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STUDY OF ELECTRON DENSITY IN PLANETARY NEBULAE

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RESUMEN

Presentamos una comparación entre las densidades electrónicas para una muestra de nebulosas planetarias estimadas a través de diferentes cocientes de líneas de emisión. Consideramos como indicadores de densidad los cocientes [O II] $\lambda3729/\lambda3726$, [S II] $\lambda6716/\lambda6731$, [Cl III] $\lambda5517/\lambda5537$, [Ar IV] $\lambda4711/\lambda4740$, C III] $\lambda1906/\lambda1909$ y [N I] $\lambda5202/\lambda5199$. Los datos observacionales fueron extraídos del catálogo de Kaler et al. (1997). Nuestros resultados muestran que estadísticamente N_e[Ar IV] $<$ N_e[Cl III] $>$ N_e[N I] $\approx$ N_e[O II] $<$ N_e[S II], estando estos indicadores ordenados por los potenciales de ionización de los iones respectivos. Estas diferencias pueden atribuirse a errores en los parámetros atómicos utilizados, a la adopción de una misma $T_{\rm e}$ para iones diferentes, y, lo que parece mas probable, a variaciones internas de densidad en las nebulosas estudiadas.

ABSTRACT

We present a comparison among electron density estimates for planetary nebulae based on different emission-line ratios. We have considered the density indicators [O II] $\lambda3729/\lambda3726$, [S II] $\lambda6716/\lambda6731$, [Cl III] $\lambda5517/\lambda5537$, [Ar IV] $\lambda4711/\lambda4740$, C III] $\lambda1906/\lambda1909$ and [N I] $\lambda5202/\lambda5199$. The observational data were extracted from the catalogue of Kaler et al. (1997). We verified that statistically $N_{\rm e}$[Ar IV] $<$ $N_{\rm e}$[Cl III] $>$ $N_{\rm e}$[N I] $\approx$ $N_{\rm e}$[O II] $<$ $N_{\rm e}$[S II], being these density sensors ordered by the ionization potentials of the parent ions. These differences can be attributed to errors on the atomic parameters used, to the adoption of a same electron temperature for different ions and, what seems to be more probable, to internal variations of density in the studied nebulae.

Key Words: **PLANETARY NEBULAE: GENERAL**

1. INTRODUCTION

The electron density, $N_{\rm e}$, is one of the key physical parameters needed to characterize a planetary nebula. Some density assessment is necessary to confidently derive the chemical abundance of the nebula, to calculate the total mass of ionized gas and is even useful to estimate the distance of the object. Most of density estimates found in the literature are based on measurements of a single emission-line ratio sensitive to it obtained from spectra taken from special areas of the nebulae, usually the brightest ones. In the presence of internal variations of electron density, these single line ratio measurements may not be representative of all ionizing zones. In fact, the analysis by Stanghellini & Kaler (1989) of a large data sample of planetary nebulae taken from the literature have indicated the existence of statistically significant discrepancies among the values of electron densities obtained from distinct density sensors such as [O II] $\lambda3729/\lambda3726$, [S II] $\lambda6716/\lambda6731$, [Cl III] $\lambda5517/\lambda5537$, [Ar IV] $\lambda4711/\lambda4740$. In special, they have found [S II] densities generally higher than those from [O II]. However, Kingsburgh & English (1992), using their own homogeneous data for 63 Galactic planetary nebulae, have found densities derived from integrated [O II] and [S II] doublet ratios in excellent agreement with each other. On the other hand, Meatheringham & Dopita (1991), for a sample of 44 planetary nebulae in the Magellanic Clouds, have found the opposite, i.e., [O II] densities systematically higher than [S II] ones. Here we re-address the subject of comparing the electron density estimated from different ions.

2. ANALYSIS

Data used were taken from the electronic emission-line catalogue for planetary nebulae by Kaler, Shaw, & Browning (1997). Instead of comparing the derived densities, as has been done by the other authors, what implies in discarding all line ratios close or beyond the saturation limits at low and high densities, we have compared the line ratios themselves with one another. For example, Figures 1 and 2 show the comparison between the [O II] and [S II] ratios and the [Cl III] and [Ar IV] ratios, respectively. The lines on these plots are the *locus* of density-homogeneous nebulae at different electron temperatures. The error bars are the standard deviations of the multiple determinations of these line ratios obtained from the Kaler et al. catalogue. We have selected the line ratios with errors less than 15%. Besides the density sensors examined

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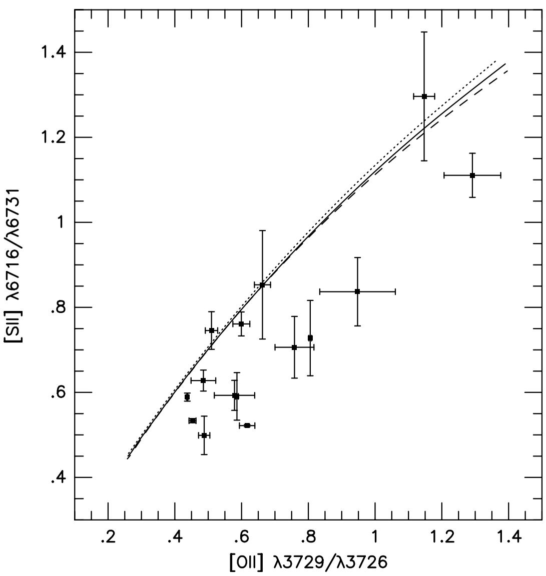

Fig. 1. Comparison between the [O II] λ3729/λ3726 and the [S II] λ6716/λ6731 line ratios. The dotted, solid and dashed lines are the *locus* of density-homogeneous nebulae at electron temperatures of 5 000, 10 000 and 15 000 K, respectively. On these curves, the density increases from the top-right to the bottom-left.

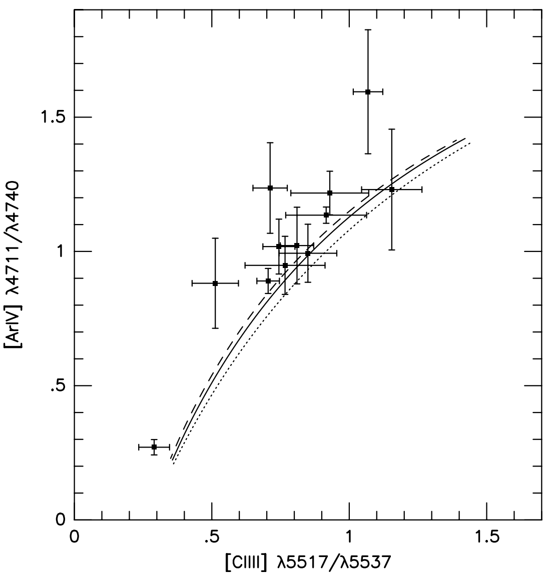

Fig. 2. Comparison between the [Cl III] λ5517/λ5537 and the [Ar IV] λ4711/λ4740 line ratios. Same convention as in Fig. 1.

by Stanghellini & Kaler (1989), we have included the C III] λ1906/λ1909 and [N I] λ5202/λ5199 ratios in our analysis.

3. RESULTS

As exemplified by Figures 1 and 2, in the comparison among the different density indicators we have found systematic deviations from the density-homogeneous models, in the sense that N_e[Ar IV] $<$ N_e[Cl III] $>$ N_e[N I] $\approx$ N_e[O II] $<$ N_e[S II], being the ionization potential of the parent ions 40.9, 23.8, 14.5, 13.6, and 10.4 eV, respectively. In principle, these discrepancies could be due to possible errors in the atomic parameters needed to derived the electron densities from the line ratios. We have studied the changes along the time of the calibrations of the electron density with different emission-line ratios in function of the development on the computations of the atomic parameters. We have observed that there were little variations recently for the [S II] and [O II] density calibrations. For the [Cl III] there was a significant change in the region of highest densities and for the [Ar IV] the variation was more accentuated than for the other line ratios. However, none of these changes seems to support the hypothesis that the observed discrepancies among density estimates from different ions are cause by errors in atomic parameters. Another possible explanation for these discrepancies could be the adoption of the same electron temperature for different ions. However, very high temperature differences up to 10^4 K should be necessary, which seems unrealistic. So, we believe that the discrepancies among different density indicators reflect general density variations inside these planetary nebulae. In particular, Rubin (1989) has suggested that [S II] densities higher than those from [O II] may be explained by a dynamic "plow effect" at the ionizing front, which would increase the density of the matter just beyond the H^+ edge.

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