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# AN OVERABUNDANCE OF OXYGEN IN PLANETARY NEBULAE OF THE SOLAR NEIGHBORHOOD

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RESUMEN

Estudiamos la abundancia de oxígeno en cinco regiones H II y siete nebulosas planetarias (NPs) situadas a menos de 2 kpc de distancia del sol que tienen espectros disponibles de alta calidad. Nuestro análisis usa un procedimiento similar y los mismos datos atómicos para calcular las abundancias en todos los objetos. Los resultados encontrados con líneas de excitación colisional para las regiones H II indican que el medio interestelar local es muy homogéneo, con $12 + \log(\mathrm{O/H}) = 8.45 - 8.54$. En cuanto a las NPs, seis de las siete muestran abundancias significativamente mayores: $12 + \log(\mathrm{O/H}) = 8.65 - 8.80$. Esta sobreabundancia de oxígeno en las NPs se mantiene cuando consideramos las abundancias que implican las líneas de recombinación.

ABSTRACT

We study the oxygen abundance in five H II regions and seven planetary nebulae (PNe) located within 2 kpc from the Sun that have available spectra of high quality. Our analysis uses a similar procedure and the same atomic data to derive abundances in all the objects. The results calculated with collisionally excited lines for the H II regions indicate that the local interstellar medium is very homogeneous, with $12 + \log(\mathrm{O/H}) = 8.45 - 8.54$. As for the PNe, six out of seven show significantly higher abundances: $12 + \log(\mathrm{O/H}) = 8.65 - 8.80$. This overabundance of oxygen in PNe also holds when we consider the abundances implied by recombination lines.

*Key Words:* H II regions — ISM: abundances — planetary nebulae: general



## 1. INTRODUCTION

We present a comparison between the oxygen abundances derived homogeneously for ionized gas in H II regions and planetary nebulae (PNe) of the solar neighborhood. This approach is the only way in which we can compare the abundances of the interstellar medium (ISM, represented in this context by H II regions) with stellar abundances (represented by PNe) using the same procedure and the same atomic data. Furthermore, the abundance analysis is based on optically thin lines, providing a large advantage over abundances derived directly for stars. We choose oxygen for this analysis because it is the element for which we can get the most reliable abundances in ionized gas. Besides, the oxygen abundance is not expected to be substantially modified by the evolutionary processes that take place in the progenitors of PNe with near-solar metallicity (although the most massive progenitors can achieve a small amount of destruction – see, e.g., Karakas 2010).

In principle, our approach has one disadvantage. Weak recombination lines (RLs) of heavy elements imply higher abundances than collisionally excited lines (CELs), by factors around or above 2, both in H II regions and PNe (e.g., García-Rojas et al. 2006; Liu et al. 2000). To avoid this difficulty, we will consider here the results implied by both RLs and CELs. However, different explanations of the discrepancy imply that the best abundance estimates will be close to the ones implied by either RLs or CELs, or will be intermediate between them (see Rodríguez & García-Rojas 2010, and references therein). Hence, the interpretation of the results must take into account that the explanation of the discrepancy can be different for H II regions and PNe.

Our sample contains five H II regions (M8, M16, M17, M20, and M42) and seven PNe (NGC 3132, NGC 3242, NGC 6210, NGC 6543, NGC 6572, NGC 6720, and NGC 6884) with deep spectra (Esteban et al. 2004; García-Rojas et al. 2006, 2007; Liu et al. 2004; Tsamis et al. 2003; Wesson & Liu 2004). All the objects have individual distance determinations locating them at distances below 2 kpc. This constraint should minimize the effects of the Galactic abundance gradient. The PNe were selected from the sample of low-ionization nebulae compiled by Delgado-Inglada et al. (2009), and are estimated to have $\mathrm{O^{3+}/O} < 0.15$. Since no [O IV] lines are observed in the optical along with all the other lines we will be using, this restriction reduces the uncertain-

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ties introduced by the correction for the presence of $O^{3+}$.

## 2. RESULTS

All the objects were analyzed in a similar way and using the same atomic data. An average electron density, $n_e$, was obtained using 2–3 diagnostic line ratios. Electron temperatures, $T_e$, for the low- and high-ionization regions inside each nebula were obtained from the usual [N II] and [O III] diagnostic line ratios (see, e.g., Osterbrock & Ferland 2006). The $O^+/H^+$ and $O^{++}/H^+$ abundance ratios were calculated using the values of $n_e$ and $T_e$ ($T_e$[N II] for $O^+$; $T_e$[O III] for $O^{++}$) and the line intensity ratios $I([\mathrm{O\,II}]\ \lambda3727)/I(\mathrm{H}\beta)$ and $I([\mathrm{O\,III}]\ \lambda\lambda4959,5007)/I(\mathrm{H}\beta)$. The total oxygen abundance was derived by adding the $O^+$ and $O^{++}$ abundances, and using ionization correction factors for the presence of $O^{3+}$ that go from $O/(O^+ + O^{++}) = 1$ (for the H II regions and some PNe) to 1.18. For the results implied by RLs, the $O^{++}$ abundance was derived using the O II RLs of multiplet 1. Then, we estimated the total oxygen abundance implied by RLs by assuming the same ionization fractions found with CELs. Further details on the procedure will be provided in Rodríguez & Delgado-Inglada (2011, in preparation).

Figure 1 shows the oxygen abundances implied by CELs and RLs as a function of $O^+/O^{++}$ for all the objects in the sample. The abundances implied by CELs in H II regions are similar, with $12 + \log(\mathrm{O/H}) = 8.45 - 8.54$, suggesting that the local ISM is very homogeneous. As for the PNe, if we exclude NGC 3242 (where the correction for $O^{3+}$ is the largest, making its total oxygen abundance more uncertain), the abundances implied by CELs are in the range $12 + \log(\mathrm{O/H}) = 8.65 - 8.80$. Since the oxygen abundances of PNe are expected to reflect the abundances in the ISM from which their progenitor stars formed several gigayears ago, this result is opposite to what we would predict using simple chemical evolution models. This overabundance of oxygen in PNe also holds when we consider the abundances derived with RLs. In fact, since the abundances implied by RLs in H II regions are similar to the abundances implied by CELs in PNe, even results intermediate between those implied by CELs and RLs (and shifted by different amounts in both kinds of objects) would indicate the presence of an overabundance in PNe.

This overabundance of oxygen in PNe could be due to different causes, like oxygen production in the stellar progenitors, large-scale gas flows in the Galaxy, recent infall of low-metallicity gas, or extensive stellar migration from the inner Galaxy. A discussion of these possibilities and a comparison of the results with those implied by stars of different ages and by those based on absorption lines in the diffuse ISM will be presented elsewhere (Rodríguez & Delgado-Inglada 2011, in prep.).

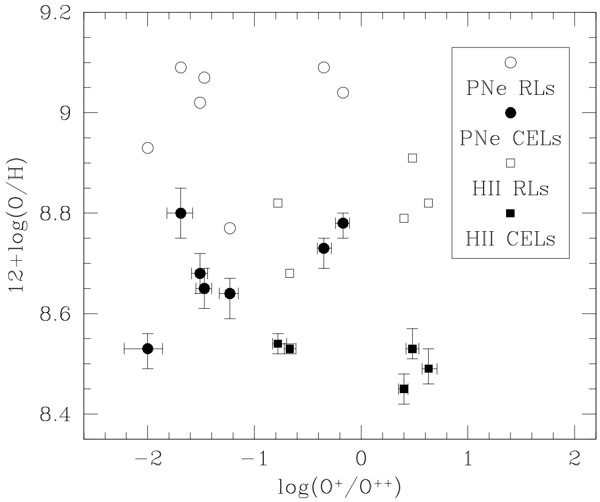


Fig. 1. Oxygen abundances implied by CELs (filled symbols) and RLs (open symbols) as a function of $O^+/O^{++}$ for H II regions (squares) and PNe (circles) in the solar neighborhood. The error bars show the observational uncertainties.

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