Demonstration of near-IR line-referenced electro-optical laser comb for precision radial velocity measurement in astronomy

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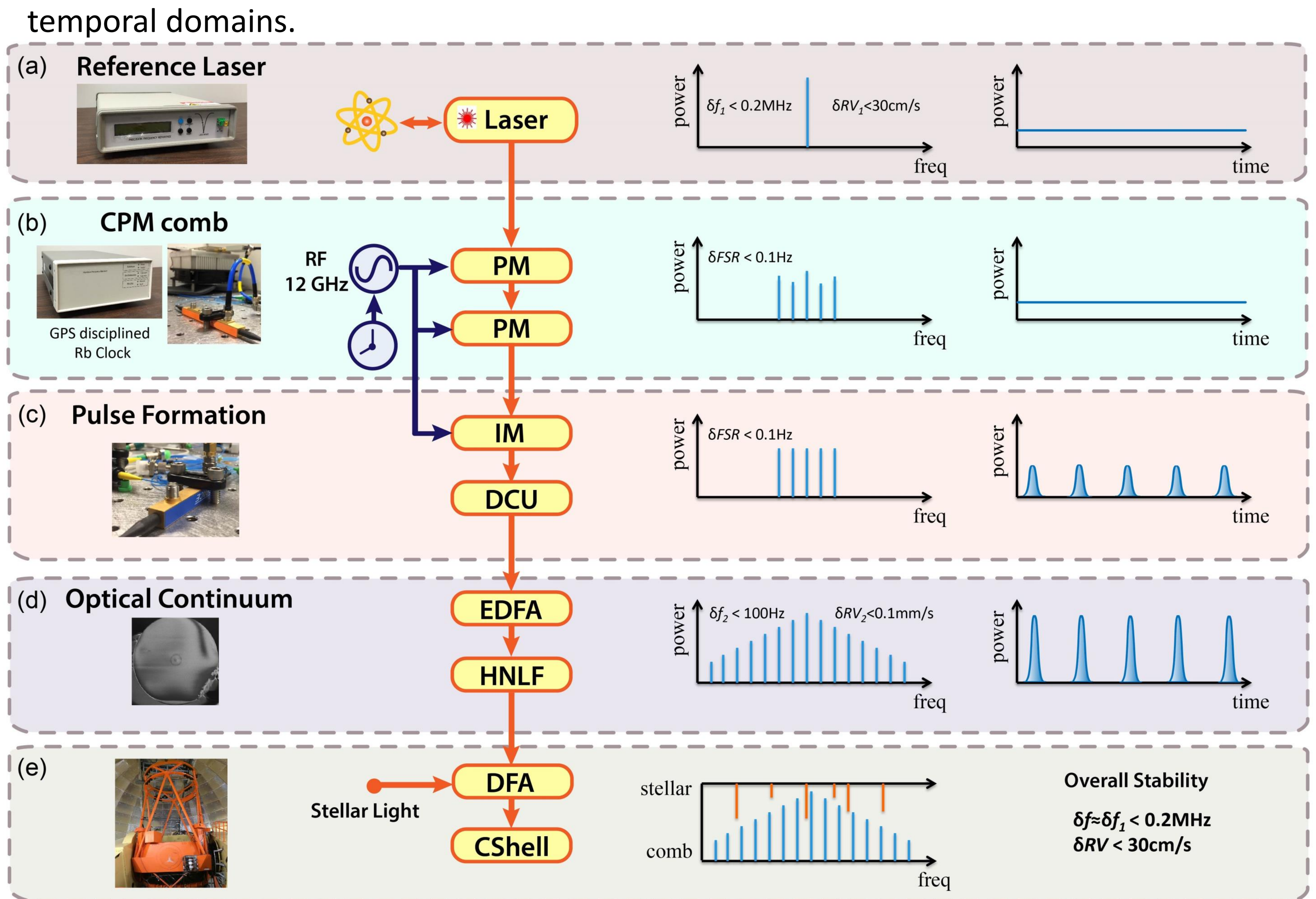
We describe a successful effort to produce a laser comb around 1.56 µm in the astronomical H band (1.5-1.8 µm) using a method based on a line-referenced, electro-optical-modulation frequency comb (LR-EOFC). The LR-EOFC produces a spectrum of equally and widely-spaced (12 GHz) comb lines generated by electro-optical modulation, with a center wavelength stabilized to a molecular or atomic reference. The LR-EOFC was built using commercial-off-the-shelf technologies and therefore is relatively simple and reliable. Proof-of-concept demonstrations were performed at the NASA Infrared Telescope Facility and the Keck-II telescope. The laser comb has a demonstrated stability of < 200 kHz, corresponding to a Doppler precision of ~0.3 m/s, which is suitable for the detection of Earth-sized planets in the habitable zones of cool M-type stars.

1.Schematic Comb Setup

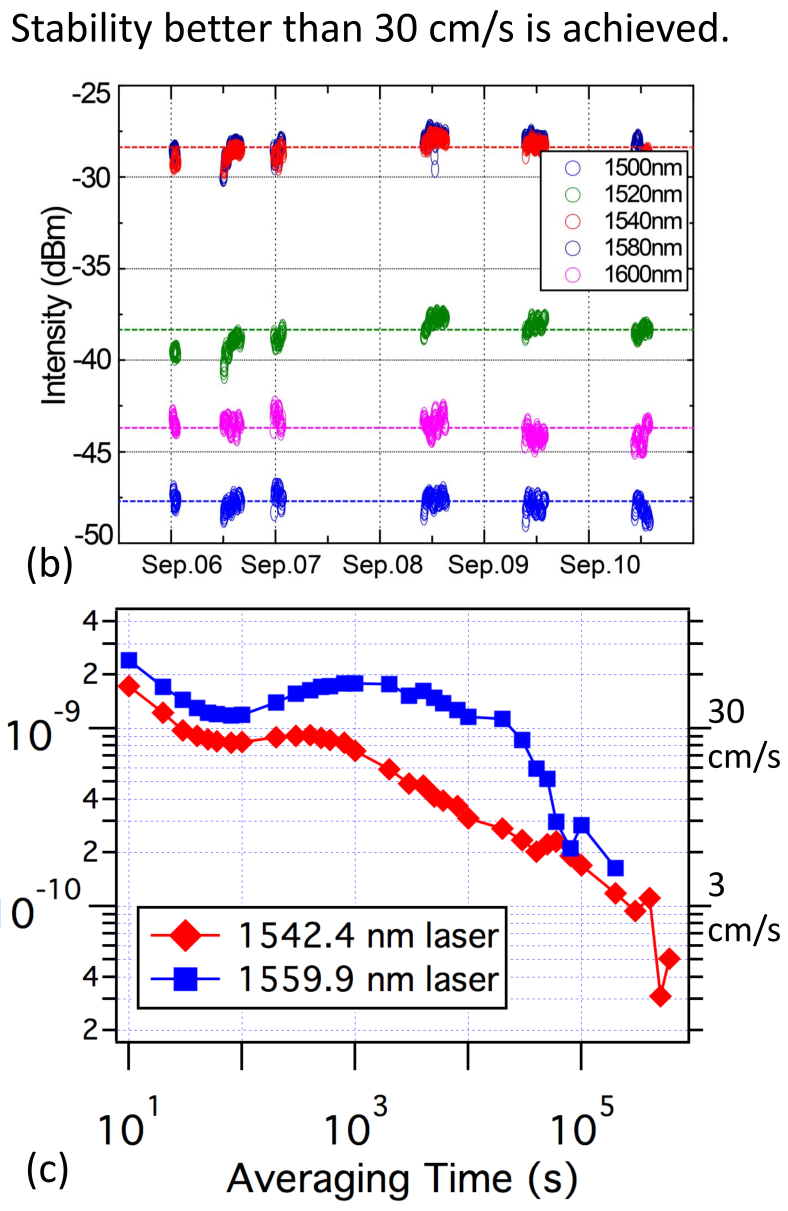
Fig. 1. Conceptual schematics of LR-EOFC astro-comb. Vertically, the first column contains photographs of key instruments. A simplified schematic of the setup is in second column. Third and fourth columns presents the comb state in frequency and temporal domains.



2. Comb in a Rack and Stability test

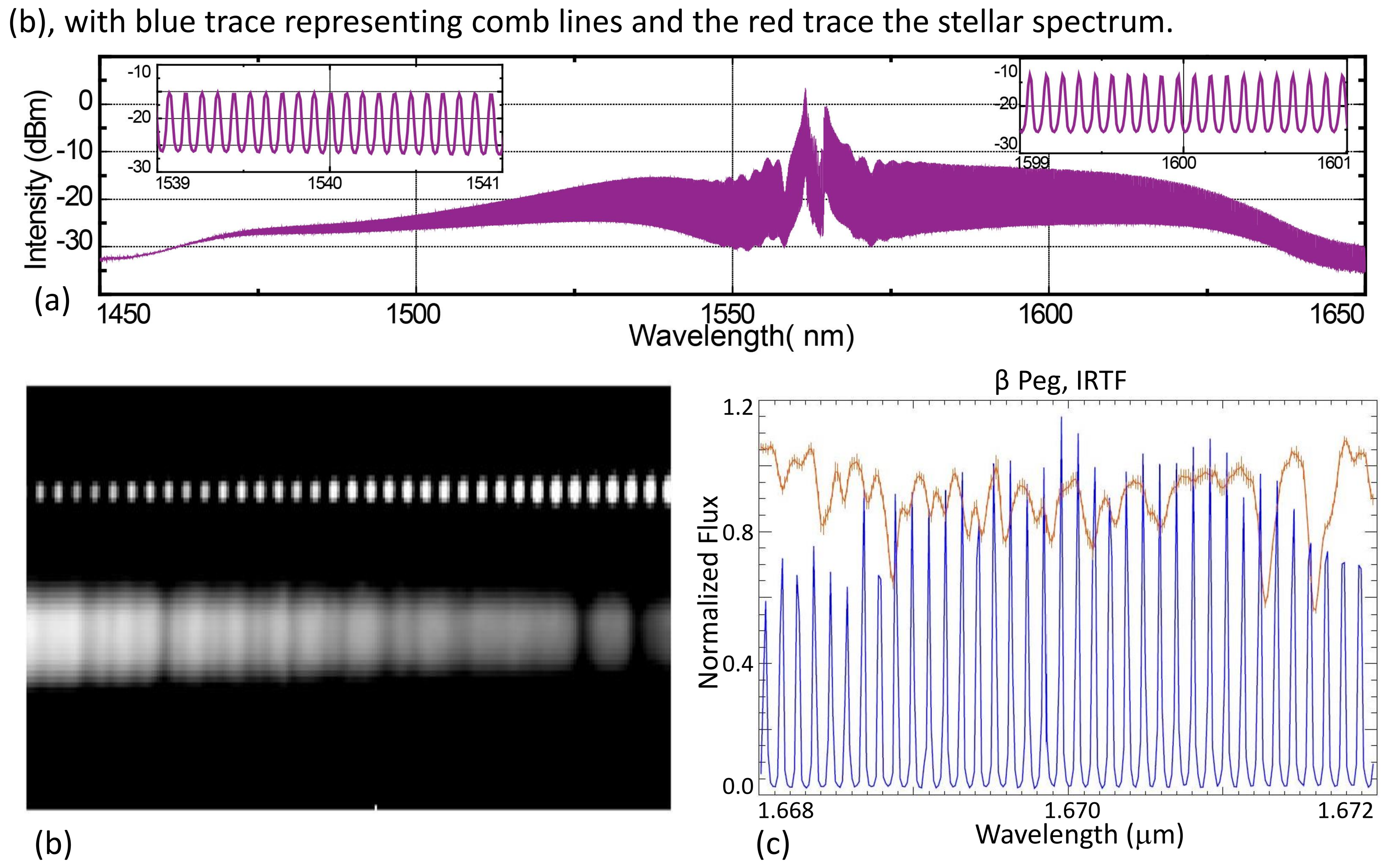
(a)

Fig. 2. (a) LR-EOFC breadboard (top of rack) and supporting equipment. (b) Comb line intensity stability: variation within 2dB over five days and power on-off cycles. (c) Allan Deviation measurement of reference laser. Stability better than 30 cm/s is achieved.



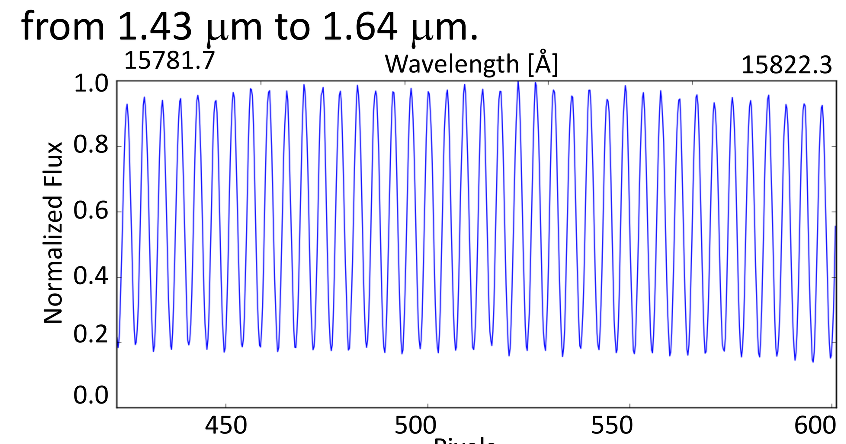
3. On-Sky demonstration on C-Shell IRTF

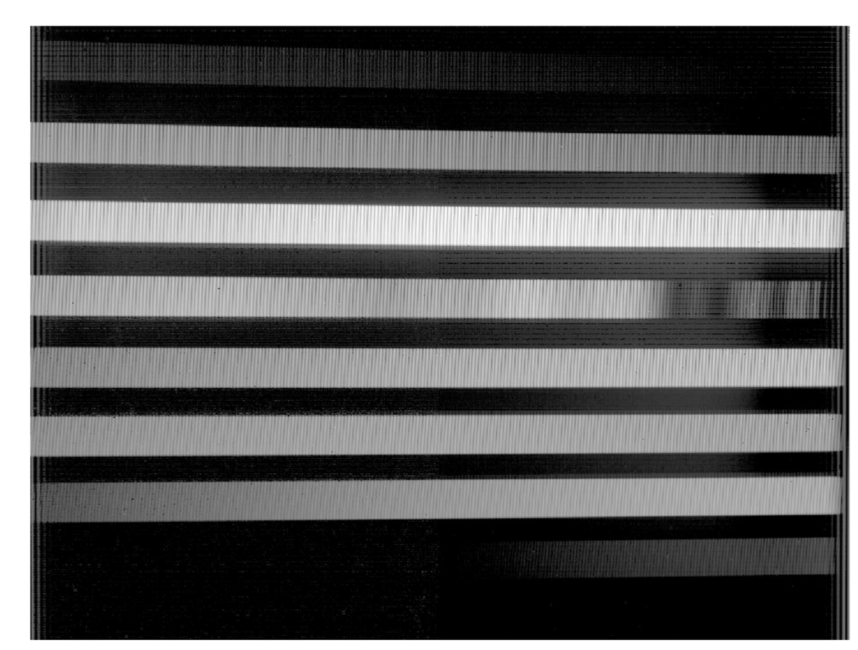
Fig. 3. (a) Optical Spectra of the LR-EOFC with >100nm span. Comb lines are resolved in the insets. (b) An image of the echelle spectrum from CSHELL on IRTF showing a 4 nm portion of spectrum around 1670 nm. The top row of dots are the laser comb lines while the broad spectrum at the bottom is from the bright M2 II-III giant star β Peg. (c) Spectra extracted from (b), with blue trace representing comb lines and the red trace the stellar spectrum.



4. 200nm Comb on NIRSPEC Keck II

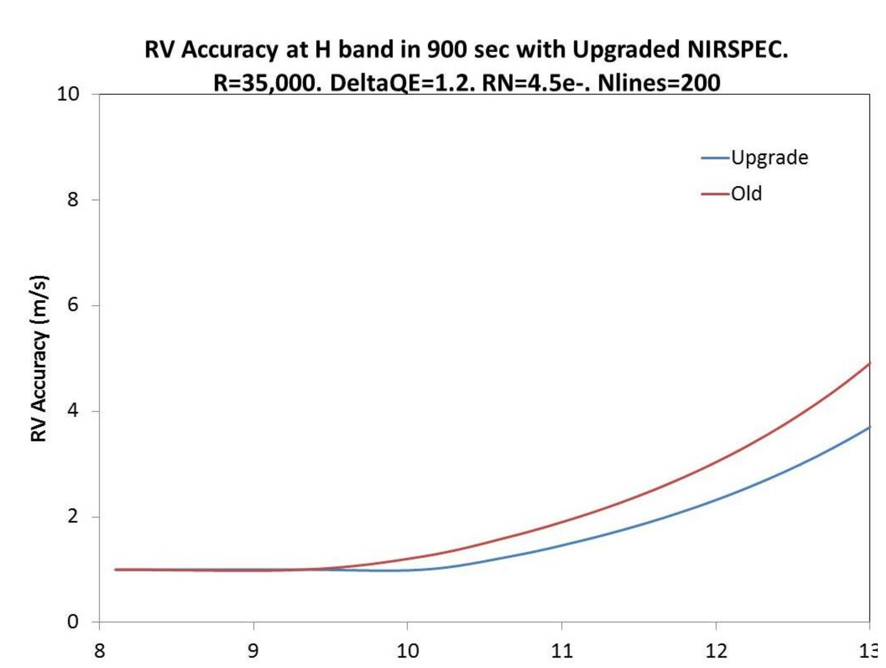
Fig. 4. Reduced Keck II NIRSPEC image from echelle orders 46 to 53, displaying the stabilized laser comb lines. The comb is injected to NIRSPEC via an integrating sphere and spans wavelengths from 1.43 µm to 1.64 µm.





5. Science Goals for NIR Precision RV

Fig. 5. Predictions for the PRV capability of Keck's NIRSPEC instrument equipped with a laser comb wavelength standard before (red) and after (blue) a proposed upgrade to an H2RG detector. The new detector would have lower noise, improved QE and smaller pixels resulting in higher sensitivity and spectral resolution (R~35,000 vs 25,000) compared with present capabilities. With the rich H-band spectrum of mid- to late-M stars, it would be possible to achieve a precision of ≤ 5 m/s across a broad range of stellar magnitudes in < 900 sec.



Reference: Yi, X. *et al*., "Demonstration of a Near-IR Laser Comb for Precision Radial Velocity Measurements in Astronomy", *arXiv:1501.02509.*

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