A Novel Optical Etalon for Precision Radial Velocity Measurements

Stephanie Leifer (JPL/Caltech), PI

Precise measurement of the Doppler shifts of starlight resulting from the radial velocity of planet-hosting stars is one of the first and most powerful methods of exoplanet detection. While spectrograph stability imposes limits on how precisely the radial velocity (RV) can be measured, spectral references play a critical role in characterizing and ensuring this precision. Only optical frequency combs and line-referenced Fabry-Perot etalons are capable of providing the stability needed for detecting Earth-like planets in the habitable zone of their Sun-like host stars. While both frequency combs and etalons can deliver high precision spectrograph calibration, the former requires relatively complex and sophisticated hardware in the visible portion of the spectrum. Specifically, ground-based, visible band astrocombs are large instruments that require multiple stages of filtering to achieve the line density resolvable by astronomical spectrographs. Other methods for achieving the desired mode spacing between 400 nm and 800 nm with frequency combs may entail second harmonic generation from NIR combs, which then must circumvent phase matching issues, or nonlinear spectral broadening of longer wavelength combs that requires high pulse power owing to the nonlinearity of materials that function in this regime.

Etalons promise a simpler, more elegant, and smaller size, weight, and power (SWaP) alternative to visible band, high repetition rate frequency combs. While mirror-based etalons have previously struggled with implementation due to factors such as thermally induced instability and dispersion, sensitivity to polarization and alignment of input light, and mirror coating degradation, recent breakthroughs in engineering thermally insensitive whispering gallery mode (WGM) microresonators [1] make their use as novel etalons for visible-band RV calibration achievable.

We propose to demonstrate a compact, reliable, and environmentally insensitive line-referenced etalon calibrator capable of operating in space and on the ground. The etalon will help next generation spectrographs to successfully detect Earth-mass Habitable Zone exoplanets. The proposed work builds on our experience developing compound microresonators with an engineered thermorefractivity. The broadband etalon (e.g. 400 nm to 800 nm) operation and comb-like spectrum is enabled by a crystalline CaF_2 or MgF_2 WGM resonator integrated with ceramic layers characterized by a negative coefficient of thermal expansion. We will first demonstrate the technology in a laboratory setting to show long-term stability, and then ultimately at an observatory.

This work directly addresses the Exoplanet Exploration Program's Technology Gap List element M-2 to provide a robust, low SWaP precise calibration source for extreme-precision radial velocity measurements in the visible spectrum.
We draw on our collective capabilities in precision radial velocity detection, expertise in engineering composite WGM microresonators, creating small, rugged, packaged devices, precision metrology, and etalons to demonstrate this technology for future NASA instruments and missions.

1. Matsko,A., Savchenkov, A, J. Opt. 20 (2018) 035801