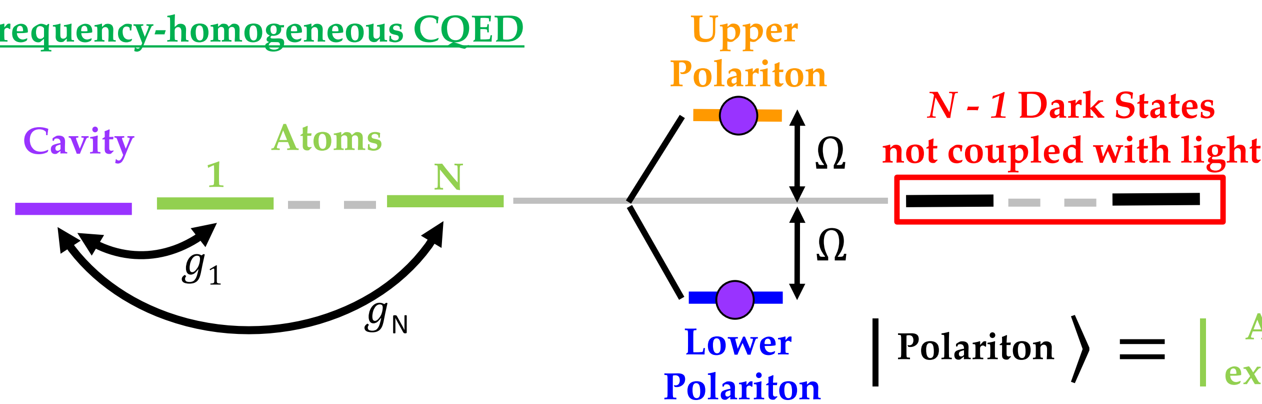
This work has been supported by the Paris Île-de-France Région in the framework of DIM SIRTEQ

Cavity-protected Multifrequency Polaritons in a Cold Atomic System

Pierre-Antoine Bourdel, Mohamed Baghdad, Sylvain Schwartz, Jakob Reichel, and Romain Long

Frequency-homogeneous CQED

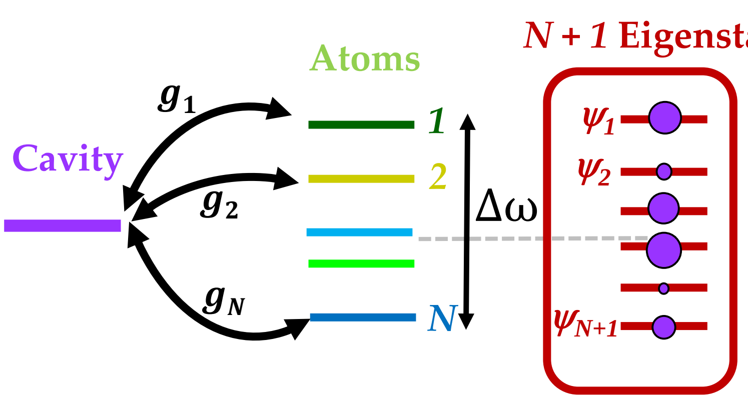


Collective Coupling

$$\Omega = \sqrt{\sum_i g_i^2}$$

$$|\text{Polariton}\rangle = |\text{Atomic excitation}\rangle \pm |\text{Photon excitation}\rangle$$

Frequency-*inhomogeneous* CQED



No "real" Dark States: All eigenstates have a photonic weight PW_i

$$= |\langle \psi_i | 1_{cav}; 0_1, \dots, 0_N \rangle|^2$$

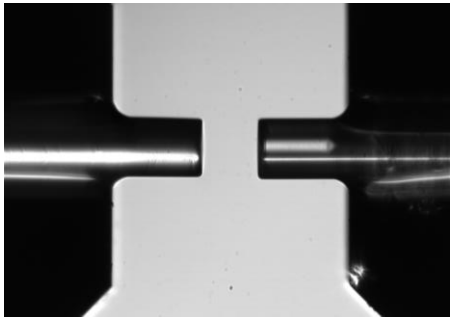
J. Dubail et al. arXiv 2105.08444 (2021)

Can we measure photonic weight distribution ?

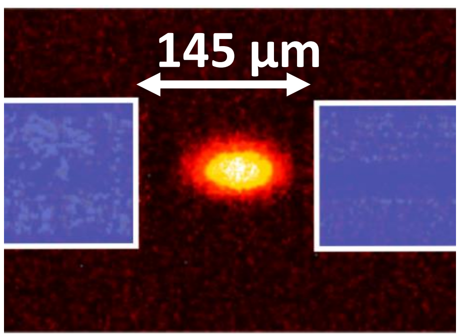
Frequency width $\Delta\omega$ ⟷ **Collective coupling** Ω

Interplay

Tunable inhomogeneous frequency in a cold atom CQED system

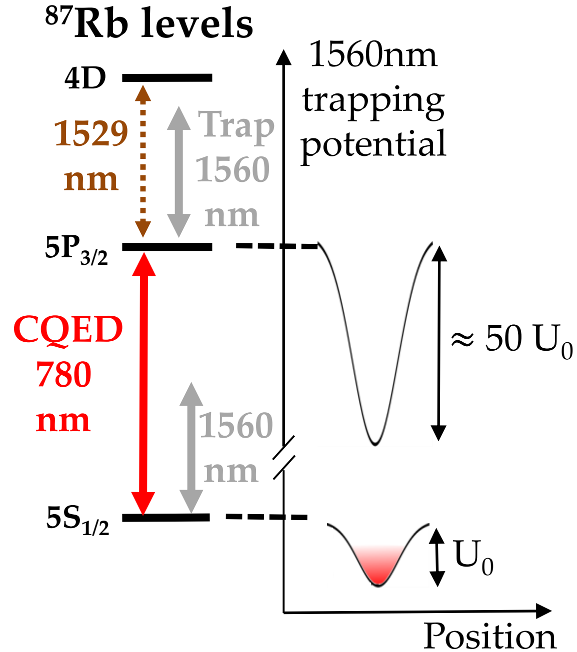


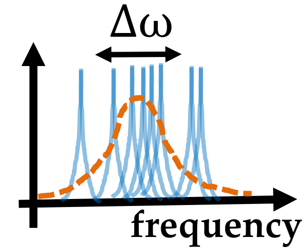
Fiber Fabry-Perot Cavity
Single atom
Cooperativity: $C \approx 60$



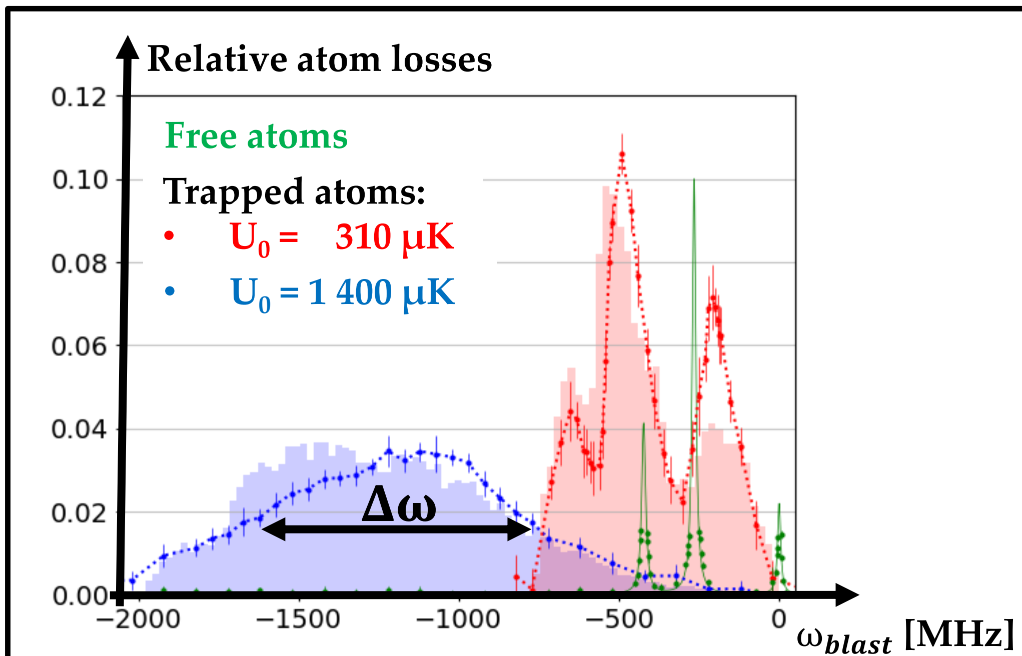
10 to 800 ^{87}Rb atoms:
Tunable collective coupling

$$\Omega = \sqrt{\sum_i g_i^2}$$



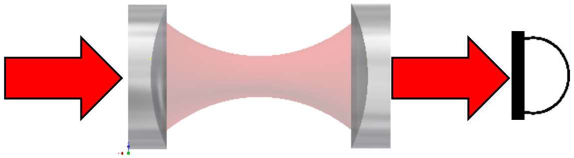


Trap intensity
→ *Tunable* distribution widths:
$\Delta\omega$ = 100s MHz → 1 GHz

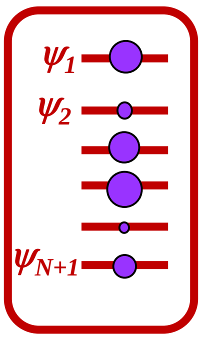


Photonic weight distribution in a CQED spectral measurement

Cavity transmission spectrum

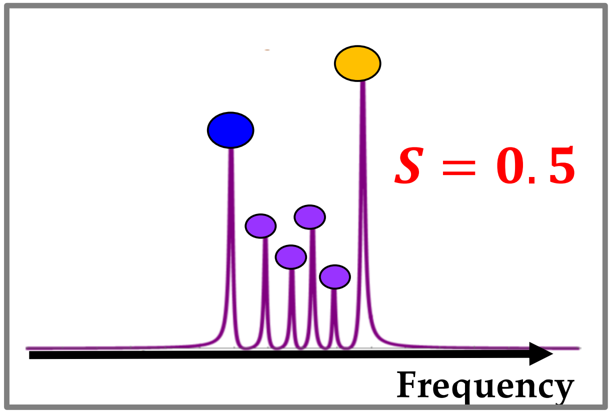


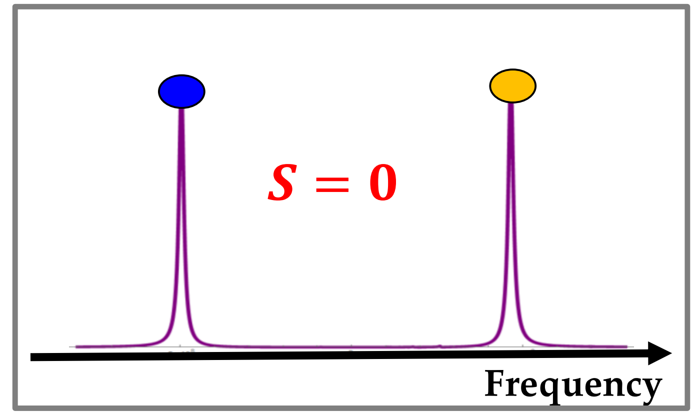
$N + 1$ Eigenstates

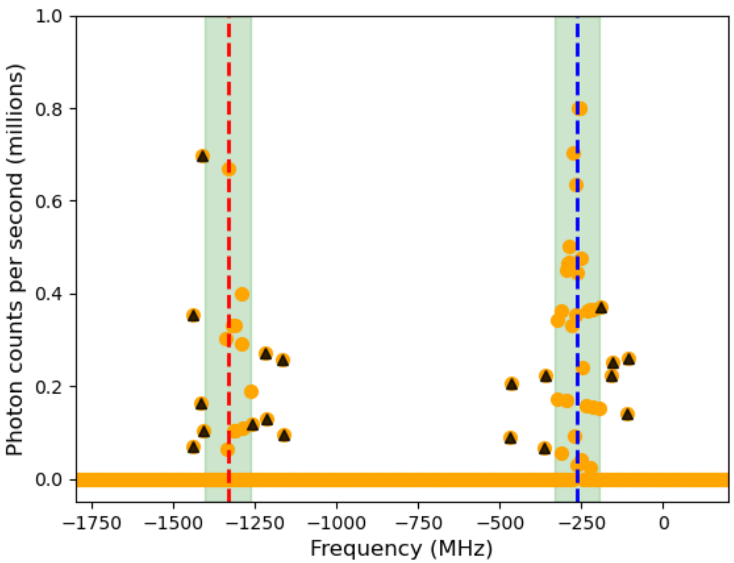


The coherence is preserved if the photonic excitation is carried by only two eigenstates: $S = 1 - (PW_{\max 1} + PW_{\max 2})$.

$S \rightarrow 0$: **High coherence**





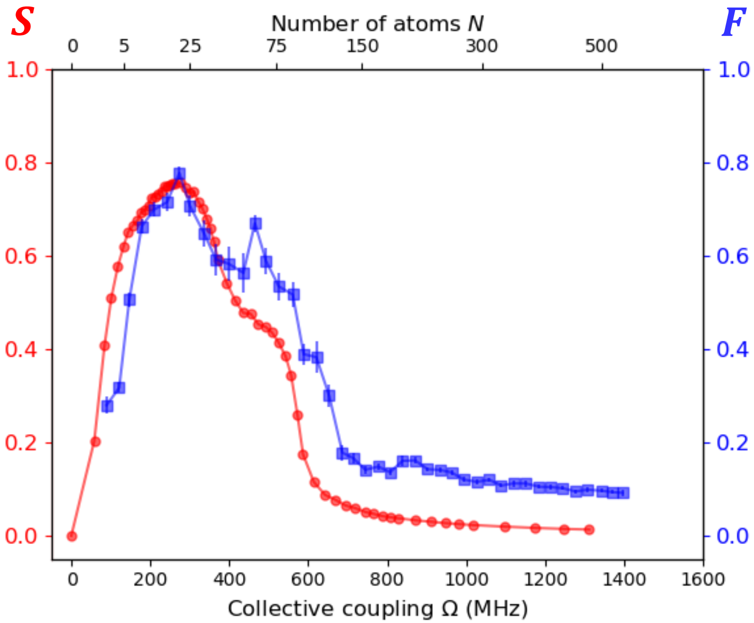


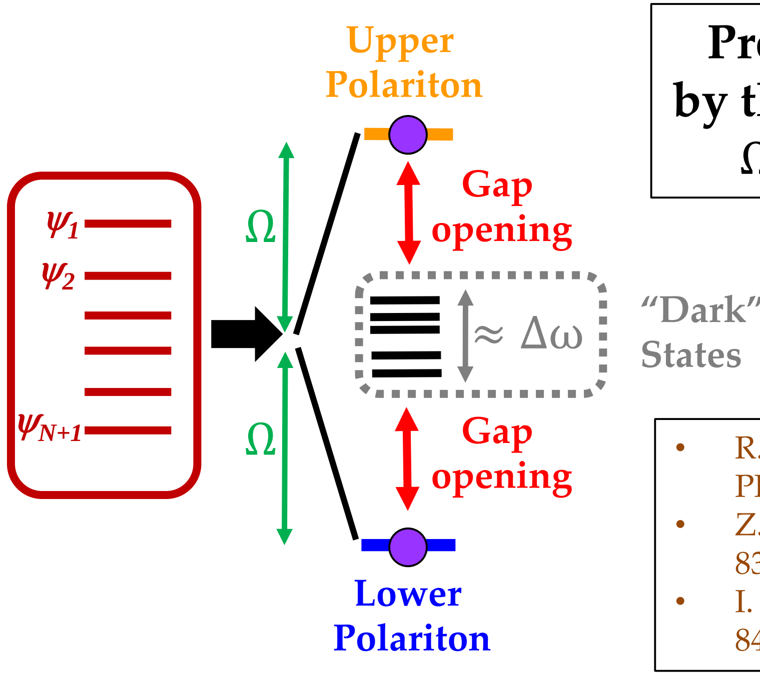
Experimentally: cannot distinguish peaks because of photon shot-noise → Fraction F of photon counts *far* from peak:

$$F = 1 - \frac{\text{counts in}}{\text{counts total}}$$

$F \rightarrow 0$: **High coherence**

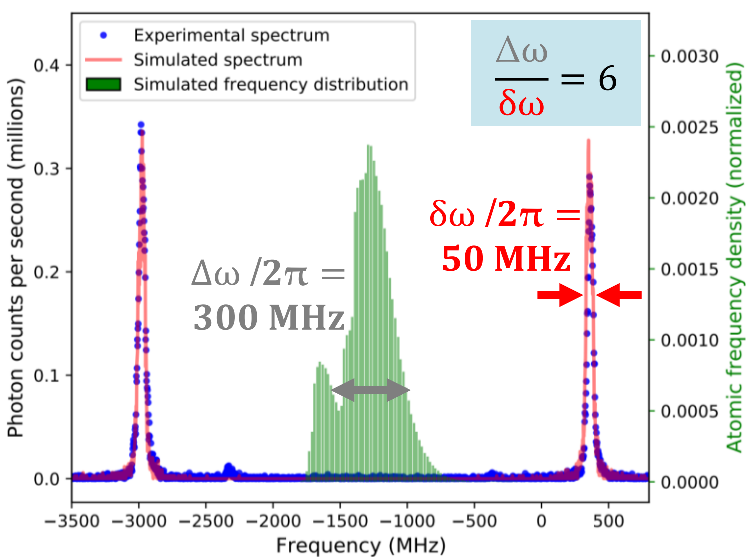
Cavity protection





Protection by the Cavity:
$\Omega \gg \Delta\omega$

- R. Houdré *et al.*, PRA 53(4) (1996)
- Z. Kurucz *et al.*, PRA 83, 053852 (2011)
- I. Diniz *et al.*, PRA 84, 063810 (2011)

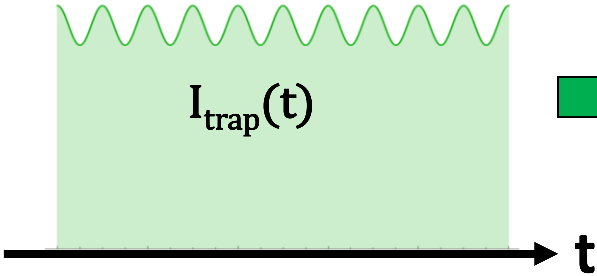


Coherent interaction despite large inhomogeneities if: $\Omega \gg \Delta\omega$

See also previous in solid state CQED:
S. Putz *et al.*, Nat. Phys., **10**(10) (2014)
T. Zhong *et al.*, Nat. Commun., 8, 14107 (2017)

Frequency modulated polaritons

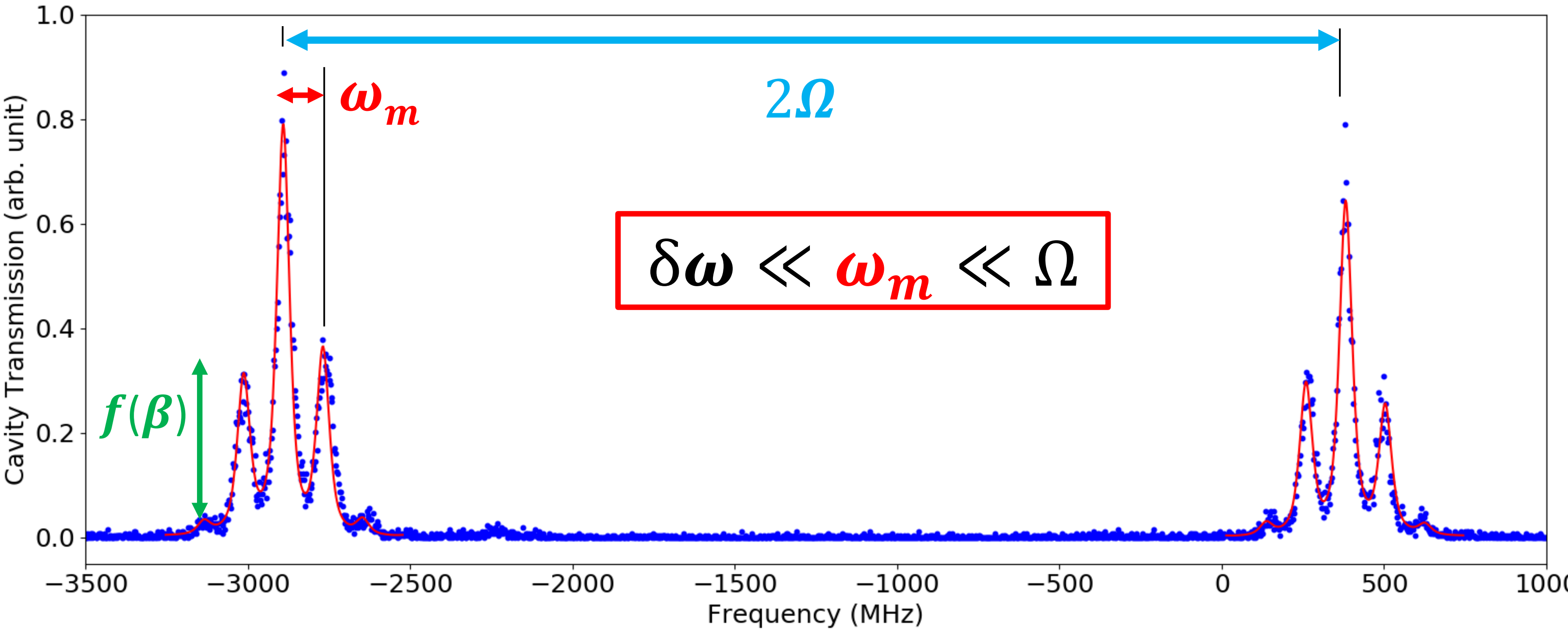
Control of atomic qubit frequency



$$\omega_a[I_{trap}(t)] = \omega_{a,0} + \beta\omega_m \cos(\omega_m t)$$

Spectral Shaping of Polaritons

D. M. Lukin et al., Quan. Inf. **6**, 1 (2020)
I. Craiciu et al., Optica **8**, 114 (2021)



Cavity-Protected Polaritons with multiple frequencies !