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Cosmological Cosmic Ray Production of Beryllium and Boron

IN2P3
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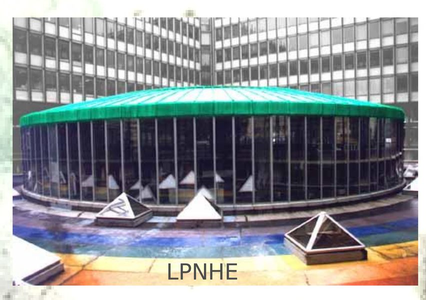

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[from E. Rollinde, D. Maurin, E. Vangioni, K. Olive & S. Inoue, ApJ ***673****, 676 (2008)]*

The abundance of ^{6}Li in Population II stars of the galactic halo has been observed at a thousand times the predicted primordial value. Cosmological cosmic rays (CCRs) induced production of ^{6}Li, which depends on the escape efficiency ϵ of CCRs from the structures, can account for this high value. In this context, we calculate the non-thermal evolution with redshift of D, Be, and B in the intergalactic medium (IGM). We take into account direct production in the IGM by *pHe* and *CNO* CCRs impinging on the intergalactic gas (*CNO* contribution is dominant). Neutrino spallation and low-energy production within the structures (later ejected by outflows to the IGM) are always sub-dominant. We find that:

1. Deuterium production is negligible compared to the BBN abundance;

2. A potentially detectable Be and B initial enrichment, coherent with the observed stars in the galactic halo, is produced by these processes at the time of the formation of the Galaxy (z~3);

3. The associated CCR-induced extragalactic γ-ray background is found to be well below existing data.

This study will be updated from new constraints of Pop III stars *(see talk of E. Rollinde, arXiv:0806.2663)*.

1. Astrophysical context and associated model

The cosmic star formation histories considered are based on the detailed hierarchical models of chemical evolution derived in [1]. The models are described by a bimodal birthrate function of the form

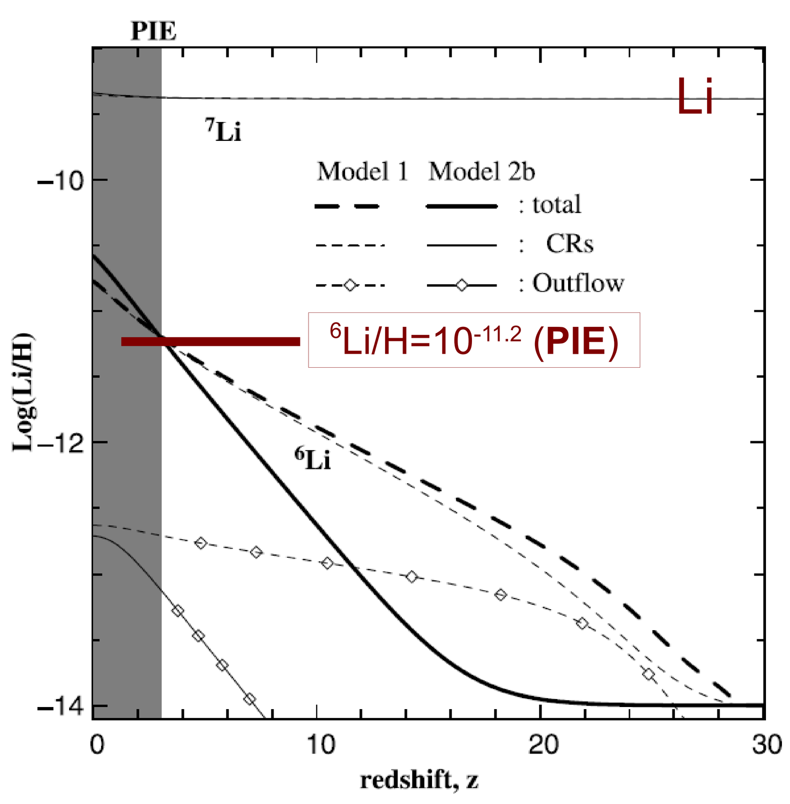
$$B(m,t,Z) = \phi_1(m)\,\Psi_1(t) + \phi_2(m)\,\Psi_2(Z)\,,$$

where ϕ is the initial mass function (IMF), Ψ is the star formation rate (SFR), and Z is the metallicity. The normal mode contains stars with mass between 0.1 and 100 M$\odot$. The SFR of the normal mode peaks at z~3. In addition to a normal mode of star formation, there is a massive component which dominates star formation at high redshift. Here, we consider two possibilities for the massive mode. First, as in [2], a model in which the massive mode corresponds to stars with masses in the range 40-100 M$\odot$ (**model 1**); these stars terminate as type II SNe. Second, we consider a model in which the massive mode corresponds to stars with masses in the range 270-500 M$\odot$ (**model 2b**). These massive stars are assumed to terminate as black holes through total collapse and do not contribute to any metal enrichment in either the ISM or IGM. It is, however, unclear whether these implosions are responsible for the acceleration of cosmic rays. Energy must get out during the collapse, but this may be entirely in the form of neutrinos and gravitational waves. We have not included any contribution to the flux of CCRs from the most massive component of model 2b stars.

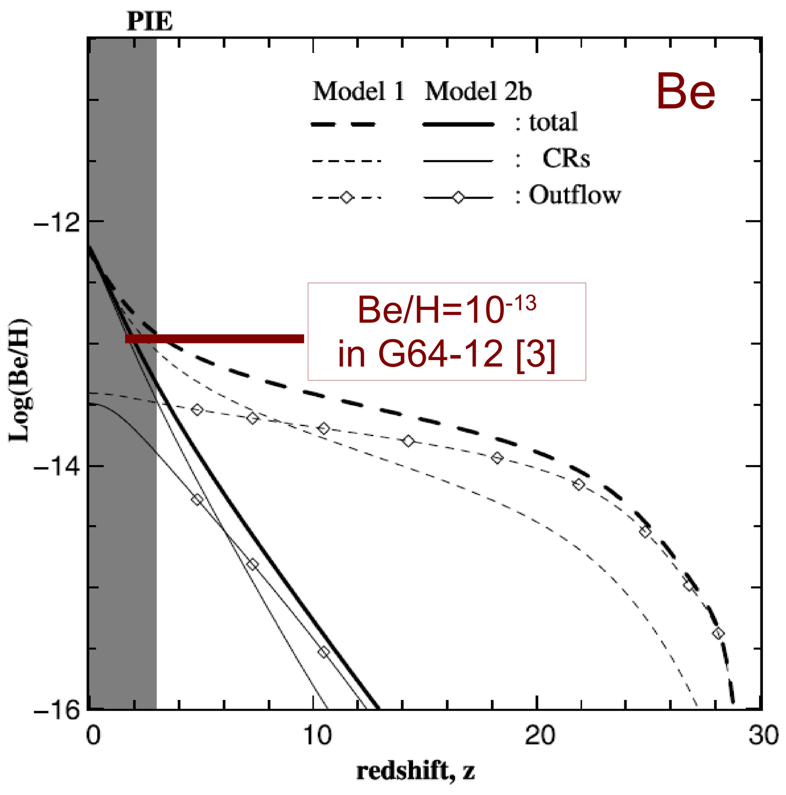
2. ^{6}Li production by cosmological cosmic rays in the hierarchical model of chemical evolution

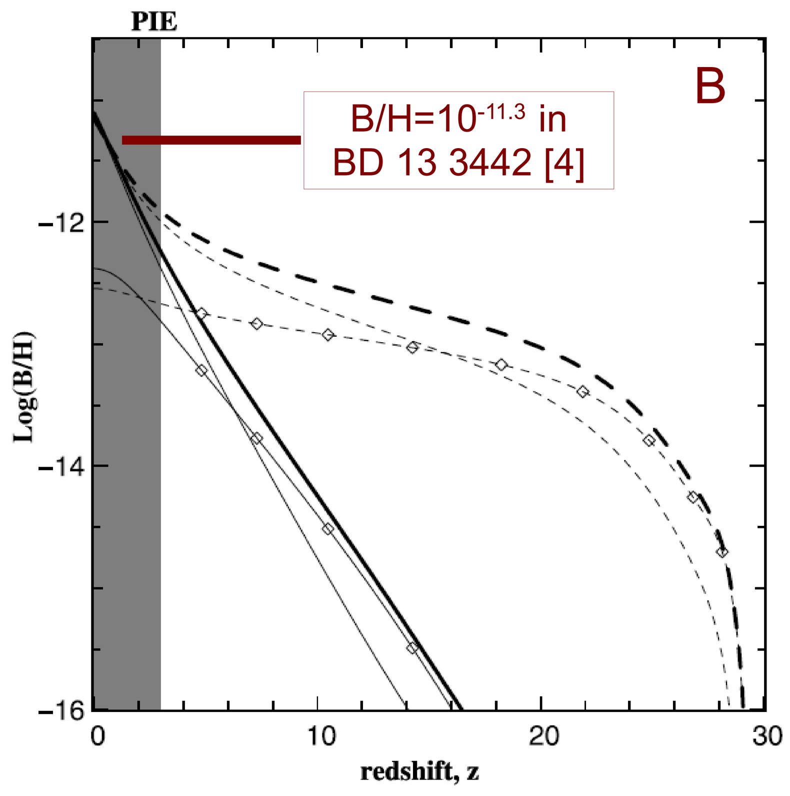
Nucleosynthesis of ^{6,7}Li through the interaction of CCR-α impinging on He in the IGM, including the effects of outflow (diamond) for Model 1 and 2b. The acceleration efficiency ϵ of the CCRs is set to obtain a prompt initial enrichment (**PIE**) which equals the observed plateau ^{6}Li/H=$10^{-11.2}$ at z=3. This leads to ϵ=0.15 for model 1 and ϵ=0.5 for model 2b.

Using the above values of ϵ, we calculate, in this cosmological context, the non-thermal production of Be and B and the γ-ray background.



3. Beryllium and boron production



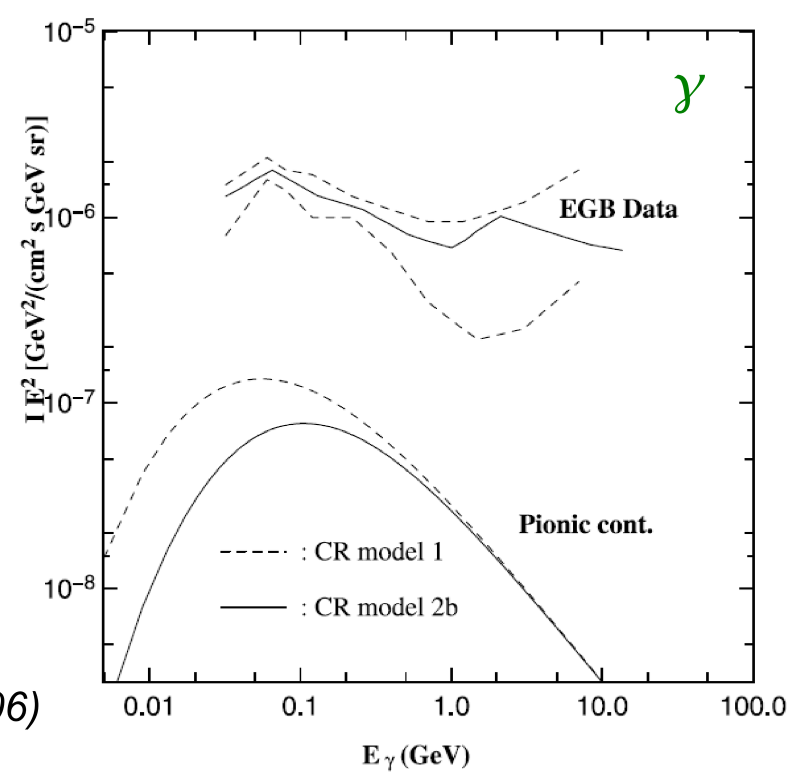


The production of ^{9}Be (left) and ^{10,11}B (right), through the interaction of CCR $p\alpha$ (*CNO*) impinging on *CNO* (*HHe*) in the IGM and including the effects of outflow (diamonds) of ^{9}Be and ^{10,11}B, is displayed as a function of redshift for models 1 and 2b. At z~3, ^{9}Be/H=$10^{-12.9}$ in model 1 (dashed lines) and ^{9}Be/H=$10^{-13.3}$ in model 2b (solid lines). This is compatible with the observed abundance at the lowest metallicity, [Fe/H]=-3.3, ^{9}Be/H=10^{-13} in G64-12 [3]. For boron, B/H=$10^{-11.9}$ in model 1 and B/H=$10^{-12.25}$ in model 2b. These values are somewhat below the observed abundance at low metallicity, B/H=$10^{-11.3}$ at [Fe/H]=-3.0 in BD 13 3442 [4].

4. γ-ray background

The interaction of the CCRs with the IGM also produces γ-rays. Assuming isotropic production, the extragalactic background flux (E^2 times intensity) is shown as a function of E for Model 1 and Model 2b.

The models are well below the observed extragalactic gamma-ray background (**EGB**) data [5].



[1] Daigne et al., ApJ 647, 773 (2006)
[2] Rollinde, Vangioni & Olive, ApJ 651, 658 (2006)
[3] Primas et al., A&A 364, L42 (2000)
[4] Primas et al., A&A 343, 545 (1999)
[5] Strong, Moskalenko & Ptuskin, Ann. Rev. Nuc. Part. Syst. 57, 285 (2007)

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