KAGRA+ Upgrade Plans

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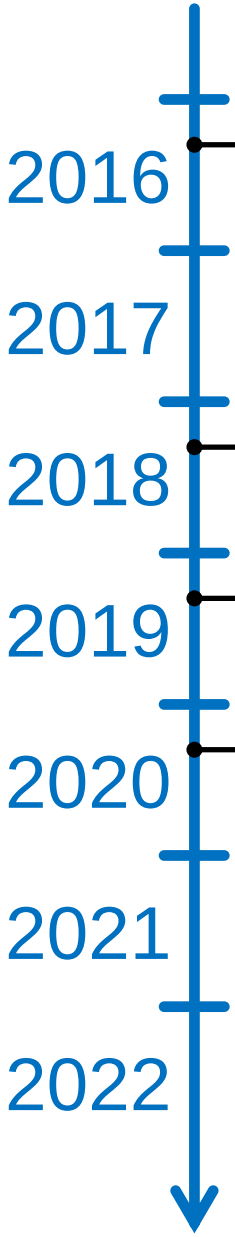
Overview

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

KAGRA+

KAGRA Timeline



Initial KAGRA (iKAGRA)
3-km Michelson
room temperature
simplified suspensions
First test operation

Phase 1
3-km Michelson
cryogenic temperature

Phase 2
3-km RSE
cryogenic temperature

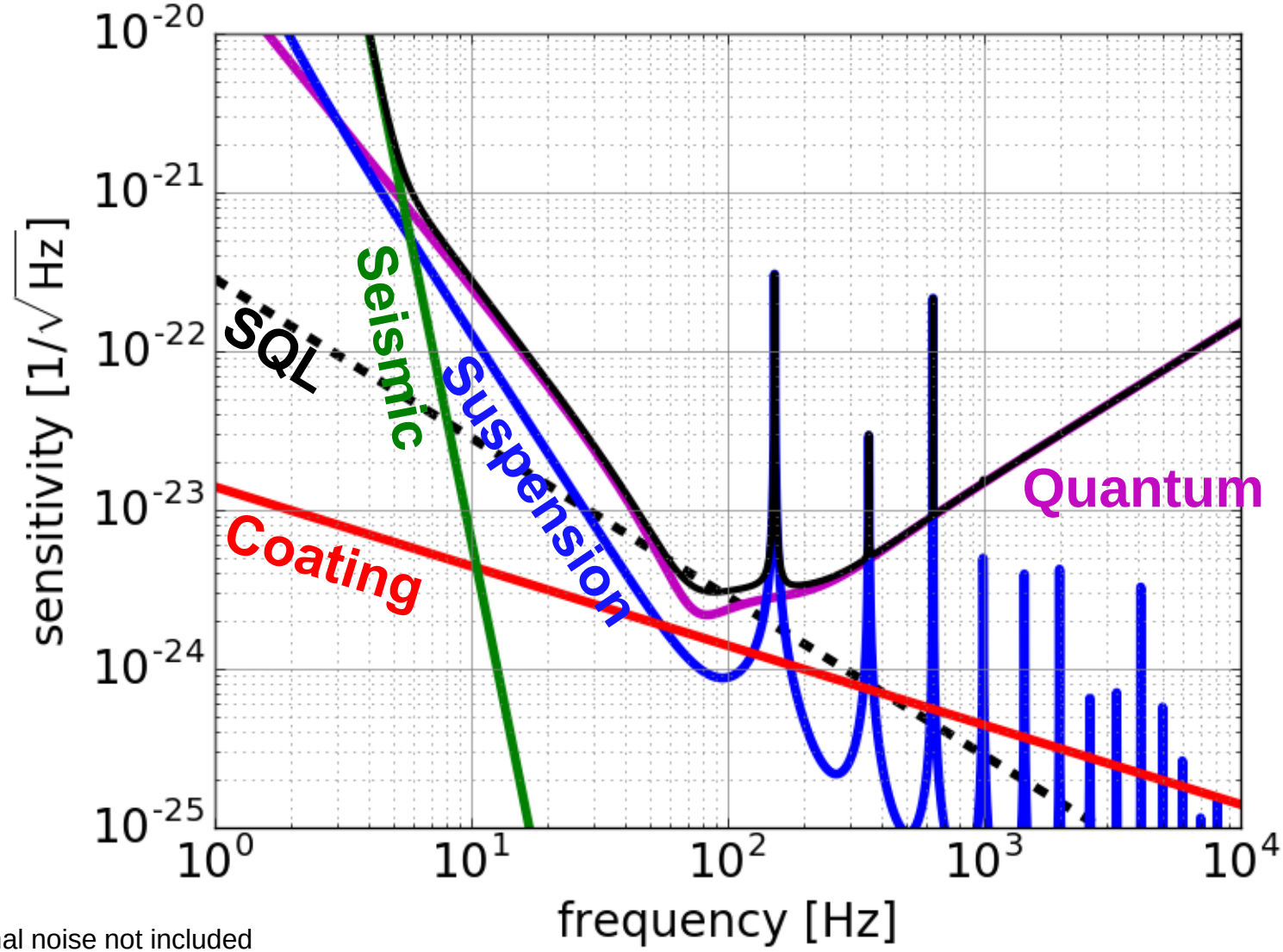
Phase 3
3-km RSE
cryogenic temperature
observation runs

Baseline KAGRA (bKAGRA)

KAGRA+ ?

KAGRA Sensitivity (v2009)

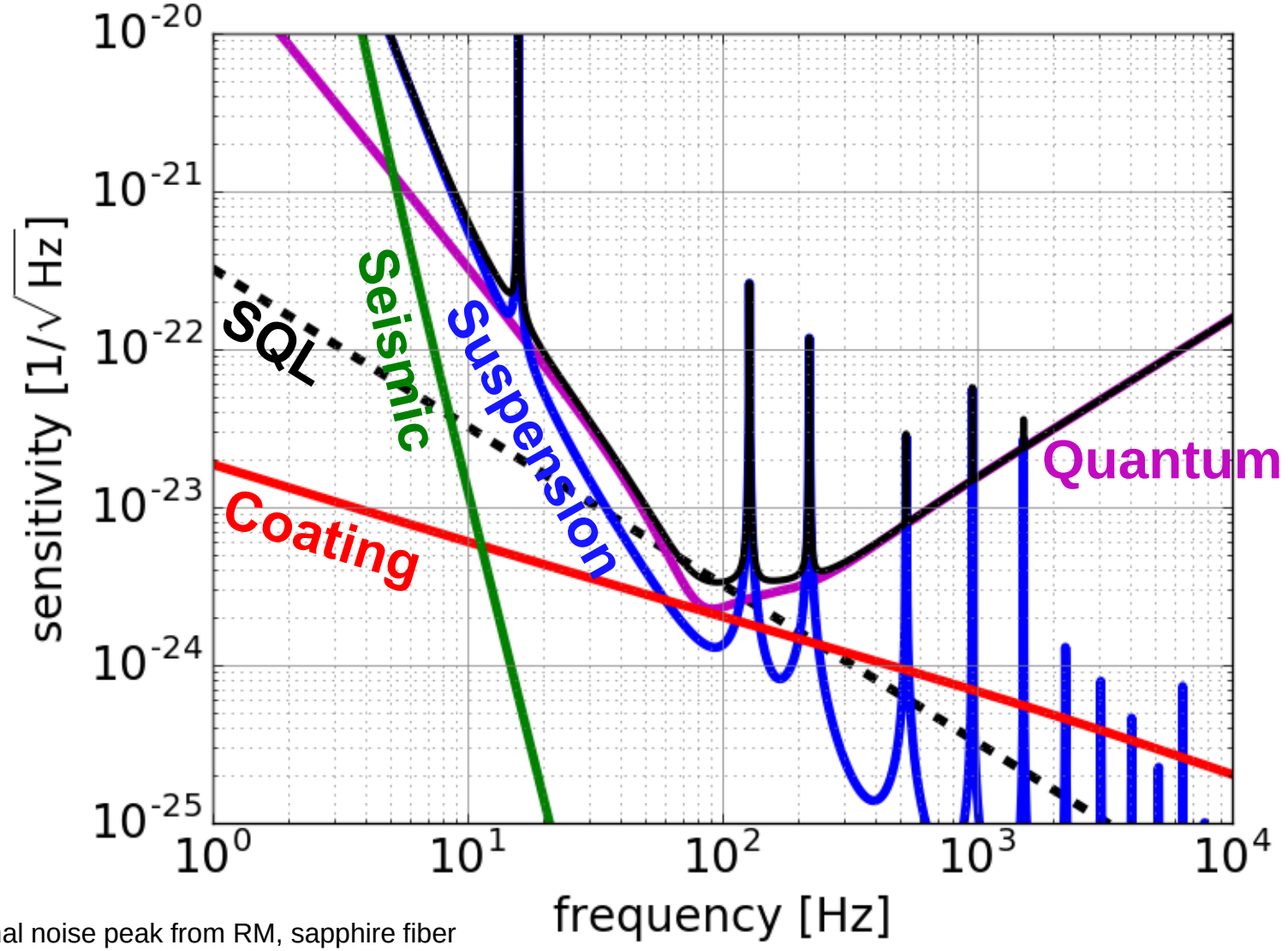
- 30 kg, 20 K, 825 W at BS → BNS 171 Mpc



Vertical thermal noise not included

KAGRA Sensitivity (v2013)

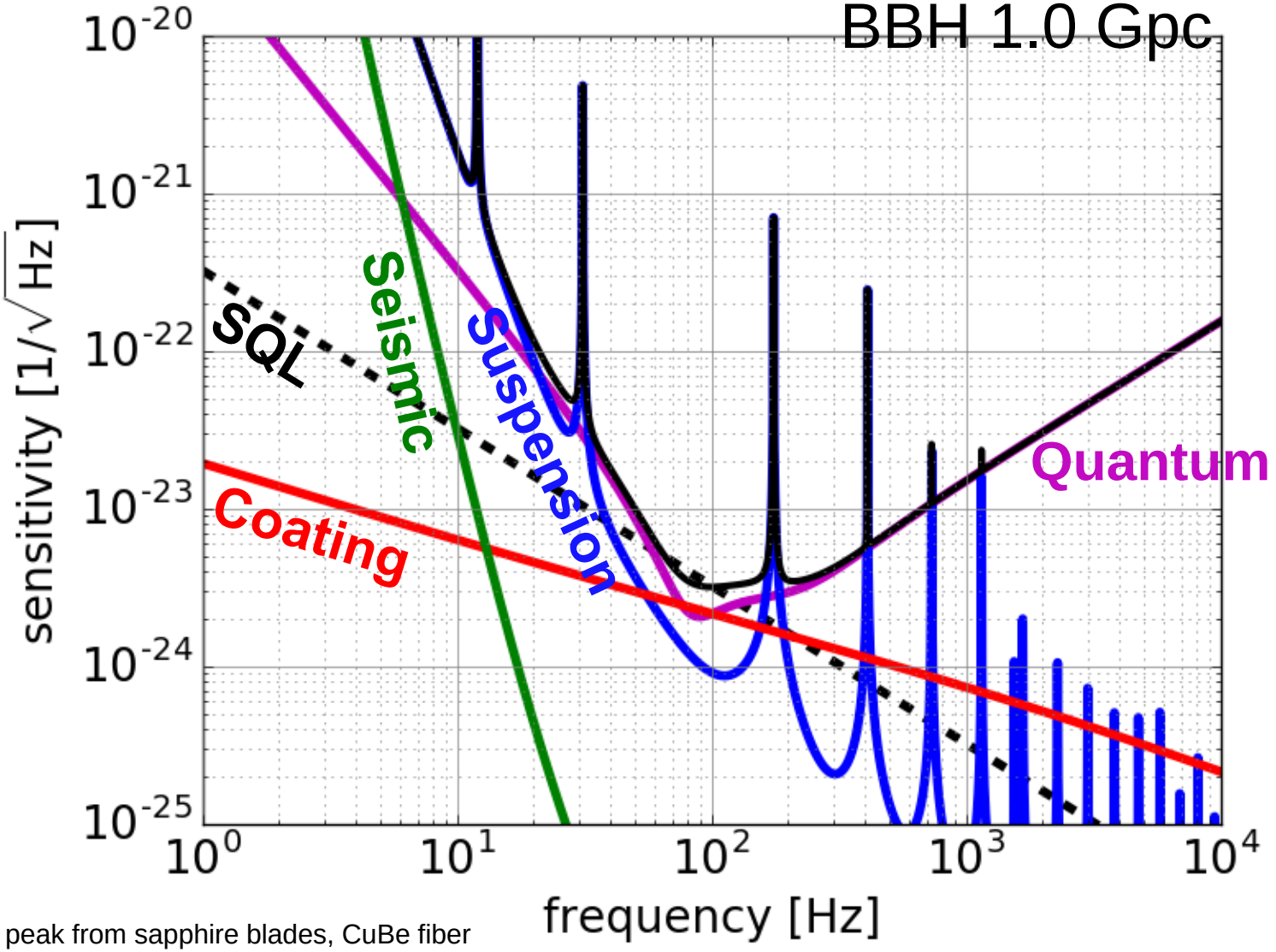
- 23 kg, 20 K, 780 W at BS → BNS 148 Mpc



Vertical thermal noise peak from RM, sapphire fiber

KAGRA Sensitivity (v2017)

- 23 kg, 21.5 K, 780 W at BS → BNS 158 Mpc
  BBH 1.0 Gpc

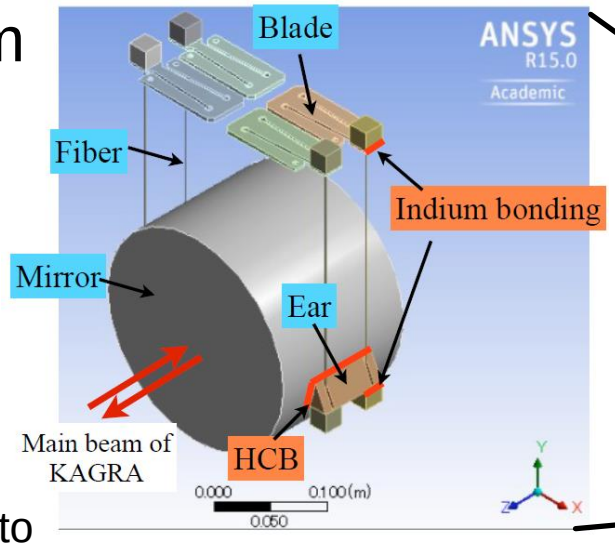


Thermal noise peak from sapphire blades, CuBe fiber

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 → 35 cm)
  less heat extraction ☹
- ITM absorption was ~30 ppm/cm ☺
  spec: 50 ppm/cm

→ 21.5 K



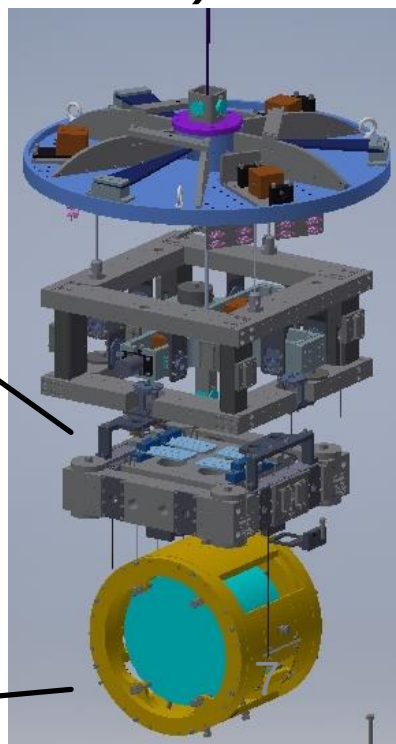
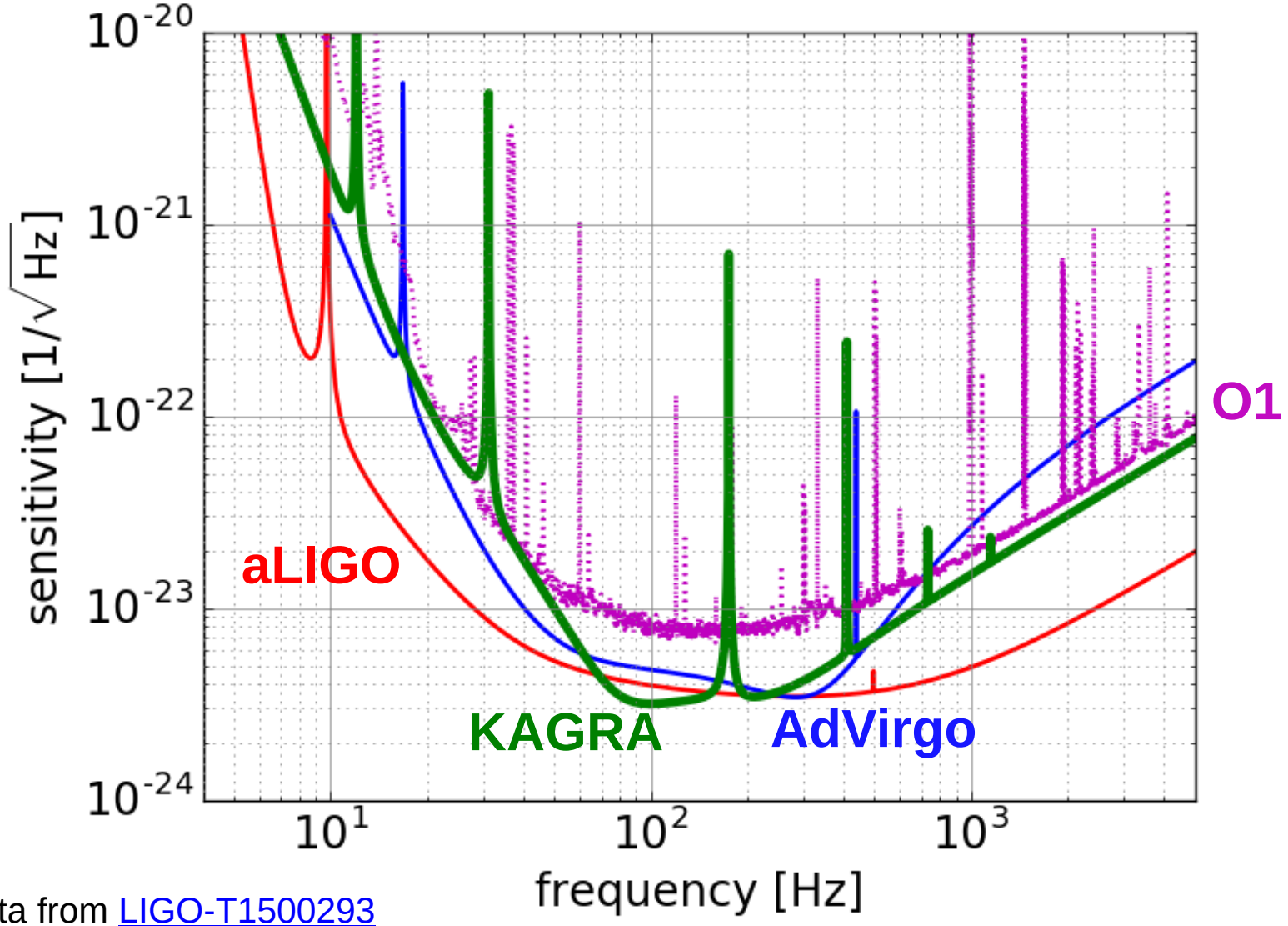


Figure from K. Craig, T. Miyamoto

KAGRA vs Other 2G

- Not better even with cryogenic and underground

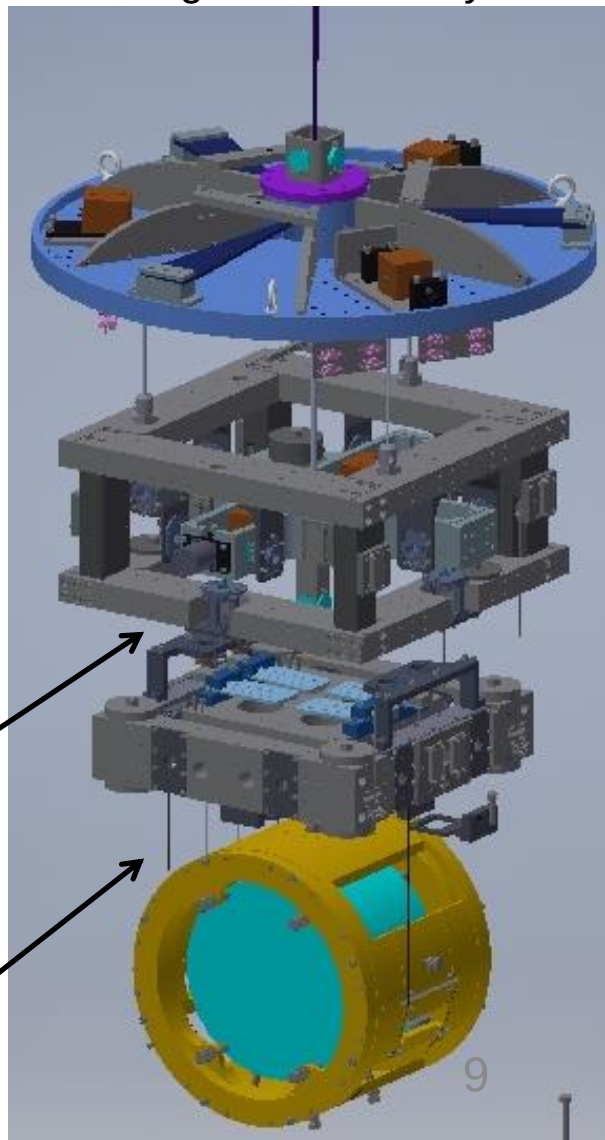


Spectra data from LIGO-T1500293

KAGRA vs Other 2G

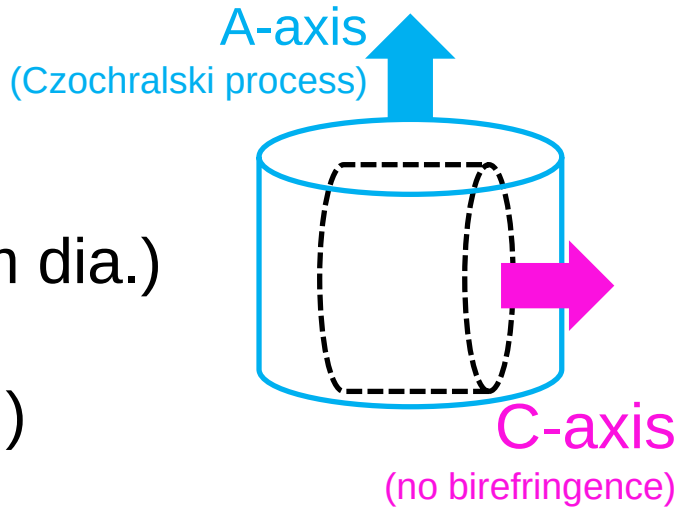
- Lighter mass because of sapphire
- Lower power for heat extraction
- Thick sapphire and lossy CuBe suspension increase suspension thermal noise
  (low frequency sensitivity is not limited by underground seismic noise)

Figure from T. Miyamoto

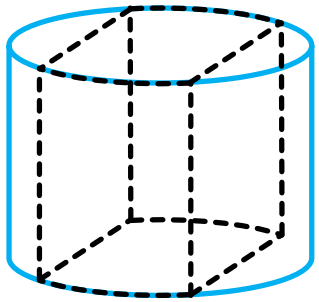


Ideas for Improving Sensitivity

- Increase the mass
  - GAST project (upto 30 cm dia.)
  - composite mass
  - A-axis sapphire (upto 50 kg, 26 cm dia.)
  - non-cylindrical mass (upto 30 kg)
  - go silicon (upto 200 kg, 45 cm dia.)



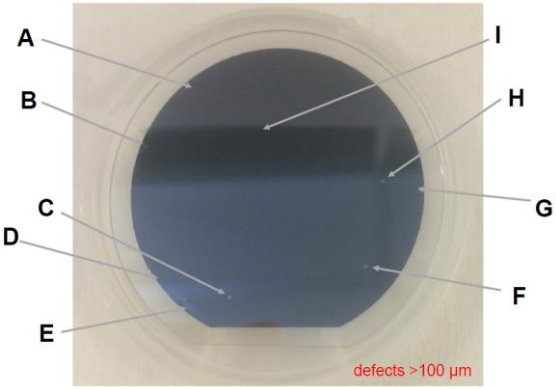
- Focus on low frequency
  - low laser power, thin and long suspension



- 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

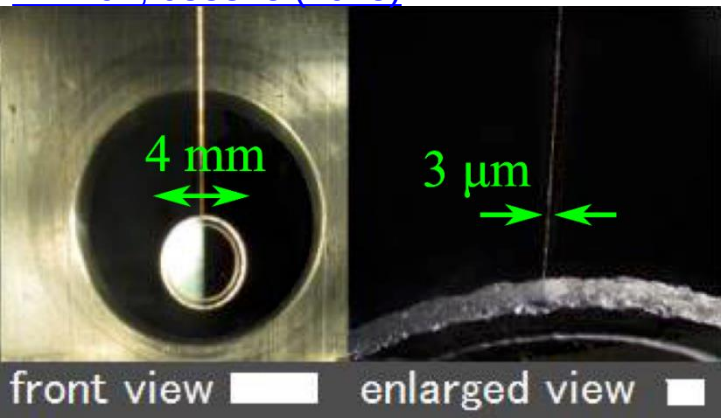


Talk by Raffaele

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)

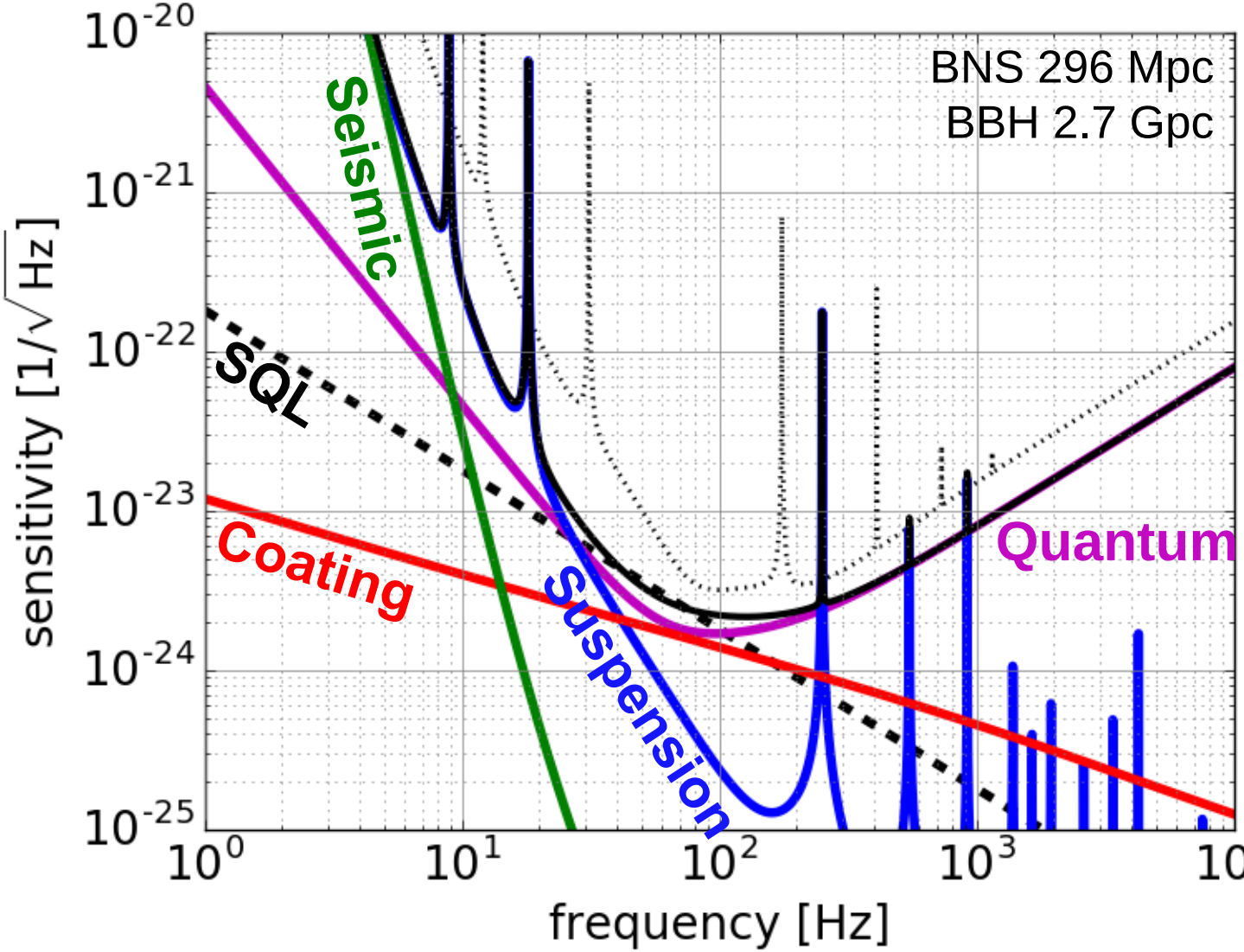


Integrated Design Study

- Informal meeting in February 2017 to start integrated study
- To begin with, appointed three students to show example sensitivity
  - **Blue Ranger** (Yutaro Enomoto)
    use heavier sapphire mirrors
  - **Black Ranger** (Kentaro Komori)
    use Silicon
  - **Brown Ranger** (Koji Nagano)
    low power to focus on
    low frequency

KAGRA+ Sensitivity: **Blue**

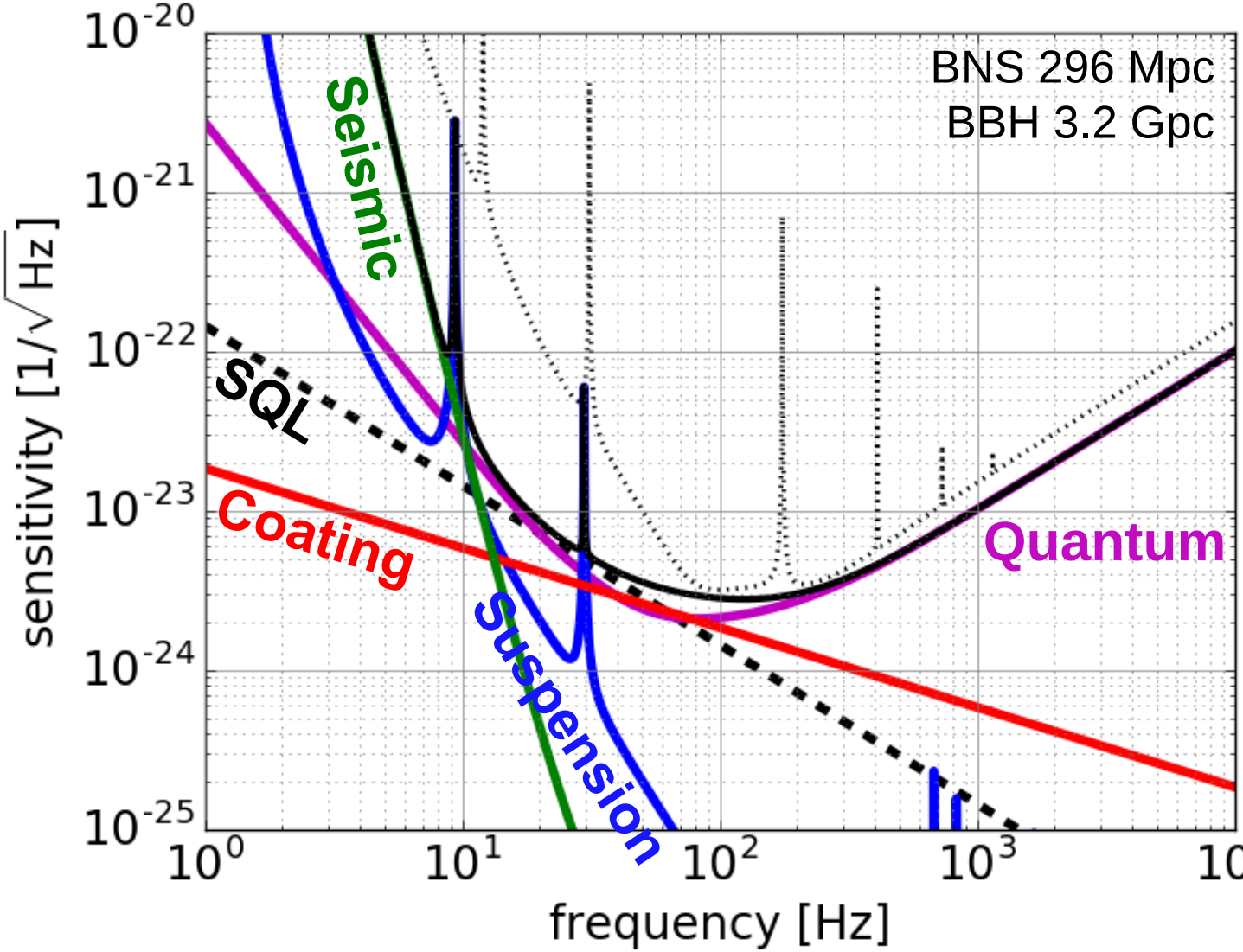
- Heavier sapphire and heavier IM, 20 K



λ = 1064 nm
Mass: 73 kg
(36 cm dia.,
18 cm thick)
P_BS: 620 W
φ_susp: 2e-7
φ_coat: 5e-4
r_beam: 5.7 cm
100m F. C.
10 dB input sqz
T_SRM: 32 %

KAGRA+ Sensitivity: **Black**

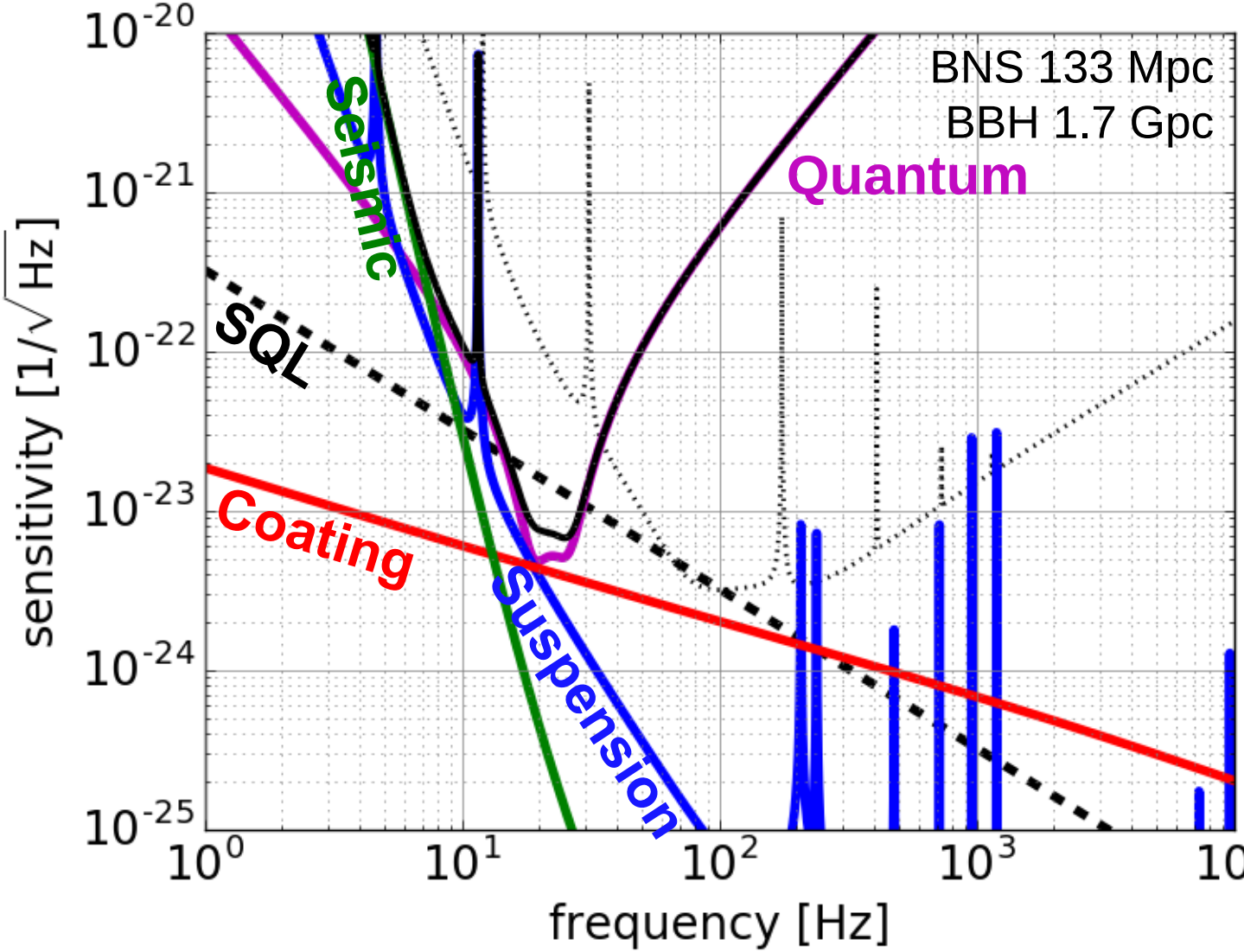
- Silicon 123 K, radiative cooling



λ = 1550 nm
Mass: 114 kg
(50 cm dia.,
25 cm thick)
P_BS: 500 W
φ_susp: 1e-8
φ_coat: 1e-4
r_beam: 8.6 cm
100m F. C.
10 dB input sqz
T_SRM: 16 %

KAGRA+ Sensitivity: Brown

- Same test mass, low power, high detuning, 20 K

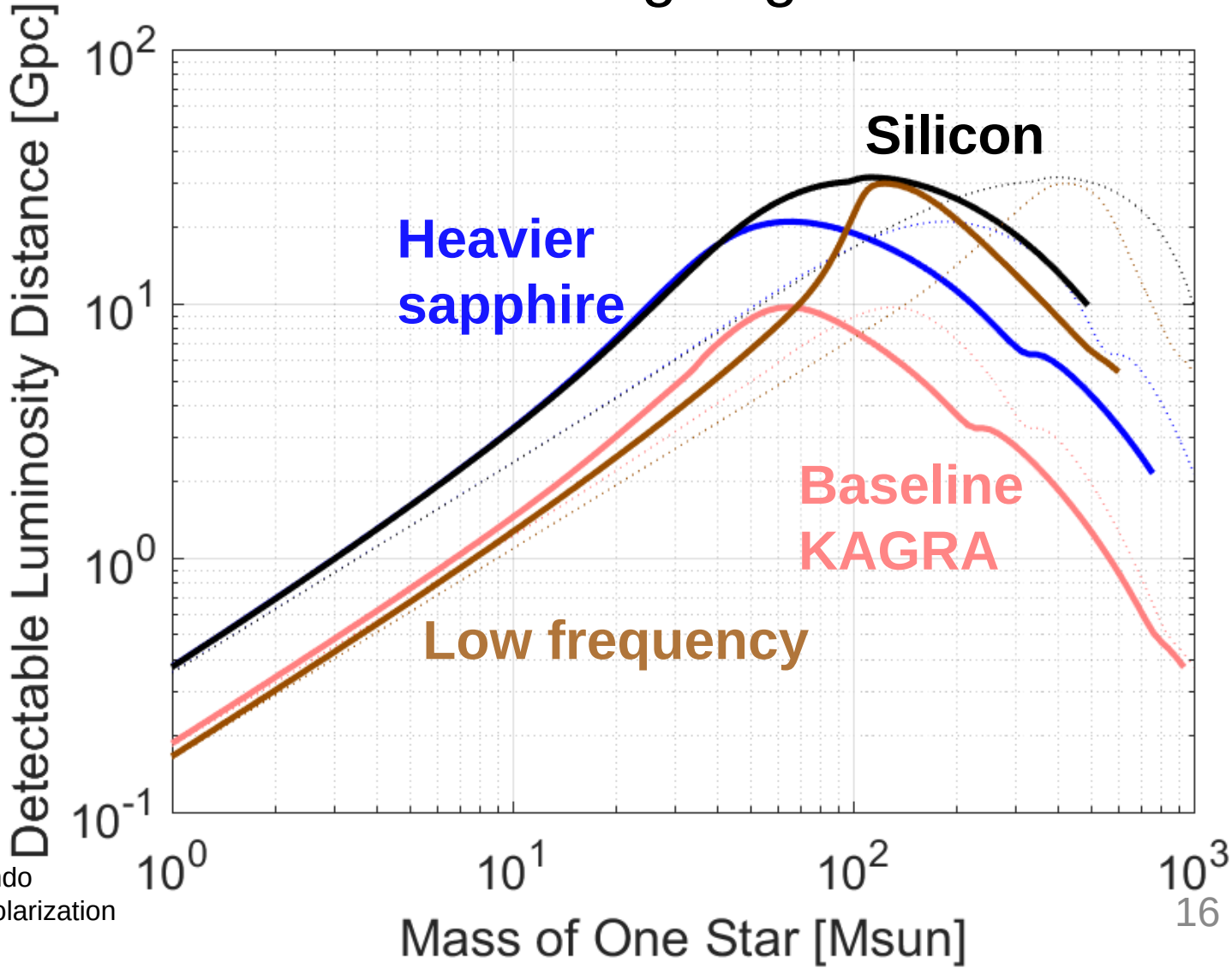


λ = 1064 nm
Mass: 23 kg
(22 cm dia.,
15 cm thick)
P_BS: 5.7 W
φ_susp: 2e-7
φ_coat: 5e-4
r_beam: 3.5 cm
No sqz

T_SRM: 4.35 %

Example Astrophysical Reach

- Science case discussion on going



Code provided by M. Ando
Optimal direction and polarization
SNR threshold 8

Summary

- R&D on going for future KAGRA upgrade
- Integrated sensitivity design study on KAGRA+ initiated recently
- Maybe we will organize three teams to compare their proposals more seriously, based on feasibility, budget, and science
- 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

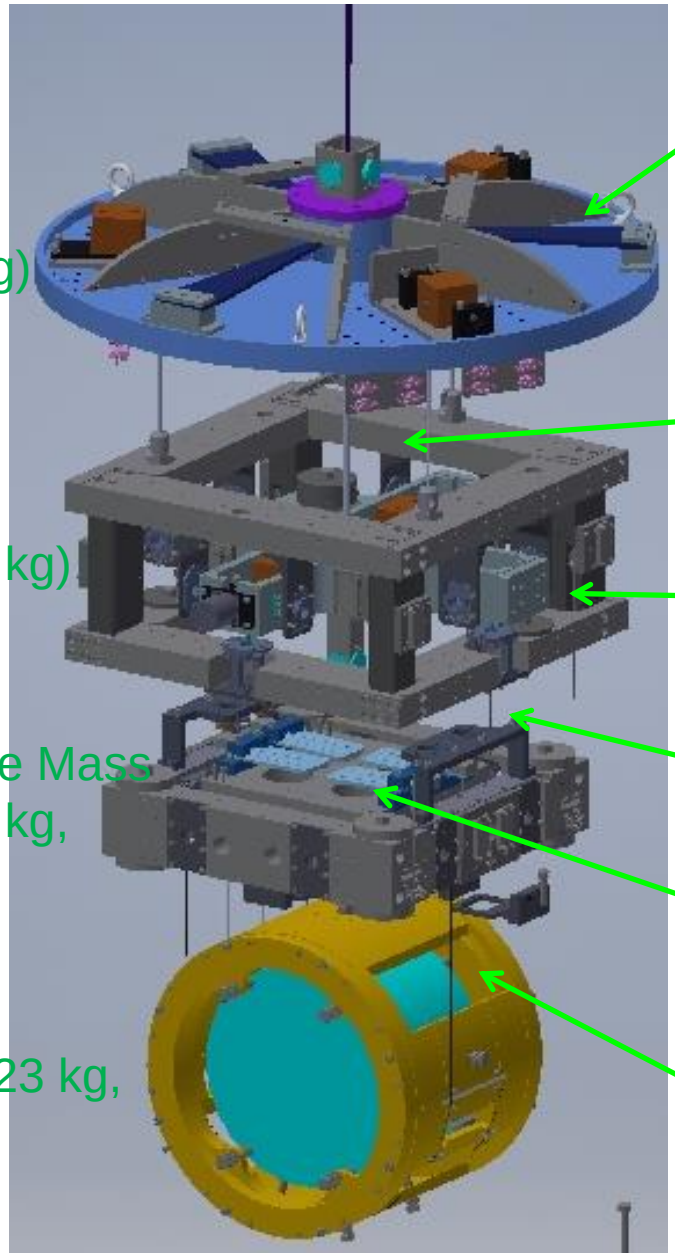
LIGO parameters from LIGO-T1600119, AdVirgo parameters from JPCS 610, 01201 (2015)

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: 21.5 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: 20 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
- **Inspiral range calculation**
  - SNR=8, fmin=10 Hz, sky average constant 0.442478

KAGRA Cryopayload

Provided by T. Ushiba and T. Miyamoto



Platform
(SUS, 65 kg)

Marionette
(SUS, 22.5 kg)

Intermediate Mass
(SUS, 20.1 kg,
16.3 K)

Test Mass
(Sapphire, 23 kg,
21.5 K)

3 CuBe blade springs

MN suspended by 1 Maraging steel fiber
(35 cm long, 2-7mm dia.)
MRM suspended by 3 CuBe fibers

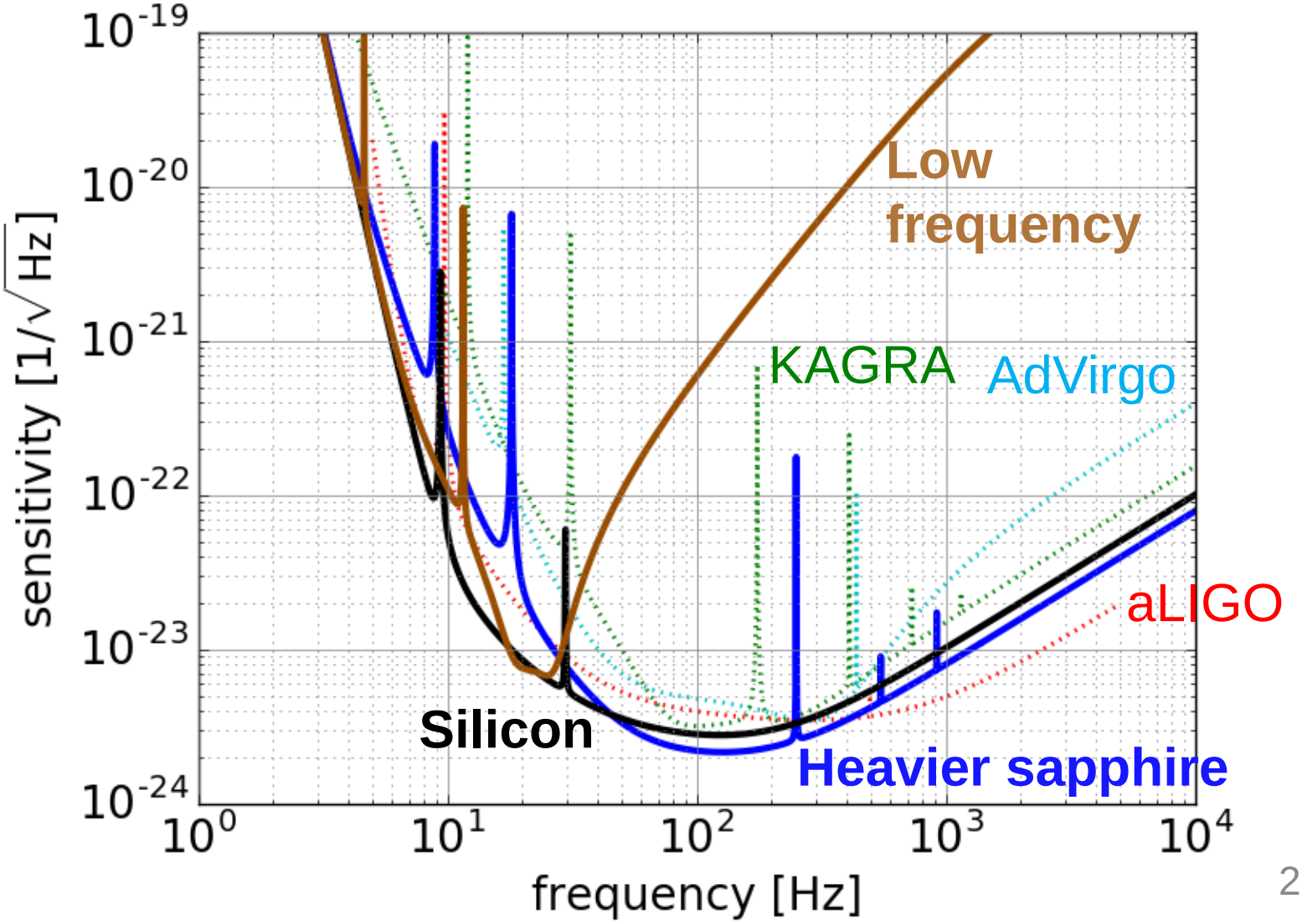
Heat link attached to MN

IM suspended by 4 CuBe fibers
(24 cm long, 0.6 mm dia)
IRM suspended by 4 CuBe fibers

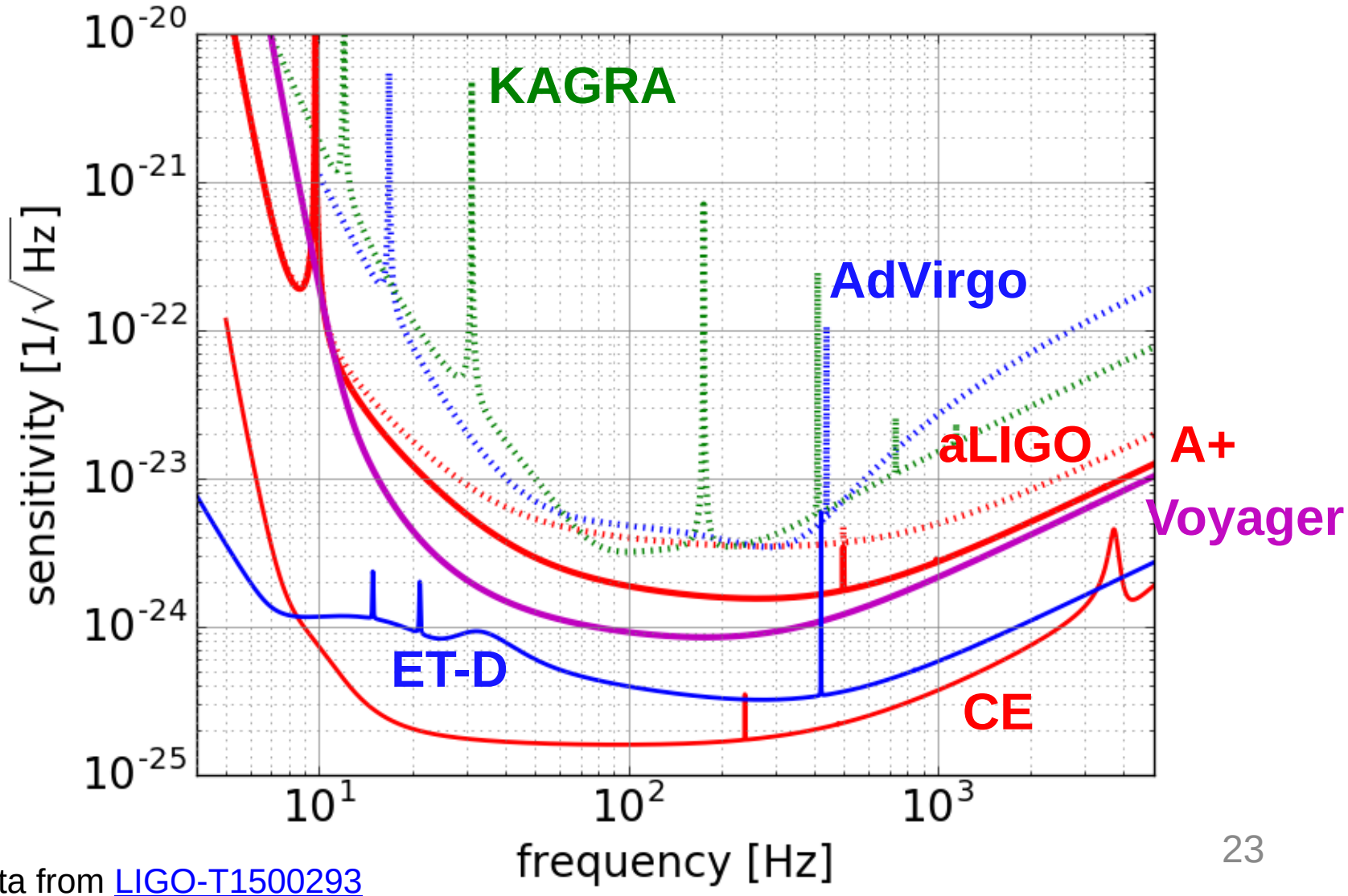
4 sapphire blades

TM suspended by 4 sapphire fibers
(35 cm long, 1.6 mm dia.)
RM suspended by 4 CuBe fibers

Example KAGRA+ Comparison



2-3G Sensitivity Comparison



Spectra data from [LIGO-T1500293]

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