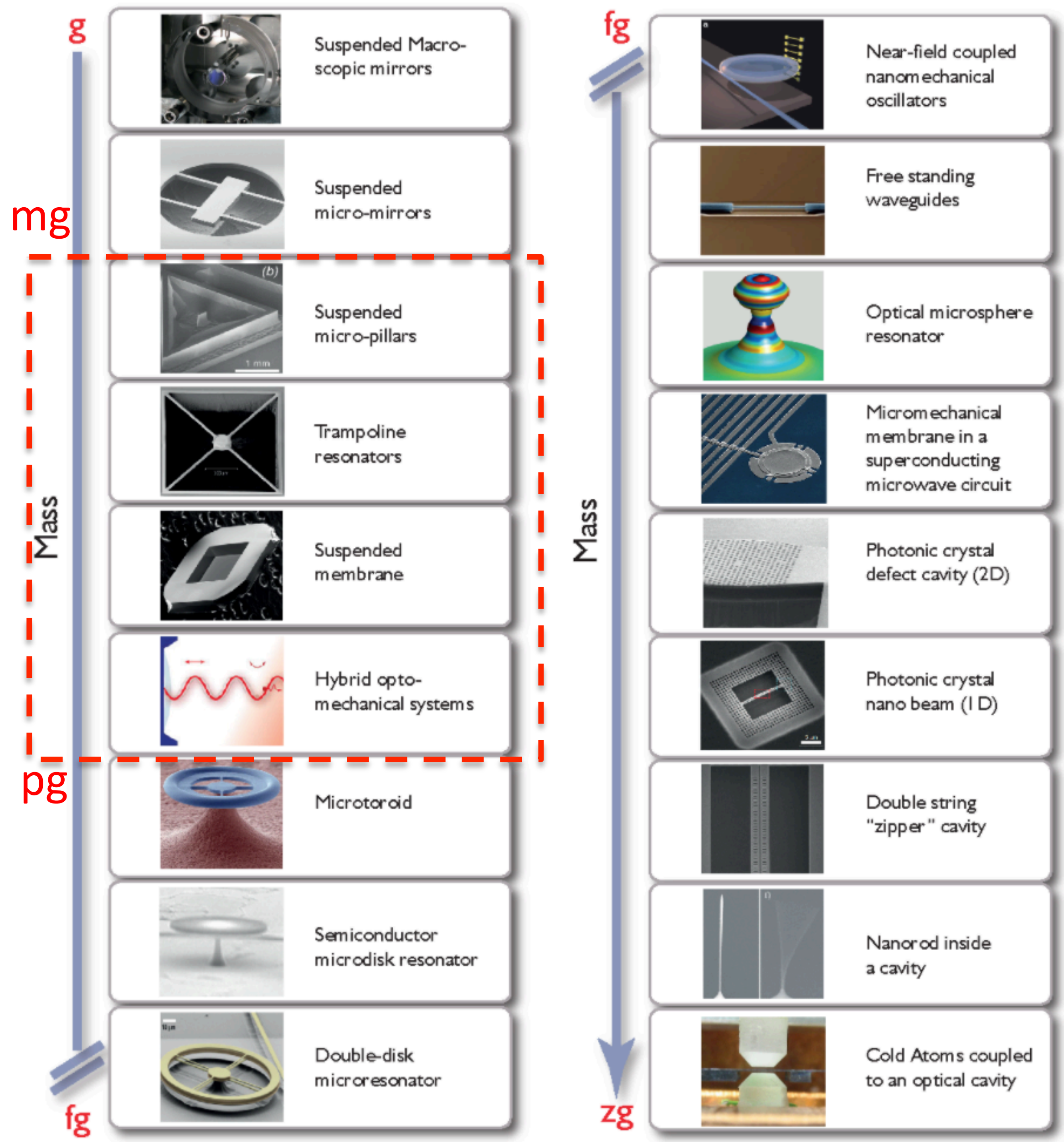
Precision force sensing

- New forces arise in a variety of proposed models of new physics
- Forces can appear at weak couplings or short distance
- "Opto-mechanical" systems can enable precise force sensors
- Allow control and measurement of ~zg to ~kg scale test masses

Aspelmeyer, Kippenberg, and Marquardt, Rev. Mod. Phys. 86, 1391 (2014)

Example opto-mechanical systems:



Levitation of ~pg-ng masses

- Optically levitate micron-sized dielectric masses in vertically oriented laser
- Ability to trap wide size range of spheres from ~1-30 μm (~0.01-10 ng)
- Long working distance (2.5 cm) allows electrodes, masses positioned around trap
- Ultimate limit from laser shot noise at SQL (roughly power needed to levitate):

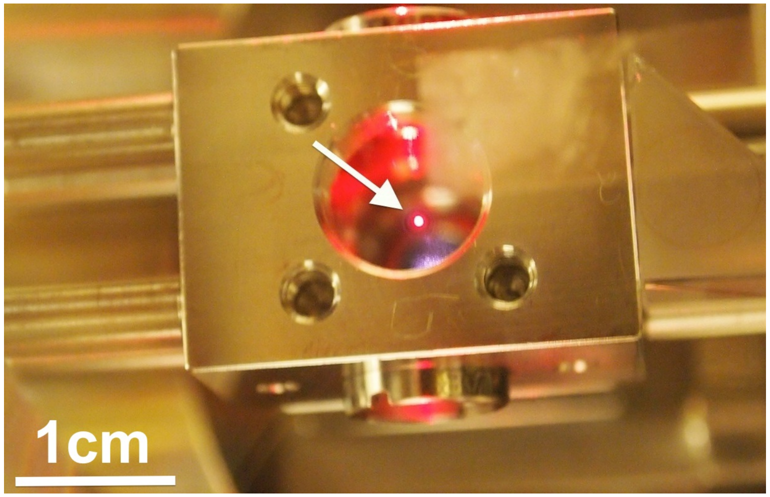
$$\sigma_F \sim 10^{-21}\ \mathrm{N\ Hz^{-1/2}}$$

$$(\sigma_a \sim 10^{-9}\ g\ \mathrm{Hz^{-1/2}})$$

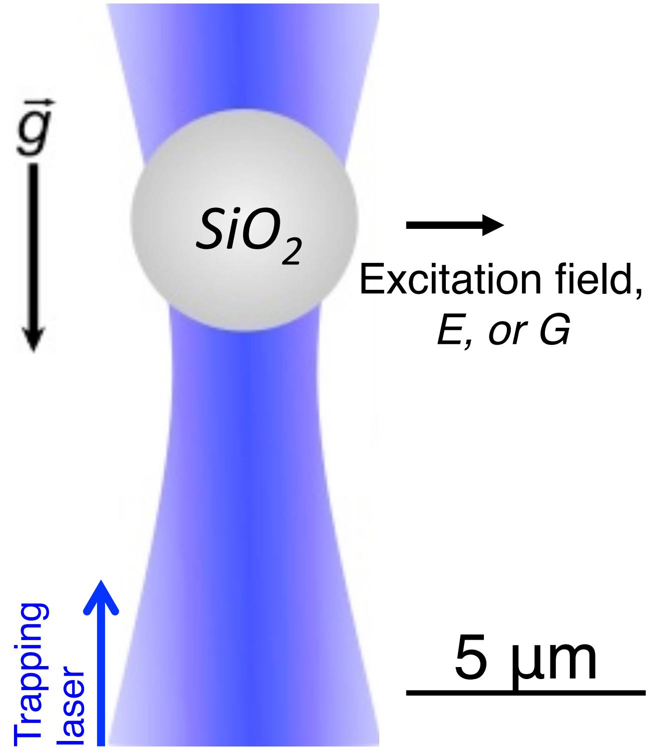
Ashkin & Dziedzic, Appl. Phys. Lett. ***19****, 283 (1971)*
Geraci et al., PRL ***105****, 101101 (2010)*

- Levitated masses are isolated both electrically and thermally

Photograph of trapped microsphere:



Schematic of optical levitation technique:



Applications

- Near term applications:
  - Neutrality of matter (hidden sector dark matter, GUTs, new forces)
  - Tests of Newton's law (hierarchy problem, new forces)
  - Tests of Coulomb's law (hidden sector dark matter, new forces)
- Technological development (with application to sensing):
  - Short term (~5 yr):
    - Cooling of levitated systems to near motional ground state
    - Read out of displacements/rotations of spheres near SQL
    - Sensing with other optomechanical systems at Yale (levitated LHe, Bulk crystalline oscillators)
  - Longer term:
    - Beyond-SQL sensitivity (e.g. squeezing/back-action evasion)
    - Matter wave interferometry with ~nano-scale masses
    - Large arrays of sensors
- Yale groups are at the forefront of developing a variety of optomechanical systems that have applications to sensing