JGW-G1910533

hyper-KAGRA

S. Haino, FPC

Motivation

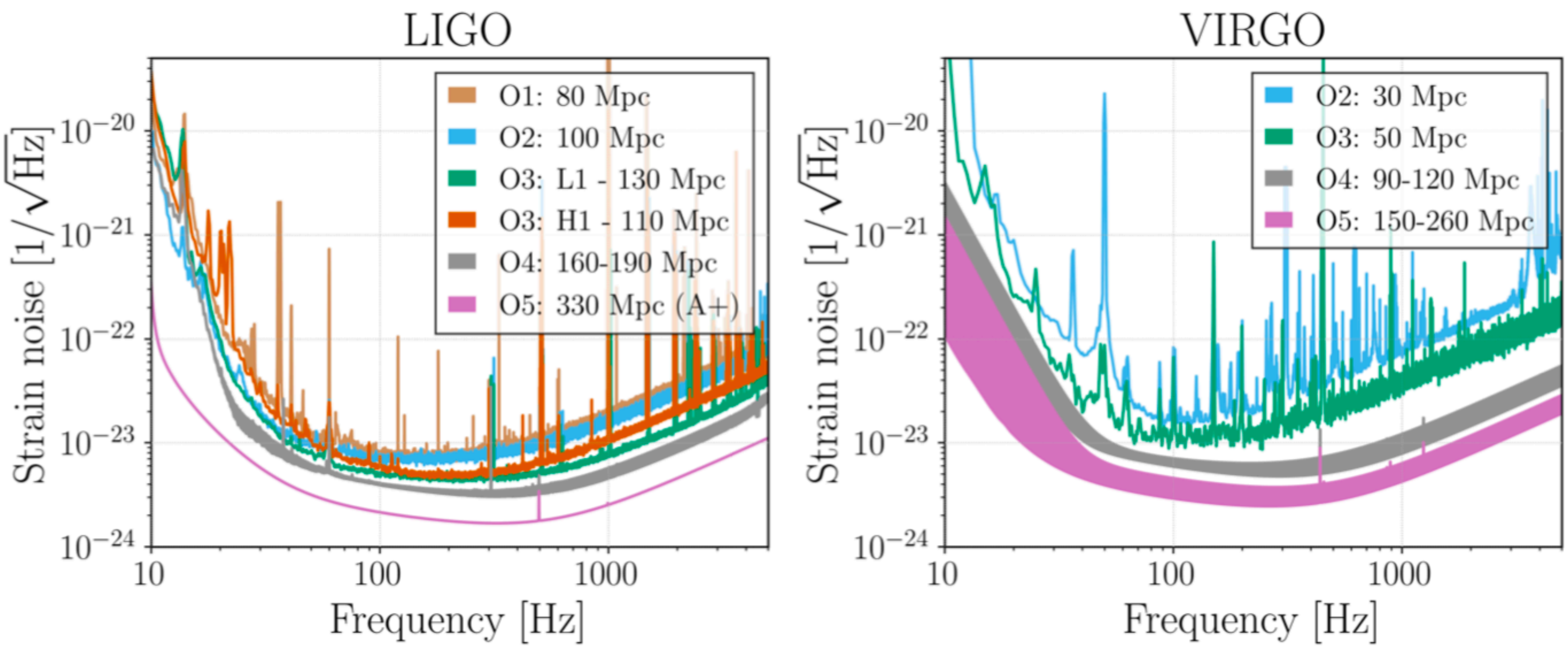
- Official designs of A+ and AdV+ in O5 are released
- U.S. and Europe community is accelerating for 3G detectors (CE and ET)
- Australian community is proposing ozGrav-HF

In that situation,

- **What KAGRA (Asian community) can consider ?**

LIGO/Virgo O4, O5 projection

- Updated on July/11/2019 at [LIGO-P1900218]
- LIGO O4: 160 – 190 Mpc   O5: 330 Mpc
- Virgo O4: 90 – 120 Mpc   O5: 150-260 Mpc



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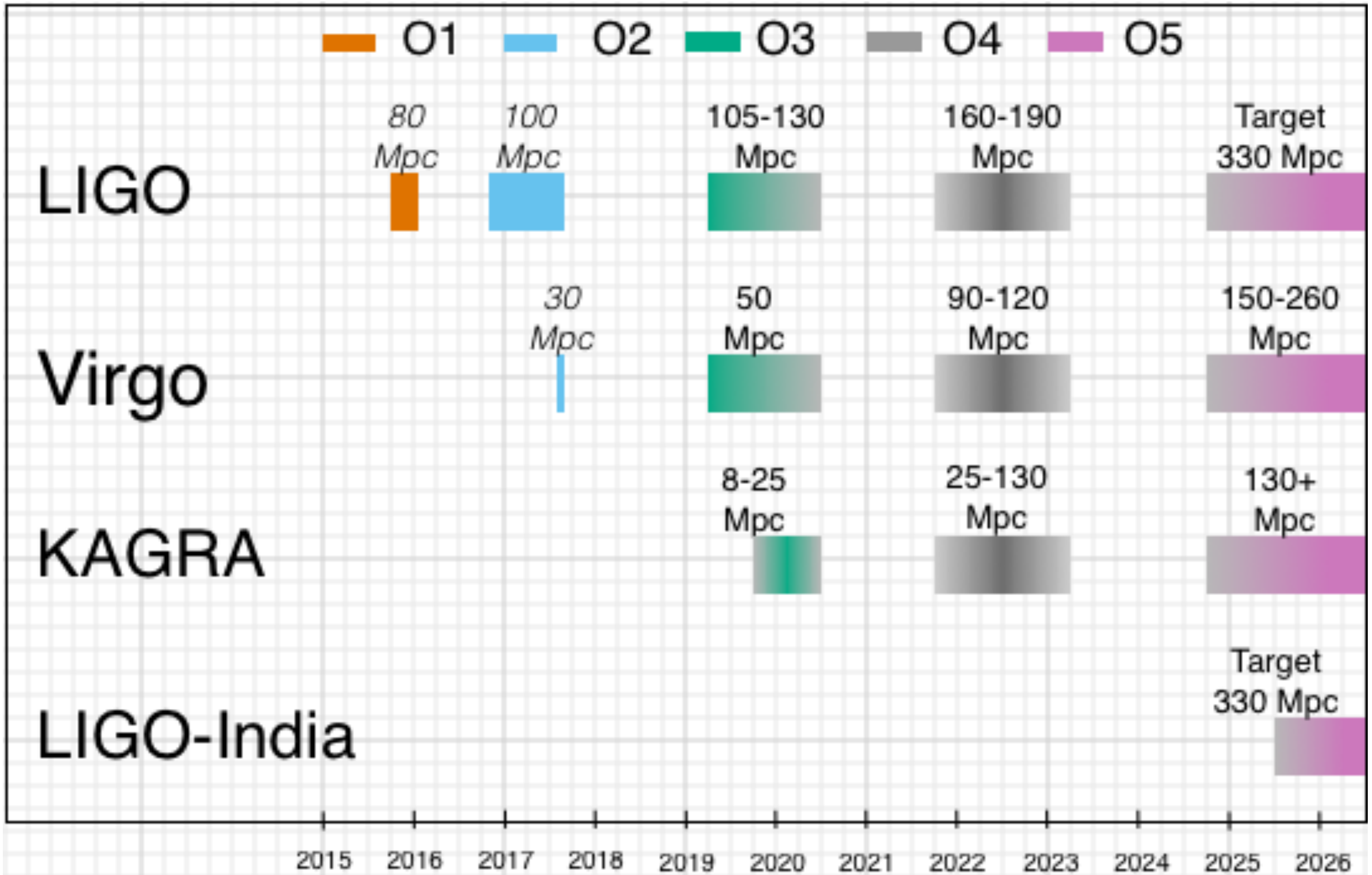
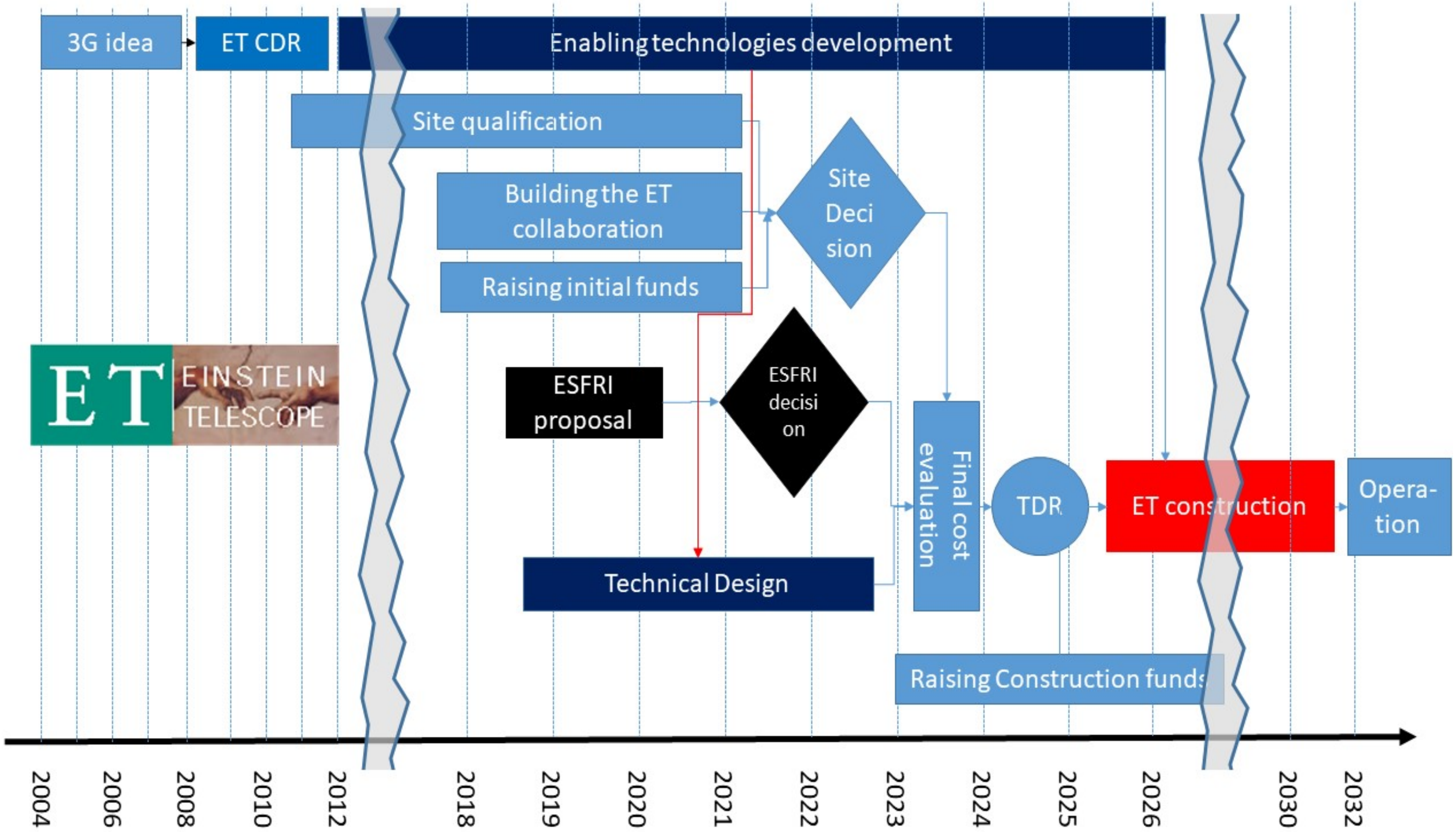
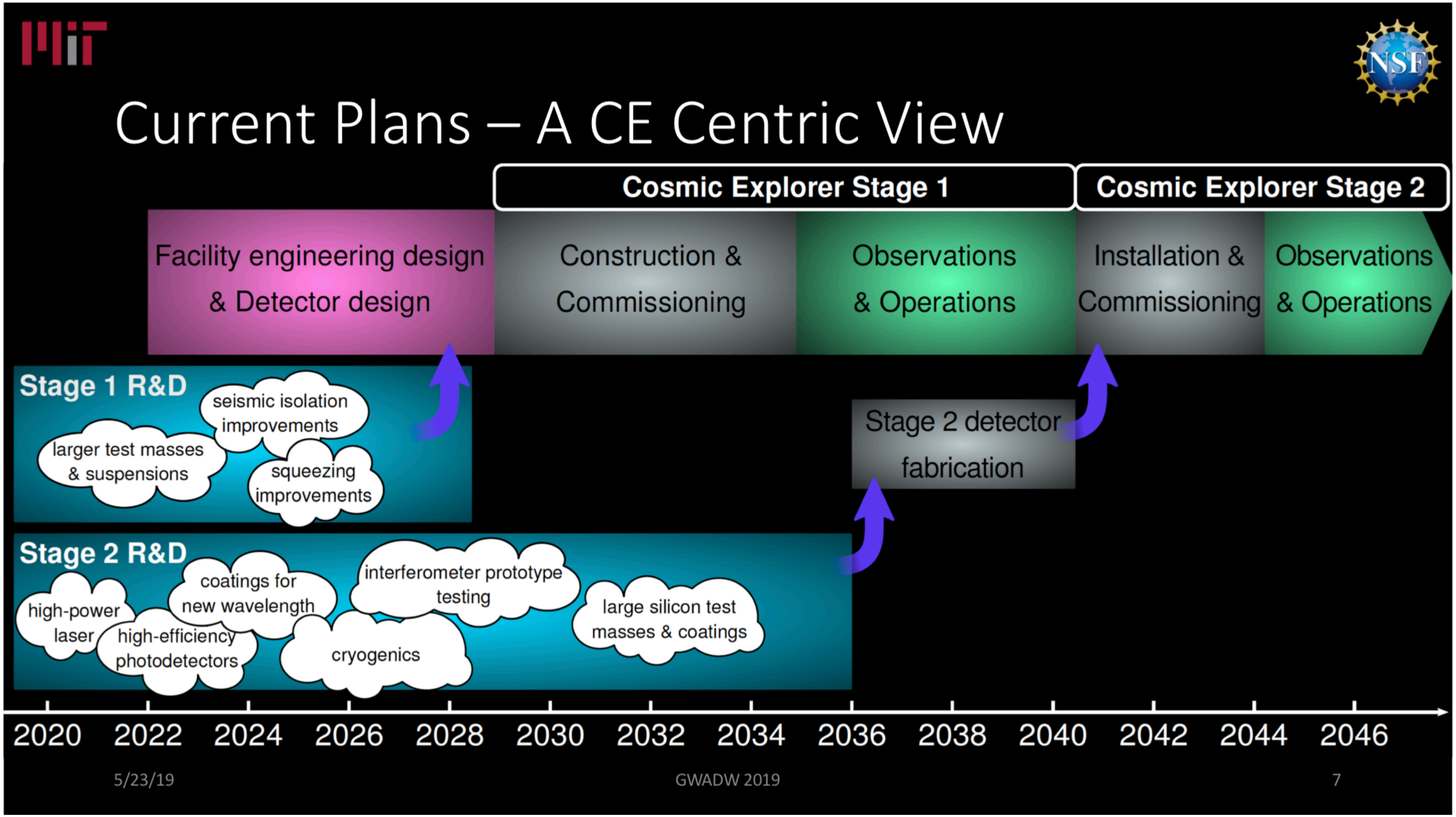


M. Punturo GWADW 2019

ET roadmap

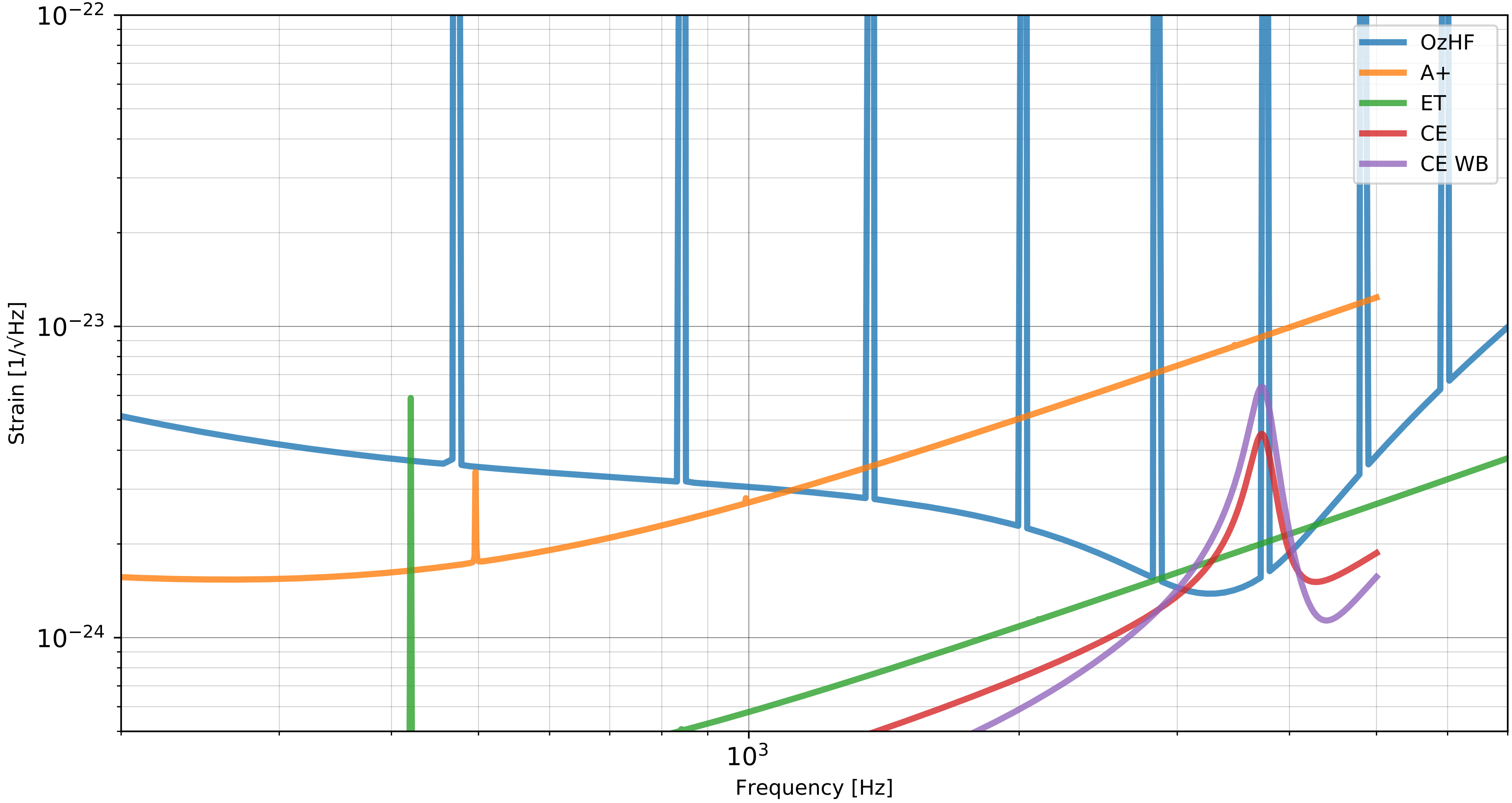


M. Evans GWADW 2019



ozGrav-HF

D. McClelland DAWN5, 2019



Ultimate configuration - hKAGRA

- iLM is proposing to produce 200 kg (ϕ45 cm) sapphire bulk with low (10 ppm/cm) heat absorption

- We consider how good sensitivity we can achieve by assuming to have 200kg and low absorption sapphire
- $\times$5 lower heat absorption, $\times$2 thermal conductivity improvement => $\times$10 power tolerance

- (Tentative name):
  hyper-KAGRA (hKAGRA or hyper-K)

Parameters assumed (dimensions)

Parameter name	bKAGRA	hKAGRA
Mirror size (and mass)	ϕ22cm $\times$15 cm (22.8 kg)	ϕ45cm $\times$31.5 cm (200 kg)
Sapphire suspension	ϕ1.6mm $\times$35cm	ϕ2.68mm $\times$50cm
Wire safety factor	12.58	5.0
Intermediate mass	20.5 kg	180 kg
Beam size	3.5 cm	7.0 cm
Clear aperture (4σ)	14 cm	28 cm
Coating improvement	None	x2
Squeezer	None	Freq. dependent (10 dB)
Filter cavity	None	300 m

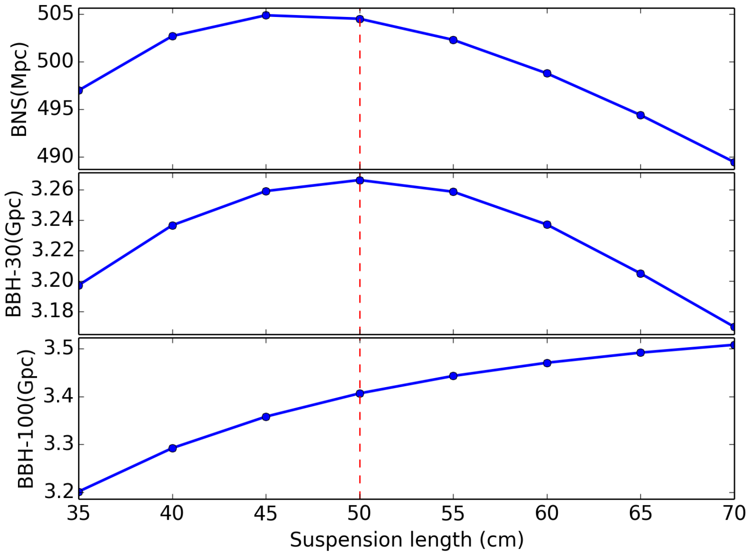
Parameters assumed (power-related)

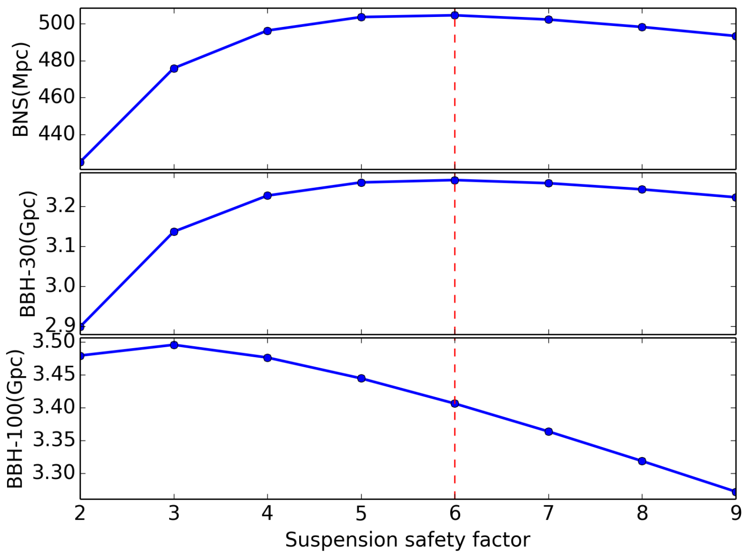
Parameter name	bKAGRA	hKAGRA
Laser power (before PRM)	70.1 W	500 W
Power at BS	674 W	4.8 kW
Arm power	0.32 MW	2.3 MW
Mirror temperature	22 K	18.4 K
Heat to be extracted (ITM)	0.72 W	2.76 W
Heat absorption	50 ppm/cm	10 ppm/cm
Thermal conductivity coefficient (α_0)*1	7.98 W/K/m	16 W/K/m
Thermal conductivity (κ)*1	7.2 kW/K/m	19.8 kW/K/m

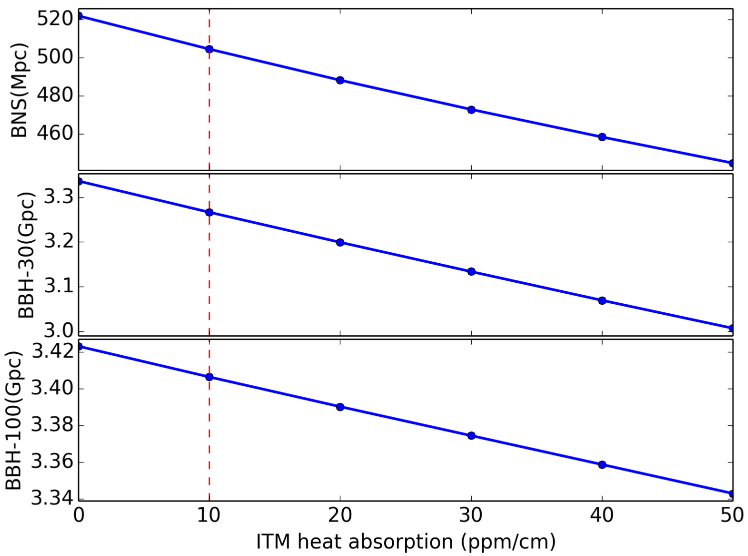
*1 $\kappa = \alpha_0\, d/d_0\, T^\beta$, where d_0 is diameter of bKAGRA wire suspension (1.6mm)

Parameter optimization

Optimized to have the best BNS/BBH(30) ranges







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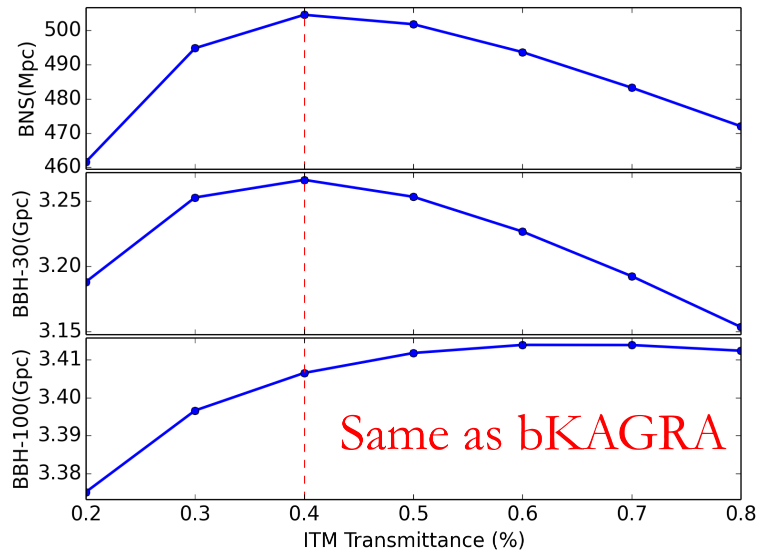
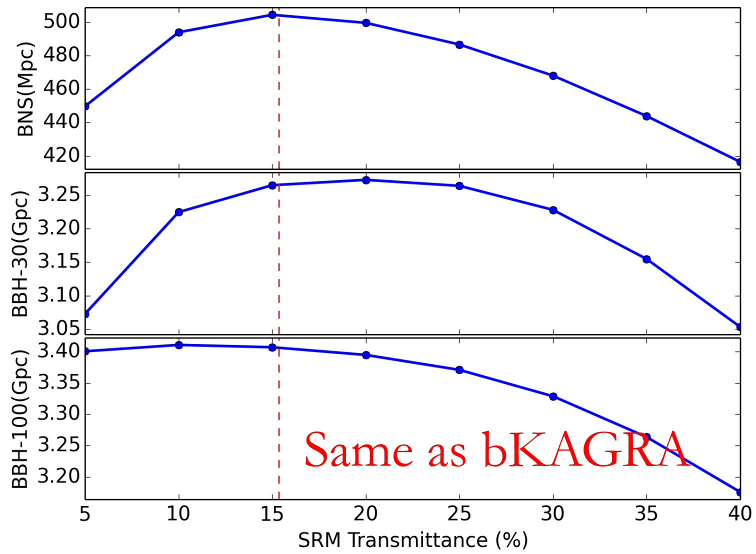
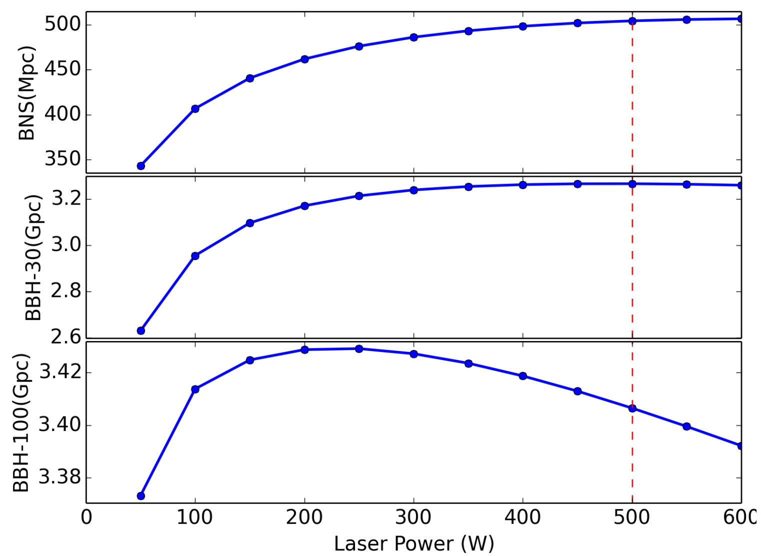
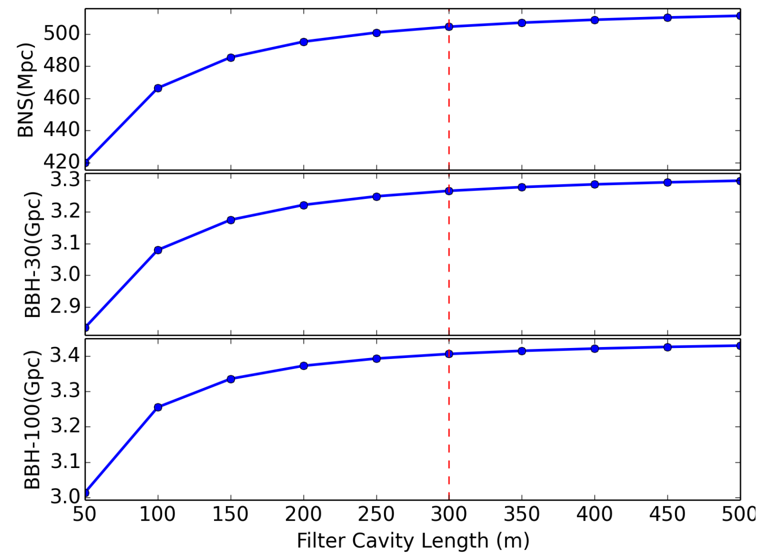
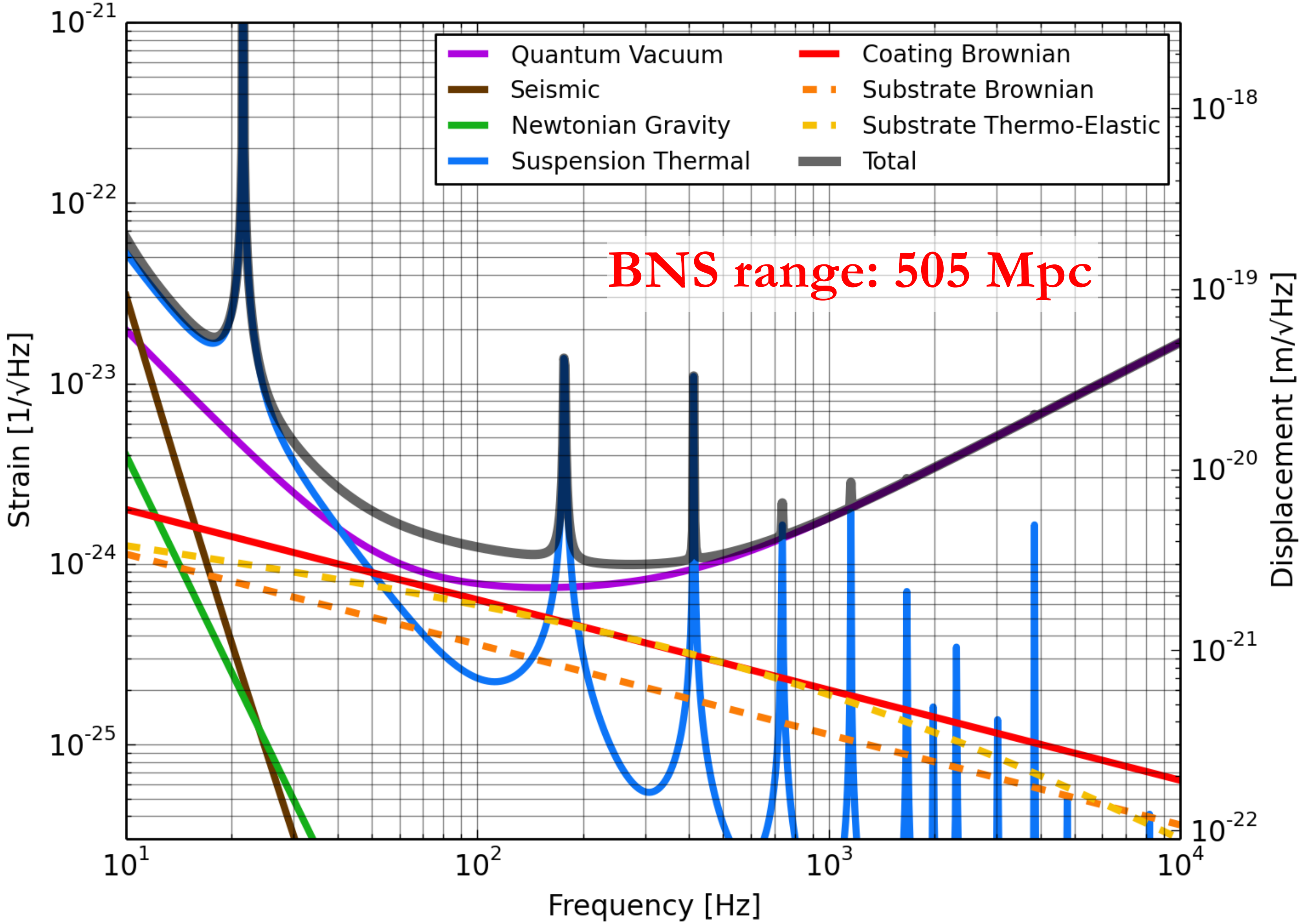




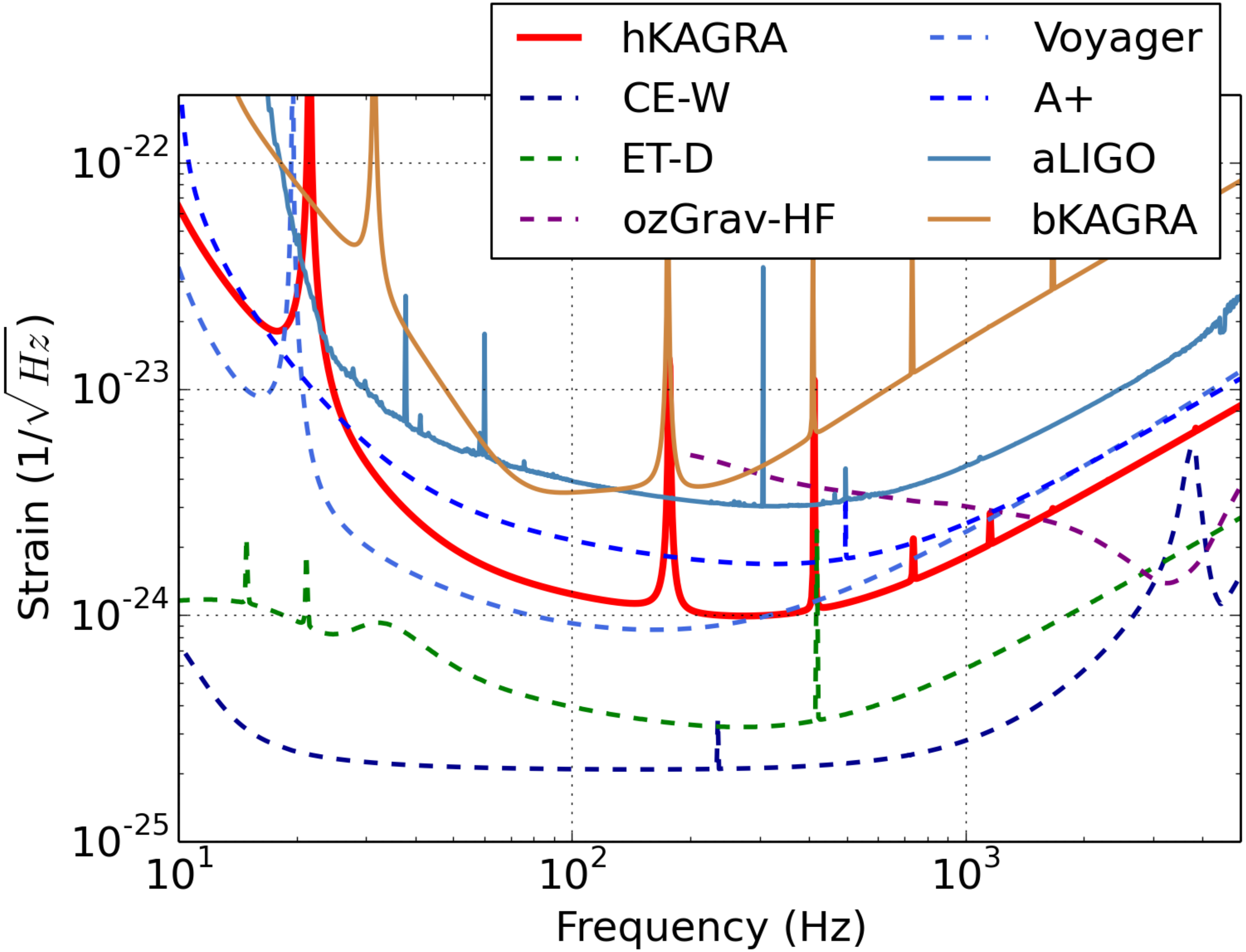




hKAGRA sensitivity curve



Comparison with other detectors



Comparison of ranges ($\sqrt[3]{V_{\mathrm{SNR}>8}}$)

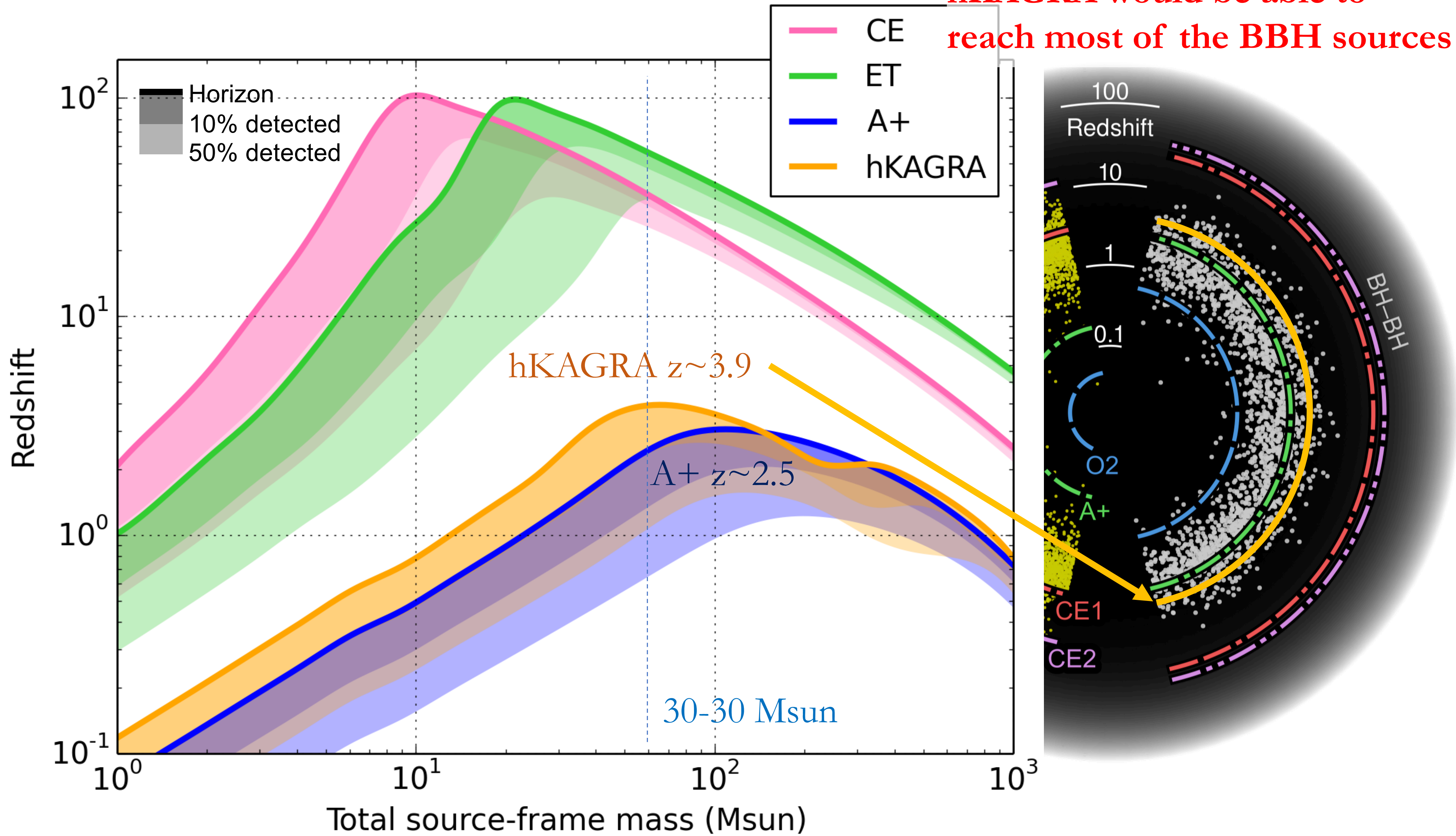
	BNS	BBH (30-30)	BBH (100-100)
bKAGRA	150 Mpc	1.4 Gpc (z=0.27)	1.8 Gpc (z=0.33)
aLIGO	185 Mpc	1.6 Gpc (z=0.30)	2.5 Gpc (z=0.44)
A+	330 Mpc	2.5 Gpc (z=0.44)	3.3 Gpc (z=0.55)
hKAGRA	**505 Mpc**	**3.2 Gpc (z=0.55)**	**3.4 Gpc (z=0.57)**
ET	2,750 Mpc	6.0 Gpc (z=0.90)	6.0 Gpc (z=0.91)
CE	3,800 Mpc	6.1 Gpc (z=0.92)	5.8 Gpc (z=0.89)

Comparison of horizon distances

	BNS	BBH (30-30)	BBH (100-100)
bKAGRA	0.4 Gpc	7.2 Gpc (z=1.0)	6.4 Gpc (z=1.0)
aLIGO	0.5 Gpc	8.0 Gpc (z=1.2)	13 Gpc (z=1.7)
A+	0.9 Gpc	20 Gpc (z=2.5)	23 Gpc (z=2.7)
hKAGRA	**1.5 Gpc**	**36 Gpc (z=3.9)**	**19 Gpc (z=2.4)**
ET	29 Gpc	710 Gpc (z=56)	280 Gpc (z=24)
CE	105 Gpc	440 Gpc (z=36)	140 Gpc (z=13)

Redshift reach VS total mass

hKAGRA would be able to reach most of the BBH sources



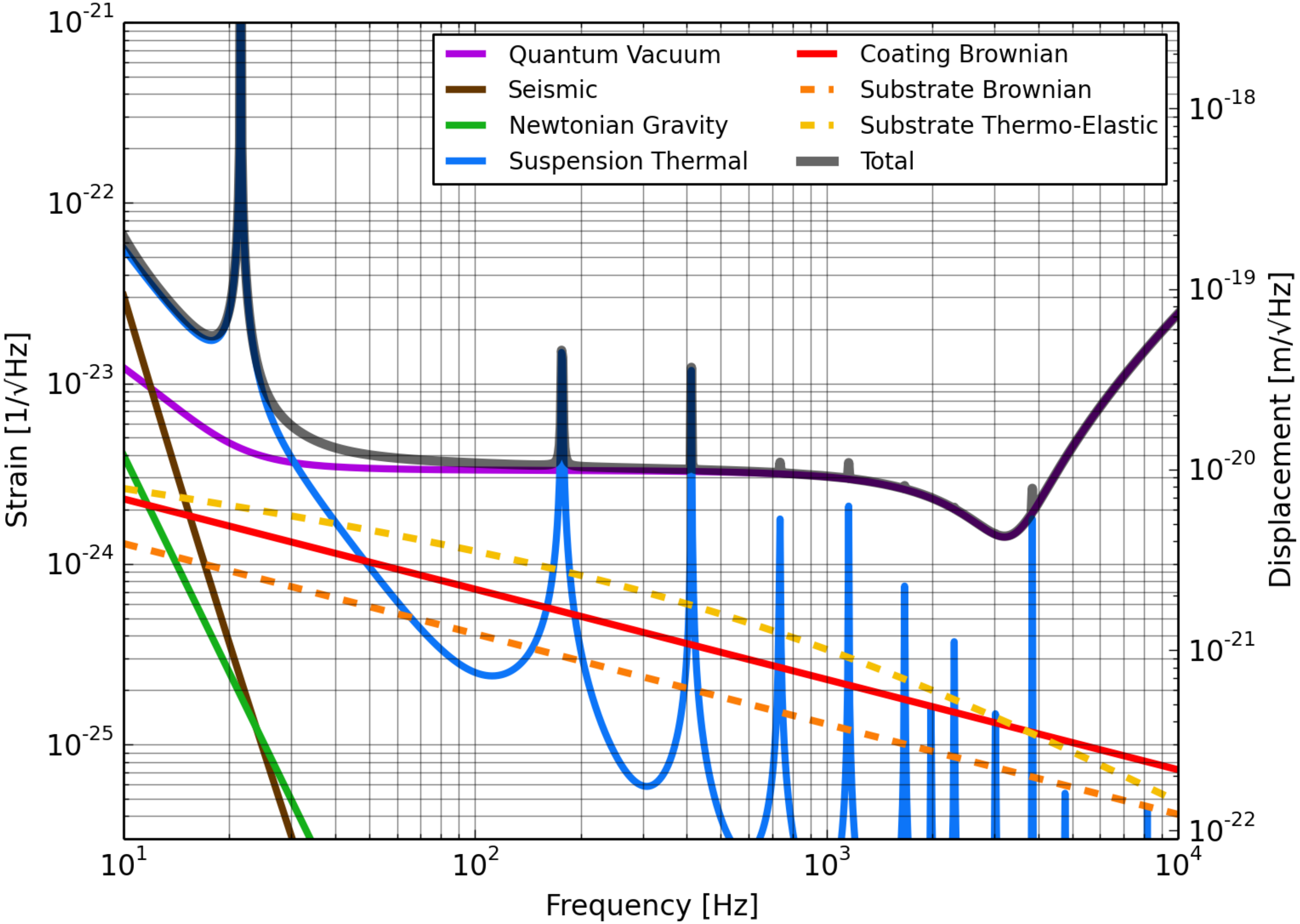
High Frequency (kHz) optimization

- T_{ITM} (Finesse) : 0.4 % (1,530) ➔ 3.0 % (208)
- T_{PRM} (PR gain) : 10.4 % (9.6) ➔ 1.3 % (69)
- T_{SRM} : 15.4 % ➔ 5.0 %
- L_{SRC} : 65 m ➔ 500 m

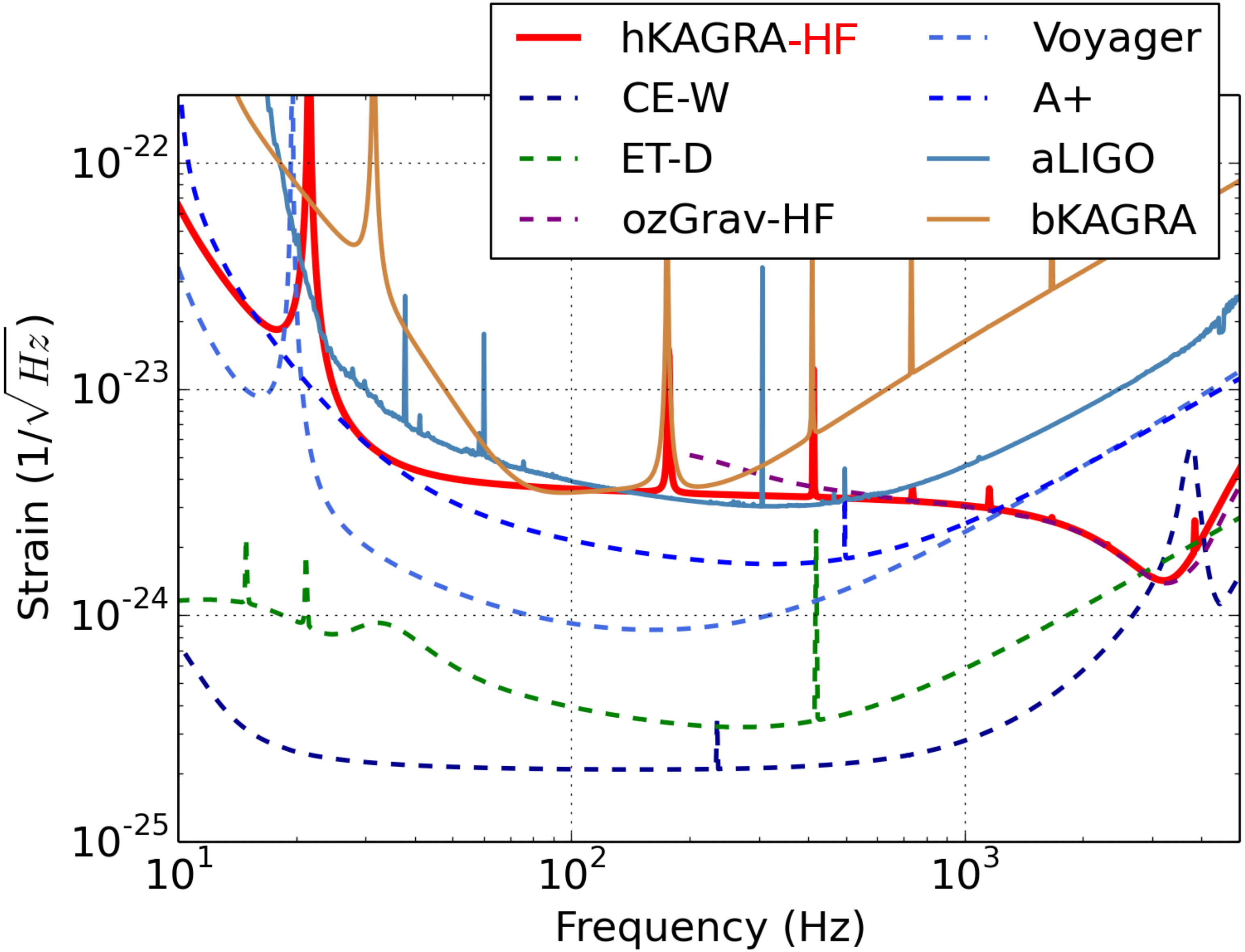
Lower Finesse causes much higher power at ITM

- BS Power : 4.8 kW ➔ 34 kW
- Heat extraction : 2.8 W ➔ 12 W
- ITM temperature : 18 K ➔ 24 K

hKAGRA-HF


Quantum Vacuum
Seismic
Newtonian Gravity
Suspension Thermal
Coating Brownian
Substrate Brownian
Substrate Thermo-Elastic
Total
Strain [1/√Hz]
Displacement [m/√Hz]
Frequency [Hz]
10^-21
10^-22
10^-23
10^-24
10^-25
10^-18
10^-19
10^-20
10^-21
10^-22
10^1
10^2
10^3
10^4

hKAGRA-HF



hKAGRA-HF
CE-W
ET-D
ozGrav-HF
Voyager
A+
aLIGO
bKAGRA
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{1}
10^{2}
10^{3}
Strain $(1/\sqrt{Hz})$
Frequency (Hz)

Summary

- hyper-KAGRA with 200kg low absorption sapphire has a potential to achieve the highest sensitivity of 500 Mpc with the conventional (1064nm, existing facility) technologies
- hyper-KAGRA can reach the horizon redshift of $z=4$ which can cover most of the (30-30) BBH sources
- hyper-KAGRA can fill the science gap to 3G

Python code: kagragwinc

- Based on Michimura et al., sensitivity calculation [JGW-T1807038] adapted to GWINC

- Uploaded at LIGO git server:
  https://git.ligo.org/sadakazu.haino/kagragwinc

  and JGW-T1909952

ITM temperature

- Calculated based on [JGW-T1707038]

$$K_{\text{abs}} = 2\beta_{\text{sub}} \underbrace{t_m}_{15\text{cm}} \underbrace{P_{\text{mich}}}_{P_{BS}/2} + \underbrace{\gamma_{\text{coa}}}_{0.5\text{ppm}} \underbrace{P_{\text{circ}}}_{10^3 P_{\text{mich}}} + \underbrace{K_{\text{rad}}}_{50\text{mW}}$$

$$\kappa(T) = 7.98 \times T^{2.2}.$$

[CQG 31, 105004]

$$K_{\text{abs}} = \underbrace{N_f}_{4} \int_{\underbrace{T_u}_{16\text{K}}}^{\overbrace{T_l}^{T_{ITM}}} \frac{\underbrace{S_f}_{2\times10^{-6}\text{m}^2}\kappa(T)}{\underbrace{l_f}_{0.35\text{m}}} dT,$$