Far-IR properties of early type galaxies

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ABSTRACT

We have investigated the IRAS colours and the far-IR to optical luminosity ratios of a complete sample of elliptical’s and S0’s brighter than $B_T = 12$. On the average, elliptical galaxies emit in the far-IR less than 1% of their bolometric luminosity, while S0’s are about a factor of three brighter in the far-IR. There is a considerable spread in the far-IR properties of individual galaxies. On the average, the photospheric emission of red giant stars can account for 50–60% of the 12 $\mu$m flux from early type galaxies; the contribution from diffuse dust at this wavelength is $< 10\%$ in the case of ellipticals, and may amount to 20–40% for S0’s. An additional, $\sim 30 - 40\%$, contribution from circumstellar emission from evolved giants with mass loss (particularly OH/IR stars) seems to be required in the case of ellipticals. This suggests a small but significant star formation activity in these galaxies at a look-back time of 1–2 Gyr, corresponding to about 10% of that typical of a disk galaxy having the same V-band luminosity. As for S0’s, the larger diffuse dust emission may swamp to some extent that of circumstellar dust, which is indicated to be, on the average, $\lesssim 20\%$. The weak emission from diffuse interstellar dust, detected mostly at 60 $\mu$m and 100 $\mu$m, has color temperatures similar to those of disk galaxies; as in that case of the latter, a warm dust component is suggested, associated to star-forming regions. The implied star formation would be a few percent of that of disk galaxies of similar V-band luminosity and could account for a fraction of the observed UV branch of early type galaxies.

Subject headings: galaxies: elliptical and lenticular – infrared: galaxies – galaxies: interstellar medium
1. INTRODUCTION

Far-IR properties of early-type systems are still poorly known because they were only weakly detected by IRAS. On the other hand, far-IR data provide important information on the interstellar medium as well as on star formation activity (Thronson & Bally 1987), and on mass loss from stars (Soifer et al. 1986; Jura, Kim & Guhathakurta 1987; Knapp, Gunn, & Wynn-Williams 1992).

Co-added IRAS data on a large sample of early type galaxies (~ 1150) have been presented by Knapp, Gunn, & Wynn-Williams (1989). As stressed by the authors, however, the sample is not complete in any sense. An even more delicate problem, also discussed by Knapp et al. (1989), is the morphological classification, which is often very uncertain; in fact spirals with faint disks may be misclassified as S0’s or even ellipticals, while elliptical with dust patches may be classified as I0, S0 or even spiral galaxies. In order to have a morphological classification as uniform and reliable as possible we confined ourselves to galaxies with $B_T \leq 12$, classified E and S0 in the second edition of the Revised Shapley-Ames catalog of Bright Galaxies (RSA; Sandage & Tammann 1987). The chosen limiting magnitude is that where incompleteness sets in, according to Sandage & Tammann (1987). IRAS fluxes or upper limits for almost all galaxies in the sample, namely for 47 E and 60 S0 galaxies, are given by Knapp et al. (1989). For “large” galaxies we have used the IRAS fluxes given in Table 7 of Knapp et al. (1989).

The IRAS detection rate for galaxies in the sample is anyway low. Therefore to obtain meaningful results, upper limits must be taken into account. To this end, we have exploited the survival analysis techniques (Feigelson & Nelson 1985; Schmitt 1985).

The plan of the paper is the following. In Sect. 2 we estimate the far-IR to optical luminosity ratios and the far-IR colours for elliptical and S0 galaxies. In Sect. 3 we summarize our model and discuss the far–IR colours. The main results are presented in Sect. 4.

2. FAR-IR TO OPTICAL LUMINOSITY RATIOS AND FAR-IR COLORS

Figures 1 and 2 show the distributions of logarithms of far-IR to $B_T(0)$ flux density ratios of E and S0 galaxies, respectively, for the four IRAS bands, reconstructed exploiting the Kaplan-Meyer estimator, taking into account upper limits. IRAS fluxes at 25, 60, and 100 $\mu$m have been taken from Knapp et al. (1989).

On the other hand, Knapp et al. (1992) found that the 12 $\mu$m emission is extended on the scale of the galaxy and pointed out that the IRAS equivalent point source flux at this wavelength underestimates the total flux. Corrected 12 $\mu$m fluxes or upper limits are given by these authors for 30 elliptical galaxies in our sample. The mean fraction of the total flux registered by the IRAS
point-source fitting procedure for these galaxies has been used to correct the fluxes of the remaining 17 ellipticals and of S0’s. As for the other IRAS bands, we assume that no correction of this kind is required since the emission is mostly due to dust (see below) which is likely to be much more centrally concentrated. Should a significant amount of dust be present in the outer parts of early type galaxies, its temperature would be anyway too low (due to the low radiation field intensity) to yield an important contribution in the IRAS bands (see below).

B-band fluxes are referred to the effective wavelength \( \lambda = 0.44 \mu m \); the calibration given by Johnson (1966) was adopted.

The use of logarithmic values minimizes the effect on the estimated means and variances of anomalous values, that may correspond to misclassified objects. Using the ratios directly leads to estimated mean values which are systematically higher by a factor 2–3. Nevertheless, particularly when the fraction of detected objects is low, the reconstructed distribution has a large peak at the lowest observed ratio, i.e. the low side of the distribution is strongly curtailed, again with the consequence of an overestimation of the mean. A safer estimator of the true average value is, in this case, the median, and we have adopted it; the error has been estimated from the width of the distribution above the median value. The results are listed in Table 1.

How crucial a reliable morphological classification is in the present context, is illustrated by Figure 3 which shows the distributions of far-IR to \( B_T \) flux ratios for galaxies classified as ellipticals in Table 2 of Knapp et al. (1989). The tails extending to high values of flux ratios are most likely due to misclassified S0 or spiral galaxies, as indicated by the fact that they largely disappear if we confine ourselves to the brightest galaxies and we adopt the morphological classification given in the Third Reference Catalogue of Bright Galaxies (de Vaucouleurs et al. 1991).

The far-IR emission is obviously very small in comparison with the optical. The total flux between 42.5 \( \mu m \) and 125.5 \( \mu m \), \( F_{\text{FIR}} \), can be estimated using the formula \( \log(F_{\text{FIR}}) = \log[1.26 \times (F_{60} + F_{100})] \) given in Cataloged Galaxies and Quasars Observed in the IRAS Survey (1989), where fluxes are in W m\(^{-2}\), \( F_{60} = 2.58 \times 10^{-14} f_{60} \), \( F_{100} = 1.00 \times 10^{-14} f_{100} \), with \( f_{60} \) and \( f_{100} \) measured in Jy. Setting \( F_B = (\lambda f_{\lambda})_{B} \), the ratio \( F_{\text{FIR}}/F_B \) can be derived either from the ratios \( f_{60}/f_{100} \) and \( f_{100}/f_{B} \) or from \( f_{100}/f_{60} \) and \( f_{60}/f_{B} \). The results are similar in both cases. We find \( F_{\text{FIR}}/F_B \approx 0.007 \) for ellipticals and \( F_{\text{FIR}}/F_B \approx 0.02 \) for S0s, i.e. the far-IR emission of S0s turns out to be significantly higher than that of ellipticals with the same \( B_T \).

Note that if the dust distribution follows that of stars, we may expect a large dust mass in the outer regions of ellipticals. Such dust would feel a low intensity radiation field and would thus be very
cold. Its contribution to flux in the IRAS bands could be small even if its global emission isn’t. It may then be possible that the global dust emission is significantly or even much larger than $F_{\text{FIR}}$ (see §3.2).

The distributions of far-IR colors of E and S0 galaxies are shown in Figs. 4 and 5, respectively; the median values are given in Table 2. The most conspicuous difference with the far-IR spectrum of nearby disk galaxies (Hawarden et al. 1986; Puxley, Hawarden, & Mountain 1988; Xu & De Zotti 1989) are the substantially higher ratios of 12 $\mu$m and 25 $\mu$m to 60 $\mu$m or 100 $\mu$m fluxes, particularly in the case of ellipticals (see Fig. 6). The 60 $\mu$m/100 $\mu$m ratios of both E and S0 galaxies are very close to those found for nearby disk galaxies.

3. DISCUSSION

3.1. 12 $\mu$m emission

The most direct indicator of possible contributions at 12 $\mu$m in addition to the photospheric emission of cool stars, which dominate at 2.2 $\mu$m, is obviously the ratio of 12 $\mu$m to 2.2 $\mu$m flux densities.

We have adopted the total fluxes at 2.2 $\mu$m, referred to the effective aperture of the IRAS 12 $\mu$m beam, given by Knapp et al. (1992) for the 30 E galaxies in our sample for which these data are available. For 28 out of the 60 S0’s, we have used the K magnitudes corrected to an aperture log $A/D_0 = 0$ and for extinction within our own Galaxy listed by Marsiaj (1992). For the remaining galaxies, the K magnitude has been derived from the B magnitude assuming $B - K = 4.1$ (Aaronson 1978; de Vaucouleurs & de Vaucouleurs 1972). The 2.2 $\mu$m flux was computed using Johnson’s (1966) calibration.

Our analysis yields a median value $f_{12}/f_{2.2} \simeq 0.145 \pm 0.02$ for ellipticals and $0.14 \pm 0.02$ for S0s, close to the mean value $\langle f_{12}/f_{2.2} \rangle = 0.138 \pm 0.014$, found by Knapp et al. (1992), based on a slightly more heterogeneous sample. There is however a considerable dispersion, as shown by Figure 5. For comparison, for the bulge of M31 such ratio is $f_{12}/f_{2.2} \simeq 0.10$ within an aperture of diameter 4′ centered on the nucleus (Soifer et al. 1986; Knapp et al. 1992).

An important contribution to the 12 $\mu$m luminosity comes from direct photospheric emission of cool stars, mostly red giants, which also account for the bulk of the 2.2 $\mu$m luminosity. The 12 $\mu$m/2.2 $\mu$m luminosity ratio of these stars increases substantially with metallicity, as expected since the giant branch is cooler for metal rich objects. For solar metallicity, from the $V - [12 \mu m]$ colors reported by Waters, Coté, & Aumann (1987), coupled with the $V - K$ colours given by Johnson (1966), we find 12 $\mu$m/2.2 $\mu$m flux density ratios, $f_{12}/f_{2.2}$, ranging from $\simeq 0.045$ for K-giants to 0.06 for M-giants. Using the $V - K$ colors given by Frogel & Whitford (1987) and the $V - [12 \mu m]$ colors by
Waters et al. (1987) we have also estimated the mean $12/2.2 \mu m$ flux density ratio for the super metal rich galactic bulge M giants (spectral types M1–M5); we find $\langle f_{12}/f_{2.2} \rangle \simeq 0.135$. Knapp et al. (1992) have analyzed two samples of evolved stars to find that most of them have $\langle f_{12}/f_{2.2} \rangle \simeq 0.08$.

On account of the fact that metallicities of ellipticals appear to decrease from $2–3 Z_\odot$ at the center to $Z_\odot$ at one half-light radius (Munn 1992), we guess that the effective metallicity is unlikely to be much different from $Z_\odot$ and, following Knapp et al. (1992), we adopt 0.08 as the reference value for the mean $f_{12}/f_{2.2}$ ratio for stellar photospheres.

Figure 5 shows that most early type galaxies have a substantial $12 \mu m$ excess over photospheric emission. If $\langle f_{12}/f_{2.2} \rangle_{\text{photosph}} = 0.08$, such excess amounts, on the average, to $\sim 40–50\%$ (however with a large uncertainty).

The contribution of diffuse dust can be estimated from the $100 \mu m$ flux, assuming a $f_{12}/f_{100}$ ratio similar to that observed for cold dust in disk galaxies (the “warm” dust component, associated to regions of higher radiation field intensity such as HII regions, has substantially lower $f_{12}/f_{100}$ ratios, due to the destruction of PAH molecules, held responsible for the bulk of the $12 \mu m$ flux in disk galaxies, by UV photons and by interactions with ionized gas; cf. Xu & De Zotti 1989). The median value of this ratio observed for the sample of $100 \mu m$ cirrus studied by Paley et al. (1991) is $\simeq 0.035$; for the sample of nearby disk galaxies defined by Hawarden et al. (1986) we get $\langle f_{12}/f_{100} \rangle \simeq 0.024$; for spirals in the Virgo cluster, surveyed by Helou et al. (1988), Knapp et al. (1992) find $\langle f_{12}/f_{100} \rangle \simeq 0.042$. Taking into account that (see Table 2) for ellipticals the median $f_{12}/f_{100} \simeq 0.5$ (taking into account upper limits), we infer that the contribution of diffuse dust to the $12 \mu m$ flux of these galaxies is less than 10\%.

In the case of S0’s the median $f_{12}/f_{100}$ ratio is $\simeq 0.1$ (Table 2), so that diffuse dust can contribute $\sim 20–40\%$ of the mean $12 \mu m$ flux.

A detailed analysis of IRAS observations of the nuclear bulge of M31, the closest example of an old stellar population similar to that of ellipticals, indicates (Soifer et al. 1986) that one further important contributor at $12 \mu m$ is hot circumstellar dust (see also Impey, Wynn-Williams & Becklin 1986), primarily associated to OH/IR stars (Soifer et al. 1986; Cox, Krügel & Mezger 1986). Knapp et al. (1992) demonstrated that the $12 \mu m$ emission is distributed like the starlight and is therefore likely due to photospheric and circumstellar emission from red giant stars. The present results suggest that circumstellar dust may provide, on the average, as much as $\simeq 30–40\%$ of the $12 \mu m$ luminosity of ellipticals and $\lesssim 20\%$ of that of S0’s.

OH/IR stars are believed to be in the final stage of evolution along the asymptotic giant branch (AGB). Their pulsation and kinematic properties are consistent with initial masses in the range
Following Mazzei, Xu & De Zotti (1992), we assume the contribution of OH/IR stars to the emission of a galaxy at each galactic age $T$ to be a fixed fraction $F$ of the global bolometric luminosity of AGB stars with initial masses in the quoted range, and we adopt the spectrum of OH 27.2+0.2 (Baud et al. 1985) as representative for stars of this class (see also Cox & Mezger 1989). Then, the total luminosity of OH/IR stars in the passband $\Delta \lambda$ is given by:

$$L_{\text{OH}, \Delta \lambda}(T) = F \int_{T_{\text{AGB}}(m_{\text{up}})}^{T} d\tau \psi(T - \tau) \int_{m_{\text{l,OH}}(\tau)}^{m_{\text{u,OH}}(\tau)} \phi(m) 10^{-0.4(M_{\Delta \lambda(m,\tau)} - M_\odot)} dm L_\odot,$$

(1)

where $\psi(t)$ is the star formation rate (SFR), $\phi(m)$ is the initial mass function (IMF), $T_{\text{AGB}}(m_{\text{up}})$ is the time when the first OH/IR stars appear, $m_{\text{l,OH}}(\tau) (\geq m_{\text{HeF}}$) and $m_{\text{u,OH}}(\tau) (\leq m_{\text{up}})$ are the minimum and the maximum mass of OH/IR stars of age $\tau$. The coefficient $F$ was determined by Mazzei et al. (1992) from the condition that OH/IR stars account for 10% of the observed 12 $\mu$m luminosity of our Galaxy (Ghosh, Drapatz & Peppel 1986; Boulanger & Pérault 1988). They find $F = 0.05$, in good agreement with Herman & Habing’s (1985) estimate based on a different approach.

Due to the steep increase of the $M/L$ ratio with mass, most of the contribution comes from stars at the upper mass limit, whose lifetime is $\sim 1$–2 Gyr. Since, moreover, the SFR is believed to be a rapidly (exponentially) decreasing function of galactic age (for early type galaxies), the contribution of OH/IR stars to the present 12 $\mu$m luminosity should essentially reflect the SFR 1–2 Gyr ago.

If OH/IR stars are to account for, say, 30% of the 12 $\mu$m luminosity of early type galaxies, the SFR at that time should be about 10% of that of a disk of equal mass, age and IMF, i.e. about 0.3 $m_\odot$ yr$^{-1}$ for a total mass of $10^{11} m_\odot$. From the contribution of circumstellar dust to the 12 $\mu$m luminosity we may derive, following Jura et al. (1987), an estimate of the total mass loss from evolved stars, which is roughly given by $\dot{M}(m_\odot$ yr$^{-1}) = 0.045(L_{12,\text{circumstellar}}/10^8 L_\odot)$, corresponding to typical values $\sim 0.2$ $m_\odot$ yr$^{-1}$.

### 3.2. Diffuse dust emission

The diffuse dust emission spectrum is modelled following Xu & De Zotti (1989), i.e. taking into account the contributions of two components: warm dust, located in regions of high radiation intensity (e.g., in the neighborhood of OB clusters) and cold dust, heated by the general interstellar radiation field. The model allows for a realistic grain-size distribution and includes PAH molecules. The
emission spectrum of PAH’s is computed following Puget, Léger, & Boulanger (1985) and using the absorption cross sections and the bandwidths at 3.3, 6.2, 7.7, 8.6 and 11.3 µm given in Table 2 of Puget & Léger (1989). We have reckoned the contributions of PAH in the IRAS 12 µm band which encompasses the emission features at 7.7 µm, 8.6 µm, and 11.3 µm, and in the ISOCAM filters LW2 and SW1, covering the wavelength ranges 5–8.5 µm and 3.05–4.1 µm, respectively.

The temperature distribution of cold dust has been computed exploiting Jura’s (1982) model, which assumes a simple, spherically symmetric, stellar density distribution, matching reasonably well King’s (1966) model. The adopted central radiation field intensity, 16 V mag arcsec$^{-2}$ corresponds to $I_0 = 46I_{\text{local}}$ (see Xu & De Zotti 1989); the core radius $r_0$ is taken to be 100 pc.

The dust is assumed to be uniformly distributed up to a galactocentric radius $r_d$. The dust temperature drops quickly with increasing radius following the decrease in the radiation intensity. Thus the dust temperature distribution peaks at lower and lower temperatures as $r_d$ increases. For example, if $r_d = 30r_0$ the cold dust emission peaks around 100 µm while for $r_d = 100r_0$ it peaks around 150 µm.

A fit of the average ratios $f_{25\mu m}/f_{60\mu m}$ and $f_{60\mu m}/f_{100\mu m}$ listed in Table 2 implies, both for ellipticals and S0s, $I_w = 110I_{\text{local}}$ if $r_d = 30r_0$ or $I_w = 90I_{\text{local}}$ if $r_d = 100r_0$, and a warm to cold luminosity ratio, $R_{w/c}$, of 0.53 or 0.27 respectively.

As already mentioned, the warm dust component is most easily understood as associated to star formation regions, so that the ratio $R_{w/c}$ is in some sense a measure of the star formation rate. The observed far-IR spectrum of E and S0 galaxies might then provide some indication of a significant residual star formation. Pursuing the argument a little further, it is possible to quantify it, albeit crudely.

The estimated warm dust emission is in the range 0.1–0.3% of the bolometric luminosity for ellipticals, and $\simeq 0.4–0.5%$ for S0’s. According to Leisawitz & Hauser (1988) roughly 37% of the total radiated energy from an OB cluster is absorbed by nearby (and hence warm) dust grains, suggesting that OB stars account for $\sim 0.3–1%$ of the bolometric luminosity of early type galaxies. For comparison, the observed UV (0.12–0.36 µm) luminosity of early type galaxies, ranges from 1.1 to 1.7% of the bolometric luminosity (Burstein et al. 1988). The above argument may suggest that a significant fraction of the UV flux could be accounted for by recent star formation; the required SFR would be a few percent of that of a disk of equal bolometric luminosity and IMF.

4. CONCLUSIONS
Only a small fraction of the bolometric emission of early type galaxies comes out in the far-IR. The blue to far-IR luminosity ratio, \( \frac{(\lambda L_\lambda)_{B}}{L_{\text{FIR}}} \) (\( L_{\text{FIR}} \) being the luminosity in the 42.5–125.5 \( \mu \)m range) is only \( \approx 0.7\% \) for ellipticals and \( \approx 2\% \) for S0’s. Integrating over a typical spectral energy distribution of early type galaxies, we find that the bolometric luminosity is about \( 4.2(\lambda L_\lambda)_{B} \). The global far-IR luminosity is made uncertain by the lack of sub-mm data; correspondingly the long wavelength emission from very cold dust is essentially unconstrained. Models discussed here imply \( L_{\text{dust, tot}} \approx 2.6–4.8L_{\text{FIR}} \), depending on the extent of the dust distribution. Thus, it is likely that dust absorbs and reprocesses only less than 1% of starlight of ellipticals and at most a few percent of that of S0’s, to be compared with a typical 30% in the case of normal disk galaxies.

Of particular interest are data on the 12 \( \mu \)m emission. As extensively discussed by several authors (Impey et al. 1986; Knapp et al. 1992), the observed 12 \( \mu \)m flux from elliptical galaxies is in excess of that expected from direct photospheric emission of red giants and from diffuse dust (or, rather, PAH molecules). A significant contribution from hot circumstellar dust, surrounding evolved, mass losing, red giants (particularly OH/IR stars) is indicated. Its amplitude, however, is difficult to ascertain; the present analysis suggests \( \approx 30\% \). We have argued that this mostly comes from stars with mass close to \( m_{\text{up}} \), the maximum mass of stars that develop a highly degenerate CO core, whose lifetimes are \( \sim 1–2 \) Gyr. This implies a small, but significant, star formation activity in ellipticals during the last few Gyrs: assuming an exponentially decreasing SFR, with a timescale \( \sim 1 \) Gyr, we find that if OH/IR stars are to account for \( \sim 30\% \) of the 12 \( \mu \)m luminosity, the SFR at a look-back time of 2 Gyr had to be \( \sim 10\% \) of that of a disk of equal V-band luminosity. This implies that the photometric evolution of early type galaxies was not purely passive.

An additional, albeit weak, evidence that some star formation may be still taking place in present day early type galaxies comes from the fact that the mean 60/100 \( \mu \)m color temperature is very close to that of disk galaxies, suggesting, as in the case of the latter galaxies, a significant warm dust component associated to star-forming regions. A star formation of a few percent of that appropriate to a disk galaxy having the same V-band luminosity is indicated (see also Thronson & Bally 1987); such star formation could account for a fraction of the observed UV branch of early type galaxies.

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TABLE 1
MEDIAN FAR-IR TO B FLUX DENSITY RATIOS FOR E AND S0 GALAXIES
($B_T \leq 12$)

|          | E*       | S0*       |
|----------|----------|-----------|
| $\log(f_{12}/f_B)$ | $0.01 \pm 0.05$ (29/47) | $-0.06 \pm 0.05$ (33/60) |
| $\log(f_{25}/f_B)$ | $-0.70 \pm 0.32$ (8/47) | $-0.25 \pm 0.09$ (23/60) |
| $\log(f_{60}/f_B)$ | $-0.22 \pm 0.155$ (15/47) | $0.40 \pm 0.13$ (45/60) |
| $\log(f_{100}/f_B)$ | $0.25 \pm 0.10$ (23/47) | $0.80 \pm 0.12$ (41/60) |

* In parenthesis is the number of detections over the total

TABLE 2
MEDIAN FAR-IR FLUX DENSITY RATIOS FOR E AND S0 GALAXIES
($B_T \leq 12$)

|          | E        | S0       |
|----------|----------|----------|
| $\log(f_{12}/f_{100})$ | $-0.35 \pm 0.20$ | $-0.95 \pm 0.17$ |
| $\log(f_{25}/f_{100})$ | $-0.8 \pm 0.4$ | $-1.10 \pm 0.16$ |
| $\log(f_{60}/f_{100})$ | $-0.45 \pm 0.15$ | $-0.40 \pm 0.05$ |
Figure captions

**Fig. 1.** Distributions of logarithms of far-IR to $B_T(0)$ flux density ratios of the 47 E galaxies brighter than $B_T = 12$ in the RSA catalog, for the four IRAS bands, reconstructed exploiting the Kaplan-Meyer estimator, taking into account upper limits (solid lines). Dashed are the distribution of galaxies detected in the relevant IRAS band; there are 29 galaxies detected at 12 $\mu$m, 8 detected at 25 $\mu$m, 15 detected at 60 $\mu$m, 23 detected at 100 $\mu$m.

**Fig. 2.** Same as in Fig. 1, but for S0 galaxies (60 objects); 33 are detected at 12 $\mu$m, 23 at 25 $\mu$m, 45 at 60 $\mu$m, 41 at 100 $\mu$m.

**Fig. 3.** Same as in Fig. 1, but for E galaxies brighter than $B_T = 16$ (513 objects) in the sample by Knapp et al. (1989). Note the extended tail towards high far-IR fluxes, likely due to misclassified galaxies.

**Fig. 4.** Distribution of 60/100 $\mu$m and 25/100 $\mu$m flux density ratios for elliptical (left) and S0 galaxies. On the right hand panels, the point corresponding to the galaxy NGC 5192 (taken to be an S0, but whose morphological classification is uncertain) does not appear because its flux density ratios ($\log f_{25}/f_{100} > 1.57$ and $\log f_{60}/f_{100} > 1.45$) fall out of the frames.

**Fig. 5.** Distribution of 12/2.2 $\mu$m against 12/100 $\mu$m flux density ratios of elliptical [panel a)] and S0 galaxies [panel b)].

**Fig. 6.** Average far-IR spectral energy distributions, normalized to the 60 $\mu$m flux, of E (circles) and S0 (asterisks) galaxies. Also shown, for comparison, are the far-IR spectra of nearby disk galaxies (squares) and of non-Seyfert Markarians (triangles), as estimated by Xu & De Zotti (1989).