Why Galaxies Care About AGB Stars: A Continuing Challenge through Cosmic Time
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A step further on the physical, kinematic and excitation properties of PNe

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Abstract. PNe are known to be photoionized objects. However they also have low-ionization structures (LIS) with different excitation behavior. We are only now starting to answer why most LIS have lower electron densities than the PN shells hosting them, and whether or not their intense emission in low-ionization lines is the key to their main excitation mechanism. Can LIS line ratios, chemical abundances and kinematics enlight the interplay between the different excitation and formation processes in PNe? Based on the spectra of five PNe with LIS and using new diagnostic diagrams from shock models, we demonstrate that LIS's main excitation is due to shocks, whereas the other components are mainly photoionized. We propose new diagnostic diagrams involving a few emission lines ([N II], [O III], [S II]) and $f_{shocks}/f_{\star}$, where f_{shocks} and $f_{\star}$ are the ionization photon fluxes due to the shocks and to the central star ionizing continuum, respectively.

Keywords. ISM: kinematics and dynamics, (ISM:) planetary nebulae: general, ISM: jets and outflows, techniques: spectroscopic

1. Motivation and data

The generalized interacting stellar winds model (Balick & Frank 2002) can adequately explain the formation of the different PN nebular components – attached- (rim) and detached-shells and haloes – and their morphological classes: round, elliptical, bipolar or multiple bipolar. There are specific PN components, the low-ionization structures (LIS, Gonçalves *et al.* 2001) that need special attention, since we lack details on their formation and ionization mechanisms, though many observational constraints are available.

Long-slit optical spectroscopic data of five PNe with several LIS were obtained using the 2.5 m Isaac Newton Telescope (INT) and the 1.54 m Danish telescope. Three (NGC 6891, NGC 6572 and IC 4846) where observed on August 2001 and two (K 1-2 and Wray 17-1) on April 1997, with the INT and the Danish telescope, respectively.

2. Data interpretation and clues on the excitation of LIS

Spectra of the different nebular regions and LIS were extracted, then allowing us to carry out a study of LIS relative to their surrounding gas. The top-left panel of Fig. 1 illustrates such regions in Wray 17-1. Physical and chemical properties of all these spectra were obtained. We (Akras & Gonçalves 2016) thus confirm that LIS have the same chemical composition as the main nebular components (Fig. 1 top-right panel). The linear relation between log(N/O) and log(N/H) is consistent with the general picture for PNe (Perinotto *et al.* 2004) and the best fit agrees with that for PNe with [WR] and weak emission line central stars (Garcá-Rojas 2013).

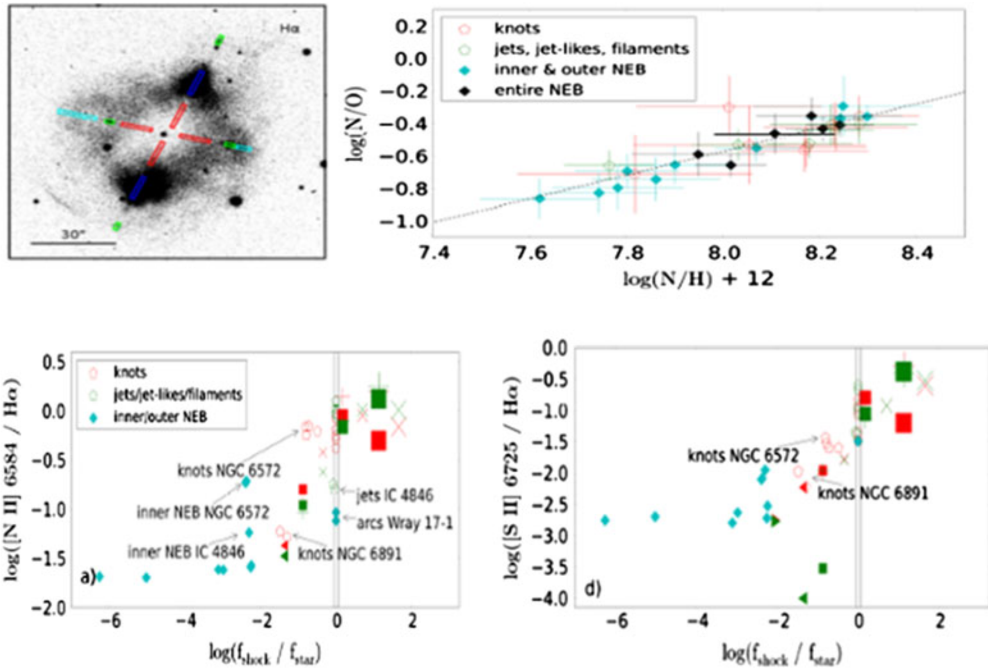

Figure 1. *Top-left*: the H_α image of Wray 17-1, highlighting the extracted spectra: LIS (dark blue and green) and inner shells and caps (red and cyan). *Top-right*: log(N/O) vs. log(N/H)+12 for all the structures of the whole sample. *Bottom:* new diagnostic diagrams to distinguish shock- from photo-excited PN components – [N II]/H_α (*left*), [S II]/H_α (*right*) vs. log(f_{shocks} /$f_\star$).

New diagnostic diagrams that apply LIS strong emission-line ratios and the $f_{shocks}/f_\star$ ratio – f_{shocks} and $f_\star$ are the ionization photon fluxes produced by the shocks and the central star's radiation field– are used to distinguish the photo-ionized from the shock-excited regions. All LIS exhibit systematically higher $f_{shocks}/f_\star$ ratio (>0.1) compared to the nebular gas (<0.01), thus indicating some shock activity in LIS (bottom panels of Fig. 1, Akras & Gonçalves 2016). For the construction of these new diagnostics both observations and models (Raga *et al.* 2008) were needed.

The presence of molecular hydrogen in several LIS of two PNe –K 4-47 and NGC 7662– has been recently confirmed (Akras *et al.* 2017). This should solve the problem of LIS's missing mass (they have systematically lower electron density than their surrounding nebula, which contradicts the models), at the same time that opens new challenges about their formation (Akras *et al.* 2017).

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