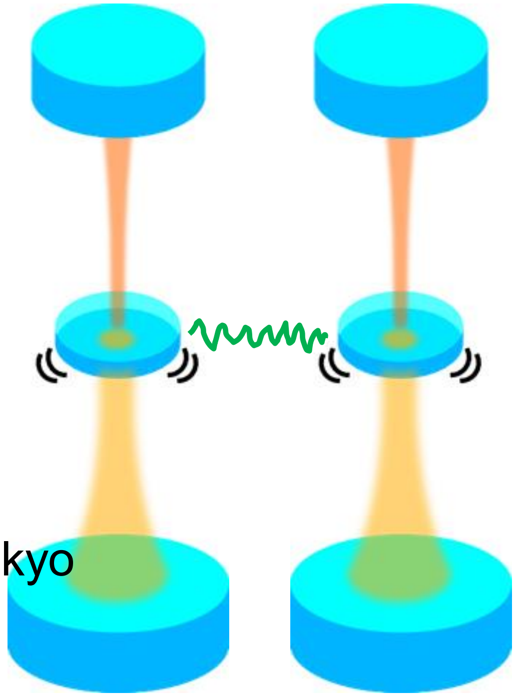
JHU/IPMU Workshop 2026 @ Kavli IPMU, University of Tokyo May 13, 2026

Probing the quantum nature of gravity with optomechanical systems



Yuta Michimura

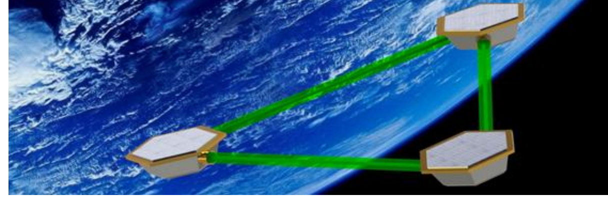
RESCEU, University of Tokyo

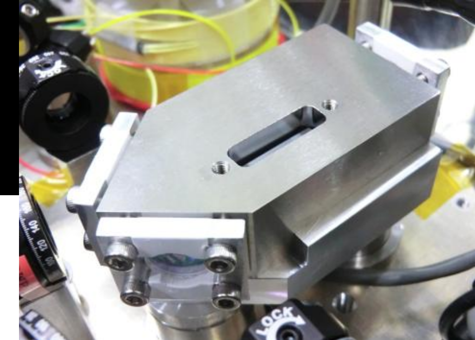
Kavli IPMU, WPI, UTIAS, University of Tokyo

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

MICHIMURA, Yuta

道村 唯太





1987 — Yokohama, Kanagawa

2014

2015 — PhD in Physics

KAGRA

Assistant Professor at
Department of Physics, UTokyo

LIGO

2022

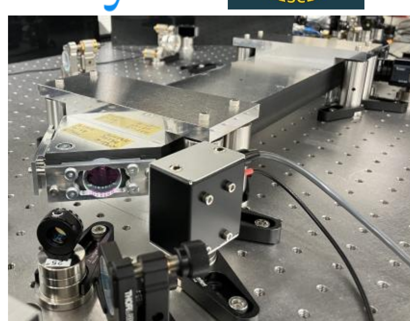
Research Scientist at
LIGO Lab, Caltech

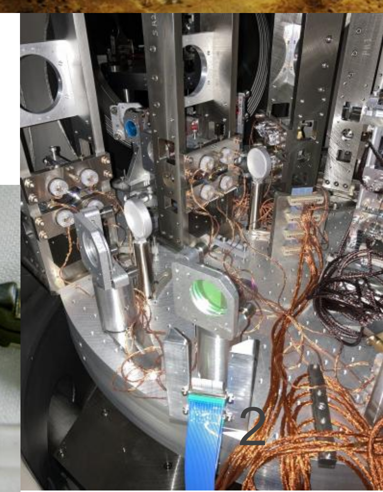
2024

Associate Professor at
RESCEU, UTokyo

RESEARCH CENTER FOR THE EARLY UNIVERSE
THE UNIVERSITY OF TOKYO
RESCEU

Today



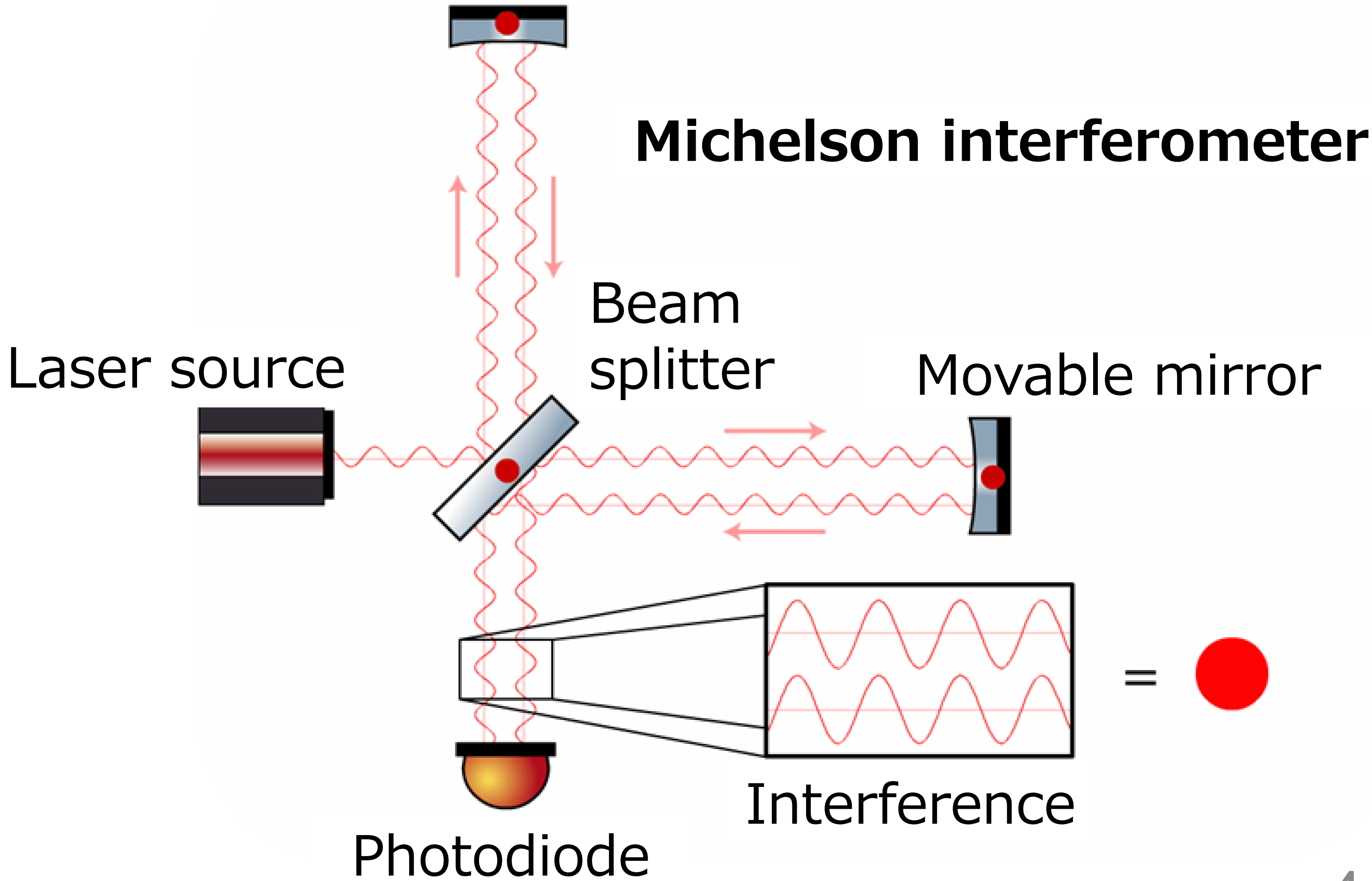


Plan of the Talk

- **Laser interferometry and optomechanics**
  - as a tool to probe quantum nature of gravity
- **Optical levitation of mirrors**
  - status of our experiment
- **Inverted oscillators for accelerating gravity induced entanglement generation**
  - T. Fujita, Y. Kaku, A. Matsumura, YM, CQG **42**, 165003 (2025)
- **Remaining issues**
  - decoherence
  - quantum measurement

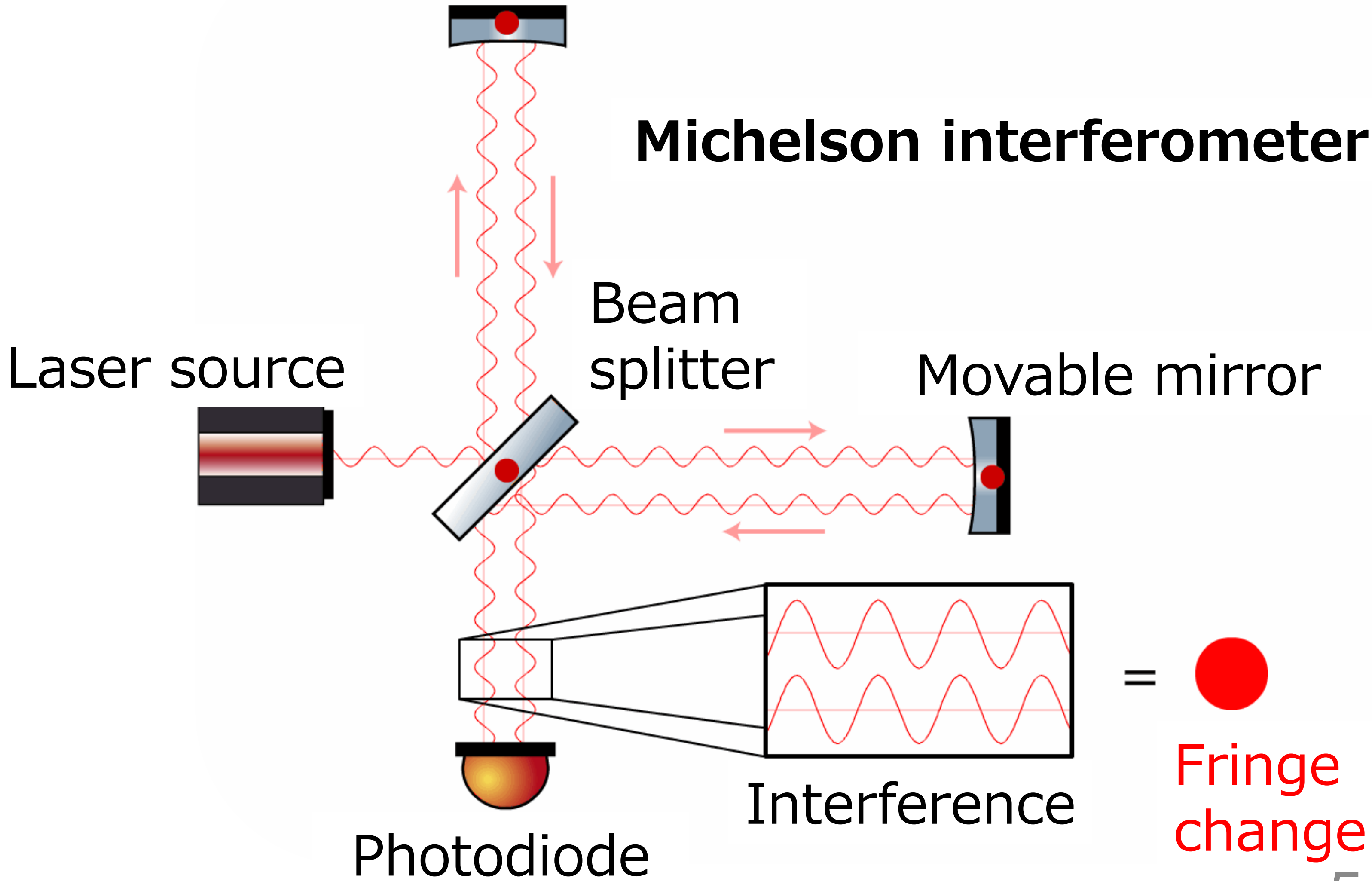
Laser Interferometry

- measures differential arm length change



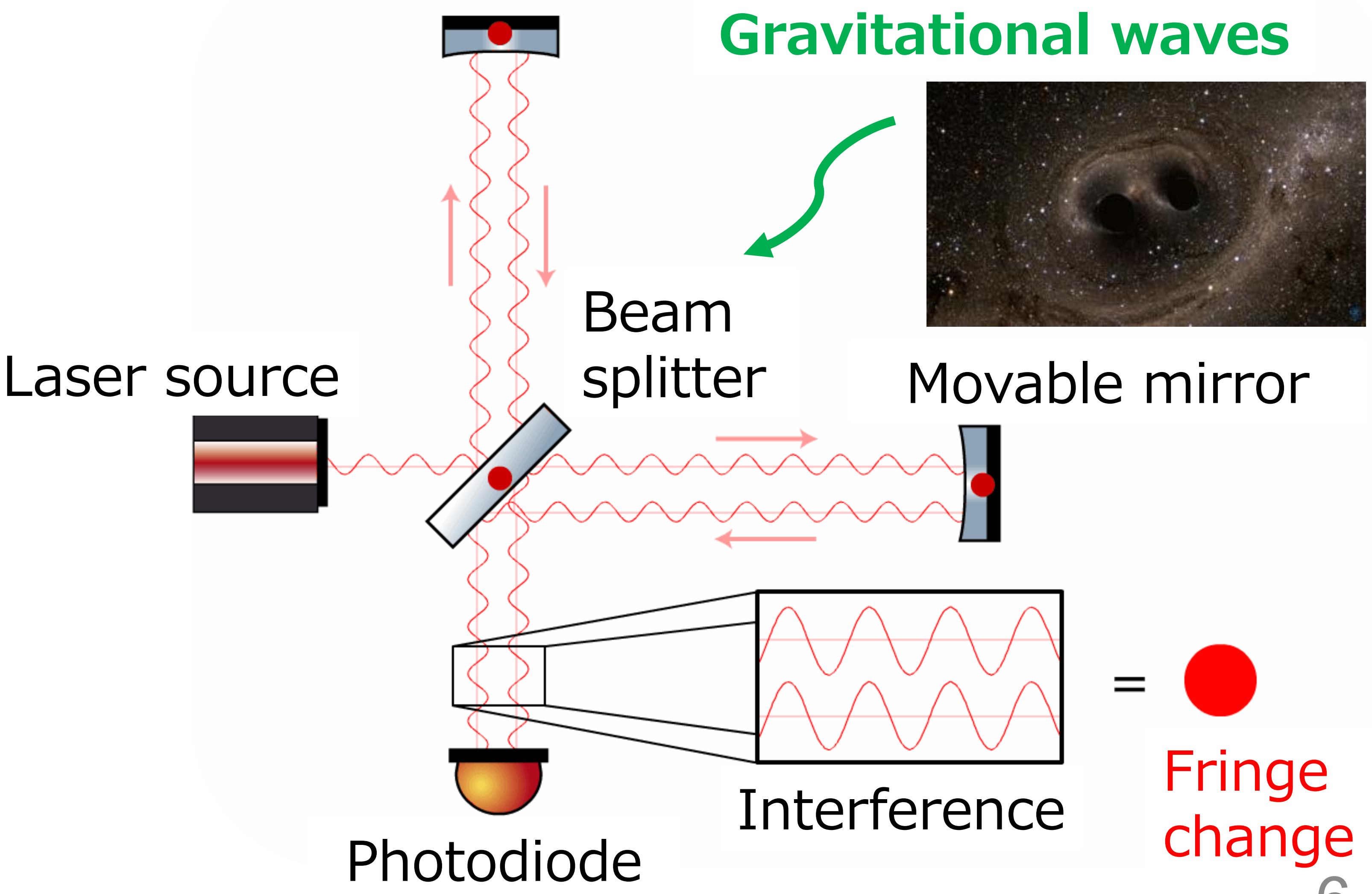
Laser Interferometry

- measures differential arm length change

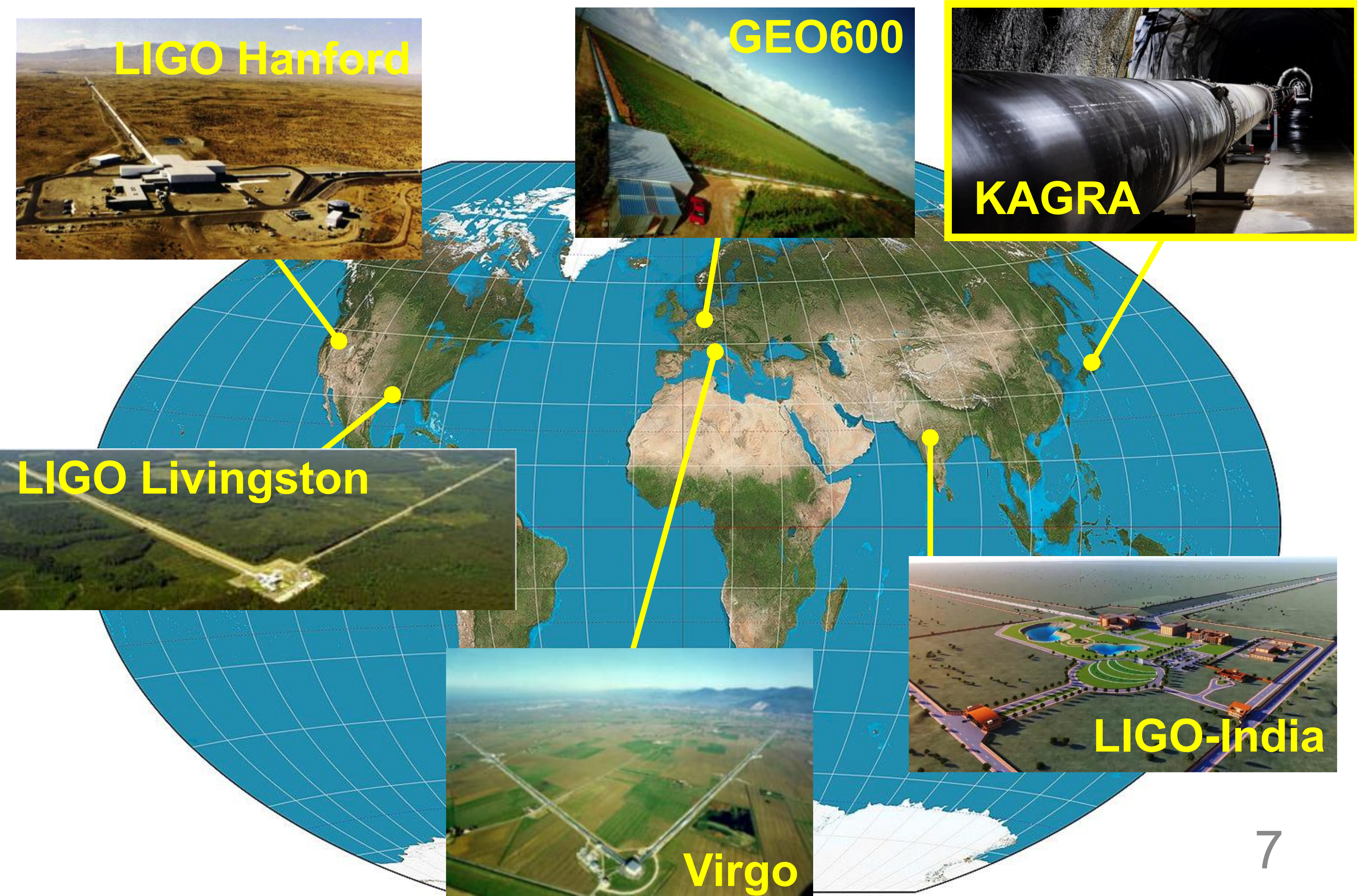


For Gravitational Waves

- measures differential arm length change

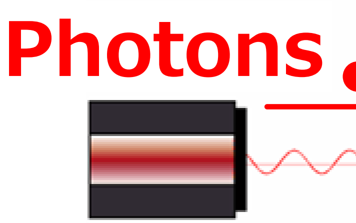


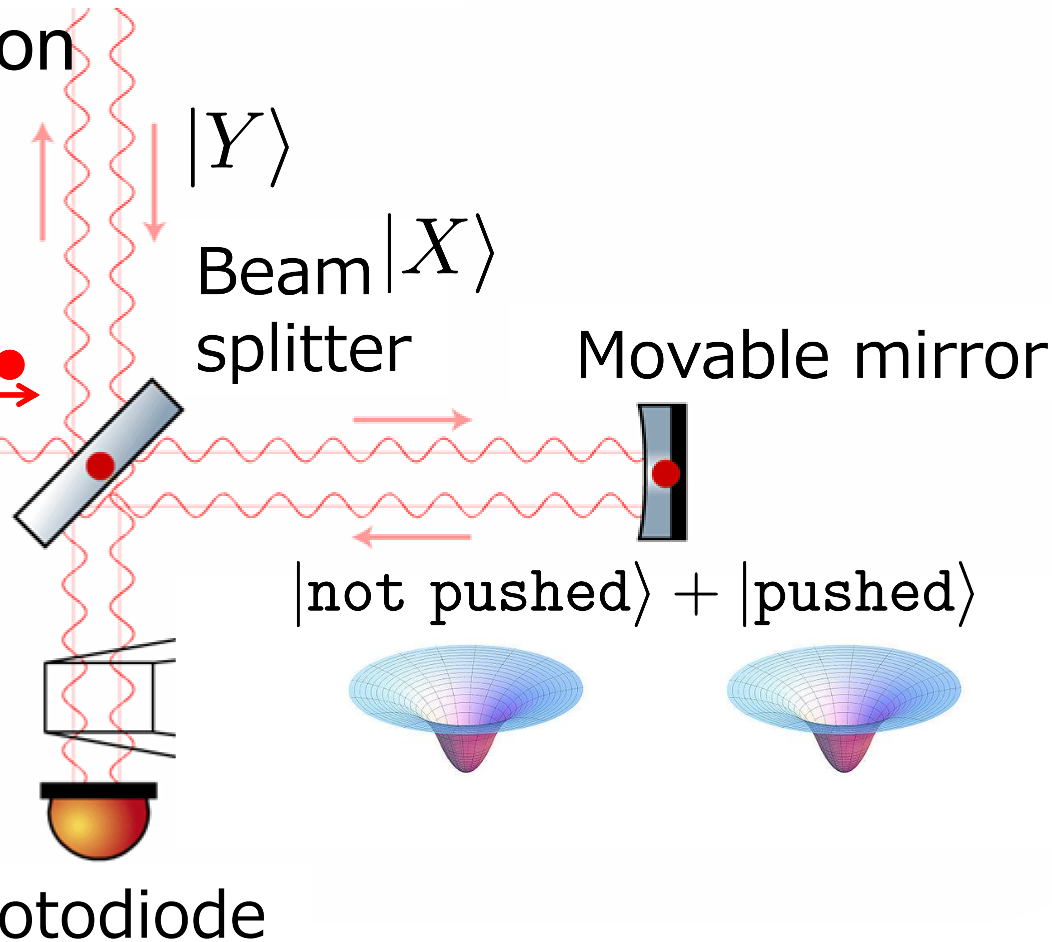
Laser Interferometric GW Detectors



As a Probe of Quantum

- Photon going to X or Y arm is in superposition
- Mirrors pushed or not pushed by radiation pressure is in superposition

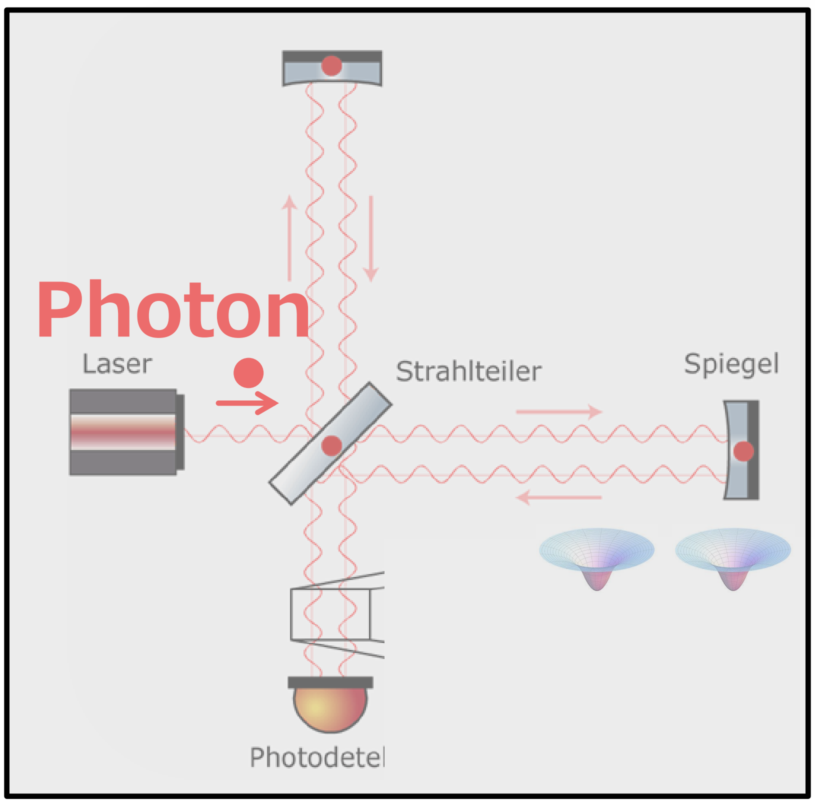


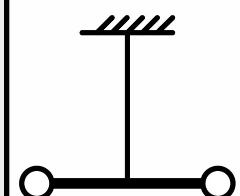


- How about gravitational field of massive mirrors?

Schrödinger's KAGRA

- If you put KAGRA in a box and bring a torsion pendulum close to one of its mirrors, will the torsion pendulum oscillate due to the mirror's gravity, not oscillate at all, or oscillate half???





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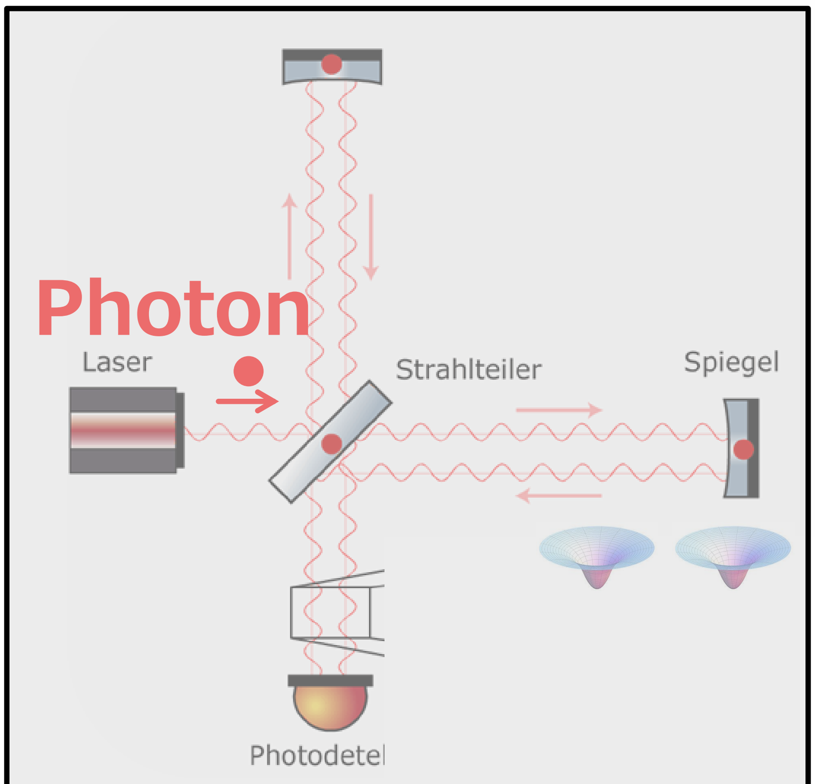
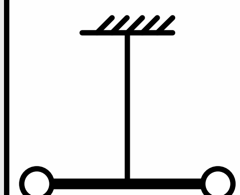


$$\nabla^2\Phi = 4\pi G\left\langle \begin{matrix}\text{Mass}\\ \text{distribution}\end{matrix} \right\rangle$$

Expectation value

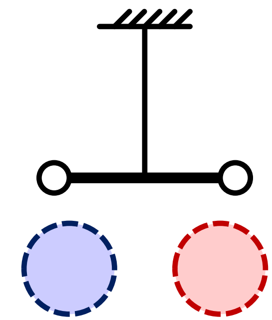


Semiclassical Gravity (Schrödinger-Newton model)

Very strange model, but not falsified experimentally

Page-Geilker Experiment

- Source mass was moved according to γ-ray emission from Cobalt 60
  → Torsion correlated with γ-ray emission



VOLUME 47, NUMBER 14 PHYSICAL REVIEW LETTERS 5 OCTOBER 1981

Indirect Evidence for Quantum Gravity

Don N. Page
Department of Physics, The Pennsylvania State University, University Park, Pennsylvania 16802

and

C. D. Geilker
Department of Physics, William Jewell College, Liberty, Missouri 64068

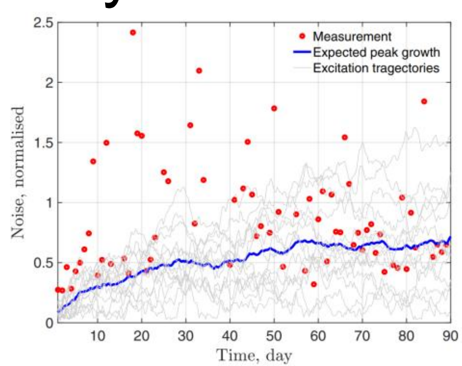
(Received 9 June 1981)

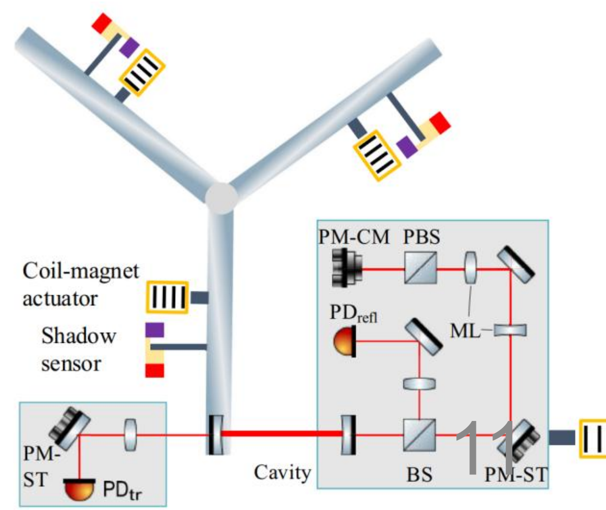
An experiment gave results inconsistent with the simplest alternative to quantum gravity, the semiclassical Einstein equations. This evidence supports (but does not prove) the hypothesis that a consistent theory of gravity coupled to quantized matter should also have the gravitational field quantized.

D. N. Page, C. D. Geilker,
[PRL 47, 979 (1981)]

- Preselection Schrodinder-Newton also tested more recently
  (resonant frequency shift from self-gravity and the growth in the resonant peak)

T. Yan+,
[PRD 111, 082007 (2025)]





Role of Quantum Measurements

TABLE I. Summary of collapse, Schrödinger-Newton, and classical gravity models that rely on auxiliary observers. We propose a unified model in which classical gravity depends on the outcomes of auxiliary observers as well as the results of experiments performed by the experimentalist.

Class	Model	Auxiliary observers introduced?	Auxiliary outcomes used to generate ϕ?	Experimental measurement outcomes used to generate ϕ?	Features
Collapse models	Diosi-Penrose [18,43]	Measure **g** everywhere	No	No	Gravity not implemented
	CSL [20,44]	Measure smeared matter distribution	No	No	
Schrödincer-Newton	Preselection [4,7] S-N	No	No	No	Violates Page-Geilker
	Postselection S-N [7]	No	No	Yes	Future measurement choices influence past.
	Causal-conditional S-N [8,9,11,12]	No	No	Obtain conditional expectation of positions then generate gravity via classical feedback	Preserves causality
Classical grmvity with auxiliary observers	N-H extension of S-N [45]	Measure **g** everywhere	Yes	No	Classical gravity via Diosi-Penrose measurements
	KTM Model [21,22]	Measure position of each mass	Uses instant outputs of position channels	No	Instant outputs are very noisy
	Oppenheim's model [23]	Yes	Yes	No	More general and includes NH and KTM
	Unified model	Measure position of each mass	Yes	Yes	Can incorporate all above models

This model is falsified by D. N. Page, C. D. Geilker, PRL 47, 979 (1981)

Violates causality

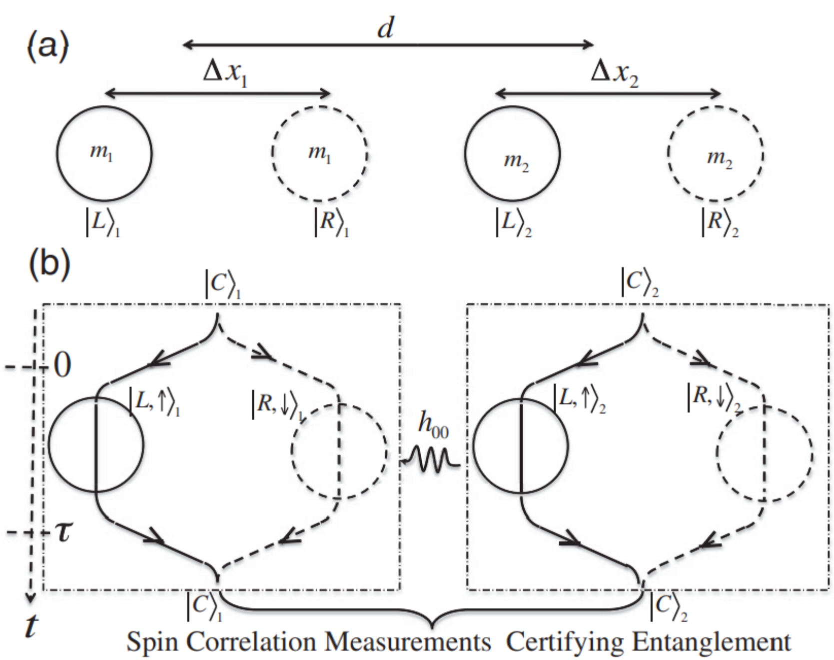
Preserves causality

D. Miki, Y. Kaku, Y. Liu, Y. Ma, Y. Chen, PRD 111, 104084 (2025)

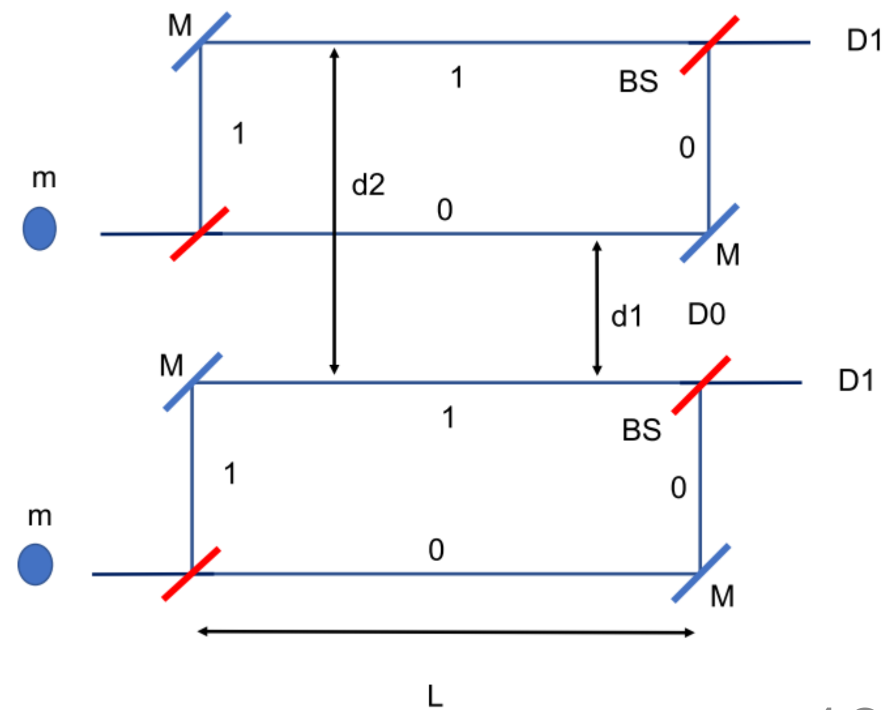
BMV Proposals

- Quantum nature of gravity can be tested by testing gravity-induced entanglement with adjacent matter interferometers

S. Bose+,
Phys. Rev. Lett. 119, 240401 (2017)



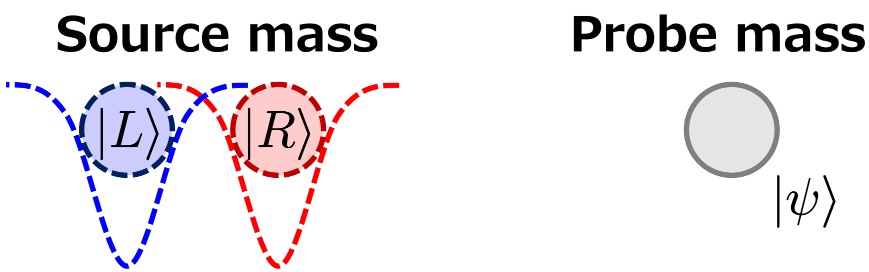
C. Marletto & V. Vedral,
Phys. Rev. Lett. 119, 240402 (2017)



Key Idea of BMV Proposals

- If gravity is quantum

$$\Phi(\hat{x}, \hat{X}) = -\frac{GM}{|\hat{x} - \hat{X}|}$$



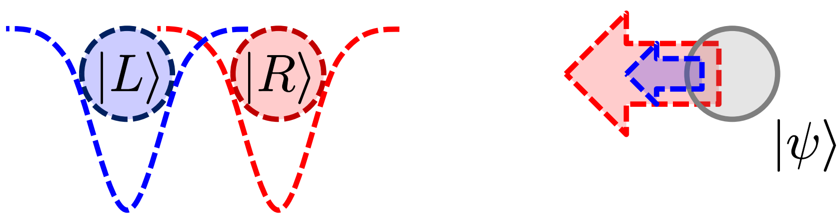
Newtonian potential act as an operator

Key Idea of BMV Proposals

- If gravity is quantum

$$\Phi(\hat{x}, \hat{X}) = -\frac{GM}{|\hat{x} - \hat{X}|}$$

Source mass **Probe mass**



Newtonian potential act as an operator

$$e^{\frac{i}{\hbar}m\Phi(\hat{X})t}\frac{1}{\sqrt{2}}(|L\rangle + |R\rangle) \otimes |\psi\rangle$$

$$= \frac{1}{\sqrt{2}}\left(|L\rangle \otimes e^{i\phi_L}|\psi\rangle + |R\rangle \otimes e^{i\phi_R}|\psi\rangle\right)$$

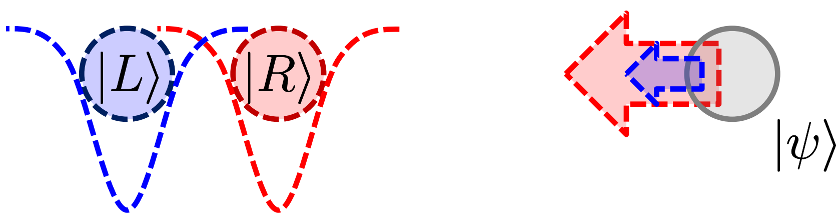
Gravity induced entanglement

Key Idea of BMV Proposals

- If gravity is quantum

$$\Phi(\hat{x}, \hat{X}) = -\frac{GM}{|\hat{x} - \hat{X}|}$$

Source mass **Probe mass**



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$$e^{\frac{i}{\hbar} m \Phi(\hat{X}) t} \frac{1}{\sqrt{2}} (|L\rangle + |R\rangle) \otimes |\psi\rangle$$

$$= \frac{1}{\sqrt{2}} \left(|L\rangle \otimes e^{i\phi_L} |\psi\rangle + |R\rangle \otimes e^{i\phi_R} |\psi\rangle \right)$$

Gravity induced entanglement

- If gravity is classical

$$\Phi(\hat{x}) = -\left\langle \frac{GM}{|\hat{x} - \hat{X}|} \right\rangle$$

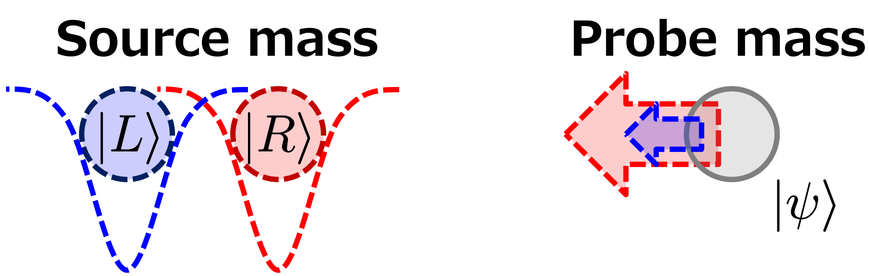
Source mass **Probe mass**

Newtonian potential act as a c-number

Key Idea of BMV Proposals

- If gravity is quantum

$$\Phi(\hat{x}, \hat{X}) = -\frac{GM}{|\hat{x} - \hat{X}|}$$



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$$= \frac{1}{\sqrt{2}} \left(|L\rangle \otimes e^{i\phi_L} |\psi\rangle + |R\rangle \otimes e^{i\phi_R} |\psi\rangle \right)$$

Gravity induced entanglement

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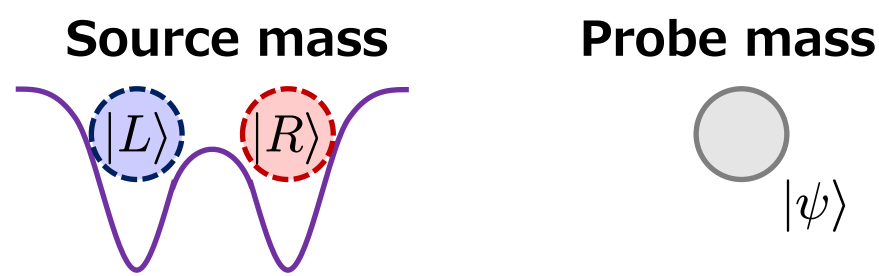
$$\Phi(\hat{x}) = -\left\langle \frac{GM}{|\hat{x} - \hat{X}|} \right\rangle$$



Newtonian potential act as a c-number

$$e^{\frac{i}{\hbar} m \Phi t} \frac{1}{\sqrt{2}} (|L\rangle + |R\rangle) \otimes |\psi\rangle$$

$$= \frac{1}{\sqrt{2}} (|L\rangle + |R\rangle) \otimes e^{\frac{i}{\hbar} m \Phi t} |\psi\rangle$$

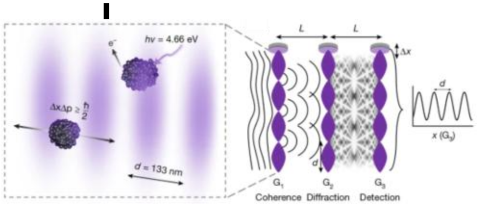
Remains separable

Quantum and Gravity Experiments

Quantum

Gravity

Mass



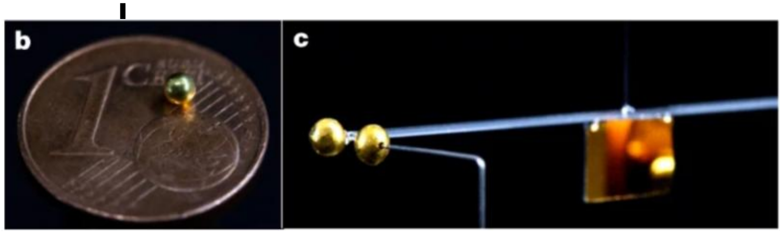
sodium nanoparticles,
3e-19 g
Pedalino+ (2026)

Interference

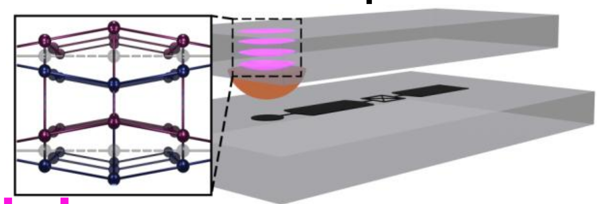
cantilever, 50 ng
Cripe+ (2019)

Backaction

Planck mass
22 ug



torsion pendulum, 90 mg
Westphal+ (2021)



Cat state

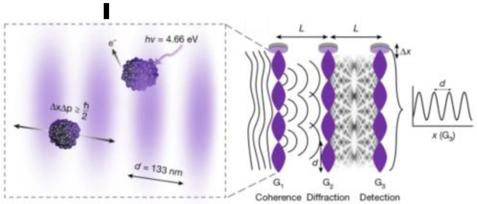
acoustic wave, 16 ug
Bild+ (2023)

Quantum and Gravity Experiments

Quantum → **Quantum regime of gravity** ← **Gravity**

Mass

Planck mass
22 ug



sodium nanoparticles, 3e-19 g
Pedalino+ (2026)

Interference

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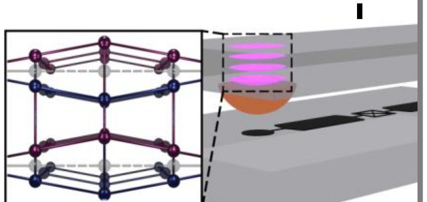
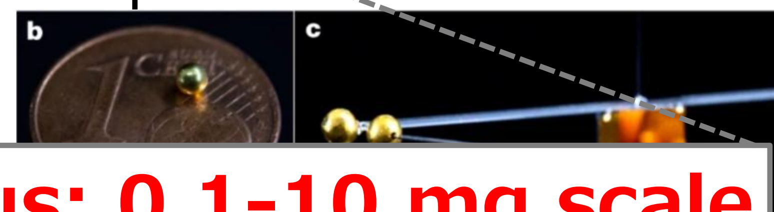
Backaction



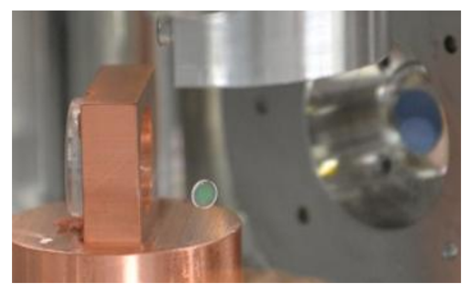
Cat state

acoustic wave,
Bild+ (2023)



Our focus: 0.1-10 mg scale

optical levitation,
~0.2 mg

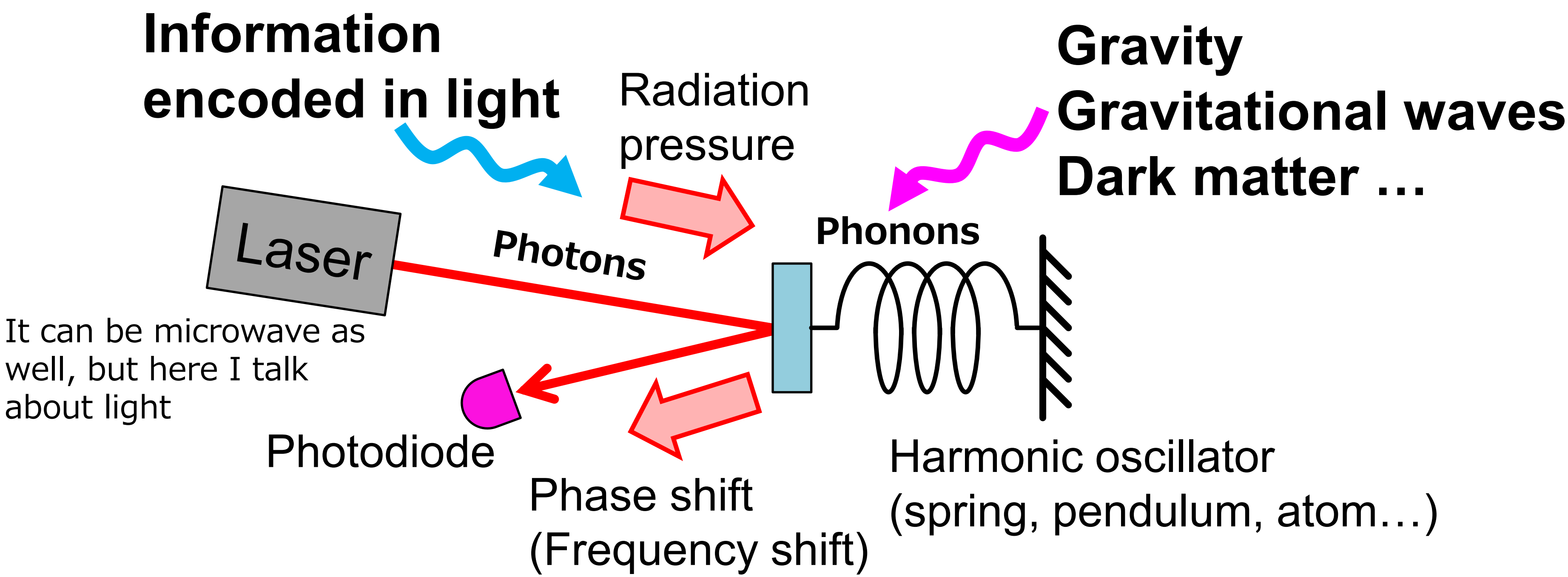


suspended disk, 7 mg
Matsumoto+ (2019)

suspended bar, 10 mg
Komori+ (2019)

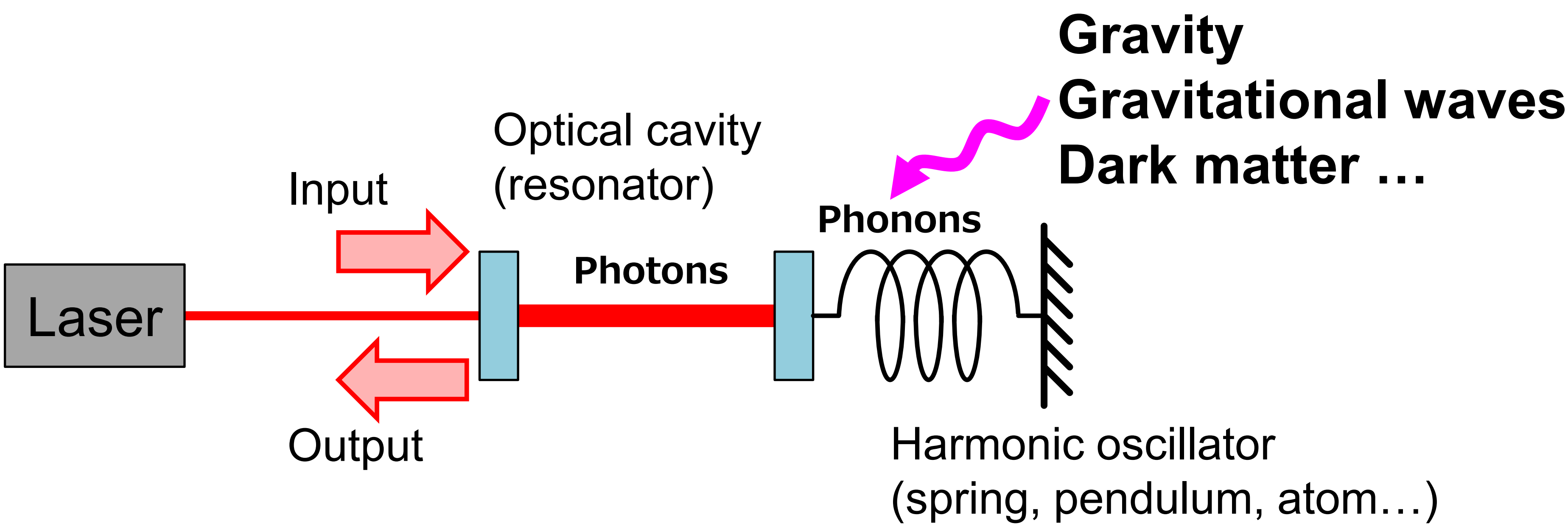
Optomechanical Systems

- Interaction between light and mechanical oscillators



Cavity Optomechanics

- Interaction between light and mechanical oscillators



- Usually, optical cavities are involved to enhance the interaction → Cavity Optomechanics

For a review, see

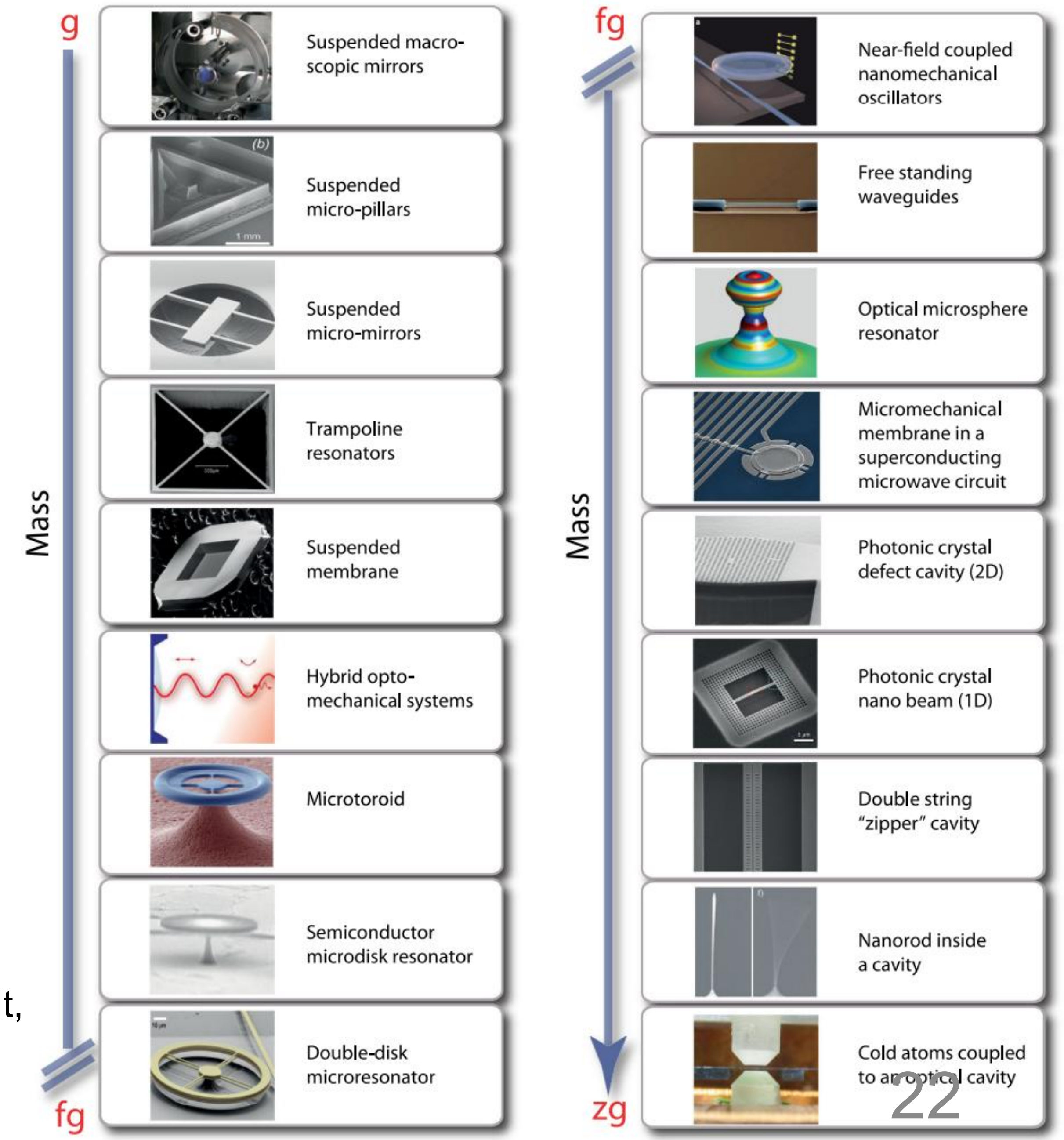
Cavity optomechanics

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

Macroscopic Quantum Mechanics

Yanbei Chen, J. Phys. B: At. Mol. Opt. Phys. 46, 104001 (2013)

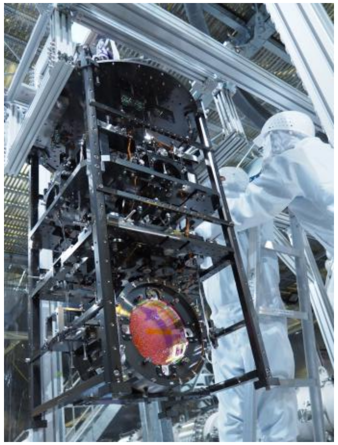
Various Mass Scales

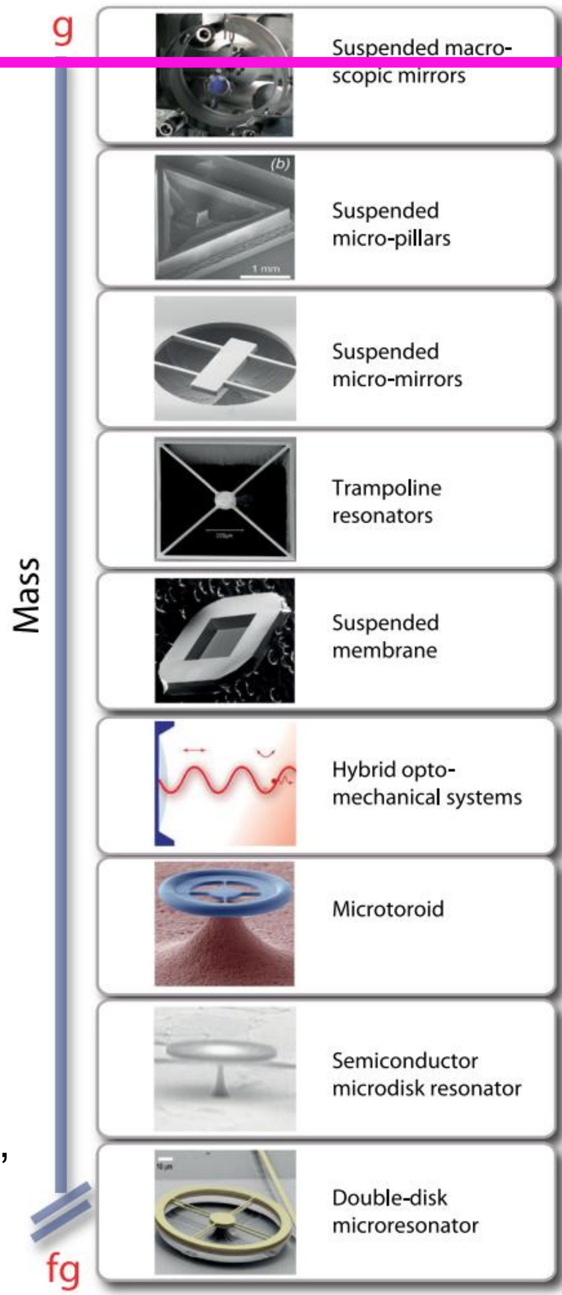


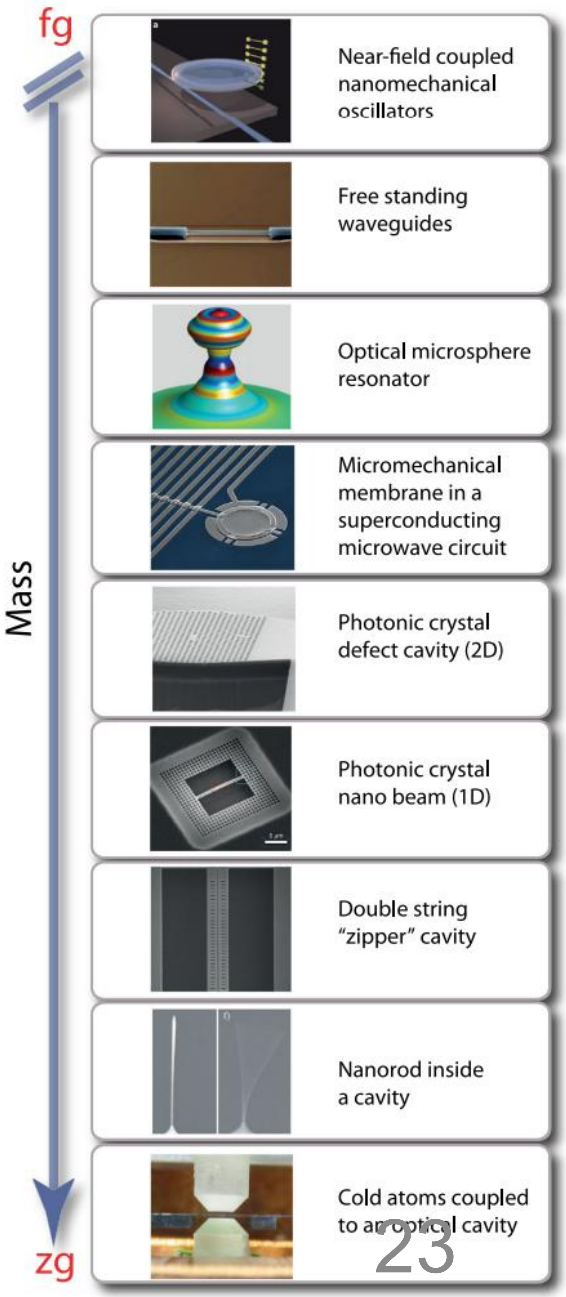
Aspelmeyer, Kippenberg, Marquardt, [Rev. Mod. Phys. 86, 1391 (2014)]

Various Mass Scales

My experiments in mg to kg scale



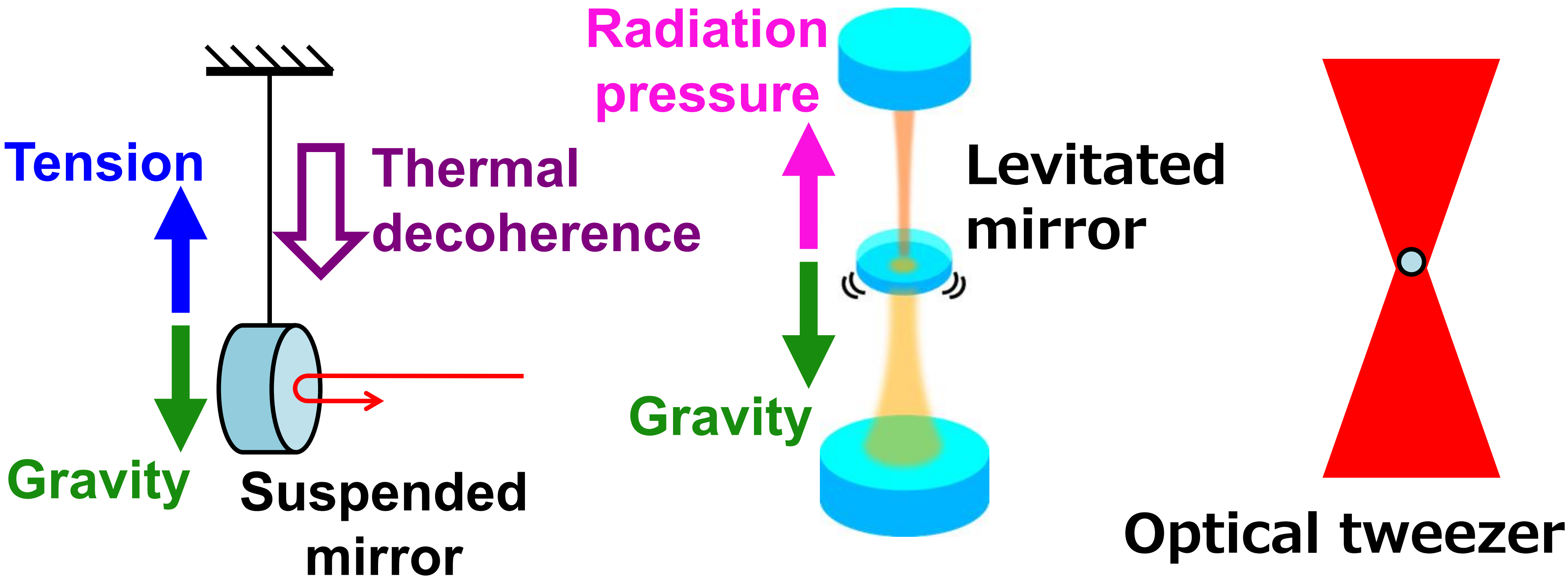




Aspelmeyer, Kippenberg, Marquardt, Rev. Mod. Phys. 86, 1391 (2014)

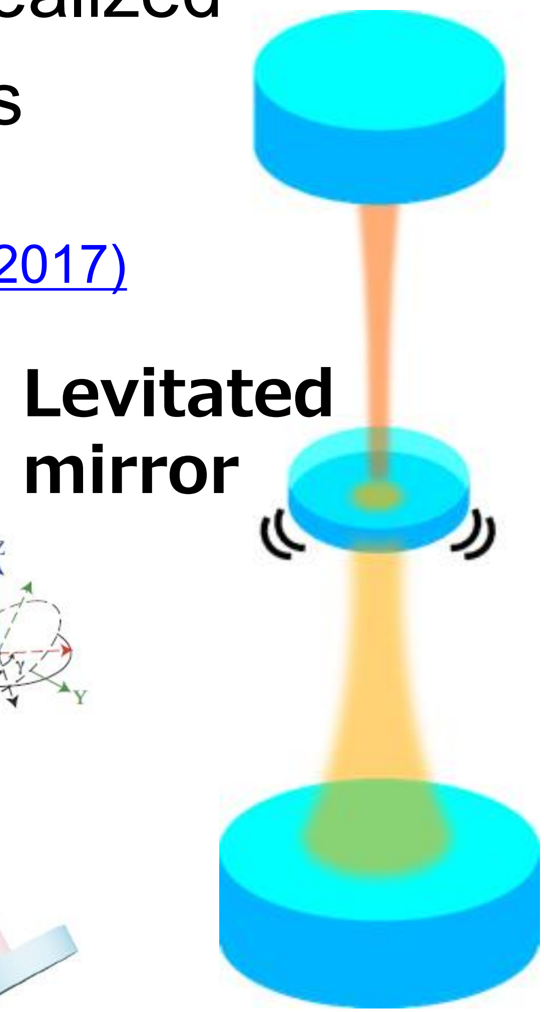
Optical Levitation of Mirrors

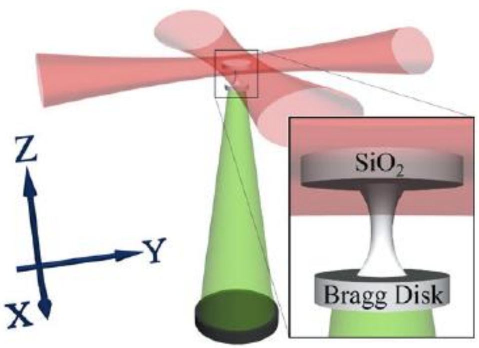
- Support a mirror with radiation pressure alone
- Free from thermal decoherence from mechanical support
- Large coupling compared with optical tweezers

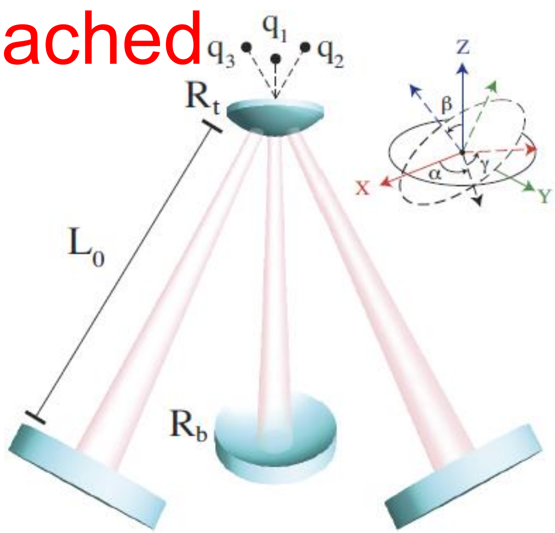


Sandwich Configuration

- 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 standard quantum limit (SQL) can be reached with 0.2 mg mirror





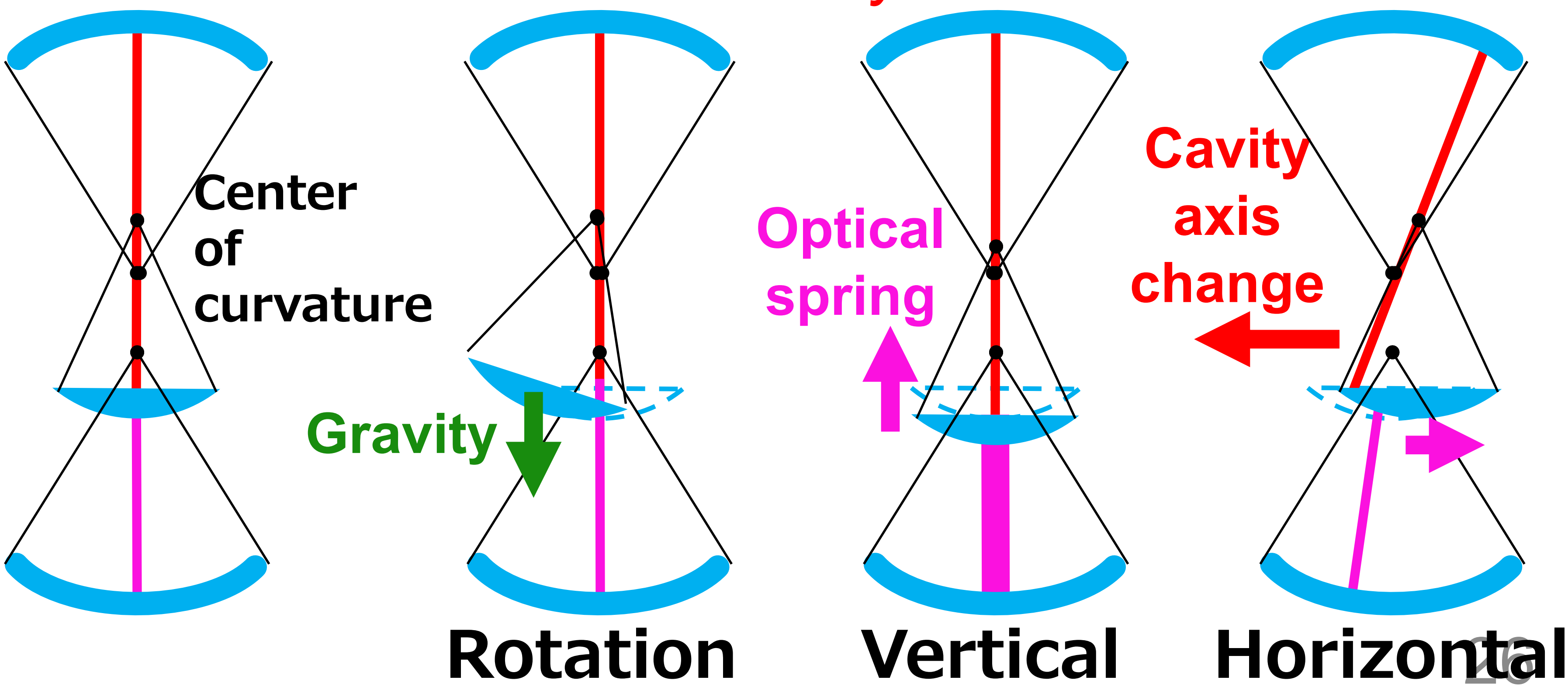


S. Singh+: PRL 105, 213602 (2010)

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

Stability of Levitation

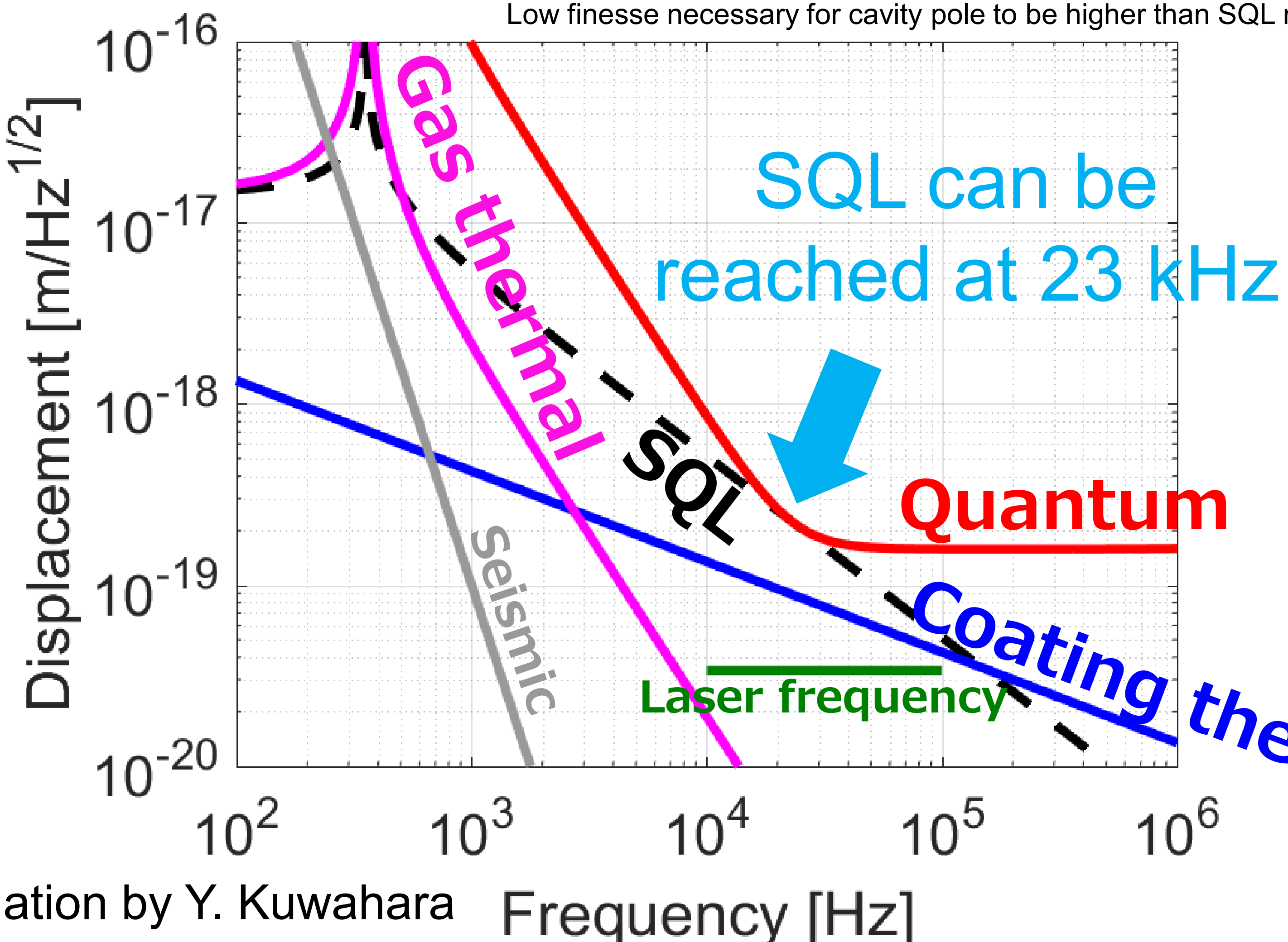
- Rotational motion is stable with gravity
- Vertical motion is stable with optical spring
- Horizontal motion is stable with cavity axis change
- *Curved mirror is necessary!*



Reaching Standard Quantum Limit

- 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

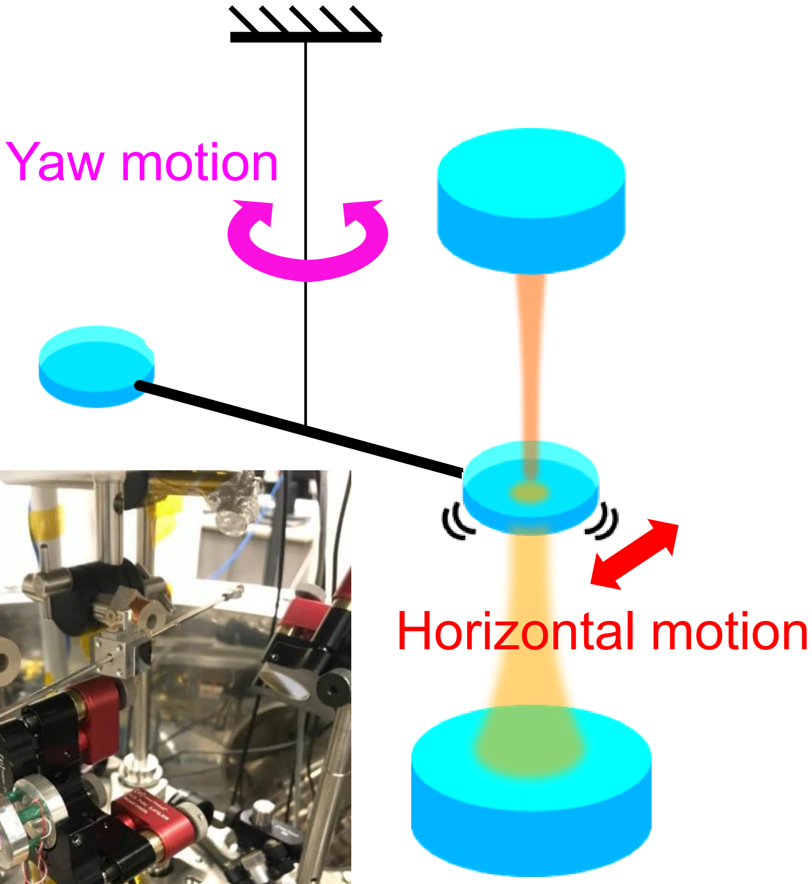


Calculation by Y. Kuwahara

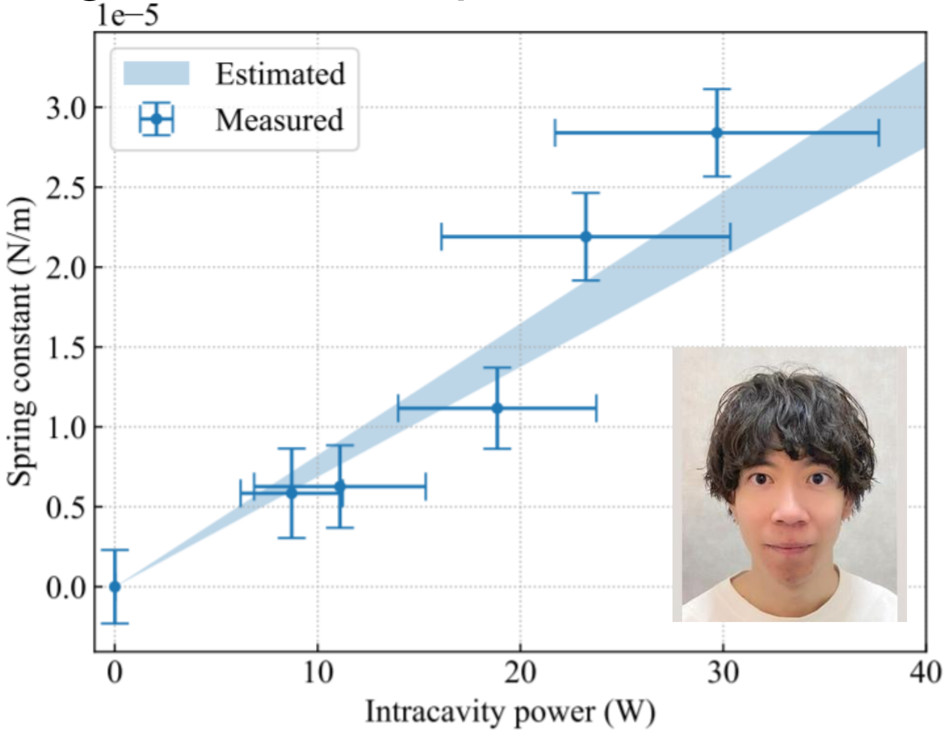
Experiment to Verify the Stability

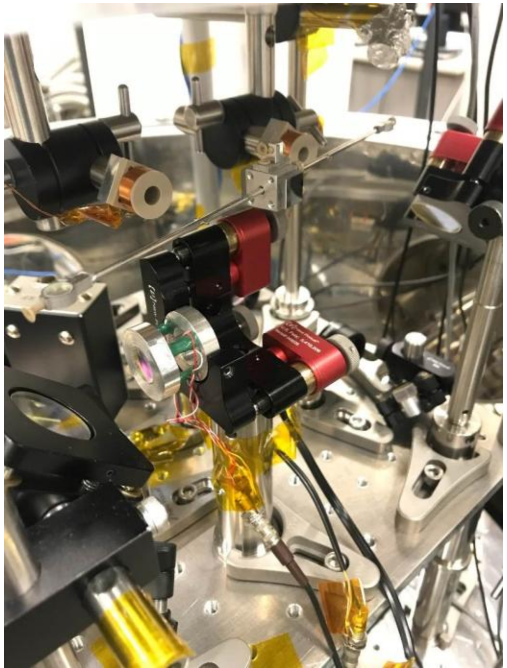
- Verified the stability with a torsion pendulum and a dummy mirror

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



Measured optical geometrical spring agreed with expectation





Fabricating Milligram Mirrors

- To support the mass:

$$mg = \frac{2P_{\mathrm{circ}}}{c}$$

Roughly 1.5 kW of power is required to levitate 1 mg mirror

- Mirror needs to be curved, high reflectivity and low absorption. Our target now is:

φ 3 mm, 0.1 mm thick (~1.6 mg for fused silica)
Curvature RoC = ~30 mm convex
Reflectivity R > 99.95 %
Absorption A < ~0.5 ppm (LIGO, Virgo, KAGRA level)

- Experiment in ANU suggest higher absorption makes the system unstable (photothermal effects)

C. Gu+, [New J. Phys. **25**, 123051 (2023)]

How to Make Tiny Mirrors

2014 Approach (Company in Japan)

(1) Make 3 mm dia. lens

(2) Coat

2020- Approach

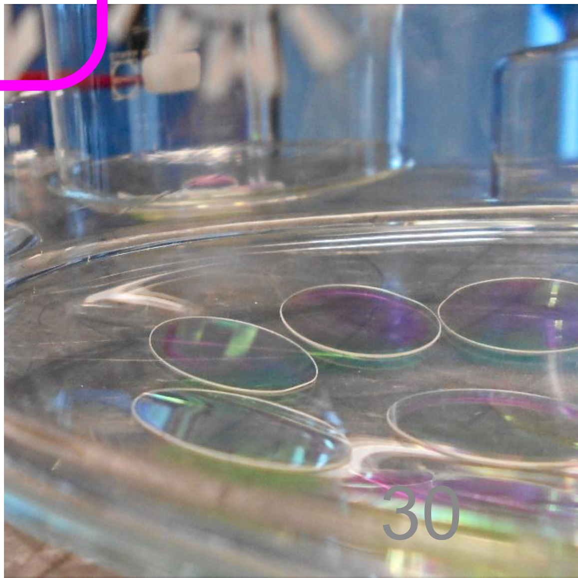
**(2018-2024 JST CREST、
2025-2027 JSPS Bilateral program)**

(1) Make 1 inch dia.
0.1 mm thick disk

(2) Coat (bend due to stress)

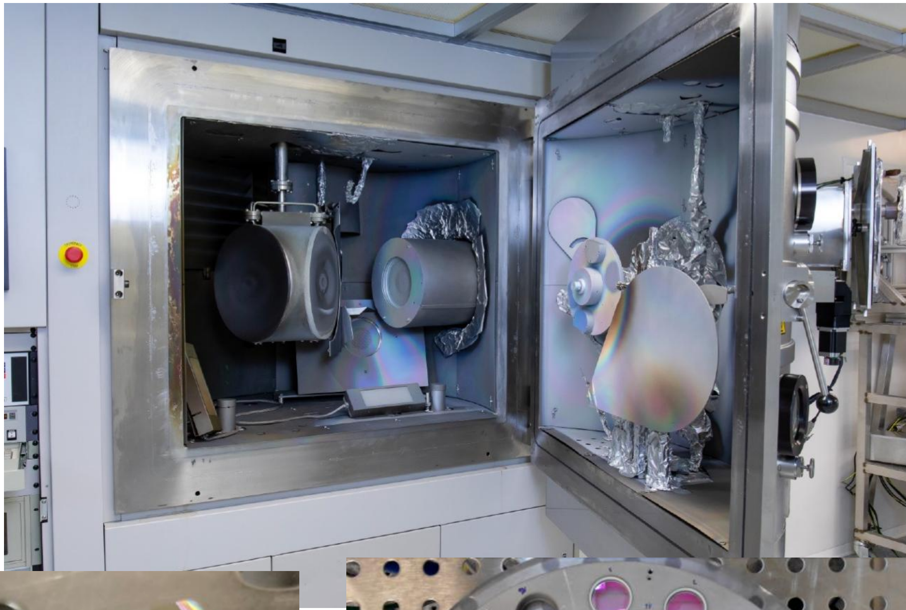
LABORATOIRE MATÉRIAUX AVANCÉS

(3) Cut into 3 mm dia.

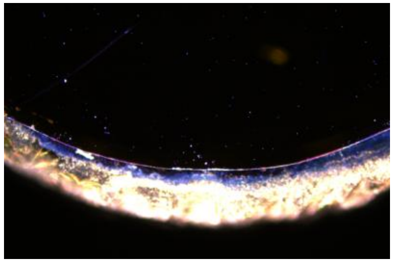


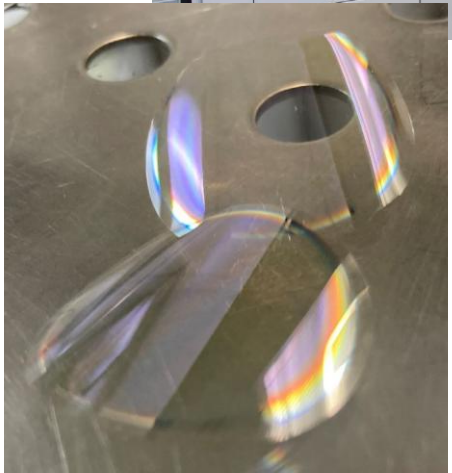
Fabrication Status in LMA

- LIGO/Virgo level high quality coating (Amplitude transmittance T=10 ppm, 6.2 um thick)
- Cut into φ3 mm is tough
- Curvature was not enough O(10 cm)
- Now trying thinner substrate (25 um) with laser cutting



1/4 thick, 1/16 curvature



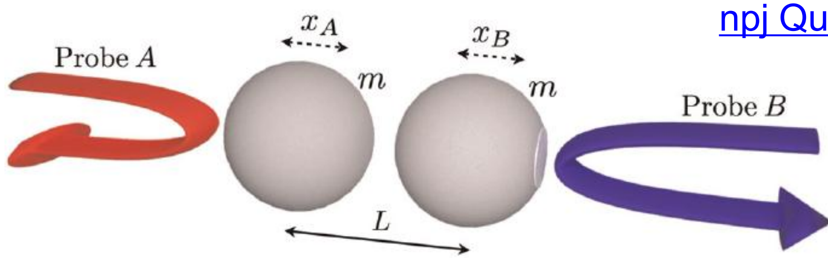


M. Croquette+, [AVS Quantum Science **5**, 014403 (2023)]

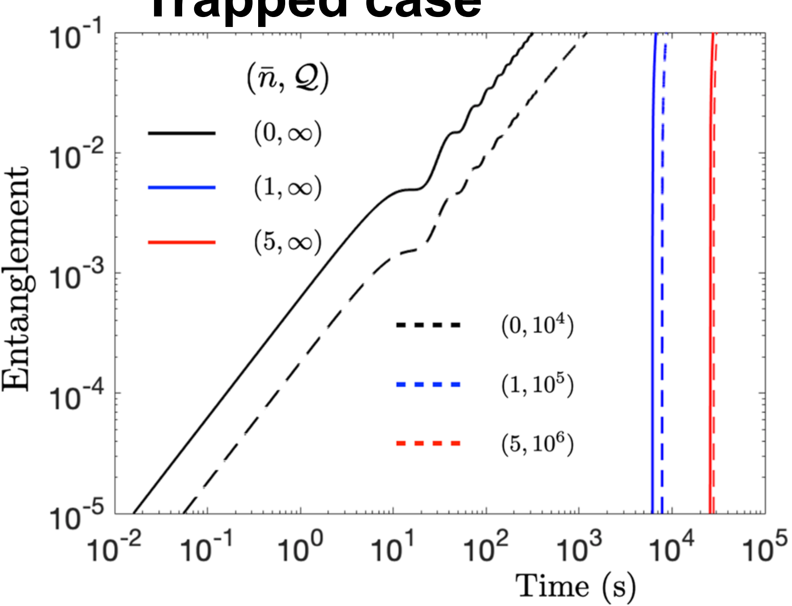
How to Test Gravity Entanglement

- Still far from BMV experiment
- Krisnanda+ proposed free-falling masses can generate gravity-induced entanglement more & faster than trapped masses

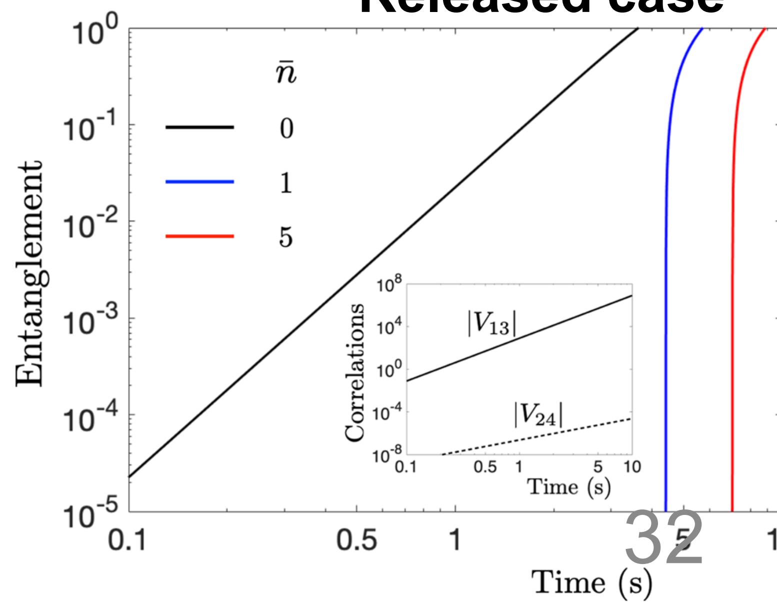
T. Krisnanda+, [npj Quantum Information **6**, 12 (2020)]



Trapped case



Released case



Decoherence Effects

- Decoherence estimates suggest
  T < 1 K and P < 10^{-16} Pa are required
- Also, free-fall time and height are in the orders of ~1 sec and ~10 m
- Sounds tough…

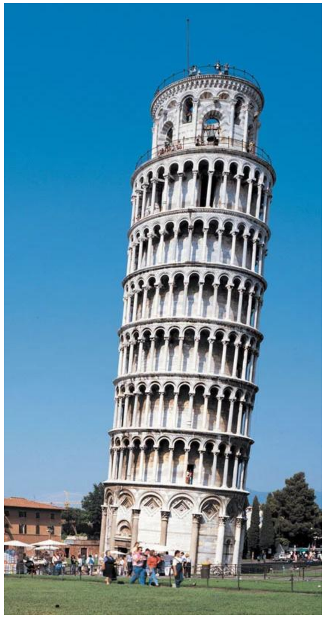


Table 3. Free-fall times t and heights $h = \frac{1}{2}gt^2$, with $g \simeq 9.8$ m s^{-2}, required to generate the amount E of entanglement at fixed values of temperature T and pressure P for the proposals of BM and Krisnanda.

Proposal	T (K)	P (Pa)	E	T (s)	H (m)
BM	1	10^{-16}	10^{-2}	0.15	0.1
	1	10^{-16}	10^{-1}	1.5	11
	1	10^{-15}	No generation	/	/
	10^{-2}	10^{-15}	No generation	/	/
Krisnanda	1	10^{-16}	10^{-2}	1.1	6.2
	1	10^{-16}	10^{-1}	2.9	42
	1	10^{-15}	No generation	/	/
	10^{-2}	10^{-15}	10^{-2}	1.2	7.6

S. Rijavec+, New J. Phys. **23**, 043040 (2021)

What is the Best Oscillator?

- We computed the amount of entanglement for arbitrary quadratic potential
- Hamiltonian

$$H = \sum_{i=1,2} \left(\frac{p_i}{2m} + \frac{1}{2}k_i x_i^2\right) + \frac{Gm^2}{d^3}(x_1 - x_2)^2$$

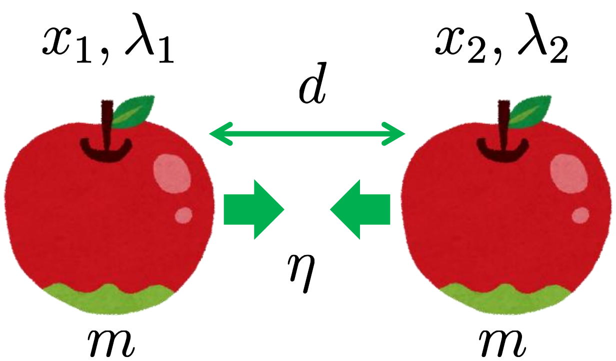
$$= \frac{\omega}{2}\left[\sum_{i=1,2}(P_i + \lambda_i X_i^2) + \eta(x_1 - x_2)^2\right]$$

Distance between masses

Sign of potential
+1 for harmonic
0 for free-falling
-1 for inverted

Strength of gravitational coupling

$$\eta = \frac{2Gm}{\omega^2 d^3}$$



T. Fujita, Y. Kaku, A. Matsumura, YM,
CQG **42**, 165003 (2025)

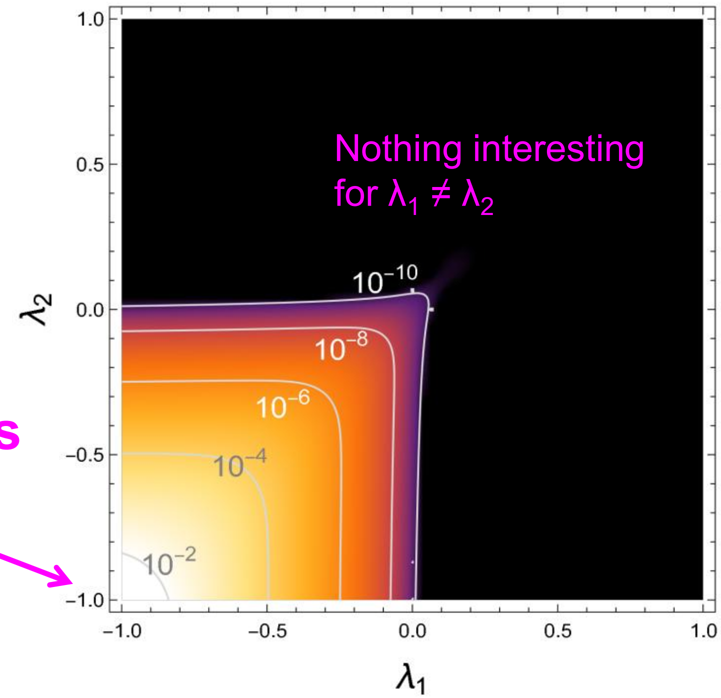
Inverted Oscillators are the Best

- Logarithmic negativity when $\lambda \equiv \lambda_1 = \lambda_2$

$$E_N \simeq 3[\eta f_{\text{gra}}(t) - \mu f_{\text{dec}}(t)]$$

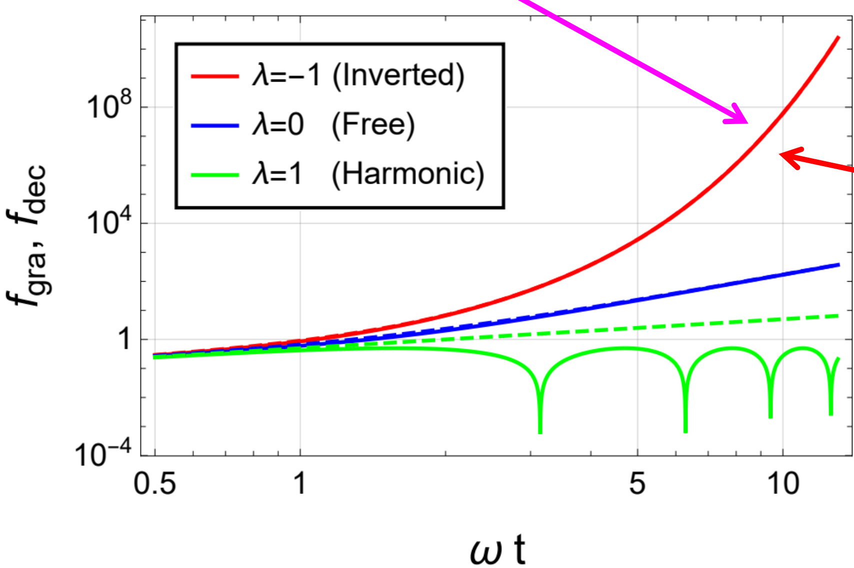
Strength of gravitational coupling

Amount of decoherence



Exponential growth of entanglement

Inverted oscillators are the best



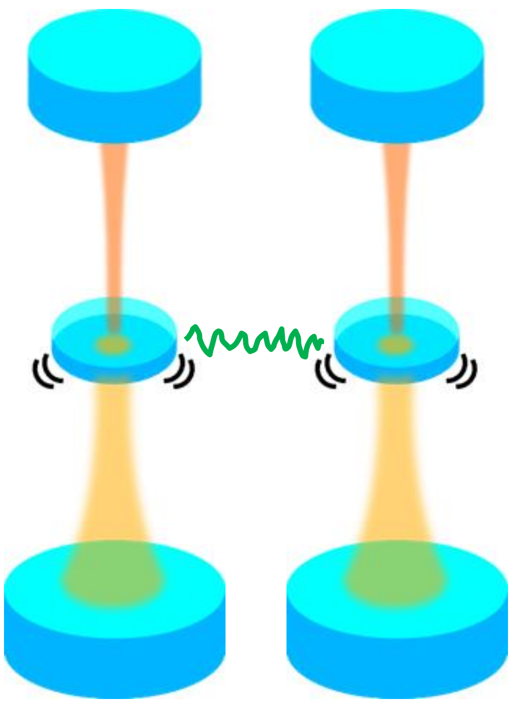
$$f_{\text{gra}}(t) \simeq f_{\text{dec}}(t) \simeq \frac{1}{8}e^{2\omega t}$$

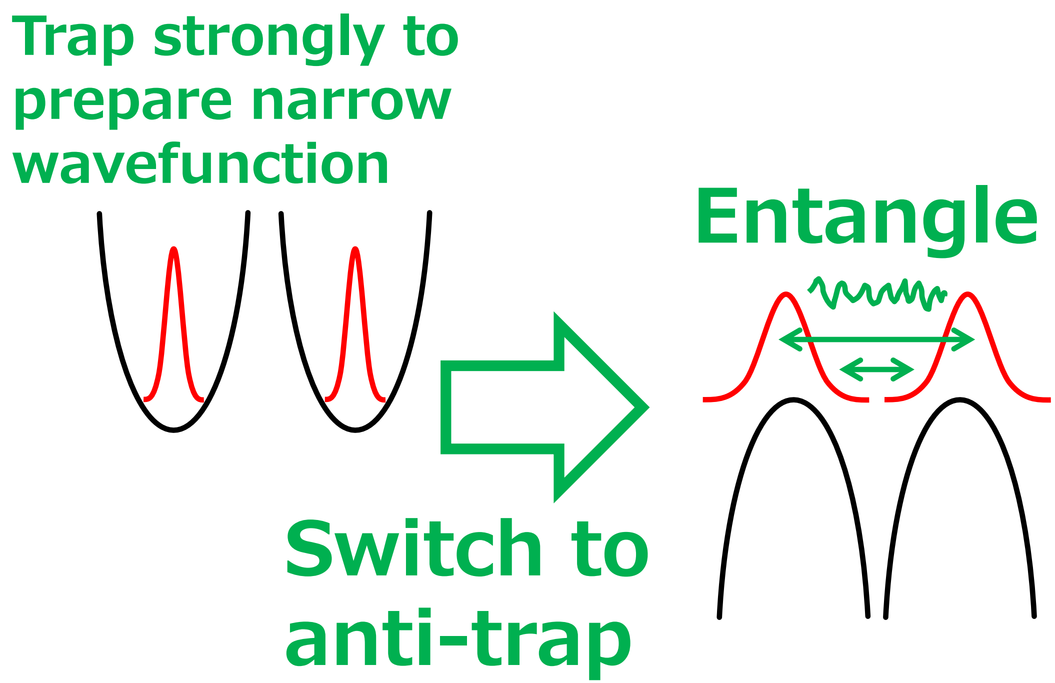
$$f_{\text{gra}}(t) \simeq f_{\text{dec}}(t) \simeq \frac{1}{8}(\omega t)^3$$

$$f_{\text{gra}}(t) \simeq \frac{1}{2}|\sin(\omega t)|, \ f_{\text{dec}}(t) \simeq \frac{1}{2}\omega t$$

Realization with Levitated Mirrors

- Switching between trap and anti-trap is easy with optical levitation
- Entanglement can be tested in horizontal motion
- Can be done similar with other systems





Example Setup

- To prepare 1 kHz anti-spring for 0.1 mg mirror

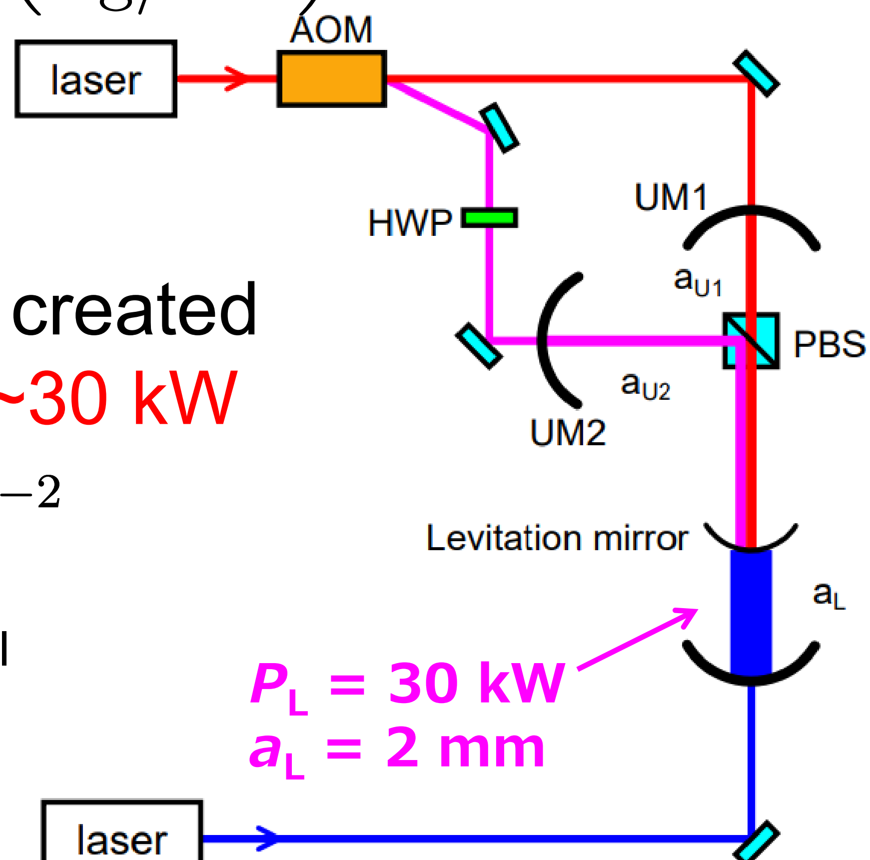
$$\mu << \eta = 2.7 \times 10^{-13} \omega_{\mathrm{kHz}} \left(\frac{m/d^3}{2\,\mathrm{g/cm^3}} \right)$$

- Requires T < ~1 K and P < ~10^-17 Pa (as usual)
- ~1 kHz anti-spring can be created with intra-cavity power of ~30 kW
- Time to generate $E_N = 10^{-2}$

$$\tau_{\mathrm{ent}} = 4.2 \omega_{\mathrm{kHz}}^{-1/3}\,\mathrm{sec}$$ for free-fall

300 times faster

$$\tau_{\mathrm{ent}} = 1.3 \times 10^{-2} \omega_{\mathrm{kHz}}^{-1/3}\,\mathrm{sec}$$ for inverted



Is Fast Good?

- The process can be repeated multiple times
  - Also, now that the oscillator is not free-falling, height is not required, and repeatable
- Air pressure requirement could be relaxed
  - Entanglement speed is so fast that no molecule will hit the oscillator during the measurement time
  - Mean free time of the scattering

$$\tau_{\mathrm{air}} = 0.64\,\mathrm{sec}\left(\frac{R}{0.2\,\mathrm{mm}}\right)^{-2}\left(\frac{p}{10^{-17}\,\mathrm{Pa}}\right)^{-1}\left(\frac{T}{1\,\mathrm{K}}\right)^{-1/2}$$

  - More rigorous study necessary for treating random force under extremely low pressure

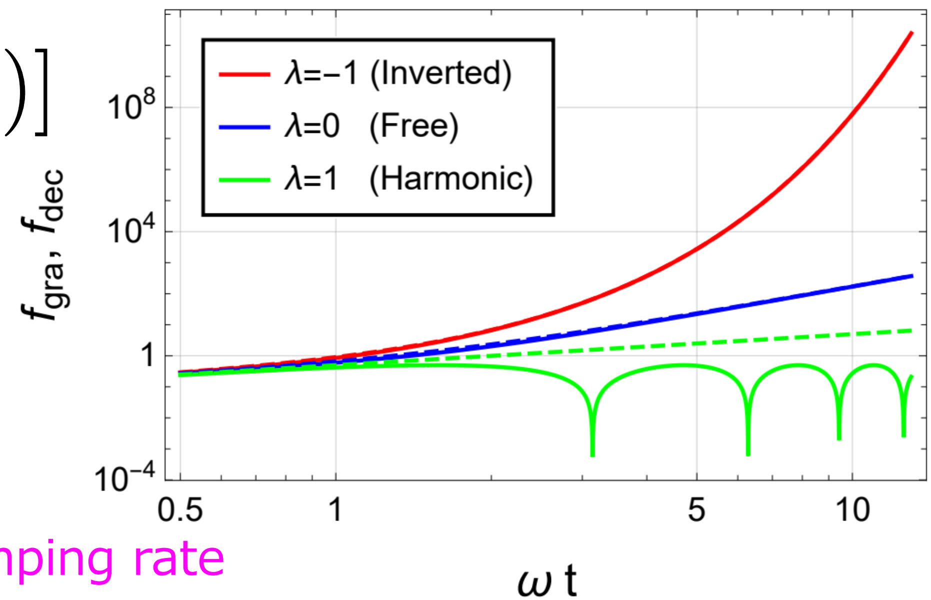
Still, Decoherence is the Issue

- Decoherence effects also increases exponentially with inverted oscillators

$$E_N \simeq 3[\eta f_{\mathrm{gra}}(t) - \mu f_{\mathrm{dec}}(t)]$$

Gravity Decoherence

Logarithmic negativity

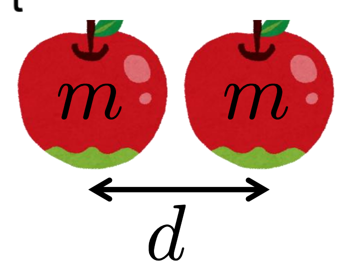


- $\eta > \mu$ is required

$$\frac{2Gm}{\omega_{\mathrm{m}} d^3} > \frac{2k_{\mathrm{B}} T_{\mathrm{th}} \gamma_{\mathrm{m}}}{\hbar \omega_{\mathrm{m}}}$$

Damping rate

For 300 K
(smaller by ~10 orders of magnitude than state-of-the-art)



$$\gamma_{\mathrm{m}} < \frac{\hbar G m}{k_{\mathrm{B}} T_{\mathrm{th}} d^3} = 1.7 \times 10^{-21}\,\mathrm{Hz}\,\frac{m/d^3}{1\,\mathrm{g/cm^3}}$$

Fused silica: 2 g/cm^3 Osmium: 22 g/cm^3

Plans for now

- Characterization of levitation mirrors
- High power operation and realization of levitation
- B-L dark matter search also possible

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Networked Exchange, United Strength for Stronger Partnerships between Japan and ASEAN
日星共同研究「量子」
Japan-Singapore joint research
Agency for Science, Technology and Research SINGAPORE

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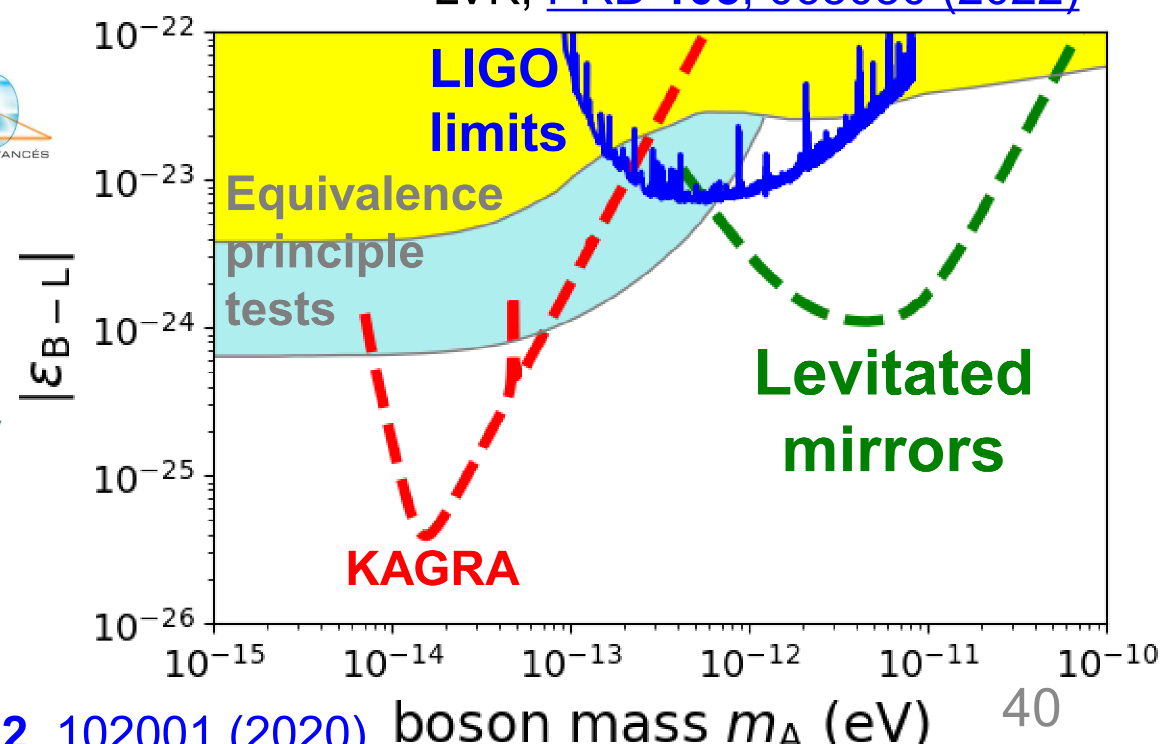
学術変革領域研究(A)
Transformative Research Areas (A)

LVK, PRD **105**, 063030 (2022)



YM+, PRD **102**, 102001 (2020)

Summary

- **Remarkable technological advances**:
  Quantum states are now realized in increasingly massive systems (16 μg), while gravity is being measured at ever smaller mass scales (90 mg)
- **Significant theoretical progress**:
  More realistic and experimentally accessible proposals to test the quantum nature of gravity are emerging
- **Still new ideas are required**:
  We must develop methods that evade decoherence and properly account for measurement effects

Bonus Slides

Comparison with $f \cdot Q$ Criterion

- Necessary condition for ground state cooling

$$f_{\mathrm{m}} Q_{\mathrm{m}} \gg \frac{k_{\mathrm{B}} T_{\mathrm{th}}}{\hbar} \simeq 6 \times 10^{12} \left(\frac{T_{\mathrm{th}}}{300\,\mathrm{K}} \right)$$

Resonant frequency

Q-value

$$Q_{\mathrm{m}} \equiv \frac{\omega_{\mathrm{m}}}{\gamma_{\mathrm{m}}}$$

- Thus,

$$\gamma_m \ll 1 \times 10^{-12}\,\mathrm{Hz} \left(\frac{f_{\mathrm{m}}}{1\,\mathrm{Hz}} \right) \left(\frac{300\,\mathrm{K}}{T_{\mathrm{th}}} \right)$$

Damping rate

- Criterion for testing gravity induced entanglement is 9 orders of magnitude harder

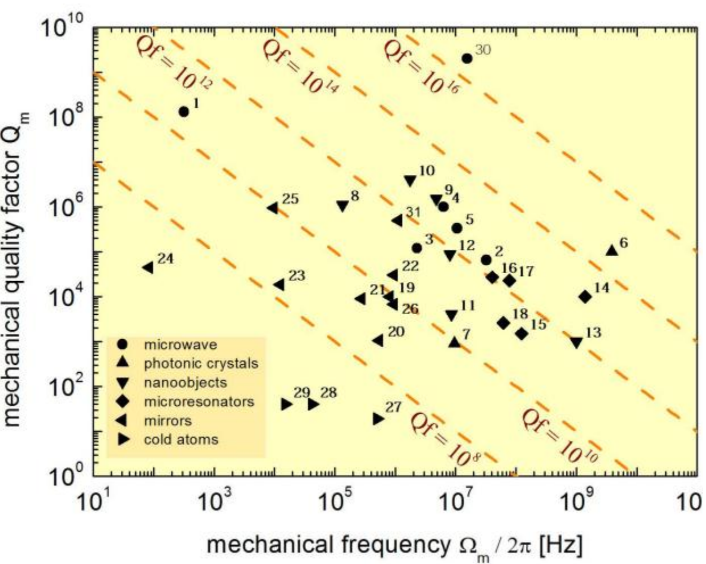
$$\gamma_{\mathrm{m}} < \frac{\hbar G m}{k_{\mathrm{B}} T_{\mathrm{th}} d^3} = 1.7 \times 10^{-21}\,\mathrm{Hz} \frac{m/d^3}{1\,\mathrm{g/cm^3}}$$

(Outdated) State-of-the-Art

	Mass m	Size of mass	Wire (bonding)	f_{m} (Hz)	Q_{m}
Arcizet [12]	0.19 mg	1 mm × 1 mm × 60 μm	Doubly-clamped silicon beam	8.14 k	1×10^4
Michimura [87]	0.2 mg	0.7 mm dia., t 0.23 mm	Optical levitation with upper and lower cavities		
Pontin [13]	0.25 mg	0.4 mm dia., $t \sim 70$ μm	Silicon micromirror at 4.9 K	170 k	1.1×10^6
Guccione [86]	0.3 mg	2 mm dia.	Optical levitation with tripod cavities		
Matsumoto [68]	5 mg	2 mm dia., t 0.2 mm	$2r_{\mathrm{w}} = 3$ μm, $l_{\mathrm{w}} = 5$ cm	2.14	1.8×10^2
			Tungsten (epoxy)		
Matsumoto [14]	7 mg	3 mm dia., t 0.5 mm	$2r_{\mathrm{w}} = 1$ μm, $l_{\mathrm{w}} = 1$ cm	4.4	1×10^5
			Silica (epoxy)		
Cataño-Lopez [56]	7 mg	3 mm dia., t 0.5 mm	$2r_{\mathrm{w}} = 1$ μm, $l_{\mathrm{w}} = 5$ cm	2.2	2×10^6
			Silica (monolithic)		
Komori [15]	10 mg	15 mm × 1.5 mm × 0.2 mm	$2r_{\mathrm{w}} = 6$ μm, $l_{\mathrm{w}} = 2.2$ cm	0.09	2.6×10^3
Torsion			Carbon (epoxy)		
Sakata [64]	20 mg	3 mm dia., t 1.5 mm	$2r_{\mathrm{w}} = 10$ μm, $l_{\mathrm{w}} = 1$ cm	3.7	N.A.
			Silica (epoxy)		
Mueller [77]	0.2 g	50 mm × 10 mm × 0.15 mm	$2r_{\mathrm{w}} = 25$ μm, $l_{\mathrm{w}} = 15$ cm	0.36	2.3×10^3
Torsion			Two tungsten, doubly-clamped		
Altin [91]	0.3 g	6.35 mm dia.	100 μm thick silicon cantilever	165	5.5×10^4
Mow-Lowry [16]	0.69 g	7 mm dia., t 1 mm	300 μm thick niobium cantilever	84.8	4.5×10^4
Corbitt [17]	1 g	12 mm dia., t 3 mm	$2r_{\mathrm{w}} = 300$ μm	12.7	2.0×10^4
			Two optical fibers (epoxy)		
Neben [50]	1 g	12 mm dia., t 3 mm	$2r_{\mathrm{w}} = 150$–3000 μm, $l_{\mathrm{w}} = 4$ cm	10	1×10^6
			Two silica fibers (epoxy)		

In milligram scale

YM, K. Komori, [EPJD 74, 126 (2020)]



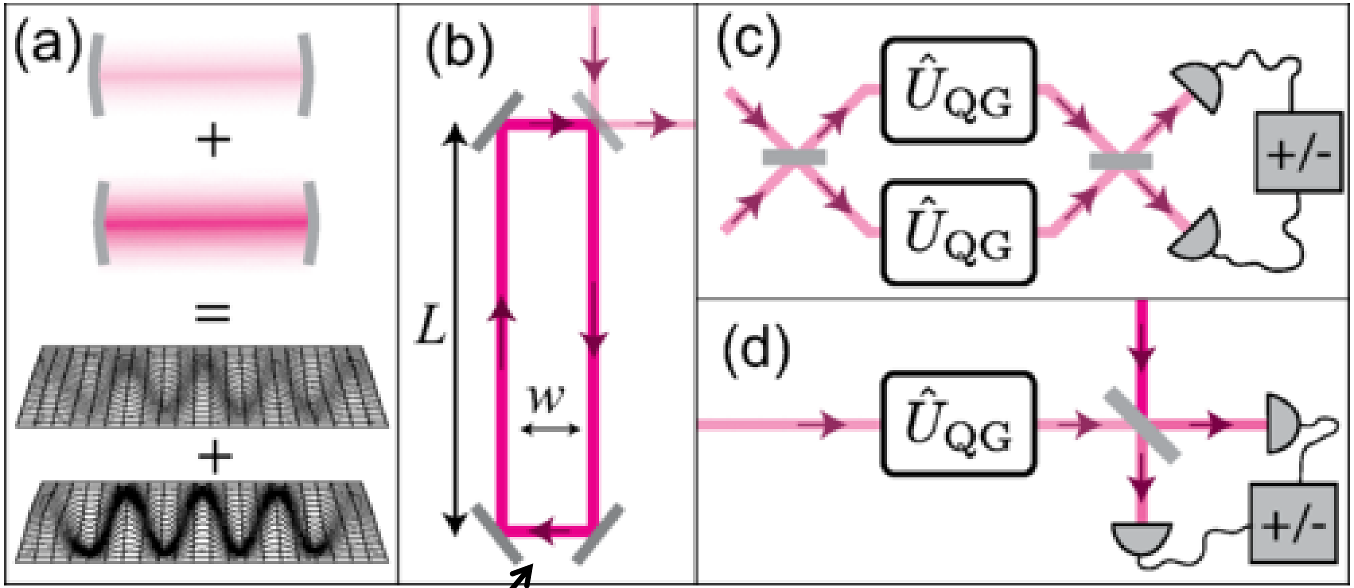
At high frequencies, ground state cooling of 16 μg is realized

Aspelmeyer, Kippenberg, Marquardt, [RMP 86, 1391 (2014)]

M. Bild+, [Science 380, 274 (2023)]

Mecha-Free Approach

- *Signatures of Quantum Gravity in the Gravitational Self-Interaction of Photons*
  Z. Mehdi+, PRL **130**, 240203 (2023)
- Nonlinear optical effects (Kerr effects, third harmonic generation) from gravity between photons
- Free of QED photon-photon interaction



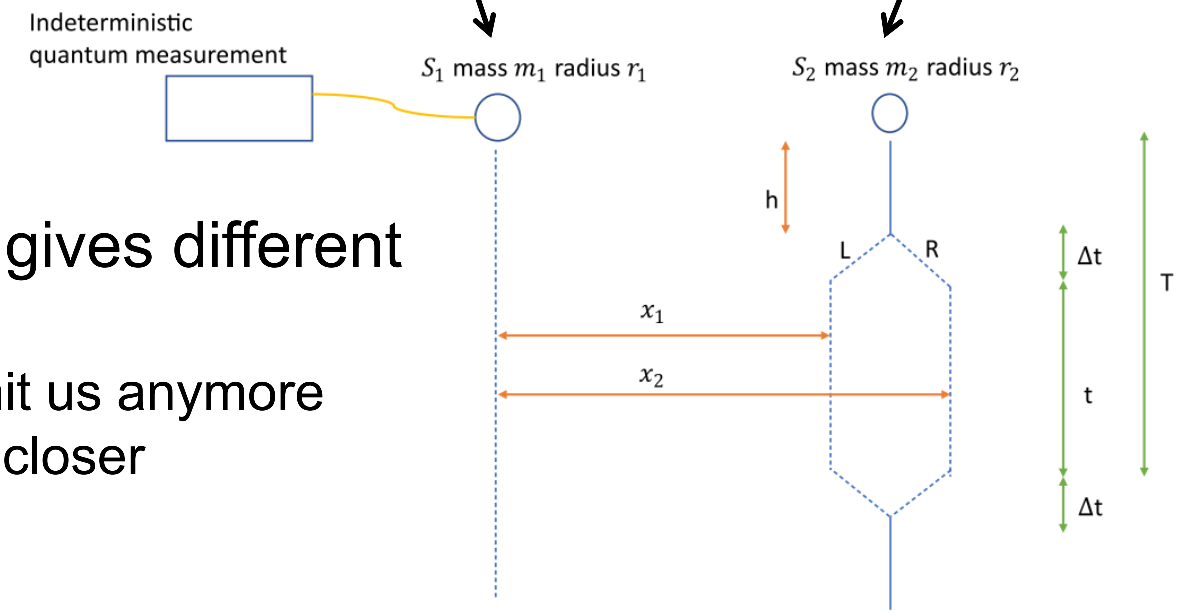
L=10 km, w=10 cm, 125 MW, for 1 year

Test Near Measurement Event

A. Kent,
PRD **103**, 064038 (2021)

Hold or Release

Left or Right



QG and Semiclassical gives different result even S1 is held

- Casimir effect will not limit us anymore
- S1 and S2 can be much closer

	S1 held	S1 released
Quantized gravity	$\vert\psi(t)\rangle \approx \frac{1}{\sqrt{2}}(\vert L\rangle + \vert R\rangle)$	$\vert\psi(t)\rangle \approx \frac{1}{\sqrt{2}}\exp(i\phi_L t)(\vert L\rangle + \exp(i(\phi_R - \phi_L)t)\vert R\rangle)$
Semiclassical gravity	$\vert\psi(t)\rangle \approx \frac{1}{\sqrt{2}}\exp(i\phi_L t/2)(\vert L\rangle + \exp(i(\phi_R - \phi_L)t/2)\vert R\rangle)$	