National Aeronautics and Space Administration

A filter based Planetary Doppler Imager

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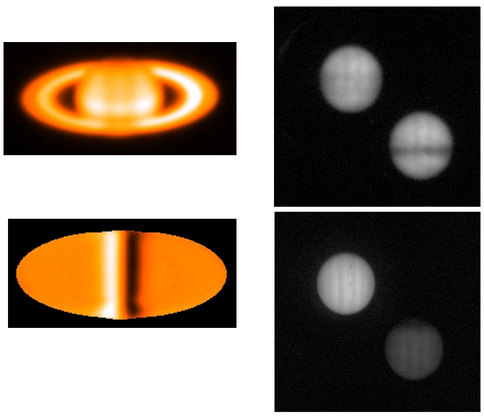
Program: Topical



Close to opposition

Far from opposition

Figure 1 upper left,: an image of Saturn taken by a Planetary Doppler Imager, lower left the resulting Doppler velocity image, showing the spatial extent of velocity sensitivity. Right: two data frames (top image in each frame is a 3nm continuum image, and the lower is a simultaneous MOF image – their ratio is a Doppler velocity image). The upper frame shows the case where data are collected on Earth close to Jupiter opposition, the lower at an Earth-Jupiter line of sight velocity of ≈ 20 km/s (≈ 3 months after opposition), where the velocity sensitive region (the dark band) is barely on Jupiter's disk.

Project Objective: An advanced multi-channel Planetary Doppler Imager (PDI), based on a magneto-optical filter (MOF), will address significant constraints in current instrument designs, increasing both dynamic range (by > x5) and signal to noise ratio (> x5). The Planetary Doppler imager works by estimating the line of sight Doppler shift in sunlight reflected from planetary tropospheres, the proposed development will enable our Planetary Doppler imager to have multiple selectable passbands over visible and near-IR spectrum, allowing multiple spectral lines to be viewed, increasing throughput and allowing tuning to account Doppler shifts induced by spacecraft motion.
In order to increase the spectral range, and signal to noise, our objective is to substantially expand the range of available wavelengths beyond the currently limited set, by using molecular, rather than atomic spectral lines. This would produce a comb of passbands, potentially covering a significant part of the visible and near IR spectrum.

Benefits to NASA and JPL:

This development of an advanced, multi-channel Planetary Doppler Imager (PDI), will directly benefit JPL's Solar System Exploration program, increasing the capability (and sale-ability) of a Doppler Imager that could be flown on at least two Decadal Survey recommended missions - The Saturn Probe and Uranus Orbiter, and which would provide significant advances beyond the important discoveries made by the Cassini and Juno missions.

A recent NASA science definition team report, in preparation for the next Decadal Survey, (Ice Giants Pre-Decadal Study Final Report, 2017) states: "The most important instruments on the orbiter (Uranus or Neptune) would be an atmospheric seismology instrument such as a Doppler Imager (providing novel measurements of interior structure) …". The report recommended the inclusion of a Doppler Imager in every Ice Giants mission's core payload (together with a magnetometer and narrow field of view imager).

FY18/19 Results: To facilitate a search through potential molecular spectral line and absorption lines on the sun, we developed a model of the PDI response that allows multiple filter passbands ands multiple solar absorption lines. The model provides a figure of merit for PDI performance, based on the mean velocity sensitivity across Jupiter's disk. The figure below compares two examples, using the same MOF passbands, but one or two solar lines. The model output has four panels: top left is the reflected solar spectrum from Jupiter, top right is the MOF passband structure, bottom left is a cross-section of the expected Jupiter line-of-sight PDI image, compared to a limb-darkened brightness profile,

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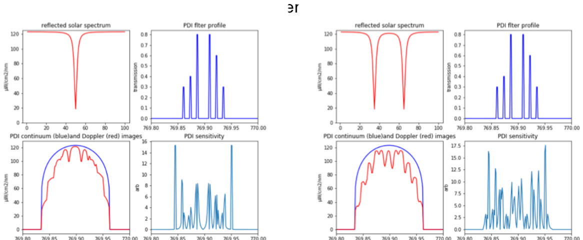
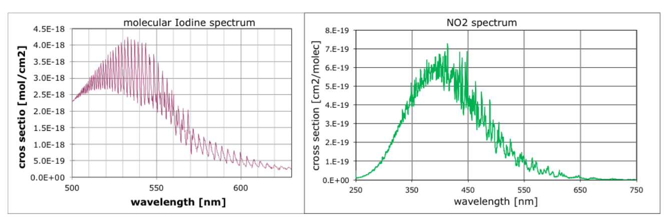


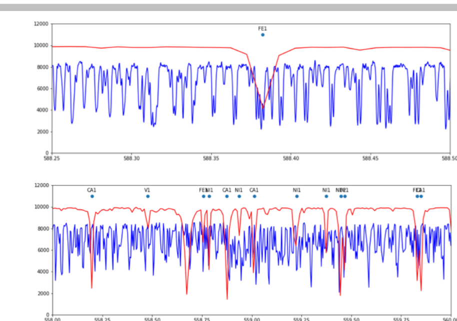
Using the model we can estimate the value of various pass-band wavelengths and configurations, for particular wavelength ranges in the solar spectrum.

Our initial choice of molecular candidates was led by molecular Iodine (I_2) as it has a rich spectrum in the visible, and a very well characterized spectrum. Its one disadvantage is that it is a polar molecule, and so Zeeman splitting is small. After surveying many molecular spectra, a more promising candidate was found – nitrogen dioxide (NO_2) – compared with Iodine below. NO_2 s a non-polar molecule, with a rich UV/visible spectrum and good potential for Zeeman splitting, but it is not well characterized.



The initial comparisons between the NO_2 and solar spectra show several promising options, where multiple solar and lines are present in the same wavelength range, and have comparable line separations (which maximizes the PDI velocity contrast, and hence the mean sensitivity). Two examples are shown to the right of two promising spectral regions – the upper panel shows a single solar line, due to Fe absorption, with an overlay of the NO_2 spectrum showing multiple potential passbands. The lower panel shows a more complex solar region, with multiple lines from several elements. Again, there is a rich band of NO_2 lines suitable for MOF passbands.

In addition to modeling, we have developed a prototype molecular PDI to test the sensitivity of a NO_2 MOF. Given the complexity of its spectrum determining the optical activity of target NO_2 lines will be done empirically using this prototype. Initial tests will image the sun and moon. if successful the PDI deployed to a larger observatory to image Jupiter and Saturn



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