# EVOLUTION AND TERMINATION OF THE 3–D SOLAR WIND

F. VERHEEST
*Sterrenkundig Observatorium, Universiteit Gent*
*Krijgslaan 281, B–9000 Gent, Belgium*

## 1. Introduction

The second session of the Joint Discussion 19 (Physics of the Sun and Heliosphere in the Era of Space Probes; Scientific Highlights of SOHO, ULYSSES and YOHKOH) was devoted to the Evolution and Termination of the 3–D Solar Wind. As was the case with the other two sessions, it consisted of three invited talks, three oral contributions, a number of posters and a general discussion.

## 2. Invited Talks

The full texts of the three invited talks are included in these "Highlights", so we can be rather brief about them.

First came the *Latitude manifestations of the solar wind* (R. von Steiger). Essential information comes from the Ulysses mission, which went over the solar poles and gave the first measurements of the solar wind properties out of the ecliptic plane. One of the puzzles is why we see in the different data, relating the solar wind properties to the solar surface features from which the solar wind is originating, a wider-opening, canopy-like structure, rather than a plain conical extension above the polar and higher latitude regions.

The following talk on *Composition of the solar wind, secondary ion generation and pick-up* (U. Mall) was mostly concerned with the pick-up of ions from interplanetary space, for which several mechanisms were presented. Some of these are also relevant for the pick-up of and assimilation into the solar wind of cometary material, belonging mainly to the water group.

Finally, in *Large-scale structure and termination of the heliosphere* (W. Macek) we were confronted with the expectations about whether the workhorse Voyager missions will last long enough to actually see the transition from heliospheric to interplanetary plasma. That there will be a termination heliospheric shock is not in doubt, because the solar wind plasma flowing supersonically away from the Sun must make a transition to the subsonic interplanetary flow. The precise location, however, is still quite uncertain, a lot of (computer) modelling notwithstanding.

## 3. Oral Contributions

Three contributions from among the submitted abstracts had been selected for oral presentation, as being the most promising for the audience as a whole.

The first dealt with *The three dimensional tomography of heliospheric features* (B. Jackson). A computer assisted tomography program optimizes a three-dimensional heliospheric model to fit the observational data. This program is used with interplanetary scintillation data from UCSD (USA), Nagoya (Japan), Cambridge (UK) and Ooty (India), and also with Helios photometer Thompson scattering data. The program iterates to a least-squares solution fit of observed data, using solar rotation and solar wind outward motion to provide perspective views of each point in space accessible to the observations. The optimized model is plotted as Carrington maps in velocity and density for the data sets, with resolutions commensurate with the original data. For the data sets with the greatest numbers of points, convolution is possible to the multiple heliospheric heights probed by the lines of sight, in order to explore the evolution of heliospheric features with solar distance.



*J. Andersen (ed.), Highlights of Astronomy, Volume 11B,* 873–876.

Second came the talk on *Study of interplanetary dust from Ulysses and SOHO observations* (I. Mann). The Ulysses spacecraft has for the first time performed *in situ* measurements in the out-of-ecliptic regions of the solar system. The dust experiment onboard Ulysses has detected a high-latitude flux of interplanetary dust particles. With the SOHO satellite, on the other hand, the LASCO coronagraph provides us with data of the brightness of the whitelight corona, which includes a component of light from scattering off interplanetary dust particles, the F-coronal brightness. Although Ulysses provides data about local dust fluxes from 1 AU outward and whitelight observations give the integrated line of sight brightness from 1 AU inward, some comparison of the different results is possible, leading to a discussion of the dynamics and orbital distribution in the dust cloud, as well as its size distribution.

Finally the *Effect of magnetic field in the 3-dimensional heliosphere* (S. Nozawa) studied via MHD computer simulation the toroidal magnetic field in the global three-dimensional outer heliosphere, due to the interaction between the solar wind and the interstellar medium. The interstellar plasma flow and the magnetic field direction are assumed to be parallel to the solar-equatorial plane. It is found that the toroidal component of the interplanetary magnetic field plays an important role in the outer heliosphere. On the other hand, in the heliosheath between the terminal shock and the heliopause, the magnetic pressure of the interplanetary toroidal field becomes comparable to the ram pressure of the solar wind plasma. The subsonic solar wind flow in the heliosheath is found to be collimated by the magnetic effect. Faraway from the terminal shock, this collimated flow changes direction tailwards under the influence of the interstellar medium flow. The magnetic pressure also contracts the scale of the terminal shock.

## 4. Poster Presentations

Regrettably, only few of the contributed posters dealt with the evolution and termination of the solar wind, and we included in this session also those posters dealing with other fundamental aspects of the heliosphere outside the Sun. The posters were briefly highlighted in the main oral session, each author getting about one minute to get the main point of investigation across, so that the audience could afterwards go and view the posters in more detail.

First in alphabetical order of authors present came *Coronal velocity determination using two-dimensional correlation techniques* (B. Jackson and P. Hick). With the availability of stable CCD images from the LASCO coronagraphs, successive coronagraph images differenced from a single base have been displayed in sequence, in order to view transient effects such as CMEs. In these video sequences, CMEs appear as the most obvious differences of outward-moving material over the east or west limb of the Sun. Also observed on the limb of the Sun are features which become more pronounced as time progresses, and they, too, appear to move outward from the Sun. These outward-moving features are from small structures which on previous coronagraph observations were too small or too poorly discerned to be visible. Samples of these differences using two-dimensional cross-correlation techniques show how well a small section of one coronagraph image corresponds to the same section on the other, and how much shift is required to align the sections of the image. This technique measures the outward motion. The latest results from this study include streamer areas and regions over the poles of the Sun.

In *On the possible influence of the solar magnetic field on the circumsolar dust complex* (A. Krivov, H. Kimura and I. Mann) a dynamical modelling is performed of the dust ring that presumably exists around the Sun near $4R_\odot$. The dust particles were assumed to be ballistic particle-cluster aggregates, acted upon by diverse forces such as solar gravity, direct solar radiation pressure, Poynting-Robertson force, sublimation, and especially the Lorentz force. The modelled grain charges resulted from taking sticking and penetration of solar wind particles into dust grains, secondary electron emission, photoelectron emission, and thermionic emission into account. For the solar magnetic field the Potential Field – Source Surface model was used, together with harmonic coefficients of the Wilcox Solar Observatory for 1976-1996. The modelling suggests that variations of solar magnetic field have little effect on the spatial distribution of absorbing (amorphous carbon) grains believed to cause the observed peak feature in the F-corona brightness. There is no support for a correlation between the solar activity phase and observability of the peak feature. However, magnetic variations may cause appreciable changes in the latitudinal distribution of transparent silicate aggregates, responsible for the continuum in the elongation dependence of the brightness.

Next came *Structural instability of discontinuous magnetohydrodynamic flows* (S. Markovskii). In recent years the interest in the structural instability of discontinuous flows has been rekindled due to new satellite observations of the solar atmosphere and the heliosphere. In MHD, a non-evolving discontinuity does not have a unique solution to the problem of how a small perturbation of it will change in time, hence such a discontinuity cannot exist as a stationary configuration. The nonlinear evolution of such discontinuities is a matter of debate. What resorts is that a non-evolutionary configuration can be represented as a set of more than one discontinuity, rendering it structurally unstable, disintegrating into evolutionary discontinuities or transforming itself into a more general non-steady flow. This principle is generalized to inhomogeneous and dissipative media, yielding new criteria for quasi-one-dimensional configurations, such as a reconnecting current sheet. This could explain features of discontinuous magnetohydrodynamic flows observed in numerical experiments.

*Observational constraints on the acceleration time of anomalous cosmic rays: a study of Pioneer 10 data* (K. Scherer, H. Fichtner and H. Fahr) goes back to one of the oldest missions. On the basis of cross-correlations of solar Lyman-$\alpha$ and cosmic ray data for the period from 1981–1987, recorded by instruments aboard Pioneer 10 during its interplanetary cruise, constraints are derived on the time required to accelerate pick-up ions to anomalous cosmic rays. The characteristic energization time of these suprathermal particles at the heliospheric shock gives rise to different phase shifts of the correlation functions of the anomalous and galactic cosmic ray data with the solar Lyman-$\alpha$ radiation, used as a proxy for long-term solar activity. A systematically greater time lag for the case of anomalous cosmic rays is interpreted as their acceleration time, which in turn allows an estimate of the efficiency of spatial diffusion of energetic particles perpendicular to the magnetic field just upstream of the heliospheric shock at low heliographic latitudes.

*Solar wind interaction with dusty cometary plasmas* (F. Verheest and P. Meuris) deals with the effect of charged dust grains on the pick-up processes of cometary ions by the solar wind. Dusty space plasmas contain charged dust grains which are much more massive than protons and carry high negative charges due to preferential capture of electrons. Fluctuations in dust charges (due to capture or liberation of additional electrons and protons) lead to momentum losses/gains and hence to wave damping/growth. On the other hand, the pickup of ions of cometary origin by the solar wind is partly due to relative streaming between cometary and solar wind ions, which excites low-frequency electromagnetic turbulence. When both processes are combined, existing instabilities can be enhanced, showing that charged dust facilitates the cometary ion pickup, or leads to new instabilities or damping. The scarce data available from recent cometary missions are used to evaluate the importance of these modifications, which are on the face of it very small.

The *3-D MHD structure of the outer heliosphere* (H. Washimi and T. Tanaka) under the interaction of the solar wind plasma and the interstellar medium was modelled using MHD simulations for average solar wind speed, density and interplanetary toroidal magnetic field at 1 AU. These are connected to values for the solar wind temperature, interstellar medium speed and density at the inner boundary of the transition from the outer heliosphere to the interstellar medium. The flow of the latter is assumed to be parallel to the solar-equatorial plane. In the simulation, the terminal shock with the Mach disk, heliopause and the outer shock are clearly determined, and it is found that the magnetic-pressure effect of the interplanetary toroidal field plays an important role in the outer heliosphere.

Lastly, the *Solar wind structure analyzed by tomography of interplanetary scintillation* (A. Yokobe *et al.*) deals with the global structure of the solar wind in the minimum phase of the solar cycle using interplanetary scintillation observation data. Since these data are biased by a line-of-sight integration through the three-dimensional structure of solar wind, a computer assisted tomography program has been produced to remove this bias. The relation between solar wind velocity and electron density fluctuations indicates that the latter are larger in a fast than in a slow wind. Data were then analyzed during Carrington rotations 1894–1896, during which Ulysses passed in its rapid latitude traversal from southern to northern hemisphere. This shows that high-speed regions are separated from an equatorial low-speed region by a sharp velocity gradient at heliographic latitudes of 15° to 20° in both hemispheres. This latitudinal variation agrees very well with Ulysses observations.

## 5. General Discussion

The general discussion started with the remark that the observational knowledge of the heliosphere is not only coming from the newer spacecraft, but that the older Voyager missions are still performing sterling work, as we will have to rely on those for the accurate determination of the heliopause and the various associated shocks and boundaries. It is to be hoped that both spacecraft will last that long, after performing already for more than twenty years! Given present-day knowledge and educated guesses, the optimists in the audience thought this would indeed happen, although just barely so.

The discussion then turned to aspects of charged dust in the heliosphere, of which very little is observationally known with any certainty, most of it being inferred in a sometimes very indirect way. In particular, there is need to devise suitable experiments which would be able to measure the charge on a dust grain in a more straightforward way. The present methods of impacting dust on foils and inferring something from the evaporating cloud leaves too many variables open to pin down the charges themselves.

Finally, it has become clear that we also would like to have more studies, both observational and computational, about the three-dimensional structure of the heliosphere. Present missions are revealing an intriguing solar wind and heliosphere, where some aspects could have been guessed at before, but others come rather as a surprise. All participants hoped that the Ulysses mission could be kept fully alive until the next solar pass occurring at solar maximum. This is vitally important to compare the behaviour of the Sun at solar minimum and maximum and its influence on the solar wind. It is also important for heliospheric physics, because Ulysses will in between have another interesting close encounter with Jupiter, on its swing-by.

## 6. Conclusions

As a final remark, I would like to remark that the participants in this Session gave a highly interesting and up-to-date picture of different aspects of the *Evolution and Termination of the 3-D Solar Wind*, based on very recent observations, both from the newer satellites Ulysses and SOHO, but also coming from the still admirably performing Voyager missions. In particular, it will fall to those veterans to give us the first *in situ* measurements of the heliopause and associated shocks delineating the transition of the heliosphere to the interplanetary medium. And of course, the newer satellites have covered the heliosphere for the first time in three dimensions. The discussion attested to a vigorous debate between the participants, involving not only the speakers but also the remainder of the audience.