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A search for high-energy counterparts to extragalactic fast radio burst sources with Insight–HXMT

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Abstract. Serendipitously discovered in 2007, fast radio bursts (FRBs) have become one of the most active research fields in the transient sky and time domain astronomy era. The combination of ms-long duration and coherent emission calls for compact object progenitors, although their nature as well as the radiative processes are still unclear. In the coming years the number of FRBs with measured distance (20 as of november 2021) is expected to ramp up. Here we report our search for simultaneous X/gamma-ray emission over a range of timescales in two different ways: (i) simultaneous gamma-ray burst-like emission within the data of the High Energy instrument aboard the Insight Hard X-ray Modulation Telescope (Insight-HXMT); (ii) simultaneous emission in the 1-250 keV energy band of periodic repeater FRB 20180916B at 150 Mpc distance through a pointed observation with the three instruments aboard Insight-HXMT over an expected peak of radio burst activity. In (i) we could rule out a systematic simultaneous association of FRBs and cosmological gamma-ray bursts, while in (ii) we could exclude the occurrence of magnetar flares with $E \gtrsim 10^{46}$ erg over timescales $\Delta t \lesssim 0.1$ s over several tens of ks net exposure.

Key words. Fast Radio Burst – fast transient – multiwavelength observations – radiation mechanisms: non-thermal – stars: magnetars

1. Introduction

Fast radio bursts (FRBs) are ms-long radio pulses emitted by sources at cosmological distances, with 19 FRB sources for which the host identification and redshift were secured to date.[1] Significant progress has been obtained since their discovery (Lorimer et al. 2007), with about 800 FRBs published to date,[2] most of which discovered with the Canadian Hydrogen Intensity Mapping Experiment (CHIME; Amiri et al. 2021). There are several observed properties that are still not explained, such as the existence of the two classes of repeating and of one-off sources, the origin for the periodic activity that is observed for a few repeaters. The variety of host galaxies and environments suggests the possibility of either different classes of progenitors or different formation channels of a common class of compact objects (Heintz et al. 2020; Safarzadeh et al. 2020). In this context, magnetars are thought to be strong candidates, given the sub-energetic FRB emitted in April 2020 by Galactic magnetar SGR 1935+2154 simultaneously with an X-ray burst (Li et al. 2021). Furthermore, their extragalactic origin makes them unique and complementary probes of the intergalactic and circumgalactic plasma and magnetic fields (see Bhandari & Flynn 2021 for a review).

Some of the numerous proposed models, both catastrophic –still valid for one-off sources– and non disruptive ones, predict a connection with sources of gamma–ray bursts (GRBs), whose isotropic-equivalent peak luminosity is 10^{52}–10^{54} erg/s: a young ms magnetar or a black hole, whose birth would be marked by the GRB, after some time could become an active FRB source, or the FRB could be nearly simultaneous with the core collapse of massive stars (long GRBs) or with the merger of compact objects (short GRBs; see Platts et al. 2019 for a review of models). Should extragalactic FRB sources be exceptionally active and young magnetars, some hard X-/γ-ray activity would be expected, encompassing the less energetic X-ray bursts (luminosities in the range 10^{36}–10^{43} erg/s) up to giant flares ($\sim 10^{47}$–10^{48} erg/s). Yet, despite several attempts, the search for associated emission at wavelengths other than radio, which would help constrain the nature of the progenitor and the radiative processes involved, has yielded no detection yet (see Nicastro et al. 2021 for a review).

[1] `https://frbhosts.org/`.

[2] `https://www.herta-experiment.org/frbstats/`.

The Insight Hard X-ray Modulation Telescope (HXMT) is the first Chinese X-ray astronomy satellite (Zhang et al. 2020). It carries on board three main instruments: the Low-Energy X-ray telescope (LE; 1–15 keV; Chen et al. 2020), the Medium-Energy X-ray telescope (ME; 5–30 keV; Cao et al. 2020), and the High-Energy X-ray telescope (HE; Liu et al. 2020). The HE consists of 18 NaI/CsI detectors which cover the 20–250 keV energy band for pointing observations (some of the HE phoswich detectors were cross-calibrated at the LARIX facility at University of Ferrara in the fall of 2015). In parallel, Insight-HXMT can also be used as an open-sky monitor of hard X-ray transients in the 200 keV – 3 MeV range, with a remarkable geometric area of $\sim$5100 cm^2 and timing accuracy of 2 μs (Xiao et al. 2020). These features make the HE ideally suited to carry out a systematic search for simultaneous emission with FRBs. In addition, pointed observations with the three instruments enable the search over an unprecedented broad band extending from X- to soft γ–rays.

Hereafter, we summarise the results we obtained by adopting two different approaches: (i) we constrained the simultaneous γ-ray activity for 39 FRBs that were observed with the HE used as an open-sky monitor (Sect. 2); (ii) we constrained the activity of periodic repeater FRB 20180916B, located at 149 Mpc distance (Marcote et al. 2020), through a pointed observation with the three instruments performed around the time of expected radio burst activity (Sect. 3). The results of each investigation were thoroughly reported in Guidorzi et al. (2020a, hereafter G20a) and Guidorzi et al. (2020b, hereafter G20b), respectively.

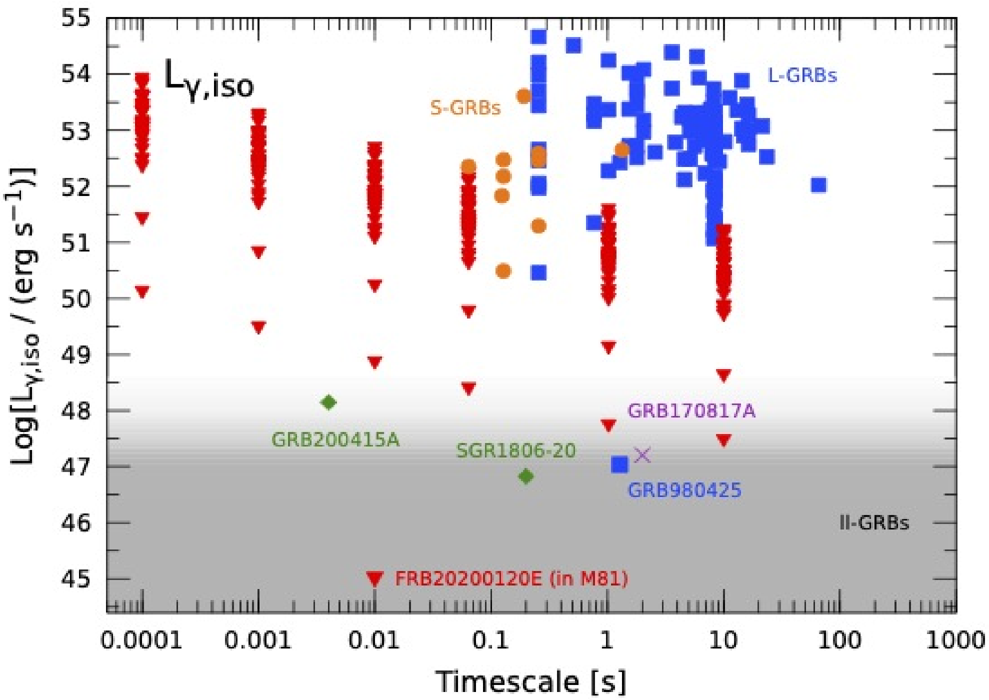

Fig. 1. Upper limits (red upside-down triangles) on isotropic-equivalent γ–ray luminosity of prompt counterparts to FRBs as a function of timescale, compared with populations of both short (orange circles) and long (blue squares) GRBs. We also show the giant flare from the Galactic magnetar SGR 1806-20, GRB 200415A (the magnetar in NGC 253), the short GRB 170817A associated with a BNS merger at 40 Mpc, and GRB 980425, which is representative of low-luminosity GRBs (shaded area). Also shown is the limit obtained for FRB 20200120E, located in a globular cluster of M81 at 3.6 Mpc distance, which is the deepest one to date (Mereghetti et al. 2021). Figure adapted from Guidorzi et al. 2020a; Nicastro et al. 2021.

2. Constraining GRB-like activity associated with FRBs

In G20a we selected 39 FRBs during which the HE was taking data and the FRB sources were not hidden by Earth. We searched for a significant excess in both individual and cumulative light curves, i.e. obtained by adding the light curves of different FRBs aligned with respect to the FRB arrival times at Insight-HXMT, over a range of time resolutions spanning from 100 μs to 10 s. At the time, only for three FRBs the redshift was known; hence, for the remaining ones we used the dispersion measures in excess of the Galactic terms, to set upper limits on the corresponding distances, and, consequently, on the possibly associated high-energy luminosities.

No significant detection was found: for each FRB we constrained the γ–ray isotropic-equivalent luminosity as a function of timescale. The results are displayed in Fig. 1, which also shows the luminosities of a sample of long GRBs and of short GRBs from the Konus-WIND catalogue (Tsvetkova et al. 2017), along with other interesting events that are representative of low-luminosity GRBs (shaded area), the short GRB 170817A associated with GW 170817, the first binary neutron star merger observed with gravitational interferometers LIGO and Virgo (Abbott et al. 2017), and giant flares from Galactic and extragalactic magnetars. Our results rule out a systematic simultaneous association of FRBs with GRB-like events, both short and long. Whilst the majority of them is still compatible with low-luminosity GRBs and magnetar giant flares. In a very few nearby cases, such as FRB 20200120E at mere 3.6 Mpc, it was possible to exclude a giant flare association (Mereghetti et al. 2021).

3. The periodic repeater FRB 20180916B

In G20b Insight-HXMT observed one the nearest FRBs to date (149 Mpc), the periodic repeater FRB 20180916B, between 4 and 7 February 2020, which corresponded to an expected peak of the radio burst activity. Observations lasted several tens of ks net exposure. By exploiting the combination of large effective area, broad band, and several independent detectors aboard, we searched for bursts from 1 ms to ~1 s with a set of algorithms that were conceived and tailored to the goal, which exploit the segmented nature of independent detectors aboard Insight-HXMT, thus increasing the statistical sensitivity and capability of rejecting particle-induced events (see Guidorzi et al. 2020b for details). Through a set of simulations, we characterised the sensitivity of the search in the released energy-duration phase space for a number of magnetar giant flares under some assumptions. We found no significant bursts, with upper limits in the 1–100 keV energy band of $E \lesssim 10^{46}$ erg for durations $\Delta t \lesssim 0.1$ s. Consequently, we could rule out the occurrence of most energetic giant flares, as we know them from the few Galactic and extragalactic cases so far observed.

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