FAR-INFRARED PROPERTIES OF OPTICALLY-SELECTED QUASARS AND SEYFERT GALAXIES

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Pointed IRAS observations and ground-based observations are used to determine the infrared properties of optically-selected Seyfert galaxies and quasars. The use of complete, unbiased, optically-selected samples means that statistical tests can be applied to probe the underlying properties of active galactic nuclei (AGNs).

We have studied the near-infrared-to-millimeter spectral energy distributions (SEDs) of the CfA Seyfert galaxies, a well-defined, unbiased sample of 25 Type 1 and 23 Type 2 Seyfert galaxies selected by optical spectroscopy. Spectroscopic selection allows low-luminosity, red Seyfert 2 galaxies to be found with a much higher success rate than in ultraviolet-excess surveys such as the Markarian survey. All but one of the objects observed by IRAS were detected at 60 μm, and 70% were detected at all four IRAS frequencies. A subsample of the ten brightest of the PG/BQS quasars with $B < 15.00$ and $M_B < 23.0$ were studied at infrared and radio wavelengths. Ninety percent were detected in at least three IRAS observing bands.

These data show strong trends in the infrared SEDs. Optically-selected quasars tend to have very flat infrared spectra with $\alpha_{12\,\mu m-60\,\mu m} = -0.69 \pm 0.41$ ($F_\nu \propto \nu^\alpha$, RMS scatter for individual objects), and $\alpha_{2.2\,\mu m-25\,\mu m} = -1.09 \pm 0.16$. Seyfert 1 galaxies have relatively flat infrared spectra with $\alpha_{12\,\mu m-60\,\mu m} = -1.08 \pm 0.44$ and $\alpha_{2.2\,\mu m-25\,\mu m} = -1.15 \pm 0.29$. The infrared spectra of Seyfert 2 galaxies are much steeper, with ($\alpha_{12\,\mu m-60\,\mu m} = -1.55 \pm 0.36$ and $\alpha_{2.2\,\mu m-25\,\mu m} = -1.56 \pm 0.34$). Figure 1 is a plot of $\alpha_{2.2\,\mu m-25\,\mu m}$ versus $\alpha_{12\,\mu m-60\,\mu m}$, which shows that quasars and most Seyfert 1 galaxies occupy a different region from Seyfert 2 galaxies.

This is strong evidence that the infrared spectra of Seyfert 2 galaxies are dominated by thermal emission from warm dust, while nonthermal emission is more important in the spectra of quasars and luminous Seyfert 1 nuclei. Objects with infrared SEDs dominated by thermal dust emission (starburst galaxies, Seyfert 2 galaxies, normal galaxies, etc.) almost always have steep infrared SEDs, while objects known to be dominated by nonthermal emission (such as BL Lacertae objects and OVV quasars) usually have flat SEDs. Edelson and Malkan (1986, Ap. J., 308, in press) found that Seyfert galaxies believed to be dominated by nonthermal emission in the infrared had $\alpha_{2.2\,\mu m-25\,\mu m} > -1.25$, while those thought to be dominated by thermal dust emission usually had $\alpha_{2.2\,\mu m-25\,\mu m} < -1.25$. All the optically-selected quasars and most of the high-luminosity Seyfert 1 galaxies have $\alpha_{2.2\,\mu m-25\,\mu m} > -1.37$ and $\alpha_{12\,\mu m-60\,\mu m} > -1.25$, while all the Seyfert 2 galaxies and the highly reddened, low-luminosity Seyfert 1 galaxies have $\alpha_{2.2\,\mu m-25\,\mu m} < -1.37$. Edelson and Malkan (1986) also found a strong correlation

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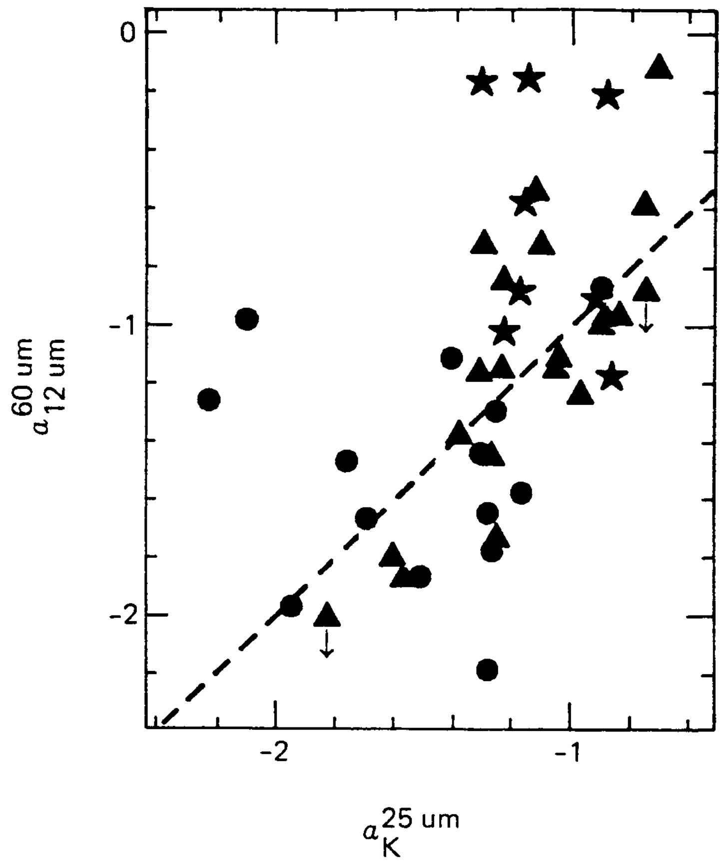

Figure 1. Color-color diagram of $\alpha 2.2\mu m/25\mu m$ versus $\alpha 12\mu m/60\ \mu m$. Quasars are denoted by stars, Seyfert 1 galaxies are denoted by triangles, and Seyfert 2 galaxies by circles. A point which lies on the dashed line has $\alpha 2.2\mu m/25\mu m = \alpha 12\mu m/60\mu m$. Quasars and Seyfert 2 galaxies occupy different regions, and most Seyfert 1 galaxies lie somewhere in between.

between reddening and infrared spectral slope. Seyfert 2 galaxies and dusty Seyfert 1 galaxies tend to have large reddenings and steep infrared SEDs, while quasars and high-luminosity Seyfert 1 galaxies have little or no detectable reddening and flat infrared SEDs.

The fact that the quasars and unreddened Seyfert 1 galaxies have straight or gently curving infrared SEDs, which extrapolate smoothly to near-infrared wavelengths, is also indicative of nonthermal emission. OVV quasars and BL Lacertae objects have infrared SEDs of this type. Dusty objects usually have infrared SEDs which curve sharply downward to higher frequencies. This is because dust cannot survive at temperatures hot enough to radiate primarily at near-infrared wavelengths.

Finally, the large 60 to 100 μm luminosities are further evidence of the dominance of nonthermal infrared emission from luminous Seyfert 1 galaxies and quasars. Assuming that the far-infrared emission from luminous quasars is thermal emission from dust, the emitting regions must be a few kpc in size. The high turnover frequencies found would imply dust high temperatures, $T_d > 70$ K. The sizes and masses are too large to be associated with the narrow-emission-line region, yet the high temperatures suggest that the dust could not lie outside the narrow-line region.

Almost one-half the Seyfert galaxies and seven of the nine quasars detected in three or more IRAS bands have far-infrared spectra which turn over between 30 and 100 μm. The nonparametric Breslow (logrank) test indicates that quasars have higher values of the turnover frequency, ν_t, than Type 1 (or Type 2) Seyfert galaxies, at the 99.4% confidence level. Furthermore, most of the least luminous Seyfert galaxies have undetected turnovers (i.e., $\nu_t < 3$ THz). A simple explanation is that both Seyfert 1 galaxies and quasars have relatively high turnover frequencies, but that cold dust emission from the disk of the underlying galaxy masks or shifts it to lower frequencies in lower-luminosity Seyfert galaxies.

The turnover can be used to determine source parameters, depending on the emission mechanism assumed. Under the assumption that the far-infrared spectra are dominated by emission from a synchrotron self-absorbed source, with $T_B \sim 10^{11-12}$ K (as appears to be the case with quasars and luminous Seyfert galaxies) source sizes of the order of a light day are derived for quasars and luminous Seyfert 1 galaxies. These sources are typically 100 to 1000 Schwarzschild radii across, similar to the size of the hypothesized accretion disk.

For the Seyfert 2 galaxies and other dusty objects, the turnover can be used to determine minimum dust sizes and masses. This calculation yields minimum dust temperatures of 35 to 70 K. This is significantly warmer than dust in normal galaxies. Minimum source sizes of order 100 pc are derived. This suggests that the infrared emission from Seyfert 2 galaxies and dusty Seyfert galaxies arises in the narrow-line region.