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Advanced Virgo suspension: study of the back up solution

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Abstract

After the several suspension failures on the NI and WI payloads, we have made and evaluation of the sensitivity (early, with input power of P=25W and without SR) of Advanced Virgo for the scenarios in which the mirrors are suspended with steel wires or with more robust, thicker silica fibers.

1 The optimized silica wires.

In the optimized configuration the silica fiber profiles are shaped with the aim to:

- Cancel the thermoelastic losses so that the wire losses are minimal at the pendulum frequency;
- Have the frequency of the fiber bouncing mode below 10 Hz, outside the sensitivity bandwidth;
- Have the frequency of the $theta_x$ mode (pitch) lower 1.5 Hz.
- Keep the violin modes frequency above 400 Hz, outside the control bandwith;

In this scheme, the fibers, pulled starting from a rod of 3 mm diameter, have two tapered neck sections decreasing in diameter to the 800 μm, then most of the fiber length has a diameter of 400 μm, thus setting the bouncing and violin frequencies at values suitable for the AdV purposes.

The thermal noise of the monolithic suspension of $5.8\ 10^{-23}\ 1/Hz^{1/2}$, where the upper clamping part is not negligible and is included (n.b. the optical noise is $1.5\ 10^{-22}\ 1/Hz^{1/2}$).

1 Temporary solution: the steel wires

To allow the north arm commissioning activity to start, we have suspended the NI mirror with the C85 steel having a diameter of 0.6 mm. The NE mirror is suspended with optimized silica wires.

The NI suspension set up is not optimized for a steel wire so we expect a loss angle of the order of 10^{-3} or worst. However, an optimized set up could give a loss angle not better than 10^{-4}. Moreover, in the steel material the thermoelastic loss angle is not cancelled by a proper choice of the diameter like in silica. For this reason the choice of the wire diameter can determine just the wire strength and the frequencies.

1.1 0.3mm

In Virgo the wire diameter was 0.2 mm giving a load stress in the wire of 1.6 GPa.

So, in principle this solution can be adopted, even if the design of the monolithic suspension must be checked to see if it can be adapted for this wire diameter.

In the case of a 0.3mm diameter for AdV the load stress is 1.4 GPa, the first violin is at about 310 Hz and the bouncing mode at 8 Hz

The thermal noise at 10 Hz is foreseen to be 8.06 10^{-22} $1/Hz^{1/2}$ with the steel wires of 0.3 mm diameter (optimized configuration, i.e. $\phi_{steel}=10^{-4}$, viscous Q of the marionette of 30000). In this case the thermal noise of the upper clamping system is negligible. The estimation of the horizons is given in the Table 1.

1.2 0.4mm

We also analyze the configuration of 0.4 mm diameter which can be easier to be used to the Advanced Virgo mirrors suspension system, not designed for using steel wires.

In the case of a 0.4mm diameter for AdV the load stress is 0.8 GPa, the first violin is at about 310 Hz and the bouncing mode at 8 Hz

The thermal noise at 10 Hz is foreseen to be 8.06 10^{-22} $1/Hz^{1/2}$ with the steel wires of 0.3 mm diameter (optimized configuration, i.e. $\phi_{steel}=10^{-4}$, viscous Q of the marionette of 30000). In this case the thermal noise of the upper clamping system is negligible. The estimation of the horizons is given in the Table 1.

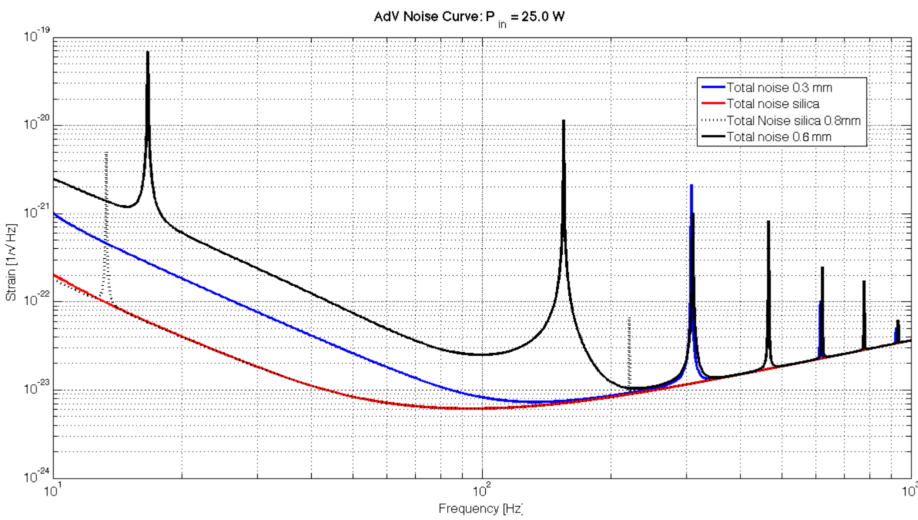


Figure 1: Comparison between the sensitivities (early) for four different cases: Official (red), Silica wires with 0.8mm diameter (black dotted), steel wires with diameter 0.3 (blue) and loss angle 10^{-4}, steel wires with diameter 0.6 (blue) and loss angle 10^{-3} (black).

	Silica opt	***Steel 400 μm***	Steel 300 μm	***Silica 800 μm***	Steel 600 μm, ϕ=1e-3 (ϕ=1e-4)	VirgoPlus 250 μm silica wires
Violin (Hz)	**440**	***231***	307	***220***	155	430
Bouncing	**8.0**	***11.1***	8.3	***13.3***	16	15
BNS Horizon (Mpc)	**109.9**	***45.4***	61	***109.8***	21 (25)	46
BBH Horizon (Mpc)	**1023**	***202***	315	***1026***	83 (109)	393
Stochastic	**5.7 10^{-9}**	***2.1 10^{-7}***	8.4 10^{-8}	***5.8 10^{-9}***	1.4 10^{-6}	1.9 10^{-8}

Table 1: Evaluation of the horizons, for 4 payloads, using the gwinc version used for the computation of the official sensitivities curves. For comparison the VirgoPlus numbers are shown.

1.3 0.6mm

In the case of a 0.6mm diameter, the first violin is at about 155 Hz and the bouncing mode at 16 Hz

The thermal noise at 10 Hz is foreseen to be 4.2 10^{-21} $1/Hz^{1/2}$ with the steel wires of 0.6 mm diameter (not optimized configuration, i.e. $\phi_{steel}=10^{-3}$, viscous Q of the marionette of 30000). In this case the thermal noise of the upper clamping system is negligible. The estimation of the horizons is given in the Table 1.

2 Silica wires with 0.8mm diameter

Another backup solution can be the use of enforced silica wires having a cylindrical shape and a diameter of 0.8 mm. In this case the suspension is safer and the sensitivity can be preserved.

In this case the sensitivity does not change as the thermal noise depends on the thicker portion of the fiber which keeps the diameter of 0.8mm. (see Figure 1)

The change is on the lower violin frequency of 220 Hz and the bouncing mode at 13.3 Hz.

We notice that although the bouncing mode is greater, the pitch mode, important for the control activity, should remain similar to the optimized silica solution as it depend on the bending zone of the wire which is still 0.8mm. The estimation of the horizons is given in the Table 1.

2 Case of only one mirror suspended with steel wire

We have made an evaluation of the sensitivities in the case only one suspension is done with steel. In this case two types of violin modes are present in the bandwidth. The horizons are shown in the Table 2

	Silica opt	***Steel 400 μm***	Steel 300 μm
Violin (Hz)	**440**	***231***	307
Bouncing	**8.0**	***11.1***	8.3
BNS Horizon (Mpc)	**109.9**	***65***	80
BBH Horizon (Mpc)	**1023**	***379***	548
Stochastic	**5.7 10^{-9}**	***2.1 10^{-7}***	2.8 10^{-8}

Table 2: Horizons in the case only one suspension is made of steel.

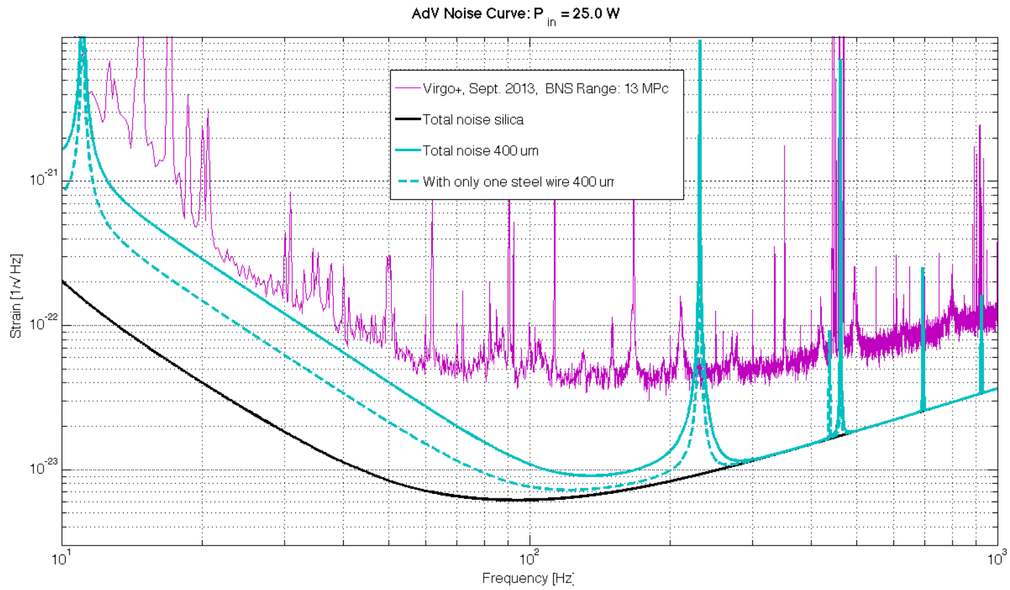


Figure 2: Green curve refers to 4 steel suspensions with 0.4mm diameter (phi=1e-4), the dotted green curve refers to 1 steel suspension (0.4mm and loss angle=10^{-4}) and 4 suspensions of fused silica. They are all compared with the official sensitivity (black curve).

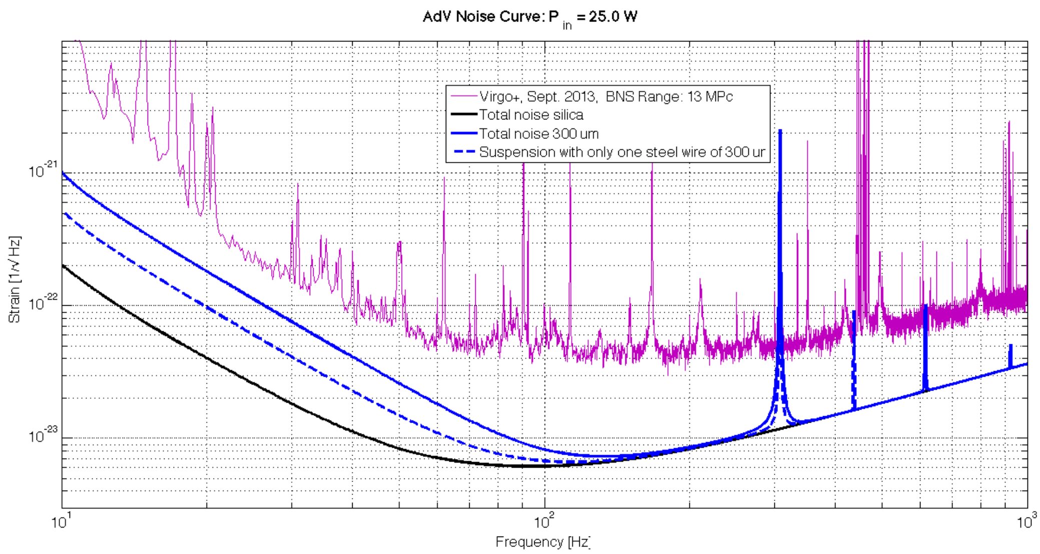


Figure 3: Blue curve refers to 4 steel suspensions with 0.3mm diameter (phi=1e-4), the dotted blue curve refers to 1 steel suspension (0.3mm phi=10^{-4}) and 4 suspensions of fused silica. They are all compared with the official sensitivity (black curve).

3 Evaluation with the new gwinc version of the case 2 silica +2 steel suspensions.

We have calculated the horizons in the case 2 suspensions are with steel wires and the other ones are in silica. This will be probably the starting configuration for Virgo Advanced that will lead to the scientific run with Ligo O2.

	Silica opt	*Steel 400 μm (ϕ=10⁻⁴) (ϕ=10⁻³)*	Steel 300 μm (ϕ=10⁻⁴) (ϕ=10⁻³)	Steel 600 μm (ϕ=10⁻³)(1 steel 0.3mm, 1 steel 0.6mm, 2 silica wires)
Violin (Hz)	**440**	***231***	307	
Bouncing	**8.0**	***11.1***	8.3	
BNS Horizon (Mpc)	**105.5**	***54 (46)***	69(59)	27(32)
BBH Horizon (Mpc)	**979**	***279(195)***	419(274)	117(159)

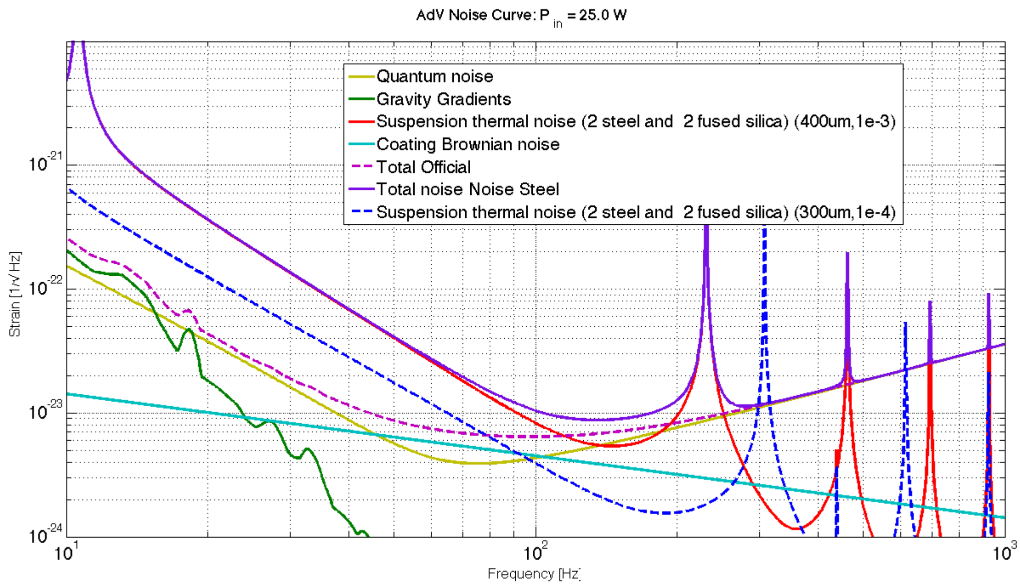
Table 3:Horizons for different suspension setup in which 2 suspensions are with fused silica fibers and other 2 with steel wires. The 600μm column contains also an estimation of the horizon supposing that one suspension is 300 μm with loss angle 10^{-4} and the other one is 600 μm with loss angle 10^{-3}.

The calculation of the horizons were performed using a new version of the gwinc, a bit different from the one used to compute the official curve.

The differences between the gwinc previously used are:

- Coating Brownian Noise based on experimental measurements performed at LMA by M. Granata (see (VIR-0204A-15) note).
- The gravity gradient noise is based on the on site measurements of the ground seismic noise performed by Irene Fiori.

We have spanned some different configurations (see Table 3) both for the steel wired diameters and for the loss angles. In the Figure 4 and Figure 5 the sensitivities for the worst and the optimal configuration are compared.



1. **Figure 4: Sensitivities for two silica+ two steel wired payloads. The dimensions of the wire is shown in the legends.**

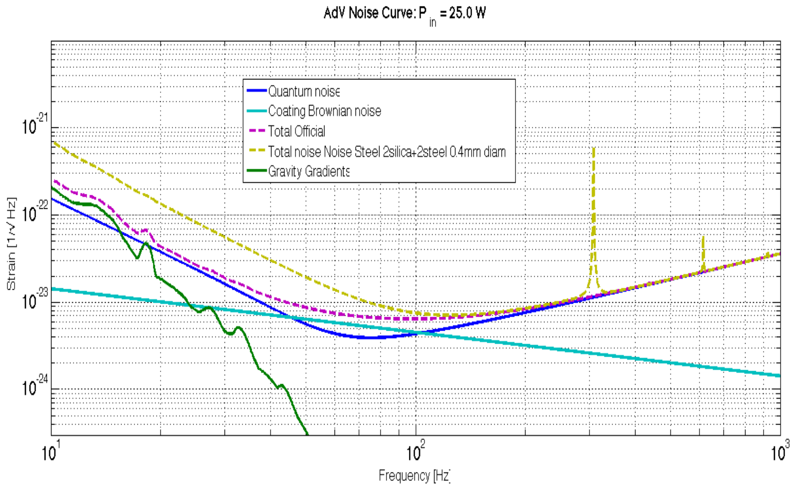


Figure 5: Sensitivity of the case with 2 steel suspensions having diameter of 0.3mm and loss angle of 10^{-4}.

4 Evaluation with the new gwinc version of the case 4 steel suspensions.

	Silica opt	***Steel 400 µm phi=1e-4 phi=1e-3***	Steel 300 µm phi=1e-4 (phi=1e-3)	***Silica 800 µm***
BNS Horizon (Mpc)	**105**	***45.4 (38)***	60 (51)	***105***
BBH Horizon (Mpc)	**978**	***202(140)***	313 (199)	***978***

Table 4: Evaluation of the horizons, for 4 payloads, using the new gwinc version used for the computation of the official sensitivities curves. For comparison the VirgoPlus numbers are shown.

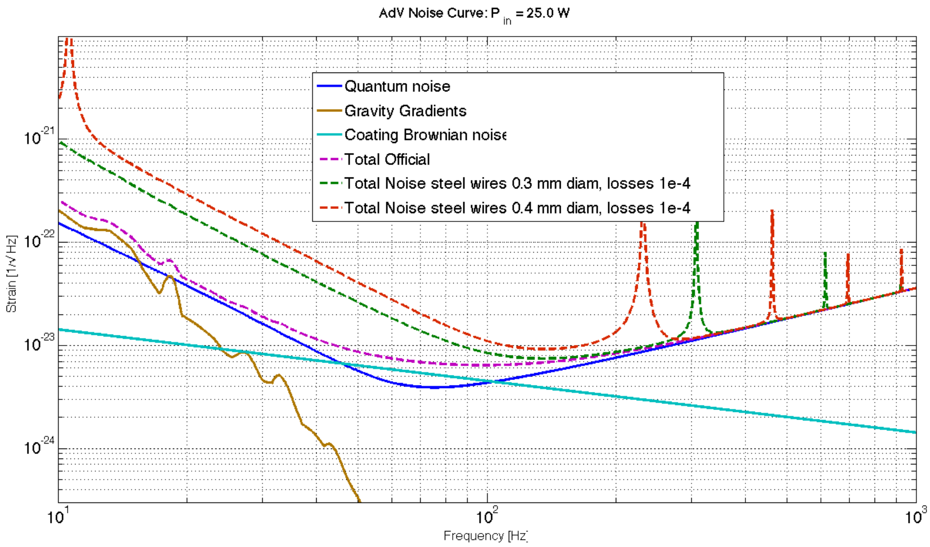


Figure 6: Sensitivity computation in the case of four steel suspensions with 0.3 and 0.4 mm diameter steel wires and 10^{-4} loss angle.

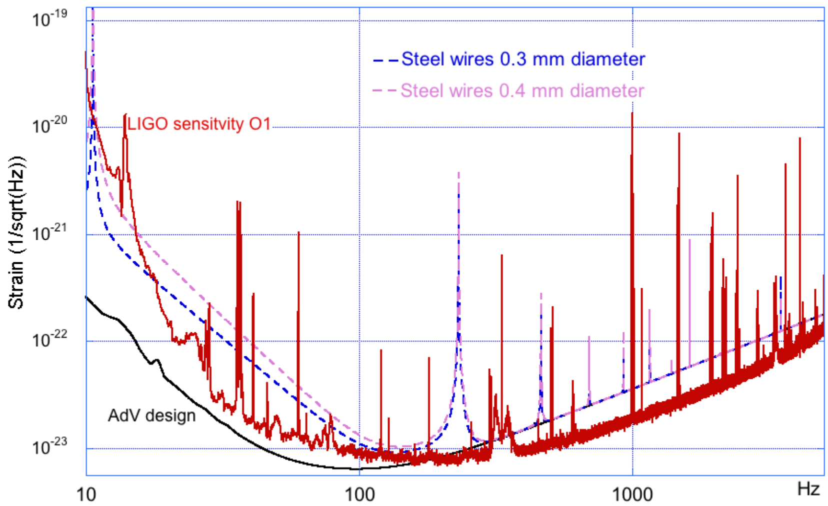


Figure 7: Comparison of the AdV sensitivity curves with the LIGO O1 noise. (phi=1e-4 for the steel)