KAGRA overview and current issues

M. Leonardi on behalf of KAGRA collab.

National Astronomical Observatory of Japan

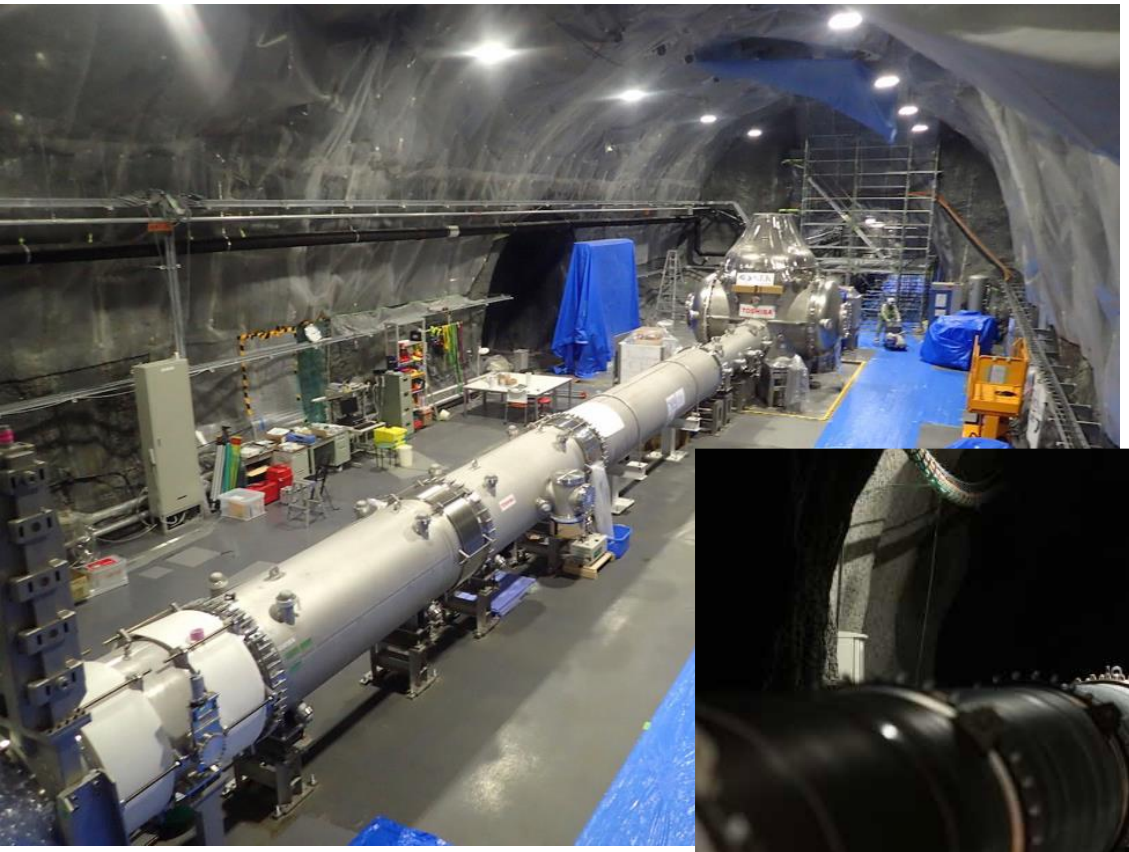
KAGRA project

- Underground and Cryogenic interferometric GW detector
- Project started in 2010
- International collaboration (103 institutions, more than 10 countries, 470 members)

KAGRA project

- Kamioka, Gifu
- Underground site close to Super Kamiokande
- First km-scale GW detector with cryogenic mirrors

Underground site



June 2010:

KAGRA was funded by MEXT

2011:

Suspension of tunnel excavation for 1 year due to the earthquake

May 2012:

Started the tunnel excavation

March 2014:

Tunnel finished

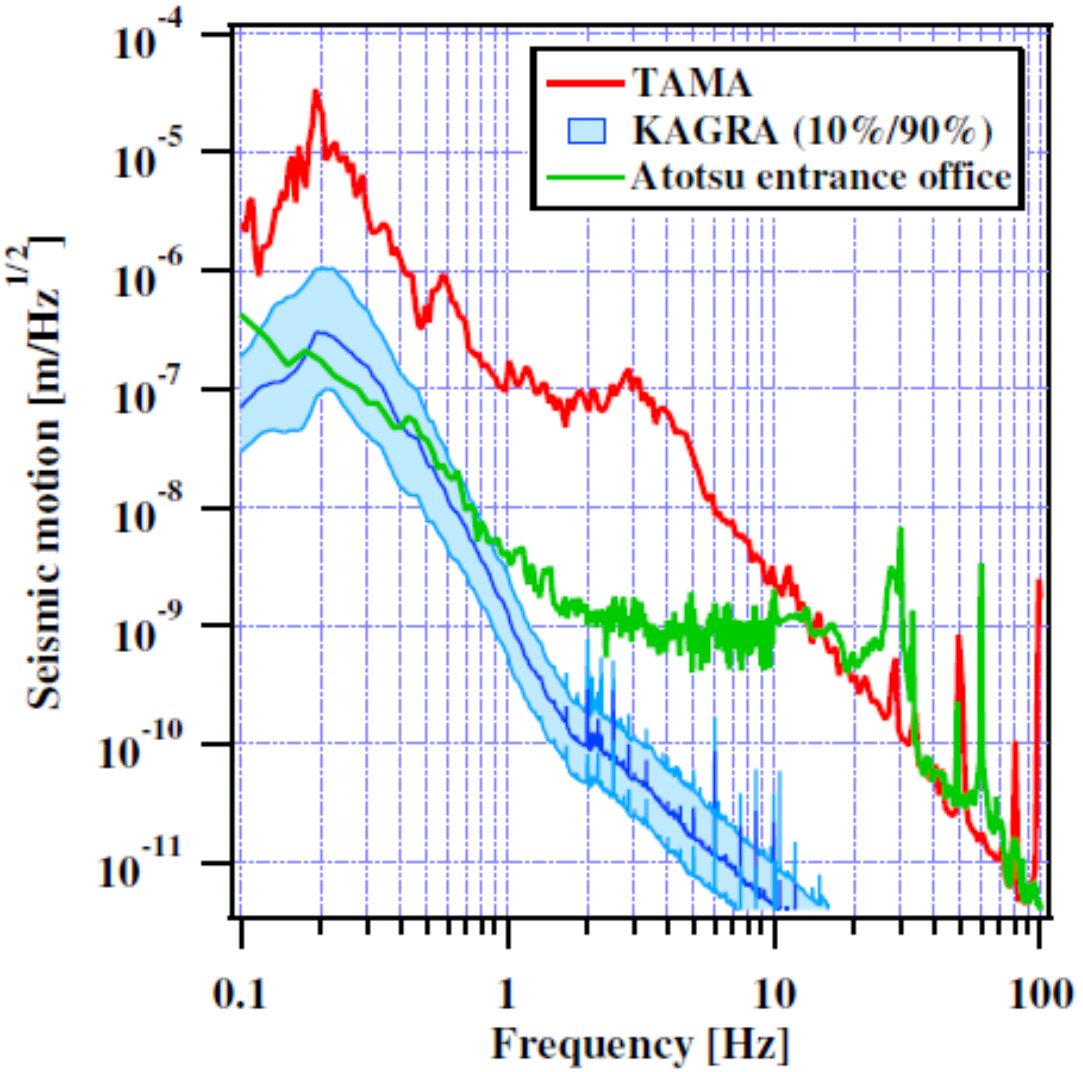
Nov. 2015:

Laboratory area mostly done

Underground site

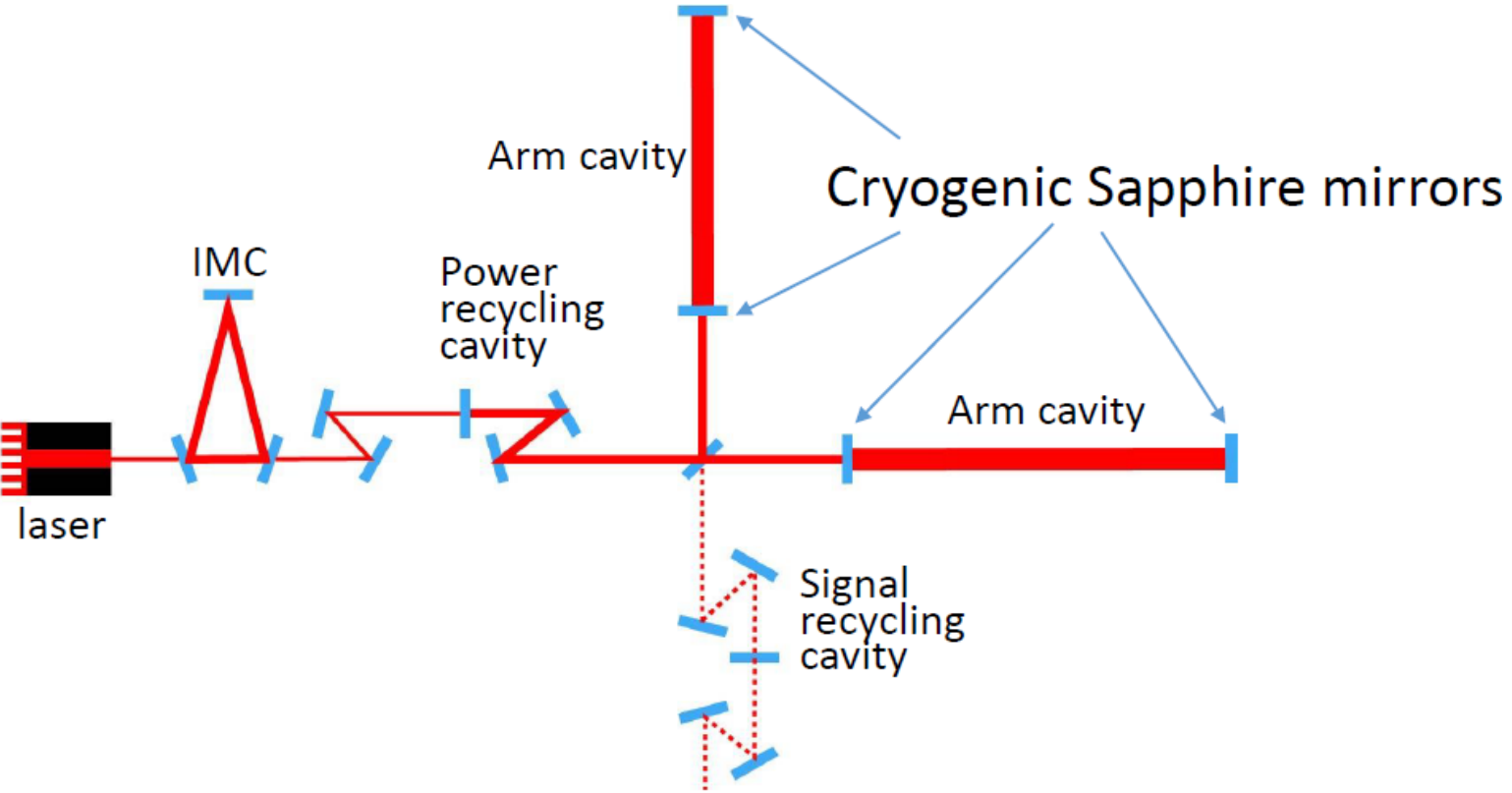
Much quieter site (w.r.t. TAMA):

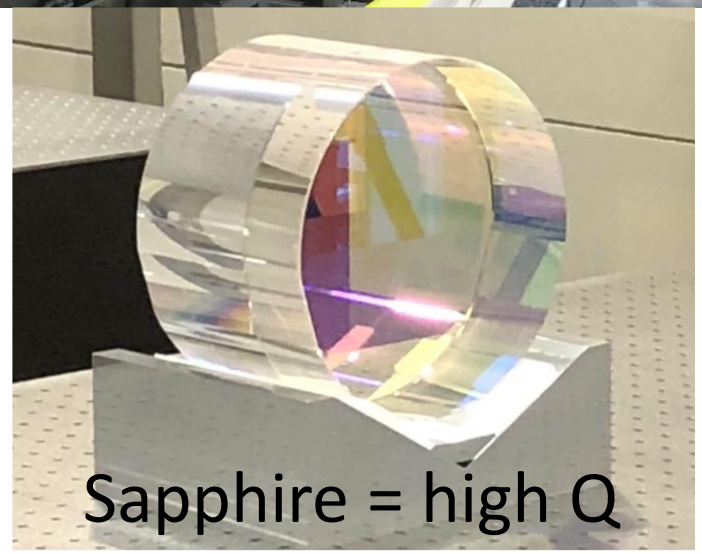
- Two order of magnitude @0.2Hz
- Three order of magnitude @10Hz



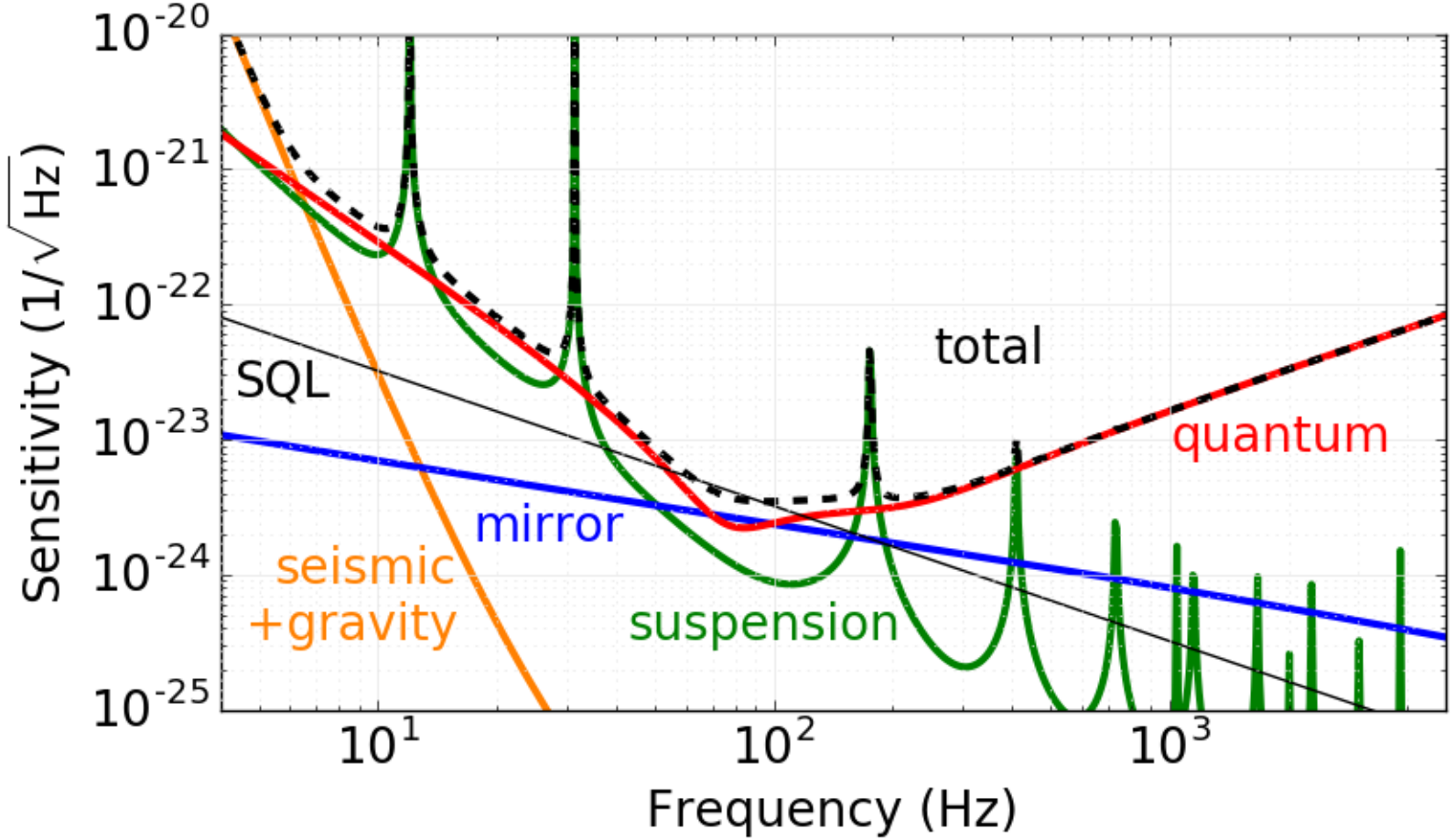
Cryogenic design to reduce thermal noise

Thermal noise level $\propto \sqrt{T}/\sqrt{Q}$





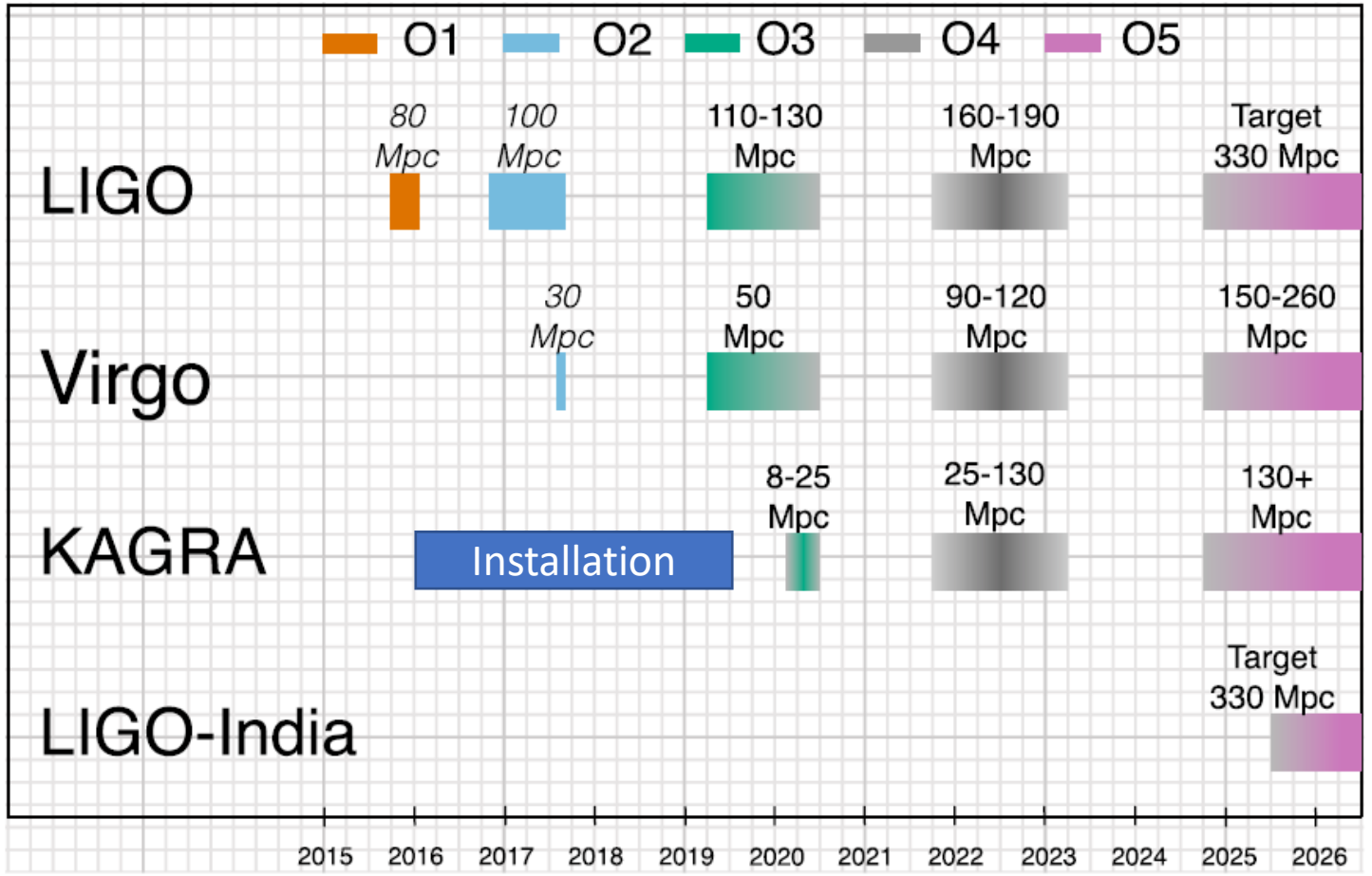
KAGRA design sensitivity



- Sensitivity dominated by quantum noise almost al all frequencies
- Suspension thermal noise quite prominent at low frequencies

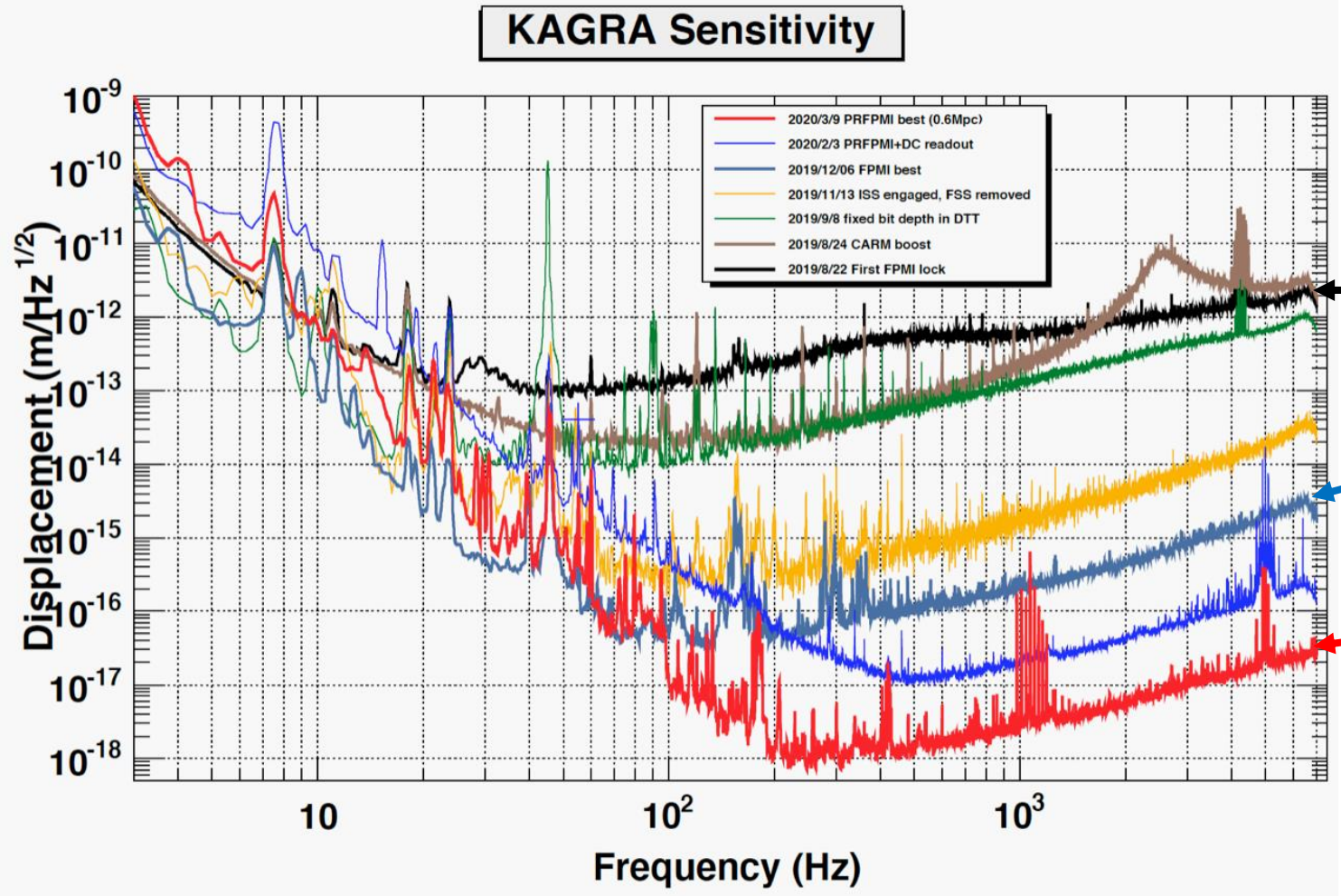
KAGRA in the GW network

- Installation officially finished mid-2019
- O3 was shortened by one month due to CoVid situation
- KAGRA could not join LIGO and Virgo in O3
- KAGRA-GEO600 joint observation run (O3GK): April 7th UTC 8:00 –21st UTC 00:00, 2020



Living Rev. Relativ. **23,** 3 (2020)

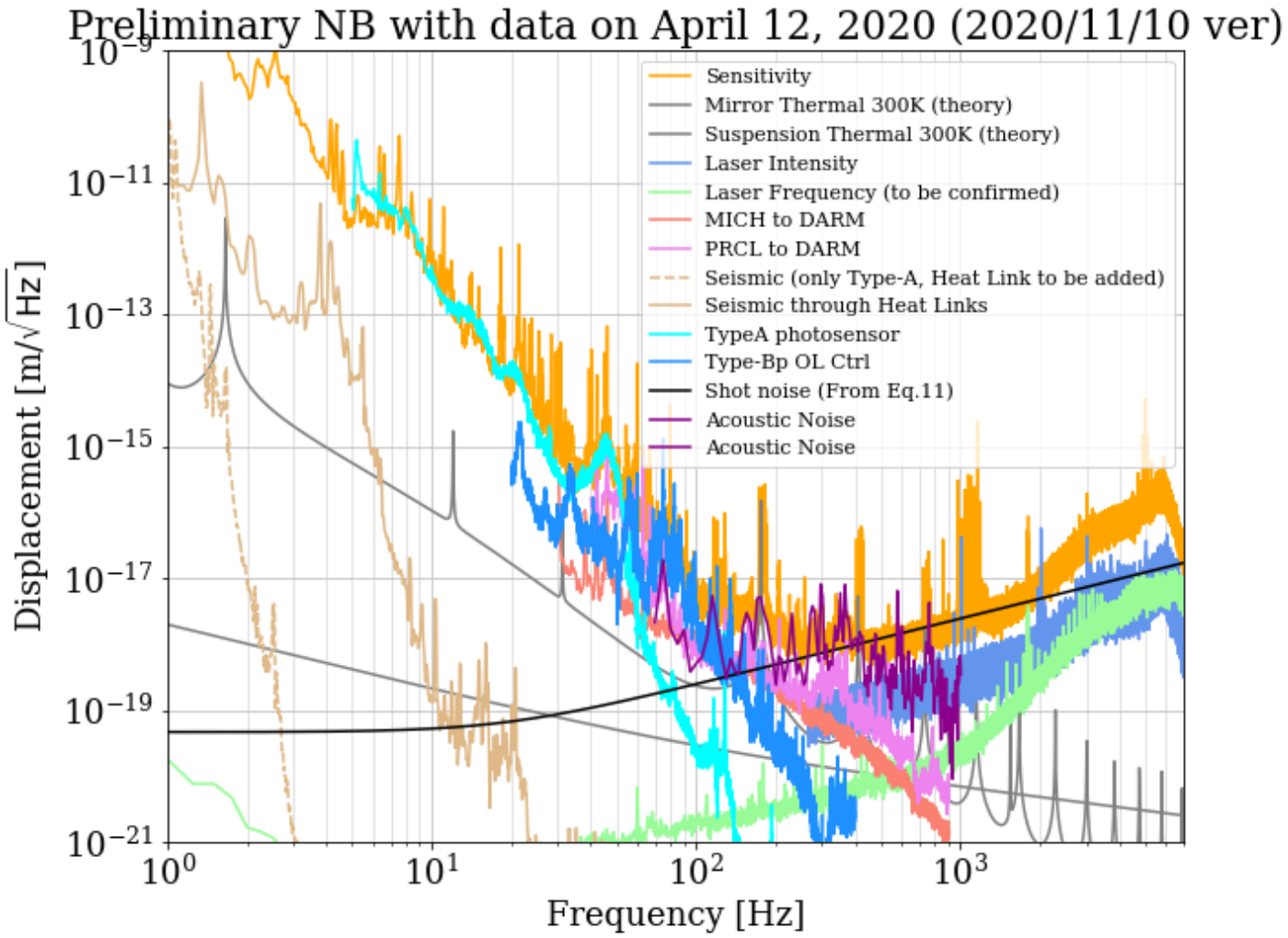
KAGRA's sensitivity



Sensitivity improvements:

- 2019/08/22: first FPMI lock
- 2019/12/06: FPMI best
- 2020/03/09: PRFPMI best

Preliminary noise budget



- Low freq. dominated by suspension control noise (TypeA and TypeBp)
- High freq. dominated by shot noise and laser noises
- Mid freq.: a collaborative effort of many noises

KAGRA's issues

(Incomplete) list of KAGRA's unique issues:

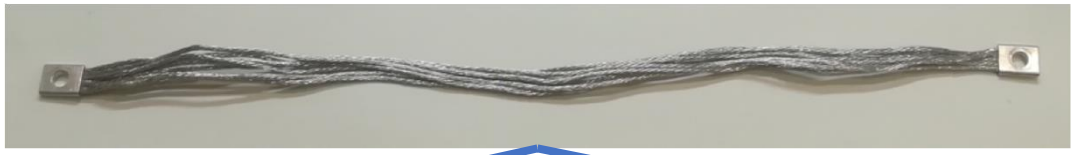
- CRY:
  - Heat link vs seismic noise
  - Frosting
- MIR:
  - Sapphire test masses' birefringence

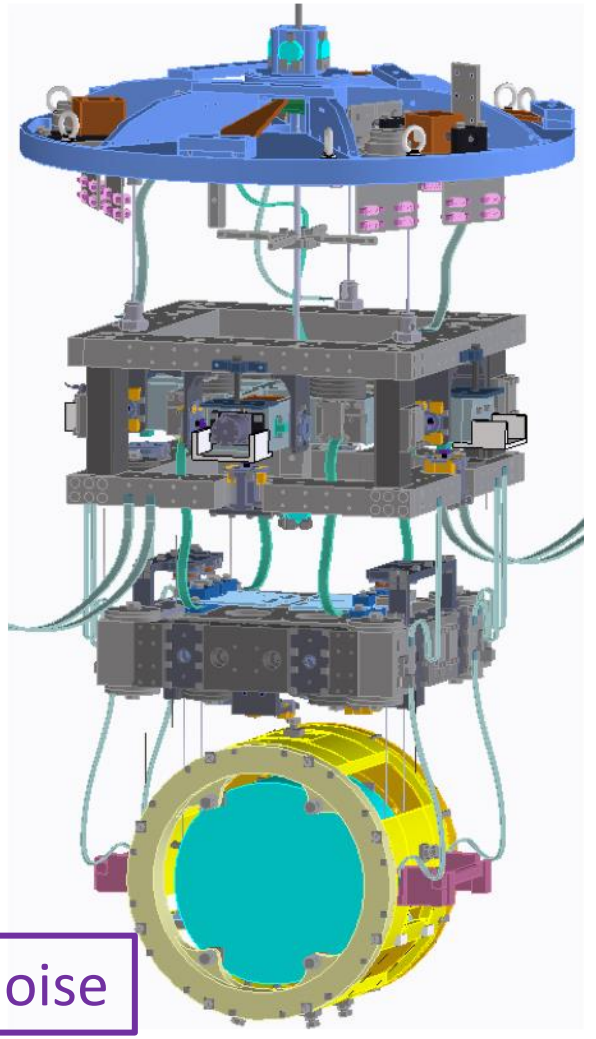
Intro: the enterprise of cooling KAGRA's TMs

What we know:

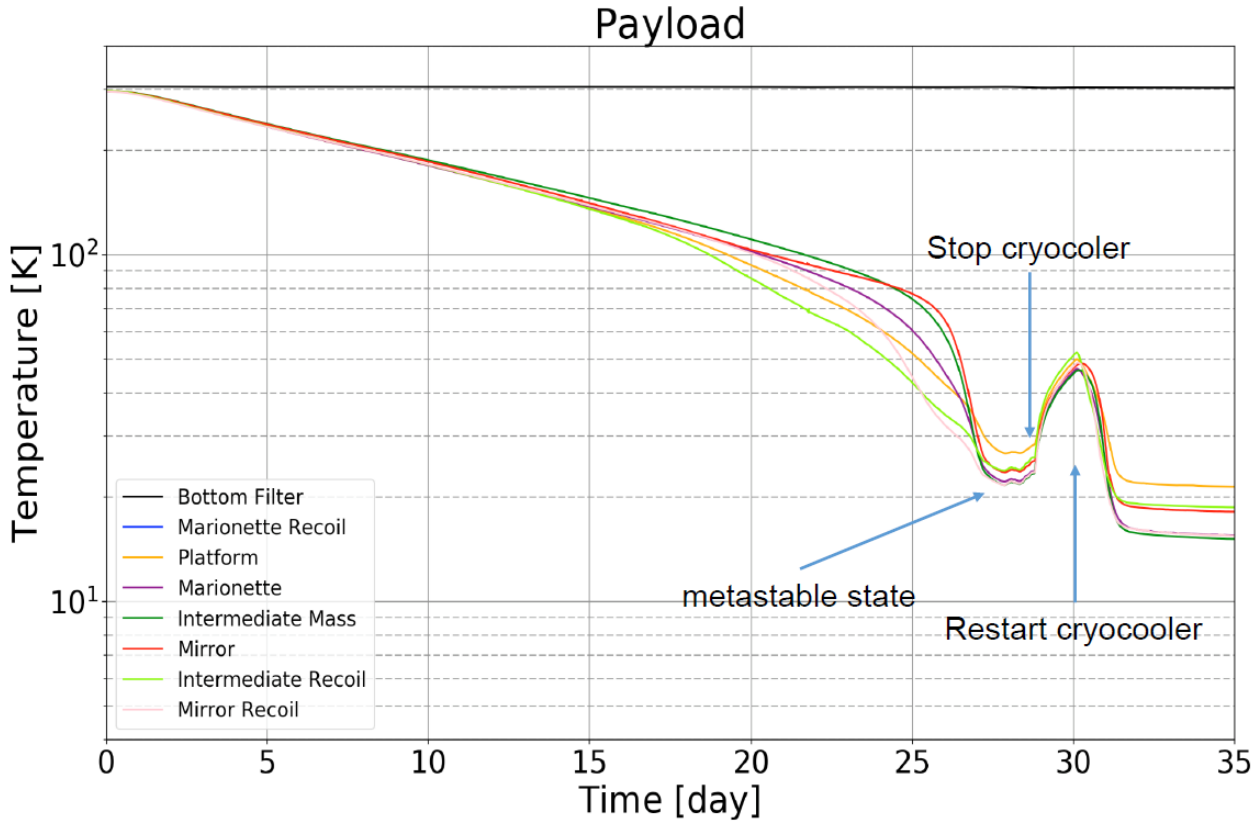
- $T_{TM} = 21K$
- $Q_{TM} = 2.3\mathrm{W}$ (final) => thermal + (sapphire + coating) abs.
- $Q_{CRYO} = 2.9W\ @8K$ => cooling power at the cooling bar

Find R_θ…

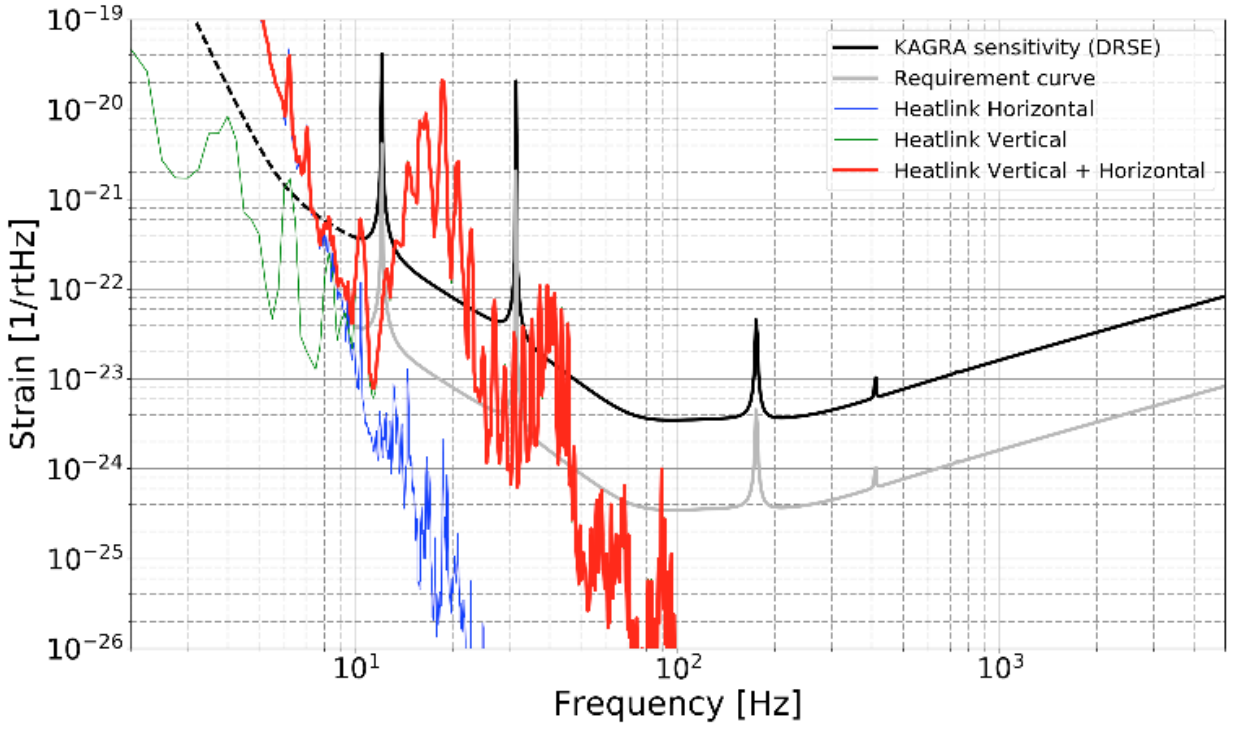




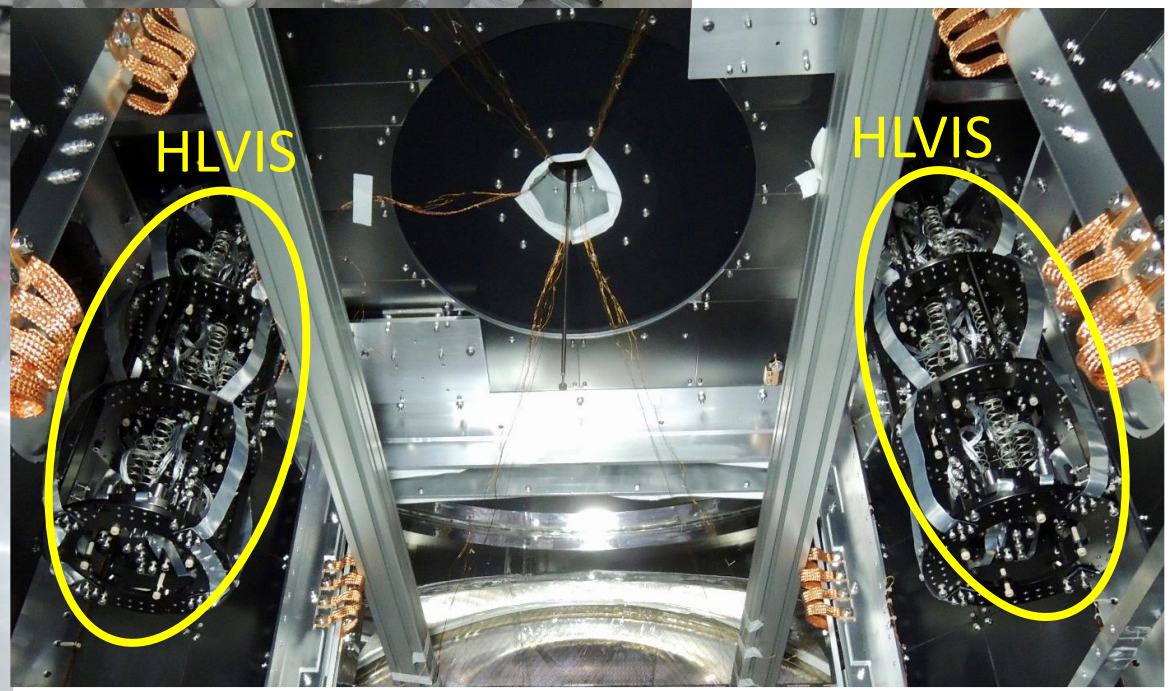
KAGRA (phase1) cooling of ETMY



- ETMY successfully cooled to sub 20K
- It took approx. 25-30 days
- Discovered strong seismic coupling due to heat links



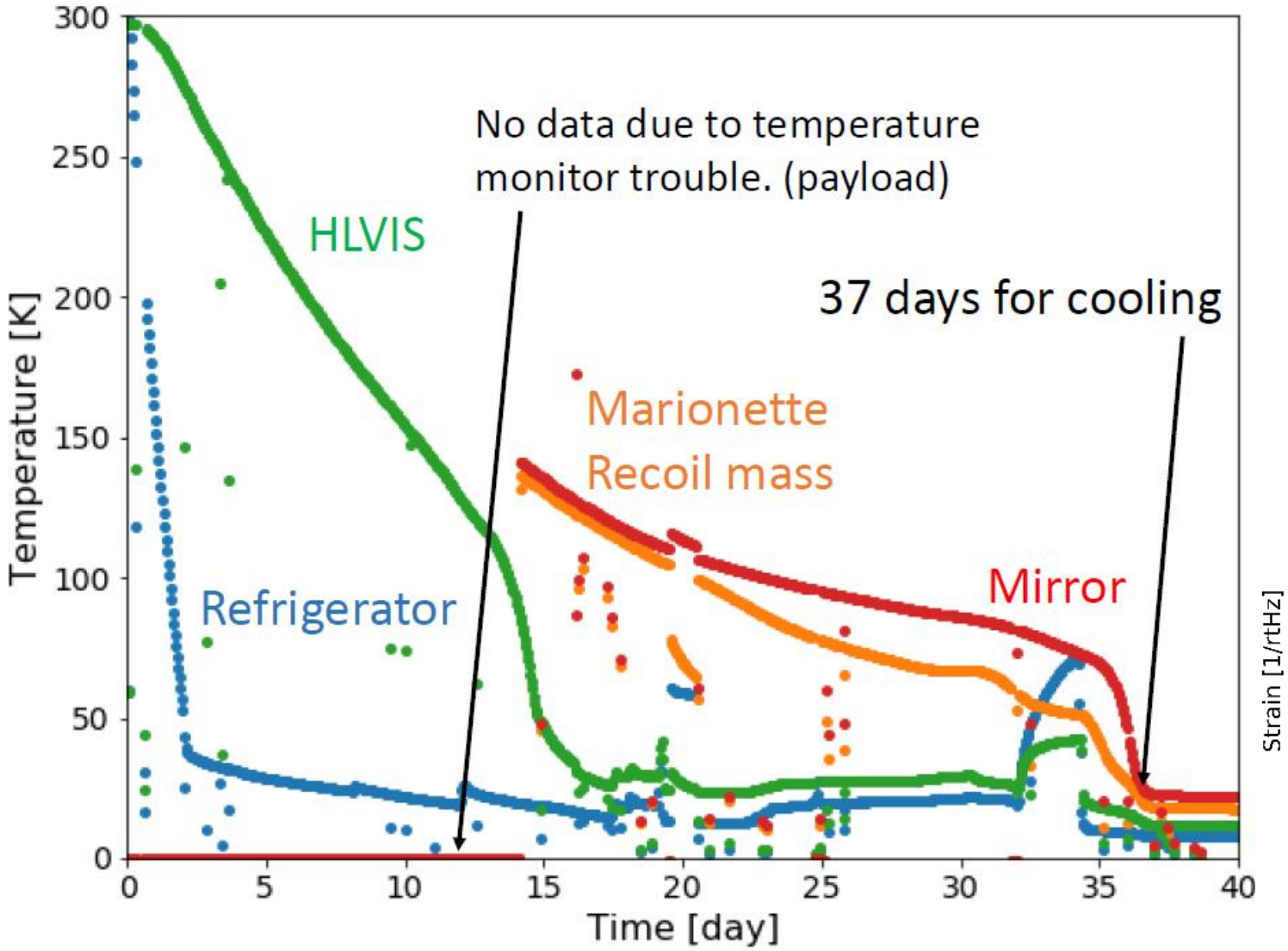
Heat-Link Vibration Isolation System (HLVIS)



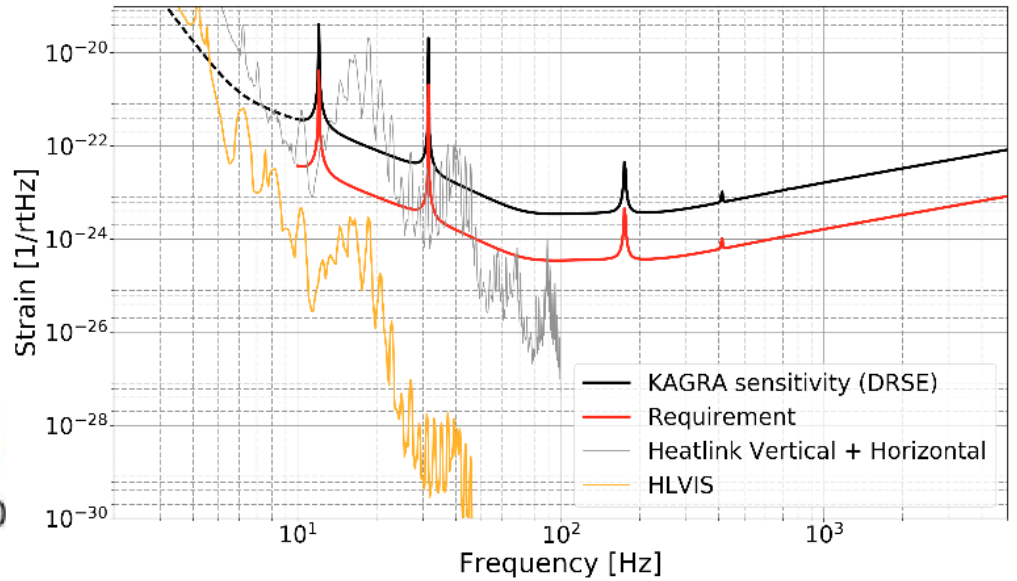
Two HLVIS installed for each TM payload:

- Seismic isolation increased
- Thermal resistance increased

ITMY cooling test (Feb. 2019)



- HLVIS reduced seismic coupling
- 37 days to reach final temperature (about 25 days before HLVIS)

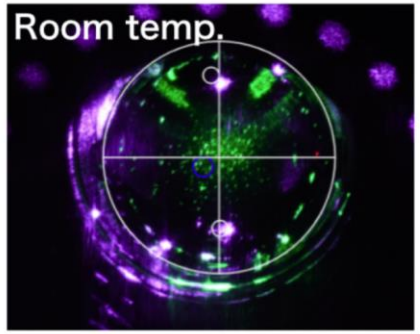


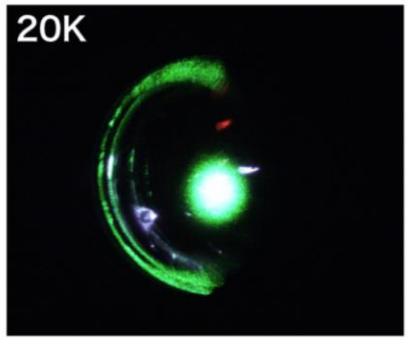
Frosting issue

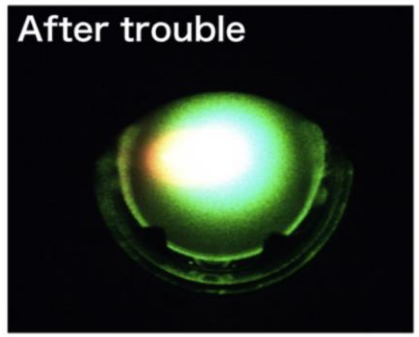
During commissioning in summer 2019 frosting of TMs and viewport was observed.

- Test mass frosting: lower finesse in the interferometer arms
- Viewport frosting: Optical Levers (OpLev) cannot be used to control the TMs' position

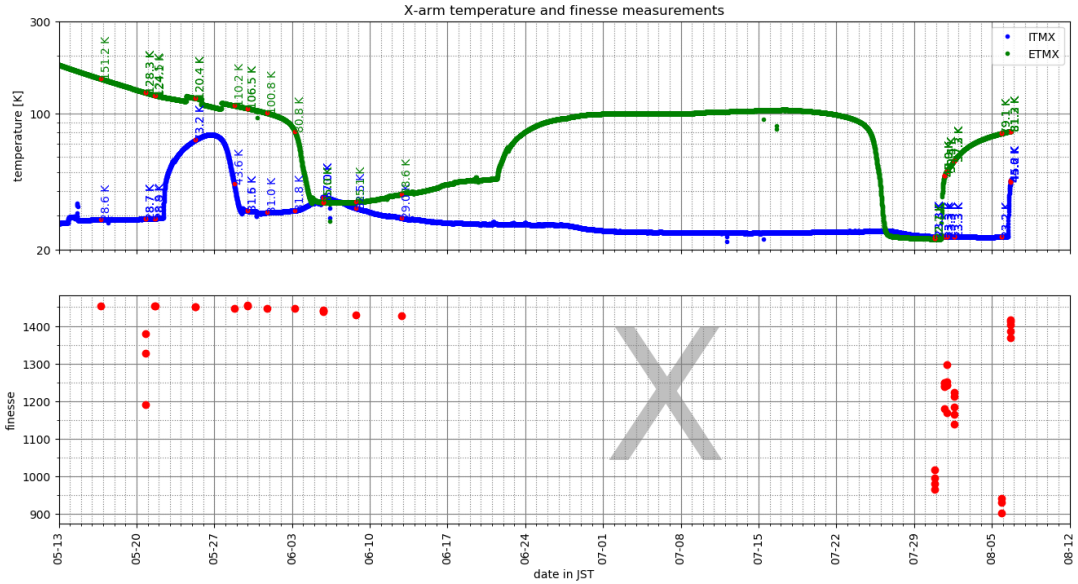
Arms finesse measurement

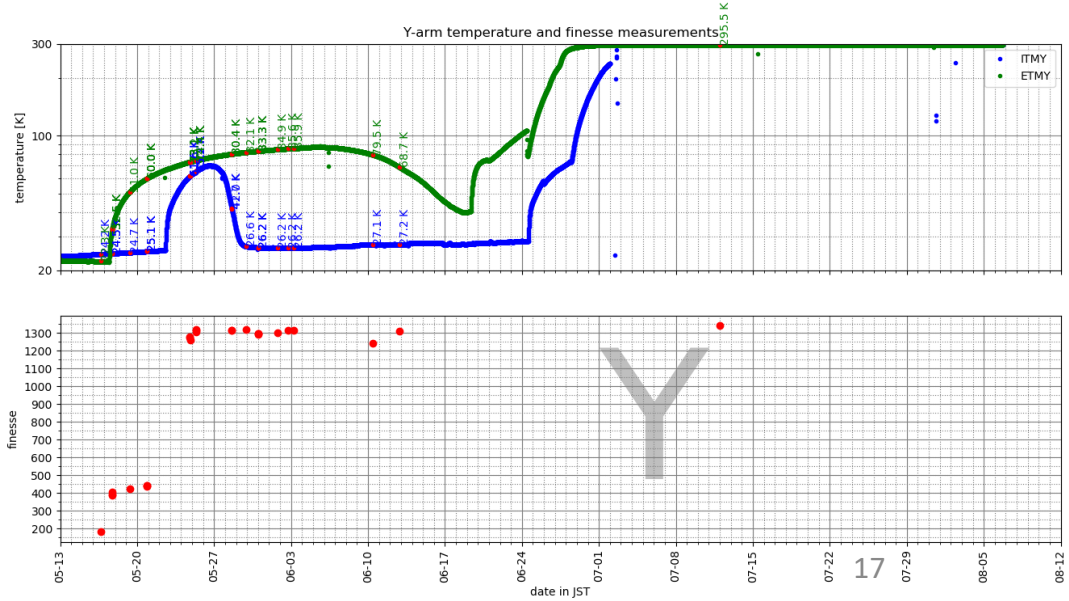






- Finesse drop observed when one of the test masses goes below 30K

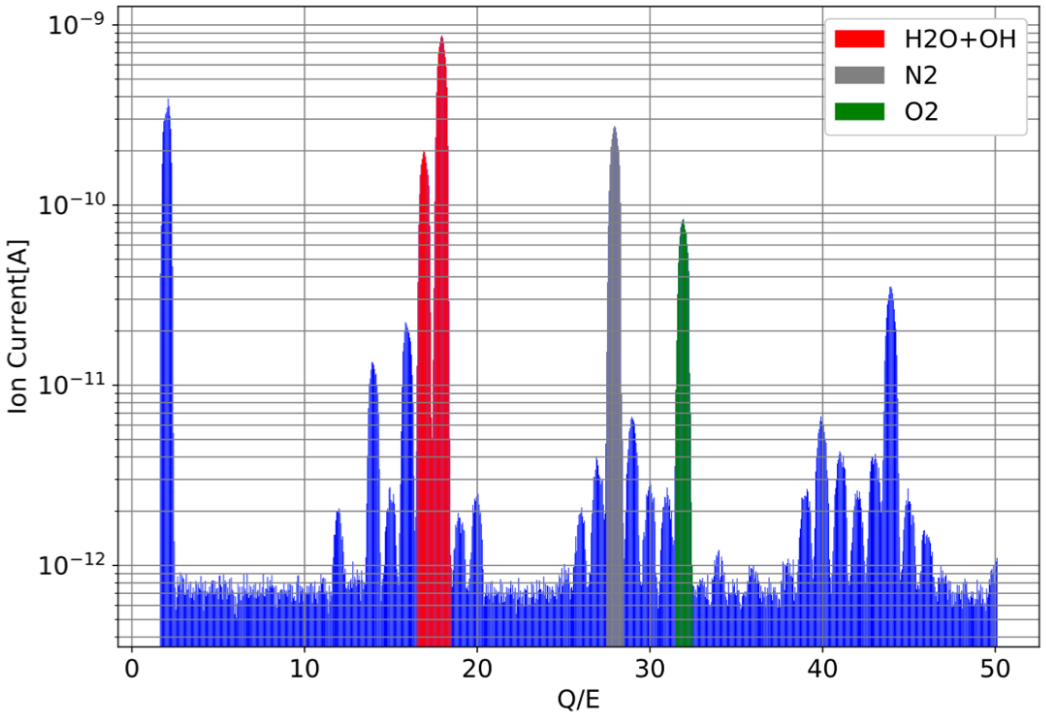


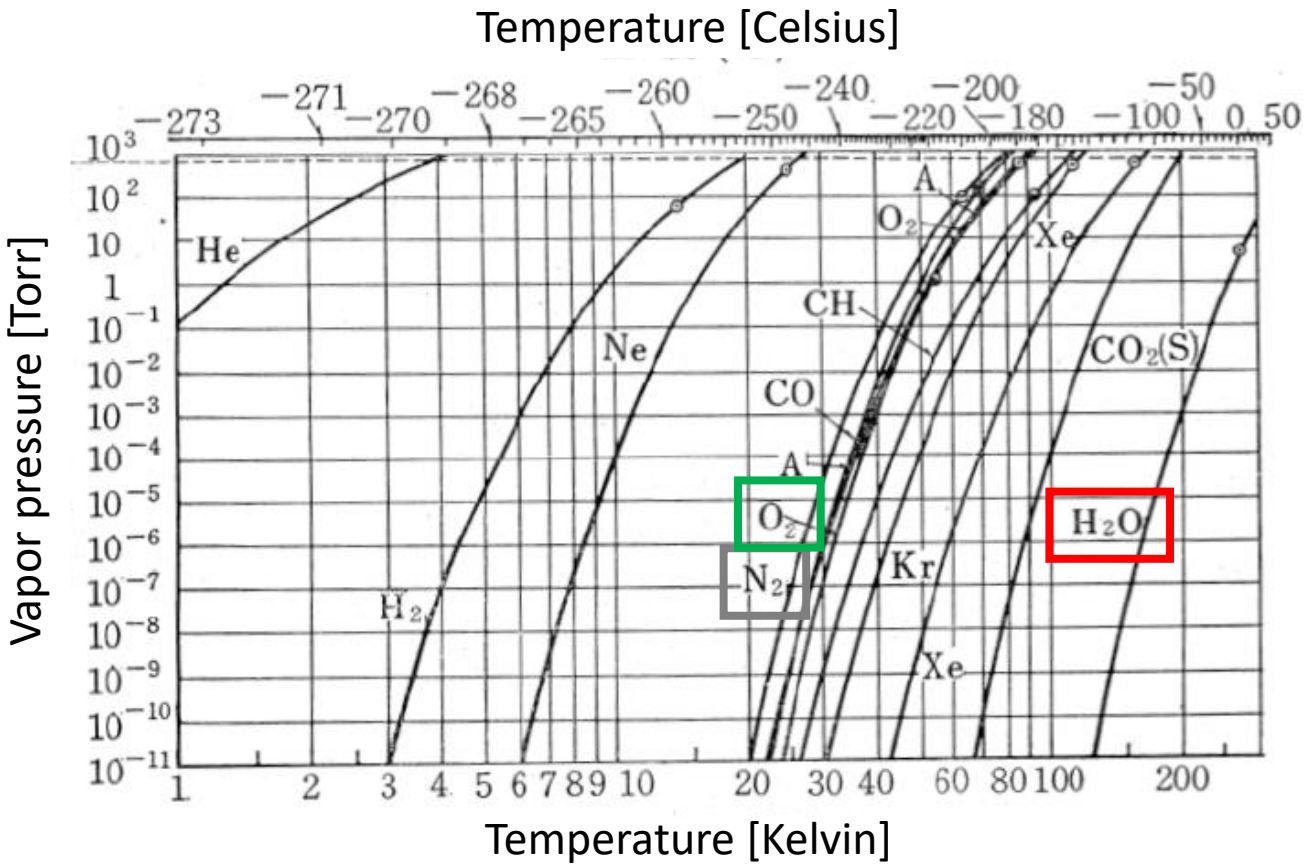


Frosting cause

Residual gas most probable cause:

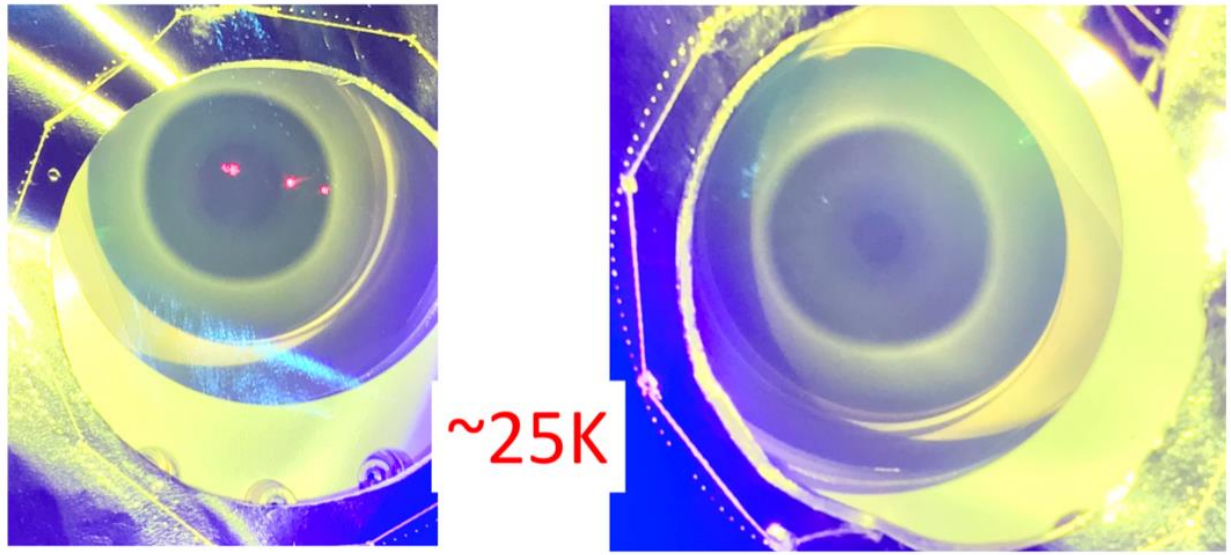
- N_2 and O_2 molecular layers

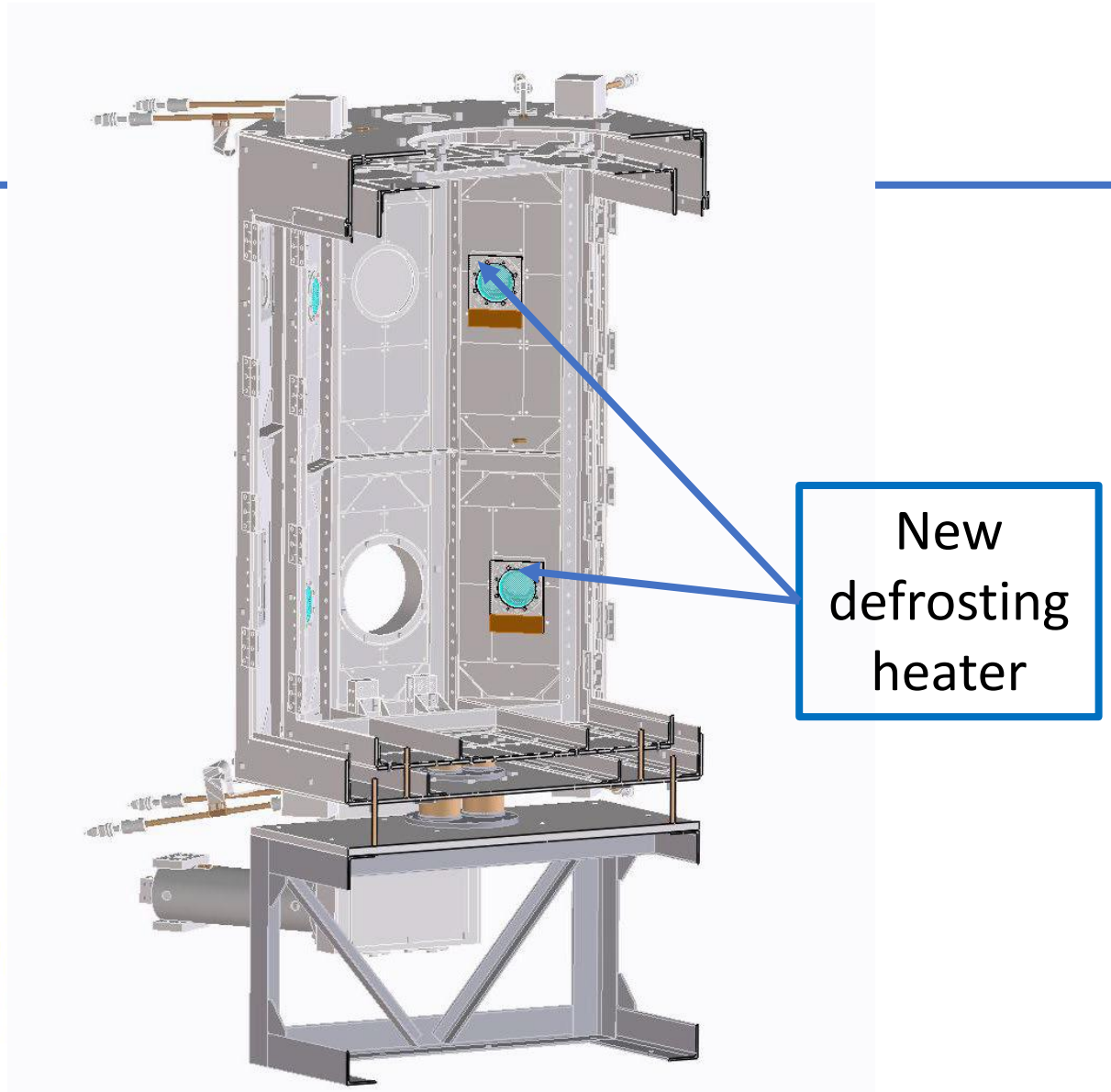




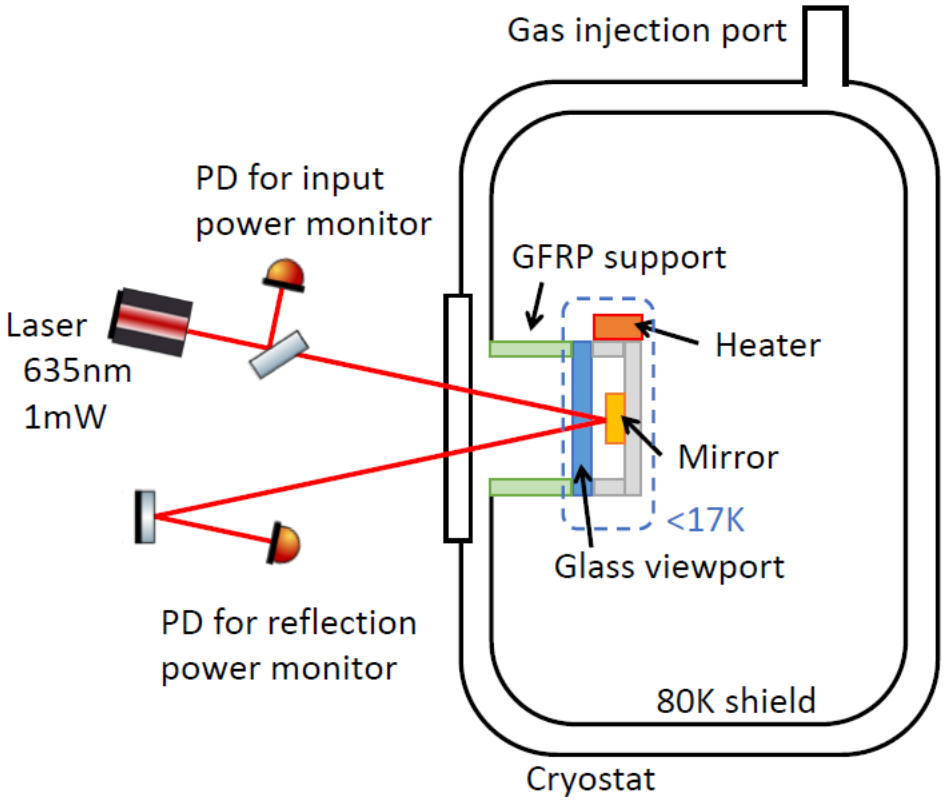
Frosting of viewport

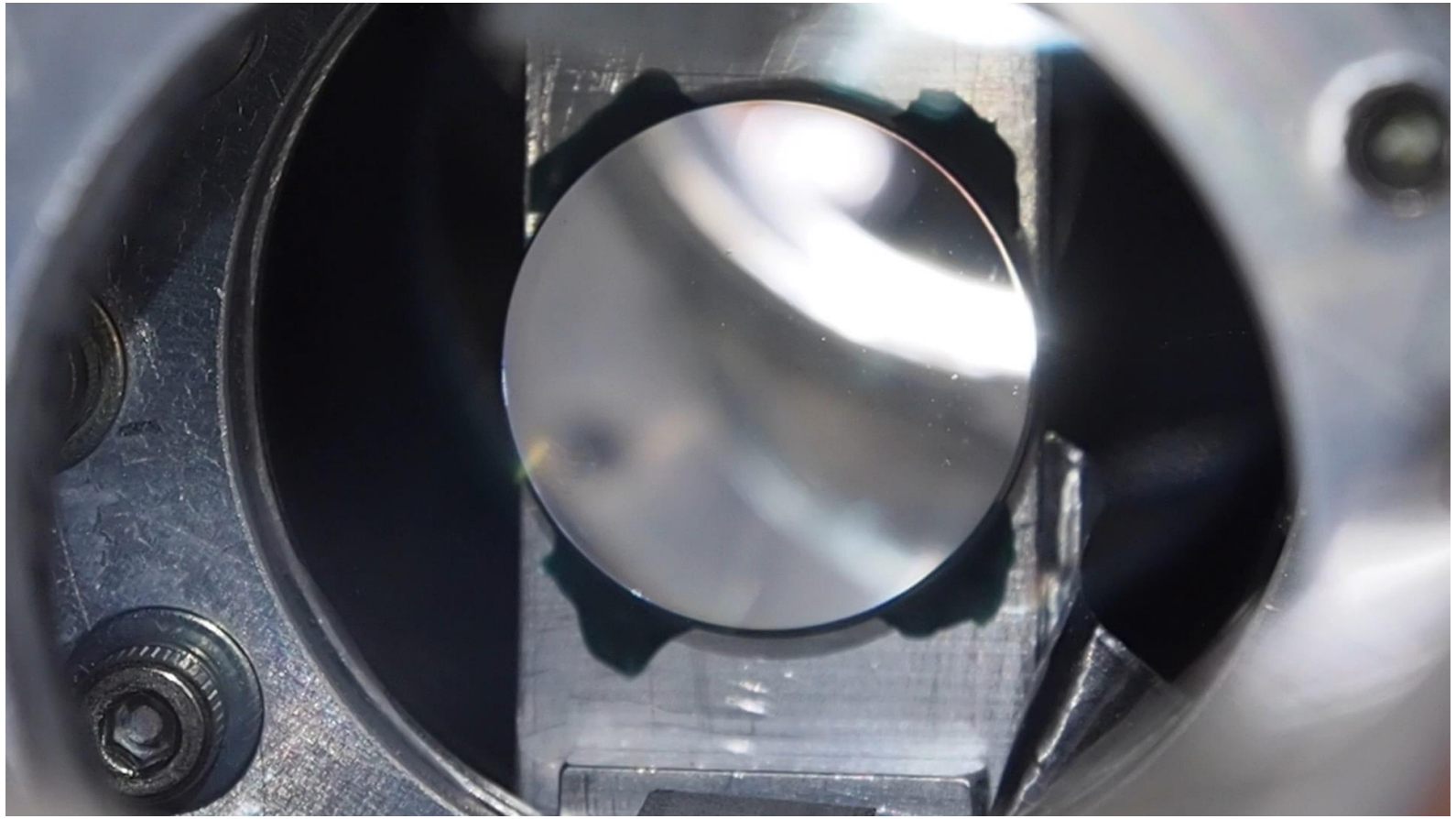
- Frosting on viewport happens below 40K and obscures OpLev signals





Test of defrosting heater

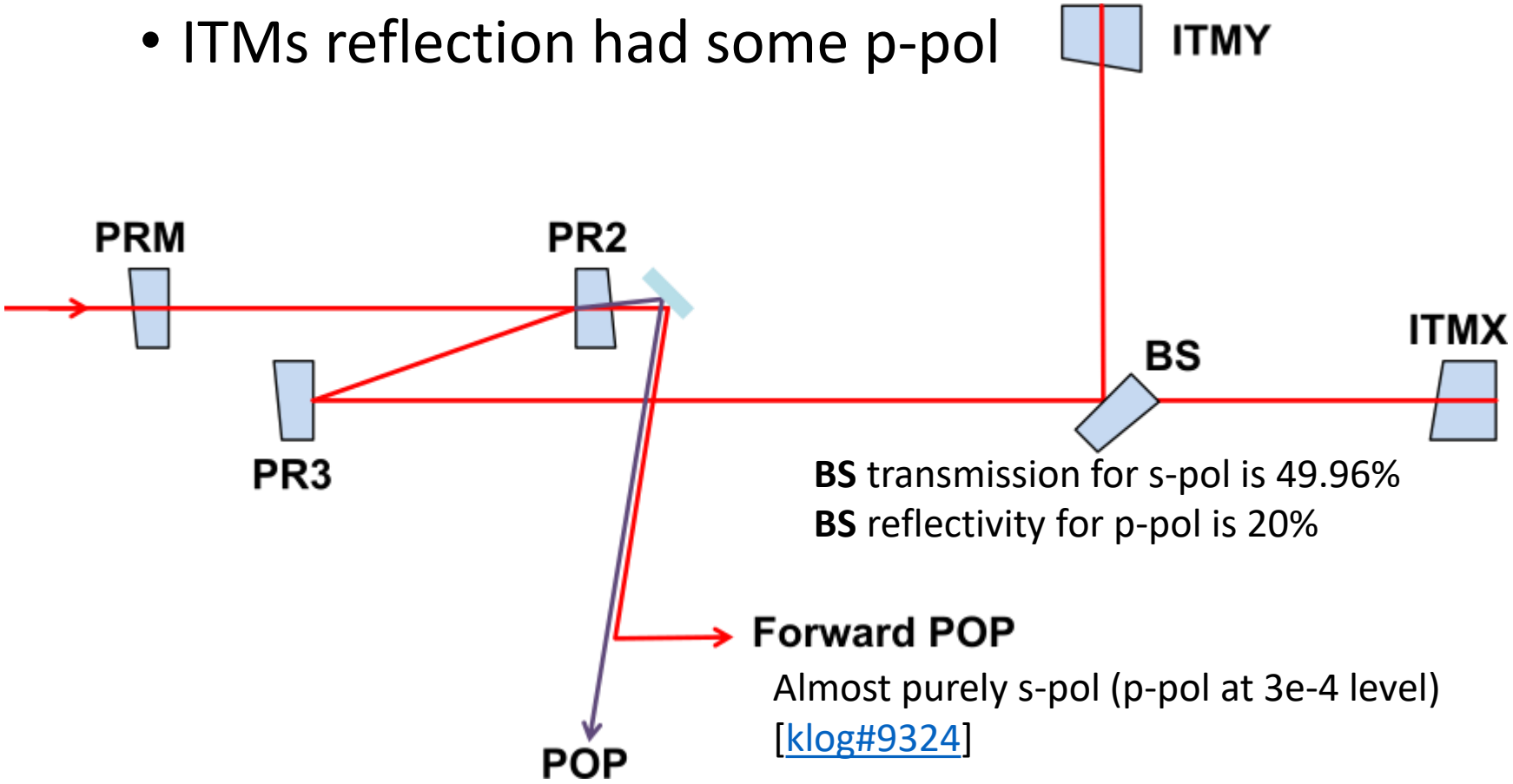




Credit: N. Kimura

Birefringence: p-pol detected

- PRC gain measured was not as expected [klog#9300, klog#9310]
- ITMs reflection had some p-pol

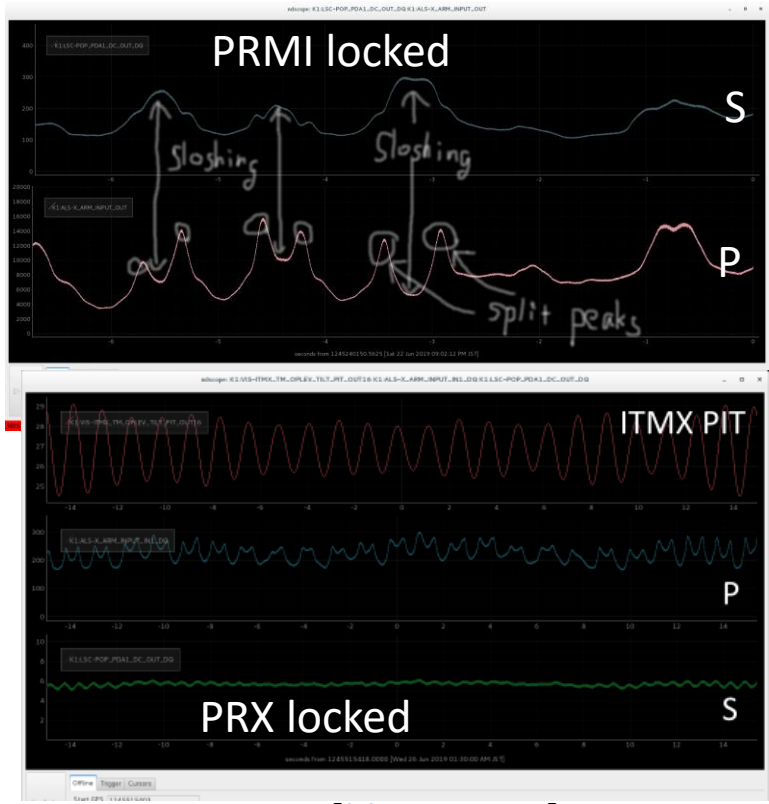


BS transmission for s-pol is 49.96%
BS reflectivity for p-pol is 20%

Forward POP

Almost purely s-pol (p-pol at 3e-4 level) [klog#9324]

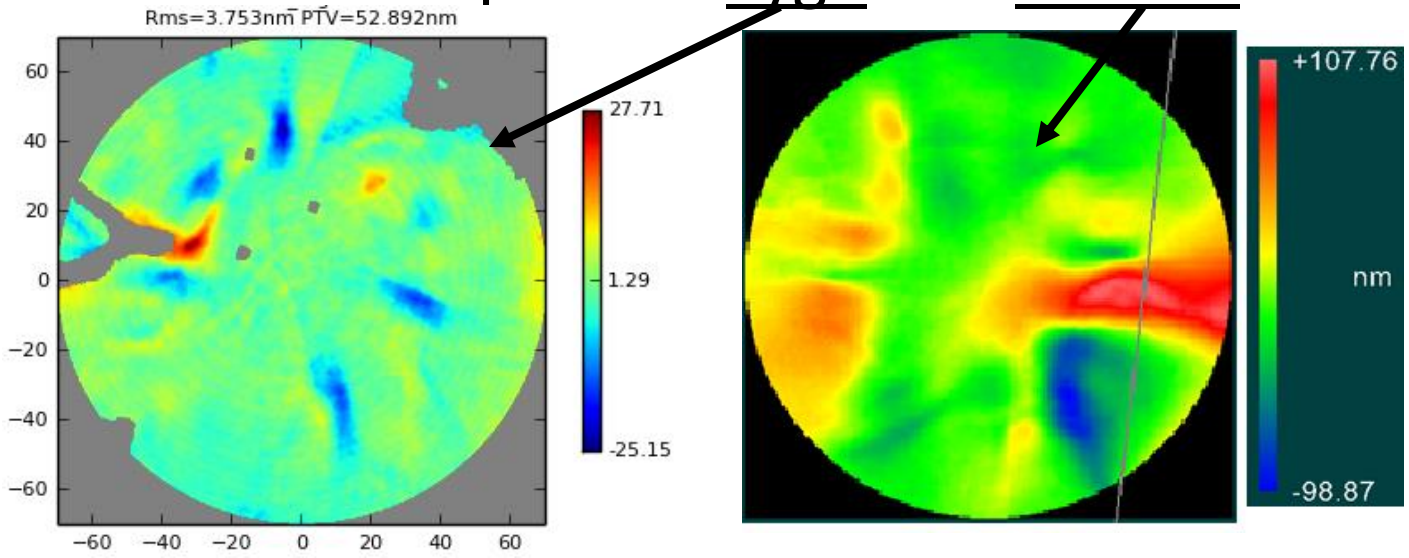
9.4 % p-pol from ITMX single bounce
4.6 % p-pol from ITMY single bounce [klog#9314]



[klog#9325]

A different issue: TWE maps of ITMs

- TWE maps from Zygo and Caltech were different

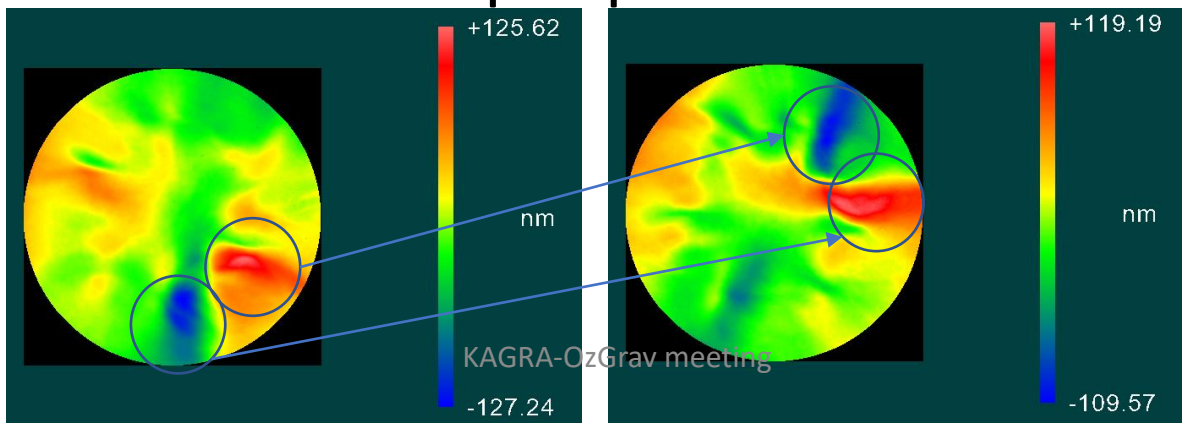


	spec.	Zygo	Caltech
ITMX	< 6nm	3.47nm	25.9nm
ITMY		4.07nm	30.1nm

More in JGW-T1809173, Phys. Rev. Applied 14, 014021 (2020) and future papers

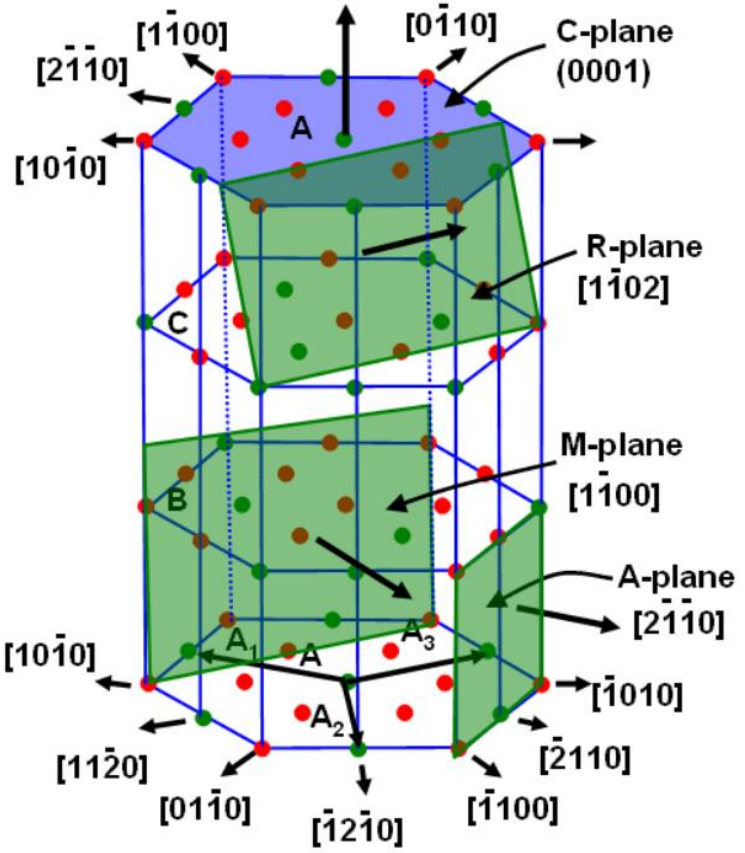
- Different maps for different input polarization

0 deg



90 deg

ITMs Birefringence



Substrate original requirements:

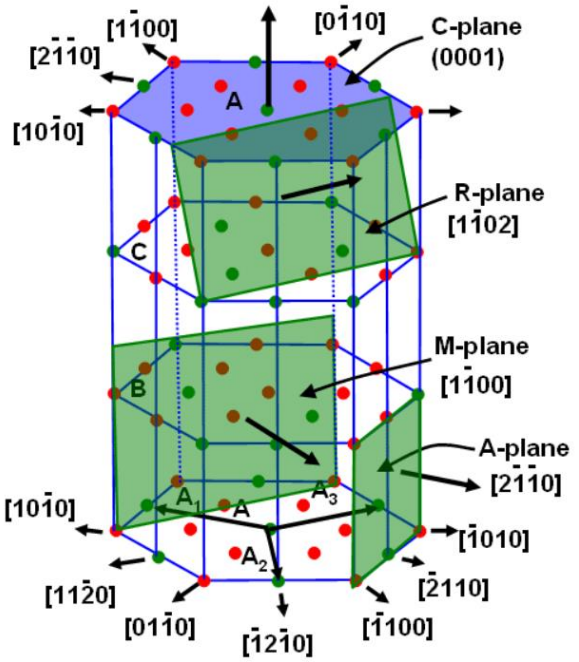
- Crystal orientation: c-plane +/- 0.2deg
- dn< 5e-7 (RMS) @633nm
  - No requirements on $dn_b \propto n_o - n_e$

Can we use the TWE maps to confirm the p-pol measurement?

$$\Delta l_b \rightarrow \alpha = \frac{2\pi\Delta l_b}{\lambda} \longrightarrow \rho \approx \alpha^2 \longrightarrow \begin{matrix} 7.0\%\ @X \\ 9.5\%\ @Y \end{matrix} \longrightarrow \begin{matrix} 10.8\% \\ 4.0\% \end{matrix} @POP \begin{pmatrix} 9.4\% \\ 4.8\% \end{pmatrix}$$

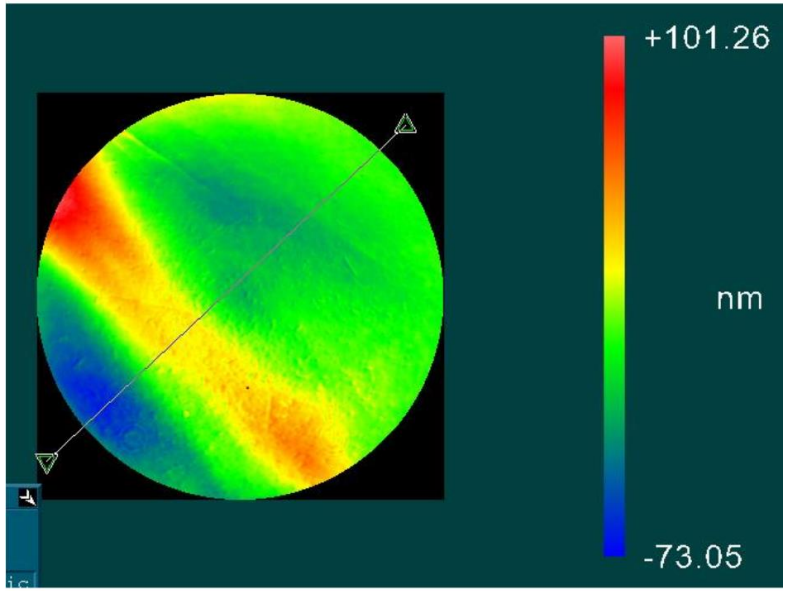
More in JGW- G1910369

Study on “spare ETMX”



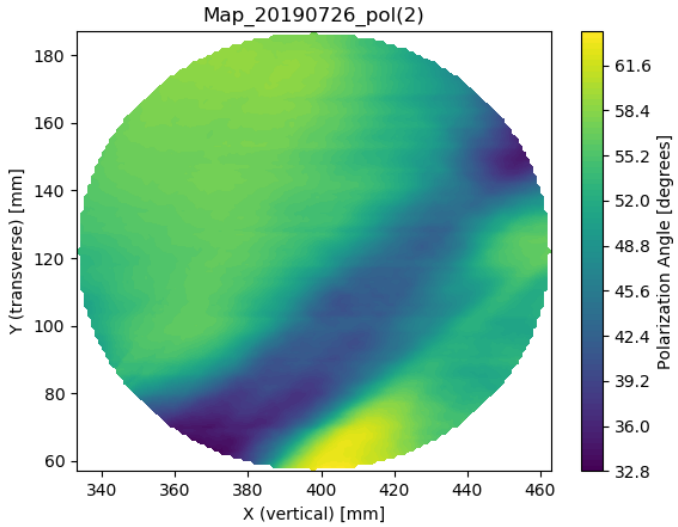
Spare ETMs

- full size sapphire substrates, pre-polished, uncoated
- characterized at Caltech (TWE maps available)



RMS @140mm = 25.9nm

JGW-T1909948



STD @130mm = 6.38deg

$\theta = \frac{2\pi\Delta l_b}{\lambda} \rightarrow 18.8\text{nm}$

Results:

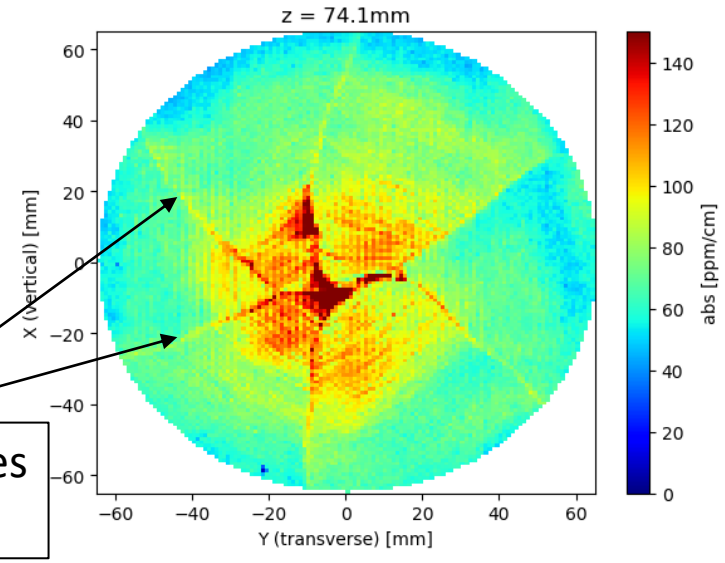
- Comparable spatial distribution
- Similar RMS/STD

Issues:

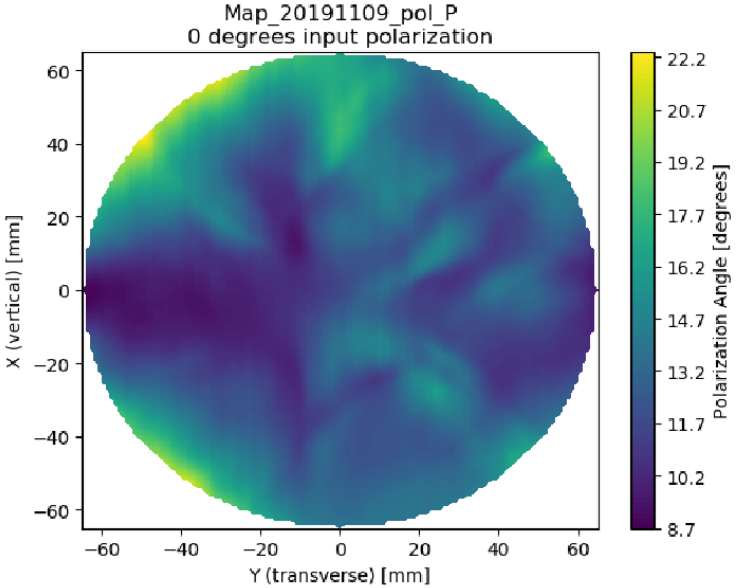
- Different growth method w.r.t. ITMs

Investigation on discarded ITM

- Absorption maps shows high optical absorption -> not suitable as ITM
- Birefringence map shows similar spatial properties compared to absorption map



M- and R-planes intersections



Optical absorption are related to crystal structure (dislocations), is birefringence too?

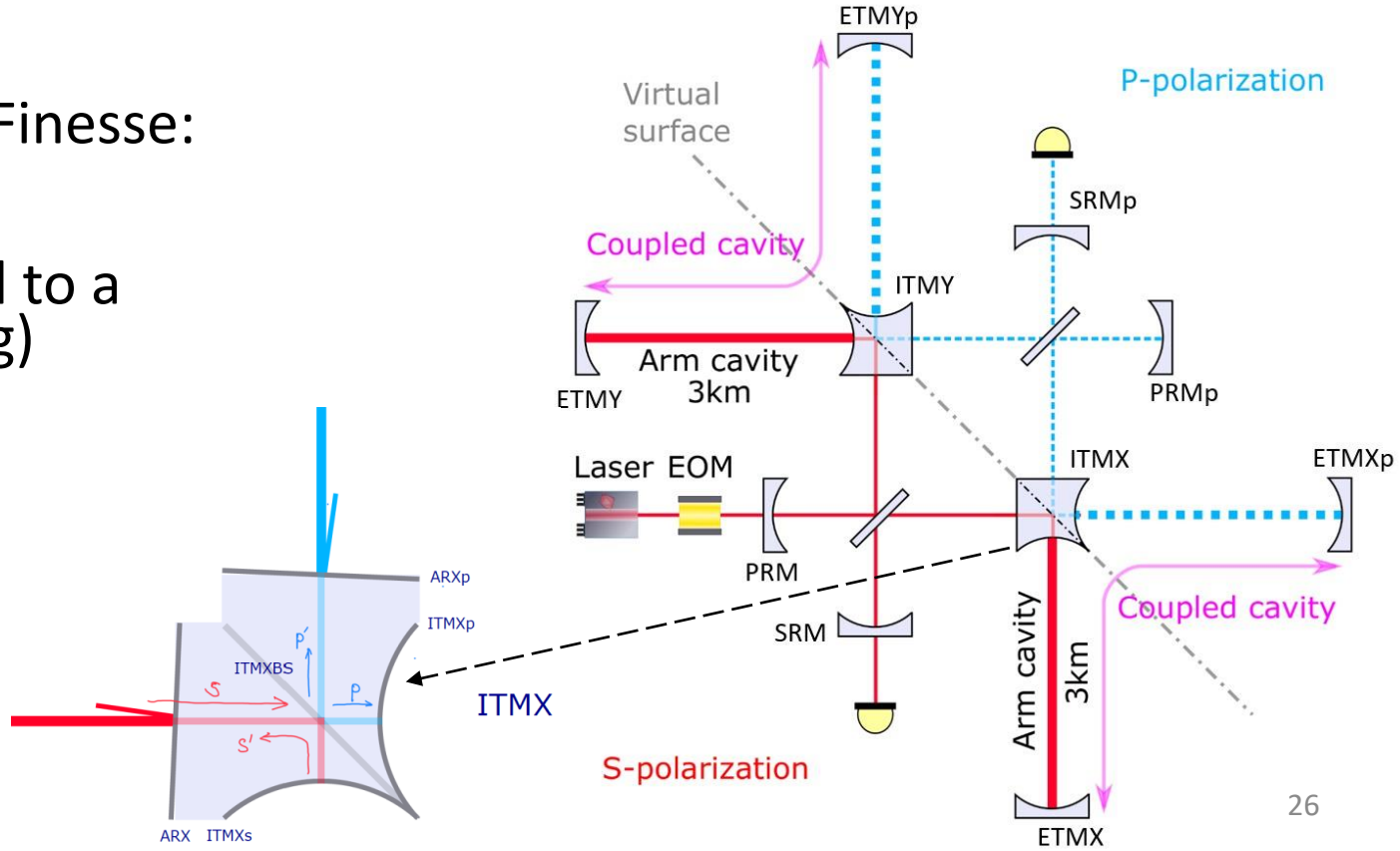
Impact on the interferometer

- When arm cavities are on resonance, birefringence does not affect the carrier (mode healing effect) -> PRG is as expected for the carrier
- Sidebands don’t enter arm cavities (no mode healing) -> PRG@sidebands is very low and error signals are affected by birefringence -> investigations ongoing

Started ad-hoc simulation using Finesse:

- s-pol/p-pol ITFs
- Birefringence maps are applied to a virtual beam splitter (AOI=0deg)
- First validation step: PRMI

More in [JGW-T2011792]



Summary

Status:

- KAGRA successfully locked in PRFPMI and performed a joint run (O3GK) with sensitivity a little below 1MPc
- Currently in upgrade phase: target of (at least) 25MPc for O4

Issues:

- Seismic coupling due to heat link reduced with HLVIS
- Frosting problem analyzed and understood: installed heater for viewports
- Birefringence in sapphire: study still ongoing