A new Thought on the Energy Dependence of the ^{10}Be/^{9}Be Ratio

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Abstract

The ^{10}Be/^{9}Be ratio recently measured by the ISOMAX instrument at energies up to 2 GeV/nucleon shows a relatively steep increase with energy, which is in contrast to published theoretical predictions. In this paper we show that uncertainties in the applied production cross sections can account for such an increase as well as an energy dependent halo size.

1. Introduction

The published results of the ^{10}Be/^{9}Be ratio recently measured by the ISOMAX instrument, a ballon-borne superconducting magnet spectrometer, at energies up to 2 GeV/nucleon show a relatively steep increase of this ratio with energy. Despite the large statistical errors of these data it might be interesting to examine some possibilities of enhancing the calculated ^{10}Be/^{9}Be ratio in this energy region. We examine the impact of parameters, such as production cross sections and we also allow an energy dependent halo size in the Diffusion Halo Model (DHM).

2. Equation and parameters of the Diffusion Halo Model

In order to obtain the equilibrium spectra of radioactive secondary cosmic ray particles within the diffusion halo model one has to solve the following equation:

$$\begin{aligned}0 = \frac{\partial}{\partial z}\left\{D(E,z)\cdot\frac{\partial}{\partial z}N_i(E,z)\right\} - \frac{N_i(E,z)}{{}_i\tau_{int}(E,z)} \\ + \frac{N_i(E,z)}{\gamma(E)\cdot {}_i\tau_{dec}} - \frac{\partial}{\partial E}\left\{\left\langle\frac{\partial E}{\partial t}\right\rangle_{ion}\cdot N_i(E,z)\right\} \\ + \sum_{k>i}\frac{N_k(E,z)}{\tau_{int}^{ki}}\end{aligned} \tag{1}$$

$N_i(E,z)$ and $N_i(E,z)$ describe the number density of particles at a given position z. The first term on the right side of Equation 1 describes the diffusion and

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$D(E,z)$ means the diffusion coefficient at position z. For simplicity we allow $D(E)$ to be independent of position. The second term on the right side of the equation accounts for the losses of i-type particles, where ${}_i\tau_{int}(E)$ stands for the mean lifetime of the i-type particles against interaction in the interstellar gas and $\gamma(E)\cdot{}_i\tau_{dec}$ accounts for the loss due to radioactive decay (γ is the Lorentz-factor). The quantity $\tau_{int}^{ki}(E)$ stands for the mean time which k-type nuclei need to produce i-type secondary nuclei in spallation reactions with interstellar gas particles. This quantity depends on the production cross section and the interstellar gas in terms of density and composition. We assumed for the interstellar gas a mixture of 90% hydrogen and 10% helium. The above equation can be solved by different mathematical techniques and we refer to the literature. To determine the free parameters, we used a collection of data for the B/C ratio (see [2]). A fit to these data allows to determine the ratio of the diffusion coefficient D to the halo size H as a function of rigidity R:

$$\frac{D(R)}{H} = \begin{cases} \nu_0\beta\left(\frac{R}{4.7\,GV}\right)^{-0.8} & for\ R < 4.7\,GV \\ \nu_0\beta\left(\frac{R}{4.7\,GV}\right)^{0.57} & for\ R > 4.7\,GV \end{cases} \tag{2}$$

With the parameters given in eq. 2 and with cross sections according to Tsao et al. [5,6] we solved eq. 1 for the beryllium isotops ^{10}Be and ^{9}Be. As can be seen in fig. 1 with a halo size of 3.5 kpc, which we kept constant in energy, we fitted the low energy data around 100 MeV/n. This curve however does not fit the ISOMAX data as illustrated in fig. 1.

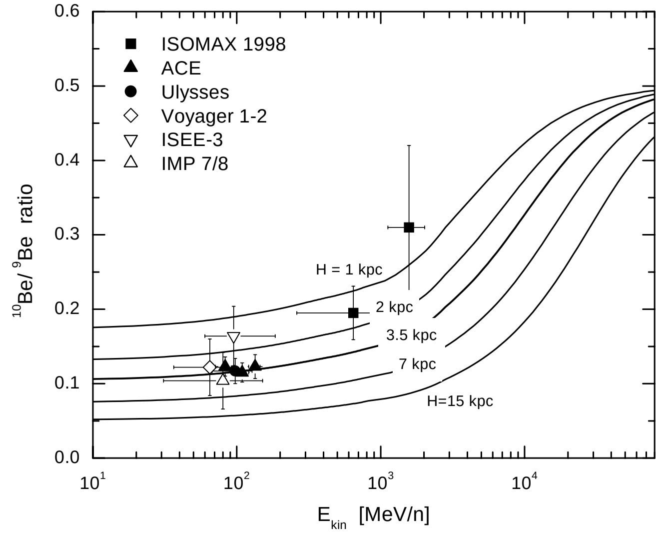

Fig. 1. The ^{10}Be/^{9}Be ratio calculated with different halo sizes. For data see [1,2,3] and references therein.

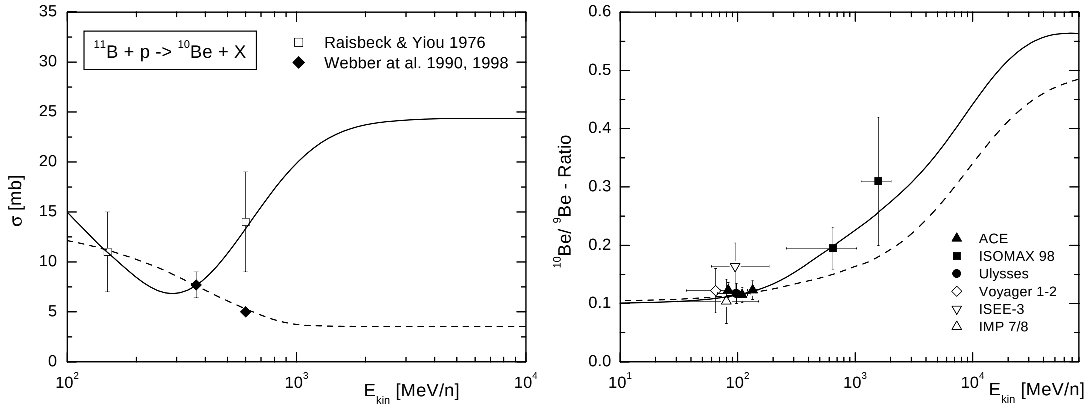

Fig. 2. The ^{10}Be/^{9}Be ratio (right) calculated with different cross sections (left). For cross section data see [4,7,8]. ^{10}Be/^{9}Be ratio data as in fig. 1.

In order to enhance the calculated curve at higher energies we pursued two possibilities:

3. The cross section effect

$^{11}\mathrm{B} + p \rightarrow {}^{10}\mathrm{Be} + \mathrm{X}$ is an important reaction in the network of ^{10}Be production within the propagation calculations. The corresponding ^{10}Be production cross section however is very badly known. This is illustrated in fig. 2 (left). The lack of good data badly defines a precise energy dependence of this cross section. The calculated ^{10}Be/^{9}Be ratio as given by the dashed curve in fig. 2 (right) refers to the energy dependence of the cross section as given by the dashed curve on the left of fig. 2. By taking an energy dependence of this cross section as given by the solid line in fig. 2 (left) one obtains a calculated ^{10}Be/^{9}Be ratio as given by the solid curve in fig. 2 (right). This results illustrate that uncertainties in cross sections alone can very well account for the steeper rise in the ^{10}Be/^{9}Be ratio as measured by ISOMAX.

4. The halo size effect

Another idea to enhance the calculated ^{10}Be/^{9}Be ratio at higher energies is visible in fig. 1. If one allows the halo size to vary with energy one can get a calculated curve which passes through the measured ^{10}Be/^{9}Be data. Such a calculation is presented in fig. 3 (right). This full line ist obtained by allowing the halo size to vary with energy as given in fig. 3 (left). If we allow the halo size to vary with energy we have to modify the energy dependence of the diffusion coefficient as well in order to keep the D/H ratio, as given in eq. 2, at the level, which fits the measured i.e. B/C ratio. So the diffusion coefficient in this case is

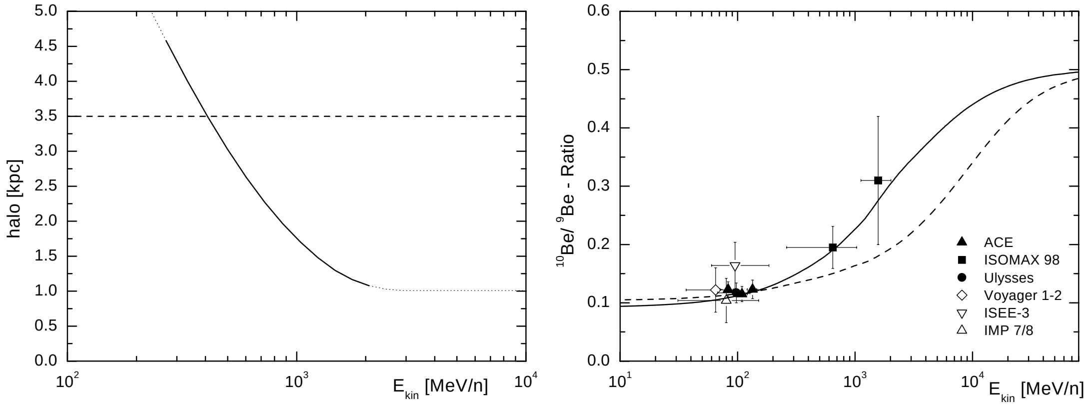

Fig. 3. The ^{10}Be/^{9}Be ratio (right) calculated with a constant and an energy dependent halo size (left). Data as in fig. 1.

roughly 2-3 times smaller at energies above 1 GeV/n and has a direct effect on the ^{10}Be/^{9}Be ratio.

5. Conclusion

In this paper we present two possibilities which might account for the steeper increase of the ^{10}Be/^{9}Be ratio as indicated by the ISOMAX measurement. At this stage however no final conclusion can be drawn. Only better measurements on cross sections and measurements on the ^{10}Be/^{9}Be ratio over a large energy regime with better statistics can help to improve our understanding.

6. References

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