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Coronal and transition region inhomogeneities of the "quiet" Sun and abundance of low-FIP elements

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Abstract. Abundance analysis of CDS spectra of the quiet Sun based on the DEM technique indicates a photospheric composition of the transition region and inner corona with small variation from region to region. Some enhancement may be present for elements with the lowest FIP, i.e. Ca and Al, but the results depend on the ionisation stage considered. The likely explanations are that either the accuracy of the atomic data are still below the requirements for this type of analysis or there is some enrichment process taking place, which affects some of the ionisation stages of the elements with the lowest FIP more than others.

Key words. Sun: atmosphere – Sun: corona – Sun: UV radiation – Sun: abundances – Atomic data – Methods: data analysis – Techniques: spectroscopic

1. Introduction

Lanzafame et al. (2005) analysis of EUV spectra obtained using the Coronal Diagnostic Spectrometer (CDS) on the SOHO spacecraft reveals that the Differential Emission Measure (DEM) in the transition region and corona of the "quiet Sun" (QS) maintains essentially the same shape in most of the regions of 2×80 arcsec^2 examined. Such a shape is the same as that obtained from the mean spectrum of the whole raster (20×240 arcsec^2). The subregions' DEM differs by a constant factor between 0.5 and 2 from the mean DEM. Departures from such a behaviour are found in areas where the transition region electron density is below 2×10^7 cm^{-3} and downflow velocities of 50 km s^{-1} are measured. Such areas are are likely to contain plasma departing from ionisation equilibrium, violating the basic assumptions underlying the DEM method. The analysis indicates, however, that departures from ionisation equilibrium may significantly affect the analysis on small areas (of the order of 2×80 arcsec^2), but when considering an average over larger areas (of the order of 20×240 arcsec^2) they tend to be of less importance because most of the plasma appears to be close to ionisation equilibrium.

The plasma is found to have a composition close to photospheric in all the subregions examined. However, large variations in the theoretical vs. observed intensity ratio as a function of ionisation stage are seen for elements with the lowest FIP, i.e. Ca and Al, leading to large uncertainties in their abundance. In this paper, the observational evidences are further discussed and possible explanations outlined.

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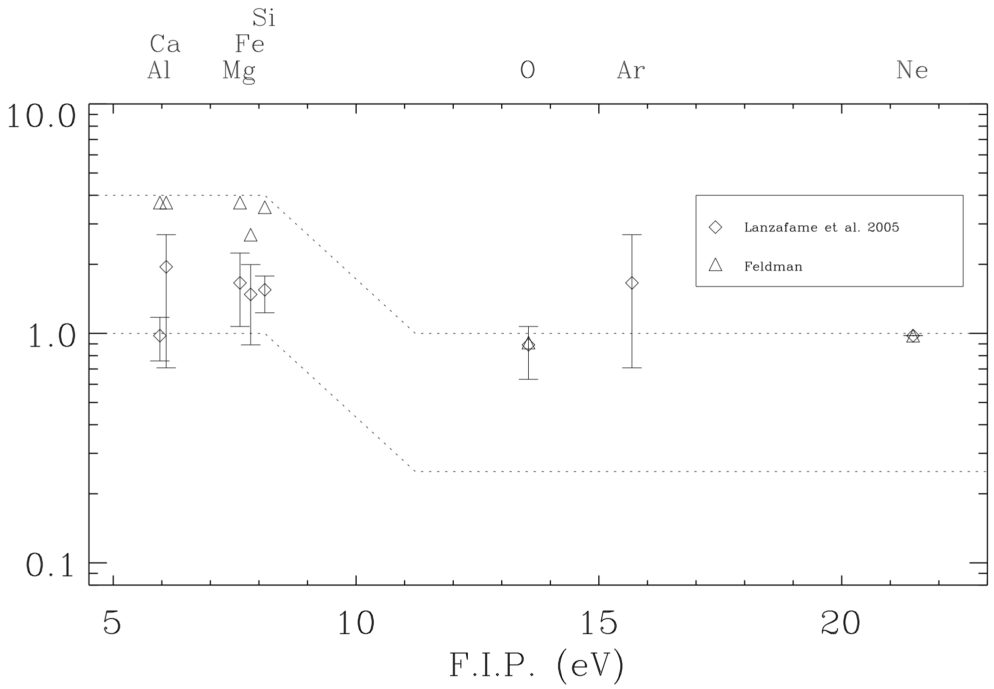

Fig. 1. Lanzafame et al. (2005) abundances compared with Feldman et al. (1992) coronal abundances. See Lanzafame et al. (2005) for details.

2. The QS abundance of Ca and Al from CDS spectra.

Lanzafame et al. (2005) find abundance enhancement factors below two except for Ca, whose abundance derived from the mean spectrum is 2.1 photospheric. However, using lines of Al x and Ca x, without considering other ions of these elements, the derived abundances would be about four times photospheric and therefore close to coronal values. It is the inclusion of lines of Ca viii, Al vii, Al viii, and Al xi that leads to estimates of the Ca and Al abundances close to photospheric. A likely explanation is that the accuracy of the atomic data for ions of Ca and Al are still below the requirements for this type of analysis. However, Lanzafame et al. (2005) suggests also the possibility that there is some enrichment process taking place, which affects some of the ionisation stages of the elements with the lowest FIP more than others, a scenario that would be in line with other observations (see Feldman & Laming 2000 and Feldman & Widing 2003 for extensive reviews) and with the recent model of Laming (2004).

Analysis of the sub-areas considered shows small abundance variations with position. The only noticeable exception is the Ca abundance, which shows enhancement factors up to 4 – 5 in some narrow brightening regions. The lines of Al vii at 356.892 Å, Al viii at 328.298 Å, Al x at 332.788 Å, and Al xi at 550.040 Å with peak formation between $\log T_e = 5.75$ and 6.15 are available for the analysis. In Fig. 2 the ratio of theoretical vs. observed intensity of these lines as a function of temperature of peak formation is shown for the mean spectrum and for some of the sub-areas considered. Such ratio shows a systematic decrease for Al viii ($\log T_e = 5.90$) and Al x ($\log T_e = 6.10$), which would imply an increase of the Al abundance well above the derived close-to-photospheric

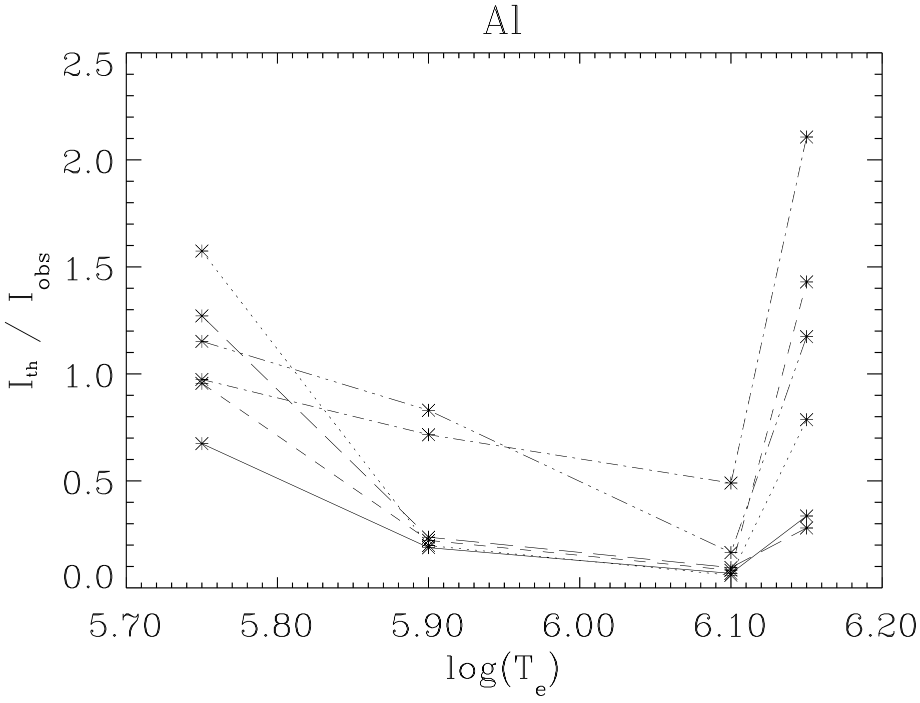

Fig. 2. Ratio of theoretical vs. observed intensity for lines of Al ions as a function of temperature of peak formation. Lines are drawn to help the eye and to mark the results for the mean spectrum (solid line) and for subregions 1 (dotted), 2 (short-dashed), 4 (dot-dashed), 5 (triple-dot-dashed), and 7 (long-dashed) (see Lanzafame et al. 2005).

value. Only lines of Ca VIII and Ca X, with peak formation at $\log(T_e) = 5.75$ and 5.80 respectively, are available for the analysis. Their behaviour is found very similar to the Al lines (see Fig. 2) in the same temperature range.

3. Conclusions

The application of the DEM technique to EUV spectra allows to derive the transition region and inner corona abundance of several elements irrespective of the ionisation stage. The analysis of QS spectra indicates a photospheric composition of the transition region and inner corona with small variation from region to region. Some enhancement may be present for elements with the lowest FIP, i.e. Ca and Al, but the results depend on the ionisation stage considered. The likely explanations are that either the accuracy of the atomic data are still below the requirements for this type of analysis or there is some enrichment process taking place, which affects some of the ionisation stages of the elements with the lowest FIP more than others.

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