## Conclusions

The conclusions are striking: although small discrepancies remain, there is generally excellent agreement between the results from observed frequencies and those from frequencies of standard solar models. On the other hand, the proposed non-standard models with low neutrino fluxes are generally inconsistent with the oscillation data. By allowing drastic departures from the standard assumptions it is still possible to construct models that agree with the observations for both neutrinos and the oscillations. Nonetheless, the helioseismic results strongly suggest that the resolution of the neutrino problem lies in the realm of particle physics rather than astrophysics. Future work (see insert) will hopefully resolve this major issue.

The most likely explanation involves departures of the properties of the neutrinos from those normally assumed. It has been suggested that the electron-neutrinos produced in the the solar core are transformed by the Mikheyev, Smirnov and Wolfenstein effect (MSW; see [9] for details) into neutrinos of other types (muon- and tau-) on the way to detectors. Such a transformation is possible if there is a finite mass difference between the three types of neutrinos, or if neutrinos have a magnetic moment. It is possible to choose parameters such that the capture rates predicted for standard solar models agree with the measurements.

The effects are too weak to be detectable over the scale of a laboratory on Earth. One way to study them lies in the analysis of solar neutrinos provided the conditions in the solar core, and hence neutrino emission, can be constrained by helioseismology.


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## One of 23 New Research Centres

The Theoretical Astrophysics Center (TAC) is one of 23 research centres set up in 1993 by a new foundation called Danmarks Grundforskningsfond (The Danish National Research Foundation). They were established in 1991 after an extensive and careful evaluation procedure, each with support for an initial five-year period, following a vote by the Danish parliament to grant additional funding for basic research. The centres cover a broad range of topics in the humanities and the natural sciences, and are in most cases associated with one or several existing university institutes.

Apart from TAC, the physical sciences are represented by several centres including the Aarhus Centre for Advanced Physics, based on the ASTRID storage ring which aims to study basic properties of matter and its interaction with radiation, and the Centre for Atomic Material Physics which will make experimental and theoretical investigations of the properties of solid materials, including the growth of atomic layers on surfaces.

TAC is located at the The Niels Bohr Institute for Astrophysics, Physics and Geophysics, Copenhagen, and at the Institute of Physics and Astronomy, Aarhus, with Professor Igor Novikov, Copenhagen, as Director. It aims to concentrate on studies of the origin of large-scale structures in the Universe, the formation and evolution of galaxies, and the structure and oscillations of the Sun and other stars. Although the emphasis will be on theoretical work, close contact will be maintained with related observational activities, both within Denmark and abroad. In particular, scientists at TAC take part in large international observational projects in several areas of astrophysics.

TAC is currently in the process of filling several long-term and post-doctoral positions, and establishing a suitable computing environment. It is expected that the Centre will fully operational this autumn. The goal is a centre of excellence in theoretical astrophysics, working closely with groups around the world, and hence providing a major boost to astrophysics research in Denmark.

# Ulysses is Proving its Worth

**Rudolf von Steiger from the Physikalisches Institut, Bern University, reports that a complete view of the heliosphere is emerging as the Ulysses spacecraft sweeps across the Sun's poles.**

Ulysses was launched in 1990 and has reached a heliospheric latitude of 60°S. It will continue to climb in latitude, reaching 80°S this September. There follows a fast passage from south to north, reaching 80°N in August 1995 (see Fig 1). Much of the new physics that is being discovered in this first visit to the third dimension of our solar system was reviewed last month at the 28th ESLAB Symposium (Friedrichshafen; 19-24 April 1994) that heralded the start of Ulysses's race across the Sun's south pole. A new view of the heliosphere as a three-dimensional, structured, dynamic entity is beginning to emerge, for which the well-known models of the ecliptic will serve as the boundary conditions of a more global view.

L. Fisk outlined the questions that need to be answered by Ulysses in order that the future judgement of the mission will be kind. They concern: the overall, three-dimensional structure of the solar wind; cosmic rays (both galactic and anomalous) propagating through the solar system; the properties of the interstellar medium entering the heliosphere, and of the so-called pick-up ions that result from its ionization; the source and the acceleration mechanism of the solar wind in the corona.

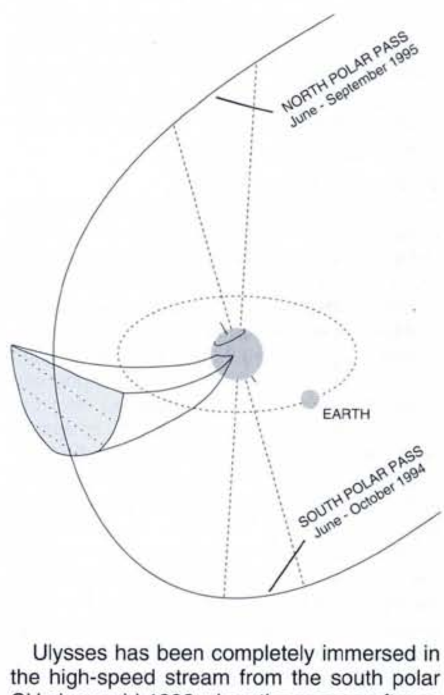


*Fig. 1 — Ulysses's trajectory as it sweeps across the Sun's poles. The spacecraft scans across a high-speed solar wind stream at increasing latitudes during each rotation of the Sun. This stream (shown issuing from the solar surface) is modelled as a co-rotating interaction zone bounded by shock waves.*

### Acceleration Mechanisms Confirmed

Owing to the declining solar activity, the polar coronal holes (CHs) have re-formed at high latitudes. The SWOOPS instrument with S. Bame and J. Phillips as the Principal Investigators (PIs) and the SWICS sensors (PIs: J. Geiss and G. Gloeckler) first detected the low-latitude extension of the south polar CH as a high-speed solar wind (SW) stream in mid-1992, when Ulysses was at 13°S. The stream subsequently reappeared every solar rotation (*i.e.,* about every 26 days), alternating with periods of low-speed SW that became shorter and shorter. The observation of these repeated transitions, which arise in periods of low solar activity, was fortuitous as they are ideal for comparing the low-speed, in-ecliptic SW with the high-speed streams from CHs.

Ulysses has been completely immersed in the high-speed stream from the south polar CH since mid-1993 when the spacecraft was at 36°S. At latitudes of this magnitude, the SW's density and pressure are found to be more uniform than those measured in the ecliptic plane by SWOOPS. However, substantial ($\approx$ 100 km/s) long-term speed variations still persist. Furthermore, SWOOPS finds at high latitudes a latitudinal gradient in the difference between the velocities of protons and alpha-particles which is larger (of the order of the Alfvén velocity) than near the ecliptic. SWICS observes that the velocities of He and heavy ions (C, O, Ne, Mg) are equal, to a high level of accuracy, and that the kinetic temperatures of all these ions are proportional to their masses. Both observations confirm the picture of Alfvén waves being important for the acceleration of the high-speed SW.

Outward-moving Alfvén waves of high amplitude are indeed observed directly by the magnetic field experiment (PI: A. Balogh), and with lower frequencies than ever before. So it is possible that the mechanisms responsible for accelerating high-speed SW have finally been pinned down. The magnetic field, which is curled up by the solar rotation into the so-called Parker spiral, is found to be less tightly wound at high latitudes than expected from the rate of solar rotation. The field lines are possibly rooted at higher latitudes on the solar surface than is currently expected, in which case they would rotate more slowly due to the differential rotation of the Sun and the heliosphere.

### Models for Shock Waves Substantiated

Each recurrence in 1992/93 of the high-speed stream was marked by a co-rotating interaction region (CIR) bounded by a pair of forward and reverse shock waves (Fig. 1). This structure arises from the penetration of a high-speed stream from the corona into the heliosphere. While the forward shocks disappear at the site of Ulysses as soon as the spacecraft's latitude exceeded the tilt angle of the current sheet separating the magnetic field polarities near the ecliptic, the reverse shocks continue to be seen up to latitudes that were about 10° higher. This is in excellent agreement with predictions of three-dimensional flow models for the co-rotation of the SW with the Sun that originates in a tilted dipole geometry back at the Sun, causing the forward shocks to propagate towards the equator while the reverse shocks propagate towards the pole.

### Global Modelling Needed

Systematic differences in the compositions of the low- and high-speed solar winds were detected by the SWICS instrument. A synopsis of the ≈ 15 recurrences of the high-speed stream is shown in Fig. 2, where the average profiles of the SW speed $v_\alpha$, the corona temperature $T_o$, and the Mg/O abundance ratio are plotted as functions of time since the onset of the stream ($T_o$ is obtained from the $O^{7+}/O^{6+}$ charge state ratio, which is frozen-in in the corona and thus acts as a thermometer). It is evident from the figure that $v_\alpha$ and $T_o$ are inversely-correlated, while $T_o$ and Mg/O are strongly correlated. $T_o$ is therefore a better indicator of the presence of a coronal hole SW than $v_\alpha$ since it avoids confusing the solar wind with mass ejections from the corona (which may also have high speeds, but are always distinguished by a high $T_o$).

Analyses of fractionation based on considering the first ionization potential (FIP) predict that elements such as Mg with small FIPs are enriched in the SW relative to elements such as O with large FIPs. The observation that the Mg/O ratio is significantly smaller in high-speed streams than in the low-speed SW implies that FIP fractionation is less in the former. Since the fractionation takes place in the chromosphere beneath the corona, heavy-ion abundances are tracers for processes occurring in this region. The figure thus connects three parameters set in vastly different domains, namely the SW (velocity), the corona (temperature), and the chromosphere (strength of the FIP fractionation). So a global approach taking into account processes from the photosphere up to interplanetary space is called for in modelling the solar wind.

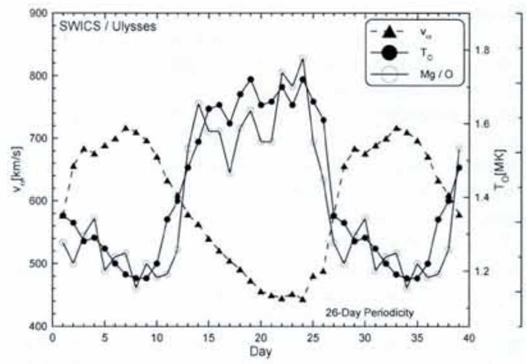


*Fig. 2 — A summary of solar-wind parameters during Ulysses's transition from the ecliptic to high latitudes. The figure superimposes data taken during 15 recurrences lasting 26 days of the high-speed stream coming from the coronal hole above the Sun's south pole. Note that the profiles of the average solar-wind velocity $v_\alpha$, the average coronal temperature $T_o$, and the average Mg/O abundance ratio are either correlated or inversely correlated. [From J. Geiss, G. Gloeckler & R. von Steiger, Proc. 28th ESLAB Symp.; Ed.: R.G. Marsden,* Space Sci. Rev. *(1994), to be published.]*

### Picked-up Ions are the Key

Ulysses's neutral-gas experiment (PI: E. Keppler) was the first experiment to detect directly the interstellar gas penetrating into the inner heliosphere (it also determined the arrival direction, speed, and temperature). This gas is the source of the ions produced by photoionization of, and charge exchange in, the interstellar medium and picked up by the solar wind. These pick-up ions ($H^+$, $He^+$, $N^+$, $O^+$, and $Ne^+$) are identified by the shape of their distribution function, which displays a sharp cut-off at twice the solar-wind velocity. Other sources of pick-up ions (Jupiter, comets, *etc.*) can be ruled out as major contributors, except for a very limited zone near these bodies.

Combined data sets from the SWICS and HISCALE (PI: L. Lanzerotti) instruments reveal that the pick-up ions are accelerated very effectively at interplanetary shocks, such as those bounding a CIR. The flux of accelerated pick-up $He^+$ exceeds that of solar wind $He^+$ by about 5-times after the passage of such a shock, as compared to only $10^{-3}$-times before the shock passed.

The conclusions are that pick-up ions are accelerated more efficiently than SW ions, and that interstellar pick-up ions dominate the intermediate-energy ion population in the outer heliosphere. Furthermore, it is known that anomalous cosmic rays (ACRs) have small abundances of C (C/O < 0.1 as compared to 0.7 in the SW), so the observation that C is missing from the pick-up ions means that the pick-up ions are probably responsible for ACRs. Current models for ACR generation are based on pick-up ions travelling outwards until they reach the heliospheric termination shock, where they are accelerated to high energies and propagate back as ACRs into the inner heliosphere.

### Lateral Cosmic-Ray Gradient

The study of the galactic cosmic rays (GCRs) is a principal objective of the Ulysses mission since theory predicts that, *via* drift and by diffusion, they should enter the heliosphere more easily at high latitudes than near the ecliptic. The major surprise is that the Ulysses cosmic-ray experiments (PI: J. Simpson) have not yet found any sign of a latitudinal gradient in the modulation of GCRs. Furthermore, solar rotation is still seen to modulate the GCRs, even in the unipolar region with a steady, high-speed solar wind stream. This modulation is possibly caused by the reverse shocks, discussed above, travelling poleward and to which Ulysses may still be magnetically connected. GCR modulation models are thus put to a severe test, but it is yet too early to discard the current theory for modulation.

### Dust is Interstellar in Origin

Finally, the Ulysses cosmic dust experiment (PI: E. Grün) continues to find dust particles at high latitudes. These populations are distinctly different from the zodiacal dust, having highly eccentric, randomly inclined, predominantly retrograde orbits. This, together with the absence of a radial or latitudinal gradient of the dust-particle flux, clearly indicates that most of these micron-sized dust grains come from interstellar regions.

The Sun will present itself in a minimum activity, dipolar configuration during Ulysses's polar passages. A completely different picture, that of the highly active Sun, may be obtained on a future orbit in 2000-2001. So it is hoped that the mission will not be discontinued after the passage across the north pole in 1995. Ulysses is in excellent shape and could be "launched" into a second orbit for what one may call a Ulysses Maximum Mission.

## M3 Studies for Four Missions

ESA's Space Science Advisory Committee recommended earlier this month that of the seven mission proposals short-listed for the next Medium-sized Mission (M3) for further study [see *EN* **24** (1993) 219], the following four proposals should move ahead to full Phase A feasibility studies: a follow-on to the cosmic background explorer COBE, the MARSNET network of meteorological and seismological stations on Mars, a fundamental test of the equivalence principle STEP, and the Moon-orbiting observatory MORO. It is anticipated that full specifications will be drawn up by September/October 1994 and that the final reports will be released about a year later. The outcome for the three remaining proposals is unclear. Some will be examined in the context of other platforms while others will be integrated into the Horizon 2000-plus Survey Committee's evaluations.