OBSERVATION OF DUST GENERATED HYDROGEN IN THE SOLAR VICINITY

H.J. Fahr, H.W. Ripken, and G. Lay
Institut für Astrophysik und Extraterrestrische Forschung
Universität Bonn
Auf dem Hügel 71, 5300 Bonn 1, Fed. Rep. Germany

Abstract. Solar wind protons impinging on interplanetary dust grains are trapped, deionized, and subsequently desorbed. The steady state distribution of desorbed neutral hydrogen inside of 0.4 AU can be deduced by observation of resonantly scattered solar 121.6 nm radiation. Calculated integral intensities and spectral profiles are given, showing the clear spectral separation of the different radiation components. Given a specific solar wind proton flux, the interplanetary dust distribution can be determined. Conversely, dust density profiles from zodiacal light measurements can be used to deduce solar wind proton fluxes at heliocentric distances of 0.4 to 0.15 AU. Observations of latitudinal and short-term temporal proton flux variations seem feasible.

Solar wind protons impinge on interplanetary dust grains orbiting the sun. Depending mainly on grain constitution and proton energy, they penetrate about 10 to 30 nm into the molecular lattice of the grains. With a high efficiency ε the protons are trapped ($\varepsilon > 0.9$) and subsequently deionized. The newly formed hydrogen atoms are retained, possibly expelling other, previously trapped hydrogen atoms from the lattice. Saturation of the dust grain surface layer is reached, depending on the grain temperature, at irradiation levels of less than $5 \cdot 10^{17}$ protons cm^{-2}. For a mean solar wind proton flux of $4.8 \cdot 10^{9}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ at 0.2 AU this occurs after 1200 d; thus it is safe to assume that all existing dust grains within the inner solar system are saturated by hydrogen. This condition of the dust grain surfaces implies that virtually no additional hydrogen can be retained, and that, on the average, for each impinging solar wind proton one hydrogen atom is immediately released from the surface. Only a minor fraction of the impinging protons is expected to be "reflected" as charged particles by quasi-elastic collision processes in the top surface layer (Lord, 1968; Bühler et al., 1966).

Assuming a continuous production of hydrogen by "dust deionization", the production rate P_h and the loss terms L can be written as (see Ripken and Fahr, 1979):

$$P_h = N_p\, v_{rel}\, \varepsilon\, \Gamma(r) = L_{ph}(N_h) + L_{ex}(N_h) + L_{eli}(N_h) \qquad (1)$$

(N_p: solar wind proton density; v_{rel}: relative velocity between dust grains and impinging protons; $\Gamma(r)$: effective geometrical cross section

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of dust grains; L_{ph} : photoionization rate of dust generated hydrogen; L_{ex}: charge exchange rate; L_{eli}: electron impact ionization rate; N_h: density of dust generated hydrogen. Eq. (1) describes the steady state condition of the dust generated hydrogen atoms. For a known interplanetary dust distribution including $\Gamma(r)$ (e.g., optically determined by zodiacal light measurements), the solar wind proton flux N_p v_{rel} can be deduced from hydrogen density observations. It is thus possible to determine solar wind proton fluxes at heliocentric distances of $r>0.15$ AU. Conversely, in assuming a specific solar wind flux, the dust distribution in interplanetary space can be determined without resorting to optical observations.

The feasibility of hydrogen density determinations inside the orbit of the Earth is examined next. Analogous to the backscatter of solar EUV radiation by interstellar neutral gas (intensities I_i), solar 121.6 nm radiation is scattered by dust generated hydrogen (intensities I_d). Model calculations locate the main radiation sources along the line of sight: for the dust component they lie close to the sun, whereas for the interstellar component, depending on the viewing position and orientation of the instrument, they lie either within 0.4 AU of the observer or about 2 AU to 20 AU away from him. Integrated intensities along the line of sight are shown in Fig. 1 as functions of solar offset angle γ and time of observation from Earth. Clearly, summer observations reveal dominant intensities I_d for $|\gamma|<15^\circ$, while spring observations yield $I_i>I_d$ for reasonable solar offset angles ($\gamma>7.5^\circ$). In order to determine N_h accurately by means of backscatter observations, it will thus be necessary to separate the two signals I_d and I_i spectroscopically. For both observing positions and an offset angle $\gamma=10^\circ$ the calculated spectra are given in Fig. 2, exhibiting strongly doppler-shifted components. Employing suitable instrumentation (resonance absorption cells or EUV spectrometers; Blamont et al., 1975; Artzner, 1978), the geocoronal, interstellar, and dust generated components can readily be separated and analyzed.

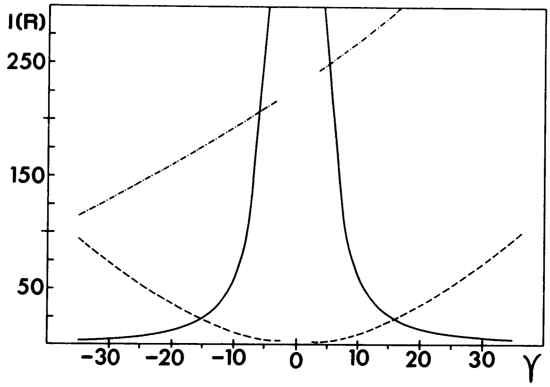

Figure 1. Calculated integrated 121.6 nm radiation intensities as functions of solar offset angle γ. Full lines: I_d; dashed lines: I_i, observation time June 21; dashed-dotted line: I_i, observation time March 21.

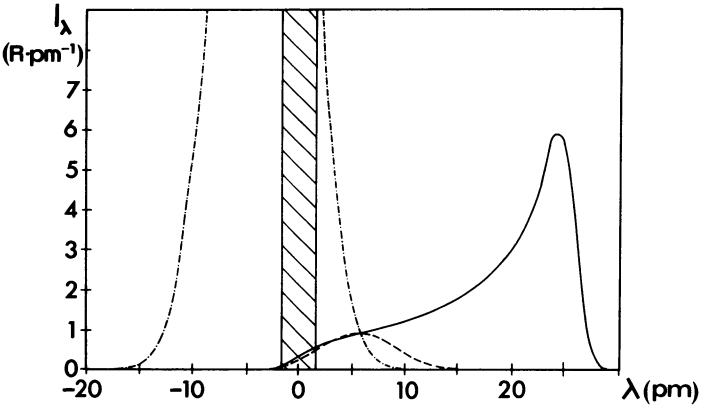

Figure 2. Calculated spectral profiles of resonantly scattered solar 121.6 nm radiation. Solar offset angle of line of sight is 10°. Full line: dust generated component, strongly doppler-shifted due to orbital velocity of dust grains; dashed line: interstellar component, observation time June 21; dashed-dotted lines: interstellar component, observation time March 21, with maximum at 29.25 R•pm^{-1}; hatched area: geocoronal component, temperature 10^3 K, optically thick.

The aforementioned desorption of hydrogen from saturated dust grain surfaces indicates that solar wind flux changes are instantaneously reflected in equilibrium hydrogen densities. This seems to indicate that determinations of temporal and spatial variations of the proton flux close to the sun are feasible. The line-of-sight source function of dust generated hydrogen backscatter radiation is peaking strongly and the corresponding spectrum exhibits maximal doppler shifts at the closest approach to the sun. Thus, for small solar offset angles ($\gamma < 10^\circ$) the linear extent of the source region producing the spectral intensity maximum of I_d is less than 0.1 AU, and flux variations in solar wind structures of limited spatial extent are expected to be observable already at solar distances of about 0.15 AU.

Analogous calculations for interstellar and dust generated neutral helium and solar wind helium ions are currently being carried out, as well as extensions of the models out of the dust plane of symmetry.

References

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DISCUSSION

Callebaut: Why is there a saturation for the dust to absorb the impinging ions? (Some materials are capable to absorb tremendous amounts of hydrogen.)

Ripken: Saturation of dust grains by impinging and subsequently trapped and neutralized protons occurs when an approximate 1-to-1 correlation with the lattice atoms of the grain is reached (Lord, 1968). No more hydrogen atoms can be retained within the dust grain crystal lattice, and desorption takes place at a rate comparable to the trapping rate of protons. These considerations are valid for freshly exposed silicate surfaces; radiation damage and "space weathering" will reduce, possibly drastically, the hydrogen retention capabilities of the grains.

Kuperus: Could the presence of the neutral particles influence the dissipation of MHD waves, e.g., by ambipolar diffusion?

Ripken: The model calculations we have performed are for a steady state problem. Possible time dependent phenomena have not been examined yet. However, I do not believe that neutral particles can appreciably influence MHD waves in the solar wind, or in general solar wind dynamics, since the maximum density of dust generated hydrogen, derived from our standard model at about 0.4 AU, is only $2.5 \cdot 10^{-4}$ cm^{-3}. This compares with a solar wind proton density of about 35 cm^{-3}, yielding a ratio of $N_h/N_p = 7.1 \cdot 10^{-6}$.