PLANETARY NEBULAE: THEIR EVOLUTION AND ROLE IN THE UNIVERSE
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Planetary Nebulae in the SMC

George H. Jacoby

WIYN Observatory, P.O. Box 26732, Tucson, AZ 85726

Orsola De Marco

Department of Astrophysics, American Museum of Natural History, Central Park West at 79th Street, New York City, NY 10024

Robin Ciardullo

Department of Astronomy and Astrophysics, Penn State University, 525 Davey Lab, University Park, PA 16802

Abstract. Using the ESO 2.2m telescope with the 8K x 8K mosaic CCD, we surveyed 2.8 square degrees ($\sim$1.6° x 1.7°) of the SMC to search for faint planetary nebulae (PN). In this region, 34 PN were previously known; we identified 25 new objects. All of these are faint and have been spectroscopically confirmed. We estimate that there should be $\sim$140 PN in the entire SMC to the limits of a survey like this one, which is complete to 6 mag down the planetary nebula luminosity function (PNLF). For a complete survey (8 mag down the PNLF), there should be $\sim$220 PN. A strong new feature is evident in the PNLF as a deficiency at 4 mags below the brightest PN.

The survey spectra that were used to confirm the candidates as PN show that the fainter PN exhibit a higher incidence ($\sim$28%) of strong [N II] emission (where I([N II]/I(Hα) > 1) relative to the bright Sanduleak et al. (1978) sample ($\sim$6%). We propose that the very faint SMC PN are selectively biased toward the chemically enriched Type I objects derived from younger, more massive progenitors.

1. Introduction

Following on the early pioneers of Magellanic Cloud planetary nebula (PN) research (Lindsay 1961, Henize & Westerlund 1963, Webster 1969, Sanduleak, McConnell, & Philip 1978, and Aller 1983), we have returned to the SMC PN to investigate the properties of the faintest PN in that galaxy. The SMC PN provide us with a unique sample of very metal-poor, spatially resolved PN at a known and nearby distance. By studying these PN, we can test for suspected biases in the abundances of extragalactic PN studies (Jacoby & Ciardullo 1999; JC). By comparing their chemical compositions with those of the brighter Stasińska, Richer, & Mc Call (1998) sample, JC identified a bias in which the more luminous PN exhibit a more metal-rich composition.

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If the bias can be shown to be small or nonexistent, or if it can be corrected for, then the door is open to use PN of any luminosity to derive the chemical enrichment history for a galaxy. Dopita et al. (1997) did so for the LMC, and Walsh et al. (2000) did so for M31 using the data from JC, but both of those results may be affected by any luminosity dependent bias.

2. Observations

The survey for new faint SMC PN was carried out with the ESO 2.2-m telescope and the 8K x 8K wide field imager (WFI). Approximately 2.8 square degrees in the central body of the SMC were imaged using the on-band/off-band method at [O III] λ5007. Our survey recovered the 34 PN previously known in this region, and found 25 new PN. None of the new PN is in the brightest 2 mags of the PN luminosity function (PNLF), indicating that prior surveys are complete to that depth. Other than the Murphy & Bessel (2000) survey, for which the PN candidates have not been confirmed spectroscopically, our survey provides the largest number of new SMC PN.

We used the CTIO 4-m telescope to confirm that the new objects have spectra that are consistent with true PN. Our original list of 31 candidates included 5 variable stars and 1 old nova (de Laverny et al. 1998). Of the remaining 25 PN, 4 are common to the Magellanic Cloud Emission Line Survey (MCELS) group (Galle, Winkler, & Smith 2001), and 4 PN are bright enough that our survey spectra allow a preliminary abundance analysis.

Based on this small survey, it is clear that many new SMC PN can be found easily with modern mosaic CCD cameras. We estimate that ~140 PN exist to the depths of this survey and that a total of ~220 PN can be found in the SMC.

Table 1. Abundances for 4 Faint SMC PN

PN ID mag =	#6 21.2	#13 20.9	#18 20.7	#20 20.7	Galaxy PN/Solar	SMC PN/HII
He/H	0.184	0.304	0.142	0.150	0.115/0.098	0.121/0.081
O/H	8.42	7.88	7.92	7.86	8.68/8.93	8.05/7.96
N/H	8.14	8.13	< 7.1	8.94	8.35/8.00	7.29/6.55
S/H	7.10	6.75	−−	6.94	6.92/7.21	6.52/6.32
Ne/H	7.91	7.21	6.66	6.59	8.09/8.09	7.28/7.17
Ar/H	5.80	5.71	−−	6.24	6.39/6.56	5.89/5.72
N/O	0.53	1.78	< 0.15	12.0		

3. Abundances

A trend was apparent even at the telescope: many of the faint PN displayed very strong lines of [N II] λ6583 relative to Hα. Compared to the bright SMP sample, in which only 1 PN out of 18 (5.5%) has $I_{6583} > I_{H\alpha}$, 7 PN from the new sample (28%) exhibit strong [N II] lines. While a proper abundance analysis is necessary to certify these 7 PN as Type I nebulae, the early statistics are very

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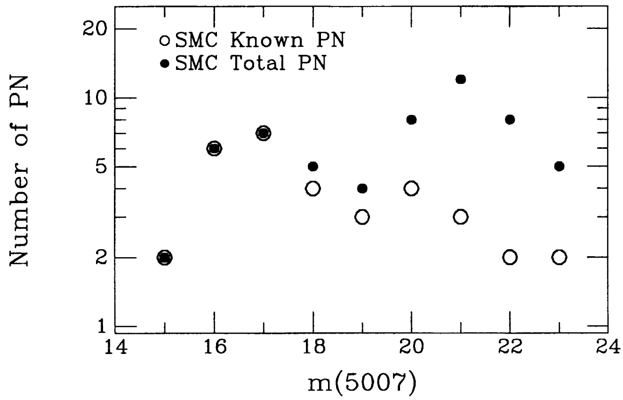

Figure 1. The PNLF for the SMC PN. The open circles represent the PNLF prior to this survey and is incomplete for PN fainter than 2 mag below the bright PN limit. This survey (solid circles) extends the completeness limit 4 additional mags. Note the dip in the PNLF at $m_{5007} = 19$.

suggestive that faint PN are more likely to be Type I than are bright PN. This correlation can be understood as a consequence of two primary factors. First, the progenitors of Type I PN are more massive stars that produce massive central stars, which in turn, evolve and fade rapidly, leaving behind a faint PN. Second, massive progenitors expel most of their mass, thereby producing a dustier environment than would a low mass progenitor. The dust-enriched material causes self-obscuration (Ciardullo & Jacoby 1999) to create a fainter PN.

If, in fact, fainter PN are 5 times more likely to be Type I PN than bright PN, then clearly there must be a bias among PN abundances that is luminosity dependent. This bias might have no impact on deriving the chemical evolution history of galaxies since the history may be correct (e.g., all the Type I enriched PN derive from young progenitors), but it does affect the estimates for the average stellar abundances.

Of the 4 PN for which abundance measurements are available, 3 would be classified as Type I according to the Peimbert & Torres-Peimbert (1983) definition. Two of these are Type I PN by any criteria (e.g., Kingsburgh & Barlow 1994; KB94). The abundances are given in Table I using the methodology from Alexander & Balick (1997), which derives ionization correction factors from photoionization models as suggested by KB94.

Based on the helium and nitrogen values in Table 1, PN #13 and #20 are certainly Type I candidates, while PN #18 is not. PN #6 has plenty of helium, but the nitrogen enrichment only marginally exceeds the Peimbert & Torres-Peimbert requirement of $N/O > 0.5$, but is well below the KB94 requirement of 0.8. Given the uncertainties in the data and analysis, this PN's classification cannot be made conclusively. The chemical compositions of just these 4 PN indicate that the elemental abundances are diverse among the SMC population, with some stars being 4 – 10 times more metal-rich than the most metal-poor.

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4. The Luminosity Function

The new PNLF for the SMC (Figure 1) represents the deepest PNLF ever, complete to 6 mag below the PN bright limit. With the added depth, a new feature emerges; a deficit of PN appears at $\sim$ 4 mag down the PNLF. The physical cause of this dip is not known, but simulations of theoretical PNLFs suggests that it can arise from the rapid evolution of PN central stars as they descend from their peak luminosity toward the white dwarf cooling sequence.

5. Conclusions

- Many faint PN should be easily discovered in nearby galaxies with modern CCD mosaic cameras.
- A bias exists for finding Type I PN among the fainter PN, probably due to the fast evolutionary speed of the more massive Type I central stars and the added dust created during the birth of the PN.

For further details, see Jacoby & De Marco (2002). We thank Jennifer Wilband of Tucson's Sahuaro High School for helping reduce the spectral data.

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