ON RELATIONS AMONG THE CALIBRATED PARAMETERS OF THE TRANSITION REGION SPECTRAL LINE

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ABSTRACT

SUMER/SOHO measurements of the O vi 1031.93 Å emission line (280000 K) in the network and internetwork of the transition region of the quiet solar atmosphere are used for a statistical analysis of the calibrated spectral parameters: the central line intensity (energetic units), the line width (mÅ) and the Doppler shift (km/s). A detailed procedure is performed in order to determine the absolute wavelength calibration of the spectra and Doppler shifts using simultaneously observed chromospheric O I 1027.44 Å and 1028.15 Å emission lines (10000 K). The spectral parameters of the O vi line are derived for both single and double Gaussian fitting of the line according to the latest findings on the multi-component nature of the transition region line profiles. Reliability of the absolute wavelength calibration and effects of two classes of the transition region transient events – explosive events and blinkers – are discussed in relation to the overall dependencies of the spectral parameters.

In this contribution the first preliminary results are presented from our statistical study of the O vi 1031.93 Å emission line (280000 K) measured in the quiet Sun network.

2. INSTRUMENT

The SUMER spectrometer is a high-resolution normal-incidence spectrometer on SOHO [3] allowing to investigate solar processes over the temperature range from \(5 \times 10^5\) to \(2 \times 10^7\) K with high spatial, spectral and temporal resolution in the EUV spectral range [4,5]. Typical exposure times of tens of seconds were found to be required for appropriate profile determination of the pronounced spectral lines with spectral resolution elements of \(\sim 22\) mÅ (2nd order) using the highest spatial resolution of the telescope which is well below 2″ [5].

3. DATA

Many 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 Doppler shifts as well as on UV continuum intensity taken in the quiet solar atmosphere have shown that both 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 the transition region lines originating in the quiet sun network away from active regions consist of multiple Gaussian profiles [1]. The decomposition of the line profiles into two components has allowed to develop forward models of the transition region in network and internetwork [2].

The SUMER data set, analyzed here, has been acquired on 5 May 1999 (6h02m – 7h58m) as a part of the joint observing program JOP 78.1 The set consists of a time series of 71 full detector spectra covering the spectral range from 1021 Å to 1043 Å including the emission line of H i Ly β, several lines of O I, two lines of C II and two lines of O vi. The integration time of 100 s was limited by the telemetry rate. Data used here were acquired on the bare part of detector B using the 0.38”×120” entrance slit oriented in the NS direction. No compensation of the solar rotation has been used; therefore the slit has rastered an area of almost 20” in EW direction for almost 2 hours of observations. A quiet sun area ~250” away from the disk center was observed to avoid active regions visible on the disk. In this contribution only the spectral window of 50 pixels around the O vi 1031.93 Å line is used together with another window containing the far red wing of the H i Ly β line where two chromospheric O I lines (1027.44 Å and 1028.15 Å) are located. The spectra extended over 114 pixels along the slit (115”).

1www.astro.sk/~choch/jop078.prop/


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Figure 1. The normalized histograms of the reduced squared residuals $\chi^2_r$ derived from the single (thin line) and double (thick line) Gaussian fits applied to all O\textsc{vi} line profiles.

4. DATA REDUCTION

The basic reduction of data was performed with help of standard SUMER reduction procedures.\textsuperscript{2} All data have been decompressed according to the compression algorithm applied on board and the local gain correction was applied. The relative sensitivities of the pixels of the detector were taken into account using the deep flat-field data obtained on 18th March 1999. Temporal shifts of the flat-field pattern have been determined and the advanced flat-field correction was applied with the odd-even pattern corrected first and then the shifted flat-field pattern was taken into account.\textsuperscript{1} Aberrations of the spectral images were corrected using the available destretching algorithm and its auxiliary data. The thermoelastic oscillations of the spectrometer mechanical structure\textsuperscript{6} were determined using positions of the O\textsc{i} lines and the residual shift of the spectral image of 0.8 pixel was found. Correction was applied with the line shift uncertainty less than 1 km/s using the special procedure\textsuperscript{7}. Counts were converted to physical units using the radiometric calibration procedure.\textsuperscript{3} Spatial binning was applied setting the final resolutions to 2" and 100 seconds. The calibration of the absolute wavelength scale was made using two chromospheric O\textsc{i} lines (see below).

Each spectral profile of O\textsc{vi} line was fitted using optimization powered by a Generic Algorithm\textsuperscript{8} which was used successfully for such tasks\textsuperscript{9,10,1,2}. The output of the global Generic Algorithm was then used as an input to the local algorithm performing fitting based on Levenberg-Marquardt least-squares fit of a function (mpfitfun from the SSW).\textsuperscript{4} These two algorithms are based on minimizing the reduced squared residuals $\chi^2_r$ which is the sum of the weighted residuals between the measured spectral data and their fit. The statistical weights were determined according to Poisson noise statistics when data noise was estimated by the square root of data values. Single and double Gaussian fitting functions with a constant background were used for each spectral profile of O\textsc{vi} line. Just single Gaussian fits with a linear background were applied in the case of two O\textsc{i} lines. Comparison of the $\chi^2_r$ values derived for the single and double Gaussian fits of the O\textsc{vi} line profiles is shown in Figs. 1 and 2. Moreover the fitted parameter of the Gaussian width was then corrected for the instrumental broadening of the line.

Two O\textsc{i} lines located less than 5\AA\ apart from the O\textsc{vi} line in direction towards the edge of the detector were selected for the wavelength calibration. The overall positions of these lines were derived from spectra corrected for the temporal shift of the spectra caused by the thermoelastic oscillations of the mechanical structure of the spectrometer. The values of the overall O\textsc{i} line positions are 16.79 px and 33.33 px in the spatial direction. The data of reference wavelength for these two O\textsc{i} lines – 1027.44 and 1028.15 \AA\ [11] – were used for the linear fit of the absolute wavelength scale. The fit coefficients of 1021.777 \AA\ and 0.0429 \AA/px give the zero wavelength value for the blue edge of the recorded spectrum and the value of the spectral dispersion for the left bare part of the spectrum, respectively. We have assumed that the chromospheric lines of neutral atoms should statistically exhibit no significant line shifts, compared to the large line shifts of the transition region lines.
5. RESULTS AND DISCUSSION

The following results on the narrower and brighter core component (CC) and the broader and weaker tail component (TC) of the O VI line profiles were derived from the performed analysis. The normalized distributions of the reduced squared residuals $\chi^2_r$ derived for the whole data set using the single and double Gaussian fits show significant decrease of residuals of the double Gaussian fits compared to the single ones (Figs. 1 and 2) in agreement with the previous results obtained for this line [2]. Nevertheless there are some line profiles for which the residuals seem to be still above the theoretical optimal curve of $\chi^2_r$.

All fits for which the corrected Gaussian line width were smaller than the ion sound speed ($\sim 17$ km/s) valid for the medium with the temperature where the O VI line is formed were excluded from the analysis (1499 profiles). The double Gaussian fits were considered to be superior to the single Gaussian fits if addition of the second component significantly decreased the $\chi^2_r$ value (ratio of the single and double fit $\chi^2_r$ values less than 0.9). Moreover only those results of the whole data set with the $\chi^2_r$ less than 1.7 were selected for the later analysis. In this way 256 single Gaussian profiles having the core component only and 1586 double Gaussian profiles consisted of both core and tail components were derived. The rest of the line profiles (707) were left without more detailed investigation due to unreliable Gaussian fits (either single or double). Nevertheless severe deviations from the single and double Gaussian profiles can be expected in these 707 line profiles. Distribution of $\chi^2_r$ values of the selected fits is shown in Fig. 2.

Scatter plots, where intensities I, Doppler shifts V and Gaussian line width W of the core component CC and the tail component TC are compared, are shown in Fig. 3. Intensities of the tail component $I_{TC}$ are mostly only a fraction (1/10–1/3) of the core component intensity $I_{CC}$. Nevertheless there were found also examples of almost similar intensities of both components. The line widths $W_{CC}$ and $W_{TC}$ of line components show quite clear linear relation. The $W_{CC}$ and the $W_{TC}$ widths were found to be in the range 17 km/s–40 km/s and 50 km/s–100 km/s respectively. Using the determined absolute wavelength scale the mean Doppler shift of the core component was found to be red-shifted only for $+0.06$ km/s contrary to the well approved previous results of $-5$ km/s (e.g., [12,10]). No other significant statistical relations between the CC and TC Doppler shifts were found.

Searching for possible explanation of this discrepancy it was found that there exists a residual curvature of the O I lines exposed near the edge of the detector (Fig. 4). If this curvature of the spectral image varies along the spectral direction of the detector it can produce an uncertainty of roughly 0.5 pixel. This value ($\sim 6$ km/s) is comparable with the value of the overall redshift of the

![Figure 4. Spatial behaviour of the residual curvature of the O I lines derived as the average from all spectra. Thick and thin lines show mean positions of the O I 1027.44 Å and 1028.15 Å lines, respectively.](image-url)
Figure 5. Scatter plots of the fits results for the core (right panels) and the tail (left panel) components of the O VI line. Dotted lines show mean Doppler shifts of the core or tail components (upper and bottom panels). For the Doppler shifts scale details see the text.

O VI line. Therefore for this moment the Doppler shift results, presented in this contribution, can be interpreted only as the commonly used wavelength scale for which the reference point corresponds the mean Doppler shift of the core component [1,2]. The difference between the mean Doppler shifts for the core and tail components was found to be +2.25 km/s what is in agreement with the previous result [2].

Comparison of the spectral line parameters I, V, and W of each component separately is shown in Fig.5. The CC results (left panels) show increase of the redshift of the Doppler line velocities $V_{\text{CC}}$ with increasing intensity $I_{\text{CC}}$. No similar relation was found for the tail component. An inverse dependence was derived between the line width $W_{\text{TC}}$ and intensity $I_{\text{TC}}$ for the tail component while no such relation was documented for the core com-
ponent. No significant relations were found between the Doppler shifts and the line width for both CC and TC components.

Reported results can be compared with the results obtained for C iv 1548 Å line (100000 K) [1] although these results come from a significantly larger data set. Only results on relation between the line width and the line intensity for the O vi tail component is in agreement with the results derived for C iv line [1].

It seems that before the final conclusions will be drawn a more detailed fitting of the O vi line profiles has to be performed introducing the rigid a priori constrains (mainly limit of the minimal Gaussian width for each component) on the whole set of O vi data (see [9]). This approach should allow us to return back to the analysis large fraction of line profiles rejected due to too narrow fitted components.

6. CONCLUSIONS

The following preliminary conclusions can be derived from the performed two-components analysis of the O vi line profiles. Firstly, roughly 1/6 of the investigated O vi line profiles show significant deviations from both single and double Gaussian profiles. This significantly large fraction calls for further analysis of these profiles in relation to the blinker and explosive events occurrence similarly to the approach already developed [13,14].

Secondly, clear correlation between the line intensity and the line width of the tail component of the O vi line and possible correlation of the Doppler shifts and the intensity for the core component were revealed using this limited data set.

Finally, the original idea to apply the absolute wavelength calibration for the SUMER data failed because of ~5 km/s difference between the derived mean Doppler shift of the core component and the overall redshift of the O vi line. Further analysis of the proposed possible reason of this difference will be performed in order to correct wavelength scale to the reasonable zero point.

It is important to confirm significance of the derived preliminary results using rigid a priori constrains applied to the fitting algorithms in order to avoid rejection of a large fraction of profiles having too narrow components of the O vi line in this data set.

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