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MAGELLANIC CLOUDS PLANETARY NEBULAE: AN UPDATED VIEW ON STELLAR EVOLUTION AND POPULATIONS

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RESUMEN

Se estudian las Nebulosas Planetarias (NPs) de la Nube Mayor de Magallanes para entender las poblaciones estelares y la evolución de las estrellas de masa baja e intermedia, en diferentes ambientes químicos. Usando observaciones del Telescopio Espacial Hubble (*HST*), para nuestro estudio morfológico de NPs de las Nubes de Magallanes, y datos de los archivos del *HST*, buscamos las relaciones entre la morfología de las NPs y su evolución y poblaciones. En este trabajo mostramos algunos de nuestros resultados recientes sobre estas relaciones, en un contexto histórico.

ABSTRACT

Planetary Nebulae (PNe) in the Magellanic Clouds are studied to understand stellar populations and evolution of low- and intermediate-mass stars in different chemical environments. Using *HST* observations from our LMC and SMC PN morphological survey and from the *HST* Data Archive, we look at the relations between PN morphology and their evolution and populations. In this paper we show some of our recent results on these relations, in an historical context.

Key Words: **MAGELLANIC CLOUDS — PLANETARY NEBULAE: GENERAL — STARS: EVOLUTION**

1. OPEN QUESTIONS ON PLANETARY NEBULA MORPHOLOGY AND EVOLUTION

During the past decades, significant progress has been made toward the understanding of the late phases of stellar evolution of low- and intermediate-mass stars through the study of Galactic and extragalactic Planetary Nebulae (PNe). Planetary Nebulae are the gaseous relics of the evolution of stars in the 1–8$M_\odot$ mass range, and they carry a wealth of information on the physical status of their progenitors.

The morphology of PNe is an essential physical parameter to know in order to construct reliable models of nebulae and stars. Pioneering studies on the connections between PN morphology and the evolution of the stars, and the progenitor populations, started in the early 1970s with the work of Greig (1972), and continued with Peimbert (1978), and Peimbert & Torres-Peimbert (1983). The work done by the Peimbert's group set the stage for more recent studies, by showing that PNe in the Galaxy are the progeny of different stellar populations, and that there is a connection between the scale height distribution of Galactic PNe and their chemical content. In fact, Peimbert (1978) found that PNe in the Galactic disk are underabundant in carbon, and overabundant in nitrogen, as expected from stellar evolution of stars more massive than about 2–3$M_\odot$. Morphology is another link between Galactic spatial distribution and chemistry of PNe: the nitrogen overabundant PNe in the Galactic disk tend to be bipolar in shape.

The early results have been later confirmed on the basis of larger databases. Stanghellini et al. (1993) suggested that the bipolar nebulae host central stars with higher masses than those hosted by elliptical and round nebulae. Manchado et al. (2000) performed a similar analysis with data in the IAC catalog of northern PNe (Manchado et al. 1996). The analysis basically confirms the earlier results, with the added bonus of the reliability of a complete and homogeneous PN sample.

Despite the large amount of important work on planetary nebulae and their evolution, there are still fundamental questions that remain unanswered. The main question related to PN morphology is the quest for the mechanism(s) that produce symmetric or asymmetric PNe, and how the appropriate mechanisms can account for the observed scenarios. An excellent description of the present understanding of the link between morphology and evolution has been presented by García-Segura at this conference (García-Segura et al. 2002). It is more and more evident that measuring absolute physical parameters of PNe is essential in order to constraint the models.

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A thorough analysis and modeling of the Magellanic Cloud PNe is very important to achieve the next level of understanding of PNe and their environment. Toward this end, it is essential to minimize the distance (and stellar luminosity) uncertainties. Studies of PNe in the Magellanic Clouds are of fundamental importance in answering the following set of open questions:

1. Is PN morphology related to the Population of the progenitor and its chemistry?
2. How does PN morphology relate to the galactic properties, such as metallicity, star formation history, and distribution of stellar populations?

2. THE IMPORTANCE OF MAGELLANIC CLOUD PLANETARY NEBULAE

2.1. *Background*

The spatial resolution achieved with *HST* observations allows to explore extra-galactic PN morphology, and its relations to the physics of the central stars and to nebular evolution. Planetary Nebulae in the Magellanic Clouds are exceptionally suited for this type of studies, for their known distances and their low field reddening.

Since the mid 1950s, planetary nebulae have been identified and confirmed spectroscopically in the Magellanic Clouds (e.g., Lindsay 1955; Webster 1969). The Magellanic Cloud (MC) PNe are typically spatially unresolved from the ground. For this reason, the early science results are mainly based on PN spectra, used to determine the nebular abundances, the plasma diagnostics, and the motion of the PNe within the host galaxies (Dopita et al. 1985; Aller & Keyes 1987; Peimbert 1987; Boroson & Liebert 1989; Barlow 1991; Torres-Peimbert 1993).

The inability to resolve the MC PNe spatially with ground-based astronomy did not prevent studying the correlations between the PNe and their central stars, using stellar physical parameters inferred from the physics of the host nebulae. Kaler & Jacoby (1990) found correlations between the central star masses and the N/O and C/O abundances of the PN shells in the MC. Their technique was to determine stellar temperature via the crossover temperature method, then get the central star masses from their location on the HR diagram. Among other findings, this work revealed the nitrogen depletion of the low-mass central stars.

The availability of the *HST* imagery naturally induced a renaissance of PN studies in the Magellanic Clouds. Even with the earlier, optically-aberrated *HST* observations, studies of LMC and SMC PNe led to morphological insight (Blades et al. 1992; Dopita et al. 1996; Vassiliadis et al. 1998; Stanghellini et al. 1999). As WFPC2 and STIS became available on *HST*, the level of accuracy of the morphological studies of MC PNe reached the level of detail of Galactic PN morphology via ground-based observations.

2.2. *Our HST/STIS Morphological Program*

In this paper, we show the early results of a large project on the morphology, evolution, and populations of the Magellanic Clouds PNe. Our project aims at studying the correlations between morphology and stellar evolution and populations in PNe in the Magellanic Clouds. To this end, we use our own *HST* observations, as well as data from the *HST* Data Archive. The archived data consists of MC PN images including 29 PNe. Most of these images are compromised by spherical aberration, thus their resolution is limited. Our own *HST* images are acquired within two *HST* snapshot programs: 8271 (LMC PNe) and 8663 (SMC PNe). The LMC program is complete with 29 PN observed to date. The SMC program is still active, counting so far about 20 PNe. Here we describe the results obtained from the LMC program, but the importance of the SMC PN observations and a preview of the early results is also discussed.

Our MC PNe are observed with STIS slitless spectroscopy (Shaw et al. 2001). This method produces a series of *narrowband* images in the prominent nebular lines, and achieve spatial and spectral resolution at once. Together with the slitless dispersion, a *clear filter* image is also taken for each nebula, as a reference for the general morphology and to locate the central star, if visible, and to determine its magnitude. The archived PN images, together with our newly observed images, where classified morphologically as Round (R), Elliptical (E), Bipolar (B), Bipolar Core (BC), Quadrupolar (Q), and Pointsymmetric (P). All types are discussed in Manchado et al. (1996), except the BC class, discussed by Stanghellini et al. (1999). The spatial resolution that we achieved with the STIS images of LMC PNe is as good as the typical ground based resolution for Galactic PNe that are 3 kpc away. This means that we can acquire a reliable morphological classification of our sample MC PNe. Nonetheless, it is impossible with the existing technology to detect the fine details in MC PNe. In particular, the pointsymmetry, when associated to bipolarity, can be hard to detect.

We found that the individual morphological types in LMC PNe are similar to those of Galactic PNe. In Figure 1 we show a sampler of LMC PNe

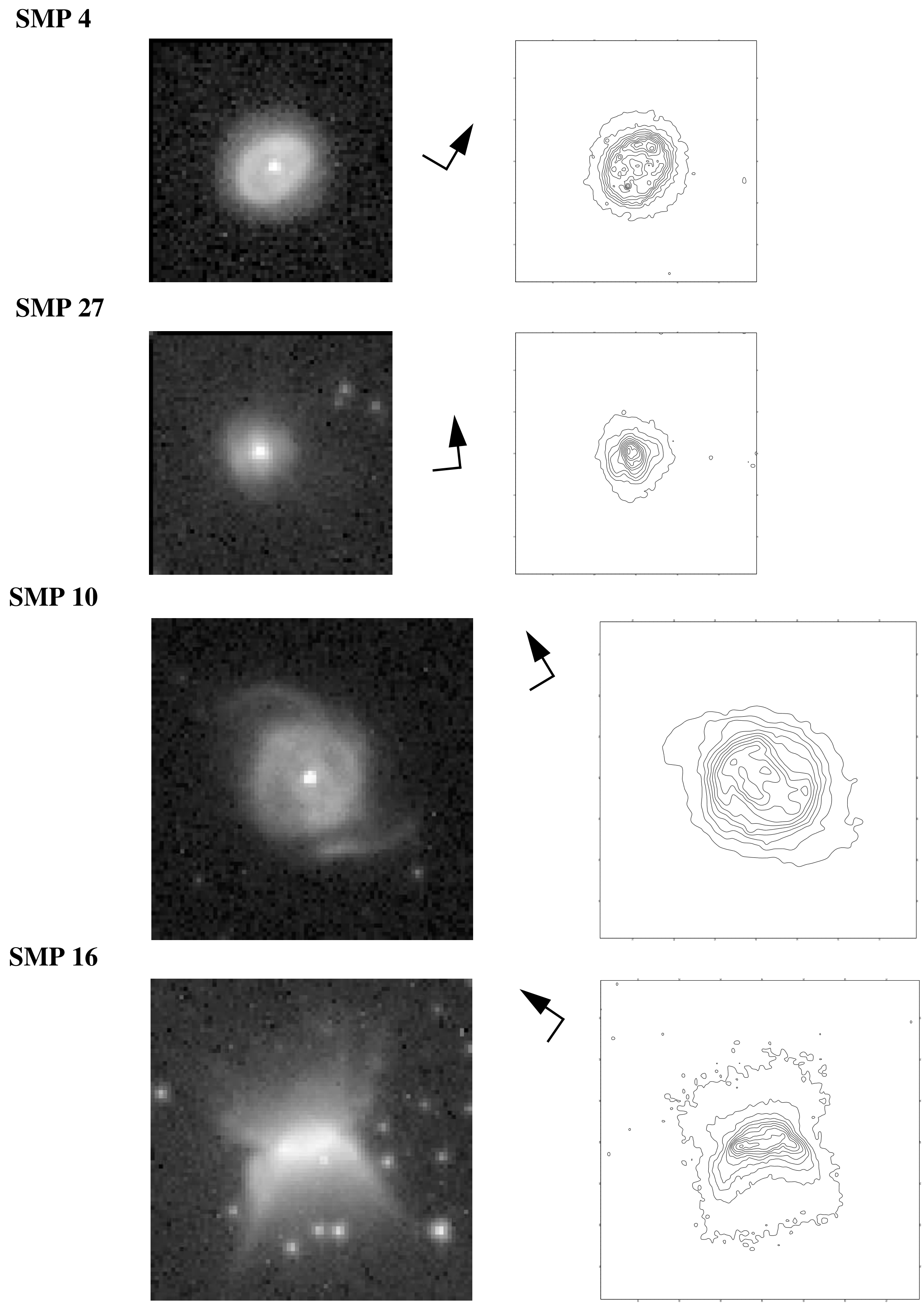

Fig. 1. Morphological sampler of LMC PNe.

from our survey. We show the images as observed through the clear filter, and the [O III] 5007 Å contour plots. We found in our sample Round, Elliptical (e.g., SMP 4), Bipolar (e.g., SMP 16), Quadrupolar (e.g., SMP 27), and Pointsymmetric (e.g. SMP 10) PNe. The ratio of symmetric-to-asymmetric PNe[3] is higher in the Galaxy than in the LMC. This is an indication that morphology traces the metallicity of the PN progenitors.

In Figure 2 we show the [O III] 5007 Å surface brightness evolution, as a function of the physical radius. The LMC PNe are indicated with different symbols, depending on their shell morphology (see Figure legend). We can see a clear morphological separation accordingly to the evolutionary rates of the different types. Round PNe show a slow surface brightness decline, while Bipolar (and, in general, asymmetric) PNe evolve fast. This is true if the physical radius is a good measure of the dynamical time of the PNe. In effect, the nebular evolution also depends moderately on the velocity of the shell expansion (see also Shaw et al. 2001).

By studying the chemical content of symmetric and asymmetric PNe in the LMC, Stanghellini et al. (2000) found that asymmetric PNe derive from the evolution of the youngest of the PN-producing stellar population. In Figure 3 we illustrate this point by showing the segregation of the LMC PN morphological types on the basis of their neon and sulfur abundances. The evolution of stars in the PN progenitor mass range do not alter the abundances of sulfur and neon, thus the plot clearly shows that there is a separation in the populations of the progenitors of the PNe with different morphological types. This finding bears on the question of formation mechanisms for asymmetric PNe: the genesis of PNe structure should relate strongly to the population type, and by inference the mass of the progenitor star, and less strongly on whether the central star is a member of a close binary system, as previously believed.

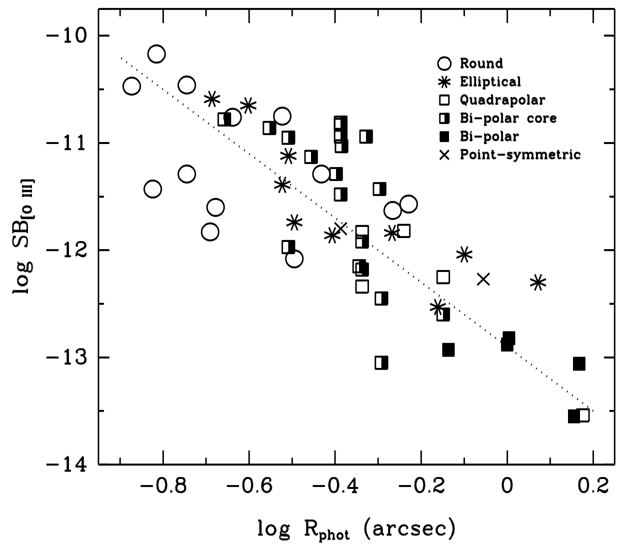

Fig. 2. The evolution of the [O III] 5007 Å surface brightness in LMC PNe.

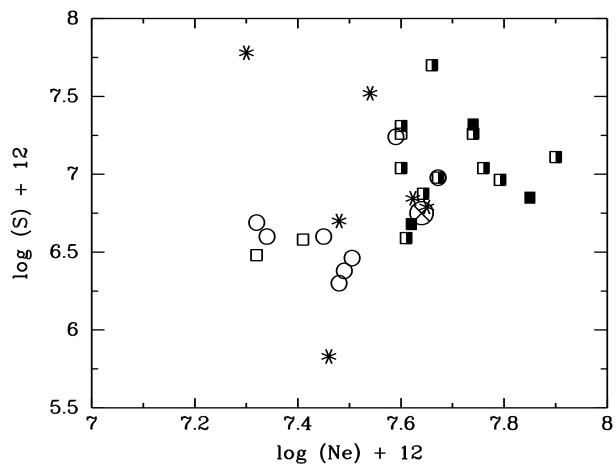

Fig. 3. Neon and sulfur abundances in different LMC PNe. Morphological types: See legend of Fig. 2.

3. SUMMARY AND FUTURE PROJECTS

Despite the large number of excellent studies of Galactic PNe, several questions on PN morphology and its formation still remain unanswered. The study of the Magellanic Clouds PNe has the great advantage to produce absolute physical parameters, to constraint and probe the existing evolutionary and hydrodynamical models. Our program on LMC PNe has already shown that, indeed, there is population and mass segregation among planetary nebulae of different morphology, and that symmetric PNe seem to evolve slower than asymmetric PNe. Furthermore, there are hints that the overall morphological distribution in a galactic PN population depends strongly on the galactic type and metallicity. A follow up on these studies bears not only on the understanding of PN morphology and evolution, but also on the stellar populations in galaxies, and on the planetary nebula luminosity function as a secondary indicator of the extra-galactic distance scale. We will strive to obtain quantitative results on solid statistical grounds to enlighten these astrophysical aspects.

A similar study in the Small Magellanic Cloud (SMC) is planned, to extend the *metallicity baseline*

[3]Symmetric PNe are Round and Elliptical PNe, Asymmetric PNe are Bipolar, Bipolar Core, and Quadrupolar PNe. We do not include Pointsymmetric PNe here, for homogeneity of the Galactic and extra-galactic samples.

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of the above findings. The LMC and SMC PN images acquired by Stanghellini and collaborators will form a database of extra-galactic PN images that will far exceed in number the Galactic PNe observed with *HST*, providing an homogeneous sample for testing the implications of metallicity variations in stellar evolution.

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