Quantum sensor cluster

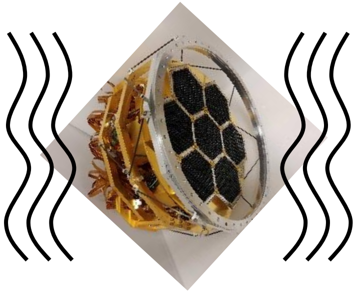


Masaya Hasegawa, ○Hideo Iizuka, Norikazu Mizuochi,
Kazunori Nakayama, Masashi Hazumi


Quantum-field Measurement Systems
for Studies of the Universe and Particles
(QUP)

Research scope of quantum sensor cluster

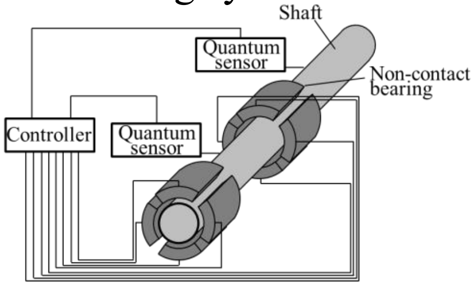
Active vibration isolation for CMB



New physics search

Circuit diagnosis

Non-contact shaft-bearing system



Particle physics /Universe

Industry /Social implementation

Casimir force control (zero force)

High sensitivity of quantum sensing

Casimir force to industries

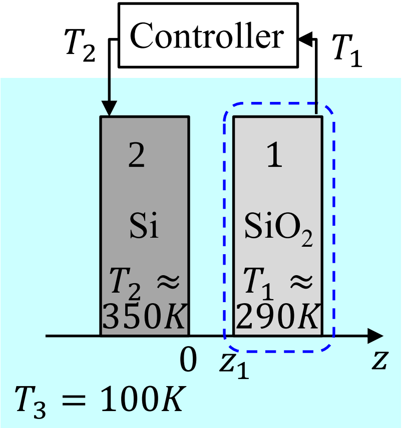
Control theory has been widely used in industries.

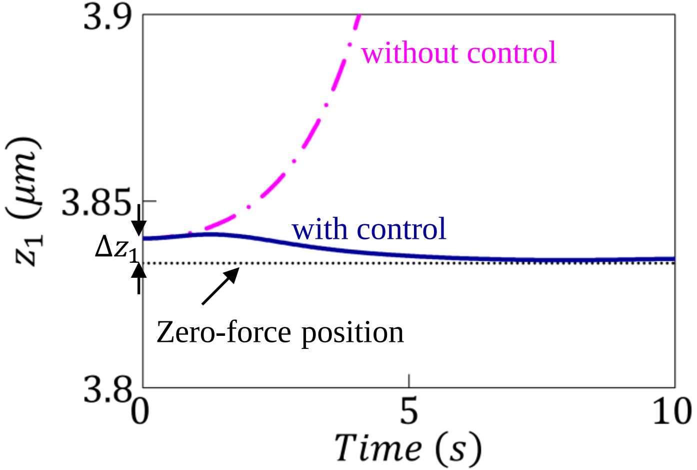
We introduce control theory to manipulate Casimir forces for the first time.

Memo of Casimir force history
1948, Casimir force prediction.
1997, Experimental verification.

Consider a system consisting of a silicon plate and a SiO_2 plate in a low-temperature vacuum environment. The silicon plate is fixed and the temperature can be adjusted while the SiO_2 plate is moved and the temperature is determined through the thermal emission exchange.

We numerically verify that the SiO_2 plate can move back to the zero-force position by monitoring the temperature of the SiO_2 plate and adjusting the temperature of the silicon plate against for a perturbation Δz_1.





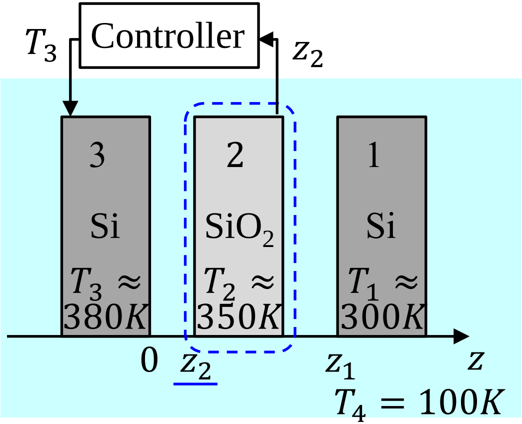
H. Iizuka and S. Fan, “Control of non-equilibrium Casimir force,” Applied Physics Letters 118, 144001 (2021).

Trajectory tracking through the control of Casimir force

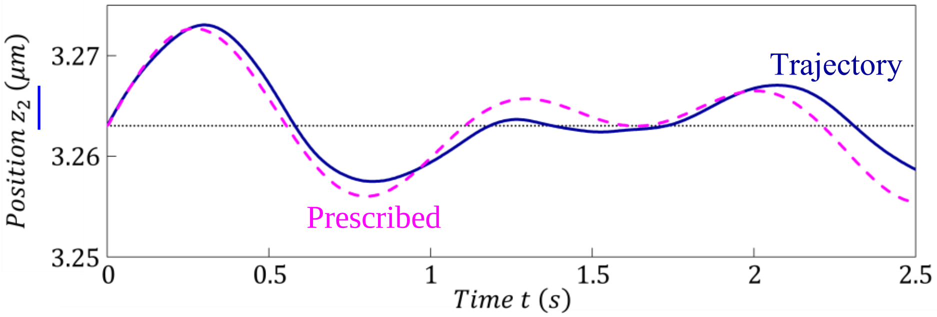
An autonomous vehicle can follow a path as we set by control theory, which is called trajectory tracking.

Quantum world

Trajectory tracking is applied to a three-body system interacting through non-equilibrium Casimir forces.



The position of the middle SiO_2 plate (blue line) follows a prescribed trajectory (pink dashed line) by adjusting the temperature of the left silicon plate (single parameter) while the right silicon plate is kept around the equilibrium position.



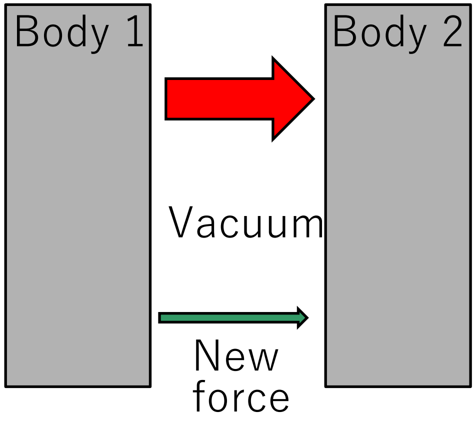
H. Iizuka and S. Fan, “Trajectory tracking through the control of non-equilibrium Casimir force,” Journal of Quantitative Spectroscopy and Radiative Transfer 289, 108281 (2022).

Casimir effect for new force search

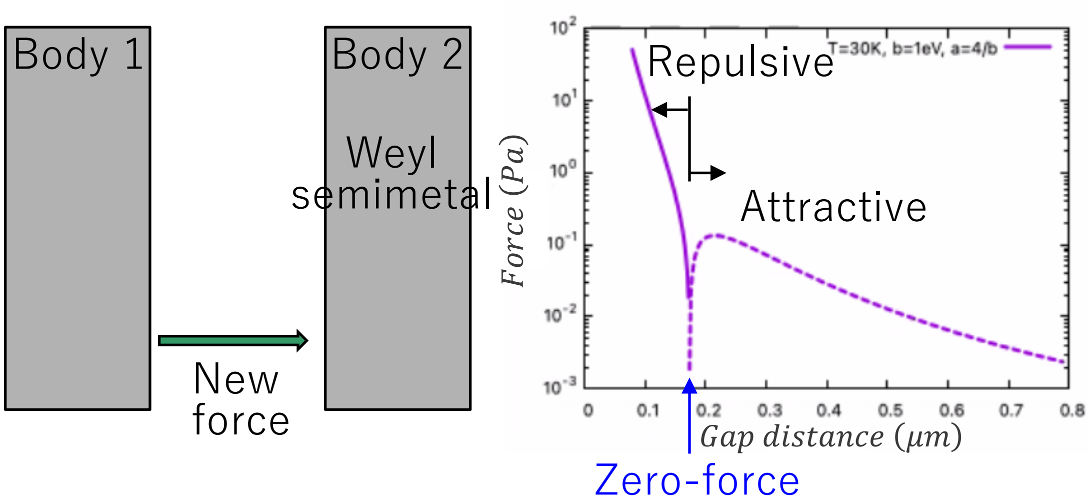
We theoretically point out that unwanted Casimir force can be zero in a system. This may give strong constraints on new force which is mediated by, e.g. new elementary particles.

Kazunori Nakayama

Casimir force (attractive) is generated in vacuum.



Casimir force can be cancelled out by introducing Weyl semimetals.



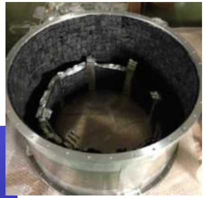
Y. Ema, M. Hazumi, H. Iizuka, K. Mukaida, and K. Nakayama, “Attractive and repulsive Casimir force on metal plates in axion electrodynamics,” in preparation.

Measuring room temperature at mK precision

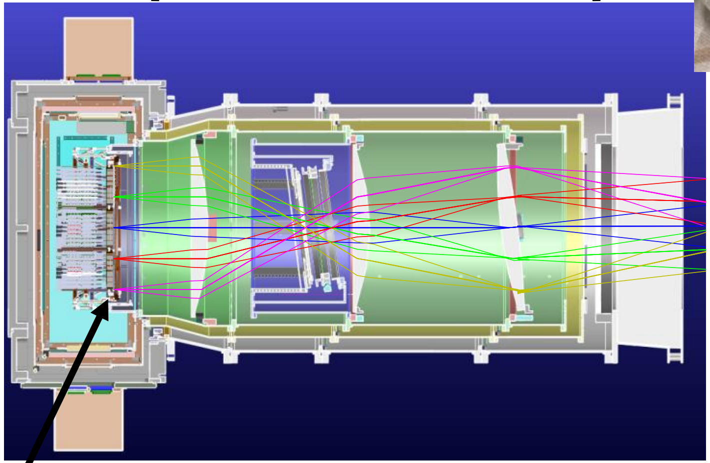
We clarify the temperature precision for monitoring room-temperature instruments for cosmic microwave background (CMB) observation. We will try a long-term monitoring test with a $1mK\sqrt{s}$ capability of our system.

Masaya Hasegawa

Optics @ $4K$:✔ $10\sim100mK\sqrt{s}$



Data acquisition system @$300K$: $\sim10mK\sqrt{s}$



Mirror@ $300K$: a few $mK\sqrt{s}$

TES @ $0.25K$: ✔ $\sim14\mu K\sqrt{s}$

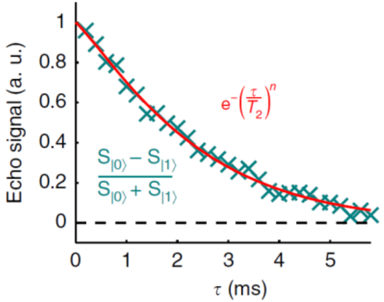
D. Tanabe, M. Hasegawa, M. Hazumi, N. Katayama, S. Kikuchi, A. Lee, Haruki Nishino, and Satoru Takakura, "High-precision temperature monitoring system for room-temperature equipment in astrophysical observations," Journal of Astronomical Telescopes, Instruments, and Systems 8, 036003 (2022).

Enhancement of coherence time of nanoscale shallow NV centers

Norikazu Mizuochi joined QUP in Aug. 2022.

Previous research

Ultra-long coherence time of NV centers in Phosphorus doped n-type diamond



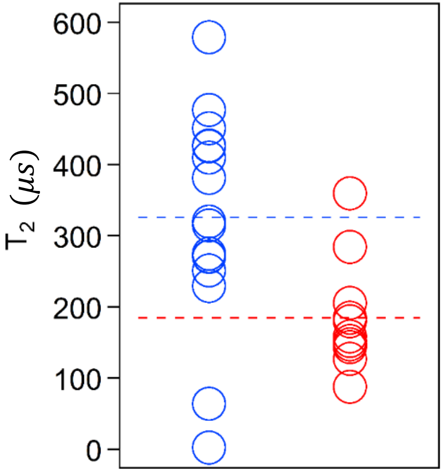
$T_2 \approx 2.4$ ms

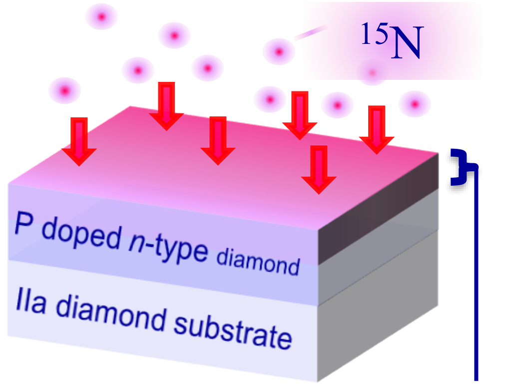
Longest coherence time among solid-state electron spins at room temperature.

Reason: Suppression of magnetic noise source (vacancies/impurities complexes) due to Coulomb repulsion between vacancies/impurities.

E. D. Herbschleb, N. Mizuochi, et al., Nature Communications, 10, 3766 (2019)

T_2 of individual NV of nanoscale shallow (~15 nm) NV centers





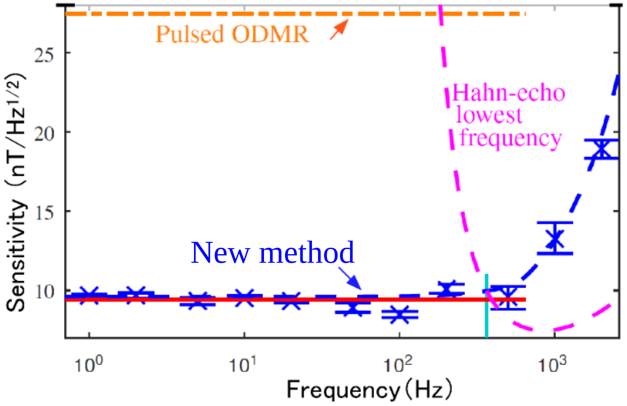
~15 nm depth (10 keV, 600 °C)

Both the longest and averaged T_2 (Blue dotted lines) in P-doped diamond are longer than those of undoped one.

A. Watanabe, T. Nishikawa, H. Kato, M. Fujie, M. Fujiwara, T. Makino, S. Yamasaki, E. D. Herbschleb, N. Mizuochi, "Shallow NV centers augmented by exploiting n-type diamond", Carbon, 178, 294-300 (2021)

Improvement of sensitivity at low frequency region by new quantum sensing technique

Recently invented " Qdyne (Quantum heterodyne) technique"



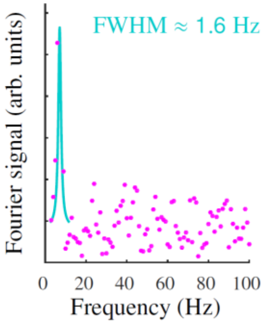
J. M. Boss, et al., *Science* 356, 837 (2017),
S. Schmitt, et al., *Science* 356, 832 (2017).

Norikazu Mizuochi joined QUP in Aug. 2022.

Advantage: Extremely narrow linewidth of NMR (Nuclear magnetic resonance)

Disadvantage: the sensitivity strongly depends on the frequency of AC magnetic field to observe as show in Pink dotted line.

New method was proposed, which results (Blue) show frequency-independent sensitivity, particularly at low frequency.



The narrowest NMR linewidth (1.6 Hz) was experimentally demonstrated by using the NV quantum sensor.

Application: This method is important for low field NMR.

Example of application: Ultralow-field NMR to search dark matter

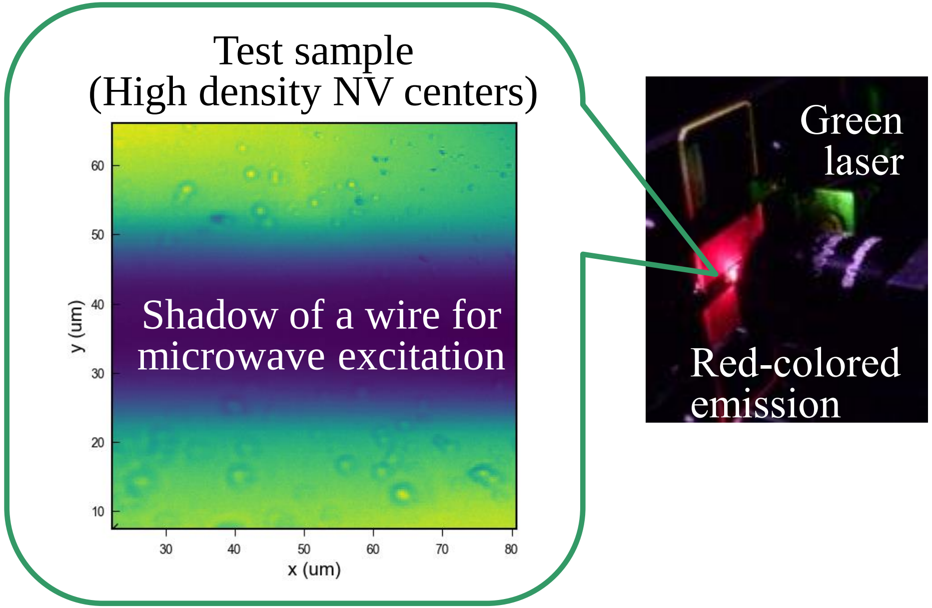
A. Garcon, D. Budker et al., *Science Advances* 2019; 5 : eaax4539.

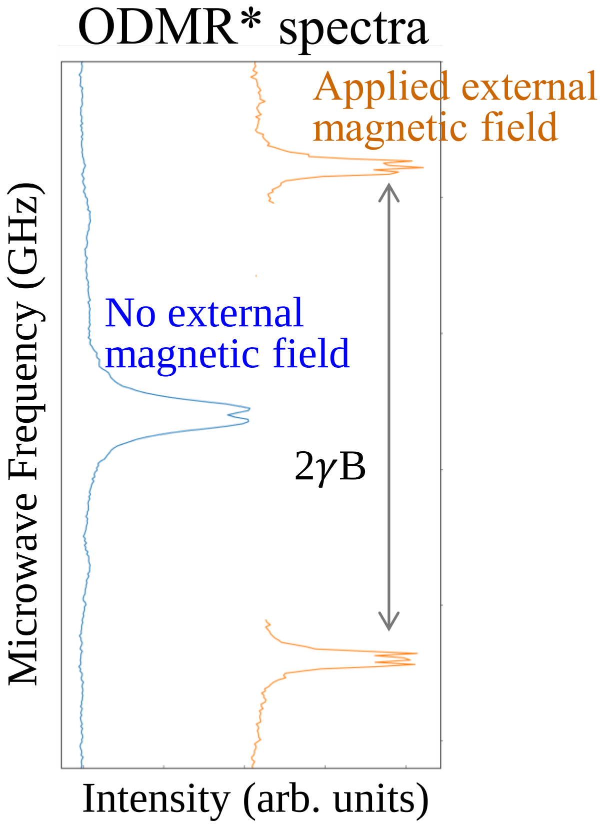
E. D. Herbschleb, Y. Ohki, K. Morita, Y. Yoshii, H. Kato, T. Makino, S. Yamasaki, N. Mizuochi, "Low-frequency quantum sensing", Physical Review Applied, 18, 034058 (2022). Selected as Editors' Suggestion

QUP satellite in Toyota Central R&D Labs

Roles of the QUP Satellite
in Toyota Central R&D Labs.
Step 1 Development of quantum sensors
Step 2 Social-implementation experiments

We have built an ODMR* setup in the satellite.



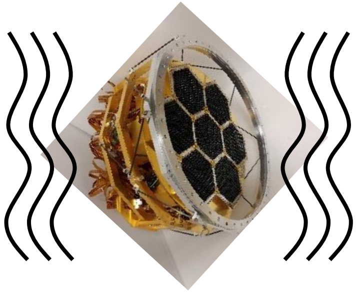


*Optically Detected Magnetic Resonance

Summary

- Established a control theory for manipulating Casimir forces.
- Presented an architecture for searching new force with zero Casimir force.
- Clarified the requirement of temperature sensitivity for CMB observation.

Active vibration isolation for CMB



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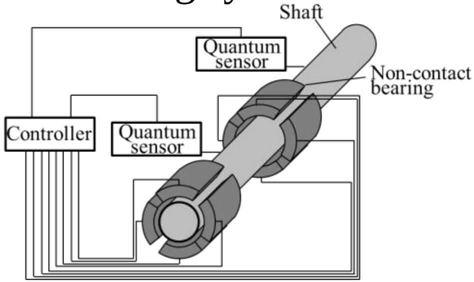

Acknowledgement

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