OBSERVATIONS OF SOLAR OSCILLATIONS IN He I 10830 Å

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Abstract. In continuation of a series of studies devoted to the dynamics of the solar photosphere and chromosphere we have attempted to further extend the range of heights in the atmosphere towards the transition region by including observations of the He I 10830 line. We have recorded simultaneous time series of He I 10830 and Mg I 8807 spectra in the quiet solar atmosphere using the echelle spectrograph at the German Vacuum Tower Telescope in Izaña, Tenerife. The velocity signal derived from the Doppler shifts of He 10830 clearly reveals oscillatory motions. The intensity of He 10830, on the other hand, is hardly affected by the oscillations. In the cell interior the 3-min oscillations prevail. Longer periods are found ain the cell boundaries of the chromospheric network where He absorption is enhanced. The V–V phase difference spectrum between the oscillations of He 10830 and those of Mg 8807 confirms previous observations of a non-propagating component that dominates the acoustic wave spectrum in the chromosphere.

Key words: infrared: stars – Sun: atmosphere – Sun: oscillations

1. Introduction

Despite the accumulation of a quite extensive observational data base, and despite considerable theoretical efforts made in the last 25 years several fundamental issues concerning the dynamics of the solar chromosphere are still unsettled, as for instance the heating mechanism (see Ulmschneider *et al.*, 1991), the driving mechanism of spicules (see, *e.g.*, Athay, 1986), the Ca K "bright point" phenomenon (see Rutten and Uitenbroek, 1991), and wave propagation behaviour (running or standing waves?). The two major obstacles on the way to a better understanding of these phenomena are: *a*) the intricate small-scale nature of the chromospheric fine structure which can only be resolved under very good seeing conditions, and *b*) the lack of optically thin lines (in the visible) that could be used as a reliable diagnostic without the uncertanties imposed by radiative transfer effects, and the broad complex line contribution functions of the commonly used lines such as H α, Ca II H and K and the lines of the Ca II infrared triplet. Both obstacles could be easily by-passed by observing UV lines from space (as was done, *e.g.*, by the OSO 8 mission). At present, however, there is no space-borne solar observatory in orbit, and – the OSL project being postponed to the end of this decade – there will be no space-borne solar telescope ready in the near future capable of tackling these problems.

The present paper deals with the last of the questions mentioned above, that of the wave propagation behaviour in the solar chromosphere. In previous studies we have observed the Ca II infrared lines at 8542 and 8498 Å and the Ca II K line (Fleck and Deubner, 1989; Deubner and Fleck, 1990; Deubner *et al.*, 1992). There we arrived at some inconsistent results, conceivably due to the observed resonance lines

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being optically thick. To overcome these difficulties and to gain further information from higher layers in the chromsophere we decided to extend our observational database by including time series of He I 10830 to serve as a reliable velocity diagnostic of the upper chromosphere. Similar motives led Lites (1986) to use He 10830 for his studies on chromospheric sunspot oscillations. Venkatakrishnan et al. (1992) studied the formation of spicules by analyzing spatio-temporal fluctuations of He 10830, and Zhang *et al.* (1991) investigated oscillations of quiescent filaments from observations in this line. He 10830 spectroheliograms, obtained at Kitt Peak National Observatory on a routine basis, were frequently used for comparisons with coronal structures such as coronal holes or X-ray bright points (*e.g.* Harvey and Sheeley, 1977; Kahler *et al.*, 1983; Golub *et al.*, 1989). Here we are using this line for the first time to study oscillatory motions in the quiet upper chromosphere.

2. Observations and Data Reduction

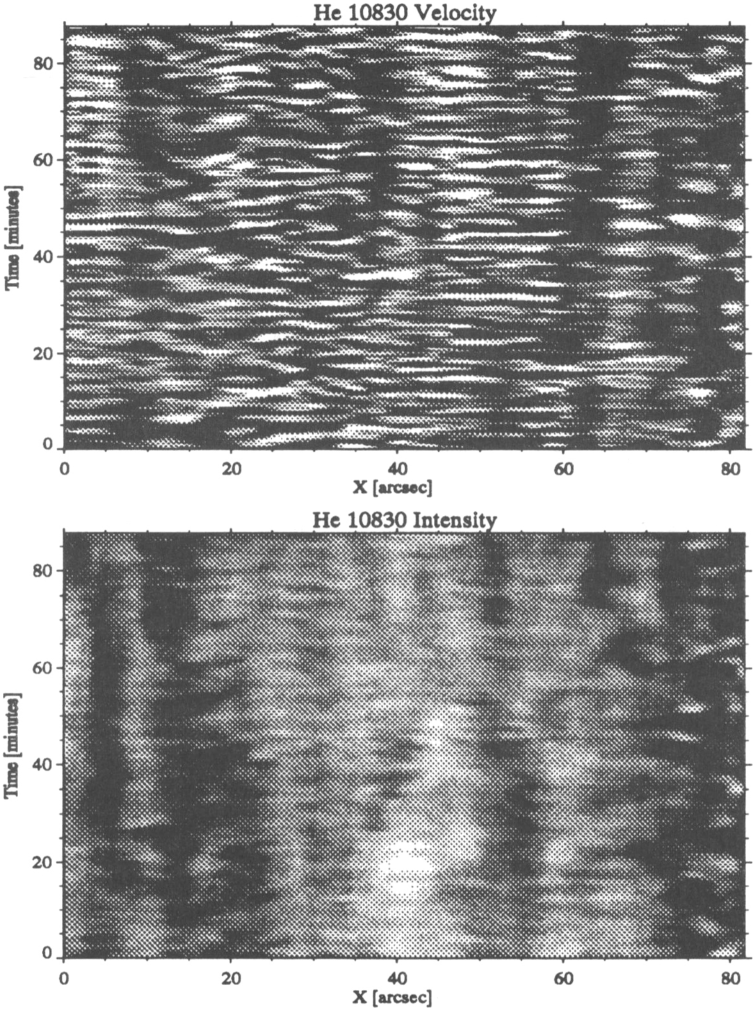
A first set of observations was collected on November 11, 1990 with the echelle spectrograph of the Vacuum Tower Telescope in Izaña, Tenerife. The OSL brassboard CCD camera with a 1024×1024 array of $(18.3\,\mu\mathrm{m})^2$ pixels was used in the 2×2 binning mode to obtain time series of He 10830 spectra alternatively in two positions, $30''$ apart in a quiet region of the disk center. The exposure time was 3 s, and the cycle time for each pair of spectra 24 s. The total duration of the time series was approximately 1.5 hours. The echelle spectrograph was used in the 21st order with an entrance slit of $85''$ length and $300\,\mu$m width ($\approx 1.4''$) With a second 1024×1024 CCD camera, spectra of Mg I 8806.8 Å were recorded synchronously with the He spectra. Seeing was fair.

The light level in the He spectra yielded typical continuum readings of 400 counts, *i.e.*, about 10% of the saturation level of the OSL camera. Therefore, special care had to be taken in performing the dark current and flat field corrections.

From the corrected spectra we deduced the continuum intensity $I_c(x,t)$, and Doppler shift $V(x,t)$ as well as minimum intensity $I_l(x,t)$ of the line profiles by means of a 4th order polynomial fits applied to the line cores. The line intensity was normalized with respect to the continuum intensity ($I = I_l/I_c$). Random excursions of the telescope and guiding errors in the direction of the slit were eliminated by using crosscorrelation techniques. Finally, the $x - t$ wave patterns were analyzed by applying standard Fourier methods (power, crosspower, phase and coherence spectra).

3. Results and Discussion

In Figure 1 we have displayed the spatio-temporal velocity and intensity fluctuations of He 10830 for one of the two time series. The velocity signal exhibits a pronounced oscillatory behaviour, similar to that observed in typical chromospheric lines (like Ca K, or the Ca IR lines). Longer periods are found in the cell boundaries of the chromospheric network (enhanced He absorption), compared to the cell interior where the 3-min oscillations prevail (*cf,. e.g.,* Damé *et al.*, 1984; Deubner and Fleck, 1990). The intensity fluctuations of the core of the He line exhibit remarkably


He 10830 Velocity

He 10830 Intensity

Fig. 1. Spatio-temporal fluctuations of velocity and brightness in the He I 10830 line. Maximum grey scale contrast corresponds to ±2 km s^{-1}, and to $0.93 < I_l/I_c < 0.98$, respectively.

less periodicity than the corresponding velocity fluctuations, and in particular also considerably less periodicity than the brightness fluctuations of the chromospheric lines mentioned before. This striking impression is confirmed qualitatively by Figure 2 where we have displayed the temporal power, phase and coherence spectra of the velocity and brightness fluctuations depicted in Fig. 1. The velocity power spectrum reveals two broad peaks centered at about 3.5 and 5.5 mHz, whereas the intensity power spectrum decreases monotonically.

The coherence spectrum in Fig. 2 indicates reliable V–I phases up to about 6 mHz. In this frequency range we measure a V–I phase of approximately −120°,

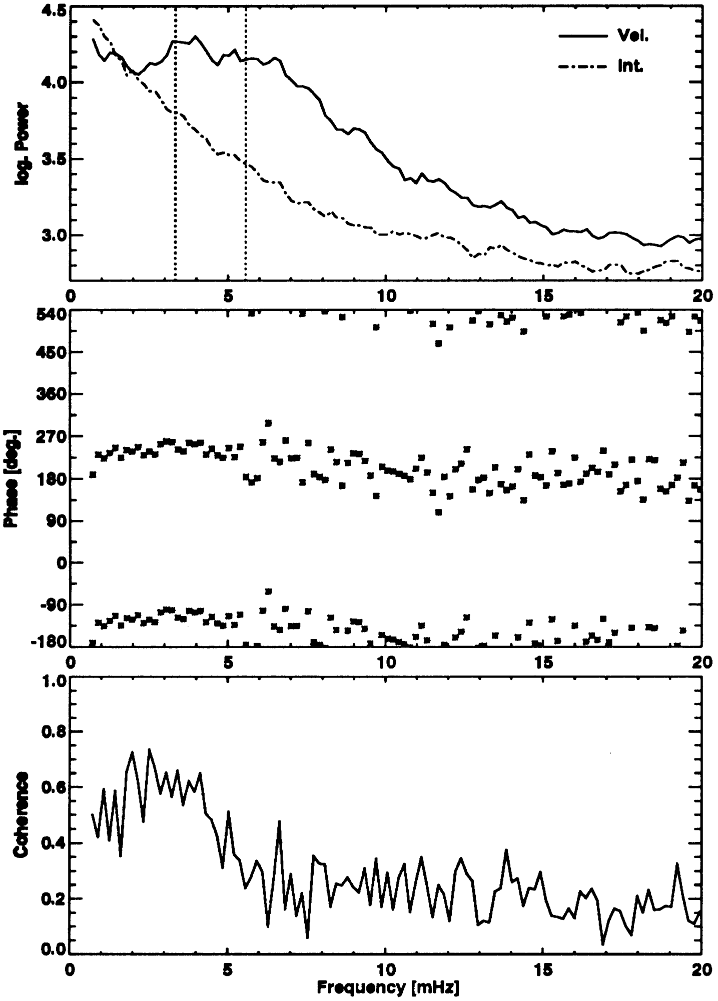


Fig. 2. Power, phase and coherence spectra from the velocity and brightness fluctuations displayed in Fig. 1

brightness preceding upward motion. This result contrasts strongly with the value of −90° expected for adiabatic evanescent oscillations in the chromosphere. We suggest that this behaviour is related to the particular conditions, in the He I absorbing layer, for excitation of the lower level of the 10830 transition, and to the back-radiation from coronal UV lines in particular.

Fig. 3 depicts the power spectra of the velocity fluctuations of He 10830 and Mg 8807 together with the corresponding V–V phase difference and coherence spectra. The Mg line is formed near the temperature minimum at about 500 km above $\tau_{5000} = 1$. As expected, its power spectrum peaks around 3.3 mHz with a slight shoulder at 5.5 mHz. A difference of almost 2 orders of magnitude between the high

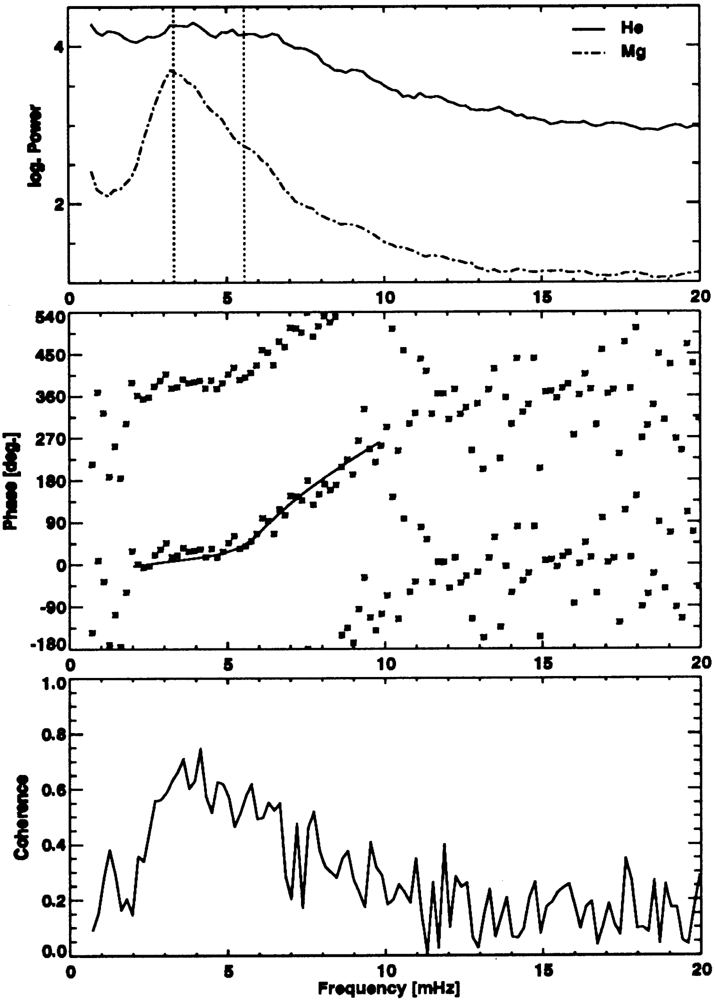


Fig. 3. Power, phase and coherence spectra from the velocity fluctuations of He 10830 and Mg 8807.

frequency levels of the He and the Mg power spectra is partially due to the higher noise amplitude in the He spectra (photon noise plus instrumental effects causing additional uncertainties in determining the Doppler shift of such a broad line).

The coherence lies above noise level in the frequency interval from about 2 to 10 mHz, indicating reliable phases in this range in which we have superimposed a theoretical V–V phase difference spectrum according to the theory of acoustic-gravity waves of Souffrin (1966). The assumed parameters are sound speed c_s = 6 km s^{-1}, mean horizontal wave number $k_x = 0.8$ Mm $^{-1}$, relaxation time $\tau_R = 50$ s, and, most importantly, a height difference Δz between the two line forming layers of only 550 km. The latter parameter is essential for the slope of the spectrum in the acoustic regime above 6 mHz. Assuming that He 10830 is formed in the upper chromosphere at about 1800 km above τ_{5000}=1 and Mg 8807 near the temperature minimum, one would expect a slope according to $\Delta z \approx$1300 km, *i.e.* about 2.5 times steeper than observed. One conceivable explanation for this striking discrepancy could be that the assumed line formation heights are incorrect, i.e. that the lines are formed only about 550 km apart. This explanation, however, appears highly unlikely. Another explanation might be that the phase speed of acoustic waves is about 3 times higher in the chromosphere than in the photosphere, conceivably due to the influence of magnetic fields. However, this explanation does not appear very satisfactory either (for details see Mein, 1977; Fleck and Deubner, 1989; or Fleck, 1991). As a third alternative we suggest a non-propagating pattern of motions in the chromosphere, composed of either standing waves generated by reflection at the transition region (see ref. above), or of harmonics of the chromospheric resonance frequency (Deubner *et al.*, 1992 in prep.). Accordingly the phase difference builds up only in the interval in between the Mg formation height, *i.e.* the temperature minimum, and the "magic height" at about 1000 km (see Fleck and Deubner, 1989; or Fleck, 1991). Above this altitude the whole atmosphere oscillates in phase (or – depending on height – in antiphase).

4. Conclusions

Our preliminary results demonstrate the feasibility of studies of the upper chromospheric dynamics using the He 10830 line as a new diagnostic, even in quiet regions with only weak absorption. A more detailed analysis (including detailed studies of the wave forms measured in He 10830) based on new observations obtained under better seeing conditions is underway.

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