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FITTING PHOTOIONIZATION MODELS TO PLANETARY NEBULAE

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RESUMEN

Modelos de fotoionización de buenos a excelentes se obtuvieron para 13 de 19 espectros de nebulosas planetarias. Las dos hipótesis más importantes fueron suponer que el continuo fotoionizante está dado por una estrella modelo de Rauch, cuya gravedad se encuentra en la condición de que la masa de la estrella central es $\sim 1\ M_{\odot}$, y que la densidad es constante y determinada por el valor observado de [S II]6717/6731. La temperatura y la luminosidad de la estrella central, el radio interior de la nebulosa y la abundancia nebular del carbono son parámetros libres en cada corrida individual, que ajusta las intensidades observadas de He II 4686, [O III]5007 and [N II]6584. La diferencia entre la temperatura observada y modelada obtenida de [N II](6548+6584)/5755 es inferior a 10%, pero los modelos usualmente subestiman la temperatura que se encuentra de [O III](4959+5007)/4363, particularmente cuando la rendija no cubre toda la extensión de la región fotoionizada. Las abundancias modeladas de helio, nitrógeno, oxígeno, neón, azufre y argón son inciertas a un 15%, 15%, 10%, 7%, 30% y 7%. La abundancia de neón ha sido subestimada y se recomienda usar un nuevo factor de corrección por ionización.

ABSTRACT

Good to excellent photoionization models based on the Cloudy code were obtained for 13 out of 19 spectra of planetary nebulae. The two most important assumptions are that the photoionizing continuum is a Rauch model star, with gravity set by the condition that the stellar mass must be $\sim 1\ M_{\odot}$, and density is constant and determined from the observed [S II]6717/6731 ratio. The temperature and luminosity of the central star, the inner radius of the nebula and the abundance of carbon are treated as free parameters in each model run, destined to obtain the best possible fit to the relative intensities of He II 4686, [O III]5007 and [N II]6584. Observed and modeled nebular temperatures derived from [N II](6548+6584)/5755 agree within 10%, but models usually underestimate temperatures found from [O III](4959+5007)/4363, more so when the slit does not cover the in-depth extent of the ionized region. Helium, nitrogen, oxygen, neon, sulfur and argon model abundances are uncertain at the 15%, 15%, 10%, 7%, 30% and 7% level. It is shown that neon abundance in PNe has been consistently overestimated, and an alternative ionization correction factor is recommended.

Key Words: ISM: abundances — methods: numerical — planetary nebulae — stars: AGB and post-AGB

1. INTRODUCTION

Optical spectroscopy in 28 planetary nebulae (PNe) was reported by the author in a couple of papers published some years ago (Bohigas 2001, 2003). Most of these PNe have been classified as type I objects following the defining criteria of Peimbert & Torres-Peimbert (1983), i.e., He/H ≥ 0.125 and N/O ≥ 0.5. Estimates of their chemical composition were produced using the ICF method, and approximate temperatures of the central stars were found from the relative intensity of He II 4686 with respect to Hβ (Kaler & Jacoby 1989). It was always clear that more reliable information can be extracted from these spectra using a photo-ionization code. Most of these spectra have been reanalyzed running Cloudy 06.02 (Ferland et al. 1998).By applying Cloudy, it has been possible to obtain more reliable numbers for the chemical composition and central star temperature of these objects, as well as a better understanding of the processes and conditions that limit the accuracy with which these quantities can be determined with the data that is available. These abundance estimates are used to check predictions on the return of chemical elements into the ISM by low and intermediate mass stars (known as yields), when, during their final years in the asymptotic giant branch phase, expel the material that will become a PN (e.g. van den Hoek & Groenewegen 1997, hereafter HG; Marigo 2001, hereafter MAR). A full version of this work can be found in Bohigas (2008). The following section describes the most important results.

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2. MAIN RESULTS

1. Photoionization models based on the Cloudy code produced good to excellent results in 13 out of 19 spectra of PNe. Model fits were poor in objects where the slit did not cover the entire extent of the photoionized region. These objects show features that can be associated to shock excitation or abnormally large helium abundances. These peculiarities are probably connected to aperture effects, not to physical differences with respect to the rest of the PNe population.

2. Observed and modeled values for the temperature found from [N II](6548+6584)/5755 differed by less than 10% in all cases but one, with no tendency to over or underestimate the observed temperature. Models underestimate the temperature found from [O III](4959+5007)/4363 in all cases but 3. This inconsistency may be connected to aperture effects: real slits do not usually contain the entire in-depth extent of the ionized region, but these models can not account for this and assume full coverage.

3. The exciting sources, assumed to be Rauch (2003) model photospheres, are in a region in the HR diagram where central stars of PNe can be found, close to a 2.5 $M_\odot$ post-AGB evolutionary track (Vassiliadis & Wood 1994), with implied post-AGB ages between 1000 an 7000 years. The condition that the central star mass should be close to 1 $M_\odot$, leads to $\log(g_*) \simeq 7$.

4. Black body continua predict larger abundances for nitrogen, oxygen, neon and sulfur, than Rauch photospheres.

5. Central star Zanstra temperatures determined from He II 4686 were found to be uncertain, since the relative intensity of this line depends on additional factors: the shape of the ionizing continuum, the dust-to-gas mass ratio, the stopping criterion and, to a lesser extent, density gradients in the nebula. Among the 18 regions modeled with a standard dust-to-gas mass ratio, the root mean square relative difference between Zanstra (Kaler & Jacoby 1989) and modeled temperatures is 0.09.

6. Numerical experiments show that a simple constant density model can not account for the complex structure of PNe close to the ionization front. This will introduce uncertainties to the abundances of helium (10%), oxygen (10%), nitrogen (15%) and sulfur (30%). Helium abundance is $\sim$ 15% uncertain without a precise knowledge of the stellar continuum. More dependable results can be obtained for the abundances of sulfur and nitrogen, if these are determined matching [S III]9069 and [N III]1750, instead of [S II](6717+6731) and [N II]6584. In the absence of a carbon emission line, the abundance of this element was left as a free parameter. A comparison with abundances determined from the measured intensity of carbon lines, indicates that the reliability of model carbon abundances is not better than a factor of 2.

7. Abundances from 92 PNe (23 type I), indicate that He tends to be more abundant when N/O is large. Models for the return of chemical elements (HG and MAR) into the ISM cover almost entirely the He/H *vs.* N/O space, and predict positive helium yields and larger N/O ratios in more massive stars.

8. There is a large oxygen abundance dispersion in all types of PNe, probably caused by an equivalent range of initial metallicities. This implies that the mean oxygen abundance has not changed much in the past $\sim$ 10 Gyr. The mean oxygen abundance of non-type I PNe is similar to the latest solar value and H II regions, suggesting that oxygen yields are small in low mass stars. In addition, O/H is slightly (but significantly) smaller in type I PNe.

9. Carbon primary production seems to drive a very tight relation between CNO/H and carbon abundance. Carbon abundances in many type I PNe indicate that carbon (and CNO) yields are increasingly smaller in more massive progenitors.

10. Models for the return of chemical elements into the ISM do a good job accounting for the relationship between N/C and carbon abundance in nearly all the mass range of progenitor stars.

11. Photoionization models predict a mean neon abundance which is very similar to the solar value, in agreement with evolutionary models, but two times smaller than previous estimates. It is argued that neon abundance has been consistently overestimated using an inadequate ionization correction factor. An alternative formula can be found in Bohigas (2008).

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