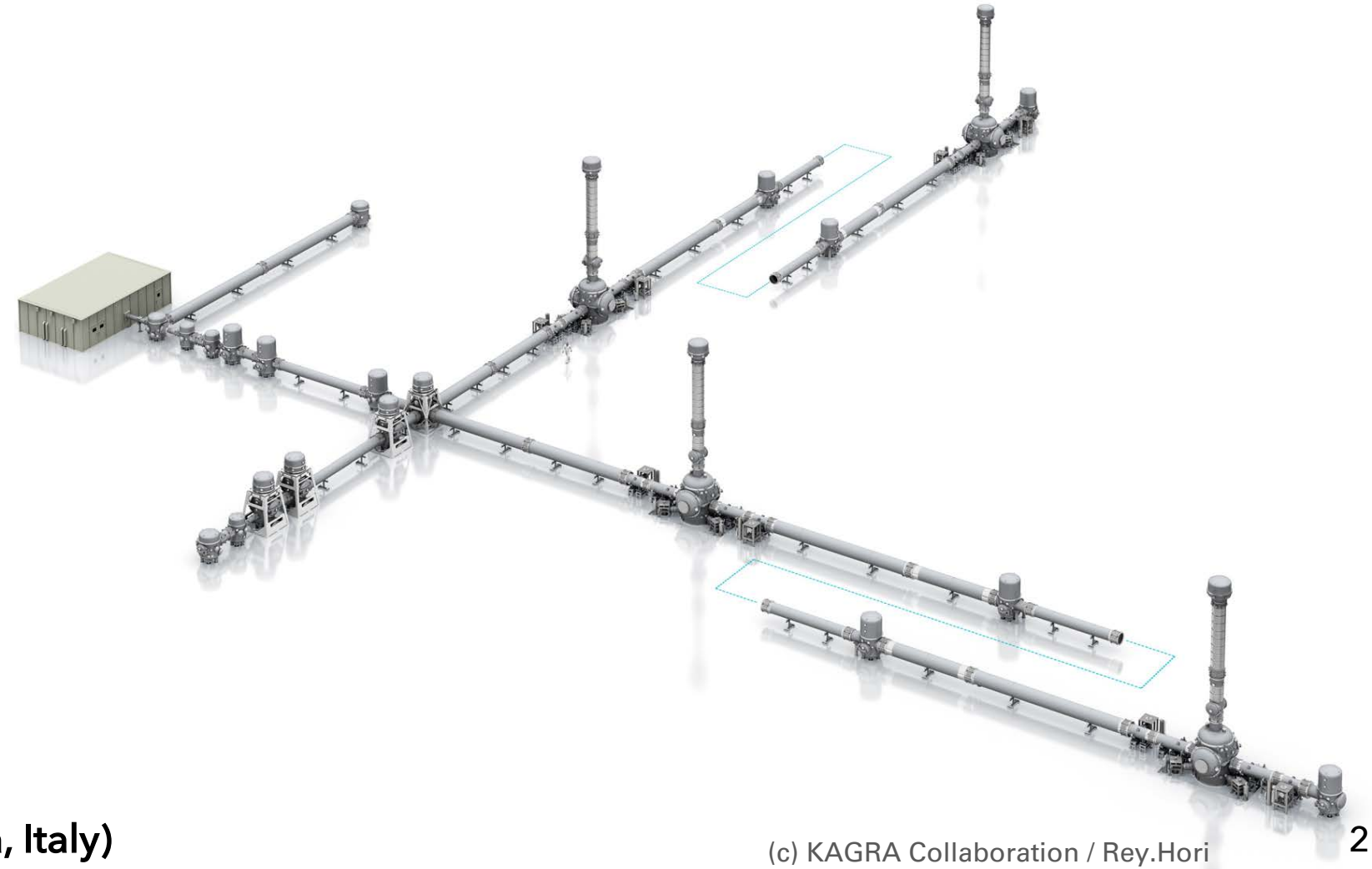
# KAGRA commissioning for O4

Tomo Akutsu (NAOJ)
for the KAGRA collaboration

# Contents

- Introduction
- Towards O4a
- Beyond O4a
- Summary



# Goal setup of the KAGRA interferometer

**Cryogenic system**
Cooling the four main mirrors down to ~23K.

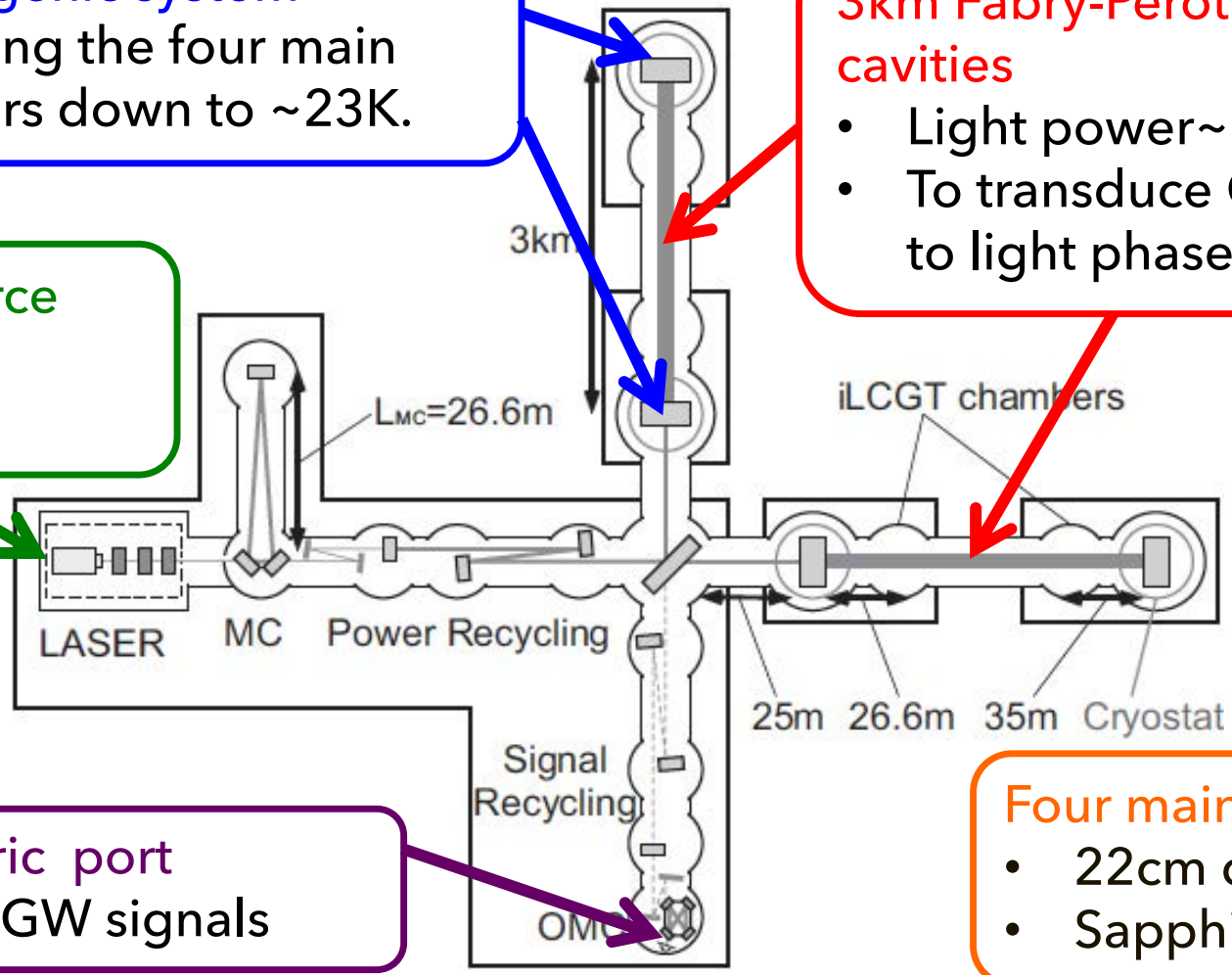
**3km Fabry-Perot optical cavities**
- Light power~ 400 kW
- To transduce GW signals to light phases

**Laser light source**
- 100~180W (planned)

**Vibration isolation system**
- Isolating mirrors from vibrations.

**Anti-symmetric port**
- To extract GW signals

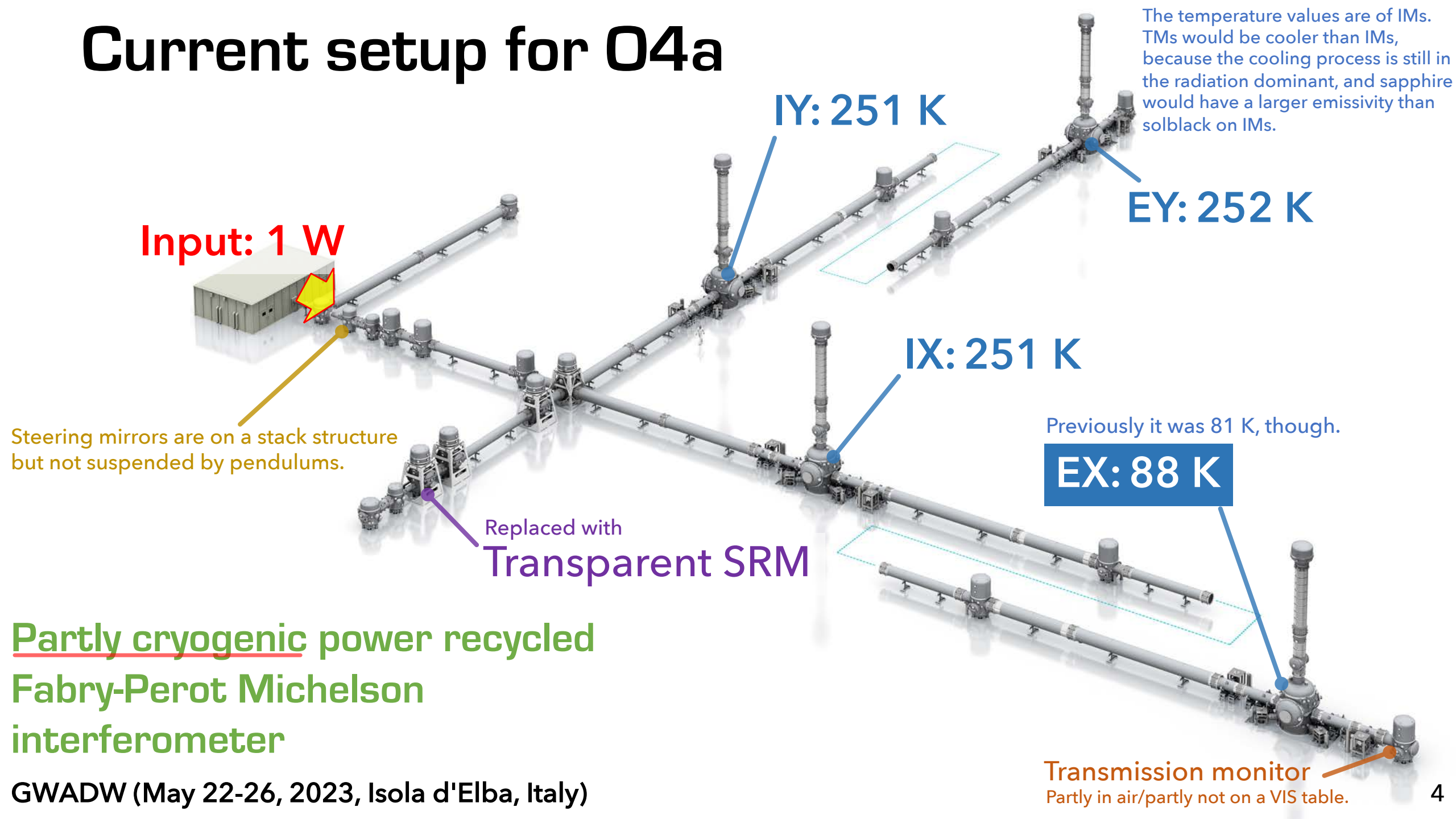
**Four main mirrors**
- 22cm diameter
- Sapphire





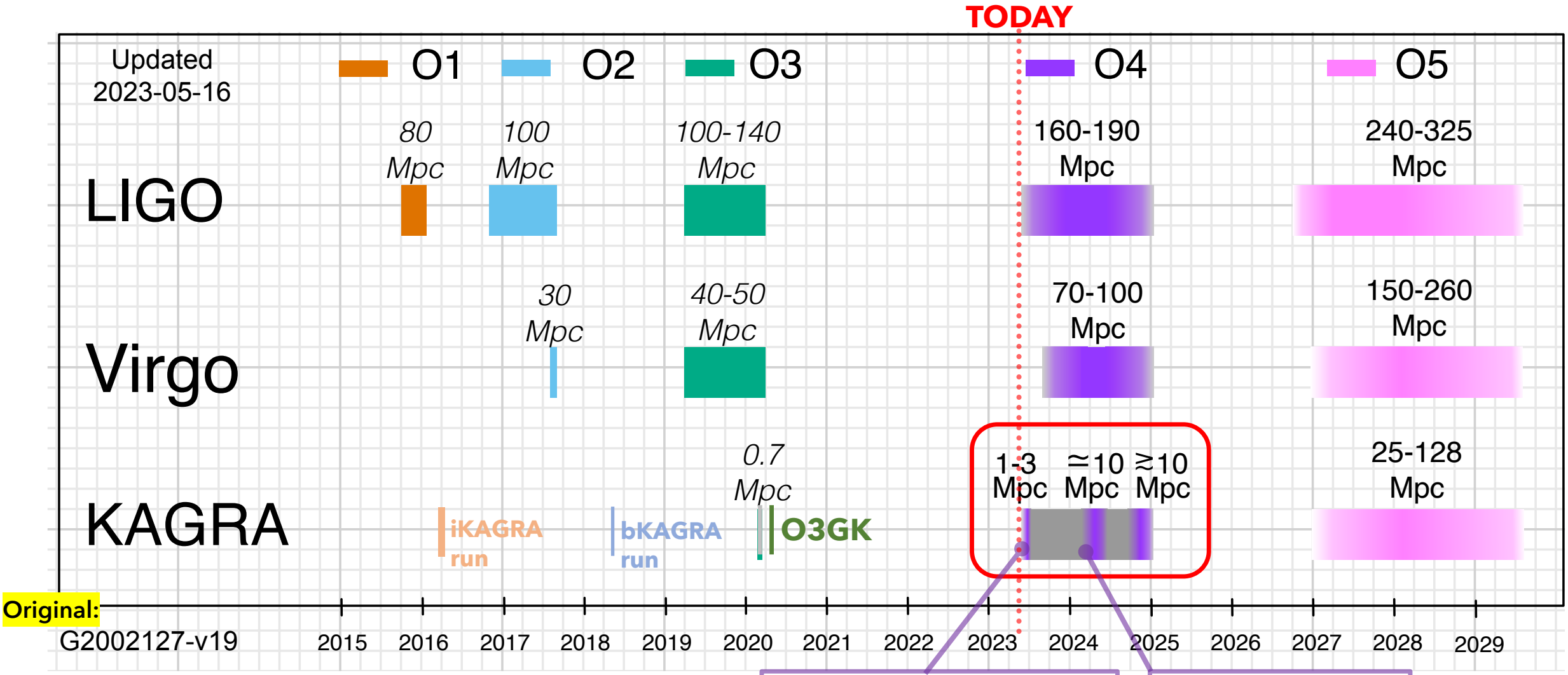

Original: K. Somiya et al., Class. Quantum Grav. 29, 124007 (2012)

# Current setup for O4a




**Partly cryogenic power recycled Fabry-Perot Michelson interferometer**

# KAGRA's run history and plan



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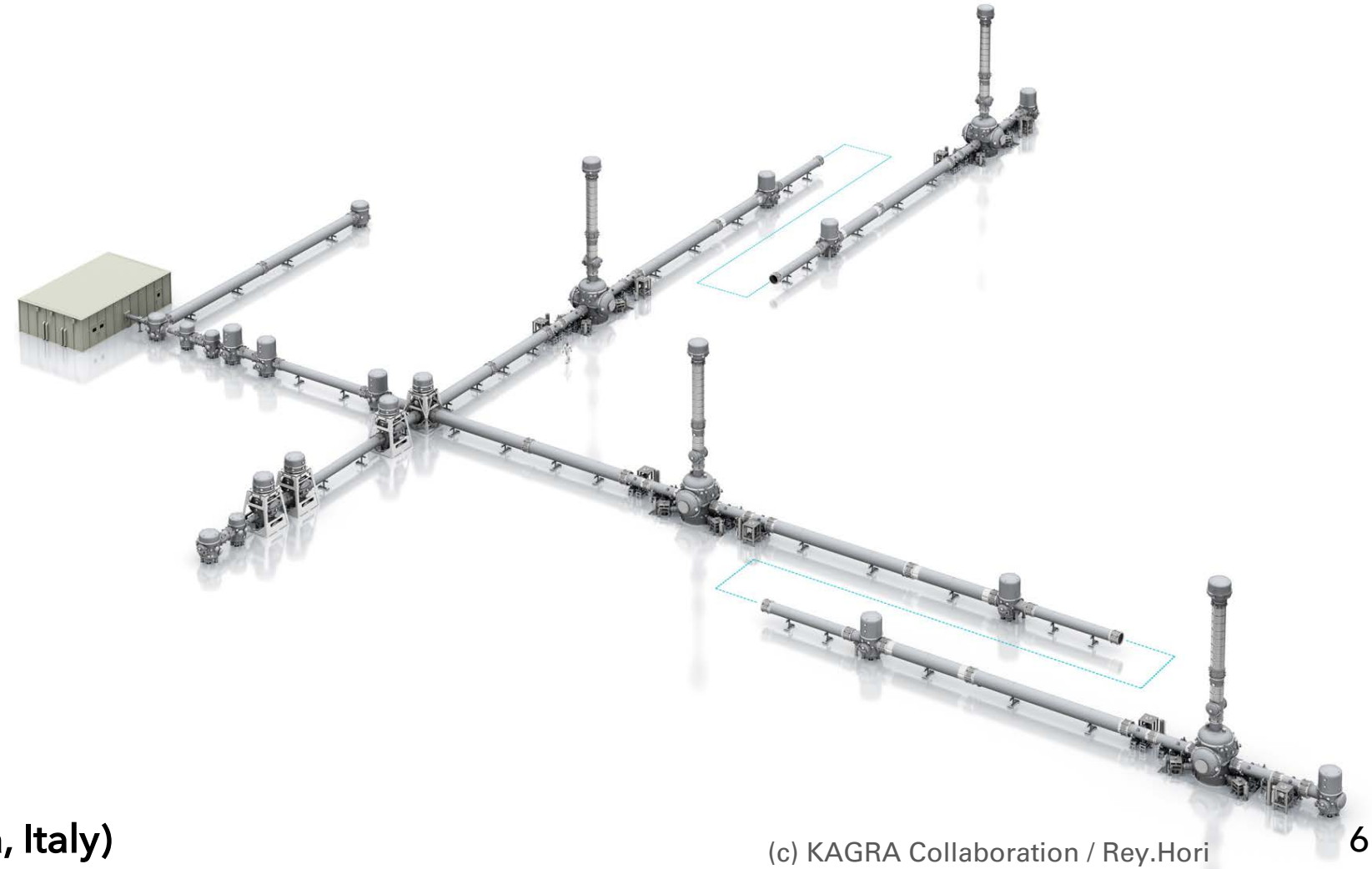


# Revisit: O3GK commissioning issues

## *Sensitivity*

- "Time-up" for satisfactory noise hunting before starting O3GK

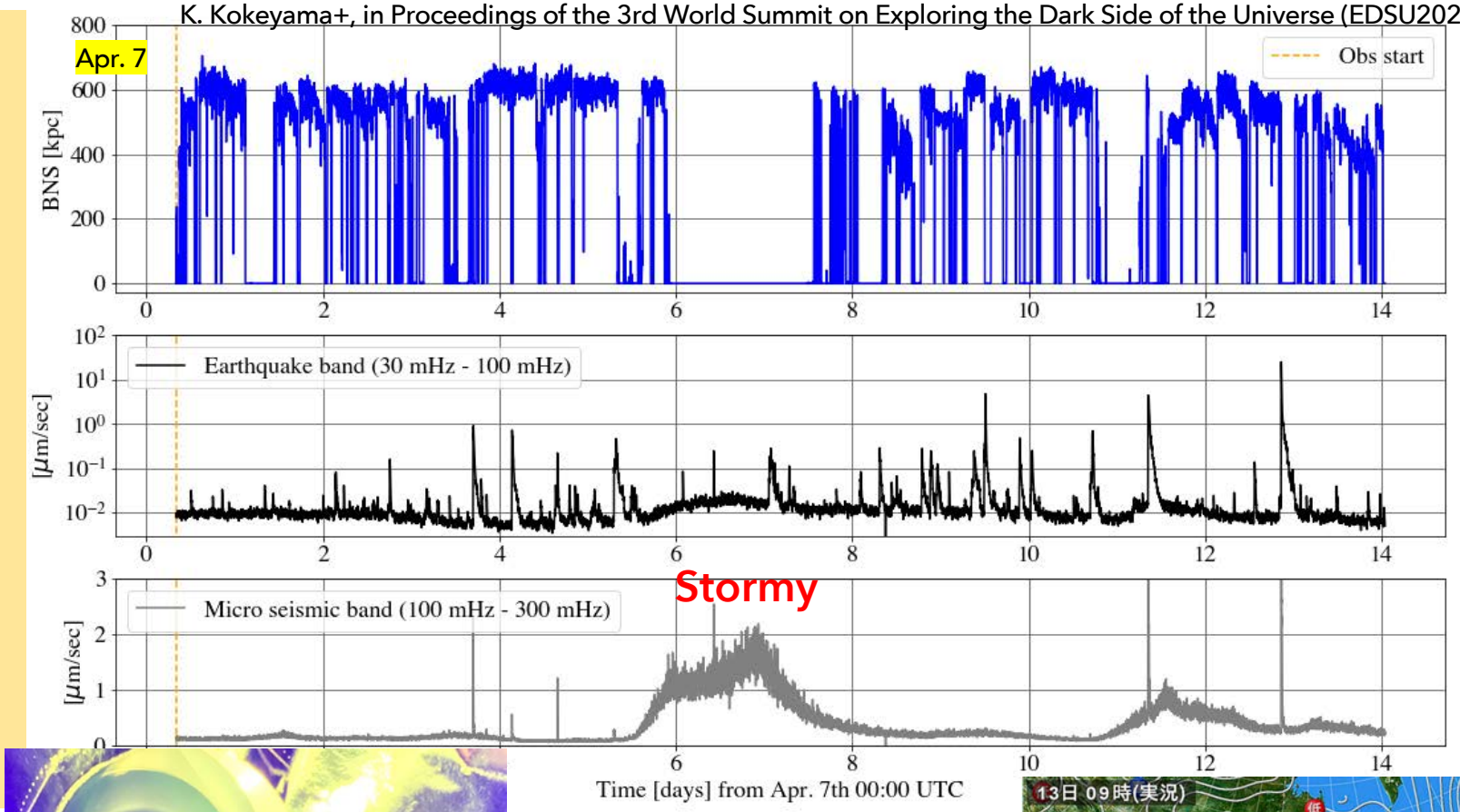
## *Stability / repeatability*

- BNS range drifting
- Frequent lock loss
- Lock acquisition failing due to storms

## *Reliability*

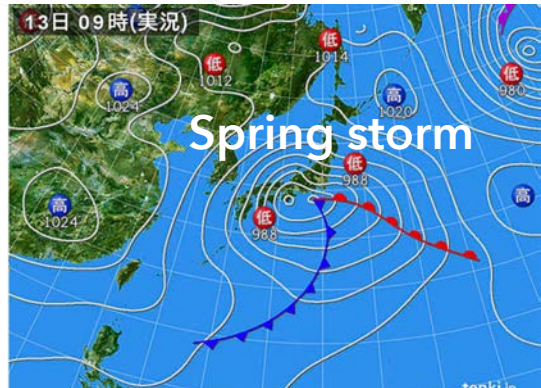
- Frost on cryogenic optics → gave up cooling for O3GK
- Unexpected power loss ← beam clipping(?), dead OMC-PD, unused SRM…

K. Kokeyama+, in Proceedings of the 3rd World Summit on Exploring the Dark Side of the Universe (EDSU2020)



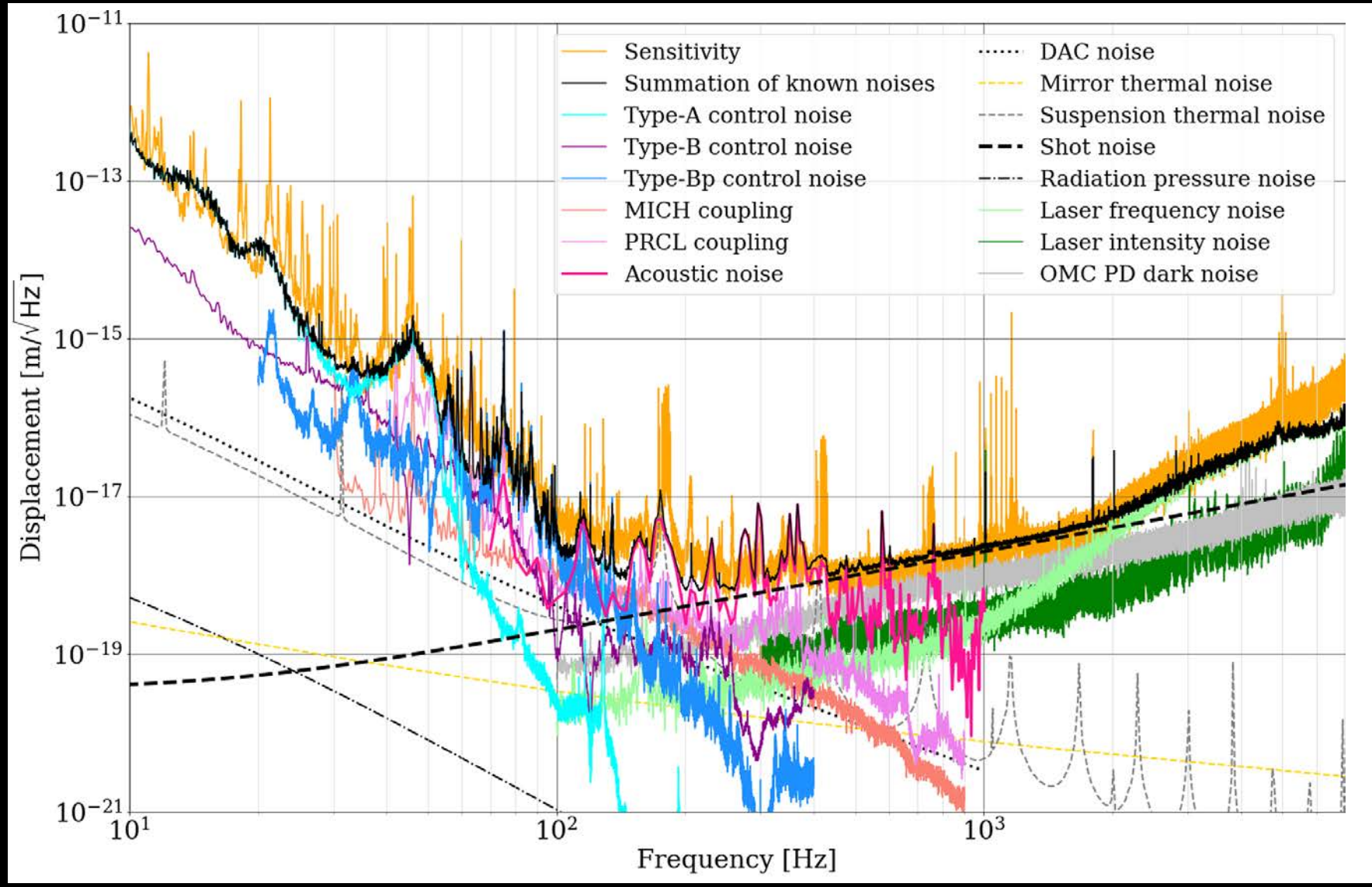


http://klog.icrr.u-tokyo.ac.jp/osl/?r=5663



# Noise budget estimation right after O3GK

KAGRA collaboration, PTEP ptac093 (2022)

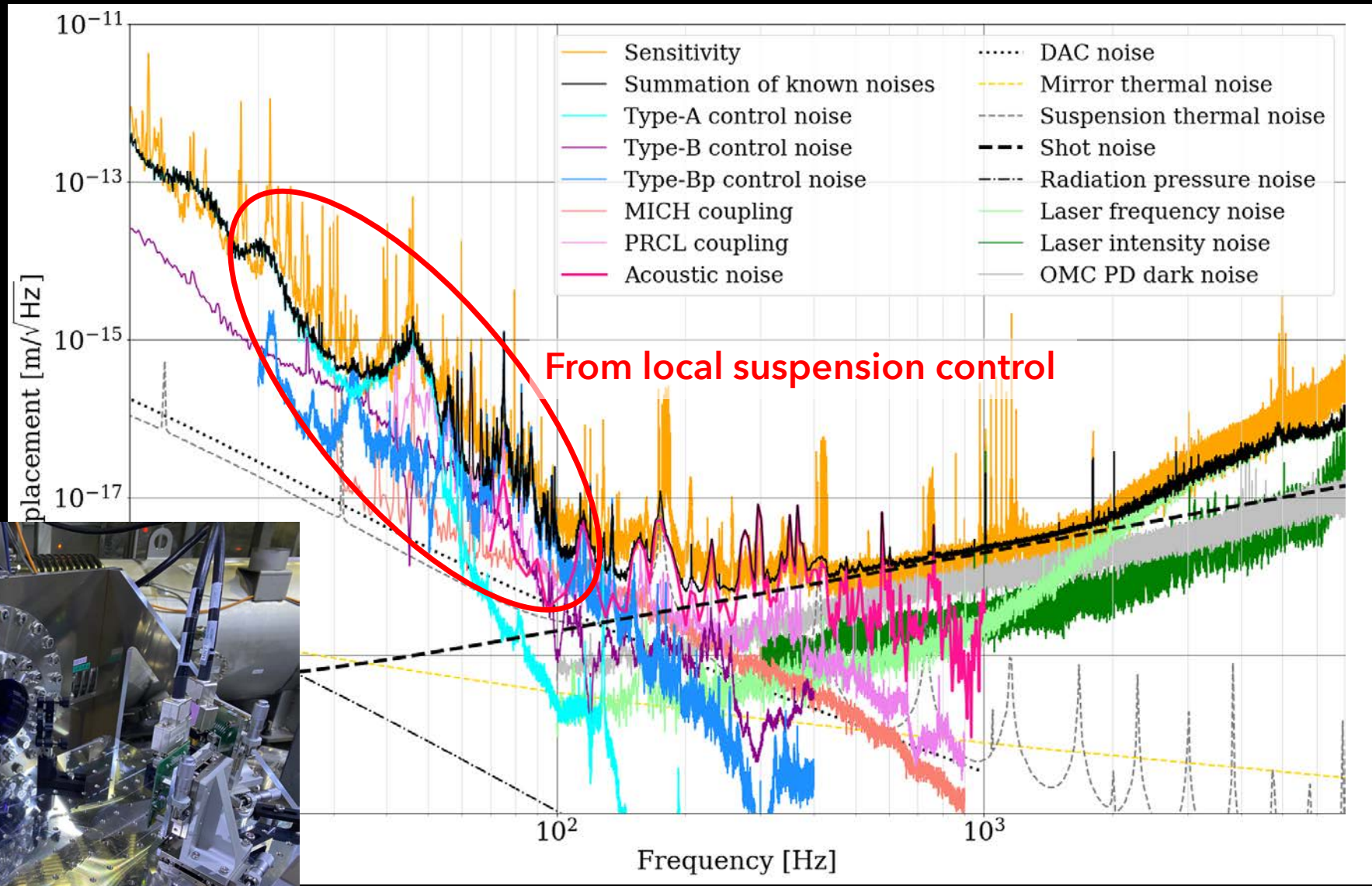


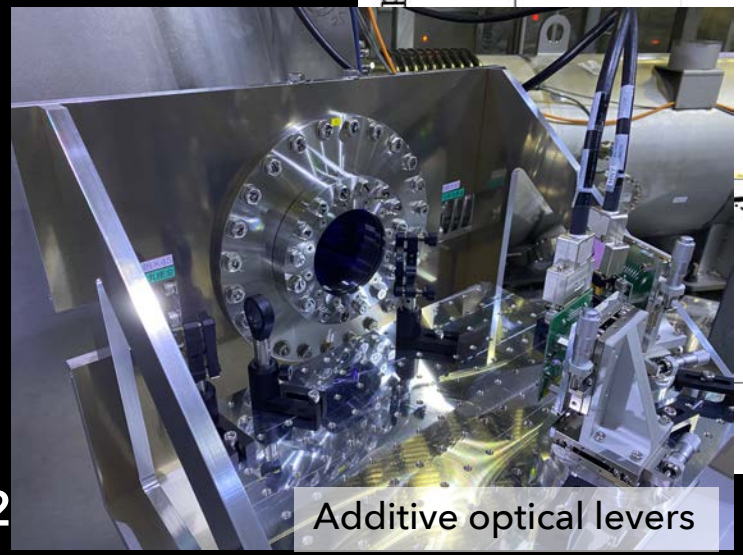
# Upgrading vibration-isolation systems

***Not to degrade the GW sensitivity***

KAGRA collaboration, PTEP ptac093 (2022)

- Inertial damping for main mirror suspensions
- Reduced electronic noise contaminating in the suspension local control
- Damped "overlooked" resonances with improved local sensors/actuators and new optical levers
- Decoupled local DoFs at hardware level as much as possible



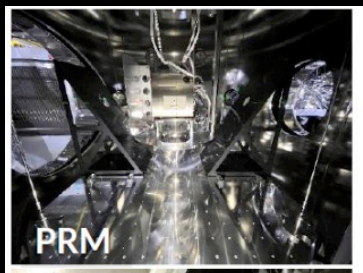



Additive optical levers

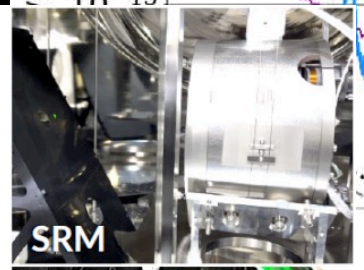
# Further stray-light mitigation

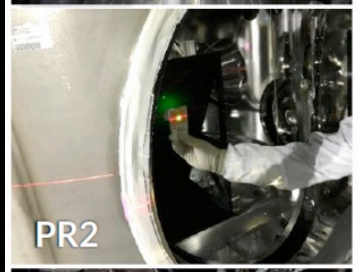
KAGRA collaboration, PTEP ptac093 (2022)

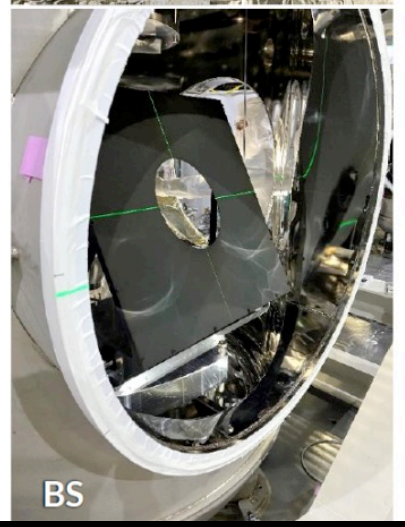
- Installed 14 mid-size baffles around the corner station
- Resolved a crowded optical path (to ISS)
- Additional optical shields
- Additional beam dumps



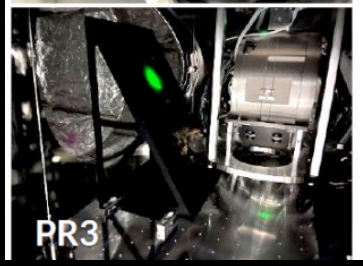


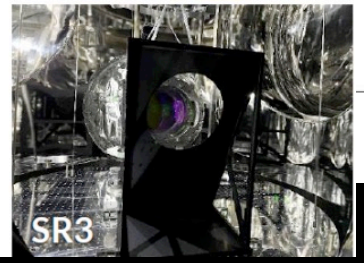




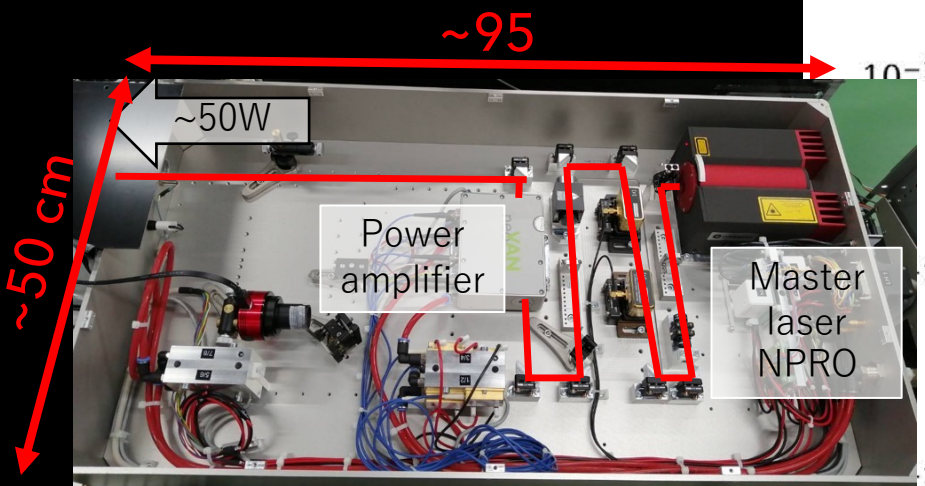


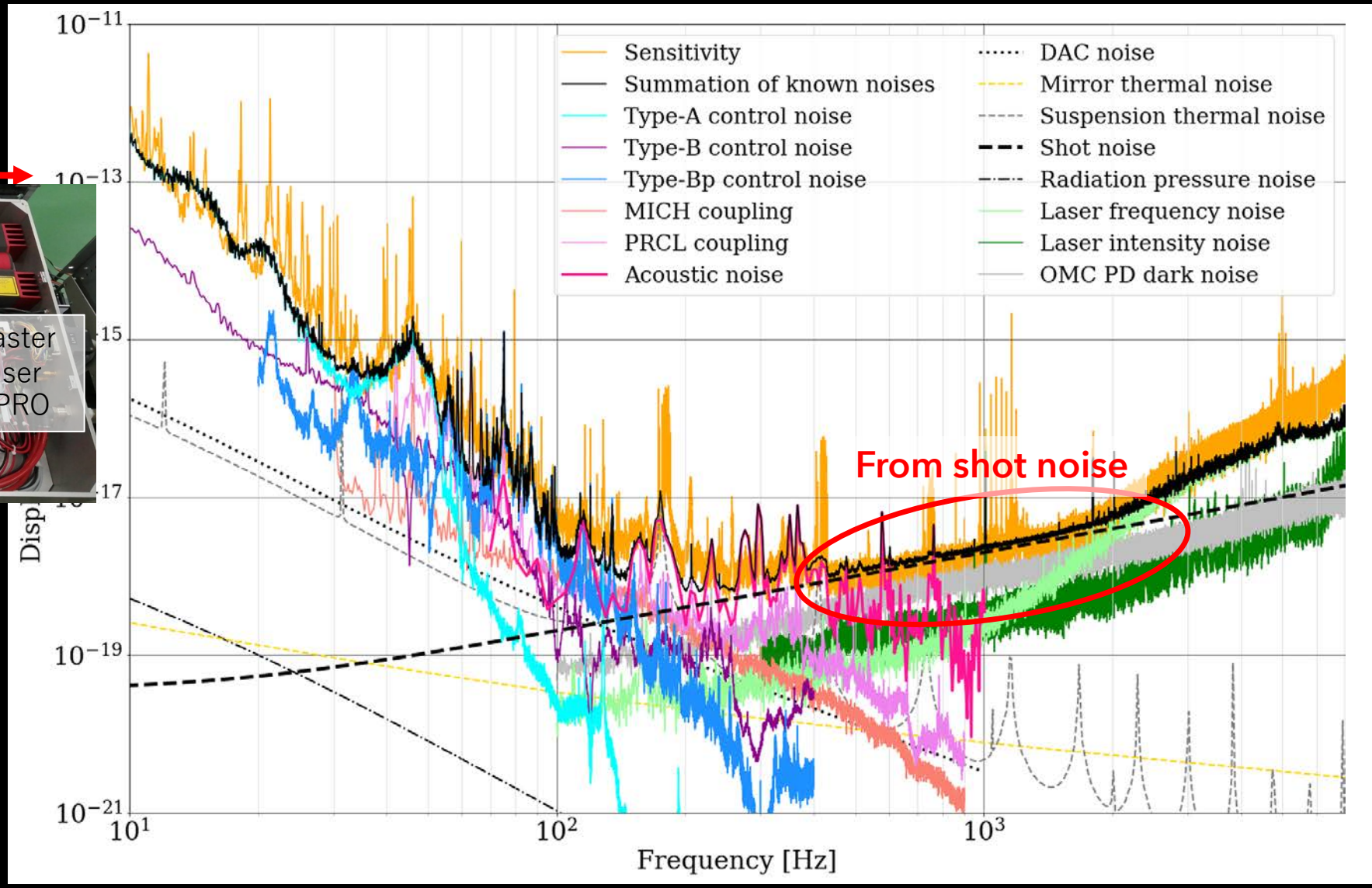



# Preparation for higher power input

KAGRA collaboration, PTEP ptac093 (2022)

- Higher power laser source is now ready (not yet replaced)



# Better stability

## *Local damping improvement*

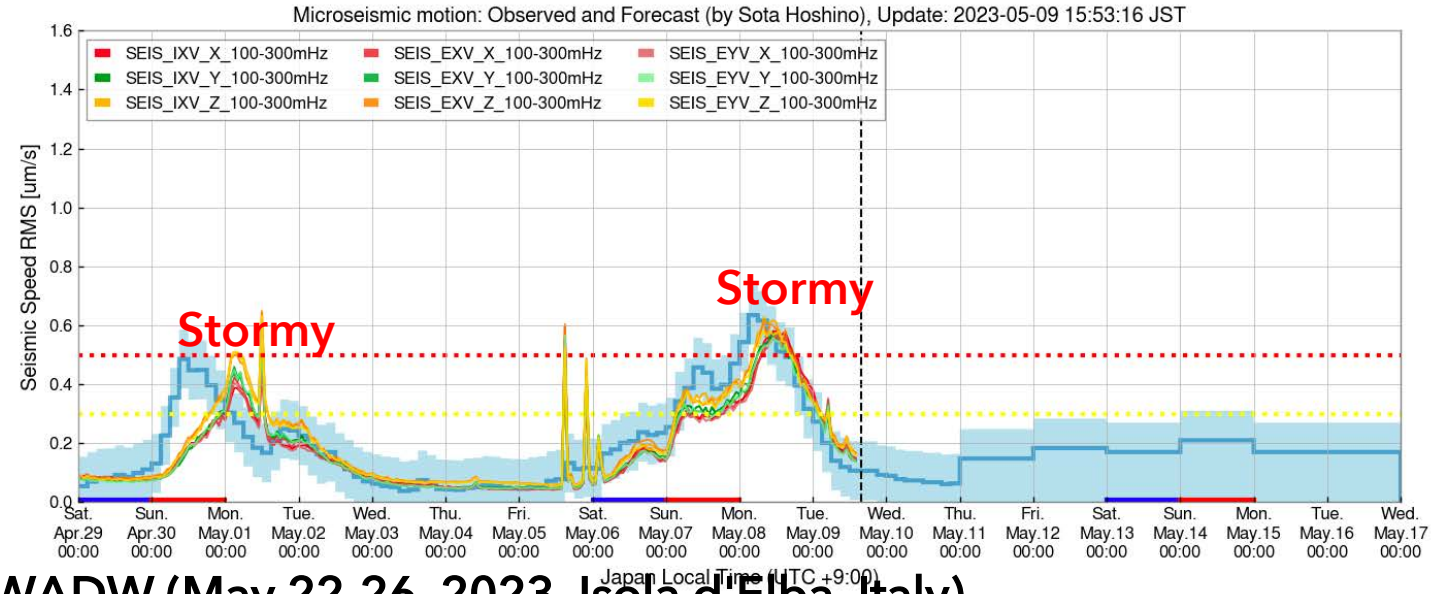
- Now PRFPMI can be maintained even in somewhat stormy days.

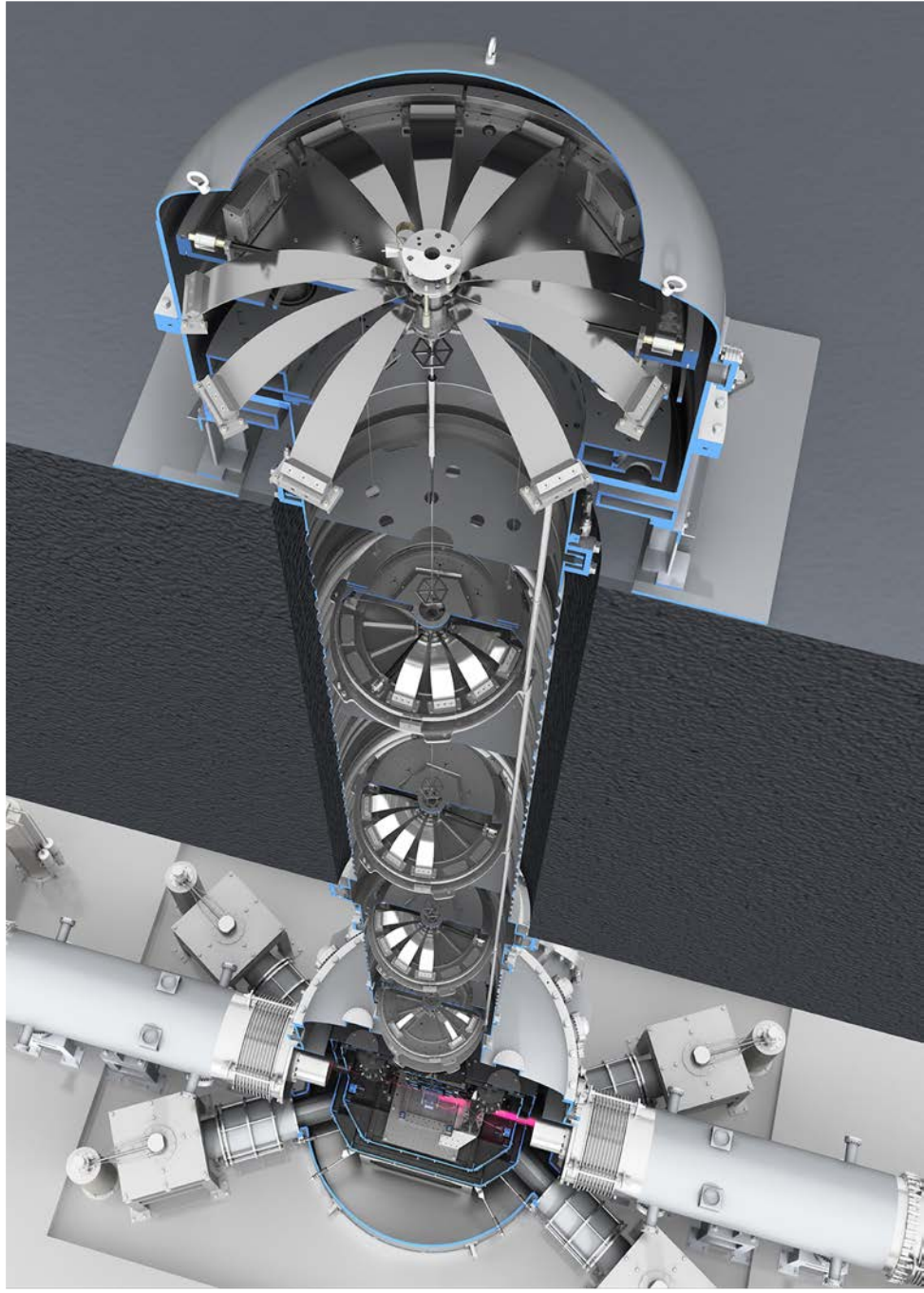
## *Alignment-sensing and control (ASC)*

- Took time for wave-front sensing (WFS) in a strategic way; now WFS can be implemented for some global DoFs; drastically improved the contrast fluctuation.
- In addition, some noise structures and noise floor got better in the sensitivity curve.

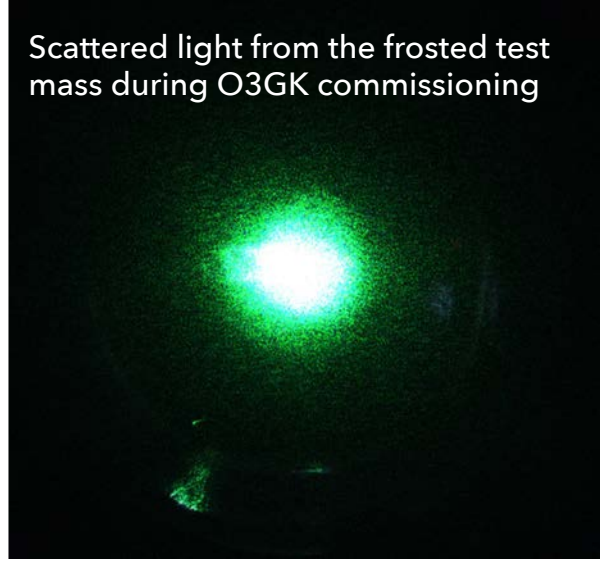
## *Doppler phase noise cancellation*

- For auxiliary green laser paths; now stable lock acquisition is possible even in somewhat stormy days.



# Better reliability


Scattered light from the frosted test mass during O3GK commissioning

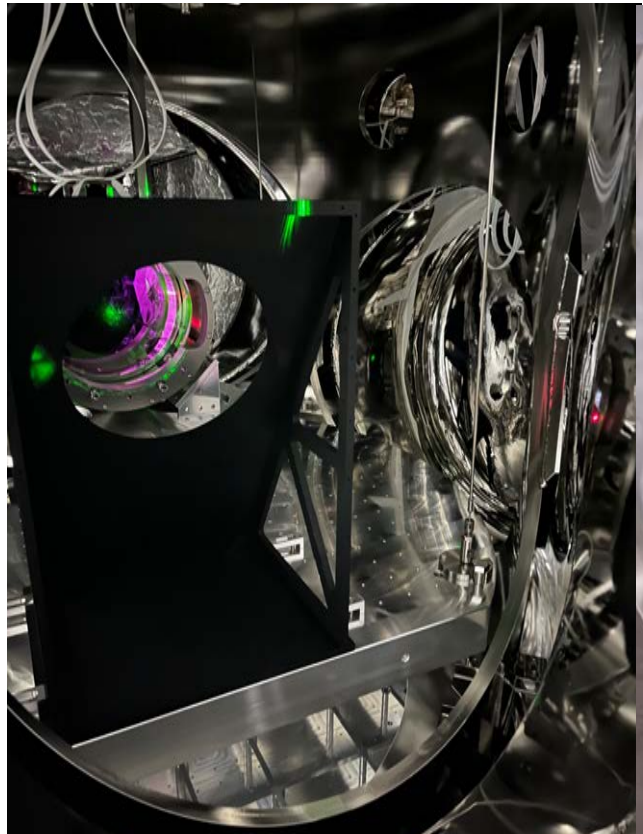
*To overcome frosting* *Unit test: cooling procedure studied at IYC: Nov. 2020-Mar. 2021*

- Better vacuum pressure with additional pumps
- Leak check allover the vac chambers thoroughly; took long time to complete.
- Monitors for partial pressures of remnant components
- Defrost heaters
- Re-consider the cooling procedure

1 of 4 main mirrors has been at ~80-90 K without frosting for ~1 yr.

*To avoid beam clipping/mis-centering*

- Adjusted heights of suspended mirrors basing on measurement for global balancing
- Reliable beam spot target plates
- Additional beam-position monitors/references
- Expanded adjustable height range for the main mirrors when cooled down.
- Implemented beam position control

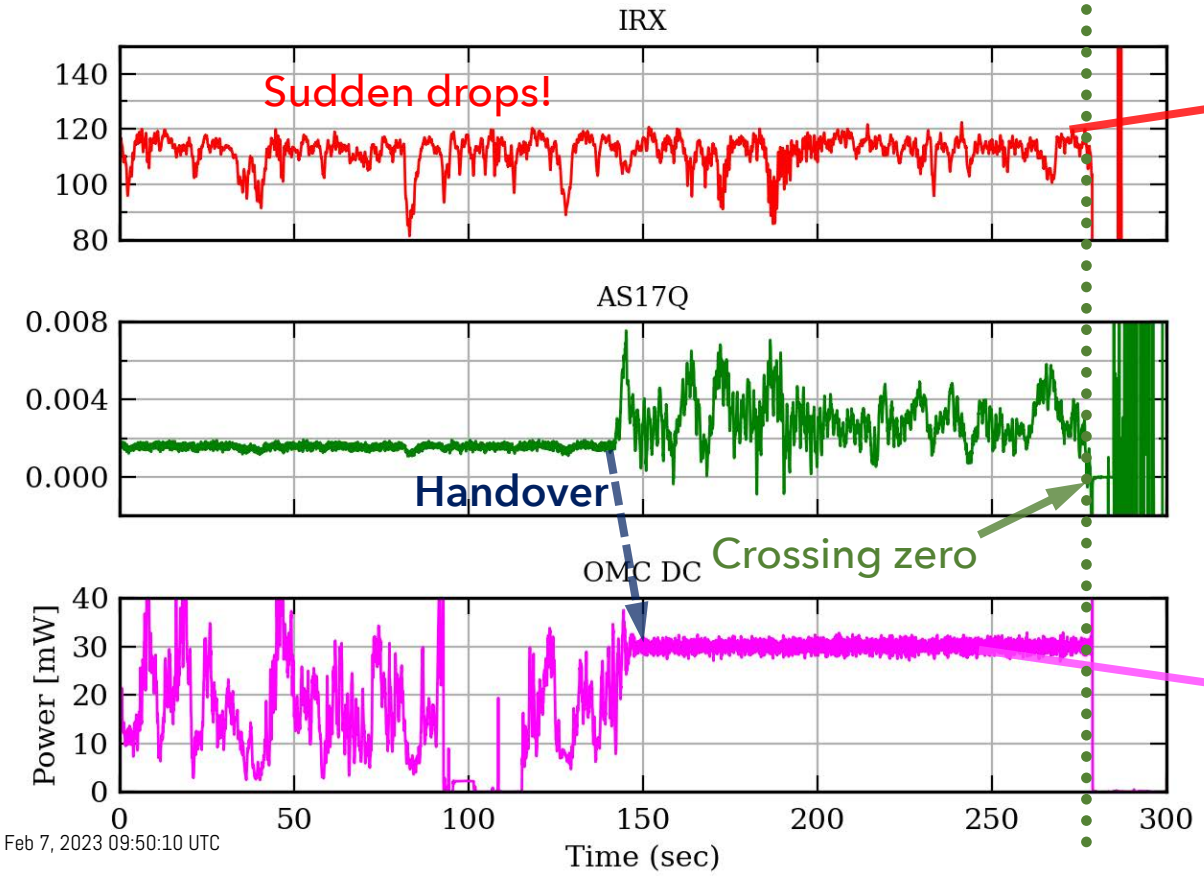


Unlike O3GK, we are not facing:
- Unwanted beam clipping, and
- Superius *severe* birefringence(?) effects that degrade WFS reliability.

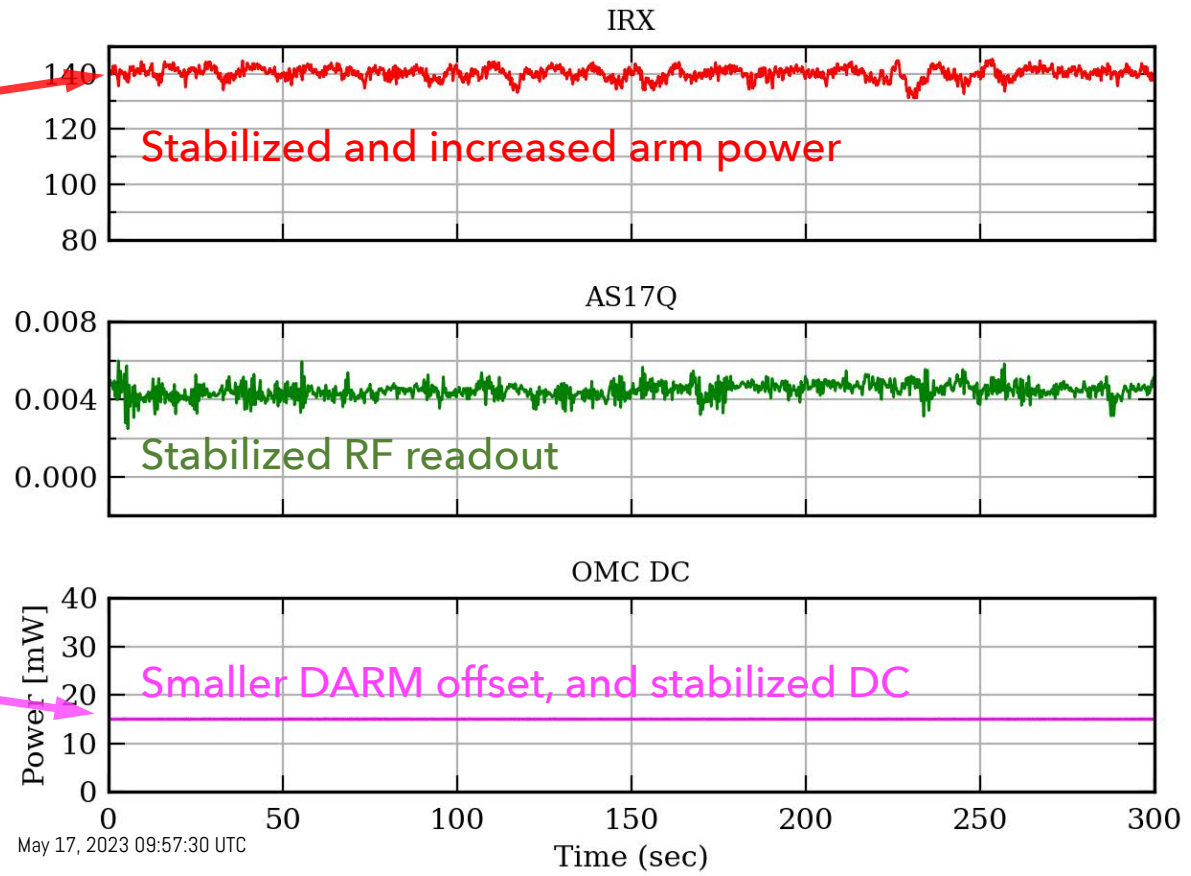
# Alignment sensing and control

## 2023 Feb

Ref: https://klog.icrr.u-tokyo.ac.jp/osl/?r=23871




## 2023 May




Data access via pastavi

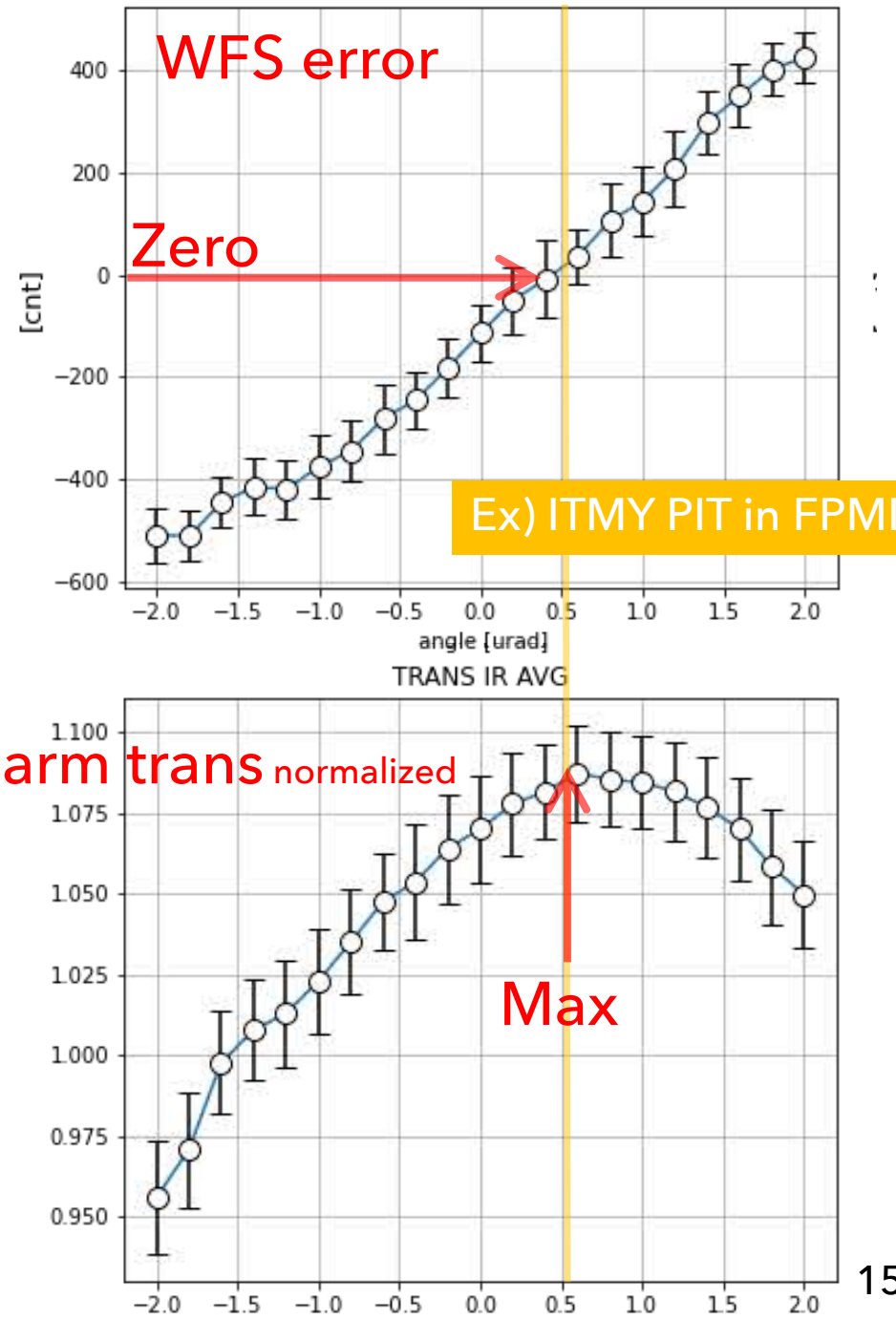
- Internal laser power is drastically stabilized; and increased.
- Better AS contrast allows to do handover with smaller DARM offset.

→ Now ready to increase the input power from 1 W for O4b!

# Birefringence???

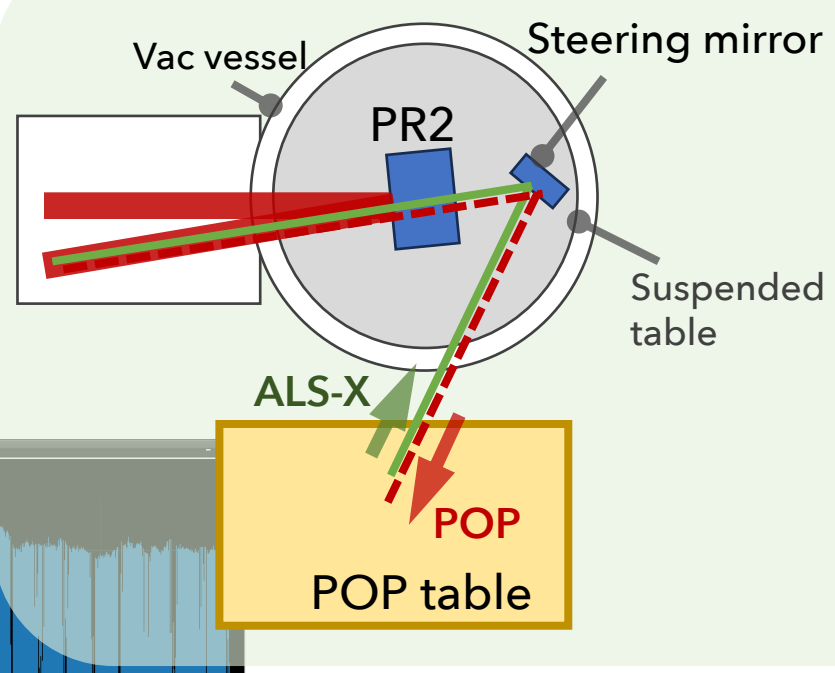
- Birefringence of the sapphire mirrors was thought to be a severe problem for WFS in KAGRA; say, WFS signal would offset depending on the beam spot position on the sapphire mirror.
- But experiments revealed ***less impact*** →
  - the WFS error crosses zero when the cavity alignment comes around the best.
- Other unwanted effects hidden so far?

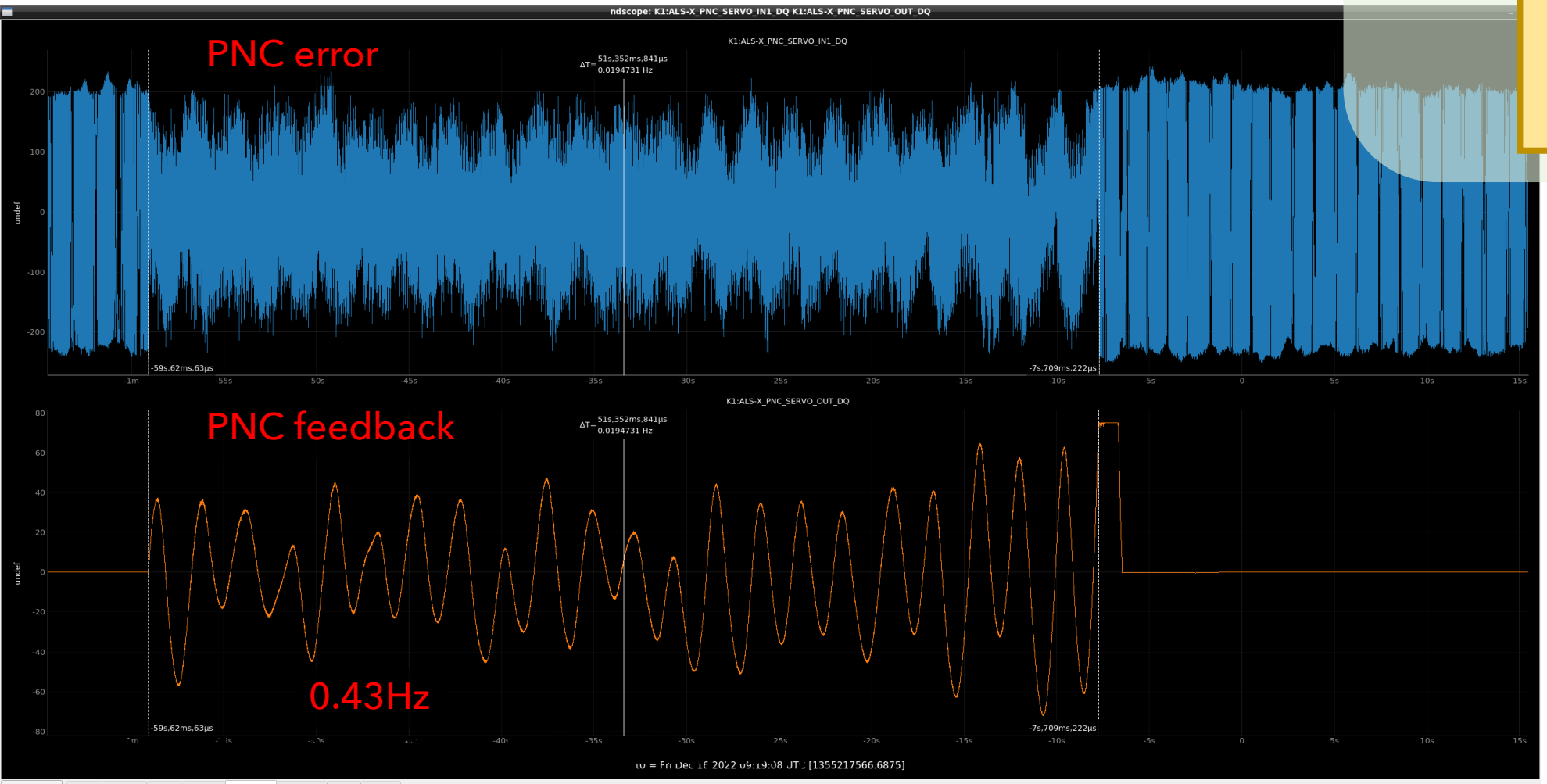
Picked up from C. Hirose et al., JGW-G2314755



# Doppler phase noise cancellation

- The suspended table seems not well damped. →
- Phase noise on ALS path due to the movement of the in-vac steering mirror on the suspended table.
- Phase noise cancellation implemented for ALS-X and Y.




https://klog.icrr.u-tokyo.ac.jp/osl/?r=23254
https://klog.icrr.u-tokyo.ac.jp/osl/?r=23271

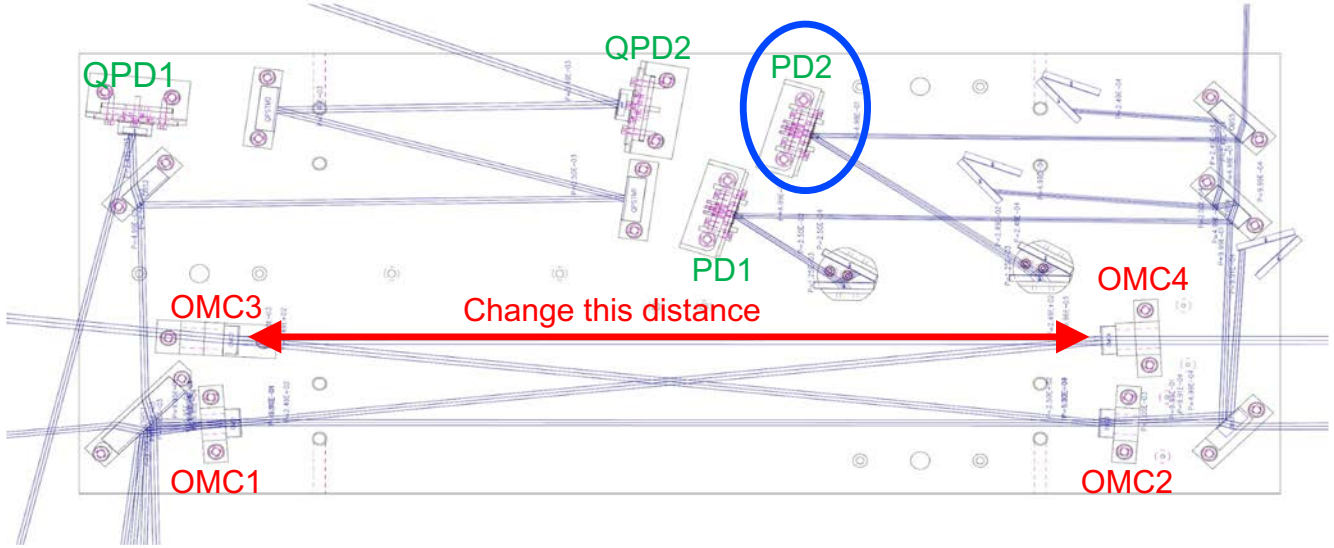
# Avoid unnecessary power loss

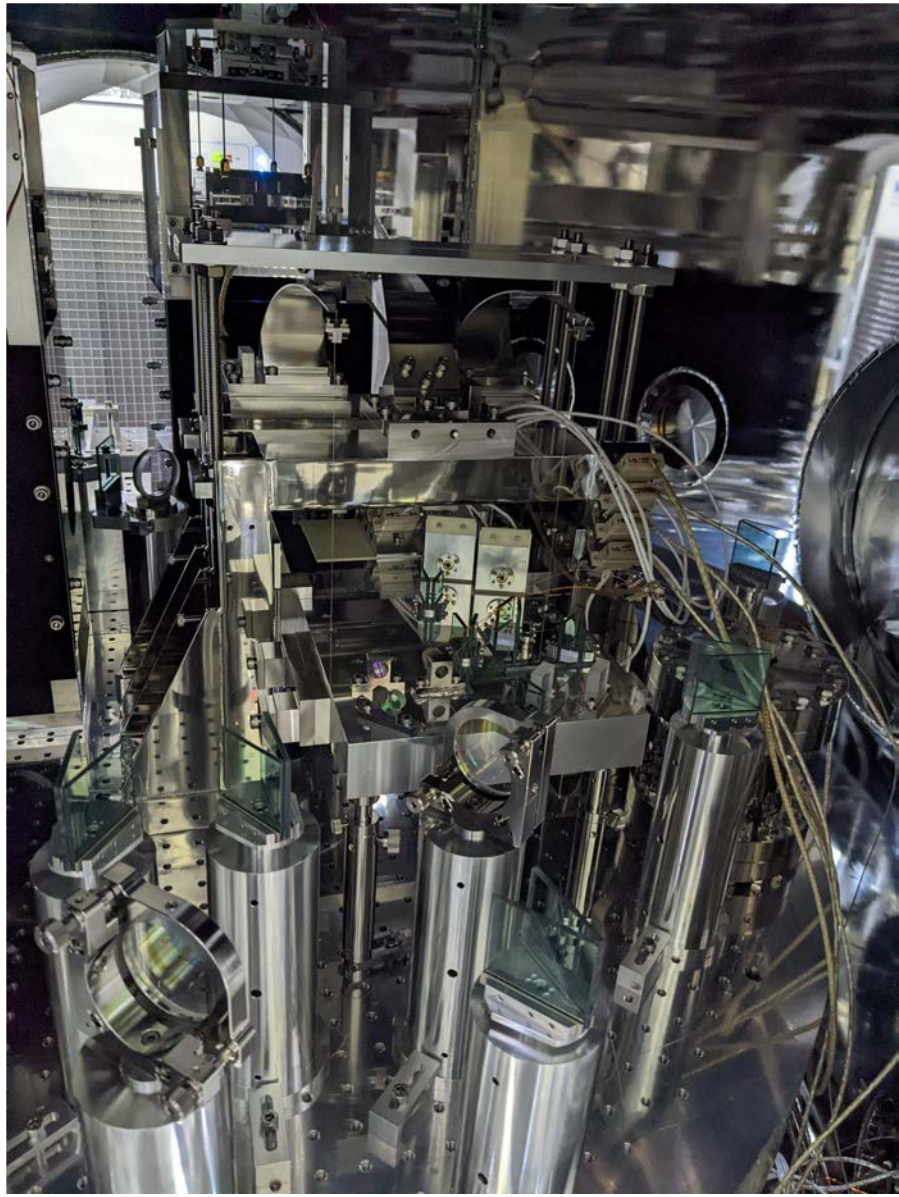
*Transparent SRM*

- During O3GK, 30% trans SRM was used, but not doing RSE.
- It has been replaced with a transparent mirror, as we may give up to do RSE during O4(?).

*Output mode cleaner (OMC) upgrade*

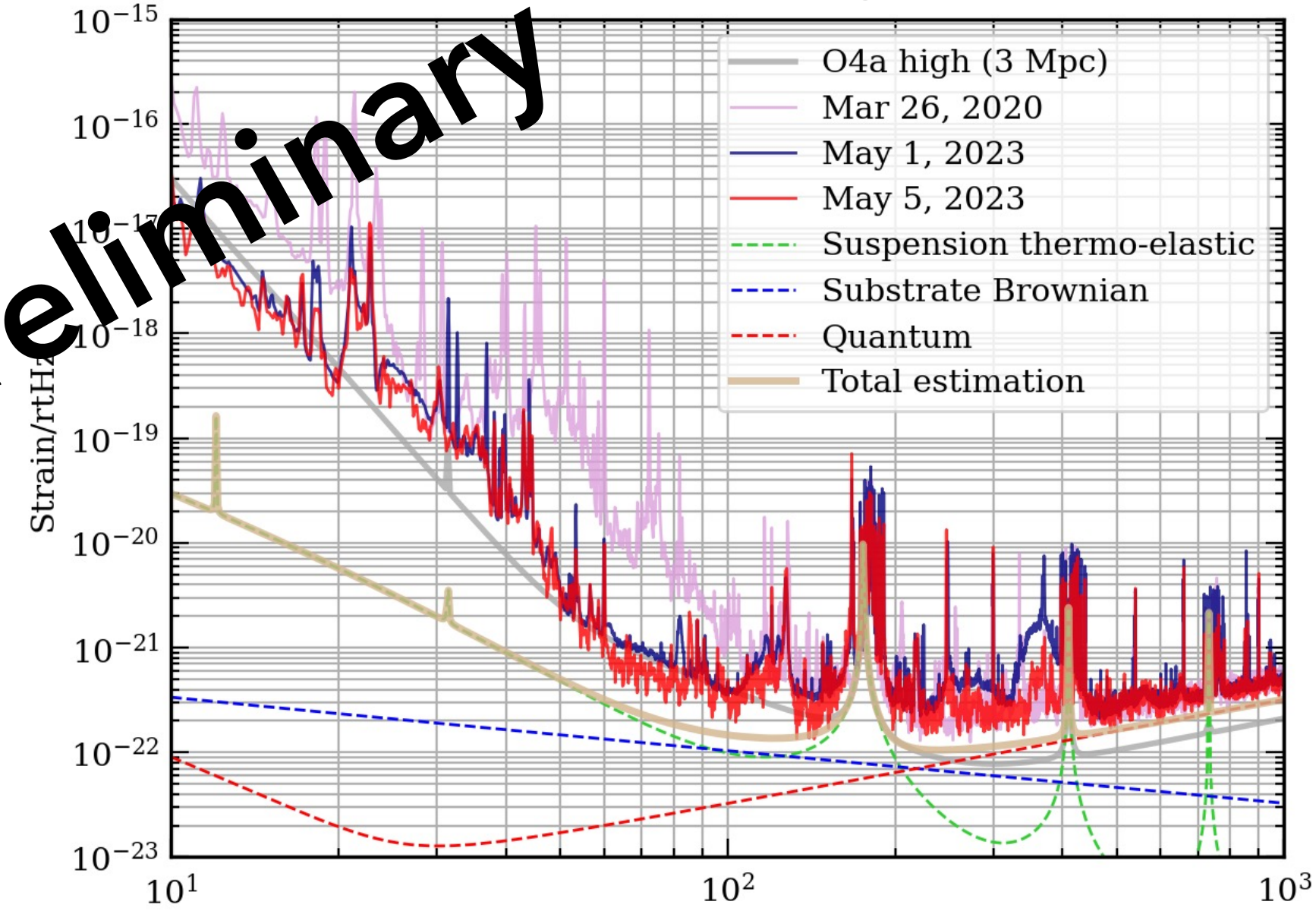
- Higher transmissivity: 80% -> 95%
- Fix the broken DCPD -> Double the GW signal
- Revise absolute length



# The latest stable sensitivity

Goal sensitivity by Michimura
Theoretical curves by Komori



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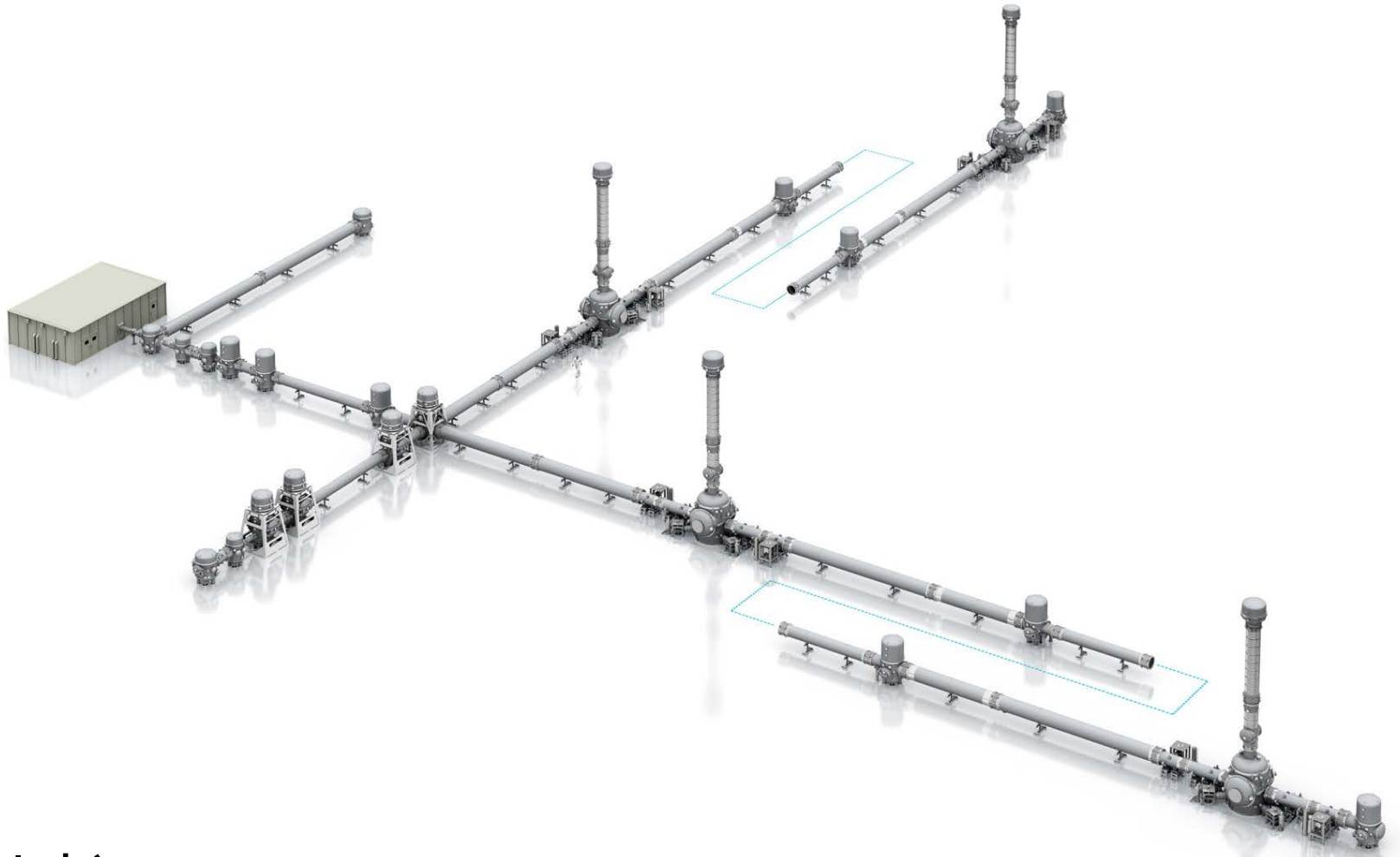


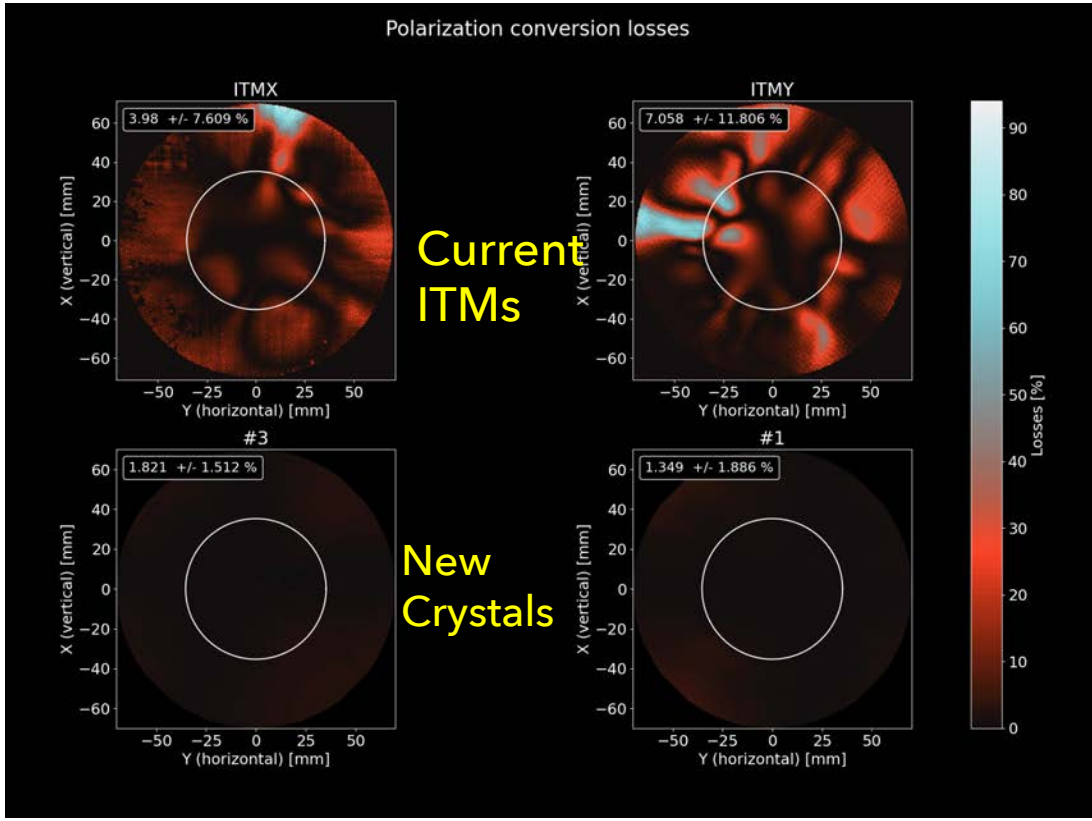
# Towards re-joining O4...

## *The strategy is under discussion*

- Open some chambers to do additional in-vac works?
- Turn on all the coolers for all the main mirrors?
- Replace with the new higher power laser source and input ~50W?
- Implement better ASC?
- Optimize more the local control?
- (RSE?)

# For O5: to replace ITMs -> Matteo Leonardi's talk on Fri

- Birefringence in the sapphire crystals will be a problem in the current KAGRA mirrors.
- Search for better crystals was carried out.
- Found that crystals from a Korean company have better birefringence homogeneity compared to the currently installed TMs and comparable absorption.
- We are in a process of making new ITMs with crystals from this company.
- Hopefully, we can install a new set of ITMs before O5.



# Summary

- KAGRA will join O4a from 24 May to 21 June 2023, and come back to O4 in the spring of 2024 with the better sensitivity.
- Now better sensitivity than that of O3GK is achieved.
- 1 of 4 main mirrors has been at ~80 K for ~1 yr without frosting.
- Despite using the same mirrors as of O3GK, ASC works mostly well; no *severe* birefringence effects.
- Upgrade plan is under discussion. New ITM preparation is in progress for O5.