

2025.

Experiment on Cavity Quantum Electrodynamics with cold Rb atoms. — By considering linear scattering of laser-driven cold atoms inside an undriven high-finesse optical resonator, we experimentally demonstrated effects unique to a strongly coupled vacuum field. Arranging the atoms in an incommensurate lattice, with respect to the radiation wavelength, the Bragg scattering into the cavity can be suppressed by destructive interference: the atomic array is subradiant to the cavity mode under transverse illumination. We showed however, that strong collective coupling leads to a drastic modification of the excitation spectrum, as evidenced by well-resolved vacuum Rabi splitting in the intensity of the fluctuations. Furthermore, we demonstrated a significant polarization rotation in the linear scattering off the subradiant array via Raman scattering induced by the strongly coupled vacuum field.

Fig. 1. *Scheme of the experiment on the scattering from a subradiant atomic configuration. Cold Rb atoms in an intra-cavity dipole lattice at wavelength 805 nm are illuminated by two counter-propagating coherent laser beams with equal intensity and opposite circular polarizations from the two opposite directions perpendicular to the cavity axis. The laser was set near resonant with the $F = 2 \leftrightarrow F' = 3$ transition of the D2 line at 780 nm (only two transitions from the sublevel $m_F = 2$ are shown by solid arrows, for simplicity, but all the other m_F sublevels are coupled similarly by σ^+ and σ^- transitions) and close to resonance with one of the fundamental cavity modes coupling to the atomic transitions denoted by dashed lines in the inset (only three transitions from $m_F = -1$ are shown but all the other sublevels are similarly coupled by the cavity modes). The cavity field output is monitored by single photon counters on discriminating the photon polarization. The cavity linewidth is $\kappa = 2\pi \times 4$ MHz (HWHM), the maximum single-atom coupling constant is $g = 2\pi \times 0.33$ MHz.*

Figure 2. Vacuum Rabi splitting with a subradiant array of atoms. The photon count rate in the first 1 ms of exposure time is plotted versus the laser drive detuning Δ for various atom numbers N . Each point and error bar is obtained from an ensemble of 70 runs assuming log-normal distribution, given that the photon count rate is a priori a non-negative quantity. The maxima of the fitted Lorentzian resonance functions, projected on the bottom plane (orange circles), fit well on a parabola $N = \Delta^2 / g_{eff}^2$ with $g_{eff} = 2\pi \times 0.26$ MHz, in accordance with the \sqrt{N} dependence known for the collective coupling of a number of N atoms to a single cavity mode, and to an even distribution of population in the Zeeman sublevels.

Reference

B. Gábor, K. V. Adwaith, B. Sárközi, D. Varga, Á. Kurkó, A. Dombi, T. W. Clark, F. I. B. Williams, D. Nagy, A. Vukics, P. Domokos: Demonstration of strong coupling of a subradiant atom array to a cavity vacuum
[EPJ Quantum Technol. 12, 93 \(2025\)](#)

Atom-light interaction in optical nanostructures We described the mechanical effects of light-matter interaction inside hollow-core optical fibers. Starting with quantized electromagnetic radiation, we demonstrated how dispersion, mode functions and losses define an open quantum system and how subsequent Langevin equations can be used to predict spatially-dependent vacuum forces. Conceptually, we revealed new, geometry-induced, forces that have no equivalence in unbounded 3-D space and, practically, show how the general spatial dependence can be greatly approximated by free-space Ince-Gaussian modes: such that the forces can be described analytically. By also considering the effects of drive and fluctuations, we provided an extensive overview of both control and cooling within the limitations of a 2-level atomic system.

Figure 3. *A seemingly complex, elliptically symmetric, mode can be concisely expressed by asuperposition of only three rectangularly symmetric Hermite-Gaussian modes.*

Figure 4. *An example trajectory fro the QED-based semiclassical simulations.*

References

T. Clark, L. Vincett, P. Domokos: Atoms in hollow-core fibers: a QED approach
[New Journal of Physics 27, 114102 \(2025\)](#)