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2D velocity trajectories of Hα spicules

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Abstract. Hα and D_3 spicule spectrograms for 3.800–9.300 km heights in the solar chromosphere were obtained using the 53-cm large non-eclipsing coronagraph of the Abastumani Astrophysical Observatory during 1982. Spectrograms in Hα line were obtained in the second series of the spectrograph, where the reversed dispersion is equal to 0.96 Å/mm, while spectrograms in D_3 line were obtained in the third series of the spectrograph, where the reversed dispersion equals 0.58 Å/mm. For Hα spicules we obtained 250 series of spectrograms during 44 min each consisting of 8 different chromospheric heights starting from 3800 km up to 8700 km reaching about 2000 spectrograms altogether. Similarly, for D_3 spicules we obtained 100 series of spectrograms during 30 min each consisting of 8 different chromospheric heights starting from 4400 km up to 9300 km reaching about 800 spectrograms altogether. On the basis of these spectrograms radial and tangential velocities were measured for a dozen of selected clearly identified spicules. It could be clearly stated that: i) a spicule motion in 2D velocity space generates a trajectory cloud which is prolonged in the tangential velocity direction with a ratio of axes equal to 2.7; ii) the spatial motion of spicules seems to be rather chaotic than oscillating.

1 Introduction

It is important to reveal the relation between dynamics of the solar fine structures and physical processes taking place in lower and upper layers of the solar atmosphere. The actual problems, like the balance of energy and physical matter of transient layer from the chromosphere to corona, generation of the solar wind and others require fundamental research.

The research of the warming mechanism of corona, one of the main sources of which is the chromospheric spicules, particularly existing magnetohydrodynamical (MHD) waves and transformation of energy from the lower to upper layers, is one of the main problems of active processes in the solar atmosphere. (Taroyan, Erdelyi, 2009). We study motion of spicules as a whole substance, while experimental and theoretical studies of processes inside the spicules are presented in reviews by Sterling (2000) and De Pontieu, Erdelyi (2006).

The 2-component model of the solar chromosphere, which consists of areas having different temperatures, is well known since R.G. Athay and D.H. Menzel (1956). Term “hot” chromosphere was defined due to emission lines in visible spectral range, where the chromosphere is significantly transparent. If we consider the fact that below the areas with heights of 3000 ± 1000 km different elements should blend significantly, then we should suggest that the “hot” areas at these heights should be surrounded by the "cold" areas. The main indicator of the chromosphere inhomogeneity is the spicules, which are observable at 3.000–10.000 km heights.

The main problem to explain inhomogeneity of the chromosphere is connected with excitation of He. Particularly, a) He is the second main element after H consisting of the chromosphere; b) He lines are observable in the chromosphere as well as in protuberances; c) He requires specific conditions for emission – either high kinetic temperature or strong emission field. He is of interest also because it consists of two elements – Para helium and orthohelium.

There are series of publications concerning He excitation stating that kinetic temperature in He areas of the lower chromosphere is about $9000^0 < T_e < 30000^0$. Presently, the resume which could be undoubtedly accepted is that H and He are not emitting with equal intensity from the whole chromosphere. The apparent example of this is the spicules. The processes having place in H and He spicules are different (radial velocities, etc.)

Particularly, radial velocities of D_3-spicules for the chromospheric heights of 4.400–5.800 km vary between ± 4 km/s and for the upper heights – between ± 6 km/s. For the same heights radial velocities of Ha-spicules vary between ± 12 km/s. Radial velocities for Hα-spicules are 2–3 times as much as for D_3-spicules (Khutsishvili, 1986). It is important to make an objective answer of whether Hα and D_3 spicules are the same physical entities (Khutsishvili, 1995).

Significant changes in tangential velocities of the chromospheric spicules (Gadzhiev, Nikolsky, 1982) indicate that considerably we observe real motion of spicules as a whole or a part of it along the solar surface. Such motions could be of different type, starting from chaotic until oscillating with definite frequencies.

Radial velocity of a spicule may consist of not only the part caused by a motion of a spicule along the Sun's surface (Kulidzanishvili, Zhugzhda, 1983). It may also contain the part caused by a motion of plasma inside a spicule which are not perpendicular to the line of sight (De Pontieu et al., 2007a, 2007b). Such motions inside a spicule may be initiated by the propagation of MHD waves along a spicule (Kukhianidze et al., 2006; Zaqarashvili et al., 2007) and have either differential or rotational behaviour, which are indicated by the Doppler shift in their observational spectra (Khutsishvili, 1986).

Apparently, it is the most informative to have the long-term observations of spicules at different chromospheric heights during the long period of time. We carried out such observations first in 1982, which are described by Khutsishvili (1986).

2 Observations

During 1982 we obtained Hα and D_3 spicule spectrograms for different heights in the solar chromosphere using the 53-cm large non-eclipsing coronagraph of the Abastumani Astrophysical Observatory.

Spectrograms in Hα line were obtained in the second series of the spectrograph, where the reversed dispersion is equal to 0.96 Å/mm, while spectrograms in D_3 line were obtained in the third series of the spectrograph, where the reversed dispersion equals 0.58 Å/mm. For Hα spicules we obtained 250 series of spectrograms during 44 min each consisting of 8 different chromospheric heights starting from 3800 km up to 8700 km reaching about 2000 spectrograms altogether. Similarly, for D_3 spicules we obtained 100 series of spectrograms during 30 min each consisting of 8 different chromospheric heights starting from 4400 km up to 9300 km reaching about 800 spectrograms altogether.

The time interval between 2 consequtive Hα spectrograms in one series equals 7 s, while the same interval for D_3 spectrograms reaches 18 s. Exposure for Hα spectrograms equals 0.2 s for lower 4 chromospheric heights and 0.4 s for the remaining 4 heights. As for D_3 spectrograms, exposures are equal to 1 s and 2 s, respectively. The angular distance between chromospheric heights is about $1''$, so observations were carried out in coronal days with the same image quality.

For Hα spicule spectrograms we managed to measure radial and tangential velocities. To make tangential velocity measurements a PC drived automatic microdensitometer ("speedometer") was used. A spectrogram was located on the speedometer table as to ensure that the spectrogram dispersion was parallel to the speedometer slit. The slit sizes were 0.015 Å$\times$ $0.5'$. The scanning was performed in parallel

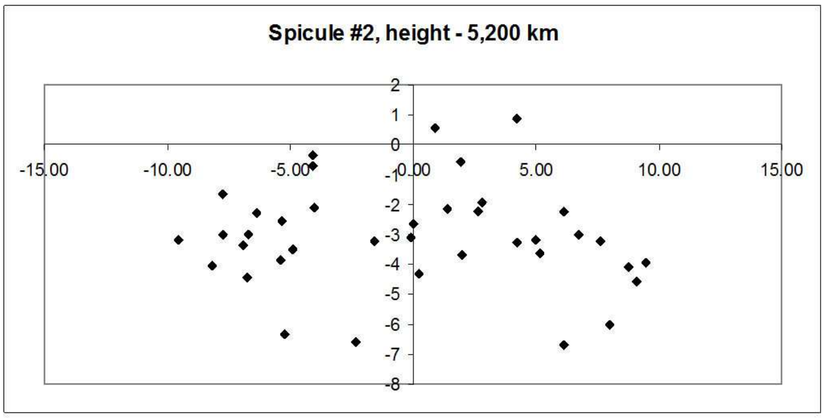

Fig. 1. Spicule #2 motion trajectories for the chromospheric height equaled to 5.200 km in 2D velocity space. X-axis represents tangential velocities in km/s, Y-axis – radial velocities in km/s

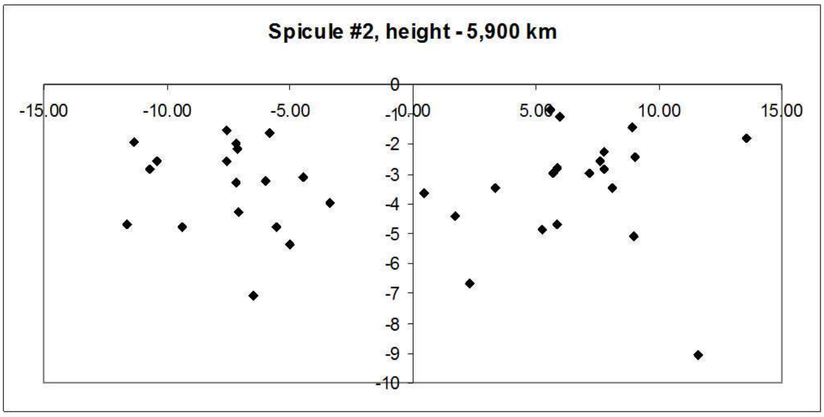

Fig. 2. Spicule #2 motion trajectories for the chromospheric height equaled to 5.900 km in 2D velocity space. X-axis represents tangential velocities in km/s, Y-axis – radial velocities in km/s

to tangential velocity vector with 10 m step. The measured relative densities were automatically registered by the PC.

For tangential velocity measurements we used 95 series of chromospheric heights including only 2 heights – 5200 km and 5900 km, with overall time duration equal to 16 min. We selected and used 12 most reliably identified Hα spicules which have 2 close neighbour reference spicules also well traced through the corresponding spectrograms.

The scans were performed for 3 different directions: along the Hα line center and wings equally distant. The scans adequately covered all 3 spicules and were processed to estimate spicule image center coordinates. Relative tangential velocities were calculated on the basis of deviations of the main spicule image center from the geometric center of the reference spicules.

Such a selection of the reference point allows to minimize the shift of the solar limb image towards the spectrograph slit caused by the atmospheric fluctuations and the rotation of the focal field in the Coude focus of the 53-cm large non-eclipsing coronagraph.

We used radial and tangential velocities for the spicules to analyze their spatial motion.

Fig. 1–4 show a spicule motion trajectories in 2D velocity space parallel to the line of sight constructed

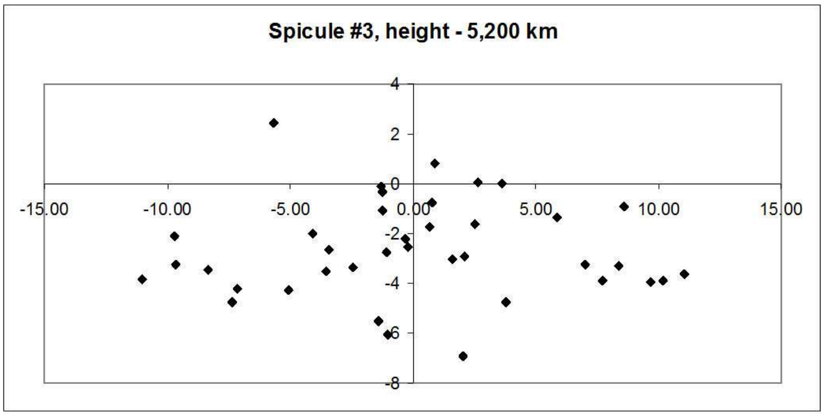

Fig. 3. Spicule #3 motion trajectories for the chromospheric height equaled to 5.200 km in 2D velocity space. X-axis represents tangential velocities in km/s, Y-axis – radial velocities in km/s

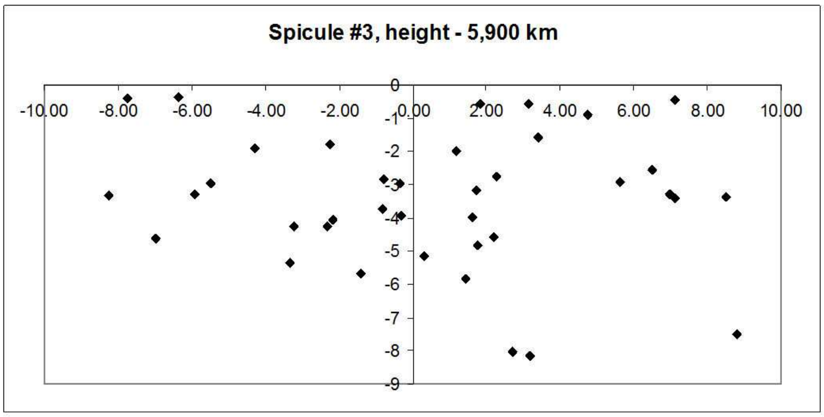

Fig. 4. Spicule #3 motion trajectories for the chromospheric height equaled to 5.900 km in 2D velocity space. X-axis represents tangential velocities in km/s, Y-axis – radial velocities in km/s

using tangential (X-axis) and radial velocities (Y-axis) in km/s units for 2 typical spicules at different chromospheric heights. Although, both velocities include their uncertainties which in 2D space constitue a corresponding dispersion ellipsoid, nevertheless, trajectory distribution may reveal some qualitative characteristics.

It could be clearly stated that: i) a spicule motion in 2D space generates a trajectory cloud which is prolonged in the tangential velocity direction with a ratio of axes equal to 2.7; ii) the spatial motion of spicules seems to be rather chaotic than oscillating.

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