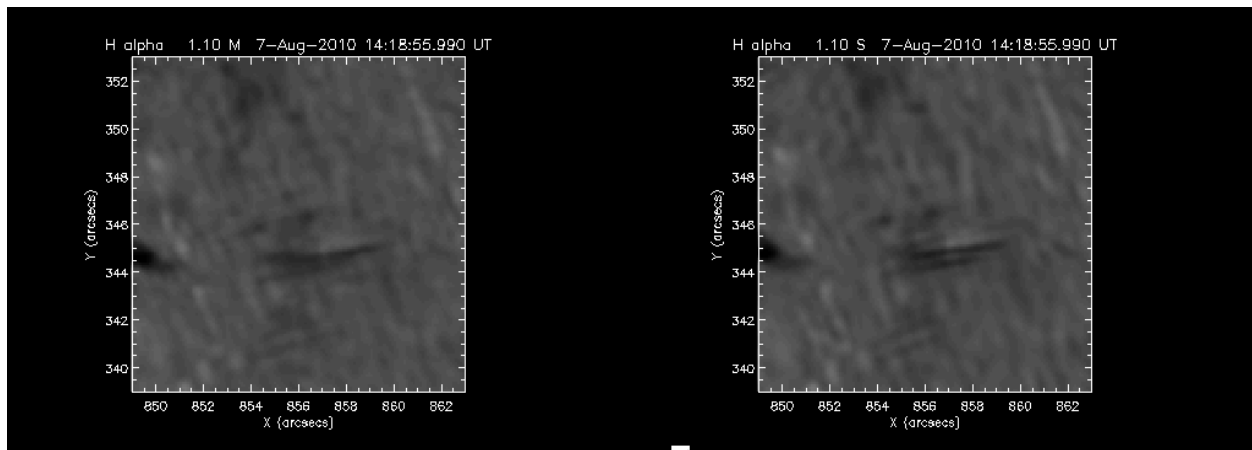


Image Reduction

We have hundreds of images of the same region of the Sun taken over a period of 20 minutes. We started our analysis of this data with a technical task: determining whether the method of reduction of this solar data affects the general properties of the resultant images. Some of these images were reduced using the MFBD process and others were reduced using the Speckle process. We intend upon using both sorts of images in our data analysis, but we first needed to ascertain that there were no major differences between both sets of images that might affect our research (i.e. we mistake an artifact from the image reduction process for a new and significant observation). I wrote a program to juxtapose two sets of Speckle and MFBD images taken in H-alpha at a blue wavelength (below the H-alpha line) and at red wavelength (above the H-alpha line). Care was taken to ensure that compared images were taken at exactly the same time exactly the same wavelength.

Below are the results of the comparison of the MFBD and Speckle images taken in red. We have here a small region on the disk of the sun. The left image is MFBD and the right image is Speckle. Aside from a few differences in clarity and darkness of sunspots (circled in red), these images are extremely similar despite their different processing mechanisms. The Speckle image appears to have a slightly more defined sunspot.



Above is another comparison of the red Speckle (right) and MFBD (left) image, here just in a different region. The Speckle image has a more resolved fibril set (center of image: one can make out two separate fibrils) while the same fibril in the MFBD image is more blurred and hard to break into two. It is important to keep in mind that the Speckle images have been averaged together over a period of time about 5 times longer than have the MFBD images. This difference in resolution thus has an explanation.

Conclusions: There is an observable difference between MFBD and Speckle images in terms of definition of structures and brightness/depth levels. Generally, Speckle images have deeper resolution as they were averaged over a longer period of time than the MFBD images. However,

the differences between each type of image (in red or blue) does not appear to be so great that they might interfere with actual identification of solar phenomena or structures. Each type of image contains the same structures and fibrils and the only real variance is the resolution of each structure. At the present, I have decided that the different processing mechanisms will not present an issue regarding data analysis and have decided to go ahead and treat them equally as their fundamental differences do not seem significant enough to distract our data analysis.

Statistical Observations

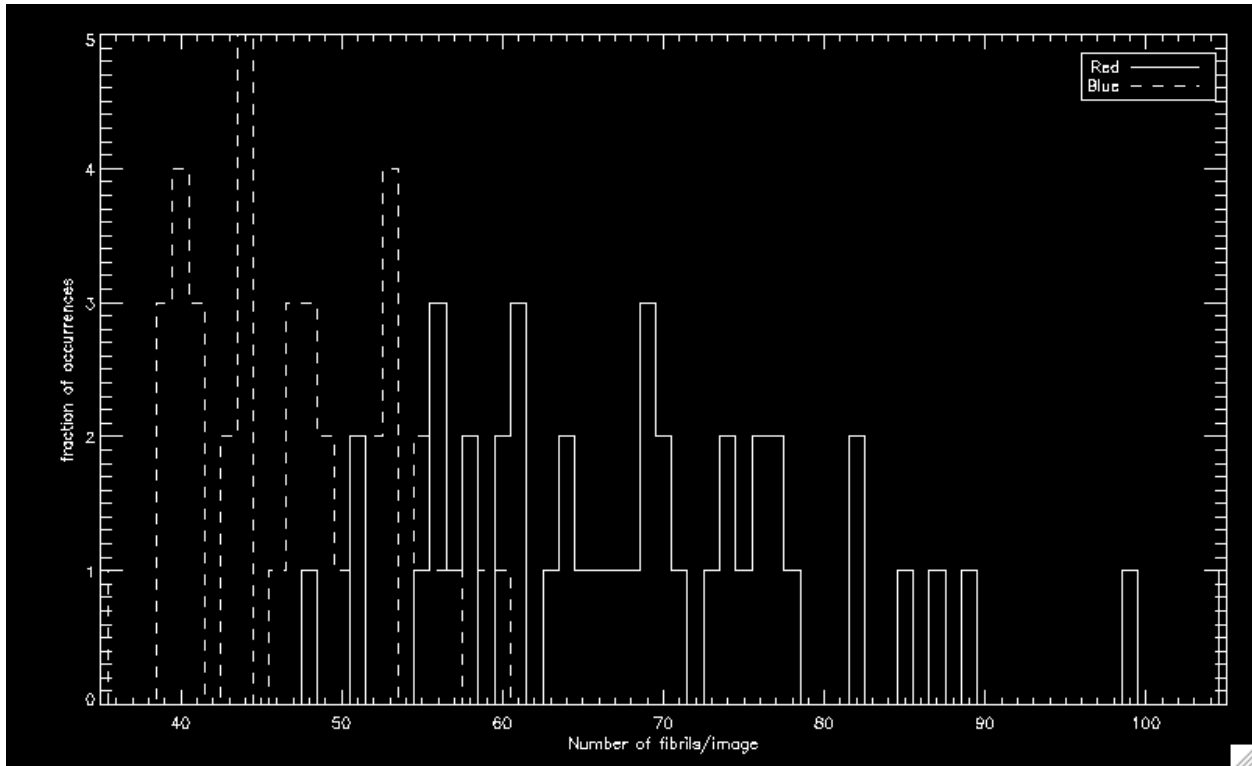
Of several thousand individual data frames, 871 processed images of the same active region on the Sun were taken at different times over a period of 20 minutes by the IBIS instrument at the Dunn Solar Telescope. These images are taken at varying wavelengths across both the H-alpha line and the Calcium II 854.2 nm line. Visible in each frame are multiple chromospheric fibrils that sometimes exhibit super-fast phenomena of interest.

We wanted to get a numerical value of the average number of fibrils per frame for images taken in H-alpha. We were curious as whether this number would be different for red frames taken at wavelengths above H-alpha and blue frames taken at wavelengths below H-alpha. I selected 96 frames: 40 of which were blue frames and 56 of which were red frames. I then developed a method to systematically count the fibrils in each frame. I plotted each image in `imap` from IDL and ordered them to be overlaid with rectangular grid boxes to make counting easier (simply count the fibrils in each grid box). The grids are arbitrary in shape in size, but each grid covers the same solid angle of the Sun as seen from Earth. Fibrils were counted only on the visible disk of the Sun, not above the limb.

I saved each frame in question and marked each fibril. I counted up a total number of fibrils for each frame. The average number of fibrils per image for the blue frames was 47.95. The average number of fibrils per image for the red frames was 73.50. As can be seen, the red frames have a significantly higher average number of fibrils than do the blue frames. There are 62 grid cells on the solar disk, so the average number of fibrils is 0.77 and 1.19 per cell.

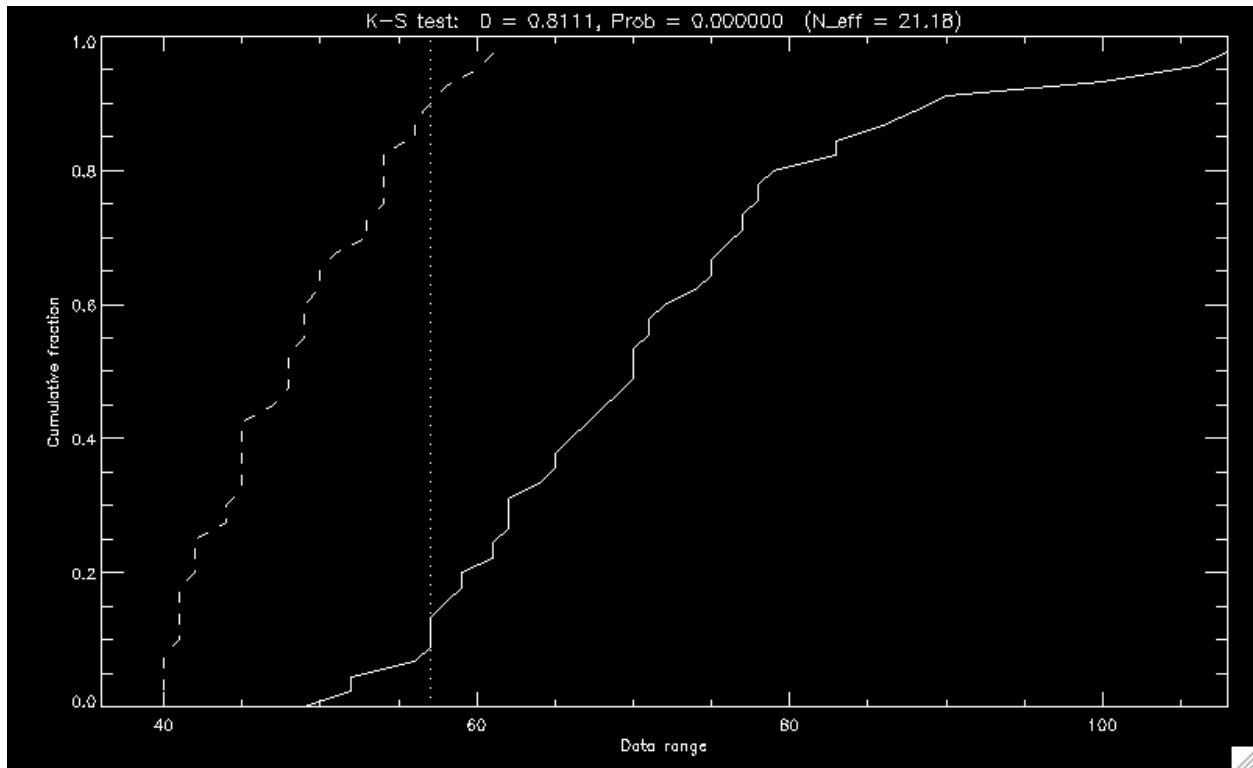
The area of the Solar disk in these images is about 100 square degrees (in heliographic coordinates) or about 0.03 steradians, about 1/400th of the solar surface. This means that at any time we might find about 30,000 of them on the Sun.

Analysis



Upper: A chart of the 40 blue frame fibril numbers and the 56 red frame fibril numbers. Both sets of data contain varying values, but it can be seen easily that the red frames have a higher maximum and in general higher fibril values.

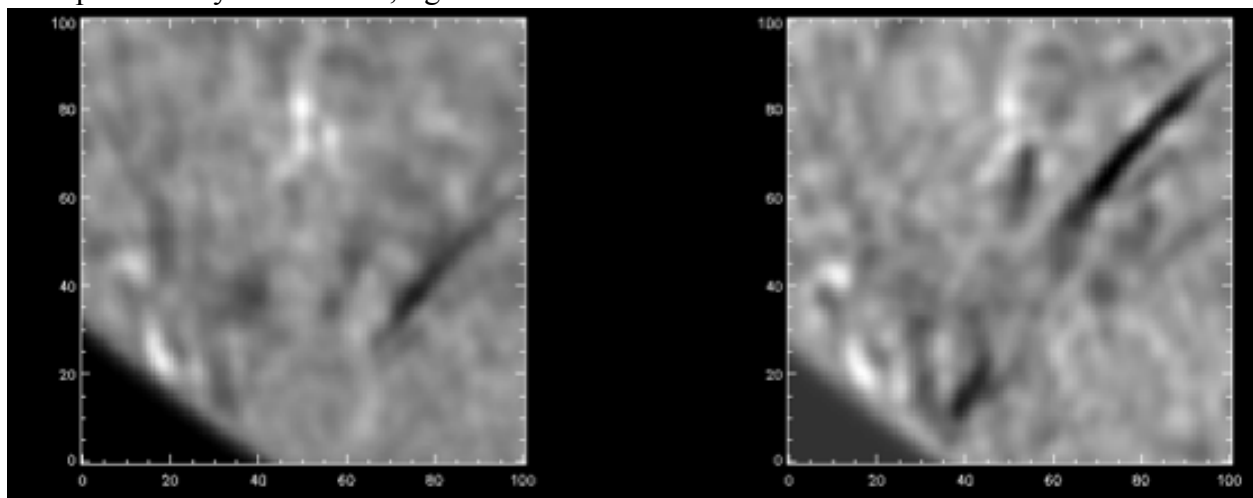
Analysis



Upper: A statistical analysis of our results depicting the cumulative percentages of data in a certain range.

H-Alpha Red Wing and Blue Wing Comparison

We compared fibrils within several simultaneous blue and red H-Alpha images. Below is an one example of many: left is blue, right is red.



The fibrils seen in the red images are consistently longer and higher than the ones in the blue images. Near-simultaneous red and blue fibrils almost never overlap.

This observation has multiple implications. One possibility is that each fibril is a separate structure moving in a unique direction. Some are moving upwards and thus absorb in the red wing relative to the image plane while others are moving downwards relative to the image plane and thus absorb in the blue wing. If we observe more red fibrils than blue fibrils, this implies that there must be a preferred direction of motion. This goes in contrast to the flux tube model where the plasma motion does not necessarily have to conform to a specific direction and should be rather random.

It is possible that we are not observing in wavelengths at equal distances from the main line. We should be looking at ± 1.1 angstroms from the center H-Alpha line, but if the whole wavelength curve has been shifted in a certain direction left or right, we might need to re-evaluate where on the curve we should observe in order to get data at equal distances from the H-Alpha main line.

Kevin Reardon proposed that while we might observe a structure absorbing in a wavelength shifted rather far from the H-Alpha main line so that its Doppler velocity must end up to be around 100 km/s. If we look for the same structure with the same velocity absorbing at an appropriate wavelength in Ca II, we might not find it. Such a conundrum might be explained by the fact that hydrogen atoms are much lighter than calcium atoms and thus much more easily bothered by thermal heating effects. Nevertheless, this proposed observation is interesting and it is difficult to say whether it contradicts either proposed model or not. Perhaps it supports the idea of apparent motion for an actual plasmatic standing wave must absorb in all possible Doppler-shifted wavelengths as appropriate for its velocity. Apparent motion could potentially resolve this problem.

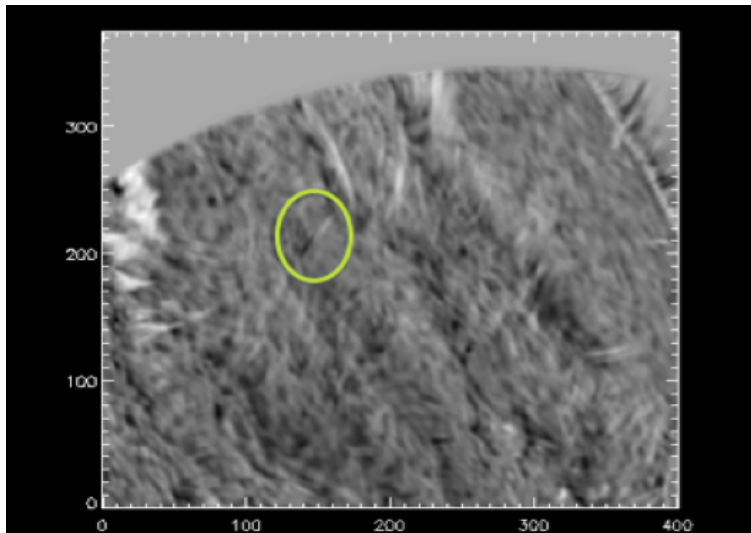
Ca II line and H-Alpha Comparison

We compared Ca II and H-Alpha images taken close in time, searching for evidence of acceleration along flux tubes. The Ca II images were taken at ± 0.06 nm (21 km/s) and the H-Alpha images were taken at ± 0.11 nm (50 km/s).

Slower moving masses of plasma would thus absorb stronger in Ca II and faster moving masses of plasma would thus absorb stronger in H-Alpha. Accelerated flux tubes of plasma should absorb strongly in Ca II at one base where they are moving slower and strongly in H-Alpha at the other base where they are moving faster. One bright fibril in one H-Alpha image should be connected to another bright fibril in another Ca II image taken at the same time. If we subtracted a Ca II image from an H-Alpha image, we should observe a sort of black-and-white gradient of a plasma flux tube.

We subtracted the background out of 20 pairs of Ca and H-Alpha images taken simultaneously and then subtracted the Ca II images from the H-Alpha images.

If acceleration were common we should observe multiple connected fibrils in the resultant image like thus:



The circled fibril is one example of a signal of plasma being accelerated within a flux tube. Significantly, this was the only clear example of acceleration we could find in 20 samples over this large field of view. Going with the traditional flux tube picture, we should have found multiple examples of these gradient flux tubes in each image, not just one measly example throughout all of 20 images!

This discovery rather discounts the flux tube model as we were certainly not observing a fundamental property described in Sekse et al, 2013 and Okamoto et al, 2011 regarding accelerated propagating waves of plasma.

Apparent motion might be suitable to describe what we are seeing. Rather than having a single connected flux tube of plasma, we might have a slightly decoupled rotating sheet structure with different components fluctuating in different directions and absorbing various wavelengths. Different components of the sheet would move with different speeds and in different directions (perhaps there is a preferred general direction to explain the abundance of red apparent fibrils). Rather than being composed of multiple standing wave flux tubes, the effects might be optical manifestations of the fluctuations of different components of a plasma sheet. Apparent shooting tubes of plasma are actually edges of a moving plasma sheet.

Wavelength Scans

To test accelerating plasma models we compared H-Alpha images at different wavelengths using the wavelength scans.

We found that the seeing in during the wavelength scans, while good, was sufficiently poor to draw conclusions.