Atmospheric Newtonian Noise (NN)

Infrasound NN

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Atmospheric sources of Newtonian Noise

- Atmospheric weak pressure waves (small $\delta p/p$)
- Atmospheric temperature perturbations
- Atmospheric shockwaves
- High-speed massive objects moving near the interferometer

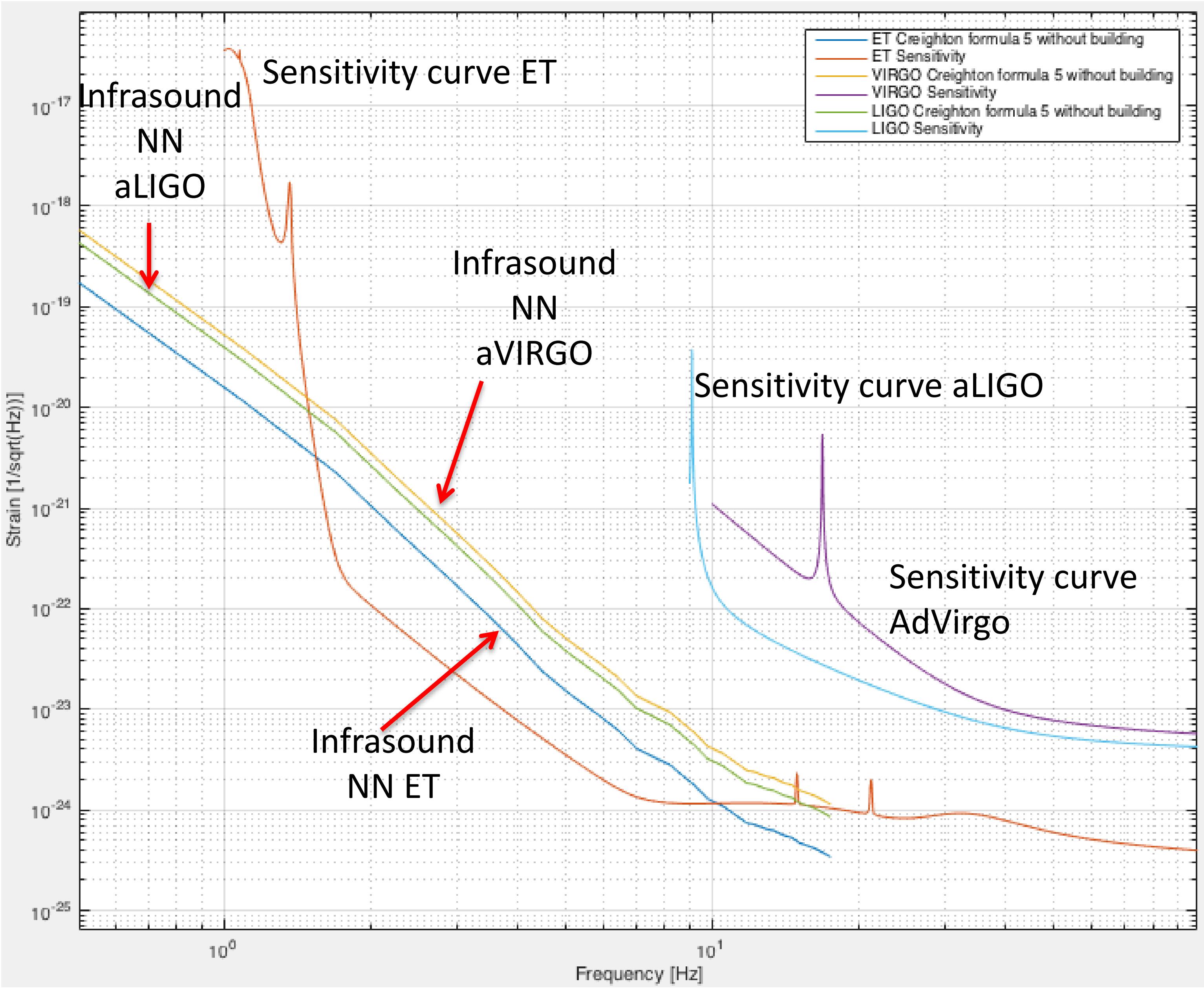
Why modeling infrasound NN?

aLIGO, AdVirgo, KAGRA → Frequency range ≈ 10Hz – 30Hz

Einstein Telescope (ET) → Frequency range ≈ 1Hz – 30Hz

Torsion bar antennae and other low frequency detectors (i.e. TOBA, TORPEDO, atom interferometers ...) → Frequency range ≈ 10 mHz-1Hz

Why modeling infrasound NN?



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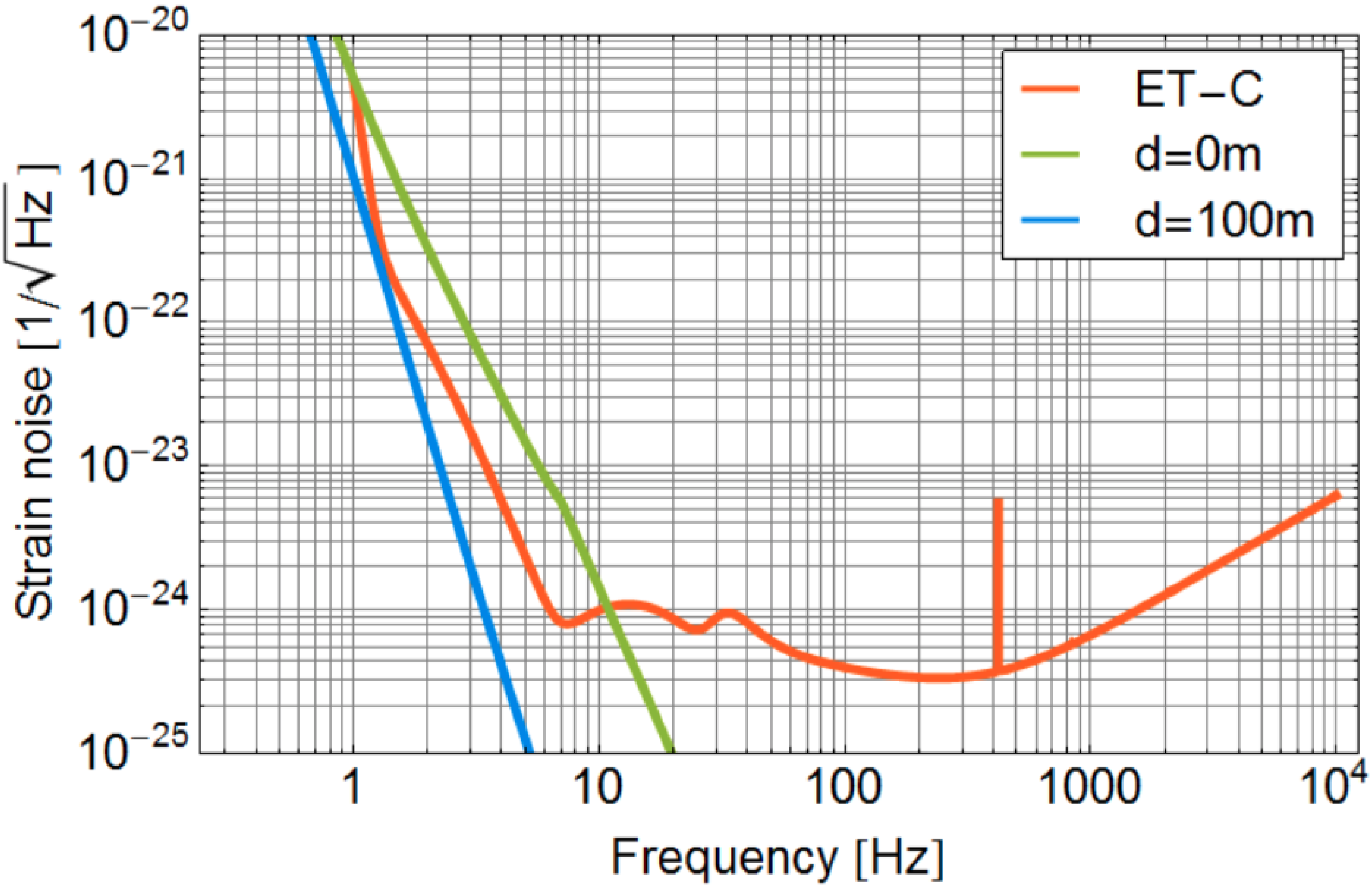
Why modeling infrasound NN?

ET Infrasound Newtonian Noise for different detector depths, d.



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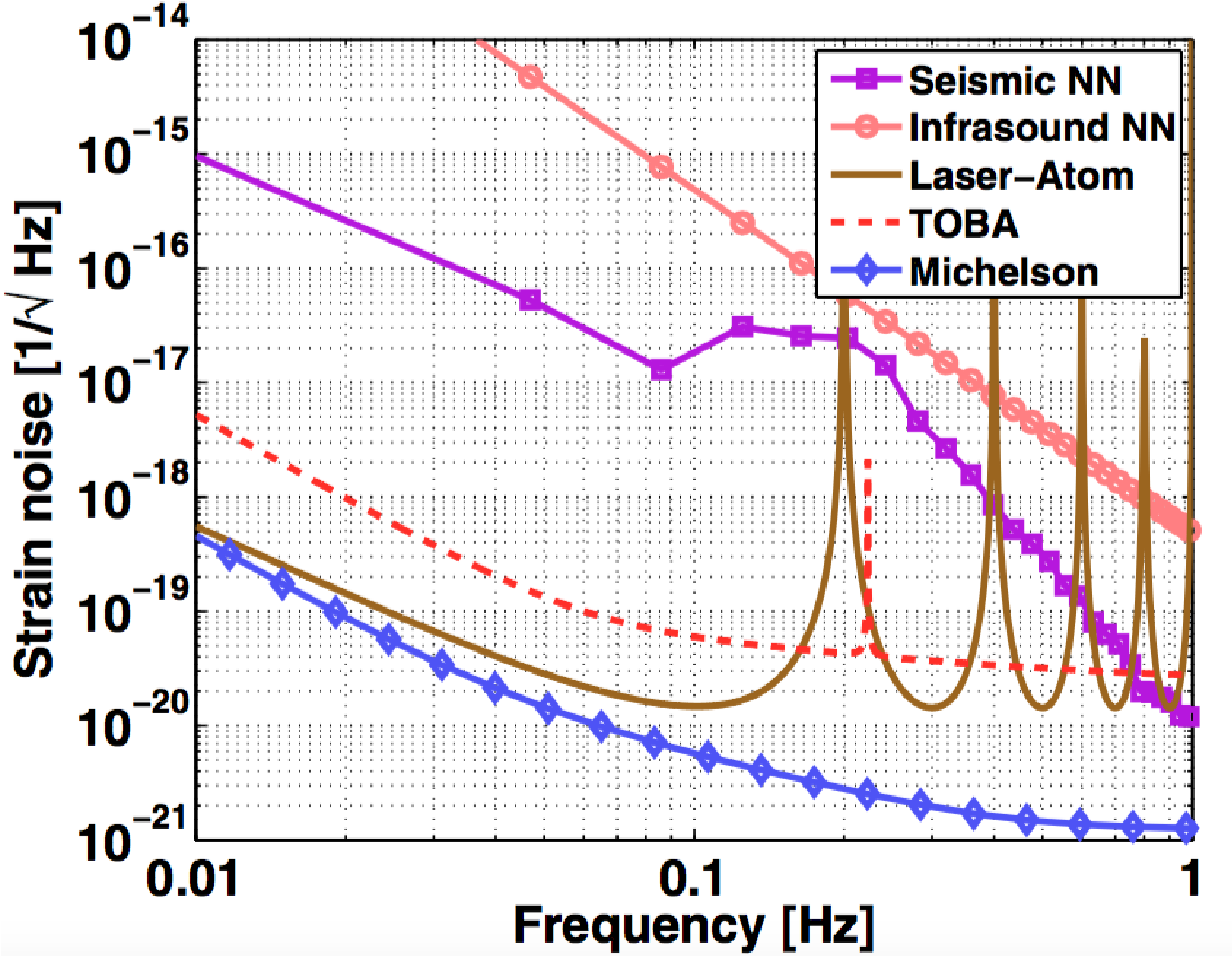
Why modeling infrasound NN?

Infrasound NN in low frequency detectors for GW and earthquakes (TOBA, TORPEDO, atom interferometers)



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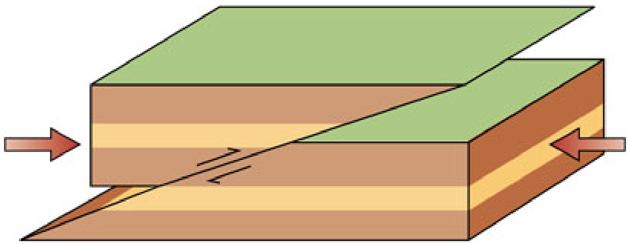
* J. Harms at al, Low-frequency terrestrial gravitational-wave detectors

E-GRAAL (Earthquake GRAvity Alerts) Project

Earthquake



Thrust fault

E-GRAAL (Earthquake GRavity ALerts): Feasibilty study of a new earthquake early warning system based on prompt gravity perturbations from earthquakes

p-waves
(a few km/s)

Gravitational field change

Seismic signal

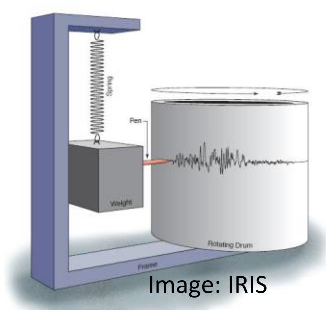
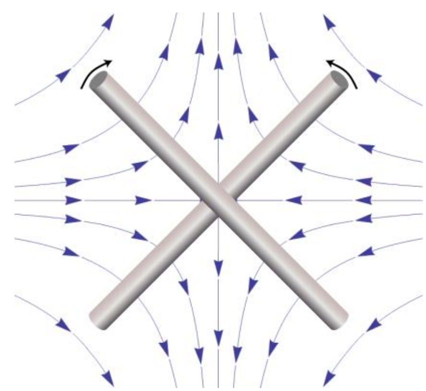


Image: IRIS



Gravity perturbations from Infrasound NN

Plane pressure wave → $\delta p/p \ll 1$, frequency f, sound speed c

Adiabatic density change $\delta\rho/\rho = \delta p/\gamma p$, $\gamma=1.4$

Gravitational acceleration caused by the waves, along its direction of propagation

$$g_z(t) = G \int z \frac{\delta\rho(t)}{r^3} dV$$

$\tilde{h}(f) = (2\pi f)^{-2}\, \tilde{g}(f) / L$ → Spectral density= $S_h(|f|) = \langle \tilde{h}(f) \tilde{h}(f')^* \rangle$

Interferometer arm length

Average over the plane wave modes contributing to the noise

Issues on Infrasound NN

2   1

$$g_z(t)^{*} = \int \frac{Gz\delta\rho}{r^3}\,\mathrm{d}V = \frac{G\rho c}{\gamma p f}\cos(\theta)\boxed{C(2\pi f r_{\min}/c)}\boxed{\delta p(t+1/4f)}$$

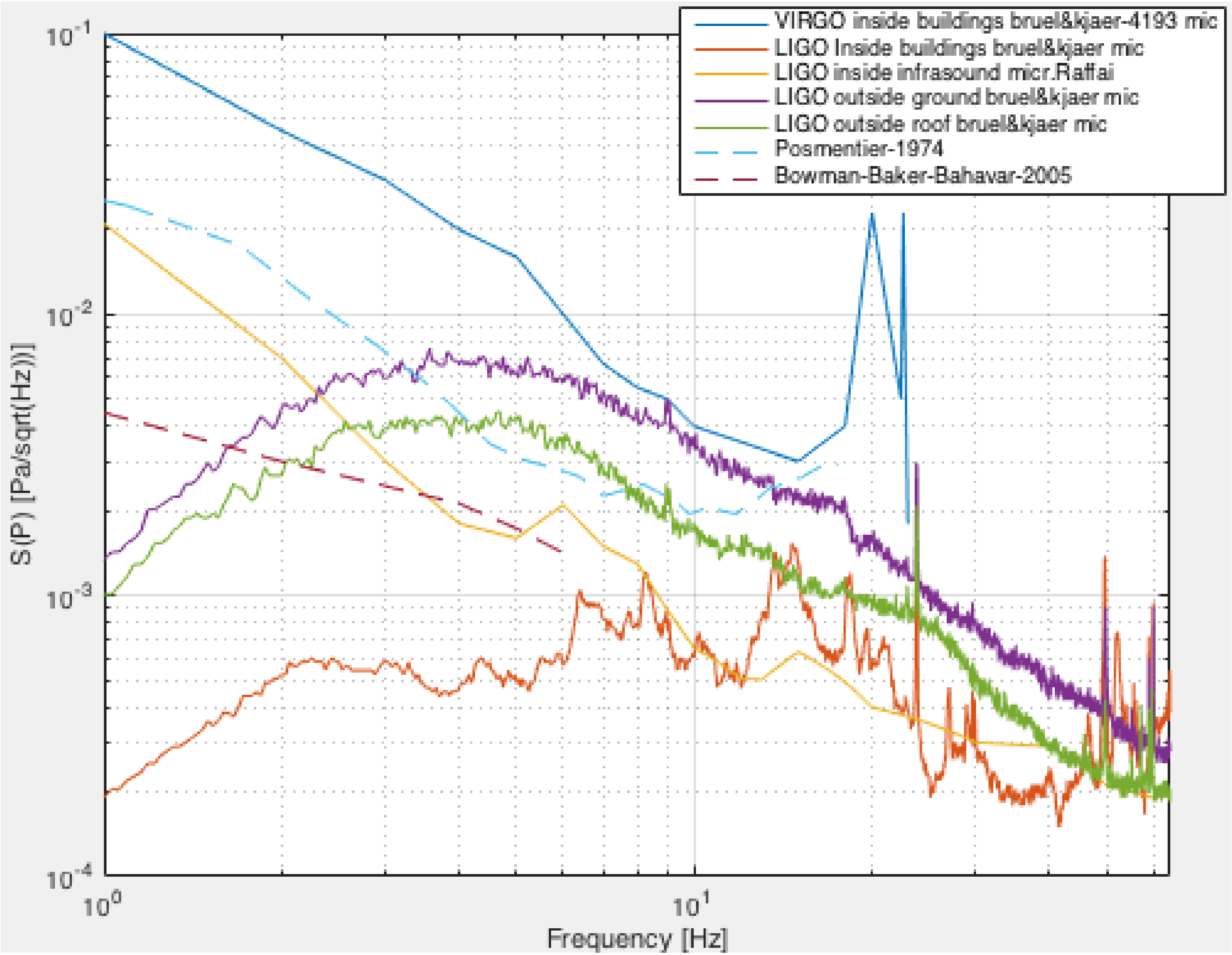
Angle between the wave propagation direction and the interferometer arm

1) Measurement of pressure fluctuations at infrasound frequencies →

- How to perform the measures
- Where to take the measures

2) Effect of the building housing the test mass → further analysis needed

Pressure Fluctuations

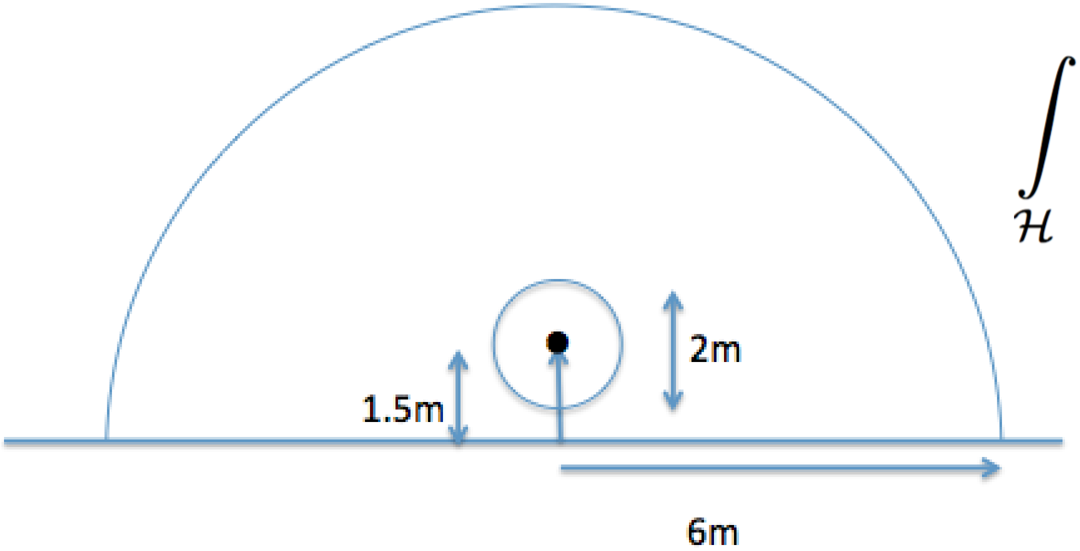


Need for data in the sub-Hz frequency range

Building effect modeling

Considered geometry: **hemispheric building**, 6m radius, centered at xo=0m,yo=0m,zo=0m

spheric vacuum chamber of radius 1m , centered at xo=0m,yo=0m,zo=1.5m

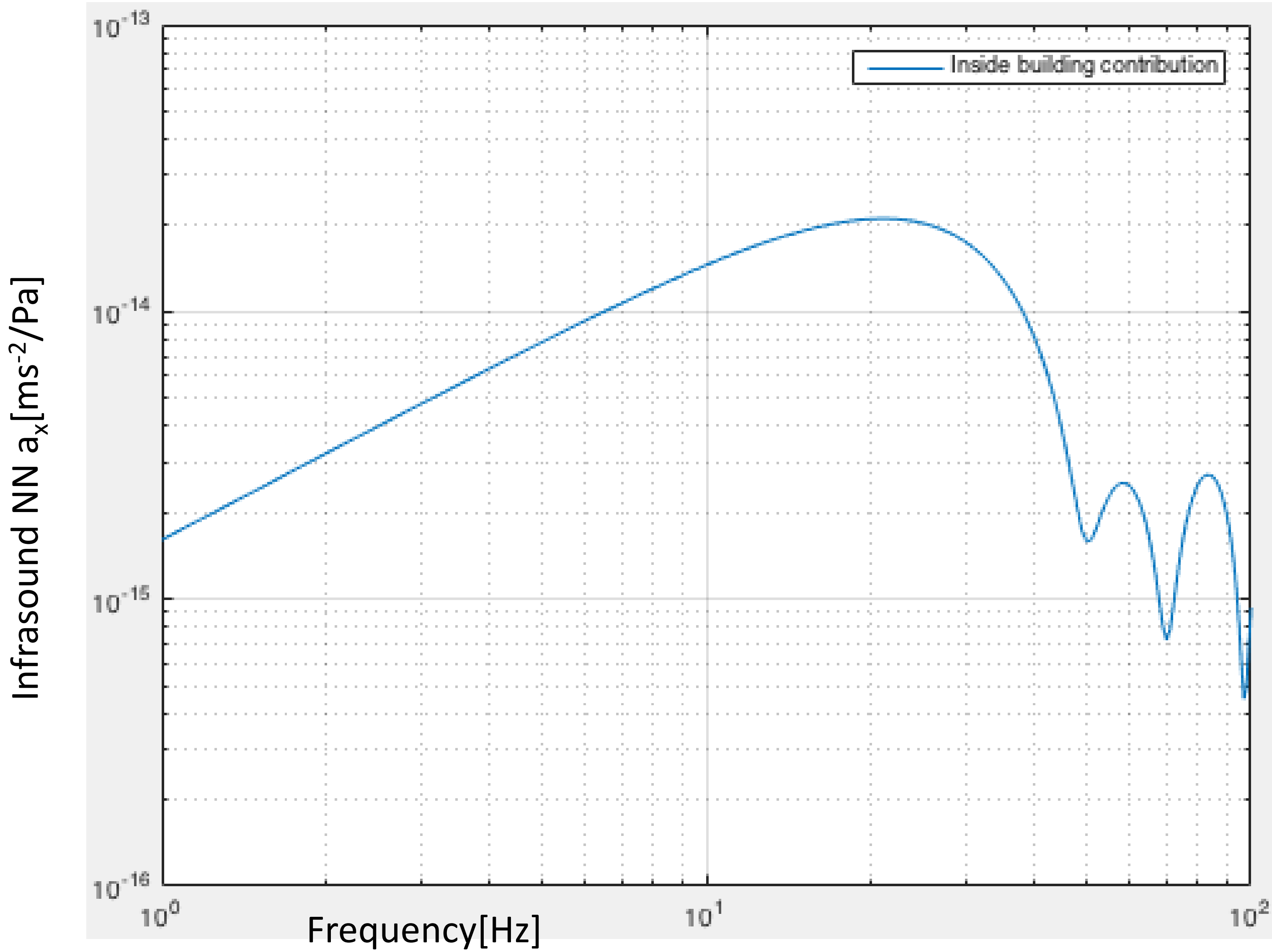


$$\int_{\mathcal{H}} \mathrm{d}V \, \frac{(\mathrm{e}^{-\mathrm{i}k_z z} + \mathrm{e}^{\mathrm{i}k_z z})\mathrm{e}^{-\mathrm{i}\vec{k}_\varrho \cdot \vec{\varrho}}}{(\varrho^2 + (z - z_0)^2)^{1/2}}$$ *

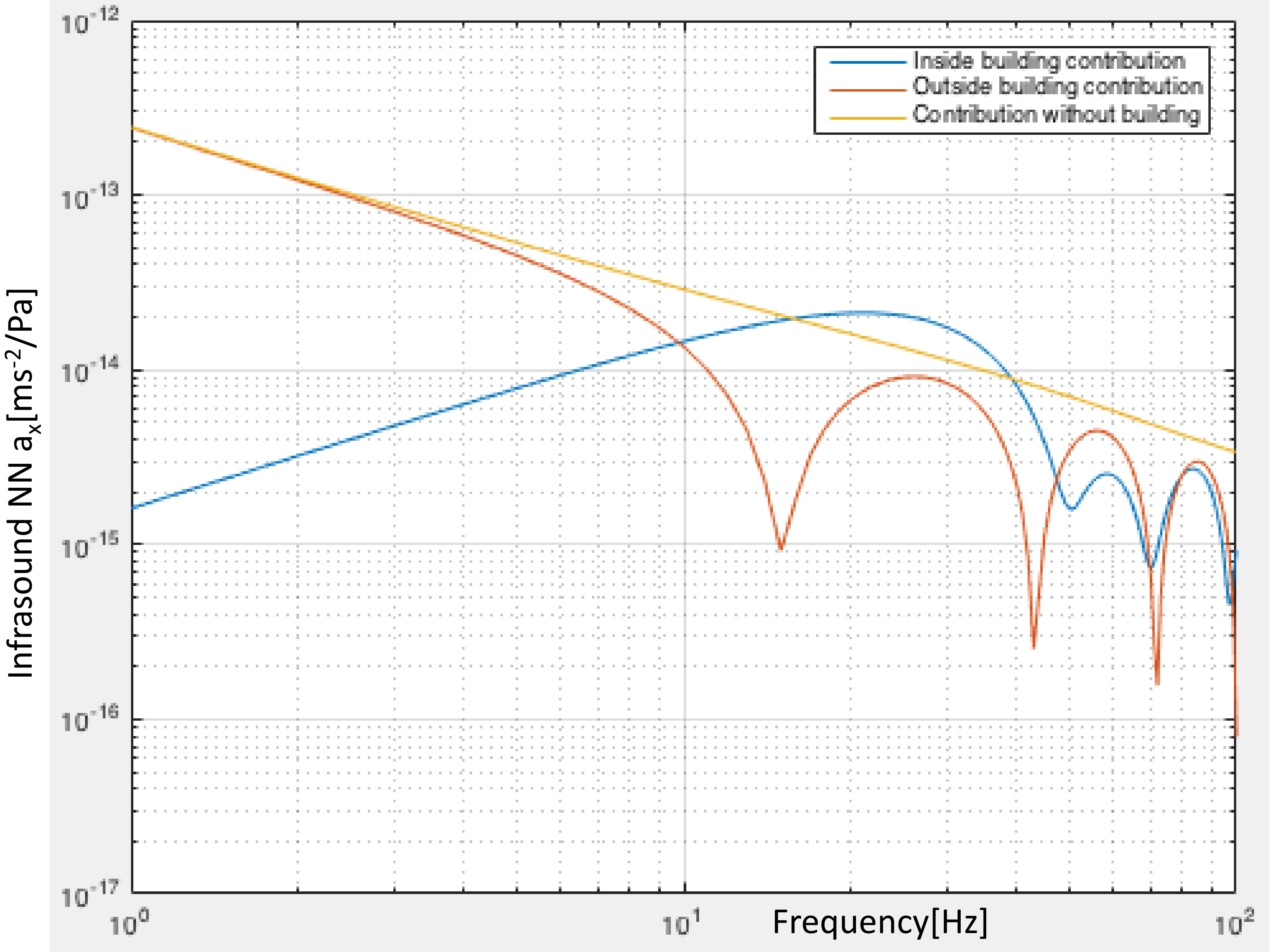
To be calculated to find the infrasound NN gravitational acceleration

Building effect modeling

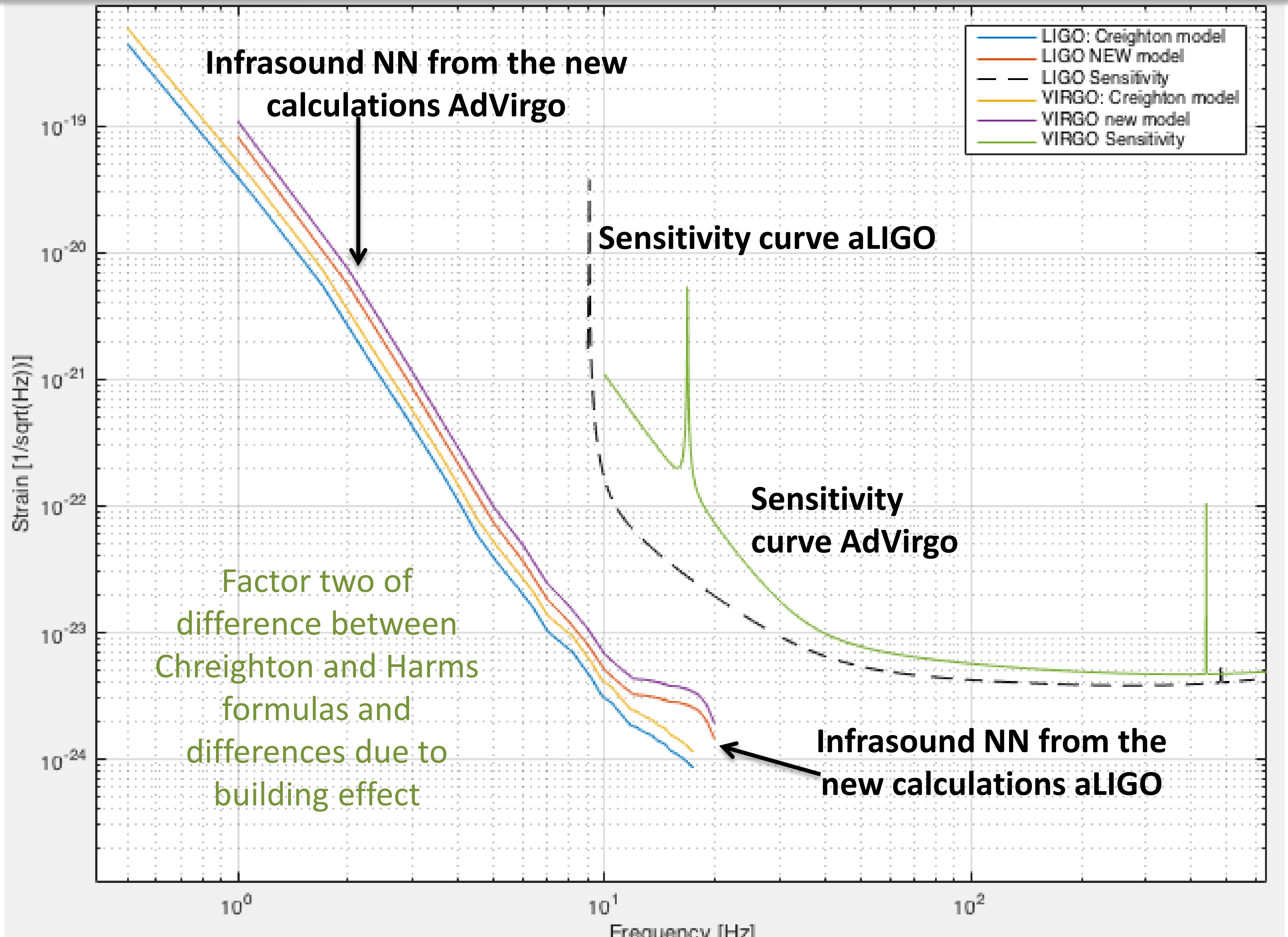
Inside building, numerical integration, average over 60 acoustic wave directions



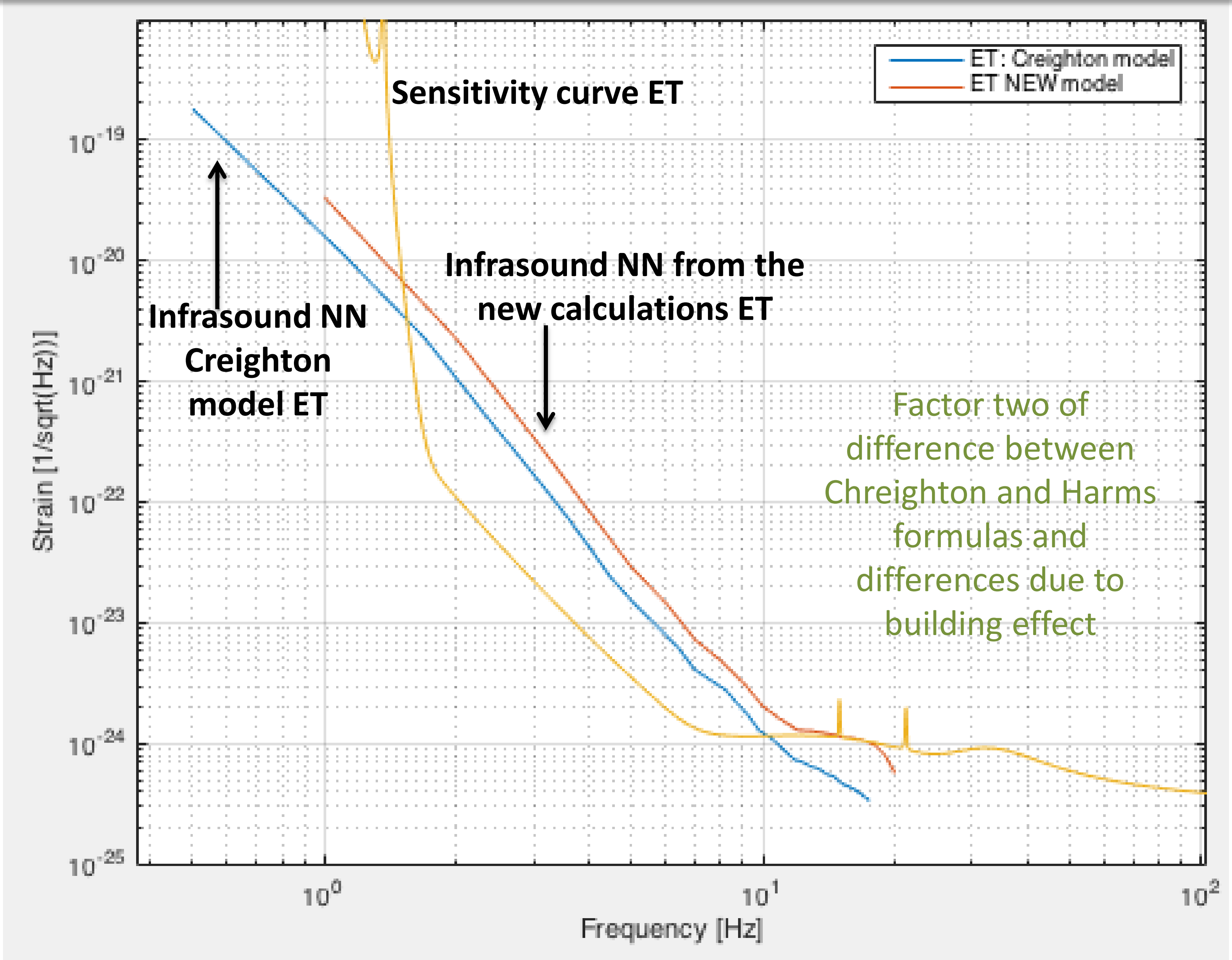
Building effect modeling-Result Comparison/1



Building effect modeling-Result Comparison/2



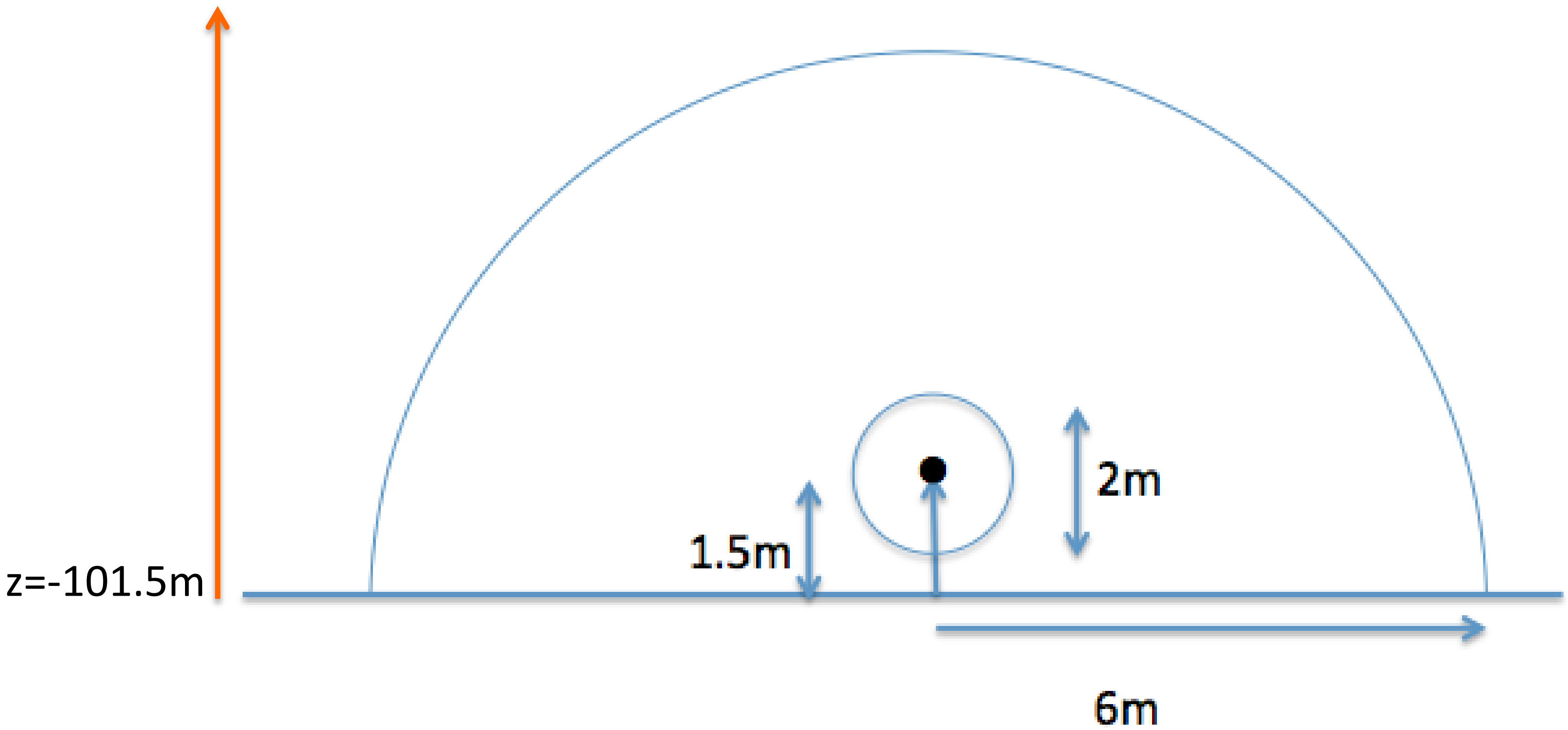
Building effect modeling-Result Comparison/3



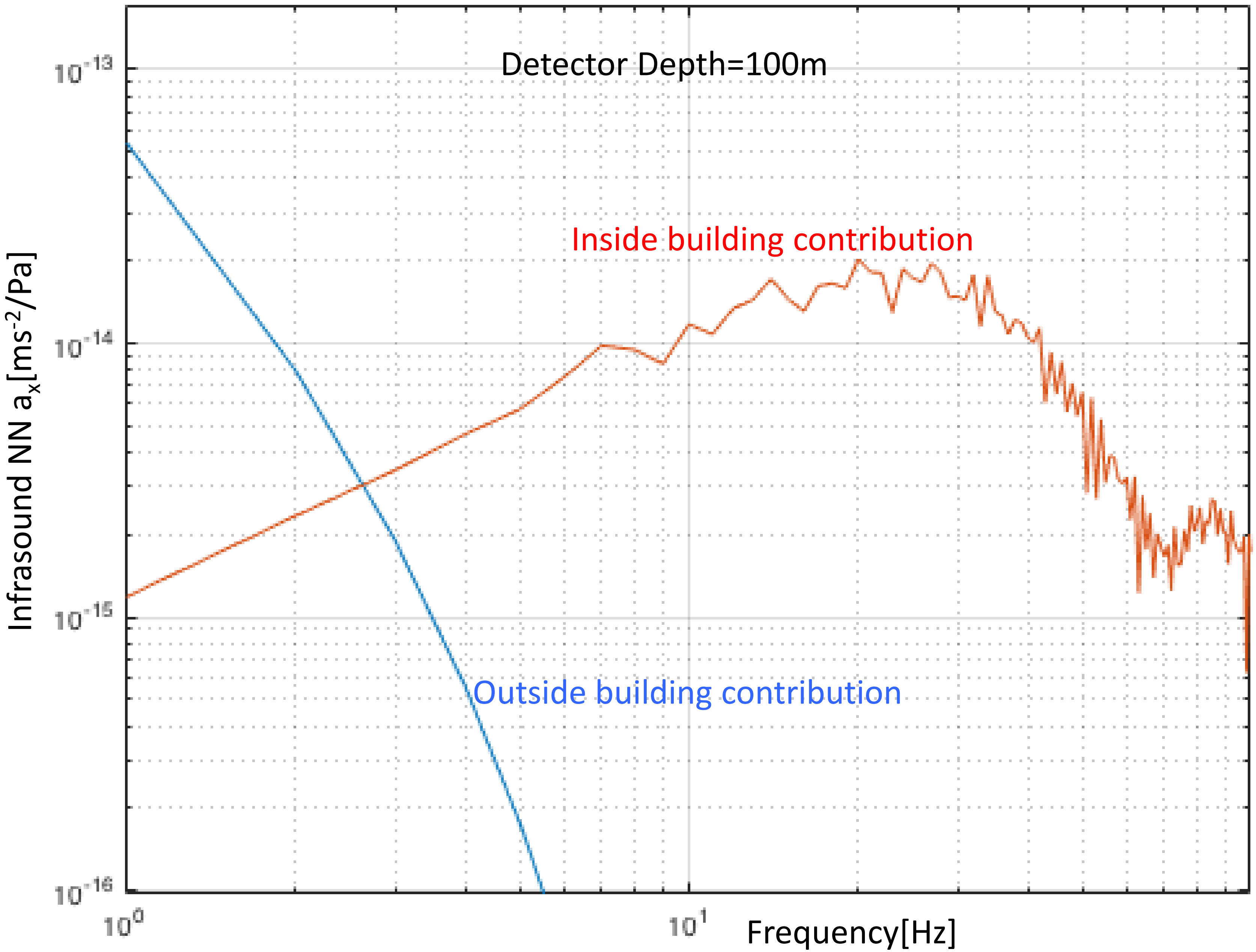
Infrasound NN-Undergound case

Considered geometry: **hemispheric building**, 6m radius, centered at xo=0m,yo=0m,zo=-101.5m

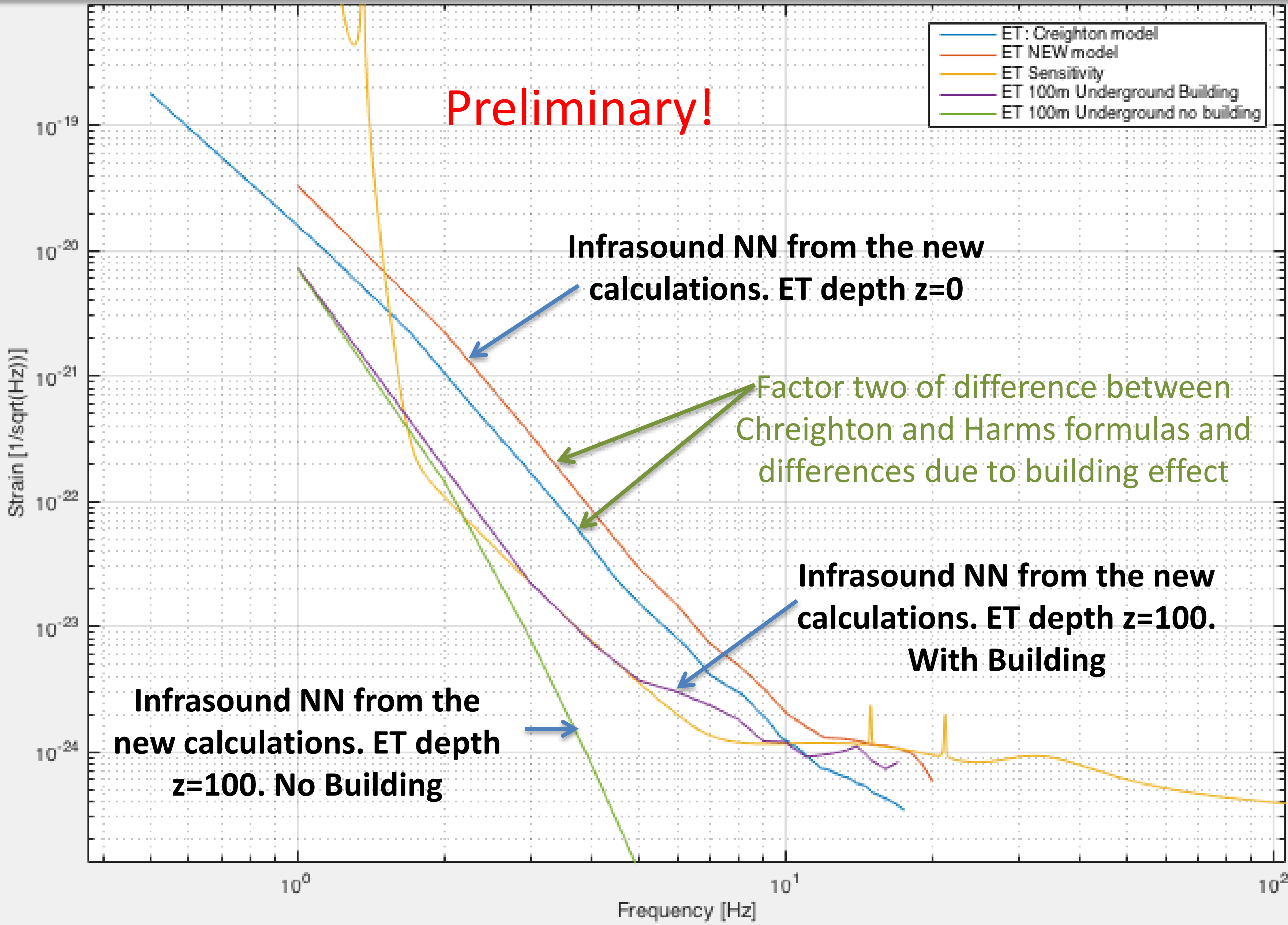
spheric vacuum chamber of radius 1m , centered at xo=0m,yo=0m,zo=-100m



ET Infrasound NN-Undergound case



ET Infrasound NN-Undergound case



Infrasound NN TOBA-I

$$\delta\vec{g}_{12}(\omega) = -\nabla\psi(\vec{r}_2,\omega) + \nabla\psi(\vec{r}_1,\omega)$$

Small test mass distance

$$\approx -(\nabla \otimes \nabla\psi(\vec{r}_1,\omega)) \cdot \vec{r}_{12}$$

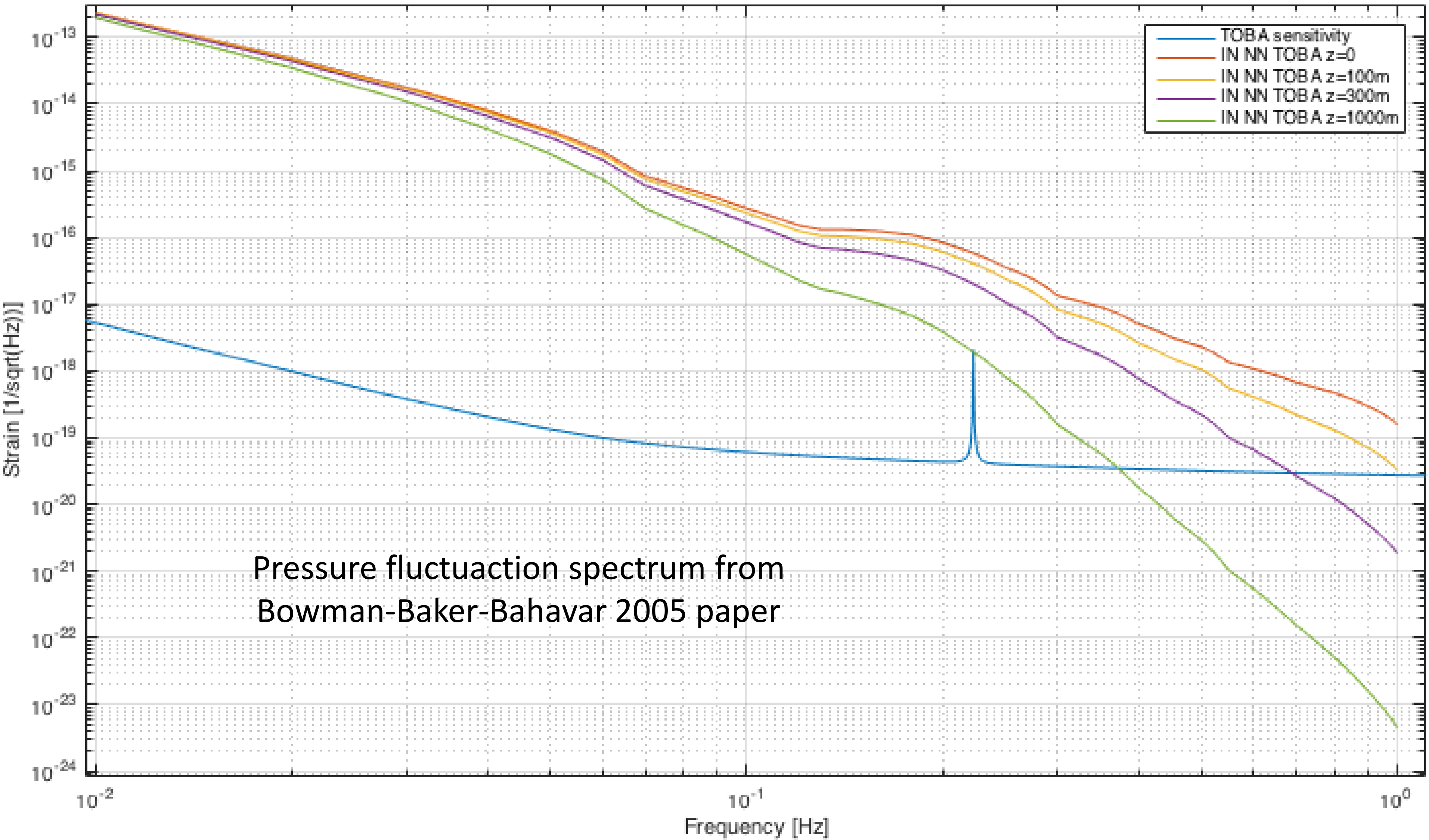
*

$$h_{\mu\nu}(\vec{r},\omega) = \frac{\nabla \otimes \nabla\psi(\vec{r},\omega)}{\omega^2}$$

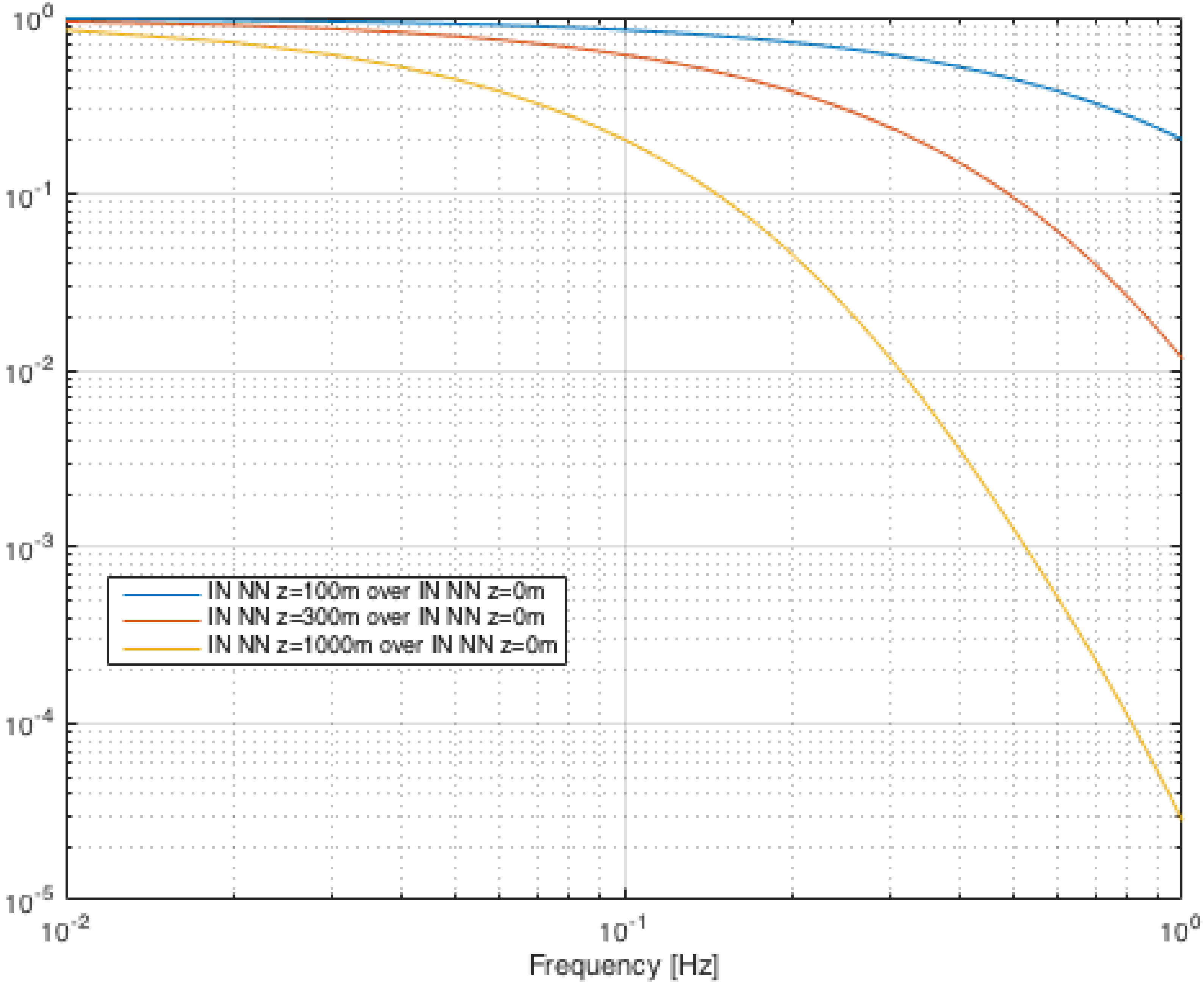
$h_{\mu\nu}$ projection for the rotational strain measurement

$$h_\times \Rightarrow S_{h_\times} = \sqrt{\langle h_\times h_\times^* \rangle}$$

Infrasound NN TOBA-II



Infrasound NN TOBA-III



Conclusions and Perspectives/1

Pressure fluctuation measurements:

- Need for suitable sensor in the infrasound range
- Choise of meaningful microphone positions inside a gravitational wave (GW) detector

Building effects on the Infrasound NN:

- Infrasound NN inside the building is more important at higher frequencies
- Infrasound NN outside the building is more important at lower frequencies
- The new infrasound NN results for LIGO, VIRGO and ET confirm that the Infrasound NN does not limit the sensitivity of the first two detectors, but it is relevant for ET.
- Going underground can reduce significantly the infrasound NN
- Deepen the analysis of infrasound NN for low frequency detectors (e.g. TORPEDO, TOBA, atom interferometers,...) used for GW detection and earthquakes.
- Make the calculations with new measurements of pressure fluctuation spectra

Conclusions and Perspectives/2

- Atmospheric weak pressure waves (small $\delta p/p$)
- Atmospheric temperature perturbations
- Atmospheric shockwaves
- High-speed massive objects moving near the interferometer