

Spitzer spectroscopy of unusual hydrocarbons in cool radiative environments

G. C. Sloan

Cornell University, Space Sciences 108, Ithaca, NY 14853-6801
email: sloan@isc.astro.cornell.edu

Abstract. The *Spitzer Space Telescope* has discovered several objects with unusual spectra, where the emission features from polycyclic aromatic hydrocarbons (PAHs) are shifted to longer wavelengths than normally observed. Previously, only two of these class C PAH spectra had been identified. The new and larger sample reveals that PAHs emit at longer wavelengths when processed by cooler radiation fields. Limited laboratory data show that samples with mixtures of aromatic and aliphatic hydrocarbons produce emission features at longer wavelengths than purely aromatic samples. The aliphatic bonds are more fragile and would only survive in cooler radiation fields. In harsher radiation fields, the aliphatics attached to the aromatic hydrocarbons are destroyed.

Keywords. Infrared: ISM, (ISM:) dust, extinction

1. Introduction

Peeters *et al.* (2002) studied 57 spectra with emission features from polycyclic aromatic hydrocarbons (PAHs) observed with the Short Wavelength Spectrometer on the *Infrared Space Observatory*. They classified the majority as class A or B, depending on whether the 7–9 μm PAH complex peaked at 7.6 or 7.8 μm , respectively. The spectra of two sources, AFGL 2688 and IRAS 13416–6243, both in transition from the asymptotic giant branch (AGB) to planetary nebula (PN), showed a peak at longer wavelengths, $\sim 8.2 \mu\text{m}$. They were the only two class C PAH spectra in the sample.

2. New spectra

The Infrared Spectrograph (IRS, Houck *et al.* 2004) on the *Spitzer Space Telescope* (Werner *et al.* 2004) has added several more sources to the sample of unusual class C PAH spectra. Sloan *et al.* (2005) studied four Herbig AeBe (HAeBe) stars with emission from PAHs, but not silicates. They noticed that the spectra were intermediate between class B and C, with the 7.6–7.8 μm feature shifted to 7.9–8.0 μm . The coolest HAeBe star in their sample, HD 135344, had the most redshifted feature.

Peeters *et al.* (2002) included isolated HAeBe stars in class B, but they are generally distinct from the rest of the class; we will refer to them as class “B’” here, with the exception of HD 135344, which is class “B/C”. Figure 1 illustrates these different classes of spectra.

Another cool object, HD 233517, a K2 giant associated with an infrared excess, also shows a class C PAH spectrum (Jura *et al.* 2006), as does MSX SMC 029, a post-AGB object in the Small Magellanic Cloud (Kraemer *et al.* 2006). The intermediate-mass T Tauri star SU Aur also shows class C PAHs in its spectrum (Furlan *et al.* 2006).

HD 100764 is the second cool red giant with PAHs detected in its spectrum. Sloan *et al.* (2007) examined this spectrum, along with all other known class C PAH spectra. Instead of measuring the peak wavelength of the PAH features, they measured the *central* wavelength, defined to be the wavelength with half the emitted flux to either side. The

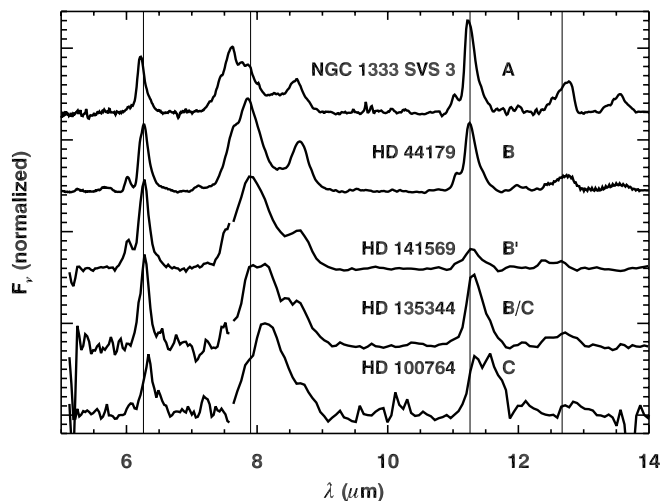


Figure 1. Representative spectra of the PAH classification originally defined by Peeters *et al.* (2002), after continuum subtraction. The vertical lines mark the positions of the PAH features for a typical class B PAH spectrum. The class A and B prototypes are from the Short-Wavelength Spectrometer on *ISO*. The spectra for the newer classes B' and B/C were published by Sloan *et al.* (2005). The class C spectrum is from Sloan *et al.* (2007).

7.6–8.0 μm PAH complex is dominated by two features at 7.65 and 7.85 μm , and while the peak wavelength will usually be either one of these two values, the central wavelength varies more smoothly.

Plotting central wavelength as a function of the effective temperature of the star exciting the PAH emission revealed a good correlation, as Figure 2 shows. This figure also includes data from more HAeBe and related stars studied by Keller *et al.* (2008), and they follow the previously recognized trends closely. Figure 2 also shows a shift in the 11.3 μm feature with temperature of the radiation field. The 6.2 and 8.6 μm PAH features shift as well (Sloan *et al.* 2007, Keller *et al.* 2008).

3. Interpretation

Generally, PAHs are observed in emission in photo-dissociation regions (PDRs) at the boundary between ionized nebulae and molecular clouds or dust shells. In these regions, the ionization front is propagating through the emitting material and destroying it. The typical PAH spectrum comes not from quiescent material, but material evolving rapidly in a harsh radiative environment. The situation is analogous to the bug collector whose only specimens have been scraped from the windshield of a car. In more pristine environments, the specimens might look differently.

Sloan *et al.* (2007) hypothesized that the wavelength shifts seen in class C PAH spectra arose from an increasing contribution from aliphatic hydrocarbons relative to the aromatic component which dominates most observed samples. There are multiple arguments in support, some of which date back to ground-based observations nearly two decades old.

Spectroscopy of post-AGB objects reveals several sources where the 3.4 μm feature is unusually strong compared to the 3.3 μm feature (Geballe & van der Veen 1990, Geballe *et al.* 1992). Both features arise from C–H stretching modes, and while the 3.3 μm feature is firmly identified as an aromatic stretch, it took observations of its overtone at 1.68 μm to verify that the accompanying 3.4 μm feature is aliphatic (Geballe *et al.* 1994). The

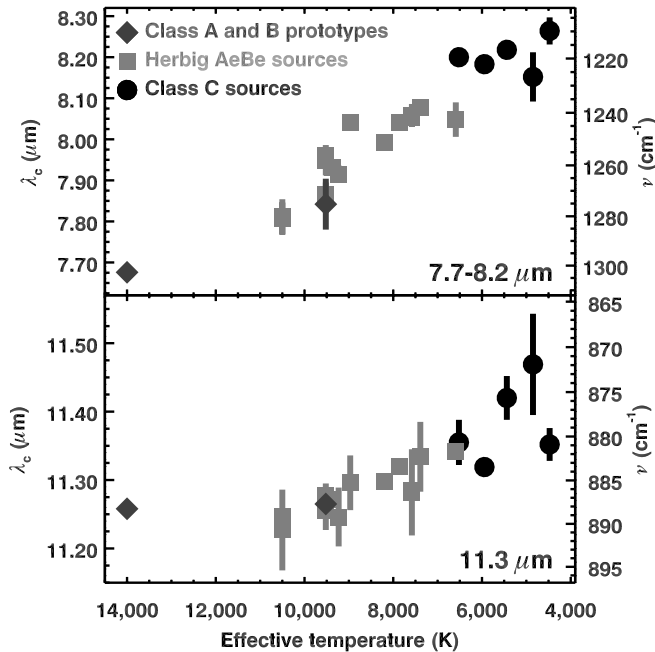


Figure 2. The dependence of the position of the PAH features at 7.6–8.2 and 11.3 μm with the temperature of the radiation field, adapted from Figure 8 by Keller *et al.* (2008).

central temperatures of post-AGB objects are considerably lower than the PNe they will become, and these hotter sources show much weaker 3.4 μm features.

Spatially resolved spectroscopy in the Orion Bar reveals a similar increase in the strength of the 3.4 μm feature compared to the 3.3 μm feature further away from the ionization front at the edge of the Orion Nebula (Geballe *et al.* 1989, Sloan *et al.* 1997). The aliphatic component survives only where it is more protected from the harsh UV radiation from the Trapezium.

While the relevant laboratory data are somewhat limited, those data examined by Sloan *et al.* (2007) reveal a shift toward longer wavelengths in samples where aromatic hydrocarbons have been mixed with or replaced by aliphatic hydrocarbons. More laboratory data are needed to confirm these preliminary conclusions.

All of these studies point to a richer hydrocarbon chemistry than the predominantly aromatic structures responsible for the typical PAH spectrum produced by a PDR.

4. Application

If the hypothesis of a redshifted PAH spectrum from aliphatic inclusions holds up, we have a useful diagnostic of the processing history of the emitting material. Not all spectra obey the relation between spectral position and temperature illustrated by Figure 2. For example, Peeters *et al.* (2002) noted that the spectral positions of *isolated* HAeBe stars were shifted to longer wavelengths, while they were not for embedded HAeBe stars. Sloan *et al.* (2007) discussed another example, reflection nebulae, which usually show class A PAHs but often are excited by relatively cool radiation fields. They suggested that the relation in Figure 2 works best for sources where the current radiation field dominates the PAH processing, but it will break down if the PAHs have been processed by other radiation fields in the past. What really matters is the integral of the radiation incident on the PAHs through time. In complex environments, it is likely that this integral does not correlate with the current radiation field as well as it does in isolated environments.

It follows that the scatter apparent in Figure 2 may not be statistical but may indicate the relative degrees of processing history in the different environments sampled.

5. A Final Note

The introduction of the PAH model to explain the unidentified infrared (UIR) emission features by Leger & Puget (1984) and Allamandola *et al.* (1985) led to a great deal of controversy that took more than a decade to sort out. Many other models have competed with the PAH model, including hydrogenated amorphous carbon (HAC, Duley & Williams 1979), quenched carbonaceous composite (QCC, Sakata *et al.* 1984), and even coal-like material (Papoular *et al.* 1989).

The community may be reaching a consensus that the UIR features as typically seen in PDRs arise from relatively simple PAHs (e.g., Allamandola *et al.* 1999, Hony *et al.* 2001, Peeters *et al.* 2002, Li & Draine 2002). However, most of the alternatives to the simple PAH model represent similar mixtures of hydrocarbons with aromatic and aliphatic bonds (e.g., Jones *et al.* 1990, Pendleton & Allamandola 2002, Kwok 2004). Evidence is mounting that in radiative environments less harsh than the typical PDR, it is these mixtures that we are observing.

References

- Allamandola, L. J., Hudgins, D. M., & Sandford, S. A. 1999, *ApJ* (Letter), 511, L115
 Allamandola, L. J., Tielens, A. G. G. M., & Barker, J. R. 1985, *ApJ* (Letter), 290, L25
 Duley, W. W. & Williams, D. A. 1979, *Nature*, 277, 40
 Furlan, E., *et al.* 2006, *ApJS*, 165, 568
 Geballe, T. R., Joblin, C., D'Hendecourt, L. B., Jourdain de Muizon, M., Tielens, A. G. G. M., & Leger, A. 1994, *ApJ* (Letter), 434, L15
 Geballe, T. R., Tielens, A. G. G. M., Allamandola, L. J., Moorhouse, A., & Brand, P. W. J. L. 1989, *ApJ*, 341, 278
 Geballe, T. R., Tielens, A. G. G. M., Kwok, S., & Hrivnak, B. J. 1992, *ApJ* (Letter), 387, L89
 Geballe, T. R., & van der Veen, W. E. C. J. 1990, *A&A*, 235, 9
 Hony, S., Van Kerckhoven, C., Peeters, E., Tielens, A. G. G. M., Hudgins, D. M., Allamandola, L. J. 2001 *A&A*, 370, 1030
 Houck, J. R., *et al.* 2004, *ApJS*, 154, 18
 Jones, A. P., Duley, W. W., Williams, D. A. 1990, *QJRAS*, 31, 567
 Jura, M., *et al.* 2006, *ApJ* (Letter), 637, L45
 Keller, L. D., *et al.* 2008 *ApJ*, in press
 Kraemer, K. E., Sloan, G. C., Bernard-Salas, J., Price, S. D., Egan, M. P., & Wood, P. R. 2006, *ApJ* (Letter), 652, L25
 Kwok, S. 2004, *Nature*, 430, 985
 Leger, A. & Puget, J. L. 1984, *A&A* (Letter), 137, L5
 Li, A. & Draine, B. T. 2002, *ApJ*, 572, 232
 Papoular, R., Conrad, J., Giuliano, M., Kister, J., & Mille, G. 1989, *A&A*, 217, 204
 Peeters, E., Hony, S., Van Kerckhoven, C., Tielens, A. G. G. M., Allamandola, L. J., Hudgins, D. M., & Bauschlicher, C. W. 2002, *A&A*, 390, 1089
 Pendleton, Y. J. & Allamandola, L. J. 2002, *ApJS*, 138, 75
 Sakata, A., Wada, S., Tanabe, T., & Onaka, T. 1984, *ApJ* (Letter), 287, L51
 Sloan, G. C., Bregman, J. D., Geballe, T. R., Allamandola, L. J., & Woodward, C. E. 1997, *ApJ*, 474, 735
 Sloan, G. C., *et al.* 2005, *ApJ*, 632, 956
 Sloan, G. C., *et al.* 2007, *ApJ*, 664, 1144
 Werner, M. W., *et al.* 2004, *ApJS*, 154, 1