Gravitational Wave Advanced Detector Workshop 2016 (Hotel Hermitage, La Biodola, Isola d'Elba, May 22-28, 2016)

Optical Levitation of a Mirror

Yuta Michimura[1], Yuya Kuwahara[1], Takafumi Ushiba[1], Nobuyuki Matsumoto[2] and Masaki Ando[1,3]

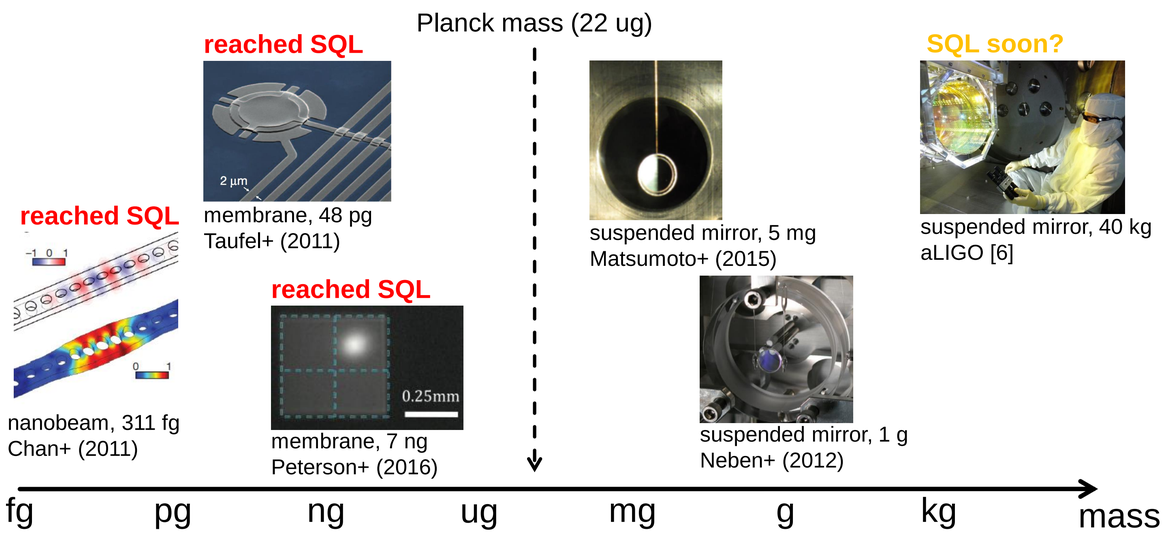
[1]*Department of Physics, University of Tokyo* [2]*Frontier Research Institute for Interdisciplinary Sciences, Tohoku University*
[3]*National Astronomical Observatory of Japan*
Email: michimura@granite.phys.s.u-tokyo.ac.jp

Abstract:
An optomechanical device reaching the standard quantum limit (SQL) of a force measurement plays a prominent roll for studying quantum mechanics. To prepare such a device, a mechanical oscillator well isolated from the environment is essential for the reduction of thermal disturbances. Here we propose optical levitation of a mirror with two vertical Fabry-Perot cavities linearly aligned. We show the stability of the system with a mg-scale mirror, and demonstrate the feasibility of reaching the SQL with this system.

1. Motivation

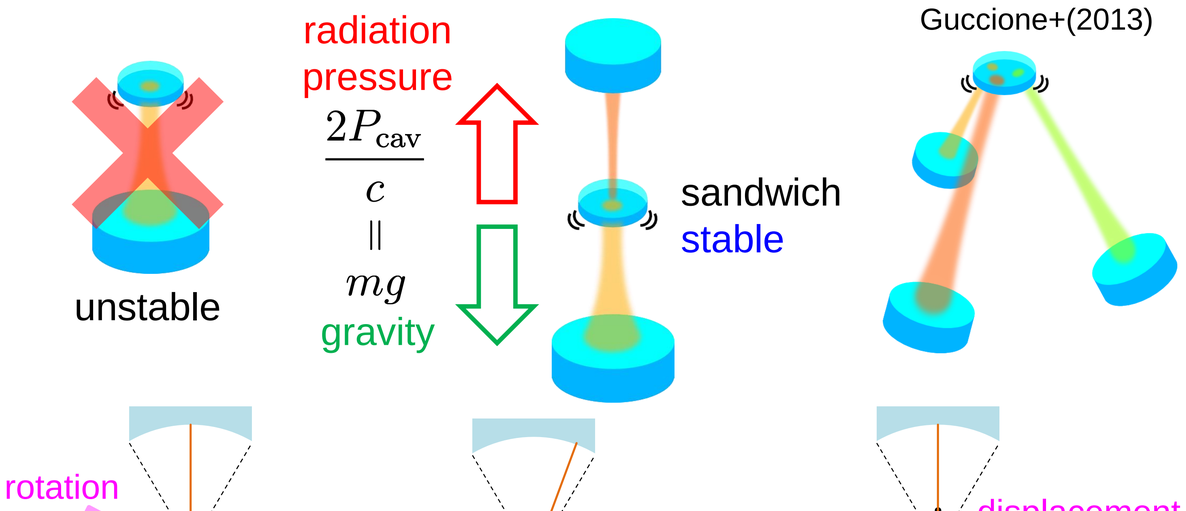
Test of quantum mechanics in macroscopic scale
- superposition not observed in macroscopic scale yet
- possible solutions:
  - too much environmental disturbances?
  - nonlinear Schrödinger equation?
  - gravitational decoherence? etc.....
- need to test in wide mass scale
  → mg scale

Optical levitation instead of mechanical support
- no thermal noise from support



2. Stability

Sandwich configuration
- two cavities are enough to support a mirror
- levitating mirror have to be convex



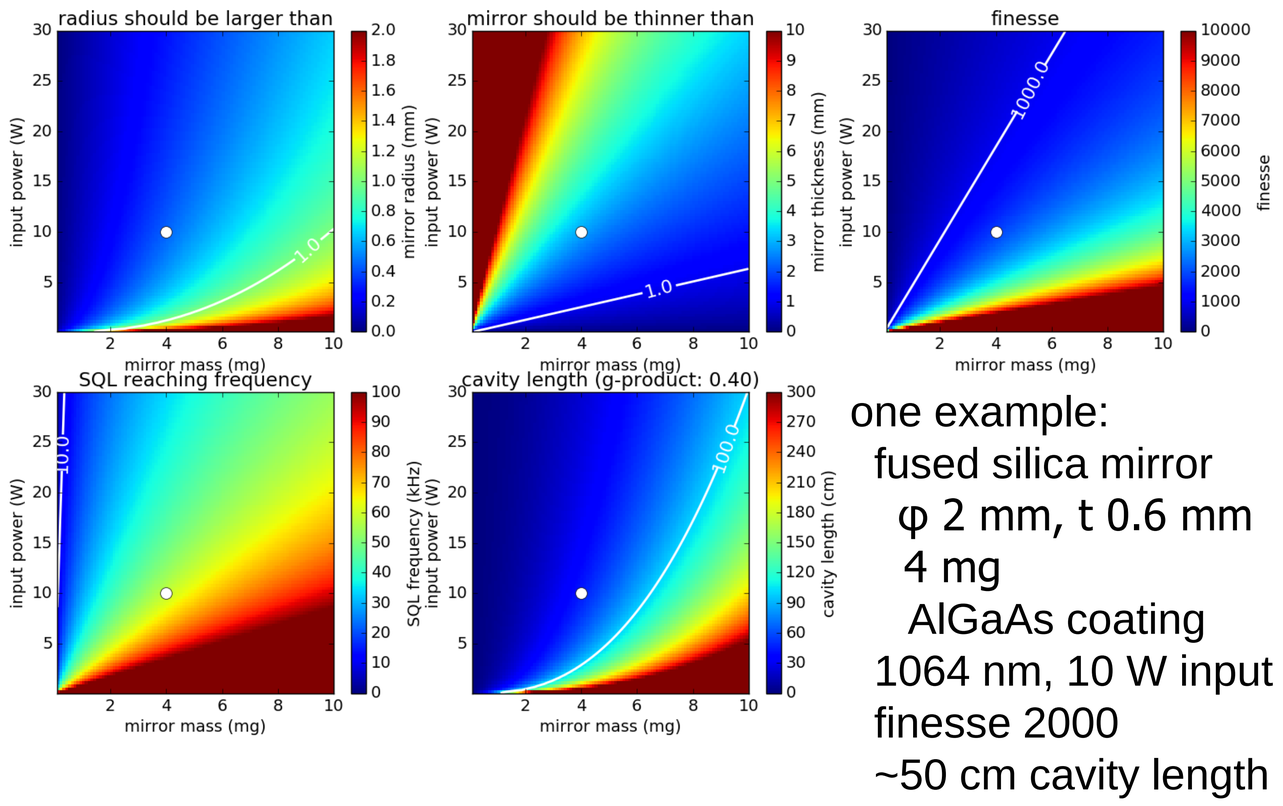
rotation around center of RoC
stable if convex

horizontal disp.
stable if $\frac{F_{\mathrm{u}}}{a_{\mathrm{u}}} > \frac{F_{\mathrm{l}}}{a_{\mathrm{l}}}$

vertical disp.
stable if optical spring

3. Reaching the SQL

Parameter search
- intracavity power from mirror mass
- mirror diameter from coating thermal
- cavity length from beam size



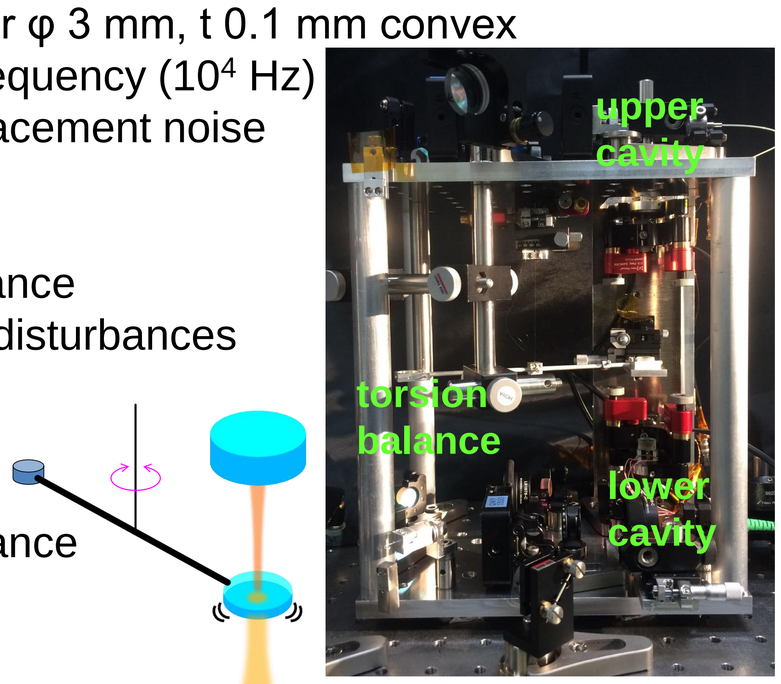
one example:
fused silica mirror
φ 2 mm, t 0.6 mm
4 mg
AlGaAs coating
1064 nm, 10 W input
finesse 2000
~50 cm cavity length
→ reach SQL at 60 kHz

4. Issues to be solved

Technical issues
- production of thin & small curved mirror
  φ 4 mm, t 0.2 mm flat mirror is feasible [4]
  6 out of 8 cracked for φ 3 mm, t 0.1 mm convex
- high SQL reaching frequency (10^4 Hz)
  10^{-20} m/rtHz in displacement noise
- levitation procedure

Calculations needed
- initial alignment tolerance
- tolerance to external disturbances

Prototype test
- check stability and levitation procedure
- test using torsion balance underway



5. Conclusion

We have proposed the use of sandwich configuration to stably levitate a mg-scale mirror. Although the levitation itself is feasible for convex mirror, beating the SQL could be tough. Since we cannot choose the mirror mass and the intracavity power independently, frequency band of the sub-SQL window will be high (10^4 Hz). Trial production of mg-scale convex mirrors and the prototype test using torsion balance is underway to check technical feasibility.

References

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