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Radioactive Clock Isotope Abundance Measurements from the CRIS Experiment aboard the ACE Spacecraft

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Abstract

Radioactive cosmic ray nuclei produced by nuclear interactions during cosmic ray propagation through the galaxy can be used to study the mean interstellar gas density in the propagation volume and the time scales associated with the propagation process. The Cosmic Ray Isotope Spectrometer (CRIS) aboard the Advanced Composition Explorer (ACE) has made high-resolution abundance measurements of the beta-decay secondary isotopes ^{10}Be, ^{26}Al, ^{36}Cl, and ^{54}Mn over the energy range 70-400 MeV/nuc. The large geometrical factor of CRIS (~250 cm^{2}sr) and the 20 months of data collection at near solar minimum conditions have made it possible since launch in August, 1997 to accumulate data samples considerably larger than previous missions. The isotopic abundances derived from these data are presented and compared with previous measurements.

1 Introduction:

Radioactive cosmic ray nuclei can serve as clocks which can provide important information on the origin of cosmic rays, their acceleration and lifetime in the galaxy, the material traversed during propagation from the source to earth, and the propagation mechanism itself (e.g Simpson,1983; Silberberg and Tsao, 1990; Casse, 1973; Ptuskin and Soutoul, 1998; and references therein). The class of radioactive isotopes which decay by β-decay and are secondary nuclei, i.e. they have been created by primary cosmic rays interacting with the interstellar medium (ISM), can be used to measure the mean confinement lifetime of cosmic rays in the galaxy. In this paper we present abundance measurements of four of these isotopes, ^{10}Be, ^{26}Al, ^{36}Cl, and ^{54}Mn relative to stable isotopes of the same element. The lifetimes of these nuclei to beta decay span the range from about 0.3-1.6 My. Within the framework of the leaky box model, the mean cosmic ray lifetime in the galaxy and the mean interstellar gas density can be determined using the interaction cross-sections for production of the βdecay and stable isotopes from fragmentation of heavier nuclei, and the β-decay halflife. The measurements reported here were obtained from the Cosmic Ray Isotope Spectrometer (CRIS) instrument which was launched aboard the NASA Advanced Composition Explorer (ACE) spacecraft on August 25, 1997. The CRIS instrument combines large collecting power (~250cm^{2}sr) with good resolution for nuclei over the charge range of 3≤Z≤34 and energy range ~50-500 MeV/nuc.

Table 1 lists the isotopic species of interest, the halflife of the radioactive species, and the energy range at the top of the instrument covered by the CRIS measurement. The halflife of fully stripped ^{54}Mn has been measured recently (Zaerpoor, et al. 1997; Kibedi, et al. 1997; Wuosmaa, et al. 1998) but is known with much less precision than the others owing to a short lifetime (312 day) electron-capture decay channel that makes laboratory measurement of the β-decay lifetime difficult. The β^- decay lifetime is not measured directly but is derived from the β^+ mode using nuclear decay systematics.

β-decay Isotope	β-decay halflife (y)	# of CRIS Particles for Element	Energy Range (MeV/nuc)
^{10}Be	1.5×10^6	6552 (θ<40°)	70-145
^{26}Al	7.1×10^5	10967 (θ<40°)	125-300
^{36}Cl	3.0×10^5	1196 (θ<30°)	150-350
^{54}Mn	$\sim 6.3 \times 10^5$	2954 (θ<30°)	178-400

Table 1

2 Measurements

In Figure 1 we show histograms of Be, Al, Cl and Mn events. The data were collected from 28 Aug. 1997 through 11 Apr. 1999, with the exception that several solar active periods were excluded. The events

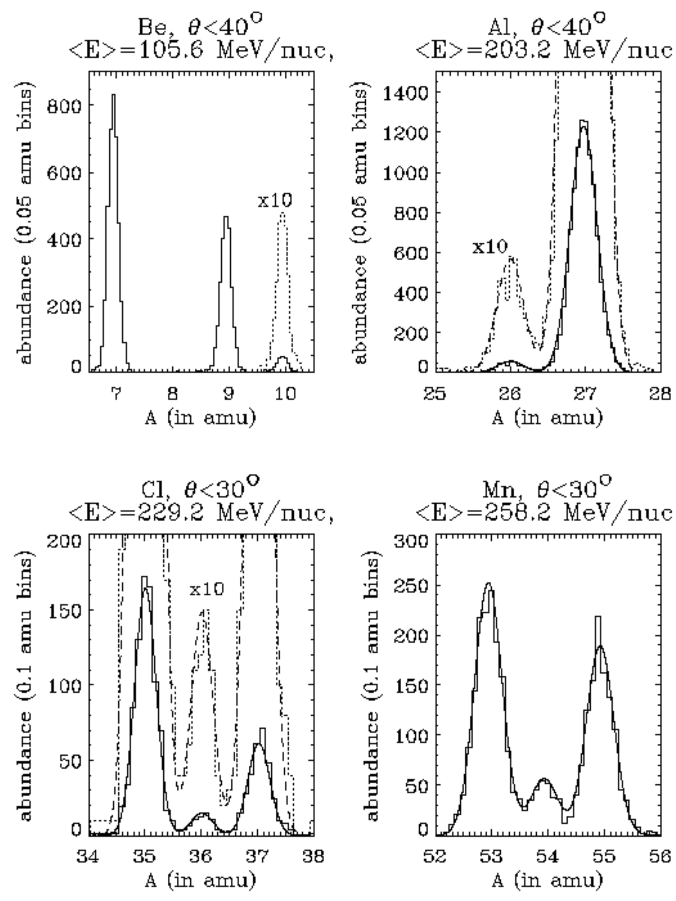

Figure 1--Histograms of Be, Al, Cl, and Mn isotopes.

were selected for angle to achieve excellent resolution while retaining adequate statistics. The Be and Al events were selected to be within 40°, and the Cl and Mn were selected to be within 30° of the normal to the

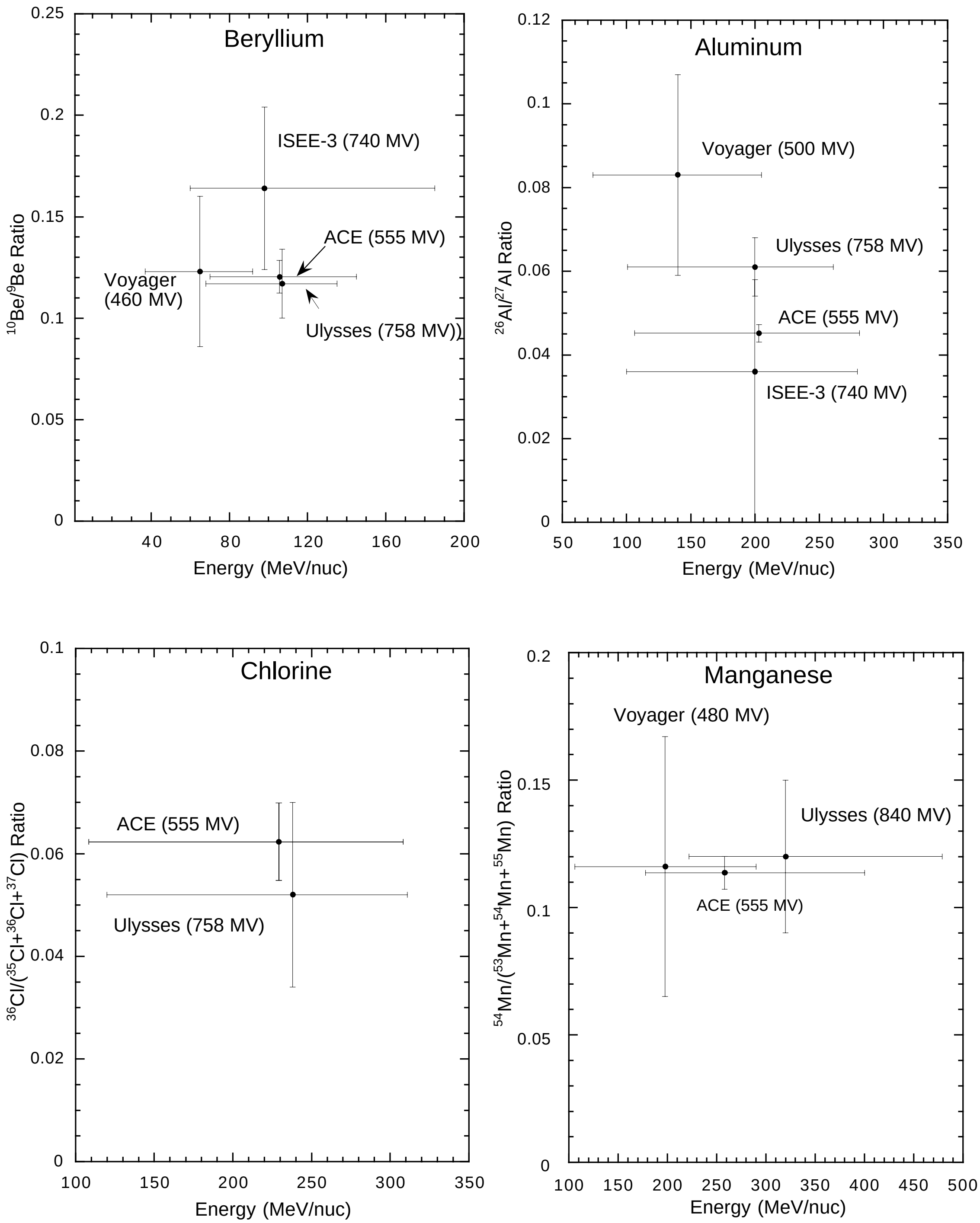

Figure 2-- Isotope abundance ratios for ACE compared to other measurements

3) demanding consistency between mass estimates from using different detector combinations for dE/dx and E_{Tot}, and 4) rejecting events with poorly defined trajectories. The solid line histograms in Figure 1 correspond to counts as indicated on the y-axis, and the dotted line histogram shown for ^{10}Be, and the Al and Cl isotopes, corresponds to the y-axis scale expanded by a factor of ten. The average event energy corresponding to each element is noted on the figure. Except for Be, the histograms are fit using a maximum liklihood routine and this is shown as a smooth curve for Al, Cl, and Mn. With Be a fit is not needed since the peaks are completely separated and a simple count of particles can be used. The Al and Cl resolution is also sufficient to obtain good abundances simply by appropriate cutting and counting particles.

In Figure 2 we plot the abundance ratios corrected to the top of the instrument and compare them with previous satellite experiment measurements. (Ulysses: Connell, 1998a and b; Duvernois, 1997; Simpson and Connell, 1998. ISEE-3: Wiedenbeck and Greiner, 1980. Voyager: Lukasiak et al., 1994, 1997a and b). For CRIS measurements, the vertical error bars are statistical errors only. For all of the measurements, the horizontal bar represents the energy band covered by the measurement. The mean solar modulation parameter ϕ for the CRIS measurement is 555MV which was obtained using Climax neutron monitor data and the method described in Badhwar and O'Neill, 1993. The ϕ parameters for the Ulysses, Voyager, and ISEE-3 are also shown in the figure. The plotted ratios are not adjusted for the different modulation levels.

3 Discussion and Conclusions:

The most striking feature of these new measurements is the substantial reduction in the size of the error bars. For Be, Cl, and Mn, the agreement with previous experiments is quite good. The CRIS value for the Al ratio appears to differ significantly from the Ulysses value (~2σ lower) and, to a lesser extent, from the Voyager value (~1.5σ lower). It is shown by Yanasak, et al. (1999) that, after adjustment for solar modulation, the discrepancy from the Ulysses value is reduced. We believe that the improved statistics and resolution of CRIS has enabled us to both reduce the ^{27}Al distribution tail contribution to ^{26}Al and to more accurately determine the magnitude of that contribution, thus improving the precision of the measured ratio. However, additional work remains to be done to optimize our fit values.

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