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DISCOVERY OF A YOUNG MASSIVE STELLAR CLUSTER NEAR HESS J1813-178

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ABSTRACT

We present the serendipitous discovery of a young stellar cluster in the Galactic disk at l=12°. Using Keck/NIRSPEC, we obtained high– and low–resolution spectroscopy of several stars in the cluster, and we identified one red supergiant and two blue supergiants. The radial velocity of the red supergiant provides a kinematic cluster distance of 4.7±0.4 kpc, implying luminosities of the stars consistent with their spectral types. Together with the known Wolf–Rayet star located 2.′4 from the cluster center, the presence of the red supergiant and the blue supergiants suggests a cluster age of $6-8$ Myr, and an initial mass of $\gtrsim 2000\ M_{\odot}$. Several stars in the cluster are coincident with X–ray sources, including the blue supergiants and the Wolf–Rayet star. This is indicative of a high binary fraction, and is reminiscent of the massive young cluster Westerlund 1. The cluster is coincident with two supernova remnants, SNR G12.72−0.0 and G12.82−0.02, and the highly magnetized pulsar associated with the TeV γ–ray source HESS J1813−178. The mixture of spectral types suggests that the progenitors of these objects had initial masses of $20-30\ M_{\odot}$.

Subject headings: stars: evolution — infrared: stars — X-rays: stars — stars: supernovae: general

1. INTRODUCTION

Young stellar clusters are important tools for investigating the structure, the chemical enrichment, and the current star formation of a galaxy. Furthermore, they are natural laboratories to study the evolution of massive stars. Massive stars explode as supernovae creating neutron stars and black-holes, and are believed to be sources of γ–ray bursts, which are the most energetic explosions in the Universe. Because of their short lifespans, massive stars are rare and predominantly observed in young (few Myrs) massive ($\sim 10^4\ M_{\odot}$) clusters. Only a handful of massive stellar clusters are known in the Galaxy: important examples include Arches, Quintuplet, Westerlund 1, and Westerlund 2 (Figer 2008). As these clusters lie in the plane, their detection is hampered both by interstellar extinction and by the relatively low numbers of member stars. Indeed, the census is severely incompletely, as demonstrated by the recent discovery of two other massive clusters (RSGC1 and RSGC2, Figer et al. 2003; Davies et al. 2007).

We have serendipitously discovered a new stellar cluster at RA= $18^{\rm h}13^{\rm m}24^{\rm s}.31$ and DEC=$-17°53'30''.83$ (J2000). Previously undetected, this cluster clearly appears as a stellar over–density at infrared wavelengths (Fig. 1), and is also visible at optical wavelength. It is located adjacent to the star forming region W33 in an extremely rich and complex region. Two supernovae remnants (SNRs), G12.82−0.02 and G12.72−0.0 (Brogan et al. 2006); a γ–ray source, HESS J1813−178 (Aharonian et al. 2006); and numerous X–ray sources (Funk et al. 2007; Helfand et al. 2007) have been detected in its surrounding area.

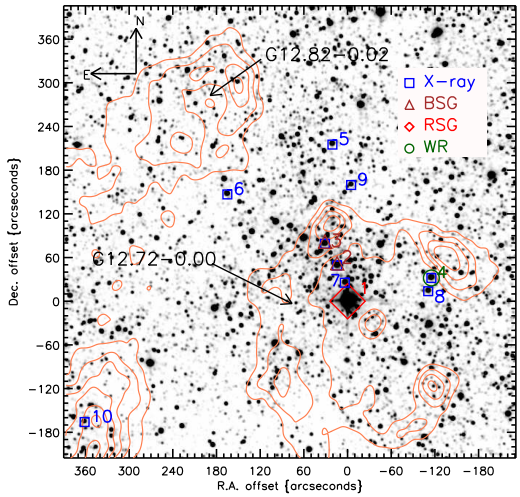

Fig. 1.— $K_{\rm s}$–band image of the cluster from 2MASS, with overlayed contours of 90 cm data (White et al. 2005). Contour levels, in mJy beam^{-1}, are: 40, 60, 80, 100, 120, 140, 160, 200. The beam size is 24″× 18″, FWHM, and the position angle of the major axis is along the North–South direction. Stellar identification numbers are from Table 1.

In this report, we present near–infrared spectra of four cluster members, of which three are identified as early B–type stars, and one as a red supergiant (RSG). Also, we analyze existing photometric infrared data and X–ray data, and find that several bright cluster members are associated with an X–ray source, one of which is a known Wolf–Rayet (WR) star (Hadfield et al. 2007). From these results, we estimate the age and distance of the cluster, which appears associated with the star forming region W33 and the high–energy source HESS J1813−178.

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2. OBSERVATIONS AND DATA

Spectroscopic observations of several candidate cluster members (see Table 1) were performed at the Keck Observatory on 2008 April 19 using NIRSPEC (McLean et al. 1998) under program U050NS (P.I. R.M. Rich). A spectrum of star #1 (K_s= 3.7 mag) was obtained with the NIRSPEC-7 filter and the $0\farcs57 \times 24''$ slit, covering $1.99 - 2.39$ μm at a resolution of R=17000 with two nodded exposures of 10s each. Low–resolution spectra of sources #2 and #3 were taken with the K filter and a $0\farcs57$ slit width, covering $1.9 - 2.35$ μm at a resolution of R=1700. Data reduction was performed as described in Figer et al. (2003). We subtracted pairs of nodded frames and flat–fielded them. The distorted 2-D spectral traces were rectified onto a linear grid, using arc and etalon frames for wavelength calibration. Atmospheric absorption and instrumental response were removed by dividing each extracted target spectrum by the spectrum of a B1V telluric standard (HD164581).

Photometric measurements of stellar point sources covering the cluster region were obtained from the Vizier database. We cross–correlated 2MASS near–infrared measurements (Cutri et al. 2003), Spitzer/GLIMPSE mid–infrared data (Benjamin et al. 2003), as well as optical data from the astrometric catalog NOMAD (Zacharias et al. 2004).

The region surrounding the cluster was observed with Chandra by Helfand et al. (2007), who detected 75 X–ray sources. We cross–identified the Chandra sources with the 2MASS and GLIMPSE catalog using a radius of $1\farcs5$, and found 44 matches.

3. SPECTRAL AND PHOTOMETRIC ANALYSIS

In order to confirm that the observed over–density is an actual stellar cluster, we analyzed the photometric properties of stellar point sources from 2MASS and GLIMPSE surveys. As an example, a (J–K_s) vs K_s diagram of 2MASS point sources within $3\farcm5$ from the peak of over–density is shown in Fig. 2. A well defined cluster sequence appears in the infrared color–magnitude diagram (CMD) at about J–K_s= 1.5 mag and K_s= $4 - 12$ mag. Its red color and bright magnitude distinguish the cluster sequence from a foreground component. An interstellar extinction of A_{K_s}= 0.83 ± 0.2 mag (Av= 9.1 mag) is estimated by matching the colors of the observed cluster sequence with a theoretical isochrone (6.3 Myr, solar composition) from the Geneva group (Lejeune & Schaerer 2001), and by assuming a power–law extinction curve $A_\lambda \propto \lambda^{-1.9}$ (Messineo et al. 2005). Because the main sequence is almost a vertical sequence when viewed in the near–infrared, this estimate is independent of age.

A variety of massive stellar objects was detected toward the new stellar cluster: a RSG star, a WR star, several BSGs (Table 1). Star #4 is associated with a known WR star (#8 in Hadfield et al. 2007). Star #1, a star with K_s= 3.7 mag, 3.5 mag brighter than other cluster members, dominates the infrared cluster surface brightness. Its high–resolution spectrum presents CO–bands in absorption as shown in Fig. 3. A radial velocity $V_{LSR} = +62 \pm 4$ km s^{-1} was measured by cross–correlating its spectrum with that of Arcturus after re–binning the latter at the same resolution. A determination of the spectral type was obtained by comparing the CO equivalent width with that of other template stars,

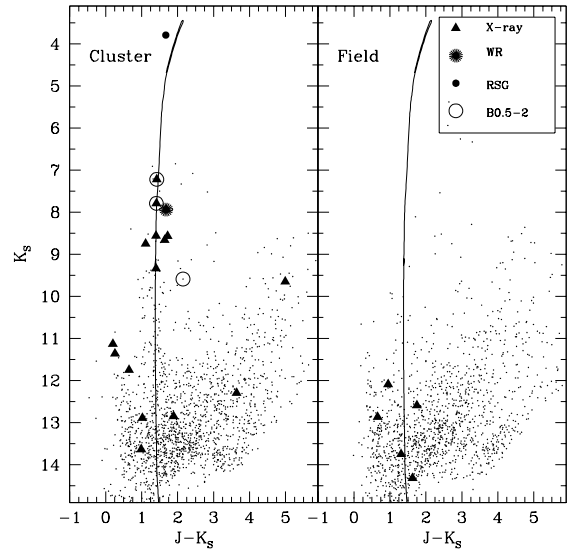

FIG. 2.— 2MASS J–K_s vs. K_s CMDs. In the left panel, we show the CMD of point sources that are within $3\farcm5$ from the center. In the right panel, field stars are plotted, which were taken from an annulus of equal area at a radius of $5'$. The vertical line indicates a solar isochrone of 6.3 Myr (Lejeune & Schaerer 2001), which was shifted to a reddening of A_{K_s}=0.83 mag and a distance of 4.7 kpc. The starred symbol indicates the location of the WR star, triangles the Chandra point sources, the large dot the RSG star, and the circles the BSGs.

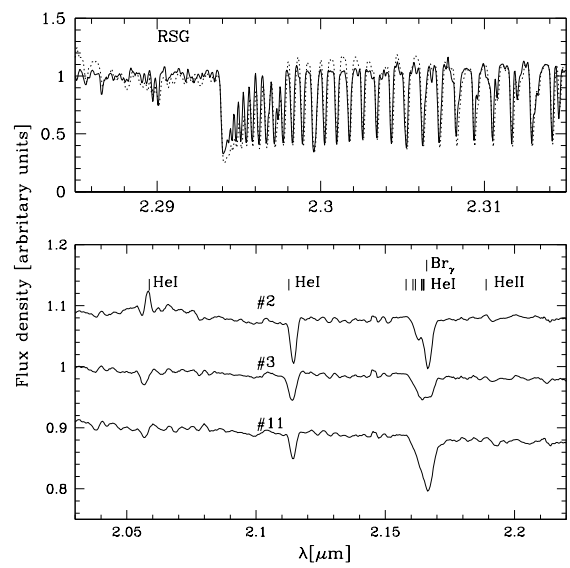

FIG. 3.— Top panel: high–resolution spectrum of the RSG star in the region of the CO band–head feature at 2.293 μm. As a comparison, a spectrum of a K3 I star (Davies et al. 2008) is also shown (dashed line). Bottom panel: low–resolution spectra of #2, #3, and #11. Helium and hydrogen lines are taken from Najarro et al. (1994).

as explained in Davies et al. (2007). The resulting CO equivalent width is consistent with that of a K2 I or an M4 III star. From the low–resolution frames, three spectra were extracted: the two spectra of sources #2 and #3, and a third spectrum of source #11, which is $6''$ away from #2, and fell on the slit. The detection of HeI lines, at 2.058 μm and 2.112 μm, and HI line at 2.166 μm, and the lack of HeII indicate that #2, #3, and #11 are early B–type (B0-B2) stars (Hanson et al. 1996). The emission line at 2.058 μm suggests that #2

TABLE 1
List of candidate massive stars.

ID	Ra	Dec	B	V	R	J	H	K_s	[3.6]	[4.5]	[5.8]	[8.0]	ID_X	L_X	Sp
01	18:13:22.255	−17:54:15.55	14.74	13.68	12.73	5.46	4.23	3.79	5.07	4.05	3.57	···	···	···	K2I
02	18:13:23.256	−17:53:26.54	20.08	15.03	14.50	8.64	7.72	7.22	6.94	6.78	6.63	6.68	39	4.1	B0.5-2I
03	18:13:24.431	−17:52:56.75	20.42	15.74	14.68	9.20	8.25	7.79	7.47	7.38	7.30	7.30	43	4.8	B0.5-2I
04	18:13:14.188	−17:53:43.60	20.48	17.57	15.20	9.62	8.60	7.94	7.34	6.93	6.70	6.35	24	80.5	WN7b
05	18:13:23.711	−17:50:40.41	19.51	16.41	14.94	9.96	9.06	8.56	8.23	8.10	7.99	8.06	41	63.4	···
06	18:13:33.817	−17:51:48.89	···	···	16.12	10.29	9.15	8.57	8.00	7.90	7.75	7.75	58	4.0	···
07	18:13:22.519	−17:53:50.14	18.63	15.60	16.57	10.30	9.27	8.66	8.03	7.70	7.49	7.30	37	10.3	···
08	18:13:14.494	−17:54:01.77	19.91	15.47	15.71	9.86	9.12	8.75	8.43	8.33	8.31	8.31	27	3.8	···
09	18:13:21.911	−17:51:35.91	21.17	···	16.24	10.74	9.80	9.34	8.95	8.90	8.83	8.91	36	2.8	···
10	18:13:47.561	−17:57:01.43	15.32	···	13.64	10.76	9.89	9.60	9.31	9.34	9.22	9.20	71	21.0	···
11	18:13:23.620	−17:53:24.50	···	···	···	11.74	10.85	9.59	10.16	10.32	10.02	···	···	···	B0.5-2

Note. — For each star, number designations and coordinates (J2000) are followed by magnitudes measured in different bands. J,H, and K_s measurements are from 2MASS, while the magnitudes at 3.6 μm, 4.5 μm, 5.8 μm, and 8 μm are from GLIMPSE. B, V, and R associations are taken from the astrometric catalog NOMAD. For sources with X–ray associations, number designations (ID_X) are taken from Helfand et al. (2007). Estimates of L_X are obtained for a distance of 4.7 kpc, by assuming $N(H) = 1.6 \times 10^{22}$ cm^{-2}, a power law model, and a photon index of 1.5 (Townsley et al. 2006). X–ray luminosities L_X are given in $10^{31} erg\ s^{-1}$.

is a blue supergiant (BSG).

4. MASSIVE STARS AND DISTANCE

From the radial velocity of star #1, we derive a kinematic heliocentric distance of 4.7 ± 0.4 kpc by using the rotation curve of Brand & Blitz (1993) and a solar Galactocentric distance of 7.6 kpc (Kothes & Dougherty 2007). Since the far distance (10.3 kpc) would make the stars over–luminous, we only consider the near distance. A spectro–photometric distance of 0.9 kpc or 4.4 kpc is inferred when assuming an M4 giant or an early K RSG, respectively, together with the absolute infrared magnitudes of Wainscoat et al. (1992). An interstellar extinction A_{K_s} of 0.48 mag is derived. We conclude that this bright star is a K2I RSG star. Star #1 is 0.′9 from the center.

By assuming a distance of 4.7 kpc, as calculated for the RSG star, an intrinsic $H-K_s$ from 0.11 to 0.27 mag (Crowther et al. 2006a), and using the extinction law by Messineo et al. (2005), we derive for the WN7b star an A_{K_s} from 0.83 to 0.59 mag and an absolute magnitude M_K from −6.0 to −6.2. This value of M_K is consistent with those of similar WN7 stars in Westerlund 1 (Crowther et al. 2006a). The 2MASS colors and magnitudes are consistent with being a cluster member. A bolometric correction of −3.5 (Crowther et al. 2006a) yields a bolometric magnitude of −9.6. Star #4 is 2.′4 from the center.

The 2MASS photometric measurements of #2 and #3 support either early nearby B dwarfs or early B supergiants at a distance of 3.7 ± 1.7 kpc. We assume the absolute magnitudes and bolometric corrections given by Crowther et al. (2006b) and Bibby et al. (2008), and consider both extinction laws by Messineo et al. (2005) and Indebetouw et al. (2005). Star #2 has A_{K_s}= 0.87 mag, and #3 has A_{K_s}= 0.81 mag (Messineo et al. 2005). However, they have the same interstellar extinction as the WR star; they are located in the same region of the CMDs, and most likely they are B0–2 supergiants, as well as members of the cluster. They are within 0.′6 from the center. Star #11 has a poor 2MASS photometry; with K_s= 9.59 mag and an extinction A_{K_s}= 1.2 mag it is consistent with being an early B dwarf.

We conclude from the CMDs and distance estimates, that the RSG, the WR star, and the BSGs are all part of the same stellar cluster. The average spectrophotometric distance of 3.7 ± 1.7 kpc is consistent with the kinematic distance 4.7 ± 0.4 kpc within uncertainties. We assume the kinematic distance.

5. THE X–RAY ASSOCIATIONS AND ENERGETICS

The 2MASS CMD (Fig. 2) shows two distinct populations of Chandra sources. One is associated with a blue foreground main sequence population, while the other is associated with redder and brighter stars that have colors and magnitudes consistent with a cluster membership. X–ray sources with a bright 2MASS counterpart (K_s< 9.6 mag), such as candidate massive members of the stellar cluster, are more spatially concentrated; except for one, they are within 3.′5, while the other X–ray detections are within 12′ from the cluster center. The nine candidate massive members with an X–ray association are included in Table 1. Star #4, the WR star (#8 in Hadfield et al. 2007), is associated with the Chandra source #24 (Helfand et al. 2007), coinciding with the XMM source #2 of Funk et al. (2007).

Massive stars can emit X–rays. Single OB stars with shocked stellar winds can emit with a typical X–ray luminosity L_X of 10^{31-33} erg s^{-1} (Pollock 1987). Shocks between the colliding winds of OB+OB or OB+WR binaries can generate a L_X of 10^{32-35} erg s^{-1} (Clark et al. 2008).

To estimate the X–ray fluxes of the nine bright infrared stars associated with an X–ray source, we used an interstellar extinction of A_V= 9.1 mag, which was estimated from the CMDs, as well as the relationship between extinction and total hydrogen column density $N(H)[\mathrm{cm}^{-2}] = A_V[\mathrm{mag}] \times 1.8 \times 10^{21}$. Count rates were estimated from the Chandra/ACIS-I counts (in the band 2-10 kev) that were given by Helfand et al. (2007). We converted them into X–ray unabsorbed fluxes by using the PIMMS v3.9d, an ACIS count estimator, with a power law model and a photon index of 1.5 (Townsley et al. 2006). Fluxes were converted into X–ray luminosities L_X by assuming a distance of 4.7 kpc. Six of the sources have L_X= $2-10 \times 10^{31}$ erg s^{-1}. The three remaining sources (#4, #5, and #10) are an order of magnitude brighter ($2-8 \times 10^{32}$ erg s^{-1}); the bright-

est, #4, is the WR star (Hadfield et al. 2007). The ratio between the X–ray and bolometric luminosities was found to be 3.8×10^{-7} for the WR star, but about 10 times fainter (0.4×10^{-7}) for #2 and #3, as expected for stars with spectral type later than B1 (Cohen 1996; Waldron & Cassinelli 2007). We conclude from the X–ray energetics that these bright infrared stars are likely to be massive stars. The WR is most likely a colliding wind binary (Portegies Zwart et al. 2002).

6. AGE AND MASS

The large variety of evolved objects – 1 WR, 1 RSG, 2 BSGs, and several X–ray emitters – allows us to constrain the age and mass of the stellar cluster by assuming coevality. The non–rotating Geneva models with solar abundance predict the onset of RSG stars at an approximate age greater than $6 - 7$ Myr (Lejeune & Schaerer 2001). In a population of 6 Myr the most massive stars have initial masses $M_{\rm initial}$ of approximately 29 $M_\odot$ (Lejeune & Schaerer 2001). In contrast, WR stars are present in populations younger than 7.9 Myr ($M_{\rm initial} > 20$ $M_\odot$). In particular, single WR stars have initial masses greater than $26 - 30$ $M_\odot$, whereas binary WR stars have initial masses greater than $20 - 25$ $M_\odot$ (Eldridge et al. 2008). The X–ray emission associated with our WR star suggests a binary system. We conclude that the cluster is $6 - 8$ Myr old since this age allows for the coexistence of both WR and RSG stars. Models with non–zero rotation increase both limits by $\sim$20% (Meynet & Maeder 2005).

Assuming that the other eight X–ray emitters associated with the cluster, other than the WR star, are BSGs with masses larger than 20 $M_\odot$, and by assuming a Salpeter IMF down to 1.0 $M_\odot$, we derive a total initial cluster mass of 2000 $M_\odot$. If we add as potential BSGs 24 other stars within 3.′5 of the center and with colors and magnitudes similar to the X–ray sources ($K_{\rm s} < 9.6$ mag, $J - K_{\rm s} < 3$ mag), the number of BSGs increases to 33, and the estimated initial mass of the cluster to 6500 $M_\odot$.

7. SUPERNOVAE REMNANTS

The cluster core is about 4.′5 away from HESS J1813−178. Several studies have recently been carried out in order to unveil the nature of the HESS γ–ray source. As a result, numerous radio and high–energy sources have been detected (see Fig. 1). Two non–thermal radio shells, G12.82−0.02 and G12.72−0.00, were identified on the 90 cm VLA survey (Brogan et al. 2006), a few arcminutes one from another (see Fig. 1). Very little is known about the SNR G12.72−0.00. The other SNR was associated with the HESS J1813−178 source by Helfand et al. (2005). A pulsar wind nebula (PWN) was detected by Chandra within this SN radio shell less than 1′ from the maximum probability centroid of the HESS source (Helfand et al. 2007; Funk et al. 2007). By analyzing the X–ray flux, the authors concluded that the SN G12.82−0.02, the HESS J1813−178 source, and the PWN lie at or just beyond 4 kpc, and might be associated with the star forming region W33. Similar conclusions were also obtained with the XMM data by Funk et al. (2007). No stellar counterpart to the PWN was found in the 2MASS or Spitzer/GLIMPSE images by Helfand et al. (2007). Dean & Hill (2008) assumed a distance of 4.5 kpc and an age of 300 yr, and found the putative pulsar to have an extremely high magnetic field (B = 1.28×10^{14} G). Funk et al. (2007) detected six other XMM sources in addition to the PWN, AXJ1813−178, and Helfand et al. (2007) detected a total of 75 Chandra sources in the region surrounding the two SNRs (Fig. 1).

The new stellar cluster is coincident (to within 1.′6) with the radio shell of SN G12.72−0.00, which suggests its association with the supernovae progenitor. The kinematic cluster distance of 4.7 kpc is consistent with the distance to the high–energy source HESS J1813−178, as inferred from the hydrogen column density by Funk et al. (2007) and Helfand et al. (2007). Massive members of this cluster were most likely the progenitors of the two supernovae and of the pulsar associated with HESS J1813−178. The progenitors of these objects had likely an initial mass similar to that of the RSG and WR stars ($20 - 30$ $M_\odot$).

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