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GRAVITATIONAL WAVES AND GRBS

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Abstract. Owing to new or upcoming facilities (Advanced LIGO/Virgo, SKA with its pathfinders or precursors, CTA, ...) multi-messenger observations will have a strong impact on the field of gamma-ray bursts (GRBs). We are interested in joint radio and gravitational wave (GW) observation of short GRBs. We estimate the prospects for such combined observations with Advanced LIGO/Virgo and the low-frequency radio phased-array NenuFAR. No radio GRB afterglows have been observed so far in the low-frequency band, and our predictions are currently limited by the uncertainty in the radio afterglow models. Our preliminary analysis indicates that there is a limited but non-zero chance to observe with NenuFAR a radio afterglow associated with a GW event.

Keywords: Gravitational waves, Gamma ray bursts, Radio continuum

1 Introduction

GRBs are the most extreme cosmic explosions. Some of them are so bright that even if they are located far away in the Universe their optical counterparts can be observed with naked eye. They are detected from space by satellites thanks to the ash of gamma-ray photons released within a transient relativistic jet, which signals the explosion. The ultra-relativistic jet is produced by a new-born accreting black hole formed after the collapse of a massive star or the merger of two compact objects (see Fig.1). The short lasting (few seconds) gamma-ray *prompt* emission is followed by an *afterglow*, detectable from the X-ray to the radio wavelengths for hours to months, depending on the frequency domain and on its intrinsic brightness.

We can distinguished two classes of GRBs, depending on the duration of their prompt emission (but not only): the *long* and *short GRBs* (Kouveliotou et al. 1993). We now know that long GRBs are associated with the explosions of very massive stars (see e.g. Hjorth & Bloom 2011), whereas we suppose that short GRBs are formed by the merger of two compact objects (stellar black holes and/or neutron stars) but we don't have any direct proof of this. The study of GRBs impacts several branches of physics and astrophysics. Moreover GRBs constitute excellent candidate sources for multi-messenger astrophysics as high-energy neutrinos and gravitational waves are expected in addition to the observed release of electromagnetic energy.

In this proceeding we discuss about the possibility of using radio observations to find the electromagnetic counterparts of gravitational waves (GW) detected by the Advanced LIGO[*]/Virgo[†] interferometers. We will focus in particular on the possible use of the NenuFAR array[‡].

2 GRBs at radio frequencies

GRB afterglows emit through the synchrotron process. The intensity and peak time of GRB radio afterglows depend on the radio frequency observed and on the characteristic of the GRB and its environment. Afterglows become fainter and peak later, as the frequency observed is smaller. GRBs less energetic show fainter radio

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[*] `https://www.advancedligo.mit.edu/`

[†] `http://wwwcascina.virgo.infn.it/advirgo/`

[‡] `http://nenufar.obs-nancay.fr/?lang=en`

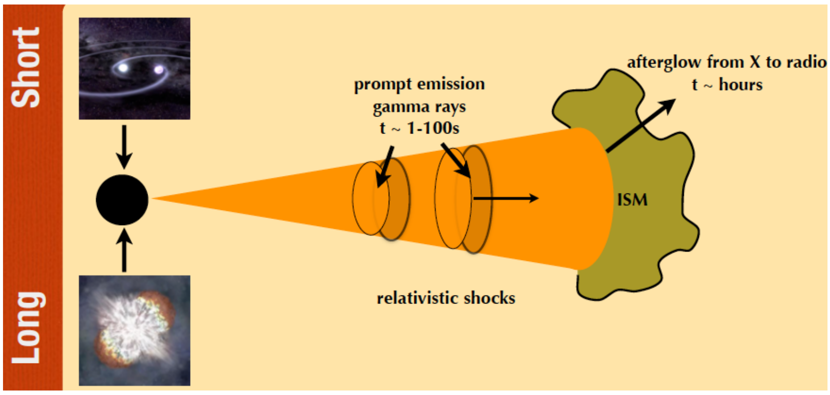

Fig. 1. Cartoon of GRBs following the so-called *fireball* model. The merging of two compact objects (for short GRBs) or the collapse of a very massive rotating star (for long GRBs) give rise to an ultra-relativistic jet within which *internal* shocks produce the *prompt* gamma-ray emission. When the jet encounters the interstellar medium surrounding the progenitor system, the *aftertglow* emission is produces by *external* shocks and can be detected for hours to years, depending on the frequency domain of the observations.

afterglow light-curves that peaks earlier, than those with higher energies. The redshift affects the radio afterglow brightness: GRBs with the same energetic and environment will have fainter afterglows as their redshift increases. The density of the environment will also impact the radio afterglow intensity. Lower densities produce fainter afterglows but the same result is also true at too much high densities due to radio self absorption.

Most of the radio data available to date refer to long GRBs. For GW we are particularly interested to the short GRB class. This class of bursts show fainter and shorter afterglow at any frequencies. In the radio domain, this fact prevented to date to collect a large amount of afterglow radio for short GRBs. Detections are available only for few of them (see Chandra & Frail 2012 for a review).

3 GW and GRBs

Advanced LIGO/Virgo interferometers are about 10 times more sensitive than their predecessors, therefore increasing the explorable volume of the universe by a factor of $\sim$1000. GW are expected from the merging of compact objects, therefore also in association with short GRBs.

Because of their random orientation, GW events are more likely to come from off-axis coalescing binaries with their orbital momentum not oriented towards the observer. In such case, the associated relativistic jet also does not point towards the observer, thus preventing the observation of the prompt high-energy emission. Those events however be observed as *orphan* afterglows, i.e. transients at optical or radio wavelengths. The radio light-curves of orphan afterglows are similar to those of regular ones, except for the fact that, to detect them, we have to wait for the beaming angle to widen enough to reach our direction. Therefore we see a later rise and peak (see e.g. in Fig. 2) compared to an afterglow seen on-axis. Orphan afterglows represent the bulk of the GRB population despite they have not been detected so far. Ongoing and forthcoming wide and deep surveys are expected (Rossi et al. 2008) to detect orphan afterglows in the optical (Ghirlanda et al. 2015) and in the radio band (Ghirlanda et al. 2014).

The big issue with GW detections will be the huge errors on their position ($> 100\,\mathrm{deg}^2$, reduced to a few $10\,\mathrm{deg}^2$ when the KAGRA[§] and LIGO[¶] india detectors will join the collaboration). Such errors make the identification of the GW electromagnetic counterpart difficult. The large field of view of radio arrays (from a few deg^2 to $> 100\,\mathrm{deg}^2$, depending on the array and its set-up) can be very helpful for the detection of GW counterparts. Radio interferometer will be able to detect and GRB orphan afterglows (and disentangle them form other transient populations; see Fig. 4 of Ghirlanda et al. 2015) and, as the peak of GRB radio afterglow light-curve is shifted towards later times (days, weeks) compared to X-ray or optical, there is no need of extremely rapid follow-up observations.

[§] `http://gwcenter.icrr.u-tokyo.ac.jp/`

[¶] `ttp://gw-indigo.org`

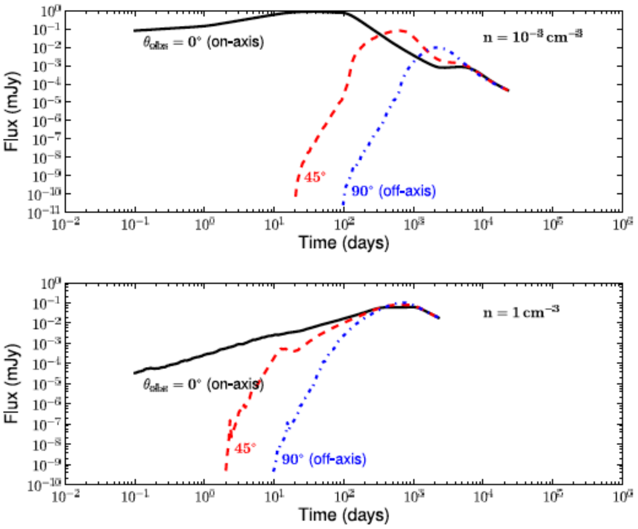

Fig. 2. Examples of GRB radio afterglow light-curves for different observer viewing angles and GRB environment densities. From Feng et al. (2014).

4 GW, short GRBs and NenuFAR

Our aim is to investigate the possibility to detect short GRB counterparts of GW using the phased-array of radio antenna NenuFAR being assembled at the Nanay station (Zarka et al. 2015). Although the radio afterglow is expected to be dimmer at low frequency because of synchrotron self-absorption, it may still be observable with NenuFAR as detectable GW sources are relatively nearby.

To this purpose, we run a simulation using the afterglow modelling of van Eerten & MacFadyen (2012), varying the GRB parameters and combine it with a population synthesis code determining the distribution of GRB rates and redshift. We then define an instrument model and the observing strategy to determine which would be the detectable flux from these events for a given exposure.

We considered initial and final configurations of NenuFAR respectively with 400 and 1800 antennas and chose 80 MHz as the reference frequency of observations. The peak of the GRB afterglow at the radio frequencies appear after at least few days from the GRB explosion. Then, the afterglow starts decaying but it can remain bright enough to be detected for months and even years. For this reason, an efficient strategy to detect the afterglow in the radio is to perform a first observation as soon as the GRB (or the GW) is detected, and then a set of observations starting a few days after the explosion. The first observation will be used to remove confusion and be used as a comparison image, especially at frequencies where quite deep observations of the whole sky are not available.

Several of the parameter and distributions used in the simulations are very uncertain. Not much is known about the real rates and redshift distributions of short GRBs, as well as about the density of the short GRB environment and about the jet opening angles.

We run the simulations considering different environment densities. In Fig. 3 we show the best case for detections ($n \sim 1\,\mathrm{cm}^{-3}$) of our preliminary results.

5 Conclusions

We presented the preliminary results of our investigation on the possibilities to detect short GRB afterglows using NenuFAR, especially looking for the electromagnetic counterparts of GW event detected by the Advanced LIGO/Virgo. Our results show that the probability of detection of such counterparts with NenuFAR is s low but non-zero. Long duration exposures (order of months) are required.

We stress that our predictions are currently limited by the uncertainty in the radio afterglow models. Moreover, there are no detections to date of GRB afterglows at these low frequencies. Detections (or even deep upper limits) with LOFAR may lead to significant change in our conclusions.

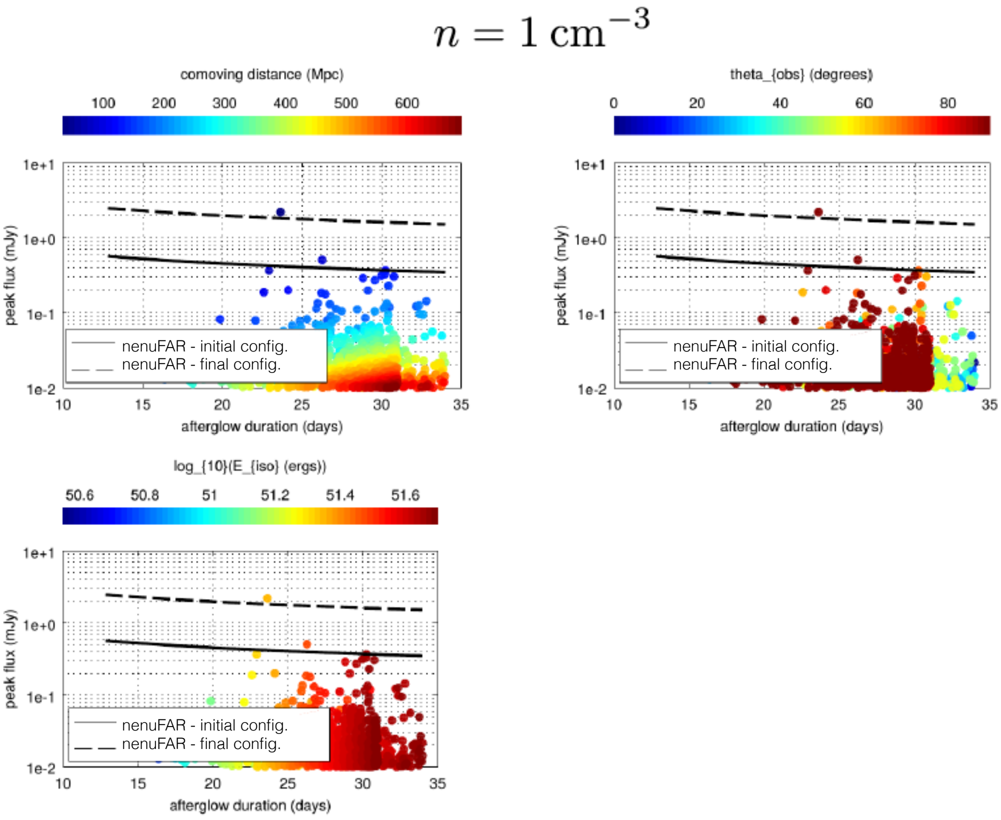

Fig. 3. Peak flux as a function of the afterglow durations from the preliminary results of our simulations, for the case of an environment electron density of $n \sim 1\,\mathrm{cm}^{-3}$. The black (dashed) line represents the flux limit reached by NenuFAR final configuration,1400 antennas (initial configuration, 800 antennas). Each point represent a simulated short GRB whose GW have been hypothetically detected by Advanced LIGO/Virgo. The color code corresponds to different distances (upper left panel), observing angles (upper right panel), and GRB isotropic energy (bottom panel).

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