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A candidate former companion star to the Magnetar CXOU J164710.2-455216 in the massive Galactic cluster Westerlund 1

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Besides carrying the distinction of being the most massive young star cluster in our Galaxy, Westerlund 1 contains the notable Magnetar CXOU J164710.2-455216. While this is the only collapsed stellar remnant known for this cluster, a further ~10^2 Supernovae may have occurred on the basis of the cluster Initial Mass Function, possibly all leaving Black Holes. We identify a candidate former companion to the Magnetar in view of its high proper motion directed away from the Magnetar region, viz. the Luminous Blue Variable W243. We discuss the properties of W243 and how they pertain to the former Magnetar companion hypothesis. Binary evolution arguments are employed to derive a progenitor mass for the Magnetar of 24-25 M_{Sun}, just within the progenitor mass range for Neutron Star birth. We also draw attention to another candidate to be member of a former massive binary.

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1. Westerlund 1

Westerlund 1 (Wd1) is a Galactic star cluster of almost Super Star Cluster dimensions. On the basis of a comprehensive photometric study, Brandner et al. (2008) estimate for Wd1 a mass of ~4.5 10^4 M_{Sun}, an age of 3.6 Myr and a distance of 3.6 kpc. Piatti et al. (1998) found a large obscuration of 12.9 magn (A_V).

The cluster harbours a Magnetar, CXOU J164710.2-455216 (Figure 1), without an optical or Near-IR counterpart (Muno et al. 2006). This is the only collapsed object known in Wd1. Depending on the maximum stellar mass still yielding a Neutron Star remnant after Supernova explosion, an extrapolation of the cluster's likely Initial Mass Function indicates that some 10^2 Supernovae leaving Black Hole remnants could have preceded the Magnetar (Brandner et al. 2008; Clark et al. 2008).

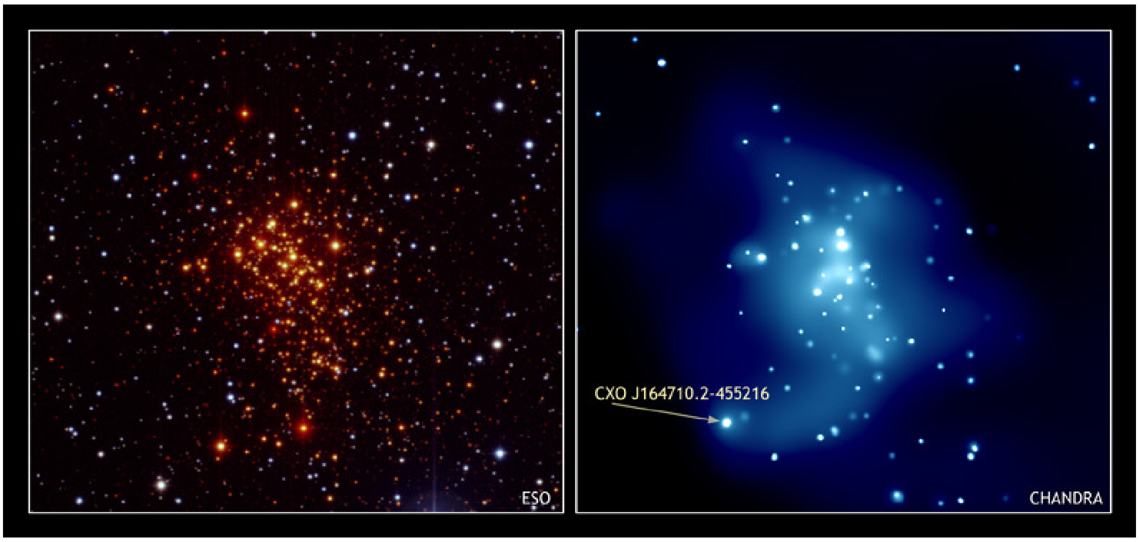

Figure 1. VLT optical image (left) and Chandra X-ray image (right) of Westerlund 1, the latter with Magnetar position indicated. (NASA/CXC/UCLA/Muno et al. 2006).

2. Candidate former companion star W243

The A-type supergiant W243 in Wd1 is found not far from the Magnetar. This star is a Luminous Blue Variable (LBV), with spectrum A2Iab. It displays spectral peculiarities and possesses a high proper motion (222 km/s; UCAC2, Zacharias et al. 2003), directed away from the Magnetar (Figure 2).

As most massive stars are born in binaries, with mass ratios (q) towards unity, W243 presents itself as a candidate former companion to the Magnetar, to have been part of a binary disrupted after the Supernova explosion of the Magnetar progenitor. Indeed, a disrupted binary has been mentioned previously as a possibility for the Magnetar (Clark et al. 2008; Belczynski & Taam 2008).

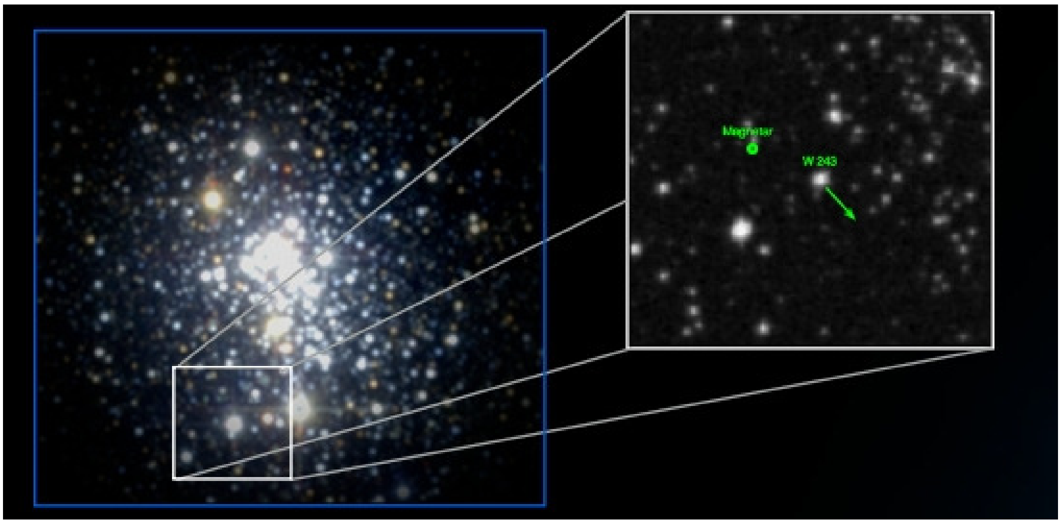

Figure 2. 2MASS image of Westerlund 1 core region (left) and Palomar Observatory Sky Survey IR image of W243 and surrounding region (right). The arrow in the right panel represents the proper motion of W243.

3. On the binarity of W243

In view of some of the spectral features of W243, an unseen hot companion (OB star) has been suggested for W243 (Ritchie et al. 2009). However, no period was found from optical monitoring of the star (Bonanos 2007).

We carried out spectro-astrometry employing 2 epochs of VLT-UVES spectra and find no evidence of a companion beyond a 25 AU binary separation (Figure 3). If indeed a hot companion is within this separation, the colliding stellar winds of the massive stars would be X-ray bright. Assuming the model of Portegies Zwart et al. (2002) for an LBV system with low velocity winds and mass loss, such a binary system exhibits an X-ray luminosity of $>10^{34}$ erg/s. No such luminous source is seen in Chandra or XMM-Newton observations of the cluster (Clark et al. 2008). Thus, we assume W243 to be a single runaway star.

4. Binary history of Magnetar

As in O'Maoileidigh et al. (2005), assuming (i) mass transfer stripping the H atmosphere of the Magnetar progenitor, (ii) a mass transfer efficiency $\propto q^2$ (which is customary), and (iii) an initial mass ratio q ~ 0.89 (for an evolved secondary, as is W243), we can estimate a progenitor mass for the Magnetar. For a post mass transfer W243 mass of ~35-36 M_{Sun} (based on comparison with evolutionary tracks for rotating stellar models in Meynet & Maeder 2000), we find for the Magnetar progenitor a mass of ~24-25 M_{Sun}.

This is lower than a recent suggestion of $M_{initial} > 40\, M_{Sun}$ for the progenitor (Ritchie et al. 2010). The difference with this value is largely due to these authors having used too large a distance to Wd1, ~5 kpc, which has been more accurately determined by Brandner et al. (2008) as 3.6 kpc. Thus, luminosities and stellar masses had been overestimated due to the large distances.

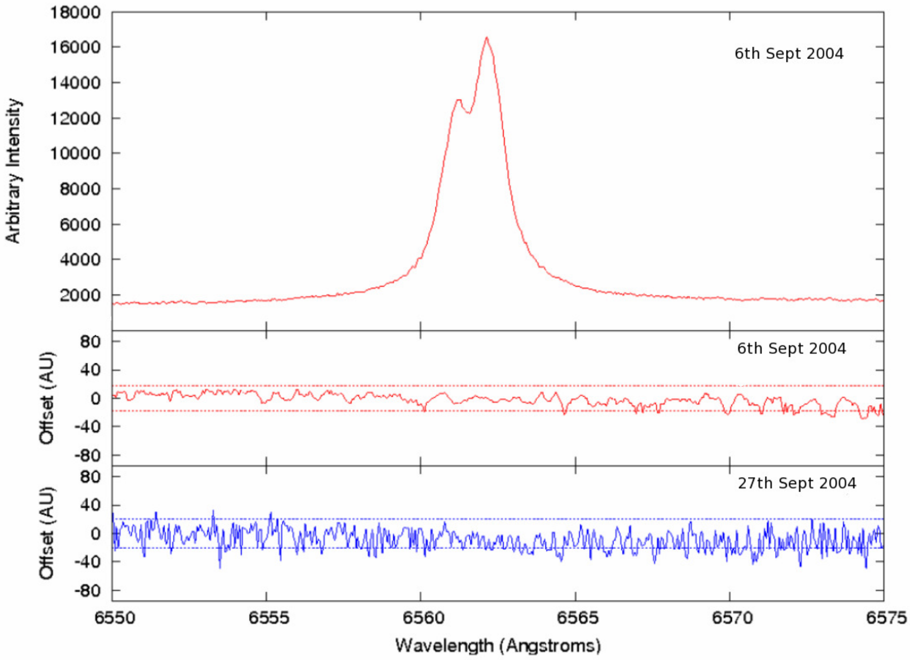

Figure 3. Spectro-photometric plot of the Hα line in the W243 VLT-UVES spectra. The top panel shows the Hα region of the spectrum obtained on 6 Sept. 2004. The bottom two panels show the variation in the continuum centroid (in AU) across the wavelength range for each of the two observations, with the dotted lines representing the 1σ error. If a binary companion were present one would expect a significant deviation in the centroid, offset across the Hα line.

Interestingly, the possibility of a 24-25 M_{Sun} progenitor for the Magnetar is right at the upper limit determined by Heger et al. (2003), 25 M_{Sun}, for Neutron Star formation from single stars, for metallicities not much exceeding the Solar value. For binaries the upper initial mass for a star leaving a Neutron Star after exploding as a Supernova could be a little lower, like 22 M_{Sun} (Fryer et al. 2002). Thus, the Magnetar could indeed be the first Neutron Star to have formed in Wd1 (after Black Holes) as lower and lower mass stars undergo a Supernova event as the cluster evolves with time, without challenging current estimated mass constraints on Neutron Star birth (cf. Richie et al. 2010). Confirmation of this picture may be obtained by a future proper motion measurement for the Magnetar. We note that the Main Sequence turn-off point of Wd1 may be around spectral types O7V-O8V (Muno et al. 2006), where O8V stars have masses of ~23 M_{Sun} (Schmidt-Kaler 1982). However, from the analysis of Brandner et al. (2008) would follow still a lower turn-off mass, around 15 M_{Sun} (B0.5V stars).

5. Another W243-like case in Wd1?

Just NE of the centre of Wd1 is another runaway star, W16a, closely resembling W243. Its spectrum is A2Ia+ (or possibly A5Ia+) and the B, V and J magnitudes of these two stars are very similar. The proper motion of W16a is 188 km/s (UCAC2, Zacharias et al. 2003). Thus, W16a could similarly have been part of a binary that was disrupted after its faster evolving companion underwent a Supernova event, presumably leaving a Black Hole. On the other hand, this star could also be an alternative candidate for a former companion to the Magnetar. Again, the proper motion of the Magnetar will be helpful to decide here.

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