

HELIUM IN THREE H II GALAXIES AND THE PRIMORDIAL HELIUM ABUNDANCE

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RESUMEN. A partir de nuevas mediciones de $\lambda 6678$ en las galaxias H II Tololo 1214-277, Michigan 461 y Tololo 0633-415 usando el telescopio anglo-australiano y un detector CCD se obtienen abundancias de helio. Estas abundancias están de acuerdo con aquellas derivadas de las líneas 4471 y 5876 observadas previamente por Terlevich. Además las estrellas excitadoras de los objetos de baja abundancia T 1214-277 y Michigan 461 son tan calientes, y [O II] es tan débil que se puede estar seguro, independientemente de los modelos de fotoionización, que la corrección por helio neutro es menor que el 5 por ciento. Este resultado refuerza estimaciones previas que la abundancia de helio pregaláctica es cercana a 0.230. Se discuten brevemente las consecuencias de este resultado para la física de partículas y la cosmología.

ABSTRACT. New measurements of $\lambda 6678$ in the H II galaxies Tololo 1214-277, Michigan 461 and Tololo 0633-415, using the Anglo-Australian Telescope and a CCD detector, give helium abundances in close agreement with those derivable from the 4471 and 5876 lines previously observed by Terlevich. Furthermore, the exciting stars for the low-abundance objects T 1214-277 and Michigan 461 are so hot, and [O II] is so weak, that one can be quite sure independently of photo-ionization models that the correction for neutral helium is below 5 per cent. This strengthens previous estimates of a pregalactic helium abundance close to 0.230. Implications for particle physics and cosmology are briefly discussed.

Key words: COSMOLOGY — INTERSTELLAR-ABUNDANCES — NUCLEO-SYNTHESIS

1. Introduction

The significance for cosmology and astrophysics of helium abundances in low-abundance extragalactic HII regions, and the difficulties in its determination and extrapolation to an estimate of the primordial value Y_p , have been extensively discussed, e.g. by Shaver et al (1983), Yang et al (1984: YTSSO), Boesgaard & Steigman (1985), Davidson & Kinman (1985) and Pagel (1982, 1987, 1989). Peimbert & Torres-Peimbert (1974, 1976) suggested the existence of a linear regression relation between helium and oxygen abundances with $dY/dZ \approx 3$ which has been confirmed (apart from a few special cases where both He and N are more abundant than usual) by Lequeux et al. (1979), Peimbert (1985), Pagel, Terlevich & Melnick (1986) and Pagel (1987, 1989); the last two references explain why doubts expressed by some other writers (e.g. Kunth & Sargent 1983; Boesgaard & Steigman 1985) as to the existence of such a relation are without foundation. On the other hand, the extent to which the relation is linear and unique remains to be investigated. In this paper we report recent progress that we have made in an on-going programme to improve the available data base for the determination of Y_p and the relation between helium, oxygen and nitrogen, in which we are making new observations and reprocessing selected data from the literature.

2. Observations

We have used the UCL Image Photon Counting System and CCD detectors with spectrographs attached to the Isaac Newton Telescope on La Palma and the Anglo-Australian Telescope. Certain problems with correcting for non-linearity have slowed down the reduction of the IPCS data and so only the results of CCD observations, taken with the AAT in April 1988, will be reported here. The detector was a GEC blue-coated chip placed at the focus of the long-focus (82 cm) camera of the RGO spectrograph at the RC telescope focus and a 270 gr mm^{-1} grating gave a dispersion of 50 \AA mm^{-1} leading to an excellent resolving power of about 2000 at the expense of a narrow slit and restricted wavelength range (λ 6400 - 7000). Fig. 1 shows a spectrum of Tololo 1214-277 resulting from $1\frac{1}{2}$ hrs exposure added over the three brightest cross-sections, and it is clear that we have a signal:noise ratio of better than 20:1 in λ 6678, which has only rarely (if ever) been achieved with this type of object before. We consider this very important because λ 6678 is less subject to underlying absorption lines (which often affect λ 4471) and to local absorption and collisional effects (which especially affect λ 5876), and the proximity to $\text{H}\alpha$ minimises flux calibration problems. A small, well-determined correction for non-linearity in the CCD system has been applied. Furthermore, our high S/N high resolution spectra are useful for the determination of electron density and (in combination with the previous observations of Terlevich and his colleagues) permit one to find the nitrogen abundance (previously unknown for T 1214 - 277) and the effective temperature of the exciting stars.

Tol 1214-277

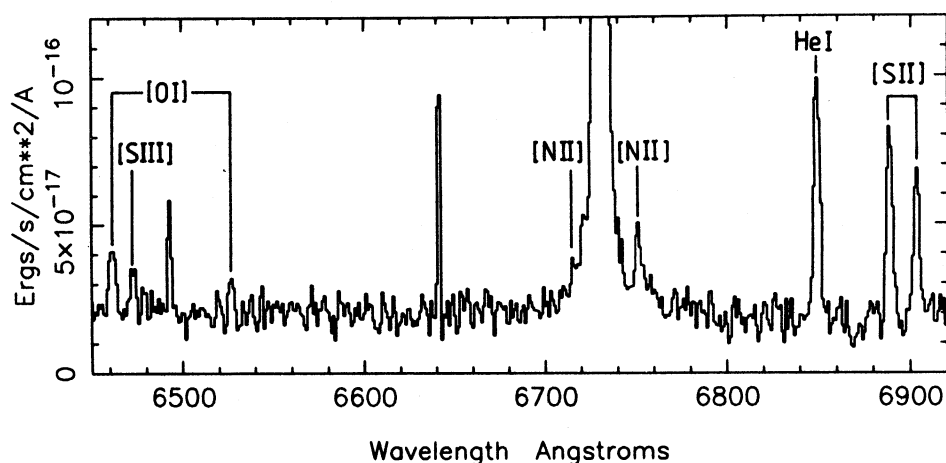


Fig. 1 AAT spectrum of T 1214-277. The two narrow spikes are "cosmic ray" events.

3. Analysis and Results

OIII electron temperatures were determined in the usual way from measurements of [OIII] $\lambda\lambda$ 4363, 4959, 5007 by Campbell, Terlevich & Melnick (1986) and by Terlevich (private communication) using McCall's (1984) 3-level atom algorithms modified to fit the tables based on newer atomic data by Keenan & Aggarwal (1987). OII electron temperatures were assumed to be lower by 30 per cent of the excess above 10^4 K (Stasinska 1982). Oxygen and nitrogen abundances were calculated using McCall's tables and assuming $\text{O}/\text{H} = \text{O}^+/\text{H}^+ + \text{O}^{++}/\text{H}^+$ and $\text{N}/\text{O} = \text{N}^+/\text{O}^+$. Electron densities were deduced from the [SII] 6717/6731 ratio using the graph in Osterbrock (1988). Raw abundances of singly and doubly ionised helium (uncorrected for collisions) were derived using algorithms equivalent to those of Kunth & Sargent (1983), based on Brocklehurst (1972). Corrections for collisional excitation were made using the formulae of Clegg (1987), based on quantum mechanical calculations by Berrington &

Kingston (1987), which are in better accordance with planetary nebula observations (Péquignot, Baluteau & Gruenwald 1988) than were the earlier theoretical rates used with such disastrous effect by Ferland (1986). (Ferland's outrageous paper did have the merit at least of provoking Berrington *et al.* to make more accurate calculations.) Peimbert & Torres-Peimbert (1987a, b) find that the 10830 line is anomalously weak in many planetary nebulae, suggesting a lower 2^3S population than is predicted by use of Berrington & Kingston's collision rates, a possible implication being that collisional corrections based on them might still be too high by a factor of 2 or so. Clegg & Harrington (1989) find that radiative effects do not appreciably reduce the 2^3S population at moderate or low densities and they suggest the operation of a hitherto unknown destruction mechanism (like charge exchange) which would be inoperative at low densities. We therefore feel justified in using Clegg's formulae for the collisional contributions which are in any case significant only for λ 5876. Our results are shown in Table 1, where the superb agreement between independent sets of data (from Terlevich and from this work, respectively) is evident.

Table 1
Results of analysis of three HII galaxies

	T 1214 - 277		UM 461		T 0633-415	
	CTM ^a	This work	RJT ^b	This work	CTM ^a	This work
t(OIII)	1.78		1.63		1.23	
n _e	250±3000:	330±270	150±1500:	100±100	200±800:	200±100
12 + log (O/H)	7.60		7.82		8.16	
O ⁺ /O	.05		.07		.33	
log (O/N)		1.58	1.49	1.59	1.38	1.39
log η		-.50		-.55		.15
γ (4471) ^c		.06±.05		.02±.02		.01±.01
γ (5876)		.12±.10		.03±.03		.025±.01
γ (6678)		.04±.03		.01±.01		.010±.005
y ⁺⁺	.004		-		-	
y ⁺ (4471)		.065 ± .011		.079 ± .013		.089 ± .017
y ⁺ (5876)		.067 ± .009		.078 ± .008		.086 ± .009
y ⁺ (6678)		.068 ± .004		.075 ± .003		.082±.004
y		.072 ± .0035		.076 ± .003		.083 ± .004
Y		.224 ± .008 ^d		.233 ± .007 ^d		.248 ± .009 ^d

^a Campbell, Terlevich & Melnick 1986
^b Private communication from R J Terlevich, based on Terlevich *et al.* 1989
^c y+ (corr.) = y+ (uncorr.)/(1 + γ)
^d Previous estimates (Pagel 1987) were .231 ± .016, .238 ± .009, .255 ± .015 respectively.

Corrections for neutral helium are based on the "softness" parameter $\eta = (\text{O}^+/\text{O}^{++}) \times (\text{S}^{++}/\text{S}^+)$ described by Vilchez & Pagel (1988); this measures the effective temperature of the ionising stars, to which the relative sizes of H⁺ and He⁺ regions are directly related (Osterbrock 1974), at least in a single HII region. In all three cases our values of η correspond to such high effective temperatures that the correction for neutral helium, read off the photo-ionisation models of Stasinska (1982), is negligible. Peña (1986), Dinerstein & Shields (1986) and Dufour, Garnett & Shields (1988) have drawn attention to the possibility that one observes an HII complex equivalent to two HII regions superposed, one of high ionisation contributing most of the [OIII] and HeI and another of low ionisation contributing [OII] and a part of the Balmer lines. If this were so, our argument based on η would be invalid. Fortunately the abundance

of O^+ in T 1214-277 and in Michigan 461 is so low that the resulting underestimate of the total helium abundance cannot be more than 5 per cent. This contrasts with the case of I Zw 18 where 15 per cent of the oxygen is O^+ (Dufour, Garnett & Shields 1988), making I Zw 18 a less suitable object for the determination of Y_p than its outstandingly low oxygen abundance might at first lead one to suppose. Our new helium abundances are plotted, along with new results from data in the literature discussed previously by Pagel (1987, 1989), in Fig. 2, where maximum-likelihood regressions are given by

$$Y = .224 + \frac{178}{\pm 5} O/H \quad (1)$$

for oxygen and

$$Y = .229 + \frac{3120}{\pm 4} N/H \quad (2)$$

for nitrogen.

4. Discussion

The slope of our regression relation of helium against oxygen, corresponding to $dY/dZ = 7 \pm 2$ if $Z = 25$ (O/H), is probably too steep, being biased by a few nitrogen-rich objects. Thus we see no reason to doubt the slope of 3.5 advocated by Peimbert (1985), which has certain implications for stellar nucleosynthesis (see Pagel 1989), and we adopt the primordial abundance from equation (2). This value can be seen in perspective from Table 2, which shows that there has been hardly any change over 10 years despite various arguments over details. Systematic errors could push the value up as far as .240 perhaps, but not significantly further than that.

Table 2

Estimates of Primordial Helium Abundance
with $\pm 1 \sigma$ errors

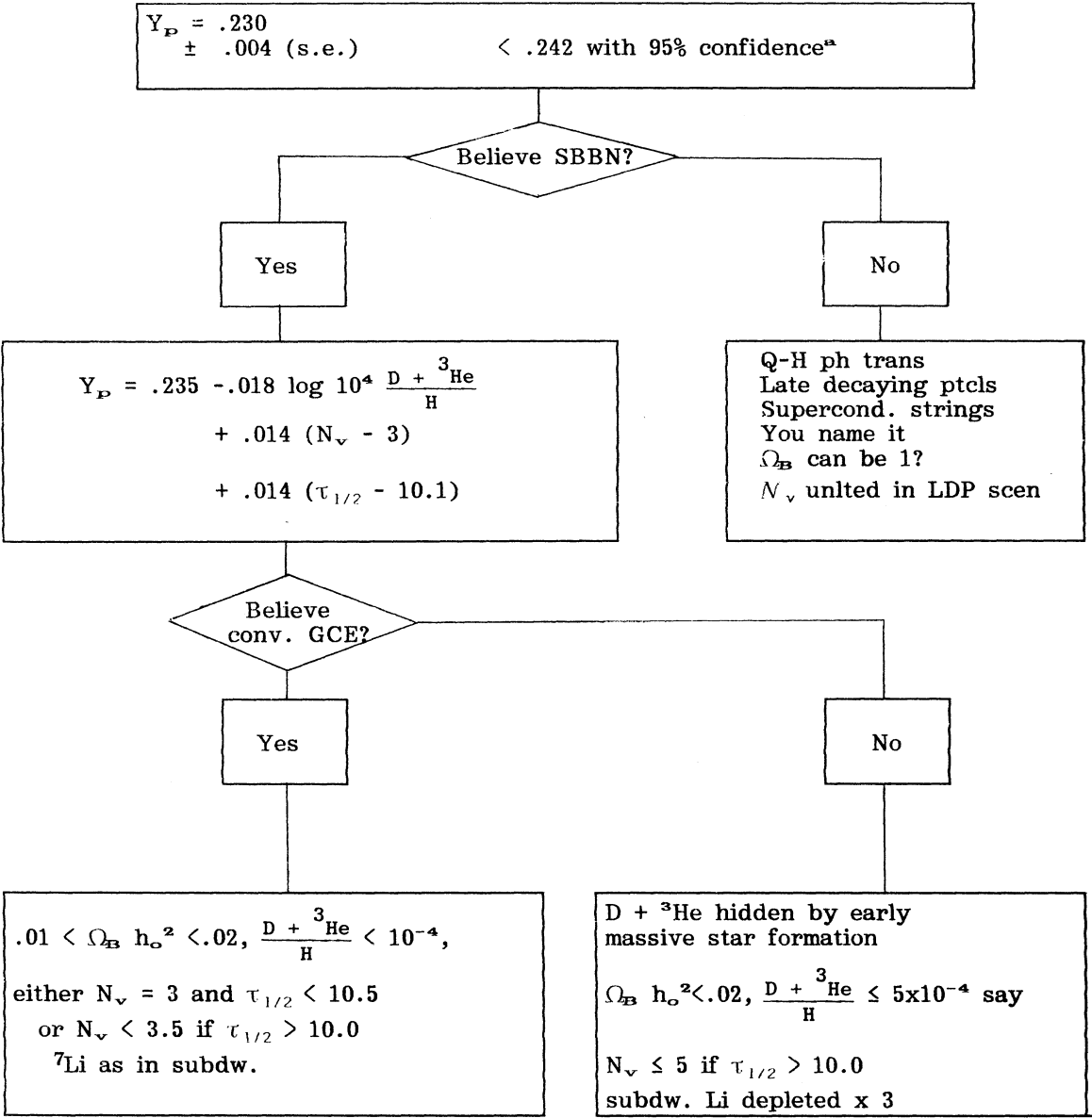
.230 \pm .004	Lequeux <i>et al</i> 1979
<.243 \pm .010	Kunth & Sargent 1983
.234 \pm .008	" " " without II Zw 40 ^a
.232 \pm .004	Peimbert 1985
.237 \pm .005	Pagel, Terlevich & Melnick 1986
.232 \pm .004	Pagel 1987
.230 \pm .006	Torres-Peimbert, Peimbert & Fierro 1989
.229 \pm .004	This work

^a See French (1980)

According to standard Big Bang nucleosynthesis (SBBN) as described by YTSSO, combined with reasonable ideas on Galactic chemical evolution that limit the primordial $(D + {}^3\text{He})/H$ ratio to a value below 10^{-4} , the existence of 3 light neutrino species requires $Y_p > 0.240$ if the neutron half-life is no less than 10.4 minutes (YTSSO assumed 10.6 minutes). Recent experiments give 10.1 ± 0.2 minutes for the half life (Last *et al.* 1988; Anton *et al.* 1989) so that SBBN plus conventional chemical evolution is perfectly viable within the uncertainties. However, unconventional models, motivated in part by the desire to have the cosmological critical density in the form of baryons, may perhaps also be made to work. The alternatives are summarised in Table 3; to our mind the one in the lower left corner is the most tidy.

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Table 3
Implications for cosmology



^a Allowing for the possibility of systematic errors of up to .005

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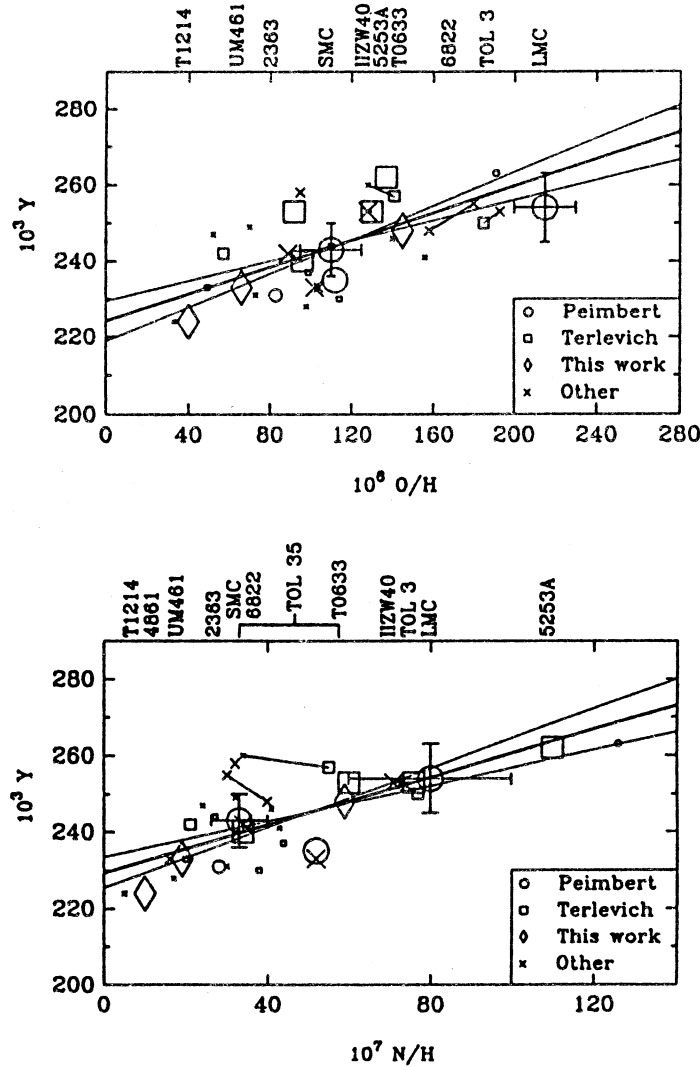


Fig. 2 Relations between helium and oxygen and nitrogen in extragalactic HII regions with maximum likelihood regression lines and $\pm 1 \sigma$ limits. Sizes of symbols are inversely related to the estimated errors. (For a detailed list of the objects see Pagel 1987).

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