Frequency Comb Generation in Coupled Microcavities

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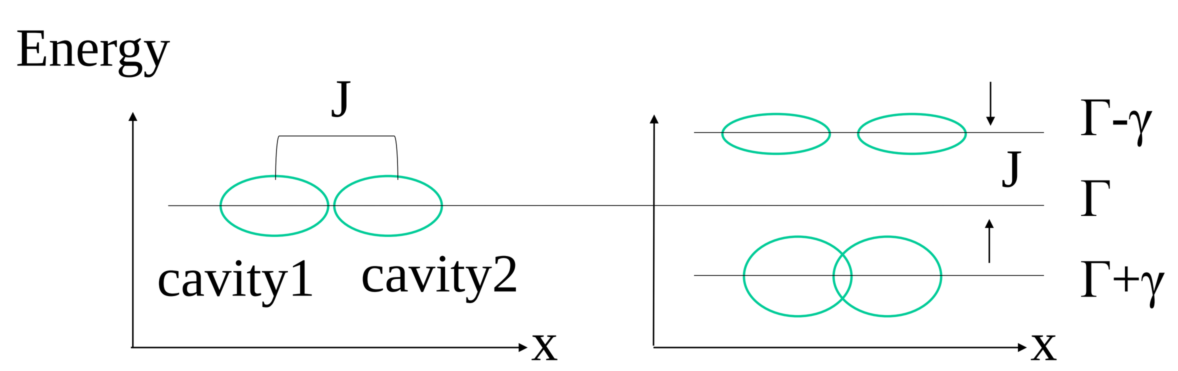
INTRODUCTION

Coupled exciton-polariton systems exhibit rich phenomena ranging from Josephson oscillation, dynamic squeezing to nontrivial phase coupling. These phenomena are possible because of strong nonlinear polariton-polariton interaction. A the same time, polariton systems are inherently open with a built-in optical interface, naturally suited for reservoir engineering through its optical mode. It is suggested recently the coexistence of on-site interaction and modified coupling with the environment can lead to a rich nonlinear dynamic phase diagram, including the existence of stable limit-cycles manifested as emergence of frequency combs.

Here, we demonstrate experimentally limit cycle and emergence of new frequency lines in two-coupled microcavities. This provides a fundamentally different mechanism of frequency comb generation than cascaded four-wave mixing in other types of micro-resonators. It is compatible with electrical pumping, and has a line-spacing tunable by the polariton nonlinearity and dissipative coupling, independent from the cavity modes.

Theoretical description



Complex Coupling:
$\boldsymbol{V_{12} = \gamma + iJ}$

Rayanov PRL **114**, 193901 (2015)

Driven-Dissipative Coupled-polariton equation

$$\frac{d\psi_{1,2}}{dt} = -\frac{1}{2}\left((\Gamma - G) - \mu|\psi_{1,2}|^2 - i2\omega_{1,2} + i\alpha|\psi_{1,2}|^2\right)\psi_{1,2} + \frac{1}{2}(iJ-\gamma)\psi_{2,1}$$

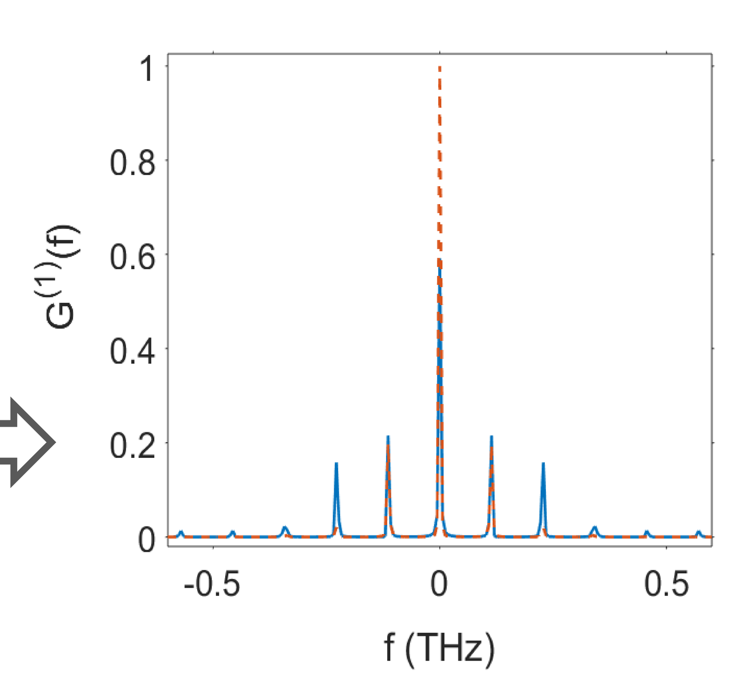
- Γ : decay rate, G : pump strength, ω : cavity frequency, α : on-site interaction
  J : Josephson coupling, γ : dissipative coupling

Power-dependent state evolution

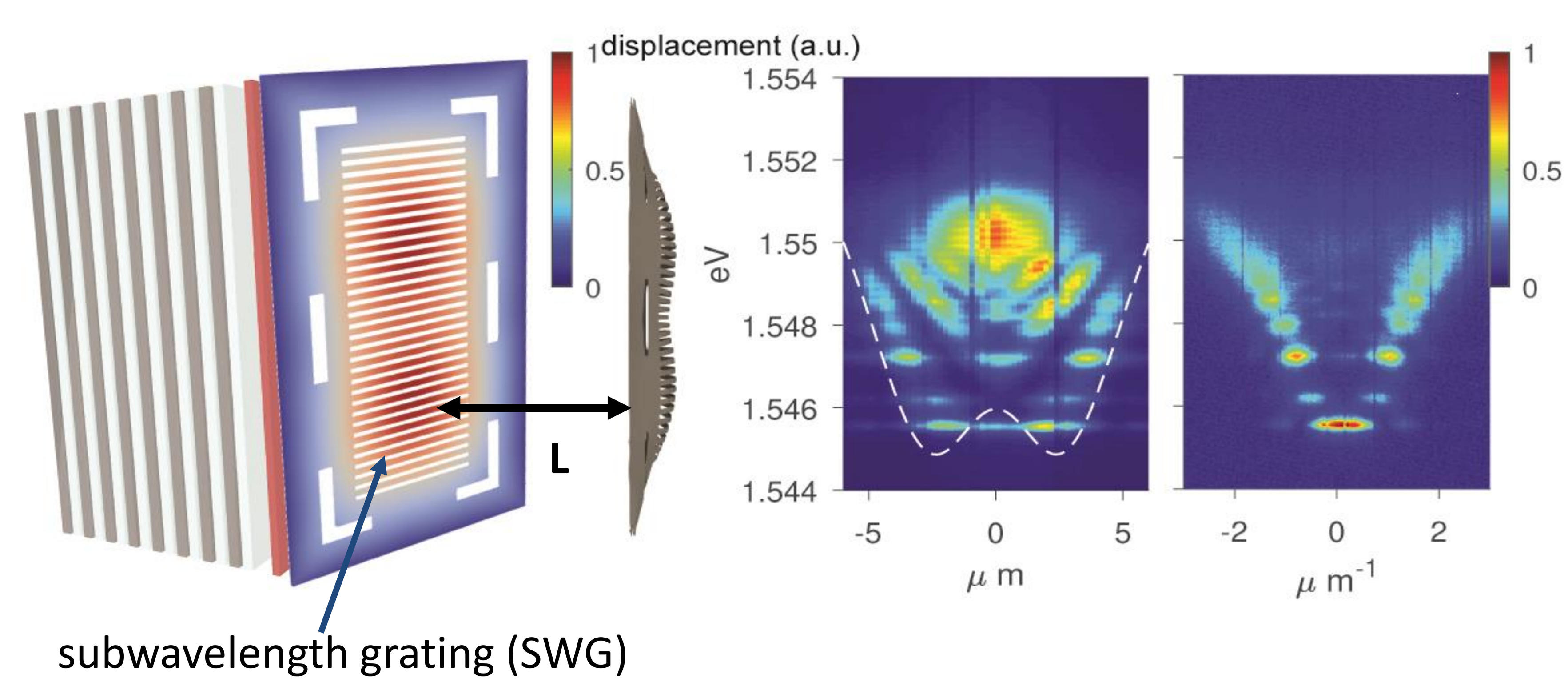
increasing G

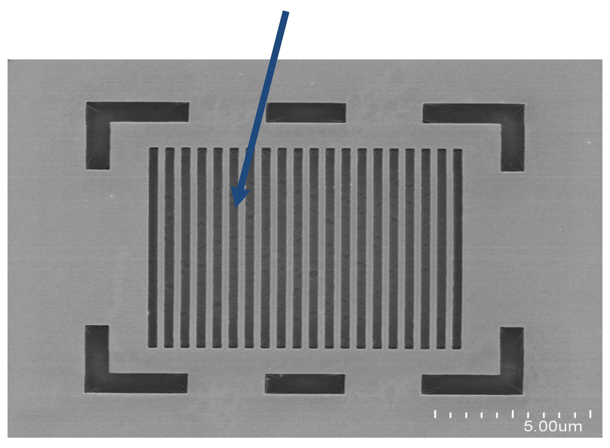
- Trivial solution : $\psi_{1,2} = 0$, no condensate
- Stable Anti-bonding : $\psi_1 = \psi_2^* \neq 0$, out-of-phase condensate
- Stable limit-cycle: period doubling with nontrivial phase coupling
- Stable Bonding: $\psi_1 = \psi_2 \neq 0$, in-phase condensate

Limit cycle from simulation



SWG based Coupled Microcavities

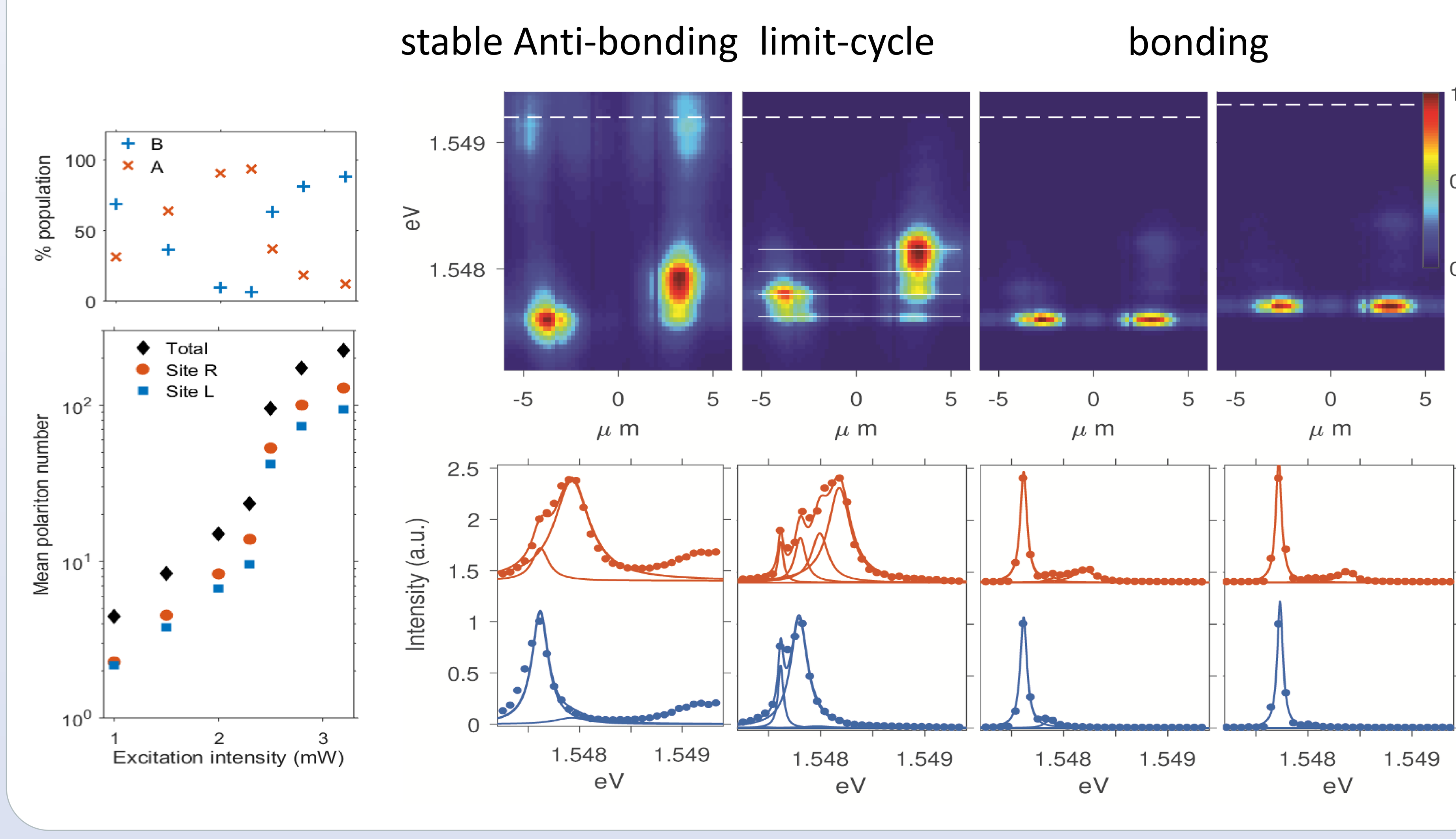




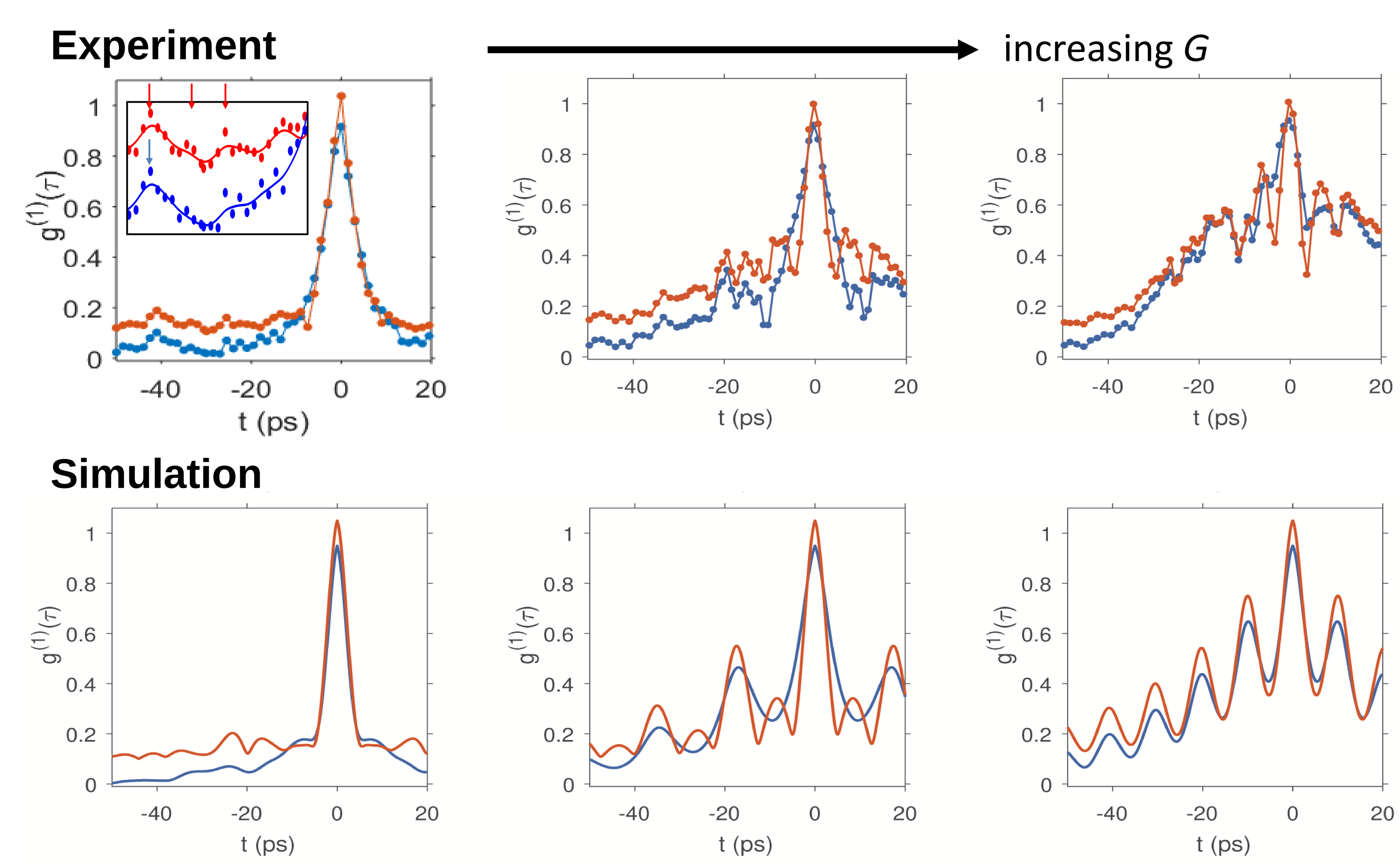
- Design of strain-release feature to control bending of the SWG
- Bending leads to different cavity length/resonance energy

→ Effective potential for polaritons
→ Interaction controlled by size
→ Tunneling controlled by spacing

Power-dependent photoluminescence

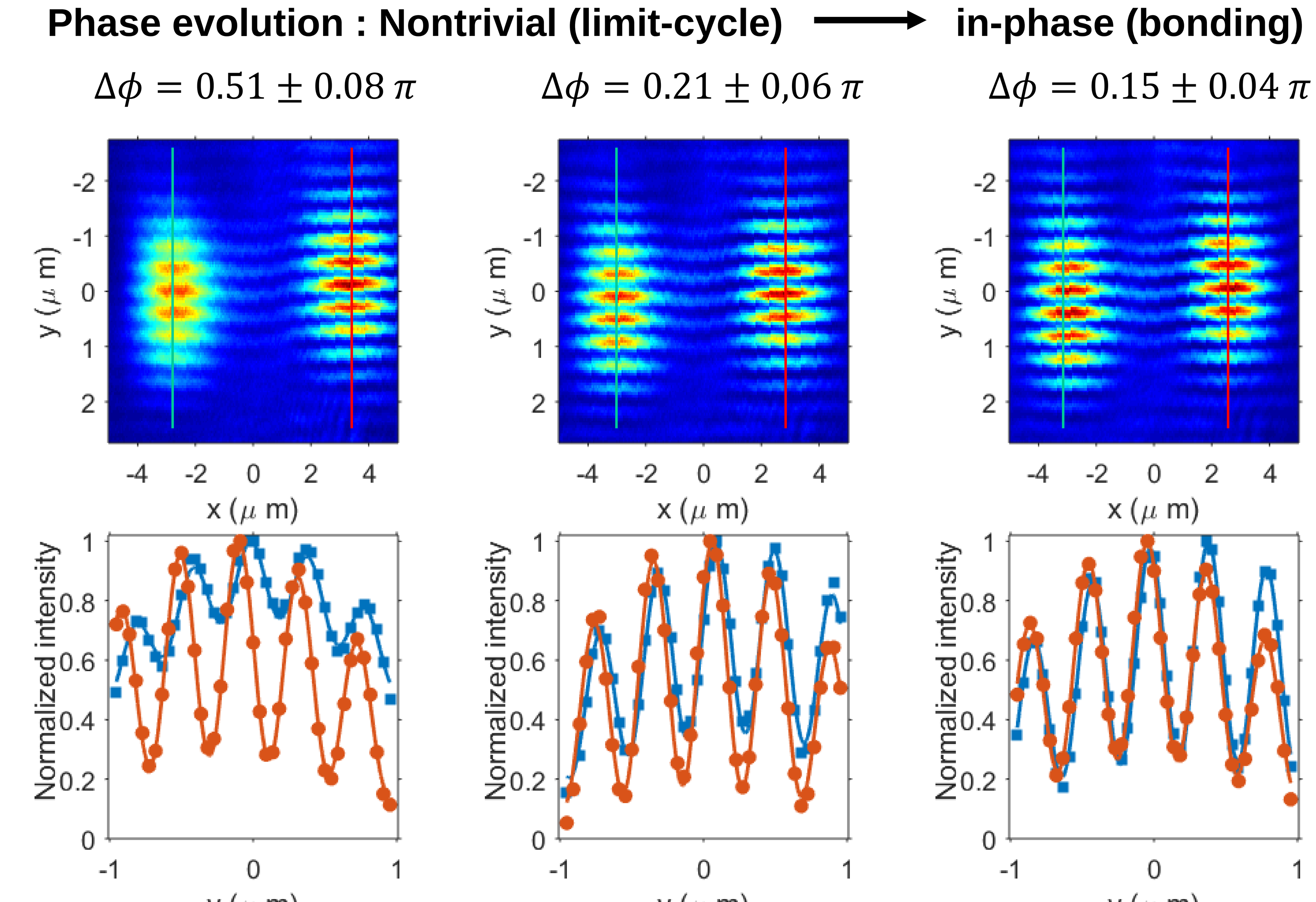


First-order temporal coherence



Relative phase measurement

Phase evolution : Nontrivial (limit-cycle) ⟶ in-phase (bonding)



Conclusion

We observed the frequency comb generation based on limit-cycle oscillations in coupled microcavities, evidenced by new equidistant spectral lines, coherence revivals and non-trivial phase between the coupled sites. Power dependent evolution of the system agrees very well with the theory and allows estimate of the dissipative coupling strength. Future work include phase diffusion measurements, electrical pumping and transitions between synchronization, limit cycles and chaos.

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