A HUBBLE SPACE TELESCOPE VIEW OF THE INTERSTELLAR ENVIRONMENTS OF YOUNG STELLAR OBJECTS IN THE LARGE MAGELLANIC CLOUD

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ABSTRACT

We have used archival Hubble Space Telescope (HST) Hα images to study the immediate environments of massive and intermediate-mass young stellar objects (YSOs) in the Large Magellanic Cloud (LMC). The sample of YSO candidates, taken from Gruendl & Chu, was selected based on Spitzer IRAC and MIPS observations of the entire LMC and complementary ground-based optical and near-infrared observations. We found HST Hα images for 99 YSO candidates in the LMC, of which 82 appear to be genuine YSOs. More than 95% of the YSOs are found to be associated with molecular clouds. YSOs are seen in three different kinds of environments in the Hα images: in dark clouds, inside or on the tip of bright-rimmed dust pillars, and in small H II regions. Comparisons of spectral energy distributions for YSOs in these three different kinds of environments suggest that YSOs in dark clouds are the youngest, YSOs with small H II regions are the most evolved, and YSOs in bright-rimmed dust pillars span a range of intermediate evolutionary stages. This rough evolutionary sequence is substantiated by the presence of silicate absorption features in the Spitzer Infrared Spectrograph spectra of some YSOs in dark clouds and in bright-rimmed dust pillars, but not those of YSOs in small H II regions. We present a discussion on triggered star formation for YSOs in bright-rimmed dust pillars or in dark clouds adjacent to H II regions. As many as 50% of the YSOs are resolved into multiple sources in high-resolution HST images. This illustrates the importance of using high-resolution images to probe the true nature and physical properties of YSOs in the LMC.

Key words: H II regions – Magellanic Clouds – stars: formation

Online-only material: color figure, extended figure

1. INTRODUCTION

The Spitzer Space Telescope, with its high angular resolution and sensitivity at mid-infrared wavelengths, has made it possible for the first time to survey massive young stellar objects (YSOs) in nearby external galaxies. In particular, in the Large Magellanic Cloud (LMC), because of its close proximity (50 kpc; Feast 1999) and low inclination (∼30°; Nikolaev et al. 2004), massive and intermediate-mass YSOs can be resolved by Spitzer and inventoried throughout the entire galaxy. The LMC was observed by Spitzer under a Legacy Program, Surveying the Agents of Galaxy Evolution (SAGE), that mapped the central 7° × 7° area of the galaxy (Meixner et al. 2006). Gruendl & Chu (2009) made use of the archival Spitzer data from the SAGE survey along with complementary ground-based optical and near-infrared observations and identified a comprehensive sample of massive and intermediate-mass YSO candidates of the entire LMC. This sample consists of a total 855 definite, 317 probable, and 213 possible massive (>10 M⊙) and intermediate-mass (>4 M⊙) YSO candidates. Most of these YSO candidates are found to be concentrated in or around molecular clouds or H II regions (Gruendl & Chu 2009).

While Spitzer enables the detection of individual massive and intermediate-mass YSOs in the LMC (e.g., Chu et al. 2005; Jones et al. 2005; Caulet et al. 2008; Whitney et al. 2008; Gruendl & Chu 2009), the angular resolution of Spitzer is not sufficient to resolve multiple sources within 1″−2″ or allow a close look at the environments of these massive YSOs. The Hubble Space Telescope (HST) on the other hand, with an angular resolution 10 times higher than that of Spitzer, reveals sub-arcsec size features and hence is very useful for a detailed examination of the environments of these massive YSOs.

We have therefore searched through the HST archive for continuum and Hα images that cover LMC YSO candidates from the above catalog. In many cases, the exposure times of the continuum images are short and hence not very useful, as noted by Chen et al. (2009). The Hα images have longer exposure times and are very useful in revealing interstellar environments of YSOs in H II complexes where the interstellar gas is photoionized by antecedent massive stars. For example, ionization fronts on the surface of dense molecular clouds can be recognized by the sharply enhanced Hα surface brightness. Hα images are also useful in revealing circumstellar environments of massive YSOs. For example, the UV flux of a YSO may photoionize its circumstellar medium and form a compact H II region, or outflows from a YSO may produce observable features like Herbig–Haro objects (Heydari-Malayeri et al. 1999; Chu et al. 2005). Thus, in this paper, we make use of primarily the HST Hα images to examine the immediate surroundings of the LMC YSO candidates. The continuum images are only used to supplement the analyses of stellar properties for a few YSOs.

The remaining paper is organized as follows: Section 2 describes the data sets used in this work and our method of analysis, Section 3 describes the environments of YSO candidates, Section 4 discusses the properties of small H II regions discovered around some massive YSO candidates, Section 5 describes the mid-infrared spectral characteristics of some YSO candidates, Section 6 discusses the spectral energy distributions (SEDs) of the YSO candidates, Section 7 presents a discussion on triggered star formation, and finally Section 8 summarizes the paper.

2. DATA SETS AND METHOD OF ANALYSIS

We searched the HST archive for Hα images observed with the Wide Field Planetary Camera 2 (WFPC2) and the Advanced
Camera for Surveys (ACS) for a field of ∼78 degree² centered on the LMC for Augusts (α = 05° 18′, δ = −68° 34′), available as of 2008 Augusts. WFPC2 consists of four cameras, PC1, WF2, WF3, and WF4, among which PC1 has a field-of-view of 36′ × 36′ with a scale of 0′′ 045 pixel⁻¹, and the remaining three cameras each have a field-of-view of 80′ × 80′ with a scale of 0′′ 1 pixel⁻¹ (McMaster et al. 2008). The ACS observations were made in the Wide Field Channel (WFC), which has a field-of-view of 202′′ × 202′′ with a scale of 0′′ 05 pixel⁻¹ (Boffi et al. 2007). The Hα filters F656N (λc = 6564 Å, Δλ = 22 Å) and F658N (λc = 6584 Å, Δλ = 72 Å) were used with WFPC2 and ACS observations, respectively.

As noted in Gruendl & Chu (2009), we have been imaging YSO candidates in selected regions throughout the LMC in the near-infrared J and Ks bands with the IR Side Port Imager (ISPI) on the Blanco 4 m telescope at the Cerro Tololo Inter-American Observatory. The ISPI camera has a 10′′ × 10′′ field-of-view imaged with a 2048 × 2048 HgCdTe Array with 0′′ 3 pixels. In total, we have imaged 113 fields in four different runs, 2005 November, 2006 November, 2007 February, and 2008 January. During our last run in 2008 January, we specifically imaged 29 fields that encompassed the HST archival data used in our study of YSO candidates in the LMC. These observations give us additional confirmation on the nature of the YSO candidates, bridging the gap between optical and mid-infrared wavelengths. Each field was imaged with a sequence of exposures with a telescope offset of ∼1′ between frames to aid in removal of bad pixels and to facilitate sky subtraction and flat fielding. For the J-band observations, thirteen 30 s exposures were obtained, while at the Ks band, twenty-three 30 s frames (each consisting of two co-added 15 s exposures) were obtained. The observations were nonlinearity corrected, sky subtracted, and flat fielded using standard routines within the CIARED and SQUID packages in IRAF. The astrometry was performed using the WCSTOOLS task IMWCS and the Two Micron All Sky Survey Point Source Catalog (2MASS PSC; Skrutskie et al. 2006). In these ISPI images, we find that point sources with \( m_J \lesssim 18.5 \) and \( m_K \lesssim 17.6 \) mag are generally detected with better than 10σ significance.

Following the method of Gruendl & Chu (2009) for assessing the nature of YSO candidates, we simultaneously displayed “postage stamp” images of each YSO candidate (field-of-view 5′ × 5′) in the following wavelengths: Digitized Sky Survey red continuum, HST Hα, ISPI J and Ks bands, Spitzer IRAC 3.6, 4.5, 5.8, and 8.0 μm, and MIPS 24 and 70 μm, along with the SED of the YSO candidate. To examine the large-scale environments, we also used the Hα images from the Magellanic Cloud Emission Line Survey (MCELS; Smith et al. 1999). By examining the source morphology and environment of each YSO candidate in the multiband images, in conjunction with its SED profile, we conclude that 82 of the 99 YSO candidates are most likely genuine YSOs. Our evaluation of the YSO nature of the sources is consistent with the previous assessment of Gruendl & Chu (2009), as they categorized the 82 confirmed YSO candidates as definite YSOs and the remaining 17 YSO candidates as probable or possible YSOs, where probable YSOs are likely to be YSOs but also show some characteristic of a possible alternative nature, and possible YSOs are more likely to be non-YSOs but cannot be ruled out as YSOs. In our analysis, the majority of these 17 non-YSOs appear to be either peaks of diffuse emission or background galaxies (see Table 4 in the Appendix). In the following discussion, we include only these 82 YSO candidates and refer to them as YSOs.

3. ENVIRONMENTS OF YSOs

The HST Hα images provide an unprecedented detailed view of the immediate environments of YSOs in the LMC. It is remarkable that all 82 YSOs are found in only three kinds of environments: (1) in a dark cloud, (2) inside or on the tip of a bright-rimmed dust pillar, and (3) in a small H ii region. Eight YSOs are found in more than one kind of environment, e.g., a small H ii region located inside a bright-rimmed dust pillar. A prototype example of a YSO in each kind of environment is illustrated by 20′′ × 20′′ (5.0 pc × 5.0 pc) images presented in Figure 1. We also show the SEDs of YSOs in Figure 1. An extended version of this figure including all YSOs is available online. For YSOs with neighboring sources within 1′, the identification of their optical counterparts in the HST images is not straightforward because of the combined uncertainties in astrometry, and it is necessary to bootstrap through images at intermediate wavelengths. Therefore, in Figure 1 we have included ISPI J and Ks, and IRAC 3.6 μm images, in addition to the HST Hα images. The IRAC 3.6 μm images show the YSOs as well as a small number of background stars. The alignment between the IRAC and ISPI images can be fine-tuned with these background stars, and a YSO’s near-infrared counterpart can be identified by it being brighter in K, than J compared with normal stars. The larger number of background stars in J makes it easier to align the ISPI images with the HST Hα image and identify a YSO’s optical counterpart. General remarks on these three categories are given below.

Dark clouds. Forty-nine YSOs are found to be associated with dark clouds. Among these, 34 show no detectable optical counterparts and 15 show faint optical counterparts in HST Hα images; their images presented in Figure 1 are labeled as categories 1a and 1b, respectively. It can be seen that these YSOs are in highly dusty environments, with dust features extending over several parsecs and sometimes tens of parsecs. Some YSOs are located near ionization fronts, as indicated by bright Hα emission on the surface of dark clouds. Note that diffuse ionized gas sometimes exists along the line of sight, and in these cases dark clouds can be diagnosed only in images larger than those shown in Figure 1, viewed with adjustable contrast. Two examples are YSO J051351.51–672721.9 and YSO J053838.45–690418.3.

Bright-rimmed dust pillars. Nineteen YSOs are associated with bright-rimmed dust pillars, of which eight are also associated with either dark clouds or small H ii regions. These YSOs are labeled as categories 2a or 2b, respectively. It can be seen that these YSOs are highly dusty environments, with dust features extending over several parsecs and sometimes tens of parsecs. Some YSOs are located near ionization fronts, as indicated by bright Hα emission on the surface of dark clouds. Note that diffuse ionized gas sometimes exists along the line of sight, and in these cases dark clouds can be diagnosed only in images larger than those shown in Figure 1, viewed with adjustable contrast. Two examples are YSO J051351.51–672721.9 and YSO J053838.45–690418.3.

H ii regions. Among the 22 YSOs in this category, the existence of small H ii regions ranges from “obviously seen” to “implied by generalization,” as discussed in detail later in Section 4. Briefly, eight YSOs are surrounded by resolved H ii regions of sizes up to 7′′5 (~1.8 pc); four YSOs appear more extended than the point spread function (PSF) in the HST Hα images, suggesting the existence of barely resolved H ii regions; four YSOs have observed fluxes in the Hα band higher than the expected stellar continuum fluxes, indicating excess Hα emission from ionized circumstellar gas; the remaining six YSOs either do not show significant excess Hα emission or have
Figure 1. Examples of the six types of YSO environments identified in this paper. From left to right each set of five panels show 20″ × 20″ *HST* Hα, ISPI J, Ks, and *Spitzer* 3.6 μm images centered on the *Spitzer* position for each YSO, and the SED of the YSO. The positions of the YSO and its optical near-IR counterparts are indicated with an open cross. The category for each YSO is indicated in the lower left corner where: YSOs in dark clouds without and with optical counterparts are marked as categories 1a and 1b, respectively; YSOs in bright-rimmed dust pillars are marked as category 2; YSOs associated with well resolved, marginally resolved, and unresolved H ii regions are marked as categories 3a, 3b, and 3c, respectively. Cases where multiple optical/near-IR counterparts are discovered within the *Spitzer* PSF are indicated with a “+” and YSOs found in more than one kind of environment are indicated with a “/.”

(An extended version of this figure is available in the online journal.)
no optical photometric data to assess the expected continuum fluxes. The images of YSOs with well resolved, barely resolved, and unresolved H\textsc{ii} regions shown in Figure 1 are labeled as categories 3a, 3b, and 3c, respectively.

To examine the molecular environment of these YSOs, we have compared the locations of YSOs with the NANTEN CO ($J = 1–0$) survey of the LMC, made with a 4 m telescope for a beam size of 2.6 (Fukui et al. 2001, 2008). We find that 70 YSOs are superposed on giant molecular clouds detected by NANTEN. The remaining 12 YSOs might be associated with small pc-sized molecular clouds with masses lower than a few $10^4 M_\odot$, the NANTEN detection limit. The high-resolution HST H\textalpha images show that indeed seven of these are in a visibly dusty environment. These results indicate that at least 95% of the 82 YSOs we examined are still associated with molecular material.

In Table 1, we summarize the YSOs and their properties: column 1 is the running number; Column 2 lists the identifier of the YSOs from Gruendl & Chu (2009); Column 3 describes the environment derived from HST H\textalpha images; Columns 4 and 5 give the names of the associated H\textsc{ii} region from Davies et al. (1976) and Henize (1956), respectively; Column 6 lists whether the YSO is associated with molecular clouds detected by the NANTEN survey (Fukui et al. 2001); Column 7 lists nearby OB associations (Lucke & Hodge 1970); Columns 8 and 9 are described in Section 3; Column 10 is described in Section 6, and finally Column 11 indicates the online supplementary set of Figure 1, in which the images and the SED of the YSO can be found. In some cases, YSOs are found in more than one kind of environment, e.g., YSOs which are surrounded by small H\textsc{ii} regions and are also associated with bright-rimmed dust pillars. For such YSOs, Column 3 indicates both the environments. There are also some cases, where more than one YSO is discovered in the Spitzer PSF. Such cases are indicated in Column 3 as well.

4. PROPERTIES OF H\textsc{ii} REGIONS

Of the 82 YSOs, 22 show small ionized regions that are well resolved, marginally resolved, or unresolved by the HST PSF (FWHM ~ 0.1). For H\textsc{ii} regions with different degrees of resolution, different methods are needed to measure the H\textalpha fluxes from the HST images and to assess whether the unresolved sources possess H\textalpha line emission.

Resolved H\textsc{ii} regions. For the eight YSOs that show well resolved H\textsc{ii} regions, we measured the H\textalpha fluxes of the H\textsc{ii} regions using the HST images, following the procedures for narrowband WFPC2 photometry.3 Images were divided by the exposure time and then the count rates were multiplied by the PHOTFLAM parameter found in the image headers to get flux densities. To obtain the fluxes, we multiplied the flux densities with the rectangular filter width calculated with SYNPHOT to be 28.3 Å and 74.9 Å for the filters F656N and F658N, respectively.

To remove the stellar continuum from the integrated H\textalpha flux of a well resolved H\textsc{ii} region, we simply excised point sources from the H\textalpha image and replaced them with the average of the surrounding diffuse emission, as most of the H\textsc{ii} regions do not have broadband continuum images available. One YSO in a resolved H\textsc{ii} region, YSO J052207.27–675819.7, has continuum images in the F675W band. Using the F675W image and the H\textalpha image, we estimate that the stellar continuum contributes ~17% of the total observed H\textalpha flux within the boundary of the H\textsc{ii} region, while using the H\textalpha image alone we find the stellar flux contributes ~14% of the total flux. These results suggest that excising point sources from the H\textalpha images is adequate for continuum subtraction. The continuum-subtracted H\textalpha fluxes of the H\textsc{ii} regions are listed in Table 2.

Assuming an electron temperature of 104 K, the H\textalpha surface brightness (SB) of an H\textsc{ii} region can be expressed as

$$SB = 1.9 \times 10^{-18} \text{ EM erg s}^{-1} \text{ cm}^{-2} \text{ arcsec}^{-2},$$

where EM $\equiv n_e^2 L_{pc}$ is the emission measure of the H\textsc{ii} region; $n_e$ is the rms electron density in cm$^{-3}$, and $L_{pc}$ is the emitting path length in parsecs. We measured the surface brightness of the H\textsc{ii} regions directly from the images. The variations in surface brightness over these small H\textsc{ii} regions are not significantly large. The peak brightnesses of the H\textsc{ii} regions are typically higher by a factor of 1.2–1.5 as compared to the average brightnesses of the H\textsc{ii} regions. We used the average value of the surface brightness and determined the emission measure of each H\textsc{ii} region using the above relation. From the emission measure and the average size of the H\textsc{ii} region (which we used as the average emitting path length of these H\textsc{ii} regions), we then determined the rms electron density of the H\textsc{ii} region. We also calculated extinction-uncorrected H\textalpha luminosities from the H\textalpha fluxes, and the required ionizing powers $Q(H^0)$ of the H\textsc{ii} regions for their H\textalpha luminosities. Finally, we assessed the corresponding spectral types for the massive YSOs using the theoretical ionizing powers provided by Panagia (1973). Table 2 lists the observed and derived properties of all the resolved H\textsc{ii} regions. Note that the H\textalpha luminosities, ionizing powers, and the spectral types given in Table 2 are lower limits to these quantities, as we have not applied an extinction correction.

Marginally resolved H\textsc{ii} regions. There are four YSOs that show marginally resolved H\textsc{ii} regions. We did not find $UBV$ photometry for any of these four YSOs in the Magellanic Cloud Photometric Survey (MCPS; Zaritsky et al. 2004). We searched for broadband continuum WFPC2 and ACS images in the $HST$ archive, and found useful images for two YSOs, J052212.24–675813.1 and J053836.36–690630.4. For J052212.24–675813.1, we found a continuum image in the wide-band filter F675W, and measured the continuum flux of the YSO. Scaling it according to the bandwidth, we find the expected continuum flux in the H\textalpha band to contribute only 25% of the total flux measured. The excess H\textalpha emission confirms the existence of a small H\textsc{ii} region. For the other YSO, J053836.36–690630.4, we found the continuum images in the wide-band filters F555W and F814W. We measured the fluxes of the YSO in these two bands and interpolated between them to make a rough estimate of its expected continuum flux in the H\textalpha band. The estimated continuum flux is ~21% of the observed flux in the H\textalpha band. This excess H\textalpha emission also confirms the existence of a small H\textsc{ii} region. The H\textalpha fluxes of these two marginally resolved H\textsc{ii} regions (see Table 3) suggest that the central stars are early-type B stars, but cooler and less powerful than the earliest B stars seen in the resolved H\textsc{ii} regions in Table 2. It is likely that the other two YSOs with extended image but no photometric data are also in small H\textsc{ii} regions, which need to be confirmed by spectroscopic observations in the future.

Unresolved H\textsc{ii} regions. There are 10 YSOs that are unresolved in the HST H\textalpha images, but it can be deduced from photometric analysis that they exhibit excess H\textalpha emission.
### Table 1

| Number | ID* | Category* | H II Region | H II Region Detection | CO Association | OB IRS Spectra | Silicate Absorption | YSO Type | Online Figure |
|--------|-----|-----------|-------------|-----------------------|----------------|----------------|---------------------|----------|---------------|
| 1      | J045625.99-663155.5 | 1a+1a<sup>c</sup> | DEM34 | N11F | Yes | LH9 | PE | No | I  1a |
| 2      | J045629.02-663159.3 | 1a | DEM34 | N11F | Yes | LH9 | PE | No | II 1a |
| 3      | J045640.79-663230.5 | 1a | DEM34 | N11F | Yes | LH9 | F | No | I 1a |
| 4      | J045742.00-662634.4 | 1a | DEM34 | N11C | Yes | LH13 | PE | No | I 1a |
| 5      | J045747.68-662816.9 | 1a | DEM34 | N11D | Yes | LH13 | PE | Yes | I 1a |
| 6      | J05207.32-675826.8 | 1a | DEM152 | N44C | Yes | LH47 | ... | ... | I 1a |
| 7      | J052211.86-675818.1 | 1a | DEM152 | N44C | Yes | LH47 | ... | ... | I 1b |
| 8      | J052212.57-675832.4 | 1a | DEM152 | N44C | Yes | LH47 | SE | Yes | I 1b |
| 9      | J05268.51-691636.6 | 1a | DEM263 | N157 | No | ... | ... | ... | I 1b |

**YSOs in Dark Clouds**

10. J05822.43-690644.4
11. J05833.09-690611.9
12. J05834.06-690452.2
13. J05834.60-690557.0
14. J05835.22-690629.0
15. J05844.32-690329.9
16. J05848.17-690411.7
17. J05848.42-690441.6
18. J05849.27-690444.4
19. J05852.67-690437.5
20. J05909.08-693005.7
21. J053630.81-691817.2
22. J053630.81-691817.2
23. J053630.81-693005.7
24. J053630.81-693005.7
25. J05384.32-690418.3
26. J05384.32-690418.3
27. J05384.32-690418.3
28. J05384.32-690418.3
29. J05384.32-690418.3
30. J05384.32-690418.3

### YSOs in Bright-Rimmed Dust Pillars

31. J045628.68-663143.4 | 2/1b<sup>d</sup> | DEM34 | N11F | Yes | LH9 | ... | ... | II 1g |
32. J045641.23-663132.9 | 2 | DEM34 | N11F | Yes | LH9 | ... | ... | II 1g |
33. J045657.25-662513.0 | 2/1a<sup>d</sup> | DEM34 | N11B | Yes | LH10 | ... | ... | II/III 1g |
34. J045659.85-662425.9 | 2 | DEM34 | N11B | Yes | LH10 | PE | No | III 1h |
35. J045737.61-662726.7 | 2 | DEM34 | N11C | Yes | LH13 | ... | ... | III 1h |
36. J045739.04-662731.3 | 2 | DEM34 | N11C | Yes | LH13 | ... | ... | III 1h |
37. J05129.16-691458.1 | 2 | DEM132A | N119 | No | LH41 | ... | ... | II/III 1h |
38. J05213.83-675443.0 | 2 | DEM152A | N44F | Yes | LH47 | ... | ... | ... 1h |
39. J052601.20-673012.1 | 2/1a<sup>d</sup> | DEM192 | N51D | No | LH54 | SE | Yes | ... 1h |
40. J052619.79-673033.6 | 2 | DEM192 | N51D | No | LH54 | ... | ... | ... 1i |
41. J053609.54-691805.5 | 2/3c<sup>d</sup> | DEM263 | N157 | No | ... | ... | II/III 1i |
42. J053623.52-691002.1 | 2 | DEM263 | N157 | No | ... | ... | II/III 1i |
43. J053838.36-690630.4 | 2/3b<sup>d</sup> | DEM263 | N157 | Yes | LH100 | ... | ... | III 1i |
44. J053839.23-690552.2 | 2 | DEM263 | N157 | Yes | LH100 | PE | No | II 1i |
45. J053839.69-690538.2 | 2/1a<sup>d</sup> | DEM263 | N157 | Yes | LH100 | PE | Yes | II 1i |
46. J053912.67-692941.4 | 2 | DEM269 | N158C | Yes | LH101 | ... | ... | ... 1j |
47. J053943.82-693834.0 | 2/3b/2/1a<sup>c</sup><sup>d</sup> | DEM284 | N160A | Yes | LH103 | Unknown | No | ... 1j |
48. J05848.17-670536.7 | 2 | DEM323 | N180B | Yes | LH117 | ... | ... | II/III 1j |

**YSOs in H II regions**

58. J045426.06-691102.3 | 3a | DEM22 | N83B | Yes | LH5 | PE | No | III 1j |
59. J05708.84-662325.1 | 3a | DEM34 | N11A | Yes | LH10 | ... | ... | III 1j |
60. J05716.25-662319.9 | 3a | DEM34 | N11 | Yes | LH10 | PE | No | II/III 1j |
Table 1

| Number | IDa | Categoryb | H II Region | H II Region | CO Detection | OB Association | IRS Spectra | Silicate Absorption | YSO Type | Online Figure |
|--------|-----|-----------|-------------|-------------|--------------|---------------|-------------|---------------------|----------|---------------|
| 61     | J052207.27–675819.7 | 3a DEM152 | N44C | Yes | LH47 | PE | No | II/III | 1k |
| 62     | J053845.15–690507.9 | 3a DEM263 | N157 | Yes | LH100 | PE | No | III | 1k |
| 63     | J053945.26–693854.6 | 3a DEM284 | N160A | Yes | LH103 | Unknown | No | III | 1k |
| 64     | J053945.94–693839.2 | 3a DEM284 | N160A | Yes | LH103 | Unknown | No | II/III | 1k |
| 65     | J054004.40–694437.6 | 3a DEM271 | N159B | Yes | LH105 | PE | No | III | 1k |
| 66     | J052212.24–675813.1 | 3b DEM152 | N44C | Yes | LH47 | ... | ... | ... | 1k |
| 67     | J052249.13–680129.1 | 3b DEM160 | N44H | Yes | LH49 | PE | No | II/III | 1l |
| 68     | J045429.42–690936.9 | 3c DEM22 | N83 | Yes | LH5 | ... | ... | II | 1l |
| 69     | J045651.82–663133.0 | 3c DEM34 | N11F | No | LH9 | PE | No | II | 1l |
| 70     | J045720.72–662814.4 | 3c DEM34 | N11 | No | ... | PE | No | II/III | 1l |
| 71     | J053549.28–660133.5 | 3c DEM243 | N63 | No | LH83 | ... | ... | ... | 1l |
| 72     | J053821.10–690617.2 | 3c DEM263 | N157 | Yes | ... | ... | ... | III | 1l |
| 73     | J053855.56–690426.5 | 3c DEM263 | N157 | Yes | LH100 | ... | ... | ... | 1m |
| 74     | J054385.42–690434.7 | 3c DEM263 | N157 | Yes | LH100 | PE | No | III | 1m |
| 75     | J054844.29–700360.0 | 3c DEM323 | N180B | Yes | LH117 | ... | ... | II/III | 1l |
| 76     | J054853.64–700320.2 | 3c DEM323 | N180B | Yes | LH117 | ... | ... | II/III | 1l |

Notes.

a The identifier of the YSO shows the J2000 coordinates of the YSOs in hhmss.s-ddmmss.s format.

b Category describes YSO environments: YSOs found in dark clouds without optical counterparts in HST Hα images are 1a, YSOs in dark clouds with optical counterparts are 1b; YSOs in bright rimmed dust pillars are 2; YSOs with resolved H II regions are 3a, YSOs with marginally resolved H II regions are 3b, and YSOs with unresolved H II regions are 3c.

c More than one YSO is discovered in the Spitzer PSF.

d YSOs are found in more than one kind of environment, e.g. 2/3b refers to YSOs which are associated with bright-rimmed dust pillars and the optical counterpart is a small H II region.

Table 2

| ID | Lengtha (pc) | Hz Fluxb (erg cm\(^{-2}\) s\(^{-1}\)) | EM (cm\(^{-6}\) pc) | \(n_e\) (cm\(^{-3}\)) | \(L_{H\alpha}\) (erg s\(^{-1}\)) | \(Q(H\alpha)\) (photons s\(^{-1}\)) | Sp.Type | IRS Spectra |
|----|-------------|----------------|-----------------|-----------------|-----------------|-----------------|---------|-------------|
| J045426.06–691102.3 | 0.96 | 6.84 \times 10^{-12} | 2.86 \times 10^5 | 546 | 1.45 \times 10^{35} | 1.03 \times 10^{47} | B0.5 | PE |
| J045708.84–662325.1 | 1.80 | 2.55 \times 10^{-12} | 7.59 \times 10^3 | 64 | 5.40 \times 10^{34} | 3.94 \times 10^{46} | B0.5 | ... |
| J045716.25–662319.9 | 1.68 | 8.64 \times 10^{-12} | 1.18 \times 10^5 | 265 | 1.83 \times 10^{35} | 1.35 \times 10^{47} | B0.5 | PE |
| J052207.27–675819.7 | 0.33 | 3.19 \times 10^{-14} | 1.08 \times 10^4 | 181 | 6.76 \times 10^{32} | 4.80 \times 10^{44} | B2 | PE |
| J053845.15–690507.9 | 0.81 | 2.38 \times 10^{-12} | 1.37 \times 10^5 | 412 | 5.04 \times 10^{34} | 3.59 \times 10^{46} | B0.5 | PE |
| J053943.26–693854.6 | 0.96 | 7.92 \times 10^{-12} | 3.33 \times 10^5 | 587 | 1.67 \times 10^{35} | 1.96 \times 10^{47} | B0 | Unknown |
| J053945.94–693839.2 | 1.44 | 1.07 \times 10^{-11} | 1.98 \times 10^5 | 371 | 2.26 \times 10^{35} | 1.61 \times 10^{47} | B0 | Unknown |
| J054004.40–694437.6 | 0.96 | 2.78 \times 10^{-12} | 1.16 \times 10^5 | 348 | 5.89 \times 10^{34} | 4.20 \times 10^{46} | B0.5 | PE |

Notes.

a Average emitting path lengths of the H II regions.

b Not corrected for extinction.

Table 3

| ID | Category | Observed Hα Flux (erg cm\(^{-2}\) s\(^{-1}\)) | Expected Cont. Flux\(^a\) (erg cm\(^{-2}\) s\(^{-1}\)) | IRS Spectra |
|----|----------|--------------------------------|-----------------|-------------|
| J052212.24–675813.1 | 3b | 5.1 \times 10^{-15} | 1.3 \times 10^{-15} | ... |
| J052249.13–680129.1 | 3b | 1.3 \times 10^{-15} | ... | PE |
| J053838.36–690630.4 | 3b | 3.1 \times 10^{-13} | 6.7 \times 10^{-14} | ... |
| J053943.80–693834.0 | 3b | 3.0 \times 10^{-13} | ... | Unknown |
| J045651.82–663133.0 | 3c | 2.4 \times 10^{-14} | 1.8 \times 10^{-14} | PE |
| J045429.42–690936.9 | 3c | 1.1 \times 10^{-13} | ... | ... |
| J045720.72–662814.4 | 3c | 6.7 \times 10^{-15} | 1.1 \times 10^{-14} | PE |
| J053549.28–660133.5 | 3c | 7.0 \times 10^{-15} | 5.0 \times 10^{-15} | ... |
| J053609.54–691805.5 | 3c | 4.4 \times 10^{-14} | 1.0 \times 10^{-14} | ... |
| J053821.10–690617.2 | 3c | 3.1 \times 10^{-14} | ... | ... |
| J053855.56–690426.5 | 3c | 9.3 \times 10^{-15} | 1.0 \times 10^{-14} | ... |
| J053858.42–690434.7 | 3c | 8.9 \times 10^{-15} | 9.7 \times 10^{-15} | PE |
| J054844.29–700360.0 | 3c | 6.6 \times 10^{-15} | ... | ... |
| J054853.64–700320.2 | 3c | 3.4 \times 10^{-14} | 4.0 \times 10^{-15} | ... |

Note. \(^a\) Expected continuum flux of the YSO in the Hα passband.
indicating the existence of unresolved H\textsc{ii} regions. No useful \textit{HST} continuum images are available for these YSOs, but we found MCPS \textit{UBV} photometry for seven of them and used these data to estimate expected stellar continuum fluxes in the H\textalpha{} band. We began by assuming \((B - V)_{0} \sim -0.3\), the color of O and early B main sequence stars, which have ionizing powers. Adopting the canonical extinction relation \(A_{V} \sim 3.2 \frac{E(B - V)}{E(U - B)}\), \(E(U - B)/E(B - V) = 0.72\) for early-type stars, and a distance modulus of 18.5, we calculated their absolute magnitudes \(E\). Adopting the canonical extinction relation and early B main sequence stars, which have ionizing powers.

For four YSOs, J045651.82–663133.0, J053549.28–660133.5, J053609.54–691805.5, and J054853.64–700320.2, their expected continuum fluxes in the H\textalpha{} passband are only 10%–76% of their observed H\textalpha{} fluxes. If we take into account the stellar photospheric absorption at the H\textalpha{} line, the expected stellar fluxes are even lower in the H\textalpha{} passband. Given that the equivalent widths of the H\textalpha{} absorption in early-B stars range from \(\sim 3.5\) \AA{} in B0 stars to \(\sim 5\) \AA{} in B2 stars (Didelon 1982), 10%–17% for the 28.3 \AA{} width of the F656N filter passband, we are confident that these four YSOs indeed have small H\textalpha{} regions that are not resolved by the \(0.1\) PSF of WFPC2.

For three YSOs, J045720.72–662814.4, J053855.56–690426.5, and J053858.42–690434.7, the observed H\textalpha{} fluxes are comparable to or somewhat lower than their expected continuum fluxes in the H\textalpha{} passband. Considering the stellar photospheric absorption of the H\textalpha{} line and the fact that the observed H\textalpha{} fluxes were not extinction-corrected, it is likely that these three YSOs also have some excess H\textalpha{} emission and small unresolved H\textalpha{} regions. The existence of unresolved H\textalpha{} regions for J045720.72–662814.4 and J053858.42–690434.7 is further supported by the presence of IR spectral features that originate from ionized and partially ionized gas, as discussed later in Section 5. For the remaining three YSOs, J045429.42–690936.9, J053821.10–690617.2, and J054844.29–700360.0, we did not find existing \textit{UBV} photometry or any \textit{HST} broadband images to estimate the continuum contribution in the H\textalpha{} passband; hence, we cannot determine whether these three YSOs have H\textalpha{} regions. Based on the results of the other seven YSOs, we consider it likely that these three YSOs also have unresolved H\textalpha{} regions. Table 3 lists the observed H\textalpha{} fluxes and the expected continuum fluxes in the H\textalpha{} passband of these ten YSOs with unresolved H\textalpha{} regions.

Finally, we note that 10%–18% of B stars are known to be emission-line B stars (Jaschek & Jaschek 1983), and that we are not able to distinguish emission-line B stars from unresolved H\textalpha{} regions. It is nevertheless certain that stellar emission lines are formed in extended regions exterior to the photospheres, and thus the distinction may be a matter of semantics.

5. YSOs WITH \textit{SPITZER} IRS SPECTRA

Seale et al. (2009) presented \textit{Spitzer} Infrared Spectrograph (IRS) spectra for 277 YSO candidates selected from the Gruendl & Chu (2009) YSO catalog. They found that the IRS spectra of massive YSO candidates can be divided into six different groups based on their spectral characteristics. They proposed that these different groups reflect different evolutionary stages of massive YSOs. The groups were defined as: spectra with silicate absorption, S group; spectra with silicate absorption and fine-structure lines, SE group; spectra showing Polycyclic Aromatic Hydrocarbons (PAH) emissions, P group; spectra showing both PAH emission and fine-structure lines, PE group; spectra showing fine-structure lines, E group; and finally spectra that appear to be featureless though they may show one or more of the above characteristics, F group. Seale et al. (2009) noted that there were five YSOs in their sample which they did not classify as the spectra for these five YSOs did not have full spectral coverage. These five YSOs showed fine-structure lines in the IRS spectra and were termed as “embedded objects with unknown classification” by Seale et al. (2009). Many of their P and PE group YSOs showed silicate absorption features at 10 \textmu{}m.

Thirty-three of our YSOs with \textit{HST} images have \textit{Spitzer} IRS spectra reported by Seale et al. (2009). Columns 8 and 9 in Table 1 list the classification by Seale et al. (2009) of these YSOs based on the \textit{Spitzer} IRS spectra, and whether or not silicate absorption features are present in the IRS spectra, respectively. The YSOs which were called as “embedded objects with unknown classification” are marked as “Unknown” in Table 1. Eighteen YSOs in dark clouds have spectra, of which 14 are classified as PE or P group (where nine of them show silicate absorption features), two are classified into the SE group, one is classified into the F group, and one is “embedded object with unknown classification.” Six YSOs in bright-rimmed globules have IRS spectra, of which three are PE (with two of them in dark clouds showing silicate absorption features), one in a dark cloud is SE, and one is an “embedded object with unknown classification.” Among the 10 YSOs whose H\textalpha{} regions are confirmed morphologically or photometrically, seven have IRS spectral type PE (none with silicate features) and three are “embedded object with unknown classification.” Finally, two YSOs whose H\textalpha{} regions are not confirmed either morphologically or photometrically have IRS spectral type PE (no silicate absorption features) indicating that they have small unresolved H\textalpha{} regions.

All the 12 YSOs with small H\textalpha{} regions show fine-structure lines in the spectra with nine YSOs also showing PAH emission features. This is understandable, as fine-structure lines are expected to be present in H\textalpha{} regions of massive YSOs, whereas PAH emission features are generated in photodissociation regions on the surface of H\textalpha{} regions. Many YSOs associated with dark clouds and bright-rimmed dust pillars also show PAH emission and/or fine-structure lines which implies that these YSOs might also have ionized regions surrounding them though not seen in the \textit{HST} H\textalpha{} images. It is interesting to note that none of the YSOs with small H\textalpha{} regions show silicate absorption features, whereas half of the YSOs in dark clouds and one-third of the YSOs in bright-rimmed dust pillars show silicate absorption features in the IRS spectra. Also, two YSOs in dark clouds, one of which is associated with a bright-rimmed dust pillar, have been classified into the SE group proposed by Seale et al. (2009) to be the less evolved stage compared to the P or PE group. These results suggest that the YSOs in dark clouds and in bright-rimmed dust pillars are less evolved compared to YSOs with small H\textalpha{} regions.

6. YSO CATEGORIES AND SEDs

It is highly interesting that all the LMC YSOs for which we found archival \textit{HST} data are found in only one of three different
Figure 2. Histogram plot showing the correlation of YSO environments and the SED Type classification. YSOs in dark clouds with no optical counterparts are 1a, YSOs in dark clouds with optical counterparts are 1b, YSOs in bright rimmed dust globules are 2, YSOs with resolved H II regions are 3a, YSOs with marginally resolved H II regions are 3b and YSOs with unresolved H II regions are 3c. (A color version of this figure is available in the online journal.)

kinds of environments. Do the SEDs of these YSOs reflect any signatures that are characteristic of their environments? To check that, we examined the SEDs (optical to mid-infrared) of the YSOs and searched for any possible correlation between the YSO environments and their SEDs. We first classified YSOs according to the empirical “Type” classification, based on the SEDs of massive YSOs, proposed by Chen et al. (2009). In this scheme, Type I has an SED that rises steeply from near-infrared to 24 µm and beyond, Type II has an SED with a low peak at optical wavelengths and a high peak at 8–24 µm, and Type III shows an SED with bright optical peak and modest near- and mid-infrared peak (see Figure 7 in Chen et al. 2009).

We could classify 62 of our 82 YSOs using the above SED criteria (see Column 10 in Table 1). For the remaining YSOs, a classification could not be made either because there are multiple sources in the near-infrared data and/or in the HST data within the Spitzer PSF, making the YSO identification difficult, or the SED does not fit into any of the above Types, e.g., YSOs that are not detected in available optical data, and are faint or not detected at 24 µm. Figure 2 shows the distribution of YSOs of different environments (Column 3 in Table 1) into the Type I, II, and III classification (Column 10 in Table 1). For many YSOs, unambiguous classification into Type II or Type III was not possible; such cases are grouped as II/III.

A correlation can be seen between YSO environments and their SEDs. YSOs in dark clouds with no optical counterparts are largely classified as Type I. YSOs in dark clouds but with optical counterparts are mostly classified as Type II. YSOs in bright-rimmed dust pillars are classified as either Type II or classification is ambiguous between II and III. YSOs with resolved H II regions are mostly classified as Type III, and YSOs with marginally resolved or unresolved H II regions are classified as Type II/III or Type III. Thus, we see that YSOs in different environments are in different evolutionary stages. YSOs in dark clouds are the youngest, YSOs with H II regions are the most evolved, and YSOs in bright-rimmed dust pillars are in the intermediate stage. Even among the YSOs in dark clouds, one can see a marked difference between the YSOs with and without optical counterparts. The YSOs with optical counterparts are more evolved as compared to YSOs without optical counterparts. The YSOs with marginally resolved and unresolved H II regions are a mix of Type II and Type III, as opposed to YSOs with resolved H II regions which are mostly Type III. This might mean that YSOs with marginally resolved and unresolved H II regions are more likely to be younger compared to YSOs with resolved H II regions.

We examined the HST Hα images of YSOs to check for multiplicity. As many as 50% of the YSOs show multiple sources within 2′ of the YSO location in the high-resolution HST images, of which 12% show multiple YSOs. In the remaining cases, the other sources are normal stars. Many of the multiples are also well resolved in the ISPI J and Ks bands. As has been cautioned by Chen et al. (2009), multiplicity is a problem in interpreting the nature of LMC YSOs using only Spitzer data. While the Chen et al. (2009) study is based only on one H II complex, N44, the current study covers a wide range of star formation environments in the LMC and demonstrates that multiplicity is indeed a prevailing problem.

7. TRIGGERED STAR FORMATION

The formation of massive stars has a significant impact on the structure and evolution of the interstellar medium. After their birth, massive stars radiatively ionize their ambient medium and mechanically energize their surroundings via fast stellar winds and supernova ejecta. While such energy feedback may disperse the natal molecular cloud and terminate the star formation eventually, the initial pressure increase in the ionization front on molecular material may actually trigger star formation. Using HST Hα images, we were able to examine the relationship between YSOs and ionization fronts of antecedent massive stars.

Bright-rimmed dust pillars are potential sites of triggered star formation caused by compression due to ionization/shock fronts. One fourth of our sample, 19 YSOs, are found to be associated with bright-rimmed dust pillars. One of these YSOs is found in a dark cloud with an optical counterpart (2/1b) and four are found in dark clouds with no optical counterparts (2/1a), indicative of their youth. Three bright-rimmed dust pillars show marginally resolved small H II regions and harbor massive YSOs. In order to assess whether the star formation was induced by external pressure in these bright-rimmed dust pillars, we calculated thermal pressures of the ionized rims of the dust pillars, and present a few examples here.

YSO J045659.85–662425.9 is associated with a bright-rimmed dust pillar that shows the brightest ionized rims in all of our sample. The peak Hα surface brightness of the ionized gas enveloping this dust pillar is 2.5 × 10¹² erg s⁻¹ cm⁻² arcsec⁻², corresponding to an emission measure of 1.31 × 10⁶ cm⁻⁶ pc, for a temperature of 10⁴ K. We adopt the average of the projected emission length of ~0.55 pc and width of ~0.18 pc (measured from the Hα image) as the emission path length, 0.36 pc, and derive a rms electron density of 1900 cm⁻³. The thermal pressure of the ionized rim of the dust globule is P/k ~1.9 × 10⁷ cm⁻³ K. The thermal pressure of the dust globule is P/k ~10⁴ cm⁻³ K, assuming typical values of density, 10⁵ H₂ cm⁻³, and temperature, 10 K, for Bok globules. The pressure of the ionized surface of the pillar is thus much higher than the thermal pressure of the dust globule, suggesting that star formation was possibly triggered by the external pressure. At the other extreme, the YSO J045641.23–663132.9 is associated with a bright-rimmed dust pillar that shows the faintest rim among those in our sample. For this case, the peak Hα surface brightness of the ionized gas enveloping the dust pillar is 3.7 ×
10^{-14} \text{ erg s}^{-1} \text{ cm}^{-2} \text{ arcsec}^{-2}, \text{ implying an emission measure of } 1.95 \times 10^{4} \text{ cm}^{-6} \text{ pc}. \text{ The projected emission length and width on the surface of the dust pillar are } 0.8 \text{ and } 0.6 \text{ pc, respectively, as measured from the } H\alpha \text{ image. Using the average of these two values as the emission length along the line of sight, we derive a rms electron density of } \approx \text{170 cm}^{-3}, \text{ and the thermal pressure of the rim } P/k \approx 1.7 \times 10^{6} \text{ cm}^{-3} \text{ K}. \text{ This is still much higher compared to the typical thermal pressure of dust globules and could also be a case of triggered star formation. We therefore conclude that most of our YSOs in the bright-rimmed dust pillars have likely formed as a result of triggering due to external pressure.}

Apart from the YSOs in the bright-rimmed dust pillars, there are two YSOs in dark clouds in juxtaposition with H\ii regions, which may also represent triggered star formation. One of these two YSOs, J053630.81–691817.2, is resolved into a stellar source and a small bright H\ii region separated by ∼0.9 in the \textit{HST} \textit{H}\alpha image. The H\ii region contains an unresolved point source near its peak emission, indicating that the star might be its ionizing source. The ISPI \textit{J} and \textit{K}_s images also show two corresponding sources, with the YSO being redder than the source in the H\ii region. The close proximity between the H\ii region and the YSO, projected distance ∼0.2 pc, suggests that the expansion of the H\ii region may have compressed the molecular cloud and triggered the formation of the YSO. Another such example is presented by the YSO J045625.99–663155.5, which is projected at ∼1 pc from a resolved small H\ii region, and is also a possible case of triggered star formation. The high-resolution \textit{HST} images are indeed very useful to examine the large-scale star formation environments in detail, and a systematic study of this nature is important to address issues related to formation of massive stars and the interplay of massive stars with the interstellar medium.

8. SUMMARY

We have used archival \textit{HST} \textit{H}\alpha images to examine the immediate environments of massive and intermediate-mass YSO candidates of the LMC. In total, archival \textit{HST} \textit{H}\alpha images were found for 99 YSO candidates. By examining the source morphology and the environment of YSO candidates in multiwavelength images, we conclude that 82 of the candidates are genuine YSOs. All of these 82 YSOs are found in only three different environments, in dark clouds, in bright rimmed dust pillars, or in small H\ii regions. Forty-nine YSOs are in dark clouds, 34 of which show no optical counterparts, and the remaining 15 show faint optical counterparts in \textit{HST} \textit{H}\alpha images. Nineteen YSOs are associated with bright-rimmed dust pillars, of which five are in dark clouds, and three show small H\ii regions. Twenty-two YSOs show small H\ii regions, of which 8 are well resolved, 4 are marginally resolved, and the remaining 10 are unresolved in the \textit{HST} \textit{H}\alpha images. We calculate observed (reddened) \textit{H}\alpha fluxes of the resolved H\ii regions and present the estimated spectral types of these massive YSOs. For the marginally resolved as well as the unresolved H\ii regions, we use \textit{UBV} photometry or \textit{HST} continuum images to estimate the stellar continuum fluxes in the \textit{H}\alpha passband, and demonstrate that most of them possess \textit{H}\alpha line emission, indicating that they indeed have small H\ii regions.

YSOs for which \textit{Spitzer} IRS spectra are available predominantly show PAH emission and/or fine-structure lines in the spectra. Nine YSOs associated with dark clouds, with two of them also in bright-rimmed dust pillars, show silicate absorption features in the IRS spectra, whereas none of the YSOs associated with small H\ii regions show silicate absorption features. YSOs in small H\ii regions including the marginally resolved and the unresolved ones, show PAH emission and/or fine-structure lines in the IRS spectra. The comparison of YSO environments with the SEDs reveals an evolutionary sequence of YSOs in different environments. YSOs in dark clouds with no optical counterparts are mostly Type I and hence the youngest. YSOs in dark clouds but with optical counterparts are mostly Type II and more evolved compared to YSOs with no optical counterparts. YSOs in bright-rimmed dust pillars are either Type II or Type II/III and are in the intermediate stage. YSOs with resolved H\ii regions are mostly Type III and are the most evolved. Finally, YSOs with marginally resolved H\ii regions and unresolved H\ii regions are a mix of Type II and Type III, and should be on average younger compared to YSOs with resolved H\ii regions. As many as 50% of the YSOs are resolved into multiple sources when seen in \textit{HST} images, signifying the importance of using high-resolution images to probe the true nature of YSOs and to study their immediate environments.

We investigate the issue of triggered star formation for YSOs in bright-rimmed dust pillars and YSOs in dark clouds adjacent to H\ii regions. The thermal pressures of ionized surfaces of bright-rimmed dust pillars are found to be much higher compared to typical thermal pressures of dust globules. Thus the YSOs in bright-rimmed dust pillars have likely formed due to triggering from external pressure. Finally, we show that by examining the immediate environments of the YSOs using the high-resolution \textit{HST} images, we can learn about the evolutionary stages of massive YSOs. A systematic survey of massive YSOs using \textit{HST} will be very useful to study the evolutionary aspects of massive YSOs and to understand star formation in a wide range of interstellar environments.

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APPENDIX

The 17 non-YSOs are presented in Table 4.

| Number | ID | Description |
|--------|----|-------------|
| 1      | J045647.11–662459.1 | Diffuse emission |
| 2      | J045658.24–662430.7 | Diffuse emission |
| 3      | J045702.52–662503.3 | Diffuse emission |
| 4      | J045726.42–662484.4 | Galaxy |
| 5      | J052218.80–675814.6 | Diffuse emission |
| 6      | J053525.90–691428.6 | Galaxy |
| 7      | J053550.40–692422.0 | Galaxy |
| 8      | J053554.84–691426.6 | Diffuse emission |
| 9      | J053627.62–691434.9 | Diffuse emission |
| 10     | J053708.79–690720.3 | A bright star |
| 11     | J053742.63–690943.6 | Diffuse emission |
| 12     | J053825.21–690405.2 | Diffuse emission |
| 13     | J053844.32–690329.9 | Diffuse emission with perhaps faint YSOs |
| 14     | J053845.99–690930.8 | Diffuse emission |
| 15     | J053848.86–690828.0 | Galaxy |
| 16     | J053906.22–692930.9 | Diffuse emission |
| 17     | J053949.18–693747.4 | Two galaxies |
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