results of model calculations for a multi-site emission. For each impact site, we have assumed emitting region diameters of 2.5" (9400 km), in order to take into account the dilution within the beam. The model parameters are an excess temperature of 30–40 K above the normal 170 K temperature and a CO mixing ratio of 4×10^{-5} above the 0.1 mbar (impact G) or 0.4 mbar (impacts Q_1 and Q_2) levels. This fit is only illustrative and the solution is far from being unique. Emission due to impact R, close to Q_2, was not included. A somewhat higher temperature and lower mixing ratio would equally fit the results, and vice versa. The present solution implies CO masses on the order of 10^{14} g for each impact site, consistent with the conclusions of Lellouch et al. (1995) derived from the IRAM data.

4. Discussion

The detection of CO in the stratosphere of Jupiter will provide strong constraints on the physics of the impacts. CO has normally a very low abundance in Jupiter's atmosphere. The derived abundance is about 50,000 times larger than the normal tropospheric abundance, making unlikely that we were observing jovian CO transported in the plume. Since the high temperatures in the fireball are expected to dissociate most of the cometary and Jovian material, shock chemistry seems to provide the most plausible explanation for the formation of CO. The inferred amount of CO is quite comparable to the oxygen expected in a 1-km sized cometary nucleus. The millimetre observations provide in addition almost unique information on the thermal structure of the Jovian stratosphere modified by the impacts and its temporal evolution. The monitoring of millimetre lines of CO, CS and the HCN line indicated that a substantial warming occurred after the impacts and persisted over one week (Lellouch et al., 1995; Marten et al., 1995). Then the lines switched over from emission to absorption, indicating important cooling down to temperatures lower than the pre-impact values (Lellouch et al., 1995; Marten et al., 1994, 1995). The SEST observations, together with the other millimetre observations, will help to better understand this unique event.

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For further information please contact:
D. Bockelée-Morvan;
e-mail: Dominique.Bockelee@obspm.fr

Evidence for Diffusely Distributed Dust in Elliptical Galaxies and its Effect on Radial Colour Gradients

P. GOUDFROOIJ, ESO-Garching

The presence of dust in elliptical galaxies has recently been shown to be quite common. Deep optical multi-colour CCD imaging has revealed the presence of dust lanes and patches, and the technique of co-adding IRAS survey scans has led to many detections of elliptical galaxies. The optical and far-infrared surveys reported similar detection rates of dust, which may indicate that dust in elliptical galaxies is generally distributed in the optically detected lanes or patches. However, we show here that the amount of dust as derived from the optical extinction values is typically an order of magnitude smaller than that derived from the IRAS flux densities, in strong contrast with the situation in spiral galaxies. To unriddle this dilemma, we postulate that the majority of the dust in elliptical galaxies exists as a diffusely distributed component which is undetectable using optical methods. Employing a multiple scattering model for the dust, we show that the presence of this newly postulated dust component implies significant radial colour gradients which were essentially thought to arise from stellar population gradients only. The energetics of the diffusely distributed dust component is shown to be consistent with the IRAS data. A comparison of the detectable amount of dust in elliptical galaxies embedded in hot, X-ray-emitting gas with the amount expected in case the production and destruction rates of dust are equal indicates that most of the dust in elliptical galaxies has been accreted from other galaxies.

1. Introduction

Although elliptical galaxies generally do not exhibit the large amounts of interstellar matter (ISM) typically found in spiral galaxies, it has recently become possible to detect various components of the ISM in elliptical galaxies (see, Roberts et al. 1991; Goudfrooij et al. 1994b). These studies have shown that the presence of dust and gas in elliptical galaxies is the rule rather than the exception.

Besides detecting the interstellar matter, we are interested in its origin and fate since this material is expected to hold clues to the formation and subsequent evolution of elliptical galaxies through both the physical properties and the dynamics of the gas and dust. There are at least two possible sources of the observed ISM: accumulation of material shed by evolved, mass-losing giant stars within the galaxy (e.g., Faber & Gallagher 1976; Knapp et al. 1992), and accretion of gas during galaxy interactions.

In order to systematically study the global occurrence and properties of dust and gas in elliptical galaxies, we (P. Goudfrooij from ESO, L. Hansen and H.E. Jørgensen from the Copenhagen University Observatory, H.U. Nørgaard-Nielsen from the Danish Space Research Institute, and T. de Jong from the University of Amsterdam) have performed an optical survey of a complete, *apparent*-magnitude selected sample of elliptical galaxies, containing all such objects (56 in number) with $B^0_T < 12$ mag. in the *Revised*

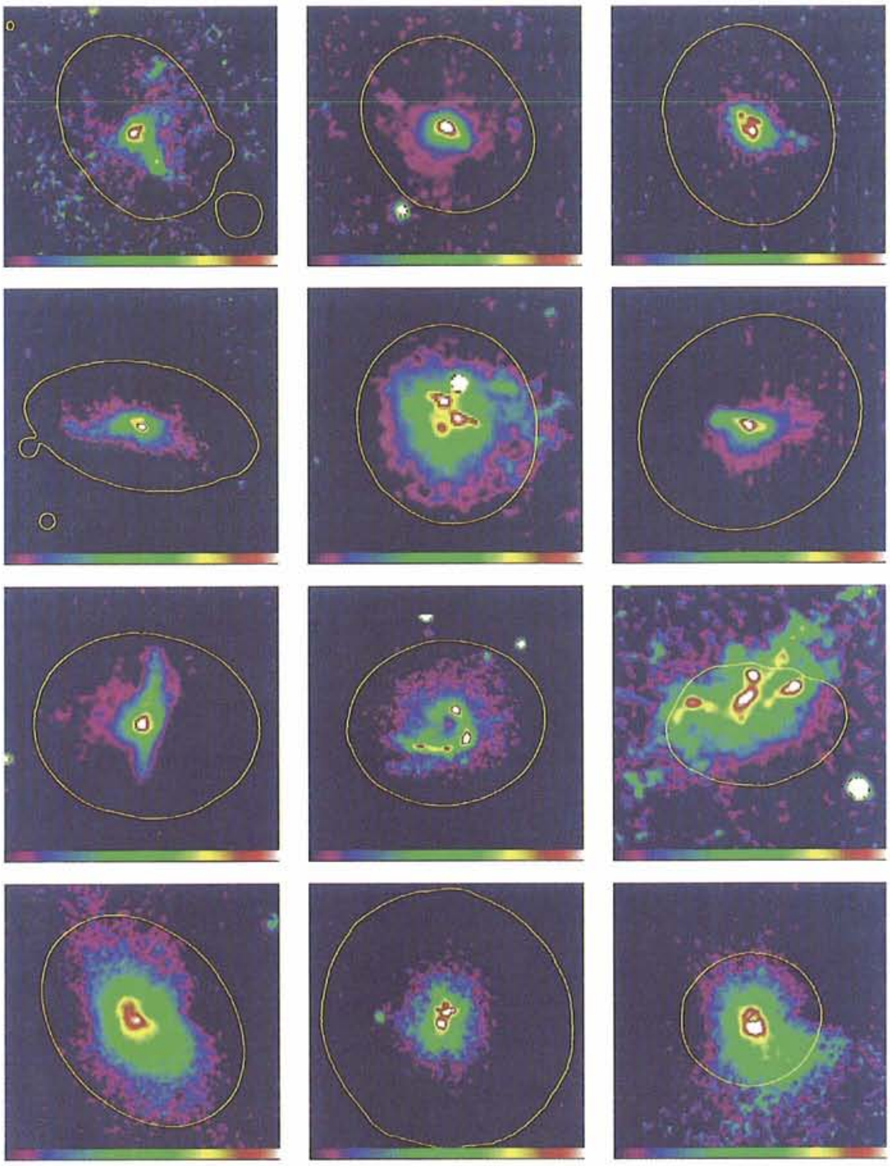

Figure 1: *B–I colour index images of (top left to bottom right) NGC 3136, IC 3370, NGC 3962, NGC 4125, NGC 4278, NGC 4374, NGC 4589, NGC 4696, NGC 5018, IC 1459, NGC 5044, and NGC 7507. For each galaxy, the B-band isophotal contour at half a de Vaucouleurs' effective radius (R_e) is superposed (except for NGC 4696 and NGC 5044, where the contour at $R_e/4$ is superposed). Dust shows as reddened structures with a morphology different from the isophote(s) of (stellar) galaxy light. The colour look up table is displayed at the bottom of each image.*

Shapley-Ames Catalog of Bright Galaxies (hereafter RSA catalog; Sandage & Tammann 1981). Deep CCD imaging has been performed through both broad-band filters and narrow-band filters isolating the nebular Hα+[NII] emission lines. For this we used the Dutch 0.91-m, Danish 1.54-m and ESO/MPI 2.2-m telescopes at ESO-La Silla for the southern galaxies, and the 1.0-m Jacobus Kapteyn telescope on the Canary island La Palma for the northern galaxies. Due to the size of the sample, the survey took several years to complete. The surface photometry and the isophotal properties of the sample galaxies are presented in Goudfrooij et al. (1994a, hereafter Paper I); distributions of dust and ionized gas are presented in Goudfrooij et al. (1994b, hereafter Paper II). Extinction properties of dust in selected dusty elliptical galaxies are presented in Goudfrooij et al. (1995, hereafter Paper III), where dust masses are also estimated from the optical extinction data.

1.1 Optical and far-infrared signatures of dust in elliptical galaxies

Optical CCD imaging is essential in establishing the presence and distribution of ISM in ellipticals in view of its high spatial resolution. However, quantitative estimates of the mass and the physical conditions of the dust from optical data alone are hampered by serious selection effects. This can be illustrated as follows: The optical methods for detecting dust in elliptical galaxies take advantage of the smooth distribution of the stellar light of these galaxies. Thus, only dust distributions that are sufficiently distinct from that of the stellar light (i.e., dust lanes, disks, or patches) can be detected. Examples of dust in elliptical galaxies in our "RSA sample" are shown in Figure 1.

In Paper II, we reported an (optical) detection rate of dust features in our RSA sample of 41 %. However, the ability to detect dusty disks or lanes in elliptical galaxies by these methods depends heavily on orientation effects, i.e., is biased towards edge-on dust distributions. The actual fraction of ellipticals containing dust features may thus be much higher (cf. Paper II; Sadler & Gerhard 1985). Furthermore, a significant fraction of the dust in elliptical galaxies may be expected to follow a smooth distribution similar to that of the stars (e.g., dust which is produced by mass-loss from late-type giant stars within the galaxies), but this dust remains undetected by optical methods.

The means to study dust in galaxies in a more quantitative way became available with data provided by the InfraRed Astronomical Satellite (IRAS). Since the dust opacity is low in the far-infrared, orientation effects do not influence the detectability of dust, thus allowing quantitative estimates of the temperature and total mass of the dust. Using the technique of co-adding IRAS survey scans, Knapp et al. (1989) have shown that a significant fraction (≥50 %) of nearby, bright E and S0 galaxies have been detected at 60 and 100 μm at a limiting sensitivity about 3 times lower than in the IRAS Point Source Catalog. Although this detection rate is similar to that of the optical methods, recent studies of individual elliptical galaxies have shown that estimates of the total mass of dust using the IRAS data are a factor of ~ 10 higher than those derived from optical colour excesses integrated over the areas where dust is found to reside (de Jong et al. 1990; Hansen et al. 1991). To address the discrepancies mentioned above, we combine in this paper our optical survey data with the IRAS data to analyse physical properties of dust in elliptical galaxies, including the distribution of the dust and heating mechanisms for the dust. A more elaborate version of this paper will be published elsewhere (Goudfrooij & de Jong 1995, hereafter Paper IV).

2. The Distribution of Dust in Elliptical Galaxies

2.1 Dust masses from optical and far-infrared data: the "Dust Mass Discrepancy"

The methods used for deriving dust masses from optical extinction values and from the IRAS flux densities are explained in detail in Papers III and IV. In summary,

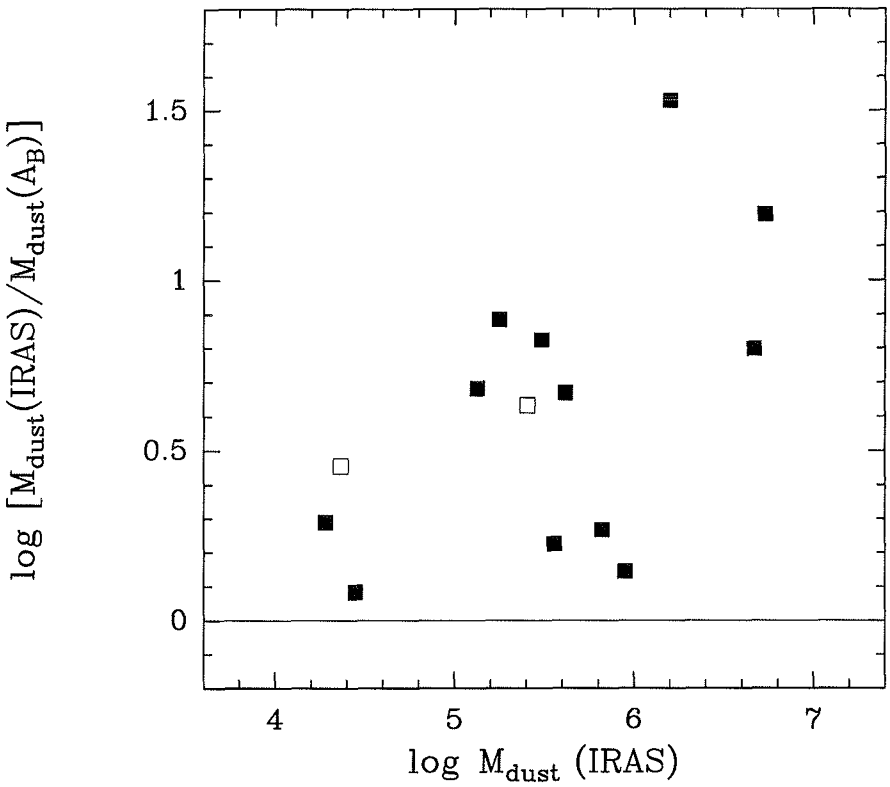

Figure 2: *The quotient of the dust mass derived from the IRAS data and the dust mass derived from optical extinction versus the dust mass derived from the IRAS data for elliptical galaxies from the "RSA sample" with optically detected dust. Filled squares represent galaxies detected by IRAS at both 60 and 100 μm, and open squares represent galaxies detected in only one IRAS band.*

optical extinction values are converted into dust mass column densities by adopting the Mathis et al. (1977) grain size distribution function and optical extinction efficiency factors taken from the literature; the IRAS 60 and 100 μm flux densities are used to determine dust masses under the assumption that the far-infrared emission of elliptical galaxies originates from dust with an emissivity law $\propto \lambda^{-1}$ at the wavelength region covered by IRAS. We assume the 60 and 100 μm emission to be due to a single-temperature component of dust. Thus, derived dust temperatures should be regarded as "representative" values, since a *range* of temperatures is appropriate for dust within elliptical galaxies. We note that IRAS is sensitive to "cool" dust with $T_d \gtrsim 25$ K, but much less to "cold" dust with lower temperatures emitting predominantly at wavelengths far beyond 100 μm (e.g., Young et al. 1986). We will see below that temperatures of order 20 K are appropriate to the outer regions of elliptical galaxies (i.e., beyond ~10 kpc), so that the dust masses calculated from the IRAS data are in principle (firm) lower limits to the real dust mass. In the following, we thus only consider the component of dust which radiates at wavelengths covered by IRAS.

A glance at Figure 2 reveals that the dust masses estimated from the optical extinction are significantly lower than those estimated from the far-infrared emission. Quantitatively, the average ratio $< M_{d,\,IRAS}/M_{d,\,opt} > = 8.4 \pm 1.3$ for the galaxies in our "RSA sample" for which the presence of dust is revealed by both far-infrared emission and optical dust lanes or patches. Strictly speaking, the dust masses derived from optical extinction are lower limits since the conversion factor from extinction to dust mass implicitly assumes the dust to be in front of the stars. Since the dust is probably embedded in the stellar systems, the optically derived dust masses may be of order 2 times higher than the calculated values. However, the disagreement between the two mass determinations is significant.

This disagreement might (partly) be due to the effect of orientation. In Paper II we reported that estimated inclinations of regular dust lanes in early-type galaxies are found to range between 0 and ~ 35°, suggesting that dust lanes are detected only if inclined by less than a certain critical angle. If this were correct, the ratio $M_{d,\,IRAS}/M_{d,\,opt}$ (hereafter "dust mass discrepancy") would be expected to be inversely proportional to cos (*i*), where *i* is the inclination of the dust lane

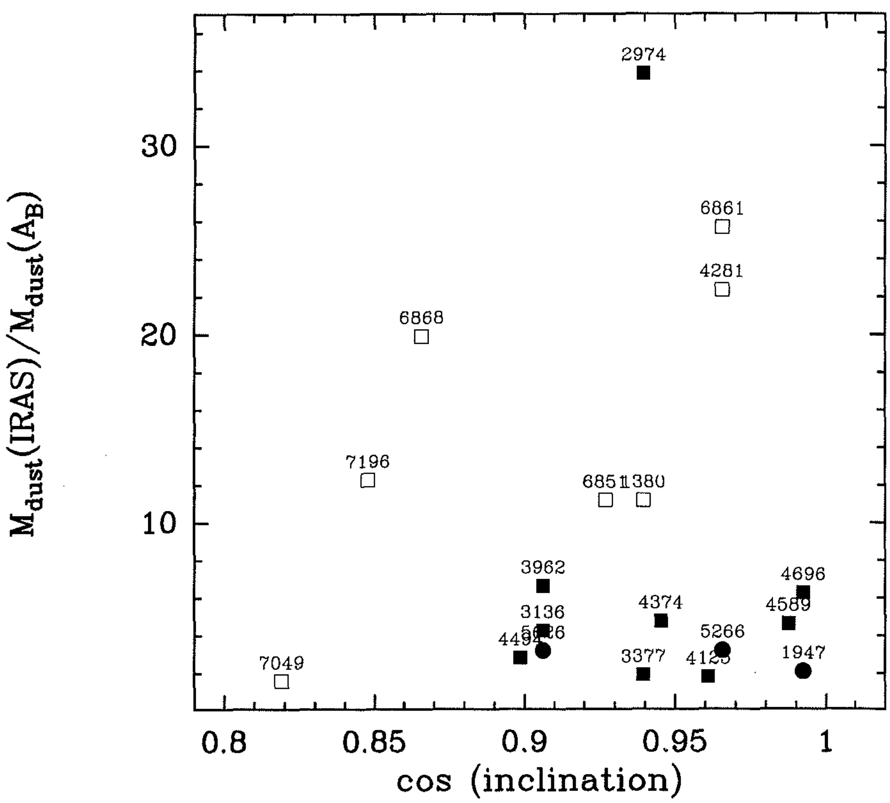

Figure 3: *The quotient of the dust mass derived from the IRAS data and the dust mass derived from optical extinction versus the cosine of the inclination angle of the dust lane in selected elliptical galaxies containing regular dust lanes. Filled squares represent galaxies from the "RSA sample", filled circles represent galaxies from Paper III, and open squares represent galaxies from the sample of Véron-Cetty & Véron (1988). The NGC numbers of the galaxies involved are indicated above the symbols.*

with respect to the line of sight. To evaluate the influence of the effect of orientation on the dust mass discrepancy, we estimated the inclinations of (apparently) regular, uniform dust lanes in elliptical galaxies from images shown in homogeneous optical CCD surveys (Paper II; Paper III; Véron-Cetty & Véron 1988). The dust masses derived from the optical reddening by Véron-Cetty & Véron were scaled up by 10 % proportional to the difference of the adopted dust mass column densities (cf. Paper III). The relation between $M_{d,\,IRAS}/M_{d,\,opt}$ and cos (*i*) is shown in Figure 3. This being a scatter plot, the effect of orientation on the dust mass discrepancy must be weak if present at all. This suggests that the dust in the lanes is concentrated in relatively small, dense clumps with a low volume filling factor.

2.2 Diffusely distributed dust: dilemma unriddled?

Having eliminated the effect of orientation, the most plausible way out of the dilemma of the dust mass discrepancy is to postulate an additional component of dust with a diffuse, uniform distribution over a large area in elliptical galaxies and therefore virtually undetectable by optical methods. We note that this diffuse component of dust is not unexpected in elliptical galaxies. For instance, the late-type stellar population of typical giant ellipticals ($L_B = 10^{10} - 10^{11}\,L_\odot$) has a substantial present-day mass loss rate (~ 0.1 – 1 $M_\odot\,yr^{-1}$ of gas and dust; cf. Faber & Gallagher 1976) which is expected to be diffusely distributed.

An interesting potential way to trace this diffuse component of dust is provided by radial colour gradients in elliptical galaxies. With very few significant exceptions, "normal" elliptical galaxies (e.g., the galaxies in our RSA sample) show a global reddening toward their centres (see Paper I and references therein). These colour gradients are generally being explained in terms of metallicity variations. This view is supported by the existence of radial gradients of metallic absorption line strengths (Davies et al. 1993; Carollo et al. 1993). There is however significant scatter in the relation between colour gradients and line strength gradients (cf. Peletier 1989; Davies et al. 1993). Although the presence of dust in elliptical galaxies is now beyond dispute, the implications of dust extinction are generally discarded in the interpretation of colour gradients. However, recent model calculations of the transfer of stellar radiation within elliptical galaxies by Witt et al. (1992, hereafter WTC) have demonstrated that a diffuse distribution of dust throughout ellipticals can cause significant colour gradients even with modest dust optical depths, without significantly changing the observed global colours.

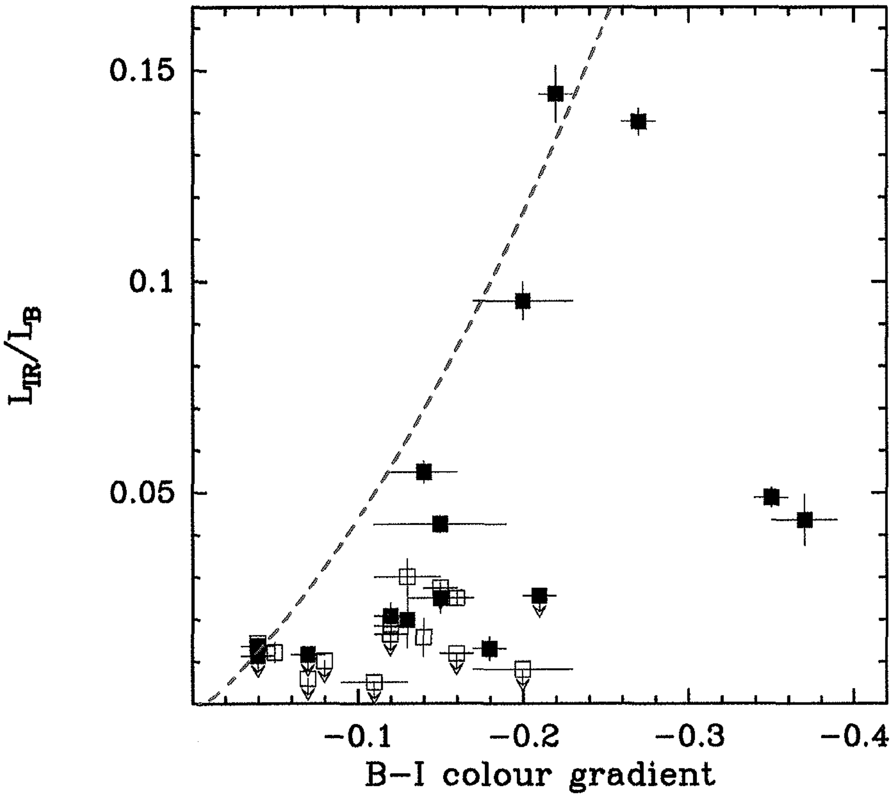

Figure 4: *The relation of L_{IR}/L_B with the radial B–I colour gradients (defined as Δ(B–I)/Δ(log r)) for elliptical galaxies in the "RSA sample". Filled squares represent galaxies detected by IRAS showing optical evidence for dust, and open squares represent galaxies detected by IRAS without optical evidence for dust. Arrows pointing downwards indicate upper limits to L_{IR}/L_B. The red dashed line represents the colour gradient expected from differential extinction by a diffuse distribution of dust (see text).*

We have exploited the elliptical galaxy model described by WTC to derive the predicted colour gradients – due to dust alone – appropriate to the far-infrared properties (and hence the dust content) of the elliptical galaxies in the RSA sample. The Monte Carlo simulations of WTC exploit a spherically symmetric distribution of stars, uniformly mixed with a diffuse, homogeneous distribution of dust. The predicted radial colour gradients are due to the effect of differential extinction (i.e. absorption *and* scattering) throughout the galaxy. The model of WTC reproduces a de Vaucouleurs surface brightness profile quite well, even for relatively high total optical depths of the dust distribution. Substantial amounts of dust can thus be present in (elliptical) galaxies while remaining undetected by conventional optical methods. Using the model computations of WTC, infrared to blue luminosity ratios L_{IR}/L_B and colour gradients [e.g., Δ(B–I)/Δ(log r)] have been derived as a function of the total dust optical depth τ_V of the diffuse dust component.

The result is plotted (as a dashed line) in Figure 4 in which the L_{IR}/L_B ratios of the galaxies in the RSA sample that are detected by IRAS are plotted versus their radial B–I colour gradients (taken from Paper I). Although Figure 4 shows that colour gradients in elliptical galaxies are generally larger than can be generated by a diffuse distribution of dust throughout the galaxies according to the model of WTC, it is obvious that the relation implied by the model of WTC fits the *minimum* of the distribution of colour gradients at a given L_{IR}/L_B quite well. Moreover, there are *no* galaxies in the RSA sample with a colour gradient significantly *smaller* than that indicated by the model of WTC. This result strongly suggests the presence of a diffuse distribution of dust in elliptical galaxies, causing a colour gradient due to differential extinction. This effect should be added to the effects of metallicity and/or age gradients of the stellar population in the interpretation of observed colour gradients of elliptical galaxies.

We have investigated whether published radial metallicity gradients (i.e., radial gradients of the Mg_2 index) of galaxies in the RSA sample are consistent with the positions of the galaxies in Figure 4. Although there are currently only a few galaxies in the RSA sample for which radial metallicity gradients have been published, it is quite reassuring that the galaxies in Figure 4 which lie nearest to the relation implied by the model of WTC

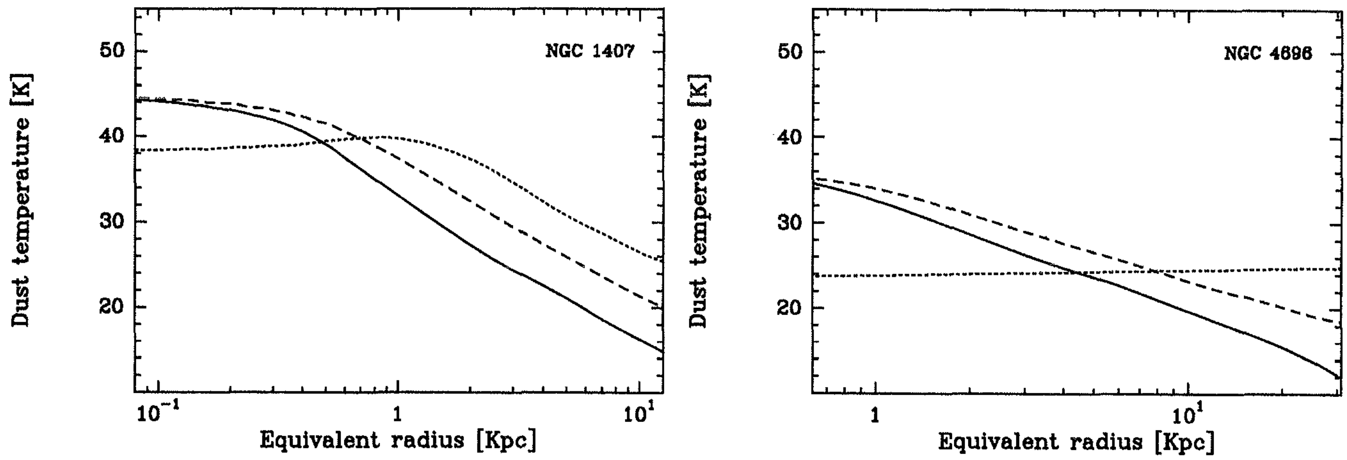

Figure 5: *Radial profiles of the local dust temperature due to optical heating (solid line), the average dust temperature inside a given radius due to optical heating (dashed line), and the average dust temperature due to heating by "hot" electrons in X-ray-emitting gas (dotted line) versus galactic radius in kpc for the elliptical galaxies NGC 1407 and NGC 4696. A mixture of graphite and "dirty silicate" (Jones & Merrill 1976) grains of radius 0.1 μm is assumed.*

have metallicity gradients which are among the smallest of the published values (e.g., NGC 3136, log $d(Mg_2)/dr = -0.035 \pm 0.011$; IC 3370, log $d(Mg_2)/dr = -0.026 \pm 0.010$ (Carollo et al. 1993)).

2.3 Radial dust temperature distribution

To check whether the assumption of the presence of a diffuse, uniformly distributed component of dust in elliptical galaxies is energetically consistent with the available IRAS data, we have investigated plausible heating mechanisms for the dust:

Heating by stellar photons: Using the extensive radial surface brightness profiles of the galaxies in our sample (Paper I), we have calculated radial profiles of the average intensity of optical radiation, from which the heating rate of a dust grain can be derived as a function of galactocentric radius (again assuming grain extinction efficiency factors from the literature; cf. Paper IV).

Heating by hot electrons in X-ray-emitting gas: Observations with the EINSTEIN X-ray satellite have shown that a substantial number of elliptical galaxies in our sample are embedded in a hot $T \sim 10^7$ K), X-ray-emitting gas (e.g., Fabbiano et al. 1992). The presence of this hot gas has important implications for the dust grains. Collisions of dust grains with protons and α-particles in the hot gas destroy the dust by sputtering (Draine & Salpeter 1979a) while collisions with "hot" electrons provide a potentially important heating mechanism for the dust grains (e.g., de Jong et al. 1990). The measured X-ray surface brightness profiles of elliptical galaxies containing hot gas are generally consistent with a "King-like" distribution (The "beta model", Cavaliere & Fusco-Femiano 1976) Using the prescriptions given by Canizares et al. (1987) which relate the central electron density to the total X-ray luminosity and the X-ray core radius, we compute radial electron density profiles (and, hence, dust heating rates, cf. Paper IV) according to the "beta model" for the galaxies in the RSA sample which are detected by EINSTEIN.

Heating by X-ray photons: From the X-ray luminosities of the hot gas and the core radii mentioned above we derive average X-ray intensities in the core region, and thus heating rates for the dust. For typical values for the X-ray luminosity ($\sim 10^{41}$ erg s^{-1}) and the core radius ($\sim$ 2 kpc) we obtain a heating rate by X-rays that is at least two orders of magnitude smaller than the heating rate by optical photons for all galaxies in our sample. The heating of dust by X-rays can thus safely be neglected in elliptical galaxies.

Dust temperatures are derived by equating the heating rate to the cooling rate of a dust grain by infrared emission,

$$L_d = 6.0\ 10^{-8}\ \kappa_{IR}\ m_d\ T_d^5\ \text{erg s}^{-1}$$

(de Jong et al. 1990) where κ_{IR} is the dust opacity in the infrared and m_d is the mass of a dust grain. Relevant physical parameters for dust grains are taken from Hildebrand (1983).

Examples of the distribution of local and average temperature as a function of equivalent radius (which is defined as $\sqrt{ab} = a\sqrt{1-\varepsilon}$, where a and b are the semi-major and semi-minor axes of the elliptical isophote of the galaxy, and ε its ellipticity) are shown in Figure 5 for two elliptical galaxies which are detected at both X-ray and far-infrared wavelengths. In general, the dust temperatures as derived from the IRAS data are found to be compatible with those calculated for a diffuse distribution of dust within the inner few kpc.

2.4 Properties of the diffusely distributed dust component

In this Section we investigate whether the dust optical depths of the postulated diffuse component of dust in elliptical galaxies as derived from the WTC model are consistent with the observed IRAS flux densities. To this end, we derive the mass and infrared luminosity of the diffusely distributed component of dust and compare the dust temperature implied through application of the model of WTC and the radial temperature profiles derived above with the temperature derived directly from the IRAS flux densities. Note that the dependence of the infrared *luminosity* (as derived from the 60 and 100 μm flux densities, cf. JISWG 1986) on the dust temperature is negligible compared to that of the dust *mass*. We limit ourselves to the elliptical galaxies in the RSA sample which are detected at $\geq 2\ \sigma$ at both the 60 and 100 μm wavelengths (cf. Knapp et al. 1989).

The derivation of the contribution of the different components of dust in these galaxies to the IRAS flux densities using our derived radial temperature distributions was done in the following way:

1. We first estimated the contribution of the optically visible dust component (if present) to the IRAS flux densities. In case of irregular (patchy) dust, this was done by extracting independent, rectangular box-shaped pieces of dust features, comparable in size with the seeing profile. Temperatures, and hence flux densities at 60 and 100 μm were calculated for these elements of dust features according to their average (projected) distance from the centre of the galaxy (cf. Fig. **2?)**. Apparently regular dust lanes were assumed to be circular disks of uniform density, reaching down to the centre of the galaxy.

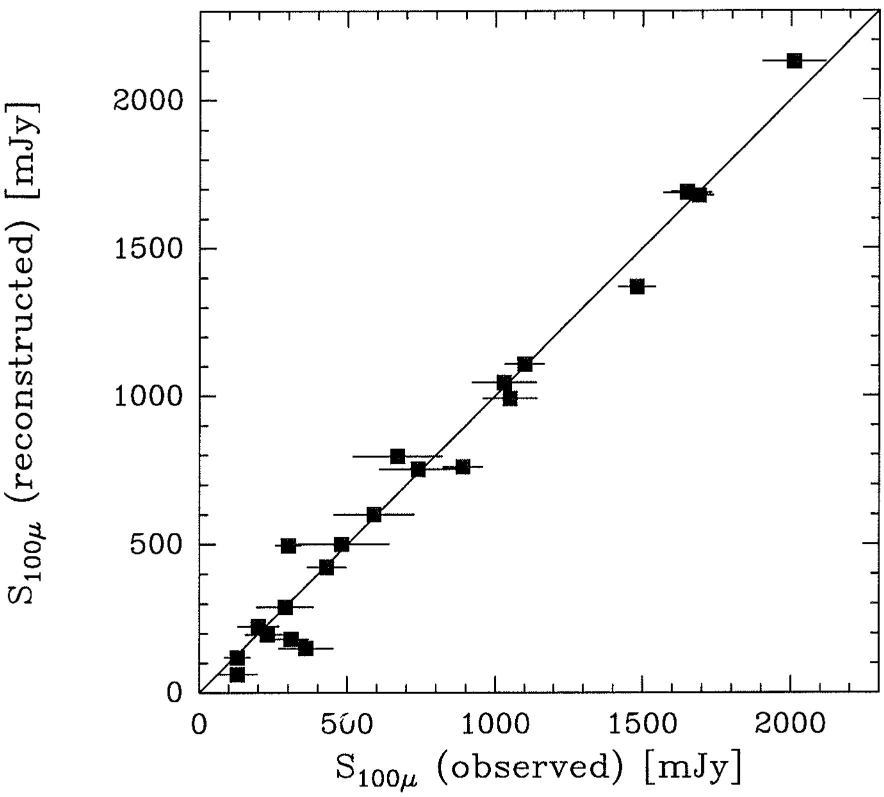

Figure 6: *The 100µm flux densities reconstructed from our calculations of the dust temperatures in elliptical galaxies (as described in the text) versus the observed 100 µm flux densities. The solid line connects loci with "reconstructed = observed".*

2. After subtracting the contribution of the optically visible component of dust (if present) to the IRAS flux densities, the resulting flux densities were assigned to the postulated diffuse dust component; for the ellipticals in which no optical evidence for the presence of dust was found, the *total* IRAS flux densities were assigned to the diffuse dust component. Dust masses and infrared luminosities of the diffusely distributed dust component were subsequently calculated.

3. From the L_{IR}/L_B ratio of the diffuse dust component, radial colour gradients and, by implication, total optical depths in the V band were derived according to the model of WTC (cf. Fig. 4). Dust mass column densities were subsequently computed for the diffuse dust component from the total optical depths τ_V (cf. Paper III).

4. Dividing the implied masses of the diffuse dust component by the dust column densities, outer equivalent radii of the postulated diffuse dust component were derived for each galaxy. Typical values for the outer radii were of the order of 2 kpc.

5. IRAS flux densities at 60 and 100 µm for the diffuse dust component were subsequently constructed from the masses of the diffuse dust component by integrating over spheres. Finally, the average temperatures of the diffusely distributed dust were calculated from these resulting IRAS flux densities.

A comparison of the observed and reconstructed IRAS flux densities (cf. Fig. 6) reveals that the *observed* IRAS flux densities can in *virtually all elliptical galaxies in the RSA sample* be reproduced *within the 1 σ uncertainties* by assuming two components of dust in elliptical galaxies: an optically visible component in the form of dust lanes and/or patches, and a newly postulated dust component which is diffusely distributed within the inner few kpc from the centre of the galaxies.

Heating of the dust by optical photons is found to be generally sufficient to account for the observed dust temperatures as derived from the IRAS flux densities, in contrast to conclusions drawn by previous studies of cool interstellar matter in elliptical galaxies (e.g., Brosch 1987).

We remind the reader that we have only considered dust which radiates at wavelengths covered by IRAS, i.e., with temperatures $\gtrsim$ 25 K. In reality, the postulated diffuse component of dust in elliptical galaxies may generally be expected to extend further out than a few kpc. Future observations with the Infrared Space Observatory (ISO) of the RSA sample of elliptical galaxies are foreseen and may reveal this cooler dust component in elliptical galaxies.

3. Origin of the Different Components of Dust

As to the origin of cool interstellar matter in elliptical galaxies, a consensus is developing that dust in these systems *always* has an external origin, i.e., accreted during a galaxy merger or interaction. For instance, spectroscopic studies of the velocity fields of gas and stars in elliptical galaxies with dust lanes show that the gas which is associated with the dust lanes is generally dynamically de-coupled from the stellar body, i.e., in disks rotating at random orientations with respect to the apparent major axis of the elliptical galaxy (e.g., Kormendy & Djorgovski 1989 and references therein). Since it is difficult (if not impossible) to envision an evolutionary scenario for a *primordial* galaxy in which gaseous and stellar components become dynamically decoupled, this strongly suggests an external origin for the dust and gas.

Other important evidence in favour of an external origin of the dust and gas is provided in several cases of X-ray-emitting elliptical and cD galaxies with suspected cooling flows. These galaxies often contain extended regions of ionized gas which have been argued to arise as condensations in thermally instable regions in the cooling flow (see, e.g., Fabian et al. 1991).

The lifetime of a dust grain against collisions with hot protons and α-particles ("sputtering") in a hot gas with $T_e \sim 10^7$ K is of the order of only 10^6–10^7 yr (Draine & Salpeter 1979a). Hence, the emission-line filaments in these galaxies are expected to be dust-free. This is illustrated by the finding that the intergalactic medium within the Coma cluster is depleted in dust by a factor of ~ 140 with respect to the Galactic dust-to-gas ratio (Dwek et al. 1990).

However, dust *has* been found to be quite commonly associated with filaments of ionized gas in these galaxies (Paper II and references therein).

Although the evidence mentioned above provides a strong case for an external origin of dust in elliptical galaxies, these arguments are all based on the *optically visible component* of dust, which, as we have seen, only accounts for $\lesssim$ 10 % of the total amount of dust in elliptical galaxies. So the question arises: What is the origin of the postulated diffusely distributed component of dust?

In Figure 7 we show the relationship of the dust mass (of the *diffusely distributed component*) derived from the IRAS data with the blue luminosities of the galaxies in the RSA sample. The dashed lines in Figure 7 connect the loci where all dust could have an internal origin, i.e., replenished by stellar mass loss at the

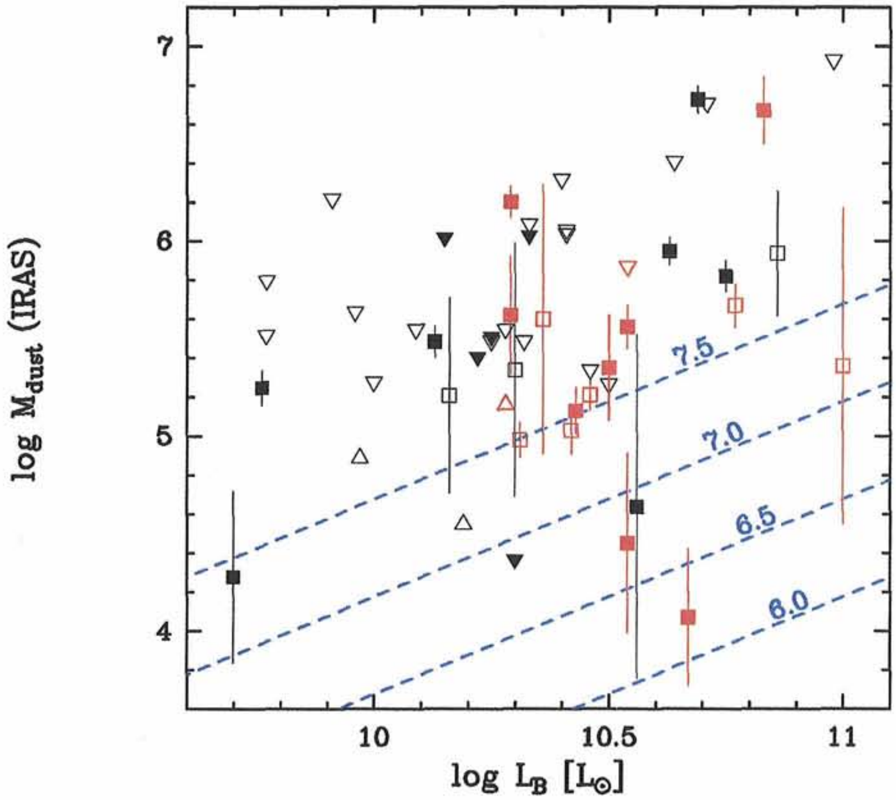

Figure 7: *The relationship of the mass of cool dust (as derived from the IRAS 60 and 100 μm flux densities) and the blue luminosity of elliptical galaxies in the RSA sample. Filled symbols represent galaxies with optically visible dust lanes and/or patches, whereas open symbols represent galaxies in which no sign of optical extinction has been found. Triangles pointing up- or downwards represent galaxies which are detected by IRAS at either 100 or 60 μm only, respectively. Red symbols represent galaxies with detected X-ray emission from hot gas. The position of M 87 is marked. The dashed lines connect loci where dust is replenished by stellar mass loss, and destroyed by sputtering at the given time scale (in dex), as discussed in the text.*

rate given by Faber & Gallagher (1976) and destroyed by (e.g.) sputtering, for different values of the destruction time scale τ_d. We adopted a gas-to-dust ratio of 100. The line with $\tau_d = 10^{7.5}$ yr should be regarded as a maximum destruction time scale in ellipticals known to contain hot, X-ray-emitting gas, since the electron density exceeds 5 10^{-3} cm^{-3} in the inner ~ 10 kpc of all galaxies studied in sufficient detail (e.g., Canizares et al. 1987). As Figure 7 shows, most elliptical galaxies in the RSA sample in which X-ray emission has been detected contain more dust than can be accounted for by stellar mass loss alone. This favours the view that the dust in elliptical galaxies generally has an external origin.

As can be seen in Figure 7, we confirm the absence of a correlation between the mass of dust and the blue luminosity of elliptical galaxies (cf. Forbes 1991). On first sight, this indicates that there is no causal relationship between the dust content and the present-day population of stars within elliptical galaxies, in contrast with the situation in spiral galaxies (e.g., Young et al. 1989), which would again suggest that dust in elliptical galaxies has an external origin. However, this conclusion is somewhat premature since the typical dust destruction time scale in elliptical galaxies is expected to be significantly different among individual objects.

Among the various destruction mechanisms for dust grains in the interstellar medium, sputtering in hot, X-ray-emitting gas is by far the most effective one (Draine & Salpeter 1979a, b; Paper III). The fate of dust within elliptical galaxies is therefore mainly determined by the presence of hot, X-ray-emitting coronal gas and its physical properties (i.e., radial temperature and density profiles). However, the present status of knowledge of these important matters is quite limited, since e.g., most of the galaxies in the RSA sample have not been observed by the EINSTEIN satellite. Future analysis of the ROSAT all-sky survey data and, especially, the gain in sensitivity and spectral resolution of the ASCA satellite should be very valuable in determining typical destruction time scales for dust in elliptical galaxies.

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For further information please contact:
P. Goudfrooij, ESO-Garching,
e-mail: pgoudfro@eso.org