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# ISO Observations of Seyfert Galaxies

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**Abstract.** A list of 41 Active Galactic Nuclei (AGN) drawn from the CfA sample has been observed with the ISO satellite. The data set consists of 2.5-11.6 $\mu$m low resolution (3000 km/s) spectra and contemporaneous images obtained through narrow band filters at 6.75 and 9.63 $\mu$m and a spatial resolution of 3 arcsec per pixel. Apart from a few close-by objects, the 2–12 $\mu$m spectra are completely dominated by the point-like nuclear source. The spectrum of type I Seyfert galaxies is statistically different from that of type IIs: the former shows a smooth power-law continuum of index -0.93$\pm$0.26 with only weak Polycyclic Aromatic Hydrocarbon (PAH) features while the latter clearly displays strong PAH emission and no or only very weak continuous emission. However, in a PAH luminosity histogram, Seyfert 1s and Seyfert 2s are virtually undistinguishable. We therefore conclude that the putative molecular torus is optically thick to the 2.5–12 $\mu$m continuum and that PAH emission originates from a region outside the torus, such as the NLR or a nuclear starburst. The mid-IR spectral index of Sy1s is not statistically different from the optical to X-ray index of quasars and Seyferts.

## 1. Introduction

According to the so-called "unified model" of AGNs, Seyfert 1 and Seyfert 2 galaxies are essentially the same objects viewed at a different angle: Sy1s are observed close to face-on such that we have a direct view to the central accretion disk responsible for the strong UV-Optical-X-ray continuum and the Broad emission Line Region (BLR), whereas Sy2s are seen at an inclination such that our view is blocked by an optically very thick dusty molecular torus which surrounds the disk and the BLR (e.g. Antonucci 1993).

This models makes specific predictions. In particular, the UV photons from the disk which are absorbed by the grains in the torus should be re-emitted as dust thermal emission in the IR. Several observational arguments constrain the torus inner radius to be of the order of $\sim$ 1 pc in which case the gas and dust temperature should peak to about 700–1000 K and give rise to a thermal emission "bump" with a maximum between 7 and 15 $\mu$m depending on the torus inclination (Pier and Krolik 1992; 1993). This model also predicts that the silicate 9.7 $\mu$m feature should appear preferentially in absorption in Sy2s and preferentially in emission in Sy1s.

## 2. Observations

In order to test the above predictions and better constrain the torus model, a sample of 41 Active Galactic Nuclei (AGN) has been observed with the PHT (Lemke et al. 1996) and CAM (Cesarsky et al. 1996) instruments on board of the Infrared Space Observatory (Kessler et al. 1996). The sample is mainly drawn from the hard X-ray selected CfA complete sample (Huchra, Burg 1992), supplemented with some additional bright galaxies and quasars. It contains 22 Seyfert 1s and 19 Seyfert 2s, where we defined Sy1s as all objects of type $\leq 1.5$ and Sy2s those for which the type is $> 1.5$.

The data set consists of 2.5 to 11.6 $\mu$m spectra obtained with the PHT-S low resolution (3000 km/s) spectrograph together with contemporaneous images obtained through narrow band filters at 6.75 and 9.63 $\mu$m and at a spatial resolution of 3" per pixel.

## 3. Calibration and data reduction

The images were reduced and calibrated using standard procedures of the interactive analysis package CIA. PHT-S was operating close to its sensitivity limit (10 to 50 mJy dep. on wavelength). The spectra were taken in chopped mode and a special calibration procedure, different from the one already provided in the standard interactive analysis software PIA, had to be applied.

The signals of the Si:Ga photoconductors show after a flux-change an almost immediate change to an intermediate level, followed by a characteristic slow transient to the final level. At the very faint fluxes, this timeconstant is extremely long, so only the initial step is observed in chopped-mode. The spectral response function for this particular mode and flux-level was derived directly from a calibration observation of the faint standard star HD132142, ranging from 2.54 to 0.15 Jy, which was performed with the same chopper frequency (1/256 Hz) and readout-timing. The S/N of the spectra was considerably improved by two measures that deviate from the standard PIA procedure. *i*) the long integration ramps (32 s each) were divided into sub-ramps of 2 sec without performing a deglitching at ramp-level *ii*) after slope-fitting and deglitching at slope-level, the maximum of the distribution of slopes was determined by fitting a gaussian to the histogram. The agreement of the CAM and PHT photometry is very good. There are only 5 mismatches, of which 3 are explained by an extended host galaxy clearly visible in the 32×32 pixel CAM-images.

## 4. Results

As illustrated in fig 1, the mid-IR spectrum of a typical Sy1 (Mrk 509, left) is markedly different from that of a Sy2 (NGC 5953, right): Sy1 have a strong continuum well approximated by a power-law ($F_\nu \propto \nu^\alpha$) of index $\alpha \sim -0.9$ and only weak emission features. By contrast, a Sy2 displays only a very weak and ill-defined continuum together with very strong emission features.

A power-law fit to each spectrum outside of the emission bands yields an average index for the whole sample of -0.93 and an r.m.s. dispersion of 0.41. Most of the scatter comes from the Sy2 for which the continuum is too weak

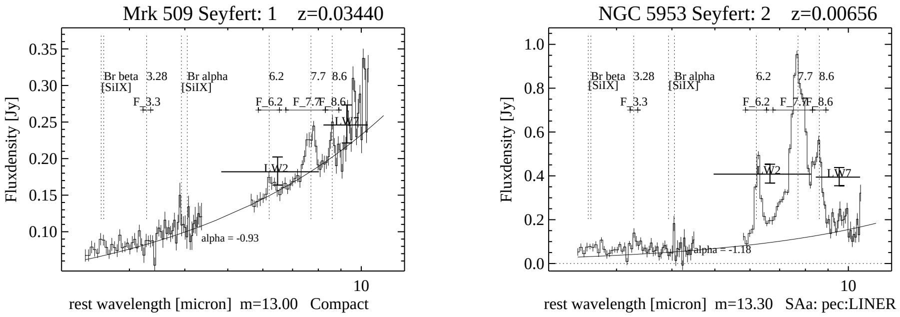


Figure 1. Two representative spectra of a Sy1 (left) and a Sy2 (right). The two data-poins with error bars give the flux from the imaging photometry

to be accurately defined. Restricting the analysis to the 22 Sy1s (i.e. type $\leq 1.5$) significantly reduces the scatter and yields $\langle\alpha\rangle = -0.93 \pm 0.26$. This is not statistically different from the mean 7500 Å–2 keV index $\alpha_{\rm rx} = -0.89 \pm 0.05$ obtained by Mushotzky and Wandel (1989) for their sample of 81 Sy1 and QSOs. The mid-IR continuum of Sy1s therefore appears to be a straight extension of the near-IR-to-X-ray spectral energy distribution (SED). In particular, it does not show the thermal bump expected from the torus.

The broad emission bands have well defined peaks at 6.2, 7.7 and 8.6 $\mu$m. In many Sy2s as well, a weaker band can be seen at 3.3 $\mu$m (e.g. fig 1). These four features are ubiquitous in many galactic and extragalactic sources in particular HII regions and starburst galaxies. They have been ascribed to Polycyclic Aromatic Hydrocarbon (PAH). We have determined their strength by integrating all the flux above the best-fit power-law continuum. The resulting distributions of the 7.7. $\mu$m equivalent widths (EW) is shown in fig 2.a with different symbols for Sy1 (light hatching at +45 °) and Sy2 (heavy hatching at -45 °). The distributions of PAH luminosities is shown in fig 2.b. Figure 2.a confirms that Sy1 PAHs are systematically weak compared to Sy2 PAHs whose EWs spread up to very large values. The mean/r.m.s. $\rm EW_{7.7}$ are $0.207/0.290\times10^{-12}$ Hz and $15.874/12.015\times10^{-12}$ Hz for Sy1 and Sy2, respectively. A two-tail Kolmogorov Smirnov test confirms that the Sy1 and Sy2 EW distributions are statistically different at the $2 \times 10^{-4}$ confidence level. However, the distributions of PAH 7.7 $\mu$m *luminosities* of Sy1 and Sy2 are undistinguishable. Indeed, the mean ($\pm$ r.m.s.) for Sy1 is $\log \rm L_{7.7} = 42.258 \pm 0.798$, not significantly different from that of Sy2, $\log \rm L_{7.7} = 42.123 \pm 1.058$. A two-tail Kolmogorov-Smirnov test yields a 47.3 % probability that the 2 distributions are drawn from the same parent population.

We therefore conclude that there is no intrinsic difference between Sy1s and Sy2s for what concerns the luminosity of the PAH bands and that the difference in EW results entirely from the weakness of the continuum in Sy2s. This is qualitatively consistent with unification schemes which predict that the torus is optically very thick in the radial direction, such that the mid-IR continuum is extinguished up to at least 12$\mu$m in objects seen edge-on (i.e. Sy2s). Because the torus is flattened, it is partially transparent to its own radiation in the vertical

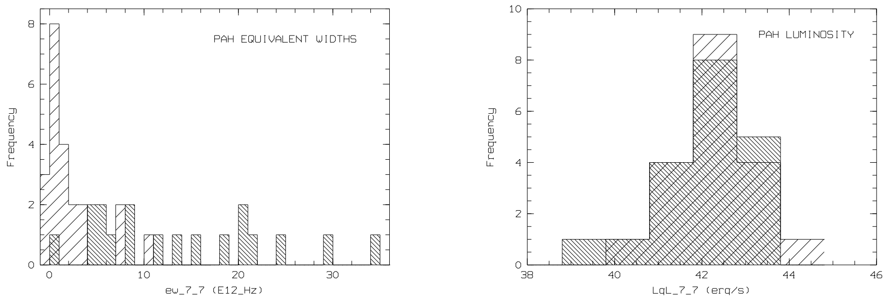


Figure 2. Distribution of equivalent widths (left) and logarithm of 7.7 $\mu$m luminosities (right) for Sy1 and Sy2.

direction. As a result, the mid-IR emission is anisotropic and beamed along the torus axis. Hence, the strong mid-IR continuum of Sy1s could, in principle, represent the torus thermal emission. However, the smoothness of the mid-IR power-law in Sy1 and the fact that it appears to be an extension of the IR to X-ray SED argue against such an origin. In other words, the Sy1 continuum looks much more like the extension of the non-thermal emission produced by the central engine than like the thermal "hump" expected from the torus.

The silicate 9.7 $\mu$m feature is either weak or absent of most Sy1 and Sy2 spectra and only appears in absorption. For instance, in Mrk 509, we obtain $\tau_{9.7} \simeq -0.15$, where, following Pier and Krolik (1992), we define $\tau$ as the natural logarithm of the ratio of the actual flux at 9.7 $\mu$m to the flux in the interpolated local continuum. Such a weak absorption and the general absence of Silicate emission in Sy1 rules-out models where the torus is optically thin in the vertical direction and requires a Thomson optical depth $\geq 1$ (see fig. 8 of Pier and Krolik 1992). On the other hand, the fact that the silicate feature does not appear strongly in absorption also rules-out models with very large radial optical depth. The best torus model so far seems to be one where the vertical and radial thomson optical depths are both about equal to unity.

Finally, the similarity of the PAH luminosities in Sy1s and Sy2s suggest that these features originate from outside the torus, either in the NLR or in a nuclear starburst.

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