From Interstellar Ices to PAHs

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INVITED TALK

The impact of the PAH hypothesis on Astrophysics

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The PAH hypothesis has been proposed in the mid 80's in response to a crisis that started at the dawn of infrared astronomy from the observations of reflection nebulae, where out of equilibrium infrared emission was detected, suggesting high temperatures, in excess of 1000 K, from an unknown grain population. Loosely associated with this emission, infrared emission features were also observed and nicknamed UIBs for Unidentified Infrared Bands. At that time, infrared spectroscopy in astronomy was at its infancy and proposed quite patchy spectra. Observers in the 3 micron range were often different from those in other spectral ranges so it was very difficult to consider these bands to belong to a same and unique set pertaining to only one family of emitters. After the proposal by Léger and Puget (1984), quickly followed by Allamandola, Tielens and Barker (1985), that Polycyclic Aromatic Molecules of a somewhat large size (say 60-300 carbon atoms) were present as isolated molecules in space, the UIBs became quickly assigned even though the PAH hypothesis remained highly controversial for a long period of 10 years about. The bands were confidently assigned to fundamental vibrational modes of PAH molecules and the emission mechanism proposed (and sharply debated at its origin) considered the absorption of only one ultraviolet photon heating large molecules and their ions whose heat capacity was small enough owing to their relatively small size. Ultrafast internal conversion (IC) following UV excitation quickly leads the isolated molecule into its lowest electronic state where Intramolecular Vibrational Redistribution (IVR) proceeds to allow defining a high vibrational temperature. Intrinsically slow infrared emission in such totally isolated molecules (an essential characteristics of interstellar molecular species) then leads each molecule back to its ground vibrational state by emitting infrared photons mainly through the fundamental vibrational bands of the molecules. Absorption of another UV photon, will allow this process to repeat days or weeks later (!) only but the high abundance, totally unexpected at that time, of these molecules in the ISM, together with the fact that emission from the whole PAH "family" summed up into the same characteristic bands, make this UIB emission easily observable and, actually, as it appeared quickly after, almost ubiquitous in astrophysical objects such as reflection nebulae, circumstellar objects but also at the large scale of a whole galaxy such as M82 for example.

The main prediction of this first idealized model, the strong emission in the mid-IR of the so-called Cirrus Clouds discovered by IRAS in bands at 12, 25, 60 and 100μm, with a clear excess emission in the two first ones by Boulanger, Baud and Van Albada (1985) and attributed to small particles (actually large PAHs) present in space (Puget, Léger and Boulanger, 1985) quickly launched up the PAH hypothesis within a very large astronomical community that grew largely over that of the one only dedicated to the interstellar medium studies. It would be difficult, if not impossible to cover-up all the major inputs this PAH hypothesis has given to astrophysics in the last thirty years. Let us mention first the fast and coherent development of Laboratory Astrophysics not only to study spectroscopic properties of isolated PAH molecules but also many other processes that govern astrochemistry: physics and chemistry of ices, ices and PAHs mixed together, small carbon grains, silicates Many observational (as well as theoretical) problems were cornered by the PAH hypothesis: the Diffuse Interstellar Band problem (that still remains an open issue), the heating of the interstellar gas from the photoelectric effect on PAHs, the relation of PAHs with other organic components and finally the importance of these organics in astrochemistry and may be more importantly for the future in astrobiology (Allamandola 2011). Its effect on observations was tremendous, boosting the scientific programs of space based missions such as the European ISO observatory and the American Spitzer telescope. It led to the elaboration of empirical diagnostics to probe physical properties in various environments and of new grain models to help establishing the energy budget of galaxies. PAHs are used almost “anywhere”, in meteorites and comets as well as in cosmology problems where redshifts of quite distant objects are deduced from the shifted emission of UIB’s. Astronomers, even those who dont know, live in a PAH world which, due to the chemical identity of these PAHs, establishes the link between dust and the Molecular Universe. This paper will try to summarize many different aspects of Astrochemistry that find their roots in the PAH hypothesis and its many developments.

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