Future Plan in/from KAGRA

1, May, 2019

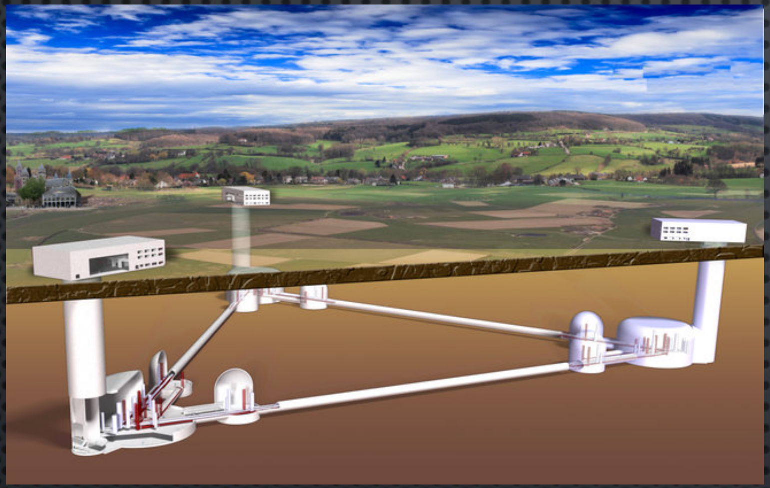
@ Vacuum Fluctuation at Nanoscale and Gravitation conference

Takayuki TOMARU on behalf of KAGRA

National Astronomical Observatory of Japan

KAGRA: 2.5nd Generation GW Detector

Einstein Telescope (Europe), 10km



Cosmic Explorer (USA), 40km

Collaboration in Technologies

KAGRA Upgrade in Near Future

10km scale Asian Telescope?

LIGO Vacuum Workshop

PRELIMINARY AGENDA: NSF Workshop on Large UHV Systems for Frontier Scientific Research					
HFD/RW/MEZ, 24 Jan 2019					
date	**start**	**duration (')**	**title**	**speaker/leader**	**affiliation(s)**
1/29/19	8:00 AM	60	*Coffee*		
	9:00 AM	0	**Introduction & Background**		
	9:00 AM	10	Welcome	D. Reitze	LIGO
	9:10 AM	5	Visitor safety briefing	R. Oram	LIGO
	9:15 AM	10	Workshop goals	R. Weiss	LIGO
	9:25 AM	30	Vacuum Requirements for GW Interferometers	M. Zucker	LIGO
	9:55 AM	5	*discussion*		
	10:00 AM		**Existing GW Interferometer Vacuum Systems**		
	10:00 AM	30	KAGRA	Y. Saito	KAGRA
	10:30 AM	10	*discussion*		
	10:40 AM	15	*Coffee*		
	10:55 AM	30	Virgo	A. Pasqualetti	Virgo
	11:25 AM	10	*discussion*		
	11:35 AM	30	LIGO	M. Zucker	LIGO
	12:05 PM	10	*discussion*		
	12:15 PM	30	***LUNCH***		
	12:45 PM	90	*LAB TOUR*	LLO staff	
	2:15 PM		**Blue Sky Brainstorming: Options & Opportunities**		
	2:15 PM	20	Example Cosmic Explorer concept illustrating key questions	R Weiss	LIGO
	2:35 PM	5	*discussion*		
	2:40 PM	10	Nested systems	J. Noonan	ANL
	2:50 PM	5	*discussion*		
	2:55 PM	10	Comparative outgassing of XHV materials	J. Fedchack	NIST
	3:05 PM	5	*discussion*		
	3:10 PM	10	Outgassing of prebaked and optically black materials	M. Poelker	Jlab
	3:20 PM	5	*discussion*		
	3:25 PM	10	Outgassing of 304LN vs. cold-rolled carbon steel	F. Dylla	AIP
	3:35 PM	5	*discussion*		
	3:40 PM	15	*Coffee*		
	3:55 PM	10	Compact UHV optical vacuum gauge concept	J. Fedchack	NIST
	4:05 PM	5	*discussion*		
	4:10 PM	10	Accelerator experience with Al alloy vacuum systems	Y. Li	Cornell
	4:20 PM	5	*discussion*		
	4:25 PM	10	Experience & concerns with microbial-induced corrosion of SS	D. Henkel	Rimkus
	4:35 PM	5	*discussion*		
	4:40 PM	10	Distributed getter pumping for very long vacuum systems	Y. Lushtak	Cornell
	4:50 PM	5	*discussion*		
	4:55 PM	10	Options to improve vacuum performance of existing LIGO tubes	J. Noonan	ANL
	5:05 PM	5	*discussion*		
	5:10 PM	10	TBD 1	TBD	TBD
	5:20 PM	5	*discussion*		
	5:25 PM	10	TBD 2	TBD	TBD
	5:35 PM	5	*discussion*		
	5:40 PM	10	TBD 3	TBD	TBD
	5:50 PM	10	*discussion*		
	6:00 PM		**DAY 1 ADJOURN**		

5th KAGRA International Workshop
February 14-15, 2019

1st KAGRA-Virgo-3G Detectors Workshop
February 16, 2019

Perugia, Italy

Ultra-high Vacuum & Cryogenics

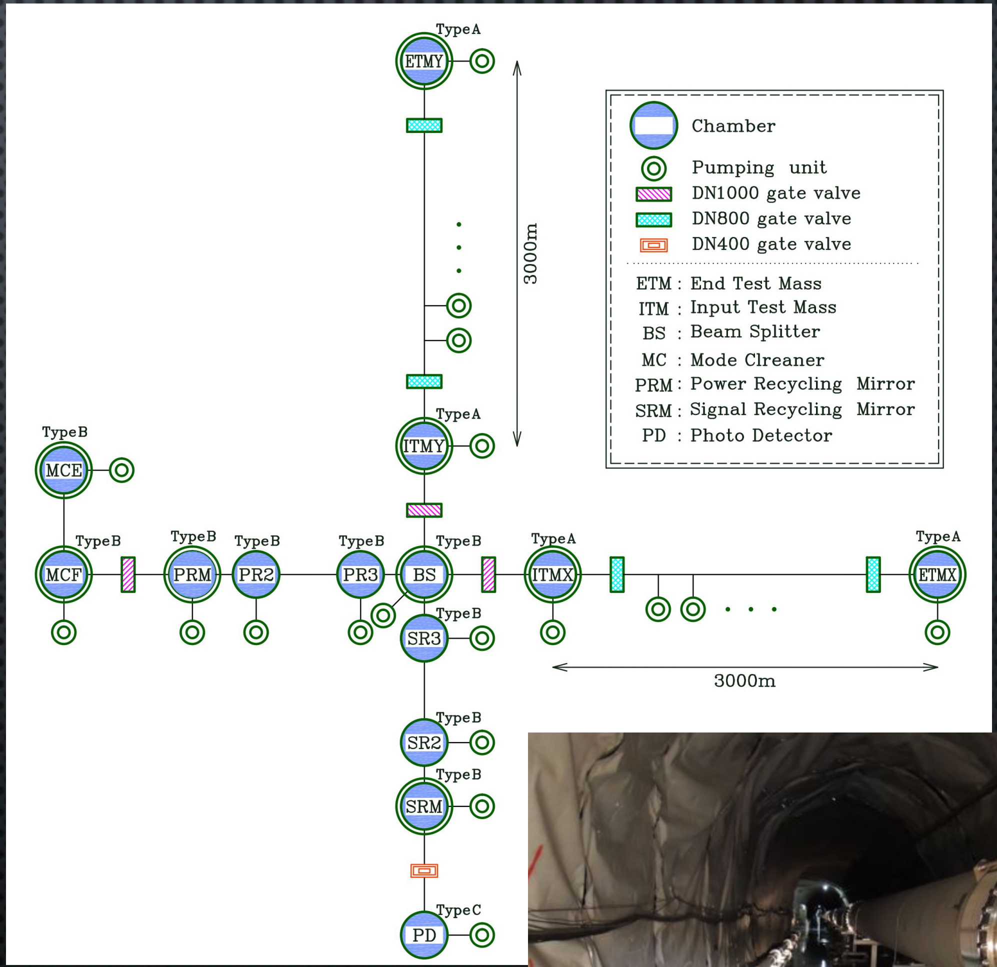
Not Quantum Vacuum but Classical Vacuum

(1) Fundamental Technologies for Future GW Telescope Demonstrated in KAGRA

① Ultra-High Vacuum Technologies in KAGRA

To have sufficiently small laser-beam fluctuation by residual gas, we need ultra-high vacuum of 10^{-7} Pa.

- 3km x 2 Beam Tubes,
  Φ800mm x L12m, 500 tubes
- 10 Major Vacuum Tanks
- 4 Main Cryostats

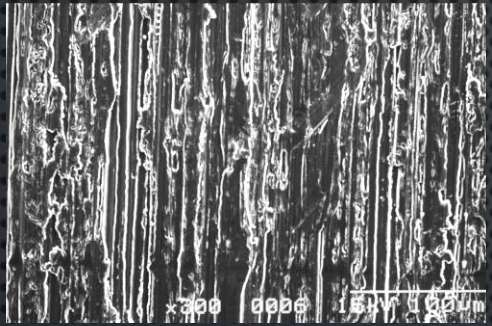


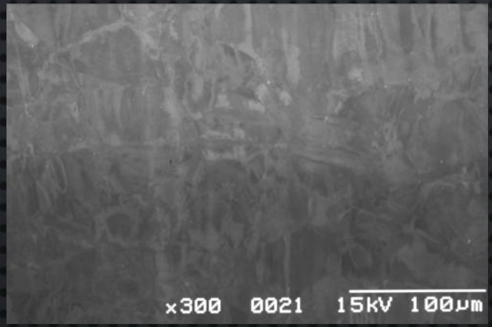
Inner Volume : ~ 3000 m³ ← ~10 x LHC
Surface Area : ~ 15,000 m² ← ~2 x LHC

Fabrication of Vacuum Tubes

Material: SS304L

Electro Polishing





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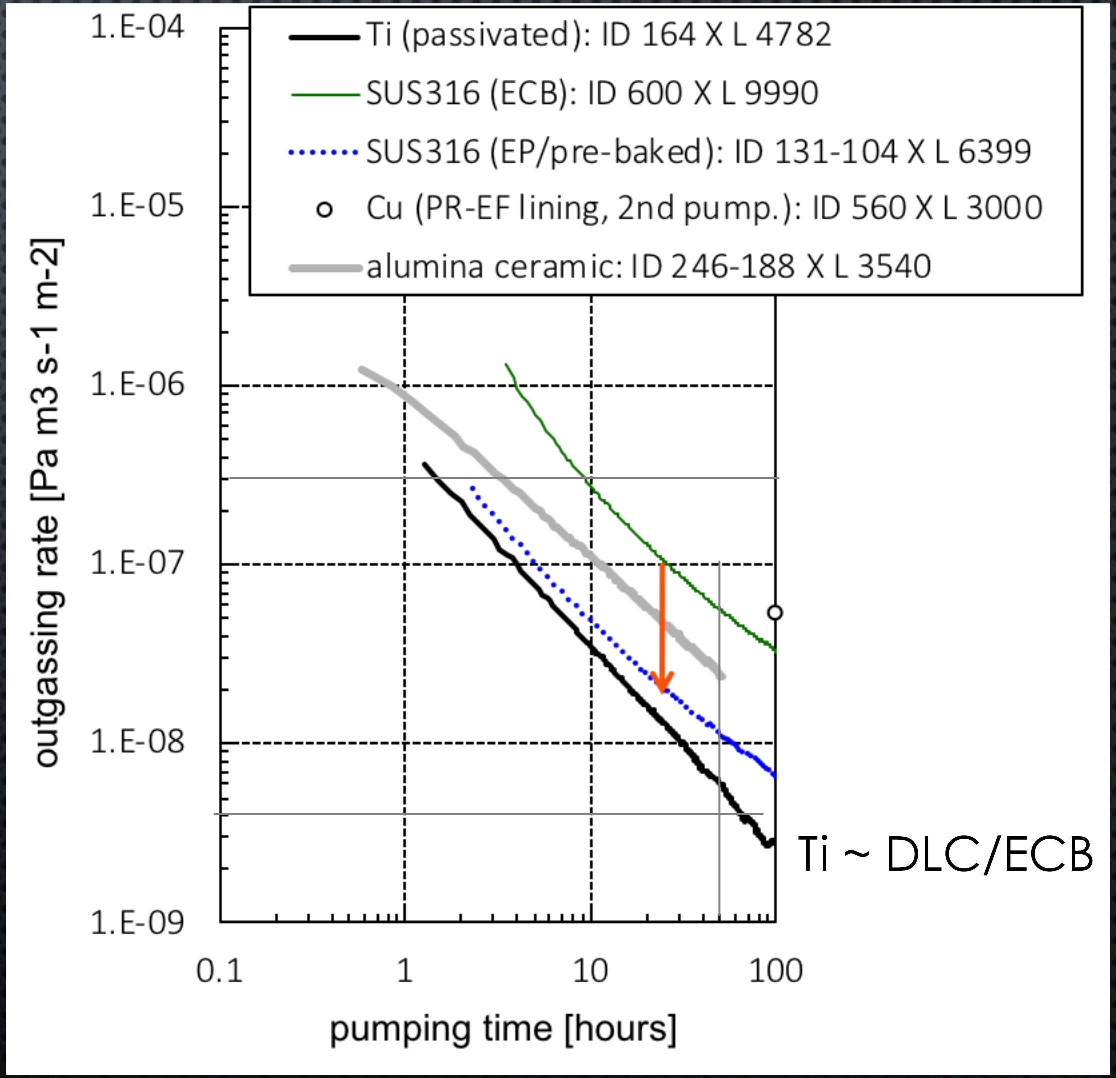
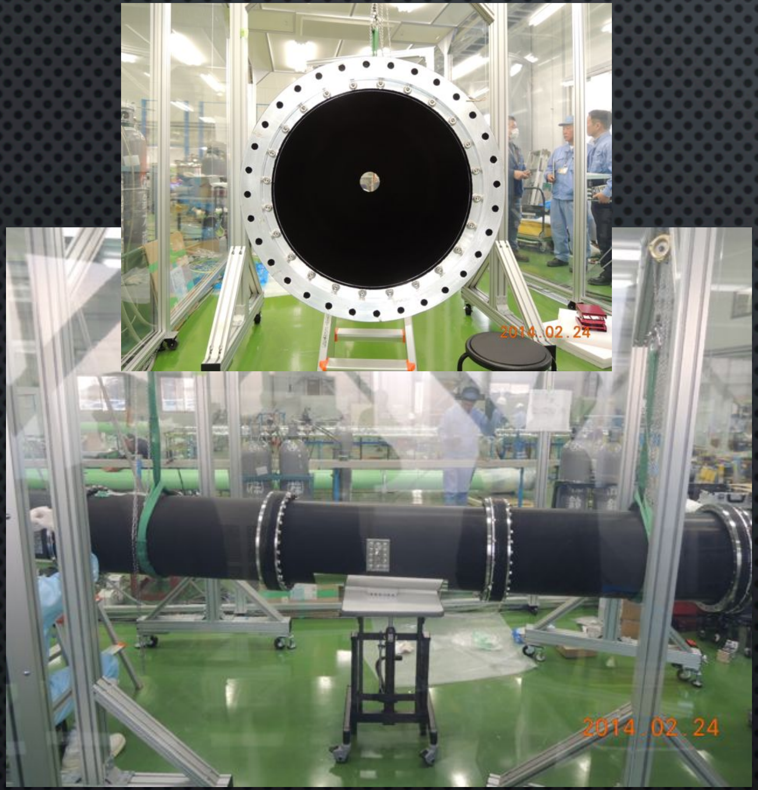
Pre-Baking

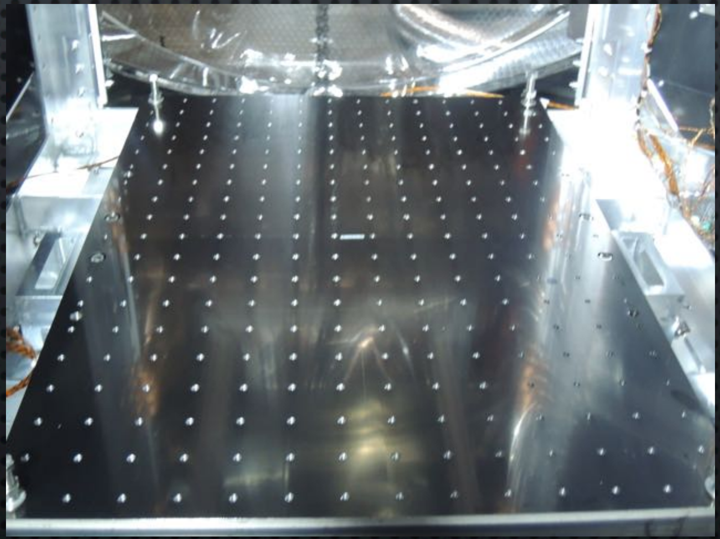


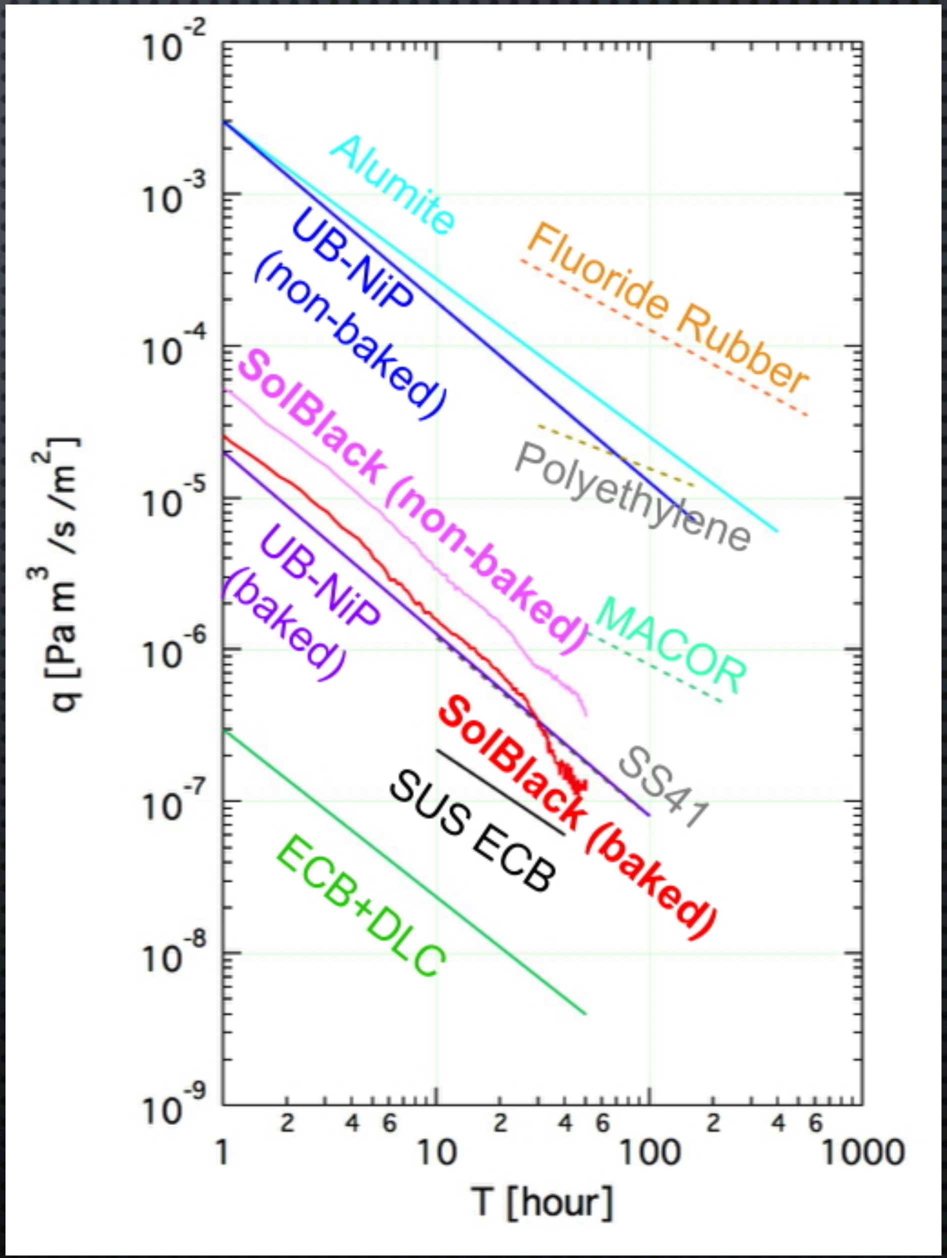
Black Coating for Ultra-high Vacuum

Nickel-Phosphorus black plating realize comparable level of outgas with Steel surface by backing.



Low-magnetism SolBlack coating
magnetism << SS316L

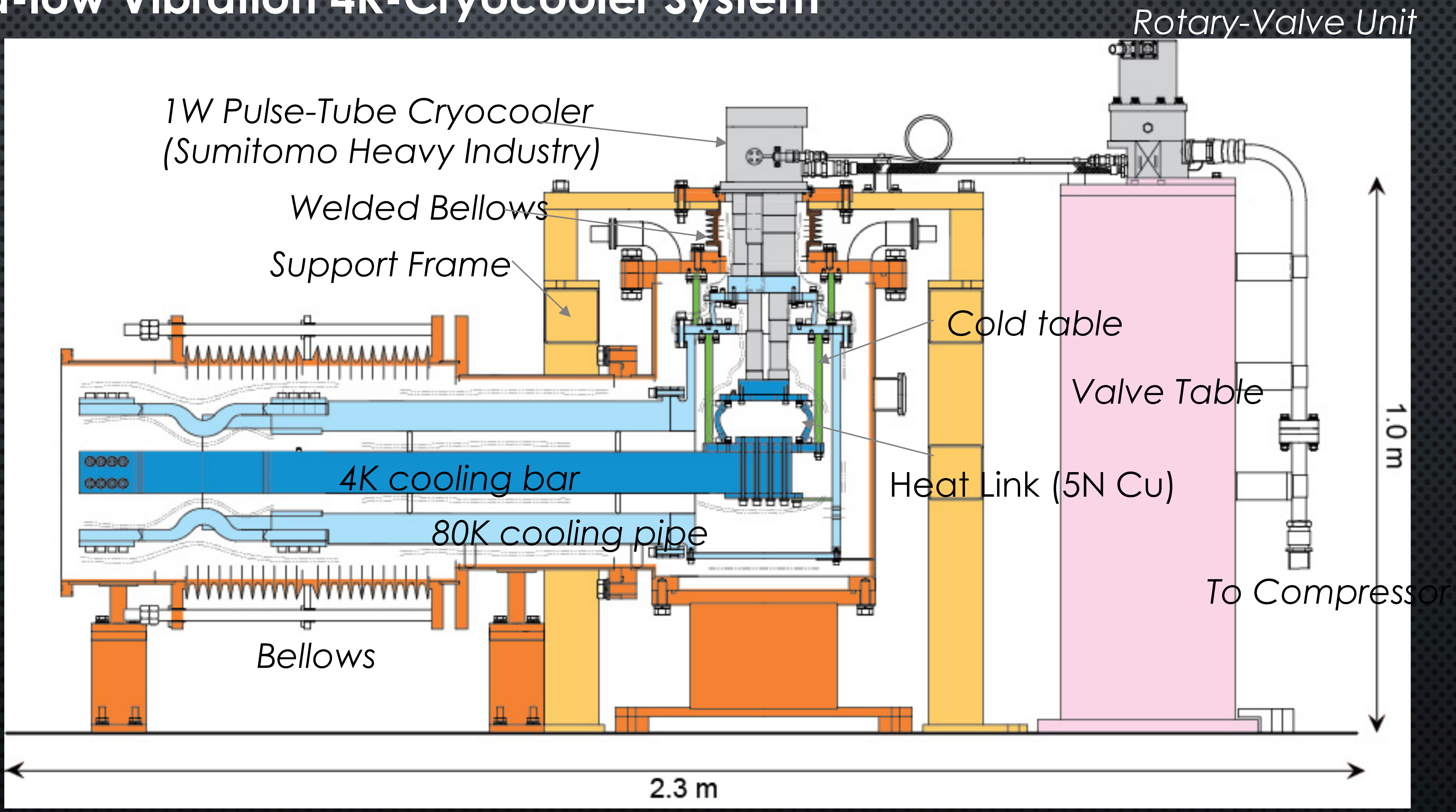




SolBlack Coating
Reflectivity~3% @1064nm

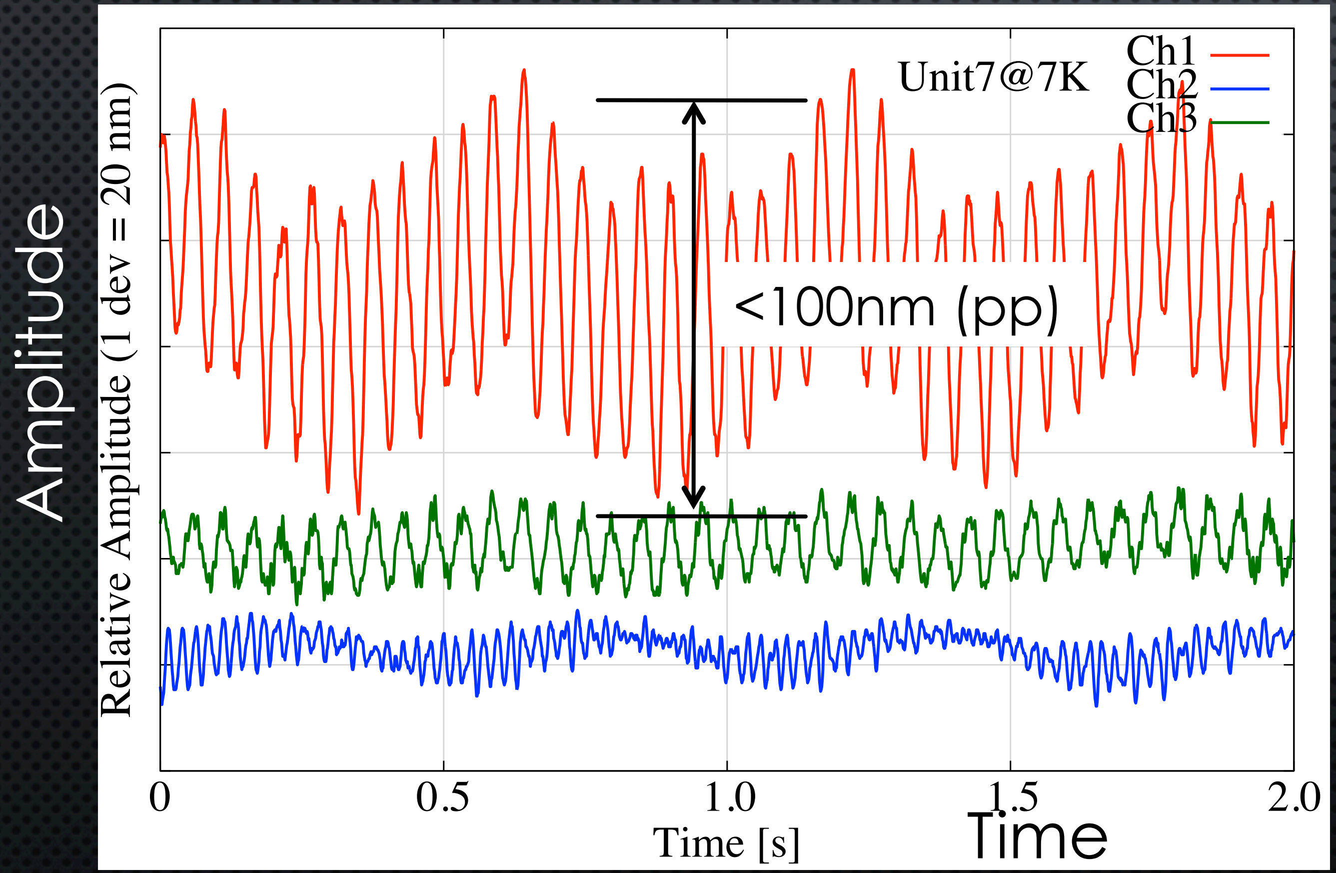
② Cryogenics Technologies in KAGRA

Ultra-low Vibration 4K-Cryocooler System

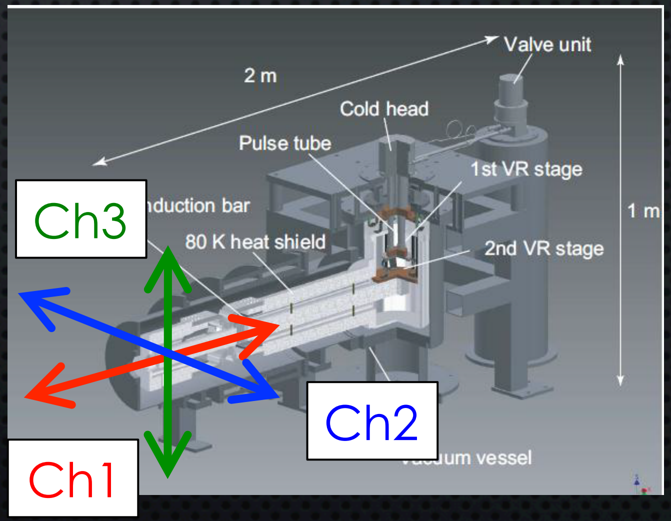


VIBRATION LEVEL OF CRYOCOOLER SYSTEM

- ~7K
- Cold head vibration: ~1.7Hz
- <100nm (peak to peak) in Ch1
- This data shows satisfying KAGRA requirement



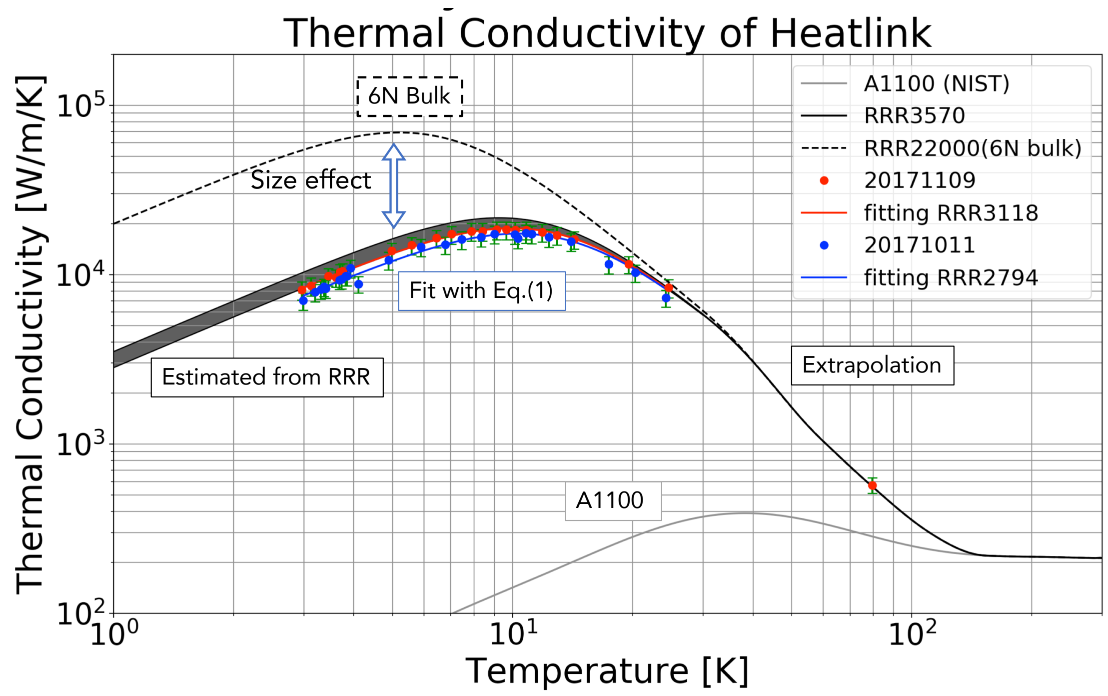
Ch1 : Conductor direction
Ch2 : Horizontal
Ch3 : Vertical



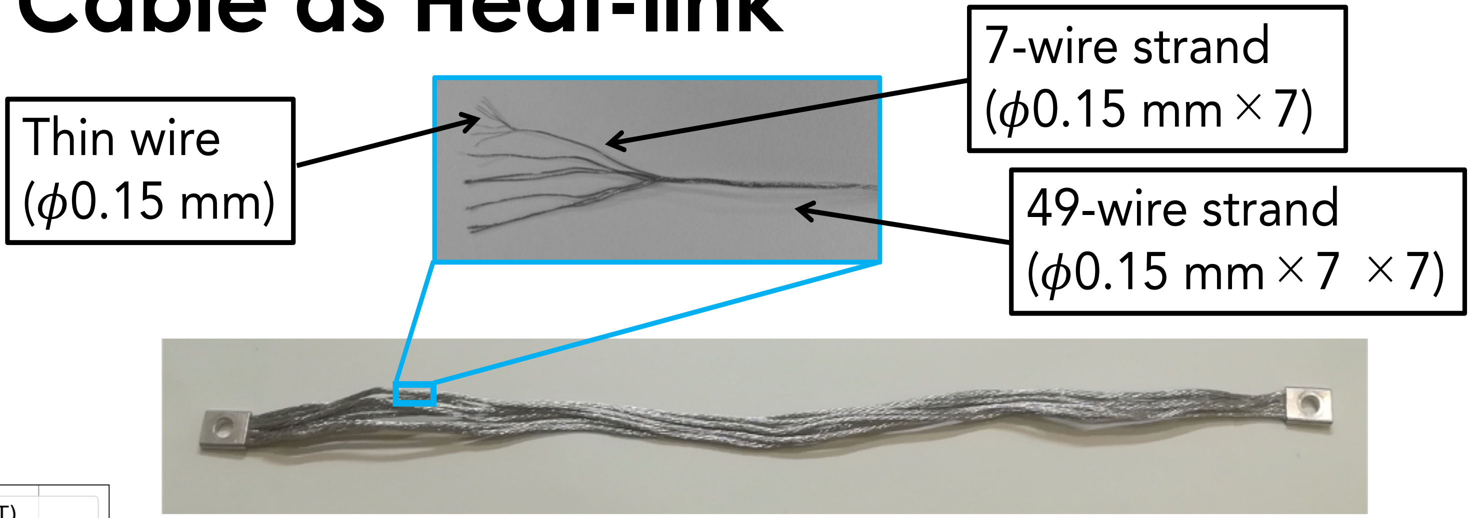
Very Soft 6N Al Stranded Cable as Heat-link

By T. Yamada

Spring constant of stranded Cable is smaller than single Wire. $k = \frac{P^2}{N}.$



Size effect dominates conductivity



Stranded-cable type heat link (ϕ0.15 mm × 7 × 7 × 7)

- **Result** (Resonant frequency)

	Area	5N	6N
ϕ1mm single	0.8 mm^2	64 Hz	64 Hz
45 wires strand	0.8 mm^2	9.6 Hz	9.8 Hz

$k \propto f^2$

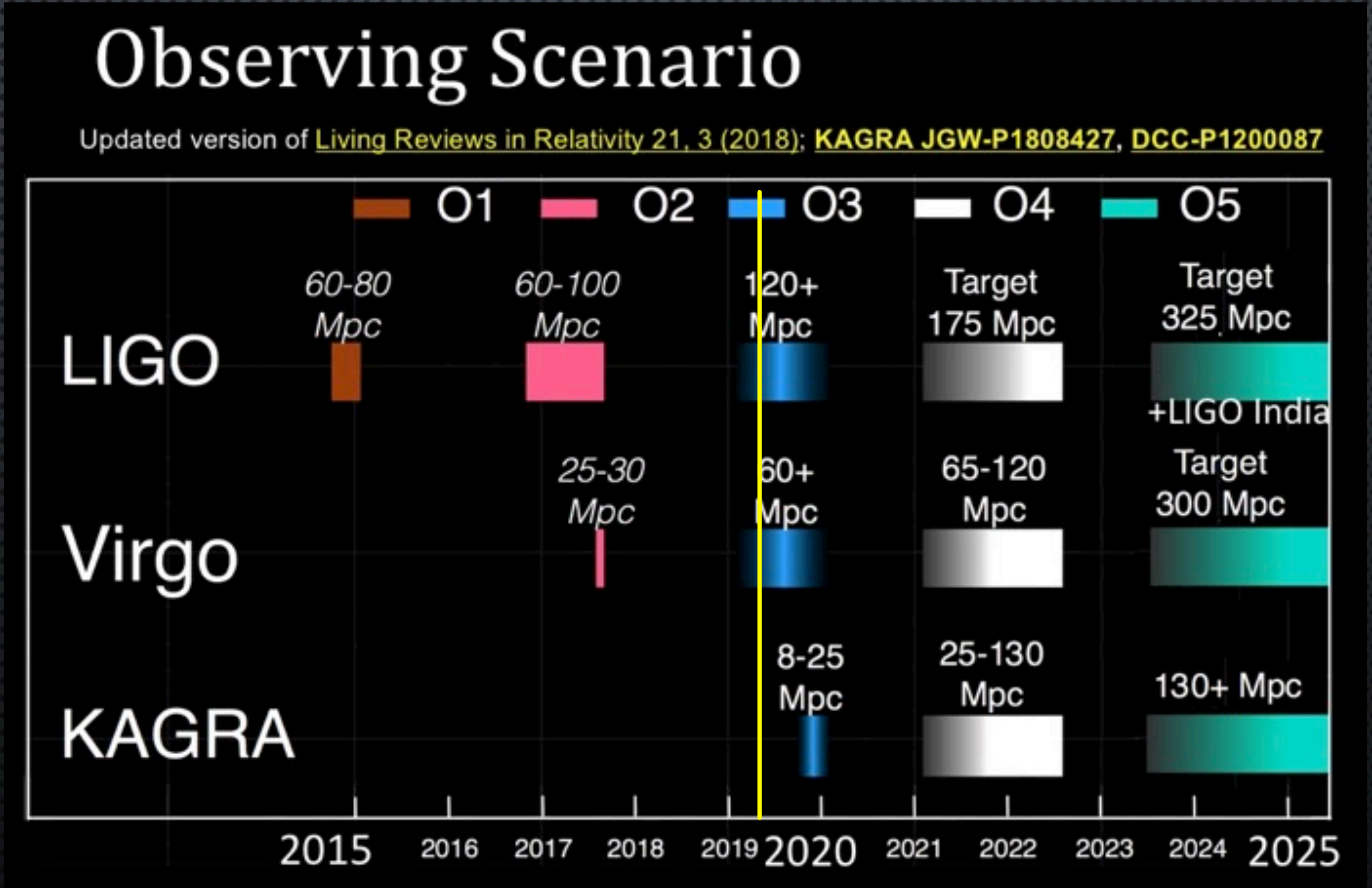
1/6.5

Spring constant: 1/43

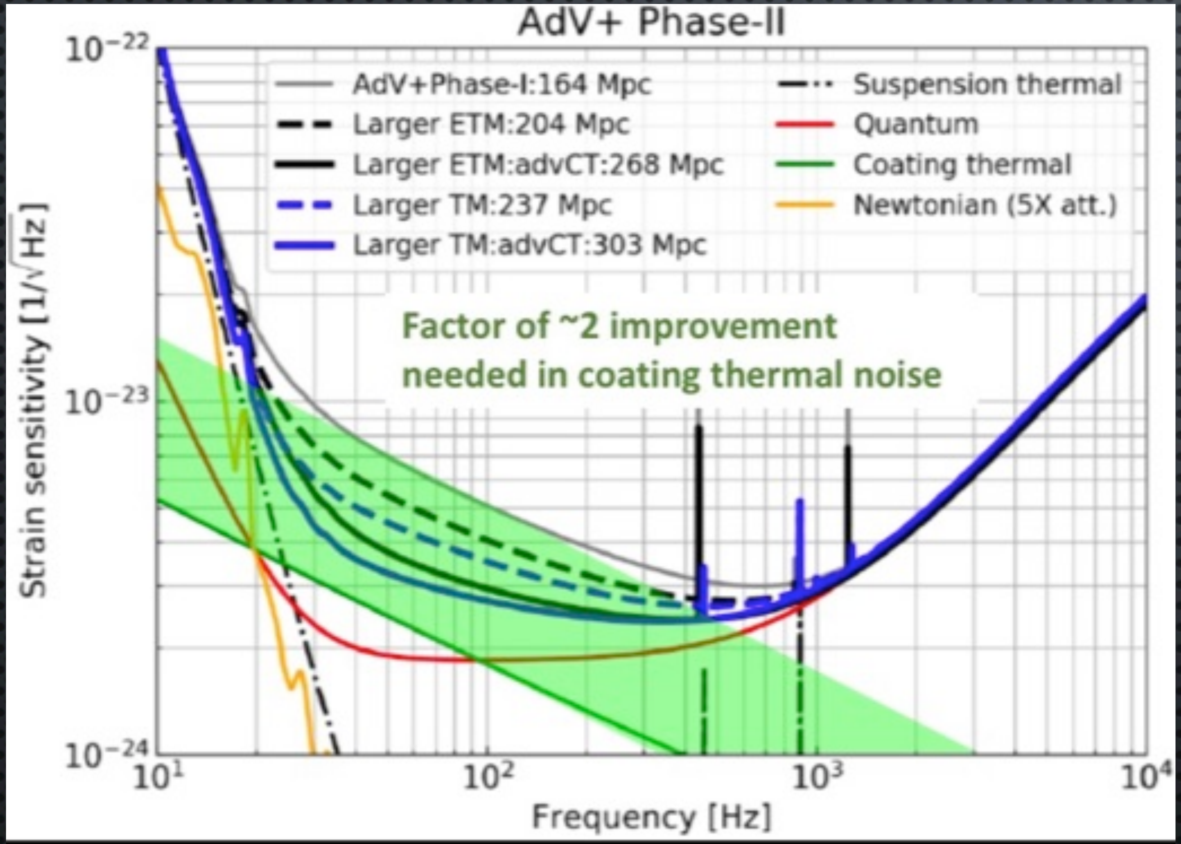
(2) (Near) Future Upgrade Plan in KAGRA

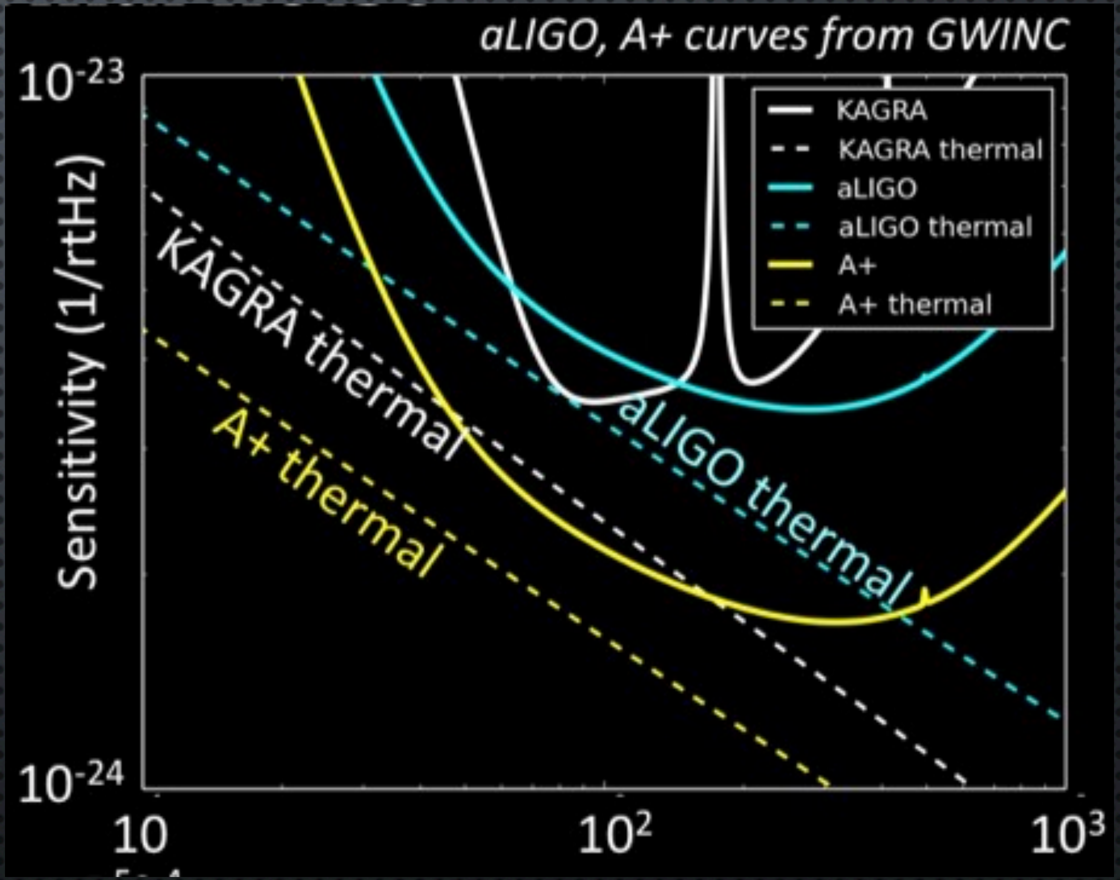
Still under discussion

Future Planning Committee in KAGRA (Chair: Haino, Taiwan) started to study KAGRA future upgrade



Mirror-Coating Thermal Noise



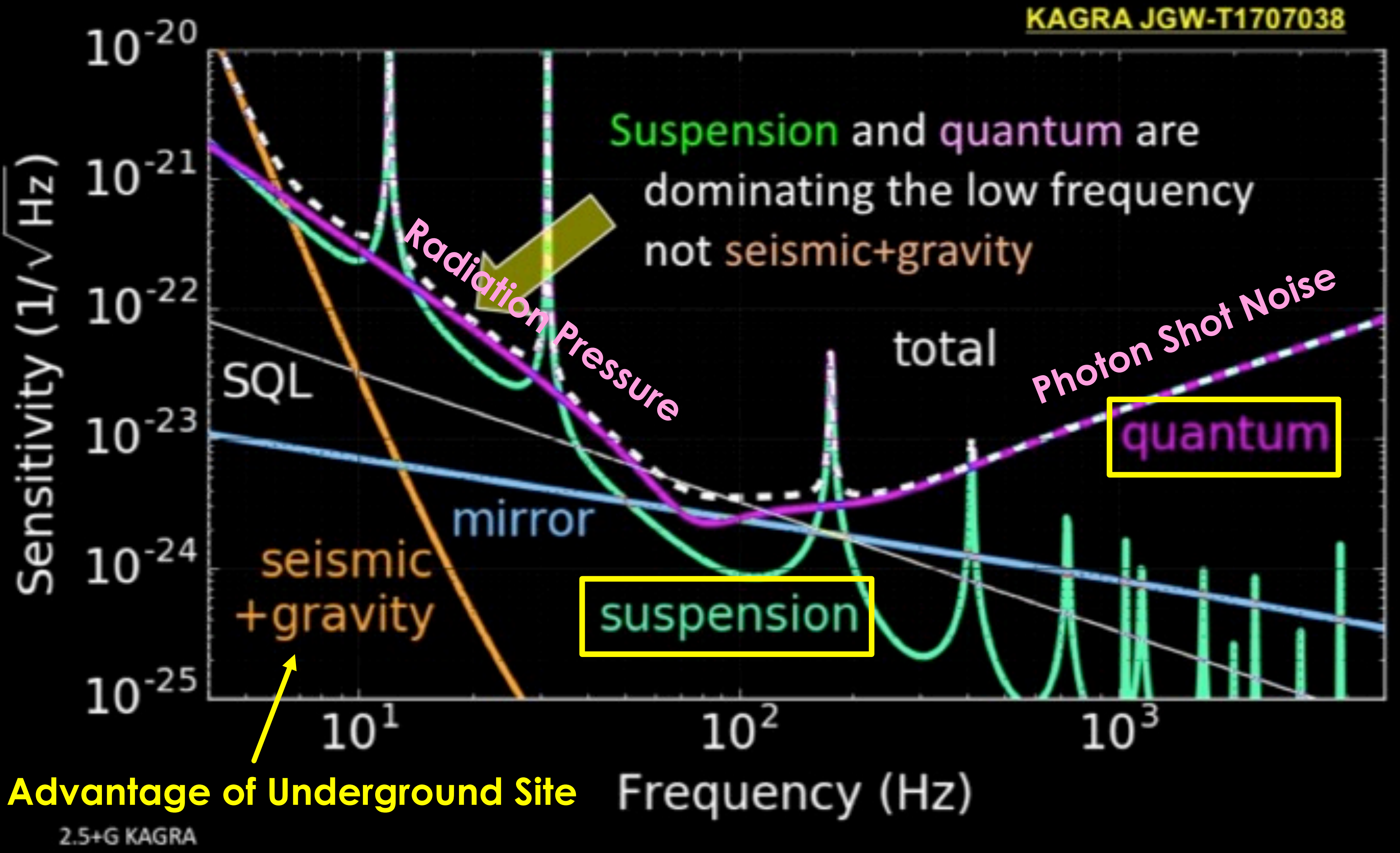


Thermal noise of mirror coating is a key issue in aLIGO+ and aVIRGO+

KAGRA thermal noise is much lower than that in aLIGO due to cryogenic mirrors but don’t reach to aLIGO+/aVIRGO+

bKAGRA noise budget

by FPC



Quantum Noise

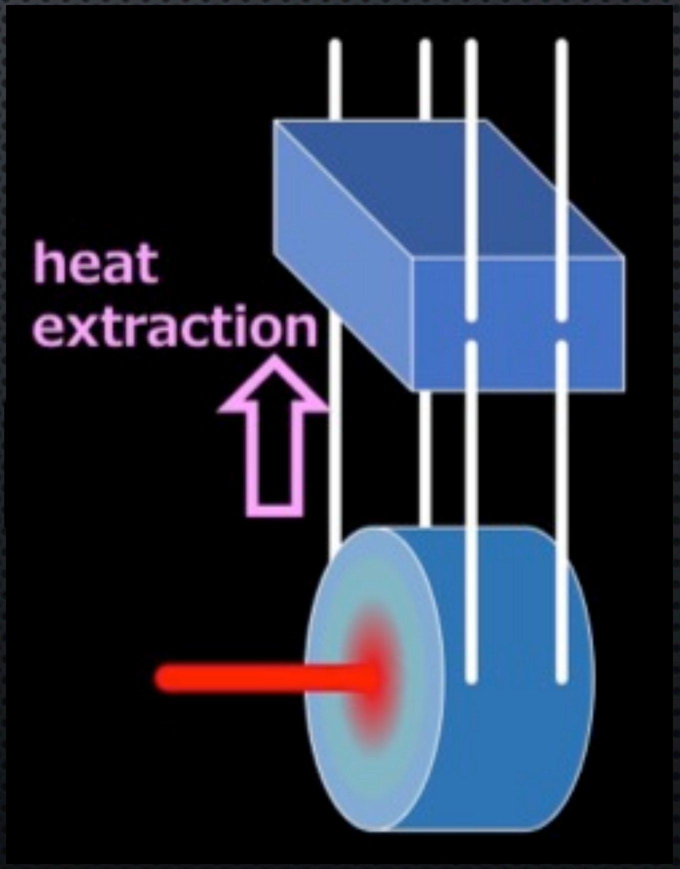
Photon Shot Noise → Higher Laser Power

Radiation Pressure Noise → Lower Laser Power
Heavier Mirror

 # Frequency Dependent Squeezing technology can improve both photon shot noise and radiation pressure noise. This is under developing in TAMA300 in NAOJ.

Suspension Thermal Noise

We need to use thick suspension fibers to cool down mirror.



- Reduce laser absorption in mirror substrate and in mirror coating
- Thinner and longer suspension fiber

Considerable Strategies

① Plan: Brown → **Tuned to Low Frequency**

- Small Laser Power
- Same Mirror
- High Detuning at Low Frequency

② Plan Blue
Plan: Black → **Wide-Frequency-Range Improvement**

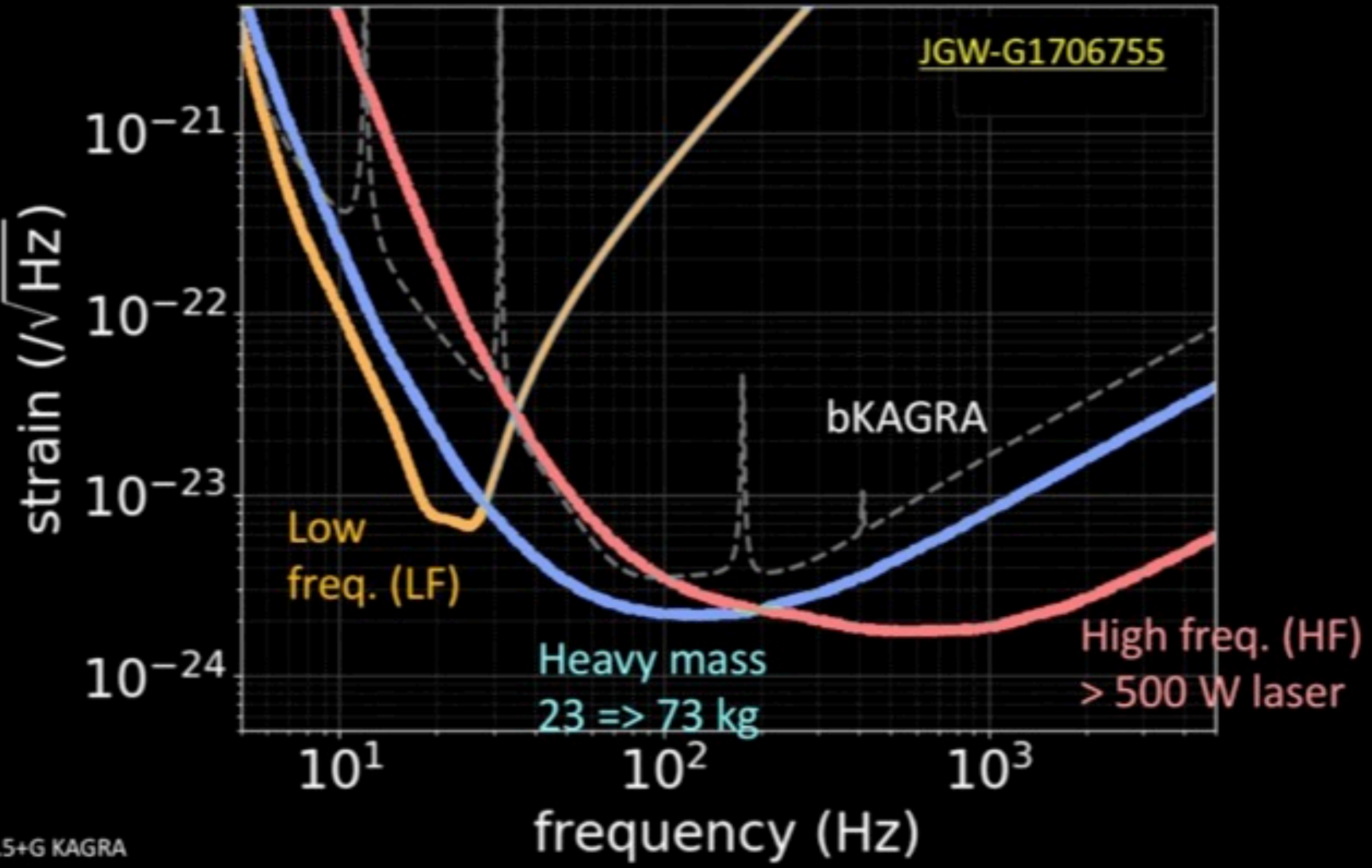
- Heavier Mirror (Blue: Sapphire, Black: Silicon ←Maybe more future)
- 10dB Squeezing

③ Plan: Red → **Tuned to High Frequency**

- Higher Laser Power
- Same Mirror
- Thicker Suspension Fiber

Example sensitivity curves

by FPC



2.5+G KAGRA

Science examples summary

by FPC

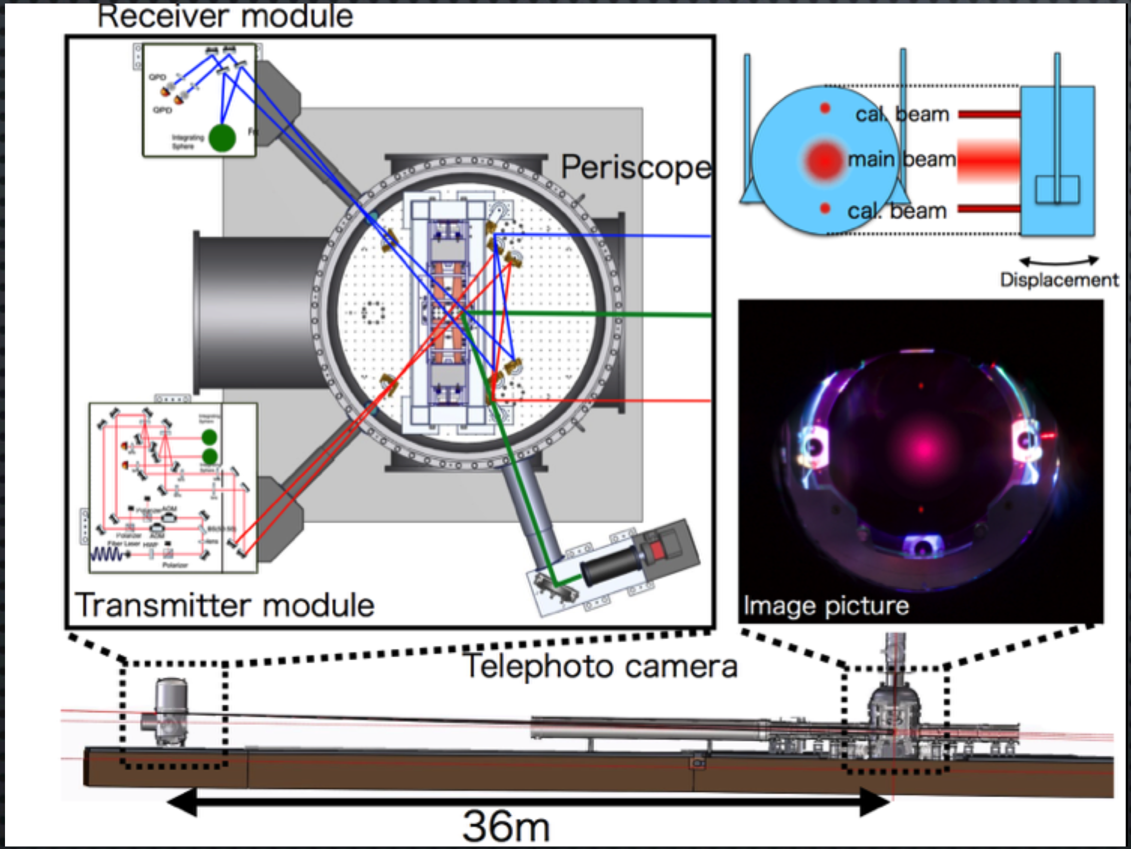
JGW-G1707125

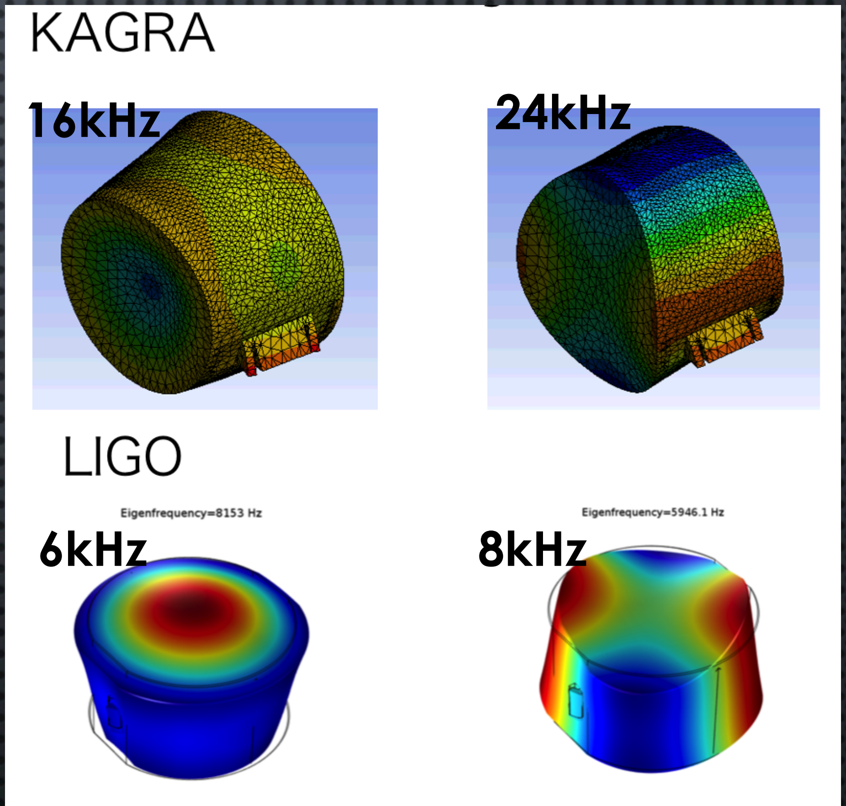
	bKAGRA	LF	Heavy	HF
test of GR with BH ringdown	×	×	△	○
existence of IMBH from hierarchical growth	△	△	○	△
existence of stellar-mass BBH from popIII	×	×	×	×
sky localization for BBH (identifying host galaxy)	△	×	○	○
pulsar ellipticity	×	×	△	○
NS equation of state	×	×	△	○

Photon-Pressure Calibrator (PCAL)

Led by my Kakenhi (Kiban A & S) budgets

Collaboration with LIGO Hanford & Taiwan



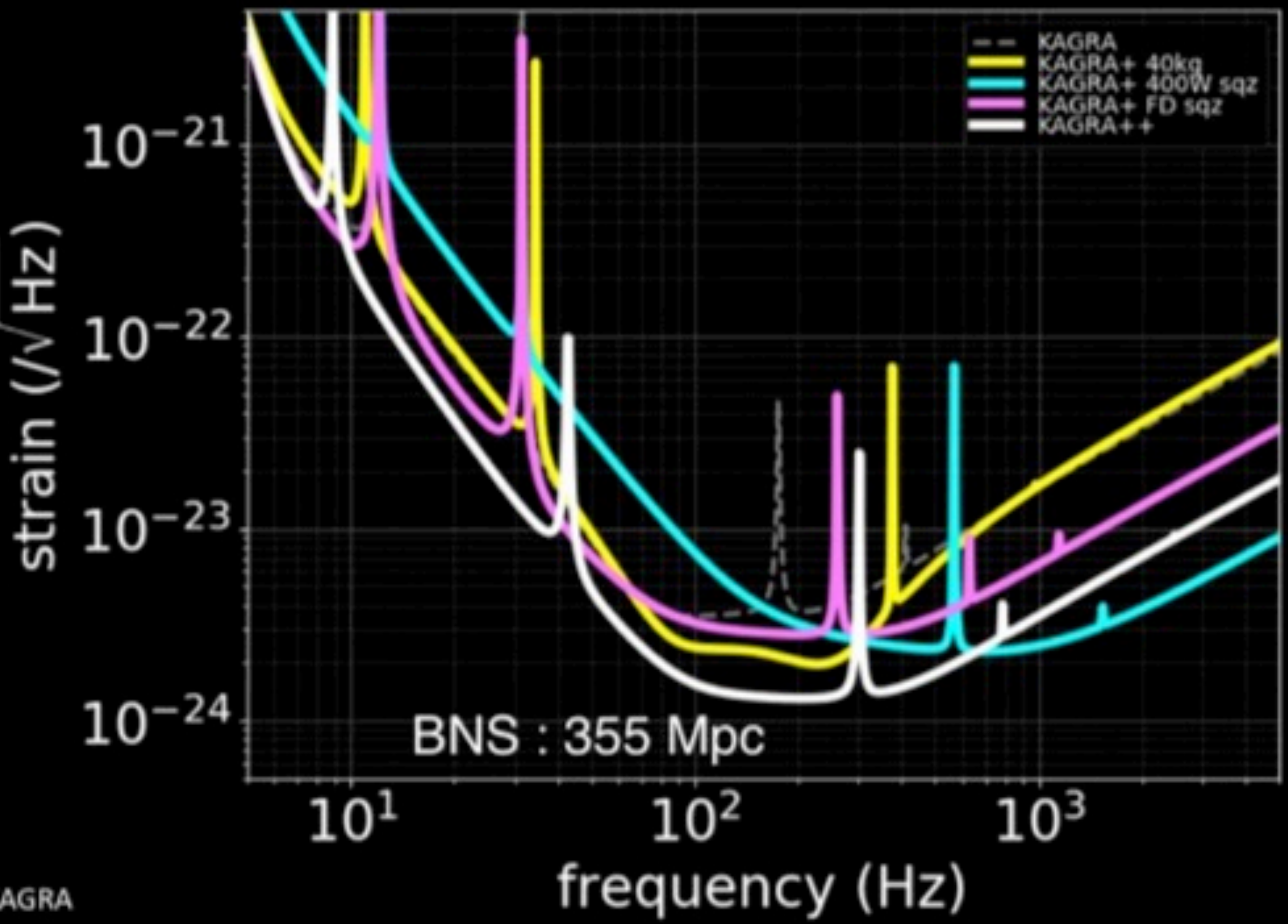


- 20W high power laser of 1047nm wavelength
- Simple optical layout
- Two AOMs
- Good Telephoto Camera monitoring system

KAGRA has an advantage at high frequency range over 5kHz
→ Fit to ringdown study

Long-term upgrades options

KAGRA++ : 100 kg mirror with 1/2 coating thermal, 320 W input, 10 dB input squeezing with 100 m filter cavity



Issues for 100kg Sapphire Mirrors

- Technological Breakthrough to produce 100kg sapphire bulk with GW detector quality is required.
  - Optical absorption level in sapphire is 20 – 50ppm/cm now.
    We still don't understand the source of optical absorption.
  - Birefringence.
    Now we set optical axis to c-axis of crystal, but crystal growth is done along m-axis. That is, we can make heavier sapphire if we use m-axis as optical axis.
- We need large design change of suspension system because the vertical vibration isolation system for cryo-payload is designed to be 200kg in total.

Summary

- KAGRA is 2.5G detector and includes some very important technologies for 3G detectors.
  We wish to use these technologies and experience to other 3G detectors like ET.
- We just started the discussion of KAGRA upgrade.
  KAGRA Future Planning Committee leads this discussion.
- We studies three options for near future upgrade:
  low frequency, wide-frequency and high frequency upgrades.
  Maybe major upgrade will be carried out before O5.

Back Up

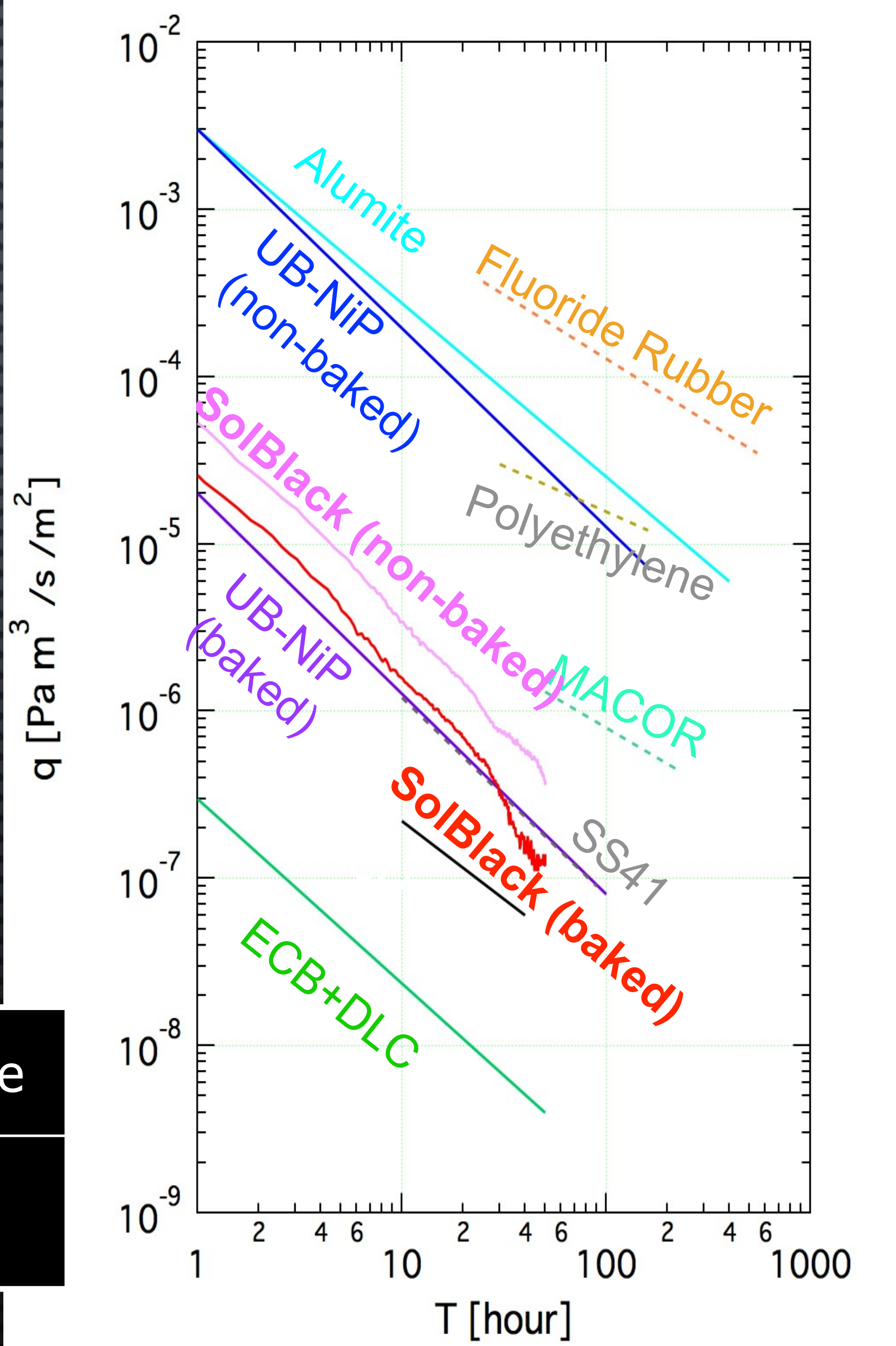
Nickel-Phosphorus Black Coating

From our studies, Nickel-Phosphorus plating is a good candidate of black coatings in UHV use.

DLC -> See Takahashi's presentation

Optical Absorption Rate @1.064um in wavelength

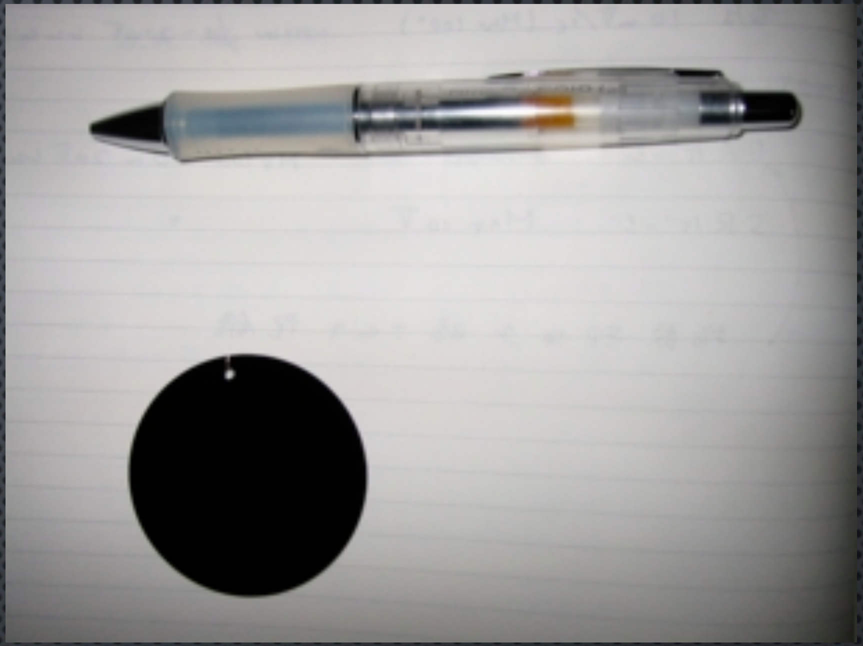
	UB-NiP	Phosblack II	ECB+DLC	Raydent	Alumite
Absorption	**99.89 %**	**85%**	**65%**	**83%**	**-**

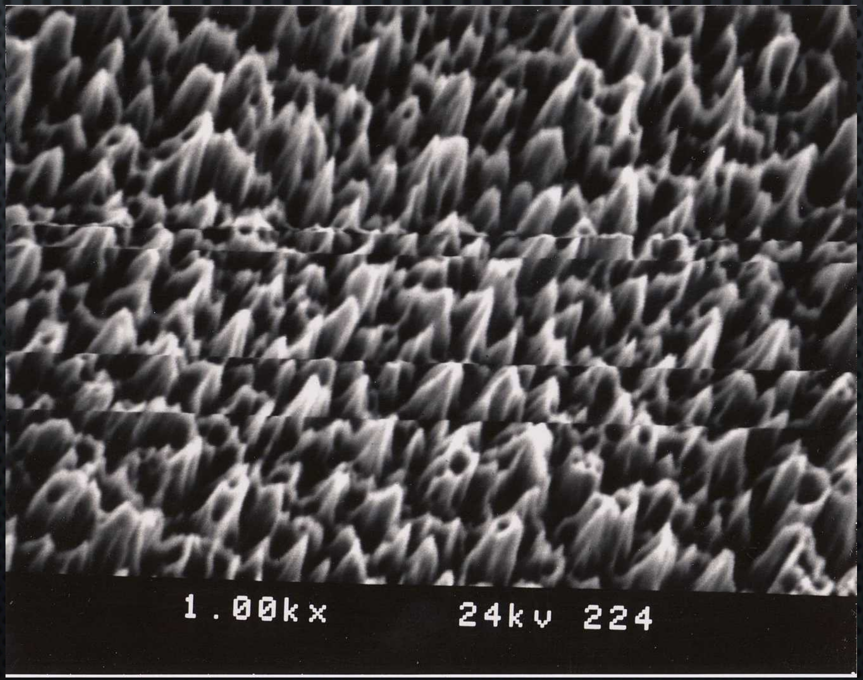


Ultra-Black NiP

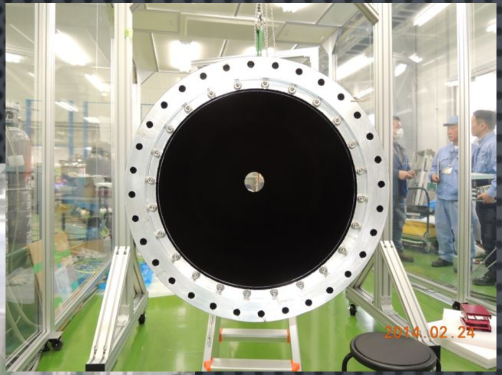
This is the one of blackest coatings in large wave-length.

- Large optical absorption of 99.8% in the range from 488nm to 1550nm in wavelength.
- About 90% absorption rate even in infrared.
- This material was (maybe is) used as optical absorber in calorimeter in laser-power standard.
- Comparable outgassing rate with SS41.
- Very rough surface. This causes multi-reflection of light and realize small surface reflection.
- Large disadvantage of fragile surface.
- Expensive

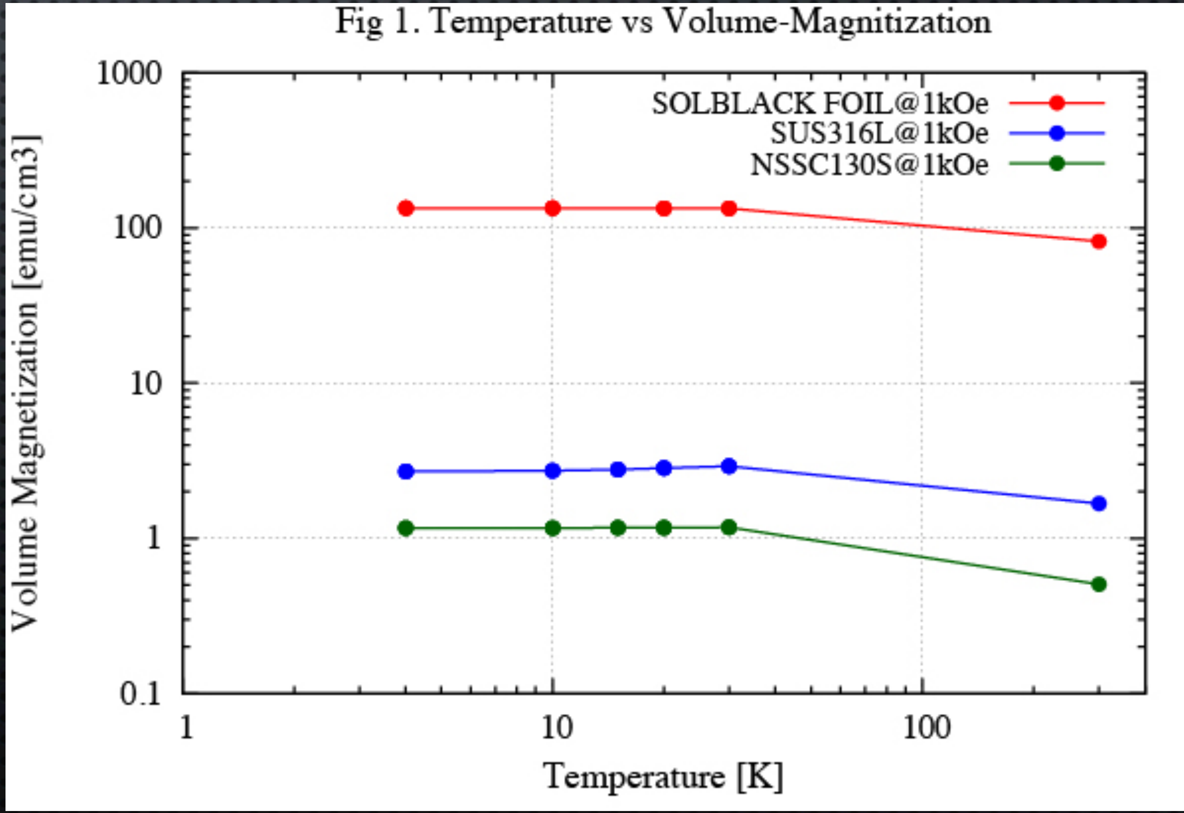




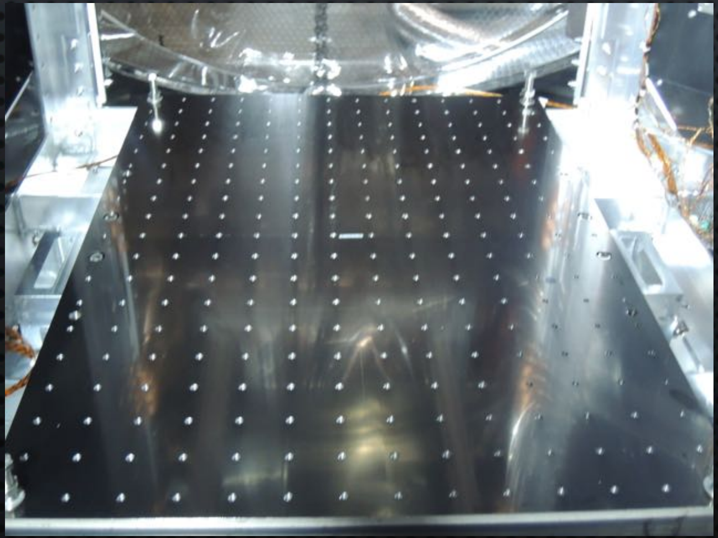
Solblack



- Commercial name of NiP plating produced by Asahi Precision Inc.
- Surface is not smooth, but not so fragile.
- This coating has magnetism.

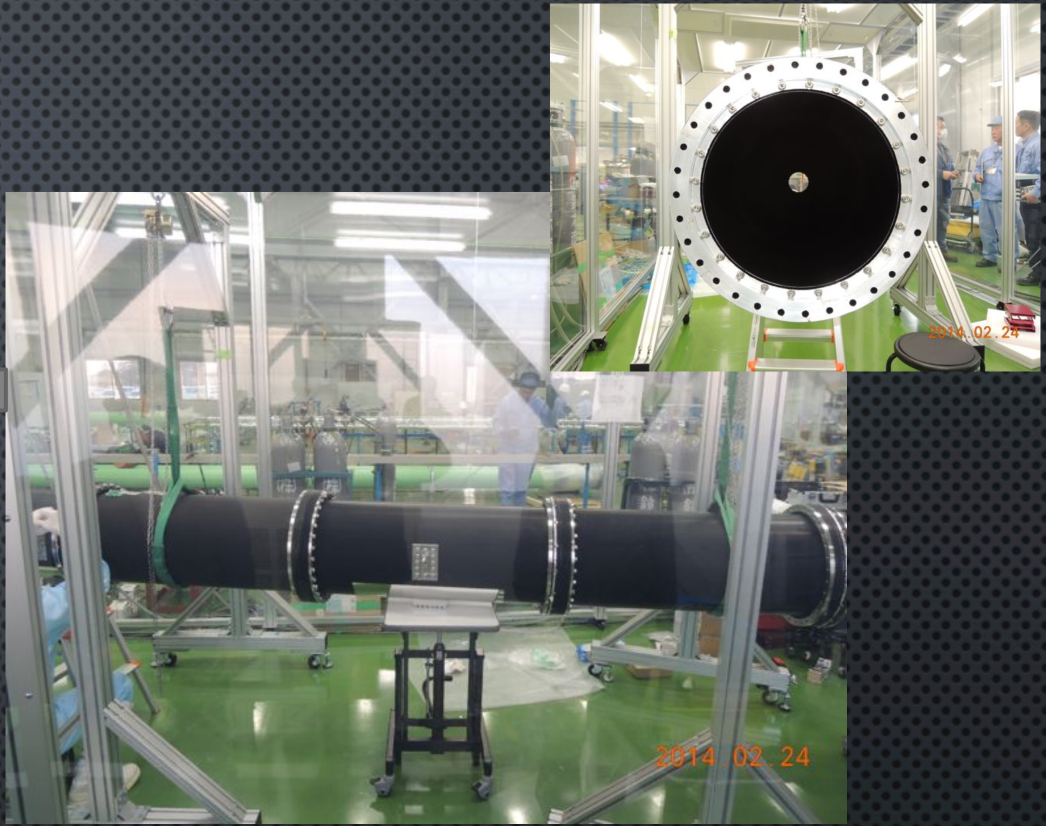


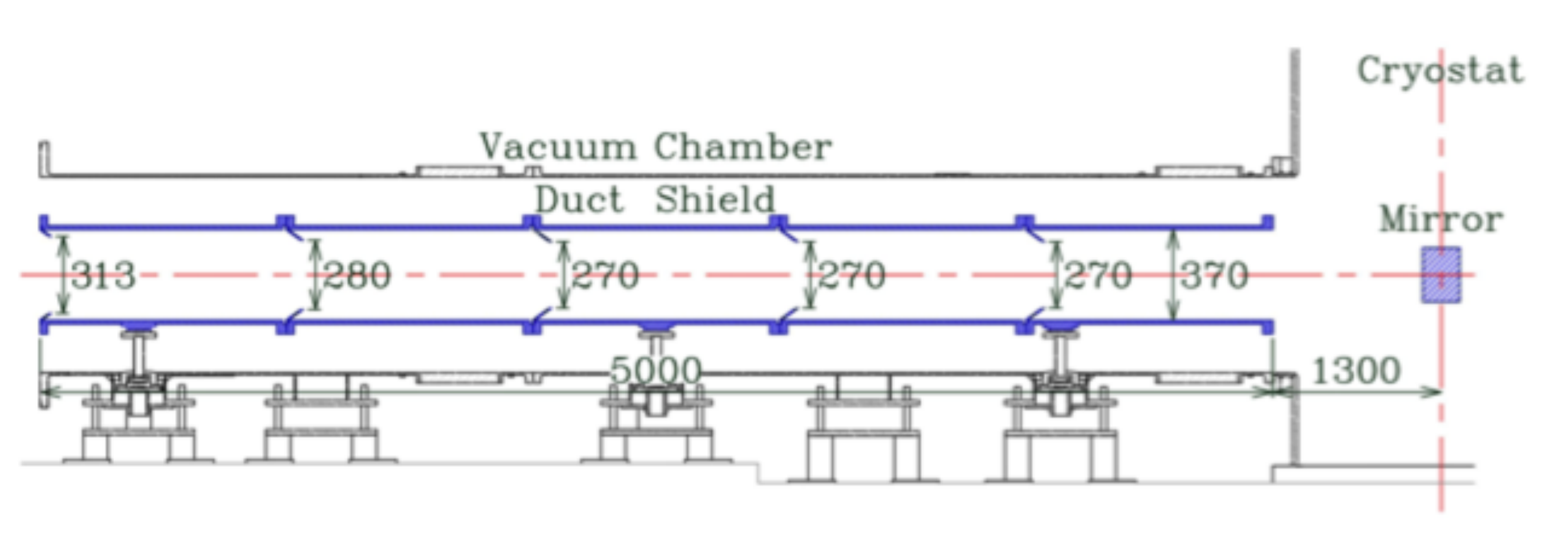
Non-magnetism Solblack coatings Used around mirror Suspension.



Duct Shield

inside



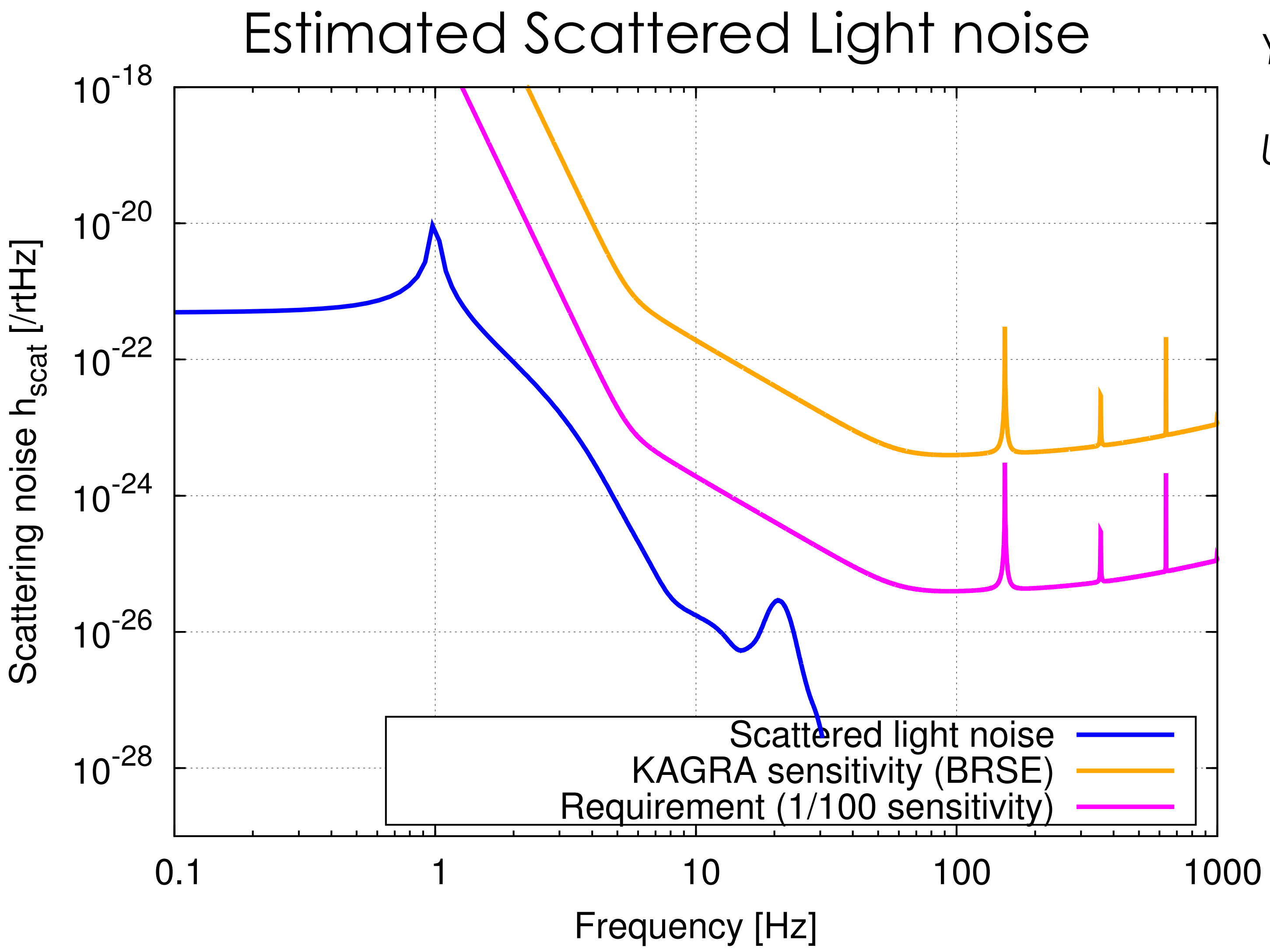


Main purpose of this duct shield is to reduce injection of thermal radiation from openings, but this is also effective to reduce laser scattering noise.

Solblack

Only the effect of duct shield is included.
KAGRA has also Baffles in beam tubes And in front of mirror (Wide angle baffle).

- Scattering: from mirror
- Vibration: Duct shield vibration by Kamioka seismic level.

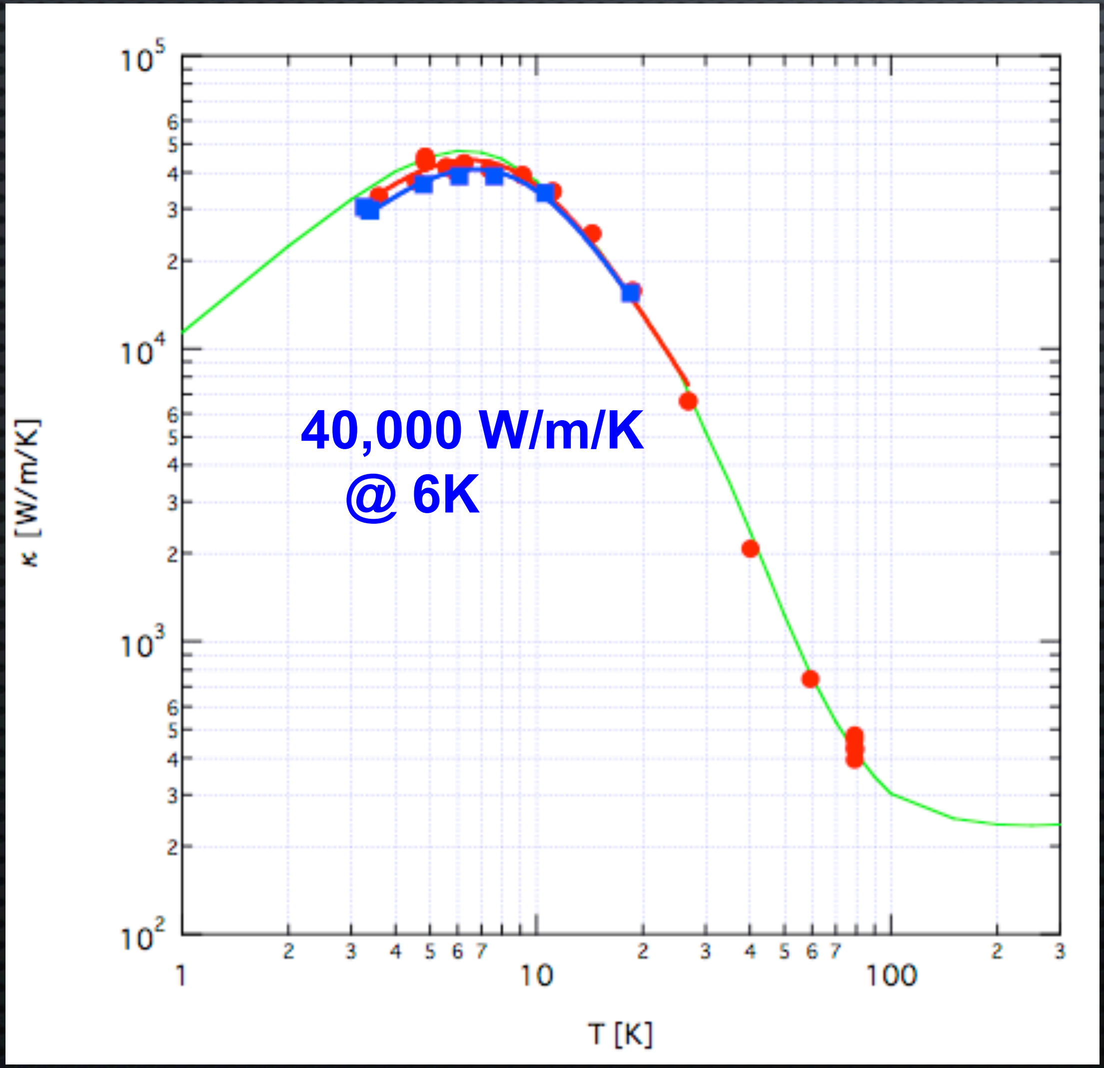


Y. Sakakibara, Ph. D theshis, Univ. Tokyo (2015)

Figure 5.22: Scattered light noise caused by the duct shield at Kamioka without any cryocoolers. KAGRA sensitivity was taken from Ref.[67].

6N purity Al heat conductor

Thermal Conductivity of Bulk 6N Al



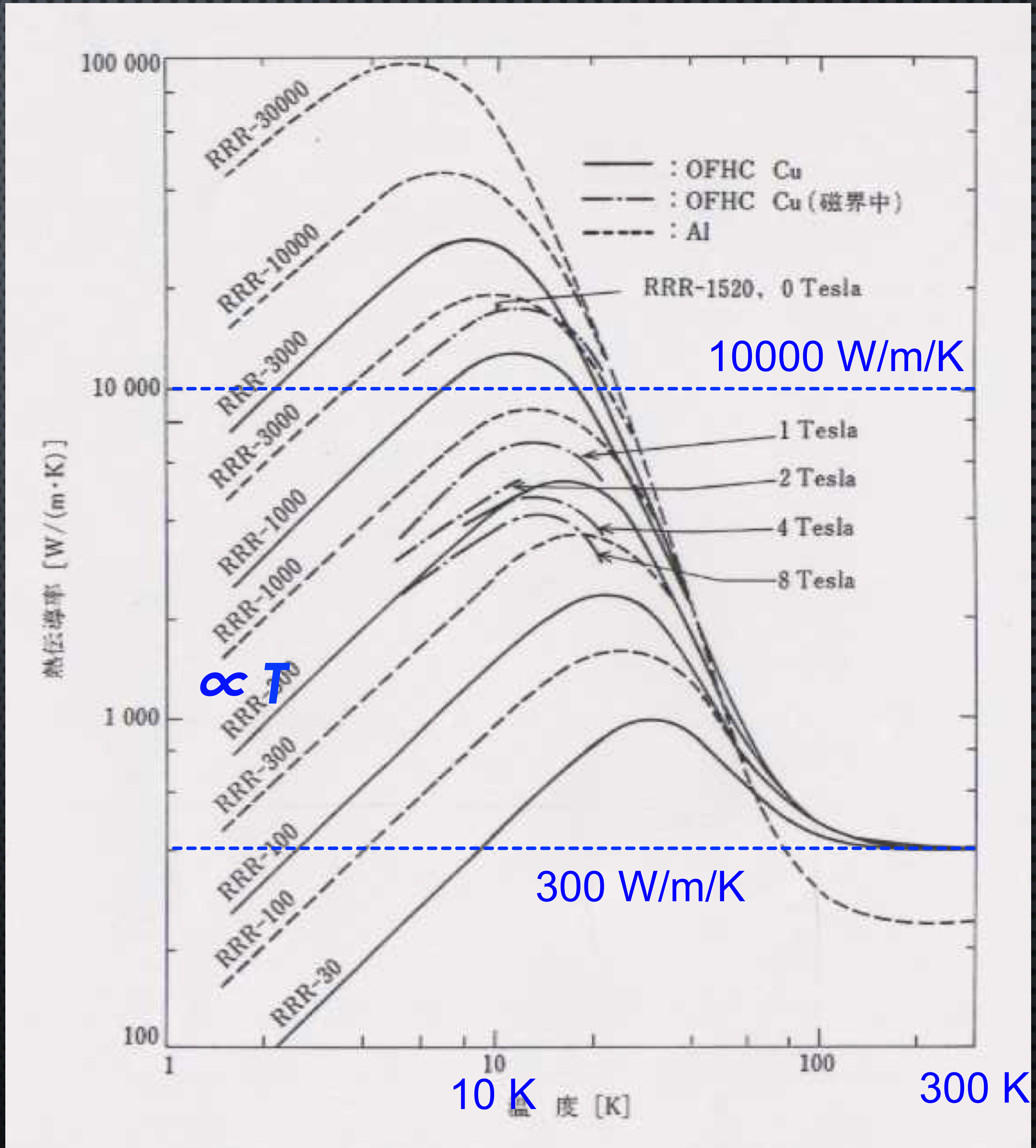
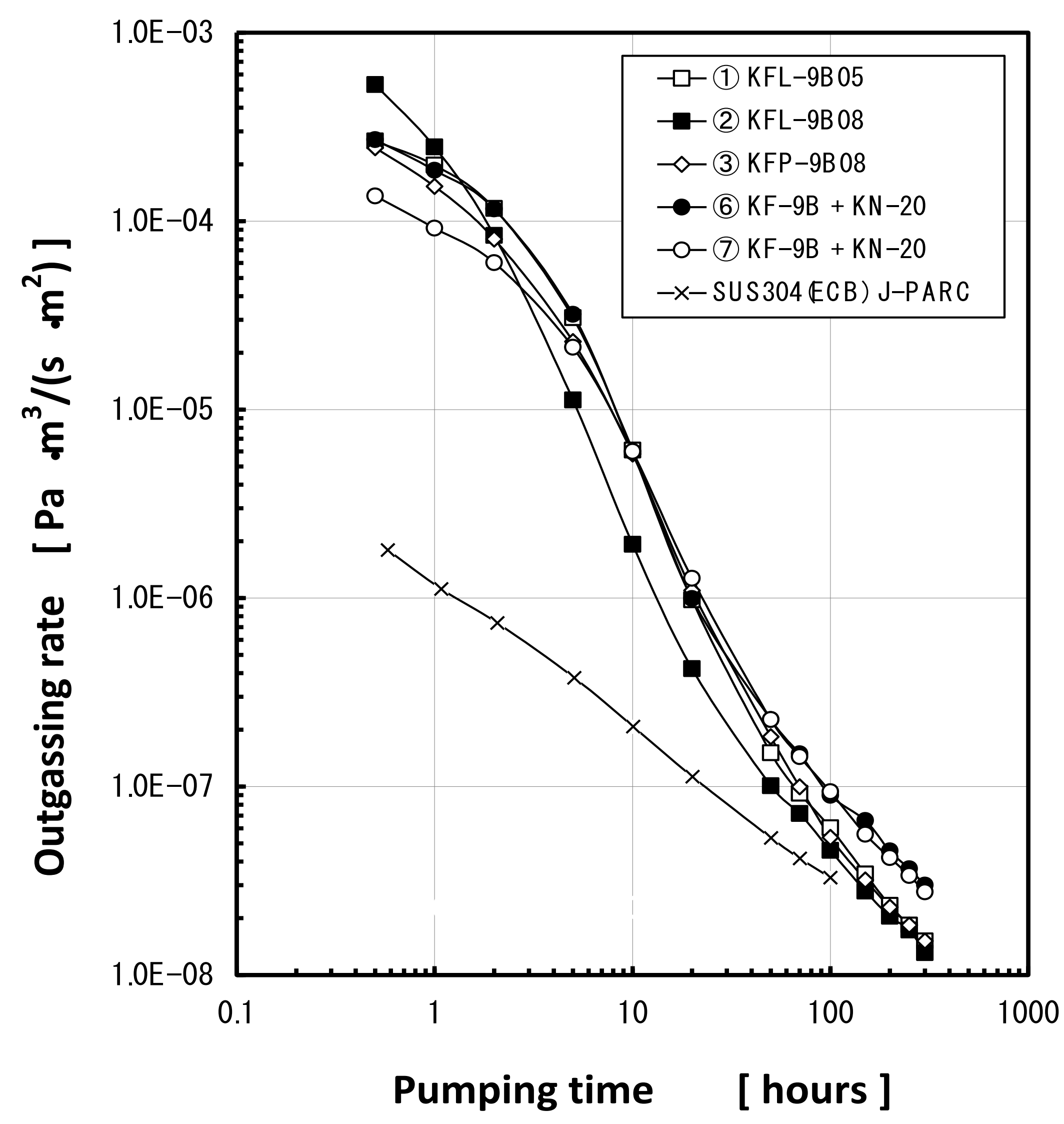


図 3・23 無酸素銅および純アルミニウムの熱伝導率

Small-Outgas Multi-Layer Insulation (MLI)

MLI is a very important material to shield thermal Radiation in cryogenic temperature.
In typical: 70K -> 60 layers,   4K -> 20 layers

MLI increases total surface area and out gas.



The samples of KFL-9B05、KFL-9B08、KFP-9B08 are new developed MLI. Each samples has both side Al coating and single-side fiber spacer on polyester film of 5μm, 8μm and 8μm in thickness, respective
The KF-9B + KN-20 sample is a typical MLI with polyester-net spacer.