

Spatio-temporal Characterization of Hot Chromospheric Fibrils

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Abstract. The exact mechanisms leading to chromospheric heating are still ill-defined. While the presence of magnetic elements is undoubtedly necessary, the details of the heating, and its spatio-temporal distribution remain poorly understood. We contribute to this topic by analyzing the behavior of hot chromospheric fibrils surrounding network and plage elements, identified via the broader H α profiles observed along their length; the H- α spectral line width has been shown to correlate with the local chromospheric temperatures through comparison with the ALMA millimeter-continuum brightness temperature. We make use of loop tracing and analysis software to investigate characteristics of the chromospheric hot fibrils including their length, number density, and transverse spatial extension in an enhanced network region.

Keywords. Sun: chromosphere, Sun: faculae, plage

1. Introduction

A clear explanation of the mechanisms leading to heating of the solar chromosphere still eludes us. The energy requirements are significant: on average, the chromosphere radiates 4 kWm⁻² in quiet Sun, and 20 kWm⁻² in active regions, as derived from the earlier work of Withbroe & Noyes (1977) and Vernazza et al. (1981). However, recent studies based on high resolution observations point to sensibly higher values, at least in some portions of plage and active regions (up to 90 and 160 kWm⁻² respectively, see Morosin et al. 2022; Díaz Baso et al. 2021).

We know that the presence of magnetic elements is an important factor: beside active regions, both quiet Sun and plage regions show increased emission in areas where strong (photospheric) fields are present. The role of chromospheric magnetic fields has also recently become a subject of study, with Leenaarts et al. (2018) finding that enhanced radiative losses are correlated with the strength of the horizontal chromospheric fields. In general, however, analyses of the spatio-temporal distribution of chromospheric heating are still sparse, as they require high spatial and temporal resolution, long-duration observations as well as significant spectral and polarimetric information to derive the thermodynamical and magnetic properties of the atmosphere (see e.g. the recent study by Morosin et al. 2022).

A constant characteristics of areas of concentrated magnetic elements such as network or plage regions, is the presence of a multitude of fibrillar structures, anchored in the strong magnetic elements at the photosphere, as usually observed in the core of strong chromospheric spectral lines. These have been long observed for example using the

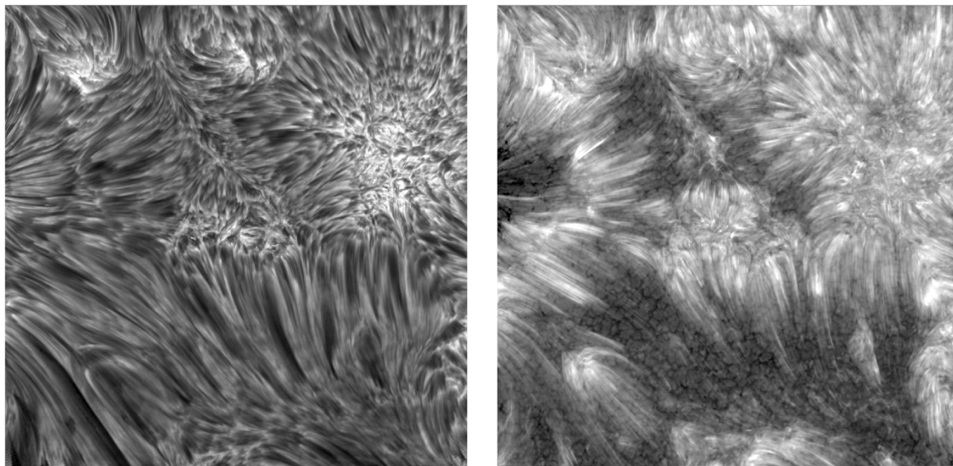


Figure 1. Left: $H\alpha$ line core intensity in the analyzed plage area. The FOV is $96'' \times 96''$ (about 70×70 Mm). Right: Map of corresponding $H\alpha$ spectral width. Values are scaled between 0.9 and 1.2 Å, which correspond roughly to T_b of 6-12,000 K, as per [Molnar et al. \(2019\)](#).

$H\alpha$ line, and variously dubbed as “mottles”, “rosettes”, or spicules ([Beckers 1968](#); [Rutten 2006](#); [Tsiropoula et al. 2012](#), among many). Their origin is still somewhat debated, but the important consideration for our present study is that such fibrils seem to be the site of strong heating events. This was originally recognized by [Cauzzi et al. \(2009\)](#), who showed how the immediate surroundings of network and plage elements would correspond to volumes of plasma hotter than the average, as indicated by the enhanced values of the spectral line widths of both $H\alpha$ and the CaII 854.2 nm line. This finding was put on firmer footing by [Molnar et al. \(2019\)](#), that clearly demonstrated how regions of enhanced $H\alpha$ spectral width coincide with area of high brightness temperature as inferred from the ALMA millimeter-continuum emission (T_b , which corresponds to the electronic temperature, T_e). The recent work of [Tarr et al. \(2023\)](#) further confirmed this correspondence.

Given the likely relevance of these “hot chromospheric fibrils” in the general problem of chromospheric heating, we have initiated a study of their quantitative characteristics, with the final objective of constraining possible heating mechanisms in this mysterious part of the solar atmosphere.

2. Analysis and results

The relevant data was acquired with the Interferometric Bidimensional Spectrometer (IBIS, [Cavallini 2006](#)) on April 23, 2017, and included sampling of the chromospheric lines $H\alpha$, NaI D₁ and CaII 854.2 nm in multiple wavelengths per line, with a cadence of ~ 16 s over a total of 46 minutes (note that this is the same dataset analyzed in [Molnar et al. 2019](#); [Hofmann et al. 2022](#)). The $96'' \times 96''$ field of view (FOV) covered a stable plage area in the vicinity of an active region, as shown in the left panel of [Figure 1](#), taken in the core of $H\alpha$. The right panel of [Figure 1](#) shows instead the map of $H\alpha$ spectral width, calculated from the whole spectral line as described in [Cauzzi et al. \(2009\)](#). A multitude of hot fibrils are clearly seen, jutting out of the plage magnetic elements. While the general orientation of the fibrillar features is the same in the two panels, note that hot fibrils (i.e. bright features in the map of $H\alpha$ spectral width) can coincide with features that are either bright or dark in the intensity image. Moreover, the hot fibrils extend only for a certain fraction of the intensity fibrils, and do not cover the whole FOV.

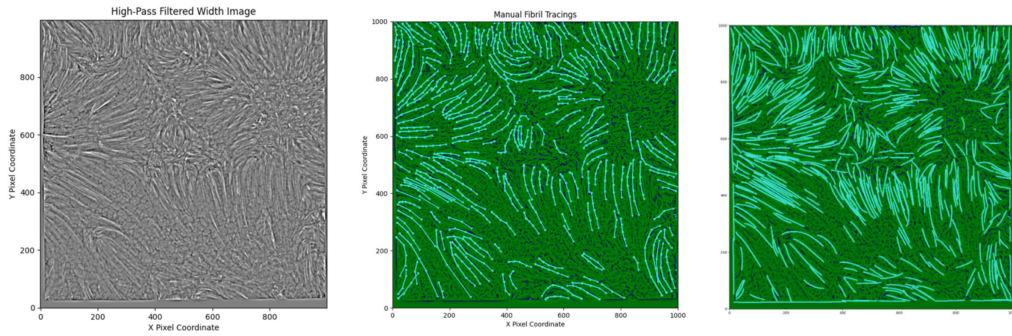


Figure 2. Left: High-pass difference image used to aid the manual identification of the hot fibrils. Center: Manual tracing (blue lines) of all visually-identifiable fibril lines in the width image (green background), for use as a control set. Right: Automatic tracing of fibrils by OCCULT-2 when using optimized parameters.

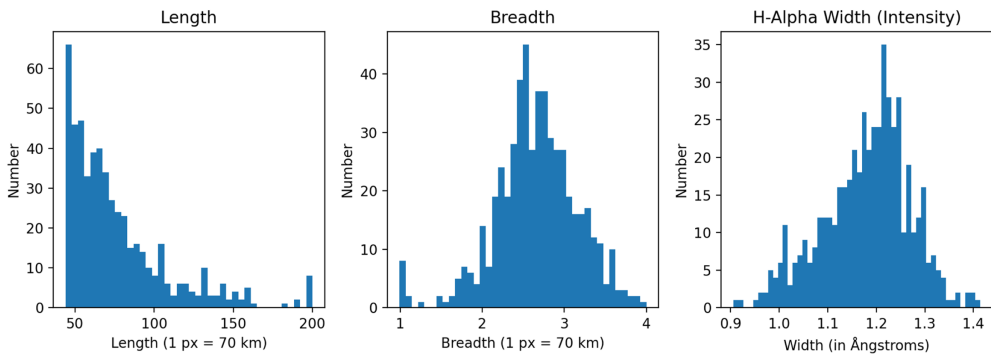


Figure 3. Left: Distribution of hot fibrils' lengths. A threshold of at least 50 pixels (3500 km) was used when selecting features. The average length of a hot fibril amounts to about 5500 km. Center: distribution of breadths. The average breadth of a hot fibril is of order 200 km, which is very close to the diffraction limit of the observations (≈ 150 km). Right: distribution of H α widths. Hot fibrils have an average H α width of 1.18 Å, which following [Molnar et al. \(2019\)](#) would correspond to an approximate temperature of over 10,000 K.

The preliminary analysis described in this paper was conducted on a single map of H α width, obtained at a time of excellent seeing. We first performed a manual identification of the hot fibrils, using a high-pass difference image obtained by subtracting a Gaussian-smoothed width map from the original image, for easier tracing of small-scale features (Fig. 2 left panel). The identification was performed multiple times, by multiple independent observers, to obtain a control set (Fig. 2 center panel). Finally, we used the OCCULT-2 algorithm ([Aschwanden et al. 2013](#)), which identifies curvilinear features from an intensity image and outputs a table of feature coordinates, to perform an automatic tracing of the hot fibrils. OCCULT-2 was first designed to trace coronal loops in images with lower spatial resolution, but we optimized its parameters using the control set defined above to guide our choices. The resulting traces are shown in Fig. 2 right panel. We identified a total of 515 fibrils in our $96'' \times 96''$ FOV.

Once we had the identified set of hot fibrils, we looked for three primary characteristics: **length** - the spatial extension of any given fibril; **breadth** - the thickness of a fibril at any given point along its length, perpendicular to the fibril's axis; **“intensity”** - the value of the Halpha spectral width at any given point along its length. The results are summarized in the histograms of Fig. 3. The hot fibrils display a large range of lengths

(note that we adopted an arbitrary threshold of 3500 km as the minimum length), all the way to 10,000 km, with an average length of 5,500 km. Their average “intensity”, e.g. $H\alpha$ spectral width, is around 1.2 Å, which is close to the upper limit reported in [Molnar et al. \(2019\)](#), and corresponds to a T_e of over 10,000 K. Maybe most interesting, the breadth distribution shows that fibrils are very narrow, with values very close to the diffraction limit of the observations (2 pixels, or 150 km). This suggests that the mechanisms that lead to heating in these chromospheric features operate on very small spatial scales.

3. Conclusions

We analyzed the spatial characteristics of the spectral width of $H\alpha$, a quantity correlated with local T_e , in a plage region. To this end we have successfully adapted the OCCULT-2 algorithm, originally developed to trace coronal loops ([Aschwanden et al. 2013](#)), to identify curvilinear features at high spatial resolution. We find over 500 “hot fibrils” (i.e. features with a large $H\alpha$ spectral width) in our 96” × 96” FOV, with a suggested temperatures in excess of 10,000 K, i.e. significantly hotter than the average chromosphere.

These features have an average length of around 5,500 km, and, while their general orientation is the same as for intensity features, their extension does not cover the whole FOV. This suggests that the heating events causing the large spectral widths occur only in a fraction of the fibrils as typically identified in the core of chromospheric lines, and, in particular, the heating occurs in the portion closer to their magnetic footpoints. Finally, their “breadth” (transversal extension) is of only 200 km, which indicates that these features are probably still under-resolved. Given these characteristics, and in particular the large aspect ratio of the hot fibrils, Ohmic dissipation of current sheets in the chromosphere appears a probable mechanism for the heating. However, a firmer interpretation will need an analysis of the temporal evolution of the heating, over multiple solar scenes.

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Supplementary material

To view supplementary material for this article, please visit <https://doi.org/10.1017/S1743921323001199>.

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SOC member Dipankar Banerjee from ARIES (India) asking a question during the Symposium.