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ON THE REDISTRIBUTION OF OB STAR LUMINOSITY AND THE WARMING OF NEARBY MOLECULAR CLOUDS

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ABSTRACT

IRAS observations of the neighborhoods of six outer-Galaxy HII regions were combined with CO observations to show that most of the far infrared (FIR) luminosity from within ~25-75 pc of the ionizing stars is contributed by dust in molecular clouds, not by dust in the low-density ionized gas. Dust associated with the clouds is warmed by absorption of UV and visible light from the cluster of stars responsible for the ionization. Most ($\gtrsim$70%) of the OB cluster starlight is not absorbed locally.

A fraction of the order of 10% of the OB cluster luminosity is absorbed by nearby molecular clouds and reradiated as FIR light. The luminosity per unit mass for the heated clouds is ~3-13 $L_\odot/M_\odot$, approximately one order of magnitude greater than the corresponding ratio for clouds found near clusters without O stars, and two orders of magnitude greater than the ratio for dark clouds heated primarily by the interstellar radiation field. If the observations of clouds near outer-Galaxy HII regions are used to characterize the molecular clouds heated by HII regions in the inner-Galaxy, then <u>at most</u> 30% of the Galaxy's molecular cloud mass is actively engaged in the formation of massive stars at the present time.

INTRODUCTION

One can infer from a number of articles that appear in this volume that the "warm dust" (Cox, Krügel, and Mezger 1986) in many spiral galaxies has been heated by massive stars. As a rule, massive stars are concentrated in the arms of spiral galaxies and are accompanied by molecular clouds and diffuse atomic gas, as well as ionized gas. In order to successfully interpret correlations between indicators of massive star formation (e.g., radio continuum, recombination line, and blue luminosity observations) and the FIR emission of galaxies, it is necessary to understand how the luminosity of massive stars is distributed among dust grains associated with the various components of the interstellar medium (ISM). To put it succinctly: as we appreciate the beauty of the forest, let's not forget what the trees are!

Analysis of the infrared emission from the neighborhoods of HII regions in the Galaxy can be used to answer two important questions. First, how much of the ionizing cluster starlight is absorbed locally? Second, what are the relative proportions of the locally-absorbed starlight involved in heating dust associated with diffuse ionized gas, diffuse atomic gas, and molecular clouds?

OBSERVATIONAL PARAMETERS

We analyzed six regions, all of which lie outside the solar circle where a molecular cloud can be associated with an HII region almost unambiguously, and where the galactic infrared background is relatively uncomplicated. Table I shows the star cluster coordinates (Alter, Ruprecht, and Vanysek 1970) and distances, and the angular and linear radii of the regions.

Table I. Analyzed Regions

Star Cluster	HII Region	Galactic Coordinates (l,b) (deg)	d[a] (kpc)	Region Radius (deg)	Region Radius (pc)
NGC 7380	S142	107.08-0.90	3.60	1.0625	66.8
NGC 281	S184	123.13-6.24	1.66	0.8125	23.5
IC 1848	W5/S199	137.19+0.92	2.31	1.0625	42.8
NGC 1624	S212	155.35+2.58	6.00	0.5625	58.9
NGC 1893	IC410/S236	173.59-1.70	4.00	1.0625	74.2
NGC 2175	S252	190.20+0.42	1.95	1.5625	53.2

[a] References for distance: NGC 7380, IC 1848, NGC 1893, and NGC 2175 from Lynga 1981, NGC 281 from Walker and Hodge 1968, and NGC 1624 from Moffat, FitzGerald, and Jackson 1979.

Observations of ^{12}CO J=1→0 emission were obtained with the Columbia University 1.2m millimeter wave telescope (Leisawitz 1985; Leisawitz, Thaddeus, and Bash 1986, hereafter LTB). A circular region, centered on the star cluster coordinates of the size indicated in Table I was mapped with a uniform sampling interval of 7.5'. The antenna beamwidth is 8.7', the velocity resolution of the spectrometer is 0.65 km s^{-1}, and the RMS baseline noise in all spectra is $T_A^* \sim 0.28$ K. A catalog and maps of the molecular clouds in the six regions of interest are given by LTB.

Maps of 12, 25, 60, and 100μm emission corresponding to the regions mapped in CO were extracted from the IRAS sky flux images (IRAS Explanatory Supplement). The spatial resolution of the IRAS images is modestly better than that of our CO observations. For comparison with the infrared data, the CO data were interpolated and mapped into 2'X2' pixels.

RESULTS

After subtraction of an appropriate background (Leisawitz and Hauser 1986), in-band and bolometric FIR luminosities were calculated for the regions of Table I and for each of the molecular clouds in these regions. Bolometric luminosities were derived from the 60 and 100μm observations (cf. Appendix B of Catalogued Galaxies and Quasars in the IRAS Survey). Two methods were applied to estimate the background levels in the directions of molecular clouds and consistent results were obtained. Most of the uncertainty in the luminosity measurements is due to uncertainty of the background intensity.

The region luminosities (bolometric) range from $\sim 5\times10^4$ to $\sim 5\times10^5$ $L_\odot$ with uncertainties $\gtrsim 10\%$. A fraction between 5 and 30% of the total OB cluster luminosity is reradiated in the FIR by dust within the regions studied. Dust associated with molecular clouds accounts for ~50-80% of the FIR luminosity from the regions considered; the rest of the emission from these regions comes, in roughly equal proportions, from dust in the low-density ionized gas and dust in diffuse atomic gas surrounding the nebulae.

Individual molecular clouds have luminosity-to-mass ratios $\langle L/M\rangle \sim 3 - 13$ $L_\odot/M_\odot$ (cloud masses were derived from the CO observations assuming $N_{H2} \simeq 2\times10^{20}$ $cm^{-2}K^{-1}km^{-1}s\int T_R^* dv$). For comparison, the molecular clouds found in regions near star clusters with members of spectral type B0 or later (LTB) have $\langle L/M\rangle \sim 0.1 - 1$ $L_\odot/M_\odot$ and the molecular clouds in the LTB survey that appear to be isolated, local clouds have $\langle L/M\rangle \lesssim 0.1$ $L_\odot/M_\odot$ and generally were not detected by the IRAS.

DISCUSSION

If the luminosity of massive stars generally is distributed among the various components of the ISM as it appears to be in the regions that we have analyzed, then it is possible to deduce the fraction, f_{wmc}, of a galaxy's molecular cloud mass that consists of warm molecular clouds heated by nearby massive stars:

$$f_{wmc} \simeq f_{loc} L_{OB}(gal) / [M_{mc}(gal)\langle L/M\rangle_{wmc}],$$

where f_{loc} is the fraction of an OB cluster's luminosity absorbed by nearby molecular clouds and $\langle L/M\rangle_{wmc}$ is the luminosity-to-mass ratio for these clouds. Radio continuum observations can be used to derive $L_{OB}(gal)$, the luminosity from a galaxy's OB star clusters and CO observations can be used to estimate a galaxy's molecular mass, $M_{mc}(gal)$. Our analysis suggests that $f_{loc} \sim 2 - 13\%$ and $\langle L/M\rangle_{wmc} \sim 3 - 13$ $L_\odot/M_\odot$. For the inner Galaxy, Dame, Elmegreen, Cohen, and Thaddeus (1986) estimate $M_{mc}(gal) \simeq 9.1\times10^8$ $M_\odot$ and, from the Lyman continuum photon production rate obtained by Güsten and Mezger (1983), we derive $L_{OB}(gal) \simeq 6\times10^9$ $L_\odot$. Accordingly, f_{wmc} should be between ~1.3 and 29% for the inner Galaxy. Observations of 13 well-studied spiral galaxies summarized by Israel and Rowan-Robinson (1984) suggest that a ratio $L_{OB}(gal)/M_{mc}(gal)$ similar to the ratio derived for the Milky Way is applicable to these galaxies as well. Apparently, it is often the case that only a small fraction of a galaxy's molecular cloud mass is actively forming massive stars at a given time.

CONCLUSIONS

From analysis of the infrared emission from regions surrounding six OB clusters in the outer Galaxy, we conclude that:

(a) at most 30% of the cluster luminosity is absorbed by dust grains within ~25-75 pc of the stars,

(b) ~50-80% of the locally-absorbed starlight is absorbed by dust associated with molecular clouds while the remainder is absorbed, approximately in equal proportions, by dust embedded in low-density ionized gas and dust associated with diffuse atomic gas, and

(c) the fraction of cluster starlight absorbed by nearby molecular clouds is of the order of 10% and the FIR bolometric luminosity-to-mass ratios that characterize such clouds are approximately a few to 13 solar units. This information can be used to estimate the fraction of a galaxy's molecular mass that is in the form of molecular clouds heated by nearby clusters of massive stars: in the Milky Way, and in 13 well-studied spiral galaxies, probably less than 30% of the molecular gas is involved in the production of the current generation of massive stars.

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