A 25 MICRON COMPONENT IN 3C 390.3[1]

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ABSTRACT

Infrared Astronomical Satellite (*IRAS*) observations show that there is a maximum in the continuum energy distribution of the broad-line radio galaxy 3C 390.3 near 25 μm and that this active galaxy emits most of its energy in the infrared. If the 25 μm component is thermal, its temperature is approximately 180 K, and its size must exceed tens of parsecs.

Subject headings: infrared: sources — radio sources: galaxies

I. INTRODUCTION

The broad-line radio galaxy 3C 390.3 has been studied intensively at radio, optical, and X-ray wavelengths. The radio source is identified with a 15th magnitude N type galaxy (Longair 1965; Wyndham 1966) at a redshift of 0.0569 (distance 227 Mpc)[2] (Sandage 1966; Penston and Penston 1973; Burbidge and Burbidge 1971; Osterbrock, Koski, and Phillips 1976; Heckman *et al.* 1981). It is a strong X-ray source, being one of the few active galaxies seen in the original *Uhuru* survey (Giacconi *et al.* 1972). Until now, there have been no published data on 3C 390.3 in the mid-infrared or far-infrared. We present the results of *IRAS* observations which show that the continuum energy distribution of 3C 390.3 peaks near 25 μm and that 3C 390.3 has its largest energy output in the infrared.

II. OBSERVATIONS AND RESULTS

The technical details of the *IRAS* satellite, its various observing modes, and the procedures used to reduce the data are described by Neugebauer *et al.* (1984a, hereafter Paper I).

Pointed observations (see Paper I) of 3C 390.3 in two modes were obtained in 1983 March–May. Twenty 1°6 × 0°5 maps of the area surrounding 3C 390.3 were constructed, each out of six raster scans 1°6 in length and separated by 0°1. The total observing time for each map was about 6 minutes. The various observations were co-added to enhance the signal-to-noise ratio. In each of the observations, a source was clearly detected at 12, 25, 60, and 100 μm close to the position of 3C 390.3. The average centroid position obtained from a point-source extraction algorithm applied to the 12, 25, and 60 μm grids differs less than 10″ from the position of the N galaxy associated with 3C 390.3 (Hargrave and McEllin 1975).

The data were calibrated in intensity by observing the planetary nebula NGC 6543 at the same relative position and in a similar manner (see Paper I). Since each of the *IRAS*

bandpasses occupies a finite range of frequency, a small correction had to be applied for the difference in infrared color between 3C 390.3 and the calibration source (Paper I).

The resultant flux densities are listed in Table 1. The final signal-to-noise ratios exceed 18 in the 12, 25, and 60 μm bands; at 100 μm, the ratio is approximately 10. The systematic uncertainties are approximately 15%. The results analyzed so far show no evidence for variability at this level. The overall spectrum of 3C 390.3 is plotted in Figure 1. 3C 390.3 shows a clear peak near 25 μm, different in this respect from most of the other 20–30 active galaxies for which *IRAS* measurements have been obtained. These have smooth spectra with flux densities at 25 μm that are smaller than those at 60 μm.

· The anomalous nature of the infrared spectrum of 3C 390.3 is most apparent when the 60 μm/25 μm spectral index ($+0.40 \pm 0.14$) is compared with values of the same quantity so far measured by *IRAS* for galaxies (-0.8 to -4.9) (Soifer *et al.* 1984; Young *et al.* 1984) and quasars (-0.7 to -1.2) (Neugebauer *et al.* 1984b). The presence of an excess 25 μm flux in 3C 390.3 is indicated by the relative curvature of its spectrum. The difference between the 60 μm/25 μm and 25 μm/12 μm spectral indices can be used as a measure of spectral curvature. For 3C 390.3, this difference is $+1.7 \pm 0.4$, which can be compared to -1.3 ± 0.4 and $+0.1 \pm 0.2$ for the mean values of the difference for the six galaxies and five quasars measured at all three wavelengths by Soifer *et al.* (1984), Young *et al.* (1984), and Neugebauer *et al.* (1984b).

In showing the radio spectrum in Figure 1, we distinguish between the compact nuclear component, whose spectrum is flat, and the total radio emission, which is dominated by steep-spectrum emission from an extended 220 kpc halo and therefore is not directly relevant for the nucleus.

Typical values for the $\log_{10}$(flux per logarithmic frequency interval [W m^{-2}]) are -15.65, -13.34, -14.07, and -14.00, at 6 cm, 25 μm, 0.5 μm, and 2–6 keV. It is thus seen that the energy output of 3C 390.3 is largest in the infrared. This statement is subject to the caveat that the luminosity of 3C 390.3 has not increased by large amounts at other wavelengths since the last reported measurements. Note that 3C 390.3 is highly variable in the X-ray and optical region of the spectrum (e.g., Barr *et al.* 1980).

[2] Throughout this *Letter*, we adopt a Hubble constant of $H = 75$ km s^{-1} Mpc^{-1}.

TABLE 1
MEAN PARAMETERS

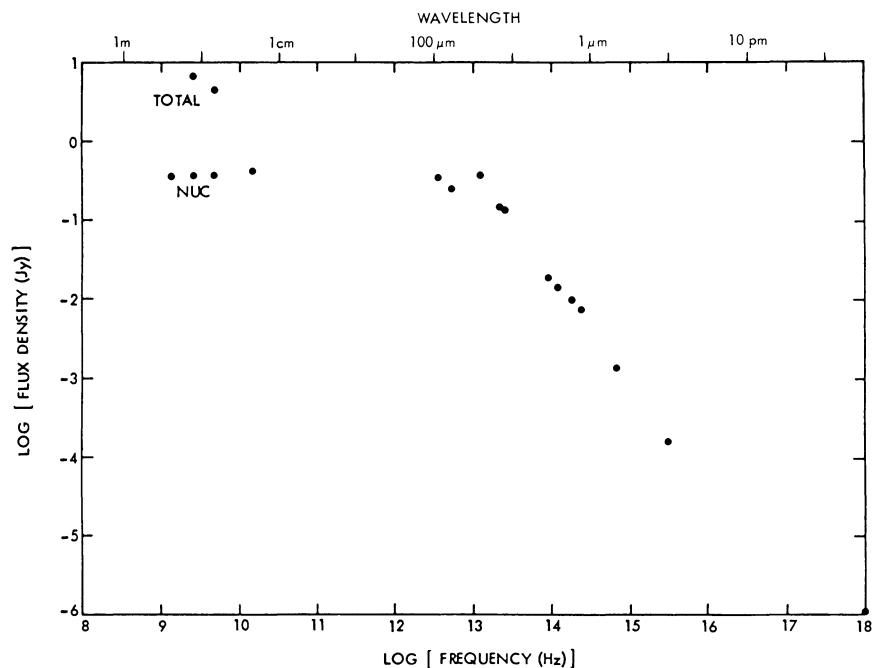| PARAMETER	WAVELENGTH (μm)			
	12	25	60	100
Flux density (Jy)	0.14 ± 0.02	0.38 ± 0.06	0.25 ± 0.04	0.34 ± 0.06
Log_{10} luminosity (W) ...	37.32	37.43	36.86	36.77

FIG. 1.—The energy distribution of 3C 390.3 over 10 decades in frequency. The emission from the compact radio nucleus is plotted separately from the total radio emission. The observations are taken from Kellermann, Pauliny-Toth, and Williams (1969) [1400, 2695, 5000 MHz]; Miley and van der Laan (1973) [1400 MHz nuc]; Harris (1972) [2695 MHz, 5000 MHz nuc]; CIT (1983, unpublished data) [1.2–2.2 μm, 10 μm]; Rieke (1983, unpublished data) [3.4 m]; Barr *et al.* (1980) [B and 2–6 keV]; Ferland *et al.* (1979) [1500 Å].

III. DISCUSSION

A crucial question is whether the 25 μm component in 3C 390.3 is due to thermal or nonthermal radiation. If the radiation is interpreted as thermal, its temperature is 180 ± 30 K. Assuming that the 30 μm component is indeed that of a 180 K blackbody, the observed maximum gives, for an emissivity ε, a blackbody radius of $7\varepsilon^{-1/2}$ pc.

More stringent physical parameters can be attached to the region emitting the 25 μm radiation if we assume either a size for the emitting region or a mean emissivity. Barr *et al.* (1980) deduced a value of $A_v = 1.4 \pm 0.4$ mag for the visual extinction in 3C 390.3 from the narrow-line Balmer decrement and also put an upper limit on the visual extinction to the optical continuum nucleus of 3C 390.3 of $A_v < 1.2$ mag. The visual extinction, A_v, can be related to the emissivity at 25 μm, ε_{25}, using the relation derived for the Galaxy by Hildebrand (1983), modified to 25 μm. Taking A_v to be between $200\varepsilon_{25}$ and $800\varepsilon_{25}$ yields a value $\varepsilon_{25} < 0.0015$, a low value, but one not atypical of emissivities assigned to grains in the Galaxy. If we assign this value to the emissivity in 3C 390.3, the size of the emitting region is greater than 180 pc.

There is evidence for the existence of a similar component near 30 μm in the infrared spectrum of the Seyfert 2 galaxy NGC 1068 (Rieke and Low 1975; Simon and Dyck 1975; Jameson *et al.* 1974). In the case of NGC 1068, the low measured brightness temperature at 10 μm (Becklin *et al.* 1973) has provided decisive evidence that the observed radiation is thermal. Jones *et al.* (1977) have interpreted the maximum near 25 μm as being heated by an ultraviolet source of approximately 2×10^{11} $L_\odot$ luminosity, similar to the luminosity of 3C 390.3. The size of this source was measured by Becklin *et al.* (1973) to be $0''.9$ corresponding to 63 pc. Thus, the assumed thermal source in 3C 390.3 resembles that in NGC 1068 in its gross properties. We should point out, however, that in many of its properties (e.g., presence of powerful extended radio emission and broad permitted lines, strong far-infrared emission, luminous X-ray emission), the properties of the activity in 3C 390.3 are almost diametrically opposed to those of NGC 1068. Hence, caution should be exercised in drawing too close a parallel between the mid-infrared components in these two galaxies.

If the 25 μm component is thermal, where does the energy come from to power it? One possibility is that the component

is heated by ultraviolet emission from the nucleus. The required extinction is consistent with the limit placed by the optical continuum measurements of the nucleus. A second possible source of energy is the beam or jet which, according to current models of radio source propagation, powers the extended radio components (e.g., Rees, Begelman, and Blandford 1981; Norman and Miley 1984).

The apparent increase in flux density between 60 and 100 μm can be indicative of a nonthermal link with the nuclear radio spectrum. Alternately, it can be the high-frequency end of colder thermal emission from the galaxy associated with 3C 390.3. The latter possibility is unlikely since thermal emission is predominantly associated with spiral galaxies (see, e.g., de Jong *et al.* 1984), and 3C 390.3 type radio sources are associated with elliptical galaxies (Miley 1980).

We cannot rule out a nonthermal origin for the 25 μm component. The "break" in the continuum spectrum between the flat-spectrum nuclear radio emission and the steep-spectrum optical N galaxy is near 25 μm. The occurrence of a maximum at this wavelength would be consistent with self-absorbed nonthermal emission from a recent burst of nuclear activity such as apparently occurred in the quasar 3C 345 (Harvey, Wilking, and Joy 1982). Simple models of evolving relativistic plasmas (e.g., Pauliny-Toth and Kellermann 1966; van der Laan 1966) predict that the peak moves to longer wavelengths and decreases in amplitude over a period of a few months as the component expands. Rapid intensity variations might thus be expected from such a nonthermal component over a time scale of a few months. Although the data presented have showed no variability over a time scale of about 2 months, 3C 390.3 has been monitored regularly for variability with *IRAS*.

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