

Atom interferometry in busy environments

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The AION-10 Experiment



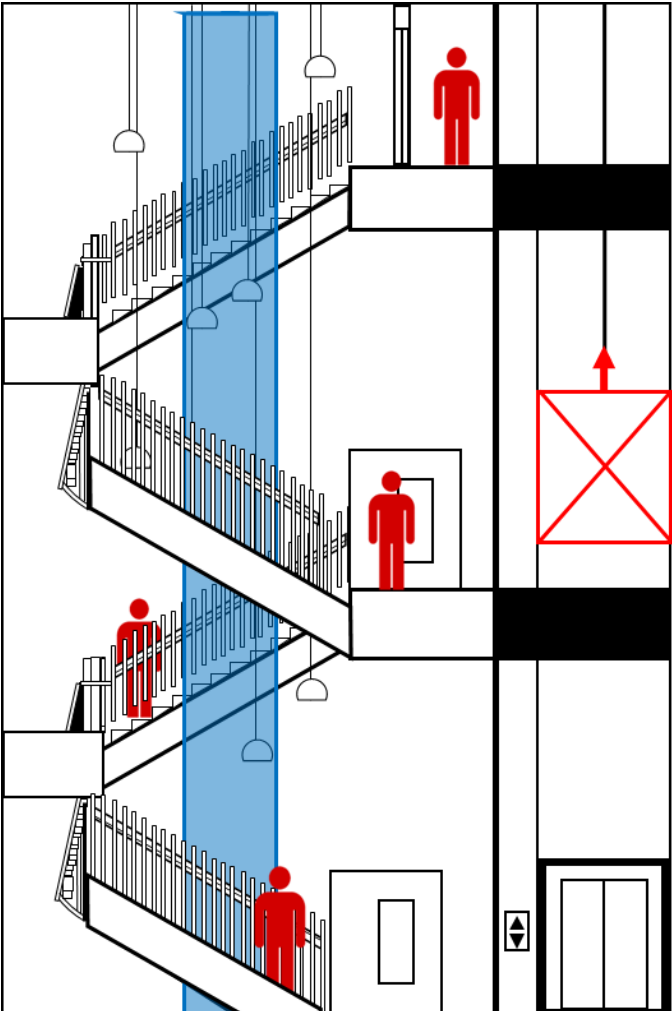
University of Oxford, Beecroft Building

The AION-10 Experiment



University of Oxford, Beecroft Building

Motivation



Moving
“test masses”

Could they hide a potential
DM/GW signal?

Passenger Lift (Elevator)

AION-10 Pulse Sequence

Sequence Assumptions:

LMT Pulses = 100

Atoms launched from 0m and 5m

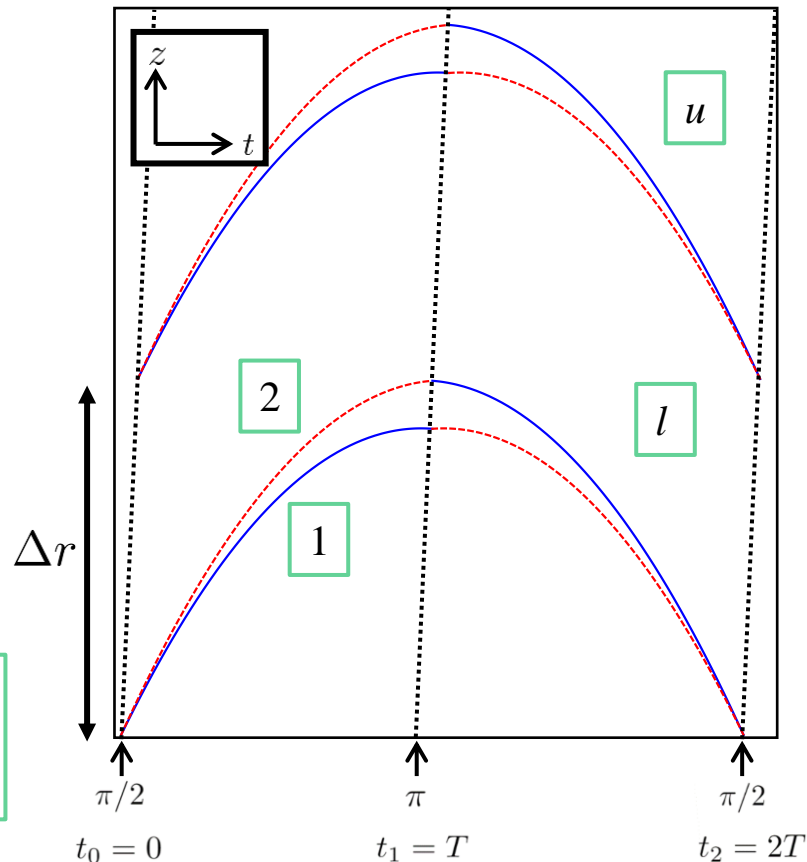
T = 0.98s

Launch Velocity = 9.25m/s

Measurements taken every 2T

$$V_{\text{Lift}}^{(u,l)}(z_{\text{Sr}}^{(u,l)}, h_{\text{Lift}}, t) = -\frac{GM_{\text{Lift}}m_{\text{Sr}}}{\sqrt{D^2 + \left(z_{\text{Sr}}^{(u,l)}(t) - h_{\text{Lift}}(t)\right)^2}}$$

$$\Delta\phi_{\text{Lift}} = \frac{1}{\hbar} \int_0^{2T} \left[V_{\text{Lift}}^{(u)}(z_{\text{Sr}}^{(u)}, h_{\text{Lift}}, t) - V_{\text{Lift}}^{(l)}(z_{\text{Sr}}^{(l)}, h_{\text{Lift}}, t) \right] dt$$



Elevator

Sequence Assumptions:

LMT Pulses = 100

Atoms launched from 0m and 5m

$T = 0.98s$

Launch Velocity = 9.25m/s

Measurements taken every $2T$

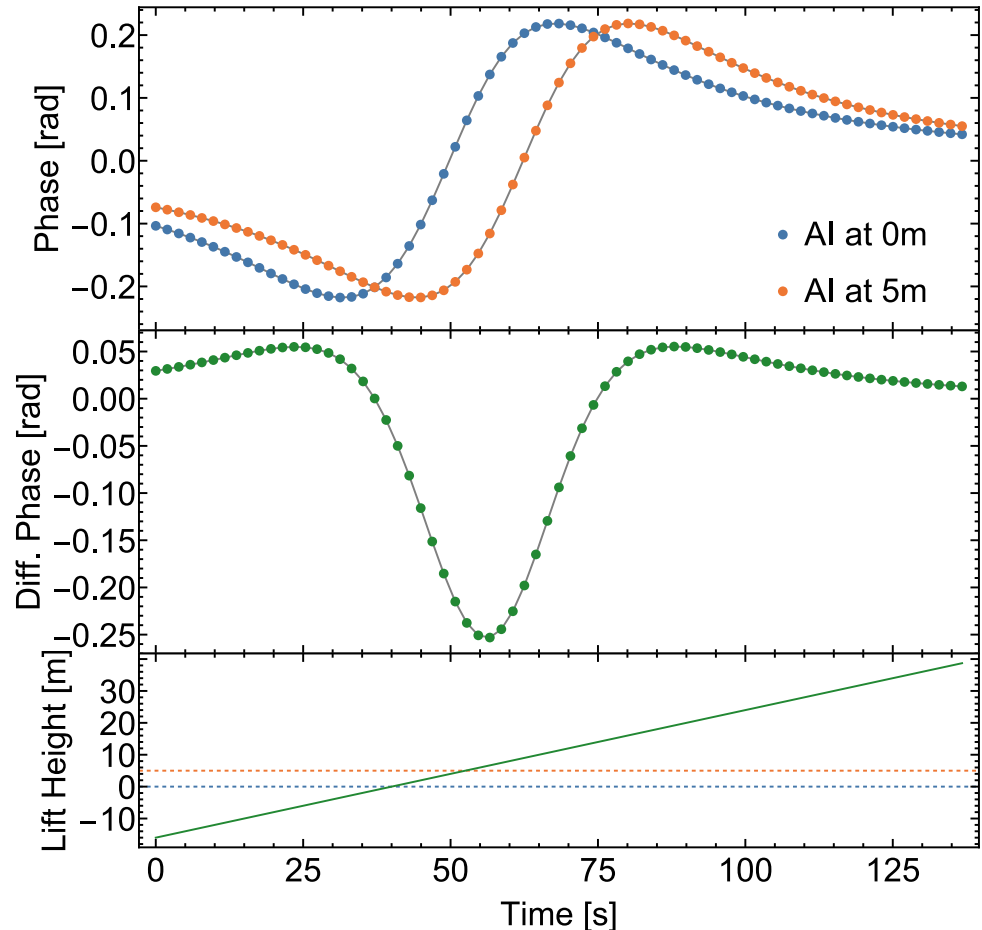
Lift Assumptions:

Travels from -16m to 35m relative to base of AION-10 tower

Speed = 0.4m/s

Horizontal distance = 10m

Mass = 1000kg



Mitigation

Speed?

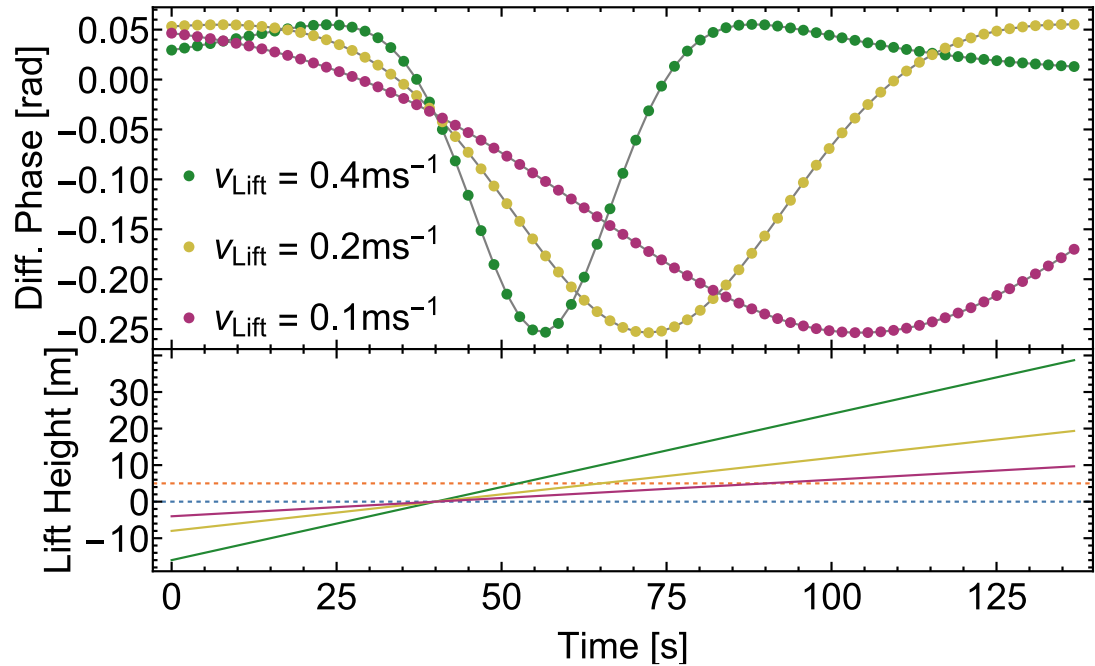
- doesn't help!

Lift Assumptions:

Three lifts travel at different speeds with the same mass and horizontal distance

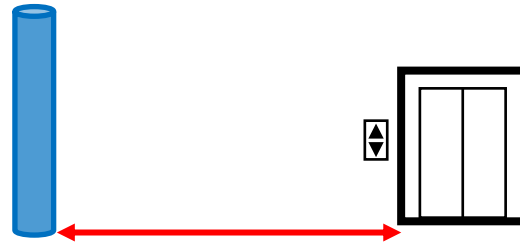
The phase shift maximum is the same for each lift.

A slower lift spreads out the phase curve.



Distance?

- helps but can't be moved!

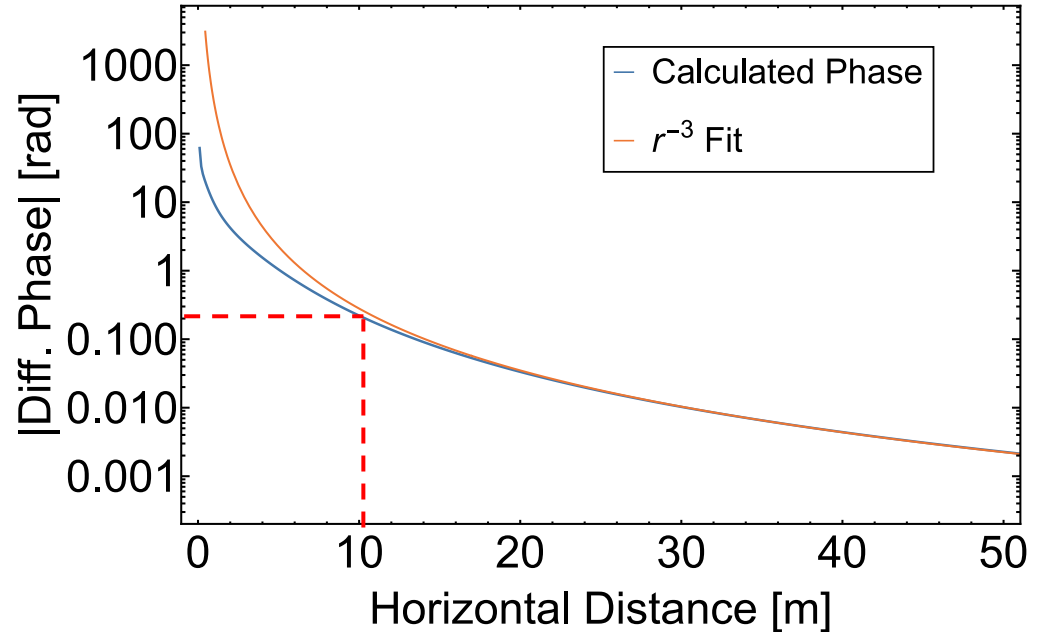


Lift Assumptions:

Mass and height fixed as horizontal distance increased (1000kg at $h = 5\text{m}$)

Greater distance reduces the maximum phase shift.

Follows inverse cube law – except within 10m.



Mitigation?

Slower lifts still induce a large phase shift

But farther lifts reduce phase greatly

Phase scales linearly with lift mass

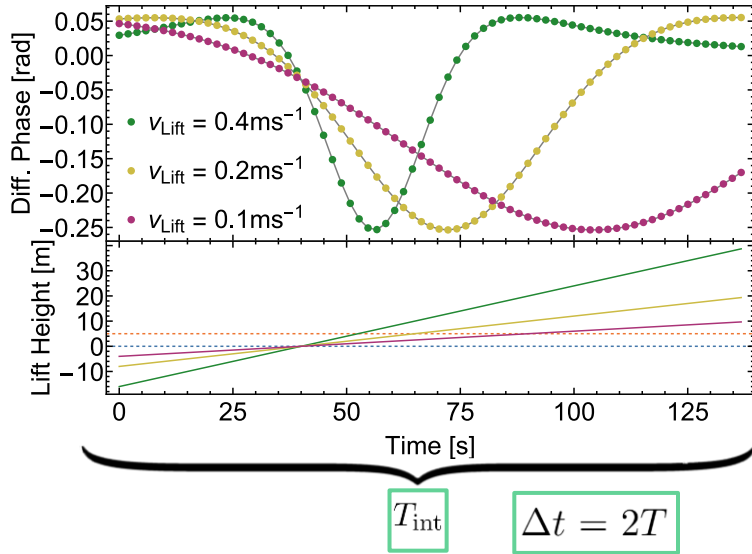
Frequency analysis

Frequency domain

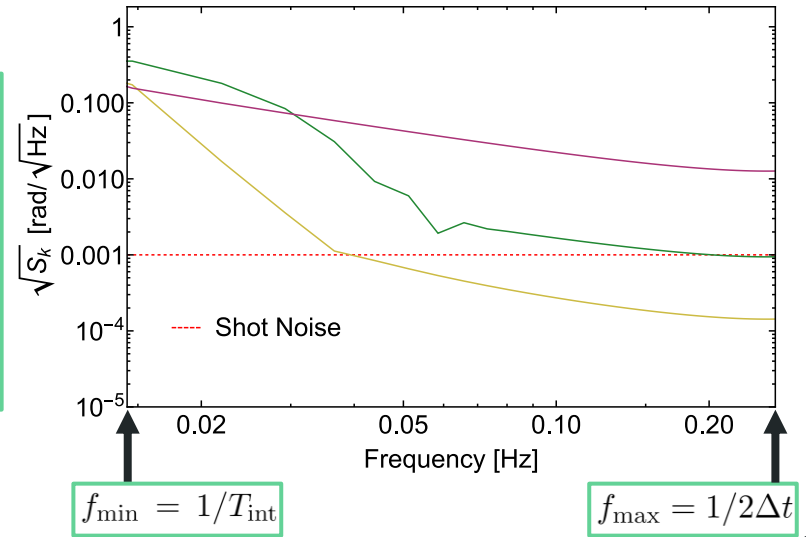
Estimator of Power Spectral Density (PSD)
from Discrete Fourier Transform (DFT)

Time-dependent effects
may not look so bad in the
frequency domain!

$$S_k = \frac{(\Delta t)^2}{T_{\text{int}}} |\Delta \tilde{\phi}_k|^2 = \frac{(\Delta t)^2}{T_{\text{int}}} \left| \sum_{m=0}^{N-1} \Delta \phi_m \exp \left[-\frac{2\pi i m k}{N} \right] \right|^2$$



Stationary
objects enter
0th bin of PSD
→
But moving
objects are a
problem



Modelling lift activity

Lift Assumptions:

Acceleration = 0.3m/s/s

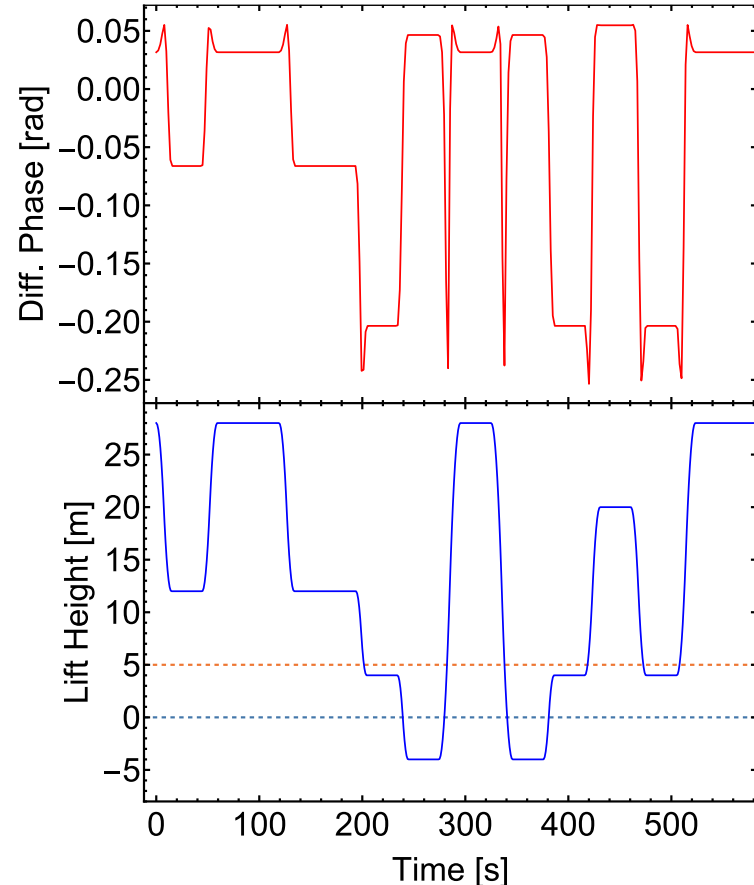
Max speed = 2.5m/s

Horizontal distance = 10m

Mass = 1000kg

Integration time \approx 10 minutes

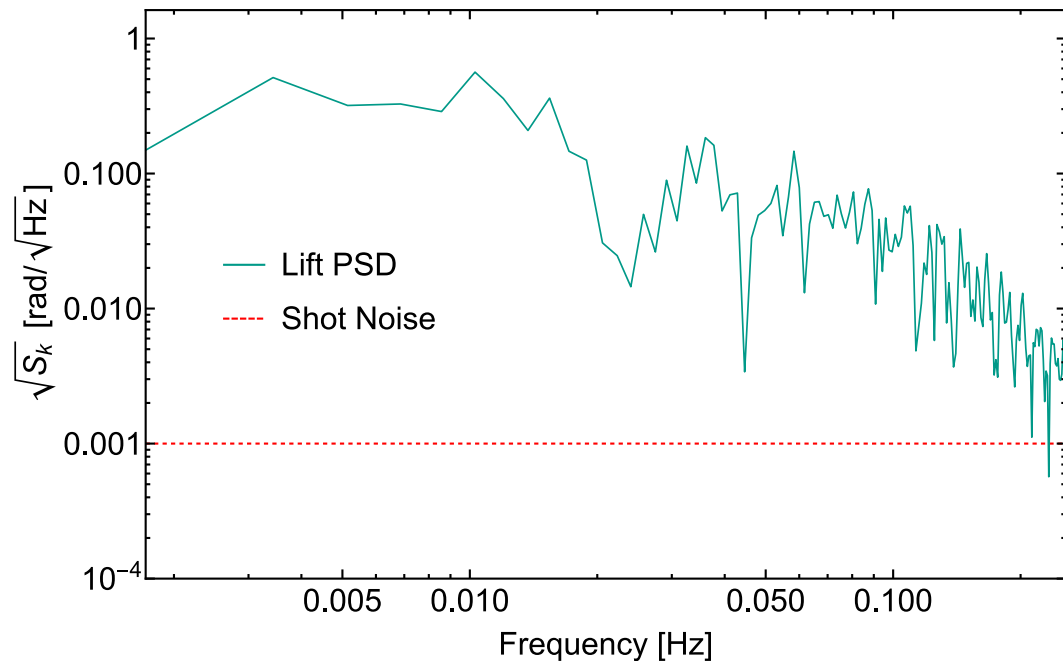
Lift accelerates between floors at set heights above and below the AION tower stopping at each for 30 seconds.



Lift PSD

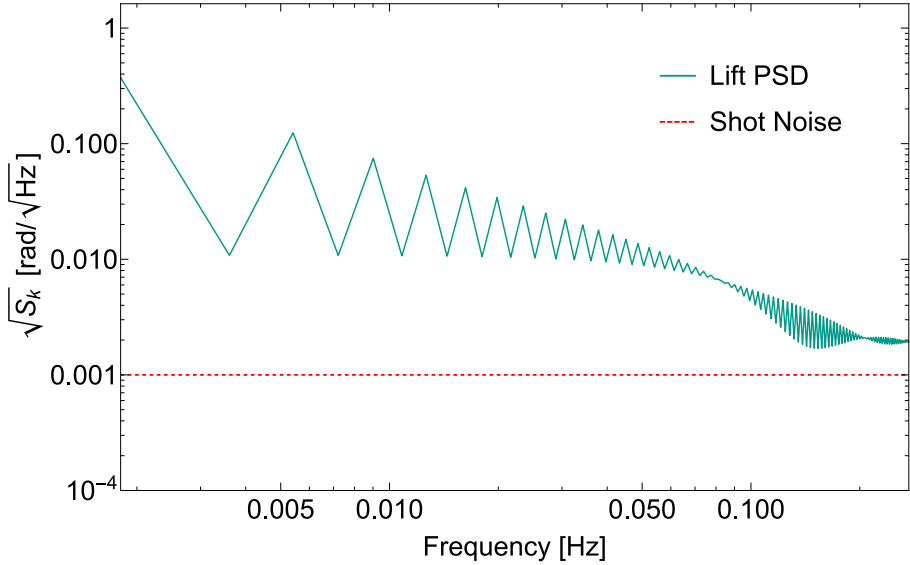
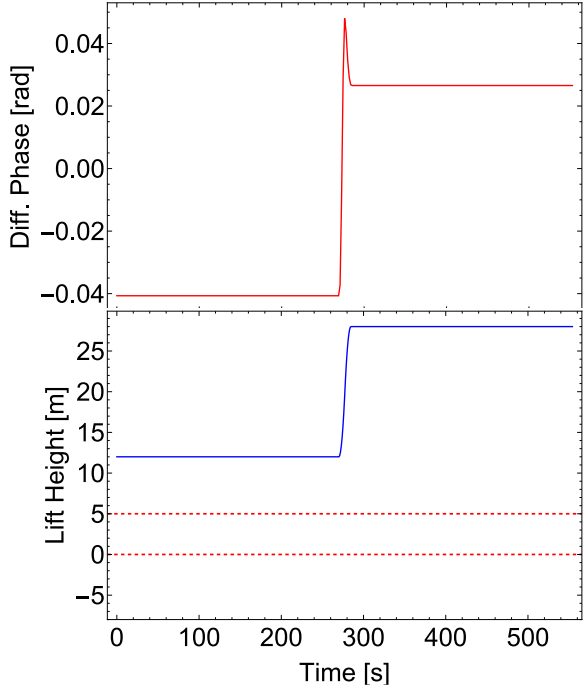
*Lift phase larger than atom
shot noise!*

Still a problem...



Loud and quiet periods

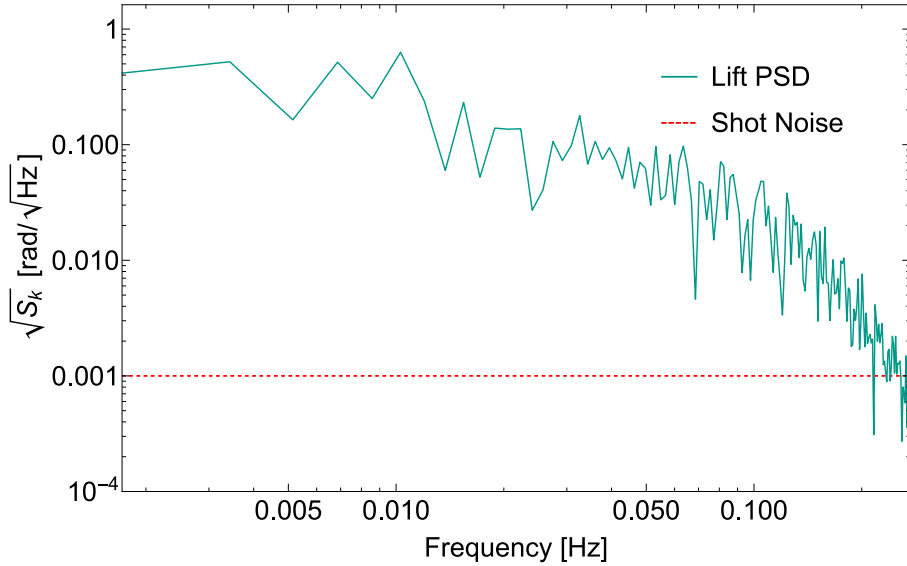
Compare PSD to a “quiet” period with the same integration time.



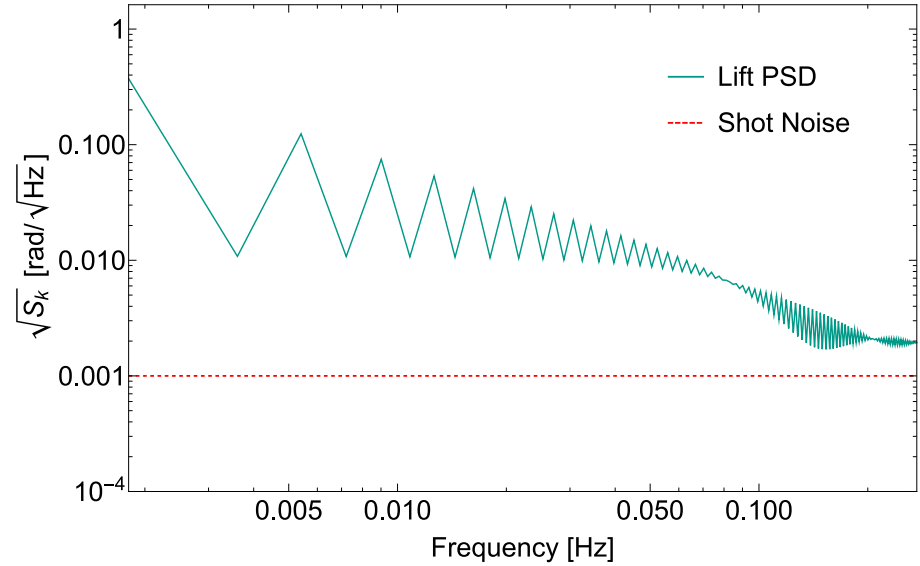
Quiet PSD

Loud and quiet periods

Compare PSD to a “quiet” period with the same integration time

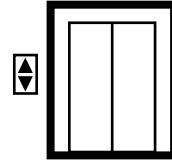


Loud PSD



Quiet PSD

Lift Summary



Lifts appear to be a problem even in quieter periods
– but the PSD is flatter.

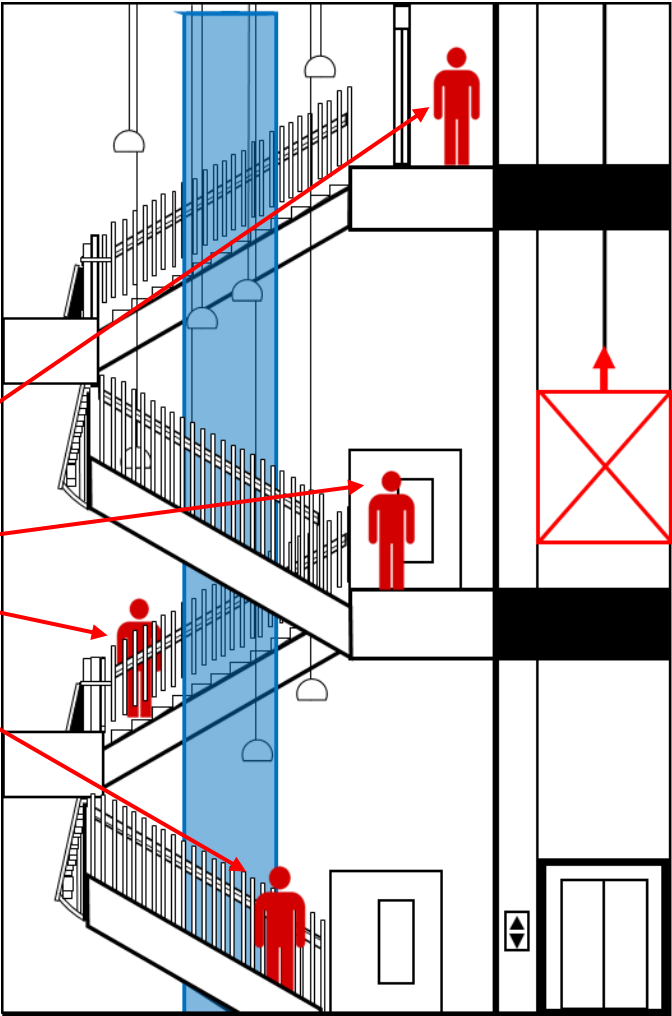
Lifts are predictable and could be filtered in real time
using cameras/accelerometers to monitor movement.

Or the experiment stops taking measurements when
the lift is in use.

Climbing the stairs

Motivation

Many moving
“test masses”



Could they be a bigger problem than the lift?

Climbing the stairs

People Assumptions:

No. people = 10

Masses distributed around 70kg

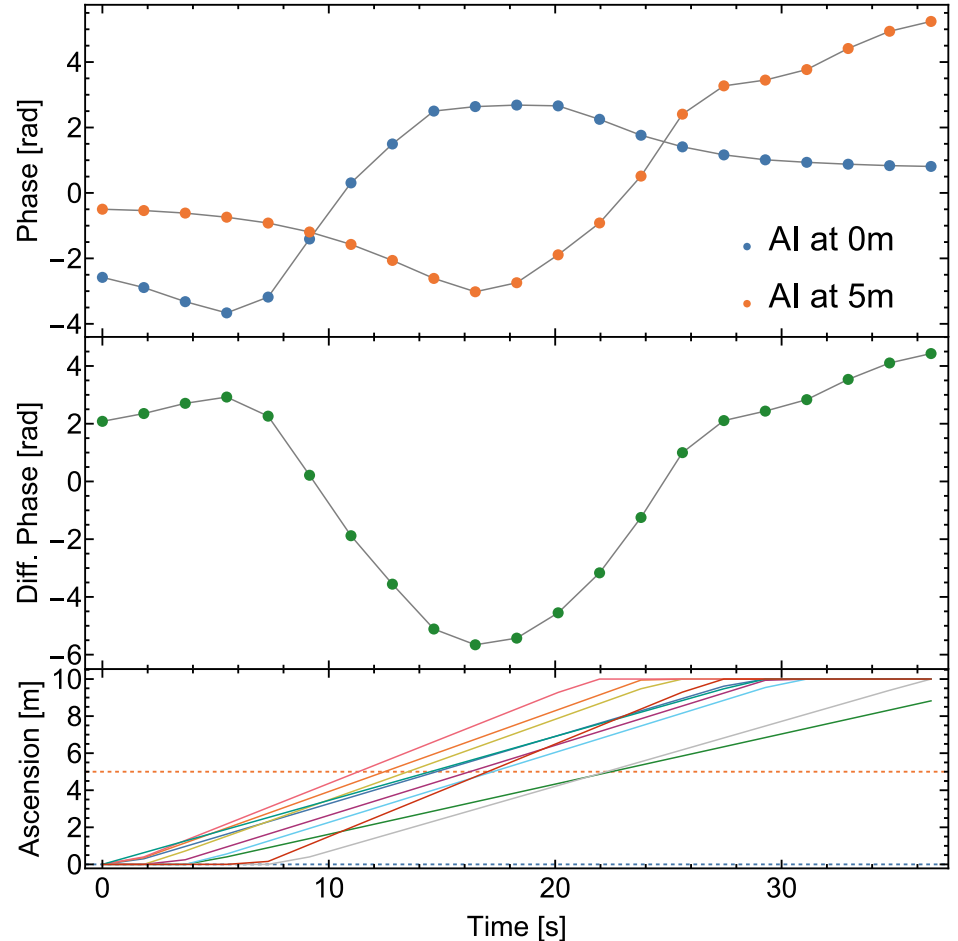
Speeds distributed around 0.4m/s

Horizontal distance = $(1.5 \pm 0.5)m$

Random delay (<10s) before ascent

*Model 10 people climbing the stairs
from the base to the top of AION-10.*

Phase is larger than lift!

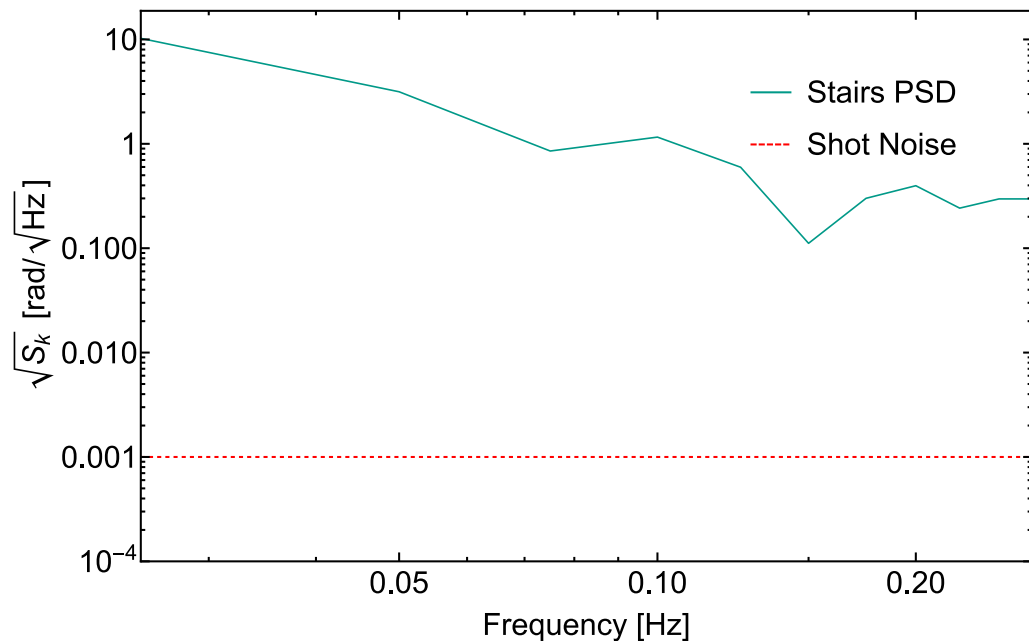


Climbing the stairs - PSD

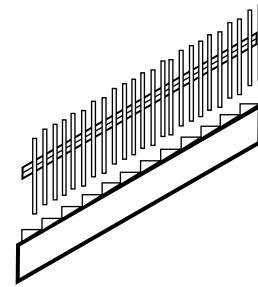
PSD is larger than lift!

Additional people add noise linearly (Each person approx. same as lift).

PSD is flatter due to more constant velocity.



Stairs Summary



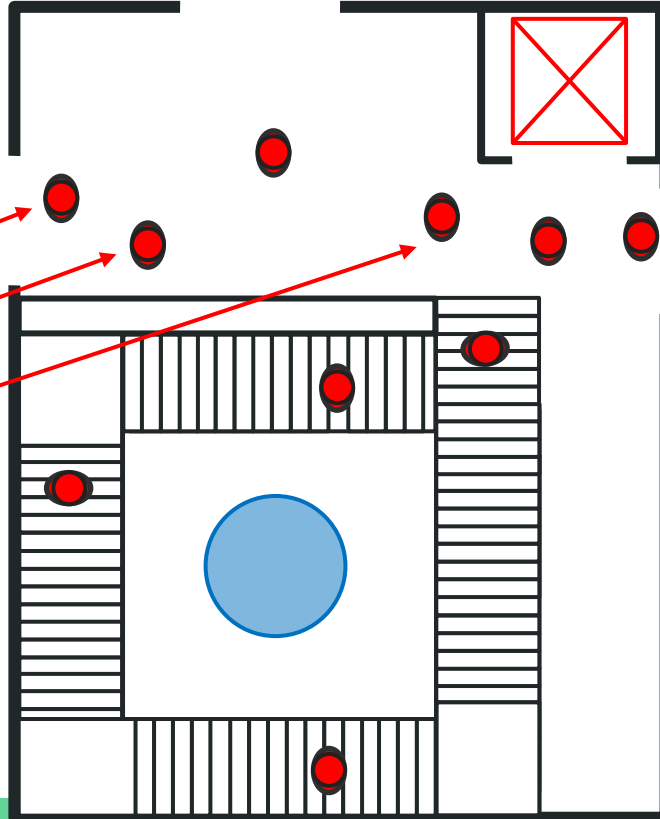
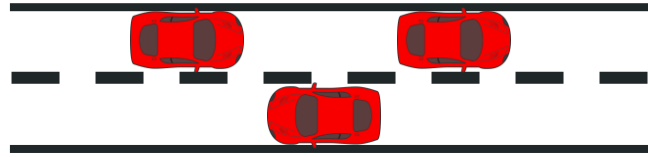
People closer to the tower induce a much larger phase.

Hard to account for the random movements of multiple people.

No people on the stairs when the experiment is running.

The foyer

Motivation



Could people crossing the foyer be a problem?

The foyer

Person Assumptions:

No. people = 1

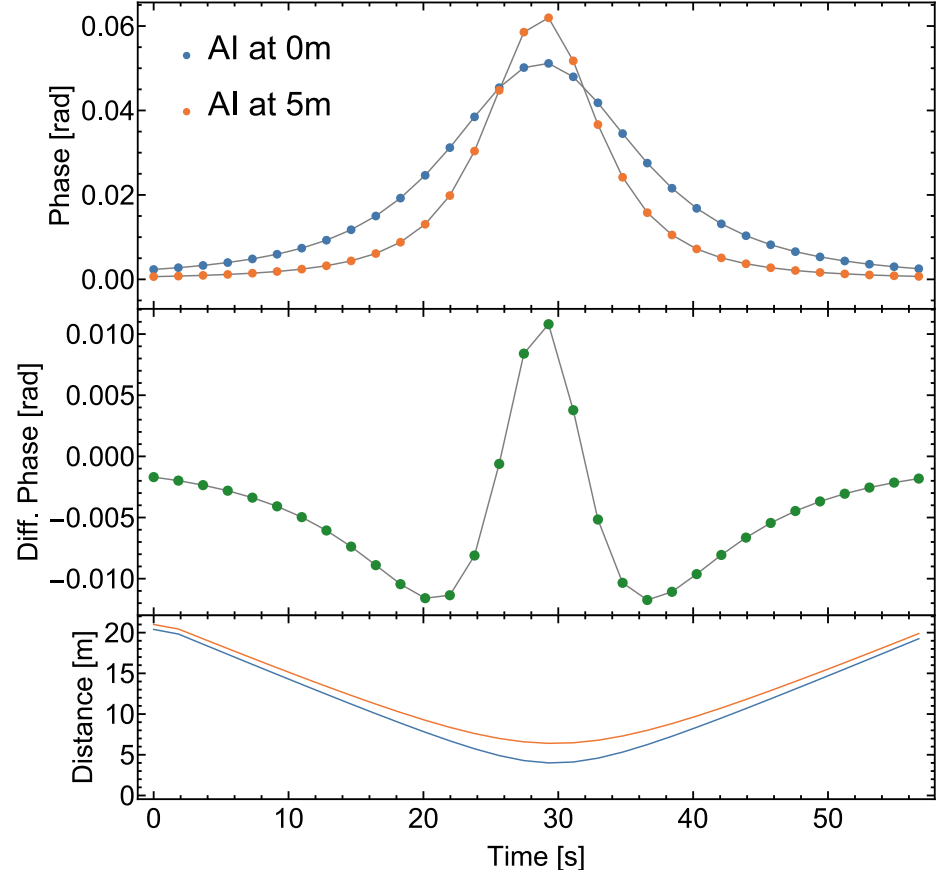
Mass = 70kg

Speed = 0.7m/s

Closest approach = 4m

Person crosses the foyer, at a height of 10m above the base of the AION tower.

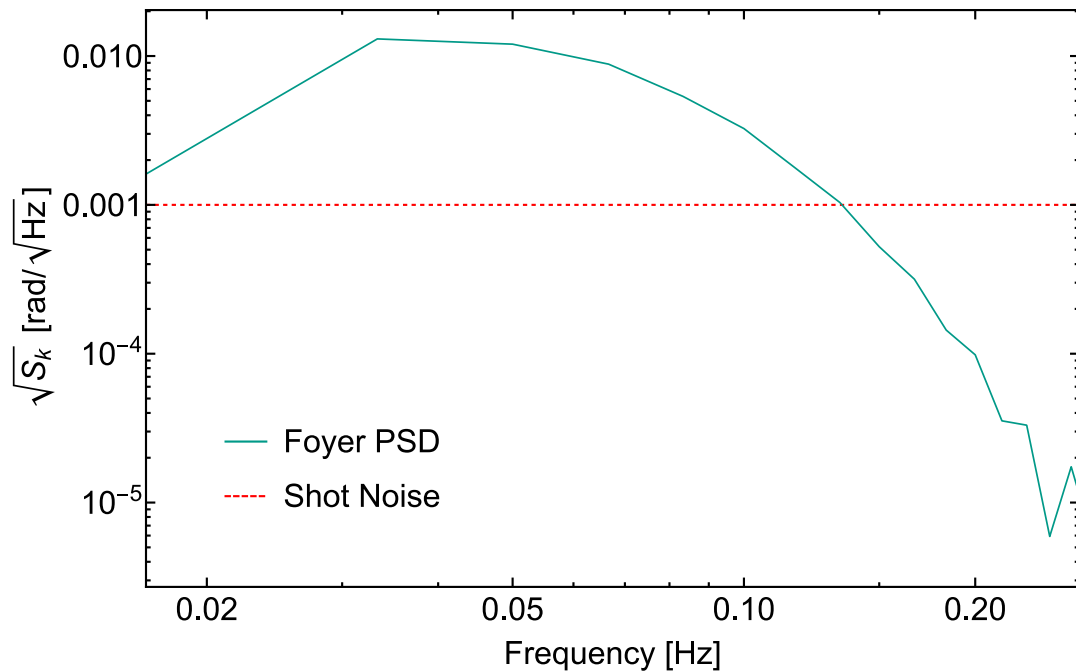
Smaller phase and characteristic curve (phase always positive).



The foyer - PSD

Phase noise less problematic at high frequency.

Scales linearly with people, so many people walking in the foyer may have a larger impact.



Foyer Summary

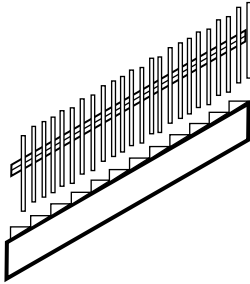


People in the foyer individually are much less of a problem
- but they may be present in larger numbers.

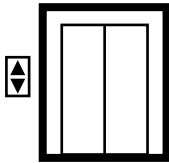
Phase curve characteristic of transiting person, combined
with visual follow-up may allow some filtering.

Would be very difficult to stop people entering the building,
experiment may have to run at night.

Summary – Site selection for future experiments



Largest phase but easiest to solve – close stairs when experiment is running.



Also a problem – but may be solved by monitoring lift movements.



Smallest phase but hardest to prevent?

Backup

Windowing – Lift PSD

