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# INTERPRETATION OF SOLAR WIND ION COMPOSITION MEASUREMENTS FROM ULYSSES

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Annual Report

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# 1. Summary

## 1.1 Scope of the Investigation

Knowledge of the plasma conditions in the inner corona is essential for solar wind modeling since any attempt to explain the expansion of the solar wind plasma depends on information in the inner corona to select and constrain the solar wind expansion models. Of particular interest are the temperatures of the different particle species. The temperatures of protons and heavy ions such as oxygen can only be derived from measurements of spectral lines. As the width of spectral lines reflects both thermal and non-thermal random motions only an upper limit can be placed on the temperature of these particles. The electron temperature on the other hand can be derived from measurements of spectral line intensities by comparing the measured line ratios to the ratios calculated from theoretical models, and from in situ charge state measurements. The idea is that the charge state of the considered element is a function of the local electron temperature only, and that the charge state "freezes in" at a certain heliocentric distance and remains constant beyond that distance. Therefore, the in situ charge state ratio reflects the electron temperature in the inner corona. In deriving these charge state temperatures it is assumed that all elements and charge states have the same flow speed and the same temperature (e.g. Bürgi and Geiss, 1986). Also inherent in these temperature estimates is the assumption that the electron velocity distribution function is Maxwellian. The effect of non-Maxwellian velocity distribution functions and differential flow speeds have been discussed in Owocki and Scudder (1983) and Esser and Leer (1990), respectively. Since the message carried by the charge states is obscured by these different assumptions, model calculations are necessary to extract the desired information from the observations. The goal of the funded study is to develop the necessary solar wind models, and to compare the derived electron temperatures to the electron temperatures derived from spectral line intensity measurements carried out from the SOHO satellite.

## 1.2 Progress Made

Solar wind models, developed in the past in order to infer the electron temperature from the charge state observations (e.g. Bürgi and Geiss, 1985; and references therein; Esser and Leer, 1990) did not include extensive heating in the inner corona. These models also assumed that all particle species have the same temperature, and that heavy ions were minor species that did not effect the background electron-proton solar wind. During the past 8 months, the time period for which we received the NASA grant, we have carried out several parameter studies to investigate the behavior of the temperature of different particle species. We can show that when heating is included in the inner corona, different particle species can have very different temperatures (Habbal et al., 1995; Esser and Habbal, 1995; Esser et

al., 1996). This result is important since it demonstrates that no conclusions can be drawn concerning the "total" temperature structure in the inner corona from the inferred electron temperatures. This contradicts the previous assumption that electrons and protons have the same temperature in the inner corona. These parameter studies include two- and three-fluid solar wind models, and an investigation about the role of the conduction in the proton gas.

It has been known for a long time that including classical conduction in the proton gas yields conductive fluxes at 1 AU that are several orders of magnitude too high, in spite of the fact that it can lead to proton temperatures at 1 AU that are in the range of observed temperatures. It is then often assumed that classical heat conduction in the proton flow even though wrong in the outer corona and solar wind, might play a role in the very inner corona. We have calculated a few examples which demonstrate how inclusion of classical proton conduction in the inner corona alters the solar wind solutions compared to models where conduction is neglected (Esser et al., 1996). Through these model studies we have increased our knowledge about the solar wind expansion which is necessary to choose the expansion models for the interpretation of the charge states.

In collaboration with Xing Li, a student from China, we have developed a solar wind model which includes $O^{+6}$ as a full fluid together with electrons and protons (Li et al., 1996). Instigated by previous studies which show that the presence of alpha particles can have a dramatic effect on the expansion of the electron-proton plasma, we were interested in the question whether minor species, other than alpha particles, might have an effect on the background solar wind flow. As an example we chose the third most abundant element in high speed streams, namely $O^{+6}$. In this initial study we have neglected the presence of the alpha particles. In the future we will investigate the behavior of oxygen ions in a fully four fluid solar wind model. Depending on the result of these studies we will decide whether we will need multifluid codes to interpret the charge state observations, or whether we can continue to treat the electron-proton solar wind separately from the minor ions.

At present we are also carrying out a study that investigates the effect of high proton and minor ion temperatures on the atomic rates used to derive the line ratio temperatures. If ion temperatures can be significantly different from electron temperatures, the proton rates should be included in the atomic rates. It seems at this point that for some elements the effect might be significant (Brickhouse et al., 1996). This study is important as it will affect the comparison between the "charge state" and "line ratio" temperatures.

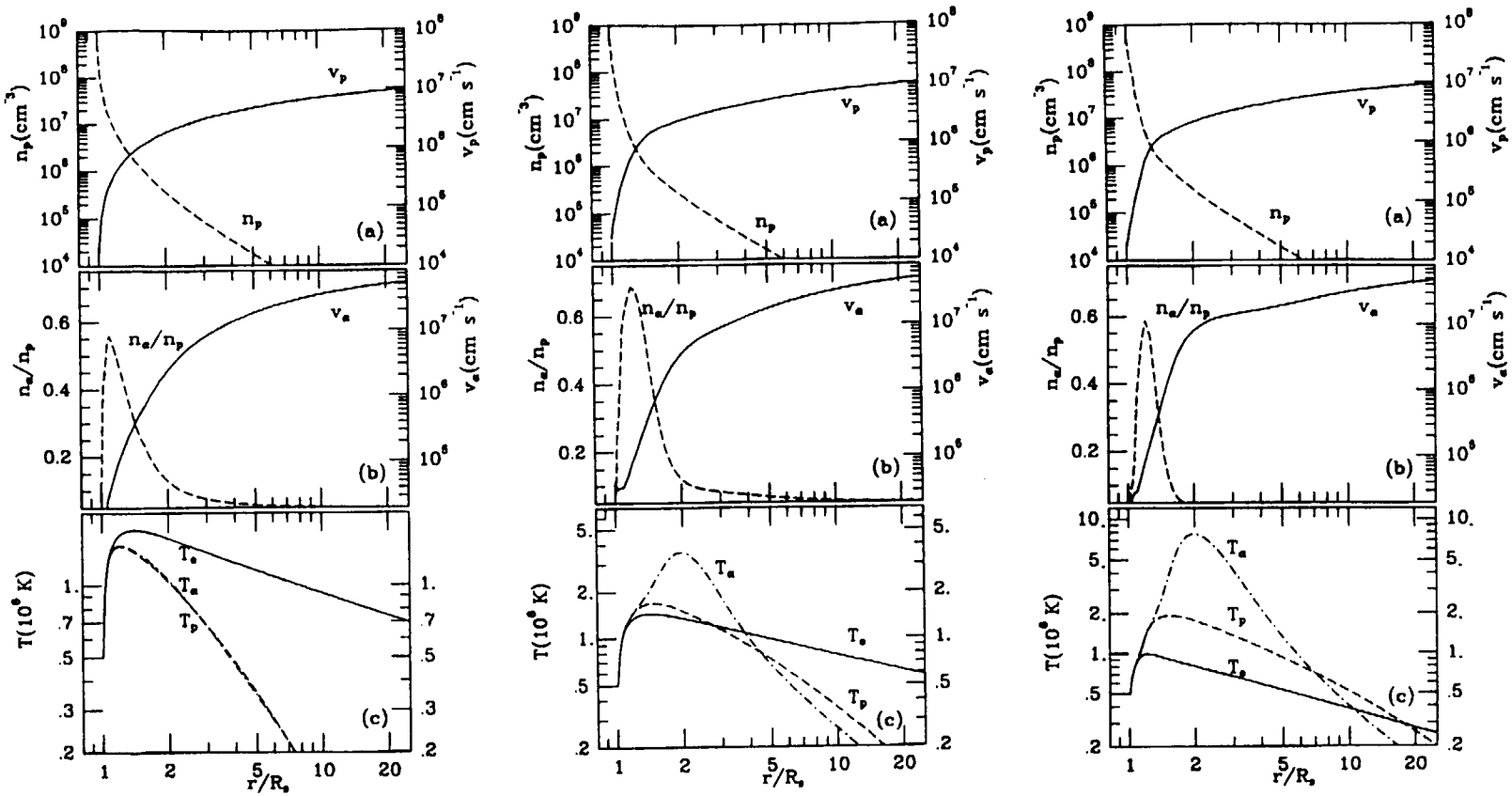


Figure 1. Composite plot of solar wind expansion models showing that different temperature conditions in the inner corona can lead to approximately the same proton flow speed, mass flux and helium abundance at 1 AU. From Esser and Habbal, 1995.

## Publications in Journals and Proceedings

R. Esser, and S. R. Habbal, Heating in the inner corona and plasma parameters at 1 AU, *Geophys. Res. Let.*, **22**, No 19, 2661, 1995.

R. Esser, and S. R. Habbal, Modeling high flow speeds in the inner corona, in *Proceedings of the Solar Wind 8 Conference*, 1996.

R.Esser, S. R. Habbal, W. A. Coles, and J. V. Hollweg, Hot protons in the inner corona and their effect on the flow properties of the solar wind, to be submitted to *J. Geophys. Res.* 1996.

X. Li, S. R. Habbal, and R. Esser, A parameter study of a three-fluid solar wind with oxygen ions, to be submitted to *J. Geophys. Res.*, 1996.

N. Brickhouse and R. Esser, Effect of high ion temperatures on the temperatures and densities inferred from line ratios, manuscript in preparation.