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From Stardust to Meteorites: The Synthesis of Inorganic and Organic Grains in AGB and Post-AGB Stars

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Abstract. Infrared spectroscopic observations of the circumstellar envelopes of AGB and post-AGB stars have identified a variety of inorganic grains including amorphous silicates, crystalline silicates, silicon carbide, carbonates, corundum, spinels and possibly rutiles. Isotopic studies of meteorites have also identified similar species of presolar origin. The existence of aromatic and aliphatic features in the spectra of post-AGB stars suggests that organic compounds in solid-state form are made during the post-AGB phase of stellar evolution. These features show similarity with the IR spectra of kerogen, which is also found in meteorites. These grains therefore represent an important link between stars and the solar system.

1. Introduction

There has been an increasing interest in recent years on the effects of exogenous delivery on the origin of terrestrial life. The mechanisms of exogenous delivery include comets, meteorties, interplanetary dust, micrometeorites, and the consequence of terrestrial impacts by these objects.

Infrared spectroscopic observations of the circumstellar envelopes of Asymptotic Giant Branch (AGB) and post-AGB stars (including planetary nebulae, PN and proto-planetary nebulae, PPN) have identified a variety of inorganic grains, including amorphous silicates, crystalline silicates, silicon carbide, carbonates, corundum (Al_2O_3), spinels (e.g., $MgAl_2O_4$) and possibly rutiles (TiO_2).

In carbon-rich PN and PPN, organic compounds with aromatic and aliphatic structures are present. The observations show that both solid materials of both inorganic and organic nature can be produced efficiently in the circumstellar environment over time scales as short as a few hundred years. The detection of some of the same compounds in meteorites suggests that stellar material can be transported to the solar system, and may play a role in the chemical enrichment of the primordial Earth.

2. Amorphous and Crystalline Silicates

Amorphous silicates are the most common solid-state component in AGB stars. The emission features of amorphous silicates at 10 and 18 μm have been detected in over 4000 oxygen-rich AGB stars (Kwok et al. 1997). In carbon-rich AGB stars, the SiC feature at 11.3 μm is detected in over 700 stars. For AGB stars that have very thick circumstellar envelopes (called extreme carbon stars; Volk et al. 2000), the dust spectrum is featureless and is believed to be due amorphous carbon.

Crystalline silicates represent the most abundant group of minerals in the Earths crust. The detection of crystalline silicates in PN, in particular in PN that also show the aromatic infrared bands (AIB) (Fig. 1) is totally unexpected. Most of the crystalline silicates are found to be magnesium rich, close to terrestrial forms of forsterite (Mg_2SiO_4) and enstatite ($MgSiO_3$).

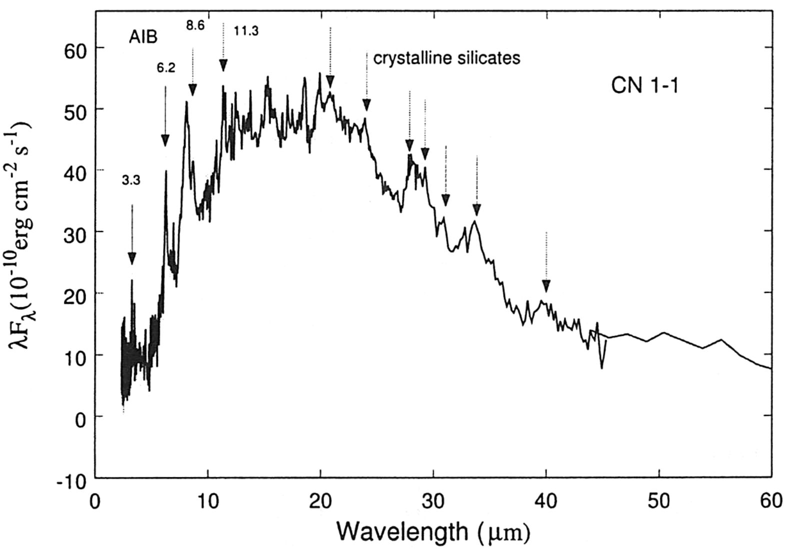

Figure 1. *ISO SWS01* spectrum of the PN CN1-1 showing the presence of both AIB and crystalline silicate features.

3. Aromatic and Aliphatic Features

Many carbon-rich PNs show strong aromatic infrared bands (AIB) at 3.3, 6.2, 7.7, 8.6 and 11.3 μm characteristic of aromatic compounds.

In addition to the AIB features, features due to aliphatic C-H stretching and bending modes are seen in PPN and young PN at 3.4 and 6.9 μm respectively (Fig. 2). Broad emission plateaus around 8 and 12 μm can also be attributed to alkane and alkene side groups on an aromatic structure (Kwok et al. 2001). These properties suggest that the carrier of the AIB features cannot be simple gas-phase polycyclic aromatic hydrocarbon (PAH) molecules, but a solid-state compound with a mixed sp^2 and sp^3 structures.

4. The 20 μm Feature

The strong emission feature at 20 μm was first discovered with the *IRAS Low Resolution Spectrometer (LRS)* (Kwok et al. 1989). An example of the 20 μm

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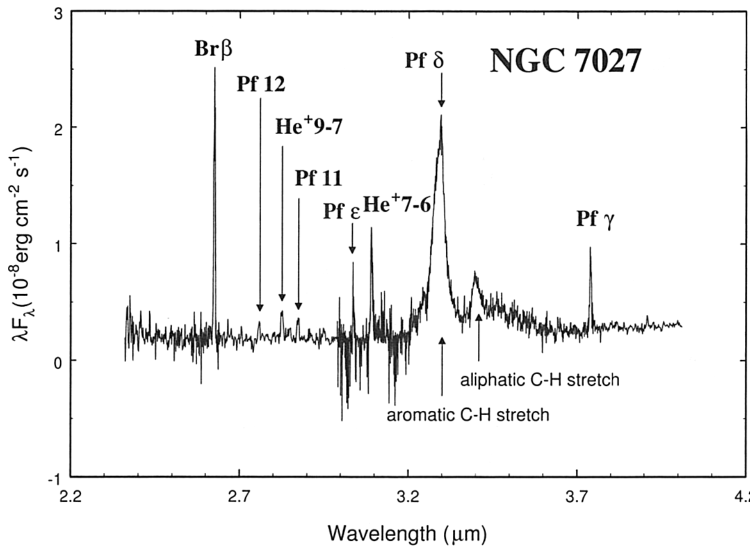

Figure 2. Both the aromatic C-H stretch and aliphatic C-H stretch emissions can be seen in this *ISO* spectrum of the PN NGC 7027.

feature observed by *ISO* is shown in Fig. 3. As of 2002, the 20 μm feature has been found in 12 objects, all carbon-rich stars in the post-AGB phase of evolution (Kwok et al. 1999). The broad and smooth nature of this feature suggests that it is due to a solid (Volk et al. 1999). The strength of this feature implies that its carrier must be made up of common abundant elements. Although the 20 μm feature has been suggested to be due to hydrogenated fullerences or titanium carbide nanoclusters, no firm identification has been made.

5. Presolar Grains in Meteorites

Isotopic studies of meteorites have also identified grains of presolar origin, including diamonds (Lewis et al. 1987), SiC (Bernatowicz et al. 1987), corundum and spinel (Nittler et al. 1997). These grains therefore represent an important link between stars and the solar system. The dominant organic matter in carbonaceous chondrites are similar to kerogen. Infrared spectra of organic extract sublimate from the Murchison meteorite show aliphatic features that are similar to those observed in PPN (Guillois et al. 1996; Papoular 2001; Pendleton & Allamandola 2002).

6. Summary

Infared spectroscopic observations have clearly demonstrated that solid-state compounds of both organic and inorganic nature are produced in abundance in the circumstellar envelopes of evolved stars. The ejection of these grains by stars and their distribution throughout the Galaxy suggest that they may have

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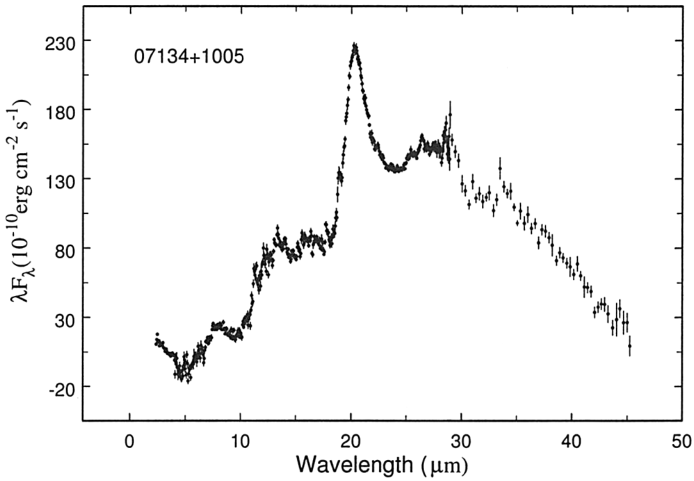

Figure 3. *ISO SWS01* spectrum of PPN IRAS 07134+1005 showing the strong unidentified emission feature at 20 μm.

been present in the solar nebula. The detection of pre-solar grains in meteorites has confirmed this stellar-solar system connection. Since solid-state compounds have a much better chance of survival than gas-phase molecules in the early solar system, chemical enrichment of the solar system from stellar ejecta is distinct possibility.

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