UNDERSTANDING RADIO-SELECTED THERMAL SOURCES IN M33: ULTRAVIOLET, OPTICAL, NEAR-INFRARED, SPITZER MID-INFRARED, AND RADIO OBSERVATIONS

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ABSTRACT

We present ultraviolet, optical, near-infrared, Spitzer mid-infrared, and radio images of 14 radio-selected objects in M33. These objects are thought to represent the youngest phase of star cluster formation. We have detected the majority of cluster candidates in M33 at all wavelengths. From the near-IR images, we derived ages 2–10 Myr, Ks-band extinctions (AKs) of 0–1 mag, and stellar masses of 10¹⁻¹⁰⁴ M☉. We have generated spectral energy distributions (SEDs) of each cluster from 0.1 to 160 μm. From these SEDs, we have modeled the dust emission around these star clusters to determine the dust masses (1–10³ M☉) and temperatures (40–90 K) of the clusters’ local interstellar medium. Extinctions derived from the JHKs, Hα, and UV images are similar to within a factor of 2 or 3. These results suggest that 11 of the 14 radio-selected objects are optically visible young star clusters with a surrounding H n region, that 2 are background objects, possibly active galactic nuclei (AGNs), and that 1 is a Wolf-Rayet star with a surrounding H n region.

Subject headings: dust, extinction — galaxies: individual (M33) — galaxies: star clusters — infrared: ISM — ISM: structure

1. INTRODUCTION

A galaxy’s morphological evolution and the properties of its interstellar medium (ISM) are driven by massive stars in young (0–10 Myr) star clusters. At these ages, star clusters produce metals from supernovae explosions, generate ionizing photons that determine the phase of the ISM, and provide mechanical energy to rearrange the ISM. These effects originate in the local ISM but eventually contribute to galaxy-wide ISM changes (see Calzetti et al. 2004). Thus, the small-scale effects of young star clusters on their ISM have evolutionary consequences on the host galaxy in general.

When a young star cluster first forms, the OB stars in that cluster have not had time to remove their natal molecular cloud material, either by photoionization or by the mechanical force from the stellar winds. Because this molecular material exhibits optical depths greater than 1 at visible wavelengths, the cluster should be detectable only at infrared (IR) and radio wavelengths. Johnson et al. (2001) found 14 thermally emitting objects in M33 using high spatial resolution radio continuum maps at 6 and 20 cm. These selected candidates have a spectral index (α₅₀₆ cm⁻¹) of 0 or greater, indicating optically thick free-free emission from a thermal source. The Lyman continuum photon rates determined from radio continuum maps imply the presence of 2–4 O7 equivalent stars and hence an age of 7 Myr or less.

To learn more about these radio-selected objects, we undertook a multiwavelength survey from the radio to the far-ultraviolet (far-UV). With the combination of the Spitzer Infrared Array Camera (IRAC; Fazio et al. 2004) and Multiband Imaging Photometer for Spitzer (MIPS; Rieke et al. 2004) images, we identify the radio-selected objects from Johnson et al. (2001) and produce spectral energy distributions (SEDs) to determine their dust properties (temperature and mass) as well as morphologies of the polycyclic aromatic hydrocarbon (PAH)/dust emission. With a near-IR color-color plot and absolute magnitudes, we determine their stellar ages, masses, and extinctions. Finally, archival Hα and ultraviolet (UV; Galaxy Evolution Explorer [GALEX]) images were used to detect objects at shorter wavelengths for which we measured UV and Hα extinctions based on stellar synthesis models. The observations and data reduction are presented in § 2. Basic results of our analysis are given in § 3, and discussion of our findings is given in § 4. In § 5 we summarize our findings.

2. OBSERVATIONS AND REDUCTIONS

2.1. Spitzer IRAC and MIPS Images

Spitzer MIPS and IRAC images of M33 were produced under the Guaranteed Time Observer (GTO) program “M33 Mapping and Spectroscopy” (PID 5) by Spitzer Science Working Group member R. D. Gehrz. Hinz et al. (2004) describe the MIPS
The near-IR JHK$_s$ data were obtained 2002 October 16–23 on the 2.1 m telescope at Kitt Peak National Observatory using the NOAO simultaneous quad infrared imaging device (SQIID) near-IR instrument. SQIID obtains simultaneous images in JHK$_s$ at a pixel scale of 0.7 pixel$^{-1}$ over a 304$''$ x 317$''$ area. One night was photometric, while another night was sporadically photometric. We observed each radio-selected object position with a standard 5 s integration time, 24 co-adds, and 3 sets of 5 dithered images (total integration times of 75 s). Throughout these nights, we observed 3–6 UKIRT faint standard stars (Hawarden et al. 2001) for flux calibration. All data reductions were performed using the Image Reduction and Analysis Facility$^{10}$ (IRAF) software. Averaged dark images were subtracted from individual images, followed by flat-fielding with the averaged flat-field image for the appropriate filter. We created sky images from each set of dithered science images and then subtracted the scaled sky background images from each science image in their respective sets. The science images were then registered and combined. Finally, a world coordinate system was generated for each JHK$_s$ image from field stars’ celestial coordinates in the Two Micron All Sky Survey (2MASS) point source catalog.

Flux calibration was performed with the standard stars. Zero points were determined using a 7$''$ aperture; we found that color terms were negligible. Between the flux calibration of the photometric and near-photometric nights, the zero-point differences were 0.01 mag for J and H, and 0.08 mag for K$_s$. We compared our derived magnitudes of field stars to those found in 2MASS, appropriately transformed to the UKIRT system (Cutri et al. 2003). These magnitudes were found to be in close agreement (~0.05 mag for all filters).

2.3. Archival Imagery

We searched multiwavelength data archives for images of these radio objects. We found four other wavelength bands that had suitable data. VLA 6 cm continuum maps of the 14 radio-selected objects were generated from the data taken for Duric et al. (1993). These radio maps were used to discern which object in the Spitzer images is the actual compact radio object, and these radio maps were also used by Johnson et al. (2001). The SQIID near-IR observations did not cover all M33 radio-selected objects. Therefore, we used the M33 2MASS mosaic produced by Jarrett et al. (2003). This image allowed us to derive JHK$_s$ magnitudes and colors for Johnson et al. (2001) objects 1–4 and 12. R-band and H$_\alpha$ images of M33 were taken from Massey et al. (2002). Continuum emission in the H$_\alpha$ image was removed by subtracting a scaled R-band image. We determined the scaling factor by comparing the aperture fluxes of 20 stars in both images. To determine what the corresponding flux is for one count (data number or DN) in the continuum-subtracted H$_\alpha$ image, we used H$_\alpha$ fluxes of three round, clearly separated H II regions given in Hodge et al. (2002; BCLMP1171a, 95Ab, and 633a+b). Hodge et al. (2002) give H$_\alpha$ fluxes as well as the areas for the H II regions. We choose isolated, spherical H II regions in order to both avoid contamination from other sources and to make use of simple circular aperture photometry. The conversion factor derived is 7.64 x 10$^{-18}$ ergs s$^{-1}$ cm$^{-2}$ DN$^{-1}$. Far-UV (0.1528 $\mu$m) and near-ultraviolet (near-UV; 0.2271 $\mu$m) archival images of M33 were downloaded from the GALEX data archive to be used for aperture photometry. Flux calibration of the GALEX data from DN s$^{-1}$ to Jy is given in the GALEX data handbook.$^{12}$

3. RESULTS

3.1. Finding the Radio-selected Objects

We located the 14 objects from Johnson et al. (2001) in the far-UV (0.1528 $\mu$m), near-UV (0.2271 $\mu$m), H$_\alpha$, JHK$_s$, and Spitzer images. Figures 1–14 show 90$''$ square images centered on each radio position. Because the far-UV and near-UV images are similar, only the near-UV is used in Figures 1–14. All images have an orientation of north up and east to the left. In all figures we have placed a ~9$''$ circle around the center coordinate from Johnson et al. (2001) to reflect the positional uncertainties, which are much larger than the positional uncertainties of all other images in this study. For all images, the wavelengths are designated in the upper right corner. The upper left corners of the near-UV and 8 $\mu$m images show the object’s designation (e.g., 1 for Fig. 1). The J and 3.6 $\mu$m images give the labeling of the objects that we think are the radio-selected sources (discussed below). In the 8 $\mu$m images we have encircled any extended dust/PAH shells near the radio position. In the 4.5 $\mu$m image, we have superimposed contours of our 6 cm radio maps.

We identify potential IR counterparts to the radio emission in the Spitzer images. Spitzer images are the obvious choice because they are closest in wavelength to the radio but even more because of the observed linkage between radio and infrared emission in star forming galaxies. Also, if these objects are embedded sources, then the dust emission around these objects should be very strong and should obscure emission from shorter wavelengths. Below, we discuss the object determination on a case-by-case basis. The celestial positions of these objects described below are given in Table 1.

**Object 1.—** At all wavelengths in Figure 1, excluding UV, the brightest potential source is found at the northeast position of the uncertainty circle around the object’s position. However, the 6 cm emission peaks to the southwest of this object. A source appears coincident with this radio emission in the near-UV, 3.6 $\mu$m, and 4.5 $\mu$m images, and we designate this as object 1. Photometry of

$^{10}$ IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

$^{11}$ Boulesteix et al. (1974).

$^{12}$ See http://galexgi.gsfc.nasa.gov/Documents/ERO_data_description_2.html.
Fig. 1.—Near-UV, Hα, JHKs, IRAC, and MIPS images of object 1. Each image is ∼90" on a side with an orientation of north up and east to the left. The radio position from Johnson et al. (2001) is designated by the circle in the center of the images. The radius of the circle reflects roughly the uncertainty in their position. In the 4.5 μm image, we have overlaid the 6 cm map from Duric et al. (1993). The candidates are labeled in both the J and 3.6 μm images. We located object 1 as the point source on the upper left of the circle. However, the 6 cm radio source is found to that candidate’s lower right. A very faint source does exist closer to this position but is detected only at near-UV, 3.6 μm, and 4.5 μm. We think that object 1 is a background object, possibly an AGN or QSO.

Fig. 2.—Near-UV, Hα, JHKs, IRAC, and MIPS images of object 2. Orientation and notation are the same as Fig. 1. Object 2 is located in the lower left of the radio position uncertainty circle. The Wolf-Rayet star is found at the western edge of the uncertainty circle. The 6 cm radio contours in the 4.5 μm image arise on the western side of the bipolar (see Hα) nebula. No radio emission appears to be associated with the bright IRAC object.
this radio-coincident source is contaminated by the closer, brighter source. The lack of detection at 24 μm of object 1 is probably inconsistent with this object being an example of a young, embedded phase of star cluster formation. Object 1 is possibly a background object, and therefore, we have eliminated it from further discussion. Johnson et al. (2001) state that some of their sample could be background galaxies.

Object 2.—The radio position from Johnson et al. (2001) is located inside a Wolf-Rayet nebula, termed BCLMP 638 or IC132. The Wolf-Rayet star ([MC83]13 23, a WN star) is located in the southwest part of the uncertainty circle in both the 3.6 μm and 24 μm images.

13 Massey & Conti (1983).
the B image in Johnson et al. (2001). We designate object 2 as the prominent dust/PAH emission part of BCLMP 638 located at the southeast portion of the uncertainty circle. The MIPS 24 μm emission is bright in this region as well. The other MIPS band-passes cannot identify whether the dust emission arises around the Wolf-Rayet star or object 2 because of lower resolution and larger pixel size of the detectors. The 6 cm radio contours suggest that the bright radio emission originates around the Wolf-Rayet star and two bright sources, probably stars, 9° west of the Wolf-Rayet star. The Hα image indicates that IC 132 is a bipolar nebula.
Knowing the size and shape of the nebula, we suspect that the bright 6 cm knots of emission are found coincidentally on top of the two bright sources in the 4.5 μm image and that the bright 6 cm knots are actually bright radio knots along the edge of the bipolar nebula. At JHK₅ wavelengths, we see the Wolf-Rayet star, but no emission is found at the bright dust/PAH emission source to the east of the Wolf-Rayet star. At UV wavelengths, the Wolf-Rayet star shows up prominently in the images, but object 2 is not detected at all.

Object 3.—We identify the IRAC object in the middle of the uncertainty circle with the radio-selected source. The 6 cm radio contours and JHK₅ emission are coincident with this IRAC source. Some Hα emission is present for this object. Note that the
dim IRAC object to the southwest of object 3 is just as bright as object 3 at Hα. Johnson et al. (2001) also detect this object in their B image, and their radio position is coincident with the H ii region IC 133 or BCLMP 623. Finally, object 3 is also detected at UV wavelengths, implying little extinction for this object.

Object 4.—Like object 1, this object is detected only at IRAC wavelengths and is located at the center of the radio uncertainty circle. The 6 cm contours in the 4.5 μm image show that this object is coincident with the radio emission. The lack of detection at 24 μm of object 4 is probably inconsistent with this object being an example of a young, embedded phase of star cluster formation. As with object 1, object 4 is possibly a background object, and therefore, we have eliminated it from further discussion.

Object 5.—The celestial position of object 5 is coincident with the H ii regions BCLMP 35/36 (Johnson et al. 2001). Two objects...
are found at the outer edge of the uncertainty circle for the radio position. We term the north object “a” and the southern object “b.” Looking at the MIPS images, object 5a is the dominant 24 \mu m source, but object 5b is also present but dimmer. The 6 cm contours superimposed on the 4.5 \mu m image suggest that the free-free emission emanates from the shell of dust/PAH emission around object 11a.

enveloped by a diffuse region of 6 cm emission. Because of this 6 cm connection, we have labeled a third object (“5s”) as the combination of the two. Object 5s is designated in the 8 \mu m image. In the JHK_S images, we do not detect either of the objects. At H_{alpha}, a complex ionized gas morphology surrounds these objects. Object 5a is detected at H_{alpha} and the morphology around this

Fig. 11.—Near-UV, H_{alpha}, JHKS, IRAC, and MIPS images of object 11. Orientation and notation is the same as Fig. 1. The large circle in the 8 \mu m image designates object 11s. Object 11a is the stellar source, but the PAH/dust emission for this cluster is emanating from a shell around object 11a. The 6 cm contours superimposed on the 4.5 \mu m image suggest that the free-free emission emanates from the shell of dust/PAH emission around object 11a.

Fig. 12.—Near-UV, H_{alpha}, JHKS, IRAC, and MIPS images of object 12. Orientation and notation is the same as Fig. 1. Object 12 is found at the southwestern part of the uncertainty circle, is the source of the brightest 6 cm emission, and appears to have a spherical morphology.
point appears shell-like. Object 5b is the brightest Hα part of a shell-like complex south of the uncertainty circle. The UV and B (see Johnson et al. 2001) images show a point source in the center of the uncertainty circle that is not associated with objects 5a and 5b. This UV-optical point source is close to the center of object 5s.

**Object 6.**—In the 3.6 μm image of Figure 6, a starlike source is found at the southeastern portion of the uncertainty circle, and we term this object “6a.” Northeast of the uncertainty circle is a source of bright PAH and dust emission, which we term “6b.” In the MIPS 24 μm image, these sources are enveloped by diffuse emission and may be interrelated. In the other MIPS images, the dominant dust emission appears to be from object 6a.
| Object Name | R.A. (J2000.0) | Decl. (J2000.0) | $J$ (mag) | $H$ (mag) | $K_S$ (mag) | $J-H$ (mag) | $H-K_S$ (mag) | $F_{\nu}(H\alpha)$ ($10^{-3}$ Jy) | $F_{\nu}(0.1528 \mu m)$ ($10^{-5}$ Jy) | $F_{\nu}(0.2271 \mu m)$ ($10^{-5}$ Jy) |
|-------------|---------------|----------------|------------|------------|-------------|-------------|-------------|---------------------------------|---------------------------------|---------------------------------|
| 1.............| 1 33 02.6     | 30 46 46.1     | ...        | ...        | ...         | ...         | ...         | 0.85 ± 1.73                     | 0.772 ± 2.9                     |
| 2.............| 1 33 16.1     | 30 56 42.4     | 16.33 ± 0.14 | 16.3 ± 0.19 | 16.19 ± 0.24 | 0.028 ± 0.235 | 0.114 ± 0.308 | 8.27 ± 0.03                    | 78.4 ± 16.7                     | 67 ± 27                         |
| 3.............| 1 33 16.6     | 30 52 49.9     | 15.65 ± 0.1 | 14.81 ± 0.08 | 14.278 ± 0.08 | 0.847 ± 0.124 | 0.528 ± 0.112 | 17.8 ± 0.01                    | 23.3 ± 9.1                      | 21.8 ± 15.4                     |
| 4.............| 1 33 37.5     | 30 47 18.5     | >17.5      | >17.1      | >17.6       | ...         | ...         | <0.8                           | <0.08                           | <0.05                           |
| 5a........... | 1 33 39.1     | 30 38 08       | >17.3      | >17.6      | >17         | ...         | ...         | 1.92 ± 0.01                    | ...                             | ...                             |
| 5b........... | 1 33 39.3     | 30 38 02.2     | >16.5      | 16         | >15.5       | ...         | ...         | 4.47 ± 0.01                    | ...                             | ...                             |
| 5s........... | 1 33 39.2     | 30 38 03.4     | >16.5      | >16        | >15.5       | ...         | ...         | 12.7 ± 0.02                    | 62.8 ± 14.9                     | 68 ± 27                         |
| 6a........... | 1 33 43.6     | 30 39 05       | 16.43 ± 0.06 | 16.12 ± 0.18 | 15.61 ± 0.12 | 0.31 ± 0.19 | 0.51 ± 0.21 | 3.68 ± 0.02                    | <0.4                           | <0.3                            |
| 6b........... | 1 33 44       | 30 39 13.5     | >18.6      | >16.9      | >15.3       | ...         | ...         | <0.5                           | <0.4                           | <0.3                            |
| 6s........... | 1 33 44.1     | 30 39 03.5     | >14.4      | >16.9      | >16         | ...         | ...         | 14.2 ± 0.05                    | ...                             | ...                             |
| 7a........... | 1 33 48.1     | 30 39 18.2     | 16.49 ± 0.12 | 15.86 ± 0.2 | 15.04 ± 0.1 | 0.63 ± 0.23 | 0.82 ± 0.22 | 2.7 ± 0.008                    | <0.3                           | <0.2                            |
| 7b........... | 1 33 48.3     | 30 39 35.5     | 18.54 ± 0.96 | 16.5 ± 0.34 | 15.5 ± 0.15 | 2.04 ± 1.10 | 1 ± 0.37  | 3.85 ± 0.01                    | 6.4 ± 4.4                      | 4.94 ± 7.3                      |
| 8............ | 1 33 59.8     | 30 32 44.2     | >17.4      | >16.9      | >17.9       | ...         | ...         | 5.15 ± 0.007                   | 6.52 ± 4.8                     | 7.81 ± 9.2                      |
| 9............ | 1 34 09.2     | 30 40 47.5     | 16.16 ± 0.07 | 15.4 ± 0.08 | 14.32 ± 0.03 | 0.76 ± 0.1  | 1.08 ± 0.08 | 4.67 ± 0.01                    | <0.2                           | <0.2                            |
| 10a.......... | 1 34 02.6     | 30 38 38.7     | >16        | >13.8      | >14         | ...         | ...         | 6.9 ± 0.04                     | 23.7 ± 9.2                     | 25.7 ± 16.7                     |
| 10b.......... | 1 34 02      | 30 38 39       | >16        | >13.8      | >14         | ...         | ...         | 2.73 ± 0.02                    | <0.3                           | <0.3                            |
| 10s.......... | 1 34 02.2     | 30 38 40.8     | >16        | >13.8      | >14         | ...         | ...         | 27.4 ± 0.05                    | ...                             | ...                             |
| 11a.......... | 1 34 06.6     | 30 41 47.3     | 15.73 ± 0.05 | 15.98 ± 0.27 | 15.38 ± 0.07 | -0.25 ± 0.28 | 0.6 ± 0.28 | 4.98 ± 0.02                    | 102 ± 19                       | 79.9 ± 29.5                     |
| 11b.......... | 1 34 06.6     | 30 41 47.3     | >15.3      | >15.6      | >14.1       | ...         | ...         | 27.9 ± 0.02                    | ...                             | ...                             |
| 12............| 1 34 13.5     | 30 34 49.3     | >17.3      | >15.8      | >15.3       | ...         | ...         | 5.25 ± 0.01                    | 7.54 ± 5.17                    | 8.37 ± 9.55                     |
| 13............| 1 34 17.5     | 30 33 45.8     | >17.4      | >16.4      | >16         | ...         | ...         | 4.6 ± 0.01                     | <0.6                           | <0.4                            |
| 14a...........| 1 34 38.6     | 30 43 56.8     | 15.49 ± 0.02 | 15.01 ± 0.03 | 14.82 ± 0.02 | 0.479 ± 0.032 | 0.187 ± 0.033 | 3.22 ± 0.01                    | 72.1 ± 16                      | 70 ± 28                         |
| 14b...........| 1 34 39       | 30 43 55.1     | >15        | >14.6      | >14.5       | ...         | ...         | 8.21 ± 0.01                    | ...                             | ...                             |

Notes.—Units of right ascension are hours, minutes, and seconds, and the units of declination are degrees, arcminutes, and arcseconds. All magnitudes and fluxes have not been dereddened. Numbers after “±” are 1 $\sigma$ uncertainties.
In the 8 and 24 μm images, a shell of PAH emission is close to the radio position, which we label as object “6s.” Faint 6 cm emission surrounds objects 6a and 6b, but no compact emission is associated with either IR source. In the JHK_s images, we can detect object 6a only. The Hα morphology is quite complex with several shells around the radio position. Object 6a does not appear to have any Hα emission, while a few points of Hα emission coincident with object 6b. Hα emission appears to fill the cavity of object 6s. Object 6a is detected faintly in the B image of Johnson et al. (2001), and the celestial position is coincident with the H II region BCLMP 39/40. No UV emission is apparent for any of the objects.

Object 7.—This radio position is coincident with [GDK99] 91, and Gordon et al. (1999) claim that this object is a H II region. An IRAC and MIPS point source (object 7a) is found almost exactly at the radio position. No 6 cm compact radio emission from our maps is associated with this object. The object “7b” is found well north of the radio position and is a compact 6 cm source. At 70 μm object 7b dominates the emission. Perhaps object 7b is the compact radio source 7 from Johnson et al. (2001). Both objects are present in the JHK_s images and at Hα. The gas morphologies around those objects appear to be simply spherical for both objects. In the GALEX UV images, only object 7b is detected.

Object 8.—In the IRAC images, a bright source appears in the southeastern part of the uncertainty circle. No additional sources appear around the radio position in either MIPS or IRAC images. This bright IRAC source is also the source of the 6 cm emission. At 8 μm the source appears to be associated with a long extended line of PAH/dust emission. However, at Hα, this arc of emission disappears, and a simple sphere explains the Hα morphology. This source is also detected in the B image in Johnson et al. (2001), and the radio position is coincident with the H II region BCLMP 703. Some UV emission is also apparent for this object. We did not detect object 8 in the JHK_s images.

Object 9.—A bright point source appears in the uncertainty circle at all Spitzer wavelengths and in the JHK_s images. The 6 cm radio emission is also centered on this Spitzer source. A bright Hα source is found on top of the location of object 9. An arc of Hα emission is present to the north of object 9. This object is also detected in the B image of Johnson et al. (2001), and the radio position is coincident with the H II region BCLMP 79. No UV emission is apparent for object 9.

Object 10.—Two point sources appear at opposite edges of the uncertainty circle at 3.6 μm in Figure 10. We have termed the easternmost “10a” and the other “10b.” Object 10a dominates at 24 μm, while object 10b dominates the PAH emission at 8 μm. The 6 cm contours envelop both objects with some radio emission connecting the two points, similar to object 5. Thus, we have also labeled a set of flux measurements with “10s” for the combination of the two. No sources are detected in the JHK_s images. At Hα, both sources are on the edge of a shell-like complex of Hα emission. The center of this shell is devoid of Hα, but according to the 6 cm contours, some thermal radio emission is apparent. At Hα, these objects do not look interconnected as when looking at longer wavelengths. Object 10a is detected in the B image in Johnson et al. (2001), and the radio position is coincident with the H II region BCLMP 87. Near-UV and far-UV emission emanates from object 10a only but not from object 10b.

Object 11.—The only bright starlike source near the radio position is found in the northeastern part of the uncertainty circle in the 3.6 μm image in Figure 11. We have labeled this source as “11a.” However, the 6 cm contours of the brightest radio emission are not coincident with this object but are associated with a ring of dust/PAH emission found around the radio position uncertainty circle. This shell is labeled object “11s” in the 8 μm image. The bright dust/PAH sources in this circle are coincident with the 6 cm emission points. However, the B image of Johnson et al. (2001) shows a clear source in the middle of the uncertainty circle that we see only at UV. This source is not object 11a because we also detect object 11a in the UV image. The radio position is coincident with the H II region BCLMP 77.

Object 12.—The only source near the radio position is found in the southwestern part of the uncertainty circle in the 3.6 μm image of Figure 12. In the MIPS images this source appears to be the dominant dust emitter. The 6 cm contours also lie directly on top of object 12. Object 12 was not detected in the JHK_s images. At Hα object 12 appears to have a spherical morphology with no shell-like emission around the object. This object is also detected in the B image of Johnson et al. (2001), and the radio position is coincident with the H II region BCLMP 714. Object 12 is also detected at UV wavelengths.

Object 13.—In Figure 13 bright 3.6 μm source is found in the middle of the uncertainty circle. In the MIPS and IRAC images, no other dominant source exists around the radio position. The 6 cm contours are also coincident with the IR source. The Hα emission appears spherical for object 13. A crescent-shaped object is located inside the uncertainty circle in the northeastern portion of the B image in Johnson et al. (2001), and the radio position is coincident with the H II region BCLMP 712. Some UV emission is found to the south of the uncertainty circle but is not associated with object 13.

Object 14.—A starlike source appears in the southwestern part of the uncertainty circle (see the 3.6 μm image of Fig. 14). We have termed this object “14a.” The dust and PAH emission in MIPS and IRAC images appear to be in a cometary V shape to the south of the radio position. Assuming that this V-shaped dust/PAH emission is related, we have labeled it “14s” and provided a circle for reference in the 8 μm image. The 6 cm contours in the 4.5 μm image show no significant radio emission around this object. Some faint emission is associated with object 14a, but no 6 cm emission appears to be associated with object 14s. At Hα the cometary emission of object 14s at 8 μm is only a small portion of the shell of Hα emission around object 14a. This shell of emission is oblong with the major axis along the northeast. No Hα emission is associated with object 14a. Object 14a is also detected in the B image of Johnson et al. (2001), and the radio position is coincident with the H II regions BCLMP 749/750. Object 14a is detected at UV wavelengths.

3.2. Aperture Photometry of the Radio-selected Objects in M33

The aperture used in the near-IR (SQIID and 2MASS), IRAC, Hα, and GALEX UV images for the starlike objects (i.e., those that are not shell apertures) had a radius of 7″. The inner and outer radii of the sky annulus for background subtraction were 7″ and 14 ″, respectively, making the sky area greater than that of the aperture. For object 2, a significant bipolar nebula is present in Hα that is not seen with the Galex data. For deriving a Hα flux, we extended the sky annulus well outside this large nebula to remove only sky emission. The shell apertures (i.e., those termed with a “s”) along with their sky annulus are much larger and set on an individual basis to encompass the brightest emission from these shells. Aperture photometry for the “s” designated objects was not done with the GALEX UV data, but it was done for the Hα images since the shells were detected at Hα. The JHK_s magnitudes and colors as well as Hα and UV fluxes are presented in Table 1. These magnitudes, colors, and fluxes are not corrected for Galactic or internal reddening. For those...
sources not detected in any of the JHK$_{S}$, H$_{o}$, or UV images, we give 3 $\sigma$ upper limits for the fluxes and lower limits for magnitudes.

Aperture corrections were mandatory for all IRAC fluxes. We generated our own aperture corrections for our specific aperture sizes using the theoretical point spread function (PSF) images provided by the SSC.\textsuperscript{14} Since the aperture and sky annulus were constant for all starlike IRAC photometry, the multiplicative values are 1.135, 1.14, 1.176, and 1.285 for IRAC 3.6, 4.5, 5.8, and 8 $\mu$m, respectively. Aperture corrections for the shell photometry were also generated with the theoretical PSF images and are $\sim$1. See Table 2 for the IRAC fluxes.

For the MIPS images, we used a constant aperture of 48$''$ for all three channels. This aperture size is the smallest reasonable aperture size for the 160 $\mu$m images where the FWHM is $\sim$40$''$. Sky subtraction was also performed with the area of the sky annulus greater than or equal to the area of the source aperture. The MIPS science images were in the units of DN s$^{-1}$. The conversion factors from DN s$^{-1}$ to $\mu$Jy arcsec$^{-2}$ were 1.032, 14,900, and 1000 for the 24, 70, and 160 $\mu$m images, respectively. Aperture corrections were also mandatory for all MIPS fluxes. We generated the aperture corrections from theoretical PSF images\textsuperscript{15} using the same size apertures and sky subtraction areas as those used for the MIPS photometry. These aperture corrections were 1.13, 1.61, and 1.89 for the 24, 70, and 160 $\mu$m images, respectively. The MIPS fluxes for the objects are given in Table 2. Because the resolution of the MIPS images is lower than those of IRAC and SQIID/2MASS, the MIPS fluxes are given in the shell designation for those objects with shells (e.g., 11s) or the best possible candidate (e.g., object 3).

3.2.1. Uncertainties

Uncertainties for all fluxes and magnitudes are given. For the IRAC fluxes, the uncertainties account for Poisson noise, variation in the background, correction for correlation in the sub-sample images, and $\pm$6% uncertainty caused by flux calibration. For the MIPS fluxes, the uncertainties accounted for are similar to those for IRAC, but the flux calibration uncertainty is $\pm$10% for MIPS 24 $\mu$m and $\pm$20% for MIPS 70 and 160 $\mu$m. For the JHK$_{S}$ magnitudes, H$_{o}$ fluxes, and UV fluxes, we account for Poisson noise and variation in the background. These uncertainties are presented in Tables 1 and 2.

3.3. Extinctions, Ages, and Masses Derived From the JHK$_{S}$ Images

In Figure 15 we plot the colors of the nine radio-selected objects with JHK$_{S}$ detections in all three bandpasses. Also plotted are the $J - H$ and $H - K_{S}$ colors as derived from the Starburst 99 (ver. 4.0) SEDs (Leitherer et al. 1999). The important parameters for these instantaneous burst models are fixed stellar masses of 10$^{6}$ $M_{\odot}$, upper and lower stellar mass limits of 100 and 1 $M_{\odot}$, and a Salpeter initial mass function (IMF). The solid line shows model colors for a metallicity of Z = 0.008. The dashed line shows model colors for a metallicity of Z = 0.02. The metallicity of each object was estimated using the M33 oxygen abundance gradient equation from Garnett et al. (1997). To derive the metallicities, we assumed that the objects’ metallicities relative to solar were proportional to the ratio of their oxygen abundances. Since Starburst 99 models have only a few discrete metallicities, we used the closest Starburst 99 metallicity, typically Z = 0.008 or 0.02.

We do not use the colors for object 2 to derive extinctions, ages, and masses because the colors found for object 2 are for the Wolf-Rayet star. Thus, the central photoionizing source is not a star cluster. We could not determine colors for objects 1, 4, 5, 8, 12, and 13 because they are not detected in all three near-IR bands.

\textsuperscript{14} 2004 January In-Flight PSF images downloaded from http://ssc.spitzer.caltech.edu/irac/psfhtml.\textsuperscript{15} Downloaded PSF images from http://ssc.spitzer.caltech.edu/mips/psffits/ on 2004 April.
3.3.1. Extinctions

Extinction measurements were estimated for seven objects by extrapolating the measured colors back along the reddening vector to the unreddened Starburst99 model colors. We know the cluster’s color, the slope of the extinction vector (Schlegel et al. 1998), and the theoretical colors. The distance between the cluster color and unattenuated model color was converted into a $K_S$ extinction, $A_{K_S}$ (Schlegel et al. 1998). The results of these extinction derivations are found in Table 3, and the values range from $A_{K_S}$ of 0.23 to 1.31 mag. These extinctions, as well as all other derived extinctions, have not had Galactic reddening removed. The $K_S$ extinction caused by the Galaxy is 0.015 mag approximately (Schlegel et al. 1998). Thus, the actual range of reddening caused by the star clusters and M33 is 0.21–1.29 mag.

3.3.2. Ages

All points on the Starburst 99 model track have an associated age. Moving the observed cluster colors back along the reddening vector, the observed colors yield an estimate of the cluster age. The 1 $\sigma$ age uncertainties are based from the 1 $\sigma$ color uncertainties. The cluster ages and their uncertainties are given in Table 3 and range from 2 to 10 Myr (i.e., young clusters).

We could not derive an age for cluster 9 because the cluster shows a significant $H - K_S$ excess indicative of dust emission and/or emission lines. These excesses have been seen in star clusters with ages less than 6 Myr (Buckalew et al. 2005). Thus, by comparison to previous results, we conclude that the $H - K_S$ excess implies an age for cluster 9 of less than 6 Myr.

3.3.3. Masses

Once the extinctions and ages are known, we can use a similar procedure to the one outlined in Buckalew et al. (2005) to derive the masses. Instead of using the blue absolute magnitudes, we use unreddened absolute $JHK_S$ magnitudes to derive the stellar masses. We compared our derived absolute magnitudes with those derived from the $10^8 M_\odot$ Starburst99 model at the appropriate age and metallicity. The scaling factor between the model’s absolute magnitude and the one that we derived gave us the scaling factor to apply to the mass. Multiplying the scaling factor

![Fig. 15.—$JHK_S$ color-color diagram of eight objects. The legend at the upper left indicates which symbol goes with which object. Uncertainties are 1 $\sigma$ in length for all colors. The connected crosses show the evolutionary model tracks for instantaneous star forming bursts from Starburst99 for metallicity $Z = 0.008$ (solid line) and for metallicity $Z = 0.02$ (dotted line). Crosses along the model tracks indicate ages in step of 1 Myr. Specific ages are labeled along the tracks (0, 6, 10, and 20 Myr). The arrow to the right shows the reddening vector for $A_f = 5$.](image)

### Table 3

| Object Name | $A_{K_S}$ (mag) | $A_{H_\alpha}$ (mag) | $A_{0.2271}$ (mag) | $A_{0.1528}$ (mag) | Stellar Age (Myr) | log (Stellar Mass) [$\log (M_\odot)$] | Dust Temperature (K) | Dust Mass ($M_\odot$) |
|-------------|-----------------|---------------------|-------------------|-------------------|-------------------|---------------------------------|--------------------|----------------------|
| 1           |                 |                     |                   |                   |                   | 64(35)                         | 12(330)             |
| 2           |                 |                     |                   |                   |                   | 64(35)                         | 12(330)             |
| 3           | 0.84            | 2.01                | 3.88              | 4.2               | 7.5               | 3.5                            | 87(44)             | 31(810)              |
| 4           |                 |                     |                   |                   |                   | 66                             | 12                 |                      |
| 5           |                 |                     |                   |                   |                   | 66                             | 12                 |                      |
| 6           | 0.23            | 1.8                 |                   |                   |                   | 3.3                            |                   |                      |
| 7           |                 |                     |                   |                   |                   | 61                             | 22                 |                      |
| 8           |                 |                     |                   |                   |                   | 66                             | 16                 |                      |
| 9           | 0.68            | 3.4                 |                   |                   |                   | 92                             | 1.5                |                      |
| 10          |                 |                     |                   |                   |                   | 65(40)                        | 55(980)            |
| 11          | 0.79            | 1.65                | 0.686             | 1.9               | 7.5               | 3.2                            |                   |                      |
| 12          |                 |                     |                   |                   |                   | 57                             | 64                 |                      |
| 13          |                 |                     |                   |                   |                   | 61                             | 15                 |                      |
| 14          | 0.3             | 1.76                | 0.15              | 0.43              | 7.5              | 3.4                            |                   |                      |
| 15          |                 |                     |                   |                   |                   | 56                             | 27                 |                      |

**Notes:** Numbers after “$\pm$” are 1 $\sigma$ uncertainties. Extinctions recorded in this table do not have the Galactic reddening component removed (an $A_{K_S}$ of 0.015 mag). $A_{K_S}$ is derived from the distance between the Starburst99 model $JHK_S$ colors and the reddened $JHK_S$ colors. $A_{H_\alpha}$ is derived from the radio and $H_\alpha$ fluxes used in the equation from Caplan & Deharveng (1986). $A_{0.1528}$ and $A_{0.2271}$ were derived by comparing Starburst99 fluxes at these wavelengths with those measured (see Table 1 for UV fluxes). Dust temperature and dust masses found in the parentheses are the second results from the two blackbody fits.
to the model mass gives us the derived stellar mass for the cluster. Table 3 lists these masses, which have a range of $10^3$–$10^{3.5}$ $M_\odot$.

### 3.4. Spectral Energy Distributions

The UV to mid-IR SEDs are plotted in Figures 16, 17, and 18. The size of the symbols used in the SEDs are equivalent to the flux uncertainties. Upper limits are given as downward-pointing arrows. Using these SEDs, we model the free-free and dust emission around these objects.

#### 3.4.1. Dust Emission

Using the three MIPS flux results, we derive dust masses and temperatures. We derive the dust temperature using simple blackbody fits of the three MIPS fluxes. With only three data points, amplitude and dust temperature are the free parameters. In some cases, the data were best fit by two blackbodies with the same amplitude but different temperatures. The best fit was found for the set of parameters that minimized the residuals between the model and measured fluxes. Two blackbodies were only used when such a fit produced a factor of 10 decrease in the residuals (objects 2, 3, and 10). The best-fit temperatures are found in Table 3 and range between 60 and 90 K.

Dust masses were calculated using the procedure outlined in Dale et al. (2001a). If only one temperature was used to model the dust emission, the MIPS 70 $\mu$m flux was used to calculate the dust mass. If two blackbodies provided a better fit, the MIPS 70 and 160 $\mu$m fluxes were used to derive the dust masses with the 70 $\mu$m flux used for the hotter of the two temperatures. The dust masses are given in Table 3 and range between 1 and 1000 $M_\odot$.

### 3.5. Extinctions from H\alpha and UV Fluxes

Using the H\alpha fluxes from Table 1 and radio fluxes from Johnson et al. (2001), we calculate H\alpha extinctions using the equations detailed in Caplan & Deharveng (1986). We assume a temperature of the H\alpha region of 10,000 K, an $N(\text{He}+)/N(\text{H}^+)$ of 0.1, densities of 100 cm$^{-3}$, and 100% thermal emission at 6 and 20 cm.

We compute extinctions for H\alpha using both the 20 cm and 6 cm fluxes from Johnson et al. (2001). We present the average H\alpha extinctions ($A_{\text{H\alpha}}$) in Table 3. The extinctions range from 0.72 to 3.46 mag. Extrapolating these extinctions to $A_{\text{Ks}}$ equivalents using the extinction law from Schlegel et al. (1998) and removing Galactic reddening, the range of $A_{\text{Ks}}$ extinctions is 0.081–0.44 mag.

We computed UV extinctions by comparing the measured UV emission of the objects to GALEX FUV and NUV fluxes calculated from Starburst 99 SEDs. The important parameters (metallicity, stellar mass, and age) for each SED came from the results derived with the JHKS colors and magnitudes. The other standard parameters of Starburst 99 were assumed (Salpeter IMF, etc.) as they were detailed in §3.3. The GALEX system response curves were taken from the GALEX data handbook. The fluxes generated with the filter response curves and Starburst 99 SEDs were assumed to be the unreddened FUV and NUV fluxes. Ratioing the measured and model fluxes, we calculate extinctions for 0.2271 and 0.1528 $\mu$m ($A_{0.2271}$ and $A_{0.1528}$) and present these extinctions in Table 3. Three objects had the necessary UV fluxes and JHKS ages and masses to derive these extinctions. The values of $A_{0.2271}$ are 3.88, 0.686, and 0.15 mag, and the values of $A_{0.1528}$ are 4.2, 1.9, and 0.43 mag for objects 3, 11a, and 14a, respectively. Converting these to equivalent $A_{\text{Ks}}$ extinctions using a factor of 15 (based on the $A_{\text{K}}/A_K$ from Schlegel et al. 1998) and removing Galactic reddening, the $A_{\text{Ks}}$ range is 0–0.26 mag.
4. DISCUSSION

4.1. Morphologies of the Radio-selected Objects

These objects in M33 exhibit a diversity of PAH/dust morphologies in the IRAC 5.8 and 8 μm images and the MIPS 24 μm image. We combine these IR morphologies with the morphologies seen at Hα to determine a multiwavelength classification of the morphologies. We find that a simple classification scheme of shell and spherical morphologies applies best to these objects. Objects 3, 7, 8, 9, 12, and 13 are classified as spherical, and objects 2, 5, 6, 10, 11, and 14 are classified as shells. We present an IRAC color-color diagram in Figure 19 using the 8, 5.8, and 4.5 μm fluxes from Table 2 for all objects. The MIPS fluxes from Table 2 are plotted in the color-color diagram in Figure 20. We conclude that no clear separation of the different morphologies can be discerned from either color-color figure.

3.6 μm. Object 6a is one of the youngest star clusters in this sample with an age of 3 Myr, and its derived stellar mass is $10^{3.3} M_\odot$. The dust mass derived for this system is $22 M_\odot$ at a temperature of 61 K. The derived extinctions from the $JHK_S$ and Hα images are similar ($A_K$ extinctions of 0.23 mag and equivalent $A_K$ of 0.24 mag, respectively).

Object 7.—Object 7a is a point source found at the exact location of the radio position. However, object 7b is also a bright point source and has bright 6 cm contours on top of its position (something not seen with object 7a; see Fig. 7). We find that object 7a has a very young age of 2 Myr and a stellar mass of $10^{3.7} M_\odot$. Object 7b is older at an age of 10 Myr and a stellar mass of $10^4 M_\odot$. The dust characteristics, which we derive for the synthesis of the two dominant objects, are a dust temperature of 73 K and mass of 7.6 $M_\odot$. Object 7a is detected at Hα but not UV. Object 7b is detected at both wavelengths. The $JHK_S$ extinction for object 7a is 1.4 times higher than that derived from Hα ($A_K$ extinctions of 0.54 mag and equivalent $A_K$ of 0.14 mag, respectively). The $JHK_S$ extinction for object 7b is 3 times higher than the extinction derived from Hα ($A_K$ of 1.31 mag and equivalent $A_K$ of 0.09 mag, respectively). The UV extinction derived for object 7b is 2.5 times smaller than that from the $JHK_S$ images ($A_K$ of 0.31 mag and equivalent $A_K$ of 1.31 mag, respectively).

Object 8.—Object 8 is a bright ellipsoid found at the southeastern section of the uncertainty circle (see Fig. 8). The point source is found along a line of unassociated extended 8 μm emission. Because the object was not detected in the $JHK_S$ images, no stellar mass, age, or extinctions were derived. We derived an $A_\text{Hα}$ of 0.36 mag. The dust characteristics are typical with a temperature of 66 K and a mass of 16 $M_\odot$.

Object 9.—This object is a strong, compact source at all infrared wavelengths and is coincident with the 6 cm radio contours (see Fig. 9). The $JHK_S$ color-color diagram in Figure 15 shows that this cluster candidate has a significant $H - K_S$ excess. The unusually red $H - K_S$ of 1.1 mag may be caused by emission from hot dust or nebular lines in the K band (see Buckalew et al. 2005) and implies an age less than 6 Myr. The $J - H$ of 0.8 mag is attributable to extinctions of at least $A_K \sim 0.68$ mag. The $JHK_S$ extinction is 1.2 times higher than the $A_K$ equivalent extinction derived from Hα. Assuming an age of 6 Myr, we find that the stellar mass is $10^{4.4} M_\odot$, the highest in the sample. The dust characteristics of this object are odd with a dust temperature of 95 K, the hottest in the sample, and mass of 1.5 $M_\odot$, the smallest in the sample.

![Fig. 19.—IRAC color-color diagram of the M33 radio-selected objects. The different symbols represent the morphologies discussed in § 4.1. Note that no clear separation occurs in the IRAC colors for the different morphologies.](image-url)
Object 10.—Object 10 is classified as having a shell-like morphology because of its multiple-peaked but associated dust/PAH sources, similar to object 5. Because objects 10a, 10b, and 10s were not detected in the JHK_s images, no stellar mass, age, or extinctions were derived. The extinctions at H_o were the only ones derived and had the values of 2.45, 3.46, and 0.96 mag for objects 10a, 10b, and 10s, respectively. The dust characteristics of this system were best fit with two blackbodies with temperatures of 65 and 40 K and with masses of 55 and 980 M_☉.

Object 11.—Object 11a is a stellar source inside a shell of dust/PAH emission termed object 11s. This shell is also the object that is associated with the 6 cm emission (see Fig. 11). The A_K_s of 0.79 mag from the JHK_s images is 1.7 times larger than that derived from H_o (equivalent A_K_s of 0.22 mag). The UV extinctions are 2 times smaller than that derived from the JHK_s images. The star cluster has an age of 7 Myr and a mass of 10^{12} M_☉. The dust characteristics are a temperature of 57 K and a mass of 64 M_☉. The overall morphology of this object suggests the presence of a UV-bright star cluster at the center of a wind-blowen shell, illuminating the surrounding ISM, which emits strongly at mid and far-IR wavelengths. Based on the age and morphology, this star cluster has similar results to old (an age greater than 6 Myr) star clusters from Buckalew et al. (2005).

Object 12.—Object 12 is a spherical source detected from the UV to mid-IR. We could not derive the stellar properties. The extinction from H_o implies a A_K_s of 0.21 mag, not a large extinction for an embedded source. The dust properties of this source are 15 M_☉ at 61 K.

Object 13.—Object 13 is not seen at near-IR nor UV but appears as a pointlike source at MIPS, IRAC, and H_o. The H_o extinction of object 13 is A_H_o = 1.44 mag. The dust properties of object 13 are a temperature 58 K and a mass of 23 M_☉.

Object 14.—A starlike source (object 14a) appears just outside the southwestern part of the uncertainty circle in Figure 14. Object 14a is surrounded by a cometary PAH/dust emission and a shell of H_o emission. The age of object 14a is 7.5 Myr, and the stellar mass derived is 10^{3.4} M_☉. Such an old star cluster should have a more evolved (i.e., shell-like) morphology (see Buckalew et al. 2005). The extinction from JHK_s is 1.06 times larger than the H_o extinction for object 14a. The UV extinction of object 14a is 1.2 times lower than that from the JHK_s images. The dust properties of object 14 are a temperature of 56 K and a mass of 27 M_☉.

5. SUMMARY

These radio-selected objects were thought to be embedded young star clusters, possibly larger analogs to ultracompact H II regions. We have observed the positions of these radio-selected objects in M33 from the UV to the mid-IR. We have detected the majority of the radio-detected candidates at all of these wavelengths. These 11 radio-detected star clusters (excluding objects 1, 2, and 4) are young, when O stars are still present, but appear to have ages and extinctions that place them in the detectable limits of optical images. All 11 star clusters are known optical H II regions.

Using the near-IR data, we derived ages, extinctions, and masses. For the limited age results, they range from 2 to 10 Myr. The stellar masses derived from the near-IR data are typically 10^{3}–10^{4} M_☉. Fluxes from the Spitzer MIPS data were used to generate the dust properties of these clusters. We find dust masses ranging from 1 to 1000 M_☉ and temperatures between 60 and 90 K. At optical and UV wavelengths, we detected the majority of clusters at H_o, 2271 Å, and 1528 Å. The free-free radii and densities range from 5 × 10^{17} to 20 × 10^{17} cm and from 1500 to 9000 cm^{-3}. Extinctions were derived from the radio, JHK_s, H_o, and UV fluxes, range from equivalent A_K_s values of 0 to 1.29 mag (removing Galactic reddening). For an individual object, the maximum difference between various A_K_s measurements is a factor of 1.6 on average (3 at worst), and considering our assumptions for calculating the extinctions and the uncertainties of the data, these factors are acceptable (see §§ 3.3.1 and 3.5 and Table 3). More data and modeling are required to determine what causes these variations: geometry or model assumptions.

The H_o/Spitzer morphologies show no differences in their IRAC and MIPS colors. Half the objects have a young (i.e., spherical) morphology, while the others have an older (i.e., shell) morphology. Objects 1, 4, 6, 9, and 13 are not detected in the UV, possibly indicating larger amounts of extinction than the rest. Objects 1 and 4 are the background objects. Objects 9 and 13 are also those with spherical morphologies, while object 6 has a shell morphology but young (3 Myr) age.

In general, 11 of the 14 objects in this radio-selected sample are optically detected star clusters. We must conclude that radio detections of pointlike thermal sources do not show embedded star clusters, but the brighter free-free emitting H II regions within M33. We propose that infrared images (e.g., MIPS 24 μm) must be used to discern which objects in a galaxy are enshrouded in their natal molecular cloud material. These 24 μm sources must be checked with optical data (e.g., UBVRI and/or H_o) to determine those that are truly embedded.

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REFERENCES

Boulesteix, J., Courtes, G., Laval, A., Monnet, G., & Petit, H. 1974, A&A, 37, 33 (BCLMP)
Buckalew, B., Kobulnicky, H., & Dufour, R. 2005, ApJS, 157, 30
Calzetti, D., Harris, J., Gallagher, J., III, Smith, D., Conselice, C., Homeier, N., & Kewley, L. 2004, AJ, 127, 1405
Caplan, J., & Deharveng, L. 1986, A&A, 155, 297
Cutri, R., et al. 2003, Explanatory Supplement to the 2MASS All Sky Data Release (Pasadena: Caltech)
Dale, D., Helou, G., Neugebauer, G., Soifer, B., Frayer, D., & Condon, J. 2001, AJ, 122, 1736
Duric, N., Viallefond, F., Goss, W., & van der Hulst, J. 1993, A&AS, 99, 217
Fazio, G., et al. 2004, ApJS, 154, 10
Garrett, D., Shields, G., Skillman, E., Sagan, S., & Dufour, R. 1997, ApJ, 489, 63
Gordon, S., Duric, N., Kirshner, R., Goss, W., & Viallefond, F. 1999, ApJS, 120, 247
Hawarden, T., Leggett, S., Letawsky, M., Ballantyne, D., & Casali, M. 2001, MNRAS, 325, 563
Hinz, J., et al. 2004, ApJS, 154, 259
Hodge, P., Skelton, B., & Ashizawa, J. 2002, An Atlas of Local Group Galaxies (Dordrecht: Kluwer)
Jarrett, T., Chester, T., Cutri, R., Schneider, S., & Huehra, J. 2003, AJ, 125, 525
Johnson, K., Kobulnicky, H., Massey, P., & Conti, P. 2001, ApJ, 559, 864
Leitherer, C., et al. 1999, ApJS, 123, 3
Makovoz, D., & Khan, I. 2005, in ASP Conf. Ser. 347, Astronomical Data Analysis Software Systems XIV, ed. P. L. Shopbell, M. C. Britton, & R. Ebert (San Francisco: ASP), 81
Massey, P., & Conti, P. 1983, ApJ, 273, 576
Massey, P., Hodge, P., Holmes, S., Jacoby, G., King, N., Olsen, K., Smith, C., & Saha, A. 2002, BAAS, 34, 1272
Reike, G., et al. 2004, ApJS, 154, 25
Schlegel, D., Finkbeiner, D., & Davis, M. 1998, ApJ, 500, 525