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IRAS[1] OBSERVATIONS OF RADIO-QUIET AND RADIO-LOUD QUASARS

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ABSTRACT

Observations from 12 to 100 μm are presented of two radio-quiet and three radio-loud quasars. Over this wavelength range, all five have grossly similar continuum energy distributions. The continua of the radio-loud quasars are consistent with synchrotron radiation. There is an indication, however, of excess 100 μm emission in the two radio-quiet quasars.

Subject headings: infrared: sources — quasars

I. INTRODUCTION

One of the potentially most important clues as to the nature of the mechanisms for the energy production in quasars is the difference between radio-quiet and radio-loud quasars at mid-infrared to far-infrared wavelengths. Throughout the visible and near-infrared, the continua of many of these two types of objects are remarkably similar in shape as well as every other parameter observed to this time (see, e.g., Neugebauer *et al.* 1979), but the ratio of the radio continuum flux density to that at optical wavelengths differs by factors up to 10^5 or more (see, e.g., Condon *et al.* 1980).

Before the flight of *IRAS*, measurements between 20 μm and 1 mm of only two quasars—3C 273 (Clegg *et al.* 1983) and 3C 345 (Harvey, Wilking, and Joy 1982)—had been published, and these were both strong radio emitters. The sensitivity of *IRAS* is such that the quasar 3C 273 can be observed in the survey with a signal-to-noise ratio of approximately 10, while pointed observations are expected to be needed in order to measure the majority of quasars.

In this *Letter*, the first *IRAS* measurements of radio-loud and radio-quiet quasars are presented.

II. OBSERVATIONS

The *IRAS* mission is described by Neugebauer *et al.* (1984*a*, hereafter Paper I). The measurements presented in this *Letter* come from both the pointed observations and the survey and are listed in Table 1. Flux densities of four objects—two radio-quiet quasars, PG 0838+770 and PG 0906+484, plus the radio-loud quasars 1641+399 (3C 345) and PKS 0537−441—were measured in the pointed mode. All but 3C 345 were measured by co-adding at least six $0'.5 \times 1'.5$ fields centered on the objects. Each individual measurement took about 200 s of observing time and resulted in an increase in the signal-to-noise ratio by a factor of about 5 above the survey. 3C 345 was observed by making seven scans over the source with the best detector in each of the wavelength bands. The resultant signal-to-noise ratios of the co-added flux densities are listed in Table 1; they represent the ratio of the signal to the local noise. The systematic uncertainties are approximately 20%, due primarily to still unprocessed calibration observations in the pointed observation mode. The flux densities f_ν of all objects given in this *Letter* were derived assuming $f_\nu \sim \nu^{-1}$. The positions of the objects as calculated from a source extraction algorithm applied to the *IRAS* observations were within 15″ of the optical positions of the quasars (Hewitt and Burbidge 1980; Schmidt and Green 1983).

Two quasars, PKS 0420−014 and PKS 0537−441, were detected in the survey proper during the first 1.5 months of survey. The observations were selected by comparing the survey results with the catalog of known quasars by Hewitt and Burbidge (1980). PKS 0420−014 was scanned 10 times, with reliable seconds-confirming measurements (defined in Paper I) at 60 μm being obtained on seven crossings. The signal-to-noise ratio on each pair of crossings at this wavelength was approximately 5. At the other *IRAS* wavelengths, there were only marginal detections until the signals were co-added. The quasar PKS 0537−441 was crossed by the focal plane nine times. Reliable seconds-confirmed detections, each with a signal-to-noise ratio of approximately 5, were obtained six times at 60 μm. Both sources were hours-confirmed four times at 60 μm. Hours-confirming detections were obtained twice at 25 μm and once at 100 μm.

III. DISCUSSION

Figure 1 shows the energy distributions around the *IRAS* wavelengths for the quasars listed in Table 1. This preliminary report more than doubles the number of quasars measured at the mid-infrared and far-infrared wavelengths and illustrates the potential of *IRAS* for these observations.

The radio-loud quasars in general show continua which join smoothly between the radio and near-infrared measurements. All three are compact radio sources with large optical or radio variations on short time scales and are grouped into the generic class "blazars" (Angel and Stockman 1980). The emission from the millimeter through infrared wavelengths has generally been attributed to electron-synchrotron radiation (see, e.g., reviews by Rieke and Lebofsky 1979 and Soifer and

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TABLE 1

FLUX DENSITIES AND SIGNAL-TO-NOISE RATIOS

Quasar	Mean Obs. Date (1983 +)	Redshift[a]	12 μm f_ν (Jy)	12 μm SNR	25 μm f_ν (Jy)	25 μm SNR	60 μm f_ν (Jy)	60 μm SNR	100 μm f_ν(Jy)	100 μm SNR
0420−014 ...	0.12	0.915	0.11	5	0.22	8	0.61	15	0.96	9
0537−441 ...	0.24	0.894	0.15	10	0.32	20	0.73	15	0.88	10
0838+770 ...	0.26	0.131	0.03	7	0.10	15	0.22	21	0.48	17
0906+484 ...	0.30	0.118	0.04	6	0.09	11	0.19	14	0.34	9
1641+399 ...	0.14	0.595	0.31	50	0.52	98	1.09	130	1.61	61

[a]Hewitt and Burbidge 1980; Schmidt and Green 1983.

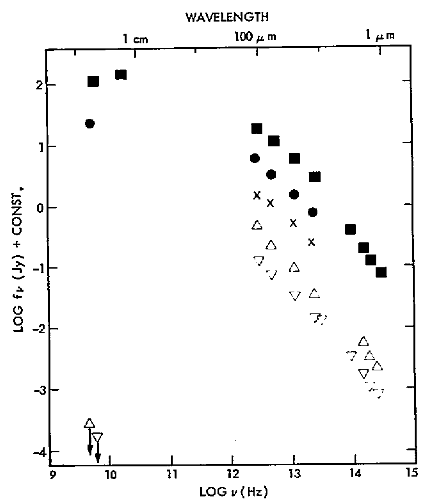

FIG. 1.—The continuum energy distributions of the quasars in Table 1 are shown around the *IRAS* wavelengths. The filled symbols indicate radio-loud quasars, and the open triangles indicate radio-quiet quasars. From top to bottom, the quasars are 1641+399, 0420−014, 0537−441, 0838+770, and 0906+484. The ordinates are offset by arbitrary constants. The near-infrared points were obtained at the Palomar Observatory in 1983 April (1641+399); in 1980 October (0838+770); and in 1980 June (0906+484). The radio data are from Condon *et al.* (1981, 0906+484), from Kellerman (1983, 0838+771), and from Perley (1983, 1641+399 [1983 March] and 0420−014 [1982 May]).

Neugebauer 1981). The smoothness of the observed continuum energy distribution indicates that thermal emission from heated dust, if present in these quasars, is masked by the nonthermal component.

An examination of Figure 1 indicates that there is no strong difference at the *IRAS* wavelengths between the radio-loud quasars and the two radio-quiet quasars. In particular, the observations indicate that the power-law dependence defined by the near-infrared data, $\sim \nu^{-1}$, extends through 100 μm. Both radio-quiet quasars have good limits to their radio flux as indicated in Figure 1; at 6 cm, limits of 0.25 mJy and 0.2 mJy have been obtained by Kellerman (1983) for PG 0838+770 and by Condon *et al.* (1981) for PG 0906+484.

The degree to which a power law fits the infrared data is shown in Figure 2. The radio-loud quasars fall near the power-law line or deviate from it in the sense that there is a deficiency in the 100 μm flux density; the full range of the observed power-law slopes is $-1.2 < \alpha < -0.7$. For these radio-loud quasars, the observations suggest that there is no measurable contribution to the infrared flux from thermal dust emission, and the shape of the energy distribution throughout the far-infrared is consistent with the transition region between optically thick and optically thin synchrotron radiation.

In Figure 2, the 100 μm flux densities of both radio-quiet quasars that have been observed show an excess over the power-law component, perhaps suggesting a contribution from an underlying galaxy, presumably a spiral, that is bright at 100 μm. This conjecture is strengthened by the fact that both

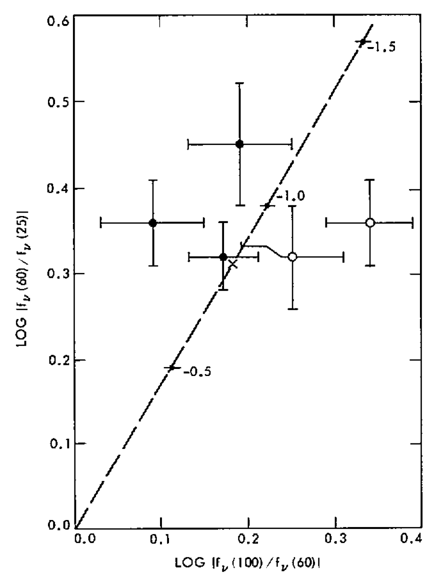

FIG. 2.—The ratio of the 60 μm to 25 μm flux density is plotted vs. the ratio of the 100 μm to 60 μm flux density. The filled circles indicate radio-loud quasars, and the open circles indicate radio-quiet quasars. The cross represents the colors of 3C 273 as measured by Clegg *et al.* (1983). The dashed line represents the power-law behavior $f_\nu \propto \nu^\alpha$ with α indicated. The uncertainties plotted represent the statistical uncertainties only and do not reflect the uncertainty in the calibration. The latter uncertainty, approximately 15% in each flux density or 0.08 in each coordinate, will serve to shift the location of the power-law slope relative to the centroid of the observations, but will not change the relative positions of the data points within their grouping.

quasars show evidence of extended emission at 1.2–2.2 μm, which may be an indication of a galaxy surrounding the quasar (Neugebauer *et al.* 1984*b*). The amount of excess observed at 100 μm over the power-law extrapolation is roughly 40% of the total 100 μm flux of PC 0838+770 and corresponds to a 100 μm luminosity that is slightly less than that of NGC 1068. The observed brightness and color temperatures of some galaxies in the far-infrared (de Jong *et al.* 1984; Soifer *et al.* 1984) suggest that the far-infrared will be a sensitive probe of a galaxy component in quasars. A refinement of the pointed-observation calibration as well as the observation of more quasars will be required to see the extent of the 100 μm excess in these quasars and if such an excess is common to radio-quiet quasars as a class.

Comparisons of observations with several models for the radio-quiet quasars have been discussed by Condon *et al.* (1981, radio observations), Ennis, Neugebauer, and Werner (1982, millimeter-wavelength observations), and Strittmatter *et al.* (1980), among others. In one broad category of models, the emission from radio-quiet quasars is synchrotron radiation which is suppressed at long wavelengths by self-absorption. Models which incorporate inhomogeneously distributed radiating sources with reasonable parameters turn over at approximately 3.3×10^{12} Hz and are not seriously constrained by the *IRAS* observations.

In the second broad category of models, the infrared emission is the result of inverse Compton scattering of soft photons into the infrared by nonrelativistic electrons in a plasma cloud. As shown by Figure 6 of Ennis, Neugebauer, and Werner (1982), such a model would also be consistent with the *IRAS* observations, although the extension of the power-law continuum to 100 μm lowers the upper limit to the frequency of the soft photons to about 5×10^{12} Hz. The new measurements are thus consistent with present models, although they put stricter constraints on them than previously possible. It should be noted that the presence of the 100 μm excess may mask the true nature of the underlying quasar continuum. Further *IRAS* measurements of quasars, both from pointed observations and those from the survey itself, should help to narrow the range of possible models.

We thank the many people whose efforts in preserving the sensitivity of *IRAS* made these measurements possible. We also thank the staff, but especially G. Kopan and C. Oken, of the science data analysis facility (SDAS) at JPL who made the reduction of these data possible.

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