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Contamination of short GRBs by giant magnetar flares: Significance of downward revision in distance to SGR 1806–20

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Abstract. We highlight how the downward revision in the distance to the star cluster associated with SGR1806–20 by Bibby et al. reconciles the apparent low contamination of BATSE short GRBs by intense flares from extragalactic magnetars without recourse to modifying the frequency of one such flare per 30 years per Milky Way galaxy. We also discuss the variety in progenitor initial masses of magnetars based upon cluster ages, ranging from $\sim 50 M_{\odot}$ for SGR 1806–20 and 1E 1647–455 in Westerlund 1 to $\sim 15 M_{\odot}$ for SGR 1900+14 and presumably 1E 1841–045 if it originated from one of the massive RSG clusters #2 or #3.

Keywords: Near infrared; Masses (stars); Distances (stars); Neutron stars; Open clusters in the Milky Way; Gamma-ray bursts
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INTRODUCTION

It is well known that the initial, intense γ-ray spike from giant flares of extragalactic magnetars – locally classified as either Soft Gamma Repeaters (SGRs) or Anomalous X-ray Pulsars (AXPs) at kpc distances – could be mistaken for cosmological short Gamma Ray Bursts (GRBs). Typical peak outputs of magnetar flares lie in the range 10^{41} erg/s (SGR 1806–20 in Jan 1979) to 10^{45} erg/s (SGR 0525–66 in Mar 1979) would not be detected in galaxies lying at Mpc distances, but the peak luminosity of the intense flare from SGR 1806–20 in Dec 2004 was $2\times10^{47} d_{15}$ erg/s where the usually adopted distance of SGR 1806–20 is d_{15} = 15 kpc. BATSE, aboard the Compton Gamma-Ray Observatory, would have detected the initial $\sim$0.1 s spike from SGR 1806–20 had it originated from a galaxy 30–50 d_{15} Mpc away.

For an adopted rate of one such intense flare, per 30 yr, per Milky Way galaxy, a total of 200-300 $d_{15}^{3}(\tau/30\text{yr})^{-1}$ flares would have been detected by BATSE over its 9.5 year lifetime, representing 40-60% $d_{15}^{3}(\tau/30yr)^{-1}$ of all short GRBs detected by BATSE (Hurley et al. 2005; Lazzati et al. 2005). Consequently, one would expect a strong correlation between the position of BATSE short bursts and nearby star forming galaxies. However, Tanvir et al. (2005) found that only 10% of short GRBs originated from within 30 Mpc, while Lazzati et al. (2005) concluded that the contribution of giant magnetar flares to short GRB statistics was no greater than $\sim$4%. A few candidate extragalactic giant flares have been identified (e.g. GRB051103 in M81, Ofek et al. 2006). Apparently, the frequency of intense magnetar flares is much lower than currently adopted, unless the widely adopted distance to SGR 1806–20 is incorrect.

Fortunately, SGR 1806–20 lies towards a young star cluster, whose near-IR appearance is shown in in Fig. 1. Photometric (colour-magnitude diagrams) and spectroscopic (stellar subtypes) tools allow ages and main-sequence turn-off masses can be derived, albeit somewhat dependent upon isochrones from evolutionary models of massive stars. Walborn (2009) discusses the characteristics of the youngest star clusters, for which O stars represent the visually brightest stars up to ages of a few Myr (e.g. NGC 3603) with AF supergiants dominating for ages closer to 4–10 Myr (e.g. Westerlund 1). Thereafter, the visual and near-IR appearance of star clusters is distinguished by red supergiants (e.g. RSG cluster #1: Figer et al. 2006; RSG cluster #2: Davies et al. 2007).

DISTANCE TO SGR 1806–20

The usual 15 kpc distance towards SGR 1806–20 relies upon kinematics (Corbel et al. 1997; Eikenberry et al. 2004; Figer et al. 2004), but if we assume that it is physically associated with a visibly obscured ($A_{\rm K}$ = 3 mag), massive star cluster (Eikenberry et al. 2004; Figer et al. 2005), we may combine their physical properties with evolutionary models to obtain the age and (spectroscopic parallax) distance to the cluster. The likelihood of chance alignment between the cluster and magnetar is low. Indeed, Muno et al. (2006) obtained a confidence of >99.97% for the association of magnetar 1E 1647–455 (AXP) with the Westerlund 1 cluster

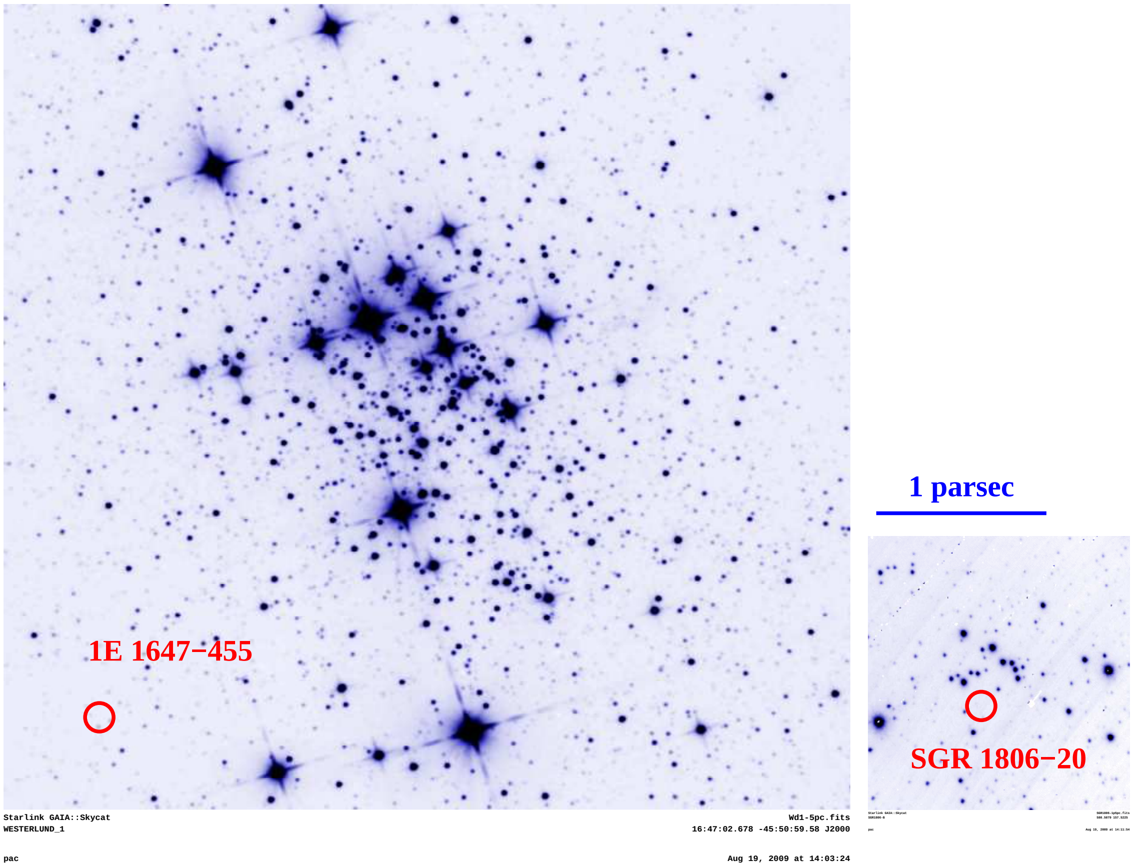

FIGURE 1. Location of magnetars within visibly obscured young massive clusters Westerlund 1 (NTT/SOFI, 200×200 arcsec, equivalent to 5×5pc at 5 kpc, left) and Cl 1806–20 (Gemini-N/NIRI, 34×34 arcsec, equivalent to 1.5×1.5 pc at 8.7 kpc, right).

(see Fig. 1). Both clusters host rare Luminous Blue Variables and Wolf-Rayet stars in addition to OB stars, although Westerlund 1 is an order of magnitude more massive (5–10$\times10^4 M_\odot$ Clark et al. 2005; Mengel & Tacconi-Garman 2007; Brandner et al. 2008), so hosts many more evolved massive stars – 24 WR stars (Crowther et al. 2006b) versus 4 WR stars in Cl 1806–20 (Eikenberry et al. 2004; Figer et al. 2005).

Bibby et al. (2008) presented Gemini-S/GNIRS near-IR spectroscopy of OB supergiants and non-dusty Wolf-Rayet stars in SGR 1806–20 from which a cluster distance of 8.7 kpc was obtained using a calibration of spectral type versus absolute magnitude. Reliable OB spectral types were obtained in two cases from comparison with the near-IR atlas of Hanson et al. (2005). Dust producing WR stars are highly unreliable as absolute magnitude calibrators since their near-IR appearance is dictated by the properties of their dust rather than underlying stellar continua (Crowther et al. 2006b). Main sequence OB stars would provide superior absolute magnitude calibrators with respect to Wolf-Rayet stars and OB supergiants, but these would require long near-IR integrations for reliable stellar classification even for present 8–10m telescopes.

Alternatively, the simultaneous presence of WN and WC-type Wolf-Rayet stars in SGR 1806–20 suggest an age of 4±1 Myr, from which an independent distance measurement was obtained using isochrones for OB stars (Lejeune & Schaerer 2001) based on the evolutionary models of Meynet et al. (1994) and the B supergiant temperature calibration of Crowther et al. (2006a). For ages of 2.8, 4 and 5 Myr, both cluster distances and magnetar masses were obtained, as presented in Fig 2, also favouring a low distance. Indeed, B supergiant photospheric lines measured in our GNIRS spectroscopy also favour a low distance (7–9 kpc). Our cluster distance is compared to previous work in Fig. 3, and is consistent with both the Cameron et al. (2005) magnetar distance and McClure-Griffiths & Gaensler (2005) reanalysis thereof.

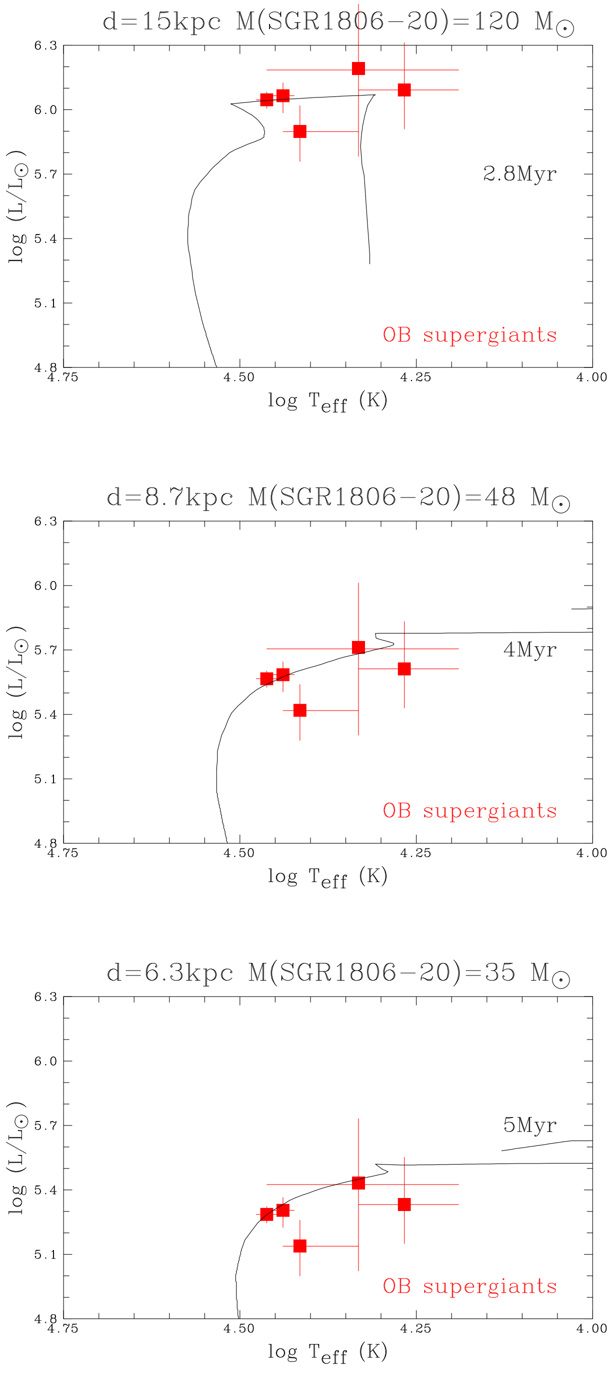

FIGURE 2. Meynet et al. (1994) isochrone fits (shown in black) to properties of B supergiants in SGR 1806–20 (shown in red from Bibby et al. 2008) for ages of 2.8 Myr (top), 4 Myr (middle) and 5 Myr (bottom), from which distances of 15, 8.7 and 6.3 kpc are obtained.

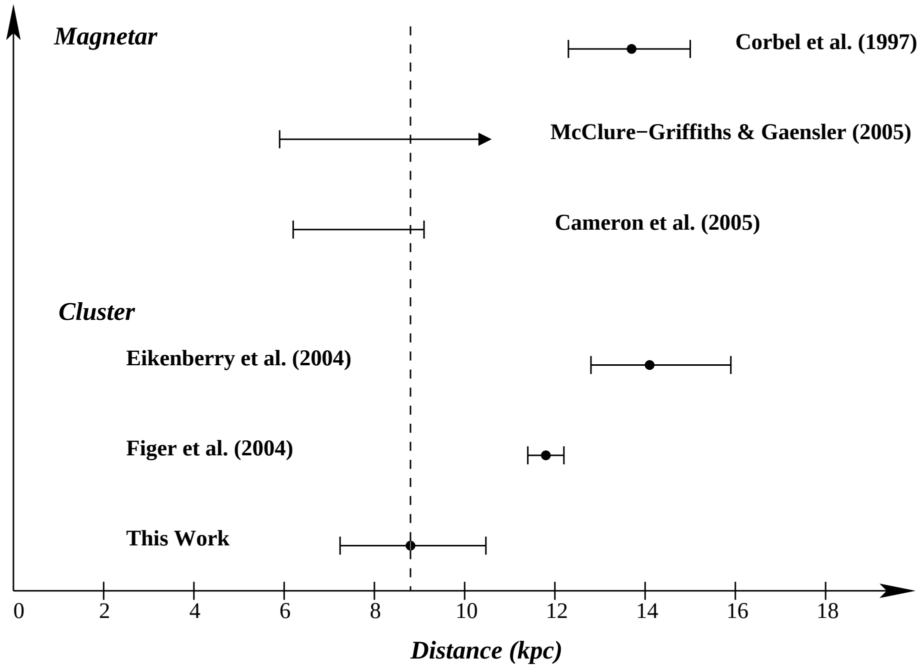

FIGURE 3. Comparison between Bibby et al. (2008, ‘this work’) and previous results for the distance to 1806–20, with previous estimates adapted to a Galactic Centre distance of 8 kpc (Reid 1993).

CONTRIBUTION OF EXTRAGALACTIC GIANT FLARES TO BATSE SHORT BURSTS

Overall, we find a reduced cluster distance of $d_{15} = 0.58 \pm 0.1$, and since the contribution of giant flares to BATSE short GRB statistics scales with d_{15}^3 we find that giant flares contribute 8^{+5}_{-4}% of all BATSE short bursts, for the *canonical* rate of one giant flare per 30 yr per Milky Way galaxy. This largely resolves the previous (low) rate problem, namely (i) $\sim$4% from the scarcity of BATSE sources with spectral properties similar to giant flares (Lazzati et al. 2005); (ii) $\sim$10% from giant flares within 30 Mpc (Tanvir et al. 2005); (iii) $<$ 15% from the lack of local host galaxies for several well-localized short GRBs (Nakar et al. 2006); (iv) a few percent contamination from the absence of giant flares from galaxies in the Virgo cluster (Popov & Stern 2006).

MAGNETAR MASSES FROM ASSOCIATED CLUSTERS

A discussed above, associated clusters allow progenitor masses of magnetars to be estimated, since magnetars are believed to be young objects. For SGR 1806–20, Bibby et al. (2008) infer a progenitor mass of $48^{+20}_{-8} M_{\odot}$, adding to evidence linking some magnetars to very massive stars. Identical conclusions were reached by Muno et al. (2006) for the AXP 1E 1647–455 in the star cluster Westerlund 1 (Clark et al. 2005) whose age and stellar content is remarkably similar to Cl 1806–20.

However, lower progenitor mass magnetars are also known. SGR 1900+14 possesses a pair of M5 supergiants (Vrba et al. 1996; 2000) from which contemporary temperature calibrations and bolometric corrections (Levesque et al. 2005), plus standard (Meynet et al. 1994) isochrone comparisons require ages of 10–16 Myr (9–12 Myr) for a distance of 12 kpc (15 kpc). These infer magnetar progenitor masses of 13–18 $M_{\odot}$ (17–20 $M_{\odot}$), and are presented in Fig. 4. Similar results would be obtained for the AXP 1E 1841–045 (within Kes 73) if it originated from either RSG cluster #2 (Davies et al. 2008) or RSG cluster #3 (Clark et al. 2009). These are located at a similar distance to 1E 1841–045, within a few degrees of its sight-line.

Table 1 provides a summary of magnetar progenitor masses inferred from potentially associated star clusters. In the Milky Way, it is apparent that magnetars can be produced by both $\sim 15 M_{\odot}$ and $\sim 50 M_{\odot}$ stars. The former presumably originated in Type II-P SN following the red supergiant (RSG) phase, while the latter are likely to have originated in a Type Ibc SN following the WR phase. From comparison with Heger et al. (2003), certainly SGR 1900+14 and possibly SGR 1806–20 would be expected to produce neutron star remnants at Solar metallicity. For metal poor populations the latter chan-

TABLE 1. Progenitor masses of magnetars based on associated star clusters.

SGR/AXP	**Cluster**	**D (kpc)**	**Age (Myr)**	**Mass ($M_\odot$)**	**Reference**
1806–20	Cl 1806–20	8.7	4±1	48^{+20}_{-8}	Bibby et al. (2008)
1E 1647–455	Westerlund 1	5	∼4.5	∼55	Clark et al. (2008)
1900+14	Cl 1900+14	12	10-16	13-18	Clark et al. (2008)
1E 1841–045	RSGC 2/RSGC 3	6	16±4	∼15	Clark et al. (2009)

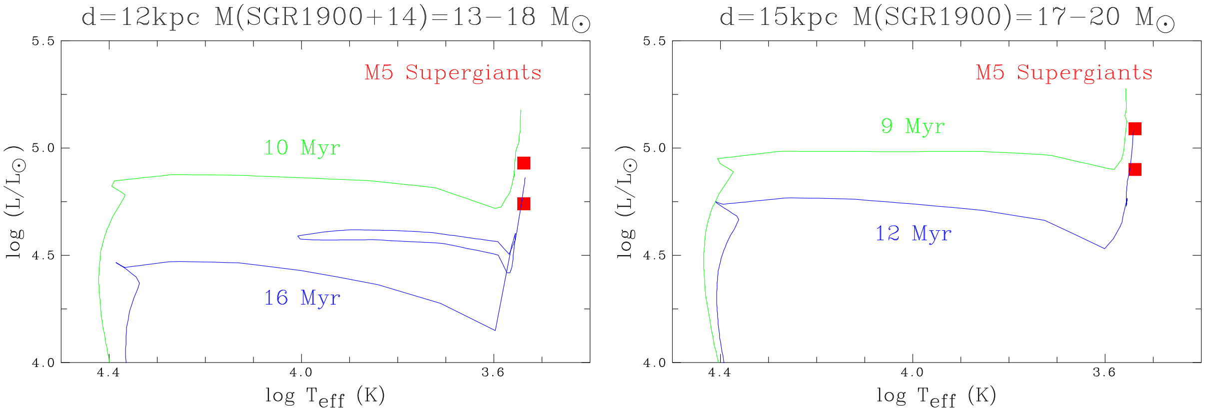

FIGURE 4. Lejeune & Schaerer (2001) isochrone fits to M5 supergiants in SGR 1900+14 (Vrba et al. 1996, 2000) for distances of 12 kpc (upper) and 15 kpc (lower). See discussion in Clark et al. (2008).

nel is unlikely to be available since reduced mass-loss rates during the main sequence and post-main sequence phases would likely lead to the formation of a black hole for such high initial mass stars. it is curious that no direct evidence for supernova remnants is known in Cl 1806–20, Westerlund 1 or Cl 1900+14 in view of the youth of their magnetar.

Finally, it should be bourne in mind that cluster ages and magnetar progenitor masses rely upon the reliability of evolutionary models. Values quoted herein are based upon a set of assumptions which have subsequently been improved upon through mass-loss rate prescriptions and allowance for rotational mixing (Meynet & Maeder 2000). Close binary evolution also further complicates inferred main-sequence turn-off masses. Therefore, one should not necessarily treat specific progenitor masses or cluster ages as robust, although the clear differences between the stellar content of clusters 1806–20 and 1900+14 undoubtedly demonstrate distinct channels leading to the production of magnetars.

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