Developing a Compact Doppler Magnetograph

Gerardo Hernandez

ElevatedSounds.gh@gmail.com
Los Angeles City College
Los Angeles, CA
&
Mentor: Dr. Neil Murphy
Jet Propulsion Laboratory - NASA
La Cañada Flintridge, CA

Abstract

This project's objective was to develop a Compact Doppler Magnetograph (CDM) in order to capture images of the Sun which contain data regarding magnetic field strength and surface oscillations taking place on the Sun's photosphere. Development of the CDM consisted of monitoring heliostat performance, modifying the optical layout, positioning a Wollaston Prism, aligning the instruments components, designing and 3D printing components, and measuring the magnetic field strength of the magneto optical filter.

Introduction

There's no doubt that due to its proximity and size, the Sun is the most abundant source of energy. Our current civilization uses the Sun to keep track of time, dry clothes, cook food, heat homes, and generate electricity to name a few. Although we use the Sun to a high degree, we lack a full understanding of the Sun's properties. Two major aspects to consider when understanding the Sun in greater detail are magnetic field strengths and oscillations taking place on the surface of the Sun. Measuring the magnetic field strength can assist in predicting hazardous solar weather by analyzing how the electrically charged gas on the Sun interacts with the magnetic forces. Measuring the speed of the oscillations taking place on the surface of the Sun can assist in producing 3D representations of the internal structure of the Sun, leading to an insight as to how our grand star was formed and how other similar stars were formed, thus resulting in acquiring more information on the origins of our universe. Even though the CDM is a remote sensing instrument, it can one day be turned into an in situ instrument which can be placed at several Lagrange points. If the CDM were placed at L3, we would have greater foresight by knowing what type of solar activity is taking place on the unviewable side of the Sun.

The Solar and Heliospheric Observatory has a 56.6kg instrument named the Michelson Doppler Imager (MDI) which was capturing magnetograms and dopplergrams but is now suspended from its services. The final goal in developing a CDM is to make a compact version of MDI having a mass of approximately 2.5kg and a volume of less than $(10cm)^3$ in order to fit inside of a CubeSat, thus making space flight and data collection achievable for a fraction of current costs.

How it Works

The Compact Doppler Magnetograph being developed in the magnetism laboratory in JPL is a remote sensing instrument which captures images that retain information in regards to the in line sight velocity and magnetic field of the Sun's photosphere. To visualize the process of capturing images with the CDM imagine a beam of light being ejected from the Sun's photosphere traveling through empty space at approximately $3x10^8$ m/s, when suddenly the beam of light encounters Earth's atmosphere and in an instant hits the heliostat located on the hill side of La Cañada Flintridge, California, home to JPL. After the beam of light is reflected off of the mirrors on the heliostat, the beam is directed towards the cold mirror, a reflective surface which transmits infrared light and reflects visible light. After being reflected off of the cold mirror, the beam of light enters the polarization analyzer, the first section of the CDM as seen in Figure1. The polarization analyzer is composed of a ¼ wave plate and a ½ wave plate. This section of the instrument converts circularly polarized light into linearly polarized light. The polarization analyzer allows us to measure the in line sight magnetic field of the Sun's photosphere by taking an estimate of the net circular polarization in the wings of the 770nm potassium solar absorption line. After exiting the polarization analyzer, the beam of light enters the filter section. The filter section is composed of two cross calcite polarizers which surround cell1. Cell 1 is a potassium vapor cell surrounded by two magnets (magnet assembly) which induce a longitudinal magnetic field on the potassium vapor cell. The composition of the potassium vapor cell and the magnet assembly forms the first Magneto Optical Filter (MOF). The magnetic field induced by the magnets allows for the Zeeman splitting of the absorption lines within the potassium vapor. The light that enters cell 1 is linearly polarized and has its plane of polarization rotated due to the magneto optical effects, therefore permitting the light to exit the second polarizer at P2. At P2, two transmission bands are created on each side of the 770nm potassium solar absorption line. Light then enters cell 2 inside the wing selector which is the second MOF. The main difference between cell 1 and cell 2 is that cell 2 is surrounded by magnets which are nearly twice as large as cell 1's magnets. The reason the magnet assembly surrounding cell 2 is larger is because a greater magnetic field strength is required to produce absorption lines that coincide with the transmission pass bands in cell 1. The 2 pass bands become circularly polarized in opposing directions due to the longitudinal orientation of the magnetic field in cell 2 which only allows circularly polarized light to be absorbed. The circularly polarized light that passes through the ¼ wave plate becomes linearly polarized so that the pass bands are orthogonal to each other. The light then goes through the Wollaston prism which splits the light into 2 beams that are then imaged on the CCD camera. (Barajas, Karen Garcia, and Duy Vo, Neil Murphy)

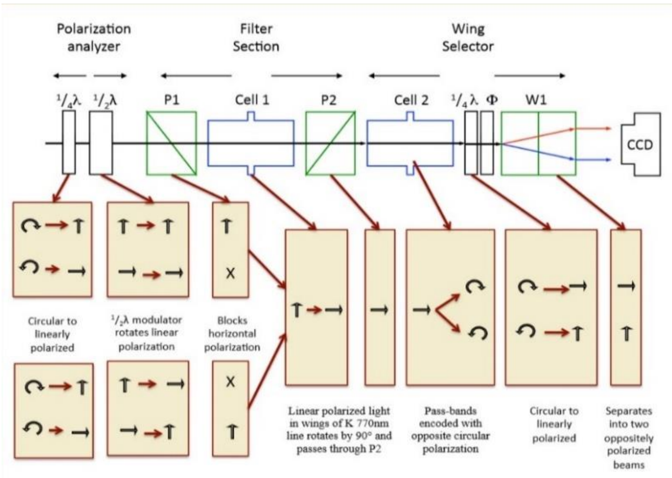

Figure 1. Barajas, Karen Garcia, and Duy Vo.

Schematic diagram of the CDM 201

Background/Development

In order to eliminate condensation from occurring on the windows of the potassium vapor cells, heaters were affixed on the body and reservoir of the cells (as seen in Figure 2). By having the reservoir heater 10 degrees lower than the body heater, we were able to prevent the potassium vapor from condensing on the windows of the cell, thus eliminating distorted images from being collected.

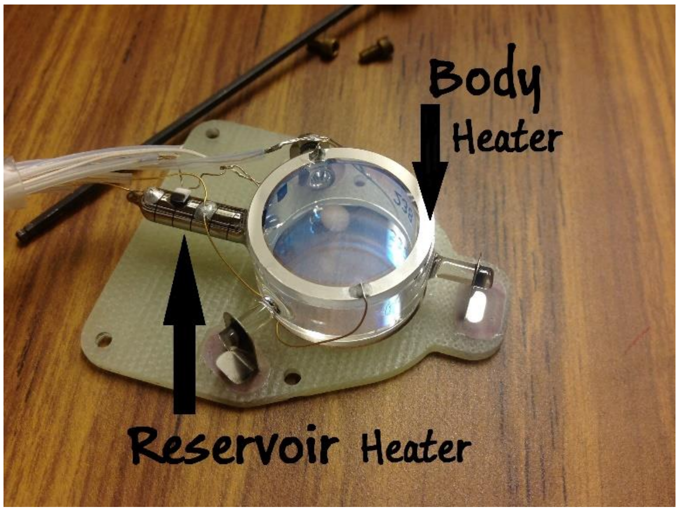

Figure 2. Potassium vapor cell with Body and Reservoir heaters (silver lining) turned off.

Previous work also consisted of designing and 3D printing rail mounts to situate both MOF's within the vacuum chamber. The previous design did not permit all the necessary components to be placed within the vacuum chamber since the main concern was to measure the power consumption of only one MOF.

In order to fit all of the necessary components inside the vacuum chamber, a new design had to be implemented. The most recent 3D printed rail mount design allows for the mounting of two polarizers, two MOF's, 1 dichroic filter, and one lens as seen in Figure 3. The design includes a combined wing selector magnet holder and rail mount holder, an extended optical rail mount, and more gussets for added support, thus shrinking the design by 7 inches. All the 3D printed components were printed using poly lactic acid at 100% infill to eliminate warping as temperatures increased within the MOF's.

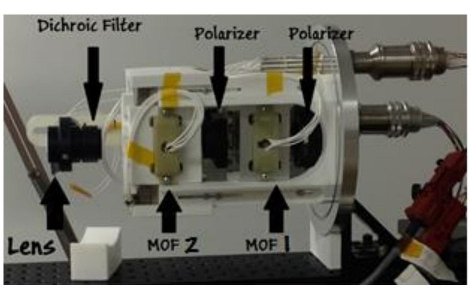

Figure 3. Vacuum Chamber Inner Components

Because the original components that held the camera in place were too bulky and did not allow for the correct placement of the ccd camera, we designed and 3D printed a camera holder which had less limitations in regards to placement. The camera holder was then mounted on a translation stage which now allows us to make fine placement adjustments along the optical axis, resulting in better focused images.

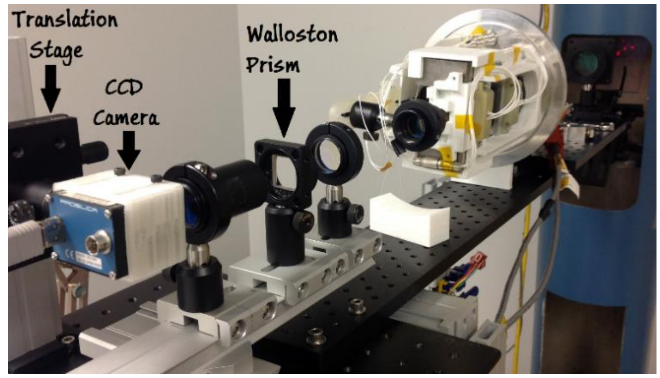

Figure 4. Full Optical Layout of instrument

One major component to developing a CDM is to understand the abnormal performances the Heliostat may undergo. These abnormalities can be caused by clouds, haze, trees, or by mechanical failures. Taking note of the abnormalities will allow us to account for the discrepancies found while processing images. As mentioned earlier, the cold mirror transmits infrared light. This infrared light travels through the cold mirror and is reflected through 3 stationary mirrors and into a quad diode. The quad diode is composed of 4 light dependent resistors (LDR's). If one LDR is receiving more light that the other 3 LDR's, the rotating mirror will adjust itself such that all 4 LDR's are receiving the same amount of light intensity. Slight adjustments were made to the 3 stationary mirrors placed after the cold mirror which resulted in improved tracking performance. Even though the heliostat tracked the Sun for many months before obtaining our images, the heliostat began to malfunction and so the heliostat was left operating in a semi-automatic fashion.

As mentioned earlier, another key component to the CDM is the Walloston prism. The Wollaston prism is a polarizing beam splitter, which is composed of 2 right triangle calcite prisms with different indices of refraction and each having an Optical axis perpendicular to each other. This composition of prisms results in the beam of light entering the Walloston prism as having both right and left circular polarization light to exit as vertically polarized and horizontally polarized light, a characteristic which is needed when measuring doppler shifts. In order to have the final images appear on the ccd camera at a specified distance apart, the Walloston prism had to be rotated by 7.6 degrees horizontally away from the optical path. Due to the thickness of pencil lines and caliper precision, we concluded that there's a 100^{th} of a degree error was possible.

Due to spatial constraints within the vacuum chamber, the optical layout had to be redesigned. With the use of WinLens3D, we were able to model the layout by specifying the refractive indices we were working with. Because the Walloston prism was not available within the program, a Wallston prism was created by joining two wedged prism at a 45 degree angle, where the first glass along the optical path being of type PFK80 and the second being of type FBDC55-40 in order to correspond with the proper indices of refraction. Unfortunately, WinLens3D was not able to model the Walloston prism as we had hoped and so Dr. Neil Murphy carried out the optical design by using Zemax (a more advanced optical design program), thus being able to meet our spatial constraints.

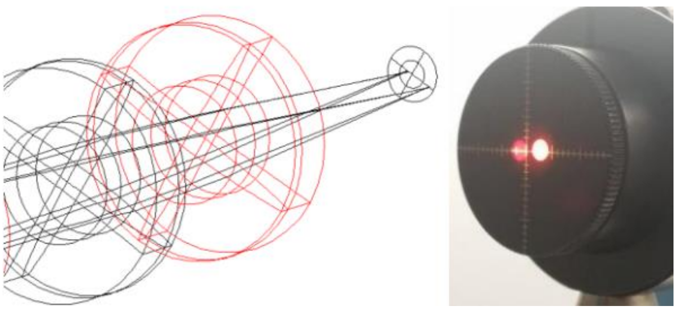

Figure 5. Image of the Sun modeled on WinLens3D (left); real image (right)

Aligning the instrument involved placing a laser such that the laser's beam was parallel to the optical bench. Fine adjustments were made to each components so that the laser traveled through the center of each component. Having the laser travel through the center of each component increased the elimination of a distorted image on the image plane.

The magnetic field strength was measured within each magnet assembly using a Gaussmeter. This data will allow Dr. Neil Murphy to optimize the LabView program used to make dopplergrams and magnetograms. The optimization will lead to better performance in regards to having the transmission absorption bands produced within the wing selector coincide with the transmission pass bands produced in the filter section.

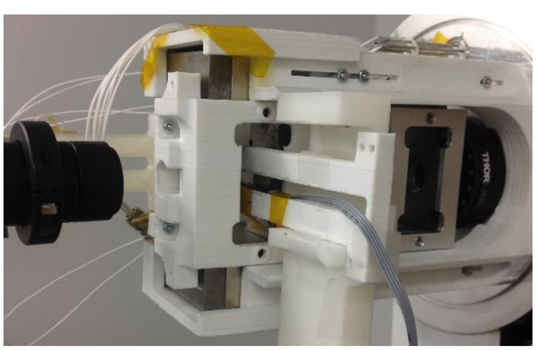

Figure 6 Measuring the magnetic field of the larger MOF using 3D printed components

Results

The filtergram shown in Figure 7 is the raw image taken by the instrument during the summer of 2015.

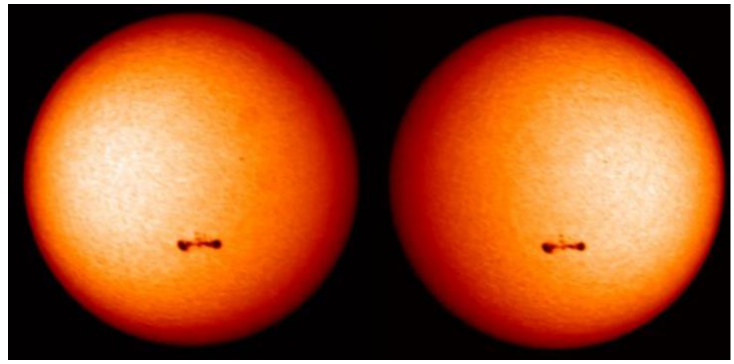

Figure 7 Filtergram

The dopplergram shown in Figure 8 is created by taking the intensity difference from the left and right filtergram images and then dividing the difference by the intensities sum.

$$V = \frac{I_A - I_B}{I_A + I_B}$$

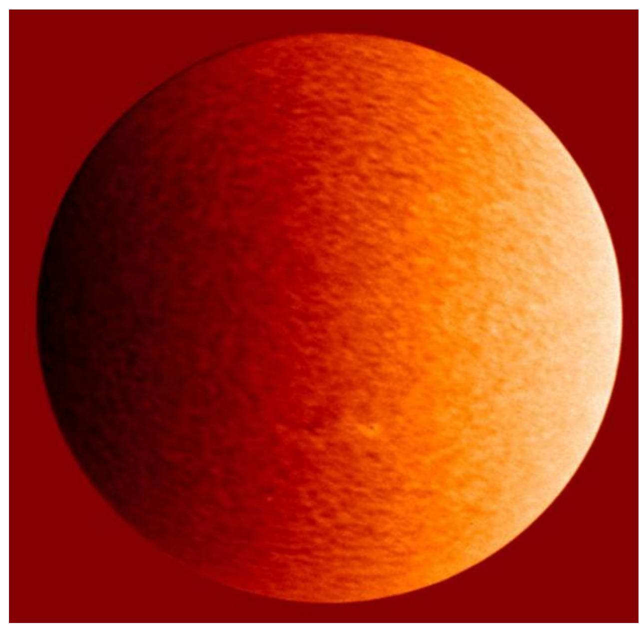

Figure 8 Dopplergram captured during the summer of 2015

By calculating the intensity in brightness, one can find out the magnitude of the velocity at any pixel seen on the Sun. The brighter side seen on the Sun indicates radial velocities towards the viewer and the darker side indicates radial velocities away from the viewer.

Future Work

Future work will consist of finding the ideal potassium vapor cell heater operation temperature, adjusting the reading range of the magnetic field, adding a heliostat window cover, correcting the heliostat's performance, adding a plate rotator to capture magnetograms, and miniaturizing the components in order to meet cube-sat spatial requirements.

Acknowledgements

I would like to thank Dean Arvidson from LACC for believing that I had skills to offer at the Jet Propulsion Laboratory and exposing me to see light from a whole new perspective. I would also like to thank Professor Zuniga from LACC for her support, advice, time, and motivation to continue my education. In addition, I would like to thank Professor Salazar and Professor VH Lee from LACC for being passionate educators which have influenced me to become an instructor. In addition, Dr. Jayesh Bhakta from LACC for dedicating so much of his time to teach me how to operate a CNC machine. Furthermore, I would like to thank Marshall Fong, the lab technician which dedicated so much of his time to sharing his wisdom. A big THANK YOU goes out to Professor McCudden from LACC for planning out some of the most memorable field trips I've experienced, being the most professional Professor I've experienced, and being a great role model. Moreover, I would like to thank Dr. Neil Murphy for taking the time to guide me through the process of developing a CDM and being such a delightful human being to be around. I'd like to also thank the National Science Foundation for supporting the Consortium for Undergraduate Research Experience (CURE) program. A loud high five goes out to my cointern, Luis Diaz, for being a great friend and problem solver. And finally I would like to thank my mother for all of her love & support.

References

Barajas, Tzitlaly, Karen Garcia, and Duy Vo. "Searching for Sunquakes in Solar Cycle 24". 2011