Gravitational wave detectors: First astrophysical results and path to next generation

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After several years of construction and commissioning, LIGO, GEO600 and Virgo gravitational waves detectors have reached or exceeded their foreseen sensitivities and have been in operation for a few years. Even if a first detection remains unlikely with these sensitivities, meaningful results from the astrophysical point of view have been obtained on gamma-ray bursts or pulsars for example. For the current joint scientific run of LSC (LIGO Scientific Collaboration) and Virgo collaborations, the "multi-messenger" approach has been reinforced and, in particular, online searches have been implemented in order to trigger external observations by satellites or telescopes.

Upgrades to the next generation of these detectors have started. With expected sensitivity increases of a factor 10, we expect GW detections to be frequent and the "multi-messenger" strategy will be fruitful when these next-generation detectors begin data collection in 2015.

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[1] Speaker

1. The LSC-Virgo collaboration

Started in the 90's, the first generation of interferometric detectors for gravitational waves (GW) has reached the expected sensitivity which leads to astrophysically meaningful results. In May 2007, LIGO [1] and Virgo [2] joined their efforts, with Virgo starting its first science run (VSR1), in coincidence with the last four months of LIGO's S5 run, ongoing since November 2005. All results presented in this proceeding are based on S5 and VSR1data. Figure 1 presents the sensitivities of all detectors involved in the LSC-Virgo collaboration.

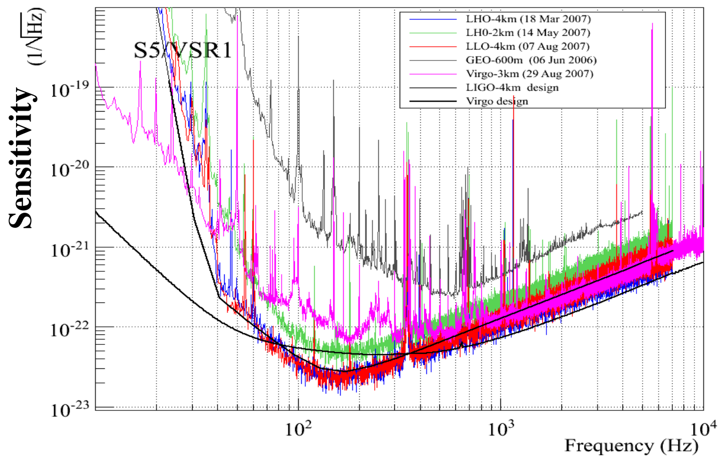

Figure 1: Sensitivities of the LSC-Virgo detectors

A second run (S6/VSR2) took place from July 2009 to January 2010 with an enhanced version of LIGO named eLIGO. After the upgrade of the Virgo detector (Virgo+) while the S6 run was ongoing on the LIGO side, a third joint run (S6/VSR3) acquired 3 months of data from August 2010 to October 2010 when LIGO detectors were stopped in order to start the installation of Advanced LIGO.

2. The first astrophysical results

Using a network of detectors allows reducing the false alarm rate and increasing the detection probability. Moreover, the source location can be reconstructed and the waveform can be extracted. The search can be performed using GW information only or in coincidence with other messengers. Some examples of recent results are given in the following sections.

2.1 Direct Searches

2.1.1 Coalescing binaries

This search aims to detect the GW emitted at the end of the collapse of binary systems composed by neutron stars or black holes. Left plot [3] on Figure 2 presents the typical reachable distance during S5/VSR1. In the best case, more than 150 Mpc is achieved. The second plot [4] shows the limit set on the rate of such coalescences for binary black holes.

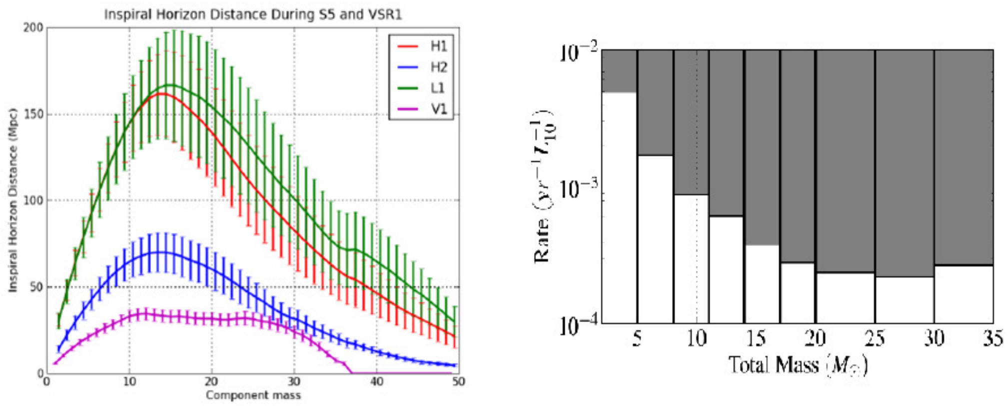

Figure 2: Left: Detection distance (Mpc) as a function of the system mass (M_{Sol}). Right: 90% rate upper limit (yr^{-1} L_{10}^{-1}) as a function of system mass (M_{Sol}) for Binary Black Holes.

2.1.2 Pulsars-Rotating neutron stars

If they have a sufficient ellipticity, rotating neutrons stars can emit detectable amount of gravitational waves. For the first time, the limits set on these GW amplitudes compete with the spin-down limit which supposes that the observed slowdown of the pulsar rotation is fully due to GW emission [5]. In the best case (Crab pulsar), the GW limit is 2% of the one given by the spin-down constraint.

2.1.3 Stochastic background

A signal coming from the early Universe could appear as a stochastic background in our detectors. As shown in the left part of Figure 3, obtained limits (at 90%CL) in the 100 Hz region are now better than the ones extracted from Big-bang Nucleosynthesis or CMB analysis [6].

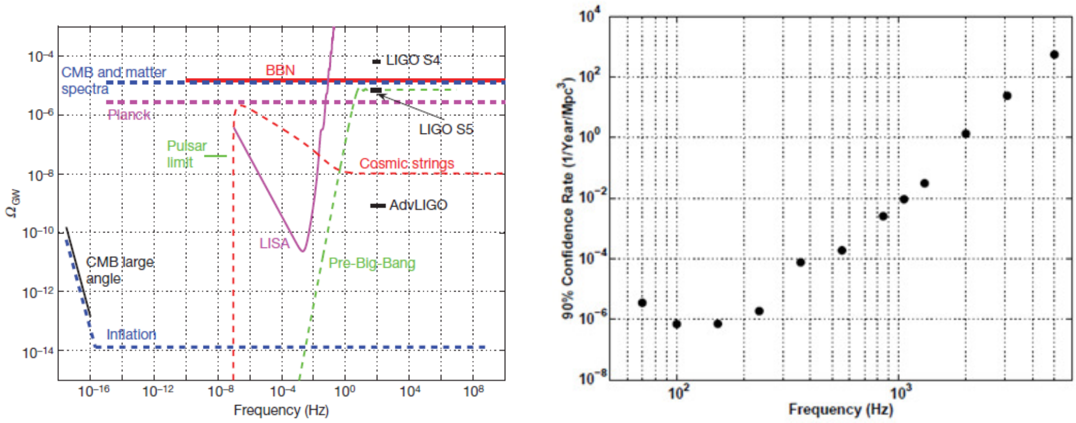

Figure 3: Left: Limits on Stochastic background in terms of the critical density. Right: 90% Rate limit per unit volume (1/year/Mpc^3) for Burst sources with E_{GW}=1M_{Sol} c^2

2.1.4 Bursts searches

Bursts searches aim to detect GW emitted by supernovae, black hole formation and ringdown, cosmic cusps and any other short duration sources. Right part of Figure 4 extracted from [7] presents the 90% rate limits obtained for this kind of sources supposing a GW emitted energy of $1M_{Sol}\ c^2$. With the S5/VSR1 sensitivity, a Galactic source emitting $1.8\ 10^{-8}\ M_{Sol}\ c^2$ should have been detected and for the Virgo cluster, the limit is $0.046\ M_{Sol}\ c^2$.

2.2 Multi-messenger strategy

Interactions with other detectors are reciprocal. First of all, information coming from electromagnetic (EM) telescopes or satellites and neutrino detectors can be used for the event localization (in time and space). Moreover, it increases the detection confidence and can help to understand the progenitor physics. On the other hand, GW detectors are able to trigger EM observations (satellites or telescopes).

2.2.1 Coincidences with GRB

Supposing that GRB progenitors are neutron stars-neutron stars or neutron stars-black holes coalescences, lower limits about few Mpc can be set on the distance of the GRB [8]. In particular, the position of GRB 070201 was consistent with M31 (D=760 kpc) and then, a GW binary signal would have been easily detectable. Such hypothesis has been ruled out at 99% CL.

2.2.2 Electromagnetic Follow-up

In order to trigger EM observations, an online data analysis with 10 minutes latency has been set up. Error regions in the sky are about several degrees. This system, which has been first successfully tested in December 2009 and routinely used during S6/VSR3 run, is able to trigger observations from wide-field telescopes or satellites like Swift.

3. The Advanced Detectors

While the first astrophysical results are extracted from current data, a first detection still seems unlikely. The sensitivity (see Figure 4) of the Advanced generation [9][10][11] will be improved by a factor 10. A first detection is very likely even in the most pessimistic cases [12]. These detectors are under installation and will perform their first science run in 2015.

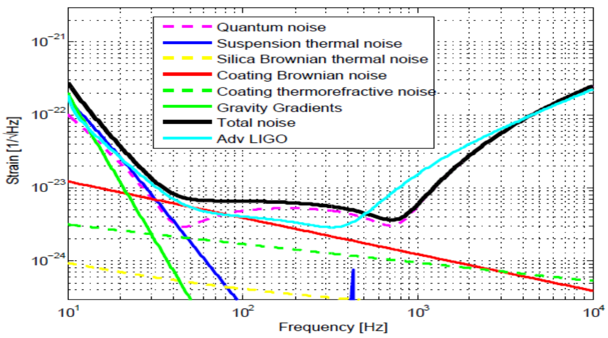

Figure 4: Expected sensitivity of Advanced LIGO

4. Conclusion

The first generation of interferometric GW detectors has reached design sensitivity and long science runs (S5-VSR1, S6-VSR2/VSR3) have been done. First astrophysical results have been published using S5-VSR1 while S6-VSR2/VSR3 data are under study. Follow-up with telescopes or satellites is now operative.

The next generation, Advanced LIGO and Advanced Virgo, is being constructed with a first science run foreseen in 2015. With a sensitivity increased by a factor 10, we hope for first detection and the birth of gravitational-wave astronomy.

Acknowledgments

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