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HEAVY ION MEASUREMENT ON LDEF

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SUMMARY

Heavy ions with nuclear charge $Z=6$ to $Z=26$ are detected in a stack of plastic track detectors. The measured energies in the range 10-240 MeV/nuc are well below the geomagnetic cutoff value of the LDEF orbit. The arrival directions of the low energy particles ($Z=6-26$, $E<40$ MeV/nuc) are consistent with a trapped component incident in the South Atlantic Anomaly.

INTRODUCTION

The Kiel experiment M0002 on tray E6 was designed to measure the charge and the arrival direction of heavy ions in the energy range 10-1000 MeV/nuc with nuclear charge equal to or greater than 3. To complement the arrival direction measurement, two additional stacks were integrated in subunits of the Biostack A0015 (DLR Cologne) on trays C2 and G2.

CR-39 and Kodak CN foils are used as visual track detectors with an excellent spatial resolution. These detectors remained sensitive throughout the whole LDEF mission. The scientific data are stored in latent tracks and are revealed in the laboratory after recovery. For a description of the detector arrangement see Beaujean et al. (1991a).

The extended LDEF mission time of $1.8\cdot10^8$ sec increased the number of collected particles without deterioration of the detector system. The objectives of the experiment are achieved and this progress report contains our present results on trapped radiation and geomagnetically forbidden particles.

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CALIBRATION OF THE DETECTOR

The specific response of a plastic track detector is given by the variation of the track etching rate with respect to the energy loss of the heavy ion. For a postflight calibration the CR-39 detector of M0002 was exposed to 200 MeV/nuc Ar^{40} ions with a 90^0 angle of incidence at the Saclay accelerator. Etching of the CR-39 was done in 6n NaOH at 70^0 C for 10 hours. At this etching time the heavy ion tracks can be clearly separated from the small etch pits which were probably produced by secondaries from proton interactions.

The measured surface area of the Ar^{40} etch cones indicates a variation of the bulk etching rate. This variation is mainly due to the nonuniform CR-39 material. The influence of track aging and fading during the mission is included in the internal flight calibration using the cosmic rays particles themselves. Fig. 1 shows the result of 113 stopping heavy ions. Individual cones along a specific track are marked by the same identification number. 48 of these ions penetrated LDEF and stopped in the detector unit coming from backward direction.

Similar to our Spacelab-1 (Sl-1) measurement (Krause, 1986b), the data show a densely populated band with a sharp intensity drop to more ionizing particles. This edge can be allocated to Fe particles based on the knowledge of the cosmic ray elemental abundances.

The calculated track etching rate deduced from this inflight calibration shows a slightly reduced sensitivity compared to the CR-39 in Sl-1. The overall low sensitivity of the CR-39 detector flown in Sl-1 and LDEF is due the low oxygen concentration within the stack containers during space flight. According to Fig. 1 the registration probability for ions with $Z < 20$ is strongly decreased with decreasing nuclear charge Z.

The calibration of the Kodak CN, integrated in the A0015 subunits, is in progress. The preliminary analysis indicates a higher sensitivity compared to the CR-39 and we expect a high registration probability of nuclear charges $Z \geq 6$ in these foils.

EXPERIMENTAL RESULTS

54 particles from Fig. 1 arrived from unshielded free space and have a nuclear charge $Z \geq 20$. Using a geometric factor of $1.2 \cdot 0.03$ $sr \cdot m^2$ and a preliminary corrected particle number of 75, the mission averaged flux of the detected particles with $Z \geq 20$ in the energy interval 40-240 MeV/nuc is

$$J(Z \geq 20) = (6 \pm 2) \cdot 10^{-8} / m^2 \cdot sec \cdot sr \cdot MeV/nuc. \qquad (E = 40 - 240 \ MeV/nuc)$$

The energy spectrum in this interval is found to be almost constant.

Using the CR-39 calibration, the analysis on the arrival direction measurements of low energy particles (Beaujean et al., 1991b) is extended to a charge identification. From Fig. 1 we conclude that completly etched stopping ends with conelength $L > 150$ µm are produced by stopping ions with $Z \geq 20$.

In the topmost foil of M0002 24 stopping particles are detected on 100 cm^2 with a conelength $L = 150 - 350$ µm. All 24 particles arrived from unshielded space direction having energies 18 - 25 MeV/nuc. A similar analysis yielded 3 particles with $L > 150$ µm on 16 cm^2, stopping in the upper CR-39 foil of A0015 on tray C2 and arriving from unshielded earth direction.

The ions with $Z \geq 20$ are part of the low energy particle population, which shows a cylindrical geometry in the arrival direction. To calculate the flux, 11 particles out of 24 are used having a conelength 150 - 200 µm (the corresponding energy is 18 - 20 MeV/nuc). Stopping ends with $L > 200$ µm are not considered, because particles with $Z = 20$ may be less represented due to the detector response. Assuming a trapped origin of these particles, the collecting time within the SAA is taken as 1% of the mission time. Using a geometric factor of $1.2 \cdot 0.01 \ m^2 \cdot sr$, the flux of the detected particles with $Z \geq 20$ in the energy interval 18 - 20 MeV/nuc is

$$J(Z \geq 20) = (2.5 \pm^{2}_{1}) \cdot 10^{-4} / m^2 \cdot sec \cdot sr \cdot MeV/nuc. \qquad (E = 18 - 20 \ MeV/nuc)$$

The Kodak CN material integrated in A0015 is used to complement the arrival direction measurements including lower charged particles. Fig. 2 shows the result for 205 particles, penetrating the topmost Kodak CN foil on C2. Due to the higher sensitivity of this material we expect that particles with $Z \geq 6$ are included in this distribution.

Note that the particles arrive from earth direction (but not from space direction). This distribution again gives a strong evidence for a cylindrical geometry and the arrival directions of all detected low energy particles follow a plane perpendicular to the magnetic field line at the northern edge of the SAA.

DISCUSSION

The detected iron/subiron particles have rigidities well below the geomagnetic cutoff value for the LDEF orbit assuming fully stripped ions. Fig. 3 shows rigidity versus kinetic energy for some ions with different (charge to mass) ratios and a rough transmission function for the LDEF orbit using vertical cutoff rigidities. From this figure we conclude that the detected iron/subiron particles in the energy range 40 to 240 MeV/nuc must have a charge state well below 14 to arrive at the LDEF orbit from outside the magnetosphere. In case the detected particles enter from interplanetary space, the given flux is a lower limit, as the ions are mainly admitted during the high latitude portions of the orbit.

Early measurements of geomagnetically forbidden particles at balloon altitude were reported by Blanford et al. (1972) and Friedlander et al. (1977), who explained them as return-albedo particles. Krause et al. (1986a) reported on 100 MeV/nuc particles below cutoff rigidity detected in the Spacelab-1 orbit (57^0 inclination, 250 km altitude). Adams et al. (1991) detected 600 MeV/nuc iron/subiron particles below cutoff rigidity in the LDEF orbit. Further investigations are in progress to analyse the published data and identify the source of the geomagnetically forbidden particles.

Because LDEF maintained a constant orientation during the mission, trapped heavy ions arrive at characteristic angles, thereby making them distinguishable from other particles. The arrival direction and the rigidity (Fig. 3) of the low energy particles ($E < 40$ MeV/nuc) indicate an origin from a trapped population. Oschlies et al. (1989) and Grigorov et al. (1991) reported on oxygen particles of magnetospheric origin. According to Grigorov et al. (1991) the trapped oxygen flux within the SAA at $2 < L < 3$ showed a strong time dependence with a peak value of about $5 \cdot 10^{-6}$ particles/$m^2 \cdot$sec in the energy range 5 - 30 MeV/nuc.

Our measurement in Kodak CN includes oxygen particles. From the preliminary analysis we deduce as $Z \geq 6$ particles per cm^2 the numbers (52 ± 4) and (34 ± 3) in the energy interval 21 - 25 MeV/nuc and 27 - 32 MeV/nuc respectively (Beaujean et al., 1991b). According to the measurements of Grigorov et al. (1991) on Cosmos satellites these particles are mainly oxygen, collected within one year from 1986 to 1987. In our measurement a definite charge identification is not yet done. Assuming again a detection in the SAA during 1% of the mission, we deduce a flux of

$$J(Z \geq 6) = (0.4 \pm 0.1)/m^2 \cdot sec \cdot MeV/nuc \qquad (E = 21 - 25 \text{ MeV/nuc})$$

as an average during $3 \cdot 10^5$ sec mission time in the SAA region with $1.2 < L < 1.3$. The measured mean flux on the LDEF is about 4% of the corresponding flux of

$$J(Z = 8)_{Cosmos} \approx 10/m^2 \cdot sec \cdot MeV/nuc \qquad (E = 5 - 30 \text{ MeV/nuc})$$

on the Cosmos satellite (averaged over one year during the maximum period).

If we assume a similar time dependence for the oxygen and subiron/iron particle flux in the SAA, the detected integral fluence of particles yields a preliminary relative abundance. Taking 52 particles/cm^2 ($Z \geq 6$, $E = 21 - 25$ MeV/nuc) and 0.11 particles/cm^2 ($Z \geq 20$, $E = 18 - 20$ MeV/nuc), the ratio is

$$N(Z \geq 6) \;/\; N(Z \geq 20) = 236 \pm^{140}_{80} \qquad (E \approx 20 \text{ MeV/nuc})$$

This preliminary ratio is about three times the ratio measured by Chan and Price (1975) on Skylab. Final relative abundances will be given after completion of the detector calibration.

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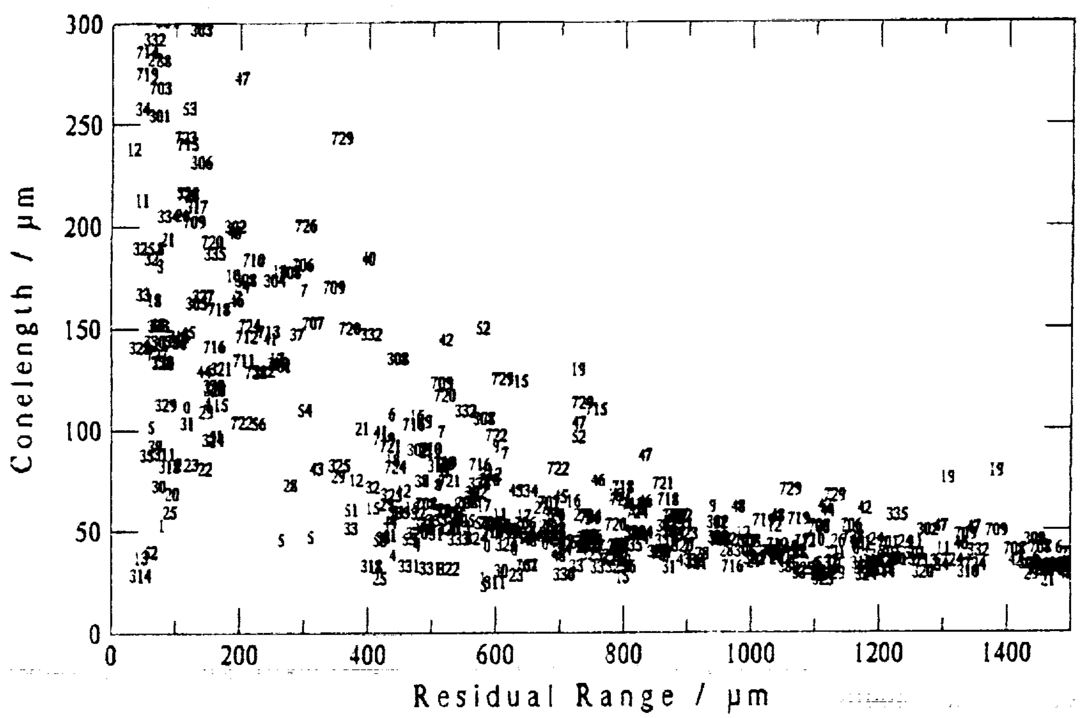

Fig. 1: Conelength-range diagram of 113 tracks in CR-39 of M0002. Cones of the same track are marked with the same number.

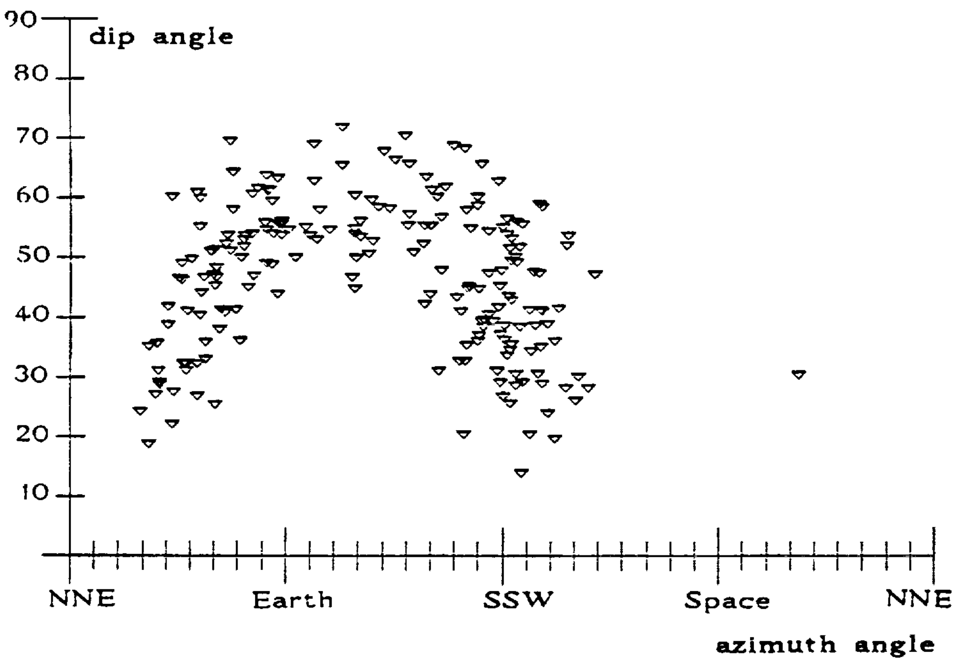

Fig. 2 Arrival directions of 205 particles with Z ≥ 6 penetrating the topmost Kodak CN foil of A0015 on tray C2.

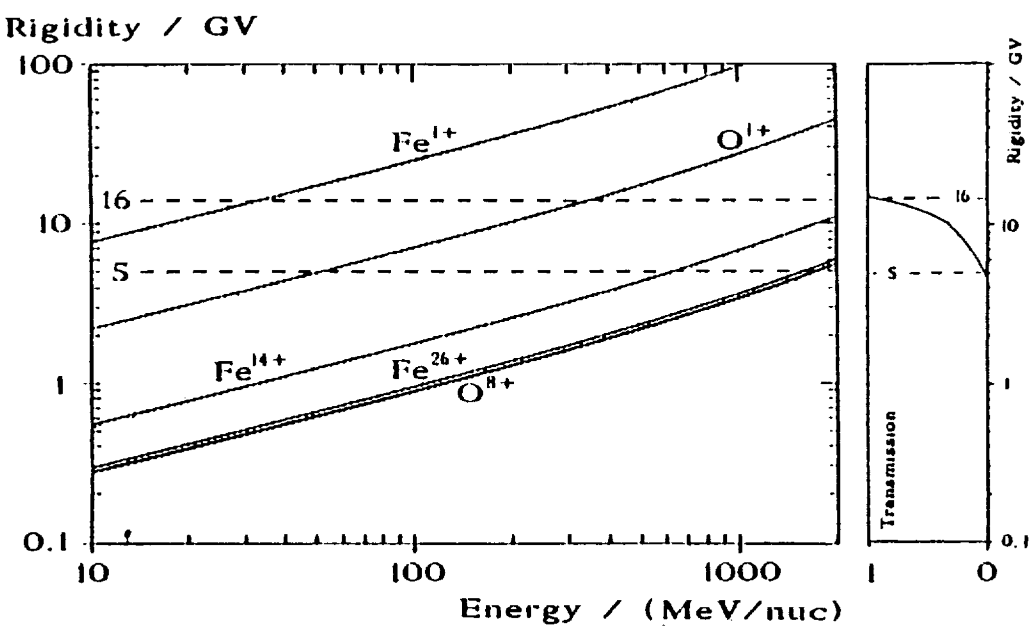

Fig. 3 Rigidity versus kinetic energy for different ions at different charge states. The rough transmission function of LDEF separates the ridigity scale: particles with a rigidity < 5 GV cannot reach LDEF, particles with a rigidity > 16 GV can reach LDEF on the whole orbit.