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ON THE [ArIV]/[ArIII] LINE RATIO IN PLANETARY NEBULAE

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ABSTRACT: Previous spectroscopic studies of planetary nebulae have shown that the observed [ArIV]/[ArIII] line ratio is not reproduced by photoionization models. We show that this discrepancy disappears if we consider an adequate combination of the filling factor and radial density profile.

Keywords: planetary nebulae, stars, emission lines, spectroscopy, ionization modeling.

SUMILLA: Estudios espectroscópicos anteriores de las nebulosas planetarias han demostrado que la razón de línea [ArIV] / [Ar III] observada no es reproducida por los modelos de fotoionización. Mostramos que esta discrepancia desaparece si consideramos una combinación adecuada del factor de llenado y del perfil de la densidad radial.

Palabras Claves: nebulosas planetarias, estrellas, líneas de emisión, espectroscopía, modelado de ionización.

1. INTRODUCTION

Photoionization modeling of planetary nebulae (PN) have been considered as an accurate way for obtaining their physical and chemical parameters (Torres-Peimbert et al. 1990; Dopita & Meatheringham 1991). Such models, however, have not been successful in describing some line ratios; for example, we find in the literature comments about the discrepancy between the calculated and observed ratios for the forbidden lines of Argon [ArIV] λ4740 and [ArIII] λ7136. Torres–Peimbert et al. (1990) have modeled two optically thin planetary nebulae and their models have produced argon ionization that is systematically higher than the observed. In a second study, Dopita & Meatheringham (1991) presented photoionization models for 38 PN of the Magellanic Clouds. These authors report a systematic discrepancy between the observed and theoretical [ArIV]/[ArIII] line ratio and suggest that it may be due to a charge exchange reaction that transforms Ar^{+3} into Ar^{+2}. However, such a reaction is quite implausible since neutral species are required for charge exchange reactions and they are not likely to be present in the Ar^{+3} region. A good fit of the argon lines would be indeed important as three degrees of ionization are observed for this element in high ionization nebulae. In the present paper we show that the observed argon line ratios can be obtained in photoionization models using adequate choices for the distribution of gas in the nebula. This can be obtained by a combination of the filling factor (ε) and the radial density profile described by

$$n = n_o\left(\frac{r}{r_o}\right)^{\gamma}$$

where n_o and r_o are the initial hydrogen density and radius respectively, n is the density at a given radius r and γ is a constant.

2. RESULTS

Photoionization models were calculated with the code CLOUDY (Ferland,1993). All models assume spherical symmetry and constant filling factor. We have adopted the default chemical abundances for planetary nebulae available in the code. In figure 1 we show the calculated [ArIV]/[ArIII] line ratio as a function of the central star temperature (T_{eff}), as well as the ratio of HeII λ4686/Hβ.

This diagram shows that for temperatures T_{eff} > 80000 K the Argon line ratio does not vary significantly, contrary to the HeII λ4686/Hβ which varies by a large factor. This means that for a model that produces HeII λ4686/Hβ > 0,01, the Argon line ratio is only a weak function of the central star temperature.

In figure 2 we show the Argon line ratio as a function of [SII] λ6716/λ6731, which is a well known density indicator. We present in this diagram observed values for the Ar and S line ratios from planetary nebulae in our Galaxy (Aller & Keyes, 1987, Gutiérrez-Moreno et al. 1985, Kaler 1985, Aller & Czyzak 1983), the SMC and LMC (Meatheringham & Dopita 1991a,b) with HeII λ4686/Hβ > 0,01. In the same diagram model calculations are shown for different values of γ.

Each curve, for a fixed γ, is obtained by varying the initial gas density. All calculations were made using filling factor 0,1. It is clear that the observed Argon line ratios show large scatter around the γ =0 model line. Probably, this is the cause of the discrepancy between observed and theoretical Ar line ratios. The range of observed Ar line ratios can not be explained using models with constant gas density. On the other hand, Fig. 2 shows that all the observed Argon line ratios can be described by model calculations using filling factor 0,1 and -1,5 < γ < 1,5. For filling factor 0,5 this is not the case as the smallest values for the Argon line ratio cannot be obtained even for γ = 2. Distinct combinations of filling factor and γ produce different variations in the ionization parameter and that is the explanation for the large range of [ArIV]/[ArIII] line ratios. Similar arguments could be made for the [OIII]/[OII] line ratios. However the O^+ region depends strongly on the optical depth of the nebula and this makes the analysis of low ionization species more complicated. But the optical depth is normally large enough so that the Ar^{+2} region is not affected.

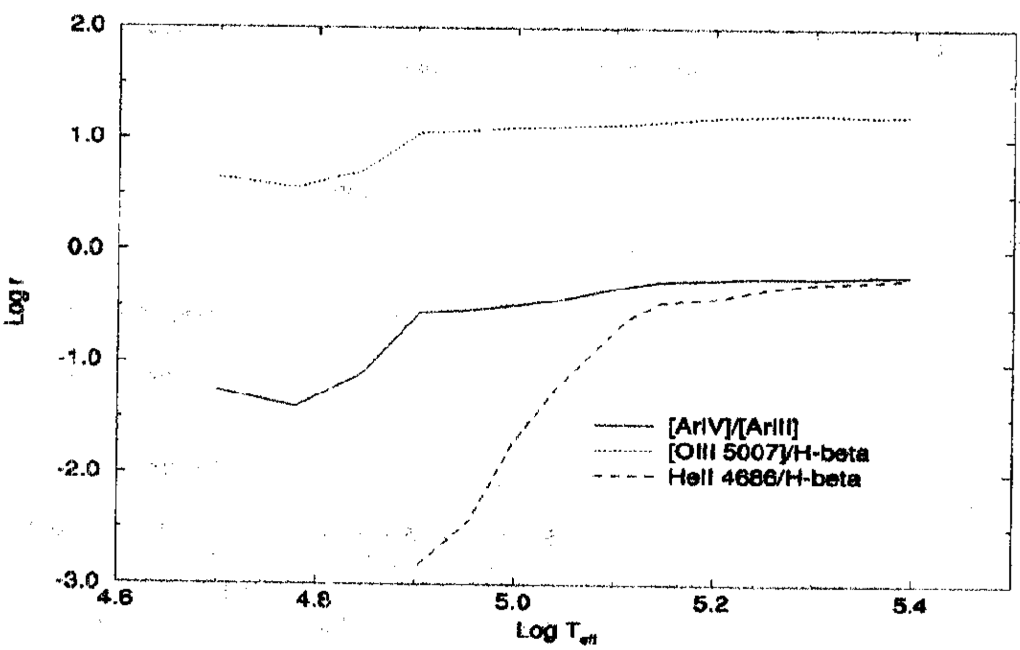

Figure 1. *Calculated [ArIV]/[ArIII] (solid line) and HeII/Hβ (dashed line) line ratio as a function of the temperature of the central star.*

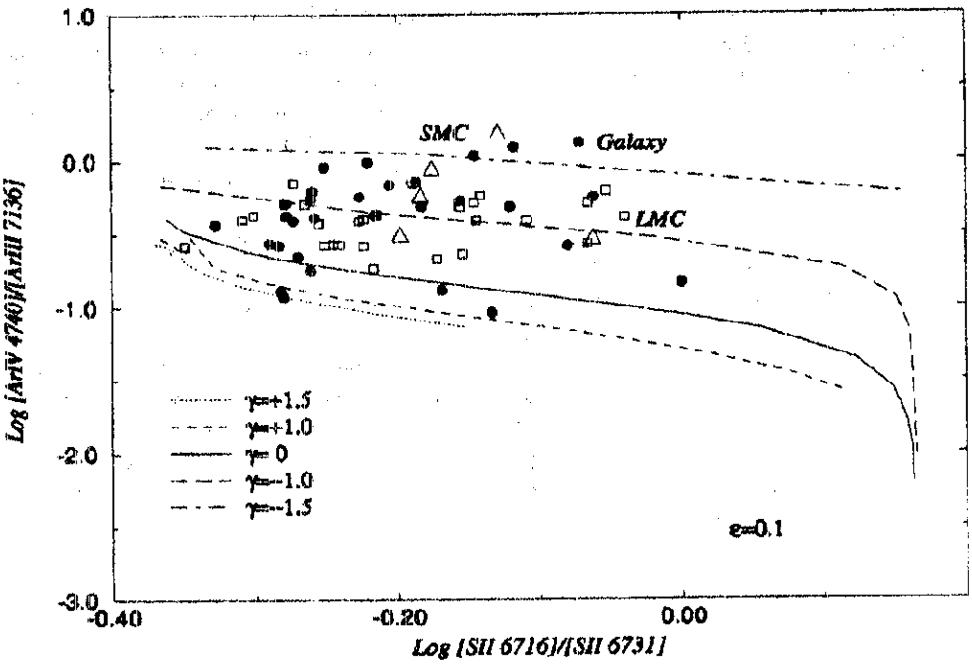

Figure 2. *Argon line ratio as a function of [SII] λ6716/λ6731, for galactic (filled circles), LMC (squares), and SMC (triangles) planetary nebulae.*

The main purpose goal of the diagram in figure 2 is to show that the observed argon line ratios can be reproduced by the presently available photoionization codes and atomic parameters.

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4. BIBLIOGRAPHY

1. **L. H. Aller and S. J. Czyzak.** ApJ S 51, 211 (1983).
2. **L. H. Aller and C. D. Keyes.** ApJ S 65, 405 (1987).
3. **M.A. Dopita and S. J. Meatheringham,** ApJ 367, 115 (1991).
4. **G. J. Ferland.** University of Kentucky, 5. Department of Physics and Astronomy, Internal Report (1993).
5. **A. Gutiérrez-Moreno, H. Moreno and G. Cortés.** PASP 97: 397 (1985).
6. **J. B. Kaler.** ApJ 290: 531 (1985).
7. **S. J. Meatheringham and M.A. Dopita.** ApJ S 75: 407 (1991a).
8. **S. J. Meatheringham and M. A. Dopita.** ApJ S 76: 1085 (1991b).
9. **S. Torres-Peimbert, M. Peimbert and M. Peña.** A&A 233: 540 (1990)