Characterization of Hot Fibrils in the Solar Chromosphere

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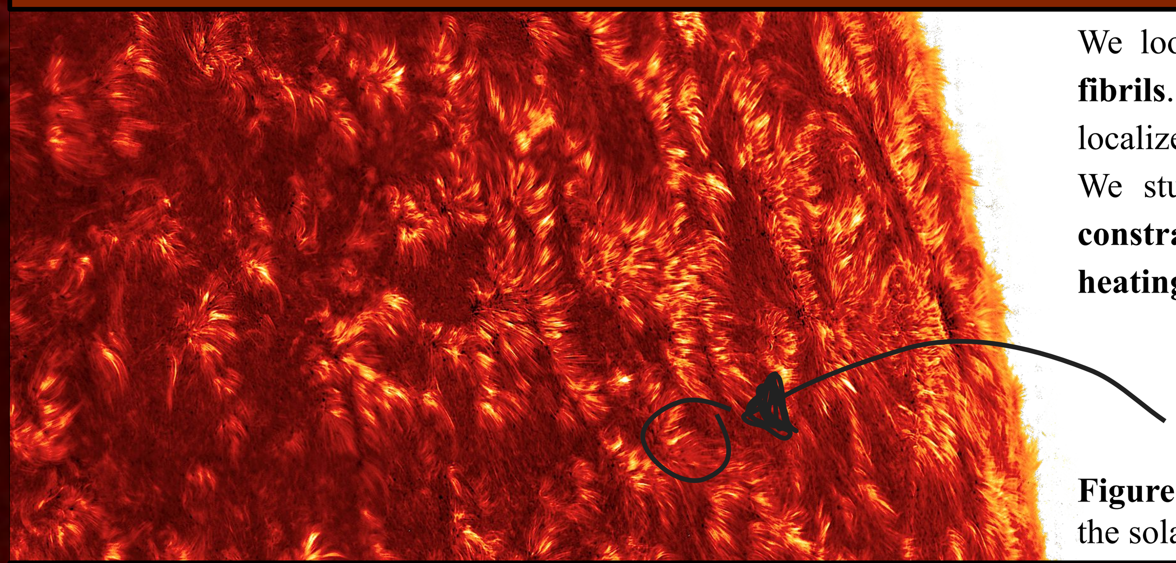
1. Abstract



We look at common features found within the chromosphere, called **fibrils**. In particular, some of these features appear to be the site of localized heating, as identified via properties of the H-alpha spectral line. We study their **quantitative characteristics,** with the objective of **constraining** possible heating mechanisms within the **chromospheric heating problem**.

Figure 1: Map of H-alpha spectral width over a large field of view (note the solar limb on the right).

2. The Chromospheric Heating Problem

The chromosphere is an important region of the solar atmosphere, where magnetic fields and plasma dynamics are intertwined.

- Visible through many strong spectral lines, including **H-alpha.**
- Temperature **generally increases** in the chromosphere, rising **above** the temperature of the underlying photosphere.

This increase is known as the **chromospheric heating problem**:

- Temperature should continue to **decrease** the further away we get from the hot interior.
- Instead, after an initial dip, the temperature **increases** outward by several thousand degrees Kelvin.
- Temperature increase requires at least 4-20 kW/m^2.

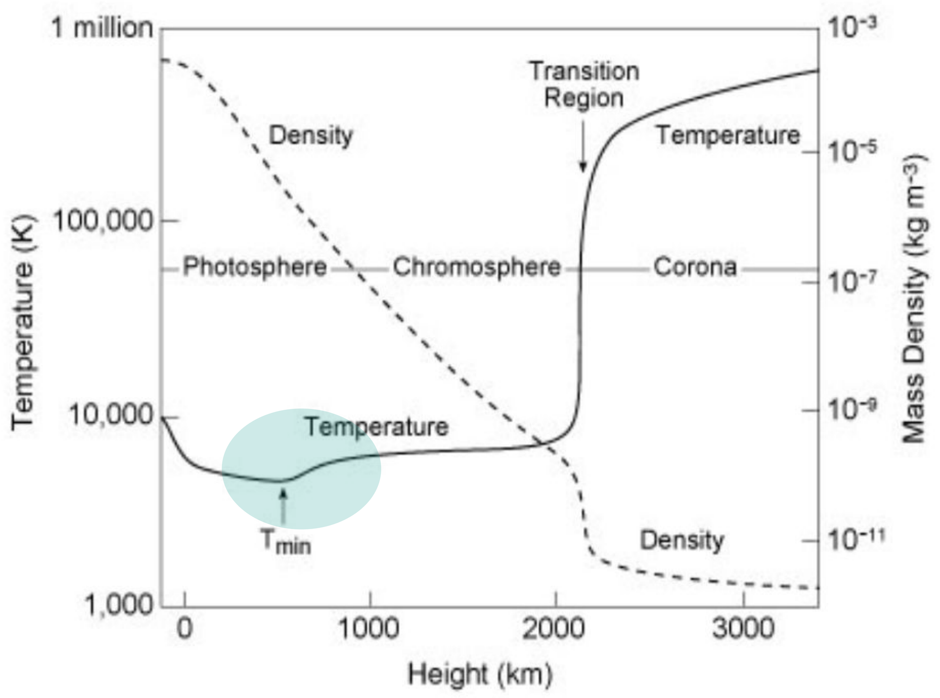


Figure 2: Temperature profile of the solar atmosphere as a function of height [1].

3. Relationship between the Width of the H-alpha Spectral Line and Temperature

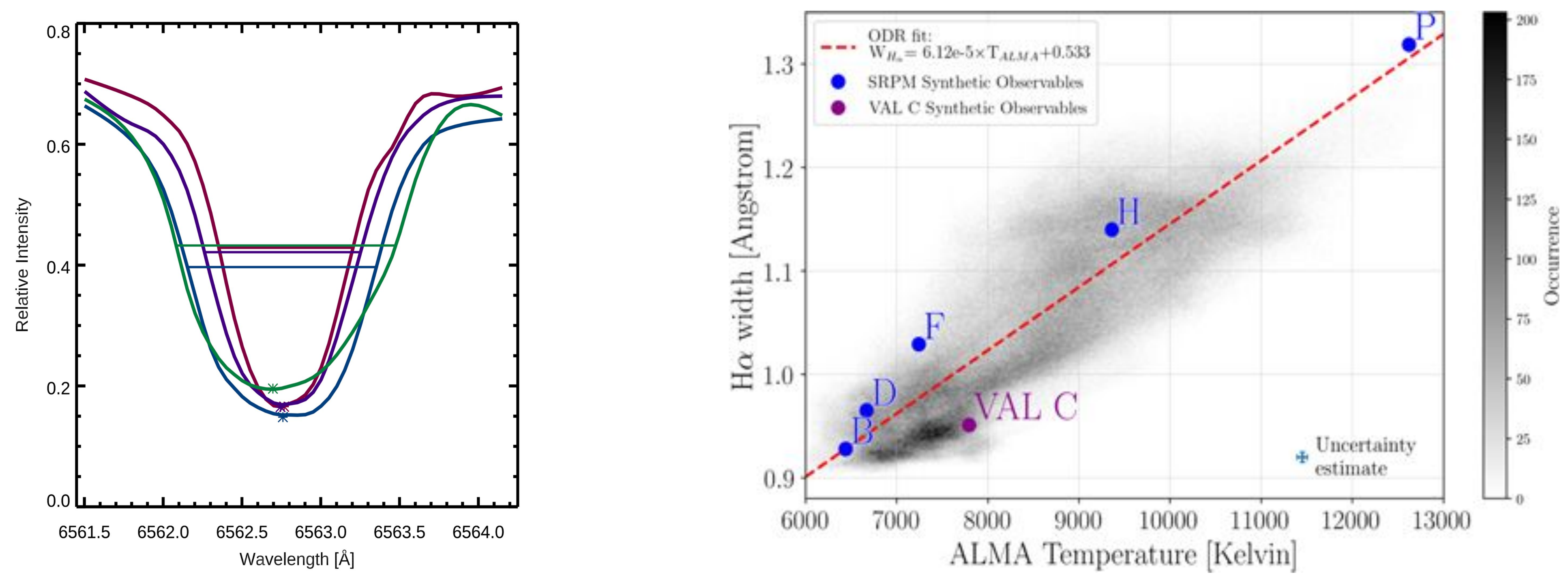
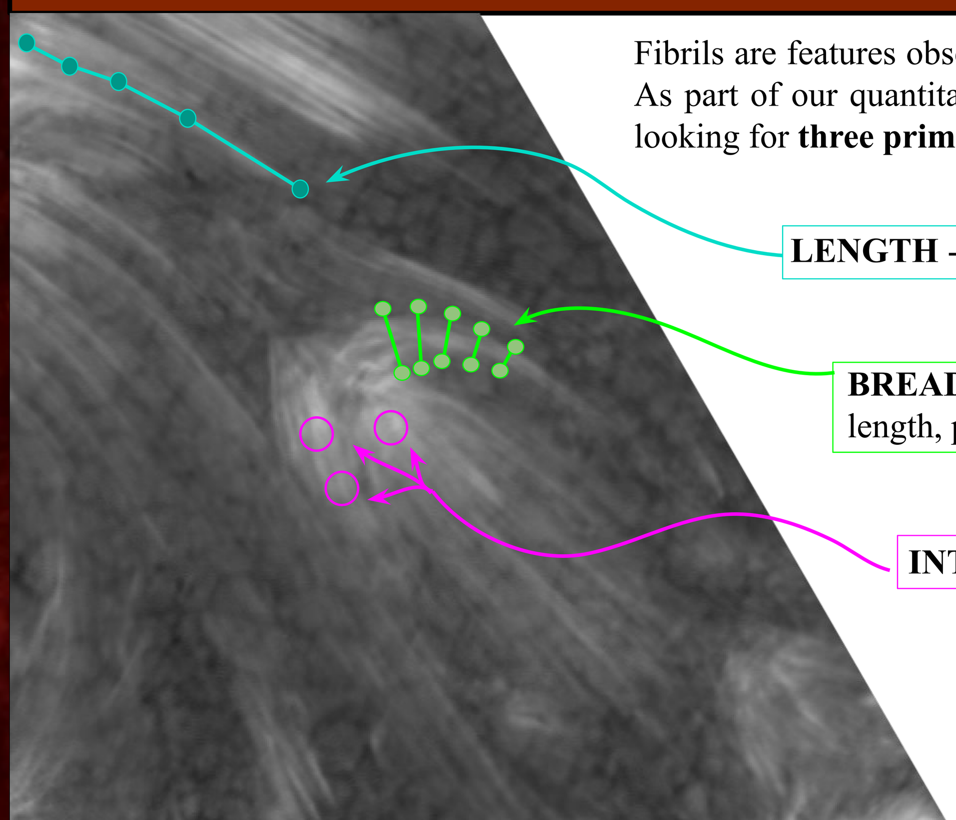


Figure 3: (Left) Visualization of the width of different example H-alpha spectral lines [2]. **(Right)** Visualization of the linear relationship between width of H-alpha spectral line and temperature [3]. This allows for the creation of temperature maps of chromospheric features.

4. Chromospheric Fibrils

Fibrils are features observable in the solar chromosphere, which seem to align with magnetic field lines. As part of our quantitative analysis of **hot** fibrils (i.e. fibrils with large H-alpha spectral width), we're looking for **three primary characteristics**:



LENGTH - The *sum of all coordinate differences* along the fibril

BREADTH - The *thickness* of the fibril at a given point along its length, perpendicular the the fibril axis.

INTENSITY - The *spectral line width* in Ångstroms along the fibril

Figure 4: Zoomed-in perspective of the H-alpha width map. Here, we can directly visualize the fibril characteristics - mainly, length, breadth (thickness) and intensity.

5. Manual Tracing of Hot Fibrils

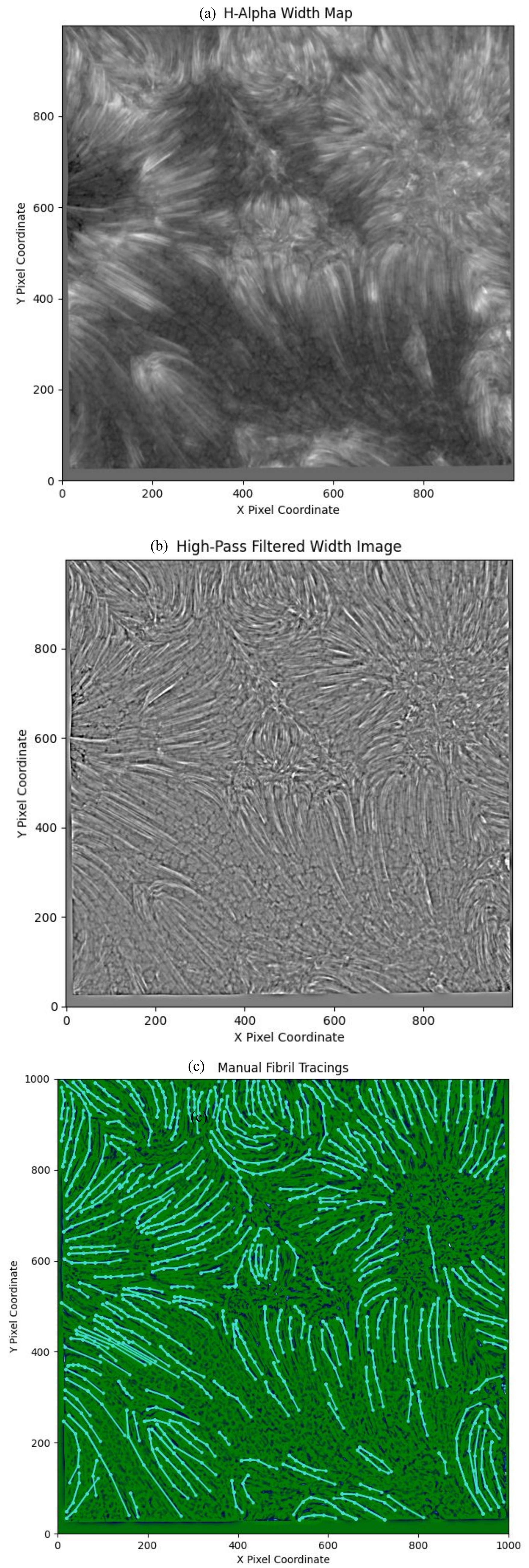


Figure 5: Processing of H-alpha width images for the manual and automatic tracing of chromospheric hot fibrils.
(a) H-alpha width map (calculated using techniques described in Section 3) over a field of view of 96 arcsec by 96 arcsec.
(b) High-Pass Difference image obtained by subtracting from a **Gaussian-smoothed** width map from the original image. This highlights the small-scale structures, making the fibrils more **easily perceptible and traceable**.
(c) Manual tracing (blue lines) of all visually-identifiable fibril lines in the width image (green background), for use as a **control set**.

6. Automatic Tracing of Hot Fibrils

Automatic tracing of fibrils was performed using the OCCULT-2 algorithm [4] which identifies curvilinear features from a intensity image and outputs a table of feature coordinates. OCCULT-2 was first designed to trace coronal loops in images with lower spatial resolution. We optimized its parameters to identify chromospheric fibrils.

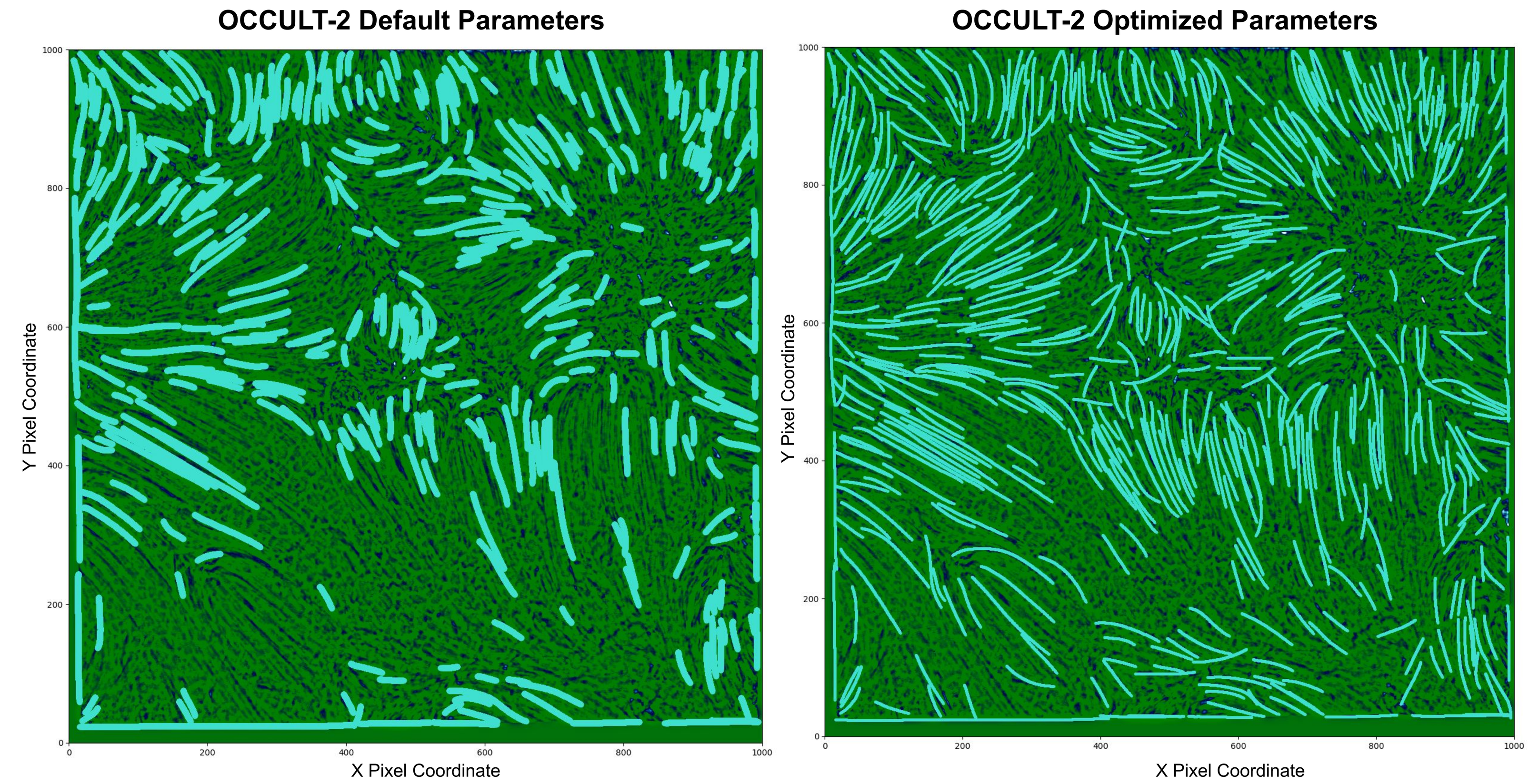


Figure 6: Automatic tracing of fibrils by OCCULT-2 when using **(left)** default parameters, and **(right)** parameters that were optimized through a visual and a quantitative characteristic comparison with the manually identified set (Figure 5c).

7. Analysis of the Characteristics of Hot Fibrils

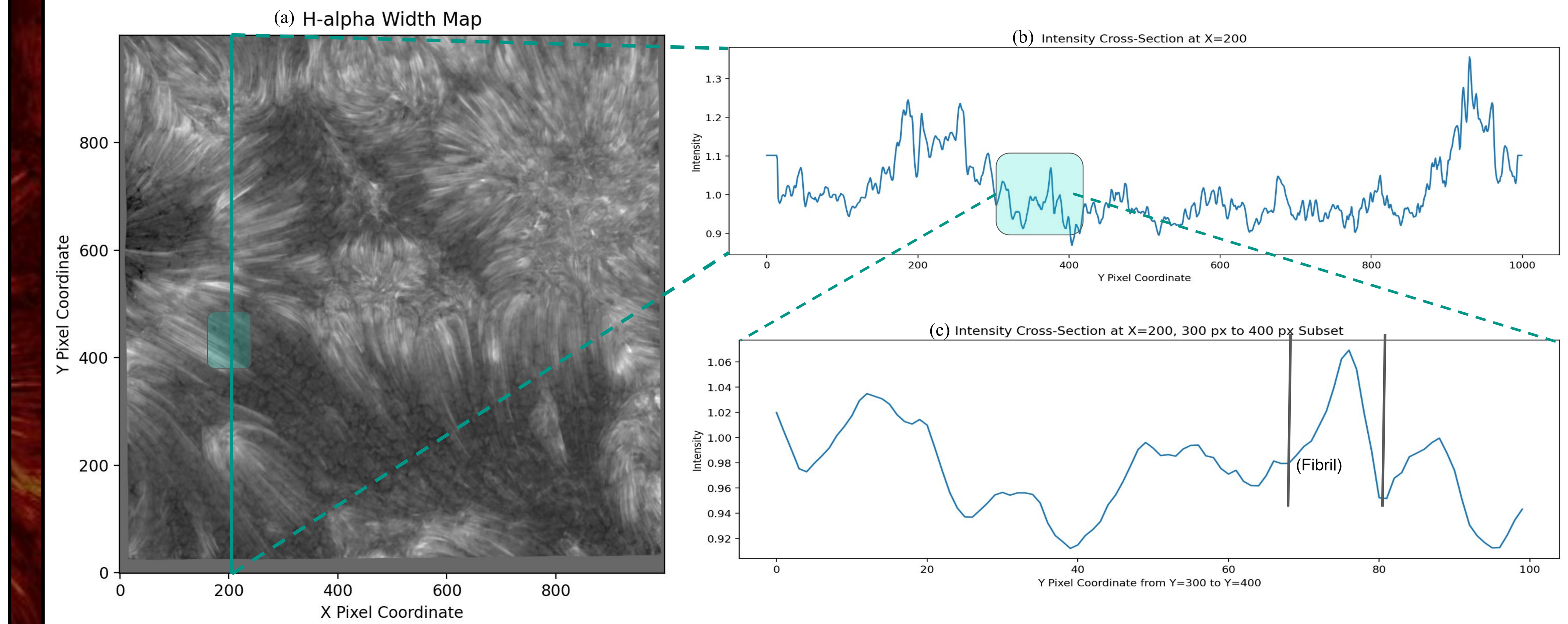


Figure 7: Visualization of how we go about calculating the breadth (i.e., thickness; see Section 4) of an identified fibril. For each fibril, we generally look for two local minima; between each minima should be a local max, our fibril.
(a) H-alpha width map over 96 arcsec by 96 arcsec (70 Mm by 70 Mm) field of view
(b) Intensity cross-section taken at x = 200 pixels. Peaks in line width generally correspond to fibrils
(c) Subset of Figure (b), used to demonstrate a close-up of a fibril.

8. Results

Given our sample H-alpha width map is 96 x 96 arcseconds, each pixel approximately corresponds to 70 x 70 km^2. After analyzing the characteristics of all **532** automatically sampled hot fibrils across the image, we determined:

- Average *length*: **77.64 px ≅ 5400 km.**
- Average *breadth*: **2.62 px ≅ 200 km.**
- Average *intensity*: **1.18 Ångstroms**, corresponding to an approximate temperature of **~10,500 K** (Temperature of the photosphere is ~6000 K).
- Assuming a constant density of fibrils on the disk, we could expect to see as many as **170,000 fibrils** on the Sun at any given point in time.

9. Conclusions & Future work

We have adapted a tool to automatically identify hot chromospheric fibrils from H-alpha profile-width maps. These fibrils are tracers of local heating in the solar chromosphere. This will allow statistical studies of the properties of these fibrils, which can provide insights on the physical mechanisms that might be depositing energy in the upper atmosphere. Future work on this subject might include:

- **Machine learning approaches**
- **Studying temporal evolution**
- **Additional spectral diagnostics**
- **Different solar structures and viewing angles**

10. Acknowledgements

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11. References

[1] Vernazza et al., 1981
[2] Cauzzi et al., 2009
[3] Molnar et al., 2019
[4] Aschwanden et al., 2013