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THE DISCOVERY OF AN EMBEDDED CLUSTER OF HIGH-MASS STARS NEAR SGR 1900+14

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ABSTRACT

Deep *I*-band imaging to $I \approx 26.5$ of the soft gamma-ray repeater SGR 1900+14 region has revealed a compact cluster of massive stars located only a few arcseconds from the fading radio source thought to be the location of the soft gamma-ray repeater (SGR). This cluster was previously hidden in the glare of the pair of M5 supergiant stars (whose light was removed by point-spread function subtraction) proposed by Vrba et al. as likely associated with SGR 1900+14. The cluster has at least 13 members within a cluster radius of ≈0.6 pc based on an estimated distance of 12–15 kpc. It is remarkably similar to a cluster found associated with SGR 1806−20. That similar clusters have now been found at or near the positions of the two best studied SGRs suggests that young neutron stars, which are thought to be responsible for the SGR phenomenon, have their origins in proximate compact clusters of massive stars.

Subject headings: galaxies: star clusters — gamma rays: bursts — gamma rays: observations

1. INTRODUCTION

The Hartmann et al. (1996) and Vrba et al. (1996, hereafter V96) survey of the original network synthesis localization (NSL) of SGR 1900+14 (Hurley et al. 1994) found a pair of nearly identical M5 supergiant stars separated by 3″.3 and at an estimated distance of 12–15 kpc. While just outside of the original NSL, they lie within the *ROSAT* High-Resolution Imager (HRI) localization of the quiescent X-ray source RX J190717+0919.3 thought to be associated with SGR 1900+14 (Hurley et al. 1996). On the basis of the small probability that even one supergiant would lie within the *ROSAT* error circle and that at least one other supergiant had been associated with a soft gamma repeater (SGR 1806−20: van Kerkwijk et al. 1995; Kulkarni et al. 1995), V96 proposed that the M star pair may be associated with the SGR 1900+14 source. The position of the M star pair has continued to be consistent with more recent X-ray and gamma-ray observations which, taken together, have narrowed considerably the actual location of SGR 1900+14 from the original NSL area of 5 arcmin^2. These recent X-ray and gamma-ray observations have also detected variations with a period of 5.16 s (Hurley et al. 1999b; Murakami et al. 1999; Kouveliotou et al. 1999) and a deceleration of $\dot{P} \approx 10^{-10}$ s s^{-1}. Taken together, these are interpreted as evidence that the SGR source is a magnetar, although there remains some uncertainty in this interpretation (Marsden, Rothschild, & Lingenfelter 1999).

Additionally, a variable and fading radio source was detected shortly after the August 27 SGR 1900+14 superburst by Frail, Kulkarni, & Bloom (1999), providing strong evidence that it was the radio counterpart to the soft gamma-ray repeater (SGR). Its subarcsecond-accurate position is located only a few arcseconds from the M stars. These positional coincidences, the lack of a plerionic radio source, and—despite arguments for SNR G42.8+0.6 in the literature—the lack of a coincident supernova remnant suggest that the system of proximate, high-mass M stars should not yet be dismissed as an evolutionary companion to the pulsating X-ray source associated with the SGR.

Finding direct evidence that the M star pair may be associated with SGR 1900+14 has proven elusive, as summarized by Guenther, Klose, & Vrba (2000). Also difficult is a theoretical understanding of how isolated, albeit high-mass, stars could play a role in the formation of a pulsating X-ray source despite the presence of a high-mass luminous blue variable (LBV) very near the SGR 1806−20 localization position, a remarkably similar situation to that for SGR 1900+14. Recent near- and mid-infrared observations of SGR 1806−20 (Fuchs et al. 1999), however, have revealed the LBV to be only the most luminous member of a compact cluster of massive stars. Such proximate regions of recent star formation provide a natural location for the birth of such pulsating X-ray sources, which cannot be very old, without the need for invoking enormous space velocities from the nearest supernova remnants.

In this Letter, we present evidence for a similar compact cluster of high-mass stars that has heretofore been hidden in the glare of its brightest components, the pair of M5 supergiant stars.

2. OBSERVATIONS

The 1998 outburst season of SGR 1900+14 presented an opportunity to search for optical and near-infrared variability of the double M stars, or other sources within the *ROSAT* HRI error circle, which might be correlated to the SGR outbursts via some process such as mass transfer to a compact object. Beginning in early May and continuing through mid-July of 1998, we carried out an *I*- and *J*-band monitoring campaign at the US Naval Observatory Flagstaff Station (USNOFS) which eventually comprised 2025 short-exposure frames of data with 54,460 s of open shutter time during 16 nights, intended to sample variability timescales down to a few seconds. The re-

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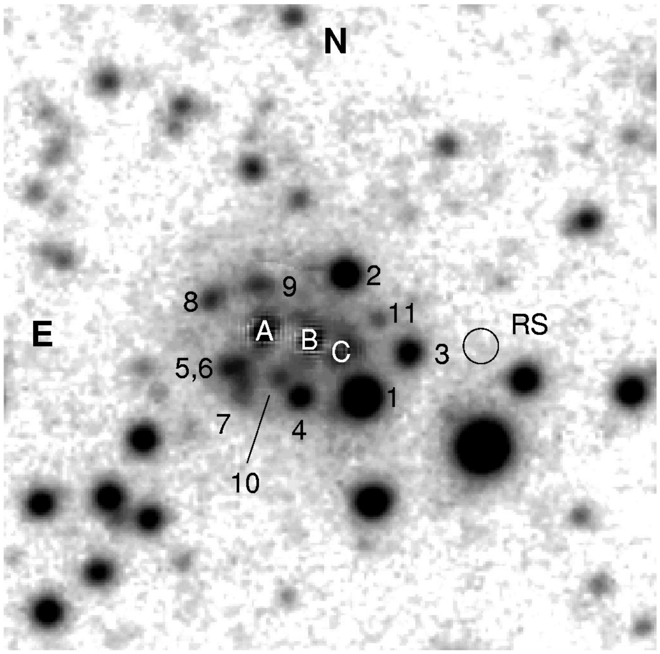

FIG. 1.—An approximately 45″ × 45″ portion of the 6.5 hr exposure *I*-band image of the SGR 1900+14 region formed from numerous short exposures as explained in the text. North is at the top, and east is to the left. In this image the bright M stars (discussed in Vrba et al. 1996) have been subtracted, revealing the cluster of faint stars. The position of the Frail et al. (1999) fading radio source is indicated by the circle. The 11 stars forming the cluster are numbered for identification.

sults of this work found no variability for any object within the *ROSAT* HRI error circle and are presented more fully in Vrba et al. (2000).

However, it was recognized that the numerous short *I*-band exposures constituted several hours of total exposure time, which could be stacked to form a deep *I*-band image to search for a counterpart at the position of the Frail et al. (1999) variable radio source. To the 1998 data were added additional short-exposure frames from 1995 and 1999. In all, 217 frames of individual exposure time between 1 and 10 minutes were co-added to form a net image of about 6.5 hr total exposure. All frames were obtained with one of two Tektronix 2K CCDs on the 1.55 m Strand Astrometric Telescope at the USNOFS. It was additionally recognized that, since the exposures used were short enough not to saturate the three bright M stars (A, B, and C of V96), their light could largely be removed by point-spread function (PSF) subtraction.

Figure 1 is an approximately 45″ × 45″ portion of the median-filtered composite *I*-band image centered on the V96 M stars, with a limiting detection magnitude of $I \approx 26.5$. In this image the M stars A, B, and C have been removed, although their positions are still apparent due to imperfect subtraction. The position of the variable radio source is shown, but no counterpart is visible to $I \approx 26.5$, which is consistent with the nondetections in the near-infrared of Eikenberry & Dror (2000). Unfortunately, none of the nearly 200 frames from 1998 were obtained simultaneously with a gamma-ray burst from SGR 1900+14.

Of greater interest is that the subtracted *I*-band image shows what appears to be a cluster of stars, and possibly nebulosity, centered on the position of the M stars. The *IRAS* source found at this location by van Paradijs et al. (1996) shows a steeply

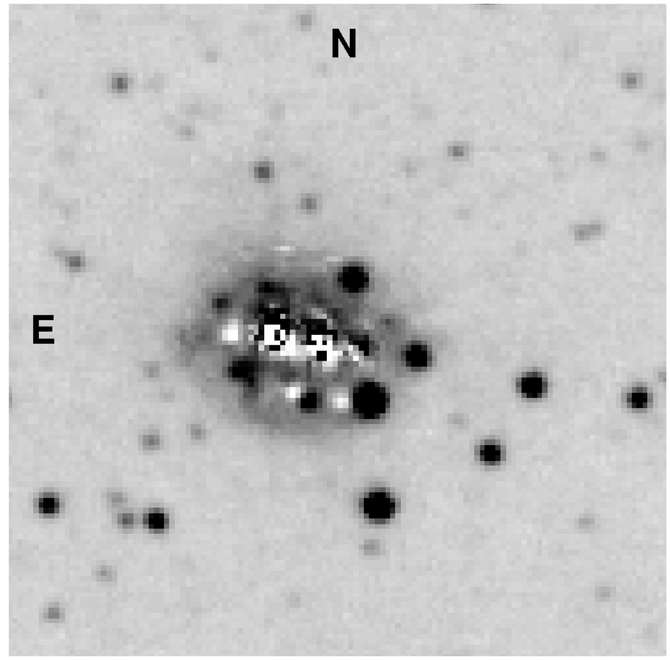

FIG. 2.—An approximately 45″ × 45″ portion of a *J*-band image of the SGR 1900+14 region. North is at the top, and east is to the left. In this image the bright M stars (discussed in Vrba et al. 1996) have been subtracted, showing the nebulosity associated with the cluster.

rising energy spectrum that can be interpreted as warm dust in the cluster region. Figure 1 also shows identification numbers of the possible cluster stars. On 1999 October 28 UT we used the ASTROCAM infrared imager, which employs an SBRC 1024^2 InSb detector, at the 1.55 m telescope to obtain a 1600 s net exposure *J*-band image of this region. An approximately 45″ × 45″ region of this image is shown in Figure 2, where again the M stars were somewhat successfully PSF-subtracted.

We obtained photometry for the cluster stars from the *I*- and *J*-band frames, calibrated with several *I*- and *J*-band local standards that had previously been set up for our variability monitoring program. The photometric results are presented in Table 1, in which the results for stars 5 and 6 are presented together because they could not be separated in the *J*-band observations. The observed $(I-J) \approx 7$ colors are far larger than for any unreddened star and indicate that they suffer extremely high extinction.

TABLE 1
I- AND *J*-BAND PHOTOMETRY OF CLUSTER STARS

Star	$I \pm \sigma(I)$	$J \pm \sigma(J)$	$(I-J) \pm \sigma(I-J)$
1	20.00 ± 0.02	13.17 ± 0.02	6.83 ± 0.03
2	21.10 ± 0.02	14.26 ± 0.02	6.84 ± 0.03
3	21.85 ± 0.02	14.51 ± 0.02	7.34 ± 0.03
4	22.01 ± 0.02	15.06 ± 0.04	6.95 ± 0.05
5	22.77 ± 0.03	...	...
6	23.18 ± 0.04	...	...
5 + 6	22.20 ± 0.04	15.47 ± 0.06	6.73 ± 0.07
7	23.16 ± 0.05	15.70 ± 0.09	7.46 ± 0.10
8	22.85 ± 0.04	15.62 ± 0.06	7.23 ± 0.07
9	23.01 ± 0.05	15.53 ± 0.05	7.48 ± 0.07
10	23.60 ± 0.06	16.41 ± 0.07	7.19 ± 0.09
11	23.78 ± 0.06	16.12 ± 0.04	7.66 ± 0.07

3. NATURE OF THE CLUSTER

Assuming that the cluster stars are at the same distance and suffer the same extinction as the M supergiant stars (12–15 kpc; $A_V = 19.2 \pm 1.0$; V96), we placed all stars in an M_I versus $(I-J)$ color-magnitude diagram (Fig. 3), assuming normal interstellar extinction (Bessel & Brett 1988); the error bars include the ranges in distance and A_V values given above. The solid curves show the approximate loci for supergiants and dwarfs later than A0 and for giants later than G0, while the dashed lines show the M0 $(I-J)$ colors for reference. The large uncertainty of the intrinsic $(I-J)$ colors of the stars after subtracting a huge baseline of extinction renders them essentially useless in estimating their spectral types. However, at this assumed distance and extinction the stars have luminosities far greater than that of main-sequence stars. We note that even assuming the stars are at a much closer distance (for instance, $d \approx 5$ kpc as has often been quoted by association with the SNR G42.8+0.6) has little affect on the conclusion that these are highly luminous stars.

Several examples of compact high-mass young clusters serve as templates for these objects: NGC 3603 (Moffat, Drissen, & Shara 1994), W43 (Blum, Damineli, & Conti 1999), and several clusters summarized in Figer, McLean, & Morris (1999). These clusters are characterized by 10–30 cluster members, radii of 0.2–1.0 pc, and ages of 1–10 Myr. The SGR 1900+14 cluster has at least 13 members (including stars A and B) and an approximate 7″ radius which, at a distance of 12–15 kpc, corresponds to a cluster radius of ≈0.4 pc. A remarkably similar example to that of the SGR 1900+14 cluster is described by Moffat (1976) in which a group of 12 luminous stars surround the M3 I supergiant star HD 143183 within a cluster radius of 0.6 pc. These examples support the idea that the small cluster of stars near SGR 1900+14 and dominated by the M5 supergiants is likely a real association. A formal astrometric solution, not previously presented, for the positions of the M supergiants based on 21 USNO-A2.0 stars gives the following results (±0″.1): star A: $\alpha = 19^h07^m15^s.35$, $\delta = +09°19′21″.4$ (J2000); star B: $\alpha = 19^h07^m15^s.13$, $\delta = +09°19′20″.7$ (J2000).

4. DISCUSSION

If the cluster was the birthplace of SGR 1900+14, this essentially excludes SNR G42.8+0.6 from playing any role in the SGR. Although one can envision scenarios in which the supernova remnant (SNR) progenitor was ejected from the cluster by dynamical interaction or a much earlier supernova, this leaves the necessity of the neutron star having been kicked back to almost exactly its place of origin by the supernova that formed SNR G42.8+0.6 (since the cluster and SGR localizations are coincident), an unlikely coincidence both in space and timing. However, despite the association of G42.8+0.6 with SGR 1900+14 in the literature, no evidence that supports this association has been offered, such as the probability of finding any SNR within a given distance, based on the number density of SNRs in the Galactic plane.

A more plausible scenario is one in which the cluster and associated dense gas/dust cloud hides a recent supernova. Evidence for this cloud comes from Figures 1 and 2 and the coincident extended strong far-infrared source indicating compact warm and extended cool dust (see V96). Optical extinction from this cloud combined with a 12–15 kpc distance explains why the supernova would not have been noticed historically. A very young SNR expanding into the dense wind-blown bubble due to mass loss from the supergiant stars in the cluster would be consistent with the otherwise unexplained persistent X-ray source at this position, RX J190717+0919.3 (Hurley et al. 1996). While no quiescent radio source is known at this position, a combination of self-absorption within the dense medium and rapid decay (Reynolds 1988) could account for this. The supernova remnant evolutionary calculations of Truelove & McKee (1999) indicate that for an ejecta mass of 1 $M_\odot$ and an external density medium of 10 cm^{-3}, one finds a characteristic size of ≈1 pc at $t = 1000$ yr, which is similar to that of the cluster dimensions at the estimated M supergiant distances.

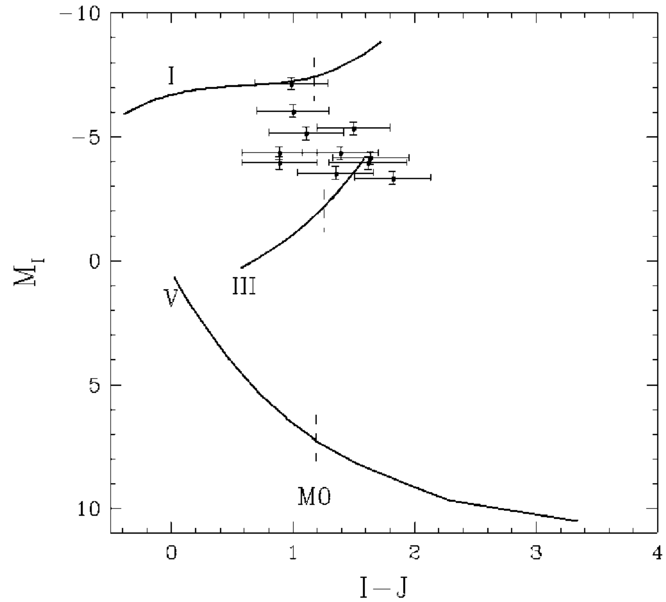

FIG. 3.—M_I vs. $I-J$ color-magnitude diagram for the 11 newly discovered cluster stars. The *I*- and *J*-band photometry has been dereddened by $A_V = 19.2 \pm 1.0$ mag, and the cluster stars have been assumed to be at a distance range of 12–15 kpc as explained in the text. The approximate loci for luminosity class I, III, and V stars are also shown by the solid curves, with the positions for M0 spectral type stars shown for reference by the dashed lines.

The most likely position for the SGR itself is the Frail et al. (1999) fading radio source located at $\alpha = 19^h07^m14^s.33$, $\delta = +09°19′21″.1$ (J2000), with positional accuracy of ±0″.15 in each coordinate. With these astrometric positions, we estimate the approximate distances from the center and edge of the cluster to the radio position as 12″ (0.7–0.9 pc) and 5″ (0.3–0.4 pc), respectively, based on the 12–15 kpc distance estimate. Thus, even at the extreme minimum age of the SGR based on the simplest magnetar physics (≈700 yr; Kouveliotou et al. 1999), this implies a tangential velocity of ≈420 km s^{-1} from the near edge of the cluster. While still an ample velocity for the runaway neutron star, it obviates the enormous space velocities implied by associating it with G42.8+0.6 (Kouveliotou et al. 1999), which is about 12′ away (Hurley et al. 1999a).

While an isolated instance of the compact, high-mass cluster found at/near SGR 1900+14 would be dismissed as a chance superposition, its striking similarity to the cluster found near SGR 1806−20 by Fuchs et al. (1999) must be recognized. In that case, an LBV supergiant is found associated with a cluster of at least another four massive young stars enshrouded in a bright dust cloud as imaged by *ISO* and located only 7″ from the SGR gamma-ray localization. With an approximate cluster radius of 8″ and an estimated distance of 14.5 kpc, this implies a cluster radius of ≈0.6 pc. Now that similar compact clusters have been found near the positions of the two best studied SGRs (SGR 1806−20 and SGR 1900+14), the possibility that young SGR neutron stars have their origins in compact clusters should be considered seriously.

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