N87-24293

STELLAR BARS AND THE SPATIAL DISTRIBUTION OF INFRARED LUMINOSITY

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ABSTRACT. New ground-based 10-μm observations of the central region of over 100 infrared luminous galaxies are presented. A first order estimate of the spatial distribution of infrared emission in galaxies is obtained through a combination of ground-based and IRAS data. The galaxies are nearby and primarily noninteracting, permitting an unbiased investigation of correlations with Hubble type. Approximately 40% of the early-type barred galaxies in this sample are associated with enhanced luminosity in the central (~1 kpc diameter) region. The underlying luminosity source is attributed to both Seyfert and star formation activity. Late-type spirals are different in that the spatial distribution of infrared emission and the infrared luminosity are not strongly dependent on barred morphology.

INTRODUCTION

I am using the IRAS data to investigate the infrared emission from normal galaxies and in particular correlations with optical morphology. Here, I would like to present some preliminary results on stellar bars and the spatial distribution of infrared luminosity.

The primary motivation for this particular study was the discovery made by Hawarden et al. (1986) that the IRAS $S_{25\mu m}/S_{12\mu m}$ flux ratio could actually segregate barred from unbarred galaxies.

THE METHOD

I have investigated the role of bars separately in early- and late-type spiral galaxies. The sample was divided into two broad categories segregating early (Sb and earlier) and late (Sbc and later) spiral types. Each category was further subdivided on the basis of barred morphology. I then compared the distributions of some property, such as luminosity or color, by using a statistical Kolmogorov-Smirnoff (K-S) test. This enabled me to quantitatively estimate whether the "bars" differ from the "unbars" in that property. I will argue the new result that the most significant differences between the bars and the unbars are seen in the early-type spirals.

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THE SAMPLE

The galaxies are selected from a volume-limited (distance $\leqslant$ 40 Mpc) catalog compiled by Dr. Brent Tully of the University of Hawaii. I believe that I have identified all galaxies with 60-μm luminosity $\geqslant 2.2 \times 10^9$ L_o, corresponding to a far-infrared luminosity, L (40-120 μm) $\geqslant 3 \times 10^9$ $L_\odot$, for $S_{100\mu m}/S_{60\mu m} \sim 3$. The lower luminosity limit was chosen to ensure completeness in the sense that IRAS would have detected all galaxies with $L_{60\mu m} \geqslant 2.2 \times 10^9$ $L_\odot$ in a volume of radius 40 Mpc, which is the outer distance limit of the catalog. Nearby galaxies, D $\leqslant$15 Mpc, were excluded, thereby reducing the number of galaxies whose large angular size would require more extensive observations. Galaxies with close neighbors were also excluded, since it was uncertain what fraction of the total IRAS flux was emitted by each galaxy. The selection criteria yielded a sample of ~230 galaxies.

RESULTS

The first property I investigated was the effect of bars on the luminosity of the central region. IRAS did not resolve the emission from most of the galaxies, and so I have used the IRTF to obtain new ground-based 10-μm observations with a small 6" aperture. These observations have enabled me to estimate the luminosity of the central (0.5-1 kpc diameter) region for a subsample of 127 galaxies in the RA range 5 $\leqslant \alpha \leqslant$ 16 hr.

The distribution of central 10-μm luminosity ($4\pi D^2 \nu S_\nu$) observed for early-type spirals is shown in Figure 1. The shaded area indicates barred galaxies,

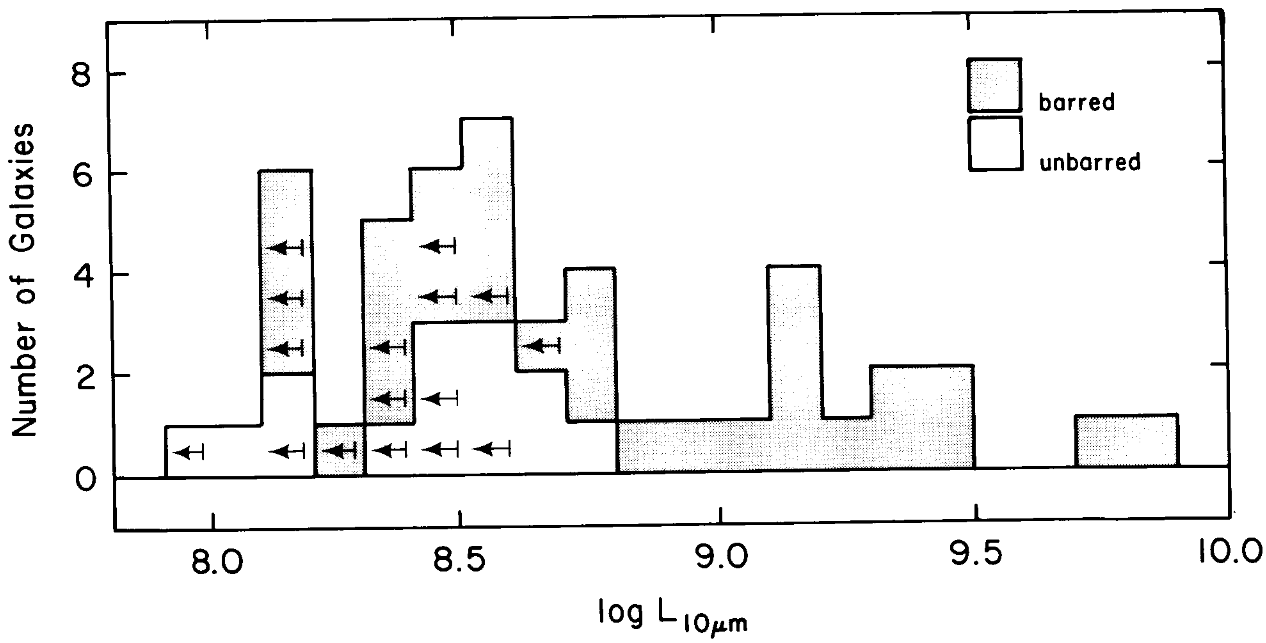

Figure 1. The distribution of central 10-μm luminosity for early-type barred and unbarred spirals. Arrows indicate 2σ upper limits. The central 10-μm luminosity in ~40% of the barred spirals exceeds the maximum central 10-μm luminosity in the unbarred spirals.

and the arrows indicate 2σ limits. The distributions for barred and unbarred galaxies are significantly different at the 95% level. The distributions are different because there is an excess component of 10-μm luminosity in ~40% of the bars that is not present in the unbars. Figure 2 illustrates the distribution for late type spirals; the K-S test indicates that the bars are not significantly different from the unbars (<90%).

The second property I investigated was the IRAS 25-μm/12-μm flux ratio to see if the effect, described by Hawarden et al. (1986), is related to the central 10-μm luminosity distributions described above.

The point source measurements for many of the sample galaxies were limits or unreliable because of extended emission. The IRAS point source measurements of 134 galaxies (~60% of the sample) were improved by line coadding raw IRAS scans. This was achieved using the facilities available at IPAC.

In Figure 3, I present the distributions of 25-μm/12-μm flux ratio for early- and late-type spirals. The distributions are significantly different at the 95% level. The difference arises because a larger fraction of the early types have $S_{25\mu m}/S_{12\mu m} \gtrsim 2$.

When considering just the early-type spirals (Figure 3, top), the distribution of the bars (shaded area) is significantly (95%) different than that of the unbars. The difference arises in that a larger fraction of the bars (50%) than the unbars (17%) has $S_{25\mu m}/S_{12\mu m} \gtrsim 2.5$. Considering the distribution for late-type galaxies illustrated in Figure 3 (bottom), the K-S test indicates a less significant (<90%) difference between the bars and the unbars.

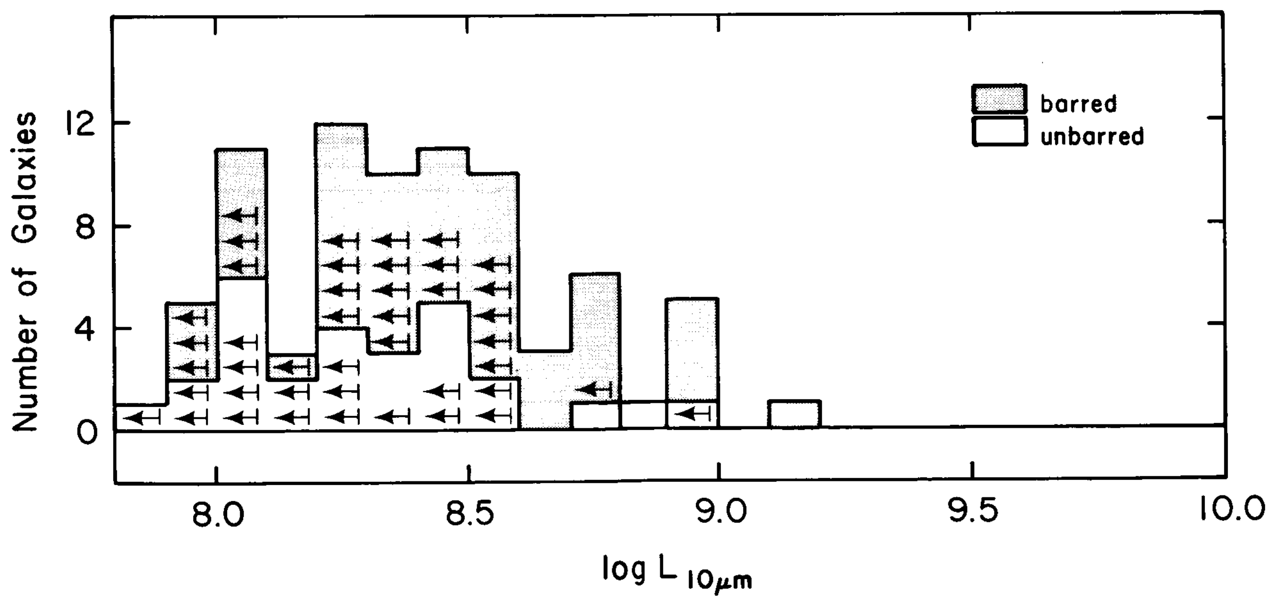

Figure 2. The distribution of central 10-μm luminosity for late-type barred and unbarred spirals. Arrows indicate 2σ upper limits. The distributions for barred and unbarred spirals are similar.

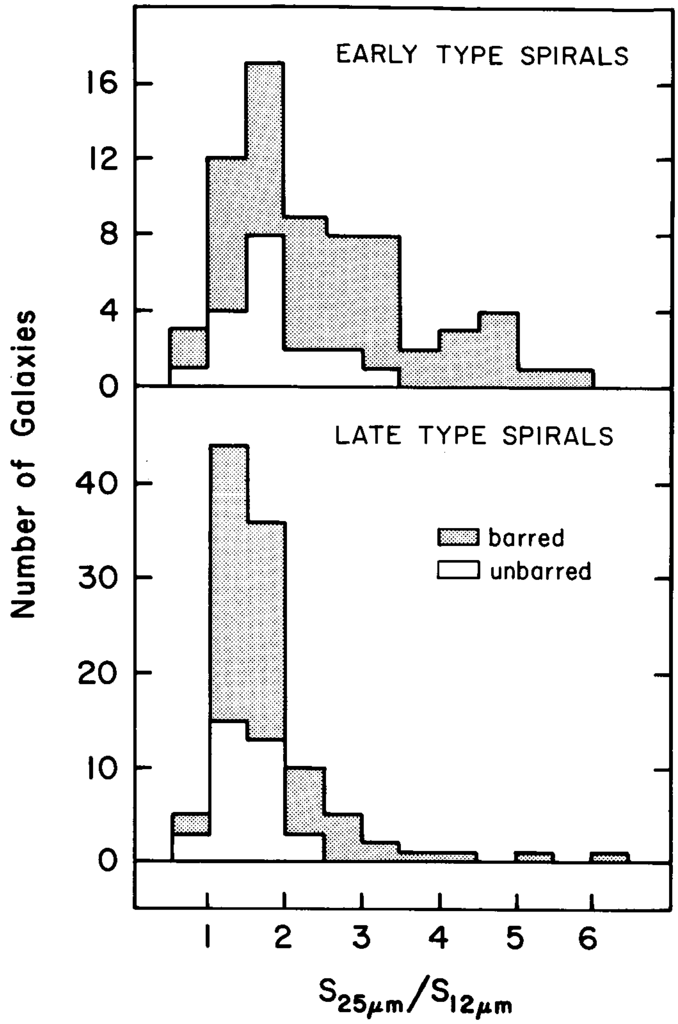

Figure 3. The distribution of the IRAS $S_{25\mu m}/S_{12\mu m}$ flux ratio for (top) early-type and (bottom) late-type spiral galaxies. The distributions for early- and late-type spirals are different largely because of an excess of early-type barred spirals with $S_{25\mu m}/S_{12\mu m} > 2.5$.

To summarise these results, I have shown that for the late-type spirals there was no significant difference between the bars and the unbars in both the ground-based and the IRAS data. In contrast, the early-type spirals did exhibit differences between the bars and the unbars, in both the ground-based and the IRAS data.

DISCUSSION

A reasonable hypothesis to explain the observations in the early-type bars would be that the luminosity of the central region is sufficient to dominate the IRAS 12-μm and 25-μm fluxes. To test this hypothesis, I define a parameter that I call the "compactness," which is the ratio of the ground-based small

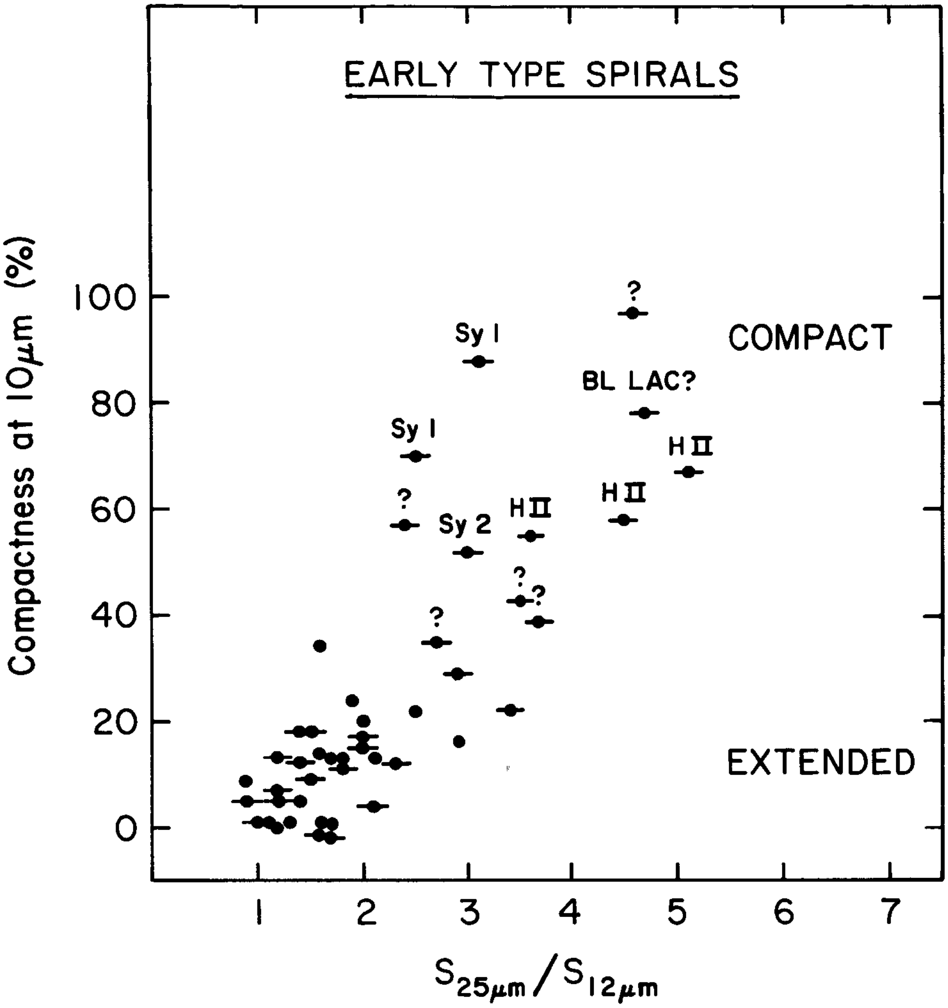

Figure 4. Compactness at 10 μm versus IRAS $S_{25\mu m}/S_{12\mu m}$. Galaxies for which the central region dominates the flux at 12 μm are compact. The IRAS $S_{25\mu m}/S_{12\mu m}$ colors for the compact galaxies indicate that the central region dominates the 25-μm flux also. Barred galaxies are indicated by horizontal bars.

beam 10-μm measurement to the larger beam IRAS 12-μm measurement, color corrected to 10 μm by extrapolating the IRAS 12-μm to 25-μm energy distribution. The compactness enables me to identify galaxies for which the central region dominates the IRAS 12-μm and quite likely the 25-μm emission.

The result of plotting compactness against the IRAS 25μm/12μm ratio is shown in Figure 4. The figure demonstrates that compact galaxies (i.e., >~30% compactness) all have 25-μm/12-μm flux ratios consistent with those observed previously in Seyfert and starburst nuclei (Lawrence et al. 1985). I have indicated the classification of the nuclei based on optical spectra when available. The figure shows that the optical classifications are consistent with the anticipated 25-μm/12-μm flux ratio in the sense that the H II region nuclei have larger ratios that the Seyfert nuclei (Lawrence et al. 1985). This supports the idea that where a galaxy's central region dominates at 12 μm it also dominates at 25 μm.

There is actually only a small number of galaxies in which the central region dominates the IRAS 12-μm and 25-μm fluxes. I estimate that there are only about 30 early-type barred galaxies with a central 10-μm excess, in the distance range 15-40 Mpc. Approximately 10% of all early-type barred galaxies are associated with enhanced central activity. The far-infrared luminosities L(40-120 μm) of the active early-type bars is $\geq 1 \times 10^{10}$ $L_{\odot}$.

It is of interest to consider these results in the context of previous studies concerning the association of central activity with stellar bars. Seyfert nuclei are found predominantly in early-type spirals, although the association with stellar bars is of less statistical significance (Heckman 1978; Simkin 1980). On the other hand, H II region nuclei are found to be significantly biased to barred galaxies of all spiral types (Heckman 1980).

There is a difference between this study and those referenced above, in that the latter investigated only the frequency with which characteristic optical emission lines were observed in the central region of barred and unbarred galaxies. I have investigated the frequency with which high central 10-μm luminosity occurs in barred and unbarred galaxies. I found that in early-type galaxies, bars are essential for high central 10-μm luminosity. Perhaps the important parameter, distinguishing the bars from the unbars, is not the frequency with which a particular form of activity is observed, but rather the intensity of the activity.

QUESTIONS TO BE ADDRESSED

These results raise some interesting questions regarding the role of the bar in the early-type spirals. Is the bar somehow stimulating star formation? Is it supplying additional fuel for star formation and/or active nuclei? Perhaps a more fundamental question may be, Why is the bar more important in the early-type spirals? The latter may indicate that the stellar mass distribution is as important as a gas reservoir in fueling activity in the central region.

ACKNOWLEDGEMENTS

I would like to thank Gareth Wynn-Williams, Steve Eales, and Eric Becklin for their enthusiastic support of this work. Thanks also to the IPAC staff, in particular Walter Rice, Carol Persson, and George Helou, for ensuring that my stay was both enjoyable and scientifically rewarding. I would also like to thank the IRTF staff, in particular Charles Kaminski.

QUESTIONS

Solomon: With regard to the question of fuel in the bar, I have mapped the CO emission in the barred spiral NGC 1530. Along the bar the CO flux is an order of magnitude greater than off the bar, thus there is more fuel.

Helou: Did you not find the early-type galaxies to be more compact than the later types? Does that not contradict the result by Judy Young and coworkers that the CO distributions are centrally peaked in the late types and have holes in the early types?

Reply: Yes, the early types are more compact than the late types. The compactness of the late-type spirals, however, is not inconsistent with the exponential distributions observed by Judy for both the CO and blue luminosity in the late-type Virgo spirals. Regarding the CO holes, I think it is important to establish the distribution of CO in the early-type galaxies in question.

Kenney: Regarding the question about CO holes in the early types, I have mapped the CO emission in about a dozen early-type Virgo spirals; most of these are centrally peaked with a resolution of 45" (~4 kpc). Only one has a definite CO hole at this resolution.

Simkin: Models of gas flows in spirals induced by bars show that the rate of flow depends on the mass distribution in the galaxy. It may be that your association of central activity with early-type barred galaxies reflects the different mass distribution in these objects.

Reply: I am aware of these results and hope to obtain observations to investigate them further. In particular I plan to obtain multiaperture photometry at near-infrared wavelengths to establish the spatial distribution of starlight in the central regions of the spiral galaxies under discussion here.

Rieke: The result shown earlier (Wynn-Williams) from Rieke and Lebofsky that showed a strong tendency for Sa's not to have high-infrared luminosities was derived only for unbarred galaxies. It would imply that a bar was nearly essential for high luminosity in an early spiral. Is that consistent with your results?

Reply: Yes.

Kennicutt: Several years ago Sersic noted that nuclear hot-spots occur almost exclusively in barred spirals. Maybe you are seeing the same thing. Could the predominance of centrally concentrated sources in early-type spirals be a contrast effect due to the lower disk star formation in the early-type galaxies?

Reply: The Sersic result is now in question in the light of a recent study by Heckman (1978). Regarding the second part of your question, I do not believe that this is a contrast effect for two reasons. Firstly, Wynn-Williams showed that the far-infrared luminosity distributions of early- and late-type spiral galaxies are similar, thus there is no evidence that the disk star formation is lower in the early types. Secondly, the effect in the early-type bars is evident not only in the colors, but also the luminosity, of the central region. The luminosity of the central region of ~40% of the early barred galaxies is greater than that observed in the late-type galaxies and the early unbarred galaxies.

Joseph: There is an important additional parameter that could undercut your comparison of early- and late-type galaxy infrared luminosities. In our J,H,K,L' study of the spirals in the Virgo cluster we found that late-type galaxies are significantly fainter than early-type spiral galaxies in this cluster. Would this systematic bias in luminosity, and therefore also in the mass of gas present, not account for the differences between early- and late-type galaxies which you find in this sample?

Reply: In the study of those same Virgo galaxies carried out by myself, Becklin, and Scoville, we found two results: the 10-μm luminosity of the central region of all spirals is comparable, whereas the near-infrared luminosity tended to be higher, on average, in the early types. Regarding my presentation, I am investigating the differences between bars and unbars separately in early and late types. I am not considering the differences between early- and late-type spirals here.

REFERENCES

Hawarden, T. G., Fairclough, J. H., Joseph, R. D., Leggett, S. K., and Mountain, C. M. 1986, in Light on Dark Matter, ed. F. P. Israel (Dordrecht: Reidel), pp.455-462.

Heckman, T. M. 1978, Pub. A.S.P., **90**, 241.

____. 1980, Astr. Ap., **88**, 365.

Lawrence, A., Ward, M., Elvis, M., Fabbiano, G., Willner, S. P., Carleton, N. P., Longmore, A. 1985, Ap. J., **291**, 117.

Simkin, S. M., Su, H. J., Schwarz, M. P. 1980, Ap. J., **237**, 404.