PLANETARY NEBULAE: THEIR EVOLUTION AND ROLE IN THE UNIVERSE
IAU Symposium, Vol. 209, 2003
S. Kwok, M. Dopita, and R. Sutherland, eds.

ISO Spectra of Planetary Nebulae

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1. Introduction

It has been well known since the *IRAS* mission that dust emission represents a significant fraction of the energy output from PNe (Zhang & Kwok 1991). Although the dust component in PNe was long thought to be due to the remnants of the envelopes of AGB stars (Kwok 1982), we now know that dust in PNe has a much richer chemical composition. In addition to amorphous silicates and SiC features commonly seen in AGB stars, PNe have been found to have strong aromatic infrared features (Russell et al. 1977), crystalline silicate features (Waters et al. 1997), and an unidentified emission feature at 30 μm (Forrest et al. 1981). In this paper, we show the *ISO* spectra of a number of PNe illustrating the diverse dust chemistry in PNe.

2. Results

Figure 1 shows *ISO* spectra of 4 PNe as examples of the following classes of dust compositions.

- Aromatic hydrocarbons: many carbon-rich PNe show strong emission features at 3.3, 6.2, 7.7, 8.6, and 11.3 μm characteristic of aromatic compounds. IRAS 21282+5050 shows strong aromatic hydrocarbon bands (AHB) with very few emission lines.
- Aromatic hydrocarbon and crystalline silicates: Cn1-1 shows a strong continuum due to AHB and crystalline silicate bands. No emission lines are seen.
- Amorphous silicates: the 10 and 18 μm amorphous silicates features, seen in over 3000 oxygen-rich AGB stars, are present in the spectra of PNe. The spectrum of H2-1 shows amorphous silicate features in emission.
- Peculiar: Mz-3 is a bipolar reflection nebula with a cool (32000 K) central star. With the exception of some crystalline silicate features, the dust continuum is of unknown origin and has a peculiar shape.

3. Discussion

While the general infrared continuum of PNe is due to dust (e.g. amorphous carbon and amorphous silicates) left over from the AGB, it is clear that new dust

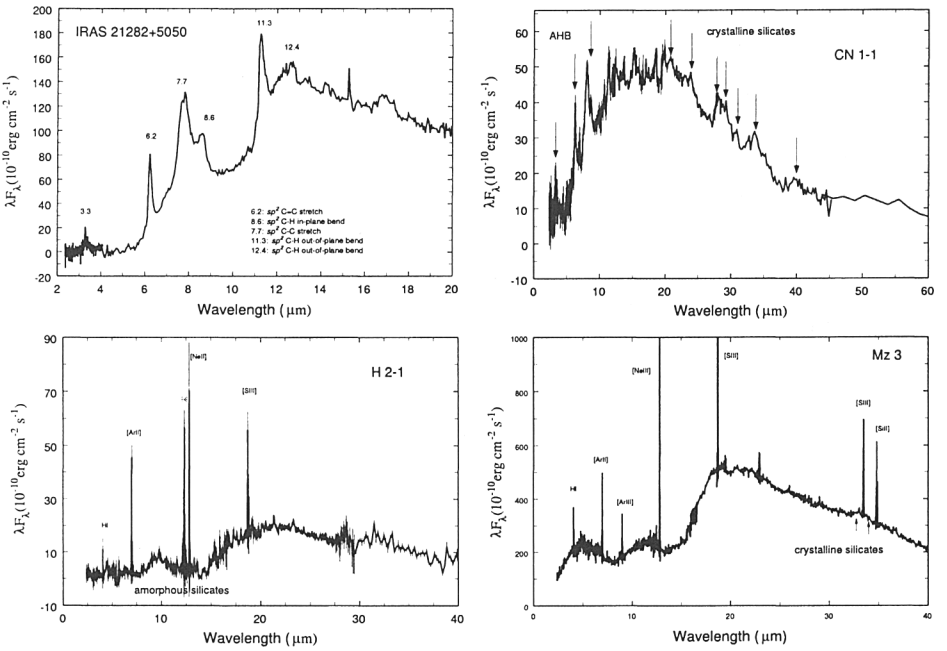

Figure 1. *ISO* spectra (clockwise from top left) of IRAS 21282+5050, Cn1-1, Mz-3 and H2-1, illustrating different dust compositions in PNe.

components (aromatic compounds and crystalline silicates) are formed beyond the AGB. Since the dynamical lifetime of the nebulae is only $\sim 10^4$ yr, the chemical processes forming these material must be extremely efficient (Kwok et al. 1999). The change in the level of the 8 and 12 μm plateau features from PPNe to PNe also suggests that photochemistry plays a role in evolution of the dust component (Kwok et al. 2001).

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https://doi.org/10.1017/S0074180900208826 Published online by Cambridge University Press