LARGE ISOTOPE SPECTROMETER FOR ASTROMAG

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ABSTRACT

The Large Isotope Spectrometer for Astromag (LISA) is an experiment designed to measure the isotopic composition and energy spectra of cosmic rays for elements extending from beryllium through zinc. The overall objectives of this investigation are to study the origin and evolution of galactic matter; the acceleration, transport, and time scales of cosmic rays in the galaxy; and search for heavy antinuclei in the cosmic radiation.

To achieve these objectives the LISA experiment will make the first identifications of individual heavy cosmic ray isotopes in the energy range from about 2.5 to 4 GeV/n where relativistic time dilation effects enhance the abundances of radioactive clocks and where the effects of solar modulation and cross-section variations are minimized. It will extend high resolution measurements of individual element abundances and their energy spectra to energies of nearly 1 TeV/n, and has the potential for discovering heavy anti-nuclei which could not have been formed except in extra-galactic sources.

EXPERIMENT OBJECTIVES AND RATIONALE

1. Elemental and Isotopic composition of CR sources--It has recently been shown that the matter from which cosmic rays originate has a distinctly different isotopic composition than typical solar system matter for several isotopes[1-3]. In particular, ^{22}Ne is at least three times more abundant in cosmic ray source material, while the abundances of the neutron rich isotopes of Mg and Si are enhanced by a factor of about

1.5. For each of the 5 isotopes for which the source composition has been determined to an accuracy of 30% or better, there is evidence for a difference between cosmic ray and solar system material. This implies a difference between the nucleosynthesis of cosmic ray and solar system matter, and has stimulated a number of theoretical suggestions as to how such a difference may have occurred. Of these, the most quantitative are the "supermetallicity" model[4] which postulates that cosmic rays are produced in "metal" rich regions of the galaxy, and the Wolf-Rayet model[5] which assumes that a fraction of the cosmic rays originate as surface mass loss of Helium burning products of WR stars.

The results from LISA will allow us to test these and other models by extending the present observations to a variety of other nuclei. The number of individual isotopes that we expect to detect and resolve with resolution ≤0.3 amu in two years of data collection is shown in Fig. 1. For isotopes such as ^{57}Fe and ^{58}Fe for which secondary contributions are small, the derived source abundances relative to ^{56}Fe will be limited by statistics, and are ~6% and ~15% respectively. Measurement of these and other species including ^{13}C, ^{18}O, ^{29,30}Si, ^{38}Ar, ^{34}S, and ^{54}Fe should make it possible to constrain and discriminate between models.

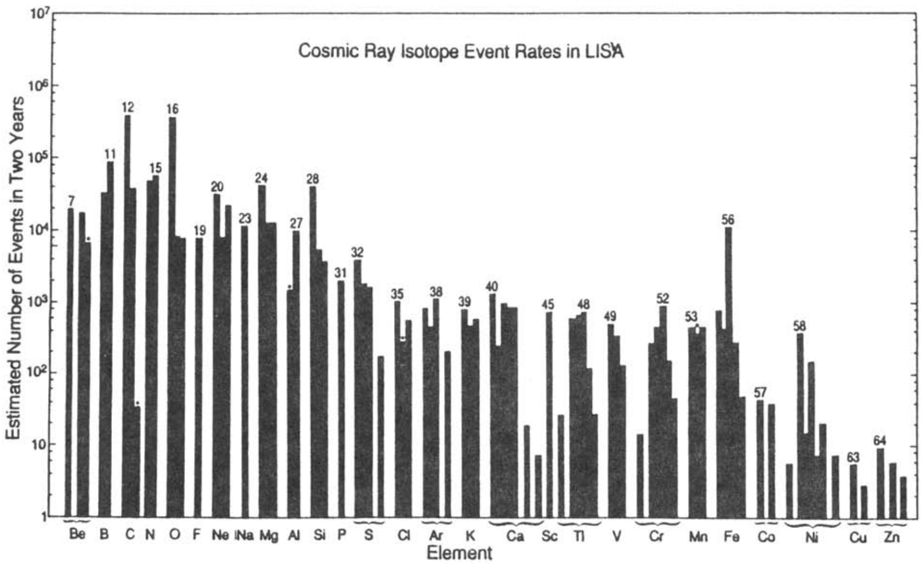

Fig. 1--Expected yields of isotopes from Be to Ni that LISA will observe with excellent mass resolution (<0.3 amu). The estimates include the effects of the geomagnetic field averaged over the orbit, nuclear interactions in instrument, and 2 years of data. Selected radioactive species which can decay in flight are marked with a star.

The abundance of isotopes such as ^{13}C and ^{18}O in cosmic rays is also an important test of galactic evolution models. Recent optical measurements[6] indicate a factor of 2 enhancement of these isotopes in the local galactic region. High precision measurements of the cosmic ray abundances, coupled with recent improved knowledge of spallation production cross-sections, should enable us to differentiate between the Wolf-Rayet, solar system, and local galactic values.

Cosmic rays with energies of ~100 GeV/n have apparently traversed only about 1 g/cm^2 of material so that their sources become almost "bare". Thus their source composition can be determined with greater precision than is possible at lower energies[7]. For example, in the iron "secondary" region, a measurement of the ratio of Cr (partly primary) to the (Sc+Ti+V) abundances (mostly secondary) as a function of energy should give a reasonably precise measurement of the Cr source abundance. Other rare source elements where this approach should work include N, F, Na, Al, K, P, Ar, Ca, and Mn.

Accurate measurements of particle energy spectra over a wide energy interval (LISA covers 2$1/2$ decades in energy/nucleon) are also important tools for identifying particle acceleration mechanisms. This is potentially important since special sources such as Wolf-Rayet stars may have atypical energy spectra. Table 1 summarizes the expected yields of representative elements.

Number of Events per Two Years		
Element	>10 GeV/n	>100 GeV/n
B	66,000	600
O	600,000	12,000
Ne	270,000	4,000
Ca	15,000	200
Fe	100,000	2,000

2. *Cosmic Ray Acceleration Time Scales*--The fundamental question of the time scale of the acceleration of cosmic ray nuclei will be addressed by measuring radioactive isotopes (and their daughters) that decay only by electron capture. Examples of such isotopes are ^{56}Ni, ^{57}Co, and ^{59}Ni (shown in Fig. 2) which have half-lives ranging from a few days to 10^5 years.

3. *Cosmic Ray Transport and Reacceleration*-- At energies greater than ~30 GeV/n, element ratios such as B/C and (Sc+Ti+V+Cr)/Fe are sensitive to propagation and may contain information relevant to acceleration. These ratios should distinguish between the energy dependent leaky box, reacceleration, and the "closed galaxy" models.

High energy isotope measurements can also add a new dimension to studies of cosmic ray propagation using radioactive isotopes such as ^{10}Be, ^{14}C, ^{26}Al, ^{36}Cl, and ^{54}Mn as natural clocks to determine the time constants associated with the storage of cosmic rays in the galaxy. Fig. 3 shows how the abundances of ^{10}Be and ^{26}Al are expected to depend on energy and on the average density of material in the cosmic ray confinement region. The LISA measurements will be made at energies

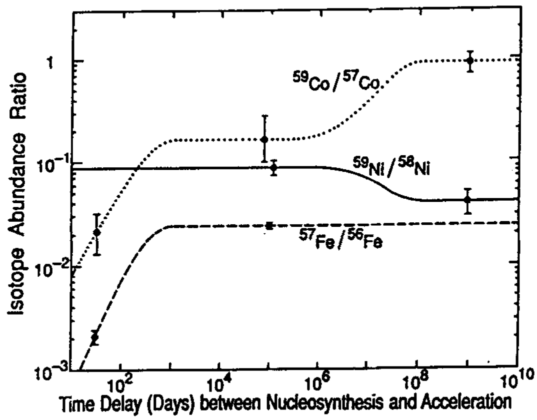

Fig. 2--Expected Fe, Co, and Ni isotope ratios as a function of the time delay between nucleosynthesis and cosmic ray acceleration. Measurement uncertainties expected from LISA are shown.

corresponding to Lorentz factors of γ= 3.6 to 5.5, where the effective half-lives of these clocks are several times greater than at low energy. Comparison of precise measurements by LISA with the improved measurements expected at 0.1 to 0.2 GeV/n from missions in the 1990's will provide sensitive tests of models which predict the energy dependence of isotope abundance ratios based on a postulated distribution of matter in the confinement volume.

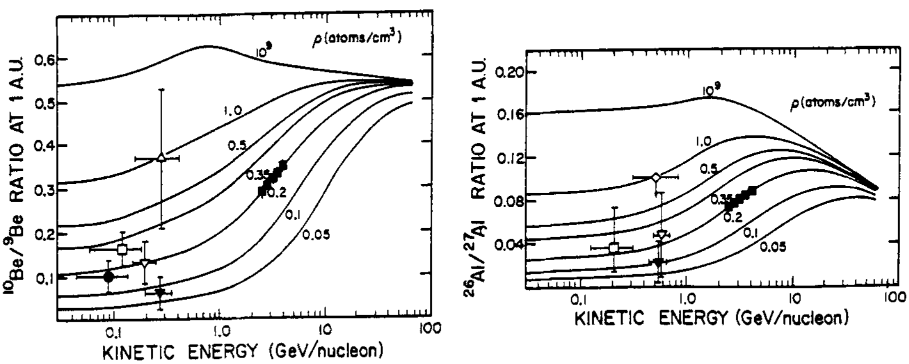

Fig.3--^{10}Be/^{9}Be and ^{26}A/^{27}Al ratios vs. energy(calculations by Guzik and Wefel[8]) parameterized by the density of the propagation region. Simulated LISA results (solid squares; statistical error bars slightly larger than the solid squares) are indicated assuming ρ=0.2/cm^3.

4. *Cosmological Antimatter*--LISA is also capable of searching for heavy antinuclei with Z>3 having energies >2 GeV/n. In 2 years of operation LISA should collect about 7 x 10^6 heavy nuclei giving an upper limit on the antimatter/matter ratio of <4 x 10^{-7}, assuming that no antimatter candidates are observed. This is an improvement of about 2 orders of magnitude over present limits.

THE LISA INSTRUMENT

The geometric arrangement of the LISA detectors is shown in Fig. 4. LISA consists of a central core for tracking particles through the magnetic field, and an outer ring of detectors for determining velocity, charge, and time-of-flight (TOF). Measurements of particle trajectories in the magnetic field are made using a scintillating optical fiber trajectory (SOFT) detector consisting of five planes (H1 through H5), each providing two-dimensional coordinates with an rms resolution of 70μm or better. The outer SOFT planes (H1 and H5) are each constructed as four segments of a polygon, as are the other sensor elements. Two aerogel Cherenkov counters (C1 and C2, or C3 and C4), one Pilot 425 Cherenkov counter (T1 or T2), and a set of scintillators (S1 or S2) are combined in each of eight modules.

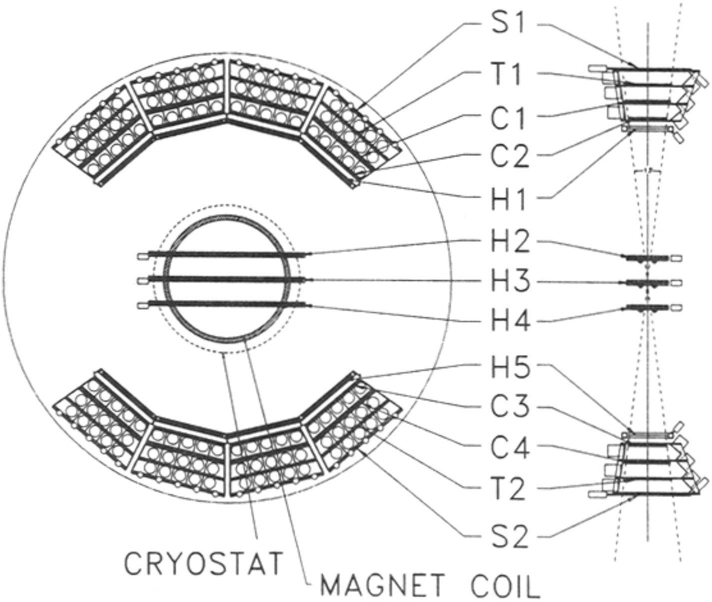

Fig. 4--Schematic cross section of the LISA instrument identifying the various sensor subsystems. The instrument is designed to just fill the shuttle bay (diameter=4.5m).

For the particles to be measured, the Cherenkov response of the Pilot 425 is nearly saturated and provides a direct measure of the atomic number, Z, after pathlength and mapping corrections are applied. Using the track positions measured in the SOFT planes we fit the particle trajectory through the magnetic field and determine the magnetic rigidity (momentum per unit charge) as well as the incidence angle and position. For particles of energy ≤ 10 GeV/n, the aerogel Cherenkov counters measure the particle's momentum per nucleon or velocity. Combining these three measurements allows us to determine the mass, charge, and energy of each nucleus traversing the LISA instrument. The TOF scintillators determine the direction in which the particle traversed the detector (up or down), thus identifying antinuclei, identifying the arrival direction through the geomagnetic field and the corresponding rigidity cutoff, and serving as a consistency check. More details of the detection method used in LISA are given in Ref. 9.

The expected mass resolution including contributions from the trajectory measurement errors and multiple scattering, as well as contributions due to uncertainties in the measured Cherenkov emission, has been calculated to lie in the range of 0.17 to 0.30amu for Fe nuclei with kinetic energy between about 2.5 and 3.7 GeV/n. For lighter nuclei this resolution is improved. For energies where the mass resolution is 0.30 amu or better, LISA will be able to separate adjacent isotopes with abundance ratios of 5:1 or less, while for mass resolution of 0.25 amu adjacent isotopes with abundance ratios as large as 100:1 can be studied.

LISA also has exceptional capabilities for energy spectra measurements. For E ≤ 300 GeV/n, the energy measurement precision is $\leq 20\%$. A useful energy determination can be obtained up to 1TeV/n.

Thus we see that LISA is capable of making precision measurements which cover a wide range of mass, charge, and energy, and will enable us to address the important scientific objectives described above.

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