Central Stars of Planetary Nebulae in SDSS and IPHAS

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Abstract. Space densities and birthrates of Planetary Nebulae (PNe) are highly uncertain. A large range of formation rates has been derived by different studies, which has led to contradicting ideas for the final evolutionary phases of low and intermediate mass stars. We started a project to deduce a birthrate using a sample of PNe within 2 kpc. The central stars will be identified in the PNe fields by their photometric colours and then used to establish improved distance estimates. To facilitate this we have created grids of photometric colours which are used to constrain stellar parameters. Our study has concentrated on PNe in SDSS and the INT Photometric Hα Survey (IPHAS) so far. IPHAS is a nearly complete northern galactic plane survey in Hα, r' and i' bands. Many previously unknown PNe have been discovered with IPHAS. We investigate implications of a more complete local sample on PN birthrate estimates.

1. Introduction

Planetary Nebulae (PNe) are thought to be the final evolutionary phase of most low/intermediate mass ($0.1M_\odot < M < 8M_\odot$) stars as they leave the asymptotic giant branch (AGB) and evolve onto the white dwarf (WD) cooling sequence. PNe are an important tool for an understanding of the final phases of stellar evolution.

A hot topic of discussion is whether PNe are formed mainly (or solely) by single or binary stellar systems. In the standard single star scenario the PN is formed when the star leaves the AGB after heavy mass loss. The ejected envelope lights up as the central star contracts and increases in temperature. Alternatively, De Marco & Moe (2005) and Moe & De Marco (2006) suggest that PN are largely created by binary stars. They argue that if the single star scenario is dominant then too many PNe will be formed in our galaxy compared to the number observed, even considering corrections for incompleteness. In the binary scenario, closely orbiting binaries will come into contact and orbital energy lost to the common envelope. The energy is used to eject the surrounding gas and drive the expansion of the nebula. Further support for a dominant binary channel comes from the non-spherical morphology of most PNe (Nordhaus et al. 2007).

A complete population census of PNe can be used to compare observations with theoretical predictions resulting from evolutionary time scales and birthrates. Current investigations predict a range of formation rates $(0.2 - 8.0) \times 10^{-12}$ pc^{-3} yr^{-1} (Soker 2006, Ishida & Weinberger 1987). As each PN forms a WD, the WD birthrate should be equal or greater than the PNe formation

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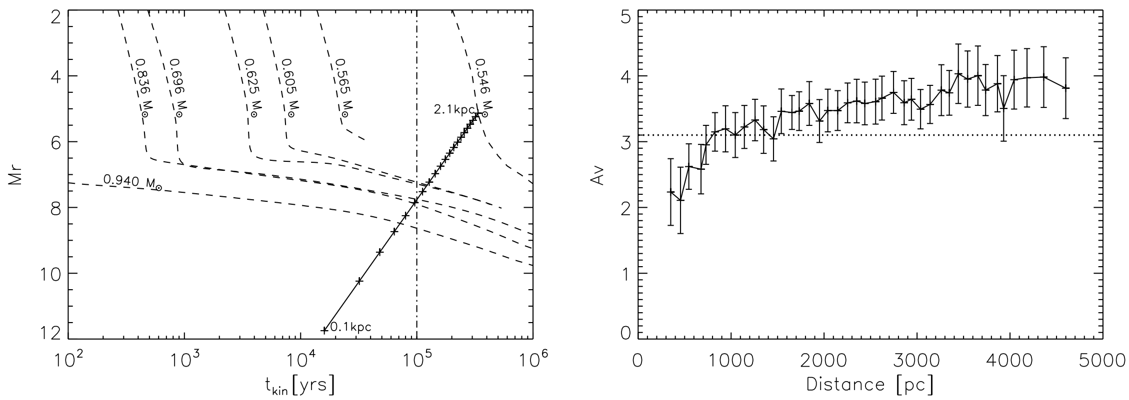

Figure 1. *Left:* PN G158.8+37.1 as an example $M_{r'} - t_{kin}$ plot with the evolutionary tracks (dashed lines) of Schönberner (1983) and Blöcker (1995). The dash-dot line indicates the time scale limit of 100,000 years. The resulting upper limit of the PN distance is 0.6 kpc. *Right:* Example of a PN (PN G126.6+01.3) in IPHAS and the projected line of sight extinction. This PN lies between 0.7 and 4.0 kpc away.

rate. The WD birthrate of $1.0 \pm 0.25 \times 10^{-12}\mathrm{pc}^{-3}\mathrm{yr}^{-1}$ (Liebert et al. 2005) poses a real problem for many PNe estimates which exceed this. Napiwotzki (2001) states that one reason for very high estimates of PNe space densities and birthrates are underestimates of PNe distances.

We intend to improve the local density estimate by collating known and newly discovered PNe within 2 kpc. An important task is to ensure we only include PNe within our volume limited sample which requires a distance estimate. We will obtain distances by using the central star of the PN (CSPN). Therefore, we must identify the CSPN within the PN field as not all are located in the centre. We discuss locating the central star in Section 2. Two methods for determining distance to CSPNe are explained in Section 3. Finally, we give details of model grids which will improve the locating the central star method previously mentioned as well as give stellar parameters using photometry in Section 4.

2. Locating the Central Star

Central stars have unique photometric colours which distinguish them from most other stellar objects, so a semi-empirical selection region was defined for the whole range of possible CSPNe parameters. The region was constructed using synthetic photometry of OB stars (Fitzpatrick & Massa 2005) and DA WDs (Holberg & Bergeron 2006) extended to hotter temperatures and adjusted to find known CSPNe in SDSS. Fitzpatrick & Massa (2005) produce Johnson photometry so we convert it to SDSS. The result positively showed that most CSPN fall within the defined region (with the remaining either saturated or their colours distorted by a companion) and no contaminate objects are detected as possible central stars. This gives us confidence, at least with no or little reddening, that CSPN are well defined with four colours and can be identified within a PN field.

3. Distance Estimates

Using the central stars we apply two ways to estimate distances. Candidate local PNe are rejected or confirmed from our sample based on the results, or inspected further if close to our distance limit.

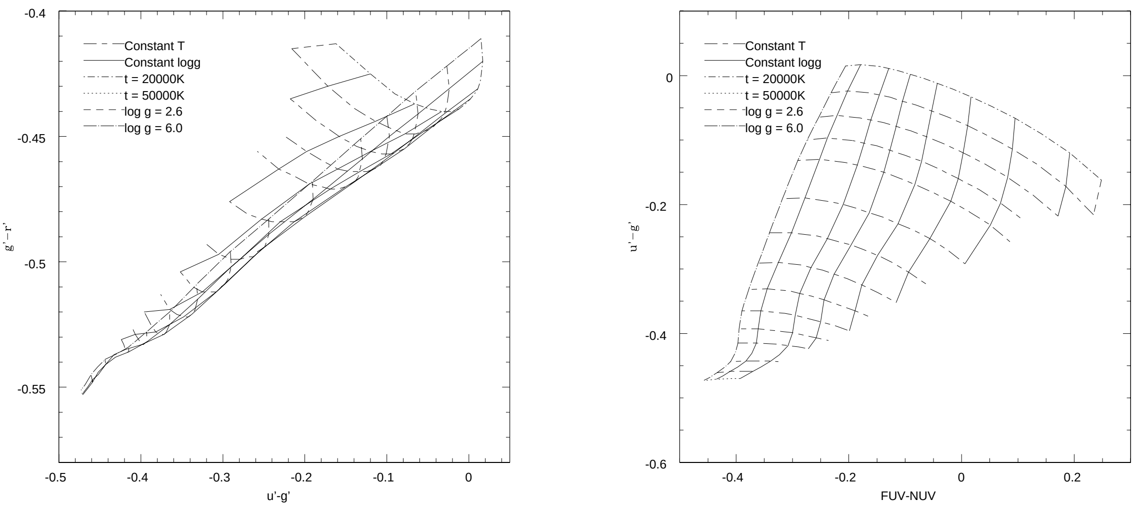

Figure 2. *Left:* PN G158.8+37.1 as an example $M_{r'} - t_{kin}$ plot with the evolutionary tracks (dashed lines) of Schönberner (1983) and Blöcker (1995). The dash-dot line indicates the time scale limit of 100,000 years. The resulting upper limit of the PN distance is 0.6 kpc. *Right:* Example of a PN (PN G126.6+01.3) in IPHAS and the projected line of sight extinction. This PN lies between 0.7 and 4.0 kpc away.

3.1. Distance Estimates from Evolutionary Tracks

For a PNe with the distance known, an absolute magnitude of the CSPN and a kinematic age, $t_{\rm kin}$, can be computed from the nebula radius and expansion velocity. Fig. 1 (left) shows the post-AGB evolutionary tracks of Schönberner (1983) and Blöcker (1995) converted to the $M_{r'} - t_{\rm kin}$ plane. This plot can be used to constrain the distance of PNe. For any hypothetical distance $M_{r'}$ and $t_{\rm kin}$ lie on a line, each point corresponding to a CSPN mass. We assume $0.6 M_\odot$ as the standard value as 80% of all white dwarfs have $M = 0.6 \pm 0.1 M_\odot$ (Liebert et al. 2005). The angular diameters and expansion velocities are taken from Acker et al. (1992). Where the expansion velocity is unknown a value of 20 kms^{-1} is assumed. Extinction is calculated using $E(r' - i')$ assuming an intrinsic $r' - i'$ value of -0.35.

We compared our results to distances from Cahn et al. (1992) and Acker et al. (1992). The results are mixed with some distances in agreement, however, most have large discrepancies. Although some uncertainty results from the the unknown CSPN mass, the statistical methods used by Cahn et al. (1992) and Acker et al. (1992) have large systematic errors (Napiwotzki 2001).

3.2. Distance Estimates from Extinction

Distances can be estimated using relations between interstellar absorption and distance. A good distance estimate can only be obtained with a detailed 3D dust map. The maps of Schlegel et al. (1998) give only the integrated extinction and thus can't be used for this purpose. Our future sample will include observations from the INT Photometric Hα survey (IPHAS, Drew et al., 2005). We will exploit the work of Sale et al. (2008) who present an algorithm which will produce a 3D extinction map across the entire Northern Galactic plane (Sale et al., in prep.). All CSPNe have a narrow range of intrinsic $r' - i'$ colours ($r' - i' = -0.35 \pm 0.04$) and so we can estimate an accurate $E(r' - i')$. Once converted to an r' band extinction, $A_{r'}$, the distance can be extracted from Sale et al.'s projection of the galactic dust. An example can be seen in Fig. 1 (right). Combining both methods, we will be able to compile a sample of good candidates for the local PN population.

4. Grids of Synthetic Photometry for CSPNe

We are in the process of refining the photometric selection and analysis by computing synthetic photometry in all filters required from model Spectral Energy Distributions (SEDs). This will be extended to include the whole parameter range for CSPNe and filters covering the UV to near-IR range. So far we have created photometric grids for OB type CSPNe from ATLAS9 models (Kurucz 1991) and hot DA WDs from Finley et al. (1997). If the star was observed with the UV satellite GALEX as well, then we can easily determine stellar parameters from photometry (Fig. 2). With the current model grids for SDSS, GALEX and IPHAS we will be able to locate the central star, and obtain an approximate distance (or range) and stellar parameters. Furthermore, with the SEDs many bands and systems (therefore surveys) can be added and the project begin to compile an accurate and more complete local sample.

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