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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 μm are observed in proto-planetary nebulae (PPNe) as well as in PNe and H II regions. Aliphatic features at 3.4 and 6.9 μm 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 μm emission feature has been found. We will present recent observations of the aromatic, aliphatic, and 21 μm emission features, along with C_2H_2 (13.7 μm) and a new feature at 15.8 μm, 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 μm, 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 μm 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 μm 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 μm 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 μm spectra have been obtained of seven PPNe. All show the 3.3 μm and most show the 3.4 μm 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 μm source and give good observations of the others. Also seen are the 11.3 and 12.3 μm emission bands.

Table 1. Summary of the Spectral Features of Carbon-Rich PPNe and 21 μm 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 μm
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 μm.

Two other emission features are seen. At 15.8 μm is a new, relatively strong, unidentified feature seen in four sources; it is strongest in the two with the strongest 21 μm feature. At 13.7 μm 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 μm: All C-rich PPNs have 3.3 μm and most have 3.4 μm emission features.
- 21 μm: (a) All have the same shape and central wavelength (20.1±0.1 μm) but differ in strength; (b) all are C-rich, (almost) all show C_2, C_3, 3.3, 11.3, 30 μm emission.
- C_2H_2: (a) Detected in four 21 μm sources; all show P-Cygni profiles; (b) first detection in emission in post-AGB stars.
- 15.8 μm: New feature seen in several of the PPNe including previous *ISO* spectra; unidentified; (b) correlated with 21 μm emission?
- Trends: (a) All 21 μm sources are C-rich, (almost) all show C_2, C_3, 3.3, 11.3, 30 μm emission; (b) no correlation found between 3.4/3.3 ratio and spectral type.

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