RevMexAA (Serie de Conferencias), **10**, 148–153 (2001)

The Seventh Texas-México Conference on Astrophysics: Flows, Blows and Glows (Austin, Texas, 6-8 April 2000)
Editors: William H. Lee and Silvia Torres-Peimbert

PRIMORDIAL HELIUM ABUNDANCE DETERMINATIONS

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RESUMEN

Usando las mejores observaciones de regiones H II extragalácticas de baja metalicidad disponibles se redeterminó el valor de la abundancia primordial de helio, Y_p; se hizo uso de todas las líneas de He I, a excepción de aquellas afectadas fuertemente por absorción subyacente. Para cada objeto se determinaron He/H, N_e(He II), T_e(He II) y $\tau(3889)$ de manera autoconsistente. Se presentan los resultados para NGC 346, I Zw 18 y NGC 2363. A partir de estas determinaciones se encuentra que $Y_p = 0.2351 \pm 0.0022$.

ABSTRACT

Based on the best observations of extragalactic H II regions of low metallicity available in the literature we redetermine the primordial helium abundance, Y_p, taking into account all the observed He I line intensities with the exception of those strongly affected by underlying absorption. We derive He/H, N_e(He II), T_e(He II), and $\tau(3889)$ self–consistently. We present results for NGC 346, I Zw 18, and NGC 2363. From these objects we find that $Y_p = 0.2351 \pm 0.0022$.

Key Words: **GALAXIES: ABUNDANCES — GALAXIES: ISM — H II REGIONS — ISM: ABUNDANCES**

1. INTRODUCTION

The determination of the pregalactic, or primordial, helium abundance by mass Y_p is paramount for the study of cosmology, the physics of elementary particles, and the chemical evolution of galaxies. In this paper we present a new determination of Y_p based on observations of the metal poor extragalactic H II regions NGC 346, I Zw 18, and NGC 2363. This determination is compared with those carried out previously by other authors.

2. NGC 346

NGC 346 is the most luminous H II region in the SMC. Peimbert, Peimbert, & Ruiz (2000, Paper I) have analyzed this object, a brief summary of their results follow. Due to the relatively small distance to NGC 346 it is possible to place the observing slit avoiding the brightest stars. From the observations of the He I lines $\lambda\lambda$ 3889, 4026, 4387, 4471, 4922, 5876, 6678, 7065 and 7281 we use a maximum likelihood method to determine simultaneously and self–consistently the electron density $N_e = 143 \pm 36 \mathrm{cm}^{-3}$, the electron temperature $T_e = 11950 \pm 370$K, and the helium to hydrogen ratio He/H $= 0.0793 \pm 0.0006$. In Table 1 we present He/H and χ^2 as a function of several N_e and T_e values, which include a few representative temperatures, and the densities favored by those temperatures. It can be seen there that this set of lines implies a strong correlation between the temperature and the density.

These He/H ratios, along with the (temperature dependent) oxygen abundance result in $Y = 0.2405 \pm 0.0018$. By adopting $\Delta Y/\Delta O = 3.5 \pm 0.9$ (see Paper I), where O is given by mass, we find that $Y_p = 0.2345 \pm 0.0026$. Table 2 presents the Y and the Y_p for the different densities and temperatures.

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TABLE 1

$N(\mathrm{He}^+)/N(\mathrm{H}^+)$[a] AND χ^2 FOR NGC 346

T_e(K)	N_e(cm^{-3})				
	53	100	143	162	247
11200	805	798	793	791	**781**[b]
	(83.2)	(47.7)	(26.4)	(20.0)	*(8.24)*[c]
11800	806	799	793	**790**	780
	(38.6)	(15.9)	(7.37)	*(6.59)*	(20.4)
11950	806	799	**793**	790	779
	(30.8)	(11.7)	**(6.53)**[d]	(7.25)	(27.7)
12400	807	**799**	793	790	778
	(15.0)	*(7.17)*	(12.5)	(17.9)	(58.6)
13000	**809**	800	793	790	777
	(9.72)	(18.2)	(38.4)	(50.2)	(118)

[a] Given in units of 10^{-4}, χ^2 values in parenthesis.
[b] The $\mathrm{He}^+/\mathrm{H}^+$ values in boldface correspond to the minimum χ^2 values at a given temperature.
[c] The minimum χ^2 value at a given temperature is presented in italics.
[d] The smallest χ^2 value for all temperatures and densities is presented in boldface, thus defining T_e(He II) and N_e(He II).

TABLE 2

Y(NGC 346) AND THE Y_p DERIVED FROM IT

T_e(K)	N_e(cm^{-3})				
	53	100	143	162	247
11200	0.2431	0.2416	0.2404	0.2399	*0.2377*[a]
	0.2363	0.2348	0.2336	0.2331	*0.2309*
11800	0.2435	0.2419	0.2405	*0.2399*	0.2375
	0.2373	0.2357	0.2343	*0.2337*	0.2313
11950	0.2436	0.2420	**0.2405**[b]	0.2399	0.2374
	0.2376	0.2360	**0.2345**	0.2339	0.2314
12400	0.2439	*0.2421*	0.2406	0.2399	0.2372
	0.2384	*0.2366*	0.2351	0.2344	0.2317
13000	*0.2443*	0.2423	0.2407	0.2400	0.2370
	0.2395	0.2375	0.2359	0.2352	0.2322

[a] Italic entries correspond to minimum χ^2 values at a given temperature.
[b] Boldface entries correspond to the overall minimum χ^2 value.

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TABLE 3

Y(I Zw 18) AND THE Y_p DERIVED FROM IT

T_e(K)	N_e(cm^{-3})					
	20	31	66	83	108	187
16720	0.2403	0.2396	0.2365	0.2359	*0.2344*[a]	0.2296
	0.2395	0.2388	0.2357	0.2351	*0.2336*	0.2288
17280	0.2408	0.2401	0.2375	**0.2363**[b]	0.2346	0.2295
	0.2400	0.2393	0.2367	**0.2355**	0.2338	0.2287
17840	0.2417	0.2407	*0.2379*	0.2366	0.2348	0.2294
	0.2410	0.2400	*0.2372*	0.2359	0.2341	0.2287
19060	0.2431	*0.2421*	0.2388	0.2374	0.2354	0.2292
	0.2424	*0.2414*	0.2381	0.2367	0.2347	0.2285

[a] Italic entries correspond to minimum χ^2 values at a given temperature.
[b] Boldface entries correspond to the overall minimum χ^2 value.

3. I ZW 18

Up to now, with the exception of NGC 346, it has not been possible to derive the ICF(He), N_e(He II), T_e(He II), $\tau(3889)$ and the He$^+$/H$^+$ ratio based only on the helium lines. Usually the T_e(O III) value and photoionized models are used to complement the information provided by the He I lines. From photoionization models of giant H II regions it has been found that T_e(He II) is from 3% to 11% smaller than T_e(O III) (e.g. Gruenwald & Viegas 1992; Kingdon & Ferland 1995; Pérez 1997, Peimbert, Peimbert & Luridiana 2001, in preparation). In the presence of additional sources of energy to those provided by photoionization the difference between T_e(He II) and T_e(O III) might be larger. From observations we found that the difference for NGC 346 amounts to $9\% \pm 3\%$.

Stasinska & Schaerer (1999) produced a detailed model of I Zw 18 and find that it predicts a T_e(O III) value 15% smaller than observed. From photoionization models of I Zw 18 based on CLOUDY (Ferland et al. 1998) we find that T_e(He II) is $10\% \pm 2\%$ smaller than T_e(O III). Based on these considerations and the observational results for NGC 346, we have adopted a T_e(He II) $9\% \pm 3\%$ smaller than T_e(O III) as one of the input parameters for the maximum likelihood method, the other ingredients being the observations of $\lambda\lambda$ 3889, 4026, 4471, 5876, 6678 and 7065 by Izotov et al. (1999) and the assumption that $\tau(3889) = 0.00$.

The maximum likelihood solution amounts to $N_e = 83^{+104}_{-63}$cm^{-3}, T_e(He II)$= 17280 \pm 560$K, and $Y = 0.2363{\pm}0.0085$. For this temperature range we obtain O/H $= (1.8{\pm}0.1) \times 10^{-5}$ and adopting $\Delta Y/\Delta O = 3.5{\pm}0.9$ (see Paper I) we find that $Y_p = 0.2355 \pm 0.0085$, in excellent agreement with our determination based on NGC 346. Table 3 presents the Y and the Y_p for a few representative temperatures and densities which include our favored values, the $\pm 1\sigma$ values, and the T_e(O III) temperature.

4. NGC 2363

Luridiana, Peimbert, & Leitherer (1999) produced detailed photoionization models of NGC 2363, they find also that the T_e(O III) predicted by the models is considerably smaller than observed; from their models they find also that T_e(He II) is from 3% to 7% smaller than T_e(O III). Based on these considerations and the observational results for NGC 346, we have adopted a T_e(He II) $7\% \pm 3\%$ smaller than T_e(O III) as one of the input parameters for the maximum likelihood method.

To estimate the total helium abundance it is necessary to estimate the helium ionization correction factor, ICF(He). From models of I Zw 18 and observations of NGC 346 it is found that the ICF(He) is equal to 1.00; alternatively from the models of NGC 2363 (Luridiana et al. 1999) we estimated for the slit used by

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TABLE 4

Y(NGC 2363) AND THE Y_p DERIVED FROM IT

T_e(K)	N_e(cm^{-3})					
	131	173	218	257	304	383
13580	0.2461	0.2444	0.2432	0.2419	*0.2406*[a]	0.2385
	0.2418	0.2401	0.2389	0.2376	*0.2363*	0.2342
14020	0.2464	0.2448	0.2433	**0.2419**[b]	0.2405	0.2382
	0.2423	0.2407	0.2392	**0.2378**	0.2364	0.2341
14460	0.2466	0.2450	*0.2433*	0.2419	0.2403	0.2378
	0.2427	0.2411	*0.2394*	0.2380	0.2364	0.2339
15100	0.2470	*0.2453*	0.2434	0.2418	0.2401	0.2373
	0.2434	*0.2417*	0.2398	0.2382	0.2365	0.2337

[a] Italic values correspond to minimum χ^2 values at a given temperature.
[b] Boldface values correspond to the overall minimum χ^2 value.

TABLE 5

Y_p COMPARISION

	This paper	Izotov et al.
NGC 346	0.2345 ± 0.0026	.....
I Zw 18	0.2355 ± 0.0085	0.2423 ± 0.0070
NGC 2363	0.2378 ± 0.0056	0.2429 ± 0.0015
SBS 0335-052	.....	0.2454 ± 0.0017
Average	0.2351 ± 0.0022	0.2452 ± 0.0015[a]

[a] Without NGC 2363

Izotov, Thuan, & Lipovetsky (1997) an ICF(He) of 0.993, indicating the presence of neutral hydrogen inside the ionized helium region (see Paper I and references therein).

From the observations of $\lambda\lambda$ 3889, 4026, 4387, 4471, 4922, 5876, 6678, 7065 and 7281 by Izotov et al. (1997), and based on the maximum likelihood method we obtain $N_e = 257 \pm 126$cm^{-3}, T_e(He II)$= 14020 \pm 440$K, $\tau(3889) = 1.62 \pm 0.47$, and $Y = 0.2419 \pm 0.0053$. Support for this set of values comes from the N_e[S II] derived by Izotov et al. (1997) that amounts to 120cm^{-3} and N_e [Ar IV] derived by Pérez, González–Delgado & Vilchez (2000) that in the inner parts of NGC 2363 is in the 400 to 800 cm^{-3} range. For this temperature range we obtain O/H$=(9.7 \pm 0.8) \times 10^{-5}$ and adopting $\Delta Y/\Delta O = 3.5 \pm 0.9$ (see Paper I) we find that $Y_p = 0.2378 \pm 0.0056$, in good agreement with our determination based on NGC 346. Table 4 presents the Y and the Y_p for a few representative temperatures, where an ICF(He) of 0.993 was adopted.

5. DISCUSSION

The Y_p value derived by us is significantly smaller than the value derived by Izotov & Thuan (1998) from the Y − O/H linear regression for a sample of 45 BCGs, and by Izotov et al. (1999) from the average for the two most metal deficient galaxies known (I Zw 18 and SBS 0335–052), that amount to 0.2443 ± 0.0015 and 0.2452 ± 0.0015 respectively.

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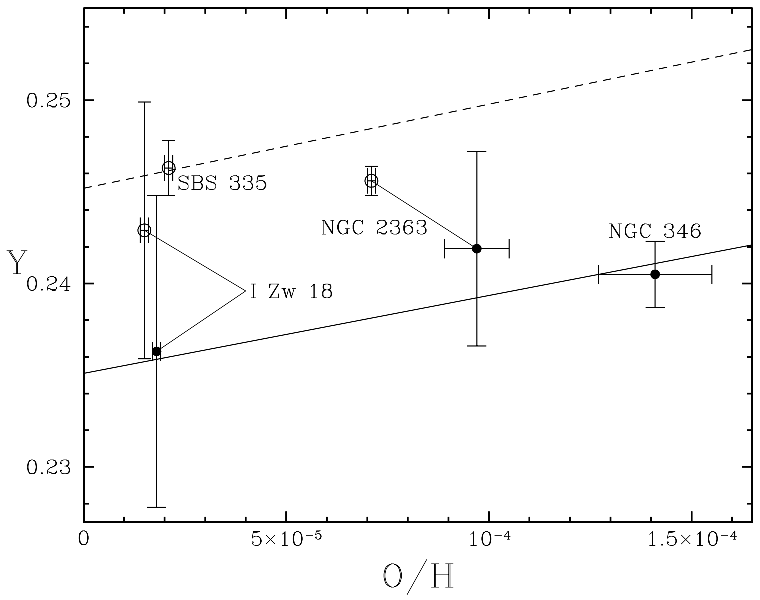

Fig. 1. Y versus O/H diagram. Objects analized by Izotov et al. (1999) and Izotov & Thuan (1998) are shown as empty circles, objects analized in this paper are shown as solid dots.

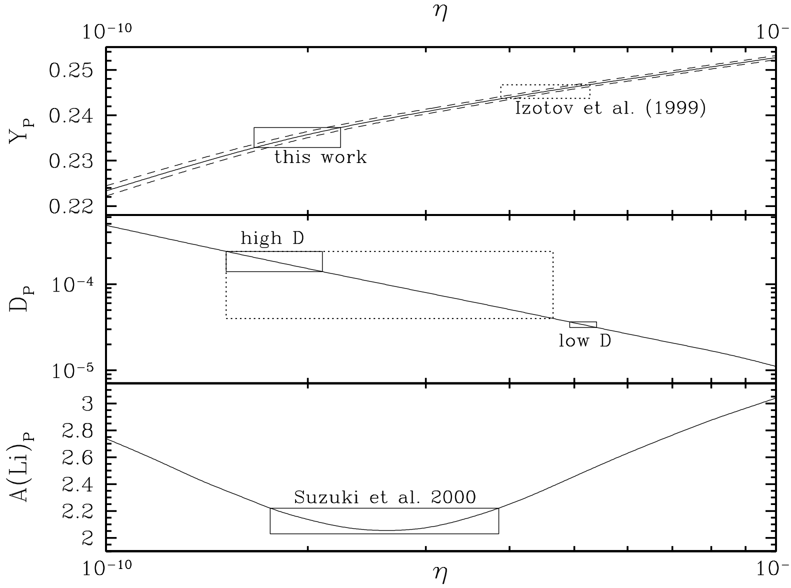

Fig. 2. Different determinations of the baryon to photon ratio η corresponding to the different determinations of helium, deuterium and lithium. The low helium box corresponds to the 1σ determinations from this work, while the high helium box correspond to the 1σ determinations by Izotov et al. (1999). The solid box for high deuterium is the 1σ determination by Ruggers & Hogan (1996), the low deuterium abundance is the 1σ determination from Burles & Tytler (1998), while the dotted line corresponds to the limits obtained from an independent analysis of a “low deuterium object” performed by Songalia, Wampler, & Cowie (1997). The lithium box is the 2σ determination by Suzuki, Yoshii & Beers (2000).

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In Table 5 we compare the Y_p obtained from each of our 3 objects with those obtained from Izotov and his colaborators; Figure 1 shows the Y and O/H values for each of these objects, along with their projection to Y_p and O/H = 0; it should be noted that the values obtained for I Zw 18 and NGC 2363 by both groups are based on the same observations. The difference for the two objects in common is mainly due to our use of a lower temperature for T_e(He II) than that provided by the [O III] lines.

From constant density chemically homogeneous models computed with CLOUDY we estimate that the maximum temperature that should be used to determine the helium abundance should be 5% smaller than T_e(O III). Moreover, if in addition to photoionization there is additional energy injected to the H II region T_e(He II) should be even smaller.

Figure 2 shows the Big Bang nucleosynthesis computations for three light neutrino species (Thomas et al. 1994, Fiorentini et al. 1998), along with different determinations for helium, deuterium and lithium abundances.

6. CONCLUSIONS

From the same data for I Zw 18 and NGC 2363 we obtain smaller Y values than those derived by Izotov, Thuan and collaborators, the differences are small but significant and are mainly due to the lower value of T_e(He II) adopted by us. In the self–consistent solutions the lower T_e(He II) values imply higher densities and consequently lower helium abundances (see Tables 1–4). The Y_p values derived by us from I Zw 18 and NGC 2363 are in good agreement with that derived from NGC 346 in Paper I.

The primordial helium abundance by mass of $0.2351 \pm 0.0022(1\sigma)$ combined with standard Big Bang nucleosynthesis computations (Thomas et al. 1994, Fiorentini et al. 1998) implies that, at the 1σ confidence level, $\Omega_b h^2$ is in the 0.0060 to 0.0081 range. For $h = 0.65$ the Y_p value corresponds to $0.014 < \Omega_b < 0.019$, a value considerably smaller than that derived from the pregalactic deuterium abundance, D_p, determined by Burles & Tytler (1998) that corresponds to $0.041 < \Omega_b < 0.047(1\sigma)$ for $h = 0.65$, but in very good agreement with the low redshift estimate of the global budget of baryons by Fukugita, Hogan, & Peebles (1998) who find $0.015 < \Omega_b < 0.030(1\sigma)$ for $h = 0.65$ and consistent with their minimum to maximum range for redshift $z = 3$ that amounts to $0.012 < \Omega_b < 0.070$ for $h = 0.65$. The discrepancy between Y_p and D_p needs to be sorted out. Further discussion of these issues is presented elsewhere (Peimbert et al. 2001, in preparation).

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