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ENHANCED STAR FORMATION - THE IMPORTANCE OF BARS IN SPIRAL GALAXIES

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1. ABSTRACT

We have found that amongst an IR-luminous subset of nearby spiral galaxies, nearly all of the systems with IRAS colours and luminosities indicative of enhanced star formation are barred. Radio continuum and IR-spectroscopic results support the hypothesis that this emission originates within the central 2kpc; possibly in a circumnuclear ring. We also find that outer rings are over-represented amongst these barred systems and suggest possible reasons for this phenomena.

Our recent investigation (Hawarden *et al* 1986) of the IRAS database for a large sample of 186 spiral galaxies indicates that nearly all of the systems with excess 25μm flux are barred. The sample includes all of the spirals in the Revised Shapley Ames Catalogue (Sandage & Tammann 1981, 'RSA') between SO/a and Scd (inclusive) and which were detected by IRAS in all four bands. We have excluded from our main sample those galaxies which are extended at 100μm or with Seyfert 1,2 or LINER spectra.

Figs. 1(a), (b) and (c) show the distributions of the ratios f_v25/f_v12 vs f_v100/f_v25, for barred (SB), unbarred (SA) and mixed-type (SAB) galaxies in our sample. Approximately one third of all the barred/mixed systems have large 25μm/12μm and relatively small 100μm/25μm ratios which are indicative of emission from the warm dust commonly found in starforming regions. Furthermore, these "25μm-excess" barred galaxies (hereafter referred to by using the prefix 'h') are considerably more luminous (typically 4.5×10^{10} Lo, with Ho = 75 kms^{-1} Mpc^{-1}) than the other barred and unbarred systems (hereafter prefixed by 'l') which have typical IR luminosities of 2×10^{10} Lo.

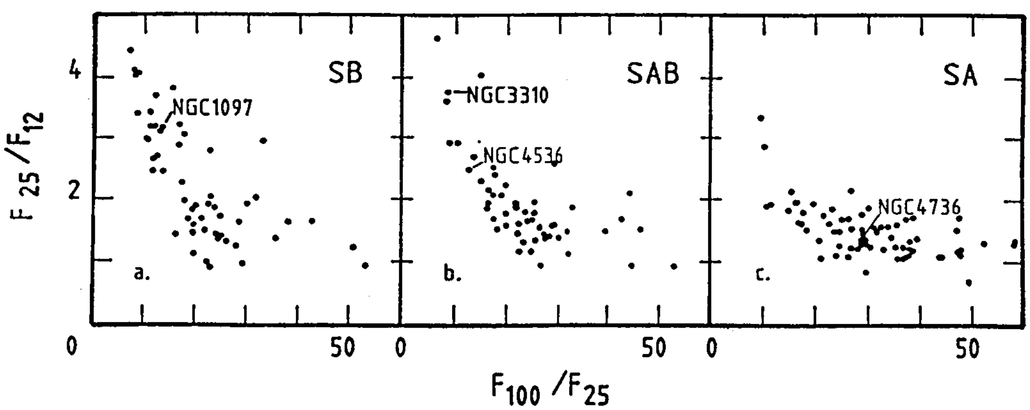

Figure 1(a), (b) & (c)

The distribution of SB, SAB and SA galaxies in the IRAS 2-colour diagram, f_v25/f_v12 against f_v100/f_v25.

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To support our conjecture that the extra IR emission is due to enhanced star formation we have constructed simple models using the average IRAS fluxes of a group of unresolved HII regions in Cygnus. Addition of about 10^5 such objects to a mean 'l' galaxy accurately reproduces the spectral shape and luminosity of an 'h' system. Only the 12μm emission is underestimated but our models so far omit the extended 12μm flux which is seen throughout the Cygnus region and which has been attributed to emission from small grains (eg Wynn-Williams & Becklin 1985).

The resolution provided by IRAS was too coarse (1-2 arcmin) to enable us to determine the exact location of the source of the extra IR emission in our barred galaxies. However, recent radio continuum results (Puxley *et al*, in preparation), together with those of Hummel (1980), show that <u>all of the barred galaxies with enhanced star formation are centrally concentrated</u> (less than 20 arcsec) at 20cm. The distribution of radio properties as a function of morphology is shown in Table 1. We have adopted the classification scheme of Hummel such that 'C' refers to galaxies with the unresolved central component, 'E' to those with extended (ie disk) emission and 'ND' refers to non-detections. Less than one third of 'l' spirals have centrally concentrated radio emission.

<u>Table 1</u>

Distribution of radio classifications with morphological type

Galaxy type	C or CE	E	ND
hSB & hSAB	20 (100%)	0 (0%)	0 (0%)
lSB & lSAB	14 (45%)	13 (42%)	4 (13%)
lSA	11 (26%)	19 (44%)	13 (30%)

We have also obtained 2.1μm-2.2μm spectra of a small number of galaxies in our sample. The aperture (20 arcsec) was chosen so as to include any nuclear ring. Preliminary reduction of the spectra indicates that Brackett gamma was detected in the hSAB galaxies NGC4536 and in NGC3310 (whose positions are shown in Fig.1) but not in the lSA system NGC4736. As NGC4536 and NGC4736 have similar continuum flux densities ~3.5 Jy at 25μm) we interpret the Brackett gamma line emission in NGC4536 as arising from star formation which dominates the IRAS fluxes of this galaxy.

The positions of the two well-studied systems NGC1097 and NGC3310 are also indicated in Figs. 1(a) and 1(b). Both of these galaxies have been mapped at 10μm by Telesco and Gatley (1981, 1984) who find that the extra IR emission originates in a ring (diameter about 2kpc) of HII regions around the nucleus. Observations of HI (Sancisi, Allen & Sullivan 1979) and optical spectroscopy (Pence & Blackman 1984) implies that, in barred systems, there is an inflow of gas/dust due to the non-axisymmetric bar potential. Numerical models (eg Combes & Gerin 1985) suggest that the "circumnuclear" rings are situated near one of the inner Lindblad resonances where material swept inwards would be expected to accumulate. In addition, Fig.1(a) exhibits a noticeable "split" at f_V25/f_V12 ~2 which we speculate arises due to 'switching-on', of the enhanced star formation once some critical density of the ISM is exceeded.

We have also found a strong correlation (see Table 2) between the occurrence of <u>outer</u> rings (classified R.. or P.. in RSA) and enhanced star formation for our complete sample (ie including 33 Seyfert's and LINER's) of 219 galaxies. Table 2 shows that,

C - 8

Table 2 Incidence of outer rings with morphological type

Galaxy type	No. of galaxies in sample	No. with outer rings
SB/SAB with vigorous star formation	59	9 (15%)
SB/SAB without vigorous star formation	72	1 (1%)
SA with vigorous star formation	2	0 (0%)
SA without vigorous star formation	86	10 (12%)

amongst barred systems, those with outer rings also have IRAS colours which we have attributed to a vigorous burst of star formation. Numerical models of barred spirals (eg Schwarz 1984) indicate that outer rings form near the outer Lindblad resonance due to the outward transport of disk material by a spiral density wave exterior to corotation. The existence of outer rings in these systems suggests that there is much interstellar material available for transport. Interior to corotation, any gas and dust may be fed inwards towards the centre by the bar-like density wave where it can form a circumnuclear ring. Table 2 also shows that outer rings are also found in unbarred galaxies and we expect a similar process to occur in these systems (with the inflow/outflow being driven by the spiral density wave) except that the lack of a bar may result in a less efficient flow, and hence we do not see vigorous star formation. This model is similar to that proposed by Simkin, Su & Schwarz (1980) who found that outer rings are a feature of many Seyfert galaxies.

In Fig. 2 we show the 2-colour diagram for the Seyfert galaxies which exhibit a remarkably similar distribution to that of the normal spirals in Fig. 1. In agreement with our assertion what the distribution in Fig. 1 is the result of circumnuclear star formation, Rodriguez Espinosa, Rudy & Jones (1986) find that the mid- and far-IR emission from Seyferts is extended and suggest that this is due to a vigorous burst of star formation around the active nucleus.

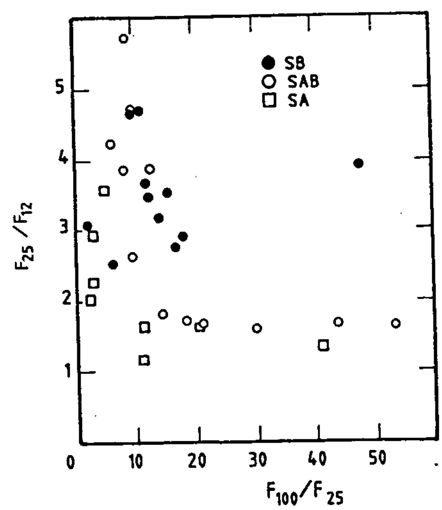

Figure 2

As for Fig. 1 but showing the galaxies whose spectra show Seyfert 1,2 or LINER features.

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