# KAGRA+ Upgrade Plans

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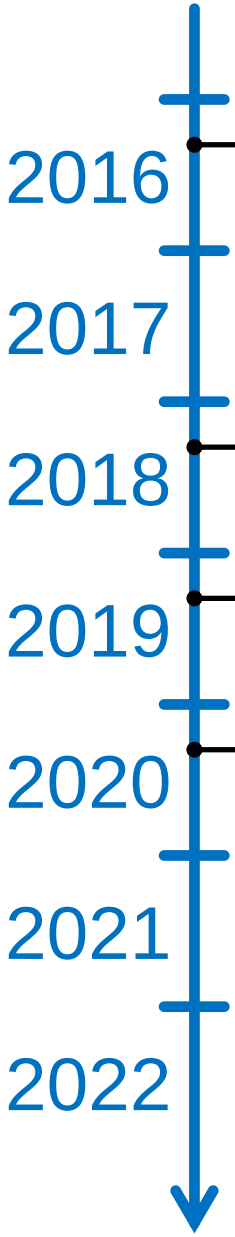
# Overview

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

# KAGRA 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

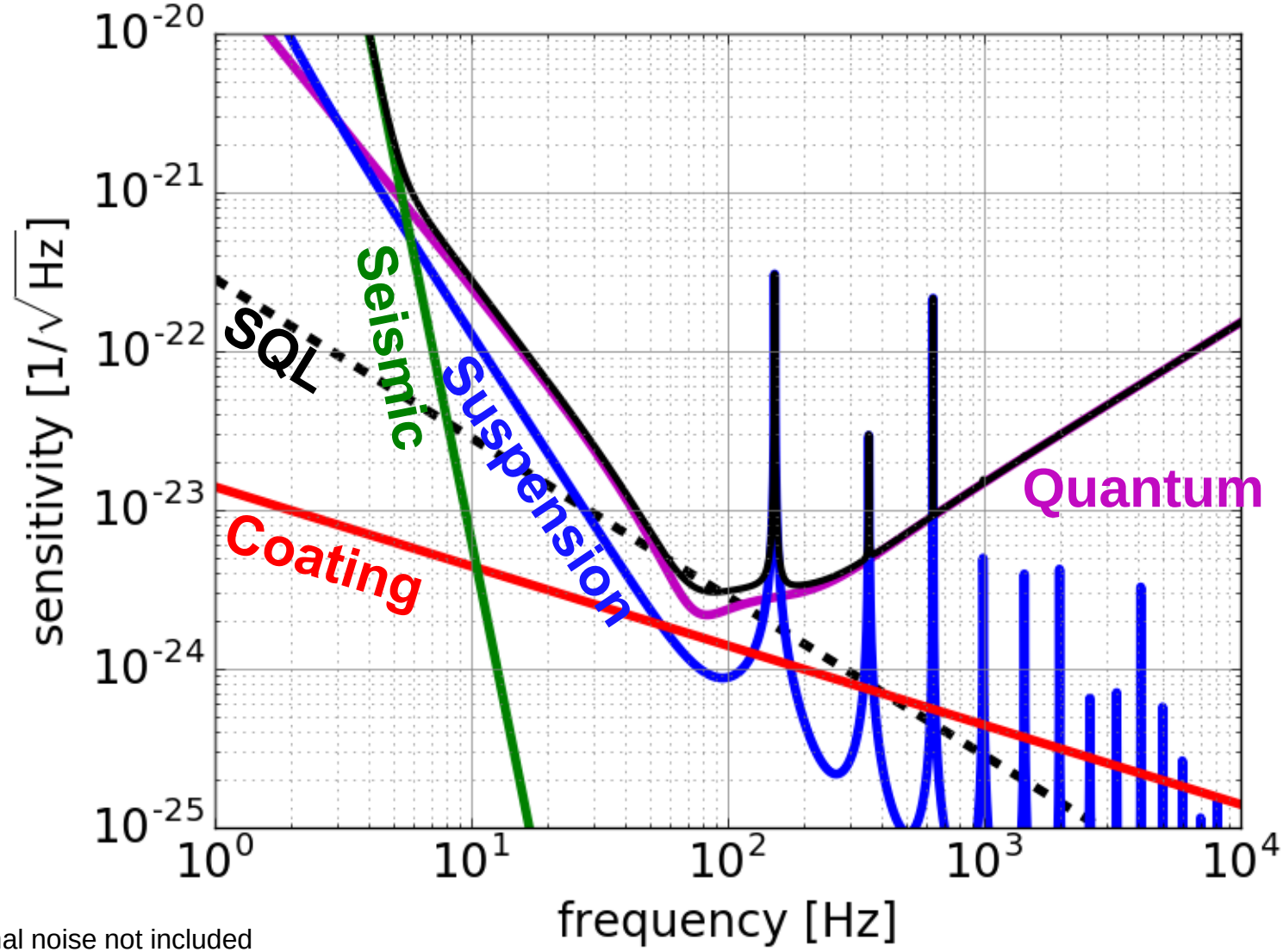
**Phase 3**
3-km RSE
cryogenic temperature
observation runs

Baseline KAGRA (bKAGRA)

KAGRA+ ?

# KAGRA Sensitivity (v2009)

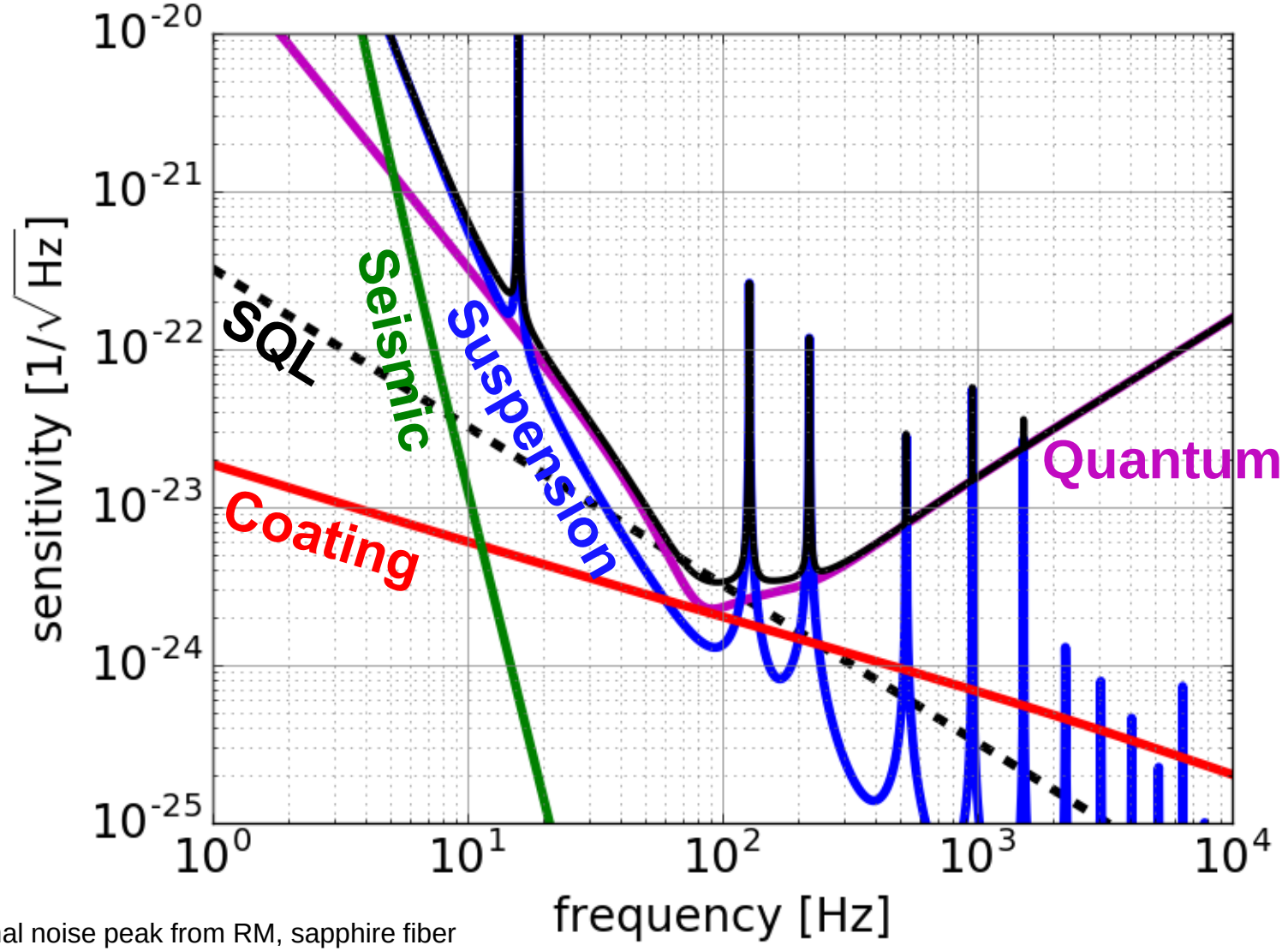
- 30 kg, 20 K, 825 W at BS → BNS 171 Mpc




Vertical thermal noise not included

# KAGRA Sensitivity (v2013)

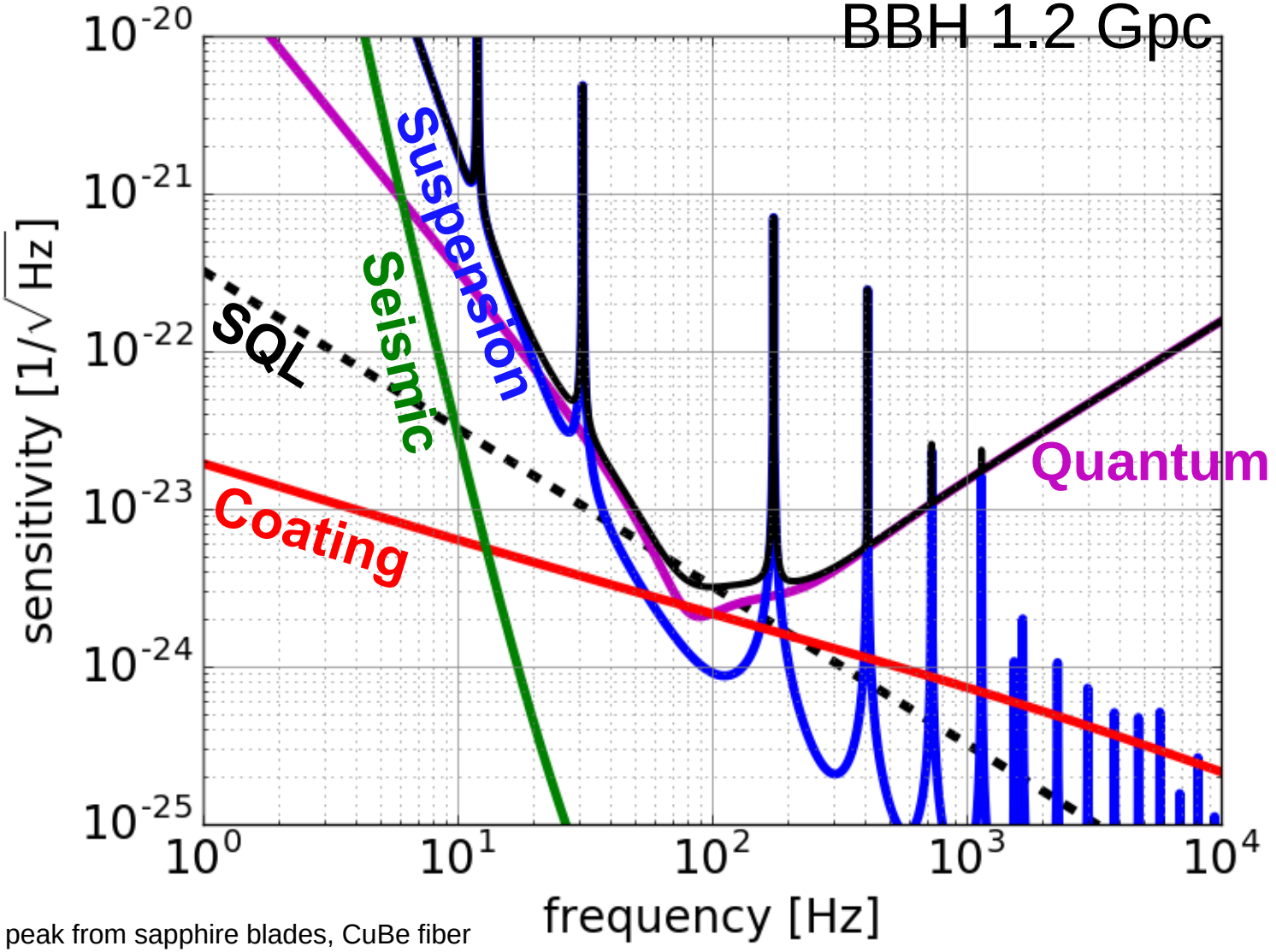
- 23 kg, 20 K, 780 W at BS → BNS 148 Mpc




Vertical thermal noise peak from RM, sapphire fiber

# KAGRA Sensitivity (v2017)

- 23 kg, 21.5 K, 780 W at BS → BNS 158 Mpc
  BBH 1.2 Gpc

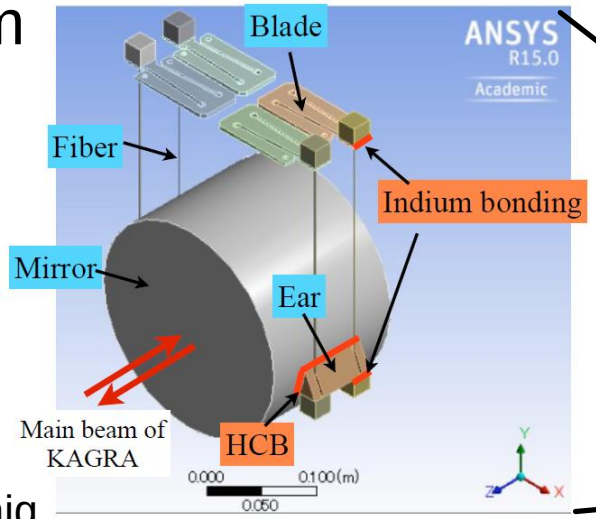



Thermal noise peak from sapphire blades, CuBe fiber

# 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



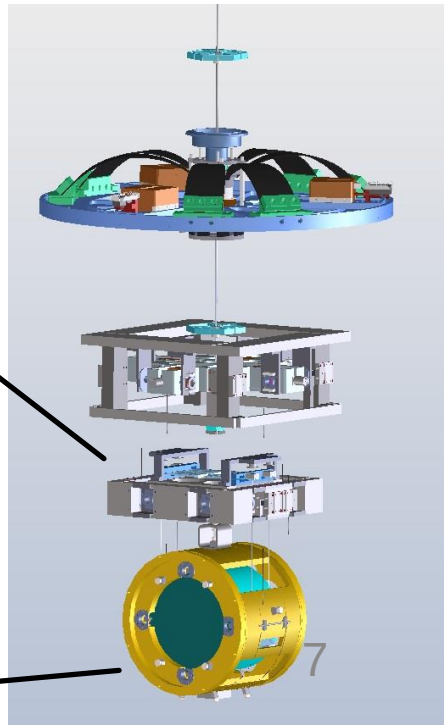
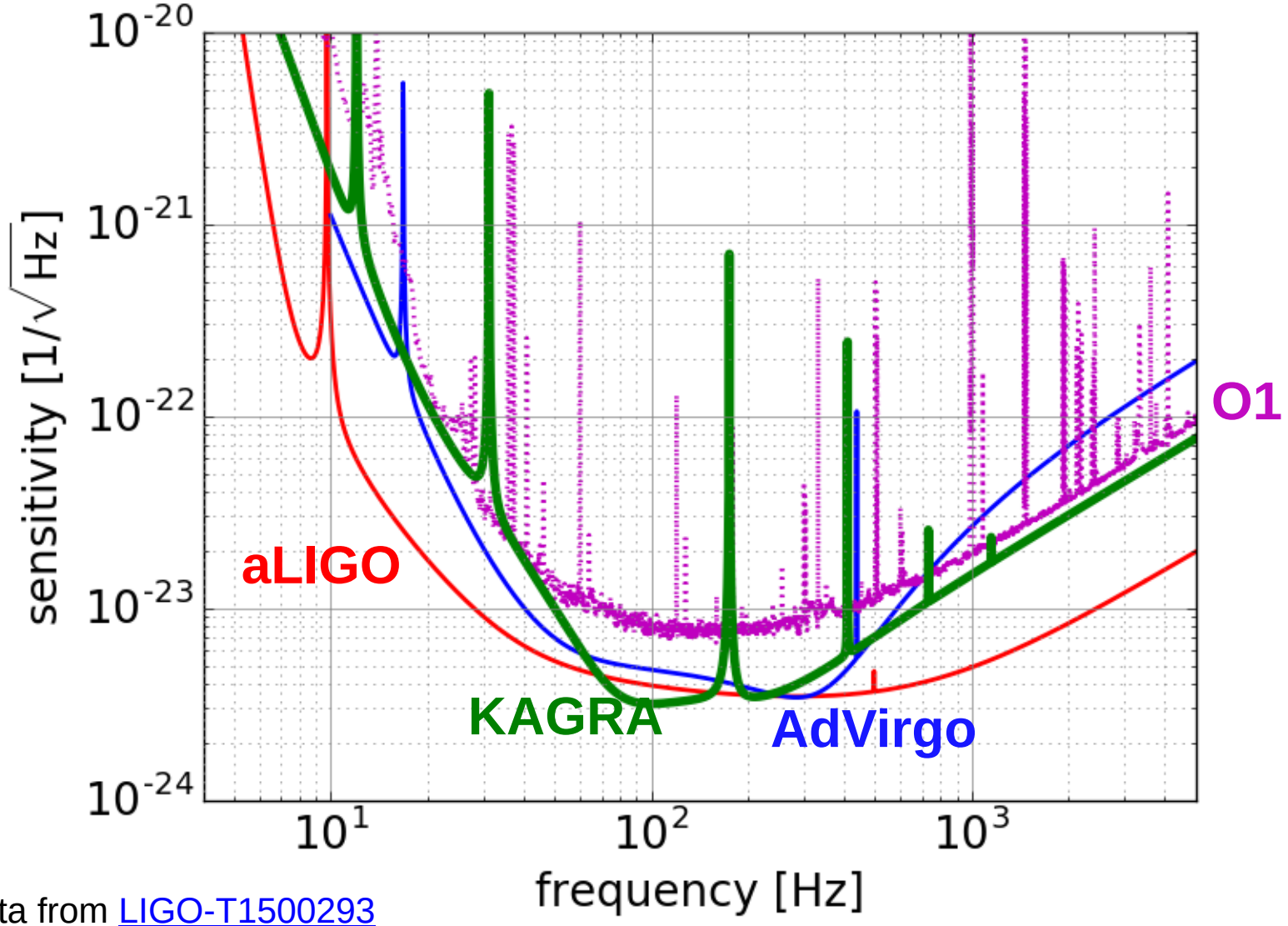



Figure from K. Craig

# KAGRA vs Other 2G

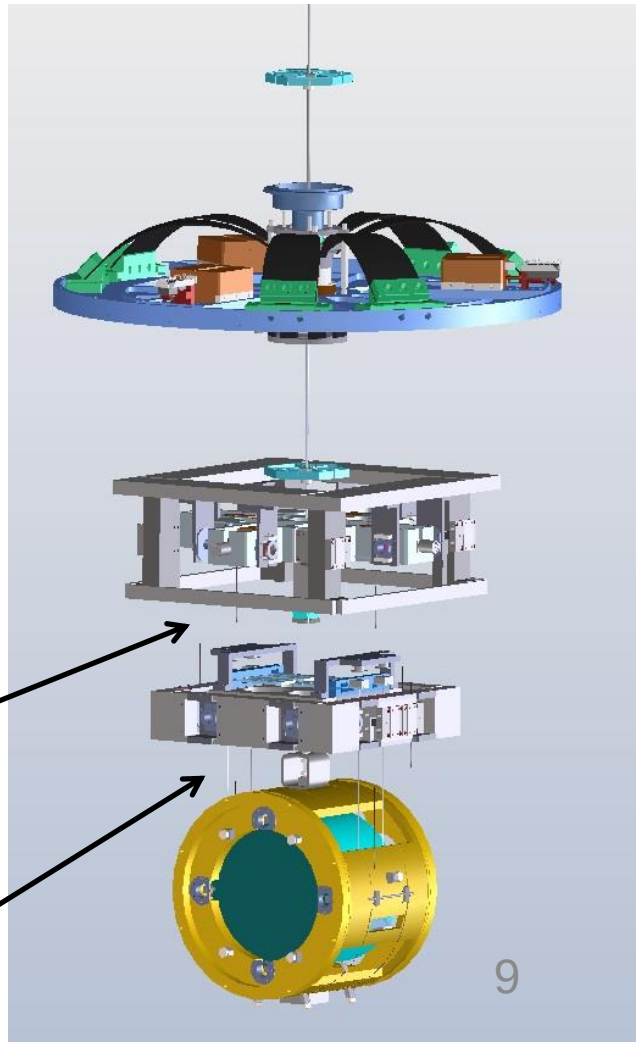
- Not better even with cryogenic and underground




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)



# Ideas for Improving Sensitivity

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

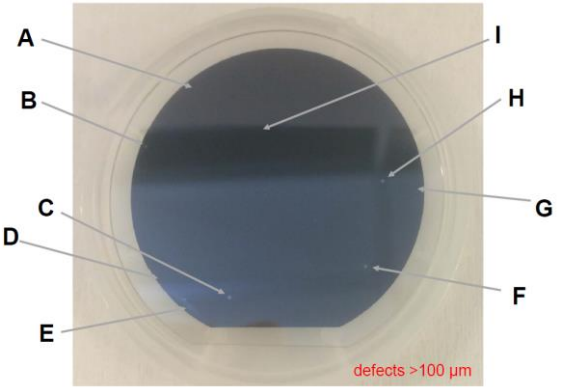
サファイア結晶から鏡をくり抜く図
廣瀬さんに聞く、LMAに聞く(スライド見る)

- 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

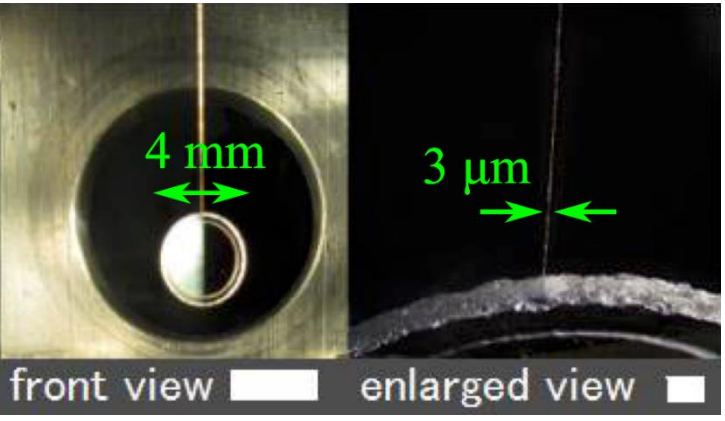
Talk by Raffaele




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)



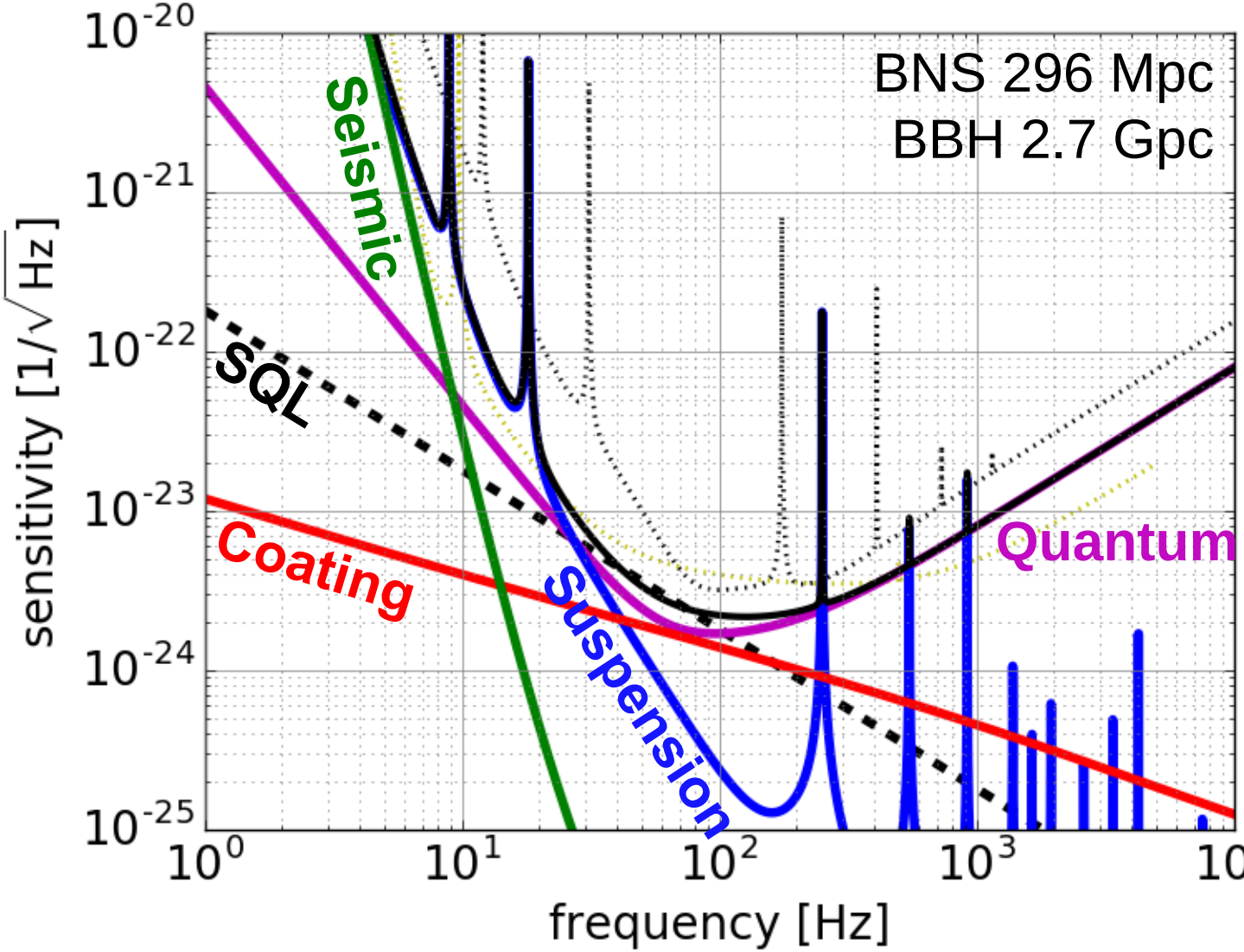


# Integrated Design Study

- 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**

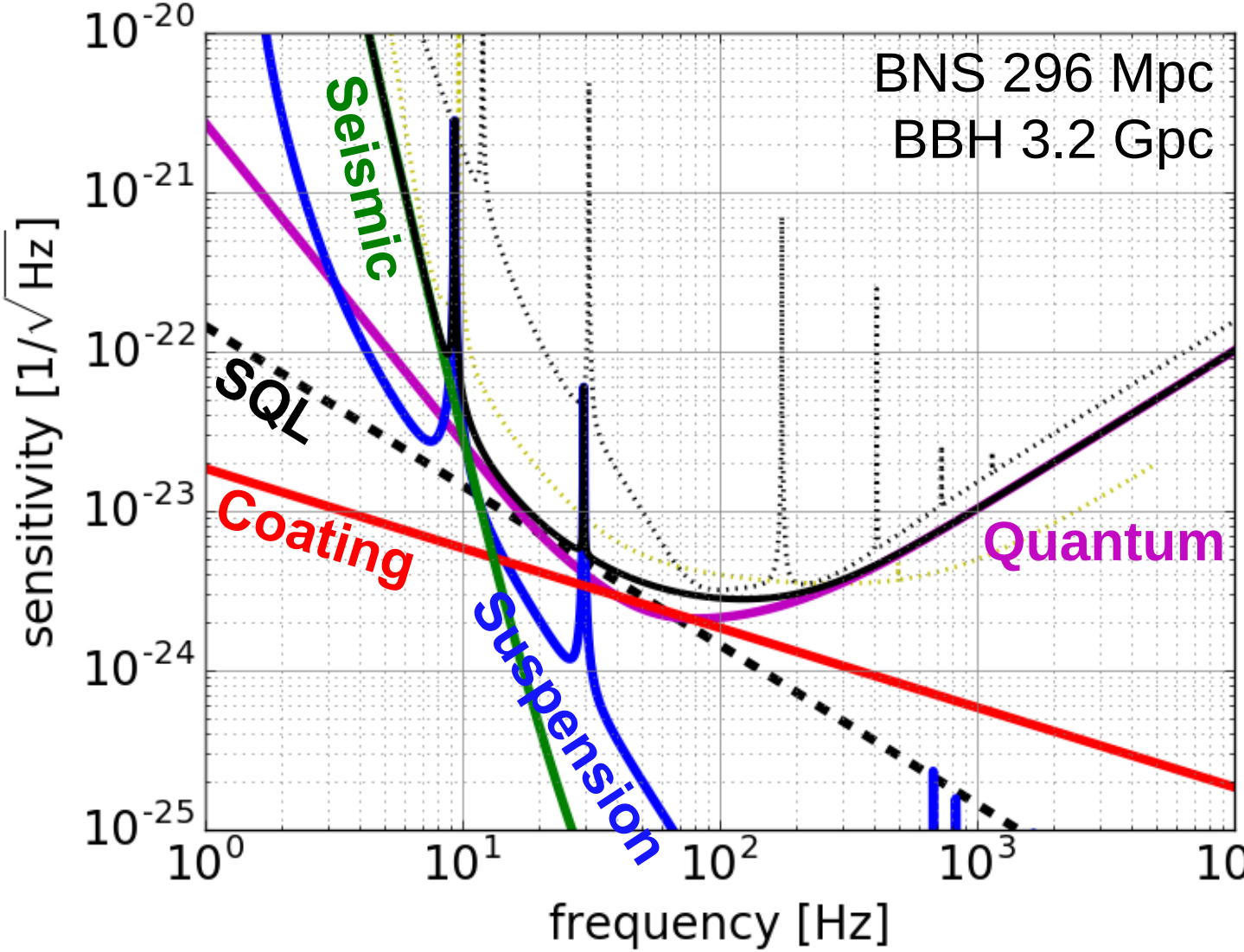
- Heavier sapphire and heavier IM, 20 K




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

# KAGRA+ Sensitivity: **Black**

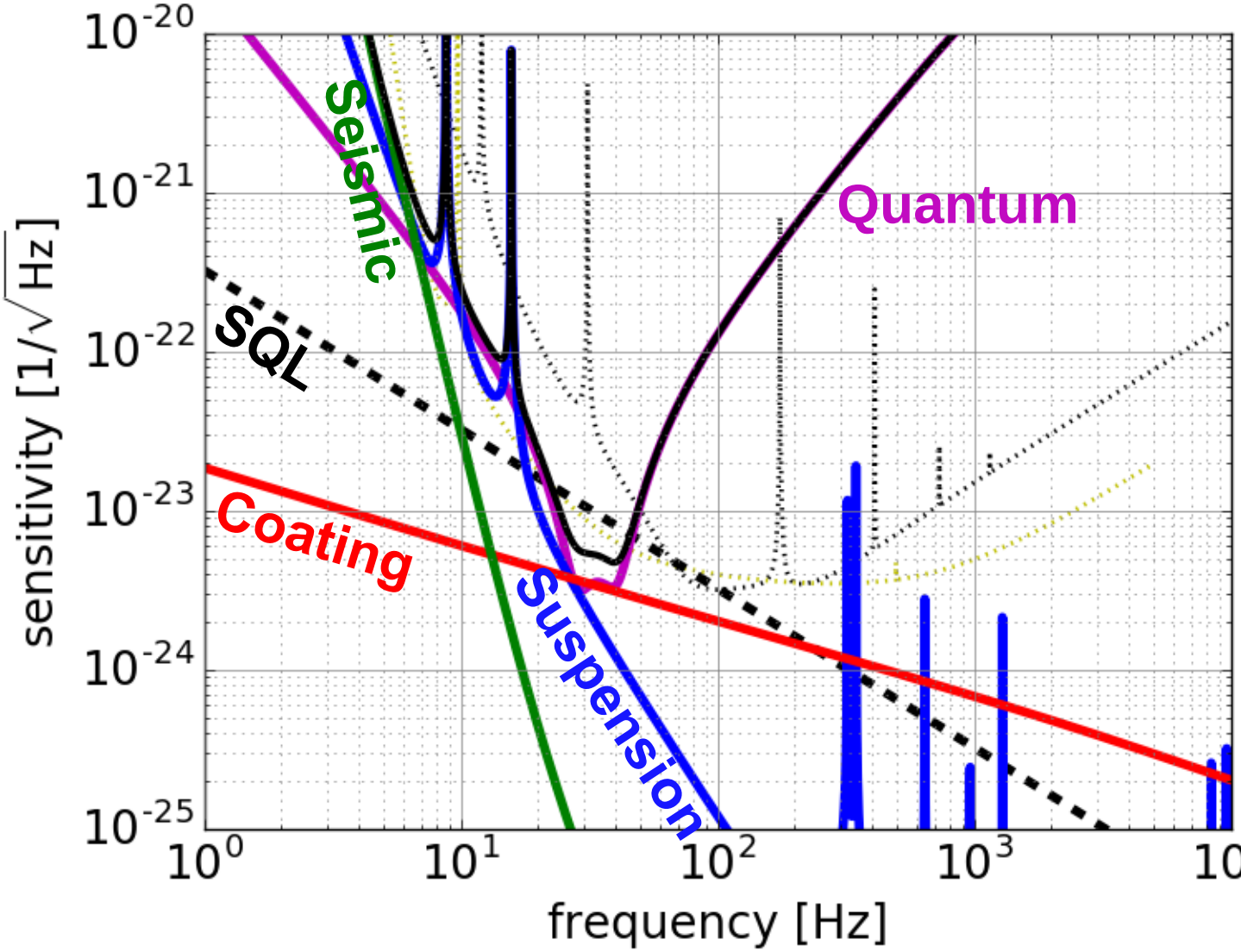
- Silicon 123 K, radiative cooling




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

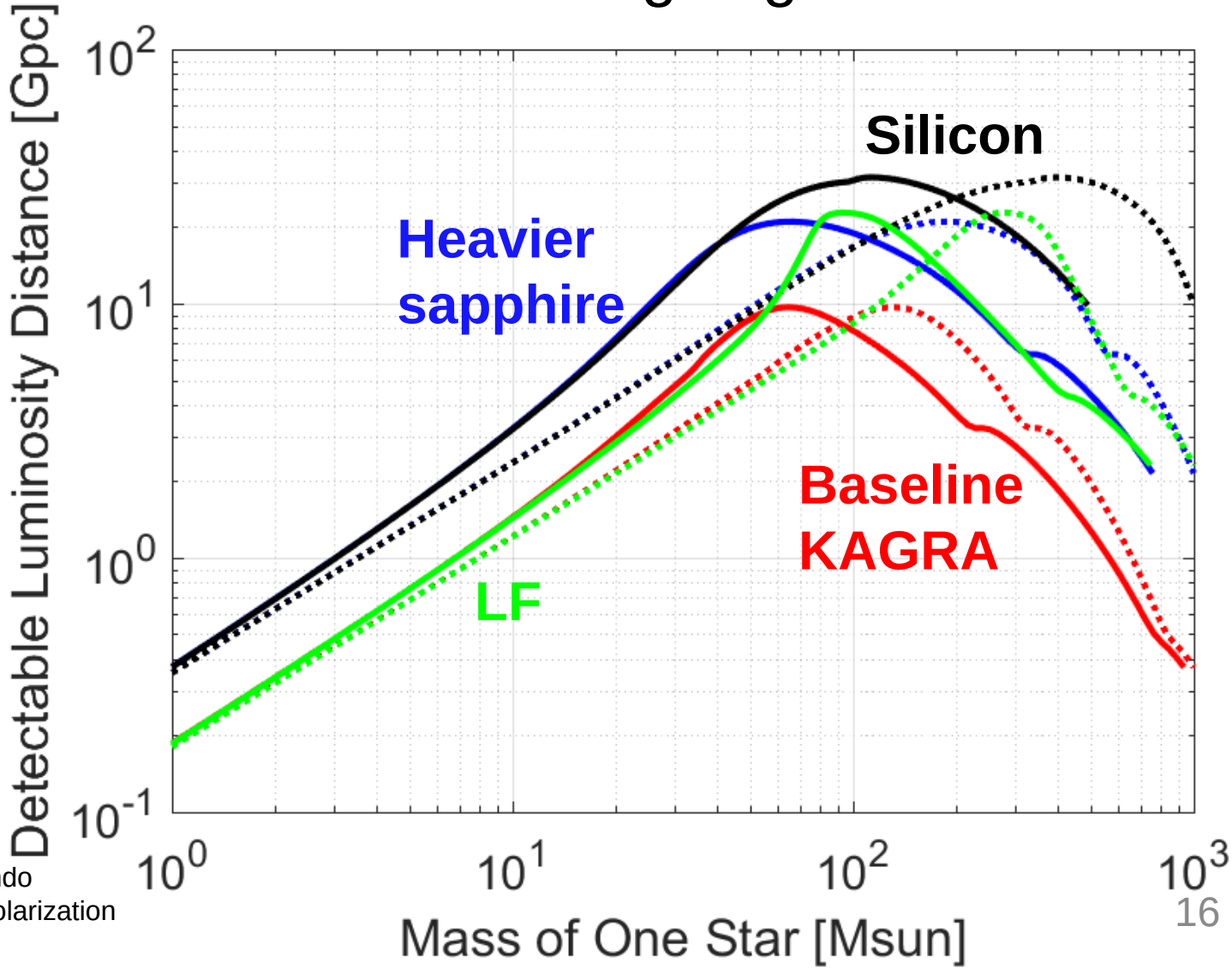
- Low power, high detuning, 20 K




λ = 1064 nm
Mass: 23 kg
(22 cm dia.,
15 cm thick)
P_BS: 20 W
φ_susp: 2e-7
φ_coat: 5e-4
r_beam: 8.6 cm
No sqz
T_SRM: 8 %

# 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 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 |



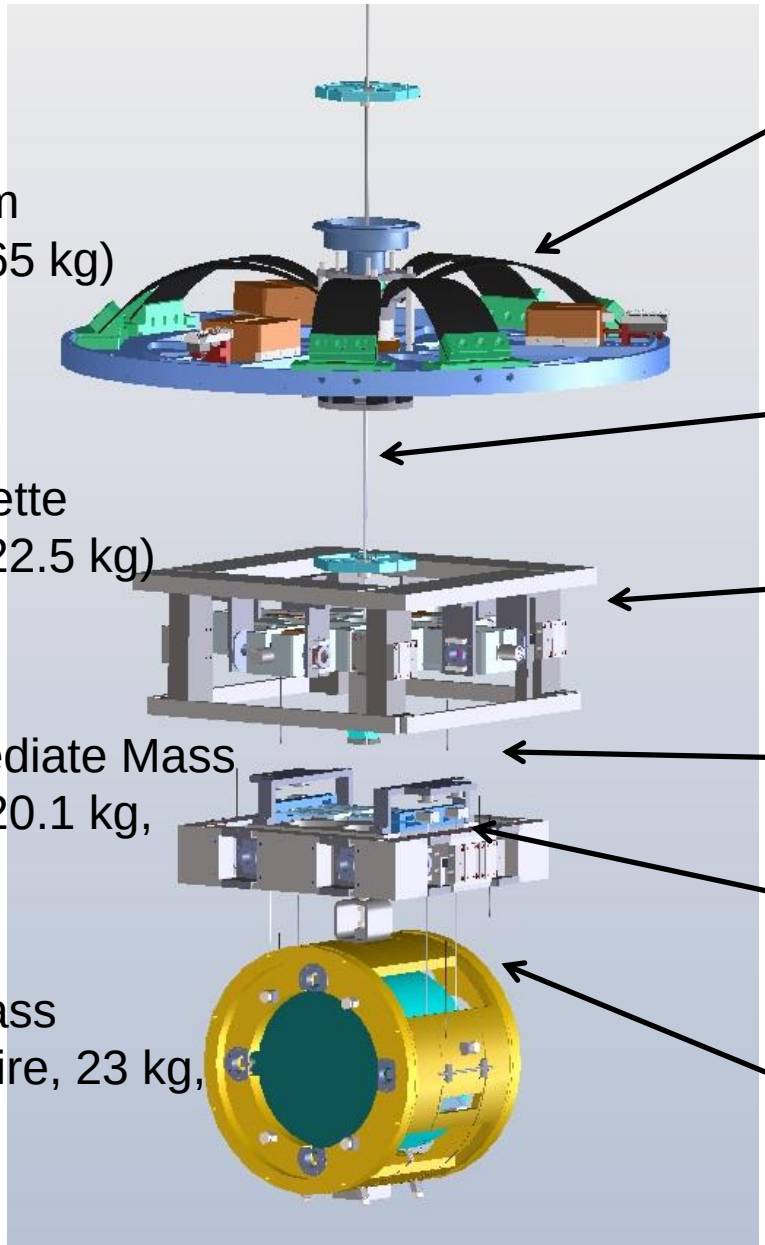
LIGO parameters from LIGO-T1600119, AdVirgo parameters from JPCS 610, 01201 (2015)

# KAGRA Detailed Parameters

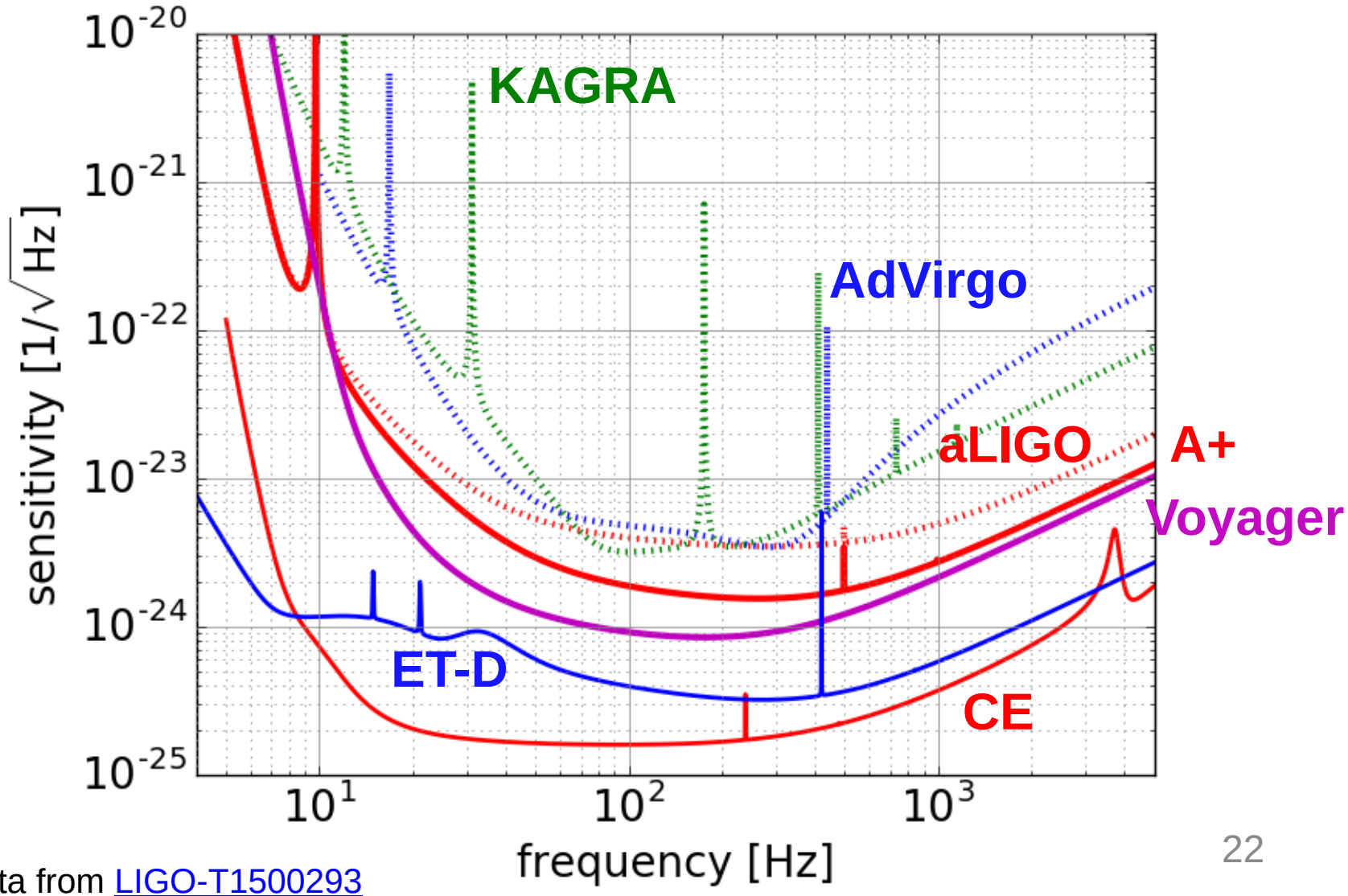
- **Optical parameters**
  - Mirror transmission: 0.4 % for ITM, 10 % for PRM, 15.36 % for SRM
  - Power at BS: 550 W
  - Detune phase: 3.5 deg (DRSE case)
  - Homodyne phase: 133 deg (DRSE case)
- **Sapphire mirror parameters**
  - TM size: 220 mm dia., 150 mm thick
  - TM mass: 22.8 kg
  - TM temperature: 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
- **Inspiral range calculation**
  - SNR=8, fmin=10 Hz, sky average constant 0.442478

# KAGRA Cryopayload

Provided by T. Ushiba and T. Miyamoto



# 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