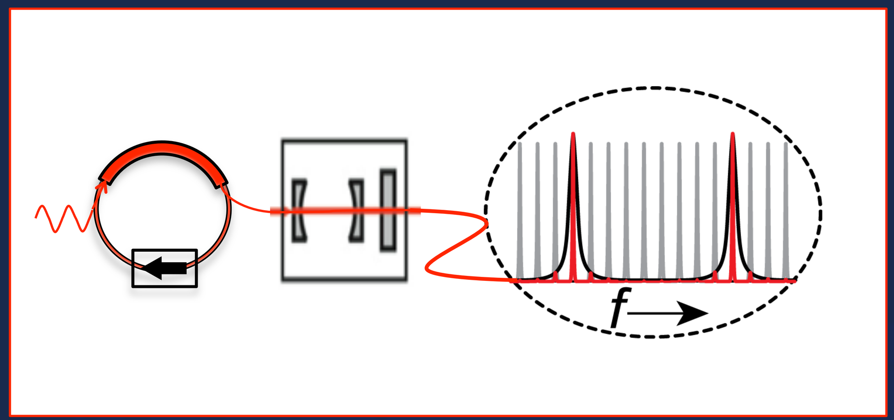

The CU/NIST Laser Frequency Comb Calibrator for High-Precision NIR Spectroscopy

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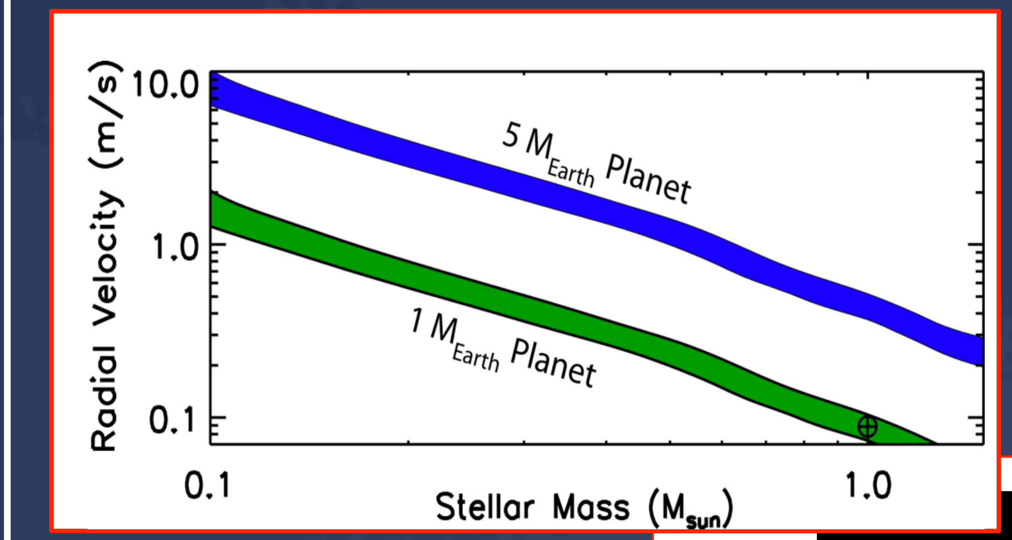
Abstract

HARPS, HIRES, etc. have shown the value of high precision spectroscopy for RV planet searches at visible wavelengths, but visible light RV planet searches are best suited to to solar like stars, making detection of an earth-analog extremely challenging. Alternatively, low mass M Dwarfs are promising subjects but are not easily observed at visible wavelengths. Precision NIR spectroscopy is becoming a reality with advances in laser comb technology, making high precision RV studies of low mass stars a possibility.

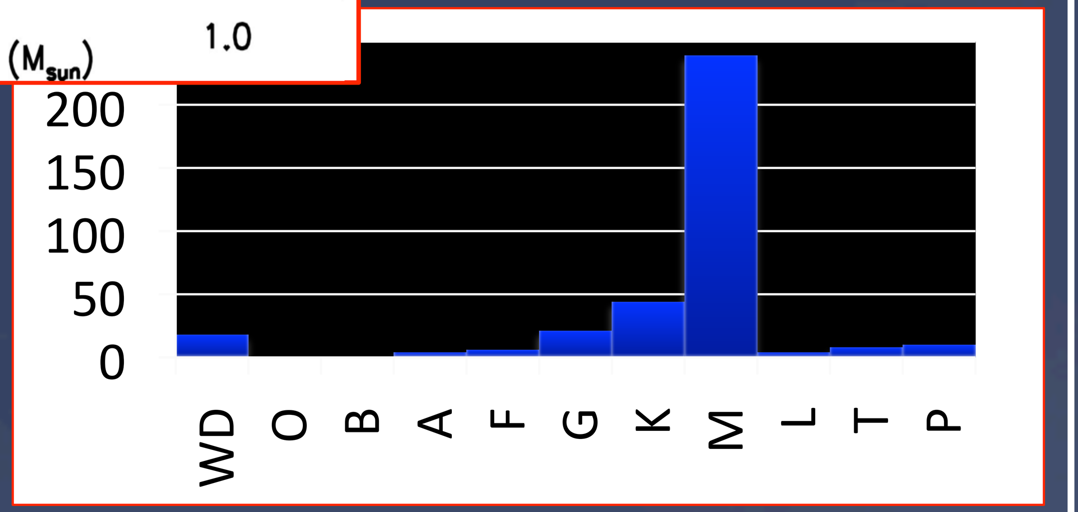
We have developed a broad-band laser frequency comb at NIST to support high-precision H-Band spectroscopy at resolutions of 50,000 and higher. We present an overview of laser frequency comb technology and detailed capabilities of the existing H-band laser frequency comb. In addition to ground-based applications, we will discuss the possibility of performing high-precision spectroscopy from the SOFIA aircraft.

Why look for planets around low mass stars?

- ✱Larger RV signature for a given planet mass in the habitable zone
  - ✱Lower mass ➔ Lower temperature
  - ✱Habitable zone is closer to the host, increasing RV signature
  - ✱Lower host mass increases RV signature
  - ✱Tighter orbit leads to shorter period (weeks)
- ✱Large number of host stars within 10pc
- ✱Cool stars brighter in the NIR
- ✱No shortage of narrow spectral features



RV signature vs Stellar Mass for 1 and 5 earth-mass planets in the liquid water habitable zone (adapted from Kasting, 1993)



Data from *RECONS* survey values (Jan 2009) showing pre-dominance of class M stars within 10 pc.

What else could be done if high precision NIR spectroscopy were possible?

- ✱ How common are terrestrial mass planets around low mass stars, and how many reside in the habitable zone?
- ✱ How and when do gas giant orbits evolve?
- ✱ How common are gas giant planets around post-main sequence red giant?
- ✱ Are "Hot Jupiters" Cannibalized by Red Giants
- ✱ How Common are Gas Giant, Brown Dwarfs, and Red Dwarfs Around Massive Super-giants?
- ✱ Planetary atmospheres
- ✱ Stellar rotation and astroseismology
- ✱ M and lower mass spectroscopic binaries

This is not just about finding planets around M stars: By improving RV precision by up to 2 orders of magnitude we open up an enormous discovery space.

The Laser Frequency Comb as a High Precision Wavelength Reference:

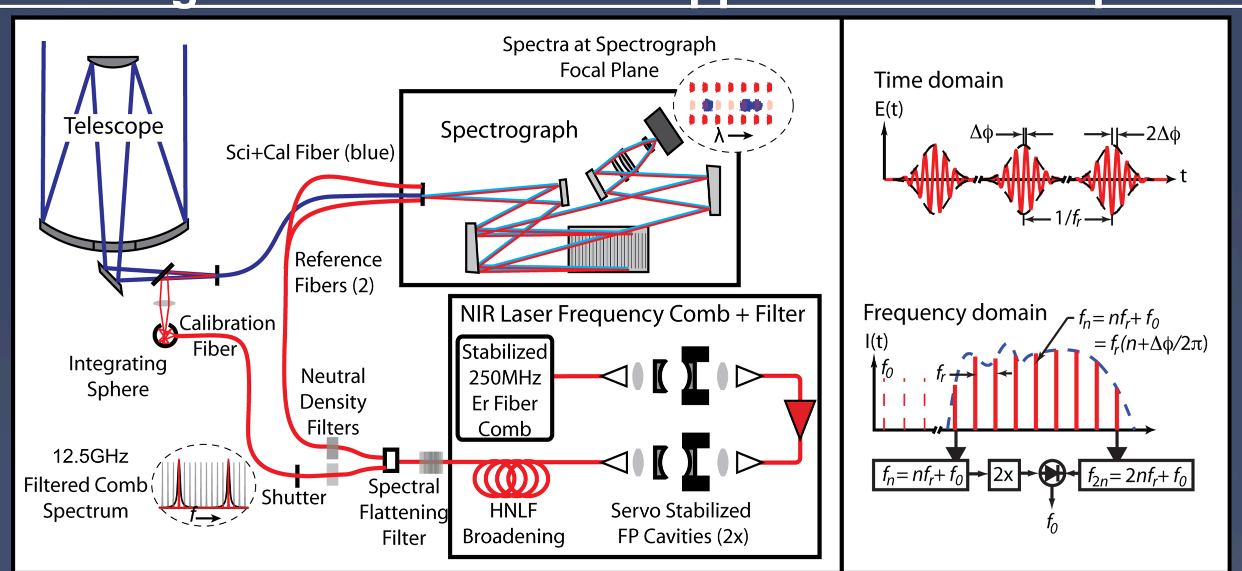
- ✱ An LFC represents an ideal wavelength standard:
  - ✱ Dense array of uniformly spaced, uniformly bright lines
  - ✱ Frequencies traceable to a fundamental standard.
  - ✱ Precision and long term stability should exceed the ultimate precision of the spectrograph.
- ✱ A laser Frequency Comb meets these requirements:
  - ✱ The LFC creates a high precision *optical frequency ruler*. Each line (*mode*) can be written as

$$f_n = nf_r + f_0$$

f_n is the frequency of the n^{th} mode
f_r is the repetition rate of the laser (~250MHz to 10GHz)
f_0 is the carrier offset frequency ($< f_r$)

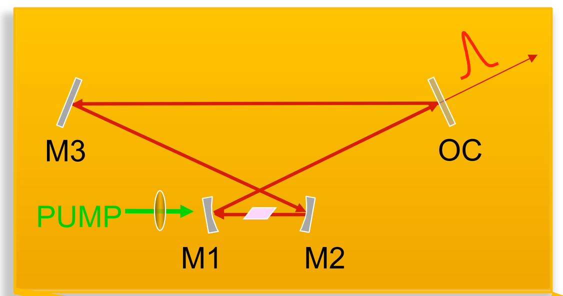
  - ✱ This relation is exact (measured to 10^{-19}).

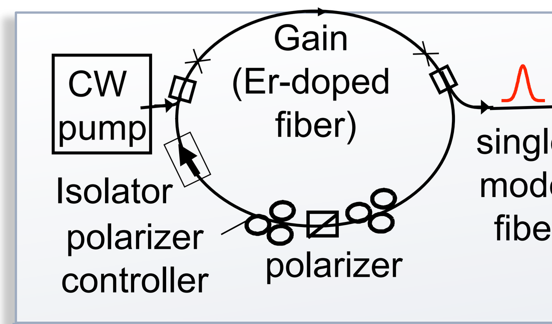
The existing H-Band comb can support < 5cm/s RV precision (1:10^{10})



(right) Laser frequency comb functioning as both a simultaneous and overlaid wavelength reference. The laser comb is well suited for use with fiber fed systems. (left) The frequency comb spectrum is the Fourier transform of a pulse train with the group and phase velocities offset by Δϕ. f_0 and f_r are RF and easily stabilized to high precision.

Principal LFC technologies



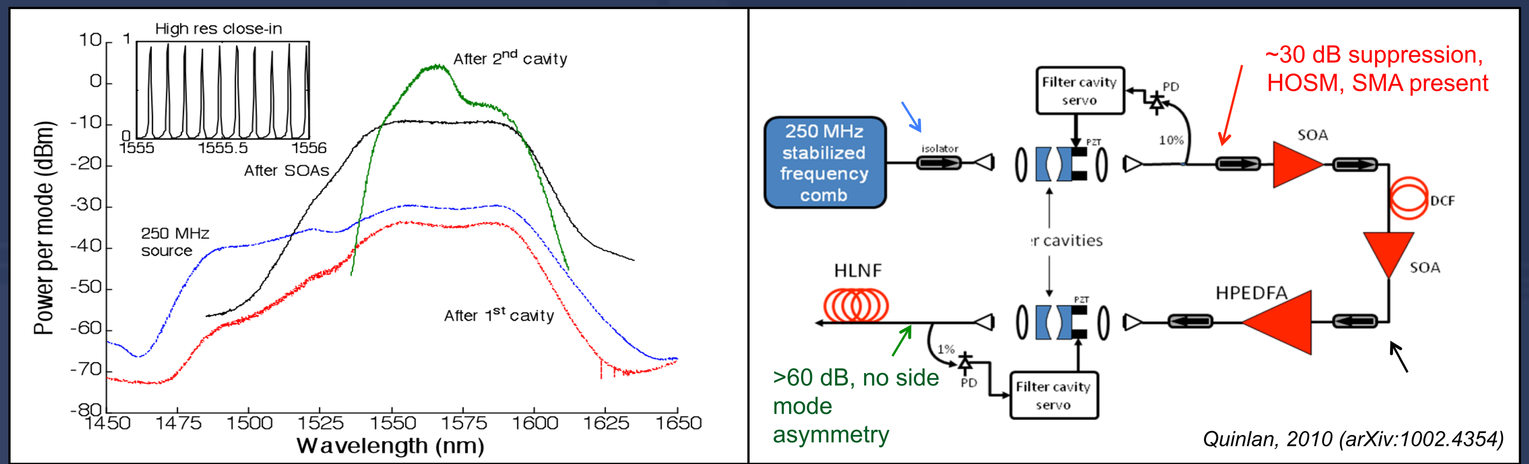


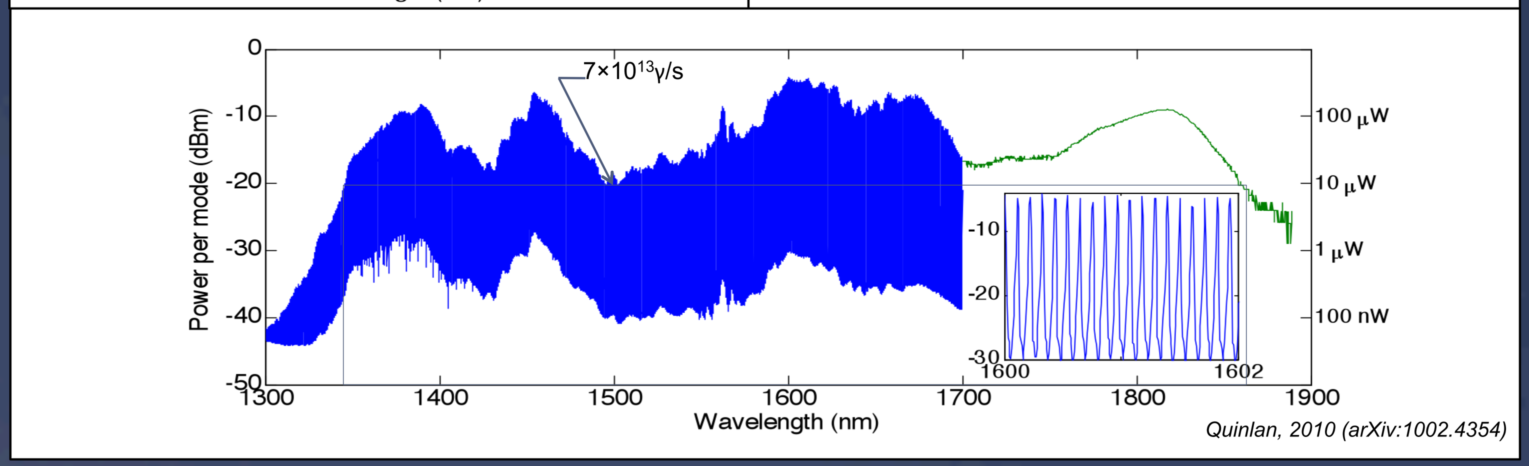
	Ti:Sapphire	Er:fiber laser	Yb:fiber laser
Wavelength Range*:	400-1200 nm	**1000-2200 nm**	500-1700 nm
Repetition Rate:	up to 10 GHz	**~ 250 MHz**	up to 1GHz
Power out:	>500 mW	**3-30 mW**	3-30 mW
Pump:	5-8 W @ 532nm	**100 mW @ 1480/980 nm**	100 mW @ 980nm
Alignment:	Required	**Easy**	Easy
Noise:	Very low	**Higher**	Higher
Pulse width:	<30 fs	**90-200 fs**	90-200 fs
Electrical Power:	~700 W	**~10 W**	~10 W

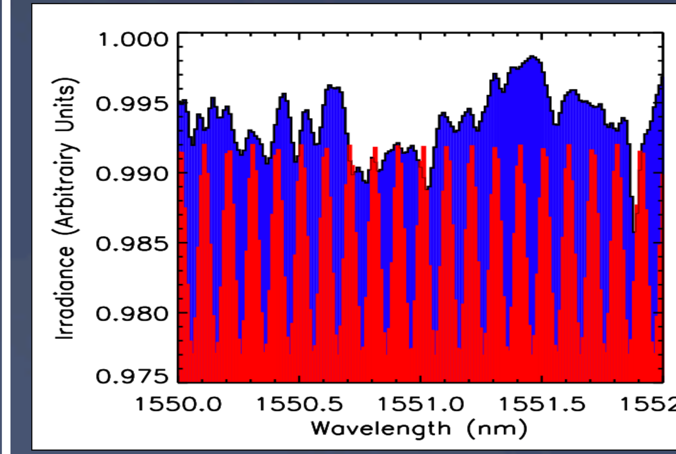
*: Wavelength range with nonlinear broadening

The CU/NIST H-Band Laser Comb

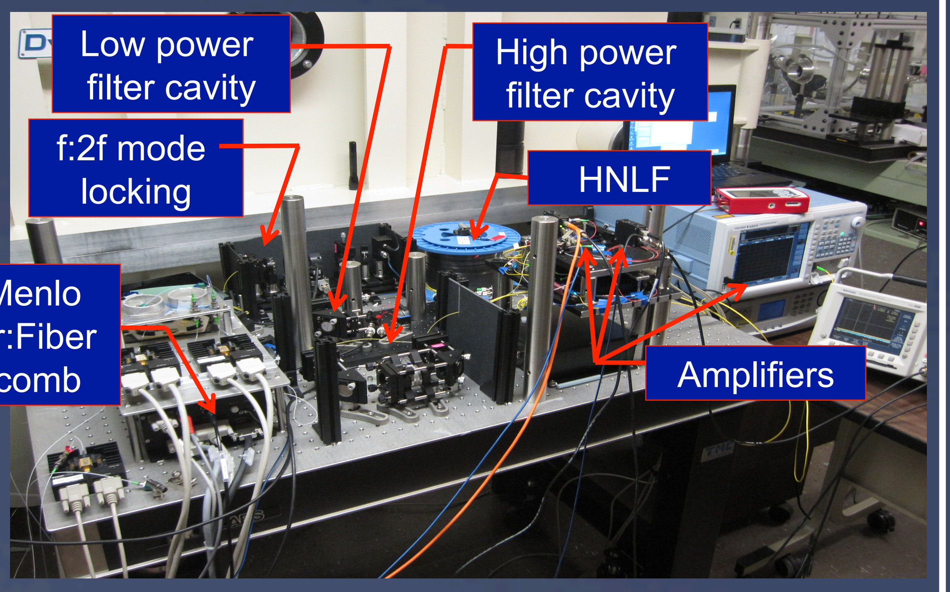
- ✱ 250 MHz Er fiber comb (0.002nm/mode at 1550nm)
- ✱ Two levels of mode filtering increase spacing to 12.5GHz (0.11nm/mode, or λ/Δλ=15,500 at 1550nm) w/ > 50nm band width
- ✱ Post filter non-linear broadening increases band width to 400nm
- ✱ Nearest neighbor suppression = 20-40dB for broadened spectrum







Simulation of a 12.5GHz laser comb spectrum overlaid on an M6 spectrum at *R*=55,000. Comb + spectrograph ⇒ 5-7m/s precision. (M6 spectrum from Peng Jiang)



CU/NIST H-Band Laser Frequency Comb

Suitability for air-born application

- ✱ Existing technology easily adapted to the H band (Er-fiber laser) or to the J Band (Yb-fiber laser)
- ✱ SWAP of flight qualified Er and Yb-based combs could be as low as 15 liters, 20 kg , 50 W (without nonlinear broadening)
- ✱ The fundamental limit is likely to be the transverse (line of sight) RV knowledge and stability of platform
- ✱ Add fast shutter to control spurious RV content