Solar Wind Acceleration from the Upper Chromosphere to the Corona in Coronal Hole Regions

NASA Grant NAG5-7319

Final Report

For the period 1 June 1998 through 31 May 1999

Principal Investigator

Dr. Ruth Esser

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Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138

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1. Summary

1.1 Scope of the Investigation

Flow speeds derived in recent years from chromospheric/transition region and coronal observations suggest that the solar wind acceleration process might start at heights in the solar atmosphere much lower than previously imagined. The goal of the proposed investigation was to study atmospheric outflows in coronal hole regions from the chromosphere into the corona using observational and theoretical approaches. In addition to outflows, other plasma properties such as electron densities, and electron and ion temperatures were also included in the study. To investigate these plasma properties in the inner corona is important as they play a crucial role in placing limits on possible coronal heating and solar wind acceleration mechanisms.

1.2 Progress Made

Over the past year we have carried out, analyzed and made use of a number of different observational techniques to achieve the above goal. In addition we have supported these observations with model calculations. In particular we have derived constraints on electron densities in the lower solar atmosphere (photosphere and chromosphere) using a number of different atmospheric models which are constrained by observed spectral lines. For the first time, we have carried out a detailed comparison between these atmospheric densities and coronal electron densities derived from polarization brightness measurements in the region from about 1.1 to several solar radii. It was discovered that there is a discrepancy between the two sets of densities. The atmospheric electron densities are in agreement with a density of maximum 10^7 cm^{-3} at 1.1 R_S. The pB densities given in the literature are typically 5×10^7 cm^{-3} or higher. It was shown that this discrepancy might be due to an overestimation of the coronal electron densities below 1.5 to 2 R_S. To derive accurate estimates of electron densities throughout the solar atmosphere is particularly important since the electron density is a fundamental parameter in the interpretation of other observations, is a key parameter in solar wind modeling, and is often used to place limits on other parameters such as outflow speeds. Corresponding discrepancies could not be found for the electron temperatures (See Figure 1).

UVCS observations in conjunction with the above densities were used to place limits on the time scales of the heating mechanism. Observations of the Lyman-α 1216 Å, the Mg X 625 Å, and the O VI 1038 Å spectral lines carried out with the UVCS (Ultraviolet Coronagraph Spectrometer) on board SOHO at distances in the range 1.35 to 2.1 R_S in the northern coronal hole, were used to place limits on the turbulent wave motions of the background plasma, and the thermal motions of the protons and Mg^{+9}, and O^{+5} ions. Limits on the turbulent wave motion were estimated from the measured line widths and electron densities derived from white light coronagraph observations assuming WKB approximation at radial distances covered by the observations. It was shown that the contribution of the turbulent wave motion to the widths of the measured spectral lines is small compared to thermal broadening. The observations revealed that the particle temperatures are neither mass nor mass to charge proportional. The proton temperature slowly increases between 1.35 and 2.7 R_S and does not exceed 3×10^6 K in that region. The temperature of the minor ions exceeds the proton temperature at all distances, the temperature of the O^{+5} ions is heigher than the temperature of the Mg^{+9} ions (Figure 2a). This behavior is in agreement with a turbulence driven solar wind flow. The flow speed, electron densities and Alfvèn speed limits are also shown in the Figure (2b). It was calculated, for the first time, that collision times between protons and minor ions are small compared to the solar wind expansion times in the inner corona (Figure 2c). At 1.35 R_S the expansion time exceeds the proton Mg^{+9} collision time by more than an order of magnitude. Nevertheless, the temperature of the Mg ions is significantly larger than the proton temperature which indicates that the heating mechanism has to act on time scales faster than minutes.

Estimates of the above plasma parameters were also used to show that for plasma conditions in the inner corona, the presence of a shear flow would lead to a mode conversion of Alfvén waves into fast mode waves which are damped more easily.

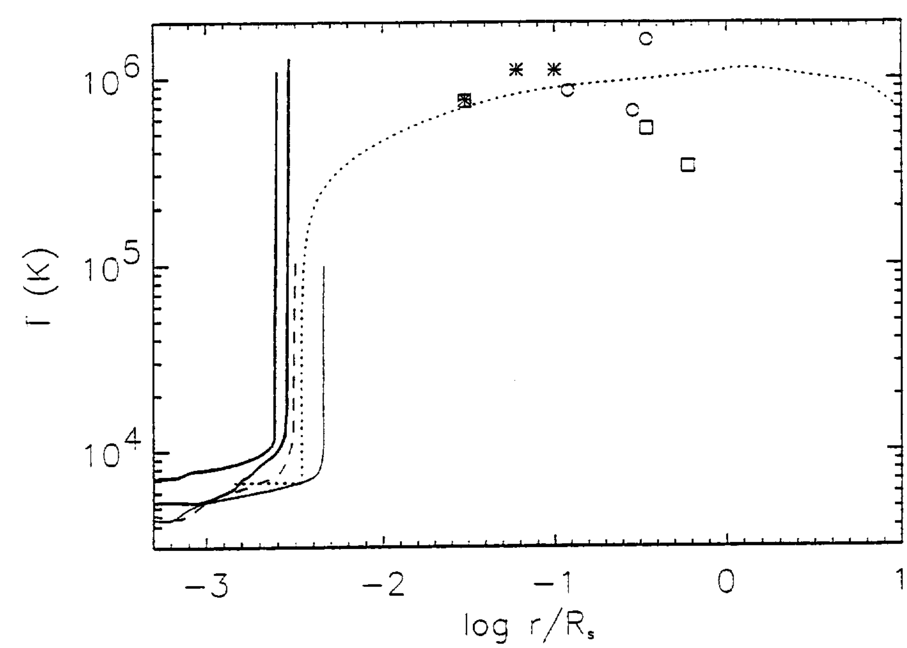

Figure 1: Electron temperatures calculated from the atmospheric models (solid and dashed lines), from a solar wind expansion model (dotted line), and the temperatures derived from observations in the corona (squares, asterisks, and circles).

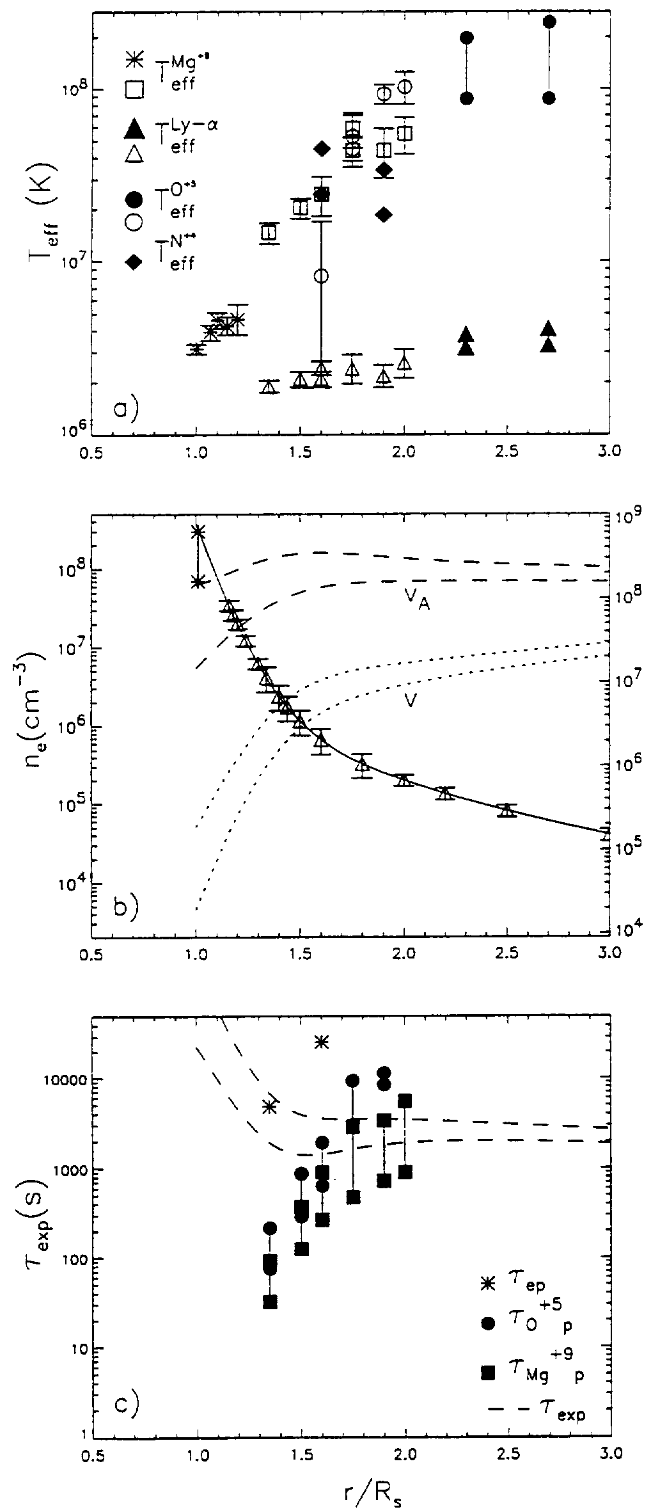

Figure 2: a) Effective particle temperatures, b) observed electron densities, and derived flow and Afvén speeds, c) collision times of the particles and expansion times calculated from b (see Esser et al. 1999 for details).

2. Publications in Journals and Proceedings Funded or Partially Funded by Grant NAG5-7319

R. Esser, S. Fineschi, D. Dobrzycka, S. R. Habbal, R. J. Edgar, J. C. Raymond, and J. L. Kohl, Plasma properties in coronal holes derived from measurements of minor ion spectral lines and polarized white light intensity, *Astrophys. J. Let.*, **510**, L63, 1999.

J. L. Kohl, R. Esser, S. R. Cranmer, S. Fineschi, L. D. Gardner, A. V. Panasyuk, L. Strachan, R. M. Suleiman, R. A. Frazin, and G. Noci, EUV Spectral Line Profiles in Polar Coronal Holes from 1.3 to 3.0 R_S, *Astrophys. J. Let.*, **510**, L59, 1999.

R. Esser, Coronal Hole Boundaries and Interactions with Adjacent Regions, *Space Sci. Rev.*, **87**, 93, 1999.

R. Esser and D. Sasselov, On the Discrepancy Between Atmospheric and Coronal Densities, *Astrophys. J. Lett.*, in press, 1999.

E. Kaghashvili and R. Esser, Density Fluctuations in Polar Coronal Holes: Mechanism and Observational Consequences, in Proceedings of SW9 Conference, eds. S. R. Habbal, R. Esser, J. V. Hollweg, and P. A. Isenberg, **AIP-471**, p341, 1999.

P. R. Young and R. Esser, Comparing Quiet Sun and Coronal Regions with CDS/SOHO, *Space Sci. Rev*, **87**, 345, 1999.

J. L. Kohl, S. Fineschi, R. Esser, A. Ciaravella, S. R. Cranmer, L. D. Gardner, R. Suleiman, G. Noci and A. Modigliani, UVCS/SOHO observations of spectral line profiles in polar coronal holes, *Space Sci. Rev*, **87**, 233, 1999.

Wood, C. H., S. R. Habbal, R. Esser, and M. Penn, in Proceedings of SW9 Conference, eds. S. R. Habbal, R. Esser, J. V. Hollweg, and P. A. Isenberg, **AIP-471**, p293, 1999.

3. Invited Talks at Meetings:

R. Esser, Working Group 3 report: Coronal Hole Boundaries and Interactions with Adjacent Regions, SOHO7, Ann Harbor, Maine, USA, 1998.

R. Esser, An update on understanding the corona, IAGA division IV reporter reviews, IAGA meeting, Birmingham, England, 1999.