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Near-infrared follow-up to the May 2008 activation of SGR 1627-41[⋆]

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ABSTRACT

Context. On 28 May 2008, the *Swift* satellite detected the first reactivation of SGR 1627-41 since its discovery in 1998.
Aims. Following this event, we began an observing campaign at near infrared wavelengths to search for a possible counterpart inside the error circle of this SGR, which is expected to exhibit flaring activity simultaneously with the high energy flares or at least some variability compared to the quiescent state.
Methods. For the follow-up, we used both the 0.6 m REM robotic telescope at La Silla Observatory, which allowed a fast response within 24 h and, through director discretionary time, the 8.2 m Very Large Telescope at Paranal Observatory, where we observed with NACO to produce high angular-resolution imaging with the aid of adaptive optics.
Results. These observations represent the most rapidly acquired near-infrared observations following activation of this SGR and the deepest and highest spatial resolution observations within the *Chandra* error circle.
Conclusions. Five sources are detected in the immediate vicinity of the most precise X-ray localisation of this source. For 4 of them, we do not detect variability, although the X-ray counterpart exhibited significant decay during our observation period. The 5th source is only detected in one epoch, where we have the highest image quality, so no variability constraints can be imposed and this remains the only plausible counterpart. We can impose a limit of $Ks > 21.6$ mag on any other counterpart candidate one week after the onset of the activity. Our adaptive optics imaging with a resolution of 0.2″ provides a reference frame for subsequent studies of future periods of activity.

Key words. stars: neutron – gamma rays: bursts – infrared: stars – stars: individual: SGR 1627-41 – techniques: high angular resolution

1. Introduction

Soft Gamma-ray Repeaters (SGR) are a rare type of astronomical sources that experience periods of activity in which they exhibit strong flares in high energy bands (X-rays and γ-rays) of typical durations 0.01–1 s (Mereghetti 2008). These activity periods usually last between a few days and weeks and are separated by periods of quiescence of several years, where a much weaker persistent type of X-ray source is generally observed. Identifications of optical and near-infrared (nIR) counterparts, crucial to the precise localisation and broad-band spectral characterisation of these sources are beginning to be achieved (Israel et al. 2005; Kosugi et al. 2005; Tanvir & Varricatt 2008; Fatkhullin et al. 2008) but are still uncommon.

Between 1979 and the end of October 2008 only 5 SGRs were identified. Four are located in the Galactic Plane (SGR 1627-41, SGR 1806-20, SGR 1900+14 and the recently discovered SGR 0501+4516), while a fifth is hosted by the Large Magellanic Cloud (SGR 0526-66). A parallel family of sources, the Anomalous X-ray Pulsars (AXP) display similar behavior of persistent emission and outburst periods. However, in this case, their burst activity is usually limited to the less energetic X-rays. There is much discussion regarding the differences and similarities between these two types of events. In 2002, AXP 1E 2259+586 exhibited a period of activity in which it produced over 80 bursts with similar properties to those observed in SGRs, as described by Woods et al. (2004) and Gavriil et al. (2004). During the latest activity period of AXP 1E 1547.0-5408 in October 2008 (Krimm et al. 2008a), it behaved more like a SGR (Krimm et al. 2008b), its bursts being detected in the γ-ray range. These examples provide strong evidence of the link between the two families. A further source, SWIFT J195509+261406, discovered in June 2007 (Pagani et al. 2007; Stefanescu et al. 2008), showed a similar behavior to SGRs, with an initial γ-ray spike and the bulk of the flares being detected at X-ray and optical wavelengths (Castro-Tirado et al. 2008; Stefanescu et al. 2008; Kasliwal et al. 2008). It was proposed to be a magnetar linking SGRs/AXPs and dim isolated neutron stars (Castro-Tirado et al. 2008). The extensive observing campaign performed for this source in optical and nIR is a good reference for comparing with the behavior of the counterparts to these types of sources.

The powering sources of SGRs and AXPs are assumed to be strongly magnetised neutron stars or "magnetars" (Duncan & Thompson 1992), which radiate at high energies due to the decay of the magnetic fields. In this model, neutron stars with initial fields of $\sim 10^{14}$–10^{15} G would be observed as X-ray pulsars with a spin down due to magnetic dipole radiation, consistent with observations of SGRs. The relation between magnetars and neutron stars is supported by several associations between AXPs and supernova remnants, which would be the result of the explosions that generated the neutron stars (Gaensler et al. 2001; Mereghetti 2008). On the other hand, several SGRs are probably

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associated with clusters of massive stars, which possibly host objects that evolve to form the required neutron stars (Mereghetti 2008; Wachter et al. 2008).

We present follow-up investigation of the second registered activation of SGR 1627-41, which began on 28 May 2008 (Palmer et al. 2008), after a ten-year period of quiescence. This SGR was first detected on 15 June 1998 (Kouveliotou et al. 1998), when it began a period of activity of 6 weeks, during which it produced approximately 100 bursts (Woods et al. 1999). We used this new opportunity to obtain deep nIR imaging, trying to identify the counterpart to this event. SGR 1627-41 has the peculiarity of being the only known SGR with a transient behavior and exhibits a persistent X-ray emission that decayed monotonically with time between the activity period of 1998 and the one of 2008 (Mereghetti et al. 2006). The increase in X-ray emission following this new activation has been used by Esposito et al. (2009) to determine a pulsation period of 2.6 s for this source, unknown until now.

In Sect. 2, we describe the follow-up campaign to SGR 1627-41 as well as the reduction and analysis techniques that were used. Section 3 presents the results of the observations and Sect. 4 discusses their implications. Section 5 summarises our conclusions.

2. Observations

At 08:21:43 UT of 28 May 2008, the BAT γ-ray detector onboard the *Swift* mission (Gehrels et al. 2004) was triggered by a bright γ-ray event related to the known SGR 1627-41 (Palmer et al. 2008). This marked the beginning of an activity period that persisted for tens of other bursts in the subsequent hours (Esposito et al. 2008).

Following this detection, we triggered observations with the 0.6 m REM robotic telescope (Chincarini et al. 2003) at La Silla Observatory (Chile). Because of bad weather conditions at the observatory, the first images were not obtained until 1.0 day after the first detected burst. Although the telescope carries both optical and infrared detectors, only infrared images were taken due to the extreme extinction of $A_V \sim 54$ magnitudes, since, in these circumstances, optical observations would have applied very limited constraints. The dataset comprises J, H, and Ks-band imaging. The data from 29 May were taken in cycles, alternating Ks, J and H-band filters, which were separately combined to produce a single image in each band.

In parallel, we applied for director discretionary time to acquire deep nIR observations with one of the 8.2 m units of the VLT telescope at Paranal Observatory. The observations were performed using NACO on Yepun (the fourth unit telescope of the VLT). The instrument NACO (Lenzen et al. 2003; Rousset et al. 2003) consists of an adaptive optics module (NAOS) and a high resolution nIR camera (CONICA). Adaptive optics correction was performed using a nearby natural guide star. We obtained two Ks-band epochs and a late observation in Brγ and Ks-band, all using the S54 camera, which provides a field of view of $56'' \times 56''$. Table 1 displays the observing log and includes the angular resolution and 3-σ limiting magnitudes of the combined frames. The exposures are given as the product of the number of exposures and the total exposure time per dither position, which in some cases represents a coaddition of shorter exposures completed to avoid saturation.

The reduction was performed using IRAF (Tody 1993) with the following steps. First we created a master flat field by combining lamp flats from which dark current had been subtracted. Once normalised, we used this image to apply a flat-field correction to all science images. We then combined these science images, which had been observed with offsets between them, to create sky images. These sky images were normalised to the background of each science image, and the resultant normalised sky frame was then subtracted from each of the science images to create the final reduced science images, corrected of the sky contribution. In the final step, these reduced science frames were aligned and combined to create a deep image for each epoch, as displayed in Table 1.

Astrometry was completed for each image using JIBARO codes (de Ugarte Postigo et al. 2005), taking as reference all objects in the 2MASS all-sky catalogue of point sources (Cutri et al. 2003) present in each of the frames, while avoiding any saturated sources. Figure 1 shows the central region of the NACO image obtained on 4 June 2008, within which we indicate a set of selected objects and the SGR 1627-41 error circle (*Chandra* 3-σ error combined with our 3-σ astrometric accuracy). The coordinates given in Table 2 were obtained using data from the first NACO epoch and by correlating with 23 reference objects. We performed aperture photometry using PHOT with IRAF, and assumed as a reference the 2MASS catalogue. Photometric values for the selected sources are given in Table 3.

3. Results

The REM observations presented here are the first rapid-response nIR observations following an activity period of SGR 1627-41, starting only 24 h after the first burst. However, the last reported high-energy burst during this activation occurred within one hour of the initial *Swift* trigger, so that none of our observations were simultaneous to any burst. In our data, we did not detect any nIR flares in individual images to typical 3-σ limiting magnitudes of $J \sim 15.2$, $H \sim 14.5$, and $K\mathrm{s} \sim 13.7$ for the REM telescope and $K\mathrm{s} \sim 20.0$ for VLT/NACO. However, we note that these values are calculated for the integrated exposure times, while the durations of flares observed in this outburst (Esposito et al. 2008) were significantly shorter than the exposure times (~0.1 s flares compared to 12 s exposures in the case of REM).

Using the deep, high angular resolution NACO data, we identified 5 sources within the immediate vicinity of the most precise *Chandra* localisation of SGR 1627-41 (Wachter et al. 2004, W04 hereafter), which we refer to as A, B, C, E, and F, following the notation of W04 (see Fig. 1). The sources A, B, and C were already identified by W04. We did not detect source D of W04, which can most probably be considered to be a noise spike in their data, as already suggested by them. Source F can only be clearly separated from source A in the first epoch data, where we had the highest angular resolution. In the datasets of the remaining epochs, the source images were blended together. In Table 2, we provide the photometry of each of these sources in the 3 NACO epochs. The objects were not detected in the REM data.

During the period between the 4th of June and the 3rd of August 2008, the X-ray emission decayed as a power law with an index of ~–0.2 (Esposito et al. 2008), implying a flux decrease of a factor ~0.6. If the nIR sources were to decay in a similar way, we would expect a loss of ~0.5 mag during this time. This was the case for other sources such as SGR 1806-20 or SWIFT J195509+261406, where the X-ray and the optical emission varied in a similar way (Israel et al. 2005; Castro-Tirado et al. 2008). However, all the nIR sources are consistent with no decay between the first and last NACO epochs.

Table 1. Observing log of the follow-up campaign for the May 2008 activation of SGR 1627-41.

Observation interval (2008 UT)	Time since trigger (days)	Telescope + Instrument	Filter	Exposure (s)	*FWHM*	Limiting Magnitude
29.3411–29.3803 May	1.012	REM+REMIR	*Ks*	50 × 12	3.6″	14.5
29.3424–29.3817 May	1.014	REM+REMIR	*J*	50 × 12	4.0″	16.5
29.3437–29.3830 May	1.015	REM+REMIR	*H*	60 × 12	3.8″	15.4
31.3858–31.3961 May	3.042	REM+REMIR	*H*	50 × 12	4.2″	15.2
4.0547–4.0953 June	6.727	VLT+NACO	*Ks*	51 × 60	0.2″	21.6
7.0399–7.1348 June	9.739	VLT+NACO	*Ks*	114 × 60	0.3″	21.3
15.1645–15.1747 June	17.821	REM+REMIR	*H*	50 × 12	3.7″	15.6
2.9908–3.0311 August	66.662	VLT+NACO	*Brγ*	18 × 180	0.3″	–
3.0344–3.0422 August	66.690	VLT+NACO	*Ks*	30 × 60	0.4″	20.2

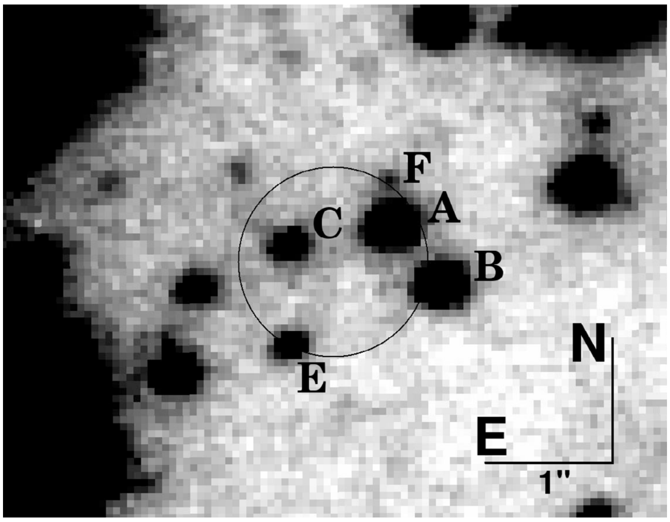

Fig. 1. NACO image showing the *Chandra* error circle of SGR 1627-41 on 4 June 2008. The error box has taken into account both the uncertainty of the *Chandra* coordinates and the precision of our astrometry (3-σ). The field of view is 5.7″ × 3.2″.

Table 2. Astrometry of the selected objects based on the 2MASS catalogue, with a 1-σ uncertainty of ±0.14″.

Object	RA(J2000)	Dec.(J2000)
A	16:35:51.789	–47:35:23.06
B	16:35:51.752	–47:35:23.51
C	16:35:51.866	–47:35:23.20
E	16:35:51.868	–47:35:23.98
F	16:35:51.792	–47:35:22.70

Decay limits between them can be inferred to be $\Delta Ks(A) < 0.3$, $\Delta Ks(B) < 0.5$, $\Delta Ks(C) < 0.2$, and $\Delta Ks(E) < 0.4$ (1-σ). A decay limit cannot be imposed for source F due to contamination by source A. Furthermore, we measured no decay in the emission of sources A and B compared to observations performed by W04 in March 2001, when the X-ray emission was lower by a factor of ~10 (2.5 mag). Since sources C and E can still be seen in the observations of W04 (Fig. 2 of their paper), we may conclude that the variability of sources A, B, C, or E does not correlate with that of the X-ray emission.

During our last NACO observing run on 3 August 2008, we obtained narrow-band imaging with a 0.023 μm wide Brγ filter centered on 2.166 μm, searching for H I Brγ emission in the spectrum of any of the sources; this emission should originate in an accretion disk if the magnetar were part of a binary system, as seen in some Galactic X-ray binaries (Castro-Tirado et al. 1996).

Table 3. *K*s-band photometry of the selected objects, using 2MASS stars as reference.

Object	Date (2008)		
	4.08 Jun.	7.09 Jun.	3.04 Aug.
A	18.08 ± 0.11	18.05 ± 0.12	18.13 ± 0.16
B	18.18 ± 0.11	18.16 ± 0.12	18.42 ± 0.16
C	19.28 ± 0.12	19.32 ± 0.13	19.12 ± 0.19
E	19.57 ± 0.12	19.50 ± 0.13	19.65 ± 0.20
F	20.10 ± 0.14	–	–

Table 4. Relative fluxes between Brγ and *K*s-band, normalised to the median ratio of all the objects in the field.

Object	$F_{Br\gamma}/F_{Ks}$
A	1.02 ± 0.07
B	1.12 ± 0.08
C	0.78 ± 0.09
E	0.82 ± 0.10
F	–

To detect any excess in this band, we measured the flux of each of the selected objects in Brγ and divided this by the corresponding flux in *K*s. To normalise these ratios,we then divided them by the average ratio for all objects in the field, so that a value of 1.0 would imply no Brγ excess. The result for each of our selected objects (except for F which is undetected in Brγ) is displayed in Table 4. None of the objects exhibit any significant excess.

4. Discussion

The extinction at the position of the SGR can be derived from the different X-ray spectra (Esposito et al. 2008) as $A_V = 54\pm6$ magnitudes. Because of the significant amount of extinction, follow-up in optical bands imposes almost no constraints, thus the need for nIR observations. Even so, this implies an extinction in *K*-band of $A_K = 6.0 \pm 0.7$ magnitudes. This is a common problem for most SGR/AXP follow-up observations in optical/nIR bands, since they are generally obscured by dust in the Galactic disk, although SGR 1627-41 is to date the case with the most extreme extinction.

During the active period of 1998, optical observations failed to detect any new source to a limiting magnitude of Ic 20 (Castro-Tirado et al. 2000). To our knowledge, no nIR follow-up was performed during this activation. Some time later, in March 2001, W04 obtained deep nIR observations of the quiescent source, identifying 3 candidates (A, B and C) within their precise localisation of the X-ray counterpart obtained using

Chandra data. In deep, high angular-resolution images obtained with VLT/NACO shortly after the May 2008 activation, we again identified these 3 sources. A fourth source (D) identified with low significance by W04 is not seen in our observations and was most probably only a noise spike in their image. We studied 2 additional sources (E and F) within the *Chandra* error circle.

Source F is only identified in the first NACO epoch, since it is blended with A in the remaining frames. In the period between 7 days and 67 days after the outburst onset, no significant variability is detected in any of the other objects, in spite of the factor ~0.6 decrease in X-ray flux. Furthermore, our measurements of sources A and B are consistent with the values of 2001 given by W04, during a period in which there was a flux increase in X-rays of a factor ~10. This is consistent with the suggestion of W04 that probably neither A nor B are the counterparts of SGR 1627-41, based on their colour indexes. All of this evidence argues against the identification of A, B, C, or E being the nIR counterpart to SGR 1627-41, leaving F as the only plausible counterpart candidate. We can impose a 3-σ limiting magnitude of $Ks > 21.6$ to any other counterpart to the SGR within the *Chandra* error circle. A combination of the data of different epochs does not produce a significant improvement to the frame created with only first epoch data, since the gain in depth due to longer exposure times corresponds to a significant decrease in resolution.

Until now, only two counterparts to SGRs have been established. Monitoring of SGR 1806-20 during the 2004 year-long activity period, which ended with a giant flare on 27 December 2004, identified a nIR counterpart with a variability in the range $Ks \sim 18.3$–21.0 within a 7 month period (Kosugi et al. 2005; Israel et al. 2005). The line-of-sight extinction to SGR 1806-20 is approximately $A_K \sim 3.5$, implying that, for the extinction of SGR 1627-41, it would have had a peak magnitude of $Ks \sim 20.8$, consistent with the measurement for object F.

The second accepted counterpart for a SGR is the one of SGR 0501+4516. On 22 August 2008, Tanvir & Varricatt (2008) responded to the activation (and discovery) of SGR 0501+4516 (Holland et al. 2008; Barthelmy et al. 2008) by identifying a counterpart of $Ks \sim 18.6$, which started 2 h after the first gamma-ray burst. The counterpart decayed during the next few days to $Ks \sim 19.2$ (Rea et al. 2008; de Ugarte Postigo et al. 2008). This counterpart was also identified at optical wavelengths with a magnitude of $\mathrm{Ic} \sim 23.3$ (Fatkhullin et al. 2008; Ofek et al. 2008). In contrast to SGR 1627-41, SGR 0501+4516 has a low line-of-sight extinction of $A_K \sim 0.2$ magnitudes. Obscured by the extinction of the line of sight towards SGR 1627-41, this object would have had a brightest magnitude of $Ks \sim 24.5$ (not considering differences in distances, since the distance to SGR 0501+4516 has not yet been established and the difference would probably be insignificant). This would be in agreement with a non-detection of the counterpart in our data.

By study of the well studied counterparts to several AXPs, unextincted magnitudes of $Ks = 19{-}21$ (Israel et al. 2002, 2003, 2004, W04) can be derived for most counterparts. This values are similar to those obtained for SGR 0501+4516 and also consistent with a non detection in our data.

With these results, we may conclude that of the 5 objects that we have studied, 4 of them (A, B, C and E) are unlikely to be related to SGR 1627-41, while object F remains a counterpart candidate. Further high-resolution observations during quiescence will be required to determine any possible relation of this source to SGR 1627-41.

5. Conclusions

The main conclusions of our study can be summarised as follows:

1. We have performed a follow-up campaign to the second registered activation of SGR 1627-41. Our observations began one day after the first burst detected by *Swift*.
2. The May 2008 outburst was extremely short, with no bursts reported after one hour, compared with the previous activation in 1998, when bursts were produced for 6 weeks. This prevented us from obtaining observations precisely as the bursting activity was occurring.
3. We studied 5 sources within the *Chandra* error circle. There was no evidence of variability in sources A and B compared to the measurements carried out by W04 in 2001, during quiescence. No variability was observed in objects A, B, C, and E within the time range of our observations, in contrast to the X-ray decay. Observations in Brγ do not show any evidence of emission signatures in any of the sources.
4. Object F is only detected in the first epoch, where the image quality was its highest, at a magnitude of $Ks = 20.10 \pm 0.14$. Thus, we cannot impose limits on its possible flux decay. It remains the only plausible counterpart. Further observations will be required to confirm or discard its relation to SGR 1627-41.
5. The imaging obtained with VLT+NACO, of an angular resolution at hightest of $0.2''$ and limiting magnitude of $Ks \sim 21.6$ will serve as reference for future observation campaigns.
6. To obtain detections in future activation periods, the use of large telescopes with infrared instrumentation will be mandatory. Follow-up should ideally be completed by the use of ToO programmes, since a fast response is necessary to secure the observation during the activity period.

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