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ISOMAX: Flight Performance of the Isotope Magnet Experiment

J.W. Mitchell[1], L.M. Barbier[1], M. Bremerich[3], E.R. Christian[1], A.J. Davis[2], G.A. de Nolfo[2],
S. Geier[1], H. Göbel[3], S.K. Gupta[1], T. Hams[3], M. Hof[3], J.F. Krizmanic[1], W. Menn[3],
R.A. Mewaldt[2], J.F. Ormes[1], S.M. Schindler[2], M. Simon[3], and R.E. Streitmatter[1],
[1] *Laboratory for High Energy Astrophysics, NASA/GSFC, Greenbelt, MD 20771, USA*
[2] *Space Radiation Laboratory, California Institute of Technology, Pasadena, CA 91125, USA*
[3] *Fachbereich Physik, Universität Siegen, 57068 Siegen, Germany*

Abstract

ISOMAX, a new balloon-borne cosmic ray instrument developed to measure the isotopic composition of the light elements in the cosmic radiation, was flown for the first time on August 4-5, 1998, from Lynn Lake, Manitoba, Canada. The main purpose of the ISOMAX program is to obtain the ratio of radioactive ^{10}Be to stable ^{9}Be over a wide range of energies, and consequently a wide range of time-dilation factors. Configured for its first flight, ISOMAX has a geometry factor of 450 cm^{2}sr and uses a large, high-field, superconducting magnet in conjunction with state-of-the-art tracking, time-of-flight, and Cherenkov detectors to measure light isotopes with a mass resolution better than 0.25 amu over the ~0.2-1.7 GeV/nucleon energy range. In the 1998 flight, the maximum detectable rigidity of the ISOMAX magnetic spectrometer was 970 GV/c for He at 60% of the full magnetic field. ISOMAX returned over 16 hours of data from altitudes of more than 36 km as well as considerable data from lower altitudes. In this paper, a description of the instrument and initial isotopic results will be presented. The performance and results from the individual detector systems are discussed in other papers presented at this meeting.

1 Introduction:

To understand the origin, transport, and lifetime of the cosmic radiation, accurate measurements of isotopic and elemental composition over an extended energy range are required. Radioactive “clock” isotopes, such as ^{10}Be, provide critical insights into the propagation lifetimes of the cosmic rays and the range of matter densities encountered. Isotopes of primary cosmic ray elements serve as indicators of the isotopic composition of the cosmic ray source, which may differ from that of the solar system. Secondary isotopes (e.g. ^{3}He) and elements (e.g. Li, Be, and B) are tracers of the amount of matter traversed by the cosmic rays. The balloon-borne Isotope Magnet Experiment (ISOMAX) has been developed to measure the isotopic composition of the light elements ($3 \leq Z \leq 8$) over an energy range extending (in multiple flights) from geomagnetic cutoff to beyond 4 GeV/nucleon. ISOMAX (Streitmatter *et al.* 1993) measures the mass of incident cosmic ray nuclei by measuring their magnetic rigidity and velocity using a superconducting magnet together with a suite of precision tracking, time-of-flight, and Cherenkov detectors which have evolved from those developed for the IMAX experiment (Mitchell *et al.* 1996; Reimer *et al.* 1998). For its first flight, in August 1998, ISOMAX was configured to measure light isotopes with a mass resolution better than 0.25 amu to an energy of ~1.7 GeV/nucleon.

ISOMAX was expressly designed to accurately measure the ratio of radioactive ^{10}Be to stable ^{9}Be to energies where relativistic time-dilation becomes significant. Beryllium is produced by fragmentation of heavier cosmic rays and is entirely secondary. As such, with a half-life of 1.6x10^{6} years, ^{10}Be has been the most important radioactive clock for measuring the age of the cosmic rays. The ^{10}Be/^{9}Be ratio is primarily sensitive to the propagation lifetime of the cosmic rays and not the total amount of matter traversed. Examined in conjunction with an energy-dependent mean matter traversal derived from elemental secondary-to-primary ratios (e.g. B/C), the ^{10}Be/^{9}Be ratio can be used to determine the mean gas density through which the cosmic rays have passed.

At relativistic energies, time-dilation extends the decay lifetime of the ^{10}Be, allowing it to probe longer mean ages. By extending measurements of beryllium isotopes to high energies (> 3 GeV/nucleon in future flights) ISOMAX can distinguish between current models of cosmic ray transport. As an illustration, Figure 1 shows the published ^{10}Be/^{9}Be ratio measured by satellite instruments compared to energy-dependent curves calculated using a Leaky-Box Model and a Diffusive-Halo Model. For a review of the models see Berezinskii *et al.* (1990). The satellite measurements are at energies too low to effectively distinguish between these models using only the ^{10}Be/^{9}Be ratio. Although data from ACE are not yet published, the CRIS instrument will reach energies only slightly higher. ISOMAX, however, probes an energy range where separation between the models becomes significant and is an important complement to ACE.

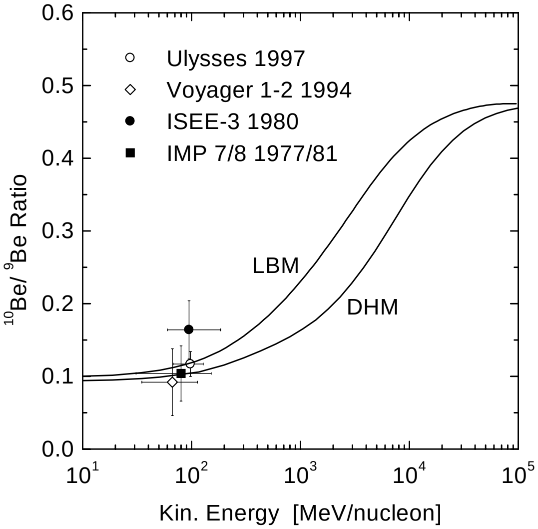

Figure 1: Comparison of the ^{10}Be/^{9}Be ratio from propagation models and from satellite data. LBM: Leaky-Box (n = 0.3 atoms/cm^3); DHM: 3.5 kpc Diffusive-Halo (Simon 1999).

2 Instrument Description:

Above a few hundred MeV/nucleon, the most effective technique for isotopic measurements is to determine the magnetic rigidity (momentum/charge), charge, and velocity of incident nuclei. The mass resolution of such an instrument for a given energy and particle species is a function of both the rigidity resolution of the magnetic spectrometer and the resolution of the velocity systems. The figure of merit for the spectrometer is the characteristic maximum detectable rigidity (MDR), the highest rigidity at which curved and straight tracks can be distinguished. To accurately measure Be isotopes to 4 GeV/nucleon, considering the performance of the ISOMAX velocity detectors, an MDR of about 700 GV/c is required.

ISOMAX, shown in schematic form in Figure 2, uses a magnetic spectrometer made up of a high-field superconducting magnet and a precision tracking system to measure the curved trajectories of particles passing through the magnetic field. The measured curvature and the magnetic field along the particle path are used to derive the magnetic rigidity. The rigidity resolution of the spectrometer is a function of the magnetic field integral, the tracking resolution, and the configuration of the tracking detectors. The ISOMAX spectrometer (Hams *et al.* 1999) is designed to maximize rigidity resolution while maintaining the critical ability to recognize scattering events which may alter the measured curvature. The ISOMAX magnet has been operated at 80% of its full design current of 200 A, and for the 1998 flight was operated at 60% (120 A). At this current, the central field is 0.8 T and the mean field integral through the tracking system is 0.54 Tm. The tracking system is made up of three drift chambers with a hexagonal-close-packed cell

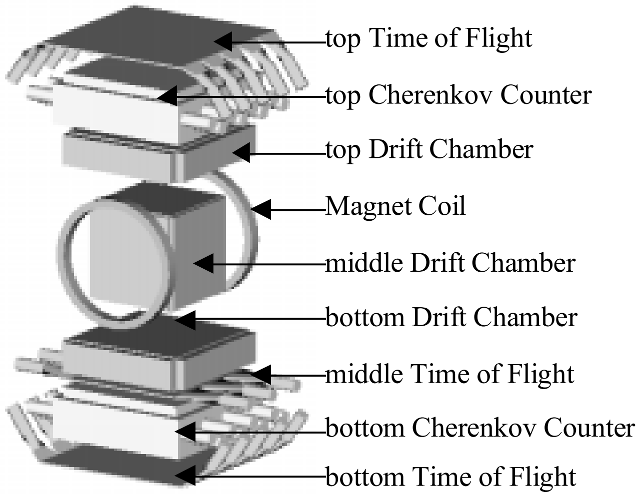

Figure 2: Schematic of the ISOMAX instrument.

structure (Hof *et al.* 1994) and pure CO_2 drift gas. The drift chambers have a typical position resolution of 65 μm for Z=1 (ground-level muons), improving to 54 μm for in-flight He and 45 μm for Be. The characteristic MDR of the ISOMAX spectrometer measured in the 1998 flight is 970 GV/c for He, which scales to 1.2 TV/c using the measured resolution for Be, well in excess of the MDR required to measure Be isotopes at relativistic energies.

Particle velocities in ISOMAX are measured by a high-resolution time-of-flight system (TOF) and a pair of Cherenkov detectors with silica-aerogel radiators. The TOF system (Geier *et al.* 1999) also determines charge from ionization energy loss and velocity, and forms the first level event trigger. The TOF uses plastic scintillators viewed by fast photomultiplier tubes. The TOF layers are separated by 2 m from top to middle and 2.6 m top to bottom. Analysis of the timing performance of the TOF system is at a preliminary stage. With no corrections applied, single-paddle time resolutions of 47 ps for He and 23 ps for C have been measured at the lower of two discrimination thresholds, equivalent to 66 ps and 32 ps respectively for pairs of paddles. In the final velocity analysis the time resolution will be improved by including all three TOF layers. For events where the signals from the TOF are well above the upper threshold, timing data from both thresholds will be used. For Be, the velocity derived from the TOF can be used to determine mass with a resolution of ≤ 0.25 amu to energies approaching 1.3 GeV/nucleon.

The two silica-aerogel Cherenkov detectors (de Nolfo *et al.* 1999) measure velocities above the range of the TOF. For the 1998 flight, radiators with an optical index of 1.14 were used to cover the energy range from 1.08 GeV/nucleon to about 1.7 GeV/nucleon and complement the TOF measurements. The Cherenkov detectors yielded a total of ~22 photoelectrons for relativistic singly-charged particles.

ISOMAX has a geometry factor of 450 $cm^2 sr$ and uses a two-level event trigger to insure that most measured particle trajectories pass through the full instrument. The first-level trigger is normally a robust four-fold coincidence between signals from both ends of the top and middle TOF planes. The required pattern can be reprogrammed in flight for any combination of signals from the six ends of the three TOF layers with a minimum requirement of one top signal and one middle or bottom signal. The second-level trigger uses the outermost eight layers of the inner drift chamber and can be programmed in flight to any logical combination, including a bypass (no hits required).

3 The ISOMAX Payload:

The ISOMAX payload is completely new. The pressure vessel utilizes flexible Kevlar fabric domes, which are relatively transparent to incident particles, and an aluminum midsection. All magnet cryogenic and electrical services can be carried out with the pressure vessel sealed. The pressure vessel is not a structural element. Mechanical loads are carried from the instrument frame through the midsection directly to the suspension. The landing platform, which also carries the batteries, switching power supplies, CIP, gas make-up system, and tape system, ties directly to the suspension attachment-points.

The control and data handling system uses PC104 format single board computers with Intel x86 CPUs. Data acquisition, event building, and slow controls are handled by one CPU, while a second CPU controls on-board recording to 8mm magnetic tape. High voltages and thresholds for all detectors are fully commandable. A custom telemetry/frame-sync board (Christian *et al.* 1995) is used. For the 1998 flight, event data acquisition electronics were largely based on commercial CAMAC modules. Slow control and housekeeping used custom, low-power electronics. To insure the highest possible timing and pulse-height resolution, great care was taken to limit noise from the power supplies reaching the electronics.

4 ISOMAX Flight and Performance:

ISOMAX was launched from Lynn Lake, Manitoba, Canada on August 4, 1998, and landed near Peace River, Alberta about 33 hours later. The payload spent 29 hours at float, with a maximum altitude of 38 km. During the night, ISOMAX flew over a large thunderstorm and descended to 30 km. ISOMAX returned over 16 h of data at altitudes above 36 km. Several hours of data were recorded at lower altitudes and will be used to help analyze atmospheric interactions.

Most of the work to date has focused on the abundant helium data. Helium mass histograms for sample energy bins in the TOF and Cherenkov energy ranges are shown in Figure 3 as an early illustration of the ability of ISOMAX to resolve isotopes. The analysis of the velocity detectors is at a preliminary stage and these do not represent the final mass resolution. Also, in the 1998 flight, the trigger was set to reject all but the lowest-energy protons and to be fully efficient in detecting Z $\geq$ 3 nuclei. The resulting trigger biases must be taken into account when comparing the relative abundance of He isotopes.

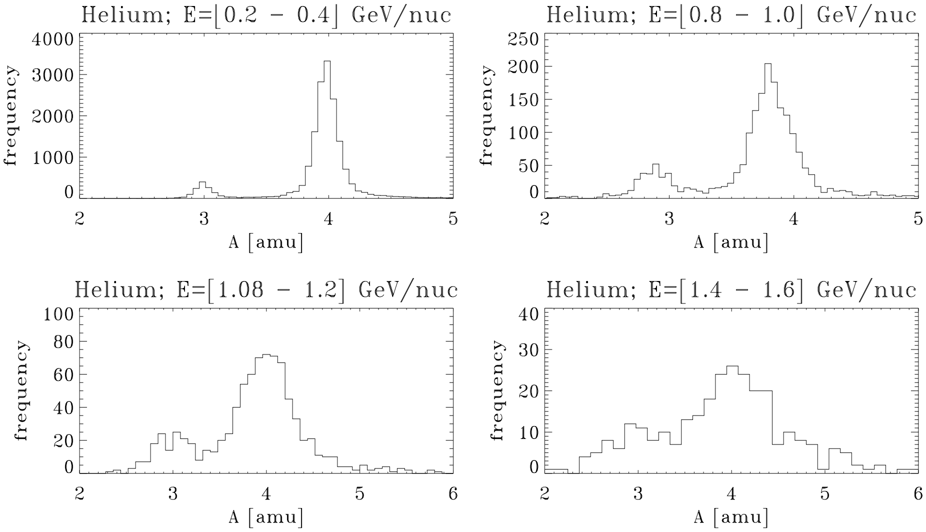

Figure 3: Helium mass histograms using velocities measured by the TOF system (upper plots) and Cherenkov detectors (lower plots).

5 Future Plans:

We are currently completing the instrument analysis of ISOMAX. The succeeding physics analysis will focus on obtaining the ratios of Li, Be, N, and O isotopes to 1.7 GeV/nucleon, the B/C ratio to the flux limit of the instrument, and elemental and isotopic spectra.

ISOMAX is presently being prepared for a second flight, in the summer of 2000, with an expected duration of at least three days. Incorporation of low-power data acquisition and trigger electronics will reduce power consumption by more than a factor of 3, allowing this flight to use a similar battery pack to that used for the one-day 1998 flight. Elimination of the heavy CAMAC electronics and other structural modifications will reduce payload weight and increase ballast margins. To measure isotopes to energies > 3 GeV/nucleon, silica-aerogel radiators with an optical index of 1.043 will be used. The magnet will be operated at 160 A, resulting in an expected MDR of 1.6 TV/c for beryllium.

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