



Impact of correlated seismic and correlated Newtonian noise on stochastic searches at the Einstein Telescope

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Co-located interferometers

The ET's triangular design

- ❖ leads to (nearly) co-located interferometers
- ❖ 5 possible short distance coupling locations
- ❖ B and C; aligned; 300m - 500m
- ❖ A, D and E; 60° angle ; 330m - 560m
- ❖ understand risk of other noise sources to be correlated on these short distance
- ❖ if correlated over long distances (~10km), additional coupling locations

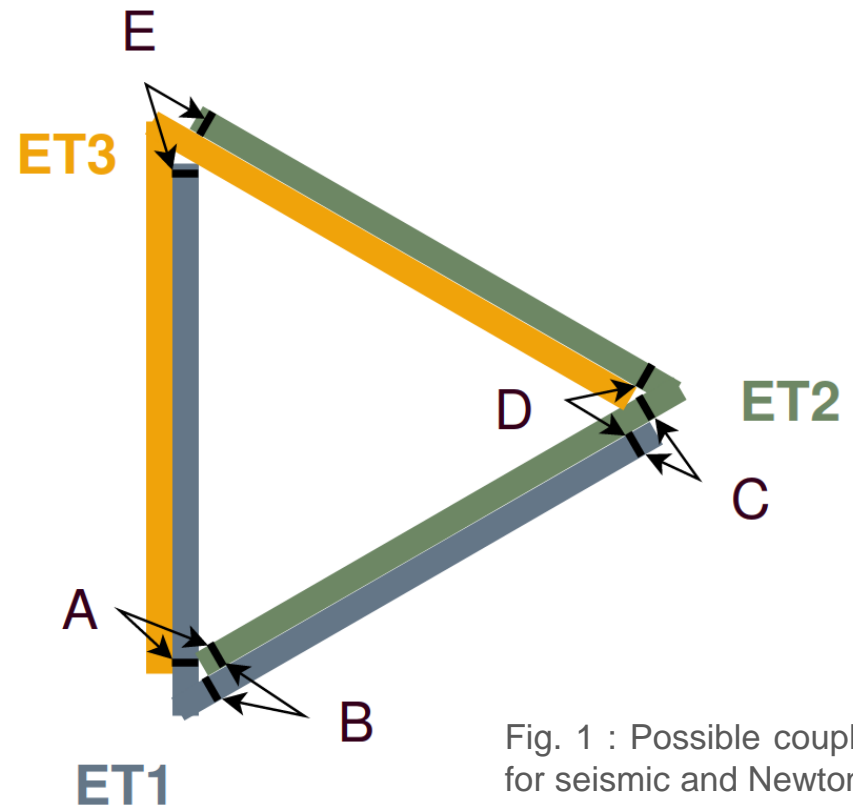


Fig. 1 : Possible coupling locations for seismic and Newtonian noise.

K. Janssens, et al, Phys. Rev. D 106, 042008 - <https://doi.org/10.1103/PhysRevD.106.042008>

Correlated seismic noise

Seismic correlations ($\Delta x=400\text{m}$, depth = 610m)

- ❖ 50% of time significant coherence $\sim 40\text{Hz}$
- ❖ night = less anthropogenic noise = higher coherence = lower CSD

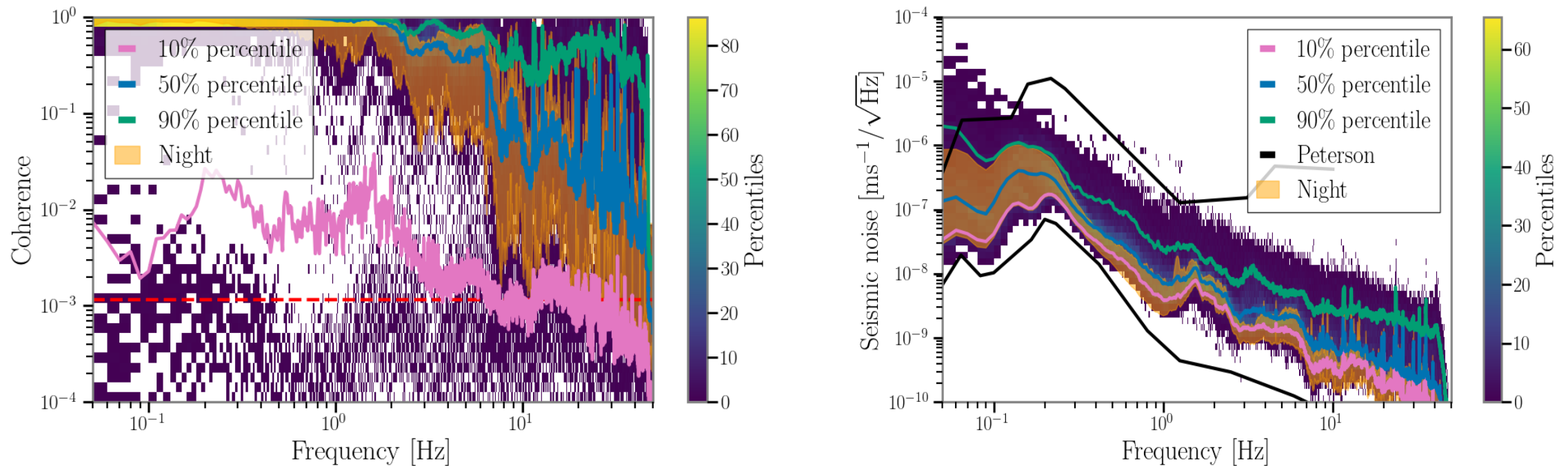


Fig. 2 (3) : Seismic coherence (correlation), measured at Homestake (US).

K. Janssens, et al, Phys. Rev. D 106, 042008 - <https://doi.org/10.1103/PhysRevD.106.042008>

Correlated Newtonian noise

Body waves

$$S_{\text{Body-wave}}(f) = \left(\frac{4\pi}{3} G \rho_{0,\text{Bulk}} \right)^2 (3p+1) \frac{1}{L^2 (2\pi f)^4} S_{\xi_x}(f)$$

Newtonian noise

- ❖ force directly exerted on test mass by density fluctuations in gravitational field.
- ❖ seismic data measured underground (Homestake, US) ($\Delta x=400\text{m}$, depth = 610m)
- ❖ similar contamination as earlier studies (Note: here correlated fields)

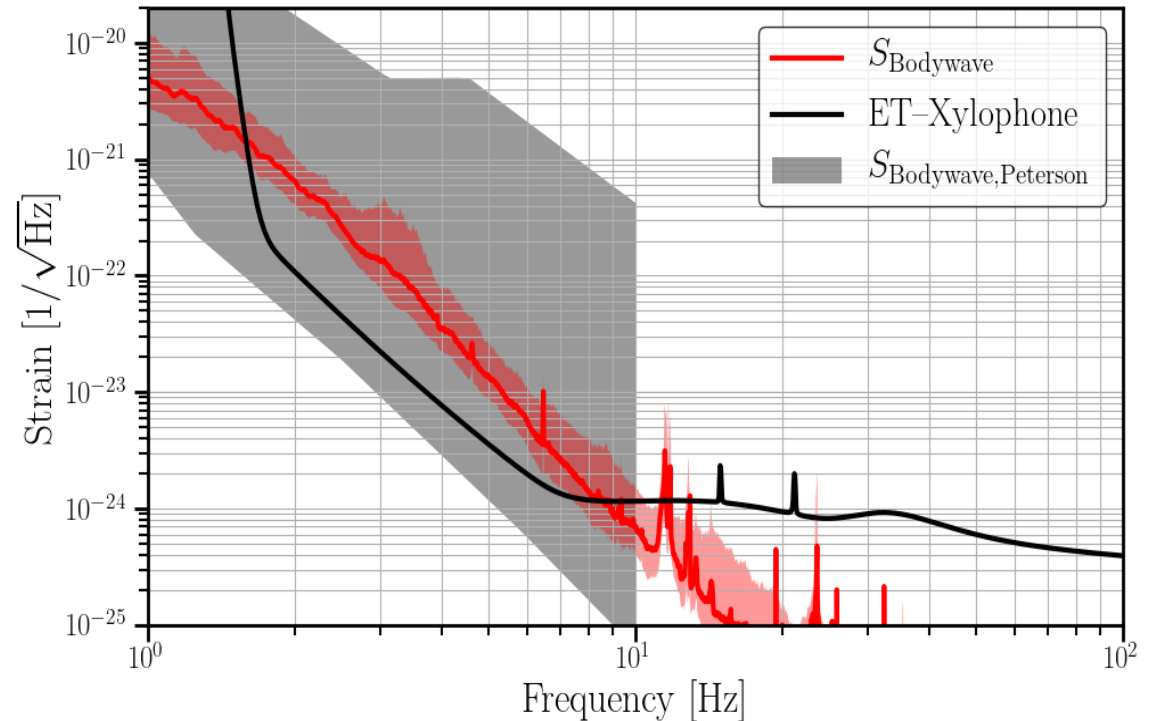


Fig. 4 : Predicted strain from NN from body waves.

K. Janssens, et al, Phys. Rev. D 106, 042008 - <https://doi.org/10.1103/PhysRevD.106.042008>

Impact on the Einstein Telescope

Body waves

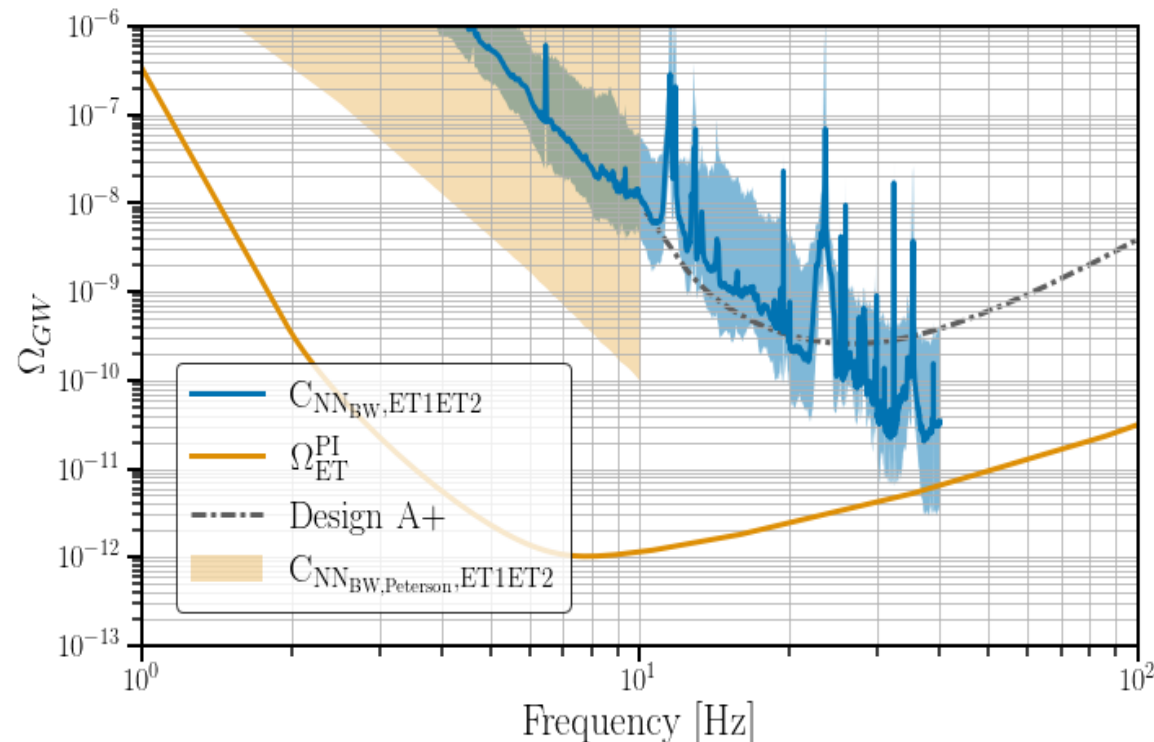


Fig. 5 : Predicted impact of correlated NN from body waves on the search for an isotropic GWB.

K. Janssens, et al, Phys. Rev. D 106, 042008 - <https://doi.org/10.1103/PhysRevD.106.042008>

$$\hat{C}_{\text{NN,ET}_1\text{ET}_2}(f) = N_{\text{NN,ET}_1\text{ET}_2},$$

where
$$N_{\text{NN,ET}_1\text{ET}_2} = \frac{S_{\text{NN}}}{\gamma_{\text{ET}_1\text{ET}_2}(f)S_0(f)}$$

Stochastic budget

- ❖ serious threat for the isotropic GWB search impacted up to ~40Hz
- ❖ @ 3Hz: $8 \cdot 10^6$ (90% percentile), $6 \cdot 10^5$ (50% percentile)
- ❖ understand better site specific noise budgets
- ❖ NN subtraction, factor ~100 (10 per detector) is optimistic

Conclusions & outlook

Correlated (seismic) and Newtonian noise

- ❖ impacts only co-located detectors, e.g. ET
- ❖ serious limit stochastic searches

Possible mitigation techniques

- ❖ noise mitigation (factor 100 is already optimistic)
- ❖ consider separated non-triangular design?
- ❖ more quiet sites

What about ...

- ❖ effect from infrastructural noise: could KAGRA be the ideal testing location?
- ❖ transient seismic effects, e.g. (micro) earthquakes
 - ❖ superposition of these events and their effect on stochastic searches
 - ❖ effect of transient events on other searches
- ❖ the impact on anisotropic stochastic searches

Back-up

Impact on the Einstein Telescope

Seismic noise

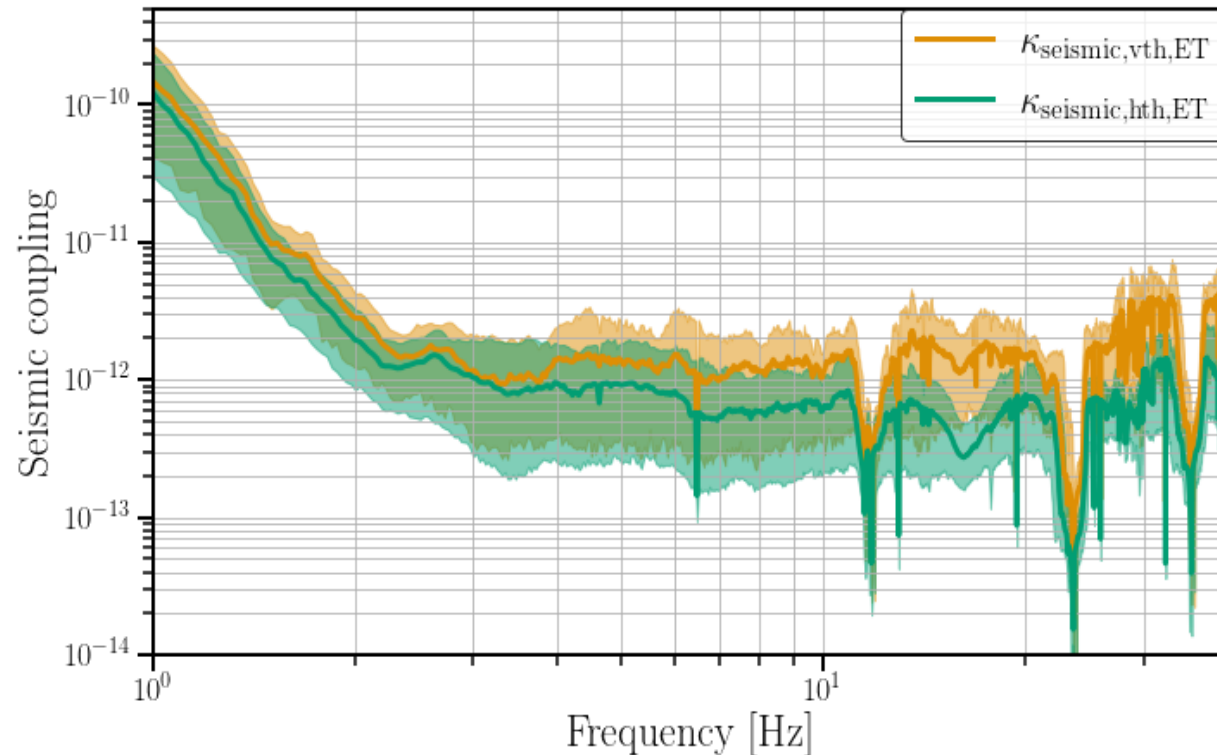


Fig. 6 : Upper limits on the seismic coupling function, such that there is no effect on the search for an isotropic GWB.

K. Janssens, et al, Phys. Rev. D 106, 042008 - <https://doi.org/10.1103/PhysRevD.106.042008>

Provide upper limits for seismic coupling

- ❖ can be used in design of the Einstein telescope
- ❖ assume independent vertical-to-horizontal (vth) and horizontal-to-horizontal (hth) coupling
- ❖ neglect tilt-to-horizontal coupling
- ❖ Fig. 9 presents UL on GWB: no effect on the broadband sensitivity the 'PI-curve' $\Omega_{ET_1 ET_2}^{PI}$
- ❖ h-t-h coupling from Virgo extrapolation reaches 10^{-12} at ~4Hz

Correlated Newtonian noise

Rayleigh waves

$$S_{h,\text{Rayleigh}}(f) = \left(\sqrt{2\pi} G \gamma \rho_{0,\text{Surface}} \right)^2 \frac{1}{L^2 (2\pi f)^4} \mathcal{R}(h, f) S_{\xi_z}(f)$$

$$\mathcal{R}(h, f) = \left| \frac{-k_R(1 + \zeta)e^{-k_R h} + \frac{2}{3}(2k_R e^{-q_P h} + \zeta q_S e^{-q_S h})}{k_R(1 - \zeta)} \right|^2$$

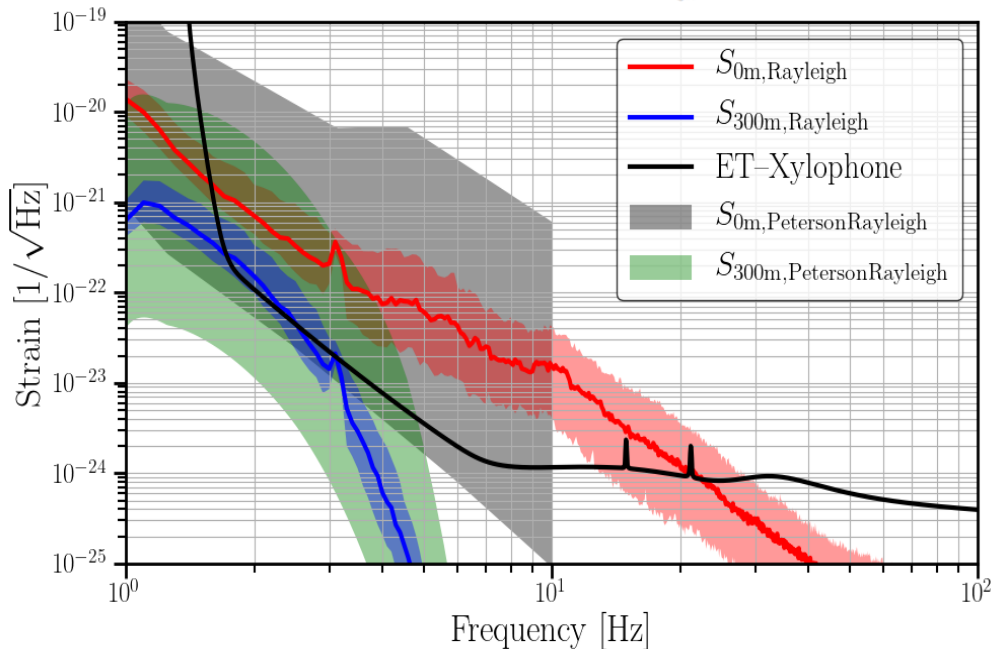


Fig. 7 : Predicted strain from NN from Rayleigh waves.

K. Janssens, et al, Phys. Rev. D 106, 042008 - <https://doi.org/10.1103/PhysRevD.106.042008>

Newtonian noise

- ❖ force directly exerted on test mass by density fluctuations in gravitational field.
- ❖ Rayleigh waves only type of surface waves producing density fluctuations
- ❖ seismic data measured at the surface (Terziet, NL) ($\Delta x=400\text{m}$)
- ❖ used data contains anisotropies
- ❖ underground facility (depth = 300m) significantly reduces induced effect
- ❖ similar contamination as earlier studies (Note: here correlated fields)

$$q_P(f) = \frac{2\pi f}{v_R(f)v_P} \sqrt{v_P^2 - v_R^2(f)}$$

$$q_S(f) = \frac{2\pi f}{v_R(f)v_S} \sqrt{v_S^2 - v_R^2(f)}$$

$$\zeta(f) = \sqrt{\frac{q_P(f)}{q_S(f)}}$$

Impact on the Einstein Telescope

Rayleigh waves

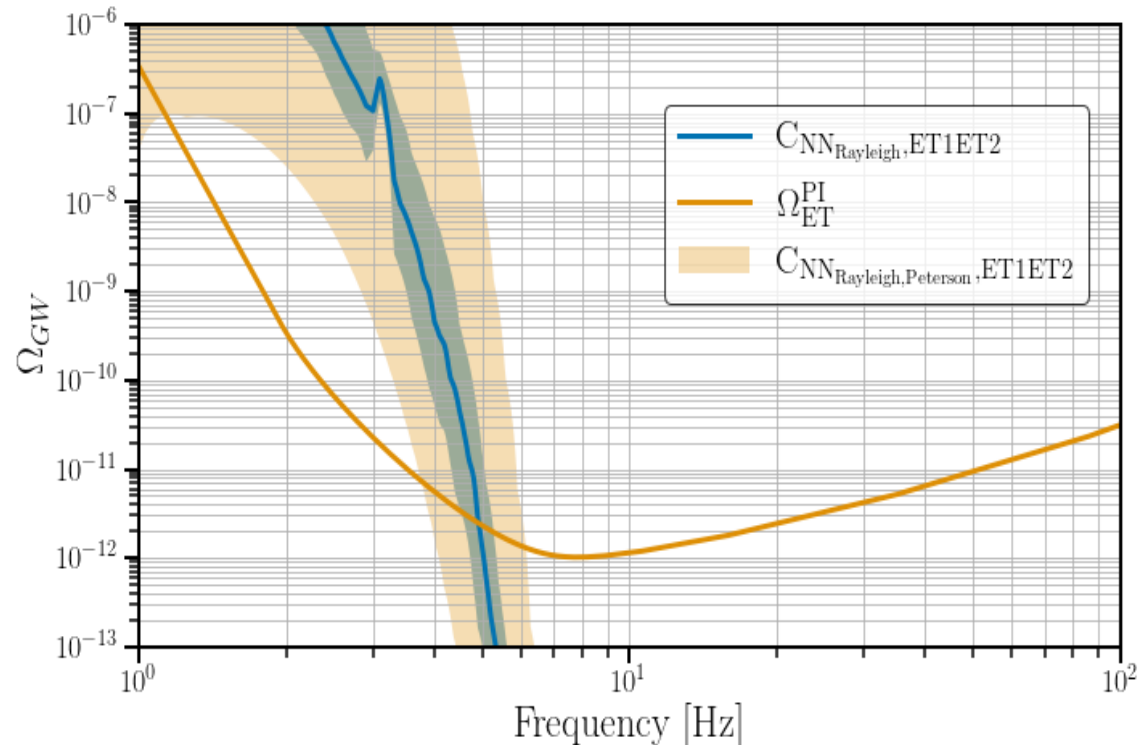


Fig. 8 : Predicted impact of correlated NN from Rayleigh waves on the search for an isotropic GWB.

K. Janssens, et al, Phys. Rev. D 106, 042008 - <https://doi.org/10.1103/PhysRevD.106.042008>

$$\hat{C}_{\text{NN}, \text{ET}_1 \text{ET}_2}(f) = N_{\text{NN}, \text{ET}_1 \text{ET}_2},$$

where $N_{\text{NN}, \text{ET}_1 \text{ET}_2} = \frac{S_{\text{NN}}}{\gamma_{\text{ET}_1 \text{ET}_2}(f) S_0(f)}$

Stochastic budget

- ❖ isotropic GWB search impacted up to ~5Hz
- ❖ mainly independent of site, day-night, ... dominant reduction caused by underground facility