The SilEye apparatus for the study of Cosmic ray on the MIR Space Station

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Since the Apollo missions it is known that the crews, after some minutes of dark adaptation, observed brief flashes of white light or pencil-thin streaks of light . The first report of "*Light Flash*" (LF) dates back to 1969 by astronaut Edwin Aldrin, on board Apollo-11 [1]. Subsequently other crews reported similar experiences. (LF) consist of unexpected visual sensations and appear to the astronaut as faint spots or streaks of light in closed eyes after a period of dark adaptation. Dedicated observation programs were performed on Apollo, Skylab, Apollo-Soyuz missions [2] and, more recently, on MIR Space Station. Since 1995 the experiment SilEye has been working inside the Space Station MIR. It involves Russian and Italian Institutions as well as other European scientific partners, and the Russian Space Corporation that has granted the use of the Space Station and the collaboration of its crews. The objective of the experiment is the study of biophysical tasks related to the radiation environment inside MIR with particular attention to the phenomenon of "Light Flashes". The frequency of LF depends on orbit parameters, especially on the latitude and grows in polar areas and in the area of the South Atlantic Anomaly. LF are practically absent on the equator, where the charged particles' flux is at minimum. There are different hypothesis on the generation mechanisms of visual effects, like direct interaction of charged particles with the retina of the eye by ionization [3] or Cherenkov effect in the ocular bulb or indirect effect from proton knocked out by protons [4]. It was also suggested that scintillation in the eye lens could cause the observed LF. For a review see [5]. Although the cause of LF is still not known, the most probable mechanism involves the passage of a cosmic charged particle through the cosmonaut visual system. Therefore, it is extremely important to determine simultaneously time, nature, energy and trajectory of the particle passing through the cosmonaut eyes, as well as the astronaut's LF perception time. This kind of measurements were not fulfilled by all the previous experiments in space. The first prototype of the detector SilEye-1 [6], [7] was placed on the Station MIR in October 1995. During the last two years 25 measurement sessions involving 6 astronauts have been performed and more than fifty LF's have been recorded. Following this mission, a new detector, SilEye-2, has been developed and placed on MIR in 1997 in order to have a more accurate nuclear identificationin selected energy range [8].

1 Apparatus description and capabilities

The detector array of SilEye-2 is derived from the technology developed for the construction of NINA Cosmic ray space detector [9] and consists of six silicon views, each composed of a $6 \times 6 \times 0.038$ cm^3 silicon wafer, divided in 16 strips 3.6 mm wide. Two views, orthogonally attached, constitute a plane, for a total of three planes, 96 strips and an active thickness of 2.28 mm. The distance between the silicon planes is 49mm in SilEye-1 and 14 mm in SilEye-2. The hit strips in different layers determine the particle position and direction. In SilEye-2 detector two passive absorbers of 1 mm Fe each are

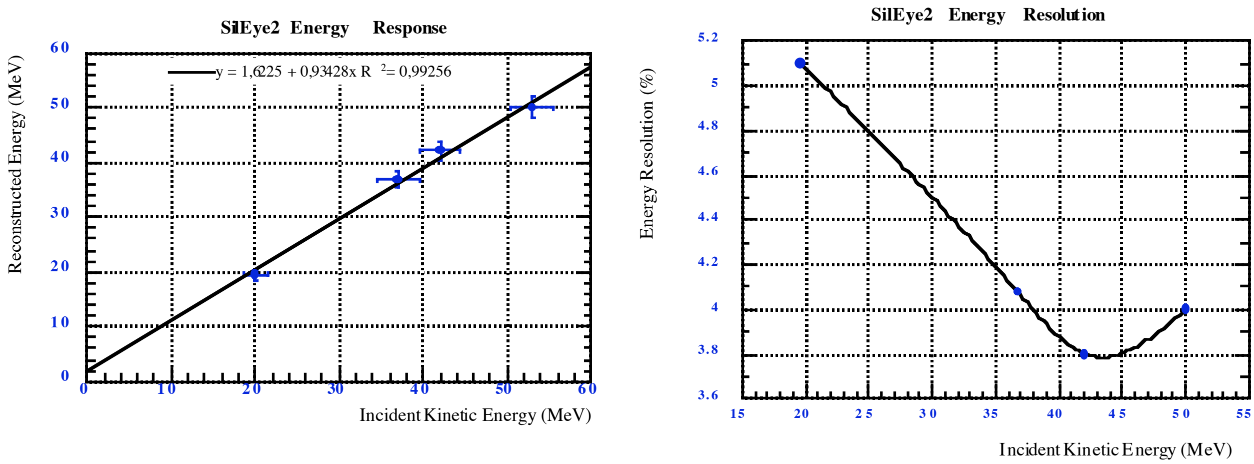

Figure 1: *Energy response of SilEye2 as a function of reconstructed proton energy (on the left) and as a function of reconstructed proton energy (on the right).*

inserted between the planes. SilEye-1 provides track positional information (with angular accuracy of 3 degrees), whereas SilEye-2 may also measure particle energy losses from 0.25 to more than 250 MeV: with these information nuclear species in the energy range 40-200MeV/n can be identified.

The detector is placed in the front and on one side of the astronaut in SilEye-1, and only on one side of the astronaut for SilEye-2; size and mass are reduced (SilEye-2 max dimension 26.4 cm and mass of 5.5 Kg). Data acquisition is performed by a portable PC with PCMCIA acquisition card which is also linked to a joystick with a button (the PC keyboard for SilEye-1) to be pressed by the astronaut when he observes a LF. Data come therefore from two independent sources: the particle track recorded by the silicon detector and the observation of the LF by the astronaut. The helmet has a mask that shields the astronaut's eyes from light; in SilEye-2, also, three internal LEDs allow to check the correct position of the detector, the dark adaptation of the observer and his reaction time.

2 Beam test performances

The calibration of the device SilEye2 was carried out on a proton beam from the CELSIUS storage ring at TSL, Uppsala. The measurements were done at two different proton energies: 48 MeV and 70 MeV.

We have simulated, with standard Geant 3.21 Monte Carlo program, all the beam conditions with different energies and absorbers. In Fig. 1 are plotted the energy response (on the left) and the energy resolution (R.M.S./E) (on the right) of SilEye2 as a function of reconstructed proton energy for events with straight tracks in both views which have declination of middle point in both views no more than one strip from the fitted line. Events with two or more hitted strips in one layer were excluded. In Fig.2 is shown a Monte Carlo study on the particle separation capabilities for several nuclei of interest, for impinging particles with low and high energy respectively. The incident energy range is chosen randomly between 50 MeV/n - 1 GeV/n. It should be noted that even in the region with (E3-E1)$\leq$ 0.2 MeV (corresponding to particles with high kinetic energy) it is

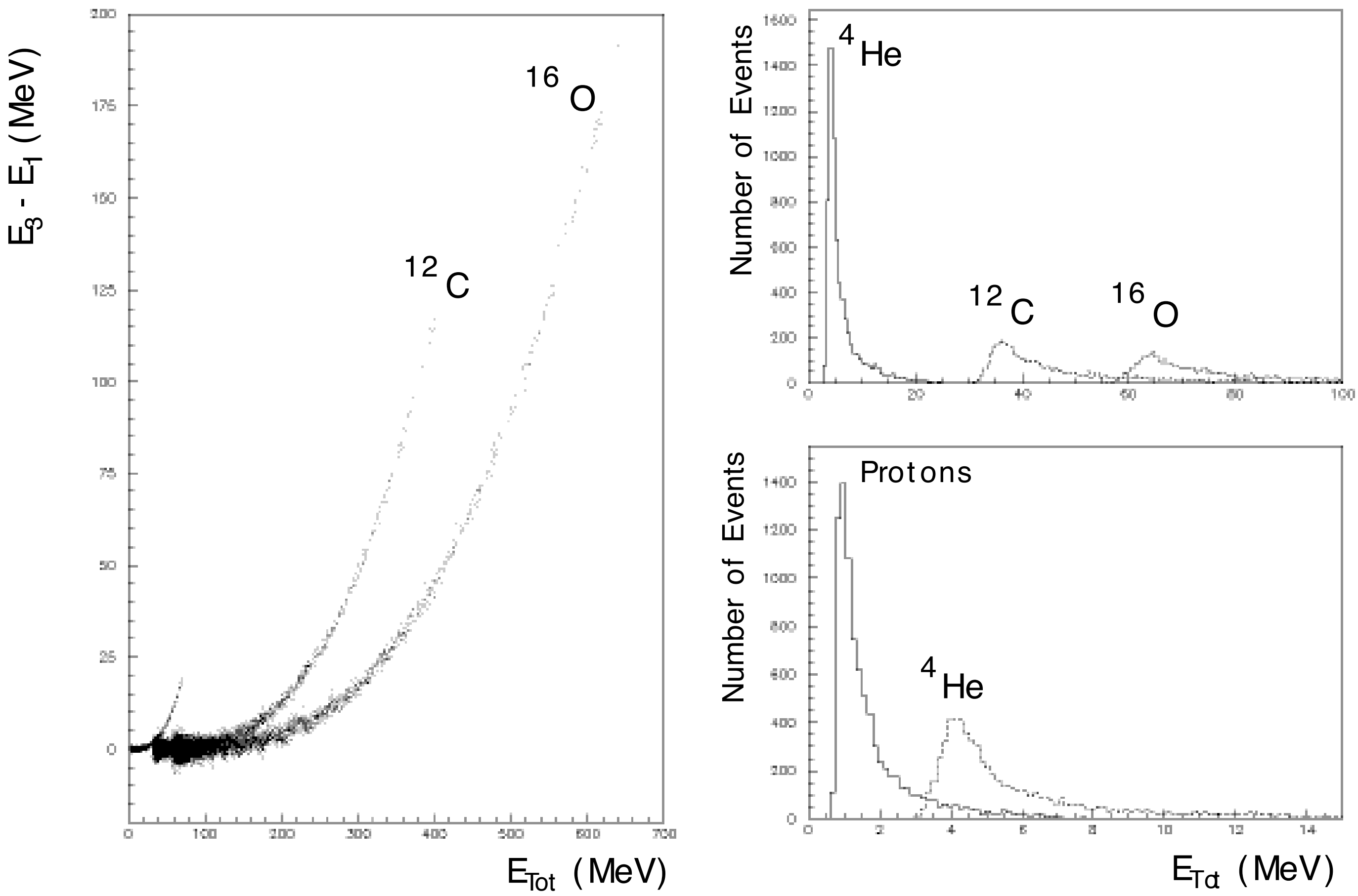

Figure 2: *Discrimination of nuclei with low incident energy (on the left) and with high incident energy (E3-E1<0.2 MeV) on the right ; Etot is the total energy released by the particles in the whole detector; E3-E1 is the released energy difference between the third and the first plane.*

possible to discriminate the nuclei, using Etot as the only parameter. In Fig. 3 (on the left) the distribution of the total detected energy versus the difference between the energy lost in the last plane and in the first view is plotted. It can be seen that the protons' energies are very well separated.

3 SilEye-1 data on LF

Data acquired with SilEye-1 apparatus come from 25 sessions each of 90 minutes average duration (one orbit). A dark adaptation sequence of 15 minutes precedes each session. Most of the sessions took place in the crew's cabins in the main module of the Station, other session in the *Kwant* or in the "D" module. In Figure 3(on the right) are shown two typical result typologies. Particle flux has been averaged over 60 seconds intervals: it is possible to observe the increase in the polar regions and in the South Atlantic Anomaly (SAA). In SAA the real flux is order of magnitudes above the maximum acquisition rate (SilEye-1 maximum acquisition rate was about 25 $Hz \simeq 1500$ Ev/min); the black point on the time axis represent the LF observed by the astronaut during the sessions. To

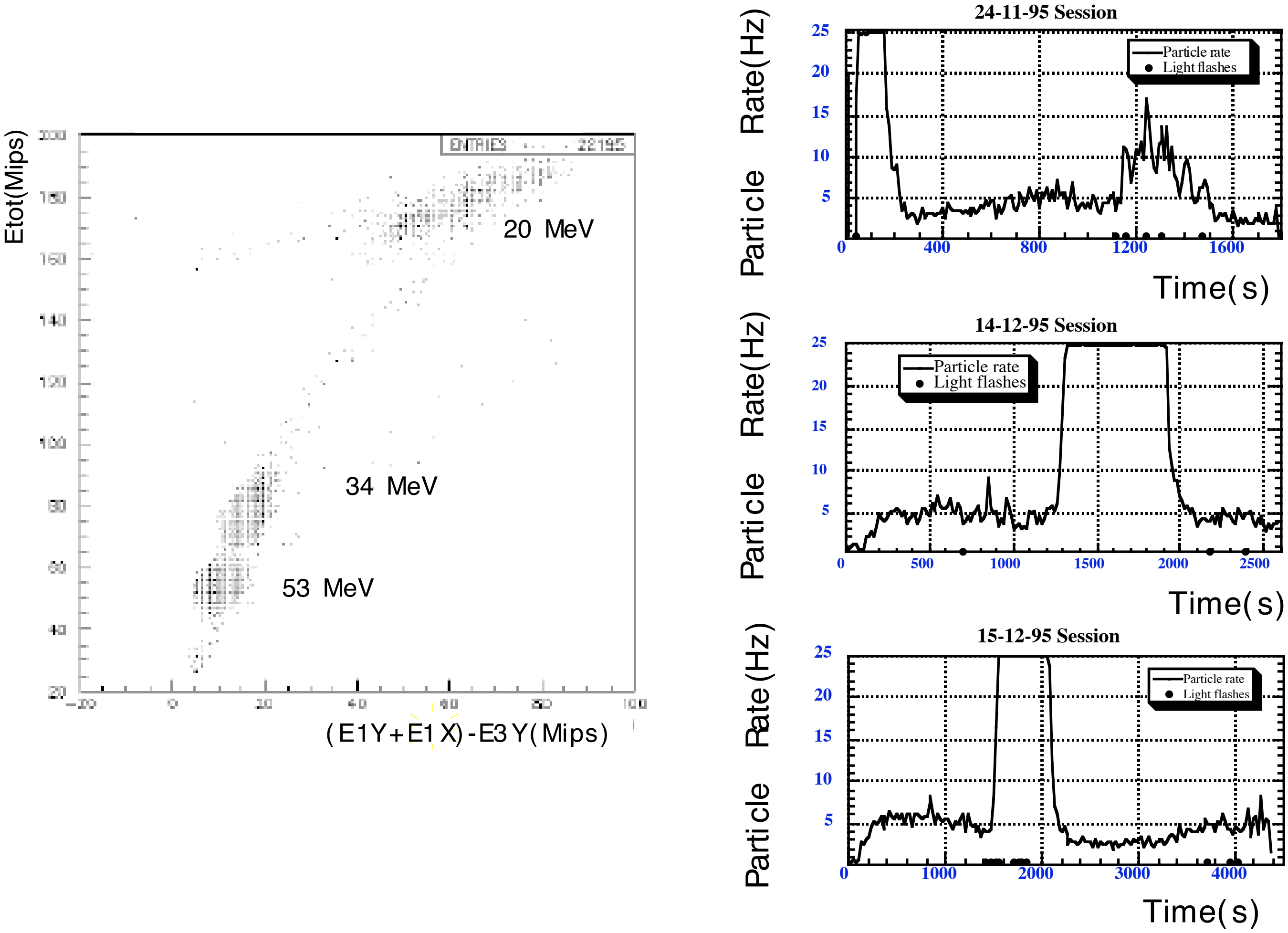

Figure 3: *Distribution of the total detected energy versus the difference between the energy loss in the last plane and in the first view (on the left). Trigger rate vs. the different position in the orbit.*

perform a quantitative data analysis on the relationship between LF and particle flux, each orbit has been divided in portions of 10° of latitude. Particle and LF frequencies have been obtained averaging the results obtained at equal latitude in the SAA over all 11 orbits, for the three astronauts involved. SAA data have been treated separately. The results are shown in figure 4: we can observe a proportionality relation between particle flux and LF observation (the probability of a chance correlation is $p < 0.02$) except in the SAA region. From this plot it is possible to see that a rather small growth of registration of LF rate in the SAA (about 2 σ) is observed while it is known that the proton flux in the SAA increases several order of magnitudes in comparison with the equator. The likely conclusion is then that protons are not the main LF source in orbit, and it seems more probable that heavy ions are the initiators.

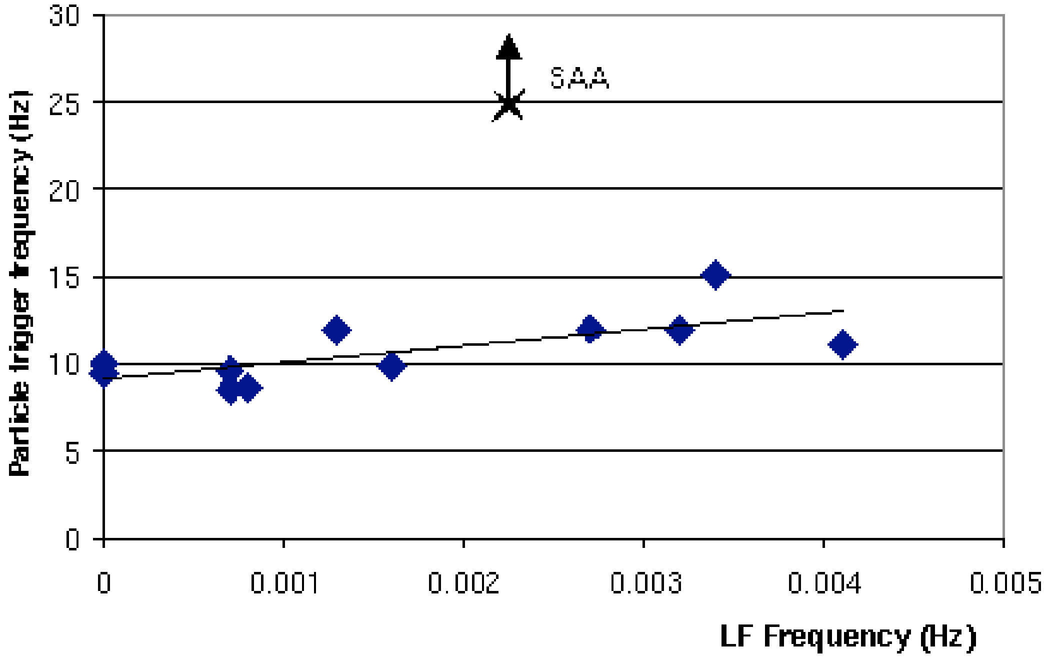

Figure 4: *Particle flux as a function of observed Light Flashes. SAA observed flux is well above the fluxes relative to other latitudes. The arrow indicates that the real SAA flux is higher than the measured one.*

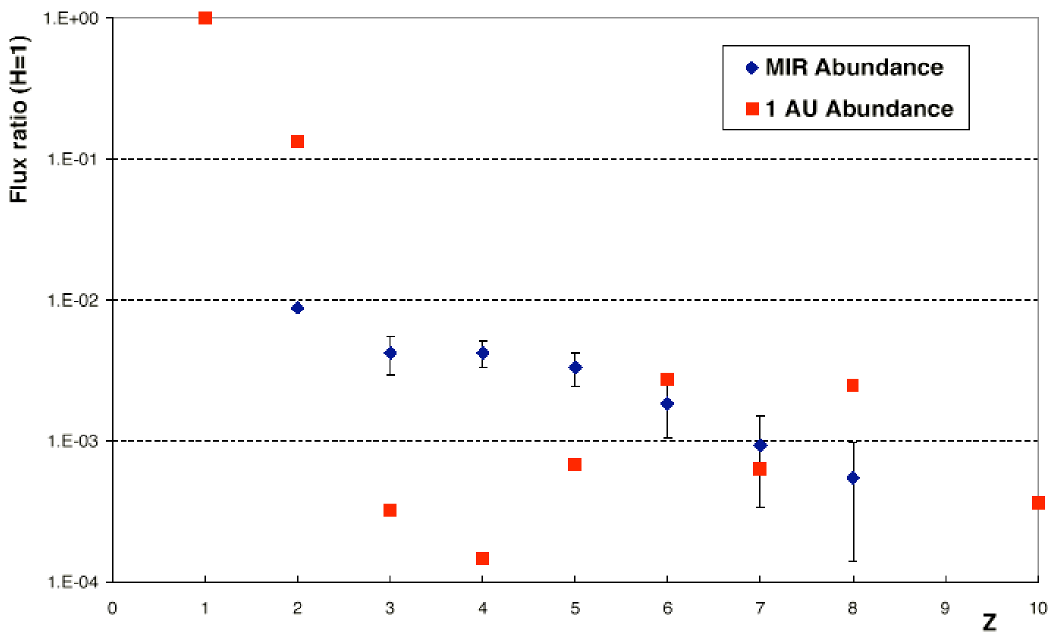

Figure 5: *MIR space station nuclear abundance with SilEye*

4 MIR nuclear abundance with SilEye-2

In the first three sessions with SilEye-2 instrument on MIR station, in three hours of work, about 19000 particle tracks have been collected. Figure 5 shows relative measured abundance ratio between nuclei and protons, as a function of the atomic number Z of the nuclei, for all data collected. The measured spectrum is very different from the usual cosmic ray nuclei distribution [10], due to the abundance of recoil nuclei from the body of the Space Station. More accurate measurements of this spectrum will be done in the future with longer sessions, to determine also the equivalent dose due to different nuclear species absorbed by astronauts in Space Station environment. In fact, high Z particles even being only the 1% of the total ionizing particle flux in cosmic radiation, contribute, due to their high quality factor, up to 25% of the total equivalent dose absorbed by Space Station crews [11].

Data analysis of SilEye-2 Flash data is now starting (at this time several sessions with astronauts have been performed). The construction [12] of a larger apparatus that combines the use of a large silicon detectors and an electroencephalograph, to directly correlate LF and particle crossing the head with brain activity, is under development (project ALTEA).

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