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# Improving the sensitivity of KAGRA gravitational wave detector

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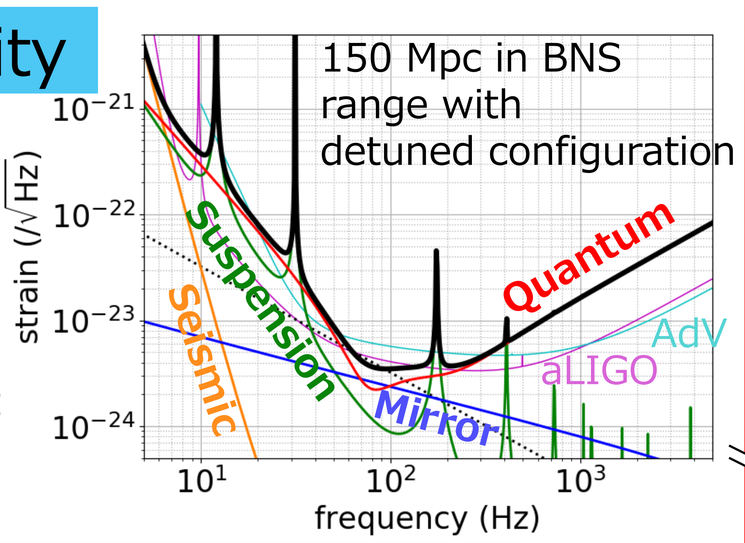
Yuta Michimura for the KAGRA Collaboration
Department of Physics, University of Tokyo
michimura@granite.phys.s.u-tokyo.ac.jp

We present the prospects for improving the sensitivity of KAGRA from O3 to O5. We show that it is likely that binary neutron star range of KAGRA will be only **a few Mpc in O3** and **about 80 Mpc in O4 at most** optimistic cases, with current birefringent sapphire input test masses. We also show that the sensitivity can be improved **upto 180 Mpc in O5**, with improved test masses and frequency dependent squeezing, without increasing the inout laser power from the originally designed value. Detector parameters critical for the sensitivity calculation are also explained.

## Designed Sensitivity

KAGRA has smaller coating thermal noise than other detectors owing to cryogenic cooling, but has larger suspension thermal noise due to **thick and short suspension fibers** to extract heat from test mass mirrors [1,2].



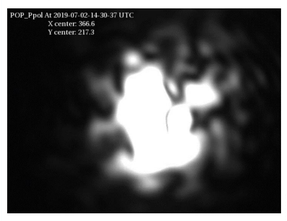

## Mirror Birefringence and Frosting

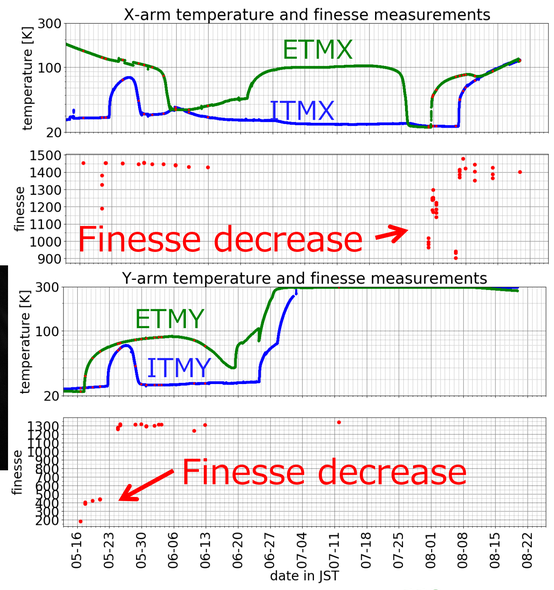
Unexpectedly **large and inhomogeneous birefringence** of sapphire input test masses (ITMs) was found. Birefringence creates unwanted polarization in the reflection of ITMs. The **optical losses** are as high as several %, and power and signal recycling cavities **cannot be locked** stably until now.

We also found arm cavity **finesse decrease at cryogenic temperatures** (<~30 K) due to frosting of the test masses.

Arm cavity parameters gives bandwidth of quantum noise
- ITM transmission: 0.4 %
- Finesse: 1530 (designed)

Shape of unwanted polarization component of reflected beam from X-arm

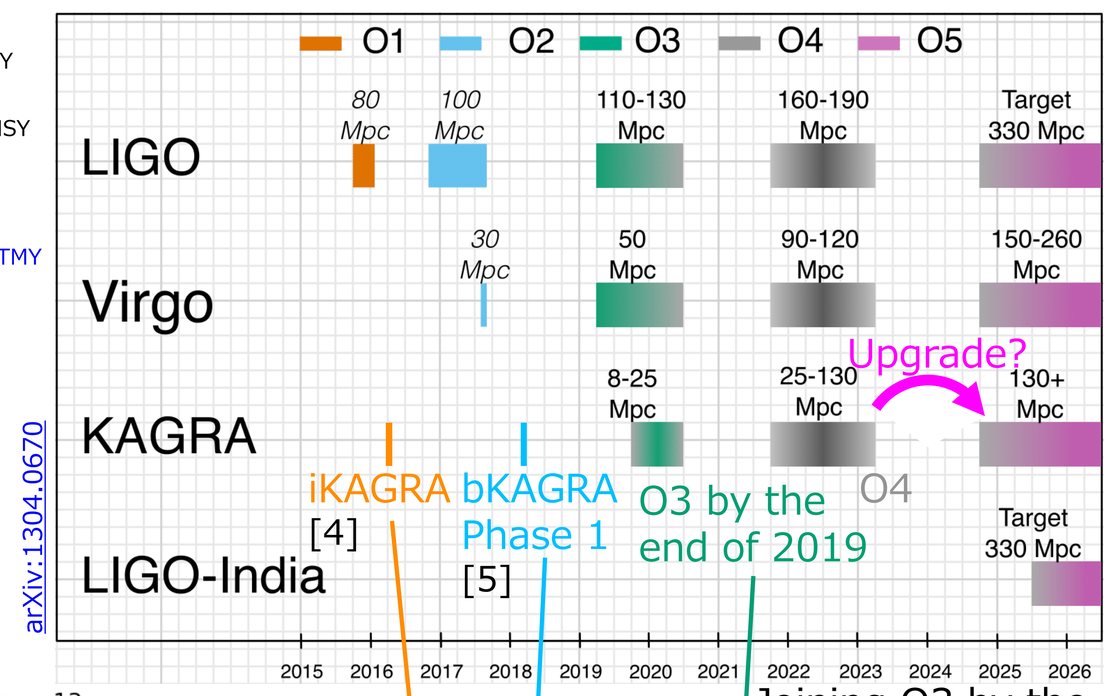


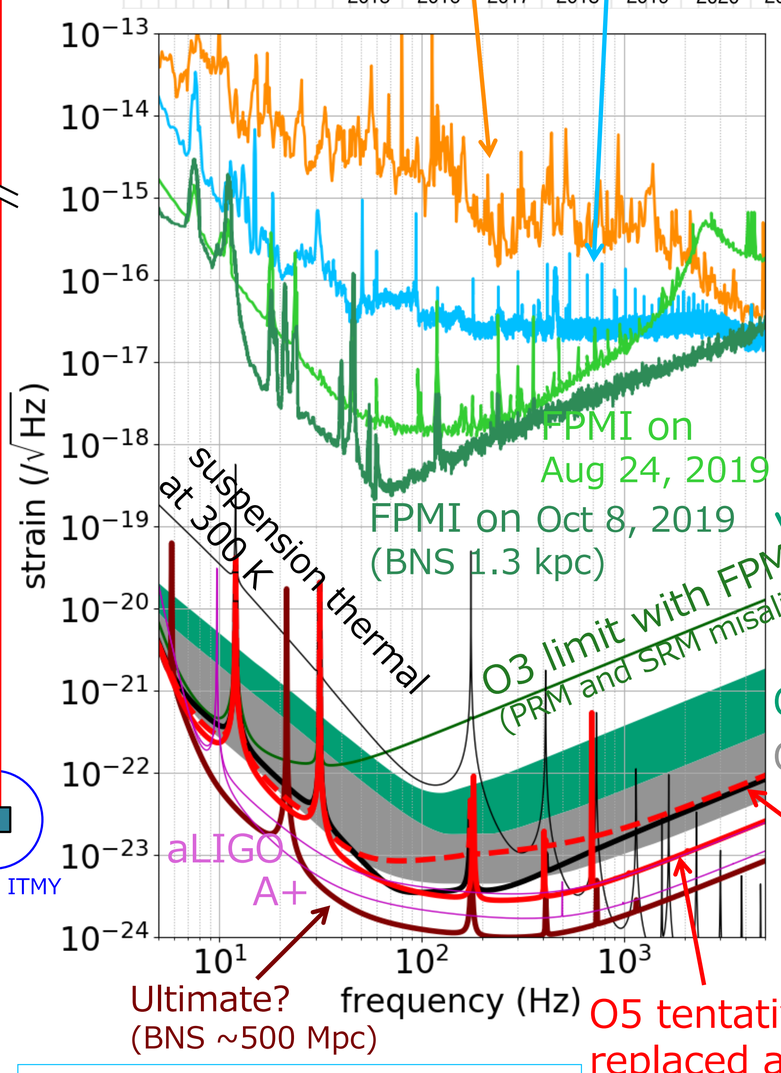



## Further Reading

[1] Y. Michimura+, PRD 97, 122003 (2018)
[2] Y. Michimura+, arXiv:1906.02866
[3] KAGRA Collaboration, PTEP 2018, 013F01 (2018)
[4] KAGRA Collaboration, CQG 36, 165008 (2019)
[5] K. Somiya, arXiv:1909.12033
[6] K. Komori+, PRD 97, 102001 (2018)
[7] E. Capocasa+, PRD 93, 082004 (2016)

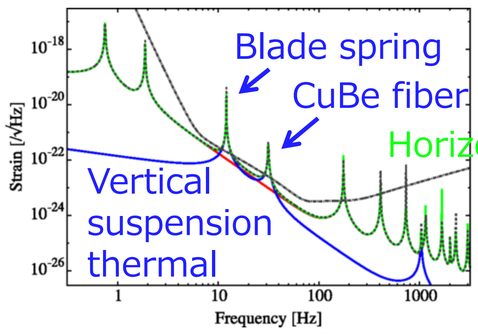
## Observing Scenario



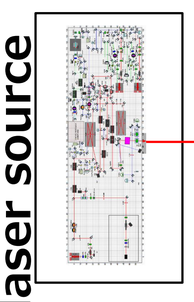




Joining O3 by the end of 2019 is considered to be a **must** even if the sensitivity is not as good. Current KAGRA sensitivity is 4-5 orders of magnitude worse than that of current LIGO and Virgo.

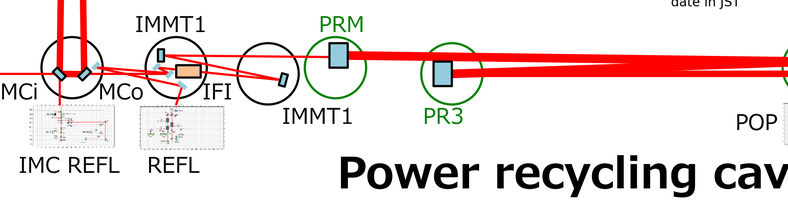
Significant vertical thermal noise comes from blade springs and CuBe fibers suspending the intermediate mass (IM)
- Blade spring resonance:
  14.5 Hz vertical
  2 kHz horizontal
  (lower the better)
- Blade spring loss angle: 7e-7
- CuBe fiber loss angle: 5e-6
- IM temperature: 16 K




Ref. [6]



**Pre-stabilized laser source**

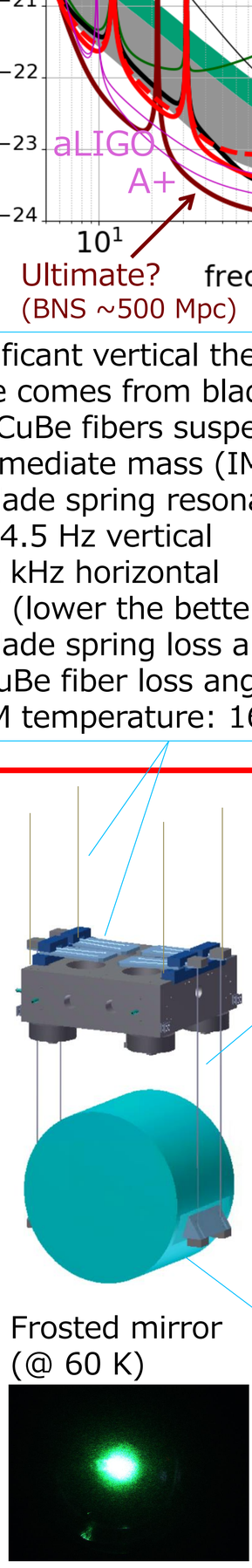



Increasing input laser power reduces quantum noise at high frequencies but increases at low frequencies.
- Power at BS:
  1 W for O3 due to no power recycling?
  200 W for O4 due to reduced recycling gain from birefringence?
  673 W for O5?

Signal recycling cavity parameters changes the shape of quantum noise
- SRM transmission:
  30% for O3
  15 % for O4-O5?
- Detuning angle:
  0 deg for O3-O5?
  3.5 deg in design

Frequency dependent squeezing would be injected from here in O5 to reduce quantum noise in broad band [7]
- Filter cavity length: 60 m in O5?
- Injected squeezing: 10 dB in O5?

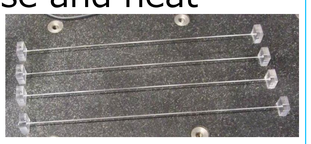
Readout quadrature changes the shape of the quantum noise [5]
- Homodyne angle:
  90 deg for O3-O5?
  135.1 deg in design



Frosted mirror (@ 60 K)



Parameters for sapphire fibers suspending the test mass is critical for suspension thermal noise and heat extraction calculations.
- length: 35 cm
- diameter:
  1.6 mm in design, 1.4 mm for O5??
- loss angle: 2e-7
- thermal conductivity: 5800 W/m/K



Mirror parameters are critical for calculating coating and substrate thermal noises
- size: 22 cm dia. 15 cm thick
- mass: 22.8 kg
- temperature: 22 K (100-250 K for O3??)
- loss angle: 1e-8
- substrate absorption:
  50 ppm/cm in design
  25 ppm/cm for O5??
- coating loss angle: 3e-4 / 5e-4
- coating absorption: 0.5 ppm