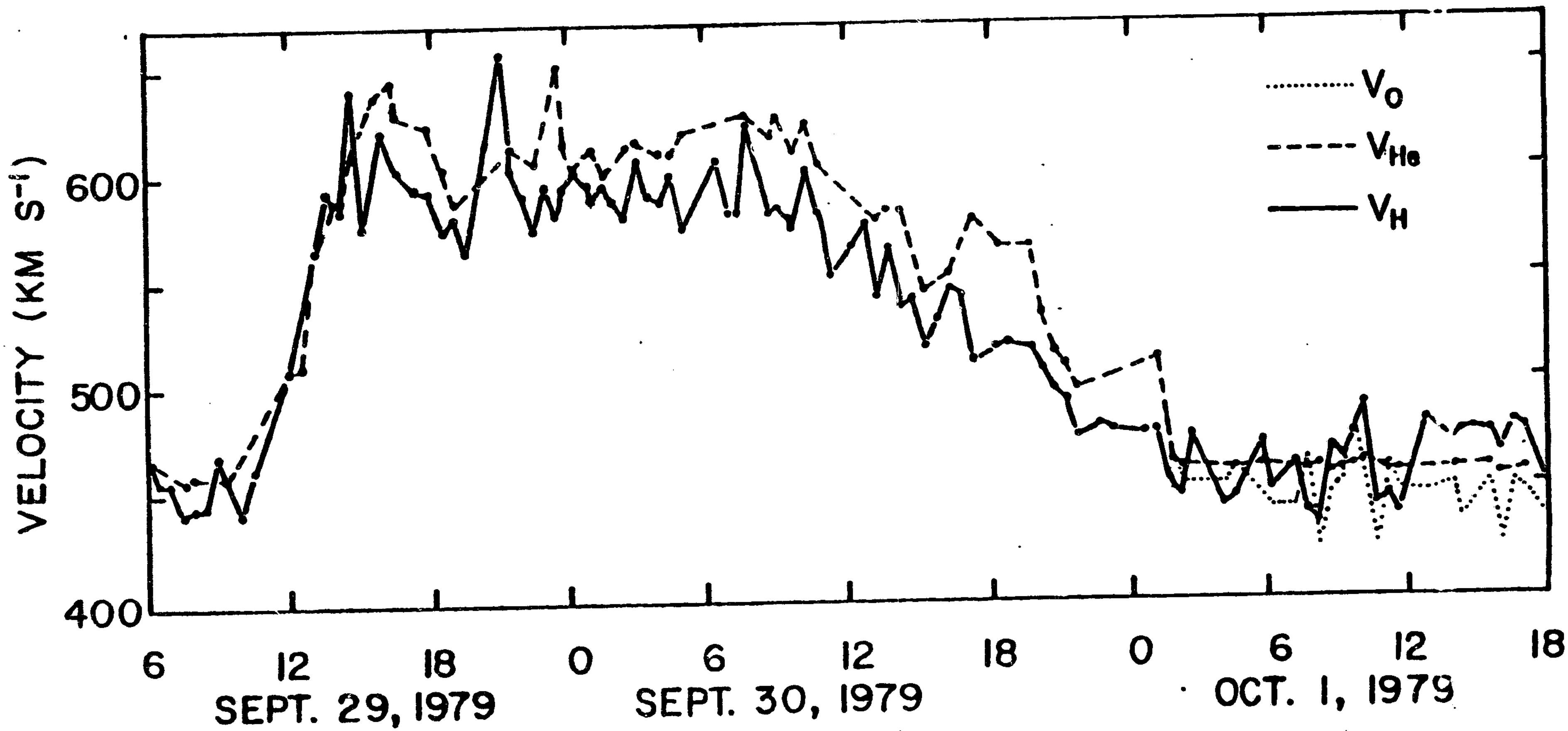

VELOCITY (KM S⁻¹)
600
500
400
V_{He}
V_H
0 6 12 18 0 6 12 18 0 6
MARCH 17, 1979
MARCH 18, 1979

Figure 4



VELOCITY (KM S-1)
600
500
400
VO
VHe
VH
6
12
18
0
6
12
18
0
6
12
18
SEPT. 29, 1979
SEPT. 30, 1979
OCT. 1, 1979

Figure 5

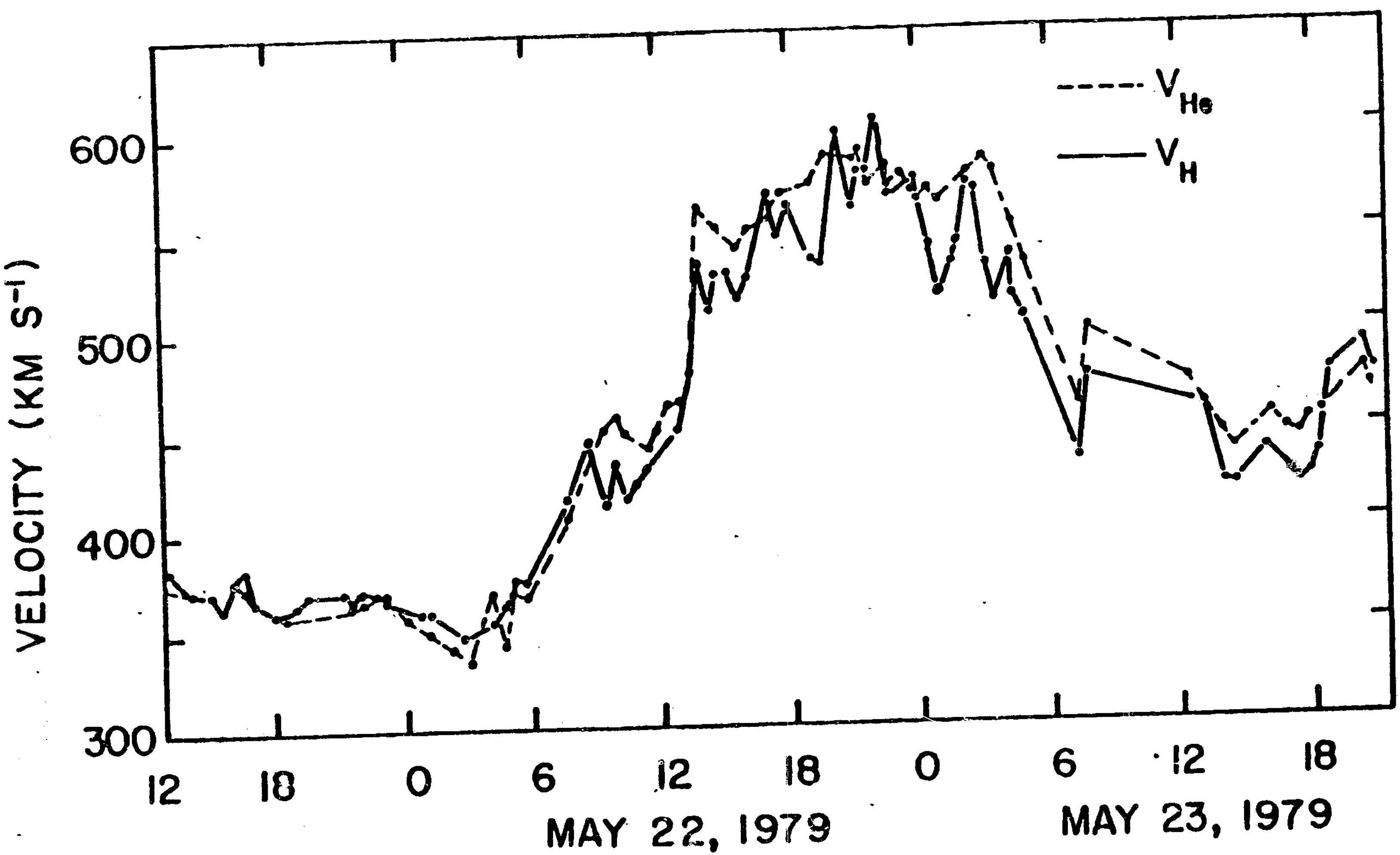
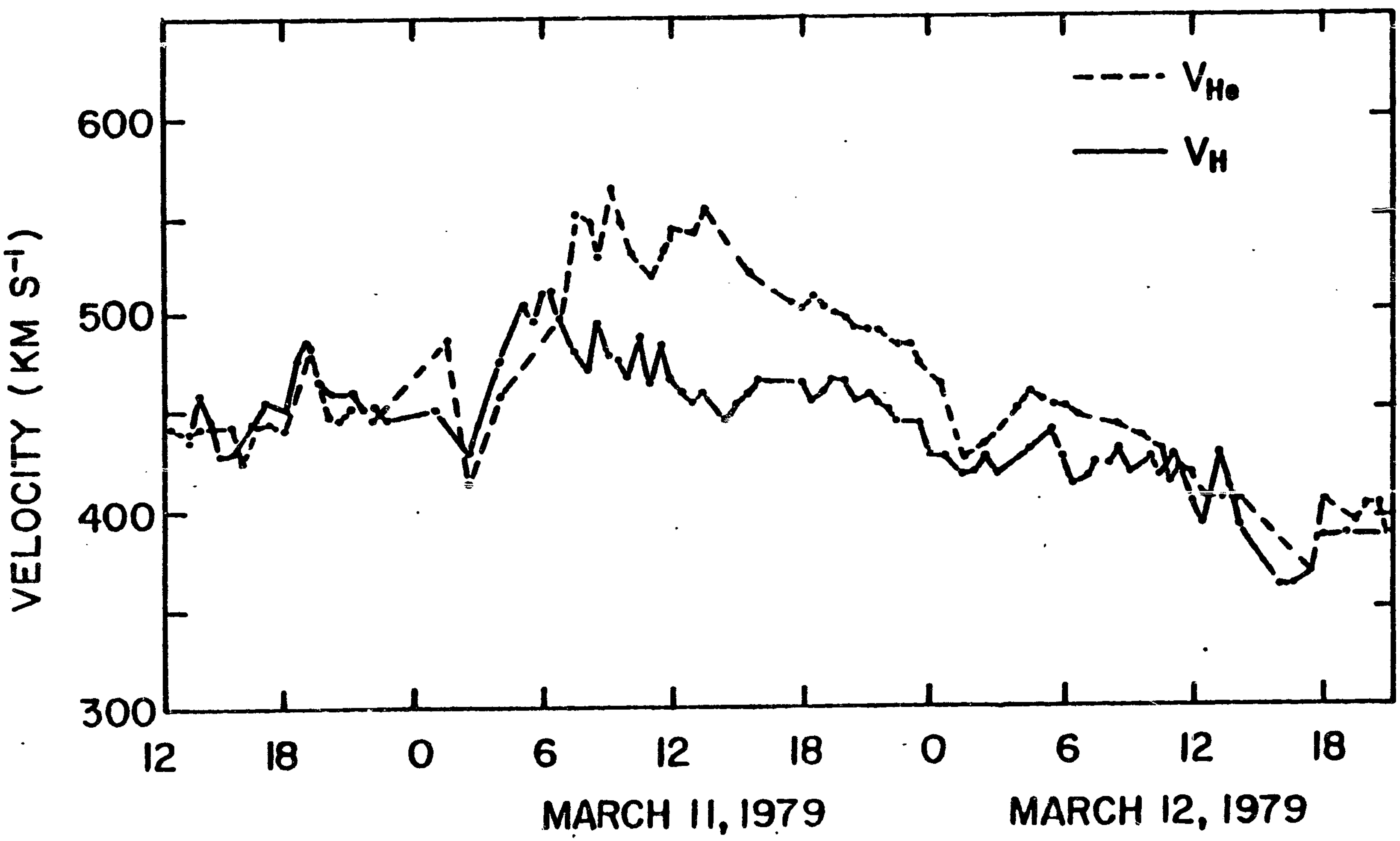

VELOCITY (KM S⁻¹)
600
500
400
300
12
18
0
6
12
18
0
6
12
18
MAY 22, 1979
MAY 23, 1979
V_He
V_H

Figure 6



V_He
V_H
600
500
400
300
VELOCITY (KM S⁻¹)
12
18
0
6
12
18
0
6
12
18
MARCH 11, 1979
MARCH 12, 1979

Figure 7

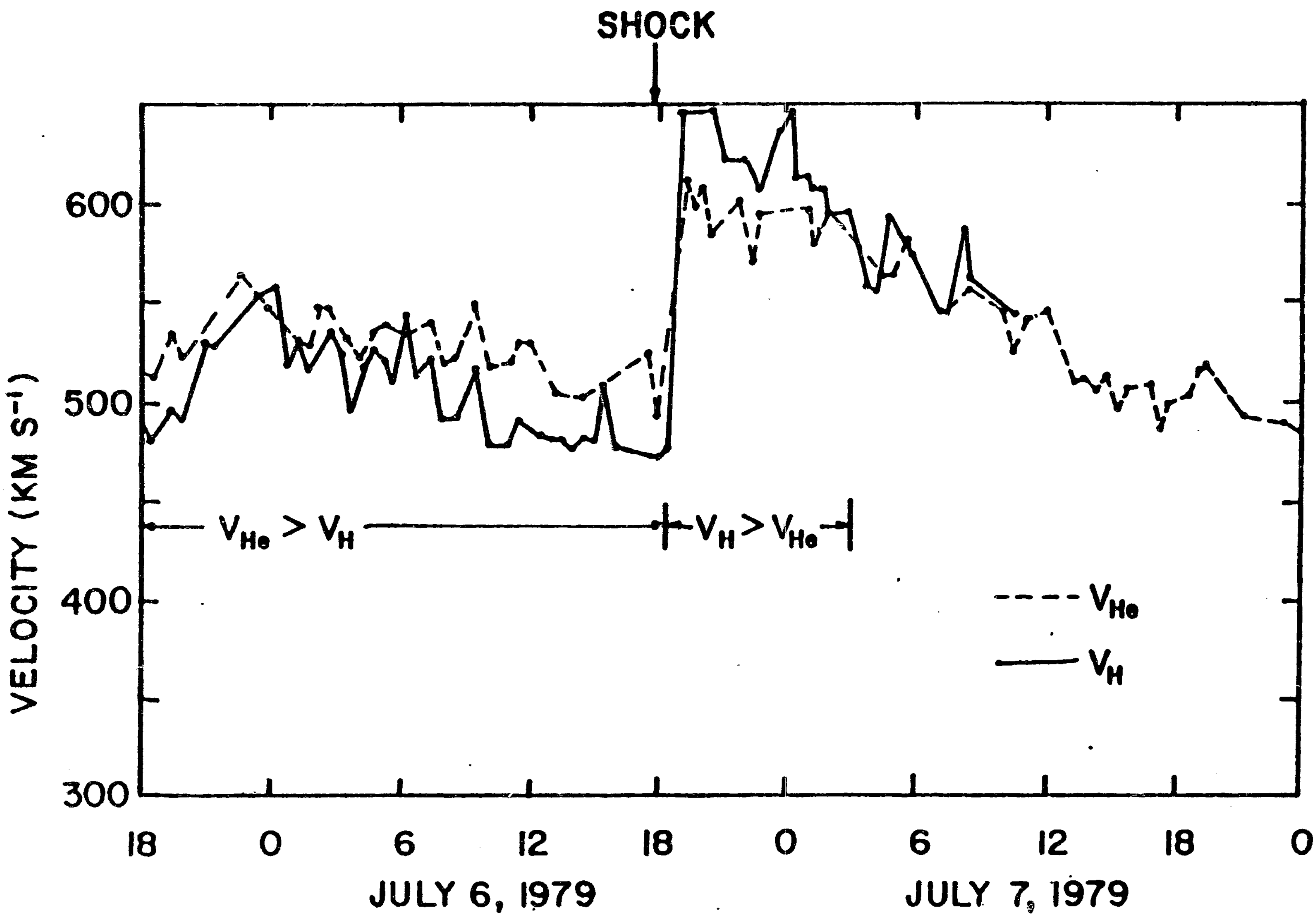

SHOCK
600
500
400
300
VELOCITY (KM S⁻¹)
$V_{He} > V_H$
$V_H > V_{He}$
V_{He}
V_H
18
0
6
12
18
0
6
12
18
0
JULY 6, 1979
JULY 7, 1979

Figure 8

APPENDIX

The data pool algorithm, used in calculating the velocity and density of the solar wind from data taken by the Los Alamos plasma analyzer on ISEE-3 was designed with several simplified assumptions to give a quick-look indication of the flow conditions of the solar wind. In order to use the solar wind velocity from the data pool in this study, it was necessary to determine the accuracy of the algorithm. We selected 50 data points covering the velocity range 300 to 620 km sec^{-1} for this study. The data pool velocity data (VDP) which were actually made up of 3-point running averages were then compared with the velocity data (VLP) generated by the full analysis programs at Los Alamos. The results are shown in Figure 9. The solid line running diagonally through Figure 9 represents VDP = VLP. There is a clear offset for solar wind velocities less than 450 km s^{-1}. To better illustrate this effect the data were divided into two velocity ranges and subtracted (VDP - VLP). The results are presented in the histograms at the top of Figure 9. The average velocity differences, standard deviations, and mean standard deviations of these two populations are given in Table IV. The offset in the data pool velocity is due to the assumption in the algorithm that all energy channels have an efficiency of 1.0, which is not the case for energies corresponding to velocities below 450 km sec^{-1}. Above 450 km sec^{-1} the agreement is very good. A similar study involving the density calculated by the data pool algorithm indicates that at low velocities the density is low by as much as a factor of 2 to 3).

The comparison between the helium velocities obtained by the ICI and the proton velocities obtained from the full analysis for these same 50 data points shows the expected difference which increases with increasing velocity. Comparison between the Los Alamos and ICI helium velocities shows very good agreement, suggesting systematic differences of less than 2%.

Table IV

Speed Range	$\langle$Velocity Difference$\rangle$	Standard Deviation	Mean Deviation
<450 km s^{-1}	8.1 km s^{-1}	9.6 km s^{-1}	1.9 km s^{-1}
>450 km s^{-1}	0.0	12.6	2.6

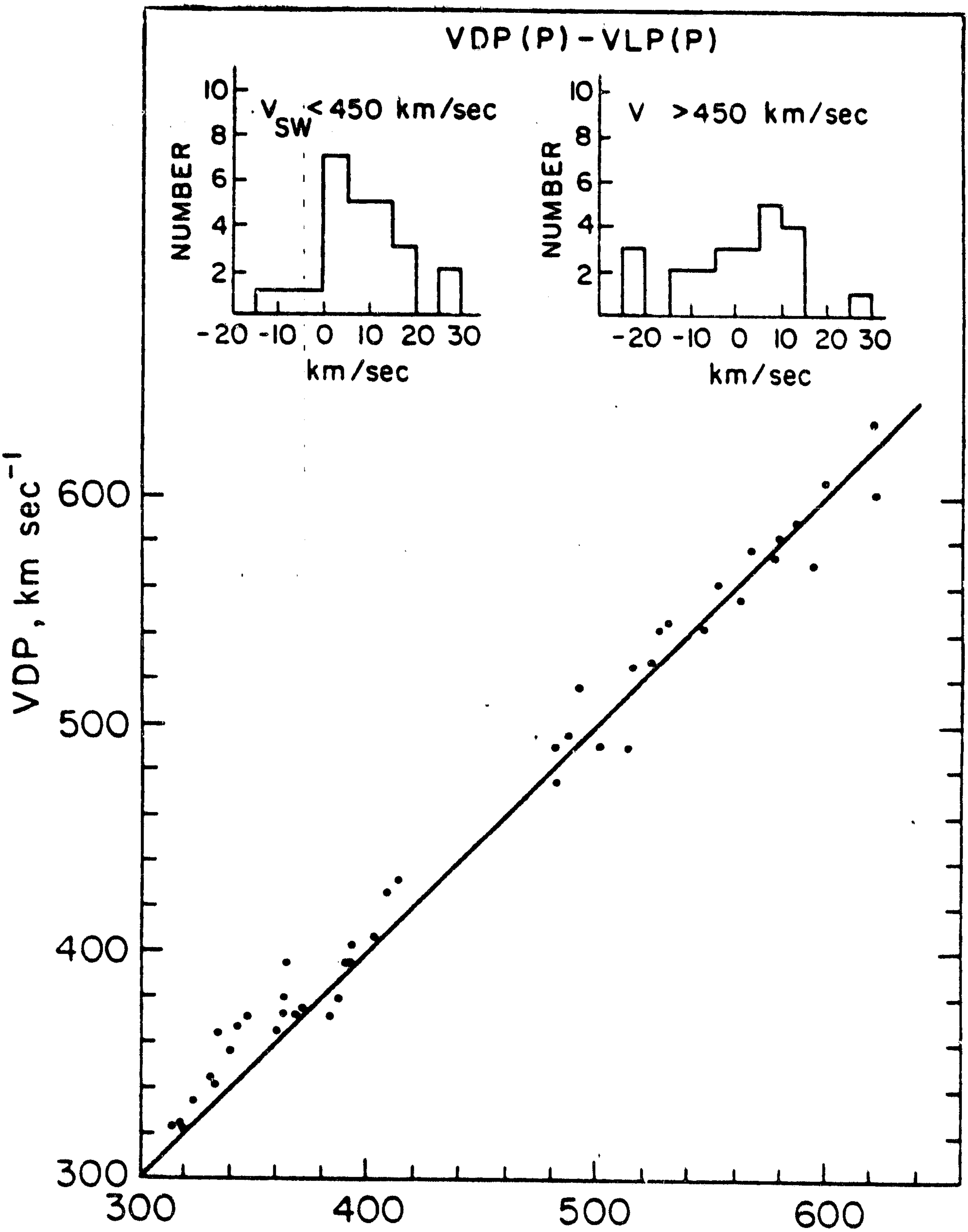

VDP(P) - VLP(P)
V_{SW} < 450 km/sec
V > 450 km/sec
NUMBER
10
8
6
4
2
-20 -10 0 10 20 30
km/sec
VDP, km sec^{-1}
VLP, km sec^{-1}
300
400
500
600

Figure 9