

Space gravitational wave antenna DECIGO and B-DECIGO

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Gravitational Wave Probes of Physics

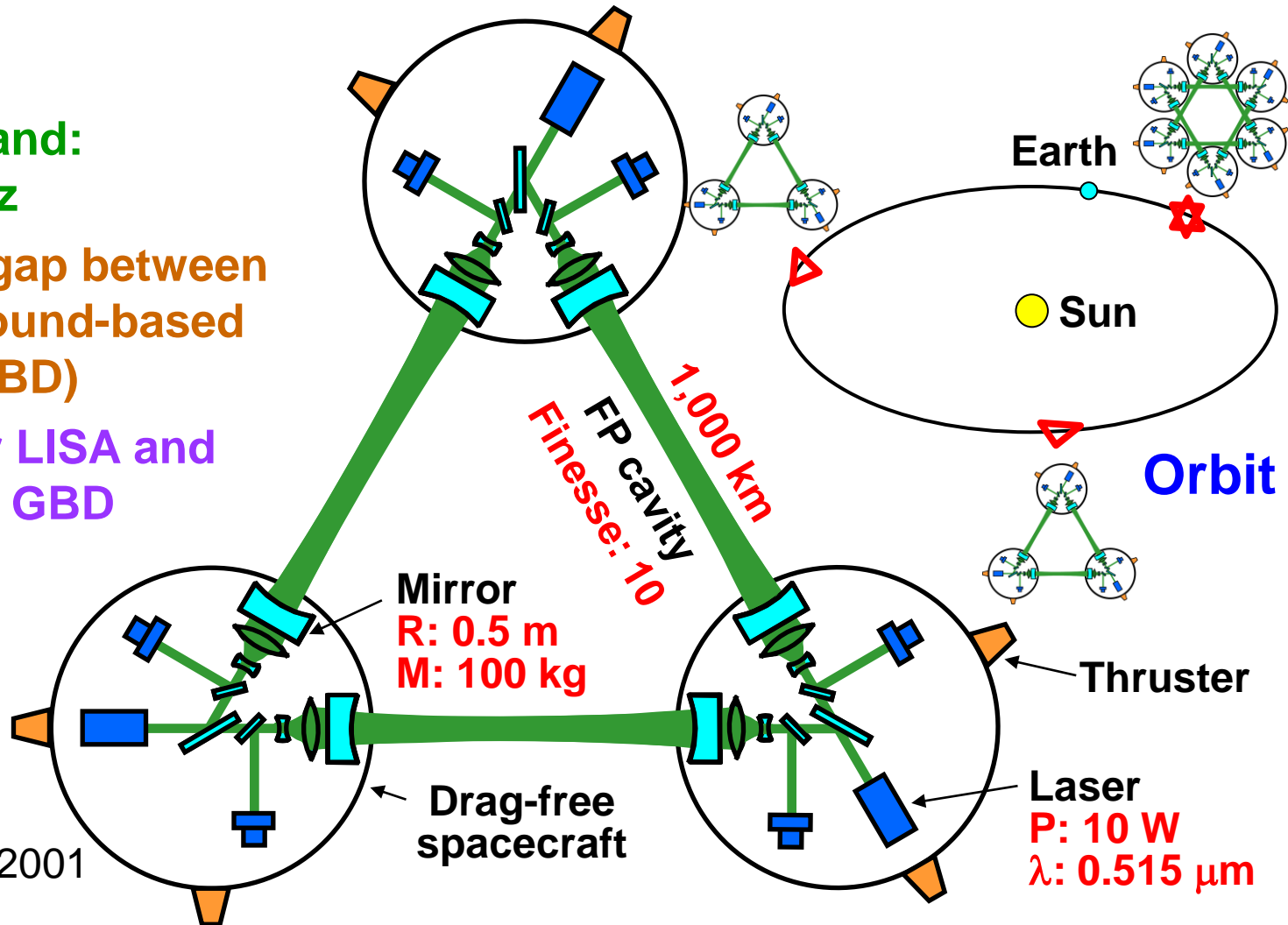
Beyond Standard Model

Nov. 7, 2023, @ Osaka Metropolitan University, Japan

DECIGO

Deci-hertz Interferometer **G**ravitational Wave **O**bservatory

- frequency band: 0.1 Hz - 10 Hz
- bridges the gap between LISA and ground-based detectors (GBD)
- follow-up for LISA and predictor for GBD



Pre-conceptual design

◆ Seto, Kawamura, Nakamura, PRL, 2001

◆ Kawamura, et al., PTEP, 2021

Target sensitivity and science

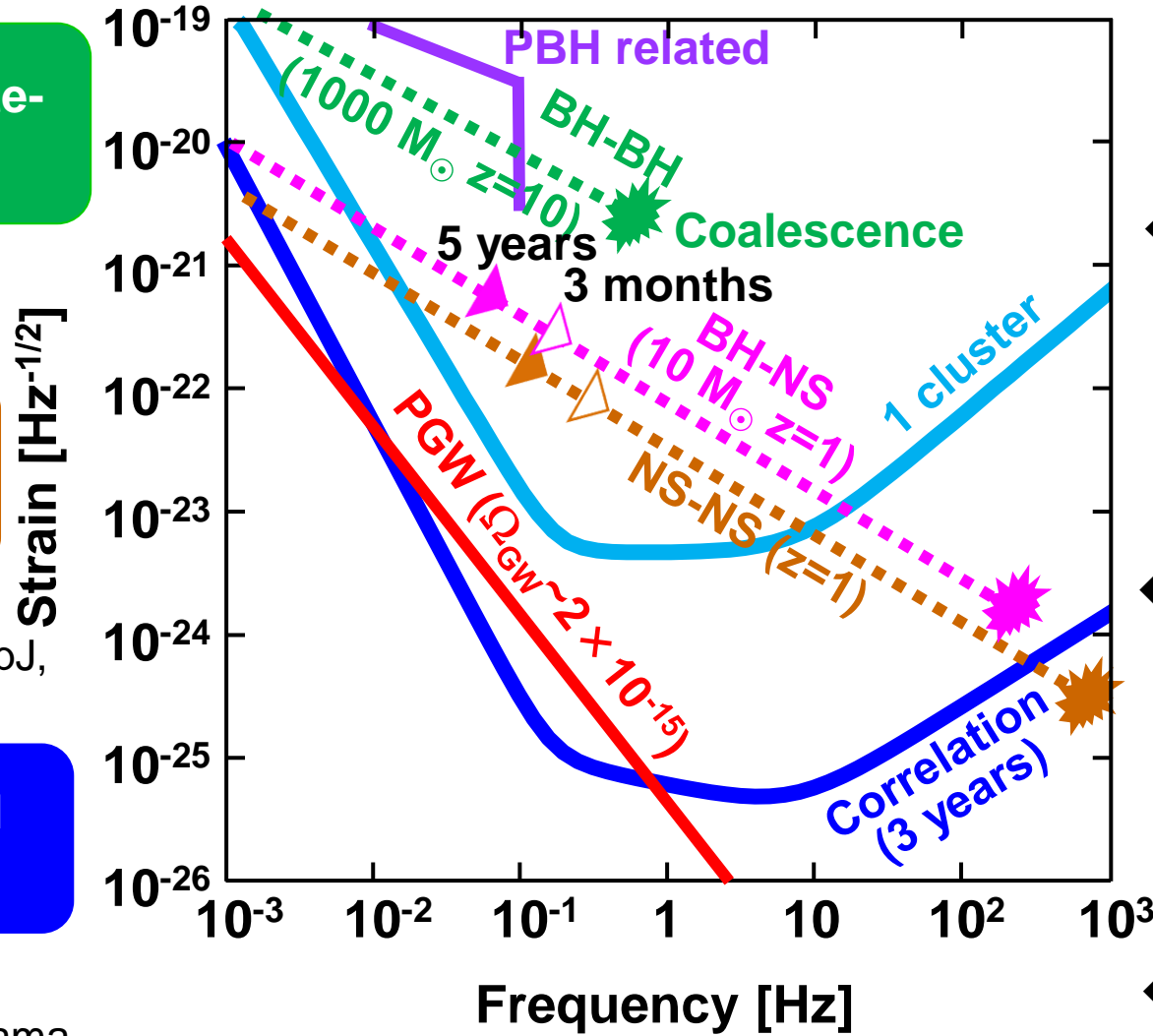
Intermediate-mass BH

Prediction of BNS coalescence

◆ Takahashi, Nakamura, ApJ, 2003

Primordial GW

◆ Kuroyanagi, Chiba, Sugiyama, PRD, 2009



Dark Matter

◆ Saito, Yokoyama, PRL, 2009

General relativity

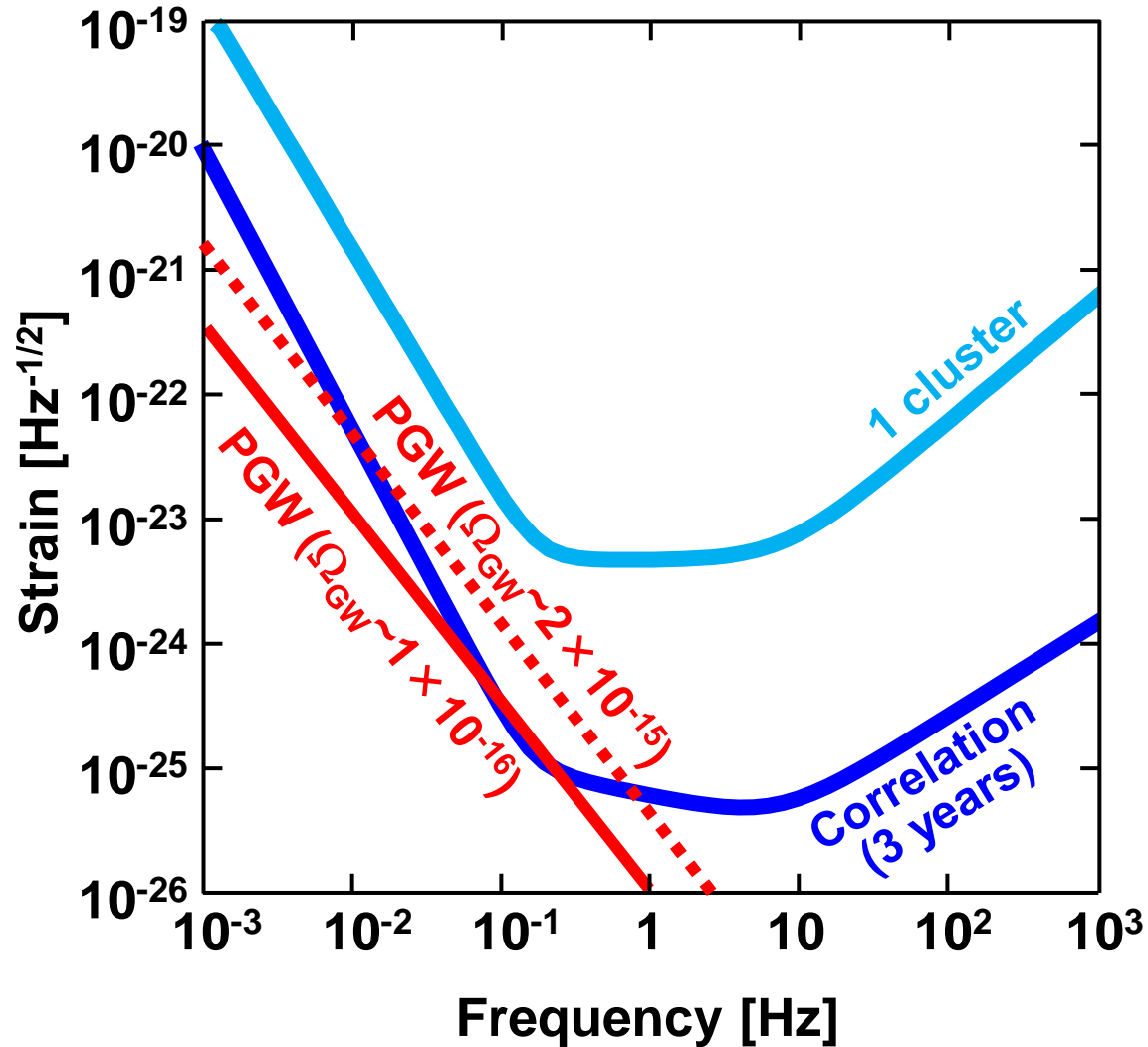
◆ Yagi, Tanaka, PTEP, 2010

Acceleration of expansion of Universe

◆ Seto, Kawamura, Nakamura, PRL, 2001

Update of PGW

- The upper limit of PGW has been reduced by the Planck observations, etc.
- ◆ Planck Collaboration, A&A, 2020
- The target sensitivity of DECIGO should be improved to enhance the possibility of detection of PGW.



Optimization with quantum noise

- The following parameters are optimized **for the best SNR for a given mirror radius**

- Cavity length
- Reflectivity of mirror
- Laser power (up to 100 W)

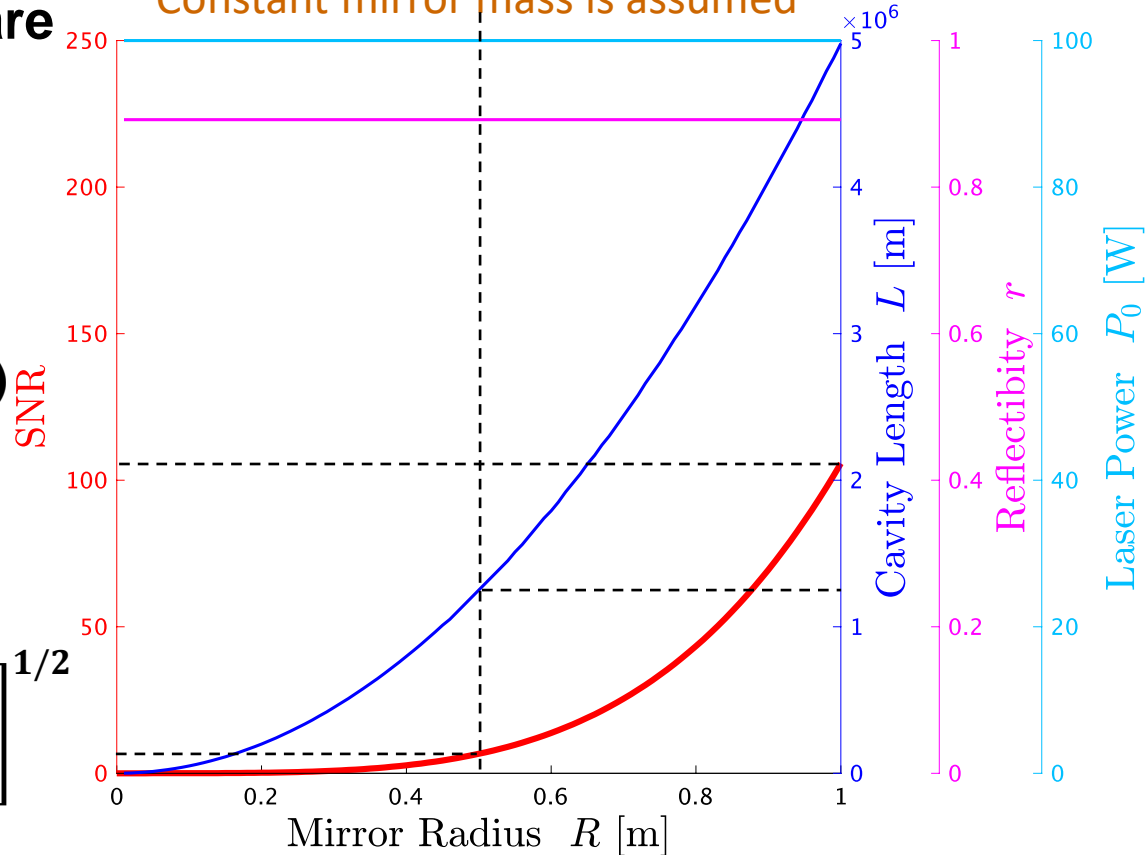
- Considering only quantum noise

SNR

$$= \frac{3H_0^2}{10\pi^2} \sqrt{T} \left[\int_{0.1}^1 \frac{2\gamma^2(f)\Omega_{\text{gw}}^2(f)}{f^6 P_1(f)P_2(f)} df \right]^{1/2}$$

- $\Omega_{\text{GW}} \sim 1 \times 10^{-16}$
- Cut-off frequency for double white dwarf (DWD) noise: 0.1 Hz

Constant mirror mass is assumed



- ◆ Iwaguchi, et al., Galaxies, 2021
- ◆ Ishikawa, et al., Galaxies, 2021

Optimization with thermal noise and DWD noise

Design parameters

For a given radius, optimize the other parameters

Parameter	Range
Mirror radius	0~1 m
Reflectivity	0~1
Laser power	0~100 W
Arm length	No limit

Values/type for each model: 2^3 in total

Parameter	Value
DWD cut-off frequency	0.07 Hz / 0.1 Hz
Pressure inside spacecraft	10^{-8} Pa / 10^{-9} Pa
Mirror model	Constant mass (100 kg) / Constant thickness (0.5 m, 100 kg)

Results

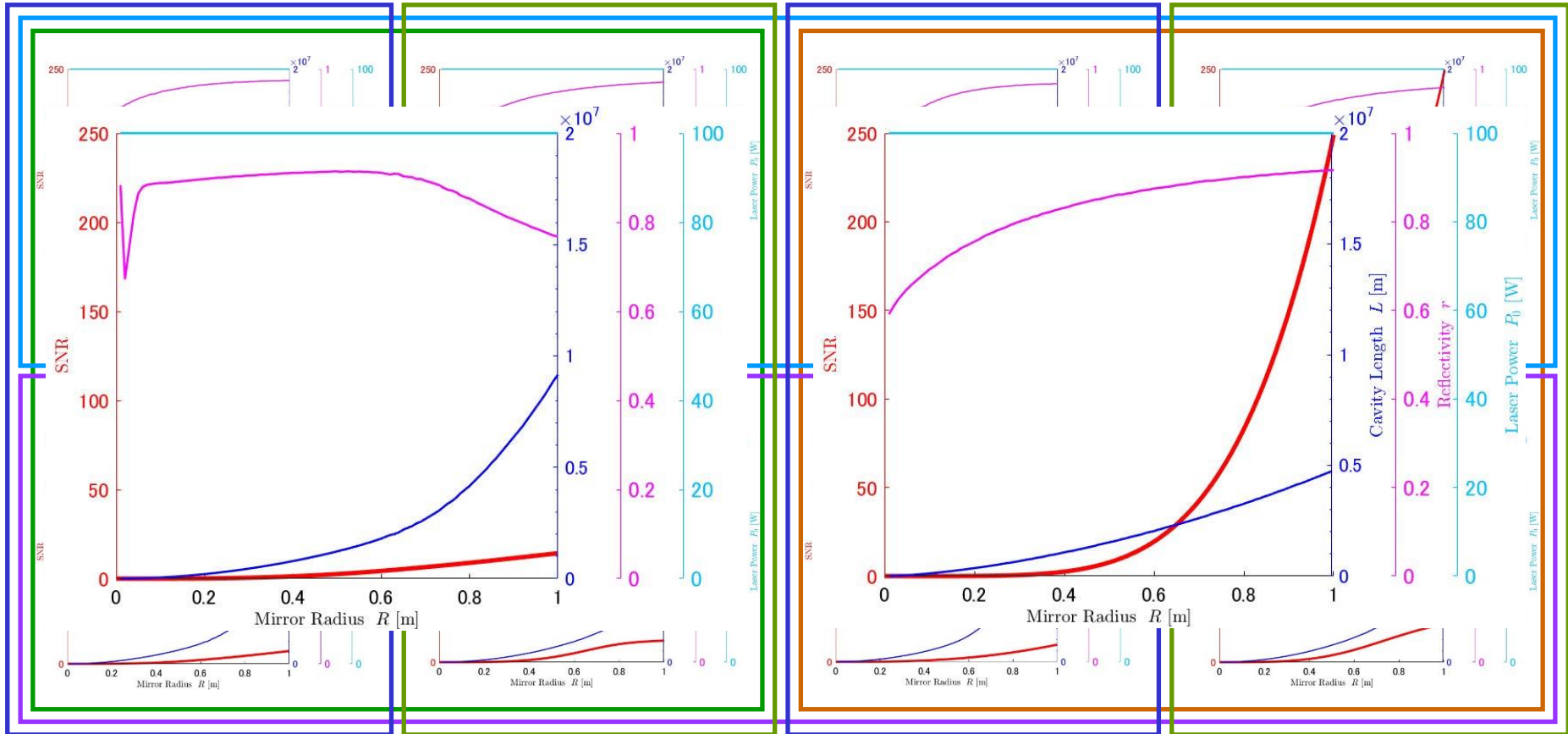
10^{-8} Pa

10^{-9} Pa

10^{-8} Pa

10^{-9} Pa

Constant thickness

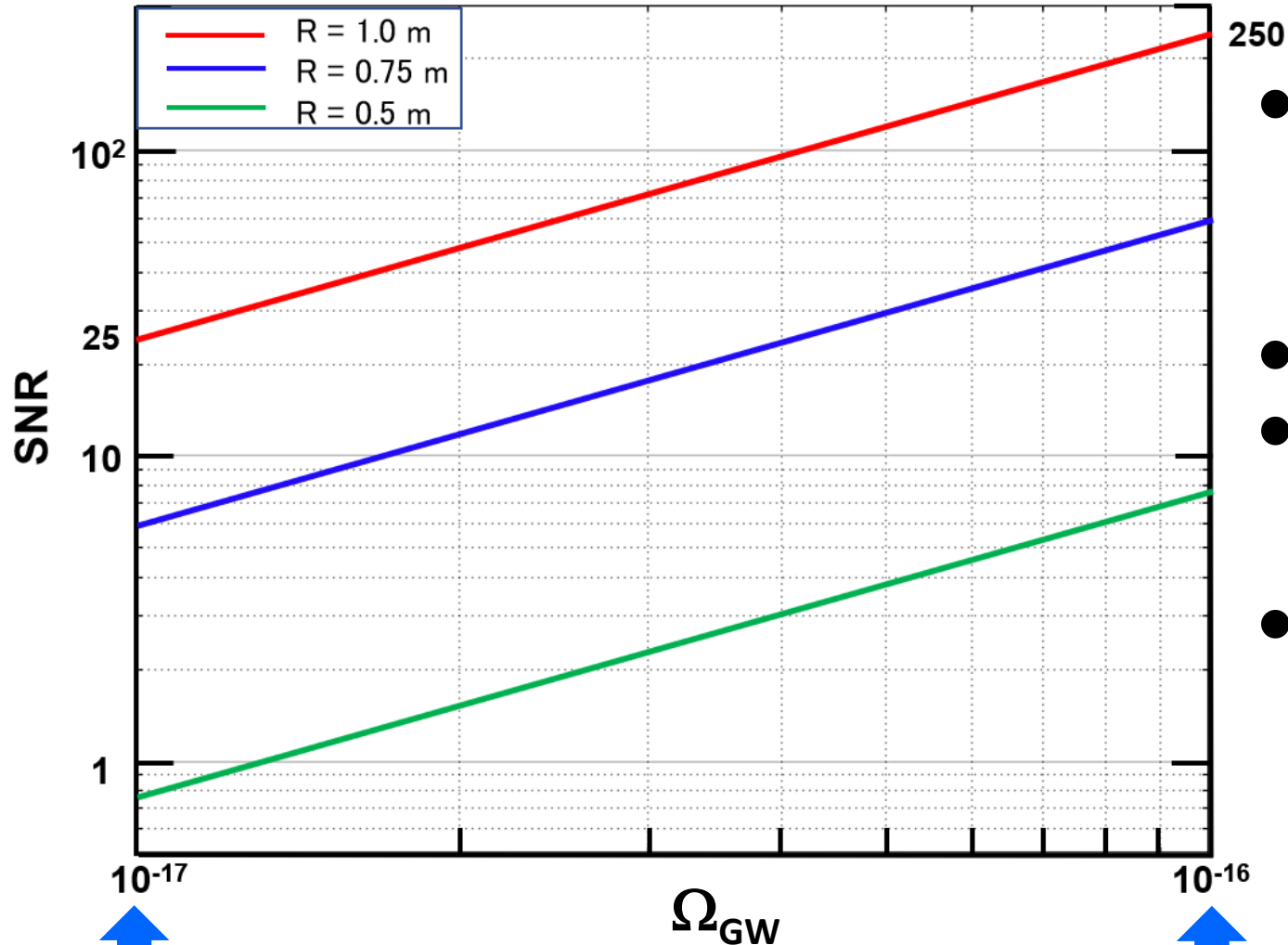


Cut-off frequency: 0.1 Hz

Cut-off frequency: 0.07 Hz

Constant mass

Relationship between Ω_{GW} @0.1Hz and SNR

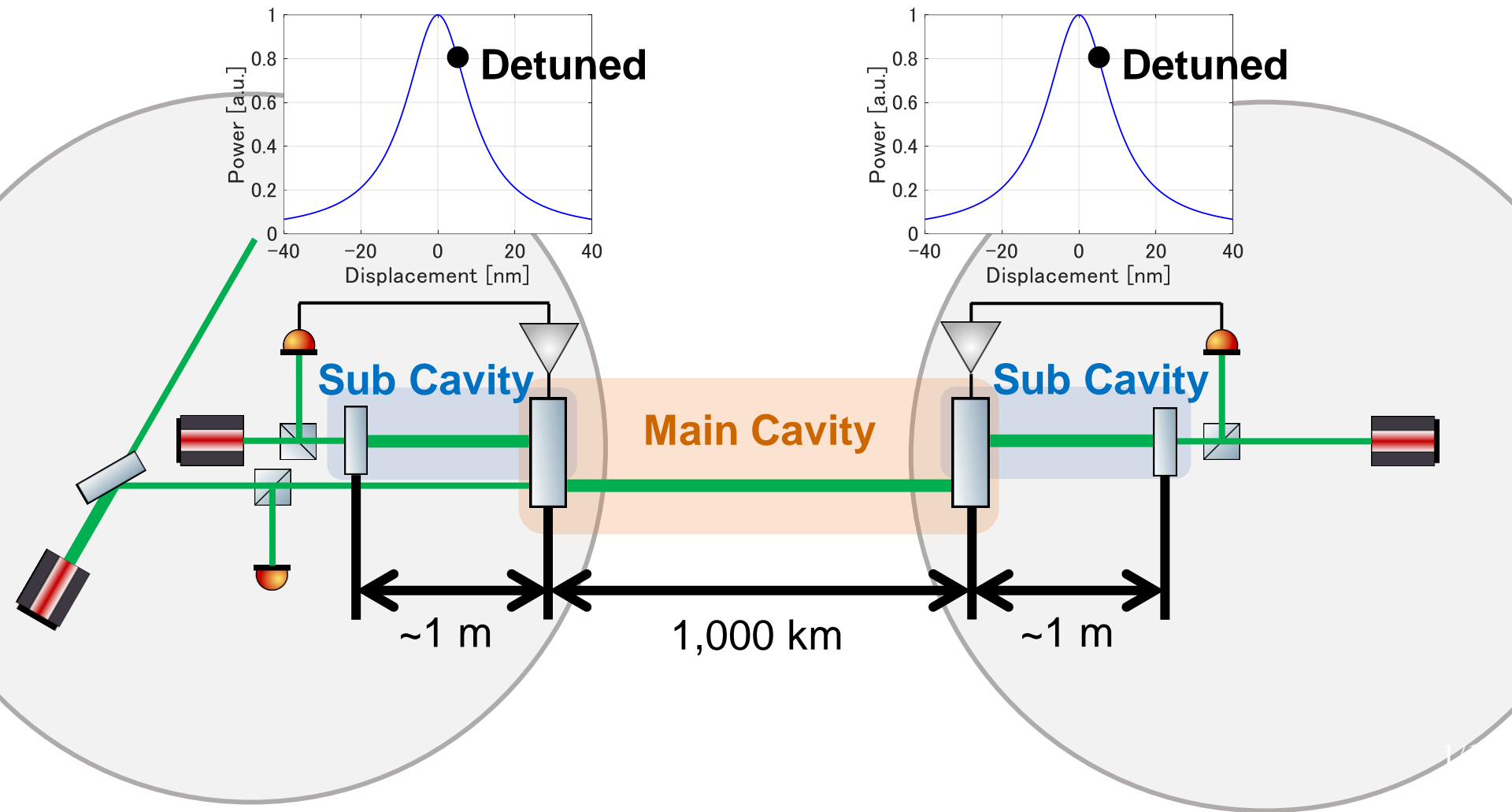


- Considering quantum noise and thermal noise
- Vacuum : 10^{-9} Pa
- DWD cut-off frequency: 0.07 Hz
- Mirror: Constant thickness

Predicted by
Starobinski model

The current
upper limit

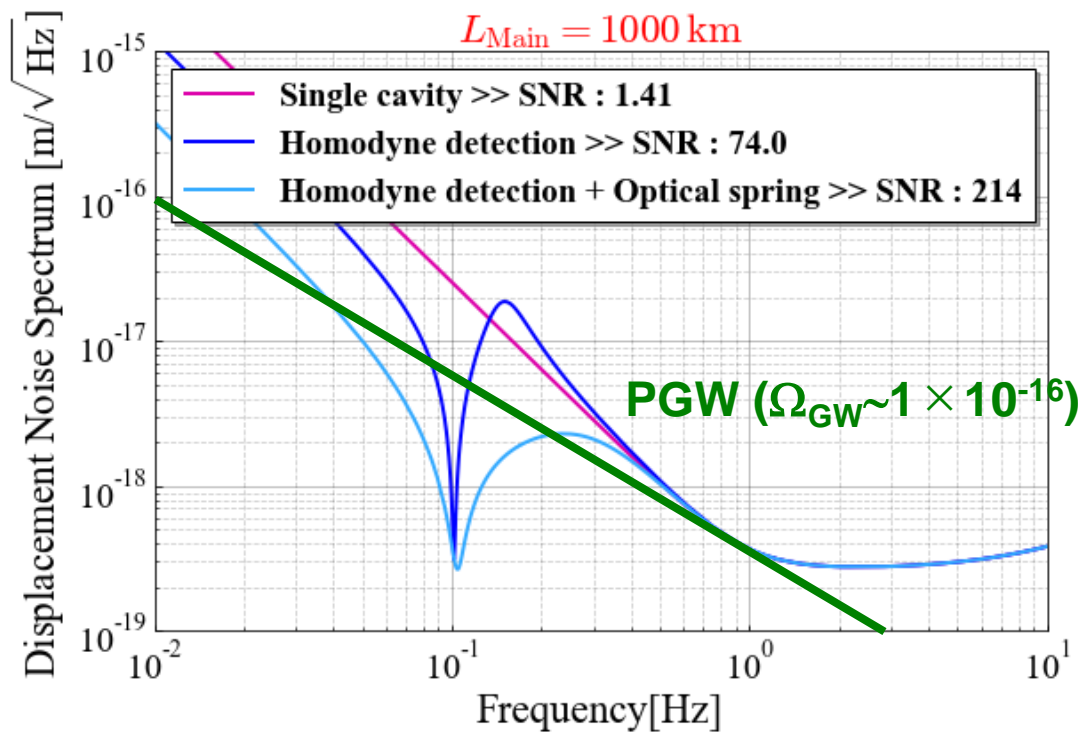
Quantum locking with optical spring



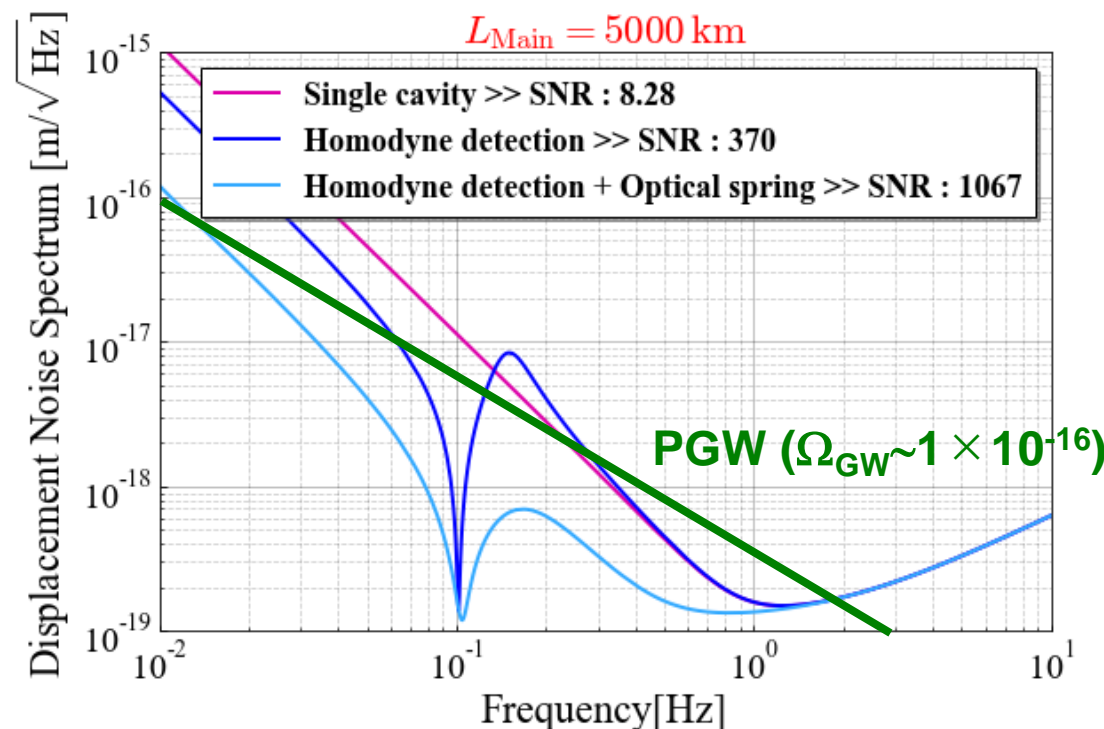
- ◆ Yamada, et al., PLA, 2020
- ◆ Yamada, et al., PLA, 2021
- ◆ Ishikawa, et al., PRD, 2023

Sensitivity

- Considering only quantum noise
- DWD cut-off frequency: 0.1 Hz
- Mass of mirror: 100 kg
- Laser power: 100 W



- Radius of mirror: 0.5 m
- Arm length: 1,000 km



- Radius of mirror: 1 m
- Arm length: 5,000 km

Roadmap

Now updating the roadmap

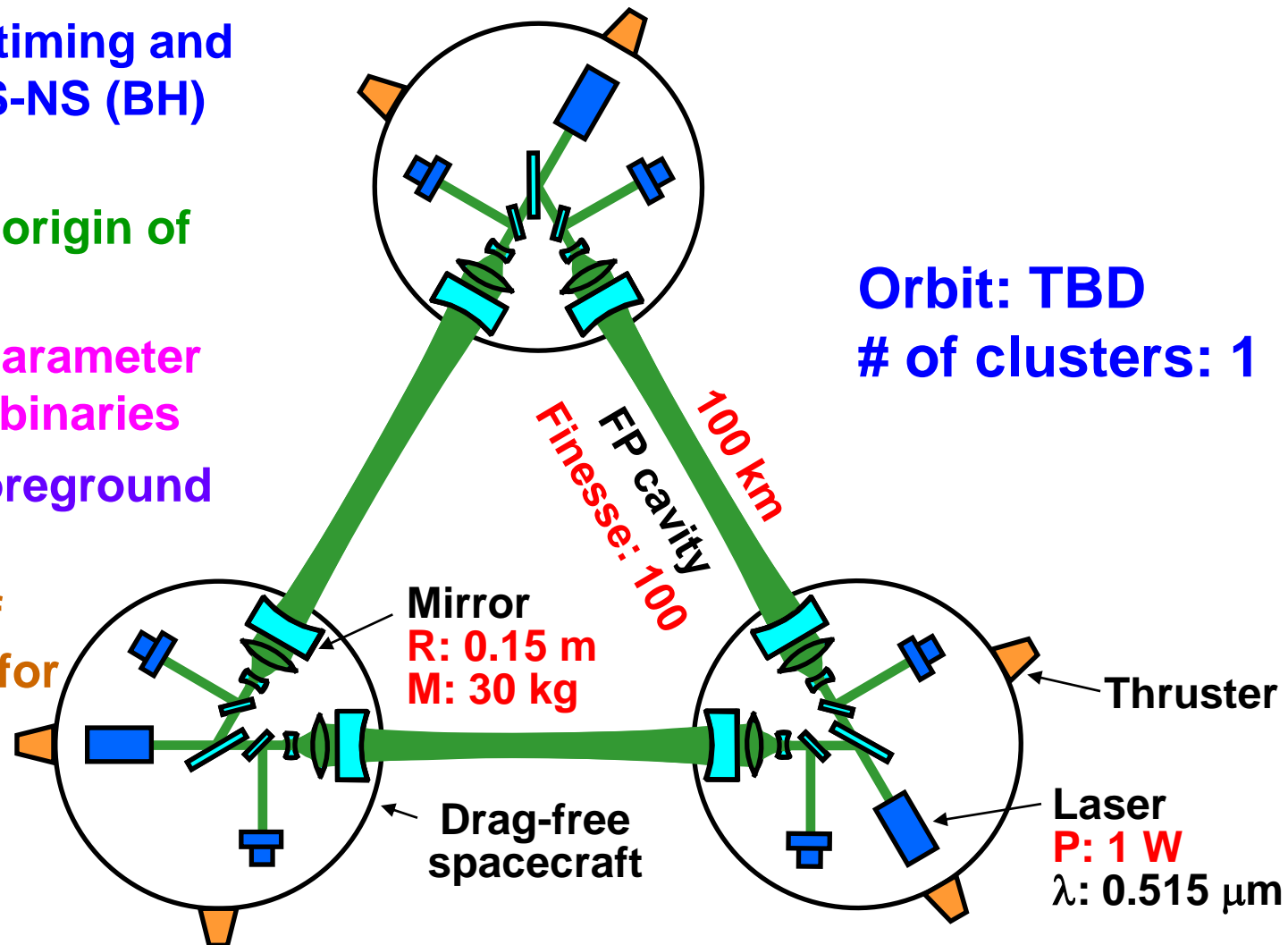
Target

												2034													
Mission																									
	<p>SWIM</p> <p>DICIGO Pathfinder</p> <p>B-DECIGO</p> <p>DECIGO</p>																								
	<p>Objectives</p> <p>Test of key technologies</p> <p>Detection of GW w/ minimum spec. Test FP cavity between S/C</p> <p>Full GW astronomy</p>																								
<p>Scope</p> <p>1 S/C 1 arm</p> <p>3 S/C 3 interferometers 1 cluster</p> <p>3 S/C 3 interferometers 4 clusters</p>																									

B-DECIGO

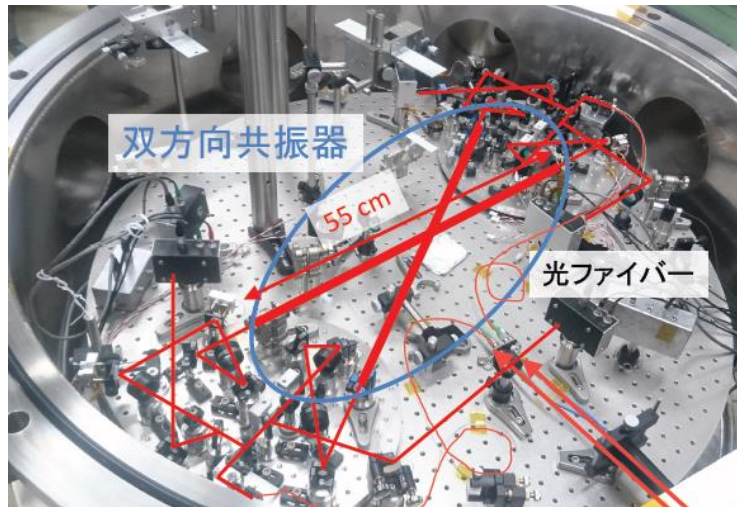
Smaller and simpler version of DECIGO

- Prediction of timing and location of NS-NS (BH) coalescence
- Revelation of origin of ~ 30 M BBH
- Much better parameter estimation of binaries
- Removal of foreground for DECIGO
- Verification of technologies for DECIGO

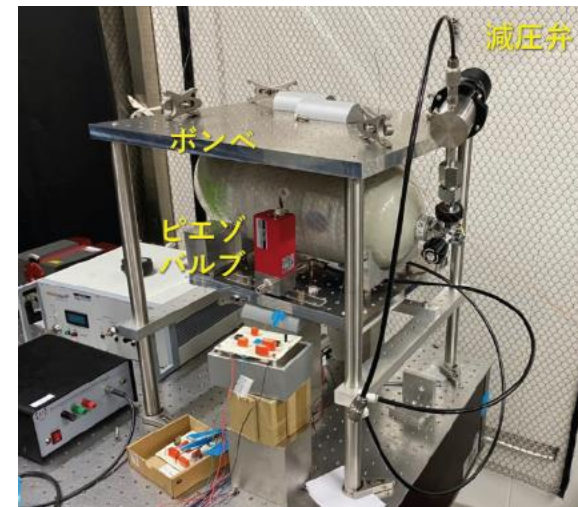


Progress on technologies for B-DECIGO

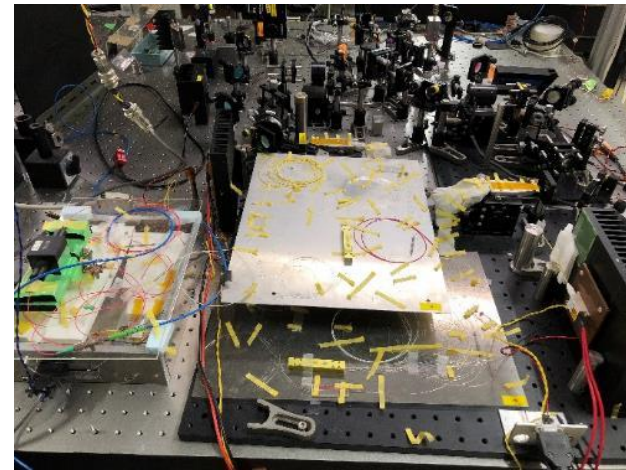
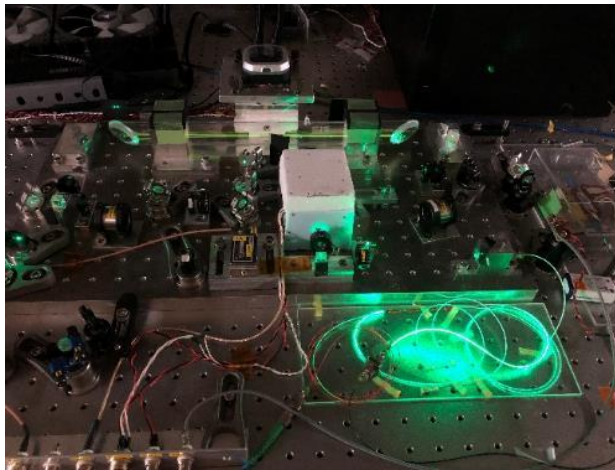
Dual-pass FP cavity



Low-noise thruster



High-power stabilized laser



Related mission: SILVIA

● SILVIA

- Space Interferometer Laboratory Voyaging towards Innovative Applications
- Candidate for small satellite mission at ISAS/JAXA in collaboration with DECIGO and infrared interferometer team
- Objectives: **Demonstration of the formation flying technology and drag-free technology**

● Recent progress

- Feb. 2020: SILVIA mission proposed to ISAS
- Aug. 2020: Approved to proceed to “Idea implementation process”
- Dec. 2022: **Approved to proceed to “Mission definition phase”**
- **Now: Study for mission definition underway**

Summary



Image of
B-DECIGO
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- DECIGO will accomplish a variety of science, including **direct detection of PGW**, for which **we are updating DECIGO design**.
- B-DECIGO will verify **technologies for DECIGO** as well as accomplish a variety of science, including **frequent prediction of NS-NS**.