Updates on the Optical Levitation Experiment

Yuta Michimura,

LIGO Laboratory, California Institute of Technology

yuta@caltech.edu

Research Center for the Early Universe, University of Tokyo

michimura@phys.s.u-tokyo.ac.jp

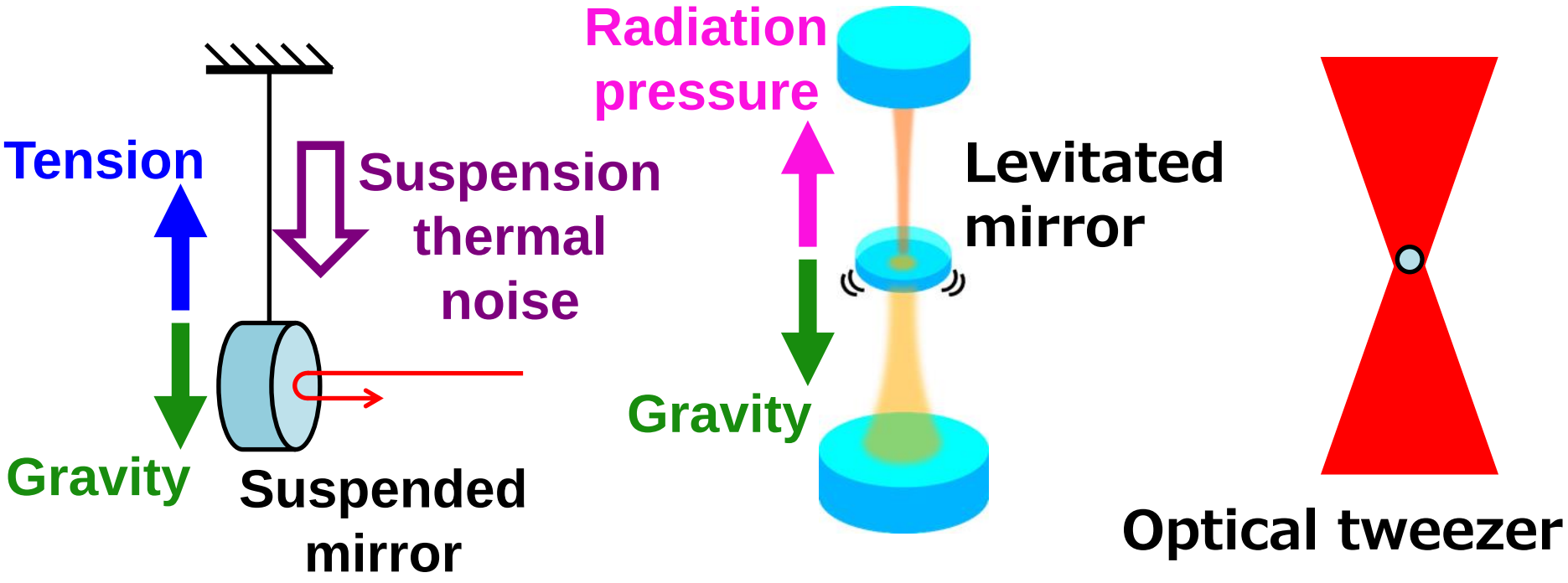
Updates

- Not much updates from the University of Tokyo group
- Great progress in the fabrication of levitation mirrors at LMA

- I moved to LIGO Lab, Caltech from April 2022

Optical Levitation of Mirror

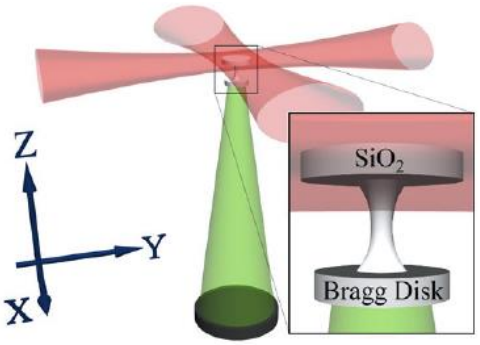
- Support a mirror with radiation pressure alone
- Free from suspension thermal noise
- Large coupling compared with optical tweezers



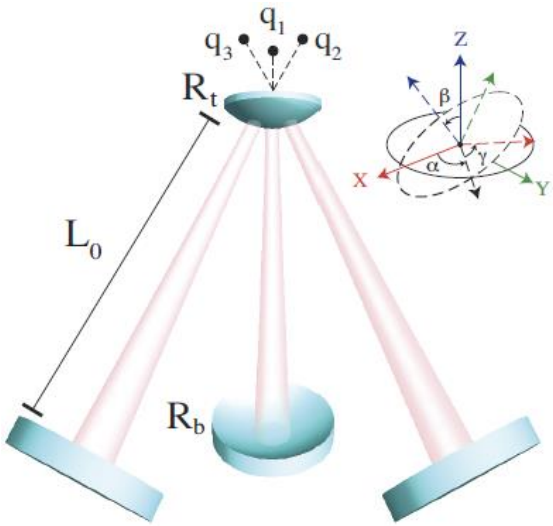
Sandwich Configuration

- 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



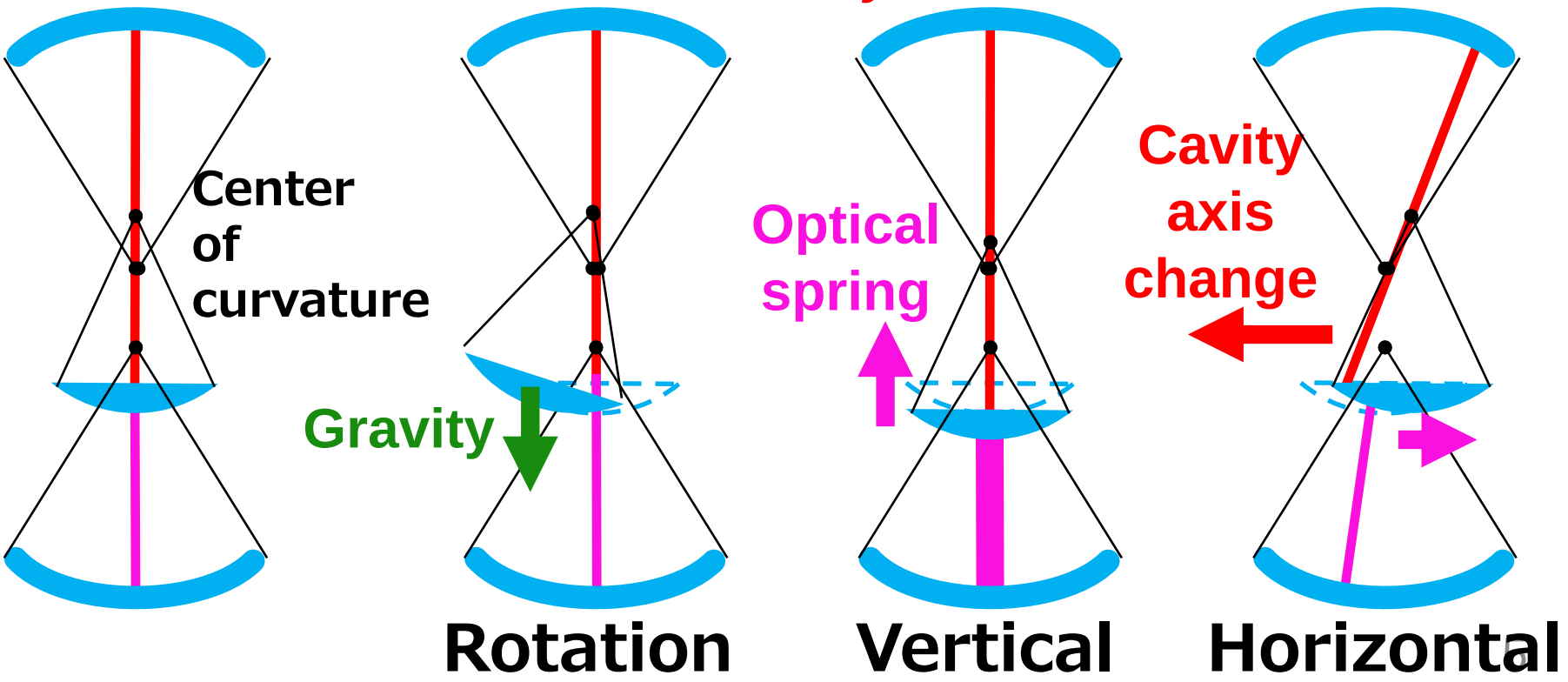
S. Singh+: PRL 105, 213602 (2010)



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

Stability of Levitation

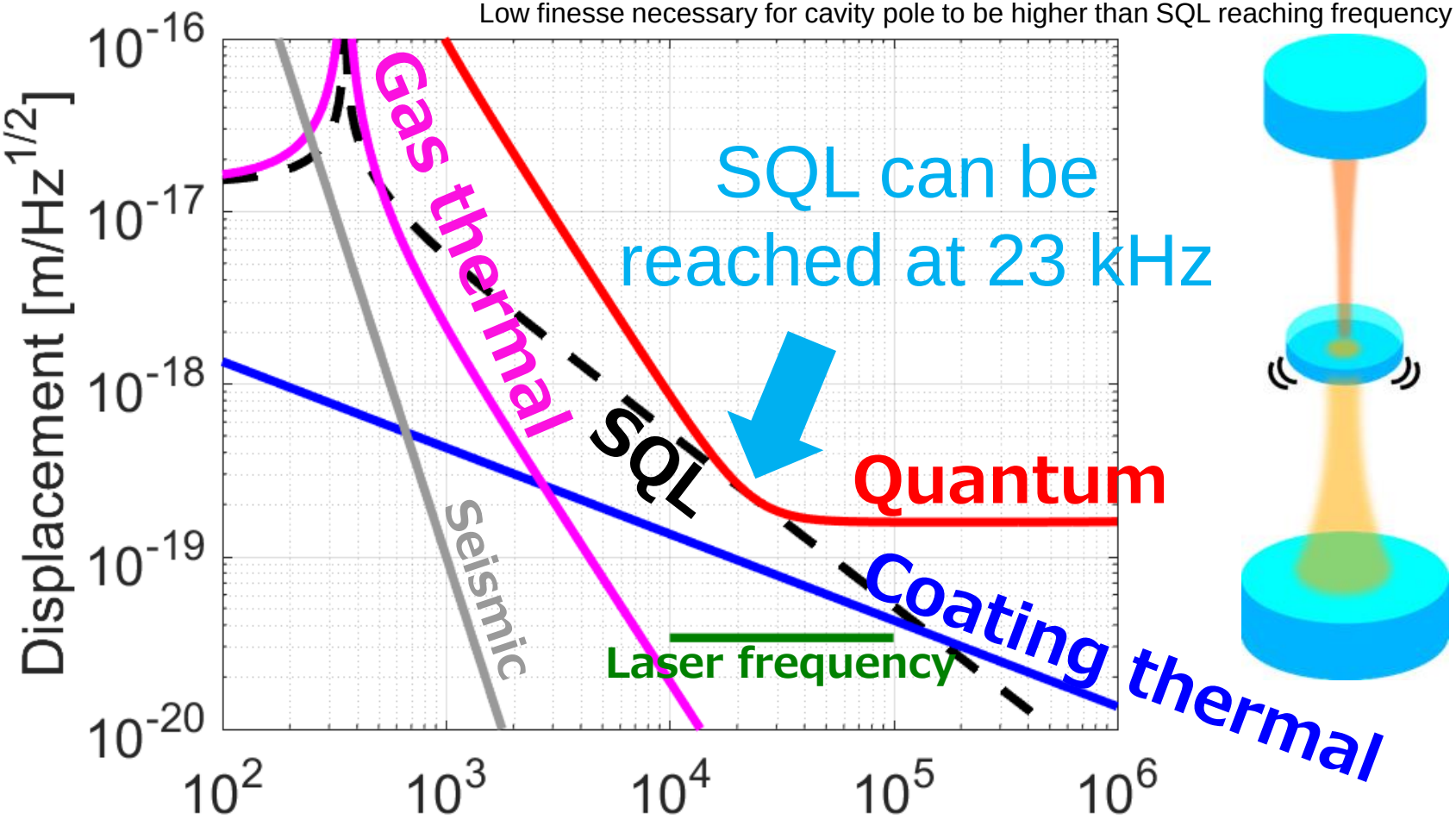
- Rotational motion is stable with gravity
- Vertical motion is stable with optical spring
- Horizontal motion is stable with cavity axis change
- *Curved mirror is necessary!*



Reaching SQL

- Constraint on design: intra-cavity power to support the mass
- 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



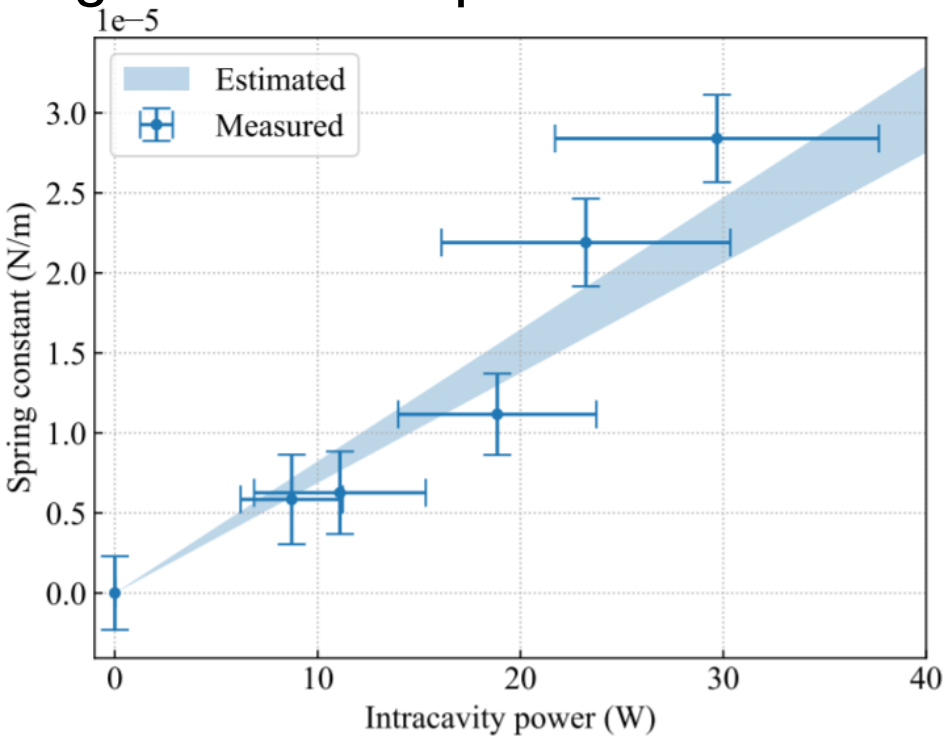
Calculation by Y. Kuwahara

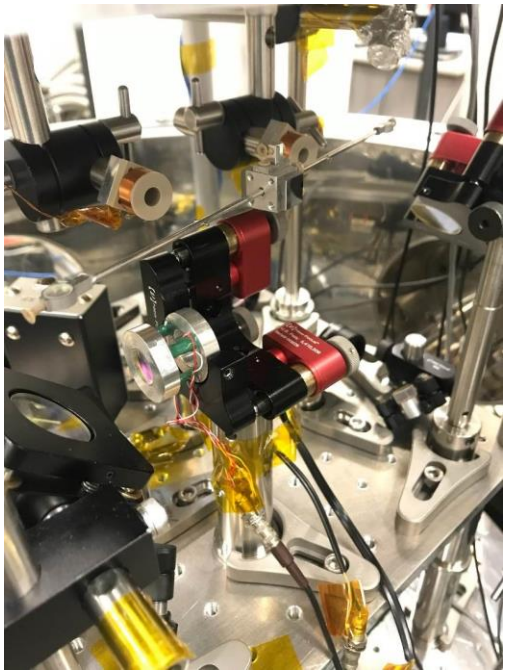
Experiment to Verify the Stability

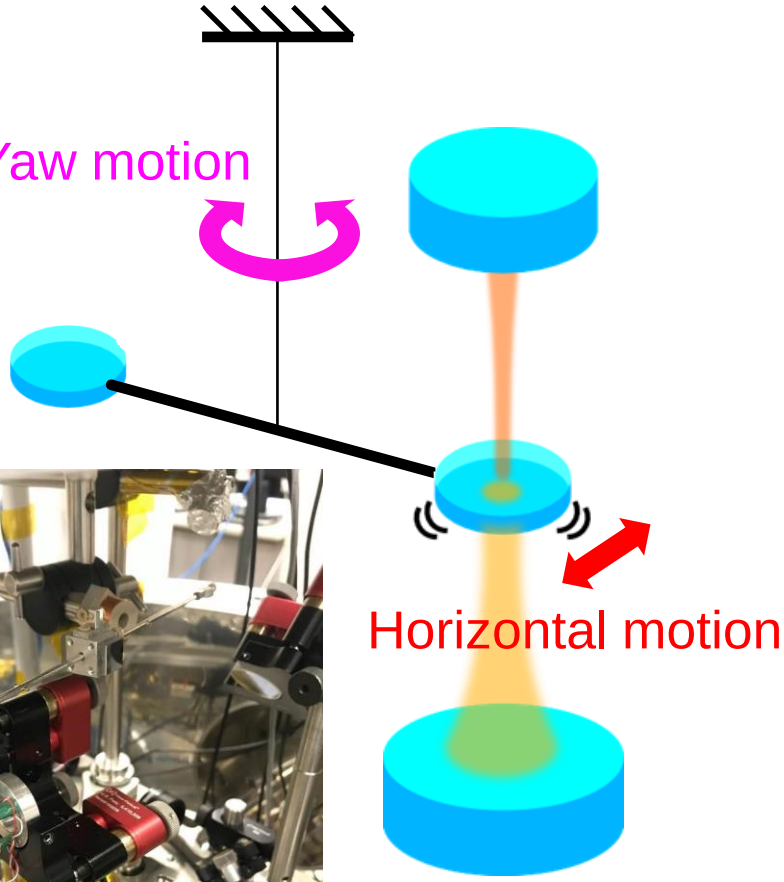
- Verified the stability with a torsion pendulum and a dummy mirror

  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

New Approach for Fused Silica

2014 Approach

(1) Make 3 mm dia. lens

(2) Coat

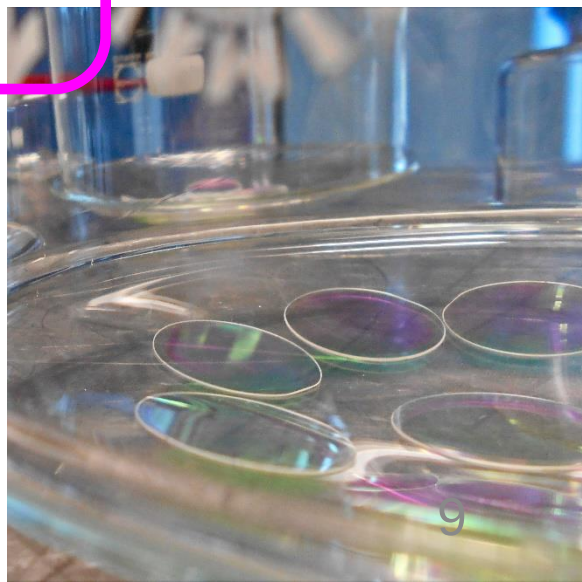
CRACKED!

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.



Thin Fused Silica Mirror Updates

- Sep 2020: R>~90% φ1 inch mirrors arrived
  - Two samples, measured to be
    (1) R=92(1)%, RoC=500^{+2000}_{-200} mm
    (2) R=88(1)%, RoC=400^{+800}_{-200} mm
  - Somehow concave, although convex is expected
    probably we measured flipped mirror

No AR coating yet

- Jan 2021: T=10ppm φ1 inch mirrors arrived
  - Expected to have RoC of -450 mm

~6 um thick coating

- June 2021: Cut T=10ppm φ3 mm mirrors arrived
  - 27 remained
  - cleaning of the protective layer wasn't great & many broke during the process

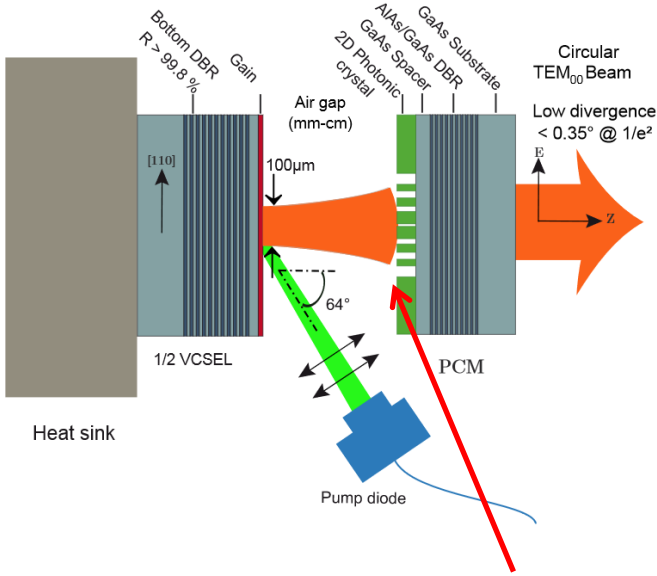
Coating thickness x2
-> RoC x~1/2
Substrate thickness x1/4
-> RoC x~1/16
-> Diameter x2

- Oct 2021: φ1 inch 25 um thick wafers arrived
- Jan 2022: Coating made it like a Pringles

Photonic Crystal Mirror

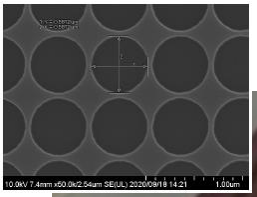
- Effective curvature possible by modulating the filling factor

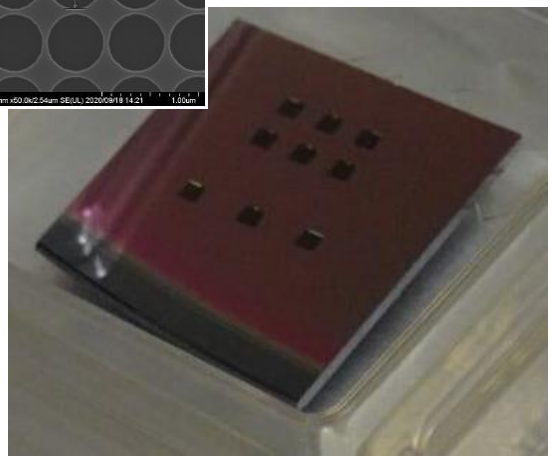
  M. S. Seghilani+,
  Optics Express 22, 5962 (2014)

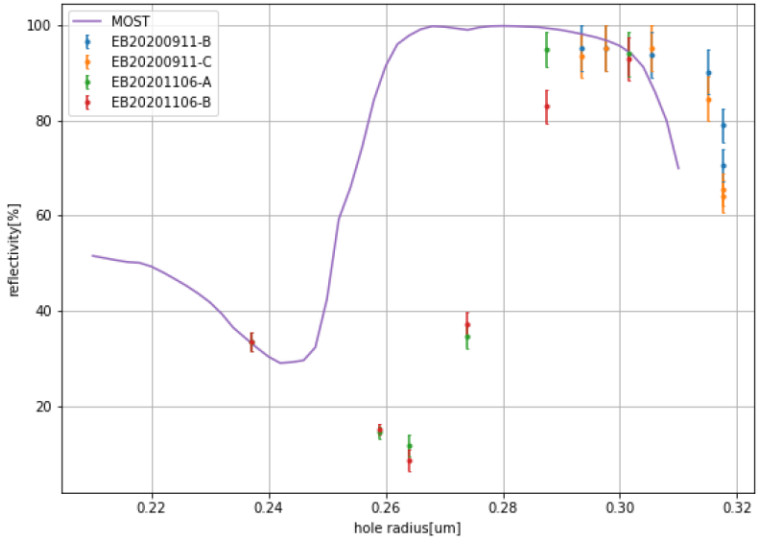


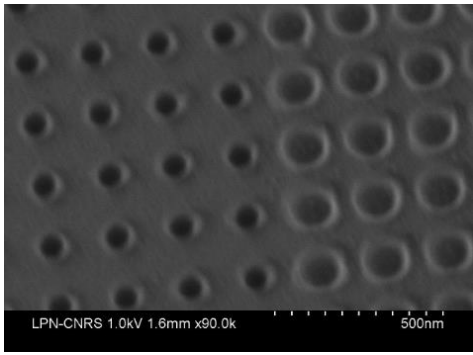
- So far trying Si photonic crystal mirror without modulation

  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: thinner wafer with thicker coating
  - Photonic crystal mirror
    R~95% achieved without modulation
    Next: higher reflectivity and modulation