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A NEAR-INFRARED SURVEY OF THE N49 REGION AROUND THE SOFT GAMMA REPEATER SGR 0526−66[1]

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ABSTRACT

We report the results of a deep near-infrared survey with the Very Large Telescope/Infrared Spectrometer and Array Camera of the environment of the supernova remnant N49 in the Large Magellanic Cloud, which contains the soft gamma repeater SGR 0526−66. Two of the four confirmed SGRs are potentially associated with compact stellar clusters. We thus searched for a similar association of SGR 0526−66 and imaged a young stellar cluster at a projected distance of ∼30 pc from the SGR. This constitutes the third cluster–SGR link and lends support to scenarios in which SGR progenitors originate in young dusty clusters. If confirmed, the cluster-SGR association constrains the age and thus the initial mass of SGR progenitors.

Subject headings: open clusters and associations: individual (SL 463) — pulsars: individual (SGR 0526−66) — supernova remnants

1. INTRODUCTION

The neutron star subclass of soft gamma repeaters (SGRs) currently consists of four confirmed (SGR 0526−66, 1806−20, 1900+14, and 1627−41; see Hurley 2000 and Kouveliotou 2004 for recent reviews) and one candidate member (SGR 1801−23; Cline et al. 2000). At random intervals, SGRs enter active states lasting between days and years, during which they emit hundreds of predominantly soft ($kT = 30$ keV) and short (0.1–100 ms duration) events. During quiescence, SGRs are persistent X-ray sources (0.1–10 keV) with luminosities ranging between $\sim 10^{33}$ and 10^{36} ergs s^{-1}. Spin periods, narrowly clustered between 5 and 8 s, have been found in three SGR quiescent X-ray light curves. Estimates of their spin-down rates indicate that SGR magnetic fields are 10^{14} to 10^{15} G (Kouveliotou et al. 1998, 1999; Kulkarni et al. 2003), confirming theoretical predictions (Duncan & Thompson 1992; Thompson & Duncan 1995) for the existence of such high *B*-field objects (magnetars).

Besides SGRs, there is today clear evidence that another class of neutron stars, anomalous X-ray pulsars (AXPs), possess similar magnetic fields and SGR-like outbursts (see Mereghetti et al. 2002 for a review; also Kaspi 2004). To date there are roughly 10 confirmed magnetars (AXPs and SGRs) and two to three candidate sources. However, it is still unclear how these two object classes are linked, how they produce their unique bursting patterns, and how they may be related to the subset of normal radio pulsars that exhibit magnetic fields comparable to or even larger than those of SGRs and AXPs (see Heyl & Hernquist 2003 for a recent discussion of these issues). Studies of possible progenitors for SGRs and AXPs would provide robust constraints on their ages and their birth rates and thus shed light on their evolutionary paths. Thus far, associations between magnetars and supernova remnants (SNRs) have been established only for a few AXPs and potentially in one SGR (Gaensler et al. 2001 and references therein). The identification of SGRs with fossils of their births thus remains an open issue. Three of the four SGRs lie in the Galactic plane with extinctions of 10–30 mag in the optical band. Consequently, IR is the optimal band for counterpart searches and for studying their environments. However, SGR 0526−66 resides in the Large Magellanic Cloud (LMC), with very low extinction ($A_V \lesssim 0.1$ mag), allowing for both optical and IR observations.

Fuchs et al. (1999) studied SGR 1806−20 with the *Infrared Space Observatory* and reported the discovery of a dusty, compact stellar cluster 7″ away both from the SGR position and from the luminous blue variable star, LBV 1806−20, previously suggested as a potential SGR counterpart (van Kerkwijk et al. 1995). Corbel & Eikenberry (2004) argue that both objects are associated with this cluster. Recently, Vrba et al. (2000) discovered a similar compact stellar cluster in the X-ray error box of SGR 1900+14. This cluster is very close (∼0.6 pc) to a transient radio source discovered by Frail et al. (1999) during the 1998 giant flare from the source (Hurley et al. 1999). The IR appearance of this cluster is dominated by its most luminous members, two M5 supergiants (Vrba et al. 1996; Guenther et al. 2000). These findings led to the suggestion that both SGRs originated in nearby compact stellar clusters (Vrba et al. 2000) and that SGR progenitors may be very massive stars. To further investigate this hypothesis we focus here on SGR 0526−66.

SGR 0526−66 was active from the mid 1970s until 1983 and has been in a quiescent state since then (Aptekar et al. 2001). On 1979 March 5, the source emitted the most energetic SGR burst ever recorded (Mazets et al. 1979), with a peak luminosity of over 5×10^{44} ergs s^{-1}. The extreme intensity and the sharp rise time (0.2 ms) of this event enabled the first accurate localization of an SGR source at the edge of the bright SNR N49 in the LMC (Cline et al. 1982). This location was later improved with *Chandra* observations to a 0″.6 uncertainty (Kulkarni et al. 2003). Kaplan et al. (2001) observed N49 with the *Hubble Space Telescope* but could not identify an optical counterpart for the SGR brighter than ∼26.5 mag (F814W filter).

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TABLE 1
Observing Log of the N49 Region with VLT/ISAAC

Date (UT)	Filter	Exposure (s)
2003 Jan 26	J_s	14 × 100
	H	8 × 95
2003 Feb 17	H	6 × 95
	K_s	14 × 75
2003 Mar 17	NB 1.26 μm	14 × 160
2003 Feb 17	NB 1.64 μm	14 × 160
	NB 2.17 μm	14 × 160

Here we report on the results of deep NIR observations of the N49 region using the Very Large Telescope (VLT). While it was not our primary goal to detect the NIR counterpart of SGR 0526−66, we searched for a third cluster–SGR association, which would strengthen the case for a physical link between SGRs and young stellar clusters of massive stars.

2. OBSERVATIONS AND DATA REDUCTION

We conducted NIR imaging of the N49 region using VLT/Infrared Spectrometer and Array Camera (ISAAC) in early 2003 (Table 1). ISAAC makes use of a 1024 × 1024 pixel Rockwell Hg:Cd:Te array and offers a plate scale of $0''.147$ pixel^{-1}. Because the spectral appearance of N49 is characterized by strong Fe emission lines and a fainter emission component in hydrogen recombination lines (Oliva et al. 1989; Dickel et al. 1995), we utilized a combination of broad- and narrowband filters for imaging. The narrowband images (in [Fe II] at 1.257 μm, [Fe II] at 1.64 μm, and Brγ at 2.17 μm) were used to subtract the nebular contribution from the broadband images (J_s, H, K_s), allowing the discrimination of continuum sources, i.e., a potentially hidden stellar cluster and emission-line knots of the SNR.

All images were analyzed consistently. After standard image processing steps (flat-fielding and stacking), all stars were extracted using DAOPHOT as implemented in IRAF.[9] Point-spread function (PSF) fitting was used with fitting width typically one FWHM radius. PSF stars were carefully selected to ensure that no background contamination was present and that all objects were stellar. After extraction, photometry was performed using United Kingdom Infrared Telescope IR standard stars FS 6, 14, and 20 observed with VLT/ISAAC.

3. RESULTS AND DISCUSSION

3.1. *The NIR View of the N49 SNR*

We first searched the NIR data for evidence of a stellar cluster very close to SGR 0526−66. After removal of the bright line emission from N49, we find no evidence for a cluster in projection against the SNR. Instead, we find a remarkable excess of K-band flux in the southeastern part of N49 (Fig. 1). This feature is not seen in our Brγ narrowband image but has a mid- and far-IR counterpart.

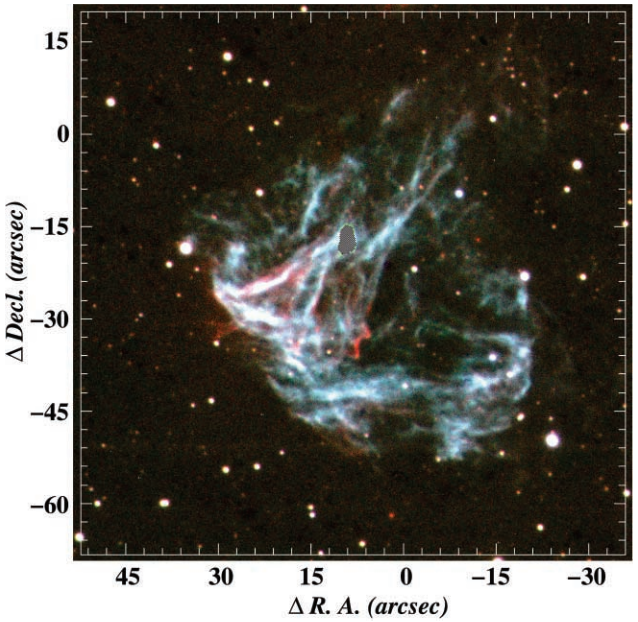

Fig. 1.—J_sHK_s composite of N49, centered at the X-ray position of SGR 0526−66 (Kulkarni et al. 2003). The figure shows the potential NIR counterpart of IRAS 05259−6607 as a region of excess K-band flux (in red color, centered at ΔR.A., Δdecl. = 15″, −30″). Note that the top right part of this region is slightly affected by a bad pixel cluster.

The N49 region was observed in the far-IR with *IRAS* and in the mid-IR by the *Midcourse Space Experiment* (*MSX*) satellite[10] during its Galactic plane survey. The *IRAS* data were discussed by van Paradijs et al. (1995, their Fig. 1). The brightest source in the field is recorded in the *IRAS* catalog with coordinates R.A., decl. (B1950) = $05^h25^m59^s.5$, $-66°07'03''$ (Schwering & Israel 1990), which dominates at 25 μm and is also bright at 12 and 60 μm. The *MSX* data of the SNR show a bright and extended source at 8.28 μm with its center approximately at coordinates R.A., decl. = $5^h26^m03^s.8$, $-66°05'05''$ (J2000.0; Fig. 2), which

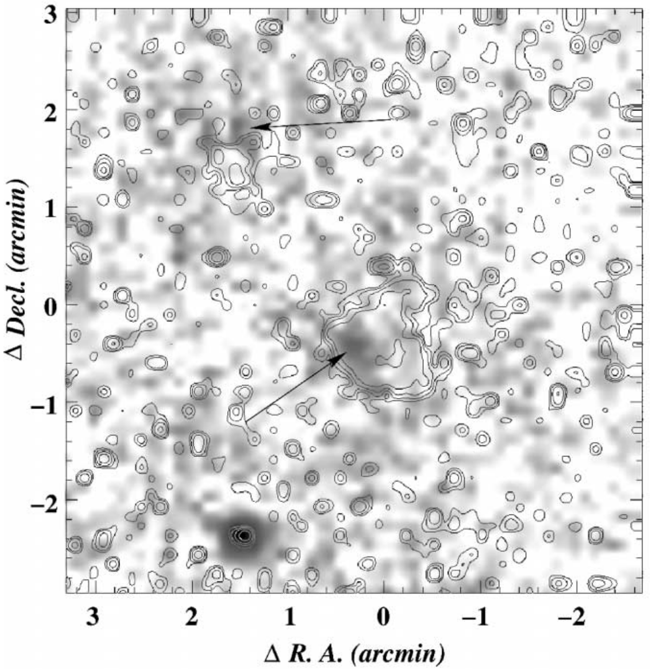

Fig. 2.—*MSX* view of the N49 region at 8.28 μm (see footnote 10) with contours of the Digitized Sky Survey red plates (DSS2) overplotted, centered at the X-ray position of SGR 0526−66 (Kulkarni et al. 2003). While the southeastern part of N49 appears as a bright source (*bottom arrow*), a fainter source is visible about 2′ northeast from the SNR (*top arrow*; see § 3.2). The bright source at the bottom of the image is a star.

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[9] IRAF is distributed by the National Optical Astronomical Observatories, operated by the Associated Universities for Research in Astronomy, Inc., under contract to the National Science Foundation.

[10] See http://www.ipac.caltech.edu/ipac/msx.

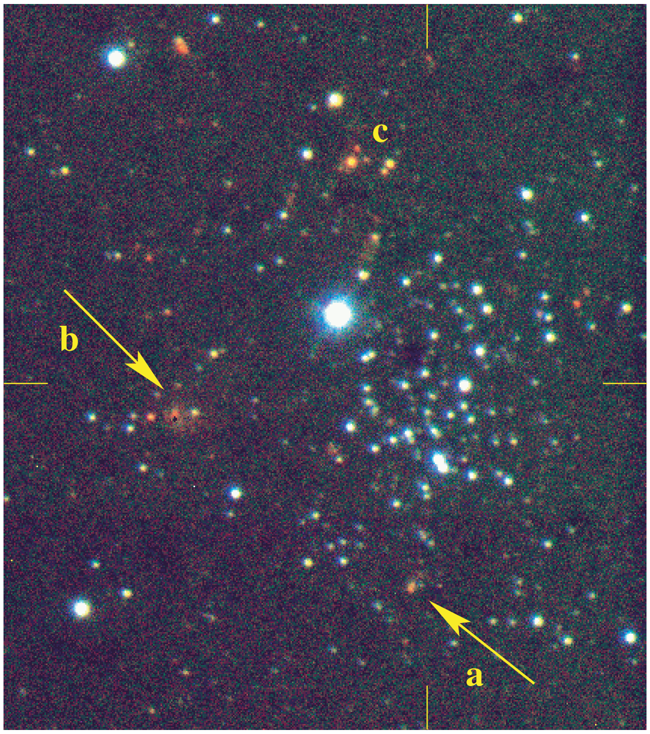

FIG. 3.—J_sHK_s composite of the stellar cluster SL 463 approximately 130″ northeast from SGR 0526−66. The SGR itself lies outside this image. The coordinate cross marks the suspected center of the cluster at R.A., decl. = $5^h26^m16^s.45$, −66°03′08″.5 (J2000.0). Object "b" is highly reddened and presumably identical to a bright submillimeter source (Yamaguchi et al. 2001), while another group of reddened objects ("a") may coincide with an excess flux at 12 μm seen by *IRAS* (van Paradijs et al. 1995, their Fig. 1). A third group of very red objects ("c") possibly coincides with an 8.28 μm source (Fig. 2). The image size is ∼75″ × 65″. North is up, and east is left.

on our images coincides with the center of the region where the SNR shows the excess of *K*-band flux. Since the coordinates of this source/region basically agree with the coordinates of IRAS 05259−6607 originally published by Graham et al. (1987), we consider it likely that we have imaged the short-wavelength counterpart of this *IRAS* source. Although it is believed that here the expanding SNR encounters an interstellar cloud (Banas et al. 1997), based on our data we cannot uniquely identify the origin of this source and the excess *K*-band flux.

3.2. *A Young Stellar Cluster Close to SGR 0526−66*

While we have not found a stellar cluster hidden by the bright line emission of the SNR, a stellar cluster in the vicinity of the SNR does exist. This cluster is located about 130″ northeast from the quiescent X-ray counterpart of the SGR (Kulkarni et al. 2003), corresponding to a projected distance of ∼30 pc (Fig. 3). This relatively unexplored cluster (cataloged as SL 463 as a member of the OB association LH 53; Hill et al. 1995; Kontizas et al. 1994; Efremov 2000) coincides with a bright submillimeter source (Yamaguchi et al. 2001), indicating that it contains large amounts of gas and dust. Many objects in this field are highly reddened, indicating ongoing star formation in this region of the LMC.

The *K* versus $H-K$ color-magnitude diagram of this cluster indicates the presence of several dozen B-type main-sequence stars and possibly one supergiant (Fig. 4), although we cannot exclude that this is a Galactic foreground star (the brightest star in Fig. 3). Most members of SL 463 are extinct by less than 1 mag, although several stars might be affected by somewhat stronger exinction. Within a radius $r = 2.1$ pc of the suspected cluster center (for an assumed distance of 50 kpc), 50 sources are visible on our ISAAC images. For 31 of them we have accurate photometry to a limiting magnitude of 19.5 mag in *JHK*. In the outer regions of the cluster, between 2.1 and 4.2 pc, an additional 90 stars are detected. On the basis of a potential relation between the radius of a young stellar cluster and its age (Maíz-Apellániz 2001), the age of SL 463 is between 5 and 20 Myr, in agreement with age estimates of the entire LH 53 complex (Hill et al. 1995; Yamaguchi et al. 2001).

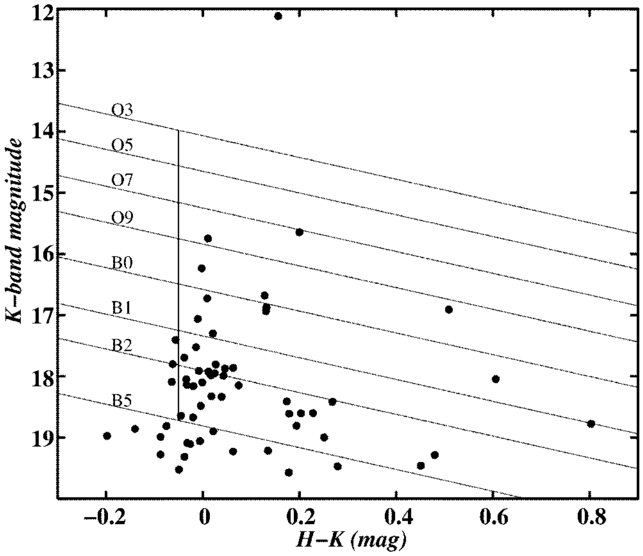

FIG. 4.—Color-magnitude diagram for all sources with *JHK* photometry within $r \leq 4.2$ pc around the suspected cluster center. Only stars with accurate photometry (error < 0.1 mag in *JHK*) are included here. The *K*-band magnitudes of unobscured main-sequence stars are shown as a vertical line and were taken from Hanson et al. (1997), while setting $H-K = -0.05$ mag (Blum et al. 2000) and assuming a distance modulus for the LMC of 18.5 mag (Bono et al. 2002). The reddening tracks for OB main-sequence stars are plotted as straight lines. For a standard extinction law, 0.2 mag change in $H-K$ color corresponds to 3.2 mag visual extinction (Rieke & Lebofsky 1985).

Compared to the clusters found in close projection to SGR 1900+14 and 1806−20, the cluster SL 463 is older and larger but apparently still enshrouded by dust and located much farther away from the corresponding SGR. With respect to the origin of SGR 0526−66, we briefly consider two scenarios. First, assuming that the cluster was the birthplace of the SGR progenitor, the SGR must have been ejected from the cluster with a space velocity of $\sim 30(\sin\theta)^{-1}n^{-1}$ km s^{-1} in order to travel a projected distance of 30 pc within *n* Myr, where θ is the angle between the line of sight and the moving direction of the SGR. If the SGR progenitor and the stellar cluster are coeval, a cluster age of ∼10 Myr would imply an initial mass of this star of greater than 20 $M_\odot$ (Hill et al. 1995). Numerical models of the dissolution of young massive clusters have shown that an ejection of stars with initial masses of 5–10 $M_\odot$ with velocities of the order of 10–40 km s^{-1} indeed occurs (Vine & Bonnell 2003), if the gas–to–stellar mass ratio in the cluster is relatively high (as seems to be the case for SL 463). Second, if SGR 0526−66 was born as a magnetar within this stellar cluster, given its current offset from the cluster and allowing for an ejection velocity of the order of $300(\sin\theta)^{-1}$ km s^{-1}, its age must be about 10^5 yr. This predicts a proper motion of the SGR of ∼1 mas $(\sin\theta)^{-1}$ yr^{-1} along a direction away from the stellar cluster.

A field strength of about 7 × 10^{14} G was inferred from the P-$\dot{P}$ relation for the quiescent X-ray counterpart of the SGR (Kulkarni et al. 2003). If the magnetar is coeval with SNR N49 (∼5000 yr), such a field strength would be consistent with the magnetar age. On the other hand, for an age of 10^5 yr required by an SGR-cluster association, the current B-field depends on the assumed evolution model. If the field evolves through crustal ohmic decay, perhaps accelerated by a Hall cascade, irrespective of the initial field strength the remaining field after 10^5 yr will be $\sim10^{13}$ G, which is inconsistent with the value inferred from the P-$\dot{P}$ relation. However, if the field is anchored in the core and evolves via ambipolar diffusion, then a surface field strength of 7 × 10^{14} G after 10^5 yr is easily conceivable. Under certain conditions, magnetars may be able to sustain high field strengths over such a long period of time (Colpi et al. 2000). In other words, the observed field characteristics of the quiescent X-ray counterpart of the SGR do not exclude the possibility that the birth of the SGR took place within the stellar cluster SL 463.

4. CONCLUSIONS

We performed a NIR survey toward the N49 region in the LMC and address the question of the circumstances of the formation of SGR 0526−66. We imaged the young and presumably dusty stellar cluster SL 463, located only ∼30 pc away (projected distance) from the SGR. It is possible that SGR 0526−66 was born in this cluster, but our observations do not allow us to claim with certainty that the SGR or its progenitor was born within this cluster. However, the fact that similar clusters have been found at or near the positions of the three best-studied SGRs (1900+14, 1806−20, and 0526−66) argues in favor of a cluster/SGR connection. If this association is real, we can constrain the age and thus the initial mass of the SGR progenitor. In all three cases the masses turn out to be $\gtrsim 20\ M_\odot$. This would place SGR progenitors among the most massive stars with solar metallicity that can produce neutron star remnants (Heger et al. 2003).

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