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# Aromatic, aliphatic, and the unidentified 21 micron emission features in proto-planetary nebulae

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**Abstract.** Aromatic features at 3.3, 6.2, 7.7, 8.6, 11.3 $\mu$m are observed in proto-planetary nebulae (PPNe) as well as in PNe and H II regions. Aliphatic features at 3.4 and 6.9 $\mu$m are also observed; however, these features are often stronger in PPNe than in PNe. These observations suggest an evolution in the features from simple molecules ($C_2H_2$) in AGB stars to aliphatics in PPNe to aromatics in PNe. In the same carbon-rich PPNe, a strong, broad, unidentified 21 $\mu$m emission feature has been found. We will present recent observations of the aromatic, aliphatic, and 21 $\mu$m emission features, along with $C_2H_2$ (13.7 $\mu$m) and a new feature at 15.8 $\mu$m, and discuss correlations among them and other properties of these PPNe.

**Keywords.** Astrochemistry, circumstellar matter, ISM: lines and bands, infrared: ISM, stars: AGB and post-AGB, planetary nebulae: general

## 1. Background and New Observations

Aromatic hydrocarbon emission features at 3.3, 6.2, 7.7, 8.6, and 11.3 $\mu$m, often attributed to PAHs, are observed in the spectra of various objects with hot irradiating sources; planetary nebulae (PNe), H II regions, reflection nebulae. They have also been observed in proto-planetary nebulae (PPNe), objects in the short-lived (∼1000 yr) transitional phase between AGB stars and PNe. In PPNe, the circumstellar envelope is detached but the central star is not hot enough to photo-ionize the nebula and is typically of spectral type F-G. Aliphatic emission features at 3.4 and 6.9 $\mu$m are also seen in PPNe and are often stronger than in PNe (Geballe 1997, Geballe *et al.* 1992). This suggests an evolution in the carbon chemistry of the circumsteller envelopes from $C_2H_2$ to aliphatics to aromatics as C-rich stars evolve rapidly from AGB to PPN to PN phases (Kwok 2004).

The unidentified 21 $\mu$m emission feature, first seen in *IRAS* spectra of four C-rich PPNe (Kwok *et al.* 1989), has subsequently been observed in additional C-rich PPNe with *ISO* (Volk *et al.* 1999) and recently with *Spitzer*. This 21 $\mu$m feature has been detected only in C-rich objects and essentially only in PPNe (and perhaps weakly in a few AGBs and young PNe). Suggested identifications include PAHs, TiC, SiC (see Speck & Hofmeister 2004 and references therein), and FeO (Guha Niyogi *et al.*, these proceedings).

New 3 $\mu$m spectra have been obtained of seven PPNe. All show the 3.3 $\mu$m and most show the 3.4 $\mu$m feature (Hrivnak *et al.* 2007). New mid-IR spectra have also been obtained of six carbon-rich PPNe using *Spitzer*. These reveal one new 21 $\mu$m source and give good observations of the others. Also seen are the 11.3 and 12.3 $\mu$m emission bands.

**Table 1.** Summary of the Spectral Features of Carbon-Rich PPNe and 21 $\mu$m Sources[a]

| Object | SpT | C/O | $C_2$,$C_3$ | 3.3 | 3.4 | 6.2 | 6.9 | 7.7 | 8.6 | 8br | 11.3 | 12.3 | Class[b] | $C_2H_2$ | 15.8 | 21 | 30 $\mu$m |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 02229+6208 | G8 Ia | ... | Y,Y | Y | Y:* | Y: | Y | N | N | Y | Y | Y | A | ... | | Y | Y |
| 20000+3239 | G8 Ia | ... | Y,... | Y | Y* | Y | Y | N | N | Y | Y | Y | A | ... | | Y | Y |
| 05113+1347 | G8 Ia | 2.4 | Y,Y | Y: | Y: | ... | ... | ... | ... | ... | Y | Y | ... | N:* | Y:* | Y | Y |
| 22272+5435 | G5 Ia | 1.6 | Y,Y | Y | Y | Y | Y | Y | N | Y | Y | Y | B | | Y: | Y | Y |
| 07430+1115 | G5 Ia | ... | Y,Y | Y | Y | ... | ... | ... | ... | Y: | Y: | ... | A | ... | ... | Y* | Y |
| 23304+6147 | G2 Ia | 2.8 | Y,Y | Y* | Y:* | Y | Y | Y | Y | Y | Y | Y | A | Y:* | Y* | Y | Y |
| 05341+0852 | G2 Ia | 1.6 | Y,Y | Y | Y | Y | Y | N | N | Y | Y | Y* | B | Y* | Y* | Y | Y |
| 22223+4327 | G0 Ia | 1.2 | Y,Y | Y | N | | | | | | Y | | A | | | Y | Y |
| 04296+3429 | G0 Ia | ... | Y,Y | Y | Y | | | Y | | | Y | Y | B | | | Y | Y |
| AFGL 2688 | F5 Iae | 1.0 | Y,Y | Y | Y | Y | Y: | N | N | Y | Y | N: | A | Y | | Y: | Y |
| 06530−0230 | F5 I | 2.8 | Y,Y | Y* | N | ... | ... | ... | ... | ... | Y* | Y* | A | Y* | Y* | Y* | Y* |
| 07134+1005 | F5 I | 1.0 | Y,N | Y | Y: | ... | Y | Y | N | Y | Y | Y | A | | Y: | Y | Y |
| 19500−1709 | F3 I | 1.0 | N,N | N | N | | | | | Y: | Y | Y: | ... | | Y: | Y | Y |
| 16594−4656 | B7 | ... | N,N | Y | N | Y | N | Y | Y | Y: | Y | Y: | A | | | Y | Y |
| 01005+7910 | B0 I | 1.2 | N,N | Y | Y* | Y | N | Y | Y | N | Y | N | A | ... | ... | N: | Y |
| 22574+6609 | ... | ... | ...,... | ... | ... | Y | Y | Y | N | Y | Y | Y* | ... | Y* | N* | Y | Y |
| 19477+2401 | ... | ... | ...,... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... | Y* | Y |

Note 1: Colon indicates a marginal or uncertain detection, blank indicates lack of information, "..." indicates that the object has not been observed in this spectral region.
Note 2: Asterisk indicates a new detection from Hrivnak *et al.* (2007) or Hrivnak *et al.* (2008).
[a] Table does not include three newly discovered C-rich PPNe IRAS 08143−4406, 08281−4850, 14325−6428 (Reyniers *et al.* 2004, 2007) that have not been observed in the IR.
[b] Classification scheme of Geballe (1997) at 3.3, 3.4 $\mu$m.

Two other emission features are seen. At 15.8 $\mu$m is a new, relatively strong, unidentified feature seen in four sources; it is strongest in the two with the strongest 21 $\mu$m feature. At 13.7 $\mu$m is seen the $C_2H_2$ feature in four sources, including the first report of $C_2H_2$ in emission in a post-AGB object (Hrivnak *et al.* 2008). Results are listed in Table 1.

## 2. Summary

- 3.3, 3.4 $\mu$m: All C-rich PPNs have 3.3 $\mu$m and most have 3.4 $\mu$m emission features.
- 21 $\mu$m: (a) All have the same shape and central wavelength (20.1±0.1 $\mu$m) but differ in strength; (b) all are C-rich, (almost) all show $C_2$, $C_3$, 3.3, 11.3, 30 $\mu$m emission.
- $C_2H_2$: (a) Detected in four 21 $\mu$m sources; all show P-Cygni profiles; (b) first detection in emission in post-AGB stars.
- 15.8 $\mu$m: New feature seen in several of the PPNe including previous *ISO* spectra; unidentified; (b) correlated with 21 $\mu$m emission?
- Trends: (a) All 21 $\mu$m sources are C-rich, (almost) all show $C_2$, $C_3$, 3.3, 11.3, 30 $\mu$m emission; (b) no correlation found between 3.4/3.3 ratio and spectral type.

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