Nature of Prominences and their role in Space Weather
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Non-LTE Modeling and Observations of Oscillating Prominences

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Abstract. Prominence oscillations have been mostly detected using Doppler velocity, although there are also claimed detections by means of the periodic variations of half-width or line intensity. Our main aim here is to explore the relationship between spectral indicators such as Doppler shift, line intensity and line half-width and the linear perturbations excited in a simple prominence model.

Keywords. Sun: oscillations, Sun: filaments, Sun: prominences

1. Model and methods

For MHD simulations we used equilibrium model described by Oliver *et al.* (1993). It consists of a bounded, vertical, homogeneous slab, permeated by a transverse magnetic field, having prominence-like physical properties. We assumed linear perturbations. Then the dispersion relation for fast and slow modes has been derived. Perturbations of temperature, gas pressure and velocity along the line of sight (LOS) axis (see Figure 1) calculated by MHD simulations were used as input parameters for one-dimensional non-LTE radiative transfer code with 5 levels and continuum of hydrogen (see Heinzel 1995; Labrosse *et al.* 2010). Considered geometry was the same as for the MHD modeling. We assumed hydrogen-helium plasma with partially ionized hydrogen and neutral helium, microturbulent velocity equal to zero and slab thickness 12000 km. Incident radiation was carefully taken into account.

2. Results

As a result of calculations we obtained the full spectral profiles of the hydrogen Hα and Hβ lines in different phases of oscillations for four oscillatory modes (see Figures 2 and 3). For each step we calculated peak intensity of the spectral profile, full width at half maximum (FWHM) and the Doppler shift (see Figure 4). Detectable variations of the Doppler velocity with the peak-to-peak amplitude of the order 2 km s^{-1} were found for the fundamental slow (fS) mode only. Other modes have variations below 0.1 km s^{-1}. Different behaviour of FWHM and maximum intensity variations (number of peaks and their relative maximum over the whole cycle) for fundamental slow (fS), first slow harmonic (1S) and fundamental fast (fF) modes brings the possibility to distinguish between modes from observational data. Asymmetry was detected for fS mode in the Hα line profile only. Only 1F mode is practically non-detectable. All variations are summarized in Table 1.

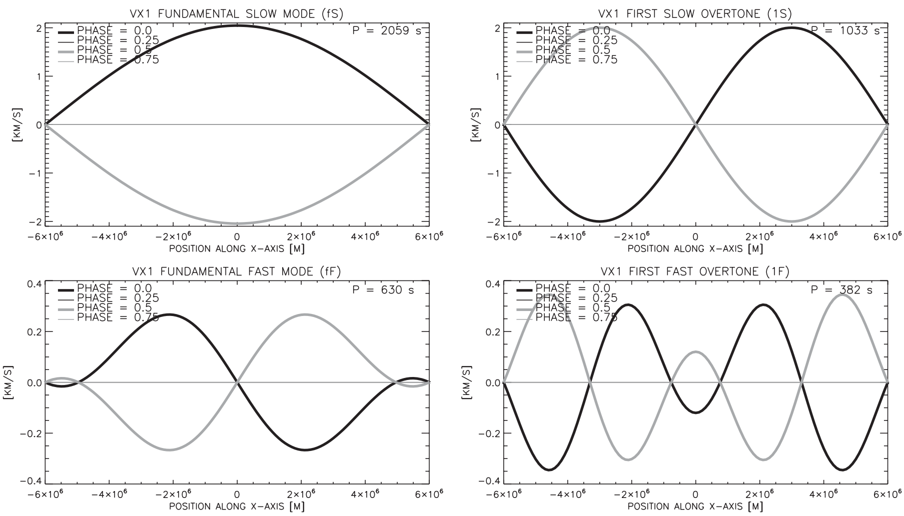

Figure 1. Velocity perturbations across the prominence slab for the fundamental slow mode (fS), the first slow overtone (1S), the fundamental fast mode (fF) and the first fast overtone (1F). The x-axes of plots are scaled in kilometers. Note the different velocity scale. Different lines represent different phases (i.e. time divided by period), labeled at the top left corner of each plot. For phase = 0.25 and phase = 0.75 the lines are merged. Oscillatory periods are shown at the top right corner of each plot.

Line	Mode	Δv_D	FWHM	$\max(I(\lambda))$
Hα	fS	2.241	0.593 – 0.622 (4.8%)	3.531 – 3.671 (3.9%) $\times 10^{-6}$
	1S	0.026	0.600 – 0.625 (4.1%)	3.521 – 3.651 (3.6%) $\times 10^{-6}$
	fF	0.004	0.581 – 0.609 (4.6%)	3.491 – 3.590 (2.8%) $\times 10^{-6}$
	1F	0.090	0.593 – 0.594 (0.3%)	3.531 – 3.531 (0.0%) $\times 10^{-6}$
Hβ	fS	2.175	0.298 – 0.303 (1.6%)	5.760 – 6.551 (12.8%) $\times 10^{-7}$
	1S	0.005	0.300 – 0.304 (1.2%)	5.690 – 6.790 (17.6%) $\times 10^{-7}$
	fF	0.018	0.293 – 0.301 (2.6%)	5.570 – 6.130 (9.6%) $\times 10^{-7}$
	1F	0.098	0.296 – 0.297 (0.2%)	5.780 – 5.820 (0.7%) $\times 10^{-7}$

Table 1. Variations of spectral indicators for Hα and Hβ. Abbreviations of modes are the same as described in the main text. Δv_D stands for peak-to-peak Doppler velocity amplitude. In brackets relative changes of each value with respect to the mean are presented.

3. Summary and future prospects

The first numerical simulations of the non-LTE radiative transfer in an oscillatory prominence slab were performed. To perform prominence seismology, analysis of the Hα and Hβ spectral line parameters could be a good tool to detect and identify oscillatory modes. Figure 5 presents results of analysis of exemplary observations of prominence oscillations performed with Ondřejov Multi-channel Spectrograph (see Kotrč, 2009). In the future we will investigate a grid of models with different physical conditions and different oscillatory parameters. Calculation of spectral profiles for different spectral lines may lead to investigation of velocity field in different optical depths and may be directly compared with observations. Ca II lines are detectable from ground, MgII h and k lines from space by the IRIS mission. Performing 2D radiative transfer simulations will bring more realistic results.

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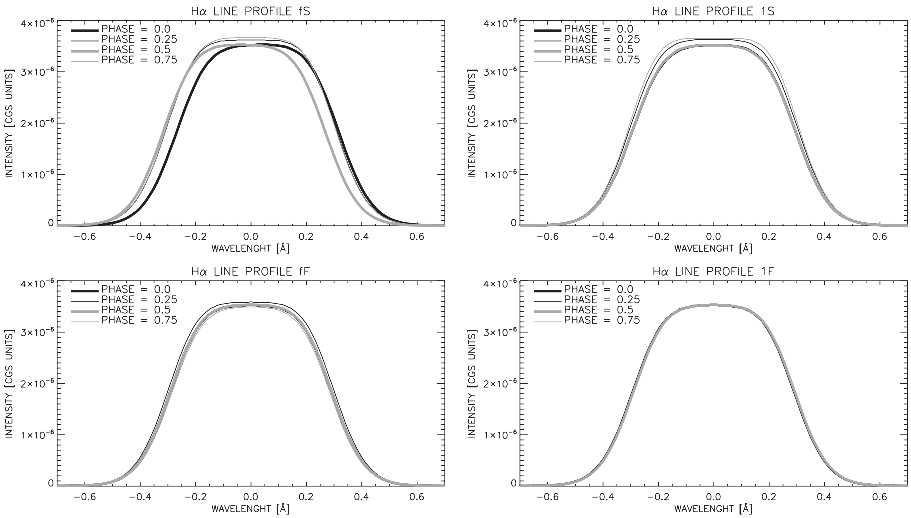

Figure 2. Time variation of the Hα spectral line profile for consecutive phases (labelled in the top left corner of each plot) and different modes. Specific line intensities are in cgs units erg sec^{-1} cm^{-2} sr^{-1} Hz^{-1}.

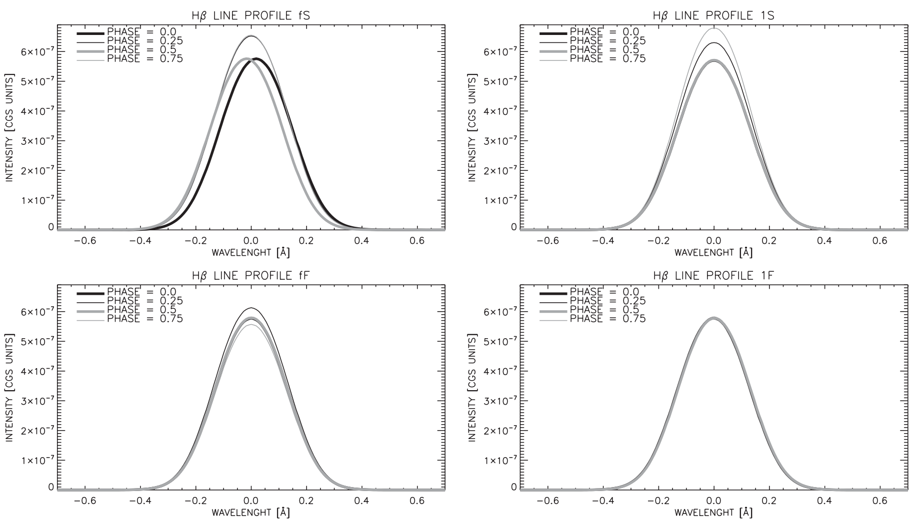

Figure 3. Same as Fig. 2, but for Hβ.

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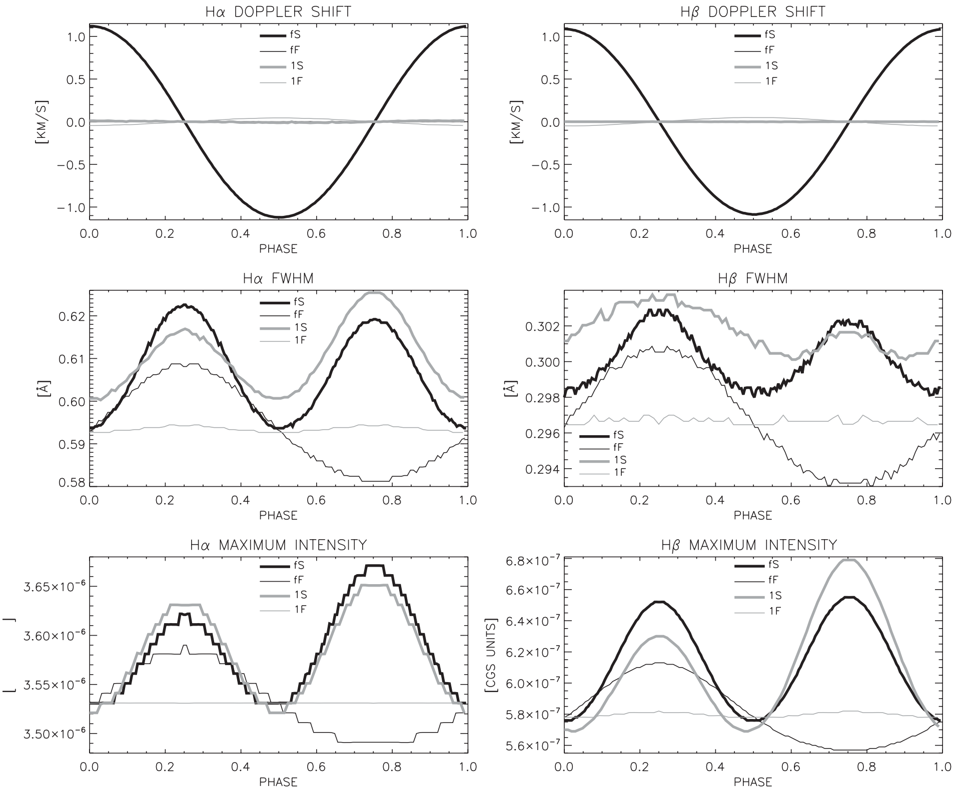

Figure 4. Time variation as a function of phase of the spectral line parameters for all modes. Different lines labelled in the plots correspond to different modes.

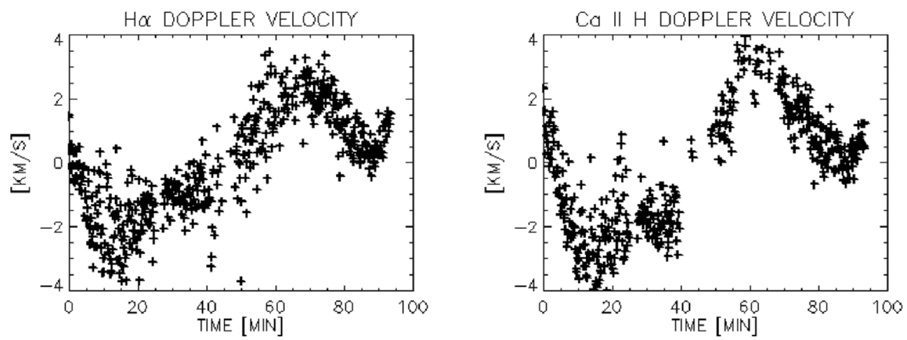

Figure 5. Variations of Doppler velocity of Hα and Ca II H spectral lines of the prominence of September 23, 2010 observed by Ondřejov Spectrograph.

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