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Compact HII regions in the Large Magellanic Cloud observed by ISO *

F. Comerón[1], **P. Claes**[2]

[1] European Southern Observatory, Karl-Schwarzschild-Strasse 2, D-85748 Garching bei München, Germany; fcomeron@eso.org
[2] ESTEC, European Space Agency, NL 2200 AG Noordwijk, The Netherlands; pclaes@astro.estec.esa.nl

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Abstract. We present ISOCAM observations of five fields in the Large Magellanic Cloud centered on IRAS point sources with colors of ultracompact HII regions. Three bright sources of parsec or subparsec size, with luminosities consistent with being embedded O stars, are detected at 15 μm in two fields belonging to the HII region N 159. Using published high resolution radio observations, it is found that two of these sources may be ultracompact HII regions with a turnover frequency above 2.4 GHz, while the other is identified with a known compact HII region. If their nature as true ultracompact HII regions is confirmed by follow-up observations, these objects can provide a first sample useful for future studies of early massive star evolution in a low metallicity environment.

Key words: Stars: early-type, formation; HII regions; Magellanic Clouds.

1. Introduction

The combined action of the ionizing flux and stellar winds from newly born massive stars deposit large amounts of power in their dense surroundings. Most of it is ultimately turned into infrared radiation visible from the outside, together with the thermal free-free emission generated in the ionized gas around the star. The subparsec size of the emitting volumes motivates their denomination as *Compact HII Regions* (CHIIR) or, in the extreme cases of very high densities and sizes below 0.1 pc, *Ultracompact HII Regions* (UCHIIR) (Habing & Israel 1979). The latter are the brightest point sources of our Galaxy at mid-infrared wavelengths (see reviews in Churchwell 1990, 1993).

UCHIIR in the Magellanic Clouds are in principle within the sensitivity range of IRAS, which detected 64 point sources in the Large Magellanic Cloud (LMC) with colors typical of embedded O-type stars (Wood & Churchwell 1989b). However, the condition of being unresolved by IRAS has limited value for objects at such distances, as LMC regions up to ~ 10 pc in size would still be unresolved. Support for the true UCHIIR nature of the Magellanic Clouds candidates demands high resolution either at infrared or centimeter wavelengths.

The large increase in both resolution and sensitivity recently provided by ISO can help to identify and investigate the properties of CHIIR and UCHIIR in the LMC, especially when combined with high resolution radio surveys. We present in this letter ISOCAM observations at 15 μm of five fields in the LMC, centered at the position of IRAS point sources with colors typical of UCHIIR. We find three bright point sources in the N 159 star forming region: one of them is a CHIIR previously observed in radio, while the other two may be true UCHIIR whose confirmation will be possible with future observations.

2. Observations

Five fields containing bright sources with IRAS colors of UCHIIR were imaged by ISOCAM. Such colors select almost no bright extragalactic sources (Wood & Churchwell 1989b), so the likelihood of a casual alignment between an unrelated background source and a LMC star forming region is vanishingly small. Our source positions and IRAS fluxes (from Schwering & Israel 1990, as well as the object denominations) are given in Table 1. All the observations were carried out in the LW9 filter ($\lambda = 15\mu$m, $\lambda/\Delta\lambda = 8$). A pixel field of view of 1"5 was chosen to maximize the spatial resolution. When convolved with the diffraction limit of ISO at 15 μm, the full width half maximum of the point spread function is ~ 3", corresponding to 0.7 pc at the LMC distance (50.5 kpc; e.g. Gieren et al. 1998, Oudmaijer et al. 1998). Thus, both CHIIR and UCHIIR should appear as point sources.

Send offprint requests to: F. Comerón

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Table 1. Positions and IRAS fluxes of the observed sources

Source	α (2000)	δ (2000)	IRAS fluxes (Jy) 12 μm	25 μm	60 μm	100 μm
LI-LMC 235	4:57:16.67	-68:25:05.4	1.26	4.99	47.6	97.8
LI-LMC 534	5:09:50.86	-68:52:15.0	7.14	52.17	314.6	447.2
LI-LMC 1367	5:35:22.69	-67:34:46.8	4.74	35.30	265.0	384.8
LI-LMC 1501	5:39:39.40	-69:46:09.1	4.44	22.20	414.0:	624.0:
LI-LMC 1518	5:40:06.50	-69:44:44.1	4.07	33.30	414.0:	624.0:

The observations were performed in microscanning mode, with a raster grid of 2 $\times$ 2 points, 2" in size. Six exposures of 2.1 s each were obtained at each position, with a detector gain of unity to avoid saturation. To allow for partial stabilization of the detector, several frames (between 10 and 26, being lower for the brighter IRAS sources at 12 μm) were obtained before starting the microscan. However, this number is still insufficient to reach a near-stable count level, and therefore a correction for the transient behaviour of the detector (using the *Saclay model*; e.g. Siebenmorgen et al. 1996) was applied in the reduction. A more detailed description of the reduction process is given in Comerón et al. 1998. When transforming from engineering to physical units, no correction was made for departures from the νf_ν = constant behaviour assumed in the conversion factors. UCHIIR have spectral energy distributions near $\nu^{2.5} f_\nu \simeq$ constant in this region; however, departures from the νf_ν = constant law are below 15 % all over the narrow transmission window of the LW9 filter, and the correction factors should not be larger than a few percent.

3. Results and discussion

Flux-calibrated contour maps of the five fields imaged are presented in Figure 1. Bright, unresolved point sources are obvious in fields LI-LMC 1501 and LI-LMC 1518, but the one in LI-LMC 534, with $S_{15\mu m} \simeq 80$ mJy, is too faint to belong to the class of objects of interest here.

3.1. Fields without bright sources

The non-detection of bright sources in fields LI-LMC 235, 534, and 1367 has several interpretations. It may be due to the selection of other classes of objects by IRAS (Codella et al. 1994, Ramesh & Sridharan 1997). However, the reliability of such criteria for bright objects is supported by the 80 % detection rate of Kurtz et al. 1994. This rate may be higher if compact structures larger than 18", filtered out by the VLA observations of Kurtz et al. are included. On the other hand, sources able to mimic the IRAS colors of UCHIIR (low mass star forming cores, planetary nebulae, or evolved stars) should be far less luminous than UCHIIR at the LMC distance.

It is possible that the IRAS point sources do contain bright compact sources, but fall outside the imaged area due to the large IRAS error box. To check this hypothesis, we compared the fluxes at 15 μm integrated over the ISOCAM frame with the flux interpolated from IRAS measurements at 12 and 25 μm, assuming a constant spectral index. Integrated fluxes were found by adding the fluxes at each pixel, after subtracting the background level of the darkest areas of the frame. The background flux is similar among the different fields, and a large flux underestimate due to bright backgrounds seems unlikely. The ratio between the IRAS flux at 15 μm and the integrated flux in fields with bright objects lies between 1.1 and 1.2, and between 1.4 and 3.4 for the fields without them. This suggests that bright, compact sources outside the ISOCAM images in the latter case may indeed strongly contribute to the IRAS fluxes. Further observations covering larger areas are needed to confirm this explanation.

3.2. The point sources

The fluxes of the bright sources detected at 15 μm are given in Table 2. The measurement uncertainities in all cases are about 200 mJy. Also given in Table 2 are fluxes at 1.4 GHz and 2.4 GHz from Marx et al. 1997, or upper limits based on the completeness fluxes quoted by them. The three sources lie very close in the sky. They belong to N 159, one of the HII regions in the area south of 30 Doradus, which has been studied in different wavelengths (see Johansson et al. 1998 for an extensive summary of previous work). The bright point source in LI-LMC 1518 is part of a known CHIIR (object N159-5 of Israel & Koornneef 1991; see also references therein). It has been observed at high resolution in radio continuum by Hunt & Whiteoak 1994 and Marx et al. 1997. Between 1.4 GHz and 2.4 GHz, Marx et al. measure a spectral index $\alpha \simeq -0.32$, indicative of an optically thin HII region at those frequencies. This probably rules it out as a UCHIIR, as the very high densities of these objects lead to emission measures in excess of 10^8 cm^{-6} pc and, consequently, turnover frequencies well above 2.4 GHz (e.g. Gordon 1986).

The infrared source associated to LI-LMC 1501 was classified as a protostar by Jones et al. 1986. Its double-peaked structure can be seen in the 4.8 GHz interferometer

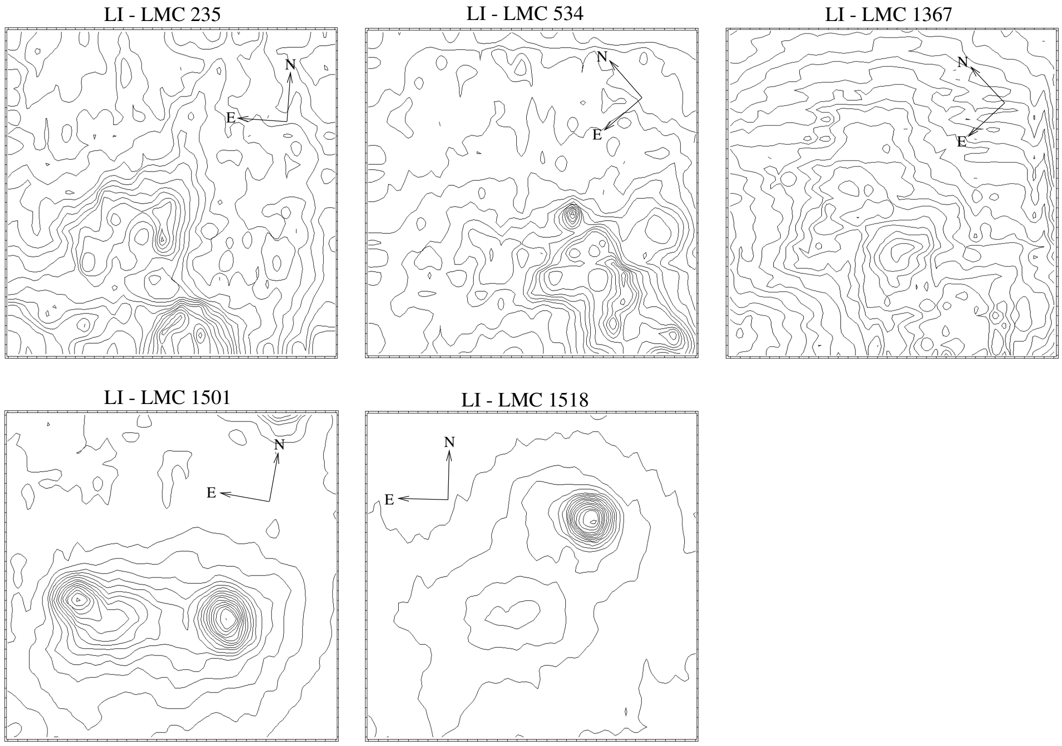

Fig. 1. Contour plots of the 15 μm emission in the imaged LMC fields. Each frame covers an area of 51" $\times$ 51" (12.5 pc $\times$ 12.5 pc) centered at the position given in Table 1. Twenty contours equally spaced in linear units are plotted, adjusted to adequately sample the dynamic range. The lowest contour corresponds to 0 mJy arcsec^{-2}, and the highest to 23.5 mJy arsec^{-2} (LI-LMC 235), 63.7 mJy arsec^{-2} (LI-LMC 534), 30.8 mJy arsec^{-2} (LI-LMC 1367), 104.7 mJy arsec^{-2} (LI-LMC 1501), and 184.6 mJy arsec^{-2} (LI-LMC 1518). The lowest contours delineate the shape of the extended emission. In LI-LMC 235, 524, and 1367, contour distortions near the edges caused by data reduction artifacts are also visible due to the smaller dynamic range.

Table 2. Point source ISOCAM and radio fluxes (in mJy)

LI-LMC	α (2000)	δ (2000)	$S_{15\mu\mathrm{m}}$	$S_{1.4\mathrm{GHz}}$	$S_{2.4\mathrm{GHz}}$
1501 E	5:39:41.9	-69:46:16	900	< 8	< 6
1501 W	5:39:37.5	-69:46:14	1500	< 8	< 6
1518	5:40:04.8	-69:44:35	1900	23	15

map of N 159 of Hunt & Whiteoak 1994. Those authors consider the source as somewhat extended, giving fluxes at 1.4, 4.8, and 8.6 GHz. However, none of the point sources is detected at 1.4 or 2.4 GHz in the survey of compact sources of Marx et al. 1997, in which extended structure is filtered out. This suggests that the fluxes reported by Hunt & Whiteoak may arise from an extended component (probably traced by the lower contours of our 15 μm map), at least at low frequencies, rather than from our unresolved sources. Interestingly, and unlike for the other compact sources mapped by Hunt & Whiteoak, the flux of LI-LMC 1501 drops significantly with decreasing frequency between 4.8 and 1.4 GHz, contrarily to what would be expected for an optically thin HII region. This could be explained if the unresolved components have turnover frequencies near 5 GHz, thus contributing to the measured flux at 4.8 GHz but not at lower frequencies. Assuming that they are optically thin and just below a detectability limit of 6 mJy at 2.4 GHz, the flux ratio $S_{15\mu\mathrm{m}}/S_{2.4\ \mathrm{GHz}}$ is > 150 for LI-LMC 1501 E, and > 250 for LI-LMC 1501 W, while it is $\simeq 125$ for LI-LMC 1518. Values of the ratio of $S_{15\mu\mathrm{m}}$ to radio continuum flux in the optically thin regime are typically in the range 30 - 100 for galactic UCHIIR (Kurtz et al. 1994). This ratio can be expected to decrease as the emitting volume grows: the radio continuum flux depends only on the number of ionizing photons, while an intense flux at 15 μm requires a high density of dust within ~ 0.1 pc from the star, due to the sharp drop in dust temperature with increasing distance to the star (Leisawitz et al. 1991, Churchwell et al. 1990). $S_{15\mu\mathrm{m}}/S_{2.4\ \mathrm{GHz}}$ may also increase due to the lower dust-to-gas ratio expected in a low metallicity system like the LMC: in addition to reducing the overall dust emission near the star, this would increase the number of energetic photons available to ionize the gas. In summary, the overall drop in the flux with decreasing frequency over the area of LI-LMC 1501, the non-detection of unresolved components at 1.4 and 2.4 GHz, and the consequently high $S_{15\mu\mathrm{m}}/S_{2.4\ \mathrm{GHz}}$ ratios implied by this, lead us to consider the two point sources in LI-LMC 1501 as likely UCHIIR. Admittedly, these are rather indirect arguments, subjected to important uncertainties affecting the determination of the infrared fluxes and the upper limits in the radio fluxes. Observations of high sensitivity and spatial resolution up to at least the turnover frequency are needed to prove it.

Table 3. Estimated characteristics of the embedded stars

LI-LMC	$\log L$ ($L_\odot$)	Sp. type	$\log N_{UV}$ (s^{-1})	Sp. type
1501 E	5.9×10^4	O7.5V	< 47.2	$> B1$V
1501 W	1.0×10^5	O6.5V	< 47.2	$> B1$V
1518	1.3×10^5	O6V	47.88	B0.2V

We can estimate the luminosities of the embedded stars by using the 15 μm fluxes to find the scaling factor to be applied on a typical UCHIIR spectral energy distribution. Although UCHIIR are known to have remarkably similar spectral energy distributions (Wood & Churchwell 1989a), the differences are large enough so that this approach is only a rough approximation. Taking as typical values from the IRAS color-color diagram (Wood & Churchwell 1989b) $\log S_{25\ \mu\mathrm{m}}/S_{12\ \mu\mathrm{m}} \simeq 0.8$, $\log S_{60\ \mu\mathrm{m}}/S_{12\ \mu\mathrm{m}} \simeq 1.9$, and using the approximate relationship between the 60 μm flux and the luminosity of the star,L_*, from Comerón & Torra 1996, we obtain $L_*(L_\odot) \simeq 6.9 \times 10^4 S_{15\ \mu\mathrm{m}}(\mathrm{mJy})$. The uncertainty in the proportionality factor is dominated by the assumed flux ratios at different wavelengths. Using the scatter in these ratios for galactic UCHIIR, we estimate that the proportionality between L_* and $S_{15\ \mu\mathrm{m}}$ is uncertain by a factor ~ 2.3, corresponding to two spectral subtypes for late O stars (Schaerer & de Koter 1997). On the other hand, we can also estimate the emission rate of ionizing photons, N_{UV}, producing the optically thin radio continuum emission. Taking the usual approximation for the continuum absorption coefficient (Altenhoff et al. 1960) and a temperature of 10,000 K in the HII region, we obtain $N_{UV}(\mathrm{s}^{-1}) = 1.8 \times 10^{46} \nu(\mathrm{GHz})^{0.1} D(\mathrm{kpc})^2 S_\nu(\mathrm{Jy})$. Both procedures allow an estimate of the spectral type of the embedded star by comparison to model atmospheres; the caveats and implicit assumptions of both methods have been discussed by Churchwell 1990.

Our estimates are given in Table 3, where the transformation between luminosity or flux and spectral type is based on Schaerer & de Koter 1997. The difference between the spectral types derived in the two ways is to be expected: using the luminosity neglects the likely presence of lower mass stars contributing to the luminosity, but not to the ionizing flux, while the use of the radio flux neglects the absorption of photons by dust. The true spectral type is expected to lie somewhere between both estimates. On the other hand, as explained above, the underlying assumption of an optically thin plasma may not apply to the LI-LMC 1501 sources if they are true UCHIIR.

In summary, our ISOCAM observations provide precise positions and 15 μm fluxes for three bright objects in the N 159 HII region of the LMC. One of them is a compact HII region, while some arguments based on the comparison between infrared and radio fluxes suggest that the other two could be ultracompact HII regions. These observations thus provide a first list of targets for detailed follow-up which, if confirming the true ultracompact nature of the two proposed sources, would imply the first detection of such objects in a galaxy different from ours.

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