ABSTRACT

In deep near-infrared imaging of the low-metallicity ([O/H] = −0.7 dex) H II region Sh 2-127 (S127) with Subaru/MOIRCS, we detected two young clusters with 413 members (S127A) in a slightly extended H II region and another with 338 members (S127B) in a compact H II region. The limiting magnitude was $K = 21.3$ mag (10σ), corresponding to a mass detection limit of $\sim 0.2 M_\odot$. These clusters are an order of magnitude larger than previously studied young low-metallicity clusters and larger than the majority of solar neighborhood young clusters. Fits to the $K$-band luminosity functions indicate very young cluster ages of 0.5 Myr for S127A and 0.1–0.5 Myr for S127B, consistent with the large extinction (up to $A_V \approx 20$ mag) from thick molecular clouds and the presence of a compact H II region and class I source candidates, and suggest that the initial mass function (IMF) of the low-metallicity clusters is indistinguishable from typical solar neighborhood IMF’s. Disk fractions of 28% ± 3% for S127A and 40% ± 4% for S127B are significantly lower than those of similarly aged solar neighborhood clusters ($\sim 50\%$–60%). The disk fraction for S127B is higher than those of previously studied low-metallicity clusters (<30 %), probably due to S127B’s age. This suggests that a large fraction of very young stars in low-metallicity environments have disks, but the disks are lost on a very short timescale. These results are consistent with our previous studies of low-metallicity star-forming regions, suggesting that a solar neighborhood IMF and low disk fraction are typical characteristics for low-metallicity regions, regardless of cluster scales.

Subject headings: Galaxy: abundances — infrared: stars — open clusters and associations: general — planetary systems: protoplanetary disks — stars: formation — stars: pre-main-sequence — ISM: H II regions

1. INTRODUCTION

Considering that the only elements in existence at the beginning of our universe were H and He (and an insignificant amount of Li), and that the present chemical composition of the universe is the result of metal pollution due to elemental synthesis inside stars and the influence of supernovae explosions, exploring the physical processes involved with star formation under different metallicity environments is of great interest. Although even at present, metals only account for 2% of the mass in our solar system and the local universe, they can be critical factors for star and planet formation; metals strongly affect heating and cooling related to radiative transfer in star formation processes. Also in planet formation processes, dust forms planet cores despite being only a very small mass fraction in disks (only $\sim 1\%$). Therefore, observations of the metallicity dependence of these processes can put strong constraints on theories of star and planet formation (Chruslińska et al. 2020; Ercolano & Clarke 2010).

If we observe the universe at redshifts $\geq 1$, we see the early universe, where metallicity is lower than at present. Even in our Galaxy, there is a wide range of metallicity, from $-1$ to $-0.5$ dex (e.g., Rudolph et al. 2006). However, to see the full details of the star formation processes, it is necessary to make spatially resolved observations down to the substellar mass regime ($\sim 0.1 M_\odot$). This enables us to compare results obtained for low-metallicity environments with those in the solar neighborhood on the same basis. Therefore, we are focusing on our Galaxy, the only region where observations down to the substellar mass regime can be conducted with existing telescopes and instruments. Although the Large Magellanic Cloud (LMC; $D \sim 50$ kpc) and Small Magellanic Cloud (SMC; $D \sim 620$ kpc) are well known as extragalactic objects that are relatively close to the Sun, the mass detection limit can only reach about $1 M_\odot$ with current facilities due to the larger distances compared to within our Galaxy ($D \sim 10–20$ kpc). Not until the availability of the extremely large telescopes that will allow a detection limit for extragalactic objects reaching the substellar limit finally be achieved (Yasui 2020; Leschinski & Alves 2020). The solar neighborhood is an environment where the metallicity is relatively high within our Galaxy, as well as relative to the local region ($\sim 100–200$ pc) (San-
tos et al. (2008). To examine the possible dependence on metallicity of the star formation process, we selected targets with low-metallicity environments (~1 dex) as a first step. A metallicity of ~1 dex corresponds to a redshift of z ~ 2 (Pettini et al. 1997), when the age of the universe was about 3.3 Gyr, and to the thick-disk formation phase in our Galaxy (Brewer & Carney 2006). The elucidation of star and planet formation processes under these circumstances is the purpose of this paper.

Prior to our campaign, there have only been a few published studies of star-forming regions in low-metallicity environments: Kobayashi & Tokunaga (2000), Santos et al. (2000), Snell et al. (2002), Brand & Wouterloot (2007), and Kobayashi et al. (2008). The mass detection limits of previous studies have been surpassed in the studies presented here and other papers in our series, reaching down to the substellar mass regime (~0.1 M_⊙): Digel Cloud 2 (Yasui et al. 2006, 2008b), S207 (Yasui et al. 2016b), and S208 (Yasui et al. 2016a). The first example is the Cloud 2 clusters, which are associated with a molecular cloud (Digel et al. 1994) located in the extreme outer Galaxy with a Galactocentric distance (R_G) of ~19 kpc in the direction of (l, b) = (137.75, −1.0). The S207 clusters are beyond the Norma-Cygnus (outer) arm (previously considered the outermost arm) but may be located in the recently discovered extension of the Scutum-Centaurus arm (Sun et al. 2015). The star-forming activities in this region were identified by Kobayashi & Tokunaga (2000), and Kobayashi et al. (2008) identified two young clusters, the Cloud 2-N and -S clusters. The metallicity of this region is estimated to be ~0.7 dex from an associated B-type star (Smartt et al. 1996; Rolleston et al. 2000) and the Digel Cloud 2 molecular cloud itself (Lubowich et al. 2004). From near-infrared (NIR) imaging, Yasui et al. (2008b) identified 72 and 66 cluster members in the Cloud 2-N and -S clusters, respectively, with a mass detection limit of ~0.1 M_⊙ and estimated the ages as ~0.5 Myr for both clusters.

This paper is one in a series of papers in which we present deep NIR imaging observations of low-metallicity young clusters in the Galaxy and analysis of those images. These clusters were selected using the following: i) the Sharpless catalog (a list of Ho-selected bright H II regions; Sharpless 1959), ii) the region associated with clusters having a significant number of cluster members, and iii) an oxygen metallicity [O/H] < −0.5 dex, assuming a solar abundance of 12 + log (O/H) = 8.73 (Asplund et al. 2009). Among ~10 selected regions, we first presented the results of S207 (Yasui et al. 2016b, hereafter Paper I) and S208 (Yasui et al. 2016a, hereafter Paper II), which are two of the lowest-metallicity H II regions (each with [O/H] ~ −0.8 dex) in the direction of (l, b) = (151.2, 2.13) in Galactic coordinates. With NIR deep imaging, we identified one cluster in each region, having 73 and 89 cluster members in S207 and S208, respectively, with a mass detection limit of ~0.1 M_⊙ for S207 and ~0.2 M_⊙ for S208. From the K-band luminosity function (KLF) fitting of the clusters, S207 and S208 are likely to be located at D = 4 kpc from the Sun, which suggests that two regions are located in the interarm region between the Cygnus and Perseus arms (Vallée 2020). The fitting also suggested that S207 is at the end of the embedded cluster phase (~2–3 Myr), while the S208 cluster is very young (~0.5 Myr).

From the results of four low-metallicity star-forming clusters (two Cloud 2 clusters, the S207 cluster, and the S208 cluster), the initial mass function (IMF) in low-metallicity clusters is suggested to be consistent with the typical IMF obtained in clusters with solar metallicity. In contrast, the estimated disk fractions in low-metallicity clusters are lower than those in the solar neighborhood, suggesting that the lifetime of protoplanetary disks in such environments is shorter than in clusters with solar metallicity (Yasui et al. 2009, 2010). However, the previous low-metallicity clusters studied are relatively small, with the number of cluster members (N_{stars}) < 100, and it is important to see if these results are also valid in larger clusters, e.g. N_{stars} > 100. For example, in a solar metallicity environment, it has been found that the IMF is different between starburst clusters with N_{stars} > 10^4 and more common clusters with N_{stars} ~ 10–10^4 (see Section 5.2), and the disk fraction in more massive or denser clusters is suggested to be low (see Section 5.3).

In this paper, we present the results for our third target, Sh 2-127 (S127), which is a low-metallicity star-forming region in the Galaxy with [O/H] ~ −0.7 dex, as for previous targets, located between the Cygnus and Scutum-Crux arms. However, within S127, we found two star-forming clusters with ~300–400 cluster members (N_{stars}), more than an order of magnitude higher than in previous targets. This paper is organized as follows. Section 2 describes previous studies of S127, focusing on studies of star-forming activities in S127 using multiwavelength data, e.g., mid-infrared (MIR) data from the Wide-field Infrared Survey Explorer (WISE), NIR data from the Two Micron All Sky Survey (2MASS), Hα data from the Isaac Newton Telescope Photometric H-Alpha Survey (IPHAS), and radio continuum emission from the NRAO VLA Sky Survey (NVSS). Section 3 describes our Subaru Multi-Object InfraRed Camera and Spectrograph (MOIRCS) deep JHKs images and data reduction. Section 4 describes the results for the star-forming clusters in S127. In Section 5, we discuss the basic cluster parameters, such as cluster scale, age, IMF, and disk fraction, of the S127 clusters. Finally, in Section 6, we discuss the IMF the low-metallicity environment.

2. S127

In this section, the properties of the target star-forming region, S127, are summarized. In Table 1, we summarize the properties from previous works, including coordinates, distance, oxygen abundance, and metallicity. We also show the large-scale NIR and MIR pseudocolor and Hα images of S127 in Figure 1.

2.1. Basic Properties from the Literature

The region S127 is located at (l, b) = (96.287°, +2.594°) on the Galactic plane with coordinates of (α_2000.0, δ_2000.0) = (21h28m41.6s, +54°37′00″) from the SIMBAD database (Wenger et al. 2000). It has an extended H II region traced by Hα (Sharpless 1959) and radio continuum (Fich 1993) emission. Strong

10 This research has made use of the SIMBAD database, operated at the Centre de Données Astronomiques de Strasbourg, France.
MIR emission is detected with IRAS, IRAS 21270+5423 in the IRAS Point Source Catalog (Beichman et al. 1988; see the large red plus sign in Figure 1) and IRAS X2127+544 in the IRAS Small-Scale Structure Catalog (Helou & Walker 1988). CO emission is reported in e.g., Blitz et al. (1982) and Wouterloot & Brand (1989), and the results of high-resolution CO observations are shown in Brand et al. (2001). A star-forming cluster is identified by Bica et al. (2003) as [BDS2003]24 using 2MASS images, with a center of \((\alpha_{2000.0}, \delta_{2000.0}) = (21h28m43s, +54°37′03")\) and angular dimensions of 1′ × 1′. The photometric distance, which is determined from spectroscopic and photometric observations, is estimated to be 9.7 kpc for the OSV-type star (Chini & Wink 1984), ALS 18695 (see the small red plus sign in Figure 1). The kinematic distance is also estimated at ≈10 kpc using the radial velocities of \(V_{\text{LSR}} \sim −95 \text{ km s}^{-1}\) derived in various observations: \(V_{\text{LSR}} = −94.5 \text{ km s}^{-1}\) for CO observations by Blitz et al. (1982), \(V_{\text{LSR}} = −98.9 \text{ km s}^{-1}\) for the H\(\alpha\) Fabry–Perot observation by Fich et al. (1990), \(V_{\text{LSR}} = −92.09 \text{ km s}^{-1}\) for CO observations by Wouterloot & Brand (1989), \(V_{\text{LSR}} = −94.7 \text{ km s}^{-1}\) for Fabry–Perot observations of the H II region by Caplan et al. (2000), and \(V_{\text{LSR}} = −94.7 \text{ and } −92.98 \text{ km s}^{-1}\) for \(^{12}\text{CO}\) line data by FCRAO and H I data by CGPS, respectively (Foster & Brunt 2015). According to Foster & Brunt (2015), the most recent derivation, the estimated distance is 9.97 ± 1.73 kpc, which is consistent with the kinematic distance. Assuming that the Galactocentric distance of the Sun is \(R_\odot = 8.0 \text{ kpc}\), the distance corresponds to \(R_G \simeq 13.5 \text{ kpc}\). Figure 2 shows a top view of the Galaxy with S127 and spiral arms. The location of S127 is shown by the filled circle, while the spiral arms are shown with different colors, e.g., red and cyan for the Norma-Cygnus (outer) and Scutum-Crux arms, respectively. The figure shows that S127 is located between the Cygnus arm and the extension of the Scutum-Crux arm.

The oxygen abundances \((\text{O/H})\) of S127 have been estimated from optical and far-IR (FIR) observations. Vilchez & Esteban (1996) estimated the abundance for eight H II regions by measuring optical emission line fluxes in spectroscopic observations, while Caplan et al. (2000) measured optical emission line fluxes for 36 H II regions based on Fabry–Perot observations. Rudolph et al. (1997) estimated the abundance for five H II regions by measuring FIR emission line fluxes with the Kuiper Airborne Observatory, while Peeters et al. (2002) measured line fluxes between 2.3 and 196 \(\mu\text{m}\) for IRAS point sources in 45 (compact) H II regions based on Infrared Space Observatory (ISO) spectroscopy. Rudolph et al. (2006) reanalyzed the elemental abundances of 117 H II regions with updated physical parameters. Among them, the oxygen abundances of S127 are estimated to be \(12 + \log(\text{O/H}) = 7.68−0.17^{+0.12}_{−0.23}, 8.20−0.17^{+0.15}_{−0.29}, 7.68−0.17^{+0.17}_{−0.29}, \) and \(8.46−0.30^{+0.34}_{−1.65}\) using the data by Vilchez & Esteban 1996, Rudolph et al. 1997, Caplan et al. 2000, Peeters et al. 2002, and Rudolph et al. 2006, respectively. This corresponds to a metallicity of \([\text{O/H}] \simeq −0.7\) dex assuming the solar abundance of \(12 + \log(\text{O/H}) = 8.73\) (Asplund et al. 2009). The electron temperatures \((T_e)\) are also sensitive indicators of the abundances, with higher temperatures for lower abundances (Shaver et al. 1983). The estimated temperatures are very high for S127, \(\sim 11000 \text{ K, e.g., 10500±820} \text{ K from Scaife et al. (2008) and 11428±305} \text{ K from Balser et al. (2011). They are some of the highest temperatures among H II regions in our Galaxy, suggesting that S127 is a very low-metallicity region. According to the relationship between the electron temperatures and oxygen abundances by Shaver et al. (1983) of \(12 + \log (\text{O/H}) = 9.82−1.49 T_e/10^4\), the temperature of S127 (\(\sim 11000 \text{ K}\)) suggests an oxygen abundance of 8.2, which is consistent with the abundance estimation described earlier.

### 2.2. Star-forming Activities

The top panel of Figure 1 shows an NIR and MIR pseudocolor image of S127 with a wide field of view (5′ × 5′) centered at IRAS 21270+5423, shown with the large red plus sign. The figure is produced by combining the 2MASS (Skrutskie et al. 2000) \(K_s\)-band (2.16 \(\mu\text{m};\) blue), WISE (Wright et al. 2010) band 1 (3.4 \(\mu\text{m};\) green), and WISE band 3 (12 \(\mu\text{m};\) red) images. Two components can be seen to the north and south of the IRAS source (large red plus sign) in WISE band 3, whose emission is mainly from polycyclic aromatic hydrocarbon (PAH) emission, tracing photodissociation regions around H II regions. The bottom panel of Figure 1 shows an H\(\alpha\) image from IPHAS (Drew et al. 2005) in gray scale and the 1.4 GHz radio continuum from NVSS (Condon et al. 1998) in blue contours. The overall distribution of H\(\alpha\) and radio continuum emissions that trace the photoionized H II region is consistent with that of 12 \(\mu\text{m}\) features. There are two NVSS radio sources in this field, NVSS 212841+543634 and NVSS 212843+543728, indicated by blue diamonds, which are located in the centers of the northern and southern components, but the distribution of the radio continuum is not divided into two components at the north and south of the IRAS source due to the relatively low spatial resolution of NVSS (45′). The images of radio continuum emissions with higher spatial resolution (5′.5) by Rudolph et al. (1996) show the two components, and there are two NVSS radio sources in this field, NVSS 212841+543634 and NVSS 212843+543728, indicated by blue diamonds, which are located in the center of the northern and southern component. Rudolph et al. (1996) refer to northern and southern regions as S127A and S127B, respectively. They estimated the properties of the H II regions (S127A and S127B) separately. Their results showed that S127A is an extended H II region (1.7 pc diameter), while S127B is a compact H II region (0.5 pc diameter). Rudolph et al. (1996) also pointed out that the two regions have cometary shapes, which may be due to pressure confinement of the expanding ionized 11 Deharveng et al. (2000) subsequently derived the abundances using data presented by Caplan et al. (2000).
12 Martín-Hernández et al. (2002) subsequently derived the oxygen abundance using data by Peeters et al. (2002).
gas, the so-called champagne flow. Brand et al. (2001) presented high-resolution CO observations. They showed northern and southern CO complexes around the S127A and S127B H II regions. The distribution of CO emissions correlates fairly well with that of radio continuum emissions. The northern CO complex around S127A obscurcs most of the optical emission, suggesting that the CO complex is located in the foreground. This is also seen as reduced emission (the gray area within S127A) in the Hα image (bottom panel of Figure 1) around the northern NVSS source.

The compact H II region (S127B) is located at the eastern edge of a patch of obscuration, which corresponds to a peak of the southern CO complex. This suggests that the H II region lies on the near side of the molecular complex. This is also seen in the Hα image (bottom panel of Figure 1) to the west of the southern NVSS source marked by the abrupt edge. Because ALS 18695 is located around the center of the southern H II region in the vicinity of the southern NVSS source, the O-type star should be the exciting source of the southern H II region. The spectral type of ALS 18695 (O8V) is consistent with the results of Rudolph et al. (1996) that the spectral type of a single zero-age main-sequence (ZAMS) star that could provide a flux of ionizing photons of the S127B H II region would be O8.5.

3. OBSERVATIONS AND DATA REDUCTION

3.1. Subaru MOIRCS JHK Imaging

Using the same instrumental setup described in Papers I and Paper II, MOIRCS (Ichikawa et al. 2006; Suzuki et al. 2008) was used on the 8.2 m Subaru telescope to obtain deep JHK s images with the Mauna Kea Observatories (MKO) NIR filters (Simons & Tokunaga 2002; Tokunaga et al. 2002) over a 3.5′ × 4′ field at 0.′′117 pixel−1.

The long-exposure observations described in this paper were performed on 2006 September 2 UT. Observing conditions were photometric, and the seeing was excellent (∼0′′35–0′′45) throughout the night. For the long-exposure images, individual exposure times for the J, H, and Ks bands were 150, 20, and 30 s, respectively, while the total integration times are 1350, 1080, and 1080 s for the J, H, and Ks bands, respectively. For counts over 20,000 ADU, the detector output linearity is not guaranteed. To ensure accurate flux calibration for the brightest targets in the cluster, we also obtained short-exposure images on 2007 November 22 UT. The exposure time for individual short-exposure images is 13 s, and the total integration time is 52 s for all bands. The whole H II region described in Section 2.2 is covered by one chip (−3.5′ × 4′0, hereafter the “S127 frame”; see the white and black boxes in Figure 1), whose center is at α2000 = 21h28m41.2s, δ2000 = +54°37′16″.2. For the background subtraction, to avoid the nebulosity of S127B, the telescope was nodded by 3′.5 north and south (equal to the field of view for one detector chip) in addition to 10″ dithering, the two chips being alternately directed to the field, continuously observing the field. After the long-exposure images were obtained, one of the MOIRCS science grade detectors was exchanged for an engineering grade detector. Although this engineering grade detector was used while gathering short-exposure images, we only included observations obtained with the science grade detector in our analysis. The 3.5′ sky region north of S127, whose images are obtained with a science grade detector in both long- and short-exposure images, is defined as the “sky frame.” We summarize the details of the observations in Table 2.

3.2. Data Reduction and Photometry

All data were reduced with IRAF using the procedure described in Papers I and II: flat fielding, bad-pixel correction, median-sky subtraction, image shifts with dithering offsets, and image combination. For the flat fielding, sky flats were used that were made with MOIRCS data in the closest run obtained from the SMOKA data archive. Before any image combination, the MOIRCS image reduction package MCSRED was used to correct for image distortion using the process described in Papers I and II. Figure 3 shows a pseudocolor image of S127 constructed by combining the J (1.26 μm; blue), H (1.64 μm; green), and Ks (2.15 μm; red) long-exposure images.

For the long-exposure images, photometry with point spread function (PSF) fitting using IRAF/DAOPHOT was performed. For deriving PSFs, we selected unsaturated bright stars where the highest pixel count was below the nonlinear sensitivity regime (20,000 ADU) that were not close to the edge of the frame and do not have any nearby stars with magnitude differences of more than 5 mag. The PSF photometry was performed using the ALLSTAR routine with two iterations, once using the original images and a second time using the images with sources from the first iteration subtracted. We used PSF fit radii of 3.5, 3.75, and 3.75 pixels for the J, H, and K bands, which are the PSF FWHM values, and set the inner radii and width of the sky annulus as four and three times as large as the PSF fit radii, respectively. Person 9166 (GSPC P330-E: J = 11.772, H = 11.455, and K = 11.419 mag), which is an MKO standard (Leggett et al. 2006), was used for the photometric calibration. The limiting magnitudes (10σ) based on the pixel-to-pixel noise of long-exposure images for the S127 frame are J = 22.0, H = 21.2, and Ks = 21.3 mag, while those for the sky frame are J = 22.2, H = 21.2, and Ks = 21.0 mag (see Table 3). The comparable limiting magnitudes for the sky frame to those for the S127 frame despite the shorter exposure times are probably due to the nebulosity of S127.

Bright stars with magnitudes of J ≤ 17, H ≤ 15.5, and Ks ≤ 15 mag are saturated in long-exposure images. For the photometry of such bright stars, the short-exposure images are used. The photometry was performed with the same procedure as for long-exposure images but using a PSF fit radii of 7 pixels, which is the PSF FWHM value, and setting the inner radii and width of the sky annulus to four and three times as large as the PSF fit radii, respectively. For the photometric calibration, stars whose magnitudes can be estimated in both short- and long-
exposure images with small uncertainties (magnitudes of $J < 18.5$, $H < 17$, and $K_S < 17$ mag, and magnitude uncertainties of $<0.05$ mag) were used. For our analysis, we preferentially adopt infrared luminosities from photometry with long-exposure images because they have higher sensitivities and angular resolution. Very bright stars with magnitudes of $J \lesssim 13$, $H \lesssim 14$, and $K_S \lesssim 12.5$ mag are saturated even in short-exposure images in both the S127 and sky frames.

4. TWO YOUNG EMBEDDED CLUSTERS IN S127

4.1. Identification of Young Clusters in S127

Using the pseudocolor image (Figure 3), enhancements of the stellar density compared to the surrounding area were identified in the center of the field observed with MOIRCS. The enhancements are located near the regions where the emission of WISE band 3 (12 $\mu$m) is very strong (Figure 1), which is often the case for young clusters (see Koenig et al. 2012).

We determined the contour map of stellar density in the frame by counting the number of stellar sources detected in the $K_S$ band that are included within circles within a 50 pixel ($\sim 6''$) radius. The circles are set all over the frame with 25 pixel steps. Because the stellar density is very high in the center of the frame, we derived the background level from outside of the cluster area, shown with a cyan ellipse in Figure 4. The average number of stars in each of the circles is 13.8 $\pm$ 6.1. Figure 4 shows the distribution of detected sources in the MOIRCS $K_S$-band image with contour levels of $3\sigma$, $4\sigma$, ..., $20\sigma$. From the map, there are two large components that are located in the north and south of the IRAS source. The peak coordinates are $\alpha_{2000} = 21^h28^m43.9^s$, $\delta_{2000} = +54^\circ37'21''$ and $\alpha_{2000} = 21^h28^m40.2^s$, $\delta_{2000} = +54^\circ36'29''$ with an accuracy of $\sim10''$. Both stellar enhancement peaks are located very close to the peaks of the NVSS radio sources, shown with blue diamonds, and the distributions of the clusters are consistent with the distribution of H II regions observed by Rudolph et al. (1996) for both S127A and S127B (Section 2.2). The obscurations by molecular complex, pointed out by Brand et al. (2001), were seen in the northern half of the S127A cluster and the west of the S127B cluster. We defined the cluster regions, enclosed with green polygons in the figure, as regions with stellar densities $3\sigma$ larger compared to that of the entire frame. The sizes of the two clusters are $\sim1.2 \times 0.8$ and $\sim0.8 \times 0.6$ for S127A and S127B, respectively. The size of the region including both clusters is $\sim2' \times 1'$, which is consistent with the cluster size of angular dimensions of $1.9 \times 1.1$ estimated in Bica et al. (2003) with 2MASS data. The size corresponds to $\sim6 \times 3$ pc with a distance of $D = 10$ kpc. We used the full sky frame as a control field. The control field is used for subtracting the contamination of field objects in the following discussion.

4.2. Color–Magnitude Diagram

For our S127 measurements, we followed the same investigation process as described in Paper II for S208. Figure 5 shows the $J - K_S$ versus $K_S$ color–magnitude diagrams for all detected point sources in the S127A (left panel) and S127B (right panel) cluster regions. We also plotted detected point sources in the control field in Figure 6. The isochrone models for the ages of 1 Myr are shown as blue lines. The models are by Lejeune & Schaerer (2001) for the mass of $M/M_\odot \geq 7$, Siess et al. (2000) for the mass of $3 < M/M_\odot \leq 7$, and D'Antona & Mazzitelli (1997, 1998) for the mass of $0.017 \leq M/M_\odot \leq 3$, and a distance of 10 kpc is assumed. Arrows show the reddening vector of $A_V = 5$ mag. In the color–magnitude diagram, the extinction $A_V$ of each star was estimated from the distance between its location and the $A_V = 0$ isochrone models along the reddening vector. Figure 7 shows the distributions of the extinction of stars in the cluster region (thick lines) and control field (thin lines) for the S127A and S127B clusters in the left and right panels, respectively. The distribution for the control field is normalized to match with the total area of the cluster regions. The resultant distribution for the control field shows a peak of $A_V = 1-3$ mag, and then the number count decreases with larger $A_V$, whereas that for the cluster region shows a peak at the much larger extinction of $A_V \sim 3-7$ and $3-4$ mag for the S127A and S127B clusters, respectively, and they continue up to $A_V \sim 20$ mag. This suggests that stars with $A_V \geq 3$ mag are concentrated in the cluster regions, while stars with $A_V < 3$ mag are widely distributed over the observed field. Therefore, based on the values of $A_V$, cluster members can be distinguished from contaminating noncluster stars that appear in the cluster region, as is the case with the S208 clusters (Paper II). The following criteria are applied to identify members of the S127 clusters: the stars (1) are distributed in the cluster regions and (2) have large $A_V$ excess compared with normal field stars (extinction of $A_V \geq 3$ mag). In Figure 5, the identified cluster members are shown by red dots, while all other sources in the cluster regions are shown by black dots. As a result, 413 and 338 sources ($N_{cl}$) are identified as S127A and S127B cluster members, respectively. The average $A_V$ value of the cluster members is estimated at $A_V = 8.3 \pm 4.1$ and $A_V = 6.3 \pm 2.8$ mag for the S127A and S127B clusters, respectively.

Considering the relatively large $R_g$ of the S127 clusters ($R_g = 13.5$ kpc), we can assume that the contamination of background stars is negligible and most of the field objects are foreground stars (the spatial density of background galaxies is negligible at our detection limits, $K = 21.3$ mag). To quantify the contamination, we compared the $A_V$ distributions of all the sources in the cluster regions and the field objects in the control field (Figure 7). Because the number of field objects in the control field decreases significantly at $A_V \geq 3$ mag, most cluster members can be distinguished from the field objects as red sources with $A_V \geq 3$ mag. The contamination by the foreground stars is estimated at 7% and 5% for the S127A and S127B cluster, respectively, by counting the normalized number of field objects in the tail of the distribution at $A_V \geq 3$ mag and dividing it with the total number of sources in the cluster regions. In contrast, there must be some cluster members at $A_V < 3$ mag that missed our identification. The fraction of cluster members missed is estimated by $(N_{cl}' - N_{cl})/(N_{cl} + (N_{cl}' - N_{cl}'))$, where $N_{cl}'$ is the normalized number of field objects with $A_V < 3$ mag, $N_{cl}$ is the number of stars in the cluster region with $A_V < 3$ mag that do not meet the classification threshold, and $N_{cl}'$ is the number of identified cluster members. The fractions of cluster members missed for the S127A and S127B clusters are estimated at 3% and
11 %, respectively.

On the isochrone models in Figure 5, the positions of 0.1, 1, 3, 5, 10, 20, 40, and 60 $M_\odot$ are shown with horizontal lines. With the average $A_V$ for all S127 cluster members of $\sim 7$ mag, the $K$-band limiting magnitude of 21.3 mag (10σ) for an age of 1 Myr corresponds to a mass of 0.2 $M_\odot$ assuming a distance of $D = 10$ kpc. The mass detection limit is sufficiently low, close to the substellar mass limit, which enables KLF fitting to derive parameters describing the IMF down to around the IMF peak (Section 5.2) and to derive the disk fraction with the same criteria as in the solar neighborhood (Section 5.3). Because the most likely age of the S127 cluster is estimated at $\sim 0.5$ Myr in Section 5.2, the mass detection limit is actually $\sim 0.2$ $M_\odot$ with the average $A_V$ of $\sim 7$ mag for all S127 cluster members.

4.3. Color–Color diagram

We constructed $J - H$ versus $H - K$ color–color diagrams for stars in the S127 cluster regions (Figure 8). Cluster members identified in Section 4.2 are shown in red, while sources in the cluster regions but not identified as cluster members are shown in black. We also constructed the color–color diagram for stars in the control field (Figure 9). All sources that are detected at more than 10σ in all $JHK$ bands are plotted. The dwarf star track for spectral types from late B to M6 in the MKO system by Yasui et al. (2008b) is shown with the blue curve. The classical T Tauri star (CTTS) locus, originally derived by Meyer et al. (1997) in the CIT system, is shown as a cyan line in the MKO system (Yasui et al. 2008b). The arrow shows the reddening vector of $A_V = 5$ mag.

Stars in star-forming regions sometimes show large $H - K$ color excesses due to their circumstellar dust disks, in addition to large extinctions (e.g., Lada & Adams 1992). We estimated the color excesses for each source using the procedure described in Papers I and II. First, the intrinsic ($H - K$) colors ($H - K)_0$ were estimated by dereddening along the reddening vector to the young star locus in the color–color diagram (see Figure 8), which was approximated by the extension of the CTTS locus. Only stars that are above the CTTS locus were used. The obtained ($H - K)_0$ distributions for the S127 cluster members and those in the control field are shown in Figure 10. After normalizing the distribution for the control field to the total area of the cluster regions, there is a larger number of red stars with $(H - K)_0 > 0.2$ mag in the distribution of the cluster members compared to those in the control field. The average $(H - K)_0$ values for cluster members are estimated at 0.39 mag for both the S127A and S127B clusters, whereas that in the control field is estimated at 0.14 mag. The difference in the average $(H - K)_0$ between the stars in the cluster regions and the field stars (±0.25 mag) can be attributed to thermal emissions from the circumstellar disks of the cluster members. Therefore, we estimated the disk color excess of the S127 cluster members in the $K$ band, $\Delta K_{\text{disk}}$, as 0.25 mag, assuming that disk emissions appear in the $K$ but not in the $H$ band.

4.4. KLF of the S127 clusters

The KLF for the S127 cluster members is shown in Figure 11 as a black line up to the $K = 20.5$ mag bin. The number counts of the KLFs are relatively constant from $K = 13.5$ and 12.5 mag for the S127A and S127B clusters, respectively, and then increase toward the fainter magnitude bins, with peaks of $K = 18.5$ mag for both clusters, and then they decrease. Although the general characteristics are the same for both clusters, the slope in the brighter magnitudes for S127A is steeper than that for the S127B cluster. Because the 10σ detection magnitude for the S127 frame is $K = 21.3$ mag, detection completeness should be $\sim 1$ in all magnitude bins (Section 3.2; see also Yasui et al. 2008b and Minowa et al. 2005); therefore, the peak of the S127 KLFs at $K = 18.5$ mag would not change.

Because of the large $A_V$ dispersion of the S127 clusters ($A_V \sim 3 - 20$ mag), detection of faint cluster members may be difficult, which could be the cause for the decrease of the KLF in fainter magnitude bins. For comparison, we also constructed KLFs for stars with limited $A_V$ values in Figure 11. $A_V = 4.2$–12.4 and 3.5–9.1 mag (from the $A_V$ distribution of the cluster members, 8.3 ± 4.1 and 6.3 ± 2.8 mag for the S127A and S127B clusters, respectively; Section 4.2), which are shown with gray lines. For clarity, the KLFs for limited $A_V$ samples are vertically shifted by +0.1 mag for both clusters. As a result, the discrepancy between the KLFs for all cluster members and those for stars with limited $A_V$ values is found to be within the uncertainty range, suggesting that the selection of stars with different limited $A_V$ values causes a negligible influence on the obtained KLF. Therefore, we used the original KLF (the KLF from all S127 cluster members) in the following discussion.

5. DISCUSSION

5.1. Scale of the clusters

Adams et al. (2006) found a clear correlation between cluster size and the number of cluster members for young clusters in the solar neighborhood from their embedded stage up to ages of $\sim 10$ Myr. Figure 12 shows the number of stars in a cluster versus cluster radius by open squares from the compilation of clusters in Lada & Lada (2003) and Carpenter (2000). The figure shows that most clusters have $\sim 10$–500 cluster members ($N_{\text{stars}}$) and radii ($R$) of $\sim 0.2$–2 pc. Adams et al. (2006) pointed out that the data can be fit by a relation of the form $R(N_{\text{stars}}) = R_{300}\sqrt{N_{\text{stars}}}/100$ with $R_{300} = \sqrt{3}$ pc shown in Figure 12 with a solid line, and most data points are scattered within a factor of $\sqrt{3}$ of $R_{300}$, shown with dotted lines.

In Section 4, we identified two clusters in S127, the S127A and S127B clusters. The S127A cluster has 413 cluster members in a region of $\sim 12' \times 0.8'$, corresponding to a cluster radius of $\sim 0.6'$, while the S127B cluster has 338 cluster members in $\sim 0.8' \times 0.6'$, corresponding to a cluster radius of $\sim 0.4'$. Because $1'$ corresponds to 3 pc at the $10$ kpc distance of S127, the cluster radii of the S127A and S127B clusters correspond to 1.8 and 1.2 pc, respectively. We plot the values in Figure 12 with red filled circles. The plots show that the density of the S127B cluster is a little higher than that of the S127A cluster. Both clusters have both $R$ and $N_{\text{stars}}$ that are within the range found for clusters in the solar neighborhood but at the upper end of that range.

We also plotted properties for other young low-
metallicity clusters (Section 1) with red open circles: S207, S208, and the Cloud 2-N and -S clusters (Papers I, II; Yasui et al. 2008b). They are relatively small clusters with $N_{\text{stars}}$ of less than 100, even though the mass detection limits are similar to the limit for S127 of $\lesssim 0.2 M_\odot$. The $N_{\text{stars}}$ is 73, 89, 52, and 59 for S207, S208, Cloud 2-N, and Cloud 2-S, respectively, while the detection limits are $\lesssim 0.2 M_\odot$ for S207, $\sim 0.2 M_\odot$ for S208, and $\sim 0.1 M_\odot$ for Cloud 2-N and -S. The cluster radii for all clusters are $\sim 1$ pc: 1.3, 0.6, 1.4, and 0.6 pc for the S207, S208, Cloud 2-N, and Cloud 2-S clusters, respectively. The radii ($R$) of the S127 clusters are comparable to the radii of those clusters. However, the numbers of cluster members ($N_{\text{stars}}$) of the S127 clusters are larger by about an order of magnitude, compared to other young low-metallicity clusters.

In the following sections, we estimate the underlying IMF and disk fractions of the S127 clusters. Because the S127 clusters are the first large-scale targets in low-metallicity environments detected down to the substellar mass regime, they are very appropriate targets to examine whether results from previous young low-metallicity clusters hold even in such large clusters. If distinguished between metallicity dependence and dependence on cluster scales (size and number of members), genuine metallicity dependencies can be derived. In fact, the possibility that the IMF and disk fraction depend on cluster scales is suggested for clusters in the solar neighborhood, i.e. a dependence on cluster mass and cluster density (see Sections 5.2 and 5.3). The S127 clusters are also useful for examining whether suggested dependencies on cluster scales seen for clusters in the solar neighborhood hold for clusters in low-metallicity environments.

5.2. Implication for the IMF and age

Although our final goal is to derive the IMF in low-metallicity environments, information about the age of the cluster is necessary for the derivation. Here we estimate ages by assuming the canonical IMF observed in the solar neighborhood as a first step, examine the adequacy of the estimated age, and finally develop constraints on the underlying IMF. We performed fitting of the KLF, which is known to strongly depend on age and IMF, in the same way as Papers I and II. We note that we use observed KLFs in Section 4.4 for the fitting. Although it would be ideal if all of the detected sources were corrected for extinctions derived in Section 4.2, this cannot be possible because not all stars are detected at more than one band, and at least two bands of data are necessary for the derivation. Moreover, especially for clusters with large extinctions, such as S208, the longer NIR wavelength can detect lower mass stars due to the smaller influence of extinctions, and that observed KLF is most appropriate for deriving the IMF only from photometric data (Muench et al. 2002). Therefore, we consider $A_V$ and $\Delta K_{\text{excess}}$ values by inputting them into model KLFs instead. The method was originally developed in Muench et al. (2002) and simplified in Yasui et al. (2006). We constructed model KLFs with ages from 0.1 to 3 Myr, which are shown with colored lines in Figure 13. A distance of 10 kpc is assumed, and $A_V$ and $\Delta K_{\text{excess}}$, which are estimated in Sections 4.2 and 4.3, are applied ($A_V = 8.3$ and 6.3 mag for the S127A and S127B clusters, respectively, and $\Delta K_{\text{excess}} = 0.25$ mag). The model KLF for 0.1 Myr has a shallower slope of bright magnitudes before the peak than the KLF for 0.5 Myr. The KLFs for 0.1–0.5 Myr have brighter peak magnitudes ($K = 18.5$ mag) than the KLFs for older ages ($K = 19.5$ mag bin for 1 Myr and $K = 20.5$ mag bin for 2–3 Myr).

The observed KLF for the S127A cluster is best fit with a model KLF for an age of 0.5 Myr in terms of the slope for bright magnitudes and the peak magnitude ($K = 18.5$ mag bin), although the brightest observed magnitude ($K = 13.5$ mag bin) is a little off the model. In contrast, for the S127B cluster, the slope of the observed KLF for bright magnitudes is between that of the model KLFs for ages of 0.1 and 0.5 Myr, while the peak magnitude of the observed KLF matches those two model KLFs. After comparing with the KLF models, the ages of the S127A and S127B clusters are estimated to be $\sim 0.5$ and 0.1–0.5 Myr, respectively.

The very young ages are consistent with the large $A_V$ values for S127A and S127B cluster members estimated in Section 4.2, up to $\sim 20$ mag with $A_V$ distributions of the cluster members of $8.3 \pm 4.1$ mag for S127A and $6.3 \pm 2.8$ mag for S127B. Brand et al. (2001) reported that the column density of $^{12}$CO at the peak position in S127B corresponds to $A_V \approx 8$ mag, which is indeed consistent with our estimated values. The distribution in the CO map by Brand et al. (2001; see their Figure 3(d)) shows that the majority of the S127A cluster is embedded in molecular clouds. Because the molecular gas disperses on a timescale of $\sim 3$ Myr (Hartmann et al. 2001), being fully embedded is consistent with the very young age of the S127A cluster. Although the S127B cluster is not fully embedded, it is located in a compact H II region (Section 2.2). Compact H II regions are thought to be a very early phase of H II regions, the next stage after the ultracompact H II phase (Habing & Israel 1979). Because the lifetime of ultracompact H II regions is estimated to be $\lesssim 0.1$ Myr (Hoare et al. 2007) and that of compact H II regions is estimated to be $\sim 0.3$ Myr (Mottram et al. 2011), the estimated age of the S127B cluster is consistent with these estimates. The estimated age of the S127A cluster, which is located in a slightly extended H II region with a diameter of 1.7 pc, is older than the estimated age of the S127B cluster located in a compact H II region with a diameter of 0.5 pc. This is consistent with older H II regions having larger radii (Dyson & Williams 1980). In addition, this is consistent with the results for S207 and S208 in Papers I and II: the age of the S207 cluster located in an H II region with a diameter of 2.6 pc is estimated to be $\sim 2–3$ Myr, while that of the S208 cluster located in an H II region with a diameter of 1.4 pc is estimated to be $\sim 0.5$ Myr.

From the KLF fitting using the typical IMF obtained in clusters with solar metallicity, the S127 clusters are estimated to be very young ($\sim 0.5$ Myr). The estimated age is consistent with the independent indications based on the very high H$_2$ column density and the size of the H II regions. This suggests that the IMF of the S127 clusters, which are in a low-metallicity environment, is consistent with the typical IMF in solar metallicity regions for masses $\gtrsim 0.2 M_\odot$. Because the KLF slope for bright stellar magnitudes before the peak strongly depends on the slope of the higher-mass region of the IMF (Muench et al. 2000, 2002), the very good fit to the KLF...
peak also suggests that the higher-mass IMF slope in the S127 clusters is consistent with the typical IMF. As for the KLF peaks, their magnitudes of $K = 18.5$ mag for an age of 0.5 Myr correspond to a stellar mass of $\sim 0.5 \, M_\odot$. This is also consistent with the canonical IMF within the margin of error, $\log M/e/M_\odot \sim 0.5 \pm 0.5$ (Elmegreen et al. 2008). This is also the case for previous studies of low-metallicity young clusters, S207, S208, Cloud 2-N, and Cloud 2-S (Paper I, II; Yasui et al. 2008b; see also Yasui et al. 2008a, Yasui et al. 2017). Even with the similar mass detection limit for S127, these other clusters are very small, with less than 100 cluster members, while the S127 clusters have about an order of magnitude higher numbers of cluster members, $\sim 300$–400 (Section 5.1).

Note that in the case that detection is sufficiently deep, e.g., down to the substellar mass regime ($\sim 0.1 \, M_\odot$), the cluster mass is roughly estimated on the very simple assumption that all stars have a mass of $1 \, M_\odot$ (e.g., Yasui et al. 2008b). With this assumption, the cluster masses of the S127 clusters are estimated as $\sim 300$–400 $M_\odot$, while those for the other young low-metallicity clusters are $<100 \, M_\odot$. Here we suggested that the IMFs for clusters with low-metallicity environments are consistent with the typical IMFs observed in clusters with solar metallicity regardless of the mass between $<100$ and $\sim 400 \, M_\odot$. This is in the same manner as for clusters with solar metallicity environments; there seem to be no clear indications that the IMF for clusters with $<10^5 \, M_\odot$ depends on their cluster scale, while the possibility has been pointed out that the IMF for starburst clusters, with $>10^5 \, M_\odot$, can change from the typical IMF (Bastian et al. 2010).

5.3. Disk Fraction

The disk fraction is the fraction of cluster member stars with protoplanetary disks out of all cluster members. It is often used for estimating disk lifetime, which is thought to be directly connected to the duration of planet formation (Haisch et al. 2001; Lada & Lada 2003). Disk lifetime is estimated using the age–disk fraction plot for various star-forming clusters (Figure 14; Lada 1999, Hillenbrand 2005). In Figure 14, we plot data for clusters in the solar neighborhood as black squares (Yasui et al. 2009, 2010). The fit shown with a black curve is from Yasui et al. (2014). Disk fractions derived with NIR JHK-band observations show very high values for very young clusters ($\sim 60 \%$) that decrease with increasing age. The disk lifetime is often defined as the time when the disk fraction reaches $\sim 5$–10%. Although NIR disk fractions are generally slightly lower than MIR disk fractions (Haisch et al. 2000) derived from ground based L-band observations and space MIR observations, the characteristics are quite similar (Lada 1999, Yasui et al. 2009; see the red line in the right panel of Figure 5 in Yasui et al. 2014).

We estimated the disk fraction for the S127 clusters using the NIR color–color diagram (Figure 8) and the same method as described in our previous papers. In Figure 8, we used the dotted–dashed line parallel to the reddening vector that passes through the point at the end of the dwarf main-sequence star curve (blue line) at the point where the $H - K_S$ value for the curve is maximum (the M6 point on the curve) as the border between stars with and without circumstellar disks (see details in Yasui et al. 2009). Assuming that disk emission is only evident in the $K$ band, we classed stars on the lower right side of the borderline as disk excess sources and calculated the ratio of the number of cluster members with disk excesses to that of all cluster members. As a result, disk fractions for the S127A and S127B clusters are estimated to be $28\% \pm 3\%$ (108/391) and $40\% \pm 4\%$ (128/318), respectively. We plotted the disk fractions for the S127 clusters against their ages estimated in Section 5.2 in Figure 14 with red filled circles with error bars. Because the disk fractions are generally high in younger clusters, the higher disk fraction for the S127B cluster than the S127A cluster is consistent with the age estimates in Section 5.2, where the S127B cluster is younger than the S127A cluster.

In Figure 15, we show the fraction of stars ($f_{stars}$) in each intrinsic ($H - K$) color bin ($H - K$) for the S127A cluster in red and the S127B cluster in blue (also shown as black lines in Figure 10), as well as those for other young clusters in low-metallicity environments: S207 (thick solid line), S208 (thin solid line), Cloud 2-N (dashed line), and Cloud 2-S (dotted line). The vertical dashed line represents the border for estimating the disk fraction in the MKO system, i.e. the dotted–dashed line in Figure 8. The distribution becomes bluer and sharper with lower disk fractions for nearby young clusters (see the bottom panel of Figure 7 in Yasui et al. 2009), which is also the case for clusters in low-metallicity environments (Yasui et al. 2009). The peak ($H - K$) of the S127 cluster is relatively red, ($H - K$) $\sim 0.4$ mag, and the distribution is relatively broad, with a maximum ($H - K$) of $\sim 1.5$ mag. The distributions of the S127 clusters resemble those of the S208 and Cloud 2-S clusters with disk fractions of $\sim 30\%$ rather than those of the S207 and Cloud 2-N clusters with disk fractions of $<10\%$. This suggests that the distributions of the S127 clusters are consistent with the estimated disk fraction.

Considering the very young age of the S127 clusters, $\sim 0.5$ Myr, their disk fraction is significantly lower than that for clusters in the solar neighborhood with the same age ($\sim 50$–60%). This is the case for other young clusters in low-metallicity environments, the S207, S208, and Cloud 2-N and -S clusters, which are shown with red open circles in Figure 14. The data are from Paper I, Paper II, and Yasui et al. (2009), and we also plot data for the S209 clusters in Yasui et al. (2010). We also show the fit for the clusters with a red curve, which is obtained using the same procedure as for clusters in the solar neighborhood (Yasui et al. 2014), assuming the same initial disk fraction at $t = 0$ as for clusters in the solar neighborhood of 64%. Yasui et al. (2010) pointed out the tendency for low-metallicity clusters to have lower disk fractions than solar metallicity clusters for a given age and suggested that the disk lifetime in low-metallicity environments is quite short, as discussed in Yasui et al. (2009). However, note that the estimated disk fraction for the S127B cluster is higher than those for other low-metallicity clusters. It may be possible that the disk fraction for the S127B cluster is elevated due to factors other than metallicity and young age (e.g., position in the Galaxy, cluster scale, etc.). However, the disk fraction for the S127A cluster is comparable to those for clusters with the same age, S208 and Cloud 2-S, despite the fact that S127A is in the same location in the Galaxy as S127B and both have identical cluster scales. Therefore, the high value of the
disk fraction for the S127B cluster is probably due to the very young age, between 0.1 and 0.5 Myr, which is the youngest among the low-metallicity cluster sample. The results that quite young clusters in low-metallicity environments have relatively high disk fractions, although disk fractions of only ≲ 30% had been obtained for the clusters previously observed, suggest that a large fraction of stars have disks even in low-metallicity environments in the very early phases and that they lose their disks on a very short timescale.

In the solar neighborhood, it is suggested that disk fraction, and thus disk lifetime, depends on cluster scales, such as cluster mass and stellar density (e.g., Fang et al. 2013; Stolte et al. 2010). Fang et al. (2013) suggested that the disks in sparse stellar associations are dissipated more slowly than those in denser (cluster) environments, while Stolte et al. (2010) suggested that disk depletion is significantly more rapid in compact starburst clusters than in moderate star-forming environments. In the previous studies of young clusters in low-metallicity environments, observed clusters are relatively small, with numbers of identified cluster members of less than 100, while the S127 clusters have ~300–400 cluster members, as discussed in Section 5.1. Although both cluster scales are common in the solar neighborhood, the S127 clusters are the largest clusters in their class. The result that the disk fractions for the S127 clusters, with their larger number of cluster members, are lower than those clusters in the solar neighborhood with similar ages, which is also the case for smaller clusters, suggests that a lower disk fraction for a given age is a characteristic of clusters in low-metallicity environments. However, because the number of low-metallicity clusters studied is small, it is necessary to study more star-forming clusters in low-metallicity environments and cover a range of cluster scales, e.g., cluster mass and age.

Finally, it should be noted that class I protostar candidates, which were seen in the S208 clusters, are also seen in the S127 clusters: nine sources in S127A and three sources in S127B. The candidates are selected here using the same method as in Paper II, i.e. sources having large $J − K$ colors of larger than 3 (equal to the sum of $J − H$ (y-axis) and $H − K$ (x-axis) colors) on the NIR color–color diagram. This suggests that young stellar objects in low-metallicity environments are initially surrounded by thick circumstellar materials, as is the case for the solar neighborhood, but they disperse very quickly, as also discussed in Paper II. This also supports that the very young age estimated for S127 in Section 5.2 (0.5 Myr) is reasonable, considering the estimated age of S208 is also estimated as ~0.5 Myr.

This work was supported by JSPS KAKENHI grant No. 26800094. We thank the Subaru support staff, in particular MOIRCS support astronomer Ichi Tanaka. We also thank Chihiro Tokoku for helpful discussions on the observation.

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TABLE 1
Properties of S127.

| Name                  | S127          |
|-----------------------|---------------|
| Galactic longitude (deg) | 96.287 (1)    |
| Galactic latitude (deg) | +2.594 (1)    |
| R.A. (J2000.0)         | 21 28 41.6 (1)|
| Decl. (J2000.0)        | +54 37 00 (1) |
| Photometric heliocentric distance (kpc) | 9.7 (2) |
| Kinematic heliocentric distance (kpc) | 9.97 (3) |
| Adopted distance (kpc) | ≥10           |
| Galactocentric distance (kpc) | ≥13.5       |
| Oxygen abundance 12 + log (O/H) | 8.10±0.12 (4, 5), 8.20±0.15 (5, 6), 8.20±0.17 (5, 7), 7.68±0.17 (5, 8) |
| Metallicity [O/H] (dex) | ~0.7         |
| Electron temperature (K) | 10500±820 (9), 11428±305 (10) |

Notes. References are shown in parentheses.

a Assuming a solar Galactocentric distance of R⊙ = 8.0 kpc.
b Assuming a solar abundance of 12 + log (O/H) = 8.73 (Asplund et al. 2009).

References. (1) SIMBAD (Wenger et al. 2000), (2) Chini & Wink (1984), (3) Foster & Brunt (2015), (4) Vilchez & Esteban (1996), (5) Rudolph et al. (2006), (6) Rudolph et al. (1997), (7) Caplan et al. (2000), (8) Peeters et al. (2002), (9) Scaife et al. (2008), (10) Balser et al. (2011).
TABLE 2
SUMMARY OF MOIRCS OBSERVATIONS.

| Modes    | Date       | Band | \( t_{\text{total}} \) | \( t \) | Coadds | \( N_{\text{total}} \) | Seeing | Sky Condition |
|----------|------------|------|--------------------------|--------|--------|----------------|--------|---------------|
| J-long   | 2006 Sep 2 | J    | 1250                     | 150    | 1      | 9 (4)         | \( 0'4 \) | P             |
| H-long   | 2006 Sep 2 | H    | 1080                     | 20     | 6      | 9 (4)         | \( 0'4 \) | P             |
| K\(_S\)-long | 2006 Sep 2 | K\(_S\) | 1080                   | 30     | 4      | 9 (4)         | \( 0'4 \) | P             |
| J-short  | 2007 Nov 22| J    | 52                      | 13     | 1      | 4 (3)         | \( 0'8 \) | H             |
| H-short  | 2007 Nov 22| H    | 52                      | 13     | 1      | 4 (3)         | \( 0'8 \) | H             |
| K\(_S\)-short | 2007 Nov 22 | K\(_S\) | 52                    | 13     | 1      | 4 (3)         | \( 0'8 \) | H             |

Notes. Column (4): total exposure time (s). Column (5): single-exposure time (s). Column (6): number of coadds. Column (7): total number of frames. Column (9): P: photometric, and H: high humidity. The values for the sky frames are shown in parentheses.

TABLE 3
LIMITING MAGNITUDES (10\(\sigma\)) OF LONG-EXPOSURE IMAGES FOR MOIRCS OBSERVATIONS.

| Frame | \( J \) Band | \( H \) Band | \( K_S \) Band |
|-------|---------------|---------------|---------------|
| Cluster | 22.0          | 21.2          | 21.3          |
| Sky    | 22.2          | 21.2          | 21.0          |
Fig. 1.— Pseudocolor (top) and Hα (bottom) images of S127 with a wide field of view of 5′ × 5′ centered at (α2000.0, δ2000.0) = (21h28m42s, +54°36′51″) in equatorial coordinates and (l, b) = (96.286°, +2.592°) in Galactic coordinates, which is the coordinate of IRAS 21270+5423. North is up, and east is to the left. The 1′ corresponds to 2.9 pc for the distances of S127. Top: the image is produced by combining the 2MASS Ks-band (2.16 μm; blue), WISE band 1 (3.4 μm; green), and WISE band 3 (12 μm; red). The large red plus sign shows the IRAS point source, while the small red plus sign shows the bright stars in the optical bands, ALS 18695. The white box shows the location and size of the MOIRCS field of view. Bottom: IPHAS Hα image of S127 shown in gray scale. The 1.4 GHz radio continuum emission by NVSS is also shown with blue contours. The contours are plotted at 1 mJy beam−1 × 20, 2−1/2, 21, ... . The blue diamonds show the NVSS radio point sources, NVSS 212841+543634 and NVSS 212843+543728. The red plus symbols are the same as those in the top panel, while the black box is the same as the white box in the top panel.
Fig. 2.— Top view of the Milky Way galaxy, showing S127 in relation to the spiral arms. The filled circle shows S127 at a distance of $D = 9.97 \pm 1.73$ kpc (Foster & Brunt 2015) from the sun. The Sun is shown at a Galactocentric distance of 8 kpc by a circled dot. Spiral arms from Vallée (2005) are shown with different colors (red, yellow, green, and cyan for the Norma-Cygnus, Perseus, Sagittarius-Carina, and Scutum-Crux arms, respectively).
Fig. 3.— Pseudocolor image of S127 produced by combining the $J$- (1.26 μm), $H$- (1.64 μm), and $K_S$-band (2.15 μm) MOIRCS images from 2006 September. The equatorial coordinates of the center of the image are $\alpha_{2000} = 21^h28^m41.2^s$, $\delta_{2000} = +54^\circ37'16.2''$. The field of view of $\sim3.5' \times 4'$ is shown with white and black boxes in Figure 1, and the symbols are the same as in Figure 1.
Fig. 4.— Stellar density of detected sources in the MOIRCS $K_S$-band image is shown with yellow contours, superposed on the MOIRCS $K_S$-band image, whose field of view is the same as Figure 3. The contour levels represent stellar densities of $3\sigma$, $4\sigma$, $5\sigma$, ..., and $20\sigma$ higher than the average stellar density in the field outside of the cyan ellipse. The green polygons show two identified star-forming clusters, S127A and S127B clusters.
Fig. 5.—\((J-K_s)\) vs. \(K_s\) color–magnitude diagram of the S127 clusters, the S127A (left) and S127B (right) cluster. Identified cluster members in the cluster region (\(A_V \geq 3\) mag) are shown with red dots, while other sources are shown with black dots. The arrow shows the reddening vector of \(A_V = 5\) mag. The dashed lines mark the limiting magnitudes (10\(\sigma\)). The black lines show the dwarf tracks by Bessell & Brett (1988) in spectral types O9–M6 (corresponding mass of \(\sim 0.1–20\ M_\odot\)). The blue lines denote the isochrone models for the age of 1 Myr by D’Antona & Mazzitelli (1997, 1998; \(0.017 \leq M/M_\odot \leq 3\), Siess et al. (2000; \(3 < M/M_\odot \leq 7\), Lejeune & Schaerer (2001; \(M/M_\odot \geq 7\). The thick and thin lines show the isochrone models assuming \(A_V = 0\) and 3 mag, respectively. A distance of 10 kpc is assumed. The short horizontal lines are placed on the isochrone models and shown with the same colors as the isochrone tracks, which show the positions of 0.1, 1, 3, 5, 10, 20, 40, and 60 \(M_\odot\).

Fig. 6.—Same as Figure 5 but for the control field.
Fig. 7. — $A_V$ distributions for the sources in the S127 clusters (thick lines) and those in the control field (thin lines). Left and right panels show the S127A and S127B clusters, respectively. The distributions for the control field are normalized to match the area of each cluster region.

Fig. 8. — $(H - K_S)$ vs. $(J - H)$ color–color diagram of S127. Identified cluster members are shown in red, while sources in the cluster region but not identified as cluster members are shown in black. The blue curve in the lower left portion is the locus of points corresponding to the unreddened main-sequence stars. The dotted–dashed line, which intersects the main-sequence curve at the maximum $H - K_S$ values (M6 point on the curve) and is parallel to the reddening vector, is the border between stars with and without circumstellar disks. The CTTS locus is shown with the cyan line.
Fig. 9.— Same as Figure 8 but for the control field.

Fig. 10.— \((H - K)_0\) distributions for the S127 cluster members (thick line) and stars in the control field (thin line). Left and right panels show the S127A and S127B clusters, respectively. The distribution for the control field is normalized to match the total area of the cluster region. The vertical black and gray dashed lines show average \((H - K)_0\) values for the S127 cluster members and stars in the control field, respectively.
Fig. 11.— Raw KLFs for the S127A cluster members (left) and S127B (right). The KLF for all cluster members with $A_V \geq 3$ mag is shown. Error bars are the uncertainties from Poisson statistics. The KLFs for limited $A_V$ samples are shown by gray lines for cluster members with $A_V$ of 4.2–12.4 and $A_V$ of 3.5–9.1 mag for S127A and S127B, respectively (see text for more detail). For clarity, the KLFs for limited $A_V$ samples are vertically shifted by +0.1 for both clusters. The vertical dotted–dashed line shows the limiting magnitudes of the 10σ detection (21.3 mag).

Fig. 12.— Correlation between the number of stars in a cluster ($N_{\text{stars}}$) and the radius of the cluster ($R$). The red filled circles show S127 clusters, while red open circles show other young low-metallicity cluster samples: S207, S208, and Cloud 2-N and -S from other papers in our series. The open squares show clusters in the solar neighborhood whose data are from Lada & Lada (2003) and Carpenter (2000). The solid line shows a rough fit to the data for clusters in the solar neighborhood; most points are scattered within a factor of $\sqrt{3}$ of $R$, shown with dotted lines. The solid and dotted lines represent lines of constant cluster density.
Fig. 13.— Comparison of the S127 KLFs (black lines) with model KLFs of various ages (colored lines). Error bars are the uncertainties from Poisson statistics. The cyan, red, blue, magenta, and green lines represent model KLFs of 0.1, 0.5, 1, 2, and 3 Myr, respectively. The vertical dotted–dashed lines show the limiting magnitudes of the 10σ detection (18.5 mag).

Fig. 14.— Disk fraction as a function of cluster age. $JHK$ disk fractions of the young clusters in low-metallicity environments are shown with red circles. The S127 clusters are shown with red filled circles, while other clusters are shown with red open circles. $JHK$ disk fractions of young clusters with solar metallicity are shown by black filled squares. The black and red lines show the disk fraction evolution under solar metallicity and in low-metallicity environments, respectively.
Fig. 15.— Comparison of intrinsic $H - K$ color distributions. The fractions of stars ($f_{\text{stars}}$) per each intrinsic color bin $(H - K)_0$ for clusters in low-metallicity environments, S208, S207, Cloud 2-N, and Cloud 2-S, are plotted. The vertical dashed line shows the borderline for estimating the disk fraction in the MKO system.