AUSTRALIA TELESCOPE COMPACT ARRAY SURVEY OF CANDIDATE ULTRACOMPACT AND BURIED H II REGIONS IN THE MAGELLANIC CLOUDS

Rémy Indebetouw and Kelsey E. Johnson
Department of Astronomy, University of Wisconsin, 475 North Charter Street, Madison, WI 53705; remy@astro.wisc.edu, kjohnson@astro.wisc.edu

AND

Peter Conti
JILA, University of Colorado, 440 UCB, Boulder, CO 80309; pconti@jila.colorado.edu

Received 2003 December 3; accepted 2004 July 21

ABSTRACT

We present a systematic survey for ultracompact (UC) H ii regions in the Magellanic Clouds. Understanding the physics of massive star formation (MSF) is a critical astrophysical problem. The study of MSF began in our Galaxy with surveys of UC H ii regions, but before now this has not been done for other galaxies. We selected candidates on the basis of their Infrared Astronomical Satellite (IRAS) colors and imaged them at 3 and 6 cm with the Australia Telescope Compact Array. Nearly all of the observed regions contain compact radio sources consistent with thermal emission. Many of the sources are related to optically visible H ii regions, and often the radio emission traces the youngest and densest part of the H ii region. The luminosity function and number distribution of Lyman continuum fluxes of the compact radio sources are consistent with standard stellar and cluster initial mass functions. This type of systematic assessment of IRAS diagnostics is important for interpreting Spitzer Space Telescope data, which will probe similar physical scales in nearby galaxies as IRAS did in the Magellanic Clouds.

Key words: H ii regions — Magellanic Clouds — stars: formation

1. INTRODUCTION

Massive stars play a major role in the dynamical evolution of galaxies: they are responsible for the ionization of the interstellar medium, their stellar winds and supernovae are dominant sources of mechanical energy, their ultraviolet radiation powers far-infrared (FIR) luminosities through the heating of dust, and they are a main driver of chemical evolution in the universe via supernova explosions at the end of their lives. However, despite the significant role of massive stars throughout the universe, their birth is not well understood, and we are only beginning to piece together a scenario for the youngest stages of massive star evolution. We have made some progress understanding the early stages of massive star formation in the Galaxy, but the current knowledge about the early stages of massive star evolution in other environments is mediocre at best.

The reasons for this dearth of information about extremely young massive stars in other galaxies are predominantly two-fold: (1) the earliest stages of massive star evolution are deeply enshrouded and inaccessible in the optical and near-infrared (NIR) regimes, and (2) high spatial resolutions are necessary to disentangle the individual massive stars from their surrounding environment and background contamination. Radio observations using the Australia Telescope Compact Array (ATCA) are uniquely capable of overcoming these obstacles for the galaxies nearest to our own, the Large and Small Magellanic Clouds. Synthesis imaging observations at centimeter wavelengths are sensitive to the free-free emission emitted by the densest compact ionized regions, and the centimeter spectral index can be used to differentiate those extremely dense regions suffering from self-absorption.

We have conducted a survey of candidate ultracompact (UC) H ii regions in the Magellanic Clouds with high (1''–2'') spatial resolution at 3 and 6 cm using the ATCA. Section 2 contains a description of the FIR-based candidate selection, the radio observing strategy, and the data reduction and lists the detected sources. The statistical properties of the population as a whole are analyzed in § 3, and individual compact H ii regions with interesting radio morphologies are described in the Appendix.

2. OBSERVATIONS

2.1. Far-Infrared Target Selection

One goal of this project was to test the effectiveness of using FIR colors at fairly low spatial resolution to discover massive protostellar objects. This exercise using IRAS data in the Magellanic Clouds is particularly interesting because the Spitzer Space Telescope probes similar spatial scales in nearby galaxies as IRAS did in the Magellanic Clouds.

The primary target selection criterion for this survey was thus FIR color. Wood & Churchwell (1989b, hereafter WC89) determined that the majority of Galactic UC H ii regions have particular mid- to far-infrared colors that distinguish them from other astronomical objects. They indicated (their Fig. 1b) that most sources with IRAS colors $F_{\nu}(60 \mu m)/F_{\nu}(12 \mu m) \geq 20$ and $F_{\nu}(25 \mu m)/F_{\nu}(12 \mu m) \geq 3.7$ are UC H ii regions. (These colors correspond to blackbody temperatures $\leq$105 and $\leq$160 K, respectively.) More importantly in the context of this work, they found that there was little color contamination; compared with a random selection of Galactic IRAS sources, most of the objects in that region of color-color space were UC H ii regions.

To exploit this fact, we first combined the IRAS Point Source Catalog with a multiwavelength Parkes radio continuum survey (Filipović et al. 1998 and references therein). The Parkes surveys have a resolution of 2'8 at 8.55 GHz (which
corresponds to a linear distance of ~49 pc in the SMC and ~41 pc in the LMC), so we took as a match to each radio source the brightest IRAS source within 2.5. We then examined the FIR-to-radio spectral energy distribution of all the objects with slightly broader colors than the WC89 criteria: \( F_{24\mu m}/F_{12\mu m} > 1 \) and \( F_{60\mu m}/F_{12\mu m} > 10 \). This sample contained 98 objects in the LMC (47 with the stricter WC89 colors) and 22 in the SMC (eight with WC89 colors). Finally, we chose those targets that were consistent with having flat or inverted radio emission at \( \lambda \sim 1-5 \text{ cm} \). Thus, our sample is FIR-color–selected, but objects that are highly nonthermal at centimeter wavelengths at the resolution of the Parkes survey are excluded. This last criterion was imposed to create a bias against supernova remnants and other sources of nonthermal emission. Sources consistent with optically thin thermal emission (slightly negative spectral index \( \alpha \sim -0.1 \), where \( F_{\nu} \propto \nu^\alpha \) were kept as candidates under the presumption that H II regions observed at low resolution are dominated by the optically thin envelopes but may still contain compact, more optically thick sources. Figure 1 shows our target objects in an IRAS color-color space identical to that of WC89’s Figure 1b. The two targets that fall farthest outside of the color selection box were cases for which the IRAS flux densities or identification were ambiguous.

2.2. Radio Observations and Data Reduction

Candidate fields were observed with the ATCA during two runs in 2001 May and 2002 May. Simultaneous observations were obtained at 3 cm (8.6 GHz) and 6 cm (4.8 GHz) in the highest resolution configurations (6F in 2001, 6A in 2002). Each field was observed for roughly 3 hr, with some time added for a few of the faintest fields. We observed 17 of the 29 selected fields in the LMC and seven of the eight selected fields in the SMC. For some of the fields, archival data were available, which allowed compact sources to be tabulated for three additional candidates. Our observations are summarized in Table 1, and the archival observations, which we completely re-reduced for consistency, are summarized in Table 2.

The receivers simultaneously detect 4800 MHz (~6 cm) and 8640 MHz (~3 cm), with primary beams (fields of view) of \( 10' \) and \( 5' \), respectively. Each frequency had a bandwidth of 128 MHz, and the resulting theoretical rms noise for these observations is \( \approx 0.07 \text{ mJy beam}^{-1} \). The absolute flux density scale was determined by assuming a flux density for PKS B1934–638 of 5.83 Jy at 4.8 GHz and 2.84 Jy at 8.6 GHz, and we estimate that the resulting flux density scale is uncertain by less than \( \approx 5\% \).

Calibration was carried out using the MIRIAD data reduction package, including gain, phase, and polarization calibrations of the flux density calibrator and phase calibrators. Following the calibration, data were loaded into the Astronomical Image Processing System (AIPS), where they were inverted and cleaned using the task IMAGR. In order to optimize the synthesized beam at 4.8 GHz, a fairly uniform weighting was used (robust = 0), whereas a more natural weighting was used at 8.6 GHz (robust = 3) in order to increase the sensitivity. In addition, the \( u-v \) range of the 4.8 GHz data was limited in order to better match the shortest \( u-v \) coverage of the 8.6 GHz data. It should be noted that this does not create matched beams at 3 and 6 cm but simply mitigates the influence of extended structures at 6 cm; the 6 cm observations still have denser \( u-v \) coverage at short spacings, and the 3 cm observations still have \( u-v \) coverage at long spacings not available in the 6 cm observations. On the basis of the resulting \( u-v \) coverage, the largest angular scales to which these data are sensitive are \( \lesssim 30'' \) at 6 cm and \( \lesssim 20'' \) at 3 cm. The images at both frequencies were then corrected for the primary beam sensitivity.

Radio flux densities were measured in AIPS++ using two methods. The first method used the VIEWER program to place identical apertures around the 3 and 6 cm images, and background levels were estimated using surrounding annuli. Several combinations of apertures and annuli were used in order to estimate the uncertainty in the flux density. The second method used the IMAGEFITTER to fit two-dimensional Gaussians to the sources. Final flux densities were determined by averaging these results, and the uncertainties were determined from the scatter of these results in combination with the uncertainty in the absolute flux density scale. Because the quoted uncertainties reflect the scatter from determining flux densities in different ways, in some cases the relative uncertainties between the flux densities at 3 and 6 cm are smaller than the absolute uncertainty for either determination. The final flux densities and spectral indices are listed in Tables 3 and 4. It is important to note that for resolved objects, the calculated spectral indices may be lower limits (in the sense of objects appearing less optically thick than they truly are), depending on the geometry of the source; the observations are more sensitive to large-scale optically thin emission at 6 cm than at 3 cm, and the synthesized beams were \( \sim 1''5 \) at 3 cm and \( \sim 2''0 \) at 6 cm.

High-resolution (6 km configuration) archival data were available for a few additional fields, and the sources detected in these data are included in Tables 3 and 4, identified with their Australia Telescope National Facility (ATNF) program number. In some cases, the archival data were centered a few arcminutes (a significant fraction of the primary beam) away from our pointing, so the same sources are detected, but the errors are significantly lower in the pointing for which the source in question is nearer the center of the primary beam. The quality
Archival observer.

The data reduction and error assessment was performed identically to our data; cases in which the calibration was suspect are omitted, and cases in which we feel secondary phase calibrator during periods of varying atmospheric conditions. The data reduction and error assessment was performed identically to our data; cases in which the calibration was suspect are omitted, and cases in which we feel

3. THE POPULATION OF DETECTED SOURCES

Many of the compact H II regions detected in this survey are associated with optically identified H II regions. This fact is not

### Table 1
**New Observations**

| Target  | R.A. (J2000) | Decl. (J2000) | Date        | Exp. Time (minutes) | Config. | Phase Calibrator(s) | Program | Name   |
|---------|--------------|---------------|-------------|---------------------|---------|---------------------|---------|--------|
| LMC     |              |               |             |                     |         |                     |         |        |
| 0452–6927 | 04 51 53.00 | −69 23 29.99 | 2002 May 6  | 169                 | 6A      | 0530–727            |         |        |
| 0452–6922 | 04 52 31.64 | −67 17 00.14 | 2001 May 10 | 262                 | 6F      | 0355–669, 0252–712, 0407–658 |         |        |
| 0454–6716 | 04 54 49.92 | −67 11 58.80 | 2001 May 11 | 249                 | 6F      | 0355–669, 0252–712, 0407–658 |         |        |
| 0456–6636 | 04 56 47.63 | −66 32 18.39 | 2001 May 9  | 190                 | 6F      | 0515–674, 0355–669  |         |        |
| 0457–6632 | 04 57 45.00 | −66 27 29.99 | 2002 May 6  | 175                 | 6A      | 0530–727            |         |        |
| 0505–6807 | 05 04 59.76 | −68 03 40.03 | 2001 May 9  | 190                 | 6F      | 0515–674, 0355–669  |         |        |
| 0510–6857 | 05 09 50.00 | −68 52 59.99 | 2002 May 6  | 166                 | 6A      | 0530–727            |         |        |
| 0519–6916 | 05 18 45.00 | −69 14 29.99 | 2002 May 4  | 178                 | 6A      | 0530–727            |         |        |
| 0523–6808 | 05 22 55.00 | −68 04 29.99 | 2002 May 4  | 174                 | 6A      | 0530–727            |         |        |
| 0525–6831 | 05 24 41.80 | −68 29 23.23 | 2001 May 10 | 184                 | 6F      | 0515–674, 0355–669  |         |        |
| 0531–7196 | 05 31 20.00 | −71 04 29.99 | 2002 May 3  | 193                 | 6A      | 0530–727            |         |        |
| 0532–6629 | 05 32 35.00 | −66 27 19.99 | 2002 May 4  | 174                 | 6A      | 0530–727            |         |        |
| 0538–7042 | 05 38 22.01 | −70 41 08.34 | 2001 May 11 | 238                 | 6F      | 0530–727            |         |        |
| 0539–6931 | 05 39 11.36 | −69 30 04.51 | 2001 May 11 | 186                 | 6F      | 0530–727            |         |        |
| 0540–6940 | 05 39 45.00 | −69 38 39.99 | 2002 May 3  | 164                 | 6A      | 0530–727            |         |        |
| 0542–7121 | 05 41 30.00 | −71 18 59.99 | 2002 May 3  | 164                 | 6A      | 0530–727            |         |        |
| 0545–6947 | 05 45 24.57 | −69 46 33.73 | 2001 May 11 | 192                 | 6F      | 0530–727            |         |        |

### Table 2
**Archival Observations**

| Target  | R.A. (J2000) | Decl. (J2000) | Date       | Exp. Time (minutes) | Config. | Phase Calibrator | Program | Name   |
|---------|--------------|---------------|------------|---------------------|---------|-----------------|---------|--------|
| LMC     |              |               |            |                     |         |                 |         |        |
| 043–7321 | 00 45 29.90 | −73 04 56.63 | 2001 May 14 | 220                 | 6F      | 0230–790        |         |        |
| 0446–7333 | 00 48 01.85 | −73 16 02.86 | 2001 May 14 | 201                 | 6F      | 0230–790        |         |        |
| 0457–7434 | 00 49 31.70 | −73 26 50.26 | 2001 May 14 | 200                 | 6F      | 0230–790        |         |        |
| 0557–7226 | 00 59 50.00 | −72 10 59.99 | 2002 May 5  | 169                 | 6A      | 0230–790        |         |        |
| 0103–7216 | 01 05 16.67 | −72 00 04.64 | 2001 May 10 | 212                 | 6F      | 0355–699, 0252–712 |         |        |
| 0107–7327 | 01 09 12.00 | −73 11 41.99 | 2002 May 6  | 159                 | 6A      | 0230–790        |         |        |
| 0122–7324 | 01 24 10.00 | −73 08 59.99 | 2002 May 5  | 169                 | 6A      | 0230–790        |         |        |

### Notes
- "Target" refers to the Filipović et al. (1998) Parkes catalog name. Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

- "Target" refers to the Filipović et al. (1998a) Parkes catalog name for our observations, whereas "Name" refers to what the source was called by the archival observer.

Notes to Table 2:
- "Target" refers to the Filipović et al. (1998) Parkes catalog name. Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.
surprising, since the H ii regions observed in the radio are probably compact sites of embedded star formation associated with the less extincted (and possibly more evolved) regions ionized by young stars and observable in optical light. Some of our radio sources have particularly interesting morphology, especially as compared with their infrared or Hα emission, and we highlight these in detail in the Appendix.

Tables 3 and 4 list all the detected compact radio continuum sources. Sources are named according to the nearest radio continuum source in the (low-resolution) Parkes surveys (Filipović et al. 1998). If there is more than one compact source in the area, the compact source most clearly associated with the H ii region as seen in the mid-IR is given the main designation, and other sources are designated with direction relative to the first one (e.g., “N”). Also listed are the nearest associated IRAS source and the familiar shortened form (e.g., N23A for LHA 120-N 23A) of the Lamont-Hussey optical designation (Henize 1956). It is important to note, as mentioned above, that because the synthesized beam is smaller at 3 cm than at 6 cm, the spectral index is probably a lower limit that depends on the geometry of the source.

The properties of the population of detected compact H ii regions should be sensitive to the physics of star formation in the Magellanic Clouds. Since our sample was selected to probe the most compact and densest H ii regions, we probe both the individual star formation mechanism and the formation mechanism of clusters, if indeed these are different. In the following subsections, we first compare the IRAS and radio properties of the sample. We then model the total luminosity and Lyman continuum flux distributions, which are sensitive to the stellar and cluster initial mass functions. Finally, we look for any trends involving the radio spectral index. Analysis of the high-resolution IR properties of the sample will be presented in a future paper.

### TABLE 3

**FLUX DENSITIES AND SPECTRAL INDICES OF COMPACT OBJECTS OBSERVED IN THE SMC**

| Radio Source a | IRAS Source b | R.A. (J2000) | Decl. (J2000) | \(F_{3 \text{ cm}}\) (mJy) | \(F_{6 \text{ cm}}\) (mJy) | \(\alpha\) c | \(\log (Q_{\nu})\) | Sp. Type d | Pgm. f | Notes, Other IDs |
|----------------|---------------|--------------|--------------|--------------------------|--------------------------|---------|----------------|-------------|---------|----------------|
| B0043–7321.....| 00436–7321    | 00 45 15.7   | −73 06 07    | <2                       | 0.8 ± 0.3                | 47.4    | B0 V          | C668        | N12B?   |                |
| B0043–7321(N)  | 00436–7321    | 00 46 13.1   | −73 00 45    | <15                      | 1.1 ± 0.5                | 47.5    | B0 V          | C668        | N12B?   |                |
| B0046–7333.....| 00462–7331    | 00 48 08.5   | −73 14 55    | 2 ± 1                    | 0.6 ± 0.4                | +1.5    | 47.8          | O9.5 V      | N26     |                |
| B0047–7343.....| 00477–7343    | 00 49 29.0   | −73 26 33    | 9 ± 2                    | 1.2 ± 0.2                | 0.8     | 48.4          | O8.5 V      | N33     |                |
| B0047–7343(N)  | 00469–7341    | 00 48 53.4   | −73 24 57    | 1 ± 0.3                  | 1.2 ± 0.2                | −0.0    | 47.5          | B0 V        | N33?    |                |
| B0057–7226.....| 00574–7226    | 00 59 14.9   | −72 11 03    | 7 ± 2                    | 2 ± 1                    | +1.8    | 48.4          | O8.5 V      | N66, Lin 350  |  
| B0057–7226(S)  | 00574–7226    | 00 59 11     | −72 11 40    | 5 ± 5                    | 7 ± 7                    | −0.5    | 48.2          | O9 V        | Diffuse, N66  |  
| B0103–7216.....| 01035–7215    | 01 05 04.1   | −71 59 25    | 14 ± 1.0                 | 14 ± 0.4                 | +0.0    | 48.7          | B0 V        | N78B    |                |
| B0103–7216(N)  | 01035–7215    | 01 05 05.2   | −71 59 01    | 2 ± 1                    | 2 ± 1                    | +0.3    | 47.9          | O9.5 V      | N78A    |                |
| B0107–7327.....| 01077–7327    | 01 09 12.9   | −71 11 39    | 34 ± 2                   | 33 ± 1                   | +0.0    | 49.1          | O6.5 V      | N81     |                |
| B0107–7327(N)  | 01077–7327    | 01 09 20.6   | −73 10 51    | 1.0 ± 0.6                | 1.5 ± 0.5                | −0.6    | 47.5          | B0 V        | N81     |                |
| B0107–7327(W)  | 01077–7327    | 01 08 32.4   | −72 11 19    | 0.6 ± 0.4                | 0.8 ± 0.3                | −0.4    | 47.3          | B0 V        | N81?    |                |
| B0122–7324.....| 01228–7324    | 01 24 07.9   | −73 09 04    | 85 ± 1                   | 91 ± 0.5                 | −0.1    | 49.5          | O5 V        | N88     |                |

3.1. **Spectral Indices and FIR Colors**

One can describe a source’s spectral shape near \( \lambda = 3–6 \text{ cm} \) with a single number \( \alpha \) if one assumes that the flux density is a power-law function of frequency \( F_{\nu} \propto \nu^{\alpha} \). Optically thin and optically thick thermal radiation have spectral indices of \( \alpha = −1.0 \) and 2 (blackbody limit), respectively. Figure 2 shows the spectral indices of detected sources, showing many that are consistent with thermal radiation, as well as some that are probably background nonthermal sources. The spectral index of the compact sources detected is often larger (more consistent with thermal radiation or a higher optical depth) than the spectral index calculated for the same source from the relatively low-resolution Parkes data. This is expected physically, because the more diffuse emission around a compact embedded source is optically thin, driving the spectral index from a positive value toward zero.

We used the WC89 FIR color criteria to select our sources, in order to maximize the chances of finding compact thermal sources or ultracompact H ii regions. Although the selection criterion did yield a very high detection rate of compact sources, many of which have flat or inverted (optically thick thermal) spectral indices, there do not appear to be any clear correlations between the FIR color and the optical depth of associated compact sources. Figure 3 explores various possible correlations between FIR (low-resolution) color and flux density and high-resolution centimeter spectral index and flux density. Nonthermal sources are plotted with thin lines and excluded from analysis of correlations. There is a weak trend for sources with higher 12 \( \mu \text{ m} \) flux densities to have higher 3 cm flux densities in compact sources. The Pearson correlation coefficient is 0.51, and the slope between \( \log (F_{12 \mu \text{ m}}) \) and \( \log (F_{3 \text{ cm}}) \) is 0.50 ± 0.17. Including nonthermal sources decreases the correlation coefficient to 0.41 and the slope to 0.40 ± 0.16. There
| Radio Source       | R.A. (J2000) | Decl. (J2000) | $F_{\delta}$ (mJy) | $F_{\alpha}$ (mJy) | $\alpha$ | log ($Q$) | Sp. Type | Pgm. | Notes, Other Ids |
|-------------------|-------------|--------------|------------------|------------------|---------|----------|----------|-----|-----------------|
| B0452−6927........... | 04 51 53.3 | −69 23 29 | 160 ± 5 | 138 ± 3 | +0.2 | 49.6 | O5 V | ... | N79A |
| B0452−6927(E)........... | 04 51 53 | −69 23 27 | 30 | 25 | +0.3 | 48.8 | O7.5 V | ... | Four weak sources on E edge of main source |
| B0452−6700(SW)....... | 04 52 09 | −66 55 23 | 45 ± 15 | 27 ± 10 | +0.7 | 48.7 | O8 V | C686 | Elongated, N4A |
| B0452−6700(NE)...... | 04 52 12 | −66 55 15 | 5 ± 10 | 8 ± 8 | −0.7 | 48.1 | O9 V | C686 | N4A |
| B0452−6722(NW)....... | 04 52 12.4 | −67 12 52 | 3.5 ± 2 | 2.3 ± 0.3 | +0.6 | 47.9 | O9.5 V | ... | N5? |
| B0452−6722(NE)....... | 04 52 33.4 | −67 13 28 | 2.4 ± 0.5 | 0.9 ± 0.3 | +1.4 | 47.7 | B0 V | ... | N5? |
| B0454−6916(E)........... | 04 54 26.1 | −66 11 02 | 39.3 ± 2 | 39.1 ± 1 | +0.0 | 49.0 | O6.5 V | C686 | N83B |
| B0454−6916(W)........... | 04 53 58.6 | −66 11 06 | 2.8 ± 1 | 3.6 ± 0.5 | +0.4 | 47.8 | O9.5 V | C686 | N83B |
| B0456−6629(E)........... | 04 57 16.2 | −66 23 21 | 30 ± 5 | 31 ± 5 | +0.0 | 48.8 | O7.5 V | ... | Diffuse, N11A |
| B0456−6629(W1)........... | 04 56 57.3 | −66 25 13 | <10 | 3.3 ± 0.4 | ... | 47.9 | O9.5 V | ... | N11B |
| B0456−6629(W2)........... | 04 56 47.8 | −66 24 34 | 1.5 ± 0.8 | 3.1 ± 1.7 | −1.0 | 47.5 | B0 V | C686 | ... |
| B0457−6632........... | 04 57 41.0 | −66 30 36 | 2 ± 0.6 | 2.6 ± 0.3 | −0.4 | 47.7 | B0 V | ... | Diffuse |
| B0505−6807........... | 05 05 05.7 | −68 03 46 | 1.0 ± 0.4 | 1.2 ± 0.2 | −0.3 | 47.4 | B0 V | ... | N23A |
| B0505−6807(N)........... | 05 05 09.7 | −68 01 37 | 1.6 ± 0.6 | 1.1 ± 0.3 | +0.5 | 47.6 | B0 V | ... | N23A |
| B0510−6857(W)........... | 05 10 59.6 | −68 53 05 | 39 ± 1 | 26 ± 1 | +0.6 | 49.0 | O6.5 V | ... | N105 |
| B0510−6857(E)........... | 05 10 59.2 | −68 53 00 | 30 ± 4 | 31 ± 2 | −0.0 | 48.5 | O7.5 V | ... | N105 |
| B0510−6857(S)........... | 05 10 59.2 | −68 53 25 | 12 ± 7 | 14 ± 2 | −0.2 | 48.4 | O8.5 V | ... | Diffuse, N105 |
| B0519−6916(E)........... | 05 19 39.3 | −69 13 43 | 5 ± 5 | 2.1 ± 0.4 | +1.2 | 47.6 | B0 V | ... | N119? |
| B0519−6916(N1)........... | 05 19 55.4 | −69 09 00 | 7 ± 7 | 4.5 ± 0.5 | +0.8 | 47.9 | O9.5 V | ... | N119? |
| B0519−6916(N2)........... | 05 19 50.0 | −69 09 32 | 6 ± 7 | 5.5 ± 0.5 | +0.1 | 48.1 | O9.5 V | ... | N119? |
| B0523−6806(NE)........... | 05 23 43.5 | −68 00 34 | 10 ± 10 | 10 ± 0.5 | −0.0 | 48.3 | O9 V | ... | N44M |
| B0522−5800........... | 05 22 12.6 | −67 58 32 | ... | 34 ± 1.5 | ... | 48.9 | O7 V | ... | N44B, C |
| B0523−6806(SE)........... | 05 23 24.7 | −68 06 41 | 4.5 ± 2 | 4.8 ± 2 | −0.1 | 48.0 | O9.5 V | ... | N44? |
| B0523−6806(SW)........... | 05 22 19.6 | −68 04 37 | 11 ± 1.5 | 10 ± 1 | +0.1 | 48.4 | O8.5 V | ... | N44G, K |
| B0523−6806........... | 05 22 55.2 | −68 04 09 | 3 ± 0.3 | 3.3 ± 0.3 | −0.1 | 47.8 | B0 V | ... | Compact source only, N44D |
| B0525−6831........... | 05 25 06 | −68 28 15 | 10 ± 5 | 10 ± 5 | +0.0 | 48.4 | O8.5 V | ... | Diffuse, N138A |
| B0525−6831(N)........... | 05 24 50.5 | −68 26 55 | <0.5 | 0.8 ± 0.3 | ... | 47.2 | B0 V | ... | N138? |
| B0525−6831(W)........... | 05 24 10.5 | −68 30 26 | <1.5 | 0.4 ± 0.3 | ... | 46.9 | B0 V | ... | N138B, D |
| B0531−7106........... | 05 31 22.9 | −71 04 09 | 2.1 ± 0.5 | 2.1 ± 0.3 | +0.0 | 47.7 | B0 V | ... | Compact core only, N206A |
| B0531−7106(SW1)........... | 05 30 56.3 | −71 06 02 | 6 ± 3 | 6 ± 3 | +0.0 | 48.1 | O9 V | ... | Diffuse, N206 |
| B0531−7106(SW2)........... | 05 30 20.6 | −71 07 44 | 20 ± 20 | 11 ± 7 | +0.9 | 48.4 | O8.5 V | ... | Diffuse, N206B |
| B0531−7106(SW3)........... | 05 30 31.3 | −71 08 56 | 4 ± 5 | 2.7 ± 0.6 | +0.6 | 47.8 | O9.5 V | ... | N206B |
| B0531−7106(SE)........... | 05 30 18.6 | −71 07 44 | 9 ± 10 | 1.7 ± 0.8 | +2.4 | 47.6 | B0 V | ... | N206? |
| Radio Source | $IRAS$ Source | R.A. (J2000) | Decl. (J2000) | $F_{\text{1 cm}}$ (mJy) | $F_{\text{6 cm}}$ (mJy) | $\alpha$ | log ($Q$) | Sp. Type | Pgm. | Notes, Other IDs |
|--------------|---------------|-------------|-------------|-----------------|-----------------|-------|--------|--------|------|----------------|
| B0532—6629  | 05325—6629    | 05 32 32    | –66 27 15   | 1 ± 0.2         | 0.8 ± 0.1       | +0.3  | 47.4   | B0 V   | …    | Compact, N55A   |
| B0532—6629(NE) | 05325—6629 | 05 32 33    | –66 27 08   | 5 ± 0.8         | 4 ± 0.5         | +0.3  | 48.1   | O9.5 V | …    | Diffuse, N55A   |
| B0538—7042(S) | 05389—7042   | 05 38 24.2  | –70 44 26   | 4.5 ± 0.5       | 5.5 ± 0.6       | –0.3  | 48.0   | O9.5 V | …    | N213?          |
| B0538—7042(E) | 05389—7042   | 05 38 26.9  | –70 41 06   | 1.0 ± 0.3       | 1.1 ± 0.3       | –0.1  | 47.4   | B0 V   | …    | N213           |
| B0539—6931(1) | 05396—6931   | 05 39 15.7  | –69 30 39   | 12 ± 2          | 15.5 ± 2        | –0.3  | 48.4   | O8.5 V | …    | N158C          |
| B0539—6931(2) | 05396—6931   | 05 39 17.4  | –69 30 49   | 3.5 ± 2         | 3.3 ± 1         | +0.1  | 47.9   | O9.5 V | …    | N158C          |
| B0539—6931(N) | 05391—6926   | 05 39 44.5  | –69 24 38   | 20 ± 20         | 5.2 ± 2         | +2.0  | 48.1   | O9 V   | …    | N158?          |
| B0540—6935   | 05404—6933   | 05 39 40.0  | –69 32 56   | <10             | 2.7 ± 1         | …     | 47.8   | O9.5 V | …    | N158?          |
| B0540—6940(1) | 05401—6940   | 05 39 46.0  | –69 38 39   | 120 ± 7         | 130 ± 7         | –0.1  | 49.4   | O5 V   | …    | N160A2         |
| B0540—6940(2) | 05401—6940   | 05 39 44.3  | –69 38 48   | 16 ± 1          | 16 ± 1          | +0.0  | 48.6   | O8 V   | …    | N160A3?        |
| B0540—6940(3) | 05401—6940   | 05 39 43.4  | –69 38 54   | 50 ± 5          | 50 ± 5          | +0.0  | 49.1   | O6.5 V | …    | N160A1         |
| B0540—6940(4) | 05401—6940   | 05 39 39.0  | –69 39 11   | 12 ± 1          | 14.5 ± 1        | –0.2  | 48.4   | O8.5 V | …    | N160A, maser   |
| B0540—6940(5) | 05401—6940   | 05 39 38.8  | –69 39 04   | 8.0 ± 1         | 6.0 ± 1         | +0.4  | 48.3   | O9 V   | …    | N160 A         |
| B0540—6940(E) | 05409—6942   | 05 40 25.2  | –69 40 14   | 15 ± 6          | …              | …     | 48.5   | O8 V   | …    | N160C          |
| B0540—6946(1) | 05405—6946   | 05 40 04.4  | –69 44 37   | 50 ± 75         | 70 ± 15         | –0.5  | 49.2   | O6 V   | …    | N159D          |
| B0540—6946(5) | 05401—6947   | 05 39 37.5  | –69 45 26   | …              | 120 ± 15        | …     | 49.4   | O5.5 V | …    | N159A          |
| B0540—6946(6) | 05401—6947   | 05 39 37.5  | –69 46 10   | …              | 30 ± 5          | …     | 48.8   | O7.5 V | …    | N159 A         |
| B0542—7121   | 05423—7120   | 05 41 37.5  | –71 19 02   | 19 ± 2          | 18 ± 1.5        | +0.1  | 48.6   | O8 V   | …    | S169, N214C, knots w/halo |
| B0545—6947(N) | 05458—6947   | 05 45 03.3  | –69 39 28   | …              | 7.3 ± 1         | …     | 48.2   | O9.5 V | …    | N168?          |
| B0545—6947(NE) | 05458—6947  | 05 45 57.3  | –69 43 56   | 1.3 ± 1.5       | 2.1 ± 0.5       | –0.7  | 47.7   | B0 V   | …    | N168?          |
| B0545—6947(1) | 05458—6947   | 05 45 27.8  | –69 46 23   | 12.3 ± 1.5      | 13.1 ± 1.5      | –0.1  | 48.5   | O6 V   | …    | N168A          |
| B0545—6947(2) | 05458—6947   | 05 45 20.0  | –69 46 45   | 2.7 ± 0.5       | 2.7 ± 0.5       | +0.0  | 47.8   | O9.5 V | …    | N168B          |

**Notes.**—All units and columns as in Table 3. Adopted distance to the LMC is 50 kpc (Alcock et al. 2004).

*a* Numbering scheme follows Hunt & Whiteoak (1994).
is also a weak trend for brighter 12 μm IRAS sources to have an envelope of redder 24/12 μm colors. The Pearson correlation coefficient between IRAS color and IRAS 12 μm flux density is only 0.14, consistent with an envelope effect.

Our sample could address whether there is any correlation between the luminosity of an H II region and how embedded it is (as indicated by the radio spectral index). It has been suggested (e.g., Beckman et al. 2000) that there is a change from ionization-bounded to density-bounded as the luminosity of an H II region increases. These investigators also find that more Hα-luminous H II regions leak more ionizing radiation than less Hα-luminous ones. The bottom left panel of Figure 3 shows the spectral index of our H II regions as a function of 3 cm flux density. There is no discernible trend; H II regions powered by more numerous or more massive ionizing stars show the same range in H II region density as less luminous regions. There is also no correlation between IRAS color and radio spectral index: a redder IRAS color does not predict a more optically thick compact H II region. The correlation coefficients for radio spectral index with radio flux density and IRAS color are −0.02 and −0.16, respectively.

### 3.2. Modeled Size and Density

We can model the radio spectral energy distribution of each source as a compact spherical H II region of constant density and electron temperature. These simple models allow for only two free parameters, radius and electron density. It is assumed that the radio emission is purely thermal in nature, but the free-free emission may be self-absorbed in order to reproduce spectral indices of α > −0.1. (Sufficiently large electron densities cause the radio spectral energy distribution to become “inverted” because of self-absorption at lower frequencies.) The radio emission is calculated for each chord through the sphere parallel to the line of sight, and this is integrated over the projected circle perpendicular to the line of sight (simple radiative transfer without scattering). More complex models are possible but are not warranted, since we only have two data points for each region. Figure 4 shows the modeled radii and densities of the sources that are consistent with thermal emission. The spectral shape of thermal emission at frequencies above that at which the emitting source is optically thin is fairly insensitive to the source density. Therefore, we only model source densities above 10³ cm⁻³. For sources consistent with lower densities, we give the radius of a 10³ cm⁻³ source as a lower limit to the radius.

### 3.3. Exciting Star(s) Ionizing Flux

If one assumes that each thermal compact radio source is an H II region and that the radio continuum emission comes exclusively from optically thin thermal bremsstrahlung radiation, the number of ionizing photons required to ionize the source is derived by (Condon 1992)

\[ Q \geq 6.3 \times 10^{52} \lambda^{-1} \left( \frac{T_e}{10^4 \text{ K}} \right)^{0.45} \times \left( \frac{\nu}{10^{17} \text{ Hz}} \right)^{0.1} \left( \frac{L_{\text{thermal}}}{10^{27} \text{ ergs}^{-1} \text{ Hz}^{-1}} \right), \]

where \( T_e \) is the electron temperature of the nebula, \( \nu \) is the frequency of observation, and \( L_{\text{thermal}} \) is the observed luminosity. The Lyman continuum flux \( Q \) calculated from the 3 cm flux density (or the 6 cm flux density, for sources with no 3 cm detection) is included in Tables 3 and 4. Note that these values are lower limits because of the assumption that the emission is optically thin. The spectral type of a single star required to produce the given ionizing flux is also tabulated, using the conversions from Smith et al. (2002) and P. Crowther (2003, private communication).

As a self-consistency check on the ionizing flux calculated using the simple Condon (1992) formula and on the simple constant-density models, we calculate the number of ionizing photons required to ionize each modeled region, assuming photoionization equilibrium. Figure 5 shows that the \( Q \) values calculated using the two methods agree favorably. The main source of the small discrepancies is the assumption of the emission being optically thick in the Condon relation above; if the emission is self-absorbed, \( L_{\text{thermal}} \) will be underestimated.

### 3.4. Cluster Luminosity Function

The luminosity function of extragalactic H II regions can be fitted with a power law of index \( a = -2.0 \pm 0.5 \), i.e.,

\[ dN/L \propto L^a dL. \]

This result is similar for Hα luminosities (e.g., Kennicutt et al. 1989), radio luminosities (e.g., McKee & Williams 1997 and references therein), and optical luminosities (e.g., Larsen 2002, in particular \( a = -2.01 \pm 0.08 \) for the LMC). Elmegreen & Efremov (1997) propose that this is due to a universal formation mechanism: all types of clusters form with constant efficiency in molecular clouds, so the cluster mass distribution reflects the interstellar cloud mass distribution, which has an index \( \sim -2 \).

The H II region or cluster luminosity function is related to the distribution of the number of cluster member stars \( N_c \) (or cluster mass) and to the stellar initial mass function (IMF). Oey & Clarke (1998) provide a detailed explanation of how these distributions are related. They draw attention to the particularly important effect of small number statistics. In rich, luminous clusters with many stars, the stellar IMF is statistically populated out to a fairly high mass, and the cluster luminosity...
simply reflects the total cluster mass. The cluster luminosity function in this regime, which Oey & Clarke (1998) call “saturated,” then simply reflects the cluster mass distribution, a power law $dN(M_c) \propto M_c^{-\beta} dM_c$ with index $\beta = -2$. Sparser clusters are dominated by one or a few high-mass members, and the statistical variation in the luminosity of clusters of a given mass can become large because of poor sampling of the stellar IMF. This flattens the cluster luminosity function at the faint end and in fact can transform power-law behavior into a more rounded distribution (see, e.g., Fig. 4 in Oey & Clarke 1998).

Figure 6 shows the luminosity distributions of all IRAS sources satisfying the WC89 color criteria and all of our selected candidate UC H II sources. The bolometric luminosity has been estimated for each H II region by the sum over the four IRAS bands of $\sum_{i=1}^{4} (i) F_{\nu(i)}$ (e.g., Casassus et al. 2000). The distributions flatten, probably because of the statistical effect described above. Single massive stars have luminosities of $\approx 10^5 L_\odot$, so most of our sample is probably in the regime of “unsaturated” stellar IMF statistics. The turnover of the luminosity function at the faint end ($L \approx 10^5 L_\odot$) is due to

Fig. 3.—Various relationships between IRAS color, IRAS flux density, 3 cm compact source flux density, and 3–6 cm compact source spectral index are explored. The size of the data point scales with the signal-to-noise ratio of the detected source. The flux densities of several compact radio sources are summed in cases in which more than one compact source is associated with a single IRAS source. Nonthermal sources are plotted as thin circles and excluded from analysis of correlations (see text).
confusion-induced incompleteness resulting from the quite large IRAS beam (e.g., ~50 pc at 60 μm at the distance of the Magellanic Clouds). The confusion limit for sources (Condon 1974) with a uniform spatial distribution and following a power-law luminosity distribution is about 10 per beam source. The effective resolution of the IRAS point source catalog is a nontrivial function of the spatial distribution of emission, but the expected confusion-limited source densities are about 40, 40, 15, and 5 sources deg⁻² at 12, 25, 60, and 100 μm, respectively (compare with the source densities at which special “high-density” algorithms were invoked in constructing the IRAS catalog: 45, 45, 16, and 6 sources deg⁻²). This translates into confusion-limited flux densities of 0.3, 0.3, 2, and 20 Jy at 12, 25, 60, and 100 μm, respectively (verified by inspection of the Point Source Catalog in the LMC), and an estimated confusion-limited total luminosity in the Clouds $2.5 \times 10^{38}$ ergs s⁻¹ (7 $\times$ 10⁴ $L_{\odot}$). The luminosity function of all IRAS sources with H II region colors (Fig. 6, solid histogram) indeed turns over at about that confusion-limited luminosity.

It is reassuring to note that the distributions above their peaks have the same power-law indices within errors ($-1.67 \pm 0.3$ for the full color-selected sample and $-1.60 \pm 0.5$ for our “radio-aware” selection), and, despite a slight bias toward observing brighter sources, we have not apparently affected our sample with selection effects beyond those unavoidable results of low spatial resolution previous observations.

It is possible to quantify the constraints that our sample, selected to probe the most compact and densest H II regions, places on the stellar and cluster mass functions. We use Monte Carlo methods to model the cluster luminosity function, similar to the process followed by Oey & Clarke (1998) and Casassus et al. (2000). We assume that the cluster masses $M_c$ follow a power-law distribution

$$p(M_c) \propto M_c^{-\beta}$$

and that the stars in the cluster follow a standard stellar IMF

$$p(M) \propto M_{\ast}^{-(1+\gamma)}.$$
Casassus et al. (2000) imposed a power law on the number of stars per cluster,

$$p(N_* \propto N_*^{-\beta}),$$

rather than on the cluster mass. We prefer to use the cluster mass, because it has physical meaning and may be related to the interstellar cloud mass distribution. The synthetic luminosity functions constructed either way are quantitatively consistent. We assume that because we selected for young star-forming H II regions, our cluster population can be adequately modeled as unevolved. Oey & Clarke (1998) showed that evolution can be an important effect for older H II regions (e.g., in interarm regions of spiral galaxies) as the most massive stars in the cluster die off and the more numerous, less massive stars become more important to ionizing the cluster.

Figure 7 shows the index of a power-law fit to the bright end of the cluster luminosity function as a function of IMF power-law index $\gamma$ and of the cluster mass function power-law index $\beta$. The results are insensitive to the stellar and cluster mass upper and lower cutoffs [for this particular run (0.5, 120) $M_\odot$ and (4, 12,000) $M_\odot$, respectively]. Such a fitted power law is sensitive to the range over which one fits, since the luminosity function rolls over, so Figure 7 should be used to understand qualitative trends, with possible systematic offsets in the index (by 0.1–0.2) if a different luminosity range is used. The effects of poor statistics on the form of the luminosity function have been well described by Oey & Clarke (1998). The high-luminosity end of the distribution is defined by a chance collection of particularly massive stars and can fall off very quickly. At the faint end, the distribution is flattened by the spread in $L$ for a given cluster mass. In this statistically unsaturated regime, the cluster luminosity function index is much more strongly dependent on the stellar mass function index than the cluster mass function index. Because of the steepness of the mass-luminosity relation for main-sequence stars, it is not hard to make a fairly bright cluster with a small number of massive stars. Instead of enforcing a power law on either data or model, we fitted the bright (unconfused) part of the observed luminosity function to theoretical models. The best fit is for $\gamma = 1.5 \pm 0.25$ and $\beta = 2.0 \pm 0.5$.

It is even more interesting to fit the distribution of Lyman continuum photon fluxes $Q$. The values of $Q$ are determined here from our radio observations, so this constitutes analysis of our observations rather than analysis of the input sample. (The total luminosities were calculated from IRAS flux densities.) The $Q$ distribution of our observed compact radio sources is shown in Figure 8. The observed (and modeled) $Q$ functions are even less easily understood as power laws; the $Q$ distribution is even further into the statistically unsaturated regime because of the extremely steep mass-$Q$ relation for main-sequence stars (even steeper than the mass-luminosity relation). For illustration only, we proceed to fit a power law to the portion of the distribution that is relatively straight and show the index of this power law as a function of $\gamma$ and $\beta$ in Figure 9. As with the total cluster luminosity, the $Q$ distribution is more sensitive to the stellar IMF index $\gamma$ than the cluster mass function index $\beta$. Again, we search for the model distribution that best fits the data without imposing a power law and find $\gamma = 1.4 \pm 0.2$ and $\beta = 2.1 \pm 0.3$. These indices agree with those determined from the total IRAS luminosity (at much lower resolution) and with observations and theories of star formation in the Milky Way.

4. CONCLUSIONS

We conducted a radio continuum survey of UC H II candidates in the Magellanic Clouds using the highest resolution configuration of the Australia Telescope Compact Array. Candidates were selected from IRAS and lower resolution radio continuum measurements, using the far-IR colors determined by Wood & Churchwell (1989b) to be characteristic of UC H II regions. We find a very high success rate for detecting compact radio sources with spectral indices consistent with thermal emission based on these selection criteria, even with the
relative poor spatial resolution of the IRAS survey. This detection rate is at least in part due to the thermal infrared luminosities of UC H\textsc{ii} regions; UC H\textsc{ii} regions are among the most luminous Galactic objects in the IRAS catalog (>60\% of the IRAS sources with flux densities greater than \(10^4\) Jy at 100 \(\mu m\) are UC H\textsc{ii} regions; Wood & Churchwell 1989a). Consequently, UC H\textsc{ii} regions tend to be dominant sources at thermal infrared wavelengths, making them relatively easy to detect on the basis of their infrared colors despite contaminating sources within the resolution element. This is good news for inferences drawn from infrared observations with the Spitzer Space Telescope and Astro-E satellites, which probe similar spatial scales in nearby galaxies as IRAS did in the Magellanic Clouds.

In many of the cases in which such information is available, we find that the compact radio sources are found in the densest, highest excitation parts of H\textsc{ii} region complexes. Simple models of the radio sources as constant-density spheres have electron densities of a few times \(10^3\)–\(10^6\) cm\(^{-3}\) and sizes ranging from 0.01 to 0.1 pc, reasonable physical characteristics for compact and ultracompact H\textsc{ii} regions. We are clearly sampling the population of the youngest embedded H\textsc{ii} regions in the Clouds.

We compare the radio flux densities of our detected compact sources with the infrared flux densities of the candidate regions and with radio flux densities at lower spatial resolution. Many of the radio sources have spectral indices that are consistent with thermal radiation, and there are some that are probably background nonthermal sources. The detected spectral index of the compact sources is often larger (more consistent with thermal radiation or a higher optical depth) than the spectral index calculated for the same source from the relatively low-resolution Parkes data. This is expected physically, because the more diffuse emission around a compact embedded source is optically thin, driving the spectral index from a positive value toward zero. Although most candidates with WC89 infrared colors apparently contain compact H\textsc{ii} regions, no obvious trends that more extreme infrared colors indicate more embedded radio sources were seen at these resolutions.

We model the total luminosity and Lyman flux (Q) distributions of the regions, using a Monte Carlo method to model those cluster number distributions as a function of the stellar mass function within a cluster and the cluster number or mass distribution. We find that the population of young clusters in the Magellanic Clouds, as observed through their compact H\textsc{ii} regions, is consistent with a stellar IMF that one would find reasonable in the Milky Way: slightly steeper than Salpeter, with a power-law index \(\gamma \approx 1.5\). We find that the Magellanic Cloud cluster distribution is consistent with a fairly broad range of cluster mass functions, but the best fit has a power-law index \(\beta \approx -2.0\), which is expected from the mass distribution of interstellar molecular clouds on many scales.

We thank Ed Churchwell for useful discussion. This work would not have been possible without the dedicated work of Robin Wark, Jim Caswell, and the other staff at the Australia Telescope National Facility. R. I. was supported at the start of this investigation by an NSF Graduate Student Fellowship to the University of Colorado and is currently supported by NASA (GLIMPSE Spitzer Legacy Grant to E. Churchwell, Univ. Wisconsin). K. J. is currently supported by an NSF A\&AP postdoctoral fellowship. P. C. acknowledges support from NSF (AST-9731570).

The Second Palomar Observatory Sky Survey (POSS II) was made by the California Institute of Technology with funds from the National Science Foundation, the National Aeronautics and Space Administration, the National Geographic Society, the Sloan Foundation, the Samuel Oschin Foundation, and the Eastman Kodak Corporation. The Oschin Schmidt Telescope is operated by the California Institute of Technology and Palomar Observatory. This research made use of the NASA/IPAC Infrared Science Archive, which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. This research also made extensive use of NASA’s Astrophysics Data
System Bibliographic Services and of the SIMBAD database, operated at CDS, Strasbourg, France.

APPENDIX

DETECTIONS IN INDIVIDUAL REGIONS

A1. SMALL MAGELLANIC CLOUD

A1.1. N66

N66 is the brightest H ii region in the SMC and should not be confused with a famous planetary nebula of the same name in the LMC. The region does not appear to have significant atomic (Staveley-Smith et al. 1997) or molecular gas (except for a cloud to the northeast; Contursi et al. 2000). Figure 10 shows the POSS II R image of N66 with important objects marked, including the location of the supernova remnant (SNR) 0057–7226 (Ye et al. 1991). Interpretation of the region is complicated by the presence of that SNR and the spatially coincident wind-blown bubble from HD 5980, which may be behind the SNR (see cartoon of the region in Fig. 6 of Danforth et al. 2003). The main H ii region (elongated to the northwest and southeast) is likely powered by the cluster NGC 346 visible in Figure 10. Massey et al. (1989) performed an extensive study of the stellar content of the region and found several very massive (40–85 \( M_\odot \)) stars and many B-type stars. Our radio contours show two compact sources to the southeast of NGC 346.

High-resolution 3 cm radio contours of the northern source (0057–7226) are shown superposed on H\( \alpha \) emission in the bottom panel of Figure 10. Filamentary structure seen in H\( \alpha \) emission is reflected by complex morphology of the radio continuum emission in N66. This source is coincident with the mid-IR peak “H” in Contursi et al. (2000), which they find to have an unremarkable mid-IR spectrum. The source has complex morphology in both radio continuum and H\( \alpha \). Although it does not appear to be associated with any of the stars Massey et al. (1989) identified as massive (and relatively unembedded) on the basis of \( U - B \) color, it is spatially coincident with the emission-line object Lin 350 (Meyssonier & Azzopardi 1993 identify it as a compact H ii region on the basis of H\( \alpha \) spectral-line morphology). This radio source also lies within the CO (2–1) contours in the observations of Rubio et al. (2000).

The other source, 0057–7226(S), is also associated with the H ii region N66 (as above). However, it does not appear to have a 7 \( \mu \)m counterpart in the Contursi et al. (2000) ISOCAM observations, and it does not fall within the CO(2–1) contours of Rubio et al. (2000). In combination with its spectral index (\( \alpha \approx -0.5 \)), this suggests that it may not be an UC H ii region but perhaps a background object (e.g., an active galactic nucleus) or SNR.

A1.2. N81 and N88

N81 (DEM 138, IC 1644) and N88 are bright H ii regions in the Shapley Wing 1:2 southeast of the main bar of the SMC. They have two of the highest optical surface brightness and magnitudes among SMC H ii regions and may be located in neighboring and interacting H ii clouds (Heydari-Malayeri et al. 1988 and references therein). Figures 11 and 12 show the optical appearance of the two regions, with compact radio sources, IRAS, and Parkes radio sources marked. Radio contours are also shown on zoomed-in optical images. The compactness and apparent simplicity of these two regions make them good candidates for single-generation simple clusters.

The source 0107–7327 is clearly associated with N81. The \( HST \) observations of Heydari-Malayeri et al. (1999c) indicate that N81 is powered by a small group of newly born massive stars. This radio source has also been detected in the CO(1–0) observations of Israel et al. (1993). The sources 0107–7327(N) and 0107–7327(W) are weak detections, but the northern source could also be associated with N81. Similarly, 0122–7324 is clearly associated with N88.

The bottom panels of Figures 11 and 12 show contours of 3 cm radio emission superposed on H\( \alpha \) images of N81 and N88, respectively. In both cases the radio and optical morphologies agree fairly well. The radio emission from N88A appears to be offset somewhat to the west of the H\( \alpha \) emission, although the \( \sim 1'' \) pointing uncertainty of \( HST \) should be kept in mind in interpreting this offset. Heydari-Malayeri et al. (1999a) describe the sharp northwestern boundary of H\( \alpha \) emission as an ionization front, but if the radio emission extends further in that direction, the lack of H\( \alpha \) could be an obscuration effect.

Heydari-Malayeri et al. (1999c) require \( 1.4 \times 10^{49} \) photons s\(^{-1} \) of ionizing radiation to account for the H\( \beta \) flux of N81. They estimate that the brightest star that they observe in Strömgren \( y \) is consistent with an O6.5 V, which would produce sufficient ionizing radiation, but argue convincingly on the basis of their images that the region is powered by a small cluster and not a single star. In N88A, Heydari-Malayeri et al. (1999a) find that the average extinction is \( A_y = 1.5 \) and rises to values at least as high as 3.5, which is unusual for low-metallicity SMC H ii regions (see also Kurt et al. 1999). Because of the heavy extinction, the exciting star (or stars) is not detected. On the basis of the H\( \beta \) flux, they estimate a Lyman continuum flux for this object of \( 2 \times 10^{49} \) photons s\(^{-1} \). The Lyman continuum fluxes implied by our radio flux densities for the central sources of N81 and the source in N88A are 1.3 and \( 3.3 \times 10^{49} \) photons s\(^{-1} \), respectively. The somewhat higher ionizing flux required to fit the observed radio emission compared with the observed H\( \beta \) in N88A is consistent with the high extinction in the area, although the flat radio spectral index indicates that the ionized gas is not itself at remarkably high density.

A1.3. N12, 26, 33, and 78

Two sources were detected near H ii region N12, but it is not clear that either is directly related to the optical or infrared emission. The source 0043–7321 may be associated with the H ii region NGC 249 (N12B). Copetti (1989) estimates that NGC 249 has a Lyman continuum flux of \( \sim 3.2 \times 10^{49} \) s\(^{-1} \), and the age of the H ii region is less than 2 Myr. The source 0043–7321(N) may be associated with the H ii shell [SS979] 106. Staveley-Smith et al. (1997) estimate that this H ii shell has a radius of \( \sim 4''7 \), an expansion velocity of 9.2 km s\(^{-1} \), and an age of 5.2 Myr. For each of the regions N12, 26, 33, and 78, Figure 13 shows a POSS II R image with important objects labeled following the convention of Figures 10–12 and a zoomed-in image showing our 6 cm radio contours.

The source 0046–7333 is nearest to the H ii region N26 but is amid a high density of H ii regions, including N20, 21, 23, 25, 26, 28, and N12 = DEM 15. This radio source is also near the dark nebulae [H74] 11–14 (Hodge 1974) and is cospatial with the molecular cloud SMC B2 (Rubio et al. 1993). Testor (2001) estimates the Lyman continuum flux powering N26 to be \( \sim 2.8 \times 10^{48} \) s\(^{-1} \).

The source 0047–7343 appears to be associated with N33 (Lin 138). The source 0047–7343(N) may be associated with N31 (DEM 44, Lin 120), which has an optical extent of 4' \times 7'
Fig. 10.—Top left: POSS II R image of the N66 H ii complex, with optically identified subregions labeled. The Parkes 3 and 6 cm source (Filipović et al. 1998) is indicated by the dashed line and the IRAS point source by the dotted line (where the size of the circle is the spatial resolution of those surveys). The compact radio sources detected in this survey are marked with plus signs. The SNR 0057–7226 is marked with a solid circle. Top right: Plot of 6 cm contours from this data set on a zoomed-in optical image. Bottom: Contours of 3 cm compact emission superposed on an HST Hα image.
Fig. 11.—Top: POSS II $R$ images of the N81 H II complex, with optically identified subregions labeled in the left panel. Parkes 3 and 6 cm sources (Filipović et al. 1998) are indicated by the dashed line and the IRAS point sources by the dotted line (with the size of the circle indicating the spatial resolution of those surveys). The compact radio sources detected in this survey are marked with plus signs. In the top right panel, 6 cm contours are shown on a zoomed-in optical image. Bottom: Contours of high-resolution 3 cm radio emission superposed on an HST H$\alpha$ image.
Fig. 12.—Top: POSS II R images of the N88 H II complex, with subregions labeled as in Figs. 10 and 11. Bottom: Contours of high-resolution 3 cm radio emission superposed on an HST Hα image.
Fig. 13.—Optical images of the N12, 26, 33, and 78 regions, with compact sources from this data set, previously known objects, IRAS, and Parkes radio sources marked. Notation is as in Fig. 11. In the left panel showing N26, the large diamonds denote the positions of the dark nebulae [H74] 11–14 (numbers are in order of increasing right ascension), presumably associated with dense gas.
Fig. 13.—Continued
and so is broadly associated with everything in this field. Also nearby is the planetary nebula candidate [JID2002] 7 (Jacoby & De Marco 2002), but as that has a diameter of only 7", it is probably unrelated. The sources 0103–7216 and 0103–7216(N) may be associated with the H ii region N78 (DEM 126). Copetti (1989) estimates that DEM 126 has a Lyman continuum flux of \( \sim 5 \times 10^{49} \) \( \text{s}^{-1} \), and the age of the H ii region is 3–4 Myr. The star cluster IC 1624 is nearby to the south but is apparently unrelated.

### A2. LARGE MAGELLANIC CLOUD

#### A2.1. N159/N160

The N159/N160 H ii region complexes are located \( \sim 40' \) to the south of 30 Doradus, in what appears to be a region in which star formation is propagating from the relatively evolved 30 Dor region out into the more quiescent southern CO arm (Bolatto et al. 2000 and references therein). Figure 14 shows a POSS II NIR image of the region, in which the main components are visible and optical H ii regions are labeled. The star clusters LH 103 and LH 105 are \( \gtrsim 5' \) in diameter and contain the entire N160 and N159 regions, respectively. See Bica et al. (2003) for a complete LMC object catalog with sizes and positions. Parkes 3 and 6 cm sources (Filipović et al. 1998) are indicated by dashed lines and IRAS point sources by dotted lines (with the size of the circle indicating the spatial resolution of those surveys). The compact radio sources detected in this survey are marked with plus signs.

In the more evolved N160 region, we detect five compact radio sources near the optical H ii region N160A. Figure 15 shows our 6 cm contours on a Stro¨mgren y (HST gray scale; Heydari-Malayeri et al. 2002). Parkes 3 and 6 cm sources (Filipovic et al. 1998) are associated with their HST point sources by dotted lines (with the size of the circle indicating the spatial resolution of those surveys). The compact radio sources detected in this survey are marked with plus signs.

The sources 0103 are required to explain the 3 cm flux densities are \( (1.4 \pm 0.2) \times 10^{49} \) and \( (3.4 \pm 0.2) \times 10^{49} \) photons \( \text{s}^{-1} \) for sources 3 and 1 (A1 and A2), respectively. These are likely strong lower limits to the ionizing flux present in the region, since there is a clear extended halo of lower density ionized gas around the two radio sources that is not accounted for in our 3 cm synthesis image flux density. Each of our sources is also detected in the near-infrared by the Two Micron All Sky Survey, but the full infrared and multiwavelength properties of this region are beyond the scope of this survey paper and will be discussed in more detail in a future paper.

The H ii region N159 lies to the south; Figure 16 shows a zoomed-in POSS II NIR image with our 6 cm contours and important previously identified objects labeled. We detect the compact sources 1, 4, and 5 imaged by Hunt & Whiteoak (1994) using the ATCA at lower resolution (their longest baseline was one quarter the length of ours; see their Fig. 1). Their sources 2 and 3 are clearly extended even at their lower resolution, so it is not surprising that there are no compact sources detected at those locations. Hunt & Whiteoak (1994) quote peak intensities at 6 cm for components 1, 4, and 5 as 66, 115, and 58 mJy, respectively. We detect compact sources of 70, 120, and 30 mJy (integrated, although since the sources are unresolved, the peak flux density per beam is very similar). These numbers indicate that sources 1 and 4 are consistent with unresolved point sources but that 5 is more diffuse (a fact that is fairly evident in their radio map).

Figure 16 also compares the radio continuum and H\( \alpha \) emission from source 1. The reader should take careful note of nomenclature, as this object is referred to as N159-5 in Heydari-Malayeri et al. (1999b) and Meynadier et al. (2004), “N159 Blob” in Heydari-Malayeri & Testor (1985), and source 1 in Hunt & Whiteoak (1994). The H\( \alpha \) emission imaged at high resolution with HST (Heydari-Malayeri et al. 1999b) shows two lobes, and the new high-resolution radio imaging reveals that most of the radio continuum is associated with the western lobe. Heydari-Malayeri et al. (1999b) quote an ionizing flux of \( 4 \times 10^{48} \) photons \( \text{s}^{-1} \) if the region is ionization-bounded but do
not postulate any ionizing sources. Our 3 cm flux density corresponds to an ionizing flux of $9 \times 10^{48}$ photons s$^{-1}$, which could be provided by a single O7–8 V star or more likely a small cluster. A radio-determined ionizing flux usually exceeds an optically determined one because of extinction, and both are lower limits if ionizing radiation is escaping the H$\alpha$ region or absorbed by dust. Deharveng & Caplan (1992) account for the ionization of the region with the five massive stars that they observe in the region, in particular their stars 204 (O5–6 V) and 205 (O7–8 V), but these stars are at least 10$^0$ to the southeast of the brightest H$\alpha$ and radio region.

### A2.2. N11

The giant H$\pi$ complex N11 has the second brightest H$\alpha$ luminosity in the LMC, after 30 Dor (Kennicutt & Hodge 1986). The complex consists of numerous H$\pi$ regions roughly on the edge of a ring or bubble (Rosado et al. 1996 provide a good overview of the region and label the optical subcomponents in their Fig. 1). The morphology probably results from (at least) two generations of star formation, the older ($\sim 5 \times 10^6$ yr; Walborn & Parker 1992) being the central OB association LH 9, with younger associations, including LH 10 (1–2 $\times 10^6$ yr old), on the periphery. Figure 17 shows the region with optical H$\pi$ regions labeled, as well as Filipović et al. (1998) and our radio sources and IRAS point sources. The older cluster LH 9 is clearly visible in the center of the ring-like H$\pi$ regions delineated by N11A, B, C, F, and H (just off the image to the west).

We detect compact sources in the two highest excitation regions A and B ("excitation" refers to the ratio of [O iii] $\lambda$5007/H$\beta$ and is probably related to the hardness of the powering radiation field; Heydari-Malayeri et al. 2001 and references therein). Figure 18 shows 3 cm high-resolution radio contours of 0456–6629(E) superposed on an HST H$\alpha$ image of N11A. The radio and H$\alpha$ morphologies of N11A agree very well, supporting the interpretation that the H$\pi$ region is less extended from the ionizing stars to the northeast because of the presence of a dense molecular cloud (Heydari-Malayeri et al. 2001). The H$\alpha$ morphology could have been highly affected by extincting material, but the unextincted radio emission confirms the lack of ionized gas to the northeast. The right panel of Figure 18 shows the western of two sources detected in N11B, 0456–6629(W2). The source is in the region of the brightest H$\alpha$ emission, on the northeast side of what appears to be the powering star cluster. Interestingly, the radio continuum source is located in the middle of ringlike H$\alpha$ emission. The complex H$\alpha$ and radio morphology indicates that the nearby material is probably inhomogeneous and clumpy, leading not only to variable extinction of the optical
light but an irregularly shaped H\textsc{ii} region. A second source, 0456–6629(W1), was detected to the east of 0456–6629(W2) but still in N11B. The radio source is pointlike or unresolved and is located very close to stars 3189 and 3193 of the extensive study of Parker et al. (1992). The authors unfortunately do not have spectra of these two stars, but they are fairly blue ($U - B = -0.9$).

A2.3. N79, 4, 5, 83, 23, 105, 119, 44, 138, 206, 55, 213, 158, 214, and 168

Figures 19–29 show the locations of the rest of the LMC compact radio sources relative to nearby optically identified H\textsc{ii} regions. In many cases, the compact radio source is not associated with the brightest optical emission. In some but not all cases, the radio emission is more similar to infrared. Many of these regions are relatively unstudied, but we describe the radio sources in as much context as possible with a literature search.

The compact radio emission from Parkes source 0452–6927 is probably related to optical H\textsc{ii} region N79B. Figure 19 shows the main compact source and a fringe of fainter emission to the east.

The N4 region in the northwest part of the LMC consists of two main optical H\textsc{ii} regions, with a molecular cloud detected in CO between them (Heydari-Malayeri & Lecavelier Des Etangs 1994). The southern and brighter region (A) has higher excitation ($\text{H} \beta / \text{H}\alpha$) and higher H\alpha surface brightness on the
Fig. 20.—Same as Fig. 19, but for Parkes source B0452−6700 and optical H II region N4.

Fig. 21.—Same as Fig. 19, but for Parkes source B0452−6722 and optical H II region N5.

Fig. 22.—Same as Fig. 19, but for Parkes source B0454−6916 and optical H II region N83.
northeast side, toward the molecular cloud, supporting a classical “champagne flow” model of the H II region. We detect two compact radio sources on that more embedded side of the optical emission (Fig. 20). The brighter radio source 0452−6700(SW) is in the optical emission and apparently represents the densest ionized gas near the two ionizing sources. The fainter source 0452−6700(NE) is off the edge of the optical emission and could be a young deeply embedded source in the cloud. Heydari-Malayeri & Lecavelier Des Etangs (1994) require 3\times10^49 photons s^-1 to account for the optical hydrogen recombination line flux. The flux density of our brighter radio source requires 1.3\times10^49 photons s^-1, but the optical emission clearly comes from a larger region of ionized gas resolved out in our high-resolution observations.

Figure 21 shows the two sources possibly related to Parkes source 0452−6722 and optical H II region N5.

We detect two compact sources associated with the optical H II region N83 (Fig. 22). The source 0454−6916(E) is coincident with the “high-excitation blob” N83B (Heydari-Malayeri et al. 1990), the eastern of several optical H II regions. As with N4, the molecular gas detected in CO peaks on the northeast side of the complex (Bolatto et al. 2003, Fig. 1), so the higher excitation optical H II region is associated with denser molecular gas and a compact radio continuum source. Heydari-Malayeri et al. (1990) calculate a required Lyman continuum flux of 0.75\times10^49 photons s^-1 to power the Hβ nebula, and we require 1.1\times10^49 photons s^-1 to account for the 3 cm radio continuum flux density. The second, much fainter compact radio source 0454−6916(W) is located in a region with little optical emission between two optical H II regions.

Figure 23 shows the two sources possibly related to Parkes source 0505−6807 and optical H II region N23. Nearby objects include an SNR, which is its own Parkes radio source, and the Lucke & Hodge (1970) star cluster LH 25.

We detect a cluster of four compact radio sources near the center of N105 (Fig. 24), an H II region associated with at least 18 OB stars, two W-R stars, and bright [O iii] emission (Ambrocio-Cruz et al. 1998 and references therein). The
Fig. 25.—Same as Fig. 19, but for Parkes source B0523−6808 and optical H II region N44. Zoomed-in images of three different sources in N44 are shown.
Fig. 26.—Compact sources near Parkes source 0519–6916 and optical H ii region N119 and near Parkes source 0525–6831 and optical H ii region N138.
Fig. 27.—Compact sources near Parkes source 0531–7106 and optical H II region N206, near Parkes source 0532–6629 and optical H II region N55, and near Parkes source 0538–7042 and optical H II region N213. Labels are as in Fig. 19.
compact radio sources are in the highest excitation part of the optical nebula, just to the west of the WRC5 + O star Brey 16a, in a region associated with masers and a proposed IR protostar.

We detect compact radio sources associated with several of the brighter optical H II regions in the N44 complex (C, D, G, and M; Fig. 25) around the edges of an H I shell possibly associated with a superbubble (Kim et al. 1998). In N44M, Nazé et al. (2002) quote an ionizing flux of 1.5–2.1 \times 10^{48} \, \text{photons} \, \text{s}^{-1} to account for the H\alpha flux, and we need 2.8 \times 10^{48} \, \text{photons} \, \text{s}^{-1} to account for the 3 cm flux density of 0523–6806(NE). Oey & Massey (1995) find many OB stars in the N44C region, but without coordinates no particular association with radio source 0522–6800 can be made.

Figure 26 shows the sources near Parkes source 0519–6916 and optical H II region N119 and near Parkes source 0525–6831 and optical H II region N138. Figure 27 shows the sources near Parkes source 0531–7106 and optical H II region N206, near Parkes source 0532–6629 and optical H II region N55, and near Parkes source 0538–7042 and optical H II region N213.

The sources 0539–6931(1) and 0539–6931(2) (Fig. 28) are located in the optical H II region N158C, very near several identified OB stars (Testor & Niemela 1998). Source 1 is near identified O7 V and O9 V stars, and source 2 is near an identified B0 V star. The Lyman continuum fluxes required by the 3 cm measurements are 3 \times 10^{48} and 1 \times 10^{48} \, \text{photons} \, \text{s}^{-1} for sources 1 and 2, respectively, consistent with single O7.5 V–O8 V and O9 V stars.

Finally, Figure 29 shows the sources near Parkes source 0542–7121 and optical H II region N214 and near Parkes source 0545–6947 and optical H II region N168.
Fig. 29.—Compact sources near Parkes source 0542−7121 and optical H\textsc{ii} region N214, and near Parkes source 0545−6947 and optical H\textsc{ii} region N168. Labels are as in Fig. 19.
REFERENCES

Alcock, C., et al. 2004, AJ, 127, 334
Ambrocio-Cruz, P., Laval, A., Marcelin, M., Anram, P., & Comeron, F. 1998, A&A, 339, 173
Beckman, J. E., Rozas, M., Zurita, A., Watson, R. A., & Knapen, J. H. 2000, AJ, 119, 2728
Bica, E., Dutra, C. M., & Barbuy, B. 2003, A&A, 397, 177
Bolatto, A. D., Jackson, J. M., Israel, F. P., Zhang, X., & Kim, S. 2000, ApJ, 545, 234
Bolatto, A. D., Leroy, A., Israel, F. P., & Jackson, J. M. 2003, ApJ, 595, 167
Casasus, S., Bronfman, L., May, J., & Nyman, L.-Å. 2000, A&A, 358, 514
Condon, J. J. 1974, ApJ, 188, 279
———. 1992, ARA&A, 30, 575
Contursi, A., et al. 2000, A&A, 362, 310
Copetti, M. V. F. 1989, Ap&SS, 156, 103
Danforth, C. W., Sankrit, R., Blair, W. P., Howk, J. C., & Chu, Y. 2003, ApJ, 586, 1179
Deharveng, L., & Caplan, J. 1992, A&A, 259, 480
Elmegreen, B. G., & Efremov, Y. N. 1997, ApJ, 480, 235
Filipović, M. D., Haynes, R. F., White, G. L., & Jones, P. A. 1998, A&AS, 130, 421
Graczyk, D. 2003, MNRAS, 342, 1334
Henize, K. G. 1956, ApJS, 2, 315
Heydari-Malayeri, M., Charmandaris, V., Deharveng, L., Meynadier, F., Rosa, M. R., Schaerer, D., & Zinnecker, H. 2002, A&A, 381, 941
Heydari-Malayeri, M., Charmandaris, V., Deharveng, L., Rosa, M. R., Schaerer, D., & Zinnecker, H. 2001, A&A, 372, 527
Heydari-Malayeri, M., Charmandaris, V., Deharveng, L., Rosa, M. R., & Zinnecker, H. 1999a, A&A, 347, 841
Heydari-Malayeri, M., Le Bertre, T., & Magain, P. 1988, A&A, 195, 230
Heydari-Malayeri, M., & Lecavelier Des Etangs, A. 1994, A&A, 291, 960
Heydari-Malayeri, M., Rosa, M. R., Charmandaris, V., Deharveng, L., & Zinnecker, H. 1999b, A&A, 352, 665
Heydari-Malayeri, M., Rosa, M. R., Zinnecker, H., Deharveng, L., & Charmandaris, V. 1999c, A&A, 344, 848
Heydari-Malayeri, M., & Testor, G. 1985, A&A, 144, 98
Heydari-Malayeri, M., van Drom, E., & Leisly, P. 1990, A&A, 240, 481
Hodge, P. W. 1974, PASP, 86, 263
Hunt, M. R., & Whiteoak, J. B. 1994, Proc. Astron. Soc. Australia, 11, 68
Israel, F. P., et al. 1993, A&A, 276, 25
Jacoby, G. H., & De Marco, O. 2002, AJ, 123, 269
Kennicutt, R. C., Jr., Edgar, B. K., & Hodge, P. W. 1989, ApJ, 337, 761
Kennicutt, R. C., Jr., & Hodge, P. W. 1986, ApJ, 306, 130
Kim, S., Chu, Y., Staveley-Smith, L., & Smith, R. C. 1998, ApJ, 503, 729
Kurt, C. M., Dufour, R. J., Garnett, D. R., Skillman, E. D., Mathis, J. S., Peimbert, M., Torres-Peimbert, S., & Ruiz, M.-T. 1999, ApJ, 518, 246
Larsen, S. S. 2002, AJ, 124, 1393
Lucey, P. B., & Hodge, P. W. 1970, AJ, 75, 171
Massey, P., Parker, J. W., & Garmany, C. D. 1989, AJ, 98, 1305
McKee, C. F., & Williams, J. P. 1997, ApJ, 476, 144
Meynadier, F., Heydari-Malayeri, M., Deharveng, L., Charmandaris, V., Le Bertre, T., Rosa, M. R., Schaerer, D., & Zinnecker, H. 2004, A&A, 422, 129
Meyssonnier, N., & Azzopardi, M. 1993, A&AS, 102, 451
Nazé, Y., Chu, Y., Guerrero, M. A., Oey, M. S., Gruendl, R. A., & Smith, R. C. 2002, AJ, 124, 3325
Oey, M. S., & Clarke, C. J. 1998, AJ, 115, 1543
Oey, M. S., & Massey, P. 1995, ApJ, 452, 210
Parker, J. W., Garmany, C. D., Massey, P., & Walborn, N. R. 1992, AJ, 103, 1205
Rosado, M., Laval, A., Le Coarer, E., Georgelin, Y. P., Anram, P., Marcelin, M., Golde, G., & Gach, J. L. 1996, A&A, 308, 588
Rubio, M., Contursi, A., Lequeux, J., Probst, R., Barbé, R., Boulanger, F., Cesarsky, D., & Maoli, R. 2000, A&A, 359, 1139
Rubio, M., et al. 1993, A&A, 271, 1
Smith, L. J., Norris, R. P. F., & Crowther, P. A. 2002, MNRAS, 337, 1309
Staveley-Smith, L., Sault, R. J., Hatzidimitriou, D., Kesteven, M. J., & McConnell, D. 1997, MNRAS, 289, 225
Testor, G. 2001, A&A, 372, 667
Testor, G., & Niemela, V. 1998, A&AS, 130, 527
Walborn, N. R., & Parker, J. W. 1992, ApJ, 399, L87
Wood, D. O. S., & Churchwell, E. 1989a, ApJS, 69, 831
———. 1989b, ApJ, 340, 265 (WC89)
Ye, T., Turtle, A. J., & Kennicutt, R. C., Jr. 1991, MNRAS, 249, 722