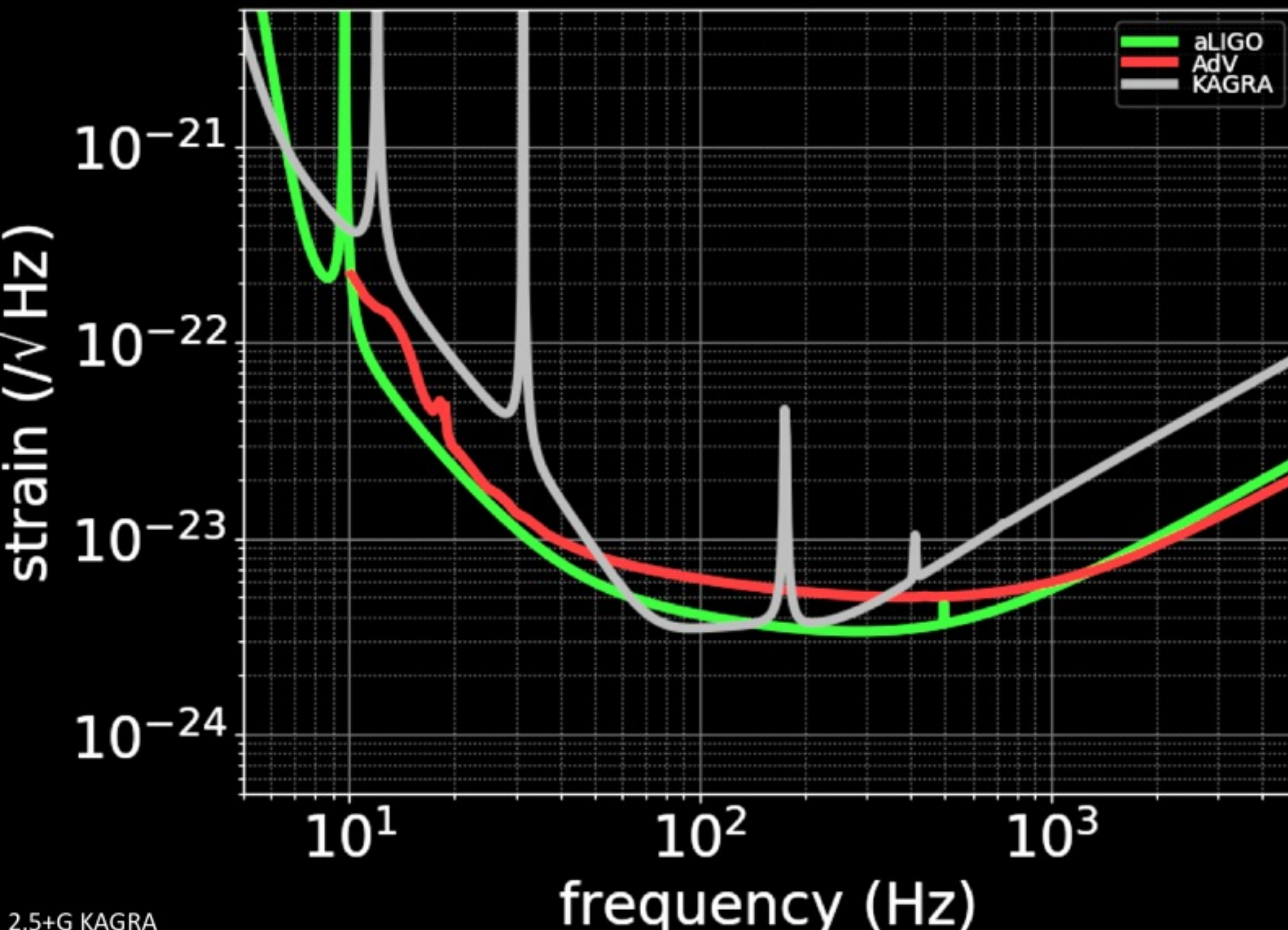
2.5+G and KAGRA: bridging between 2G and 3G

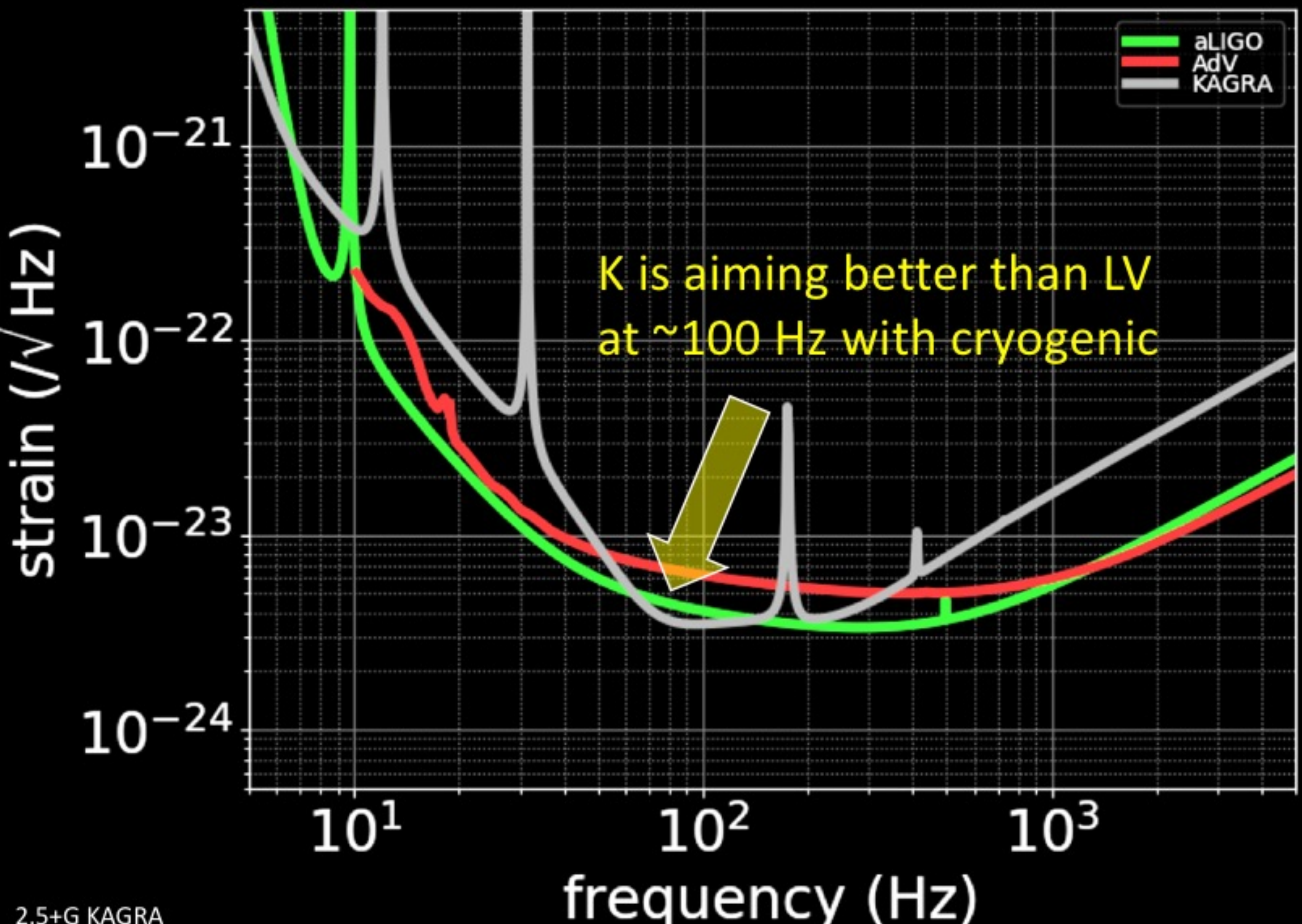
S. Haino

KAGRA collaboration

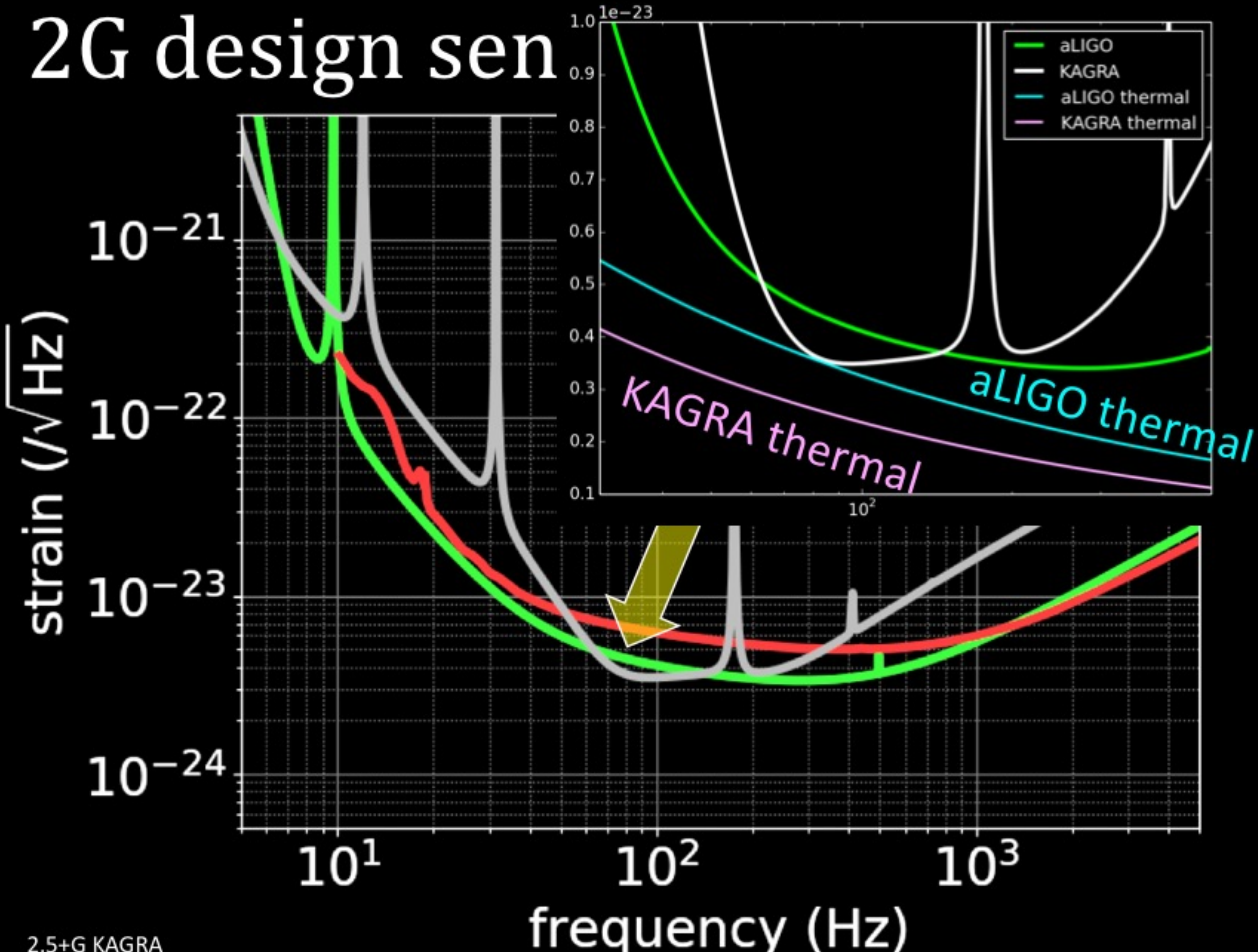
2G sensitivity comparison



2G design sensitivities

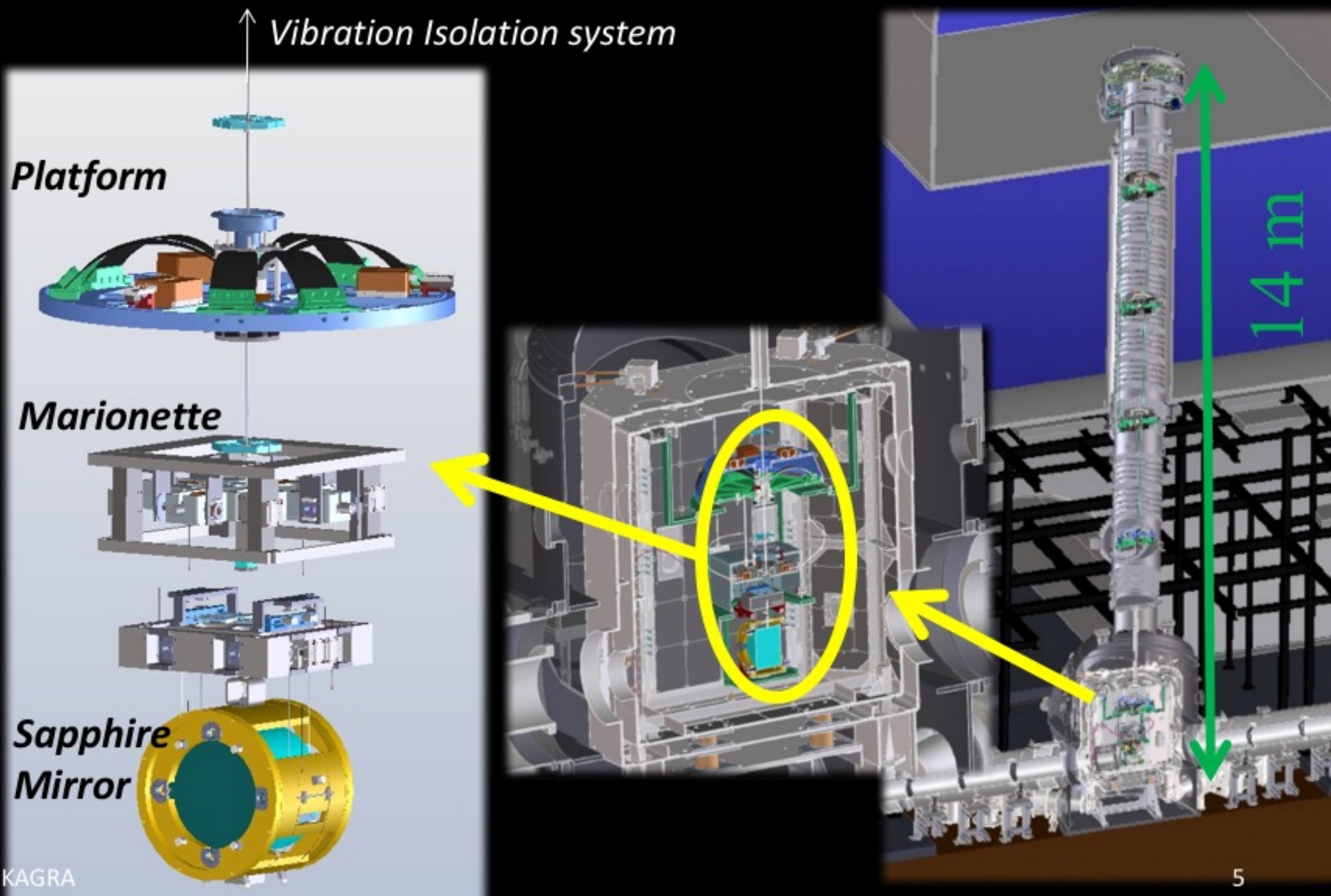


2G design sen

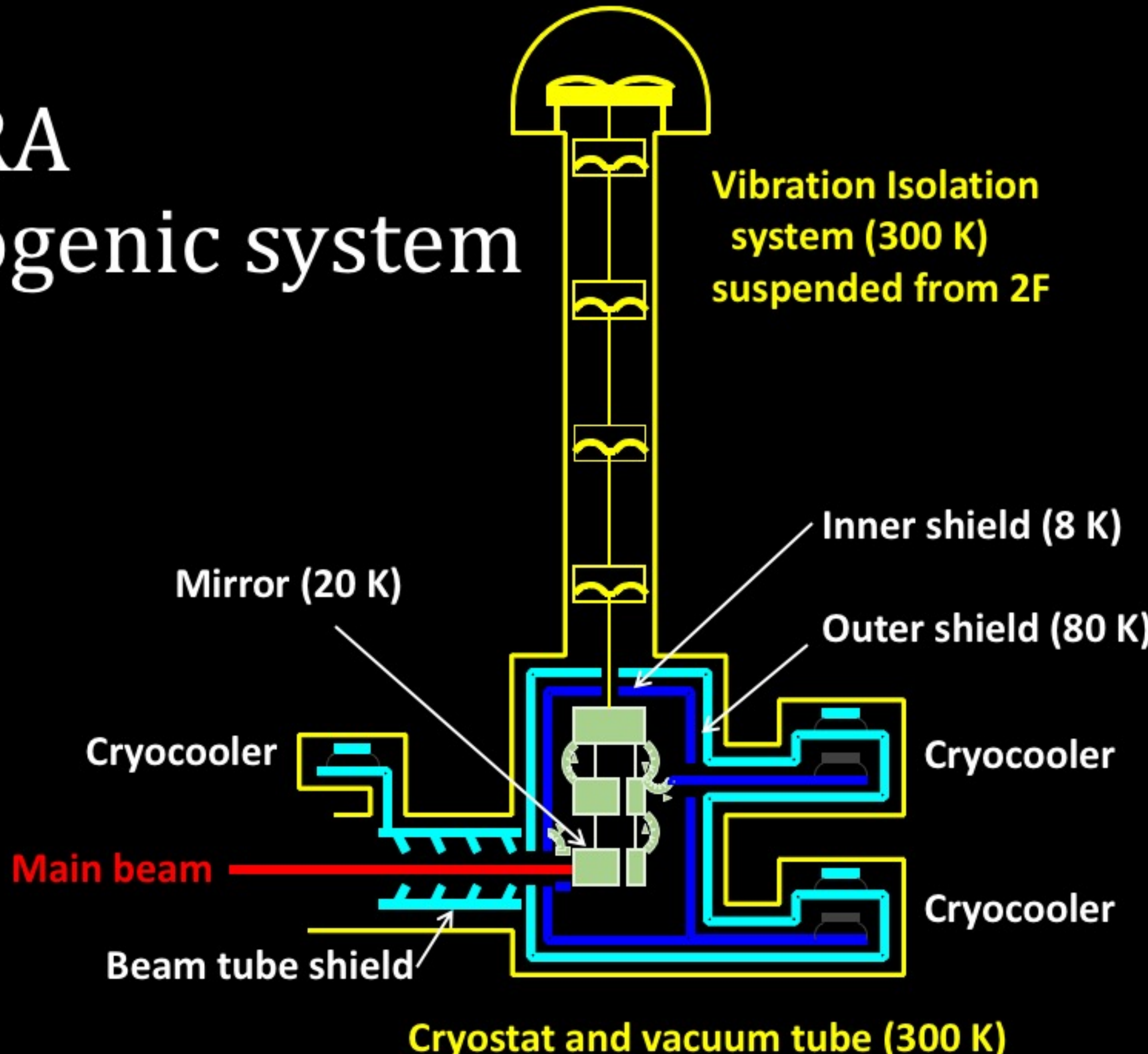


Chief: T. Tomaru

Cryogenic suspension system



KAGRA Cryogenic system



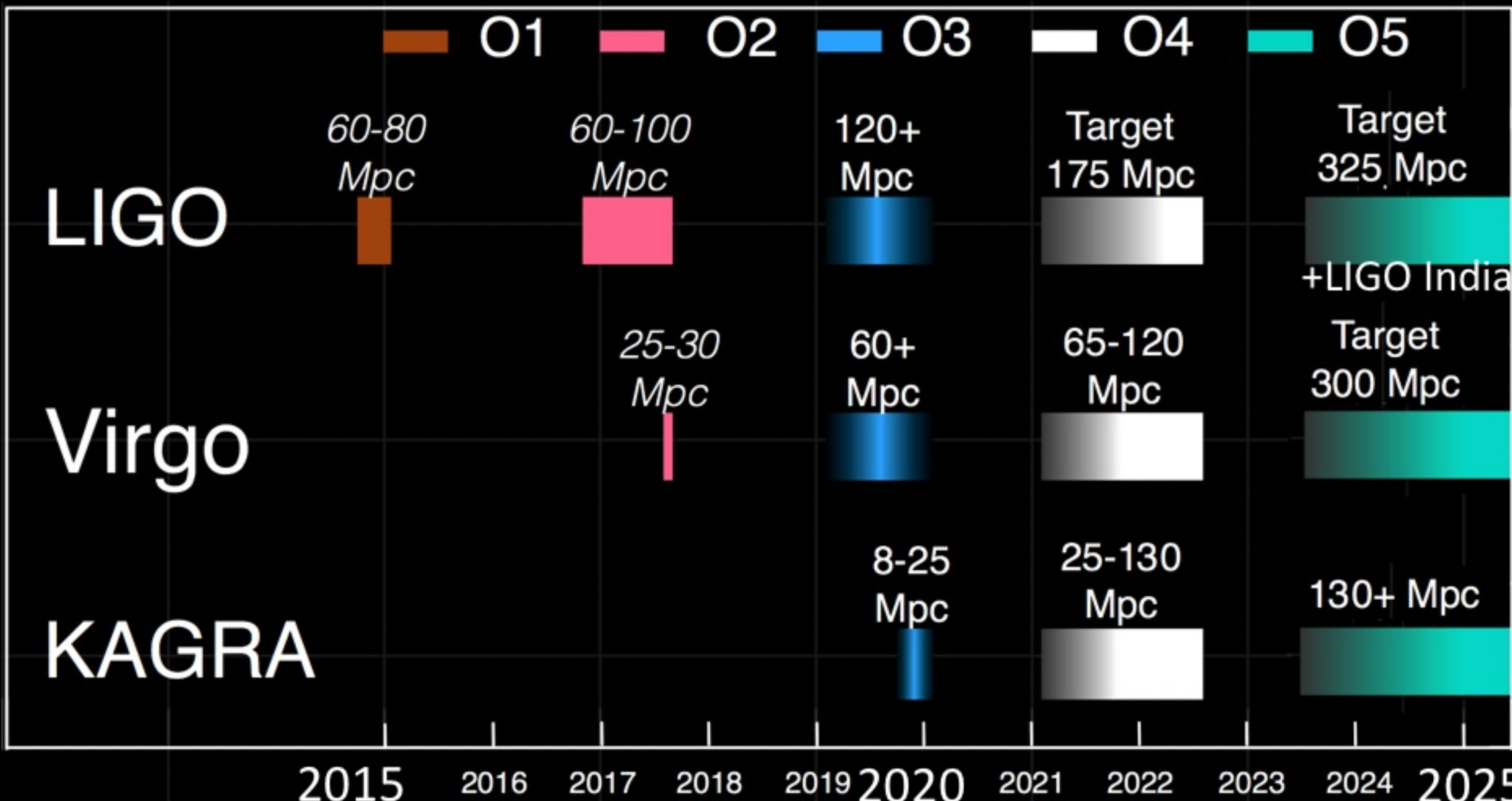
Application of Accelerator technologies to KAGRA

J-PARC neutrino
super-conducting beam line

KEK cryogenic center is leading the development of KAGRA cryogenic system

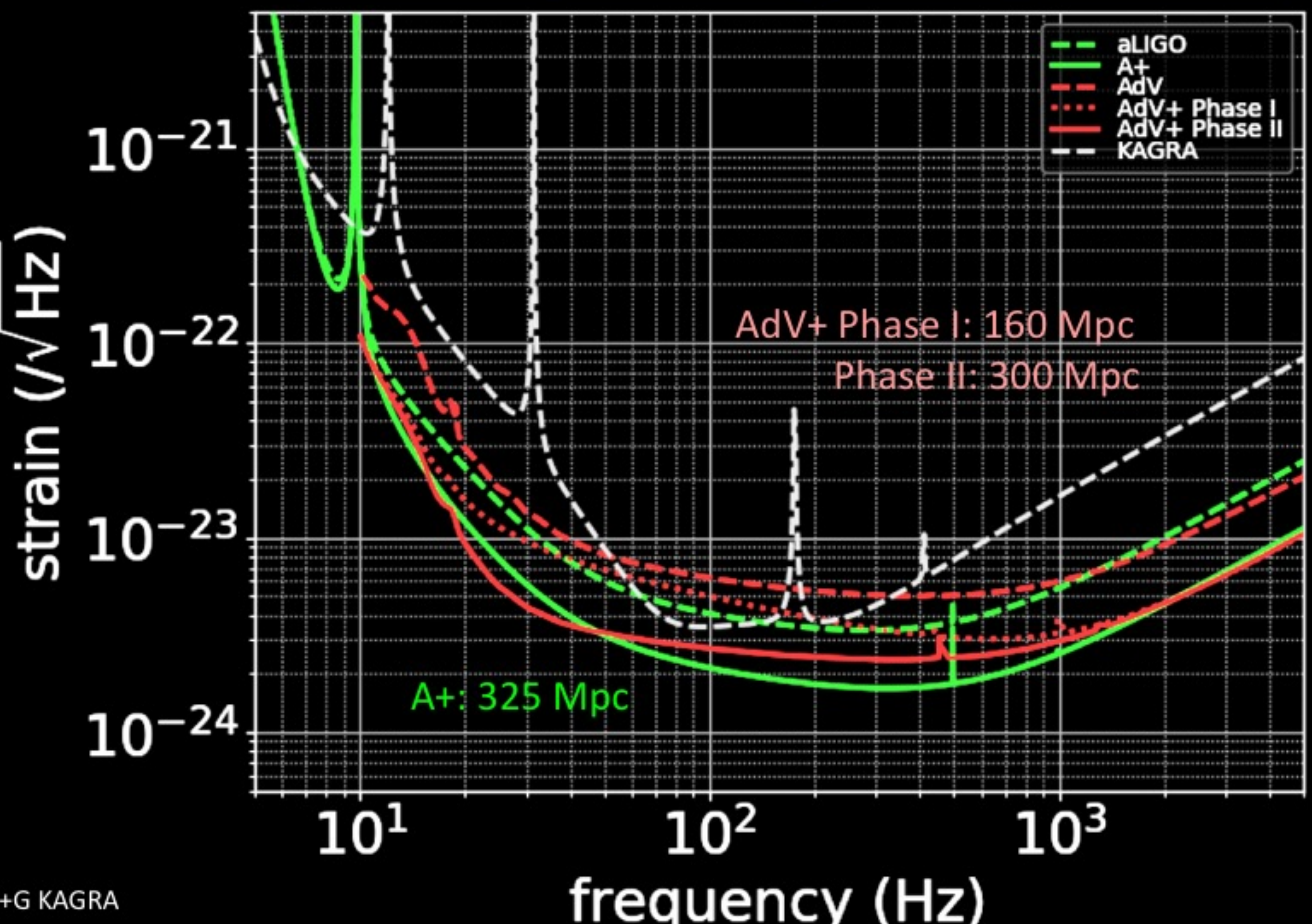
Observing Scenario

Updated version of Living Reviews in Relativity 21, 3 (2018); **KAGRA JGW-P1808427**, **DCC-P1200087**

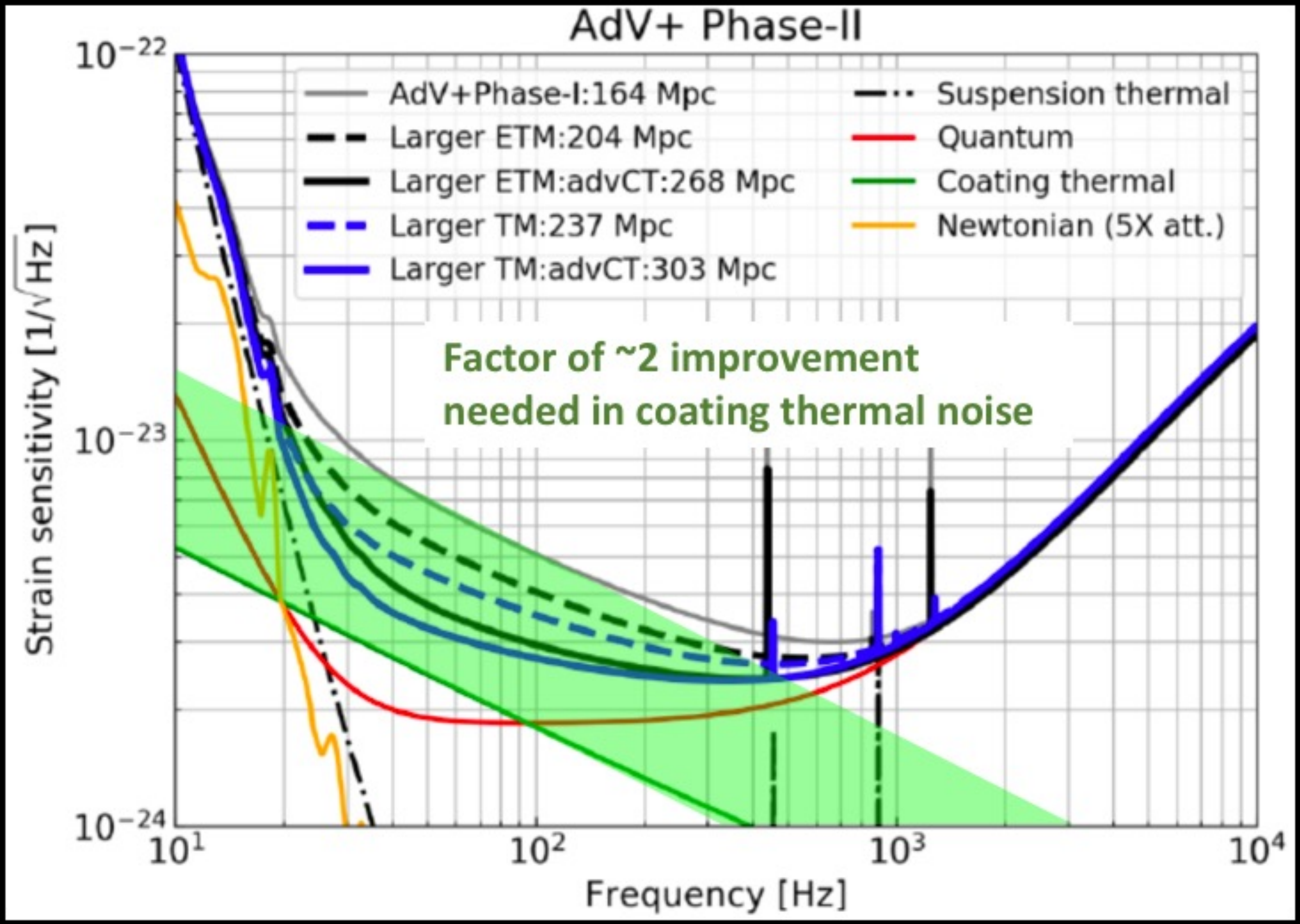


Comparison between 2 and 2.5G

LIGO-T1800044, LIGO-T1800042, VIR-0325B-18, JGW-T1707038

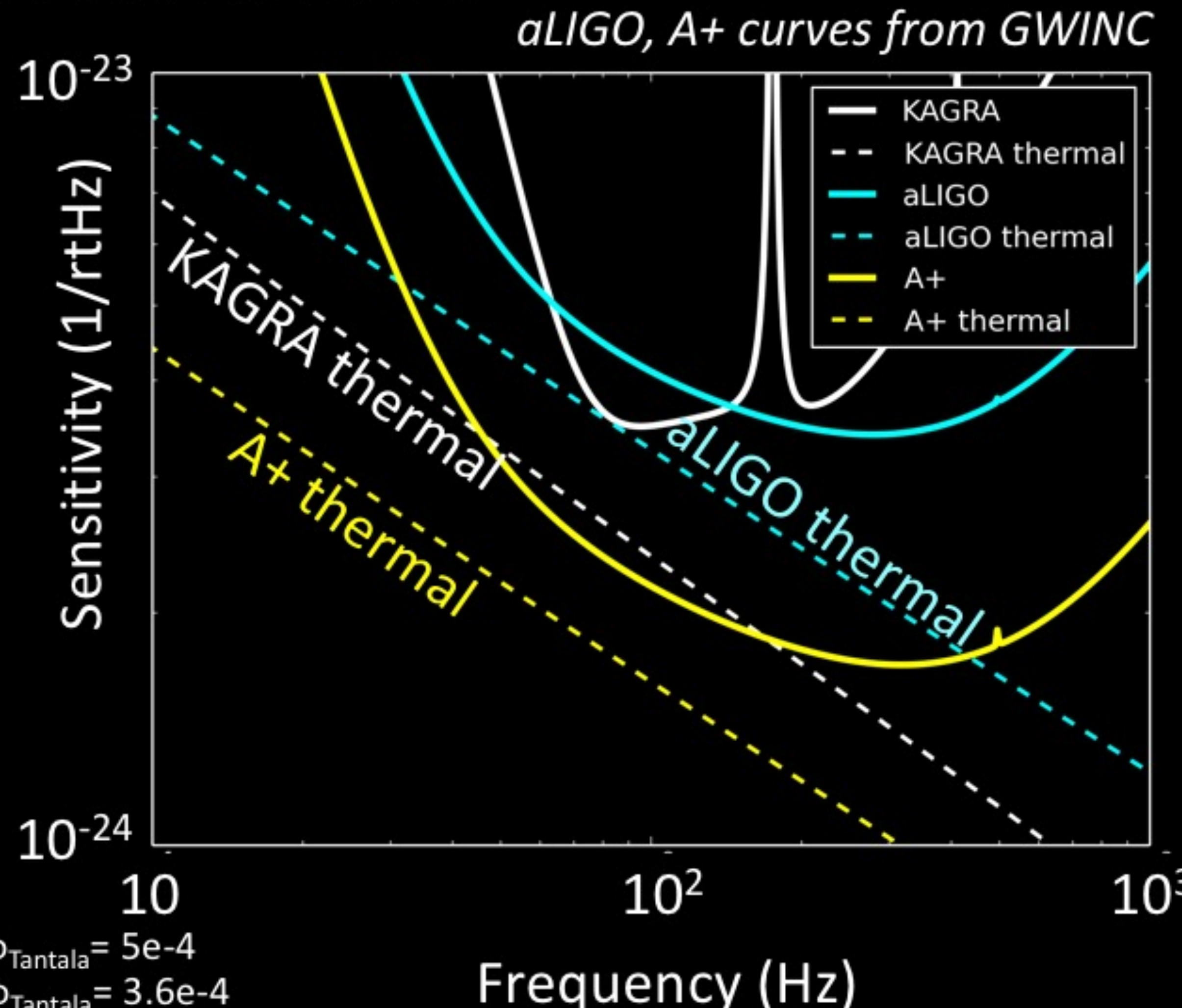


Coating is the key for A+, AdV+



KAGRA thermal noise

Owing to cryogenic KAGRA thermal noise is already in the middle of aLIGO and A+

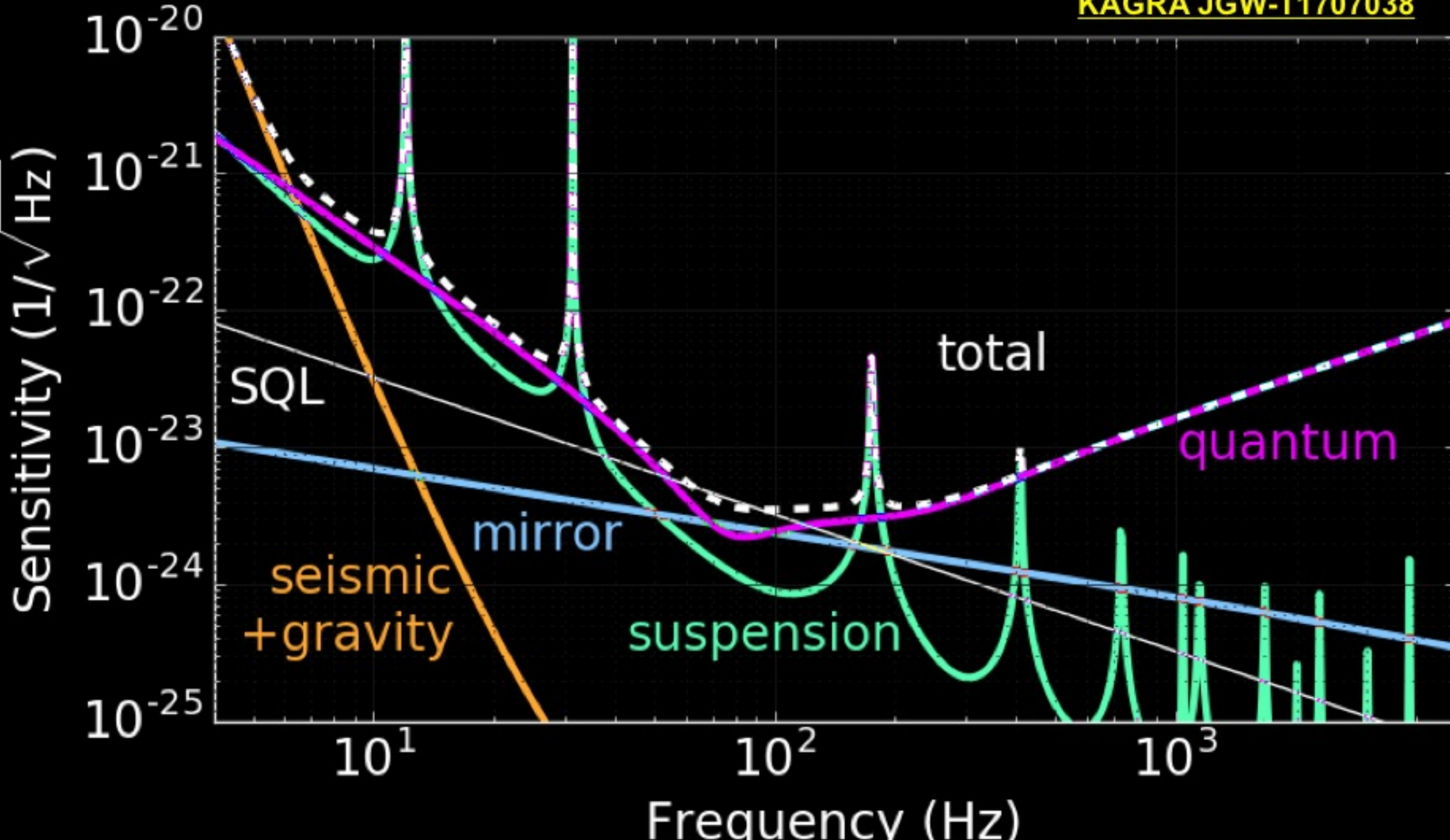


... and still the conservative estimation (based on measurements)

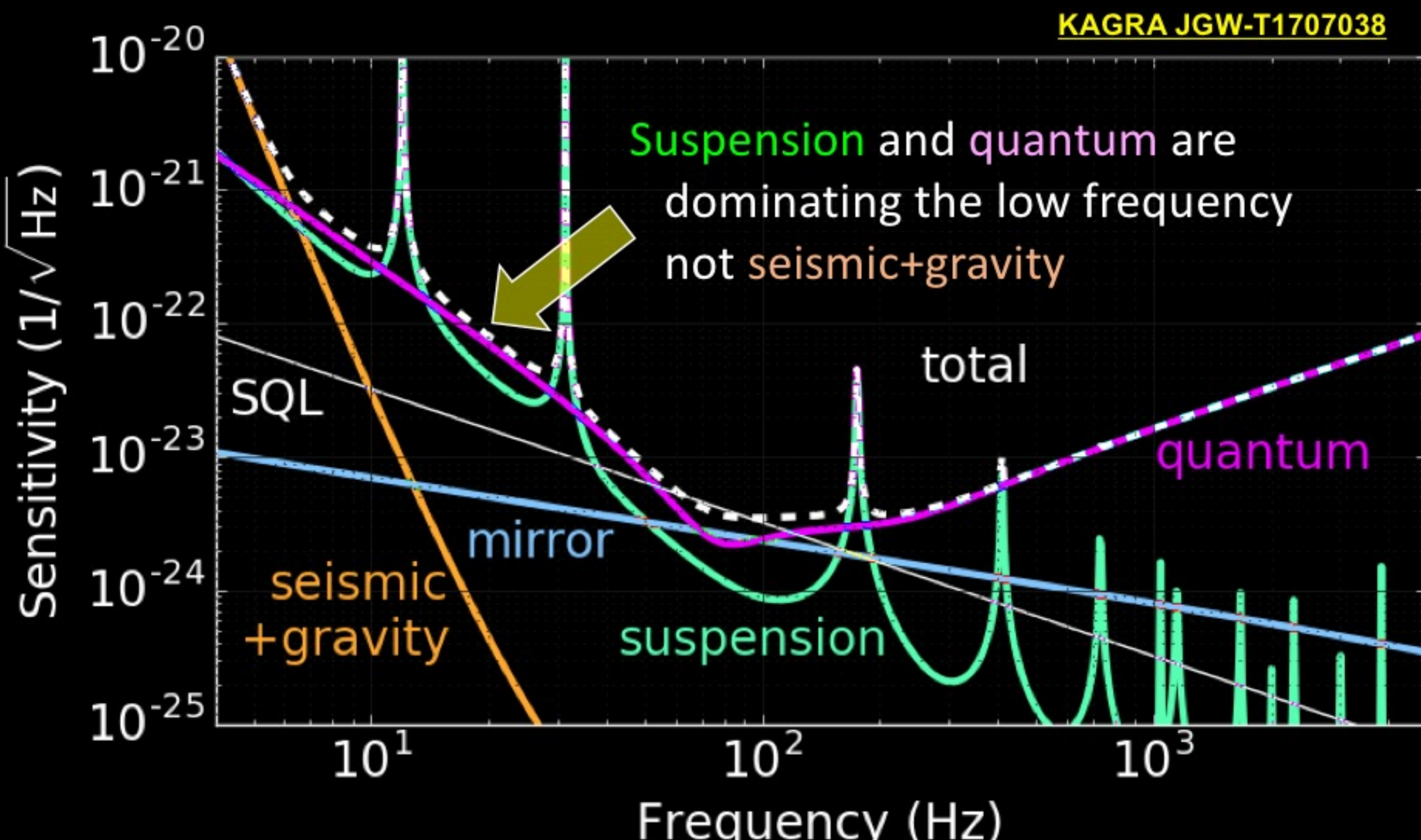
KAGRA (cryogenic) : ϕ_{Silica}= 3e-4, $\phi_{Tantala}$= 5e-4
aLIGO (room temp): ϕ_{Silica}= 5e-5, $\phi_{Tantala}$= 3.6e-4

bKAGRA noise budget

KAGRA JGW-T1707038



bKAGRA noise budget



bKAGRA feature and issues

- Cryogenic → Low thermal noise
  → Heat extraction (thicker fiber)
  → Suspension noise
- Sapphire → Production mass limit (23 kg)
  → Heat absorption
- Underground → Low seismic and Newtonian noise
  → Not dominant in low freq.

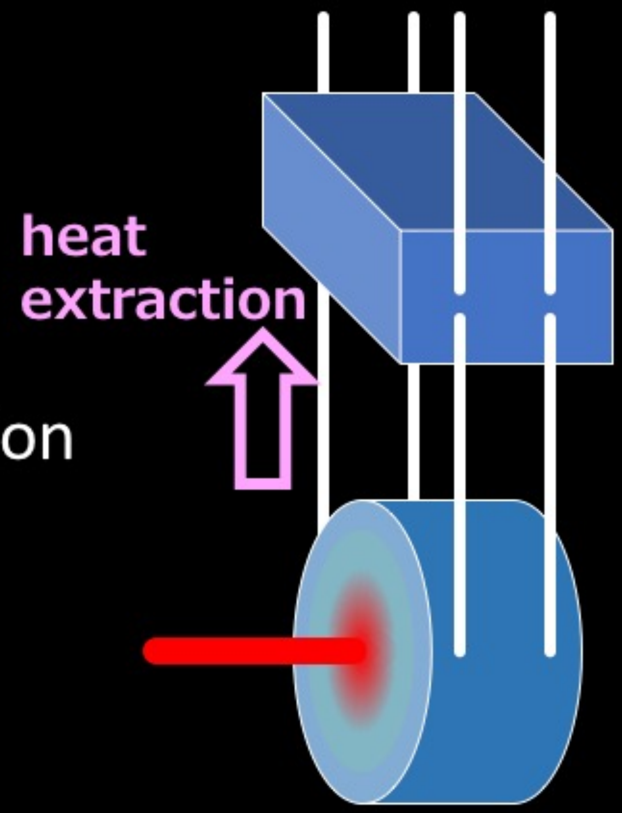
Specific issues for cryogenic

- Not trivial to do both
  - high power (400 kW on mirror)
  - low temperature (20 K)

thinner and longer fibers preferred
for suspension thermal noise reduction

Dilemma

thicker and shorter preferred
for efficient heat extraction



Future Planning Committee (FPC)

- Approved by KAGRA Science Congress (KSC) in Dec./2018 to make the plan for KAGRA+ upgrades and future
- Based on the past discussions, more realistic proposals will be prepared as a white paper
- A few candidates for KAGRA+ upgrades will be discussed and proposed soon (hopefully Apr./2019)
- (Initial) members: C. Kim, K. Komori, M. Leonardi, Y. Michimura, A. Nishizawa, K. Somiya, S. Haino(Chair)

History of KAGRA+ Discussions

- Mar. 2017 F2F @ Niigata U.
- May 2017 KIW3 @ Taiwan
- Aug. 2017 F2F @ U. Toyama
- Dec. 2017 F2F Satellite @ Tokyo Tech.
- Jun. 2018 KIW4 @ Seoul, Korea
- Dec. 2018 F2F Satellite @ NAOJ

  ... and
- Feb 2019 KIW5 @ Perugia

KAGRA’s tough situation

- LVK joint GW detection in O3 is absolutely necessary to go forward to KAGRA+
- At the same time, A+ funding was already approved [1] for 2024-2025 (aka O5)
- For KAGRA+, with the limited resources/time, broadband improvement is not easy

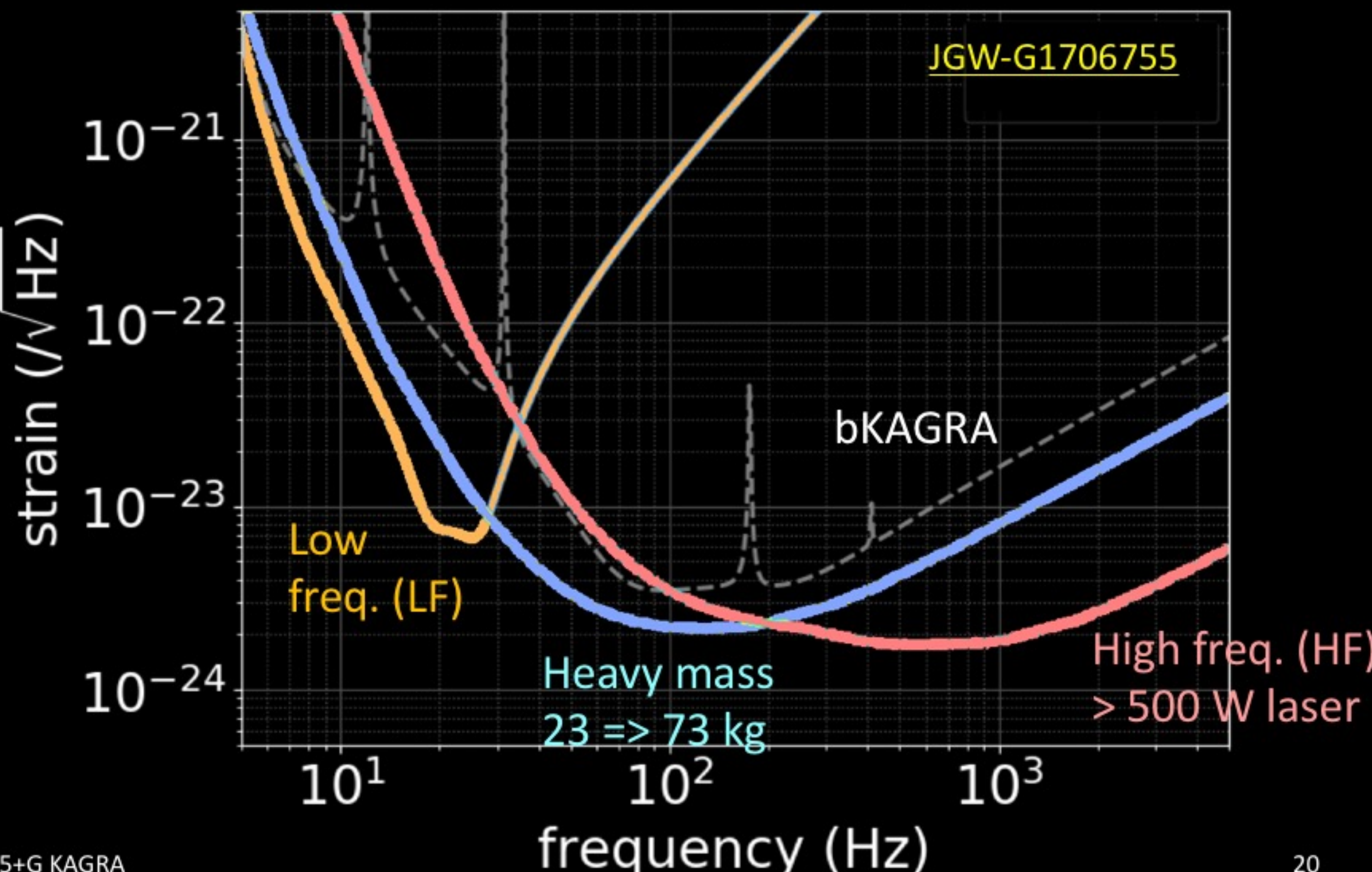
[1] https://www.ukri.org/news/us-uk-australia-funding-to-improve-global-gravitational-wave-network/

Four proposals

- Example sensitivity curves were necessary to start science case study
- Plans technically not too ambitious

- Plan **Blue** - heavier sapphire mirrors
- Plan: **Black** - silicon mirrors (ambitious for O5 ?)
- Plan: **Brown** - tuning to the low frequency
- Plan: **Red** - high power laser (high frequency)

Example sensitivity curves



Science examples summary

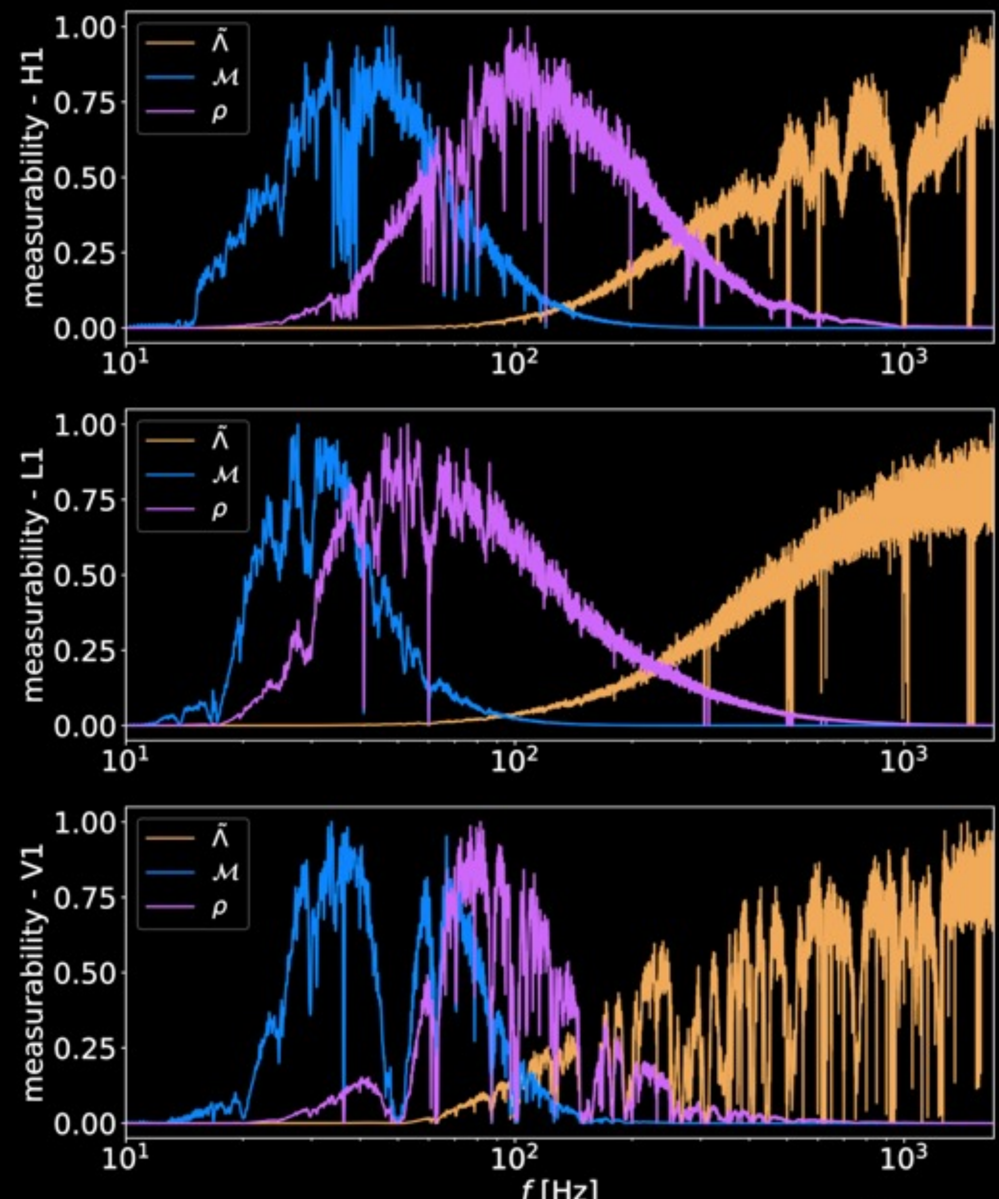
JGW-G1707125

	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	×	×	△	○

arXiv: 1804.08583

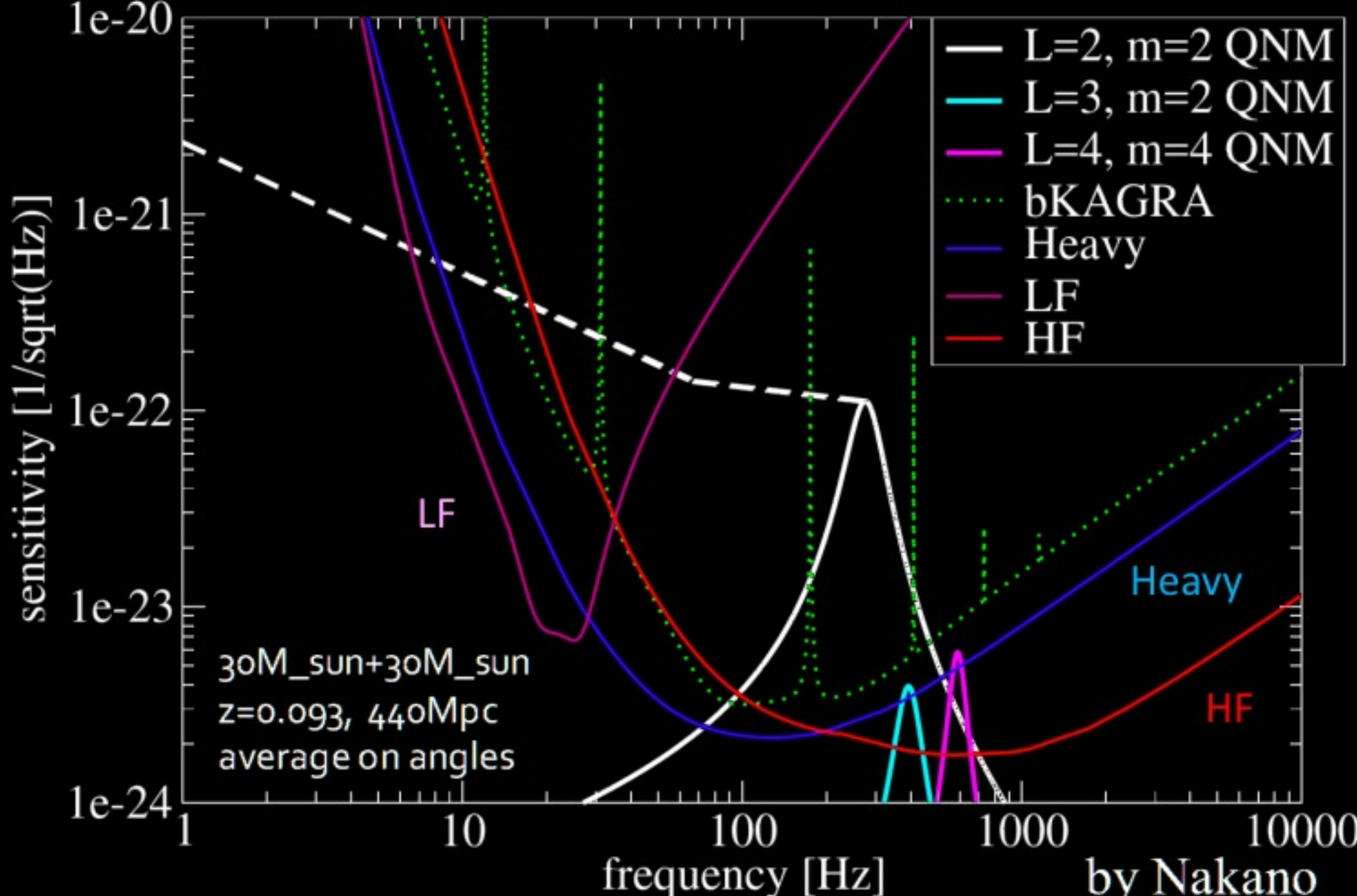
Measurability

- GW170817 at LV
- Mid. frequencies
  = SNR
- Low frequencies
  = Chirp Mass
- High frequencies
  = deformability

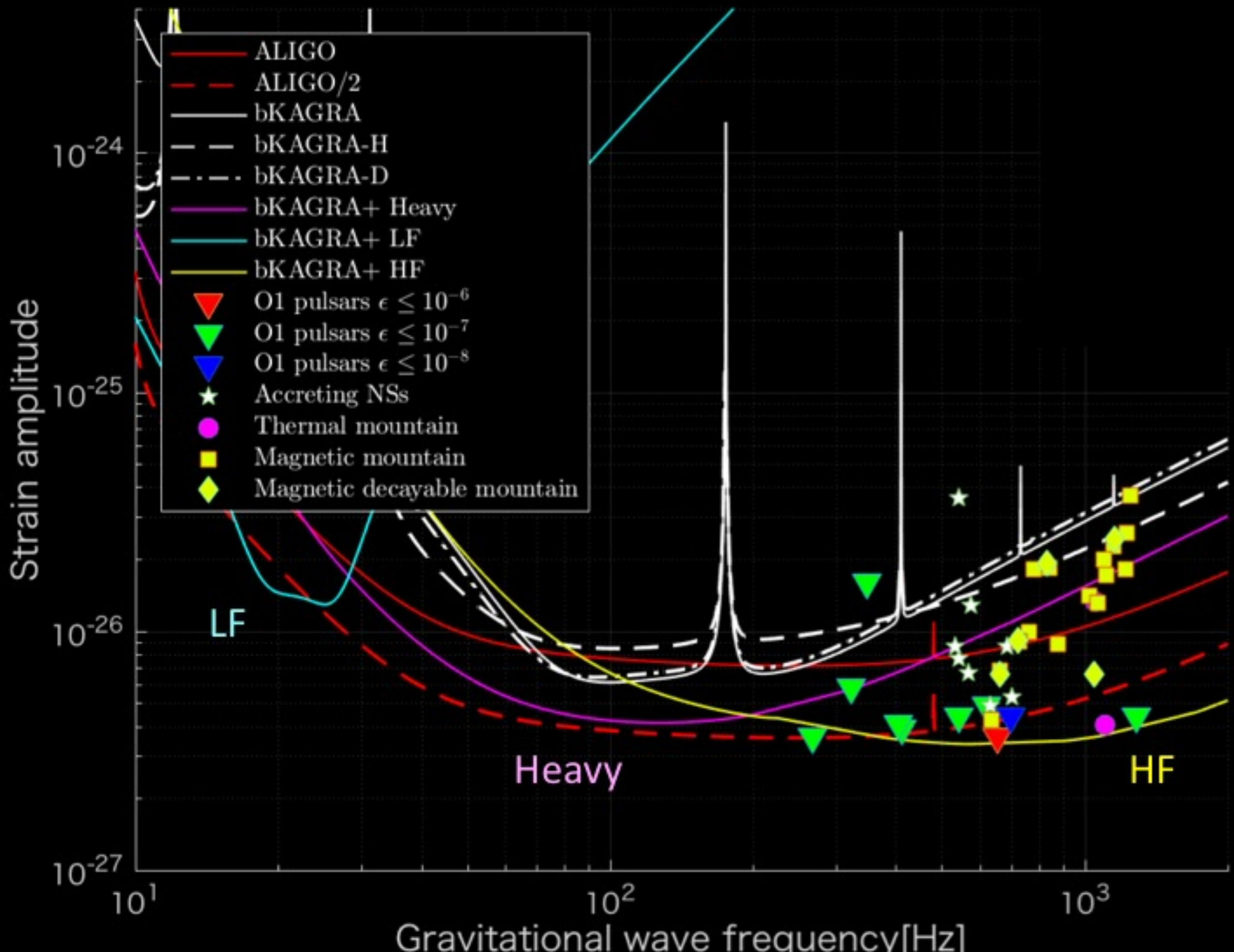


Multiple quasi-normal modes

GW150914-like events based on PRD 90, 124032 (2014)



Continuous wave searches



Continuous wave searches

	aLIGO	aLIGO/2 ~ A+	bKAGRA	bK+ LF	bK+ Heavy	bK+ HF
-6	1	8	1	0	2	9
-7	1	8	1	0	1	8
-8	0	1	0	0	0	1
Accretion balance	4	8	1	0	3	8
Thermal	0	0	0	0	0	1
Magnetic	0	6	0	0	0	10
Decayable Magnetic	0	2	0	0	0	2

Gravitational wave frequency[Hz]

Possible Near Term Plans

- Candidates would be
  A. 40 kg mirror with better coating
     and new sapphire fibers
     (use existing cryostat and Type-A tower)
  B. 400 W laser with (Freq. indep.) squeezing
     and new sapphire fibers
  C. Frequency dependent squeezing
     and new sapphire fibers

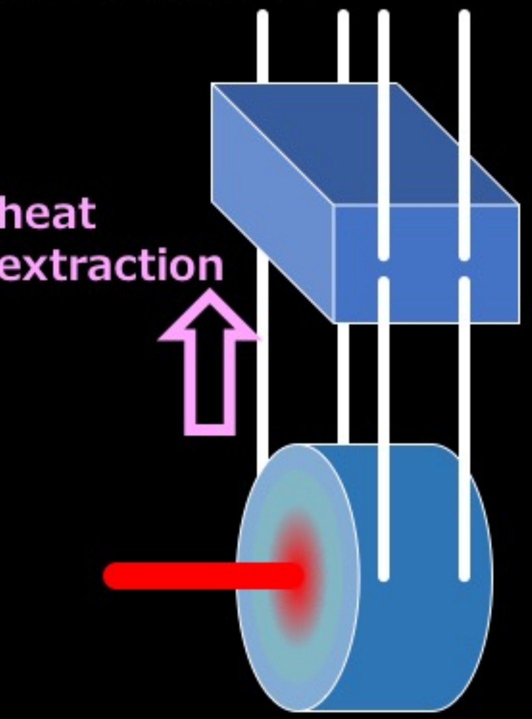
(Ref: E. Capocasa and R.K. Lee's talk)

- Sensitivity optimization with particle swarm
  Y. Michimura et al, Phys. Rev. D 97, 122003 (2018)

KAGRA with high power extension

- Cryogenic sapphire mirrors may have some advantages for high power extension compared with room-temperature Silica mirrors

- Disadvantages:
  - Heat extraction issue
    (= thicker and shorter fibers)
  - Mass limits
    (= more radiation pressure noise)



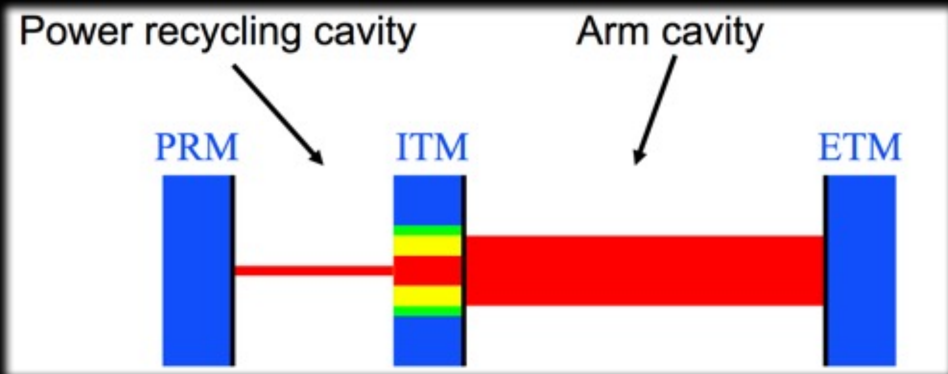
Parametric Instability (PI)

- Currently one of the issues for LIGO/Virgo to go to higher power laser

- KAGRA should have advantages of rigid Sappire mirror to reduce the PI (~1/10 w.r.t. Silica)
  ~1/5 by higher Young's modulus (400/73)
  ~1/2 by number of modes (3/7)

J. Phys.: Conf. 122 (2008) 012015.
JGW-T0900057

Thermal lensing comparison



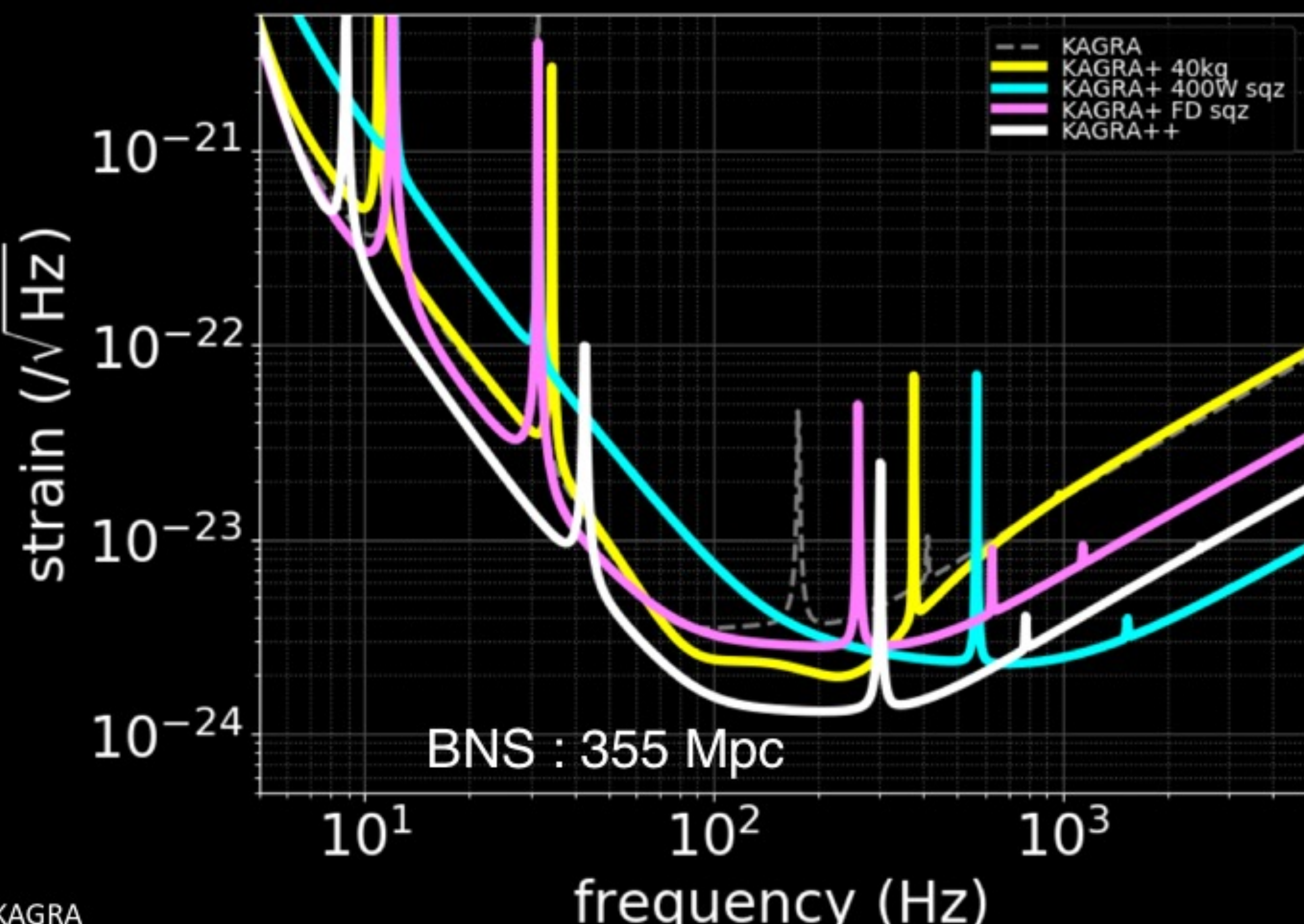
Thermal lensing effect is significantly reduced with cryogenic sapphire mirror

		Fused silica (300 K)	Sapphire (300 K)	Sapphire (20 K)
Abs. coeff.	α (ppm cm^{-1})	2–20	40–100	90
Th. conductivity	$\kappa\,(\mathrm{W m^{-1} K^{-1}})$	1.4	46	4.3×10^3
dn/dT	$\beta\,(\mathrm{K}^{-1})$	1.4×10^{-5}	1.3×10^{-5}	$\leqslant (9 \times 10^{-8})$
Wave front distortion	$\alpha\beta/\kappa\,(\mathrm{W}^{-1}) \times 10^{-9}$	2–20	1–3	$\leqslant (2 \times 10^{-4})$

T. Tomaru et al., Class. Quantum Grav. 19 (2002) 1

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

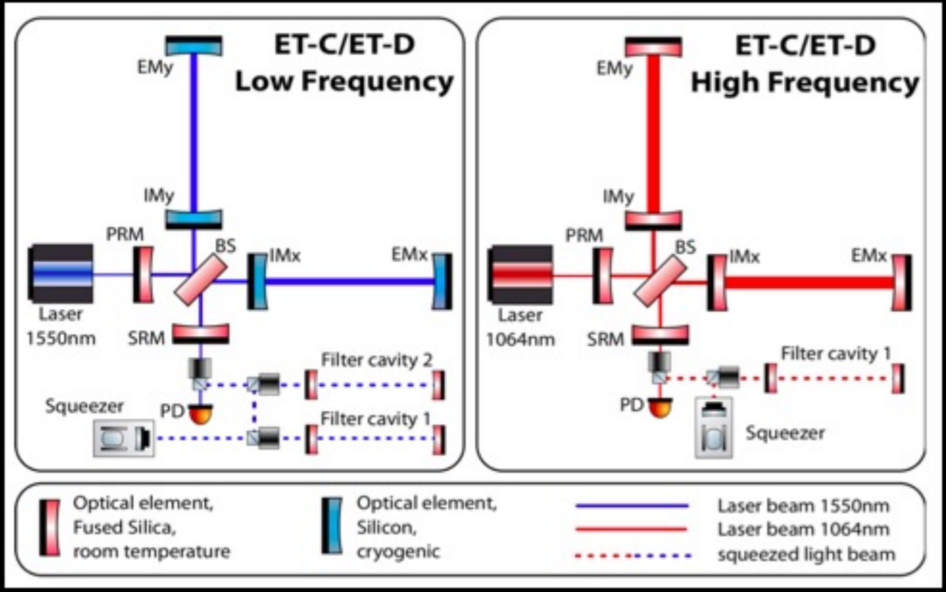
- Current KAGRA cryostat may not be able to afford bigger mirror
  => replacement of cryostat
  => the vacuum tubes (3km arms) may need
    to be extracted from the tunnel to make the path

Advanced interferometry ?

- Extreme RSE (Resonant Sideband Extraction)
  - No PRM, high arm finesse => lower power at ITM
- Speedmeter
- EPR (Einstein-Podolsky-Rosen) entanglement
- …

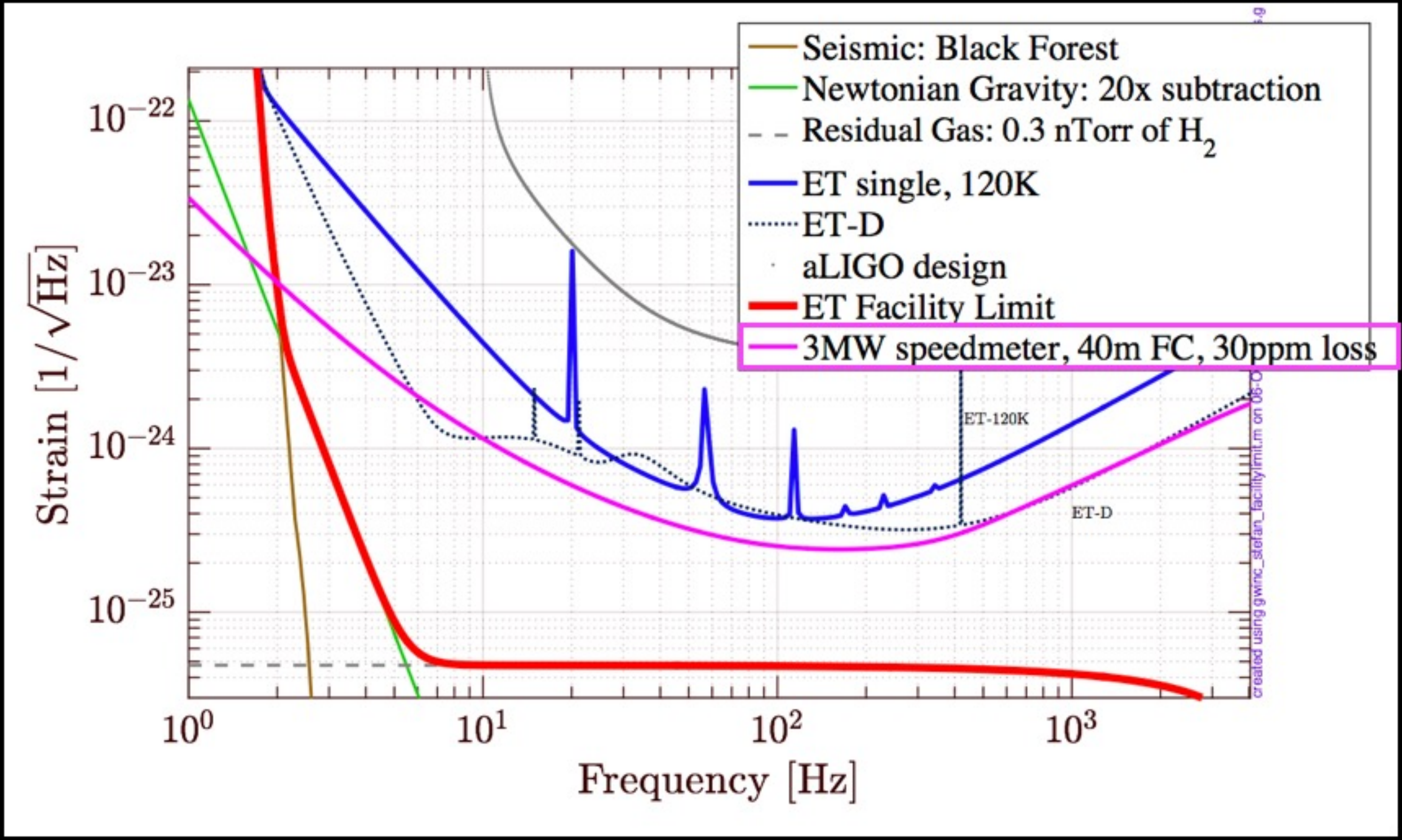
Possible collaborations with ET

- High power (500W, 1064 nm) laser (ET-HF)
- High power mitigations (e.g. Parametric Instability)
- Efficient heat extraction (fiber, heat link) (ET-LF ?)
- QND to reduce rad. press. noise (e.g. speedmeter)
- Newtonian Noise study at underground site



Speedmeter as an option in ET ?

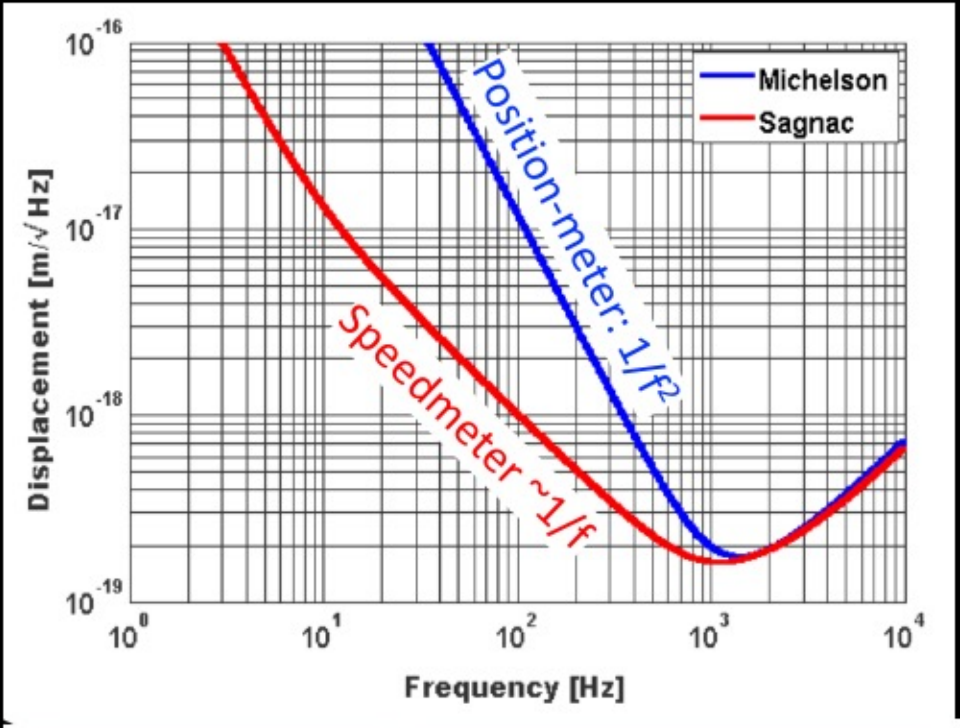
ET workshop at Glasgow

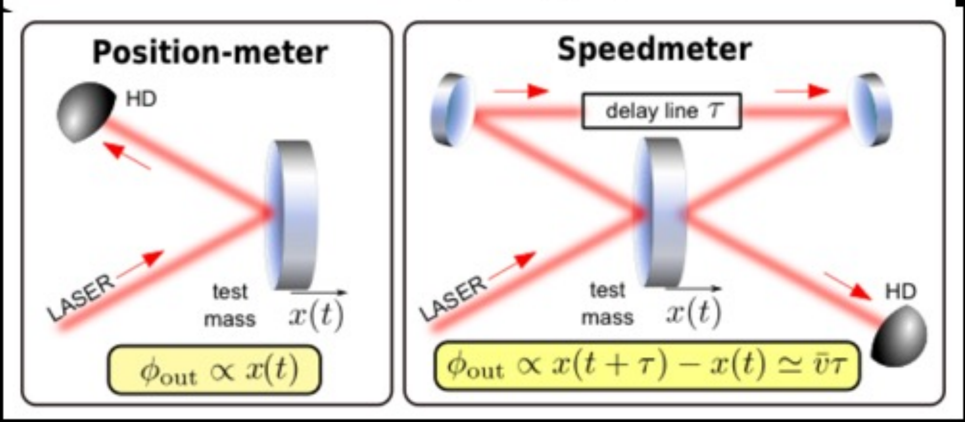


Speedmeter

by S. Hild

KAGRA may have more benefits from speedmeter with:
- combination with high power
- lower radiation pressure noise even with small mirrors
- Shorter filter cavity for freq. dependent squeezing





Summary

- KAGRA Future Planning Committee has just formed and started the discussion of KAGRA upgrades
- Optimization of design with current technology limits and maximum science merits should be considered
- Some of challenges can be shared with 3G (e.g. ET) detector developments

Acknowledgements

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