A luminosity distribution for kilonovae based on short gamma-ray burst afterglows

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Abstract

The combined detection of a gravitational-wave (GW) signal, kilonova (KN) and short gamma-ray burst (SGRB) from GW170817, marked a scientific breakthrough in the field of multi-messenger astronomy. But even before GW170817, there have been a number of SGRBs with possible associated KN detection. Here I present my work that aims to constrain KN luminosity distribution exploiting the observations of nearby SGRB with and without a possible KN associated. Fitting the SGRB afterglow lightcurves with both afterglow and KN models, the distributions of merger's ejecta velocity, mass and lanthanides fraction have been derived. The posterios on KN parameters obtained in this way were turned into distributions for the peak absolute magnitude of the KN emission in different bands. From the magnitude distributions of GW170817/AT2017gfo, KN candidates and the upper limits from all the other SGRBs not associated with any KN detection for the first time a KN lumminosity distribution in different bands has been obtained. This could be of great advantage fro astromers in order to optimize an observation strategy for detecting these elusive transients.

Key words: workshop: proceedings — gravitational waves — gamma- ray burst — kilonova

1. Introduction

During binary neutron star (NS) or some NS - black hole (BH) coalescence we expect part of the NS matter to form an accretion disk surrounding compact object resulting from the merger, while an other part of NS matter is expelled from the system in the form of a mildly relativistic quasi-isotropic ejecta. The accretion disk is expected to launch a relativistic jet, whose kinetic energy is dissipated firstly internally, generating a brief flash of gamma-rays known as *SGRB prompt emission* and then externally due to the interaction with the interstellar medium, powering a fading synchrotron emission from X-ray to radio known as *SGRB afterglow* (Zhang 2018).

On the other hand the expanding ejecta, heated by the radioactive decay of the elements newly synthesized from the decompressed NS matter, radiates energy through thermal emission, generating in this way a transient in the optical and near infrared (NIR) called KN or macronova (Li & Paczyński 1998).

Few KN candidates, appearing as late-time NIR rebrightening emerging from the fading SGRB afterglow had been identified in association with the gamma-ray bursts (GRBs) GRB130603B (Tanvir et al. 2013; Berger, Fong & Chornock 2013), GRB050709 (Jin et al. 2016) and GRB060614 (Yang et al. 2015). However only with the recent observation of GW170817 and thanks to the measure of spectra of its optical and NIR counterpart, we had for the first time a compelling detection of a KN (*e.g.* Coulter et al. (2017), Pian et al. (2017)).

Here I summarize part of the results presented in Ascenzi et al. (2019) where we constrained the luminosity distribution of KNe in nine different filters (u, g, r, i, z, y, J, H, K) and obtained also an estimate of the time (measured from the GW maximum) at which the peak of the emission is expected to occur.

The paper is organized as follows: in Section 2. I describe the method we used and in 3. I described the results.

2. Method

We identified a sample of SGRB characterized by nearby events (redshift $z < 0.5$) that had been detected in optical or/and in NIR. These SGRBs are: 170817A, 130603B, 050709, 060414, 150101B, 140903A, 050724A, 061201, 080905A, 070724A, 160821B and 150424A (references in Table A1 of Ascenzi et al. (2019)), which is a subset of the sample of Gompertz et al. (2018). We fitted the multicolored lightcurves of these afterglows with KN and afterglow+KN models. For the KN model we used the single component model described in Coughlin et al. (2018) and dependent on the mass M_{ej}, the velocity v_{ej} and the lanthanide fraction X_{lan} of the ejecta. For the afterglow model we used the model described in Troja et al. (2018b), which follows the semi-analytical model from van Eerten, Zhang & MacFadyen (2010), and implemented in *afterglowpy* (Ryan et al. 2019). For each burst we sampled over the posterior distributions of M_{ej}, v_{ej} and X_{lan} obtaining for each sampling a set of lightcurves in the filters u, g, r, i, z, y, J, H, K with the aid of KN model of Metzger et al. (2010) implemented in https://github.com/mcoughlin/gwemlightcurves. We selected in each of those filters the value of the peak magnitude obtaining in this way, for each burst in each filter, a distribution of the peak absolute magnitude. I report here the distributions in g and H filters in Figure 1. For the magnitude distributions obtained by SGRBs with a KN candidate we consider three characteristic values: the upper limit (5th percentile), the median and the lower limit (95th percentile). For the other distributions we considered only the upper limit and set the median and the lower limit to an infinitive magnitude (null luminosity). With these values we obtained in each filter three cumulative distribution functions (those of upper limit, median and lower limits) which are reported in Figure 2 and correspond to the luminosity distributions in three limiting cases.

3. Results and Conclusions

In the work presented in this proceeding, fully exposed in Ascenzi et al. (2019), we produced for the first time luminosity distributions of KNe in u, g, r, i, z, y, J, H, K filters and in three limiting cases. Our analysis identify a peak absolute magnitude of the emission in H filter to occur, with a 95 % of confidence, in the range $[-16.2, -13.1]$ in the time interval $[0.8, 3.6]$ days after the merger. In g filter the distribution of peak absolute magnitude results broader, with a value in the range $[-12.3, -16.8]$ and a peak time occurring within the first 18 hrs after the merger.

Furthermore, additional KN candidates have been recently claimed to be found in association with SGRBs (Lamb et al. 2019; Troja et al. 2018a; Troja et al. 2019; Rossi et al. 2019). Since some of them are also in our sample we promoted them in a separate analysis as event with a KN candidate and obtaining different results for the distributions of the lower limits and the median. These last results are reported in Ascenzi et al. (2019).

In the future, when more KNe will be detected with lightcurves sufficiently densely sampled in time, we expect to repeat our analysis employing a more realistic multi-component KN model.

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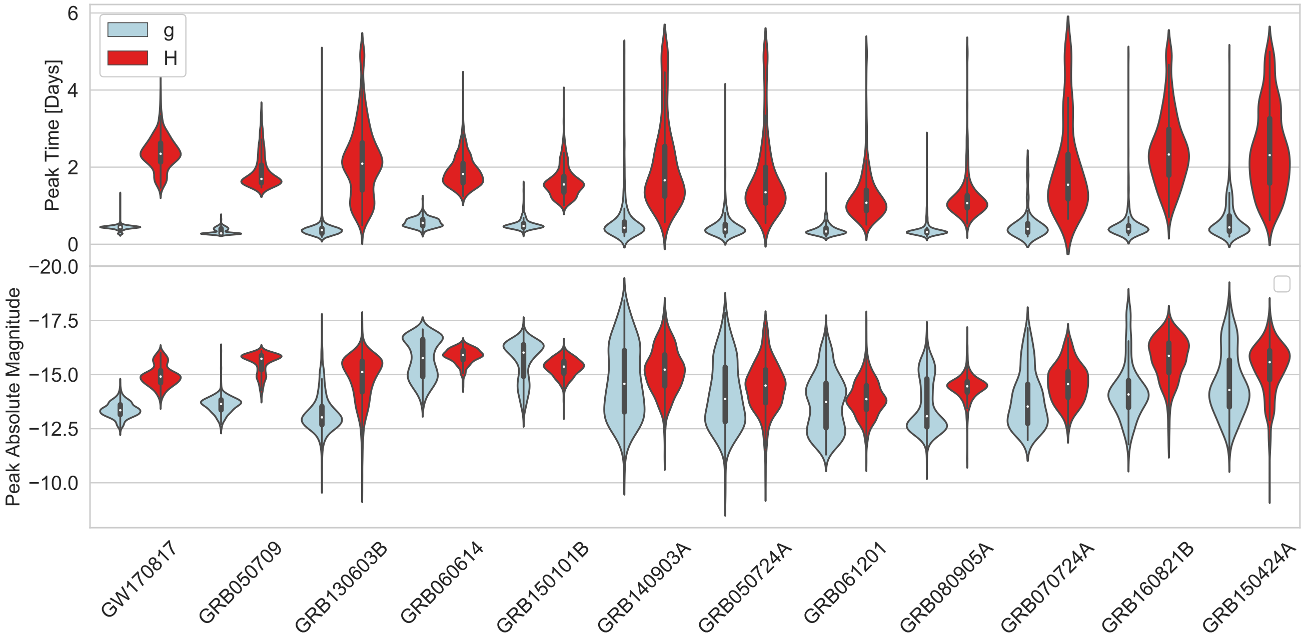

Fig. 1. Distributions of KN peak time (top) and peak absolute magnitude (bottom) for the events in our sample. To each SGRB are associated two distributions: the leftmost (lighter color) corresponds to the distribution in g filter while the rightmost (darker color) to the distribution in H filter.

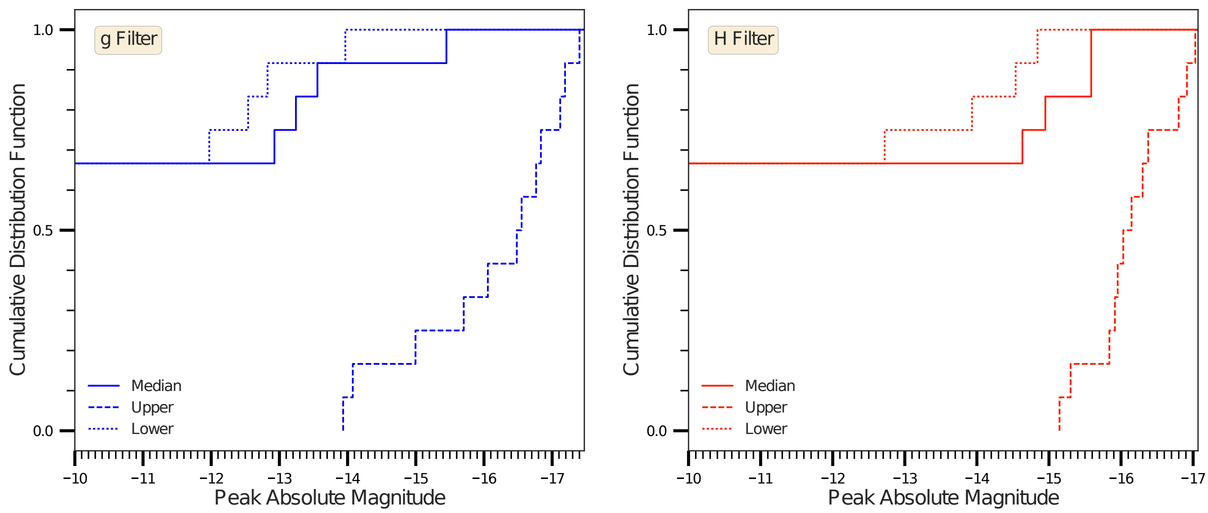

Fig. 2. KN luminosity distribution in g (leftmost panel) and H (rightmost panel) filters. The solid, dashed, and dotted lines represent the distributions of the median, the upper, and the lower limits respectively.