Towards understanding the planetary nebula luminosity function

Paola Marigo[1,2], Achim Weiss[2], Martin A.T. Groenewegen[2], Léo Girardi[1,2]

[1] Dipartimento di Astronomia, Vicolo dell'Osservatorio 5, I-35122 Padova, Italy
[2] Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Str. 1, D-85740 Garching bei München, Deutschland

Abstract. We report on a theoretical work in progress about the planetary nebula luminosity function. A new synthetic model is developed to follow the evolution of a planetary nebula and its central star, starting from the onset of AGB phase up to the white dwarf cooling sequence. Both H- and He-burning Post-AGB tracks are used. Basic properties of the circumstellar nebula are predicted, namely: the dynamics and chemical composition of the stellar ejecta, the photoionisation of H and He by the central star, the formation of a few relevant optical emission lines (e.g. Hβ; HeIIλ4686; [OIII]λ5007). As a first application, the planetary nebula luminosity function in the LMC is analysed adopting a population synthesis approach. It turns out that a reasonable reproduction of the observed bright end in the [OIII]λ5007 luminosity cannot be obtained assuming that all central stars are H-burners, but rather considering that the observed population of PNe is excited by a mixture of H- and He-burner central stars.

1 Introduction

The bright end of the planetary nebula luminosity function (PNLF) has been suggested to be used as an extragalactic distance indicator, given its apparent nearly invariance with respect to age population and metallicity (see, for instance, Mendez & Soffner 1997 and references therein; cf. also Mendez, this conference).

In this perspective, an improved synthetic model for PN evolution is being developed (Marigo et al., in preparation) in order to investigate the sensitiveness of the bright cut-off of the PNLF to various possible factors, such as: metallicity of the progenitor stars, mass-loss during the AGB phase, initial-final mass relation, transition time from the tip of the AGB to the onset of ionisation, dynamical expansion of the nebula, evolutionary properties - luminosities and time-scales - of the central star depending on either H- or He-burning nuclear regimes, star formation history of the parent galaxy.

2 A new synthetic model of PN evolution

The main ingredients of the model are summarised in the following. The AGB phase is described by detailed synthetic models covering the evolution of low-/intermediate-mass stars from the first thermal pulse up to the complete ejection of the envelope (Marigo 1998; Marigo et al. 1996, 1998, 1999). These models provide the mass of the central star as a function of the initial mass and metallicity of the progenitor, the density and the chemical composition profiles of the ejected material as a function of time (assuming spherical symmetry), and the possible dynamical interaction of AGB shells ejected at different instants with different velocities.

Post-AGB tracks are taken from Vassiliadis & Wood (1994) for both H- and He-burning central stars over the relevant range of stellar masses and metallicities.

The prescription for the fast wind during the Post-AGB phase is derived from Pauldrach et al. (1988). The dynamical evolution of a PN is described adopting the prescriptions of Kahn & Breitschwerdt (1990) for the momentum-driven phase and the interacting stellar winds model by Volk & Kwok (1985) for the energy-driven phase. The dynamical effect of the shell thickening caused by ionisation is included following Kahn (1983). The fluxes

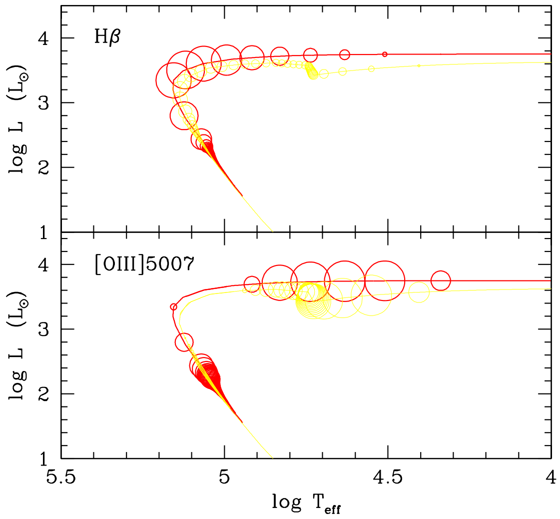

Fig. 1. Representation of the detection probability (circles) of a PN ionised by either a H- or a He-burner central star (thick and thin line, respectively) in the luminosity emitted in the Hβ line (top panel) and [OIII]λ5007 line (bottom panel). See text for further explanation.

emitted by the central star for the ionisation of both H and He^+ are specified as a function of the effective temperature and surface gravity, according to non-LTE model atmospheres (Clegg & Middlemass 1987). The intensities of few relevant optical emission lines (Hβ, HeIIλ4686, [OIII]λ5007) are calculated assuming a constant electron temperature $T_{\rm el} = 10^4 K$. This approximation will be improved with the adoption of the Cloudy photoionisation code.

3 H-burner versus He-burners central stars

The detection probability of a PN depends on whether its central star is H- or He-burner. The circles along the Post-AGB tracks shown in Fig. 1 are equally spaced in time (10^3 yr) and have a radius proportional to the logarithm of the luminosity emitted by the nebula both in the Hβ line (top panel) and in the [OIII]λ5007 line (bottom panel). In the case of Hβ emission, the detection probability increases as the H-burner central star heats up and then reduces as both bolometric luminosity and effective temperature decrease. The distribution of circles along the He-burning track reflects its systematically lower bolometric luminosity and the longer evolutionary time-scales. In the case of [OIII]λ5007 emission a notable feature is the nearly absence of this line as the central star passes through the hottest knee of the track, since at these temperatures the bulk of oxygen is expected to be three (and four) times ionised.

4 The bright cut-off of the PNLF in the LMC

The theoretical PNLF is constructed combining PN models (corresponding to central stars in the mass range $0.6 M_{\odot} - 1.1 M_{\odot}$ and initial metallicity $Z = 0.008$), with an initial-final mass relation consistently derived from AGB calculations, and simple prescriptions for the history of the star formation rate (constant) and the initial mass function (Salpeter). The results are shown in Fig. 2. It turns out that assuming all central stars of PNe in the LMC are H-burners, the observed bright end is not reproduced. A steady decrease of the distribution towards high luminosities (rather than a sharp cut-off) is predicted, and the brightest end is fainter than the observed one (top right-hand side panel). Part of the discrepancy is removed when using He-burning Post-AGB tracks to construct the PNLF (bottom left-hand side panel), and a satisfactory agreement is finally obtained assuming a mixture of H- and He-burning central stars in the proportions suggested by Dopita et al. (1996, bottom right-hand side panel). The main reason for this resides in the longer evolutionary time-scales characterising the He-burning tracks, which results in a higher probability of detecting PNe in the bright bins of the [OIII]λ5007 luminosity distribution.

Acknowledgments P. Marigo is grateful to the MPA (Garching) where most of this work has been carried out, and to ESO for financial support to attend the workshop.

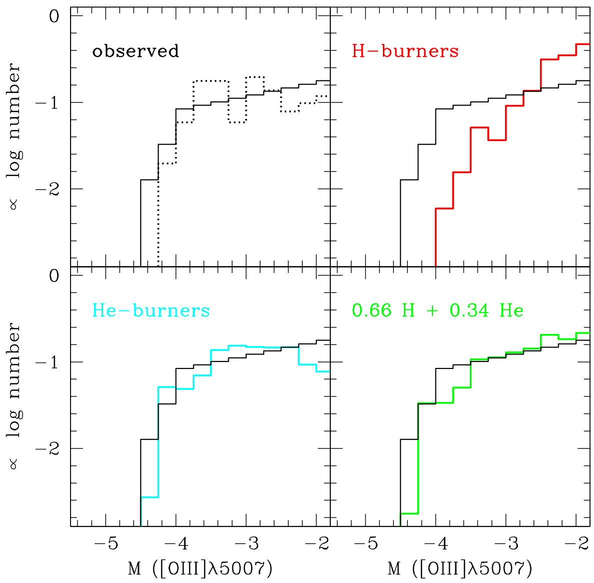

Fig. 2. Bright cut-off of the PNLF in the LMC. Top left-hand side panel: observed distribution according to the original data sample from Jacoby et al. (1990; dashed line), and including the completeness correction suggested by Ciardullo (1995; thin solid line). The absolute magnitude M([OIII]λ5007) is calculated according to the definition by Jacoby (1989). Normalisation is applied for M([OIII]λ5007)≥ -2. Other panels: comparison between observed (thin solid line) and theoretical (thick solid line) PNLFs. See text for more details.

References

1. Ciardullo R., (1995) Highlights of Astron. **10**, 507
2. Clegg R. E. S., Middlemass D. (1987) Mont. Not. Roy. Astr. Soc **228**, 759–778
3. Dopita M. A., Vassiliadis E., Meatheringham S. J. et al. (1996) Astrophys. Journ. **460**, 320–341
4. Jacoby G. H. (1989) Astrophys. Journ. **339**, 39–52
5. Jacoby G. H., Walker A. R., Ciardullo R. Astrophys. Journ. **365**, 471–477
6. Kahn F. D. (1983) Planetary nebulae IAU Symp. **103**, Dordrecht, D. Reidel Publishing Co., 305–315
7. Kahn F. D., Breitschwerdt D. (1990) Mont. Not. Roy. Astr. Soc **242**, 505–511
8. Marigo P. (1998) Astron. Astrophys. **340**, 463–475
9. Marigo P., Bressan A., Chiosi C. (1996) Astron. Astrophys. **313**, 545–564
10. Marigo P., Bressan A., Chiosi C. (1998) Astron. Astrophys. **331**, 564–580
11. Marigo P., Girardi L., Bressan A. (1999) Astron. Astrophys. **344**, 123–142
12. Mendez R. H., Soffner T. (1997) Astron. Astrophys. **312**, 898–906
13. Pauldrach A., Puls J., Kudritzki R. P. (1988) Astron. Astrophys. **207**, 123–131
14. Vassiliadis E., Wood P. R. (1994), Astrophys. Journ. Suppl. Ser. **92**, 125–144
15. Volk K., Kwok S. (1985) Astron. Astrophys. **153**, 79–90