A COMPARISON BETWEEN SPICULES IN H$\alpha$ AND C IV

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ABSTRACT

We study the interaction of the chromosphere with the transition region by examining the properties of short-lived chromospheric jet-like features, that we will collectively call “spicular jets,” at different heights and temperatures. Our observations cover the middle and upper chromosphere (H$\alpha$ observations from the Swedish 1-meter Solar Telescope) and the low and upper transition region (C IV and Fe x/x image sequences from the Transition Region and Coronal Explorer). We study C IV emission from these jets and its correlation to red-shifted H$\alpha$, as well as the phase difference between locations of co-temporal wave-trains in Fe x/x of 5-minute periodicity (“moss”). We find that some, but not all spicular jets show closely correlated C IV emission, indicating that these jets are heated, at least in part, to transition region temperatures. We also find that the moss oscillations are in phase on distances of less than 4″, suggesting that the driver mechanism is also in phase on a similar length scale.

Key words: Sun: magnetic fields – Sun: chromosphere – Sun: transition region – Sun: UV radiation.

1. INTRODUCTION

The classical transition region (TR) is defined as the interface between chromospheric and coronal plasma. It plays an important role in the upwards transfer of momentum and energy from the photosphere and chromosphere, which is thought to be responsible for the heating and structuring of the corona. However, due to the rapid changes in this layer, both temporal and spatial, the TR is difficult to study. There are several issues currently without a conclusive answer. Here, we will address two such issues, both dealing with short-lived (a few minutes) chromospheric jet-like features that bring cold, dense plasma up to larger heights than expected from hydrostatic equilibrium models (e.g., Suematsu et al. 1995). These structures are more commonly known as spicules (seen at the limb in quiet sun), H$\alpha$ mottles (seen on the disk in quiet sun), and active region H$\alpha$ fibrils. We refer the interested reader to the excellent reviews by Beckers (1968, 1972) and more recently by Sterling (2000) and references therein. Since it appears likely that all phenomena share common origin (Tziotziou et al. 2004), we will therefore refer to them as “spicular jets,” though all our observations are of active regions. The first issue we will study is the temperature to which these spicular jets are heated, thereby returning to and expanding on a previous study by De Pontieu et al. (2003b). This is an important factor in the energy balance of the chromosphere and corona, because of the large mass flux these jets carry up to and down from coronal heights. The second issue we address deals with the driving mechanism of these jets.

2. OBSERVATIONS AND DATA REDUCTION

The analyses presented here use two data sets. The first consists of image sequences recorded on June 16 2003 between 8:02 and 9:07 UT of NOAA Active Region 10380. The active region was at a viewing angle of 48 degrees ($\mu = 0.66$). We use ground-based H$\alpha$ observations from the Swedish 1-m Solar Telescope (SST, Scharmer et al. 2003), in conjunction with space-borne UV imaging from the Transition Region And Coronal Explorer (TRACE, Handy et al. 1999).

The SST H$\alpha$ images were taken at $-700$, $-350$, $+350$, and $+700$ mÅ relative to line center at 6562 Å, with the SOUP tunable filter (Title et al. 1986). Figure 1 displays sample images from each of these positions in the line. The bandwidth of the SOUP filter at this wavelength is 0.13 Å. The images consist of $1534 \times 1032$ square pixels of 0.0655″ size, taken at a cadence of 55 ± 5 s. The images sample the middle and upper chromosphere. All
Figure 1. Sample Hα images. The images were corrected for dark current, flat-fielded, and were rotated so that solar north is up. Top left: Hα −350 mÅ. Top right: Hα −700 mÅ. Bottom left: Hα +700 mÅ. Bottom right: Hα +350 mÅ. The left side of the image shows a small active region with many loop-like structures visible particularly well in −350 and +350 mÅ. On the right, many small, dynamic features are visible during the sequence.
Figure 2. Sample Hα spicules with co-temporal and co-spatial CIV emission. Bottom row: Hα +700 mÅ cutouts. Middle row: CIV cutouts. Top row: scatter plots of the Hα intensity versus the CIV intensity. The Pearson linear correlation coefficients are printed for each example in the top-right corner of each scatter plot. The mask over which the scatter plots and Pearson correlation coefficients are computed is enclosed by the black and white contours in, respectively, the bottom and middle row. The correlation is not perfect, even in the cases where the time difference between the Hα and CIV images is small.
of the raw SST images were corrected for dark current, flat-fielded, rotated to solar north, and carefully aligned using Fourier cross-correlation.

The TRACE data was recorded in the three UV passbands at 1550, 1600, and 1700 Å, with a cadence of 20 ± 1 s and a spatial resolution of 0.5”. The images were corrected for dark current, were flat-fielded, and carefully aligned using Fourier cross-correlation. We use a technique developed by Handy et al. (1998) to construct an image sequence in the C IV resonance lines around 1548 and 1550 Å from the three wide-band UV image sequences. In order to get the best possible constructs, we interpolate the 1600 Å and the 1700 Å UV images to the time of observation of the 1550 Å images. Finally, the C IV images were scaled and aligned and cut out to the match the SST H α images.

The second data set consists only of a TRACE 171 Å image sequence, recorded on June 4 1999, sampling emission primarily from Fe x and Fe x ions (approx. 1 MK). These images were corrected for dark current and were flat-fielded. Furthermore, cosmic ray hits were removed by a median-filter algorithm. This TRACE passband is well-known for showing a highly dynamic structure called “moss”. Moss has been studied extensively by, e.g., Berger et al. (1999), Fletcher & de Pontieu (1999), and De Pontieu et al. (1999). Berger et al. (1999) showed that the dynamic, spongy appearance of moss is caused by the presence of spicular jets intermittently obscuring the footpoints of hot loops. Martens et al. (2000) confirmed that indeed the Fe x/x emission in moss originates from these footpoints. Further studies by De Pontieu et al. (2003a) again showed that the wave-trains seen in moss are closely related to spicular jets, making it an ideal diagnostic to study these jets in the high transition region.

3. ANALYSIS, RESULTS AND DISCUSSION

3.1. C IV emission from spicules

We manually compared locations of enhanced C IV emission to the H α data. Though brightness enhancements in C IV often do not have any counterpart in the H α data, some are clearly correlated with dark features in redshifted H α. In this case, we identified 16 cases in which the correlation between the C IV emission and the redshifted H α is particularly evident. Five example locations of correlations between C IV and H α +700 mÅ are shown in the lower two rows of Fig. 2. Obviously, the correlation is not perfect, even in those cases where the time difference is small. It is possible that seeing effects in the H α data distort the image, thus reducing the correlation with the seeing-free TRACE observations. Also, the TRACE CCD has lost considerable sensitivity since its launch. This makes C IV constructs noisy, and likely introduces spurious brightening and darkening.

![Figure 3](image-url)

**Figure 3.** Two sample plots of the Pearson correlation coefficient as a function of time delay. The two curves are the correlations between H α +700 mÅ (solid, diamonds) and H α +350 mÅ (dashed, squares).

3.2. Pearson correlation coefficients

We computed Pearson linear correlation coefficients for the locations described in Sect. 3.1 as a function of delay by correlating the C IV image to the closest 5 H α images. The Pearson correlation coefficient $r$ is given by

$$r = \frac{\Sigma d_1 d_2 - (\Sigma d_1)(\Sigma d_2)}{\sqrt{\Sigma d_1^2 - (\Sigma d_1)^2}\Sigma d_2^2 - (\Sigma d_2)^2}}.$$

We computed the Pearson correlation coefficient over the region surrounding the brightness enhancement that is more then two standard deviations brighter than the average. The regions are indicated in Fig. 2 in the bottom row by a black outline, and by a white in the middle row. The minimum correlation coefficient (i.e., the maximum anticorrelation) for the examples shown in Fig. 2, shown in the upper right corner of the intensity scatter plots (top row), is also computed over the area enclosed by the outlines in the bottom two rows. Over the 16 cases described in Sect. 3.1, we found an average correlation coefficient of −0.5, with a minimum of −0.7 and a maximum of −0.2. The average delay between C IV and the best H α match is about 21 s. For the first two examples shown in Fig. 2, the correlation coefficient is plotted against time in Fig. 3 for both the H α +700 mÅ (diamonds) and the H α +350 mÅ (squares) sequences.

These observations are in agreement with those of De Pontieu et al. (2003b). We expand on their analysis by computing the delay between the C IV emission and the best matching H α image. Our result indicates that the red-shifted H α half a minute before the C IV emission is seen gives the best anticorrelation. Due to the width of the SOUP passband (13 mÅ), these H α filtergrams only sample a narrow range of speeds. Possibly with a wider filter one would give a better detailed correspondence. In any case, the time delay shows that the C IV brightness enhancement occurs some time after the spicule is visible in red-shifted H α. It is tempting to assume that it is still accelerating downward. By the time it reaches TR temperatures and produces significant C IV emission, it is already partly outside the SOUP passband.
3.3. Phase difference versus distance

During the above analysis, we noted that it seems that adjacent spicules, with or without correlated C iv emission, appear in phase. We attempted to verify this suspicion by analyzing the phase difference of concurrent moss oscillations in the 1999 171 Å data sequence. We apply a wavelet analysis to find positions with oscillations with greater than 95% confidence between periods of 250 and 450 s for more than 23 min. Next, we compute the average crosspower over the area in period and scale in which both locations have significant power. Those sets of positions that do not have overlapping significant power are discarded. Figure 4 shows the resulting scatter plot of phase difference versus distance. It shows an obvious blob around zero phase difference at small (< 4") scales. At larger distances, the phase difference becomes random, indicating the absence of a signal.

The size scale of 4'" is curiously similar to size scales typically associated with p-modes. These results may provide support for the work by De Pontieu et al. (2004), which suggested that p-modes may drive some spicular jets. Further analysis of Hα data, in conjunction with photospheric dopplergrams, should provide better insights in the correlations between p-modes and spicular jets.

4. CONCLUSION

We have identified a number of brightness enhancements in TRACE C iv constructs that are closely correlated with dark features in red-shifted Hα images. These structures are commonly identified as spicular jets, and we therefore conclude that at least some of these are ultimately heated at least in part to transition-region temper-atures. It is of interest to study the heating mechanism involved. Two candidates are cross-field thermal conduction (Athay 1990) and heating by EUV radiation from the corona.

We have used TRACE 171 Å data to study brightness oscilla-tions in moss that appear as wave trains of 4 to 7 periods in length. These wave trains are known to be caused to spicules. We compared the phases of the observed oscillations at different locations to the distance between the oscillations. We find a phase difference around zero for distances less than 4", and a random phase difference for larger distances. This is an indication that the driving mechanism for quasi-periodic or recurring spicules is in phase on a length scale of approximately 4", regardless of direction. Possibly this result can be interpreted as support for the p-mode driver proposed by De Pontieu et al. (2004), which one would expect to be coherent and in phase on a length scale similar to the one we find. Further investigation on the Hα data, possibly in conjunction with photospheric data to determine p-mode specifics, could well to provide further evidence.

REFERENCES