Chapter 5

NATURAL C₆₀ AND LARGE FULLERENES: A MATTER OF DETECTION AND ASTROPHYSICAL IMPLICATIONS

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Abstract: Fullerene was theoretically predicted and experimentally discovered, but its detection in laboratory studies is still underrepresented with respect to its theoretical abundance. Recent High Resolution Transmission Electron Microscopy (HRTEM) studies of soot samples, however, lead to single fullerene molecule detection in higher amounts than was previously established. HRTEM is able to identify fullerenes even if they are only present in small quantities that would be below the detection limit of chemical techniques. Fullerenes will probably remain largely undetected until higher signal to noise ratio measurements are used to search for them. Such studies could yield different conclusions on fullerene abundances both in terrestrial and in extraterrestrial samples. For the latter, important astrophysical implications have to be considered.

Key words: Carbon chain molecules; carbon monocyclic ring molecules; carbon vapor condensation; carbonaceous chondrites; cosmic dust; fullerenes; high-resolution transmission electron microscopy (HRTEM); interplanetary dust particles; meteorites; polycyclic aromatic hydrocarbons (PAHs); PAH molecules; Raman microspectroscopy; soot
Chapter 5

1. **INTRODUCTION**

The prediction by Kroto et al. (1985) that fullerene molecules, including \( \text{C}_{60} \), ought to be abundant seems not yet to be borne out by the analyses of natural soot samples but, more importantly, they are apparently also not seen in soot that was produced in the laboratory under carefully controlled conditions that should have led to fullerene formation. In fact, while Krätschmer et al. (1990) synthesized macroscopic amounts of \( \text{C}_{60} \), this molecule remains under-represented in natural samples and it seems that experimental conditions for its production are either too peculiar to prove its theoretical pervasiveness (Taylor et al., 1991), or some other factors control the existence of natural fullerenes. Fullerene searches included circumstellar and interstellar environments, Interplanetary Dust Particles (IDPs), meteorites, lunar rocks, terrestrial hard-rocks, coal, and sedimentary rocks (Heymann et al., 2003). The only diagnostic tool available for fullerene detection in astronomical environments (e.g. Snow and Seab, 1989; Foing and Ehrenfreud, 1994, 1997; Webster, 1997; Sassara et al., 2001) relies on the analysis of electromagnetic radiation, which requires a synergy between laboratory and theoretical studies. Because of the prediction that fullerenes should exist and their subsequent detection in astronomical environments, the search for fullerenes in meteorites was a next logical step. In particular, carbonaceous chondrites rich in presolar grains, and being more carbon-rich than any other meteorites, were considered the most likely to contain fullerenes. Some chemical analyses of carbon-rich residues extracted from these meteorites gave positive results (e.g. Becker and Bunch, 1997; Becker et al., 1994, 1999) while others did not find fullerenes in other allocations of these same meteorites (e.g. Ash et al., 1993; DeVries et al., 1993; Gilmour et al., 1993; Heymann, 1997).

Chondritic aggregate IDPs and cluster IDPs from ca. 2 \( \mu \text{m} \) to ca. 1 mm in size are considered the least-modified debris from the solar nebula because they were not processed in small protoplanets such as the meteorite parent bodies (Rietmeijer, 2002). The carbonaceous phases in these IDPs contain D/H “hot spots” of interstellar origin that were incorporated during solar nebula dust accretion (Keller et al., 2000; Messenger, 2000) and these particles should be good candidates to contain astronomical fullerene. Carbon XANES (X-ray Absorption Near Edge Spectroscopy) spectra of carbon-rich IDP L2008F4 show a notable similarity to the C-XANES spectrum of \( \text{C}_{60} \), but the search for