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The ^{7}Li/^{6}Li ratio in the energy range from 150 to 1300 MeV/nucleon measured with the balloon-borne ISOMAX98 instrument in the upper atmosphere

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Abstract. We report on the measured ^{7}Li/^{6}Li ratio at an atmospheric depth of 4.6 g/cm^2 in the energy range from 183 to 1314 MeV/nucleon, using the Isotope Magnet Experiment (ISOMAX). This balloon-borne magnetic spectrometer in combination with a Time-of-Flight system (TOF) and a silica-aerogel Cherenkov detector was built to measure the isotopic composition of the light elements ($3 \leq Z \leq 8$) in the cosmic radiation up to several GeV/nucleon. ISOMAX was flown on August 4-5, 1998, from Lynn Lake, Manitoba, Canada. The data was collected during 13 hours at an altitude which corresponds to a residual atmosphere of less than 5 g/cm^2. The results on ^{10}Be/^{9}Be ratio are presented in the these proceedings by Hams *et al.* (2001) in the TOF regime and by de Nolfo *et al.* (2001) in the Cherenkov regime.

1 Introduction

The "secondary" constituents of the cosmic rays, e.g. lithium, beryllium, and boron, produced by spallation in interactions of heavier nuclei, mainly carbon, nitrogen, and oxygen, with the ambient gas in our galaxy can serve as a tracer for the encountered matter during their propagation in the interstellar medium before reaching the earth. Thus, accurate measurements of the elemental and isotopic composition of the cosmic rays can help to develop a better understanding of the transport and acceleration processes of particles as well as the identification and composition of galactic cosmic ray sources.

We will present measurements of the ^{7}Li/^{6}Li ratio above the instrument at an average residual atmosphere of 4.6 g/cm^2 from the maiden flight of the ISOMAX instrument in 1998 with an unprecedented quality of mass resolution in the energy ranges from 183 to 617 MeV/nucleon and from 617 to 1314 MeV/nucleon in the TOF regime.

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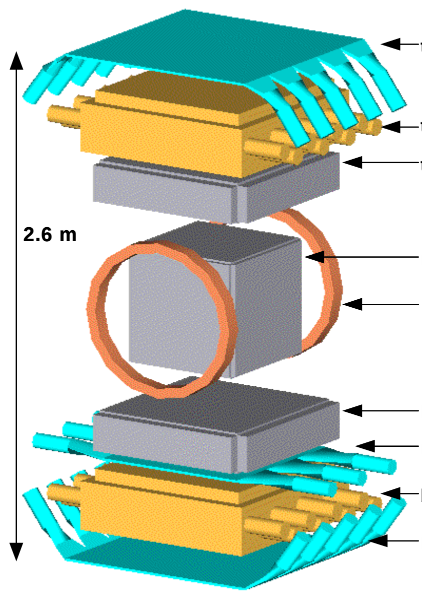

Fig. 1. Schematic of the ISOMAX instrument.

2 Instrument

ISOMAX was designed and built to measure the isotopic abundances of cosmic rays from lithium to oxygen in the energy range from about 100 MeV/nucleon to 4 GeV/nucleon with a mass resolution better than 0.25 amu. A special emphasis of the ISOMAX balloon program was on the radioactive "clock" isotope ^{10}Be with a half-life of 1.6 million years (Streitmatter *et al.*, 1995). The schematic of the ISOMAX instrument is shown in Fig. 1.

To identify isotopes, we measure the magnetic rigidity, the velocity, and the charge of the incident particles. The superconducting magnet spectrometer is comprised of a Helmholtz-like coil pair and three drift chambers as a tracking system. The magnet was operated at 120 A which gives a central field

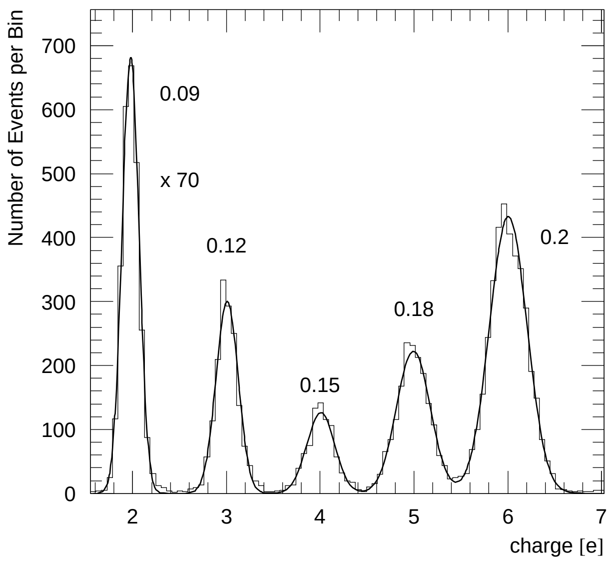

Fig. 2. Charge histogram of the top scintillator with a 3σ cut on the middle and bottom scintillator. The charge resolution (in units of e) is written next to the peaks.

of 0.8 T. The tracking system consists of 480 drift cells arranged in 16 layers in bending and 8 layers in non-bending view with total stack height of 150 cm. The spatial resolution of the tracking system is 54 μm for helium and 47 μm for lithium. The mean maximum detectable rigidity (MDR) of the spectrometer is 970 GV/c for helium, the mean field integral through the tracking system is about 0.54 Tm (Hams *et al.*, 1999).

For the velocity measurement a Time-of-Flight system (TOF) and two silica-aerogel Cherenkov counters were used. The TOF hodoscopes consisted of three layers of fast Bicron BC-420 scintillators. The distance between the top and the middle layer was 206.8 cm and the top and the bottom layer was 260.0 cm (Geier *et al.*, 1999). The timing resolution of the system is 70 ps for helium and 65 ps for lithium. Furthermore, the energy loss, dE/dx, of the incident particle in each TOF layer in combination with the velocity measurement provides information on its charge.

The Cherenkov detector consists of two large diffusive-light-integration counters. Each counter contains two layers of silica-aerogel radiator with a nominal index of refraction $n = 1.14$, giving an energy threshold of 1.08 GeV/nucleon. The number of photoelectrons is about 22 for both counters together ($Z = 1$, $\beta = 1$), see de Nolfo *et al.* (1999). For the determination of the ^{7}Li/^{6}Li ratio in this paper the Cherenkov detector was not used.

A more detailed report on the performance of ISOMAX instrument in the 1998 flight was given by Mitchell *et al.* (1999) and Hof *et al.* (2000).

3 Data Selection

ISOMAX had its first flight on August 4-5, 1998, from Lynn Lake, Manitoba, Canada. We recorded 13 hours of data for which the residual atmosphere was less than 5 g/cm^2.

For the data analysis we regarded events for which only one scintillator per layer was hit and the track in the spectrometer was reconstructed. The efficiency for a successful reconstruction of a track in the spectrometer is about 93% for lithium and independent of the energy in the range of 150 - 1300 MeV/nucleon. To reduce biases on the isotope ratio of an element we applied only loose cuts on the track quality, i.e. at least 8 of the 16 layers in bending (N_x) and 4 of 8 layers in non-bending view (N_y) were required, but no cut on the χ or the error of the deflection ($\Delta\eta$=1/MDR) of the reconstructed track was used.

In order to separate the isotopes of an element we need the charge of the incident particle. Figure 2 shows the measured charge in the top TOF layer for $\beta_{TOF} > 0.6$. The charge resolution is better than 0.2 charge units for helium to carbon. To reduce the contamination of the lithium sample by misidentified charge and to get good statistics we apply the following cut for all three charge measurements Z_i (i=top, middle and bottom TOF scintillator layer): $\mid Z_i - 3 \mid \leq 0.5$. Thus, we get a contamination from helium into the lithium sample of less than 10^{-7} and from beryllium of less than 10^{-5}. The efficiency for this cut is about 94%.

$\rho_{alt} \leq 5$ g/cm^2
single paddel hit in each TOF layer
DC single-track fit: $N_x \geq 8$ and $N_y \geq 4$
$\lvert Z_i - 3\rvert \leq 0.5$
$150 \leq E_{kin} \leq 1300$ MeV/nucleon

Table 1. Cuts applied to the data to select lithium events.

4 Instrumental corrections and the ^{7}Li/^{6}Li ratio above the instrument

Applying the discussed cuts above (Table 1) we obtain 1104 lithium events in the energy range of 150 - 1300 MeV/nucleon from the 13 hours of data at a residual atmosphere less than 5 g/cm^2. Figure 3 shows two mass histograms for those events divided into two energy ranges in the TOF regime. We fitted two gaussian on each mass peak (^{8}Li isotopes are produced in the atmosphere) and obtained an isotope ratio of ^{7}Li/^{6}Li = 1.06±0.09 for the lower energies and ^{7}Li/^{6}Li = 0.85±0.08 for the higher energy range.

To determine the ratio of ^{7}Li/^{6}Li at top of instrument (TOI) one has to take into account energy loss and fragmentation of the incident particle in the instrument. The energy ranges from 150 to 600 MeV/nucleon and from 600 to 1300 MeV/nucleon were given with respect to the middle drift chamber. The integrated grammage of the instrument above the middle DC

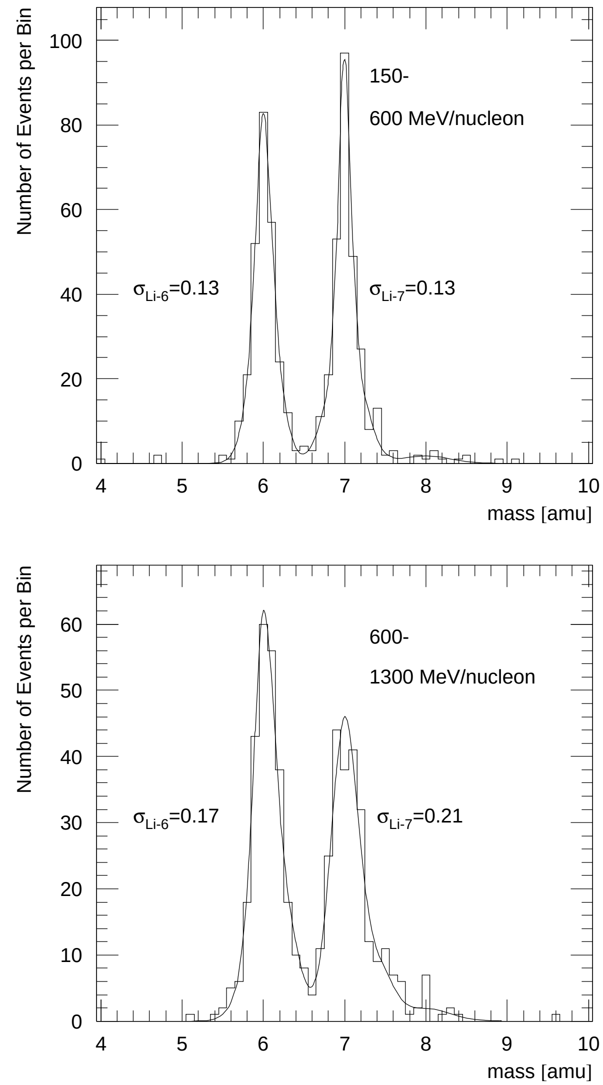

Fig. 3. Mass histograms of lithium isotopes in two energy ranges in the TOF regime. The bin width is 0.1 amu.

is about 5 g/cm^2. Thus we find the energy range at 183 - 617 MeV/nucleon and 617 - 1314 MeV/nucleon respectively at top of instrument. The probability that an incident particle does not fragment during its flight through the whole instrument was calculated for ^{7}Li and ^{6}Li. The total inelastic cross sections are calculated with the method of Kox (Kox *et al.*, 1987). The mean ratio of these surviving probabilities of ^{7}Li/^{6}Li is about 0.94 for the relevant energies.

From these considerations we obtain a ^{7}Li/^{6}Li ratio at top of instrument of 1.13±0.10 in the energy range of 183 - 617 MeV/nucleon and 0.90±0.09 in the energy range of 617 - 1314 MeV/nucleon.

The mean residual atmosphere above the experiment was about 4.45 g/cm^2. The mean incident zenith angle of the particles is 15°. Taking this geometrical aperture of the instrument into account, an average grammage of 4.6 g/cm^2 has to be used in the atmospheric correction which is not yet done.

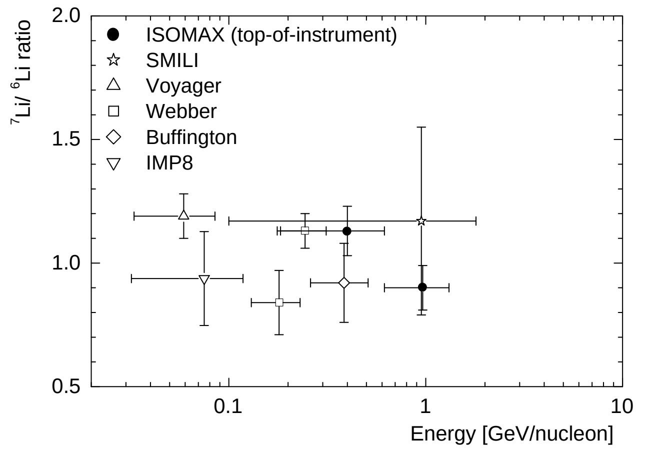

Fig. 4. ^{7}Li/^{6}Li ratio measured by ISOMAX (this work) and SMILI (Ahlen *et al.*, 2000), Yoyager (Lukasiak *et al.*, 1999), Webber *et al.* (1977) and Webber and Kish (1979), Buffington *et al.* (1978) and IMP-8 (Garcia-Munoz *et al.*, 1975)

5 Conclusions

We have shown the unprecedented quality of mass resolution for lithium isotopes (Fig. 3) of about 0.13 amu in the energy range from 183 to 617 MeV/nucleon and better than 0.21 amu for 617 - 1314 MeV/nucleon using a superconducting magnet spectrometer in combination with a precise Time-of-Fight measurement.

Figure 4 shows our results for ^{7}Li/^{6}Li ratio at top of instrument together with previous measurements at top of atmosphere.

While the ^{6}Li isotope is a pure product of interactions of galactic cosmic rays (GCR) with the interstellar medium (ISM), the ^{7}Li isotope has several sources. In addition to the production of ^{7}Li by spallation during the propagation of GCR, the stellar production and primordial nucleosynthesis of ^{7}Li are possible sources. All shown measurements have values which are much smaller than the value 12.5 ± 0.5 for protosolar gas (4.5 billion years ago) (Krakowski and Muller, 1967) or the value of 12.5 ± 4.0 if a stellar contribution to the interstellar medium is regarded (Lemoine *et al.*, 1993). Walker *et al.* (1985) and Reeves (1994) obtained a ^{7}Li/^{6}Li ratio of 1.43 in a standard GCR plus ISM calculation, see also Lukasiak *et al.* (1997). Another source of ^{7}Li is the decay of ^{7}Be into ^{7}Li via electron capture. The observed energy dependence of ^{7}Be/Be by Buffington *et al.* (1978) suggesting the onset of electron capture at about 500 MeV/nucleon is not consisted with the ISOMAX measurement (de Nolfo *et al.*, 2001) and with measured ^{7}Li/^{6}Li ratios.

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References

Ahlen, S.P. *et al.*, ApJ, 534, 757–769, 2000.

Buffington, A., Orth, C.D., Mast, T.S. , ApJ, 226, 355–371, 1978.

de Nolfo, *et al.*, Proceedings of the 26th International Cosmic Ray Conference, Salt Lake City, 3, 29–32, 1999.

de Nolfo, G.A. *et al.*, Proceedings of the 27th International Cosmic Ray Conference, OG 1.1, 2001

Garcia-Munoz, M. , Mason, G.M. and Simpson, J.A., ApJ, 201, L145, 1975.

Geier, S. *et al.*, Proceedings of the 26th International Cosmic Ray Conference, Salt Lake City, 3, 117–120, 1999.

Hams, T. *et al.*, Proceedings of the 26th International Cosmic Ray Conference, Salt Lake City, 3, 121–125, 1999.

Hams, T. *et al.*, Proceedings of the 27th International Cosmic Ray Conference, OG 1.1, 2001.

Hof, M. *et al.*, Nuclear Instr. & Meths., A 454, 180–185, 2000.

Kox, S. *et. al.*, Physcis Review C35, 5, 1678, 1987.

Krakowski, D. and Muller, O., Geochim. Cosmochim. Acta, 31, 1833, 1967.

Lemoine, M. *et. al.*,A& A, 269, 469, 1993.

Lukasiak, A., McDonald, F.B. Webber, W.R., Proceedings of the 25th International Cosmic Ray Conference, Salt Lake City, 3, 389, 1997.

Lukasiak, A., McDonald, F.B. Webber, W.R., Proceedings of the 26th International Cosmic Ray Conference, Salt Lake City, 3, 41, 1999.

Mitchell, J.W. *et al.*, Proceedings of the 26th International Cosmic Ray Conference, Salt Lake City, 3, 113–116, 1999.

Reeves, H., Rev. Mod. Phys., 66, 193, 1994.

Streitmatter, R.E. *et al.*, ISOMAX Proposal number SSC-4A, NASA/GSFC, Greenbelt, 1995.

Walker, T.P., Mathews, GJ. and Viola, V.E., ApJ, 299,745, 1985.

Webber, W., Lezniak, J.A., Kish, J.C. and Simpson, G.A., ApL, 18,125, 1977.

Webber, W.R and Kish, J.C., Proceedings of the 16th International Cosmic Ray Conference, Kyoto, 1, 389, 1979.