Newtonian Noise (NN)
@ low frequency

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Newtonian Noise (NN) in low frequency detectors (10mHz-1Hz)

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

Newtonian Noise (NN) in low frequency detectors (10mHz-1Hz)

Atmospheric NN main sources:

- Quasi-static temperature perturbations
- Infrasound waves created by pressure fluctuations

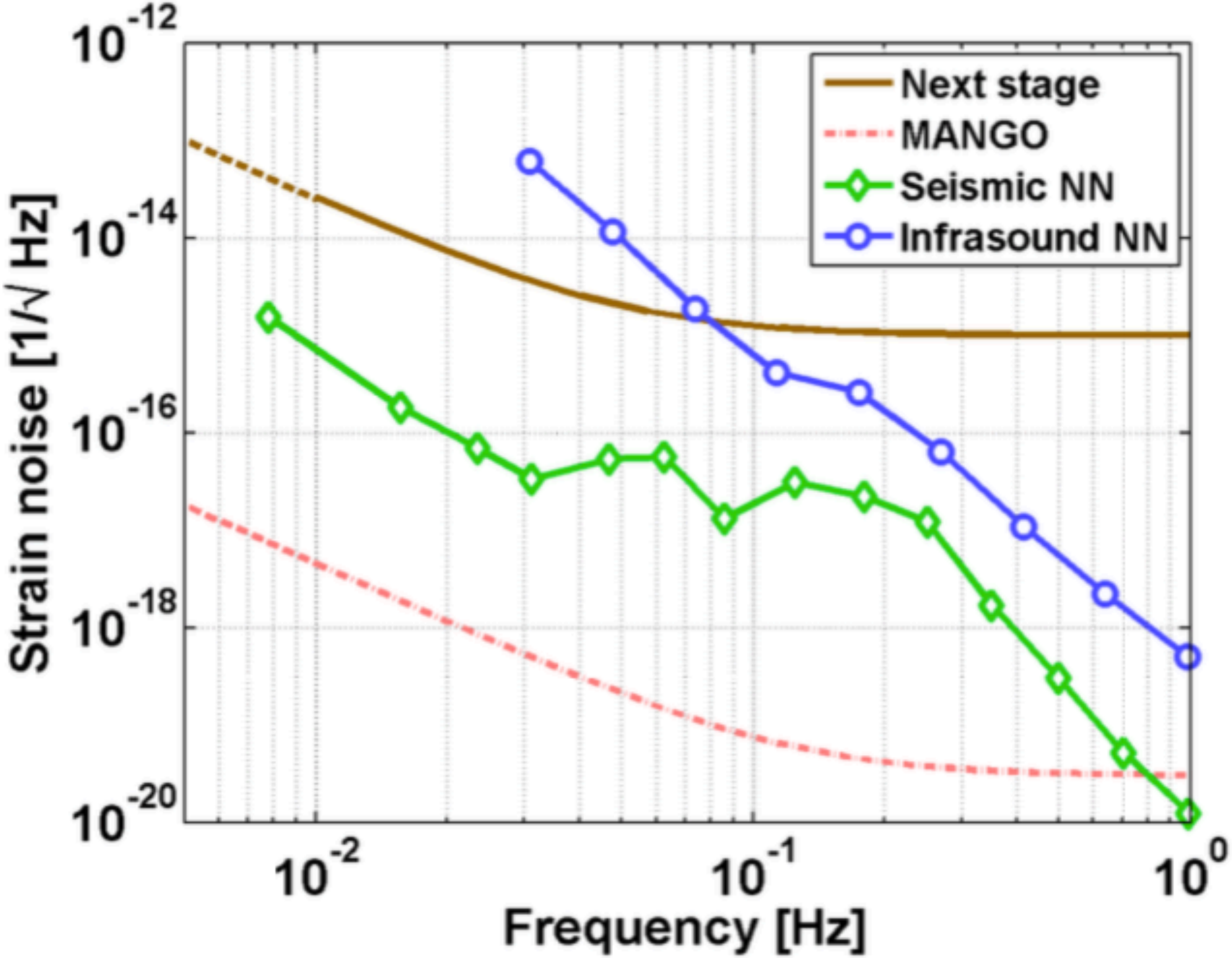
Seismic NN main source:

- Rayleigh waves

NN from objects:

- Objects moving with constant speed

Infrasounf vs Seismic NN



Infrasound vs Seismic NN

Rayleigh wave gravity perturbation → $x(\omega) \propto \dfrac{1}{\omega^2}$

Infrasound gravity perturbation → $x(\omega) \propto \dfrac{1}{\omega^3}$

Test mass noise correlation → $\dfrac{L}{\lambda_{IN/Rayleigh}} \lesssim 1$

Rayleigh wavelenght $\lambda_R \approx 35$ km @0.1 Hz

Infrasound wavelenght $\lambda_{IN} \approx 3.4$ km @0.1 Hz

→ Lower correlation for Infrasound noise

Infrasound NN is higher than Seismic NN at low frequency (0.01Hz-1Hz)

Infrasounf vs Seismic NN

Underground attenuation factor

$$\exp(-h\,\omega/\,c_{IN/Rayleigh})$$

Rayleigh wave c_{IN} ≈3.5 km/s @0.1 Hz

Infrasound wave $c_{Infrasound}$ ≈340 m/s

Lower attenuation of Seismic NN than of Infrasound NN at low frequency 0.01Hz-1Hz

Infrasound NN

Plane pressure wave

δp/p <<1, frequency *f*, sound speed c

Adiabatic density change δρ/ρ = δp/γp, γ=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

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

Angle between the wave propagation direction and the interferometer arm

1) Effect of the building housing the test mass

2) Measurement of pressure fluctuations at infrasound frequencies →

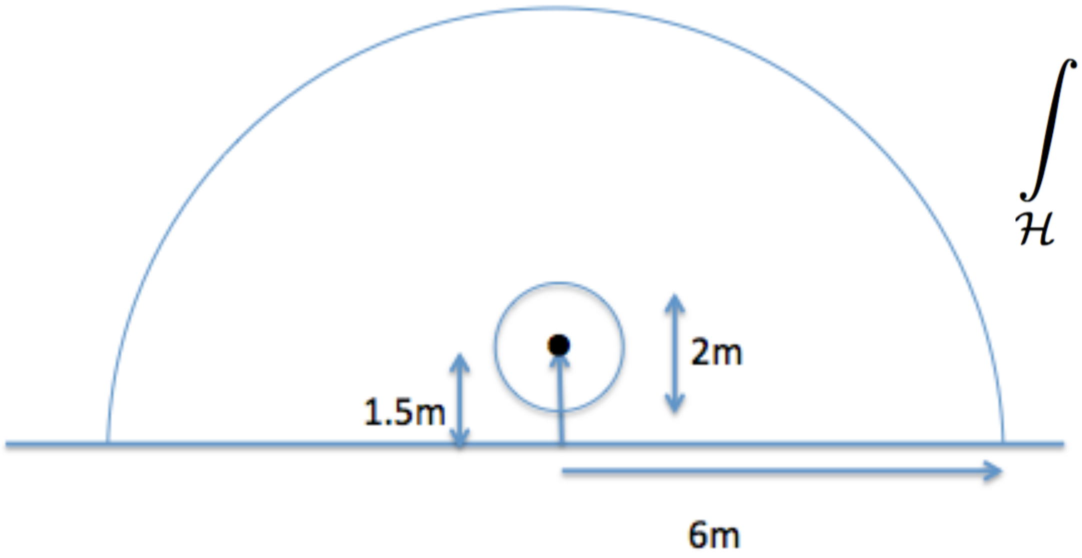
- How to perform the measures
- Where to take the measures

* CQG. **25** (2008) 125011

Building effect modeling

Considered geometry: **hemispheric building**, 6m radius

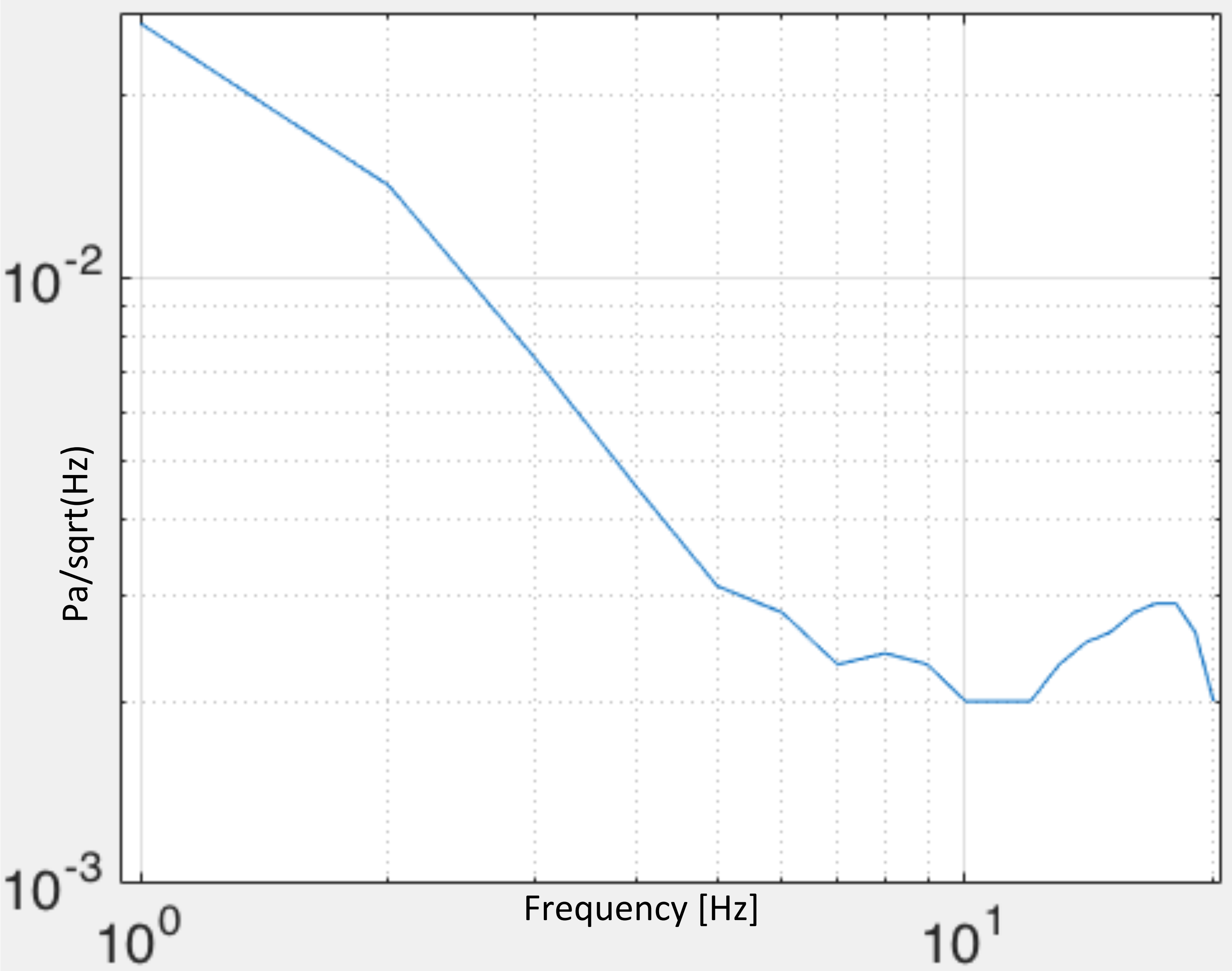
spheric vacuum chamber of radius 1m , centered at xo=0m,yo=0m,zo=1.5m



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

To be calculated to find
the infrasound NN
gravitational acceleration

Pressure fluctuations for the calculation of the ET IN NN



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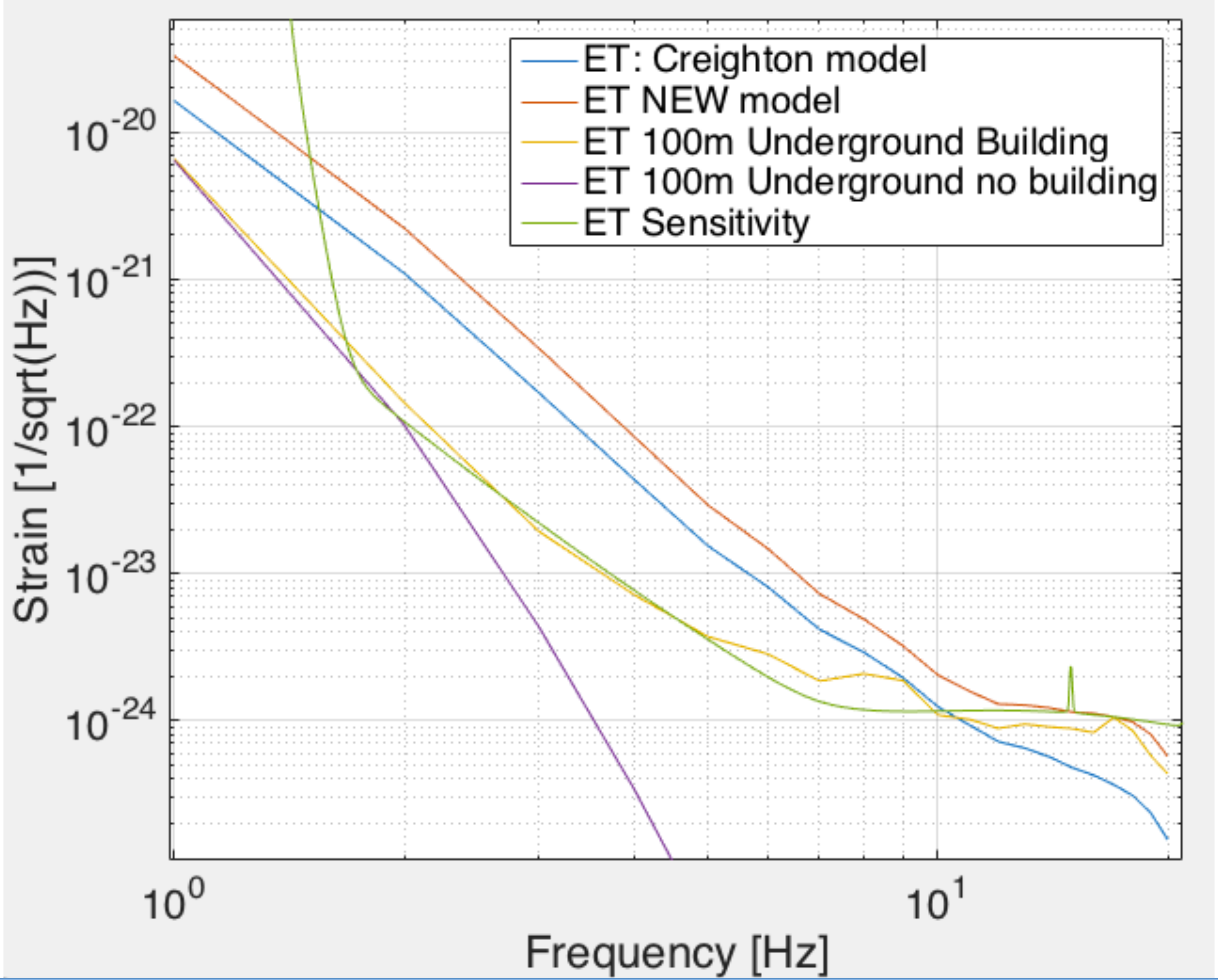
ET IN NN-Building effect



Infrasound NN TOBA

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

Small test mass distance

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

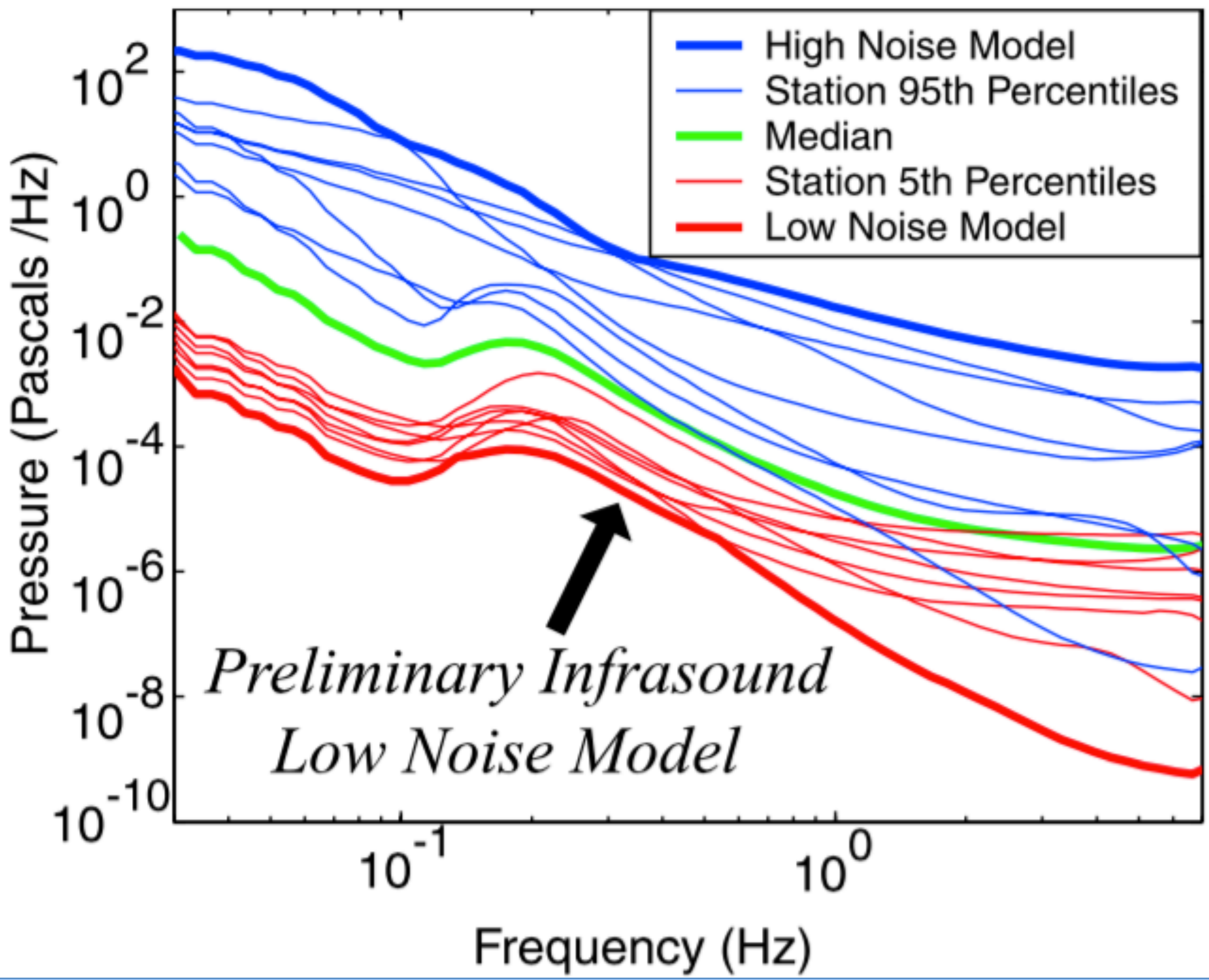
$$h_{\mu\nu}(\vec{r},\omega) = \frac{\nabla\otimes\nabla\psi(\vec{r},\omega)}{\omega^2}$$

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

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

- J. Harms, Terrestrial Gravity Fluctuations

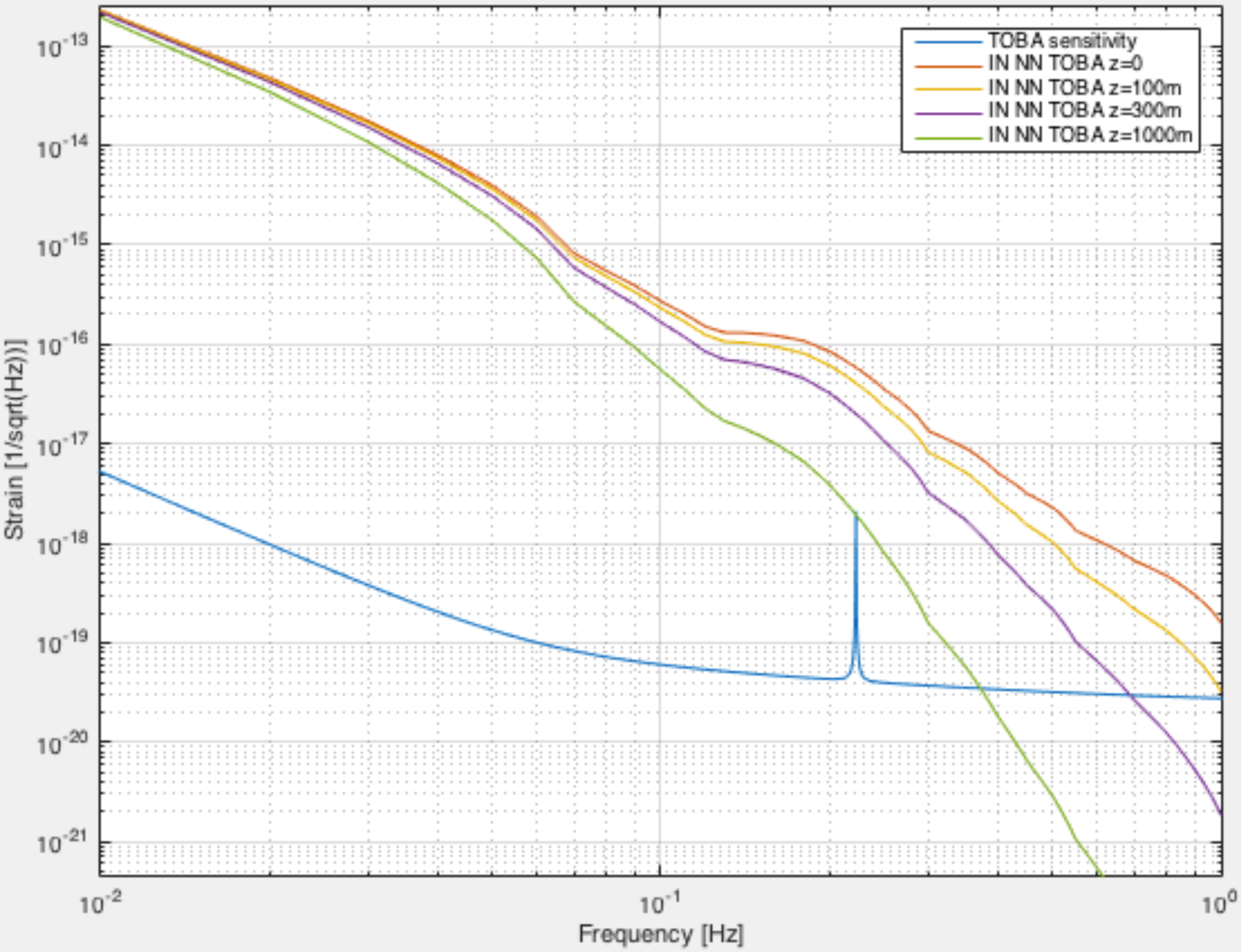
Pressure fluctuations for the calculation of TOBA IN NN



GEOPHYSICAL RESEARCH LETTERS, VOL. 32, L09803,2005

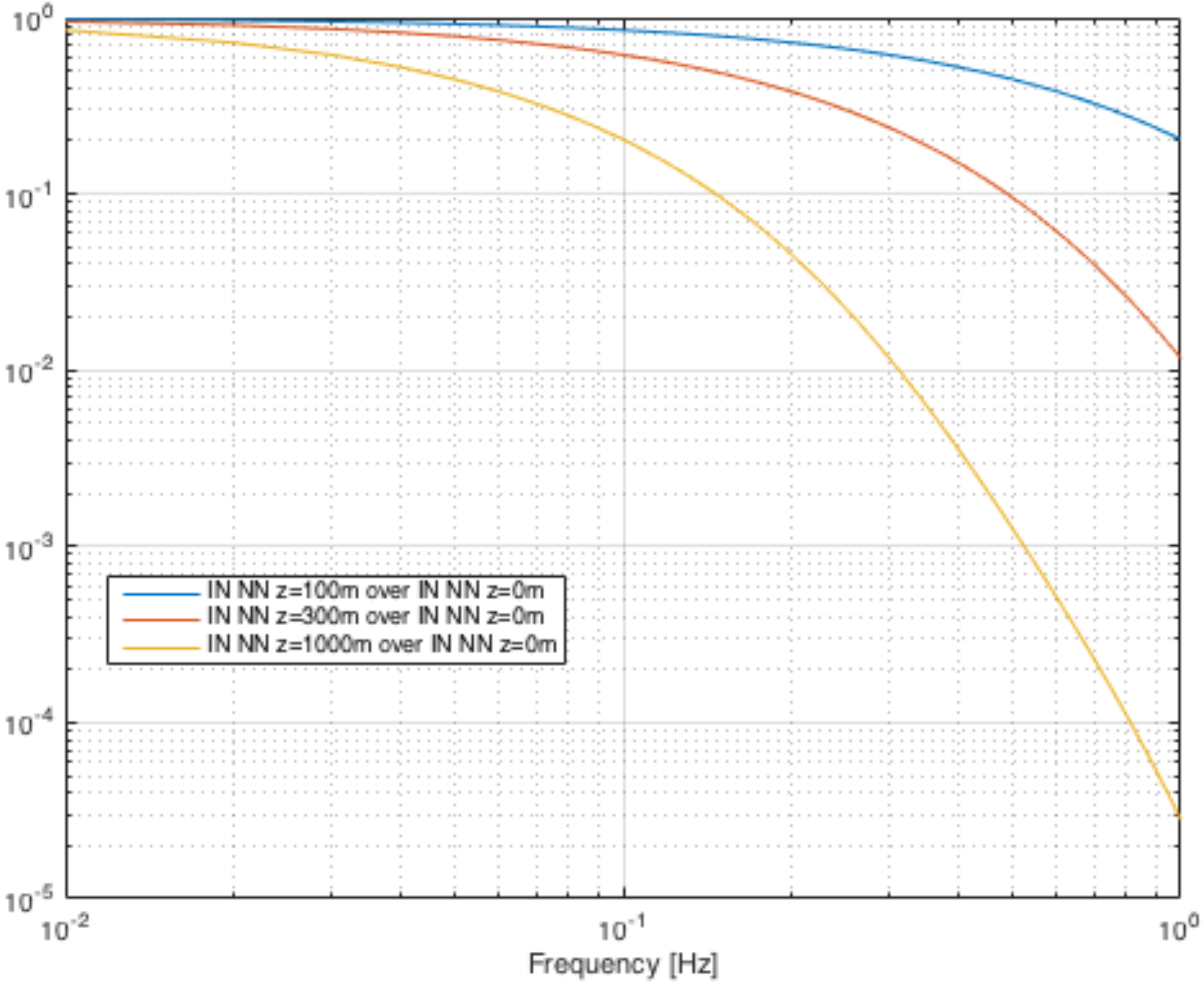
TOBA IN NN surface and underground

Median noise model of the pressure fluctuations



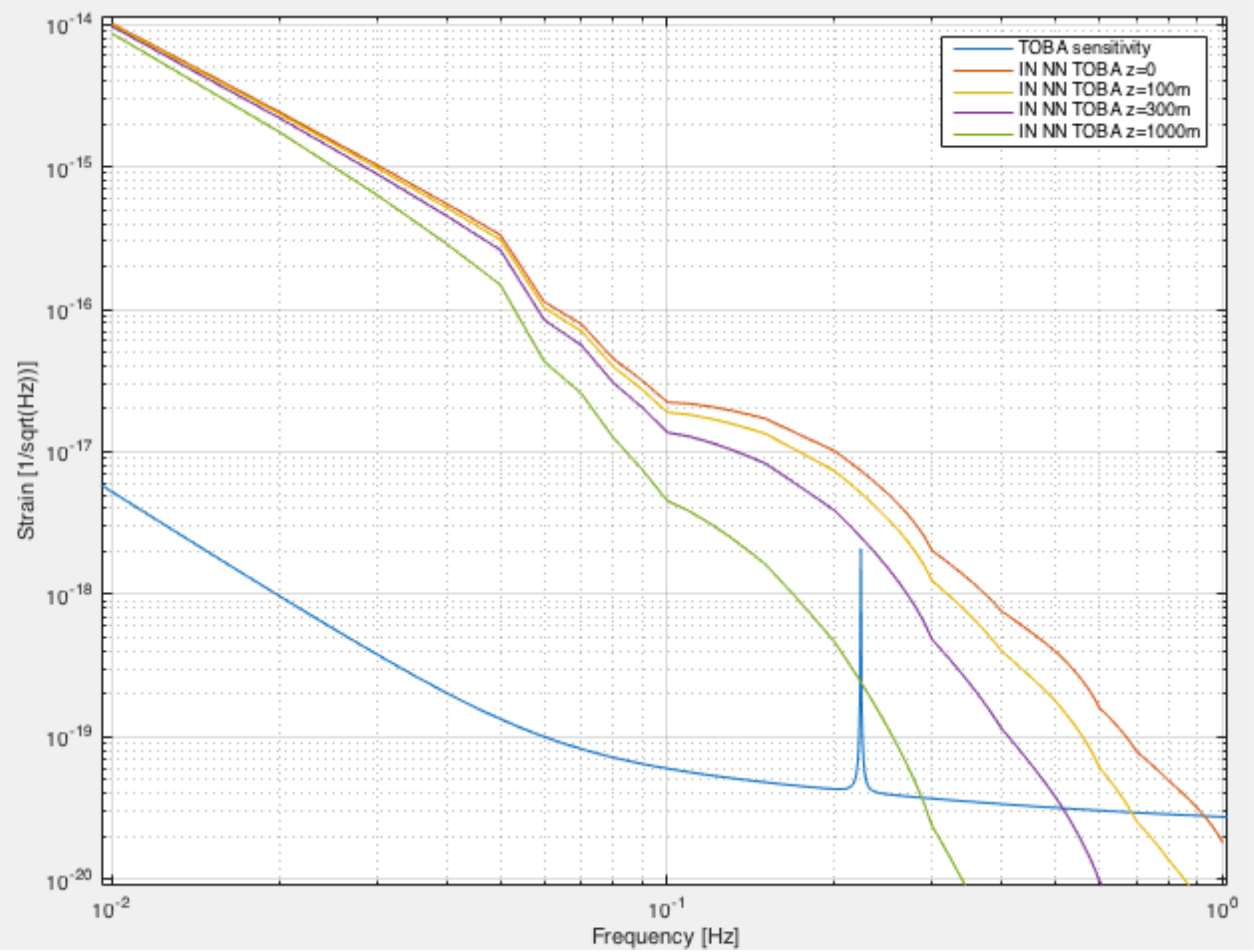
TOBA IN NN surface and underground

Median noise model of the pressure fluctuations



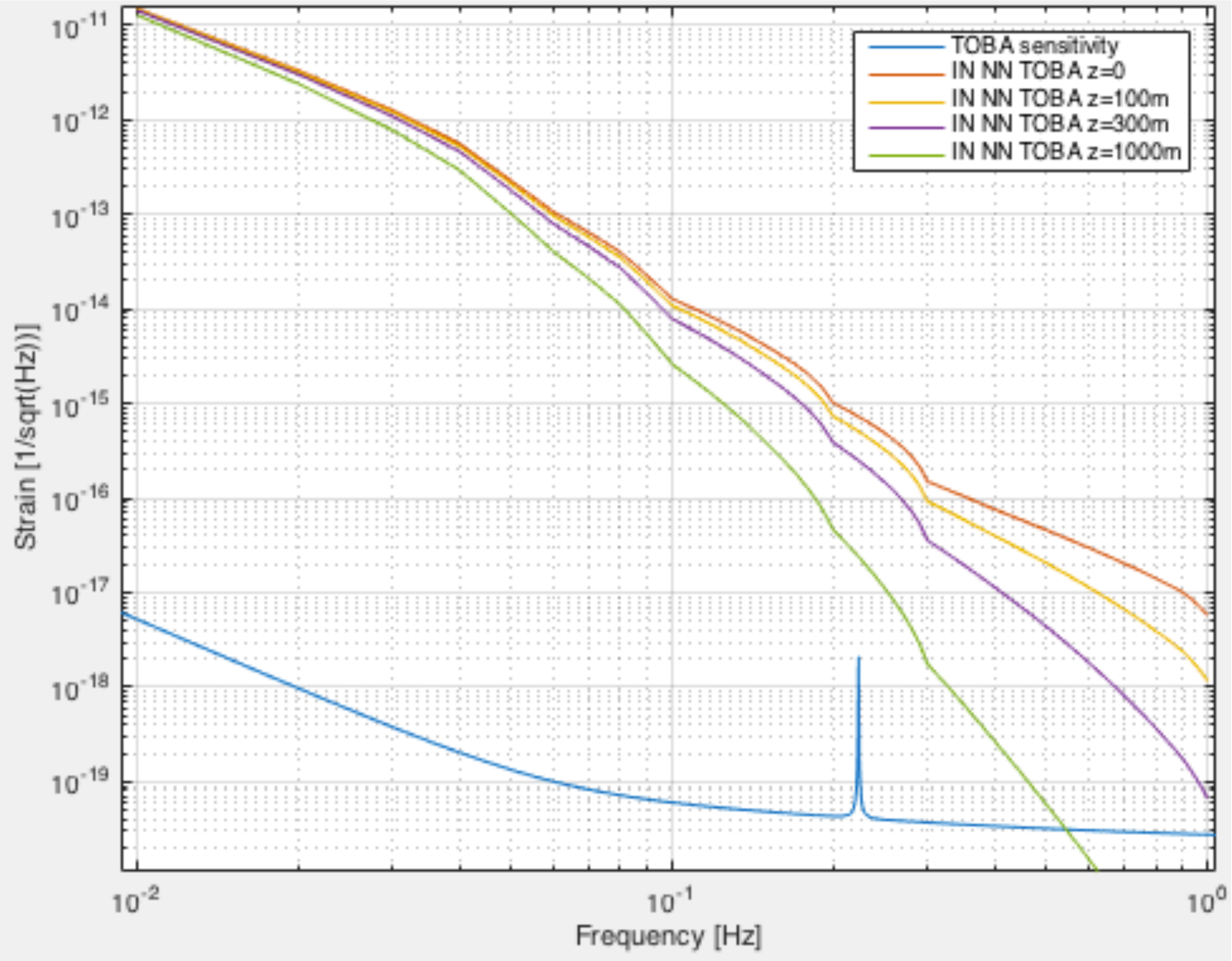
TOBA IN NN surface and underground

Low noise model of the pressure fluctuations



TOBA IN NN surface and underground

High noise model of the pressure fluctuations



Moving objects NN in TOBA

$$\psi(\vec{r},t) = -\frac{Gm}{\sqrt{x^2(t)+y^2(t)+z^2(t)}}$$

$x(t)=r1x+v1x(t-t1)$
$y(t)=r1y+v1y(t-t1)$
$z(t)=r1z+v1z(t-t1)$

$\ddot{h}_{\mu\nu} = -\nabla\otimes\nabla\psi(\vec{r},t)$ → Gravity gradient

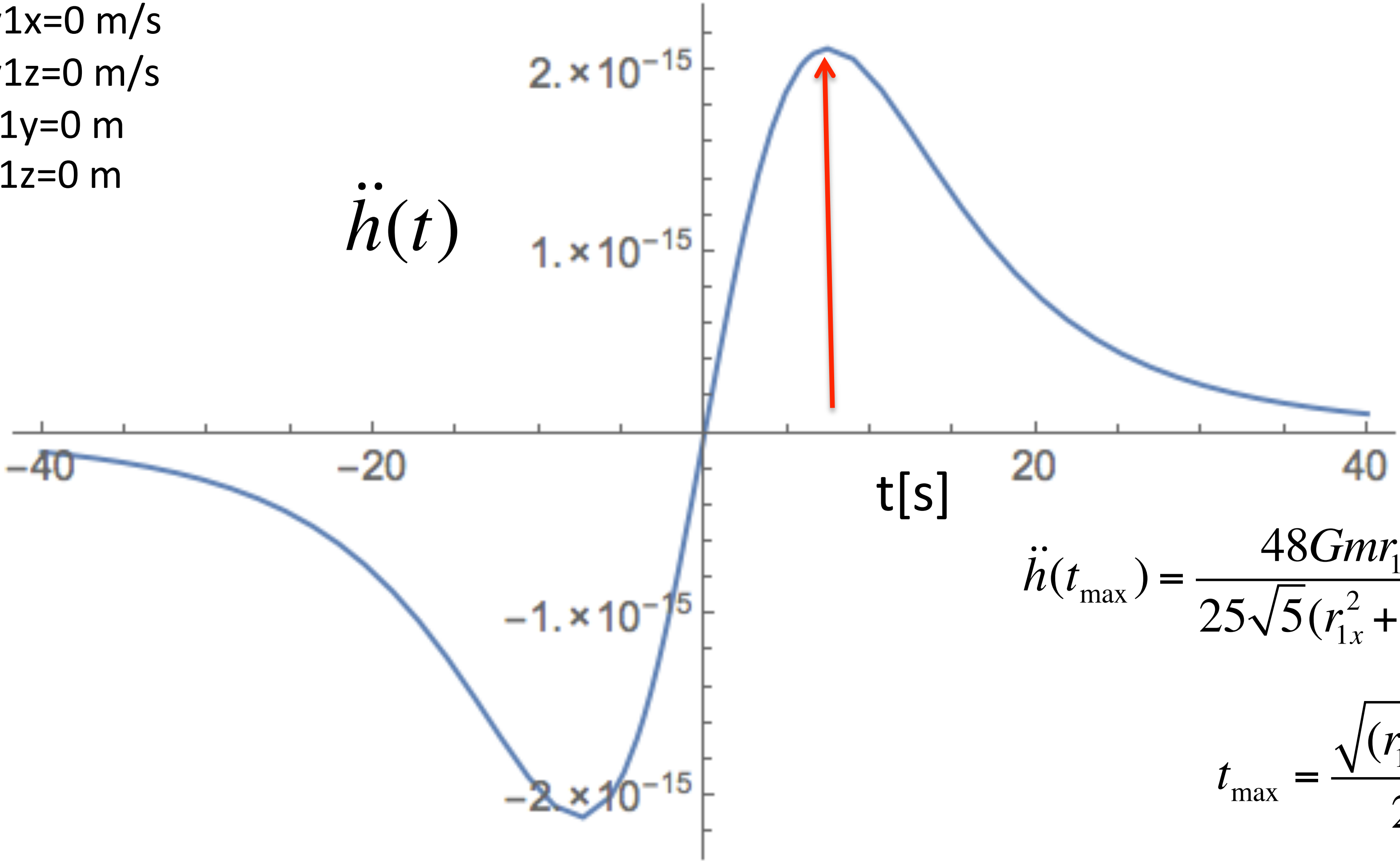
Gravity gradient projection

$$\ddot{h}(\vec{r},t) = \left(\left(\begin{pmatrix}1 & 0 & 0\end{pmatrix}.\ddot{h}_{\mu\nu}.\begin{pmatrix}0\\1\\0\end{pmatrix}\right) - \left(\begin{pmatrix}0 & 1 & 0\end{pmatrix}.\ddot{h}_{\mu\nu}.\begin{pmatrix}-1\\0\\0\end{pmatrix}\right)\right)\Big/2$$

$$\ddot{h}(t) = \frac{3Gm(r1x+(v1x(t-t1)))(r1y+(v1y(t-t1)))}{((r1x+(v1x(t-t1)))^2+(r1y+(v1y(t-t1)))^2+(r1z+(v1z(t-t1)))^2)^{5/2}}$$

Moving objects NN in TOBA

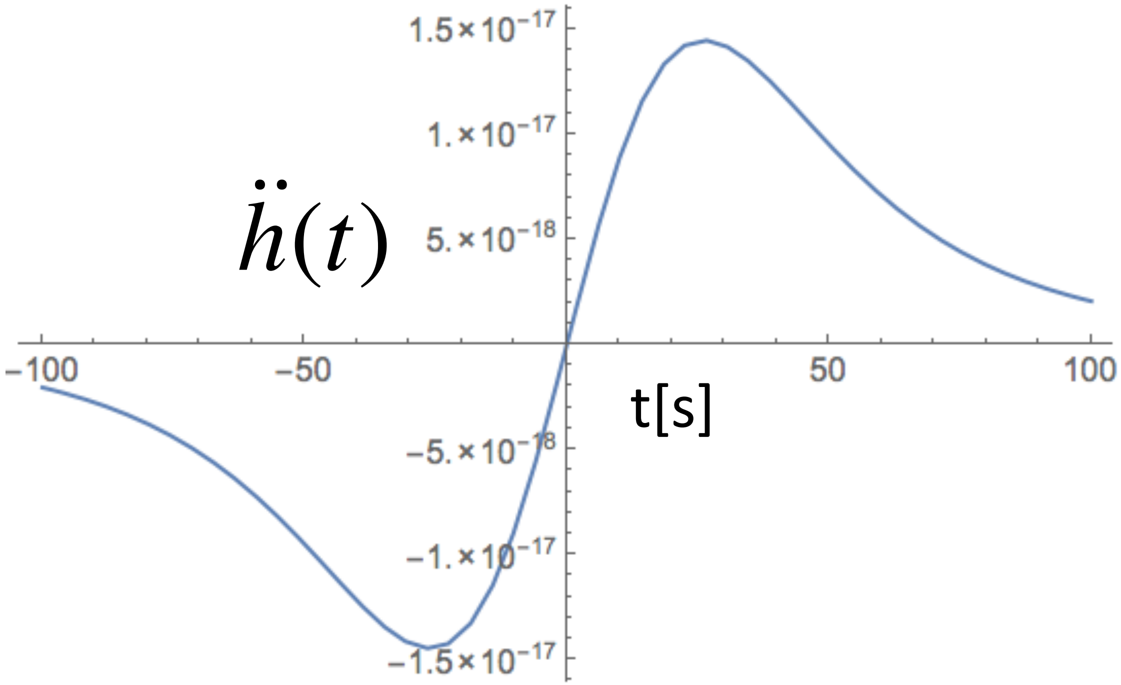
$G=6.67\text{x}10^{-11}\ \text{m}^3/\text{kg s}^2$
m= 1000 kg
r1x=300 m
v1y=20 m/s
t1=0s
v1x=0 m/s
v1z=0 m/s
r1y=0 m
r1z=0 m



$$\ddot{h}(t_{\max}) = \frac{48Gmr_{1x}}{25\sqrt{5}(r_{1x}^2+r_{1z}^2)^2}$$

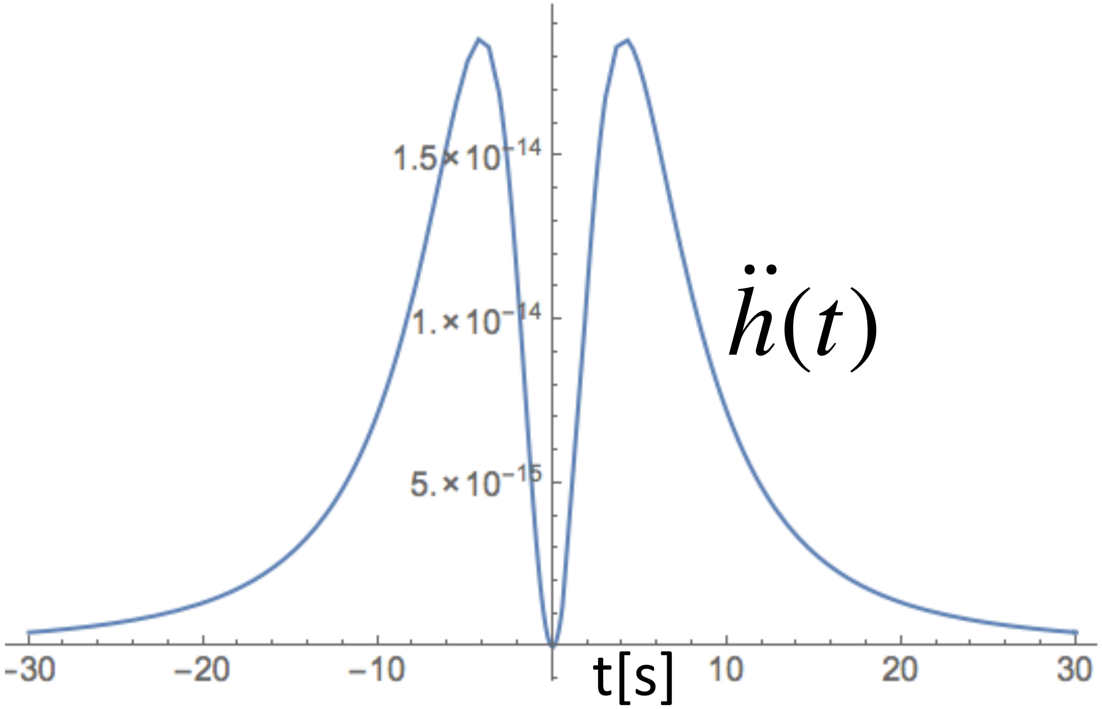
$$t_{\max} = \frac{\sqrt{(r_{1x}^2+r_{1z}^2)}}{2v_{1y}}$$

Moving objects NN in TOBA

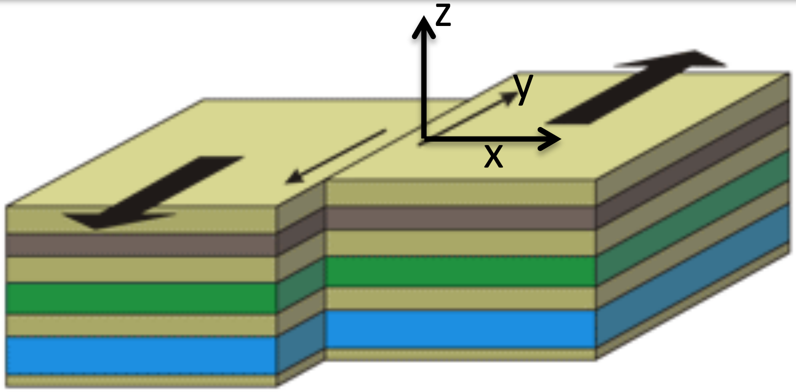


$G=6.67\times10^{-11}\ m^3/kg\ s^2$
m= 1000 kg
r1x=300 m
v1y=20 m/s
t1=0s
v1x=0 m/s
v1z=0 m/s
r1y=0 m
r1z=1000 m

$G=6.67\times10^{-11}\ m^3/kg\ s^2$
m= 1000 kg
r1x=0m
v1y=14.14 m/s
t1=0s
v1x=14.14 m/s
v1z=0 m/s
r1y=0 m
r1z=100 m



Earthquake prompt gravity perturbations



$$\delta\psi(\mathbf{r}_0\,,t) = -R_{\mathrm{P}}(\theta_0,\phi_0)\frac{3G}{r_0^3}I_2[M_0](t).\ ^{*}$$

*Equation (12)-Geophys.J.Int.(2015)201,1416-1425

$$R_p = 2\frac{x}{\sqrt{x^2+y^2+z^2}}\frac{y}{\sqrt{x^2+y^2+z^2}}$$

$$\psi(\vec{r},t) = -2\frac{x}{\sqrt{x^2+y^2+z^2}}\frac{y}{\sqrt{x^2+y^2+z^2}}\frac{3GI_2[Mo(t)]}{\left(\sqrt{x^2+y^2+z^2}\right)^3}$$

$$I_2[Mo(t)] = \frac{Mot^5}{20}$$

$$Mo = 1.5\times10^{18}\,\mathrm{Nm}$$

$$\ddot{h}_{\mu\nu} = -\nabla\otimes\nabla\psi(\vec{r},t)$$

$$\ddot{h}(\vec{r},t) = \left(\left(\begin{pmatrix}1 & 0 & 0\end{pmatrix}.\ddot{h}_{\mu\nu}.\begin{pmatrix}0\\1\\0\end{pmatrix}\right) - \left(\begin{pmatrix}0 & 1 & 0\end{pmatrix}.\ddot{h}_{\mu\nu}.\begin{pmatrix}-1\\0\\0\end{pmatrix}\right)\right)\Big/2$$

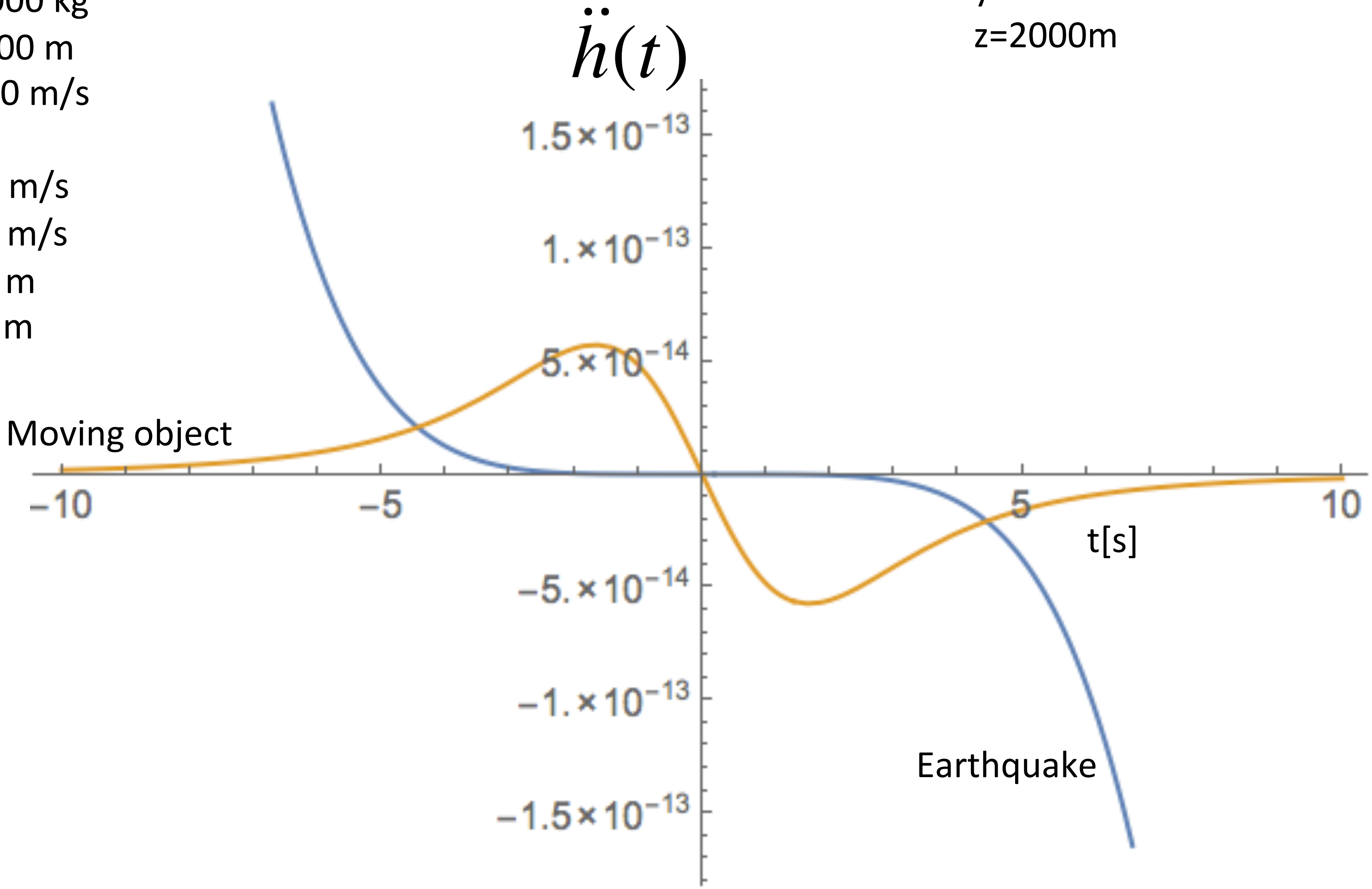
Earthquake vs Moving object gravity perturbations

Parameters for moving object:

$G=6.67\times10^{-11}\ m^3/kg\ s^2$
m= 1000 kg
r1x=100 m
v1y=30 m/s
t1=0s
v1x=0 m/s
v1z=0 m/s
r1y=0 m
r1z=0 m

Parameters for Earthquakes:

x=100000m
y=0m
z=2000m



Conclusions and Perspectives

Infrasound Noise:

- Lower than $10^{-15}/\sqrt{Hz}$ @0.1 Hz for median and low pressure fluctuation models
- Need for suitable microphones at low frequencies (e.g.≈ 10mHz)
- Characterization of the detector sites in terms of pressure fluctuations
- Building effect to be considered while modeling IN NN in the detector sites

Seismic Noise:

- Lower than $10^{-15}/\sqrt{Hz}$ @0.1 Hz
- Possibility for efficient seismic NN cancellation

Moving objects at constant speed:

- Conditions can be found to have analogies with signal from earthquake prompt gravity perturbation
- it seems always possible to distinguish the earthquakes signal