# A Self-Oscillating Phase Conjugate Resonator as an Optical Frequency Comb


Zhifan Zhou*, Jie Zhao*, Rory W. Spiers, Nicholas Brewer, Meng-Chang Wu, Paul D. Lett

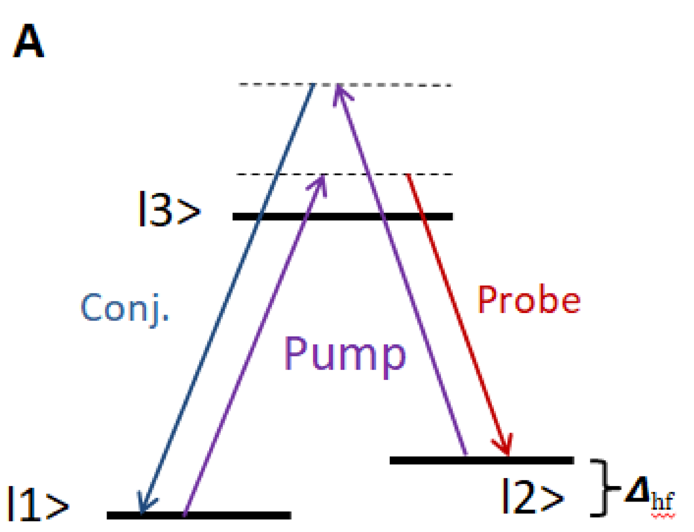
Joint Quantum Institute, National Institute of Standards and Technology and the University of Maryland, College Park, MD 20742, USA

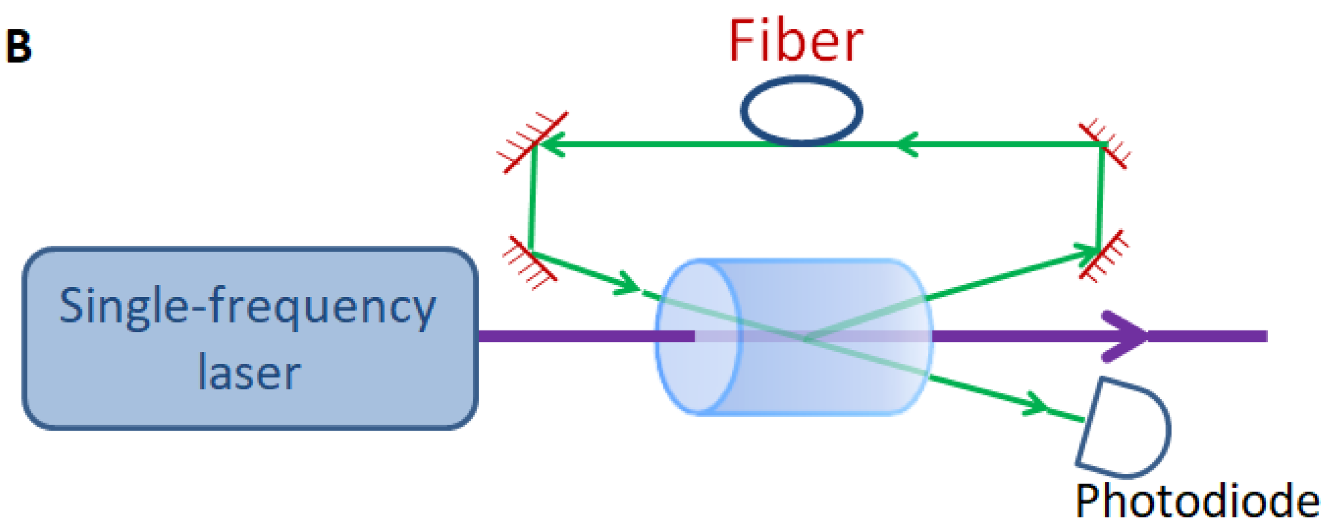
*These authors contributed equally to this work. Author e-mail address: zhifan@umd.edu (Z. Z.), lett@umd.edu (P. L.).



We demonstrate a phase conjugate resonator with a forward-propagating four-wave mixing process that oscillates with the build-up of spontaneous emission. The oscillation exhibits optical frequency comb properties: phase coherence among different comb lines. Furthermore, we show that the longer the resonator, the better coherence among the comb lines.

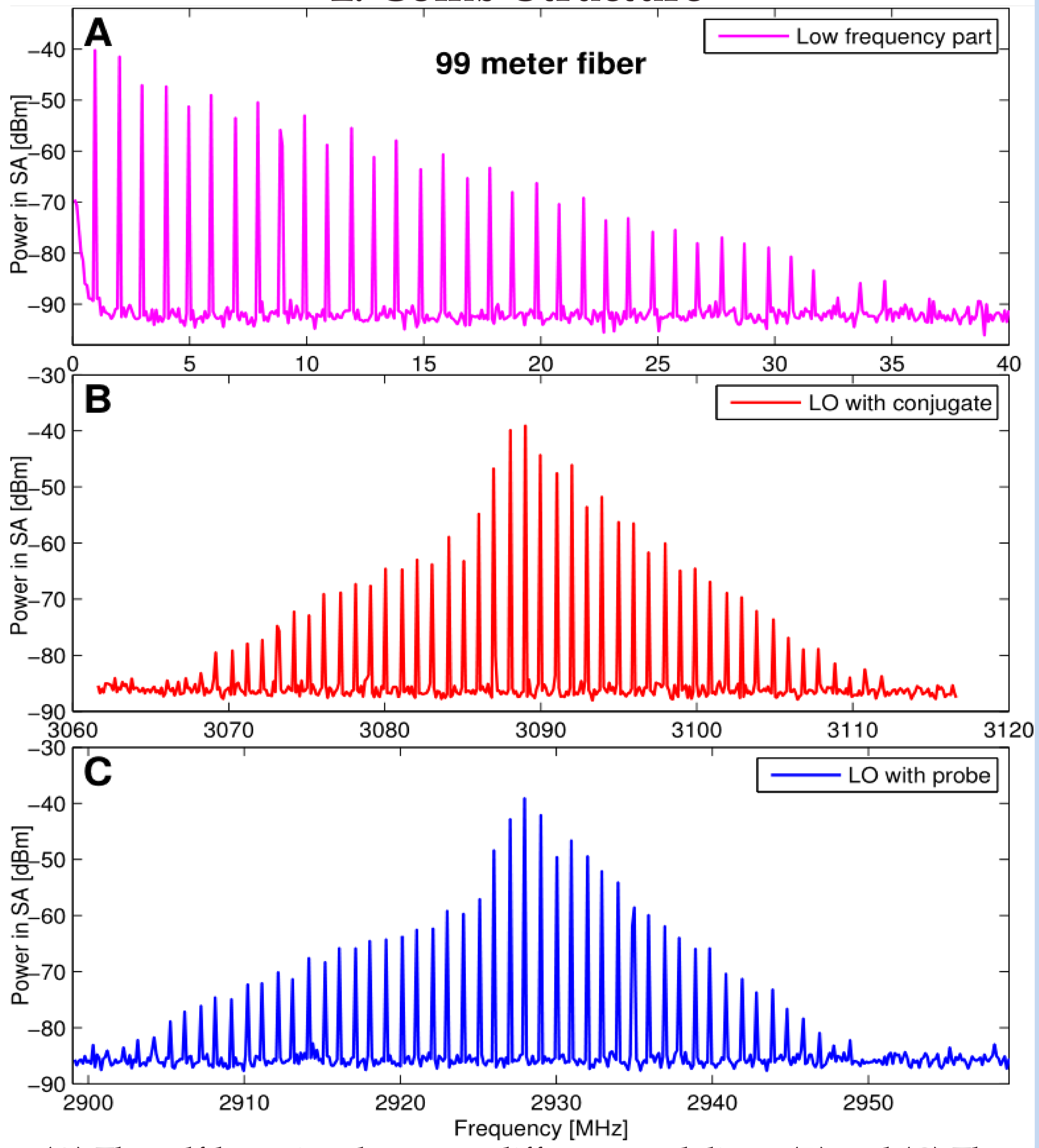

## 1. Background and Experimental Scheme



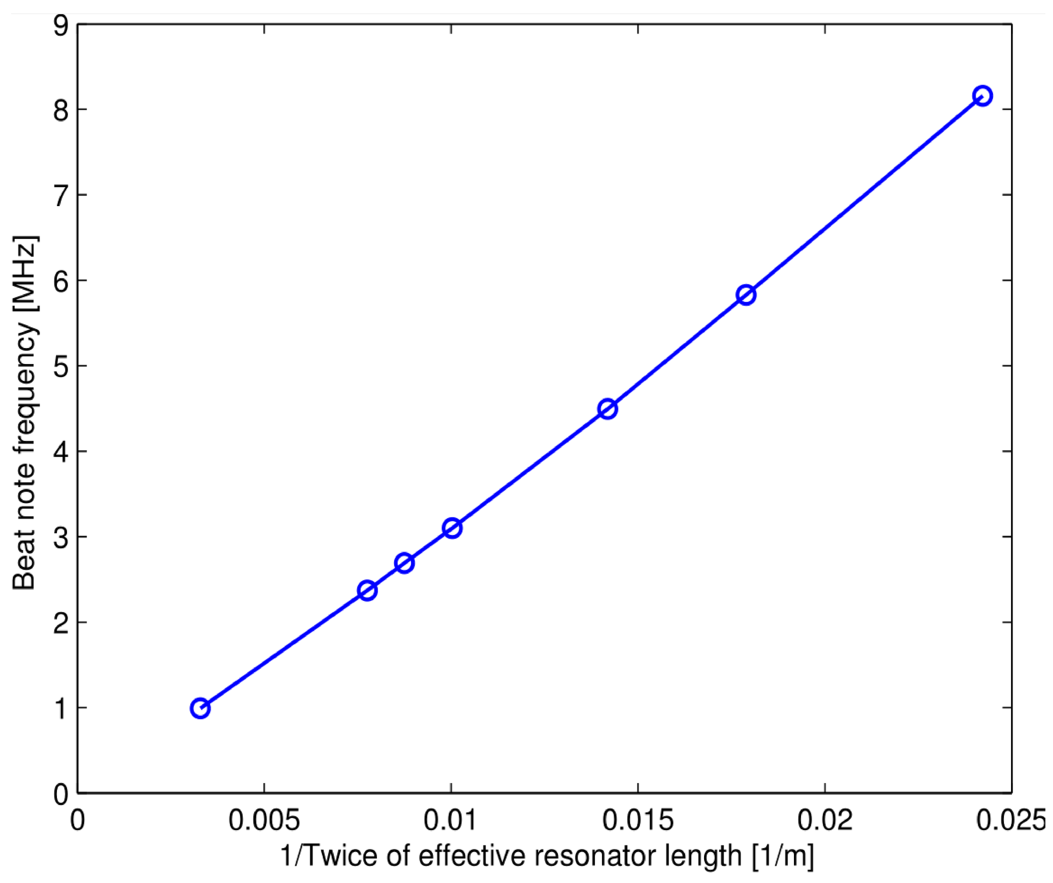

- An optical frequency comb (OFC) [1] is a light source with a series of equidistant frequency components, which is a versatile tool for a variety of applications, ranging from molecular spectroscopy to boosting communication capacity.
- A phase conjugate mirror (PCM) [2-4] typically consists of counter-propagating beams with degenerate frequency or nearly-degenerate frequencies, which forms a grating. The grating results in the generation of a conjugate beam by four-wave mixing (FWM) upon the injection of a probe beam. The unique property of PCM is the conjugate beam possesses a phase of $-\phi$, which is exactly the reversal of the incoming beam's phase, $\phi$. This phase conjugation allows for aberration correction in an optical system. A phase conjugate resonator (PCR) is a resonator with PCM serving instead of a normal mirror.
- Here we realize a PCR with a forward-propagating PCM with large gain, so that it oscillates in a fiber-optical cavity with the build-up of spontaneous emission. A multi-tooth comb is observed and the phase coherence is confirmed by measuring the beating signal.
- The forward-propagating PCM is based on a FWM process in hot rubidium vapor with a double-lambda scheme [5]. Due to this arrangement, the feedback photons are first converted into the conjugate frequency and get converted back to the probe frequency after a second trip in the loop. Each conversion happens with phase conjugation, thus the phase coherence is promised. The forward FWM has also been shown to possess high gain, thus the PCR can oscillate just with spontaneous emission. A fiber is used in the feedback loop to tune the resonator length and the consequent resonator mode spacing.

## 2. Comb Structure




- **(A)** The self-beat signals among different comb lines. **(B)** and **(C)** The output of PCR consists of both probe and conjugate frequencies and is sent to beat with a local oscillator.

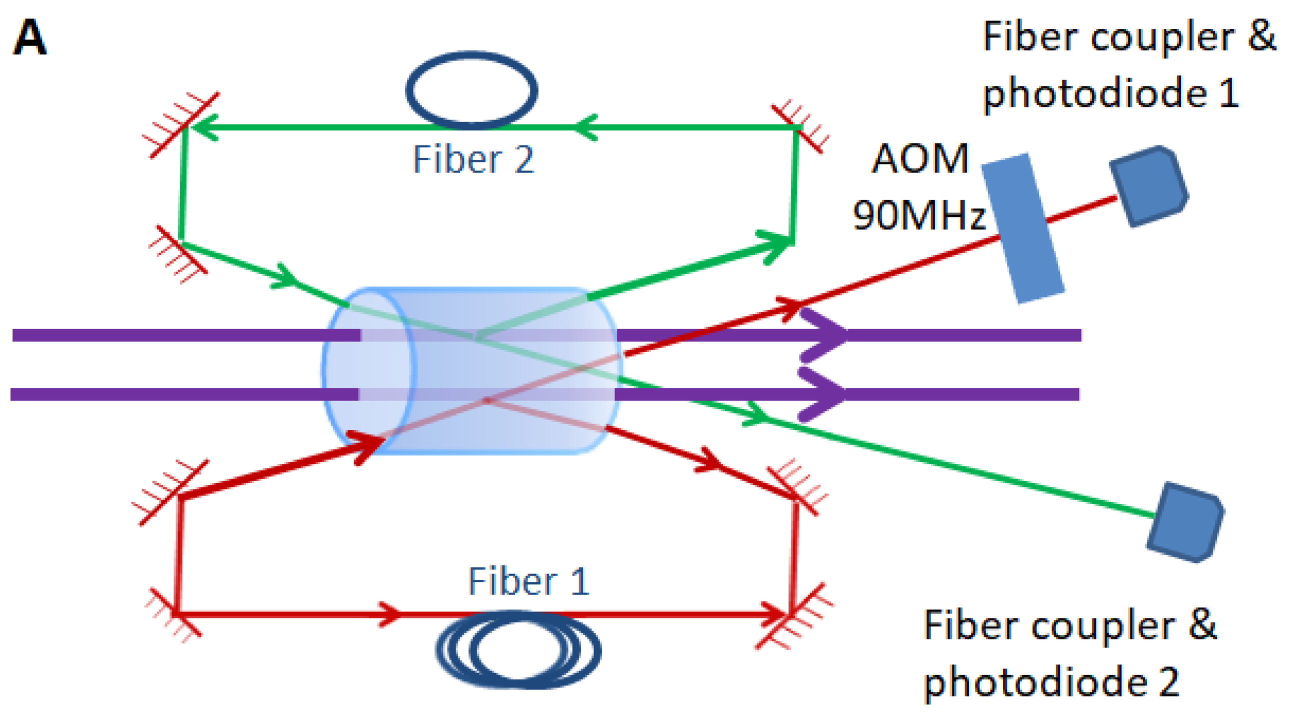
## 3. Comb line spacing

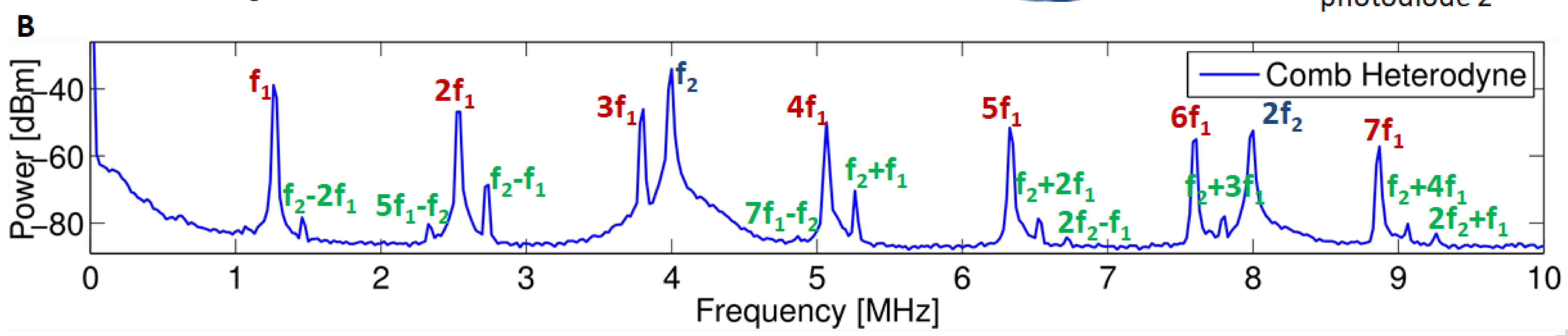



- The comb line spacing depends on the resonator length, with a relation of c/2L, where c is the speed of light, L is the effective resonator length (including the refraction index of the optical fiber).

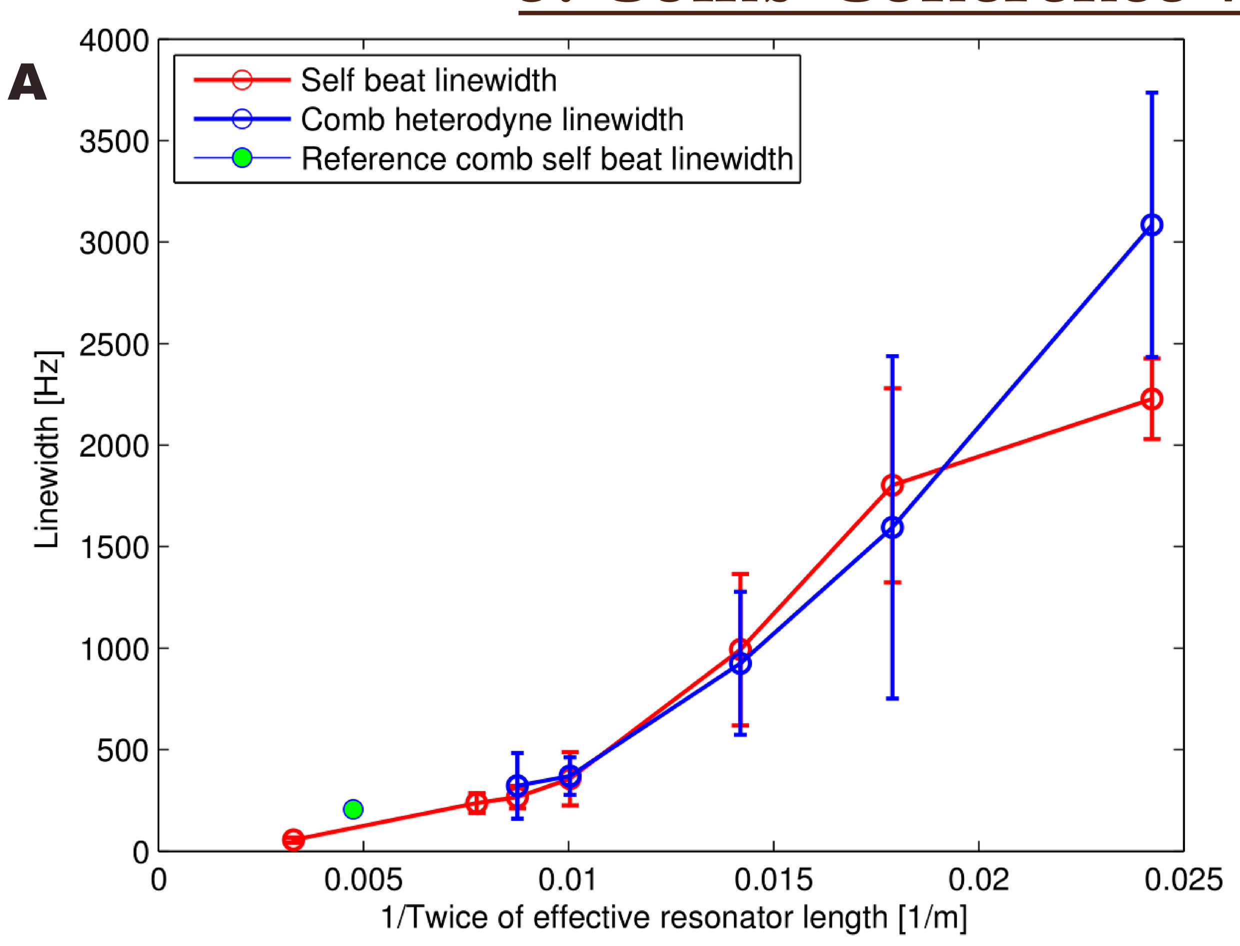
## 4. Comb Heterodyne

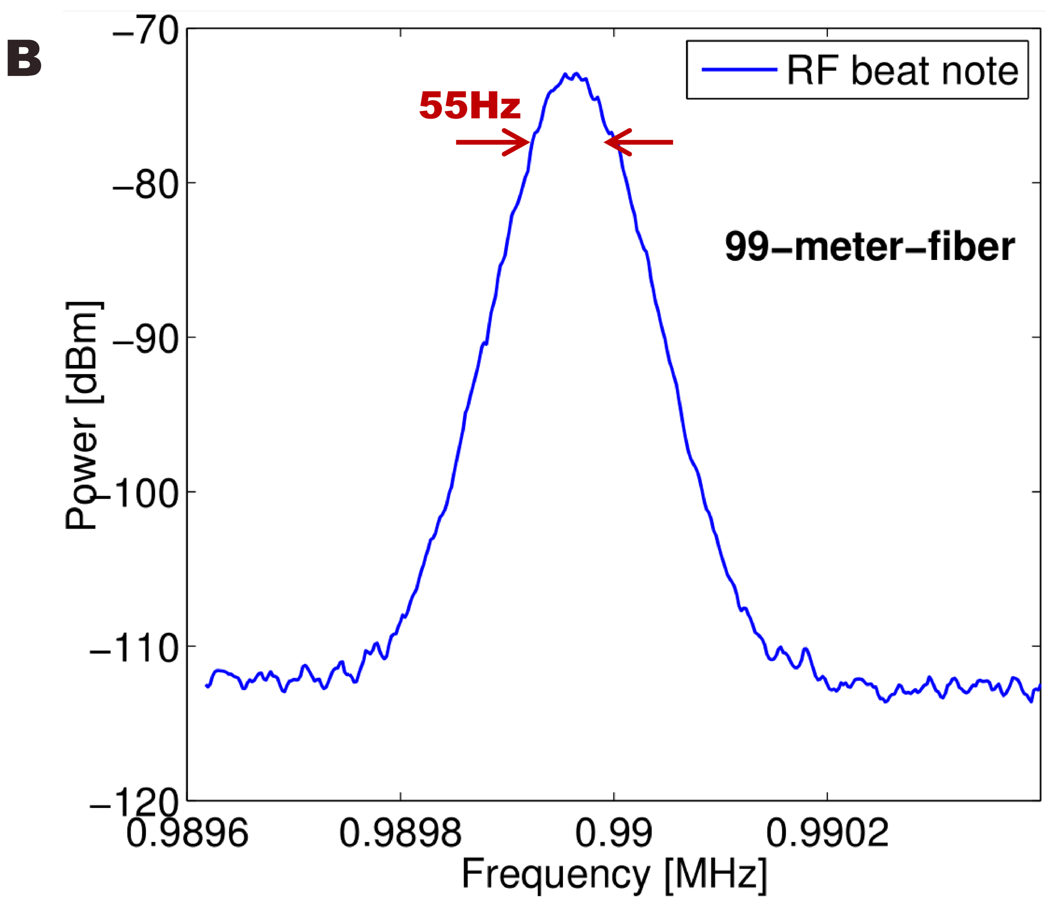
- **(A)** To test the comb coherence, we split the pump beam into two to prepare two sets of PCR combs with different resonator lengths and bring them together for coherent interferometry by detecting the heterodyne beat between them.
- **(B)** The repetition rates from the two combs are marked with f1 (the red font) and f2 (the blue font) in the spectrum.(b). The observed beat signals are marked with the green font.




## 5. Comb Coherence vs Resonator Length




- **(A)** The self beat linewidth is measured when the output of PCR hits on the photodiode. The comb heterodyne linewidth is when the output of PCR is sent to beat with a reference comb as shown in the section 4. The reference comb is with self beat linewidth of 200Hz (the green dot). **(B)** The example of self beat linewidth when the resonators consists of a 99 meter fiber. The linewidth is 55Hz, which is much smaller than the situations for the shorter fibers, as shown in the red line in **(A)**.

## 6. References


[1] Scott A. Diddams, Kerry Vahala, and Thomas Udem, "Optical frequency combs: Coherently uniting the electromagnetic spectrum", Science 369 (6501), eaay3676 (2020).

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[5] Vincent Boyer, Alberto M. Marino, Raphael C. Pooser, and Paul D. Lett, "Entangled Images from Four-Wave Mixing", Science 321 (5888), 544-547 (2008).