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HIGH-ENERGY EMISSION IN SHORT GRBS AND THE ROLE OF MAGNETAR CENTRAL ENGINES

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Abstract. A significant number of long Gamma-ray Bursts (GRBs) detected by the *Swift* Satellite have a plateau phase signifying ongoing energy injection. Using BAT and XRT observations, we find that many short GRBs show similar behavior which challenges the typical short GRB progenitor model. We suggest the remnant of neutron star - neutron star mergers may not collapse immediately to a black hole (or even collapse at all) forming instead a magnetar. This model predicts that there would be a plateau phase in the X-ray lightcurve followed by a shallow decay phase, if it is a stable magnetar, or a steep decay if the magnetar collapses to a black hole within a few hundred seconds. By fitting this model to all short GRB BAT-XRT lightcurves, we show that a magnetar could power the observed energy injection. This model can be tested using the next generation gravitational wave observatories.

1 Introduction

The standard progenitor theory for Short Gamma-Ray Bursts (SGRBs) is the merger of two neutron stars (NSs) or a NS and a black hole (BH) which then collapse to form a BH (*e.g.* Lattimer & Schramm 1976; Eichler *et al.* 1989) and the majority of the material in the accretion disk will be accreted in $\sim$2 s (Rezzolla *et al.* 2011). This model can be used to explain flares in the X-ray lightcurve via the late time accretion of material on highly eccentric orbits (*e.g.* Rosswog 2007), but is not able to explain any prolonged energy injection.

However, there are some SGRBs that show evidence of significant energy injection which cannot be explained by the BH central engine model. For example GRB 090515, a SGRB with a bright X-ray plateau (Rowlinson *et al.* 2010). An alternative model, which can explain X-ray plateaus in SGRBs, is that the merger

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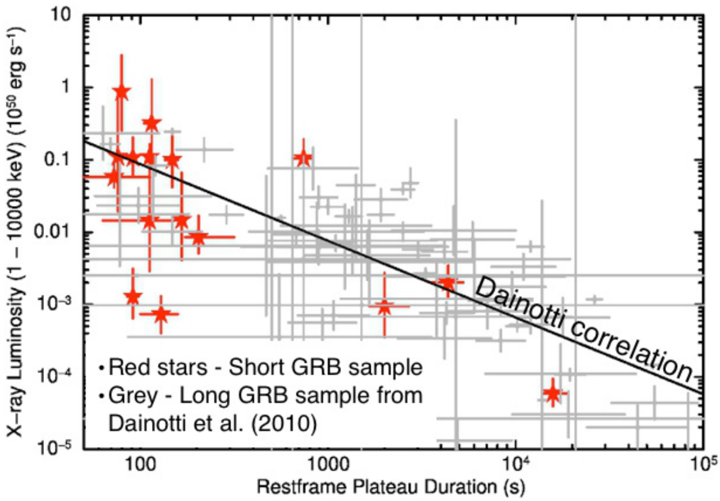

Fig. 1. The sample of SGRBs lie on the correlation between plateau luminosities and durations identified for Long GRBs by Dainotti *et al.* (2010).

of two NSs forms a magnetar (millisecond pulsar) with sufficient rotational energy to prevent immediate gravitational collapse (*e.g.* Dai & Lu 1998; Dai *et al.* 2006). The magnetar will be rotating with initial spin periods of a few milliseconds and will spin down rapidly via the emission of gravitational waves and dipole radiation (Zhang & Mészáros 2001). The mass of the central engine will determine its evolution. If the mass is $>1.5\ M_{max}$, where M_{max} is the maximum possible mass of a NS, then the central engine will immediately collapse to a BH (the typical SGRB progenitor model). Alternatively if the mass is $<1.5\ M_{max}$, the merger will form a magnetar which is supported by its own rapid rotation. If the mass of the magnetar is $>M_{max}$, as it spins down it will reach a critical point at which it is no longer able to support itself and the magnetar will collapse to a BH.

In this conference proceeding, we summarise the search conducted for evidence of prolonged energy injection in SGRB lightcurves and show that a magnetar central engine could explain many of the observed features (the full analysis is described in Rowlinson *et al.* 2013).

2 Short GRBs show signs of energy injection

We created combined BAT-XRT, 0.3–10 keV, lightcurves for all SGRBs in the *Swift* sample with $T_{90} \leq 2$ s detected by the Burst Alert Telescope (BAT) until March 2012 and which were promptly observed by the X-ray Telescope (XRT), giving a sample of 43 SGRBs. We fitted them using a simple broken powerlaw model (utilising the method in Evans *et al.* 2009). Using the SGRB redshift (known for 10 SGRBs in the sample), or the average redshift for SGRBs when the redshift is

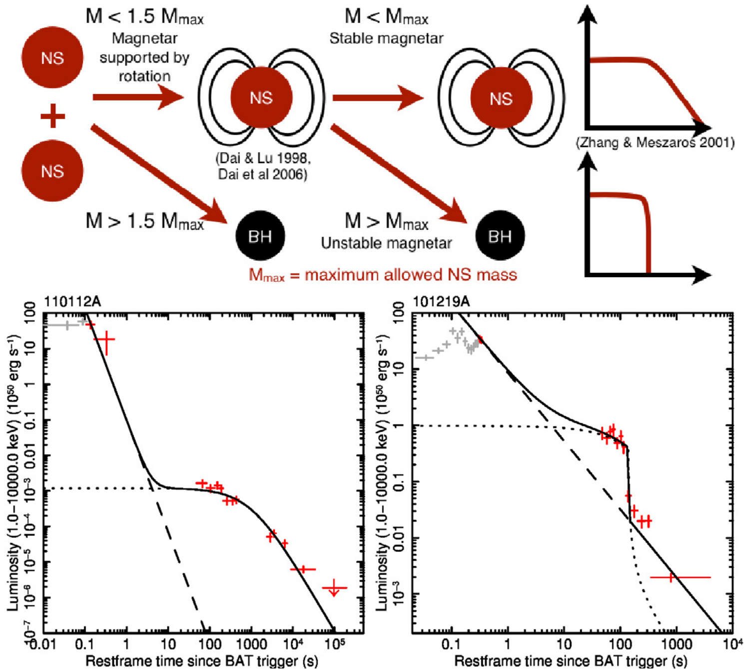

Fig. 2. *Top*: a cartoon illustrating the possible outcomes of the merger of two NSs, depending on the mass of the central object, and a sketch of the expected lightcurves for stable and unstable magnetars. *Bottom left*: GRB 110112A fitted with the stable magnetar model. *Bottom right*: GRB 101219A fitted with the unstable magnetar model.

unknown, the BAT-XRT lightcurves were converted to restframe lightcurves using a k-correction (Bloom *et al.* 2001).

Some of the SGRB sample ($\sim$50%) show evidence of a shallow decay phase or plateau, consistent with prolonged energy injection. In Figure 1, we plot the X-ray luminosity of the plateau phase against the restframe duration of the plateau for the sample of SGRBs. These SGRBs are consistent with a correlation identified by Dainotti *et al.* (2010) for a sample of long GRBs. This energy injection cannot be explained by the typical progenitor model.

3 A magnetar central engine can explain energy injection

In the magnetar model, each possible outcome of the merger of two NSs give a characteristic lightcurve as shown in Figure 2. Assuming constant radiative efficiency, the dipole radiation from a magnetar predicts a plateau phase with a shallow decay phase (for stable magnetars) or a steep decay phase (when an unstable magnetar collapses to a BH).

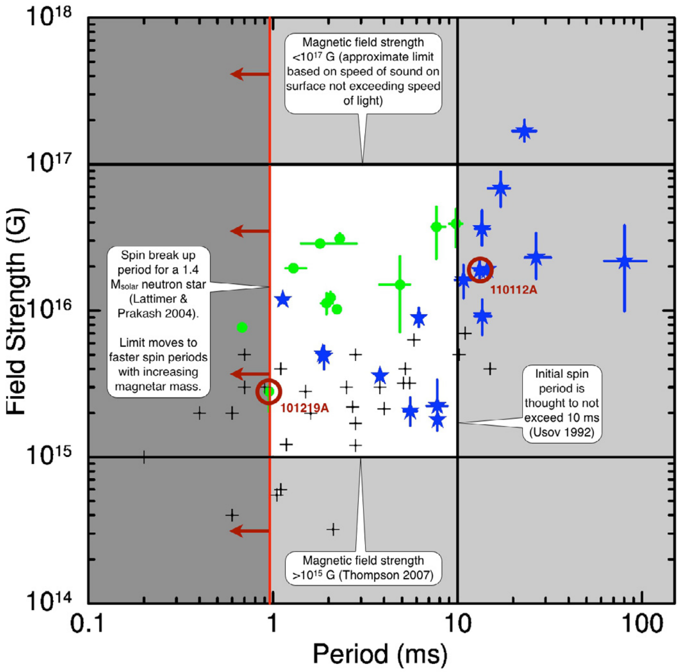

Fig. 3. The magnetic field strengths and initial spin periods of the magnetar fits for the sample of SGRBs. Blue stars - stable magnetar candidates, green circles - unstable magnetar candidates and black crosses - LGRB magnetar candidates (Lyons *et al.* 2010; Dall'Osso *et al.* 2011; Bernardini *et al.* 2012). Circled in red are the two SGRBs plotted in Figure 2. Dark grey regions are forbidden regions, light grey regions are those which are loose constraints on the initial magnetar properties from different theoretical arguments (given in figure) and the white region is the expected region for newly born magnetars.

We fit the magnetar model (as described in Zhang & Mészáros 2001) to 28 rest frame SGRB lightcurves (those with sufficient X-ray data), with an additional powerlaw component whose decay rate is governed by the curvature effect (Kumar & Panaitescu 2000). The emission is assumed to be 100% efficient and isotropic. Additionally, the model neglects enhanced angular momentum losses at early times due to neutrino-driven mass loss (Metzger *et al.* 2011).

All the SGRBs fitted can be explained using a magnetar central engine, with 18 firm candidates and the remaining are possible candidates depending on various assumptions within the model. Two example fits are shown in Figure 2. The magnetar model outputs the initial spin period and magnetic field strength of the fitted magnetar. These values are plotted in Figure 3 along with theoretical constraints on the magnetic fields and spin periods of newly formed magnetars. Many of the candidates lie within the expected region for a newly formed magnetar.

4 Conclusions

We have shown that SGRBs show evidence of prolonged energy injection that can be explained by the magnetar central engine model. This model may be testable using the next generation gravitational wave detectors as each phase of the model (inspiral, magnetar and collapse to BH) has an associated gravitational wave signal. Using predicted sensitivities, Advanced LIGO may be able to detect all 3 phases for sources within 100 Mpc (Abadie *et al.* 2010), although the rates are expected to be very low, whilst the Einstein Telescope would have a much higher chance of detection (Hild *et al.* 2011).

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