Modeling chromatic mode frequency shifts in etalons for high precision spectrograph calibration

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Detecting an Earth analog requires radial velocity measurement precision on the order of ~10 cm/s. Conventional spectrograph calibration sources, including atomic lamps and gas emission cells, have intrinsic limitations making them incapable of reaching this precision level. In recent years, laser frequency combs have achieved the highest attained precision levels, but they are both costly and complex. Fabry-Perot etalons, which are optical cavities formed by two parallel mirrors, are capable of achieving similar precision levels on shorter timescales through their comb-like mode spectra. They have the additional advantage of being much simpler and more cost-effective. However, measurements of the Habitable-zone Planet Finder (HPF) spectrograph, as well as several other etalon systems worldwide, indicate that the etalon modes experience complex, wavelength-dependent drifts over time. For the HPF etalon, some modes are slowly drifting to the red, while others simultaneously drift to the blue, which poses a clear calibration challenge. We have used the optical transfer matrix method to model perturbations in the dielectric mirror coatings of the etalon to determine the primary mechanism of this behavior. Our modeling can reproduce the complex wavelength-dependent drifts of the HPF etalon and indicates that the aging process in the outermost layers of the mirror coatings is responsible. In the modeling process, we have ruled out other possible explanations for the observed behavior, including incident angle alignment changes, polarization variation, and manufacturing tolerances. These results will be important for improved calibrations and future design considerations for etalons used in radial velocity detection. Molly Kate Kreider
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