Gas damping of Advanced LIGO test masses

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Following the detailed investigation of the gas damping in constrained volumes, that brought us to interesting figures for the LISA experiment, and discussion with Norna Robertson, we extended our simulation code to handle the geometry of the Advanced LIGO test masses.

The simulation code and the experiments that validate it are described in [1]. The simulated geometry is sketched in figure 1. The test mass is cylindrical with radius $R = 170$ mm and length $L_1 = 200$ mm, and is coupled to a cylindrical reaction mass of the same radius and length $L_2 = 130$ mm, separated by a distance $D = 5$ mm. In order to simulate an infinite surrounding volume, the system is contained in a cylindrical volume of radius $R_3 = 10 \times R = 1700$ mm and length $L_3 = L_1 + D + L_2 + 10 \times L_1 = 2335$ mm. The gas is supposed to be composed of a single specimen with molecular mass of 30 amu. The obtained results scale with the square root of the molecular mass m and thus can be easily referred to gasses of different mass.

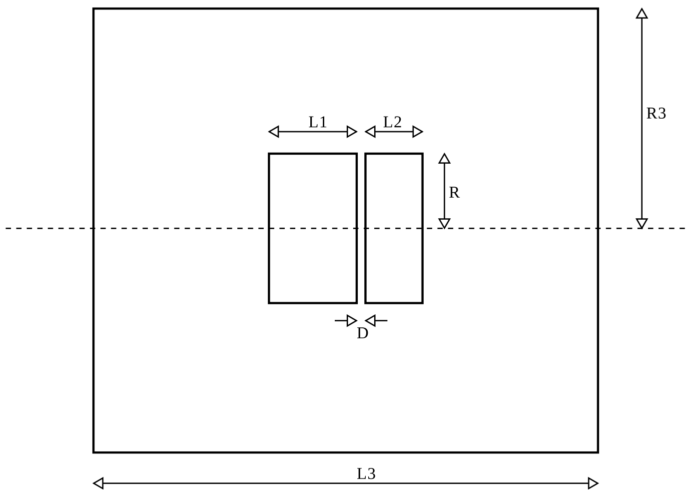

Figure 1: Sketch of the simulated geometry. Not to scale.

The simulation has been performed as a function of the distance D between test masses. The length of the enclosing volume L_3 is adjusted so that the distances between the outer faces of the test masses and enclosing surfaces is kept constant. Results are shown in figure 2.

We find that for the nominal gap $D = 5$ mm the gas damping coefficient β increases by roughly a factor 40 over the prediction for the damping of a cylindrical test mass in an infinite volume, with $\partial\beta/\partial P = (4.5 \pm 0.1)$ m s. Assuming a mass $M = 40$ kg for the test mass and a residual gas pressure $P = 10^{-6}$ Pa this produces an acceleration noise

$$S_a^{1/2} = \frac{S_F^{1/2}}{M} = \frac{(4kT\beta)^{1/2}}{M} = 6.7 \times 10^{-16} \times \left(\frac{P}{10^{-6}\ \text{Pa}}\right)^{1/2} \ \text{m s}^{-2} \tag{1}$$

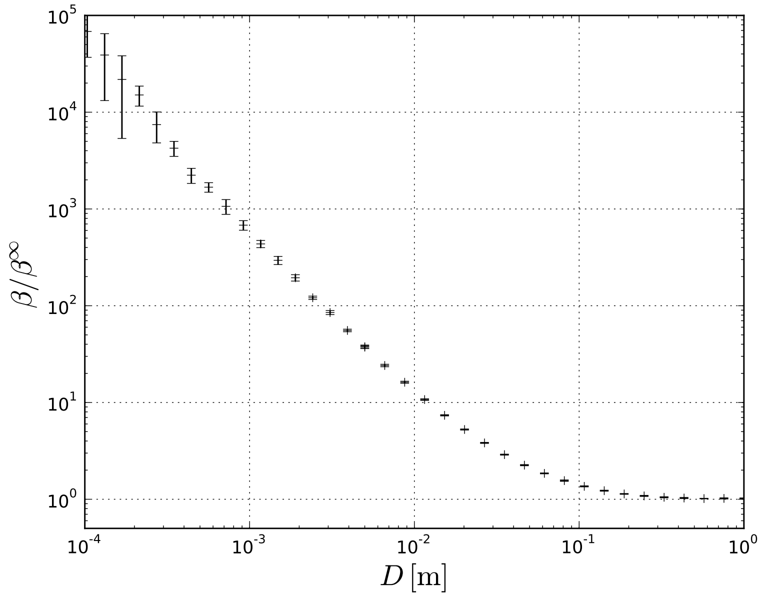

Figure 2: Gas damping β^{sim} obtained from the numerical simulation for different gap sizes D, normalized to the infinite-volume model prediction β^∞.

The damping coefficient for the translation in an infinite volume of a cylindrical test mass along its axis, derived on the same assumptions of the simulation [2], is

$$\beta^\infty = P\pi R^2 \left(1 + \frac{L}{2R} + \frac{\pi}{4}\right)\left(\frac{8m}{\pi k T}\right)^{1/2} \tag{2}$$

That prediction is indeed obtained in the simulation for large gaps. This confirms that there is no contribution to the observed increased damping by the presence of the enclosing surfaces of the system. The gas damping increase is found to be proportional to

$$\frac{R^2}{D^2 \ln\left(R/D\right)} \tag{3}$$

which approaches an inverse square power power law D^{-2} for vanishing gap, as expected by the considerations contained in [1], and to be expanded in an article that will be published shortly.

References

[1] A. Cavalleri *et al.* Phys. Rev. Lett. **103**, 140601, (2009).

[2] A. Cavalleri *et al.* arXiv:0907.5375v1.