Morphology and Evolution of the SMC Planetary Nebulae

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The SMC Survey with *HST*

Planetary Nebulae (PNe) have for many years been used as probes of the late stages of stellar evolution. While in many ways such studies have been very successful, and have inspired elaborate theoretical work on stellar evolution, they have been hampered by the great difficulty of determining accurate distances to PNe. As well, extinction within the Galaxy introduces substantial selection effects in the observed samples, making a direct comparison with theory very challenging. These are the single greatest limitations to further advances in the study of post-AGB evolution. These problems are being addressed using the superior resolution and instrumentation of *Hubble Space Telescope* by studying PNe in the Magellanic Clouds, where the spatial resolution is comparable to that for typical Galactic PNe observed from the ground.

We present images and slit-less spectra from a survey of SMC planetary nebulae (PNe), which is now underway. These data on 18 targets were obtained within the last half-year with *HST* using the Space Telescope Imaging Spectrograph. The data permit us to determine the nebular dimensions and morphology in the monochromatic light of several emission lines, including those that have traditionally been used for morphological studies in the Galaxy (Hα, [N II] 6583 Å and [O III] 5007 Å), plus others of varying ionization, such as [O I], He I, and [S II]. The broad-band images allow us to determine the central star magnitudes (for the brighter stars), which will yield the evolutionary state of the central stars, and to distinguish spatial from velocity structure in the slit-less spectra. This paper examines the evolution of the nebulae themselves, as well as the morphology and other nebular properties. We combine our SMC sample with that published for the LMC PNe (Shaw et al. 2001), and compare the samples to understand nebular evolution in contrasting host environments.

Morphology and Nebular Evolution

We revisit the question posed by Shaw et al. (2001) of temporal evolution of the nebular morphology by examining the change in surface brightness of nebulae as a function of nebular size (Fig. 1). We see the tendency noted in the LMC sample of bipolar-core nebulae to be found preferentially at intermediate sizes ($0.05 < R_{neb} < 0.16$ pc), but not at large sizes, and with little overlap with the pure bipolar PNe. This suggests that BC nebulae evolve to a pure bipolar morphology by the time they reach a large size.

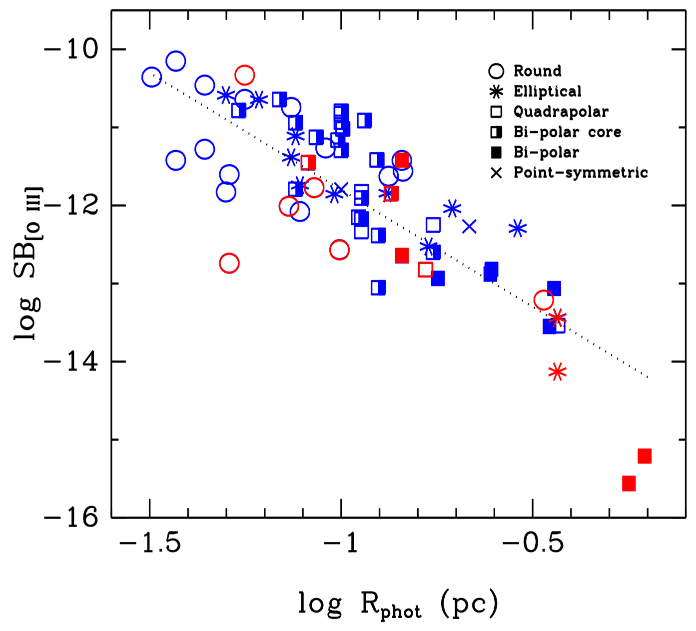

Figure 1: The decline of surface brightness (in the light of [O III] 5007 Å) with nebular radius is consistent with $SB \sim R^{-3}$ (*dotted line*). Symbols indicate morphological type, as shown in the legend; LMC nebulae are in blue, and SMC in red.

Morphology and Environment

Although the number of resolved SMC PNe is still quite small, Table 1 suggests that the "asymmetrical" PNe may be less common in the SMC than in the LMC. If true, this would be consistent with the result from Stanghellini et al. (2000) that PN asymmetry is correlated with the alpha-element abundances (and hence, the local stellar Population) of the progenitor stars. Since the SMC is relatively metal poor compared to the LMC, we would expect to see fewer asymmetric PNe. The LMC and Galaxy may differ due to selection effects in the latter sample.

Table 1: PN Morphology Fractions in Host Galaxy

Morphological Class	Galaxy	LMC	SMC
Elliptical	49%	17%	29%
Round	23%	29%	35%
Bipolar	14%	10%	18%
Bipolar-Core	9%	34%	6%
Quadrupolar	3%	7%	6%
Point-Symmetric	3%	3%	6%
Total Asymmetric (B+BC+Q)	**26%**	**51%**	**29%**
Number of Objects	264	59	16

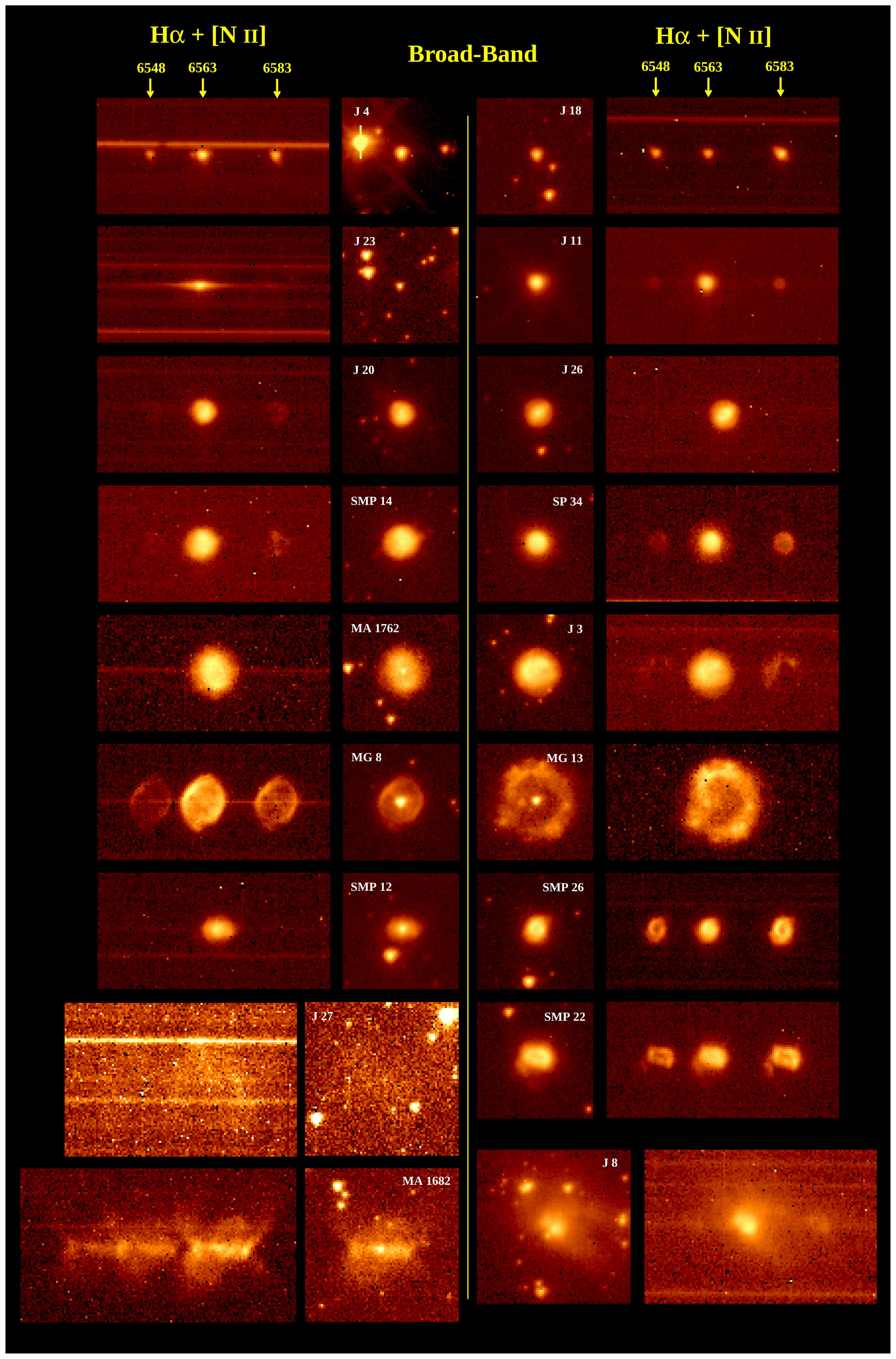

Figure 2: Broad-band images and slitless spectra of the observed SMC nebulae in this GO program, arranged in two columns by morphological type. All images are on the same spatial scale, with a square-root intensity stretch; the field of view in most images is 3 x 3 arcsec. The physical scale is ~0.282 pc/arcsec.

Morphology and Ionized Mass

The ionized mass of a PN can be computed from the Hβ flux, once the distance and interstellar reddening are known. While the range of ionized mass in Galactic PN (to which the distance is known by some independent means) was known to vary by roughly an order of magnitude, a mean value (near ~0.2 $M_{\odot}$) has been used as the basis of a number of "statistical" distance methods (see, e.g., the analysis by Boffi & Stanghellini 1994). Figure 3 shows that the nebular mass varies by at least a factor of 20. There is little evidence that the ionized mass varies with morphological type, although there is some hint that the range of ionized masses is slightly broader for BC nebulae.

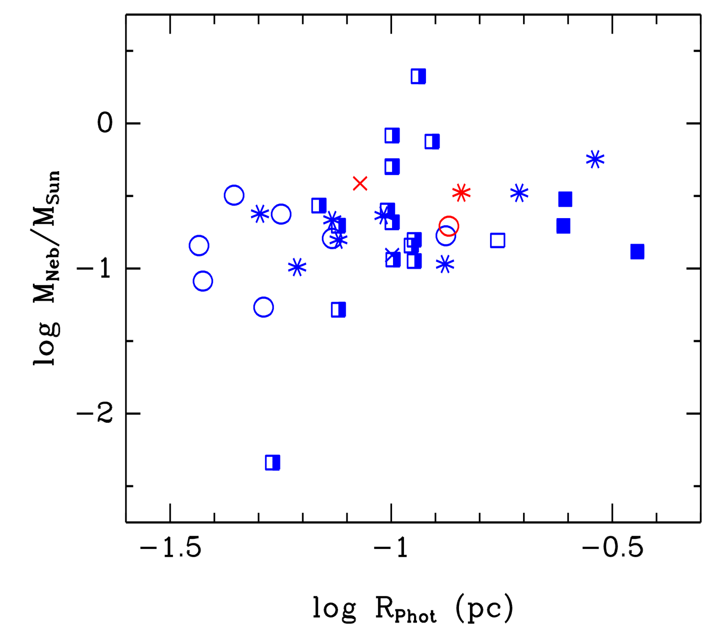

Figure 3: Ionized nebular mass as a function of nebular radius for LMC (blue symbols) and SMC (red symbols) PNe. Symbols as in Fig. 1.

Morphology and Nebular Expansion

We examine in Figure 4 the relationship between nebular expansion velocity and radius, which is important for inferring the correct dynamical age of the nebulae. The trend toward higher expansion velocity with size may result from an acceleration of the PN shells by wind and radiation from the CS, up to about 0.1 pc in radius. Alternatively, R-type nebulae may simply expand more slowly than other types, and fade below our detection threshold before they reach large size.

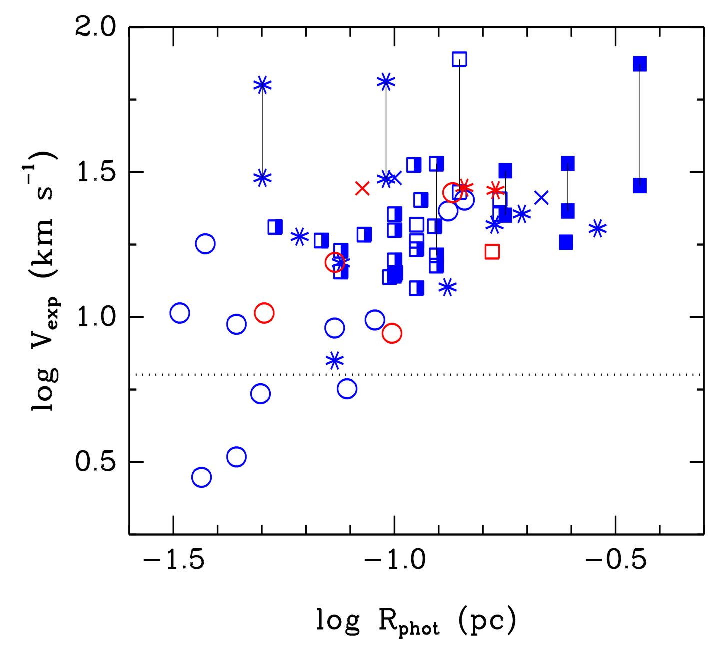

Figure 4: Nebular expansion velocity (adapted from Dopita, et al. 1988) as a function of nebular radius for LMC (blue) and SMC (red) PNe. Greater uncertainty likely applies to values of V_{exp} for which the correction for the instrumental resolution (dotted line) is large. Nebulae with multiple velocity components are shown at the extrema of the published velocity range, and are connected with vertical lines. Symbols as in Fig. 1.

Conclusions

This study of SMC PNe, which is still underway, is giving us significant insight into the formation and evolution of the nebulae and their central stars, and the effect of metal abundance in the host galaxy on that evolution. This is possible because we can study a relatively unbiased sample of PNe to examine the formation and evolution of the nebulae. Specifically, there is good evidence for at least some evolution in the morphological type as PNe age. As well, this morphological study places some constraints on the mechanism for PN formation and subsequent evolution. Finally, this survey will be greatly expanded in an HST Cycle 10 program to image an additional 224 LMC PNe.

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References

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