ON THE MORPHOLOGY AND INTERNAL KINEMATICS OF PNE

A. MANCHADO

Instituto de Astrofísica de Canarias
E–38200 La Laguna (Tenerife) Spain

1. Introduction

The study of the morphology of planetary nebula (PN) is fundamental for addressing several questions in the context of stellar evolution. An AGB star can loose most of its mass due to strong stellar winds. Kwok *et al.* (1978) proposed that the interaction of a low-density fast wind with a high-density slow wind, will form the PN. This model can account for the round observed PNe with a great degree of symmetry. However as we will see later, round PNe are not the most common ones. Therefore a mechanism for causing asymmetry has to be invoked. Several processes have been proposed by different authors.

Mellema & Frank (1995) have reproduced some of the observed elliptical morphologies using an interacting wind model with equatorial density enhancement.

Morris (1987) proposed a collimating disk, formed by a binary system, as the cause of asymmetry.

Soker & Livio (1989) and Bond & Livio (1990) explained the asymmetric shapes as binary stars evolving through a common envelope phase.

Rotation has been proposed as a cause of asymmetry by Calvet & Peimbert (1983). Ignace *et al.* (1996) and García-Segura *et al.* (1996) have proven that rotation can produce an asymmetric shaping in the nebula.

Magnetic fields have also been invoked as a cause of asymmetry by Pascoli (1992), Chevalier & Luo (1994) , and García-Segura *et al.* (1996).

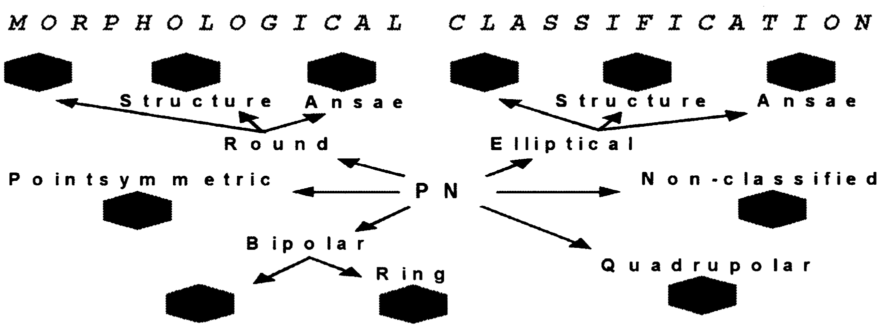
Therefore, a detailed morphological classification is necessary in order to discern which is the predominant mechanism responsible for the observed morphology.

H. J. Habing and H. J. G. L. M. Lamers (eds.), Planetary Nebulae, 184–189.

https://doi.org/10.1017/S0074180900130256 Published online by Cambridge University Press

2. Morphological classification

Attempts to establish a morphological classification have been made by several authors. Pioneering work was done by Greig (1972). He divided his sample in two main groups: "binebulous" and "circular nebula". Later, Zuckerman & Aller (1986) with a larger sample (108 non-stellar PNe) divided the PNe into bipolar, round, disk-like and annular. Balick (1987) constructed a empirical–evolutionary sequence of three different types of PNe: round, elliptical, and butterfly. However, Balick's survey was limited to about fifty PN's. Chu *et al.* (1987) studied a sample of PNe with multiple shells. Finally, Schwarz *et al.* (1992) observed 250 southern PNe which included stellar objects, and excluded large PNe. They divided the sample into stellar, elliptical, bipolar, pointsymmetric and irregular PNe. All the works mentioned above suffer from selection effects which invalidate the sample for statistical purposes.



The recent release of *The IAC morphological catalog of northern galactic PNe* by Manchado *et al.* (1996a) has overcome this problem. This is a complete catalog, which includes all the northern PNe larger than 4 arcseconds (see these proceedings for further details).

This catalog has allowed us to establish a sound morphological classification. We have separated nearly all PNe in the catalog into five main groups: the first group (R) is represented by round, featureless shapes; accurate diameter measurements do not reveal any ellipticity for these nebulae. The second, and most numerous group, is that of elliptical PNe (E); among them, we find simple ellipticals (E) as well as multiple shell ellipticals (EM), PNe with inner structures (ES), and elliptical PNe with ansae (EA). The PNe of the third group also show in many cases an elliptical body, but their main characteristic is their pointsymmetric features; therefore, they are named pointsymmetric PNe (P). The fourth group of PNe consists of the bipolar objects (B), all of which are axisymmetric and show a waist;

we can separate these into several subclasses: the simple bipolars (B) have featureless bilobate shapes; the multiple event bipolars (BM) show more than one pair of lobes/ejections, all pairs with the same axis of symmetry; the bright ring bipolars (BR) are regular bipolars, with a marked bright ring at their waist; finally, the fifth group are the quadrupolar PNe (Q), namely, PNe with a waist that show more than one pair of lobes, whose axes of symmetry are not the same. PNe that were too faint or that did not follow the above scheme were non-classified (NC)

Figure 1 shows some PNe from each morphological class.

3. Statistics

For the first time the existence of a complete morphological catalog allows us to carry out proper statistics. The catalog of Manchado *et al.* (1996a) covers the whole northern sky (declination greater than -10°) and a great portion of the Galactic plane (see Fig. 2 in that catalog). In our sample we have included not only the PNe in this catalog, but also 37 PNe observed by Balick (1987) and Schwarz *et al.* (1992) in the same region.

In order to find out whether our morphological classification is physically sound, the frequency and the distance to Galactic plane of each morphological class were analyzed. The total sample includes 280 PNe and the following results are obtained: 149 (53.2 %) are elliptical (E) with $|b| = 7.2^\circ$; 65 (23.2 %) are round (R) with $|b| = 13.2^\circ$; 36 (12.8 %) are bipolar (B) with $|b| = 2.9^\circ$; 8 (2.9 %) are pointsymmetric (P) with $|b| = 4.3^\circ$; 7 (2.5 %) are quadrupolar (Q) with $|b| = 1.47^\circ$ and 15 (5.4 %) are non classified (NC).

From this result it is clear than there is a segregation between the morphological classes and the height above the Galactic plane. Most PNe are ellipticals. It is also clear that the height above the Galactic plane of the bipolar PNe is much smaller than that of the round ones, thus pointing to higher mass and luminosity.

However, caution has to be taken when analyzing these results because of selection effects. First of all, the sample of quadrupolar and pointsymmetric is very small. Secondly, there is an observational bias. Most of the quadrupolar PNe were observed under excellent seeing conditions, so the number of quadrupolar PNe has to be considered as a lower limit. Most of the round PNe have large angular diameters, and therefore low surface brightness. Interstellar extinction makes it very difficult to detect these nebulae when they are far away, so the number of round PNe has to be considered as a lower limit.

Bipolar nebulae have high mass progenitor stars. Therefore, their central stars have higher luminosities and the nebula can be seen much further away that the round nebula. This makes the actual percentage of bipolar PNe

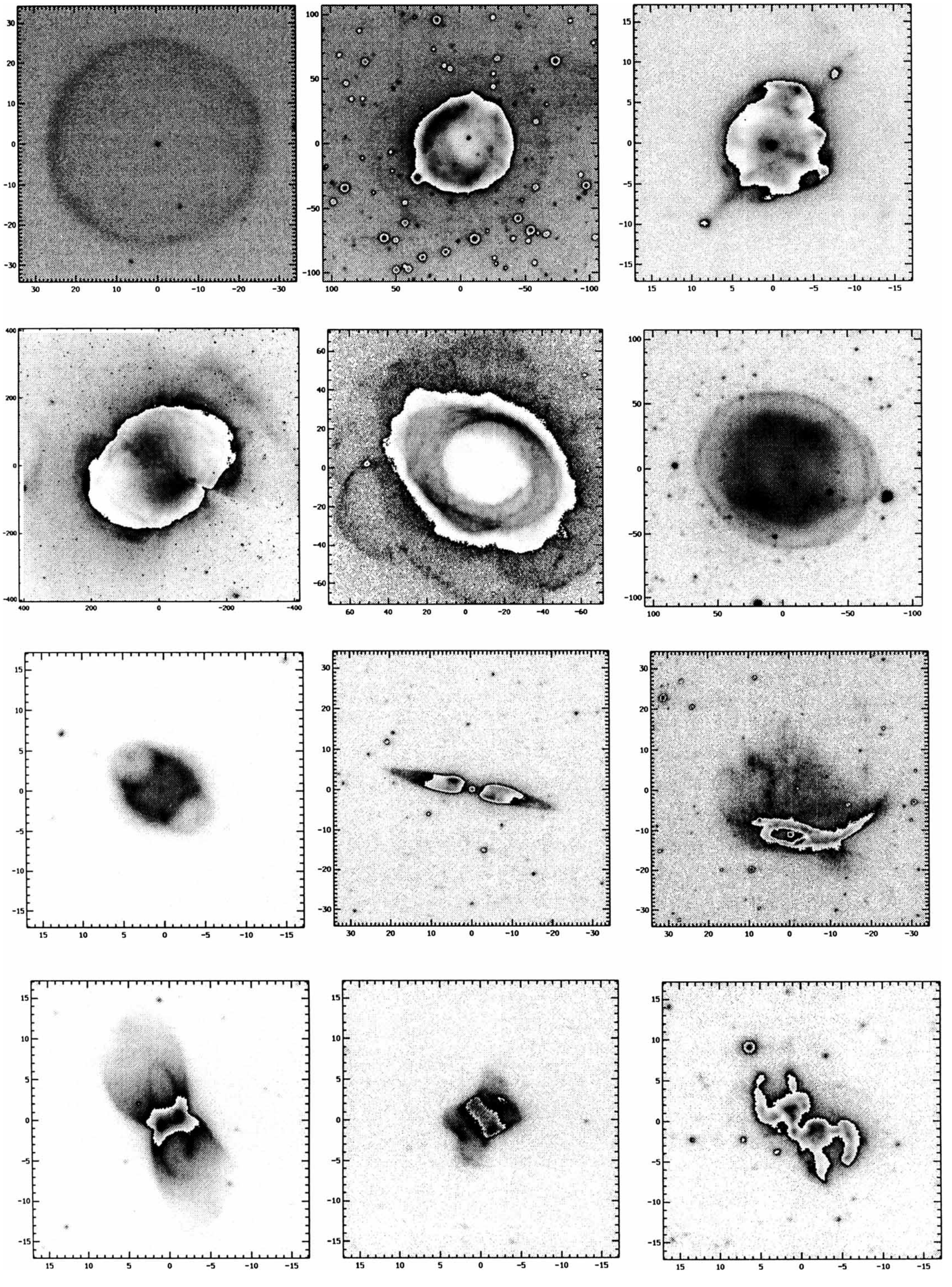


Figure 1. From left to right, top to bottom: narrow band images of the PNe A 39, NGC 2438, IC 4593, NGC 6853, NGC 6720, IC 1295, K 3-26, He 2-437, He 2-428, M 2-46, K 3-24, and Pe 1-17.

https://doi.org/10.1017/S0074180900130256 Published online by Cambridge University Press

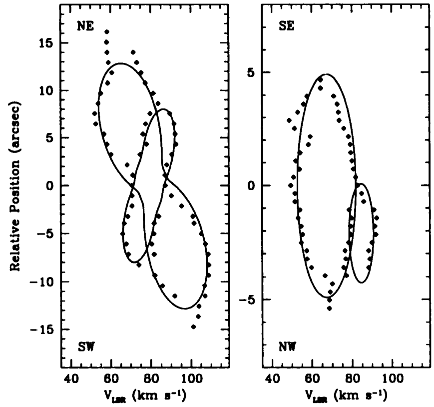


Figure 2. Velocity versus position diagram from the [N II] line of M 2-46. Black points are the observed data while solid lines are the model fit.

much lower than that in our sample. As distances to the PNe are rather uncertain it is very difficult to correlate different morphological classes with their distances.

4. Kinematics

Morphology only gives bi-dimensional information. We only see the projection on the plane perpendicular to the line of sight. This may lead to misinterpretations, for instance an elliptical PN seen pole-on will appear to be a round PN. In order to carry out a tri-dimensional analysis of PNe, it is necessary to study their kinematic structure.

Weinberger (1989) compiled a catalog of PN expansion velocities. However, most of the data have no spatial resolution and not enough spectral resolution, and so they are not useful for a tri-dimensional analysis.

Individual PNe have been studied by several authors (Meaburn *et al.* 1996, Bryce *et al.* 1996, Miranda & Solf 1992, Guerrero *et al.* 1996, Manchado *et al.* 1996b) allowing a detailed morphological analysis. As an example we will discuss the quadupolar PN M 2-46. This PN was studied by Manchado *et al.* (1996b) with a spatial resolution of $0\farcs3$ and spectral resolution of 6 km s^{-1}. Figure 2 shows a velocity position diagram for two slit positions. The data were fitted with a semi-empirical model of Solf & Ulrich (1985). This model assumes a bipolar expanding nebula where,

$$v_{\rm exp}(\phi) = v_{\rm e} + (v_{\rm p} - v_{\rm e})|\sin\phi\,|^{\gamma}$$

where ϕ is the colatitude angle, varying from 0° at the pole to 90° the equator; $v_{\rm e}$ and $v_{\rm p}$ are the polar and equatorial velocities, and γ is a shape

https://doi.org/10.1017/S0074180900130256 Published online by Cambridge University Press

parameter. In Figure 2 the model is in excellent agreement with the observational data. In this nebula two expanding lobes can be fitted, with $\gamma = 3.5$, $v_p = 40$ km s^{-1} and $\gamma = 4.5$, $v_p = 25$ km s^{-1}, respectively, and $v_e = 7$ km s^{-1} with an inclination angle of 60° and 110° respectively.

When combining all the data, a tri-dimensional model of the nebula can be inferred. For M 2-46, Manchado *et al.* (1996b) propose that a precessing star with two episodic mass losses has caused the observed morphology.

5. Future work

The morphology studies should be extended to the molecular gas (H_2 and CO). The *HST* will enable the extension of morphological studies to other galaxies. Kinematic analyses, with high spectral resolution, should be made of a larger sample of PNe.

New stellar evolution models with rotation and magnetic fields are needed. New hydrodynamical simulations with realistic parameters should also be carried out.

References

Balick, B. 1987, AJ 94, 671

Bond, H., & Livio, M. 1990, ApJ, 355, 568

Bryce, M., Mellema, G., Clayton, C.A., Meaburn, J., Balick, B., Lopez, J.A. 1996, A&A, 307, 579

Calvet, N., & Peimbert, M. 1983, Rev. Mex. Astron. Astrofis. 5, 319

Chevalier, R. A. & Luo, D. 1994, ApJ, 421, 225

Chu, Y.-H., Jacoby, G., & Arendt, R. 1987, ApJSS, 64, 529

Corradi R. L. M., & Schwarz H. E., 1995, A&A 293, 871

García-Segura, G., Langer, N., Różyczka, M., Mac-Low, M. Franco, J. 1996, (these proccedings)

Greig, W.E. 1972, A&A, 18, 70

Guerrero, M., Manchado, A., & Serra-Ricart, M. 1996, ApJ. 456, 651

Ignace, R., Cassinali, J. P., & Bjorkman, J. E. 1996, ApJ, 459, 671

Kwok, S., Purton, C. R., & Fitzgerald, P. M. 1978, ApJ, 219, 17

Manchado, A., Guerrero, M., Stanghellini, L., & Serra-Ricart, M. 1996, The IAC Morphological Catalog of Northern Galactic planetary nebulae , (La Laguna: IAC)

Manchado, A., Stanghellini, L., & Guerrero, M., 1996, ApJ, 466, L95

Meaburn, J, Lopez, J. A., Bryce, M., Mellema, G. 1996, A&A 307, 579

Mellema, G., & Frank, A. 1995, in *Asymmetrical PN*, eds. A. Harpaz and N. Soker, 229

Miranda, L. F., & Solf, J. 1992, A&A, 260, 397

Morris, M. 1987, PASP, 99, 115

Pascoli, G. 1992, PASP, 104, 350

Schwarz, H. E., Corradi, R., & Melnick, J. 1992, A&AS, 96, 23

Solf, J., & Ulrich, H. 1985, A&A, 140, 27

Soker, N., Livio, M. 1989, ApJ, 339, 268

Weinberger, R. 1989, A&ASS, 78, 301

Zuckerman, B., & Aller, L. H. 1986, ApJ, 301, 772