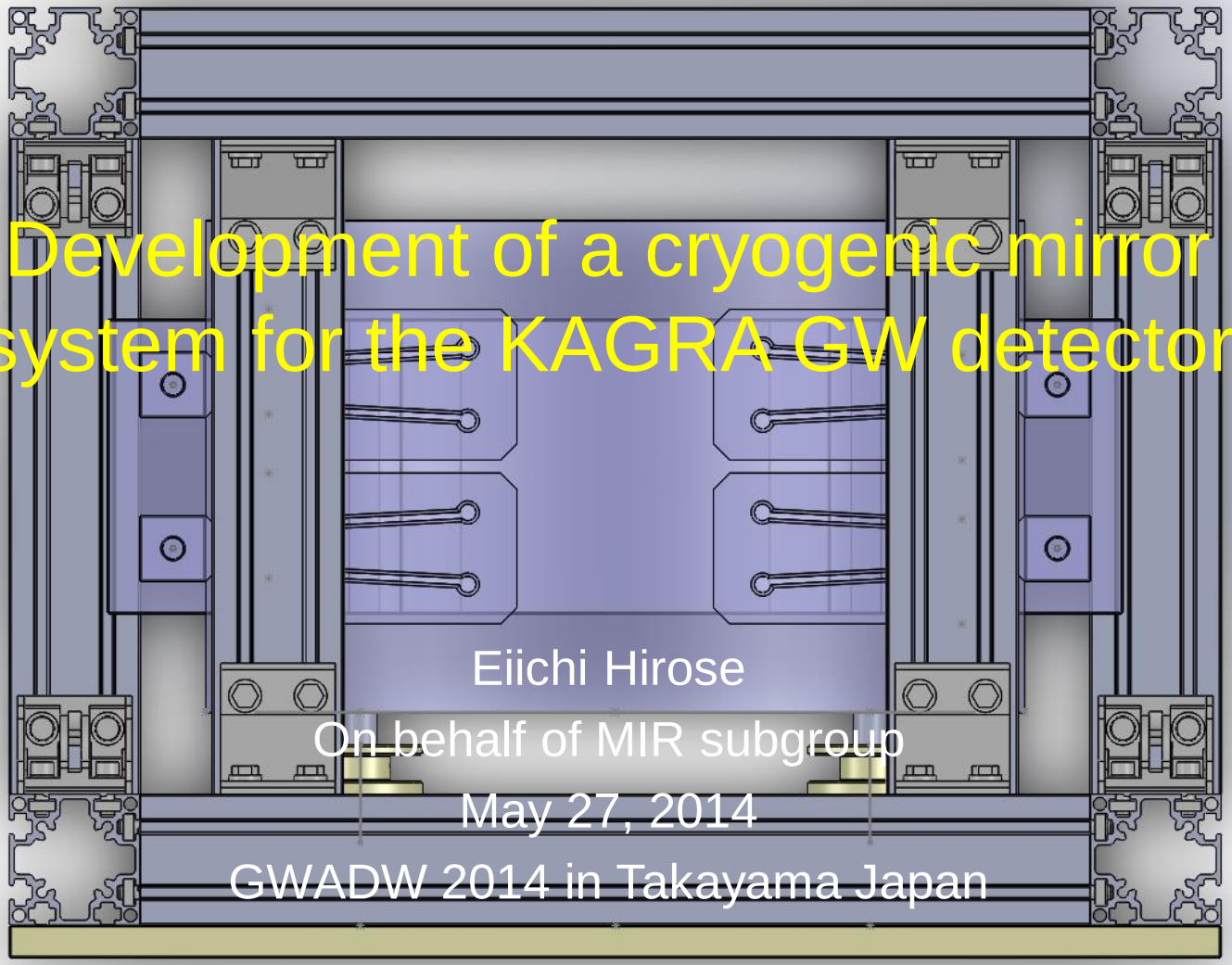
# Development of a cryogenic mirror system for the KAGRA GW detector



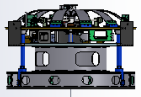
Eiichi Hirose

On behalf of MIR subgroup

May 27, 2014

GWADW 2014 in Takayama Japan

Type-A



F0: IP+GASF

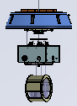
F1: MD+GASF

room temp

F2: GASF

F3: GASF

F4: GASF

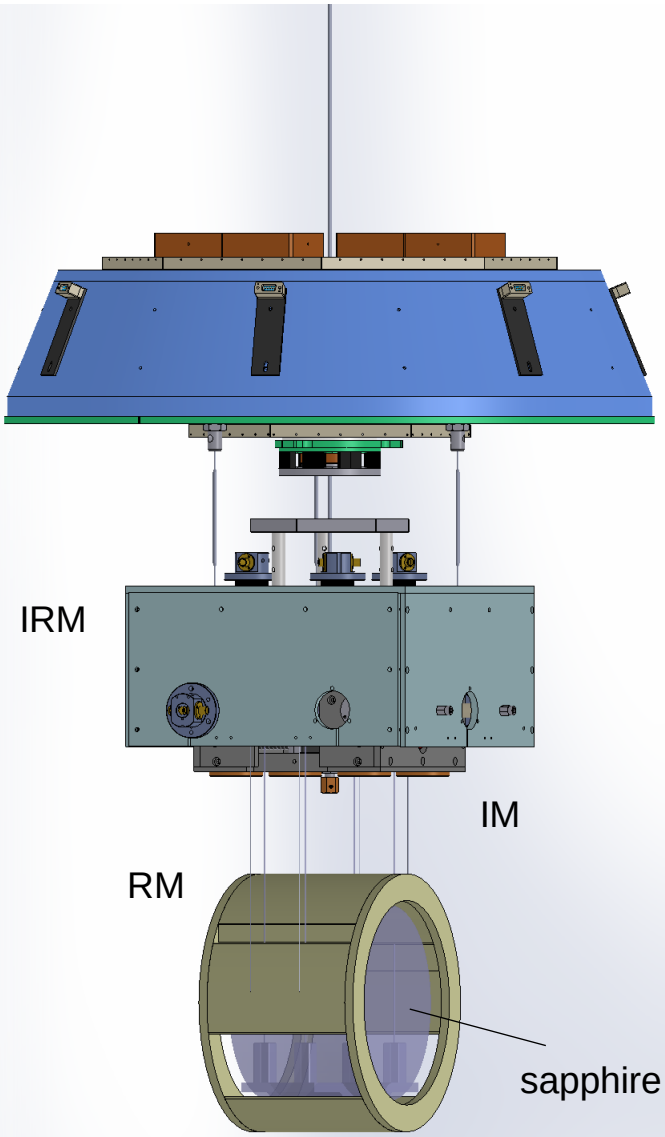


PF: GASF

IM+IRM

TM+RM

cryogenic

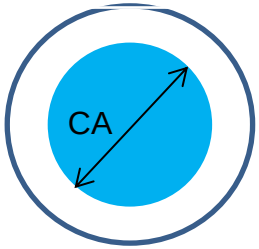


# Summary

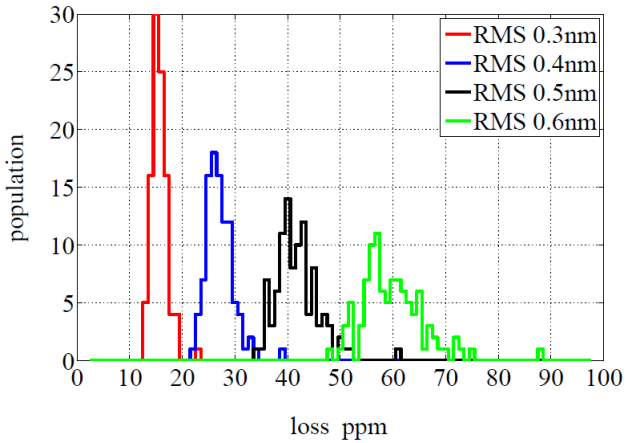
| **Mirror** | |
|---|---|
| Bulk | Crystal maker is working for smaller absorption / inhomogeneity |
| test polish | Successfully done (Phys. Rev. D 89, 062003) |
| coating R&D | ETM-like coating R&D is in progress and will be characterized in the near future. Joint coating research between ICRR and Glasgow is in progress (mechanical loss measurement) |
| side design | Not determined |
| **Type-A SAS** | (the room temp. part is designed and manufactured by VIS) |
| Mathematical model w/ control | Takanori Sekiguchi developed a tool for SAS (SUMCON) and implemented a feedback control with Simulink. |
| Preliminary design | Followed the room tem. SAS, reflecting the above model. But, lots of detailed design has to be addressed, such as vertical GASF that works below 20K, moving masses for attitude control for PF and IM, sensors and actuators, how to suspend TM, … |
| Final design of PF+IM+IRM | We contacted a company for the final design based on the above preliminary design and are discussing what can be done. |
| sapphire fiber and its bonding | Extensively investigated by the CRY group with EliTES collaboration. |
| sapphire suspension | In consideration. A prototype is being made for upper stage design |

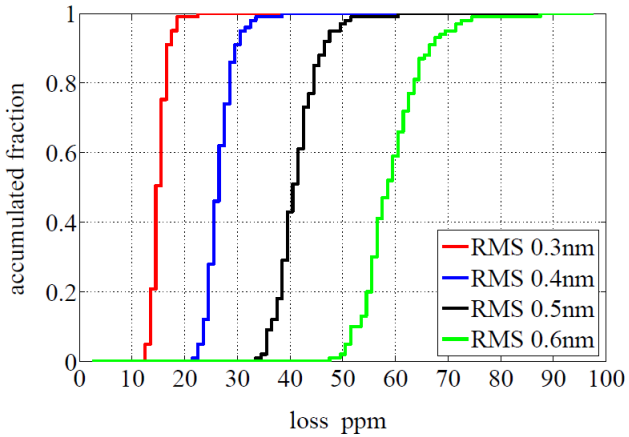
# Design with SIS

| [ppm] | KAGRA | | Advanced LIGO |
|---|---|---|---|
| | budget | evaluation | budget |
| **diffraction** | (1) | substrate's size | 1 |
| **defect in polished surface** | 1+1 | surface quality | 0 |
| **scattering in coating** | 9+9 | measurement | 4+4 |
| **figure (LSF)** | 30+30 | SIS | 20+20 |
| **roughness (HSF)** | 5+5 | $\sigma_{rms}$ | 10+10 |
| **absorption in coating** | 1+1 | measurement | 0.5+0.5 |
| **ETM transmission** | 7 | measurement | 5 |
| Total | 100 | - | 75 |




CA: R = 140mm
r < 70mm: RMS = 0.5nm
r > 70mm: RMS = 2nm



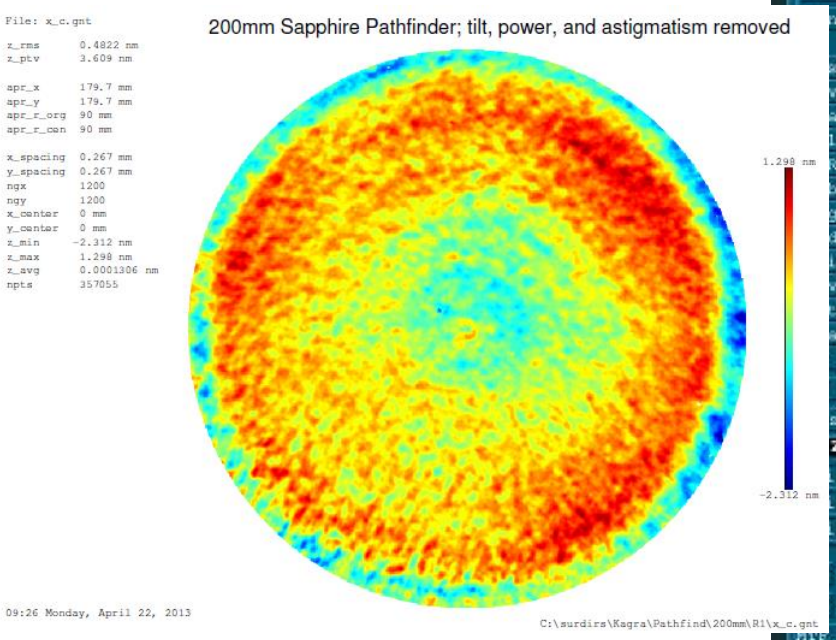



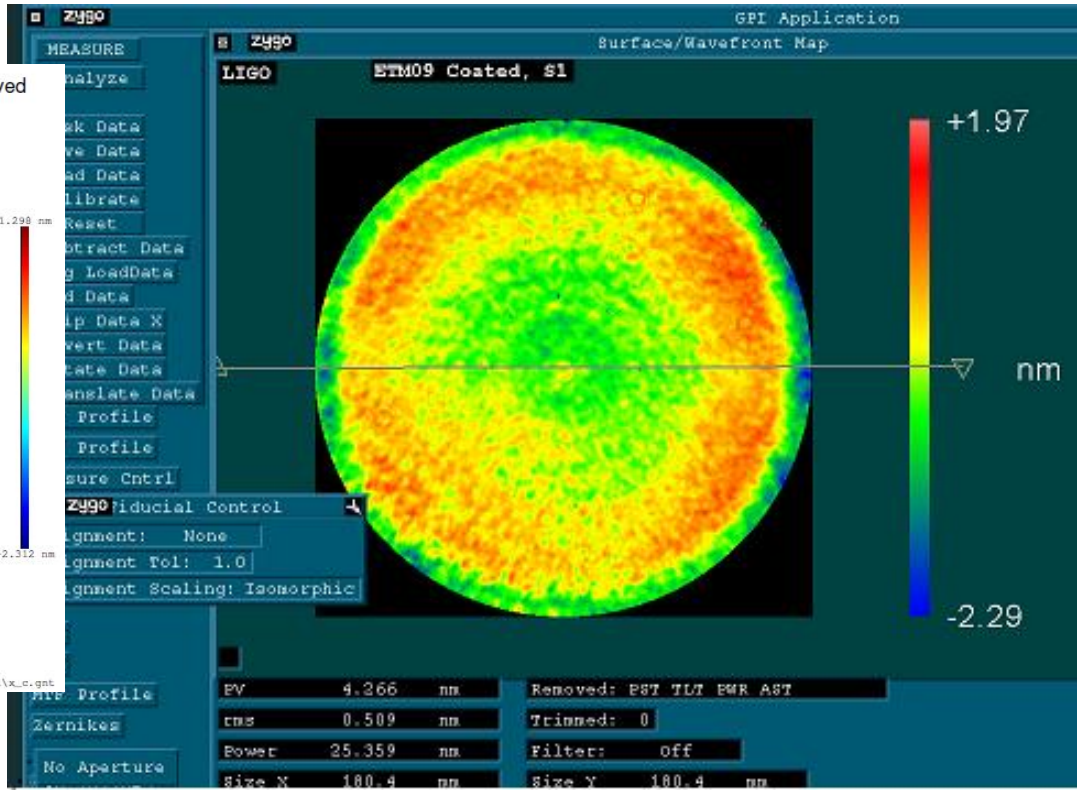
# Pathfinder (test polish)

## 200mm Pathfinder Result Summary

| | Final Results | | Pass / Fail | Specification Values | | |
|---|---|---|---|---|---|---|
| R1 @ 180mm Diameter | Value | Units | | Target Spec. | + | - |
| Radius | 2250.64 | m | | -- | | |
| $Z_{2,2}$ | -0.68 | nm | | -- | | |
| $Z_{2,-2}$ | 0.45 | nm | | -- | | |
| RSS ($Z_{2,2}$ & $Z_{2,-2}$) | 0.81 | nm | | -- | | |
| Figure $Z_{0,0}$ $Z_{1,1}$ $Z_{1,-1}$ & $Z_{2,0}$ Removed rms | 0.59 | nm | | -- | | |
| Figure $Z_{0,0}$ $Z_{1,1}$ $Z_{1,-1}$ $Z_{2,0}$ $Z_{2,2}$ & $Z_{2,-2}$ Removed rms | 0.48 | nm | pass | 0 | 2 | |
| | | | | | | |
| R1 @ 140mm Diameter | | | | | | |
| Radius | 2001.90 | m | pass | 2000 | 10 | 10 |
| $Z_{2,2}$ | -0.41 | nm | | -- | | |
| $Z_{2,-2}$ | 0.26 | nm | | -- | | |
| RSS ($Z_{2,2}$ & $Z_{2,-2}$) | 0.48 | nm | pass | 0 | 3 | |
| Figure $Z_{0,0}$ $Z_{1,1}$ $Z_{1,-1}$ & $Z_{2,0}$ Removed rms | 0.31 | nm | | -- | | |
| Figure $Z_{0,0}$ $Z_{1,1}$ $Z_{1,-1}$ $Z_{2,0}$ $Z_{2,2}$ & $Z_{2,-2}$ Removed rms | 0.24 | nm | pass | 0 | 0.5 | |
| | | | | | | |
| R1 High Spatial Frequency Errors | | | | | | |
| 1-750 mm-1 | 0.11 | nm | pass | 0 | 0.16 | |
| | | | | | | |
| R1 Surface Quality | | | | | | |
| Defect area @ 100mm Diameter | 0 | $\mu m^2$ | pass | 0 | 2000 | |
| Defect area @ 180mm Diameter | 14200 | $\mu m^2$ | pass | 0 | 30000 | |
| Point Defect > 2 µm Count @ 100mm Diameter | 0 | | pass | 0 | 10 | |
| Point Defect > 2 µm Count @ 200mm Diameter | 0 | | pass | 0 | 82 | |
| Point Defect < 2 µm Density @ 180mm Diameter | 0.00 | 1 / $mm^2$ | pass | 0 | 0.25 | |

A target specification value of "--" Indicates that there is no specification.
Zernikes from Born and Wolf pp. 523-525.

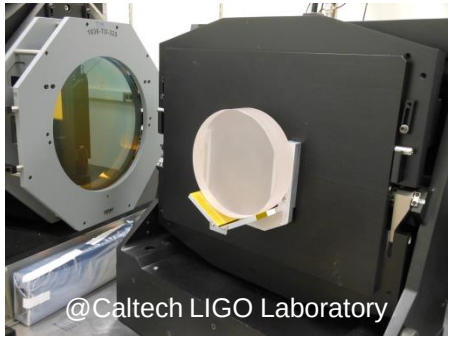


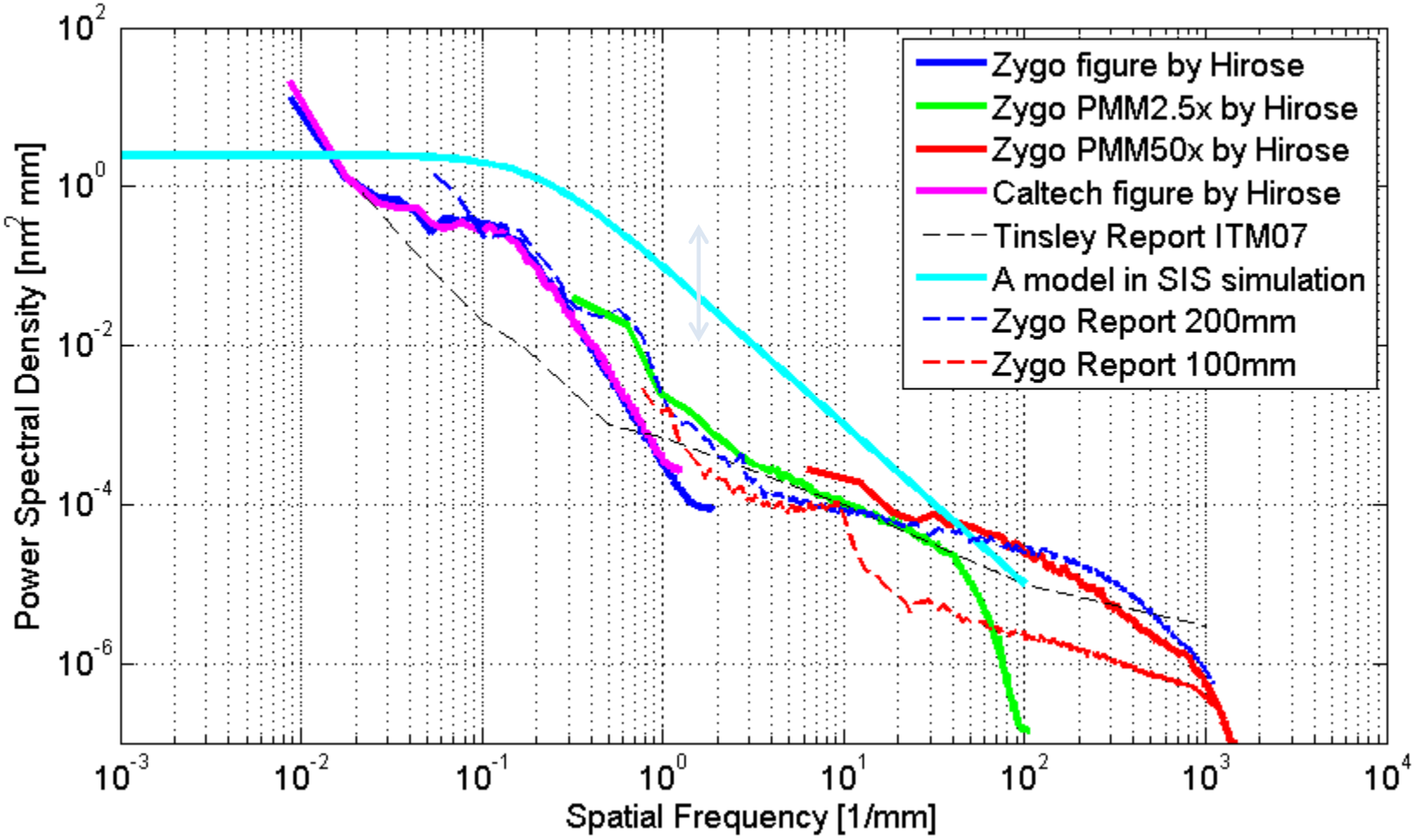

**ZYGO's report**

**Measurement at Caltech**

| Unit: [nm] | 180mm | 140mm | 180mm | 140mm |
|---|---|---|---|---|
| RMS (6 terms subtracted) | 0.48 | 0.24 | 0.45 | 0.21 |
| Z2,2 | -0.68 | -0.41 | -0.30 | -0.13 |
| Z2,-2 | 0.45 | 0.26 | 0.29 | 0.27 |



# PSD

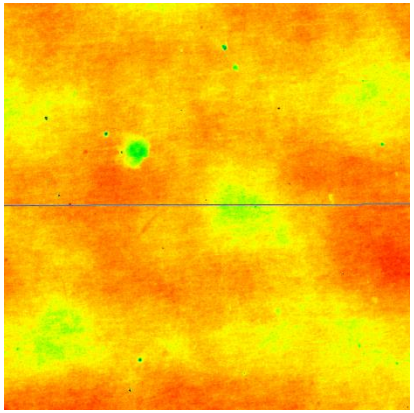

Zygo figure by Hirose
Zygo PMM2.5x by Hirose
Zygo PMM50x by Hirose
Caltech figure by Hirose
Tinsley Report ITM07
A model in SIS simulation
Zygo Report 200mm
Zygo Report 100mm
Power Spectral Density [nm² mm]
Spatial Frequency [1/mm]
10^2
10^0
10^-2
10^-4
10^-6
10^-3
10^-2
10^-1
10^0
10^1
10^2
10^3
10^4

# High spatial frequency

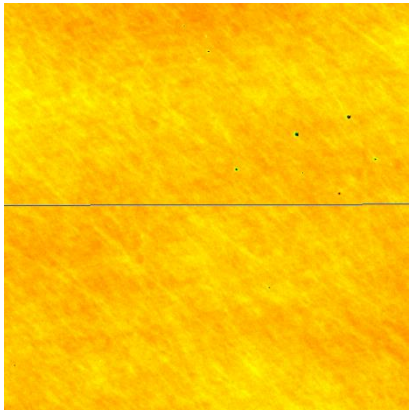
4.9mm

0.25mm

Standard
(200mm)



PV = 1.764nm
rms = 0.112nm

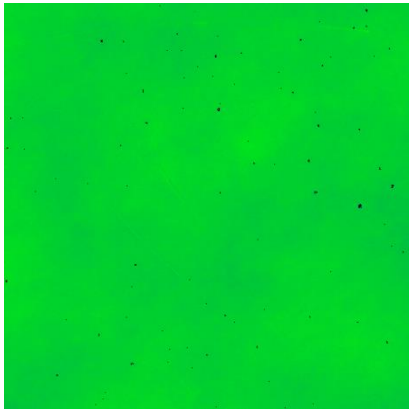


PV = 3.428nm
rms = 0.079nm

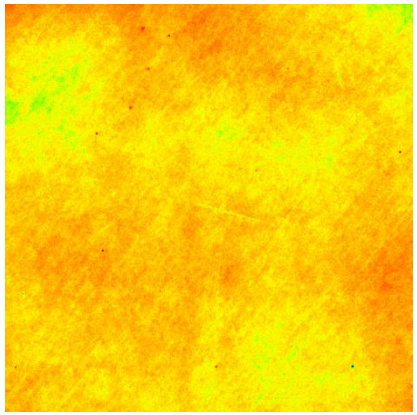
2.5x

50x

LAOS
(100mm)



PV = 8.469nm
rms = 0.074nm

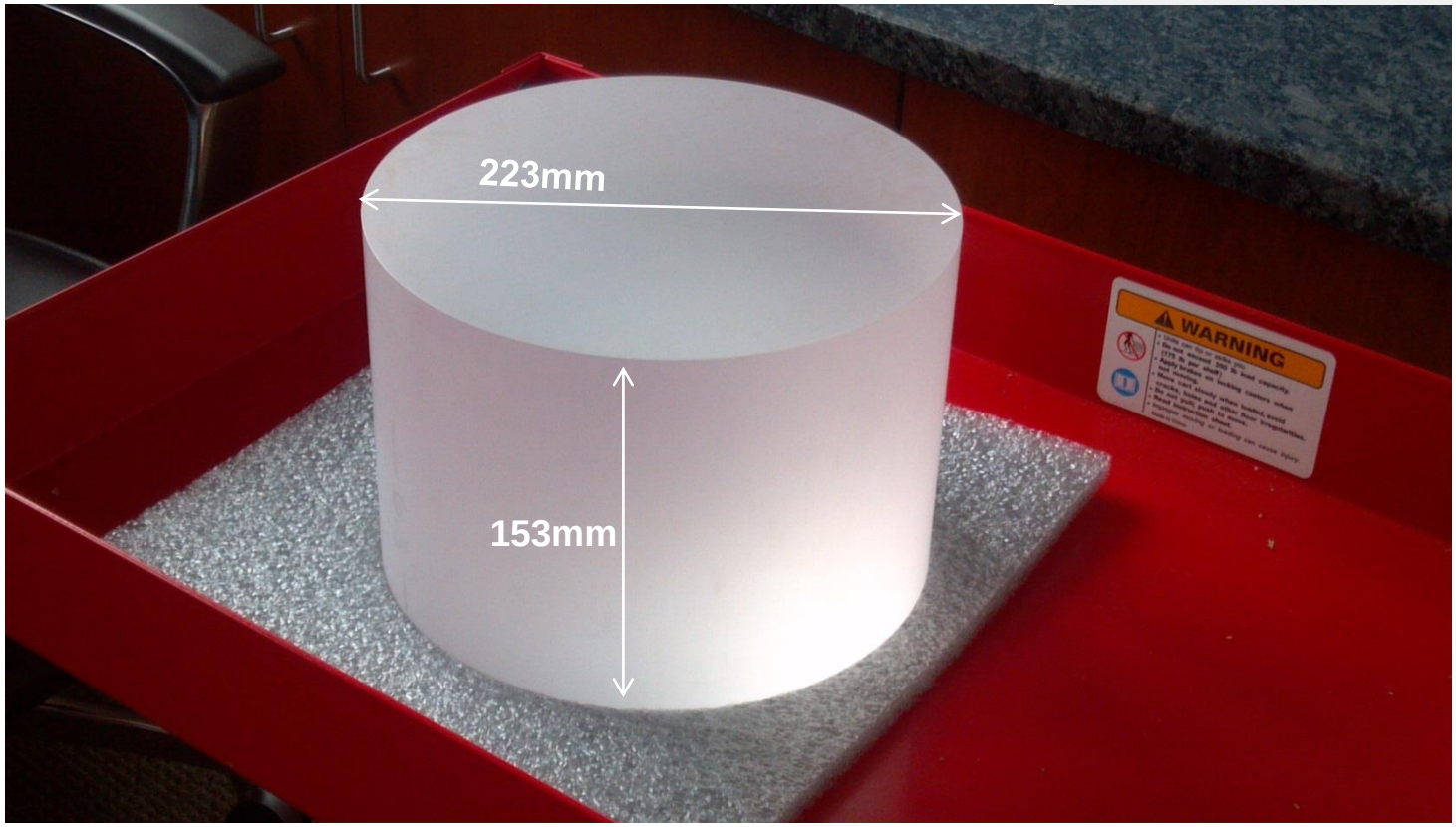


PV = 1.082nm
rms = 0.049nm

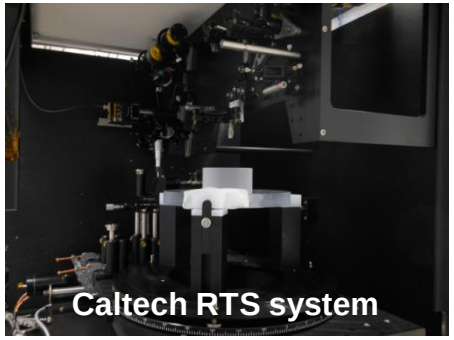
2.5x

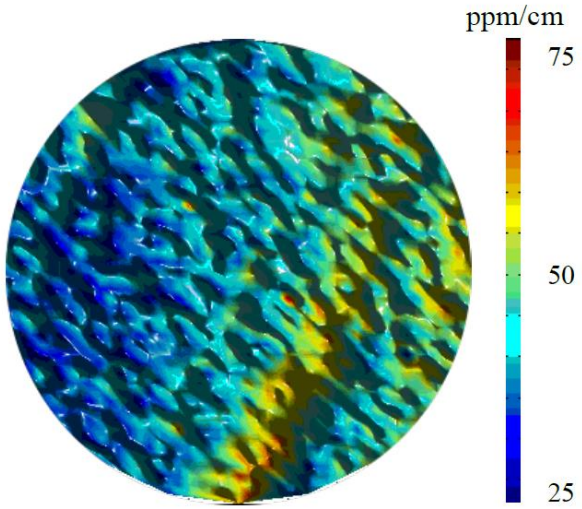
50x

# Sapphire crystal

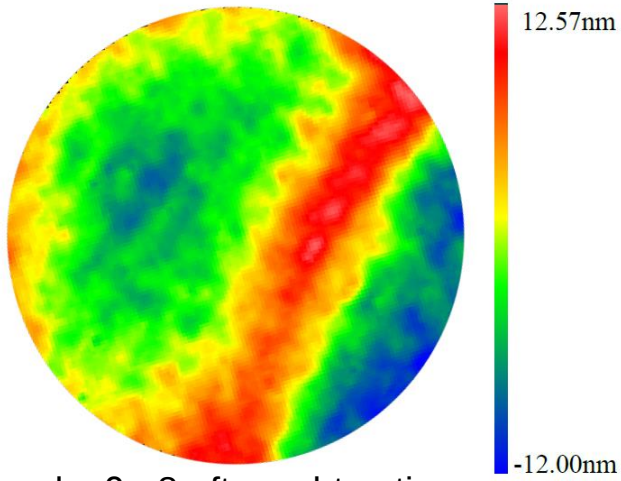


# Absorption and homogeneity of bulk

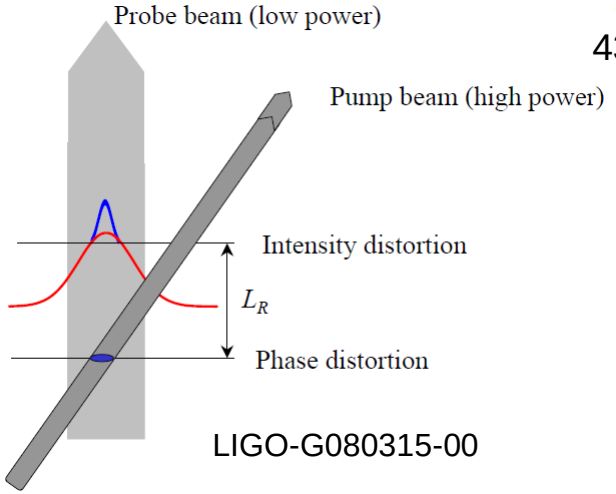


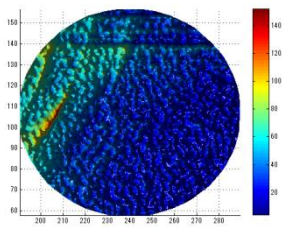

43.4ppm/cm




dn≈8e-8 after subtraction
up to power term

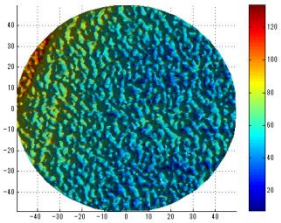



LIGO-G080315-00



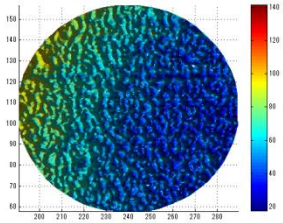
35.1ppm/cm

side1



55.5ppm/cm

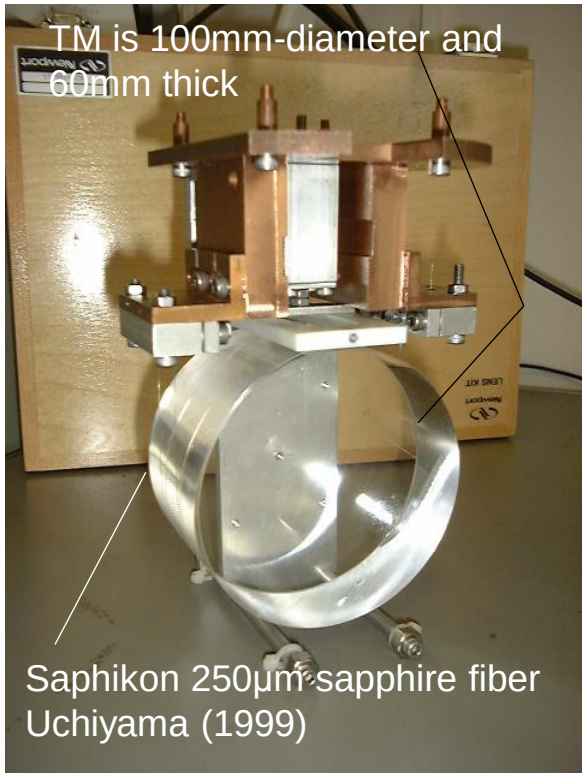
central



55.1ppm/cm

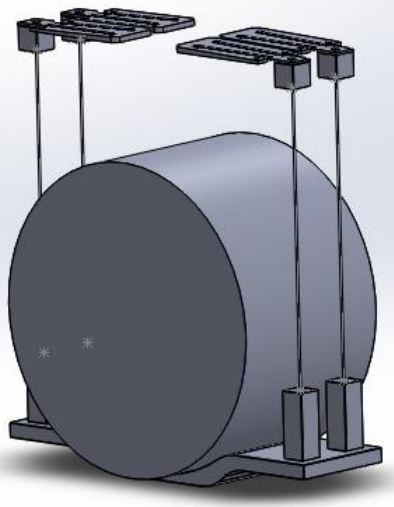
side2

# Sapphire suspension

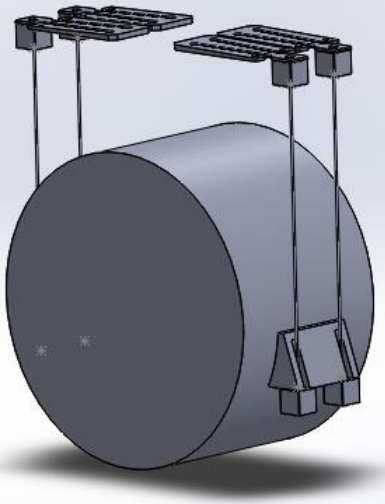



loop type

TM is 220mm-diameter and 150mm thick, and sapphire rods have to work as heat paths
→ thicker fiber (~1.6mm) is needed and making a loop is tough.



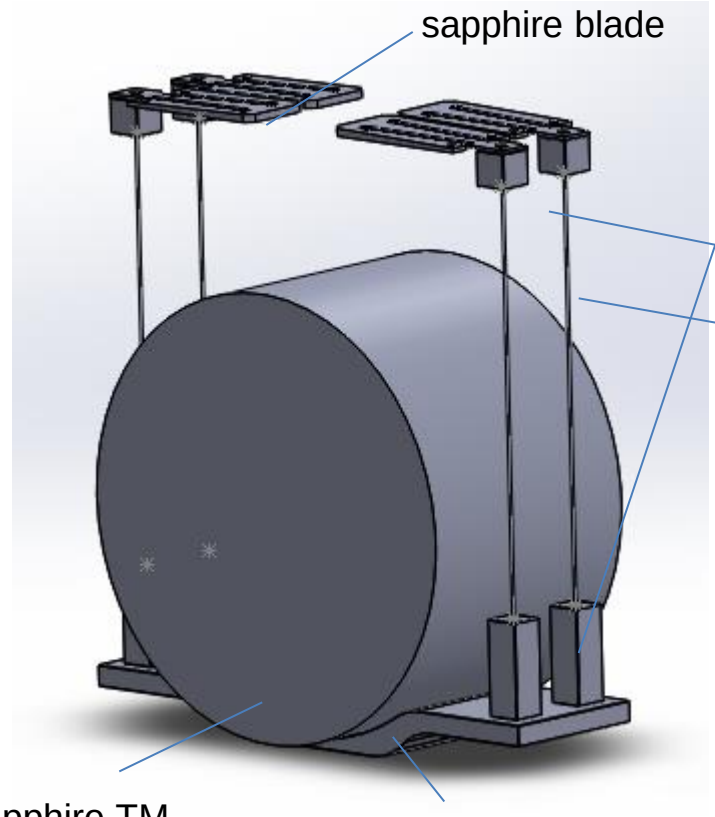
cradle+bolts



ear+hooking

**It is a challenging issue, but we need to start with a configuration with which we can develop upper stages (PF+IM+IRM).**

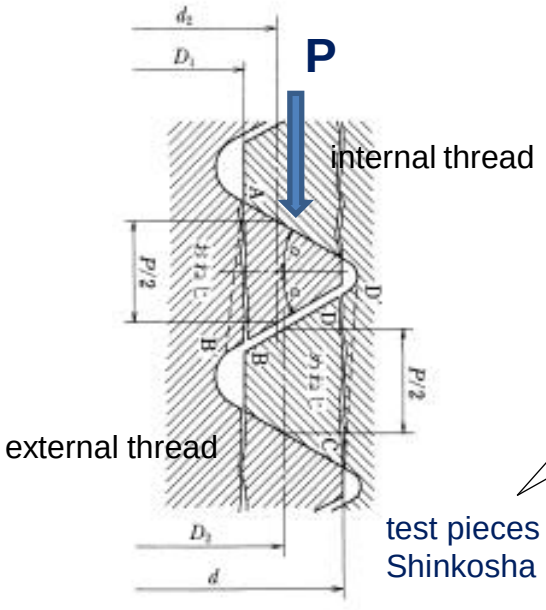
# Prototype fabrication

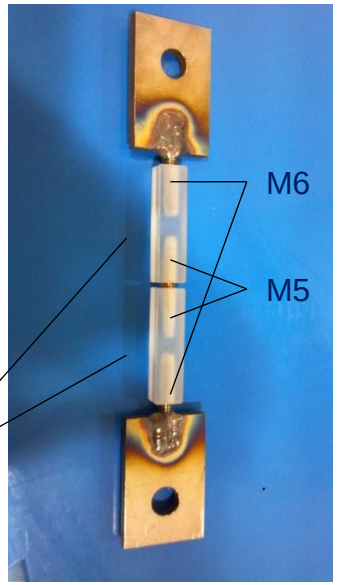


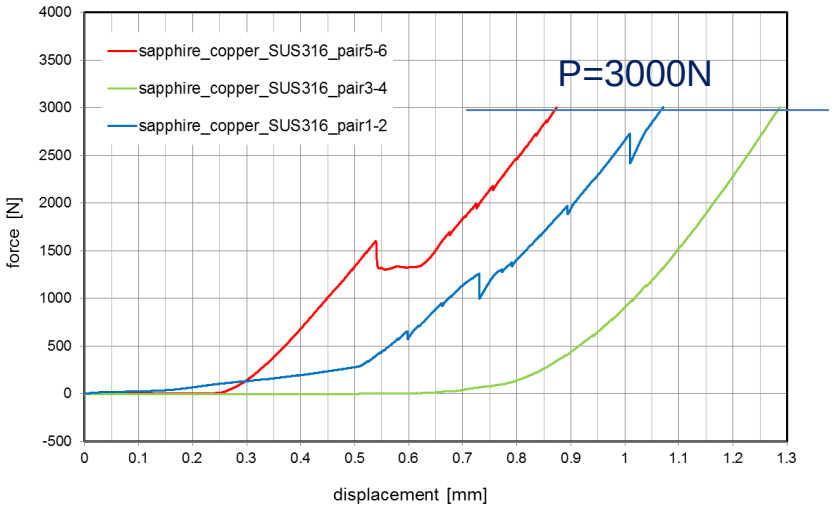

**Shinkosha Co., ltd is working on these parts and they will be delivered in a month or so.**

# pulling test of screw thread @ 77K

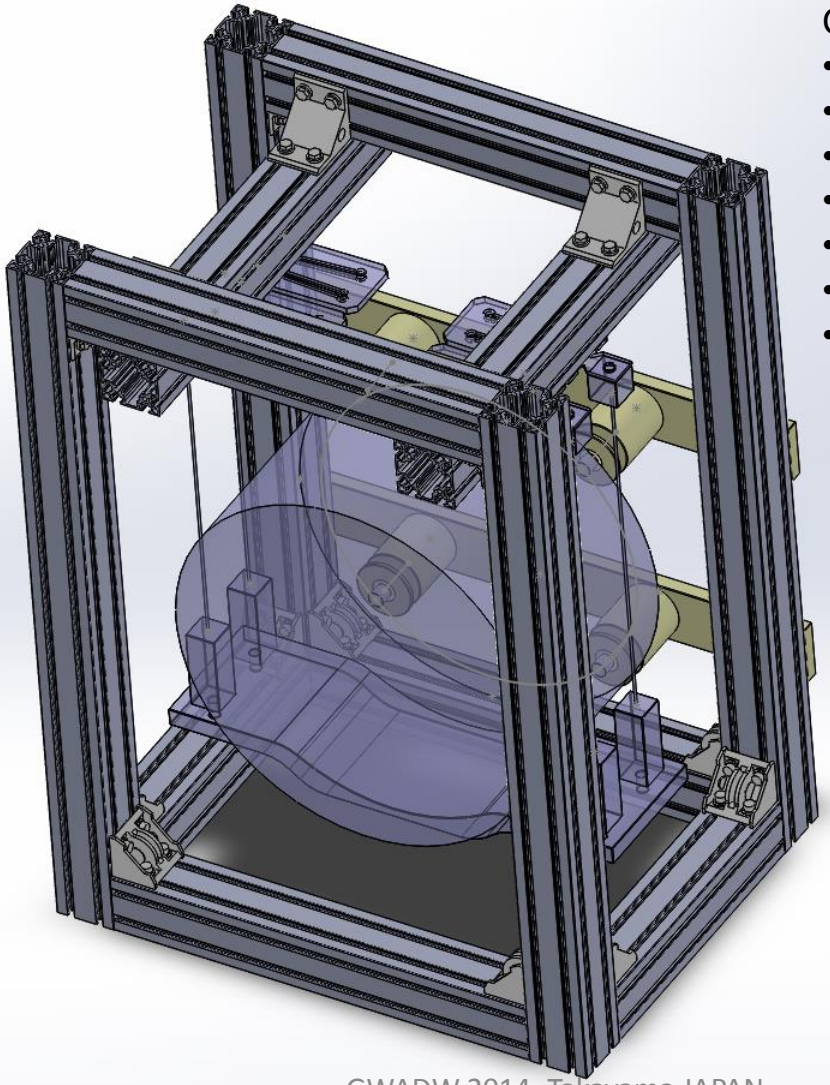
| | diameter | length | minor dia. of external thread | pitch | # of threads | shear stress | | bending stress | | flank surface pressure | stress @ min. dia. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | d = D | L [mm] | d1=D1 [mm] | Pitch, Pp [mm] | z = L/Pp [mm] | external τ1 [MPa] | internal τ2 [MPa] | external σ1 [MPa] | internal σ2 [MPa] | σ3 [MPa] | P/(d1^2/4) σ0 [MPa] |
| tested P [N] | 3000 | | | | | | | | | | |
| M6 | 6 | 10 | 4.917 | 1 | 9.5 | 27.26 | 19.71 | 59.09 | 37.89 | 34.01 | 157.99 |
| M5 | 5 | 7 | 4.134 | 0.8 | 8.25 | 46.67 | 34.04 | 101.16 | 65.45 | 58.53 | 223.51 |
| expected P [N] | 60 | | | | | | | | | | |
| M6 | 6 | 10 | 4.917 | 1 | 9.5 | 0.55 | 0.39 | 1.18 | 0.76 | 0.68 | 3.16 |
| M1.8 | 1.8 | 7 | 1.421 | 0.35 | 19.5 | 2.63 | 1.83 | 5.69 | 3.52 | 3.21 | 37.83 |
| M1.6 | 1.6 | 5 | 1.221 | 0.35 | 13.79 | 4.32 | 2.91 | 9.37 | 5.60 | 5.18 | 51.24 |



# prototype test



Check list

- Strength
- Integration / disintegration
- Heat resistance between interfaces
- Blade performance (bounce mode)
- Fiber Q
- dynamics (pitch, yaw, longitudinal)
- Improvement by replacing parts or changing configuration

**Important message**

We will start with this configuration but try improving the system continuously. It would be bad if we did not do anything until we know the perfect configuration

# contributors

**Sapphire mirror design and fabrication**
E. Hirose, D Bajuk, G. Billingsley, T. Kajita, B. Kestner, N. Mio, M. Ohashi, B. Reichman, H. Yamamoto, and L. Zhang

**ICRR-Glasgow joint research on mechanical loss measurement**
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**type-A SAS development for the KAGRA sapphire mirror**
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# acknowledgments

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