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Dust properties in the circumstellar shells of evolved stars: Observational constraints from ISO and Spitzer infrared spectroscopy

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Abstract. We present the results of a systematic analysis of the solid state features identified in the circumstellar environments of a large sample of evolved stars with ISO/SWS and Spitzer/IRS spectroscopy. The sample includes several hundred stars with a wide variety of progenitor masses evolving from the early AGB phase to the PN stage. Our observations are used to propose an evolutionary scheme in which the results obtained can be interpreted as a consequence of the nucleosynthesis processes that take place in this short phase of the stellar evolution, in particular the third dredge-up and hot bottom burning, which in turn are also strongly modulated by the stellar metallicity.

Keywords. Circumstellar matter, stars: AGB and post-AGB, planetary nebulae

1. Selection of the sample

Three subsets of objects were analysed located in different metallicity environments: the Galactic Bulge, the Galactic Disk and the Magellanic Clouds. The overall efficiency of dust production, as well as the physical and chemical properties of the dust grains were analysed in each case.

2. Results

Galactic Bulge (high metallicity): 46 sources were observed with Spitzer/IRS. All of them showed a very strong dust continuum, indicative of efficient dust formation. Solid state features usually correspond to O-rich dust grains, in most cases crystalline silicates. The more luminous sources appear heavily obscured in the optical, indicative of a recent and strong mass loss. The higher frequency of O-rich shells in the Bulge is consistent with an inefficient third dredge-up operating during the AGB phase, predicted by nucleosynthesis models. The O-rich nature of the most luminous and obscured sources may correspond to a young population of high-mass bulge stars experiencing hot bottom burning. This is predicted to occur only for masses $\geqslant$3.5–4.0 $M_\odot$ at these very high metallicities.

Galactic Disk (intermediate metallicity): 350 sources with available ISO/SWS spectra show a proportion of C-rich and O-rich shells close to unity. The chemical branching

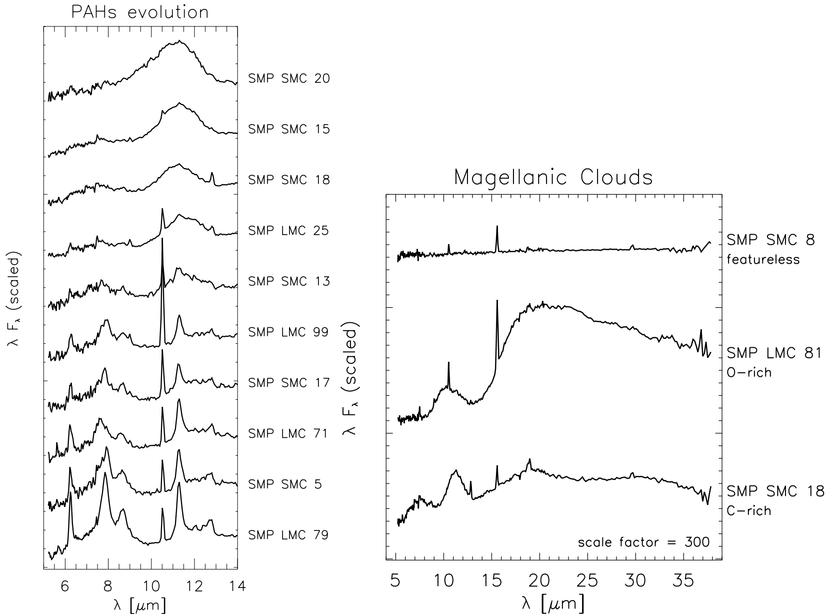

Figure 1. Different carbonaceous features observed with Spitzer/IRS in the sample of Magellanic Cloud PNe (left); at low metallicities these sources show unusual spectra (right).

observed is induced mainly by the third dredge-up and hot bottom burning, leading to a population of: *i*) low-mass O-rich PNe, the result of the evolution of O-rich bright Mira variables; *ii*) intermediate-mass C-rich PNe, the result of the evolution of carbon Miras; or *iii*) high-mass O-rich PNe, N-rich as well, also called *type I PNe*. The solid state features evolve from amorphous to crystalline as the AGB stars become PNe in the case of O-rich shells and from aliphatic to aromatic in C-rich shells.

Magellanic Clouds (low metallicity): 41 sources were observed with Spitzer/IRS showing very little dust continuum, indicative of an inefficient dust formation. Solid state features, when observed, correspond to C-rich dust grains in most cases, usually a combination of SiC and very small carbonaceous grains (VSGs), with only a few sources showing the characteristic PAH features observed in Galactic PNe. Among the O-rich sources (only 3), two of them display amorphous silicates, very rarely observed in their galactic analogues. Dust processing by the UV photon irradiation from the central star seems to be inhibited in LMC and SMC PNe, suggesting a more distant location for the dust in the shell. Little or no obscuration in the optical is observed even in the most luminous PNe studied, indicative of the relatively small mass loss experienced by these stars in the AGB phase. A much higher frequency of C-rich PNe versus O-rich sources (more extreme in the SMC, where metallicity is lower), is consistent with a very efficient 3rd dredge-up operating at low metallicities, as predicted by nucleosynthesis models. The O-rich nature of a few luminous PNe may be the consequence of these stars having experienced hot bottom burning in the AGB. At the low metallicity of the MCs this is predicted to occur for masses $\gtrsim$2.5–3.0 $M_\odot$ by the theoretical models.

3. Conclusions

The chemical properties of the dust grains present in the circumstellar shells of evolved stars are confirmed to be strongly correlated with their progenitor masses, as predicted by nucleosynthesis models. In addition, our results show that the size and physical properties of the grains may also strongly depend on the metallicity.

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