New Folder Name Noise from Local Gravitational Disturbances

Noise from Local Gravitational Disturbances

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From: R. Spero

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Abstract

This memo addresses the concern that movement within the office buildings at a LIGO site or nearby activity outside the buildings may generate background noise via Newtonian forces acting on the test masses.

A test mass is subject to a time-varying force accompanying the changing Newtonian gravitational fields of moving nearby bodies. The acceleration $a(t)$ suffered by a test mass from a disturbing mass M a time-varying distance $x(t)$ away is

$$a(t) = \frac{GM}{x^2(t)}; \tag{1}$$

here $x(t)$ is the distance to the nearest test mass. If the amplitude of motion s at frequency $\omega = 2\pi f$ is small compared to the average distance to the test mass x_0, then the resulting amplitude of the test mass motion at ω is

$$l(\omega) \approx \frac{2GMs}{\omega^2 x_0^3}. \tag{2}$$

The equivalent strain rms amplitude is

$$h_{\mathrm{rms},s}(f) = \frac{l(\omega)}{\sqrt{2}L} = \frac{\sqrt{2}GM}{L}\frac{s}{(2\pi f)^2\, x_0^3}\,, \tag{3}$$

where L = length of one interferometer arm.

In a similar analysis[1], K. Thorne concludes that the dimensionless gravity-wave amplitude is

$$2f\tilde{h}(f) \equiv h_{\mathrm{rms},v}(f) = \frac{GM}{\pi L}\frac{v}{(2\pi f)^3 x_0^3}\,, \tag{4}$$

where $\tilde{h}(f)$ is the Fourier transform of the gravity wave signal, and v is the speed of an object of mass M that is brought to rest quickly. (If the mass is brought to rest in a time τ,

[1]Memo of 11 September, 1994, "Gravity Gradient Noise in LIGO"

the gravity-wave amplitude is given by Equation 4, for all frequencies below $1/(2\pi\tau)$. The effect is reduced by momentum conservation in the source, but the reduction may be small if the reacting mass is large in extent compared to x_0 (a plausible situation at frequencies below 10 Hz).

Table 1 below includes two numerical examples: a dog scratching its ear for one cycle at a frequency of 4 Hz, and a door slamming shut at a velocity of 1 m/sec. The value of $h_{\rm rms}$ for the door is a factor of 2 higher than in the memo from K. Thorne, following a discussion with him about the interpretation of Equation 4. Note that the effect drops as the cube of the distance from the disturbance to the nearest test mass, and that a distance of 10 m is assumed.

For comparison, the Advanced Detector sensitivity curve in the April 1992 Science article, Figure 10, shows the S/N = 1 level of $h_c = 1 \times 10^{-23}$, at approximately 80 Hz. A slamming door could be a significant noise source at this frequency, as indicated in the table, but the effect of moving humans or other animals is likely to be concentrated below 10 Hz, the assumed cutoff in Advanced detectors. A scratching dog will not present a significant disturbance until the low-frequency cutoff is reduced to approximately 5 Hz or below.

This comparison with Advanced Detector sensitivities is conservative, in that S/N must be greater than approximately 5 for a background event to be mistaken for a signal. On the other hand, the effect of a periodic background, as from rotating machinery, could be relatively larger in a search for periodic sources.

From comparison with the expected performance with the first detector systems, it is evident that in their first few years of operation LIGO interferometers are unlikely to be sensitive enough to be disturbed by changing gravitational fields. Ultimately, however, activity within a radius of 20 m could produce a significant noise background. The following steps can minimize the effect of local disturbances. They need not be built into the initial installation, but should be carried as possible upgrades.

1. Make the laboratory building walls a minimum distance of r_0 from any test mass, including the end and mid stations. This may be necessary to keep moving animals sufficiently distant. Determining the precise value of r_0 may require further study, but about 20 m is probably safe. Human activity, including people in offices, should also be restricted to a minimum distance on the same order as r_0.

2. Monitor local activity to provide vetos. This may be difficult for the case of animal activity.

Source	Eqn.	M	x_0	s	v	f	$h_{\rm rms}$
Dog scratching ear	(3)	0.1 kg	10 m	0.1 m		4 Hz	5×10^{-22}
Door slamming shut	(4)	5 kg	10 m		1 m/sec		4×10^{-23}

Table 1: Examples of local gravity noise sources