A new [O\textsc{iii}] $\lambda5007$ Å Galactic Bulge Planetary Nebula Luminosity Function

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Abstract. The Planetary Nebulae Luminosity Function (PNLF) describes the collective luminosity evolution for a given population of Planetary Nebulae (PN). A major paradox in current PNLF studies is in the universality of the absolute magnitude of the brightest PNe with galaxy type and age. The progenitor central-star mass required to produce such bright PNe should have evolved beyond the PNe phase in old, red elliptical galaxies whose stellar populations are $\sim10$ Gyr. Only by dissecting this resolved population in detail can we attempt to address this conundrum. The Bulge of our Galaxy is predominantly old (Zoccali et al. 2003) and can therefore be used as a proxy for an elliptical galaxy, but with the significant advantage that the population is resolvable from ground based telescopes. We have used the MOSAIC-II camera on the Blanco 4-m at CTIO to carefully target $\sim80$ square degrees of the Galactic Bulge and establish accurate [O\textsc{iii}] fluxes for 80% of Bulge PNe currently known from the Acker and MASH catalogues. Construction of the [O\textsc{iii}] Bulge PNLF has allowed us to investigate placement of PNe population sub-sets according to morphology and spectroscopic properties the PNLF and most importantly, whether any population subset might constitute the bright end of the LF. Our excellent, deep data also offers exciting prospects for significant new PNe discoveries and [O\textsc{iii}] morphological studies.

1. Introduction

For the past $\sim20$ yrs, the [O\textsc{iii}] PNLF has developed into a well-established and widely used reliable extra-galactic distance indicator, permitting accurate distance measurement for galaxies out to the Fornax and Virgo clusters (Jacoby, Ciardullo, & Ford 1990; Feldmeier, Jacoby, & Phillips 2007; Gerhard et al. 2007). Ciardullo, Jacoby, & Ford (1989) published the refined fit to the luminosity function:

$$N(M) \propto e^{0.307M}(1 - e^{3(M^* - M)})$$

(1)

When the distance to the population is accounted for, the fit to the bright-end cut-off is found to have a precisely defined absolute magnitude of $M^* = -4.47^{+0.02}_{-0.03}$ (Ciardullo et al. 2002). Except for a weak metallicity dependence (Dopita, Jacoby, & Vassiliadis 1992), this bright-end cut-off is found to be invariant to galaxy type or age. This fundamental inconsistency was outlined by Ciardullo et al. (2005).
The central stars of the brightest planetaries have luminosities of $\sim 6000 \, L_\odot$, which infers masses of $>0.6 \, M_\odot$ (Marigo et al. 2004) and consequently that they evolved through the main-sequence with a mass $>2 \, M_\odot$ (Weidemann 2000). Stars with these relatively high masses only live for $\sim 1$-2 Gyr and therefore we do not expect to detect such stars in old populations such as elliptical galaxies that are $\sim 10$ Gyr old and have undergone no recent star formation. However, they are nonetheless observed in such old populations (for a more detailed discussion see Jacoby 1997).

This paradox has seriously inhibited our understanding and interpretation of the observed invariability of the PNLF bright-end cut-off to population age. We propose to address this problem via construction of a new, significantly deeper Bulge PNLF to identify whether the bright-end of the luminosity function is comprised of PN that have evolved from old, population-II stars via some peculiar path to enhanced luminosity, e.g. through binarity (Ciardullo et al. 2005), or whether it is primarily populated by younger, higher mass, bipolar nebulae of Type-I (Torres-Peimbert & Peimbert 1997).

2. Optical observations and correcting for extinction

We obtained [O$_{\text{iii}}$] photometry for 435 previously known and MASH PN (Parker et al. 2006; Miszalski et al. 2008) in a $10^\circ \times 10^\circ$ region toward the Galactic Bulge (Kovacevic et al. 2010a). From these data, we measured [O$_{\text{iii}}$] fluxes and angular diameters, both of which were in agreement to within the errors of the most trusted literature sources. Previously, only 48 PN in this region had published [O$_{\text{iii}}$] fluxes, so we are increasing the number of PN with fluxes by a factor of eight. These data provide accurate fluxes and diameters for the largest sample of PN towards this region of the Bulge ever published.

Optical observations made toward the Galactic Bulge are subject to a large amount of patchy and highly variable interstellar absorption and scatter due to dust along the line-of-sight. It is therefore important to ascertain the magnitude of extinction towards PN individually. We note that by correcting for the amount of dust towards each PN, we are also correcting for the dust internal to the nebula shell. This is not done for extragalactic PNLF studies, where a singular global extinction correction is applied to all PN. Accounting for this in PN that have evolved from high-mass central stars, where their inherently large dust content would usually act to self-extinct their bright [O$_{\text{iii}}$] emission, may prove detrimental and place them at a significantly higher value than $M^*$. This has also been observed when correcting the extinction towards individual PN for PNLF construction in the Bulge of M31.

To deredden our fluxes we undertook spectroscopic observation of $\sim 400$ PN towards the Galactic Bulge (see Miszalski et al., 2009a). For $\sim 350$ of these objects which also had [O$_{\text{iii}}$] photometry, we obtained Balmer decrement measurements with which to derive extinction estimates. These data are given in Kovacevic et al. (2010b).

3. The new Galactic Bulge [O$_{\text{iii}}$] PNLF

Previously defined criteria to identify and exclude disc PN from any Bulge PNLF construction are more assumption than fact, having never undergone rigorous testing. We re-evaluate and re-define the criteria required for PN Bulge membership in terms of location, radio flux, radial velocity, surface brightness and radio and optical angular diameters.
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Figure 1. The [O\textsc{iii}] luminosity function for Galactic Bulge Planetary Nebulae.

With this disc-cleaned sample, we present a new, preliminary version of the [O\textsc{iii}] PNLF (Fig. 1). After fitting equation (1) to the distribution, we calculate the bright-end cut-off has an absolute magnitude of $-4.38 \pm 0.13$, assuming a distance to the Galactic Centre of 7.52 kpc (Nishiyama et al. 2006). This agrees, to within the errors, with the canonical value of $M^* = -4.47^{+0.02}_{-0.03}$ (Ciardullo et al. 2002). The high-resolution of the MOSAIC-II Imaging has permitted preliminary elucidation of morphology of some Bulge PN for the first time. This, together with SHS H\textalpha images (Parker et al. 2005) and other imagery where it exists in the literature, will enable us to assign more conclusive morphological classifications from a multi-wavelength approach.

Interestingly, within our sample, we find that neither Type I nor bipolar PN populate the bright-end in agreement with Jacoby & De Marco (2002). Instead they dominate the faint end of the SMC PNLF, perhaps as a consequence of fast evolution and a high amount of dust present.

4. Future work

Our [O\textsc{iii}] data not only allows for accurate measurement of fluxes, diameters and identification of morphologies of PN, but also, the sensitivity attained has permitted the discovery of faint nebular extensions pertaining to previous periods of mass loss in some PN. This is exemplified by the case of IC 4673 (see Fig. 2), where a halo surrounds the PN (Corradi et al. 2003) together with external east-west arcs which could signify the presence of a binary central star (Miszalski et al. 2009b). The depth of the survey data has also allowed for discovery of numerous faint new PN candidates. The [O\textsc{iii}] images of PN and extensions around PN will be made available online in the near future.

5. Conclusions

We provide accurate [O\textsc{iii}] fluxes and angular diameters for the largest sample of PN in the $10^\circ \times 10^\circ$ region toward the Galactic Bulge ever obtained. We obtained optical spectroscopy to provide accurate measurement and derivation of the reddening corrections towards $\sim 350$ of the PN with [O\textsc{iii}] fluxes. The general criteria considered for Bulge
membership was re-defined, and implemented to exclude any disc PN. This cleaned sample was then used to construct our preliminary new Galactic Bulge PNLF.

This is the deepest Bulge PNLF ever constructed, ranging over 8 orders of magnitude and is complete to 4 magnitudes below $M^*$. The fit to the bright-end cut-off has an absolute magnitude of $M^* = -4.38 \pm 0.13$, using a distance of 7.52 kpc. After a brief analysis of high quality spectra from the literature, the PN constituents residing in the brightest bins are not found to be of Type-I or have bi-polar morphology.

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