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Advanced Virgo design: Comparison of the Advanced Virgo sensitivity from Bench 4 and GWINC (v1)

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1 Scope of this document

The AdV Conceptual Design [1] introduced a *baseline* sensitivity curve for AdV. That curve, with the expected contribution for the various noise sources, had been calculated using the version 4 of BENCH [2], a code developed and maintained at LIGO. So far, the assumptions and choices done to make the calculations have not been widely discussed. AdV is now entering a phase of intense design activity. It is expected that more people start working on the noise calculation. An organized effort is therefore needed to maintain the parameters file updated and to keep track of the changes. Moreover, the same BENCH code has evolved and an updated version, carrying the name GWINC (v1) [3] is now available. Important changes have been done. In this note we describe the impact of such changes on the AdV sensitivity model.

The scope of this document is to set the framework for a wide use of the AdV BENCH model, spreading the useful information to allow the Virgo members to use it and to cross-check the available results.

2 The bench scenarios used in this document

In this document we compare the following three scenarios of bench simulations:

- **Advanced Virgo baseline scenario**: This is the configuration used to produce the advanced Virgo baseline senstivity described in [1]. Bench 4 was used in combination with the `IFOModel_conceptual_design.m` as input file.
- **Consistency scenario**: This scenario was created to perform a consistency check between Bench 4 and GWINC (v1). The same input parameter as in the baseline scenario are used, but the calculation is done with GWINC. The corresponding input file is `bench7_conceptual_design_parameters.m`
- **New Advanced Virgo reference scenario**: This configuration uses the input parameter described in Section 5 of this document. GWINC was used in combination with `adv_27062008.m` as input file.

3 AdV baseline scenario: main parameters used

In this section we list the main choices and assumptions done to calculate the AdV baseline sensitivity shown in [1]:

- **laser power:** we have assumed that 125 W go through the IMC, same choice done for Adv LIGO

- **losses:** 75 ppm are assumed for the round trip losses in the arm cavities, 300 ppm for the BS losses
- **silica fibers:** cylindrical fibers are considered[1] , with a diameter of 206 μm
- **mirrors:** the baseline mirrors are 35 cm in diameter, 20 cm thick and have a mass of 42.33 kg
- **beam geometry:** a beam radius of 6 cm at the test masses is assumed.
- **interferometer tuning:** the values of the transmittance are: 5e-6 for the end mirrors, 7e-3 for the input ones, 4e-2 for the SR. The SR phase is tuned at 0.07.

4 From BENCH4 to GWINC: main changes in the code

The evolution of the BENCH code is well documented on the dedicated LIGO web page [2]. GWINC includes an important update on the coating thermooptic noise. In BENCH4 the thermorefractive and thermoelastic contributions appeared separately. It has recently been shown [4] that there is some cancellation of the two contributions. Thus, the resulting *thermooptic* noise becomes negligible and the coating limits the sensitivity of the advanced detectors only through the Brownian motion. With respect to BENCH4 a modelling of the thermal compensation system (TCS) effect is also included.

First of all, we have checked which parameters have a different value inGWINC with respect to BENCH4 (see the list afterwards). Such modifications originate in most cases from new findings in the literature. We have then run GWINC with configuration file containing the former values of such parameters. Finally, we have compared the AdV sensitivity obtained with the AdV baseline calculated with BENCH4. The result is shown in fig. 1.

The observed differences are:

- the total mirror thermal noise is reduced in GWINC. This is due to the relevant change in the calculation of the thermooptic coating noise. This effect is also responsible for the sensitivity improvement in the 40-400 Hz range;
- there is a tiny difference in the coating Brownian noise. This effect is to be understood;
- the quantum noise is slightly changed above 400 Hz. In fact, with the same transmittance for the input and end mirrors the finesse value calculated by BENCH goes from 884 (BENCH4) to 888 (GWINC), with a variation of 0.4%. This is to be understood, but the effect is not so big.

The figure of merit in the two cases (BENCH 4 - GWINC respectively) are:

- **BNS inspiral range:** 121.1→123.6 Mpc (+2%)
- **BBH inspiral range:** 858.9→877.9 Mpc (+2.2%)

The improvement is mainly linked to the new model for the thermooptic coating noise.

5 The new AdV sensitivity model

In this section we list the parameters whose values have changed in GWINC with respect to those used in BENCH4 to calculate the AdV baseline sensitivity.

- **general -** temperature: 300→290 $^\circ K$
- **optics -** BS power loss: 3e-4→2e-3 ppm

[1] A complete model for the Adv LIGO quadruple pendulum is contained in BENCH. To calculate the AdV suspension thermal noise we have constrained the model to the last stage only by setting the marionette mass to 10000 kg. The results of such an approximation need to be cross checked by an independent calculation.

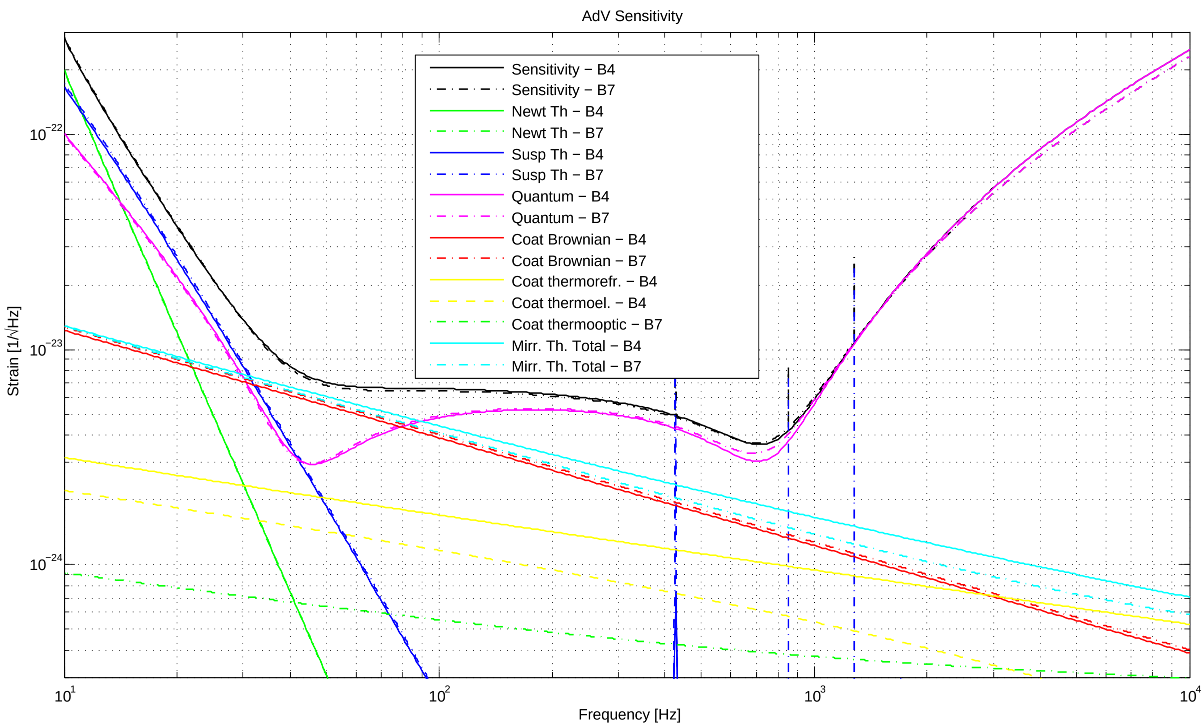

Figure 1: **Consistency scenario:** AdV design sensitivity calculated with BENCH version 4 (traces labeled B4, baseline scenario) and GWINC (v1) (traces labeled B7, consistency scenario). For both analyses the same set of input parameter (i.e. the set described in [1]) has been used.

- **suspensions -** fused silica α: 5.1e-7→3.9e-7 $1/^\circ K$
- **suspensions -** fused silica Y: 7.27e-10→7.2e-10 Pa
- **suspensions -** ribbons are used instead of cylindrical fibers. They provide an upper limit to the expected noise for tapered fibers [5]
- **coating -** tantala β: 1.2e-4→1.4e-5 $1/^\circ K$
- **coating -** tantala ϕ: 2.4e-4→2.3e-4
- **coating -** silica β: 1.5e-5→8e-6 $1/^\circ K$
- **coating -** silica ϕ: 1e-4→4e-5
- **substrate -** surface loss limit (α_s): 3.1e-12→5.2e-12
- **substrate -** poisson ratio (σ): 0.17→0.167

Using the new set of parameters the AdV sensitivity is calculated again and compared to the AdV baseline sensitivity in fig 2. Due the improvements of sensitivity for frequencies below 200 Hz the new reference scenario yields to significantly increased inspiral ranges compared to the advanced Virgo baseline sensitivity. The figure of merit in the two cases (BENCH 4-GWINC respectively) are:

- **BNS inspiral range:** 121.1→136.8 Mpc (+13.0%)
- **BBH inspiral range:** 858.9→1078.0 Mpc (+20.3%)

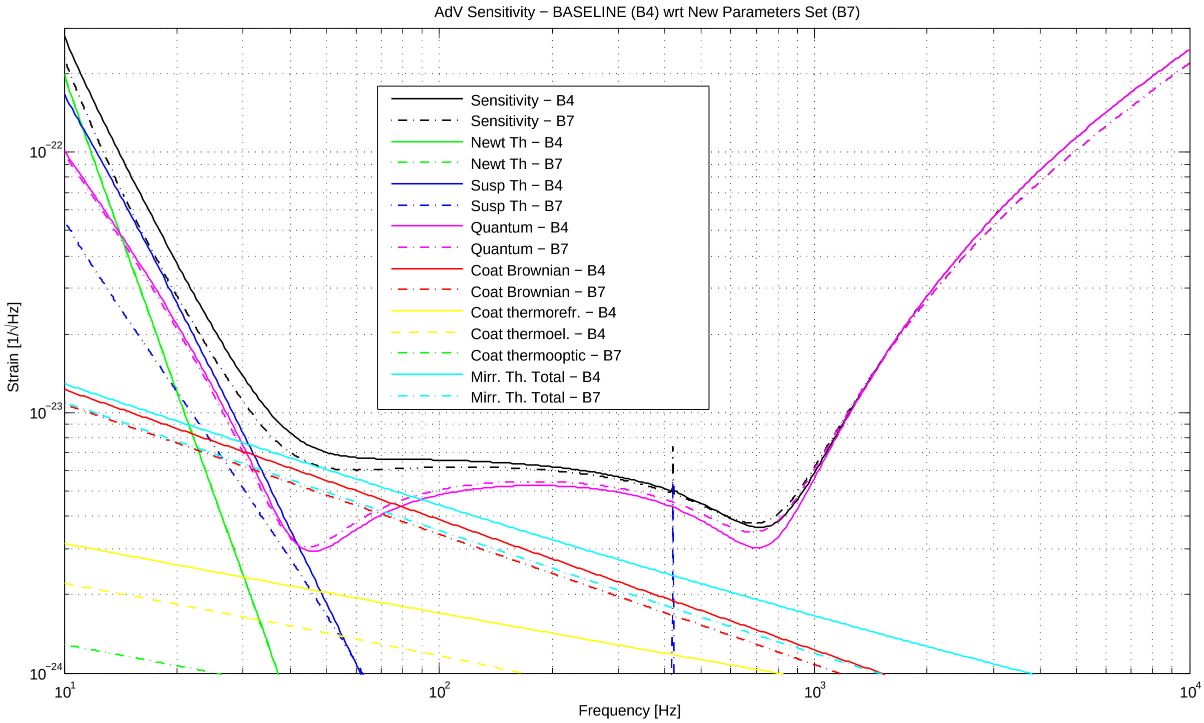

Figure 2: AdV baseline sensitivity from [1] (traces labeled B4, baseline scenario) and the new reference sensitivity, calculated with GWINC and using the parameter set described in Section 5 of this document (traces labeled B7, new reference scenario). The corresponding input files are `IFOModel_conceptual_design.m` for B4 and `adv_27062008.m` for GWINC.

6 Documentation and Storage of the Advanced Virgo BENCH and GWINC files

All files related to the BENCH and GWINC simulations for Advanced Virgo are stored in a dedicated subversion (SVN) repository which provides backup as well as version control. This svn repository is available for the whole Virgo collaboration and can be read by the public without username and password (server: `svn://lnx0.sr.bham.ac.uk`, repository: `adv-bench`).

This SVN repository is split into two main parts:

- The **current** Advanced Virgo bench simulation can be found in the directory `'current'`: This includes the current version of the bench / GWINC code (in the directory `'current/bench_code'`) as well as the current Advanced Virgo interferometer model file (in the directory `'current/Configuration_file'`).

- **Outdated** Advanced Virgo simulations are also stored within the repository to allow comparison and crosschecking with previous analyses. The directory `'old_bench_versions'` contains old versions of the bench / GWINC code, while the directory `'old_adv_models'` hosts old configuration files.

Detailed information about the file structure of the bench SVN repository can be found in `'file-structure-readme.txt'`

In addition to the inherent version control of the svn there are manual maintained history files available for the Advanced Virgo configuration files (`'current/Configuration_files/history.txt'`) and the bench / GWINC versions used for Advanced Virgo analyses (`'current/bench_code/history_of_bench_code.txt'`).

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Acknowledgements

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References

[1] The Virgo Collaboration, "Advanced Virgo Conceptual Design", Virgo note VIR-042A-07 1, 3, 4

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[4] M. Evans, talk at GWADW 2008, Isola d'Elba, May 2008. 2

[5] A. Heptonstall, talk at the LSC/Virgo joint meeting, CALTECH, March 2008. 3