LIGO and VIRGO: large interferometers searching for gravitational waves

F. Acernese, P. Amico, M. Alshourbagy, F. Antonucci, S. Aoudia, P. Astone, S. Avino, D. Babusci, G. Ballardin, F. Barone, et al.

To cite this version:

F. Acernese, P. Amico, M. Alshourbagy, F. Antonucci, S. Aoudia, et al.. LIGO and VIRGO: large interferometers searching for gravitational waves. XXXIII International Conference on High Energy Physics (ICHEP'06), Jul 2006, Moscou, Russia. World Scientific, à paraître, 2007. <in2p3-00190863>

HAL Id: in2p3-00190863
http://hal.in2p3.fr/in2p3-00190863
Submitted on 23 Nov 2007

LIGO AND VIRGO: LARGE INTERFEROMETERS SEARCHING FOR GRAVITATIONAL WAVES

GIOVANNI LOSURDO
Istituto Nazionale di Fisica Nucleare, Firenze, Italy
**E-mail: losurdo@fi.infn.it*

The largest interferometric detectors for gravitational waves, LIGO and Virgo, have reached (or are close to) the design sensitivity and have started taking science data. The operation of such detectors is reviewed and the expected sources and detection rates are discussed. LIGO and Virgo might make the first detection, but more advanced detectors will be needed to truly open the field of gravitational wave astronomy: the current ideas and plans for the upgrades of the existing interferometers are presented.

Keywords: Gravitational waves; Interferometers; Astronomy

1. Introduction

The existence of gravitational waves (GW) has been predicted long time ago[1]. Although some indirect evidence of GW existence has been provided by the observation of binary systems of compact stars[2,3], they have not been detected so far. The direct detection would be of major importance for fundamental physics and astrophysics. Certainly, it would be a further test for general relativity. But, as the detectors sensititivity improves, it should be possible to discriminate between genral relativity and other metric theories of gravity[4]. Thanks to the extremely weak coupling with matter GW can cross the universe undisturbed. The detection of the relic stochastic background of GW would reveal the state of the universe at the time of the inflation era[5], allowing to probe a scale of energy otherwise unaccessible. GW are a unique mean of investigation of the relativistic universe[6]. They can reveal what happens in the inner core of a supernova during the collapse or beyond a black hole horizon, can determine the equation of state of the matter in a neutron star[7] or reveal the nature of the engine of gamma bursts[8]: a completely new window on the universe can be opened by GW astronomy.

2. Interferometric detectors

The first attempts to detect GW have been done using cryogenic resonant detectors[9], characterized by a narrow bandwidth centered in the kHz region. The interferometric detectors[10], based on a completely different concept, may have a bandwidth spanning from a few Hz to a few kHz, allowing to investigate astrophysical sources of different kind: from slow periodic sources such as spinning neutron stars, to star core collapses, from coalescing compact binaries to the wideband stochastic background of relic GW. This feature makes such instruments suitable to pioneer the way to an new astronomy based on GW observations.

Interferometric detectors are built according to the optical scheme of fig.1: they are arranged in Michelson configuration, which gives sensitivity to differential displacements of the orthogonal arms. An infrared continuous laser (1064 μm wavelength, 20 (10)[a] W power), prestabilized in amplitude and frequency, is filtered through a tri-

---

[a] The values for Virgo (LIGO) are indicated.

angular optical cavity to select the TEM_{00} mode. The two arms are 3 (4) km long and the optical path is enhanced by using Fabry-Perot resonators. A further mirror (PR), set between the mode cleaner and the beam splitter (BS), recycles the light otherwise wasted towards the laser, increasing the effective power into the interferometer and thus reducing the shot noise level. All the test masses are suspended from vibration isolation system and the whole detector is under vacuum at a level of 10^{-9} mbar for H_2 partial pressure. The mirrors are made of special grade fused silica in orderto minimize optical losses and thermal noise due to internal dissipation.

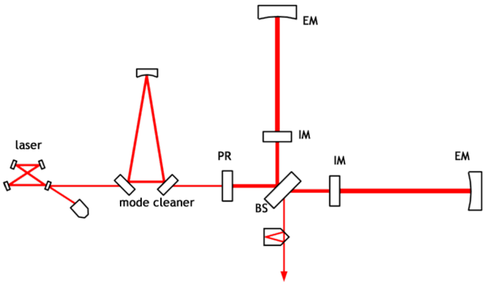

Fig. 1. Optical scheme of an interferometric detector: the input and end mirrors (IM and EM) in the arms form the 3-4 km long Fabry-Perot cavities.

A few detectors have been built around the world. This paper deals with the two largest projects among them: the US project LIGO[11] (fig.2) and the France-Italy one Virgo[12] (fig.3), the only detectors on kilometric scale (4 km and 3 km of length respectively).

The target sensitivity for Virgo and LIGO is remarkable (fig.4): in order to be able to detect the coalescence of two neutron stars bound in a binary system at the distance of the Virgo cluster they must be able to sense displacement of their test masses (the 10-20 kg mirrors) of less than 10^{-18} m.

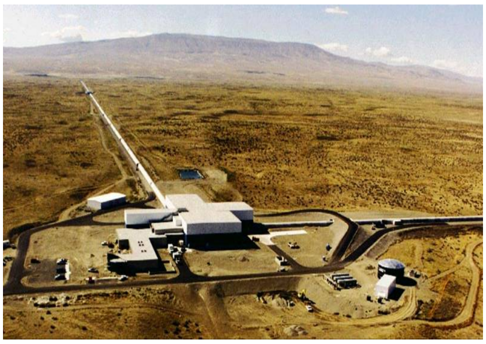

Fig. 2. One of the two LIGO facilities, Hanford (WA).

Fig. 3. The Virgo detector at Cascina, near Pisa (Italy).

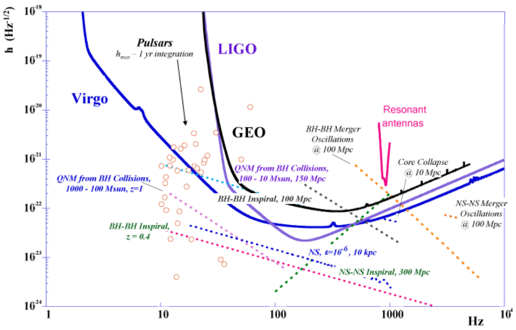

Fig. 4. The sensitivity curves of LIGO, Virgo and of the British-German project GEO600 are compared. The estimates for the signals coming from some possible astrophysical sources are indicated.

3. LIGO status

The LIGO project, is sponsored by NSF and jointly hosted by Caltech and MIT. LIGO has two facilities, located at Hanford (WA) and Livingston (LA), about 3000 km away. The WA facility contains in fact two interferometers, one of which is 2 km long. Therefore the LIGO project is composed by three interferometers that can be run in coincidence. The scientific program is carried out by the LIGO Scientific Collaboration (LSC), a worldwide network of more than 500 scientists from 35 institutions. The 600 m long British-German detector GEO600[16], located at Hannover, is also part of LSC. A remarkable result has been recently achieved: the LIGO detectors have reached almost at all frequencies the design sensitivity (fig.5). Such achievements has demonstrated the technology and the feasibility of an enterprise that has sometimes faced skepticism in the scientific community.

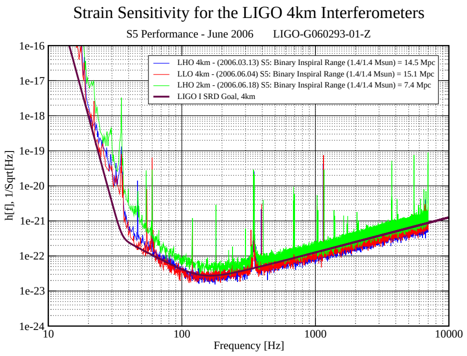

Fig. 5. Measured sensitivities of the three LIGO detectors compared with the target one.

LIGO has started in November 2005 a long science run with the goal of recording one year of integrated data with the three detectors in coincidence at design sensitivity. The LSC has already established some upper limits using the data of the previous science runs (with a worse sensitivity). The most recent LIGO papers are[13,14]. A complete list of the published papers is on the web[15].

4. Virgo status

Virgo is sponsored by INFN and CNRS and run by about 180 scientists. The construction of the detector was completed a few years later with respect to LIGO and the commissioning started in 2003. Virgo mirrors are suspended from a sophisticated vibration isolator, the so called *superattenuator*[17], that will allow to extend the detection bandwidth down to a few Hz, where a larger number of periodic sources (spinnining neutron stars) is expected to radiate. Virgo is now close to the design sensitivity in the higher frequency range (see fig.6). Though the commissioning work is still going on (with the final goal of achieving the design sensitivity), weekends are dedicated to data taking in *science mode*.

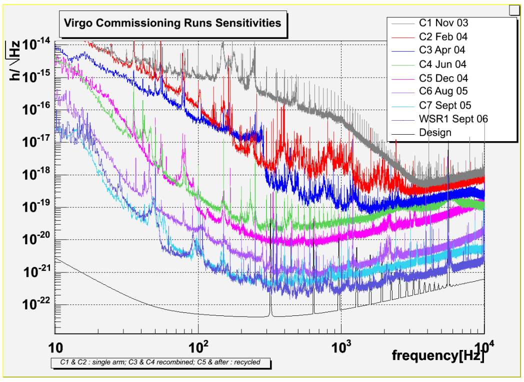

Fig. 6. The progress of the Virgo sensitivity since the beginning of the commissioning.

5. Network

The effect of GW of the test masses of an interferometric detectors is really tiny. One of the main problems to be faced is the vetoing of noisy events that can mimic a GW. Operating several detectors in coincidence can dramatically reduce the false alarm rate. Morover, it can allow to pinpoint the source directions and to measure the signal parameters, and it ensures a better sky coverage and a longer observation time. These are the reasons why LSC and Virgo have started a process towards a scientific collaboration: a Memorandum of Understanding will be signed soon, to rule the full exhange of the data, the joint analysis and publication of the results, the coordinated scheduling of shutdowns.

6. The next future

LIGO and Virgo have a real chance of catching the waves for the first time ever. Nevertheless, the rate of detected events expected on the basis of the astrophysical population models will be low[18]: in the most optimistic scenario a few event/year of compact stars binary coalescences are expected. Thus, LIGO and Virgo are not the right instruments to start GW astronomy. An upgrade plan is ready: LIGO and Virgo will enhance the sensitivity a first time with a limited set of upgrades around 2008-2009, while a major upgrade towards second generation detectors is foreseen at the beginning of next decade. The sensitivity of second generation interferometers will be $\sim$ 10 times better than LIGO/Virgo, thus allowing to explore a volume of universe $\sim$ 1000 times larger. The *Advanced LIGO* project[20,21] has been already approved by NSF and a robust R&D program is being carried on. Virgo Collaboration is also working at the design of a second generation detector. The main foreseen upgrades concern the laser power, the optical configuration, the mirror geometry. The LIGO vibration isolators will be replaced by new ones, while the superattenuators are already suitable for *Advanced Virgo*. Both projects will use fused silica fibers to suspend the mirrors and reduce the thermal noise, but Virgo plans to implement such change in the 2008 upgrade[19].

The first light of *Advanced LIGO* and *Advanced Virgo* might mark the birth of the GW astronomy.

References

1. Einstein A., *Annalen der Physik*, **49**, 769 (1916)
2. Hulse R., *Rev. Mod. Phys.*, **66** (3), 699-710 (1994)
3. Taylor J.H., *Rev. Mod. Phys.*, **66** (3), 711-719 (1994)
4. Damour T., Esposito-Farése G., *Phys. rev.*, **D58**, 042001 (1998)
5. Grishchuk L.P., *Sov. Phys. JETP*, **40**, 409 (1975)
6. Thorne K.S., in *300 years of gravitation*, Hawking S. and Israel W. eds., Cambridge University Press (1987)
7. Benhar O., *Mod. Phys. Lett.*, **A20**, 2335-2350 (2005)
8. van Putten M.H.P.M., *et al.*, *Phys. rev.*, **D69**, 044007 (2004)
9. Weber J., *Phys. Rev.*, **117**, 306 (1960)
10. Saulson P.R., *Fundamentals of interferometric gravitational wave detectors*, World Scientific (1994)
11. Waldman S.J. (for the LIGO Scientific Collaboration), *Class. Quantum Grav.*, **23**, S653-S660 (2006). See also http://www.ligo.caltech.edu
12. Acernese F. *et al.* (Virgo Collaboration), *Class. Quantum Grav.*, **23**, S635-S642 (2006). See also http://www.virgo.infn.it
13. Abbott B., *et al.* (LIGO Scientific Collaboration), *Class. Quantum Grav.*, **23**, S29-S39 (2006)
14. Abbott B., *et al.* (LIGO Scientific Collaboration), *Phys. Rev. Lett.*, **95**, 221101 (2005)
15. http://www.ligo.org/results/
16. Willke B., *et al.*, *Class. Quantum Grav.*, **19**, 1377 (2002)
17. Braccini S., *et al.* (Virgo Collaboration), *Astrop. Phys.*, **23**, 557-565 (2005)
18. Nutzman P., *et al.*, *Astrophys. J.*, **612**, 364-374 (2004)
19. Acernese F. *et al.* (Virgo Collaboration), *Journ. Phys.*, **32**. 223-229 (2006)
20. Fritschel P., *Second generation instruments for the Laser Interferometer Gravitational Wave Observatory (LIGO)*, in *Proc. SPIE vol 4856-39*, pp 282-291 (Waikoloa, HI, 2002)
21. Advanced LIGO Team, *Advanced LIGO Reference Design*, LIGO internal note M-060056-06-M (2006). http://www.ligo.caltech.edu/docs/M/M060056-07/M060056-07.pdf