Developing a Planetary Doppler Imager

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***Abstract*—Knowing how the giant planets in our solar system formed and evolved can provide us with knowledge of the formation and evolution of not just our solar system, but other solar systems as well. To achieve this, it is important to learn about their interior structure. By observing the Doppler shifts of the absorptions lines at the surface of the planet caused by pressure wave oscillations, we can infer the densities of the interiors. This can be done to some extent for Jupiter and Saturn using a ground based Doppler imager.**

I. Introduction

Studying our solar systems giant planets, Jupiter, Saturn, Neptune, and Uranus, can provide vital information into the creation and evolution of our solar system as well as extrasolar planetary systems. Giant planets capture a significant part of the mass of a planetary system, dominating the formation process. These are also typical of most of the exoplanets so far discovered due to size and methods of detection. Understanding the giant planet's internal structure and evolution can provide key insight into the early stages of planetary system formation and the conditions in which the planets were formed. Jupiter and Saturn, the gas giants, are composed primarily of hydrogen, making them similar in composition to our sun. Using similar techniques developed for helioseismology, we can probe the interiors of these planets by observing their resonant oscillations. These observations can be made by imaging the Doppler shifts at the surface of the planet cause by these oscillations. The planetary Doppler imager is a ground based instrument that utilizes magneto-optical filters and only allows light to pass in two narrow pass-bands.

II. Previous Attempts

Two attempts at a similar instrument have been made in the past with various changes in the design. The first attempt used a polarizing beamsplitter to split the incoming light into two polarizations. The reflected beam was passed through a magneto-optical filter and then through a wing selector (Fig. 1). The second attempt was similar in design with the exception of the wing selector which was removed.

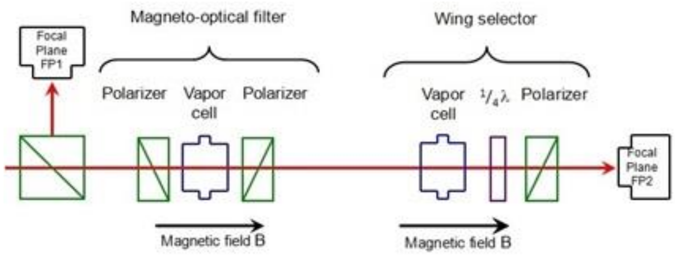

Figure 1: Previous Design Schematic

III. New Design

The new design for the planetary Doppler imager included a number of changes to increase the amount of light being captured. Originally the light passed through a beamsplitter and only the reflected light was used. In this new design, both the reflected beam and the non-reflected beam are used. This doubles the amount of light that is captured. The absence of a wing selector also increases the captured light (Fig. 2). The camera used in the new design is significantly better than the cameras used in previous attempts, again increasing the amount of light captured. This amounts to eight times more light than the first attempt.

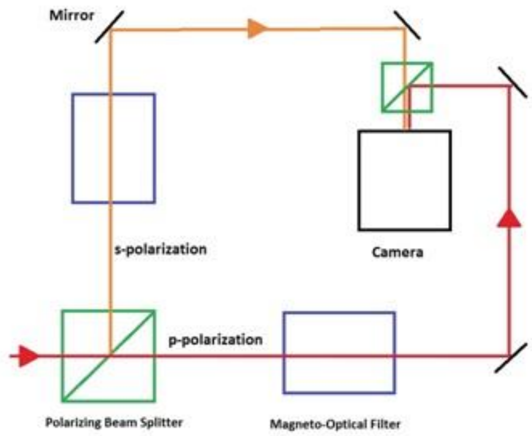

Figure 2: New Design Schematic

IV. How it Works

Seismic activity in Saturn's interior causes wave oscillations to propagate throughout the planet. These waves cause perturbations on the surface of the planet that can be detected by observing the Doppler shift in the absorption lines. This instrument takes a narrow passband of light (770nm), splits the beam into s- and p-polarizations, passes them through magneto-optical filters and a series of lenses and mirrors, and then focuses both beams side by side on a CCD camera to produce a Doppler image.

V. CAD & Optics Design

Designing the Doppler imager was an iterative process. The optics design needed to be worked out first. This produced a model with exact measurements between optical components for maximum image quality. Using this model, the mechanical design could be worked out. With computer-aided design software, the instrument could be built and analyzed using CAD models of hardware components made available by Thorlabs Inc. The instrument needed to be built with a square base to reduce the size of the footprint, but large enough to fit both arms of the optical design. Because the instrument used both beams of light, it was imperative that both optical paths be exactly the same length with exactly the same distance between components. Before both beams entered the camera, each beam had to be offset just enough to fit both images onto the CCD. As a result, the optics design and the mechanical design had to be adjusted many times before and during construction of the instrument.

Initially the goal was to fit all of the components for the instrument onto a twelve inch by twelve inch optical breadboard. This would make the instrument easy to transport but more importantly able to fit neatly on the mounting plate of the telescope. The optical components needed to have the smallest footprints possible to allow everything to fit on the desired board size. Lots of time and creativity went into selecting ideal components. In more than one place, pieces were used for purposes they were not intended for (Fig. 3). A mechanical design had to be created to fit the optics design. The first mechanical design did not fit the optics design because of the available hardware. The optics design then had to be reworked around the available hardware. This process of reworking each design to fit the other went on for several iterations.

Figure 3:
a) A 2" mount for flat optics and filters. b) The flat optic mount adjusted to fit a 2" beamsplitter cube. c) The beamsplitter cube mount with attached translation lens mount, iris, fixed lens mount, and polarizer mount.

The last part of the design involved creating a way to mount the instrument to the base plate of the Shane Telescope at the Lick Observatory. A schematic of the plate was provided by the Observatory. The final design required a larger board and had the instrument mounted at 90 degrees on the telescope base plate (Fig. 4).

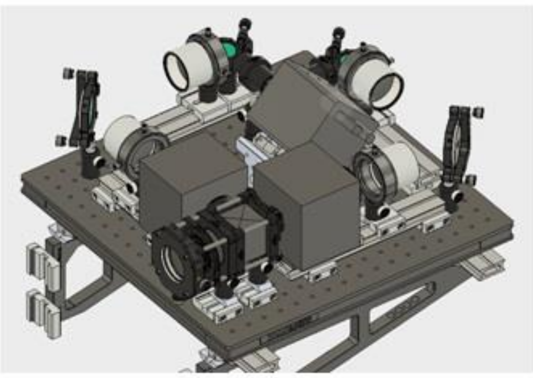

Figure 4a: Final CAD Design

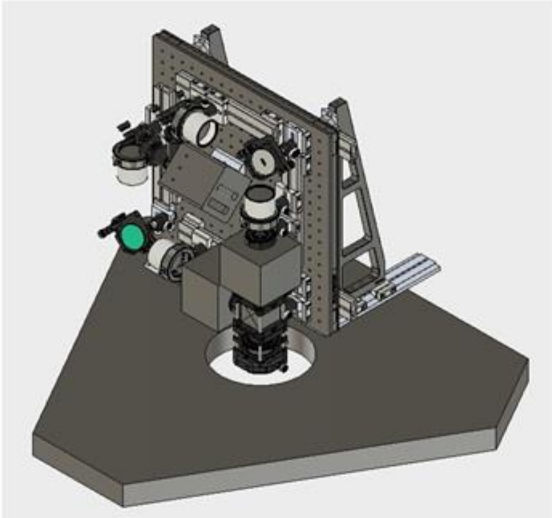

Figure 4b: Mounted at 90 degrees to Telescope Mounting Plate

VI. Assembly and Alignment

Once a design that satisfied both the optics and hardware was found, physical assembly began. The instrument had to be precision aligned because both beams of light had to be perfectly focused. This meant that both arms of light and components had to be identical. A low powered laser was used for the initial alignment. Once the components were in place, the camera was added. The position of the camera and the final beamsplitter was adjusted to fit the images side by side.

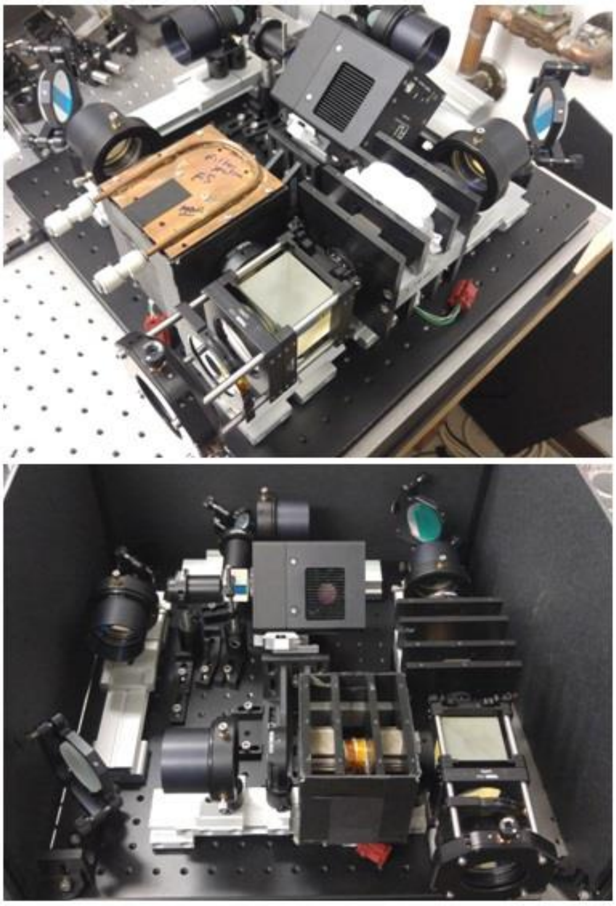

Figure 5: a) Doppler Imager without enclosure and back mount. B) Doppler Imager with enclosure.

VII. Future Plans

The ground based Doppler imager is a prototype, a proof of concept. In late August, the instrument will be taken up to the Shane 3 meter telescope at the Lick Observatory and used to image Saturn. It will be taken up again in March to image Jupiter. If results are promising, proposals can be made for flight based instruments to collect more accurate data. A flight version of this Doppler imager would allow us to image Jupiter and Saturn as well as Uranus and Neptune, which are too far away to image from the ground.

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