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Electron Density and Temperature Measurements, and Abundance Anomalies in the Solar Atmosphere

Anita Mohan[1], Bhola N. Dwivedi[1,2]* & Enrico Landi[2]
[1] *Department of Applied Physics, Institute of Technology, Banaras Hindu University, Varanasi 221005, India.*
[2] *Max-Planck-Institut für Aeronomie, 37191 Katlenburg-Lindau, Germany.*
**e-mail: dwivedi@banaras.ernet.in*

Abstract. Using spectra obtained from the SUMER (Solar Ultraviolet Measurements of Emitted Radiation) spectrograph on the spacecraft SOHO (Solar and Heliospheric Observatory), we investigate the height dependence of electron density, temperature and abundance anomalies in the solar atmosphere. In particular, we present the behaviour of the solar FIP effect (the abundance enhancement of elements with first ionization potential <10 eV in the corona with respect to photospheric values) with height above an active region observed at the solar limb, with emphasis on the so-called transition region lines.

Key words. Solar atmosphere—abundance anomalies—EUV diagnostics—emission lines.

Dwivedi, Curdt & Wilhelm (1997, 1999a) carried out an observing sequence based on a theoretical study by Dwivedi & Mohan (1995), with intercombination/forbidden Ne VI and Mg VI lines, which are formed at essentially the same temperature (4×10^5 K), according to Arnaud & Rothenflug (1985). The FIPs of Ne and Mg are 21.6 and 7.6 eV, respectively: they form a high-FIP/low-FIP pair. This observing sequence provided new observational facts in transition region emission lines in the corona (Dwivedi, Curdt & Wilhelm 1999a,b). In the present paper, we extend this investigation taking account of other high-FIP/low-FIP pairs such as K/Ar, Si/Ar and S/Ar present in the spectra. For want of space, we only present highlights of our findings and a full paper will be published elsewhere (Mohan, Landi & Dwivedi 2000).

The observations were made with the SUMER spectrograph on 1996 June 20 above an active region NOAA 7974 on the east limb, starting at 20:11 UT. Fig. 1 shows the position and extension of the SUMER raster superimposed on the He II 304 Å image of the eastern limb of the Sun taken at 19:41 UT with the EIT ultraviolet imager (Delaboudiniére *et al.* 1995). For the observations in the present contribution, Dwivedi, Curdt & Wilhelm (1997, 1999a) used the slit 4 arc-sec × 300 arc-sec with a raster step of 3.8 arc-sec to a total of 35 positions in the east-west direction. The raster started 40 arc-sec off-limb, above the position of the bright He II protrusion seen in the EIT image. With a step size corresponding to the slit width of 4 arc-sec, the spectrograph slit was stepped eastward for 133 arc-sec. At each

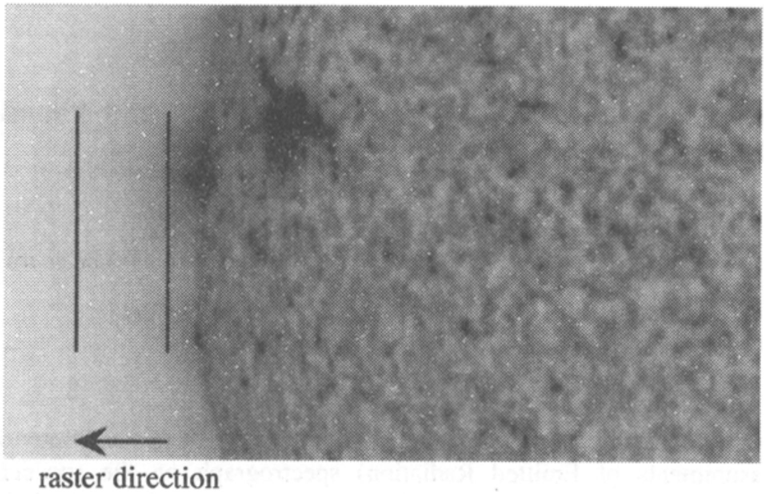

Figure 1. SUMER raster superimposed on a section of the He II 304 Å EIT image taken at 19:41 UT, showing the active region NOAA 7974 on the limb and its neighbour NOAA 7973 in photonegative representation. (Courtesy, EIT/SOHO consortium).

position, two 40Å wide spectra were obtained. The first spectrum was centered on the Ne VI 999 Å line, while the second spectrum was centered on the Mg VI 1192 Å line.

We have used density-sensitive 1196/1212 S X line ratio to determine N_e. In our dataset N_e is sufficiently low to let photoexcitation play an important role for S X density diagnostics. Using CHIANTI (atomic database described in Dere *et al.* 1997) and taking account of this process, the inferred log N_e values as a function of height are shown in Fig. 2. Uncertainties increase with height, and the last 5 density values are only an estimate of an upper limit, due also to the “flattening” of the theoretical ratio. Apart from the very last ratios, these values lie more or less on a straight line as a function of height which allows to measure density scale heights etc.

We measured electron temperature T from S X/Si XI line ratio shown in Fig. 3 as a function of height. We then calculated other lines' ratios using the $N_{e,}$ T values we deduced as a function of height and compared them with observations. It is to be noted here that such a T measurement is biased to any problem in the relative S/Si abundance. Si is a low-FIP element while S is just at the border (its FIP is 10.4 eV), so this can be a bias to our results. We found from this ratio that the electron temperature was more or less constant with height. Its mean value is log T = 6.28 ± 0.03, maximum log T value = 6.31, and minimum log T value = 6.25.

In order to calculate theoretical line ratios, we need to use not only the correct N_e and T values, but also the ion fraction dataset. We made the comparison between the two most recent different ion fractions datasets found in the literature (Arnaud & Rothenflug 1985; Mazzotta *et al.* 1998). We calculated the Si XI/Ar XII and the S X/Ar XII ratios using these two ion fraction datasets. The difference between the two resulting values for each of these ratios are of a factor 2.2 (Si/Ar) and 2.5 (S/Ar). We, therefore, stress the fact that ion fraction datasets play a major role as uncertainty in quantitative FIP analysis. Our results show this in a clear way, which is also

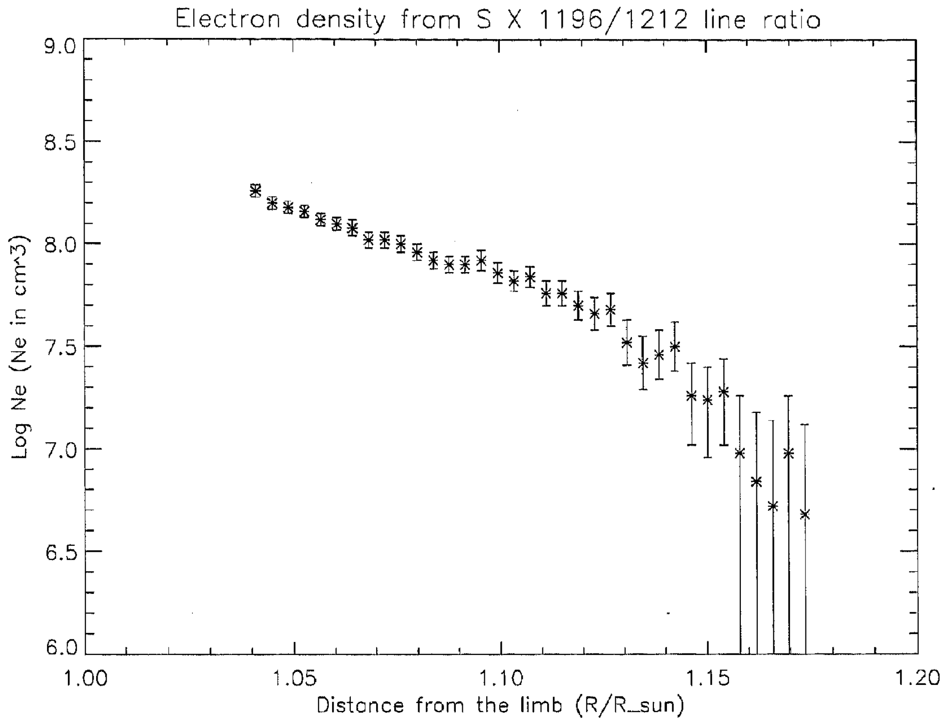

Figure 2. Height dependence of electron density from S X 1196/1212 line ratio.

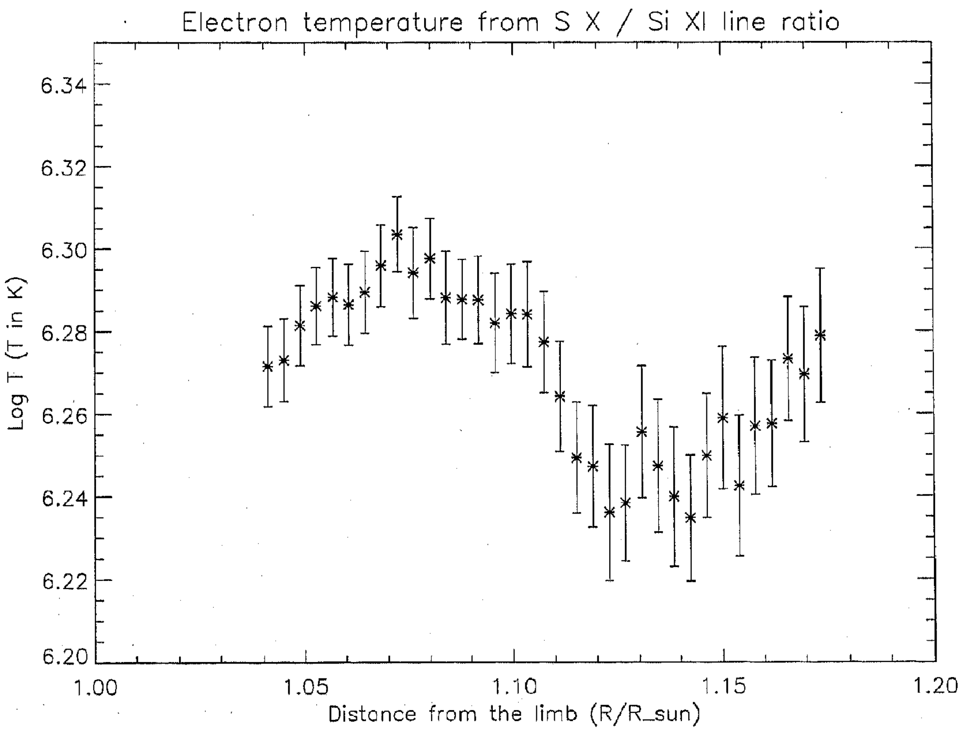

Figure 3. Height dependence of electron temperature from S X/Si XI line ratio.

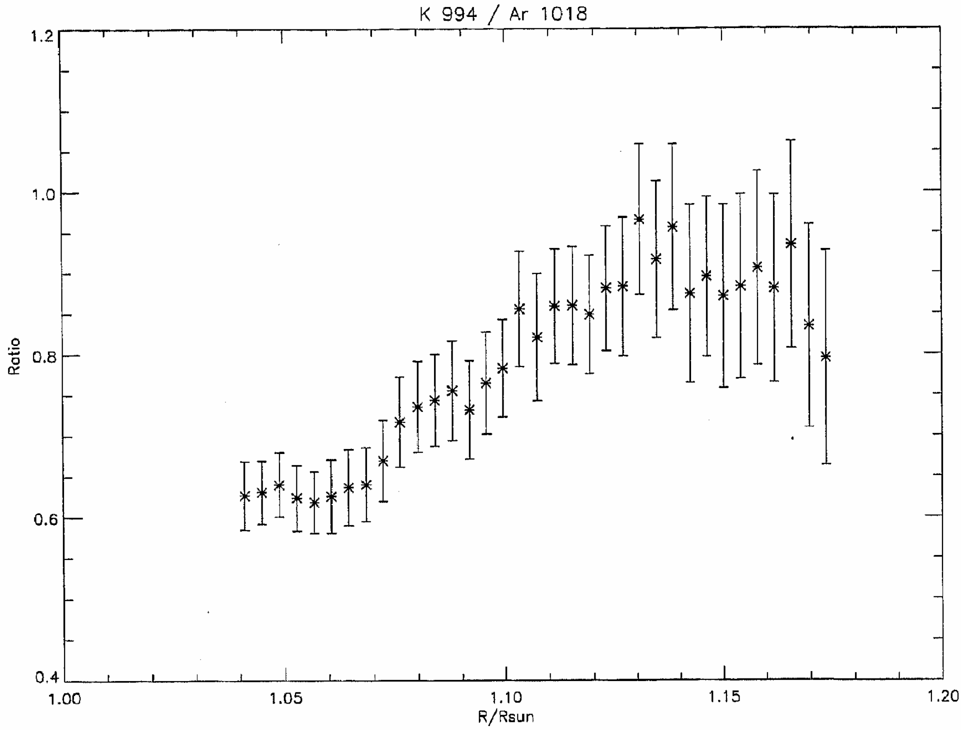

Figure 4. Height dependence of experimental K XIII/Ar XII (994/1018).

independent of possible temperature structure in the atmosphere as the plasma we have is isothermal.

We studied low-FIP/high-FIP pairs such as Si/Ar, S/Ar and K/Ar and their height dependence. The FIPs for K, Si, S and Ar are 4.3, 8.2, 10.4 and 15.8 eV respectively. We have investigated experimental K XIII/Ar XII, Si XI/Ar XII and S X/Ar XII. However, we report here only the height dependence of experimental K XIII/Ar XII as shown in Fig. 4. The observations reported in this paper have both active region at the limb and some plasma outside the structures of the active region. We, therefore, prepared the intensity maps from Ne VI, Mg VI and S X. We find that Ne VI and Mg VI maps are similar, thereby indicating that the plasma structures emitting both the ions are likely to be the same (although spatial resolution is not enough to be definitive on this conclusion). The S X, however, has no memory at all of the region, thereby indicating that the structures are cool. The results for the K/Ar, Si/Ar and S/Ar ratios outside the structures show different behaviour. This may be due to the fact that K, Si and S have an increasing FIP This could imply that the FIP effect bias depends on the magnitude of the FIP effect itself. However, further studies are required to confirm this.

In conclusion, this investigation provides new observational facts about electron density, temperature, and the FIP effect in the corona. A detailed analysis of this investigation can be found in Mohan, Landi & Dwivedi (2000).

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