

Long-baseline Atom Interferometer Ambient Environmental Site Requirements

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Terrestrial Very-Long-Baseline atom Interferometry
Workshop

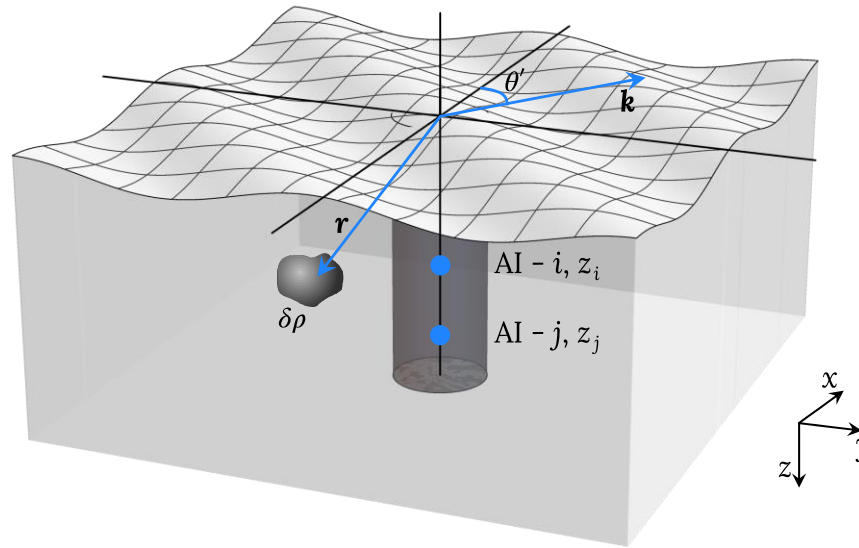


Outline

- Impact of ambient noise
- Seismic
- Atmospheric
- Site selection

Ambient effects and phase shift

- Consider effects which affect the propagation phase i.e. the wavefunction trajectories (Newtonian Noise, to be discussed later)
- Time-dependent gravitational potential fluctuations sourced by density fluctuations



Local vibrations

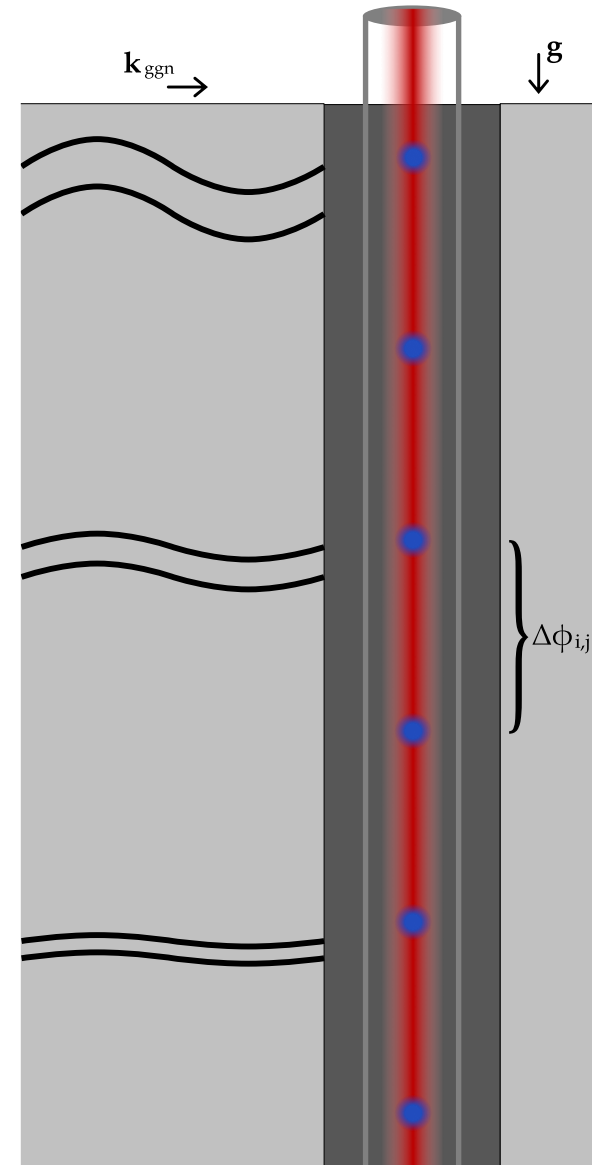
- Motion of floors and walls for mounting
- Connection couples into shot-shot variations of phase shift
 - Steering optics and mirrors for interaction lasers, optics and systems associated with the cold atom cloud production
- Mitigated through damping, isolation, or decoupling
- Actively tracked through auxiliary instrumentation

$$\delta\phi_{\text{vibration}} \sim \left(10^{-8} \text{ rad}/\sqrt{\text{Hz}}\right) \left(\frac{n}{100}\right) \left(\frac{\Delta v}{100 \text{ } \mu\text{m s}^{-1}}\right) \left(\frac{T}{1 \text{ s}}\right) \left(\frac{\delta a}{10^{-4} \text{ m s}^{-2}/\sqrt{\text{Hz}}}\right)$$

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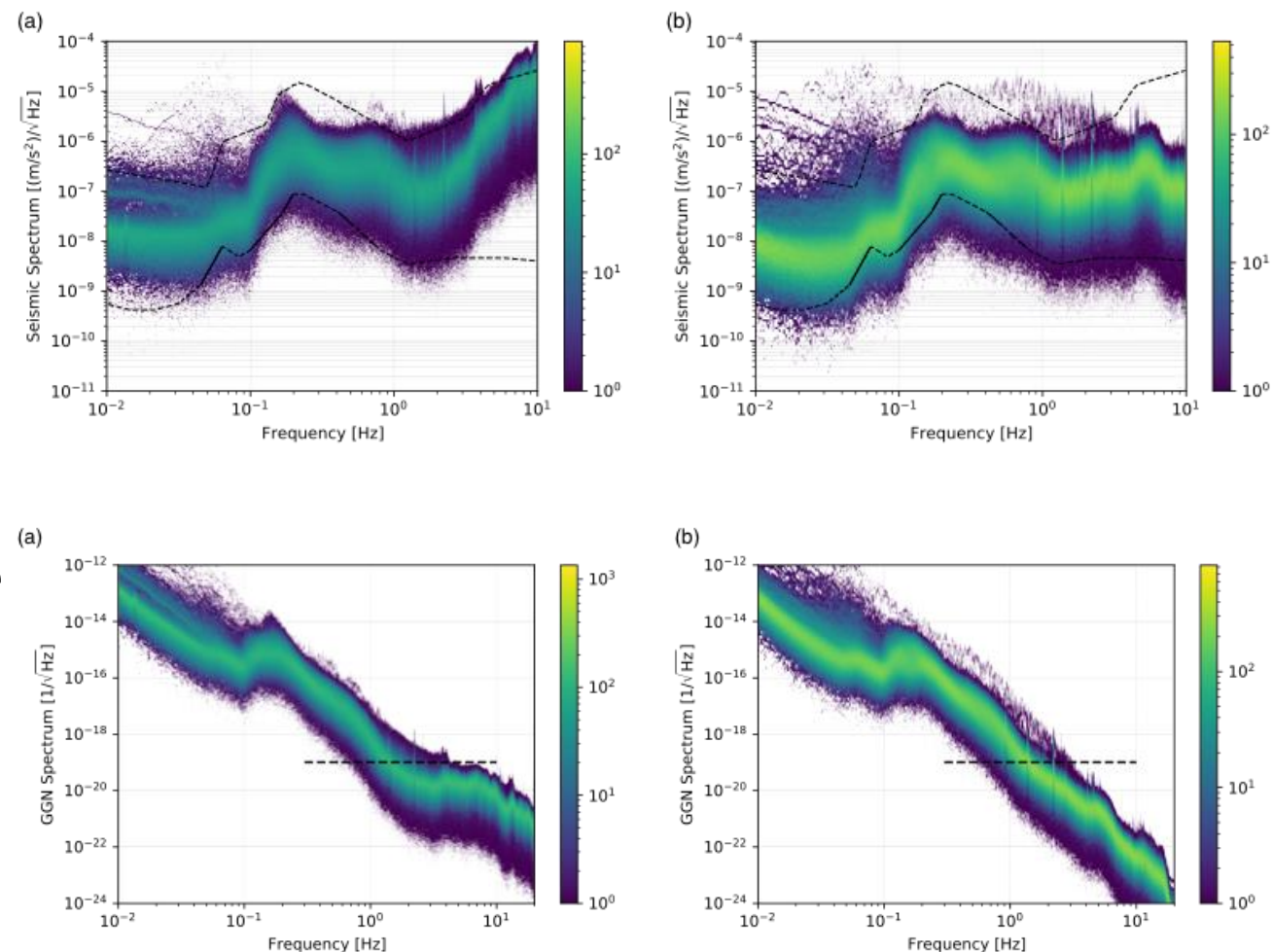
Seismic waves

- P-waves
 - Longitudinal body waves
- S-waves
 - Transverse body waves
- Rayleigh waves
 - Surface waves in counter-elliptical motion
- Love waves
 - Horizontal surface waves



Seismic gravity gradient noise (GGN)

- Coupling of test masses to gravitational potential perturbations
- Present for test masses in vacuum and free-fall
- Rayleigh waves dominant source close to surface
- Cannot screen gravity
 - Use density perturbation characteristics



Atmospheric gravity gradient noise

- Any time-dependent density perturbation = GGN
- Weather systems
- Scale of these fluctuations and duration push into target frequency band (0.1 Hz, 10 Hz)
- Worked out effects in terms of large-scale horizontal laser interferometers 2008 *Class. Quantum Grav.* **25** 125011
- Active investigation for atom interferometry

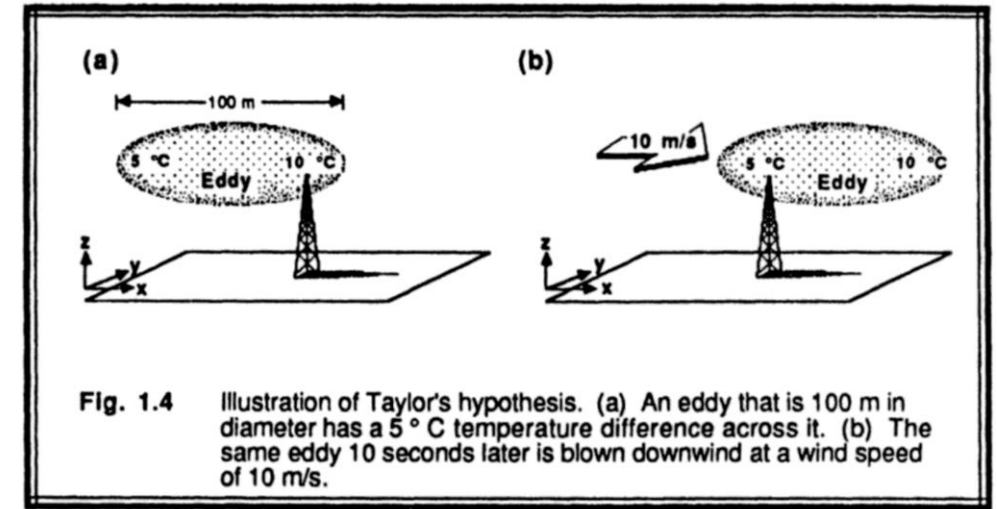
Infrasound (pressure wave) sourced

- Infrasound in atmospheric boundary layer travels like waveguide
- Reflection and absorption off ocean waves leads to Rayleigh surface waves
- Reflection off land mass leads to standing fluctuations

$$\delta h \propto 1/f^6$$

Advected temperature gradients

- Taylor's hypothesis of turbulence: eddies correspond to spatial gradients with an advection velocity
- Characterized by temperature fluctuation spectrum
- Not of much concern in higher frequency detection ranges
- Leading atmospheric GGN for low frequencies



Stull, R. B. (1988). Springer Science & Business Media.

$$\delta h = (10^{-13} \text{ Hz}^{-1/2}, 10^{-20} \text{ Hz}^{-1/2})$$

For

$$f = (0.1 \text{ Hz}, 3 \text{ Hz})$$

What does this mean for site selection?

- Atmospheric effects → Go underground, monitor weather precisely, Large structures around detectors to increase distance between test mass and density fluctuation
- Seismic effects → Find quiet site, stable seasonal variations, understand and quantify the power spectral densities, auxiliary instrumentation for monitoring

Summary

- Ambient environmental noise in atom interferometers is highly site specific
- One can attempt to find either quiet site i.e. low amplitude noise, or highly stable site where noise power can be well predicted
- Mitigations include going underground, building large structures for shielding, active monitoring and feedback
 - In-situ
 - Auxiliary weather and seismic sensor arrays
- Very active area of research with upcoming workshop between Earth sciences and Atom interferometry

Thanks

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Backups

