ABUNDANCES OF THE VERY LIGHT ELEMENTS (D, ^{3}He, ^{4}He AND ^{7}LI) AND PRIMORDIAL NUCLEOSYNTHESIS

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ABSTRACT. The determinations of the primordial abundances of D, ^{3}He, ^{4}He and ^{7}Li play a major role in building up models of Big Bang nucleosynthesis. Much progress has been made recently in that respect but there are still large uncertainties on these determinations. Although canonical Big Bang models predicting a cosmological baryonic parameter $\Omega_B \sim 0.10$ consistent with the dynamics of small groups of galaxies and three different families of neutrinos seem to be the most appropriate in accounting for these abundances, the simplest models of galactic evolution lead to discrepant comparisons concerning D and ^{4}He. The relatively small abundance of ^{4}He might challenge the canonical Big Bang models unless specific models of galactic evolution are invoked.

1. INTRODUCTION

As expressed by Dennis Sciama during the first ESO-CERN meeting held in Geneva on november 1983 "Early nucleosynthesis is a triumph for the Big Bang theory". Several recent reviews (Audouze 1984, and 1986 and Boesgaard and Steigman, 1985) present the current comparisons between the determinations of the primordial D, ^{3}He, ^{4}He and ^{7}Li abundances and the predictions of the simplest ("canonical") models of Big Bang nucleosynthesis (such as Yang et al., 1984). These comparisons allow (in principle !) to fix up (i) the number of neutrino (lepton) families ; the accepted value is $N_\nu \sim 3$ consistent with the Grand Unification schemes and (ii) the present baryonic density which seems to be such that the cosmological baryonic parameter Ω_B is ~ 0.10 - i.e. that of a open universe if the amount of non baryonic dark matter is small.

The purpose of this communication is to examine critically the present determinations of the primordial abundances of these very light elements. Although some of these determinations are still uncertain, the comparisons mentioned above may not be as straightforward as it is generally thought. Some of the implications of the apparent discrepancies between the predictions of the models of Big Bang nucleosynthesis and these primordial abundances are quoted in the concluding section.

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2. THE PRESENT DETERMINATIONS OF THE D, ^{3}He, ^{4}He AND ^{7}LI PRIMORDIAL ABUNDANCES

2.1. Deuterium

The deuterium abundance can be estimated in the interstellar medium and in the Solar System. The interstellar D abundance comes from the UV (950 Å) Lyman line analysis (see e.g. Vidal-Madjar et al., 1983 who conclude that $(D/H)_{interstellar} = (1 \pm 0.5\ 10^{-5})$. Concerning the Solar System, D has been observed in the atmosphere of giant planets and in meteoretical and terrestrial deuterated water. But the best determination comes from the analysis of the ^{3}He/^{4}He ratio in the Solar wind (Geiss and Reeves, 1972) since the presolar D has been transformed into ^{3}He inside the Sun. The Solar System D/H ratio is then $(1.5 \pm 0.5)\ 10^{-5}$. Even with these two determinations, the primordial D abundance determination is still quite complex and depends critically on the stellar and galactic evolution processes. Following the analysis of Delbourgo-Salvador et al., (1985), Delbourgo-Salvador, Audouze and Vidal-Madjar (1986) are proposing a test to evaluate the effect of galactic evolution on the D abundance: (i) either there is a large variation of the D abundance between galactic regions with different rates of star formation ; in this case the galactic evolution affects largely the D abundance which means that the primordial D/H can be $> 10^{-4}$ (up to $3\ 10^{-4}$ - table 1). (ii) if such variation is not observed it implies that during the galactic evolution a significant fraction of D is not destroyed (as noticed in the galactic evolution models worked out by Audouze and Tinsley, 1974), the primordial D/H is then $\approx 3\text{-}5\ 10^{-5}$ (table 1).

Element	Primordial Abundance	Solar system Abundance	Interstellar abundance
D	$3\ 10^{-5}$-$3\ 10^{-4}$	$(3\pm1)10^{-5}$	$3\ 10^{-6}$-$2\ 10^{-5}$
^{3}He	$2\ 10^{-5}$-$6\ 10^{-5}$	$(4\pm2)10^{-5}$	$4\ 10^{-5}$-$2\ 10^{-4}$
^{4}He	0.22 - 0.25	0.15-0.24	0.22 - 0.30
^{7}Li	$(6\pm0.3)10^{-10}$	$\sim10^{-8}$	$7\ 10^{-10}$-$2\ 10^{-9}$

TABLE 1.
Abundances (by mass) of the very light element produced by the primordial nucleosynthesis

2.2. Helium 3

Concerning its interstellar abundance, Rood, Bania and Wilson, 1984, have determined the $^3He^+/^4He$ ratio in a few galactic HII regions by observing the 8.7 GHz radio line of $^3He^+$. The corresponding interstellar $^3He/H$ abundance goes from $< 2\ 10^{-5}$ (W49 and M17A determinations) to $5\ 10^{-4}$ (W3). In the Solar System, the ^3He abundance is deduced from the gas rich meteorites and the Solar wind $(^3He/H)_{Solar\ System} \sim (1.4 \pm 0.4)\ 10^{-5}$. From these determinations the range for the $^3He/H$ primordial value is not as large as that for D, $2\ 10^{-5} < ^3He/H < 6\ 10^{-5}$, although the interstellar $^3He/H$ ratio cannot be considered as yet known.

2.3. Helium 4

A lot of ^4He abundance determinations have been performed in various astrophysical sites (blue compact galaxies, old stars, planetary nebulae, HII regions, Solar System ...) and are well compiled in the book of Shaver, Kunth and Kjar (1984). The most often adopted primordial ^4He comes from Kunth and Sargent (1983) who deduced from their analysis of blue compact galaxies $Y_{prim} = 0.245 \pm 0.003$. This value is higher than that deduced previously by Lequeux et al., 1979, analyzing the same type of objects and who found $Y_{prim} = 0.230 \pm 0.004$. Several very recent papers discuss again this important determination[1] and lead us to conclude that the primordial ^4He abundance should be closer from the Lequeux et al. (1979) value than from that of Kunth and Sargent (1983). They are (i) the recent reanalysis by Davidson and Kinman (1985) of I ZW 18 which is the most metal poor blue compact galaxy ; these authors deduce from it $Y_p = 0.23 \pm 0.02$. (ii) the analysis proposed by Vigroux et al. (1986) who showed that if one can deduce $Y_p \sim 0.24$ from the He/H versus O/H correlation in such blue compact galaxies, one may have Y_p as low as 0.20 when one uses the He/H, N/O correlation. (iii) most recently Pagel (1986) has proposed his own analysis of the He/H versus O/H correlation by putting weight on galaxies where ionization correction can be considered as negligible and found $Y_p \sim 0.234 \pm 0.004$. Some of the implications of this possible decrease of Y_p by about 1 % relative to the Kunth and Sargent (1983) value are envisaged in section 3.

2.4 Lithium 7

Spite and Spite (1982) have argued that the Li abundance they observed in F type, population II stars, i.e. $Li/H \sim 10^{-10}$ should be close to its primordial abundance. The Solar System abundance deduced from meteoritical determination is as high as $1.2\ 10^{-9}$ while

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[1] As shown by Yang et al. (1984), an increase of Y_p by 1% corresponds to a correlative increase of the actual number of neutrino families by 1.

the interstellar abundance ranges from 1.5 10^{-10} to 5 10^{-10} (table 1).

3. IMPLICATIONS ON THE BIG BANG NUCLEOSYNTHESIS - COSMOLOGICAL AND PARTICLE PHYSICS ASPECTS

With the exception of ^{4}He for which the primordial abundance seems to be at first glance determined with some accuracy but the uncertainty is still high given its consequence on the number of neutrino families, the primordial abundances of the three other very light nuclear species are quite poorly known. This is due to the difficulty of measuring their abundances in the interstellar medium, the sensitivity of D (and in a less extent of ^{3}He) to stellar and galactic evolution, and for ^{7}Li on our present unability to evaluate its depletion in the atmosphere of population II stars induced by superficial convective motions.

Even with such inaccurate determinations our group has claimed at several occasions (see e.g. Vidal-Madjar and Gry, 1984, Delbourgo-Salvador *et al.*, 1985 and Audouze (1986) that one *cannot deduce the same value of the baryon to photon ratio* referred to as η in the current literature (i.e. the baryoinic cosmological parameter Ω_n) from these different nuclear species *in the absence of important D destruction* during the galaxy life : A Y_p value <0.24 leads to a much lower value for η_p than that predicted from D if $(D/H)_{primordial} < 10^{-4}$. This conclusion is also endorsed by Pagel (1986).

In front of this possibly serious discrepancy, two different conclusions can be drawn up (i) either one requires the primordial D/H to be high enough to be in agreement with the relatively low ^{4}He/H. In this case, it is not necessary to question the simple models of Big Bang nucleosynthesis which bring such exciting constraints on the number of neutrino and the baryonic cosmological parameter Ω_B. However this implies that D is thoroughly processed into stars during the galactic evolution like in the models considered by Delbourgo-Salvador *et al.*, 1985. In this case another consequence is that the predicted Ω_n, $0.004 < \Omega_n < 0.06$ might be lower than that currently favoured by Boesgaard and Steigman, 1985 or Yang *et al.*, 1984, $0.011 < \Omega_N < 0.19$. (ii) The second possibility is to abandon some of the hypotheses implied by the simple models of Big Bang nucleosynthesis. For instance, as shown in different contributions of our group, it is possible to reconcile the primordial abundances of the light elements which are presently available with Big Bang models assuming that the total cosmological parameter Ω is as high as 1. This can be done if one assumes either the existence of massive neutrinos or gravitinos ($m > 500$ MeV, $\tau > 10^5$-10^6 sec) as suggested by Audouze, Lindley and Silk (1985) or that of stable quark nuggets such that their atomic mass is ~10^{17} (Schaeffer, Delbourgo-Salvador and Audouze, 1985) or photinos with mass ~ 10 GeV and lifetime ~10^4 sec (Salati, Delbourgo-Salvador and Audouze, 1985). To sum up the Big Bang nucleosynthesis and therefore the cosmology deduced from it might be significantly more complex and therefore different than the perhaps too optimistic view adopted in the current literature.

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