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Interstellar and Circumstellar Fullerenes

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In recent years, it has become clear that fullerenes (and in particular C_{60}) are widespread and abundant in space, following their detection in a variety of astrophysical environments (see e.g. Cami *et al.* 2010, and many others) and the identification of several diffuse interstellar bands (DIBs) as due to C_{60}^+ (Campbell *et al.* 2015). However, many aspects about their formation and excitation are not clear yet.

Much research has focused on understanding fullerene formation in these environments. Laboratory experiments have shown that the temperature determines carbon condensation in bottom-up routes (Jäger *et al.* 2009): high temperatures ($T \geqslant 3500$ K) result in fullerenes (and fullerenic soot) while polycylic aromatic hydrocarbon (PAH) molecules (and graphitic soot) form at lower temperatures ($T \leqslant 1700$ K). A H-poor environment also results in fullerenes (even at those low temperatures; see Wang *et al.* 1995). Fullerenes also form from UV irradiation of large PAHs in a top-down process (Zhen *et al.* 2014); this is probably at work in the reflection nebula NGC 7023 (Berné & Tielens 2012).

By far the majority of all infrared C_{60} detections corresponds to young, low-excitation planetary nebulae (PNe), where the fullerenes are typically located far away from the central star (Bernard-Salas *et al.* 2012). This excludes an in-situ bottom-up formation process. However, PAH photo-processing is not a likely formation route either, given that there are many mature PNe that display copious amounts of PAH emission: if PAH photoprocessing would result in fullerenes far away from the central star in low-excitation objects, then the PAHs in these more mature objects should all have been converted to fullerenes as well. The key to resolving the formation of C_{60} in PNe may be in the dust. The C_{60}-PNe may represent objects where – for some reason – dust condensation (in an earlier phase, presumably on the asymptotic giant branch) happened at higher temperatures (or in a H-poor environment), producing fullerenic rather than graphitic dust. When the object becomes a planetary nebula, a fast wind overtakes a slow wind, and an ionization front develops. These processes could perhaps destroy much of the dust, and only the fullerenes (as the most stable species) survive. This would explain why we only see the fullerenes in young PNe. Further research about the nature and evolutionary status of these objects will help to pin down the C_{60} formation route.

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