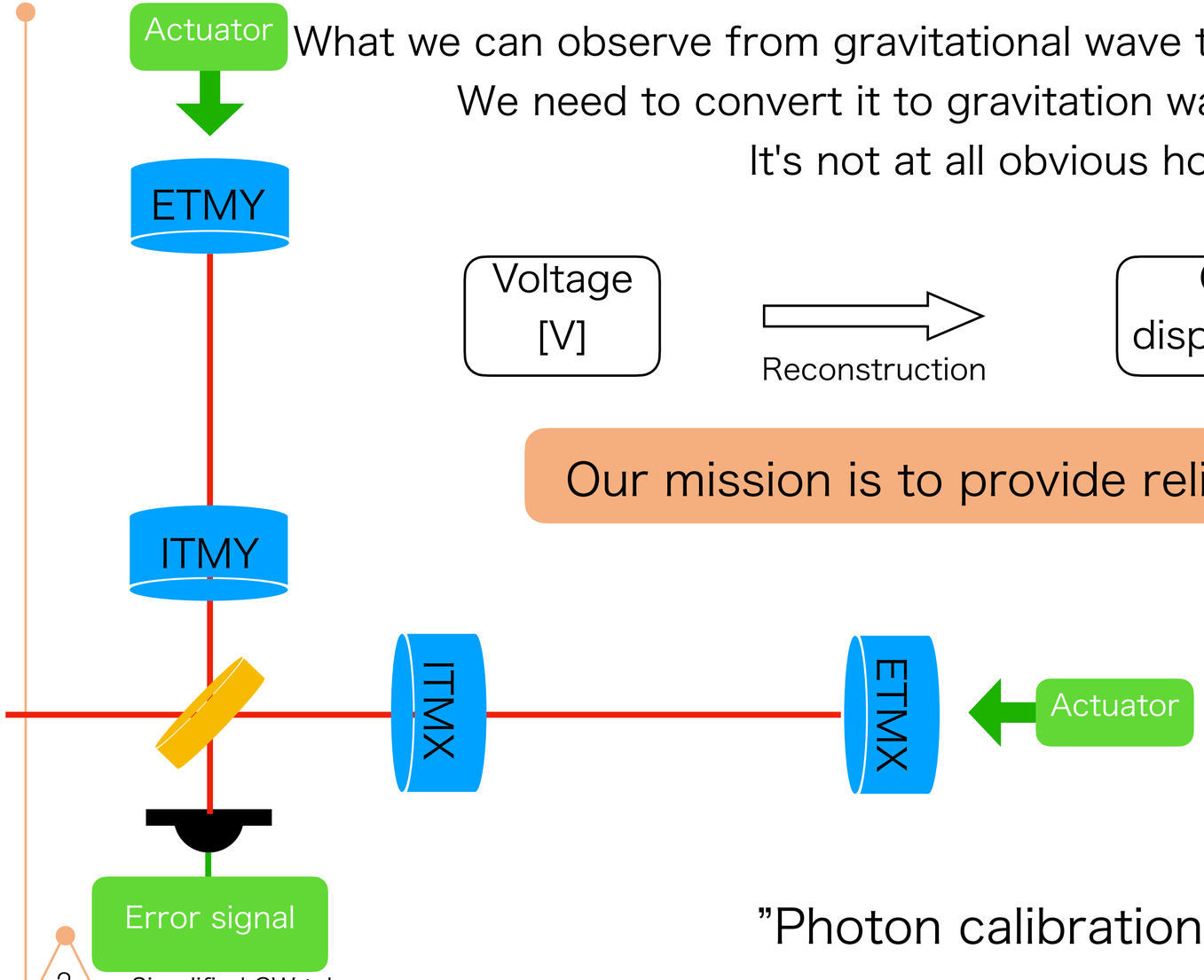
Status of KAGRA Calibration System Upgrade Toward O4

Dan Chen on behalf of the KAGRA collaboration

2021/7/7 KAGRA International Workshop 8

Mission of calibration(CAL) sub-group



Simplified GW telescope

What we can observe from gravitational wave telescope is voltage signals from Photo Detectors(PDs).
We need to convert it to gravitation wave signal h(t): reconstruction of calibrated h(t)
It's not at all obvious how many meters one volt equals.

Voltage [V] → (Reconstruction) → Calibrated displacement [m] → (× 1/L) → GW signal h(t) [-]

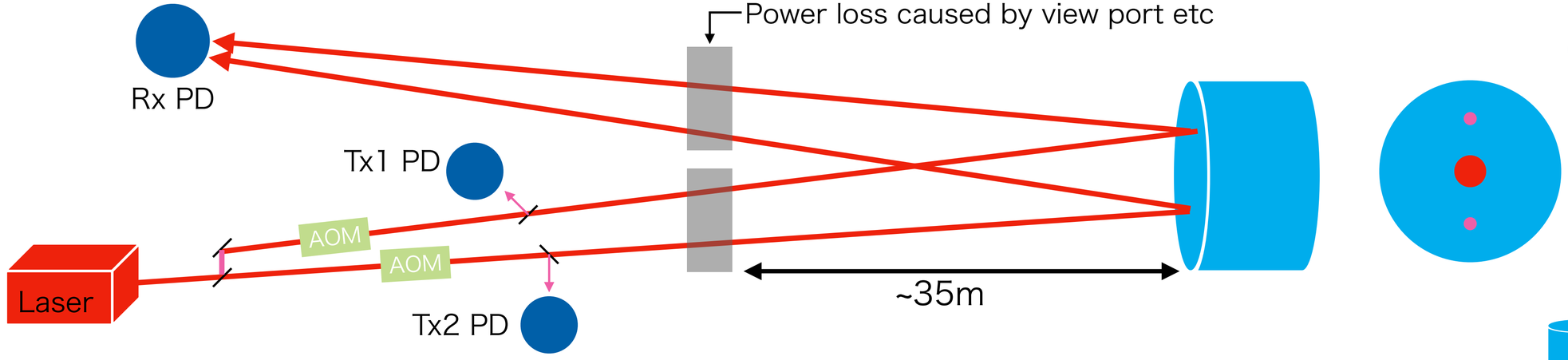
Our mission is to provide reliable and timely calibrated strain data h(t)

A View from the hardware.

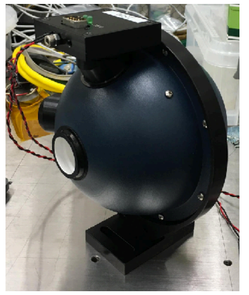
In order to calibrate the signal, we need accurate and precise calibration systems

”Photon calibration system(=Pcal)” based on radiation pressure

Photon calibration system = Pcal



Integration sphere: measure the laser power precisely.



★We use accurate PDs (calibrated integration spheres) to measure the laser power.

★Error of P is most significant on calibration error.

$$x(\omega) = -\frac{2P\cos\theta}{cM\omega^2}\left(1+\frac{\vec{a}\cdot\vec{b}\,M}{I}\right)$$

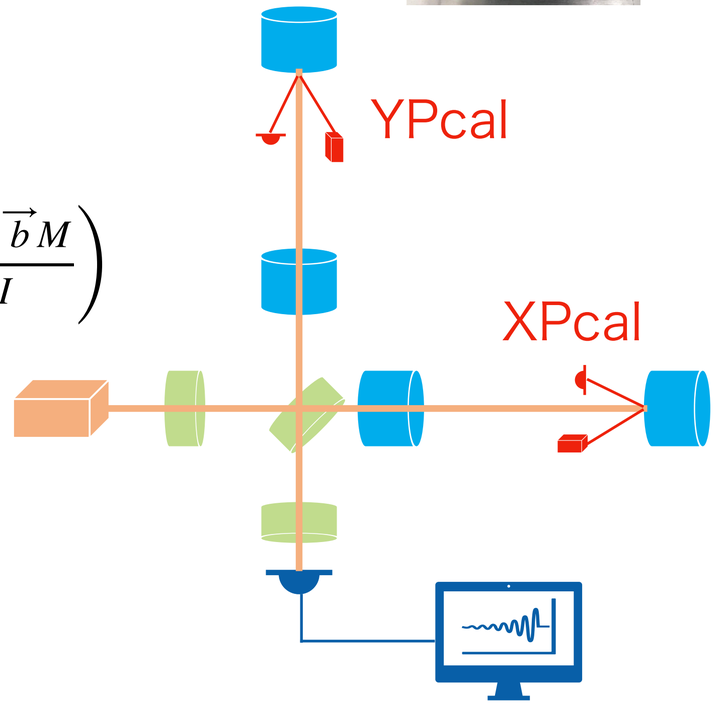
★Modulation by AOM (Acousto-Optic Modulator) makes calibration works in frequency domain.

★AOMs also enable laser power stabilization.

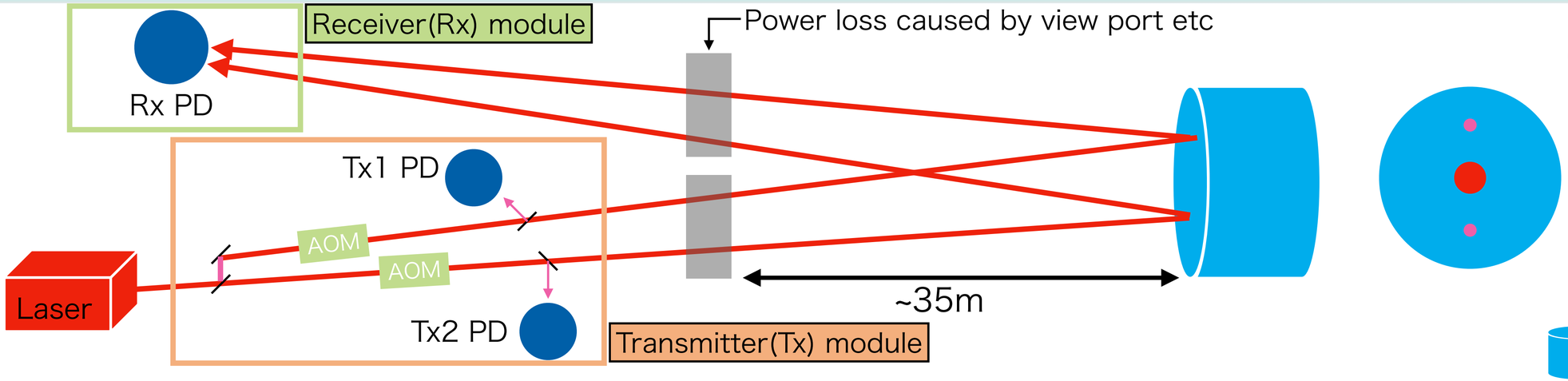
★We inject 2 laser beams on ETM.

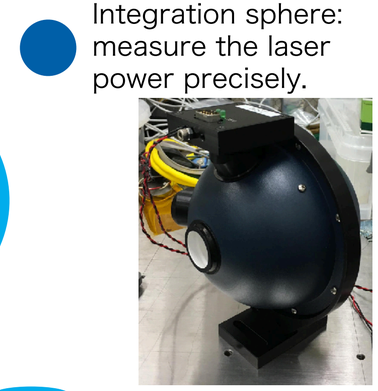
★We can reduce the influence of internal mode excitation.

★We can avoid to rotate TM by Pcal laser beams.



Photon calibration system = Pcal





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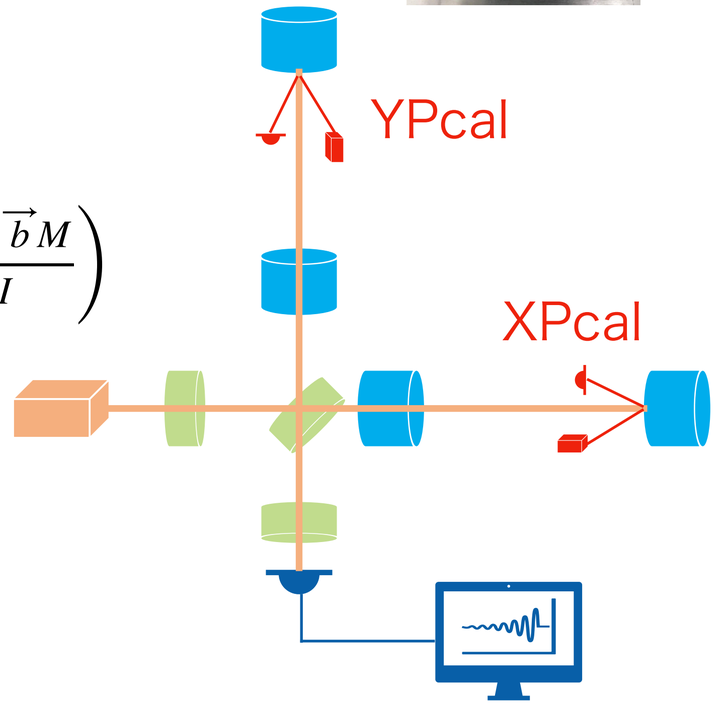


Pcal improvement toward O4
~What we found in/after O3GK~

★Repair YPcal

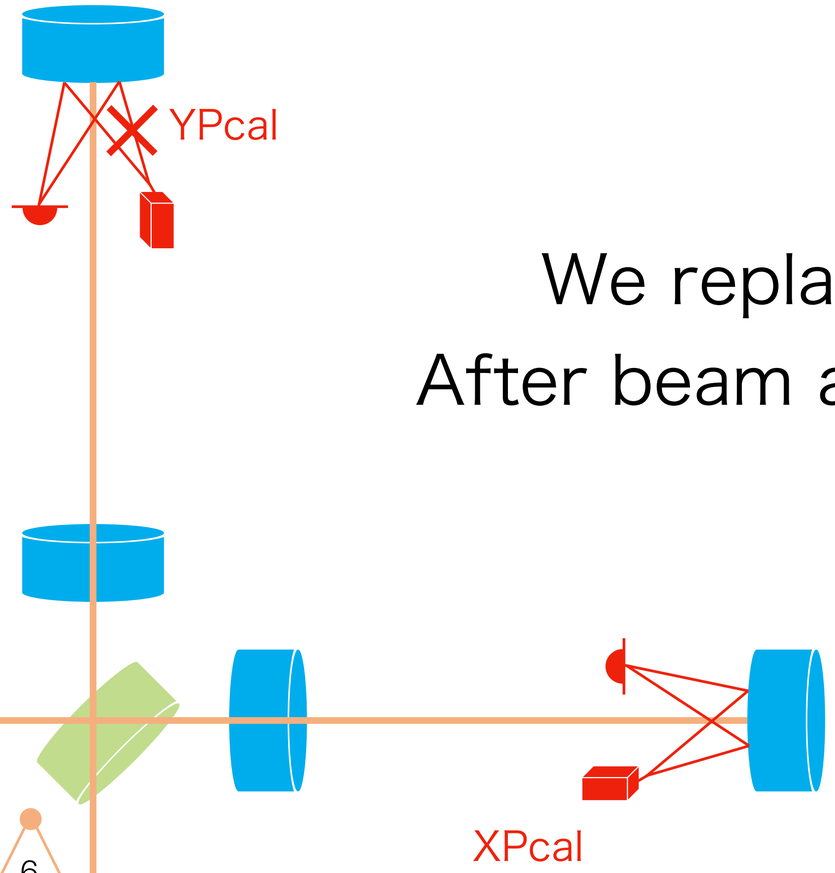
★Alignment tools improvement

★Noise improvement

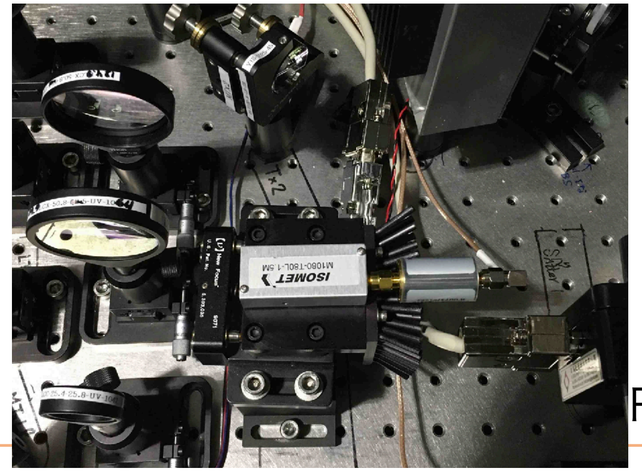
★Hardware uncertainty improvement

Repair YPcal

One of AOMs in YPcal was broken before O3GK.
We could not use YPcal in O3GK.

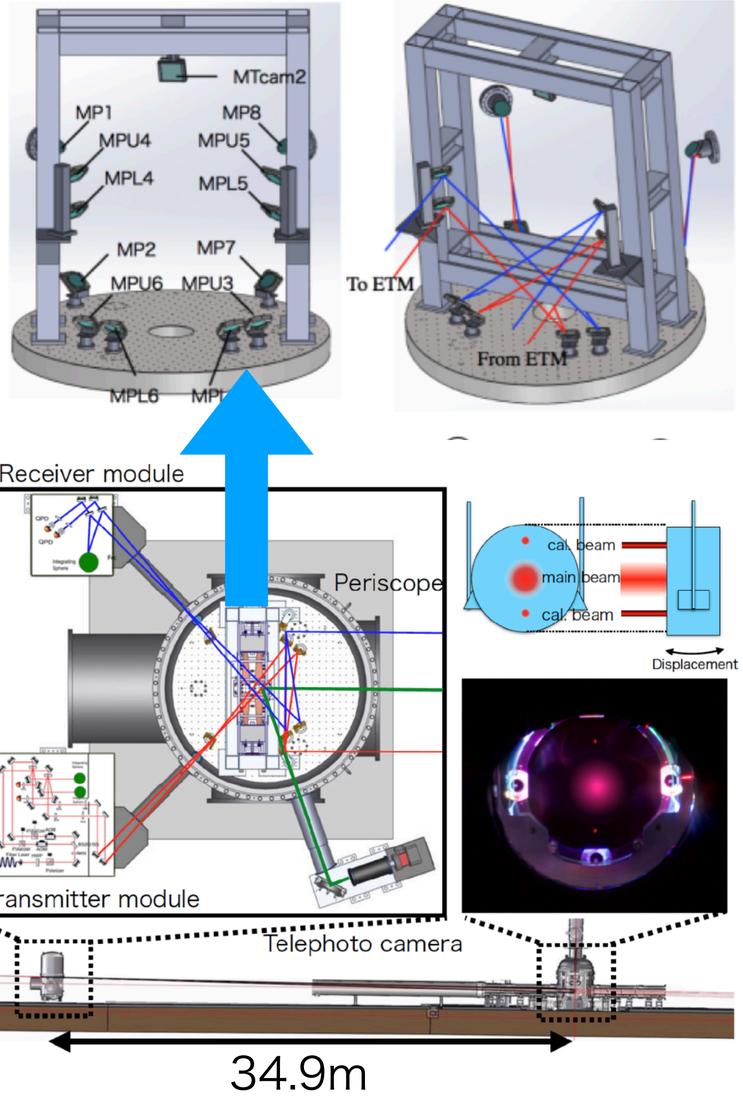


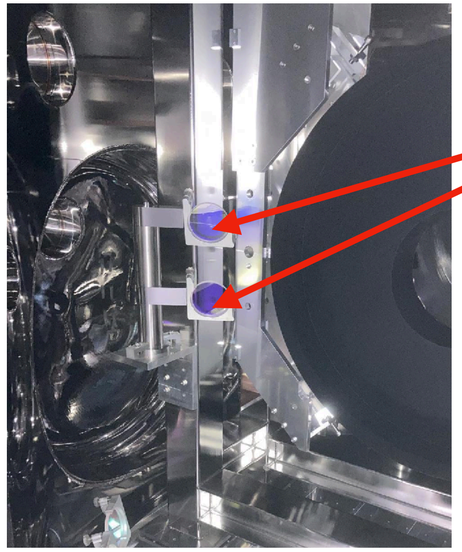
We replaced the broken AOM after O3GK.
After beam alignment, YPcal will be ready for use.



Replaced AOM

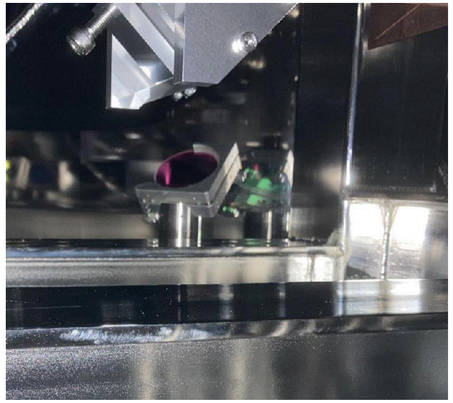
Alignment tools improvement

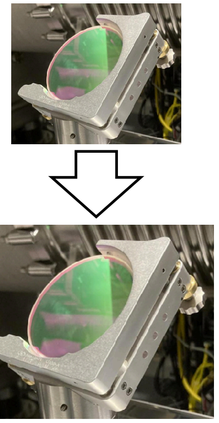




Newport 8823-UHV

Install picomotors on mirrors before long path



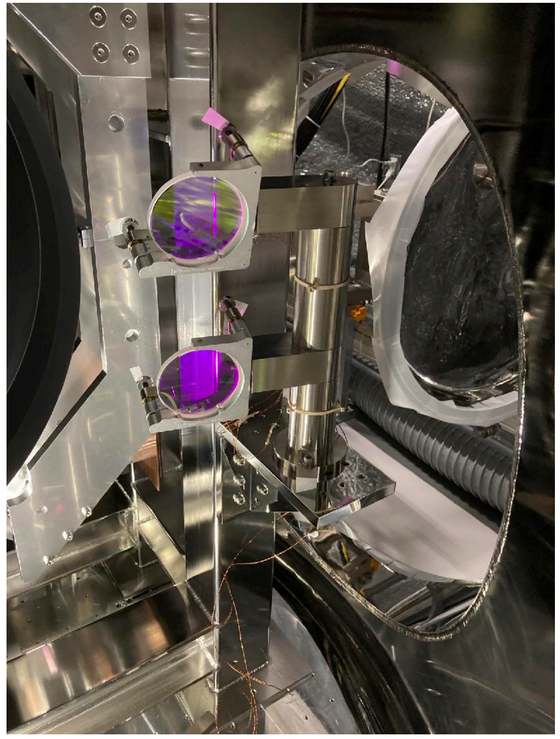


Replace the mirror receives 2 beams with a bigger mirror. This also improves reliability.

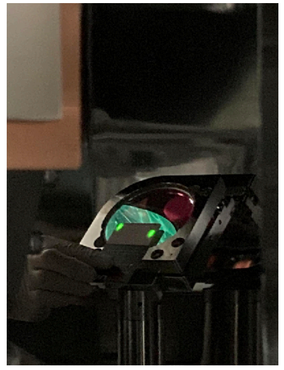
Alignment tools improvement

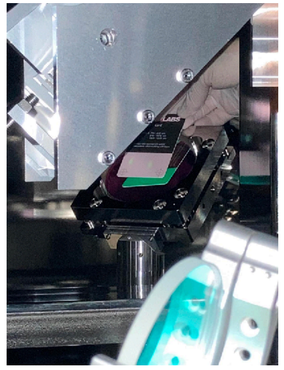
We have already installed all items we planed.

XPcal

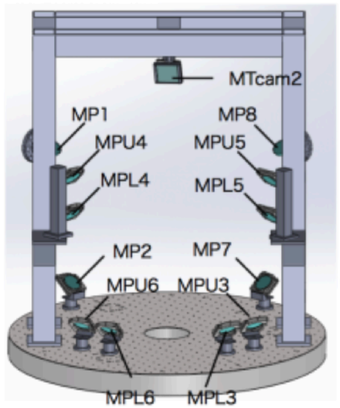


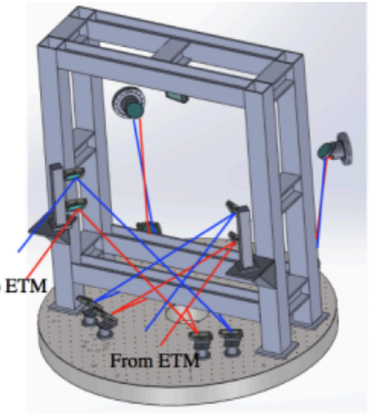
Pico-motor

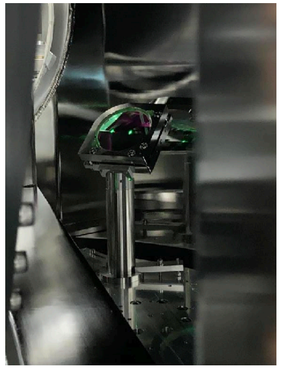




4 in mirror



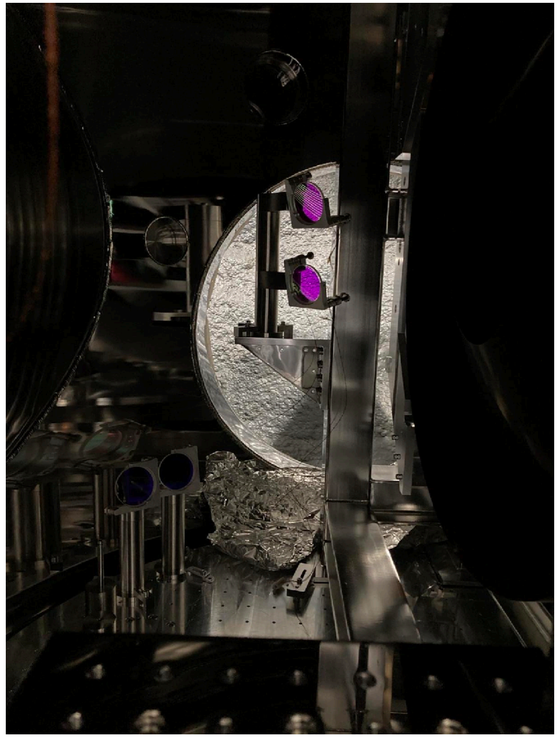




4 in mirror

Forgot to take a pic

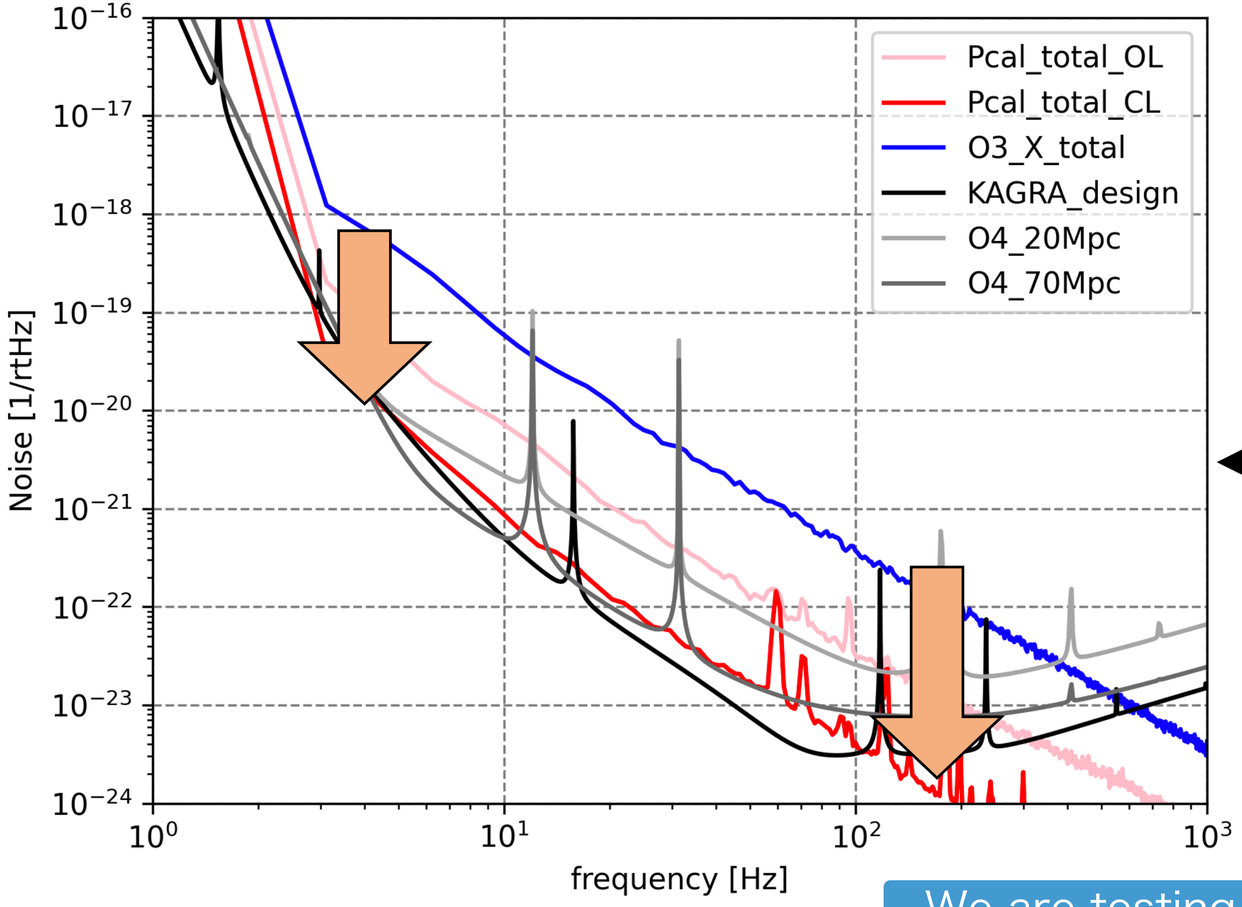
YPcal



Pico-motor

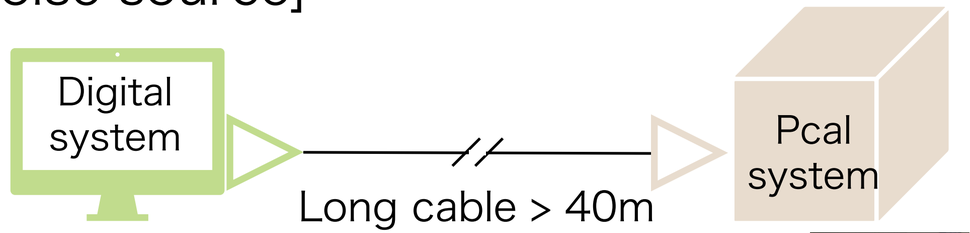
Noise improvement

Pcal noise

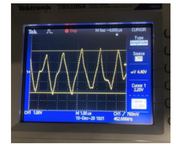


50dB improvement of laser power noise

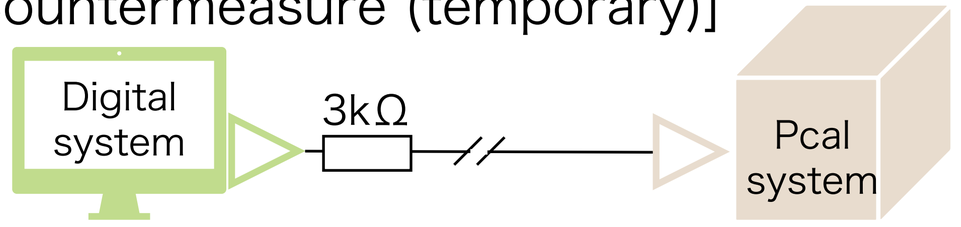
[Noise source]



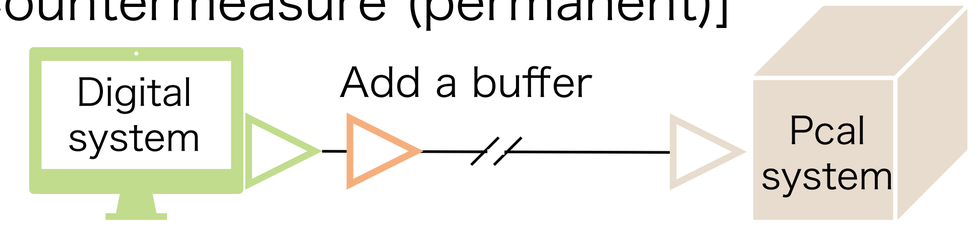
Oscillation at 500kHz with 5Vpp



[Countermeasure (temporary)]



[Countermeasure (permanent)]



We are testing this.

Hardware uncertainty improvement

O3GK

Error source	Effect on x(w) [%]
Laser power measurement	2.5
Optical efficiency measurement	1.7
Laser position fluctuation	0.99
Other	0.48

3% error in total
(Pcal hardware error)

Displacement caused by Pcal:

$$x_{tot}(\omega) \simeq \frac{2P_m \cos\theta}{Mc\omega^2}\left(1+\frac{\vec{a}\cdot\vec{b}M}{I}\right)$$

Estimated power on TM

$$P_m = f(P_{TX1}, P_{TX2}, P_{RX}, e_{T1}, e_{R1}, e_{T2}, e_{R2})$$

Laser power measurements by integration spheres are the main error source

Possible cause 1: Measurement process has some problem.
(Warming time before measurement was too short or others.)
Possible cause 2: Stray light in Tx module

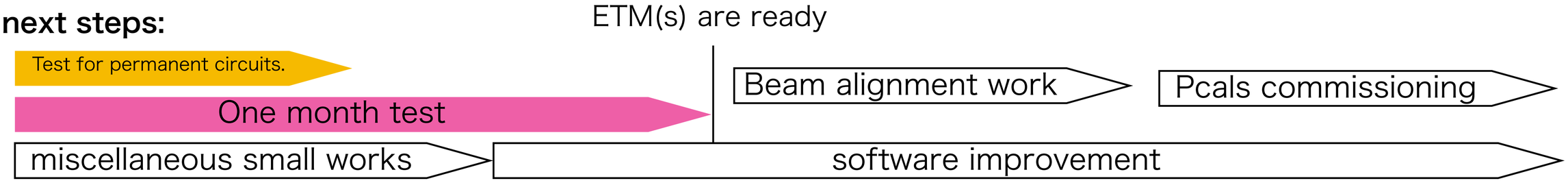
Countermeasure 1: We made a new measurement process based on studies of equipment stability time.
Countermeasure 2: We installed dumpers against stray light.

We just started “one month test” to check the improvement.

Summary of Pcal improvement toward O4

	Repair YPcal	Alignment tools improvement	Noise improvement	Error improvement
Issue	An AOM was broken before O3GK run.	Difficulty of beam alignment.	Pcal laser noise is close to O3GK sensitivity, which is higher than O4 target sensitivity.	Pcal has a 3% error, which can be improved.
Goal	Make the YPcal work.	Reduce alignment work time.	Noise lower than O4 target sensitivity.	Lesser than 3% error.
Current Status	Repaired AOM.	We have already installed all items we planed.	The noise is reduced by 50dB, which is lower than O4 target.	We made a new calibration procedure and stray light management was done.
Remaining tasks	Nothing special!	Nothing special!	Test for permanent buffer circuits.	Check the improvement. (= “one month test”)

Our next steps:



Back up

Pcal improvement toward O4
~What we found in/after O3GK~

★YPcal did not work because an AOM was broken.

★We need improvement of alignment tools

★Pcal noise can be bigger than KAGRA O4 sensitivity.

★Pcal had a 3% uncertainty. (Uncertainty of h(t) is larger)

- ★Variation of measured optical efficiency (~1.7%)
- ★Variation of integration sphere calibration factors (~2.5%)
- ★Fluctuation of laser beam positions on the ETM (~1%)

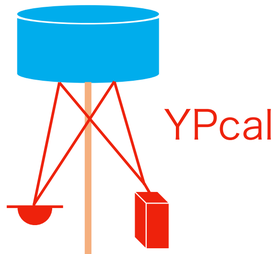
Repair YPcal

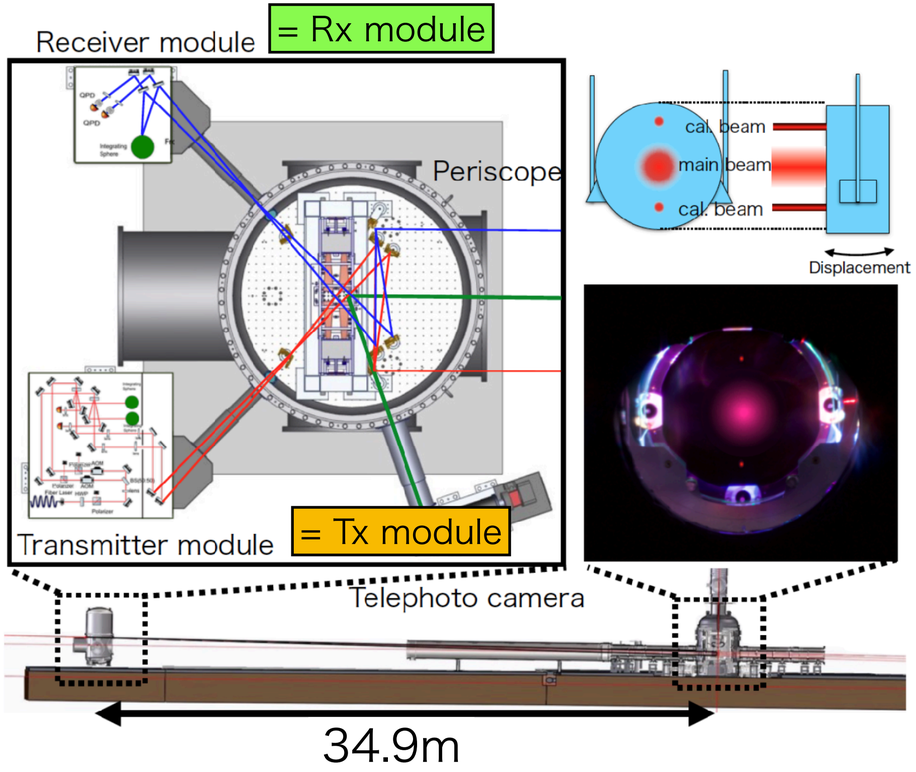
Alignment tools improvement

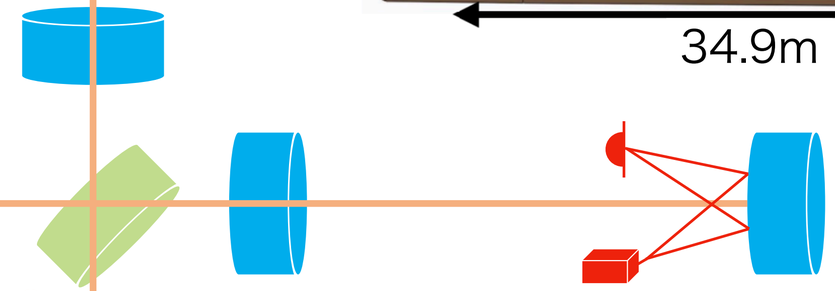
Noise improvement

Hardware uncertainty improvement

Photon calibration system = Pcal







Tx module

- Generate 2 beams
- Power stabilization
- Make periodic excitation of power
- Precise measurement of input laser power

Rx module

- Precise measurement of output laser power

We can use measured power in both modules to estimate power on the test mass.