

Characterization of Hot Fibrils in the Solar Chromosphere

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Fibril(s)!



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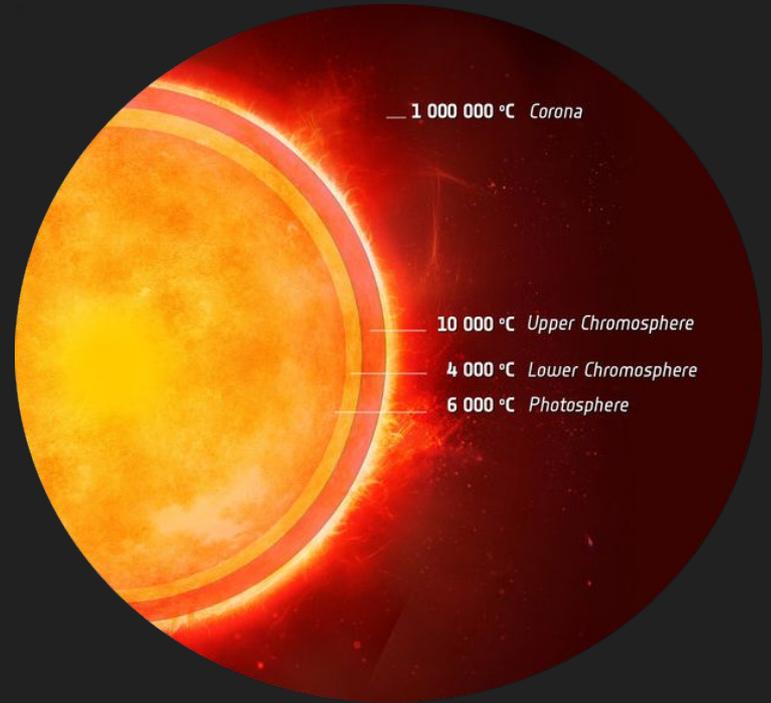
Overview

This project looks at common features found in the solar chromosphere, called **fibrils**, with the goal of extracting new information about their role in the chromospheric heating problem.

- **Introduction** 
- **Methods** 
- **Results** 
- **Next Steps** 

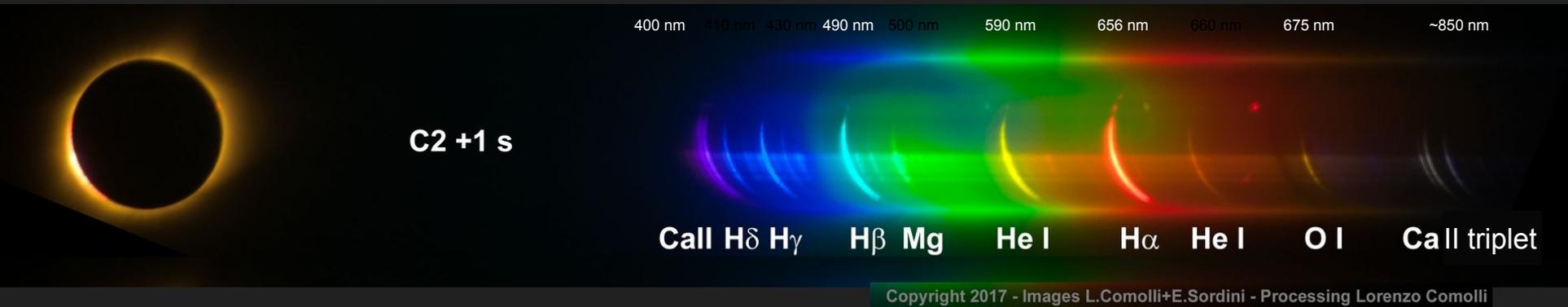
Introduction - The Chromosphere

- Located between the photosphere and the corona.
- Temperature: 6,000 - 12,000 K.
- Thickness: 1000 - 1500 km*.
- Emits in a few strong spectral lines, including H-alpha.



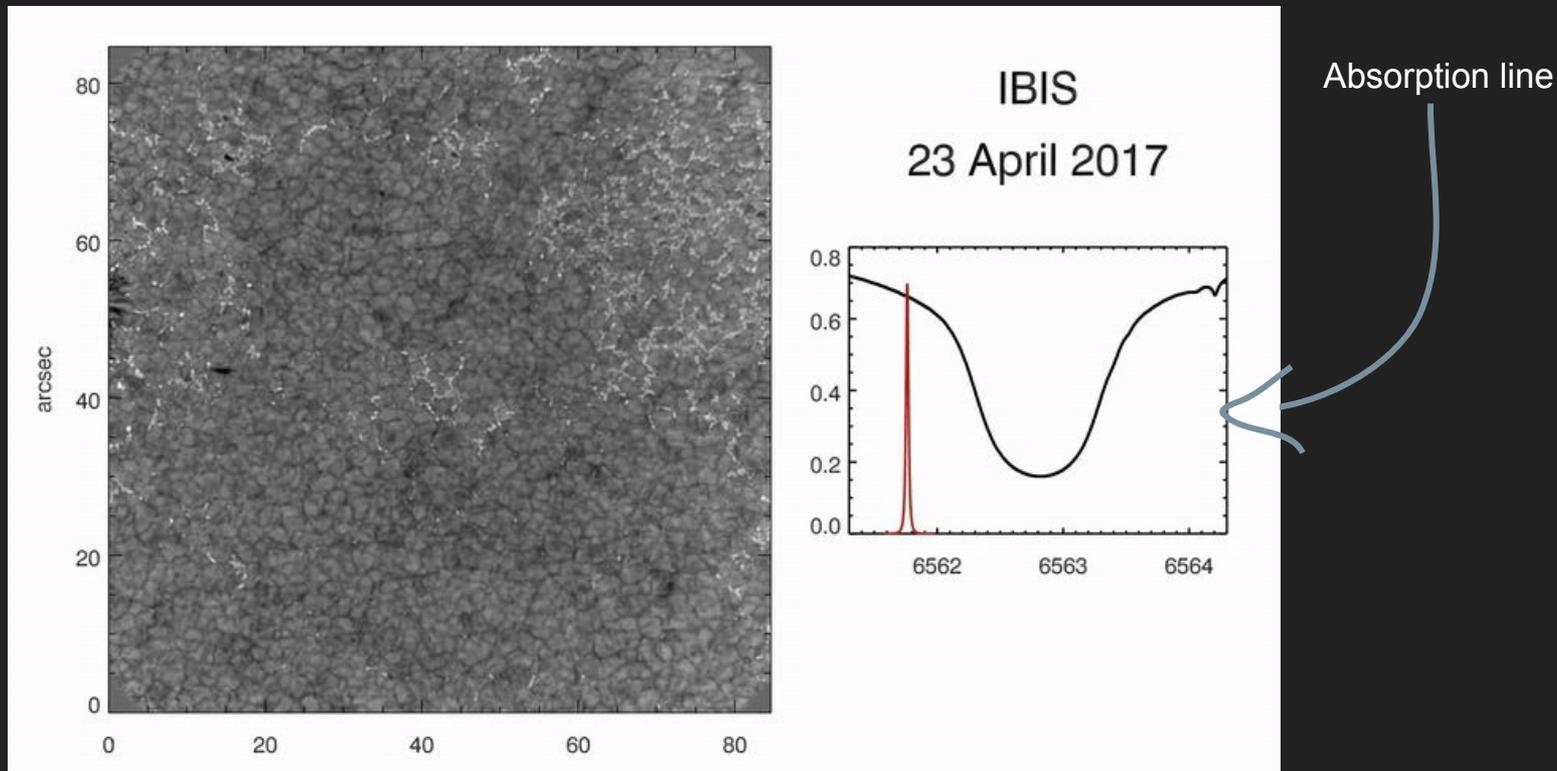
Simplified depiction of the solar atmosphere ([space.com](https://www.space.com))

Introduction - The Chromosphere



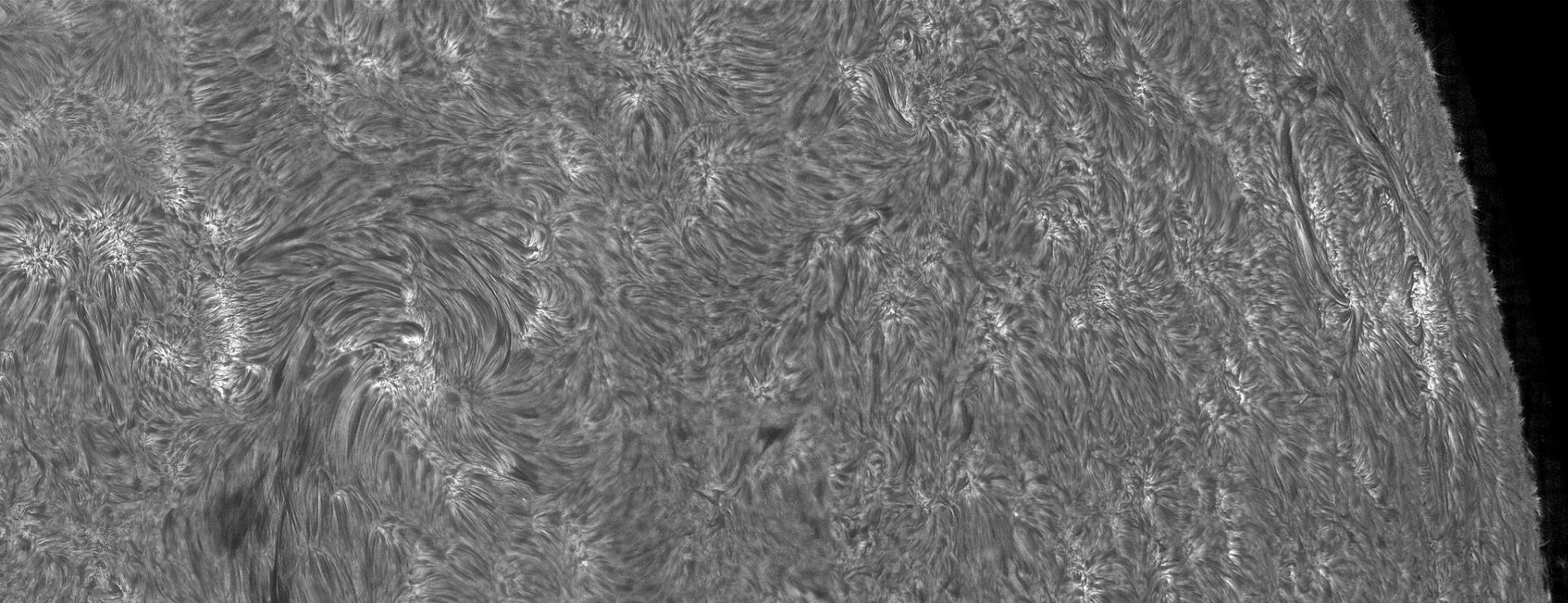
The chromosphere viewed during a solar eclipse, through several individual spectral lines (astrosurf.com)

Introduction - The Chromosphere



Movie showing a scan of spectrally resolved images through the H-alpha line. The chromospheric fibrils become more apparent as the transmission profile samples the central portion of the line. (K Reardon, 2021)

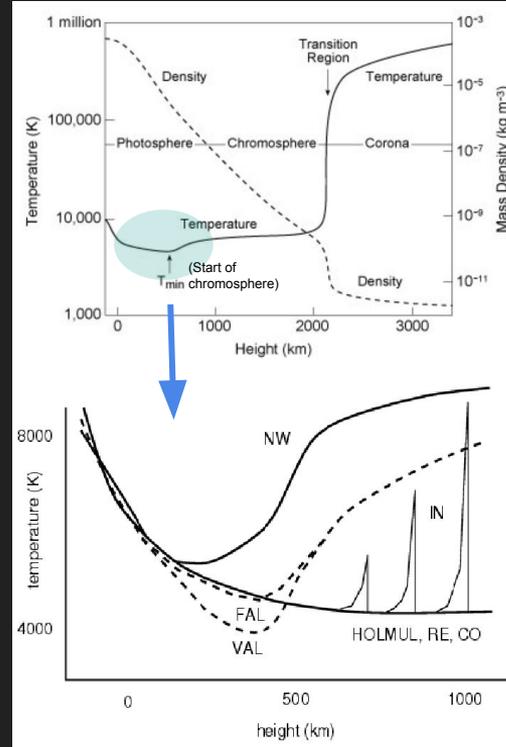
Introduction - The Chromosphere



The sun when viewed through a H-alpha filter. The high opacity (absorption) of the H-alpha line means that photons at this wavelength originating from the photosphere are absorbed or scattered, and we observe only photons emitted from the chromosphere. (K Reardon, 2021)

Introduction - The Chromospheric Heating Problem

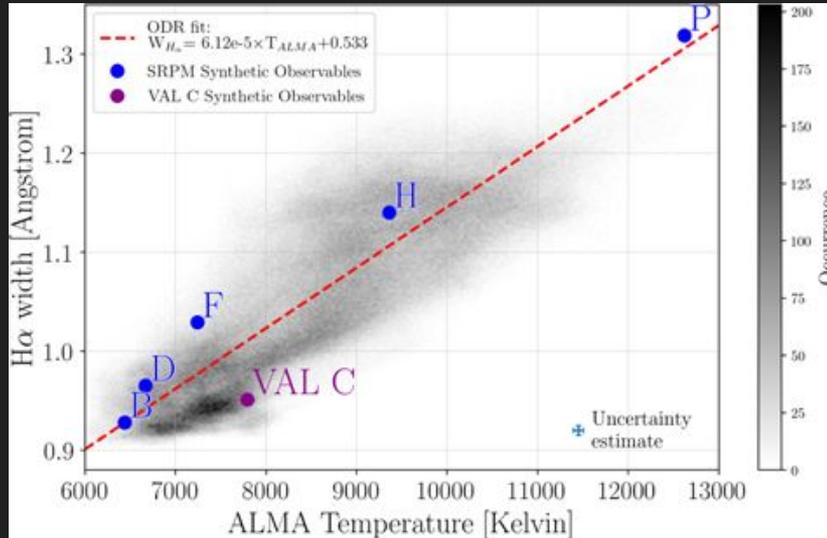
- As distance from the hot interior **increases**, temperature should **decrease**.
- Increasing from 5000-8000 Kelvin at this density takes an estimated $4\text{-}20 \text{ kW/m}^2$
- Increase generally **only occurs along specific features**
 - It is **not uniform** throughout the chromosphere



Top: A temperature profile of the solar atmosphere ([Vernazza et. al. 1981](#))
Bottom: a close-up of the chromospheric section ([J McAteer, 2004](#))

Introduction - Spectral Line Widths

- Width of a H-alpha is **linearly proportional** to temperature.



Depiction of the positive correlation between spectral line width and temperature ([Molnar et. al. 2019](#))

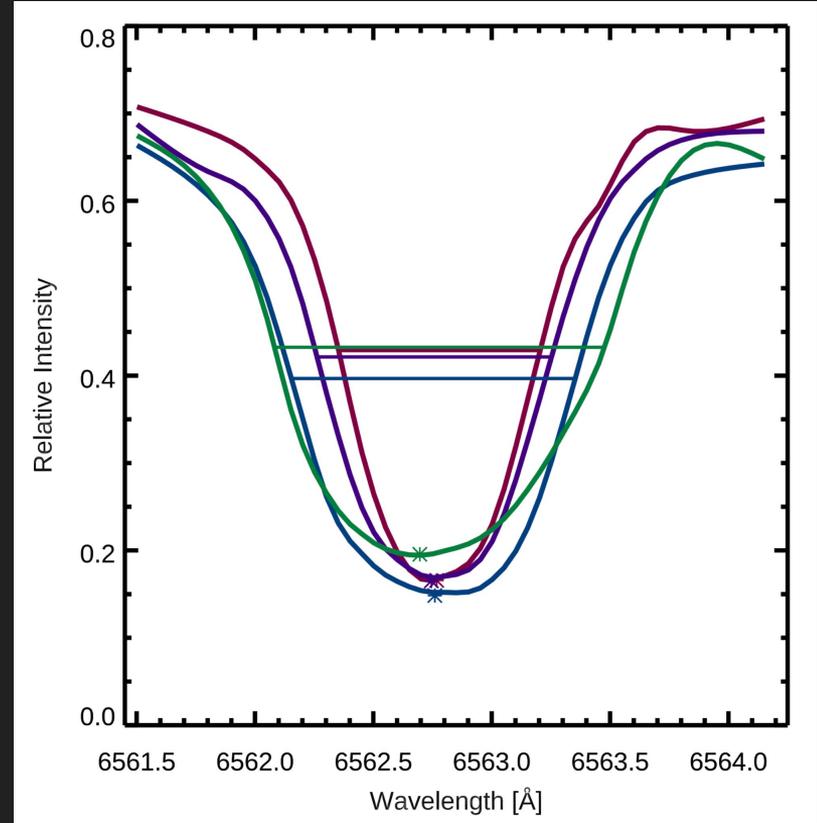
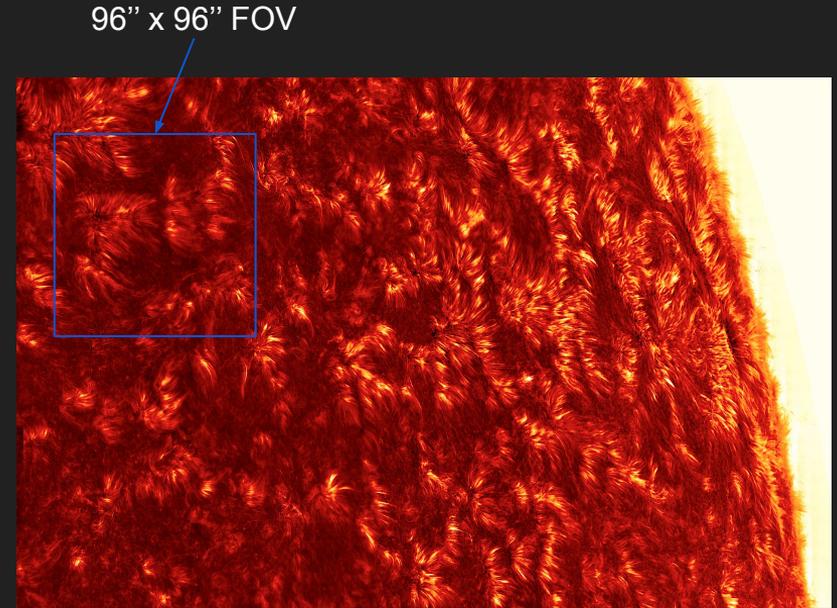
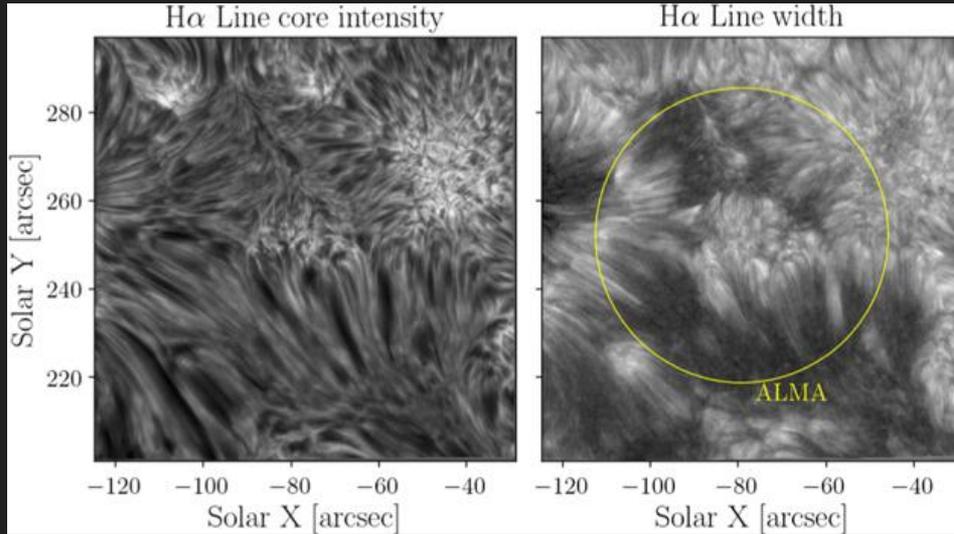


Illustration of the width of the H α line ([Cauzzi et. al. 2009](#))

Introduction - Spectral Line Widths



Direct observation of the chromosphere through a narrow H-alpha filter (left) and a map of the corresponding H-alpha line width (right) (Molnar et al. 2019)

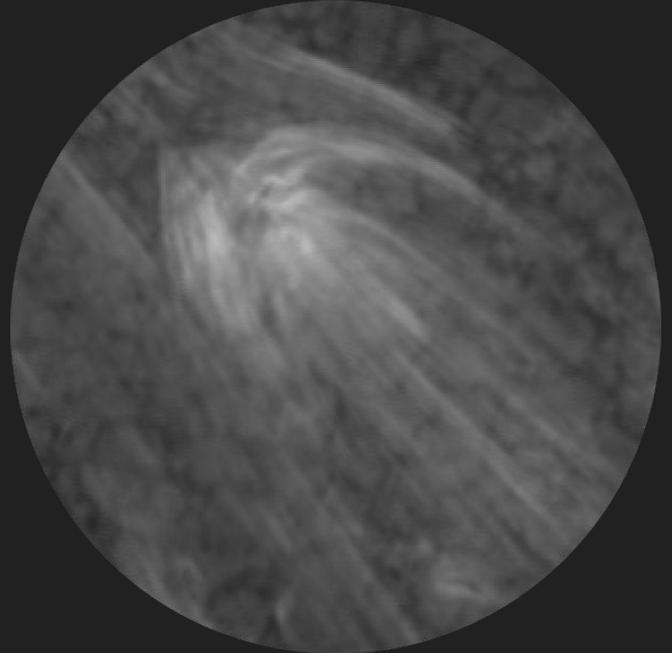
The chromosphere, viewed through a calculated H α width map from the IBIS telescope, taken on June 21, 2017 (K Reardon, 2021)

Objectives

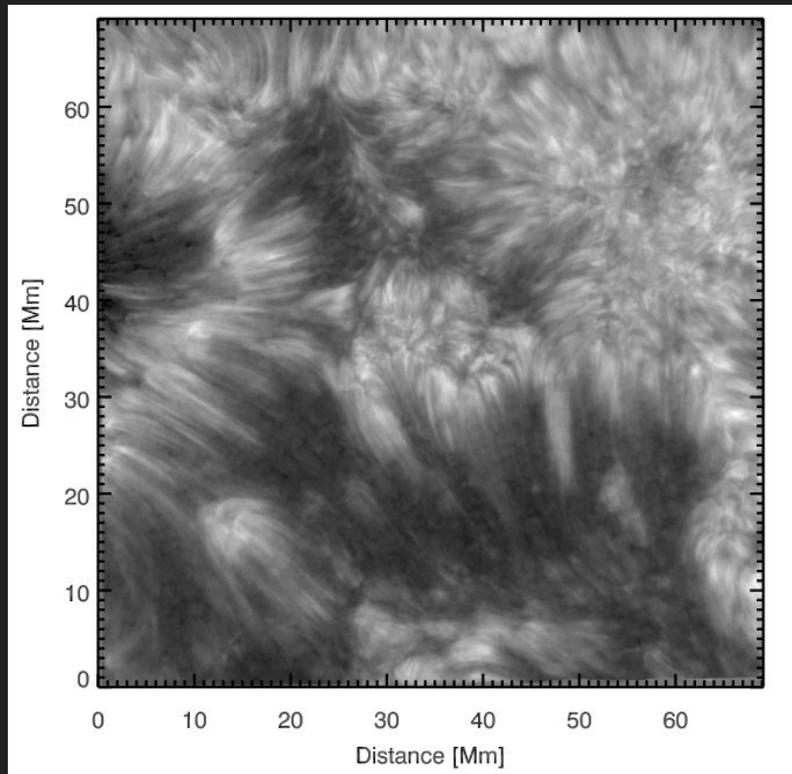
Quantitative Observations of Hot Fibril Characteristics

Including:

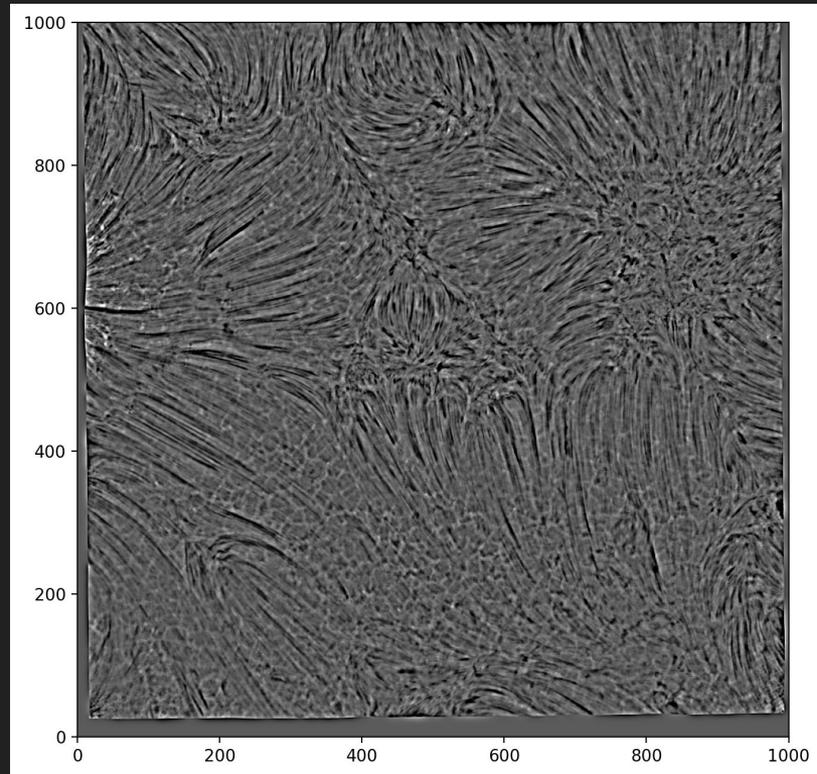
- Breadth
- Length
- Number
- Number Density
- Intensity
- Proximity to active regions



Methods - Manual Curve Tracing

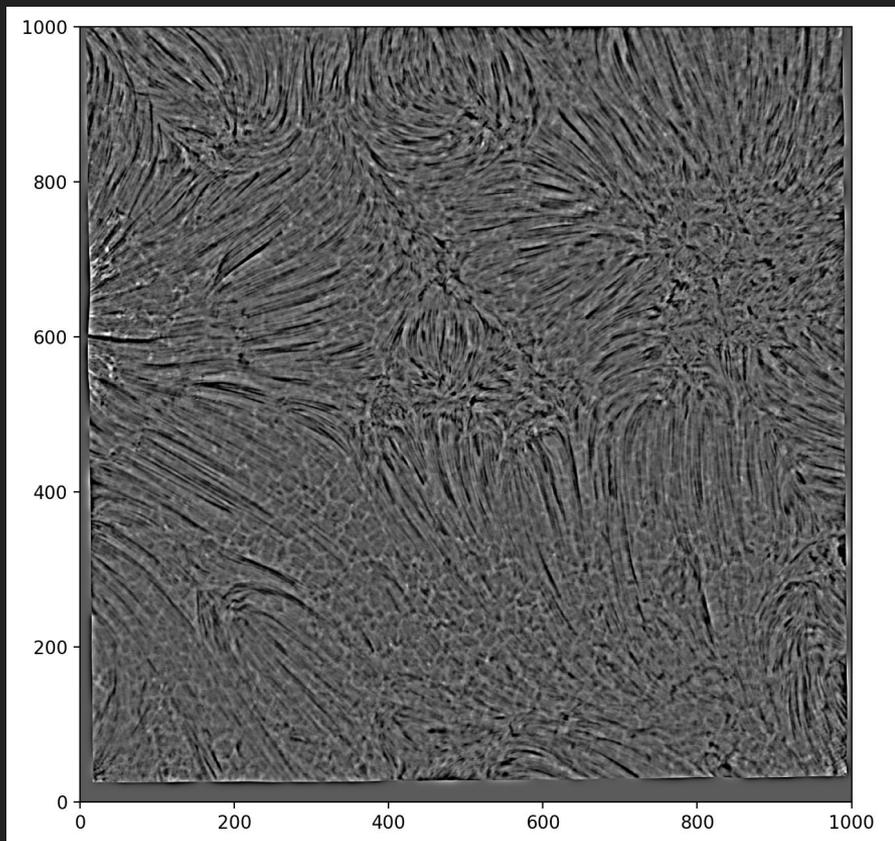


Width image

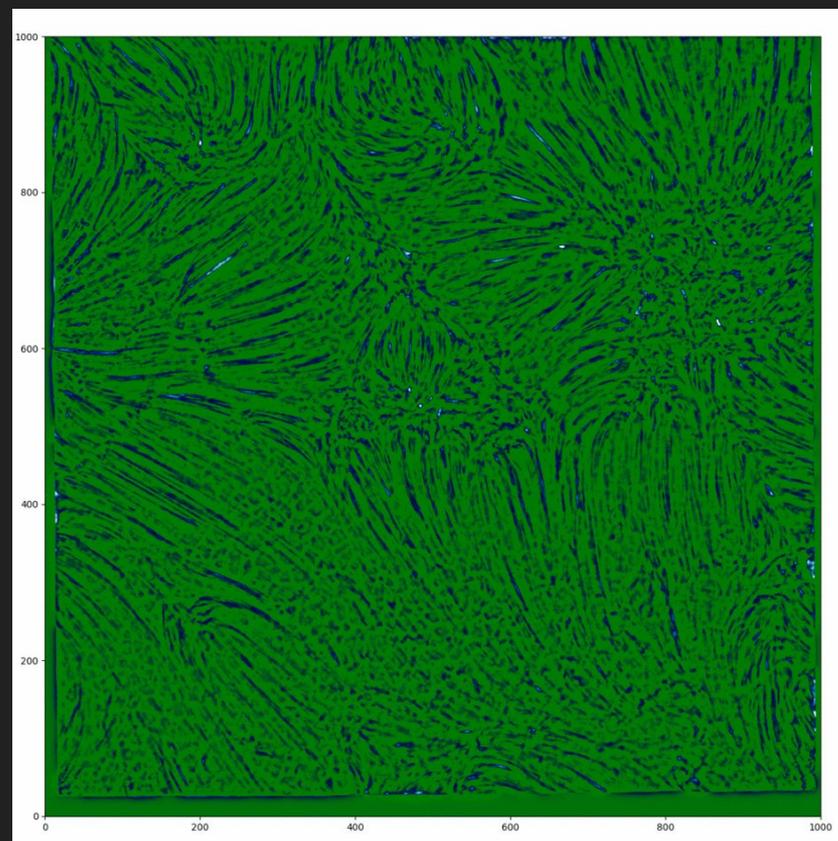


Original width image with subtracted Gaussian smoothing

Methods - Manual Curve Tracing

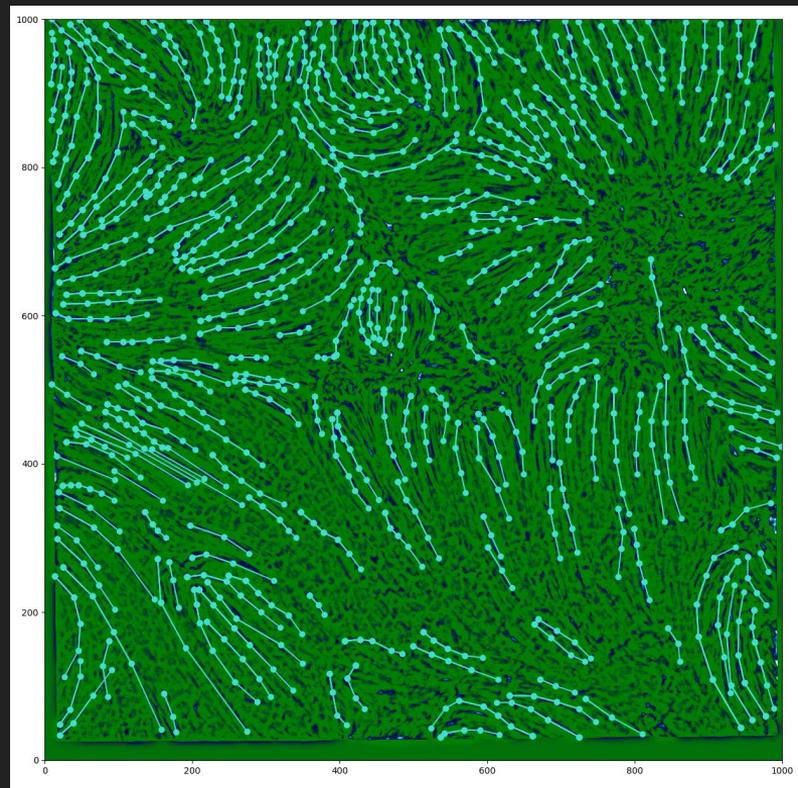
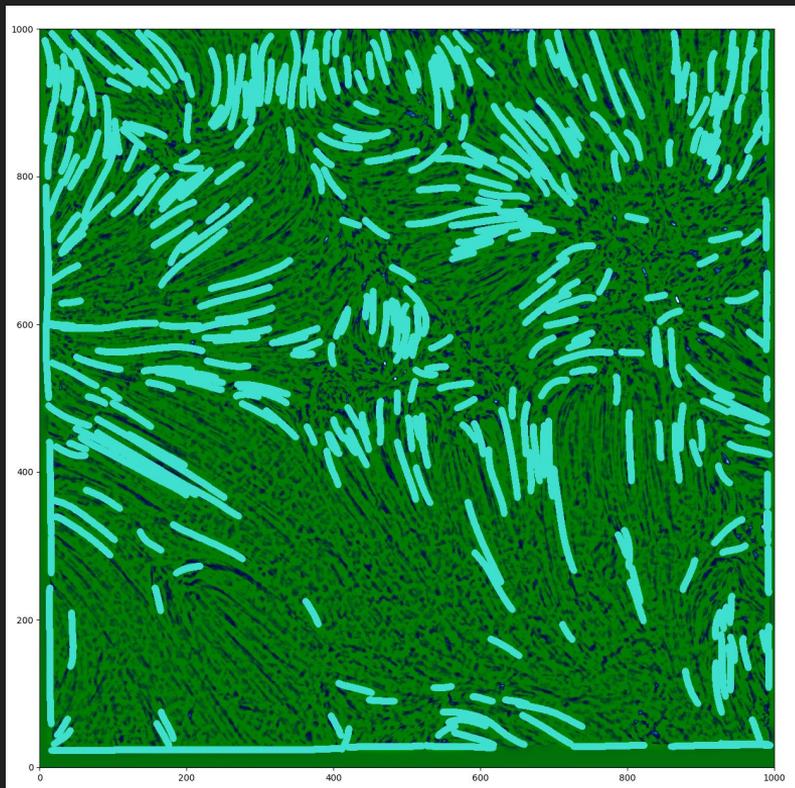


Sample Ha width map used for most of our tracing (K Reardon)



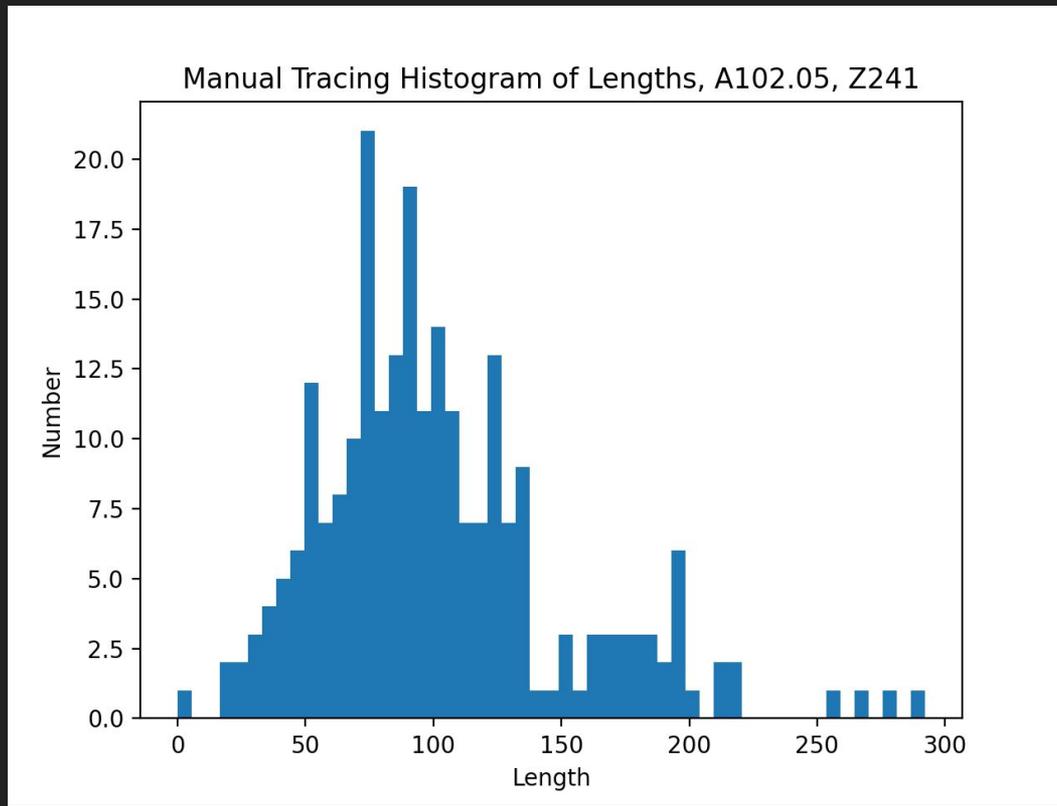
Manual curve tracing script designed in Python

Methods - Automatic Curve Tracing



Running OCCULT-2 with default parameters (left) compared with manual fibril tracing (right) ([Aschwanden, 2013](#))

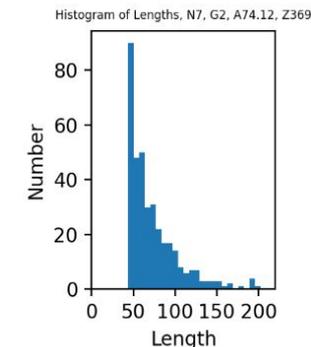
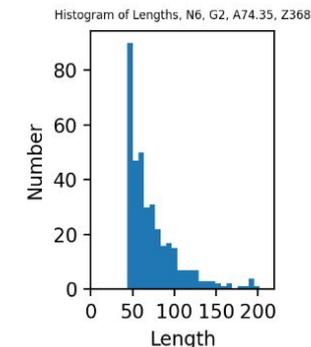
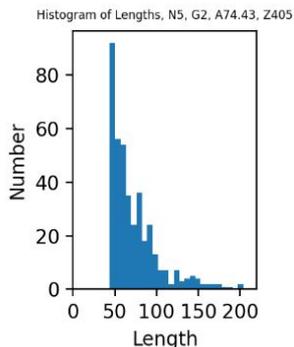
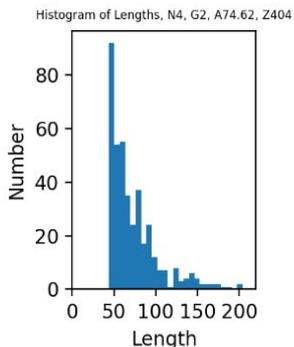
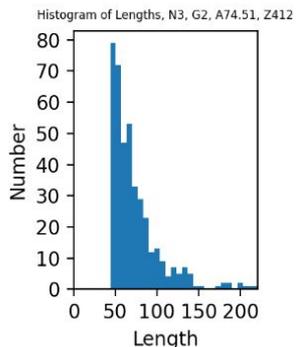
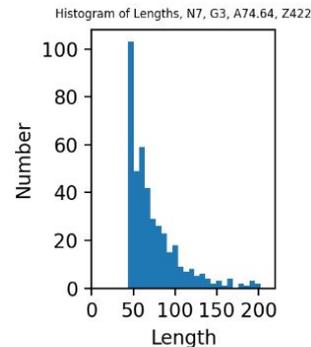
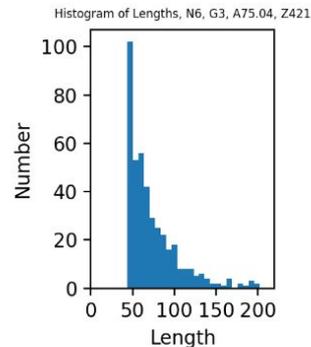
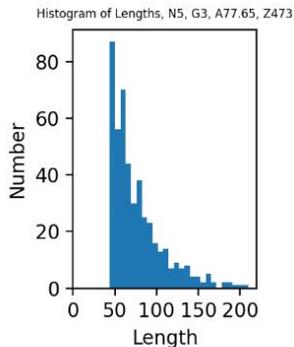
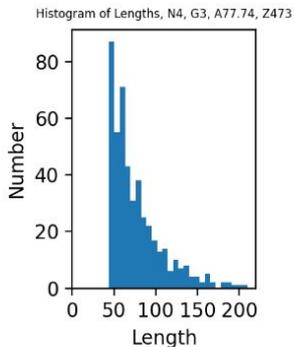
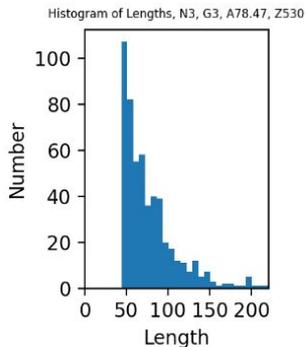
Methods - Optimizing Parameters for Automatic Tracing



A = Average Length
Z = Num. Fibrils

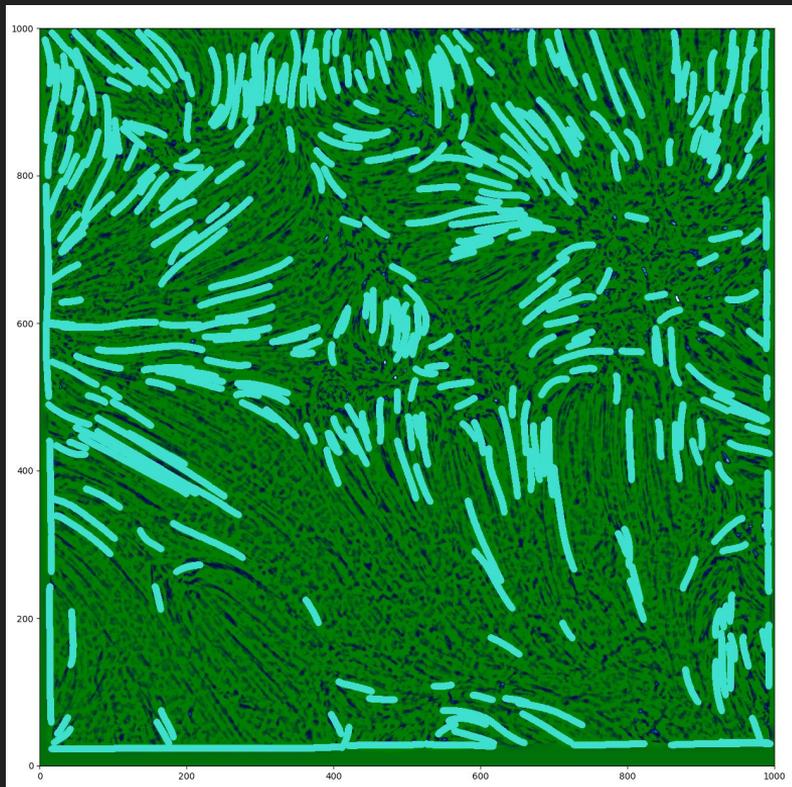
Histogram of manual fibril lengths (pixels)

Methods - Optimizing Parameters for Automatic Tracing

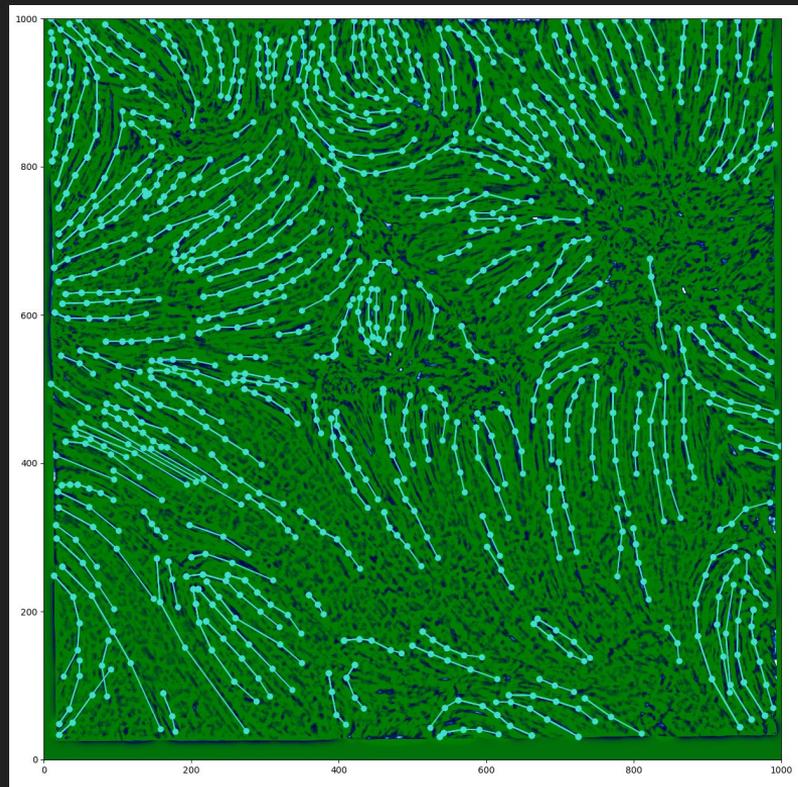


Using an array of histograms to calculate an optimized parameter set using different parameters for OCCULT-2

Methods - Optimized Automatic Analysis

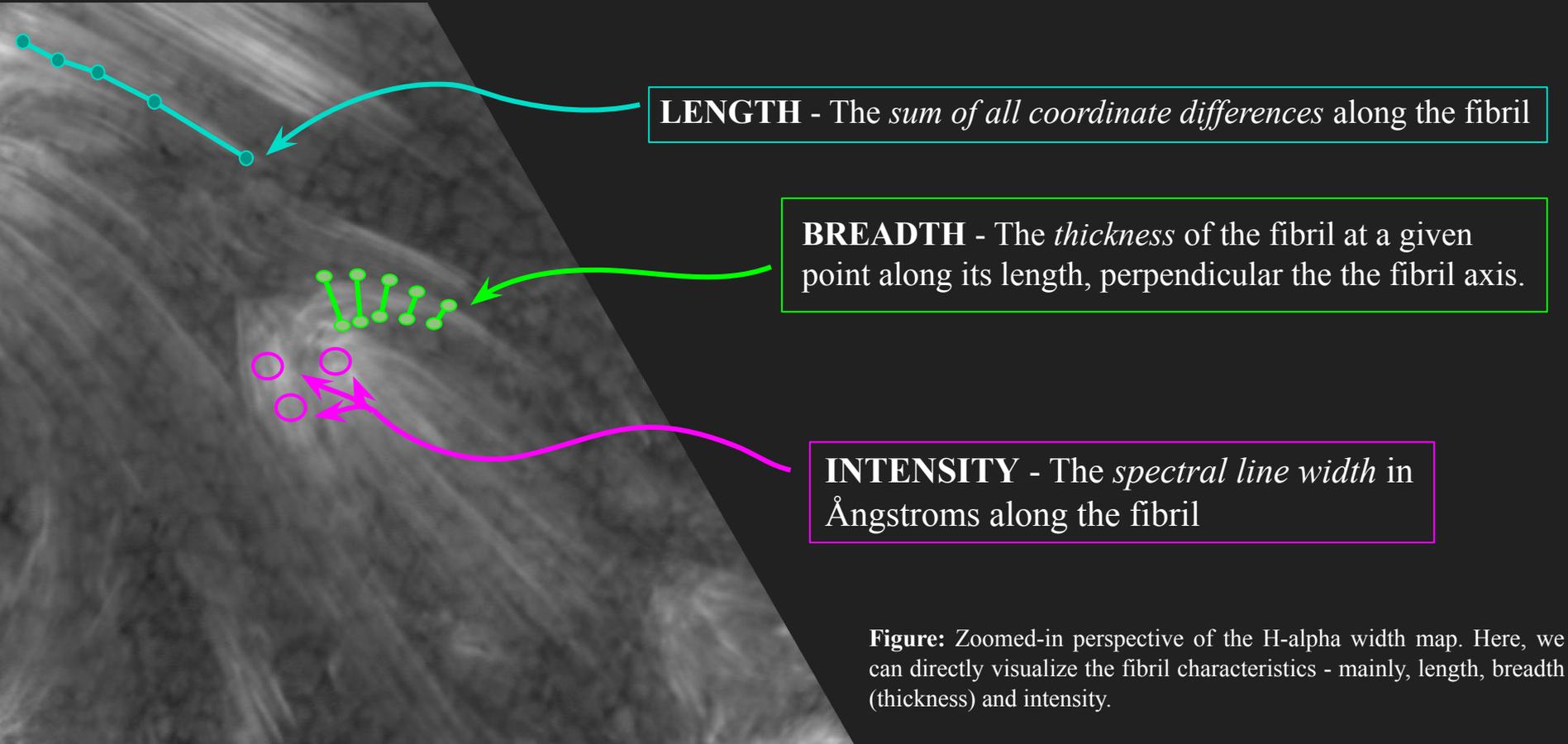


Optimized automatically traced image



Manually traced lines

Methods - Analysis



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

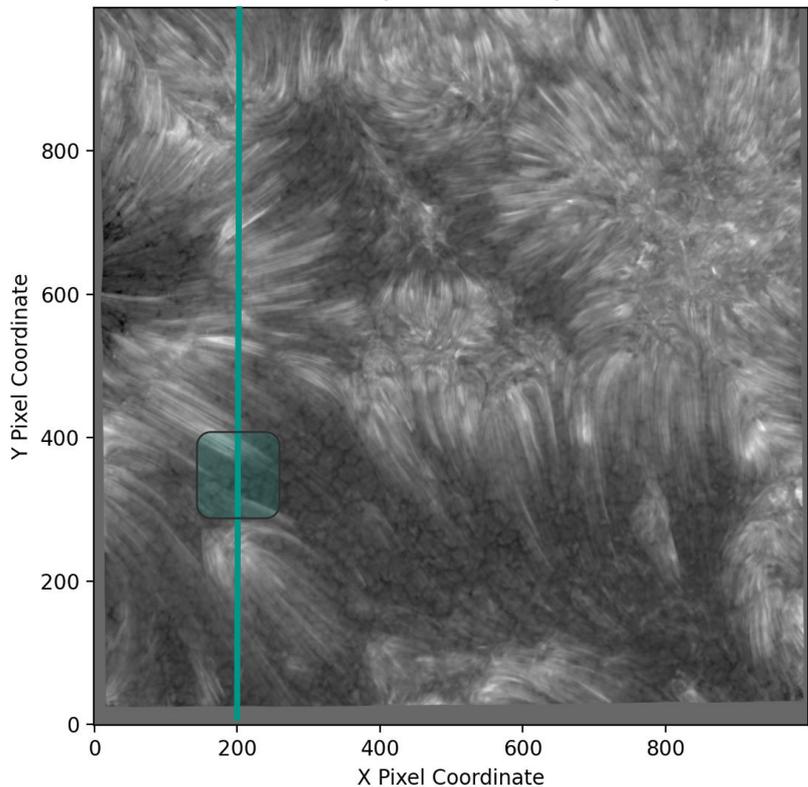
BREADTH - The *thickness* of the fibril at a given point along its length, perpendicular to the fibril axis.

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

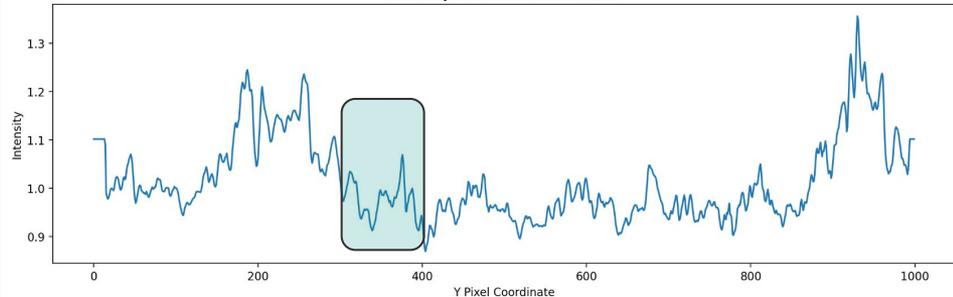
Figure: Zoomed-in perspective of the H-alpha width map. Here, we can directly visualize the fibril characteristics - mainly, length, breadth (thickness) and intensity.

Methods - Analysis (Breadth Calculation)

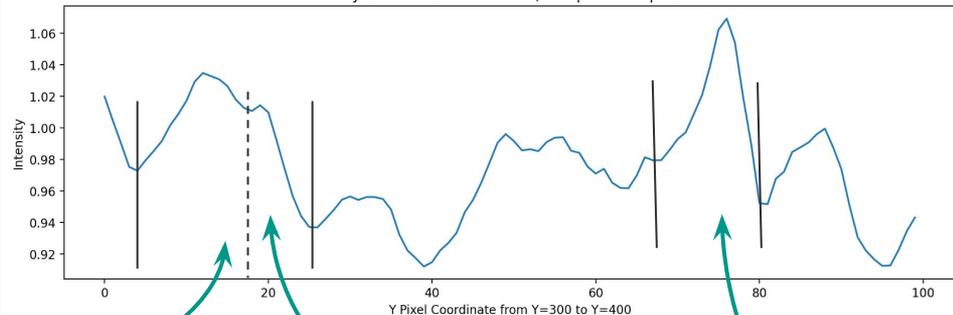
H-alpha Width Map



Intensity Cross-Section at X=200



Intensity Cross-Section at X=200, 300 px to 400 px Subset



Fibril

... Fibril?

Fibril

Visualization of breadth calculation

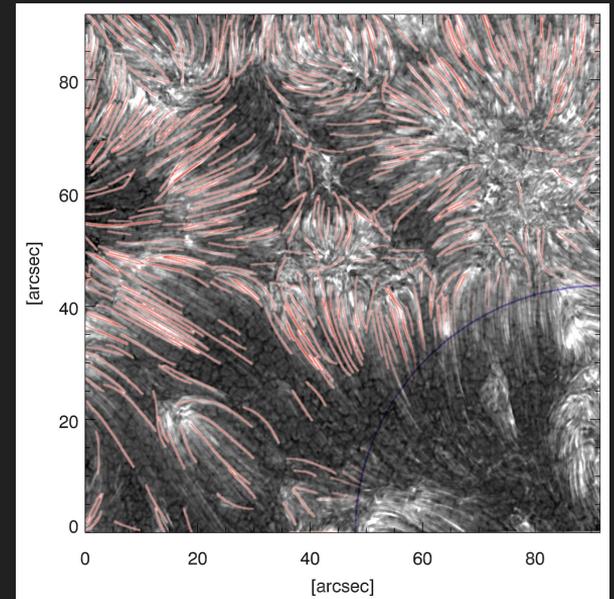
Results

Total number of detected fibrils: **532**

Average fibril *breadth*: 2.62 px \cong **200 km**

Average fibril *length*: 77.64 px \cong **5400 km**

Average fibril *intensity*: 1.18 Angstroms



Hot fibril “density” is then:

$$532 / 70000^2 = 1.08 \times 10^{-7} \text{ fibrils / km}^2$$

$1.08 \times 10^{-7} * 1.55 \times 10^{12} \cong$ **170,000** fibrils on the sun at any given point in time

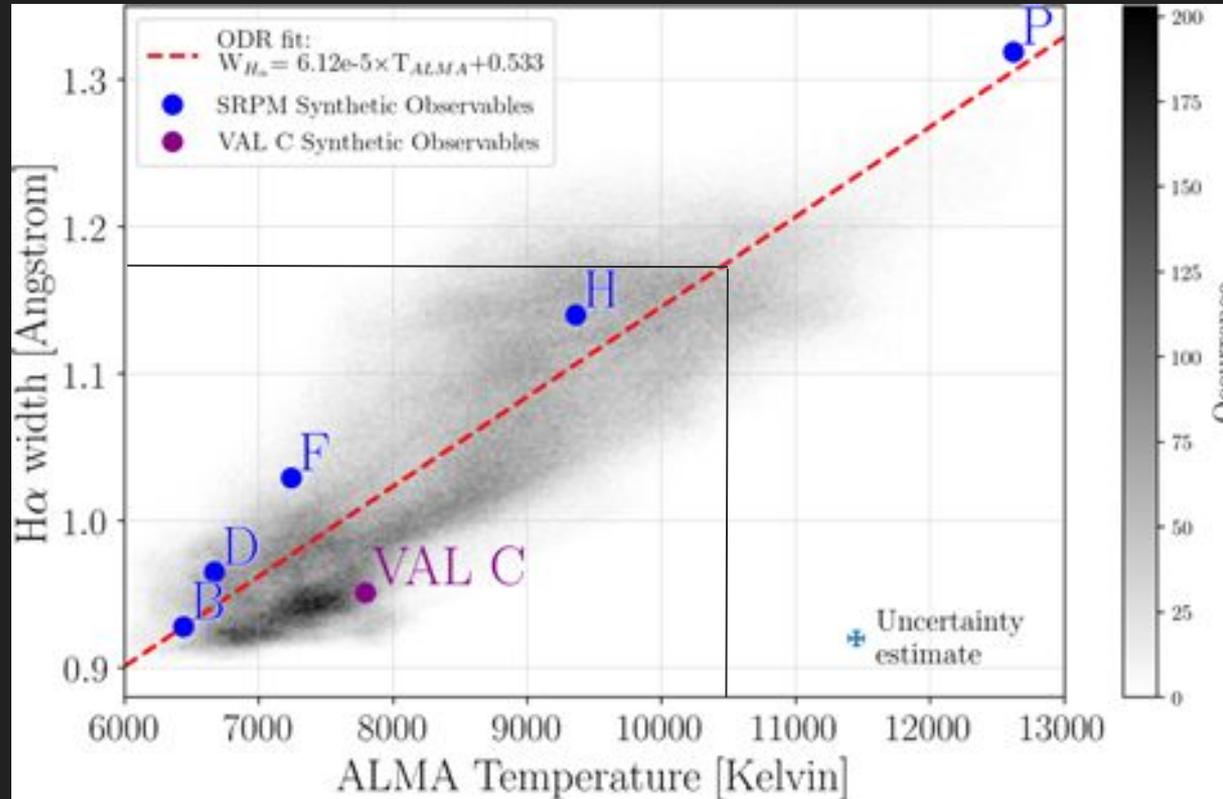
Note: this value assumes constant fibril density

Image details:

- FOV: 96 x 96 arcsec²
- Size: 70,000 x 70,000 km²

Note: surface area of the sun is 1.55×10^{12} km². (Image is only 0.316% of the SA of the sun!)

Results



Using the average measured line width to approximate temperature (Molnar et. al. 2019)

Future Work

Remaining questions:

- Do fibril characteristics change when looking at different fields of view?
- How do fibrils evolve over time?
 - What is the *expected lifetime* of a given fibril?
- Can we confirm H-alpha characterizations using other spectral diagnostics?
- Direct relation between temperature and spectral width, to calculate temperature change along fibrils?
- Could we approach identification and analysis using machine learning?