*The Diffuse Interstellar Bands*
*Proceedings IAU Symposium No. 297, 2013*
*J. Cami & N. L. J. Cox, eds.*

doi:10.1017/S1743921313015871

# Organic Nanoparticles as a Component of the Interstellar Medium

**S. Kwok**

Faculty of Science, The University of Hong Kong, Hong Kong, China
email: sunkwok@hku.hk

**Abstract.** Mixed aromatic/aliphatic organic nanoparticles (MAON) are suggested as the carrier of the unidentified infrared emission (UIE) features. The carriers of the diffuse interstellar bands (DIB) may be gas-phase molecular products released from MAON in the interstellar medium.

**Keywords.** astrochemistry, ISM: dust, planetary nebulae: general, stars: mass loss

## 1. Introduction

The diffuse interstellar bands (DIB) is one of the unexplained spectral phenomena in the interstellar medium (ISM). The others include the UIE features, the extended red emission (ERE), the 220 nm extinction feature, and the 21 and 30 $\mu$m emission features. The fact that these spectral mysteries have remained unsolved for so long (almost 100 years for the DIB and several decades for the others) led to the question whether we are missing some fundamental understanding of the constituents of the ISM. With the detection of over 160 molecular species in the ISM (mostly through their rotational transitions), we have come to realize that organic molecules are common in the universe. Emission features due to aromatic compounds are seen in galaxies as early as 10 billion years ago. The 3.4 $\mu$m absorption feature, attributed to the C–H streching mode of aliphatic compounds are commonly seen in the diffuse ISM. Organic compounds, some with very high degree of complexity, have been found in Solar System objects such as asteroids, comets, meteorites, planetary satellites, and interplanetary dust particles (Kwok 2011). Is it possible that the DIB and the other unexplained spectral phenomena are manifestations of complex organics?

The possible existence of organic grains in space was first raised by Hoyle & Wickramasinghe (1977) and Duley & Williams (1979). Recently, there have been increasing interests in the theoretical and experimental studies of amorphous hydrocarbon solids (Jones 2012, Hu & Duley 2008). These solids are composed of islands of randomly oriented aromatic rings linked by aliphatic chains of different lengths. By varying the aromatic to aliphatic ratio and the H content, geometric structures of different long- and short-range order can be constructed. These solids have bandgaps in the UV and are capable of self luminescence in the visible, making them possible candidates as the carriers of the 220 nm and the ERE, respectively (Gadallah *et al.* 2011).

In laboratory experiments, amorphous hydrocarbons are also frequently the products of laser ablation of graphite (Mennella *et al.* 1999, Jäger *et al.* 2008), laser pyrolysis of gases (Herlin *et al.* 1998), arc discharge (Mennella *et al.* 2003), microwave irradiation (Godard *et al.* 2011), UV photolysis (Dartois *et al.* 2004), and flame synthesis (Carpentier *et al.* 2012). In the late stages of stellar evolution, a large variety of gas-phase hydrocarbons are synthesized in the stellar winds of carbon-rich stars. When these molecules are subjected to the strong radiation field of the star, similar solid condensation may also happen in the circumstellar environment (Kwok 2004).

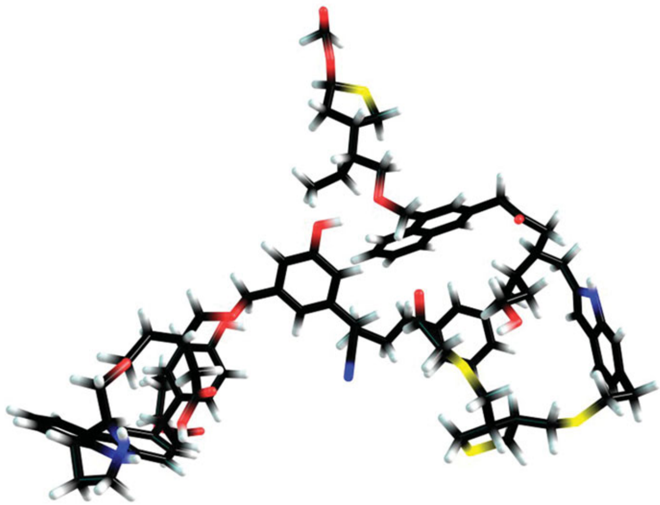

**Figure 1.** A 3-D illustration of a possible partial structure of a MAON particle. Carbon atoms are represented in black, hydrogen in light grey, sulphur in yellow, oxygen in red, and nitrogen in blue. There are 101 C, 120 H, 14 O, 4 N, and 4 S atoms in this example. The number of O, N, S elements have been intentionally exaggerated for the purpose of illustration.

## 2. Unidentified Infrared Emission (UIE) features

The UIE phenomenon consists of strong emission features at 3.3, 6.2, 7.7, 8.6 and 11.3 $\mu$m, which have been identified as stretching and bending modes of aromatic compounds (Duley & Williams 1981). Although these features are commonly attributed to polycyclic aromatic hydrocarbon (PAH) molecules, they can also come from other aromatic materials such as hydrogenated amorphous carbon (HAC, Jones *et al.* 1990; Gadallah *et al.* 2012), quenched carbonaceous composites (QCC, Sakata *et al.* 1987), soot (Pino *et al.* 2008), carbon nanoparticles (Hu & Duley 2008), coal (Papoular *et al.* 1989), and petroleum (Cataldo *et al.* 2013). Also present in the spectra of planetary nebulae and proto-planetary nebulae are emission features arising from the aliphatic stretching and bending modes at 3.4 and 6.9 $\mu$m, as well as strong plateau emission features around 8 and 12 $\mu$m. The plateau features have been identified as collective in-plane and out-of-plane bending modes of a mixture of aliphatic side groups (Kwok *et al.* 2001). It should also be mentioned that the UIE features sit on top of a strong continuum, extending from 1-1000 $\mu$m. Although the underlying continuum is often interpreted to originate from a separate entity of micron-size grains, it has been suggested that the continuum arises from the skeleton modes of organic solids (Papoular 2013).

## 3. Mixed aromatic/aliphatic organic nanoparticles (MAON)

On the other extreme of the PAH model (which represents pure aromatic molecules), we can imagine solids of totally disorganized aromatic/aliphatic structures mixed with impurities (O, N, S). This model is proposed by Kwok & Zhang (2011, 2013) as possible carriers of the UIE features (Fig. 1). The MAON model has the advantage of naturally explaining the broad profile of UIE features, the presence of aliphatic features, as well as the associated strong emission plateaus.

Since the DIBs have numerous, well-defined narrow bands, they are likely to originate from electronic transitions of molecules. In interstellar conditions, there are frequent exchanges between the solid and molecular phases as the result of radiative processing. The $C_{60}$ molecule, e.g., has been suggested as the breakdown products of MAONs (Bernard-Salas *et al.* 2012; García-Hernández *et al.* 2012). We note that $C_{60}$ was unknown in the laboratory before 1985 and was only detected in the ISM in 2010 (Cami *et al.* 2010). Is it possible that the DIB carriers are organic molecules released from stellar produced MAONs as the result of interstellar UV radiation field? Further laboratory studies would be useful to pursue these possibilities.

**Acknowledgements**

This work was partially supported by the Research Grants Council of the Hong Kong Special Administrative Region, China (project no. HKU 7027/11P.)

## References

Bernard-Salas, J., Cami, J., Peeters, E., Jones, A. P., Micelotta, E. R., & Groenewegen, M. A. T. 2012, *ApJ*, 757, 41
Cami, J., Bernard-Salas, J., Peeters, E., & Malek, S. E. 2010, *Science*, 329, 1180
Carpentier, Y., *et al.* 2012, *A&A*, 548, 40
Cataldo, F., Garcia-Hernádez, D. A., & Manchado, A. 2013, *MNRAS*, 429, 3025
Dartois, E., Muñoz Caro, G. M., Deboffle, D., & d'Hendecourt, L. 2004, *A&A*, 423, L33
Duley, W. W. & Williams, D. A. 1979, *Nature*, 277, 40
Duley, W. W. & Williams, D. A. 1981, *MNRAS*, 196, 269
Gadallah, K. A. K., Mutschke, H., & Jäger, C. 2011, *A&A*, 528, 56
Gadallah, K. A. K., Mutschke, H., & Jäger, C. 2012, *A&A*, 544, 107
García-Hernández, D. A., *et al.* 2012, *ApJ*, 760, 107
Godard, M., Féraud, G., Chabot, M., *et al.* , 2011, *A&A* 529: 146
Herlin, N., Bohn, I., Reynaud, C., Cauchetier, M., Galvez, A., & Rouzaud, J.-N. 1998, *A&A*, 330, 1127
Hoyle, F. & Wickramasinghe, N. C. 1977, *Nature*, 268, 610
Hu, A. & Duley, W. W. 2008, *ApJ*, 677, L153
Jäger, C., Mutschke, H., Henning, T., & Huisken, F. 2008, *ApJ*, 689, 249
Jones, A. P., 2012, *A&A*, 542, 98
Jones, A. P., Duley, W. W., & Williams, D. A., 1990, *QJRAS*, 31, 567
Kwok, S. 2004, *Nature*, 430, 985
Kwok, S. 2011, *Organic Matter in the Universe*, Wiley
Kwok, S. & Zhang, Y. 2011, *Nature*, 479, 80
Kwok, S. & Zhang, Y. 2013, *ApJ*, 771, 5
Kwok, S., Volk, K., & Bernath, P. 2001, *ApJ*, 554, L87
Mennella, V., Brucato, J. R., Colangeli, L., & Palumbo, P. 1999, *ApJ*, 524, L71
Mennella, V., Baratta, G. A., Esposito, A., Ferini, G., & Pendleton, Y. J. 2003, *ApJ*, 587, 727
Papoular, R. 2013, *MNRAS*, 434, 862
Papoular, R., Conrad, J., Giuliano, M., Kister, J., & Mille, G. 1989, *A&A*, 217, 204
Pino, T., Dartois, E., Cao, A.-T., *et al.*2008, *A&A* 490: 665.
Sakata, A., Wada, S., Onaka, T., & Tokunaga, A. T. 1987, *ApJ*, 320, L63