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A Survey of Recombination-line Abundances in Planetary Nebulae and H II Regions

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We have derived C, N and O abundances, relative to H, using optical recombination lines (ORLs), for a number of galactic planetary nebulae and for three Magellanic Cloud PNe (LMC N66, N141, SMC N87) and compared them with the corresponding abundances derived from collisionally-excited lines (CELs). Our goal was to investigate the fact that PNe ORL abundances are in most cases larger than those obtained from CELs. Our scanning, long-slit observations were combined with large-aperture *IUE*, *IRAS* and *ISO* data to yield integrated abundances for more than half of our target objects.

The ORL abundances for our PN sample are found to be consistently higher than those derived from UV, optical or IR CELs. In our overall sample (Tsamis et al., in preparation), the ORL/CEL discrepancy factors for both C^{2+}, N^{2+} and O^{2+} span a range from $\sim$2 to >20 and are positively correlated with the difference between the [O III] forbidden-line and Balmer recombination continuum temperatures, thus confirming a trend found by Liu et al. (2001) for O^{2+} in a sample of galactic PNe. These effects might be attributed to real temperature variations across the nebular volumes (Peimbert 1967), or they may be caused by density inhomogeneities, in the form of dense inclusions embedded within the ambient, diffuse ionized gas (Viegas & Clegg 1994). We find, however, that the discrepancies are not correlated with the excitation energies of CELs. Thus temperature-insensitive abundances, such as those derived from IR CELs, are found to be very similar to those yielded by UV and optical CELs, which are severely temperature dependent. Taken together, this points away from Peimbert-type, simple temperature fluctuations as the main cause of the problem. We find that the O^{2+} and C^{2+} ORL/CEL discrepancy factors are anticorrelated with the intrinsic nebular Hβ surface brightness, $S(\mathrm{H}\beta)$. We further find that in the case of the C^{2+} ORL/CEL abundance discrepancy, the discrepancy factor is positively correlated with the absolute nebular radius, R. This means that young, bright PNe display smaller abundance discrepancies than older, more extended nebulae, confirming a recent result by Garnett & Dinerstein (2001). We also find that the difference between the Balmer-jump and forbidden-line temperature is anticorrelated with $S(\mathrm{H}\beta)$ and positively correlated with R, suggesting that evolved, extended nebulae are more likely to have temperature discrepancies than younger, more compact objects.

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We compared the C/O and N/O elemental ratios derived just from ORLs with those derived just from CELs. We found that in most cases both types of line yield rather similar values. This has been commented upon in the past; cf. the study of NGC 6153 by Liu et al. (2000). Those authors constructed empirical composite models of the nebula, in which the sources of strong ORL emission were H-deficient, high density inclusions, while CEL emission originated mainly from the diffuse ambient gas. In the context of that model the equality of the elemental ratios derived from ORLs with those derived from CELs, suggests that the inclusions originated from the same nuclear-processed AGB material as the ambient gas. However, for some PNe the ORL ratios are found to be higher than the CEL ones; e.g. NGC 5315, 2022, 3132, 6302 and IC 4406, for which $(C/O)_{ORL}/(C/O)_{CEL}$ ~1.7 - 2.4; also NGC 2022 and IC 4191, for which $(N/O)_{ORL}/(N/O)_{CEL}$ ~2.9 - 3.3. This result, if real, may be indicative of enhanced nucleosynthetic effects in the inclusions.

We observed the Galactic nebulae M 17, NGC 3576 and the Magellanic Cloud regions 30 Doradus, LMC N11 and SMC N66. Our intent was to investigate whether ORL/CEL abundance discrepancies also occur in H II regions, since the elemental composition of such nebulae is of paramount importance in the scheme of galactic chemical evolution. In Table 1 we present ORL/CEL discrepancy ratios found (Tsamis et al., in preparation) for the O^{2+} ion, along with the C^{2+}/O^{2+} and N^{2+}/O^{2+} ratios derived from C II λ4267 and from N II and O II ORLs. It is clear that ORL/CEL discrepancies are present in H II regions too – objects in which H-deficient knots are not, in general, expected to occur. Note the excellent agreement between the temperature-insensitive ORL C^{2+}/O^{2+} ratios for the galactic systems and between the two LMC systems. The ORL N^{2+}/O^{2+} ratios for M 17 and NGC 3576 are quite uncertain, since the ORL N^{2+}/H^{+} abundances in these nebulae could only be derived from N II multiplets V 3 and V 5, which are potentially affected by fluorescence excitation.

Table 1. ORL/CEL O^{2+} abundance discrepancies and pure ORL ionic ratios.

H II region	ORL/CEL O^{2+}	ORL C^{2+}/O^{2+}	ORL N^{2+}/O^{2+}
M 17	2.1	0.77	0.62
NGC 3576	1.8	0.76	0.71
Orion	1.5	0.77	0.15
30 Doradus	2.0	0.25	≤0.16
LMC M11B	4.9	0.25	*
SMC N66	2.3	<0.20	*

References

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