Bioastronomy 2002: Life Among the Stars
IAU Symposium, Vol. 213, 2004
R.P.Norris and F.H.Stootman (eds.)

Synthesis of Organic Compounds in the Circumstellar Environment

Sun Kwok

Department of Physics and Astronomy, University of Calgary, Calgary, Canada T2N 1N4

Abstract. Recent developments in infrared spectroscopy have made possible the detection of the stretching and bending modes of organic molecules in space. Infrared emission bands of the C-C and C-H stretching and bending modes of aromatic compounds have been widely observed in carbon-rich planetary nebulae, the descendents of carbon stars. Infrared spectra of the transition objects between carbon stars and planetary nebulae, called proto-planetary nebulae, have shown definite signatures of a variety of aliphatic side-groups attached to aromatic rings. This suggests that molecular synthesis is actively ongoing in the circumstellar environment and the chemical nature of these compounds evolve over time scales as short as several hundred years.

1. Introduction

The chemical element carbon is produced by triple-α reactions and dredged up from the helium-burning shell above the core to the surface during the asymptotic giant branch (AGB) phase of stellar evolution. Some time later, the star undergoes large-scale mass loss in the form of a stellar wind. When the entire hydrogen envelope of the star is depleted by this mass loss process, the stellar core is exposed and the surface temperature of the star gradually increases. When the surface temperature exceeds 30 000 K, the ultraviolet photons emitted by the star begin to photoionize the circumstellar material, creating a planetary nebula (PN; Kwok 2000, 2001).

The material ejected by the stellar wind during the AGB consists primarily of molecular gas and solid-state dust particles. Over 60 gas-phase molecules have been detected in AGB stars by millimeter-wave spectroscopy through their rotational transitions. The list of detected molecules includes inorganics (e.g., CO, SiO, SiS, NH_3, AlCl), organics (e.g., C_2H_2, CH_4, H_2CO, CH_3CN), radicals (e.g., CN, C_2H, C_3, HCO^+), rings (C_3H_2), and chains ($HC_{2n+1}N$). The most common solid-state material observed are amorphous silicates and silicon carbide (SiC). Over 4000 stars have been found to show the silicate feature, and over 700 stars showing SiC (Kwok et al. 1997).

There is now increasing evidence that a large amount of solid-state organic compound is being synthesized in the circumstellar environment during the post-AGB phase of evolution. In this paper, we will review recent observational results from *ISO*, and discuss the implications of the synthesis of complex organic molecules on the enrichment of the interstellar medium and the solar nebula.

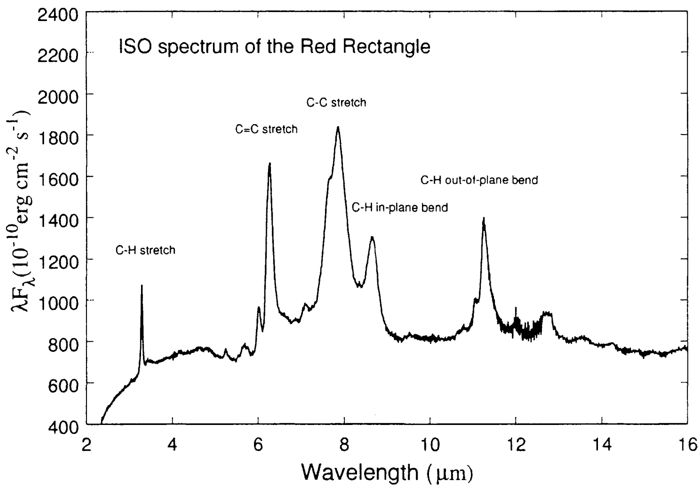

Figure 1. *ISO SWS01* spectrum of the Red Rectangle (HD 44179) showing the AIB emission features.

2. Aromatic and aliphatic compounds

A family of infrared emission features at 3.3, 6.2, 7.7, 8.6 and 11.3 μm, first discovered in the spectrum of the PN NGC 7027, is now postively identified as the stretching and bending modes of aromatic compounds (Fig. 1). These aromatic infrared bands (AIB) are detected in PN, reflection nebulae, HII regions, and the diffuse interstellar medium of our own and other galaxies. While the AIB features are not seen in AGB stars, they begin to appear in the spectra of proto-planetary nebulae (PPN), objects in evolutionary transition between the AGB and PN (Kwok 1993). When the star evolves to the PN stage, the AIB features become very strong.

In addition to the aromatic features, emission features at 3.4 and 6.9 μm due to the C-H aliphatic stretching and bending modes, respectively, have also been detected in the spectra of PPN and young PN (Kwok et al. 1999; Hrivnak et al. 2000). In Fig. 2, we show the infrared spectrum of the young PN IRAS 21282+5050 in the 3 μm region.

While the aromatic C-H stretch at 3.3 μm dominates the spectrum, emission features at 3.4 μm corresponding to C-H stretchs from aliphatic -CH_2 and -CH_3 sidegroups can be seen. There is also a feature at 3.56 μm, which could be due to an aldehyde group.

The spectra of PPN also show broad emission plateaus around 8 and 12 μm regions (Fig. 3), probably due to a combination of in-plane and out-of-plane bending modes of various aliphatic side-groups attached to aromatic rings (Kwok et al. 2001).

The above observations suggest that the emitting material has a mixture of sp^2 and sp^3 sites, and is likely to be a bulk solid-state grain. Proposed candidates for such carbonaceous material include hydrogenated amorphous carbon (HAC; Jones et al. 1990), quenched carbonaceous composite (QCC; Sakata et al. 1987),

https://doi.org/10.1017/S0074180900193234 Published online by Cambridge University Press

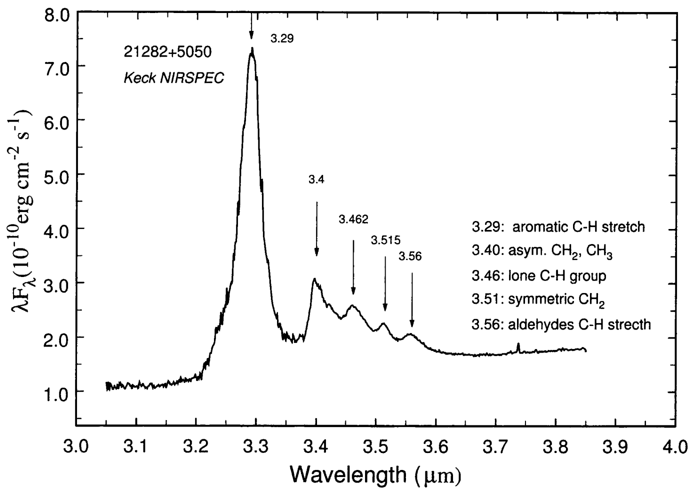

Figure 2. *Keck NIRSPEC* spectrum of the young PN IRAS 21282+5050 showing the presence of the 3.4 μm aliphatic bands besides the 3.3 μm aromatic band.

or coal (Papoular et al. 1996), all of which show broad emission plateaus similar to those observed in PPNs.

The process of chemical synthesis probably starts with the formation of acetylene during the AGB phase, leading to formation of benzene in the PPN phase (Cernicharo et al. 2001). The benzene molecules form the basic aromatic units from which various aliphatic side groups attach.

As the star enters the PN phase, the onset of ultraviolet emission destroys the aliphatic side groups and transform them into larger aromatic units (Kwok et al. 1999, 2001).

3. Summary

The circumstellar environment is an excellent laboratory for the study of astrochemistry because the physical conditions (temperature, density, radiation, etc) are well determined from other observations.

Most importantly, the chemical time scale is well constrained by the dynamical time scale of envelope expansion (10^4 yr for the AGB, 10^3 yr for PPN, and 10^4 yr for PN). By observing the spectral changes from AGB to PPN, to PN, we can obtain valuable information on the synthesis and processing of organic materials.

There is now strong evidence that carbonaceous compounds of considerable complexity are being made in the circumstellar envelopes of evolved stars, under extremely low density conditions and over very short time scales. Provided these grains can survive journeys through the interstellar medium, they would make up part of the solar nebula or even the primordial Earth. The extent to which these stellar organic grains contribute towards the origin of life on Earth remains to be studied.

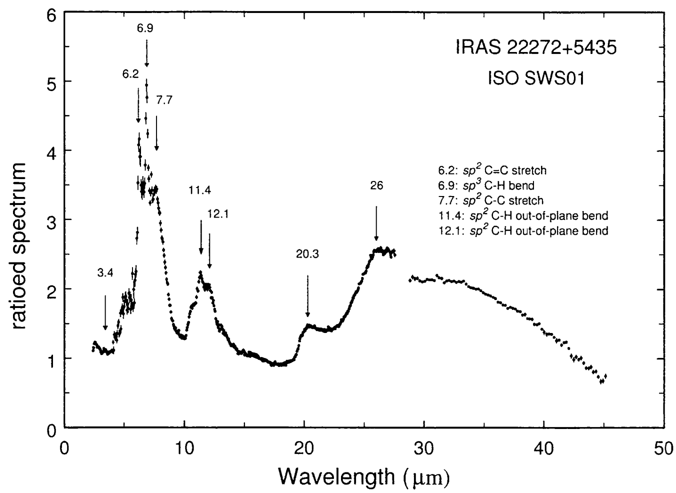

Figure 3. The *ISO SWS01* spectrum of the PPN IRAS 22272+5435 after the removal of the continuum. The spectrum shows emission plateau features at 8 and 12 μm, as well as unidentified emission features at 20 and 30 μm.

Acknowledgments. I thank K.M. Volk for processing the *ISO* spectra presented here. The Keck observations were made in collaboration with Tom Geballe and Bruce Hrivnak. This work is supported by the Natural Sciences and Engineering Research Council of Canada and the award of a Killam Fellowship by the Canada Council for the Arts.

References

Cernicharo, J., et al. 2001, ApJ, 546, L123

Hrivnak, B.J., Volk, K., & Kwok, S. 2000, ApJ, 535, 275

Jones, A. P., Duley, W. W., Williams, D. A. 1990, QJRAS, 31, 567

Kwok, S. 1993, ARA&A, 31, 63

Kwok, S. 2000, The Origin and Evolution of Planetary Nebulae, (Cambridge: University Press)

Kwok, S. 2001, Cosmic Butterflies: the Colorful Mysteries of Planetary Nebulae, (Cambridge: University Press)

Kwok, S., Volk, K., & Bidelman, W. P. 1997, ApJS, 112, 557

Kwok, S., Volk, K., & Hrivnak, B. J. 1999, A&A, 350, L35

Kwok, S., Volk, K., & Bernath, P. 2001, ApJ, 554, L87

Papoular, R., Conard, J., Guillois, O, Nenner, I., Reynaud, C., Rouzaud, J.-N. 1996, A&A, 315, 222

Sakata, A., Wada, S., Onaka, T., & Tokunaga, A.T. 1987, ApJ, 320, L63