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Upper limits of gravitational-wave bursts associated with Gamma-Ray Bursts

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Abstract. In this paper We will give an overview of present Gravitational Bursts Wave research status associated with Gamma-Ray Bursts, taking into account the achieved target sensitivity from either criogenic GW bar antennas like Auriga, or interferometric laser GW antennas like Tama, Geo, Ligo and Virgo .

Key words. Gravitational waves - Gamma ray bursts

1. Introduction

The effort to detect gravitational waves started humbly fifty years ago with Joe Webers bar detectors(1960,1966 see P.S. Shawhan, 2010). They opened the way to the present day interferometric detectors: starting from a bandwidth of a maximum of 50 Hertz around 960 Hz(bar criogenic antennas) nowadays we realized antennas with useful bandwidths of thousands of Hz, namely $10Hz \div 10kHz$ for Virgo(Bradaschia, C. et. al. 1990), $40Hz \div 10kHz$ for Ligo (Abramovici A. et. al., 1992), BUT, until now, no direct detection of GW credited signal nor detection of GW signal has been announced, notwithstanding the target sensitivity was practically reached (see fig. 1) for both VIRGO and LIGO.

We only have upper limits, for either criogenic bar or for interferometric laser GW antennas! For a comprehensive review on the state of art of Physics, Astrophysics and Cosmology of Gravitational Waves see B.S. Sathiaprakash and B.F.Schutz, 2009 (http://livingreviews.org/lrr-2009-2) and references therein . We shall divide our paper according to the following framework:

- Experimental GW detection strategies;
- The Network of joint interferometric GW and electromagnetic (EM) detectors: Multi frequency observations;
- The GW transient sources associated with Gamma-Ray Bursts: Results in terms of upper limits;
- Conclusions? → Open Questions

2. Experimental GW detection strategies

To detect directly GW, mainly two strategies were implemented until now:

- Resonant cryogenics Weber bar antennas
- Interferometric laser GW antennas

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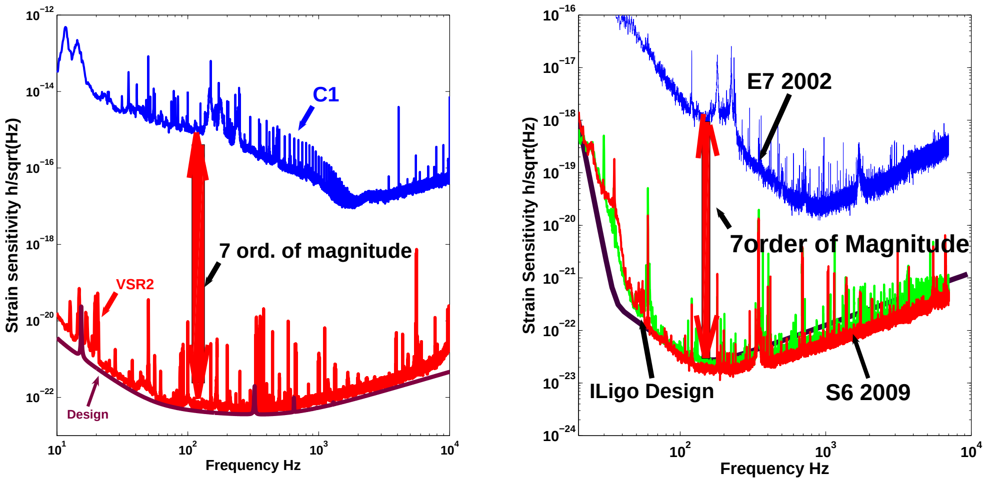

Fig. 1. On the left sensitivity curve of Virgo interferometer:more than 7 order of magnitude gained in 7 years! Virgo reached the target sensitivity, a part a small difference on low frequency side(10Hz). On the right Ligo sensitivity curve: the actual performance, exceeds the requirement by about a factor of three.From S1 to S6 run there was a gain of 7 order of magnitude.

3. The network of joint interferometric GW and electromagnetic (EM) detectors: multi frequency observations

The wide antenna pattern of a single GW detector has the advantage of being nearly omnidirectional but the cost is a poor angular resolution. In order to detect either a GW signal with low false alarm rates or to determine the parameters of a GW, a network of detectors is mandatory.

Though such a network exists, consisting of the two LIGO sites (B. P. Abbott et al., 2009, see), Virgo and GEO600 (H. Grote et al., 2010), it is well known that it has poor angular resolution along directions perpendicular to the line connecting the USA and Europe, and correspondingly poor polarization information.

One of the remedies is to implement a joint network of GW and electromagnetic (EM) antennas that will allow a network multifrequency coherent analysis giving a lot of advantages: sensitivity increase, source direction determination from time of flight differences, sources polarizations measurement, test of GW Theory and GW physical properties.

False alarm rate will be dramatically reduced by coupling EM multifrequency observations to network GW searches. For instance, impulsive GW sources, like short GRB, are believed to originate from the merging of NS/BH, while long GRB should be related to collapsar models, i.e. the collapse of a massive star down to a black hole with the formation of an accretion disk, in a peculiar type of SN-like explosion.

There is no clear understanding yet on the time delay between a GW emission and a GRB emission (if you ask different experts, you get different numbers!). Foreseen collaboration are with:

- Swift coupled with multi-wavelength (optical, UV, Xray), RXTE and AGILE satellites, Space telescope
- Wide-field optical telescopes: ROTSE, TAROT,SkyMapper;
- Radio telescopes like LOFAR;
- Neutrino detectors: Antares, IceCube, LVD, Borexino, Super-Kamiokande;

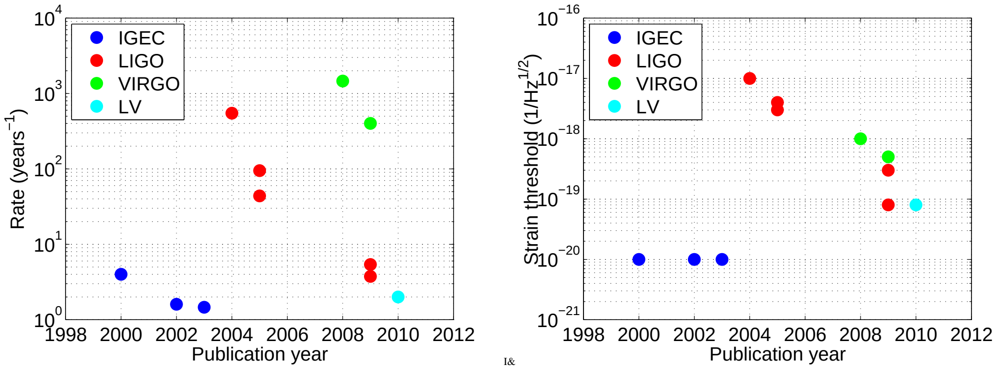

Fig. 2. In figure there are shown the evolution of upper limits in rate(left) and strain(right) achieved during the last 10 years by criogenic resonant bar antennas and interferometric antennas, in untriggered (all sky search) .

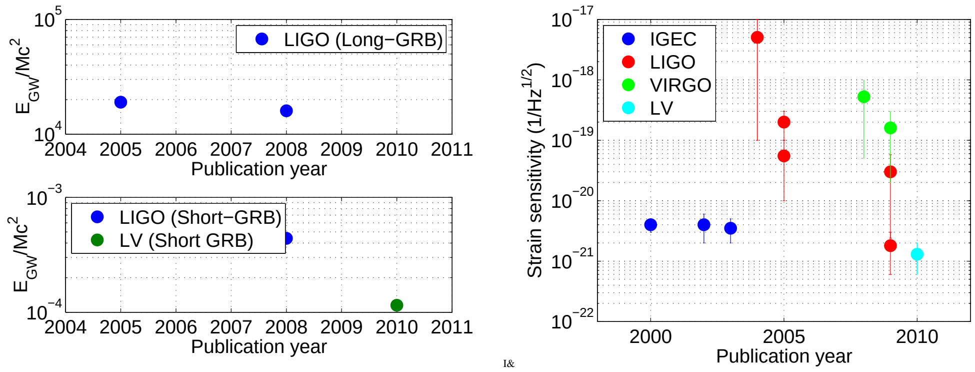

Fig. 3. In figure there are shown the evolution of upper limits in emitted Energy(left) and strain(right) gained during the last 5 years scientific runs by interferometric GW antennas, in triggered search from GRB detected in EM by Swift and Fermi satellites .

4. The GW transient sources and $\gamma RayBurst$

In the last years, since the ground based GW interferometric detectors have come into operation, several studies have been carried out to detect GW signals from different sources, both by the single interferometers and by coherent searches with other detectors, i.e. other interferometers, resonant bars, GRB detectors on ground and in space, X-ray satellites, but until now (june 2011) only upper limits have been the result of such researches.

Among the promising sources of GW there are GRBs, whose credited model could be a narrow beam of intense radiation released during a supernova event, as a rapidly rotating, high-mass star collapse to form a neutron star, quark star, or black hole.

The observed distribution of GRBs is isotropic and for the fraction with measured redshifts the typical distance is of the order of $1 \div 10Gpc$. If the $\gamma - ray$ emission is isotropic the typical energies emitted by each burst could be of the order of $10^{-3} \div 1M_{\odot}c^2$.

From the observed distribution of their duration, GRBs have been classified in two groups: short GRBs with a duration of less than 2 seconds and long GRBs which are longer than 2 seconds.

The duration is characterized by the length T_{90} of the time interval containing the $5 \div 95\%$ of above background photon counts in the $15 \div 350$ keV energy range. This classification is confirmed by $\gamma - ray$ spectra, as short bursts tend to have a harder spectrum than long bursts. In the last ten years several studies have been carried out by the single interferometers and by coherent searches with other detectors, i.e. other interferometers, resonant bars, GRB detectors on ground and in space, X-ray satellites to detect GW Burst signals from different sources : both searches – un-triggered and searches triggered by observations from gamma-ray and X-ray satellites – were performed for long and short duration gamma ray bursts (GRB030329 and hundreds of GRBs since 2004, including $GRB070201$) and for Galactic soft gamma repeaters(including the 2004 hyperflare of $SGR1806 - 20$).

Interesting upper limits in the rate and strain threshold have been obtained for GW Bursts:

- **Explosive GW transient sources (Bursts)**: Limits on GW bursts have been placed since the first LIGO Scientific Run (S1) in 2004 using ad-hoc waveforms (B.P. Abbott et al. 2004) then in S2 the coherent analysis of the two LIGO interferometers with wavelets (B.P. Abbott et al., 2005) and between LIGO and TAMA (B.P. Abbott et.al., 2005) improved the sensitivity. A search for GW bursts associated with the very bright gamma ray burst $GRB030329$, using the two detectors at the LIGO Hanford Observatory also showed no result (B.P. Abbott.et al., 2005). In the S3 (2005) LIGO run, besides a LIGO-only analysis with no waveform model, a coincident search for bursts has been carried out with the Auriga bar detector (L. Baggio et al., 2008) in the narrow band where simulations showed a high fraction of the GW power in the resonant detector. Using 14 days of S4 LIGO data (Abbott et al., 2009) and a matched filtering technique, a search for bursts coming from cosmic strings cusps ruled out many grand unified theory-scale models (with string tension $G\mu/c^2 \approx 10^{-6}$) at 90% confidence. A LIGO-GEO analysis (B.P. Abbott et al., 2007, B.P. Abbott et al., 2008) has been performed with one month of coincident data in S4 where the two interferometers were particularly stable. Further searches for bursts in coincidence with bright flares and GRBs have been carried out in S4 and S5 (B. P. Abbott et al., 2008), (B.P. Abbott et al., 2008 , B. P. Abbott et al., 2009) also in coincidence with the first VIRGO Scientific Run (VSR1) (B. P. Abbott et al., 2010). In J. Abadie et al.,(2010) an all-sky search for GW bursts is presented with data coming from S5, VSR1, and GEO for 266 days between 2006 and 2007, setting an upper limit on the rate of detectable GW bursts in the $64 \div 2048$ Hz band to 2.0 events per year at 90% confidence. This is the first untriggered burst search to use data from the LIGO and Virgo detectors together.
- **Compact Binaries coalescences (CBC)** Black Hole-Black Hole (BHBH) (B. P. Abbott et al.,2009), Black Hole-Neutron star (BHNS)(B. P. Abbott et al.,2009) and neutron star-neutron star (NSNS) binary systems coalescences have been searched in S4 and S5 setting an upper limit to their rates to 7.3×10^{-4}, 3.6×10^{-3} and $1.4 \times 10^{-2} L_{10}{}^{-1}$(being $L_{10} = 10^{10}$ the solar blue luminosity). NSNS and BHNS coalescences as progenitors of GRBs have been jointly searched in S5/VSR1 setting exclusion distance of 6.7 Mpc (J. Abadie et al., 2010).

For some GRB the red-shift is known and it is possible to set-up an upper limit in the energy emitted during the process. For long-GRB the upper limits, assuming an axi-symmetric emission are still very close to the source maximum luminosity , so there are not useful information. For short-GRB with known distance some more upper limits were set.

The evolution of upper limits in rate and strain gained during the last 10 years by criogenic resonant bar antennas and interferometric antennas, in untriggered (all sky search) and triggered search from GRB detected in EM by Swift and Fermi satellites during the

Interferometer antennas runs in the last five years, are shown in fig. 2 and 3. For the untriggered burst GW serach the best upper limits in terms of rates are still fixed from the resonant bar antennas owing to the longer integration time. The best strain sensitivity is nowdays coming from data collected by interferometric GW antennas. The real problem is the horizon of the antennas either bar or interferometric: it is still too small, in the best case, until now, we have an horizon of $\sim 10 \div 15 Mpc$.

5. Conclusions? → Open questions

In this paper we have given a scenario of the Explosive GW transient sources (Bursts) astrophysics. There are a lot of questions still open like:

- Upper limits for GW burst: when a direct detection?
- What fraction of GRB's energy is emitted in the form of gravitational waves?
- Can we have direct inferences on the GRB jet parameters from gravitational waves?
- Can gravitational waves detectors give an early warning to EM observers to allow the detection of early light curves?

At present either with the interferometers (Ligo ,Geo, Tama, Virgo) or the resonant criogenic bar antennas we only succeeded to put interesting upper limits, but the cherished belief is that the first direct detection is behind the corner.

6. Discussion

DANIELE FARGION's Comment: GRB-GW will rise if model of GRBs are explosive. BUT if just steady beaming jets precessing THEN real GRB Power much much less and so negligible GW emission . However from ANDROMEDA a SN MAY SOON or LATER SHINE and even TIME DELAY between $GW - \nu$ prompt neutrinos MAY TEST ALSO ν mass even at atmospheric limit $\Delta m \gtrsim 0.05 eV$.

7. Acknowledgments

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