

KAGRA+ Upgrade Plans

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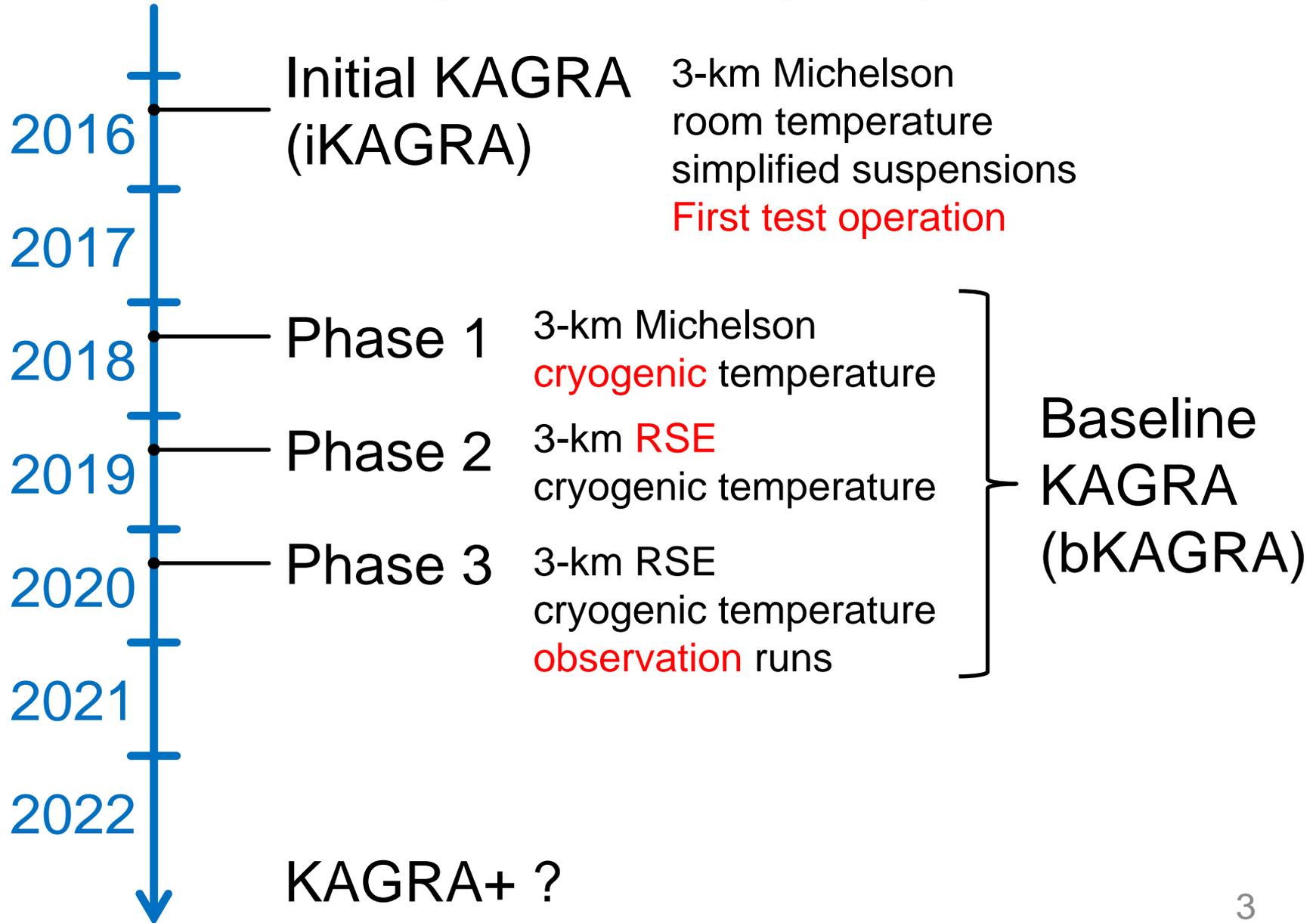
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Overview

- No concrete plan, no consensus yet
- Some R&D on-going
- Integrated study initiated recently
- Upgrade within current facility

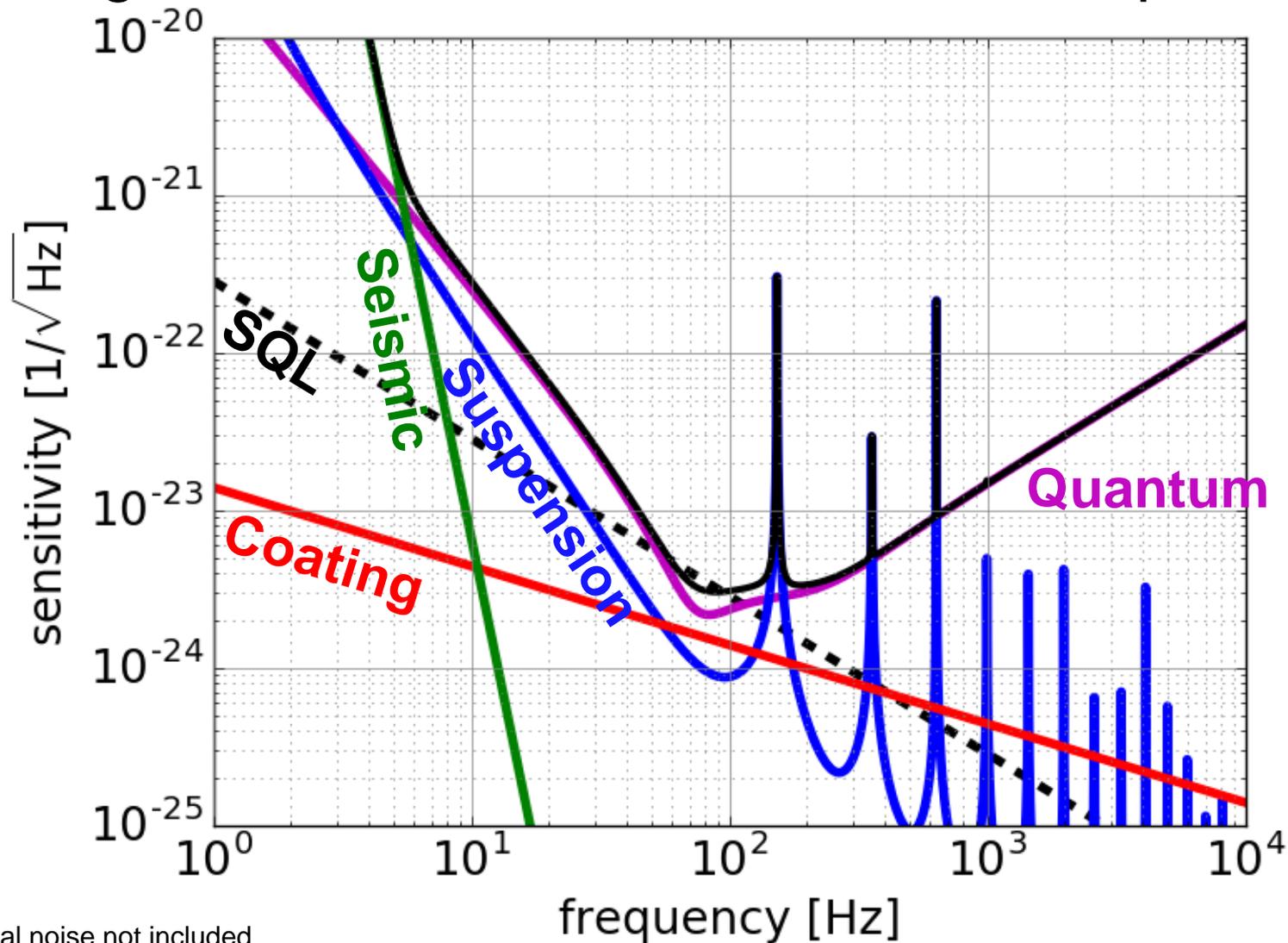


KAGRA Timeline



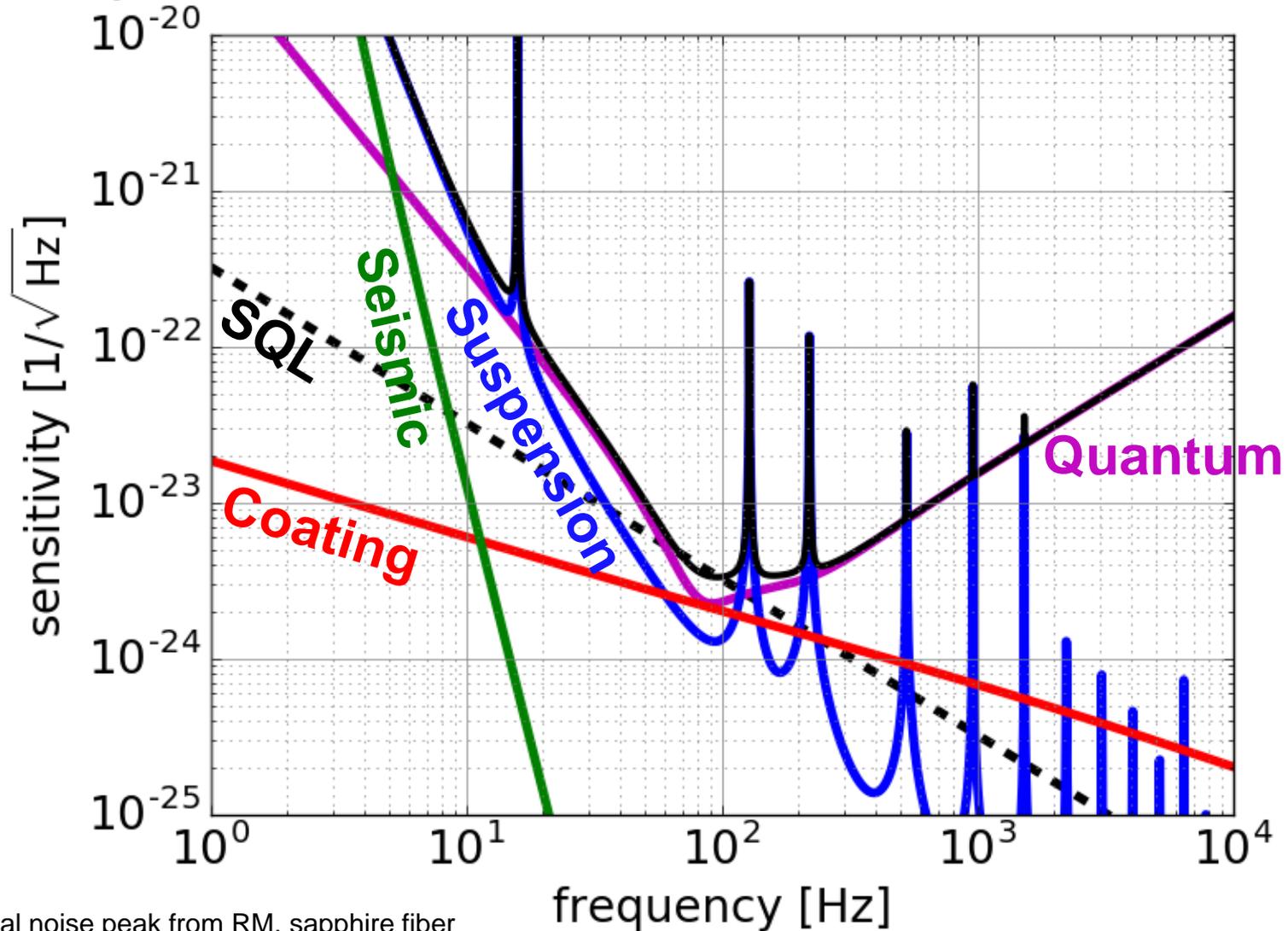
KAGRA Sensitivity (v2009)

- 30 kg, 20 K, 825 W at BS → BNS 171 Mpc



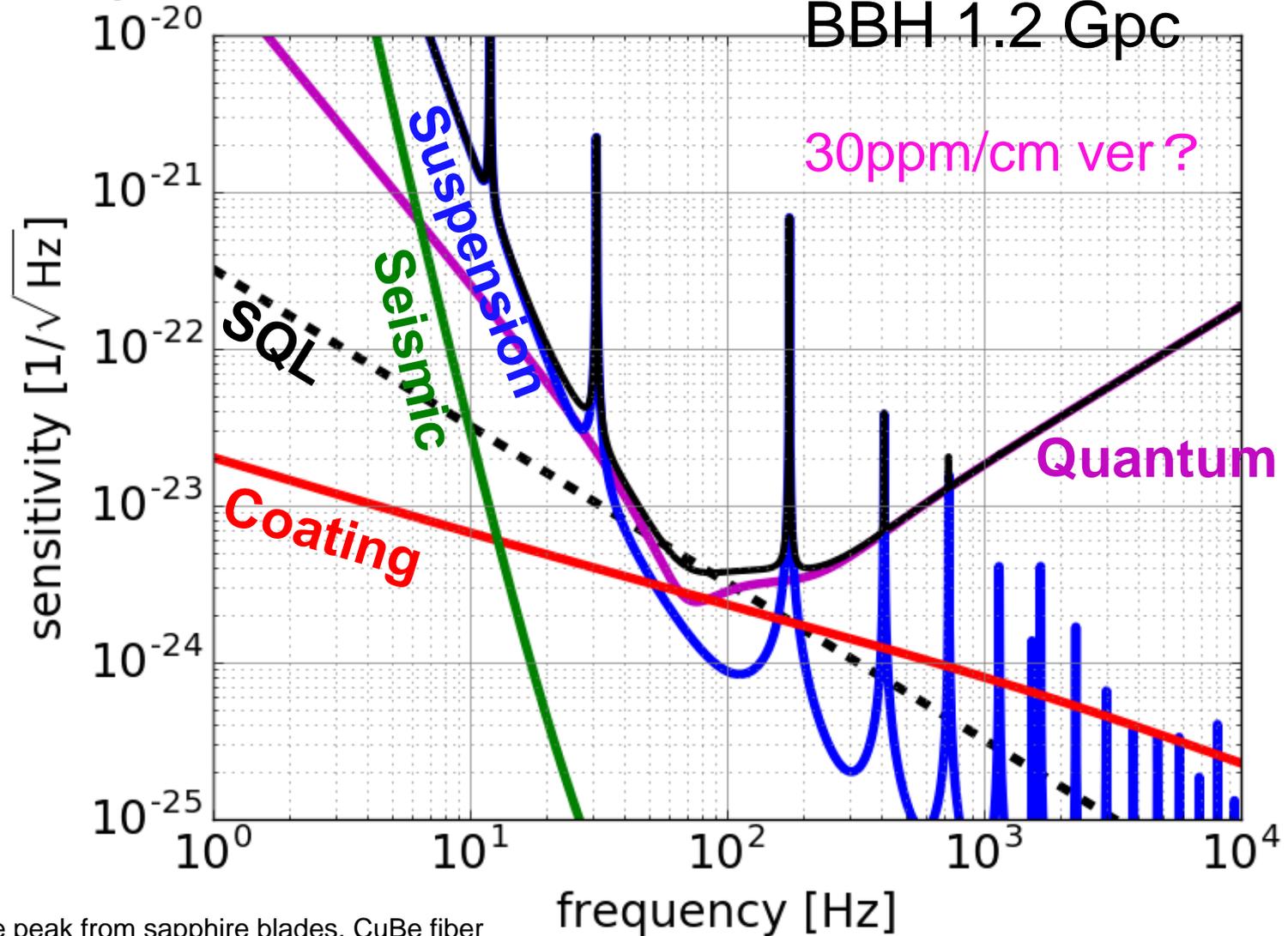
KAGRA Sensitivity (v2013)

- 23 kg, 20 K, 780 W at BS \rightarrow BNS 148 Mpc



KAGRA Sensitivity (v2016)

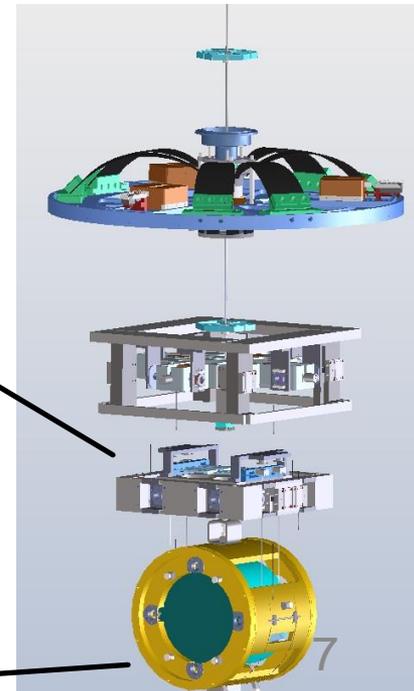
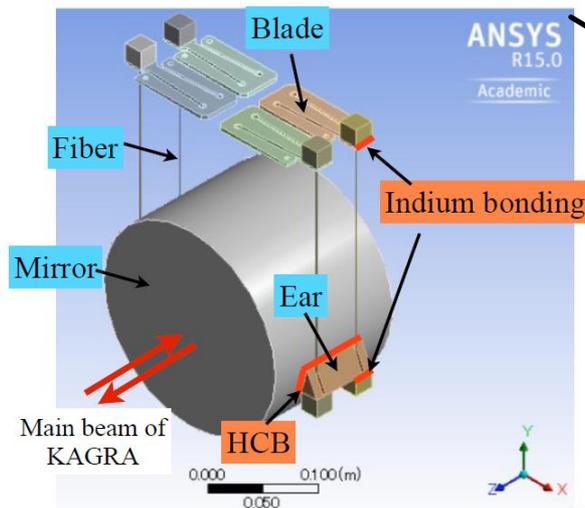
- 23 kg, 23 K, 550 W at BS → BNS 152 Mpc
BBH 1.2 Gpc



Update Details

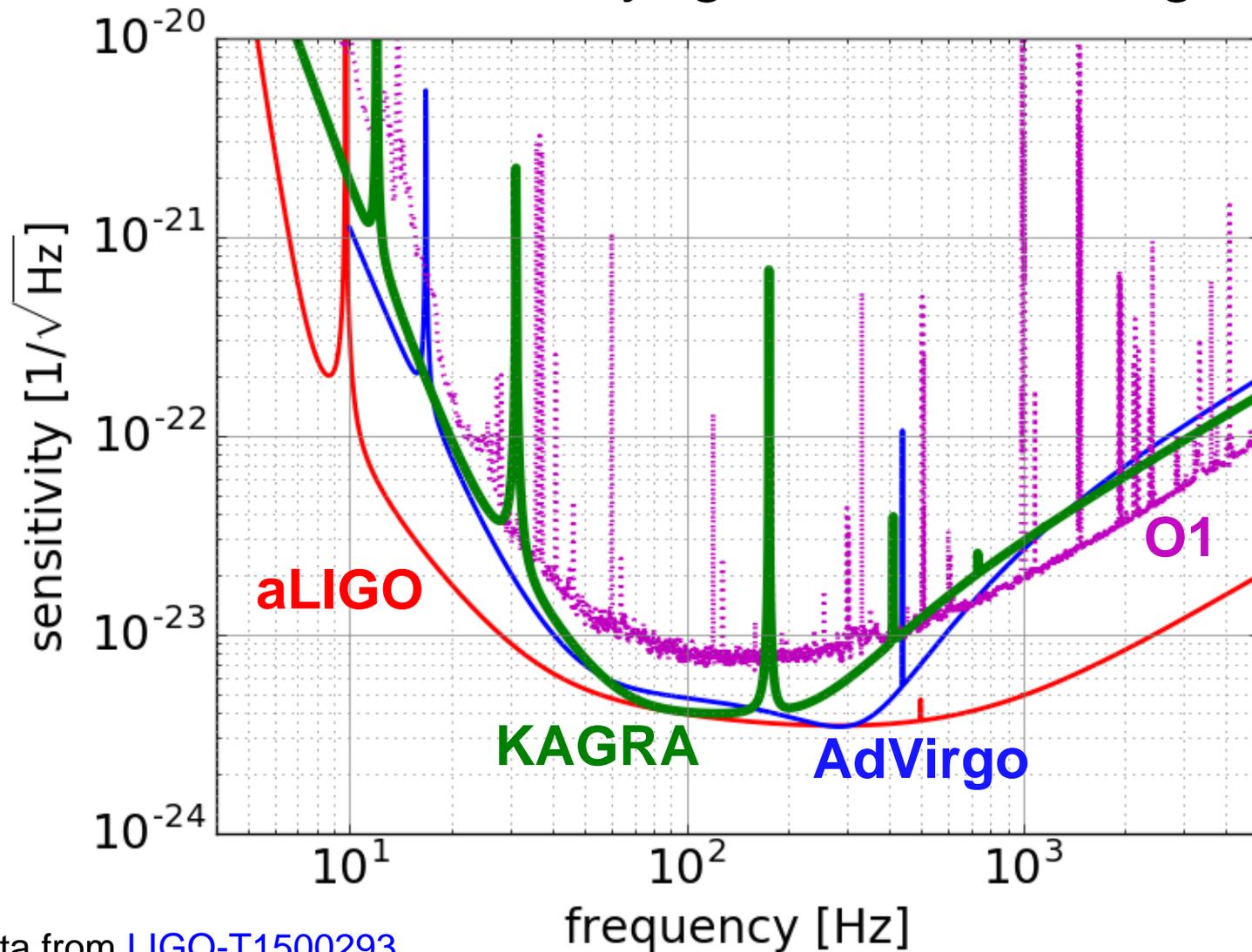
- Included sapphire blades into calculation
120 Hz vertical thermal noise peak now at 1.5 kHz
- Temperature increased by 0.5 K from sapphire blades and indium bonding
- Sapphire fiber length change (30 cm \rightarrow 35 cm)
less heat extraction
- ITM absorption might be 80 ppm/cm

\rightarrow 23.1 K



KAGRA vs Other 2G

- Not better even with cryogenic and underground

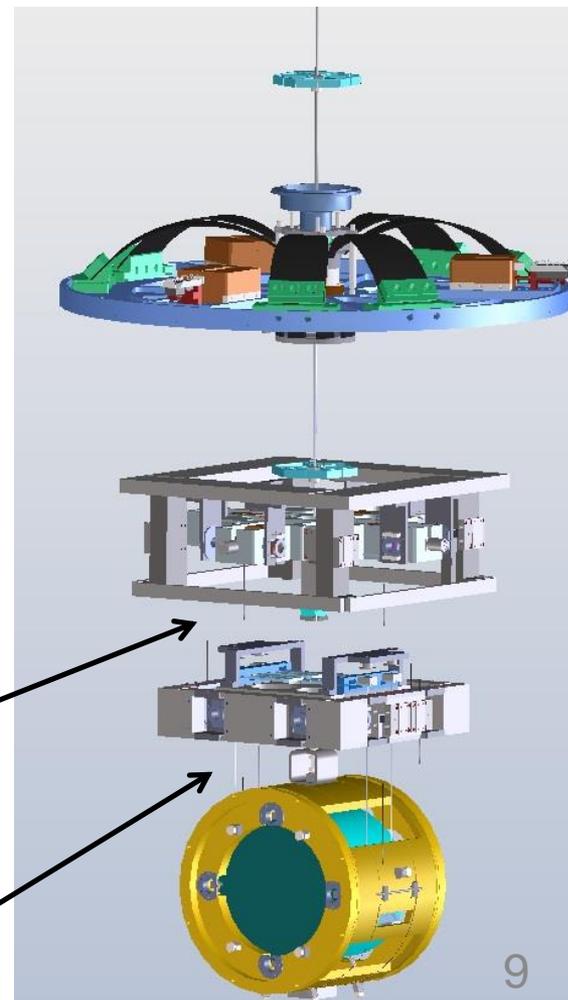


KAGRA vs Other 2G

- Lighter mass because of sapphire
- Lower power for heat extraction
- Thick sapphire and lossy CuBe suspension increase suspension thermal noise
(low frequency sensitivity is not limited by underground seismic noise)

CuBe fibers ($\varphi=5e-6$)

1.6 mm dia. Sapphire fibers



Ideas for Improving Sensitivity

- Increase the mass

- LMA GAST

- composite mass

- A-axis sapphire mass (upto 50kg, 26 cm dia.)

- non-cylindrical mass (??kg)

- go silicon (upto 200 kg, 45 cm dia.)

かまぼこのサイズと重さ

サファイア結晶から鏡をくり抜く図

廣瀬さんに聞く、LMAに聞く(スライド見る)

- Focus on low frequency

- low laser power, thin and long suspension

- Filter cavity

- effectively increase mass and laser power

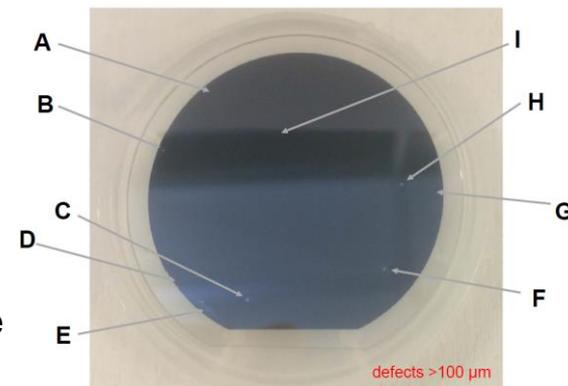
- Better cryopayload design

- ETM different from ITM, half-cryogenic, delay-line, folded arms, higher-order modes ???

R&D Activities

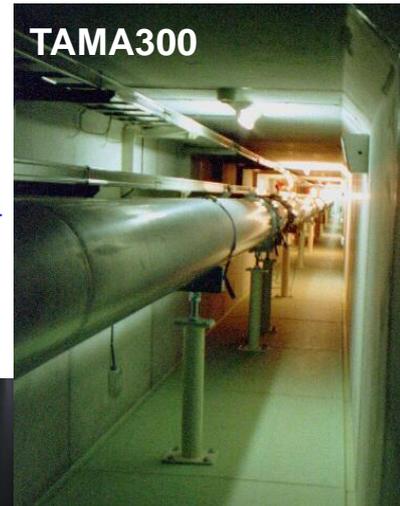
- Crystalline coating on sapphire
- Cryogenic silicon cavity for thermal noise measurements
- Mirror absorption characterization
- 300m filter cavity at TAMA300
- Quantum radiation pressure noise measurement with mg-scale mirror

Talk by Raffaele

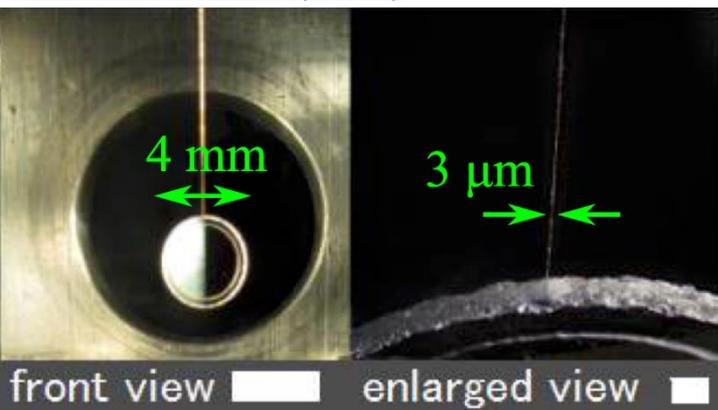


2-inch GaAs/AlGaAs on sapphire
6ppm scattering, 9 large defects
(M. Marchio, R. Flaminio)

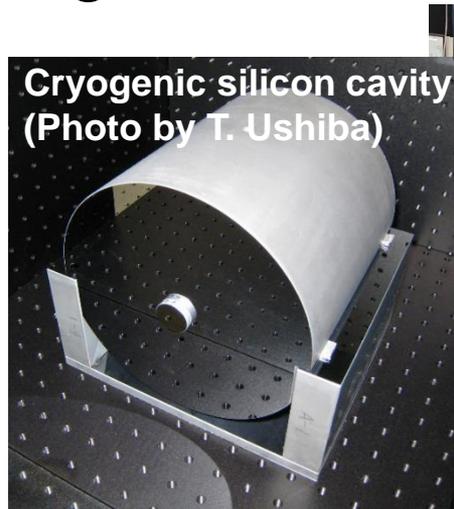
E. Capocasa *et al.*: [PRD 93, 082004 \(2016\)](#)



N. Matsumoto, K. Komori *et al.*:
[PRA 92, 033825 \(2015\)](#)



Cryogenic silicon cavity
(Photo by T. Ushiba)

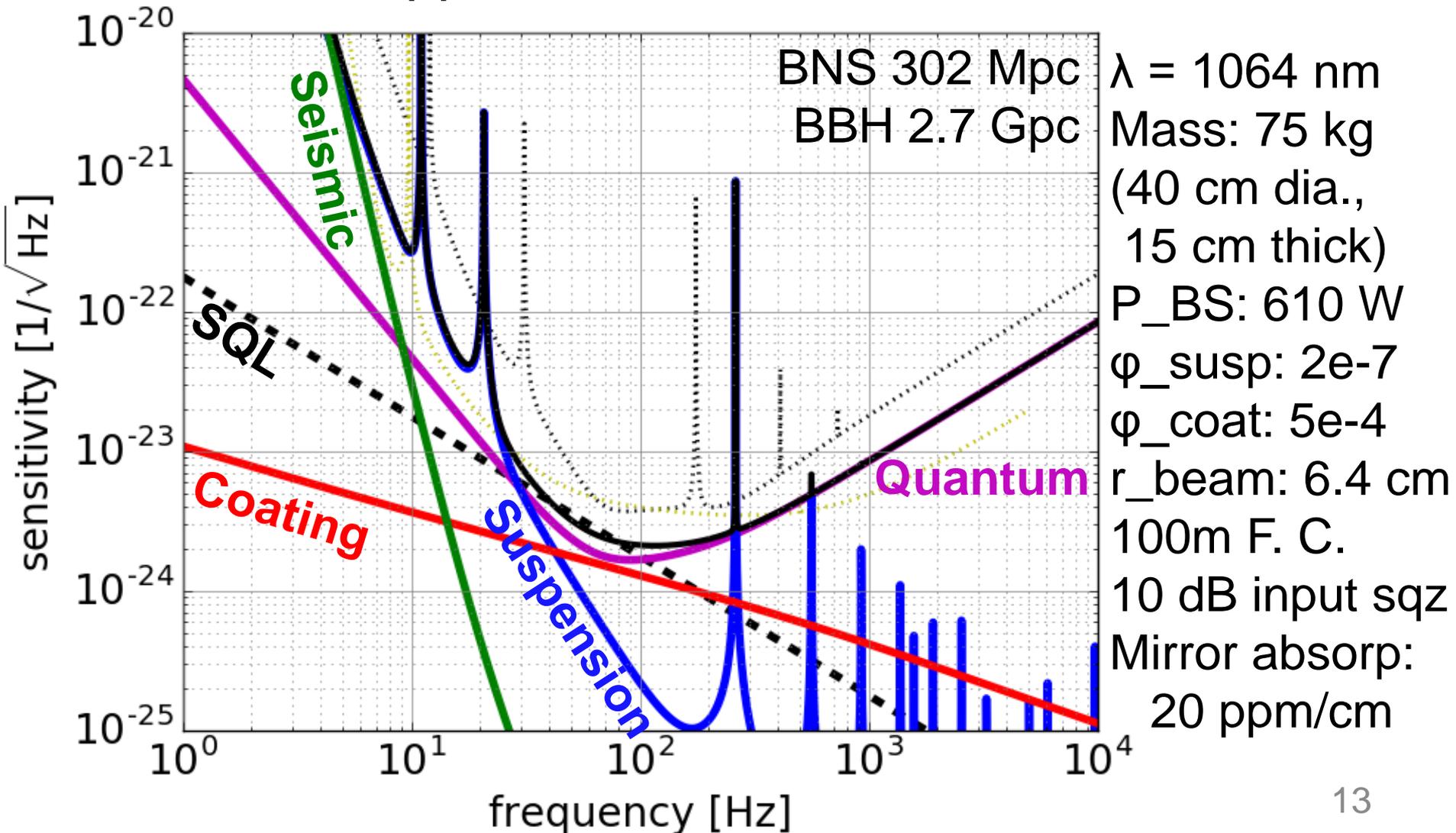


Integrated Design Study

- Informal meeting in February 2017 to start integrated study
- To begin with, appointed three students to show example sensitivity
 - **Team Blue** (Y. Enomoto *et al.*)
use heavier sapphire mirrors
 - **Team Black** (K. Komori *et al.*)
use Silicon
 - **Team Brown** (K. Nagano *et al.*)
focus on low frequency with low power

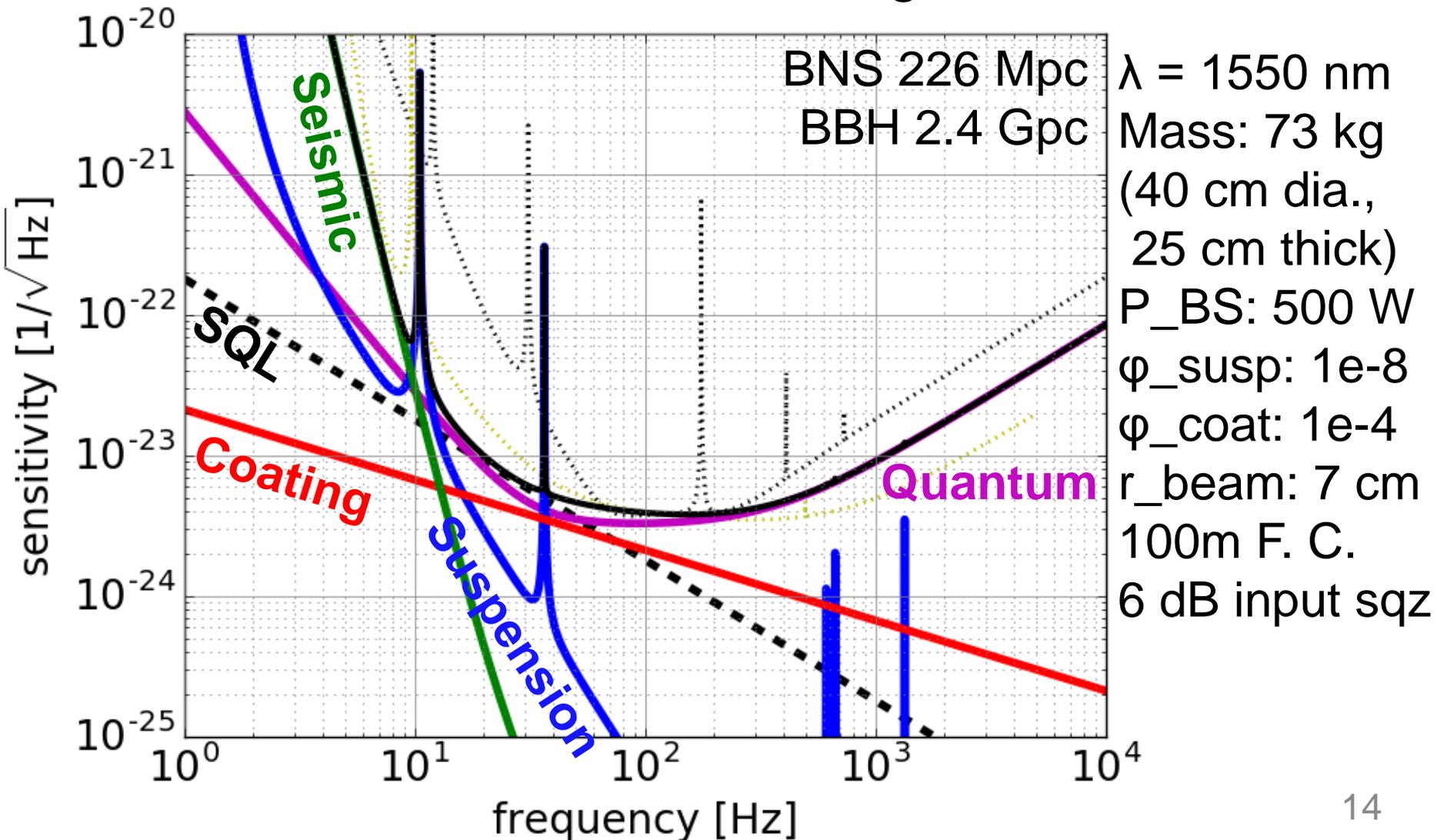
KAGRA+ Sensitivity: **Blue**

- Heavier sapphire and heavier IM, 20 K



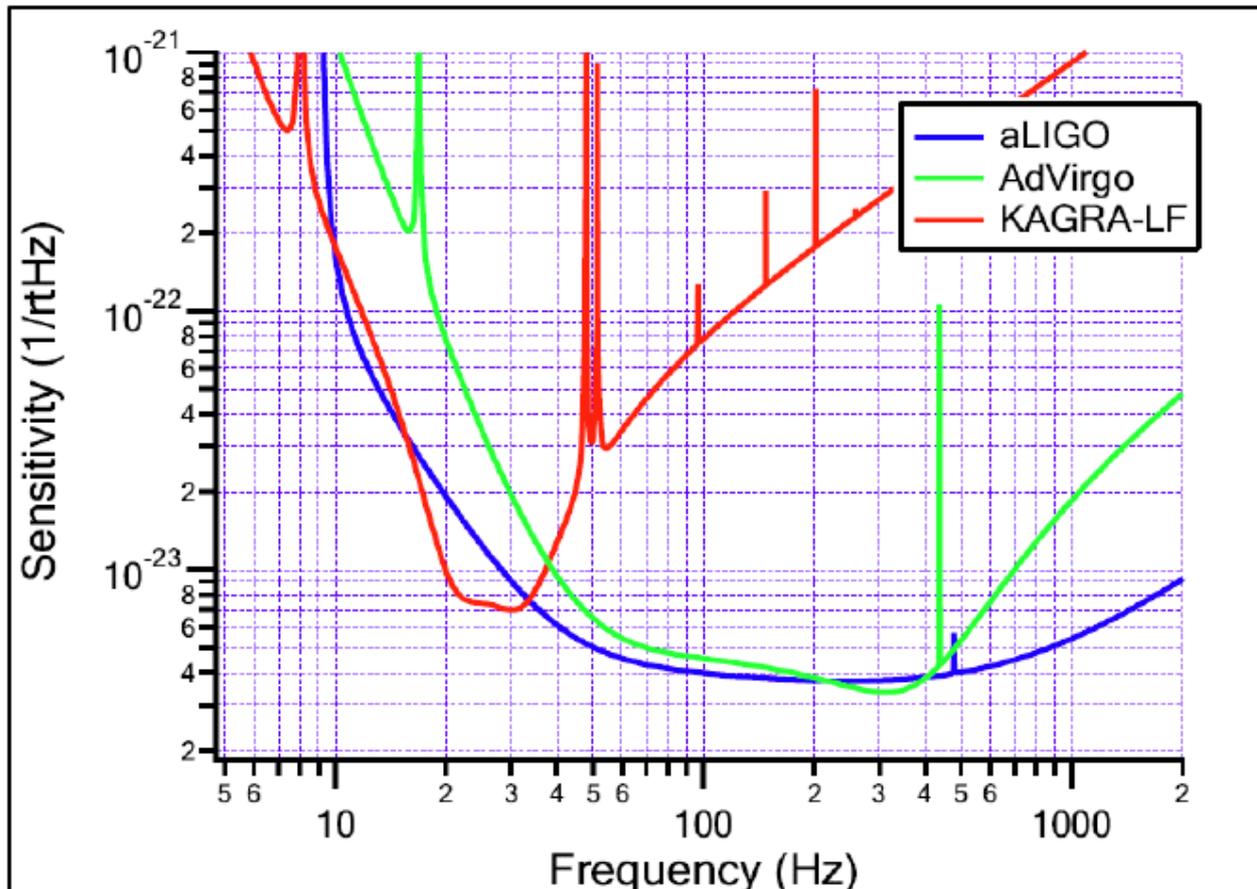
KAGRA+ Sensitivity: Black

- Silicon 123 K, radiative cooling



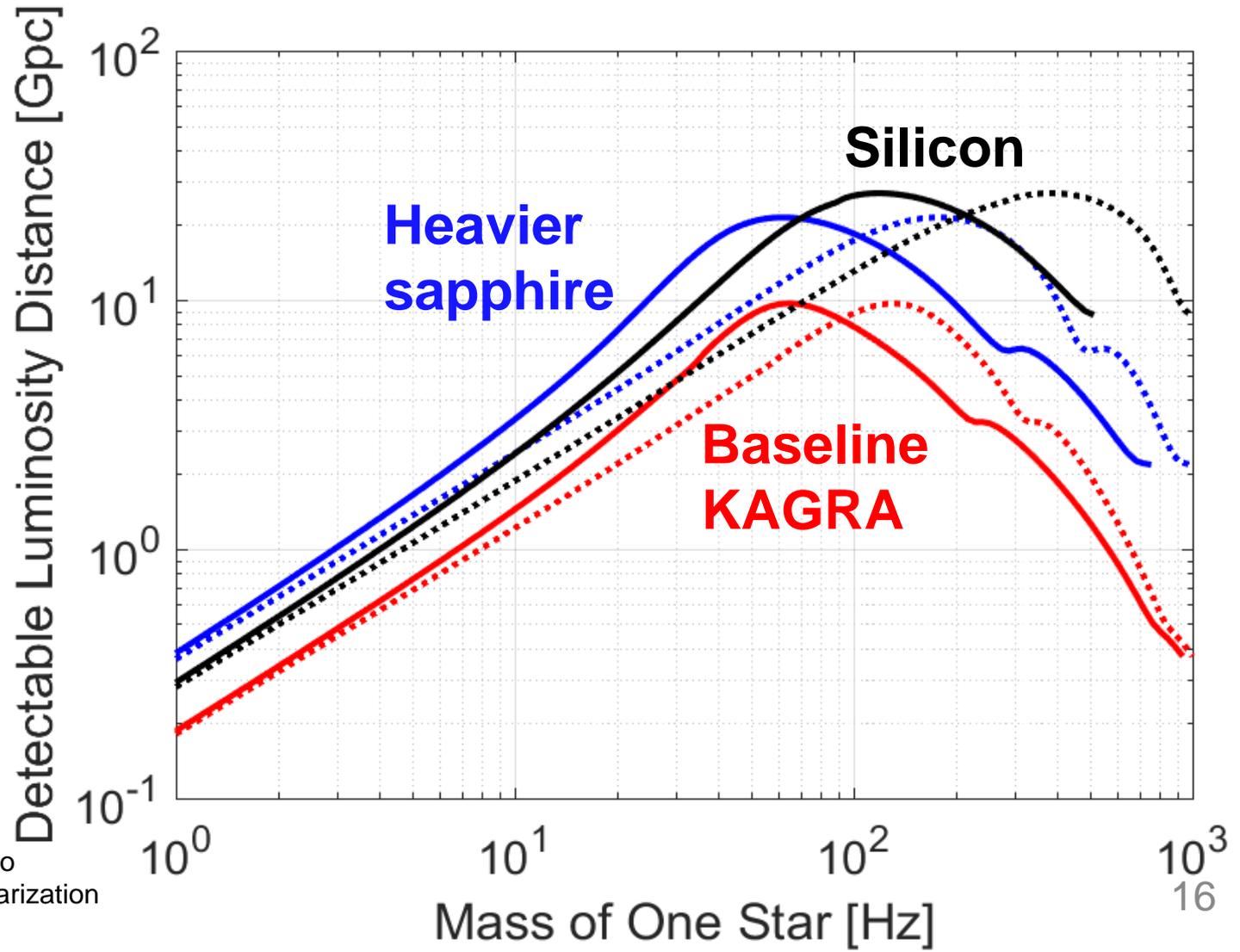
KAGRA+ Sensitivity: **Brown**

- Low frequency (under calculation)



Example Astrophysical Reach

- Science case discussion on going



Summary

- R&D on going for future KAGRA upgrade
- Integrated sensitivity design study on KAGRA+ initiated recently
- Maybe we will make three teams to compare their proposals
- Science case discussion also on going
- Any comments are welcome

Supplementary Slides

2G/2G+ Parameter Comparison

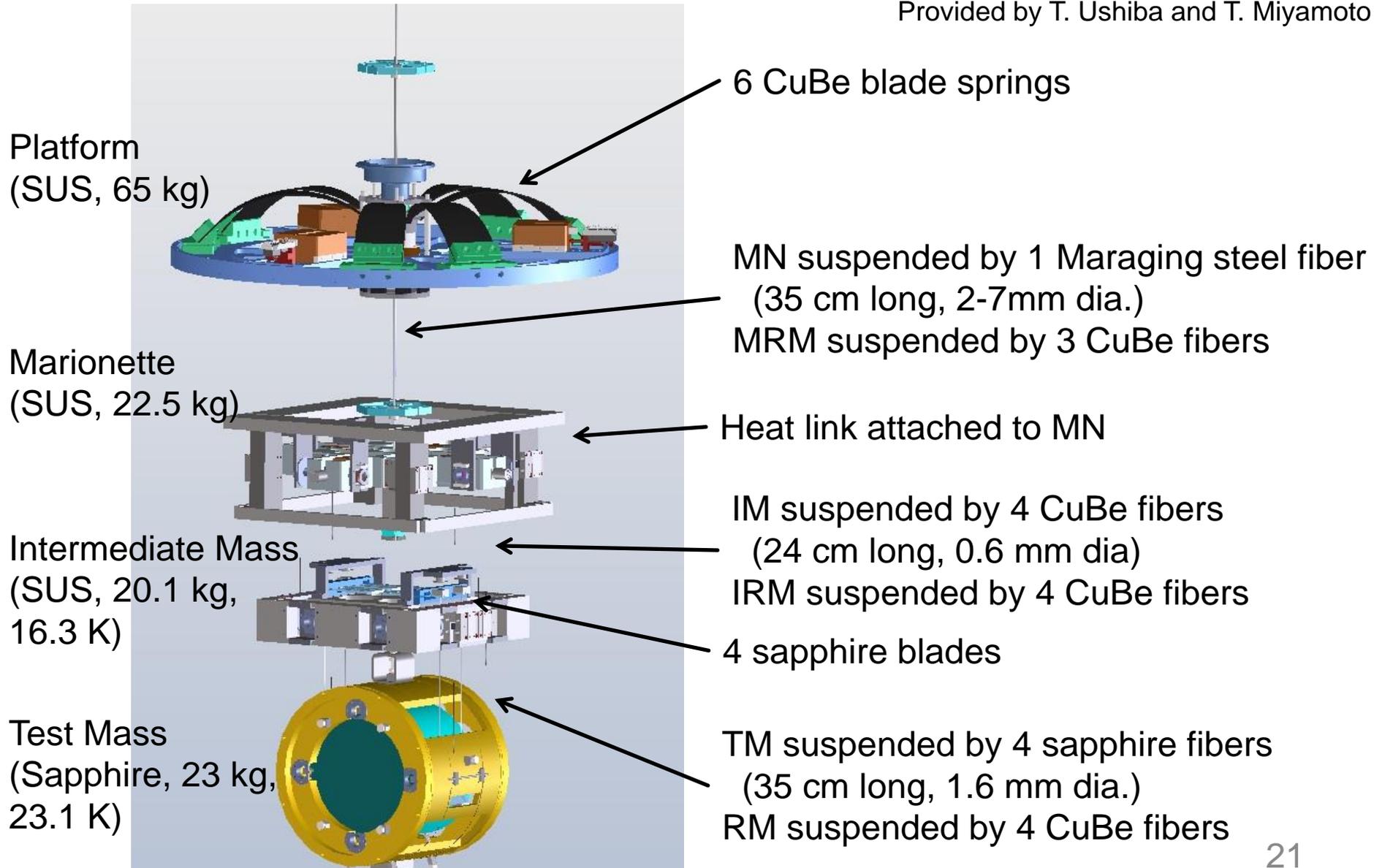
	KAGRA	AdVirgo	aLIGO	A+	Voyager
Arm length [km]	3	3	4	4	4
Mirror mass [kg]	23	42	40	80	200
Mirror material	Sapphire	Silica	Silica	Silica	Silicon
Mirror temp [K]	23	295	295	295	123
Sus fiber	35cm Sap.	70cm SiO ₂	60cm SiO ₂	60cm SiO ₂	60cm Si
Fiber type	Fiber	Fiber	Fiber	Fiber	Ribbon
Input power [W]	55	125	125	125	140
Arm power [kW]	290	700	710	1150	3000
Wavelength [nm]	1064	1064	1064	1064	2000
Beam size [cm]	3.5 / 3.5	4.9 / 5.8	5.5 / 6.2	5.5 / 6.2	5.8 / 6.2
SQZ factor	0	0	0	6	8
F. C. length [m]	none	none	none	16	300

KAGRA Detailed Parameters

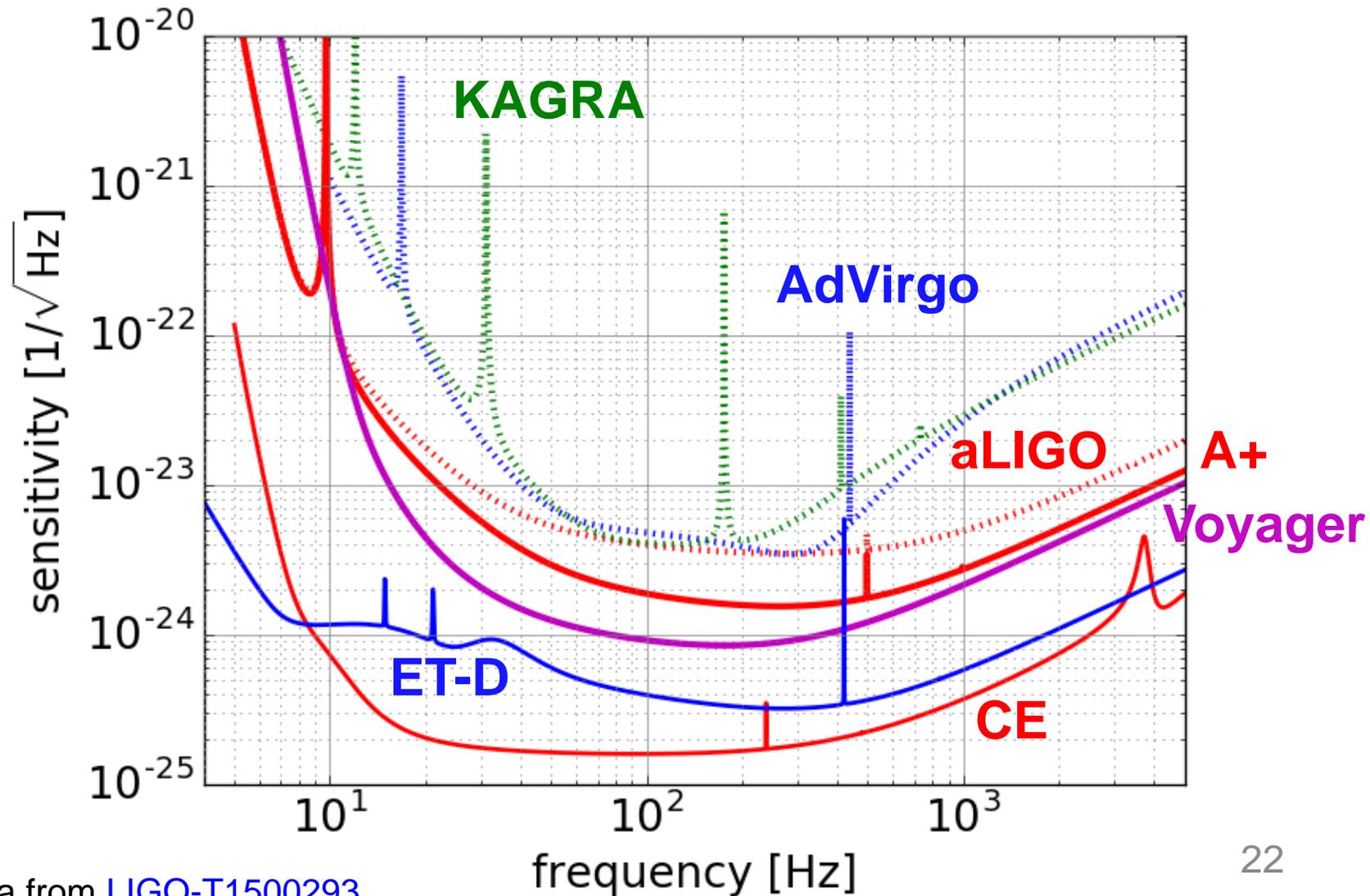
- **Optical parameters**
 - Mirror transmission: 0.4 % for ITM, 10 % for PRM, 15.36 % for SRM
 - Power at BS: 550 W
 - Detune phase: 3.5 deg (DRSE case)
 - Homodyne phase: 133 deg (DRSE case)
- **Sapphire mirror parameters**
 - TM size: 220 mm dia., 150 mm thick
 - TM mass: 22.8 kg
 - TM temperature: 23.1 K
 - Beam radius at ITM: 3.5 cm
 - Beam radius at ETM: 3.5 cm
 - Q of mirror substrate: $1e8$
 - Coating: tantala/silica
 - Coating loss angle: $3e-4$ for silica, $5e-4$ for tantala
 - Number of layers: 9 for ITM, 18 for ETM
 - Coating absorption: 0.5 ppm
 - Substrate absorption: 80 ppm/cm
- **Suspension parameters**
 - TM-IM fiber: 35 cm long, 1.6 mm dia.
 - IM temperature: 16.3 K
 - Heat extraction: 6580 W/m/K
 - Loss angle: $5e-6/2e-7/7e-7$ for CuBe fiber?/sapphire fiber/sapphire blade
- **Inspirial range calculation**
 - SNR=8, $f_{min}=10$ Hz, sky average constant 0.442478

KAGRA Cryopayload

Provided by T. Ushiba and T. Miyamoto



2-3G Sensitivity Comparison



Other References

- K. Somiya, 感度について [JGW-G1605698](#)
On recent official sensitivity update
- K. Somiya, KAGRA2020 [JGW-G1503551](#)
Slides for GWADW2015 on KAGRA upgrade
- K. Somiya *et al.*: LCGT-LF report [JGW-T1100446](#)
Study report on a reconsideration of the LCGT
bandwidth for low-frequency measurements
- M. Ando *et al.*: Study report on LCGT
interferometer observation band [JGW-T1000065](#)