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A study of spicules from space observations

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Abstract. We have studied spicules observed at the northern solar limb by using simultaneous high resolution image sequences. The images were obtained by Hinode/SOT (in the Ca II H passband) and TRACE (in the 1600 Å passband) during a coordinated campaign. Both data sets were reduced and then carefully co-aligned in order to compare the observed patterns in this highly dynamic region of the Sun. The identification of individual structures in both spectral bands allows us to trace their spatial and temporal behaviour. Persistent intensity variations at certain locations, indicate that at least some spicules have a recurrent behavior. Using wavelet analysis we investigate oscillatory phenomena along the axis of off-limb spicules and we construct 2-D maps of the solar limb with the observed oscillations.

Keywords. sun:chromosphere, sun:oscillations

1. Observations, data reduction and analysis

Simultaneous time series observations of the northern solar limb were obtained by TRACE and Hinode/SOT on October 15, 2007. All necessary corrections were carried out, such as dark current, flat-field corrections and spike removal. The images of each data set were carefully co-aligned using cross-correlation between consecutive images, achieving sub-pixel offsets. The Ca II H data set was rebinned to the spatial resolution of TRACE (0.5 arcsec/pixel) and then the two data sets were cross-aligned in order to identify and compare similar structures, if any. The cadence of the observations is 53 s for TRACE and 60 s for SOT and they cover about 1 hour.

The small-scale temporal variation of every pixel on each image was limited by smoothing the time series over 5 consecutive exposures. Then, for every row its minimum value was subtracted from each pixel. Although this last step introduces errors in the form of horizontal lines due to the fact that we did not take into account the curvature of the limb, it helps to increase the contrast of the off-limb structures. To further improve the visibility of the fine-scale off-limb structures we applied the MADMAX operator (Koutchmy & Koutchmy 1988) on all images. This helps discriminate individual spicules (Fig. 1).

2. Morphology and general remarks

The network is visible in both passbands with almost one to one spatial correspondence, while off-limb there are only coarse similarities (Fig. 1). Most spicules are concentrated in groups (bushes), are relatively inclined and show excessive spatio-temporal variations, due to plasma motions and/or ionization. The Ca II H filter has a FWHM of 2.2 Å, while TRACE's 1600 Å passband is very wide (275 Å) and perhaps this is the reason

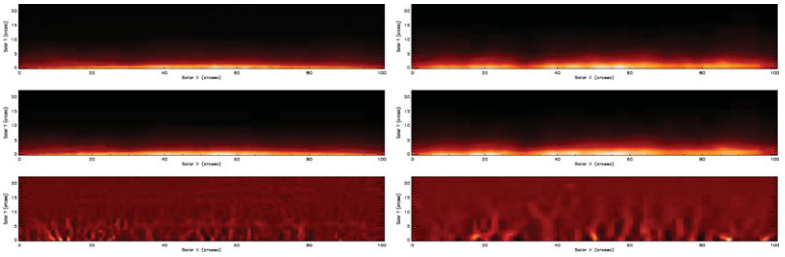

Figure 1. SOT Ca II H *(left)* and TRACE 1600 Å *(right)* filtergrams. *Top to bottom*: the original, enhanced (see text) and after the application of the MADMAX operator images.

why spicules in TRACE appear more diffuse. Thus, emission in both passbands comes from plasma with a wide range of temperatures. Despite that, it seems that some spicules appear at almost the same position when comparing almost co-temporal images. It is very hard, however, to follow their temporal evolution in the two passbands simultaneously. Enhanced images (Fig. 1) show that several spicules attain heights greater than 15″. The shapes of these structures are sometimes irregular and complicated, probably due to superposition effects. Most of them appear and fade within less than 5 frames (i.e. 5 min). Superposition effects, as well as the low cadence of the present observations (1 min) make difficult the study of the evolution of these short-lived structures.

3. Wavelet analysis along individual spicules

In Figure 2 we present two different spicules, each one observed in a different passband. As the same structures do not appear for the same duration in the two passbands a simultaneous analysis was not possible. We performed a wavelet analysis (Torrence & Compo 1998) at every height along their central axes (Fig. 3).

In the Ca II H spicule, periods of 180 s and 300 s were detected very close to the limb. In the TRACE spicule a 300 s period was detected around 3″-4″ above the limb.

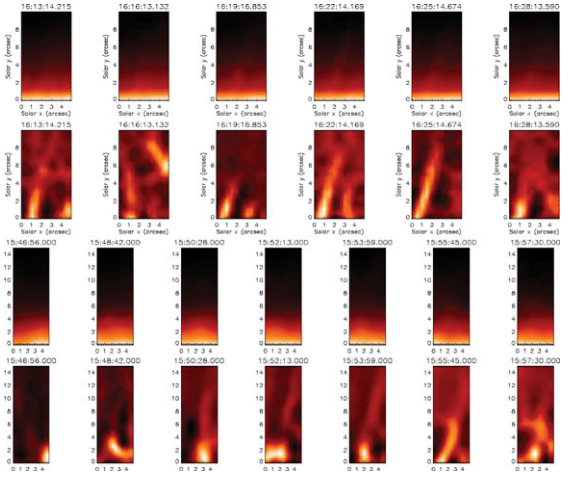

Figure 2. *First and second row*: A spicule in the Ca II H passband. The images in the second row are enhanced using the MADMAX operator. *Third and fourth row*: Same for a spicule at 1600 Å.

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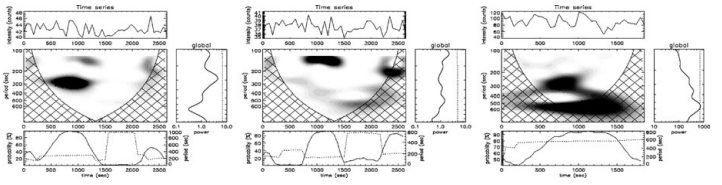

Figure 3. Wavelet analysis of a Ca II H spicule, at 0.″5 (left) and at 1″ (middle) and a 1600 Å spicule, at 3″ above the limb.

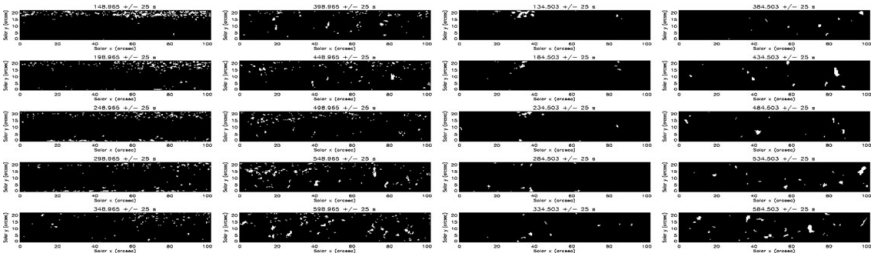

Figure 4. 2-D off-limb period maps for Hinode/SOT Ca II H at first and second columns and TRACE 1600 Å passbands, at third and fourth columns.

4. 2-D period maps of oscillatory phenomena

We averaged over a 1.″5 x 1.″5. area of the images and performed wavelet analysis for every "new" pixel above the limb. The periods corresponding to the peaks of the global wavelet spectrum were determined and their probability from the randomization method (Tziotziou *et al.* 2004) was calculated. We considered only periods with probability greater than 80 % to construct 50 s - broad, 2-D period maps (Fig. 4).

Ca II H passband: Periods between 180 s and 320 s are found very close to the limb. In some cases they appear off-limb but no more than 2″ - 3″ above it. They are associated with spicular material but not all spicules show this behaviour. Periods in this range are also found higher than 15″, but are probably due to noise. Periods longer than 400 s are found only off-limb and are probably indicative of spicules' lifetimes.

1600 Å passband: Very few oscillations are detected. Periods up to 350 s are found close to the limb, some of them reaching 5″ high. Almost all of them appear to coincide with periods at the Ca II H line, while the opposite does not happen. Periods longer than 350 s appear almost exclusively off-limb, most probably indicative of spicules' lifetimes.

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