New Measurements of the Li, Be, and B Isotopes as a Test of Cosmic Ray Transport Models

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Abstract

Precise measurements of predominantly secondary cosmic-ray Li, Be, and B together with current well-measured production cross-sections for these isotopes help to improve our understanding of galactic cosmic ray propagation models. The Cosmic Ray Isotope Spectrometer (CRIS) on ACE has been measuring isotopic composition of cosmic rays since 1997 with high statistical precision. We present the isotopic abundances from CRIS and discuss these observations in the context of cosmic-ray transport models and previous cosmic-ray measurements.

1. Introduction

The well-established excess of lithium, beryllium, and boron (LiBeB) in galactic cosmic rays (GCR), compared with the relatively rare LiBeB abundances found elsewhere in nature, has been attributed to inelastic collisions of cosmic rays with the interstellar medium (ISM), predominantly the fragmentation of cosmic-ray C,N,O from collisions with ISM hydrogen and helium. Given the secondary nature of LiBeB galactic cosmic rays, LiBeB abundance measurements provide important constraints on cosmic ray propagation, especially abundance observations as a function of energy.

CRIS on ACE has been measuring the isotopic composition of cosmic rays between $2 \leq Z \leq 30$ in the energy interval ∼30-500 MeV/nucleon since 1997. CRIS observations have sufficient statistical accuracy to sample the flux of LiBeB nuclei over an extended energy range for the first time and thus allow for a more detailed study of cosmic ray propagation. In this paper, we present absolute energy spectra and abundance ratios of cosmic ray LiBeB and compare these with previous measurements and predictions from a current propagation model.

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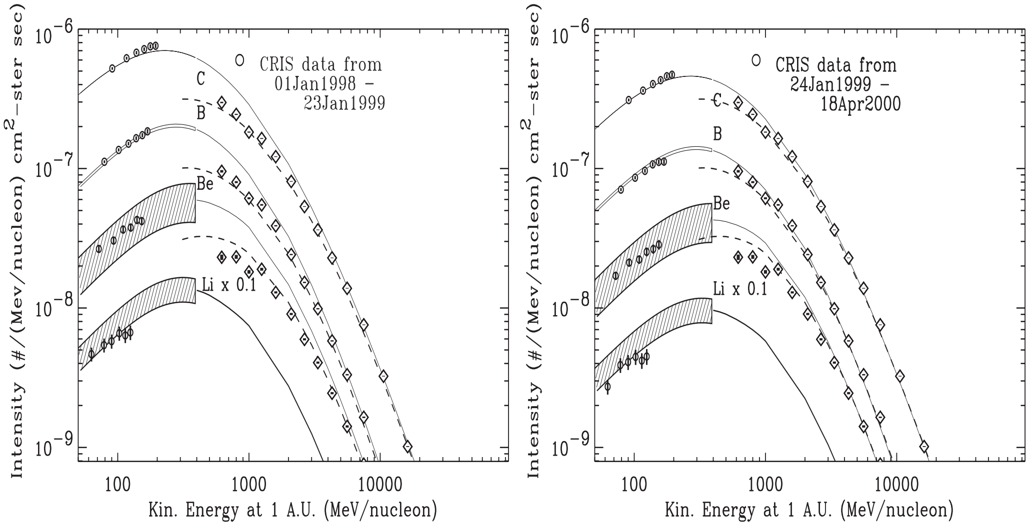

Fig. 1. Absolute flux observations of CRIS in two separate time periods compared with model predictions [10] (solid & dashed curves, see text) and the high energy measurements of HEAO-3 [5] (diamonds). Hatched region is 1 σ uncertainty on model predictions.

2. Data Analysis

The charge and mass of stopping particles are identified with CRIS using the dE/dx versus residual energy method [8]. To study the behavior of the light nuclei under varying degrees of solar modulation, CRIS observations are divided into two time intervals corresponding to periods of differing solar modulation. The first time interval is from January 1, 1998 to January 23, 1999 and the second is from January 24, 1999 to April 18, 2000. A solar modulation parameter, as determined in [4], of $\phi \sim 400$ MV describes the first period and $\phi \sim 590$ MV describes the second.

The methods used to assign charge and mass to incident light nuclei have been described previously [4]. In addition, a detailed study of the Scintillating Optical Fiber Hodoscope (SOFT) [8] tracking efficiency has resulted in an improved understanding of the systematic uncertainties associated with the efficiency for tracking light charges. The tracking efficiency for each of the four CRIS telescopes was determined separately and the resulting fluxes for the light nuclei (He-C) for each telescope were compared for consistency. Based on these studies, an overall systematic uncertainty of 15% is assumed for the SOFT tracking efficiency for lithium, 8% for beryllium, and 2% for boron and carbon.

In addition, corrections (typically 10-20%) are applied to account for the probability of incident nuclei surviving fragmentation within the instrument. The cross-section formulation of Barashenkov et al. [1] appear to be in good agreement with the cross-section data for lithium and beryllium, and we assume this formulation for the computation of interaction lengths for LiBeB and C. We

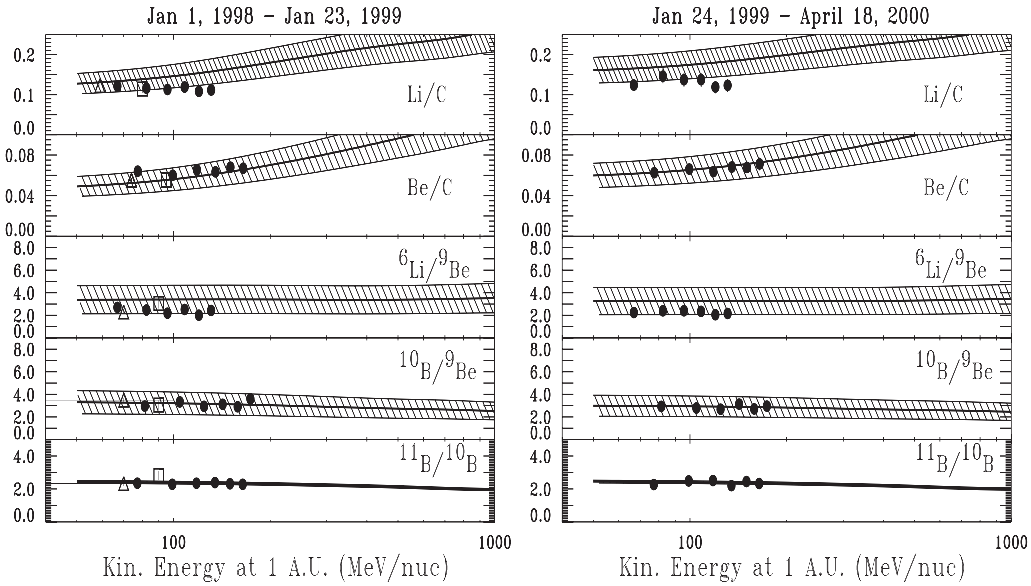

Fig. 2. Elemental and isotopic ratios observed by CRIS (solid circles) for two separate time periods compared with model predictions [10] (solid curves) and with previous measurements of Voyager 1&2 [7] (triangles), IMP 7&8 [6] (squares), and Ulysses [2] (diamond).

estimate a systematic uncertainty of 3% for the spallation correction.

3. Results and Discussion

Figure 1 shows the absolute fluxes of LiBeB and C for the two time periods covered in this study; the low energy data are CRIS observations and the high energy data are earlier observations from HEAO-3 [5]. Uncertainties in the observations for CRIS include both statistical and systematic uncertainties while uncertainties for HEAO-3 observations are statistical only. Also shown are the predictions of a steady state Leaky Box model [10] of the arriving GCR abundances (solid & dashed curves). The predictions take into account the amount of solar modulation experienced for a given time period. For the time period covered by HEAO-3 observations (1980), the propagation model used a solar modulation parameter $\phi = 800$ MV (dashed lines). The hatched region shown for E $<$ 400 MeV/nucleon indicates one standard deviation of uncertainty for cross-sections as discussed in [10]. Both CRIS and HEAO-3 observations are generally consistent with the absolute intensities and energy dependence of the predicted spectra. The flux of carbon is slightly above the predictions ($\sim$ 10%) at high CRIS energies. The absolute flux of lithium is low by 1σ, possibly due to some residual inefficiency in the SOFT tracking efficiency. The determination of the SOFT tracking efficiency is a complicated calculation with typical tracking efficiencies for lithium as low as 20-40% . The propagation model assumes fragmentation cross-sections based on the formula of Westfall [9], which does not appear to be the best representation for the current cross-section measurements of light nuclei at the energies covered by CRIS. A more detailed study of how cross-section data compare with standard cross-section formulas for LiBeB and C interactions in the instrument is currently underway and will help to pin down uncertainties associated with the spallation correction.

Figure 2 shows the elemental and isotopic abundances measured by CRIS for the two time periods covered in this study. CRIS measurement uncertainties include both statistical and systematic errors. Also shown are observations from Voyager 1&2 [7], IMP 7&8 [6], and Ulysses [2]. These observations were obtained during periods of solar modulation consistent with the first time period (e.g. solar minimum) studied in this analysis. CRIS observations are in good agreement with previous measurements. Also shown are the predictions of a Leaky Box model [10]. The observations are clearly consistent with the model predictions within the 1σ uncertainties (hatched region). The Li/C ratio appears to be flatter than predicted and may result from the choice of cross-section formula for fragmentation loss as discussed earlier.

4. Summary

CRIS observations of LiBeB isotopes are made with excellent mass resolution and dramatically improved statistics, permitting a measurement of the absolute spectra over an extended energy range. A comparison with previous measurements and with the predictions of a cosmic-ray transport model show generally good agreement with CRIS results, although the flux of lithium is consistently low compared with model predictions by 1σ. The relative isotopic ratios do not vary between the two time periods, suggesting that the effects of solar modulation are not important, at least for modest differences in solar modulation. The next step is to extend this study to solar maximum.

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5. References

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