

## Daily Log

Solar Physics Journal  
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High-Speed Phenomena in the Sun's Atmosphere  
Advisor: Phil Judge

Week 1: June 3rd-9th.

-Monday:

Got CatCard/keys/explored MSU. Got IDL and Helios up and running. Practiced some basic IDL. Met with Phil to discuss nature of project: investigating plasma tubes vs plasma sheets in the Sun's atmosphere. Mixer at Jiong's House.

-Tuesday:

More intense IDL session- learned about logic commands, loops, other sorts of statements. Lecture regarding the pressure-gravity balance in the Sun and fusion in the Sun. Discussed more solar physics theory with Phil. Discovered that tubes filled with plasma (magnetic tubes/phenomena) have generally been accepted as the norm in the Chromosphere but that there appears to be some holes regarding this theory. Evidence as Phil has found demonstrates that there actually might be sheets (like curtains) of plasma rather than tubes and that the appearance of tubes might actually be an optical phenomenon? There are many papers published regarding tubes and so much explanations on how the physics works there to produce what we see, but it seems that everything is kind of "forced to fit".

-Wednesday:

Learned how to import data into IDL and some means of manipulating it. Read through many papers: both from Phil and others which reject Phil's idea. Opponents say that this is still a 1-D phenomenon (tubular) and that what we see can be explained by rapid wave motion and variation. Phil says that this is too complicated an explanation and that this is actually simplest if we say it is a 2-D phenomenon (the sheets). See document 'Tubes vs. Sheets' for more notes on this. Skyped Phil regarding this.

Learned about Phil's scientific philosophy: he believes that too much science is about 'proving' something and not enough about asking questions and discovering new things. He likes Popper. He believes also that a lot of science is forced to become 'useful': like predicting when solar flares will happen (not a useful goal- they are far too unpredictable!). Too many scientists are grabbing on to accepted theories and making new discoveries 'fit/work' within them and are ignoring very important inconsistencies because they are afraid of change! This appears to be the case with the tubes/vs. sheets problem. Phil is a minority in the solar physics community advocating for a revision for the previously held tube idea. Many other solar physicists (whom he calls not very bright!) are ignoring critical issues and inconsistencies with the tube model

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because they do not want to change it. They say that sticking with the tube model is much more simple but Phil says that the sheet idea is closer to Occam's Razor than 'making things fit' within the tube model.

Apparently, these thin plasma magnetic flux tubes are not easily replicable on Earth and mathematically we have evidence for the plasma sheet reality. Theoretical science actually supports the sheet idea much more than it does the tubes, but because we have 'observed' tubes (which might be an optical manifestation), everyone really is unwilling to revise what we have previously been thinking.

In the 1970s, Parker proposed evidence for sheets in the chromosphere/ a theoretical model. And now, as I have read Judge et al's papers, there appears to be some solid evidence in favor of this sheet phenomenon as the magnetic corrals of plasma.

Went hiking with the Roskie dorm to the big letter M written in rocks on a nearby mountain by students in the 1800s. Was very tiring. Carla nearly knocked us off the mountain in her enthusiasm when we reached the M. Saw a snake.

-Thursday:

Learned to plot data, graph it, view it, etc. Began a small project manipulating some sample data provided by Chris Lowder. We are going to take a small region of an image where there is a solar flare and find the average intensity and plot it. Read some more papers for Phil. Had a lecture regarding the magnetic field of the Sun and energy transport in the Sun (and sunspots). Discussed how to manipulate data with Phil. Learned about the data we have: the .fits files have already been corrected and reduced by the telescope. We have ground-based data.

The goals now are to work with the .sav file data (which cannot simply be brought in to IDL using read\_sdo, etc. We want to map these images and properly center them and find the correct scaling/coordinates relative to where they were taken at the Sun. Learned how to import data, restore, data, and map/rotate images. Our .sav files are composed of a 2-D+ data array, some of which are 3-D because there are many different images taken over a period of time. Some of them are 4-D because of the time thing and because they were taken for different wavelengths. We can use the reform command and xmovie to manage them: make a movie to view them over time.

-Friday:

Finished project with Chris Lowder. Able to plot median, average, total intensities over a 2-D region. Worked on my own exploring the data (.fits and .sav): plotting it, xmovie-ing it, and writing a few introductory programs and scripts. Wrote a start\_up script to open and load the data. Worked on a program that would subtract each successive image from the previous one for a 3-D .sav file and then display the subtracted pieces in xmovie so one can view the changes in intensity solely. Applied it to two .sav files: s\_4 and s\_12. Might be a good idea to somehow remove for loops to speed it up if it turns

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out that this is useful. Ok for now. Might also be a good idea to not subtract each image from the next but to find an average overlying intensity and subtract that from the whole set. More to come on this.

Worked on the mapping issue. Made a map for one of the images (s\_12) and tried to rotate it and compare it to the .fits files.

Skyped Phil and discussed more of the programming/the project. Read the parts he has finished of the paper that will be published in the near future regarding this project. Phil wants a brain uninfluenced by preconceptions of the sheet vs tube issue to explore the data and contest both viewpoints (me!). We are not here to merely promote sheets over tubes or something. We are here to try and disprove one or the other and discover evidence that might reveal inconsistencies in the 'only-tubes!' idea.

Went swing-dancing with the REU group. Met the Chemistry REU students.

-Saturday:

Went hiking with the REU group up the drinking-horse trail. Went into town afterwards with other students to explore. Pointed out the constellations during the evening to the chemistry students.

-Sunday:

Went rafting with some students and the outdoor recreation center. A very nice trip. Played Volleyball with some more students. I am terrible at it but that's ok.

**Week 2: June 10th-16th.**

-Monday:

Read through the papers (for/opposing) once again and made some more notes of arguments supporting tubes/ supporting sheets. See document 'Tubes vs. Sheets'.

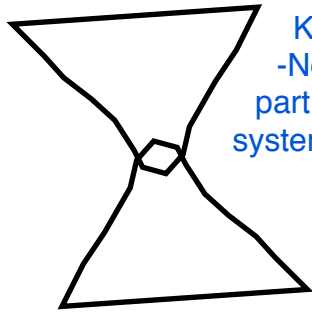
One advantage of having extreme synesthesia is that it makes programming much easier. I don't need to have an editor color code things for me. Everything already appears like this regardless. Makes it easy to find numerical mistakes. Although reading black-and-white documents is actually pretty difficult!

Discussed further solar physics theory with Phil regarding this project.

-We are dealing with the Hydrogen-A line 656.3 nm. Due to doppler shifting, random motion kinetic energy of atoms (and maybe magnetic field splitting), this line is rather broad.

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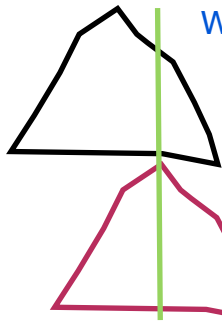
-Observed head-on, it is an absorption line as the solar atmosphere absorbs the energy from the outgoing radiation. Observed from the top of the Sun, it is an emission line as the radiation is re-emitted.



Kind of like this!

-Not only is there random motion due to the kinetic energy of the particles (which are ionized plasma), the gas that we are observing is systematically moving upwards, downwards (oscillating).

-This therefore leads to Doppler brightening/dimming if we look at the same wavelength as the gas is moving back and forth.



We are looking at the same wavelength in both images, but in the lower, red-shifted one, we end up seeing a brighter outcome as we are actually looking at a red-shifted wavelength that is automatically brighter when stationary.

It is the other way around for Doppler dimming.

-We have images taken for a single wavelength over a period of oscillation and for several wavelengths over one or multiple times. There is the issue that we cannot take data fast enough to have it done before one period of oscillations is finished.

-Kevin manipulated this data.

-Pressure of the gas = its average kinetic energy. Pressure of a collision is 2-D, looking at random motion from one line of sight is 1-D.

-The overall motion of the plasma is likely to exceed the random motion.

-The idea here is that the motion of the plasma (oscillatory), is far too fast! If you work it out using doppler broadening ( $\frac{\Delta \lambda}{\lambda} = \frac{\Delta v}{v} = \frac{v}{c}$ ), then the speed of the gas could be about 10 times the speed of sound: faster than the Alfvén speed allowed in this region!!

-But if it is super-Alfvénic, why aren't there the shocks/ general excitement that have to accompany things traveling faster than sound?

-Thus, it is possible that this is an optical thing: we are just seeing the 1-D manifestation of something that is actually 2-D (there are sheets).

-Other people studying this say that these are set up standing waves. The issue that over the proposed flux tube, the density changes and that an actual standing wave could only exist over a portion of the tube (the middle).

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-We would need a massive shock at each end to cause such a standing wave! The people supporting the flux tube model state that the standing waves are a combination of two moving waves that are moving in different directions.

-Let's say we could somehow set up such a standing wave.

$y = y_0 \sin(kx - \omega t) + y_0 \sin(kx + \omega t)$ . The period of such a wave with the granted speed (from the Doppler broadening calculations) and length of the tube must be more than a few seconds! But we are observing these propagations over a much shorter time period!

-So what is going on? There could be some deeper complexities going on that require plasma physics for an explanation.

-We are dealing with this situation via magnetohydrodynamics: treating the moving matter as a fluid under the influence of a magnetic field.

-But that is much more complex! At the moment, we are going to continue using magnetohydrodynamics.

-We thus have an argument for the sheets: what we observe is not consistent with the flux tube idea as things are moving too fast! The other researchers try to cram in explanations and make things fit but Phil believes their argument is crumbling.

-We are going to further analyze the data we have and make measurements of velocities and Doppler shifts.

-The data consists of the same thing analyzed at different angles: One wavelength over a time period and multiple wavelengths over a single time.

-We might end up doing some modeling for the plasma sheet idea as it is backed up mathematically/theoretically where as the flux tubes are not so much.

-Tuesday:

Had a lecture regarding the magnetic field of the Sun and how we can measure it (via the Zeeman Effect and others; extrapolation).

Worked further on mapping the images via 'eye-balling' the data. Skyped Phil and discussed how this process might be quantified.

See document June 11, 2013 for better details but basically, the idea is that we are going to have to use some plotting tricks to compare our .sav files to an already-finished .fits file and get everything aligned.

We want 5 numbers for our image: center (x and y), stretch (x and y), and rotation.

We can thus use these parameters to ensure each image is correctly aligned and mapped relative to where it is in the Sun and can be accurately analyzed.

We will put this into action tomorrow.

Read up on why standing wave idea is not correct (see Tubes vs Sheets paper).

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Ideas on inconsistencies we might observe:

- No curvature of the 'tube'.
- No density gradient at 'transition region'. No transition region.
- Stuff moving far too fast (extreme redshifts, etc).
- Too much energy losses/ messy medium.
- Too much rapid variability.
- A lot of strange randomness (Team Tube's argument demonstrates a rather systematic world).
- Brightness of spicule does not depend on density of plasma/ does depend on plasma temperature and velocity (they said vice versa).

Having at it tomorrow!

-Wednesday

Phil mailed me a program last night called `isabel_align.pro` that described how to correctly align images.

-Basically, the idea is to take the time average of the entire sequence to be mapped (the image), estimate the necessary coordinates (xcenter, ycenter, dy, dx, rotation) and put them into the `make_map` command, and save that file as a reference map (a `.sav` file).

-Then, it is necessary to find one or two `.fits` reference files close to the time the image to be mapped was taken at (they can be gotten from <http://sdac.virtualsolar.org/cgi/search>). These should be made into maps via the `index2map` command: `index2map, index, data, map` and saved as `.sav` files.

-Use the `smooth` command and `inter_map` command to interpolate the `.fits` data onto the `.sav` data and make the `.sav` file into a map.

The `blink` command: `blink,[0,1,2,3]` will blink windows for you.

Played with this program during the morning and worked at understanding it. Made a few program versions that use our actual data. These are:

`make_a_map.pro` and `smap1600.sav`, `smap1700.sav`, `refmap.sav`, `smptest.sav`

In the afternoon, Phil and I discussed where we are further going with this regarding data analysis.

We have 23 `.sav` files. Some were reduced using the speckle process and some were reduced using the MFBF process. Each of the 23 is a 'packet' that includes the times the images were taken over and their wavelengths.

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The speckle images have this stored in a structure that becomes available when you use the 'restore' command. We can use the command: help, 'name', /str to reveal the components of the structure and read the wavelength files/times files.

The MFBD packets have different files containing such information.

The goal now is to compare the different files that we have: compare the speckle process to the MFBD process. This means that we have to compare apples to apples: similar times to similar times, similar wavelengths to similar wavelengths. A good idea will be to divide out the median of each image to normalize them and then blink the images. We can repeat this process over several images to compare how they are similar and different. This is necessary to know as we need to understand the effects due to data reduction and due to actual significant observations. If we observe an inconsistency in one image with respect to another we need to be able to say whether it is a significant observation or just due to how the data was reduced.

It would also be a good idea to do as the environmental scientists do in a field with determining the population density of dandelions but with the population density of fibers in the Sun. (See document 'What we observe').

This could be done using a computer algorithm but there is the chance that this will be rather complicated to perform as it might take us ages to actually find such an algorithm and tweak it so it works for the fibrils. Phil suggested that we might co-opt a program used to find rivers on a map or jet streams in the air (as the fibrils are rather snaky) but right now I am going to attempt things with my eye!

I plan on getting several images and gridding them and determining the population density average in each grid.

We also discussed more of the theory behind this project and its relation to Parker's work on magnetic sheet structures and tangential discontinuities. I have written about it in 'Tubes vs Sheets' (the part with the pictures and it is in teal-blue).

-Thursday

We had a lecture (from Phil) regarding solar variability (it is largely due to magnetism fluctuations!). Found out that we actually do not 'understand' a lot of what goes on regarding the Sun (like WHY do sunspots happen, etc)- we are just able to show what happens and qualitatively describe it.

Worked at making comparison programs. At the moment, I have made three.

comparison\_general.pro compares two general speckle and MFBD images.  
s[13] for the speckle and s[6] for the MFBD

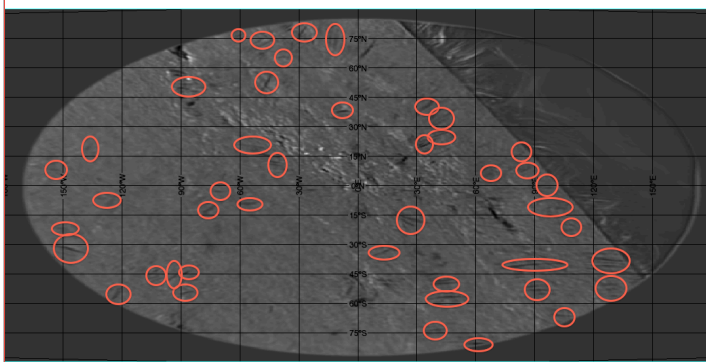
Note: The compared images have been median corrected (divide out the median).

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compare\_blue.pro compares two blue speckle and MFBD images.  
s[14] for the speckle and s[7] for the MFBD.

compare\_red.pro compares two red speckle and MFBD images.  
s[14] for the speckle and s[12] for the MFBD.

Also began the counting of the fibrils.



I have done this for several images and I will do it for a few more and then try and find a sort of population density per image.

More analysis tomorrow.

Went to check out the Bike Kitchen but got caught in the rain.

-Friday

Continued the counting of the fibrils. So far, I have completed this for 21 images: 11 general images, 5 red wavelength images, and 5 blue wavelength images. My method is that I count the number of fibrils in each image (generally somewhere around 50, but sometimes as much as 70) and then I divide by the number of whole grid boxes. Each mapped image contains 88 whole grid boxes. This is just to get a number to quantify things.

Of course, we need a good distribution so 20 is not enough! I am going to make more-maybe get about 100? Probably 50 general images and 25 each of red and blue images. I will compute a total average of fibrils using all the images and then compute some sub-averages using the red and blue images.

Phil suspects that we might observe different average values of fibrils in the red vs. blue images. I have at a glance observed this too: the red images so far seem to have higher numbers of fibrils than the blue images. Maybe this means that more fibrils are redshifted (moving away from us) than are those moving towards us?

Going to use IDL to do some statistical analysis once I have a good widespread distribution. I can ask my best friend and IDL genius Wanda for help if necessary. Love that girl. She is a brilliant planetary geologist.

Wrote a program to better compare the two differently processed image batches: speckle and MFBD. I did this for blue and red (mainly because I am confident that my



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previous programs comparing blue MFBD vs blue speckle and red MFBD vs red speckle used images that had the same time averages).

The programs are Compare\_blue.pro and Compare\_red.pro. What I do is subtract the median-corrected MFBD from the speckle and then take a small section of the subtracted image ([600:800, 300:500]) and plot it next to the same small section of one of the original median-corrected images (I ended up using the speckle). This small section was chosen because it contains a region of activity that is a good case study to really see the difference between MFBD and speckle. A 200 by 200 plot was the smallest I could get without everything getting terribly pixellated! I blink the frames to demonstrate their differences and the programs also write the subtracted segment and the MFBD segment to a file using the set\_plot, 'ps' command.

I think I will add in a few more comparisons following a similar program format but using different images to get a good sample. At the moment, I can see that there is a bit of difference in the speckle and MFBD by looking at the subtracted image, but I want to see how significant this difference might be by getting a few more samples.

It is important to understand the exact nature of the difference in the image correction programs so we know whether an observation we make on one image in the future that is inconsistent with other observations regarding different images is due to an actual solar phenomenon or just due to how the images were reduced! And I need to get more samples to write such a conclusion on the nature of MFBD vs speckle.

So, the work to be continued involves getting a larger sample size. At the moment, I have a few theories and observations, but I need a statistical sample (or semi-statistical sample) to properly draw some conclusions!

Went to town to see the ArtWalk. May or may not have walked into a wedding reception by accident, taken some hors d'oeuvres, and walked out again.

Went swing dancing. Getting better.

-Saturday

Hiked up Sypes Canyon. Went to town, got bread. Played games in the evening.

-Sunday

Cleaned room, went to the Daily Coffee Bar, planned for next week.

**Week 3: June 17th-23rd.**

-Monday

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Had lecture on the Sun's atmosphere. It has a lot of activity! Did more work comparing speckle and MFBF images (subtracted them from each other and compared the original images to the subtractions).

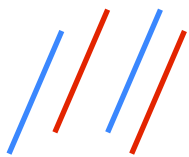
Did more work regarding the statistical averaging and computations of fibrils per image. At the moment, I have 63 counts of data, but I am going to need more!

Began comparing the red and blue images to each other: wrote a program to blink two blue and red images taken at around the same time. I had the program get very close up to fibrils in each image and compare them.

Going to have to do this for a lot more images and get a good sample.

-Tuesday

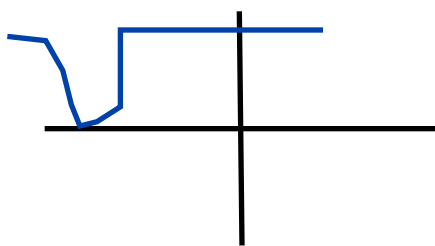
Finished more of the statistical counting and averaging. Showed the red and blue comparison (blue\_vs\_red) program to Phil and we noticed that things appears like this:



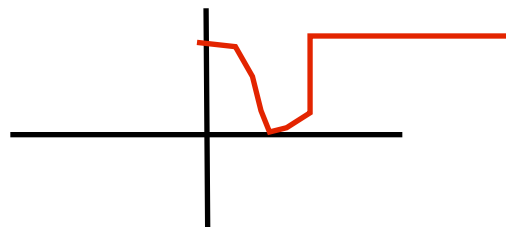
The blue-shifted fibrils (moving towards us in our line of sight) are less numerous than the red-shifted fibrils (moving away from us in our line of sight). And they are different things: some things that appear in the blue image do not appear in the red image and vice versa. So it appears that some of the gas is moving in one direction and some is moving in another direction.

I learned to use x-slice to analyze the spectra of these activity spots. X-slice is a tool that displays the image and has spectral plots for x and y next to it. X will plot the intensity of a certain line in the x direction with wavelength on one axis and x position on the other. Y will do the same, but for y.

Thus, much of the spectra we can observe look like this:



blue shifted



red shifted

We need to make more of these to better analyze the difference between the red and blue images. This, so far at least, is evidence for motion in different directions and maybe more complex motion. The red fibrils and blue fibrils do not overlap in any case as far as I can find.

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Got a bike from the bike kitchen. It rides rather well! Named it Tarra.  
-Wednesday

We had a lecture regarding magnetic fields snapping and reconnecting in the Sun's atmosphere and how this causes and relates to solar flares.

Took group picture near the 'L' statue.

Phil and I decided that it might be a good idea to build a database that will record the wavelengths of the different images and the times at which they were taken. If you search for times in a structure or other file, you will only get the Julian time which is accurate to 2.4 hours (the whole data was taken over 20 minutes!). A script can be written to convert this to Greenwich Mean Time and that is better. Once the database is made, we can just search for a time and find all the images that were made at that time.

This will improve the created comparison for speckle images vs MFBD as we need to have them taken at the same time for a valid comparison!

The plan now is to make more comparisons of the red and blue images and see not only how the different red and blue activity spots vary in space but also in time. Hopefully, this will work out to a plausible demonstration of how this might be caused by blowing and turning sheets.

The problem is now that we have observed a lot of evidence for motion 'upwards' away from the sun but not a ton of evidence for motion towards the sun of hot plasma! At the moment, that supports the propagating tube wave idea more as they could be geared to a certain direction. Shouldn't we, with sheets, see equal motion in both directions? At the moment, it is possible that this is due to matter cooling off as it gets very high up and giving off less radiation? Maybe there is a relationship between temperature, height, and  $n$  (number density of electrons) that could explain the cooling and harder-to-see nature as things get higher up? Lower  $n$  means lower temperature as we get higher and thus less radiation. Can we see this or disprove it?

The goal now is to disprove the sheet model as much as possible, a la Popper science. The key is to remember the difference between what is actual motion and what is apparent motion. Right now, Phil is finishing the database and hopefully I can soon better plot the red and blue images and compare them.

Eric Priest is here from Scotland. He is a very famous solar physicist. I have talked with him about my research and he was rather receptive. One thing I forgot to mention is that our data comes from the IBIS instrument at the Dunn Solar Telescope.

-Thursday

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Phil finished the database although I am having a hard time getting it to work on my computer. The trick is to know how to order things by time differences, etc. A lot of indexing! I want to explore all that, but I just can't seem to get the database to appear?! Worked more on the counting project! Phil and I further discussed magnetohydrodynamics. As far as I understand, it is the application of fluid mechanics to ionized plasma. I learned that a good deal of classical physics is basically Newton's Laws, just on varying levels. When you have a group of particles, you need a more complicated system to describe them. You always need to consider what forces are acting on which particles (gravity, magnetism, pressure). We can study the force balance (or lack thereof) and see what is happening with the system.

I still need to go through Maxwell's Equations as I have yet to take Electricity and Magnetism. Phil lent me Parker's book on the complexities of solar magnetism so I will be checking it out soon!

-Friday

We had a lecture about the solar wind and what is going on with that. Some particles in the corona basically are able to get away and they certainly do!

Phil has decided to revamp the whole database idea: basically, each individual frame is going to be rewritten to a map, properly orientated, and we are going to have 871 frames with the timing information written in. This is necessary because if I want to properly compare MFB and speckle images or red and blue images, they need to be taken at around the same time. At the moment, it is rather complicated to do that as they are all in these 20 or so .sav files! Things are going to be better this way.

Today, Phil worked on that and I spent a lot of time getting the webpage up.

Finally finished the counting project! All the data has been written to a spreadsheet and I have the means and all. Going to import it into IDL for some further data analysis (standard deviation and all).

Had dinner with Phil and Terri, went in the hot tub! Went swing dancing :)

-Saturday

Went to Target, went to a cool Thai restaurant with Adeleine & co., saw a zombie movie. Hung out in Marcello's room till 4 AM!

-Sunday

Went biking up to Hyalite Canyon at Gallatin National Forest. Adeleine and I got rather tired because going uphill is absolutely awful and I haven't had a lot of training! So we turned back earlier than the rest of the guys but we had a nice picnic and got Fro-yo at Culture.

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It was really nice going downhill! We didn't have to pedal once!

Week 4: June 24th-30th.

-Monday

We had a lecture from Eric Priest about solar phenomena and basic overviews. We learned that the solar cycle might account for 1/3 of the Earth's warming but humans definitely affect the crisis greatly with our augmentation of the greenhouse effect!

Professor Priest sought to debunk the myth that the Sun is boring as well as the myth that British guys always dress well for a talk, so he took off his business shirt and tie to reveal a t-shirt haha!

Phil and I developed further our future plans. The database has been developed and I am learning how to use it with the program that he wrote that selects MFBD, speckle, hydrogen, calcium, closely wavelengthed, closely timed files or select combinations of the above. You can't search for MFBD and speckle at once.

The program is `getindex.pro`. You use it like this: `getindex,'hdtm',sel,m` This command uses the index program to search for h (Hydrogen alpha wavelength), d (different wavelengths close in time), t (close in time), and m (MFBD). Files that meet the criteria are saved in the list m. Sel is a numerical list that holds the index numbers of the desired files.

t: time series (fast); m: MFBD; s: Speckle; d: different wavelengths very close in time; h: H-Alpha; c: Calcium line; r: red side; b: blue side; w: wavelength scans only (not MFBD or Speckle). p: similar times yet different processing (for comparing MFBD and Speckle).

The goals for the near future are:

1. Compare MFBD and Speckle better (whole images, select regions) and write a report finalizing what their differences are. We can use the program to find images appropriate for comparison. We might need to combine several MFBD images as speckles are averaged over a longer time period (50 sec) vs MFBDS (5-10 sec).
2. Do the standard deviations for the counting project and write a scientific report on the difference between the red and blue images. The reds have a higher average of fibrils per image so far as compared to the blues. We need to document the procedure and what we found.
3. We have analyzed how structures change from images in one wavelength to images in another. But how do they change over a whole time series? We need to study movies and sets of images in either wavelength over time to better understand how the sun moves and changes.

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Finally: the mapping command DROT (we found via sswloc) is able to take an activity region and show how it would look a few hours or days ago when it was at a different region of the Sun. This is done by taking into account differential rotation, models, and some good extrapolation. But of course, it is not going to be perfect- it cannot fully differentiate between each sunspot on the underlying photosphere and a fibril we are studying at the chromosphere!

-Tuesday

We had another lecture regarding magnetohydrodynamics from Eric Priest. This subject is complicated, intricate, and beautiful at once! Basically, it is what happens when you combine magnetic field studies with hydrodynamics: fluid mechanics plus Maxwell's equations. I hope to be able to study more of these two fields soon at Smith and get a better understanding of the equations we ran through today.

Finished the counting project finally! All the images are online at the web page as is the report. The conclusions of this project came to that we observe a much higher level of fibrils in the red images than we do with the blue images. We are now ready to move on to higher levels of analysis. The fact that we observe higher activity levels with red than we do with blue might actually be in opposition to what De Pontieu et al are saying. With their flux tube picture, it seems that we might have a more random level of activity in each image and the fact that they are systematically different is interesting.

We discussed further the theory behind this project. Regarding the standing wave flux tube idea, it seems as if we would need to have a shock happening above and below the standing wave region in order to generate two waves that will move in opposite directions and be standing waves. And they need to have roughly the same amplitude and properties. It rather seems strange that this is going to happen at the same time in order to generate such a wave! And then there is the claim that there is a steep pressure gradient at the top of the region where the waves are reflected (we would need this pressure gradient or some sort of change to ensure such a reflection could happen). We just don't seem to observe such a pressure gradient or change as modeling and calculations show (the temperature, pressure relationships with physics).

-Wednesday

We had a final lecture from Eric Priest which discussed the reconnection phenomenon observed in the solar atmosphere and its connection to the magnetohydrodynamics equations. This is very interesting- it appears that magnetic field lines can cross after all!

I now very well understand the data we have! We have MFBF frames and Speckle frames. Red time series and blue time series for H alpha and Ca II (multiple images taken over a rapid time sequence- about 10 seconds). We also have wavelength scans for Ca and Ha: multiple wavelength frames. This is all for the same region on the Sun.

## Daily Log

I wrote a program to compare the MFBD and Speckle images: basically subtracting the two and looking at specific regions within them. Phil has written a program called `roi.pro` (region of interest) that understands how to isolate the specific regions with the map files.

I have concluded that there is no major difference between MFBD and Speckle images. The Speckles were averaged over a longer time period than were the MFBDs so there is thus a greater definition and deeper resolution with the Speckles. But there are no large major differences between two separately processed images (taken at the same wavelength and at the same time). The same amounts and densities of fibrils are there as well as the underlying structures themselves. I have written a report on this with examples which has been posted online. I have confidence that we can go forward and not be concerned about the Speckle and MFBDs having major differences. The program is called `MFBD_Speckle_Compare`.

We now are interested in comparing the H-alpha and Ca II images: those taken at the same time and with the same color wavelength. We compare  $-0.60$  Ca II images to  $-1.0$  or  $-1.1$  H-alfas (this is blue). We compare  $+0.60$  Ca II images to  $+1.0$ ,  $+1.1$  images (this is red) and take care to match up times. This program is `Ca_vs_HAlpha` and it uses the region of interest program as well to isolate regions that have high fibril levels and compare them. At the moment, we get something rather interesting. There will be one fibril in the Ca image in one place and then there will be a similar fibril in the Ha image at the same time but kind of shifted left or right. It is almost as if we are looking at a sort of (flux tube!?) that has the plasma in it moving at different rates: faster in one place where it is more red or blue shifted from the norm and is thus emitting H-Alpha  $\pm 1.1$  from the norm H-Alpha. And slower in the other place where it is less red or blue shifted than it could be from the norm and is thus emitting Ca II  $\pm 0.6$  from the norm Ca line.

We are going to explore this further and even subtract the images to try and 'see' the flux tube and connectivity.

-Thursday

Did more work with comparing Ca II and H-Alpha images. I made the program subtract and blink them to try and see the continuity of Ca, then Ha all in one sort of flux tube. ROI does not work with `plot_image` (and when you subtract things in this new format, you have to take the `.data` extension of the structure and you end up with a single image) so I had to try and isolate the regions I wanted to compare: Ha, Ca, and then Ha minus Ca! This project is still in progress as we did not actually get them correctly aligned, unfortunately. I am going to apply `align_map` to the Ha, Ca images and see if I can get them straight.

At the moment, we do not really see that gradient continuity that we want to observe. I found about one example of it fading from black to white: the result of subtracting Ca from Ha and getting a fibril that is emitting partly in Ca emission (moving slower in one place) and that is emitting partly in Ha emission (moving faster in that place). The dark

## Daily Log

region is Ca and the light region is Ha due to the nature of the Ha-Ca subtraction. This is an indication of one of those flux tube fibrils described by De Pontieu et al. I am going to try and do some more subtractions to see if we can see more of these interesting observations.

-Friday

Worked on the time series project observing H-alpha emission in red and blue (over several seconds) that I described on Monday. I tried to map individual seconds and identify fibrils to see how they move across the image/ appear and disappear. But that is taking a rather long time so Phil helped write a program to view these specific timeseries in xmovie. I will have a better report on what is going on here soon!

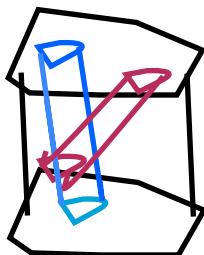
Worked on the Ca and H-Alpha project some more as well. We basically have 12 sets of Ca, Ha frames that can be compared to each other as they have been taken at the same time and are of appropriate wavelengths. I found four average values for Ca in the red wavelength, blue wavelength and Ha in the red wavelength, blue wavelength. 6 frame sets are of Ca, Ha in red wavelengths and the other 6 are of the two in the blue wavelengths. For each frame set, I subtracted the appropriate averages (which were found by averaging a time series of red and then blue Ca, Ha) and subtracted the images from each other.

At the moment, within the subtractions, I have only found one solid example of the gradient speed flux tube that is an illustration of the ideas posed by De Pontieu that there is an accelerated flux tube of plasma in the chromosphere (going slow, then fast). I need to align the images better and see if I can find more examples. It seemed in the individual frames of Ca and Ha that we might have evidence for this.

Phil has drawn up a chart of what we want to look for in the images. We have already found a numerical value for the red fibrils vs blue fibrils and we have found zero examples of where red fibrils in one image overlap with blue fibrils. We want to look for the 'flux tube' Ha, Ca connection in red and blue and we want to observe the time series for red and blue fibrils that appear as sheets.

If I cannot find more of the Ha, Ca connection even after align\_map, this goes against what De Pontieu is saying- you'd think there would be more connected gradient flux tubes if the superfast phenomena we are seeing is indeed plasma accelerated in a flux tube form. Magnetic fields can indeed form flux tubes, but the magnetodynamics of the chromosphere is incredible complex. We can have a tube with tubes inside it! We have x-point and null points where the reconnection occurs.

The main idea here that things might not be so simple and tube-y as others say it might be like as magnetic fields have the option of doing whatever they feel like doing! What about if these many disorganized tubes cross or interact with each other and form a sort of sheet at their boundaries plasma interspersed like jelly?





## Daily Log

The important thing here is that we need to be on the lookout for observations that support or go against either idea. What Phil is arguing is valid due to the fact that things are incredibly complicated up in the chromosphere and we cannot simply state that things must be all collected and all in tubes. What we are seeing certainly might be due to the rotations of a plasma sheet. It is going to be an interesting step if we do not observe extensively these gradient tubes!

Went swing dancing again.

-Saturday

Went thrifting in town, hiked up the M again (in my best dress!)

-Sunday

Went biking around, went for pizza, saw 'This Is The End'.

Week 5: July 1st-7th.

-Monday

Worked on mapping images with the align\_map command. We want to align the H-Alpha and Ca II images that we are comparing. I finally got it to work, but I cannot really see any more flux tubes than those that I saw earlier. Need to discuss with Phil what this all means.

Used the xmovie program Phil wrote to make a few movies of the red and blue time sequence. Monitored the red and blue fibrils and tried to determine for how long were they all were on the screen. Some appeared to be around for more than a minute whereas some were only present for around 9-10 seconds! Not sure of the meaning of all this. Is this expected?

Here is a summary of what I found:

```
getindex,'tbmh',b,blue
```

```
90 frames from 14:18:45.60 to 14:20:54.97, display (300:600,300:600,*)
```

```
Number of frames fibril 1 lasted, starting from beginning: 20 frames  
Translates to over 9 seconds
```

```
Number of frames fibril 2 lasted, starting from beginning: 18 frames  
Translates to about 9 seconds
```

```
Number of frames fibril 3 lasted, starting from frame 40: 23 frames  
Translates to about 10 seconds.
```

## Daily Log

Fibril 4 lasted over 45 frames, which is about 50 seconds.

Fibril 5 must have lasted about 62 seconds.

Fibril 6 lasted about 62 seconds.

display (600:800,600:800,\*)

Fibril 7 lasted over 9 seconds.

Fibril 8 lasted over a minute.

getindex, 'trmh',r,red          display (300:600,300:600,\*)

Fibril 1 lasted for about 19 frames, about a minute

Fibril 2 lasted for about a minute as well.

Fibril 3 lasted for about half a minute

Fibril 4 lasted for about 20 seconds

Fibril 5 lasted for about 20-30 seconds

Fibril 6 lasted for about a minute

Fibril 7 lasted for about 20 seconds

Fibril 8 lasted for about 10 seconds

Conclusion of the day: Not sure what this all means, need to ask Phil!!

-Tuesday

Going to delay worrying about the work done on Monday as we decided to finish the H-Alpha and Ca II comparison. Used align\_map to align the Ca images to the H-Alpha images and subtracted the background photosphere. The program is called Ca\_vs\_Halpha.

Ran the program with bated breath. Annnddd: No more flux tube evidence than that which we saw earlier!! Out of 20 or so samples, there is literally one solid example of the black-and-white gradient we should extensively observe! Only one example indicating faster motion with one part of the flux tube and slower motion in the other part which is proposed in the flux tube standing wave model- accelerated tubes of plasma!

## Daily Log

Interesting results. We decided to plan for the future. Perhaps we will write a modeling program that will represent the curtain-plasma-sheets that we are hoping to observe and compare it to what we are seeing in the data.

Or we might continue with what we are doing (scrutinizing the data) and try to find some evidence proving/disproving the sheet model.

-Wednesday

The Solar Physics Division of the American Astronomical Society is going to be holding its conferences at MSU this year! So we are all working on midterm posters and presentations because as solar physics REU students, we are going to get to be represented!

Worked on the poster all day; the link is posted online.

Nothing much to report, just solidified the results we have so far.

### RESULTS WE HAVE SO FAR

-----There are more spicules observed in the red wing than the blue wing of H-Alpha. This might mean that the stuff is moving more in one direction than another.

-----There has only been one observed flux tube in our Ca, H-Alpha image comparisons. We should have seen a much higher number of these as predicted by the flux tube model: there should be a whole ton of accelerated flux tubes!

### THEORETICAL DISCUSSIONS

-----Standing waves require a set of shocks to generate at either end of the flux tube and propagation region. A lot of maybes.

-----There appears to be not a steep enough pressure gradient at the transition region to ensure reflection.

-----Flux tubes like these appear to require theoretical acrobatics to generate?

-----Parker's theory of tangential discontinuities resulting in sheet structures of plasma at those TDs and where flux tubes get weird could be applied here.

-----We are not denying the existence of flux tubes- they do work to explain Type I Spicules. The idea here is that the Type II's might be caused by something else- rather than standing waves of plasma.

-----Why should it be necessary to stretch one theory to fit everything, especially when its problems are apparent.

## Daily Log

-----Maybe we need to move on to something new to properly explain what we are seeing. Motion exceeding Alfvén speed allowed in this region of chromosphere is a result of the standing waves of plasma theory and we are just not really seeing that. Maybe the motion can be better explained as apparent motion- an optical manifestation of rotating and moving sheets of plasma.

-Thursday

4th of July. We went hiking up a mountain near Fairy Lake with the chemistry students and went to watch fireworks with Adeleine.

-Friday

Finished the poster! We are going to have an e-poster as well that will showcase the videos of the H-Alpha and Ca II timeseries along with a few movies that Kevin and Phil made. Write\_gif writes images played in a looped sequence to a gif so I used it to make a few gifs of the Ca II and H-Alpha timeseries.

-Saturday

Left to go camping. Drove to Tally Lake near Glacier National Park with the chemistry students and a few physics students. Went to a cool pizza place with 'sawdust and peanut shells on the floor' in Kalispell. Set up the tents and all and went swimming. Made hot dogs and S'mores and told ghost stories in the tent.

-Sunday

Rode up the Sun Road in Glacier and hiked up to see waterfalls and a cool mountain. Went swimming again.

**Week 6: July 8th-14th.**

-Monday

Left to go back home. Hung out with some more chemistry students! Very tired from camping.

-Tuesday

Put up the still poster and went to several talks at the SPD conference. Had a poster session in the afternoon and many people were interested in the work Phil and I are doing. Everyone loves a good controversy!

-Wednesday

## Daily Log

Finished the e-poster, went to more talks. Phil is upset at many people for manipulating the data to fit their theories! Had another poster session.

-Thursday

Went to a few more talks, displayed the e-poster. Many people were interested in the movies and asked us about what we are trying to do. Explained the issues at hand and the data we have/are working with.

-Friday

Phil sent me a program that will model a curtain moving in the wind. A curtain modeling program works by designing a curtain as a series of oscillators in a big row that move with different frequencies and different offsets. The combination (kind of like a Fourier series) of different oscillators will result in the wave-y curtain-y effect that we want to see.

Parents came, went downtown, got some sun!

-Saturday

Went white-water rafting. Was really cool!! Category 2-3.

-Sunday

Went to Yellowstone with the parents. Saw sulfurous pools and bison, elk! Saw Old Faithful erupt, was very cool!

**Week 7: July 15th-21st.**

-Monday

Kevin Reardon, who produced and reduced the data, was here and able to discuss with us what we have done so far and future proceedings.

In short:

-The Ca II, H-Alpha project we worked on demonstrates an argument against the flux tube model as we did not observe masses of the predicted flux tubes!

-The results from the red and blue wavelength scans we worked with (where we found that there were little to zero cases where the red and blue spicules were aligned and in the same place), could have a lot of meanings. This is summarized in the paper I have written documenting our results so far that will be integrated into the larger paper we are working on. Basically:

**This observation has multiple implications. One possibility 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**

## Daily Log

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  $\pm 1.1$  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.

-Future plans are to publish a paper detailing our findings. This is important to complete before IRIS gets some data going as Phil predicts that will result in a torrent of papers!

-We are still working on the tubes vs sheets problem, but we can still publish a paper even if we do not actively disprove the one or the other! The chromosphere is a very much confusing and mysterious place and we want to get out any information we can regarding its exact nature! As Phil says: 'You don't have to be insane to study the chromosphere, but it helps.'

-We might work on studying the velocities of these fibrils by looking at the wavelength scans and studying the wavelength profiles of these bad boys. We can see if they are shifted to the right or left (redshifted or blueshifted) and by how much. Therefore, we can determine how fast these are moving and whether the standing wave idea is thus possible. If they are moving too fast and we are not seeing otherwise evidence for this very fast motion, there is going to be a problem!

-We might need to make use of the wavelength scans even if their quality isn't too great.

-We also might need to use some extra data from Kevin different from the time series. It might be a good idea to look at movies of the region in different wavelengths spanning from the main line!

Went out to dinner with Phil and Kevin. Phil is currently working on a computer modeling program to model curtains and hopefully we will be able to apply it to the data and compare the program to what we are seeing. We could get a qualitative answer regarding whether the super-fast phenomena could be an optical manifestation of sheets frolicking!

Here is a brief manifesto of the sheet idea:

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.

Here is a brief summary I wrote earlier of the Tubes vs Sheets debate:

## 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

A few notes from Kevin:

Discussions with Phil and Isabel - 15 July 2013

Talked with Isabel about analysis of data:

We need to understand possible sources of extra absorption in H-alpha and Ca II 8542 wings.

- thermal broadening: would imply symmetric features in both wings; but Isabel finds very different occurrence rates for the red and blue wings. Nearly simultaneous red and blue wing images ( $\Delta t = 1$  second) show non-coincident structures.
- Doppler shifts: would explain wing differences, but would naively imply similar absorption features at a greater wavelength offset in the Ca II 8542 line than in H-alpha. This does not appear to be the case. Could explain red/blue asymmetry through a supposed magnetic field configuration.
- time-varying path lengths through an over-dense "curtain" : might explain "Doppler discrepancy" between H-alpha and Ca II line wavelengths where these structures appear. Not sure why this would produce the observed differences between the red and blue wings. Also, we need to think of mechanisms that could cause the "curtains" to have a higher density than surrounding plasma.
- density/opacity enhancement : but little to no propagation is seen.
- line formation/atomic level population : hydrogen might be more sensitive to high temperatures to populate the atomic levels.
- some evil combination of the above!

Thing to look at:

-----

- 1) relative location of **footpoints** of blue and red fibrils: our interpretation might depend on whether these two are nearly co-spatial or not.
- 2) distribution of line widths in and around the wing fibrils: are fibrils embedded in regions of broadened profiles? Are we seeing the fast, narrow fibrils as a perturbation on already broadened profiles? Can we get a rough calibration of the required bulk velocities needed to produce the observed intensity drop using the actual, local line profiles?
- 3) line asymmetries: lack of correspondence between red and blue wings indicates some level of asymmetry, but what is overall distribution?
- 4) wavelength dependence of fibril appearance. Could difference in red and blue wing structures be due to a (strong) wavelength dependence of fibril characteristics? Can we find two wavelengths in the wings where the structures are statistically similar? This is perhaps related to the asymmetry measure above. We may not have a fine enough sampling in wavelength to fully resolve this question.
- 5) What are the possible line-of-sight inclination angles, lengths, and velocities of fibrils that would be consistent with the red and blue wing fibril characteristics if we assume their appearance is due to Doppler shifts?



## Daily Log

6) Co-align AIA images (304, 171) to get an idea of the overlying structures. Can we get any idea of these sheets continuation into the corona?

### Tasks:

#### Kevin:

- will produce co-aligned maps of line widths and asymmetries (addressing #2 and #3);
- will make co-aligned AIA filtergram (#6);

#### Isabel:

- #1 and #4?

-Tuesday and Wednesday

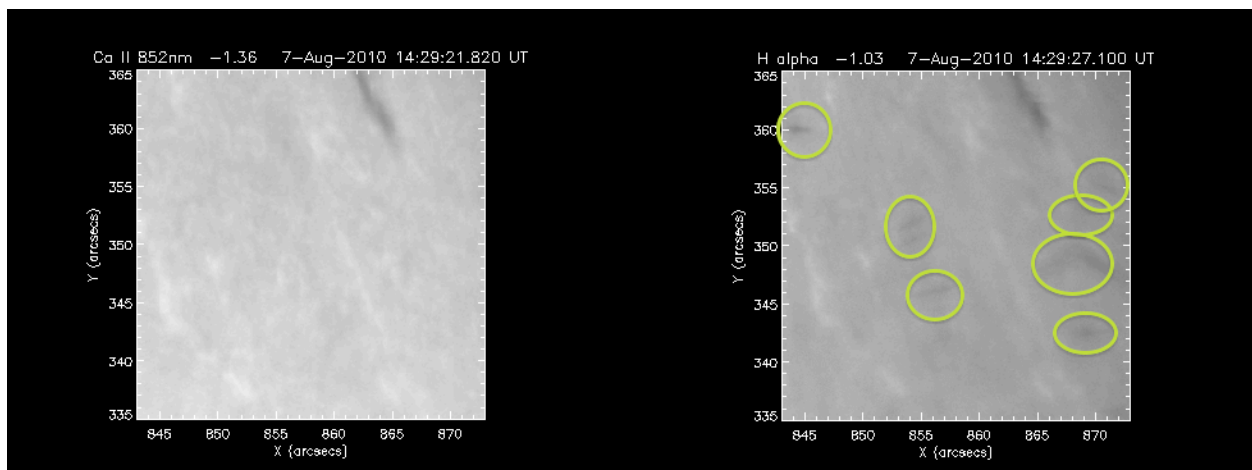
Worked on studying something that Kevin mentioned we might want to look into. What we investigated and the results are written below:

*We observe a strong amount of spicules appearing in images taken at +/- .11 nanometers shifted from the H-Alpha main line (656.28 nm). This translates to the spicules having velocities with magnitude of about 50 km/s. If we wanted to observe the same spicules in Ca II light, taking into account their velocity, we would have to look at wavelength shifts of about +/- .143 nm from the main line of 854.2 nm.*

*I wrote a program to compare H-Alpha images taken at -.103 nanometers (in the blue wing) to Ca II images taken a -.136 nm (also in the blue wing). In order to ensure that both sets of images would be very close in time and working within the constraints of the wavelength scan data we had, I had to select such wavelengths which vary from the desired .11 and .143 wavelengths. Fortunately, it works out that .103 nm for H-Alpha and .136 for Ca II both correspond to approximately the same velocity of 47 km/s!*

*Each set of H-Alpha and Ca II images were taken within 7 seconds of each other and were co-aligned. Even though the quality of these images isn't great (they were not reduced using either Speckle or MFBD), one can easily see that the super-fast phenomena observed in the H-Alpha images is not observed in the corresponding Ca II images.*

*Below is one example out of 10 observed where there are spicules in a H-Alpha image (circled in green) but not in a Ca II image: (Ca II is to the left, H-Alpha is to the right)*



## Daily Log

*Theoretical models of the Sun of course predict that, if an object is moving at a certain speed, it should absorb all possible Doppler shifted wavelengths. With these models, there is no valid reason for why we are not seeing the same spicules in Ca II as we are seeing in H-Alpha.*

*In reality, there might be a plausible explanation for what we are seeing. The ability for an atom to absorb incoming photons relates to the conditions of the plasma it is in as well as the properties of the atom itself. Atoms with electrons at the H-Alpha transition versus atoms with electrons at the Ca II transition H-Alpha have a better ability to absorb their respective photons. There is in general a higher population of hydrogen atoms than there are calcium atoms as well and due to this and the general nature of the H-Alpha transition (as well as the fact that hydrogen atoms are lighter and perhaps much more sensitive to changes in thermal conditions), absorption of Balmer photons happens much more frequently than the absorption of Ca II transition photons. In short, plasma eligible for the Balmer transition is far more opaque to appropriate incoming photons than is plasma eligible for the Ca II transition.*

*The above explanation is not a sure thing, but is indeed one possibility in understanding what we are observing in the chromosphere with this data. This explanation is valid for consideration upon the fact that it should be expected that what we actually observe might deviate from theoretical assumptions that do not yet realize the vast complexity of the corona.*

### -Thursday

Phil sent me a program earlier to model curtain-like structures. Allowed it to run several times; made a few movies from the program.

I compared these videos to actual data of fibrils moving on the sun from a few of the time series. Qualitatively at least, they do look like they might be solar curtains!

Phil also sent me a program to model the wavelengths and redshifts from a place on an image. Going to investigate that some more and maybe determine the red and blue-shifts of different fibrils in order to find their velocities.

### -Friday

Had a lecture regarding our grad school options, etc. We are going to have to work hard (get good GRE scores, recommendation letters, etc). Phil and I discussed the continuation of our project. We need to finish the paper! Write up the results we have and finish up some more analysis. We need to write the images we want to .eps files so they can be used in the L<sup>a</sup>T<sub>E</sub>X code.

-I made several images of the Speckle and MFB<sup>2</sup>D comparisons to be used in our data section and an image of the one lone flux tube we discovered.

-We plan to include a section linking the chromosphere and its activity to the photosphere and corona. This will involve including images of the corona imposed upon the underlying chromosphere. Downloaded several images from VSO. Phil is working on putting them together, some color stuff as well.

-We hope to link flux tubes/ etc to coronal loops...

## Daily Log

-Reading through the paper, deciding what we need to include, etc.

-Saturday

Went to Museum of Rockies with parents, hung around. Went to dinner with Phil, Terri, and parents.

-Sunday

Went around town and biking. Went for pizza dinner with the guys.

**Week 8: July 22nd-28th.**

-Monday

Read some work by Rouppe van der Voort and another paper by De Wijn which discussed essentially how the high-speed phenomena we are seeing is certainly comparable to Type II Spicules. Have copied my analysis below:

Several ideas and models have been postulated to describe the nature of these high-speed phenomena in the chromosphere. Perhaps most popular is the model proposed by De Pontieu et al (2012) that describes these phenomena as standing waves of plasma within magnetic flux tubes. This is backed up by Sekse et al (2013) as well as Okamoto et al (2011), where the different components of this propagative motion are outlined.

Rouppe van der Voort et al (2009) decided that Rapid Blue Excursions were a phenomena comparable to the mysterious high-speed Type II Spicules we are studying. This study discusses how both phenomena exhibit properties of high-speed and accelerated plasma as a central link to the connection between the two. Far more blue-shifted phenomena were observed than red-shifted phenomena. These two observations are in contrast to what we have observed ourselves/ We found a much higher population per image of red-shifted phenomena than blue-shifted phenomena and we could certainly not make the conclusion that 'type II spicules only demonstrate upward flows'. We also did not observe such plasmatic accelerations, as seen earlier with the discussion of the subtraction of Ca II images from H-Alpha images.

Rouppe van der Voort et al also found that H-Alpha RBEs have higher Doppler velocities and widths than do Ca II RBEs, which corresponds to that observed with Type II spicules. This observation actually has been confirmed by us. Phenomena has been observed to absorb radiation from H-Alpha but not in Ca II with an appropriate corresponding Doppler wavelength shift. Rouppe van der Voort et al ascribe this to H-Alpha transition-enabled atoms having a far higher opacity to incoming radiation than Ca II transition-enabled atoms. This is a thought we had as well. In this sense, Type II spicules might share a similar property with RBEs, but we are not convinced that RBEs are a surefire model for Type II spicules as there are many aforementioned discrepancies.

On that note as well, we have observed many discrepancies regarding the flux-tube plasma standing wave model proposed by De Pontieu et al....

Discussed more future plans with Phil. Add the coronal/chromosphere section. We are also going to start an analysis section based on comparing the different types of fibrils.

## Daily Log

We are going to try and get an account of how many are tube-like, how many are sheet-like.

-Tuesday

Had a session with information regarding taking the GRE, etc.

Finished up an analysis paper regarding the second counting project described earlier. What I did was basically break the red and blue timeseries into 25 square sections and play those sections like movies: counting the total number of fibrils that appeared in each section and making note of those that really looked like snaking flux tubes and which ones looked like they could be an optical phenomenon.

In order to qualify as a snaking flux tube, the fibril must have had a transverse motion and have the appearance of plasma moving within it. In order to qualify as a curtain/sheet structure, the fibril must appear and disappear in relatively the same location and shimmer in a way- blink fast and come and go. With multiple of these, one might even think that they look like a rippled curtain being shaken out!

I ended up finding, on average, many more structures that qualified as sheets than those that qualified as flux tubes. When I showed my work to Phil, he noticed that many of those that I saw to be flux tubes were actually matter from the chromosphere raining down! So the flux tube number should actually be a bit lower than what I actually recorded.

We are now working on making gifs and mpeg movies that demonstrate what we see as curtains rippling in the wind. One effect of my counting project was to allow me to investigate the data more thoroughly and Phil and I were able to detect some solid examples of our sheet phenomenon idea. We were also able to find things that DID indeed resemble De Pontieu et al's flux tubes, but they were NOT AS COMMON as the sheet-like structures!!!!

We are using image2movie to make these movies. The ones that come out are rather bad quality- one can hardly see anything! I need to figure out how to put in a color scale or something. One cannot also make small sections of frames as movies, as far as I have found out...

The paper is coming along rather well. We are working on the corona, chromosphere comparison and studying the nature of the fibrils!

Went biking from midnight to 4 AM with the guys, saw the beautiful full moon! No grizzlies!

-Wednesday and Thursday

-Worked more on making movies- have completed two rather good ones which demonstrate the flux tube phenomena and the sheet phenomena respectfully

## Daily Log

-Movies can be made in small segments and I worked to adjust the color table so that the phenomena can be easily discerned.

```
getindex, 'tbmh', r, red
```

```
mapmov, arr, index=r
```

```
arr=arr[300:600,300:600,*]
```

```
image2movie, bytscl(arr, min=0.3, max=1.5),  
movie_name='sheet_example2_blu.mpg', movie_dir='.', table=1
```

This will produce a movie over that small area segment using the blue and white color table.

-Discussed more of the paper with Phil. He showed me the section where he is going to include some connections between the chromosphere and the corona/transition region.

-Paper is going to include: introduction to problem; discussion of issues at hand; previous results/ideas; new results and observations; connections; and implications.

-Friday

Went to Yellowstone camping! Rented very big truck, walked around the volcanoes.

-Saturday and Sunday

Hiked the 7 mile hike down a mountain and back up again! Saw the geysers/ pretty pools and went home again for bison!

**Week 9: July 29th-August 4th**

-Monday and Tuesday

Completed a few more tasks for the paper at hand!

-Analyzed the spectra of a red fibril in the wavelength scans and studied the occurrence of fibrils in the Ha, Ca wavelength scans. Quality is not great, but you can indeed make out a few of them.

-Put the earlier analysis of the occurrence of sheet-like structures vs tube structures done last week to good use. Made note of the percentages of tubes/sheets found out of the total number for the red and blue timeseries.

-Read through the paper, made a few more images that we needed to include!

## Daily Log

-Worked on the REU presentation for next week. Need to go over with Phil the rest of the stuff that needs to be put in.

-Wednesday and Thursday

Read the latest paper by Rouppe Van der Voort, Sekse, and De Pontieu discussing a new observation comparing these Type II Spicules to RREs and RBEs. I had several comments on this and I have reproduced the main argument below. The entire discussion I wrote is included in the links at the bottom of this whole log.

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here is where the response to the Sekse et al 2013 paper comes in

Demonstrating this is evident in a 2013 paper published by Sekse et al. where a third type of motion of the Type II Spicules is explored: torsional motion. Rouppe Van der Voort et al in 2009 explored the comparison of this high-speed phenomena to RBEs. Here, the RRE and RBE properties of the spicules are explored in depth and the torsional rotational properties of these spicules is described. This paper may be seen as a small example embodying our reservations regarding the flux tube model and its hold on the solar physics community. Our response to this paper has three components of its own.

It appears that the scientists working on this project began with the assumption that these Type II Spicules will have properties comparable to RBEs and RREs. A detection routine designed for finding RREs and RBEs was used to analyze the data. It is fine to make an assumption, but the theoretical rootings of said assumption were never discussed. As with the 2009 paper discussing RBE, Type II Spicule correspondence, the connections between the two phenomena were purely observational. Furthermore, it is understandable that one might find such a connection between two phenomena, especially if the whole game is rigged towards making such a connection!

### Red vs Blue

There was some broken symmetry described within this paper, namely that RRE components had a lower average Doppler width than RBEs and the number density of RREs compared to RBEs varies around certain regions of the Sun observed. The reason for this broken symmetry is explored by invoking different types of motion in the flux tube spicules over different areas of the Sun. We failed to understand, from the results of this paper, the exact equations and physics that results in this motion. Results were certainly descriptive and comprehensive. However, it did seem at times that some 'explaining away' was occurring as the theoretical groundings for these very complicated motions and the equations of magnetohydrodynamics that might produce them were never explored! The flux tube model implies a certain randomness from fibril to fibril. Sekse et al implied that there was a systematic difference between RRE comparable phenomena and RBE phenomena. We have similarly observed a red and blue wing discrepancy (red wing fibrils are more elongated than blue ones). Unfortunately, the question still remains of why such a red and blue discrepancy and, most importantly, does it reject or confirm the flux tube model. We gathered possible reasons for such a discrepancy in terms of complex motion, but we failed to see an analysis of the implications for this discrepancy in terms of disproving or proving the model. It appears that the flux tube model has been taken for granted and results are fit into the model! As far as we can see, the flux tube model implies randomness and an equal distribution of RBE-like phenomena and RRE-like phenomena. The possibly contrary implications were ignored all together in favor of 'making things fit'. Sekse et al mention that there must be more plasma

## Daily Log

upflows than downflows. The reasons for this (in terms of the model- why must this be so?) are not clearly presented.

Finally, what never was explored was why is it better to invoke more and more complicated motions to explain this phenomena? Again, going back to Occam's Razor, why is it better to introduce yet another component of motion and yet more limitations, considerations, qualifications to a model just to make it fit in with new observations. We failed to see, in this paper, the reason WHY the flux tube model is desirable (again, why not discuss its rootings in magnetohydrodynamics). We did not see any mention of why torsional motion HAD to be the reason for what we are seeing and why apparent motion could be completely ruled out. Why is it better to add multiple components of motion to a phenomenon where it could quite simply be explored as an optical manifestation and apparent motion!

What we are afraid is happening regarding the flux tube model is that it has been accepted with minimal reservations despite the fact that we have not seen very strong mention of its theoretical groundings. We are afraid that new observations and data are being fit into the model, where what should be happening is the model being revised in light of new observations and data. We are afraid that our sheet model is being rejected out of convenience despite its validity in magnetohydrodynamics. We want open scientific dialogue and to further discovery and that cannot happen provided that other scientists are not open to discussing alternative possibilities. We want answers to the questions we have ourselves posed, and, perhaps most importantly, models and claims to be rooted in theoretical solar physics. Otherwise, science deviates from the scientific method and simply becomes description.

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Made several more movies, which will be included in the links. Worked on the final presentation; added images, movies, and some textual analysis.

Discussed conclusions of this project and we have decided to add in a few analyses of fibrils found in the wavelength scans. We have opened up several more questions: why the difference in Red and Blue, why did we not observe any of those flux tubes, can sheets and flux tubes coexist?

Maybe some of the fibril analysis will help us answer these questions?

-Friday

Worked on the program to map the spectra of fibrils in the wavelength scans. Made a few more movies and sorted everything that should be included in the paper. Finished some more images for the paper; made them better.

Phil and I discussed 'good science'- following the scientific method, keeping things rooted in theoretical bases, drawing conclusions based upon the data (not shaping results to fit a model!), and not ignoring contradictory evidence!

Research science gets frustrating, confusing, and requires someone dedicated to practicing good science. I think that this is what I want to do with my life.

-Saturday

## Daily Log

Went to town with Filip and Adeleine, saw a parade for the Sweet Pea Festival

-Sunday

Adeleine and I holed up all day at the Rockford Coffee and finished our final presentations and synthesis.

**Week 9: August 5th-August 10th**

-Monday and Tuesday

Prepared for final presentation (and presented it). Phil and all seemed to get a lot out of it and thought it was rather good. Success!

-Wednesday and Thursday and Friday

Watched other's presentations, finished up the paper we are writing based upon our results, and packed up to leave MSU :(

-Saturday

Moved out and caught flight back home. Can't believe our time here is up, but it was certainly a wonderful summer. I learned a lot (physics and otherwise), and I am very glad I came! Paper has been submitted for revision, hopefully it will be published!

### **CONCLUSIONS FOR RESEARCH PROJECT**

*To get a good sense of our conclusions, please read the latest draft of the research paper we wrote along with my cumulative mini-reports and summaries. Here, however, is the results of what we found in brief.*

*What are the nature of Type II Spicules?*

*DATA: Taken over a period of 20 minutes in 2010 by the Dunn Solar Telescope at the National Solar Observatory. Around 875 individual frames: some of which are red-wing (+1.1 angstrom above Ha) and some of which are blue-wing (-1.1 angstrom below Ha) timeseries. Some are wavelength scans of varying wavelengths in Ha, Ca II from -1.7 angstroms below to +1.7 angstroms above. 1s cadence and very high resolution. This is the limb of the Sun, other Type II Spicule studies are usually done more at the Sun's belly (disk center)*

*-There is definitely a difference between red-shifted and blue-shifted fibrils taken at this certain region of the sun moving relative to our line of sight.*

*-Redshifted fibrils appear more often and are never really overlap with blue fibrils (red ones are higher and more elongated).*



## Daily Log

-It is possible that, due to pressure differences and changes at that region and due to the rotation of the Sun, red-shifted fibrils will be favored and will appear more often and be bigger. The rotation of the Sun means that instead of -1.1, +1.1 blue, red, we actually see absorption at -1.3, +.98 blue, red about the H-Alpha line. We know that redder wavelengths are less easily scattered (why the sky is blue, sunsets are red!). We are thus seeing higher in the Sun's atmosphere with the red fibrils as the radiation comes from the interior and it is possible that the higher fibrils are longer? One possible idea. Their general appearance/motion is favored by pressure balances in the chromosphere and the general rotation of the Sun. **HORIZONTAL MOTION IS FAVORED!!**

-By observing the mapped spectral intensities of the wavelength scans, we found that any fibril has absorption peaks at +/- 1.1 (what should be, at least, with solar rotation being taken into account) H-Alpha light. This indicates some thermal/Doppler broadening, stuff is moving in the fibrils to broaden it in general. There is also a lack of symmetry in the mapped spectral intensities: some are darker towards the blue, while some are darker towards the red. This lack of symmetry suggests a general direction of motion for the 'stuff'- red-shifted or blue-shifted. This matches up with what we observed!

-We did not observe the gradients of black and white indicating accelerated flux tubes when we subtracted Ca from H-Alpha images (different velocities for each sort of image). We found one maybe example (it may turn out to show two separated flux tubes, not one continuous one!). One or none, this is a big strike against the flux tube of accelerated plasma theory if we didn't observe a main implication!

-When we looked at one image in H-Alpha corresponding to a certain red-shift, we saw fibrils. When we calculated the corresponding Ca II redshifted wavelength for the same velocity, we did not see any fibrils! This taught us more about the chromosphere: the matter in it is such that H-Alpha is more easily absorbed than is Ca II radiation (mean free path, all that good stuff).

-There might be a connection between what we are seeing in the chromosphere and matter/magnetic field lines in the chromosphere. Phil plotted a coronal image over a few of our chromospheric images and the coronal 'stuff' seems to hover over our fibrils and match it rather well! This might be a future interesting point worth exploring.

-Plasma sheets might help explain the coronal heating problem/ transfer of energy between chromosphere, transition region, and corona. You wouldn't cook your dinner using a very hot pinhead. Maybe a sheet of hot plasma could explain how heat is transferred from chromosphere to corona/TR/ etc!? Maybe it is getting from the corona TO the chromosphere, rather than shuttled UP by waves (Alfvénic, otherwise?) from chromosphere to corona?

-Phil had the idea that **STUFF IS MOVING FROM CORONA TO CHROMOSPHERE** (energy, etc) rather than the other way around. Corona/chromosphere correlation makes it appear that way, how the 'stuff' is connected.

-**POSSIBLY:** Idea of cyclones might supersede plasma sheet idea (red and blue fibrils are close, possibly rotational motion), but red>blue- not balanced. For actual cyclone, we should see symmetry. Not sure about this, but no symmetry so maybe no?

## WE THINK WE MIGHT HAVE DISPROVED THE FLUX TUBE PICTURE

*-In general, the idea of plasmatic standing waves implies that there must be nodes and thus variations of velocities along the supposed plasmatic flux tube (velocity=0 at the nodes, maximum at the humps). We should thus see a gradient of grays when we observe it in varying absorption wavelengths due to the different velocities. But we don't, as Phil put it, 'they look like uniformly dark logs!!'.*

*-Few/none of the proposed accelerated flux tubes were observed, as I mentioned earlier!*

*-Scientists have to add more and more complexities of motion to the flux tube picture- to the point where we seem to be getting 'epicycle upon epicycle!' (torsional motion, linear plasma shooting up or down, swaying motion!)*

*-Megameters of material light up within a few seconds- in order for this to occur, stuff would have to be traveling faster than the Alfvén speed for waves measured in this region of the chromosphere (super-Alfvénic).*

## IN SUMMARY, THE SHEET PICTURE

*-Like your grandma's lace curtains blowing in the wind: sometimes they look transparent and other times, they bunch up to look opaque.*

*-A potential Occam's Razor for this difficult motion and scenario.*

*-Plasma sheets result due to tangential discontinuities coming from the weak solutions to equations of magnetohydrodynamics- need to take those into account.*

*-Parker postulated these could occur since the 1970s- maybe this is the prophecy being fulfilled!*

*-Possible alternative explanation/contributor for the heat transfer in the solar atmosphere.*

*-Maybe flux tubes can explain some of these Type II Spicules, but for others, sheets might fit the bill better.*

*-Flux tubes picture getting rather full of complications, qualifications, consternations with the advent of new data. Occam's Razor, please!?!*

*-Maybe we can disprove (have disproved this summer?) the flux tube picture, but it might be hard to 'prove' sheet picture. Maybe need magnetic field measurements/ magnetic flux measurements? At least, we haven't disproved sheets!*

*-Made some good movies of what we believe to be possible examples of both pictures/ models (coexistence?!?).*

*-Our picture is fair and based upon good science. We deserve to have our ideas respected and taken into account, not dismissed!*

## FUTURE PLANS

*-Work on paper, edit, finish good version, send to Kevin for more edits, revise, send to Astrophysical Journal.*

*-Work with data some more, get more out of it?*

*-New measurements, different region, or magnetic field/flux measurements?*

*-Continue to try and disprove either picture.*

## Daily Log

- Continue to challenge flux tube picture.
- Continue to advocate for our sheet model to be respected/considered.
- Continue to practice GOOD SCIENCE!!!!!!!!!!

### WHAT I LEARNED THIS SUMMER

#### ABOUT LIFE

- Biking uphill is really hard!
- Frozen yogurt is a wonderful and magical thing.
- Biking downhill is wonderful!
- I love to climb mountains and jump in lakes :)
- Glacier National Park is a special, excellent place.
- Camping is really fun, just stay warm!
- Country music is great.
- Swing dancing is hard but incredibly fun.
- I met some excellent people here who were wonderful friends and extremely supportive.
- The West is awesome, definitely worth returning to (Grad School?!)

#### ABOUT SOLAR PHYSICS

- The Chromosphere is complicated....
- Read the log/attached files for more, I can't type it all here!

#### ABOUT PRACTICING GOOD SCIENCE

- Follow the Scientific Method
- Try to disprove, rather than prove
- Don't mold your results to fit the model you might have in mind- review everything with an open mind and be critical
- Never ignore contradictions or paradoxes- they might lead to deeper discoveries!
- Don't force things to fit (or add epicycle upon epicycle!)
- Listen/acknowledge others and foster useful, respectful scientific dialogue
- Be dedicated, keep things in the name of science!
- Give credit to others who make suggestions/give you extra help
- Critique your own papers/work, be your own worst critic
- Don't just churn out papers- make sure you have something to say

*I have to give credit to Dr. Philip Judge for teaching me this. Thanks to him, I have learned so much about being a good scientist and I am very well prepared to put this into practice.*

#### ABOUT MYSELF

- I love the outdoors/ exploring nature.

## Daily Log

- I love learning and in turn, teaching others*
- I love people and maintaining good friendships*
- I love the mountains and Montana (perhaps the West in general)*
- I love research and, more than perhaps ever before, I want to go into physics. I want to go to physics grad school and get my doctorate. I am not sure yet if I want to go into academia or work at a research institution, but I definitely plan to go for a PhD and perhaps a few post-doc positions.*