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IRAS[1] OBSERVATIONS OF SHAPLEY-AMES GALAXIES

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ABSTRACT

We present a preliminary discussion of the infrared properties of a representative subsample of galaxies in the *Revised Shapley-Ames Catalog* ($B < \sim 13$ mag). Of the 165 galaxies in our sample, 108, predominantly spiral galaxies, are detected in the infrared by *IRAS*. None of the elliptical galaxies and only about 25% of the lenticular galaxies scanned were detected. The range of infrared to blue luminosity ratios, a measure of the infrared excess of galaxies, is large, varying from roughly 0.1 to roughly 5. The data suggest that weakly infrared emitting galaxies are cool (100–60 μm color temperatures of ~ 25 K), while the more infrared luminous ones tend to be warmer (~ 50 K). The rate of star formation in barred spiral galaxies is apparently higher than in normal spirals. About 1 $M_\odot$ yr^{-1} of interstellar matter is converted into massive stars in the typical spiral galaxy.

Subject headings: galaxies: general — infrared: sources — stars: formation

I. INTRODUCTION

Almost all energy produced by newly born stars emerges as infrared radiation from their parental gas and dust clouds (e.g., Wynn-Williams 1982). thus, the infrared is the wavelength range "par excellence" to study the distribution, energetics, and the rate of star formation in galaxies (Rieke and Lebofsky 1979). In this *Letter*, we present a preliminary statistical study of the infrared properties of a representative subset of a complete optical sample of galaxies.

II. SELECTION OF THE GALAXY SAMPLE

We have restricted ourselves to galaxies in the *Revised Shapley-Ames Catalog of Bright Galaxies* (Sandage and Tammann 1981, hereafter RSA) which is complete down to about $B = \sim 13$ mag. Galaxies were selected from the RSA by requiring that they lie within the area of sky that was scanned at least four times during the first 100 days of the *IRAS* mission (Neugebauer *et al.* 1984, hereafter Paper I). For association with an RSA galaxy, an *IRAS* source had to be hours-confirmed and weeks-confirmed (Paper I) and lie within 2′ of the visual position of the Galaxy.

These selection criteria resulted in a sample of 165 RSA galaxies, of which 108 were associated with well-confirmed infrared sources. Differences between the *IRAS* positions of the infrared sources and the cataloged position typically amount to a few tenths of an arc minute, exceeding 1′ in only nine cases. The limiting signal-to-noise ratio of approximately 7 for the data base at the preliminary analysis facility (Paper I), from which the infrared data discussed here were extracted, implies that sources are brighter than 0.9 Jy at 12 μm, 0.5 Jy at 25 μm, 1 Jy at 60 μm, and 2 Jy at 100 μm. The calibration and its associated uncertainties are discussed in Paper I. Inspection of detector outputs shows that galaxies with optical diameters less than approximately 5′ usually appear pointlike at 60 and 100 μm. Flux errors due to resolution effects are estimated to be less than 20%.

The infrared spectral energy distributions of galaxies are strongly peaked toward long wavelengths. Of the 108 infrared galaxies in our sample, 21 (19%) are detected at 12 μm, 52 (48%) at 25 μm, 103 (95%) at 60 μm, and 107 (99%) at 100 μm.

III. DISTRIBUTION WITH MORPHOLOGICAL TYPE

We show in Figure 1 the distribution of morphological types of the 165 RSA galaxies in our sample. The distribution of the barred types is shown separately in the upper part of the figure. A comparison with the distribution of all 1246 galaxies in the RSA shows that our sample is a representative subset of the RSA although early morphological types (elliptical, lenticular, and early spiral galaxies) are slightly overrepresented. Following the RSA, we have included galaxies with two alternative assignments of morphological type in each type bin. The hatched area shows the distribution of those galaxies which were detected by *IRAS*.

A striking but not unexpected feature of Figure 1 is the complete absence of elliptical galaxies in the infrared, indicating the dust-free nature of ellipticals. Lenticular galaxies are underrepresented in the infrared by a factor of 4. Only about half of the earliest spiral galaxies show up in the infrared, while virtually all galaxies with later morphological types are detected. The group named "special" in Figure 1 consists of what the RSA calls "amorphous" galaxies, of which M82 (incorporated in our sample) is the most infrared-bright example. The infrared distribution of the barred spiral galaxies in Figure 1 shows a similar preponderance of late morphological types in the infrared.

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[1] The *Infrared Astronomical Satellite* was developed and is operated by the Netherlands Agency for Aerospace Programs (NIVR), the US National Aeronautics and Space Administration (NASA), and the UK Science and Engineering Research Council (SERC).

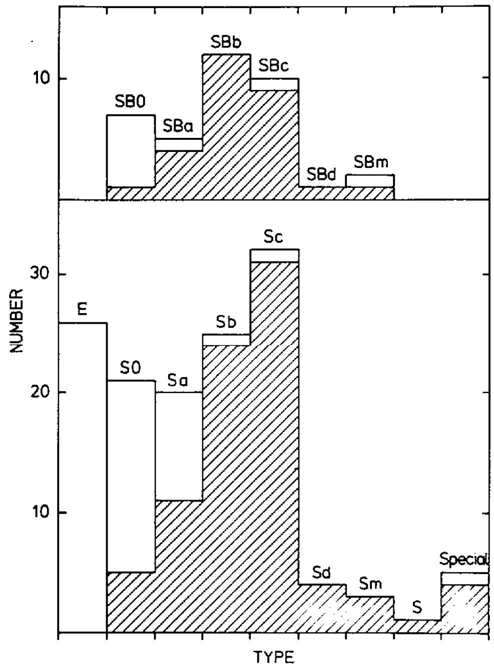

FIG. 1.—Distribution of the galaxies in our sample with morphological type. The hatched area represents the distribution of galaxies detected in the infrared. Galaxies with ambiguous morphological types are included separately in each possible type bin.

IV. INFRARED PROPERTIES OF SHAPLEY-AMES GALAXIES

We have calculated integrated infrared luminosities from the *IRAS* data for 89 infrared galaxies in our sample with optical diameters less than 5′. This restriction was introduced to simplify the calculation of integrated infrared luminosities in view of the finite detector sizes at 60 and 100 μm. Since galaxies emit virtually all their infrared energy at long wavelengths, we computed infrared luminosities from the interpolated flux density at 80 μm, intermediate between the two long-wavelength bands, using the relation $F_{\rm IR} = \nu F_\nu$. In converting in-band flux to flux densities, no color corrections were applied. This procedure introduces errors of at most 10%. Distances were obtained from the corrected radial velocities listed in the RSA, adopting a Hubble constant of 50 km s^{-1} Mpc^{-1}. For one nearby galaxy, IC 5152, we took the distance recommended by Kraan-Korteweg and Tamman (1981). All galaxies detected in the infrared are within about 100 Mpc. The average distance of galaxies of all morphological classes is approximately 50 Mpc except for the irregular galaxies which are very nearby, on the average at about 3 Mpc. Blue luminosities were computed from the integrated magnitudes in the RSA using standard values for the effective wavelength and for the flux calibration of the blue photometric band. The integrated magnitudes in the RSA are corrected for internal and external extinction. We also computed the ratio of the monochromatic flux densities at 100 and 60 μm, S_{100}/S_{60}. In Table 1 we summarize average properties of RSA galaxies, and we discuss the results below.

The infrared and blue luminosities of galaxies turn out to be roughly correlated, which is consistent with the fact that both are generated by recently born stars. Introducing the infrared to blue luminosity ratio as a measure of the infrared excess of galaxies, we find an average value of $L_{\rm IR}/L_B \approx 0.4$ (see Table 1). However, large deviations from the average occur for individual galaxies. In Figure 2, we have plotted $L_{\rm IR}/L_B$ versus S_{100}/S_{60} for the 89 infrared galaxies in our sample. The temperature displayed at the top of Figure 2 assumes a dust emissivity proportional to frequency. Dots are used to indicate normal spirals, pluses for barred spirals, circled dots for lenticulars, and stars for irregulars. Leaving lenticular and irregular galaxies aside for the moment, the data in Figure 2 suggest that there is a statistical correlation between the two quantities plotted. Spiral galaxies with low color temperatures ($T_c \approx 25$ K) emit only about 10% of their total luminosity in the infrared while infrared-warm spiral galaxies ($T_c \approx 50$ K) emit up to 5 times more energy in the infrared than in the blue.

To attempt to interpret this correlation, we postulate two infrared components in a galaxy: one (see Jura 1982) due to interstellar dust distributed throughout the disk which reradiates a small fraction (of the order of the dust optical thickness of the disk) of the general visual-ultraviolet interstellar radiation field at a color temperature of approximately 25

TABLE 1

AVERAGE INFRARED PROPERTIES OF SHAPLEY-AMES GALAXIES

Type	No. of Galaxies	log($L_{\rm IR}$)	log($L_{\rm IR}/L_B$)	log(S100/S60)
S(B)0	6	10.07	−0.45	0.32
		0.12	0.15	0.10
Sa–bc	29	10.29	−0.37	0.50
		0.08	0.05	0.03
Sc–d	29	9.91	−0.42	0.52
		0.13	0.05	0.02
SBa–bc	14	10.37	−0.20	0.33
		0.09	0.13	0.04
SBc–d	6	10.06	−0.31	0.42
		0.18	0.10	0.07
Sdm, Sm, Im, Amorphous ...	4	8.19	−0.26	0.24
		0.38	0.21	0.10

NOTE.—Errors indicated directly below the quantities tabulated are mean statistical errors.

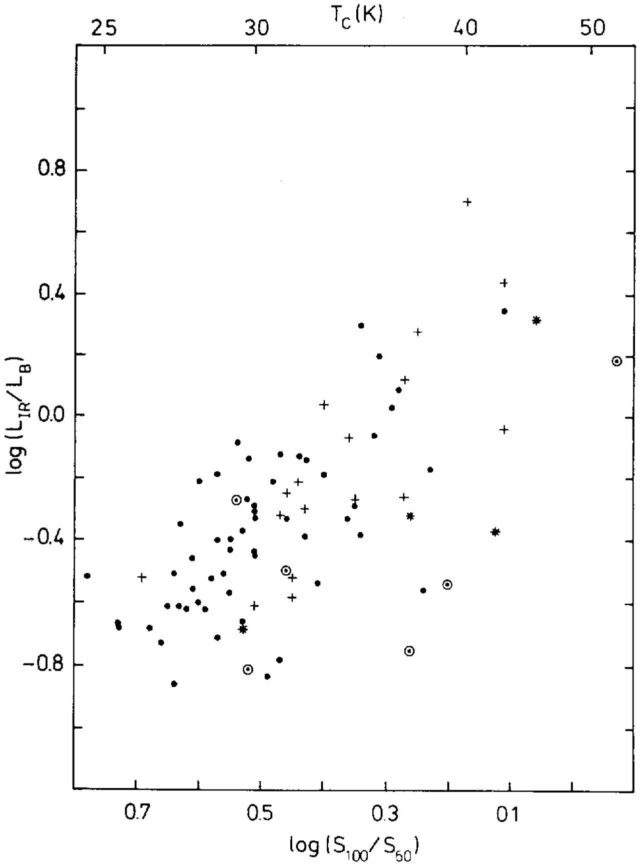

FIG. 2.—Infrared to blue luminosity ratios versus far-infrared monochromatic flux density ratios. The upper scale gives color temperatures for a dust emissivity proportional to frequency. Separate symbols are used to indicate lenticulars (*dotted circles*), normal spirals (*dots*), barred spirals (*pulses*), and irregulars (*stars*).

K; and another due to interstellar dust associated with H II regions and molecular clouds which reradiates the stellar radiation of the most recently born O stars at a color temperature of approximately 50 K. When the rate of star formation in a galaxy is high, the warmer component increases in importance as more, approximately 50 K radiation due to (invisible) O stars embedded in molecular clouds is emitted. Thus the relative intensity of star formation increases as shown in Figure 2, from the lower left-hand corner to the upper right-hand corner.

We further conclude from Figure 2 (see also Table 1) that, on the average, the star formation activity in barred spirals is greater than in normal spirals. Since stellar bars are usually located in the central regions of a galaxy, the enhanced infrared emission in barred spiral galaxies is probably concentrated toward the center as well. Detailed future studies by *IRAS* of well-resolved nearby barred spiral galaxies will verify this suggestion.

Lenticular and irregular galaxies, indicated by circled dots and stars in Figure 2, although few in number, seem to differ from spiral galaxies in that they are on the average somewhat hotter or somewhat less luminous, or both, in the infrared than are spiral galaxies (see also Table 1). The interpretation of this trend in the context of the simple two-component model discussed above is not immediately obvious, but it is attractive to speculate that, in the absence of spiral structure in these galaxies, this trend is related to the occurrence of star formation in bursts. It might also be due to the fact that lenticular and irregular galaxies usually contain less dust than spiral galaxies.

Using the infrared data discussed by Habing *et al.* (1984), we find that M31 would be located outside the boundaries of Figure 2 in the extreme lower left-hand corner. This location is consistent with their conclusion that the star formation activity in M31 is quite low. We note that, at the average distance of galaxies in our infrared sample (~ 50 Mpc), the Sb galaxy M31 would not have been detected by *IRAS* at a signal-to-noise ratio greater than 7.

Discussions of infrared-complete samples of galaxies by Soifer *et al.* (1984) and by Young *et al.* (1984) show that there exists a class of distant galaxies with large infrared to blue luminosity ratios which populate the area shown in the upper part of Figure 2. These extreme galaxies are apparently not present in a complete, optically bright sample, consistent with the fact that they comprise only a small fraction of all galaxies (Soifer *et al.* 1984). Selection effects will cause these galaxies to be strongly overrepresented in an infrared-complete sample.

The infrared data allow us roughly to estimate the average rate of hydrogen conversion into stars. If the stars that produce the far-infrared radiation in galaxies are O stars with $L \approx 10^4 L_\odot$, $M \approx 10 M_\odot$, and a lifetime of approximately 10^7 years, then a typical spiral galaxy with $L_{IR} \approx 10^{10} L_\odot$ (see Table 1) converts roughly 1 $M_\odot$ of hydrogen gas per year into O stars. Making plausible assumptions about the mass spectrum of stars at birth, we then estimate an average conversion rate of about 10 $M_\odot$ of interstellar material into stars per year. This number is similar to values derived for our own Galaxy (e.g., Mezger, Mathis, and Panagia 1982).

IV. CONCLUSIONS

IRAS observations of a subset of a complete optical sample of galaxies reveal the following facts.

1. Infrared emission is strongly correlated with galaxy type, ranging from elliptical and lenticular galaxies which emit little or no infrared to late-type spiral galaxies which can emit up to 5 times more energy in the infrared than in the visual.
2. Weakly infrared-emitting galaxies tend to have low far-infrared color temperatures (~ 25 K), while strongly infrared-emitting ones tend to be warmer (~ 50 K). This result is interpreted in terms of a higher rate of star formation in the warmer, more infrared-luminous galaxies.
3. A typical spiral galaxy converts approximately 1 $M_\odot$ yr^{-1} of interstellar material into massive stars.

The *IRAS* project derives its success from the contributions and dedication of numerous individuals. At this place, we would like to express our special thanks to the Preliminary

Analysis Support Team at the *IRAS* Ground Station in Chilton, England, and in particular to J. H. Fairclough, J. Abolins, and B. C. Stewart for their assistance in extracting from the daily avalanche of *IRAS* data the information discussed here.

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