ISO OBSERVATIONS OF DUST IN ELLIPTICAL GALAXIES

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ABSTRACT

We have mapped 15 elliptical galaxies with ISO using ISOCAM and ISOPHOT at wavelengths from 4.5 to 200 μm. In this paper we will highlight results from CAM (4.5, 6.75 and 15 μm) and PHT-04 (21 μm). These observations should enable us to discern if the dust in the centers of these galaxies is distributed in the same way as the stars or is in discrete clumps at the nucleus. This is crucial to understanding the origin of the 12 and 25 μm IRAS emission and deciding if it is associated with stellar or circumstellar dust as opposed to truly interstellar dust.

Key words: Elliptical Galaxies, Dust

1. INTRODUCTION

Twenty years ago, elliptical galaxies were considered to be devoid of interstellar matter and to consist of an old coeval stellar population established at the time of galaxy formation. As observational sensitivities have improved, it has been found that typical elliptical galaxies contain small amounts of interstellar matter in all its familiar phases, and to have varied and complex star formation histories. IRAS detected weak infrared emission from a significant fraction of nearby elliptical galaxies, allowing the typical global cold interstellar dust (and by inference gas) content to be characterized in these galaxies, its relationship with star formation to be investigated, and the current rate of gas injection via mass loss from evolving stars to be measured (Jura et al. 1987; Knapp et al. 1989). The flux densities emitted by these galaxies are generally very weak, only a few times the r.m.s. noise of the IRAS observations, and are almost always of low statistical significance (see Bregman et al. 1998): also, the IRAS data provide little information on the spatial distribution of the emitting material. The ISO observations described herein were made to measure and map the broad-band emission of a sample of elliptical galaxies from short (4.5μm) to long (200μm) wavelengths to allow the contributions of evolved stars, hot interstellar dust, active nuclei and cold, extended dust to be measured. The much improved sensitivity and mapping capability of ISO are of particular importance to this work.

These observations were obtained under the ISO Guest Investigator Programme. Our goal was to observe as many elliptical galaxies as possible with a wide range of intrinsic properties (blue/red colors; low/high luminosity; detected/not detected by IRAS; with/without a bright AGN; in regions of low and high galaxy spatial density; with relatively strong and weak diffuse X-ray emission; etc.). The strategy was to provide complete wavelength coverage of several galaxies of interest and to provide complementary wavelength coverage for others which were being observed by CAM or PHOT as part of the ISO Core Programme, with the eventual goal of providing maps with complete wavelength coverage for a significant number of elliptical galaxies.

2. OBSERVATIONS AND DATA REDUCTION

2.1. ISOPHOT observations

The ISOPHOT observations were made in two modes. The broadband emission at 60, 100, 135 and 200 μm was measured by the long wavelength arrays to search for cold extended dust (e.g., Haas et al. 1998). These data are not yet in a state of analysis that they can be discussed further here; almost all observed galaxies were detected, including at the longest wavelengths. Observations were also made at 20 μm using the multiaperture photometer (Klaas et al. 1994). Six apertures, from 23″ to the largest, 180″, were used.

Fifteen galaxies were successfully observed: NGC 807, NGC 855, NGC 1052, NGC 1172, IC 2006, NGC 3998, NGC 4261, NGC 4374, NGC 4486 (M87), NGC 4552, NGC 5173, NGC 5363, NGC 5666, IC 1459 and NGC 7768. The data were reduced using the ISOPHOT Interactive Analysis tool PIA (Gabriel et al. 1998). The processing included: subtraction of dark current, deglitching, and correction of the

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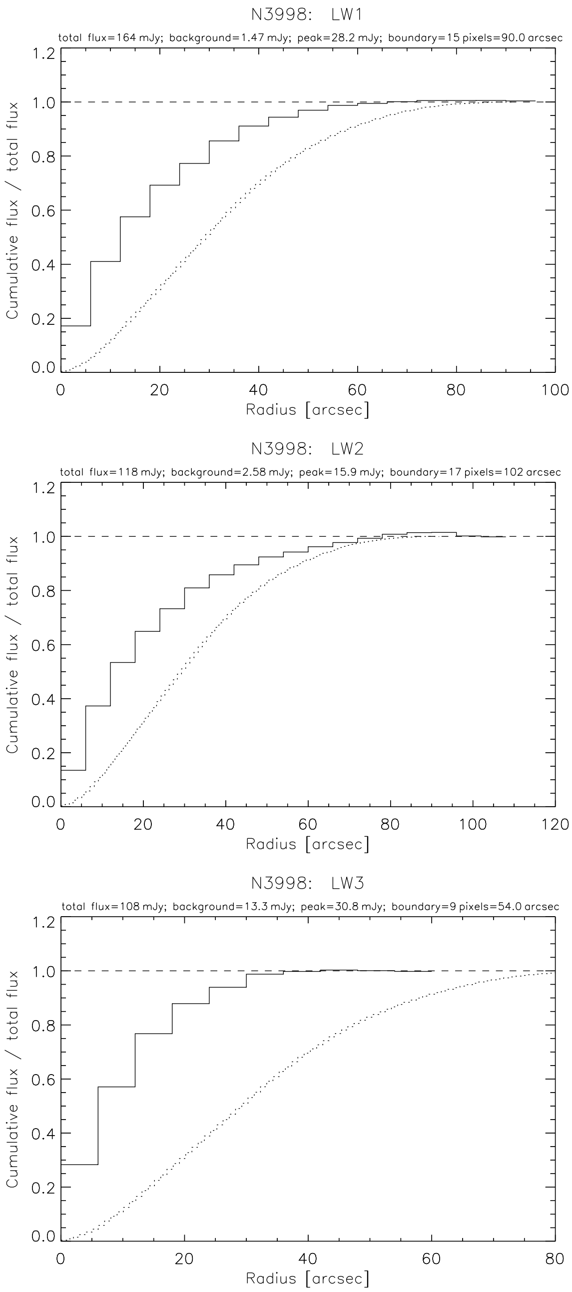

Figure 1. Aperture photometry results for NGC 3998 from ISOCAM. The total flux in each panel is shown at the top of each plot and the horizontal dashed line marks the point at which the cumulative flux reaches this level. The solid line gives the cumulative flux within the specified radius for the ISOCAM filter specified in the title for each panel. The dotted line shows the cumulative flux seen at optical wavelengths.

largest apertures for vignetting. The median differential surface brightness counts were calculated for each aperture.

The photometer is internally calibrated. As a check on the calibration and pointing, we observed three isolated stars with no (known) circumstellar dust: ι Gru, γ Tuc and HR 13. Form these calibration observations we conclude that the instrumental PSF is as measured before launch, and that the flux calibration and pointing of the instrument are good. However, we found evidence of hysteresis, rendering the observations through the smallest aperture relatively low and making the source appear extended on this scale - this is probably due to the weakness of the sources and the brightness of the background (mostly zodiacal light) at this wavelength. The data reduction is described in detail by Knapp et al. (1998).

2.2. ISOCAM observations

The ISOCAM observations were made with three broad-band filters: LW1 (4.5μm central wavelength), LW2 (6.75 μm) and LW3 (15μm). Small galaxies (D_{25} < 2 arcminutes) were observed at a scale of

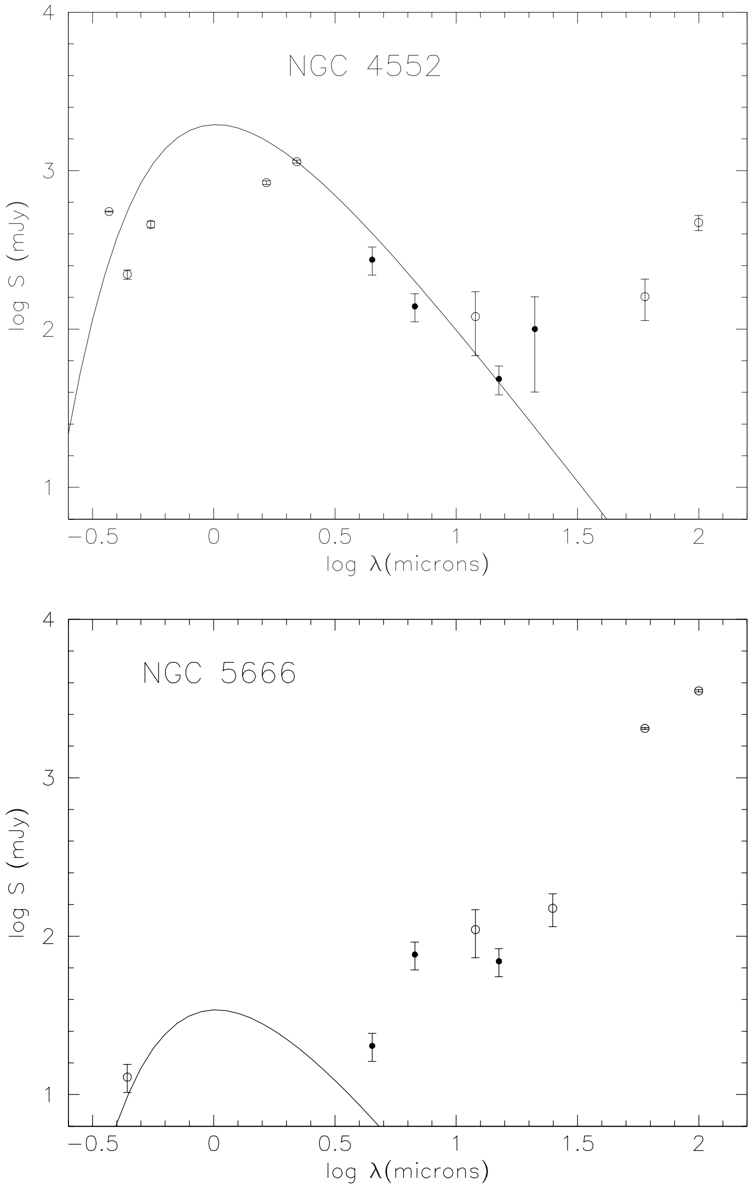

Figure 2. The spectral energy distribution for two quite different cases. Open circles: photometry from NED and Knapp et al. (1989). Filled circles: total fluxes measured by ISOCAM. The solid line shows a 5000 K blackbody spectrum normalized to the 2.2 μm flux density. The top panel shows NGC 4552 which has only a small amount of (cold) interstellar dust. The bottom panel shows the spectral energy distribution for NGC 5666 which is dominated by dust at all infrared wavelengths.

3″ per pixel and a total unvignetted field of about 1.5 arcminutes; larger galaxies at 6″ per pixel and the largest, NGC 4472 and IC 1459, by scans across the galaxy. Although observations were programmed for all three filters, not all of the observations were made. The observed galaxies are: NGC 807 (LW2 only): NGC 855, IC 2006 (LW1 only), NGC 2293 (LW1 only), NGC 2328 (LW3 only), NGC 3998, NGC 4472 (LW1 only), NGC 4552, NGC 5061 (LW2 only), NGC 5666 and IC 1459.

The data were reduced using the ISOCAM Interactive Analysis (CIA) package running under IDL (Ott et al. 1998). Standard instrumental flat fields obtained by the ISOCAM team were used. The sky background was calculated assuming that the corner pixels of the images are free of emission from the galaxy. The preliminary analysis discussed in this paper does not take account of the instrumental point spread function, and the emission centroid is presently determined only as the brightest pixel. The total flux densities were found by performing aperture photometry on the data.

3. RESULTS

Our results are still preliminary. However we have detected at least 10 of the 15 galaxies observed, most of which show evidence of *extended warm/hot dust.* Our ISOCAM data are in good shape, with relatively small uncertainties in the final fluxes and are consistent with prior observations. *Our ISOPHOT-04 data are not yet well understood.* We will refine these observations and continue to work on other relevant ISO data we obtained in this program. We will also continue our program of ground-based submillimeter observations to compare the cold dust content of these galaxies to the warmer dust seen with ISO.

The 20 μm ISOPHOT observations detected NGC 807, NGC 855, NGC 1052, NGC 3998, NGC 4486, NGC 5666, and IC 1459. The emission for NGC 1052 and NGC 3998 appears to be centrally concentrated and anomalously strong, and likely much of it arises from the active nucleus. The emission from NGC 4486 is extended (almost certainly more than the largest aperture, 180″) and shows no central concentration, i.e. the AGN is not detected. The extension, and the total flux density (2.4 $\pm$ 0.8 Jy) shows that this emission arises from the stellar population - it is probably mostly emitted by the circumstellar dust shells produced by mass loss.

Preliminary examination of the ISOCAM data shows that the total flux densities are in reasonable agreement with those expected from the IRAS data. The infrared colors of the galaxies show a wide range, due to the different strengths of different components. The emission from NGC 3998 becomes more concentrated with increasing wavelength (Figure 1) and is a superposition of two components: a hotter component which is distributed like the stars and a cooler unresolved component which may be due to hot dust associated with the active nucleus. NGC 2293 is weakly detected, if at all, but there are several point sources in the field (probably due to the low latitude of this galaxy) which may be confusing the emission. In Figure 2 we show the spectral energy distributions of two of the galaxies we observed, combining IRAS, optical and ISOCAM data. The emission from NGC 4552 is typical of that from a galaxy with little interstellar dust (Figure 2, top panel): the emission observed by ISOCAM arises almost entirely from the starlight, and there is little or no excess emission which can be attributed to interstellar dust. This galaxy shows weak emission at the longer IRAS wavelengths suggesting the possible presence of small amounts of interstellar dust; we should be able to check this with our observations with ISOPHOT. The spectrum of the dusty galaxy NGC 5666 is shown in Figure 2 (bottom). The emission at all wavelengths longer than about 2 μm is dominated by interstellar dust.

As might be expected, given the wide range of galaxy properties our sample contains, we have found a wide range of infrared properties in these galaxies. We expect that, over the next year, we will be able to make significant progress in sorting out the meaning of all of these.

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