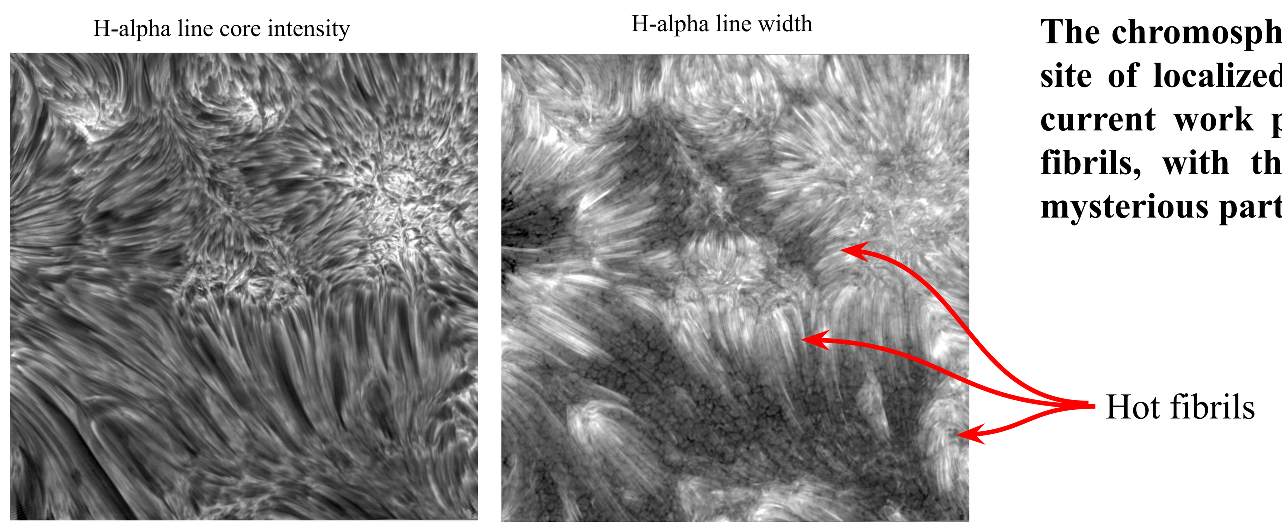
Characterization of Hot Fibrils in the Solar Chromosphere

Parker Lamb[1], Gianna Cauzzi[2], Kevin Reardon[2] and Benoit Tremblay[3]
[1]NSF Undergraduate Research at LASP, [2]National Solar Observatory (NSO), [3]Laboratory for Atmospheric and Solar Physics (LASP)

1. Abstract

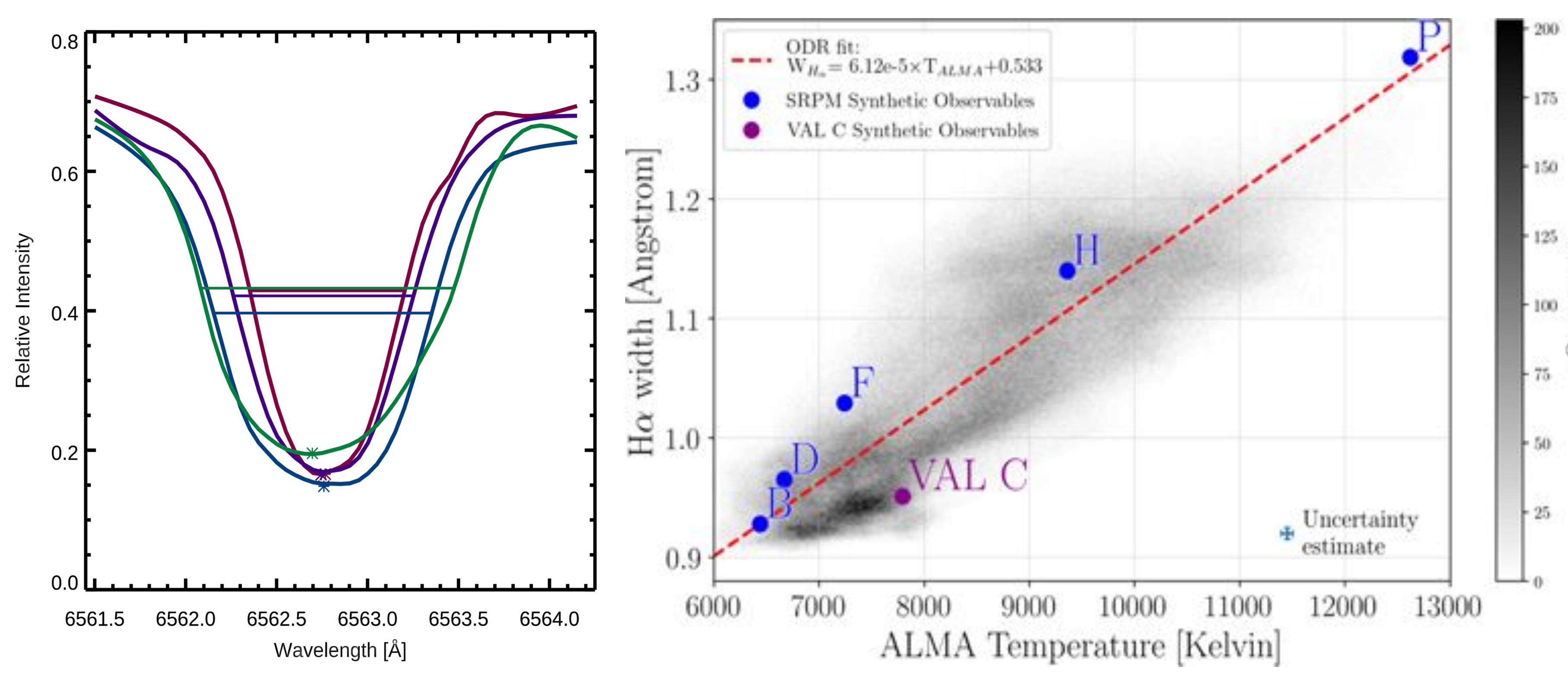


The chromospheric network is "surrounded" by fibrilar structures that appear to be the site of localized heating, as identified via the spectral width of the H-alpha line. The current work presents an initial study of the quantitative characteristics of such hot fibrils, with the final objective of constraining possible heating mechanisms in this mysterious part of the solar atmosphere.

Figure 1: H-alpha line core intensity (**left**) and line width (**right**) over a network/plage region 96" x 96".

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

Figure 2: (Left) Visualization of the width of various H-alpha spectral profiles acquired in different solar features [1]. **(Right)** The width of the H-alpha spectral line (y-axis) is clearly proportional to the electron temperature, as determined from ALMA 3-mm observations [2]. This allows for the creation of high-spatial resolution maps of the chromospheric temperature, as displayed in Fig. 1, by using spectrally and spatially resolved H-alpha data acquired with IBIS [3].



3. Hot Chromospheric Fibrils

As part of our quantitative analysis of **hot** fibrils (i.e. fibrils with large H-alpha spectral width), we looked for **three primary characteristics**:

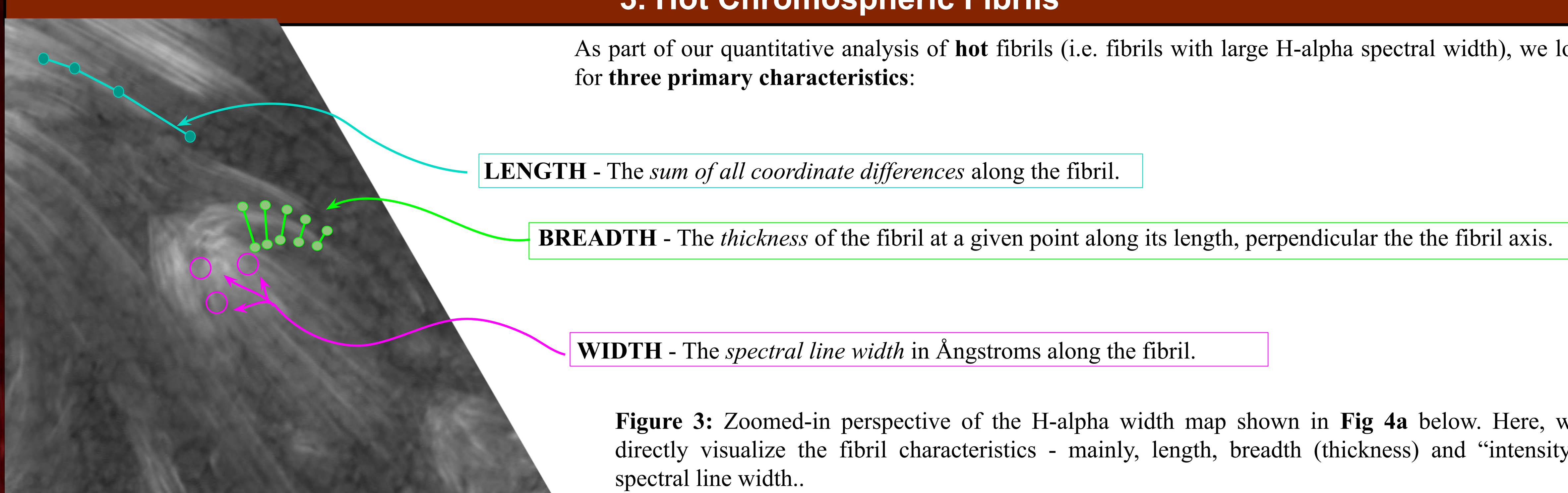


Figure 3: Zoomed-in perspective of the H-alpha width map shown in **Fig 4a** below. Here, we can directly visualize the fibril characteristics - mainly, length, breadth (thickness) and "intensity", i.e. spectral line width..

4. Manual Tracing of Hot Fibrils

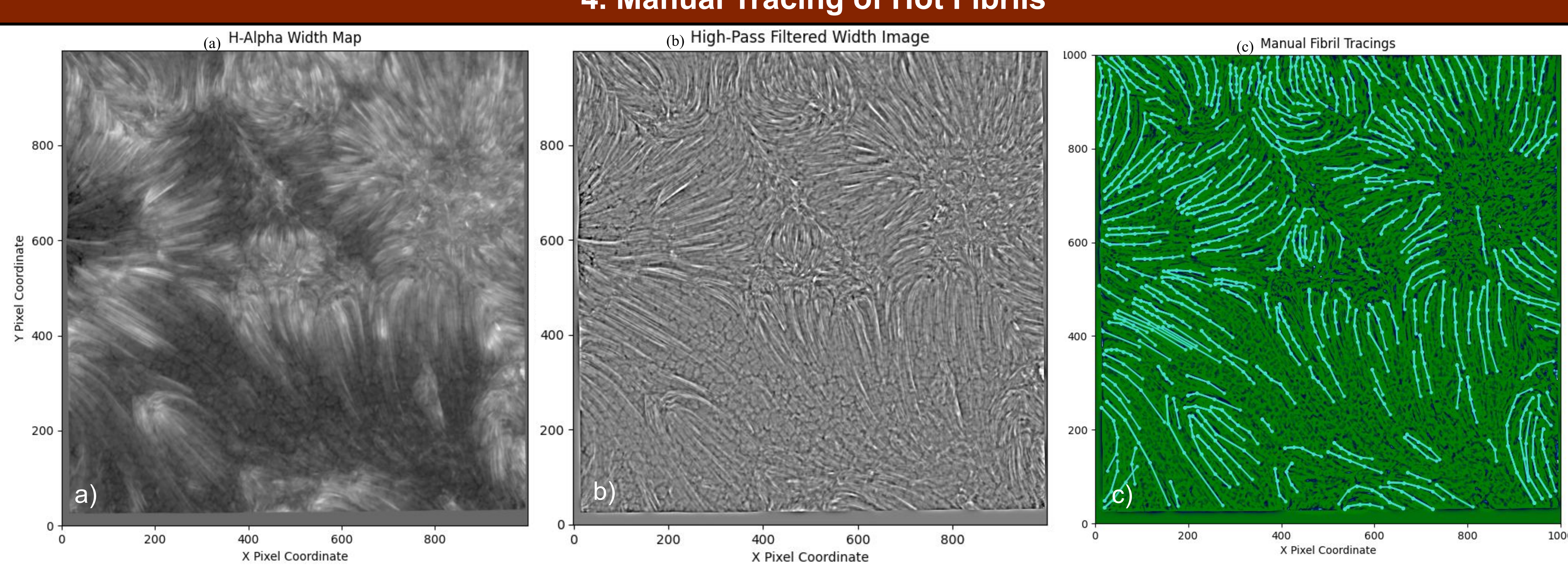
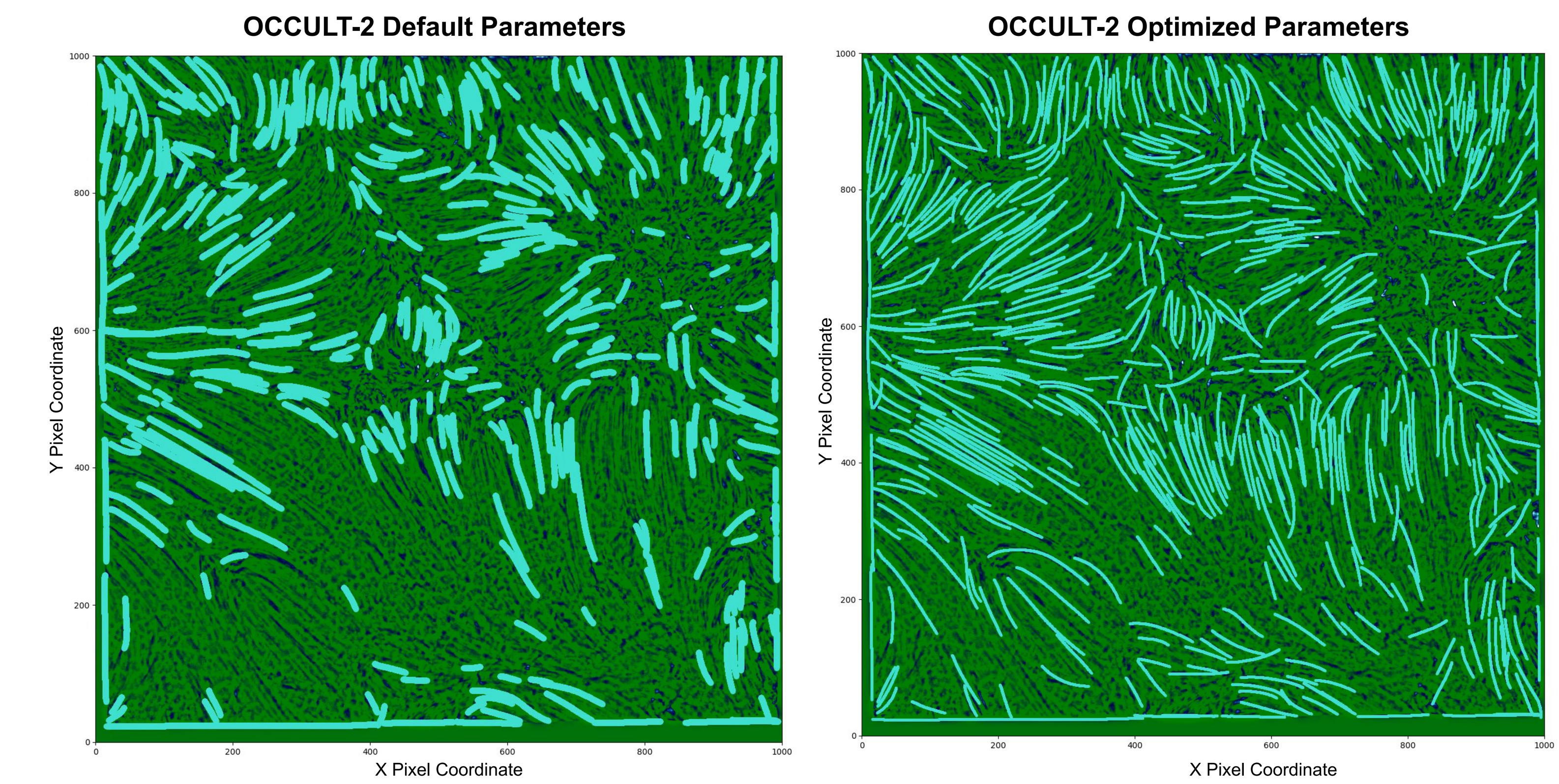


Figure 4: Processing of H-alpha width images for the tracing of hot fibrils. **(a) H-alpha width map** over the FOV of 96" x 96" (1 pixel = 70 km at the solar surface). **(b) High-pass difference image** obtained by subtracting a Gaussian-smoothed width map from the original image for easier tracing of small-scale features. **(c) Manual tracing** (blue lines) of all visually-identifiable fibril lines in the difference image (green background), for use as a control set.

5. Automatic Tracing of Hot Fibrils

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

Figure 5: 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 4c**).



6. Results

The automatic tracing identified **515** hot fibrils within our 96" x 96" FOV. The histograms below show the distribution of several parameters characterizing the fibrils.

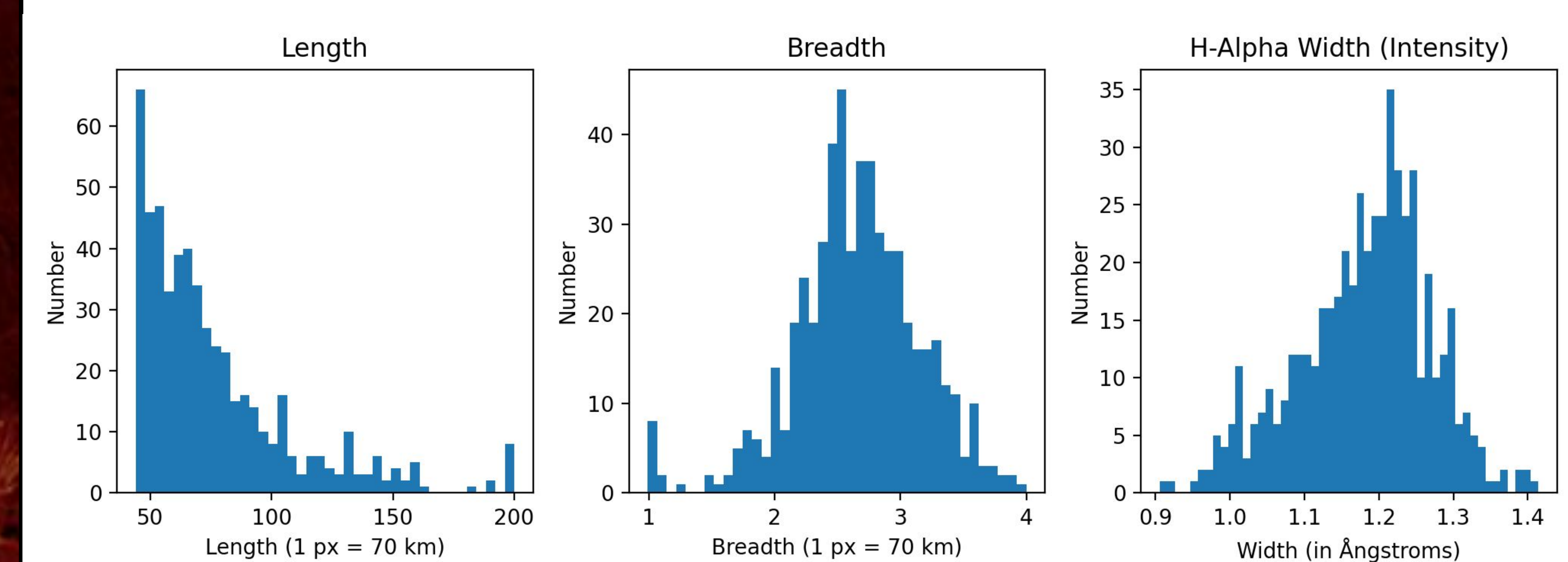


Figure 6. Left: distribution of hot fibrils' lengths. A threshold of at least 50 pixels (~3500 km) was used when selecting features. **The average length of a hot fibril amounts to ~ 5500 km.** Middle: distribution of breadths. **The average breadth of a hot fibril is ~ 200 km,** which is very close to the diffraction limit of the observations (~ 150 km). **Right:** distribution of H-alpha width). **Hot fibrils have an average H-alpha width of 1.18 Å,** which from the scatterplot of Fig. 2 would correspond to an approximate temperature of over **10,000 K.**

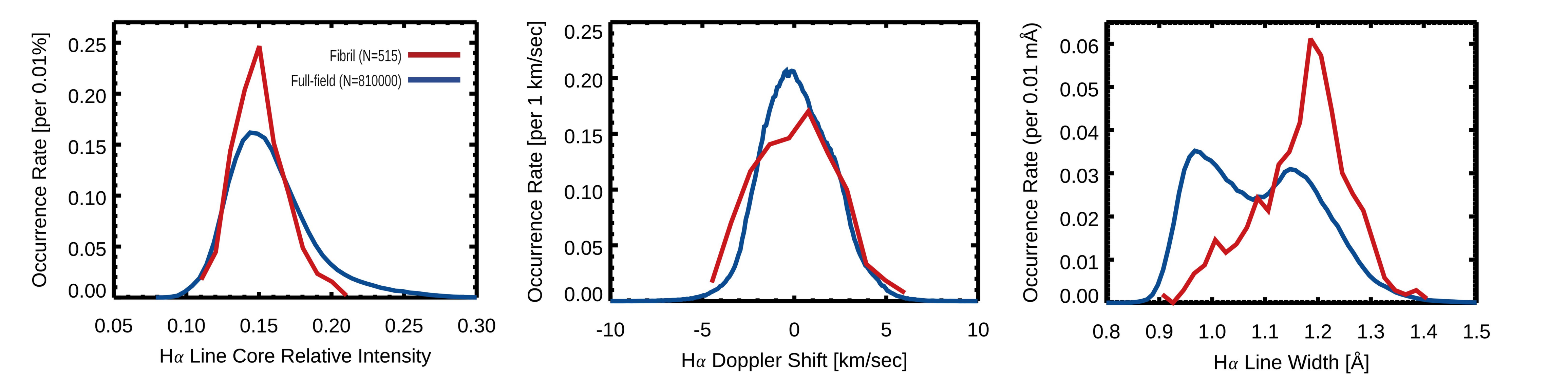


Figure 7: Comparison of the distribution of some fibrils' parameters (**red**) to that within the whole field of view (**blue**). All plots are normalized to the total number of pixels in the distribution. **Left:** Hα core image intensities; **Center:** plasma velocity determined from Doppler shift at the 50% bisector level ; **Right:** Hα spectral line widths. As expected, the hot fibrils have a much larger average value of Hα line width with respect to the background, although no threshold on this parameter was directly applied for their identification. This distribution over the whole field of view shows two well separate peaks, corresponding to the the internetwork, and the surrounding of the magnetic network, respectively. From the left and center plots we find that the hot fibrils do not stand out from the overall background , when using "standard" diagnostics like the core intensity or Doppler shift. In particular, the latter result seems to indicate that no bulk motion is involved in the creation of these hot features.

7. Conclusions & Future work

We have adapted the OCCULT-2 algorithm to automatically identify fibrils in H-alpha line-width maps, which pinpoint local heating in the solar chromosphere. This will allow statistical studies of the properties of these fibrils, providing insights on the physical mechanisms that might be depositing energy in the upper atmosphere.

From an initial analysis of a network/plage region, the automatic tracing identified **515** hot fibrils within a 96" x 96" FOV. These fibrils are very elongated, with an average length **over 5000 km,** and a "breadth"of only **~200 km,** which indicates that these features are probably still under-resolved. Their Halpha line-width suggests temperatures in excess of **10,000 K,** i.e. significantly hotter than the average chromosphere. Interestingly, the hot fibrils are not clearly distinguishable from the general solar background when looking at either line core intensity or Doppler shifts. The lack of bulk motions in particular might provide clues on their origin.

We plan to extend this work in the future via a multi-pronged approach, including:

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

8. Acknowledgements and References

This research was supported by the National Science Foundation REU program, award #1659878. This research was performed under the Laboratory for Atmospheric and Solar Physics (LASP) Undergraduate Research Program.

[1] Cauzzi et al., 2009 ; [2] Molnar et al., 2019 ; [3] Cavallini 2006 ; [4] Aschwanden et al., 2013

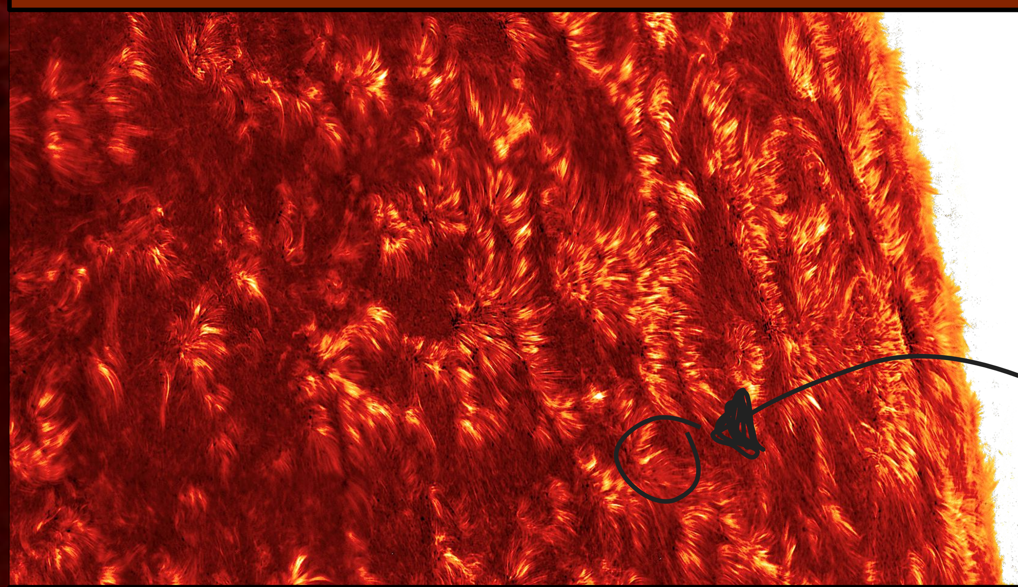
Characterization of Hot Fibrils in the Solar Chromosphere

Parker Lamb[1], Gianna Cauzzi[2], Kevin Reardon[2] and Benoit Tremblay[3]

[1]NSF Undergraduate Research at LASP, [2]National Solar Observatory (NSO), [3]Laboratory for Atmospheric and Solar Physics (LASP)

Laboratory for Atmospheric and Space Physics
University of Colorado Boulder

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.

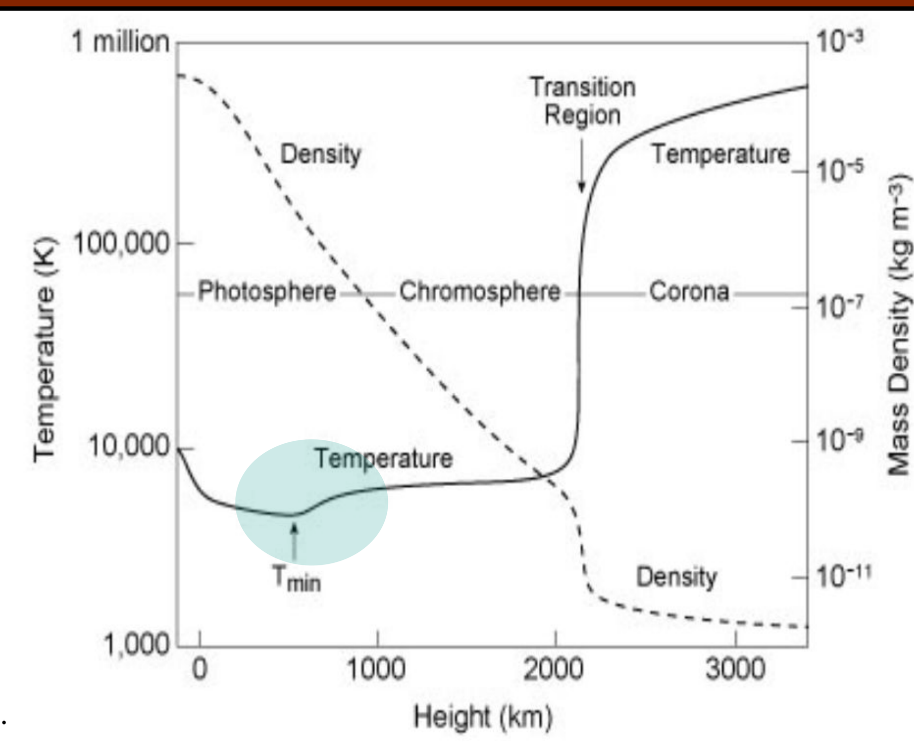


Figure 2: Temperature profile of the solar atmosphere as a function of height [1].

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

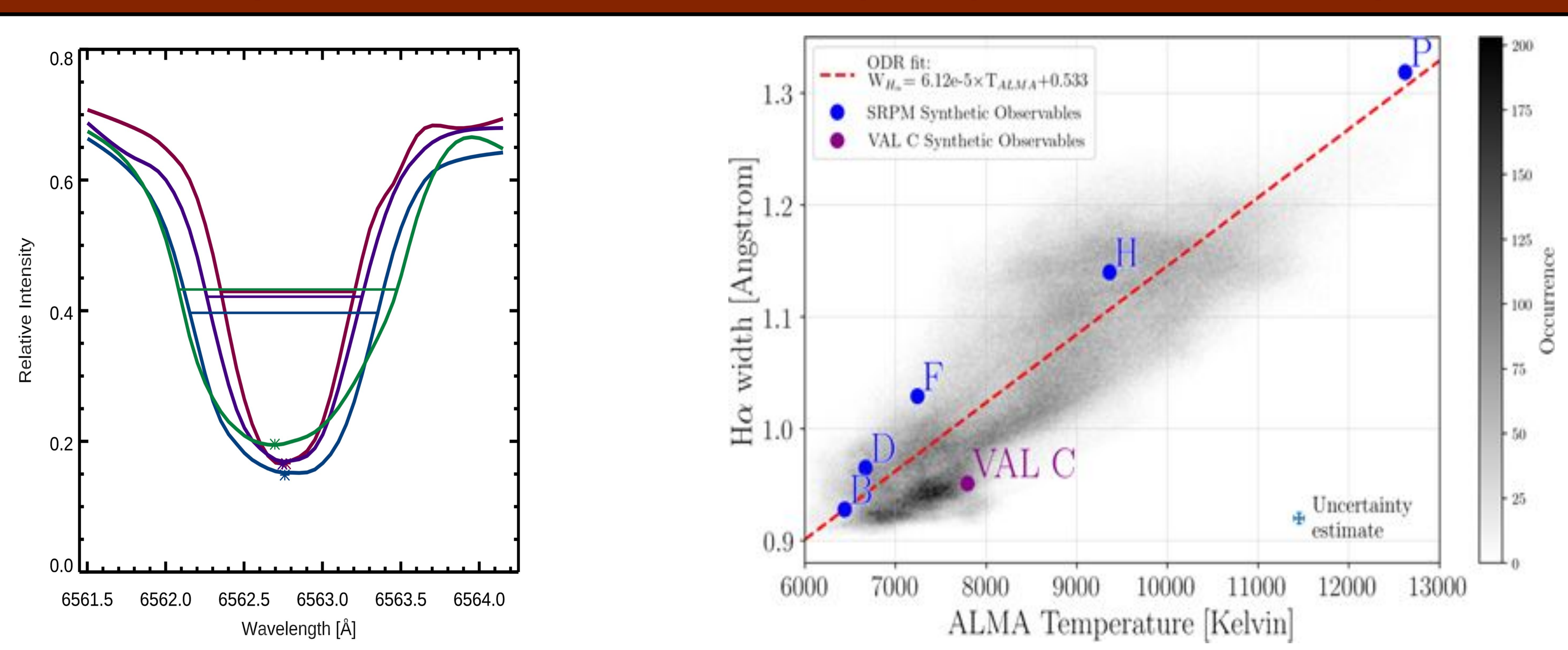
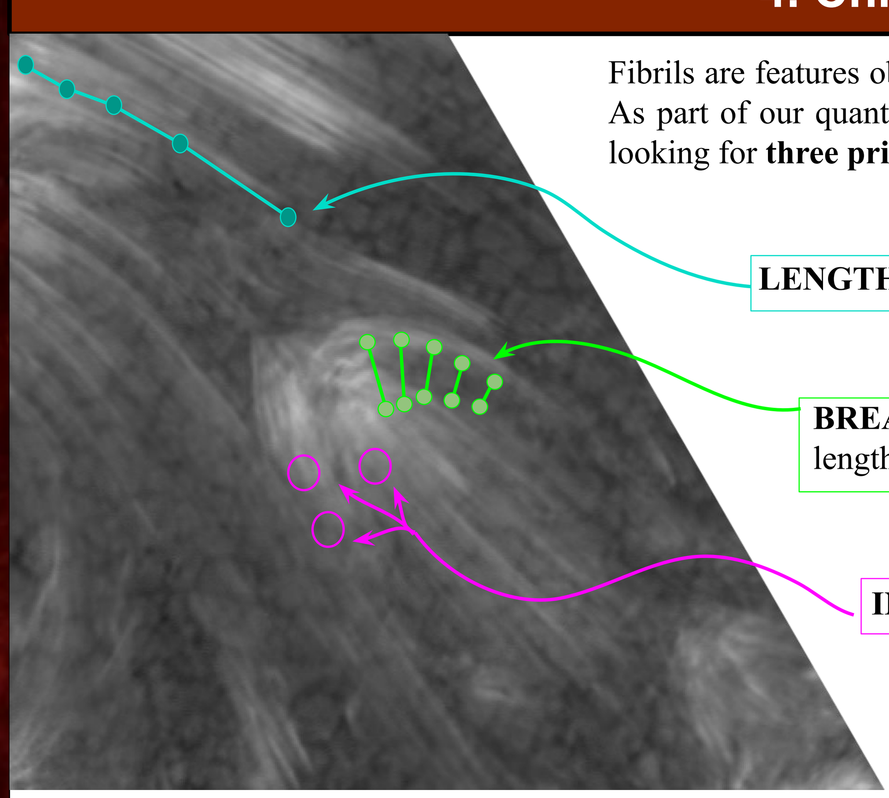


Figure 3: (Left) Visualization of the width of different example H-alpha spectral lines [2]. **(Right)** Visualization of the linear relationship between width of H-alpha spectral line and temperature [3]. This allows for the creation of temperature maps of chromospheric features.

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

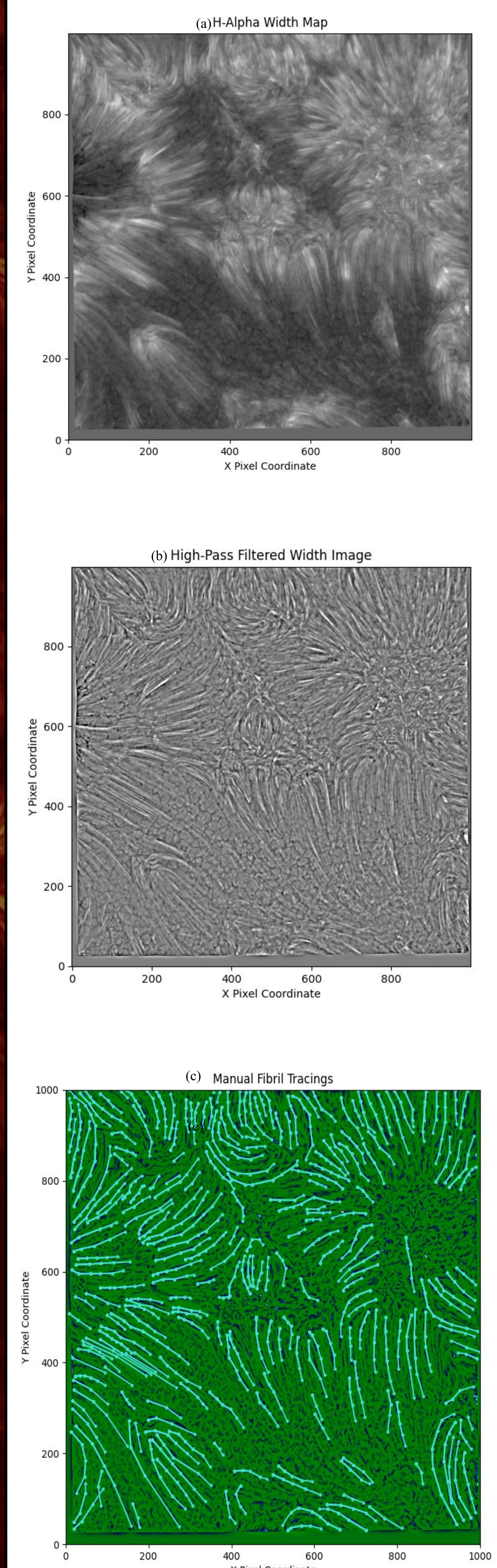


Figure 5: Processing of H-alpha width images for the manual and automatic tracing of chromospheric hot fibrils.
(a) H-alpha width map (calculated using techniques described in Section 3) over a field of view of 96 arcsec by 96 arcsec.
(b) High-Pass Difference image obtained by subtracting from a **Gaussian-smoothed** 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.

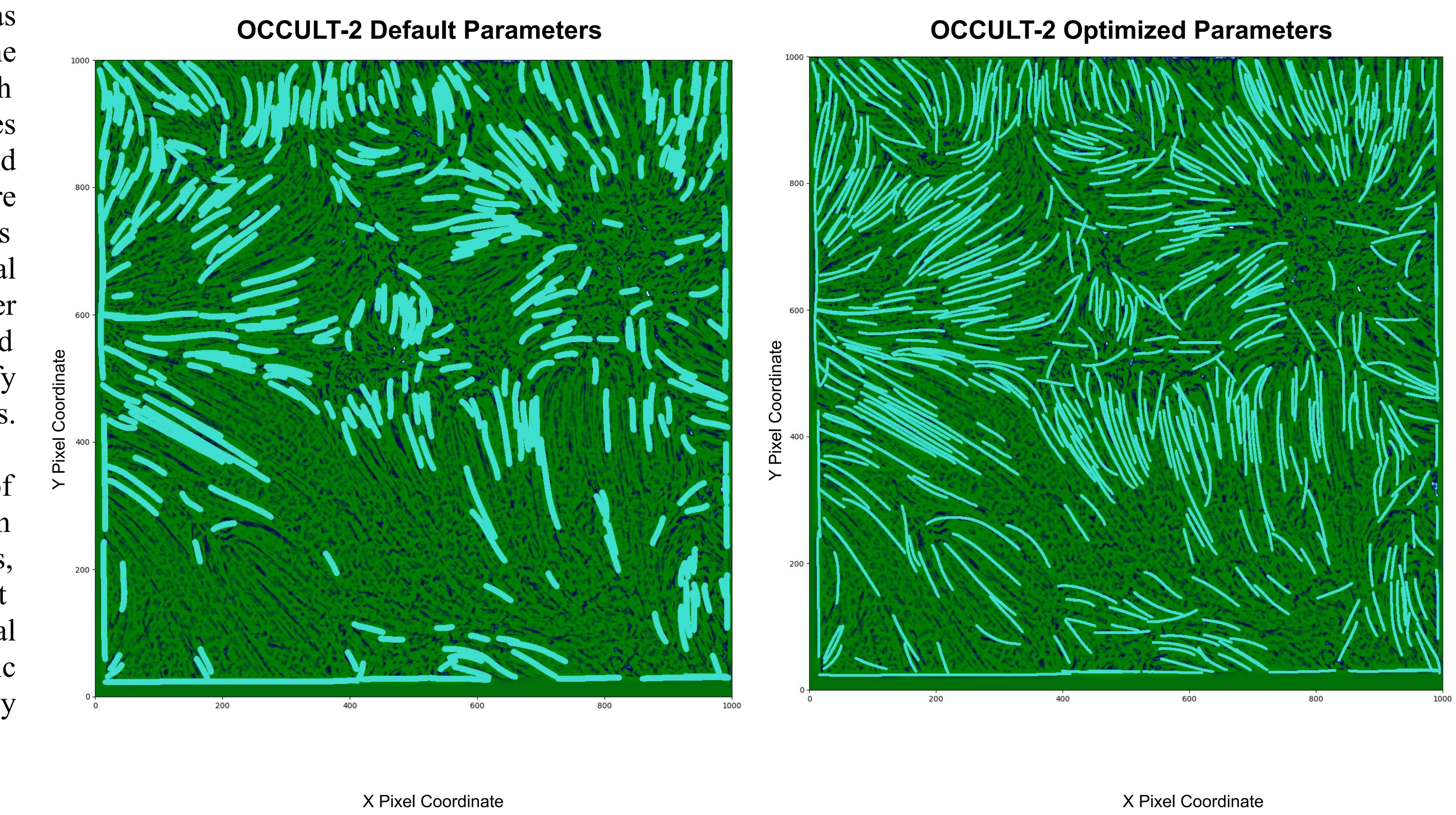


Figure 6: Automatic tracing of fibrils by OCCULT-2 when using **(left)** default parameters, and **(right)** parameters that were optimized through a visual and a quantitative characteristic comparison with the manually identified set (Figure 5c).

7. Analysis of the Characteristics of Hot Fibrils

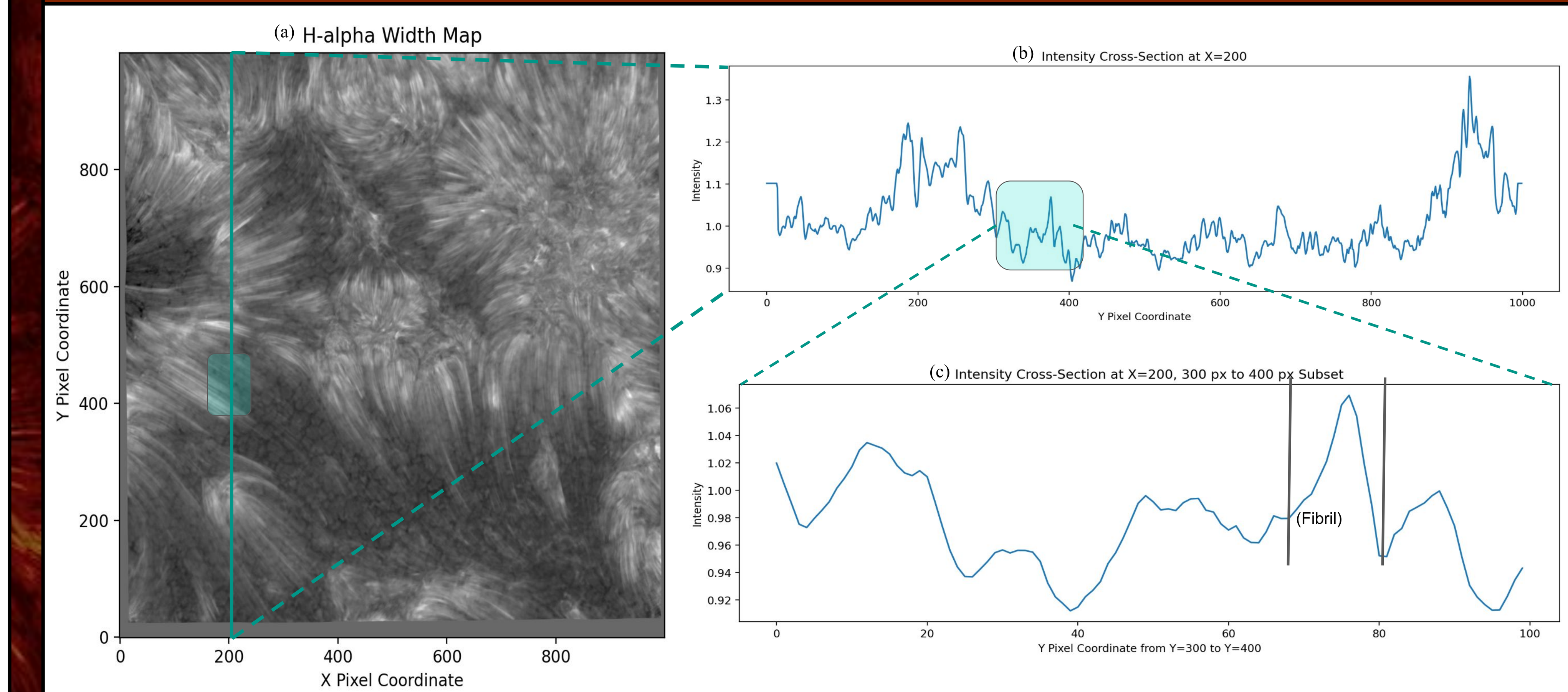


Figure 7: Visualization of how we go about calculating the breadth (i.e., thickness; see Section 4) of an identified fibril. For each fibril, we generally look for two local minima; between each minima should be a local max, our fibril.
(a) H-alpha width map over 96 arcsec by 96 arcsec (70 Mm by 70 Mm) 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 and References

This research was supported by the National Science Foundation REU program, award #1659878. This research was performed under the Laboratory for Atmospheric and Space Physics (LASP) Undergraduate Research Program.

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