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Ribbons and Riblets: The Key to Understanding Solar Flares

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Abstract : The driving mechanism behind solar flares is magnetic reconnection. This allows for energy to transfer from the magnetic field to the plasma, resulting in accelerated particle beams composed of electrons and ions . In addition to the energy deposited in the coronal plasma locally, energy is also transferred from the electron beams when the electrons impact upon the chromosphere. This results in Hydrogen 656.3nm (Hα) emission and so-called "ribbon" formation. Recent access to high-resolution Swedish 1-m Solar Telescope (SST) CRISP data has allowed us to examine the ribbons and their substructures, which we refer to as "riblets", in unique detail sampling 43 km per pixel at 0.2 s cadence. Here we present a detailed statistical and kinematic analysis of the sub-structures of flare ribbons for an X-class solar flare observed on 10 June 2014. This approach requires automated detection of riblets to better understand how energy becomes deposited in the chromosphere both locally and globally.

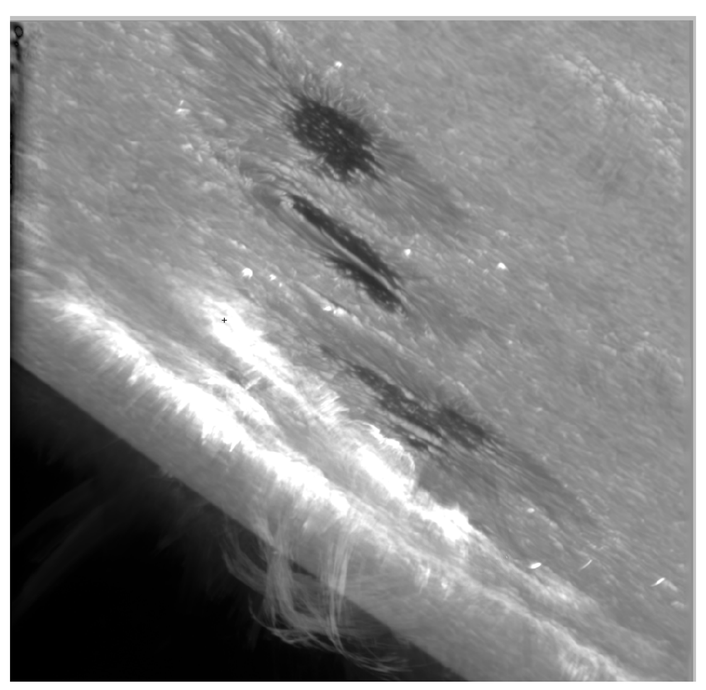
Aim

Detect, track and analyse the appearance of riblets in ribbons in high resolutions ground based observations of an X-class solar flare from the Swedish 1-m Solar Telescope.

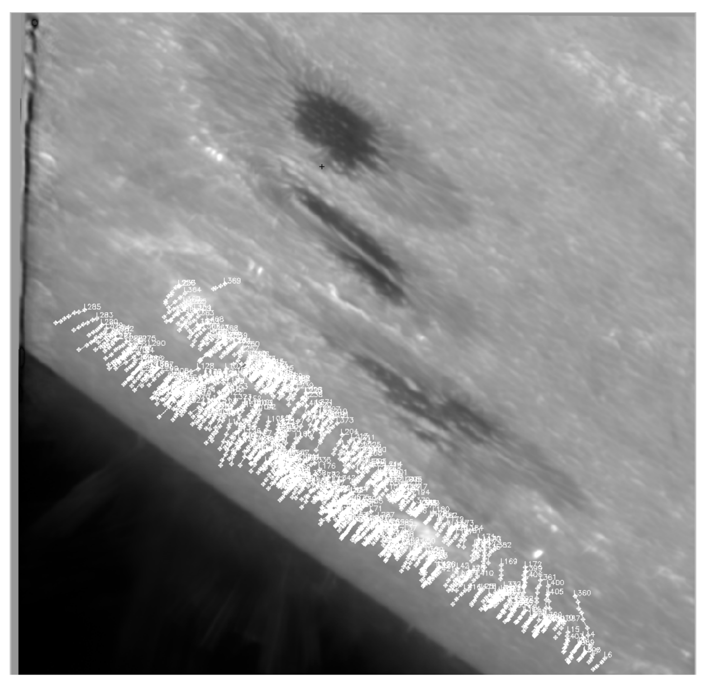
We want to answer the following questions:
What are the properties of ribbons in a solar flare? For example, how many riblets exist in the rise phase of an X-class solar flare? What is the velocity distribution of the riblets? How many appear to rise and how many appear to fall? Does the velocity distribution change in time? Do the most intense riblets exhibit the largest velocities?

What is a ribbon?

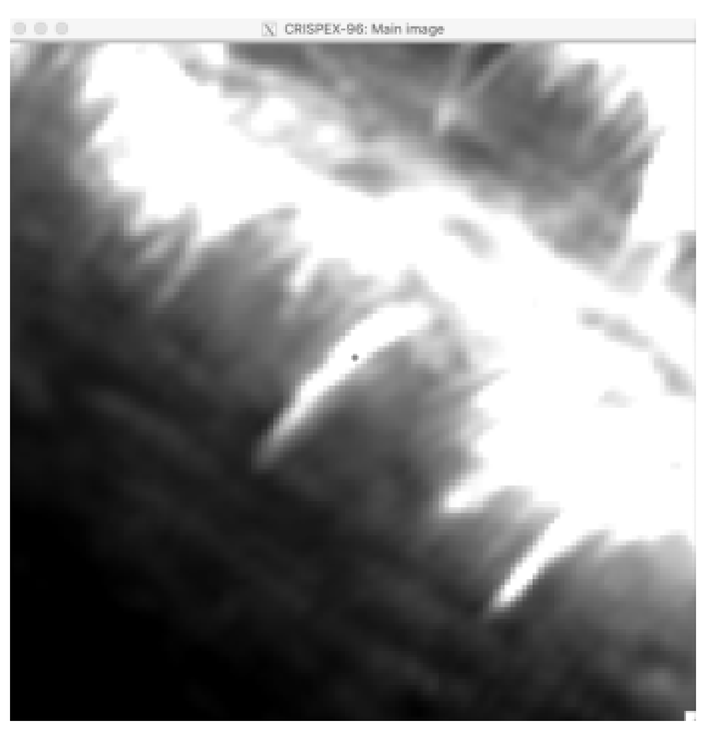
In Solar flare data, the Hard X-Radiation brightenings, which are commonly observed as paired compact sources, are referred to as foot-points, while the elongated structures found in Hα pictures are referred to as ribbons [3].



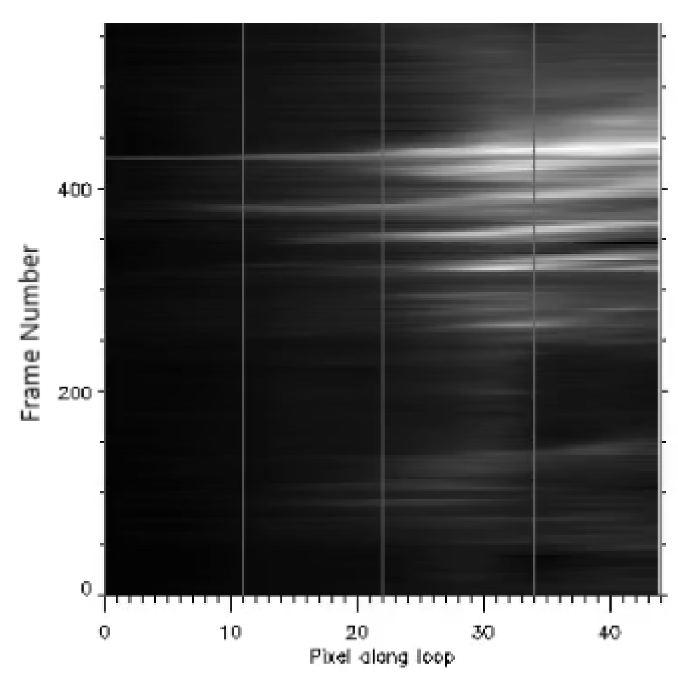
(a) A snapshot of the flare



(b) Plot of the tracked ribbon micro-structures



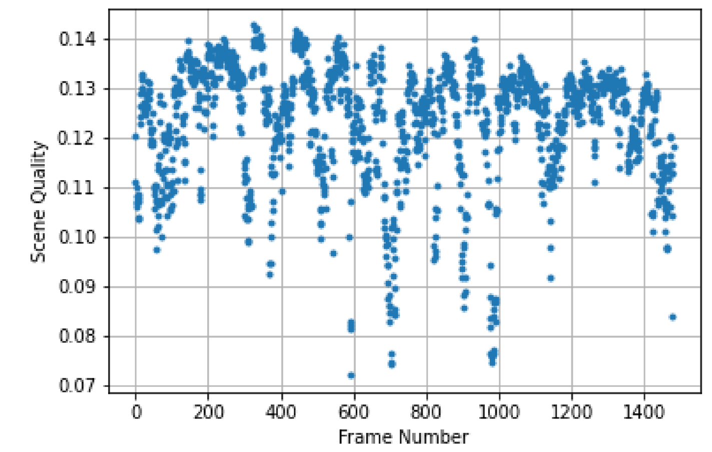
(c) A typical ribbon micro-structure



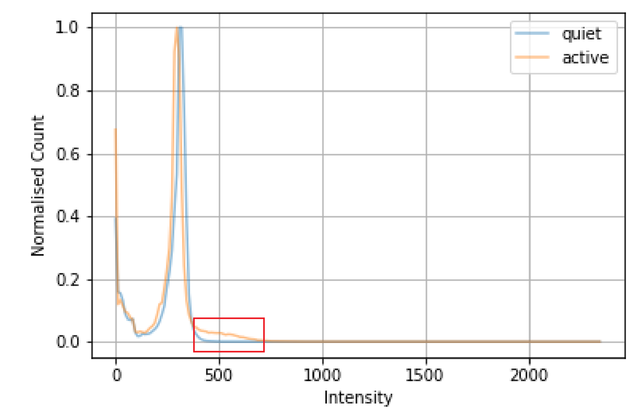
(d) T slice along the ribbon micro-structure

This by-eye riblet tracking technique gives us preliminary statistics. But we need an automated approach for masking out the riblets in the T-slice (x-t cuts). To do this we need to calculate background intensity and ribbon intensity. We calculated background intensity by choosing a random area in the data with no activity and fitting the histogram of intensities with a kappa profile giving us a $\mu_{background} = 299.1$ and $\sigma_{background} = 7.13$.

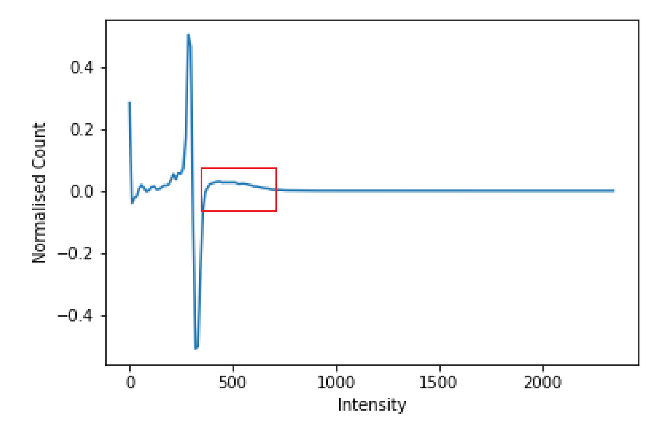
Finding ribbon intensity



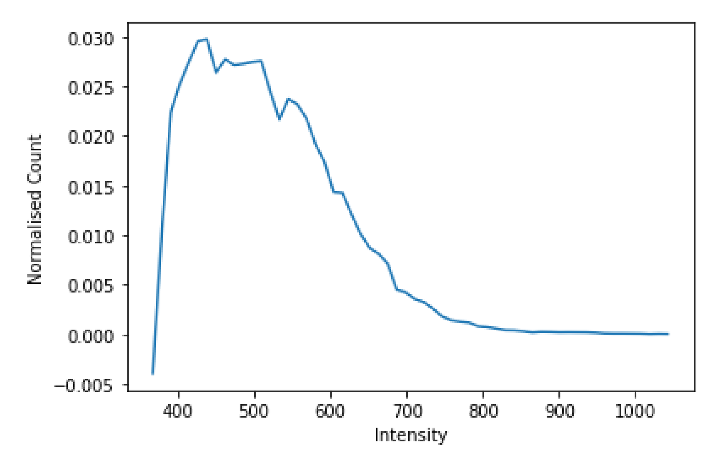
Scene Quality (ratio of standard deviation and mean of intensity values in a frame)



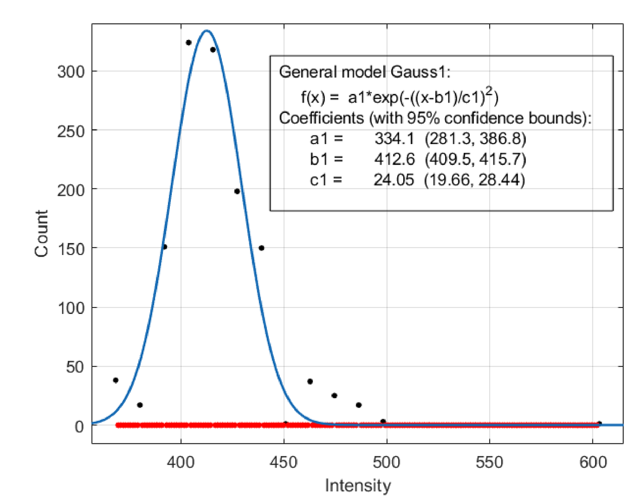
(a) Intensity histogram of a quiet and active frame.



(b) Difference of the histograms.



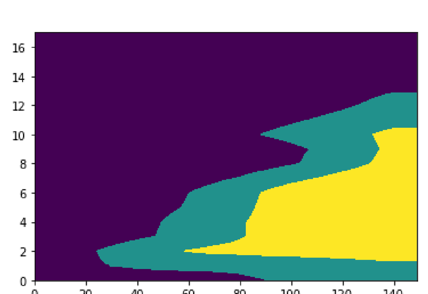
(c) Isolated riblet contribution to the intensities in difference histogram.



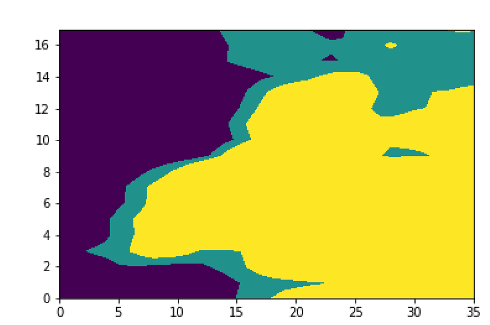
(d) Gaussian fit of peak value intensities of riblet contribution from the difference histogram across all good scene frames.

This process gives us $\mu_{ribbon} = 412.6$ and $\sigma_{ribbon} = 24.05$. We can now use these values to mask the riblet.

Riblets come in all shapes and sizes



(a) A riblet with constant velocity (X-T cut)

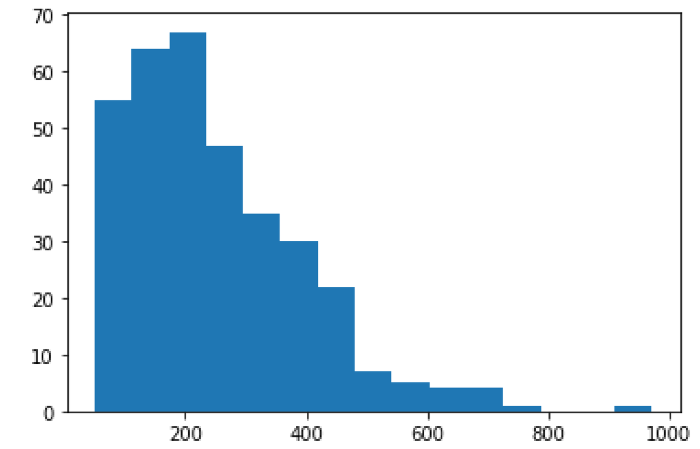


(b) An accelerating riblet (X-T cut)

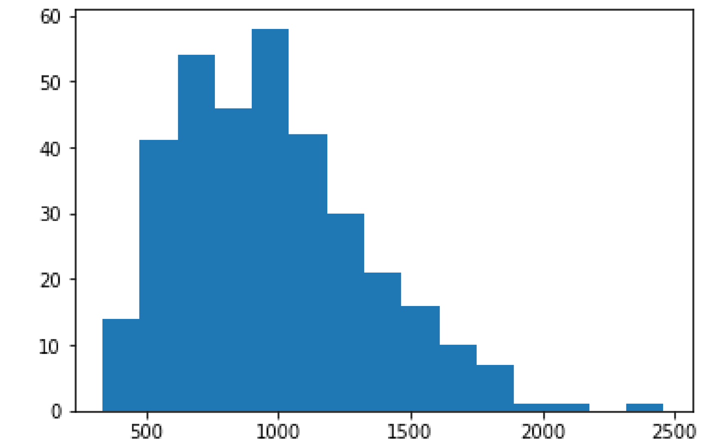
Contours with $\mu_{background}$ + 5$\cdot\sigma_{background}$ and μ_{ribbon} - 3$\cdot\sigma_{ribbon}$

Riblet Statistics

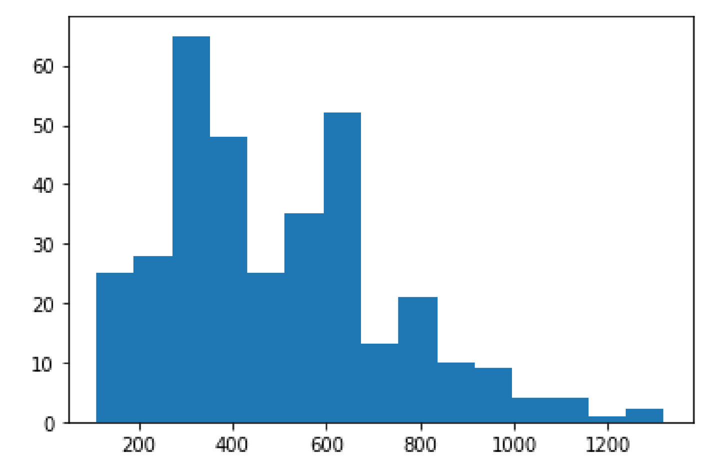
Riblet statistics from the by-eye tracking are as follows.



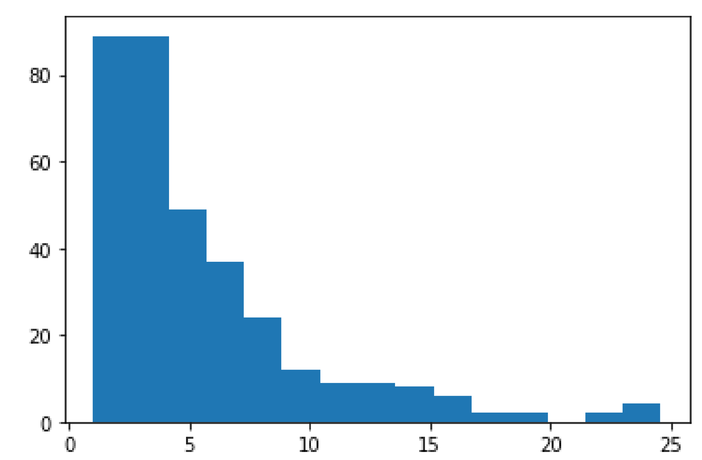
(a) Speed distribution of measured riblets (km/s).



(b) Length distribution of measured riblets (km).



(c) Starting time of the riblets (frame number).



(d) Lifetime of the riblets(s).

The majority of the riblets have a velocity of around 200km/sec, are around 972km long, and last for around 2 sec.

These statistics need to be updated with the automated masking technique for scientific reliability.

Conclusion and Future Work

- The velocities seen in the by-eye statistics are in agreement with the Druett model [2] for a flare with energies in the X-class regime.
- Apply the automated masking procedure over all the tracked ribbons to get updated statistics. And use the updated statistics to verify [2]
- The by-eye statistics assume constant velocity. The masking method allows us to look at velocity profiles and extract more in depth details about the velocity and acceleration distribution of the riblets
- Compare spatio-temporal statistics of riblets with GOES X-ray curve to find insights regarding impact of energy on riblets which will be used in the next stage of the project where we will study the properties of solar flare accelerated electrons .

References

[1] Arnold O. Benz. Flare Observations. *Living Reviews in Solar Physics*, 5, 2008.

[2] M. Druett, Eamon Scullion, Valentina Zharkova, Sarah Matthews, Sergei Zharkov, and Luc Rouppe Van der Voort. Beam electrons as a source of Hα flare ribbons. *Nature Communications*, 8(1):15905, August 2017.

[3] L. Fletcher, B. R. Dennis, H. S. Hudson, S. Krucker, K. Phillips, A. Veronig, M. Battaglia, L. Bone, A. Caspi, Q. Chen, P. Gallagher, P. T. Grigis, H. Ji, W. Liu, R. O. Milligan, and M. Temmer. An observational overview of solar flares. *Space Science Reviews*, 159(1-4):19–106, September 2011.

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