PROCEEDINGS OF SCIENCE

The nature of circumstellar hydrocarbons

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Infrared spectroscopy of carbon-rich objects past the asymptotic giant branch reveals a rich variety of dust, including fullerenes, polycyclic aromatic hydrocarbons (PAHs), aliphatic hydrocarbons, the unknown carrier of the 21 μm feature, and the 26–30 μm feature which may arise from MgS. Many of the spectra also show a strong 11 μm feature due primarily to SiC. With these spectra, we can refine the newly identified Class D PAH emission, which shows unusual spectral structure at 7–9 and 11–14 μm. This sample also reveals the presence of alkyne hydrocarbon features in spectra which also show the 21 μm feature. The photometric properties of the spectra suggest that we detect fullerenes when we have a clearer line of sight to the central regions of young planetary nebulae.

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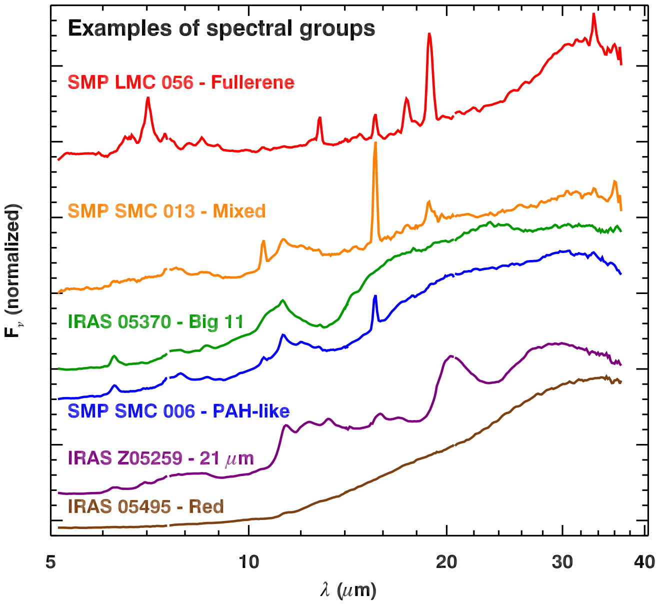

Figure 1: Examples from the spectral groups defined from the carbon-rich Magellanic post-AGB sample. SMP LMC 056 is a new detection of fullerenes.

This contribution highlights the results of our study of infrared spectra of carbon-rich objects in the Magellanic Clouds between the asymptotic giant branch (AGB) and fully developed planetary nebulae (PNe). Sloan et al. (2014; [6]) present a more complete analysis and discussion. The sample was observed using the Infrared Spectrograph (IRS) ([2]) on the *Spitzer Space Telescope* ([7]), and it includes 42 carbon-rich post-AGB objects in the Magellanic Clouds observed as part of several *Spitzer* programs. The PNe in our sample are young, and while they are the warmest objects in our sample, they are simultanouesly the PNe with the coolest central sources.

Fig. 1 illustrates the different spectral groups in our sample. The young PNe frequently show fullerene emission features at 6.5–8.5, 17.4, and 18.9 μm. We classify these sources as Fullerene or Mixed, depending on whether the 6–9 μm region shows just fullerene features or a mixture of fullerenes and PAH features. By measuring both the width and position of the 18.9 μm feature, one can disentangle it from the 18.7 μm [S III] forbidden line, even at low spectral resolution. Many of the spectra of carbon-rich PNe show a broad 11 μm feature which is predominantly SiC. The Big-11 group is defined as those spectra showing this feature but no evidence of fullerenes. The remaining groups show PAH-like emission features (PAH-like) or the 21 μm and related features (the 21 μm group), or they are very red and show no clearly definable features in their spectra (the Red group).

Fig. 2 focuses on some features which can dominate the spectra below $\sim$15 μm. Our larger paper ([6]) compares the Big 11 spectra to SiC profiles of carbon stars in the Magellanic Clouds and the Galactic Halo and shows that the big-11 feature consists mostly of SiC emission, with residuals from PAHs. The Class D PAH emission defined by Matsuura et al. (2014; [3]) actually shows two distinct sub-classes, with Class D2 showing no minimum between the 7.85 and 8.6 μm PAH components and a different structure in the 11–14 μm region, with the features usually observed

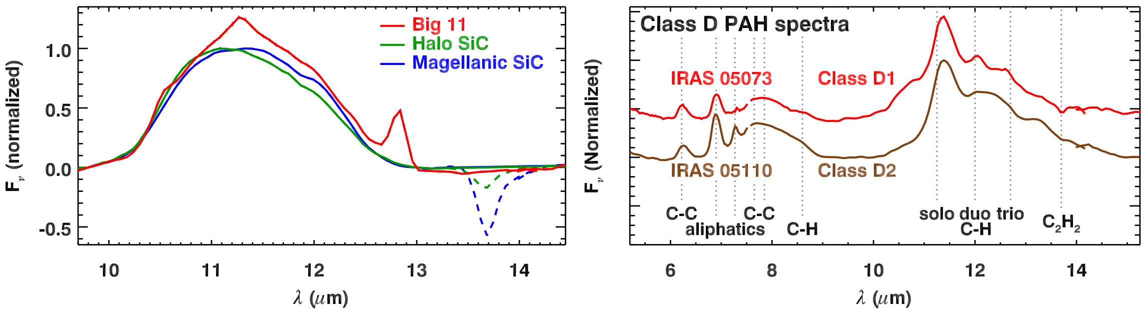

Figure 2: Left: SiC emission, as seen in carbon stars (green and blue traces), dominates the big-11 feature (red trace). The residual arises from PAHs. **Right:** Examples of Class D1 and Class D2 PAH emission.

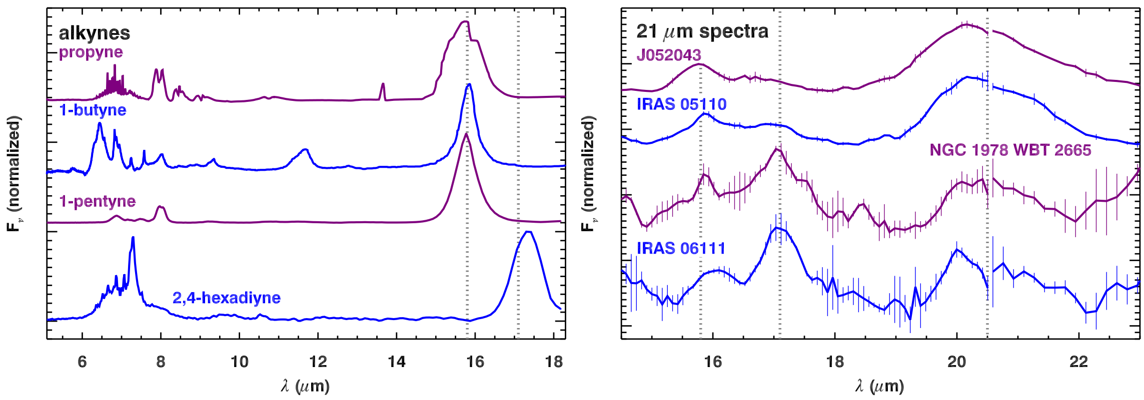

Figure 3: Left: Laboratory spectra of four alkyne species, based on data from the NIST Chemistry Web-Book. **Right:** Spectra of four of the 21 μm spectra, chosen to exemplify the variations in the strengths and positions of the 15.8 and 17.1 μm features. The 21 μm feature is actually centered at 20.5 μm in our sample.

at 12.0 and 12.7 μm shifted to $\sim$12.4 and 13.2 μm. The cause of these shifts is uncertain, but the presence of aliphatics in aromatic samples is known to shift the resonances to longer wavelengths (e.g. [5]; [4]).

The 21 μm sources show several spectral features alongside the 21 μm feature, including Class D1 or D2 PAH emission and emission features at 15.8 and 17.1 μm. Fig. 3 compares the laboratory spectra of four simple alkynes with some examples from the 21 μm group in our sample. The 15.8 and 17.1 μm features can be fit reasonably well with propyne and related aliphatic hydrocarbons. Propyne ($CH{\equiv}C{-}CH_3$) and longer alkyne chains (with additional CH_2 groups) all show 15.8 μm features. Fig. 3 includes a spectrum of 2,4-hexadiyne ($CH_3{-}C{\equiv}C{-}C{\equiv}C{-}CH_3$), where the triple bonds have shifted one group away from the ends and the resonance shifts to the vicinity of the observed feature at 17.1 μm. Thus this class of aliphatics could explain the presence of two of the spectral features commonly associated with 21 μm emission. Six of the 11 spectra with 21 μm features also show Class D2 PAH emission, and the possible connection of D2 emission to aliphatics adds to the growing body of circumstantial evidence connecting the 21 μm feature to aliphatic hydrocarbons (e.g. [1]).

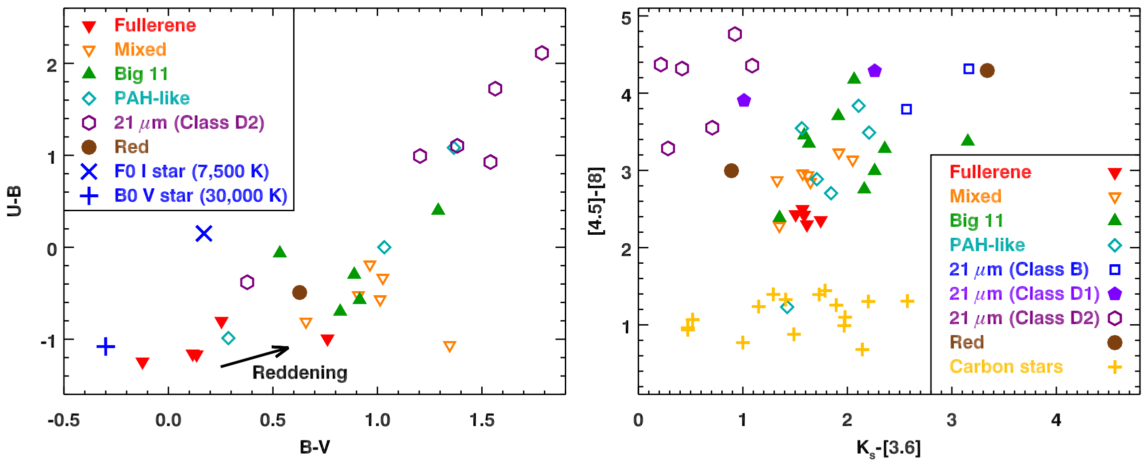

Figure 4: The distribution of our sample in color-color space, optical (**left**) and infrared (**right**).

Fig. 4 shows the distribution of our sample in optical and infrared color-color space. The sources showing the clearest fullerene spectra are the bluest in $B-V$, suggesting that we have the clearest line of sight to the central regions of the PNe when we can see fullerenes. The infrared colors of the fullerene sources are tightly constrained as well.

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