大型低温重力波望遠鏡に関する研究(XI)

S.Miyoki and KAGRA Collaboration
(ICRR.UT)

Research Result Presentation Meeting of the ICRR Inter-University Research Program 2021

January 24th, 2022

発表内容

1. “G01” を親としてサポートされている研究項目
2. KAGRA の進捗の流れ
3. LIGO-Virgo-KAGRA 重力波共同観測O4 の状況
4. KAGRA がO4 に参加するための戦略
5. O4に向けた、KAGRAのUpgrade状況

G01を親とする研究課題（18）

課題番号	研究代表者	研究課題	査定額（千円）
G01（親）	大橋　正健	大型低温重力波望遠鏡に関する研究（XI）	¥300
G03	都丸　隆行	高性能極低温鏡制御系の開発	¥500
G04	山元　一広	大型低温重力波望遠鏡（KAGRA）の低温懸架系の研究	¥200
G05	清水　洋孝	KAGRA実験に向けた伝導冷却の方法の高度化	¥300
G06	森脇　喜紀	KAGRAにおけるレーザー強度安定化のためのR&D	¥400
G07	大河　正志	重力波望遠鏡KAGRAの測定感度向上に資する雑音低減および極微小散乱光計測技術の開発Ⅱ	¥450
G09	鷲見　貴生	KAGRAにおける環境由来のノイズ削減に関する研究	¥150
G10	横澤　孝章	KAGRA検出器における注入試験による環境雑音評価手法の研究	¥150
G11	高橋　弘毅	機械学習・深層学習を用いたノイズ特徴の分析と干渉計診断への応用	¥350
G12	押野　翔一	機械学習を用いた突発性雑音解析によるKAGRA重力波データの信頼性向上	¥200
G13	鈴木　敏一	熱計測によるサファイアの極低温吸収測定	¥300
G14	三代木　伸二	重力波望遠鏡における電磁波散乱・伝搬シミュレーション IX	¥150
G15	牛場　崇文	高性能サファイア鏡懸架系の開発	¥250
G17	神田　展行	KAGRAデータ転送・保管系の構築（7）	¥400
G18	澤田　崇広	KAGRAデータを低遅延国際重力波探索網へ組み込むための共同研究推進	¥200
G19	山本　尚弘	重力波探索のための望遠鏡診断システムの構築	¥250
G20	真貝　寿明	重力波観測装置KAGRAコラボレーションの共同研究推進，および重力波データ解析の手法開発	¥100
G21	端山　和大	KAGRAを用いたモデル化されていない突発性重力波探査II	¥200
全18課題		合計	¥4,850

KAGRA の進捗の流れ

- **iKAGRA (~ Mar 2016): Room Temperature MI**
- **bKAGRA phase-1 (~ Mar 2018) : Cryogenic MI**
- **bKAGRA phase-2 (~ Apr 2019) : Almost are installed**
- **bKAGRA phase-3 to O3 (May 2019 ~ April 2020)**
  - FPMI → PRFPMI was realized, stable operation, Noise hunting
  - Requested items preparation for Joint Run with LV for O3
  - MOA with LV (Oct. 2019)
  - BNS range sensitivity of 1 Mpc was realized around the end of March 2020.
  - KAGRA Solo OBS (Feb ~ Mar 2020) and, O3GK with GEO600 (April 2020).
- We are now in bKAGRA phase-4 to O4 (May 2020 ~ Dec 2022)

KAGRA のO4に向けた背景的状況

- **bKAGRA phase-4 towards O4 from 2020 to 2021**
  - **With Several Hard Conditions**
    - **Suspension from May to June 2020. There was less activities at the KAGRA site.**
    - **Less expert members took more time to proceed many upgrade items.**
    - **Another impact of COVID-19 during July-September 2021 was severe.**
  - **With troubles that required time for overcome**
    - **Identification of the source of the Type-Bp suspensions' instability.**
    - **Several defects that were left during O3 commissioning. Some were known and some were newly found. Their repair delayed the planned schedule.**
    - **ETMY mirror surface pollution was found, and its recovery took 5 months.**
  - **With O4 start delays again mainly due to**
    - **Hurricane disaster on LLO in September,**
    - **Continuous activities restriction due to COVID-19 pandemic in any places,**

O4 はいつはじまるのか？

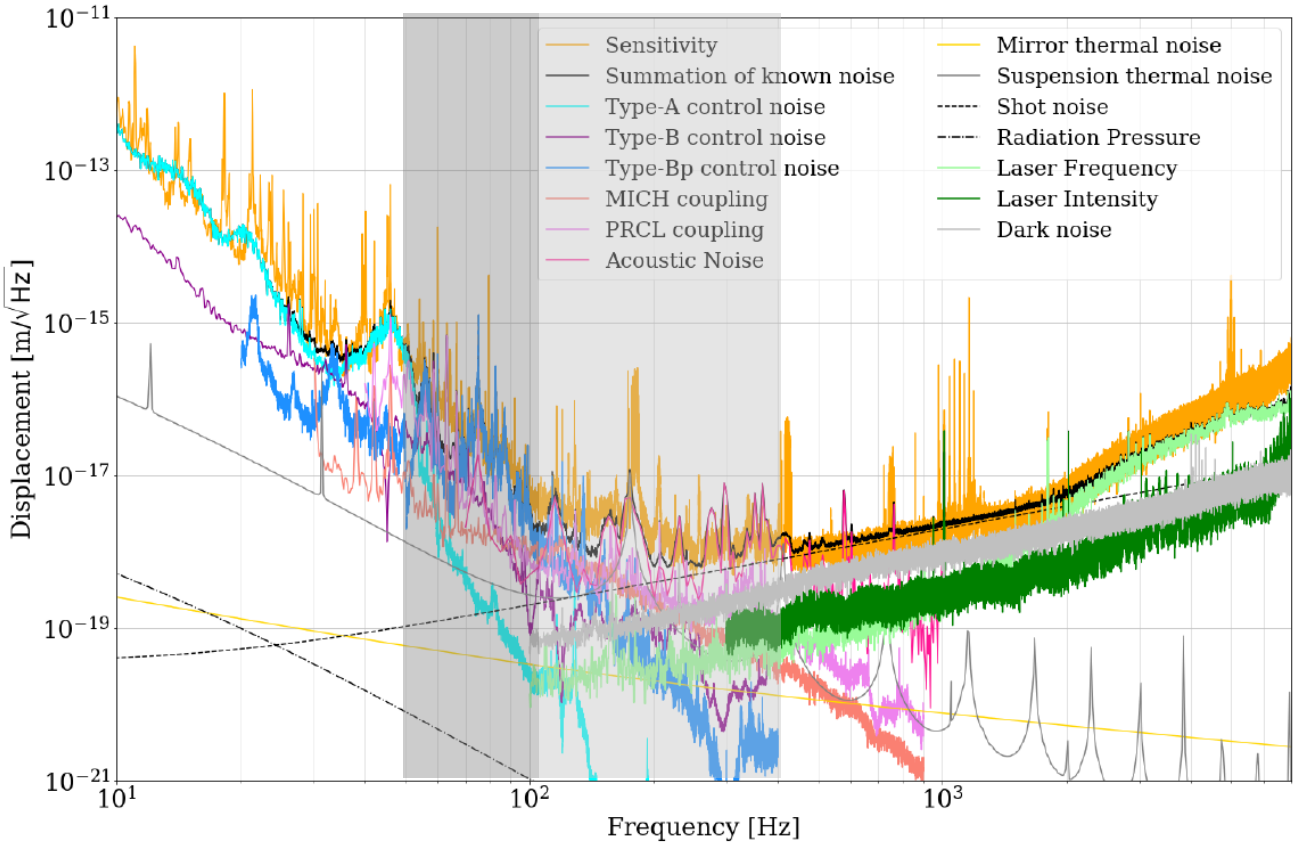
- **O4 start was discussed among LVK management calls and (extended) JRPC meetings among LVK collaboration**
  - **Original plan (before COVID-19 pandemic)**
    - January 2022.
  - **Pre-pre-plan, considering the hard activity restriction due to COVID-19 pandemic**
    - **"no earlier than July 2022"** was announced especially for the research groups in EM observatories from the point of view of multi-messenger astronomy collaboration. (6 months delay)
  - **Pre-plan considering preparation delay due to some troubles in LLO, etc**
    - "not earlier than August 2022"was discussed
    - However, it was not announced in the LVK meeting in September because of another disaster in LLO by the hurricane attack.
    - Some other troubles in LLO were also one of reason for reconsidering the O4 start.
  - **The present plan,**
    - **"From Mid December 2022" was announced in November 2021 (11.5 months delay)**
    - The next announcement will be in March 2022, considering the actual progress status until March 2022 in each observatory.

How Long is O4 and O4-O5 upgrade?

- **The O4 observation length has not been decided yet.**
  - **Original plan**
    - O4a(6 months), break(1 month), O4b(6 months).
  - **It will be discussed soon (Winter 2022)**
- Anyway, the KAGRA upgrade plan should be performed step by step.

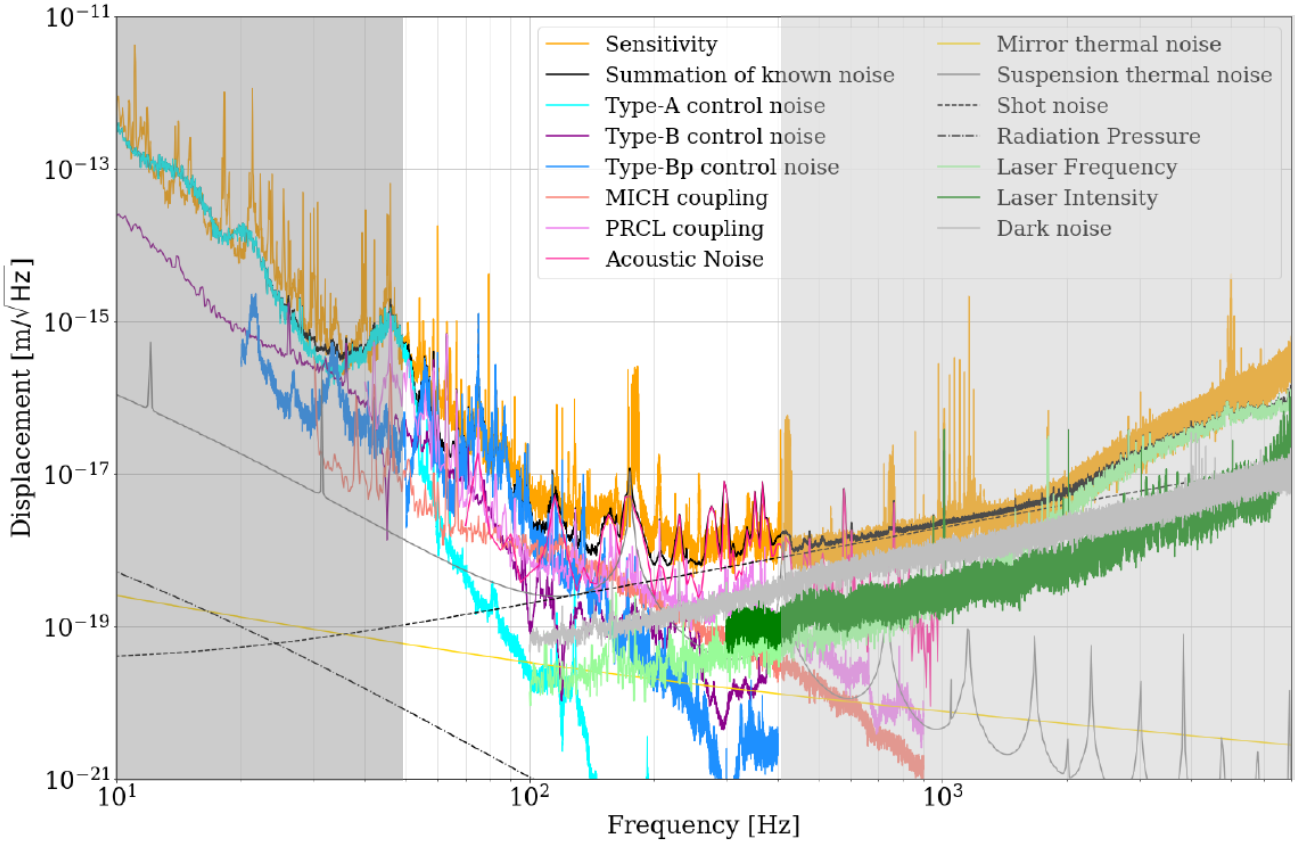
感度向上計画

- 100Hz ~ 400 Hz :
  - 散乱光雑音 : 干渉計マイケルソン部分にバッフルを挿入
  - マイケルソン・パワーリサイクリング部制御雑音 : 制御系の最適化?
- 50Hz ~ 100Hz :
  - Type-B/Bp の制御雑音 : Type-B/Bpの制御系の最適化
  - 熱雑音 : すべての雑音を落として顕在化した熱雑音を鏡と懸架装置の冷却

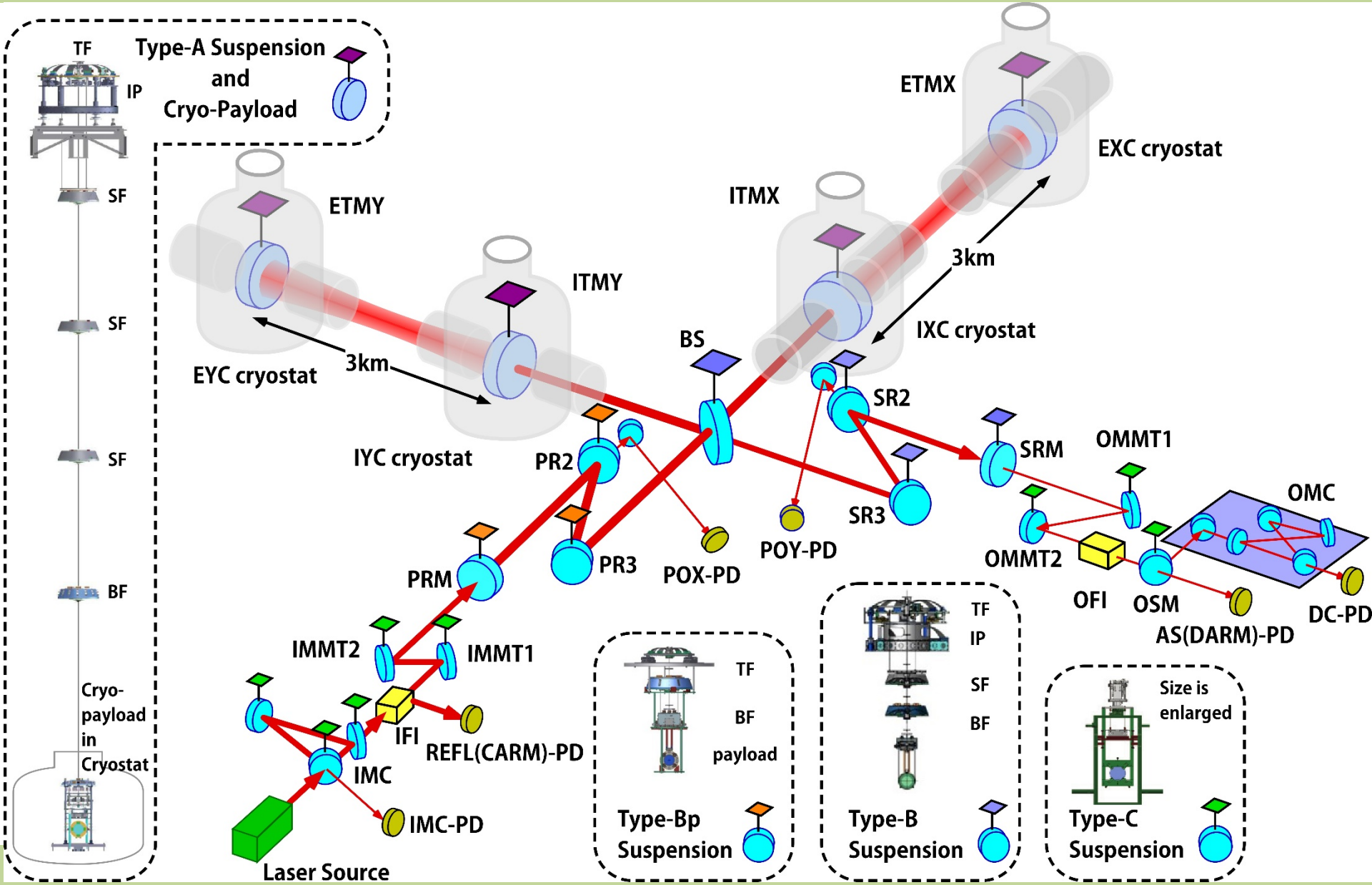


感度向上計画

- < ~ 50Hz :
  - Type-Aの制御雑音低減: Type-AのHealth Checkの徹底
- > ~ 400Hz :
  - Shot Noiseの低減: O%SRM, High-Power Laserの導入,
    OMC 鏡の品質改善 と Photo Detectorの修理
    周波数雑音と強度雑音の低減



KAGRA Optical Configuration (DRFPMI)



Progress towards O4

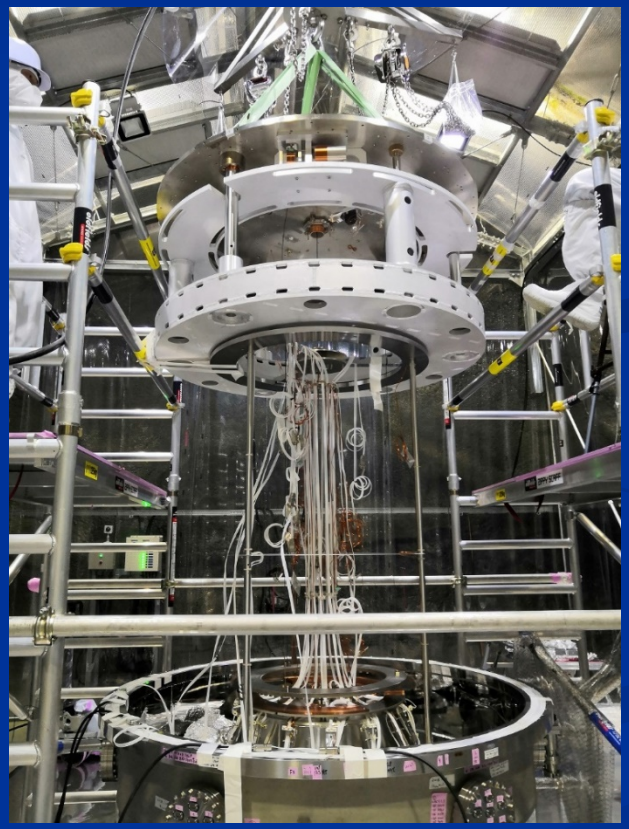
Repair and Improvement of Suspension System (R.Takahashi)

- **Type-A EYC several GAS filters lost its isolation function due to sitting on the counter part.**
  - → **Progress:** Repair and reconstruction of the tower and cryo-payload was done. Health check is ongoing.
- **Noisy LVDT and New Accelerometer Preparation.**
  - → **Progress:** Low noise LVDT was prepared for IX/EX. While, we are preparing for IY/EY. The control scheme refinement will be introduced by using these new LVDTs.
- **No temperature control for GAS in Type-A/B/Bp.**
  - → **Progress:** Ribbon heaters were installed. Test will be done under vacuum condition
- **Identification of the Type-Bp (PR2/3) unstable performance.**
  - → **Progress:** PR2 was fixed. While we have no time to completely repair SR3. The jumping amount was reduced, but it remains.
- **Preparation of Type-B(SRMs/BS).**
  - → **Progress: ongoing. There are many to do.**

Reinstallation of Type-A tower in ETMY (R.Takahashi)

- We started the extraction of the type-A tower in November 2020 and the reinstallation in January 2021. The cryo-payload was connected in August 2021. The final tuning of each GAS filter was performed hanging the cup from the upper stage.

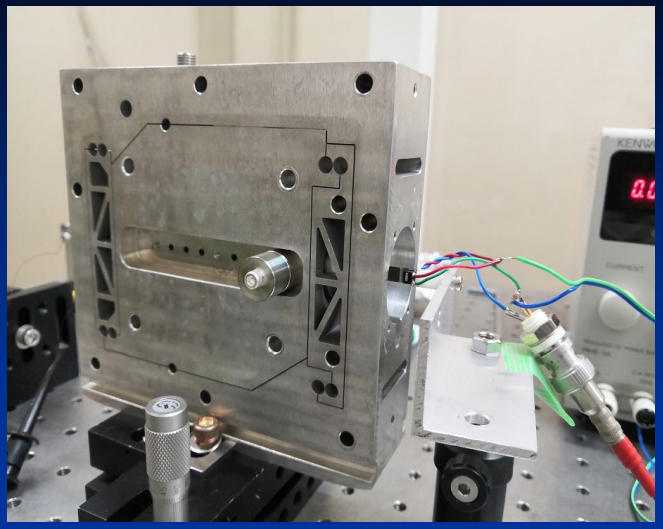
Installation of BF with DP



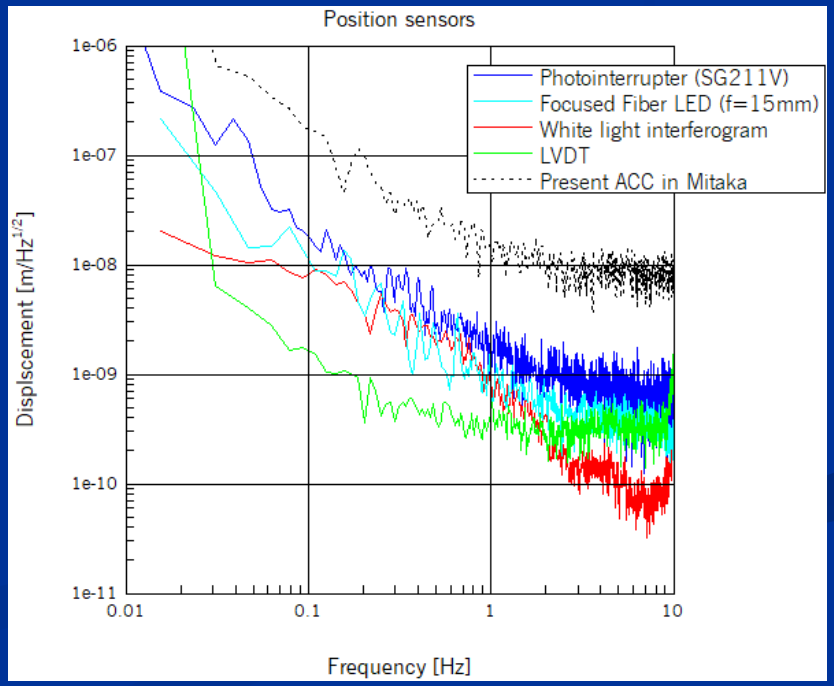
Tuning of F1 hanging from F0

Cabling for cryo-payload

Improvement of inertial sensors for IP control (R.Takahashi)



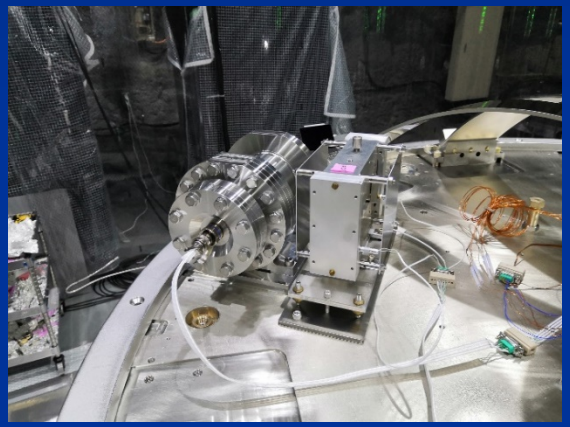
- The servo type accelerometers (IX, IY) and the commercial geophones (EX, EY) were used as inertial sensors in Type-A towers.
- The sensitivity of these inertial sensors were not good enough to control the IPs around 0.1Hz.
- We replace the inertial sensors to better accelerometers.
  - Replace the present position sensors.
  - Tune the folded pendulums to 0.2Hz.
- Some kinds of position sensors have been evaluated. The LVDT had the best sensitivity around 0.1Hz.



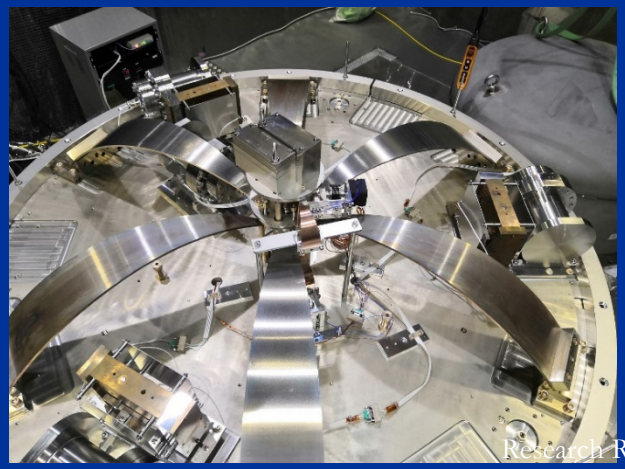
Sensitivities of some kinds of sensors

Prototype test and installation (R.Takahashi)

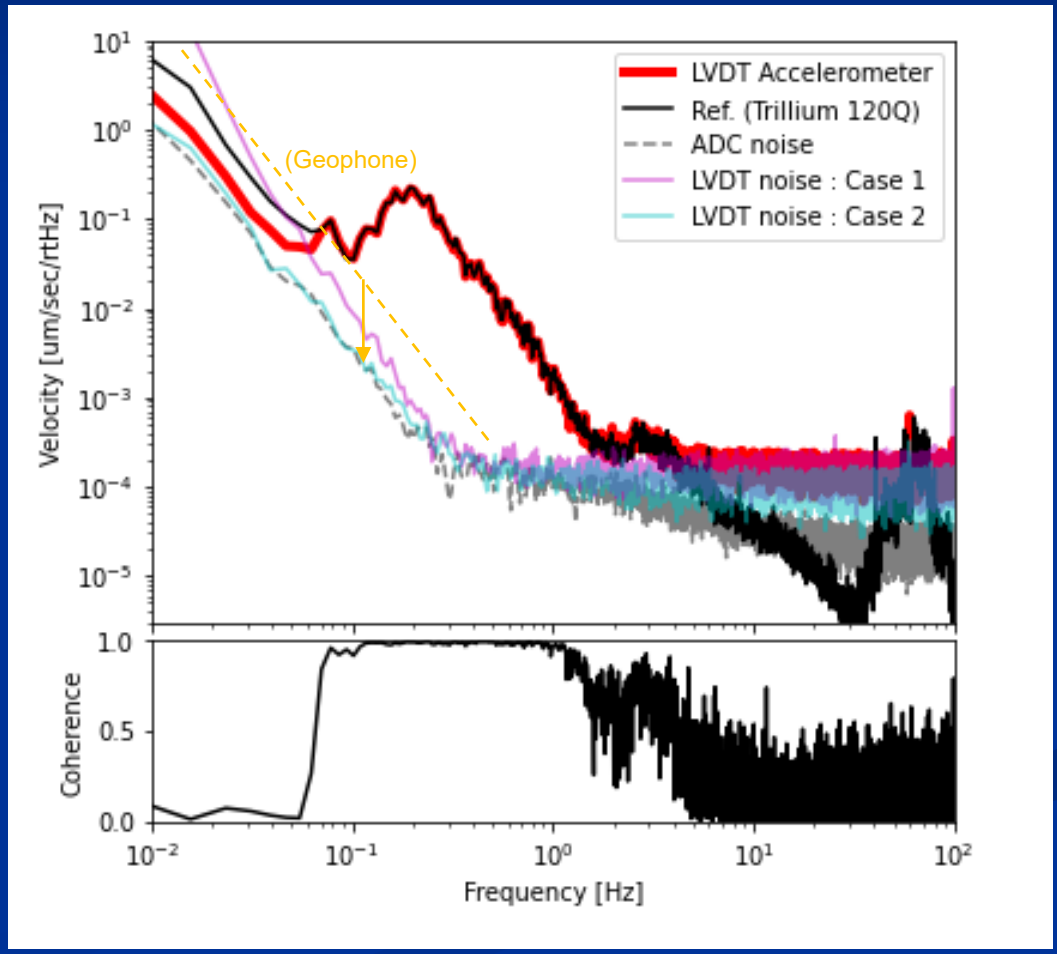
- Prototype accelerometer with the LVDT was evaluated at the KAGRA site. One order improvement at 0.1Hz is expected.
- Six accelerometers have been installed to IX and EX.



IX



EX



Measured spectra of prototype

Progress towards O4

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Progress towards O4

Suspension Commissioning from in Air to in Vacuum (T.Ushiba)

- **Suspension Health check :**
  - **The suspension tower including Type-A and Cryo-Payload should perform as we expect with proper margin.**

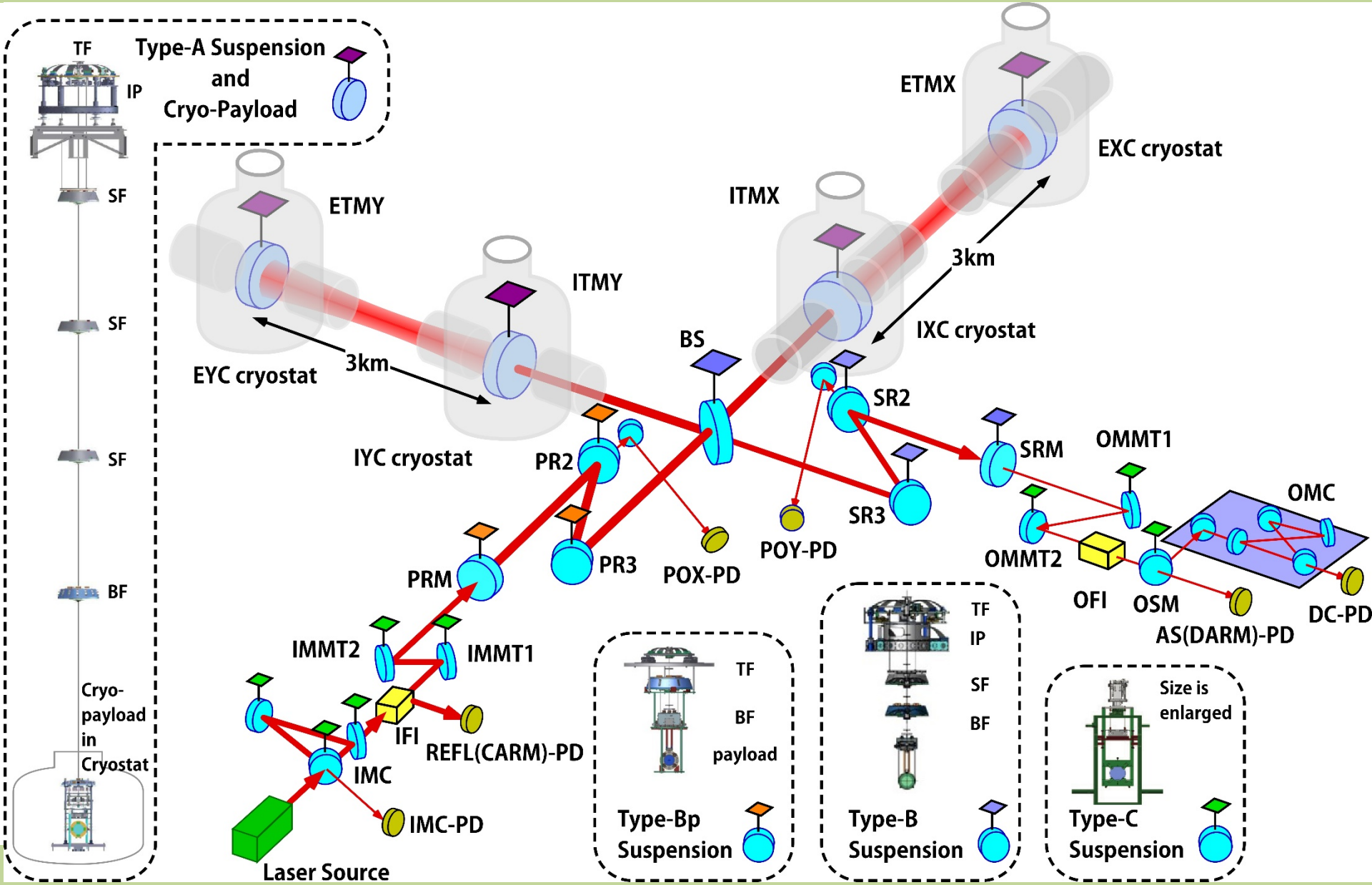
→ **progress:**

- The tower of IX/EX was once verified to be healthy from the point of view of
  - ✓ sensor spectrum,
  - ✓ transfer functions,
  - ✓ actuator performance and balance,
  - ✓ low actuator coupling,
  - ✓ enough gap between instruments/sensors,
  - ✓ proper default positions and so on.
- Acceptance check was done, and approved. The We can go to the next step.

→

- (I/E)X(C/A/V) area was pumped down, while IX(C/A/V).
- EX(C/A/V) leak check was done, and the only very small leak was found in EXC area.

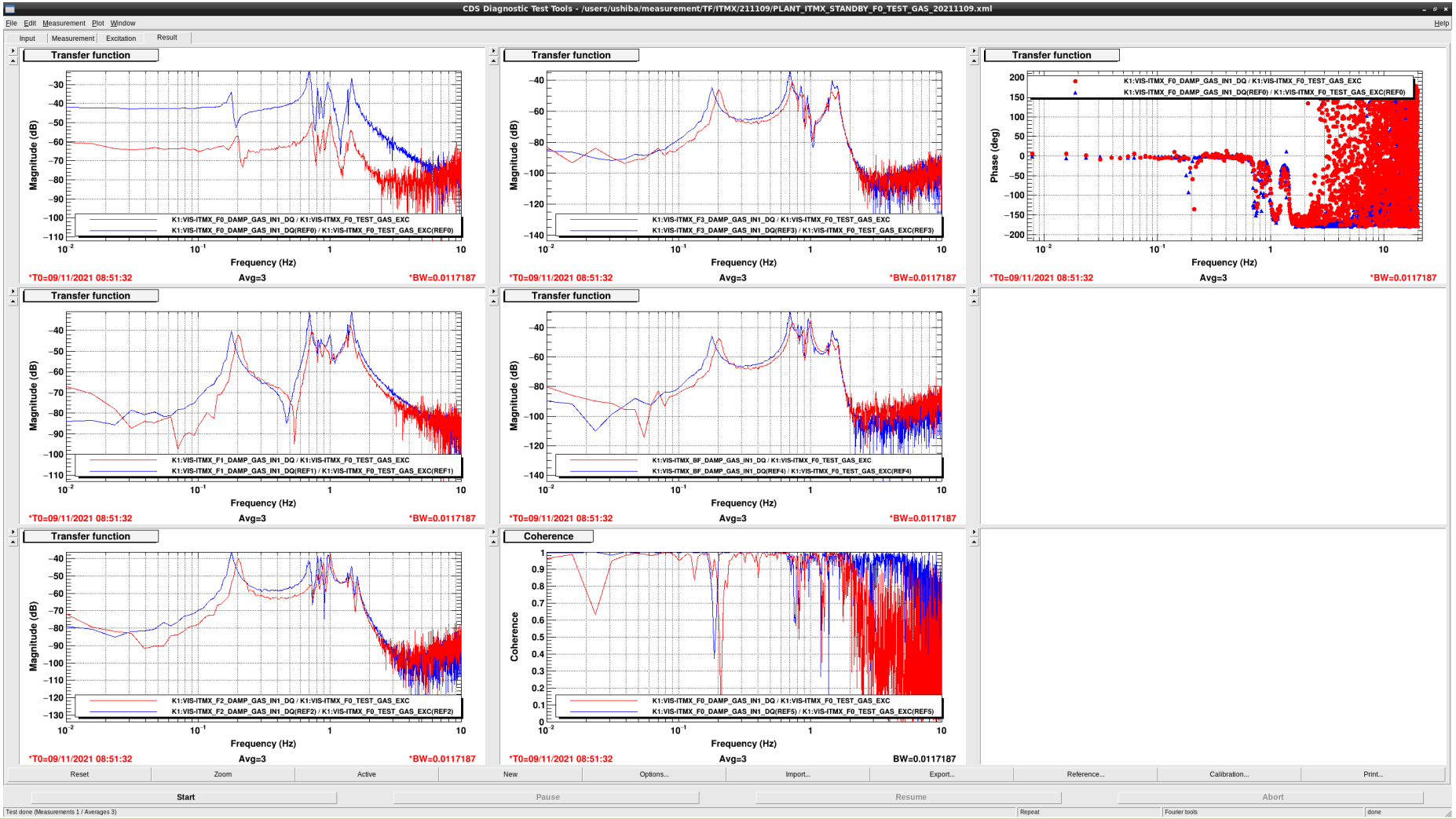
KAGRA Optical Configuration (DRFPMI)



Example of suspension health check

T.Ushiba

After the height adjustment of ITMX, mechanical response of F0 GAS filter seemed to change a lot. → We concluded this situation is fine (unavoidable).



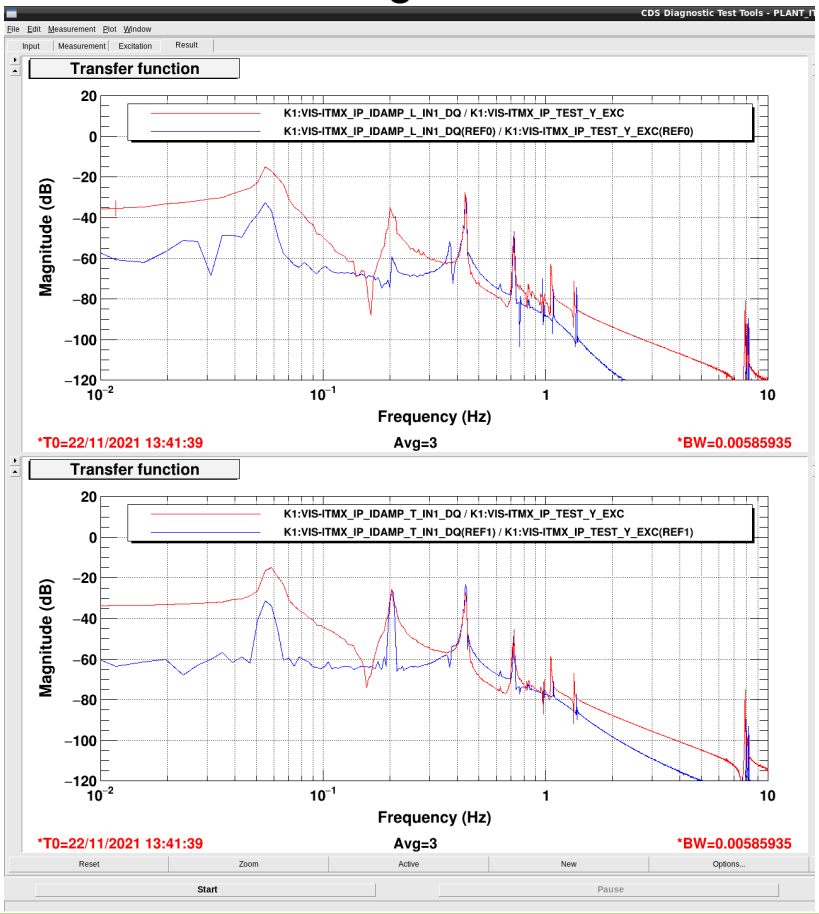
Example of management of MEDM parameters

T.Ushiba

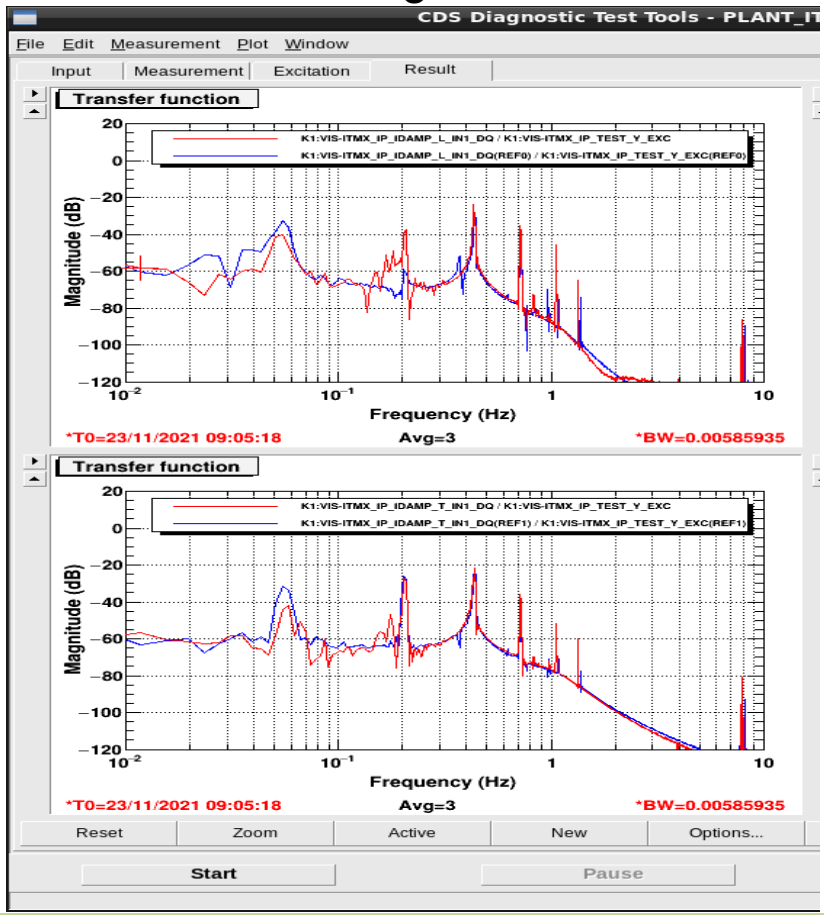
At the Top stage of Type-A suspension, large coupling was observed after the height adjustment of ITMX.

→ Implementing diagonalization matrices and reducing the coupling.

Before diagonalization



After diagonalization

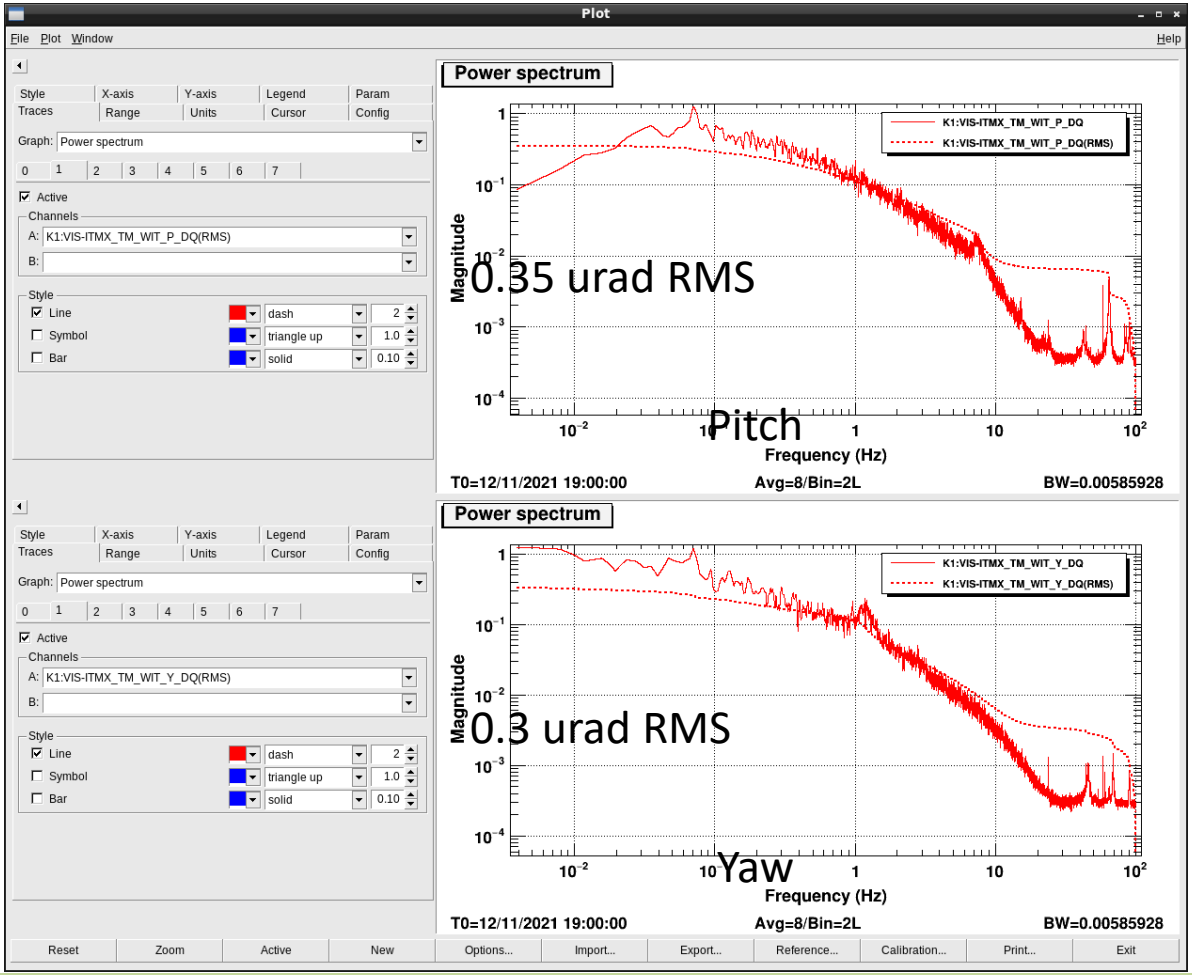


Example of controls of suspensions

T.Ushiba

For the initial alignment of ITMX, we engaged angular controls to reduce the RMS angular motion less than 1 urad.

→ This was achieved and X arm lock with green laser was succeeded.



Progress towards O4 :

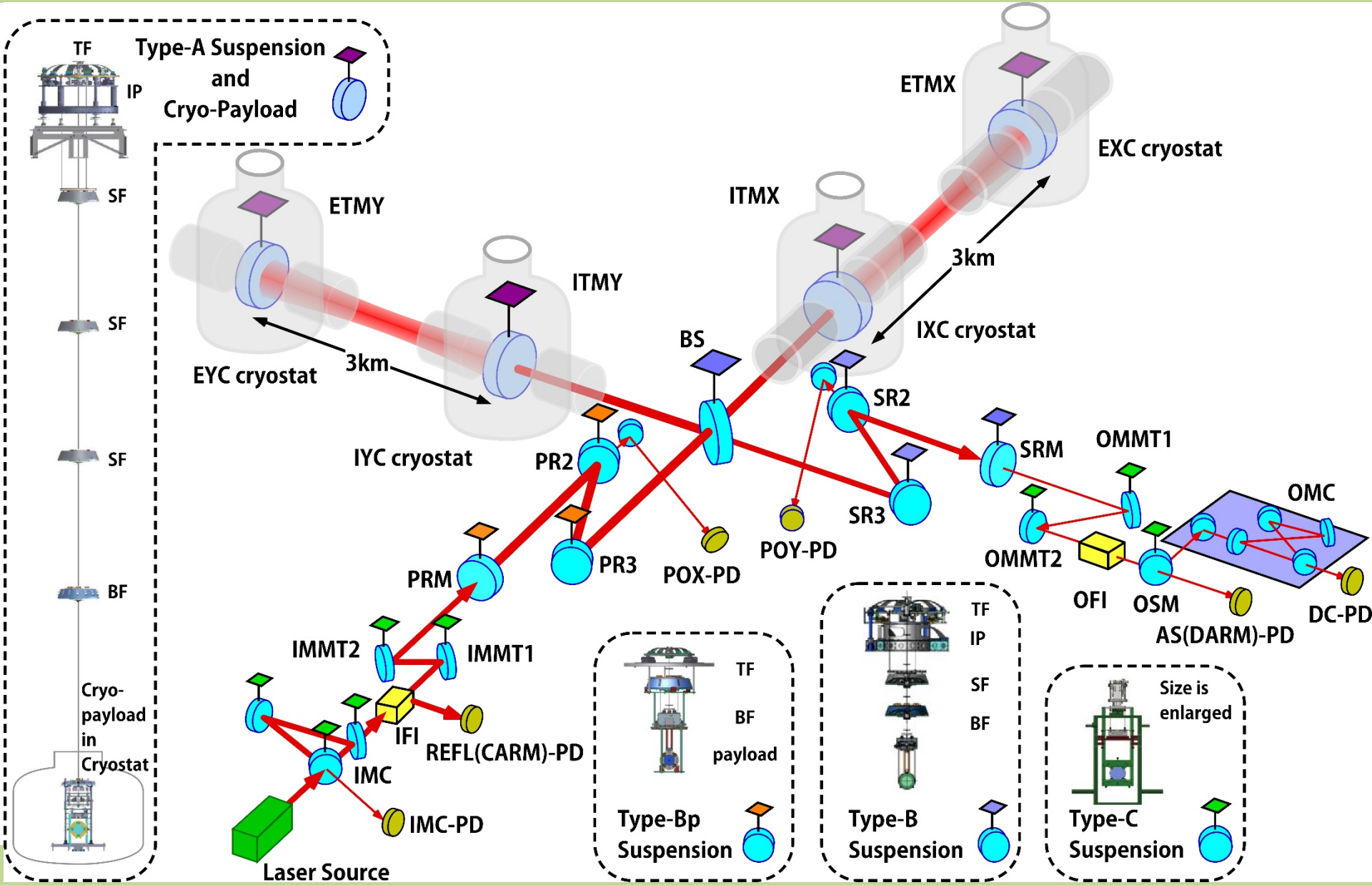
Frosting on Mirrors and Windows on Radiation Shields (by Kimura)

- **We encountered fatal results due to**
  - Stuck of a moving mass for the rough alignment for mirrors at cryogenic temp
  - Frosting on Mirrors
    → Super Low Finesse in Arm cavities → Bad Sensitivity
  - Frosting on windows where the oplev light pass through
    → Unreliable mirror alignment information,
    → no P/Y damping control for mirrors.
    → No operation of IFO

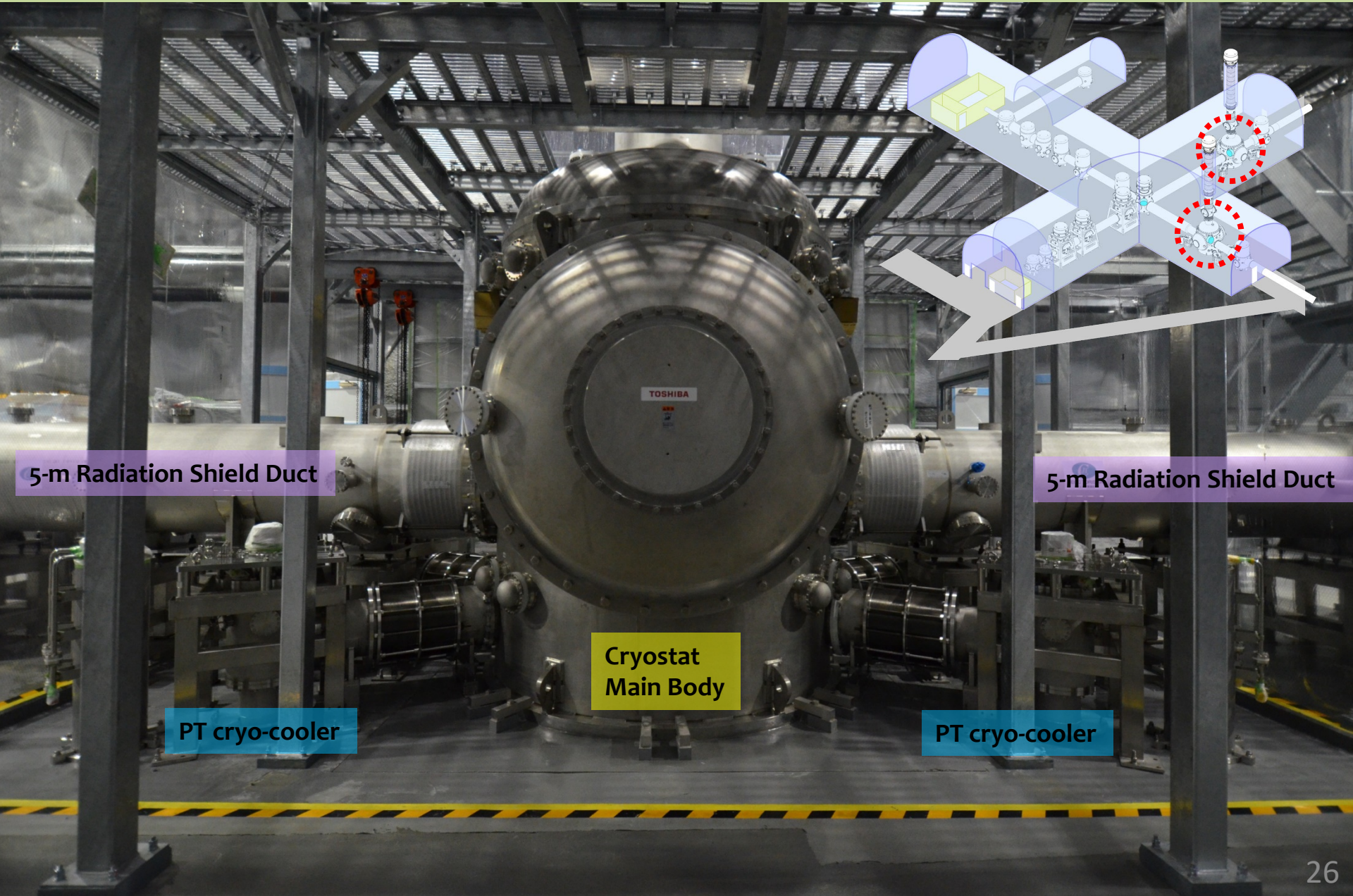
Progress

- **All new designed moving mass was installed**
- **All oplevs for MN/PF for cryo-payload were also installed for better suspension control**
- **Defrosting tool preparation for windows on Inner/Outer radiation shields**
  - Test in IYC was successfully done.
  - All cryostats were equipped with heaters.
- **Short life-time previous coolers were replaced new coolers for the duct radiation shields**.
- **All are waiting for tests and actual operations.**

KAGRA Optical Configuration (DRFPMI)



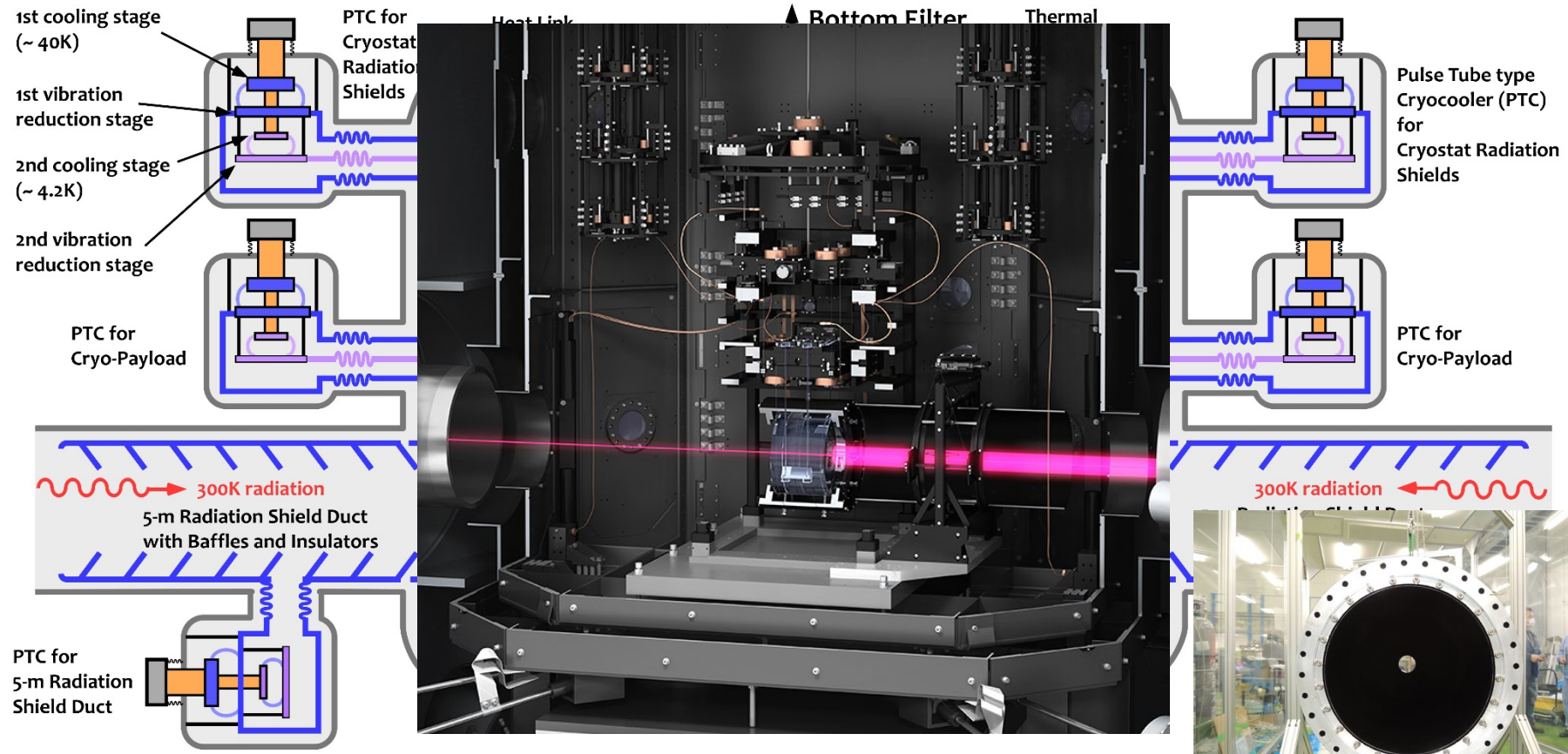
KAGRA Cryogenic System Outlook



KAGRA Cryogenic System

Cryostat Chamber Dimensions:
Diameter: 2.4 m, Height: ~4.3 m, Mass: ~ 12 ton
I/O shields Mass: 8K: ~455 kg, 80 K: ~590 kg

Cryocoolers: 2 stage Pulse tube type
Cooling power: 0.9 W at 4K (2nd)
36 W at 50K (1st)



Cryogenic payloads:
SOLBLACK coating
—low cost, can be coated on large area
—some magnetism, higher outgas

5-m Radiation shield Duct :
Diamond Like Carbon (DLC) coatings
—low outgas, no magnetism
—only small area, expensive

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Progress towards O4

Mid-size Baffle for PRMs/SRMs and Baffles in IFI/IMMT tank (T.Akutsu)

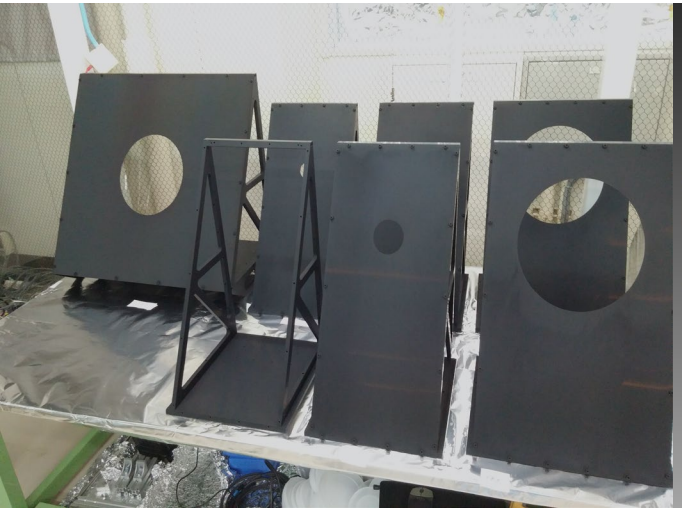
- **Stray light mitigation is key issue to clean the sensitivity curve and enhance the data quality by removing non-stational noise**

  → **Progress:**

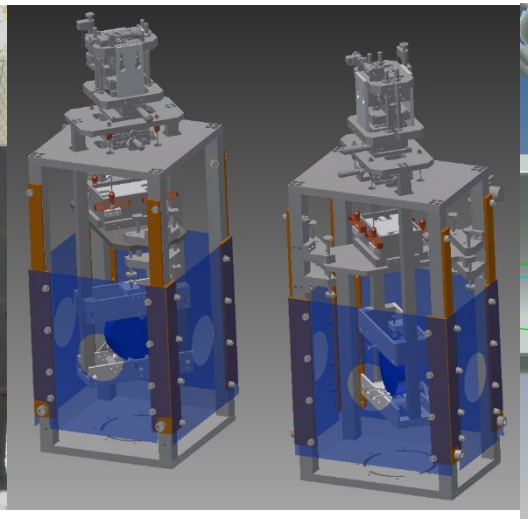
  (1) Preparation of mid-size baffles in 2019. We have a plan to install them according to the well aligned optical axis of PRFPMI configuration.

  (2) Installation of Baffles for IMC suspensions was completed.

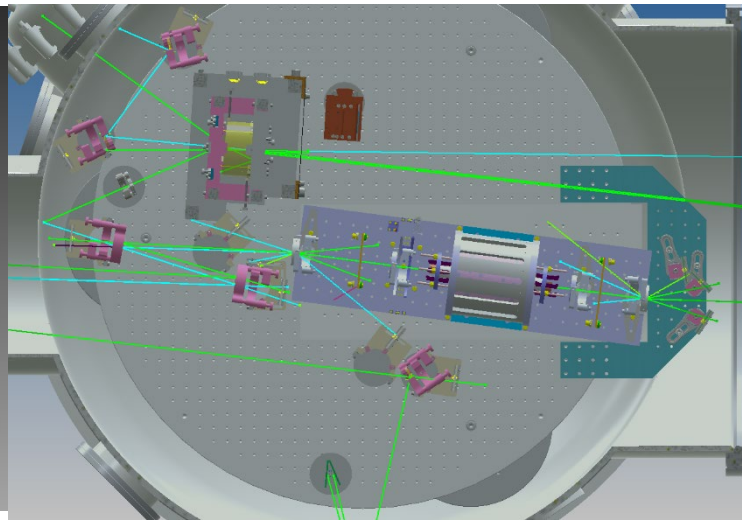
  (3) We have started to put support frames for baffle for Type-B/Bp suspensions. PR2 had a baffle now.



Mid-size baffles



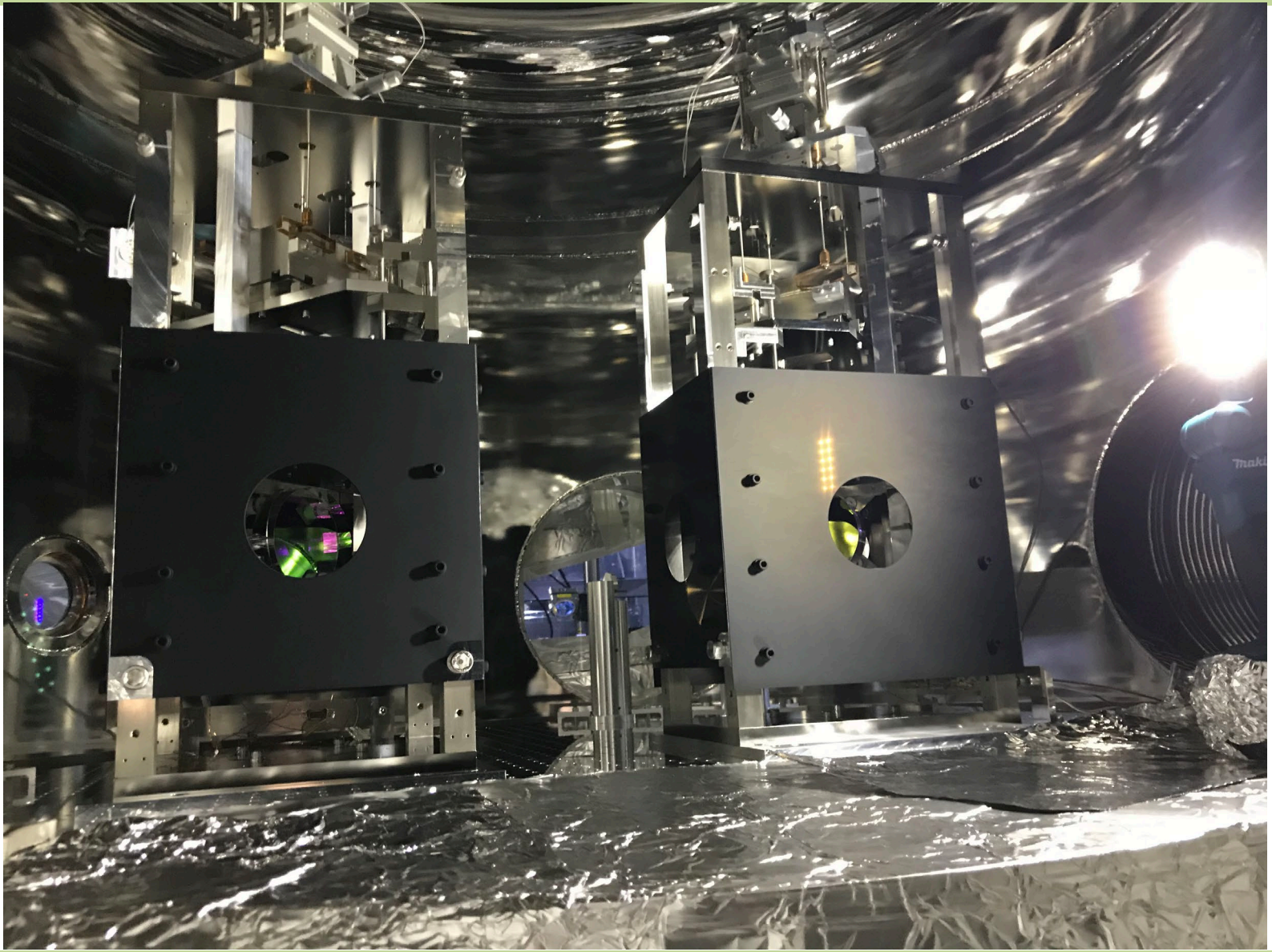
IMC baffles



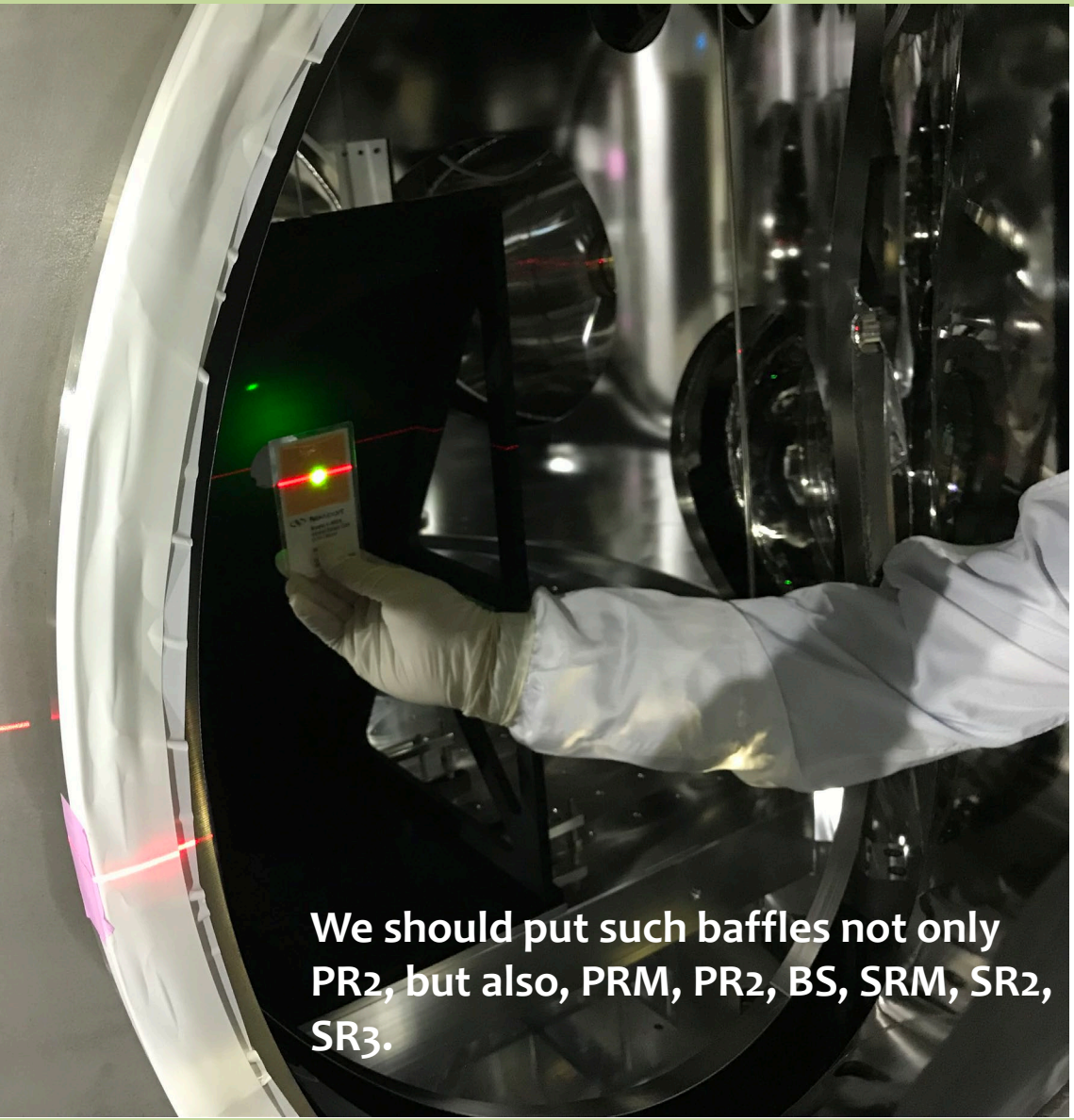
Optical components Position in IFI

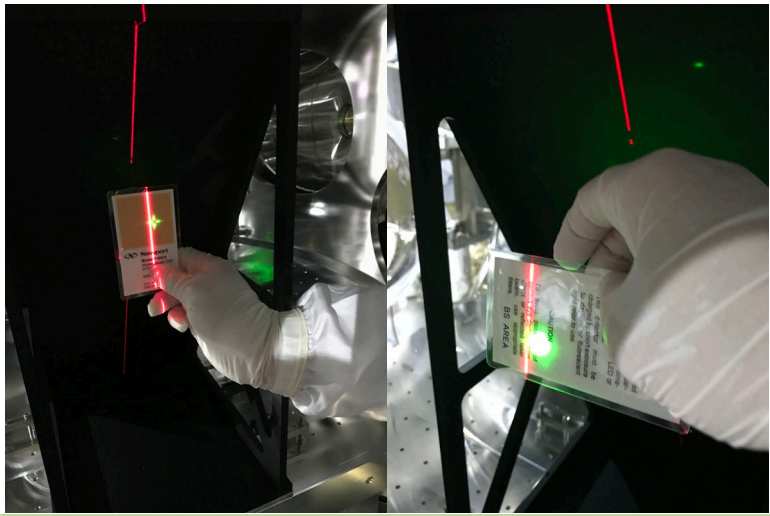
Baffles on Input Mode Cleaner MCi/o mirrors

(T.Akutsu)



Mid-size baffles for PR2 (T.Akutsu)





NAOJ Mitaka Control Room for KAGRA

Real-time control of KAGRA is possible from Tokyo! (T.Tomaru)

KAGRA control room
in the Kamioka site

KAGRA Mitaka
Control Room

Tokyo Area

Real-time Connection
(L2VPN on 1Gbps)

Oversea Collaborators

Other Updates for O4

Several upgrade items ongoing in parallel

1. New Intensity noise stabilization system (IOO/LAS: ongoing in Toyama U)
2. OMC reconstruction using low loss mirrors. (ASO: On going)
3. DGS/AEL upgrade for O5. (DGS/AEL: ongoing)
4. IMMT2 suspension frame modification to keep a clear beam path of transmitting IR and oplev. (AOS, VIS : done)
5. IFI height adjustment (SEO: done)
6. High power laser pre-preparation (LAS/IOO + Haino + Miyakawa). We plan to use it for O4. (Miyakawa/Haino+LAS+Toyama U : ongoing)
7. Optical simulation for birefringence effect (MIF: ongoing)
8. Water flow meter setting for Newtonian noise estimation (PEM: done)