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Laser Frequency Combs for Precision Astrophysical Spectroscopy

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Searches for extrasolar planets using the periodic Doppler shift of stellar spectral lines resulting from the motion of the host star around the barycentre of an extrasolar system have recently achieved a precision of 60 cm/s [1]. To find a 1-Earth-mass planet in an Earth-like orbit, a precision of 5 cm/s is necessary. The sensitivity of astrophysical spectroscopy is presently limited by its wavelength calibration sources [2, 3]. The combination of a laser frequency comb with a Fabry-Perot (FP) filter cavity has been suggested as a promising approach to improved sensitivity [4-7]. Here we report the fabrication and tests of a filtered comb with up to 40-GHz ($\sim$ 1 Å) line spacing, generated from a 1-GHz repetition-rate source, without compromising long-term stability, reproducibility or spectral resolution [8]. This astro-comb is well matched to the resolving power of high-resolution astrophysical spectrographs. The astro-comb should allow a precision as high as 1 cm/s in astronomical radial velocity measurements.

A 1-GHz repetition-rate Ti:sapphire laser generates comb lines spanning 6,000 Å to 12,000 Å. Both the repetition rate and the offset frequency are referenced to an atomic clock via low-noise synthesizers [Fig. 1(a)]. A FP cavity increases the line spacing by filtering unwanted comb lines, and is stabilized to a diode laser, which is phase-locked to the comb. With plane-parallel FP mirrors of 99% reflectivity and optimized group delay dispersion (< 50 fs^2) in the range of 7,500 Å to 9,200 Å, we have observed astro-comb lines with up to 40-GHz spacing, spanning 1,000-Å.

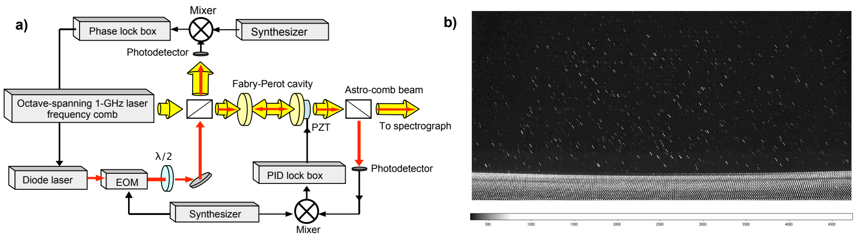

Fig. 1. (a) Astro-comb schematic. An octave spanning 1 GHz frequency comb, filtered by a Fabry-Perot cavity produces a 40 GHz comb feeding the spectrograph. (b) Spectrograph images of the sparse, irregular Th-Ar spectrum (above) and the dense, regular astro-comb spectrum (below).

The astro-comb has been deployed to calibrate the TRES spectrograph for the 1.5-m telescope at Whipple Observatory. TRES is a multi-order echelle spectrograph with a resolving power of 60,000 and wavelength coverage from 3,800A-9,300 Å. A calibration image is shown in Fig. 1(b). Preliminary data analysis indicates that the astro-comb is able to improve the Doppler shift precision of TRES. We are currently employing the astro-comb and TRES in studies of exoplanets around M-dwarf stars.

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