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#### Solar Wind Interaction with Venus, Mars and Comets

M.K. Wallis

To model and quantify the comet-like interactions with the atmosphere of Venus the extent and time-variability of the suprathermal exospheric coronas need to be established. An extensive suprathermal O corona hypothesized to arise via dissociative recombination of the dominant O<sub>2</sub><sup>+</sup> ion was confirmed by the Orbiter's UV spectrometer. Uncertainties remain, firstly because the O-corona's extension beyond the observed limit of 1500 km altitude depends on the poorly-known partition between dissociation channels, secondly because the O<sub>2</sub><sup>+</sup> ionosphere varies substantially with solar UV inputs, and thirdly because the ionosphere and therefore O-corona decrease strongly from dayside to nightside (Kliore *et al.*, Adv. Space Res. 5(11), 1985).

Copious data available from Pioneer Venus Orbiter has allowed detailed study of atmospheric modification at Venus (Luhmann, Space Sci. Rev. 44 p 241, 1987). Confirming suggestions from the early Venus missions (Wallis 1972), the bow-shock is displaced sunwards from the position given by MHD modelling: this has been put on a firm statistical basis (Alexander *et al.*, GRL 13, p 917, 1986) and a solar cycle dependence demonstrated. Whether there is some weakening of the shock due to atmospheric ions created upstream of it - as strongly evident in Halley's comet - is unclear. The sunwards displacement and increased divergence (flaring) of the shock limbs has been demonstrated by gasdynamic modelling (Krymskii & Breus, Kosm. Issled. 24, p 778, 1986) with the atmosphere treated as sources of mass within the flow.

On one side of Venus, O<sup>+</sup> ions tend to be injected into atmosphere, but on the opposite side ejected further out. The precipitated flux from 30-80° zenith angle is calculated at 1-2% of the solar wind (Wallis, Geophys. Res. Lett. 9, p 427, 1982). Solar wind protons also probably penetrate into the ionosphere in similar fluxes, "diffusing" through to the ionopause under fluctuating fields (Gombosi *et al.*, JGR 85, p 7747, 1980). Other evidence for permeability of the 'magnetosheath' of enhanced B-field (adjacent to the ionopause) are the small-scale "flux ropes" of twisted B found in the ionosphere. Consequent on the large O<sup>+</sup> gyroradii, asymmetry in the flow as registered by the bow shock distances on the flanks has now been demonstrated statistically (Alexander *et al.*, GRL 13, p 917, 1986). These authors also find

dependence on the inclination of the  $\mathbf{B}$ -field: "pick-up" of the  $\text{O}^+$  ions appears less efficient when  $\mathbf{B}$  is roughly parallel to the flow. Phillips *et al.* (1986) have developed  $\text{O}^+$  ion trajectory calculations in the specific magnetized flow model, demonstrating both the ionosphere precipitation and that "mass addition" is likely to be a poor approximation (Wallis, *Adv. Space Res.* 6(1), p 195, 1986) for extensive atmospheric sources. Luhmann *et al.*, (*JGR* 92, p 2544, 1987) have demonstrated that pick-up does operate with parallel mean  $\mathbf{B}$ , via low frequency fluctuating fields propagating from the ionopause or adjacent mantle (ionosheath).

While a distinct ionopause is confirmed, dividing ionosphere plasma from the external flow with a current layer a few gyroradii thick, it turns out to be highly variable. The combined external plasma plus magnetic pressure is balanced by the internal ionospheric pressure, so the sub-solar position varies significantly with solar wind dynamic pressure. But Phillips *et al.* (*JGR* 89, p 10676, 1984) found that it varies even more strongly at zenith angles  $60\text{--}90^\circ$ , between 300 and 1200 km altitude. Such a range presumably reflects fluctuations and instability of the ionopause and surrounding "mantle" loaded with atmospheric ions, corresponding to the clouds of thermalized  $\text{O}^+$  intruding from the ionosphere (Brace *et al.*, *Planet. Space Sci.* 30, p 29, 1982). This mantle or ionosheath of planetary ions that extends into the tail thus appears to be a mixture of ionospheric clouds and implanted  $\text{O}^+$  ions. The Venera spacecraft have given a lot of detail on the ionosphere and ion sources (Breus *et al.*, *Kosm. Issled.* 24, 1986) and particularly on the strongly variable polar ionosphere (Savich *et al.*, *Kosm. Issled.* 24, 1986). The longstanding problem of what maintains the nightside ionosphere now seems related to this ionopause variability. When it is high - generally around solar UV maximum,  $\text{O}^+$  flows from the dayside ionosphere driven by pressure gradients (Theis *et al.*, *JGR* 89, p 1477, 1984) and perhaps by effective viscous forces near the ionopause (Perez-de-Tejada, *JGR* 91, p 6765, 1986). When the ionopause is low, irregular precipitation of tail electrons are dominant. The magnetic "flux ropes" of 10 nT intensities and widths up to  $\sim 10$  km were an anomalous discovery. They arise from penetration of the dayside ionopause, probably due to MHD instability, but some fluid turbulence is thought necessary to twist and concentrate the field (Luhmann & Elphic, *JGR* 90, p 12047, 1985). To explain their evolution, diffusion-convection modelling of material transport down in the ionosphere is being developed (Phillips *et al.*, *JGR* 89, p 10676, 1984; Shinagawa & Cravens, *JGR* 92 (July), 1987). The wake of Venus contains much more magnetic flux than in these 'ropes'; its double-lobed structure arises from the draped interplanetary field, strengthened from being hung-up on slower planetary plasma analogously to the cometary case. Saunders & Russell (*JGR* 91, p 5589, 1985) showed that part of the field closes across the tail, while Russell (*Adv. Space Res.* 6(1) p 291, 1986) demonstrated that Maxwell stresses suffice to accelerate the planetary ion. The tail is flattened, corresponding to asymmetry in ion pick-up if not to anisotropy in magnetosonic speeds (Vaisberg & Zeleny, *Icarus* 58, p 412, 1984). The pick-up ions modelled by Phillips *et al.* (1986) are too energetic for PVO detection, while those detected spasmodically (Mihalov & Barnes, *GRL* 8, p 1277, 1981) suggest an erratic tail structure of rays or clouds.

In case of Mars, Vaisberg & Smirnov (*Adv. Space Res.* 6(1), p 301, 1986) reaffirm their strong influence in the ionotail with comet-like properties. Compared with Venus, the Martian shock and ionosheath lie further out, but not necessarily due to a planetary magnetic field (Vaisberg *et al.*, 1972). Breus (*Adv. Space Res.* 6(1), p 167, 1986) argues that suprathreshold oxygen provides an extensive enough exosphere under the low gravity to "mass load" the plasma flow and displace the bow shock out by 200-400 km. Whether or not this oxygen-corona exists, the solar wind is strong enough at times to press down to the ionosphere and presumably induces magnetic fields to resist its

penetration analogous to Venus under enhanced solar wind (Wallis & Ip, *Nature* 298, p 229, 1982). In modelling the exterior plasma flow mass sources have recently been introduced (Breu $\ddot{s}$  1986, Breu $\ddot{s}$  et al., *Pl. Space Sci.*, 1987). Large gyroradii of picked-up O<sup>+</sup> ions make this modelling unsatisfactory. The magnetic field is treated as weak, which may not be appropriate for studying unsteady situations with enhanced interplanetary field (Luhmann et al., *JGR* 91, p 3001, 1986). A possible magnetic barrier has been studied on an approximate analytic scheme (Krymskii & Breu $\ddot{s}$ , *Kosm. Issled.* 24, p 778, 1986).

The wealth of *in situ* data from the cometary probes yields a picture to a first approximation surprisingly close to theoretical predictions. Cometary ions "picked-up" far out in the coma by solar wind fields are accelerated to high energies and strongly affect the supersonic flow. The bow shock is weak ( $\sim$ Mach-2), positioned at a few times  $10^5$  km in front of Halley, and the flow deflects around the comet rather than being absorbed. The energetic ions are lost *via* charge exchange, allowing cometary ion structures ("envelopes") to form inside  $10^5$  km (Galeev, *ESA-SP* 250, 1, p 3, 1986). The interplanetary magnetic field adopts the draped topography and is enhanced around the tail core but only to the 50 nT level comparable to dynamic pressures. Cometary pick-up ions deviate strongly from the mean flow in such large-scale draped fields, which might explain structure and deviations seen at Giacobini-Zinner (Wallis, *Adv. Space Res.* 6(1), p 239, 1986; Luhmann, *GRL* 14(8), 1987). Several field reversals registered on GIOTTO's inbound path can be matched to ones outbound (Raeder et al., *ESA-SP* 250, 1, p 173), suggesting that solar wind field reversals are convected "frozen-in" the plasma flow with negligible magnetic diffusion ("reconnection").

Identification of the bow shock at both comets has been controversial. At Giacobini-Zinner, gyroradii of pick-up ions were comparable to fluid scales, so a gradual "bow-wave" transition was plausible. But even at Halley with the 10 times larger fluid scale there was no classical bow shock (Riedler et al., *Nature* 321, p 288). SUISEI detected the clearest example (Mukai et al., *Nature* 321, p 299), with  $20^\circ$  deflection and 50% speed reduction, but that may be confused with a discontinuity in solar wind. Of VEGA's shock passages, one is identified by changed level of fluctuations, the two others by flow speed changes but over many gyroradii thickness (Galeev et al., *GRL* 13, p 841, 1986). GIOTTO's ion, electron and magnetometer experiments (having better resolution) agreed on the inbound shock crossing, though it is clear that the weak jumps in speed, density or field by 10-20% are readily confused with large and widespread fluctuations associated with the overall interaction. There has been no demonstration that Rankine-Hugoniot relations are satisfied - and they appear not to be at GIOTTO's inbound shock (Coates et al., *ESA-SP* 1, p 263). No heating of the protons and electrons is discernible; deflection of the flow and phase scattering (pitch angle) of the ions are apparent, but take place too at other locations. The energetic cometary ions constitute a source of free energy and unstable beams in  $v_{\perp}$  and  $v_{\parallel}$  space, and so doubtless generate the observed fluctuations, whether *via* ion-cyclotron, lower hybrid, or Alfvén wave instabilities (Galeev, *ESA-SP* 250 1, p 3). While they must lose some energy, they do not thermalize, but primarily suffer scattering in pitch angle, converting "ring" to "shell" distributions (Neugebauer et al., *ESA-SP* 250 1, p 10; Johnstone et al., *Astron. Astrophys.*, October 1987). The energetic ions are rather lost, spiralling away in the outer regions of draped magnetic field, or *via* charge exchange with neutrals in the inner region. That many gain high energies, up to several 100 keV were detected, was a surprise - explained as the operation of Fermi acceleration (Sagdeev et al., *GRL* 13, p 85, 1986; Gribov et al., *ESA-SP* 250, p 271) *via* the large amplitude fluctuations.

Interstellar Neutrals in the Heliosphere and Their Interaction with  
the Solar Wind  
H. J. Fahr

#### LISM PENETRATION INTO THE HELIOSPHERE

The neutral component of the local interstellar medium (LISM) can deeply penetrate into the heliosphere. This fact is both observationally well confirmed by interplanetary EUV glow data and theoretically well established as shown e.g. in the more recent reviews on this field by Fahr (1983), Bertaux (1984), Fahr (1986a/b), Ajello *et al.* (1987).

The puzzling problem that turns out from all up-to-now helium and hydrogen glow interpretations concerns the fact that the derived thermodynamic parameters for the LISM helium and hydrogen do not seem to be rooting back into one common thermodynamic status of the unperturbed LISM. Especially the magnitude of the bulk flow velocity for hydrogen (~20 km/s) appears to be appreciably smaller than that of helium (~27 km/s) as raised by Bertaux (1984). Furthermore the hydrogen temperature (~8000 K) is pointed out to be substantially lower than the helium temperature (~15000 K) when evaluated with the help of conventional interplanetary glow models (Dalaudier *et al.*, 1984, Chassefière *et al.*, 1986). These results call for plausible physical explanations. Possibly the most promising idea to solve the problem of seemingly incompatible LISM parameters is to look for changes that the neutral LISM flows may experience in the plasma interface region ahead of the heliosphere. This idea has first been quantitatively evaluated in the works by Ripken and Fahr (1983) and Fahr and Ripken (1984). There it was shown that the LISM hydrogen due to its strong interaction with the perturbed LISM plasma in the interface region via resonant charge exchange processes is subject to substantial change of its momenta of the velocity distribution function, like density, bulk velocity and temperature. In a simplified approach to this problem also Wallis (1984) confirmed the prediction of appreciable density depletion in the LISM hydrogen flow. A comprehensive study of the interface effect has recently been given by Fahr (1986b). Of special interest, also for pick-up ion problems and the question of the origin of the anomalous component of the cosmic rays (Fisk *et al.*, 1974, Jokipii, 1985, Cummings *et al.*, 1984), is the fact that the "interface effect" operates in a very gas-specific way. LISM oxygen suffers the highest losses in the interface due to the lack of any production processes there for O-atoms. The LISM hydrogen will be depleted by a much smaller amount (about 50%) and helium nearly penetrates the interface unmodified due to the very low charge exchange interaction rate. LISM helium is possibly only subject to some, however weak interaction with the interface plasma due to elastic collisions with the interface ions (Chassefière and Bertaux, 1987).

#### MODELLING OF LISM NEUTRALS IN THE INTERPLANETARY SPACE

As recently reviewed by Fahr (1986a) there existed some flaws in the theoretical modelling of the distributions of interplanetary neutrals and the related EUV resonance glow intensities. For instance it was felt that part of the discrepancy of the derived LISM helium and hydrogen temperatures could be dissolved by treating the dynamics of interstellar He atoms more carefully, taking into account a kind of drag force connected with elastic collisions of neutrals and solar wind ion species (Fahr *et al.*, 1985). The amount of temperature reduction that was derived on the basis of this process, however, was questioned by Gruntman (1986) and Chassefière and Bertaux (1986) with the argument that the cross section used by the above authors probably is too large. Since the elastic interaction potential at large impact parameters still is a matter under debate, Nass and Fahr (1986) have shown for illustrative purposes how much the density structure in the helium cone and the derived LISM helium temperature is changed by the elastic drag effect for a large range of cross section values.

A further complication has been pointed out in the work by Lallement *et al.* (1985), who showed that a satisfactory fit of interplanetary Ly- $\alpha$  glow intensities as observed with the satellites Prognos 5 and 6 requires to take into account the solar wind latitudinal flux asymmetries. This point was already stressed in earlier papers by Witt *et al.* (1979, 1981) in connection with Ly- $\alpha$  data obtained with Mariner 10. It seems therefore that the LISM hydrogen loss rate needs a solar latitudinal modulation, disregarding its physical nature.

Furthermore it was criticized by Fahr *et al.* (1987) that up to now only stationary models have been used for the resonance glow interpretations. As the authors show in their recent paper the strongly time-dependent solar EUV-emissions can only be adequately taken into account by a time-dependent modelling. Especially the upwind-to-downwind helium density and He-584Å resonance intensity ratios are strongly influenced by solar cycle variation of the helium photoionization rate. This may easily have led earlier He-glow interpreters to derive too high LISM helium temperatures by about 3000 K (Dalaudier *et al.*, 1984, Ajello, 1978, Weller and Meier, 1981).

A subject of deeper investigations presently is the relevance of solar wind electron impact ionization collisions for neutrals in the inner solar system. In contrast to earlier work in this field (see Holzer, 1977) it is now felt that due to the pronounced core-halo structure in the solar wind electron velocity distribution functions, electron impact ionization is important for He inside the orbit of the earth (Ruciński and Fahr, 1987). Since this ionization process has a complicated dependence on the solar distance, its inclusion into modelling of interplanetary densities of LISM neutrals requires enhanced computational efforts which, however, can be shown as a necessary prerequisite for a reliable derivation of the LISM helium temperature.

The region inside the orbit of the earth not only leads to intensive ionization processes, by which secondary (pick-up) ions are produced, but also gives rise to deionization processes. These latter ones are connected with neutralization of solar wind ion species at zodiacal dust surfaces. The production rates of neutrals and ions connected with this interaction process are strongly piling up towards small solar distances. This context is reviewed as a whole in Fahr and Ripken (1985).

#### PICK-UP IONS IN THE SOLAR WIND

An interesting feature has been detected in the He<sup>+</sup>-pick-up ion fluxes in the solar wind when observed from the orbit of the earth (Möbius 1986). The fluxes strongly increase in magnitude while the ion-detecting earthbound satellite AMPTE is moving from upwind towards downwind regions. This feature can be understood as action of the enhanced neutral helium densities in the downwind helium cone structure. There exists now a new independent method to determine the LISM He temperature from the upwind-to-downwind He<sup>+</sup>-flux ratio. As raised by Fahr and Ruciński (1987) it is, however, indispensable to correctly take into account all relevant helium ionization processes inside the orbit of the earth, especially also electron impact ionization processes, since otherwise a theoretical fit of this He<sup>+</sup>-flux ratio would lead to much too high LISM helium temperatures.

#### ASSIMILATION OF PICK-UP IONS TO THE SOLAR WIND BULK

It has been recognized since quite some time that the initial distribution function developing immediately after the pick-up of freshly generated secondary ions in the solar wind rest frame is unstable with respect to linear plasma wave growth. A conclusive solution for all the aspects of this problem has not yet been reached (Winske *et al.*, 1985, Price and Wu,

1987, Winske and Gary, 1986) and much more work in this field is still in progress (Lee *et al.*, 1987, Gaffey *et al.*, 1987, Fahr and Ziemkiewicz-Dąbrowska, 1987).

The pick-up process in its first step leads to the formation of a population of secondary ions that initially move with a velocity  $V_{0\parallel} = V_{sw} \cdot \cos\beta$  parallel and gyrate with a velocity  $V_{0\perp} = V_{sw} \cdot \sin\beta$  perpendicular to the local magnetic field, with  $V_{sw}$  and  $\beta$  being the solar wind bulk flow velocity and its inclination with respect to the local magnetic field. Due to some minor thermal spread in the initial velocities of the freshly picked up ions, this scenario leads to a primary toroidal velocity distribution function. This function when convected outwards with the solar wind bulk is subject to a series of interaction processes: 1) pitch-angle scattering at intrinsic and selfgenerated Alfvén waves, 2) energy diffusion due to nonlinear coupling to selfgenerated plasma waves, 3) adiabatic cooling due to the tendency to conserve the magnetic moments, and 4) relaxation processes due to Coulomb collisions between the different ion populations. To all of these processes typical time periods  $\tau_1$  through  $\tau_4$  can be ascribed. It is thought at present that the following hierarchy amongst these periods may be valid:  $\tau_4 > \tau_2 > \tau_3 > \tau_1$ . This view is only unquestionable in what concerns the fact that, at least at regions not too far from the sun ( $< 2$  AU), pitch angle scattering with intrinsic Alfvénic turbulences has the smallest time period. According to this recognition the initially toroidal distribution is predicted to quickly be transformed into a shell distribution which then as such drives hydromagnetic waves (Lee *et al.*, 1987, Isenberg, 1987). Due to the relatively weak effectiveness of processes 2), 3) and 4) competing with pitch angle scattering, the pick-up ion population is not likely to become assimilated to the solar wind ion bulk, rather the solar wind expanding to larger distances may require to be considered as a tri-fluid plasma consisting of electrons, primary thermal ions and secondary suprathermal ions. Therefore the effect of pick-up ion heating of the distant solar wind, predicted in papers by Holzer and Leer (1973), Fahr (1973), Ripken and Fahr (1980), Petelski *et al.* (1980), Isenberg *et al.*, (1985), Grzędzielski and Ratkiewicz, (1975) may now need some revision. The attempt to model the distant solar wind as a tri-fluid plasma expansion with no thermal coupling between primary and secondary solar wind ion populations has recently been undertaken by Isenberg (1986). As it turns out from his theoretical approach, no solar wind temperature minimum can be expected in the outer solar system, unless unreasonably high neutral LISM hydrogen densities are considered. It appears, however, not to be assured that no energy dissipation from suprathermal ions to the solar wind bulk ions is occurring. Possibly this may also be a question of what regions in the solar system - ecliptic, low or high latitude, polar, upwind or downwind regions - are considered.

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