
A principal component analysis approach to the morphology of Planetary Nebulae

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Summary. Principal Component Analysis (PCA) is a well-known technique used to decorrelate a set of vectors. It has been applied to explore the star formation history of galaxies or to determine distances of mass-losing stars. Here we apply PCA to the optical data of Planetary Nebulae (PNe) with the aim of extracting information about their morphological differences. Preliminary analysis of a sample of 55 PNe with known abundances and morphology shows that the second component (PC2), which results from a relation produced by the parameters $\log(N/O)$, initial and final mass of PNe, is depending on the morphology of PNe. It has been found that when $\log(N/O) < -0.18$ the PNe nitrogen is low independently on the oxygen abundance for either Bipolar (*B*), Elliptical (*E*) or Round (*R*) PNe. An interesting result is that both *E* and *R* PNe have $\log(N/O) < 0$ while only *B* PNe show negative and positive values. Consequently, *B* PNe are expected to have higher nitrogen values than the *E* and *R* PNe. Following that and a second sample of 35 PNe, n_e is also found to be higher in *B* PNe. Also, in all PNe morphologies PC2 appears to have a minimum at 0.89 and PNe initial mass at $2.6 M_{\odot}$. 5-D diagrams between PCAs components and physical parameters are also presented. More results will follow while simple models will be applied in order to try to give a physical meaning to the components.

Key words: planetary nebulae: general

1 Introduction

Planetary Nebulae (PNe) are powerful tools in the study of the evolutionary scenario of intermediate mass stars. They play an important role in the chemical enrichment history of the interstellar medium and many efforts have been devoted to determine the physical parameters of Galactic PNe (like T_e , n_e , T^* , L^* , distance, abundances; [3] and references therein). For this study a number of methods have been used either by using the observational results directly or by developing simulation models like CLOUDY [5]. Using the latter, the values of the physical parameters can be determined (i.e. [1]) but not any possible correlation among them. So far, only statistical methods had been used in order to find correlations between the parameters. However, there is a well-known technique (PCA) which can be used in order to study

the possible correlation between these parameters. PCA technique uses a sample of observed parameters and creates a new sample of independent components which are linear combination from the previous parameters.

2 PCA methods and 5-D diagrams

PCA is a useful tool in statistical studies, especially when there are many observed parameters. It has been applied to explore the stars formation history or to describe and classify the stellar spectra. The basic idea of this method is that it minimizes a set of observed parameters to a new set of independent parameters. The number of these new components reveals the true dimension of the space generated by the observed parameters. Also, a 5-D diagram has been developed in order to study if there is any correlation between the new components and the measured parameters. These diagrams are like common 3-D diagrams with the difference that, they illustrate two more variables using different colors and sizes.

3 Preliminary results

In this work, we applied PCA method to a set of optical data of 55 PNe with known abundances and morphology [6], in order to extract information correlated to their morphological differences. The new principal components PC_1 , PC_2 and PC_3 ((1)-(3)) resulted by using a set of parameters ($\log(N/O)$, core Mass M_c and initial Mass M_i) which are correlated according to the star formation history ([2] & [7]). It can be seen from (1)–(3) that the difference between PC_1 , PC_2 and PC_3 is that each one is strongly depended on one of these parameters only.

$$PC_1 = 0.89 \times \log(N/O) + 0.43 \times M_c - 0.12 \times M_i \quad (1)$$

$$PC_2 = -0.43 \times \log(N/O) + 0.90 \times M_c + 0.07 \times M_i \quad (2)$$

$$PC_3 = 0.14 \times \log(N/O) - 0.07 \times M_c + 0.99 \times M_i \quad (3)$$

The PC_1 and PC_3 components do not provide any significant result, while PC_2 shows that it depends on the morphology of PNe. From (2), we produced the diagrams shown in Figures 1(a),(b) & 2, where it can be seen that when $\log(N/O) < -0.18$, the PNe nitrogen abundance is low independently on the oxygen for either B , E or R morphology. Moreover, the $\log(N/O)$ is negative, if the PN morphological type is either E or R , while it takes both negative and positive values in the case of B morphology. PC_2 component appears to have a minimum value at 0.89 for all morphological types, resulting to an initial mass for the progenitor star of $2.6 M_\odot$. PCA method was also applied to another sample of 35 PNe [4], using a set of different parameters (abundance $\epsilon(N)$, $\epsilon(S)$ and electron density n_e) which are important to PNe study. In this case, the new principal components PC_4 , PC_5 and PC_6 ((4)–(6)) were calculated to:

$$PC_4 = 0.91 \times \epsilon(N) - 0.41 \times \epsilon(S) - 0.05 \times n_e \quad (4)$$

$$PC_5 = 0.41 \times \epsilon(N) - 0.91 \times \epsilon(S) + 0.04 \times n_e \quad (5)$$

$$PC_6 = 0.06 \times \epsilon(N) + 0.02 \times \epsilon(S) + 0.99 \times n_e \quad (6)$$

In Figure 3, we present a 5-D diagram with PC_4 , PC_5 and PC_6 on X,Y and Z axis respectively and $\epsilon(S)$, n_e on different colors and sizes. In particular, it can be seen that $\epsilon(S)$ increases when PC_5 increases (the circular color bar on the right of Figure 3 shows the increase of $\epsilon(S)$ as we go from 0° ($\epsilon(S)=4.2$) to 360° ($\epsilon(S)=7.7$)). Also, it is clear that n_e increases (larger size means higher value of n_e) linearly with PC_4 and PC_5 . This 5-D representation shows that there is a strong dependence between PC_4 and PC_5 , $\epsilon(S)$ and n_e since for the same value of $\epsilon(S)$ (same color i.e. blue), we result to a linear equation $PC_5 = 0.8 \times PC_4 + 6.04$ (7). By using (4),(5) and (7) we produce the relationship $n_e = 4 \times \epsilon(N) + 75.5 - 15.5 \times \epsilon(S)$ (8). Since in that case $\epsilon(S)$ is constant, then n_e increases when $\epsilon(N)$ increases. Following this result and the one from the previous sample, it appears that the *B* PNe must have higher n_e values than either *E* or *R* PNe. These preliminary results show that the use of new components which are correlated with physical parameters can provide useful information therefore must be explored further in the future.

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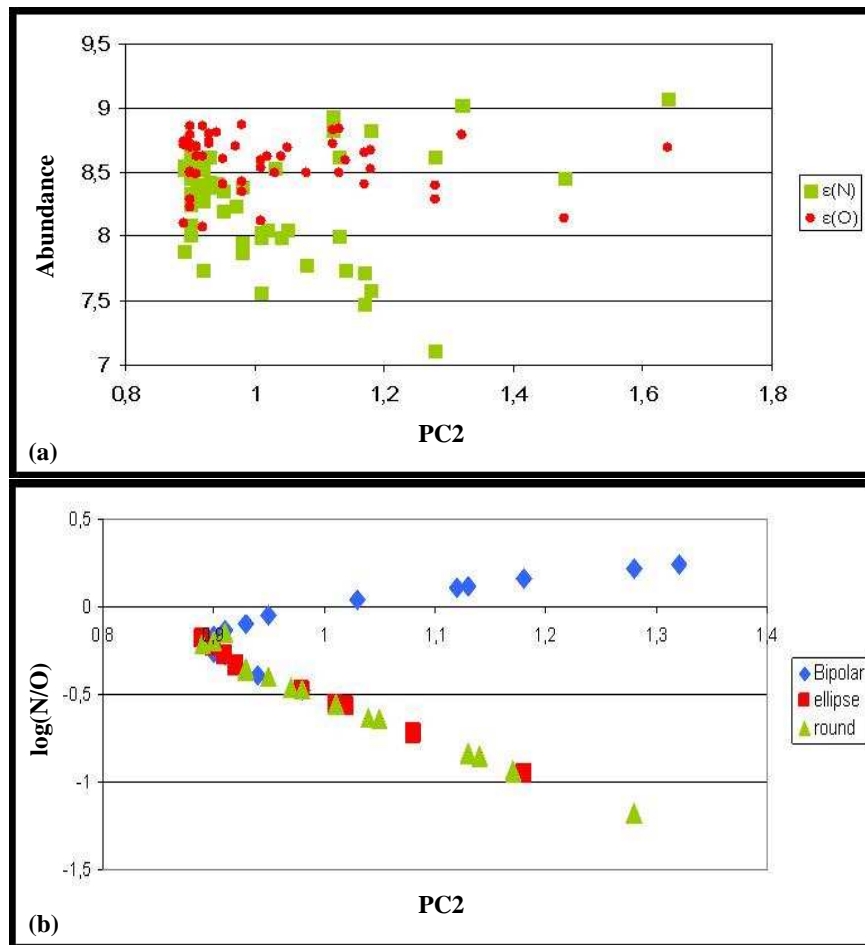


Fig. 1. (a) Diagrams of Nitrogen and Oxygen abundances vs PC₂ component for the 55 PNe. (b) Diagram of $\log(N/O)$ vs PC₂ where the different morphological types are shown (see text).

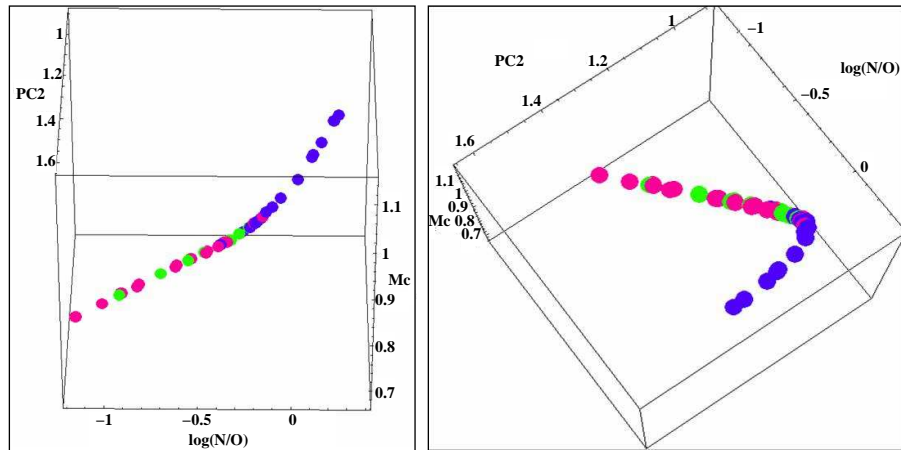


Fig. 2. Two different 4D representations of Fig. 1(b).

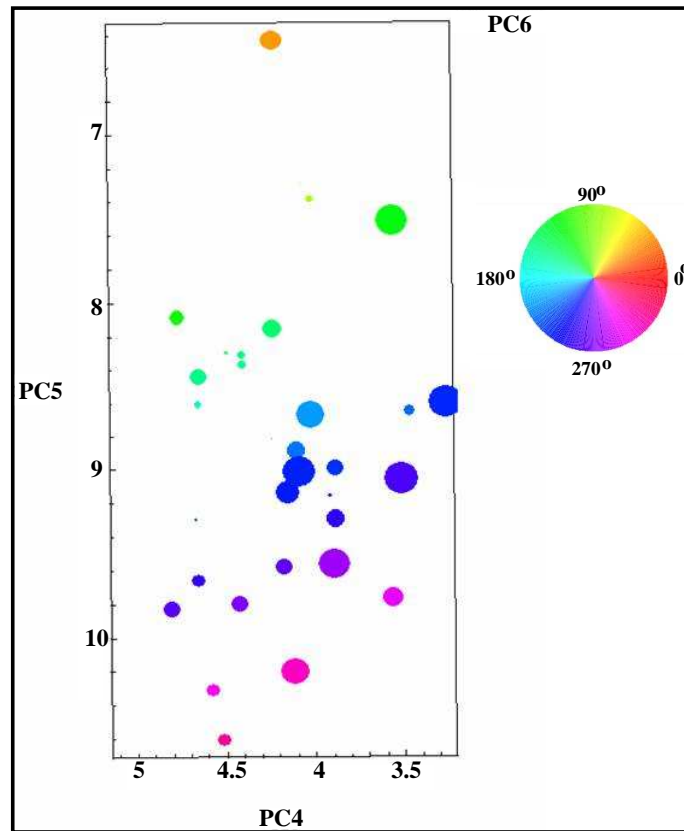


Fig. 3. PC₄ vs PC₅; $\epsilon(S)$ and n_e are shown with different colors and sizes (see text).