The 2007 Europhysics Conference on High Energy Physics IOP Publishing
Journal of Physics: Conference Series **110** (2008) 062016 doi:10.1088/1742-6596/110/6/062016

Interferometric detectors of gravitational waves on Earth: the next generations

Giovanni Losurdo
for the LIGO Scientific Collaboration and the VIRGO Collaboration
INFN Firenze - Via G.Sansone 1, 50019 - Sesto F. (Firenze), Italy
E-mail: losurdo@fi.infn.it

Abstract. First generation long-baseline interferometric detectors of gravitational waves are now taking data. A first detection might be possible with these instruments, but more sensitive detectors will be needed to start the field of gravitational wave astronomy. Second generation interferometers will improve the sensitivity by a factor ten, allowing to explore a universe volume 1000 times larger. The technology is almost ready and the construction will start at the beginning of the next decade. The community of the physicists involved in the field has also started to make plans for third generation detectors, for which a long term technology development program will be required. The plans for the upgrades of the existing detectors and the scenario for the evolution of the field will be reviewed in this paper.

1. 1st generation interferometers

The construction of the 1st generation of interferometric detectors of gravitational waves (GW) started in the mid '90s. LIGO [1] in the US, Virgo [2] in Italy, GEO600 [3] in Germany are now taking data. The LIGO interferometers have reached their design sensitivity demonstrating the technology and have almost completed one year of coincident data, while Virgo and GEO600 will need more commissioning and noise hunting (see fig. 1). LIGO is able to detect the inspiralling of two binary neutron stars at about 15 Mpc (*BNS inspiral range*, averaged over sky directions and source orientations), while for optimal orientation, a BNS can be detected at a distance of 32 Mpc. The expected detection rate with such sensitivity is in the range 0.01 to 0.1 event/year [4]: even though the existing interferometers could make the first detection, the statistics of the events will be poor. More sensitive instruments are needed to increase the event rate and signal-to-noise ratio, making them a new tool to observe the universe and starting the field of GW astronomy. Thus, an intense R&D program is being carried out worldwide to break the current noise limits: high power lasers have been developed to reduce the shot noise, less dissipative mirror coatings and fused silica suspensions are being investigated to reduce thermal noise. A big effort to improve seismic isolation (LIGO) and to reduce the couplings with technical noises is also being done. The outcomes of such program are making possible to design more advanced interferometers.

2. The next step: Enhanced LIGO and Virgo+

It is already possible to improve some parts of the existing detectors, enhancing the sensitivity by a factor 2-3 without changes in the vacuum and vibration isolation setup, and allowing to

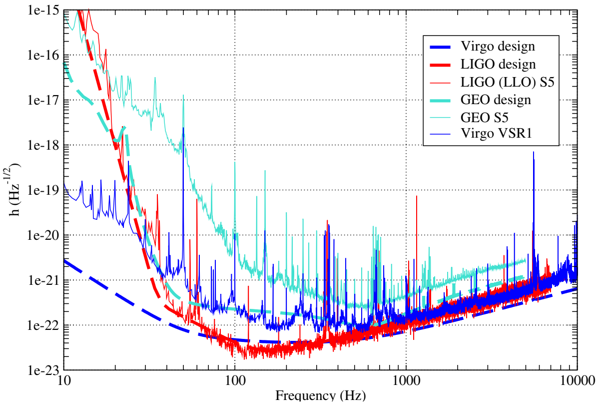

Figure 1. The sensitivities of LIGO (red), Virgo (blue) and GEO600 (cyan) compared with the design sensitivities (thick dashed lines).

increase the detection rate by a factor ~ 10 or more. Both LIGO and Virgo have planned such upgrades, to be performed in 2008 (see fig. 2,3). The so called *Enhanced LIGO* [5] and *Virgo+* [6] are expected to be taking data in 2009. Some foreseen upgrades are:

- **Enhanced LIGO:**
  - the increase of the laser power (from 10 to 30 W) to improve the shot-noise limited sensitivity above 100 Hz;
  - the installation of seismic and acoustic isolation for the photodiodes;
  - the installation of an output mode cleaner and the implementation of the DC detection scheme, to take care of technical noise couplings and allow the high power operation.
- **Virgo+:**
  - the increase of the laser power (from 20 to 30-50 W);
  - the installation of a system for the thermal compensation of the mirrors, to be able to cope with higher laser power;
  - the installation of new mirrors that increase the finesse of the Fabry-Perot cavities (from 50 to 150), to enhance the sensitivity in the mid-frequency range;
  - the possible installation of fused silica suspension fibers (under evaluation), to reduce the thermal noise associated to the steel suspension wires currently used.

The BNS inspiral range corresponding to the design sensitivity for Enhanced LIGO will be 33 Mpc, the one for Virgo+ will be 28 Mpc if fused silica suspensions are not used, 49 Mpc if they are.

Also GEO600 will undergo a series of incremental upgrades, with the aim of preparing a competitive detector to continue operations while Virgo and LIGO commission the advanced detectors. This program is called *GEO HF* [3] and includes the increase of the laser power, the change of the mirrors and the use of less dissipative coatings, the DC detection scheme and, when ready, the possible use of squeezed light. GEO HF might achieve a sensitivity better than Advanced LIGO/Virgo at high frequencies.

3. Towards GW astronomy: Advanced LIGO and Advanced Virgo

In 2011 the construction of the 2$^{\text{nd}}$ generation detector *Advanced LIGO* [7],[8] will start, with the aim of improving the sensitivity by a factor ~ 10 in the whole range with respect to LIGO (see fig. 4) and expand its detection band below the current 40 Hz seismic wall, thus increasing

The 2007 Europhysics Conference on High Energy Physics IOP Publishing
Journal of Physics: Conference Series **110** (2008) 062016 doi:10.1088/1742-6596/110/6/062016

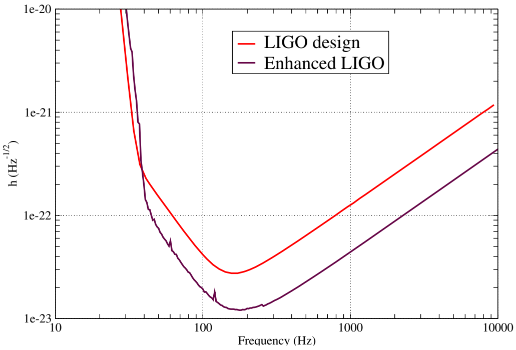

Figure 2. Enhanced LIGO sensitivity.

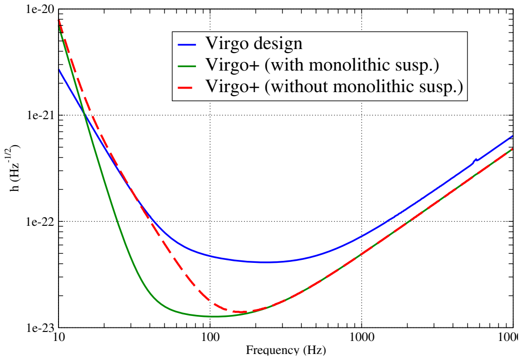

Figure 3. Virgo+ sensitivity.

the detection rate by a factor $\sim$ 1000. The foreseen BNS inspiral range for Advanced LIGO is 175 Mpc and a rate of events of 1/week to 1/day is expected. In parallel Virgo is pursuing the *Advanced Virgo* program [9] with the aim of achieving a sensitivity competitive with that of Advanced LIGO on a similar timescale.

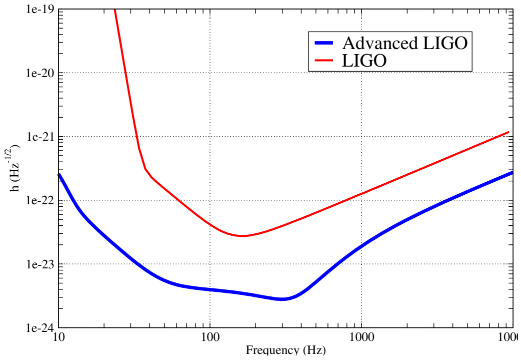

Figure 4. Advanced LIGO sensitivity vs LIGO one.

To get the foreseen important modifications to the detectors must be done:

- **Laser:** the laser power will be increased to about 200 W to reduce the shot noise significantly.
- **Mirrors:** heavier mirrors (about 40 kg) will be used to reduce the effect of the radiation pressure. New low loss coatings are being developed to reduce the related thermal noise.
- **Suspensions:** fused silica fibers (instead of steel wires) will be used to suspend the test masses, in order to reduce the suspension thermal noise.
- **Interferometer topology:** the *dual-recycling* scheme will be used, which allows to *shape* the noise curve and enhance the sensitivity in some chosen range. The cavity finesse and the intracavity power will be much higher as well. The waist of the beam on the mirrors will be increased by about three times to reduce the mirror thermal noise contribution.
- **Vibration isolation:** LIGO will change completely its vibration isolation system. An active one has been designed for Advanced LIGO, allowing to extend the detection bandwidth down to 10 Hz. The Virgo superattenuator will remain basically the same, though some parts will be re-engineered and the control strategy will be improved.

The 2007 Europhysics Conference on High Energy Physics IOP Publishing
Journal of Physics: Conference Series **110** (2008) 062016 doi:10.1088/1742-6596/110/6/062016

Advanced LIGO has been approved by the NSF and appears in the US President's and congressional 2008 plans, with a start once the funding bill is signed. The Advanced Virgo conceptual design is in preparation and will be submitted to the funding agencies (INFN/CNRS) in November 2007. According to the current plans, the advanced detectors will begin taking data in 2014, although not with full sensitivity. Commissioning periods, aimed at noise hunting and sensitivity improving, will be alternated with data taking periods.

2016 will be the centennial year of the GW prediction [10]: it could also be the starting date of GW astronomy.

4. Plans for the 3rd generation: Einstein Telescope

The GW community is already looking beyond the advanced detectors. Detectors of 3rd generation (having a sensitivity 100 times better than LIGO/Virgo) could open the GW cosmology era, e.g. detecting the GW counterpart of high redshift gamma bursts. The detection of a BNS with very high signal-to-noise ratio could give the chance to discriminate between general relativity and other metric theories of gravity or allow to determine the equation of state of a neutron star. To achieve such an amazing sensitivity the detector must be underground and the mirrors must be cooled at cryogenic temperature. A proposal for a design study of a 3rd generation interferometer, called *Einstein Telescope* [11], has been submitted to the European Commission within the Framework Programme 7 by a number of European institutions.

5. Summary

While the existing detectors of GW are taking data and setting the first upper limits. Though the first detection has not been achieved yet, physicists are convinced that the observation of GW will open a new window on the universe. More sensitive detectors are needed to start GW astronomy and the plans for the future of the field are ready:

- by 2009 LIGO and Virgo will be upgraded to enhance their sensitivities by a factor 2-3, thus increasing the detection rate by ~ 10;
- by 2014 Advanced LIGO and Advanced Virgo will be ready. They are expected to enlarge to observed volume of universe by a factor ~ 1000 with respect to LIGO/Virgo and to detect a large number of events;
- looking further, different technologies will be needed to develop the 3rd generation of gravitational-wave interferometers. A conceptual design effort in this direction is starting in Europe.

References

[1] Waldman S, *Class. Quantum Grav.*, **23** (2006), S653-S660.
[2] Tournefier E, *these proceedings*
[3] Willke B, *et al.*, *Class. Quantum Grav.*, **24** (2007), S389-S397.
[4] Nutzman P, *et al.*, *Astrophys. J.*, **612** (2004), 364-374.
[5] Adhikari R, *et al.*, *Enhanced LIGO*, LIGO-T060156 (2006). http://www.ligo.caltech.edu/docs/T/T060156-01.pdf
[6] Acernese F, *et al.* (The VIRGO Collaboration), *Journ. Phys.*, **32** (2006), 223-229.
[7] Fritschel P, *Proc. SPIE*, vol 4856-39 (2002), 282-291. http://www.ligo.caltech.edu/docs/P/P020016-00.pdf
[8] Advanced LIGO Team, *Advanced LIGO Reference Design*, LIGO-M060056 (2006). http://www.ligo.caltech.edu/docs/M/M060056-08/M060056-08.pdf
[9] Flaminio R, *et al.* (for the VIRGO Collaboration, *Advanced Virgo White Paper*, Virgo Note VIR-NOT-DIR-1390-304 (2005). http://wwwcascina.virgo.infn.it/advirgo/docs/whitepaper.pdf
[10] Einstein A, *Ann. der Phys.*, **49**, 769 (1916).
[11] *Einstein gravitational wave Telescope* Proposal to the European Commission, Framework Programme 7 (2007). http://www.ego-gw.it/ILIAS-GW/FP7-DS/fp7-DS.htm