Astron. Astrophys. 315, L129–L132 (1996)

ASTRONOMY
AND
ASTROPHYSICS

Bimodal dust emission in three classical Seyfert galaxies: NGC 3227, NGC 4051 and NGC 4151*

J.M. Rodríguez Espinosa[1], A.M. Pérez García[1], D. Lemke[2], and K. Meisenheimer[2]

[1] Instituto de Astrofísica de Canarias, E-38200 La Laguna (Tenerife), Spain
[2] Max Planck Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany

Received 24 July 1996 / Accepted 23 August 1996

Abstract. Far Infrared observations of the Seyfert galaxies NGC 3227, NGC 4051 and NGC 4151 are presented. These are the first data from a complete sample of Seyfert galaxies that is being observed by ISO as part of the ISOPHOT guaranteed time. The new ISO data, in combination with the IRAS data, show that the mid to far IR emission in all three objects can be ascribed to two well defined regimes, namely a warm dust emitting region which we claim is heated by the emission from the respective active nuclei and a second colder emitting region which we attribute to dust heated in star forming regions.

Key words: galaxies: individual (NGC 3227, NGC 4051, NGC 4151) – galaxies: spectral energy distribution – galaxies: Seyfert – galaxies: photometry

1. Introduction

It is well known since the time of IRAS that Seyfert galaxies are extremely bright far IR sources (Miley *et al.* 1985; Rodríguez Espinosa *et al.* 1987). However, IRAS with only four wavelength bands could not properly define the spectral energy distribution of these objects, whereas, the large number of filters available with ISO are ideal to study the entire IR range with enough definition to characterize physical parameters like the size, temperature and opacity of the emitting regions, or to distinguish between different emission mechanisms. In particular, whether the far IR emission from AGN is of thermal or non-thermal origin is still controversial (see e.g. the review by Telesco 1988, and Bregman 1990) in spite of recent advances made in the field (Giuricin *et al.* 1995; Maiolino *et al.* 1995).

In this paper we present ISO observations of three well studied, classical Seyfert galaxies, all of which happen to be of the same Hubble type SAB. They are part of an ongoing programme of observations in the optical, near IR and mid and far IR with ISO of the entire CfA sample of 48 Seyfert galaxies. The latter observations are currently being performed with the ISOPHOT instrument (Lemke *et al.* 1996), spanning the IR range from 16 to 240 μm. The objects selected, NGC 3227, NGC 4051, and NGC 4151 are the first which we have analysed partly as a check on the validity of the data reduction process. The three objects have large intrinsic surface brightnesses, which has facilitated the data reduction tasks. A further advantage of these objects is the existence of a wealth of previous IR data, including IRAS, with which our results can readily be compared. NGC 3227 is a Seyfert 1.5 galaxy undergoing an interaction with its nearby companion NGC 3226. Both NGC 4051 and NGC 4151 are Seyfert type 1, although the latter has undergone periods of intermediate type activity (Penston & Pérez 1984).

Table 1. Log of ISO observations

Object	Type	Date	Start(UT)	End (UT)
NGC 3227	Sy1.5	25 Apr 1996	04:42:24	05:16:19
NGC 4051	Sy1	9 May 1996	08:33:23	09:06:19
NGC 4151	Sy1	9 May 1996	09:47:46	10:07:03

2. The Observations

The observations of the objects discussed in this paper were done with the P1, P2, C100 and C200 detectors on the dates given in Table 1. The observation with the P1 and P2 detectors were performed in chopping mode through an aperture 180" in size. The C100 (3×3 pixels array, 43.5" per pixel) and C200 (2×2 pixels array, 89.4" per pixel) observations were done in staring mode. Background measurements were made with the array detectors in a nearby region prior to the object observations to avoid memory effects which are known to be present in the far IR detectors. An integration time of 32 seconds, enough to correct for detector drifts in most cases, was employed in all measurements.

The data were reduced using the PHT Interactive Analysis (PIA) tool, kindly provided to us by the MPIA and ESA. The data were deglitched, in order to eliminate the effects of cosmic

Send offprint requests to: J.M. Rodríguez Espinosa

* Based on observations with ISO, an ESA project with instruments funded by ESA Member States (especially the PI countries: France, Germany, the Netherlands and the United Kingdom) and with the participation of ISAS and NASA.

Table 2. ISO Data (Fluxes are in Janskys)

Filter	λ_c (μm)	FWHM (μm)	NGC 3227	NGC 4051	NGC 4151
16μm	15.14	2.86	2.44	2.32	7.88
25μm	23.81	9.18	2.01	2.41	6.17
60μm	60.8	23.9	10.92	7.8	5.00
90μm	95.1	51.4			6.40
120μm	119.0	47.3	18.06	28.0	5.08
135μm	161.0	82.5	18.59	29.0	4.64
180μm	185.5	71.7	16.03	23.5	3.58
200μm	204.6	67.3	12.61	19.93	2.54

particle hits on the detectors. The integration ramps were linearized through a PIA built-in algorithm that takes into account the dynamic range of the detectors and the flux level of the observed sources, and, finally, another built-in algorithm was applied to the data in order to check and correct for detector drifts. This process was repeated for all the data files including the background measurement files. For the C100 and C200 frames, once the above mentioned process was applied to both the object and background files, the latter were subtracted from the object files. Note that the dark current is also subtracted when subtracting the background, since both the object and background frames were acquired with the same integration time.

The photometric calibration was achieved using an updated responsivity value kindly provided to us by J. Acosta (a member of the ISOPHOT team at Vilspa). We estimate the uncertainty in our calibration to be of the order of 30%, much larger than the photon noise of each of the individual measurements which are of only a few percent. We have therefore adopted 30% as the error for all the calibrated data. As the ISO mission progresses and the detectors behaviour is better characterized we are confident that the calibration errors will be drastically reduced.

3. Results

The PHT data for the three objects considered in this study are shown in Table 2 and in Figure 1 which also includes IRAS data for these objects. It can be seen that the agreement between both sets of data is quite acceptable.

Two features are noteworthy in Figure 1, namely the 20 μm emission peak and the excellent definition of the Rayleigh-Jeans tail provided by the long wavelength ISOPHOT bands. It is also interesting to note the similarity of the spectral energy distributions (SEDs) of the three active galaxies studied in this paper as well as that of NGC 1068, obtained by Telesco *et al.* (1984) prior to ISO.

In an attempt to model these mid to far IR SEDs we have fitted two emissivity weighted black body functions, one representing warm dust and a second one representing lower temperature dust. We have used a dust emissivity function, adopted from Fich and Hodge (1991), of the form $Q_{em} = Q_0 a(250/\lambda)^{\beta}$, where β is normally varied between 1 and 2 depending on the grain composition (Draine and Lee 1984; Draine & Anderson 1985), and λ is in microns. We have taken $\beta = 1.5$ throughout this paper. Q_0 is an arbitrary scaling parameter, and a is the radius of the dust grains. Both the ISO and IRAS data have been included in the fit. The best fitting curves are shown in Figure 1, the solid line being the sum of the two black bodies, each one of which is in turn shown with dashed lines.

Table 3. Dust temperatures.

Object	Warm dust (K)	Cold dust (K)
NGC 3227	161	27
NGC 4051	177	24
NGC 4151	170	36

We do not seem to require any additional component, other than the two black body functions, to adequately fit the mid to far IR data, nor have we attempted to model a broader spectral range that would certainly require additional components. Table 3 and Figure 1 show that in all three objects there is a mid IR component with dust temperatures of about 170 K and a far IR component with much cooler dust at around 30 K.

4. Discussion

The first interesting result shown by these ISO data is the clear cut separation between two distinct emission regions in the three Seyfert galaxies studied. The mid to far IR SEDs for these Seyfert galaxies is well represented by a combination of a warm dust component peaking around 20μm, plus a cooler dust component peaking around 100μm. We discuss each one of them in what follows.

4.1. The cold dust component

A cold emitting component is clearly seen in Figure 1, which is adequately fitted by an emissivity weighted black body function. The corresponding black body temperatures for NGC 3227, NGC 4051, NGC 4151 are given in Table 3.

The most likely explanation for this cold component is emission by dust heated in star forming regions. This claim is supported by the temperature range obtained from our blackbody fit to the long wavelength data. Indeed the range 25 to 35 K is typical of dust generally found in HII region/molecular cloud complexes (Telesco *et al.*, 1980). Further support to this claim comes from the similarity of the SEDs of the three active galaxies discussed in this paper with the SED of NGC 1068, also a well known Seyfert galaxy, for which Telesco *et al.* (1984) were able to determine the existence of a 3 Kpc region of emission peaking at around 100μm, which they found coincided with a visually bright region containing a massive ring of molecular clouds.

Our data for NGC 4051 also agree with previous far IR data from Smith *et al.* (1983) who, based on KAO observations with filters having cut-on wavelengths at 85 and 140μm respectively, found a cold component of 28 K for this object. These authors concluded that this cold dust emission is produced in regions of active star formation, but this activity is less intense than that observed by Telesco *et al.* (1980) in NGC 1068, due to the

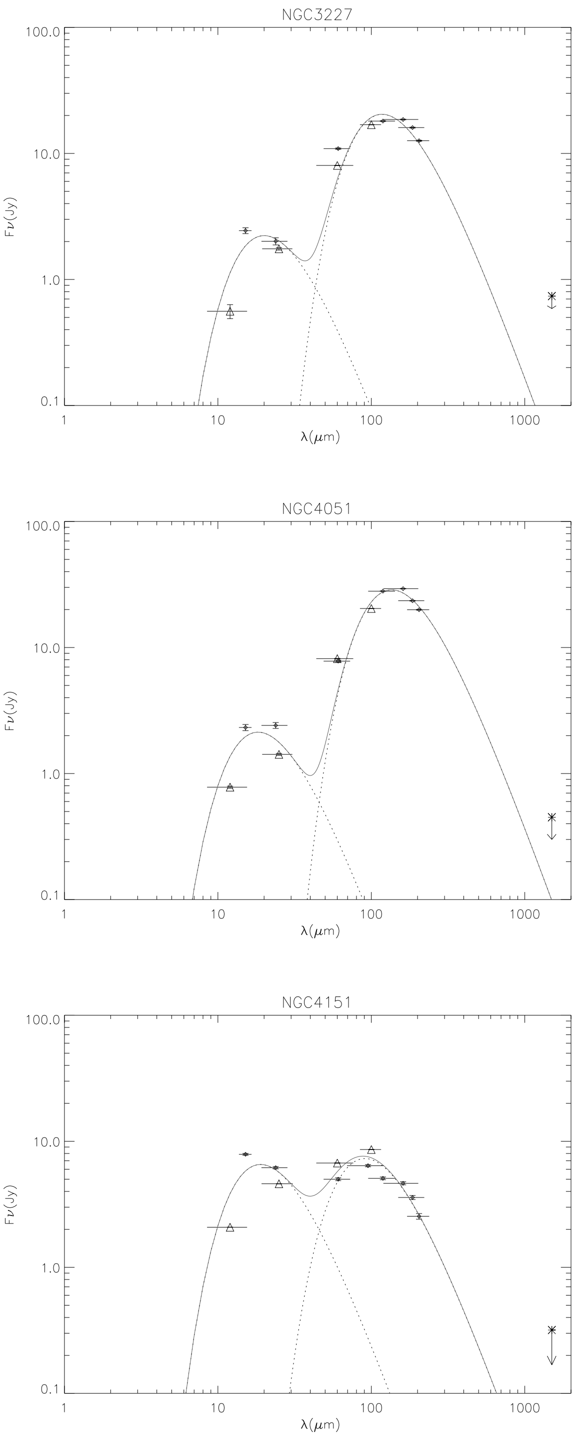

Fig. 1. Mid to far IR spectral energy distribution for NGC 3227, NGC 4051 and NGC 4151. ISO data are represented with dots, while the IRAS data are shown with triangles. The 1.3mm upper limit, from Edelson *et al.* (1987), is shown with a star. The data have been fitted with two emissivity weighted blackbodies (dotted lines), one representing warm dust and a second one representing cold dust (see text). Horizontal error bars indicate the FWHM of the different filters. All the ISO data have callibration errors of 30% (see text).

fact that the amount of material available for star formation is considerably less than in NGC 1068.

We therefore conclude that the cold dust component seen in the three galaxies studied here is produced by dust heated in regions of active star formation. A quantification of this activity will however rely on the fraction of the total mass of the galaxy that is undergoing star formation for which additional data is required. We will address this point in a future paper.

4.2. The warm dust component

The data also show (Fig. 1) the existence of a warm emitting region in all three objects with black body temperatures as given in Table 3. A similar warm dust component is also present in NGC 1068 (Telesco *et al.*, 1984). These authors showed that in NGC 1068 the dust in this warm region is heated by short wavelength radiation produced by the active nucleus. The nuclear origin of the warm dust emission is supported by the relatively high temperature of the dust ($\sim$170 K), far warmer that typical dust grain temperatures (20-50 K) in conventional star-forming regions and galactic molecular clouds (Telesco *et al.* 1980).

Another piece of evidence in support of the nuclear origin of the heating of the warm dust is the correlation found by Rudy (1984) between the [OIII]λ5007Å line emission and the 10μm emission for a sample of QSOs, Seyfert and radio-galaxies, implying that the dust responsible for the emission at 10 (and 20) μm could be mixed with the ionized gas in the NLR that produces the [OIII]λ5007Å line. A different explanation for this warm dust component is the possible presence of a thick dust torus that would be responsible for the mid-IR emission in AGNs. This torus (see *e. g.* Granato & Danese 1994 and references therein) would also be the cause of the anisotropic radiation field observed in the optical in a growing number of AGNs. Note that a combination of both mechanisms is also a plausible scenario.

Further support for the nuclear heating of the warm dust component comes from the recent work of Giuricin *et al.* (1995), who have found that the small aperture 10μm luminosities in a sample of over 100 active galaxies correlate very well with their IRAS luminosities at 12 and 25μm, while the correlation is much poorer with the 60 and 100μm luminosities.

We therefore conclude that the warm dust emission which is observed in all three galaxies in this paper is produced by dust being heated by the active nucleus, either because the dust is part of a warm thick torus, or because this dust is mixed with the gas in the NLR, or both.

Although the number of objects is still small to produce meaningful statistics, we anticipate that the existence of a mid IR emitting zone peaking around 20μm and a far IR emitting zone peaking around 100μm may be a common feature in Seyfert galaxies. We are now processing data for a larger number of objects and expect to substantiate this idea.

Finally, note also the large difference in the relative strengths of the warm and cold dust components between NGC 4151 and the other two galaxies studied in this paper. While in NGC 4151 the warm dust is very prominent relative to the cold dust, in both

NGC 4051 and NGC 3227 the cold dust component dominates. This is clearly related to the strength of the active nuclei relative to the colder emission from star forming regions, which will likely depend on the fraction of galactic material involved in star forming processes.

5. Conclusions

We present in this Letter mid and far IR data obtained with ISO for three well known Seyfert galaxies. We have found that the SEDs for these three objects are very well explained if one assumes two distinct regions of thermal emission. These regions are well fitted by blackbody curves of two different temperatures, namely, a cold region which we claim is due to dust heated to about 30 K in regions of star formation, and a region of warmer dust which we claim is heated to about 170 K by the respective active nuclei.

We also point out the similar SEDs of the three Seyfert galaxies discussed here, and that of NGC 1068, all of them with two distinct zones of emission. We anticipate that this may be a common feature of all Seyfert galaxies, though data for a larger number of objects is required before this conclusion can be taken as definitive.

Acknowledgements. JMRE and AMPG are pleased to acknowledge very valuable advice and insight provided to us by Jose Acosta about the PHT data calibration. H. Castañeda, U. Klaas, H. Krüger, and A. Ulla are also thanked for their help at various stages of this work. This research is supported by a CICyT grant number ESP94-0034 from the Spanish Ministry of Education. The ISOPHOT instrument was funded by the Deutsche Agentur für Raumfahrtanelegenheiten (DARA) and several European Institutes. The ISOPHOT instrument includes the spectrophotometer ISOPHOT-S, funded by CICyT and built in Spain by CASA and the IAC.

References

Bregman, J. N. 1990, A&AR **28**, 15.
Draine, B. T., and Anderson, N. 1985, ApJ, **292**, 494.
Draine, B. T., and Lee, H. M., 1984, ApJ, **285**, 89.
Edelson, R. A., Malkan, M. A. & Rieke, G.H., 1987, ApJ, **321**, 233.
Fich, M. and Hodge, P., 1991, ApJ, **374**. L17.
Giuricin, G., Mardirossian, F., and Mezzetti M. 1995, ApJ, **446**, 550.
Granato, G. L., and Danese, L. 1994, MNRAS, **268**, 235.
Lemke, D., et al. 1996, A&A, this volume.
Maiolino, R., Ruiz, M., Rieke, G. H., & Keller, L. D. 1995, ApJ, **446**, 561.
Miley, G. K., Neugebauer, G., and Soifer, B. T. 1985, ApJ, **293**, L11.
Penston, M. V. & Pérez, E. 1984, MNRAS, **211**, p33.
Rodríguez Espinosa, J.M., Rudy, R.J., and Jones, B. 1987, ApJ, **312**, 555.
Rudy, R.J. 1984. ApJ, **284**, 33.
Smith, H. A., Lada, C. J., Thronson, H. A., Glaccum, W., Harper, D. A., Loewenstein, R. F., and Smith J. 1983, ApJ, **274**, 571.
Telesco, C. M., 1988, ARA&A, **26**, 343.
Telesco, C. M., Becklin, E. E., and Wynn-Williams, C. G., 1984 ApJ, **282**, 427.
Telesco, C. M., Becklin, E. E., and Wynn-Williams, C. G., 1980 ApJ, **241**, L69.