Formation and Evolution of Galaxy Bulges
Proceedings IAU Symposium No. 245, 2007
M. Bureau, E. Athanassoula & B. Barbuy

doi:10.1017/S1743921308017432

Variations in the 24 μm morphologies of nearby galaxies

G. J. Bendo[1]

[1]Imperial College, Blackett Laboratory, Prince Consort Road, London SW7 2AZ, UK
email: g.bendo@imperial.ac.uk

Abstract. To study the distribution of star formation and dust emission within nearby galaxies, we measured five morphological parameters in the 24 μm wave band for 73 galaxies observed as part of the *Spitzer* Infrared Nearby Galaxies Survey. The morphological parameters demonstrate strong variations along the Hubble sequence, including statistically significant differences between S0/a-Sab and Sc-Sd galaxies. Early-type spiral galaxies are generally found to be compact, centralized, symmetric sources in the 24 μm band, whereas late-type spiral galaxies are generally found to be extended, asymmetric 24 μm sources. These results suggest that processes that increase the real or apparent sizes of galaxies' bulges also lead to more centralized 24 μm emission.

Keywords. infrared:galaxies, galaxies: ISM, galaxies: structure

1. Introduction

Variations in integrated properties of the interstellar medium (ISM) and integrated star formation activity along the Hubble sequence are clearly defined. Gas surface density, the ratio of gas mass to total mass, and star formation normalized by total stellar content have all been observed to increase when proceeding along the Hubble sequence from elliptical galaxies through early-type spiral galaxies to late-type spiral galaxies (Roberts & Haynes 1994, Kennicutt 1998). However, few investigations have carefully studied whether the spatial distribution of the ISM or star formation varies among spiral galaxies. While some observational studies have shown that molecular gas, dust, or star formation may be more broadly distributed in late-type spiral galaxies than in early-type spiral galaxies (Hodge & Kennicutt 1983, Young *et al.* 1995, Bendo *et al.* 2002, Thomas *et al.* 2004, Pahre *et al.* 2004), others have produced contradictory results (Dale *et al.* 2001a, Koopmann *et al.* 2006). Moreover, many of these previous surveys have suffered from various problems, including limited sample sizes, limited coverage of the galaxies' optical disks, or uncertainties from dust extinction. If present, variations in the distribution of the ISM and star formation among spiral galaxies could have fundamental implications for the stellar evolution and the evolution of structure within galaxies. Moreover, such variations may provide clues to the processes that form galaxies' disks and bulges.

Here, we briefly discuss quantitative measures of the variations in the distribution of the 24 μm emission within nearby galaxies observed in the *Spitzer* Infrared Nearby Galaxies Survey (SINGS; Kennicutt *et al.* 2003), with a more complete overview presented by Bendo *et al.* (2007). We use 24 μm data because the wave band has been shown to be an effective tracer of dust-obscured star formation in many nearby galaxies (e.g. Calzetti *et al.* 2005, Perez-Gonzalez *et al.* 2006, Calzetti *et al.* 2007, Prescott *et al.* 2007). While the 24 μm band is particularly sensitive to dust heating (Dale *et al.* 2001b, Li & Draine 2001) and may therefore be less than ideal for tracing dust mass, the high spatial resolution (6 arcsec) and signal-to-noise ratios in the 24 μm data are superior to

Table 1. Statistics on 24 μm Morphological Parameters

Hubble Type	Number of Galaxies	C	$\overline{M}_{20}$	$\log(\overline{R}_{eff})$	A	G
All	73	2.51 ± 0.14	-1.47 ± 0.08	-0.50 ± 0.03	0.59 ± 0.06	0.764 ± 0.012
E-S0	11	2.6 ± 0.3	-2.23 ± 0.17	-0.80 ± 0.06	0.25 ± 0.09	0.83 ± 0.03
S0/a-Sab	16	3.0 ± 0.3	-2.07 ± 0.18	-0.60 ± 0.06	0.35 ± 0.07	0.77 ± 0.03
Sb-Sbc	13	3.0 ± 0.3	-1.47 ± 0.18	-0.50 ± 0.08	0.45 ± 0.08	0.82 ± 0.02
Sc-Sd	19	2.3 ± 0.3	-1.14 ± 0.10	-0.41 ± 0.04	0.69 ± 0.05	0.745 ± 0.019
Sdm-Im	14	2.0 ± 0.3	-1.01 ± 0.15	-0.48 ± 0.05	1.24 ± 0.20	0.68 ± 0.03
SA0/a-SAd	21	2.66 ± 0.16	-1.24 ± 0.11	-0.39 ± 0.05	0.51 ± 0.05	0.72 ± 0.02
SAB0/a-SABd	15	2.5 ± 0.4	-1.25 ± 0.19	-0.53 ± 0.06	0.69 ± 0.07	0.80 ± 0.02
SB0/a-SBd	12	4.1 ± 0.4	-2.31 ± 0.17	-0.70 ± 0.09	0.48 ± 0.09	0.81 ± 0.02

any other mid- or far-infrared tracer of dust available from *Spitzer* or elsewhere at this time.

2. Analysis

The sample is selected from the SINGS sample of galaxies as well as additional sources that were serendipitously observed in the SINGS MIPS observations. We excluded galaxies with surface brightnesses that did not exceed three times the background noise in any MIPS bands, galaxies where a substantial fraction of the observed 24 μm emission in the optical disk contained emission from other galaxies, and NGC 3034 (which was saturated in the 24 μm image). The resulting sample contains 65 SINGS galaxies and 8 serendipitous galaxies.

Five quantities, mostly based on parameters from Conselice (2003) and Lotz *et al.* (2004), are used to describe the 24 μm morphologies of these galaxies. The concentration parameter (C) and the normalized second order moment of the brightest 20% of the emission (M_{20}) are both used to quantify concentration. Highly concentrated emission will correspond to high C and low M_{20} values. The logarithm of the half-light radius to the optical radius given by de Vaucouleurs *et al.* (RC3; 1991) is used to characterize the concentration of 24 μm emission relative to optical light; this is written as $\log(\overline{R}_{eff})$. The asymmetry parameter (A) is used to quantify asymmetry, with high A values corresponding to very asymmetric emission. The Gini coefficient (G) is used to describe the smoothness of the emission, with high values indicating that the emission is located within one peak and low values indicating that the emission is uniformly distributed. For this analysis, the parameters were measured within the optical disks of the galaxies as defined by RC3 with the exception of two irregular galaxies, where the measurement regions were extended to include emission outside the galaxies' optical disks. Foreground stars and companion galaxies were masked out of the measurement regions. We also derived and applied corrections for distance and inclination effects.

The medians and standard deviations of the means for these parameters as measured in various morphological subsets of the sample are given in Table 1. The table shows $> 3\sigma$ differences in the median M_{20} and A values between the S0/a-Sab and Sc-Sd galaxies, and weaker variations are also seen in the C and $\log(\overline{R}_{eff})$ parameters. These variations indicate that the 24 μm emission in early-type spiral galaxies is generally centrally-concentrated and symmetric while the 24 μm emission in late-type spiral galaxies is

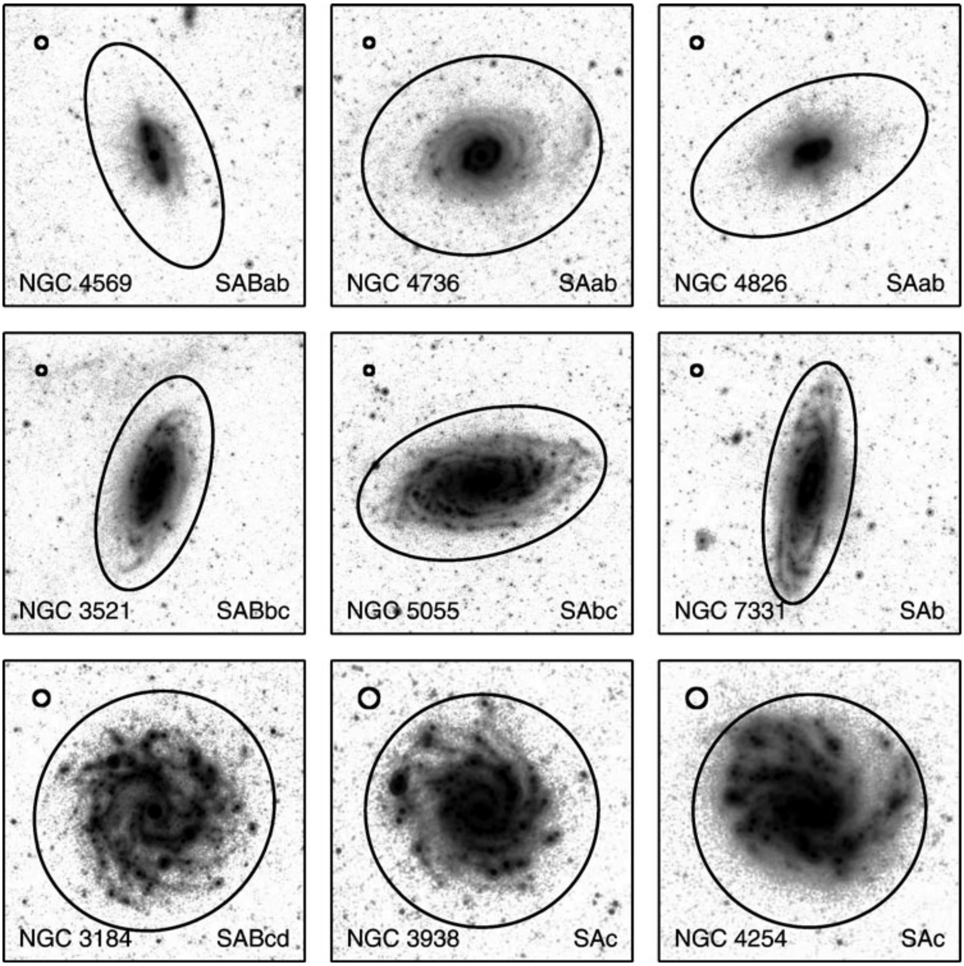

Figure 1. 24 μm images of galaxies with typical morphological parameters for their Hubble types. Each row contains galaxies with similar Hubble types. The Hubble type of each galaxy (from RC3) is listed in the lower left corner of each image. The D_{25} isophote from RC3 is overplotted on the data. An 18 arcsec circle representing three times the full width at half-maximum of the 24 μm data is plotted in the upper left corner of the images.

extended and asymmetric. This is also reflected by the images in Figure 1, which compare galaxies with typical morphological parameters from the S0/a-Sab, Sb-Sbc, and Sc-Sd subsets.

Table 1 also shows $> 3\sigma$ differences in the C, M_{20}, $\log(\overline{R}_{eff})$, and G parameters between barred and unbarred galaxies, indicating that barred spiral galaxies have more centrally concentrated and more peaked emission. However, since most of the barred spiral galaxies in this sample are early-types and most of the unbarred spiral galaxies are late-types, the differences between the barred and unbarred galaxies observed here may be biased by differences between early- and late-type spiral galaxies. Unfortunately, the sample is not large enough to permit us to separate effects related to bars and effects related to evolutionary (early- versus late-) type.

https://doi.org/10.1017/S1743921308017432 Published online by Cambridge University Press

3. Discussion

A number of mechanisms have been proposed for increasing the real or apparent size of bulges in spiral galaxies, and these mechanisms may also make the 24 μm emission appear more centralized in early-type spiral galaxies compared to late-type spiral galaxies. First, inequal mass merger events may transform smaller galaxies with modest bulge/disk ratios into larger galaxies with much larger bulge/disk ratios (e.g. Schweizer 1998) and may drive gas into the centers of these galaxies. This is exemplified by NGC 4826 (top left in Figure 1), a galaxy with counterrotating gas in its disk that is probably such a merger remnant (Braun *et al.* 1992). Second, pseudobulge formation mechanisms such as bars could both drive gas into the centers of galaxies and trigger star formation, as seen in NGC 4736 (top center in Figure 1; Kormendy & Kennicutt 2004). Third, in cluster environments, ram pressure stripping may remove gas from the disks of spiral galaxies (Gunn & Gott 1972) as seen in NGC 4569 (top right in Figure 1; Koopmann & Kenney 2004). As the stellar populations evolve, the disks would fade compared to the nuclei, where gas is still present and where star formation continues, and the galaxies would appear to have large bulge/disk ratios. Although these are different processes for forming galaxies with large bulges, the resulting galaxies all have large optical bulge/disk ratios, and they all appear relatively compact at 24 μm.

References

Bendo, G. J., *et al.* 2002, *AJ* 123, 3067
Bendo, G. J., *et al.* 2007, preprint (astro-ph/07071303)
Braun, R., Walterbos, R. A. M., & Kennicutt, R. C., Jr. 1992, *Nature* 360, 442
Calzetti, D., *et al.* 2005, *ApJ* 633, 871
Calzetti, D., *et al.* 2007, preprint (astro-ph/07053377)
Conselice, C. J. 2003, *ApJS* 147, 1
Dale, D. A., Giovanelli, R., Haynes, M. P., Hardy, E., & Campusano, L. E. 2001a, *AJ* 121, 1886
Dale, D. A., Helou, G., Contursi, A., Silbermann, N. A., & Kolhatkar, S. 2001b, *ApJ* 549, 215
de Vaucouleurs, G., de Vaucouleurs, A., Corwin, H. G., Buta, R. J., Paturel, G., & Fouque, P. (RC3) 1991, *Third Reference Catalogue of Bright Galaxies* (Berlin: Springer-Verlag)
Gunn, J. E., & Gott, J. R., III 1972, *ApJ* 176, 1
Hodge, P. W. & Kennicutt, R. C., Jr. 1983, *ApJ* 267, 563
Kennicutt, R. C., Jr. 1998, *ARAA* 36, 189
Kennicutt, R. C., Jr., *et al.* 2003, *PASP* 115, 928
Koopmann, R. A., Haynes, M. P., & Catinella, B. 2006, *AJ* 131, 716
Koopmann, R. A. & Kenney, J. D. P. 2004, *ApJ* 613, 866
Kormendy, J. & Kennicutt, R. C., Jr. 2004, *ARAA* 42, 603
Li, A. & Draine, B. T. 2001, *ApJ* 554, 778
Lotz, J. M., Primack, J., & Madau, P. 2004, *AJ* 128, 163
Perez-Gonzalez, P. G., *et al.* 2006, *ApJ* 648, 987
Prescott, M. K. M., *et al.* 2007, preprint (astro-ph/07063501)
Roberts, M. S. & Haynes, M. P. 1994, *ARAA* 32, 115
Schweizer, F. 1998, in: Friedli D., Martinet L., & Pfenniger D. (eds.), *Galaxies: Interactions and Induced Star Formation* (Springer-Verlag: Berlin), p. 105
Thomas, H. C., Alexander, P., Clemens, M. S., Green, D. A., Dunne, L., & Eales, S. 2004, *MNRAS* 351, 362
Young, J. S., *et al.* 1995, *ApJS* 98, 219