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Measurement of Nuclear Mass Distribution of Primary and Recoil Heavy Ions inside MIR Space Station with SilEye Silicon Detector

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Abstract

The SilEye experiment aims to study, using a silicon detector composed of six 380 micron-thick strip planes, the nuclear radiation environment inside MIR Space Station. Particular interest has been devoted to the "Light Flashes" phenomenon and to the study of its causes. Here we present preliminary results for nuclear discrimination of light nuclei from data collected inside the Space Station MIR. These measures show the abundance, inside the station, of secondary nuclei and may yield to new results for dose absorbed by astronauts and electronics in space.

1 Introduction:

Long duration manned space flights have brought out the problem of assessing the effects of primary and secondary cosmic ray radiation in order to guarantee the safety of the crews. The presence of High Z Elements (HZE) in the ionizing radiation increases the difficulties in understanding and monitoring these effects. Results obtained from dedicated observation programs (Horneck, 1992) show that energetic HZE could have a quality factor higher than 20. This means that a single fast heavy ion its path through a tissue will cause a damage higher than the several protons or electrons required to release the same amount of energy in the living medium. Many experiments, based mainly on passive detectors, have been conducted to obtain an estimate of the total dose absorbed during long duration space flights and to study the Single Event Effects (SEE) (McNulty, 1996).

The most impressive example of radiation-induced effects on humans is the Light Flash (LF) phenomenon (Tobias, 1952), first reported during the Apollo flights in early 70s (Malachowski, M. J., 1978),: it consists of an anomalous and unexpected visual sensation and appears to the astronaut as a faint spot or a streak of light in closed eyes after dark adaptation.

It is not known whether LFs are generated by particles interactions within the retina or if they occur at different level in the visual system, from the optic nerve to the visual areas in the occipital regions of the cortex. Ground based accelerator experiments to reproduce this effect were also performed (Budinger, et al., 1971, Tobias, et al., 1975) with different results. As far as we know, LF perception is the only functional anomaly directly caused by a single particle, therefore it is important to determine simultaneously time, energy and trajectory of the particle passing through the cosmonaut's visual system, to recognize its kind and origin.

The LF phenomenon was studied in the past decades with dedicated observation programs on Apollo, Skylab and Apollo-Soyuz spacecraft, but new impulse has been given since 1995 with use, for the first time, of silicon detectors in SilEye-1 and SilEye-2 experiments, sent by our collaboration to MIR Space Station. The first prototype, SilEye-1, in 25 hours of work with different astronauts, in two years, has tracked more than 50 LFs, correlating them with radiation background (Galper, at. Al., 1996,). SilEye-2 detector, on board MIR station since October 1997, has collected up to now more than 7 million particles and hundreds of LFs that partially clarify the problem but still do not answer many questions.

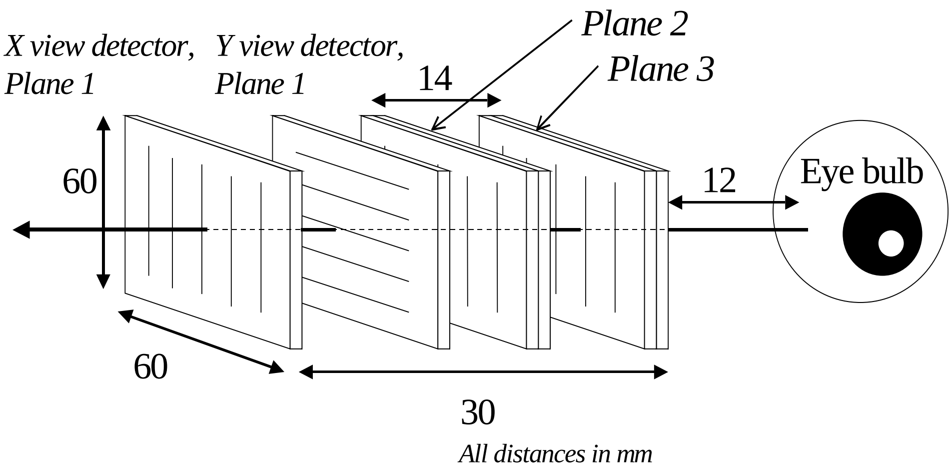

Figure 1. Silicon detector setup scheme for SilEye-2 (see text for details). Passive Iron absorbers of 1 mm interposed between planes are not shown.

A significant correlation between the particles fluxes and the number of perceived phosphenes has been demonstrated, however detectors used, mainly because of their small geometric factor, do not allow the identification of a correlation between the perception of a phosphene and the passage of a single particle with good statistical level. In addition, the SilEye-2 apparatus allows to measure, for the first time with a segmented active detector, the total equivalent dose for high Z particles absorbed in Space Station environment, which, even being only the 1% of the total ionizing particle flux, contribute, due to their high quality factor, to about the 25% of the total equivalent dose absorbed by Space Station crews.

2 Experimental Set-Up:

The SilEye-2 detector is derived from the technology developed for NINA cosmic ray space apparatus (Bakaldin, et al., 1997). Two 60x60x0.38 mm^3 silicon layers, each divided in 16 strips are bundled together to constitute an x-y reading plane. The whole detector array is constituted of three planes, spaced by 15 mm, interleaved by two 1-mm Iron absorbers to increase particles energy loss within the detector's body. The hit strips in different planes determine the particle position and direction (see Figure 1 for a scheme of the detector setup). An analog preamplifier system is mounted on silicon plane sides and provides an energy range from 0.25 to about 260 MeV, corresponding to a maximum released charge in the silicon detector of about 12 pC: nuclear species in

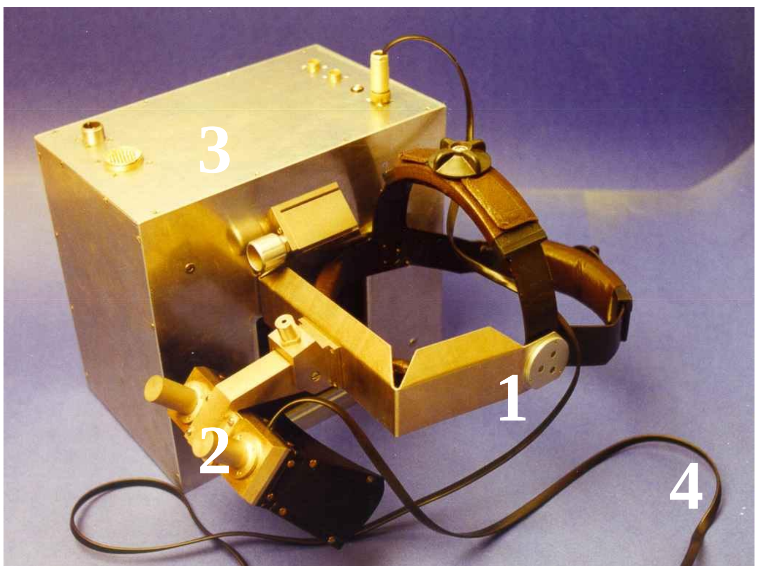

Figure 2: The SilEye2 apparatus: 1. Head Mounting 2. Eye mask 3. Detector box (it is placed on one side of the head). 4. Connection cables for dark adaptation LED.

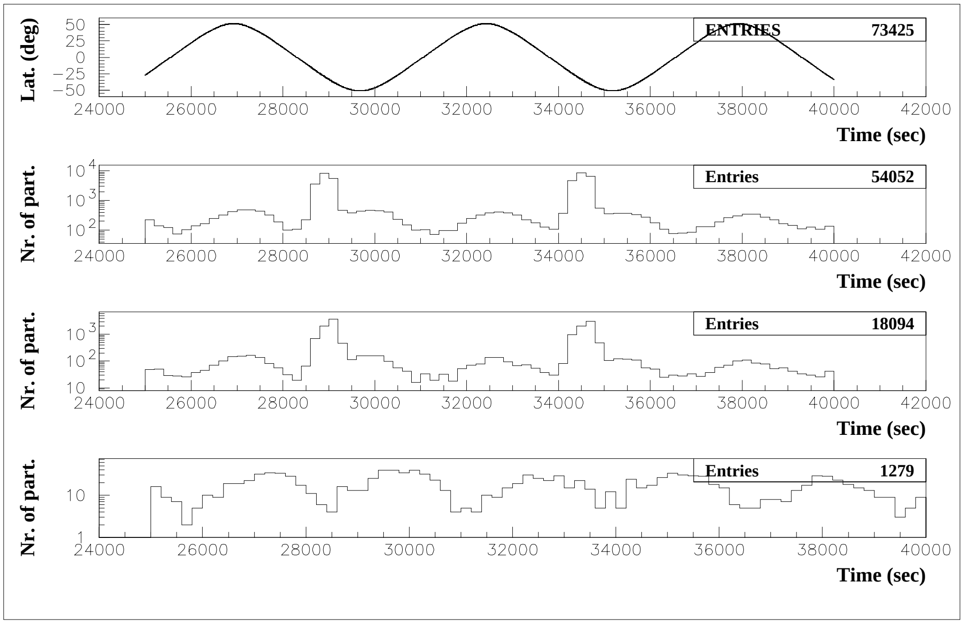

Figure 3: A typical acquisition session inside MIR. From top to bottom: 1. Latitude of MIR vs. time. 2.,3.,4. Hydrogen, Helium and Z>2 events vs. time. It is possible to see how rate increases far from the equator due to the geomagnetic shielding. The two peaks at t=29000 and t=34500 correspond to passage in the South Atlantic Anomaly. Note the increase of Z=1 and 2 nuclei but not of Z>2.

the energy range 40-200 MeV/n can be identified. A valid trigger for the data conversion is produced by the occurrence of at least one signal over threshold in each plane, to discard slow particles and electrons. The trigger threshold is adjustable to completely exclude protons and Helium nuclei from detection, avoiding the device saturation in the high flux regions. The detector is encased in an Al box and coupled a mask, to shield the astronaut's eyes from light, and three LEDs to provide checks on the correct position of the detector (Figure 2), the dark adaptation of the observer and his reaction time. Data acquisition is performed by a portable PC equipped with a PCMCIA card, linked to a joystick button, too. The astronaut presses the button at the occurrence of a LF. Therefore, data come from two different sources: the particle track recorded by the silicon detector and the observation of the LF by the astronaut.

3 Data Analysis:

Data analysis has been performed on about 5 million raw events. After pedestal subtraction, a pre-analysis filter has been applied to eliminate both the spurious tracks and the detector noise, obtaining about 4 million valid events. Single, multiple tracks and showers are easily identified, due to the segmentation of the detector planes. In Fig. 3 a typical behavior is shown: total flux for nuclei with Z≤2 is shown as a function of time: it is possible to recognize the SAA region corresponding to a significantly higher proton flux. In fig 3d, in which the total flux of nuclei with Z>2 is reported, the SAA is no more recognizable.

In the first phase of the analysis, we have selected a set of events in which at least one strip in each silicon layer is hit, but no more than three adjacent strips contribute to the energy release, i.e. only straight tracks are accepted. The energy release inside the silicon detector is linearly proportional to the effective thickness, requiring a correction due to the angle of incidence of the particle.

A detailed study of the detector has been done by MonteCarlo simulation, using the GEANT code, version 3.21 (see ref) in order to obtain a set of variables for particle discrimination (Z, incident energy). An efficient Z selection can be obtained by bidimensonal cuts in the plane individuated by the total energy detected vs the ratio of the deposits in the last and first plane, as shown in Fig. 3, where the data are superimposed to the MonteCarlo results (2≤Z≤8).

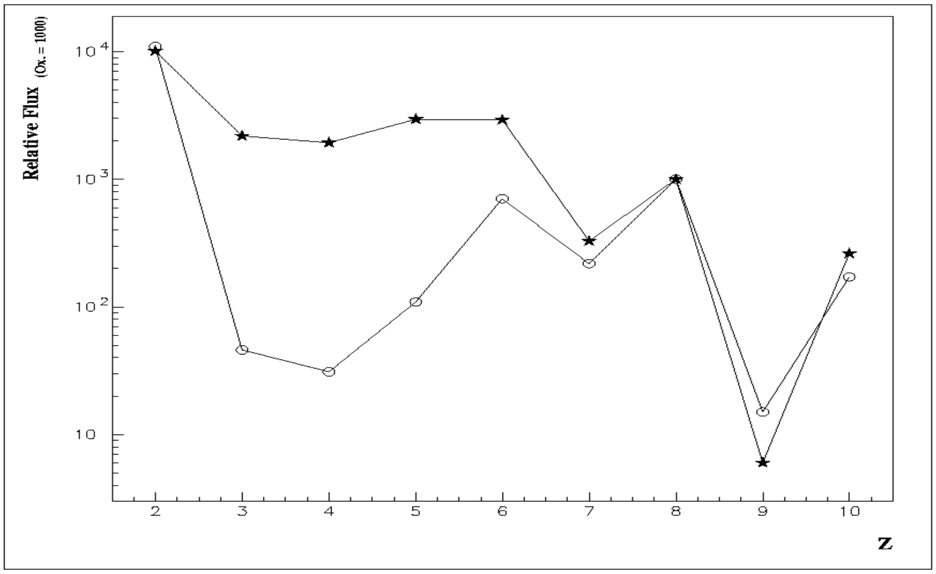

Figure 4: Comparison between elemental abundances (normalized to Oxygen) measured by SilEye (black stars) inside MIR and at 835 km height by the cosmic ray telescope NINA (empty bullets). It is possible to see the high increase of nuclei below Nitrogen due to the interaction with the hull of the Space station.

In Fig. 4, a comparison between the total nuclei fluxes ($2 \leq Z \leq 10$) measured by the SilEye-2 and the NINA detectors (Bakaldin, 1997) shows the role played by the Space Station structures. The NINA apparatus is installed on the top of the Resurs-O1 satellite in an Aluminum container 3 mm thick, while the SilEye-2 detector is well inside the MIR. The increase in the abundance of low Z nuclei is probably the consequence of the interactions of high energy protons with the Space Station materials.

The experiment is planned to work at least until the next crew shift: the first data received has allowed to evaluate the good performance of the instrument and to give feedback to the astronauts on MIR in order to exploit its characteristics at maximum. The construction (Casolino, 1997, Bidoli et al. 1999) of a larger apparatus that combines the use of a large silicon detector and an electroencephalograph, to directly correlate LF and particle crossing the head with brain activity, is under development (project ALTEA).

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