SEARCHING FOR SIGNATURES OF SOLAR FLARES

Duy Vo, Karen Garcia, Tzitlaly Barajas
California State University, Los Angeles

and

Neil Murphy
Jet Propulsion Laboratory, California Institute of Technology

ABSTRACT

Solar flares are extremely energetic outbursts from the sun that are seen as bright flashes in the extreme ultraviolet, x-ray and gamma ray. They are often associated with coronal mass ejections (CMEs). Both phenomena originate in magnetically active regions in the sun′s atmosphere, and can have significant effects on the Earth and orbiting spacecraft. The photosphere underlies the less opaque chromosphere and corona, where CMEs and flares are formed. There are reports of signatures in the photosphere associated with flares. These are seen as circular wave fronts expanding from the flare site. The purpose of our study is to make high sensitivity measurements to identify and study these signatures. To do this we are using a Doppler/magnetograph imager, which makes images of the velocity and magnetic fields in the photosphere. The instrument views the sun using a heliostat, which uses a rotating mirror to track the sun during the day. The project has involved modifying the tracking system of the heliostat to make it more stable, developing control and data acquisition software to select and track sub-images around active regions, and collecting the resulting data. Although the data remains to be analyzed to determine whether these signatures are indeed visible, the system is now stable and functions as intended. The next step is to analyze the data.

INTRODUCTION

The purpose of our research is to make high sensitivity measurements to identify and study signatures of solar flares. These signatures are illustrated in Figure 1 below. In order to make the measurements we have to take very precise data very quickly. To this end, we fine tune both the Doppler/magnetograph imager, which makes images of the velocity and magnetic fields in the photosphere, and the data acquisition software to allow greater precision and speed. The project also involved modifying the tracking system of the heliostat for stability, developing control and data acquisition software to select and track sub-images around active regions, and eventually analyzing the resulting data.

INSTRUMENTATION

To collect data we use three different instruments that work together: The heliostat, the Compact Doppler Magnetograph (CDM), and the quad diode.

The Heliostat

The heliostat is located on the roof of building 253 at the Jet Propulsion Laboratory. It has a primary mirror that is used to reflect the image of the sun onto a second mirror. The second

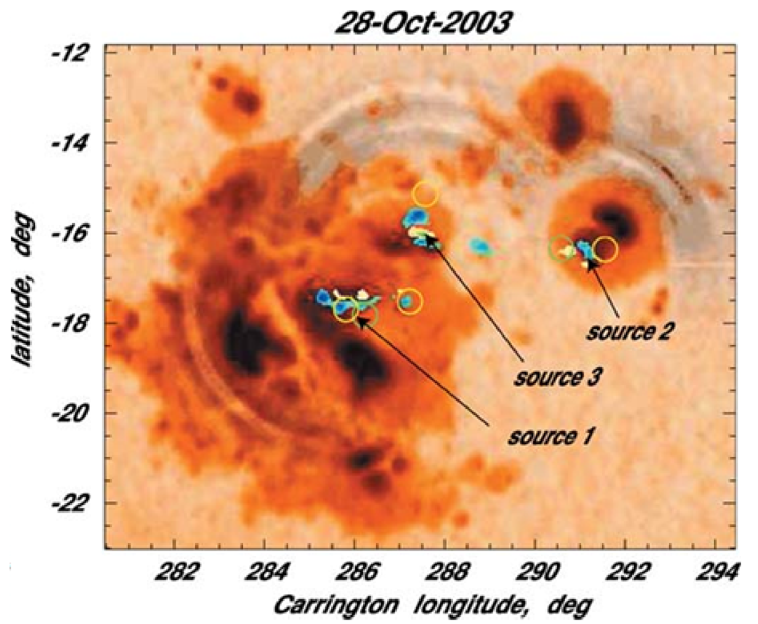

Figure 1: A white-light image of active region NOAA 10696 observed on October 28, 2003, and superimposed images of the Doppler signal at the impulsive phase, 11:06 UT (*blue* and *yellow spots* show up and down photospheric motions with variations in the MDI signal stronger than 1 km s^{-1}), positions of three wave fronts at 11:37 UT, and also locations of the hard X-ray (50 – 100 keV) sources (*yellow circles*) at 11:06 UT and 2.2 MeV γ-ray sources (*green circles*).

mirror reflects the image of the sun down a tube onto a third mirror that reflects the image onto a beam splitter. The beam splitter sends the light in two directions that are perpendicular to each other. In one direction the light is sent into the CDM and in the other direction the light is sent onto the quad diode.

The Quad Diode

The quad diode is a tracking device that is made up of four quadrants calibrated to have the same sensitivity. These diodes center and stabilize the image of the sun and track the sun throughout the day. Each diode measures the amount of light hitting it with respect to the other diodes. As the sun changes position in the sky, the image of the sun moves on the quad diode. To center the image of the sun on the diode and therefore the CDM, the tracking system shifts the moved image onto a point where equal amount of light hits each diode. To do this, the motors of the tracking system that are attached to the heliostat adjust the position of the primary mirror in Right Ascension and Declination. This makes it possible to track the sun throughout the day.

The Compact Doppler/Magnetograph

The Compact Doppler Magnetograph, illustrated in Figure 2, is the instrument is used to measure the line of sight velocity and magnetic fields of the sun. The light that is sent onto the CDM will go through the CDM's three different components before we get polarized images of the sun. It will first go through the polarization analyzer, then through the filter section, and finally through the wing selector.

The polarization analyzer consists of a quarter wave plate and of a half wave plate. Light that is incident on the quarter wave plate is randomly polarized. Our interest lies with the left and right circularly polarized light that hits the quarter wave plate. These two polarization

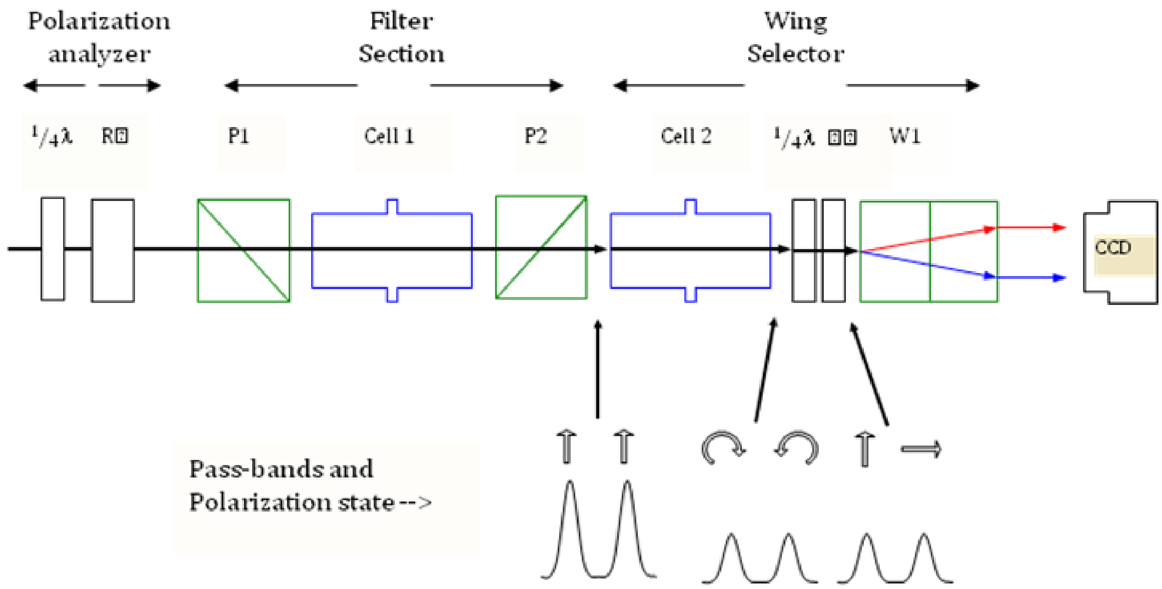

Figure 2: The Compact Doppler Magnetograph

states allow the CDM to be sensitive to the magnetic fields of the sun. The quarter wave plate is positioned so that it transforms the circularly polarized light into linearly polarized light.

The half wave plate changes the lights orientation. Its first position is at 0° with respect to its optic axis and its second position is at 45°. It oscillates back and forth between these two angles. The half wave plate rotates the polarization of the light that passes through it by 2 times the angle it is positioned at, so linearly polarized light coming into the half wave plate at 0° will be rotated by 0°. When this light makes its way to the crossed entrance polarizer of the filter section only the light that was initially right circularly polarized makes it through because the polarization direction of the crossed entrance polarizer has the same polarization direction of the rotated linearly polarized light. The polarization of the light that hits the wave plate at 45° is rotated 90°. When this light gets to the entrance polarizer the light that was initially left circularly polarized makes it through the polarizer. Thus as the half wave plate oscillates between 0° and 45° we are able to observe two polarization states that gives us sensitivity into the magnetic fields of the sun.

The filter section is a Magneto Optical Filter (MOF). It consists of three components: an entrance crossed calcite polarizer, a potassium vapor cell, and an exit crossed calcite polarizer. When two polarizers are placed 90° from each other, light is blocked and does not pass through them. However, when a potassium vapor cell is placed between two polarizers that is no longer the case.

A longitudinal magnetic field is imposed on the vapor cell by magnets placed around it. The interaction of the light and the magnetic field result in the Zeeman splitting of the absorption lines of the potassium vapor. Two transmission bands are then symmetrically spaced about the potassium resonance line, which is 770 nm. Furthermore, the polarization of these transmission bands is also rotated within the vapor cell. This allows the light that carries these two transmission bands to pass through the exit polarizer.

The wing selector is composed of a second potassium vapor cell, a quarter wave plate, a narrow band filter and a Wollaston prism. A

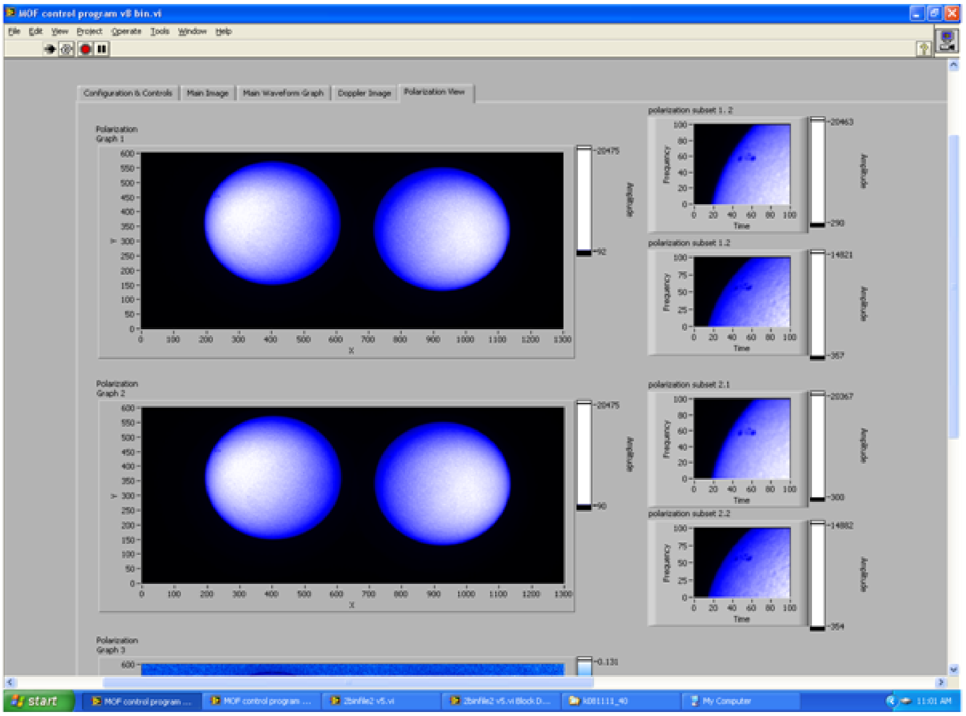

Figure 3: LabView VI, tracking the sun's active regions.

longitudinal magnetic field is also imposed on the second potassium vapor cell. The interaction of the light and the magnetic filed in second cell cause the light to be partially absorbed light via the inverse Zeeman effect. This causes the two transmission bands to become circularly polarized in opposing sense. This is followed by a second quarter wave plate, which switches the circularly polarized light back into linearly polarized light. The narrow band filter then rejects out of band light that leaks through.

This is followed by a Wollaston prism, which consists of two right triangle prisms that are placed together. Each of their optic axis is perpendicular to each other. When the polarized light hits the prism at the point where these two right triangle prisms meet, the light is split into beams that diverge from the prism. These two beams are imaged onto a CCD camera.

The program then takes these two subsequent images, the first containing two images of what was originally right circularly polarized light, the second left polarized light, and finds the difference between them divided by the sum. This gives a map of the line-of-sight velocities, called a Dopplergram. A map of the magnetic field strengths on the sun can similarly be found by taking the difference between successive Dopplergrams.

METHOD

This summer we were concerned with both improving the quality of the data we collected, and with increasing the frame rate of the system. In order to do this, we had to align the instrument, increase its stability, troubleshoot the tracking system, and create a new tracking program.

When we actually began taking the data, we realized that the suns image on the camera shifted when we focused the image. In order to make the instrument more physically stable, we added stabilizers to the back end of the CDM so that the camera would not change position. In addition to this, we noticed that the tracking system was not as stable as it should be: when the image would go off-center on the diode, instead of pushing the image back to center, the tracking system would push the image completely off the CDM. We tested each diode quadrants sensitivity using a laser and voltmeter and found that one of the quadrants was actually moving the motors in the wrong direction in Declination when light hit it. We also noticed that the tracking system was not as sensitive as it could be. By measuring the focal lengths of the lenses, and readjusting the distance to the quad diode to make the image incident on it much larger, the tracking system became much more sensitive to changes in position, and therefore made the position of the image on the camera much more stable.

In order to make the data acquisition software more efficient, we utilized LabVIEW to modify the way the existing program saves FITS files, and we allowed it to take longer integrations without over saturating. In addition to this, in order to save disk space, we created a new program that allows the system to track and save just the active regions of the sun. Since the primary mirror rotates the image of the sun throughout the day, this turned out to be a somewhat difficult task. A screenshot of the program in action can be seen in Figure 3. It allows the observer to input the centers of both images on the left, and the coordinates of the sunspot on the left, and then run the program. Since the tracking system is now stable, this program is able to successfully track the sunspots throughout the day.

RESULT

The data acquisition program that was written in LabView is still under construction. Its primary goal was to track and save to disk a region of interest on the image of the sun in hopes to increase data acquisition speed and save disk space. In its current state, the program is able to track a sub image of the sun, however adjustments to the code must be made so that the program is able to save those sub images to disk.

Furthermore, at this juncture in our project, reducing data is still in progress. After rearranging the optics of our tracking system and repairing the malfunctioning quadrant of the quad diode, emphasis was placed on data acquisition. Solar observations were made, and continue to be made, on a daily basis. 20-25GB worth of solar data were gathered each observing run. The collected data will be reduced using IDL. From this data reduction we expect to see signatures of solar flares on the photosphere.

CONCLUSION

Several weeks were spent on preparing the Compact Doppler Magnetograph and the tracking system for observations. The optics of the tracking system were given a different setup to increase the stability of the image of the sun. A malfunctioning quadrant on the quad diode was repaired so that the tracking system would function properly. Once the CDM and tracking sys- tem were set to collect data, observations were made. The CDM uses right and left circularly polarized light to measure the line of sight velocity and magnetic fields of the sun. These two polarization states of light allow the instrument to have sensitivity to the magnetic fields of the sun. The CDM makes it possible to collected data that once reduced, will give us insight into the signatures of solar flares in the photosphere.

In the future, the focus of this project will be directed towards data reduction and adjusting data acquisition code. IDL will be used to reduce data and analyze that reduced data to and traces of the signatures of flares in the photosphere of the sun. Due to the fact that we gather vast amounts of data each observing session, it is essential to install a faster computer capable of collecting more data as well as to continue adjusting the data acquisition program so that it is able to save only sub images to disk.

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