N87-24337

Far-infrared activity and starburst galaxies

P. Belfort, R. Mochkovitch, M. Dennefeld
Institut d'Astrophysique de Paris
98 bis, boulevard Arago
75014 Paris – France

Abstract

After the IRAS discovery of galaxies with large far-infrared to blue luminosity ratio, it has been proposed that an enhanced star formation could be the origin of the far-infrared emission through dust heating. We have investigated whether a simple photometric model is able to account for the FIR and optical properties of IRAS galaxies. The L_{IR}/L_B ratio, (B−V) color and H_α equivalent width of normal spirals are well reproduced with smooth star formation histories. In the case of starburst galaxies, several theoretical diagrams allow us to estimate the burst strength and extinction. L_{IR}/L_B ratio up to 100 can be rather easily reached, whereas extreme values (~500) probably require IMF truncated at the low end.

1.Introduction

One of the most striking IRAS discoveries is the discovery of galaxies with far-infrared activity (L_{IR}/L_B) of several tens, some extreme objects even exhibiting L_{IR}/L_B ratios of 100 or greater. According to the energy distribution and optical spectra of these galaxies, bursts of star formation have been proposed to explain their far-infrared (FIR) emission.

The purpose of this work was to check whether a simple photometric model could reproduce the FIR and optical properties of both normal and starburst galaxies.

A sample of "normal" spirals has been studied first. Then, the effects of bursts occuring in normal underlying galaxies have been investigated. Several theoretical diagrams were obtained which allow us to estimate the burst strength b (as defined by Larson and Tinsley, 1978) and internal extinction E_b(B−V) for two samples of starburst and interacting galaxies. Finally, the case of the most extreme IRAS galaxies (with $L_{IR}/L_B \sim 500$) is discussed.

2.Normal galaxies

The stellar population of a normal galaxy is computed for a given initial mass function (IMF) and a history of the star formation (ratio of the present SFR to the average past SFR). The dust content is described by the internal extinction E(B−V) and the fraction (1−f) of the Lyman continuum photons directly absorbed by dust.

The IMF proposed by Kennicutt (1983) for normal galaxies has been adopted. Both on observational (Vrba et al., 1984) and theoretical (Serra et al., 1980) grounds, we have assumed that massive stars, which spend most of their life inside or in the vicinity of molecular clouds, are on average more reddened than lower mass stars. So, a specific extinction e' for stars more massive than $\sim 20\ M_\odot$ has been introduced in addition to a uniform extinction e affecting all stars.

As shown in figures 1 and 2, the Hα equivalent width and FIR activity of our 44 sample galaxies are well reproduced with this model.

Carol J. Lonsdale Persson (Editor)
Star Formation in Galaxies

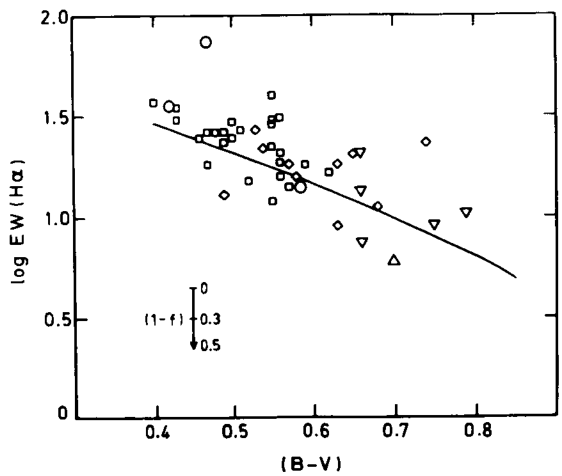

Figure 1

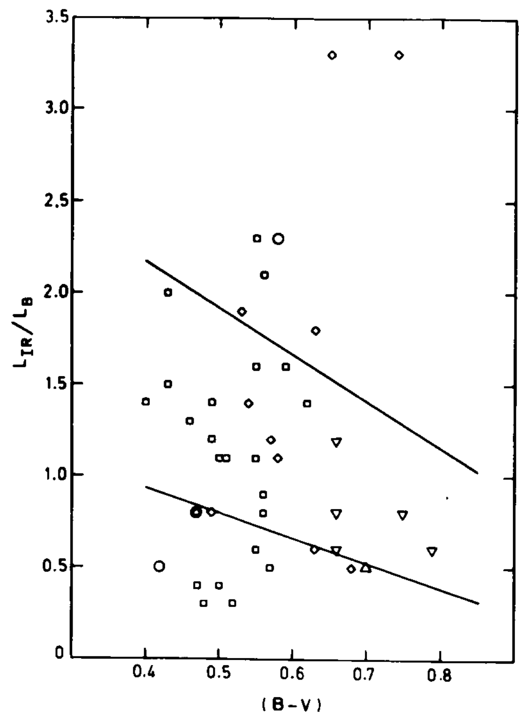

Figure 2

Figure 1. Log EW(H_α) vs (B−V) diagram : normal spirals.
The EW(H_α) are from Kennicutt et al. (1983) and (B−V) colors (corrected for galactic reddening) are from the RC2 catalog (1976). Morphological types : Δ Sab, ∇ Sb, ◇ Sbc, □ Sc, O Sm–S pec. The theoretical line has been obtained with e = 0.05, e' = 0.35, (1−f)=0.3 and a galactic extinction law (Savage et al., 1979).

Figure 2. L_{IR}/L_B vs (B−V) diagram : normal spirals.
The relation $F_{IR} = 1.75\,10^{-11}\,(12.66\,S_{12} + 5.00\,S_{25} + 2.55\,S_{60} + 1.01\,S_{100})$ erg.cm^{-2}.s^{-1} (Boulanger et al., 1985) has been used to estimate the FIR luminosities. The flux densities (in Jansky) are from the Point Source Catalog (1985). Most of the galaxies lie within the area between the two theoretical lines which may represent a realistic range of extinction for typical spirals (lower line : e = 0.02, e' = 0.35 and upper line : e = 0.10, e' = 0.35).

The few galaxies outside of the "normal" range in figure 2 can be accounted for by lower or larger internal extinction. However, NGC 4666 and NGC 6574 have a rather large L_{IR}/L_B ($\sim$ 3.3), more likely due to a slightly enhanced star formation.

3.Starburst galaxies

We have built starburst galaxies from normal ones by adding an enhanced star formation event, simply represented by a step function. Three new parameters are then required : the duration τ of the burst, its age Δt and its strength b (as defined in Larson and Tinsley, 1978). The IMF has been assumed identical in burst and host galaxy and we have adopted a uniform extinction E_b(B−V) in the burst where the stars have been formed recently and are then all located near their birth–place.

Figures 3, 4 and 5 show how the FIR activity, UBV colors and H_α equivalent width are affected by bursts of different strength and extinction.

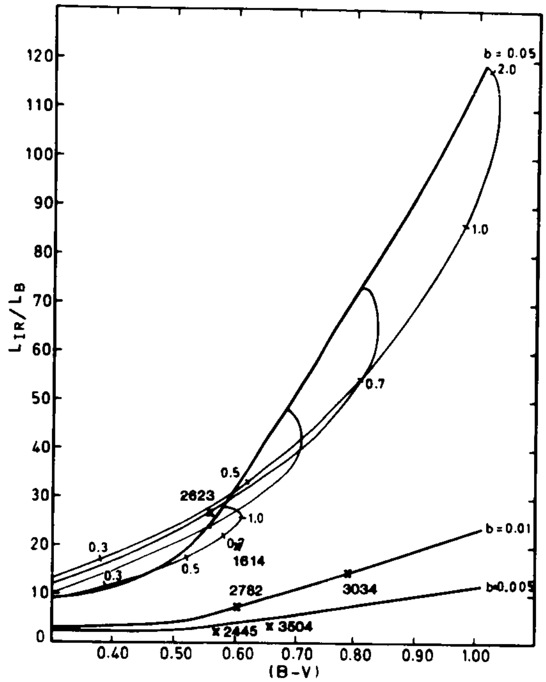

Figure 3. L_{IR}/L_B vs (B−V) : starburst galaxies.
The three heavy lines correspond to galaxies experiencing bursts of strength b = 0.005, 0.01, 0.05 and internal extinction E_b(B−V) = 3. Thin lines show the effect of a decreasing extinction on the FIR activity and (B−V) color (the E_b(B−V) values are indicated).

This diagram can be used to estimate the strength b in starburst galaxies. The corresponding UBV and log EW(H_α) vs (B−V) diagrams (fig. 4 and 5) then give an estimation of the burst extinction E_b(B−V) . As an example, NGC 1614, 2445, 2623, 2782, 3034 and 3504 are reported. Estimation of b and E_b(B−V) are summarized in the table.

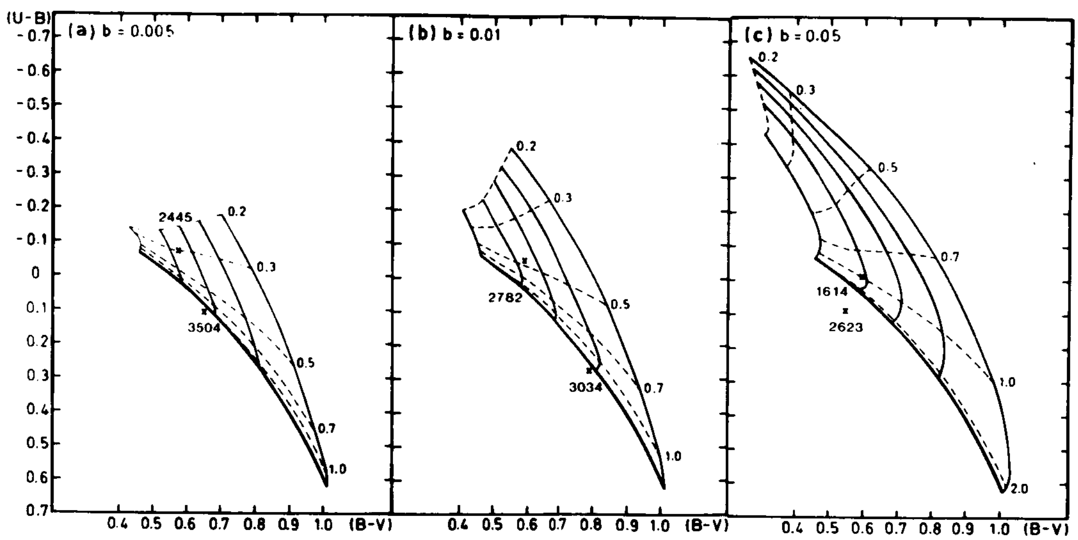

Figure 4. (U−B) vs (B−V) diagram : starburst galaxies.
Sequences of normal galaxies are represented by heavy lines. Thin lines show the effect of a

decreasing $E_b(B-V)$ on the UBV colors. Dashed lines are sequences of same $E_b(B-V)$.

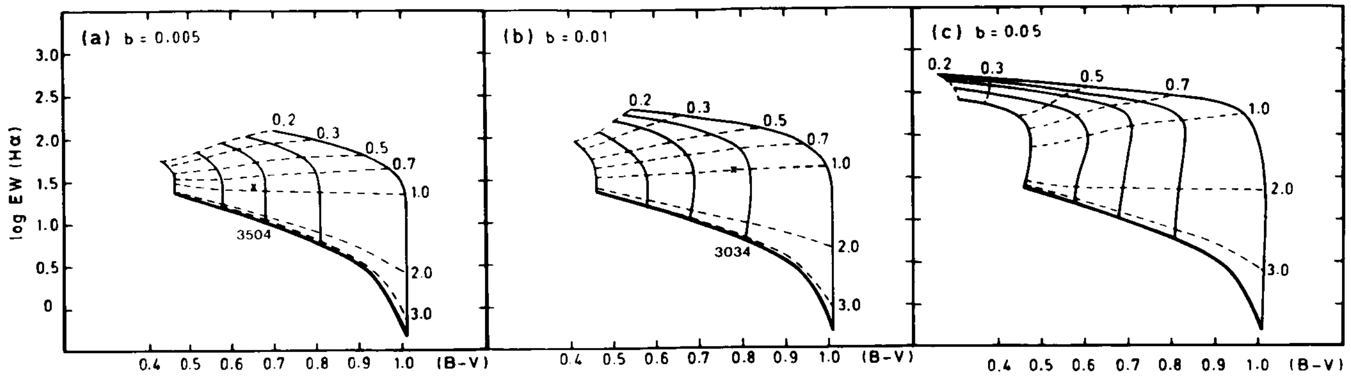

Figure 5. same as figure 4, but for logEW(H_α) vs (B−V) diagram

Table : Estimation of the strength b and extinction $E_b(B-V)$ for the galaxies reported in fig. 3, 4, 5.

NGC	b	$E_b(B-V)$
1614	~0.04	>0.7
2445	<0.005	~0.3
2623	~0.05	>1
2782	~0.01	≥0.5
3034	~0.01	>1
3504	<0.005	0.5–1

In the figures 3, 4 and 5, all the bursts have been assumed to be in progress since 2.10^7 years. Of course, when a burst gets old these figures cannot be used to estimate b and $E_b(B-V)$. However, as the L_{IR}/L_B ratio decreases quickly after the end of a burst, a galaxy with large FIR activity likely experiences a recent burst. Furthermore, if $E_b(B-V)$ is not too large, only a current or very young burst contributes significantly to the H_α equivalent width.

4.Extreme IRAS galaxies

Figure 3 shows that L_{IR}/L_B ratios up to 100 are rather easily reached (at least in red host galaxies) but extrême values ~ 500 are observed in IRAS 0404+101 and IRAS 0413+122 (Aaronson et al., 1984;Houck et al., 1985). Such FIR activities would imply bursts of strength b ~ 0.4– 0.5, clearly too large for a typical gas content. If these extreme L_{IR}/L_B ratios are actually due to starburst events (Allen et al., 1985), more reasonable b would be obtained with an IMF forming massive stars only. For instance, with a lower mass limit at ~ 9 $M_\odot$, a strength b of 8–10% could produce L_{IR}/L_B ~500.

5.Conclusion

Thus, a simple photometric model is able to account for the FIR and optical properties of both normal and starburst galaxies. Of course uncertainties in the duration and age of the burst complicate the interpretation of the observational data. However, bursts of star formation, put forward on observational evidences to explain many of the luminous IRAS galaxies, appear to be realistic from this theoretical study.

Effects of other choices for the burst parameters (age, duration, IMF) are discussed with more details in a paper submitted to Astronomy and Astrophysics, main journal.

References.

Aaronson, M., Olzewski, E.W. : 1984, Nature, **309**, 414.

Allen, D.A., Roche, P.F., Norris, R.P. : 1985, Monthly Notices Roy. Astron. Soc., **213**, 67p.

Boulanger, F., Baud, B., van Albada, G.D. : 1985, Astron. Astrophys. Letters, **144**, L9.

de Vaucouleurs, G., de Vaucouleurs, A., Corwin, N.C. : 1976, Second Reference Catalogue of Bright Galaxies, Austin : University of Texas Press.

Houck, J.R., Schneider, D.P. Danielson, G.E., Beichman, C.A., Lonsdale, C.J.,Neugebauer, G., Soifer, B.T. : 1985 , Astrophys. J. Letters, **290**, L5.

Joint IRAS Science Working Group : 1985, IRAS Point Source Catalog, Washington : US Government Printing Office.

Kennicutt, R.C. : 1983, Astrophys. J., **272**, 54.

Kennicutt, R.C., Kent, S.M. : 1983, Astron. J., **88**, 1094.

Larson, R.B., Tinsley, B.M. : 1978, Astrophys. J., **219**, 46.

Savage, B.D., Mathis, J.S. : 1979, Annu. Rev. Astron. Astrophys., **17**, 73.

Serra, G., Puget, J.L., Ryter, C.E. : 1980, Astron. Astrophys., **84**, 220.

Vrba, F.J., Rydgren, A.E. : 1984, Astrophys. J., **283**, 123.