Laser frequency comb supported stellar radial velocity determination in the NIR: Initial results

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Why a NIR Laser Frequency Comb?

- M dwarf stars make up 70% of our nearest neighbors.
- Low mass, cool stars have close in habitable zones resulting in larger reflex velocities and shorter periods.
- Cooler stars emit most strongly in the NIR, necessitating high-precision NIR spectroscopy.
- A major limitation to high-precision NIR spectroscopy is the lack of calibration sources.

(Ycas, 2010)
The Laser Frequency Comb

- The LFC creates a high precision “optical frequency ruler.”

\[ f_n = n f_r + f_0 \]

- This relation is exact (measured to 1:10\(^{19}\)).
- 1:10\(^{11}\) precision achievable in the field.

- Ideal wavelength standard:
  - Dense array of uniformly spaced, uniformly bright lines
  - Frequencies traceable to a fundamental standard.
  - Precision and long term stability should exceed the ultimate precision of the spectrograph.
Mode Filtering

At 1600nm...

- $f_r = 250\text{MHz} \Rightarrow 0.002\text{nm mode spacing at 1550nm}$
  \[\frac{\lambda}{\Delta \lambda} = 750,000\]

- Much too narrow to support an $R = 50,000$ instrument

- High finesse FP filter knocks out 99/100 modes, giving line spacing of 25 GHz (0.2nm/mode)

- Second filter increases intermode suppression.
25GHz Broadened Comb

12.5 GHz comb performance:
- ~45nm un-broadened bandwidth, 500nm broadened

25 GHz comb performance:
- ~200nm broadened coverage
- 50dB side mode suppression at 1631nm

Quinlan, Rev Sci Instrum 81, 2010
The optical spectrum in the lab

Ycas (CLEO 2011)

Wavelength (nm)
The optical spectrum in the lab

Optical Heterodyne Spectrograph Instrument Profile

Pathfinder-H FWHM

39, 37 dB NN suppression

Relative Optical Power (dB)

1616.43
1616.45
1616.47

Wavelength (nm)

Ycas (CLEO 2011)
Sub-m/s Shifts due to Asymmetric Side-Mode

Fractional Shift of Line Center

Wavelength (nm)

10^{-8}

10^{-10}

10^{-12}

1425

1525

1625

10m/s

3cm/s

0.3cm/s

Pathfinder H Bandpass

Ycas (CLEO 2011)
Laser Frequency Comb at HET

- Supported Penn State Pathfinder Spectrograph at HET from August 4-12, 2010.
- 1.45- >1.635 μm, 25GHz coverage
- 8 days operation with no unintended loss of signal during observations.
- 1 abrupt mode shift during evening operations – easily identified in data and telemetry (250MHz ~ 400m/s).
Laser Frequency Comb at HET

12 September 2011

Osterman

Extreme Solar Systems II
Modal Noise

- Substantial modal noise/speckle apparent in HET LFC data despite use of integrating sphere. Modal noise reproduced in subsequent lab tests (below).
- Agitation at spectrograph feed is of limited utility for LFC signal.
- Several promising mitigation techniques under investigation.

Incandescent source ⇒ diffuser ⇒ multimode

Coherent source ⇒ Single mode ⇒ sphere ⇒ multimode

Coherent source ⇒ Single mode ⇒ sphere ⇒ multimode + 27Hz agitation
Moving to the Y band

Highly Nonlinear Fiber

250 MHz Mode
Locked Er:Fiber Laser

Er:Fiber Amplifier

Yb:Fiber Amplifier

30 GHz Fabry-Perot Cavity

30 GHz LFC Spectrum
Summary

- Frequency combs can support astronomical observations and operate for extended periods outside of the lab

- Speckle and modal noise were the dominant sources of RV error

- Future work:
  - Address speckle/modal noise
  - Increase comb autonomy/automation
  - Push to shorter wavelengths

- Continued collaboration with Pathfinder/HZPF team