National Aeronautics and Space Administration

FY24 R&TD Innovative Spontaneous Concepts (ISC)

Multi-spectral Doppler Imaging

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Strategic Focus Area: Innovative Spontaneous Concepts

Our objective was to develop a planetary Doppler imager (DI) capable of at least order-of-magnitude improvement in sensitivity compared to current Doppler imagers (Shaw et. al., 2022). This would enable measurement the amplitudes of trapped pressure waves (p-modes) of 1 cm/s for Jupiter (current estimates for Jupiter p-mode amplitudes are ≈10cm/s), and may allow ground-based telescopes to observe p-modes on Uranus. A time series of Doppler images that captures p-modes can be used as a seismic probe the interiors of the giant planets.

Our current DI, Figure (1) uses magneto-optical filters (MOFs) to produce very narrow (≈40mÅ) passbands that are stable, have high background rejection (> 10^5), and a wide field off view. MOFs use Faraday rotation and circular dichroism in a vapor of the target element to produce pass-bands in the wings of corresponding solar absorption lines. An example is shown in Figure (2), which shows results from a of K 770nm MOF transmission model, compared to the solar K absorption line at 770nm. The MOF passbands straddle the solar line and the ratio of their intensities is a sensitive measure of Doppler shift.

To provide a significant increase in Doppler sensitivity (>10x), we will expand the number lines available to the magneto-optical filters.

Currently, MOFs use glass vapor cells containing an element with a desired spectral line, which is vaporized thermally. This restricts the choice of operating element to those easily vaporized (We use the Na and K to access lines at 589nm and 770nm, other lines used include Ca 422 nm and He 1083 nm (Murphy et al 2005).

Producing an MOF that generates the vapor through ion sputtering rather than vaporizing the target elements using a heater, will provide a dramatic increase in the available spectral lines for the MOF (for example Fe has 100s of lines that are potentially useful), which will enable the increased sensitivity.

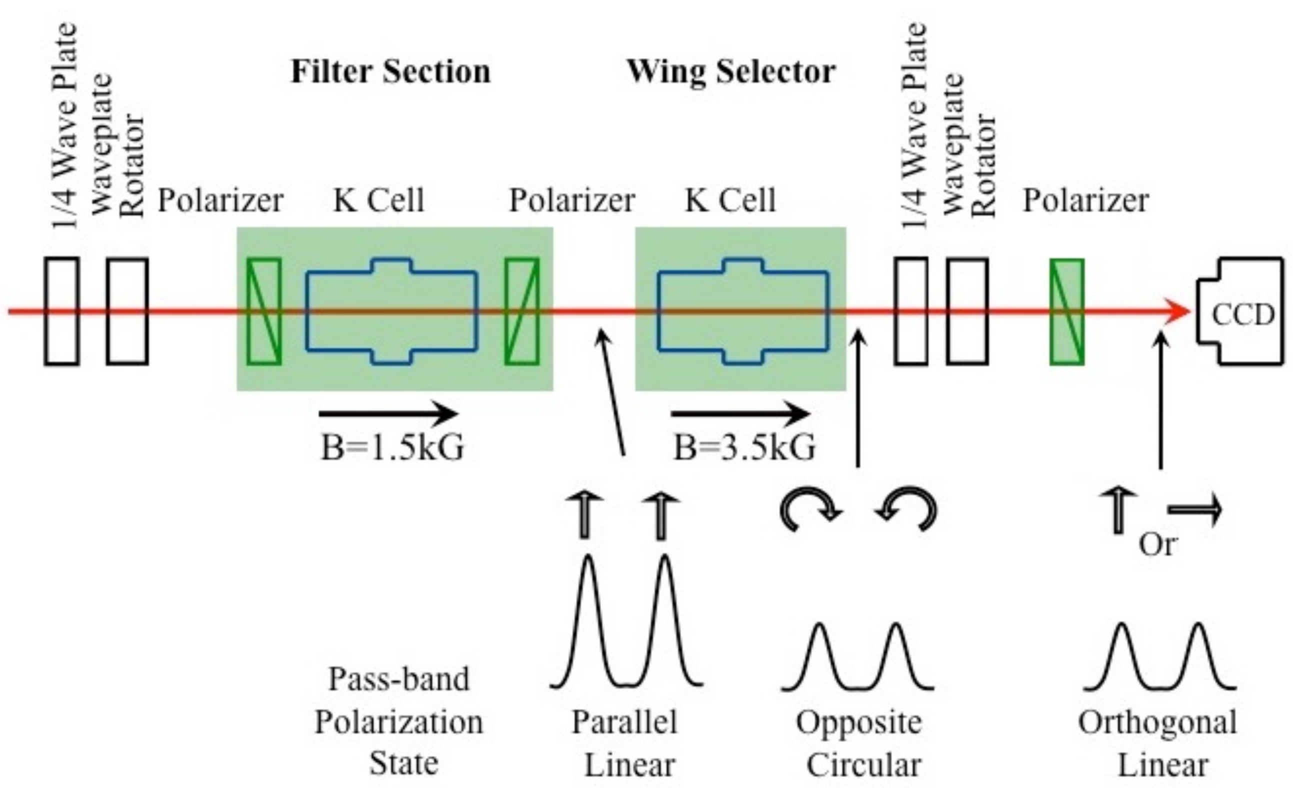

Figure 1 – a schematic of the Doppler imager. This version uses two MOF assemblies, labeled Filter section and Wing selector

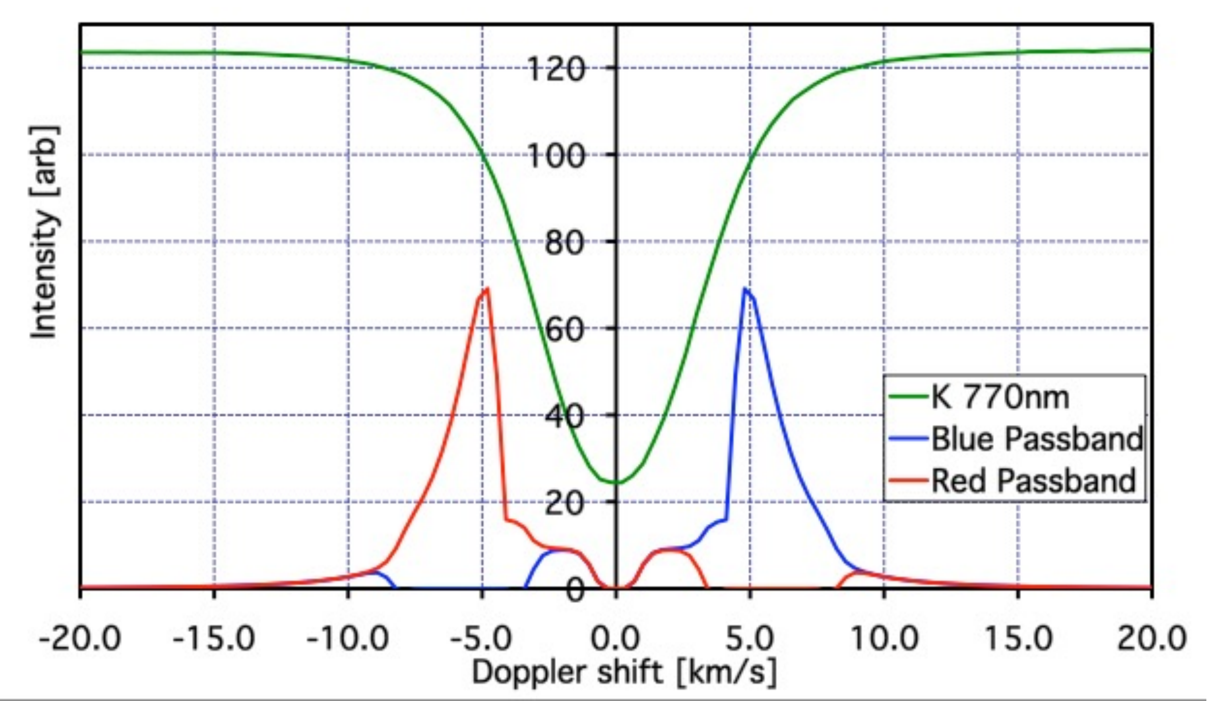

Figure 4 – simulation of a K 770 nm MOF transmission profile, compared to the solar 770nm absorption line

Figure 3 – ceramic discs used to form the cathode array

Figure 4 – the complete MOF testbed

The physics of the hollow cathode lamp (HCL) was our starting point. HCLs use sputtering to produce bright discharges from many different elements . We designed and built an MOF testbed that will sputter target elements, but does not swamp our observations with light from the discharge. Parameters considered were the number of cathodes, their diameter, depth, and composition, the discharge voltage, and the choice of back-fill gas. The core of the testbed is an array of hollow cathodes. This array is formed from a stack of ceramic discs with multiple holes, as shown in Figure 4. By changing the number of discs used, we can adjust the depth to radius ratio.
Figure 3 shows the completed testbed. Our initial plan was to build and test the sputtering MOF, however, we have not completed the testing.

To initiate and control the sputtering, the testbed uses a high voltage source, programmable from 0V to 10kV. and and 27MHz signal to further manipulate the properties of the discharge. The key to HCL performance is the choice of buffer gas and its pressure, which both sputters material from the electrode and decreases ion diffusion to the cell wall. We will start with He which, has has a metastable state 19.8 eV higher than the ground state, providing ≈ 40 times the energy of a neutral He atom in a collision with the sputtering target. Different backfill gases will be tested, to compare the effects of gases with lower energy, but multiple metastable states.

Initial target elements will be Na, K Fe, Ca, and Mg. Although Na, K, and Ca can be used in conventional MOFs, combining them in the same thermally heated cell is not effective because of their differing vapor pressures result in the partial vapor pressure of each element being radically different. The sputtering-based MOF overcomes this disadvantage, as the partial vapor pressure is stoichiometric, so we can select the desired vapor partial pressure using the target composition

Value to JPL & NASA. The increase in sensitivity and spectral coverage of an advanced MOF - based DI a will allow comprehensive measurements of atmospheric flows and waves in giant planet atmospheres, with the ability to measure velocities at different planetary albedos, enabling a 3-D view of the atmosphere. Future missions include giant planet missions, including a Uranus orbiter

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