STATUS OF LF AT VIRGO

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DEFINITIONS OF LOW FREQUENCY

1. The left side of a GW detector band.
2. The frequency region where the noise limiting the sensitivity is ‘mechanical’ (excess motion of the test masses, or some other part of the detector).
3. The frequency region where the contribution to the detector overall range of observation is low and the difficulty to achieve some improvement is high, therefore it is always left behind.
4. The frequency region where the initial phase of large black holes merging would be observable for a long duration.

Currently, for the detectors in activity, LF is: f<20 Hz

GW DETECTORS FIRST GENERATION

VIRGO:

- Complex seismic isolation system installed since the beginning.
- The detection band was supposed to start at **10 Hz**.
- Sensitivity @ 10 Hz: $h=3\cdot10^{-21}$ 1/sqrt(Hz), corresponding to an arm length noise of **10^{-17} m/sqrt(Hz)**

LIGO:

- Minimalistic suspension system.
- Detector band starting from **30 Hz**.
- Expected GW signals from binary neutron stars coalescence (black holes not taken into account).

INITIAL LF NOISE SCENARIO

Fundamental noise

Noise intrisically correlated to the infrastructure, which cannot be reduced in commissioning phase. It constitutes the target sensitivity.

- Pendulum thermal noise, produced by the metallic wires suspending a test mass of 20 Kg, associated to the dissipations in the material or other dissipation at the level of the links.
- Seismic noise: residual motion of the test mass, coming from the ground and suppressed by the seismic isolation system. **Supposed to disappear at 3-4 Hz.**

Technical noise

Noises that can be kept low by the correct implementation of the devices and by some further improvements in commissioning phase. The list is too long and many of them were not quantified in advance.

As a matter of fact, control noise and scattered light were the limitation up to 30 Hz, and there was no way to push them below the fundamental noise, even because. commissioning was almost entirely devoted to fix problems at higher frequency.

COMMISSIONING OF LF

20 years of VIRGO activity

- Focus always kept on the need to improve the range, **mainly linked to the high frequency performance.**
- Commissioning on seismic isolation almost entirely devoted to guarantee stability of working point and detector duty cycle. Understanding and fixing issues about total rms motion and control noise have never been a priority.

Actions done for the improvement the LF performance at Virgo:

- **Simplification and softening** in pitch and roll of the last stage suspension.
- More sensors and actuators, for controlling ‘forgotten’ d.o.f.s
- Optimization of alignment control loops; reduction of local angular sensing noise.
- Improved control electronics.
- Suspension control strategy adaptation, by the use of the arm length optical measurement in several actuation points far away from the TM.

Not enough time and resources devoted to:

- Modeling, noise projection, noise hunting, designing solutions.
- Documentation production.

TOWARDS THE SECOND GENERATION

VIRGO improved the fundamental low frequency noise in 2008 (**VIRGO +**), anticipating a step towards the second generation detector.

- test masses suspended to fused silica wires (low losses); thermal noise 10 times lower
- No fundamental change of the **seismic suspensions** was considered to be mandatory. Mechanics, sensors, control strategy, economic and human resources remained at the level of the **first generation**.
- **ADV VIRGO** installation did not included any relevant change in the seismic suspension. The only upgrades done for improving the low frequency performances were:
  - low noise electronic boards used for suspension and test mass control;
  - suspension of the external benches, for the stray light issue.

Advanced LIGO installed low-frequency **seismic isolation** and fused silica suspensions in 2014. The improved performance uncovered an array of additional technical noises not seen in Initial LIGO.

STATUS OF THE SENSITIVITY AT LF

VIRGO sensitivity at **10-20 Hz** obtained in **O3** was quite variable, depending on the environmental condition and working point quality and stability.

Here is a list of LF noise sources, not all and not always clearly visible above 10 Hz, but quite evident below 10 Hz:

- Straylight noise injected by the residual motion of the scattering points.
- Angular control noise.
- Auxiliary d.o.f.s control noise (MICH, PRCL)
- Excitation of TM not controlled resonances (bouncing, roll).
- Higher suspension stage control noise.

At 10 Hz the measured noise has never been lower than **$3 \cdot 10^{-21}$ 1/sqrt(Hz)**, the expected noise for **initial VIRGO**.

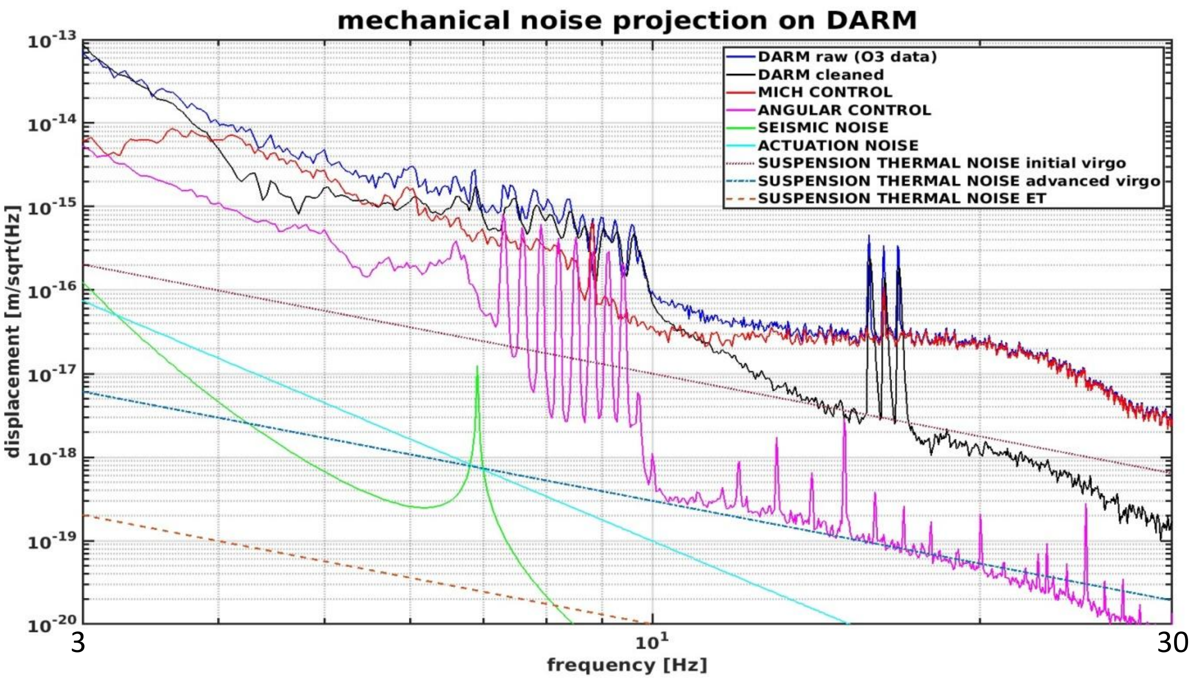
LIGO LF noise was dominated by angular control noise starting from 20 Hz.

Below 10 Hz VIRGO was better than LIGO, probably thanks to softer suspensions, requiring less control on the orthogonal d.o.f.s

UNOFFICIAL O3 NOISE BUDGET @ LF

TEST MASS motion @ LF is mainly control noise:

- MICH
- ANGULAR
- ACTUATION



NOT INCLUDED:

- Scattered light
- PRCL
- Control of other SUSP d.o.f.s
- High Q resonances of the test masses
- Newtonian
- Magnetic

improvements of suspension thermal noise below 20 Hz have never been appreciated in 20 years of commissioning

WHAT WE SHOULD DO NOW?

The first experience on LF must achieve the target sensitivity

- The community interested in LF should be active in VIRGO.
- Manpower have to be moved onto the study of VIRGO data and LF issues understanding. Data taking of the next years need to be exploited.

A second generation LF detector must be prepared NOW

- Develop suspension and control models.
- Develop mechanics, sensors, control electronics compatible with the present infrastructure, to be integrated in a short time scale
- A LF detector, on surface, at room temperature, can born in 4 or 5 years on VIRGO infrastructure.
- Focus on mechanical and environmental noise, eventually downgrading HF.
- Realistic sensitivity at low frequency: **$h=10^{-22}$ @ 10Hz** **$h=10^{-21}$ @ 4Hz** enough for producing astrophysical data never collected before.

The third generation LF detector project is not trustable without an intermediate step