Cavity Optomechanics: Exploring the coupling of light and micro- and nanomechanical oscillators

EPFL , Switzerland
Prof. Dr. Tobias J. Kippenberg (PhD)

The mutual coupling of optical and mechanical degrees of freedom via radiation pressure has been a subject of interest in the context of quantum limited displacements measurements for Gravity Wave Detection for many decades, however light forces have remained experimentally unexplored in such systems. Recent advances in nano- and micro-mechanical oscillators have for the first time allowed the observation of radiation pressure phenomena in an experimental setting and constitute the emerging research field of *cavity optomechanics*(*1*).

Using on-chip micro-cavities that combine both optical and mechanical degrees of freedom in one and the same device(*2*), radiation pressure back-action of photons is shown to lead to effective cooling(*3*-*6*) of the mechanical oscillator mode using dynamical backaction, which has been predicted by Braginsky as early as 1969(*4*). This back-action cooling exhibits many close analogies to atomic laser cooling. With this novel technique the quantum mechanical ground state of a micromechanical oscillator has been prepared with high probability using both microwave and optical fields. In our research this is reached using cryogenic precooling to ca. 700 mK in conjunction with laser cooling, allowing cooling of micro-mechanical oscillator to only 1.7 quanta. – implying the oscillator resides more than 1/3 of its time in the quantum ground state. Moreover it is possible in this regime to observe quantum coherent coupling in which the mechanical and optical mode hybridize and the coupling rate exceeds the mechanical and optical decoherence rate (7). This accomplishment enables a range of quantum optical experiments, including state transfer from light to mechanics using the phenomenon of optomechanically induced transparency(*8*).

From a broader perspective the described experiments that exploit optomechanical coupling are motivated both by the effort to realize quantum measurement schemes on mechanical systems in an experimental setting as well as to explore the behavior of nanomechanical systems at low temperatures.

References:

1. T. J. Kippenberg, K. J. Vahala, Cavity Optomechanics: Backaction at the mesoscale. *Science* **321**, 1172 (2008, 2008).
2. T. J. Kippenberg, H. Rokhsari, T. Carmon, A. Scherer, K. J. Vahala, Analysis of Radiation-Pressure Induced Mechanical Oscillation of an Optical Microcavity. *Physical Review Letters* **95**, 033901 (2005).
3. V. B. Braginsky, S. P. Vyatchanin, Low quantum noise tranquilizer for Fabry-Perot interferometer. *Physics Letters A* **293**, 228 (Feb 4, 2002).
4. V. B. Braginsky, *Measurement of Weak Forces in Physics Experiments*. (University of Chicago Press, Chicago, 1977).
5. A. Schliesser, P. Del'Haye, N. Nooshi, K. J. Vahala, T. J. Kippenberg, Radiation pressure cooling of a micromechanical oscillator using dynamical backaction. *Physical Review Letters* **97**, 243905 (Dec 15, 2006).
6. A. Schliesser, R. Riviere, G. Anetsberger, O. Arcizet, T. J. Kippenberg, Resolved-sideband cooling of a micromechanical oscillator. *Nature Physics* **4**, 415 (May, 2008).
7. E. Verhagen, S. Deleglise, S. Weis, A. Schliesser, T.J. Kippenberg, *Nature* (2012)
8. S. Weis *et al.*, Optomechanically Induced Transparency. *Science* **330**, 1520 (Dec, 2010).