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Advanced Virgo

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Summary. — The upgrade of Virgo to Advanced Virgo has been completed in 2016. The detector is now being commissioned, with the goal of starting taking data with the two LIGO interferometers during summer 2017.

1. – Introduction

During the first decade of the century the km-scale first-generation interferometric detectors of gravitational waves (GW) LIGO and Virgo have been successfully operated. No detection was made but the technology was demonstrated. At the end of the decade the projects to upgrade them to second-generation detectors started. Advanced LIGO [1] and Advanced Virgo [2] were conceived to enhance the potential of the first-generation detectors enlarging the observable volume of the universe up to a thousand times.

The two Advanced LIGO detectors started their first run in September 2015. On September 14th they recorded the first ever GW signal [3]. Virgo made its last science run (VSR4) in summer 2011. Then, the decommissioning of the detector started to allow the construction of Advanced Virgo, about two years later than Advanced LIGO. The integration of the detector was completed in fall 2016. Since then, the detector is being commissioned.

The addition of a third detector to the network will mark a historical moment for GW research and multi-messenger astronomy: besides improving the overall time and sky coverages, a significant improvement in the sky localization of the source is expected [4]. An accurate sky localization is essential to enable the multi-messenger astronomy which includes observations with electromagnetic and neutrino telescopes.

2. – Advanced Virgo design and technology aspects

The optical setup of Advanced Virgo is a dual recycled Michelson interferometer with 3 km long Fabry-Perot arm cavities (see fig. 1). In the following we summarize the main upgrades which have been implemented.

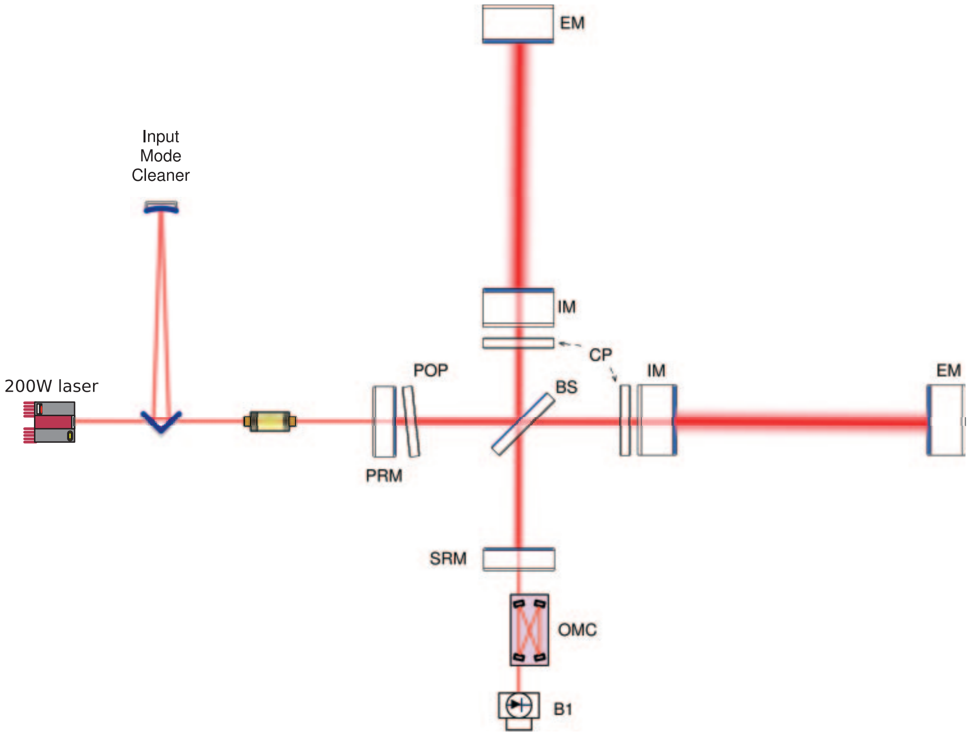

Fig. 1. – Simplified optical layout of the Advanced Virgo interferometer. Each 3 km long arm-cavity is formed by an Input Mirror (IM) and an End Mirror (EM). The recycling cavities at the center of the interferometer are 12 m long and are formed by the Power Recycling Mirror (PRM), the Signal Recycling Mirror (SRM) and the two IM.

- *Optical setup*
  With respect to Virgo a Signal Recycling (SR) cavity will be added, the tuning of which allows to change the shape of the sensitivity curve and to optimize it for specific targeted sources. To further reduce the impact of mirror thermal noise, the beam spot has been made larger (about 5 cm on the test masses). The finesse of the Fabry-Perot cavities is about ten times larger.

- *Laser power and thermal compensation*
  In the final configuration a power of 200 W will be provided by the laser, 10 times higher than in Virgo. The combination of high circulating power (up to 600 kW of light in the arm cavities) and the residual optical absorption in the mirrors leads to aberrations which can spoil the performance. The distortions are monitored in real time by two dedicated light beams probing the input mirror substrates and sensed by Hartmann sensors. In parallel, phase cameras are used to analyze the magnitude and the shape of the interferometer control sidebands which are extremely sensitive to any defects from the polishing tolerances of the optics, to misalignment or thermal aberrations. Error signals are derived from these sensors and used to build control signals for the thermal actuators (ring heaters and CO_2 lasers) for active aberration control.

- *Mirrors*
  A major step forward between Virgo and Advanced Virgo has been done on the technology to produce the mirrors. The test masses, the most critical optics, are cylinders 350 mm in diameter, 200 mm thick and weighing about 42 kg (twice the Virgo test masses). The substrate is made of the purest fused silica glass available. The polishing which gives the shape of the surface is done at the atomic level and a sub-nanometer rms roughness is achieved. Finally, the uniform multi-layer coating on the surface allows a reflection of more than 99.999% of the light while absorbing less than 1 part per million. Overall, absorption and scattering from the test masses are kept at a level never reached before.

- *Stray light mitigation*
  The first generation detectors had to tackle the impact of scattered light on their sensitivity. Advanced Virgo has a state-of-the-art optic, But, even in this case, a small fraction of the incident light is diffused. This might in principle introduce excess phase noise by recombining with the main beam after hitting non-isolated parts of the detector. A significant investment has been done to mitigate this risk:
  - absorbing baffles are placed around all the critical optics and in the vacuum system in such a way to intercept the diffused photons;
  - all the critical photodiodes are seismically and acoustically isolated. This is achieved by placing them on benches suspended from a compact vibration isolator (MSAS), inside a vacuum chamber.

Moreover, the final stage of the superattenuator (the payload) has been re-designed in order to ease the mirror control and to allow accommodating a larger mirror together with additional optics (compensation plates and absorbing baffles); the acquisition and control electronics has been redone; the vacuum system has been upgraded adding cryolinks at the end of the 3 km tubes; the input optics has been made compliant with the larger power.

3. – Starting configuration

As the Advanced Virgo project started about two years after Advanced LIGO, the need to realize as soon as possible a network of three interferometer to maximize the scientific output of the observations pushed for choosing a simplified starting configuration. Therefore, in the early phase Advanced Virgo will be operated in power-recycled mode (the absence of the signal recycling makes the interferometer easier to control) and with a laser power not larger than 25 W (to reduce the risk of thermal aberrations). Moreover, during the installation, several failures of the monolithic suspensions occurred with the breaking of the thin fused silica fibers supporting the test masses. This issue has been thoroughly investigated but has remained a mystery for months. In order to allow the commissioning to proceed the test masses were temporarily suspended with steel wires, while in parallel the problem was investigated: this allowed, at the cost of worsening the target sensitivity below 100 Hz, to complete the integration, put the interferometer in vacuum and start the commissioning of the machine. At the end of 2016 the reason of the failures was understood: a contamination of the vacuum system due to dust generated by the scroll pumps and blown towards the fibers during the venting. A plan for getting rid of the problem has been defined and the monolithic suspensions will be re-installed immediately after the end of the O2 science run.

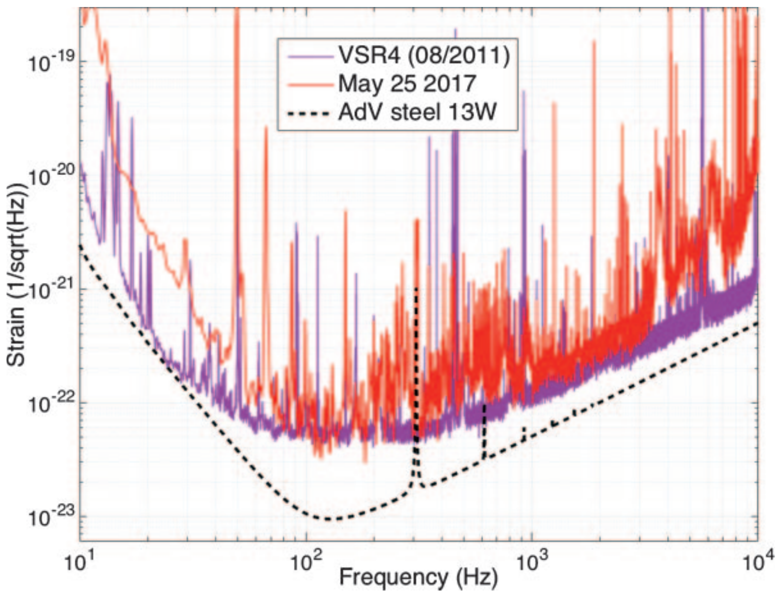

Fig. 2. – Sensitivity measured on May 25th compared with the best Virgo sensitivity and the target sensitivity for the current configuration.

4. – Current status

As of May 25th 2017, the interferometer is in the following state:

- stability: lock stretches as long as 8 hour have been achieved. In a recent 2 days run a duty cycle of $\sim 85\%$ was recorded;

- sensitivity: the inspiral range for binary neutron stars (common figure of merit) is ~ 7 Mpc, about half of the best range ever reached by Virgo (see fig. 2).

5. – Short-term upgrades

In the current plans the time between the end of the O2 run and the start of O3 is about one year. Advanced Virgo will use this time to progressively improve its sensitivity by installing new hardware and doing more commissioning. The highest priority is the re-installation of monolithic suspensions on the test mass, along with upgrades of the vacuum system to get rid of the contamination issue. Moreover, a 100 W laser and a squeezed light source (provided by the Albert Einstein Institute, Hannover) will be installed. The installation of the SR mirror (along with the auxiliary lasers necessary for the locking of the dual-recycled interferometer) is currently planned after the O3 run.

6. – Conclusive remarks

The first detections of gravitational waves have strengthened the case for a network of detectors capable of localizing a GW source and enabling the electro-magnetic follow-up. Advanced Virgo will soon make this possible, joining the two LIGO instruments in the observations.

REFERENCES

[1] Aasi J. *et al.*, *Class. Quantum Grav.*, **32** (2015) 074001.
[2] Acernese F. *et al.*, *Class. Quantum Grav.*, **32** (2015) 024001.
[3] Abbott B. P. *et al.*, *Phys. Rev. Lett.*, **116** (2016) 061102.
[4] Abbott B. P. *et al.*, *Liv. Rev. Relativ.*, **19** (2016) 1.