Nanocosmos and Laboratory Astrophysics: from molecules to dust.

The chemistry of carbon in evolved stars

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Introduction: The Nanocosmos Project

Evolved stars are the factories of interstellar dust. This dust is injected into the interstellar medium and plays a key role in the evolution of astronomical objects from galaxies to the embryos of planets. However, the processes involved in dust formation and evolution are still a mystery. The increased angular resolution of the new generation of large telescopes, is providing for the first time a detailed view of the conditions in the dust formation zone of evolved stars, as shown by our first observations with ALMA (Cernicharo et al. 2013, Agúndez et al. 2017).

The aim of the NANOCOSMOS project is to take advantage of these new observational capabilities to change our view on the origin and evolution of dust grains. We are combining astronomical observations, modelling, and top-level experiments to produce star dust analogues in the laboratory and identify the key species and steps that govern their formation. We have built two innovative setups: the Stardust chamber to simulate the physical conditions of the atmosphere of evolved stars, and the gas evolution chamber to identify novel molecules in the dust formation zone. We are also improving existing laboratory setups and combine different techniques to achieve original studies on individual dust grains, their processing to produce complex polycyclic aromatic hydrocarbons, the chemical evolution of grain precursors and how dust grains interact with abundant astronomical molecules. Our simulation chambers have been equipped with state-of-the-art in situ and ex situ diagnostics.

Our astrophysical models, improved by the interplay between observations and laboratory studies, provide powerful tools for the analysis of the wealth of data provided by the new generation of telescopes. The synergy between astronomers, vacuum and microwave engineers, molecular and plasma physicists, surface scientists, and theoreticians in NANOCOSMOS is the key to provide a cutting-edge view of cosmic dust.

Carbon Chemistry in evolved stars

The chemistry of carbon in evolved stars will be discussed from the observational and chemical modelling point of view. From the photosphere of the central star to the external layers of the circumstellar envelope different chemical processes allow the formation of different carbon molecules, among them carbon clusters and carbon chain radicals. The chemistry is not completely understood as many reactions are involved in the formation of these molecular species (see Figure 1 for a detailed view of the molecular content of a carbon-rich evolved star). Nevertheless, a picture is emerging with the new data collected with ALMA and other telescopes as part of the ERC Nanocosmos project. Only small carbon clusters have been detected so far in the photosphere while chains as long as C_8H have been detected in the external layers of the envelope. The formation of carbon clusters is not controlled by thermodynamical equilibrium chemistry but by reaction kinetics of carbon molecules. Hence, time evolution becomes a limitation in the growth of carbon clusters as it competes with the dynamical evolution of the envelope. However, the growth of carbon-dust around Si-C grains in the near surroundings of the photosphere seems to be the main reservoir of carbon in these objects. Observations, chemical models, and important missing reactions will be discussed.

The post-AGB phase of these objects, their planetary nebula phase, is characterized by the presence of the strong infrared bands of PAHs while in the proto-planetary nebula phase, i.e., immediately after the central object starts its travel toward the white dwarf phase, aliphatic bands or simply large carbon molecules are found. These facts suggest that the PAH kingdom appears from gas and carbon-dust processing in these late stages of stellar evolution. Chemical models for the behavior of carbon species in these preliminary phases of carbon processing will be presented.

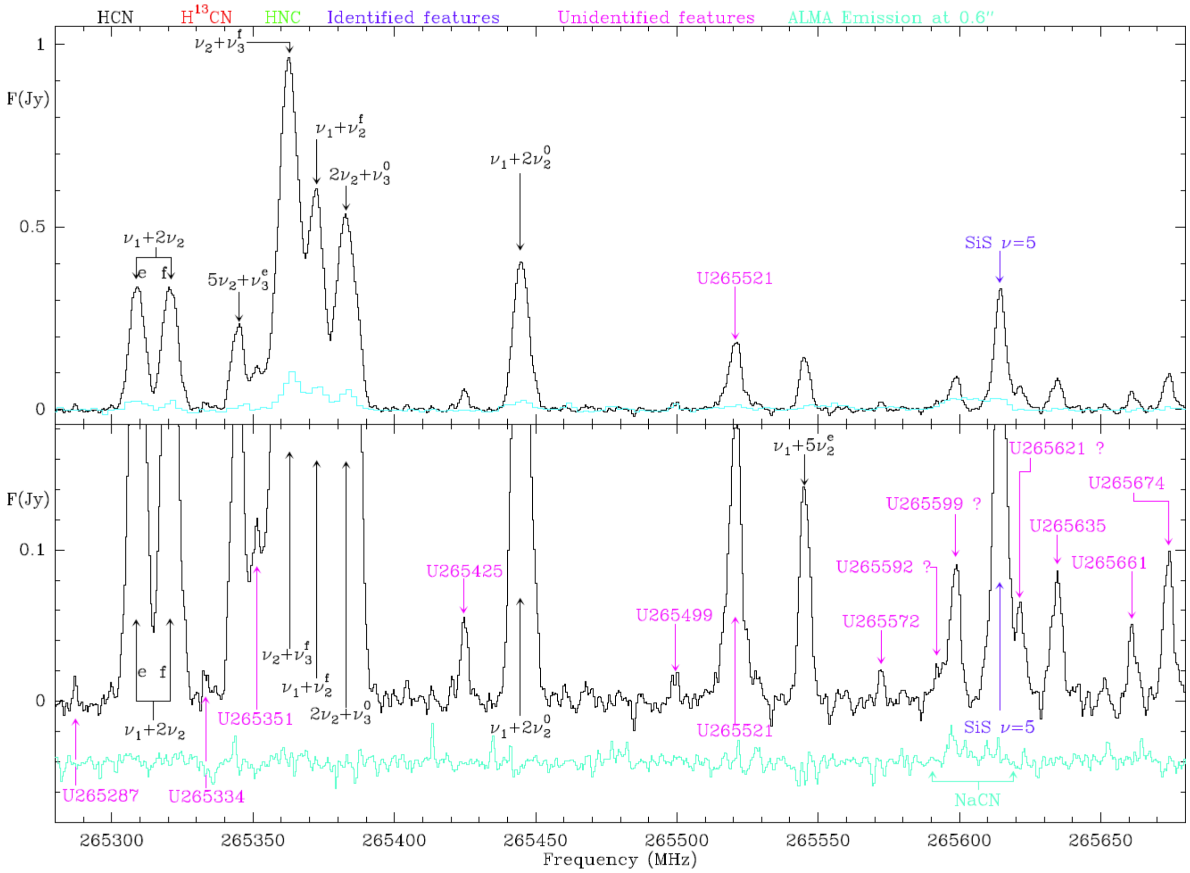

Figure 1: ALMA observations of the carbon star IRC+10216 showing the J=3-2 line of HCN and the J=15-14 line of SiS in several highly excited vibrational levels. In addition to these lines arising from the photosphere a forest of U lines, also formed in the same region, is also detected. The carriers of these lines are the building blocks of dust grains.

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References

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