Applied Physics Seminar

Lunch time, Every Wednesday

APPH E4901: Discussion of specific and self-contained problems in areas such as applied EM, physics of solids, and plasma physics. Topics change yearly.

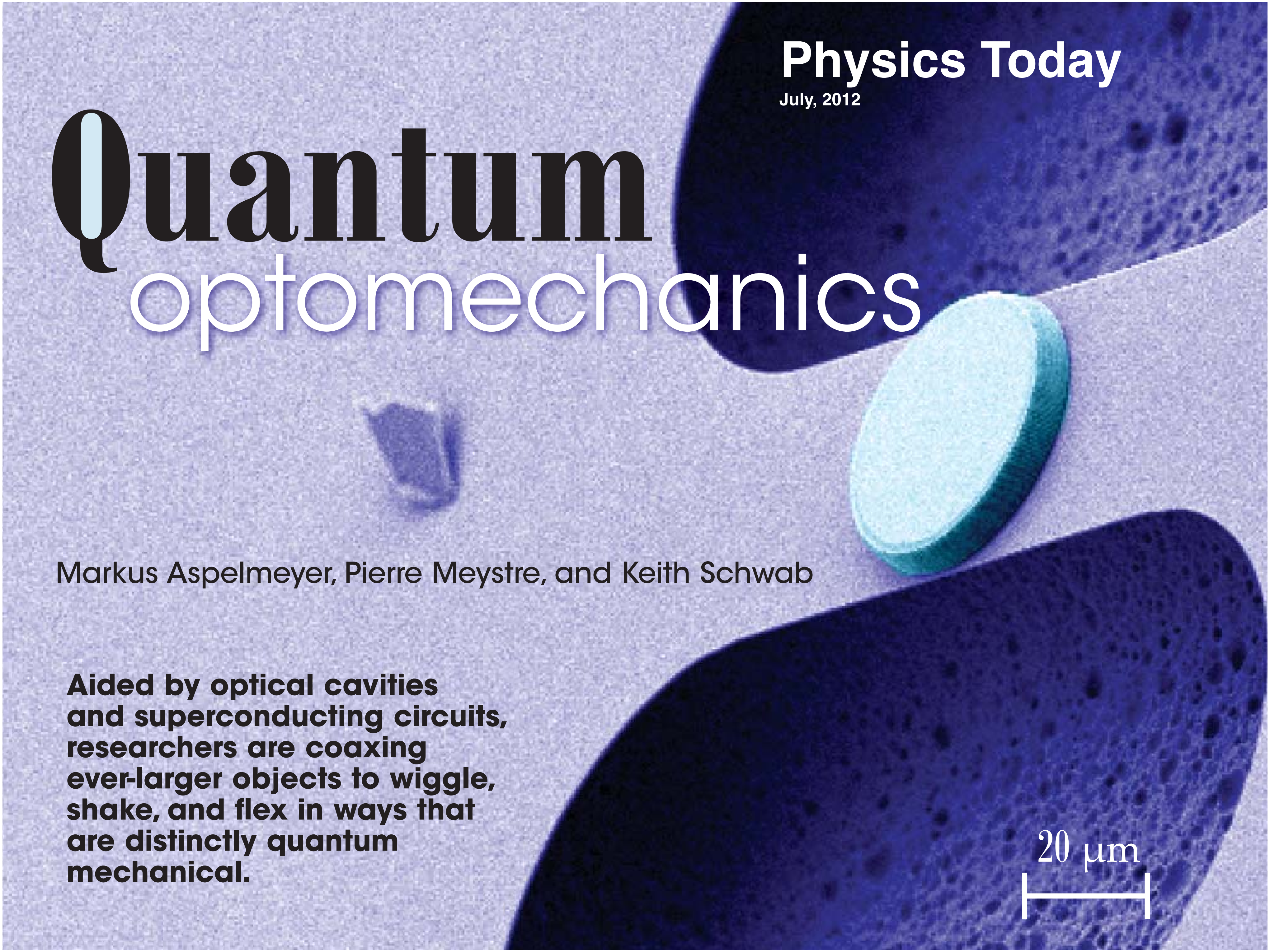
APPH E4903: Discussion of specific and self-contained problems in areas such as applied EM, physics of solids, and plasma physics. **Formal presentation of a term paper required.** Topics change yearly.

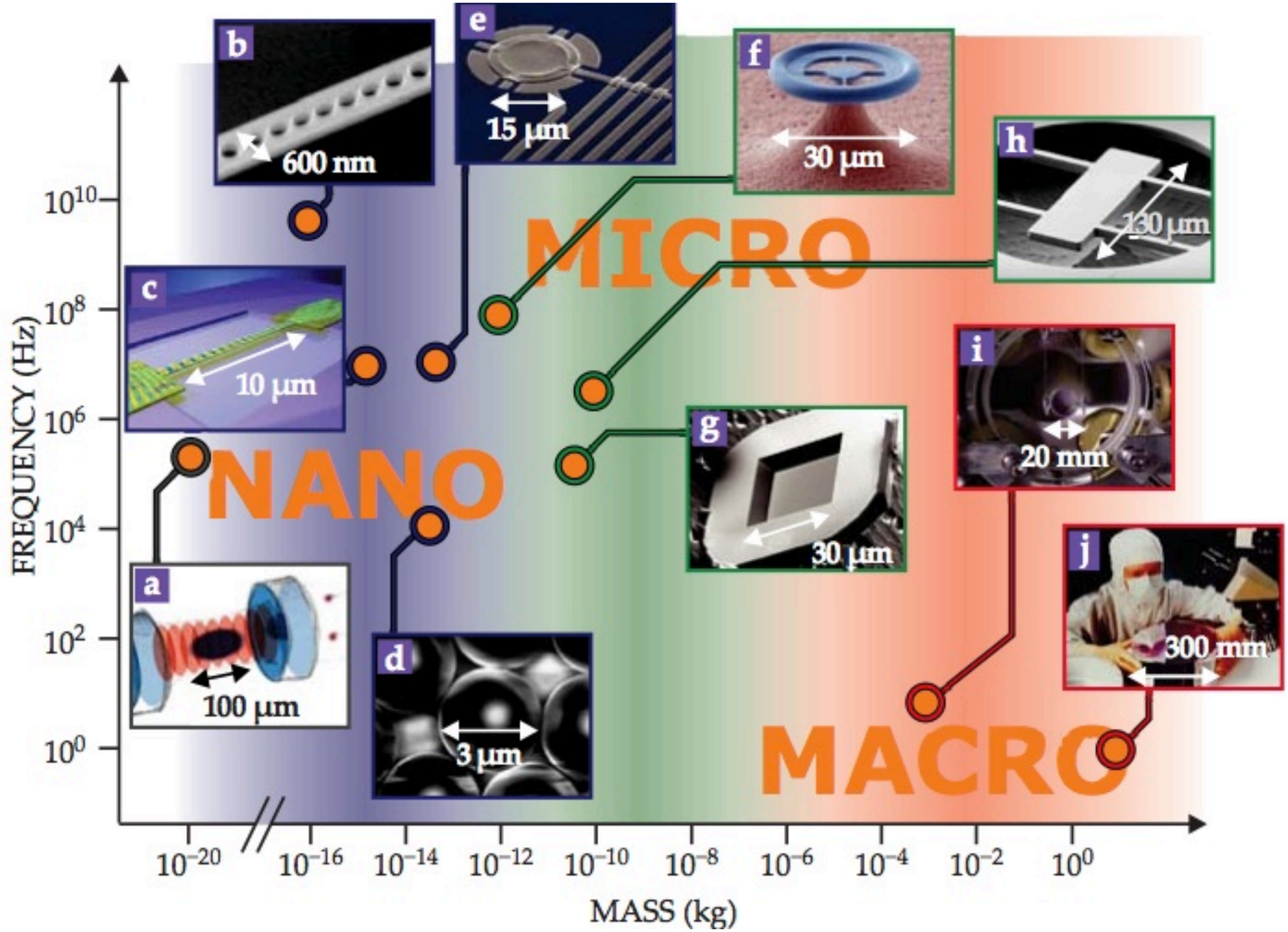
Physics Today
July, 2012

Quantum optomechanics

Markus Aspelmeyer, Pierre Meystre, and Keith Schwab

Aided by optical cavities and superconducting circuits, researchers are coaxing ever-larger objects to wiggle, shake, and flex in ways that are distinctly quantum mechanical.





Cavity optomechanical devices range from nanometer-sized structures of as little as 10^7 atoms and 10−20 kg to micromechanical structures of 10^{14} atoms and 10−11 kg to macroscopic, centimeter-sized mirrors comprising more than 10^{20} atoms and weighing several kilograms. They include (a) gases of ultracold atoms, (d) microspheres, and (g) micro-scale membranes, all of which have mechanical resonances that can couple with the light inside an optical cavity; (b, c) flexible, nanoscale waveguides that have both optical and mechanical resonances; (e) superconducting membranes that exhibit drum-like vibrations and can be integrated into microwave cavities; (f) microtoroidal waveguides having both optical and mechanical resonances; and mechanically compliant mirrors, which can range from the microscopic (h) to the macroscopic (i, j) and which introduce mechanical degrees of freedom to an optical cavity when incorporated as an end mirror.

LIGO

Laser Interferometer Gravitational-Wave Observatory

operated by Caltech and MIT ::: supported by the Na

LIGO Science · for scientists

LIGO Scientific Collaboration

Advanced LIGO

LIGO Laboratory

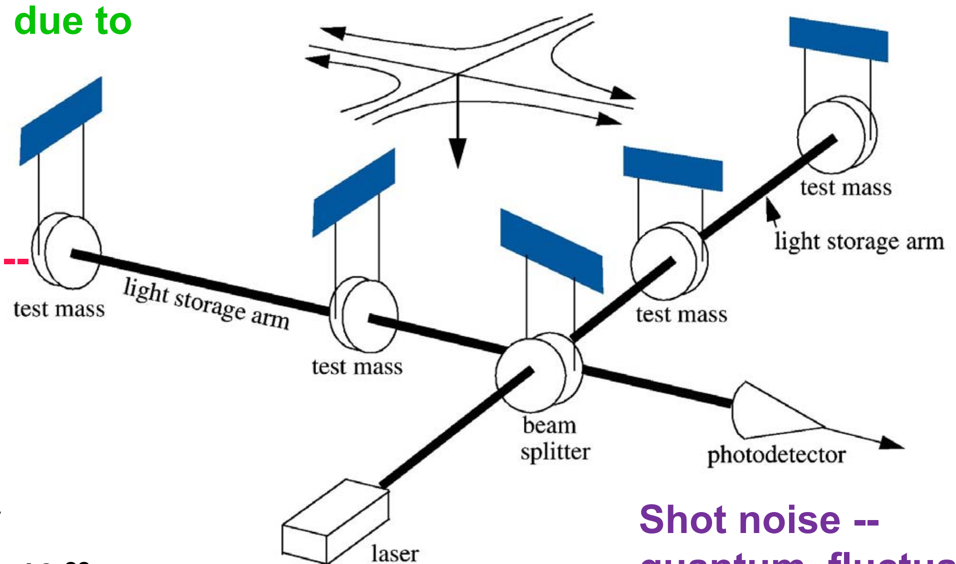
http://www.ligo.caltech.edu

Understanding Cavity Optomechanical Systems

GW detector at a glance

Seismic motion -- ground motion due to natural and anthropogenic sources

Thermal noise -- vibrations due to finite temperature



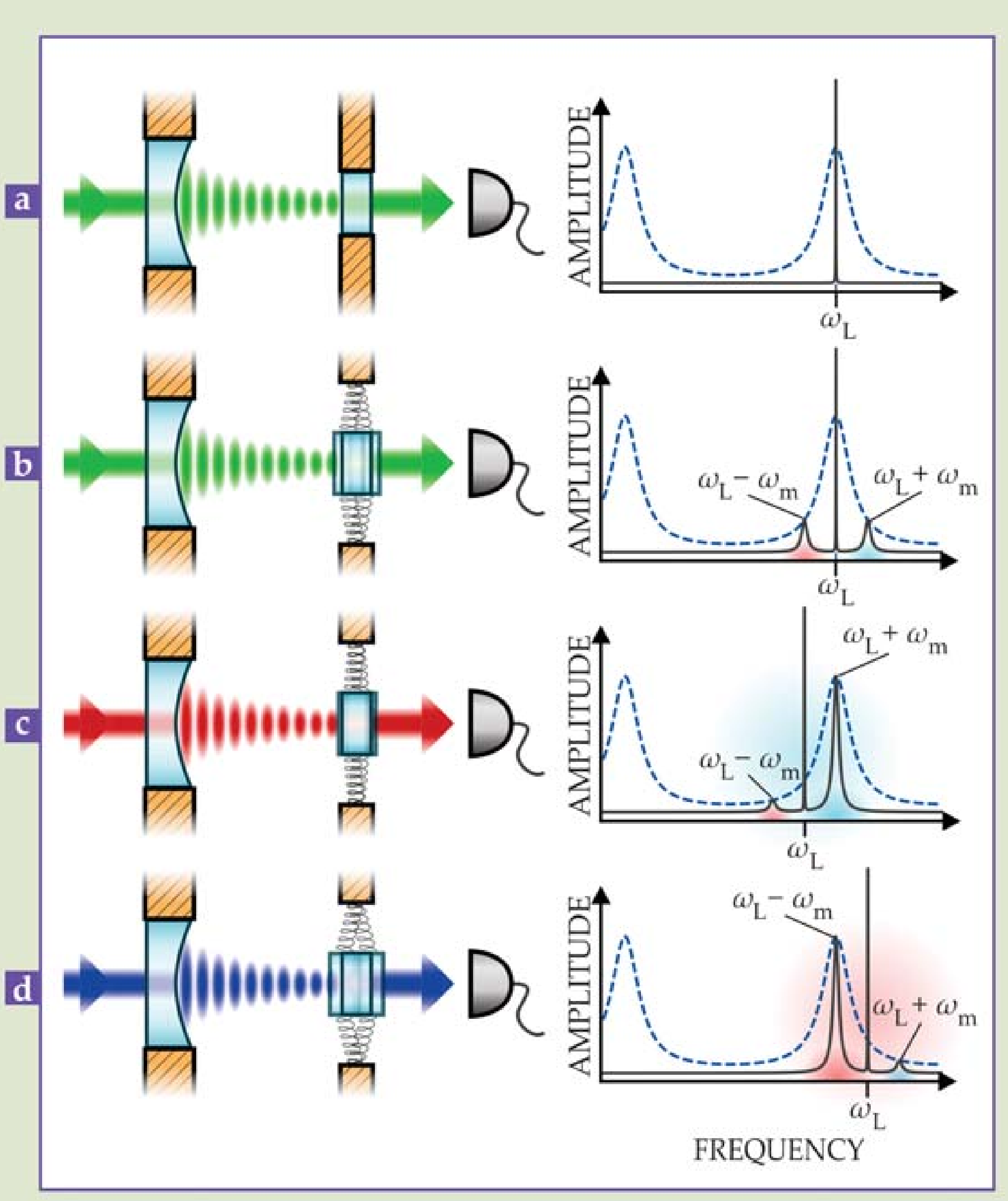
$$h = \Delta L / L$$

want to get $h \leq 10^{-22}$; can build L = 4 km; must measure $\Delta L = h\,L \leq 4\times10^{-19}$ m

Shot noise -- quantum fluctuations in the number of photons detected

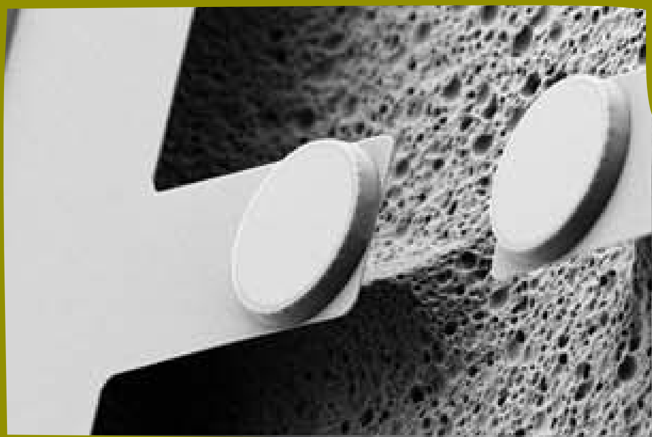
AJW, LIGO SURF, 6/16/06

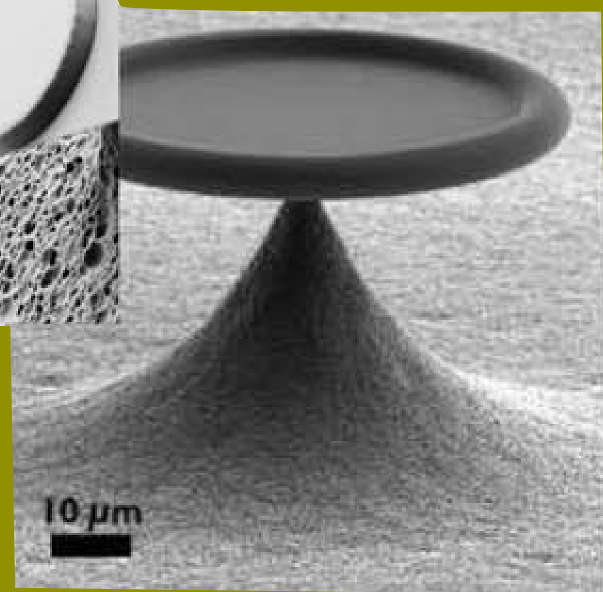
Quantum Optomechanical Cavity

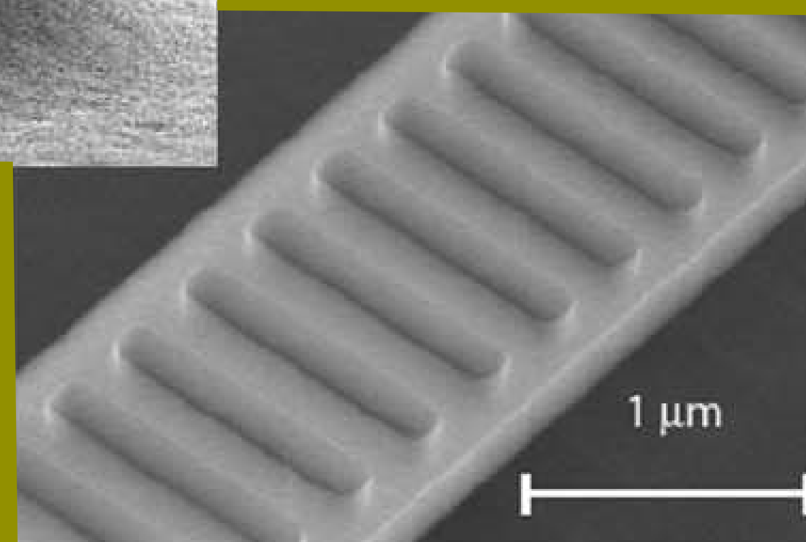


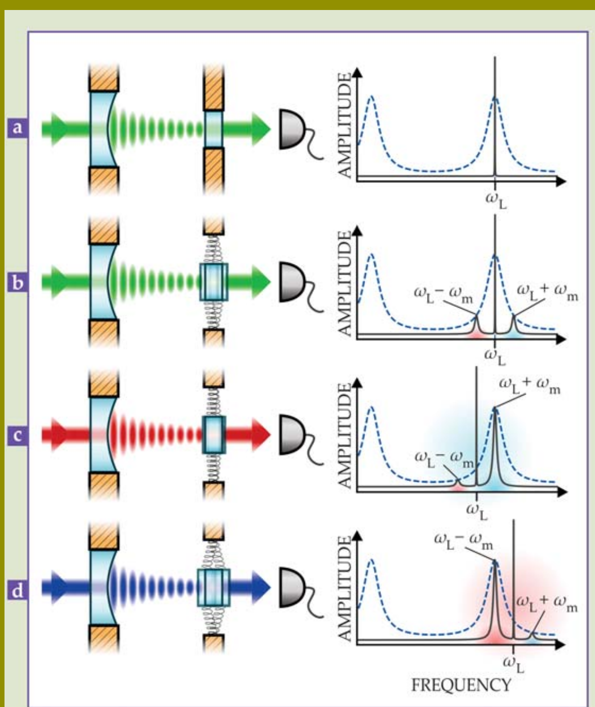
- **Quantum optomechanics: the basics**.
- (a) If both end mirrors of a Fabry-Perot cavity are fixed in place, pump-laser photons having frequency ω_L tuned to a cavity resonance arrive at a detector with no frequency modulation.
- (b) However, if one mirror is allowed to oscillate harmonically, pump photons are modulated by the oscillation frequency ω_m: A pump beam tuned to a cavity resonance will yield sidebands of equal amplitude at frequencies $\omega_L \pm \omega_m$. Each photon in the upper sideband acquires energy by extracting a phonon from the oscillator, and each photon in the lower sideband sheds energy by depositing a phonon.
- (c) By red-detuning the pump laser, one can enhance the upper sideband and thereby cool the oscillating mirror.
- (d) By blue-detuning the pump laser, one enhances the lower sideband and amplifies the mirror oscillations.

Quantum Optomechanical Cavity









Research Questions

- What are the properties of optical resonators?
- What is required to observe quantum properties of a mechanical structure?
- What can we learn when direct quantum effects are essential effects in our optomechanical systems?
- Applications:
  - Measurement of single molecules…
  - Magnetic resonances of single atomic/electron spins
  - LIGO
  - Structural dynamics of single molecules, proteins, …
  - Nanoresonators for sensing and detecting everything small
  - Qubits from phonons

Research Plan

- Optical resonators: electrodynamics
- Mechanical oscillations and resonant modes: beams & springs to quantum phonons
- Laser cooling
- Optomechanical systems
- Research examples

Assignment for Next Week

- What are the resonant optical frequencies of a cube? Numbers please.
- What are the resonant frequencies of an "optical fiber ring"?
- What is a Fabry-Pérot interferometer? And other types of interferometers, ... ?