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Thermal Coupling between Neutral Hydrogen and Protons in the Fast Solar Wind: Models and Inferences

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Abstract

In response to the recent Spartan and UVCS/SOHO observations of Ly α spectral line profiles in the inner corona implying large temperature anisotropies and proton temperatures as high as 6×10^6 K [*Kohl et al.*, 1996, 1997][1], we investigate the thermal coupling between neutral hydrogen atoms and protons in the fast solar wind. We include charge exchange between neutrals and protons, radiative recombination, collisional ionization of the neutrals, and the effects of Alfvén waves, described by a single frequency or a spectrum. We follow the approach developed by *Olsen et al.* [1994][2] to incorporate the collisional interaction between the neutrals and protons and the resulting wave motion of the neutrals. A fluid approach is used in which the neutrals are treated as test particles in a background electron-proton solar wind driven out from the Sun by thermal and Alfvén wave pressure against gravity. Coulomb collisions and thermal conductivity of the electrons and protons are included, as well as the allowance for non-radially expanding flow tubes and additional heating to the electrons and protons. We study the behavior of the neutral hydrogen in the solar wind for cases with isotropic and anisotropic proton temperatures.

Our model computations show that an anisotropy in the neutral hydrogen temperature develops in the directions parallel and perpendicular to the magnetic field,

[1]*Astrophys. J.*, 465, L141-144, 1996; *Sol. Phys.*, 175, 613-644, 1997.
[2]*Astrophys. J.*, 420, 913-925, 1994

with the perpendicular temperature, $T_H^\perp$, exceeding the parallel temperature, $T_H^\parallel$, within 1-3 R_s. In the case of anisotropic proton temperature, a greater temperature anisotropy in the neutral hydrogen develops, as compared to the case when the proton temperature is isotropic, as a result of the coupling between the respective parallel and perpendicular components of the neutral hydrogen and proton temperatures. Our model solutions show, and we confirm by analytical calculation, that the effective temperature, $T_{H(eff)}^\perp$, incorporating both random and wave motions of the neutral hydrogen, is independent of Alfvén wave frequency. We find that for solutions with either isotropic or anisotropic proton temperatures the proton and neutral hydrogen effective temperatures and outflow velocities are comparable, with a temperature difference less than 5×10^5 K, below 3 R_s. For plasma conditions typical of the fast solar wind, these results imply that the measured Ly α spectral line profiles, from which the neutral hydrogen temperature, anisotropy ratio, and outflow velocity are inferred, are equivalent to measurements of protons below 3 R_s.

To relate our model to observations, we compute the Ly α profiles in the solar corona for each of our solutions. We include in our calculation the effects of the temperature anisotropy, non-spherical geometry, and incident solar rays from the visible solar disk. The dominant contribution to the profiles comes from $T_{H(eff)}^\perp$ at the point of closest approach to the Sun along the line of sight (LoS). The width of the profiles are significantly narrowed by non-90° scattering along the LoS and broadened by outflow velocity, especially in combination with large temperature anisotropies and non-radial expansion of the flux tubes. While these opposing effects tend to cancel in most cases, this does not always occur. Modeling, combined with additional observations to infer outflow velocity and temperature anisotropy, is necessary to correctly interpret the observed profiles.