LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
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The updated Advanced LIGO design curve

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This is an internal working
note of the LIGO project.

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1 Overview

This document describes the updated projection of the Advanced LIGO design curve, based on recent measurements on coating samples that provide more accurate estimates of coating thermal noise (see P1700448).

The Advanced LIGO curve is based on a GWINC model[1] that includes estimates for the main fundamental noises of the interferometer, in particular: seismic noise, thermal noise and quantum noise. The comoving range values reported in the tables and in the plots are calculated with the GWINC int73 function that includes cosmological effects, as documented in T1500491.

For a description of the February 2018 changes to GWINC incorporating the recent coating thermal noise parameters, see section 3.

2 Updated Advanced LIGO design curve

Figure 1 shows an updated Advanced LIGO noise curve.

With respect to the original estimates in P1400177, the main differences are:

- coating thermal noise has been updated to reflect P1700448, see full details in section 3;
- the transmission of the SRM installed after O2 is 0.325 (original value in previous design: 0.2).

[1]GWINC svn revision 2894. GWINC can be downloaded from the MIT svn.

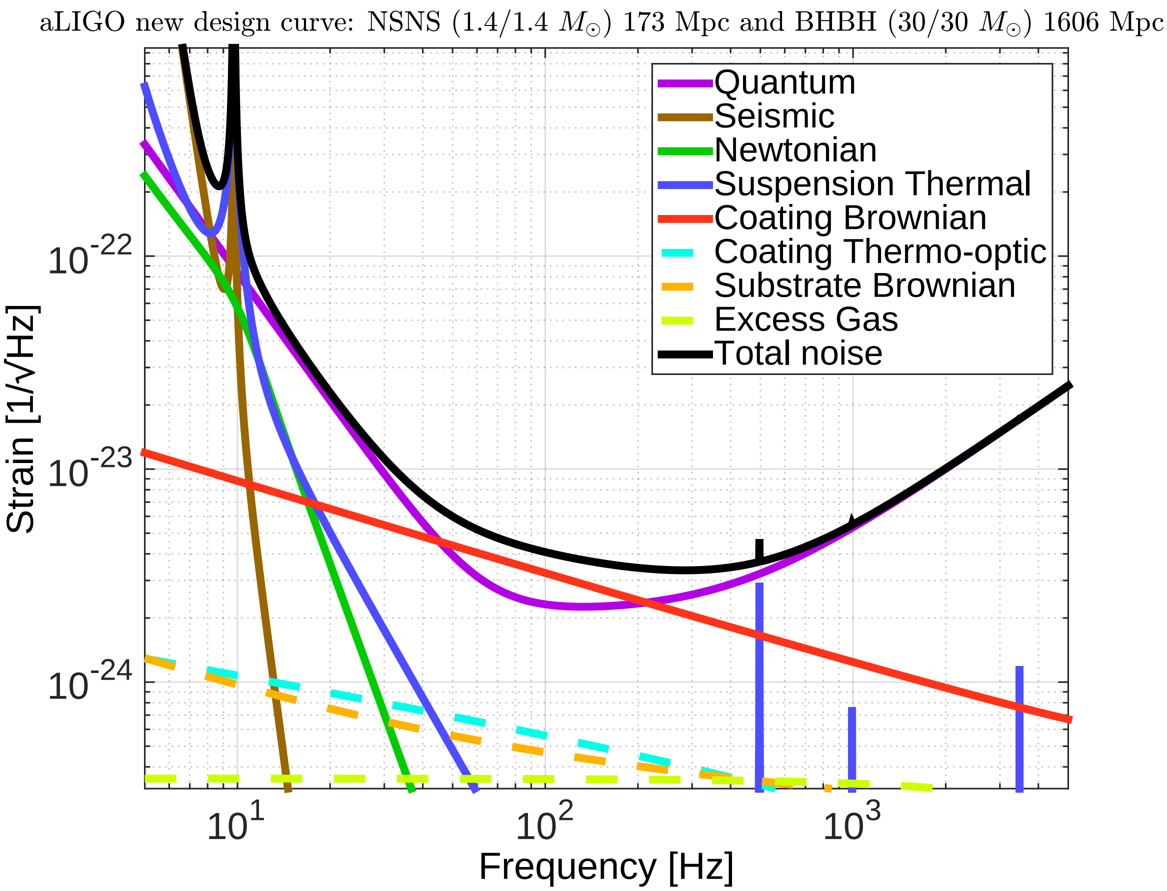

Figure 1: Updated estimate of the Advanced LIGO design curve.

3 GWINC model update

The core GWINC code was upgraded to allow for coating materials with frequency dependent loss angles. This appears in the `IFOModel` structure as a new fields under `Materials.Coating` named `Philown_slope` and `Phihighn_slope`. The coating loss angle for each material is then given by

$$\phi(f) = \phi_{100} \times \left(\frac{f}{100\text{Hz}}\right)^{\text{slope}} \tag{1}$$

where ϕ_{100} is the value at 100 Hz given in `Philown` or `Phihighn`. The values for the coating loss angle slopes are estimated from P1700448 and G1600641 to be 0.1 for tantala and 0.4 for silica. (The value for IBS silica is poorly constrained, but seems to reside between 0.3 and 0.5 and is clearly between the nominal 0.8 for fused silica and 0. This value is also of very little importance in current coatings since silica losses are sub-dominant.)

The overall loss values for both tantala and silica have also been updated again based on P1700448 and G1600641. The new values are `Philown` $= 0.5 \times 10^{-4}$ and `Phihighn` $= 3.6 \times 10^{-4}$. (The previous values were `Philown` $= 0.4 \times 10^{-4}$ and `Phihighn` $= 2.4 \times 10^{-4}$.)

The full list of GWINC parameters is shown in table 1.

Table 1: Gwinc parameters for the updated aLIGO design sensitivity.

Gwinc Parameter	**Value**	**Comment**
ifo.Materials.Coating.Phihighn	3.6×10^{-4}	tantala mechanical loss
ifo.Materials.Coating.Philown	5×10^{-5}	silica mechanical loss
ifo.Laser.Power	125	full power
ifo.Optics.Loss	37.5e-6	75ppm round trip loss in arm cavities
ifo.Optics.BSLoss	0.5e-3	based on O2 model
ifo.Optics.PhotoDetectorEfficiency	0.9	
ifo.Optics.SRM.Transmittance	0.325	New SRM transmission
ifo.Optics.SRM.Tunephase	0	SRM tuning
ifo.Optics.Quadrature.dc	90*pi/180	Readout phase
Gwinc Output	**Value**	**Comment**
Finesse	446	
Power Recycling Factor	43	
Arm power	750 kW	
Power on beam splitter	5.35 kW	
BNS range	173 Mpc	(comoving)
BBH range (30/30)	1.61 Gpc	(comoving, z = 0.4)

A Quantum noise model of the representative L1 noise curve in O2

Figure 2 shows the representative noise curve measured during O2 in L1 (see G1701571), together with the current best projections for coating thermal noise (based on P1700448) and quantum noise (see parameters in table 2). The quantum noise model has been tuned to match the measured shot noise and other parameters, like the arm cavity loss and the power recycling gain.

Table 2: Gwinc model for aLIGO L1 sensitivity during O2

Gwinc Parameter	**Value**	**Comment**
ifo.Laser.Power	20.25	23 W input, 88% throughput to PRM
ifo.Optics.Loss	45ppm	90 ppm round trip loss in arm cavities
ifo.Optics.BSLoss	0.5e-3	parameter tuned to have PRG = 37
ifo.Optics.PhotoDetectorEfficiency	0.78	Loss: QE, Faraday, OMC + Mode match
ifo.Optics.SRM.Transmittance	0.369	Measured transmittance of SRM
ifo.Optics.SRM.Tunephase	0	SRM tuning
ifo.Optics.Quadrature.dc	90*pi/180	Readout phase
Gwinc Output	**Value**	**Comment**
Finesse	446	
Power Recycling Factor	37	
Arm power	105 kW	
Power on beam splitter	0.75 kW	
BNS range	146 Mpc	(comoving), no technical noises
BBH range (30/30)	1.44 Gpc	(comoving, z = 0.4) no technical noises

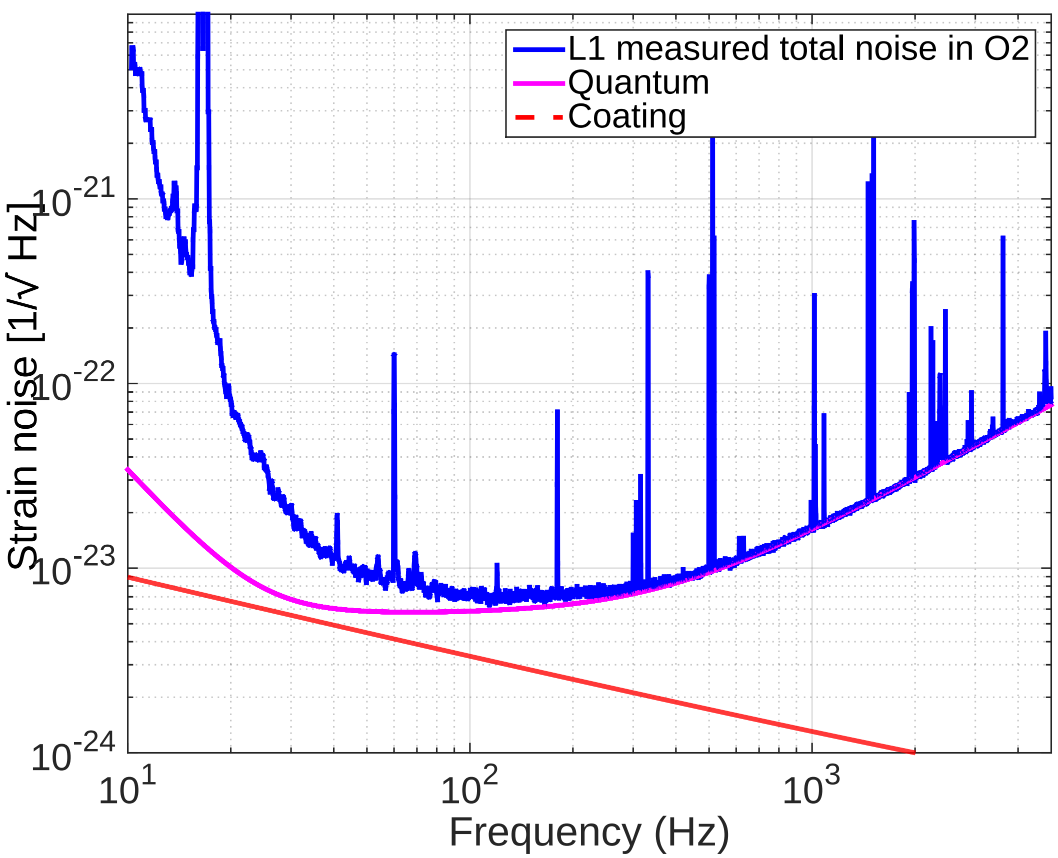

Figure 2: Representative noise measured in O2 (96 Mpc, L1 interferometer), with estimates of coating thermal noise (see P1700448) and quantum noise (see table 2).