IRAS AND GROUND-BASED OBSERVATIONS OF STAR FORMATION REGIONS IN THE MAGELLANIC CLOUDS

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ABSTRACT

The Infrared Astronomical Satellite (IRAS) detected several hundred individual regions of star formation in the Large and Small Magellanic Clouds. Nearly two dozen of the brightest such sources have been searched for from the ground at 10 microns; most of these have been located and measured at wavelengths from 0.6 to 20 microns. Three principal results emerge from this study: First, the IRAS data show that star formation is considerably less active in the SMC than in the LMC, relative either to mass, luminosity, or H I content. The reduced activity in the SMC is consistent with the smaller amount of molecular material inferred from CO observations. Second, the sizes of the objects range from less than a few arcsec - objects which look like extremely compact HII regions, with little or no extended radio, optical, or infrared emission - to some tens of arcsec across - giant H II regions, of which the largest and brightest is 30 Doradus. Third, there are no obvious differences in the characteristics of the central portions of the LMC and SMC sources; all look like compact Galactic H II regions of similar luminosity.

IRAS DATA BASE

IRAS detected over 400 12 micron sources in the general direction of the LMC, and roughly 100 such sources in the direction of the SMC. Most of these have the characteristics of star formation regions: flux rising steeply from 12 to 100 microns. Specifically, star formation regions can be distinguished from evolved Magellanic Cloud or foreground objects on the basis of their 25 to 12 micron flux density ratios, which are typically greater than 4, and always greater than 3. Furthermore, only star formation regions have 60 to 25 micron flux density ratios significantly greater than 1. Many of the star formation regions are resolved by IRAS, which implies angular sizes of the order of an arcminute. Many, but not all, can be identified with catalogued visible or radio H II regions. In an effort to better understand these sources, we embarked on a ground-based observational program of LMC and SMC IRAS star formation regions detected by IRAS. The program had three aims: to identify and locate precisely the stronger IRAS sources; to extend wavelength coverage to shorter wavelengths - into the visible in some cases - and to obtain information on sizes, by comparison of the small-beam ground-based data with the IRAS data (principally at 10 microns) and by mapping. The ultimate goal of the program is to make a comparison between the SMC, the LMC, and the Galaxy. A separate but related program is a study of evolved objects in the Magellanic Clouds detected by IRAS (Elias, Frogel and Schwering, 1986; Elias and Frogel, in preparation).

The principal result from the IRAS data themselves is that the SMC contains far fewer bright star formation regions that the LMC; the brightest 12 micron point sources in the SMC have flux densities of roughly 1 Jy, while the brightest LMC sources (excluding 30 Dor) are roughly 10 Jy, and there are more than 100 1 Jy sources. (In fact, confusion limits over much of the LMC are greater than 1 Jy.) Similar comparisons can be made at 25, 60, and 100 microns. This parallels the relative weakness of CO emission from the SMC, as compared with the LMC (e.g. Cohen, Montani, and Rubio 1984; Rubio, Montani, and Cohen 1984; Israel *et al.* 1986). Since the IRAS data measure most of the star formation luminosity in these galaxies, it appears that the simplest explanation of these observations is that star formation is currently much less active in the SMC than it is in the LMC. The much higher flux limits in the LMC, compared with the SMC, account for the fact that the total numbers of IRAS sources in the two Clouds do not show so great a disproportion.

Another interesting result is that in the SMC, the brightest sources are located in the eastern portions of the galaxy, with the brightest object (IRAS 01228-7324) located outside the main body. Since the distribution of H I in the SMC also shows more concentration to the east than do the stars, it may be that ongoing star formation is occurring in a different pattern than in the past.

IDENTIFICATION OF IRAS SOURCES

Two main considerations led us to search primarily at 10 microns rather than at some shorter wavelength. The first was a desire to be certain that the IRAS sources were being correctly identified, and the position of maximum flux located; this could in practice be done only at 10 microns. A second concern was confusion at shorter wavelengths; since some of the star formation sources proved to be extremely red, they could not be reliably located at wavelengths less than 10 microns.

Most of the searches were done on the CTIO 1.5m telescope, using the "D2" bolometer system and a beam size of 12.7 arcsec; follow-up observations were made on the CTIO 4m telescope with beams sizes of 4 to 7 arcsec. A total of 12 LMC sources and 6 SMC sources were searched. With the exception of 4 of the fainter SMC sources, 10 micron flux was measured from all objects and an approximate position of peak flux located. In many cases, the sources were extended, with peak fluxes several times less than the total IRAS flux, extrapolated to 10 microns. In two cases, however, the flux in a 5 arcsec beam was not significantly less than the IRAS flux, suggesting a very compact source. Both of the these objects (IRAS 01228-7324 [=N88a; cf. Testor and Pakull 1985] and 05216-6753) have visible counterparts with H II region spectra, but no strong radio emission. Energy distributions of these objects are shown in Figure 1. One should note, though, that because of the distance of the Magellanic Clouds, these "compact" objects may easily be up to a parsec in extent. Nevertheless, it appears that there exist regions in both the SMC and LMC similar to compact H II regions in the Galaxy.

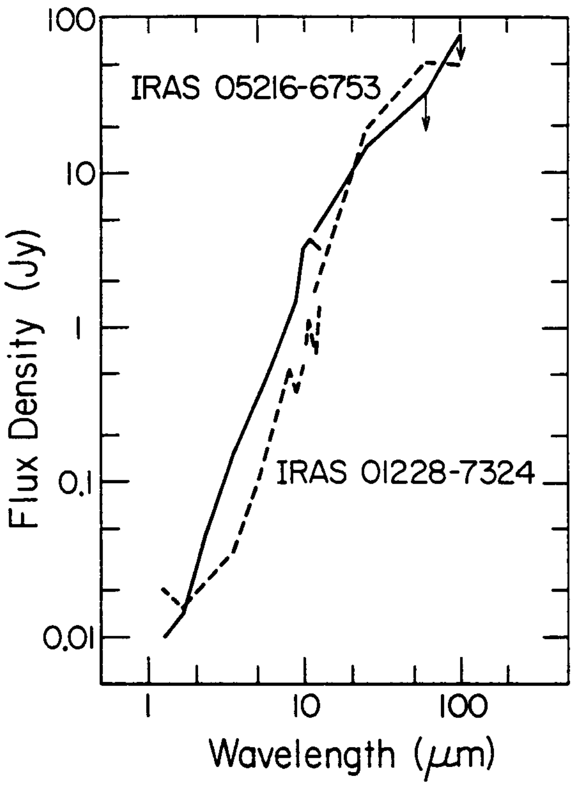

Figure 1. Flux Density Distributions of Two Compact Magellanic Cloud H II Regions. The data from 1 to 12 microns are ground-based measurements with a 4.5 arcsec beam, and the 12 to 100 micron data are IRAS Point Source Catalog data. The data for IRAS 05216-6753 are shown with a solid line, and the data for IRAS 01228-7324 are shown with a dashed line. The 60 and 100 micron upper limits for IRAS 05216-6753 are set by confusion.

Another noteworthy aspect of the IRAS "star formation" sources searched for is that all those that were identified proved to have one or more characteristics identifying them as including H II regions: that is, regions with stars producing substantial amounts of ionizing radiation. Most of the objects have obvious,compact, visible counterparts, whose spectra are characteristic of H II regions; the remainder are most likely H II regions obscured by intervening molecular cloud material, and show generally redder near-infrared energy distributions. Most sources, also, could be identified with thermal radio sources. What is not clear is that these H II regions are in fact the dominant source of far-infrared flux, since there are indications that the 10 micron sources are not precisely coincident with the visible compact H II regions. This apparent association of IRAS sources with H II regions suggests that luminous star formation regions containing only pre-main-sequence objects are relatively rare - possibly because pre-main-sequence lifetimes are so short compared with main-sequence lifetimes. A survey at high spatial resolution might not be so dominated by H II regions, since (as noted above) much of the flux from the IRAS sources come from regions several arcseconds or tens of arcseconds across.

ACKNOWLEDGEMENTS

Portions of this work were supported under the IRAS extended mission program, and by the National Science Foundation. Cerro Tololo Interamerican Observatory is operated by AURA, Inc., under contract with the National Science Foundation.

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