First Results from Hinode
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High Resolution Observations of Spicules with *Hinode*/SOT

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Abstract. High time cadence unprecedented images at the limb with Ca II H line filtergraph from the Solar Optical Telescope (SOT) aboard *Hinode* have revealed that a spicule consists of highly dynamic multi-threads (typically twin) as thin as a few tenths of an arcsecond, and shows prominent lateral movement or oscillation with rotation on its axis during its life. This multi-thread structure and lateral motion indicate that the spicules can be driven by magnetic reconnection at unresolved spatial scales at their footpoints.

1. Introduction

Solar spicules are hair-like structures seen on the solar limb anytime in optically thick chromospheric lines such as the Balmer lines of Hydrogen (Hα) and resonance lines from singly ionized Calcium (Ca II H & K). The individual spicules show jet-like motion, shooting up into the hot corona (T$\sim$$10^6$ K) from the cool chromosphere (T$\sim$$10^4$ K) with a typical apparent velocity of 25 km sec^{-1} and a lifespan of 5–15 min (Beckers 1968, 1972). The spicules are supposed to be one of main ingredients of the chromosphere. The features on the solar disk similar to spicules are called mottles or fibrils which emanate from small-scale magnetic elements both in active regions and quiet Sun (e.g. De Pontieu 2004; Suematsu 1998). The origin and evolution of the spicules remains unresolved because their structure and dynamics were under available observational resolution limits (e.g. Sterling 2000). We here report some new features of the spicules, which may imply that they are ejected by magnetic reconnection at their footpoints, revealed with a series of unprecedented images on the limb from the Solar Optical Telescope (Suematsu et al. 2008) on-board *Hinode*.

2. Observations and Data Analysis

To study the dynamical nature of the spicules, the solar limb was observed at various positions with the broad-band filtergraph instrument (BFI) of the SOT, with the wavelength pass-band centered at Ca II H 396.8 nm with a width of 0.3 nm. The observations were performed in continuous fashion over a few hours with a cadence of $5 \sim 8$ sec with diffraction-limited spatial resolution (0.2 arcsec) of the 50 cm aperture telescope, and with reduced scattered light from the solar bright disk even in this short wavelength. Usual CCD data processing methods were performed on the Ca II H images, such as dark current subtraction, flat-fielding and image registration using a cross-correlation technique.

To enhance the visibility of the off-limb faint spicules as well as features inside the disk at the same time, we subtracted a background which consists of minimum brightness in a time series data set at a pixel and shifted entirely by ten pixels (0.54 arcsec) toward the disk centre. This is a kind of unsharp masking method, but gives rise to less unrealistic sharpened structure than the usual ones, because the background is monotonic off-limb except at the very limb (Figure 2). To delineate detailed fine structure, we applied the mad-max algorithm (Koutchmy and Koutchmy 1989) which is helpful to extract line-like structure (Figure 3).

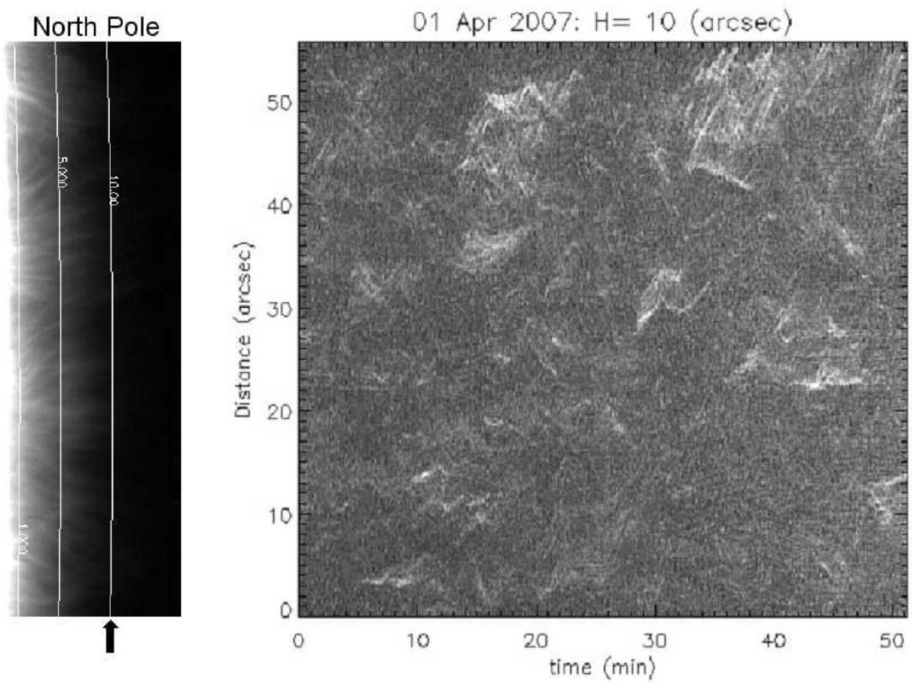

Figure 1. Time slice map along the limb at the off-limb height of 10 arcsec. Lateral motion (excursion) and oscillation get more prominent as the height goes up. The period of oscillation is between 1 and 4 min, the amplitude is about 1 arcsec and maximum lateral velocity is about 15–25 km sec^{-1}.

3. Results and Discussion

We analyzed several time series of spicules. The movies revealed that most spicules do not show a simple up-and-down motion along a rigid path line. They start with bright structure emanating from Ca II H bright region, and get wider and more diffuse with time and ascent, showing expansion with lateral or even rotational motion. It should be noted that small and short-lived spicules tend to fade out quickly after ascent; some show an ascent velocity of more than 100 km sec^{-1} (see also De Pontieu et al. 2007b).

Figure 2. Spicules at the limb taken with the Ca II H broad-band filtergraph of SOT. The image was processed to enhance a visibility by subtracting a background. This kind of high resolution image indicates that most spicules show up double thread structure (indicated by arrows) during their life.

To study the lateral motion in detail, time slice maps along the limb were made at the off-limb heights of 1, 5 and 10 arcsec (Figure 1). Lateral motion and oscillation get more prominent as the height goes up. The period of oscillation is 1 to 4 min, the amplitude is about 1 arcsec and maximum lateral velocity is about 15–25 km sec^{-1}. This lateral motion might be direct observational evidence of Alfvén waves propagating through the spicules (De Pontieu et al. 2007a).

We found that most spicules (more than 50%) show up double thread structure during their evolution (Figure 2). Each thread and its separation is a few tenths of an arcsec wide. Tanaka (1974) also found about 30% of all the dark mottles are double or can be resolved into double at any one instance in high resolution Hα wing observations. The similar double-thread structure found both in the spicules and the mottles implies that these two features have the same origin. The new findings here are that the separation of some of the double thread spicules changes with time, repeating single-thread phase and double-thread one (Figure 3). This change in separation can be interpreted as a spinning of the spicule as a rigid body (spin period: 1–1.5 min, v $\sim$ 15 km sec^{-1}). The existence of spinning has been previously speculated on because of the tilt of spectral lines (Pasachoff, Noyes and Beckers 1968).

The fine structure and lateral motions suggest that the spicules can be driven by magnetic reconnection at unresolved spatial scales at their footpoints. Most spicules emanate from seemingly uni-polar magnetic regions and the relevant magnetic reconnection must take place at unresolved spatial scales, contrary to the larger-scale jets such as macro-spicules and surges associated with

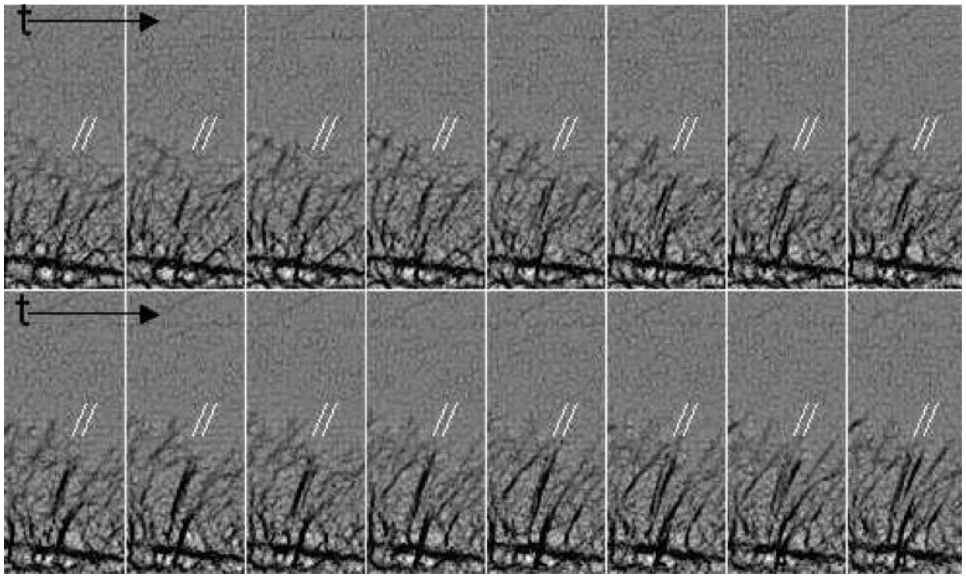

Figure 3. Time series of sharpened images using the mad-max algorithm. The cadence is 5 sec. This series clearly shows that the spicule of double threads (indicated by white lines) is spinning as a whole body.

an emergence of small bipoles. It is worth pointing out that driving mechanism, whatever it is, should explain the large aspect ratio of the spicules found here: length/width ≥ 10 (= 5 arcsec/0.5 arcsec).

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