

Dust in elliptical galaxies: a new dust mass evaluation

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Abstract. In order to investigate the nature and origin of dust in elliptical galaxies, a method for the dust mass evaluation, which accounts for the dust temperature distribution, is here presented and discussed. The derived dust masses turn out to be a factor 2-6 larger than those obtained with the single temperature approximation. A correlation between the far-infrared and the blue luminosity has been also found. The results are discussed in terms of dust “mass discrepancy” and of the possible evolution scenarios: *evaporation flow* and/or *cooling flow*. While the present data cannot discriminate between these two scenarios, it is conceivable that the dust in elliptical galaxies can be accreted by the contribution of different mechanisms, according to the history of the individual objects.

Key words: galaxies: elliptical and lenticular, cD – galaxies: ISM – cooling flows – infrared: galaxies – ISM: dust, extinction

1. Introduction

Evidence for the presence of dust in elliptical galaxies was given by the optical observations of obscured regions in some systems (see for instance Bertola et al. 1985, Véron & Véron 1988) and was finally confirmed by the FIR observations of the IRAS satellite (Knapp et al. 1989, Roberts et al. 1991). The low resolution IRAS data (> 1 arcmin) have to be processed by adequate techniques to provide detailed (~ 1 arcmin at $100 \mu\text{m}$) information about the dust spatial distribution in nearby elliptical galaxies. In general, only the integrated flux of the detected source is available in the IRAS bands.

Despite the intrinsic limits due to the low resolution, Knapp et al. (1989) showed that a significant fraction (48%) of the nearby E and S0 galaxies from the Revised Shapley-Ames Catalogue (Sandage & Tammann 1981, hereafter RSA) have been detected by IRAS at 60 and $100 \mu\text{m}$ at the limiting sensitivity (about 3 times lower than in the IRAS Point Source Catalog).

It is not surprising that ellipticals contain dust, since the presence of dust is directly related to the stellar formation. But the coexistence of solid particles with the dominant gas component, which in these galaxies is heated to $\sim 10^7$ K and radiates at X-ray wavelengths, is a matter of discussion. In fact, dust grains should be quickly destroyed by sputtering (Draine & Salpeter

1979) when in direct contact with the hot gas. In such an environment the dust has a lifetime of $10^6 - 10^7$ yr. The question thus follows: where does the dust come from?

At FIR wavelengths (60 and $100 \mu\text{m}$) the thermal emission is mainly due to large grains (radius $\sim 0.1 \mu\text{m}$) which may have different heating sources, e.g. the general interstellar radiation field or OB stars. In order to discriminate between the two different contributions and to estimate the weight of each of them, several efforts were undertaken (see for instance Calzetti et al. 1995). A reasonable approach is to consider the $60 \mu\text{m}$ flux entirely due to the warm dust (~ 40 K), while the $100 \mu\text{m}$ flux should be considered the result of two contributions: the warm and the cold (~ 10 K) dust. While a two-component dust model is used to explain the spectral trend for different types of galaxies, it is rarely adopted for elliptical galaxies, which are often characterized by weak FIR emission and which are not always detected in all IRAS bands. Therefore, a single color temperature (from the 60 and $100 \mu\text{m}$ data) is usually taken as the dust temperature. It follows that no information about the dust temperature distribution and the dust spatial distribution is available for elliptical galaxies. The availability of the ISO data will provide spectra in a wider IR wavelength range (2.5-240 μm). Several attempts to understand the dust nature and origin suggest interesting interpretations by comparing optical and FIR data (Goudfrooij & de Jong 1995, hereafter GJ95, Tsai & Mathews 1995, 1996), by studying the stellar content, or by using a severe and critical approach to the data (Bregman et al. 1998). Finally, few elliptical galaxies have been observed at sub-millimeter wavelengths by Fich & Hodge (1991, 1993).

GJ95 found that the dust masses determined from the IRAS flux densities are roughly an order of magnitude higher than those determined from optical extinction values of dust lanes and patches, in contrast with what happens for spiral galaxies. The authors suggest that this “mass discrepancy” may be explained by the existence of a diffuse component (within 2 Kpc from the center), which is not detectable at optical wavelengths. On the other hand, Tsai & Mathews (1996) suggested that, while the distributed dust component is associated with dust recently ejected from evolving stars, another “extra” component of dust is present in ellipticals both in dust lanes and rings and/or in other galactic regions. In particular, they postulated that a substantial mass of cold gas remains “observationally elusive without form-

ing completely into stars". If the extra dust is optically thin in the visible it should be located far from the galactic core region, where the intensity of the starlight and therefore the grain heating is reduced.

The dust spatial distribution suggested by GJ95 and by Tsai & Mathews (1996) support the two most popular scenarios respectively: the *evaporation flow* picture and the *cooling flow* picture. In the *evaporation flow* scenario the clouds of dust and gas currently observed in ellipticals have mainly an external origin, being associated to events of galaxy interaction and/or mergers and being heated by thermal conduction in the hot gas (de Jong et al. 1990, Sparks et al. 1989). On the contrary (*cooling flow*), the internal origin of gas and dust may be explained with both red giant winds (Knapp et al. 1992) and by the *cooling flow* mechanism, in which mass loss from stars within the galaxy is heated by supernova explosions and by collisions between expanding stellar envelopes during the galaxy formation stage, and then cools and condenses (Fabian et al. 1991).

Therefore, in ellipticals, the presence of dust and the dust "mass discrepancy" are related with the dust spatial distribution, which depends on the nature and the evolution of these systems. Hence, in order to investigate the dust content, dust mass evaluations as accurate as possible are required to estimate the amount of the "mass discrepancy". Since both scenarios suggest the presence of different dust components and the very nature of the galactic environments involves the existence of dust grains at different temperatures, it is necessary to take into account a dust temperature distribution for the dust mass evaluations.

Kwan & Xie (1992) suggest a theoretical approach to take into account the effects of the dust temperature distribution in the dust mass evaluation. I present here an application of their method which is discussed and implemented in Sect. 2. The results obtained for the sample of ellipticals, introduced in Sect. 3, are presented and discussed in Sect. 4 by comparing the FIR with the visual dust mass evaluation and by discussing the correlation between blue and FIR luminosities.

2. Dust mass evaluation from FIR observations

The dust mass can be derived both from optical and from FIR observations. The value of the mass depends on the physical-chemical properties of the solid particles (i.e. grain radius, grain density and emissivity). The usual approach consists of assuming some values for the grain properties (Hildebrand 1983), while a color temperature is derived from the FIR emission. Different authors, however, present slightly different formulae for the evaluation of the dust mass (Thronson & Telesco 1986, Greenhouse et al. 1988, Young et al. 1989, Roberts et al. 1991 and Thuan & Sauvage 1992). The differences between these relations are only due to different assumptions on the grain parameters and to different derivations of the color temperature. It should be noticed that, within a flux uncertainty of 10% (which is typical of the high quality IRAS data), all the dust mass values obtained by using the different formulae are in agreement.

A single temperature model is a rough approximation in describing a galactic environment. The dust is in fact heated

by the radiation field, which in turn depends on the sources of luminosity and on their spatial distribution in the galaxy. The total FIR emission is thus likely due to the contribution of dust at different temperatures. Moreover, the IRAS FIR measurements are not adequate to detect the emission coming from cold dust (10 – 20 K) which peaks at wavelengths between 200 and 300 μm .

I adopt the dust temperature distribution given by Kwan & Xie (1992):

$$g(T) = \frac{(T/T_L)^\gamma e^{-\beta(T/T_L)}}{\int_{T_L}^{T_U} (T/T_L)^\gamma e^{-\beta(T/T_L)} dT} \quad \text{for } T_L \leq T \leq T_U, \quad (1)$$

$$g(T) = 0 \quad \text{otherwise.} \quad (2)$$

T_L and T_U are the lower and upper limits of the temperature T ; β and γ are free parameters that determine the shape of the distribution. The equations relating the temperature distribution $g(T)$ to the luminosity emitted by the dust and to the dust mass are detailed in Kwan & Xie (1992).

Due to the observed spectral range, I adopt $T_L=7$ K and $T_U=60$ K, taking into account only temperature distributions peaking at a value intermediate between T_L and T_U and excluding those pairs of β and γ which produce unrealistic distributions (as, for instance, monotonically increasing or decreasing functions).

The main problem in the present approach is to select the proper values for the parameters β and γ , the choice being constrained by the ratio of the flux densities at two different wavelengths.

I first identify a range of β and γ pairs which produce the observed flux ratio. Since the same flux ratio can be obtained by functions having quite different shapes, a further constraint is needed. Unfortunately, for none of the galaxies in the sample submillimeter observations are available. Nevertheless, their color temperature may be derived from the flux density ratio (Henning et al. 1990). Taking into account the uncertainty in the computed color temperature, I select those distributions $g(T)$ that produce the observed flux density ratio and whose peak temperature is comparable to the color temperature. The selected family of $g(T)$ functions obviously satisfies two conditions which are not independent (being both related to the flux ratio). This fact could in principle affect the reliability of the results. It turns out, however, that pairs of β and γ which satisfy the same constraints give the same dust mass within the flux uncertainty.

In order to check the method a simple numerical simulation has been performed. I considered an artificial galaxy which is not resolved by IRAS both at 60 and 100 μm with a given dust mass and, then, I evaluated the dust content following the present method. The galaxy dust mass M_d may be roughly estimated by using the equation

$$M_d = \frac{4}{3} \pi r^3 \rho N_d, \quad (3)$$

where r is the dust grain radius, ρ is the dust grain density and N_d is the number of dust grains. Eq. 3 implies the following approximations. The dust grain radius r characterizes the dust grains

which contribute to the thermal emission at FIR wavelengths. Actually, the uncertainties in the total dust mass introduced by using an average radius instead of a size distribution, are much smaller than those arising from uncertainties in the dust emissivity spectral trend and in the dust temperature distribution (Kwan & Xie 1992). N_d is the total number of the dust grains within the observing beam. Since the galaxy is not resolved by IRAS, as it is often the case, Eq. 3 gives the total dust mass of the point source. A dust radius of $0.1 \mu\text{m}$ and a dust grain density of 3 g cm^{-3} are currently adopted (Hildebrand 1983) and also used in the present article.

Concerning the dust emissivity, the power-law approximation $\epsilon(\lambda) = \epsilon_0(\lambda_0/\lambda)^\alpha$ is used in the computations, with $\alpha = 1$ and $\epsilon_0 = 9.38 \cdot 10^{-4}$ (Hildebrand 1983).

By assuming a value for N_d and the temperature distribution $g(T)$, and accounting for the spectral responses of the IRAS detectors at 60 and $100 \mu\text{m}$, the luminosity emitted by the N_d dust grains, as observed within the filter bandpass, can be estimated. The flux ratio and the color temperature of the galaxy are then computed, while the dust mass of the source is derived from N_d by Eq. 3.

A galaxy with $M_d=10^5 M_\odot$ turns out to contain about $N_d=1.6 \cdot 10^{52}$ dust grains. The galaxy distance is assumed to be 10 Mpc. By assuming a $g(T)$ with $\beta = 5$ and $\gamma = 20$ the flux ratio turns out to be about 0.5. I use the flux ratio as a constraint to select the pairs β - γ producing a $g(T)$ whose peak temperature is comparable to the galaxy color temperature of 36 K. Among these pairs also the pair $\beta = 5$ and $\gamma = 20$ is found (i.e. exactly the values adopted for the input $g(T)$). For the selected pairs of parameters I compute the dust mass which ranges between $6 - 9 \cdot 10^4 M_\odot$. Therefore, the derived values are in agreement with the dust mass of the galaxy within the flux uncertainties, thus confirming the reliability of the method. Furthermore, by using the single temperature model and taking into account the different formulae available (see Sect. 2) a dust mass of $4 \cdot 10^4 M_\odot$ is derived. This result shows that the single temperature model underestimates the dust content.

The same test was performed for different ‘‘artificial galaxies’’ with different temperature distributions obtaining always consistent results.

3. The sample of elliptical galaxies

The 21 elliptical galaxies listed in Table 1 have been extracted from the sample by GJ95, who evaluated their FIR luminosity and dust mass from FIR data. All the galaxies are classified as E both in RSA and in de Vaucouleurs et al. (1991) and have magnitudes $B_T^0 < 12$. I selected those galaxies which have been detected at both 60 and $100 \mu\text{m}$ by IRAS (Knapp et al. 1989). $H_0 = 50 \text{ Km s}^{-1} \text{ Mpc}^{-1}$ is assumed throughout this paper.

For each galaxy the FIR luminosity, the flux ratio, the dust temperature and the dust mass from FIR data (hereafter FIR dust mass) have been derived and listed in Table 1. The FIR fluxes by Knapp et al. (1989) have been corrected taking into account the contribution of hot circumstellar dust (GJ95) and have been used for the computation of: the FIR luminosity in the

Table 1. The selected sample of elliptical galaxies.

Galaxy	$\log L_B$	$\log L_{\text{FIR}}$	$\frac{f_{60}}{f_{100}}$	T_{dust}	M^{opt}	M_T^{FIR}	$M_{\text{g(T)}}^{\text{FIR}}$
(1)	$[L_\odot]$	$[L_\odot]$	(4)	[K]	$[M_\odot]$	$[M_\odot]$	$[M_\odot]$
N1395	10.36	8.27	0.17	25.0		$5.43 \cdot 10^5$	$1.61 \cdot 10^6$
N2974	10.29	9.16	0.25	28.1	$4.57 \cdot 10^4$	$1.77 \cdot 10^6$	$1.11 \cdot 10^7$
N3377	9.70	7.56	0.45	33.8	$9.77 \cdot 10^3$	$1.39 \cdot 10^4$	$5.06 \cdot 10^4$
N3557	10.86	9.22	0.37	31.7		$9.42 \cdot 10^5$	$3.16 \cdot 10^6$
N3904	10.16	8.45	0.44	33.4		$1.15 \cdot 10^5$	$5.01 \cdot 10^5$
N4125	10.75	9.08	0.49	34.7	$4.47 \cdot 10^5$	$3.90 \cdot 10^5$	$1.46 \cdot 10^6$
N4261	10.56	8.35	0.62	38.0		$4.47 \cdot 10^4$	$1.49 \cdot 10^5$
N4278	9.76	8.25	0.36	31.4	$2.34 \cdot 10^4$	$1.05 \cdot 10^5$	$4.75 \cdot 10^5$
N4374	10.43	8.43	0.50	35.0	$3.47 \cdot 10^4$	$8.38 \cdot 10^4$	$3.00 \cdot 10^5$
I 3370	10.69	9.59	0.28	29.1	$3.47 \cdot 10^5$	$3.87 \cdot 10^6$	$2.11 \cdot 10^7$
N4486	10.67	8.45	1.11	49.5	$1.48 \cdot 10^3$	$1.52 \cdot 10^4$	$3.79 \cdot 10^4$
N4589	10.29	8.92	0.36	31.2	$8.51 \cdot 10^4$	$5.10 \cdot 10^5$	$1.44 \cdot 10^6$
N4697	10.46	8.59	0.43	33.2		$1.64 \cdot 10^5$	$7.31 \cdot 10^5$
N4696	10.83	9.06	0.14	23.7	$4.47 \cdot 10^5$	$5.19 \cdot 10^6$	$3.02 \cdot 10^7$
N5018	10.63	9.67	0.59	37.4	$2.82 \cdot 10^5$	$9.90 \cdot 10^5$	$3.38 \cdot 10^6$
N5044	10.54	8.68	1.08	48.8	$1.82 \cdot 10^4$	$2.76 \cdot 10^4$	$6.76 \cdot 10^4$
I 4296	11.00	9.02	0.61	37.8		$2.13 \cdot 10^5$	$7.00 \cdot 10^5$
N5322	10.77	9.07	0.48	34.6		$3.89 \cdot 10^5$	$1.37 \cdot 10^6$
N5576	10.27	8.13	0.47	34.4	$3.31 \cdot 10^3$	$4.59 \cdot 10^4$	$1.47 \cdot 10^5$
N7144	10.30	8.54	0.31	29.9		$2.83 \cdot 10^5$	$1.16 \cdot 10^6$
I 1459	10.54	9.00	0.50	35.0	$1.86 \cdot 10^5$	$3.13 \cdot 10^5$	$2.09 \cdot 10^6$

Column (2): total blue luminosities taken from GJ95. Columns (3), (4) and (5): computed values for FIR luminosities, flux ratio and dust color temperatures. The dust masses in Column (6) are taken from GJ95. The FIR dust mass in Column (7) is derived by averaging the results of formulae which are usually adopted, while the FIR dust mass in Column (8) is derived by adopting a temperature distribution model as described in Sect. 2. The uncertainties for the mass evaluations are shown in Fig. 1. N and I stand for NGC and IC respectively.

band $40\text{-}120 \mu\text{m}$ (Helou et al. 1985), the flux ratio and the dust color temperature (Henning et al. 1990). The uncertainties in the three quantities depend on the flux uncertainties, which are estimated to be in the range 10%-30% (Knapp et al. 1989). The chemical and physical properties of the dust grains play a critical rôle in the evaluation of the uncertainties on temperature and mass. On the other hand, the present paper is mainly addressed to the dependence of the dust mass on the choice of a particular temperature distribution, and I will not discuss the problem of the dust properties (which will be studied in a forthcoming paper). A spectral index $\alpha = 1$ for the dust is used in all the computations. The FIR dust masses listed in Table 1 are evaluated from the FIR fluxes by means of the single temperature and the temperature distribution models respectively.

4. Temperature distribution model: results and discussion

4.1. FIR dust masses

The dust masses computed by adopting a single temperature and a temperature distribution are compared in Fig. 1. Both methods lead to a temperature dependence, as expected when the dust amount is derived by using thermal emission. In fact,

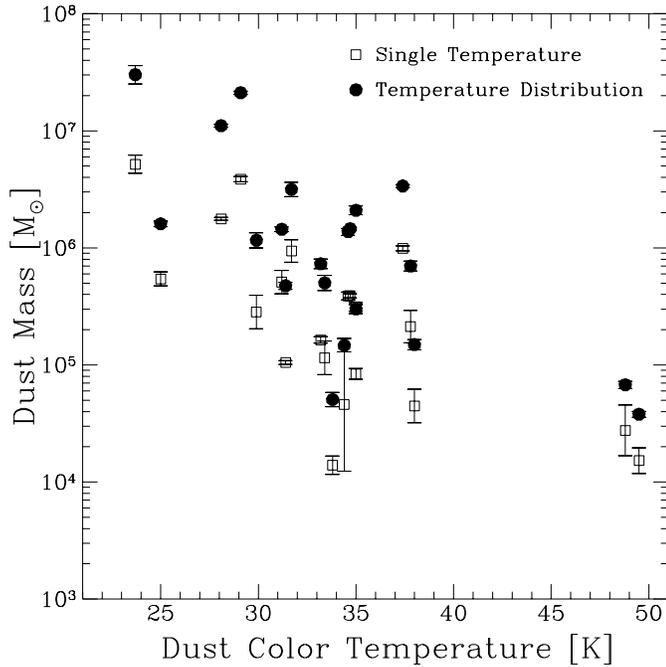


Fig. 1. The dust masses computed by adopting a single temperature (open squares) and a temperature distribution (filled circles). The error bars account for the uncertainties in $g(T)$ (filled circles) and in the color temperature (open squares).

the colder the dust grains, the larger should be their total number in order to produce a given FIR emission.

The dust masses obtained with a temperature distribution are larger than those derived from a single-temperature model. This confirms that IRAS measurements allow to determine the warm (30-54 K) dust amount only, while the contribution of the cold dust is neglected. Moreover, it turns out that, in the present sample, the FIR luminosity does not depend on the color temperature, thus confirming that the FIR emission is a result of different contributions and cannot be properly explained by a source with a single equilibrium temperature. The two models give masses differing by factors from 2 to 6. This wide range is due either to the shape of the temperature distribution and/or to the uncertainties in the dust parameters. On the other hand, the ratio between the two dust mass evaluations (Fig. 2) shows a general temperature dependence which suggests that colder galaxies have a larger amount of missed dust.

4.2. Dust “mass discrepancy”

The temperature distribution model enhances the dust “mass discrepancy”. In order to explain that discrepancy, it has to be noticed that the dust mass evaluated from optical observations critically depends on the spatial distribution of the dust with respect to the stars. Usually the extinction is thought to be due to an overlying absorbing screen of dust grains. That is the geometry where a given amount of dust has the strongest effect on the starlight. In order to test how a peculiar and oversimplified spatial distribution affects the dust mass evaluation from optical

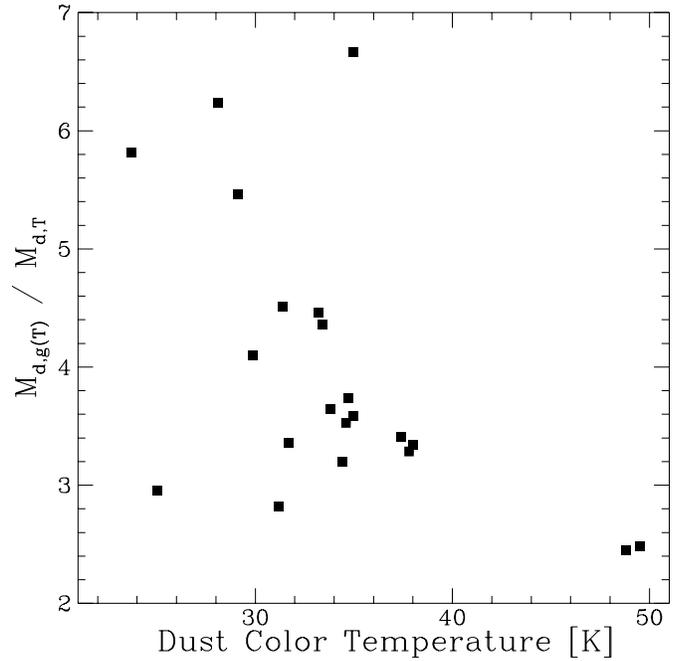


Fig. 2. The ratio between the FIR dust masses computed by using a temperature distribution and a single temperature model. The temperature dependence suggests that larger amounts of cold dust are neglected in sources with lower color temperature. The two galaxies on the left bottom, which do not follow the general trend are, from left to right, NGC 1395 and NGC 4589.

data, I compared the optical dust masses in Table 1 to those derived by assuming a more realistic spatial distribution (e.g. Witt et al. 1992) and by using the optical data by Goudfrooij et al. (1994a, b). The new optical masses turn out to be enhanced by a factor 2-4, cutting the “mass discrepancy” down. However, even if the “mass discrepancy” is reduced by assuming a more realistic spatial distribution, the optical absorption can only account for the dust in the obscured galaxy regions, while the distributed dust component is always neglected.

A similar case concerns the “extra” dust component suggested by Tsai & Mathews (1996) to explain the 60-100 μm flux ratio: due to its low temperature, it is not detected by IRAS. Following their model, it is possible to estimate the contribution of the “extra” dust in the sample. Taking into account the “extra” dust amount, the dust masses derived by a single temperature model are slightly enhanced, but the large uncertainties due to the observations and, then, to the temperature evaluation do not allow to judge this enhancement as significant. One can argue that, with a model of temperature distribution, it is possible to overestimate the dust amount. Actually, this cannot happen because of the severe constraints which are chosen, whether two different flux ratios are available or when a flux ratio and the relative color temperature are used as it is here suggested. In this respect, the last method is also the more conservative, since the warm dust observed at 60 μm affects the dust mass evaluation in the sense of underestimating the cold dust amount.

Therefore, since these computations are very sensitive to the assumed dust temperature, the model by Kwan & Xie (1992)

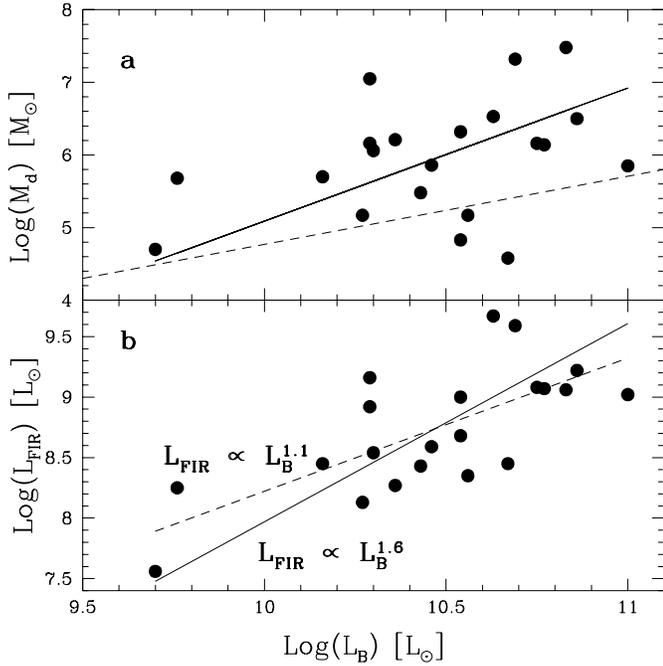


Fig. 3. **a** Dust mass (with the temperature distribution model) and blue luminosity relation: the solid line is the least squares bisector fit (confidence level greater than 95%) while the dashed line is the loci where dust is replenished by stellar mass loss and destroyed by sputtering with the maximum destruction timescale ($10^{7.5}$ yr). Most of the galaxies present an observed dust mass larger than the amount predicted by the dust formation and destruction model. **b** FIR and blue luminosity relation: the solid line is the least squares bisector fit (confidence level greater than 99.5%). For comparison the theoretical prediction (dashed line) by Tsai & Mathews (1996) is also shown.

greatly improves the mass evaluation by taking into account a wide temperature range, and can be applied to a wide range of galaxy morphological types when, because of lack of the data, it is not possible to adopt and to develop a suitable radiation model.

5. Temperature distribution and heating mechanisms: the origin of the dust

Actually, the uncertainty on the temperature distribution is directly connected to the study of the heating mechanisms and, therefore, to the knowledge of the UV interstellar radiation field.

To this aim, and in order to investigate the origin of the dust in elliptical galaxies, I plot in Figs. 3a and b the dust mass M_d and the FIR luminosity L_{FIR} versus the blue luminosity L_B for the galaxy sample. Both M_d and L_{FIR} are correlated to L_B , in contrast with what has been found by GJ95. Therefore, while the absence of correlation between dust mass and blue luminosity in their sample was considered to support the external origin of the dust in ellipticals and the *evaporation flow* picture, the present result indicates that a relationship between the dust content and the present day population of stars should be not excluded. But, as already pointed out by GJ95, a lack or a presence of correlation between M_d and/or L_{FIR} and L_B cannot be a definitive

proof of the external or the internal origin of the dust, due to the fact that the dust destruction mechanisms and timescales in elliptical galaxies are expected to be different depending on the evolutionary state and on the hot gas content of the individual objects.

For this reason, further analysis and, above all, high resolution FIR observations are required to understand the origin and the fate of dust in these systems. Waiting for a complete analysis of the ISO data, a reasonable approach is the comparison between the available observations and models of star formation and dust heating mechanisms. I plot in Fig. 3a the loci where dust is replenished by stellar mass loss at the rate given by Faber & Gallagher (1976) and destroyed by sputtering with the maximum destruction timescale ($10^{7.5}$ yr) in ellipticals which contain hot gas (see GJ95 for details). In 85% of the galaxies the dust having an internal origin does not account for the computed dust masses, which are larger. Therefore, one can argue that in 85% of the ellipticals an alternative supplying mechanism for the dust is required to account for the FIR observations. Mergers with spirals or small, dust-rich irregular galaxies and, then, the *evaporation flow* scenario are, in fact, strongly supported by the previous evidence (Fig. 3a). The critical point of this picture is to identify the observed diffuse dust, located within 2 Kpc from the center, as the dust accreted during the galaxy interaction when high hydrodynamic instabilities are expected. In particular, the external dust had to be somehow protected from the interaction with the hot gas when moving toward the center.

The problem could be solved with the “extra” dust component (Tsai & Mathews 1996) located in very large disks out to the effective radius and, therefore, cold enough to emit at FIR and submillimeter wavelengths. This dust can have, in principle, both internal and external origin. In particular, due to the low temperature “dust may re-form and grow in these cold disks” (Tsai & Mathews 1996). Unfortunately, due to the large uncertainties, it is not possible to evaluate the exact amount of this dust component. Therefore, since the external origin of the dust is far from fully verified, I experimented with an alternative approach to interpret the relation between the FIR and the blue luminosity. By using the least squares bisector method, I find $L_{FIR} \propto L_B^{1.64 \pm 0.39}$ (Fig. 3b), in agreement with Bregman et al. (1998). The luminosity correlation supports the scenarios in which a significant amount of dust has internal origin (Tsai & Mathews 1995, 1996), coming from stellar mass loss and being heated by stellar photons and the general interstellar radiation field.

The problem of the coexistence of dust and hot gas might be resolved with a dust grain distribution containing grains larger than the maximum size suggested by Mathis et al. (1977) and usually adopted in the current models. In fact, this assumption would increase the sputtering time and, then, the dust grain density. Tsai & Mathews (1996) found that the FIR luminosity is proportional to $L_B^{1.1}$ when the maximum grain size increase from $0.3 \mu\text{m}$ to $0.9 \mu\text{m}$. This theoretical prediction (dashed line in Fig. 3b) and the observed relation (solid line in Fig. 3b) is consistent in the luminosity range covered by the present

sample¹, therefore the luminosity correlation seems to support the *cooling flow* scenario.

Finally, the two comparisons between observations and empirical-theoretical models show a clear conflict: while the canonical star formation rate cannot account for the dust amount in elliptical galaxies, thus supporting the *evaporation flow* scenario, the trend of the L_{FIR} - L_B can be explained with a proper dust model which increases the sputtering time and which suggests an *ad hoc* dust distribution. Concerning this last possibility it has to be stressed that, although the L_{FIR} - L_B relation can be affected by different hot gas contents and stellar populations in the individual objects, the correlation between these quantities is characterized by a trend predicted by theoretical models. Furthermore, both in Bregman et al. (1998) and in the present work, severe selection criteria are applied (see Sect. 3), which take into account the reliability of the observations and the different contributions to the FIR emission. I compare the present sample and the sample of Bregman et al. (1998) which rejected the galaxies whose FIR fluxes can be contaminated by AGN emission, position uncertainties, background objects and inhomogeneity. The L_{FIR} - L_B relation in Fig. 3b is not affected by the exclusion from the sample of the four AGNs (NGC 4374, NGC 4486, I 4296 and I 1459) and of NGC 3557 that has a non-homogenous background.

Taking into account the results of the present analysis it seems difficult to choose between the *evaporation flow* or the *cooling flow* scenario and to affirm that the dust in ellipticals has mainly an external or an internal origin. A reasonable conclusion is that the individual objects have experienced different mechanisms of dust accretion during their evolution and that only a detailed study of the individual systems will allow to describe for each object the different evolution phases and the contributions of the different mechanisms of dust accretion.

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¹ Incidentally, an ordinary least squares fit to the data gives $L_{FIR} \propto L_B^{1.07 \pm 0.25}$.