



# High-Speed Phenomena in the Sun's Atmosphere

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## The Problem

- The nature and origin of fast moving spicules and fibrils is under debate:
  - The **traditional** 'flux tube' picture: spicules are a manifestation of plasma accelerated within magnetic flux tubes (de Pontieu and associates), versus
  - The **unconventional** 'sheet' picture: spicules are a manifestation of plasma sheets arising in magnetic tangential discontinuities (Judge and associates)

The latter was recently proposed to account for **super-Alfvénic apparent changes** along the lengths of H alpha fibrils that appear to correspond to "type II" spicules

## Why should anyone care?

- We can examine evidence for/against Parker's hypothesis for **spontaneous formation of current sheets**
- There are dramatic effects on the interpretation of data in terms of **mass, momentum, energy supply to the corona**
- There is a **long standing problem of the energy balance** of the **solar transition region**

## A Unique Dataset

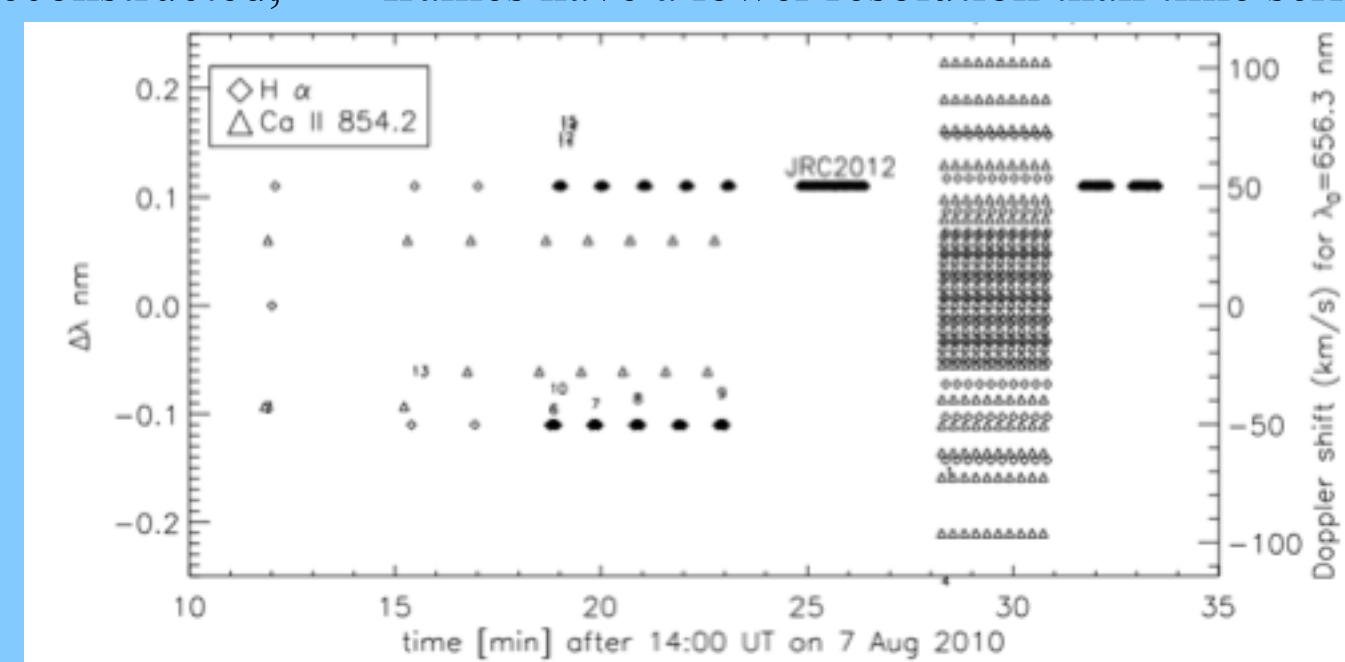
- Dunn Solar Telescope/IBIS observations of H alpha and Ca II 854.2 nm by K. Reardon
- 0.1s cadence, reconstructed to 871 frames taken over a period of 20 minutes
- FOV includes mature limb active region NOAA 11261 on 7th August 2010

## Time Series

- Processed using MFBD and Speckle reconstruction methods
- H-Alpha line of 656.3 nm, frames at +0.11 ("red") and -0.11 nm ("blue")
- Ca II line of 854.2 nm, frames at +.06 nm -.06 nm
- Consecutive frames **processed to a final cadence of 1s**

## Wavelength Scans

- H-Alpha images with wavelength range +/- 0.156 nm
- Ca II images with wavelength ranges +/- 0.259 nm
- Not reconstructed, => frames have a lower resolution than time series



## Some Statistics

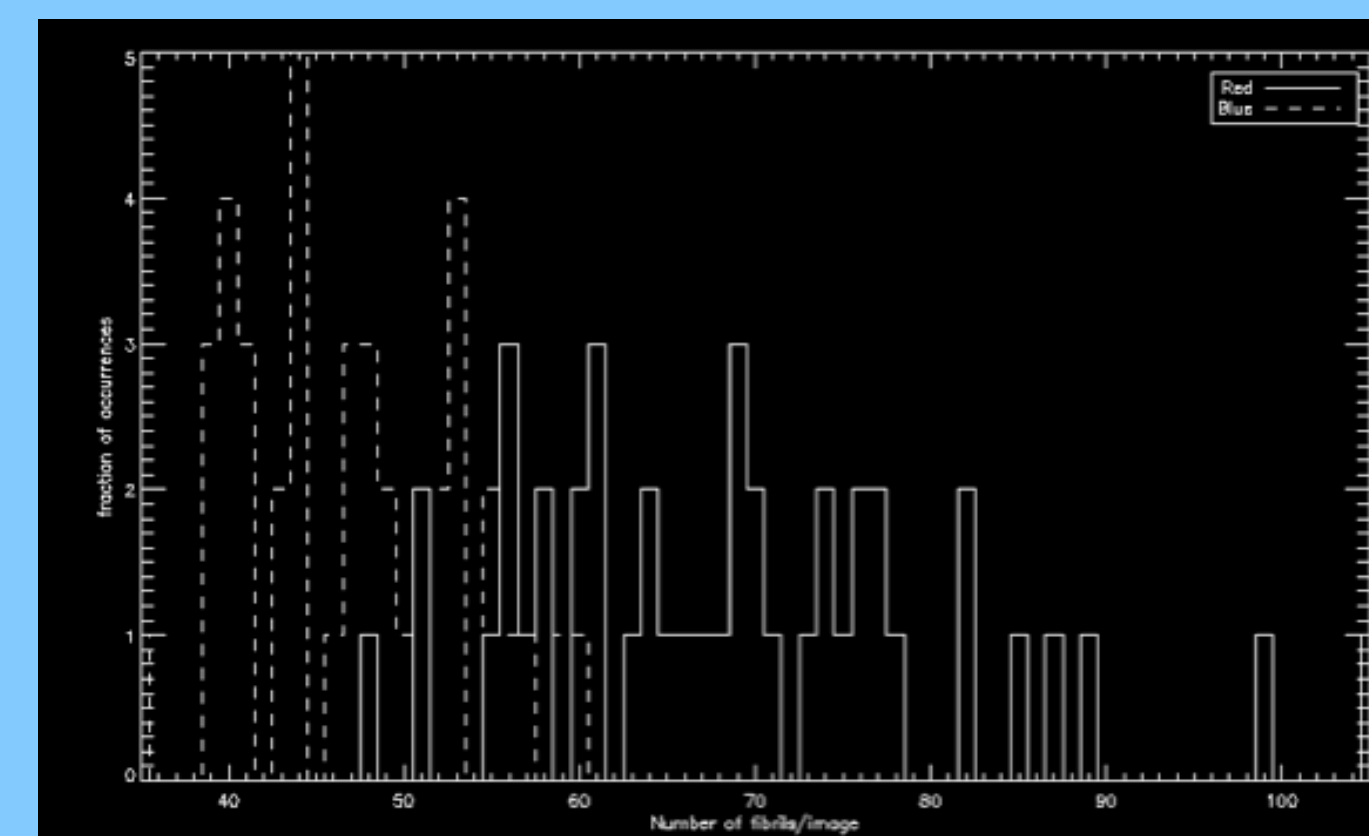
We wanted the **average number of fibrils** per frame for images taken above and below the H-Alpha line. We analyzed 40 blue frames 56 red frames.



We plotted each image in imap from IDL and ordered them to be overlaid with rectangular grid boxes to make counting easier. Fibrils were counted only on the visible disk of the Sun, not above the limb.

Conclusions:

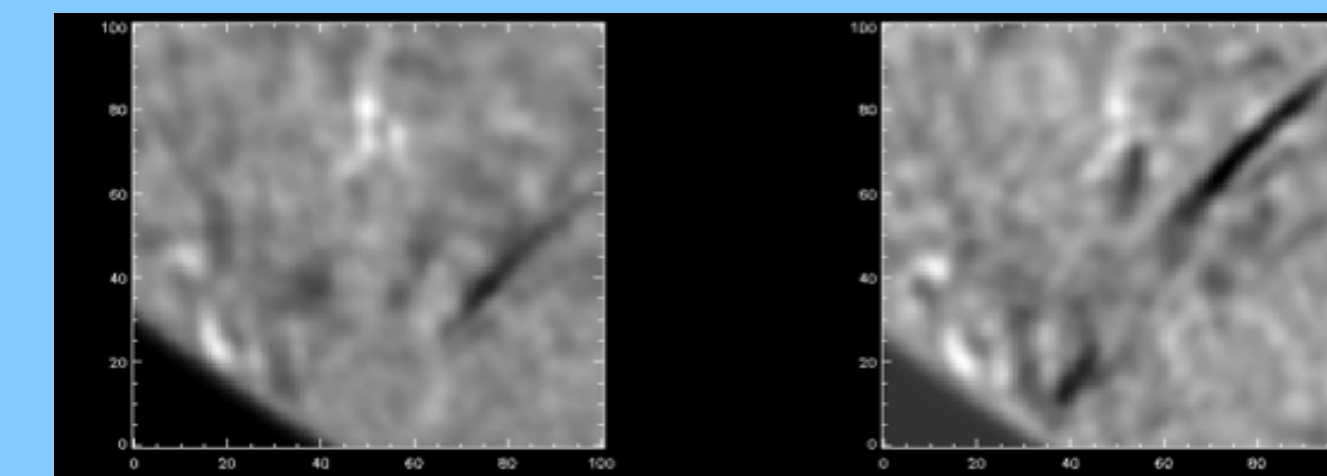
- Average number of fibrils per blue image: 48**
- Average number of fibrils per red image: 74**
- The area of the Solar disk in these images is about 100 square degrees (in heliographic coordinates) or about 0.03 steradians.
- This means that at any time we might find about 30,000 of them on the Sun.
- Histograms show that red frames have a **higher** average number of fibrils than blue frames with a **very high significance** (Kolmogorov-Smirnov):



## More analysis

### Red vs Blue Images

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

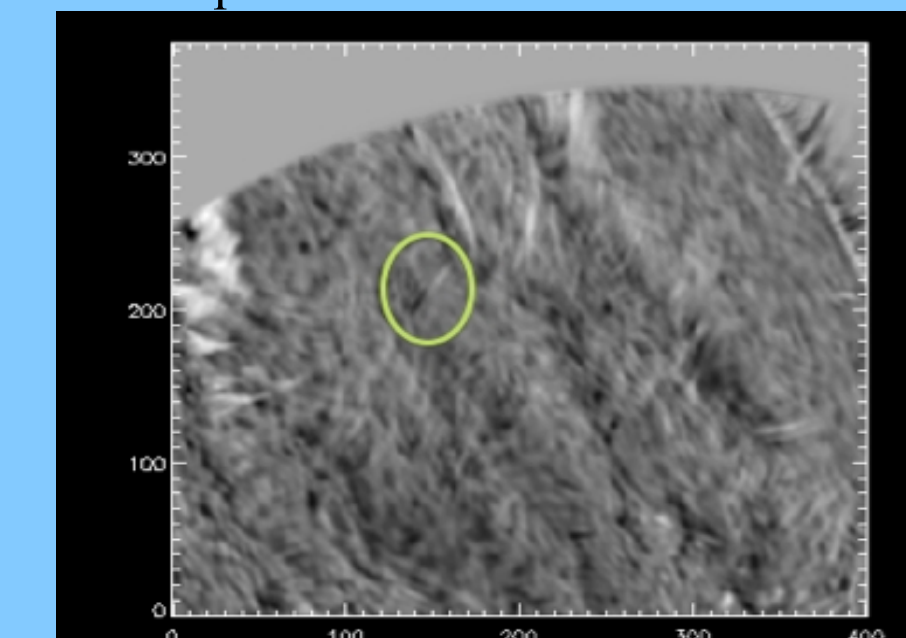


The fibrils seen in the red images are consistently longer and higher than the ones in the blue images. Near-simultaneous red and blue fibrils **almost never overlap**

### Calcium vs H-Alpha Images taken ~1 s apart

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 +/- .06 nm (21 km/s) and the H-Alpha images were taken at +/- 0.11 nm (50 km/s).

We subtracted Ca images from H-Alpha images. If acceleration were common we **should observe** multiple connected fibrils in the resultant image like this:



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.**

### Wavelength Scans

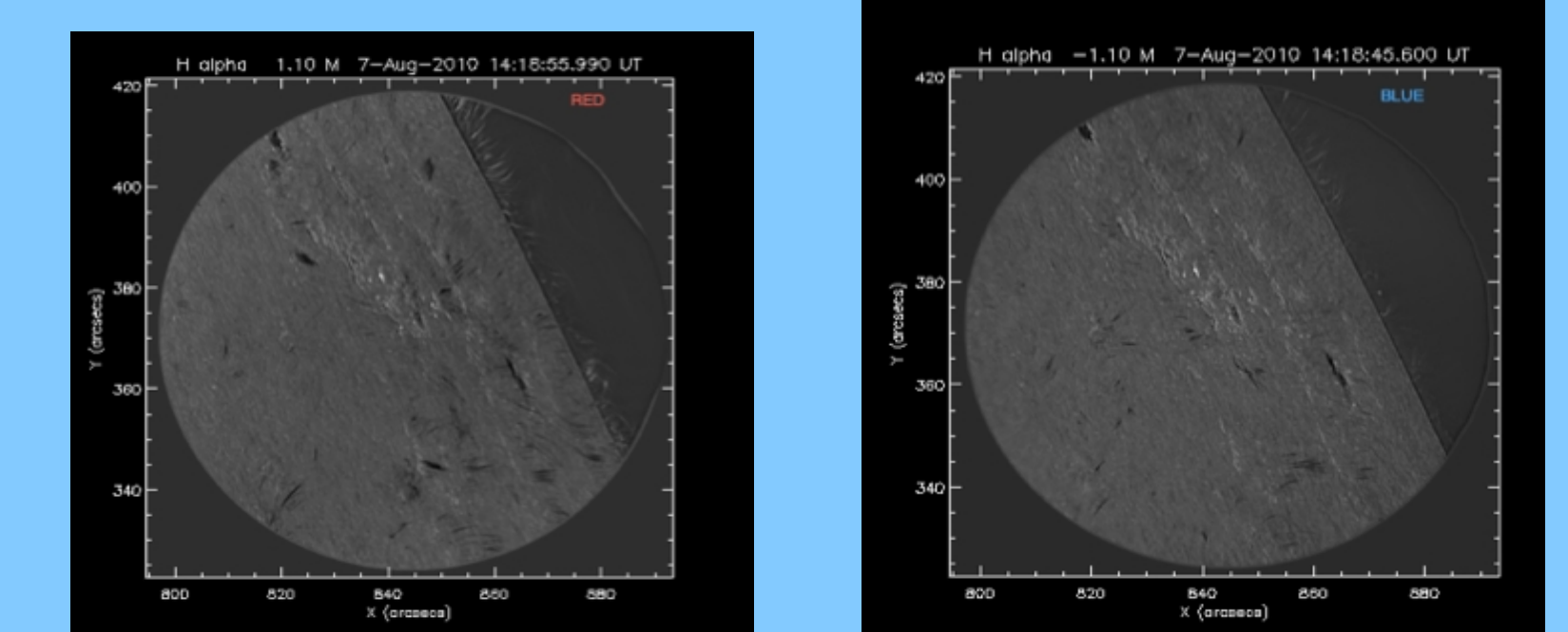
To test accelerating plasma models we compared H-Alpha images at different wavelengths using the wavelength scans.

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

## Implications of Our Results

### Red vs Blue Images

- No red/blue spatial overlap => not linewidths, form in different structures
- N(red) > N(blue). Blue are harder to detect seen obliquely. Is this consistent with plasma outflow from horizontally (canopy-like) expanding fields?



### Calcium vs H-Alpha Images

- We successfully identified only **one** example of plasma accelerated along a flux tube in 20 images
- In the **traditional picture** one would expect to find **multiple** examples of acceleration in each Ca II -H Alpha image comparison
- Is the traditional picture consistent with our data?

### Future Work

- Obtain **further critical observations** as fast as possible using
  - DST/IRS: image reconstruction techniques (seconds cadence)
    - interleaved 2s cadence H Alpha at two or three wavelengths (e.g. interleaved 2s cadence H Alpha 0.05 and 0.1 nm)
  - IRIS UV/NUV chromospheric data
- Search for cases to test critically the two hypotheses
  - evidence for/against standing waves in tubes
  - evidence for/against curtain-like dynamics

### References

- Judge et al. (2012). Evidence For Sheet-Like Elementary Structures In The Sun's Atmosphere? The Astrophysical Journal Letters, 755:L11 (5pp)
- Okamoto and De Pontieu. (2011). Propagating Waves Along Spicules. The Astrophysical Journal Letters, 736:L24 (6pp)

## Flux Tube Picture

### Basic Claims

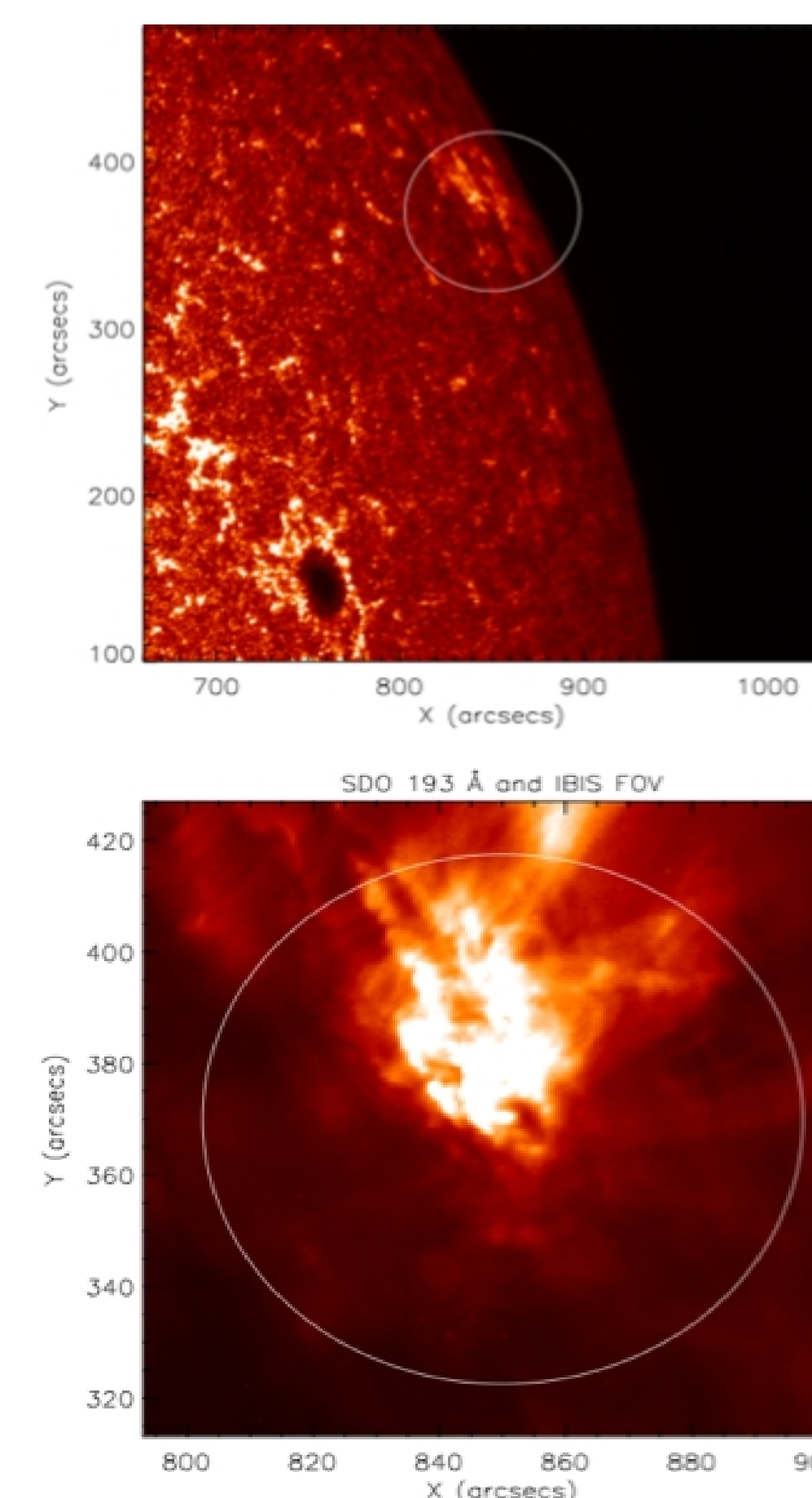
- Type II spicules are plasma propagating through a tube of flux from photosphere to corona
- Motion includes field-aligned flows, torsional motion, and transverse swaying

### Supporting Evidence

- Spicules of type II certainly **appear** tube or straw-like in nature
- Type I spicules are compatible** with field-aligned flows (Hansteen and colleagues)

### Unresolved Issues

- Model of tubes generally ignore 'weak' solutions to MHD equations and the resultant tangential discontinuities that can result in sheet structures
- Wave reflection or highly oblique waves are **required** to account for observed very high phase speeds
- Generally, there is **lack of evidence for (1) steep thermal gradients at transition region to ensure wave reflection, and (2) for oblique waves.**



## Plasma Sheet Picture

### Basic Claims

- Many, if not a majority, of the spicules we are observing are actually optical manifestations of plasma sheets moving around like partially opaque (lace) curtains in the wind
- The observed motions appear fast because of optical superposition effects. The question of **plasma acceleration** is **neither required nor rejected.**

### Supporting Evidence

- The equations of MHD have weak solutions which result in **tangential discontinuities** that can in principle produce sheets of plasma
- Sheets might more readily explain the **high aspect ratio** (length/radius) and **collective behavior** (movies) seen in many fibril groups
- They appear the **only** reasonable explanation compatible with the data we have analyzed (Judge et al. 2012)
- Occam's Razor:** is this picture then **the simplest compatible with the data?**

### Unresolved Issues

- Detecting solid evidence of sheets in the chromosphere (stereoscopy not possible)
- Can tangential discontinuities produce sheets with the right characteristic scales and behavior?
- Proportions of tubes compared to sheets