JW3A.71: Raman Comb Formation in Silica Rod Microresonator

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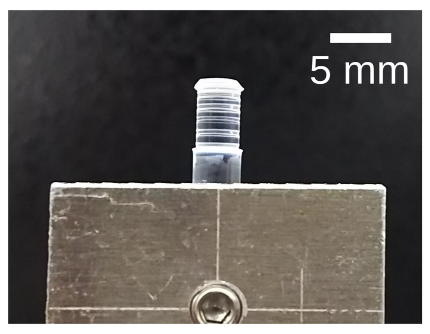
Silica microresonators have potential for broad and phase-locked Raman comb generation, which can be used for applications such as sensors, microwave oscillators, and compact pulse laser sources. However, the formation dynamics in the broadband gain regime has not revealed well. Here we studied Raman comb formation in silica rod microresonators theoretically and experimentally. Controlling pump detuning and coupling strength could change the Raman offset wavelength, which correspond to two large peaks in the gain spectrum and generate Raman combs with a smooth envelope. The Raman comb had 3 dB linewidth of 6 kHz and 20 dB linewidth of 59 kHz.

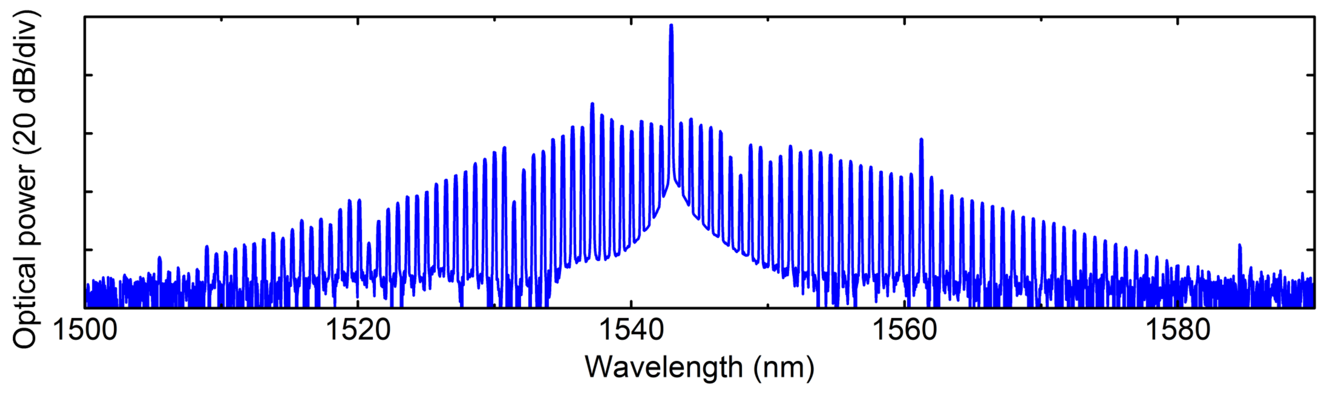
Background

Optical microresonators are suitable devices to achieve low threshold lasing from a continuous wave (CW) pump. Soliton and phase-locked Kerr combs, which are generated via four wave mixing, have been well studied recently. On the other hand, Raman comb formation has not been understood.

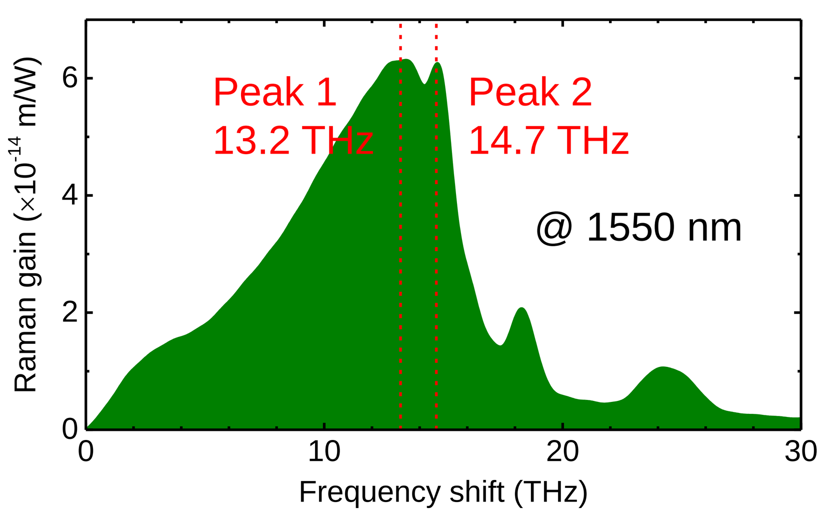
Silica rod microresonator

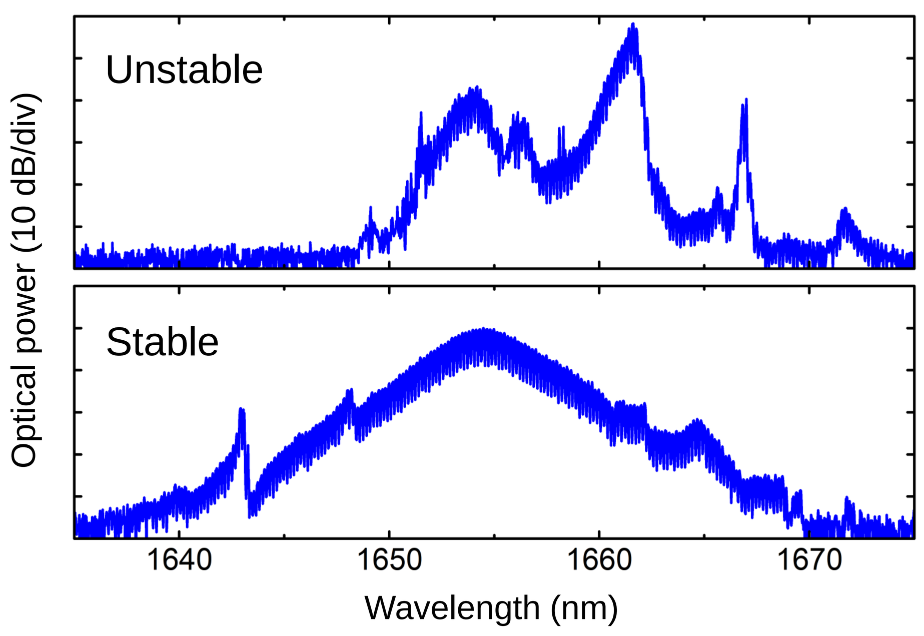


Kerr comb spectrum



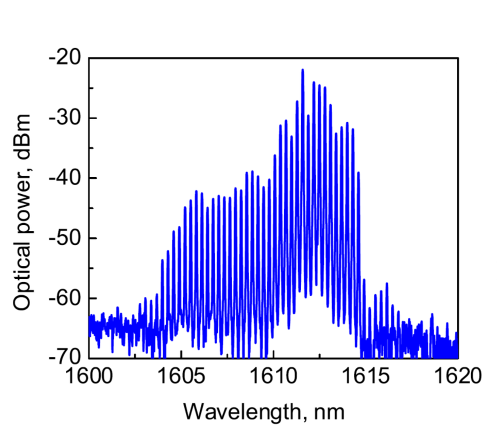
Raman comb from a silica microresonator

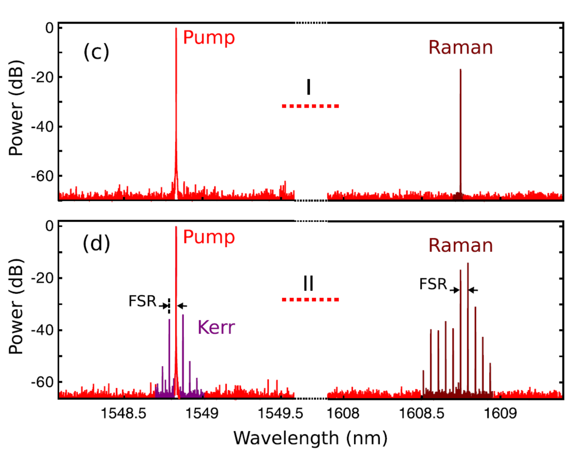


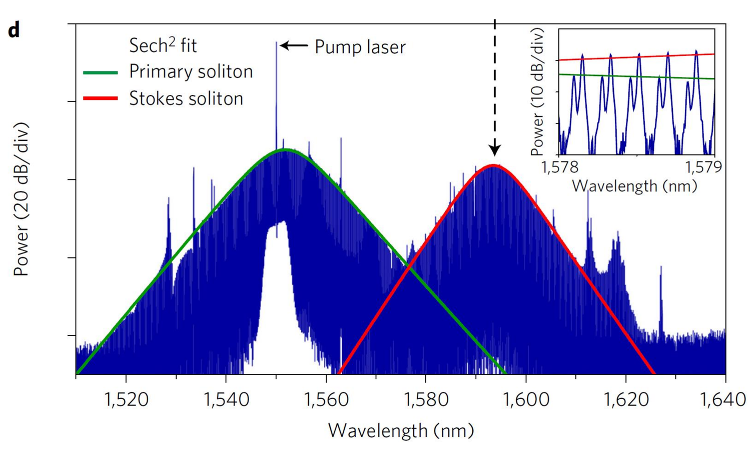


Silica has broadband Raman gain,
Which induces an asymmetrical Raman comb.

Phase locking has been reported with CaF_2, BaF_2, and SiO_2 microresonators.







W. Liang et al., PRL 105, 143903 (2010). G. Lin and Y. K. Chembo, OL 41, 3718 (2016). Q.-F. Yang et al., Nat. Phys. 13, 53 (2017).

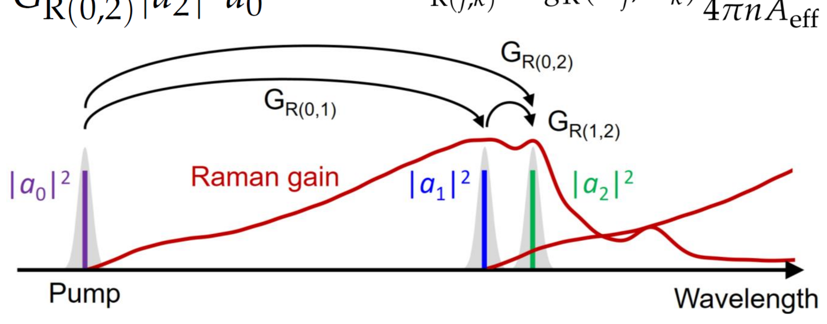
Three mode system

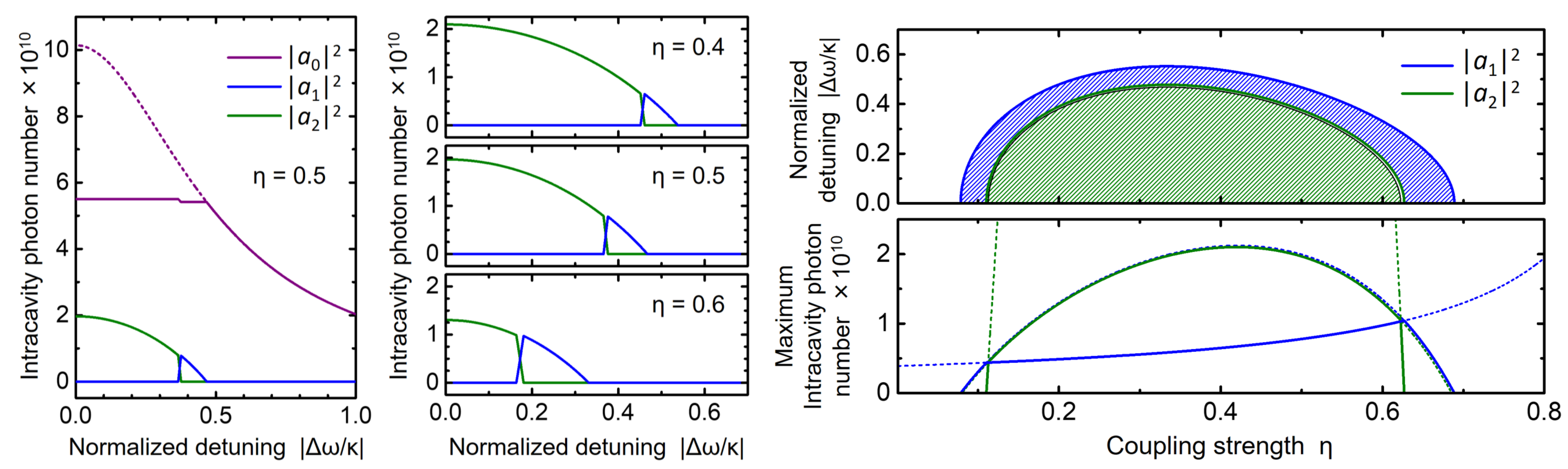
To consider energy exchange between pump and Raman modes at 13.2 and 14.7 THz, we analyzed intracavity photon numbers by using a simple three mode system.
The weak (strong) coupling induces efficient Raman scattering at 14.7 (13.2) THz.

$$\frac{\partial a_0}{\partial t} = -\frac{1}{2}\kappa a_0 + i\Delta\omega a_0 + \sqrt{\kappa_c}s_{\text{in}} - G_{R(0,1)}|a_1|^2 a_0 - G_{R(0,2)}|a_2|^2 a_0 \qquad G_{R(j,k)} = g_R(\omega_j,\omega_k)\frac{cD_1\hbar\omega_j}{4\pi n A_{\text{eff}}}$$

$$\frac{\partial a_1}{\partial t} = -\frac{1}{2}\kappa a_1 + G_{R(0,1)}|a_0|^2 a_1 - G_{R(1,2)}|a_2|^2 a_1$$

$$\frac{\partial a_2}{\partial t} = -\frac{1}{2}\kappa a_2 + G_{R(0,2)}|a_0|^2 a_2 + G_{R(1,2)}|a_1|^2 a_2$$

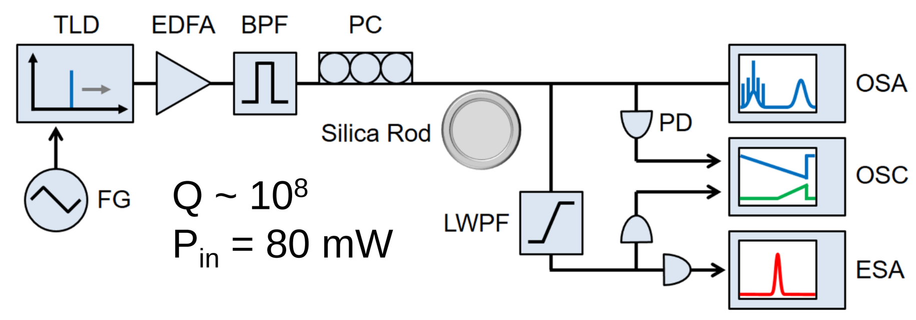




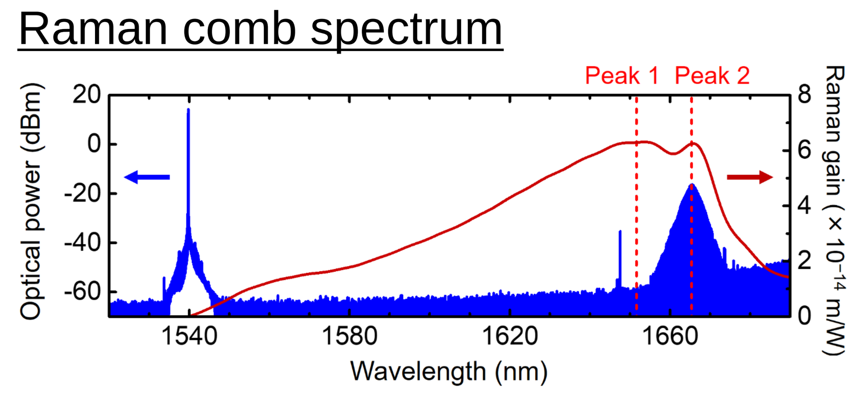
Raman comb formation

Although Raman combs are prone to having complex spectrum due to the broadband gain, the coupling control can cause obvious offset transition from Peak 1 to Peak 2.

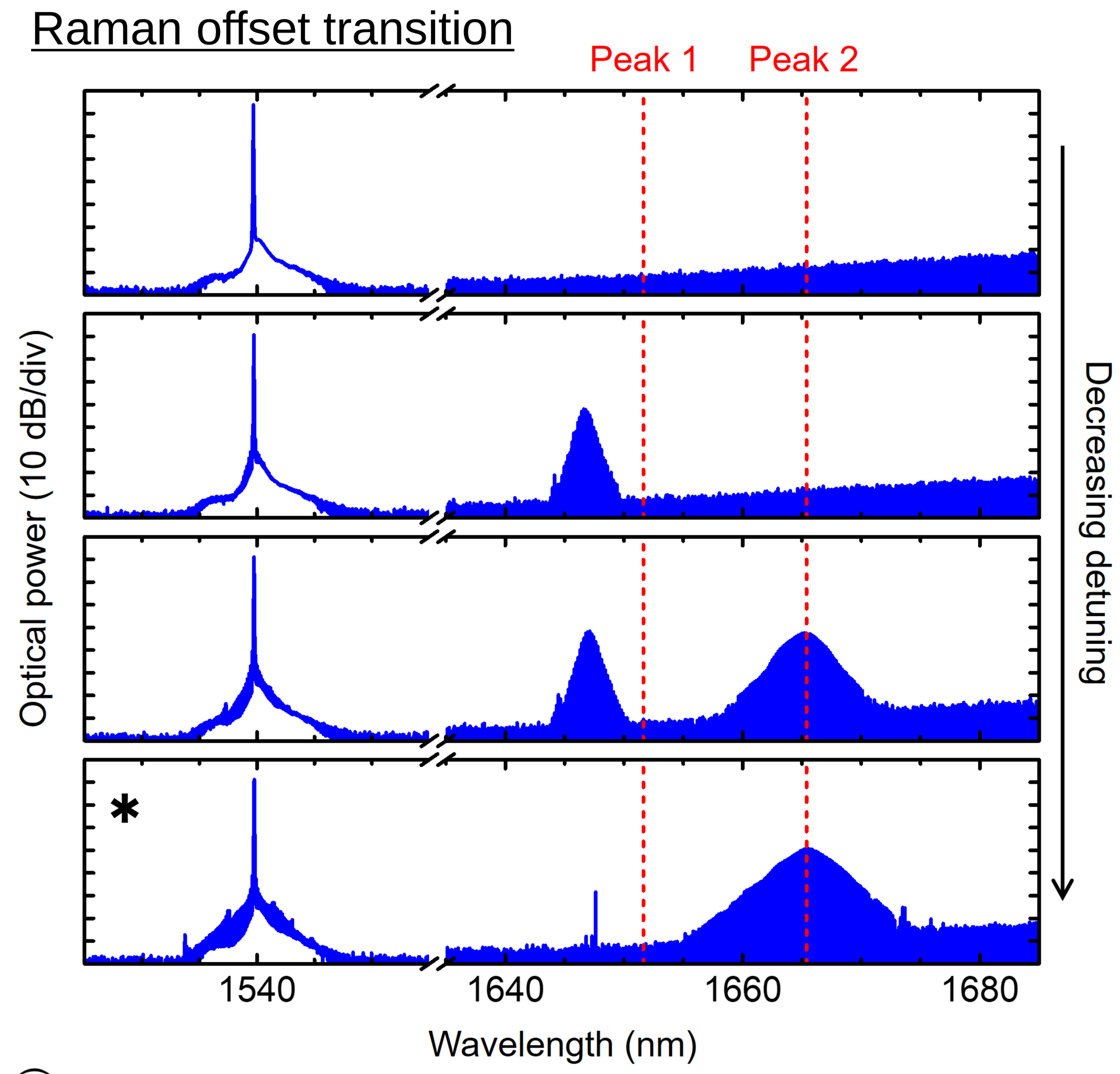
Experiment setup



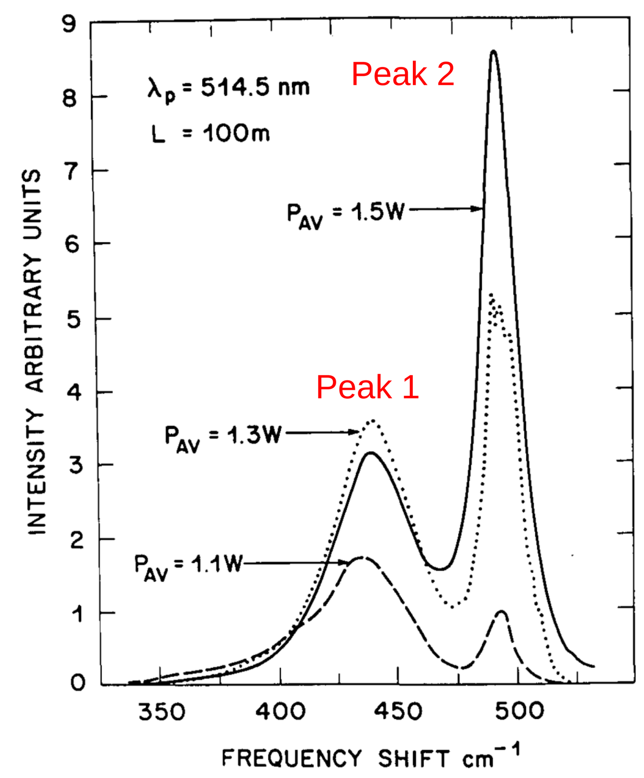
Raman comb spectrum



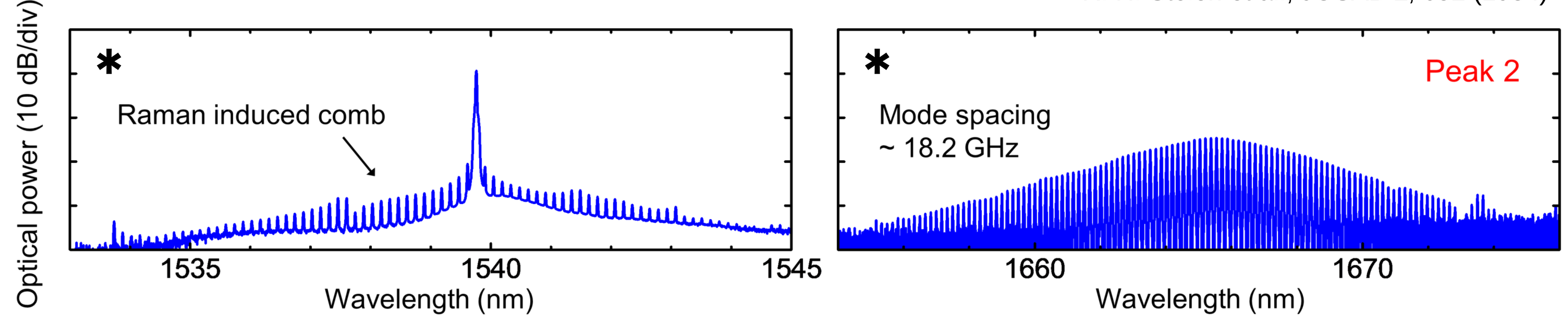
Raman offset transition



The similar behavior was observed in silica fibers, which depends on the input pulse power

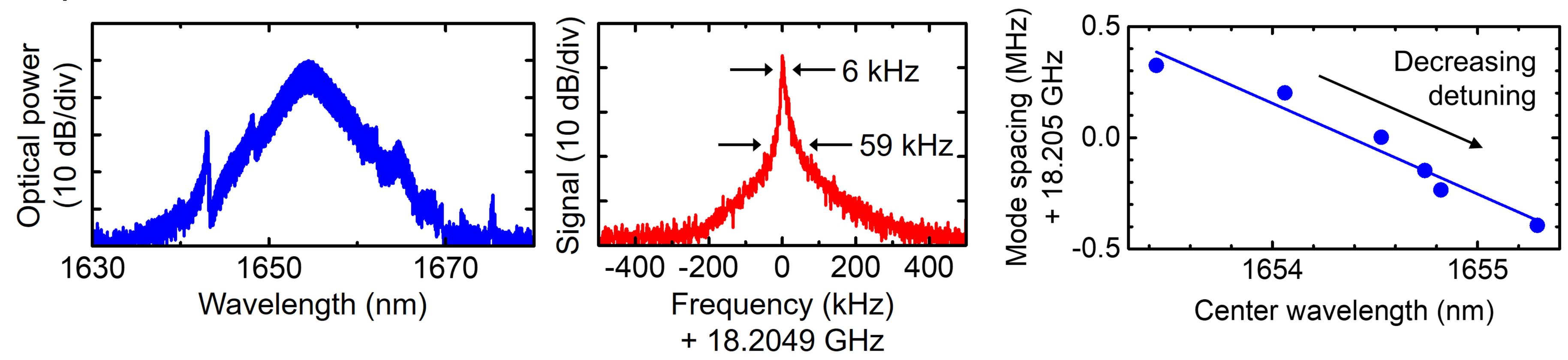


R. H. Stolen et al., JOSAB **1**, 652 (1984)



Linewidth & Mode spacing

The Raman comb with 18.2 GHz mode spacing has 3 dB linewidth of 6 kHz and 20 dB linewidth of 59 kHz, which indicates it has a potential to obtain smooth and phase-locked Raman combs. The detuning stabilization and the dispersion engineering can improve the coherence.



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