Developing a Compact Doppler/Magnetograph for Solar Diagnostics

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Abstract:

Line-of-sight velocity and magnetic field measurements on the Sun's surface are used frequently in the field of Helioseismology. Instruments capable of making these measurements are often called Doppler/Magnetographs. Future NASA and ESA missions call for a Doppler/magnetograph as part of their instrument package. To meet the payload mass constraints of these missions a compact and low mass version of such an instrument is being researched at JPL that is a fraction of the mass of similar space borne Doppler/Magnetographs. The design verification model of this instrument has been built and will soon be ready to gather data for solar diagnostics.

Introduction:

To further our understanding of the Sun scientists cannot directly measure seismic activity as they do here on Earth. To get around this problem they take advantage of the luminous plasma. Light emitted from the Sun is Doppler shifted by the motion of granules (giant convection currents) in the various layers in the Sun. In the field of Helioseismology scientists observe pressure waves in these granules as they travel through the Sun's interior in order to understand the forces at work there. In addition to making Doppler measurements, magnetic field measurements are also made to help understand how magnetic forces influence the electrically charged gases. The SOHO spacecraft, currently in operation, has a Doppler/Magnetograph on board known as the Michelson Doppler Imager (MDI) as part of its instrument package. Researchers at JPL are investigating the possibility of building an instrument of similar performance capability to the SOHO MDI, but only one tenth of the mass.

Project goal:

The primary goal of this project is to develop an instrument capable of measuring line of sight velocity and magnetic fields in the solar chromosphere. This instrument, known as a Compact Doppler Magnetograph (CDM), operates at the 770nm absorption line, and will be a factor of ten lighter than current flight instruments. Since an instrument of this type has never been made this small before, a prototype must be built on an optical breadboard to test performance and verify the design.

Methods used:

Work began during the summer of 2009 in the magnetometer building at JPL. The first task was to build a relatively economical breadboard version of the instrument that will be used to perfect the design of the flight version. The first of the optical components to be installed on the breadboard were the lenses and mirrors. Since these are the only components that need to be aligned with precision, it was important to align them before other components were put in the way. To allow for reasonable image quality, the prototype needed each component to be mounted in its own individual mount that could be adjusted on several axes. This compounded the difficulty of the alignment process, which lasted several weeks. The breadboard was then mounted in front of a solar telescope in the magnetometer building at JPL. The beam from the solar telescope was used to center the optical axis of the instrument with the image of the sun.

To reduce the footprint of the instrument, the CDM uses two mirrors to bend the light path at right angles in two places. This reduces the length of the instrument by 17 inches, while keeping its width under 9 inches. In between these mirrors is where the main components of the instrument lie. To mount several of these components centered on the optical path an aluminum box was modified and used to house the magnet assembly, the two potassium cells, a linear polarizer, and a quarter wave plate. These components form the heart of the instrument and occupy less than 10 cm of optical path length. The box housing these components is then placed carefully between a lens, a Wollaston prism, and the two mirror mounts. The confined space in and around the box called for careful planning before mounts were permanently modified to fit in place.

Near the end of the summer, the breadboard was complete and ready for testing. Initial tests showed that the prototype did not function properly. Refinements had to be made in order to get Dopplergram and Magnetogram images that could be used in solar research. Work continued into the fall and winter semesters to solve the problems with the prototype.

The initial tests with the instrument showed low light intensity was reaching the CCD. This was attributed to a failure in the filter section and wing selector of the instrument. The CDM relies on a magneto-optical filter to select two very narrow, 100mA wide, pass-bands of light near the 770nm absorption line. Narrow pass-bands are needed to accurately image specific layers of the Sun. This is combined with a wing selector that splits the two Doppler shifted pass-bands into two separate images on the CCD. Both of these components consist of heated glass cells containing potassium. The cells were designed to function in vacuum where they vaporize potassium into a gas. If the cells are operated under atmospheric pressure they will lose too much heat to the surrounding air and fail to vaporize the potassium inside. Therefore, in order for the CDM to function properly the entire instrument box containing the filter section and wing selector had to be under vacuum.

The design and construction of a vacuum sealed environment for the instrument box was the focus for the fall and winter semesters. Tests performed on the sealed instrument box during winter showed that it was capable of holding a steady 250miliTorr vacuum.

For the first two weeks of spring, the CDM was seeing a steady increase in performance with each test. Then suddenly each day of testing resulted in a mysterious decrease in signal strength and sensitivity to velocity and magnetic fields.

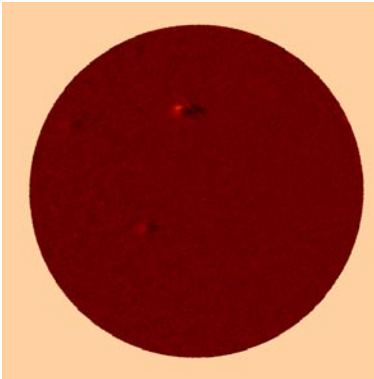


Figure 1

Figure 2

The Magnetogram produced by the CDM in Figure 1 shows a fuzzy image of the Suns disk with dark and bright contrasts representing different magnetic field intensity and polarity. The Magnetogram in Figure 2 is an image taken on the same day from the SOHO spacecraft. The SOHO image clearly reveals many magnetic regions on the Sun that are not visible with the CDM.

The poor performance of the CDM could partially be attributed to low amounts of potassium vapor in the cells, but this was puzzling since the tests were performed using the same temperature and procedures each day. There was also no leak in the cells that could allow gas to escape. The culprit for this strange behavior has not been precisely determined. However, progress has been made that appears to have solved the problem.

After dismantling the instrument box containing the filter section and wing selector it became apparent that the close proximity of one of the cell windows with the magnet assembly was creating a cold spot. This is obvious because the potassium vapor created during operation will condense on the coldest part of the cell after it is shut down. Since the cell window on the wing selector is covered in potassium, then it is obvious that the window on the wing selector is the coldest part of the cell. This helps explain the poor sensitivity to magnetic fields and velocity on the Sun. Condensation of potassium crystals on the end windows of the filter section may also be responsible for the strange behavior of the filter section.

The vacuum in the instrument box has been improved from 250 milliTorr to less than 50 milliTorr. This factor of five performance increase helped reduce the condensation problem.

The two potassium cells have a heat sink built in to them that is intentionally kept colder than the rest of the cell. This is known as the reservoir, and was created so that any condensing vapor will do so away from the windows. After modifying the experimental procedure to allow these regions to cool long before the heaters are shut off, the condensations on the windows has diminished. The lack of condensation on the windows has increased performance of the prototype.

Results:

All the modifications that have been made since the summer have led to improved data quality. The instrument is now performing at nearly one half of its predicted resolution in terms of velocity and magnetic field.

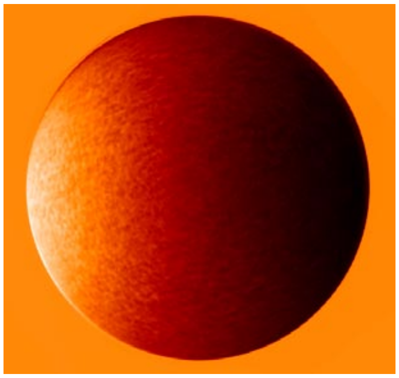


Figure 3

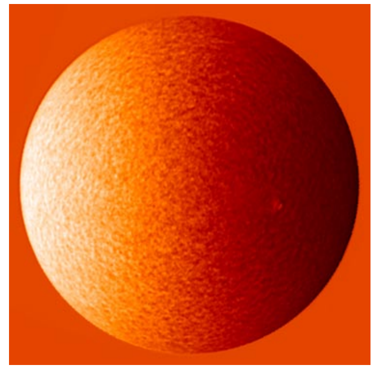


Figure 4

The Dopplergram produced by the CDM in Figure 3 is an image from one of the most recent test. The image in Figure 4 was taken at JPL by a similar instrument that operates on the same spectral line as the compact version. The difference in contrast on the images of the Sun correlates to different line-of-sight velocities of regions at that point. The images darken from left to right, which shows the rotation of the Sun.

The magnetic field sensitivity has improved drastically from recent tests. Before, only large active regions with very intense magnetic fields were visible. Now it is possible to see much more detail in the Magnetogram. This is because the temperature in the filter section and wing selector cells can both be adjusted independently to achieve higher efficiency.

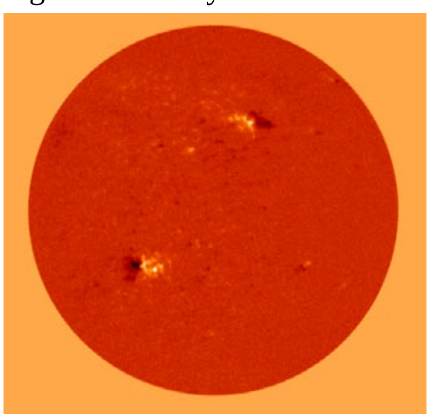


Figure 5

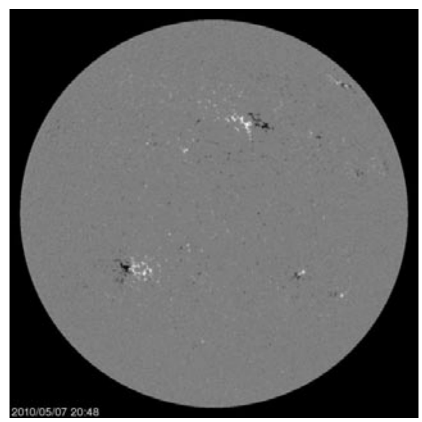
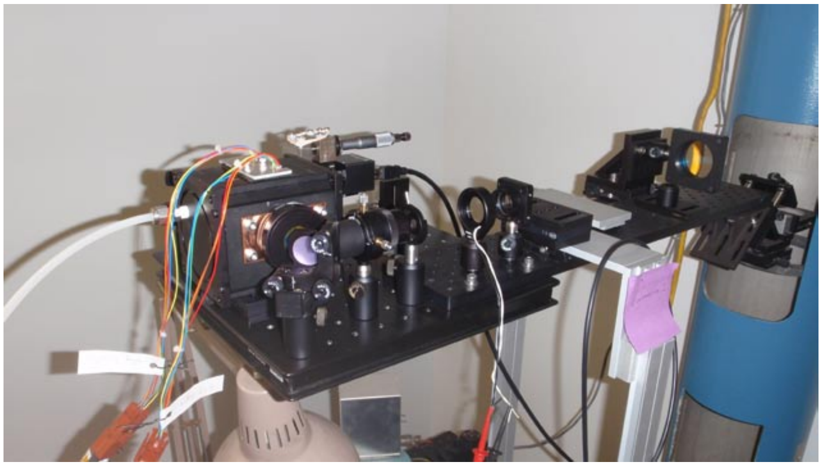


Figure 6

The Magnetogram in Figure 5 is one of the most recent produced by the CDM breadboard. To the right in Figure 6 is a Magnetogram produced by the SOHO MDI on the same day. The images are very similar in detail. It is hard to calculate the exact resolution of the CDM at this point, but it is estimated to be around 20 Gauss in one minute, which is equivalent to the 20 Gauss in one minute of the SOHO MDI (song). It is expected that the CDM could be improved to at least 10 Gauss in one minute in the near future.

Future plans:

With knowledge gained from recent experiments it is possible to improve performance of the breadboard instrument even further. There are currently some issues with the focusing of the instrument. The slightly blurred images are affecting data quality. These are minor problems, but will eventually need to be eliminated. Along with perfecting the focus, the temperatures of the cells during operation will be adjusted to find a sweet spot where we expect better performance. It is anticipated that the CDM will soon improve to match or exceed initial design expectations of 10 Gauss in one minute, and similar quality in the Dopplergram images.



Above is an image taken of the instrument mounted on the solar telescope in the magnetometer building at JPL. This is where research on the CDM will continue in the future.

Acknowledgement

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