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

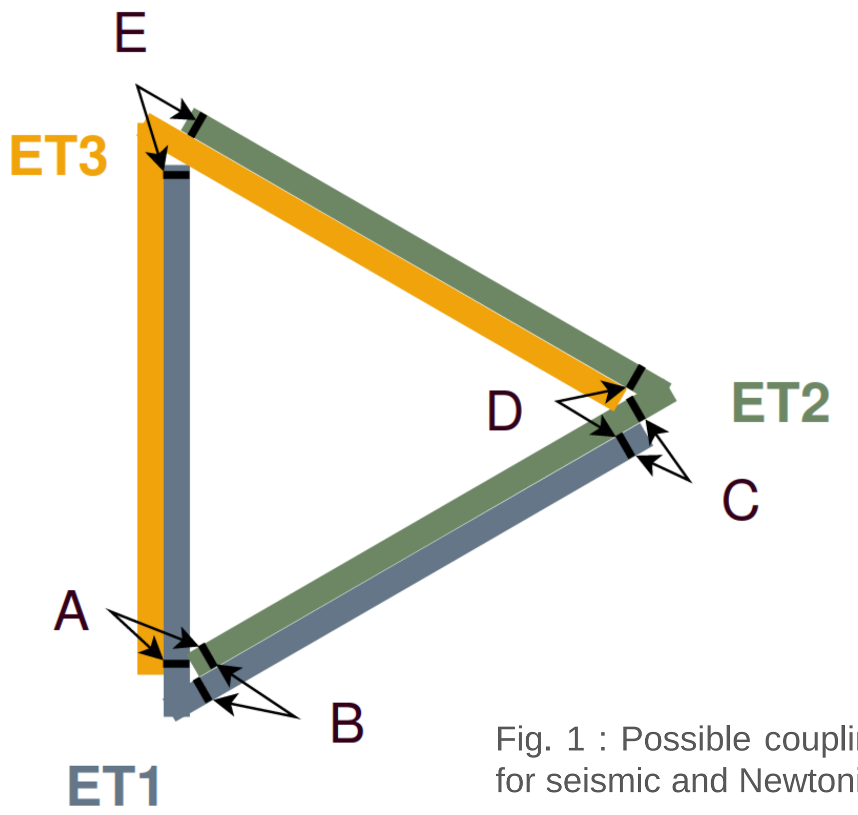
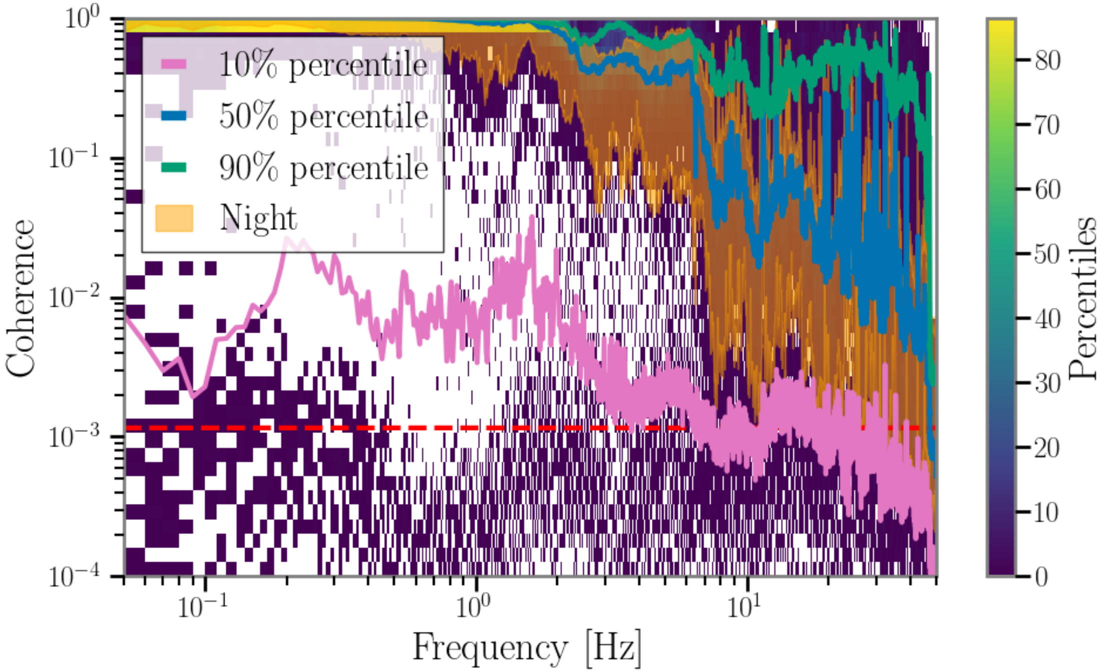


Fig. 1 : Possible coupling locations for seismic and Newtonian noise.

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

Correlated seismic noise

Seismic correlations (Δx=400m, depth = 610m)
- 50% of time significant coherence ~40Hz
- night = less anthropogenic noise = higher coherence = lower CSD



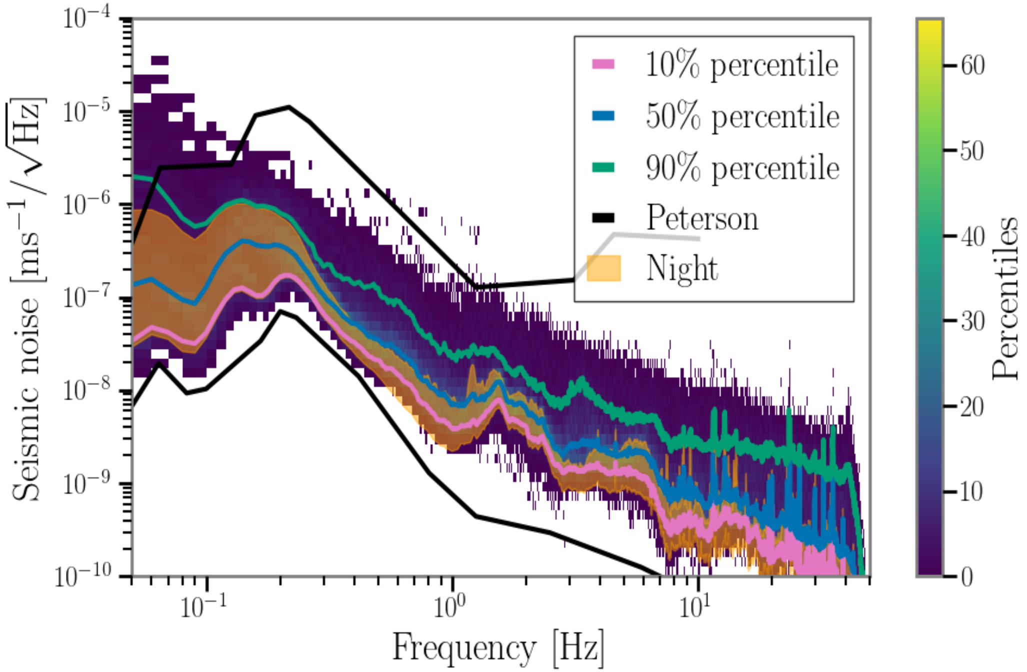


Fig. 2 (3) : Seismic coherence (correlation), measured at Homestake (US).

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Impact on the Einstein Telescope

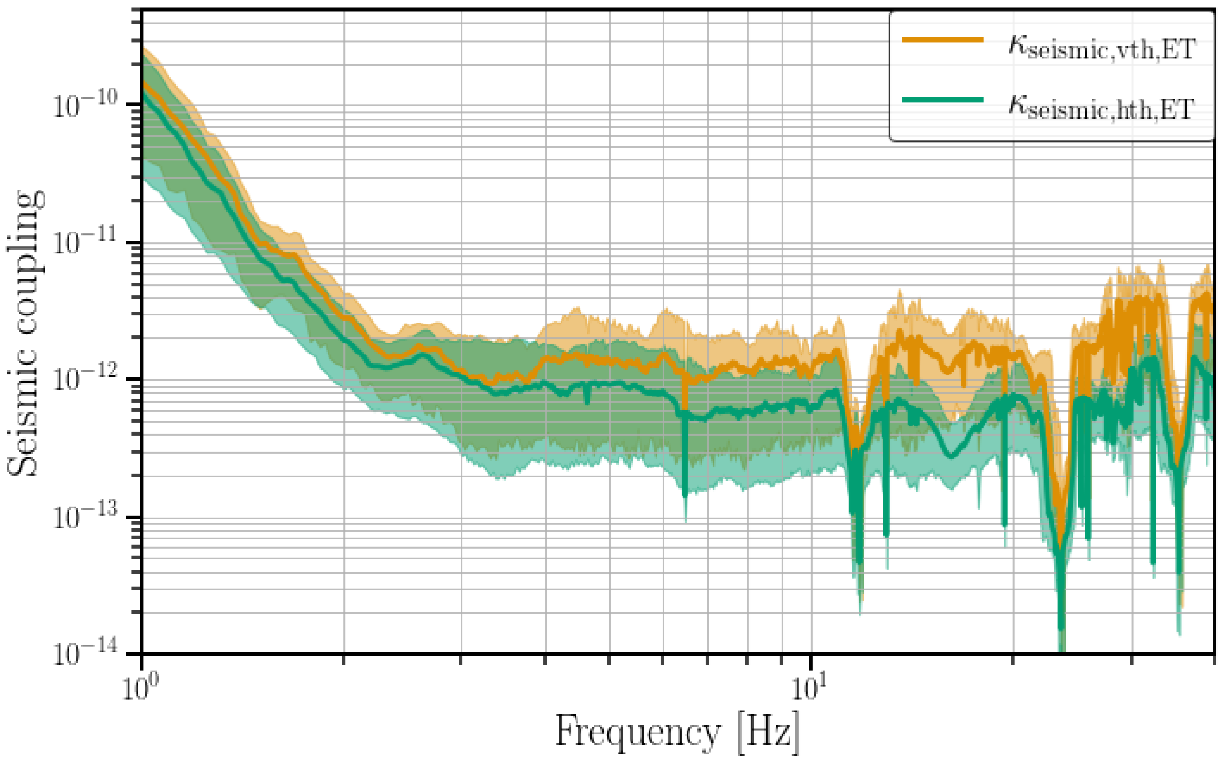

Fig. 4 : Upper limits on the seismic coupling function, such that there is no effect on the search for an isotropic GWB.

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' $\Omega^{PI}_{ET_1 ET_2}$
- ❖ h-t-h coupling from Virgo extrapolation reaches 10^{-12} at ~4Hz

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) (Δx=400m, depth = 610m)
- similar contamination as earlier studies (Note: here corelated fields)

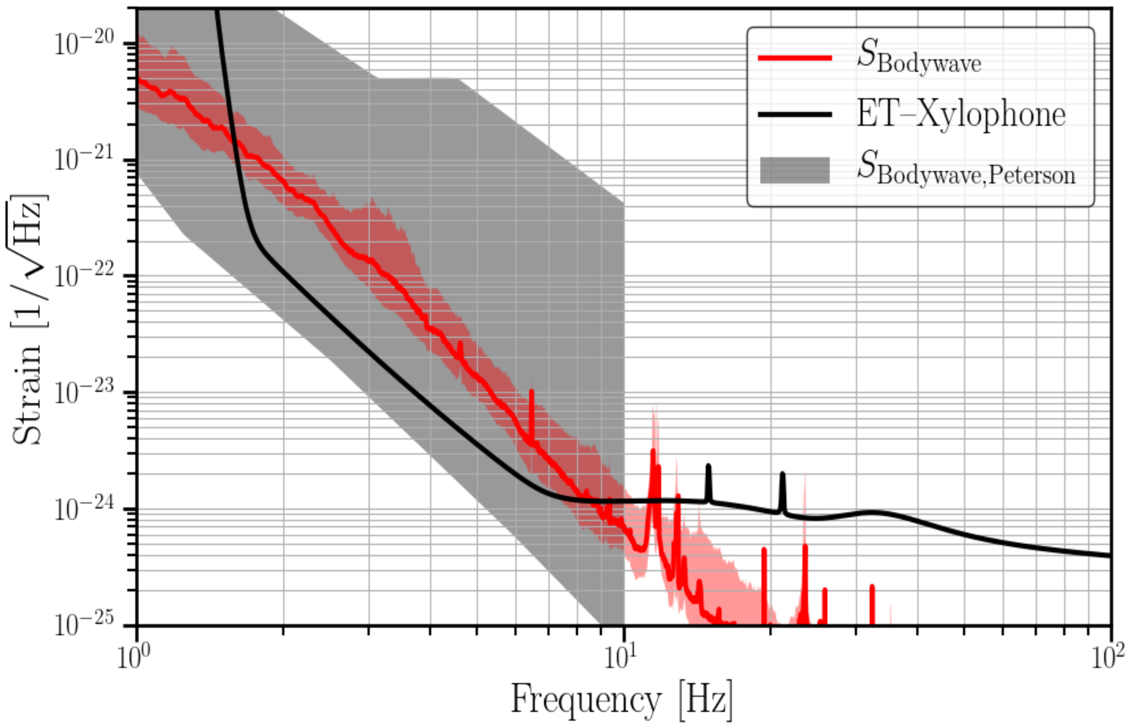

Fig. 5 : Predicted strain from NN from body waves.

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Impact on the Einstein Telescope

Body waves

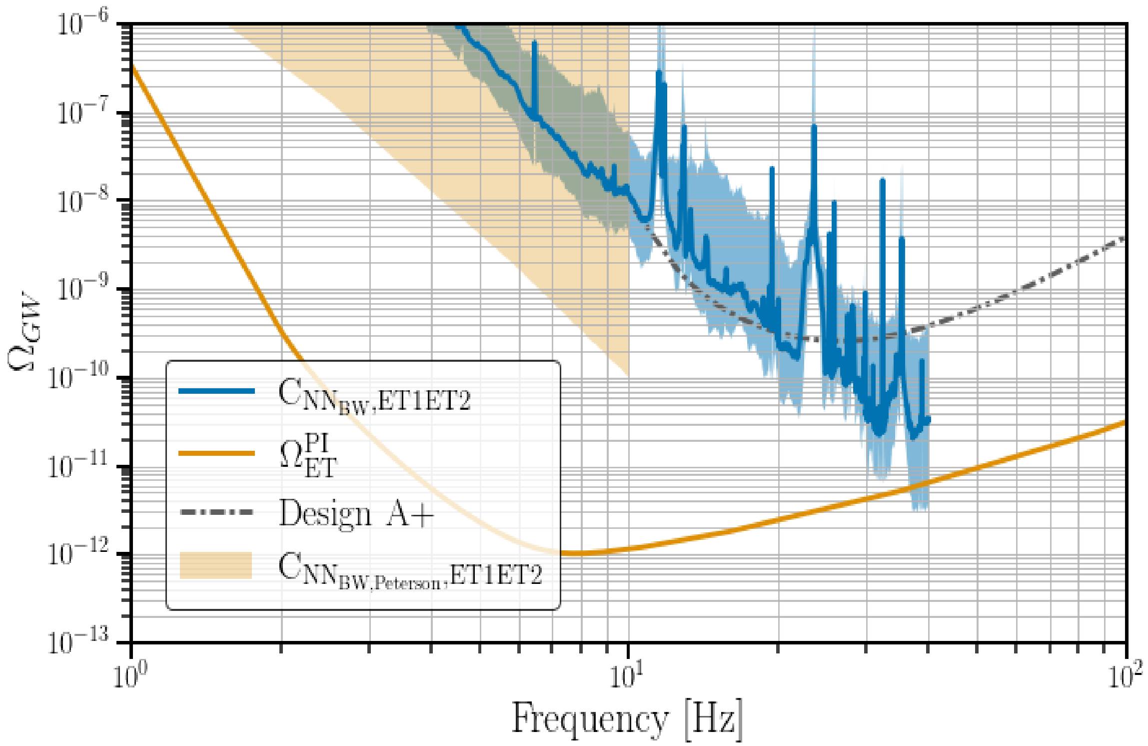

Fig. 6 : Predicted impact of correlated NN from body waves on the search for an isotropic GWB.

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

$$\hat{C}_{\mathrm{NN,ET_1ET_2}}(f) = N_{\mathrm{NN,ET_1ET_2}},$$

$$\text{where} \quad N_{\mathrm{NN,ET_1ET_2}} = \frac{S_{\mathrm{NN}}}{\gamma_{\mathrm{ET_1ET_2}}(f) S_0(f)}$$

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 by 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

Correlated Newtonian noise
Rayleigh waves

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

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

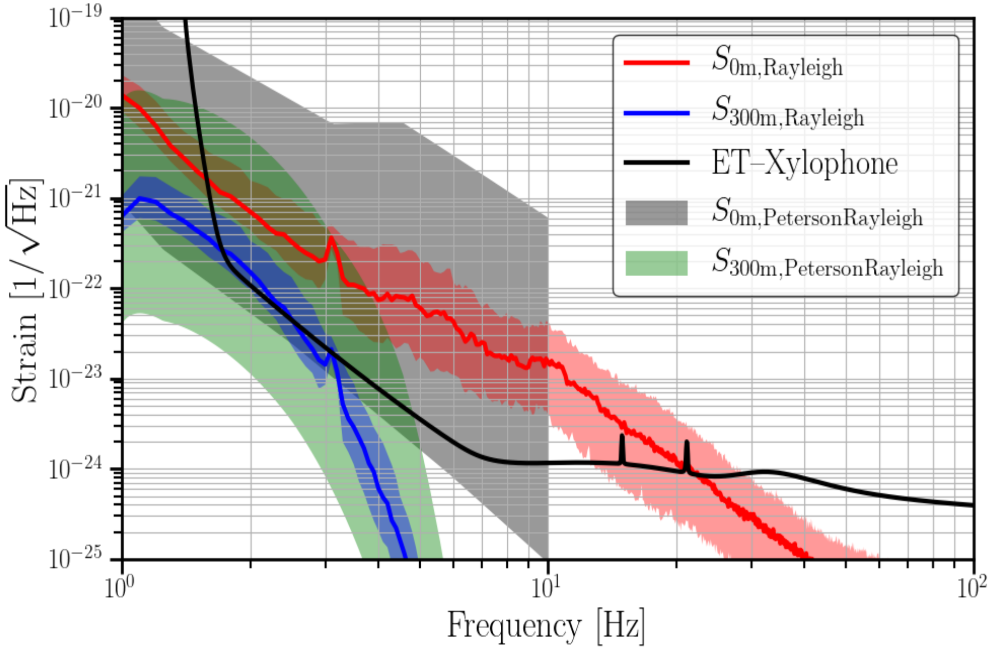

Fig. 7 : Predicted strain from NN from Rayleigh waves.

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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) (Δx=400m)
- used data contains anisotropies
- underground facility (depth = 300m) significantly reduces induced effect
- similar contamination as earlier studies (Note: here corelated 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

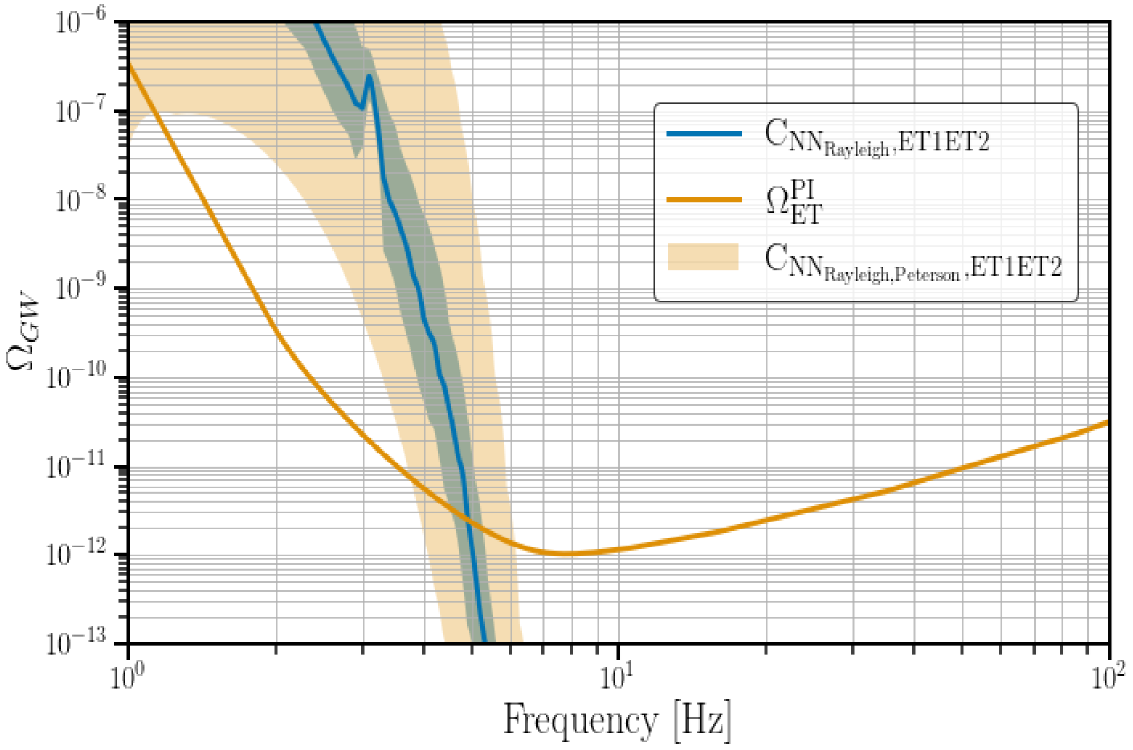

Fig. 8 : Predicted impact of correlated NN from Rayleigh waves on the search for an isotropic GWB.

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$$\hat{C}_{\mathrm{NN,ET_1ET_2}}(f) = N_{\mathrm{NN,ET_1ET_2}},$$

$$\text{where} \quad N_{\mathrm{NN,ET_1ET_2}} = \frac{S_{\mathrm{NN}}}{\gamma_{\mathrm{ET_1ET_2}}(f) S_0(f)}$$

Stochastic budget

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