Interplanetary Scintillation Observations of the Solar Wind Close to the Sun and Out of the Ecliptic.

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ABSTRACT

A brief review is given of recent developments in the observation of the solar wind by the method of interplanetary scintillation. The emphasis is on observations of the velocity structure, the electron density and the effect of propagating disturbances in the interplanetary medium as detected principally by intensity and phase scintillation and by spectral broadening.

Introduction

Interplanetary Scintillation (IPS) observations provide our only present method of making routine, although indirect, measurements of the solar wind out of the ecliptic and close to the sun. Although new developments in coronal diagnostics (Withbroe et al, 1982) will permit inference of the flow properties very close to the sun and, for the interval during which International Solar Polar Mission spacecraft will be out of the ecliptic, *in situ* measurements of the solar wind in that region will be available, we will depend on IPS for our continuing knowledge of these regions of interplanetary space. It is thus appropriate to review the contribution made by IPS over the last few years.

Given essentially a solar cycle's worth of observations of the global solar wind velocity, and with the increasing availability of observations close to the sun, the subject has developed to the point where it can provide information of interest to the solar and interplanetary physics community at large. In particular, IPS observations exist now of relevance to three major fields of current interest in interplanetary physics: namely heliospheric structure, the heating and acceleration of the solar wind, and the morphology of transient disturbances in the interplanetary medium following coronal transients.

For brevity, this presentation will be limited in scope and cover only those topics which deal primarily with intensity and phase scintillation and radio source spectral broadening. This choice is based on the ease of discussion of these methods in this context and the fact that it allows presentation of topics related to the fields mentioned above.

Consequently, this is not an exhaustive review and a number of important areas will be omitted entirely. The reader is referred to other articles, beginning with the original work of Hewish and colleagues (Hewish et al., 1964) for more comprehensive treatment of the methods, and the underlying physics, and also for more penetrating discussion of the results. Bird (1982) has given a thorough review of coronal radio sounding measurements made using spacecraft as sources, including a discussion of the detection of Faraday

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rotation observations; a subject which will be almost entirely neglected here. Woo and Armstrong (1983) have similarly covered the subject of single and multiple station observations of spacecraft telemetry link scintillations. Further, more extensive expositions of the techniques used and applicable theory are also given in Coles et al. (1974), Woo (1975), Coles (1978) and Armstrong and Woo (1981).

Methods and Measurables

It is valuable to begin by outlining briefly the quantities measured in scintillation measurements and the physical bases of the phenomenon, and to indicate the means by which inference of solar wind properties can be made.

The basic process arises from the interaction of a plane wave traversing the interplanetary medium with irregularities in the refractive index, due to an inhomogeneous electron density. The perturbed wave fronts propagate to earth where their amplitudes and phases, or simply intensities, are recorded. Estimates of various field statistics can be made, and from the spatial and temporal distribution of these estimates, inferences of the properties of the scattering medium are drawn.

In perhaps the simplest case, intensity scintillations, the time series of intensity fluctuations is recorded and from this the root mean square fluctuation, or a temporal spectrum, of the flux is estimated. This spectrum is related to the irregularity spectrum. The rms fluctuation, when normalized by the non-varying flux of the source is called the scintillation index. Since the temporal fluctuations in the signal are viewed as being caused by the mapping of the spatial distribution of irregularities in the medium by the moving solar wind into a temporal distribution, appropriate sampling of these variations at several sites enables one to estimate a projected velocity vector for the solar wind. This multi-station technique, the assumptions implicit in it, and various tests of consistency for it have been discussed thoroughly by Coles et al.(1974), Coles and Maagoe, (1972), Coles,(1978), and Coles and Kaufman (1978). The related field of phase scintillations, in which phase fluctuations are recorded, and the practical realization of such observations is discussed by Woo (1977).

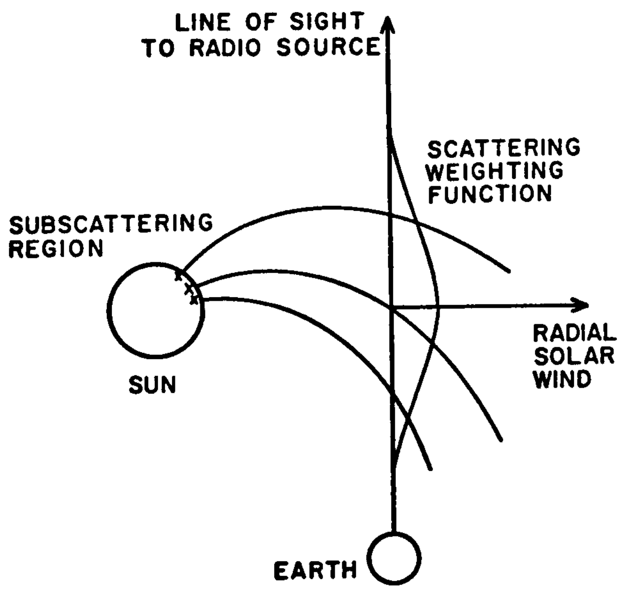

Figure 1: The geometry of an IPS observation showing the line of sight, the scattering weighting function along the line of sight and the point on the sun which is taken as the source of the observation.

It is important to recall in interpreting IPS data that the scattering which leads to the scintillation arises along an extended portion of the line of sight (see figure 1), so the received signal results from the convolution of effects arising at various points in space. An early working assumption was that the electron density irregularities, which are the cause of the scintillation are proportional to the local ambient density ($\Delta n \propto n$) so that the overall radial density fall off would maximize the scattering at the point at which the line of sight passes closest to the sun. This assumption has been tested in comparison with *in situ* data, and it does appear, with minor modifications, to be an adequate one. Allusion is thus made to observations at a position in space, the reference being to the point of closest approach to the sun of the particular line of sight. Any references to the heliographic position of the observation usually are to the point on the sun reached by a projection with constant radial velocity from that point of closest approach back towards the sun. As discussed later, it should be recognized that the test of this assumption involved observations which were dominated by large scale, long lived solar wind features and therefore does not necessarily indicate that there is a high degree of certainty in the position of small short lived features.

The efficiency of the scattering which causes the scintillation depends on the radio frequency of the observations in such a sense that the scintillation is measurable only at higher frequencies as the line of sight approaches the sun (Hewish and Symonds, 1969). Thus observations of velocities within the interplanetary medium ($\sim 0.3 \leq R \leq 1.0 AU$) are generally made at meter wavelengths, while the observations closer to the sun involve centimeter wavelengths. Consequently, observations near the sun benefit from the availability of spacecraft in near occultation by the sun, while observations closer to the orbit of the earth utilize natural sources.

The observation of the scintillation effect relies on two physical conditions; the existence of density irregularities and their motion across the line of sight. Interpretation of the observations thus requires the recording of two (at least) data sets, or an assumption concerning one or other of the properties.

The inference of solar wind properties is thus indirect, involves line of sight integration and may not refer to an exactly known location. However, with careful application of the methods and assumptions, much can actually be achieved.

Solar Wind Velocity Measurements

Inference of the solar wind velocity from multiple station intensity scintillation data is the easiest of the observations to understand and interpret; it relies on the adequate detection of a projected intensity pattern as it moves across the ground. For essentially a solar cycle, synoptic 74 MHz IPS measurements of the solar wind velocity have been made by the group at San Diego (Armstrong and Coles, 1972). As a result of this prolonged effort, a large data set has been accumulated which has allowed many of the uncertainties and assumptions involved in the method to be tested (e.g., Coles and Kaufman 1978). This has included the demonstration of a favorable comparison of both velocity and density structure of large scale features as observed by IPS with the results of *in-situ* measurements (Ananthakrishnan et al. 1980).

From these synoptic measurements, made predominantly in the range 0.3 to ~1.0 AU from the sun, the global configuration of the solar wind has been reconstructed, providing resolution of the unclear picture provided by earlier spot observations. This overall structure was expressed by Coles and Rickett (1976) as an average velocity gradient with latitude showing clearly the tendency, in yearly average measurements, to higher velocity at higher heliographic latitudes. Although this result was not confirmed by inferences from comet tail measurements (Brandt et al.,1975),it did verify the earlier indications of such an effect by Dennison and Hewish (1967). It was pointed out by Hundhausen (1978) that, of course, the process of averaging over longitude masked the true gradients which existed in the medium, and that a more appropriate estimate of the actual gradients was that found from *in situ* observations which did not average (e.g., Rhodes and Smith, 1976a,b).

The identification of the polar regions as areas of high speed flow was further refined and the existence of regions of much higher than average gradients demonstrated with the assembly of averaged distributions of IPS velocity as functions of latitude and longitude (Sime and Rickett, 1978). These showed the restriction of high speed flow to regions which mapped into coronal holes, and demonstrated directly the extension of polar high speed flows into equatorial regions whenever the polar coronal holes were so extended. These maps showed also that the configuration of the solar wind matched that of the corona in being consistent with the geometry of a tilted dipole with flow from the open regions (Hundhausen, 1977), and that the appropriate geometry in which to describe the solar wind was based on the magnetic properties of the sun rather than the rotational axis (Zhao and Hundhausen, 1981).

Further, the evolution of this magnetic configuration as witnessed in the corona (Hundhausen et al., 1981) allowed Sime (1979) to demonstrate that even if individual comet tail observations were highly reliable, the poor sampling across the solar cycle of that data set would probably prevent the cometary observations from showing this large scale gradient. The need exists now for point by point comparison of simultaneous IPS and comet tail observation.

Now that the data exist for a solar cycle, the evolution of this average velocity distribution with latitude can be followed along with the coronal evolution. Coles et al. (1980) have shown the elements of this development, as depicted in figure 2. The overall shape of the velocity vs latitude curves, with a minimum yearly average velocity near the equator and significantly higher velocities above about 30 degs. latitude, is preserved throughout the interval shown. The high values are the result of the prevalence of high speed streams at these latitudes. However, the effect is markedly diminished in 1978 and almost absent in 1979 as the poleward retraction of the coronal holes begins and restricts the high speed regions of the solar wind. This effect was suggested by Hewish and Symonds (1969) at the previous solar maximum, when they failed to repeat the observations of such high speed from a year earlier by Dennison and Hewish (1967). The evolution of the complete cycle of data is discussed elsewhere in these proceedings by Rickett and colleagues.

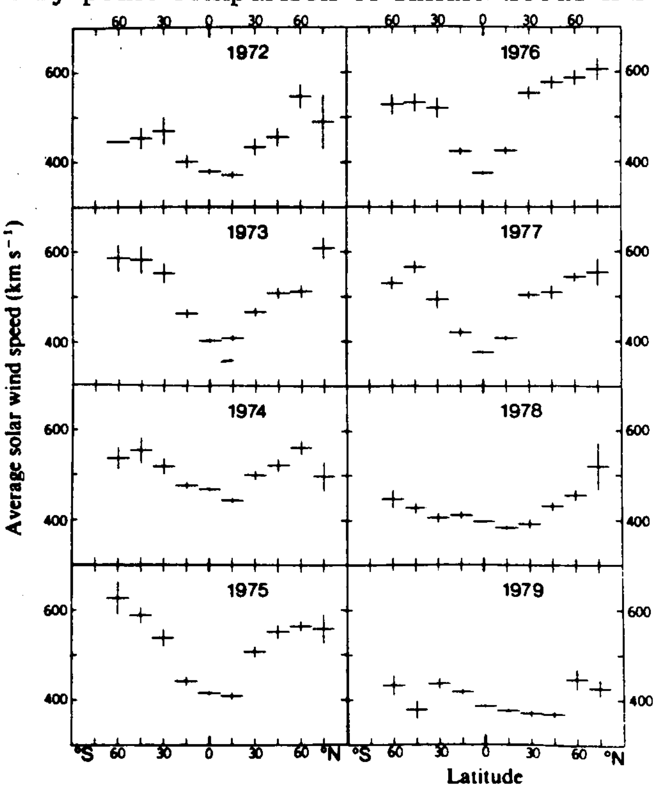

Figure 2: The average solar wind speed as a function of latitude for the interval 1972 to 1979. Taken from Coles et al. (1980).

These data also allow the construction of the overall, or global, average solar wind velocity. This quantity is plotted in fig. 3 along with the yearly average equatorial IPS velocity estimate. The global value shows an overall variation of 20-25% over the course of the last cycle, again showing the influence of the high speed polar flow at times other than near the maximum.

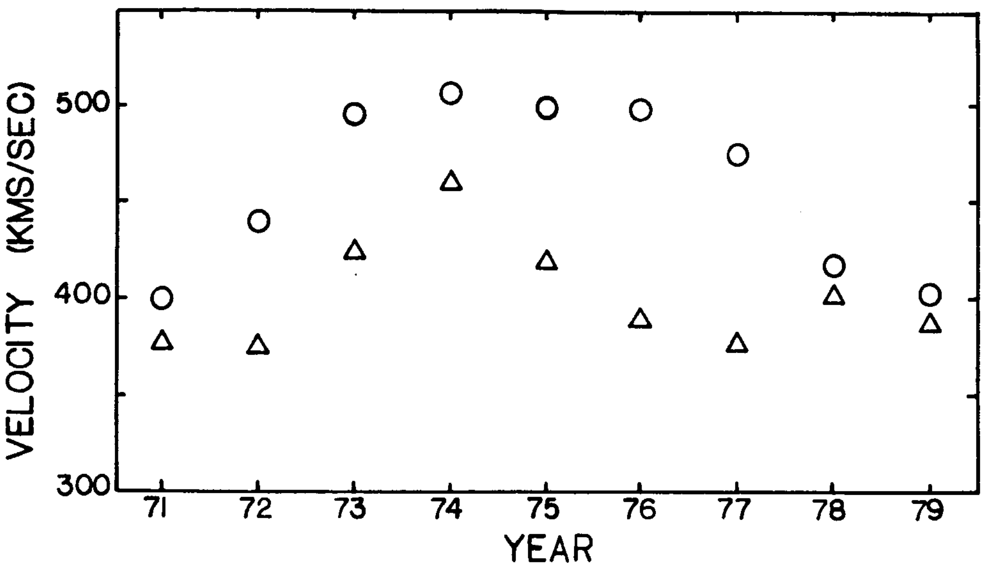

Figure 3: The average solar wind speed for the interval 1971 to 1979 showing both the equatorial average speed (triangles) and the global speed (circles).

Near the maximum, the equatorial and global averages are quite similar, and as the cycle progresses towards minimum, we see an increase in both values, reflecting both the increase in influence of the coronal holes and the rearrangement of the corona to bring the holes close to the equator. Although the global average velocity remains high until 1978, the equatorial value is reduced, beginning in 1975, as the near equatorial extensions of the polar holes retract. That is, as the interplanetary current sheet straightened out,(Zhao and Hundhausen, 1983) the high speed contribution to the equatorial wind was removed and the difference between the equatorial and global values increased; the in ecliptic measurements no longer sampling solar wind far from the current sheet. The IPS equatorial value agrees well with the *in situ* observations over this interval (Feldman et al., 1978; Schwenn, 1983), although there is a slight ($\lesssim$ 50 kms/sec) downward bias on the IPS results. Thus a view of the solar wind based entirely on the in ecliptic data would be somewhat misleading since the solar cycle variation in speed is not as marked as the global estimate indicates, and there is even some indication that the variation seen in the ecliptic during this cycle may be somewhat anomalous (Gosling et al., 1977). Understanding of the evolution of the heliosphere therefore cannot rest on in-ecliptic measurements alone.

The extended heating of the corona to produce the solar wind remains as one of the most fundamental problems in solar physics (Leer et al., 1982). With the acceptance of the importance of coronal holes (Zirker, 1977) and magnetic topology in the acceleration process (Holzer and Leer, 1980) and the apparent exclusion of acoustic waves as important contributors to the energy flux,(e.g., Athay and White, 1978) interest in this question has been renewed. IPS observations can provide information on the acceleration region since the rapid motion of natural sources in elongation near the sun enables a profile of velocity and other attributes with height to be detected readily. The paucity of these observations in part reflects the lack of equipment for doing multi-station observations on natural sources and partly due to the lack of sources. Recently, two interesting approaches have been developed to accommodate this problem.

Scott (1978) and others (Coles et al., 1978a) have developed a technique to identify a breakpoint in the spectrum of intensity fluctuations recorded at a single station, and from a characterization of the behavior of that feature, to establish the radial profile of velocity. From such observations, Scott and colleagues have shown a general increase of velocity to interplanetary values at about 20-30 R_o with an increase of about 10 kms/sec/R_o below this. Accompanying the general increase in the bulk flow velocity, there is a decrease in the random component of the velocity estimated from the same data.

Armstrong and Woo (1981) on the other hand, have used spacecraft telemetry scintillations to probe the inner reaches of the solar wind. They have applied the analysis of Ekers and Little (1971) to their two-station observations and estimated both a random and bulk velocity component of the flow within 30 R_o. Their figure 4, reproduced here, summarizes most of the available observations, including those of Scott mentioned above, showing in general, an approximately linear increase of velocity with distance from the sun from values of 100 kms/sec at 5 R_o to ~ 500 kms/sec at 20-30 R_o. There is a slight decrease in the random component estimate over this interval --or rather, a significant decrease in the random *fraction* of the velocity (see their figure 5). Although there are exceptions to the trend (Coles et al., 1978a) the general consistency of these data is rather surprising since they arise from single radial scans taken at significantly different times and in differing coronal conditions.

As mentioned below, Armstrong and Woo also show that the density spectrum steepens with increasing distance from the sun over this same range. The simultaneous evolution of the observed density spectrum and the velocity is presumedly an important diagnostic, but one which has not yet been fully utilized. The time is ripe for a circumspect interpretation of these data.

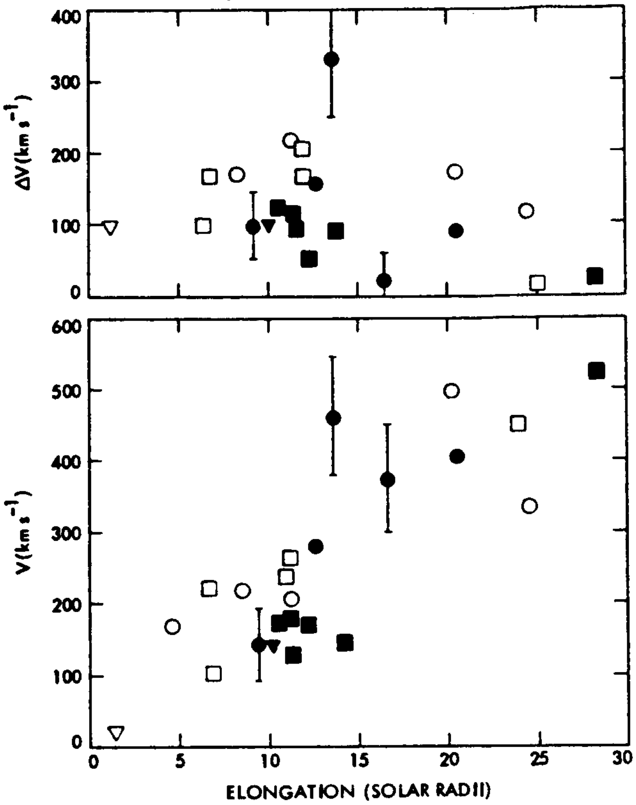

Figure 4: A summary of solar wind speed measurements near the sun, from Armstrong and Woo, 1981. Panel a shows mean solar wind speed and panel b shows the rms solar wind speed versus elongation. Open triangle: James (1964) radar backscatter measurement. Open boxes: Ekers and Little (1971). Open circle: Coles et al,(1978a), Scott (1978). Filled symbols: Armstrong and Woo, 1981 (triangle = 1976 data; circles = 1977 data; boxes = 1978 data)

It is likely that future work with recently available antennas (Bourgois, this proceedings) and with the VLA will permit a more conclusive picture of the acceleration region to be established, especially in conjunction with the progress in resonance line coronagraph diagnostics, Withbroe et al., (1982).

Density Fluctuations

Since the scintillation phenomenon results from the fluctuation in the interplanetary electron density, IPS permits the measurement of only the fluctuations themselves, and not the average or background density. In general, only those fluctuations with scale sizes in a restricted range can be measured by any one technique, all others either averaging to zero or contributing to the effective background. Consequently, any conclusions about the actual background density relies on rather indirect inferences.

The study of the spectrum of electron density irregularities in the interplanetary medium has been the subject of considerable activity over the last decade. Early spacecraft measurements of scales greater than 10^{-5} kms showed a power law dependence on wavenumber with an index of about -3 for the three dimensional spectrum. These measurements were later extended to wave number regimes of about 10^{-4} to 10^{-1} kms^{-1} both by *in situ* measurements and by IPS observations (Unti et al., 1973; Harmon 1975). In each case, a fairly solid estimate for a power law index of close to the Kolmogorov value of -11/3 was established. Observations covering many years and many positions in the interplanetary medium (at $R \gtrsim 0.3 AU$), failed to show any significant variability of the spectrum with solar cycle, radial distance or latitude, at least to the extent that it was tested by inference from the IPS spectrum or from the constancy of the scintillation index. Woo and Armstrong (1979) have now extended the identification of the spectrum in to distances of as low as $2R_o$, and by using measurements of phase scintillations, have sampled the wave number range 10^{-2} to 10^{-4}. Again, the single power law description is best, but at distances of < $20R_o$, there is considerable evolution of the spectrum, with the index varying from ~11/3 at $20R_o$ to ~3 at ~$5R_o$. This is confirmed by Harmon and Coles (1983) from their observations of planetary radar signals, and appears to be the only systematic variation of spectral properties.

A continuing problem has been the identification of the regions which actually produce the scintillations, and in particular, what exactly does the IPS velocity represent. Early attempts (see, e.g, Coles et al., 1978b) led to a reasonable "consistency" with the notion that the density fluctuations were proportional to the background density. However, models based on this, although they allow calculation of velocity series which are in fairly good agreement with observation, failed to predict scintillation indices which were in good agreement with the data. This is important since it is the index which is most directly related to Δn.

A more recent analysis by Ananthakrishnan et al. (1980), has tied down better the region most responsible for the scintillation signal. They produced a model scintillation signal for a source in the ecliptic using *in situ* spacecraft plasma measurements mapped to the appropriate position along the line of sight. This model yielded a velocity and scintillation index series which could be compared with that actually recorded on the source in question. The initial model, based on $\Delta n \propto n$, was then perturbed to improve the agreement with observation, and yielded the result that for this fit, the position of the Δn peak is at the position of highest positive velocity gradient. Thus the proportionality of Δn and n is not consistent with these observations. It is not yet clear what physical process leads to this increase in levels of "microturbulence", but it should be remembered that the tests were made for in-ecliptic solar wind at a time during which it was dominated by large scale, slowly evolving structures, and it remains to be tested for other conditions.

Observations of Transient Disturbances

Even before the identification of coronal mass ejection events, it was apparent that interplanetary disturbances plausibly associated with impulsive solar activity travelled out to the orbit of the earth. *In situ* measurements soon established the shock nature of the events directly and were frequent enough to allow the general properties of these events to be established (Hundhausen, 1972). Statistical assemblies of these single point observations (spacecraft plasma and field measurements(e.g., Taylor, 1969) and sudden commencement occurrence (Hirshberg, 1968; Chao and Lepping, 1974)) showed that the extent of these events at 1 AU in the ecliptic was quite large, typically a circle of radius several tenths of an AU. Theoretical calculations(De Young and Hundhausen, 1971), however, showed that the size at 1 AU was not a powerful discriminator of the conditions near the site of the source of the disturbance.

With the awareness of the existence of coronal transients (MacQueen, 1980) we have the more general problem now of establishing the signature of any interplanetary manifestation of these events. Following the *in situ* identification of a disturbance following one of the transients observed from SKYLAB (Gosling et al.,1975), significant progress has been made in the identification of plasma disturbances within 1AU which are plausibly associated with coronal transients (Sheeley et al., 1983). The recent suggestion of a magnetic signature for the events (Klein and Burlaga, 1982) was followed by the association of one such event with an observed transient (Burlaga et al., 1982). However, we are still far from having established the uniqueness of such identifications and understanding the physics involved.

IPS provides an opportunity of detecting propagating interplanetary disturbances in three dimensions, and can therefore improve our knowledge of the existence, extent and dynamics of propagating disturbances following coronal ejections. However, uncertainty as to the signature of these events and limits on what the IPS technique is sensitive to ,limit progress. For example, if neither a change in the local density fluctuation level, nor in the bulk velocity occurs, then intensity or phase scintillations will not detect the event. Faraday rotation observations, however, could detect changes in the magnetic field (Bird, 1982).

Nonetheless, the potential has been explored, since the multiple lines of sight available for low frequency scintillating sources allow simultaneous detection in all three dimensions and can provide limits on the interplanetary morphology of these events, at least to the same order as is available from other techniques. Further, the repeated observation of a single disturbance at succeeding locations can give an indication of the evolution of the event. It must, however, be stressed that the IPS detection of these features is subject to the same difficulties as all other methods; even if the disturbance is identified, the association with a solar event must be made. This is a difficult step and involves projections across large fractions of an astronomical unit. Two particular points of note with respect to identification by IPS are the relatively coarse time resolution along a particular line of sight (up to ~24 hours) and the uncertainty (up to ~ 1/2 AU) in the distance from the earth at which the disturbance crosses the line of sight. However, by combining information from several observations, one can often diminish the effects of these uncertainties.

The remarkable disturbances in the interplanetary medium following the flares of early August 1972 provided an early opportunity for a demonstration of the IPS detection of such events (Armstrong et al. 1973). Rickett (1975) combined spacecraft and scintillation data to identify three major propagating events following the flares, which could be distinguished from neighbouring recurrent high speed solar wind. The picture that emerged was of enhancements , both in velocity and in density fluctuation, that were very broad by the time they reached the vicinity of the earth, extending tens of degrees in both latitude and longitude from the flare normal. The comparison of the velocity observed in the disturbed region and the time of flight from the sun, under the assumption that the time of the flare was the start time for the disturbance, indicated very little deceleration for the event, leading Rickett to conclude that the disturbance was driven rather than being a blast wave. This event was also analysed by Kakinuma and Watanabe (1976) who improved the resolution of the data by combining these observation with data from Toyokawa and Cambridge.

By identifying less spectacular, but none the less significant velocity and density fluctuation enhancements, in the IPS measurements Sime (1976) attempted to identify all interplanetary disturbances in 1973 and 1974. Since the data were somewhat noisy, Sime followed the example of Hundhausen (1972) in taking the occurrence of coincident type II and type IV radio bursts to indicate the presence of a propagating disturbance. A fairly high proportion of the events examined led to a detection (33 out of 42), many involving multiple lines of sight so that limits could be put on extent, shape and thickness of the disturbances. Further, by use of repeated observations, an indication of the evolution of many events was built up, showing, in general sense, an initially quite narrow front which gradually broadened as it approached 1AU. Typical broadening is indicated in figure 5, where, for the event of 19, May 1973, the positions of the IPS observation of the disturbance are indicated for the first 2 days after the flare. The front is seen near the flare normal on the first day, and not at wider separations. However, on the second day identification is made at positions less than 1AU from the sun but at much larger angles from the flare normal than on the previous day.

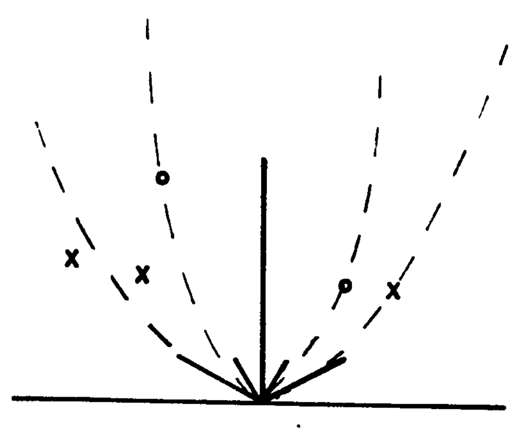

Figure 5: Observations of the interplanetary disturbance following the flare of 19 May 1973 shown relative to the flare site. Identifications are represented on a polar plot with the axes drawn to represent a scale of 1AU. Dots show identifications made between 16 and 20 hours after the flare and crosses show those made between 40 and 54 hours after the flare. A consistent envelope for the front is indicated.

Near the orbit of the earth, the shape of the fronts was quite well described by a spherical shell with radius some fraction of an AU. However, although a generally consistent picture prevailed, variation from event to event in the ambient solar wind, the observing conditions, and presumably in the events themselves prevented an average profile from being built up. As with the results of Rickett, these observations were entirely consistent with the development of the shape of the disturbance as calculated by De Young and Hundhausen (1971), i.e., with the broadening of the disturbance as its radial momentum is lost to the ambient medium until it becomes comparable to the non-radial component. One consequence of this is that the shape of the disturbed front at 1AU is not strongly controlled by the extent or shape of the region over which the ejection from the sun occurred. However, the development of its shape as it travels from the sun does depend on the initial angular extent of the ejection from the corona (De Young and Hundhausen, 1971). IPS, therefore, by providing an outline of that development, should be able to help solve another outstanding problem in coronal physics, the morphology of coronal transients, by inference from their manifestations in the interplanetary medium.

Other investigators have concentrated more on the dynamics of disturbances. Watanabe (1978) has discussed the velocity evolution of the disturbances associated with solar events in March and April 1976. From their velocity measurements, and assuming isotropic expansion of the disturbance, they conclude that the fronts are not well explained by either purely driven or by purely blast waves, but rather a combination of the two mechanisms seems to be required. This may indicate that the disturbances are driven only in the earlier stages of the event.

Other efforts have utilised single line of sight measurements to infer some property of the disturbance. Since they involve essentially a measurement at a single region in space, they do not offer much more than a single *in situ* measurement, except, of course, that they are not restricted to the ecliptic, or to regions $\gtrsim 50\ R_o$ from the sun. Many depend on the assumption of radial propagation, and some, especially some Faraday rotation observations, may be confused by coronal evolution which would not be classified as transient.

An example of the value of such single line of sight observations has been given by Cane et al.(1982) who utilised observations of Woo and Armstrong (1981) showing the passage of an interplanetary disturbance across their line of sight at about 13 R_o. Although a presumed initiation time for the event at the sun allowed the derivation of a time of flight for the event out to 13 R_o, the subsequent crossing of another line of sight, at $73R_o$, permitted a propagation velocity in interplanetary space for the disturbance to be established. Cane et al. (1982) then used this velocity to scale a model density for the interplanetary medium from which they could deduce the shock velocity implied by Type II radio bursts observed on board the ISEE-3 spacecraft. Their final composite velocity profile, comprising data from scintillation, time of flight and radio burst observations spans the range of $\sim 10R_o$ to 1AU. It shows an initially accelerating out to about 30 R_o which is followed by a decreasing velocity proportional to about $r^{-0.8}$. This kind of measurement is especially important since it bridges the gap between interplanetary and solar events, and, in principle, should allow better associations with coronal phenomena to be developed.

One final set of data of particular promise is the 81.5 MHz intensity scintillations reported by Gapper et al., (1982). In these, daily scintillation index data are recorded for some 900 sources covering the entire sky from about -15^o to 70^o declination. By measuring significant departures from the predicted or mean scintillation indices, these workers can map out regions of the sky which are responsible for enhanced (or indeed depleted) scintillation levels, and which ,by inference, consist of enhanced, or depleted density levels. Large regions of the sky, several hours R.A. by tens of degrees in declination appears to be so affected, both by corotating events and in occasional transient disturbances. Gapper et al. used these maps to distinguish corotating and noncorotating regions of enhanced scintillation, however, since only index data is recorded, propagation velocities for these disturbed regions have to be derived from the fitting of model geometries to the data. Good consistency for the method has been shown, however, in comparison with *in situ* density and velocity measurements. Similar 'all-sky' increases in scintillation indices at large elongations have been reported by Erskine et al. (1978) in coincidence with proton density increases near the earth. In this case, however, the scintillation signal is interpreted as arising near the earth and does not show the expected signature of structures rotating towards the earth. Jackson (1981) has examined the 73.8 MHz data from UCSD for the same effects, but finds no general east-west asymmetry in the days of widespread scintillation enhancement that he observes and concludes that the effects are near earth phenomena rather than interplanetary and, consistently, finds no obvious solar or coronal counterpart. These latter two data sets perhaps involve stronger events intrinsically since they are in general taken from the anti-sun hemisphere, and are detected (in Jackson's (1981) case) as increased SNR or radical changes in the inferred scale sizes (Coles and Kaufman, 1978) of the scintillation pattern.

Thus, the overall picture which emerges from these attempts to characterize propagating interplanetary disturbances is one of an initially accelerated front with restricted angular width. Once the front is some fraction of an AU from the sun, the acceleration ceases and the event coasts outwards with decreasing radial velocity and increasing angular width. Eventually, once the front is close to 1AU, it covers several tens of degrees in latitude and longitude, and may be fairly well described as lying on a sphere of radius almost 1AU.

Summary

IPS observations exist in a form and to an extent to be of value in a number of current questions in coronal and interplanetary physics. For brevity, this article has emphasized only three topics.

A global view of the solar wind velocity has been derived and its evolution throughout the last solar cycle followed. The large scale relationship to coronal structure has been established. Further, a reasonably consistent, but not yet fully interpreted, view of the flow at heights of $\lesssim 30\ R_\odot$ has been developed, and further work in this area holds promise for the understanding of coronal heating and acceleration.

Although the working hypothesis that Δn is proportional to n is still useful, a comparison of scintillation observations with *in situ* spacecraft velocity and density data reveals that the variations to which intensity scintillations are most sensitive peak where the positive velocity gradient is highest. This result, established with ecliptic solar wind dominated by corotating structures remains to be verified for transient increases, but should be kept in mind when positional information is sought from IPS observations.

The potential for sensing the morphology of propagating disturbances associated with solar eruptive phenomena has been demonstrated. The simple approach of testing shape and velocity for these events to establish whether they are driven or not has yielded mixed results indicating both blast and driven waves. However, a large extent at 1AU, in both latitude and longitude is indicated quite clearly. The possibility of detecting frontal passages with observations at $< 50\ R_\odot$ and the prospect of full sky snapshots of transiently disturbed regions is exciting and should lead to a better understanding of the processes of importance.

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References

Ananthakrishnan, S., W. A. Coles and J. J. Kaufman, Microturbulence in solar wind streams, *J. Geophys. Res.*, *85*, 6025, 1980.

Armstrong, J. W., and W. A. Coles, Analysis of three station interplanetary scintillations, *J. Geophys. Res.*, *77*, 4602, 1972.

Armstrong, J. W., W. A. Coles, J. K. Harmon, S. Maagoe, B. J. Rickett and D. G. Sime, Radio scintillation measurements of the solar wind following the flares of August 1972, *World Data Center A, Report UAG-28*, 1973

Armstrong, J. W., and R. Woo, Solar wind motion within 30 R_o; Spacecraft radio scintillation observations, *Astron. Astrophys.*, *103*, 415, 1981.

Athay, R. G., and O. R. White, Chromospheric and coronal heating by sound waves, *Astrophys. J.*, *226*, 1135, 1978.

Bird, M. K., Coronal investigations with occulted spacecraft signals, *Sp. Sci. Rev.*, *33*, 99, 1982.

Brandt, J. C., R. C. Harrington,and R. G. Roosen, Interplanetary gas XX: Does the radial solar wind speed increase with latitude?, *Astrophys. J.*, *196*, 877, 1975.

Burlaga, L. F., L. Klein, N. R. Sheeley, Jr., D. J. Michels, R. A. Howard, M. J. Koomen, R. Schwenn and H. Rosenbauer, A magnetic cloud and a coronal mass ejection, *Geophys. Res. Lett.*, *9*, 1317, 1982.

Cane, H. V., R. G. Stone, and R. Woo, Velocity of the shock generated by a large East limb flare on August, 18, 1979, *Geophys. Res. Let.*, *9*, 897, 1982.

Chao, J. K. and R. P. Lepping, A correlative study of ssc's (sic), interplanetary shocks, and solar activity, *J. Geophys. Res.*, *79*, 1799, 1974.

Coles, W. A., Interplanetary scintillations, *Space Sci. Rev.*, *21*, 411, 1978.

Coles, W. A., and S. Maagoe, Solar wind velocity from IPS observations, *J. Geophys. Res.*, *77*, 5622, 1972.

Coles, W. A. and B. J. Rickett, IPS observations of the solar wind speed out of the ecliptic, *J. Geophys. Res.*, *81*, 4797, 1976.

Coles, W. A. and J. J. Kaufman, Solar wind velocity estimation from multistation IPS, *Radio Sci.*, *13*, 591, 1978.

Coles, W. A., B. J. Rickett and V. H. Rumsey, Interplanetary scintillations, in *Solar Wind Three*, ed. C. T. Russell, U. C. L. A., 1974.

Coles, W. A., B. J. Rickett, and S. L. Scott, Scintillation observations near the sun, in *A Close-Up of the Sun*, 1978a.

Coles, W. A., J. K. Harmon, A. J. Lazarus, and J. D. Sullivan, Comparison of 74 MHz interplanetary scintillation and Imp-7 observations of the solar wind during 1973, *J. Geophys. Res.*, *83*, 3337, 1978b.

Coles, W. A., B. J. Rickett, V. H. Rumsey, J. J. Kaufman, D. G. Turley, S. Ananthakrishnan, J. W. Armstrong, J. K. Harmon, S. L. Scott and D. G. Sime, Solar cycle changes in the polar solar wind, *Nature*, *286*, 239, 1980.

Dennison, M. D., and A. Hewish The solar wind outside the plane of the ecliptic, *Nature*, *213*, 343, 1967.

De Young, D. S., and A. J. Hundhausen, Two-dimensional simulation of flare-associated disturbances in the solar wind, *J. Geophys. Res.*, *76*, 2245, 1971.

Ekers , R. D., and L. T. Little, The motion of the solar wind close to the sun, *Astron. Astrophys.*, *10*, 310, 1971.

Erskine, F. T., W. M. Cronyn, S. D. Shawhan, E. C. Roelof and B. L. Gotwols, Interplanetary scintillation at large elongation angles: Response to solar wind density structure, *J. Geophys. Res.*, *83*, 4153, 1978.

Feldman, W. C., J. R. Asbridge, S. J. Bame and J. T. Gosling, Long-term variations of selected solar wind properties: Imp 6, 7, and 8 results, *J. Geophys. Res.*, *83*, 2177,1978.

Gapper G. R., A. Hewish, A. Purvis, and P. Duffet-Smith, Observing interplanetary disturbances from the ground, *Nature*, *296*, 633, 1982.

Gosling, J. T., E. Hildner, R. M. MacQueen, R. H. Munro, A. I. Poland, and C. L. Ross, Direct observations of a flare related coronal and solar wind disturbance, *Solar Physics*, *40*, 439, 1975.

Gosling, J. T., J. R. Asbridge and S. J. Bame, An unusual aspect of solar wind speed variations during solar cycle 20, *J. Geophys. Res.*, *82*, 3311, 1977.

Harmon, J. K., Scintillation studies of density microstructure in the solar wind plasma, Ph.D. Thesis, Univ.of Calif., San Diego, La Jolla, 1975.

Harmon, J. K. and W. A. Coles, Spectral broadening of planetary radar signals by the solar wind, *Astrophys. J.*, in press, 1983.

Hewish, A., P. F. Scott and D. Wills, Interplanetary scintillation of small diameter radiosources, *Nature*, *203*, 1214, 1964.

Hewish, A., and M. D. Symonds, Radio investigation of the solar plasma, *Plan. Sp. Sci.*, *17*, 313, 1969.

Hirshberg, J., The transport of flare plasma from the sun to the earth, *Planet. Space. Sci.*, *16*, 309, 1968.

Holzer, T. E., and E. Leer, Conductive solar wind models in rapidly diverging flow geometries, *J.Geophys. Res.*, *85*, 4665, 1980.

Hundhausen, A. J., Interplanetary shock waves and the structure of solar wind disturbances, in *Solar Wind*, eds. C. P. Sonnet, P.J.Coleman Jr., and J. M. Wilcox, NASA, SP-308, 1972.

Hundhausen, A. J., An interplanetary view of coronal holes, in *Coronal Holes and High Speed Wind Streams*, ed. J. Zirker, Colorado Assoc. Univ. Press, 1977.

Hundhausen, A. J., Solar wind spatial structure: The meaning of latitude gradients in observations averaged over solar longitude, *J. Geophys. Res.*, *83*, 4186, 1978.

Hundhausen, A. J., R. T. Hansen and S. F. Hansen, Coronal evolution during the sunspot cycle: Coronal holes observed with the Mauna Loa K-coronameters, *J. Geophys. Res.*, *86*, 2079, 1981.

Jackson, B. V., All sky days and their solar cycle dependence, preprint, 1981.

James, J. C., Radar Echoes from the sun, *Trans. IEEE. Ant. Prop. AP-12*, 876, 1964.

Kakinuma, T., and T. Watanabe, Interplanetary scintillation of radio sources during August 1972, *Sp. Sci. Rev.*, *19*, 611, 1976.

Klein, L. W., and L. F. Burlaga, Magnetic clouds at 1 AU, *J. Geophys. Res.*, *87*, 613, 1982.

Leer, E., T. E. Holzer and T. Fla, Acceleration of the solar wind, *Sp. Sci. Rev.*, *33*, 161,1982.

MacQueen, R. M., Coronal transients: A summary, *Phil. Trans. R. Soc. Lond. A*, *297*, 605, 1980.

Rhodes, E. J. and E. J. Smith, Evidence of a large scale gradient in the solar wind velocity, *J. Geophys. Res.*, *81*, 2123, 1976a.

Rhodes, E. J. and E. J. Smith, Further evidence of a latitude gradient in the solar wind velocity, *J. Geophys. Res.*, *81*, 5833, 1976b.

Rickett, B. J., Disturbances in the solar wind from IPS measurements in August 1972. *Solar Phys.*, *43*, 237, 1975.

Schwenn, R., The 'average' solar wind in the inner heliosphere: structures and slow variations, This Proceedings.

Scott, S. L., Density spectrum and velocity of the solar wind inferred from scintillation observations, Ph.D. Thesis, Univ.of Calif., San Diego, La Jolla, 1978.

Sheeley, Jr., N. R., R. A. Howard, M. J. Koomen, D. J. Michels, R. Schwenn, K.-H. Muehlhauser and H. Rosenbauer, Association between coronal mass ejections and interplanetary shocks, this proceedings, 1983.

Sime, D. G., Structure of the solar wind inferred from interplanetary scintillations, Ph.D. Thesis, Univ.of Calif., San Diego, La Jolla, 1976.

Sime, D. G. and B. J. Rickett, The latitude and longitude structure of the solar wind speed from IPS observations, *J. Geophys. Res.*, *83*, 5757, 1978.

Sime, D. G., Indirect measurements of the solar wind speed out of the ecliptic, *EOS*, *60*, 93, 1979.

Taylor, H. E., Sudden commenscment associated discontinuities in the interplanetary magnetic field observed by IMP 3, *Solar Physics*, *6*, 320, 1969.

Unti, T., M. Neugebauer and B. E. Goldstein, Direct measurements of solar wind fluctuations between 0.0048 and 13.3 Hz, *Astrophys. J.*, *180*, 591, 1973.

Watanabe, T., IPS observations of flare-generated interplanetary shock waves during the second STIP interval (March 15 - May 15, 1976), *Proc. Res. Inst. Atmos., Nagoya Univ.*, *25*, 19, 1978.

Withbroe, G. L., J. L. Kohl, H. Weiser and R. H. Munro, Probing the solar wind acceleration region using spectroscopic techniques, *Sp. Sci. Rev.*, *33*, 17, 1982.

Woo, R., Multifrequency techniques for studying interplanetary scintillations, *Astrophys. J.*, *201*, 238, 1975.

Woo, R., Measuring solar wind velocity with spacecraft phase scintillations, *Nature*, *266*, 574, 1977.

Woo, R., and J. W. Armstrong, Spacecraft radio scattering observations of the power spectrum of electron density fluctuations in the solar wind, *J. Geophys. Res.*,*84*, 7288, 1979.

Woo, R., and J. W. Armstrong, Measurements of a solar flare-generated shock wave at $13.1R_o$, *Nature*, *292*, 608, 1981.

Woo, R., and J. W. Armstrong, *Sp. Sci. Rev.*, in press, 1983.

Zhao, X-P., and A. J. Hundhausen, Organization of solar wind plasma properties in a tilted, heliomagnetic coordinate system, *J. Geophys. Res.*, *86*, 5423, 1981.

Zhao, X-P., and A. J. Hundhausen, Spatial structure of solar wind in 1976, *J. Geophys. Res.*, *88*, 451, 1983.

Zirker, J., Coronal holes and high speed wind streams, Colorado Assoc. Univ. Press., 1977.