Calculation of Elemental and Isotopic Abundance of Cosmic Rays Using Markov Stochastic Theory: The Effect of Local Superbubble

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Abstract

A Markov stochastic method [8] is employed to study cosmic ray propagation in the galaxy using a halo diffusion model. The result is an energy dependent path-length probability distribution that is combined with a weighted slab calculation to determine the production of secondary cosmic ray nuclides. The flexibility of this method allows the seamless incorporation of the low density local bubble surrounding the Solar system. While the effects of the local bubble on the primary to secondary abundance ratios of stable isotopes in minimal, the effect on unstable secondaries particulary such relatively short lived isotopes as ^{36}Cl (half-life 0.3 Myr), is significant.

1. Introduction

The Solar system is embedded in a low density region known as the local bubble. We study the effects of the local bubble on the composition of cosmic rays. In this paper a Markov stochastic method [8] is used to calculate cosmic ray propagation within a halo diffusion model. The model includes a three-dimensional distribution of cosmic ray sources, interstellar density and an energy dependent diffusion coefficient. The result is an energy dependent path-length probability distribution (PLD) that is combined with a weighted slab calculation to determine the production of secondary cosmic ray nuclides. The flexibility of this method allows the simple inclusion of the local bubble. Thus, the effect of the local bubble on cosmic ray isotopic and elemental composition can be determined.

2. Description of Method

We use a backward Markov stochastic simulation method to solve stochastic differential equations for the trajectory of diffusing particles in the galaxy from [5]. From these solutions, we determine the path-length probability as a function

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Table 1. Cosmic Ray Source and Denisty Distribution.

Source Distribution	$q(R,z) = q_0(\frac{R}{R_0})^{0.5} exp(-\frac{R-R_0}{R_0} - \frac{\lvert z \rvert}{0.2kpc})$
Atomic Hydrogen Distribution	$n_{HI}(R,z) = n_{HI}(R) e^{-(ln2)(\frac{z}{z_0})^2}$
Molecular Hydrogen Distribution	$n_{H2}(R,z) = n_{H2}(R) e^{-(ln2)(\frac{z}{70pc})^2}$
Diffusion Coefficient	$2 \times 10^{28} (\rho/3GV)^{0.6} cm^2/s$
Halo Height	$z_h = 3kpc$
Galactic Radius	$R_h = 30kpc$
Convection Speed	v=20 km/s

of cosmic ray energy. The galactic model parameters are listed in Table 1,where q_0 is a normalization constant, ρ is the rigidty, $n_{HI}(R)$, $n_{H2}(R)$ and the ionized hydrogen distribution are taken from [3] such that the solar system is located at a galactic radius of 8.5 kpc, and

$$\mathbf{z_0}(R) = \begin{cases} 0.25kpc, & R \leq 10kpc \\ 0.083e^{0.11R}, & R > 10kpc \end{cases}$$

The path-length probability distributions are fitted to a double exponential equation. The resulting fitted parameters were used with a weighted slab model [2] to calculate the production of secondary species. The interstellar medium consisted of 90% of hydrogen and 10% of helium. The propagation region in the models is bounded by $R = R_h$ and $z = z_h$. The model without bubble is identical to one in [6]. The low density local bubble with an average radius 120 pc and an average density of $0.06 atom/cm^3$.

3. Results

Figure 1 shows the path-length distribution function for 1 GeV/nucleon cosmic ray ions with and without the bubble. At large path-lenghts there is no difference between the two cases. However for short path-length (see Figure 2) we find a significant difference between the two models. This is expected since the low density inside the bubble will contribute to short path-lengths. Figure 3 shows the result of the B/C ratio calculation. Boron is a stable element and thus samples the whole of the path-length distribution. Thus, the existence of the local bubble will has a minimal effect on the abundance ratio. Figure 4 shows the $^{26}Al/^{27}Al$ with a half life of 0.9 Myr [7]. This half life limits the distance of its source to a maximum of 230 pc. Within this distance, the bubble makes a large contribution. The effect of the bubble is also shown for the $^{36}Cl/^{35}Cl$ in Figure 5.

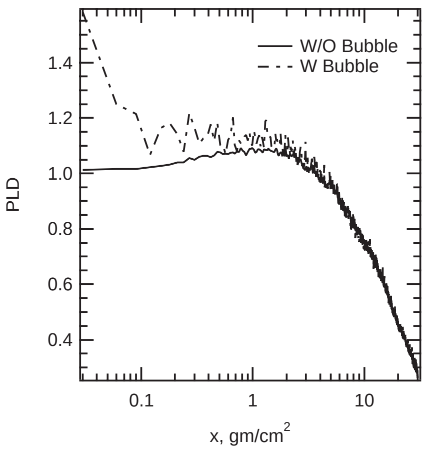

Fig. 1. Path-length distribution for the cosmic ray particles passing through the ISM with and without a bubble.

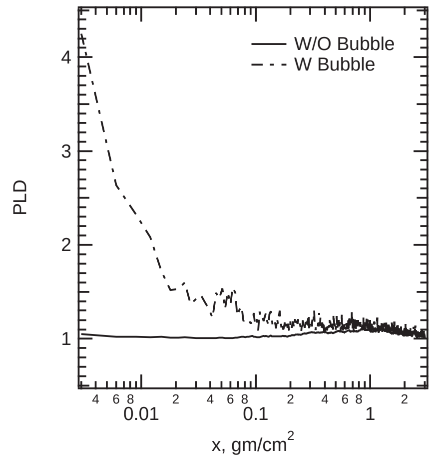

Fig. 2. Detailed path-length distribution. The same as in Figure 1 for small path-lengths.

4. Conclusions

The effect of the super local bubble on the path-length distribution function was studied. For large path-lengths there was no significant difference between models with and without the local bubble. The probability of short path-lengths is significiantly affected by the local bubble. The bubble is found to makedly change the abundance ratio of the elements with low half lives such as $^{26}Al/^{27}Al$ and $^{36}Cl/^{35}Cl$ due to their short diffusion distance while not affecting the abundance ratios of stable cosmic ray secondary elements such as B/C.

5. References

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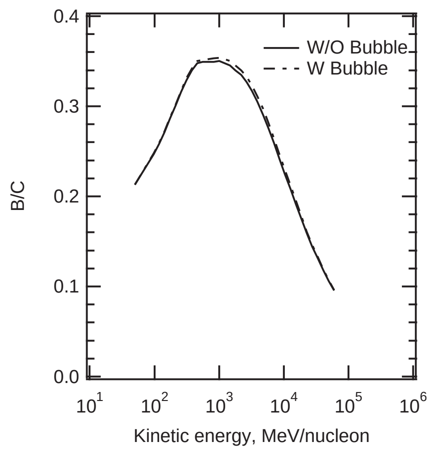

Fig. 3. B/C ratio for diffusion model without a break in the diffusion coefficient, dv/dz=0kms^{-1}kpc^{-1}, z_h = 3kpc with and without the existance of the local bubble.

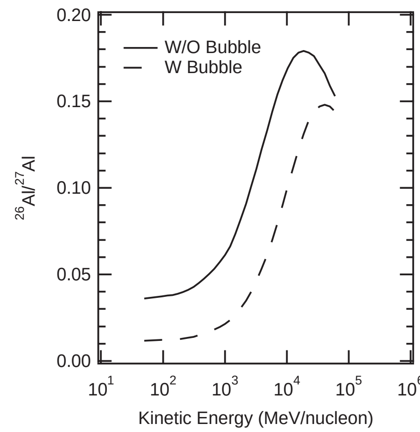

Fig. 4. $^{26}Al/^{27}Al$ ratio for diffusion model without a break in the diffusion coefficient, dv/dz=0kms^{-1}kpc^{-1}, z_h = 3kpc with and without the existance of the local bubble.

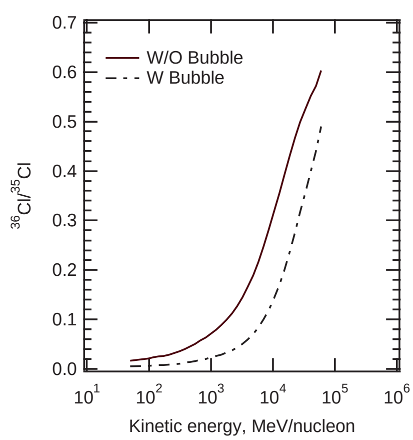

Fig. 5. $^{36}Cl/^{35}Cl$ ratio for diffusion model without a break in the diffusion coefficient, dv/dz=0kms^{-1}kpc^{-1}, z_h = 3kpc with and without the existance of the local bubble.