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Near Infrared Optical Frequency Comb Calibrators for the Habitable-Zone Planet Finder

We describe the laser frequency comb that is now installed and operating as the primary wavelength calibrator for the Habitable Zone Planet Finder (HPF) spectrograph at the 10 m Hobby-Eberly Telescope. The laser frequency comb, with 30 GHz mode spacing, is built around a combination of electro-optic and integrated-photonic technologies to address the challenges of bandwidth, mode spacing, and robustness. The central tooth of the comb is the 1064 nm continuous wave (CW) light from a semiconductor laser that feeds waveguide electro-optic modulators driven by a 30 GHz microwave source. This results in a comb of approximately 100 teeth spaced exactly by the microwave drive frequency. The CW laser, microwave source, and all other frequencies in the system are referenced to a GPS-disciplined clock that provides absolute traceability to the SI second with fractional uncertainty below $1e-12$ at 1 night of averaging. The initial comb is amplified, spectrally broadened and temporally compressed to a pulse width of 70 fs, and then focused into a 25 mm long nonlinear silicon nitride waveguide. The waveguide provides the combination of tight confinement and engineered dispersion for nonlinear spectral expansion of the 30 GHz comb across 700-1600 nm with only 525 mW of incident average power (18 pJ of pulse energy). This low power reduces the thermal loading and aides long-term operability. Static and programmable amplitude filters are used to flatten the spectral envelope across the HPF band of 800-1300 nm. The laser frequency comb has been running autonomously and continuously since May 2018, and we have used it to achieve on-sky stellar RV's with precision near 1.53 m/s. We have further shown that the intrinsic stability of the HPF and comb support RV precision below 10 cm/s. This same electro-optic frequency comb architecture can be employed for coverage from <600 nm to >2500 nm.

In addition to the 30 GHz LFC, we have built and installed an evacuated and temperature-controlled plane-parallel Fabry-Perot etalon as a supplementary calibrator for the HPF. Extensive pre-deployment testing allowed us to simultaneously track multiple Fabry-Perot resonances between 800 and 1300 nm. While showing slow linear drift and excellent frequency stability of the etalon modes below $1e-9$ per day, these laboratory tests revealed chromatic variation in the linear drift not supported by a simple description of the etalon. This study has continued post-deployment, where interleaved comb and etalon exposures at the HPF provide the ability to cross-calibrate and track the drift of each individual mode of the etalon relative to the absolute reference provided by the comb. Such measurements across the full HPF bandpass with precision <1m/s have further confirmed unexpected chromatic structure in the etalon drift. Updated results and our interpretation of the etalon's chromatic drift properties will be presented.

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