# 47. COSMOLOGY (COSMOLOGIE)

PRESIDENT : J. Audouze
VICE-PRESIDENT : G. Setti
ORGANIZING COMMITTEE : J. Gunn, S. Hayakawa, M.S. Longair, I. Novikov, G.A. Tammann, V. Trimble, and G. de Vaucouleurs.

## Introduction

(Jean Audouze)

The preparation of a report dealing with such a large domain is almost an impossible task. Because so many different questions, problems and expertises are assembled under the word "Cosmology", my approach has been the following : first to divide this field in a somewhat arbitrary fashion into the following sections : very early universe - elementary particle and cosmology - early nucleosynthesis - cosmological parameters (Hubble constant, deceleration parameter, cosmological constant) - large scale structures, intergalactic gas, missing mass - clusters of galaxies and intercluster gas - anisotropy of the black body radiation - formation of galaxies - quasars and their evolution - cosmological evolution of radiosources. I have then asked to the most knowledgeable specialists to review briefly each of these most important questions on which many exciting and very new results have been obtained not only by the astrophysicists themselves but also by particle physicists, nuclear physicists, theoretical physicists,... This is why the reader will read in section 1 the report on primordial nucleosynthesis written by G. Steigman, in section 2 Anisotropy of the black body radiation by D.T. Wilkinson and F. Melchiorri, in section 3 Clusters of galaxies by J. Einasto, in section 4 Galaxy formation by B.J.T. Jones, in section 5 Quasars and their evolution by M. Schmidt and in section 6 the Cosmological evolution of radio sources by R.A. Windhorst. Let me thank these colleagues for their excellent work in writing these various reviews.

The reader who wishes to obtain supplementary and very recent information on this very fast moving field could consult many recent review articles such as those gathered in Annual Review of astronomy and astrophysics. They could also read many recent books of proceedings, such as those edited by myself and J. Tran Than Van in Editions Frontières which are based upon an annual series of workshops called the Rencontres d'Astrophysique de Moriond - The book of 1981 is entitled Particles and Cosmology, 1982 The birth of the Universe, 1983 Formation and evolution of galaxies and large structures (published by Reidel), 1984 High energy astrophysics. Three other books could also be quoted in this respect : Astrophysical cosmology edited in 1982 by the Scientific Pontifical Academy, in 1984, A tribute to the memory of Mgr Lemaître (edited by A. Berger and published by Reidel) and the same year, the proceedings of the first ESO-CERN conference held in November 1983 at Geneva and edited by L. Van Hove and G. Setti under the title "Large Scale Structure of the Universe, Cosmology and Fundamental Physics". This list is of course like this report quite fragmentary and it is up to the readers to browse in a huge amount of literature to be informed before contributing to any topic of their choice.

## 1. Primordial Nucleosynthesis - A progress report 1981-1984

(Gary Steigman)

Primordial nucleosynthesis provides a unique window on the early evolution of the Universe. To test the "standard" hot big bang model it is necessary to confront the theoretical predictions with observational data. The last three years have witnessed a wide variety of important observational work of relevance to the goal of deriving the primordial abundances of the light elements.

https://doi.org/10.1017/S0251107X00006726 Published online by Cambridge University Press

*Deuterium* : Since deuterium is destroyed in stars during the course of galactic evolution, the present interstellar abundance of D or that in the presolar nebula provide a *lower* bound on the primordial abundance; if the D-to-H ratio by number is $y_2$ then, $y_{2P} > y_{2\odot} \gtrsim y_{2ISM}$ is expected. From observations of deuterated methane in the atmosphere of Jupiter, Kunde et al (1982) derive from a *comparison of* $CH_3D$ *to* $CH_4$ : $y_2$ *(Jupiter)* = $3.6^{+1.0}_{-1.4} \times 10^{-5}$. *For Jupiter and Saturn,* Encranez and Combes (1982) compare observations of $CH_3D$ with those of $H_2$ and - once a C/H ratio has been adopted - derive : $y_2$ (Jupiter) = $1.2 - 3.1 \times 10^{-5}$, $y_2$ (Saturn) = $2\text{-}15 \times 10^{-5}$. An indirect approach to the presolar deuterium abundance is to compare the $^3He$ content of the gas rich meteorites or the solar wind (where presolar D has been burned to $^3He$) with that of the primitive, carbonaceous chondrites (presumably $^3He$ uncontaminated by D). From the data summarized by Geiss (1982) we may derive : $y_{2\odot} \equiv y_{23\odot} - y_{3\odot} = 2.9 \pm 0.5 \times 10^{-5}$. All these results - as well as older data - are consistent with a presolar deuterium abundance in excess of $\sim 1\text{-}2 \times 10^{-5}$ suggesting that $y_{2P} > y_{2\odot} \gtrsim 1\text{-}2 \times 10^{-5}$. A cautionary note sounded by Geiss and Reeves (1981) is worth echoing - they point to the enormous enhancement of deuterium in interstellar molecules, especially in dark clouds, and suggest that the presolar D abundance need not have been representative of the D/H ratio in the "average" interstellar gas 4.5 billion years ago. The wide variation in the D/H ratio inferred from the study of interstellar molecules ($10^{-4} \lesssim$ D/H $\lesssim 3$) reminds us that observations of deuterated molecules in the atmospheres of the giant planets may provide more information about the physics and chemistry of planetary atmospheres than about the protosolar abundance of deuterium.

Exciting - and confusing - developments have occured concerning the interstellar abundance of deuterium. Earlier ultraviolet observations of deuterium absorption features in the wings of the much stronger hydrogen Lyman lines had led to estimates of the D abundance which spanned an uncomfortably large range ($4 \times 10^{-6} \lesssim y_{2ISM} \lesssim 8 \times 10^{-5}$). Bruston et al (1981) discussed various mechanisms which may have produced such variations and concluded that the data was consistent with a "universal" interstellar abundance : $y_2$(ISM) $\approx 2\text{-}2.5 \times 10^{-5}$. Given the uncertainties in the solar system and interstellar abundances, it was unclear if there had been any destruction of D since the formation of the solar system. However, an upheaval occured when Vidal-Madjar et al (1982) had great difficulty in finding a consistent model describing the line-of-sight to εPer; although their data was compatible with $y_2 = 1.5 \times 10^{-5}$, it was, apparently, also compatible with $y_2 \sim 10^{-4}$. More important, they found a high velocity feature which *varied* by at least a factor of 3 in column density within a few hours. In a follow-up study, Vidal-Madjar et al (1983) argued that the "deuterium" observations in εPer were not D at all but, "wrong" velocity ($\sim -80 km^{-1}$) hydrogen in a stellar wind. They discovered variable features in the spectra towards other stars and concluded that this "contamination" of the previous deuterium abundance determinations would argue for the *lowest* observed D/H ratio as the best interstellar value; Vidal-Madjar et al (1983) suggest $y_2$(ISM) $\lesssim 5 \times 10^{-6}$. If their suggestion is correct, it is curious that stars whose line-of-sight hydrogen column densities range over more than two orders of magnitude, must have "wrong" velocity stellar wind hydrogen column densities which - in lock step - also range over two orders of magnitude so that we have been fooled into believing that $y_2 \approx 2 \times 10^{-5}$. If, indeed, D/H in the present interstellar gas is as low as $5 \times 10^{-6}$, then deuterium has been destroyed by at least a factor of 2-4 in the last 4.5 byr. In this case, interstellar deuterium observations are of little value to primordial nucleosynthesis but of great value to studies of galactic evolution. An excellent survey of the observational situation is to be found in Laurent's (1983) article.

*Helium-3* : Since some stars ($M \lesssim 1\text{-}2\ M_\odot$) are net producers of $^3He$ while others destroy $^3He$, the value of He in constraining the "standard" hot big bang model is questionable. However stars do burn deuterium to $^3He$, *some* of which - in the cooler, outer layers, - will survive. Yang et al (1984) exploited this result to place an *upper* limit on the *sum* of the primordial abundances of D and $^3He$ survives as D or $^3He$. Using the presolar abundances of D and $^3He$, Yang et al (1984)

https://doi.org/10.1017/S0251107X00006726 Published online by Cambridge University Press

find : $y_{23P} \lesssim 6\text{-}10 \times 10^{-5}$. It is expected that $^3$He production in low mass stars would have led to enhanced abundance of interstellar $^3$He in the time since the formation of the solar system (Rood et al, 1976). After years of heroic effort, Rood et al (1984) reported the detection of interstellar $^3$He via the hyperfine line (8.7 GHz) of $^3$He$^+$ in three galactic HII regions; they also found upper limits to $^3$He/H in three other HII regions. The surprise of the results of Rood et al (1984) is that the $^3$He abundance ranges over more than an order of magnitude : $y_3 = 4\text{-}40 \times 10^{-5}$ for the three positive detections; $y_3 < 2\text{-}6 \times 10^{-5}$ for the hupper limits. Although none of the upper limits is *yet* in conflict with the presolar value of $y_{3\odot} \approx 1.5 \times 10^{-5}$, the range and magnitude of the apparent enhancements are a puzzle for galactic evolution.

*Lithium* : Perhaps the single most important set of observations of relevance to primordial nucleosynthesis in the last three years has been that of lithium in old years of Population II by the Spites (Spite and Spite 1982a,b; Spite et al 1984). Since, in the course of normal stellar evolution, surface lithium is convected to the interior and burned away, no detectable lithium was anticipated in Pop II stars. In observations of more than two dozen Pop II stars, the Spites have found for those with an effective surface temperature in the range $T_{eff}$ = 5500-6250 K, a constant abundance of lithium : $y_7(\text{Pop II}) = 1.1 \pm 0.4 \times 10^{-10}$ which they interpret as the primordial value ($y_{7P} \approx y_7(\text{Pop II}) \approx 1 \times 10^{-10}$). This value for Li/H is an order of magnitude lower than that derived for the presolar nebula from meteoritic studies, from the present ISM and for Pop I stars of a variety of ages. Indeed, the apparent constancy of the "Pop I" lithium abundance ($y_7(\text{Pop I})$ 1 x $10^{-9}$) over the last 4.5 byr has, until the Spites' observations, led to the natural conclusion that $y_{7P} \approx y_7(\text{Pop I})$. If their exciting discovery withstands further scrutiny, the Spites' abondance for Pop II is of immense importance for primordial nucleosynthesis ($y_{7P} \approx y_7(\text{Pop II})$), for stellar structure and evolution (Why haven't the Pop II stars destroyed their lithium ?) and for galactic evolution.

*Helium 4* : The primordial abundance of $^4$He is the Rosetta Stone of the hot big bang model. Since the predicted primordial mass fraction of $^4$He, $Y_p$, is insensitive to the universal density of nucleons (more precisely, to the nucleon-to-photon ratio $\eta \equiv N/\gamma$) and is only weakly dependent on other parameters (neutron half-life $\tau_{1/2}$; number of light, 2-component neutrino species $N_\nu$), the standard model stands or falls as a result of the outcome of a detailed comparison between theory and observation. Unfortunately, the accuracy of the data required for such a comparison is unprecedented; to truly test or significantly constrain the standard model the primordial abundance inferred from observational data should be determined to better than 2% ($\Delta Y_p \lesssim 0.005$). As Tully et al (1981), Shaver et al (1983), Kunth and Sargent (1983) and, especially, Kinman and Davidson (1984) have emphasized, there are myriad obstacles to deriving highly accurate estimates of $Y_p$ even from observational data of extraordinary quality. Two of the most serious problems are the necessary - and uncertain - correction for neutral helium (Shaver et al 1983) and, the contamination of the primordial abundance by stellar produced $^4$He - the correction for evolution. Failure to make these corrections and to account for the *uncertainties* of these corrections leads to conclusions of questionable value. From a very careful study of several HII regions in M101 Rayo et al (1982 derived a $^4$He abundance for one HII region (NGC5471) which they extrapolated to a (very low) primordial abundance $Y_p$ = 0.216. In deriving this value, Rayo et al (1982) took no account of possible neutral helium nor did they include any uncertainty for the evolutionary correction. In contrast, Rosa (1983) showed that the apparent abundance varies across NGC5471, depending on the aperture used; correcting for neutral helium, Rosa (1983) found $Y_p \approx 0.24$. Steigman (1983) too found that the ionization corrections is unlikely to be negligible (He$^0$/He$^+$ ≈ 0.07-0.13; Smith (1975) found 0.10-0.16) and derived from the data of Rayo et al (1982) : $Y_p = 0.235 \pm 0.010$.

The most extensive, high accuracy study of extragalactic HII regions has recently been completed by Kunth and Sargent (1983). Having studied 13 low metal abundance HII regions (to minimize the contamination from stellar produced $^4$He)

https://doi.org/10.1017/S0251107X00006726 Published online by Cambridge University Press

they derive : $Y_p = 0.24 \pm 0.003$, a result they find in agreement with *all* previous high quality data. Although Kunth and Sargent (1983) did correct for neutral helium (but assigned no uncertainty to that correction) they argued that no correction was necessary for stellar contamination. With allowance for possible contamination - as well as account for the various uncertainties, Steigman (1983) derives from the Kunth-Sargent data : $Y_p = 0.241 \pm 0.008$. The bottom line - at present - is that it is likely that the primordial mass fraction of $^4$He is in the range $0.23 \lesssim Y_p \lesssim 0.25$; if one were less sanguine about the uncertainties then, $0.22 \lesssim Y_p \lesssim 0.26$ is not inconsistent with current data.

For the best recent work on the abundances of the light elements the Proceedings of the ESO Workshop on Primordial Helium (1983) is recommended; the excellent review by Pagel (1982) as well as that by Steigman and Boesgaard (1984) are also recommended. Lest this summary become unbalanced we turn to the theoretical developments of the last three years.

*Limits To "New" Light Particles* : Olive et al (1981a) considered the uncertainty in the bound on $N_\nu$ - the number of light neutrino flavors - from the primordial $^4$He mass fraction due to the uncertainty in the value of the neutron half-life. Olive et al (1981a) noted that if nucleons dominated the mass on the scale of binary galaxies and small groups of galaxies (so that the nucleon-to-photon ratio $\eta \gtrsim 2 \times 10^{-10}$), then $N\nu < 4$ if $Y_p < 0.25$. However, since the dark mass on such scales need not be nucleonic, Olive et al (1981a) found that if only the mass in the luminous parts of galaxies is nucleonic ($\eta \lesssim 3 \times 10^{-11}$) then there is *no* limit to $N_\nu$.Olive et al (1981b) noted that limits (if they existed!) to $N_\nu$ actually provided constraints on *all* weakly or superweakly interacting light particles. Kolb and Scherrer (1982) considered the effect of neutrino masses to better define "light".Kolb and Scherrer (1982) find that each neutrino species with $M_\nu \lesssim 0.1$ MeV contributes $\Delta N_\nu = 1$; those with $M_\nu \gtrsim 25$ MeV, contribute $\Delta N_\nu \lesssim 1$ ($\Delta N_\nu \to 0$ for $M_\nu >> 25$ MeV). However, for $0.1 \lesssim M_\nu$ (MeV) $\lesssim$ 10-15 MeV, $\Delta N_\nu \gtrsim 1$. Schramm and Steigman (1984) pointed out that the constraint on $N_\nu$ from the width of the $Z^0$ boson is complementary to that from nucleosynthesis. The Width of the $Z^0$ increases with the addition of species which couple directly to the $Z^0$ even if they are heavy ($M_\nu \lesssim 45$ GeV). In contrast, the constraint from big bang nucleosynthesis is sensitive to all light ($M_\nu \lesssim 25$ MeV) particles even if they don't couple directly to the $Z^0$.

The bound $N_\nu < 4$ was reestablished by Yang et al (1984) who discovered how the bound $\eta$ from below. Yang et al (1984) noted that D and $^3$He are overproduced in low $\eta$ Universes and that *some* of the primordial $^3$He (plus primordial D burned to $^3$He) will survive stellar processing. Using the solar system observations of $^3$He, Yang et al (1984) argued that $[(D+{}^3He)/H]_p \lesssim 6\text{-}10 \times 10^{-5}$. This *upper* bound to primordial D and $^3$He leads to a *lower* bound to the nucleon-to-photon ratio : $\eta \gtrsim 3\text{-}4 \times 10^{-5}$ which, for $Y_p \lesssim 0.25\text{-}0.26$ leads to $N_\nu \lesssim 4$.

*Consistency Of The Standard Model* : Yang et al (1984) have made a detailed comparison of the predictions of the standard model ($N_\nu = 3$, $\tau_{1/2} = 10.6 \pm 0.2$ min.) with the observational data (see also Pagel 1982). They find the standard model is consistent with the data for the nucleon abundance in the range : $3\text{-}4 \lesssim 10^{10}\ \eta \lesssim 7\text{-}10$. With these values for $\eta$ the ratio of the nucleon mass density to the critical density, $\Omega_N$, is for - $H_0 \approx 50\text{-}100$ kms$^{-1}$ Mpc$^{-1}$ and $T_{\gamma 0} = 2.7 - 3.0$ K - in the range : $0.01 \lesssim \Omega_N, \lesssim 0.14 - 0.19$. The lower bound on $\Omega_N$ is consistent with that inferred from the dynamics of the *luminous* parts of galaxies; the upper limit suggests that much - perhaps all - the dark mass observed could be nucleonic.

Beaudet and Reeves (1983) and Yang et al (1984) probed the sensitivity of the predicted abundances to possible variations in various - crucial - nuclear cross sections. While the predicted abundances of D, $^3$He and $^4$He should be accurate to better than a few percent, the $^7$Li abundance is uncertain by a factor of two. Since very detailed comparisons between the predicted and observed abundances of $^4$He are required to test the standard model, the predicted abundance should be accurate to better than a few percent. In a very detailed study of radiative, finite temperature and density, coulomb and plasma corrections to the weak inter-

https://doi.org/10.1017/S0251107X00006726 Published online by Cambridge University Press

action rates, Dicus et al (1982) found a small but systematic decrease ($\Delta Y_p \approx -0.003$) in the predicted $^4$He mass fraction; see also Cambier et al (1983) and Johansson et al (1983).

Constraints On Deviations From The Standard Model : The excellent agreement between prediction of the standard model and the observed abundances (Yang et al 1984) leaves little room for deviations from the standard model. The upper limit $N_\nu < 4$ corresponds to a limit on the speed-up on the expansion rate - during the epoch of nucleosynthesis; the Universe can have expanded no more than 8% faster than the rate given by the standard model. Although this leads to significant constraints on isotropy, Barrow (1984) notes that anisotropic models (even during the present epoch) could yield abundances which are not in conflict with the data.For models which do become isotropic by the present epoch, Rothman and Matzner (1984) find even more stringent limits to anisotropy than found in earlier work.

Nucleosynthesis in inhomogeneous cosmologies has been studied recently by Matzner (1982), Yang et al (1984) and Barrow and Morgan (1983) who find that $\delta\rho/\rho$ is limited to ~ few if $^4$He is not be overproduced.

The effect of neutrino degeneracy was investigated by Fry and Hogan (1982), Rana (1982), Scherrer (1983) and Steigman (1984). The agreement of the standard - nondegenerate - model is lost if the neutrinos are "too" degenerate; for $\mu$- or $\tau$-neutrinos, $|\zeta_\nu| \lesssim 1.4$; for e-neutrinos, $-0.05 \lesssim \zeta_e \lesssim 0.10$ (Steigman 1984). Also, even for degenerate e- and $\mu$- (or $\tau$-) neutrinos, a Universe closed by nucleons ($\Omega_N=1$) is not allowed (Steigman 1984).

The theoretical and observational activity of the last three years have led to issues and questions which promise to keep us all busy for (at least) the next three years.

REFERENCES

Barrow, J.D., M.N.R.A.S., 211 (In press) (1984).
Barrow, J.D. and Morgan, J., MNRAS 203, 393 (1983)
Beaudet, G. and Reeves, H., In Proc. of ESO Workshop, p. 53 (1983)
Bruston, P., Audouze, J., Vidal-Madjar, A. and Laurent, C., Ap.J. 243, 161 (1981)
Cambier, J-L., Primack, J.R. and Sher, M., Nucl. Phys. B20, 372 (1983).
Dicus, D.A., Kolb, E.W., Gleeson, A.M., Sudarshan, E.C.G., Teplitz, V.L. and Turner, M.S., Phys. Rev. D26, 2694 (1982).
Encrenaz, T. and Combes, M., Icarus 52, 54 (1982).
Fry, J.N. and Hogan, C.J., Phys. Rev. Lett. 49, 1873 (1982).
Geiss, J., Sp. Sci. Rev. 33, 201 (1982).
Geiss, J. and Reeves, H., Astron. Astrophys. 93, 189 (1981).
Harris, M.J., Fowler, W.A., Caughlan, G.R. and Zimmerman, B.A., Ann. Rev. Astron. Astrophys. 21, 165 (1983).
Johansson, A.E.I., Peressutti, G. and Skagerstam, B-S.K., Phys. Lett. B117, 171 (1982).
Kinman, T.D. and Davidson, K., Ap. J. (In press) (1984).
Kolb, E.W. and Scherrer, R.J., Phys. Rev. D25, 1481 (1982).
Kunde, V., Hanel, R., Maguire, W., Gautier, D., Baluteau, J.P., Marten, A., Chedin, A., Husson, N. and Scott, N., Ap. J. 263, 443 (1982).
Kunth, D. and Sargent, W.L.W., Ap. J. 273, 81 (1983).
Laurent, C., In "Proc. of ESO Workshop" p. 335 (1983).
Matzner, R., In "Numerical Astrophysics" (eds., J. Centrella, J. LeBlanc and R. Bowers, Jones & Bartlett, Boston) In Press (1982).
Olive, K.A., Schramm, D.N., Steigman, G., Turner, M.S. and Yang, J., Ap. J. 246, 557 (1981a).
Olive, K.A., Schramm, D.N. and Steigman, G., Nucl. Phys. B180, 497 (1981b).
Pagel, B.E.J., Phil. Trans. Roy. Soc. London A307, 19 (1982).
Rana, N., Phys. Rev. Lett. 48, 209 (1982).
Rayo, J., Peimbert, M. and Torres-Peimbert, S., Ap. J. 255, 1 (1982).
Rood, R.T., Steigman, G. and Tinsley, B.M., Ap. J. (Lett.) 207, L57 (1976).
Rood, R.T., Bania, T.M. and Wilson, T.L., Ap. J. 280, 629 (1984).

https://doi.org/10.1017/S0251107X00006726 Published online by Cambridge University Press

Rosa, M., In "Proc. of the ESO Workshop", p. 317 (1983).
Rothman, T. and Matzner, R., Phys. Rev. D30, 1649 (1984).
Scherrer, R.J., M.N.R.A.S. 205, 683 (1983).
Schramm, D.N. and Steigman, G., Phys. Lett. B141, 337 (1984).
Shaver, P.A., McGee, M.X., Newton, L.M., Danks, A.C. and Pottasch, S.R., M.N.R.A.S. 204, 53 (1983).
Smith, H.E., Ap. J., 199, 591 (1975).
Spite, F. and Spite, M., Astron. Astrophys. 115, 357 (1982a).
Spite, F. and Spite, M., Nature 297, 483 (1982b).
Spite, M., Maillard, J.P. and Spite, F., Astron. Astrophys., In Press (1984).
Steigman, G., In Proc. of Yerkes Conf., In Press (1983).
Steigman, G., "How Degenerate Can We Be " (In Preparation) (1984).
Steigman, G. and Boesgaard, A.M., Ann. Rev. Astron. Astrophys. 23, In Press (1984).
Tully, R.B., Boesgaard, A.M., Dyck, A.M. and Schempp, W.V., Ap. J. 246, 38 (1981).
Vidal-Madjar, A., Ferlet, R., Laurent, C. and York, D.G., Ap. J. 260, 128 (1982).
Vidal-Madjar, A., Laurent, C., Gry, C;, Bruston, P., Ferlet, R. and York, D.G., Astron. Astrophys. 120, 58 (1983).
Yang, J., Turner, M.S., Steigman, G., Schramm, D.N. and Olive, K.A., Ap. J. 281, 493 (1984).

Note added by J. Audouze : Like many other fields of cosmology, the consequences of primordial nucleosynthesis on the actual present density of the Universe and the number of lepton flavours might not be as firmly established as written in the report of Professor Steigman. There is now a friendly debate between (1) the Chicago-Bartol school who claims as written e.g. in Yang et al. 1984 that the baryonic density of the Universe is necessarily equal to about 5% of the critical density and that canonical primordial nucleosynthesis implies also a number of three lepton flavours (in agreement with the Grand Unification theory scheme) and (2) the "french" school. Our group has attempted in several publications to write some words of caution about these conclusions.

As shown by Vidal-Madjar and Gry (1984) and by Audouze (1984) the baryonic density deduced from $^4$He and D primordial abundances seem to be inconsistent to each other. This is why Delbourgo-Salvador et al. (1985) have shown that in order to restore such a consistency, one must invoke some specific models of chemical evolution of galaxies leading to a large destruction of D (by about a factor 10) during the history of the galaxy. Moreover Audouze et al. (1985) and Schaeffer et al. (1985) are proposing some mechanisms by which the results of primordial nucleosynthesis could be consistent with a closed ($\Omega > 1$) Universe.

In the first scenario, if the baryonic density is very large, $^4$He and $^7$Li could be synthetized but not D and $^3$He. Those two last nuclear species could be formed by a secondary process like partial photodestruction of $^4$He induced by high energy photons coming from the decay of hypothetical massive neutrinos and/or gravitinos. In the second the baryonic density would be still low but the bulk of the matter density could be made of nuggets of quark matter. Finally I do concur with Professor Steigman on his last statement according which our community will kept busy during the next coming years.

Additional references

Audouze, J. : 1984, in Primordial Helium, ed. by P.A. Shaver et al, ESO p.3.
Audouze, J., Lindley, D. and Silk, J. : 1985, Ap. J. (in press).
Delbourgo-Salvador, P., Gry, C., Malinie, G. and Audouze, J. : 1985, Astron. Astrophys. (in press).
Schaeffer, R., Delbourgo-Salvador, P. and Audouze, J. : 1985, submitted to Nature.
Vidal-Madjar, A. and Gry, C. : 1984, Astron. Astrophys. 138, 285.

https://doi.org/10.1017/S0251107X00006726 Published online by Cambridge University Press