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IRAS OBSERVATIONS OF NGC 1052

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The galaxy NGC 1052 has been observed with the *IRAS* satellite. The infrared emission at 100 μm is substantially larger than a smooth extrapolation of the radio data. Because of the large diaphragm size of *IRAS*, it is impossible to decide uniquely if the infrared radiation represents a self-absorbed nonthermal spectrum or thermal reradiation by heated dust.

Key words: galaxies—infrared emission

I. *IRAS*[1] Observations of NGC 1052

The elliptical galaxy NGC 1052 is an unusual galaxy known to have an infrared excess at 10 μm and 20 μm which is too high to be attributed to the general stellar content of elliptical galaxies (Rieke and Low 1972; Rieke, Lebofsky, and Kemp 1982 (henceforth RLK); Becklin, Tokunaga, and Wynn-Williams 1982 (henceforth BTW)). RLK conclude that NGC 1052 contains a blazar (Angel and Stockman 1980) with an exceptionally low luminosity, and argue that the excess infrared emission is due to the blazar. Impey (1984) has described NGC 1052 as archetypical of a class of low-luminosity blazars. On the other hand, BTW contend that the infrared excess in NGC 1052 is the result of thermal emission from dust heated by a nonthermal source.

Both RLK and BTW conclude that the 10 μm and 20 μm emission comes from a nuclear core (hereinafter referred to as the core), which BTW show to be $< 4''$ in diameter. Surrounding this core is an elliptical galaxy which BTW and RLK conclude has the colors of a normal elliptical galaxy. Both BTW and RLK also observe that the core dominates the emission at wavelengths between ~ 3.5 μm and 20 μm and that the emission rises steeply, approximating a power law of slope $\alpha \sim -1.5$ to -2 ($f_\nu \propto \nu^\alpha$), in the near infrared. Carter et al. (1983) have combined the infrared data of RLK with visual CCD observations and conclude that a power law with slope $\alpha = -1.5$ fits the emission continuum from the core at wavelengths ranging from the visible through 20 μm. At radio wavelengths a compact and variable core of diameter $0\farcs001$ is present (Cohen et al. 1971), accompanied by a $30''$ double source containing two active regions (Wrobel 1984). A strong emission-line spectrum is seen in the visible from a region $\sim 20''$ in diameter (Fosbury et al. 1978). In this paper we present the results of observations from the *IRAS* survey which extend the infrared measurements to 100 μm.

II. Observations

The *IRAS* mission and satellite have been described by Neugebauer et al. (1984*a*). NGC 1052 was observed in eight separate scans forming three hours-confirmed (Neugebauer et al. 1984*b*) scans. The observations were made in 1983 July 27, August 7, and August 30. NGC 1052 was clearly detected at 25 μm, 60 μm, and 100 μm in the survey with signal-to-noise ratios around 10 in each hours-confirmed set. There was no indication of variability in the observations larger than the 10% attributable to the systematic photometric inaccuracies.

Coaddition of the scans was necessary to measure the source at 12 μm; the resultant signal-to-noise ratio at 12 μm after coaddition of all the scans was 11. The results are given in Table I and plotted in Figure 1. The *IRAS* flux density at 12 μm is well above the fluxes of RLK and BTW, who use diaphragms of $5\farcs5$ and $4''$ diameter, respectively. Presumably this is due to the large diaphragms used in *IRAS* ($0.8' \times 4.5'$ at 12 μm and 25 μm), and the presence of the elliptical galaxy; see below.

The observations have been calibrated using the June

[1]The *Infrared Astronomical Satellite* (*IRAS*) was developed and operated by the Netherlands Agency for Aerospace Programs (NIVR), the United States National Aeronautics and Space Administration (NASA), and the United Kingdom Science and Engineering Research Council (SERC).

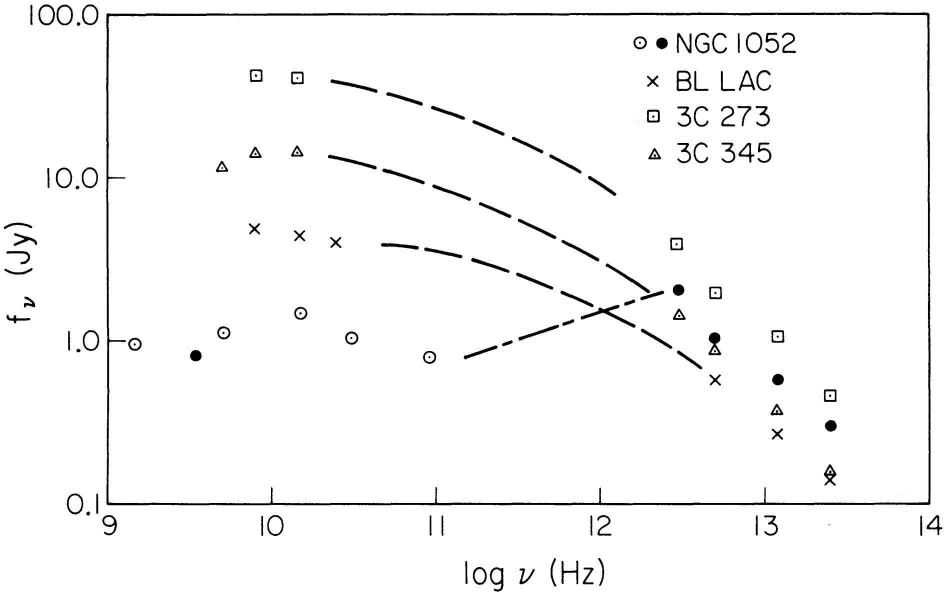

FIG. 1—The energy distributions of NGC 1052 and three well-known radio sources. The infrared observations are all from *IRAS*. The 100 μm observations of BL Lac are confused by infrared "cirrus" (Low et al. 1984) and thus no flux density at 100 μm can be quoted. The radio measurements of NGC 1052 indicated with the filled circle were taken by Heeschen (1984) at the same time as the *IRAS* observations. The open circles represent observations of NGC 1052 made in 1980 and 1981 (Wrobel 1984). The radio observations of BL Lac, 3C 345, and 3C 273 were taken at the same time as the *IRAS* observations by Aller, Aller, and Haddock (1984).

TABLE I

Infrared Flux Densities (Jy) of NGC 1052

	wavelength (μm)			
	12	25	60	100
IRAS	0.27 ± 0.03	0.53 ± 0.08	0.89 ± 0.06	1.88 ± 0.07
Case I**				
core	0.20 ± 0.03*	0.60 ± 0.10*	0.9	1.9
galaxy	0.07	0.04	0.0	0.0
Case II**				
core	0.20 ± 0.03*	0.60 ± 0.10*	0.6	0.0
galaxy	0.07	0.04	0.3	1.9

*From Carter et al. 1983.
**See text.

1984 *IRAS* absolute calibration (Aumann et al. 1984). The calibration incorporates a refined determination of the nonlinear load resistor curve which results in flux values of the secondary standard NGC 6543 which are 0.93, 0.88, 0.85, and 0.89 times the preliminary *IRAS* calibration of that source (Neugebauer et al. 1984*a*) at 12, 25, 60, and 100 microns. The calibration is probably accurate to 5% at 12 and 25 microns and 10% at 60 and 100 microns. The *IRAS* measurements are broad band and thus need a color correction (Neugebauer et al. 1984*a*). For these corrections, the intrinsic energy distribution of NGC 1052 was assumed to rise into the infrared with a power law of slope $\alpha = -1$; the change in the color correction if $\alpha = -2$ would be $< 5\%$.

III. Discussion—Core Versus Galaxian Emission

In order to interpret the *IRAS* observations it is necessary to separate out that portion of the total flux observed from NGC 1052 (Fig. 1, Table I) which arises in the compact nuclear core from that which arises in the elliptical galaxy which presumably has a stellar-like energy distribution. Although many assumptions about the split between the core emission and the galaxian emission are well within the combined uncertainties of the ground-based and *IRAS* measurements, we will adopt the hypothesis that at 12 μm and 25 μm the core contributes the flux densities derived by Carter et al. (1983) from the small-diaphragm ground-based observations. Critical to this assumption is the observation by BTW that the infrared core at 10.6 μm is not extended by more than 4″.

The ground-based and *IRAS* observations can be shown to be consistent with each other. It is first necessary to predict the contribution of the elliptical galaxy outside the core. Observations by Becklin and Neugebauer (1970) show that the 2.2 μm flux density of NGC 1052 within a 13″.5 diameter diaphragm is $f_\nu(2.2\ \mu\mathrm{m}) = 0.18 \pm 0.02$ Jy. The growth curve for elliptial galaxies at 2.2 μm given by Frogel et al. (1978) indicates that the 2.2 μm flux density attributable to the galaxy within the 0′.8 $\times$ 4′.5 *IRAS* diaphragm size is consequently ~ 0.60 Jy. The extrapolation of these observations to 12 μm and 25 μm is uncertain since Impey, Wynn-Williams, and Becklin (1984) have shown that the central regions of many "normal" elliptical galaxies have $f_\nu(10\ \mu\mathrm{m})/f_\nu(2.2\ \mu\mathrm{m})$ as high as 0.22 ± 0.1. If this large $f_\nu(10\mu\mathrm{m})/f_\nu(2.2\ \mu\mathrm{m})$ ratio holds for the entire galaxy sampled by the *IRAS* diaphragm, the contribution of the galaxy to the *IRAS* observation at 12 μm could be as large as 0.13 Jy and the core would contribute only 0.14 Jy, less than the determination of 0.2 Jy by Carter et al. (1983). Thus the high $f_\nu(10\ \mu\text{m})/f_\nu(2.2\ \mu\text{m})$ ratio presumably does not hold for the entire elliptical galaxy surrounding the core of NGC 1052. If, on the other hand, the energy distribution of the galaxian component of NGC 1052 were to follow that of a hot blackbody between 2.2 μm and 12 μm the flux density at 12 μm of the galaxy would be $f_\nu(12\ \mu\text{m}) \sim 0.02$ Jy. Thus the value implied if the core emits 0.2 Jy at 12 μm, namely 0.07 Jy at 12 μm (see Table I), lies well within the range of possibilities.

The emission from the core at 25 μm must be determined by an extrapolation from the ground-based measurements at 20 μm. If the power-law slope is $\alpha = -1.5$ the flux density at 25 μm contributed by the core alone would be 0.6 Jy, larger than the total measured with *IRAS*. The observations, then, if taken at face value, would imply no or little contribution from the galaxy at 25 μm. The uncertainties in the combined measurements and in the extrapolations, however, easily encompass the 25 μm flux density at 0.04 Jy (see below and Table II) predicted from a normal elliptical galaxy whose flux density at 12 μm is 0.07 Jy. Changing the assumed power law slope of the energy distribution of the core to $\alpha = -1$, consistent with the longer wavelength *IRAS* observations, decreases the amount attributable to the core at 25 μm and would clearly make the fit better.

In order to estimate the flux densities of the core at 60 μm and 100 μm, it is again necessary to estimate the flux densities of the galaxy surrounding the core. Unfortunately, few measurements of elliptical galaxies at the longer *IRAS* wavelengths have been analyzed at this time. A preliminary search for infrared emission associated with galaxies in the *Revised Shapley-Ames Catalog of Bright Galaxies* (Sandage and Tammann 1981) showed a complete absence of elliptical galaxies at the *IRAS* wavelengths (deJong et al. 1984*a*). Furthermore, a preliminary study of many elliptical galaxies in the *IRAS* data has not shown significant 100 μm emission except in those cases when visual observations would have given evidence for dust or gas (deJong 1984*b*). In this regard, it should be noted that Carter et al. (1983) show the presence of a weak diffuse dust lane extending $\sim 20''$ along the minor axis of NGC 1052.

TABLE II

Infrared Flux Density Ratios of Elliptical Galaxies

	M31 (nuc)	M32	NGC 205
$f_\nu(25\ \mu\text{m})/f_\nu(12\ \mu\text{m})$	0.54	0.58	0.68
$f_\nu(60\ \mu\text{m})/f_\nu(12\ \mu\text{m})$	5.1	<0.9	4.8
$f_\nu(100\ \mu\text{m})/f_\nu(12\ \mu\text{m})$	25	<4.1	34

Some elliptical galaxies do show significant 100 μm emission, however. Table II gives the observed flux density ratios at *IRAS* wavelengths of M32, NGC 205, and the nucleus of M31 where there is evidence that little gas and dust is present (Habing et al. 1984, revised). In each case, $f_\nu(25\ \mu\text{m})/f_\nu(12\ \mu\text{m}) \sim 0.6$. It is clear from Table II, however, that these apparently old stellar systems show a wide range in their far infrared properties. NGC 205 is also known from optical and radio studies to contain significant amounts of gas and dust.

Although there is no evidence from visible images for large amounts of dust in the elliptical galaxy associated with NGC 1052, it is necessary to consider two extreme cases when examining the nature of the core. In the first case (case I of Table I), the elliptical galaxy contributes negligible flux at 60 μm and 100 μm, and the observed flux densities—0.9 Jy and 1.9 Jy—represent the core. In the second case (case II of Table I), the galaxy outside the core has an energy distribution like NGC 205 and dominates the observed emission at far infrared wavelength. Clearly, any case in between these two cases is possible. In fact, the ratio $f_\nu(100\ \mu\text{m})/f_\nu(12\ \mu\text{m})$ cannot be as extreme for the galaxian component in NGC 1052 as it is in NGC 205 if the galaxy indeed contributes 0.07 Jy to the *IRAS* observations at 12 μm.

IV. Discussion—Nature of the Core

For comparison, Figure 1 includes the radio and infrared flux densities of three well-known radio sources—3C 273, 3C 345, and BL Lacertae; the latter two are representative blazars. The radio observations were made contemporaneously with the *IRAS* observations. The observed infrared continua of all four sources in Figure 1 are amazingly similar, with slopes $\alpha \sim -1$. The infrared continua of BL Lac, 3C 345, and 3C 273 form a smooth extension of the radio observations; in the case of blazars at least, this is almost certainly associated with synchrotron emission characteristic of blazar emission in this wavelength region.

The observed energy distribution of NGC 1052 is distinguished from those of the other sources in Figure 1 and from that of the canonical blazars by the fact that the infrared continuum of NGC 1052 falls well above the extrapolation of the radio flux (1.9 Jy vs. < 0.8 Jy). (In this respect the observed energy distribution resembles a less extreme example of those of the radio-quiet quasars observed by Neugebauer et al. (1984*b*).) If the Hubble constant is taken as 75 km s^{-1} Mpc^{-1}, NGC 1052 is at a distance of 19 Mpc, implying a total luminosity for the assumed far-infrared emission from the core of 5×10^8 $L_\odot$. This luminosity is comparable to the luminosity between 5 μm and 20 μm and that of the stellar component in the core as deduced from the 1–3 μm emission (BTW).

RLK postulate that the nonthermal emission from the core of NGC 1052 extends from the radio through the infrared at 20 μm and 10 μm. If this is true, a mechanism, presumably self-absorption, is needed to attenuate the flux density by more than a factor of 2 between 100 μm and 9 cm, i.e., to provide a continuum with slope $\alpha >$ 0.2. Such a mechanism is needed whether the core or the galaxy emission dominates the *IRAS* measurements (case I or II), although the qualitative requirements are slightly different. For a homogeneous synchrotron source which is self-absorbed, the spectral index is 2.5, so that this mechanism is consistent with the observations. Alternatively, Marscher (1977) has shown that if the radiating source is inhomogeneous, the self-absorbed synchrotron continuum can exhibit an optically thick spectral index between 0.5 and 1.5. Although these mechanisms are both sufficient to account for the observed drop-off, the source would be unique among known blazars in having the absorption occur at such a high frequency. In particular, there is no evidence for the rapid variability expected for a source with a turn-off frequency at 60 μm.

If the infrared continuum is assumed to be due to thermal emission from heated dust, the conditions in the source depend strongly on the assumption as to the division between core and galaxy. If the observed 60 μm and 100 μm emission represents the core (case I, Table I) the color temperature implied by the 60 μm and 100 μm fluxes is $T_c = 42$ K. If the physical temperature of the radiating material equals the color temperature, the total source must subtend an angular diameter larger than $0\farcs2$ or 22 pc. If the source consists of a shell of 22 pc diameter surrounding a central luminosity source of 5×10^8 $L_\odot$, the equilibrium temperature would be 31 K. Emissivity variations observed in the Galaxy such, as emissivity proportional frequency^{-1} could easily bring the color and equilibrium temperatures into agreement.

If the 60 μm and 100 μm flux densities observed by *IRAS* are dominated by the galaxy, the details of the core energy distribution are quite arbitrary. In the case shown in Table I, if the infrared is thermal emission the color temperature derived from the observed 25 μm and 60 μm flux densities is 150 K, implying the dust grains are located close to the luminosity source. Again this interpretation is consistent with the observations.

V. Conclusions

The *IRAS* measurements, because of their big beam size, cannot uniquely decide whether the infrared emission represents the high-frequency tail of the radio emission or if it represents a thermal component in the nucleus of NGC 1052. The choice is largely one of preference and intuition at this point. The ad hoc assumptions necessary to continue the radio continuum into the infrared persuade us, however, that it is more reasonable to explain the observed emission by thermal radiation from dust heated by a nonthermal source, thus supporting the suggestion by BTW. It should be emphasized that this does not preclude the radio source being a mini-blazar as evidenced by its variability and continuum shape. The *IRAS* observations give evidence for the presence of thermally heated dust in this galaxy system which dominates the emission in the far infrared.

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