News from Virgo: present status and future upgrades

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The Virgo interferometer is designed to detect gravitational waves emitted by astrophysical sources in the frequency range from a few Hz to a few kHz. After the first phase of commissioning the Virgo interferometer has been operated with a good stability and a sensitivity close to the design. Consequently a first long science run (VRS1) took place in 2007 in coincidence with the LIGO detectors. Since then, a serie of upgrades have been scheduled (Virgo+) to further improve the detector sensitivity with the aim of a longer science run (VSR2) started mid 2009 in coincidence with the LIGO S6 run. In parallel the Advanced Virgo detector is being designed, aiming at a sensitivity 10 times better than the actual design. Its construction phase is expected to start mid 2011.

1 Introduction

Virgo [1] is a gravitationnal waves antenna based on a Michelson interferometer with 3 km long arms; each arm contains a Fabry-Perot cavity and the power recycling technique is used (see Fig. 1) in order to enhance the sensitivity. The goal of this experiment is the first direct detection of gravitationnal waves. The sources of gravitationnal waves that Virgo is looking for consist of periodic signals from rotating neutron stars, stochastic signals from the early universe gravitationnal waves background, transient signals from supernovae or compact coalescing binaries (these last ones having the potential of being used standard candles).
The commissioning of Virgo started mid 2003. An important step was a scientific run of 4 months in 2007. Data were collected in coincidence with the LIGO detectors [2] and jointly analysed. Virgo is now very close to its design sensitivity and its first upgrade (Virgo+) is in progress with the aim of a sensitivity 2 to 3 times better. The collaboration is also preparing the next generation detector, Advanced Virgo, which installation is planned to start in 2011.

2 Virgo commissioning

The installation of Virgo started in 1998: the central part of the interferometer was commissioned while the long arms were completed. The commissioning of Virgo started mid 2003. It consisted of two main phases: during the first one the interferometer has been controled in order to keep the optical cavities at the required resonance conditions, then the technical noises spoiling its sensitivity have been identified and reduced. The control of the full interferometer was achieved with a reduced power (0.8 Watts instead of the foreseen 10 Watts were incident on the interferometer) at the end of 2004. After a serie of improvements it was possible to control the full interferometer in 2006, at a power close to the nominal value (8Watts). The absorption of few ppm of the laser power inside the mirror substrates resulted in the distortion of the mirrors

(thermal lensing) and prevented a good control at full power. It was therefore decided to develop a thermal compensation system to correct this effect. This system is based on a CO2 annulus beam which heats the mirror in a complementary way to the main laser beam. As a result the temperature is more uniform in the mirror substrate, leading to a more robust control of the interferometer.
A good enough sensitivity was obtained in 2007 and scientific data taking could start with Virgo first scientific run (VSR1, May 18th to October 1st, 2007). This run was in coïncidence with LIGO S5 run and a MoU was signed between the 2 collaborations for full data exchange and joint data analysis. LIGO-Virgo joint data analysis results were reported elsewhere in this conference [3,4]. VSR1 was a very succesfull run: a duty cycle of 81%, long uninterupted segments with the interferometer at resonance (the longest of 94 hours) and a NS-NS horizon reaching 4 Mpc (the horizon is the mean distance at which a coalescence of neutron stars can be observed). After this run another serie of detector improvements led to an increase of the horizon by a factor 2.
Some important upgrades have been implemented during a 5 months long shutdown mid 2008. This is the first step towards Virgo+ (see next section) for which the main scheduled changes are: the instalaltion of more powerfull and less noisy readout and control electronics and the instalaltion of a laser amplifier in order to reach a power of 25 Watts on the interferometer. The thermal compensation system was also completed and commissioned, thus allowing today a good control of the interferometer up to 17 Watts.
The second scientific run, VSR2 in coincidence with LIGO S6 run, announced at the time of the conference has just started (July 7^{th}, 2009) and the detector shows promising performances (very good duty cycle and stability). This run should last at least one year.

The Virgo sensitivity is now very close to the design sensitivity on all the detector bandwidth. (see Fig. 2). Thanks to a very good seismic isolation system adopted for the mirrors suspension [5] Virgo has a much better sensitivity than LIGO's detectors at low frequency (below 40 Hz). In practice it is very difficult to reach good sensitivity at these low frequencies due to the presence of many technical noises. It is therefore a very important step towards the next generation detectors to show that a good sensitivity is feasible at these frequencies. Indeed, Virgo is not only very near to its nominal sensitivity at these frequencies but the remaining technical noises are well understood (as shown in Fig 2) and can be further reduced. A good example of the campaign for noise reduction is given by the mitigation of diffused light to which a lot of commissioning work has recently been devoted: The optics located on the external benches can retro-diffuse light into the interferometer due to the imperfections of their surface. Since these objects are not isolated from seismic noise the retro-diffused light carries some phase noise (proportional to the motion of the optic) which is equivalent to a de-phasing induced by a gravitational wave. In order to reduce the diffused light noise several improvements have been performed: reduction of the environmental noise (improved machines for air conditioning,...), acoustic isolation of the benches, improved optical systems on the benches. More improvements will be performed during VSR2 to reduce the remaining noises.

3 Virgo+

Virgo+ is the first upgrade of Virgo. The aim is to improve the detector sensitivity by a factor 2 to 3 (see Fig. 3), thus increasing the observable volume of the universe by a factor 8 to 30. In order to reach this goal the technical noises have to be further reduced and the interferometer has to be upgraded for lowering the fondamental noises such as the photons shot noise (high frequencies), the mirrors thermal noise (intermediate frequency range) and the suspension thermal noise (low frequencies).

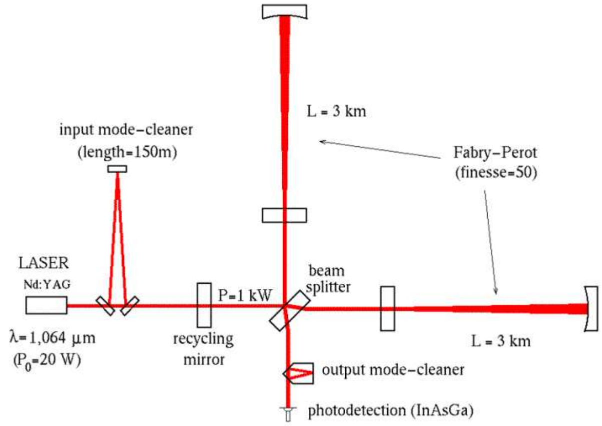

Figure 1: Virgo optical scheme

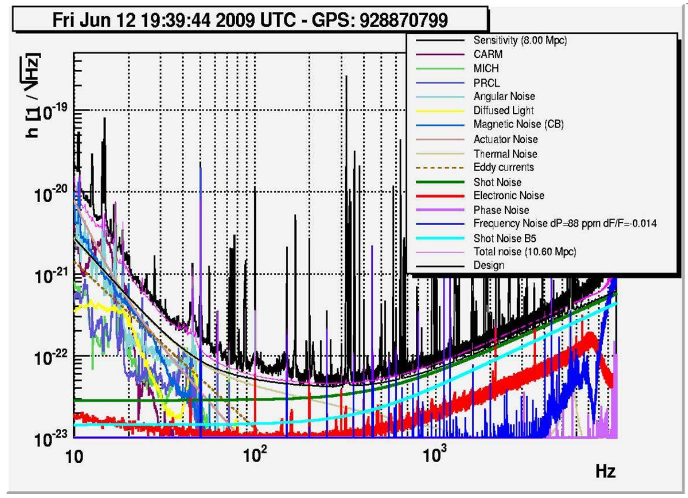

Figure 2: Virgo noise budget. The black curve is the measured Virgo noise (defining the sensitivity). The colored curves represent the known and modelled technical noises and the thin purple curve is the sum of all technical noises.

The shot noise will be reduced increasing the laser power. The laser amplifier is already in place and the laser power is slowly increased (from 8 to 17 Watts in the first half of 2009). Running at 25 Watts will require some upgrade of the injection system which is presently affected by thermal effects distorting the input beam.
At low frequency the Virgo sensitivity is limited by the thermal noise of the pendulum to which the mirror is suspended. This noise is due to friction between the mirror substrate and the metallic suspension wire used in a cradle configuration to support it. In order to reduce this noise monolithic suspensions must be used: in this case the mirror is suspended to fused silica fibers. A technique for pulling these fibers and gluing them to the mirror substrate using the silicate bonding process has been developped and validated.
In the intermediate frequency range (around 100 Hz) the sensitivity is limited by the mirror thermal noise (from the substrate and coating). New mirrors are being prepared for Virgo+ with better substrates and improved coating.
Since the mirrors will be changed we take the opportunity to increase the finesse of the arm cavities (by a factor 3) in order to further improve the sensitivity in the 100 Hz region.
The first monolithic dummy suspension has been produced and succesfully tested. The new mirrors are being coated and their installation is scheduled for the first part of 2010.

4 Advanced Virgo

In parallel with the activities mentioned in the previous sections the collaboration is preparing the next generation detector, Advanced Virgo (AdV). With Advanced Virgo the sensitivity should be improved by a factor 10 with respect to the Virgo original design, thus increasing the observable volume by a factor 1000. The AdV design sensitivity is shown in Fig. 4. With such a sensitivity the expected rate of gravitationnal wave events is of the order of 30 events per year making the detection possible, while it is unlikely with Virgo+. With such a rate the gravitationnal astronomy could start. The advanced detectors (Advanced Virgo and Advanced LIGO) will be operated in a network and coincidence with other messengers (electromagnetic radiation and neutrinos) will be looked for. The Virgo seismic isolation system is already compliant with the AdV design sensitivity, thus the suspensions will not be changed though some

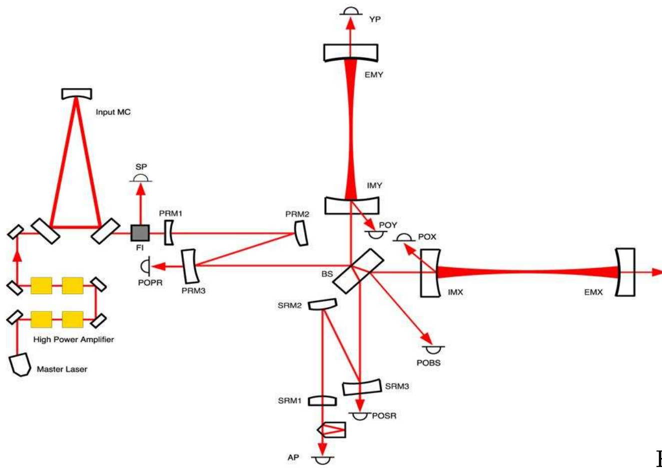

Figure 3: Advanced Virgo optical scheme

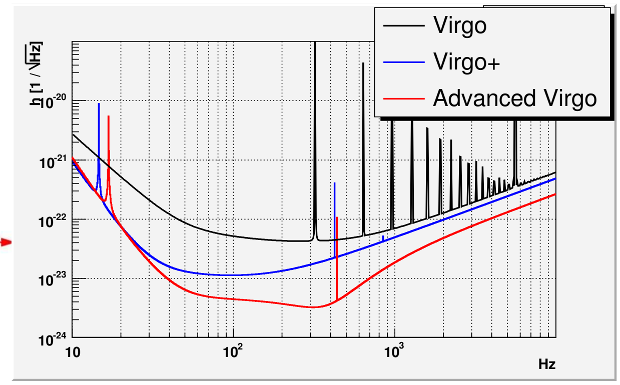

Figure 4: Virgo, Virgo+ and Advanced Virgo design sensitivities.

upgrades are in preparation. The main features of AdV are: a laser beam with higher power (up to 200 Watts) larger beams, heavier mirrors with improved polishing and coating for thermal noise reduction, monolithic suspensions, thermal compensation, more complex optical scheme and new readout scheme (homodyne detection). The optical scheme will use dual recycling: the signal recycling technique will be used in addition to the power recycling technique already present in Virgo. The recycling cavities will be non-degenerate since degenerate recycling cavity caused problems for the control of the interferometer slowing down the detector commissioning. The AdV optical scheme is shown in Fig. 3. Virgo+ is a big step towards AdV since a thermal compensation system and monolithic suspensions will already be used.
The AdV baseline design has been prepared and reviewed. The project is now in the approval phase (expected in fall 2009). The AdV installation is expected to start in 2011 and its commissioning in 2013. Its cost is estimated to 22 MEuros.

5 Summary

The Virgo detector is now very close to its design sensitivity and its second scientific run has just started with good performances. Since the first Virgo science run (VRS1 in 2007) data are exchanged with the LIGO detectors and jointly analysed. The first upgrade of Virgo, Virgo+, is being installed in several steps, the last one is scheduled in 2010 with the installation of monolithic suspensions. Virgo+ is also the place where some Advanced Virgo technologies will be tested like the monolithic suspensions. The Advanced Virgo baseline design is defined and the project is under approval. With a rate of gravitationnal wave events increased by a thousand (with respect to Virgo) Advanced Virgo should open the era of gravitationnal astronomy.

References

1. The Virgo Collaboration, Final Design Report, *Virgo Technical Note* VIR-TRE-DIR-1000-13 (1997).
2. B. Abbott et al., *Nucl. Instrum. Methods* in Phys. Res., **517**, 154 (2004)
3. R. Gouaty on behalf of LSC and Virgo collaborations, *Searches for gravitational waves from compact binary coalescences with LIGO and Virgo*, these proceedings.
4. N. Leroy on behalf of LSC and Virgo collaborations, *Searches for Gravitational Waves Bursts in the first common run between LIGO, GEO600, and Virgo*, these proceedings.
5. The Virgo Collaboration, *Astrop. Phys.*, **23**, 557-565 (2005).