CHROMOSPHERIC OSCILLATIONS FROM SIMULTANEOUS SEQUENCES OF HeI 1083 AND CaII K 393.4 SPECTROSCOPIC MEASUREMENTS

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ABSTRACT
Recent numerical simulations based on rather new views of chromospheric models succeeded in reproducing the details of the temporal behavior of the H or K line profiles of Ca II. Upward propagating 3 min shocks are predicted for a stratified or 1D non-magnetic chromosphere.

Thanks to the capabilities offered by modern detectors, chromospheric oscillations can now be analyzed up to the bottom of the transition region with high temporal resolution, and several heights of line formation can be recorded simultaneously. From observations collected at the VTT of NSO/SPO using the horizontal spectrograph, new dynamical properties of the quiet chromosphere were derived over an 83 mn long sequence.

For both the magnetic network and especially the intra-network (no trace of magnetic field), amplitude spectra of Doppler velocities were computed in K3 and 1083 of He I. We focus the present analysis on the high frequency part of oscillations above 4 mHz. Time-frequency diagrams computed using the wavelet transform of velocities in both lines in 2 intra-network regions are presented to illustrate the temporal behavior of chromospheric oscillations in the whole frequency range. Several wavevains presumably propagating at different heights where the lines are formed are analysed. We confirm that the waves simultaneously measured in different lines are well in phase, therefore excluding a propagation. Wavevains with power at frequencies up to 12 mHz and more are observed in both lines. Possible inferences for future SOHO observations are considered.

1. INTRODUCTION

An abundant literature is available on chromospheric oscillations; we notice that an excellent review exists by R. Rutten (1994), with 140 citations, where some relevant good papers are still missing, e.g. Kosovichev and Popov (1981) or Venkatakrisnan et al. (1992). These last papers considered 2 points we want to emphasize here: i) the occurrence of 3 min oscillations as the result of the existence of a cut-off frequency in the chromosphere; ii) the use of the 1083 nm He I line as an excellent diagnostic for waves at the top of the chromosphere and also, because it is an optically thin line where velocities are readily extracted. Oscillations in the intra-network (IN) called also cell interior or internetwork, are well observed on chromospheric lines, starting from the Ca II K line; however, the interpretation of its profile is tightly connected to the problem of the modelling of the chromospheric atmosphere. Recently Carlsson and Stein (1994), performed beautiful numerical simulations and succeeded in reproducing in details the Ca II H line profile based on a model of the chromosphere which does not require the classical temperature increase above the temperature “minimum” when the time-average is considered. This result, if correct, has important consequences on the work of modellers of both the chromosphere and the transition region. An other crucial aspect of these simulations concerns the propagating properties of the waves which were already questioned by Fleck et al. (1994), based on the analysis of a large f.o.v. material. The numerical simulation assumes a stratified 1D-atmosphere; measurements are performed over the real solar atmosphere which is highly inhomogeneous (in space and time) starting from the bottom of the chromosphere; therefore it is not clear how the heights of formation of lines or even parts of lines are related; a convincing well-known example is the Hα line. To test the propagating properties of wave phase-shifts measured between velocities of different lines, values averaged in horizontal direction were used (160° x 160°) in the case of Fleck et al. (1994).

In this paper we will consider more limited areas of the IN and the top layers of the chromosphere simultaneously observed in K3 and in He I 1083. Precise measurements were made possible thanks to the use of modern CCD detectors with a linear response and a large dynamics. More importantly in our case, especially for the analysis of the weakly deep 1083 line, we used detectors with a highly reproducible and stable flat-field over the whole sequence. Additionally, excellent earth-atmospheric photometric properties have made possible a large improvement of signal-noise ratio by integrating over many pixels in both spectral and space directions, without losing the effective resolution imposed by both the rather wide slit-width and the seeing, distortion, blurring and image motion. The regions we measured were accurately chosen based on photographic UBF filtergrams taken in different lines and also by looking on the video movie recorded in real time in the wing of...
the Hα line (Hα-70 pm). They are well outside active regions, at the center of the disc, and they avoid the network.

2. OBSERVATIONS

Observations of the quiet Sun were performed at the Vacuum Tower Telescope of the NSO/SP on March 22, 1993, simultaneously in two lines: He I line at 1083 nm and Ca II K line at 393.3 nm. Different channels of the spectrograph and different CCD cameras were used to collect the data. The key parameters are summarized in Table 1. The field of view of the analysed intra-network regions (IN1 and IN2) is shown in the blue wing of the Hα line (Fig. 1a) and in the red wing of the Hα line (Fig. 1b). More details concerning the observations are given in Bocchialini et al. (1994).

Table 1: Observation key parameters.

<table>
<thead>
<tr>
<th>Exposure time</th>
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<tr>
<td>Cycle time</td>
<td>5 s</td>
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<tr>
<td>Duration</td>
<td>83 mn</td>
</tr>
<tr>
<td>Field of view</td>
<td>38&quot;x2.3&quot;</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>2.3&quot;</td>
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<tr>
<td>Spectral dispersion</td>
<td>5.8 pm/px in Ca II K</td>
</tr>
<tr>
<td></td>
<td>17.2 pm/px in He I</td>
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</tbody>
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3. ANALYSIS

The procedure concerning the dark current and flat-fields corrections are described in Bocchialini (1994).

We recorded a 910 s movie (Bocchialini et al., 1995) of the spectra in both lines and we extract typical sequences to illustrate the large variabilities observed simultaneously in both lines (Fig. 2). The absence of any detectable motion of the telluric H2O line at 1083.2 nm indicates that the observed variabilities over He I at 1083 nm and Si I at 1082.7 nm are of solar origin; this is specially convincing watching the movie.

We first focus our analysis on the Doppler velocities of the two lines, in IN1 and IN2. The Doppler velocity is computed from the difference of the intensities in the blue and in the red wings, close to the line center. The temporal variations over the 83 mn of the sequence is displayed in Fig. 3. We observed a periodic signal, with a dominant frequency close to 6 mHz. The amplitudes are smaller in He I 1083 (peak to peak value: ±3 km/s in IN1 and ±2 km/s in IN2) than in Ca II K (±11 km/s in IN1 and ±8 km/s in IN2); these values are comparable with the results presented by Fleck et al. (1994), who used a

Figure 1: a) b1:40 pm filtergram to show the f.o.v of the analysed regions IN1 and IN2; we show the selected parts of the quiet chromosphere taken along the slit. b) the same in Hα+50 pm. Note the absence of trace of magnetic activity in the analysed regions IN1 and IN2, and a well-defined network element between these regions. Prints are both in positive.
Figure 2: Selected spectra in Ca II K (at left) and He I 1083 (at right) to illustrate the large variabilities observed simultaneously in both lines. The black line on the right side of the He I spectra is the H$_2$O line (1083.2 nm); on the left side of the same spectra is the Si I line (1082.7 nm). Note near the center of each frame the signature produced by the network element.
Figure 3: Temporal variations of the velocities measured over the regions IN1 and IN2, in Ca II K and He I 1083 lines.

Figure 4: Time/frequency diagrams computed using the method of wavelet transform.
Figure 5: Variation of the correlation coefficient $C(\text{He}/K)$ as a function of time lags. Several wave trains are considered for IN1.

In order to obtain information both in time and frequency, we performed a wavelet transform (see Bocchialini and Baudin, 1995, for details) on these velocities. The squared modulus of the wavelet transform (energy) is displayed for the two lines separately for region IN1 and region IN2 (Fig. 4). We observe several wave trains; the maximum of the energy is often located around 6 mHz. Moreover, the wave trains have significant energy at higher frequencies, up to 12 mHz. Furthermore, we looked for phase shifts between velocities observed in He I 1083 and Ca II K. As a result of the time/frequency analysis, we selected the most representative wave trains in IN1 (around $t=3000$ s and around $t=4000$ s) and in IN2 (around $t=4000$ s). The computation of the variations of the correlation coefficient for different time lags, $C(\Delta t)$,

$$C(\Delta t) = \frac{\Sigma(v_{Ca}(t),v_{He}(t+\Delta t))}{\sqrt{\Sigma(v_{Ca}^2(t)),\Sigma(v_{He}^2(t))}}$$  \hspace{1cm} (1)$$

was performed using these wave trains. The result is shown in Fig. 5; we observe a maximum of the correlation coefficient for a 0 time lag, which means no phase shift between velocities measured in both lines. Considering the signal/noise ratio in each burst we selected from the wavelet analysis, we found not useful to perform a frequency dependant analysis of phase shifts. Accordingly, we claim here only an absence of phase shift at the dominant frequency which is close to 6 mHz, see Fig. 4.

Finally, we looked at intensity modulations in the He I 1083 line which is optically thin. The measured depth is typically 2% (in the network, see Fig. 1b, we measured a depth several times larger). Depending on the region, their very low frequency fluctuations are up to $\pm 1\%$. The same analysis performed over the nearby continuum shows amplitude variations of the same amount. As far as the high frequency variations are concerned, the behaviors are different. Fig. 6 presents the results of a Fourier analysis of the whole sequence in both regions. For the depth variations, it clearly shows the presence of power in the frequency range 3-12 mHz; for the continuum, it is not exactly the case. These preliminary results seem to indicate that oscillations can be measured using the optical depth of the He I 1083 line.

4. DISCUSSION AND CONCLUSIONS

After selecting 2 regions of the intra-network situated at different distances from a well developed network region (see Fig. 1a and b), we performed a careful analysis of velocity oscillations over the whole range of frequencies situated in the 4 to 14 mHz range (see Fig. 3 and 4); we found no phase shifts between velocities measured in K$_3$ of Ca II and those measured in 1083 of He I (see Fig. 5). When a canonical hydrostatic 1D model of the chromosphere is used, these lines are formed at significantly different levels, which would mean that chromospheric oscillations we observed, with peak amplitudes close to 7 mHz, are non-propagating; it confirms the Fleck et al. (1994) result which is a serious objection against the Carlsson and Stein, (1994) numerical simulations also based on a 1D models of the chromosphere. Fur-
thermore, we also confirm that amplitudes of velocities are smaller in 1083 compared to $K_3$, also in agreement with Fleck et al. However, let us notice that the amplitude of velocities is also a function of the spatial integration length, because the effects due to chromospheric grains probably responsible for a large part of the dynamics of the "non-magnetic" chromosphere are rather concentrated (see Rutten, 1994). More generally, all parameters we measure are averaged values, including integration with heights. We know that the real chromosphere is inhomogeneous and we cannot exclude differential effects of filling factors, e.g. on the formation of the lines.

The result on the absence of phase shifts in IN (see Fig. 5), seems safe if we remember that the same analysis, using exactly the same instrumental parameters, has shown an alternative result when the region of the network was considered, see Bocchialini et al. (1994) and Bocchialini and Baudin (1995). There, a definite phase-shift of order of 20 s was observed, depending on the wavetrain we used; the frequencies are lower, close to 3.3 mHz.

Looking at the high frequency parts of our diagrams (see Fig. 3 and 4) we should first notice that a tendency seems to appear in favor of a possible secondary maximum near 12 mHz, which is the first harmonic of the main oscillation near the cut-off frequency of the chromosphere (see Kosovichev and Popov, 1981, Fleck and Schmitz, 1991). This is specially true if we take into account effects due to the modulation transfer function of the chromosphere, a point which would need a special treatment, although it is clear that velocity oscillations at $f > 10$ mHz are considerably attenuated and the attenuation is different when oscillations of the line depths are considered (see Fig. 6). Harmonics of the main oscillation occurs when non-linear effects due to the formation of the hydrodynamical shock is present. An other effect comparable to a splitting was pointed out by Zuzhzhda (1995). Oscillations are occurring, at the top of the chromosphere which is also the bottom of the transition region, in a moving atmosphere (downflow). Then frequencies are splitted and Zuzhzhda estimated the effect to $\Delta f \sim f/4$. Upward velocities would have higher frequencies, in a downflow. The downflow was measured on the He I 1083 line over the IN, see Bocchialini et al. (1994), and a rather good agreement was found with Venkatakrishnan et al. (1992), although a completely different method was used. Here again we note that in the network region something different is observed; no downdraft is measured at the line center. We conclude that the magnetic field drastically influences the type of oscillations observed at the top of the chromosphere.

Finally, we saw that already with the intensity variations of the Ca II K line, oscillations are well measured; the interpretation is difficult. Therefore, we rely on the He I 1083 line measurements (see Fig. 6), to claim that using for example, EIT observations of He II 30.4 nm line filtergrams, new measurements (free of Earth atmospheric disturbances!) will be possible on SOHO to check how important is the dissipated energy of waves in the high frequency range, compared to radiative losses.

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References