NEW INSIGHTS INTO THE PHYSICAL STATE OF GASEOUS NEBULAE

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ABSTRACT

The impact of our knowledge of H II regions, planetary nebulae and supernova remnants due to IUE is briefly examined. Some of the more relevant aspects related to the physical conditions of gaseous nebulae are reviewed. The analysis of IUE data is under process and already significant results have been obtained on the following properties of gaseous nebulae: a) density and temperature distribution, b) ionization structure, c) chemical composition, d) internal dust, and e) shock velocity for supernova remnants. The CNO abundances of planetary nebulae are compared with stellar evolution models.

INTRODUCTION

To understand the nature of gaseous nebulae it is necessary to study their physical properties; the most important are: density and temperature distributions, ionization structure, chemical composition, dust presence and mass motions. From a profound knowledge of gaseous nebulae, it is possible to derive accurate chemical compositions to study such important problems as stellar and galactic chemical evolution. The three types of gaseous nebulae that will be considered in this review are: H II regions, planetary nebulae (PN) and supernova remnants (SNR).

There are at least four areas in which ultraviolet observations are paramount for our understanding of gaseous nebulae: a) the determination of the ionization structure from the detection of ions without strong optical emission lines such as CII, CIII, CIV, NIII, NIV, NV, OIV, OV, SiII, SiIII, SiIV and MgII, b) the determination of the density structure from the ratio of emission lines such as 1907/1909 of CIII and 2422/2425 of NeIV, c) the determination of the temperature structure by comparing the line intensity of the same ion originating from three different energy levels like λλ1663, 4363 and 5007 of OIII which for an electron density $N_e < 10^4$ cm^{-3} permits us to determine the electron temperature, T_e, and the mean square temperature variation over the observed volume, t^2, d) the presence of internal dust from the optical thickness of resonance lines like 1548 and 1551 of CIV and from the gaseous abundances of certain elements that might be partially locked up in grains like Mg, Si and C.

Excellent review papers on the possibilities for UV research of gaseous nebulae and on PN results derived from IUE data are presented elsewhere (ref. 1,2).

H II REGIONS

There have been three determinations of abundances of the Orion nebula based on IUE data (ref. 3,4,5). The three groups find a C/O ratio similar to the solar one (see table I) implying that the amount of carbon locked up in grains inside the Orion nebula is not substantial.

Perinotto and Patriarchi (ref. 3) obtain log $Mg^+/H^+ \leqslant -6.7$ for the Orion nebula; to estimate Mg/H they make use of the value $Mg^+/Mg = 0.15$ derived from a model of IC 418 by Harrington et al. (ref. 8) and conclude that their observed upper limit corresponds to a Mg/H value an order of magnitude smaller than the solar value implying that most of the Mg is locked up in grains. The Mg ionization correction factor should be verified due to its very large value and to the higher ionization degree of the Orion nebula relative to that of IC 418; furthermore from the models by Köppen (ref. 9) for objects like IC 418 and the Orion nebula with $33000 \leqslant T^* \leqslant 40000$ °K and $1 < (R^*/R_{\odot})(N_e^{1/2}/100) < 10$ it is obtained that $0.008 \leqslant Mg^+/Mg \leqslant 0.04$. The possibility of resonance line scattering reducing the Mg 2800 line intensity should also be considered.

By comparing the C^{++} 1907+1909 intensity with that of C^+ 4267 it is found that $t^2 = 0.016$ for the Orion nebula (ref. 4).

Rosa (ref. 10) has observed two extragalactic H II regions, NGC 604 and NGC 5471, which show a continuum energy distribution with stellar absorption and emission lines. In addition NGC 5471 shows strong C^{++} 1907+1909 emission of nebular origin.

From the work of Bohlin et al. (ref. 5), Perinotto and Patriarchi (ref.11) and others, it is found that most of the continuum observed in galactic H II regions is due to dust-scattered light from the ionizing O and B stars. From these data the dust-scattering efficiency and albedo as a function of wavelength have been estimated. The results depend on the model adopted for the spatial distribution of the dust and stars, therefore more observations and better models are needed to decide among several possibilities.

The relatively low temperatures and high dust content of H II regions with solar abundances makes the detection of UV emission lines very difficult and consequently the determination of their chemical abundances. Alternatively, extragalactic metal-poor H II regions have higher electron temperatures which produce emission lines relatively brighter than the stellar dust-scattered continua. Metal-poor H II regions that can be observed without their ionizing stars, like those in the Magellanic Clouds, are particularly good for the study of emission lines.

The determination of the electron density, N_e, from UV lines is particularly important for the study of the regions of high degree of ionization. From the ratio 1907 [CIII] to 1909 CIII] and the computations by Nussbaumer and Schild (ref. 12) the N_e values of several PN have been obtained (ref. 13, 14). From the [Ne IV] 2422/2425 ratio the N_e value has been obtained for NGC 7662 (ref. 15).

There is no good method to determine directly from visual data T_e for the region where helium is twice ionized. This can be done by combining IUE data with visual observations or by using only IUE data. From the [NeIV] 1602/(2422+2425) and 2422/2425 ratios it is possible to obtain N_e and T_e. The [N_eIV] 1602/(2422+2425) ratio has already been measured in NGC 3918 (ref. 16). By comparing λ4267 of CII and λλ1907+1909 of CIII it has been found that t^2= 0.02 for IC 418 (ref. 4); while from λλ1663,4363 and 5007 of OIII it has been found that t^2= 0.00 for the regions where the OIII lines originate.

The most important result derived so far on PN from IUE data is a set of CNO abundances that are presented in table II. The O/H ratios are very similar to those derived from visual data. The UV carbon abundances are mainly based on C^{++} and C^{+} ionic concentrations and ionization structure models; for CIV 1548, 1551 the dust-free models predict higher intensities than observed (ref. 2, 16), the difference is most likely due to the presence of internal dust that absorbs the resonance line radiation. The UV carbon determinations are of higher accuracy than those based on the λ4267 CII lines (ref. 18) due to the larger number of observed ions and to the faintness of the λ4267 lines which typically have been overestimated by factors ranging from 1.5 to 2.5 (ref. 4). The UV nitrogen abundances in Table II are based on N^{++}, N^{+++} and N^{++++} ionic concentrations while the visual determinations are based only on N^{+}, which for many PN is only a trace ion; therefore the UV results are more reliable. It can be seen from Table II that the difference between the IUE and visual N/O determinations increases with degree of ionization which implies that the visual method breaks down by underestimating the N/O ratio in objects of high ionization degree.

The C abundances in Table II include only the gaseous component in the PN shell, and since part of the C might be locked up in grains inside the nebula, correspond to lower limits to the total values. For NGC 7027 it has been estimated that the amount of carbon locked up in grains is similar to that listed in Table II (ref. 24). In Table II the abundances of the sun and the Orion nebula are presented for comparison. It is clear from this table that, even without considering the amount of C in the form of dust, C and N have been substantially enriched during the evolution of their central stars. Renzini and Voli (ref. 25), based on the work by Iben's group, have computed the evolution of the surface abundances of He, C, N and O in intermediate mass stars from the main sequence phase up to the ejection of the PN. In figures 1 and 2 we compare the models with the observations of Table II. For C/O the models agree reasonably well with the observations. Alternatively for N/O not only PN of Type I (ref. 26) with high He/H values present large N/O values but also other PN of Type II like NGC 7027, NGC 6886 and IC 2448, which originated from stars with $M/M_\odot \leq 2.4$ (ref. 27), present N/O values larger than predicted, possibly indicating that the stellar evolution models should include turbulent diffusion and meridional circulation (ref. 25).

The intensity ratio of the NV, CIV and MgII resonance doublets ($\lambda\lambda$1239/1243, 1548/1551, 2796/2803) is expected to be equal to 2, the ratio of the respective collision strengths in dust-free nebulae. In all the reported cases the ratios are smaller than 2 (ref. 13,14) indicating dust presence. Moreover the ionization structure models without dust predict a higher intensity than observed for the CIV doublet (see above) possibly indicating that the doublet has been attenuated by internal dust. Pequignot and Stasinska (ref. 28) have found that the observed MgII doublet in NGC 7027 is a factor of 10 smaller than the value predicted by their dust-free models, they have estimated that a fraction of this difference is due to internal dust attenuation and that the rest is due to a substantial amount of Mg embedded in dust grains. From the Mg doublet ratio and a model containing dust it will be possible to quantitatively evaluate these two effects.

SUPERNOVA REMNANTS

Most of the SNR lines in the UV originate in regions where $4\times10^4 < T_e < 4\times10^5$ °K this temperature range corresponds to the gap left by the visual and X-ray observations. The UV is particularly well suited to derive accurate shock velocities, v_s, for cases where $v_s \sim 100$ km s^{-1}. From the value of v_s, the emission line intensities and models available, it is possible to determine the chemical composition of the SNR.

From IUE observations of the Cygnus Loop v_s values in the 100-130 km s^{-1} range have been obtained (ref. 29,30,31). By combining these observations with shock models and neglecting radiative transfer models due to the presence of dust it is found that $\lambda\lambda$1548+1551 CIV, 1907+1909 [CIII] + CIII] and 2326 CII] are too weak by factors of 10, 2.5 and 1.5 (ref. 29,30) and by 10, 1.6 and 1.4 (ref. 31) respectively; it has been suggested that these observations can be explained by progressive destruction of graphite grains. Benvenuti et al. (ref. 30) find that λ1335 CII is too weak by about an order of magnitude while Raymond et al. (ref. 31), from the 1335/2326 ratio, find that the optical depth in the resonance lines due to dust reduces the λ1335 flux by a factor of ten. As mentioned before, resonance line scattering reduces the CIV line intensities in PN and it is highly probable that in SNR a similar situation prevails which would make the C underabundance in the Cygnus Loop marginal. Considering that C is depleted by about an order of magnitude in the interstellar medium this result would imply that substantial destruction of graphite grains occurs in shocks with $v_s \sim 130$ km s^{-1}. Raymond et al.(ref. 31) present some evidence in favor of a depletion of $\sim$3 in Si.

The Crab nebula is the only young SNR observable with the IUE; this SNR has not been significantly contaminated by the interstellar medium, therefore its chemical composition still corresponds to that of the SN. Davidson et al. (ref. 32) from preliminary IUE results obtain for the Crab nebula that $N(C)/N(O) < 3$. By considering that in this object $O/O_\odot \sim 1/3$ (ref. 33) the C/O upper limit implies that, contrary to expectations, at least this SN did not produce much carbon.

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TABLE I.- ORION NEBULA - CHEMICAL ABUNDANCES[a]

Object	O/H (optical)	C/H (UV)	Mg^+/H^+ (UV)	Mg/H	t^2	Ref.
Orion	....	8.40	$\lesssim$5.3	....	0.00	3
"	8.65	8.57	....	....	0.02	4
"	8.52	8.35	....	....	0.00	4
"	8.52	8.48	....	....	0.00	5
Sun	8.92	8.76	....	7.62	....	6,7

[a] Given in 12+log N(X)/N(H).

TABLE II.- PLANETARY NEBULAE - CHEMICAL ABUNDANCES

Object	O/H[a] (UV)	C/O[b] (UV)	N/O[b] (UV)	(C+N)/O[b] (UV)	N/O[b] (visual)	He/H[c] (visual)	Ref.
NGC 2392	8.74	-0.39	-0.33	-0.06	-0.29	0.091	17,18,19
NGC 2440	8.72	-0.20	+0.08	+0.26	+0.33	0.135	17,18,19
NGC 2867	8.65	+0.19	-0.55	+0.26	-0.52	0.112	17,19
NGC 3918	8.78	+0.20	-0.39	+0.30	-0.60	0.113	16,18
NGC 6302	8.79	+0.43	+0.25	+0.65	-0.15	0.191	17,19
NGC 6741	8.84	+0.26:	-0.14:	+0.41	-0.13	0.123	17,19
NGC 6886	8.72	+0.18:	+0.08:	+0.43	-0.53	0.102	17,19
NGC 7027	8.62	+0.49	-0.10	+0.59	-0.37	0.113	20,18,19
NGC 7662	8.58	-0.07	-0.54	+0.06	-0.88	0.094	21,18
IC 418	8.60	+0.26	....	....	....	....	8
IC 418	8.70	+0.33	....	....	....	....	4
IC 2448	8.46	+0.10	-0.27:	+0.25	-1.08	0.111	16,18
IC 4997	8.04	-0.40	....	....	....	....	22
Me 2-1	8.86	+0.05	-0.74	+0.12	....	....	17
PN[d]	8.70	+0.14	-0.24	+0.30	-0.42	0.119	
Orion	8.65	-0.08	....	-0.03	-0.97	0.100	23
Sun	8.92	-0.25	-0.93	-0.17	-0.93	....	6

[a] Given in 12+log N(O)/N(H). [b] Given in log N(X)/N(Y). [c] Given in N(He)/N(H).

[d] Average of this table without IC 4997 .

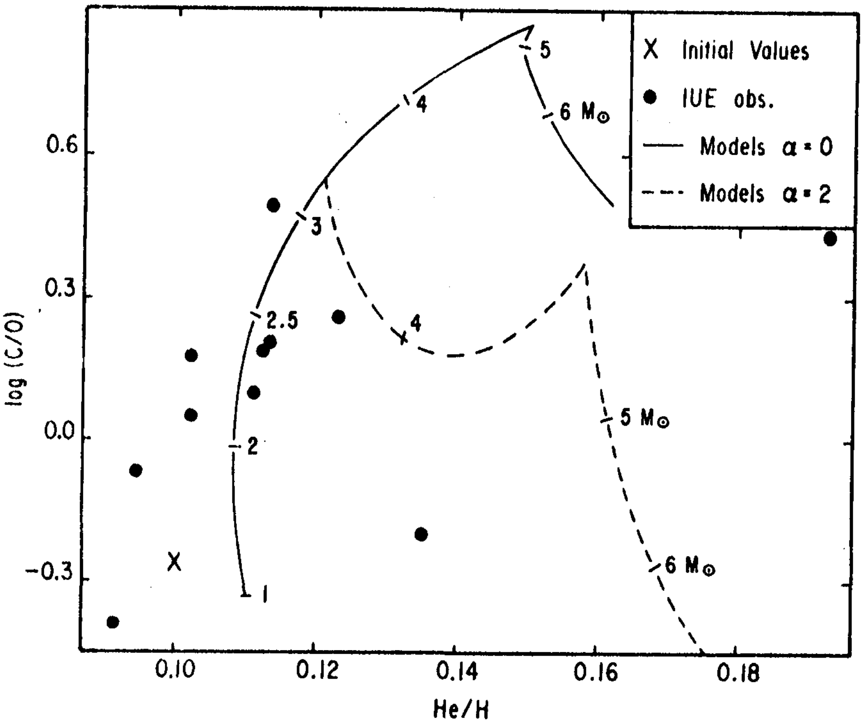

Figure 1. The model values (Renzini and Voli, ref. 25) correspond to the surface abundances at the time of the PN ejection. Along each sequence the values of the initial stellar mass are reported. The parameter α is the ratio of the mixing length to the pressure scale height, and α= 0 simply means that hot-bottom nuclear burning has been omitted.

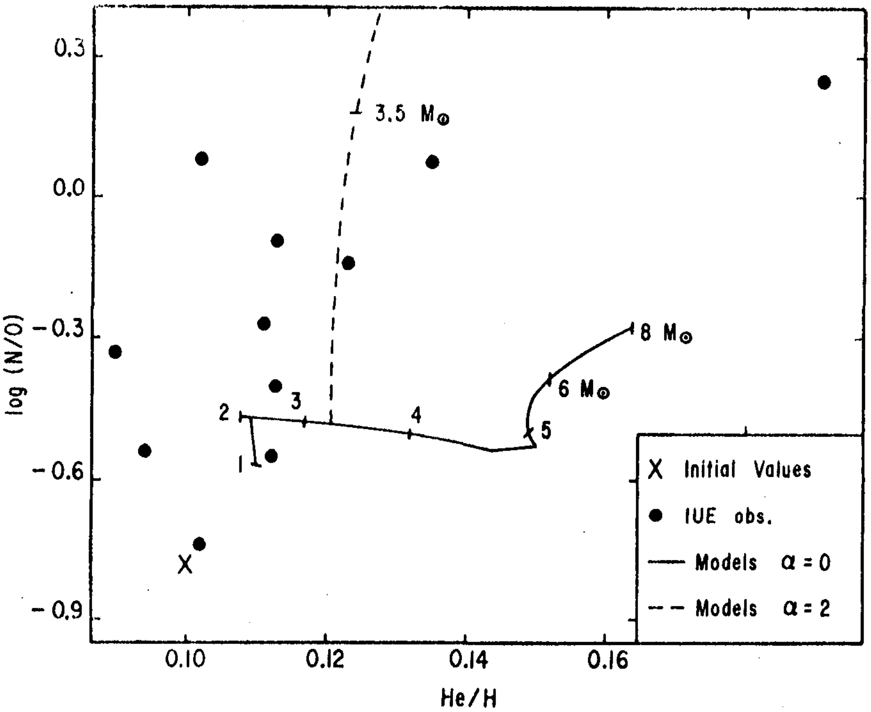

Figure 2. Same as Figure 1.