THE MID-INFRARED EMISSION FROM EARLY-TYPE GALAXIES

S.C. Madden, L. Vigroux, & M. Sauvage
CEA Saclay, Service d'Astrophysique

ABSTRACT

We have conducted a survey of E and S0 galaxies using ISOCAM's imaging broad band filters covering 4.5 to 18 μm, to probe the dust content of early-type galaxies. While emission from the evolved stellar population can be dominant in the mid-infrared, dust in the form of either small hot grains and/or UIBs can also be shown to be present in some cases. Several galaxies in our sample are dominated in the mid-infrared by non-thermal nuclear activity. Due to the high sensitivity and high resolution of ISO, we can begin to comprehend the origin and distribution of the mid-infrared emission from early-type galaxies.

Key words: mid-infrared astronomy; elliptical galaxies; dust.

1. INTRODUCTION

Early-type galaxies contain a diversity of interstellar media, consisting largely of hot (10^6 to 10^7 K) gas (Sarazin 1997; Brown & Bregman 1998) and to a lesser degree, cold gas in the form of CO and HI (see Henkel & Wiklind 1997 and Knapp 1999 for reviews). Since the stellar distribution of early-type galaxies is often dominated by the evolved red giant population, the presence of dust, apriori, should not be unexpected. Mass-losing red giants expel dust through stellar winds into circumstellar envelopes and subsequently into the ISM. Several analyses of IRAS observations of early-type galaxies confirm the presence of cold (on the order of 30 K) dust, with 60 and 100 μm detections as high as 50 % of E and S0 galaxies (Knapp et al. 1989, 1992; Jura et al. 1987), or much lower, when applying more stringent criteria and excluding galaxies harboring AGNs and peculiar systems (Bregman et al. 1998). While dust masses from IRAS observations are of the order of 10^5 to 10^6 $M_\odot$, colder dust emitting at submillimeter wavelengths has been detected with masses up to an order of magnitude greater (Fich and Hodge 1993). Dust patches and lanes observed from optical obscuration provide further evidence for cold dust (eg. Ebneter and Balick 1985; Goodfrooij & de Jong 1995; van Dokkum & Franx 1995).

The question of the presence of hot dust grains (of order of 100's K) was brought to the fore with 12 μm IRAS observations (Knapp et al. 1992; Sauvage & Thuan 1994). The distribution and origin of dust in early-type galaxies has been difficult to ascertain with IRAS data, due to the lack of resolution and the fact that some of the 12 μm emission may arise from evolved stars at 4000 to 6000 K.

Possible origins of dust include: (1) merging events resulting in galaxies donating large amounts of dust and gas, often seen in dust patches and dust lanes; (2) cooling flow condensations (eg. Fabian et al. 1991), often accounting for dust centrally concentrated; and (3) mass loss from late-type stars (Knapp et al. 1992), which would result in dust more widely distributed throughout the galaxy. Although the presence of dust in early-type galaxies may not be surprising, the quantity of dust seems high relative to expected life-times in the hot ISM (Draine & Salpeter 1979; Tsai & Matthews 1996). Knowledge of the properties of dust in local elliptical galaxies is an essential step in understanding the cosmological star formation rate since the lack of knowledge of dust remains one of the outstanding uncertainties in the models (Franceschini et al. 1998).

Given the imaging capabilities and the unrivaled sensitivity and spatial resolution of ISOCAM, we have conducted a survey of the mid-infrared emission of a sample of early-type galaxies using 3 broad-band filters centered at 4.5, 6.7, and 15.0 μm. We can interpret the contributions from the MIR broad-band filters in light of what we have deduced from other ISOCAM observations of spiral galaxies (see reviews by Vigroux et al. 1998, and, Helou et al. and Vigroux et al. in these proceeding). Noteworthy characteristics of the MIR filters are:

- 4.0 to 5.0 μm (LW1): The Rayleigh-Jeans tail emission of the evolved stellar population.
- 5.0 to 8.5 μm (LW2): The UIB carriers of 6.3, 7.7, 8.6 μm, if present and excited, can dominate the emission in this filter. These bands are proposed to be of carbonaceous origin, stochastocally heated to high temperatures (for example, PAHs: Léger & Puget 1984; Allamandola et al. 1989; coal grains: Papoular et al. 1991).

- 12.0 to 18.0 μm (LW3): Continuum emission in the LW3 15 μm band is seen in HII regions and IR luminous galaxies, thought to originate in very small grains (VSGs) which are transiently heated to high temperatures, i.e. 100 to 200 K (Désert et al. 1990). The UIBs at 11.3 and 12.8 μm can also be present in the LW3 15 μm filter. Non-thermal emission associated with AGNs and central radio sources can dominate the emission of the LW3 band.

If no dust were present, the 6.7 and 15 μm bands would contribute only to the diminishing emission of the old stellar population.

2. DISCUSSION

One example of ISOCAM images is shown for NGC 5266 in Figure 1. The 4.5 μm stellar emission traces the optical extent of the galaxy, while the 15 μm emission is confined to an obvious dust lane. This dust lane is also seen in the optical and is probably a remnant of a merging event, as is thought to be the case for the gas (Morganti et al. 1997). The 6.7 μm band contains emission from both components.

The various spectral energy distributions can be discussed with a color-color diagram constructed with the 3 ISOCAM bands (Figure 2). Regions dominated by various MIR emission origins are delineated in the diagram by dashed lines. Galaxies falling in the left hand side of the diagram, such as NGC 4486, Abell 426, NGC 1052 and NGC 3928, appear to be dominated in the overall emission from the galaxy, by non-thermal emission processes from AGNs and radio sources. Those dominated by their evolved stellar emission such as, for example, NGC 2300, and NGC 1399, are located near the line marked in the upper right quadrant, which indicates 4000 to 5000 K. To verify this, the CVF spectrum of NGC 1399 is shown in Figure 3, with a 4700 K blackbody continuum fit. The spectrum is relatively featureless and ostensibly has some excess dust emission toward the long wavelength part of the spectrum and a very speculative broad feature around 10 μm that may be amorphous silicate. In any case, the dominant MIR emission is stellar in this case. Progressively dustier galaxies move in the color-color diagram (Figure 2), from the stellar continuum line toward the left and below. In the bottom right quadrant lie galaxies exhibiting excess in the 6.7 μm band, above the 4.5 and 15 μm emission levels - clear evidence for the presence of UIB features in the 6.7 μm band. Galaxies located in the upper right quadrant may also contain smaller amounts of UIBs in addition to VSGs, but NGC 5866, NGC 5266 and NGC 5363 unequivocally contain UIBs. The presence of UIBs in early-type galaxy environments may help constrain the nature and excitation of UIBs, the PAHs hypothesis of which requires UV photons to excite. (Sellgren 1984). We can determine whether there is sufficient UV energy to excite the UIBs in these sources, or if other sources, such as optical photons, are necessary (Sellgren et al. 1990; Uchida et al. 1998).

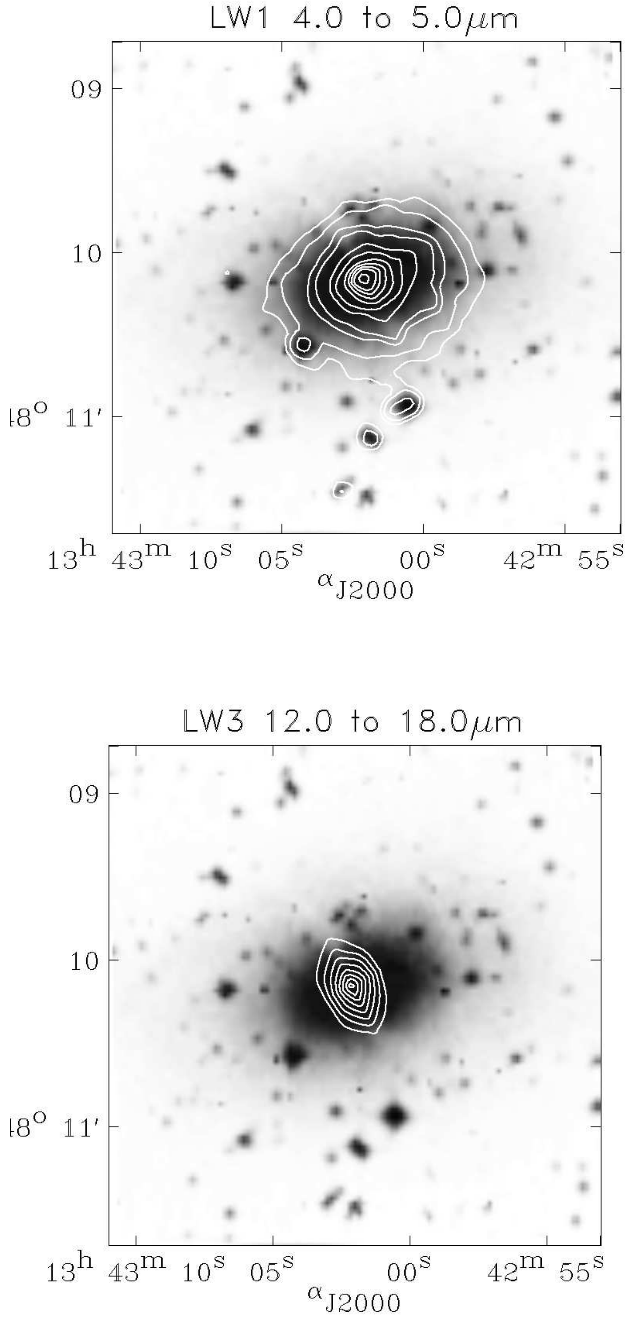

Figure 1. ISOCAM MIR emission distribution (white contours) from NGC 5266 superimposed on the optical. (top): LW1 covering 4.0 to 5.0 μm; (bottom): LW3 covering 12.0 to 18.0 μm. A dust lane is apparent in the 15 μm band while the 4.5 μm band is dominated by the stellar continuum.

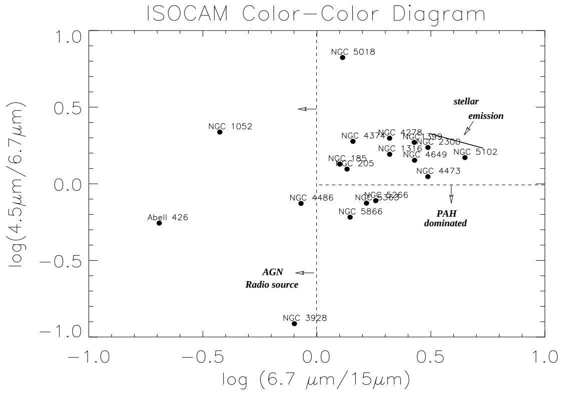

Figure 2. ISOCAM color-color diagram for early-type galaxies. The dashed lines delineate regions of characteristic dominant emission processes: left: non-thermal emission from AGNs and radio sources dominate the emission; bottom right: UIBs dominate in the 6.7 μm band; top right: a progression of mostly stellar emission (indicated by line) to dustier galaxies (to the left and below).

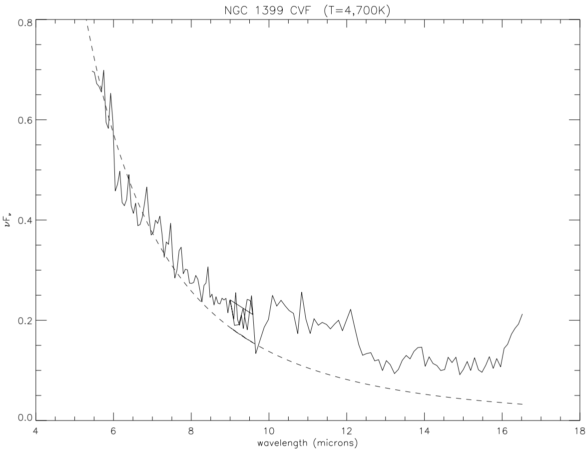

Figure 3. CVF spectrum of NGC 1399. The dashed line is a black body fit to stellar emission of 4700 K). The spectrum is relatively featureless, and shows some excess dust emission toward long wavelengths. There is some speculation that a broad 10 μm emission feature is present, in the form of amorphous silicate.

We are fitting model spectral energy distribution profiles for our sample where the UV to NIR data exist with consistent apertures. One example of such a model derived from the PEGASE population synthesis model (Fioc & Rocca-Volmerange 1997) is shown in Figure 4 for NGC 4473 with our 3 MIR ISOCAM data points along with the UBVRIJHK. The ISOCAM points fill in critical wavelength regimes in the fitting of the SED. The data are fit with a synthetic spectrum of a 13 Gyr old instantaneous star formation burst. While most of the MIR emission, arising from the central 36 arcsec, is consistent with an origin dominated by a population of evolved AGB stars, there is some residual emission in the MIR.

The behavior of the MIR emission in the early-type galaxies is compared to other types of galaxies in the ISOCAM color- IRAS color diagram in Figure 5. Galaxies from a variety of other CEA Saclay guaranteed time surveys are indicated by the filled circles, while early-type galaxies are the open triangles. Spiral and barred galaxies, for the most part, show relatively little variation in the ratio of the 6.7 μm/15 μm bands for f60/f100 ranging from 0.2 to 0.5 (Roussel et al., these proceedings). As the radiation field increases beyond this, the subsequent increase of the temperature of the small grains, in addition to the possible destruction of the UIBs in the more intense radiation fields, results in the decrease of the 6.7 μm/15 μm ratio. This turnover begins the regime typifying AGNs, starbursts and blue compact dwarf galaxies (Charmandaris et al. and Laurent et al., these proceedings). Most of the early-type galaxies do not contain as much dust as diskier late-type galaxies and are, therefore, located above these galaxies in the diagram, while some galaxies which have evidence for recent star formation, such as, NGC 185 and NGC 205 (the 2 left most points in the diagram), resemble the disk galaxies. Those which lie well above this horizontal branch in the ISOCAM color - IRAS color diagram are progressively more and more dust-free. AGN-dominated early-type galaxies are evident as they occupy the space beyond the turn-over, as do other well-known galaxies containing AGNs (Note: As the IRAS FIR values for some of the early-type galaxies are upper limits or not very firm values, some of these galaxies can shift along the f60/f100 axis in this diagram. Nevertheless, noteworthy characteristics of the early-type galaxies in this diagram are still apparent.)

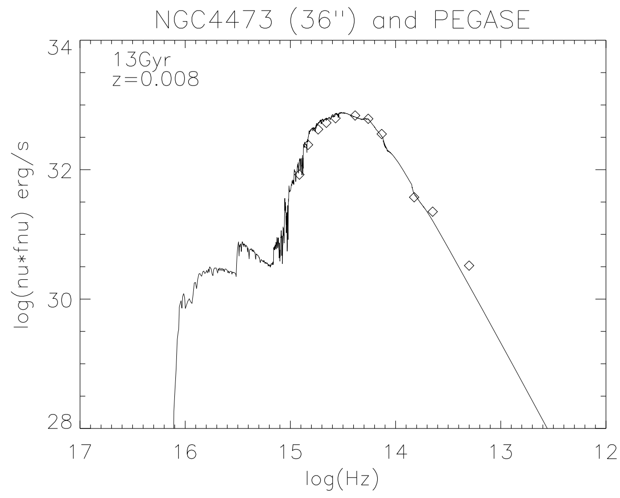

Figure 4. Spectral Energy Distribution for NGC 4473 with observed UBVRIJHK points and ISOCAM 4.5, 6.75, 15 μm observations indicated by the open boxes and the synthetic spectrum for a 13 Gy instantaneous burst of star formation stellar population modelled by PEGASE (Fioc & Rocca-Volmerange 1997). Errors for the observed data are contained within the boxes.

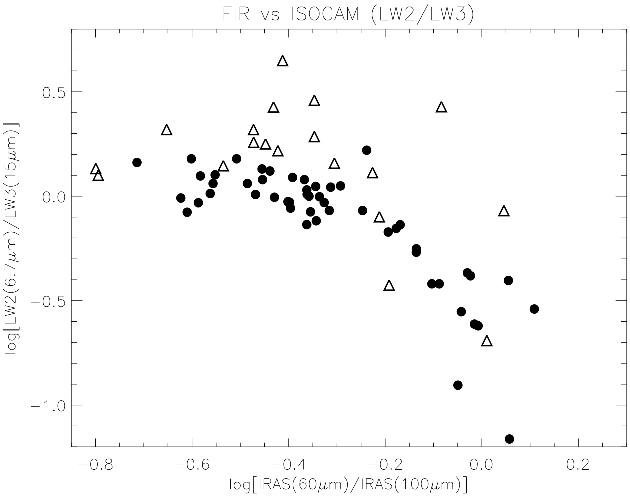

Figure 5. ISOCAM LW2(6.7 μm)/LW3(15 μm) and FIR emission for early-type galaxies (open triangles) compared with that for a variety of other types of galaxies from the CEA guaranteed time programs (filled circles).

3. CONCLUSIONS

From our survey of early-type galaxies with ISOCAM, we find a variety of characteristics in the spectral energy of the 3 MIR broad bands. Using diagnostic color-color diagrams, we can delineate the different MIR emission origins from mostly stellar emission to non-thermal emission from AGNs/radio sources, and galaxies with a range of dust contributions. From SEDs, we determine that about 1/2 of the sample have some measurable MIR excess originating from the heating of small grains, and UIBs, which have been widely attributed to aromatic bonds in molecules or large particles. Several galaxies show no observable evidence for infrared dust excess, with MIR emission arising solely from a population of cool evolved stars. This evidence in early-type galaxies for the presence of the UIBs will provide further constraints on the nature and excitation of the UIBs. The ISOCAM 6.7 μm/15 μm ratio, in conjunction with FIR observations, may also be used as a tool to differentiate dusty galaxies from from those which are dust-free. These conclusions will be further refined through modelling of the spatial distribution of the MIR emission.

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