A Sound of Thunder
Atmospheric Gravitational Noise

Teviet Creighton

University of Texas at Brownsville

A. Infrasonic Newtonian Noise
B. Thermal Newtonian Noise
C. Transients

A. Infrasonic Newtonian Noise

- $$\sqrt{S_h} \;\sim\; 4\pi G\rho\,\frac{\sqrt{S_p}}{\gamma p}\,\frac{1}{\omega^2} \quad\times\quad \begin{cases} v/\omega L & \text{if} \quad \omega \gtrsim v/L \\ Q^2(v/\omega d)^3 & \text{if} \quad \omega \gtrsim Qv/d \end{cases}$$

  where $v \approx 300\,\mathrm{m/s}$, $L =$ arm length, $d =$ exclusion distance.

- For $f \sim 10\,\mathrm{Hz}$, $\lambda \sim 30\,\mathrm{m}$, spatial correlations $\sim$ several λ.

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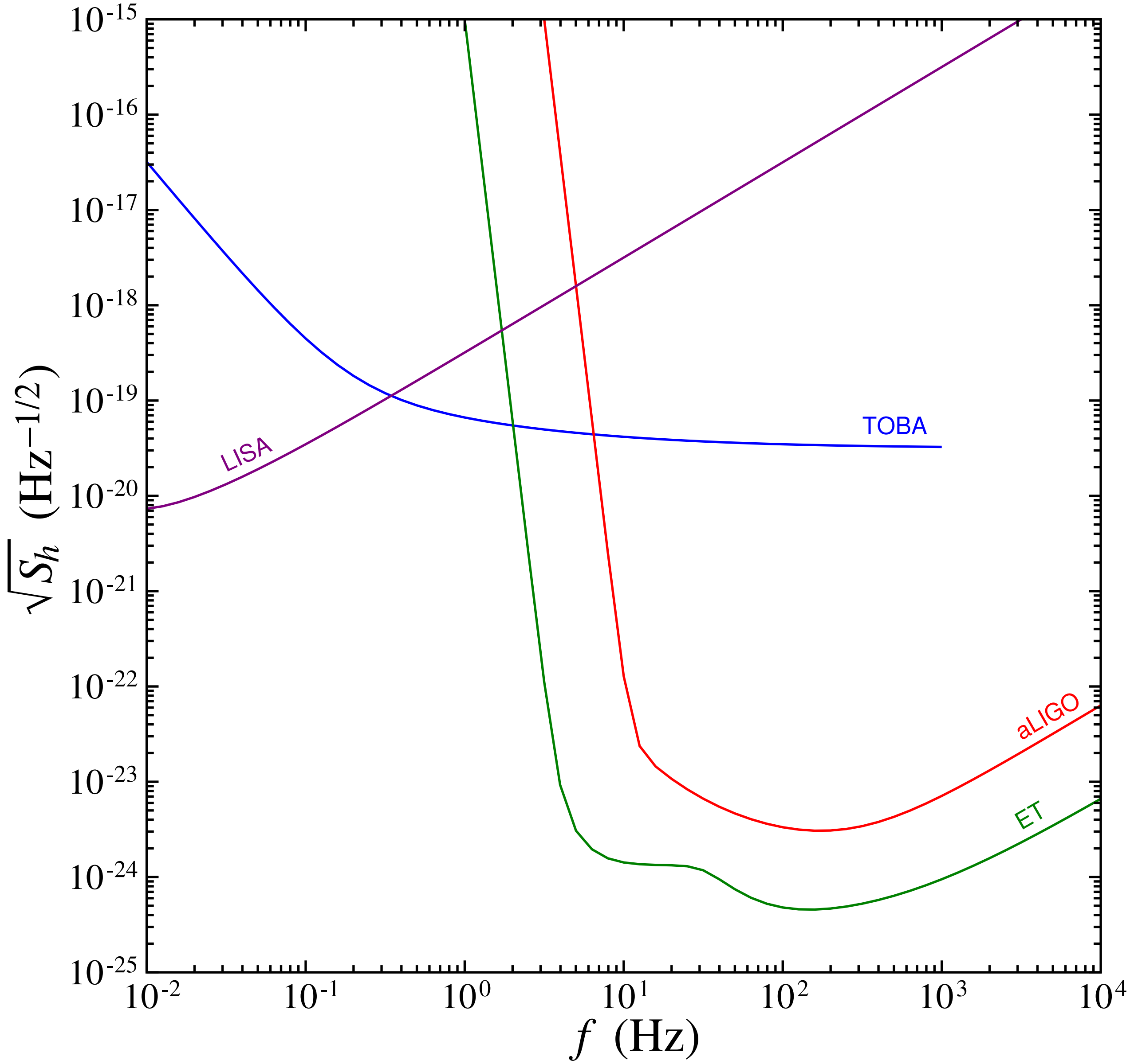
- For $f \sim 10\,\mathrm{Hz}$, $\lambda \sim 30\,\mathrm{m}$, spatial correlations $\sim$ several λ.

- Disturbance typically dominated by gravity difference from nearest wave crest and trough.

$$\sqrt{S_h} \approx \left(2\times 10^{-21}\mathrm{Hz}^{-1/2}\right)\left(\frac{\sqrt{S_p}}{3\,\mathrm{mPa\,Hz}^{-1/2}}\right)\left(\frac{f}{\mathrm{Hz}}\right)^{-3} \quad \text{(4km)}$$

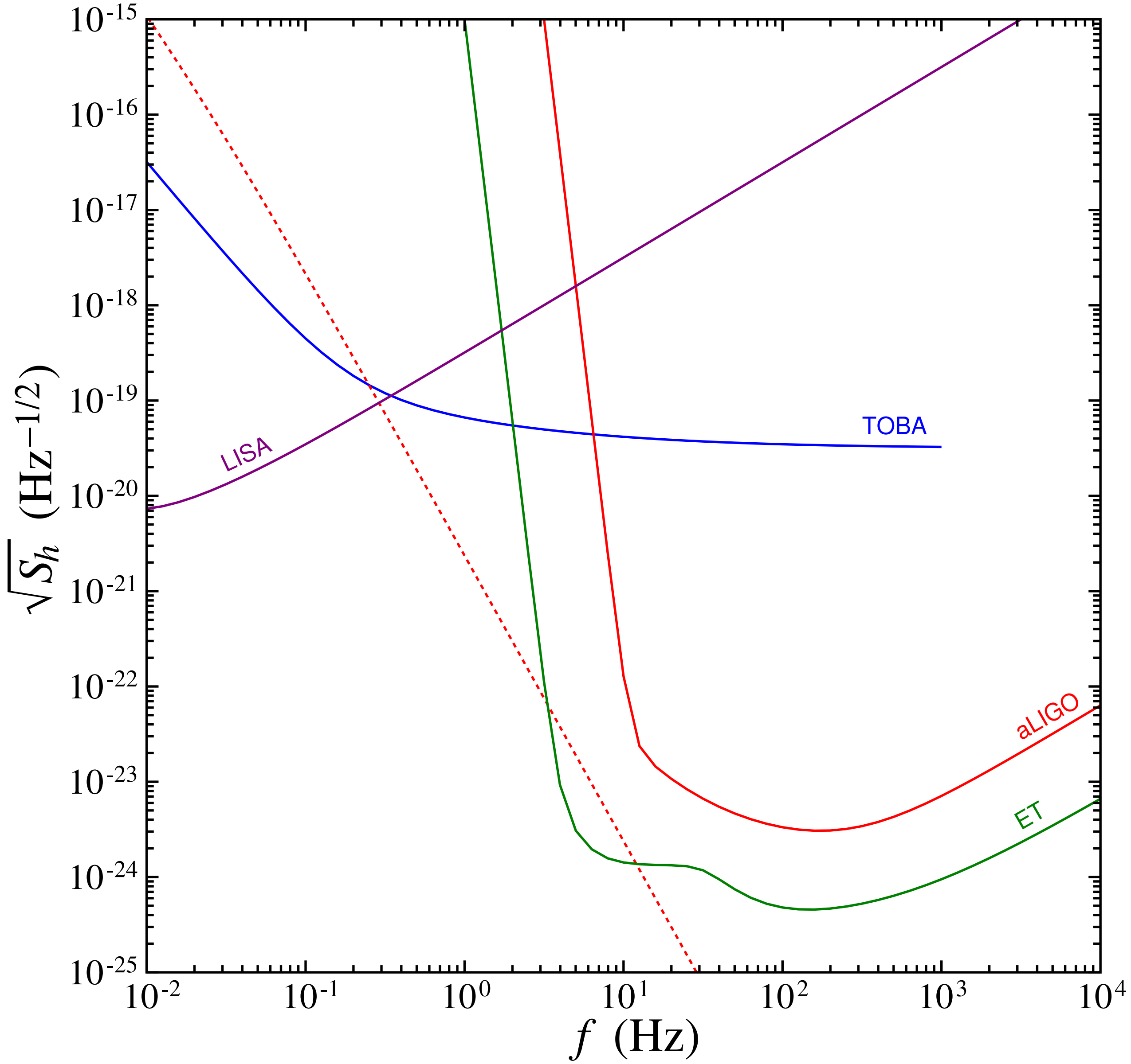
$$\approx \left(2\times 10^{-19}\mathrm{Hz}^{-1/2}\right)\left(\frac{\sqrt{S_p}}{3\,\mathrm{mPa\,Hz}^{-1/2}}\right)\left(\frac{f}{\mathrm{Hz}}\right)^{-2} \quad \text{(gradiometer)}$$

A. Infrasonic Newtonian Noise



Unshielded NN

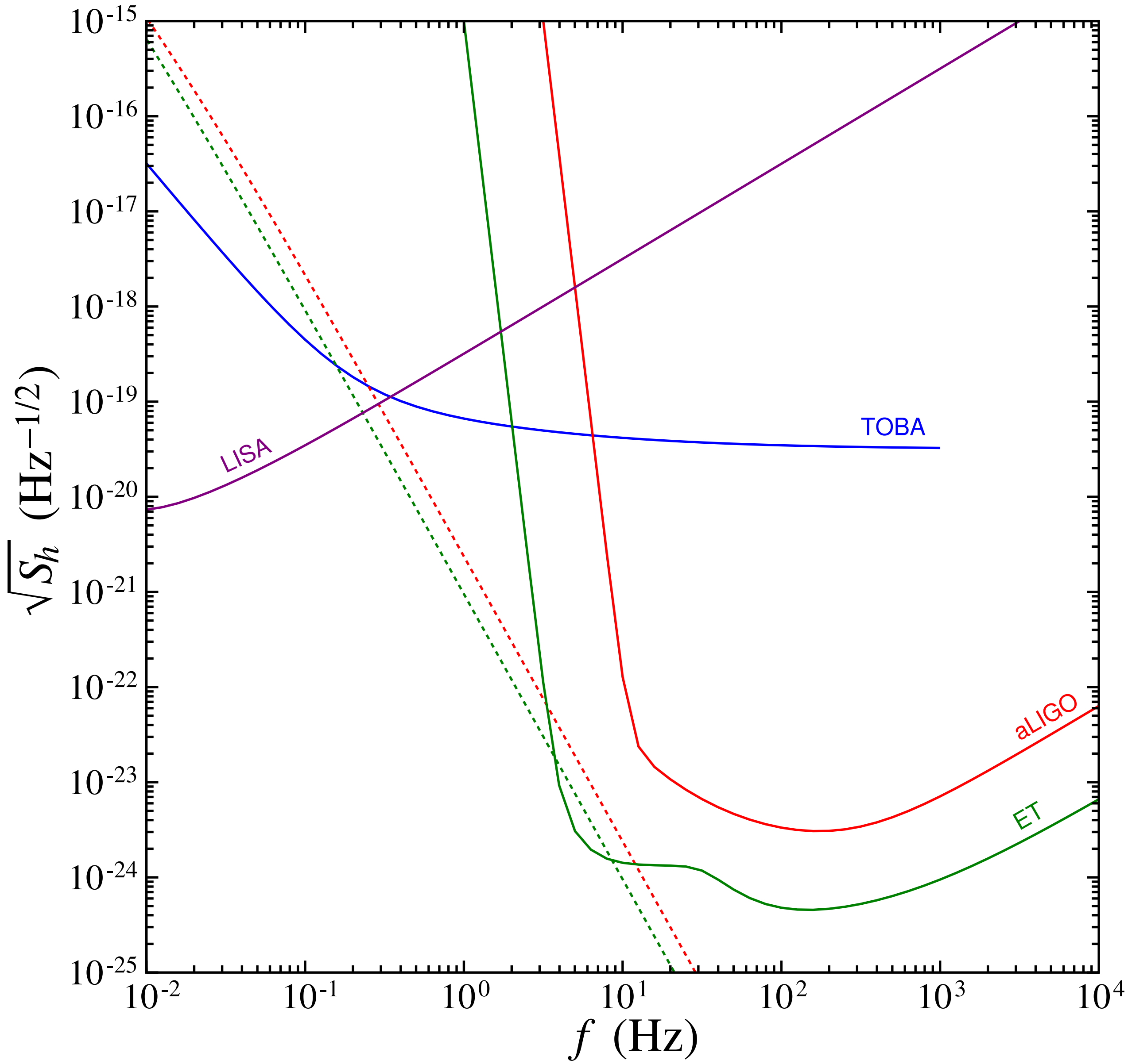
A. Infrasonic Newtonian Noise



Unshielded NN

4km arms

A. Infrasonic Newtonian Noise

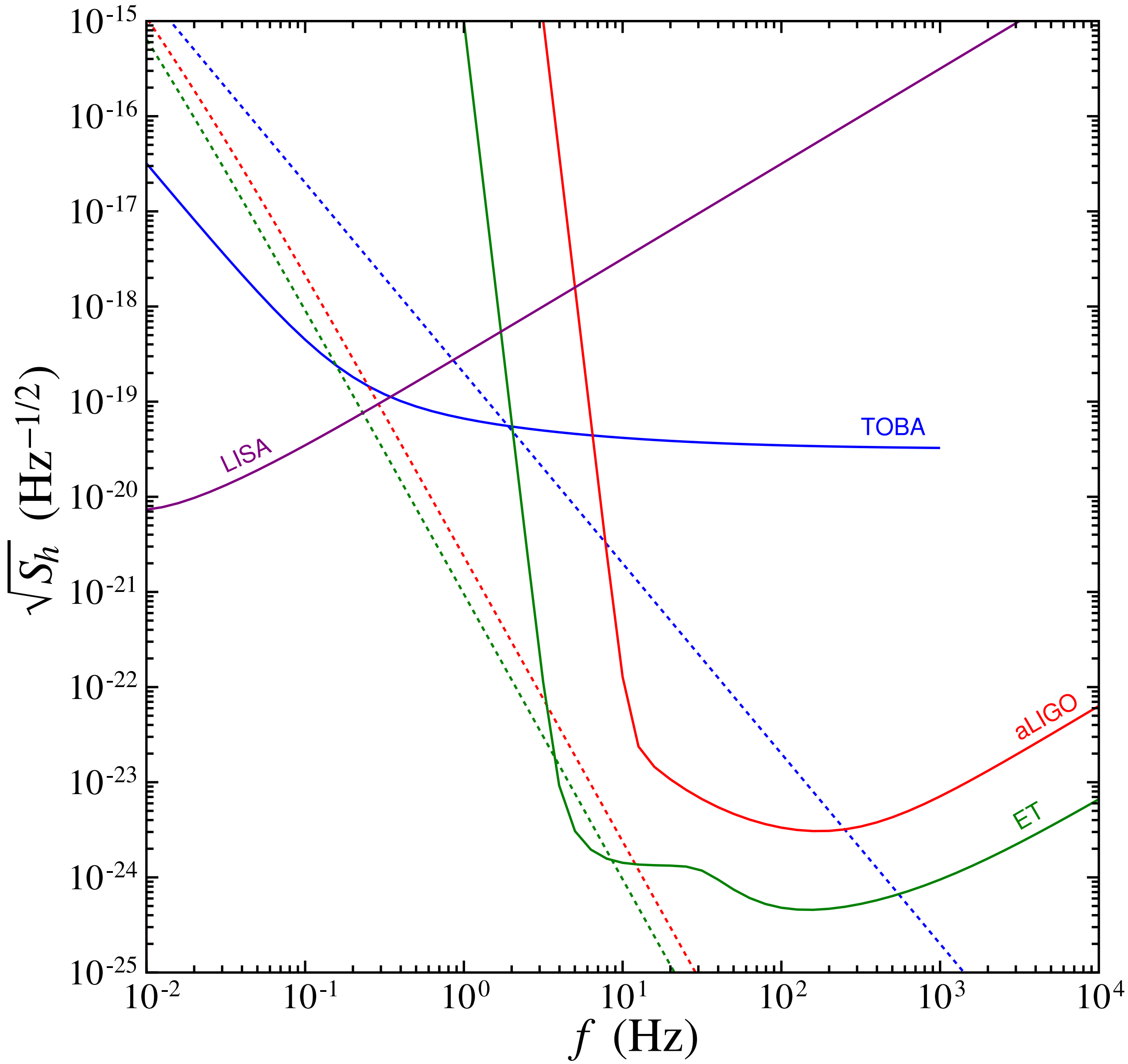


Unshielded NN

4km arms

10km arms

A. Infrasonic Newtonian Noise



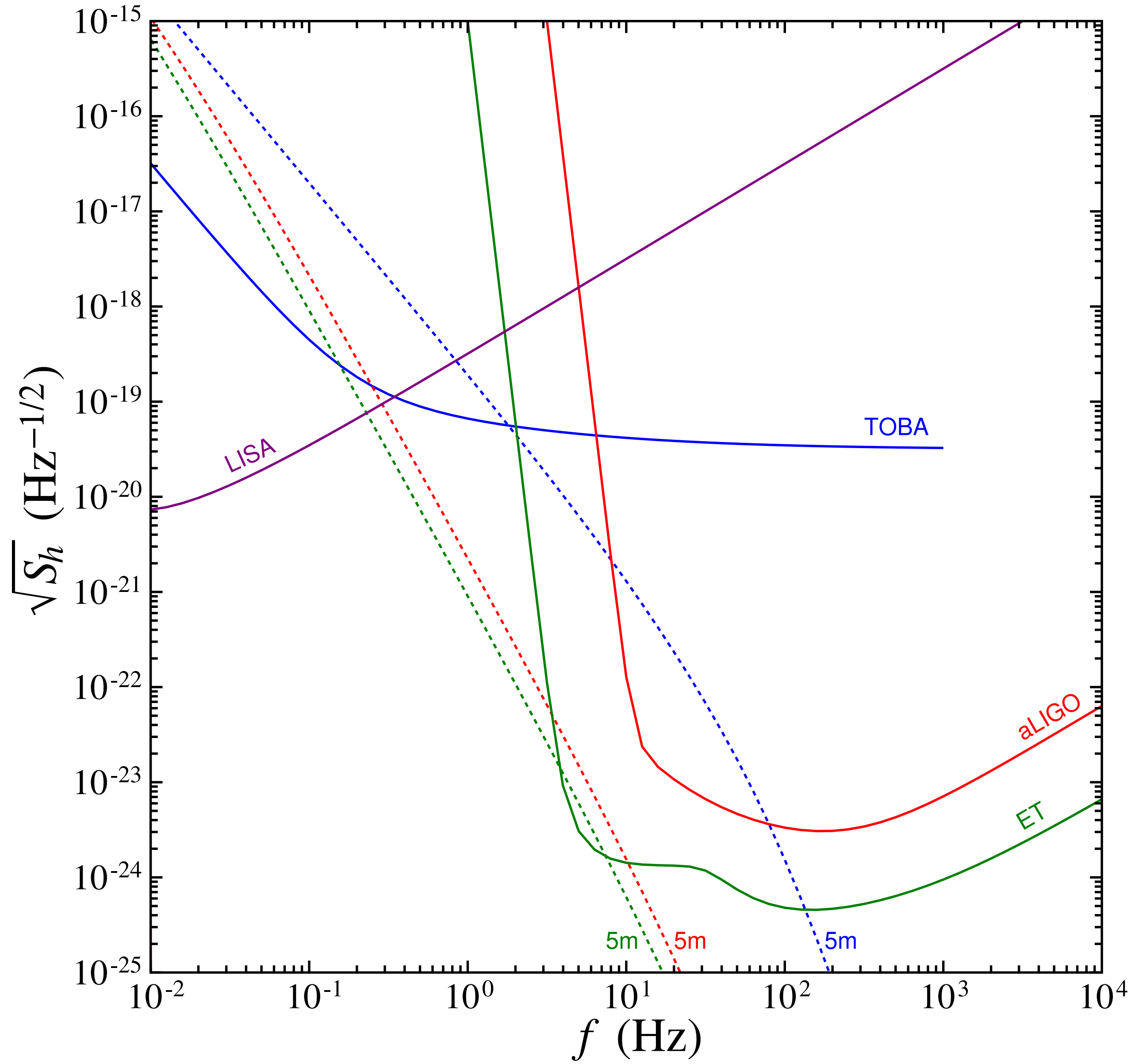
Unshielded NN

4km arms

10km arms

gradiometer

A. Infrasonic Newtonian Noise



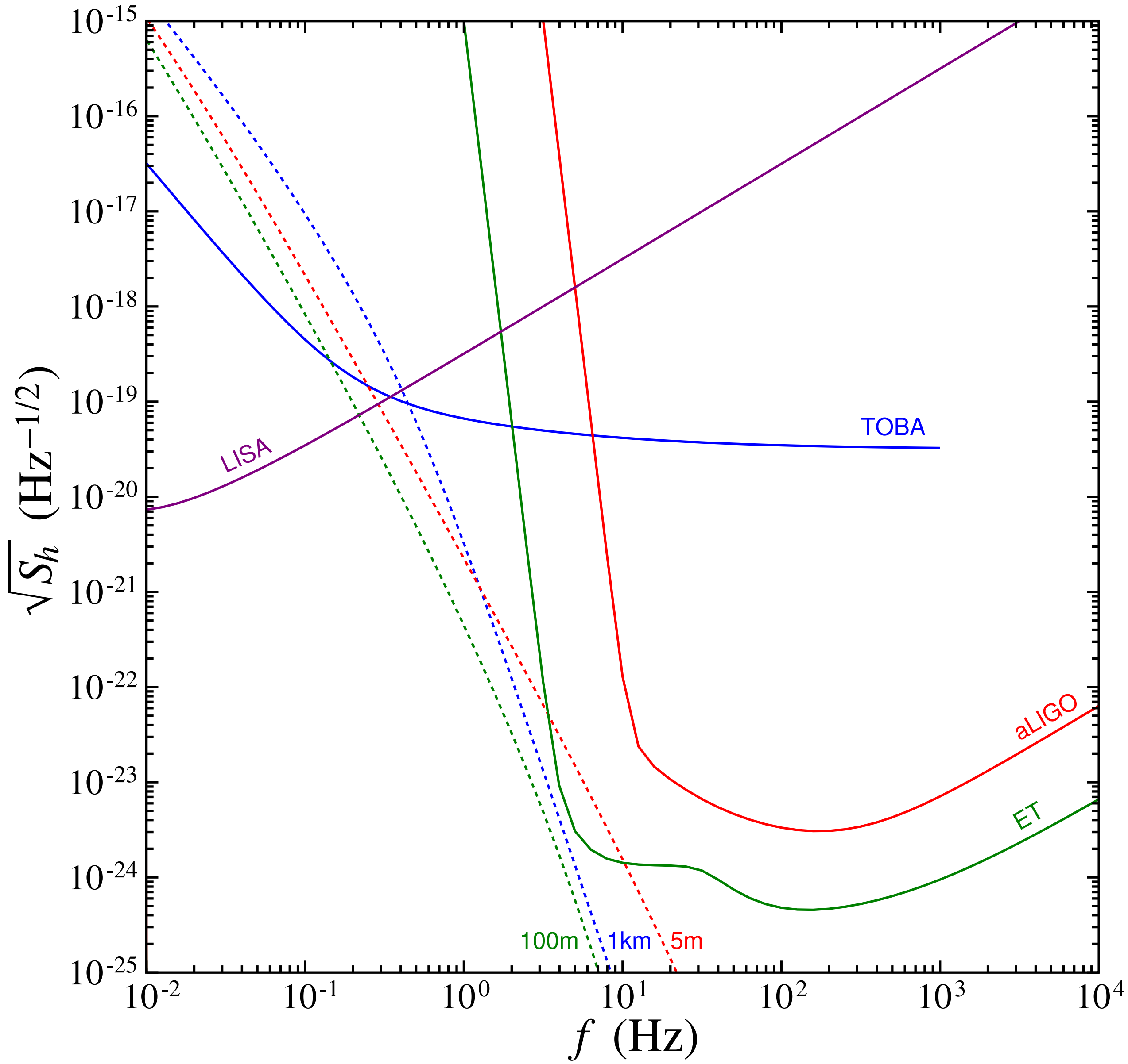
Surface structures

4km arms

10km arms

gradiometer

A. Infrasonic Newtonian Noise



Underground

4km arms

10km arms

gradiometer

A. Infrasonic Newtonian Noise

Considerations ($f \gtrsim$ few Hz):

- Surface: About $0.1\times$ amplitude of seismic NN.
- Underground: further dampened by λ/d, l^2_{coh}/d^2.
- (If infrasound generated by ground motions, or vice-versa, seismic NN will dominate by factor $\propto \rho^{3/4} C^{-1/4} \sim 30$ in $\sqrt{S_h}$.
  $\Rightarrow$ Only worry about non-seismic sources of infrasound.)
- Since $\lambda \sim 30\,\mathrm{m}$, atmosphere is homogeneous on these scales: should be possible to use infrasonic pressure sensors to map exact pressure distribution.

A. Infrasonic Newtonian Noise

Considerations ($f \lesssim$ few Hz):

- Underground: l_{coh}/d may *not* be small.
- Correlation lengths shorter than seismic, and atmosphere is not stationary or homogeneous on these scales: may be harder to map and subtract.

B. Thermal Newtonian Noise

- $$\sqrt{S_h} \sim 4\pi G\rho \frac{c_T}{T} \left(\frac{v}{\omega}\right)^{\alpha} \omega^{-5/2} \quad \times \quad \begin{cases} v/\omega L & \text{if} \quad \omega \gtrsim v/L \\ e^{-\omega d/v} & \text{if} \quad \omega \gtrsim v/d \end{cases}$$

  where $\sqrt{\langle(\Delta T)^2\rangle} = c_T(\Delta r)^{\alpha}$, $\alpha \approx 1/3$, $c_T \sim 0.5\,\mathrm{K\,m}^{-1/3}$; and $v \sim 0-30\,\mathrm{m/s}$ (advection).

$\Rightarrow$ Density perturbations *much* larger than infrasound, but v smaller.

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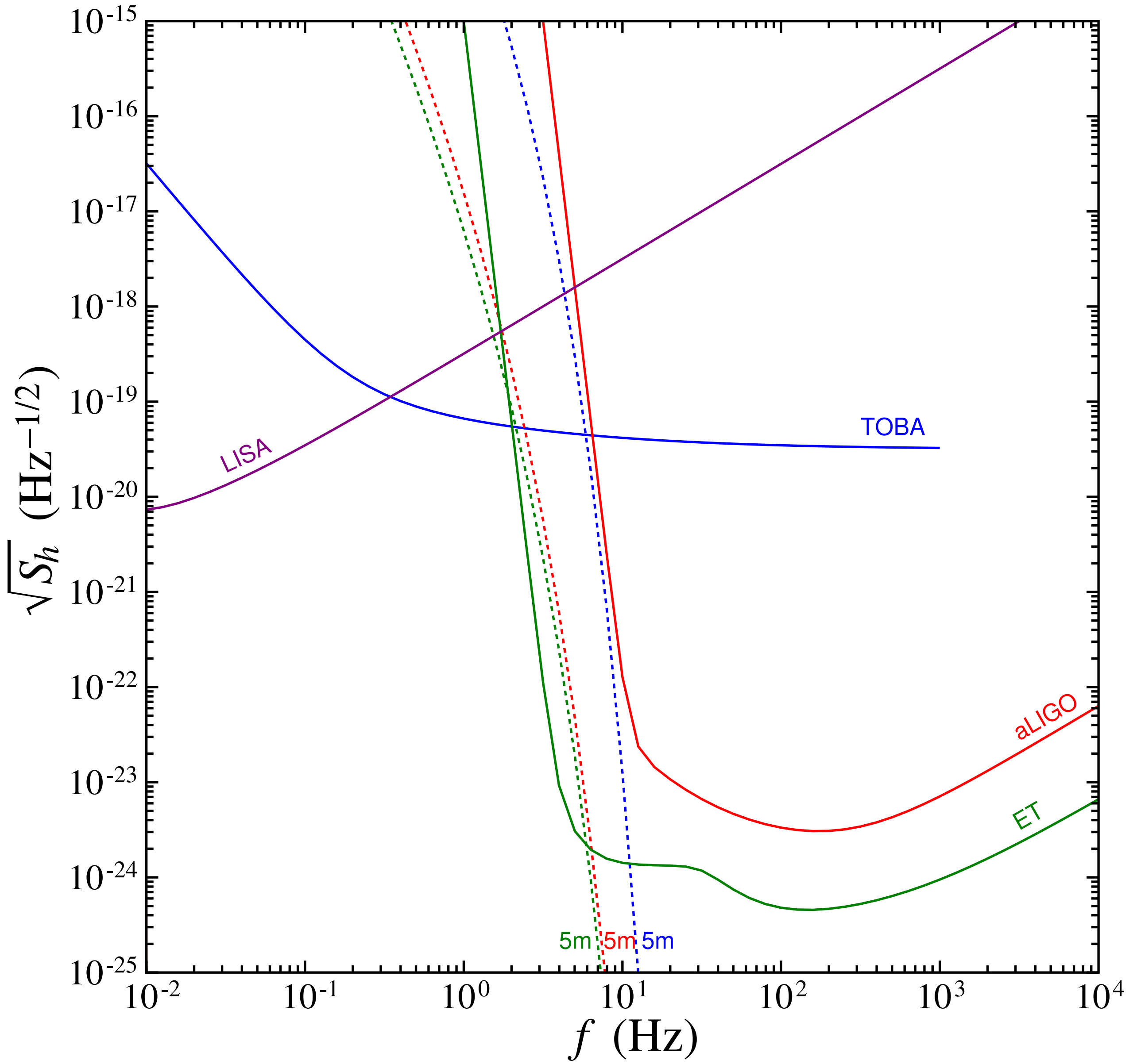
$\Rightarrow$ Density perturbations *much* larger than infrasound, but v smaller.

$$\sqrt{S_h} \approx \left(10^{-16}\mathrm{Hz}^{-1/2}\right)\left(\frac{c_T}{0.5\,\mathrm{K\,m^{-2/3}}}\right)\left(\frac{f}{\mathrm{Hz}}\right)^{-23/6} \qquad \text{(4km)}$$

$$\sqrt{S_h} \approx \left(10^{-13}\mathrm{Hz}^{-1/2}\right)\left(\frac{c_T}{0.5\,\mathrm{K\,m^{-2/3}}}\right)\left(\frac{f}{\mathrm{Hz}}\right)^{-17/6} \qquad \text{(gradiometer)}$$

- But above a few Hz, cutoff at $f \gtrsim v/2\pi d$ usually kills this, *provided* airflow is smooth.

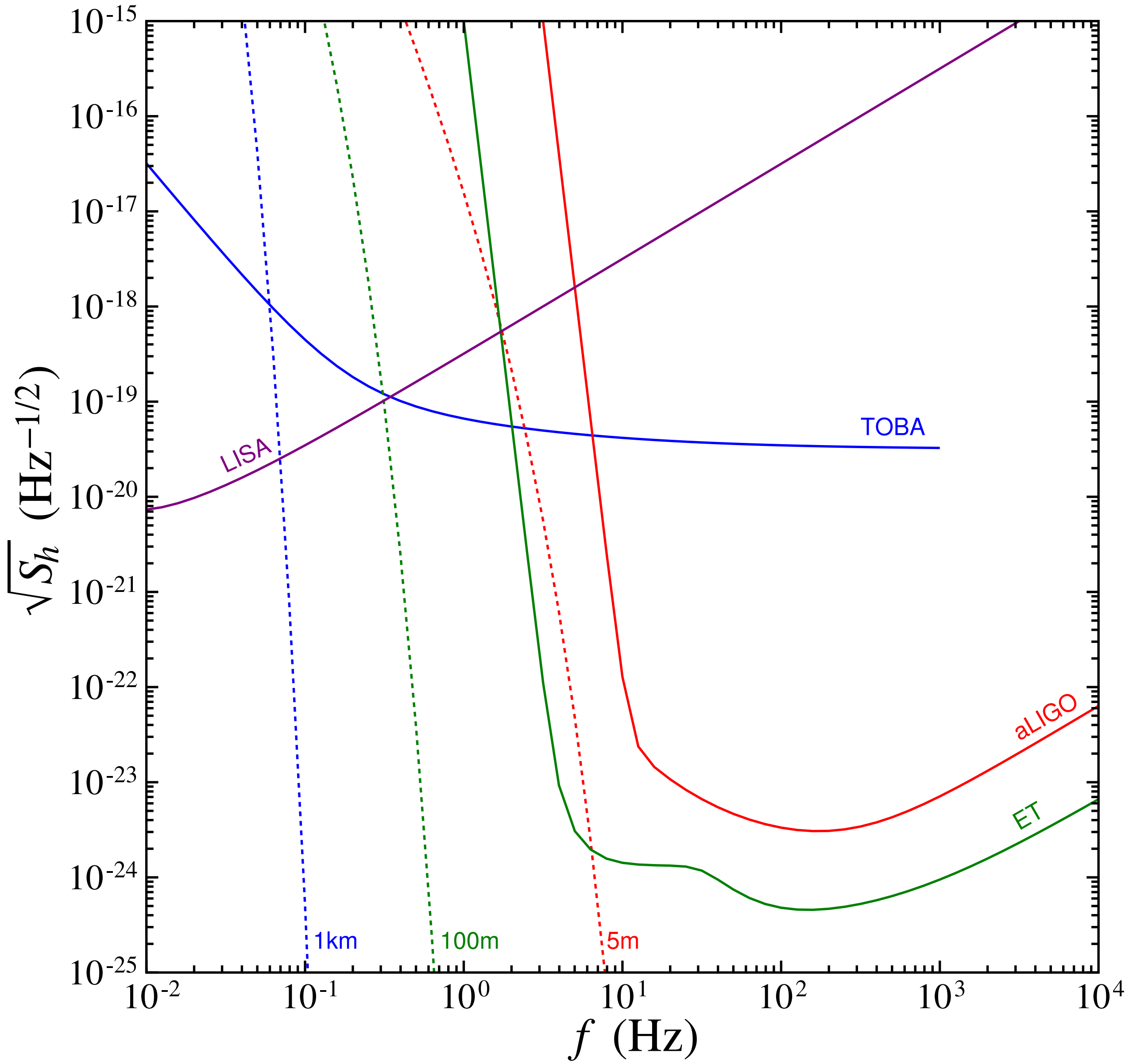
B. Thermal Newtonian Noise



Smooth airflow

Surface structures

B. Thermal Newtonian Noise



Smooth airflow

Underground

B. Thermal Newtonian Noise

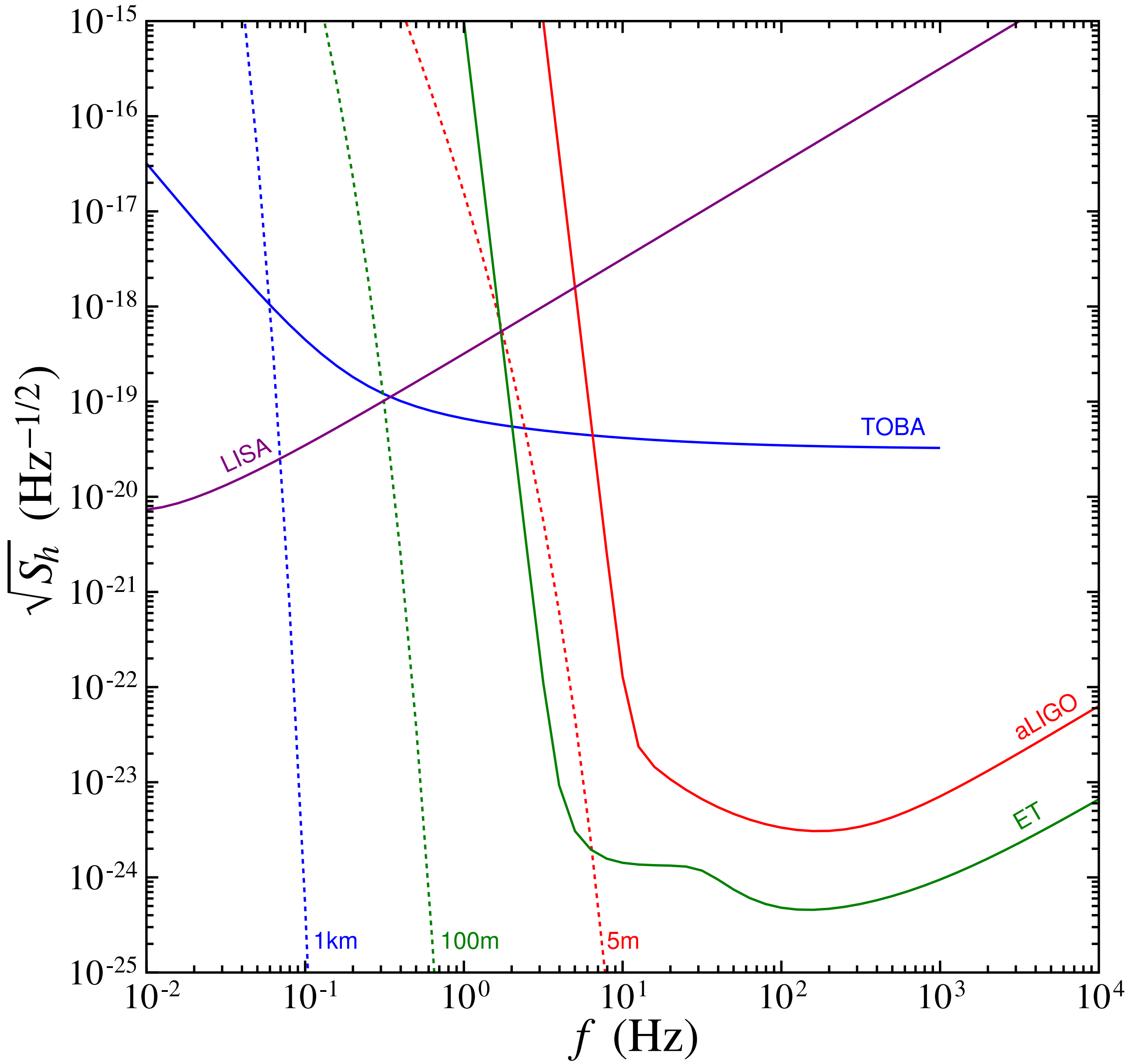
Considerations (any f):

- If airflow is not smooth, $g(t)$ may have discontinuous derivatives $\Rightarrow$ power law tail in frequency.
  - ⋆ Discontinuous Δv : $e^{-\omega d/v} \rightarrow v\Delta v/d^2\omega^2$.
  - ⋆ Discontinuous Δa : $e^{-\omega d/v} \rightarrow v\Delta a/d^2\omega^3$.
  - ⋆ Vortices : $e^{-\omega d/v} \rightarrow (v/d\omega)^2$. (Heuristic!)
- Need hydrodynamic modeling to determine likely streamlines.

$$\sqrt{S_h} \sim \frac{4\pi G\rho}{L}\frac{c_T}{T}\left(\frac{v}{\omega}\right)^{\alpha+2}\omega^{-3/2}\sqrt{\int\left|\mathrm{FT}\left\{\frac{x(t)}{r(t)^3}\right\}\right|^2 dA}$$

- Likely impossible to map and subtract.

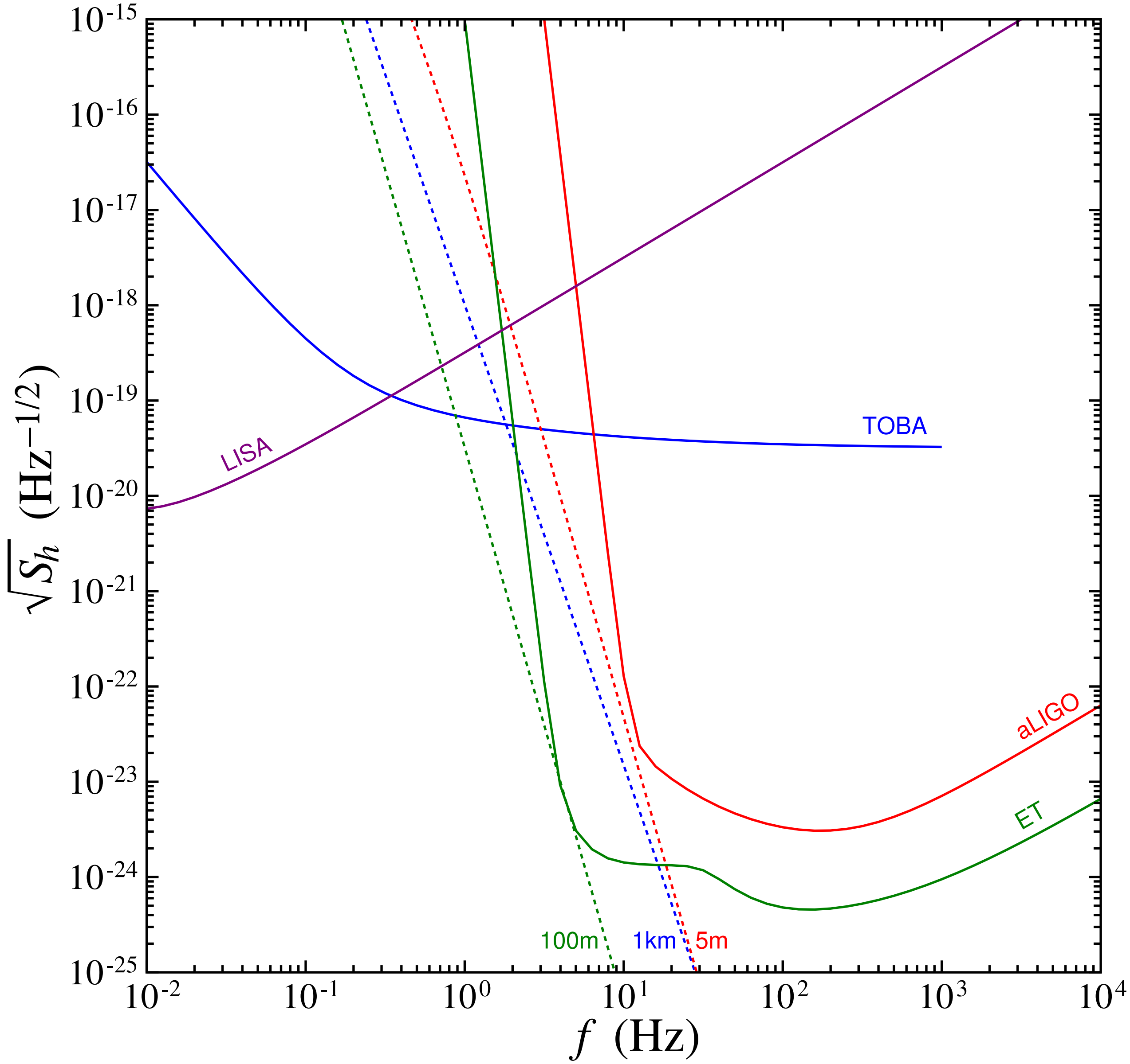
B. Thermal Newtonian Noise



Smooth airflow

Underground

B. Thermal Newtonian Noise



Turbulent airflow

Underground

CAVEAT: approximations not based on hydrodynamic simulations

C. Transients

- Sharp changes in atmospheric density:

$$\tilde{h} \sim \frac{4\pi G\rho}{L}\frac{v}{\omega}\frac{1}{\omega^3}\times\frac{\Delta p}{\gamma p} \sim 10^{-16}\left(\frac{f}{\mathrm{Hz}}\right)^{-4} \quad \text{(fighter jet)}$$

Solid objects passing near test masses:

$$\tilde{h} = \frac{GM}{L\,\omega^2}\times \mathrm{FT}\left\{\frac{x(t)}{r(t)^3}\right\} \sim 10^{-18}\left(\frac{f}{\mathrm{Hz}}\right)^{-4} \quad \text{(tumbleweed)}$$

- For $f \gtrsim$ few Hz, assume we can detect & veto individual events; mitigators (exclusion areas, door springs) for anthropogenic sources.
- For $f \lesssim$ few Hz, may be difficult! (Small-N Poisson noise floor.)