TRANSITION REGION DYNAMICS FROM SUMER/SOHO OBSERVATIONS: SHAPE OF THE EMISSION SPECTRAL LINES

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ABSTRACT

The quiet sun network/internetwork transition region line profiles of CII 13036.34 Å and OVI 1037.61 Å are outlined emphasizing the temporal/spatial behaviour of their deviations from the Gaussian shape. Systematic deviations of the line profiles from the single-Gaussian shape indicate that transition region emission lines consist of two Gaussian components over almost the whole quiet sun internetwork except their small innermost parts. This finding is in qualitative agreement with the transition region model of Peter (2001).

1. INTRODUCTION

One of the principal scientific objectives of the SOHO mission is the study of heating mechanisms of the upper solar atmosphere including the transition region and the corona. Some of the previously proposed mechanisms should be detected by spectral profile changes or by the spatially unresolved spectral profile broadening of the lines originating in the chromosphere, transition region and corona.

Several SUMER observations of the dynamics of the solar outer layers, especially in the chromosphere and the transition region, have been performed up to now in the quiet solar atmosphere. Results based on line intensities and line shifts as well as on UV continuum intensity, taken in the quiet solar atmosphere, have shown, that both, the internetwork and network transition region are highly dynamic, displaying different spatial and temporal properties of plasma motions. Other studies of the quiet solar atmosphere have been focused on the average Doppler shifts of lines and the non-thermal line broadening of the emission lines, originating in the transition region and in the corona. Recently it was clearly shown that not only the transition region lines originating in explosive events (e.g., Innes et al., 1997, Perez et al., 1999) but also in quiet network away from active regions (Peter, 2000) consist of multiple Gaussian profiles. The decomposition of the line profiles into two (network) or more (explosive events) components has allowed to develop forward models of the transition region in network as well as of explosions (e.g., Peter, 2001, Roussev et al., 2001).

Working with emission line profiles recorded by SUMER, which originate in the transition region, we have investigated how large are the deviations of the line profiles from the single Gaussian shape for different areas in the solar quiet atmosphere transition region. Here the first results are presented including some new results for the internetwork line profiles.

2. INSTRUMENT

The SUMER spectrometer is a high-resolution normal-incidence spectrometer on SOHO mission allowing to investigate solar processes over the temperature range from 10⁴ to 2 × 10⁶ K with high spatial, spectral and temporal resolutions in the EUV spectral range (Wilhelm et al., 1995). Summaries of its in-flight performance were presented in papers of Wilhelm et al. (1997) and Lemaire et al. (1997). The typical exposure times of tens of seconds were found to be required for the appropriate profile determination of the pronounced spectral lines with spectral resolution around 22 mÅ using the highest spatial resolution of the telescope which is well below 2″ (Lemaire et al., 1997).

3. DATA

The SUMER data set, analysed in this contribution, has been acquired on 5 May 1999 (6ʰ02ᵐ – 7ʰ58ᵐ) as a joint observing programme (JOP 78).¹ The set is a time series of 71 full detector spectral images covering the spectral range 1021 – 1043 Å containing the emission line of H\textsc{i} Ly\alpha, several lines

¹JOP 078 proposal is available at www.astro.sk/~choc/jop078.prop/

of OI, two CII lines and two lines of O VI. The integration time was 100 s limited by the telemetry rate. Data were acquired on the central part of detector B using the 1"×120" entrance slit oriented in the NS direction. No compensation of the solar rotation has been used; therefore the slit has rastered an area almost 20" wide in the EW direction during almost 2 hours of observations. A quiet sun area ~250" away from the disk center was observed, thus avoiding active regions visible on the disk. In this contribution only the spectral subimage around two CII lines (1036.34 and 1037.00 Å, 3×10^{4} K) and one O VI line (1037.64 Å, 3×10^{5} K) is used together with two other sub-images containing the UV C I continuum areas between 1034.35–1035.50 Å and 1039.7–1040.6 Å. These sub-images are 100, 26 and 20 pixels wide respectively.

4. DATA REDUCTION

The basic data reduction was performed with help of the standard SUMER reduction procedures. All data have been decompressed according to the compression algorithm applied on board. The relative sensitivity of the pixels of the detector was taken into account using the deep flat-field data obtained on 18th March 1999. Aberrations of the spectral images were corrected using the available destretching algorithm with its auxiliary data. The thermoelastic oscillations of the spectrometer mechanical structure (Curdt et al., 1997) were carefully corrected with the line shift uncertainty less than 1 km/s using the procedure described by Rybak et al. (1999). Slight curvatures of the spectral lines remaining after the destretching correction were removed subtracting the residual line position variations along the slit, derived from measurements of the internetwork regions. Data were also converted to physical units using the radiometry procedure. Neither spatial nor temporal binnings were applied setting the final resolutions to 1" and 100 seconds respectively. The spatial dimension of the final spectral images was limited to 117 illuminated pixels (118°). The wavelength scale calibration was made using the lower temperature OI and CII lines from all available spectra of the internetwork measurements. The UV continuum intensity was calculated as a mean intensity over the whole width of both continuum spectral sub-images.

References:

2. www.lmipi.mpg.de/english/projekte/sumer/text/cookbook.html
Finally each spectral profile containing two C II and one O VI line was fitted using 3 simple Gaussians and a constant background simultaneously. The CFIT algorithm of S.V.H. Haugan was used for this exercise using the relative weights of the data. The data weights were determined according to Poisson noise statistics when data noise was estimated by the square root of data intensity (in instrumental units). The CFIT algorithm determines the best fit by minimizing the weighted $\chi^2$ values,

$$\chi^2 = \frac{1}{\nu} \sum_{i=1}^{N} \frac{(y_i - y(x_i; a_1, ..., a_M))^2}{\sigma_i^2},$$

where $\sigma_i$ is the weight for each spectral point $(x_i, y_i)$, $N$ is number of spectral points, $M$ is number of fitting parameters, and $\nu = N - M$ is the degree of freedom.

Our search for the deviations of the line profiles from the simple Gaussian was made with help of the normalized fit residuals $n_i$ calculated as $(y_i - y(x_i; a_1, ..., a_M))/\sigma_i$ for each spectral point $(x_i, y_i)$. These normalized fit residuals should be featureless without any systematic structure along the spectral profile as well as along the spatial and/or temporal direction if the measured profiles of spectral lines are really simple Gaussians.

5. RESULTS AND DISCUSSION

The time-slit maps of C II and O VI lines (Fig. 1, upper panels) show that during measurements the slit passed over two low emission internetwork areas, $[30^\circ - 45^\circ] \times [40^\circ - 60^\circ]$ and $[55^\circ - 75^\circ] \times [80^\circ - 115^\circ]$, one very pronounced network area $[(75^\circ - 85^\circ] \times [30^\circ - 115^\circ)]$ with four brightenings seen, especially in the O VI line, and some other network areas (e.g. $[10^\circ - 35^\circ] \times [80^\circ - 115^\circ]$). The rest of the time-slit area, created by the slit drift scan, is occupied by intermediate emission intensity of both lines and continuum. Fit residuals $\chi^2$ (Fig. 1, lower right panel) are mostly below 1 in internetwork and areas of the intermediate emission. Just in network $\chi^2$ is above this level reaching values higher than 8 in the network brightening ($\sim 80^\circ$ at $45^\circ, 55^\circ, 70^\circ$ and $90^\circ$).

The time-wavelength behaviour of the C II and O VI line profiles for two particular slit positions—the most enhanced network intensity (81") and the lowest internetwork intensity (40") are shown in Fig. 2.

Deviations of the explosive events spectral profiles seen in the transition region lines from the single Gaussian are well known for a long time (see e.g. Mariska, 1992). This is also documented in case of our measurements in form of the normalized residuals in Fig. 3 (left panel), where the temporal behaviour of C II and O VI line profiles is displayed in the enhanced network position 81". Here especially in four brightenings large deviations from single Gaussians are visible as bright/dark areas dominantly on the red wings of the spectral lines. Parallel vertical double strips in this panel, which are seen on all profiles also before the network enhancement starts, show that also the quiet network transition region profiles are composed of two simple Gaussians what is also already known fact (e.g. Peter, 2000).

Surprisingly, systematic deviations of the measured line profiles from single Gaussians were found also at the most quiet internetwork position 40" (Fig. 3, right panel). They are again represented by similar parallel vertical double strips as in the left panel of Fig. 3. The only temporal interval where these strips...
Figure 3. Normalized residuals after simple Gaussians fits of the measured spectral profiles as a function of time for two CII lines and one O VI line at two slit position mentioned above (Fig.2). While the continua (e.g., on the left edges of the plots) display no significant systematic features, the line profiles show systematic vertical structures, symmetrically placed along the line centers, which result form deviations of the fitted spectral lines from the single Gaussians.

are missing is that of the lowest C II and O VI line emission in period from 45"-60", what corresponds just to 2"-3" in the EW spatial direction. The normalised residuals show that the core intensities of the measured lines were higher than the fitted maximal Gaussian intensities. The wings of the measured lines were less intensive than the fitted Gaussian wings. Therefore it seems that for almost whole internetwork area the transition region line profiles are composed from two Gaussian profiles. Thus it can be expected that through and comprehensive multi-Gaussian-fit analysis may provide more detailed information on the structure and dynamics of the transition region.

Nevertheless this result has to be confirmed by other sets of SUMER observations first, while particular interest should be given to the signal-to-noise estimation, which plays a significant role in the process of spectral line fitting. Also other possible solar effects (e.g. line blends) and/or instrumental effects (e.g. detector destretching algorithm residuals) should be checked carefully.

6. CONCLUSION

Systematic deviations of the C II and O VI line profiles from the single Gaussian shape indicate that two Gaussian components are needed for the transition region emission lines fitting over almost the whole quiet sun internetwork except for the small innermost parts of internetwork. This is qualitatively consistent with the transition region model developed by Peter (2001). In case of analysis presented here, the small loops should occupy rather large areas of the internetwork except for its lowest emission center.

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