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Infrared SEDs of Seyfert Galaxies: Starbursts and the Nature of the Obscuring Medium

Catherine L. Buchanan¹, Jack F. Gallimore², Christopher P. O’Dea¹, Stefi A. Baum³, David J. Axon¹, Andrew Robinson¹, Moshe Elitzur⁴, & Martin Elvis⁵

Abstract. We present the results of IRS low-resolution spectroscopy of 51 Seyfert galaxies, part of a large *Spitzer* observing program to determine the mid-to-far infrared spectral energy distributions of a well-defined sample of 87 nearby, 12 μm -selected Seyferts. We find that the spectra clearly divide into groups based on their continuum shapes and spectral features. The infrared spectral types appear to be related to the Seyfert types. Some features are clearly related to a starburst contribution to the IR spectrum, while the observed power-law continuum shapes, attributed to the AGN, may be dust or non-thermal emission. Principal component analysis results suggest that the relative contribution of starburst emission is the dominant cause of variance in the spectra. We find that the Sy 2’s show on average stronger starburst contributions than the Sy 1’s.

1. Introduction

Understanding the inner workings of Active Galactic Nuclei (AGNs) is important for understanding the role of supermassive black holes in galaxy evolution. The mid-to-far infrared (MFIR) is a key wavelength regime for testing the AGN unified scheme and probing the nature of the nuclear obscuring medium. The *Spitzer Space Telescope* allows studies to be made at higher sensitivity and spatial resolution than previous IR missions¹. We are conducting a large observing program with all three *Spitzer* instruments to determine the MFIR spectral energy distributions (SEDs) of 87 Seyfert galaxies (PI: J. Gallimore, PID: 3269). The sample of Seyfert galaxies used for this study comprises all Seyfert galaxies from the extended 12 μm sample of Rush et al. (1993) that

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have $cz < 10000 \text{ km s}^{-1}$. Here we discuss the 51 objects in the sample for which the low-resolution, $5 - 35 \mu\text{m}$ IRS spectra are currently available². The analysis of these spectra and a more detailed discussion of the results are presented in Buchanan et al. (2006).

2. Infrared Spectral Shapes and Seyfert Types

We find four distinct types of continuum shapes and spectral features among the IRS spectra of the Seyfert nuclei. Figure 1 shows typical spectra in each group. We group the spectra according to the following main properties:

- Twenty-four objects (47% of the observed objects) have spectra dominated by strong PAH emission features and very red continuum suggestive of cool dust; Mrk 938 is the archetype. Many (16) of these objects show clear or weak silicate absorption at $10 \mu\text{m}$.
- Sixteen objects (31%) have continua that can be described by a broken power-law; they show a flattening in the continuum slope at $\sim 20 \mu\text{m}$; NGC 4151 is the brightest of this class. This flattening may be due to a warm ($\sim 170 \text{ K}$) dust component, peaking at $\sim 20 \mu\text{m}$, dominating the mid-IR emission (e.g., Weedman et al. 2005; Perez Garcia & Rodriguez Espinosa 2001; Rodriguez Espinosa et al. 1996), however, a simple model of an emissivity-weighted blackbody function does not fit the continuum of these spectra well. Two of these objects, Mrk6 and Mrk335, show clear silicate emission features. A further 9 objects in this group, including NGC4151, show weak excesses at 10 and $18 \mu\text{m}$ that may be due to silicate emission.
- Eight objects (16%) have power-law continuous spectra. NGC 3516 is representative of this class. These spectra show no strong dust emission or absorption features, though most have weak excesses at 10 and $18 \mu\text{m}$ that may be due to silicate emission.
- Two objects (NGC 1194 & F04385–0828) show a broad absorption feature at $9.7 \mu\text{m}$ due to silicate dust.

One object (NGC 7603) appears to show both PAH and silicate emission features and otherwise fails to meet any of the above classifications.

The spectral shapes may be quantitatively characterized by the IR colors, or spectral indices, derived from the spectra. The spectral index between 20 and $30 \mu\text{m}$ quantifies the slope of the spectrum (above the $\sim 20 \mu\text{m}$ ‘break’ for broken power-law spectra), while the spectral index between 8 and $10 \mu\text{m}$ indicates the presence or absence of the $9.7 \mu\text{m}$ silicate feature and PAH features. The resulting color-color diagrams are given in Figure 2. One Sy 2 (NGC3079) with extreme colors, $\alpha_{20-30 \mu\text{m}} = 4.7$ and $\alpha_{8-10 \mu\text{m}} = -12.5$, is not shown. The Sy 1’s (Seyfert types 1.0, 1.2 and 1.5) lie in the lower-right part of the diagram, occupied by unbroken and broken power-law spectra, specifically avoiding the region of the reddest PAH emitters. Sy 2’s are found in both regions. Earlier type Seyferts (i.e. 1 – 1.5) have the bluest colors, while Seyfert 2’s with hidden broad line regions (HBLRs; type 2h) span the range of colors. The fact that Sy

²The IRS was a collaborative venture between Cornell University and Ball Aerospace Corporation funded by NASA through the Jet Propulsion Laboratory and Ames Research Center.

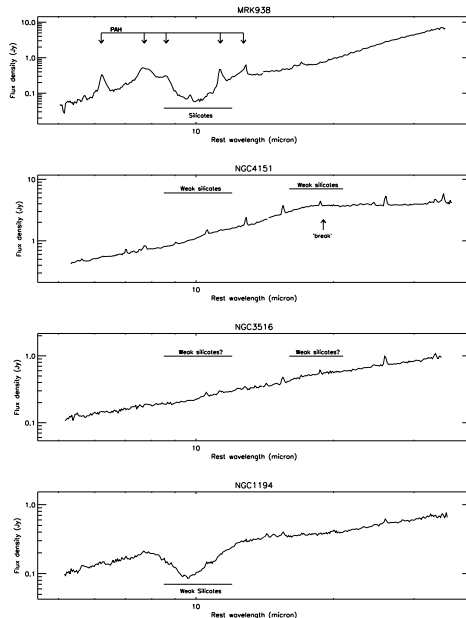


Figure 1. Typical spectra in each group: Mrk 938 (red continuum with PAH features), NGC4151 (broken power-law), NGC3516 (power-law), and NGC1194 (silicate absorption). All spectra have been converted to restframe.

1's consistently show the bluest infrared colors and the Sy 2's are the reddest sources indicates the IR spectra are changing systematically with Seyfert type.

We performed a principal component analysis (PCA) on the spectra to determine the component spectral shapes (eigenvectors) producing the variety of spectra seen in the sample (see, e.g., Francis & Wills 1999; Shang & Wills 2004). We find that the first eigenvector is the most dominant and contributes 91% of the variance in the spectra. We find that the relative contribution of eigenvector 1 to each spectrum relates strongly to the shape of the SED, as the different shapes have significantly different contributions from this eigenvector (Figure 3).

The similarity in the features between the red objects like MRK 938 and the IR spectra of starburst galaxies such as M 82 strongly suggests these objects are dominated by the starburst contribution to the dust heating at mid-infrared wavelengths (Figure 4). We find a significant difference between the contribution of the first eigenvector to the spectra of the Sy 1's and Sy 2's (Figure 5). Our results confirm the previous findings of Maiolino et al. (1995) and Gorjian et al. (2004), based on ground-based photometry, that Sy 2's show more star formation than Sy 1's.

3. Conclusions

We present the results of Spitzer IRS nuclear spectra for the first 51 of a complete sample of 12 μm selected Seyfert galaxies. We find the following main

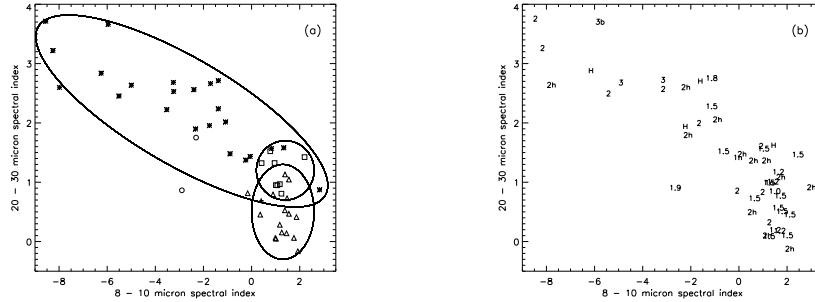


Figure 2. IR color-color diagrams derived from the IRS spectra. (a) The symbols indicate the shape of the spectrum: red continuum with PAH features (*stars*), broken power-law (*triangles*), unbroken power-law (*squares*), and silicate absorption (*circles*). The ellipses show the areas occupied by the three largest groups. (b) The numbers indicate the Seyfert spectral type. Numbers 1.0 – 1.9 and 1n represent Seyfert 1 subtypes. Symbols 2h and 2 represent Seyfert 2’s with and without HBLRs, respectively. LINERs, with and without broad lines, are shown by numbers 3 and 3b, respectively, and starburst galaxies are indicated by the letter H.

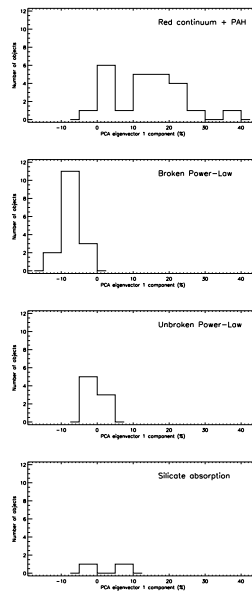


Figure 3. Distribution of the relative contribution of eigenvector 1 for the different shapes of the mid-infrared SED in the sample.

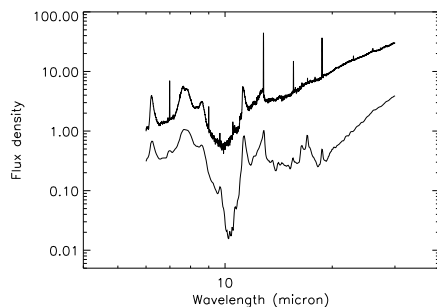


Figure 4. The first eigenvector of the PCA which we interpret as dominated by a starburst component but also including contribution from other features (*thin line*), and, for comparison, the ISO spectrum of starburst galaxy M82 (*thick line*), from <http://isc.astro.cornell.edu/~sloan/library/swsatlas/atlas.html>. The eigenvector clearly shows the PAH features and silicate absorption seen in starburst galaxies. The shape of the eigenvector at the longer wavelength differs slightly from a starburst shape. It is possible that this shape in the eigenvector produces the break in slope in the NGC 4151-like objects.

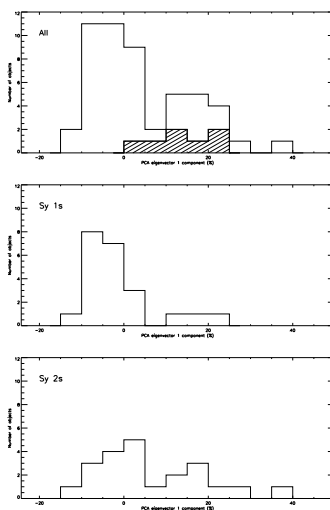


Figure 5. Distribution of the relative contribution of eigenvector 1 for all observed objects (*top*), Sy 1's (*middle*) and Sy 2's (*bottom*). The hashed region in the top panel indicates the objects reclassified as non-Seyferts (LINERs and starburst galaxies).

conclusions:

- The spectra clearly divide into groups based on their continuum shapes and spectral features. The largest group (47% of the sample of 51) shows very red continuum suggestive of cool dust and strong emission features attributed to PAHs. Sixteen objects (31%) are well described by a broken power-law continuum. A further 16% of the sample show power-law continua with unchanging slopes. Two objects are dominated by a broad silicate absorption feature. One object in the sample shows an unusual spectrum dominated by emission features, that is unlike any of the other spectra. Some features are clearly related to the starburst contribution to the IR spectrum, while the mechanisms producing the power-law continuum attributed to the AGN component are not yet clear. The IR SEDs are related to the Seyfert types but the precise correspondence between the IR types and the optical spectral types is unclear.
- Principal component analysis suggests that the relative contribution of starburst-heated dust emission to the SED is the dominant cause of variance in the observed spectra.
- We find that the Sy 2's typically show stronger starburst contributions in their IR spectra than the Sy 1's, confirming previous results found using photometric data.

Detailed modeling of the continuum emission is underway to separate in detail the starburst and AGN contributions to the IR spectrum in order to place constraints on the opacity and geometry of the nuclear obscuring material, and to compare the relative starburst contributions of Seyfert types 1 and 2.

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