Levitating Optomechanics: Optical Levitation

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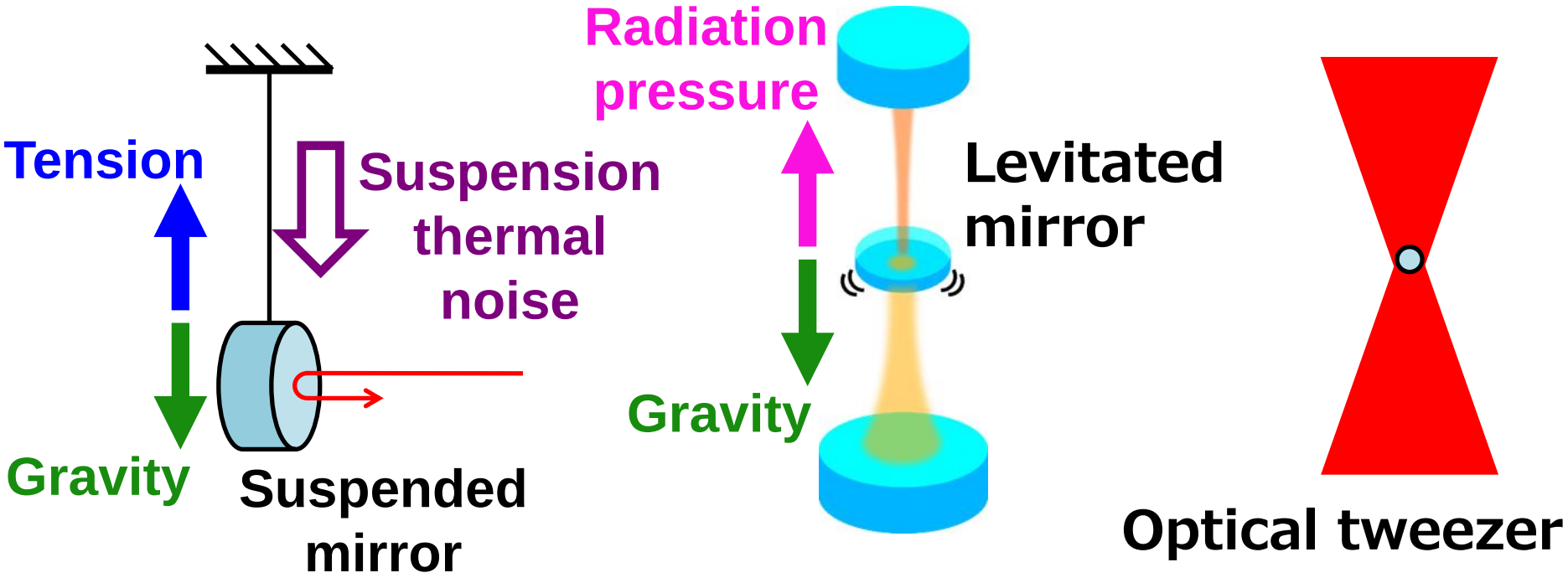
Optical Levitation of Mirror

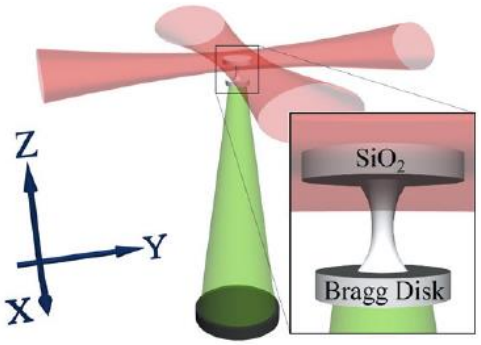
- Support a mirror with radiation pressure alone
- Free from suspension thermal noise
- Large coupling compared with optical tweezers

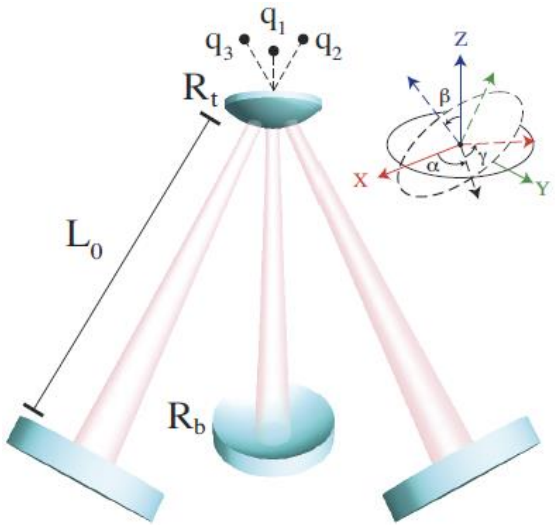


Sandwich Configuration

- Mirror levitation have never been realized
- Simpler configuration than previous proposals

  YM, Y. Kuwahara+, Optics Express 25, 13799 (2017)
- Proved that stable levitation is possible and SQL can be reached with 0.2 mg mirror



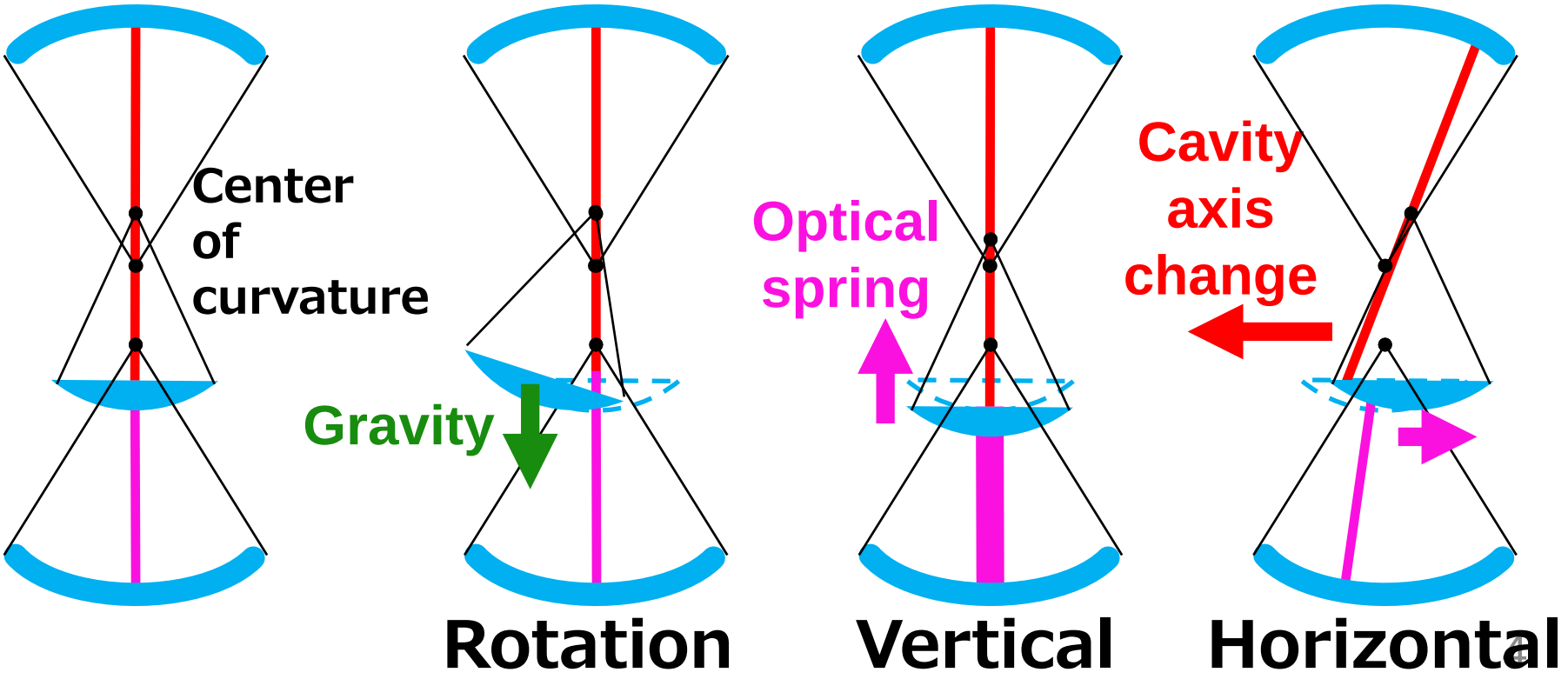


S. Singh+: PRL 105, 213602 (2010)

G. Guccione+: PRL 111, 183001 (2013)

Stability of Levitation

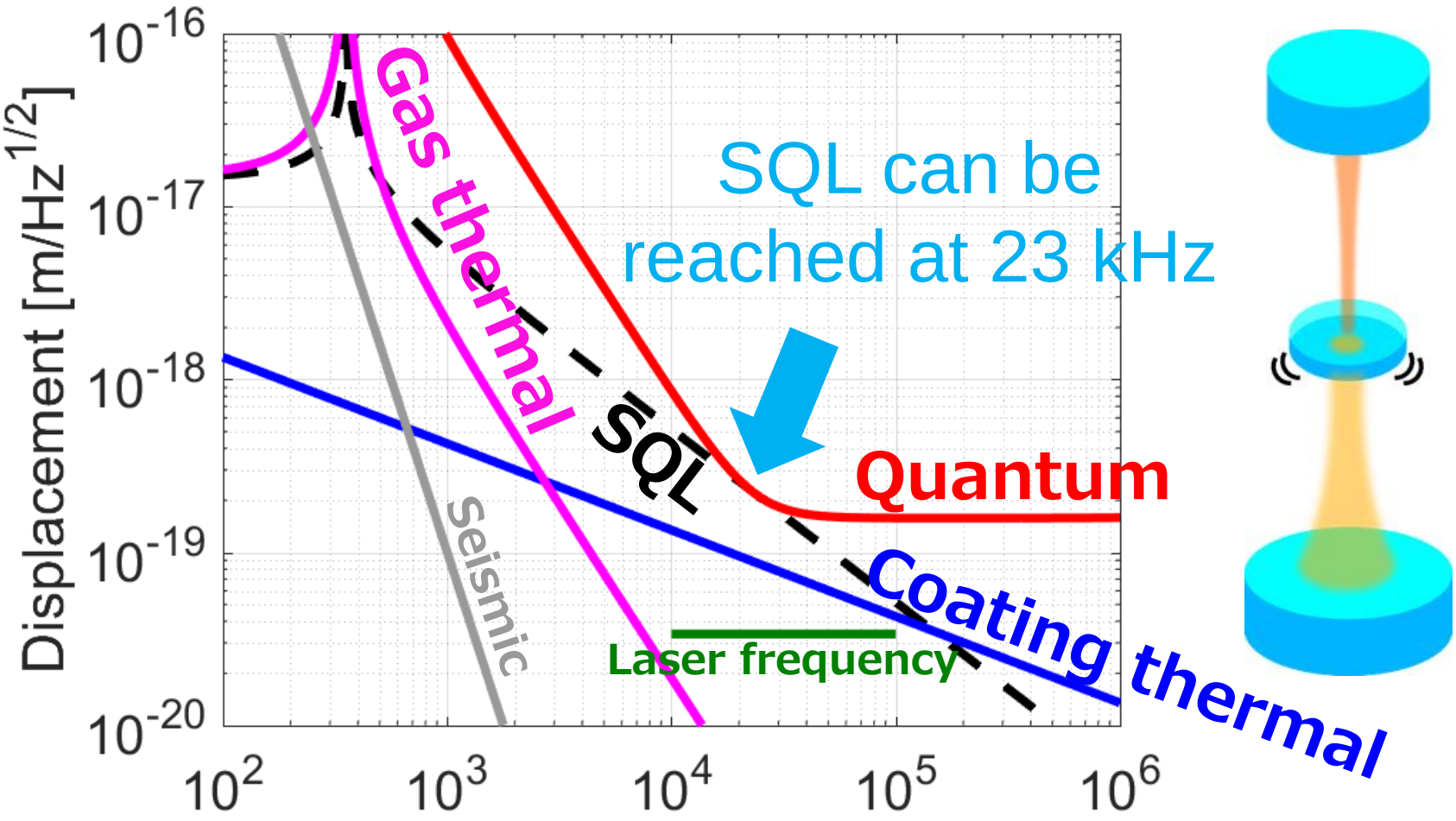
- Rotational motion is stable with gravity
- Vertical motion is stable with optical spring
- Horizontal motion is stable with cavity axis change



Reaching SQL

- 0.2 mg fused silica mirror, Finesse of 100, 13 W + 4 W input

Low finesse necessary for cavity pole to be higher than SQL reaching frequency

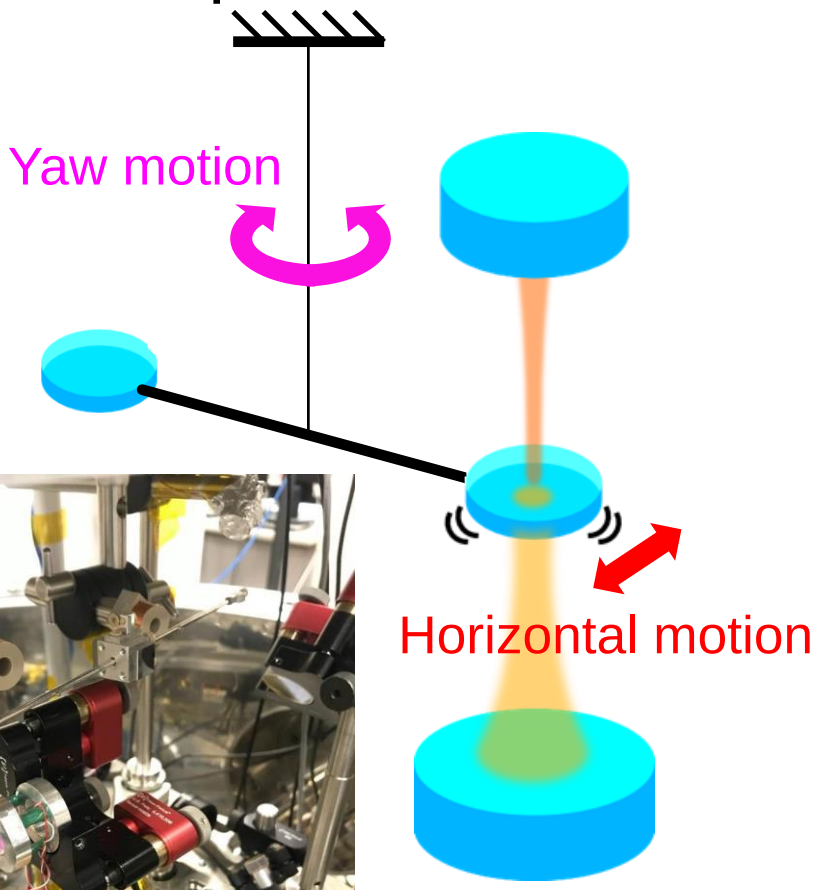


Calculation by Y. Kuwahara

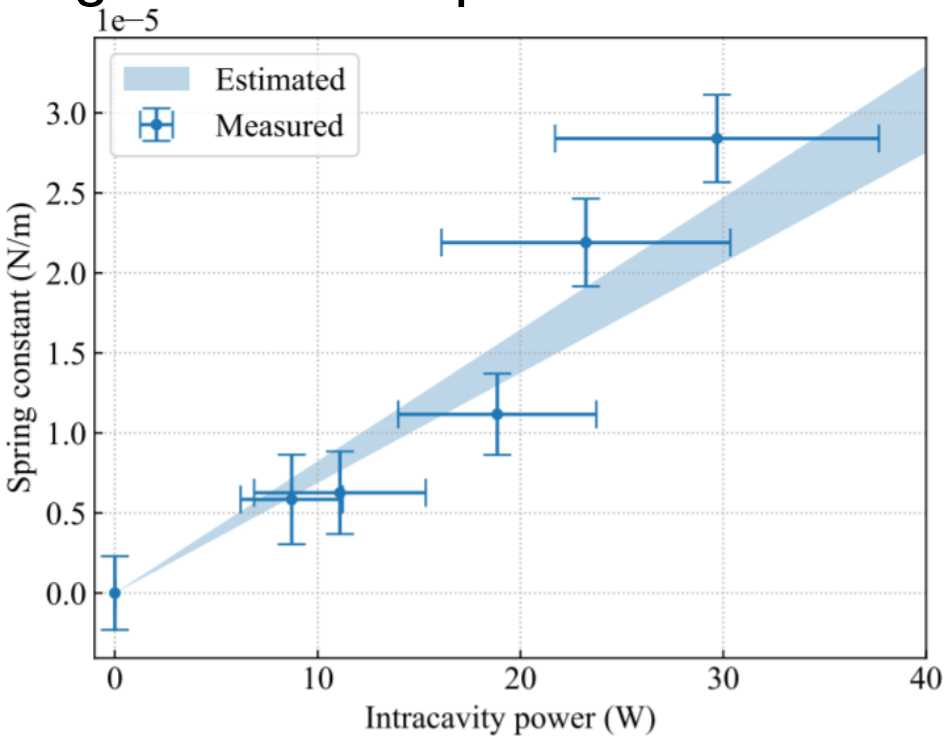
Experiment to Verify the Stability

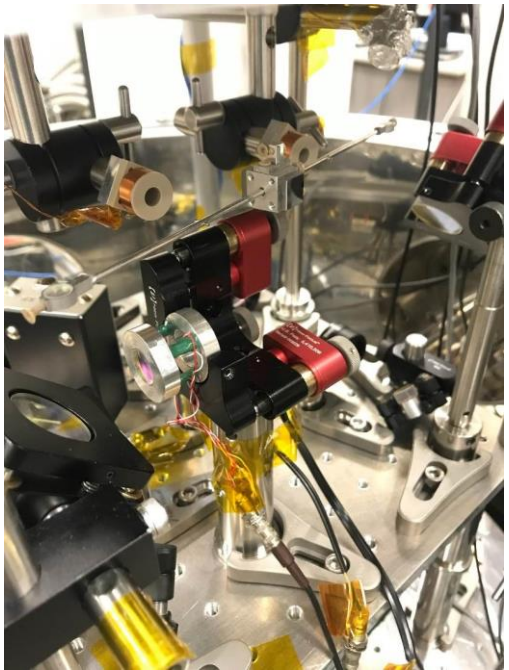
- Verified the stability with a torsion pendulum and a dummy mirror

  T. Kawasaki, …, YM,
  PRA 102, 053520 (2020)



Measured optical geometrical spring agreed with expectation





Fabrication of Levitation Mirrors

- mg and mm-scale curved mirror necessary
  e.g. For levitation demonstration
  φ 3 mm, 0.1 mm thick (~1.6 mg for fused silica)
  RoC = ~30 mm convex
  R > 99.95 %
- Two approaches
  1. Coat thin fused silica mirror to bend the mirror
  2. Photonic crystal mirror to create effective curvature

Supported by ANR-JST
QFilter project

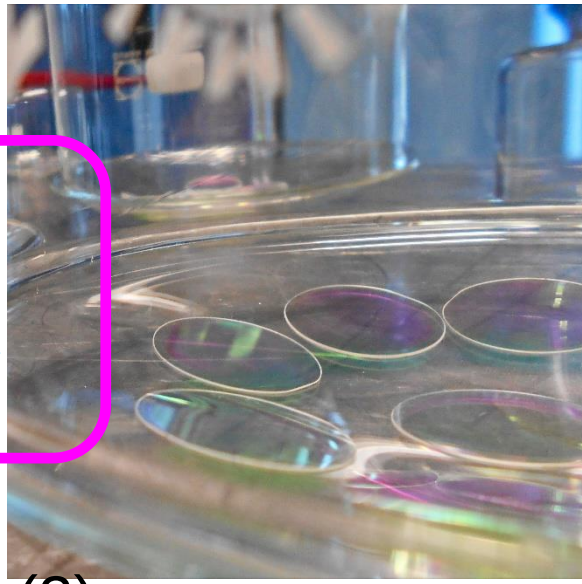
New Approach for Fused Silica

2014 Approach

(1) Make 3 mm dia. lens → (2) Coat → CRACKED!

2020-2021 Approach

(1) Make 1 inch dia. 0.1 mm thick disk → (2) Coat (bend due to stress) → (3) Cut into 3 mm dia.



Somehow concave instead of convex
Coating thickness x2
-> RoC x~1/2
Substrate thickness x1/2
-> RoC x~1/4

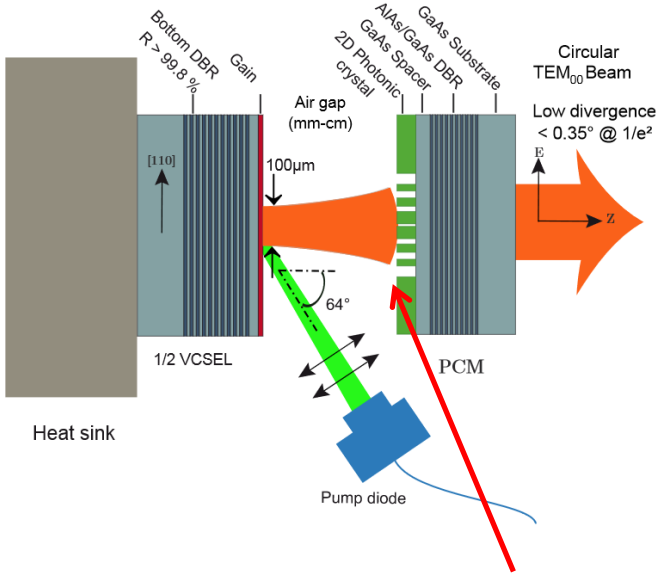
So far successful upto (2)
- R=92(1)%, RoC=500^{+2000}_{-200} mm
- R=88(1)%, RoC=400^{+800}_{-200} mm

Trying (3) and thicker coating (would try thinner substrate)

Photonic Crystal Mirror

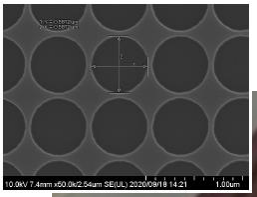
- Effective curvature possible by modulating the filling factor

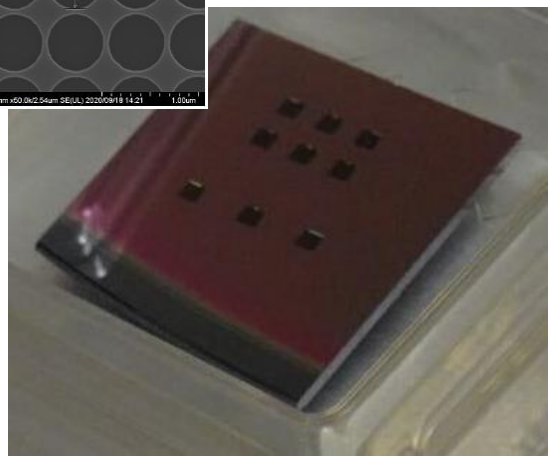
  M. S. Seghilani+,
  Optics Express 22, 5962 (2014)

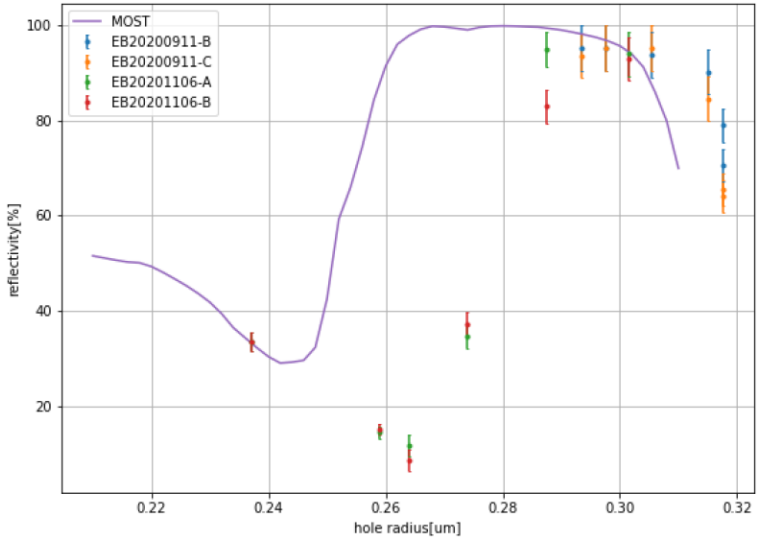


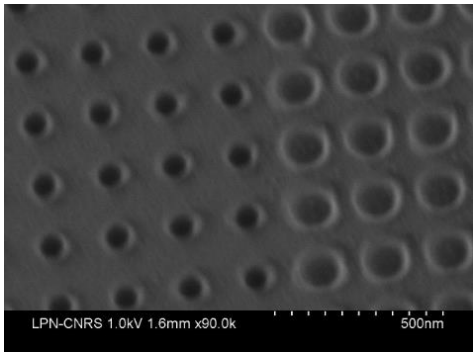
- Currently trying Si photonic crystal mirror without modulation

  So far achieved 95(5) % reflectivity









Summary

- Milligram scale mirror can be levitated with realistic parameters YM, Y. Kuwahara+, Optics Express 25, 13799 (2017)
- Succeeded in experimentally verifying the stability of the levitation T. Kawasaki, …, YM, PRA 102, 053520 (2020)
- Trying two approaches for the fabrication of a milligram mirror with high reflectivity and curvature
  - Coated thin fused silica mirror
    R~90% achieved with RoC~500 m
    Next: thicker coating and mirror cutting
  - Photonic crystal mirror
    R~95% achieved without modulation
    Next: higher reflectivity and modulation