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Soft Gamma Repeaters and Short Gamma Ray Bursts: Making Magnetars from WD–WD Mergers

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Abstract. Recent progress on the nature of short duration Gamma Ray Bursts (GRBs) has shown that a fraction of them originate in the local universe. These systems may well be the result of giant flares from Soft Gamma Repeaters (SGRs) believed to be magnetars (neutron stars with extremely large magnetic fields $\geq 10^{14}$G). If these magnetars are formed via the core collapse of massive stars, then it would be expected that the bursts should originate from predominantly young stellar populations. However, correlating the positions of BATSE short bursts with structure in the local universe reveals a correlation with all galaxy types, including those with little or no ongoing star formation. This is a natural outcome if, in addition to magnetars forming via the core collapse of massive stars, they also form via accretion induced collapse following the merger of two white dwarfs (WDs), one of which is magnetic. We investigate this possibility and find that the rate of magnetar production via WD–WD mergers in the Milky Way is comparable to the rate of production via core collapse. However, while the rate of magnetar production by core collapse is proportional to the star formation rate, the rate of production via WD–WD mergers (which have long lifetimes) is proportional to the stellar mass density, which is concentrated in early-type systems. Therefore magnetars produced via WD–WD mergers may produce SGR giant flares which can be identified with early-type galaxies. We also comment on the possibility that this mechanism could produce a fraction of the observed short duration GRB population at low redshift.

Recent observations of short GRBs have shown them to be associated with a variety of host galaxy types (e.g. Gehrels et al. 2005; Fox et al. 2005; Berger et al. 2005). Tanvir et al. (2005) have performed correlation analyses indicating that up to 25% of short duration GRBs originate in the local universe (within 100 Mpc), and this correlation (seen with all galaxy types) was strongest when restricted to Sbc and earlier types. SGRs are thought to be formed in the core collapse of massive stars, and due to relatively short lifetimes ($\sim 10^4$ years; e.g. Kouveliotou 1999) would therefore be expected predominantly in star forming galaxies, while essentially none should be seen in ellipticals. Here we consider an alternative model for the creation of SGRs, and thus potentially GRBs: namely

SGRs which are created via the Accretion Induced Collapse (AIC) of white dwarfs to neutron stars (e.g. Nomoto and Kondo 1991).

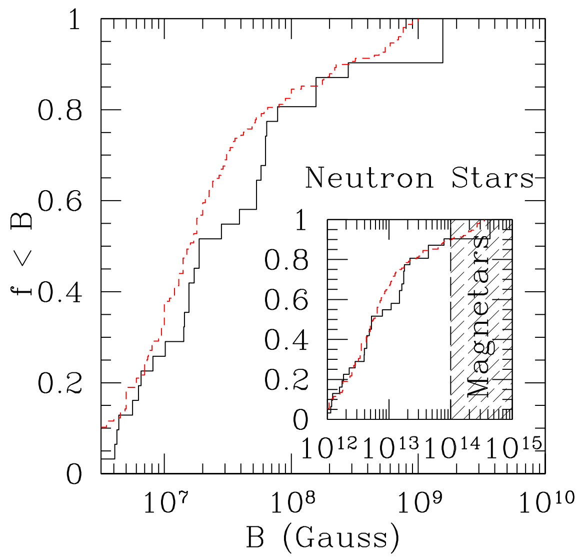

Figure 1. The distribution of WD magnetic fields seen in magnetic Cataclysmic Variables (mCVs) (solid line – 33 stars from Norton et al. 2004) and isolated white dwarfs (dashed line – 148 stars with $B > 2$MG, from Wickramasinghe & Ferrario 2000; Schmidt et al. 2003; Vanlandingham et al. 2005). For mCVs magnetic moment was converted to B-field assuming $B = \mu/R^3$ and $R = 4 \times 10^8$cm. The inset shows the fields following collapse to a neutron star of radius 1×10^6 cm. Magnetars are defined as having $B > 10^{14}$G.

Usov (1992) and King, Pringle, & Wickramasinghe (2001) have suggested that the merger of two white dwarfs (one or more of which was highly magnetic) may result in the production of a magnetar via AIC. However, the required field strengths for the white dwarfs are very large. For typical white dwarf and neutron star parameters, white dwarf B-fields of several hundred MG are necessary for magnetar creation. Such fields are relatively rare, but do exist within the magnetic white dwarf population. Figure 1 shows the distribution of magnetic fields in isolated white dwarfs and in magnetic CVs.

To estimate the formation rate of SGRs via the WD–WD channel within the Milky Way, we construct a mass distribution containing both magnetic and non-magnetic CO white dwarfs (Figure 2). The fraction of magnetic WD ($B > 2$MG) is $\sim 9\%$. For magnetic WDs we calculate the B-field formed upon collapse to a neutron star of radius 10^6cm. Picking a WD at random from the entire mass distribution, and a second from a gaussian centred on the mass of the first produces binaries with mass ratios close to unity, in agreement with observations. The fraction of double degenerate systems formed above the Chandrasekhar mass (M_c) is $\sim 25\%$, and $\sim 40\%$ of these contain at least one magnetic WD. In $\sim 10\%$ of the double degenerate population, the B-fields are strong enough to form a magnetar upon AIC after merger. Population syntheses suggest a merger rate of 3×10^{-3}yr^{-1} for WD binaries with masses $>M_c$, and thus we

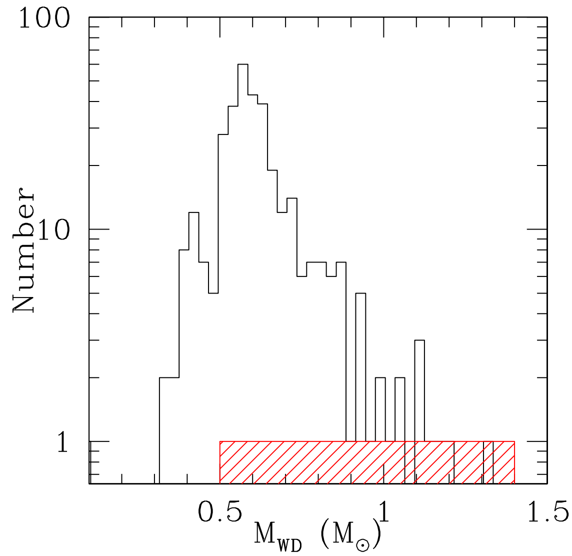

Figure 2. The mass distributions assumed for this work. The non-magnetic white dwarf distribution has been taken from Liebert, Bergeron, & Holberg (2005) while the magnetic distribution is assumed to be flat over the mass range of $0.5M_\odot < M < 1.4M_\odot$, as is shown in the hatched area.

expect a galactic rate of magnetar production $3{\times}10^{-4}\mathrm{yr}^{-1}$ via WD–WD mergers, comparable to the rate via core collapse. Note that this is a conservative estimate based on the magnetic field of the newly formed magnetar arising solely from flux conservation of the progenitor field during collapse. It is eminently plausible, and probably inevitable, that any seed field will be significantly amplified by an $\alpha{-}\omega$ dynamo mechanism within the newly formed neutron star given sufficiently rapid rotation (Thompson & Duncan 1993).

Taking a 30Mpc radius sample from the Third Reference Catalogue of Bright Galaxies (de Vaucouleurs et al. 1991), we extrapolate these results via galaxy type (T-type), mass and SFR to predict the rate of magnetar formation via both routes (Figure 3) where it can be seen that the the rates of each channel within the local universe are comparable and thus we may expect to see a correlation between the locations of short bursts and all galaxy types. The rate of formation in $T < 4$ galaxies accounts for $\sim 70\%$ of the total rate. Therefore SGR flares appearing as short GRBs may be found in all galaxy types.

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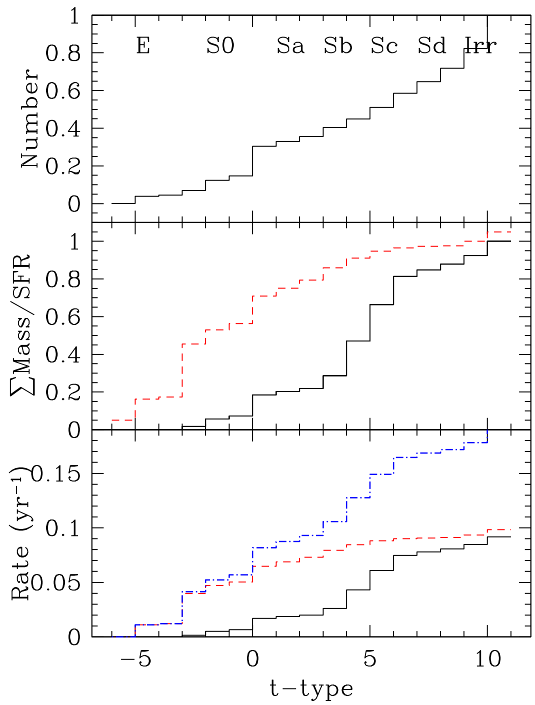

Figure 3. *Top:* The distribution of different T-types within the Third Reference Catalogue of Bright Galaxies (RC3 – de Vaucouleurs et al. 1995) with $v < 2000$ km s^{-1}. *Middle:* The cumulative distribution of stellar mass (dashed) and star formation rate (solid) within the same velocity cut. *Lower:* Extrapolated rates of SGRs which follow stellar mass (dashed line), and star formation rate (solid line). The rates of each channel within the local universe are comparable and thus we may expect to see a correlation between the locations of short bursts and all galaxy types. The dot-dashed line shows the cumulative rate of SGR formation via both channels.

References

Berger, E., et al. 2005, Nature, 438, 988

de Vaucouleurs, G., de Vaucouleurs, A., Corwin, H. G., et al. 1991, Third Reference Cat. of Bright Galaxies, (Berlin: Springer-Verlag) (VizieR Online Data Cat. VII/155)

Fox, D. B., et al. 2005, Nature, 437, 845

Gehrels, N., et al. 2005, Nature, 437, 851

King, A. R., Pringle, J. E., & Wickramasinghe, D. T. 2001, MNRAS, 320, L45

Kouveliotou, C. 1999, Proceedings of the National Academy of Science, 96, 5351

Liebert, J., Bergeron, P., & Holberg, J. B. 2005, ApJS, 156, 47

Nomoto, K., & Kondo, Y. 1991, ApJL, 367, L19

Norton, A. J., Wynn, G. A., & Somerscales, R. V. 2004, ApJ, 614, 349

Schmidt, G. D., et al. 2003, ApJ, 595, 1101

Tanvir, N., Chapman, R., Levan, A., & Priddey, R. 2005, Nature, 438, 991 (T05)

Thompson, C., & Duncan, R. C. 1993, ApJ, 408, 194

Usov, V. V. 1992, Nature, 357, 472

Vanlandingham, K. M., et al. 2005, AJ, 130, 734

Wickramasinghe, D. T., & Ferrario, L. 2000, PASP, 112, 873