Broadband gigahertz frequency comb via mechanical-optical-mechanical multimode lasing

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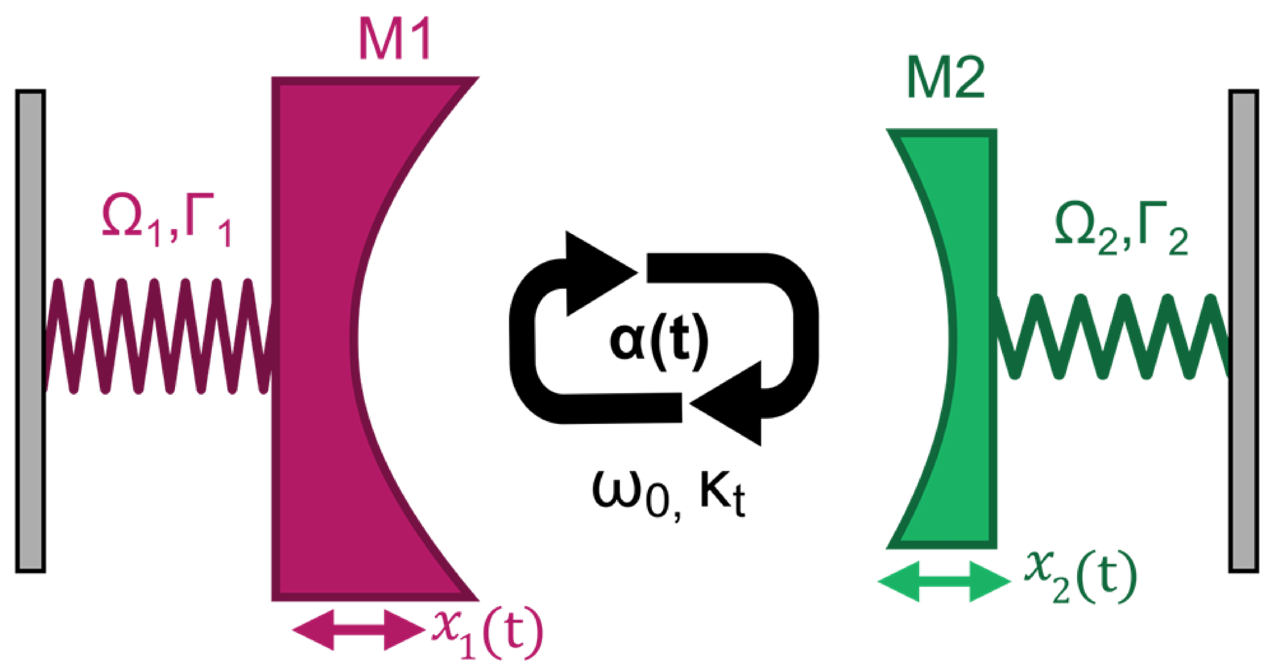
Abstract

We report a broadband (>15 GHz) optomechanical frequency comb resulting from two-mode lasing in a mechanical-optical-mechanical (MOM) system.

MOM configuration: concept

Archetypal optomechanical picture



Multimode optomechanical system with ***two independent mechanical modes*** that interact with the same optical cavity

A bit of theory[1]

Master equations

$$\begin{cases} \dot{\alpha}(t) = (j(\Delta + g_1 x_1 + g_2 x_2) - \kappa_t)\alpha(t) + \sqrt{\frac{\kappa_e}{2}\frac{P_{in}}{\hbar\omega_l}} \\ \ddot{x}_i(t) = -\Gamma_i \dot{x}_i - \Omega_i^2 x_i + 2\Omega_i g_i |\alpha|^2 \end{cases}$$

Mechanical susceptibilities

$$\boldsymbol{\chi_{\mathrm{eff},i}^{-1} = \chi_{\mathrm{m},i}^{-1} + \Sigma_{\mathrm{OM},i} + K_i}$$

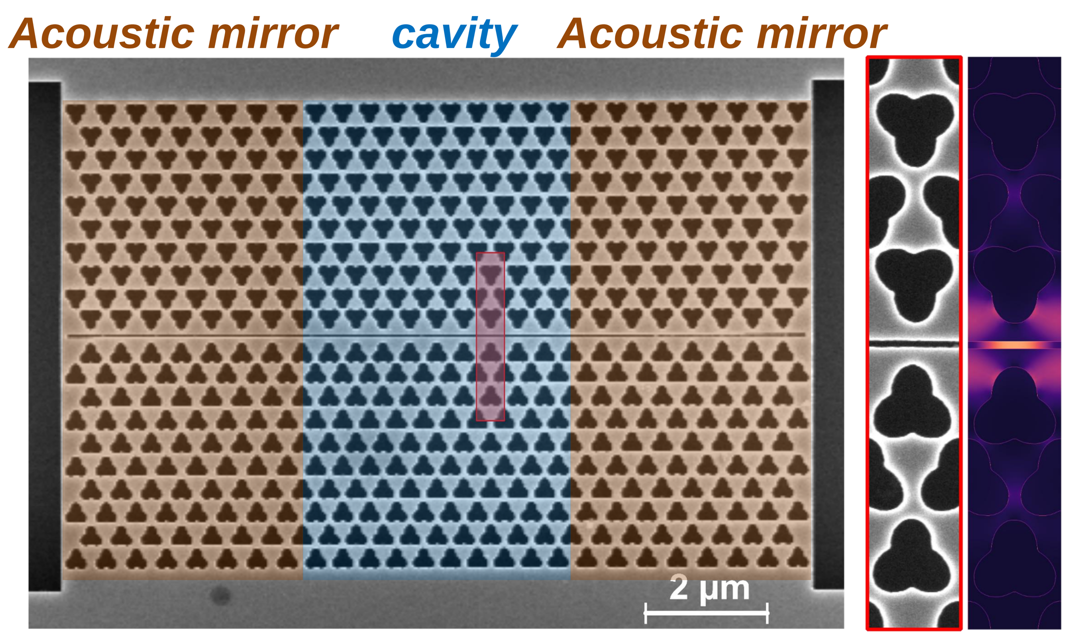
$$\begin{cases} \Omega_{\mathrm{eff},i} = \Re\{\chi_{eff,i}^{-1}\}/2\Omega_i \\ \Gamma_{\mathrm{eff},i} = \Im\{\chi_{eff,i}^{-1}\}/\Omega_i \end{cases}$$

$$\Sigma_{\mathrm{OM},i}[\omega] = 2\Omega_i g_i^2 \sigma[\omega]$$ → *Direct* optomechanical coupling

$$K_i[\omega] \propto \frac{\Sigma_{\mathrm{OM},i}[\omega] \times \Sigma_{\mathrm{OM},j}[\omega]}{\chi_j[\omega] + \Sigma_{\mathrm{OM},j}[\omega]}$$ → *Indirect* MOM coupling

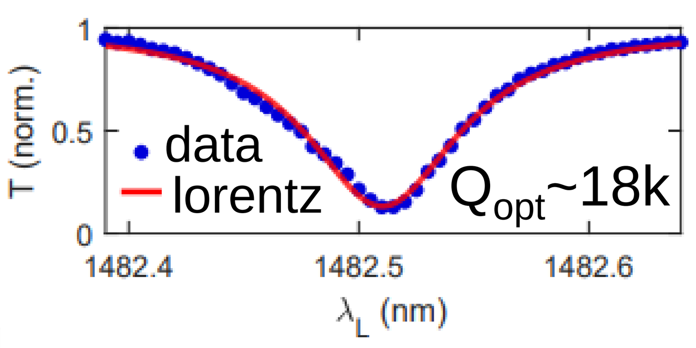
Experimental platform[2]

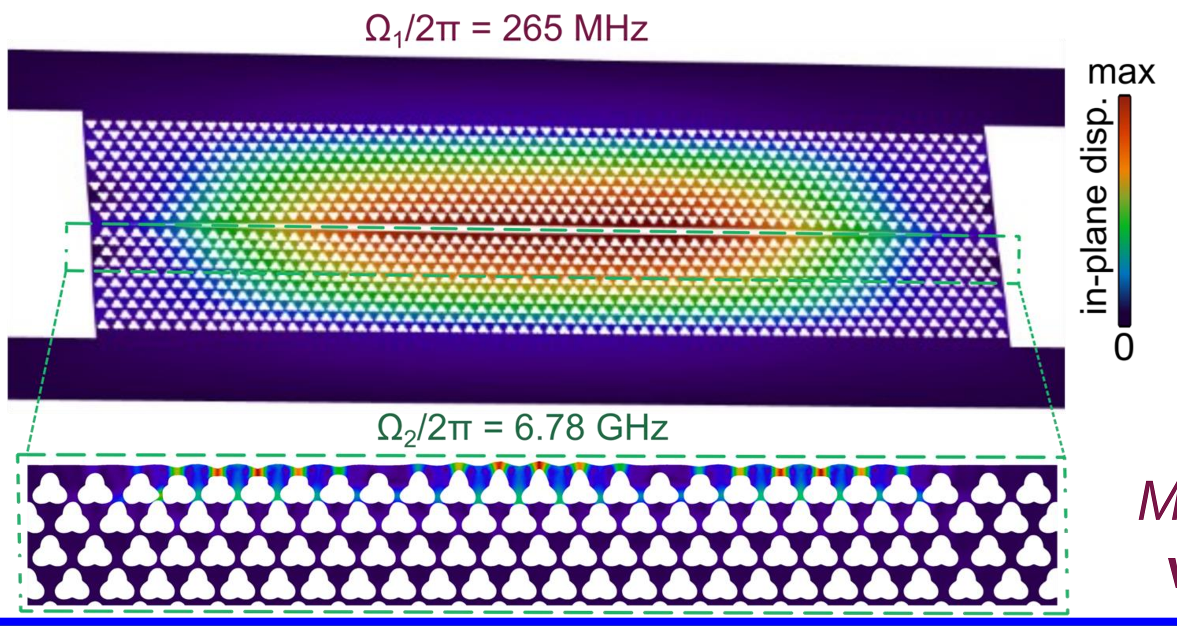
We design a platform achieving the MOM configuration



Optics

Disorder-induced mode localization in the air-slot





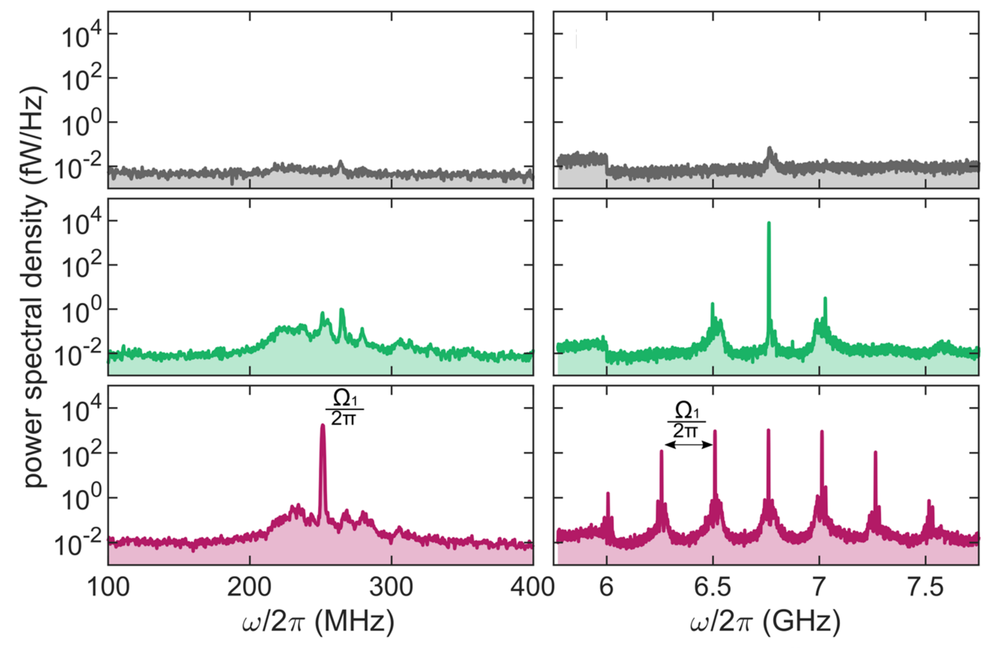
Mechanics

M1: in-plane **breathing** mode

M2: phononic **standing wave** at the interface

Frequency domain

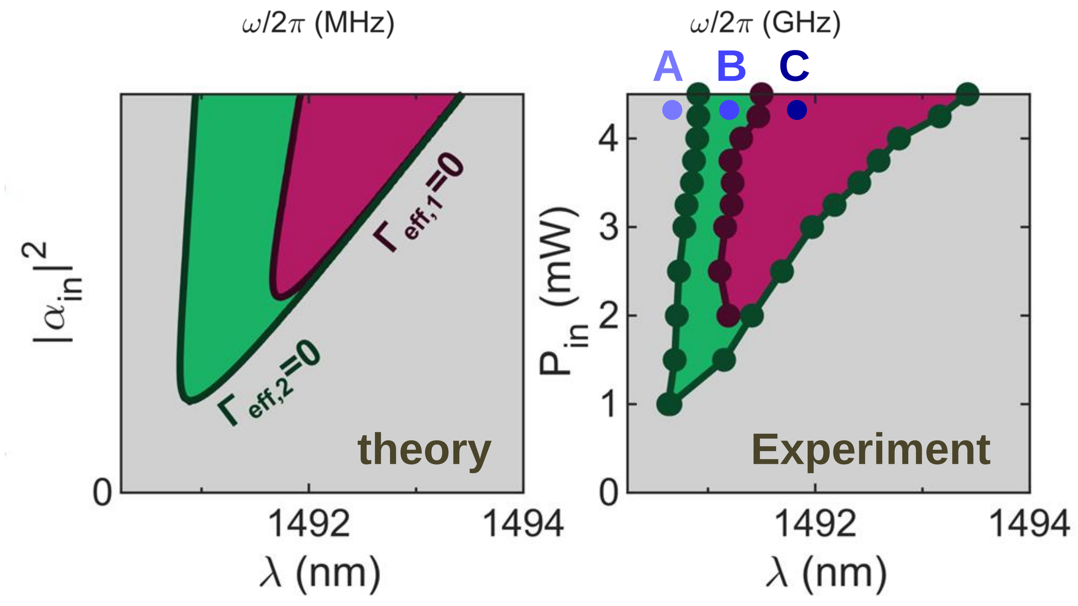
We study the lasing dynamics of the mechanical modes v.s. laser wavelength λ and power P_{in}



A No lasing - *M1* and *M2* are thermally excited

B Single lasing - *M2* is lasing

C Comb – *M1* and *M2* are lasing, comb formation



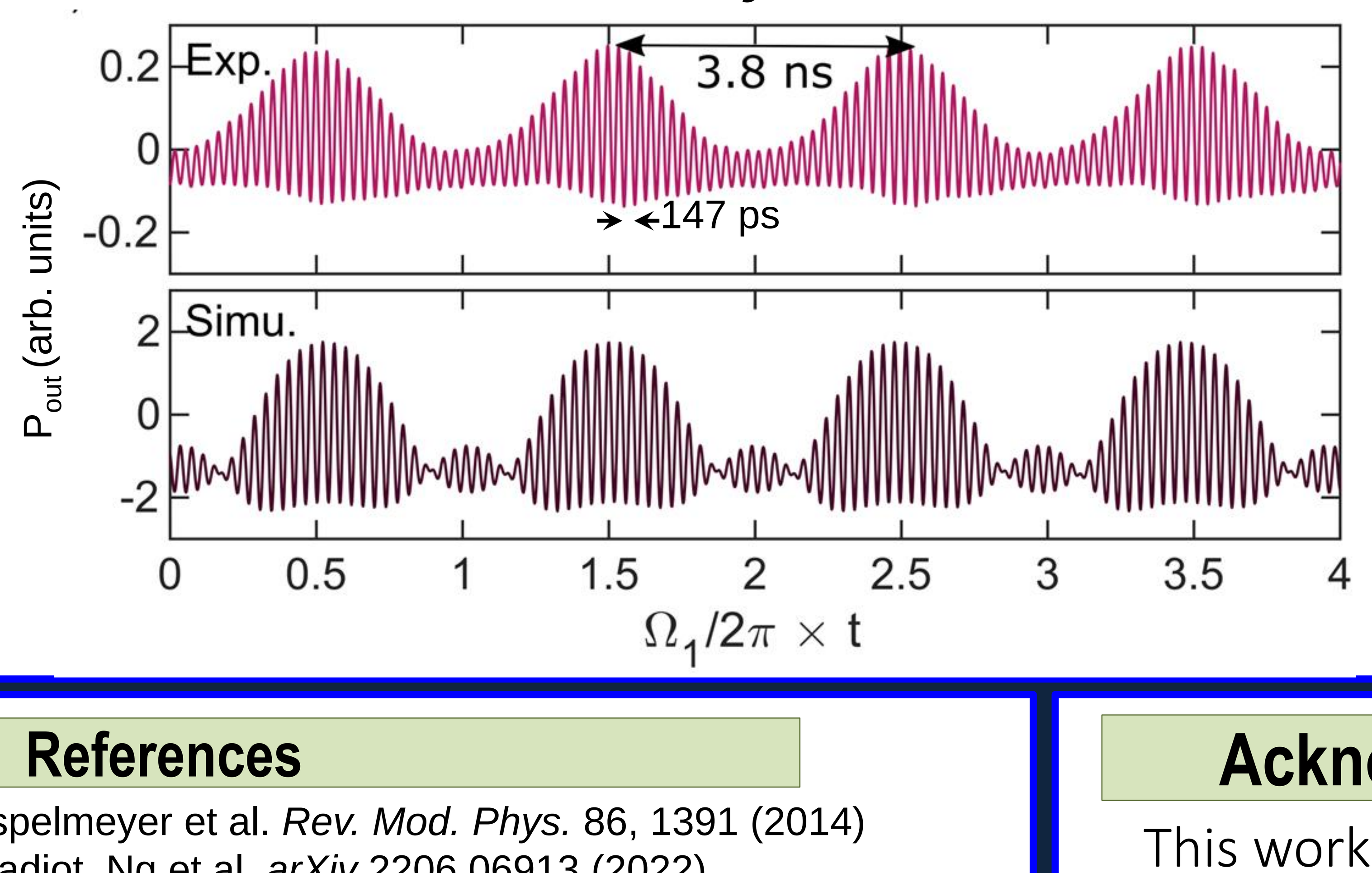
Lasing thresholds

$$\Gamma_{\mathrm{eff},1} < 0$$

$$\Gamma_{\mathrm{eff},2} < 0$$

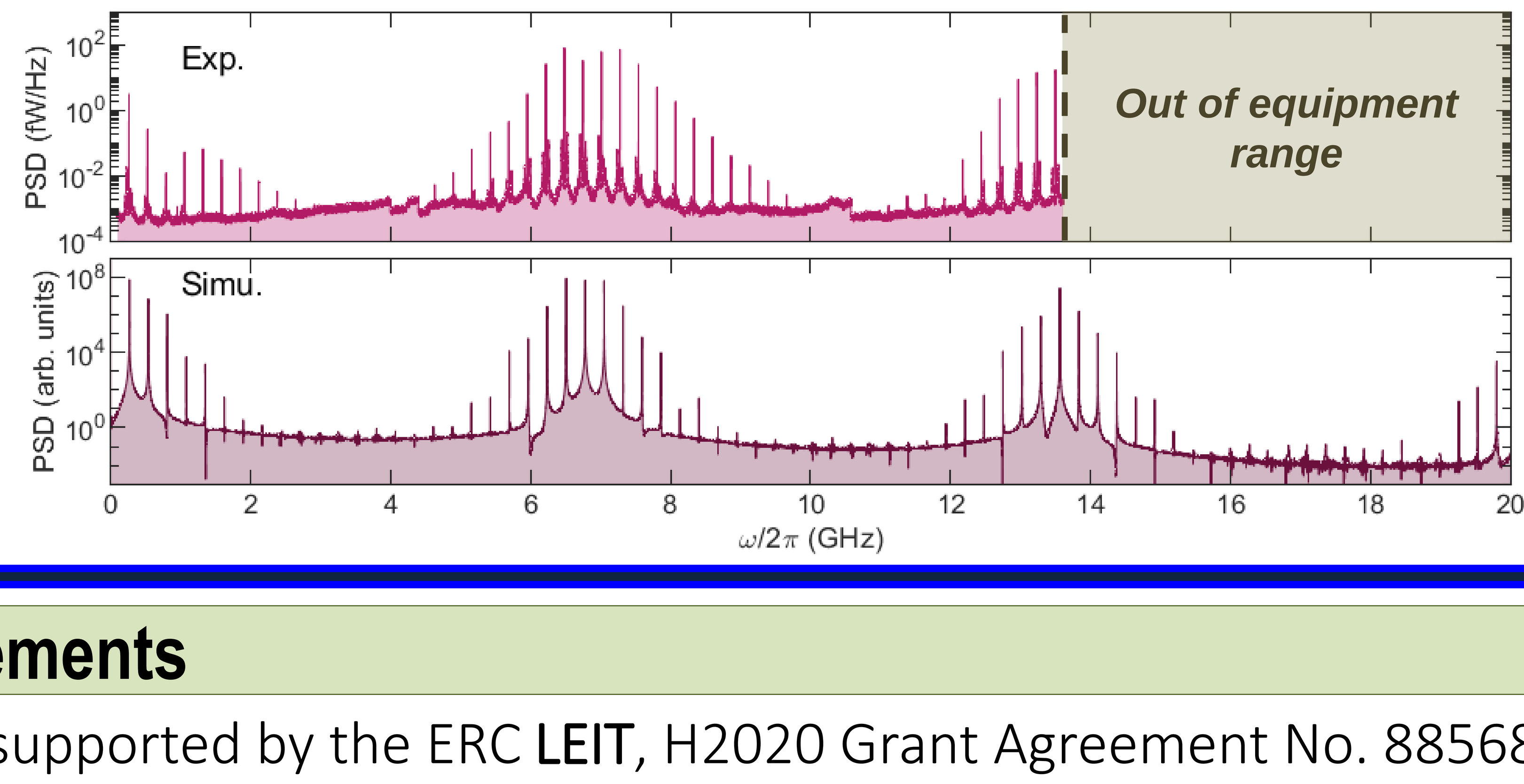
Time domain

Checking the real-time output optical power reveals the modulation dynamics.



Conclusion

- Double optomechanical lasing leads to a **frequency comb** with center Ω_2 and spacing Ω_1.
- Operation regime can be controlled using λ and P_{in}
- ***Dynamics ranging over 15 GHz:***



References

[1] Aspelmeyer et al. *Rev. Mod. Phys.* 86, 1391 (2014)
[2] Madiot, Ng et al. *arXiv* 2206.06913 (2022)
[3] Ng, Nizet et al, *arXiv* (2022)

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