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# Do All PNe Come From Binaries?

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**Abstract.** We present a population synthesis calculation to derive the total number of planetary nebulae (PNe) in the Galaxy from single stars and binaries. By combining the most up-to-date literature results regarding galactic and stellar formation and evolution, we determined the total number of PNe with radii <0.8 pc deriving from single stars and binaries to be 46 000±15 000. By using common envelope (CE) calculations and observational results of main sequence binaries, we predict that 5 000±1 600 post-CE PNe with radii <0.8 pc exist in the Galaxy today. We compare these predictions with the observationally-based estimate of 7 200±1 800 PNe in the Galaxy with radii <0.8 pc. This suggests that many single stars do not produce PNe and that 69±28% of PNe we observe derive from CE interactions on the Asymptotic Giant Branch (AGB).

**Keywords.** planetary nebulae, binaries: close, stars: statistics, Galaxy: stellar content

## 1. Introduction

The primary mechanism for producing PNe can be better understood by predicting the number of PNe deriving from single and binary systems via a population synthesis and comparing these predictions to the observationally-based estimate of the Galactic PN population. De Marco & Moe (2005) used simple averages of the mass of the Galaxy, initial mass function (IMF), stellar lifetimes, and PN visibility times and predicted the possibility that galactic PNe might come primarily from binary interactions. This prompted a more refined calculation to constrain the errors.

## 2. Population Synthesis for Single Stars and Wide Binaries

Our population synthesis calculation (see Moe & De Marco 2006, for details of the model) incorporates the masses, star formation histories, IMFs, metallicities, mass/metallicity-dependent stellar lifetimes and PN visibility times as well as their uncertainties for the different components of the Galaxy. The mean PN visibility time was determined to be (25 000±5 000) yr based on the post-AGB evolutionary tracks of Vassiliadis & Wood (1994) and Bloecker (1995) and setting a kinematic age limit of 35 000 yr, which corresponds to a maximum radius of detectability of ∼0.8 pc. It was also shown that only (74±12)% of single stars would pass through a visible PN phase since progenitors below ∼0.9 $M_\odot$ have evolutionary transition times too long to produce PNe, and that ∼10% of systems will never ascend the AGB due to a CE event during the red giant branch (RGB). The number of PNe predicted in the Galaxy from single stars and binaries is (46 000±15 000) objects. The predicted white dwarf formation rate is $1.0\pm0.3\times10^{-12}$ PN $yr^{-1}$ $pc^{-3}$, which is identical to the observational estimate of Liebert *et al.* (2005).

## 3. Population Synthesis for Close Binary Systems

About 57% of late F-G type systems have a stellar companion (Duquennoy & Mayor 1991), but not all of these will create PNe via CE interactions. De Marco *et al.* (2003) used nested-grid simulations of CE interactions to show that a companion-to-primary mass ratio of 0.15 is sufficient to eject the envelope of a typical AGB primary star during a CE event. According to Duquennoy & Mayor (1991), 92% of binaries have mass ratios above this limit and will therefore survive a CE on the AGB, producing a close binary in the middle of a PN.

It is assumed that RGB and AGB stars can tidally capture companions up to ∼5 and ∼3 times their radius, respectively (Soker 1996). Since a representative 1.5 $M_\odot$ progenitor star will expand to 100 $R_\odot$ and 500 $R_\odot$ at the tips of the RGB and AGB, respectively (Falk Herwig, priv. comm.), then the orbital separation must lie in the range 500 $R_\odot$ $< a$ $<$ 1500 $R_\odot$ for a CE to occur on the AGB. About 11% of binary systems will experience a CE interaction on the AGB, while 23% will undergo a CE event on the RGB according to the period distribution of Duquennoy & Mayor (1991). Only binaries that undergo a CE event *on the AGB* are assumed to make central stars of PNe, since central stars of PNe are found observationally to be post-AGB objects (Napiwotzki 1999).

The PN visibility times of post-CE PNe should be 1.9 times longer (1.0 / 0.74 × 35 000 yr / 25 000 yr) than the PN visibility times of single stars and binaries which do not undergo a CE event. This is because the CE ejection shrinks the stellar radius of the primary in a matter of a decade (Sandquist *et al.* 1998, De Marco *et al.* 2003), propelling the central star to a much hotter temperature and effectively shortening the transition time. Therefore, the number of PNe in the Galaxy with radii <0.8 pc that derive from CE interactions on the AGB is (46 000±15 000) × 0.57 (binary fraction) × 0.92 (adequate secondary mass) × 0.11 (correct orbital separation) × 1.9 (adjustment of PN visibility time) = (5 000±1 600) objects.

## 4. Conclusion

Peimbert (1990) calculated that there should be (7 200±1 800) PNe with radii <0.8 pc in the Galaxy based on observational estimates. Our prediction of (46 000±15 000) galactic PNe that should derive from single stars and binaries is discrepant at the 2.6 $\sigma$ level, suggesting that only a subset of the eligible stars can actually make PNe. The (5 000±1 600) PNe predicted to derive from CE binaries is much closer to the observational estimate. Taken at face value we would predict that (5 000±1 600)/(7 200±1 800) = (69±28)% of the PNe observed in the Galaxy derive from a CE event.

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