

International school for advanced studies

MASTER THESIS

THE BIG BANG AND THE LIGHT ELEMENTS

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1.0 INTRODUCTION

In the recent International Astronomical Union meeting (Patras 1982) the soviet physicist Jacob Zel'dovich said that we can regard the Big Bang model to be as well established as celestial mechanics.

Apart this shocking conclusion a variety of facts suggests that the Universe had a hot dense origin:

1. The red shifts of distant galaxies (i.e. the expansion of the universe)
2. The cosmic microwave radiation and its isotropy
3. The cosmic abundances of helium and of the other light elements Deuterium, Helium-3 and Lithium-7
4. The isotropic distribution of galaxies and radio sources
5. The evolution of extragalactic radio sources
6. The ages of galactic and extragalactic objects.

In the present work we will discuss only the point concerning the light elements.

The standard (i.e. the simplest) version of the Big Bang produces a primeval chemical composition for all the four light elements that is in fairly good agreement with the abundances deduced from observations giving the idea that basically the Big Bang model is the correct one.

Moreover the simultaneous fit of the entire tetrad of

elements must be considered a tetrade of arguments in favour of the Big Bang (BB) since their different nuclear properties make difficult to imagine an alternative mechanism or mechanisms to build them in the exact amount.

In the last few years the improved accuracy of the experimental observations has put the light elements again to the attention of cosmologists. New and more precise determinations of Helium-4, Deuterium and of Lithium-7 seems to restrict the "free" parameters that play role in the Big Bang Nucleosynthesis (BBN) or ,according to other authors, to be in conflict with its predictions.

A critical inspection of these last experimental determinations and of their implications on the BBN is the subject of the present work.

CHAPTER 1

BIG BANG NUCLEOSYNTHESIS

The nucleosynthesis processes responsible for the formation of the observed chemical species are:

1. Primordial nucleosynthesis responsible for the bulk of the light elements
2. Spallation processes responsible for the formation of Lithium-6, Berillium-9, Boron-9 and 10 and a fraction of Lithium-7
3. Stellar burning and stellar explosions that create a fraction of Helium and all heavier ($A > 12$) elements

In the following chapter we will review the main points of the BEN.

1.1 THERMAL HISTORY OF THE UNIVERSE

The current model of primordial nucleosynthesis needs specific assumptions:

1. The early universe was homogeneous and isotropic (the Cosmological Principle) that implies that the universe can be described by the Robertson-Walker metric:

$$ds^2 = dt - R^2(t) \left\{ \frac{dr^2}{1-Kr^2} + r^2 d\Omega^2 \right\}$$

2. The early universe is correctly described by Einstein's theory of relativity. The time of the evolution is given by:

$$\frac{\dot{R}^2}{R} = \frac{8}{3} \pi G \rho - \frac{K}{R^2}$$

Energy conservation relates the energy density to the pressure p

$$\frac{d}{dt} (\rho R^3) = -3PR^2$$

The curvature term $K/(R)^{**2}$ becomes important only late in the universe's evolution.

Since K is very high in the early universe we are legitimate to neglect the curvature term so we have directly:

$$\frac{\dot{R}^2}{R} \sim \frac{8}{3}\pi G\rho$$

$$t \sim (G\rho)^{-\frac{1}{2}}$$

From the fact that the early stages of the expansion were dominated by radiation we have:

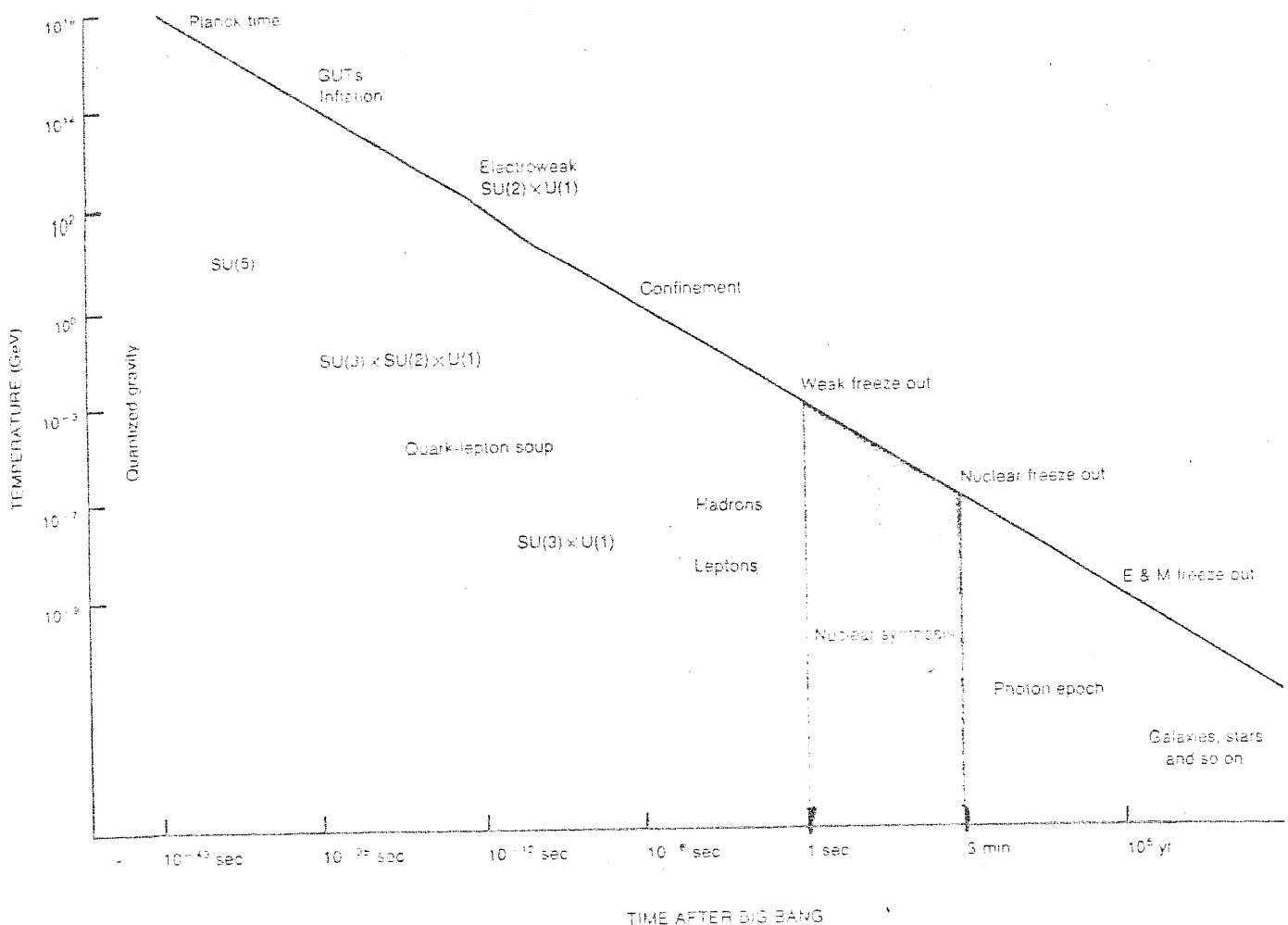
$$\epsilon = eT^4 \quad e = 7.6 \cdot 10^{-15} \text{ erg cm}^{-3} \text{ K}^{-4}$$

are they the
same?

$$\left\{ \begin{array}{l} \rho = \frac{\epsilon}{c^2} \\ \rho = \frac{eT^4}{c^2} \end{array} \right.$$

$$t \sim G\rho^{\frac{1}{2}}$$

$$T(K) \sim 10^{10} / t \text{ sec}$$



Early history of the Universe as predicted by the standard Big Bang model and conventional quantum field theory. Confirming data are expected from experiments using high-energy accelerators to duplicate

the extreme conditions of energy and matter at times in the life of the Universe earlier than 10^5 years, when the Universe finally became transparent.

Fig. 1-1; The "Temperature clock" of the early Universe. The detection of the fossil light elements gives the unique opportunity to "observe" the first three minutes;

that is the "Temperature clock" of the universe. (see fig 1-1)

3. The universe was asymmetric (i.e. prevalence of matter against the antimatter)

4. The ratio of baryons to photons was approximately $\frac{B}{\text{ph}} \sim 10^{-10}$
dex(-10)

It is remarkable that the confirmation of the BBN through the light elements observations must be considered as an indirect confirmation of these assumptions.

1.2 THERMAL EPOCH OF NUCLEOSYNTHESIS

If we wish to fuse light nuclei from primordial protons and neutrons in the Big Bang then it will only be possible in a particular temperature region:

$$5 \cdot 10^8 \text{ K} < T < 5 \cdot 10^{10} \text{ K}$$

that means:

$$4 \cdot 10^{-2} \text{ sec} < t < 5 \cdot 10^2 \text{ sec}$$

Above $5 \text{ dex}(10) \text{ K}$ thermal energies are so high, and energetic particles so abundant, that any light nucleus would be photodissociated as soon as it formed.

Below $5 \text{ dex}(8) \text{ K}$ particle energies are so low that charged

nuclei could not overcome the Coulomb barrier of repulsion.

1.2.1 Initial Neutrons-protons Ratio

The final abundances of light elements are directly determined by this input.

Neutrons and protons become non relativistic after

$$t > 10^{-6} \text{ sec}$$

$$T < 10^{13} \text{ K}$$

after this value they are maintained in numerical equilibrium by the weak interactions:

$$P(e, n) \nu_e$$

$$n (e^+, p) \bar{\nu}_e$$



(i.e. beta decay)

$$n (\nu_e, e^-) p$$

In this situation

$$1 \text{ MeV} < T < 1 \text{ GeV}$$

we have that the neutrons are equal in number to photons:

$$n=p$$

If the rate of interactions is faster than cosmological expansion rate the interaction are in equilibrium

$$\eta_p = \exp(-\Delta M/T)$$

$$\Delta M = M_m - M_p = 1.893 MeV$$

These interactions will only maintain equilibrium whilst the expansion time:

$$t_{exp} \sim 10^{10} \left(\frac{k}{T}\right)^2 ne$$

exceeds the weak interaction time:

$$t_{weak} \sim 10^{10} \left(\frac{k}{T}\right)^5 ne$$

that is until T falls to about =ldex(10) K

$$T >> 10^{10} K \quad t_{weak} \ll t_{exp}$$

$$T << 10^{10} K \quad t_{weak} \gg t_{exp}$$

When T falls to $\sim 10^4$ K the ratio between neutrons and protons is fixed.

The equilibrium imposed by the weak interactions will cease at a temperature T_f defined by:

$$t_{weak}(T_f) = t_{exp}(T_f)$$

and the resulting n/p is:

$$\frac{n}{p} = \exp\left(-\frac{\Delta H}{T_f}\right)$$

As T falls to 0 (K) it becomes more likely that the less massive proton is produced and the n/p ratio becomes less than 1. The weak interaction rates "freeze out" at $T=1$ Mev and the n/p ratio becomes relatively fixed at

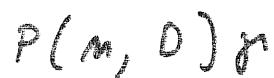
$$\frac{n}{p} \approx \frac{1}{6}$$

$T \sim T_f$ at $t_f \sim 1$ sec

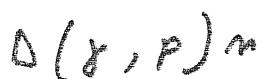
Then thereafter free-neutron decay will occur between $T \sim 1$ Mev, when the weak interactions "freeze out", and $T \sim 0.1$ Mev when the nucleosynthesis begins as we will show soon. The net result of this neutron decay is to make the

$$\frac{n}{p} \approx \frac{1}{7}$$

The first, and slowest, nuclear reaction is the capture



which is unable to build up a Deuterium abundance until T falls to $Dex(9)$ K because until then the photodissociation

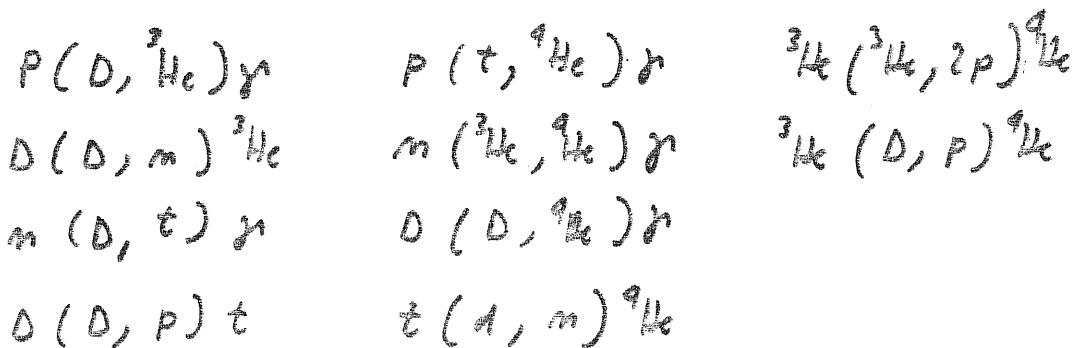


is equally rapid. The rate of the dissociation reaction is connected to the density of gammas. Nucleosynthesis is prevented until the photodissociation reaction becomes small compared with reaction that builds Deuterium. This depends on the factor

$$\tilde{\epsilon}' \propto p(-\Delta n/\tau_i)$$

When this is 0(1) (i.e. at $T_i \sim 0.1$ Mev) nucleosynthesis can begin.

After Deuterium is produced by this p-n capture it can be built-up into heavier nuclei via a chain of reactions:



Primordial nucleosynthesis is different from stellar nucleosynthesis since in primordial nucleosynthesis there is a high quantity of neutrons and the matter density is extremely low:

$$\rho < 10^{-6} \text{ g/cm}^3$$

at $t \sim 1 \text{ sec.}$

In this conditions the nuclear statistical equilibrium between D and He-4 is completely in favour of He-4.

The freeze out of the nuclear reactions is determined by the number and masses of neutrinos.

The baryon density is parametrized by h :

$$h \equiv \frac{\rho}{T_9^3}$$

where the ρ is the baryon density in g/cm^{3*3} and T_9 is the temperature in units of $\text{dex}(9) \text{ K}$.

If $h(\text{NS}) > 2 \text{ dex}(-6)$

the baryon density will be large enough at nucleosynthesis so that almost all the neutrons are processed into He-4. In this case the unique effect on the He-4 abundance of the increased expansion rate due to the additional neutrinos is to increase the n/p ratio which leads to more He-4.

If $h(\text{NS}) < 2 \text{ dex}(-6)$

the nucleon density at nucleosynthesis is too low to process all the neutrons into He-4 and any increase in the expansion rate due to neutrinos results in less He-4 but more D.

Because there is no stable nucleus at A=5 the bulk of the universe ends up in H and He-4 with small amounts of D, He-3 and traces of heavier elements like Lithium-7.

There are some further reactions



etc.

But again there are no stable nuclei with A=8 so apart from very small amounts of Li-6 and Li-7 no other elements are produced in BBN.

The full network of nuclear reactions can be integrated numerically (Hoyle and Tayler 1964, Peebles 1966, Wagoner Fowler and Hoyle 1967, Wagoner 1974) and the time-development is shown in fig. 1-2.

The synthesis process is a very short event. It starts when $T \sim 3 \text{ dex}(9)$ and ends when $T \sim 1 \text{ dex}(9)$.

The neutron fraction drops dramatically being all incorporated into He-4 while Deuterium and Tritium fractions peak before dropping slightly as also these nuclei are incorporated into He-4.

The abundances are fixed at $T \sim 0.3 \text{ dex}(9) \text{ K}$ except for the neutrons which continues to decay.

Since $(n/p)f \sim 0.2$ and virtually all the neutrons end up in Helium we will have $\text{He-4/H} \sim 0.1$, or an Helium-4 mass fraction of $\sim 25\%$

The nuclear reaction rates depend on the baryon density at the time of nucleosynthesis and hence ,via the expansion of the universe, on the present baryon density. This is shown in fig 1-3.

As we can see the He-4 abundance is relatively insensitive to the matter density. This is because the Helium abundance is determined principally by the n/p ratio at T_f , which depends very sensitively on T_f , and T_f is determined by the cosmological expansion rate.

At the time of nucleosynthesis the total density is dominated by radiation and so the matter density does not play role in the final amount of He-4.

On the contrary the other light elements are very sensitive to the matter density.

This leads to a fundamental distinction between He-4 and the others light elements.

As the baryon density increases more Deuterium and Helium-3 ends as Helium-4 so their abundance drops while the Helium-4 abundance slightly increases. The case of Li-7 is unique

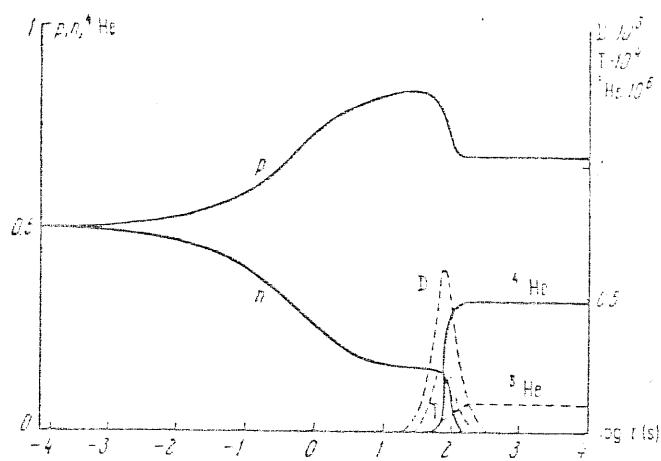


FIG. 33 --Evolution of the abundances of protons (p), neutrons (n), deuterium (D), helium-4 (${}^4\text{He}$), helium-3 (${}^3\text{He}$), and tritium (T) in the hot model as a consequence of nuclear reactions. The vertical scale on the left applies only to p , n , and ${}^4\text{He}$; that on the right only to D , T , and ${}^3\text{He}$.

Fig 4-2 ; From Wagoner 1973

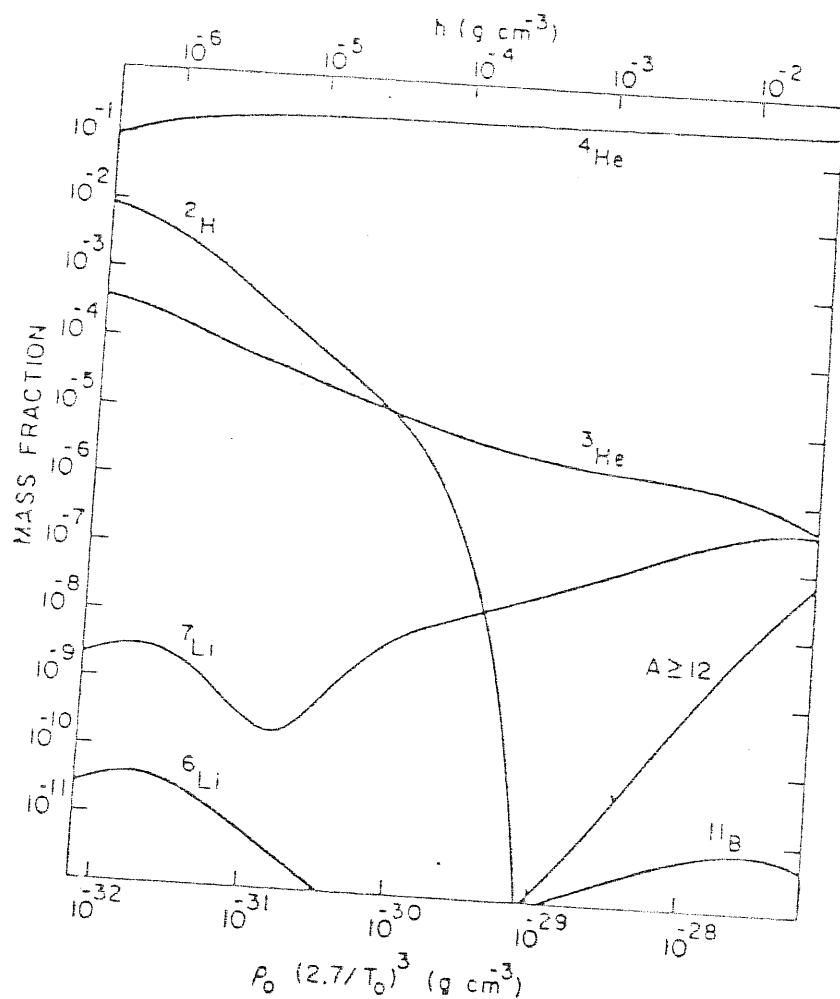


FIG. 5. Abundances of the light elements at the end of the primordial nucleosynthesis plotted by Wagoner (1973) against the present density of the universe (in the context of the canonical Big Bang model). From this very well known diagram one can see that the calculated abundances are quite in agreement with the observations for $\rho_{\text{univ}} \approx 3 \cdot 10^{-31} \text{ g cm}^{-3}$ corresponding to an open universe (cosmological parameter $\Omega = 0.04$).

Fig. 1-3. From Wagoner 1973

and need particular attention; it has an especial behaviour with the baryon density as it is possible to see in the figure 1-4.a and b

1.2.2 Light Elements As A Test For Cosmological Models

In the alternative models to the BBN of Carr AA 61,705, MN 181,293 AA 98,57 there is an under or over production of the light elements. If it is possible to show that they are not created or destroyed by evolutionary processes in the galaxy they represent a severe obstacle to the alternative cosmologies.

On the contrary they are one of the most powerfull arguments in favour of the BBN and indirectly they give a number of confirmations:

1. The Universe had a hot past
2. The universe was asymmetric
3. General Relativity gives a satisfactory description of the expansion of the early universe.

Other finer informations will be extrapolated in chapter 3.

1.3 "PARAMETERS" OF THE BBN

In the standard model of primordial nucleosynthesis which we have briefly described above, the mass fraction of He-4 produced depends upon some critical parameters that cannot be exactly known

1. The neutron half life $\tau_{1/2}$ (α_4)
2. The baryon to photon ratio : η
3. The number of the two-component neutrino species (i.e. the expansion factor)
4. The actual knowledge of nuclear reaction rates

Let's discuss such dependences deeply:

1.3.1 The Neutron Half-life

It determines the rate for the nuclear reactions which hold the equilibrium between neutrons and protons.

$$n(e^+, p) \nu_e$$



$$n(\nu_e, p) e^-$$

If the neutron half-life increases then t_{wk} , the time of the weak interactions, decreases and so the weak interactions "freeze out" earlier, i.e. at higher temperatures.

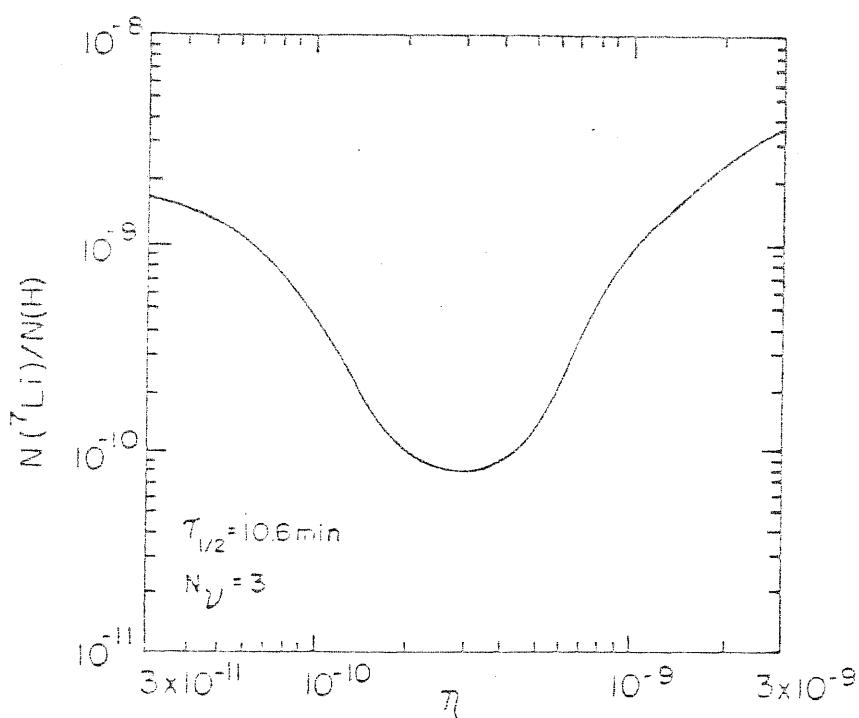


FIGURE 2. The primordial abundance (by number) of ^7Li in the standard model as a function of the nucleon abundance.

Fig. 1-4 a). From Steigman 1983

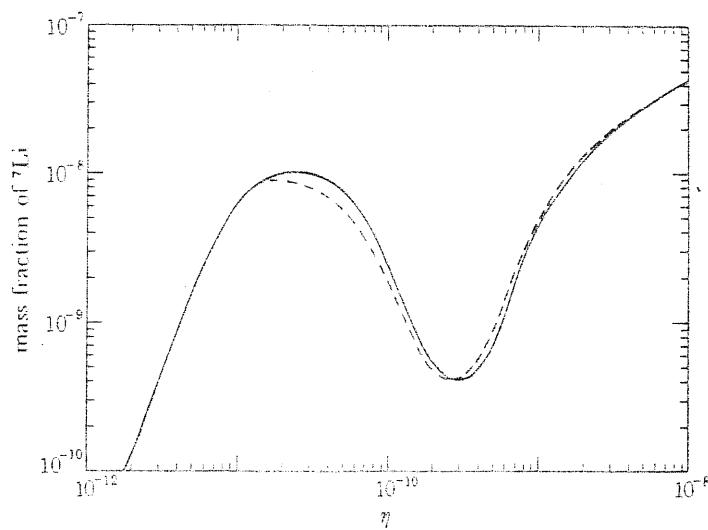


FIGURE 1. The mass fraction of ^7Li plotted against η for two and three neutrino species (from Yang *et al.* 1982).

Fig. 1-4 b). From Schramm 1982

Since higher T_f means more neutrons that for the discussion of the previous paragraph means more Helium-4.

LONGER NEUTRON HALF-LIFE MORE HELIUM-4

1.3.2 Baryons/photons Ratio (η)

We have seen that the first reaction that takes place is the $p(n,D)\gamma$, but this reaction cannot build D at the beginning since it is destroyed by photodissociation that depends on the density of photons. We have seen that BBN is prevented until the photodissociation becomes negligible compared to the Deuterium synthesis, i.e. when

$$\eta^{-1} \exp(-\Delta H/T_c) \sim 0(1)$$

If we have more photons this condition is fulfilled at higher T_i . This means that the Deuterium "bottle-neck" breaks earlier and the BBN can starts at higher temperatures.

The net result is that the fraction of time in which betha decay can works is reduced and so more neutrons are available when BBN begins.

Anyway the dependence of He-4 from eta is rather weak.

HIGHER ETA - MORE HELIUM-4

1.3.3 The Number Of Leptons (i.e. The Expansion Parameter ξ)

Changing the expansion rates affects the time when the weak interactions and the nuclear reaction freeze out.

Wagoner (1973) had shown clearly the effects of changes in the speed of the expansion in the products of BBN. Fig 5 e 6.

Yang et al (1979) have proposed the following relation:

$$X(\text{He}) \approx 0.33 + 0.02 k + 0.38 \log \xi$$

From figure 5 is possible to see that changes in ξ not affect significantly (i.e. less than one order of magnitude) the outputs of D, He-3 and Li-7, while fig 6 show that He-4 is very sensitive:

$$\text{for } P \sim 10^{-31} \text{ g/cm}^3$$

$$\xi = k \quad Y_p \sim 0.1$$

$$\xi = 1 \quad Y_p \sim 0.2$$

$$\xi = t \quad Y_p \sim 0.35$$

The authors have discussed several ways by which the parameter ξ can be affected:

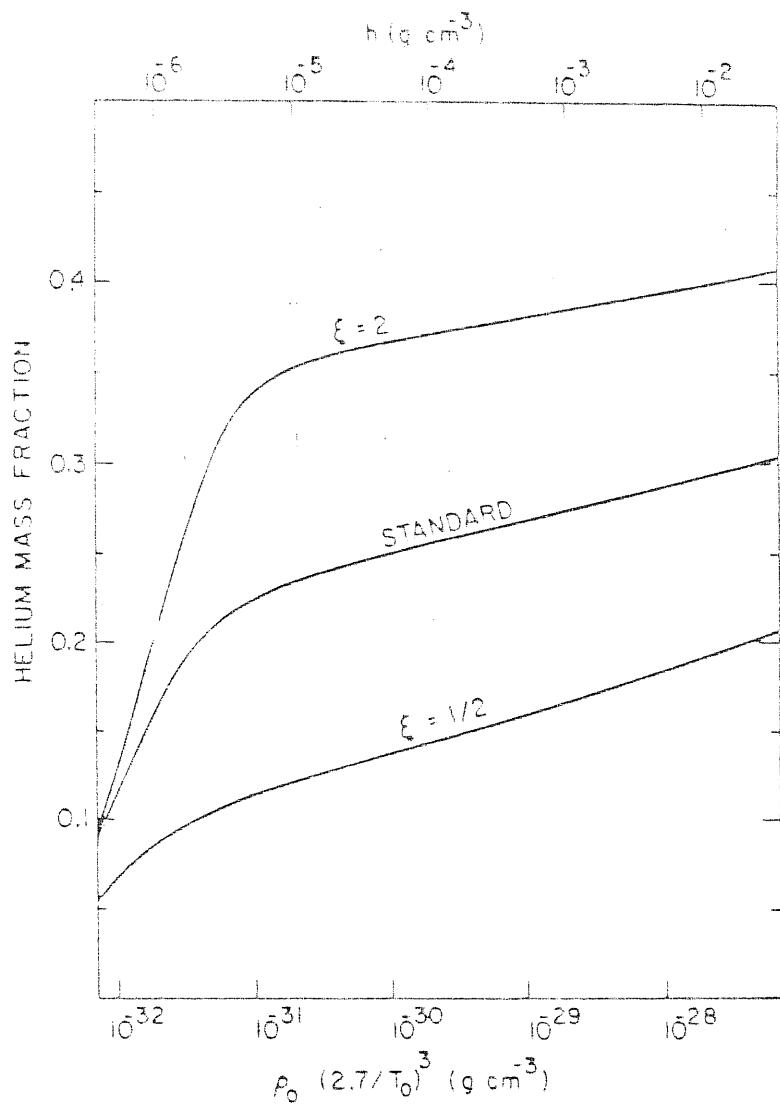


Fig. 6b. Enlargement of Figure 6a to show the dependence of Y with E (from Wagoner 1973).

Fig. 1-5. From Wagoner 1973

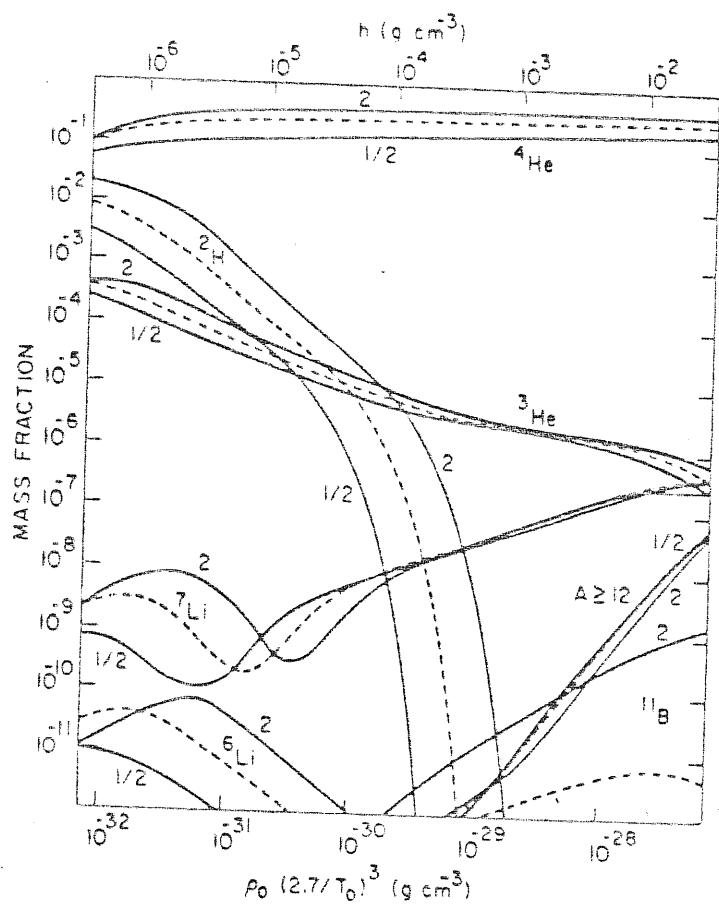


FIG. 6a. Final abundances of the light elements with respect to the present density of the universe calculated in the frame of the canonical Big Bang by Wagoner (1973) for different values of the parameter ξ governing the speed of the expansion: $\xi = 2$ (rapid expansion); $\xi = 1$ (dashed lines, free fall expansion) and $\xi = 0.5$ (slow expansion).

Fig. 1-6. From Wagoner 1973

1. A change of gravity (not likely).

2. A departure from homogeneity and isotropy. When the matter density is larger the expansion increase to up the He-4 abundance (this will be discussed in chapter 4)

3. the existence of new Lepton families.

The number of leptons affects the energy density of the universe and, therefore the expansion rate. The energy density depends on the number of relativistic particles species present

$$\begin{aligned} \rho &= \rho_r + \rho_e + \sum_i \rho_{N_i} \\ &= \frac{\pi^2}{15} T^4 + \frac{1}{g} \frac{\pi^2}{15} N_\nu T^4 + \frac{1}{4} \frac{\pi^2}{15} T^4 \\ &= \frac{\pi^2 T^4}{15} \left(1 + \frac{1}{g} + \frac{1}{4} N_\nu \right) \end{aligned}$$

increasing N_ν , the energy density increases and hence the expansion rate so T_f , i.e. the temperature at which $t_{(wk)} = t_{(exp)}$, is higher, but if the weak interactions "freeze out" at higher temperatures we have more neutrons and ultimately more Helium-4

MORE N_ν - MORE HELIUM-4

1.3.3.1 Massive Neutrinos - Recently several suggestions has been made that neutrinos might have a small but finite rest mass. As long as neutrino species is relativistic during the epoch of nucleosynthesis ($M_\nu < 1$ Mev) it will contribute to the energy density and affect the BBN just as a MASSLESS specie.

The electronic neutrino and the muonic neutrino both satisfy this conditions ,however the properties of the tau neutrino are not well known and is possible that its mass is as large as 250 Mev.

If other neutrinos exist they can be light (< 0.1 Mev) or massive (> 0.1 Mev).

Both an heavy neutrino and a massless neutrino increase the expansion rate of the universe by increasing the energy density. However the time dependence of the energy density for an heavy neutrino is different from that of a light neutrino:

$$\rho(M < a_1 M_w) \sim T^4$$

$$\rho(M > a_1 M_w) \sim m T^3 Y$$

where $Y = \text{number density neutrinos}/\text{number density photons}$

for $M \sim 1$ Mev, $Y \sim 1$

for $M > 5$ Mev, γ decrease exponentially with the mass.

Therefore in general the energy density increase for neutrinos with $m < 5$ Mev and decrease for neutrinos with $m > 5$ Mev. The effects of massive neutrinos on BBN will be treated in chapter 3.

1.3.3.2 Cross Sections - According to Wagoner 1969 the numerical errors associated with the integration scheme in the code and the uncertainties in the nuclear reaction rates for Helium-4 are

$$< 0.004$$

So in practice this source of uncertainty can be neglected for Helium-4

In summary Helium-4 increase with the increasing of the neutron half-life ,the number of leptons and weakly with eta.

Knowledge of any three of these quantities constrains the fourth. With this philosophy primordial nucleosynthesis can be used to derive (or constrain) cosmological and particle physics quantities. This will be the subject of one of the next chapters.

For what concerns the other light elements the only dependence is from eta as we have already discussed. The uncertainties in the reactions rates has been discussed by Schramm 1982. For D and He-3 they are $< 10\%$ but for Li-7 they

can reach a factor 2 or 3.

1.4 ESTIMATES OF THE " FREE PARAMETERS "

1.4.1 The Life-time Of The Neutron

10.61 ± 0.16 Christensen et al 1972

10.13 ± 0.09 Bondarenko et al 1978

$10.62 (> 10.5 \pm 0.8)$ Kugler et al 1978

10.82 ± 0.20 Byrne et al 1980

The value 10.6 min is the more likely at least because it had more recontres than others values.

We stress that the uncertainty in this quantity is of the order of the time of the primordial nucleosynthesis so the effects are not at all negligible.

1.4.2 The Baryon To Photon Ratio

The number of baryons has remained constant since nucleosynthesis because the baryon number is conserved for low energies $< \text{dex}(14)$ GeV, while the number of photons increased because electron positron annihilation at a temperature of $\sim 3 \text{ dex}(9)$ so that

$$\eta = \frac{m_b}{m_p} \quad m_b = \rho_b h_0^2 = \frac{\Omega_b \rho_c}{m_b} = 1.13 \cdot 10^{-5} \Omega_b h_0^2 \text{ cm}^{-3}$$

$$m_p = 400 \left(\frac{T_0}{T_f} \right)^3 \text{ cm}^{-3}$$

$$\eta = 2.81 \cdot 10^{-8} \Omega_b h_0^2 \left(\frac{T_0}{T_f} \right)^3$$

$$\Omega_b = 3.53 \cdot 10^7 \eta h_0^{-2} \left(\frac{T_0}{T_f} \right)^3 \quad \rho_b = 6.69 \cdot 10^{-11} \text{ cm}^{-3} \eta \left(\frac{T_0}{T_f} \right)^3$$

so its value depends from the baryonic density, the Hubble constant and the temperature of the Background Radiation
 The temperature of the Background Radiation ranges between

$$2.2 < T_b < 3 \text{ } ^\circ\text{K}$$

$$\ln \quad T < 3^\circ\text{K}$$

$$\Omega_b < 4.84 \cdot 10^2 \eta \text{ h}^{-2}$$

The present knowledge of the Hubble constant is between:
 $50 < H_0 < 100 \text{ km sec}^{-1} \text{ Mpc}^{-1}$ $h_0 = \frac{H_0}{100}$

h_0 is the "ignorance factor"

Using $h_0 > 1/2$ we obtain for the baryon density

$$\Omega_b \leq 1.94 \cdot 10^8 \eta^8$$

Estimates of the baryon density:

$$\langle \rho \rangle = \langle n/L \rangle L$$

$$\langle M/L \rangle_c = \frac{\rho_c}{L}$$

$$\Omega = \frac{H/L}{(M/L)_c}$$

The observed mass to light ratios on various scales with the critical value are: (from Olive et al 1981)

Solar neighborhood $\Omega \sim 0.0014/h_0$

Galaxies $\Omega \sim 0.006$

Binaries and small groups $\Omega \sim 0.04$

clusters $\Omega \sim 0.2 \div 0.7$

Hot gas in clusters $\Omega \geq 0.03 h^{-2}$

It is important to discuss whether or not the mass density of the universe is dominated by nucleons. If neutrinos or other non-baryonic matter play some contribution it becomes very difficult to estimate the contribution of only nucleons.

The solar neighborhood is probably dominated by nucleons so

$$h_{S.N.}^{10} > 0.14$$

The inner parts of galaxies are also probably dominated by nucleons

$$h_{I.G.}^{10} > 0.29$$

Finally the hot gas in rich clusters X ray emitting is surely nucleons but the amount of gas is rather uncertain in this case

$$h_{H_2}^{10} > 1$$

So the data may be summarized as

$$\eta^{10} > 0.1$$

In chapter 3 we shall see as the BBN can be used to derive a value for eta.

CHAPTER 2

PRESENT KNOWLEDGE OF THE LIGHT ELEMENTS

In the present chapter we will consider the new observational results that have motivated the present reinvestigation of the BBN

2.1 HELIUM-4

Since Helium-4 is produced during stellar and galactic evolution, the abundance derived from objects at the present epoch is an upper limit to the primordial abundance (Y_p).

There are many methods to infer the He-4 value:

1. Absorption lines in hot stars
2. Emission lines in gaseous nebulae
3. Mass luminosity relation
4. Pulsation characteristics
5. Location of the zero-age or evolved main sequence in the Luminosity-Effective Temperature plane

6. Globular clusters, i.e. stellar evolution, position of horizontal -branch, relative numbers of red giants and horizontal-branch stars
7. others

Generally the abundance of Helium-4, by mass, in objects not greatly affected by internal nuclear processing, is found to be in the range

$$0.2 < Y < 0.3$$

which is within the range predicted by the standard BBN (Schramm and Wagoner 1977)

There is no evidence of objects with $Y < 0.20$. The few exceptions can have other explanations than the BB and so are not important from the cosmological point of view. (Pagel 1982)

Here we report a table²⁻⁴ that summarize all the results taken from V. Madjar and C. Gry (1983).

As is possible to deduce from the table 24 the determinations give:

$$Y_p < 0.27$$

that is encouraging in the sense that is in the range predicted by the BBN but not useful to put constrains to the theory itself.

The only hope to set limits on Y more accurate than ± 0.02 is provided by observations of hydrogen and Helium

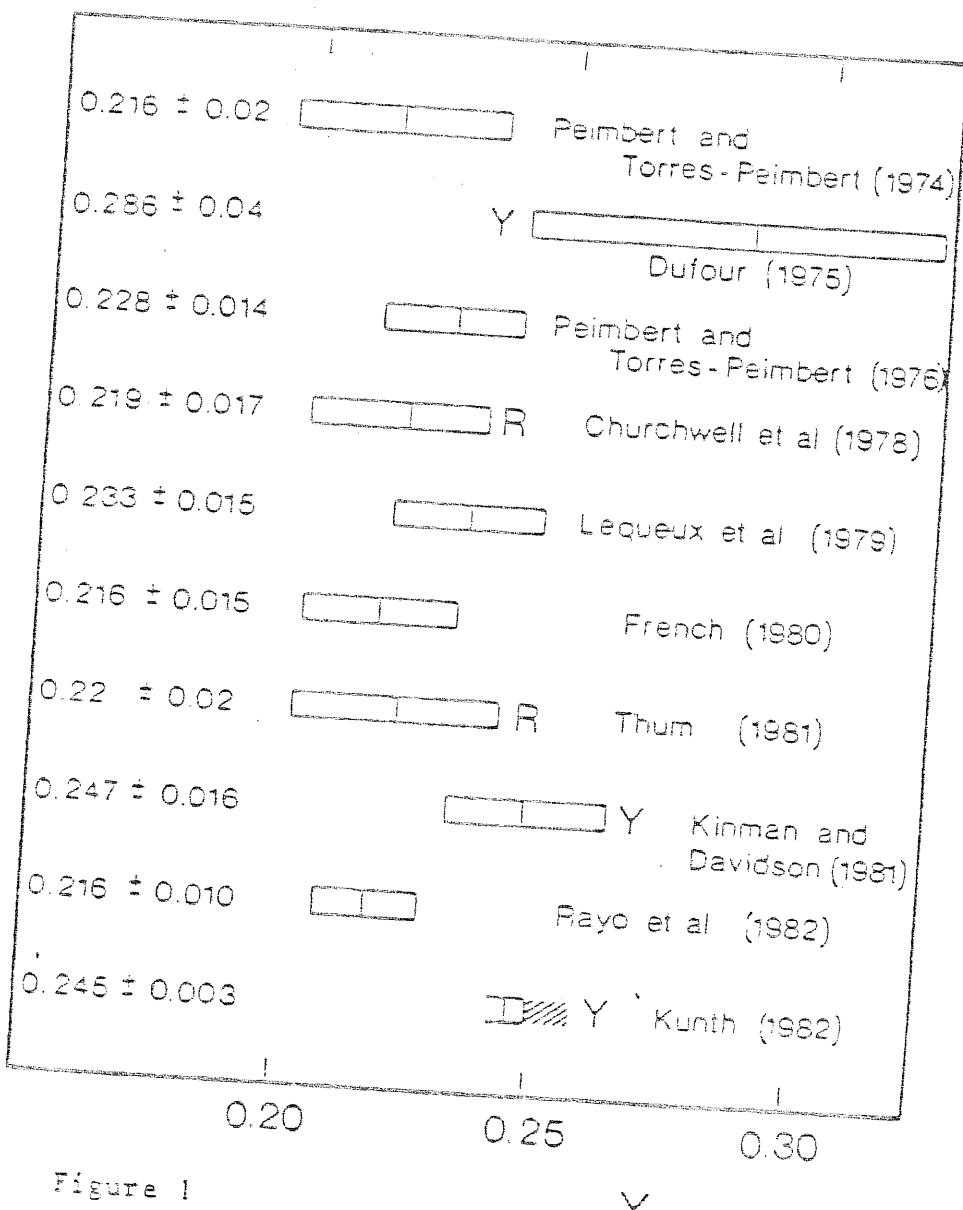


Figure 1

Table 2-1. From Vidal Madjar and C. Gry 1983

recombination lines in H II regions, i.e. clouds of interstellar material ionized by UV radiation from one or more stars newly formed from the same cloud.

If we assume that massive stars synthetize both Helium and heavy metals and supply them to the interstellar medium a simple model of galactic chemical evolution leads one to expect a linear relation between helium and metals of the type:

$$Y = Z(dY/dZ)$$

so

$$Y = Y_p + Z(dY/dZ)$$

Where Y_p is the primordial Helium mass fraction. Collecting evaluations of Y made in H II regions presenting very different metallicities (i.e. very different evolution stages) is possible to look for a linear correlation and so estimate Y_p by the extrapolation of Y toward zero Z values.

In some cases a clear correlation between Y and Z could be found and subsequently a value for Y_p .

With this method are derived the Y_p given in the table with the exception of those of Kunth (1982).

2.1.1 The "Lazy" Galaxies

These are blue dwarf galaxies showing H II metal deficient spectra (H II galaxies). The current thinking is that they are galaxies in which star formation is just started. If this is the case they represent good candidates for the detection of the primordial Helium.

Kunth and Sargent (1983) from the analysis of 12 of them have found no correlation between Helium and the metals represented by the O/H ratio. They therefore suggest that the mean value:

$$Y_p = 0.245 \pm 0.003$$

can be the best estimate of the primordial Helium.

It is remarkable that they show that the previous works quoting lower values of Y_p do not stand up to critical analysis of the error sources.

Terlevich and collaborators (1983) from the preliminary analysis of hundreds of these objects confirm the results of Kunth.

2.1.2 Helium In Jupiter

The determination of the He-4 abundance in the Jupiter's atmosphere has been made possible by the Voyager. Gautier et al (1983) have derived a value of:

$$Y = 0.19 \pm 0.05$$

The critical point is to establish whether or not the Helium in the Jupiter atmosphere is representative of the composition of the primitive nebula.

For instance the Helium derived in Saturn with the same equipment is of $Y \approx 0.13$ that clearly indicates that some differentiation between Helium and Hydrogen have been occurred in the history of the planet. According to the authors such a phenomenon have not worked in Jupiter.

In summary no definitive conclusion can be drawn on the "true" Y_p . Perhaps the more logical thing is to assume as a firm upper limit 0.25 but keeping in mind the possibility that the primordial Helium could be lower.

2.2 DEUTERIUM

2.2.1 Deuterium In The Universe: The Scatter Problem

The Deuterium abundance has been extensively studied during the 70's mainly by means of the Copernicus satellite and using the atomic absorption features corresponding to the Lyman lines. The results are reported in the table taken from V. Madjar et al 1983.(for references see this paper)

The evaluation of the deuterium abundance presents a scatter of 1 order of magnitude significantly higher than the 30% of the precision of the measure itself, so the scatter seems to be real.

Of course a consequence of a cosmological deuterium formation is a CONSTANT D/H ratio everywhere in the galaxy

except where the deuterium has been non uniformly astrated or depleted in molecular grains. The scatter must be explained in someway otherwise it can be considered a prove against the primordial origin of the D.

The canonical explanation of the scatter is a SEGREGATING MECHANISM in interstellar clouds. The result of such a interpretation is that the upper value of the scatter is significative.

$$D/H = 2.25 \text{ dex}(-5)$$

A new and recent interpretation has been suggested by Vidal Madjar et al. 1983. Having noticed hourly variations in the deuterium line of Epsilon Persei that cannot have an interstellar origin they suggest that the scatter can be the result of a contamination of the line by stellar wind. A correlation between the Luminosity class (strength of the wind) and the deuterium abundance supports their suggestion.

The effect of such an interpretation is that the lower value of the scatter is the significative:

$$D/H = 5(\pm 3) \text{ dex}(-6)$$

Cesarsky et al 1973 detected the 92 cm. hyperfine transition toward the galactic center and showed that:

$$3 \cdot 10^{-5} < D/H < 5 \cdot 10^{-5}$$

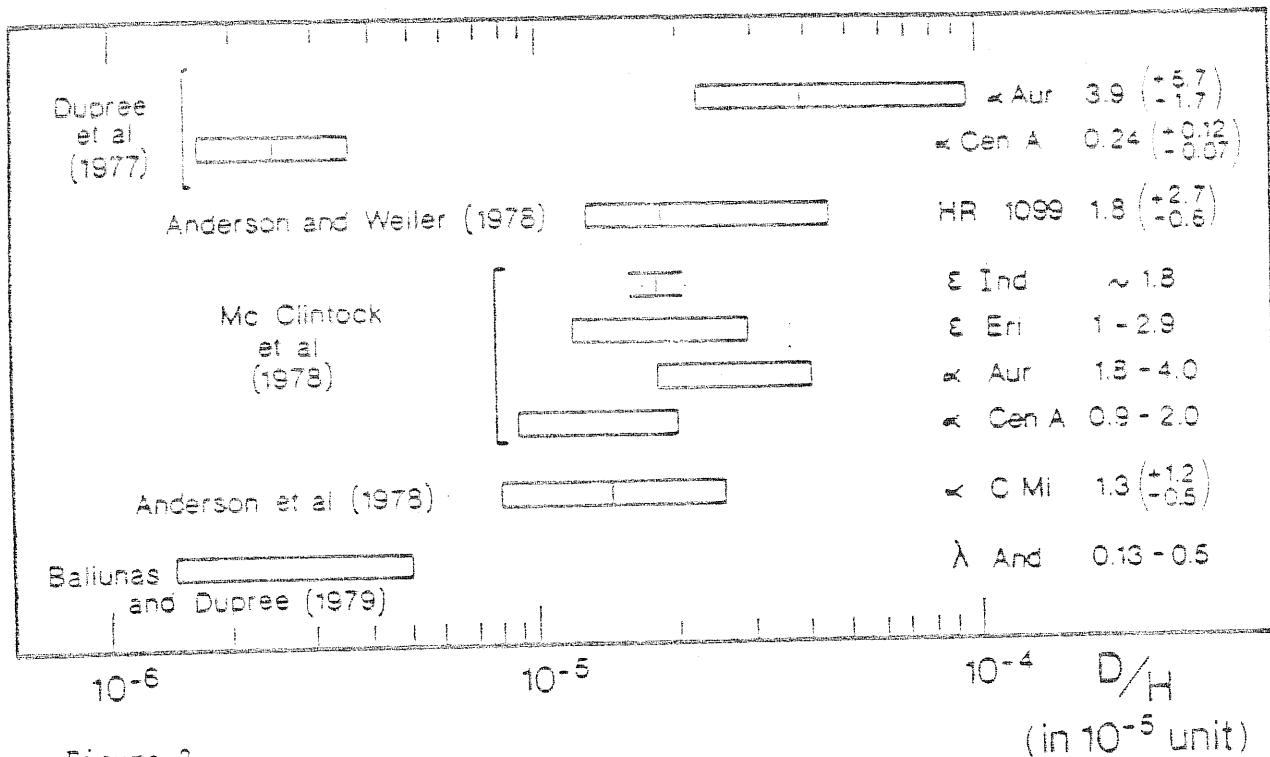


Figure 2

Using only H

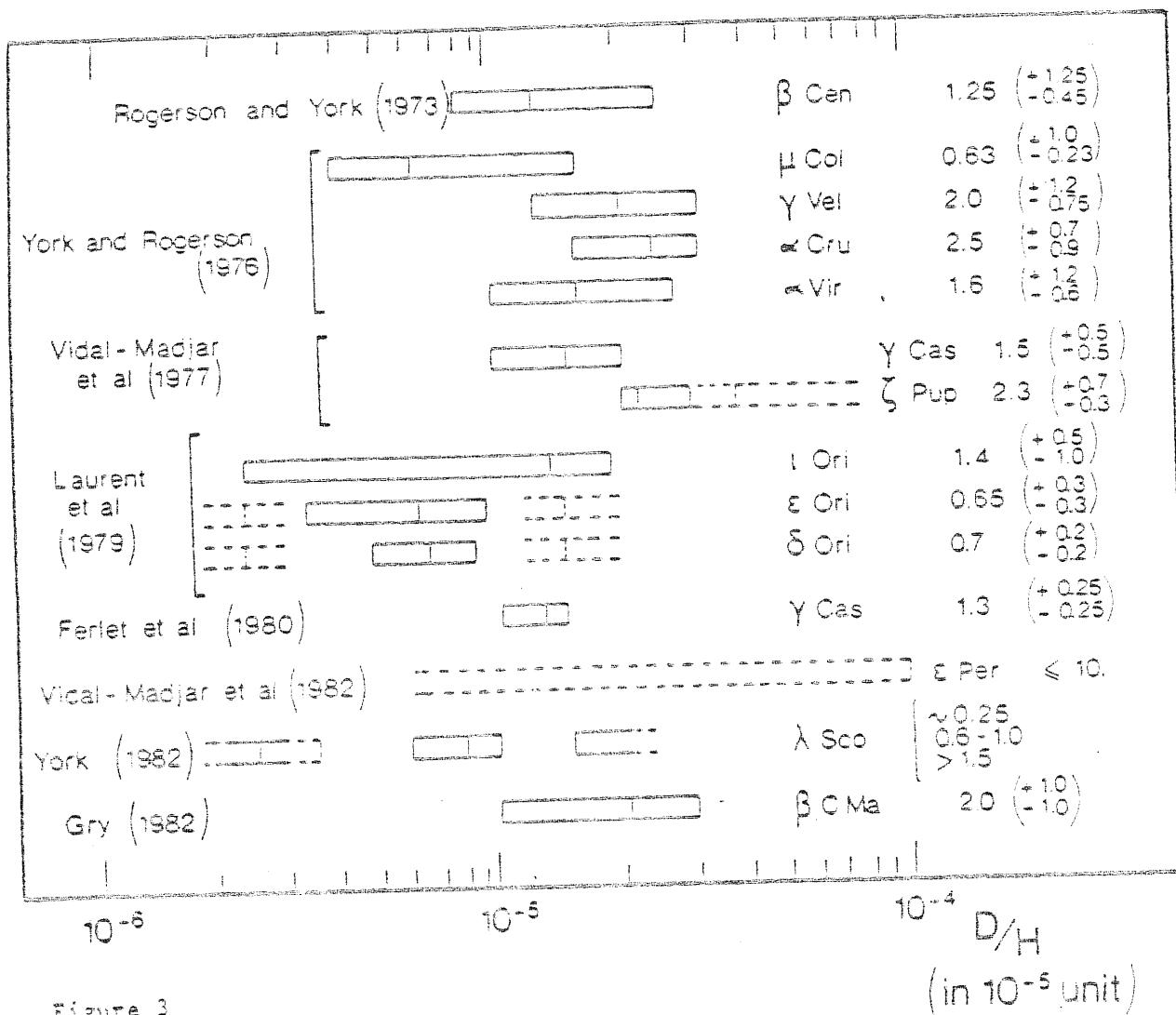


Figure 3

Table 2-2. Deuterium determinations using all the Lyman lines

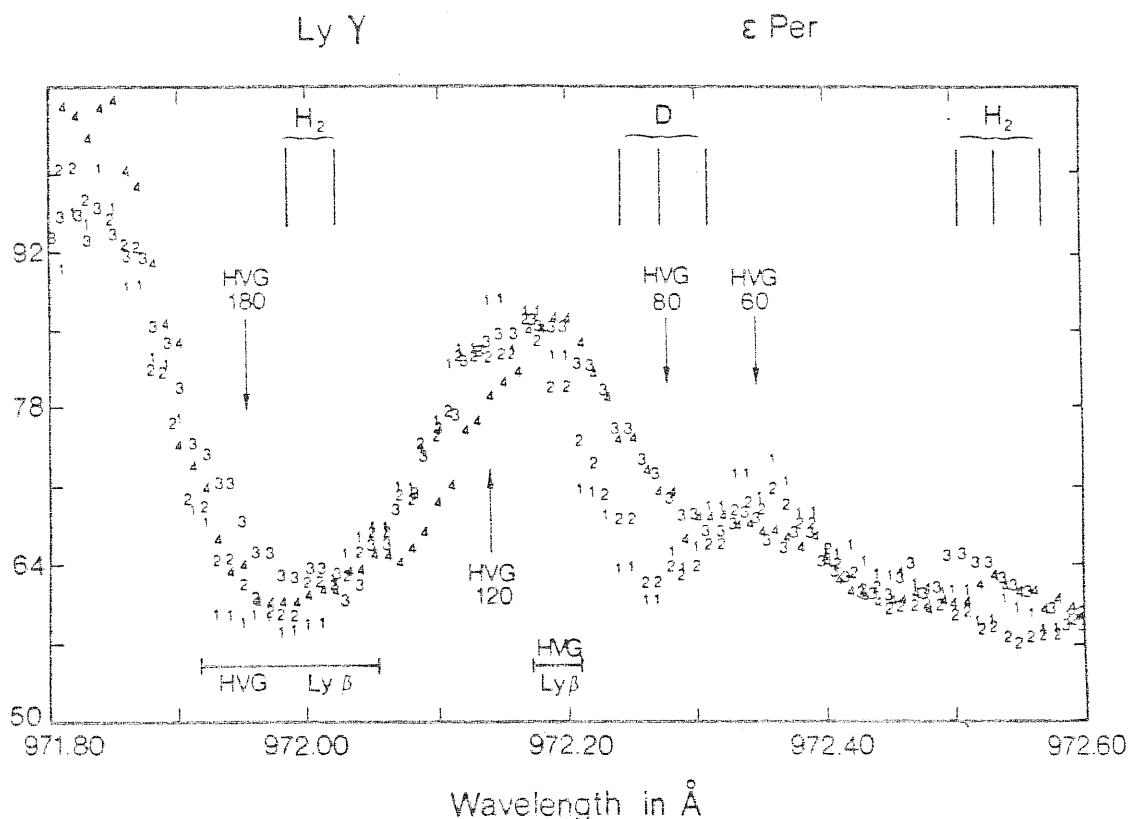


Fig. 3. Lyman γ profile of ϵ Persei. Same as Fig. 2a but the observations are separated in 4 sets (marked 1, 2, 3, 4), the mean time interval between two successive sets is 4 h. Note that a time variation is now also evident at -60 km s^{-1} , as in the Lyman δ profile (see Fig. 2)

Fig. 2-1. From C. Gry et al. 1983

2.2.1.1 Deuterium In The Solar System -

1. Jupiter:

Beer and Taylor 1973:

$$D/H = 6.5 (\pm 3) \text{dex}(-5)$$

Gautier 1983:

$$D/H = 3.6 (+1.0, -1.4) \text{dex}(-5)$$

2. D in the Ocean and Meteorites

Boato 1954:

$$D/H = 1.6 \text{ dex}(-4)$$

It has been noted (Reeves 1973) that this is a very high value difficult to reconcile with the low He-3/He-4 value and with the other D determinations.

2.2.2 Deuterium And Chemical Evolution Of The Galaxy

Since it is not possible to observe less evolved regions as in the case of Helium the evaluation of the primordial Deuterium is not straightforward but needs the understanding of the evolution of the element during the

galaxy life.

It is commonly admitted that D is completely destroyed when processed in any kind of stars.

Even in extreme forms, current models, for nuclear burning of Deuterium in stars predict a primordial abundance for D which should not exceed 5 times the value found in the interstellar medium.

So if we try to fit the solar-system value with the i.s. value we fall in contradiction if we choose the lower value for the i.s. D.

It is impossible to match within a standard model of galactic evolution the two abundances observed. This should mean that the lower i.s. value is not significative but also that the evolutionary track for this element is not adequate or that the solar system had a peculiar history.

2.2.3 Origin Of Deuterium

As Pagel (1982) said the most exciting thing about Deuterium is that it is there.

We believe that Deuterium has been synthesized in the BBN essentially because we do not know alternative way to build it. So before accepting the powerful implications of the D abundance we investigate alternative processes that has been proposed.

The basic problem in order to synthesize D is its extreme fragility and it rapidly burns to He-3 in hot environments. Thus to build it conditions of relatively low

temperature and low density are required. At the same time a sufficient number of neutrons should be available to produce it via $p(n,D)\gamma$. Alternatively a sufficient number of high-energy particles must be available to produce it from heavier elements by spallation. This way is strongly constrained by the observed abundances of Berillium, Boron and lithium as they also should be produced by the same mechanisms.

Colgate 1973, 1974 and Hoyle and Fowler 1973 proposed an alternative way of making Deuterium in Super Novae shock waves. The shock broke nuclei into nucleons which later recombine to build D. However Weaver and Chapline 1977 showed that actual shocks do not seem to reach strengths sufficient to break the nuclei. In addition Epstein Arnett and Schramm 1974, 1976 showed that even if such strength could be reached, the invariable outcome is an overproduction of Li, Be and B relative to D.

Generally in order to avoid the above mentioned problem of the overproduction one must consider pregalactic events. This possibility is still open because the physical conditions in the early history of galaxies are not known. M. Rees (1983) has shown as inhomogeneities before recombination lead to Pop III objects that evolve as black holes. Deuterium and Lithium can be produced in the accretion disks and rejected out of the black hole. A difficulty is that with such a mechanism the observed abundance are easily overproduced.

2.3 HELIUM-3

2.3.1 Helium-3 In The Universe

The Helium-3 abundance is the less known of all the light elements of cosmological interest due to observational difficulties.

1. Protosolar: from an analysis of trapped rare gases in meteorites Blak 1972 has obtained:

$$\text{He-3/H} = 2(\pm 1) \text{ dex}(-5)$$

2. Interstellar: from radio observations of the 3.64 cm. hyperfine line of single ionized He-3:

< 4 dex(-5) Salting and Heiles 1969

< 5 dex(-5) Predmore et al 1971

= 4(± 1) dex(-5) Rood et al 1979

3. Stars: has been detected only in peculiar stars where $\text{He-3/He-4} > 1$ in this case other processes like spallation on the surface of stars are invoked and there is not cosmological interest in them.

2.3.2 Origin And Evolution Of He-3

Apart of the likely BB origin it can be made and destroyed in stars in normal nuclear burning processes.

Low mass stars produce substantial amount of He-3 which

is mixed into the convective envelope when stars become giants. This envelope is then lost enriching the interstellar medium in He-3. Moreover a considerable fraction of primordial deuterium has been converted into He-3. We do not know however if the net result of processing on He-3 could be a complete or partial destruction or a net production. Works made by Rood (1976), Tinsley (1977) and Yang et al (1982) reach the conclusion that Deuterium is in average produced rather than destroyed.

Rood (1976): Since the astrated material has made $X_3 = \text{dex}(-3)$ and since only 30 % of interstellar gas has been astrated we have:

$$X_3 > 3 \text{ dex}(-4)$$

Tinsley (1977) stated that the production in giant phases is much greater than the cosmological value and that the predictions for the present He-3 are greater than observed

Yang (1982)(preprint not yet seen but rather famous) conclude that in any stellar population He-3 will be expected to be enhanced rather than destroyed.

Since all these works conclude that He-3 is enhanced rather than destroyed on average during the galactic evolution the problem is as has been pointed out by Pagel (1982): WHY SO LITTLE HE-3 IS OBSERVED? Perhaps an alternative and empirical way to approach this problem is to

regard the He-3 rather neutral respect to stellar evolution. The ambiguity of the situation should be kept in mind when we will try to deduce informations from He-3 abundance.

For these arguments it seems unlikely that He-3 can be used to supplement the informations from BBN.

2.4 LITHIUM-7

2.4.1 Lithium-7 In The Universe

We report in the table 2-3 the Li-7 determinations taken from Reeves (1974)

Protosolar: $\text{Li}/\text{H} = 1.5 \text{ dex}(-9)$ Nichiporuk 1971

Solar: $= \text{dex}(-11)$

All the young stars appear to be formed with the same initial $\text{Li}/\text{H} = \text{dex}(-9)$.

The comparison between interstellar value with the protosolar value gives the indication that Li participates in the general depletion of the interstellar gas even if the differences are inside the uncertainties of the measurements.

Li-6 has been detected only in the solar system. In all the cases studied Li-6 has not been detected in F and G stars (Cohen 1972) implying $\text{Li-7/Li-6} > 10$.

In the giant phase stars show a large increase up to $\text{Li-7/H} = \text{dex}(-7)$ (Boesgaard and Merchant 1970). Moreover Li-7 decrease with the decreasing of the effective temperature due to the depletion by the deeper and deeper convecting zone. Until recently Li-7 was believed to

decrease with the galactic evolution, but new observations of Li-7 on Pop II stars by Spite and Spite have changed radically this assumption.

2.4.2 Observations Of Spite And Spite (1982)

These authors observed Li-7 in pop II and old pop I stars selected in the disk on the bases of the low metallicity and high longitudinal galactic velocity and great eccentricity.

According to these authors we have the following points:

For pop II stars:

$$\text{Li-7/H} = 1.1 \text{ dex}(-10)$$

For pop I old stars:

$$\text{Li-7/H} = 5 \text{ dex}(-10)$$

For pop I young stars:

$$\text{Li-7/H} = \text{dex}(-9)$$

Two important conclusion are derived:

1. Li-7 has increased since the Galaxy born and the primordial Li-7 is less then the actual one (see fig 2-2)

2. The minimum Li-7 observed should be primordial since several old stars with different metallicity content show the same amount of Li-7. (see fig 2-3)

2.4.3 Origin And Evolution Of Li-7

Li-7 can be produced in several ways:

1. Big Bang
2. Spallation processes by cosmic galactic radiation (CGR)
3. Red giant phases
4. Novae

All this contributions have to be taken in account in order to obtain the evolutionary abundance curve for Lithium-7. Since the old evolutionary curve has been shown to be wrong Audouze et al (1983) are recomputing a new curve.

2.4.4 Why Some Li-7 Is Cosmological

In Reeves et al 1973 to this isotope was not assigned a definitive origin since both BBN and CGR predict a quantity too small by about one order of magnitude.

Recently the case for a BB origin has received some support from the new computations made by Olive et al 1981 using new

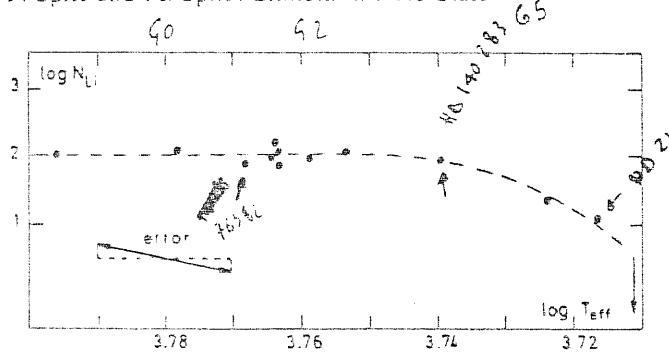
Table 2 Lithium abundances

	Hyades	Praesepe	Pleiades	NGC 2264	T Tauri stars	FU Orionis
Li/H	8×10^{-10}	1.6×10^{-9}	10^{-9}	10^{-9}	5×10^{-10}	10^{-9}
<u>"Initial" abundances</u>						
Main sequence field stars		Red giants field stars		Solar		Chondrites
Li/H	up to 10^{-9} ^b	up to 10^{-7} ^c	10^{-11} ^e	10^{-11} ^f	1.5×10^{-9} ^h	
^b Li/ ⁷ Li	≤ 0.1 ^c		^d Li/ ⁷ Li ≤ 0.1 ^b		^g Li/ ⁷ Li = 125 ^h	
<u>Interstellar matter</u>						
Li/H	3×10^{-10} ⁱ					
For meteorites the normalization is made through the solar Si/H = 3×10^{-5} ^j						

Table 2-3. From Reeves 1974

F. Spite and M. Spite: Lithium in Halo Stars

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nuclear cross sections. The Lithium produced in the BB is increased by a factor 3.

Meneguzzi, Audouze and Reeves (1971) (MAR) showed that the galactic cosmic radiation at their present rate over the last 10 billions years could account for the stellar observations of Li-6, Be-9, B-10, B-11 but not for Li-7 that is underproduced by a factor of 5. Possible variation of the CGR rates with time and of the targets abundances were considered by Truran and Cameron (1971) and Mitler (1972) but the effects of this changes are not large and the conclusions of MAR essentialaly hold.

The critical fact about Li-7 that prevents us to derive definitive conclusions on the origin of this isotope is that we do not know how much Li-7 can be produced in red giant phases or novae.

2.5 LIGHT NOT COSMOLOGICAL ELEMENTS: LI-6, BE-9, B-9, B-10

Due to the fragility of their nuclei these elements are not synthesized in the stellar interior neither in the observable quantities in the BBN. Their low cosmic abundance is explained rather satisfactory by spallation processes only and there is no necessity to think about other mechanisms; MAR 1971.

One of the major clues in deriving the primordial value of the cosmological species is to understand their evolution. We shall show here that observations of Li-6,

Be-9, B-9, B-10 can be usefull to understand the Li-7 evolution.

2.6 BE-9 PROJECT AND COSMOLOGICAL IMPLICATIONS

Boron and Lithium-6 are hopeless elements. Up to now they are detected with some reliability only in the solar system.

The best known of this triplet is Be-9 measured both in the sun and stars.

My project is a determination of the Be-9 abundances for the same sample of pop II stars used by Spite and Spite in order to derive the Li-7/Be-9 ratio.

No observations of Be-9 in pop II stars has been made up to now and is quite important to establish if there is an increase of Be-9 during the galactic life as has been observed for Li-7.

From the fact that Li-7 and Be-9 suffer similar processes of depletion but Be-9 can be produced only by spallation processes the Li-7/Be-9 ratio in pop II stars gives direct insights on the primordial component for the Li-7.

An analysis of an IUE spectrum for one old star (HD 76932) has been performed and the results are given in chapter 4.

CHAPTER 3

WHAT CAN WE LEARN FROM BIG BANG

SBBN is one of the most powerful tools to exploring the nature of the early universe giving informations on eta (i.e. the baryonic mass of the universe) and N_V , the number of lepton families.

3.1 ARE THE OBSERVATIONS IN CONFLICT WITH THE SBBN PREDICTIONS?

Before starting to analize what we can learn from the SBBN we must look if there are some inconsistencies between the predictions of the SBBN and the observations.

The reliability of the deductions that will be derived in the next paragraph is, of course, strictly dependent on this point.

We have to answer to the following test-questions:

1. Do the light elements D,He-3 and Li-7 match the BBN predictions for the same value for Eta?
2. Does this Eta agree with that of He-4, considering anyway also the other parameters that play role to make He-4? (i.e. is there overlap in eta between He-4 and the other light elements in fig 3-1?)
3. Is possible using 3 of the 4 parameters ($Y_p, N_v, \eta, T_{au}/2$) to derive the fourth in disagreement with some observation?

In Fig 3-2 are reported the predictions and the observations. We stress here that often there is not a unique value for the observations.

In doing this comparison we have to take in account the error boxes that are associated to each determination and the intrinsic uncertainties in the extrapolation to the primordial values due to the poor knowledge of the chemical evolution of the galaxy.

From the fig 3-2 we see that the answer to the first question should be positive at least at the first order of approximation.

Since a disagreement is obviously more important than an agreement in the following we discuss all the papers that have claimed some contradiction between predictions and observations.

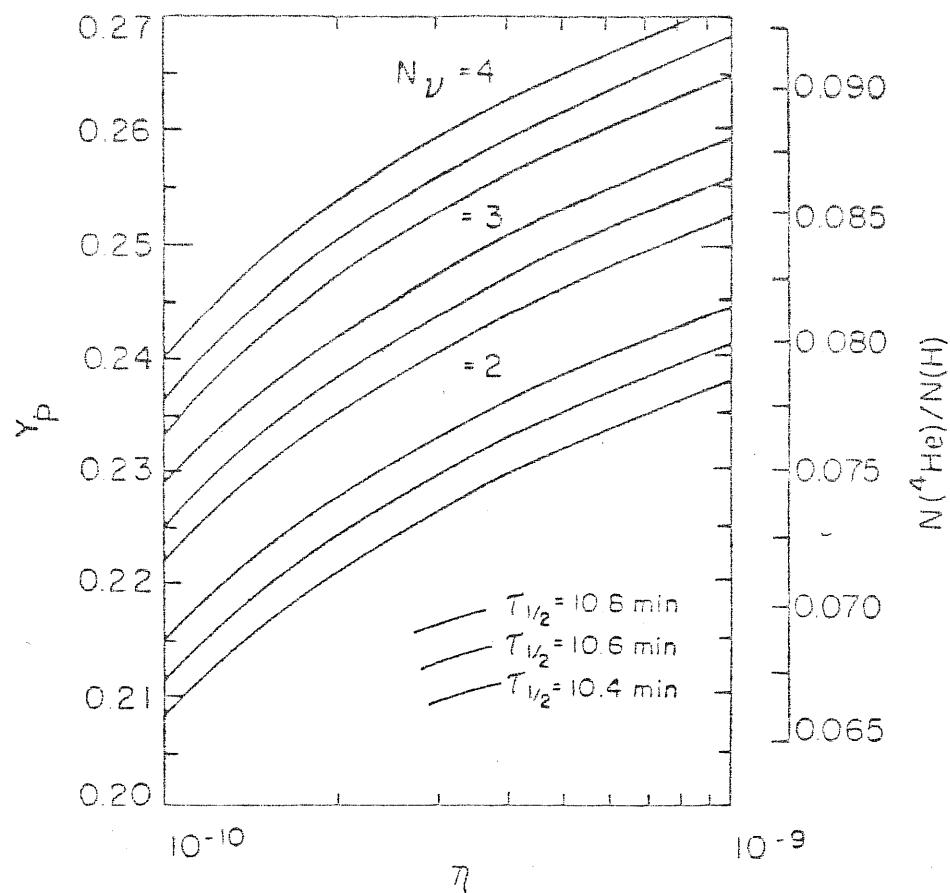


Figure 4. As in Figure 3 but for each value of N_ν , the results are shown for three choices of $\tau_{1/2}$.

Fig 3-1 a) From Steigman 1983

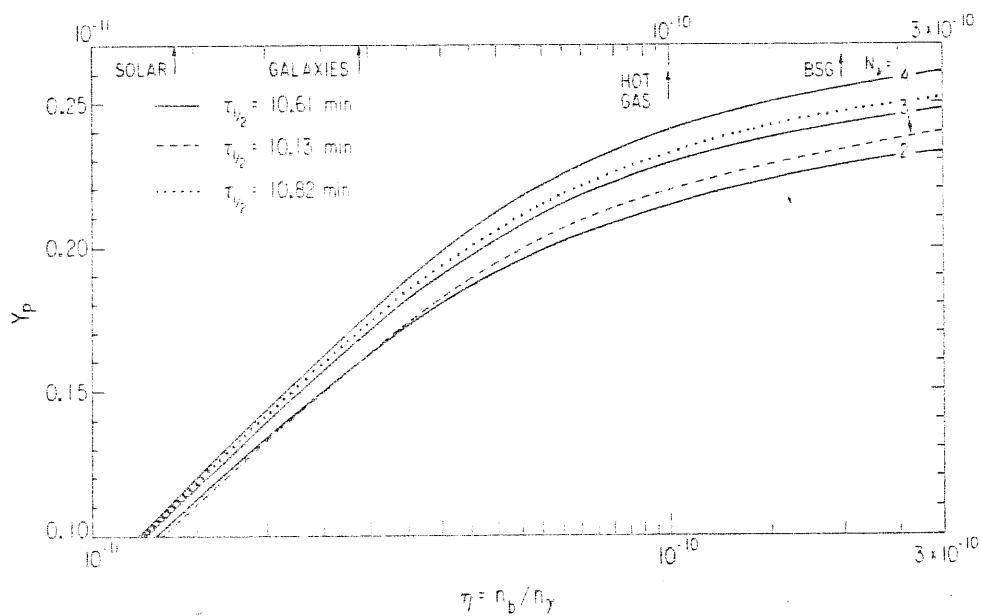


FIG. 3.—The mass fraction of ^3He synthesized, Y_p , as a function of η for $\tau_{1/2} = 10.13$ ($N_p = 3$), 10.82 ($N_p = 3$), and 10.61 ($N_p = 2, 3, 4$) min. Only for reasons of clarity are the curves for $\tau_{1/2} = 10.13$ ($N_p = 2, 4$) min. and 10.82 ($N_p = 2, 4$) min. not shown.

Fig 3-1 b) From Olive et al 1981

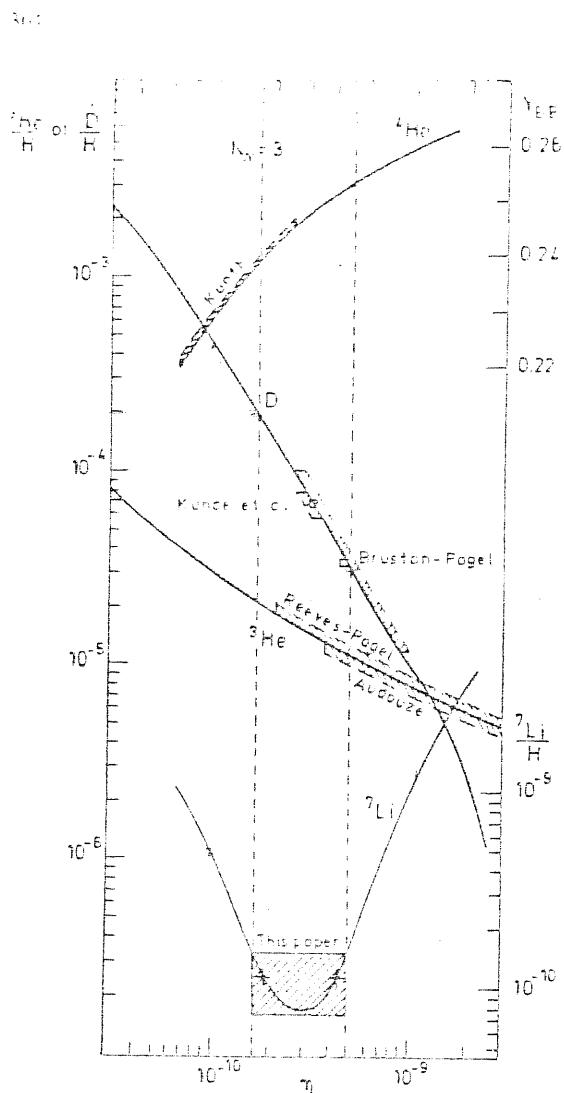


Fig. 7. D, ^3He , ^7Li by number and primordial ^4He by mass (Y_{BB}) versus the ratio of baryons to photons in the Universe. The theoretical curves are from Schramm (1982). Our determination of Li/H and the determinations of Y_{BB} , D/H, $^3\text{He}/\text{H}$ from different authors are plotted on the diagram.

Fig. 3-2. From Spite and Spite 1982

3.1.1 Stecker Point Of View

Stecker claims some inconsistencies in the SBBN of the type of the test-question 3.

He assumes for $Y_p < 0.228$ then taking for $\Omega > 0.02$ and $N_\nu = 3$ he finds an overproduction of Y_p respect to the chosen value (See fig 3-3).

In order to save the BBN framework some Y_p must be destroyed and one possible mechanism suggested by Stecker is the photodisintegration of He by radiation produced by N and anti-N annihilation in the early BB. Olive et al (1981) have replied to this objection essentially saying that if we take into account all the uncertainties of the parameters Y_p can be as low as 0.12 if the universe is neutrino dominated and $\Omega < 0.02$. Anyway this point will be considered with more details later.

3.1.2 Rana Point Of View

Rana 1981 claims some inconsistency in the Eta values derived from He-4 and D, of the type of the test-question 2, making the BBN untenable:

$$\text{In } Y_p < 0.288 \quad N_\nu = 3 \quad \tilde{\zeta}_2 = 0.13 \text{ and} \\ \Rightarrow \eta \cdot 10^{10} < 1.4$$

$$\text{In } D_p < 6 \cdot 10^{-5} \quad \Rightarrow \eta \cdot 10^8 > 4.7$$

see fig 3-4.

The assumption on Deuterium has been justified assuming that 25-50 % of the material has been processed in stars. The choose for He-4 comes from the average of some Y_p determinations obtaining

$$Y_p = 0.288 (\pm .008)$$

I would like to criticize the Rana assumptions on two points

- 1) No firm upper limit to the D_p can be used
- 2) There is an underestimation of errors in choosing the Y_p value.

3.1.3 The "french" Point Of View

I have mentioned in the section of the Deuterium that a new interpretation of the scatter leads to assume for the present Deuterium the value of

$$\frac{D_p}{\mu} = 5 \pm 3 \cdot 10^{-6}$$

It is clear that with this assumption the gap in Δ_p/μ between He-4 and D is even larger of that noticed by Rana.

In fact if we assume that the D has been depleted by a factor 5 (the largest value given by evolutionary considerations) the primordial Deuterium should be:

$$\Delta_p/\mu < 4 \cdot 10^{-5}$$

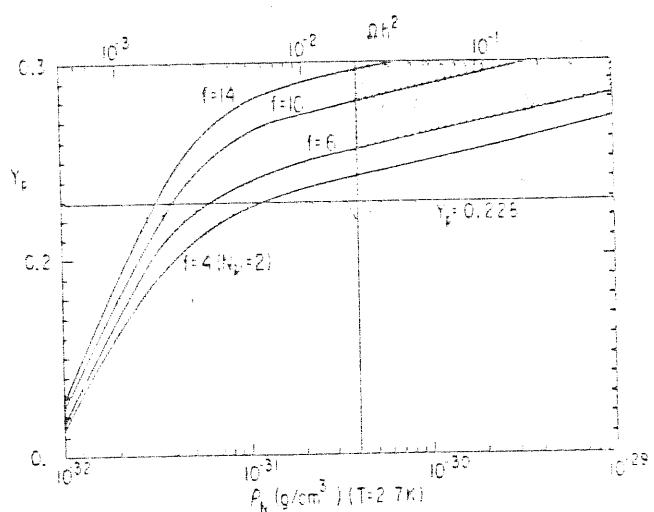


FIG. 1. Helium abundance Y_p from big-band nucleosynthesis vs present mean nucleon density ρ_N for quark flavor numbers f (Ref. 1). The null intersection of the independent data sets indicated by the cross-hatched area and upper-limit line $Y_p = 0.228$ shows the basic inconsistency in the standard scenario.

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Fig. 3-3 . From Stecker 1980

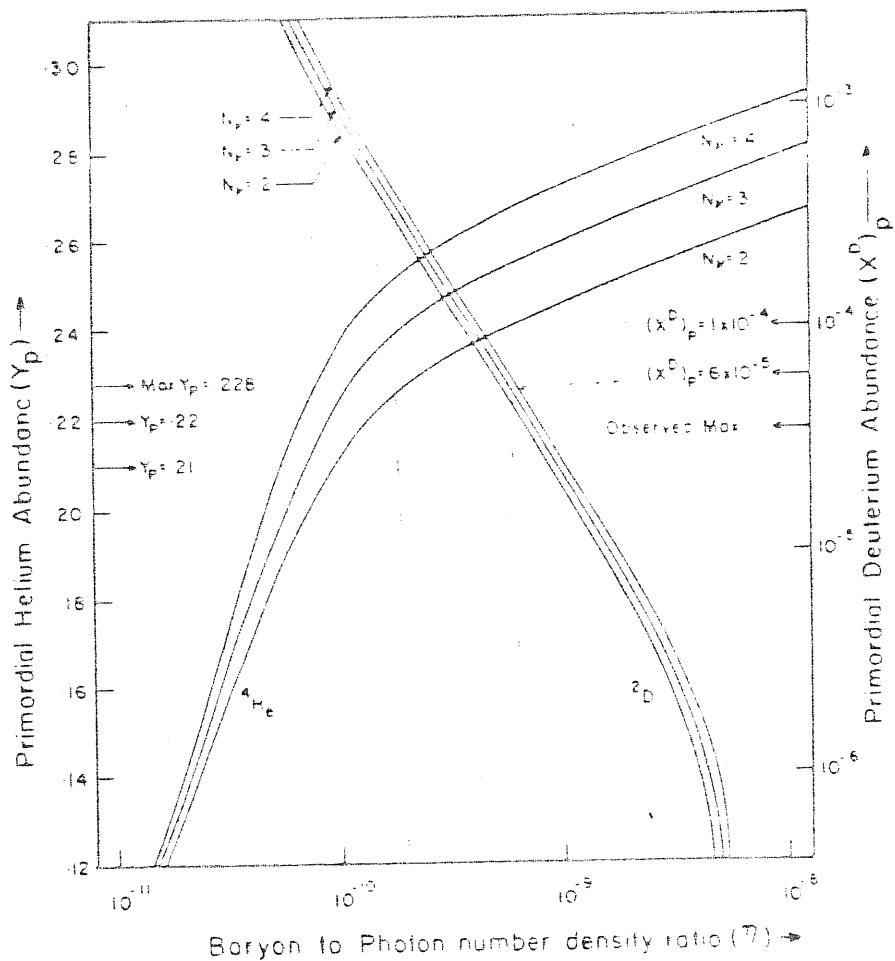


FIG. 1. Calculated primordial abundances of ^3He and ^2D on the basis of Table I given by Yang et al. (Ref. 1). No single value of η can simultaneously satisfy both the abundances as required by the up-to-date observations.

giving a value for $\eta \sim \text{dex}(-9)$ higher of that assumed by Rana, see fig 3-5^a from V. Madjar and C. Gry (1983). C. Gry, G. Malinie, J. Audouze and V. Madjar (1983) suggest some ways to skip such a difficulty invoking infall on the disk of processed (D-poor) material. With this assumption the primordial D correspond to the model B in the fig 3-5.b). On the contrary if the infall is of primordial material (model A) the disagreement is still there. V. Madjar and C. Gry suggest that some pregalactic events can have destroyed a considerable fraction of D.

In summary I think there are not clear evidences that some observations conflict with the BBN predictions and we are legitimate to investigate what kind of informations is possible to derive from SBBN.

3.2 BOUNDS ON ETA

We have seen in chapter 2 that from observations is possible to put lower limits to this quantity ($\eta > 0.1 \text{ dex } (-10)$) we shall see here that SBBN offer the way to put upper limits to η .

3.2.1 Using Helium-4

Since Y_p increase with the increasing of the neutron half-life, the number of leptons and η using upper limits

for the primordial Helium-4 abundance and lower limits to the neutron half life and to the number of Leptons is possible to give an upper limit to Eta.

All the possibilities are reported in the table 3-1 from Olive et al (1981)

A conservative upper limit is:

$$\left. \begin{array}{l} \eta < 0.25 \\ N_\nu > 3 \\ \tilde{\epsilon}_{\frac{1}{2}} > 10.13 \end{array} \right\} = \eta^{10} < 10$$

combining the constraints we obtain that Eta can vary inside two order of magnitude:

$$0.1 \text{ ("haloes")} < \eta^{10} < 10 \text{ (He4)}$$

Using values for T_0 and h_0 is possible to translate the table on Eta into a table on Ω_b . See table 3-2.

3.2.2 Bounds On Eta Using He-3,D And Li-7

From the previous discussion we have seen that Eta can be constrained in the box:

$$\text{dex}(-11) < \text{Eta} < \text{dex}(-9)$$

This box is quite large but King and Austin (1977), Schramm

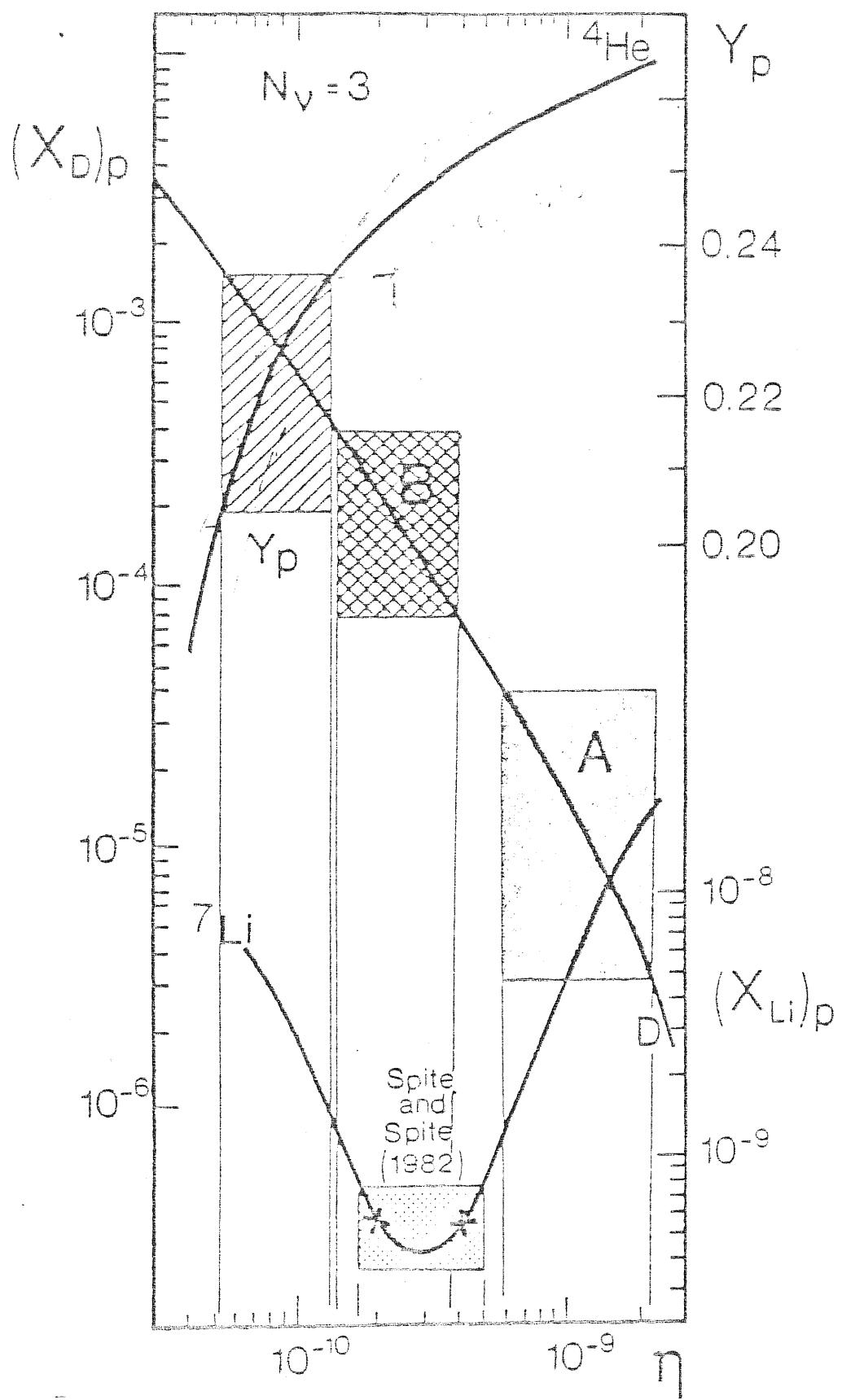


Fig. 3-5. a) From C. Gry et al 1983

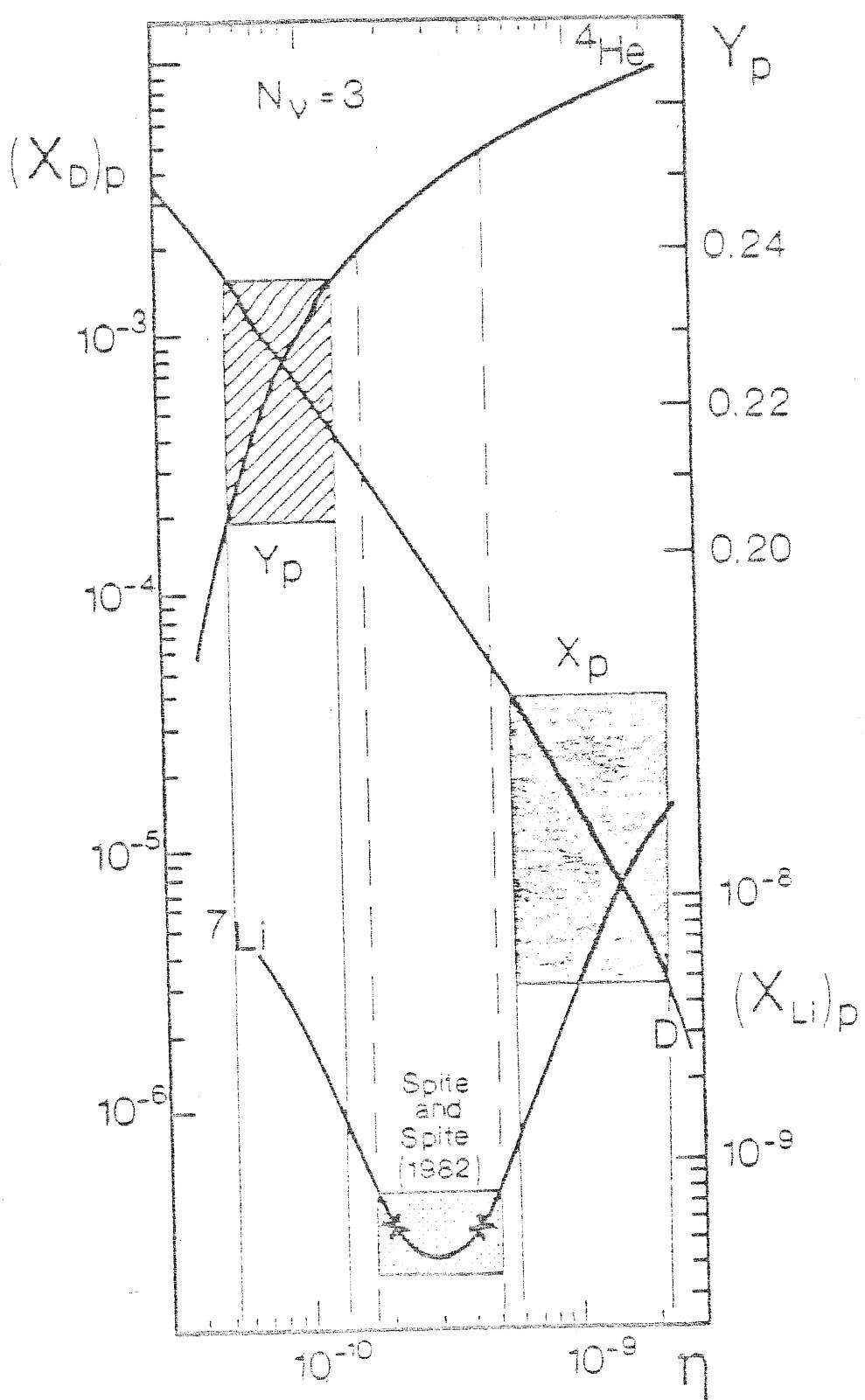


Fig. 3-5 b) From V. Madjar et al 1983

TABLE 4A
UPPER BOUND ON η FROM PRIMORDIAL NUCLEOSYNTHESIS

η_{max}	$\tau_{1/2} \geq 10.13 \text{ min.}$	$\geq 10.61 \text{ min.}$	$\geq 10.82 \text{ min.}$
$Y_p \leq 0.27 \dots$	$10^{-8.0}$	$10^{-8.4}$	$10^{-8.6}$
$Y_p \leq 0.25 \dots$	$10^{-8.0}$	$10^{-8.4}$	$10^{-8.5}$
$Y_p \leq 0.23 \dots$	$10^{-8.8}$	10^{-10}	10^{-10}

TABLE 4B
UPPER BOUND ON Ω_Λ FROM PRIMORDIAL NUCLEOSYNTHESIS

$\Omega_{\Lambda \text{max}}$	$\tau_{1/2} \geq 10.13 \text{ min.}$	$\geq 10.61 \text{ min.}$	$\geq 10.82 \text{ min.}$
$Y_p \leq 0.27 \dots$	2.0	0.75	0.51
$Y_p \leq 0.25 \dots$	0.19	0.076	0.055
$Y_p \leq 0.23 \dots$	0.032	0.021	0.018

Table 3-1 From Olive et al 1981

1982 have shown that is possible to use the other light elements in order to put narrower bounds to the allowed value for Eta. This is of fundamental importance since is in principle the best present way to weight the baryonic mass of the Universe. Secondary the knowledge of Eta is of critical importance using SBBN to derive limits on Nv. It is remarkable that this derivation of eta does not require assumptions on the background temperature or on the Hubble constant.

Since the abundance of all the light elements is sensitive mainly to Eta they are in principle the best tool to derive it without making assumptions on Nv or Taul/2.

1. Deuterium; This element is decreasing with the increasing of Eta so since the observed D is a lower limit of the primordial deuterium it gives an upper limit on Eta.

using

$$D/H > 10^{-5}$$

$$\Rightarrow \eta^{10} < ?$$

using

$$D/H > 6 \cdot 10^{-6}$$

$$\Rightarrow \eta^{10} < 15 \text{ (unbs)}$$

Lower limits for Eta are deduced only if it is possible in some way to fix upper limits to D. I notice that is this kind of approach to lead the more severe difficulties to the BBN.

2. Helium-3; Also He-3 is decreasing with the increasing of Eta as D but the observed He-3 is an upper limit to the primordial He-3 so the observed He-3 gives lower limits on Eta

using $\frac{^3\text{He}}{\text{H}} < 5 \cdot 10^{-5}$

we have

$$\eta^{10} > 0.4$$

Since there are a lot of problems to understand the evolution of He-3 during the life of the galaxy I think that the use of he-3 does not permit us to say nothing more using He-3.

3. Lithium-7; the case of Lithium-7 is more complex. Its behaviour with Eta shows a valley as is possible to see in fig 3-1. This valley gives to Lithium-7 the unique privilege among the light elements to offer simultaneously upper and lower limits to Eta.

using $\frac{^7\text{Li}}{\text{H}} = 4.1 \cdot 10^{-10}$

we obtain:

$$1.6 < \eta^{10} < 5$$

Since the Deuterium observations are now puzzling after the discovery of hourly variations of the so believed Deuterium line the Li-7 will be the best light element to be used in order to derive constraints on Eta, provided that the Li-7 observed by Spite and Spite is really primordial

4. Deuterium+He-3; Several authors as Schramm (1982), G. Steigman (1983) have suggested that the constraints on Eta can be tightened significantly using He-3 and D together. Keeping in mind that deuterium primarily burns to He-3 via the reaction



an appreciable fraction (g) of the primordial Deuterium will be returned to the interstellar medium as He-3.

This fraction has been computed by Schramm (1982)

For massive stars $M > 10 M_{\odot}$, $g = 1/4$

$M < 6 M_{\odot}$, $g = 1$

$6 M_{\odot} < M < 10 M_{\odot}$, $g = \text{small}$

In conclusion he takes $g = 1/4$

using the two elements together they write:

$$W: [D + {}^3\text{He}]_p < [D + \frac{1}{g} {}^3\text{He}]$$

$$W \left(\frac{D_H}{H} = 2 \cdot 10^{-5}, \frac{{}^3\text{He}_H}{H} = 5 \cdot 10^{-5} \right) < 3 \cdot 10^{-4} \Rightarrow 2 \cdot 10^{10} > 1.5 \cdot 10$$

$$W \left(\frac{D_H}{H} = " , \frac{{}^3\text{He}_H}{H} = 2 \cdot 10^{-5} \right) < 1 \cdot 10^{-4} \Rightarrow 2 \cdot 10^{10} > 3$$

See fig 3-6 and 3-7.

I would like to criticize this approach.

The full equation should be written:

$$[D_p + {}^3He_p] = [D_p + {}^3He_p - D(\text{MATTERED})]$$

$$+ {}^3He(\text{PRODUCED IN*}) - {}^3He(\text{DESTROYED IN*}) + {}^3He(\text{FROM 0})$$

In this second term of the equation we don't know the fraction g of deuterium converted to He-3, it depends of the mass of the stars involved and so to the mass distribution of stars; moreover we do not know accurately the evolutionary curve for He-3 that, despite the theoretical predictions, instead of increasing with the age of the galaxy it is observed to remain almost constant. (cfr. paragraph on the evolution of He-3.)

Putting together all the constraints:

Solar Neutron	0.19	≈ 10	Helium
Interpret of g	0.29		
Groups of g	2	$< 2 \cdot 10^{10} <$	7-15 Dens.
Hot gas inc.	1		
3He	0.4	5	3He
3Li	1.5		
$D + {}^3He$	$4.5 \div 3$		

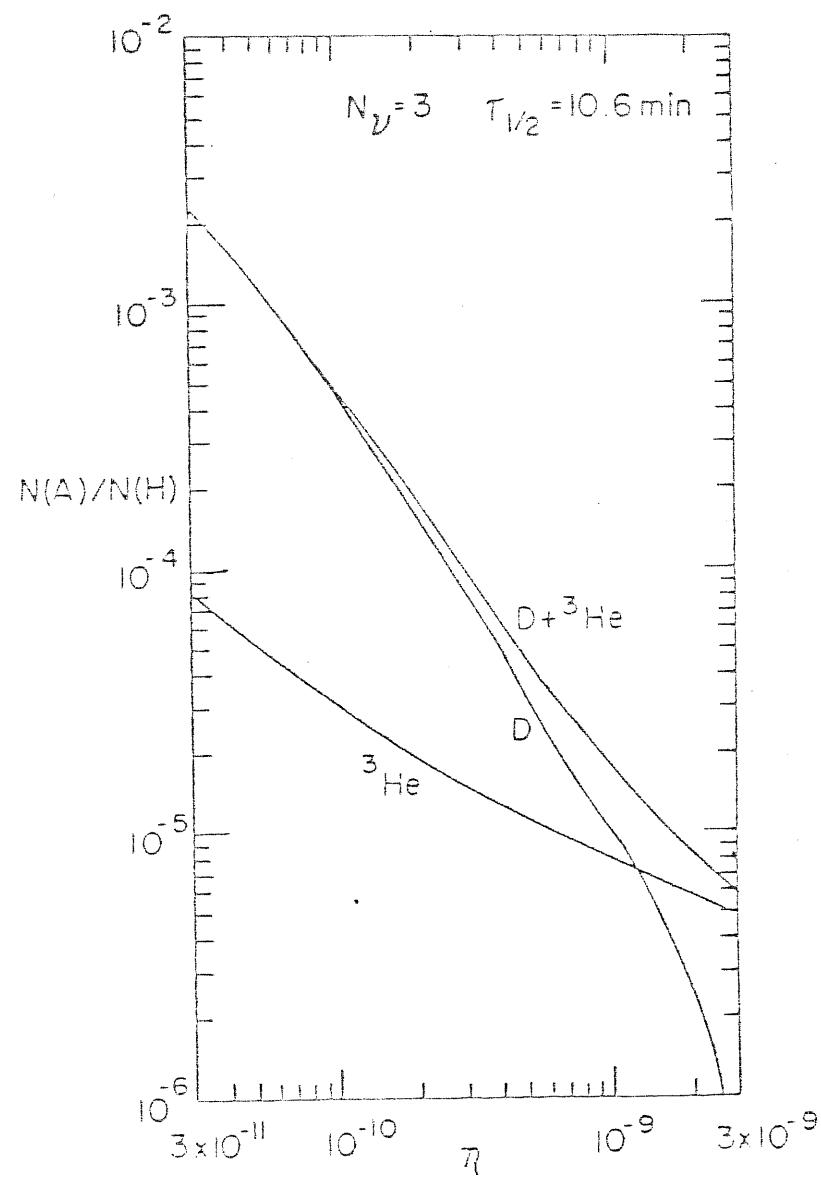


Figure 1. The predicted abundances (by nuclei) of D and ^3He in the standard model as a function of the nucleon abundance. The sum of the ab values is also shown.

Fig. 3-6 From Steigman 1983

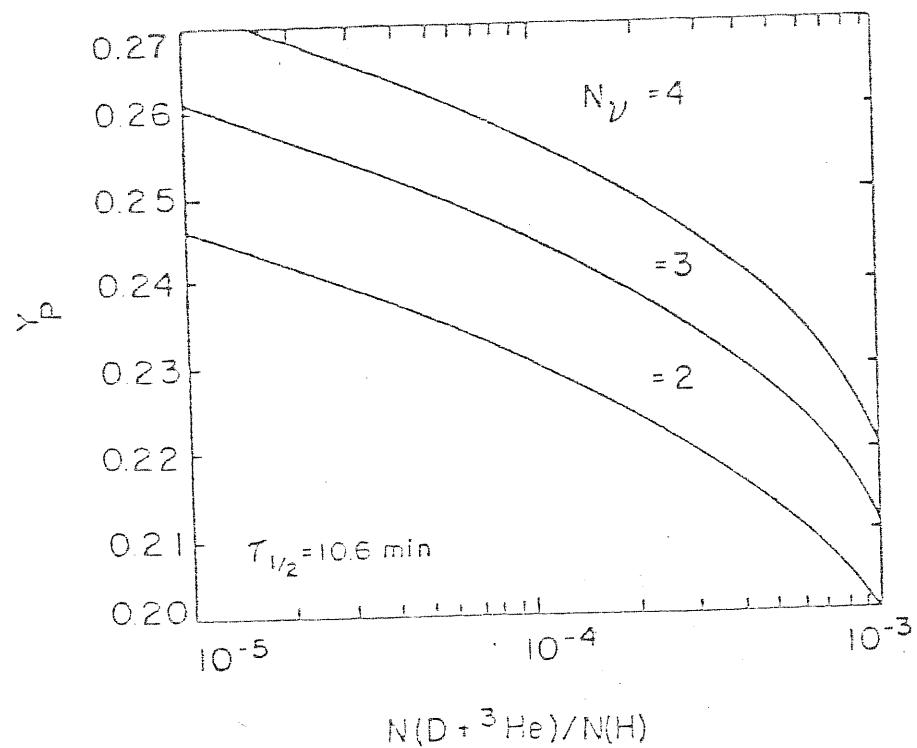


Figure 5. The predicted abundance (by mass) of primordial ${}^4\text{He}$ is plotted versus the corresponding prediction for $\text{D} + {}^3\text{He}$ (by number) for three values of N_ν and one value of $T_{1/2}$.

Fig 3-7 From Steigman 1983

3.3 BARYON MASS OF THE UNIVERSE

Since

$$\Omega_b = 3.5 \cdot 10^7 h^{60} \left(\frac{I}{2.7}\right)^3$$

The eta value derived from BBN gives

$$1.5 < h^{10} < 15$$

$$0.01 < \Omega_b < 0.1 \quad \begin{matrix} \frac{1}{2} < h < 2 \\ 2.2 < T < 3.7 \text{ K} \end{matrix}$$

It is interesting that this result overlaps very well with the implied range for the values as derived from binary galaxy and small groups.

It implies that if the amount of mass derived from groups or clusters of galaxies ($\Omega \sim 0.3-0.7$) is greater than the average Omega derived from BBN then the mass should not be nucleons.

It should be also noted that because from solar neighborhood and inner part of galaxies we have $\Omega < 0.01$ the dark matter on a small scale (galaxies, binaries, small groups) has an appreciable if not complete baryonic component. The only place that may require there to be non-baryonic dark matter are the large clusters of galaxies. This location is particularly well fitted with the neutrino hypothesis since neutrinos can cluster easily on

scales of large clusters of galaxies while have great difficulty with clustering on a small scale.

The so called "Flatness argument" in cosmology require

$$\Omega \sim 1$$

while the BBN gives

$$\Omega \sim 0.1$$

the dark matter could be non-baryonic matter. M. Rees (1983), on the contrary suggested that it can be still baryonic. Assuming inhomogeneity at the time of nucleosynthesis it is possible to think that the dark matter is in baryonic form without conflict with the BBN value. He assumes that half in volume of the universe was in low density regions with the 10 % of the baryonic mass and the other half in high density with the 90 % of the baryons. The output of the BBN comes from the low density regions and gives the observed abundancies and $\Omega \sim 0.1$. On the other side the high density regions could be evolved through the recombination in pop III objects giving not observable Black holes as remnants.

3.4 LIMITS ON THE NUMBER OF NEUTRINO TYPES

Since Y_p increase with $N_\nu, E_\eta, T_{\text{au}}/2$ an upper limit to Y_p and lower limits for E_η and $T_{\text{au}}/2$ put an upper limit to the number of Leptons.

The most elusive quantity is Eta.

If we suppose that the mass which is inferred from observations of binary galaxies and small groups of galaxies (BSG) is not predominantly baryons then the lower bounds on Eta must be obtained from solar neighborhood (SN) and galactic mass to light ratio (G)

$$\eta_{SN} 10^{10} > 0.14$$

$$\eta_G 10^{10} > 0.29$$

If we choose these values for Eta the result is NO LIMITS ON Nv. (fig 3-10)

We know that increasing the number of leptons the expansion rates speeds up resulting in more synthesized He-4 but if the expansion rate increases more rapidly the amount of He-4 produced begins to drop simply because there is not enough time for the He-4 producing reactions to run to completion

It is possible to see from the figures 3-9,3-10 that unless He-4 can be constrained to be less than 21% or 12% these lower bounds on Eta result in no limits to Nv.

I notice that since Yp must be > 0.20 whatever is the neutrino number, we have:

$$\eta 10^{10} > 0.28$$

For values of Eta from the Hot gas X-ray emitting inside the clusters of galaxies (HG):

$$\text{for } \left\{ \begin{array}{l} \eta_{\text{HG}}^{10^{-6}} > 1 \\ Y_p < 0.25 \\ \tilde{\alpha}_t = 10.60 \end{array} \right. \Rightarrow \begin{array}{l} \eta_{\text{HG}} \Rightarrow N_\nu < 5 \\ \eta_G \quad \quad \quad N_\nu < 4 \end{array}$$

$$\text{for } \left\{ \begin{array}{l} Y_p < 0.23 \\ \tilde{\alpha}_t = 10.60 \end{array} \right. \begin{array}{l} \eta_{\text{HG}} \rightarrow N_\nu < 4 \\ \eta_G \quad \rightarrow N_\nu < 3 \end{array}$$

the limits are reported in fig 3-10

Since the fact that most theories of elementary particles are Quark- Lepton symmetrical for each quark there is a corresponding Lepton pair

up e

down	$\bar{\nu}_e$
strange	muon
charme	$\bar{\nu}_m$
top	tau
bottom	$\bar{\nu}_t$

So the counting of the neutrino types allows one to count the number of Quarks and leptons pairs (or generations)

3.4.1 Limits On N_v Using Eta From SBBN

We have seen that the narrowest bounds on Eta comes from the SBBN and the light elements that are able to constrain Eta inside:

$$1.5 \text{ dex}(-10) < \text{Eta}$$

Using the results published in the paper of Olive et al 1981 we derive:

$$N_v < 4$$

probably 3

I notice that if we take the more extreme value of

$$\eta 10^{10} > 3$$

coming from He-3 + D, for Y_p < 0.23 we find

$$N_v < 2$$

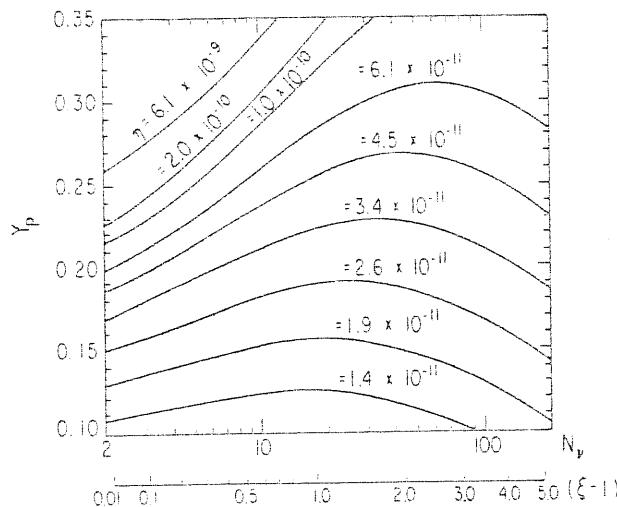


FIG. 2a

FIG. 2a.—Mass fraction of helium synthesized, Y_P , as a function of N_p (or ξ) for $\tau_{1/2} = 10.61$ min. and various values of η . The speed-up factor, $\xi \equiv (\text{expansion rate})/(\text{expansion rate for } N_p = 2) = (\rho'/\rho)^{1/2}$. As N_p (or ξ) increases, Y_P increases since n/p freezes out at a higher value (see § I). Eventually, the expansion is so rapid that the reactions which synthesize ${}^4\text{He}$ do not have time to run to completion, and Y_P decreases with increasing N_p ; hence, as a function of N_p (or ξ) Y_P reaches a maximum value. Note that, for $\eta = 0.14$, 0.29×10^{-10} , the maximum value of Y_P is 0.125, 0.21, and unless Y_P can be constrained to be less than ~ 0.12 , 0.21, these lower bounds on η result in no limits on N_p .

FIG. 2b.—The maximum value of Y_P produced (as a function of N_p , see Fig. 2a) as a function of η for $\tau_{1/2} = 10.13, 10.61, 10.82$ min. and the minimum value of Y_P produced ($N_p = 2$) also as a function of η for $\tau_{1/2} = 10.13, 10.61, 10.82$ min. The actual mass fraction of ${}^4\text{He}$ synthesized (in the standard model) must lie between the two sets of curves.

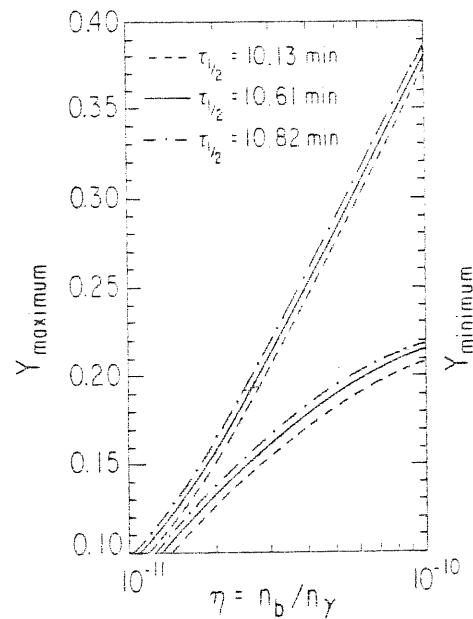


FIG. 2b

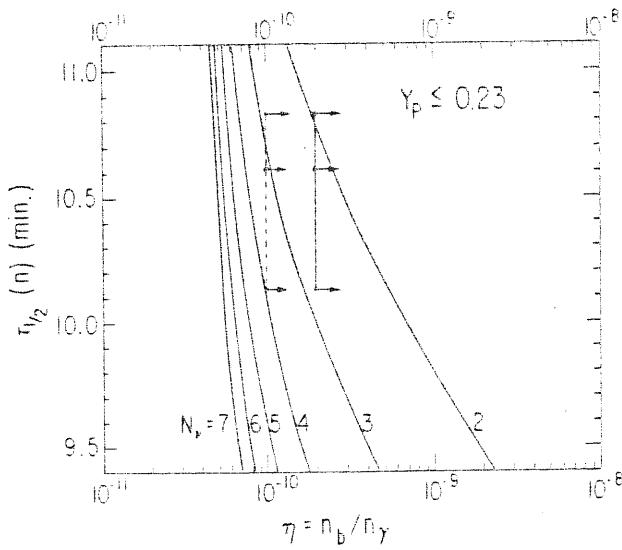


FIG. 1a

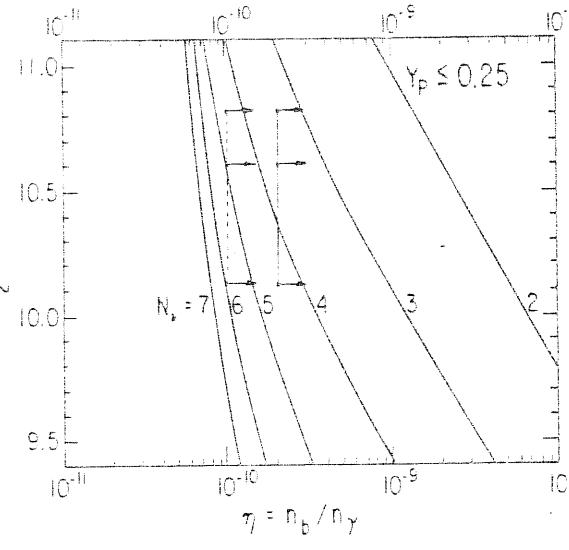


FIG. 1b

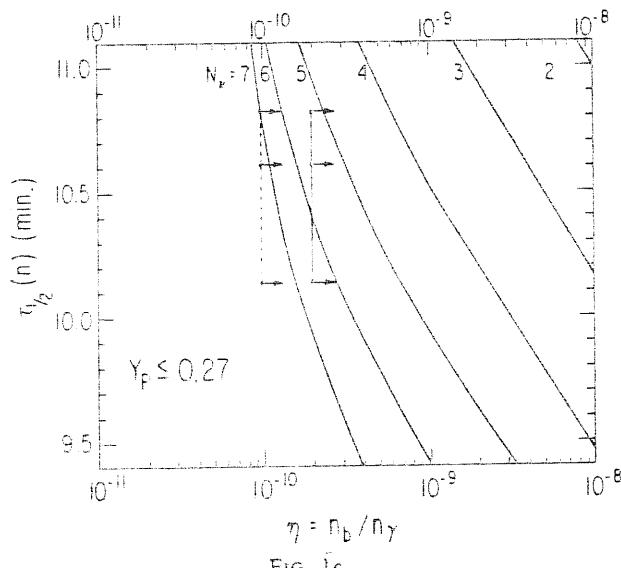


FIG. 1c

FIG. 1a.—Contours of the allowed number of two-component neutrino species in the $(\eta, \tau_{1/2})$ -plane for $Y_F \leq 0.23$. The points and arrows correspond to $\tau_{1/2} = 10.13, 10.61, 10.82$ minutes and $\eta \geq 1.0 \times 10^{-10}$ (lower bound from hot gas), 2.0×10^{-10} (lower bound from BSG). To determine the number of allowed species, pick a point in $(\eta, \tau_{1/2})$ -space, and read the value of N_p . 1b.—Same as 1a for $Y_F \leq 0.25$. 1c.—Same as 1a for $Y_F \leq 0.27$.

3.5 EFFECTS OF MASSIVE NEUTRINOS ON NUCLEOSYNTHESIS

Kolb and Scherrer (1981) have modified the computer code of Wagoner to include the additional contribution to the energy density from massive neutrinos.

The resultant abundances of He-4, D, He-3 as a function of the masses of neutrinos are shown in figs. 3-11 and 3-12

The more relevant results are :

Neutrinos with $m < 10$ Mev will increase He-4 more than a massless neutrino.

The abundances of the light elements increase with increasing neutrino mass if $m < 5$ Mev, then the abundances decrease with increasing mass.

For $m > 25$ Mev the neutrino will have a negligible effect on BBN.

If we enter with a fixed η the abundances are a function of the number and of the masses of neutrinos.

Anyway the conclusions are not firm since there is the complication that the neutrino decay products may photodissociate D, He-3 and Li-7.

From the figures we can see that the BBN is not in favour of the existence of massive neutrinos.

I notice that the observed Li-7 abundance ($\text{Li-7} = 1.1 \text{ dex}(-10)$) implies an η larger than $\text{dex}(-9)$ if a massive neutrino of 5 Mev is present.

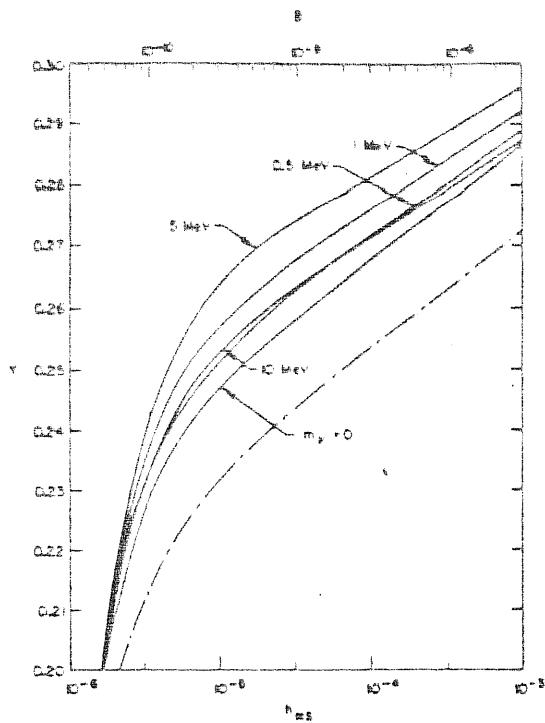


FIG. 2. The primordial mass fraction of ^3He (Y) as a function of h_{NS} [Eq. (2.2)] with two massless neutrinos (dashed curve) plus a neutrino of the indicated mass (solid curves).

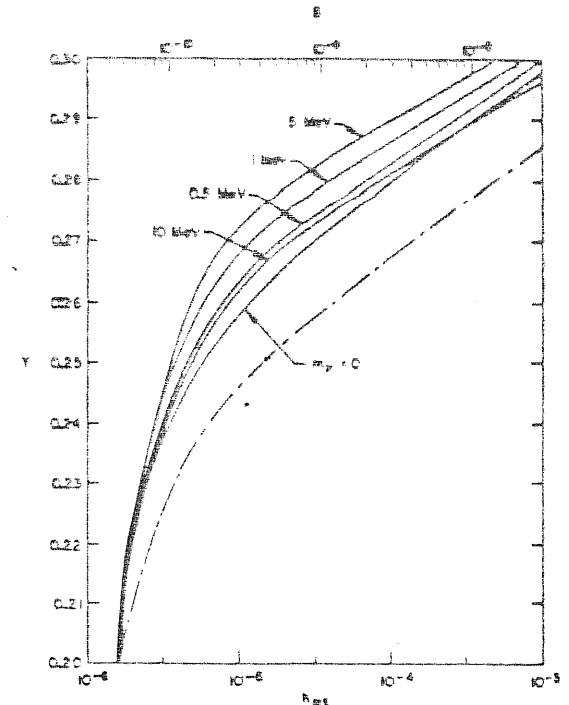


FIG. 3. Y with three massless neutrinos (dashed curve) plus a neutrino of the indicated mass (solid curves).

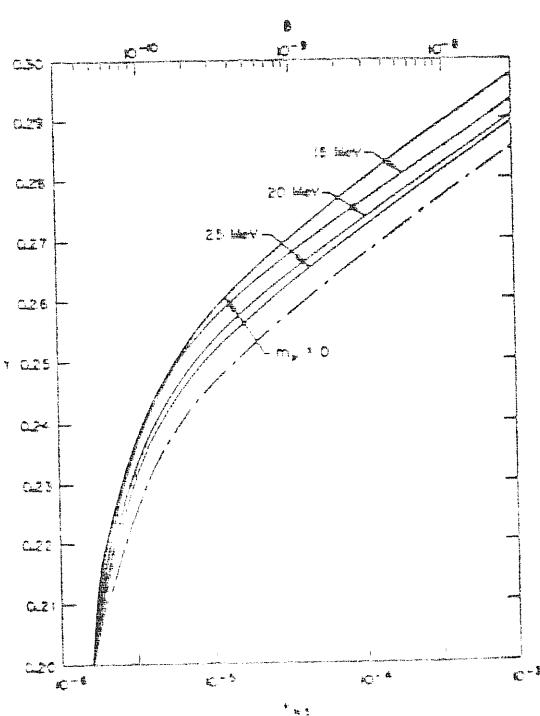


FIG. 4. Same as Fig. 3.

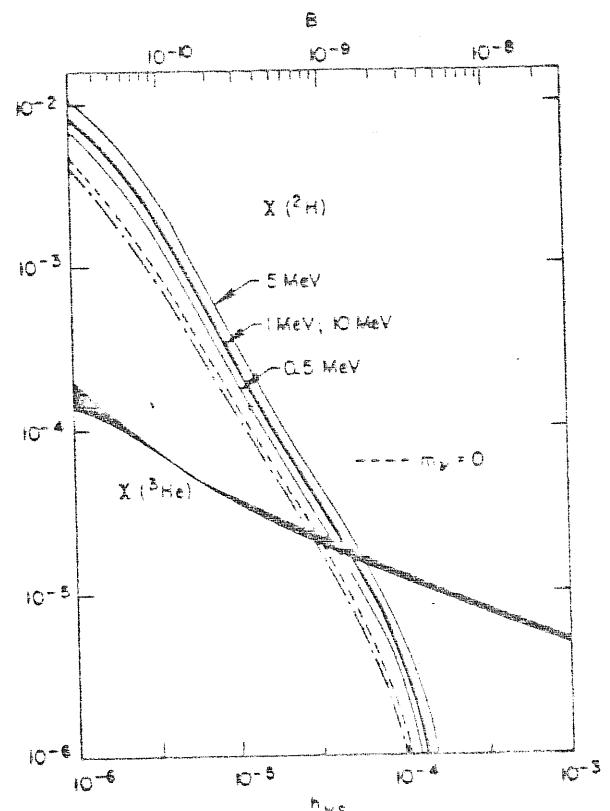


FIG. 5. The primordial mass fractions of ^2H and ^3He for two massless neutrinos (lower dashed curve) plus a neutrino of the indicated mass.

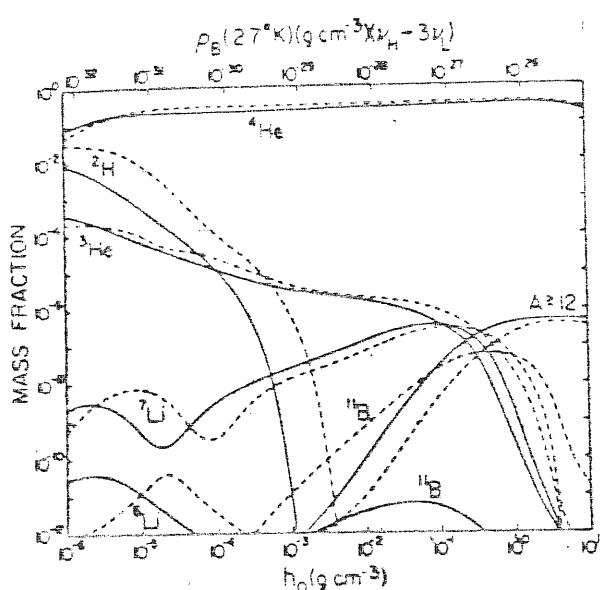


FIG. 2. A comparison of the canonical abundances (solid line) and the abundances predicted for the case of a 5-MeV neutrino with vector coupling and $\sigma/10$ (dashed lines) (assuming the neutrino has not decayed before nucleosynthesis). All other cases in Table I lie between these two extremes.

Fig 3-12 From Kolb 1981

3.6 ADDING ANISOTROPIES AND INHOMOGENEITIES

The Friedmann model employed to derive the conclusions in the previous chapters is, by assumption, completely homogeneous and isotropic. The real world of course not.

Small deviations from exact isotropy in the microwave background radiation and significant inhomogeneity in the baryon distribution over small scales $M < \text{dex}(15) M_\odot$ exist.

We should, therefore, ask how stable are our conclusions on η and the max N_γ to small changes in the cosmological model.

3.6.1 Anisotropy

Small anisotropies increase the expansion rate so the He-4 at the beginning is increased but then it drops while the abundance of the other light elements is increased.

From the fig 3-13 it is possible to see that when the anisotropy is so large that Y falls to 0.25 the levels of Deuterium and He-3 produced are many orders of magnitude in excess of those observed. This is due to the fact that the annihilation times for D and He-3 become larger than the expansion time when the anisotropy is so large.

The addition of very small anisotropies to the expansion dynamics of the early Universe mimics the addition of neutrinos and go in the direction to strengthen the

constraints on N_{ν} derived in an isotropic model.

3.6.2 Baryon Inhomogeneity

Barrow and Morgan (1983) have calculated the output of Deuterium and He-4 from a cosmological model which expands isotropically at the Friedmann rate, dominated by an isotropic radiation density, but which contains an inhomogeneous baryon distribution. Since the deuterium is very sensitive to the baryon density content, it is also very sensitive to inhomogeneities.

Barrow et al assume a quasi-gaussian form for the baryon inhomogeneity

The fraction of the baryon density within the range $(\rho, \rho + d\rho)$ at the temperature of the nucleosynthesis is therefore:

$$f(\rho) = (4\pi/6^2)^{-1/2} \rho^{-1} \exp[-(k_B(\rho - \mu))^2/2\sigma^2]$$

The density contrast is defined by:

$$\delta = \frac{(\bar{\rho}^2 - \bar{\rho}^2)^{1/2}}{\bar{\rho}} = [\exp(\sigma^2) - 1]^{1/2} \gtrsim 0$$

The general conclusion is that increasing the inhomogeneity makes it harder to accomodate extra neutrino species. The conclusion is that the maximum number of

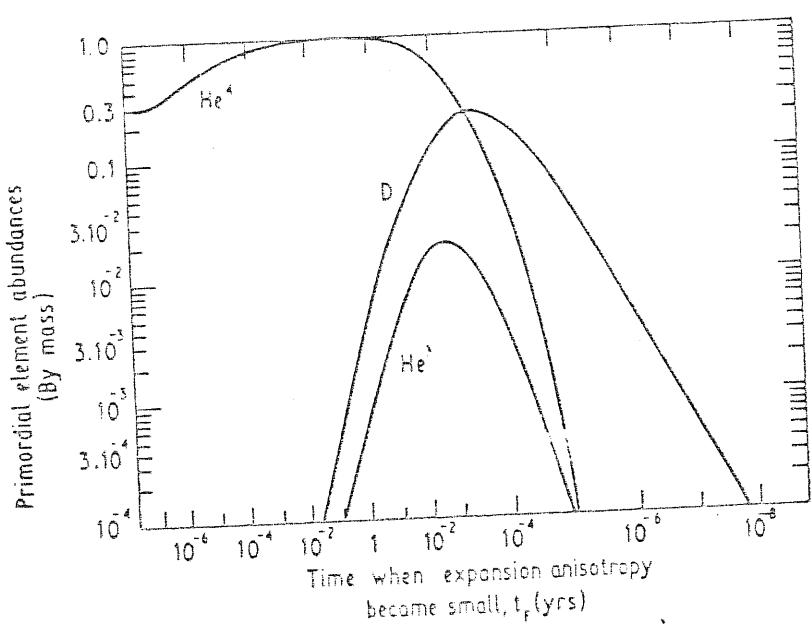


FIGURE 19 Variation of the mass fractions of helium-4, helium-3 and deuterium with an increasing anisotropy, (Thorne, 1967). The influence of collisionless neutrinos with an *anisotropic* momentum distribution has been ignored in these calculations (Barrow, 1982).

Fig 3-13 From Barrow et al 1983

two-component stable neutrinos is 3.(fig 3-14).

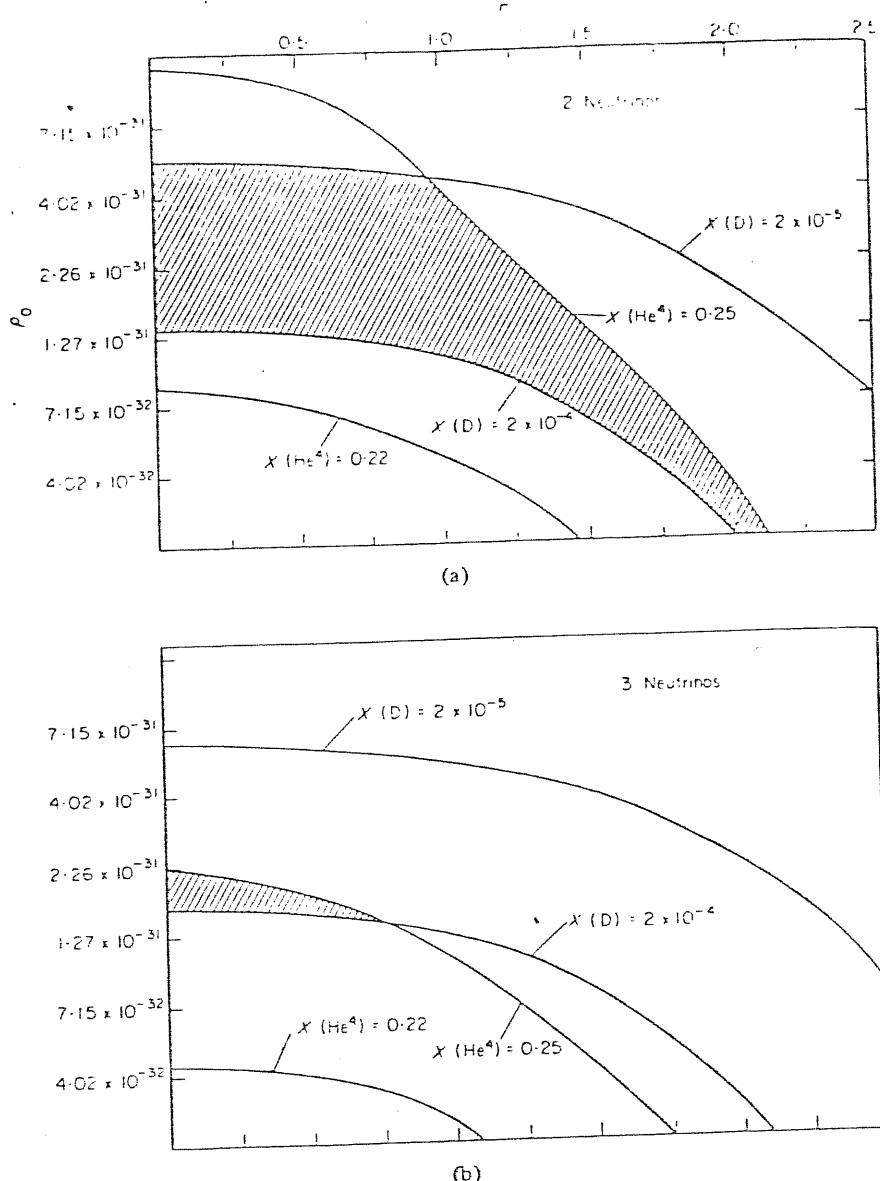


Figure 2. The regions of present mean density, ρ_0 , and the variance σ in the baryon distribution at nucleosynthesis giving rise to helium fractions of 0.22 and 0.25 along with deuterium fractions of 2×10^{-5} and 2×10^{-4} are shown. The shaded regions are the portions of (ρ_0, σ) space compatible with the observed abundances. The plots (a), (b) and (c) are performed for two, three and four light two-component neutrino species respectively.

Fig 3-14 From Barrow et al. 1983

CHAPTER 4
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BE-9 IN POP II STARS: AN INDIRECT CONFIRMATION OF THE PRIMORDIAL ORIGIN OF LI-7

1.1 Summary

An upper limit on the Be-9 abundance in HD 76932, a popII star, has been derived at 3 dex(-12). The present upper limit is significantly lower than the average abundance for pop I stars .This implies an increase of the Be-9 abundance during the galactic life. The Li-7/Be-9 for this star is greater than 30, more than three times of the predicted ratio for a spallation origin. Since others mechanisms proposed for Li-7 production as red giants and novae, cannot have operated effectively in changing the chemical composition of very old stars, the present lower limit should be considered as an indication of the primordial origin of Li-7.

1.2 Introduction

Berillium is the lightest element not synthesized in the Big Bang unless the baryon density has the very unlikely value of dex(-29) g/cm³. (Wagoner 1973) It can be produced by spallation of heavier stellar synthesized ions by energetics cosmic rays but burnt in the hot stellar interiors. Its detection offers insights on the chemical evolution of the galaxy, the physics of the cosmic rays and the structure and evolution of stars.

Due to observational difficulties our knowledge of Be

in the Universe is restricted to the solar neighborhood.

In the meteorites the Be/H is $\sim 2 \cdot 10^{-11}$ (Busek 1971), while in the sun is $\sim 1.2 \cdot 10^{-11}$ according to Ross and Aller (1974) or $1.4 \cdot 10^{-11}$ according to Chimielewski et al 1976.

The observations on a large sample of 38 relatively young F and G stars have given the mean value of $1.3 \cdot 10^{-11} \pm 0.36 \cdot 10^{-11}$ (Boesgaard 1976).

It is relevant to the present analysis to notice that one-third of the stars of this sample hotter than 6600 K show Be deficiency as well as Li deficiency. This anomalous depletion is probably due to diffusion and rotational mixing.

No Berillium has been detected in the interstellar gas but an upper limit at $5 \cdot 10^{-11}$ has been given by Boesgaard (1974).

Dravins and Hultqvist (1977) have observed $2.5 \cdot 10^{-11}$ in α Cen A a solar analogous 8 billions of years old. They also estimate the age for μ Her A in $7 \cdot 10^9$ ys. and in ζ Eri in $8 \cdot 10^9$ ys. for which Boesgaard and Chesley (1976) founded Be/H equal to $2.5 \cdot 10^{-11}$ and $.22 \cdot 10^{-11}$ respectively.

They explain the low value of ζ Eri as the result of a post main-sequence depletion by a factor three.

The network of all these data is that the Be abundance inside the observational horizon is of some units of 10^{-11} practically unchanged during the last 8 billions of years.

Several theoretical models have been proposed to account for the present Be abundance Meneguzzi, Audouze and Reeves (1971), (MAR), Truran and Cameron (1971) (TC) Quirk and Tinsley (1973), (QT), Audouze and Tinsley (1974), (AT).

They all assume Be built-up by spallation processes but with different stellar birthrate at the early infancy of the galaxy. Since all these models fit fairly well the above mentioned observations but differ drastically in the predictions of Be abundance in the early stages of the galaxy observations of very old stars permit to choose between the models.

1.3 The Data And Data Processing

For the analysis I have used an IUE image LWR 7182 of HD 76932 taken in the High Resolution mode and Large Aperture available in the Vilspa Data Bank.

For what concerns a quantitative analysis of Berillium the IUE equipment is not the optimum one because its resolution (.2 Å) is not enough to separate the blends with the other lines. On the contrary the instrument gives a nearly ideal signal to noise ratio that permits to detect also faint lines. The low metallicity of the star under study play in favour of the detection of the Berillium lines since there is no correlation between the metals that are synthesized in stars and the Berillium that has a spallation origin.

A little improvement in the resolution has been obtained reprocessing the data with the procedure of Ramella et al (1983).

Unfortunately a reseaux mark falls exactly on the position of the 3130.2 BeII line. This line is severely blended by

the strong VII at 3130.2 Å and the fainter BeII line at 3131.04 Å is usually used to estimate the Berillium abundance.

In fig 1 it is displayed the region of the BeII doublet after the reprocessing. The position of the reseaux is marked with crosses. The electronic noise has been estimated in portions of the image without signal and 1σ of its average value is represented by the line at the bottom of the figure.

1.4 The Analysis Of The Spectra

An identification of the lines in the Be region has been performed using the synthetic spectrum method and these are listed in table 1.

Since no reliable identification of the fainter line of the Be II doublet (3130.4 Å) is possible due to the not sufficient resolution so only an upper limit to the hypothetical presence of the line can be given.

The characteristics of the atmosphere of the star have been taken from the Cayrel et al (1980) catalogue: the $T_{eff} = 5860$ K, the gravity $g = 3.5$ and the metal deficiency $\log[\text{Fe}/\text{H}] = -1.1$ relative to the sun.

The atmospheric model has been interpolated in the grid of Kurukz, with lightly modification in the region of interest for what concerne lines and log gf according to the more

specifics works of Ross et al. (1974) and Boesgard (1976). The lines and their oscillator strengths for the region between 3129.0 and 3133.0 Å are reported in table 2. The radiative transfer equation has been solved within the LTE hypothesis because in the solar atmosphere according to Ross et al. (1974) the departures from LTE are negligible for the Be lines.

The microturbulence adopted is 1 Km/sec. Anyway the increase of the microturbulence decrease the abundance derived so the low value adopted makes more consistent the upper limit that I shall derive.

The Be equivalent width and its abundance is almost insensitive to temperatures between 5700 and 6600 K (Boesgard 1976).

In the fig 2a are reproduced the stellar spectrum and the synthetic spectrum with a solar Berillium abundance (1.3 dex(-11)). It is possible to see that the synthetic spectrum with a solar abundance for Berillium overflow the observed spectrum indicating a deficiency of this element in the atmosphere of the star compared to the sun.

In fig 2b are reproduced the observed stellar spectrum and the synthetic spectrum with a Berillium abundance of 1.26 dex (-12).

Using the Berillium abundance as free parameter I fixed an upper limit to the Berillium abundance as

$$\text{Be/H} < 3 \text{ dex}(-12)$$

A further indication, even more qualitative, is the comparison with the solar spectrum and other pop I stars. In the solar spectrum the central depth of the line is 0.55 while in the case of HD 76932 the central depth of a virtual line at the same position is 0.35. This means that there is more signal for the halo star in coincidence of the Be II 3130.4 Å line respect to the sun and this is despite the fact that the blending of the lines, due to the IUE instrumental profile, acts to depress the level of the signal.

2.0 EVOLUTIONARY BEHAVIOUR OF BE

The age of the star under study has been discussed by Spite and Spite (1982), (SS) in about 15 billions of years. In the fig 3 are plotted the Be/H observations together with the theoretical models.

The present upper limit is definitively below all the previous estimations. Depletion should be excluded since according to SS it has not worked for Li-7 for all the pop II of their sample hotter than 5500 K.

From the fact that we are dealing with a very old star the low upper limit derived implies a strong increase of the abundance of this element during the first billions of the galactic life.

From the fig 3 it is possible to see that the models that assume a constant (MAR), or exponentially decreasing (TC) stellar birthrate with the life of the galaxy are favourite

respect to those of AT and QT that assume an initially very efficient star formation that makes for old star a Be/H abundance higher than the solar one.

3.0 LI/BE AND COSMOLOGICAL IMPLICATIONS

The Li-7 in pop II stars has been recently measured by SS. The constant value for the Li-7 abundance derived in stars with different metallicities has been interpreted by SS to be the effect of the primordial character of the Lithium observed.

These observations are among the most powerful tool to measure the baryon density of the universe via the standard Big Bang model (Steigman 1983) so any additional argument on its primordial character strengthens our confidence on its applications.

The star that I have analyzed belongs to the sample used by SS to derive the Li-7 abundance. Using their value of 0.9 dex(-10) and the present upper limit the ratio is:

$$\text{Li/Be} > 30$$

While the predicted value by spallation reactions of abundant nuclei (C-12, N-14, O-16, Ne-20) and cosmic ray protons and alpha particles with a cosmic ray spectrum is ~ 10 .

Li-7 can be built up in several ways as spallation, red giants, Novae and Big Bang while Be-9 only through spallation.

In very old stars red giants and novae have not effectively operated to change the chemical composition of the material from which these old stars are formed so we have only:

$$[\text{Li(BB)} + \text{Li(S)}]/\text{Be(S)}$$

In HD 76932 this ratio is more than a factor 3 the value predicted by the spallation so a conspicuous amount of Li-7 cannot have been built up by spallation but should be primordial or made in a pregalactic epoch through mechanisms other than spallation.

The upper limit to the Be abundance constrains to less than 30 % the fraction of Li-7 that can be built up by spallation processes so the bulk of the Li-7 observed by SS should be primordial and we are allowed to use it to derive informations from the Big Bang model.

It is remarkable that if in the future it will be possible to estimate the amount of Be/H ,instead of upper limits, it will be possible to separe the fraction of Li-7 produced by spallation from the primordial one. From the particular valley of the behaviour of the Li-7 abundance against the baryon/photon parameter a lower value of primordial li-7 means a narrower constrain on the Eta value.(Steigman 1983)

4.0 CONCLUSIONS

A careful analysis of a IUE spectrum of a very old star has been performed in the attempt to derive the Berillium abundance. No evidence of the BeII resonance lines has been

found .With the synthetic spectrum method the star has been found to be deficient in Berillium by nearly one order of magnitude respect to the sun. Since this is the first analysis on a pop II star it suggests an increase of the Berillium abundance during the galactic life .From the fact that this star belong to the sample in which SS detected the primordial Lithium the low value for the berillium given in this work exclude the possibility that the Lithium observed by them could be built by spallation processes in the early times of the galaxy life.

Since the present work needs further confirmations- and better data it will be carried on in the future using ground observations in collaboration with J. Audouze ,F. Spite,M. Spite and J.E. Beckman .

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I like to thank D. Sciama that stressed me the importance of light elements in cosmology, Pagel , J. Audouze and J.E. Beckman for useful discussions, F. Castelli and C. Morossi for the programs of the synthetic spectrum.

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Captions to the figures

-Fig. 1;The spectral region of the Be II doublet.The crosses show the reseau mark. The 1 G level of the electronic noise is rapresented by the line at the bottom of the figure.

-Fig. 2 a);The observed spectrum (the fin line) and the synthetic one (thik line) are superimposed. The theoretical model has been computed using the solar abundance for Berillium.

-Fig. 2 b);The same of fig. 2 a), but the Berillium abundance of the synthetic spectrum is 1.3 dex(-12).

-Fig. 3;The fig is adapted from Dravins et al (1977).The theoretical models are reported together the Be determinations.

Captions to the Tables

Table 1;Identification of the main contributors of the lines in the region of the Be II resonance lines.

Table 2;The full list of the lines used in the synthetic model computation with their Log gf, the energy potential of the low level and the damping costant.

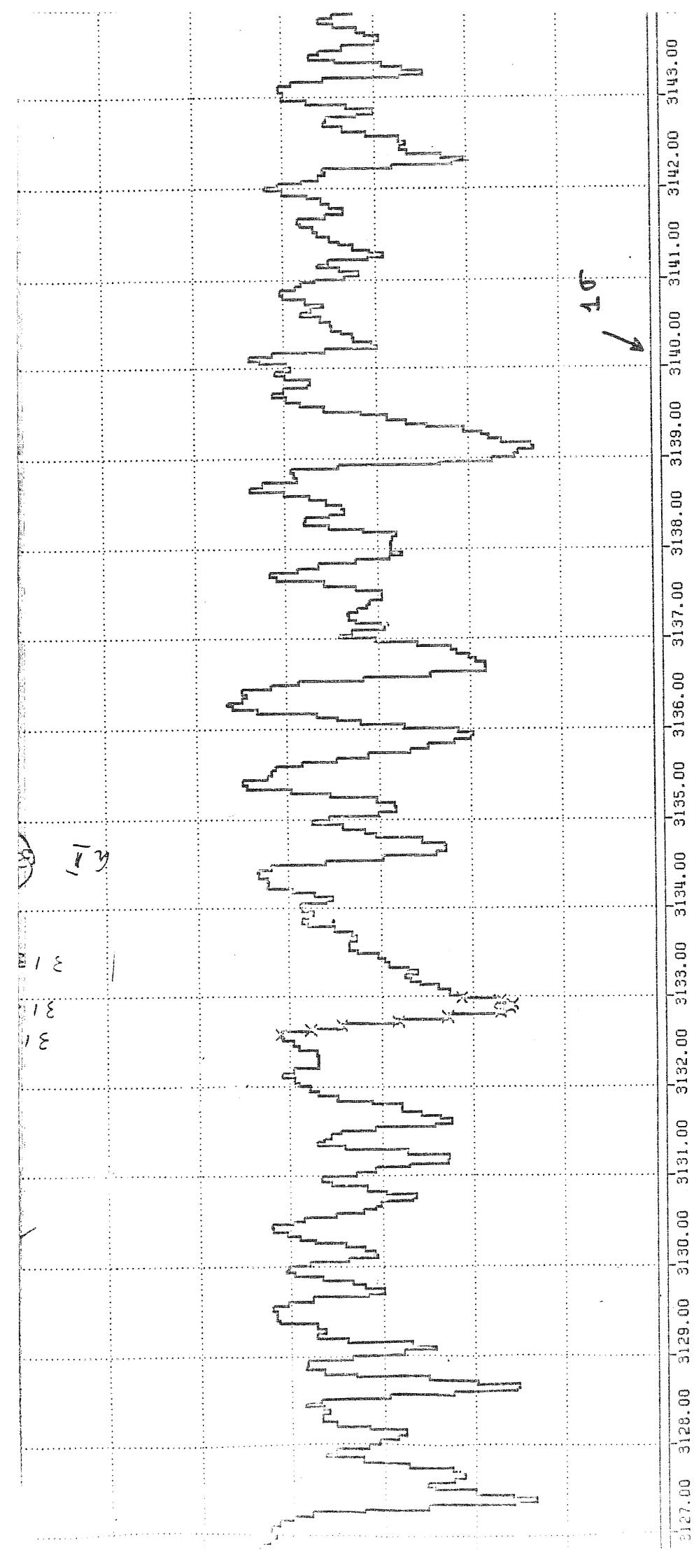


Fig 4

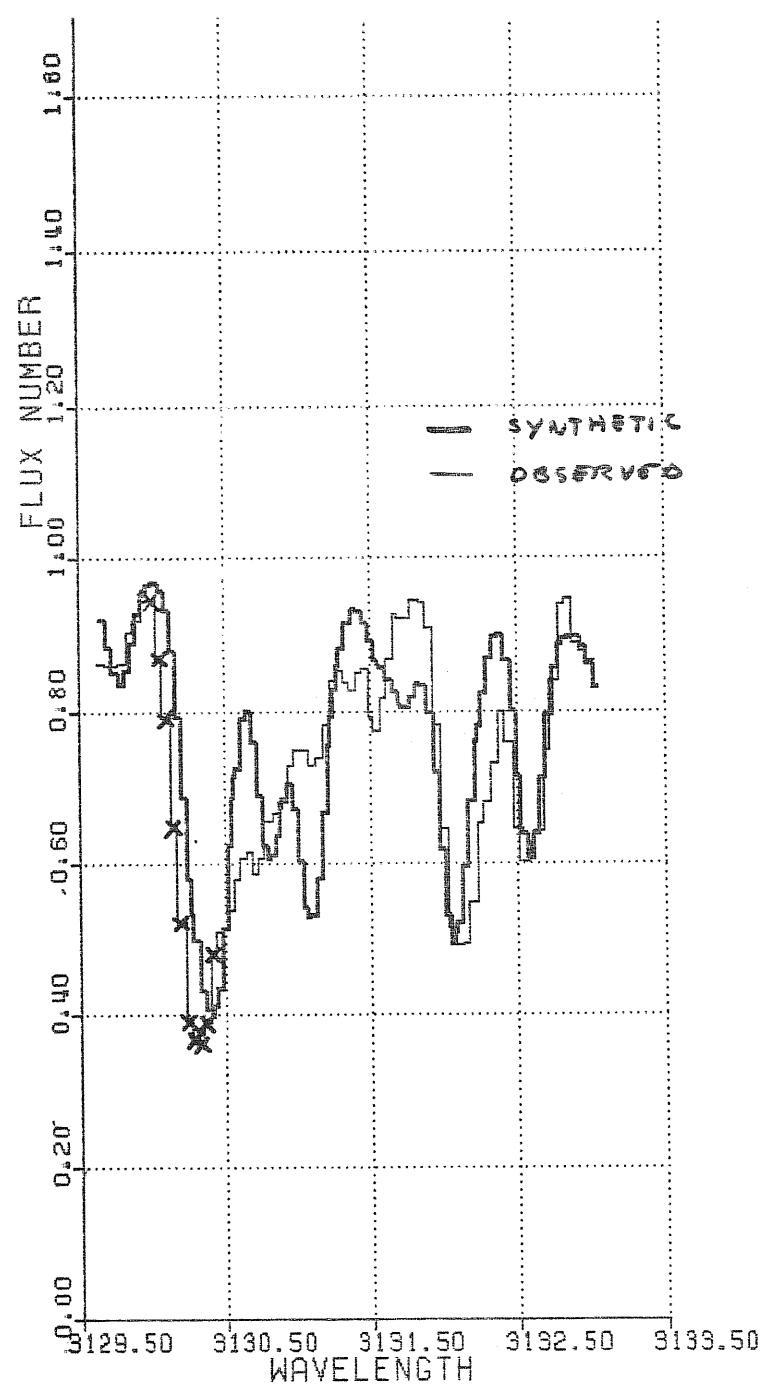


Fig 2a

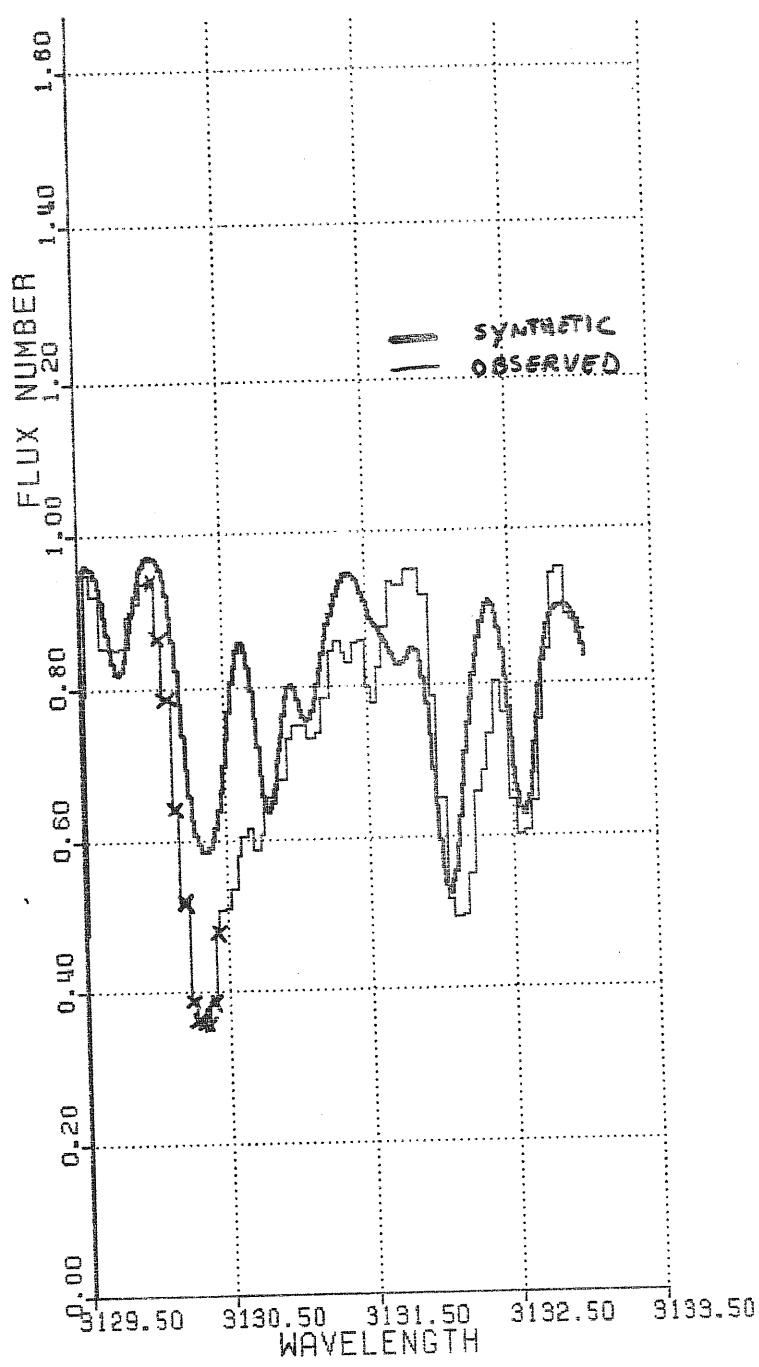


Fig 2 b

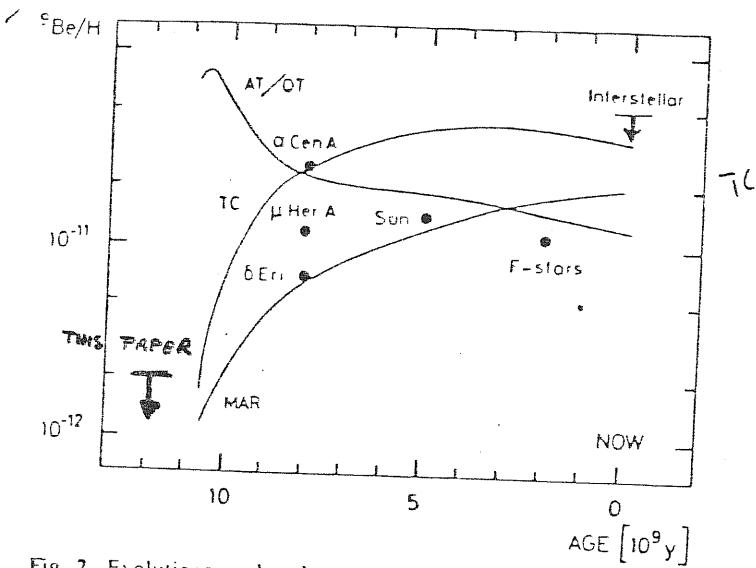


Fig. 2. Evolutionary abundance curves for beryllium in the interstellar medium according to models by Meneguzzi et al. (1971); MAR, by Truran and Cameron (1971); TC and, using a galactic evolution model by Quirk and Tinsley, by Audouze and Tinsley (1974); AT/QT, compared with observed beryllium abundances in objects of different ages. The point marked "F-stars" indicates the average abundance for 23 stars as studied by Boesgaard (1976), placed at the reasonable average age of $2 \cdot 10^9$ years

Fig. 3

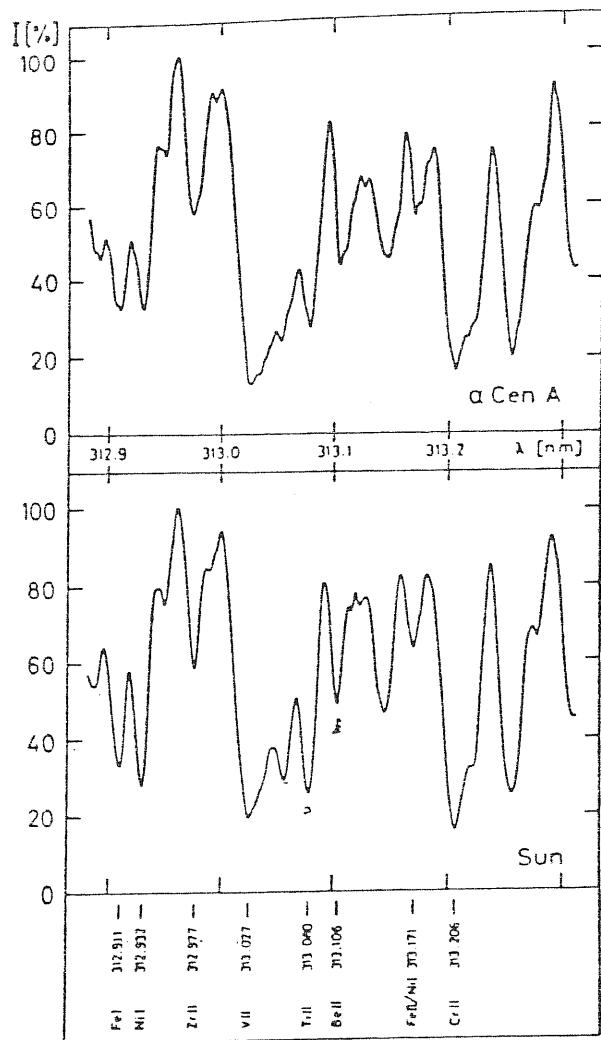


Fig. 1. Spectra for a region around the Be II $\lambda 313.1$ nm resonance line for α Cen A (top) and integrated sunlight, recorded with identical instrumentation as the former (bottom). Identifications are given for relatively unblended lines. Wavelengths are solar values

Fig 4 (NOT IN THE TEXT)

THE SUN SPECTRUM IN Be II

FROM DRAVINS et al 1977

Obser. Main contrib.

3129.1	ZR II	3128.180
	Ti I	3129.183
	Ni I	3129.299
	Fe I	3129.335
3129.8	Zr II	3129.760
3130.3	V II	3130.261
	Be II	3130.420
	Ti II	3130.791
	Be II	3131.065
3132.0	Cr II	3132.036
3132.5	Fe I	3132.514
	V II	3132.587
3133.4	V II	3133.327
	Zr II	3133.480

