Newtonian Noise
Measurement by Torsion Bar Antenna

Satoru Takano, Tomohumi Shimoda, Ching Pin Ooi, Yuta Miyazaki, Yuta Michimura, Masaki Ando
The Univ. of Tokyo
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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 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

[Image: http://physics.tutorcircle.com/waves/p-wave.html]
NN in KAGRA

Estimated to be enough small

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

surface NN & bulk NN

Total

Quantum

Seismic

Suspension thermal

Mirror thermal
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NN in ET

- Estimated to be dominant at $f < 10 \text{ Hz}$
- Direct measurement
  - reduction strategies

S. Hild+ (2011)
TOBA : TOrsion-Bar Antenna

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

Design sensitivity of TOBA

M. Ando+ (2010)
Seismic NN in different scale

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

NN is coherent in detector scale
- independent in scale

NN is incoherent at distant two point
- decreasing with scale ($\propto 1/L$)

Response (Strain / Rayleigh wave)

0.01 0.05 0.10 0.50 1.00 5.00 10.00
L / $\lambda$
0.1 0.2 0.5 1.0 2.0
Response (Strain / Rayleigh wave)

J. Harms (2015)
Seismic NN in different scale

- Rayleigh wave length: $\lambda \sim 30 \text{ m} @ 10 \text{ Hz}$ ($v \sim 300 \text{ m/s}$)
- TOBA: $L \sim 10 \text{ m}$  
  KAGRA, Advanced Virgo: $L \sim 3 \text{ km}$  
  ▶ more sensitive  
- ET: $L \sim 10 \text{ km}$

![Graph showing response functions for different scales and detectors.](image-url)
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

![Graph showing strain vs frequency with markers for bulk NN, surface NN, and KAGRA sensitivity. The upper limit of bulk NN and surface NN are indicated.](image-url)
TOBA development plan

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

- Prototype: $10^{-15} / \sqrt{\text{Hz}} @ 0.1 \text{ Hz}$
  - 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 $\sim 10^2$
  - @ 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 $\sim 10^2$ @ 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