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The kinematics of the nebular shells around low mass progenitors of PNe with low metallicity

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Abstract. In the past few years we provided strong observational support for theoretical studies regarding the internal kinematics of Planetary Nebulae (PNe). A total of 257 objects segregated by different galactic populations were analized. Based upon spatially-resolved, long-slit, echelle spectroscopy drawn from the San Pedro Mártir Kinematic Catalogue of PNe †, we characterized the kinematics of PNe shells measuring their global expansion velocities. We present here a brief summary of these observational results, with a focus on our most recent study of about 26 PNe with low metallicity that appear to derive from progenitor stars of the lowest masses (including the halo PNe population). Low expansion velocities were found for these nebulae, less than $20\,\mathrm{km\,s^{-1}}$, which are most likely associated with a weak central star wind driving the kinematics of the nebular shell in this particular population.

Keywords. ISM: kinematics and dynamics, planetary nebulae: general, stars: evolution, low-mass, abundances

1. Introduction

Since the discovery of the existing link between the expansion velocity of PNe and the escape velocities of red giants by Abell & Goldreich (1966), the study of the internal kinematics of nebular envelopes has became crucial in understanding the final stages of intermediate and low-mass star's evolution. By analyzing the properties of the central stars of PNe and their influence on the kinematics of the nebular shells, we can investigate the mass-loss history of the AGB phase and the chemical evolution of the interstellar medium in their host galaxies. As a dynamically active system, the shells of planetary nebulae are perfect targets to study these processes and to test the predictions of stellar evolution models.

2. Overview

Current hydrodynamical simulations have successfully predicted the kinematic evolution of nebular shells through the entire planetary nebula phase, considering different masses and stellar populations for their progenitor stars (Mellema (1994), Villaver *et al.* (2002), Perinotto *et al.* (2004), Schönberner *et al.* (2005), García-Segura *et al.*

† Observations acquired at the Observatorio Astronómico Nacional in the Sierra San Pedro Mártir (OAN-SPM), B. C., Mexico. Available at *http://kincatpn.astrosen.unam.mx/*

(2006), Schönberner *et al.* (2010)). In the past few years, observational studies to support these predictions have also been performed (López *et al.* (2016)). By characterizing the internal kinematics of 131 objects from the Bulge population, Richer *et al.* (2010) have shown that the nebular shell starts expanding in a momentum driven phase with velocities of around 10-15 km s^{-1}, very similar to the escape velocity of the AGB wind. This Bulge sample also provided strong evidence of the acceleration of the nebular shell predicted by hydrodynamical models at early stages of the central star's evolution, as the star evolves towards higher effective temperatures and the velocity of the stellar wind increases. According to models, at the very late stages, the nebular shell will lose its energy input power as the stellar wind weakens and the luminosity of the central star decreases. The effects of these changes have been observed in 100 PNe from the disc population analyzed by Pereyra *et al.* (2013). In this work, they found that the nebular shells with the largest velocities tend to have high luminosity central stars and a high degree of excitation. On the contrary, nebular shells with lower degree of excitation have lower velocities and correspond to the most evolved central stars.

3. Nebular shells around low mass progenitors of PNe

The sample under study includes 11 PNe from the Halo population and 15 seemingly bona-fide, low metallicity PNe (log(O/H) + 12 $\leqslant$ 8.0 dex) with kinematic data available from the SPM Catalogue (López *et al.* (2012)). The global expansion, or bulk flow velocity, of the nebular shell was determined from the matter with the highest emission within the spectrograph slit (i.e., *not* the post-shock velocity; Schönberner *et al.* (2005)). We obtained velocity measurements from [NII] λ6584, [OIII] λ5007, and Hα λ6563 emission lines, when available. Further details about data selection and velocity measurements can be found in Pereyra *et al.* (2016). The average velocity obtained for both groups, Halo and Low Metallicity PNe, is very similar in all of the emission lines considered (Table 1). The velocity distributions for the whole sample tend towards low values, with 62%, 70%, and 87% of the objects having expansion velocities below 20 km s^{-1} in the Hα λ6563, [OIII] λ5007, and [NII] λ6584 emission lines, respectively.

Table 1. Average expansion velocities for Halo and Low Metallicity PNe.

Group	$\overline{V}_{[\mathrm{N\,II}]}$ ±2 (km s^{-1})	No. Objects considered	$\overline{V}_{\mathrm{H}\alpha}$ ±2 (km s^{-1})	No. Objects considered	$\overline{V}_{[\mathrm{O\,III}]}$ ±2 (km s^{-1})	No. Objects considered
Halo PNe	17	8	19	10	20	6
Low Metal PNe	17	7	19	14	18	11

By selecting Halo and low-metallicity PNe we bias our selected sample to a group of CSs of the lowest masses. Locating the central stars of these PNe in the Hertzsprung-Russell diagram, when temperatures and luminosities were available, we confirmed that they populate the low mass post-AGB tracks (1.5M$\odot$ or below, see Fig. 1). Although most of their nebular shells have low expansion velocities, which are among the lowest observed in PNe, their velocities do correlate with effective temperature. These results are not only in agreement with our previous findings but also with theory, which predicts that the stellar winds and the ionizing photon power output from the central star of a PN will be a consequence of the previous AGB evolution and both will increase during the post-AGB phase (Perinotto *et al.* (2004), Schönberner *et al.* (2005)). We conclude that

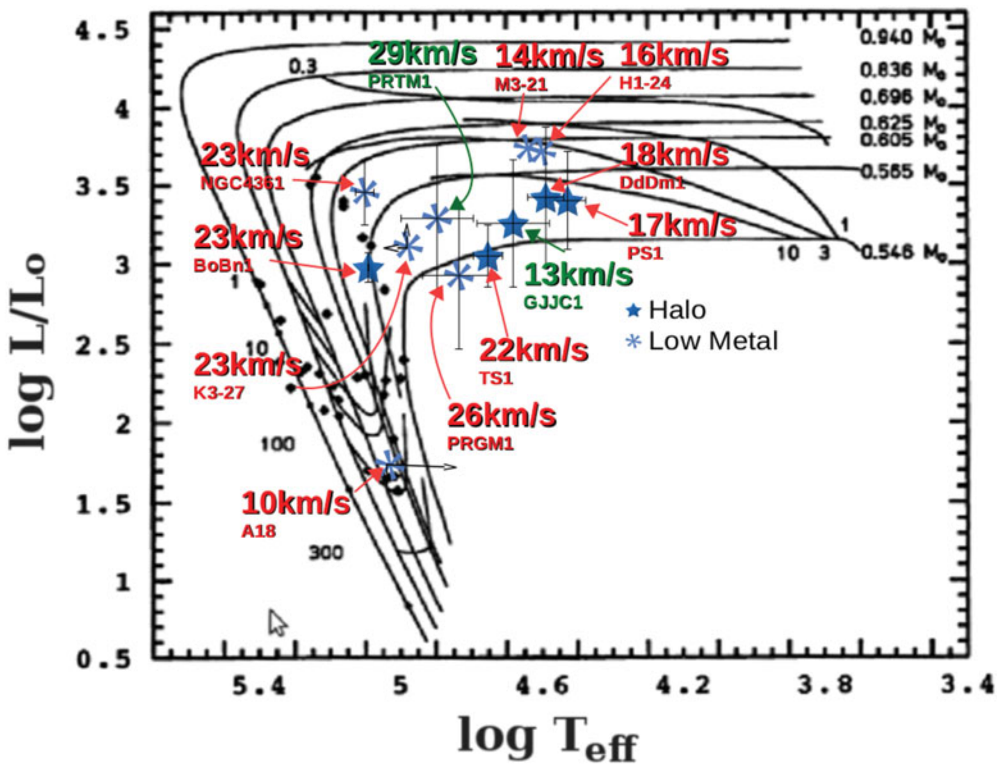

Figure 1. Coupling with the central star evolution. The central stars of these PNe with sub-solar metallicity seem to originate from low mass progenitors. Velocity measurements from Hα spectra are shown for most of the PNe (red label), except for GJJC1 and PRTM1 nebulae for which only [OIII] emission line spectrum was available (green label). The acceleration of the nebular shell is also observed in this sample, as expected from theory and previous observational results. Evolutionary tracks taken from Schönberner & Blöcker (1996).

the low expansion velocities found in this sample are directly related to the weaker stellar wind from the low-mass central stars driving the kinematics of their nebular shells.

4. Conclusions

By analyzing the internal kinematics of large samples of PNe segregated by stellar populations, we provided firm observational support for the theoretical predictions from hydrodynamical models. This work establishes a general description of the global kinematics of nebular shells and its time evolution throughout the entire planetary nebula phase (see Fig. 2). Both perspectives, theoretical and observational, are now consistent with each other but still there are some unanswered questions that need to be addressed. Our current understanding of the dynamics of PNe envelopes is mainly based on the assumption that all the nebular shells are produced by single star progenitors. However, a significant amount of binary central stars have been discovered over the past few years in the PNe Galactic population. These results suggest that the formation and evolution of planetary nebulae could be more complicated (De Marco (2009), Jones *et al.* (2014)). On the other hand, the newest theoretical models for the evolution of the post-AGB stars have pointed out that the evolutionary timescales for the central stars of planetary nebulae are at least 3 to 10 times faster than those computed by previous models (Miller

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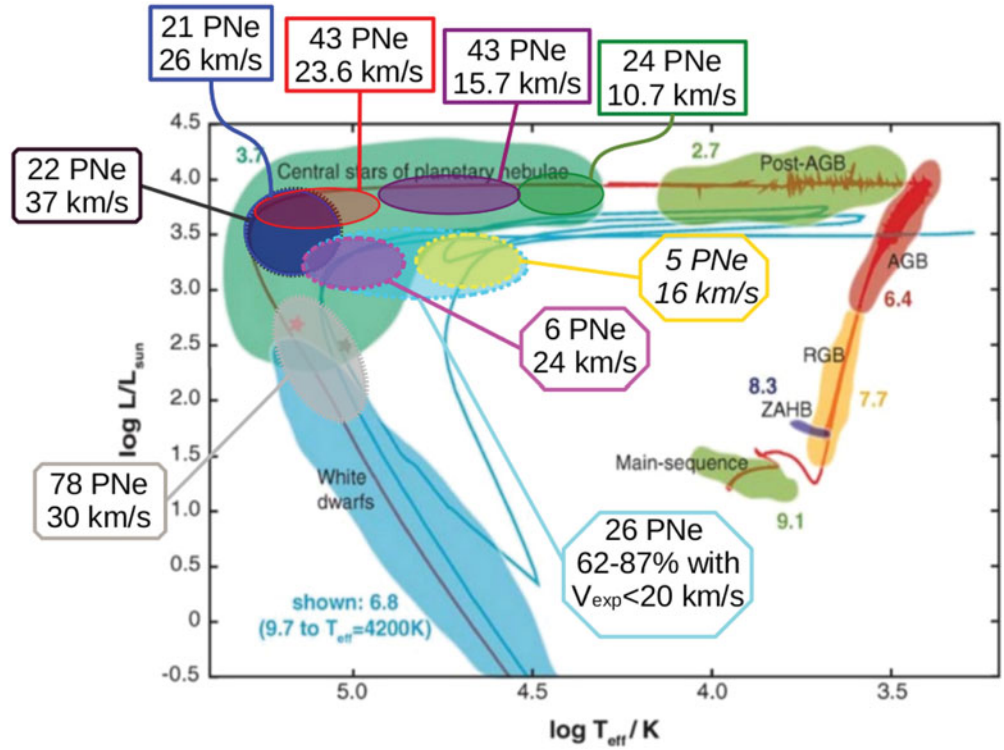

Figure 2. Observational framework for the time evolution of the internal kinematics of planetary nebulae. Hertzsprung-Russell diagram of a complete $2M_{\odot}$ evolutionary track from Herwig (2005). The labels indicate the average velocities obtained from the Bulge, Disc and Low-Mass samples. Our results clearly show that the nebular shells are accelerated at the early stages of the central star evolution in the planetary nebula phase, as the star becomes hotter and the stellar wind velocity increases. In the following evolution, when the inner parts of the shell lose their input energy from the central star, the expansion of the bulk of matter in the nebular shell slows down. For the PNe with low-mass progenitor stars we found nebular shells that expand slower that those around PNe originating from more massive AGB progenitors, which reflects the impact of the weaker stellar winds driving their kinematics.

Bertolami (2016)). These new timescales will have strong impact in the dynamics of the nebular shells of PNe, particularly for those nebulae with low-mass progenitors and should be taken into account in the radiation-hydrodynamic numerical simulations.

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Discussion

Q: We see that the expansion speeds of PNe increase as they traverse the HR diagram. What does this imply about the evolution of the nebulae?

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