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13. ABSTRACT *(Maximum 200 words)*

Solar disturbances produce major effects on the corona, the solar wind, the interplanetary medium, and the Earth along with its magnetosphere. We have developed new techniques for studying plasma disturbances in the inner heliosphere by remotely sensing them. These techniques use data from the HELIOS spacecraft zodiacal light photometers and *in situ* data, the ISEE-3 spacecraft *in situ* and kilometer radio-wave experiments, and a variety of other spacecraft and ground-based instruments. We use interplanetary scintillation (IPS) data from the Cambridge, England radio telescope. The zodiacal-light photometers on board the two HELIOS spacecraft (data coverage from 1974 to 1986) provide the first reliable information about the heliospheric masses and shapes of propagating disturbances. The investigations into the physics of the disturbances sensed by these techniques, and the ability to forecast them, are underway.

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Remote Sensing of Inner Heliospheric Plasmas

I. Introduction

The outermost parts of the solar atmosphere - the corona and solar wind - experience dramatic perturbations related to flares and mass-ejection transients. These disturbances extend to the Earth's magnetosphere and to Earth itself. In the past, observations of the origins of these disturbances in the lower corona have been restricted to coronal emission-line observations and the meter-wave radio band, but since the 1970's we have seen the addition of powerful new observing tools for observation: sensitive coronagraphs, both in space and at terrestrial observatories; X-ray imaging telescopes; low-frequency radio telescopes; space-borne kilometric wave radio receivers; and interplanetary scintillation data.

The primary object of earlier research has been to understand the physics and spatial extents of heliospheric structures such as coronal mass ejections and streamers. In comparison with spacecraft *in situ* and ground-based data, this leads to a better determination of the total mass and energy of these structures. In addition, we have addressed the question of how easy these features are to observe and how we can forecast their effects on Earth. This study has resulted primarily from analyzing the data from the zodiacal light photometers on board the HELIOS spacecraft.

We describe our recent results on HELIOS photometer observations of mass ejections, co-rotating density enhancements and other heliospheric features in Section II of this report. The new research section (Section III) emphasizes the studies we have continued and concludes with a list of papers and abstracts which have been supported by this contract. Section III also contains a list of the personnel who have been supported by this contract. Section IV states the future goals of the project. Conclusions and an executive summary of the analysis to be performed in the next year under a grant titled 'The Physics of Remotely-Sensed Heliospheric Plasmas' is to be found in Section V.

II. Scientific Background and Recent Results

In association with filament eruptions or large solar flares, the Sun emits clouds of ionized gas and entrained magnetic fields (the "coronal mass ejection") and hydrodynamic disturbances (the "shock wave") responsible for some of the magnetic-storm sudden commencements at the Earth. Coronal mass ejections are the most dramatic disturbances of the heliospheric mass distribution and the ones first detected in the HELIOS photometer data (Richter *et al.*, 1982). The quantitative study of mass ejections essentially began with the Skylab coronagraph (e.g., Rust and Hildner *et al.*, 1980), and has been greatly enhanced by the advent of new coronal instruments. There are data available from the P78-1 and SMM spacecraft, and from mountaintop observatories such as Sacramento Peak and Mauna Loa. In addition, ground-based radio observations provide information on interplanetary scintillations, which are especially useful at high ecliptic latitudes and large solar elongations. In addition to these astronomical observations, there are extensive *in situ* observations from a wide variety of past and present spacecraft. These measurements are generally restricted to the vicinity of the ecliptic plane.

In the lower corona the major ejections observed in Hα are termed "eruptive prominences," and are typically associated with a particular kind of flare characterized by two expanding bright ribbons in the chromosphere and a growing system of coronal loops rooted in these ribbons (e.g., Švestka, 1986). The X-ray loops appear to move gradually upward in a steady sequence of diminishing temperature and velocity, and their emission decays with time scales of hours (e.g., Švestka, 1981). These long-duration X-ray events (Kahler, 1977; Sheeley *et al.*, 1983) are known to have a strong association with the ejection of mass into the corona (the coronal transient), the acceleration of interplanetary protons (Kahler *et al.*, 1978), and meter-wave radio phenomena (Webb and Kundu, 1978).

Recent solar X-ray imaging observations (including those from the Japanese YOHKOH spacecraft) have added new data for the phenomenological picture of the origins of coronal mass ejections. Using X-ray imaging and coronagraph data, Harrison *et al.* (1985) argue that rising X-ray arches are involved in the initiation of coronal mass ejections, and in some instances flares (when they occur) are secondary activity at the feet of the arches. We now have evidence that these long-enduring coronal structures may also trap extremely hot thermal sources (e.g., Tsuneta *et al.*, 1984). Cliver *et al.* (1986) argue that such extended hard X-ray bursts are evidence of the acceleration of non-thermal particles in the post-flare loops following mass ejections. X-ray imaging data also revealed large, long-enduring X-ray arches associated with metric radio continua following flares on 21-22 May 1980 (Švestka *et al.*, 1982a), several times on 6 and 7 November 1980 (Švestka *et al.*, 1982b; Švestka, 1984; Farnik *et al.*, 1986) and on 20-22 January 1985 (Hick *et al.*, 1987). These arches coexist with the loop systems, but extend to higher altitudes, survive longer, and coincide in space and time with coronal metric radio phenomena such as type I (short, segmented in time and frequency) and type IV (broad-band continuous) radio emission. Extended bursts of non-thermal hard X-ray emission (Frost and Dennis, 1971; Hudson, 1978) provide another sign that major energy release and particle acceleration may take place in the corona high above, and for long periods after, the disturbance at the solar surface.

As shown by Webb *et al.* (1980), the ejected coronal mass at the time of a solar flare may be more important energetically than its chromospheric manifestations. Thus it is imperative to study the masses and 3-dimensional structures of the mass ejections in order to understand the flare process. This provides an additional incentive for the study of mass ejection phenomena, over and above our interest in the physical mechanisms involved in the acceleration of mass and particles associated with the mass motions themselves. The observations from the HELIOS spacecraft photometers (Leinert *et al.*, 1981) provide a link between coronal observations and those obtained *in situ* near Earth. Prior to these observations, the most frequently used way to remotely sense information about the interplanetary medium was by radio data.

II.A. The HELIOS Photometer Data

The HELIOS spacecraft, the first being launched into heliocentric orbit in 1974, contained sensitive zodiacal-light photometers (Leinert *et al.*, 1981). Each of the two HELIOS spacecraft contained three photometers for the study of the zodiacal-light distribution. These photometers, at 16°, 31°, and 90° ecliptic latitude, swept the celestial sphere to obtain data fixed with respect to the solar direction with a sample interval of about five hours. The spacecraft were placed in solar orbits that approached to within 0.3 AU of the Sun. The photometers of HELIOS 1 viewed to the south of the ecliptic plane; HELIOS 2 to the north. These photometers were first shown to be sufficiently sensitive to be able to detect variations in brightness from coronal mass ejections by Richter *et al.* (1982).

An evaluation of these photometer brightness variations provides us with an opportunity to extend the coverage of transient phenomena produced by the Sun in the corona and to reduce some of the ambiguities in the coronal data obtained from the Earth's direction. This stereoscopic capability has been a major objective of the International Solar Polar Mission and of several other proposed deep-space probes, but some of the desired capability exists in these serendipitous HELIOS data. In many mass-ejection events, the mass can be followed right past the HELIOS zenith direction and into the antisolar hemisphere. In the HELIOS data, the contributions of background starlight and zodiacal dust have been calculated and removed from each photometer sector by Leinert and his colleagues, and the complete data set was made available to the National Space Science Data Center (NSSDC). An optical disk containing this data set is now available at UCSD and on request from NSSDC.

The image processing system we have developed has been demonstrated by construction of images of the interplanetary medium in video form for specific mass ejection sequences of the data; these data and additional images of specific events have been used to trace the time history of a variety of density enhancements. Recently, these programs have been transferred to the Vax computer at the Geophysics Laboratory, Hanscom AFB, Massachusetts, and the Johns Hopkins Applied Physics Laboratory, Laurel, Maryland. Thus, the capability exists to carry out HELIOS data analysis at any site with a vax computer. This capability is especially important for co-investigator D. Webb at the Geophysics Laboratory who (though not funded by this program) retains significant interest and collaborative expertise in the analysis of this unique data set.

These data are of interest to the Air Force for several reasons: 1) The understanding of the processes in the heliosphere and its plasma environment are of great importance to the Air Force that operates spacecraft systems and at times maintains a manned presence in space. 2) The ability to observe the outward propagation of structures from the Sun allows researchers to forecast their arrival at Earth. This in turn leads to both a better understanding of how these features interact with the Earth environment and how to determine a more accurate prediction of their effects on Air Force space and communication systems. 3) In recent years the Air Force has proposed placing an orbiting Solar Mass Ejection Imager (SMEI) in space to forecast the arrival at Earth of solar mass ejections, heliospheric shocks, and co-rotating dense regions. By studying the data from the HELIOS spacecraft photometers it is possible to assess the usefulness of the data which an Earth-based imager such as SMEI would provide.

II.A.1. Prior Research with the HELIOS Photometer Data Set

A major achievement of past research at UCSD has been the measurement of interplanetary masses and speeds of CMEs observed by coronagraphs, interplanetary scintillation measurements, and from *in situ* spacecraft measurements. A 2-D imaging technique which displays HELIOS photometer data has been developed here. The combination of these images with data from the perspective of Earth has been used to provide stereoscopic views of CMEs for many of the events studied. With HELIOS photometer data it is possible to sample the brightness of any given ejection over a far greater range of heights at one instant than with coronagraph instrumentation. Also, by measurement of the outward motion of an ejection determined from the photometers, the total extent of mass flow past a given latitudinal set of photometer sectors can be found and then checked by the second set of photometer sectors (*e.g.*, see Jackson, 1985b). The HELIOS data show that not only do CMEs supply significant mass to the interplanetary medium, but also that the mass flow from the Sun extends over times that can be greater than one day and in amounts somewhat greater than measured by coronagraphs. Webb and Jackson (1988) were able to determine the occurrence rate of plasma events from solar minimum to near maximum from the HELIOS 2 90° photometer and showed that the rate increased significantly over that period.

We have followed the mass ejection of 7 May 1979 from near the solar surface to the furthest extent that can be observed by HELIOS (Jackson *et al.*, 1988). Near-surface observations of this mass ejection from the Wroclaw observatory show the Hα manifestations and position of the associated loop-like eruptive limb prominence near the solar surface. This ejection accelerated between the SOLWIND field of view, and when observed later by HELIOS eventually reached a speed of about *500 km* s^{-1}. *The analysis also includes* UCSD IPS measurements which show an enhancement of the scintillation level and speed during passage of the excess mass of small-scale turbulence which compares favorably with the 500 km s^{-1} speed of bulk motion obtained from HELIOS data. A three-dimensional reconstruction technique developed at UCSD is introduced in the same paper (Jackson *et al.*, 1988).

Studies provide HELIOS and SOLWIND comparisons of the CMEs observed during and after the appearance of slowly rising coronal arches observed in November 1980 (see Švestka, 1984). Culgoora Radioheliograph data obtained during that time interval reveal a type IV burst associated with the source flare of the first arch at 03:30 UT on 6 November, extending to heights as great as 2 $R_{\odot}$. Evidence from SOLWIND images indicates that a large pre-existing structure was expelled from the inner corona in association with this event. We determined that the mass observed by the HELIOS spacecraft photometers is consistent with the observed excess coronal mass measured by the SOLWIND coronagraph and that no large amount of new material was expelled into the corona from a height below the large pre-existing structure. We also have checked whether any mass ejection might have been associated with another coronal arch (see Hick and Švestka, 1987) that followed after the first one at 15 UT on 6 November. Discussion of this set of events is reported in the paper by Švestka *et al.* (1989).

II.A.2. Three-Dimensional Reconstruction Technique

The true three-dimensional geometry of mass ejections has long been a question for researchers. Much of the information of recent years suggests that a CME fills a large three-dimensional volume, but that CMEs may not be configured like either a simple arch or a bubble as once thought. While some of these results have come from the HELIOS analysis and from coronagraph (*e.g.*, MacQueen, 1993) observations, a larger amount of evidence about their large extents is inferred from the positions of CMEs observed *in situ* and the spatial locations of them near the Sun (*e.g.*, Sheeley *et al.*, 1985) sensed either by coronagraphs or other techniques. The importance of the CME shape goes beyond a simple accounting of its structure and its cross section movement through the heliosphere. The measurements of magnetic field *in situ* for CMEs imply that portions of them contain highly organized current systems which may extend back to the solar surface. The CME shape is derived from the processes (as yet poorly known) which drive the CME outward from the Sun. Modelers need to know the organization of the mass within the ejection to determine how the energy needed to eject the material was distributed.

The unique stereoscopic aspect of the HELIOS data can be fully utilized if three-dimensional models of the CMEs can be produced for specific events. The 7 May 1979 and 24 May 1979 events were ideal in this respect because they were well-observed by both SOLWIND and HELIOS 2 when they were widely separated from one another in solar longitude. We have developed a computer program which constructs excess interplanetary and coronal densities in three dimensions, projects the brightness of this material to the SOLWIND or HELIOS views, and then iterates to find the best density fitting the observed brightnesses from both instruments. Two different versions of this type of computer assisted tomography or CAT-scan analysis have been developed at UCSD: an algebraic reconstruction technique (ART) and an iterative least squares technique (ILST). In the HELIOS view both brightness and polarization brightness are matched by the constructed density distribution.

II.B. *In Situ* Recognition of a CME

The question of how to recognize the passage of a CME past Earth (or a spacecraft) has received considerable attention ever since the first plasma, magnetic field and particle detectors were put on spacecraft. The most energetic CME events, with propagation velocities significantly higher than the ambient solar wind, drive shock waves ahead of them. Most results on interplanetary signatures of CMEs are derived from the search for 'unusual' (as compared to the undisturbed solar wind) particle, plasma and/or magnetic properties of the solar wind plasma driving these interplanetary shocks. Several unusual signatures have been identified for these shock-associated events (see *e.g.*, Schwenn, 1986; Gosling, 1990), such as high magnetic field strength, low temperature, gradual rotation (over many hours) of the magnetic field vector over large angles, low magnetic field variance, low plasma beta and high He abundance. It seems reasonable to expect that some of these signatures will continue to be present when less-energetic CMEs, moving too slow to cause the formation of a shock, move past a spacecraft in the inner heliosphere. The basis for identifying these signatures is largely correlative in nature.

CMEs originate in the lower corona in closed magnetic field configurations (beneath streamers, for example). It is generally assumed (and confirmed by coronagraph observations for the rise of the CME over the first few solar radii) that the closed topology is maintained as the CME moves outward into the heliosphere. Magnetic field lines (generally described as magnetic 'bottles', loops or flux ropes) expand outward, but remain rooted with both footpoints in the Sun. In some cases reconnection may lead to the formation of a magnetic structure completely detached from the Sun and convected outward embedded in the solar wind ('plasmoid'). If this picture is correct, then an *in situ* diagnostic for the magnetic field topology would be a potentially valuable tool for detecting the passage of a CME. Counterstreaming heat flux events, which are presumably indicative of a closed magnetic topology, have been used for just this purpose.

The heat flux in the solar wind is carried almost entirely by supra-thermal halo electrons with energies larger than about 100 eV. Usually this heat flux is uni-directional, flowing outward from the hot solar corona along the interplanetary magnetic field and connected with the hot corona at only one end. Occasionally, discrete events lasting for many hours are observed when the field-aligned electron flux becomes distinctly bi-directional (Montgomery *et al.*, 1974; Pilipp *et al.*, 1987; Gosling *et al.*, 1987). A counterstreaming electron flux event occurs on 'closed' field lines, either still rooted with both footpoints in the hot corona, or (in the case of a plasmoid) with a trapped (counterstreaming) electron flux in it.

This line of reasoning suggests that counterstreaming electron events can be used as tracers of closed magnetic field structures, and, by extension, of the passage of CMEs. In a recent paper Gosling *et al.* (1992) advocated the position (based on an analysis of electron observations with energies >80 eV from the Los Alamos ISEE 3/ICE electron analyzer during the years 1978-90) that counterstreaming electrons are 'a reliable signature of coronal mass ejections in the solar wind at 1 AU'. This suggests that the counterstreaming signature is the closest to a 'necessary and sufficient' condition currently available for identifying the passage of a CME.

Even though the relation between counterstreaming heat flux events and closed magnetic field structures (and by inference CMEs) seems plausible, this result is not yet firmly established. Given the important role counterstreaming events of low-energy electrons currently play in the discussion about interplanetary signatures of CMEs, additional information about the characteristics of these events from an independent source would be extremely valuable.

III. Research Completed Under This Contract

During the first three years of this contract we have continued research on several aspects of the solar-terrestrial connection. With the HELIOS photometer data available to us on optical disk at the beginning of the contract, we began a series of studies which fully utilize the entire HELIOS photometer data set. Over the last year we have also made available the extensive *in situ* data set from the HELIOS spacecraft to be used in comparative studies with the photometer data. One of the associated benefits of this study and our recent acquisition of interplanetary scintillation (IPS) data daily from Cambridge, England has been its analysis using the very same techniques developed for the HELIOS spacecraft. In addition, the synoptic map technique has been adapted to plot Sacramento Peak coronagraph and YOHKOH SXT (soft X-ray telescope) data to be used in comparative studies with the other data sets.

III.A. HELIOS Photometer Remote Sensing

Since the entire HELIOS photometer data set has been available on optical disk, we have begun filling in data for the heliospheric southern hemisphere using observations from HELIOS 1. This is particularly important because the time interval through which HELIOS 1 operated spanned eleven years (one complete solar cycle) from 1974 through 1985. The HELIOS 2 90° photometer was normally not available for this analysis on the zodiacal light data tapes because of a questioned absolute calibration due to the presence of the Large Magellanic Cloud and an uncalibrated wobble of the HELIOS 1 spacecraft over its 6-month orbital period. However, we are interested primarily in the short-term variations in the data temporal sequence. Using data from the optical disk at UCSD and a data set normally not used but available on the optical disk, we displayed the HELIOS data for all orbits of the *HELIOS 1* spacecraft and *selected all of the significant events* observed in the data (~300) for further study.

Using this extensive list we published a preliminary study of the solar cycle variation of these data (Webb and Jackson, 1992; 1993) showing that the events are far more numerous during solar maximum when more sunspots are present. A further refinement has been the continued analysis of these events by plotting the available lower photometer sequences for them. This allows identification of each event, its detailed comparison with *in situ* observations and imaging. To make this analysis tractable, we have developed several automatic analysis schemes to handle the bulk of photometer data more efficiently. One new data reduction procedure has largely replaced the time-consuming hand-editing that was previously required to make available each section of data. The technique works by filtering the photometer data temporally, after first removing the large component of *zodiacal light brightness* from the data. To check our procedure, as a control we have also re-analyzed all (~80) of the significant HELIOS 2 events including those from an earlier (Webb and Jackson, 1990) analysis. We have a table listing these events and intend to publish this list within a few months after the beginning of 1994.

III.A.1. HELIOS CME Events

Most of the events in the list are CMEs. Over 160 CMEs have now been observed and catalogued in the HELIOS 1 and 2 photometer data. Since the HELIOS photometer data are well calibrated in intensity, and very consistent in spatial and temporal characteristics, it has been possible to determine not only the solar cycle occurrence rate of mass ejections, but also their mass flux, size and temporal distribution. These results are being presented and published in many papers (Webb and Jackson, 1990; 1992; 1993, Webb *et al.*, 1993a; 1993c and Jackson *et al.*, 1993). We have heliospheric masses for 60 of these CMEs, with most of the difficult work completed for this determination for all 160 CME events.

These analyses and the ready availability of the data have been continued by further studies of the relationship of CMEs and their location within corotating solar wind structures. The analyses have lead to a preliminary paper by Webb and Crooker (1991) that shows the heliospheric current sheet is dynamic, and that CMEs are often involved with these current sheet dynamics. Both *in situ* and HELIOS photometer data are used to sort out the different structures in these complex regions of space (Crooker *et al.*, 1993; Shodhan-Shah *et al.*, 1993).

The Jackson (1991b) presentation at the Solar Wind 7 conference in September in

Goslar, Germany was a video of mass ejections observed by the HELIOS photometers. These videos show a sequence of images of five mass ejections as they move outward from the Sun to the farthest distances observed by HELIOS. The Jackson (1991c) review paper presented at the first SOLTIP conference in September in Liblice, Czechoslovakia compares the HELIOS photometer data with IPS data for specific time intervals. Compared are several mass ejections observed by HELIOS with available data from IPS velocity measurements from UCSD (Coles and Kaufman, 1978) and additional data from IPS using the Cambridge, England array (Hewish and Bravo, 1986). The SOLTIP analyses in some instances have been published previously (*i.e.*, Jackson *et al.*, 1988), but here the information is gathered together. In the final portion of the review, there is an attempt for the first time to reconcile the differences between the Cambridge IPS and the HELIOS masses for a mass ejection observed leaving the Sun on 27 April 1979.

III.A.2. Co-Rotating Structures (CRSs)

The co-rotating structures (CRSs) observed by both HELIOS 1 and HELIOS 2 from this set of events (~56 total) also show a general solar cycle variation that is similar in nature to the CME solar cycle variation - more are present at solar maximum. However, the variation with solar cycle of the CRSs is by no means as pronounced as observed for the CMEs. As in the case of the CMEs, the CRSs are compared with the *in situ* manifestations of each event observed in the plasma and interplanetary magnetic field observed by the HELIOS spacecraft. A portion of this study reported in Jackson *et al.* (1993) shows that many of the CRSs are associated with sector boundaries observed in the solar wind.

III.A.3. The Quiet Solar Wind

In order to understand the extent and significance of CME and CRS events in the HELIOS data, it has also been necessary to define the normal or quiet solar wind conditions in the observations. The automatic HELIOS analysis techniques we developed have allowed the display of photometer data into month-long data sequences in the form of synoptic maps (as in Hick *et al.*, 1990). In the preliminary report (Hick *et al.*, 1992) we have been able to compare these maps with IPS velocity maps (Rickett and Coles, 1991), K-coronameter maps (Fisher and Sime, 1984) and magnetic field maps (Hoeksema *et al.*, 1983). The HELIOS observations clearly show the organized heliographic equator enhancement of density at solar minimum and a depletion of the density over the solar poles. As solar maximum approaches, the enhanced density increases in latitude until at the time of maximum the whole of the Sun is surrounded by dense solar wind. This effect has been concluded from circumstantial evidence nearer the solar surface by others, but has never before been as directly observed above the primary region of solar wind acceleration (where the HELIOS photometers are sensitive).

These observations above the acceleration region of the solar wind allow a direct comparison of the solar wind density variations with solar wind speed from IPS velocity data. In particular Hick and Jackson (1993a) in a preliminary analysis show that over different heliographic latitudes, momentum flux (mV^2) [and not mass flux (mV) or energy flux (mV^3)] is most likely conserved for different speed solar wind. The implications of this observation are far reaching, for it means that the total energy input by the Sun to the solar wind is constant over latitude and does not depend on the solar magnetic field near the solar surface.

III.B. Three-Dimensional Reconstruction Technique

The three-dimensional density analysis of CMEs has advanced considerably following the use of display techniques available to us in IDL software at the beginning of this contract. These display techniques have allowed the rapid display of the three-dimensional structures produced. Figure 1 shows an example of the results of the current CAT analysis applied to the 24 May 1979 CME. The reconstruction technique converges in an iterative fashion to a solution that shows the gross features of the excess ejected mass. This CAT-scan analysis is described in Jackson *et al.* (1988) and Jackson (1989), and forms the basis of a complete paper now in progress on the subject of the 7 May 1979 CME by Jackson and Froehling (1993). A preliminary announcement of the results of the deconvolution of the 24 May 1979 CME (the "cap" of dense material shown in Figure 1) (Jackson, 1993) is currently in progress.

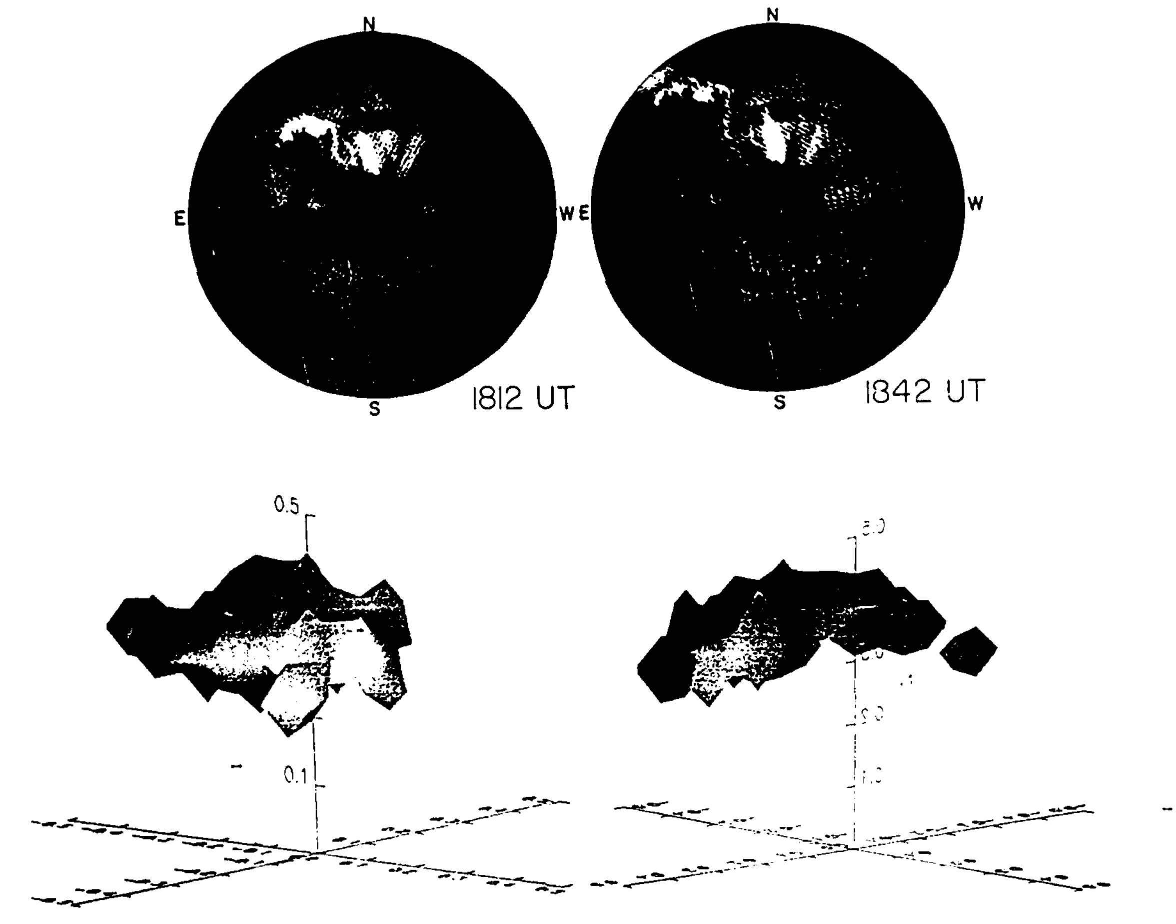

Fig. 1. (a) and (b) SOLWIND coronagraph difference images of the May 24 CME observed on that date at the times indicated. (c) and (d) A CAT depiction of the arch-like portion of this CME at 09:22 UT 25 May 1979. The density is contoured at a level of 50 e^{-} cm^{-3}.

III.C. *In Situ* Data Analysis and Comparisons

The HELIOS 1 and HELIOS 2 spacecraft carried a plasma experiment, which included a detector for electrons with energies up to 1445 eV (Schwenn, *et al.*, 1975). The instrument measures a two-dimensional cut through the electron distribution function, seeing only those electrons incident nearly parallel (within ±5°) to the ecliptic. The effective time resolution is 40 seconds.

These electron observations provide a valuable source, as yet virtually untapped, for studying the phenomenon of counterstreaming heat fluxes, which have been suggested as effective *in situ* tracers for the passage of a CME. So far the HELIOS electron observations have been analyzed primarily on a single event basis and a few counterstreaming electron events have been identified (Pilipp *et al.*, 1987). No systematic search for counterstreaming events in the HELIOS data base has been made yet, primarily due to the fact that it was difficult to simultaneously access the electron count rates, magnetic field data and the plasma quantities (derived from the ion data). During two visits in past years to the Max-Planck Institute for Aeronomie in Lindau, Germany (where all relevant HELIOS data are available), P. Hick has assisted scientists at the German institute to set up a procedure to merge all data from the HELIOS plasma experiment (which includes the electron analyzer) and magnetic field data on a single medium (optical disk). As a result it is now possible for the first time to efficiently execute a global search and analysis of the electron data base in comparison with the HELIOS event data. We have currently established a procedure with the group in Germany to access these data remotely from UCSD.

III.D. *Interplanetary Scintillation Observations*

We now obtain the IPS data daily by direct access from Cambridge, England, from the IPS array telescope there. With very little effort, we have been able to modify our HELIOS photometer data display programs to produce a daily map of the sky around Earth much as is done at NOAA in their attempts to forecast the arrival of heliospheric disturbances at Earth. We clearly see these heliospheric disturbances, but note as does the group at NOAA, that by the time most disturbances are well-observed, they have already reached the Earth. We have tried to improve the signal to noise present in the data by careful editing or displaying the data in the hope that they may become more useful as a disturbance forecast technique. Comparisons of these data with other similar data sets are currently underway. This includes data from the Japanese YOHKOH images of the Sun.

The Carrington synoptic presentation of data used to compare the HELIOS photometer data with other data sets has been modified to read daily IPS intensities and forecast the co-rotating component of the IPS level (Winfield *et al.*, 1993). These synoptic maps have been compared with other forms of solar surface and heliospheric *in situ* data from Earth-orbiting IMP spacecraft. Each day we produce a forecast map for co-rotating IPS scintillation levels. From statistical comparison of the co-rotating component of the IPS intensity level shown in the map, we find a slight positive correlation between the forecast level of IPS intensity several days in the future and the proton density at Earth or the interplanetary magnetic field data when that day arrives. An even higher positive correlation to date has been found between the forecast IPS scintillation level and the

Earth geomagnetic Ap index. We expect the co-rotating component of the solar wind to become more dominant as solar activity declines, and we expect our ability to forecast changes at Earth to increase with declining solar activity.

III.E. Recent Publications

The publications which have benefitted from this grant or form the basis of research from it follow:

<u>Research Articles</u>

1. Jackson, B. V. and Y. Leblanc, "Type III Electron Beamwidth from Solar Flare Longitudinal Distributions," in *Plasma Phenomena in Solar Physics* M.A. Dubois, D. Gresillon and F. Bely Dubou, eds., L'Edition Du Physique, L'Ecole Polytechnique, 91128 Palaiseau Cedex, France, 209 (1989) (pg. 209 - 217).
2. Leblanc, Y. and B. Jackson, "Type III Bursts Traced from the Solar Surface to 1AU," in IAU Symposium 142, *Basic Plasma Processes on the Sun*, E.R. Priest and V. Krishan, eds., 509 (1989) (pg. 509 - 512).
3. Hick, P., B.V. Jackson and R. Schwenn, "Synoptic Maps for the Heliospheric Thomson Scattering Brightness as Observed by the Helios Photometers", *Astron. Astrophys.*, 285 (1990) (pg. 1 - 9).
4. Jackson, B.V. and J.L. Steinberg, "Broad-Band Images of AKR from ISEE-3", in the proceedings of the Low Frequency Astrophysics from Space Workshop in Crystal City, Virginia January 8 and 9, 1990, in *Lecture Notes in Physics*, **362**, Namir E. Kassim and Kurt W. Weiler eds., 102, (1990) (pg. 102 - 105).
5. Webb, D.F. and B. Jackson, "The Identification and Characteristics of Solar Mass Ejections Observed in the Heliosphere by the Helios-2 Photometers," *J. Geophys. Res.*, **95**, 20641 (1990) (pg. 20,641 - 20,661).
6. Jackson, B., R. Gold and R. Altrock, "The Solar Mass Ejection Imager", *Adv. in Space Res.*, **11**, 337 (1991) (pg. 377 - 381).
7. Hick, P., B.V. Jackson and R. Schwenn, "Synoptic Maps Constructed from Brightness Observations of Thomson Scattering by Heliospheric Electrons", *Adv. in Space Res.*, **11**, 61 (1991) (pg. 61 - 64).
8. Jackson, B.V., "Helios Spacecraft Photometer Observations of Elongated Corotating Structures in the Interplanetary Medium," *J. Geophys. Res.*, **96**, 11,307 (1991) (pg. 11,307 - 11,318).
9. Jackson, B.V. and Y. Leblanc, "Electron Groups Traced From the Sun to 1 AU", *Solar Phys.*, **136**, (1991) (pg. 361 - 377). +
10. Jackson, B.V. D.F. Webb, R.C. Altrock and R. Gold, "Considerations of a Solar Mass Ejection Imager in Low-Earth Orbit", in *Eruptive Solar Flares - Lecture Notes in Physics*, **399**, the proceedings of IAU Colloquium 133 held in Iguazu, Argentina 2-6 August, 1991, Z. Švestka, B.V. Jackson and M.E. Machado, eds. Springer-Verlag, Heidelberg, (1992) (pg. 322 - 328).

11. Jackson, B.V., "Remote Sensing Observations of Mass Ejections and Shocks in Interplanetary Space", in *Eruptive Solar Flares - Lecture Notes in Physics*, **399**, the proceedings of IAU Colloquium 133 held in Iguazu, Argentina 2-6 August, 1991, Z. Švestka, B.V. Jackson and M.E. Machado, eds. Springer-Verlag, Heidelberg, (1992) (pg. 248 - 257). +

12. Jackson, B.V., "Comparison of Helios Photometer and Interplanetary Scintillation Observations", in Proceedings of the First SOLTIP Symposium held in Liblice, Czechoslovakia 30 September - 5 October, S. Fischer and M. Vandas, eds. Astronomical Institute of the Czechoslovak Academy of Sciences, Prague, (1991) (pg. 153 - 164). +

13. Hick, P.L., Jackson, B.V. and R. Schwenn, "Synoptic Maps of Thomson Scattering Brightness from 1974 - 1985 as Observed by the Helios Photometers", in *Solar Wind Seven*, E. Marsch and R. Schwenn, eds., Pergamon, Oxford, (1992) (pg. 187 - 190). +

14. Webb, D.F. and B.V. Jackson, "Characteristics of CMEs Observed in the Heliosphere Using the Helios Photometer Data", in *Solar Wind Seven*, E. Marsch and R. Schwenn, eds., Pergamon, Oxford, (1992) (pg. 681 - 684). +

15. Jackson, B.V., "Solar Generated Disturbances in the Heliosphere", in *Solar Wind Seven*, E. Marsch and R. Schwenn, eds., Pergamon, Oxford, (1992) (pg. 623 - 634). +

16. Crooker, N.U., G.L. Siscoe, S. Shodhan, D.F. Webb, J.T. Gosling and E.J. Smith, "Multiple Heliospheric Current Sheets and Coronal Streamer Belt Dynamics", *J. Geophys. Res.* **98**, (1992) (pg. 9371 - 9386).

17. "Eruptive Solar Flares", *Lecture Notes in Physics*, **399**, the proceedings of IAU Colloquium 133 held in Iguazu, Argentina 2-6 August, 1991, Z. Švestka, B.V. Jackson and M.E. Machado, eds. Springer-Verlag, Heidelberg (1992) (pg. 1 - 409).

18. Jackson, B.V, "A model for coronal streamer observations using the SOHO coronagraph instrumentation", in *Proceedings of the SOHO Workshop on Coronal Streamers, Coronal Loops and Coronal and Solar Wind Composition* in Annapolis, Maryland 25-28 August 1992 **ESA SP-348**, 97 (1992) (pg. 97 - 100). +

19. Jackson, B.V, P. Hick and D.F. Webb, "Co-Rotating structures of the inner heliosphere from studies of Helios photometer and in-situ data", *Adv. in Space Res.* **13**, (1993) (pg. 43 - 47). +

20. Webb, D.F., B.V. Jackson, P. Hick, R. Schwenn and V. Bothmer and D. Reames, "Comparison of CMEs, magnetic clouds, and bidirectionally streaming particle events in the heliosphere using Helios data", *Adv. in Space Res.* **13**, (1993) (pg. 71 - 75). +

21. Jackson, B.V. and R.A. Howard, "CME Mass Distribution Derived from Solwind Coronagraph Observations", *Solar Phys.*, **148**, (1993) (pg. 349 - 361). +

Work In Progress

1. Hick, P., and B. Jackson, "Solar wind mass and momentum flux variations at 0.3 AU", submitted to *Adv. in Space Res.* (in press, 1993) (4 pages). +

2. Webb, D.F., and B.V. Jackson, "Characteristics of CMEs Observed in the Heliosphere Using Helios Photometer and In-situ Data", to the Solar Terrestrial Predictions Workshop 4 in Ottawa, Canada 18 - 22 May, A. Huruska *et al.* (eds.), NOAA, Boulder (in press, 1993) (6 pages). +

3. Jackson, B.V., A. Buffington, P.L. Hick, S.W. Kahler and D.F. Webb, "A spaceborne near-Earth asteroid detection system", *Astronomy and Astrophys.* (in press, 1993) (13 pages).

4. Jackson, B.V. and H.R. Froehling, "Three-Dimensional Reconstruction of Coronal Mass Ejections", submitted to *Astron. Astrophys.*, (1993) (15 pages). +

5. Hick, P., Jackson, B.V., Rappoport, S., Woan, G., Slater, G., Strong, K., and Uchita, Y., 1993, "Synoptic Comparison of IPS and YOHKOH Soft X-ray Observations", to be submitted to *Geophys. Res. Lett.* (1993) (4 pages). +

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Abstracts

1. Hick, P., B.V. Jackson and R. Schwenn, "On Representing the Large-scale Structure of the Inner Heliosphere in Synoptic Maps", SPD/AAS June meeting, 1990, *BAAS*, **22**, 810 (1990).

2. Jackson, B., R. Gold and R. Altrock, "The Solar Mass Ejection Imager", XXVIII COSPAR meeting The Hague, The Netherlands 25 June - 6 July (1990).

3. Hick, P., B.V. Jackson and R. Schwenn, "Synoptic Maps Constructed from Brightness Observations of Thomson Scattering by Heliospheric Electrons", XXVIII COSPAR meeting The Hague, The Netherlands 25 June - 6 July (1990).

4. Gold, R., B.V. Jackson and R. Altrock, "The Solar Mass Ejection Imager", AGU fall meeting, 1990, *EOS*, **71**, 1516, (1990).

5. Jackson, B.V., "Broad-Band Images of AKR From ISEE-3", AGU fall meeting, 1990, *EOS*, **71**, 1524, (1990).

6. Jackson, B.V., "Magnetospheric Event Analysis from AKR Observed from ISEE-3", AGU spring meeting, 1991, *EOS*, **72**, 242, (1991).

7. Jackson, B.V. D.F. Webb, R.C. Altrock and R. Gold, "The Solar Mass Ejection Imager", presented at the IAU General Assembly held in Buenos Aires, Argentina 29-30 August (1991).

8. Jackson, B.V. and R. Altrock, "The Solar Mass Ejection Imager", presented at IAU Colloquium 133 on Eruptive Solar Flares held in Iguazu, Argentina 2-6 August (1991).

9. Jackson, B.V. "Remote Sensing Observations of Mass Ejections and Shocks in Interplanetary Space", presented at IAU Colloquium 133 on Eruptive Solar Flares held in Iguazu, Argentina 2-6 August (1991).

10. Jackson, B.V., "The Dynamics of Mass Ejections in the Heliosphere Observed Using Helios Photometer Data", presented at Solar Wind 7 held in Goslar, Germany 16-21 September (1991).

11. Hick, P.L., Jackson, B.V. and R. Schwenn, " Synoptic Maps of Thomson Scattering Brightness from 1974 - 1985 as Observed by the Helios Photometers", presented at Solar Wind 7 held in Goslar, Germany 16-21 September (1991).

12. Webb, D.F. and B.V. Jackson, "The Characteristics of CMEs Observed in the Heliosphere and in the Vicinity of the Earth Using the Helios Photometer Data", presented at Solar Wind 7 held in Goslar, Germany 16-21 September (1991).

13. Jackson, B.V., "Solar Generated Disturbances in the Heliosphere", presented at Solar Wind 7 held in Goslar, Germany 16-21 September (1991).

14. Webb, D.F. and N.U. Crooker, " Heliospheric Evolution of the Coronal Streamer Belt", presented at Solar Wind 7 held in Goslar, Germany 16-21 September (1991).

15. Jackson, B.V., "Comparison of Helios Photometer and Interplanetary Scintillation Observations", presented at the first SOLTIP Symposium held in Liblice, Czechoslovakia 30 September - 5 October (1991).

16. Webb, D.F., and B.V. Jackson, "Characteristics of CMEs Observed in the Heliosphere Using Helios Photometer and In-situ Data", to the Solar Terrestrial Predictions Workshop IV meeting in Ottawa, Canada 18 - 22 May (1992).

17. Webb, D.F., B.V. Jackson and D.V. Reames, "Study of CMEs Observed in the Heliosphere Using Helios Photometer, Magnetic Field and Plasma Data", to the Solar Physics Division Meeting of the AAS held in Columbus, Ohio 7 - 11 June (1992).

18. Webb, D.F., D.V. Reames and B.V. Jackson, "Study of the Structure of CMEs Observed in the Heliosphere Using Helios Photometer and Bidirectionally Streaming Proton Data", to the STEP Workshop in Laurel, Maryland 24 - 28 August (1992).

19. Jackson, B.V, P. Hick and D.F. Webb, "Co-Rotating Structures of the Inner Heliosphere from Studies of Helios Photometer and In-situ Data", XXIX COSPAR meeting Washington, D.C. 28 August - 5 September (1992).

20. Webb, D.F., B.V. Jackson, P. Hick, R. Schwenn and V. Bothmer, "Comparison of CMEs, Magnetic Clouds, and Bidirectionally Streaming Particle Events in the Heliosphere Using Helios Photometer and In-situ Data", XXIX COSPAR meeting Washington, D.C. 28 August - 5 September (1992).

21. Hick, P., and B. Jackson, "Solar Wind Mass and Momentum Flux Variations at 0.3 AU", XXIX COSPAR meeting Washington, D.C. 28 August - 5 September (1992).

22. B. Jackson, P. Hick, and D. Webb, "Co-rotating Structures in the Inner Heliosphere From Helios Photometer and In-situ Data", AGU Fall meeting, 1992, *EOS*, **73**, 435, (1992).

23. Webb, D., B. Jackson, P. Hick, R. Schwenn, V. Bothmer and D. Reames, "CMEs in the Heliosphere - Helios Photometer and In-situ Data", AGU Fall meeting, 1992, *EOS*, **73**, 435, (1992).

24. Hick, P., and B.V. Jackson, "Solar Wind Mass and Momentum Flux as Derived from IPS and Helios Thomson Scattering Observations", AGU Fall meeting, 1992, *EOS*, **73**, 448, (1992).

25. K.A. Winfield, S.A. Rappoport, J.A. Nelson, J.P. Lang, L.A. Lones, J.A. Jones, B.V. Jackson, P.L. Hick and T.E. Davidson, "Display Techniques for Use in Interplanetary Scintillation (IPS) Analysis and Space Environment Forecasting", AAS January meeting, 1993, *BAAS*, **24**, 1254 (1992).

26. A. Buffington and B.V. Jackson, "Solar Mass Ejection Imager: A Precision Photometer for Time-series Measurements of Stars Solar System Objects", AAS January meeting, 1993, *BAAS*, **24**, 1283 (1992).

27. Shodhan-Shah, S. N.U. Crooker, W.J. Hughes, D.F. Webb, B.V. Jackson and G.L. Sisco, "Streamer Belt Variability and Heliospheric Current Sheet Stability Near Solar Maximum", AGU spring meeting, 1992, *EOS*, **74**, 238 (1993).

28. Jackson, B.V., A. Buffington, P.L. Hick and D.F. Webb, "A spaceborne near-Earth asteroid detection system", AAS June meeting, 1993, *BAAS*, **25**, 815 (1993).

29. Rappoport, S.A., B.V. Jackson, P.L. Hick, T.E. Davidson and K.A. Winfield, "Synoptic Interplanetary Scintillation (IPS) Maps For Use in Heliospheric Data Analysis and Space Environment Forecasting", AAS/SPD July meeting, 1993, *BAAS*, **25**, 1211 (1993).

30. Hick, P.L., B.V. Jackson and D.F. Webb, "Observations of Solar Wind 'Halo' Electrons", AAS/SPD July meeting, 1993, *BAAS*, **25**, 1210 (1993).

31. Jackson, B.V., A. Buffington, S.W. Kahler, D.F. Webb, R. Altrock and R. Gold, " The Solar Mass Ejection Imager", AAS/SPD July meeting, 1993, *BAAS*, **25**, 1191 (1993).

32. Jackson, B.V., "Three Dimensional Reconstruction of Coronal Mass Ejections", AAS/SPD July meeting, 1993, *BAAS*, **25**, 1211 (1993).

33. Jackson, B.V., "The Three-dimensional Reconstruction of Two Coronal Mass Ejections", AGU fall meeting, 1993, *EOS*, **74**, 484, (1993).

34. Hick, P. and B.V. Jackson, "Synoptic Comparison of IPS and YOHKOH Soft X-ray Observations", AGU fall meeting, 1993, *EOS*, **74**, 496, (1993).

35. Webb, D.F., B.V. Jackson, P Hick, "Geomagnetic Storms and Heliospheric CMEs as Viewed From HELIOS", AGU fall meeting, 1993, *EOS*, **74**, 486, (1993).

36. Altrock, R.C., P. Hick, G. Slater, B.V. Jackson, T.W. Henry, "Solar Coronal Structure: A Comparison of NSO/SP Ground-Based Coronal Emission Line Intensities and Temperatures with Yohkoh SXT and WCO Magnetic Field Line Data", AGU fall meeting, 1993, *EOS*, **74**, 495, (1993).

III.F. UCSD Personnel Supported by this Contract

1. B. Jackson – Associate Research Physicist
2. P. Hick – Assistant Research Physicist
3. T. Davidson – student
4. J. Jones – student
5. J. Lang – student
6. J. Nelson – student
7. S. Rappoport – student
8. K. Winfield – student
9. S. Pettijohn – secretary

IV. Future Projects

IV.A. HELIOS Photometer Remote Sensing – CMEs

We now have a list of approximately 400 events observed by the HELIOS photometers from 1974 through 1985, and we have determined whether each event is either a CME or a CRS. All 160 certain CMEs have had speeds determined for them and a quality of this measurement is given for each. We are well on our way to determine the masses for each CME observed by HELIOS 1 and 2. Following a study of Solwind coronagraph CME masses (Jackson and Howard, 1993), there should be enough events present in HELIOS CME sample to determine if the number of events versus mass follow an exponential curve, and to what limits these masses agree with the values derived from coronagraph observations. The CME masses observed by HELIOS are a more direct measure of the masses present in the solar wind since the measurements are obtained beyond the region of primary solar wind (and CME) acceleration. The Jackson and Howard (1993) coronagraph CME mass determination shows that perhaps as much as 16% of the solar wind mass at solar maximum is comprised of CME mass. We wish to compare the HELIOS determined masses with the coronagraph results. Our preliminary analysis using the 60 CME heliospheric masses currently determined from the HELIOS spacecraft indicate that the mass associated with heliospheric CMEs may be even somewhat larger than 16% at solar maximum.

We would like to determine the solar surface origins of mass ejections by imaging individual events and comparing those from 1979 to 1985 with coronal mass ejections observed by SOLWIND and the SMM coronagraphs. In addition we would like to compare the HELIOS mass ejections with other forms of solar activity such as disappearing filaments and solar flares. One comparison study of these data deals with the extent of mass ejections and whether it is possible to determine the magnitude of the southward-directed magnetic field component when a mass ejection arrives at Earth using pre-existing magnetic fields. We will attempt to extrapolate models of pre-existing solar surface magnetic fields to the HELIOS spacecraft location and compare them with HELIOS *in situ* magnetic field observations.

IV.B. HELIOS Photometer Remote Sensing – CRSs

Also, still to be studied are the solar surface manifestations of co-rotating structures (CRSs) and the available heliospheric observations which can be compared with them. We can do this by comparing the HELIOS synoptic map data with other synoptic maps or more directly, feature by feature. Each of the 56 CRSs in the newest sample from HELIOS 1 and 2 has been modeled as in Jackson (1991a) to determine the solar latitude, longitude and material speed of each. In addition, each has been modeled to determine if it is decreasing or increasing in density relative to the ambient with height above the Sun. The majority of the features in this new sample decrease in density relative to the ambient with height above the Sun, and thus were probably most dense near the solar surface and could have been observed as coronal streamers (Jackson, 1991a). However, a few of the features increase in density with height above the solar surface. We wish to ascertain the conditions surrounding each class of feature in order to determine what interplanetary characteristics they have in common. The preliminary Jackson *et al.* (1993) study shows that 40% of these CRSs are associated with sector boundaries *in situ*. When projected back to the solar surface 40% of the CRSs also show a one-to-one association with the heliospheric neutral line determined by solar magnetic field data.

IV.C. HELIOS Photometer Observations Compared with *In Situ* Measurements

The HELIOS photometer data allow an approximate three-dimensional extent determination for any observed CME or CRS. Many of the structures (~90%) also engulf the HELIOS spacecraft as they pass it. Because we can unambiguously place the HELIOS spacecraft at a given location within the CME for some events, these observations can be used to test the validity of the *in situ* CME and co-rotating structure proxies that have been determined by others. These *in situ* observations can also be related to the CMEs as a whole in an attempt to trace the *in situ* manifestation of the event beyond the column convected past the spacecraft or to its origin at the Sun.

Specifically, we are interested in comparing the HELIOS mass ejections with other related interplanetary events such as magnetic clouds, bi-directional streaming events and shocks. Important in this study will be collaborations with others (*e.g.*, Don Reames of Goddard, Maryland, and Jack Gosling of Los Alamos) who have had experience working with these data sets in the past. We access these data for individual events and have produced the software required to view it (Hick *et al.*, 1993a). We have begun to use the HELIOS photometers to determine the approximate spatial extents of the best-observed CMEs and CRSs showing evidence of associated counterstreaming electrons. We wish to compare these observations with the other *in situ* measurements in order to locate the observations at the spacecraft with their position within the structure as a whole.

Other studies with these *in situ* data are currently underway at UCSD, at Phillips Laboratory in Boston (Webb *et al.*, 1993c) and at the Max Planck Institute, in Lindau Germany. These studies propose to search the HELIOS *in situ* data base for counter-streaming electron heat flux events especially at times of CME passage. In the Webb *et al.* (1993c) study, CMEs which pass both the HELIOS spacecraft and Earth are studied (see Jackson, 1985a). We expect to compare the brightnesses observed by HELIOS as CMEs to these electron flux data for each event. The optical disk data access and display programs to enable these comparisons have been produced over the last several years by students at UCSD from a two-week sample of data available from a preliminary version of the Lindau optical disks. Thus, we are ready for these analyses as the data become available.

IV.D. Three-Dimensional Density Reconstruction

The UCSD CAT analysis of CMEs is now available to determine the detailed three-dimensional structure of two events – that of 7 May 1979 and of 24 May 1979. While the basic analysis technique was available nearly five years ago, the three-dimensional visualization techniques needed for an accurate interpretation of the results on these CMEs have only recently become available to us at UCSD. These visualization techniques have allowed an expedient check of the CAT software so that it can be modified to operate precisely. After certifying that the software operated correctly on test data, we have used digitized CME data and deconvolved it. A description of the technique is currently under review at *Astron. Astrophys.* (Jackson and Froehling, 1993). Within limits, the technique allows the three-dimensional deconvolution of a CME and measurement of its expansion from the coronagraph (in this case SOLWIND) to the HELIOS spacecraft view. In the next year we would like to include more tests of these analyses and some smoothing of the data from both events prior to publication of the results. We have two digitized images of the 24 May 1979 CME from the SOLWIND coronagraph, and we intend to use both of these to perform the CAT analysis to check the consistency of the results. Yet one more CME exists for which we have digitized data from the SOLWIND coronagraph – on May 8, 1980. We would like to begin attempts to deconvolve this CME.

IV.E. Synoptic Heliospheric Observations

Synoptic Maps made of YOHKOH X-ray data for the first 11 solar rotations in comparison with the IPS synoptic maps for the same rotations show an interesting phenomena. Bright active regions observed in YOHKOH data are often observed as enhancements in interplanetary scintillation level. Often even the detailed shapes of the active regions can be seen as enhanced scintillation level in the solar wind. Neither the heliospheric current sheet or coronal holes appear as regions of enhanced scintillation (Hick and Jackson, 1993b). Hick *et al.* (1993b) ready a preliminary paper about this analysis. At this time it isn't clear what the final significance of this comparison shows. Hewish and Bravo (1986) have long maintained that coronal holes were the primary solar origin of heliospheric disturbances observed in IPS. For synoptic (corotating) IPS enhancements this is clearly not the case. The current sheet also does not appear as an enhanced region in IPS even though this might be expected from solar coronal density enhancements observed by the Mauna

Loa white light coronagraph. Active regions are generally thought of as closed magnetic regions around which solar wind flows and does not escape. If active regions appear as enhancements in IPS level in the solar wind and these enhancements are related to bulk density (as is believed at both Cambridge, England and UCSD), then these observations imply that dense solar wind escapes upward from active regions.

As additional YOHKOH data become available we are ready to use them in our comparison. The YOHKOH SXT (Soft X-ray Telescope) data work extremely well to define coronal hole locations, but are limited to the times YOHKOH has been in operation (since August 30, 1991). These times do not include periods when HELIOS photometer data was present. Fortunately a ready set of excellent data exists nearly as good as YOHKOH data to define coronal holes and active regions on the Sun - namely the Sacramento Peak Fe XIV (green line) data. These data, readily available from Dr. R.C. Altrock at Sacramento Peak Observatory have been used and compared with the 40 available IPS synoptic rotations to confirm the result that active regions are a predominant source of enhanced scintillation in the solar wind. Because these data exist since 1974, we intend to use them to compare with the HELIOS photometer synoptic maps (which view Thomson scattering from interplanetary electrons more directly than the IPS) to confirm that active regions rather than the heliospheric current sheet are the solar origins of dense solar wind material.

IV.F. Sacramento Peak Observatory Synoptic Maps

Synoptic maps of Sacramento Peak green-line coronagraph data compare almost identically with low-resolution synoptic maps of YOHKOH soft x-ray data (Altrock, *et al.*, 1993). While this comparison has been presumed in the past, the near one-to-one comparison is a welcome confirmation of the analysis techniques used at Sacramento Peak over the years. In mapping the 1992 Sacramento Peak coronagraph data and in comparing them with Fe X (red line) coronagraph data also from Sacramento Peak, one of us (P.L. Hick) discovered that the maps which measure the Fe XIV/Fe X ratio (or temperature) generally show a remarkable correspondence of high coronal temperature with the heliospheric neutral line. Good coronal temperatures can form the basis for realistic steady-state solar wind models. In addition, the heliospheric current sheet is thought to be the general solar location of the onset of coronal mass ejections (Webb *et al.*, 1993b; Hundhausen, 1993). Thus, with R.C. Altrock, D.F. Webb, J.T. Hoeksema and X.P. Zhao, our UCSD group has begun to sort out both the temporal and height correspondence of high temperature coronal regions and CME locations derived from the Sacramento Peak and SMM observations. We speculate that these regions of high temperature may have something to do with the formation of CMEs along the neutral line, and are interested in looking at this in detail.

With the YOHKOH SXT group, we are trying to confirm the locations of these large regions of high temperature and extend the ground-based temperature data to individual structures. If the high-temperature regions trace the heliospheric neutral line, the simplest scenario for this is that the current present at the location of the neutral line is responsible for heating the corona on a global scale along the neutral line. Sacramento Peak data are obtained at a height of 1.15 $R_\odot$, and the high temperature regions and the heliospheric neutral line should be even more closely correlated at higher heights. We hope to obtain several months of Sacramento Peak data at double the normal height to help confirm this. We also propose to use data obtained at the May 1994 annular eclipse at Sacramento Peak Observatory in order to trace the regions of higher temperature at the solar limb at the time of the eclipse to as high as possible above the solar surface.

V. Conclusions and Executive Summary

Much work has been accomplished from the comparison of HELIOS photometer observations with coronagraph observations and other data. We have begun new studies by using the whole data set more effectively. Our data base provides a uniform and sensitive observational foundation for long-term global studies. The wealth of data provides a statistical base to study the effect of each event and its comparison to other known manifestations of the event. One further objective of the study with D. Webb at the Geophysics Lab is to continue and extend our work on mass ejections and co-rotating structures including their comparison with the bi-directional electrons supposed to be one of the best *in situ* manifestations of solar wind CMEs. To do this we have made the HELIOS *in situ* data available on optical disk.

The outcome of the Cambridge, England intensity IPS data comparison with other data sets leaves much to be desired as far as its use as a disturbance forecast technique is concerned. However, we wish to pursue these comparisons as solar activity declines in the hope that co-rotating features of the solar wind become more dominant, and will allow a more fruitful forecast of corotating structures at times of low solar activity. From the comparison of YOHKOH X-ray images and IPS data, we have discovered that active regions play a dominant role in the solar wind. With this understanding we are far better able to forecast conditions at Earth from processes in the quiet solar wind.

These studies are of vital interest to the Air Force. This interest goes beyond a wish to know the detail of how the processes work in order to form a more comprehensive understanding of them. In each case for this research we include in the study the possibility of being able to forecast the arrival of these structures at Earth or their occurrence prior to their manifestations in the near-Earth environment.

In summary, the object of this research is to study the problems associated with heliospheric plasma processes by viewing interplanetary structures. Prior to our development of new methods to determine heliospheric structures, studies of these features had to rely on large, incomplete extrapolations from *in situ* spacecraft measurements and near-solar surface observations. This research will greatly enhance the study of these heliospheric structures to the point that it will be possible to tell how they interact quantitatively with the Earth. The quantitative assessments include the basic heliospheric structure parameters which affect Earth such as shape, mass, speed and magnetic field. These parameters are not currently available by any other means.

References

1. Altrock, R.C., P. Hick, G. Slater, B.V. Jackson, T.W. Henry, 1993, *EOS*, **74**, 495.

2. Cliver, E.W., Dennis, B.R., Kiplinger, A.L., Kane, S.R., Neidig, D.F., Sheeley, N.R., Jr. and Koomen, M.J., 1986, *Astrophys. J.*, **305**, 920.

3. Coles, W.A. and Kaufman, J.J., 1978, *Radio Science*, **13**, 591.

4. Crooker, N.U., Siscoe, G.L., Shodhan, S., Webb, D.F., Gosling, J.T. and Smith, E.J., 1993, *J. Geophys. Res.*, **98**, 9371.

5. Farnik, F., van Beek, H.F. and Švestka, Z., 1986, *Solar Phys.*, **104**, 321.

6. Fisher, R. and Sime, D.G., 1984, *Astrophys. J.*, **285**, 354.

7. Frost, K.J. and Dennis, B.R., 1971, *Astrophys. J.*, **165**, 655.

8. Gosling, J.T., 1990, in C.T. Russell, E.R. Priest and L.C. Lee (eds.), *Physics of Magnetic Flux Ropes*, Geophys. Monogr. Ser., **58**, p. 343.

9. Gosling, J.T., Baker, D.N., Bame, S.J., Feldman, W.C., Zwickl, R.D., and Smith, E.J., 1987, *J. Geophys. Res.*, **92**, 8519.

10. Gosling, J.T., McComas, D.J., Phillips, J.L. and Bame, S.J., 1992, *J. Geophys. Res.*, **97**, 6531.

11. Harrison, R.A., Waggett, P.W., Bentley, R.D., Phillips, K.J.H., Bruner, M., Dryer, M. and Simnett, G.M., 1985, *Solar Phys.*, **97**, 387.

12. Hewish, A and Bravo, S., 1986, *Solar Phys.*, **106**, 185.

13. Hick, P. and Švestka, Z., 1987, *Solar Phys.*, **108**, 315.

14. Hick, P., and Jackson, B., 1993a, *Adv. Space Res.,* (in press).

15. Hick, P. and Jackson, B.V., 1993b, *EOS*, **74**, 496.

16. Hick, P., Švestka, Z., Smith, K.L. and Strong, K.T., 1987, *Solar Phys.*, **114**, 329.

17. Hick, P., Jackson, B.V. and Schwenn, R., 1990, *Astron. Astrophys.* **285**, 1.

18. Hick, P.L., Jackson, B.V. and Schwenn, R., 1992, in *Solar Wind Seven*, E. Marsch and R. Schwenn, eds., Pergamon, Oxford, 187.

19. Hick, P.L., B.V. Jackson and D.F. Webb, 1993a, *BAAS*, **25**, 1210.

20. Hick, P., Jackson, B.V., Rappoport, S., Woan, G., Slater, G., Strong, K., and Uchita, Y., 1993b, to be submitted to *Geophys. Res. Lett.*

21. Hoeksema, J.T., Wilcox, J.M. and Scherrer, P.H., 1983, *J. Geophys. Res.*, **88**, 9910.

22. Hudson, H.S., 1978, *Astrophys. J.*, **224**, 235.

23. Hundhausen, A.J., 1993, *J. Geophys. Res., 98*, 13177.

24. Jackson, B.V., 1985a, *Solar Phys.*, **95**, 363.

25. Jackson, B.V., 1985b, *Solar Phys.*, **100**, 563.

26. Jackson, B.V., 1989, *Adv. Space Res.*, **9**, 69.

27. Jackson, B.V., 1991a, *J. Geophys. Res.*, **96**, 11,307.

28. Jackson, B.V., 1991b, presented at Solar Wind 7 held in Goslar, Germany 16-21 September 1991.

29. Jackson, B.V., 1991c, in Proceedings of the First SOLTIP Symposium held in Liblice, Czechoslovakia 30 September - 5 October, S. Fischer and M. Vandas, eds. Astronomical Institute of the Czechoslovak Academy of Sciences, Prague, 153.

30. Jackson, B.V., 1993, *EOS*, **74**, 484.

31. Jackson, B.V. and Howard, R.A., 1993, *Solar Phys.* **148**, 349.

32. Jackson, B.V. and Froehling, H.R., 1993, submitted to *Astron. Astrophys.*

33. Jackson, B.V., Rompolt, B. and Švestka, Z., 1988, *Solar Phys.*, **115**, 327.

34. Jackson, B.V., Hick, P.L. and Webb, D.F., 1993, *Adv. in Space Res.*, **13**, 43.

35. Kahler, S.W., 1977, *Astrophys. J.*, **214**, 891.

36. Kahler, S.W., Hildner, E. and van Hollebeke, M.A.I., 1978, *Solar Phys.*, **57**, 429.

37. Leinert, C., Link, H. and Salm, N., 1981, *J. Space Sci. Instr.*, **5**, 257.

38. MacQueen, R.M., 1993, *Solar Phys.*, **145**, 169.

39. Montgomery, M.D, Asbridge, J.R., Bame, S.J. and Feldman, W.C., 1974, *J. Geophys. Res.*, **79**, 3103.

40. Pilipp, W.G., Miggenrieder, H., Montgomery, M.D., Mühlhäuser, K.H., Rosenbauer, H., Schwenn, R. and Neubauer, F.M., 1987, *J. Geophys. Res.* **92**, 1093.

41. Richter, I., Leinert, C. and Planck, B., 1982, *Astron. Astrophys.*, **110**, 115.

42. Rickett B.J., and Coles, W.A., *1991*, *J. Geophys. Res.*, **96**, 1717.

43. Rust, D.M., Hildner, E. and 11 co-authors, 1980, Introduction in *Solar Flares, A Monograph from Skylab Solar Workshop II* (ed. P.A. Sturrock), Colorado Associated Press.

44. Schwenn, R., 1986, *Space Sci. Revs.*, **44**, 139.

45. Schwenn, R., Rosenbauer, H., Miggenrieder, H., 1975, *Raumfahrtforschung*, **19**, 226.

46. Sheeley, N.R., Jr., Howard, R.A. and Michels, D.J., 1983, *Astrophys. J.*, **272**, 349.

47. Sheeley, N.R., Jr., Howard, R.A. Koomen, M.J., Michels, D.J., Schwenn, R., Mühlhäuser, K.H., 1985, *J. Geophys. Res.*, **90**, 163.

48. Shodhan-Shah, S., Crooker, N.U., Hughes, W.J., Webb, D.F., Jackson, B.V. and Siscoe, G.L., 1993, *EOS*, **74**, 238.

49. Švestka, Z., 1981, in E.R. Priest (ed), *Flare Magnetohydrodynamics* (Gordon and Breach), p. 47.

50. Švestka, Z., 1984, *Solar Phys.*, **94**, 171.

51. Švestka, Z, 1986, in D.F. Neidig (ed.), *Proceedings of the NSO/SMM Symposium: The Lower Atmosphere of Solar Flares*, p. 332.

52. Švestka, Z. and 14 co-authors, 1982a, *Solar Phys.*, **75**, 305.

53. Švestka, Z., Dennis, B.R., Pick, M., Raoult, A., Rapley, C.G., Stewart, R.T. and Woodgate, B.E., 1982b, *Solar Phys.*, **80**, 143.

54. Švestka, Z.F., Jackson, B.V., Howard, R.A. and Sheeley, N.R., Jr., 1989, *Solar Phys. 122*, 131.

55. Tsuneta, S. and 9 co-authors, 1984, *Astrophys. J.*, **280**, 887.

56. Webb, D.E. and Kundu, M., 1978, *Solar Phys.*, **57**, 155.

57. Webb, D.F. and Jackson, B.V., 1988, *Proc. of the 6th Intl. Solar Wind Conference*, NCAR TN-306 Technical Proc., Boulder, 267.

58. Webb, D.F. and Jackson, B., 1990, *J. Geophys. Res.*, **95**, 20641.

59. Webb, D.F. and Crooker, N.U. 1991, presented at Solar Wind Seven held in Goslar, Germany 16-21 September 1991.

60. Webb, D.F. and Jackson, B.V., 1992, in *Solar Wind Seven*, E. Marsch and R. Schwenn, eds., Pergamon, Oxford, 681.

61. Webb, D.F. and Jackson, B.V., 1993, in press in the proceedings of the Solar Terrestrial Predictions Workshop meeting in Ottawa, Canada 18 - 22 May, 1993, A. Huruska *et al.* (eds.), NOAA, Boulder.

62. Webb, D.E., Cheng, C.C., Dulk, G.A., Edberg, S.J., Martin, S.F., McKenna-Lawlor, S. and McLean, D.J., 1980, in *Solar Flares, A Monograph from Skylab Solar Workshop II* (ed. P.A. Sturrock), Colorado Associated Press.

63. Webb, D.F., Jackson, B.V., Hick, P., Schwenn, R., Bothmer, V. and Reames, D., 1993a, *Adv. in Space Res.*, **13**, 71.

64. Webb, D.F., McIntosh, P.I. and Kahler, S.A., 1993b, *BAAS*, **25**, 1200.

65. Webb, D.F., B.V. Jackson, P Hick, 1993c, *EOS*, **74**, 486.

66. Winfield, K.A., Rappoport, S.A., Nelson, J.A., Lang, J.P., Lones, L.A., Jones, J.A., Jackson, B.V., Hick, P.L. and Davidson, T.E., 1993, *BAAS*, **24**, 1254.