Newtonian Noise Measurement by Torsion Bar Antenna

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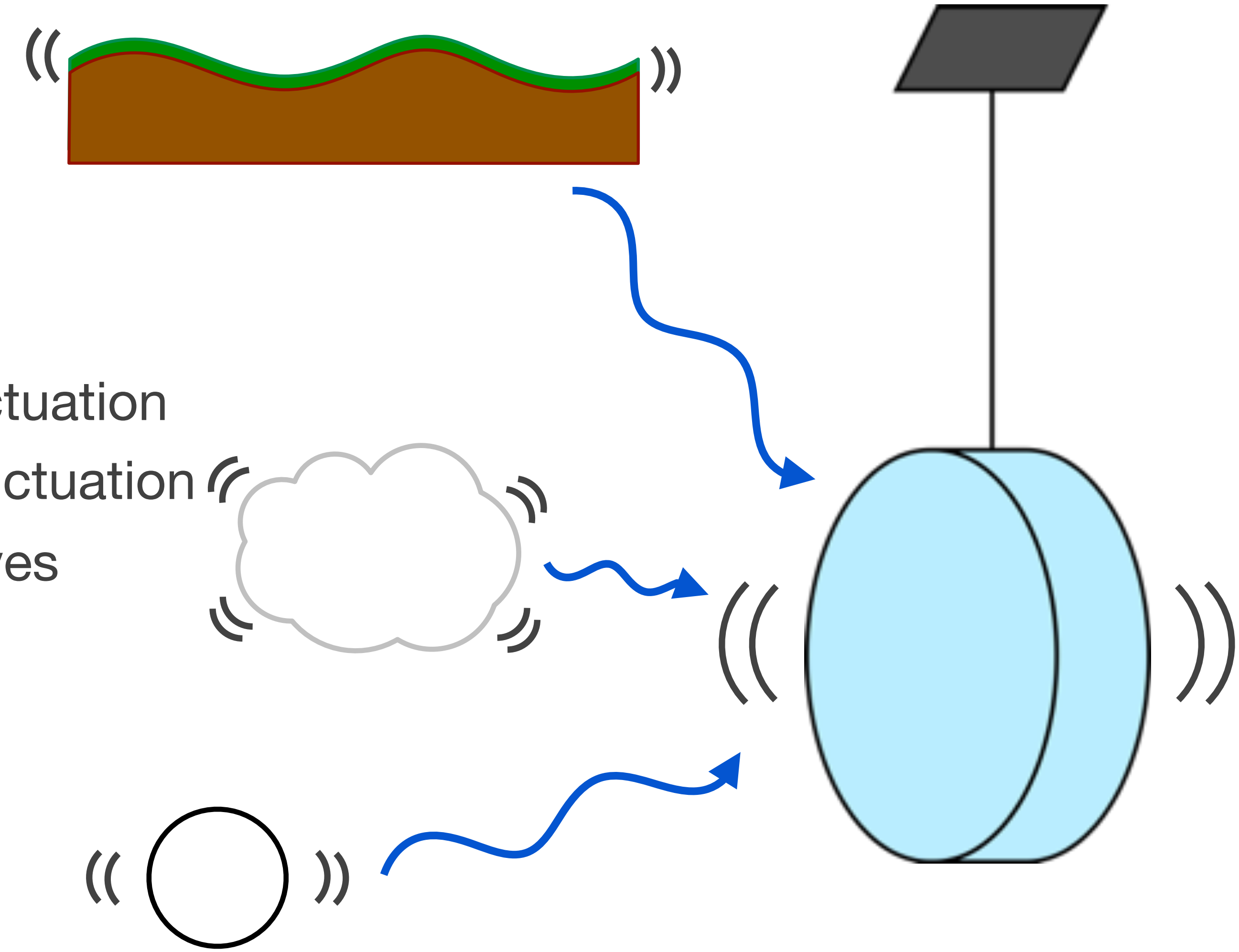
Newtonian Noise

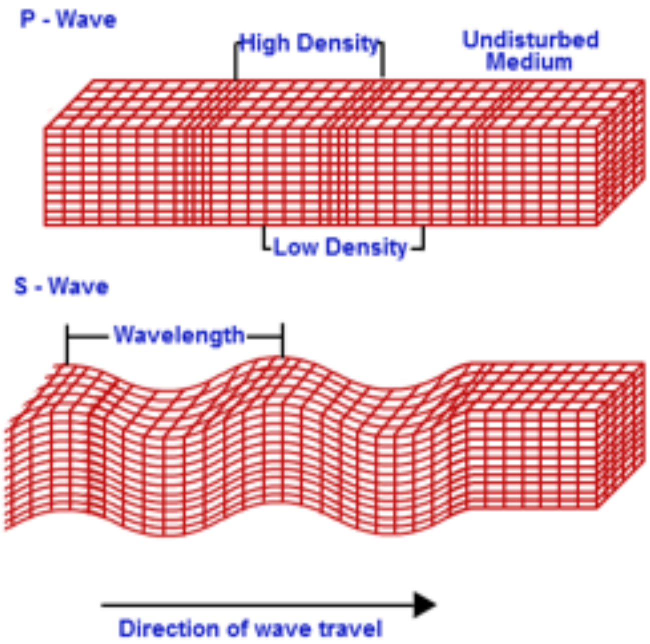
Newtonian noise: comes from local gravity gradient fluctuation

- Seismic waves
  - body wave
  - surface wave
  - etc.
- Atmospheric fluctuation
  - temperature fluctuation
  - infrasound waves
  - etc.
- Moving masses

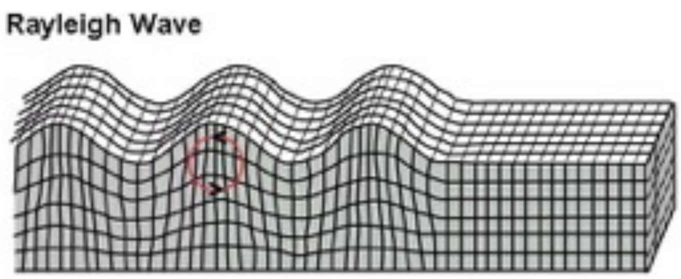


Seismic NN

- Seismic waves:
  - ◉ body wave
    - ○ P-wave: compressional wave
    - ○ S-wave: shear wave
    - ▶ propagate though media
  - ◉ surface waves
    - ○ Rayleigh wave
    - ▶ propagates on the surface of media
- can be divided by
  surface and bulk contribution

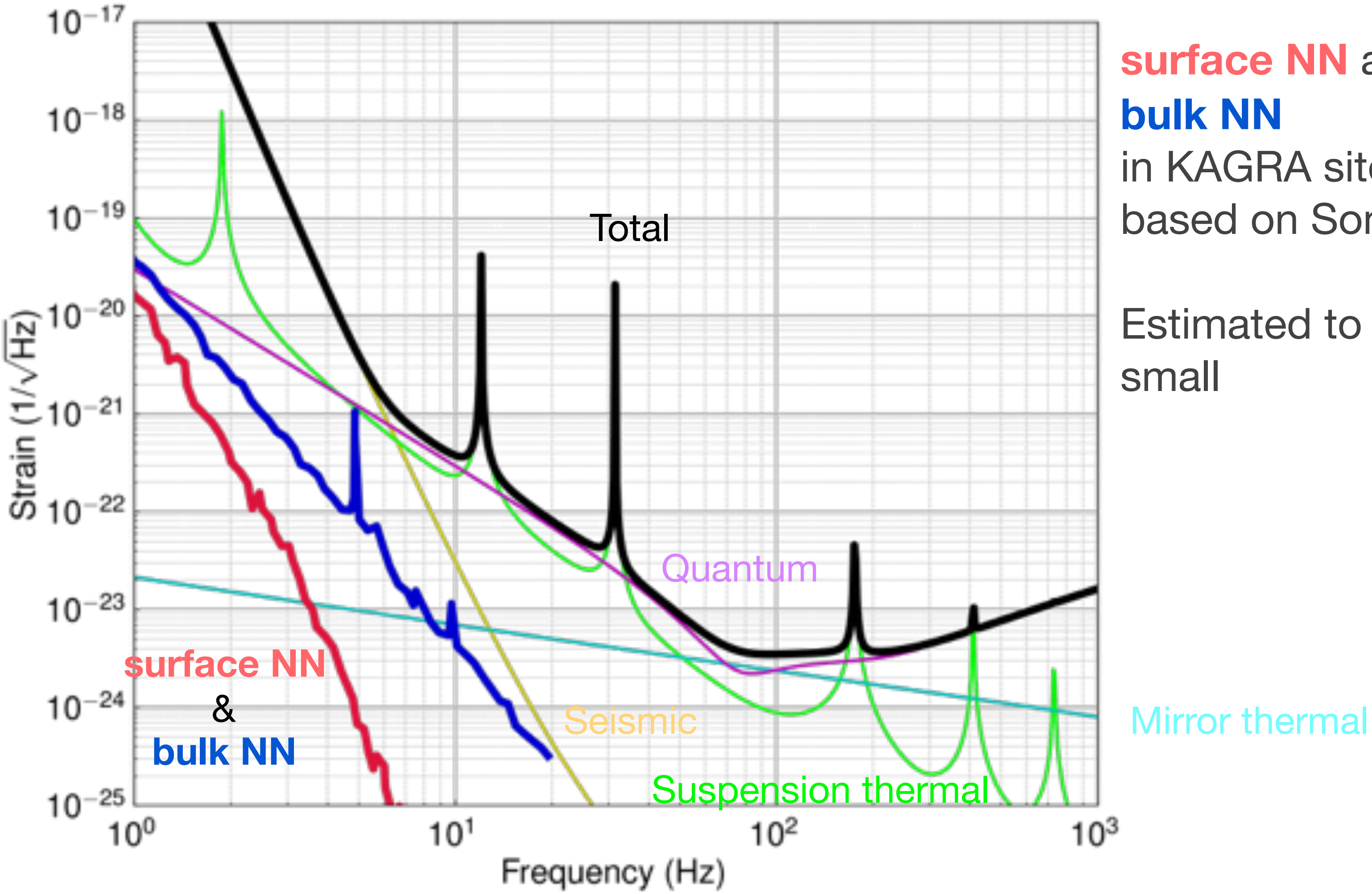


http://physics.tutorcircle.com/waves/p-wave.html



https://earthquake.usgs.gov/learn/glossary/images/rayleigh_web.jpg

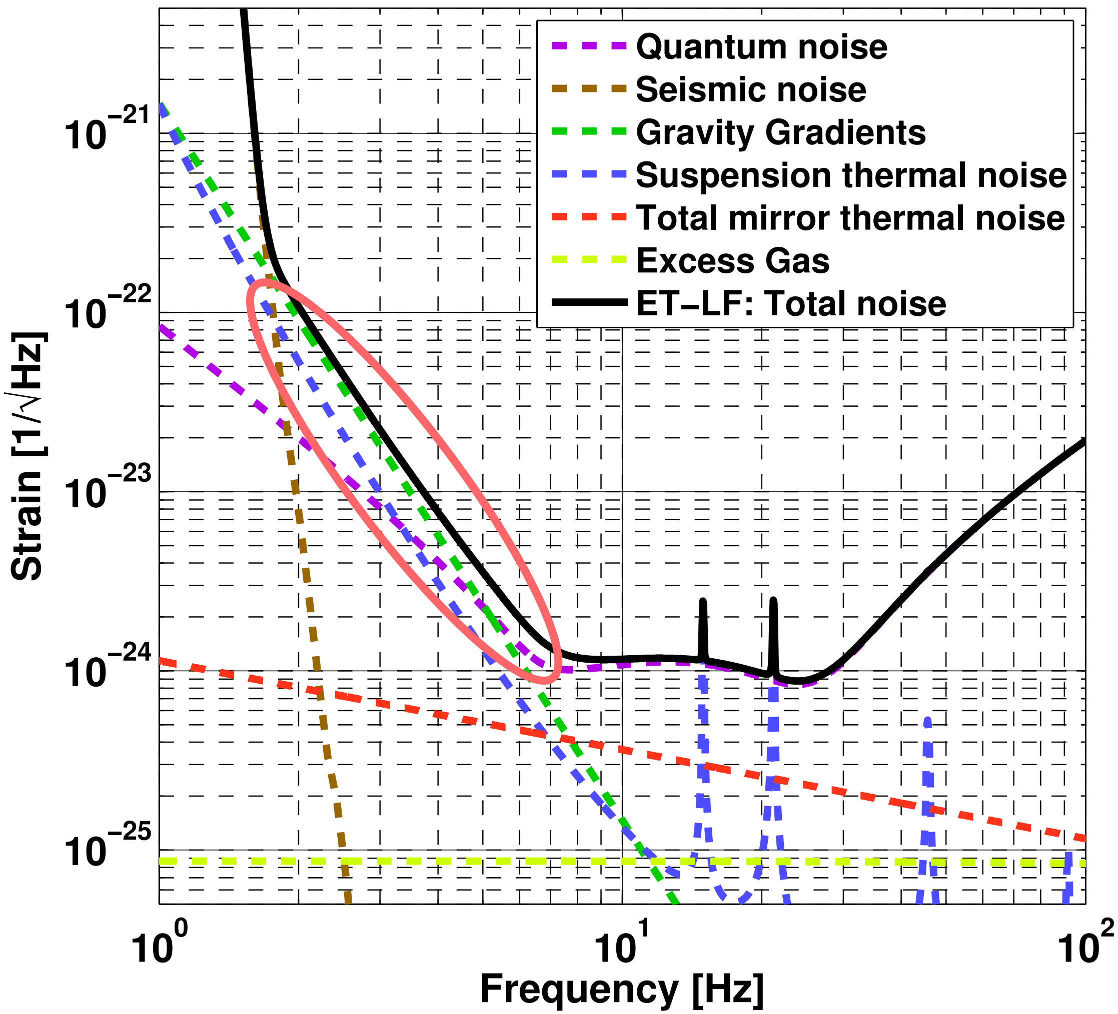
NN in KAGRA



surface NN and
bulk NN
in KAGRA site
based on Somiya+ (2012)

Estimated to be enough small

NN in ET



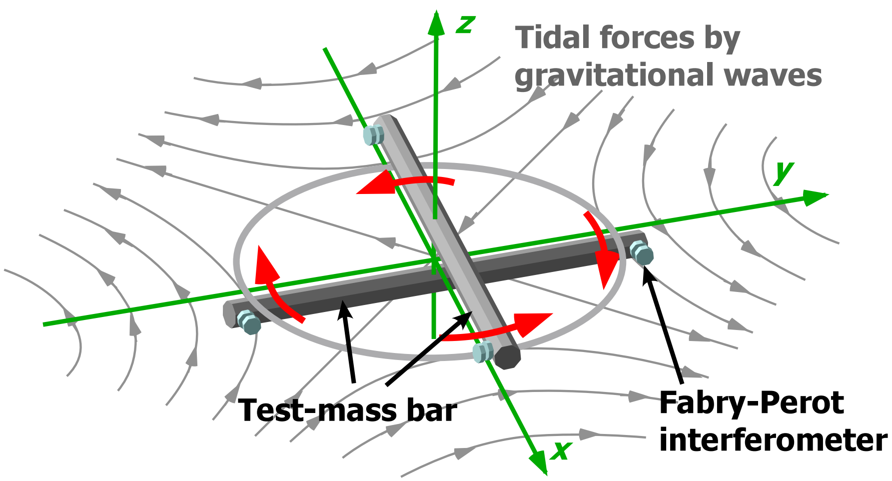
- Estimated to be dominant at f < 10 Hz
- Direct measurement
  - reduction strategies

S. Hild+ (2011)

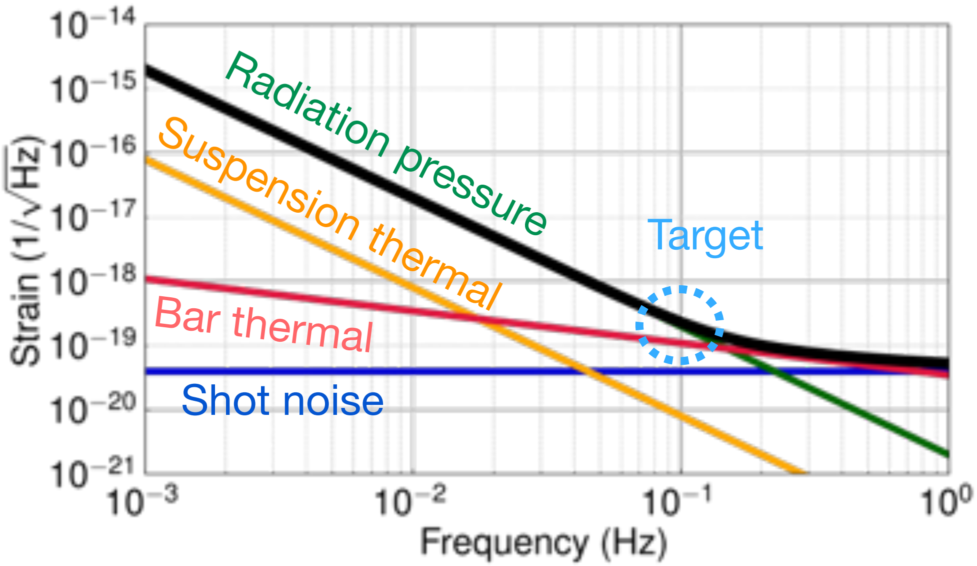
Torsion Bar Antenna (TOBA)

TOBA : TOrsion-Bar Antenna

- Gravity gradiometer using two suspended torsion pendulums
- Resonant frequency ~ mHz
- Target sensitivity h ~ 10^{-19} / $\sqrt{\text{Hz}}$ @ 0.1 Hz with 10 m bars



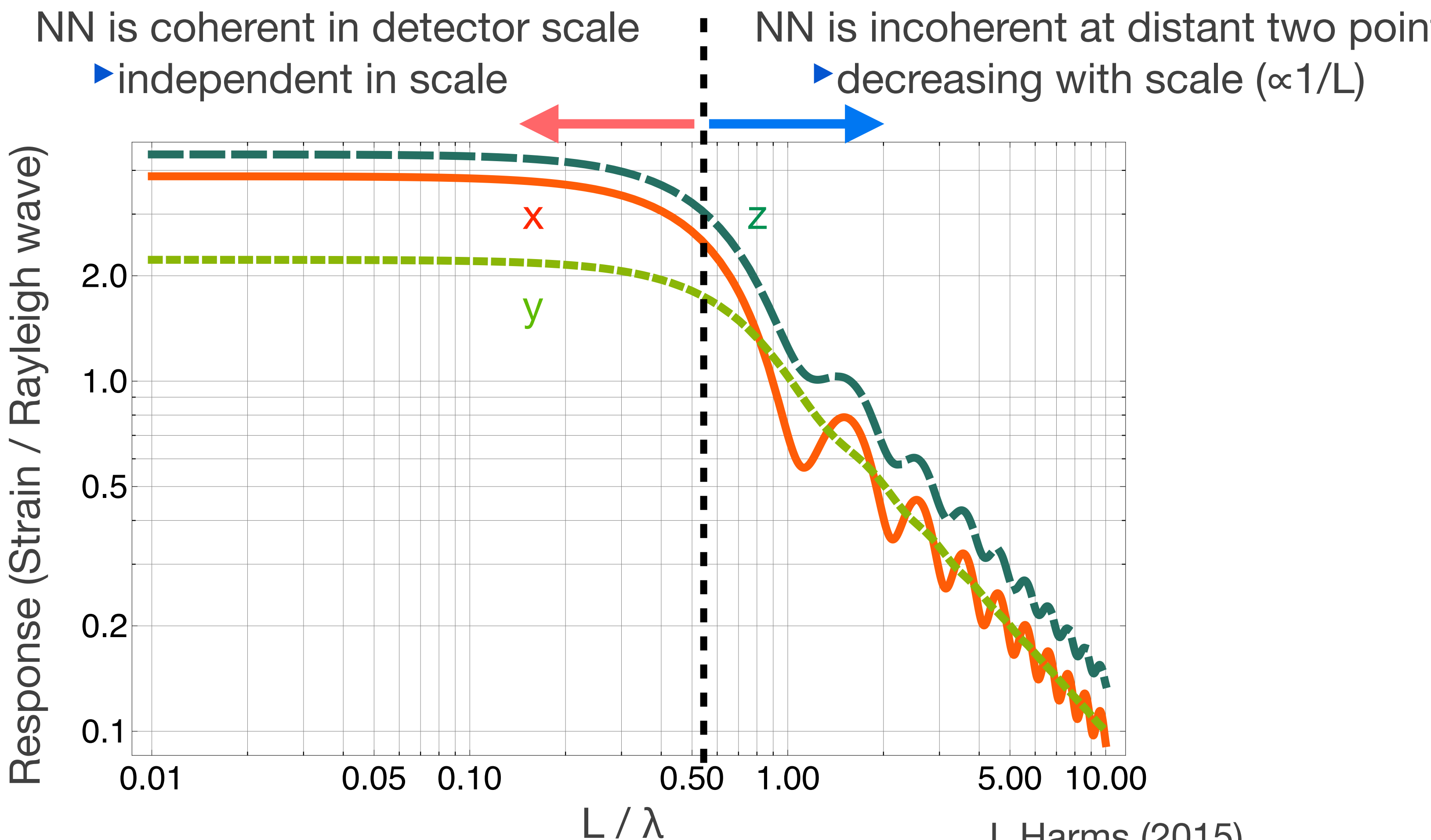
M. Ando+ (2010)



Design sensitivity of TOBA

Seismic NN in different scale

- Response from Rayleigh waves to NN (arm: x direction)

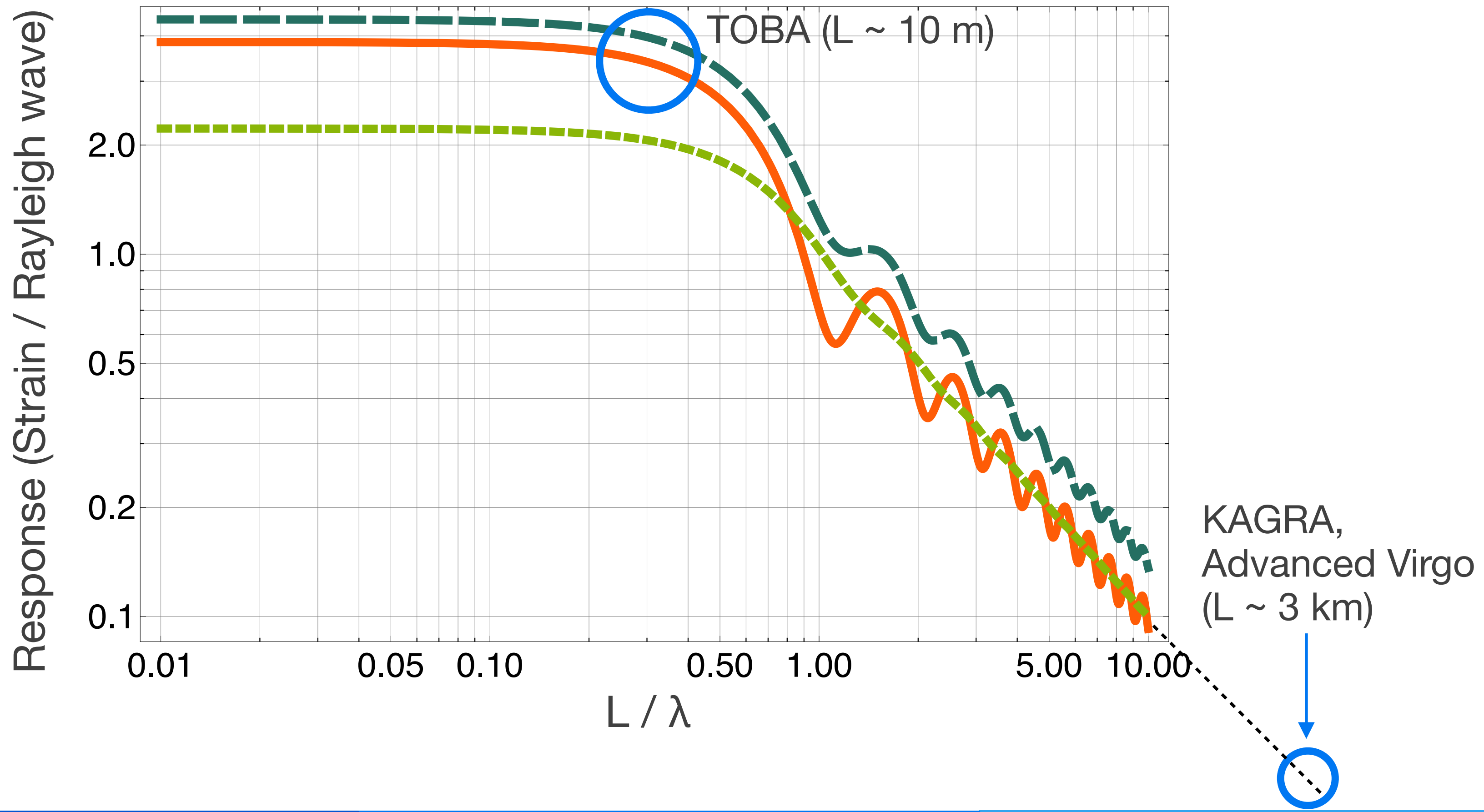


J. Harms (2015)

Seismic NN in different scale

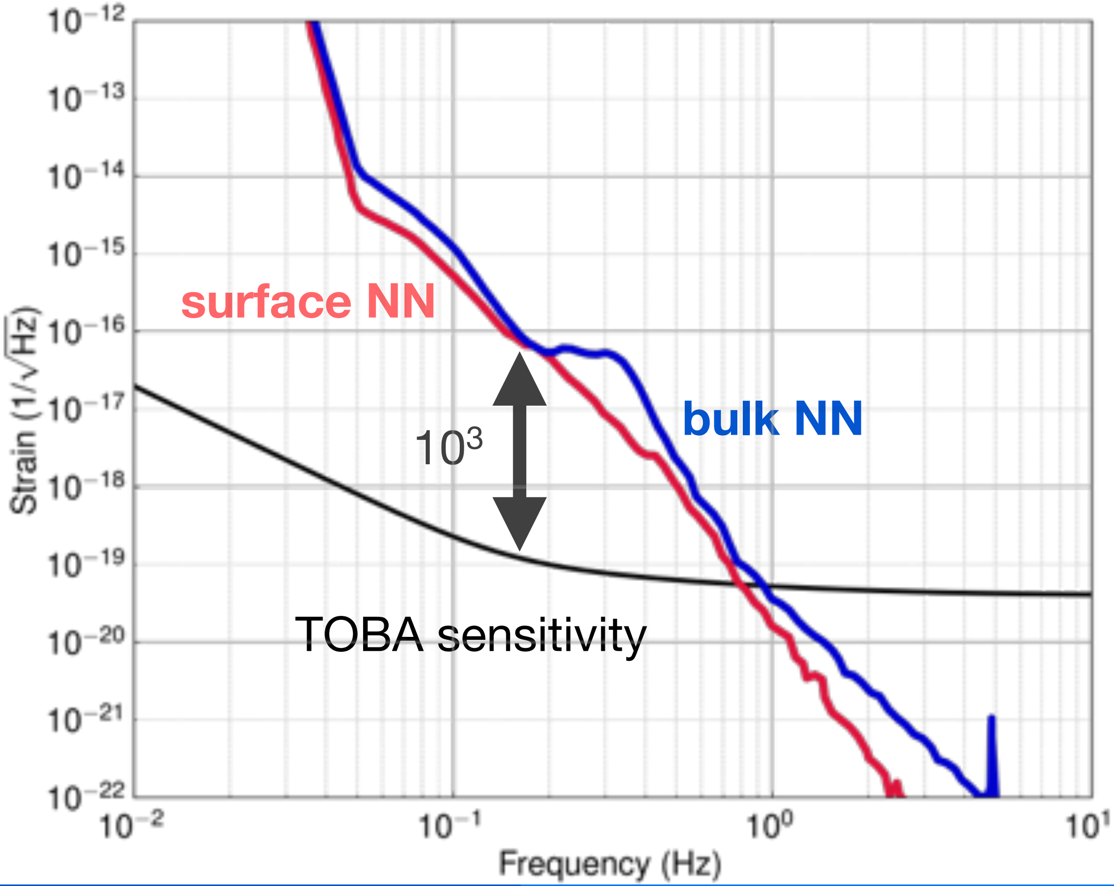
- Rayleigh wave length: λ ~ 30 m @ 10 Hz (v ~ 300 m/s)
- TOBA: L ~ 10 m ⟷ KAGRA, Advanced Virgo: L ~ 3km
  - **more sensitive**

  ET: L ~ 10 km



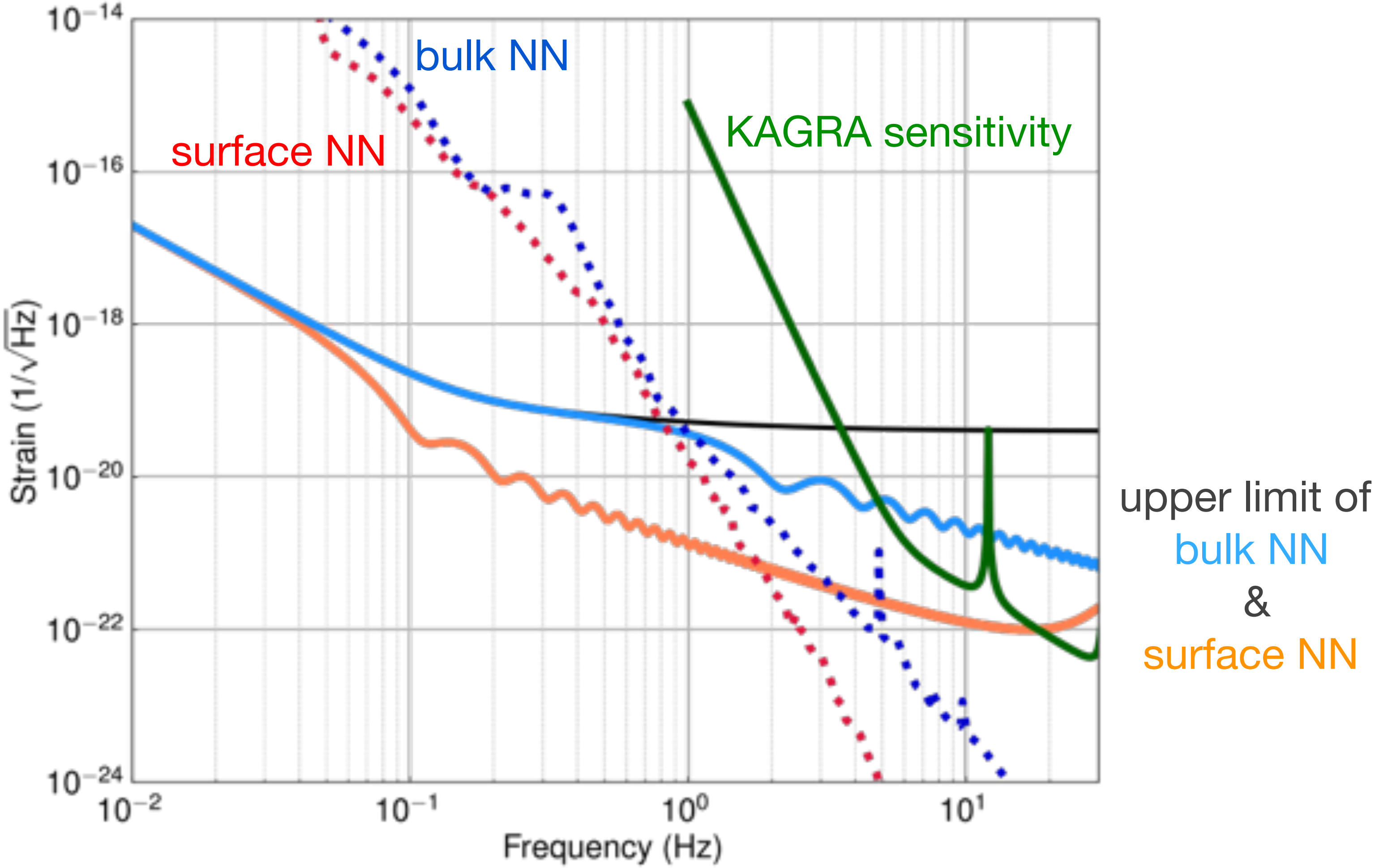
NN measurement by TOBA

- Direct measurement of NN (S/N ~ 10^3 at f < 0.1 Hz)
  - test of NN models
  - demonstration of NN mitigation



NN constraint in KAGRA

- Set upper limit 10^{-21} @ 10 Hz
- Can be used as physical environmental monitor



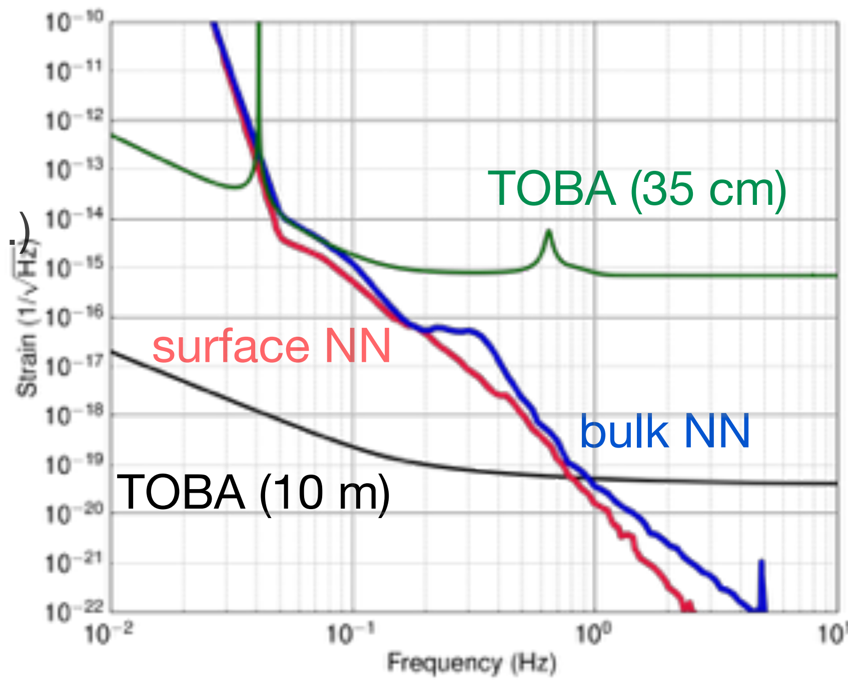
TOBA development plan

- Final plan: 10^{-19} / √Hz @ 0.1 Hz
  - 10 m masses
  - measurement of NN with high S/N
  - detection of GW at low frequency (f ~ 0.1 Hz)

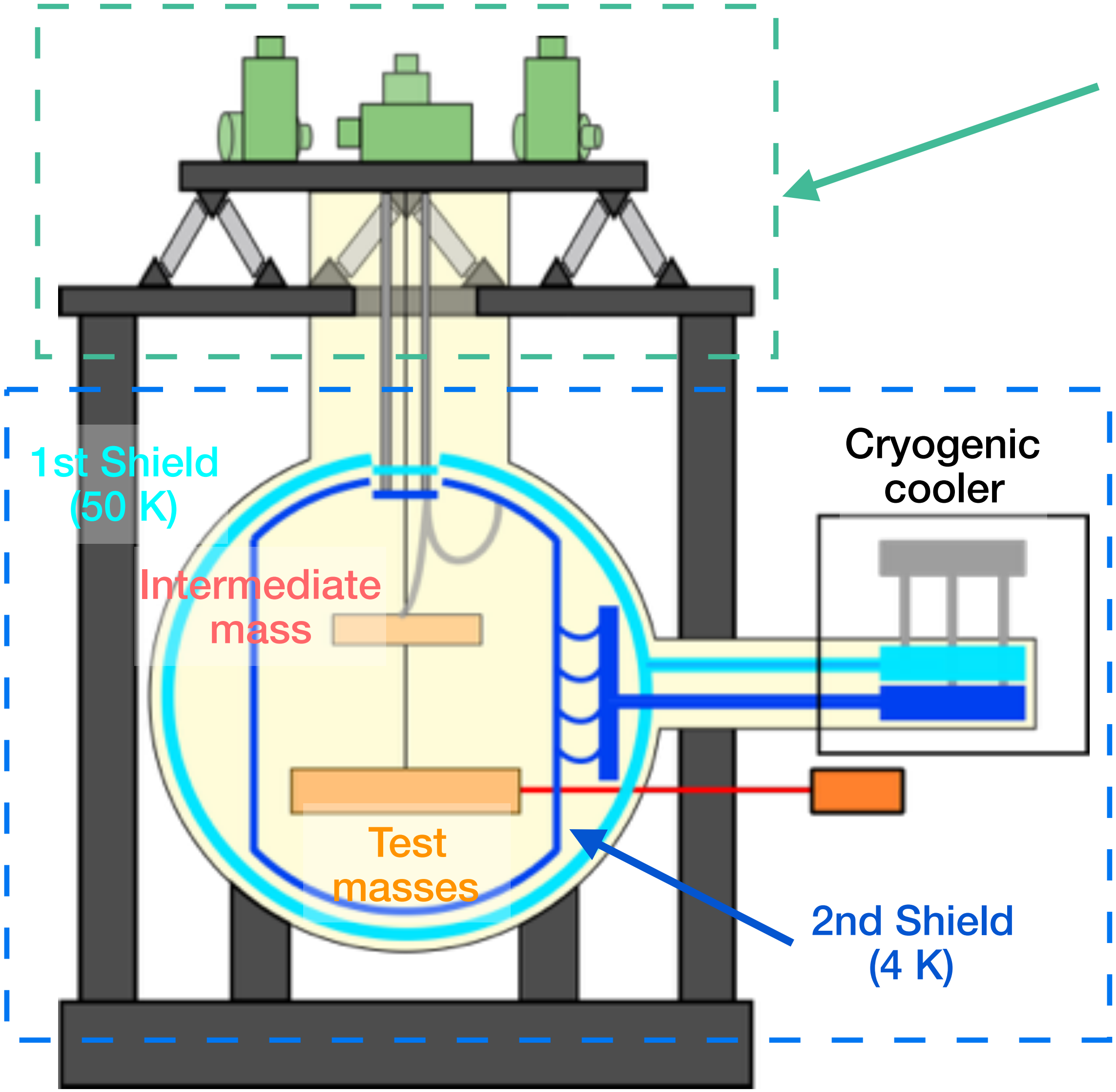
- Prototype: 10^{-15} / √Hz @ 0.1 Hz

ongoing

  - 35 cm masses
  - technical demonstration (cryogenic, active vibration isolation, …)
  - may be able to measure NN



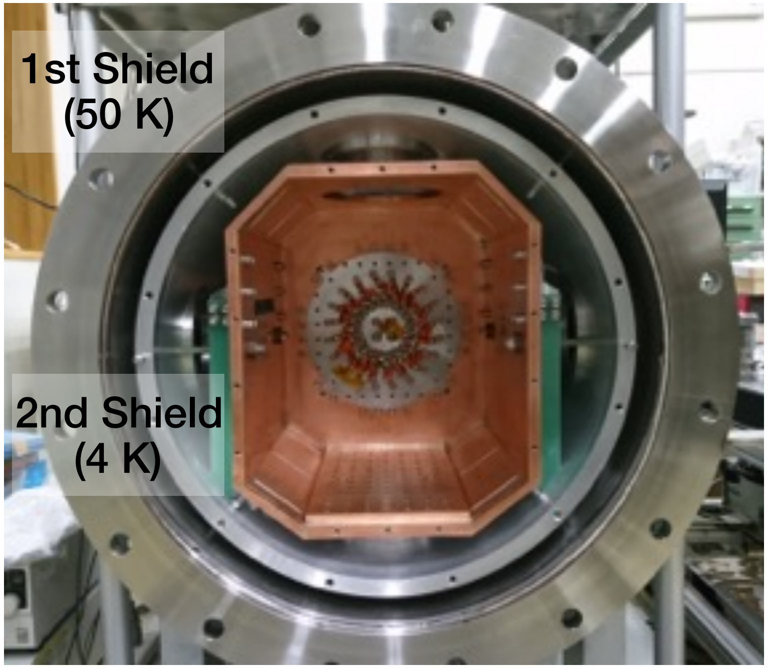
Schematic of 35 cm Prototype

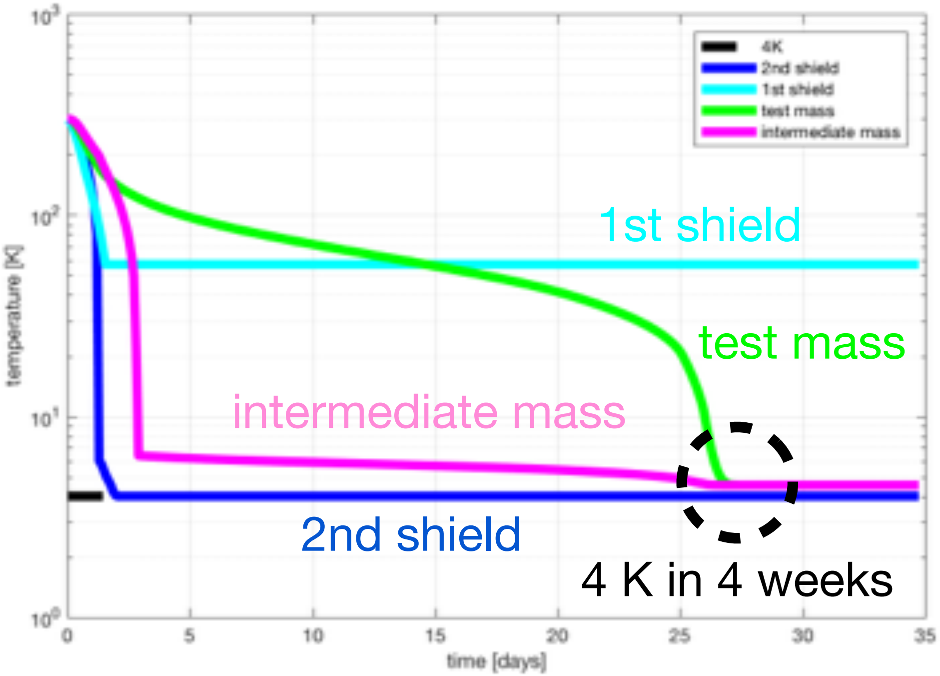


- Active vibration isolation
  - isolation ratio ~ 10^2 @ 0.1 - 1 Hz
  - reducing vibration caused by the cooler via heatlinks
- Cryogenic
  - cooled down to 4 K
  - Silicon wire with High Q ($Q \sim 10^8$)

Cryogenic

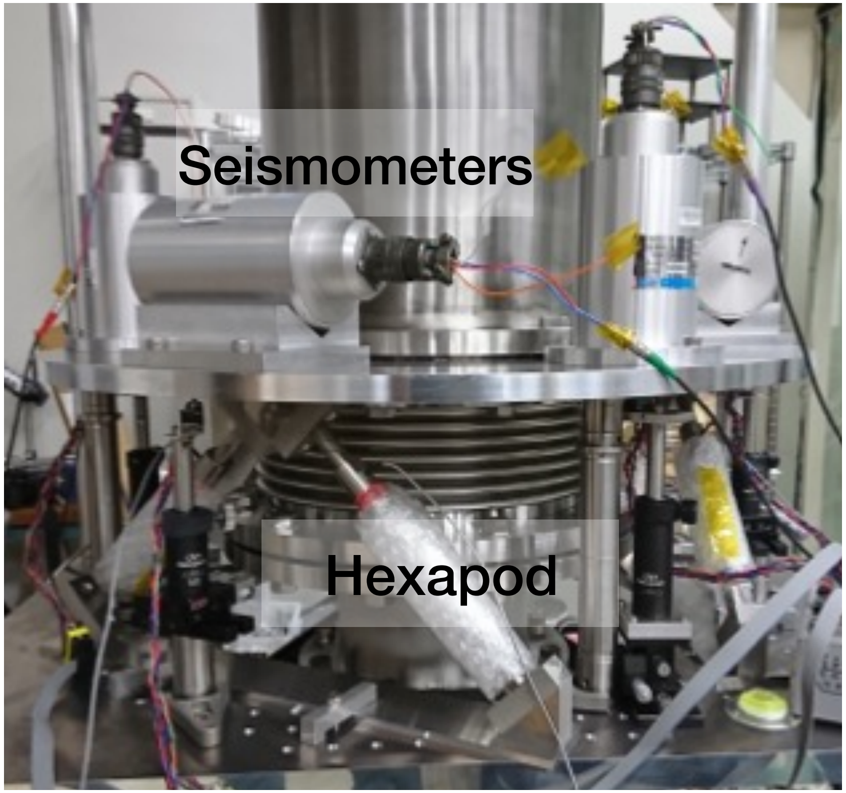
- Test masses are cooled to 4 K in 4 weeks
- Shields are installed
- Silicon wire is under considering
- Cooling test will be done (using CuBe wires)

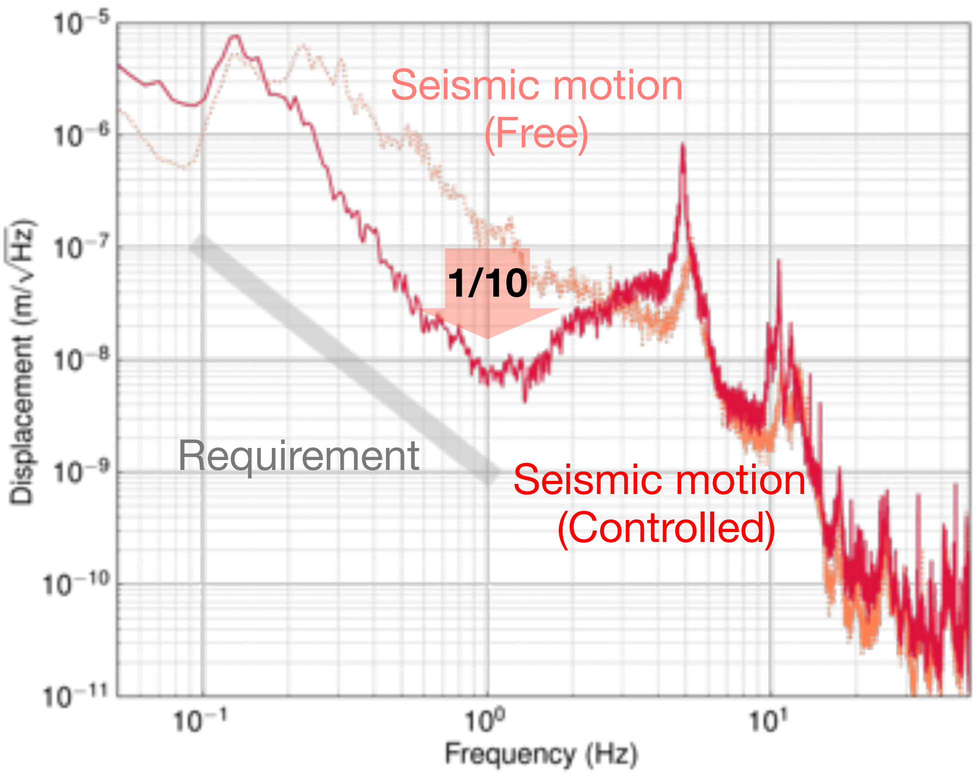




Active Vibration Isolation

- Seismometers + Hexapod actuator (PZTs)
- Isolation ratio ~ 10^2 @ 0.1 - 1 Hz
- Currently achieved 10 @ 1 Hz





Summary

- TOBA can measure NN with high S/N
  - S/N ~ 10^3 in f < 0.1 Hz
  - put upper limit 10^{-21} @ 10 Hz on NN of KAGRA
- Currently a small prototype is developing
  - 35 cm scale
  - May be able to measure NN
- Future works
  - How to identify NN from measurement
  - How to cancel NN