The Accordion Effect: A Consequence of Polarized Light in Precision Radial Velocity Spectrometers

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Motivated by the search for small rocky planets in the habitable zone of their host stars, radial velocity instruments will soon exceed 1 m/s precision and accuracy. The Palomar Radial Velocity Instrument (PARVI) is one such instrument. PARVI is a J & H band, high resolution ($R \sim 80,000$) spectrograph on the Hale 5.08 m telescope at Palomar Observatory. It is designed to measure precise radial velocities (PRVs) of cool, low-mass stars to determine the masses of orbiting companions. A key aspect of PARVI's design is the use of single-mode fibers (SMFs) rather than the more common multi-mode fibers (MMFs), to feed light from the telescope into the spectrograph. MMFs are larger (∼100 μm diameter core) and accommodate seeing-limited PSFs. SMFs are smaller (∼10 μm diameter core) and allow only one mode of light to propagate. As a result the beam is diffraction-limited and the spectrograph optics are smaller, more compact, and therefore easier to stabilize than those required for seeing-limited instruments. A challenge with SMFs is that for fiber lengths > 1 m the output polarization state (PS) is completely decoupled from the input polarization. When combined with polarization-sensitive optics in the spectrograph the resulting spectrum is polarization dependent. We find that stress and strain on PARVI's cross-dispersing optic (a monocrystalline silicon prism) is responsible for radial velocity (RV) errors on the order of 10 m/s. Polarized light passing through the prism is displaced in both the dispersion and cross-dispersion directions resulting in a periodic signal in the spectrum we call the accordion effect. This work illustrates the necessity of considering the polarization response of optics when designing PRV spectrometers.