Planetary Nebulae: Enriching the Interstellar Medium

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The chemistry of planetary nebulae (PNe) has been the central focus of my research to date. PNe are the final evolutionary phase of low- and intermediate-mass stars, where the extensive mass lost by the star on the asymptotic giant branch (AGB) is ionised by the emerging white dwarf. This ejecta quickly disperses and merges with the surrounding ISM, whereby the ensuing mass loss constitutes approximately half the Milky Way's interstellar gas and dust. PNe represent an important tool for investigating dust formation and evolution, and are thus a key role in galactic evolution. The ejecta in the AGB phase comprise mainly three zones; the molecular zone, the dust formation zone and the photochemical reactions zone. In the molecular zone, the CO molecule locks away the less abundant element, leaving the remaining free oxygen (O) or carbon (C) to drive the chemistry and dust formation. Accordingly a dichotomy between carbon-rich and oxygen-rich PN is observed. O-rich PN are characterised by silicate dust, while C-rich PN show polycyclic aromatic hydrocarbons (PAHs), amorphous carbon, graphite and SiC.

A small fraction of PNe show both O- and C-rich features and are therefore classified as mixed-chemistry objects. The origin of their mixed-chemistry is still uncertain. In the Galactic Disk the mixed-chemistry phenomenon has been observed in PNe with Wolf-Rayet-type central stars ([WC]) (Zijlstra et al. 1991, Waters et al., 1998a,b; Cohen et al., 1999, 2002). It is attributed to the presence of old O-rich material in a circumstellar disk, with the PAHs forming in a more recent C-rich outflow. However in 2009 Perea-Calderón et al. showed that the simultaneous presence of O- and C-rich dust features is common in Galactic Bulge PNe, and is not restricted to objects with [WC] type stars. The traditional explanation relating the mixed-chemistry to a recent transition of the central star from O-rich to C-rich is unlikely for the Bulge objects, as these old, low-mass stars are not expected to become C-stars, and therefore should not show enhanced C/O ratios.

In an effort to understand this phenomena I was able to analyse a sample of 40 PNe in the Galactic Bulge, using *Spitzer* and *HST* showing that 70% of them are bipolar/multipolar showing a dense/compact torus whereas in the Galactic Disk only around 30% of the PNe show bipolar/multipolar morphologies. Using the MonteCarlo 3D (MC3D) radiative transfer code I was able to fit the *Spitzer* spectra of the PN M1-31 using only O-rich dust. Thus constraining M1-31 as an O-rich nebula. The Meudon chemistry code was then used to show that long C-chains can be formed in dense O-rich environments. The chemistry here is driven by a photon-dominated region, where the CO molecule is dissociated (Guzman-Ramirez et al., 2011). Assuming that, after forming, these long C-chains then form the PAHs, this makes the strongest explanation for the formation of these C-rich molecules in a very O-rich environment. For this chemistry to occur the torus plays a key factor. The torus observed in all of the PNe that present the mixed-chemistry phenomenon could provide the dense, irradiated environment needed to form the PAHs detected. In Guzman-Ramirez et al., (2012, in prep.) I present observations made using the instrument VISIR in the *VLT* where the PAHs were detected in the tori of all the PNe observed.

More observations of C- and O-rich PNe in the Galactic Bulge and in the Galactic Disk, are needed to further understand the processes occurring in these objects. Questions as to the causes of this mixed-chemistry could then be addressed, for e.g. external consequences (metallicity of the Galactic Bulge, density of stars) or internal causes (binarity, age). The mixed-chemistry phenomenon opens up a window that has never been explored before: how does the torus form and, more importantly, why PNe in the Galactic Bulge are so different from the Disk PNe. It has been hypothesised (De Marco & Soker, 2002) that the bipolar/multipolar morphologies of PNe are due to the central star interacting with an orbiting star or planet. If this is correct, it will imply that the incidence of binarity in the Galactic Bulge is higher than any other place. To investigate this hypothesis a proposal for *ALMA* cycle 1 (with myself as PI) has been initiated in which we aim to observe a sample of 10 PNe that show the morphology needed to be associated with PAHs. These targets are in the Galactic Disk, so comparing these observations with the targets in the Galactic Bulge will give us insights on the differences between these PNe.

During my PhD I have also been involved in the INT Photometric Hα Survey (IPHAS). The IPHAS survey is the deepest Hα survey that has been done to date. Stellar formation rates calculate that we should observe between 20,000 and 50,000 PNe in our Galaxy. So far only $\sim$3,000 have been identified. Within this consortium, I have been confirming detection of PNe through follow-up spectroscopy (Parker, Q. A., Cohen, M., Stupar, M., Frew, D. J., Green, A. J., Bojicic, I., Guzman-Ramirez, L., et al., 2012). Using these spectra, we are able to calculate the chemical abundances, temperatures, densities and kinematics of the PNe (Parker, Q., Guzman-Ramirez, L. and Sabin, L., in prep). Surveys like IPHAS can be used to compare the population of PNe in the Galactic Disk versus the Galactic Bulge.

I propose to uncover the PAH formation mechanisms in PNe of different environments over the next 4 years. I will do it by comparing already observed data of PNe in the Galactic Disk and the Galactic Bulge and by applying for new observations of PNe in other satellite galaxies like the LMC, SMC and the Sagittarius Dwarf Spheroidal Galaxy. Making use of ESO instruments like VISIR in the *VLT* and *ALMA* I will be able to analyse the relationship between morphology and PAH formation in all of the PNe and compare their different environments. I will be able to test the chemical models in other galaxies with similar metallicity and age as the Galactic Bulge and analyse their similarities (or differences). This will provide a better understanding of the processes occurring in these objects. If the CO photodissociation occurring in the very dense tori is the main PAH formation mechanism, this will constrain the PAH formation models. In addition the tori-formation mechanisms will also be addressed, affirming or invalidating the binary scenario of these objects. I can develop my research independently but I believe collaborations make the strongest interpretation of science. Therefore this project is complementary to the growing PNe group and the binary group already working at ESO-Chile.