Mem. S.A.It. Suppl. Vol. 22, 189

Memorie della
Supplementi

Reducing the space for a nuclear physics solution of the cosmic ^{7}Li problem

C. Broggini[1], L. Canton[1], G. Fiorentini[2,4], and F. L. Villante[3,5]

[1] Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Padova, Padova I-35131, Italy
[2] Istituto Nazionale di Fisica Nucleare (INFN), Laboratori Nazionali di Legnaro (LNL), Legnaro (PD) I- 35020, Italy
[3] Istituto Nazionale di Fisica Nucleare (INFN), Laboratori Nazionali del Gran Sasso (LNGS), Assergi (AQ) I-67010, Italy
[4] Dipartimento di Fisica, Università di Ferrara, Ferrara I-44100, Italy
[5] Dipartimento di Fisica, Università di L'Aquila, L'Aquila I-67100, Italy

Abstract. The primordial abundance of ^{7}Li as predicted by Big Bang Nucleosynthesis (BBN) is more than a factor 2 larger than what has been observed in metal-poor halo stars. Herein, we analyze the possibility that this discrepancy originates from incorrect assumptions about the nuclear reaction cross sections relevant for BBN. To do this, we introduce an efficient method to calculate the changes in the ^{7}Li abundance produced by arbitrary (temperature dependent) modifications of the nuclear reaction rates. Then, considering that ^{7}Li is mainly produced from ^{7}Be via the electron capture process $^7\mathrm{Be} + \mathrm{e}^- \rightarrow {}^7\mathrm{Li} + \nu_\mathrm{e}$, we assess the impact of the various channels of ^{7}Be destruction. Differently from previous analysis, we consider the role of unknown resonances by using a complete formalism which takes into account the effect of Coulomb and centrifugal barrier penetration and that does not rely on the use of the narrow resonance approximation. As a result of this, the possibility of a nuclear physics solution to the ^{7}Li problem is significantly suppressed.

Key words. big bang nucleosynthesis, physics of the early universe

1. Introduction

In standard BBN, the primordial abundances of light elements, namely ^{2}H, ^{3}He, ^{4}He and ^{7}Li, depend on only one free parameter, the present baryon-to-photon ratio $\eta \equiv (N_\mathrm{B} - N_{\overline{\mathrm{B}}})/N_\gamma$, which is related to the baryon density of the universe by $\Omega_\mathrm{B} h^2 = 3.65 \cdot 10^7\,\eta$. This quantity can be constrained with high accuracy from the observation of the anisotropies of the Cosmic Microwave Background (CMB). The latest WMAP-7 results suggest $\Omega_\mathrm{B} h^2 = 0.02249 \pm 0.00056$[1], which corresponds to $\eta_\mathrm{CMB} = 6.16 \pm 0.15 \times 10^{-10}$. If this value is accepted, then BBN is a parameter free theory which can be used to test the standard cosmological model and/or the chemical evolution of the universe.

However, comparison of theoretical predictions with observational data is not straightforward. Data are subject to poorly known evo-

[1] Due to space limitation, we provide a limited reference list. For a complete list of references see Broggini et al. (2012).

lutionary effects and there are systematic errors. Even so, the agreement between the predicted primordial abundances of ^{2}H and ^{4}He and the values inferred from observations is non-trivial. The situation is much more complicated for ^{7}Li. Using $\eta = \eta_{\rm CMB}$, the predicted primordial ^{7}Li abundance is (Cyburt et al. 2008)

$$({\rm Li/H})_{\rm BBN} \simeq (5.1^{+0.7}_{-0.6}) \times 10^{-10}. \quad (1)$$

This is a factor ~ 3 larger than that inferred by observing the so-called 'Spite Plateau' in the ^{7}Li abundance of metal-poor halo stars, which has been given (Nakamura et al. 2010) as

$$({\rm Li/H})_{\rm obs} \simeq (1.7 \pm 0.06 \pm 0.44) \times 10^{-10}. \quad (2)$$

The quoted errors take into account the dispersion of the various observational determinations.

The abundance of ^{7}Li is a central unresolved issue in BBN (Cyburt et al. 2008) about which there has been recent concern regarding erroneous evaluation of nuclear reaction rates responsible for ^{7}Li production. Coc et al. (2003) noted that an increase by a factor greater than 1000 in the sub-dominant $^7{\rm Be}(d,p)2\alpha$ cross section could provide the necessary suppression of ^{7}Li. This enhancement was not found in experimental data (Angulo et al. 2005) but could have escaped detection if it were produced by a sufficiently narrow resonance, as suggested by Cyburt & Pospelov (2009). Other possible resonant destruction channels have been considered by Chakraborty et al. (2011) as well, such as the channels $^7{\rm Be} + {}^3{\rm He} \to {}^{10}{\rm C}$ and $^7{\rm Be} + t \to {}^{10}{\rm B}$ that await experimental verification.

In this small review, that is based on the results of Broggini et al. (2012), we provide an updated discussion showing that the possibility of a nuclear physics solution to the cosmic ^{7}Li problem is substantially suppressed.

2. The ^{7}Li response to nuclear reaction rate modifications

At $\eta = \eta_{\rm CMB} \simeq 6 \times 10^{-10}$, ^{7}Li is mainly produced from ^{7}Be that undergoes at late times (*i.e.* long after the ^{7}Be synthesis) the electron capture process $e^- + {}^7{\rm Be} \to {}^7{\rm Li} + \nu_e$. Following Esmailzadeh et al. (1991), we thus expect that the lithium-7 abundance $Y_{\rm Li}$ is approximately given by:

$$Y_{\rm Li} \sim \left.\frac{C_{\rm Be}}{D_{\rm Be}}\right|_{T=T_{\rm Be,f}}, \quad (3)$$

where $C_{\rm Be}$ and $D_{\rm Be}$ are the total ^{7}Be production and destruction rates and $T_{\rm Be,f} \sim 50\,{\rm keV}$ is the freeze-out temperature for ^{7}Be, i.e. the temperature below which the rates $C_{\rm Be}$ and $D_{\rm Be}$ become smaller than the Hubble expansion rate. The dominant ^{7}Be production mechanism is through the capture reaction $^3{\rm He}(\alpha,\gamma)^7{\rm Be}$. This process has been well studied both experimentally and theoretically and its cross section is known to $\sim 3\%$ uncertainty. A sizeable reduction of the ^{7}Li predicted abundance can, thus, occur only if large increase of the ^{7}Be destruction rate is allowed.

In order to discuss this possibility, we introduce a simple formalism to describe the response of ^{7}Li to a generic (temperature dependent) modification of the ^{7}Be destruction rate. Motivated by Eq.(3), we assume that a linear relation exists between the *inverse* ^{7}Li abundance, $X_{\rm Li} \equiv 1/Y_{\rm Li}$, and $D_{\rm Be}(T)$. This relation can be expressed in general terms as[2],

$$\delta X_{\rm Li} = \int \frac{dT}{T}\, K(T)\, \delta D_{\rm Be}(T), \quad (4)$$

where

$$\delta X_{\rm Li} = \frac{X_{\rm Li}}{\overline{X}_{\rm Li}} - 1, \quad (5)$$

and

$$\delta D_{\rm Be}(T) = \frac{D_{\rm Be}(T)}{\overline{D}_{\rm Be}(T)} - 1. \quad (6)$$

The integral kernel $K(T)$ has been evaluated numerically by considering the effects of localised (in temperature) increases of the reaction rate $D_{\rm Be}(T)$. Our results are shown by the black solid line in Fig. 1. We checked numerically that Eq. (4) describes accurately large variations of the ^{7}Li abundance (up to a factor ~ 2) and, thus, it is adequate for our purposes. The kernel $K(T)$ is peaked at ~ 50 keV;

[2] Here and in the following, the notation $\overline{Q}$ refers to the standard value for the generic quantity Q.

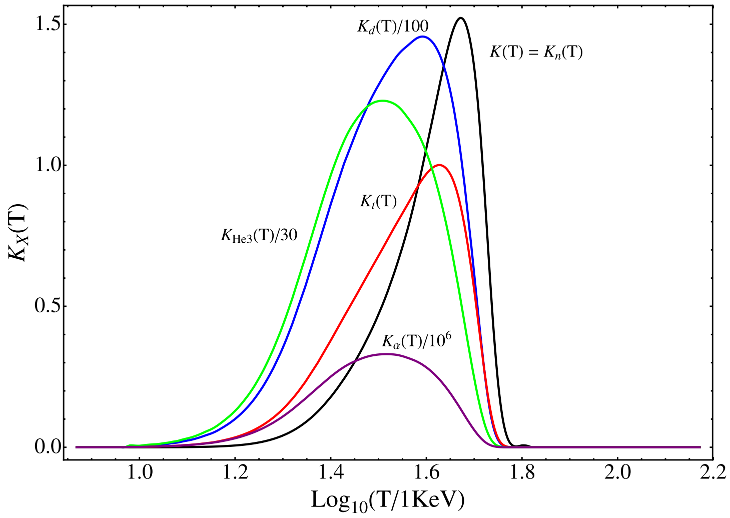

Fig. 1. *Left Panel: The kernels $K_a(T)$ defined in Eqs.(4,10).*

roughly corresponding to the ^{7}Be freeze-out temperature $T_{\rm Be,f}$. The area under the curve is equal to $\simeq 0.7$ which indicates that the total destruction rate of ^{7}Be should be increased by a factor ~ 2.5 to obtain a factor 2 reduction in the abundance of ^{7}Li.

We can use Eq. (4) to assess the sensitivity of the abundance of ^{7}Li with respect to a specific reaction channel. The total ^{7}Be reaction rate is given by

$$D_{\rm Be}(T) = n_{\rm B} \sum_a Y_a(T)\,\langle\sigma_a v\rangle_T, \tag{7}$$

where σ_a is the cross section of the reaction ^{7}Be + a and Y_a represents the elemental abundance of the a nuclei. In standard BBN, the dominant contribution is provided by the ^{7}Be$(n,p)^7$Li reaction; accounting for about $\sim 97\%$ of the total ^{7}Be destruction rate. The standard rate $\overline{D}_{\rm Be}(T)$ can then be set with a few percent accuracy by,

$$\overline{D}_{\rm Be}(T) \simeq n_{\rm B}\,\overline{Y}_{\rm n}(T)\,\langle\overline{\sigma}_{\rm np} v\rangle_T, \tag{8}$$

where $Y_{\rm n}(T)$ is the neutron abundance and $\sigma_{\rm np}$ is the cross section of ^{7}Be$(n,p)^7$Li. Subdominant reaction channels can provide a non-negligible contribution only if there is a large increase of their assumed cross section values. The fractional enhancement of $D_{\rm Be}(T)$ due to a generic ^{7}Be + a process can be evaluated from,

$$\delta D_{{\rm Be},a}(T) = \frac{\overline{Y}_a(T)}{\overline{Y}_{\rm n}(T)}\,\frac{\langle\sigma_a v\rangle_T}{\langle\overline{\sigma}_{\rm np} v\rangle_T}, \tag{9}$$

under the reasonable assumption that the inclusion of a new channel for ^{7}Be destruction does not alter the abundance of the a nuclei. By using eq.(9), we rewrite Eq. (4) as

$$\delta X_{\rm Li} = \sum_a \int \frac{dT}{T}\; K_a(T)\;\frac{\langle\sigma_a v\rangle_T}{\langle\overline{\sigma}_{\rm np} v\rangle_T}, \tag{10}$$

where

$$K_a(T) = K(T)\frac{\overline{Y}_a(T)}{\overline{Y}_{\rm n}(T)}. \tag{11}$$

The kernels $K_a(T)$ are shown in the left panel of Fig. 1 for the cases $a = n,\ d,\ t,\ ^3$He, ^{4}He

3. Is a nuclear physics solution of the cosmic ^{7}Li problem possible?

The kernels $K_a(T)$ can be used to quantify the requirements for a nuclear physics solution of the cosmic ^{7}Li problem. To be more consistent with observed data, a reduction of the ^{7}Li abundance by a factor 2 or more is required and that corresponds to $\delta X_{\rm Li} \geq 1$. To obtain this, the ratios $R_a \equiv \langle \sigma_a v \rangle_T / \langle \overline{\sigma}_{\rm np} v \rangle_T$ at temperatures $T \simeq 10 - 60$ keV should be, $R_{\rm n} \geq 1.5$ for reactions in the ^{7}Be + n channel, $R_d \geq 0.01$ for reactions in the ^{7}Be + d channel, $R_t \geq 1.5$ for reactions in the ^{7}Be + t channel, $R_{\rm He3} \geq 0.03$ for reactions in the ^{7}Be + ^{3}He channel, and $R_{\rm He4} \geq 4 \times 10^{-6}$ for reactions in the ^{7}Be + ^{4}He channel. We explore these possibilities on the basis of general nuclear physics arguments.

3.1. The ^{7}Be + n channel

At $T \sim T_{\rm Be,f} \simeq 50$ keV, the ^{7}Be$(n,p)^7$Li reaction accounts for $\sim 97\%$ of the total ^{7}Be destruction rate. This process has been very well studied both experimentally and theoretically. The cross section near threshold is enhanced by a 2^- resonance at $E_x = 18.91$ MeV.[3] In addition, the data show evidence for two peaks that correspond to the (unresolved) 3^+ states at 19.07 and 19.24 MeV and to the 3^+ resonance at 21.5 MeV. The reaction rate has been determined by R-matrix fits to the experimental data with uncertainties $\sim 1\%$. It should be noted that the cross section of ^{7}Be$(n,p)^7$Li reaction is extremely large. At the relevant energies for ^{7}Be synthesis, $E_{\rm Be} \simeq T_{\rm Be,f} \simeq 50$ keV, we have $\sigma_{\rm np}(E_{\rm Be}) \simeq 9$ barn that is quite close to the unitarity bound $\sigma_{\rm max}(E_{\rm Be}) = \pi/(2\mu E_{\rm Be}) \simeq 15$ barn, where μ is the reduced mass of the ^{7}Be + n system.

As an alternative process, we consider the reaction ^{7}Be$(n,\alpha)^4$He for which no experimental data exist in the energy range relevant for primordial nucleosynthesis. To obtain a factor of 2 reduction in the cosmic ^{7}Li abundance, the cross section of the ^{7}Be$(n,\alpha)^4$He reaction should be $\sigma_{\rm n\alpha}(E_{\rm Be}) \simeq 1.5\, \sigma_{\rm np}(E_{\rm Be}) \sim 15$ barn. This possibility seems extremely unlikely. An upper bound on the non-resonant contribution to $\sigma_{n\alpha}$ can be obtained by considering the upper limit on the Maxwellian-averaged cross section $\langle \sigma_{\rm n\alpha} \rangle_T \leq 0.1$ mbarn that was derived by Bassi et al. (1963) using thermal neutrons. Due to parity conservation of strong interactions, the process cannot proceed via an $s-$wave collision. If we assume a $p-$wave collision, the measured value can be rescaled to $T_{\rm Be,f} \sim 50$keV according to $\langle \sigma_{\rm n\alpha} \rangle_T \propto \sqrt{T}$, obtaining the value $\langle \sigma_{\rm n\alpha} \rangle_{T_{\rm Be,f}} \leq 0.02\, \langle \sigma_{\rm np} \rangle_{T_{\rm Be,f}}$.

One can question the above estimate because it involves extrapolation over several orders of magnitude. Irrespective of this, the process ^{7}Be$(n,\alpha)^4$He will be suppressed at low energies with respect to ^{7}Be$(n,p)^7$Li because of centrifugal barrier penetration; a quantitative estimate of which can be obtained by considering the ratio between $p-$wave and $s-$wave transmission coefficients. At low energy, one expects $\sigma_{\rm n\alpha}/\sigma_{\rm np} \sim 2\,\mu\, E\, R^2$. By considering $E = E_{\rm Be}$, and by taking $R \leq 10$ fm as a conservative upper limit for the entrance channel radius, we obtain $\sigma_{\rm n\alpha}(E_{\rm Be}) \leq 0.2\ \sigma_{\rm np}(E_{\rm Be})$; that is insufficient to explain the ^{7}Li discrepancy.

Finally, we note that we do not expect a large resonant contribution to the ^{7}Be$(n,\alpha)^4$He cross section. The ^{8}Be excited states relevant for ^{7}Be$(n,p)^7$Li reaction, due to parity conservation, do not decay by α-emission. In summary, in view of experimental and theoretical considerations, it appears unlikely that the ^{7}Be + n destruction channel is underestimated by the large factor required to solve the ^{7}Li problem.

3.2. Other ^{7}Be destruction channels

In standard BBN, the ^{7}Be destruction channels involving charged nuclei are strongly subdominant. To produce sizeable effects on the ^{7}Li abundance, their efficiency has to be increased by a very large factor. This seems possible only if new unknown resonances are found. We discuss this possibility by using the Breit-Wigner formalism, according to which the cross section of a resonant process ^{7}Be + $a \to C^* \to b + Y$ is described by:

$$\sigma = \frac{\pi\,\omega}{2\mu\, E} \frac{\Gamma_{\rm in}\Gamma_{\rm out}}{(E - E_r)^2 + \Gamma^2_{\rm tot}/4} \tag{12}$$

where $\Gamma_{\rm in}$ is the width of the entrance channel, $\Gamma_{\rm out}$ is the width for the exit channel and $\Gamma_{\rm tot} =$

[3] The entrance energy of the ^{7}Be + n channel with respect to the ^{8}Be ground state is $E_{\rm in} = 18.8997$ MeV. Thus the listed resonances correspond to a collision kinetic energy equal to $E_r = E_x - E_{\rm in} = 0.01,\ 0.17,\ 0.34$ and 2.6 MeV, respectively.

$\Gamma_{in} + \Gamma_{out} + \ldots$ is the total resonance width. In the above expression, the factor

$$\omega = \frac{2J_{C^*} + 1}{(2J_a + 1)(2J_{Be} + 1)} \tag{13}$$

takes into account the angular momenta J_a and J_{Be} of the colliding particles and the angular momentum J_{C^*} of the compound nucleus excited state.

For resonances induced by charged particle reactions at energies below the Coulomb barrier, the partial width of the entrance channel Γ_{in} varies very rapidly with energy as can be understood by writing:

$$\Gamma_{in} = 2P_l(E, R)\,\gamma^2_{in} \tag{14}$$

where R is the entrance channel radius, the factor $P_l(E, R)$ describes the penetration through the Coulomb and centrifugal barrier, while the reduced width γ^2_{in} incorporates all the unknown properties of the nuclear interior. A similar expression can be written for Γ_{out}. However, we neglect the energy dependence of Γ_{out} since the energy of the emitted particle is increased by an amount equal to the Q-value of the reaction.

In order to keep the discussion self-contained, we make some simplifying assumptions which are intended to maximize the cross section (12). Namely, we assume that:
i) the reduced width of the entrance channel is equal to its maximum value, i.e. we assume $\gamma^2_{in} = \gamma^2_W$ where:

$$\gamma^2_W = \frac{3}{2\mu R^2}\ . \tag{15}$$

is the Wigner limiting width ;
ii) the orbital angular momentum of the entrance channel is $l = 0$ and the factor ω has the maximum possible value allowed by angular momentum conservation, i.e. we assume $J_{C^*} = J_{Be} + J_7$;
iii) the total resonance width is equal to $\Gamma_{tot} = \Gamma_{in} + \Gamma_{out}$.
With these assumptions, the resonant cross section is described in terms of two free parameters that are the resonance energy E_r and the exit channel width Γ_{out}.

We have determined the effect of resonances on the ^{7}Li abundance by using Eq. (10). The thermally averaged cross section $\langle\sigma_a v\rangle_T$ has been evaluated numerically without using the narrow resonance approximation. Our results are shown in Fig. 2 as a function of the parameters (E_r, Γ_{out}). The 'coloured' lines represent the iso-contours for the ^{7}Li abundance,

$$\delta Y_{Li} = 1 - \frac{Y_{Li}}{\overline{Y}_{Li}}. \tag{16}$$

The various panels correspond to the processes ^{7}Be + a with $a = d,\ t,\ ^3$He and ^{4}He respectively, starting from the upper left corner.[4] In our calculations, we assumed the entrance channel radius to be $R = 10$ fm. That is quite a large value considering the radii of the involved nuclei but it has been chosen to provide a conservative upper estimate of the resonance effects.[5]

^{7}Be + d: With this initial channel, the maximum achievable effect is a ∼ 40% reduction of primordial ^{7}Li abundance. This reduction could substantially alleviate the discrepancy between theoretical predictions and observational data. The maximal effect is obtained for a resonance energy $E_r \sim 150$ keV with a total width $\Gamma_{tot}(E_r, R) \sim 45$ keV and partial widths approximately equal to $\Gamma_{out} \sim 35$ keV and $\Gamma_{in}(E_r, R) \sim 10$ keV. Our results basically coincides with those found by Cyburt & Pospelov (2009) using a different approach. Note that there is an excited state in ^{9}B at 16.71 MeV. It lies just 220 keV above the ^{7}Be + d threshold and it decays by gamma and particle (proton or ^{3}He) emission. However, this state has been very recently ruled out as a solution of the cosmic ^{7}Li problem (Kirsebom & Davids 2011). A non negligible suppression would, therefore, require the existence of a new (not yet discovered) excited state of ^{9}B around $E_r \sim 150$ keV. In O'Malley et al. (2011), this possibility was

[4] We do not consider the ^{7}Be + p entrance channel since this is known to be sub-dominant, see e.g. Chakraborty et al. (2011), and it is well studied at low energies due to its importance for solar neutrino production.

[5] The dependence of the ^{7}Li suppression on the assumed value for R is discussed in Broggini et al. (2012).

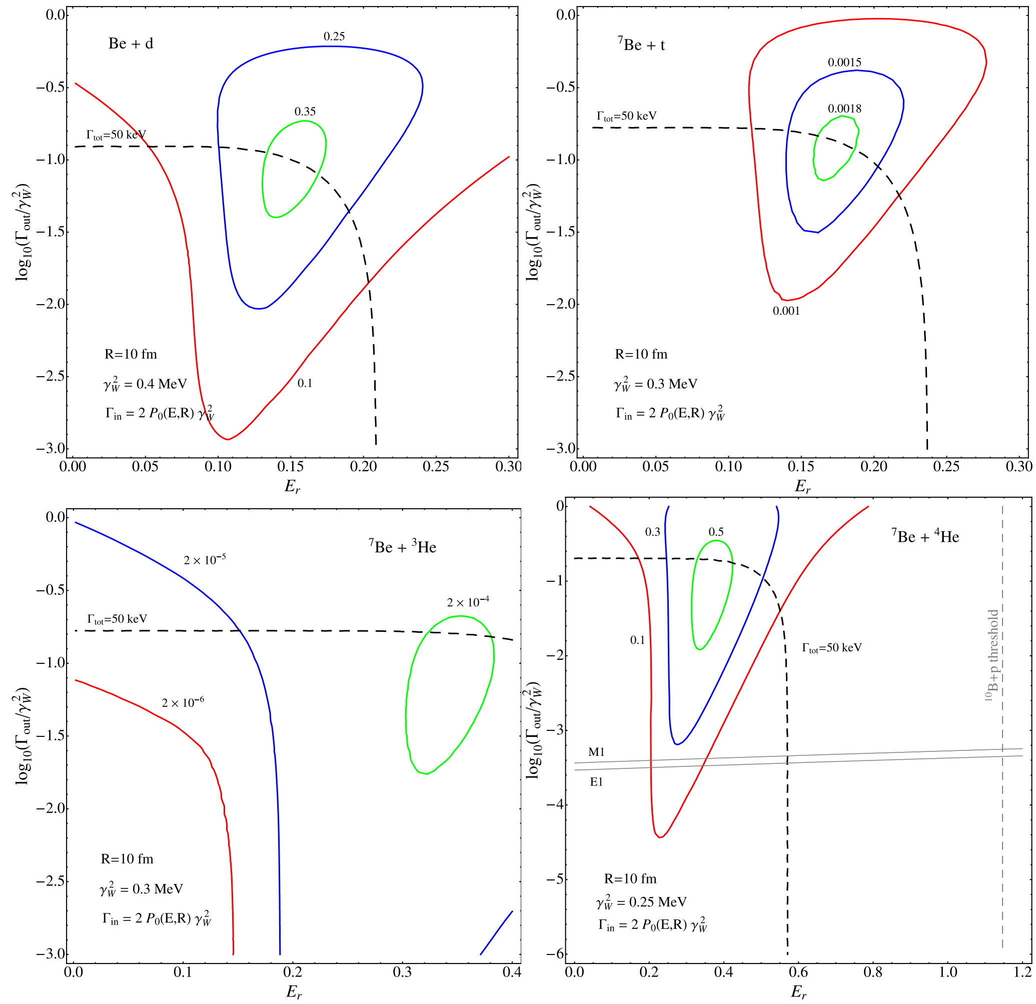

Fig. 2. *The coloured lines show the fractional reduction of the primordial* ^{7}Li *abundances that can be achieved by a resonance in the* ^{7}Be + *a reaction. The various panels correspond to* $a = d$, t, ^{3}He *and* ^{4}He, *respectively, starting from the upper-left corner. The black dashed lines correspond to the condition* $\Gamma_{tot}(E_r, R) = 50\,\text{keV}$, *which is the limit for narrow resonance. The gray solid lines in the lower-right panel correspond to the upper limits for* Γ_{out} *when we assume E1 and M1 electromagnetic transitions to* ^{11}C *ground state.*

studied by using the ^{2}H(^{7}Be, d)^{7}Be reaction. The data show no evidence for new resonances and allow to set an upper limit on the resonance width at the level of ~ 1 keV.

^{7}Be + t: With this initial channel, the maximum achievable effect is a ~ 0.2% reduction of primordial ^{7}Li abundance. The existence of a resonance in this channel cannot solve the cosmic ^{7}Li problem, as can be easily explained. Indeed, in order to produce a significant ^{7}Li reduction, the ^{7}Be destruction rate due to the ^{7}Be + t reaction should be comparable to that form ^{7}Be + n processes. Clearly that is impossible because: *i)* neutrons are more abundant than tritons at the relevant temperature T_{Be} ~

50 keV; *ii)* the cross section of ^{7}Be+t collisions is suppressed by Coulomb repulsion.[6]

^{7}Be + ^{3}He: With this channel, the maximum achievable effect is a $\sim 10^{-4}$ reduction in the abundance of primordial ^{7}Li. Again then, a resonance in this channel cannot solve the cosmic ^{7}Li problem. The small effect is due to strong Coulomb repulsion suppressing the partial width of the entrance channel ($\Gamma_{\rm in}(E_r, R)$).

^{7}Be + α: With this channel, the maximum achievable effect is, in principle, a $\sim$ 55% reduction of primordial ^{7}Li abundance. This is obtained for a resonance with a relatively large centroid energy $E_r \sim 360$ keV, with a total width $\Gamma_{\rm tot}(E_r, R) \sim 21$ keV and with partial widths $\Gamma_{\rm out} \sim 19$ keV and $\Gamma_{\rm in}(E_r, R) \sim 1.5$ keV. The strong suppression of the cross section due to Coulomb repulsion in this case is compensated by the fact that the α nuclei are $\sim 10^6$ times more abundant than neutrons when the temperature of the universe falls below $\sim$ 70 keV. However, one should note that for $E_r \leq 1.15$ MeV there are no particle exit channels for the compound ^{11}C nucleus. As a consequence, the only possible transition is the electromagnetic one whose width is expected to be smaller than $\sim$ 100 eV. In Fig. 2, we show with the gray solid lines the recommended upper limits for the width of electric (E1) and magnetic (M1) dipole transitions given by Endt (1993). These corresponds to 0.5 Weisskopf units (W.u.) and 10 W.u. respectively and have been calculated by assuming a $\gamma-$transition to the ^{11}C ground state. If we consider an $s-$wave collision, the quantum numbers of the compound ^{11}C nucleus only allow M1 radiation to be emitted. Taking the corresponding limit into account, one obtains at most a $\sim$ 25% reduction of the ^{7}Li abundance for $E_r \sim 270$ keV, with a total width $\Gamma_{\rm tot}(E_r, R) \sim 160$ eV and with partial widths $\Gamma_{\rm out} \sim 100$ eV and $\Gamma_{\rm in}(E_r, R) \sim 60$ eV. The existence of resonance with these parameters would imply a non negligible counting rate in ^{7}Be + α experiments. We estimate that a ^{7}Be beam with an intensity $\sim 5 \times 10^4$ ^{7}Be/s (i.e. comparable to that used in O'Malley et al. 2011) would produce $\sim$ 50 events/day in a thick ^{4}He target with the emission of a $\sim$ 7.8 MeV $\gamma-$ray. Such a rate would be measurable in an underground laboratory.

The possibility of a missing resonance in the ^{7}Be + α channel was further discussed in Broggini et al. (2012) where the spectrum of ^{11}C was calculated by using a coupled-channel model for the n-^{10}C system, with coupling involving the excited quadrupole state of ^{10}C. A multi-channel algebraic scattering (MCAS) was used with which account is made of constraints imposed by the Pauli principle on single-particle dynamics besides coupling interactions to the collective excitations of the ^{10}C states. A comparison between the calculated spectrum and the observed levels of ^{11}C (Ajzemberg-Selove 1990) was performed, obtaining a one to one correspondence except for a $\frac{1}{2}^-$ state predicted at 6.885 MeV. That excitation energy lies relatively close to entrance of ^{7}Be + ^{4}He channel which is 7.543 MeV above the ^{11}C ground state and would require a $d-$wave collision (or a coupled-channel transition to the ^{7}Be first excited state) to ensure angular momentum and parity conservation.

However, it should be remarked that the existence of a new state for ^{11}C would imply the existence of a corresponding state for the mirror ^{11}B nucleus with comparable energy and width. ^{11}B is stable and well studied experimentally by using photon and electron scattering reactions. At present, there is no evidence for such a state as can be seen by comparing the the observed levels of ^{11}C and those of ^{11}B (Ajzemberg-Selove 1990) .

4. Conclusions

We have investigated the possibility that the cosmic ^{7}Li problem originates from incorrect assumptions about the nuclear reaction cross sections relevant for BBN. To do so, we introduced an efficient method to calculate the changes in the ^{7}Li abundance produced by an

[6] Conclusions reached by Chakraborty et al. (2011) differ from ours. Theirs are artifacts from using of the narrow resonance approximation outside of its regime of application.

arbitrary (temperature dependent) modification of the nuclear reaction rates. Then, taking into account that ^{7}Li is mainly produced through ^{7}Be, we used this method to assess whether it is possible to increase the total ^{7}Be destruction rate to the level required to solve (or alleviate) the cosmic ^{7}Li puzzle. Our conclusions are summarized in the following:

i) given present experimental and theoretical constraints, it is unlikely that the ^{7}Be + n destruction rate is underestimated by the $\sim$ 2.5 factor required to solve the cosmic ^{7}Li problem.

ii) on the basis of very general nuclear physics considerations, it is unrealistic to assume that new resonances in ^{7}Be + t and ^{7}Be + ^{3}He channels can solve the ^{7}Li problem.

iii) the only destruction channels that could have a non negligible impact on the ^{7}Li abundance are ^{7}Be + d and ^{7}Be + α. However, new resonances must exist at specific energies and with suitable resonance widths. This possibility is strongly challenged by recent experimental results and theoretical considerations.

In summary, the present study reduces significantly the space for a nuclear physics solution of the cosmic ^{7}Li problem. An extremely favorable combination must occur in the character of still undetected resonances, and such situations could be excluded with ease by new experimental efforts.

Acknowledgements. We thank the participants of "Lithium in the cosmos" for useful discussions. We thank M. Pospelov for pointing out the importance of missing low-energy particle exit channels for the ^{7}Be + α reaction.

References

Broggini, C. et al. 2012, arXiv:1202.5232

Cyburt, R. H. et al. 2008, JCAP, 0811, 012.

Nakamura, K. et al. 2010, J. Phys. G, 37, 075021.

Coc, A. et al. 2004, ApJ, 600, 544.

Angulo, C. et al., 2005, ApJ, 630, L105.

Cyburt, R. H. & Pospelov, M. 2009, arXiv:0906.4373

Chakraborty, N. et al. 2011, Phys. Rev. D, 83, 063006.

Esmailzadeh, R. et al. 1991, ApJ, 378, 504.

Bassi, P. et al. 1963, Nuovo Cimento, 28, 1049.

Kirsebom, O. S. & Davids, B. 2011, Phys. Rev. C, 84, 058801

O'Malley, P. D. et al. 2011, Phys. Rev. C, 84, 042801(R)

Endt, P. M 1993, Atomic Data and Nuclear Data Tables, 55, 1, 171.

Ajzenberg-Selove, F. 1990, Nucl. Phys. A, 506, 1.