

The Sileye-3/Alteino Experiment for the Study of Light Flashes, Radiation Environment and Astronaut Brain Activity on Board the International Space Station

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In this work we describe the instrument Sileye-3/Alteino, placed on board the International Space Station in April 2002. The instrument is constituted by an Electroencephalograph and a cosmic ray silicon detector. The scientific aims include the investigation of the Light Flash phenomenon, the measurement of the radiation environment and the nuclear abundance inside the ISS and the study of astronaut brain activity in space when subject to cosmic rays.

INTRODUCTION

Cosmic rays are the cause of radiation to which astronauts in space are subject. The dose absorbed depends from the spacecraft orbit and shielding as well as from external causes such as solar cycle (modulation of galactic cosmic rays) and Solar Particle Events.

Recent human activity in space has been limited to work in low earth orbit (LEO), at an height of 300–400 km. With the re-entry of Mir Space Station long term permanence in space has taken place on the International Space Station (ISS), currently in the completion phase. The last (and only) missions outside the protective shielding of the magneto-

sphere date back to the Apollo program, although plans for a future human mission to Mars are under way.

Cosmic ray flux and composition is the subject of extensive studies for their importance in different fields of physics, ranging from the cosmological implications of the antimatter component of cosmic rays to solar physics and solar-terrestrial phenomena. Particle energy extends over many orders of magnitude, from the keV range of solar wind to the highest energy (3×10^{20} eV) particles currently detected. Particles of galactic and solar origins are mostly protons and electrons (in equal parts) at lower energies, with the proton component dominating (>90%) from the MeV energy range¹. All heavier nuclei are present in cosmic rays, with Helium as the most abundant component ($\approx 10\%$). In LEO

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particles can be roughly divided — according to their nature — into galactic, solar and trapped components; their relative abundance and energy spectrum is further complicated by the interposition of the passive material of the hull and the instruments of the spacecraft or the station. For the determination of the equivalent dose absorbed by astronauts it is of crucial importance to have a picture of the time and orbit dependent particle rate and composition. A number of detectors have been flying on board spacecraft (Mir, Shuttle, ISS...) to have a detailed picture of the particle fluence in space.

In addition to the relatively well quantified absorbed dose, another effect due to the interaction of cosmic rays with the human body is the so called “light flash” (LF) phenomenon. Light Flashes (LF) are visual phenomena originated by the interaction of cosmic radiation with the human eye. They are perceived in a variety of shapes (streaks, lines, etc.) and have a different structure from the diffuse glow observed when subject to X rays. This phenomenon was originally predicted by Tobias¹⁾ in 1952 and observed for the first time on board Apollo 11. In the ‘70s a number of investigations on board Apollo^{2,3)}, Skylab⁴⁾, and Apollo-Soyuz Test Project⁵⁾ (ASTP) were performed, giving evidence to several mechanisms (direct ionization, Cherenkov light, knock-on protons) without, however, identifying the precise cause and mechanisms involved in this phenomenon. In parallel, a number of ground experiments was also performed using low intensity particle beams on human subjects⁶⁻¹⁴⁾. The use of a Nitrogen beam, which scanned different

regions of the eye¹⁵⁾, seemed to pinpoint the LF phenomenon to occur in the posterior globe of the eye and be in favor of a direct ionization of the retina, although LF observed in space may be due to several of the aforementioned effects and be dependent on particle species and energy and therefore on the spacecraft orbit and shielding.

The Sileye-3/Alteino experiment is an apparatus devoted to the investigation of the LF phenomenon and the study of cosmic ray particle flux and composition inside the ISS; in addition, astronaut brain activity is monitored with an electroencephalograph (EEG). These three measurements are correlated in real time to provide information on the relationship between cosmic rays and astronauts perception.

Sileye-3/Alteino is the third experiment with these aims to fly in a space station: Sileye-1 and -2¹⁶⁾ were operational inside Mir in the years 1995-1998 and 1998-2000 respectively and have provided information on the relative nuclear abundance¹⁷⁾ and LF perception¹⁸⁾.

INSTRUMENT DESCRIPTION

Sileye-3 is shown in Fig. 1. It is composed of two distinct detectors: the cosmic ray detector (AST – Advanced Silicon Telescope) and the EEG. They can be operated independently, with separate power sources, but are usually used in conjunction to correlate both measurements. LF perception is recorded with pressure of a joystick button; the signal is recorded on one of the EEG channels.



Fig. 1. Photo of the Sileye-3 detectors. Left: the EEG box and sensor caps. Right: the cosmic ray telescope. On the rightmost part it is possible to see the joystick for LF detection.

¹⁾ The highest cosmic ray flux is due to solar neutrinos coming from nuclear fusion processes in the interior of the Sun: on Earth the particle rate from the pp reaction is 0.4×10^{11} p/s.

EEG

The electroencephalograph is used to continuously monitor the astronauts brain activity during flight. Data coming from the sensors and the joystick are saved on a 64 Mbyte card which is changed each session.

AST

The cosmic ray detector consists of 8 silicon strip detector planes, each divided in 32 strips, with 2.5 mm pitch. There are 4 planes oriented along the X view and 4 planes along the Y view. Two scintillators, S1 and S2 (1 mm thick each) are located on top (S1) and bottom (S2) of the silicon stack to provide the trigger. Each plane is 8 cm×8 cm, with a thickness of 380 μm ; interplanar distance is 1.4 cm, resulting in a geometric factor of 24 $\text{cm}^2 \text{sr}$. A Read Out Board, based on an Analog Devices DSP, performs the tasks of trigger handling and data acquisition. A trigger, defined in a logical AND (product) of the signals of the two scintillators starts the multiplexed acquisition of the 256 channels and their analog-digital conversion. Each event data reduction, consisting in the pedestal subtraction and removal of all strips not crossed by particles, is performed. Data are then stored in a temporary buffer to be sent via a ISA interface to a storage and data handling computer, based on an AMD586 processor (PC-104 industrial standard board). Data storage is performed on 660 Mbyte memory cards, periodically substituted and sent to Earth after each measurement sequence.

INSTRUMENT RESPONSE AND CALIBRATION

The silicon detector plane and amplification electronics has been developed for the calorimeter of the magnetic spectrometer PAMELA, a satellite-borne apparatus for the study of antimatter component of cosmic rays. The front-end is based on the "CR1" chip, with a peaking time of 2 μs , a sensitivity of 5mV/MIP (1 MIP=1 minimum ionizing particle = the energy released by a proton with 2 GeV kinetic energy), thus with the and a maximum counting rate of 30 kHz. The dynamic range of the electronics allows read-out of particles with energy release form 0.4 to 1200 MIPs² (330 KeV/ μm in Si).

A typical session begins with the calibration of the silicon strips of the detector. This consists in the acquisition of 1024 pedestal events and the calculation of the pedestal

average P_i and rms σ_i for each strip i . Thresholds T_i are set according to the formula $T_i = P_i + n \sigma_i$, where n is a number set to $n=1$. The choice of n was done compromising between data compression and strip hit lost due to pedestal fluctuation or drift due to temperature. Temperature drift, non negligible before thermal equilibrium in the device is reached (some hours after turn on), influences pedestal position; to compensate for this effect calibrations are repeated every 120 seconds. Each calibration takes 2 seconds, after which particle acquisition begins. A raw event consists in a 512 byte (256 channels×2 byte/channel) matrix, which is reduced by pedestal suppression with the removal of all hits below the threshold T_i . Each event also includes scintillator counters (S1, S2, S1×S2) and clock, to synchronize it with the PC-104 clock. All events are stored in one of the two DSP (Digital Signal Processor) buffers (15 kbyte each); when one of the buffer is filled the PC-104 begins data transfer while the other buffer is being filled. This procedure allows reduction of the dead time due to data transfer between the two CPUs (Central Processing Units).

A typical event, due to a single cosmic ray crossing the device is shown in Fig. 2 (left); in Fig. 2 (right) it is possible to see a multi-hit event, showing the capability of the detector to register showers in the device.

The device has been tested on accelerator in Uppsala (TSL laboratory) with low energy ($\cong 45 \text{ MeV/n D, C, O}$) and Dubna (500 MeV/n He).

THE SOYUZ-34 MISSION

Sileye-3 was placed on board of the International Space Station on April the 27th 2002 in the framework of the Soyuz-34 taxi flight mission. The cosmic ray detector was active for the whole duration of the mission, which lasted until May the 5th.

8 Light Flash and EEG sessions were performed by the Italian cosmonaut Roberto Vittori – part of the Soyuz-34 crew - resulting in the observation of 44 Light Flashes during a total observation duration of 10 hours. Light flashes were observed for the first time on board ISS in a controlled environment and have been reported for the first time to be visible also in condition of not ideal dark adaptation.

The particle acquisition rate observed with Sileye-3 for a part of the acquisition session (total duration of 130 hours) is shown in Fig. 3. It is possible to see the typical modulation due to passage between the low latitude regions (geomagnetic equator), where the rate is lowest and the high latitude regions, (marked N and S) where the geomagnetic cutoff is lower and particle rate is higher. The highest peaks

² The MIP (Minimum Ionizing Particle) is defined as the minimum energy loss (0.27 keV/ μm in silicon), of a proton in matter, corresponding to a 2 GeV kinetic energy proton.

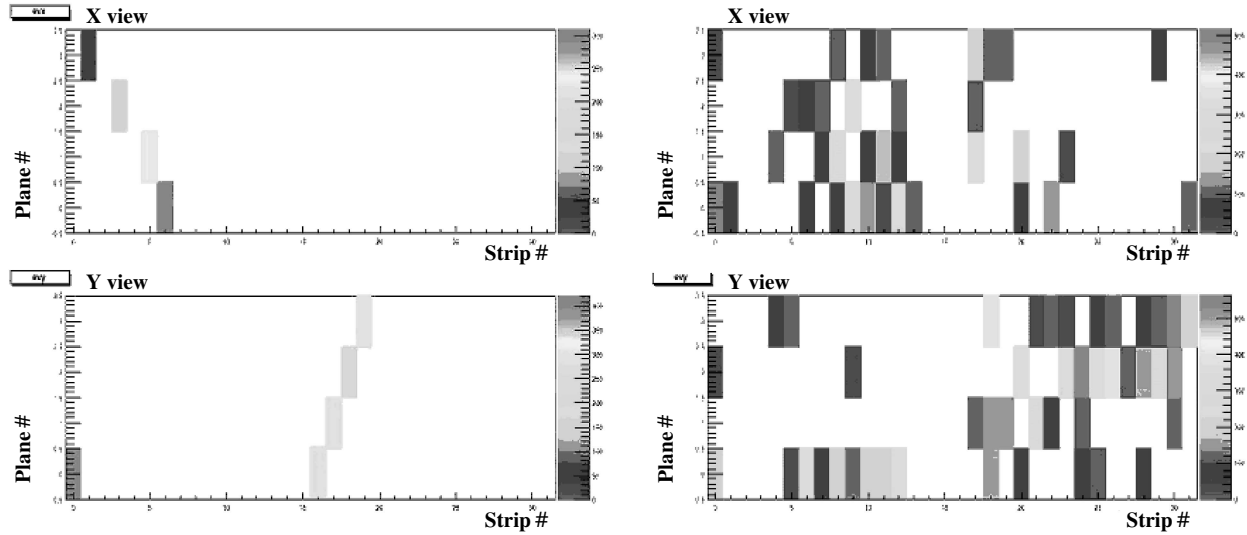


Fig. 2. Sample events in the cosmic ray detector. Left: a single particle. Right: a multiparticle event.

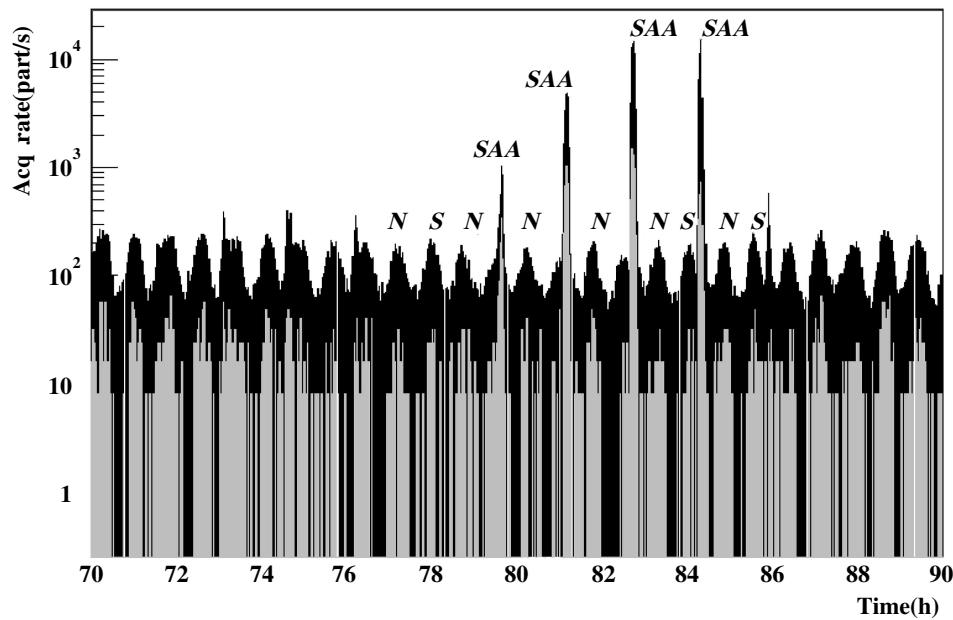


Fig. 3. Cosmic ray flux vs time for part of the acquisition; note the passage in the SAA (highest peaks) and the modulation due to passage through the equator (lower rate) and the poles (higher rate). Black: all particle rate; Grey: $Z > 5$ nuclei.

are observed during passage in the South Atlantic Anomaly (SAA), where the ISS crosses the inner radiation belt, consisting mostly of protons.

Nuclear abundances measured inside ISS with Sileye-3 are shown in Fig. 4. The sample shown refers to high energy ($E_{\text{kin}} > 100$ MeV) events, obtained requiring that the energy released in the first and the last planes does not differ more than 20% and plotting the total energy released in the telescope. At relativistic energies the energy lost in the silicon

detectors is negligible if compared to the kinetic energy of the particles and therefore the energy loss in the silicon planes is constant and proportional to Z^2 (the square of the electric charge). The highest peak is due to protons and helium, composing more than 90% of observed radiation. It is possible to clearly distinguish the BCNO ($4 \leq Z \leq 8$) peaks, the even-numbered abundances up Si and the contributions due to Ca and Fe. From the position of the peaks P_{adc} in ADC (Analog to Digital Converter) channels, it is possible,

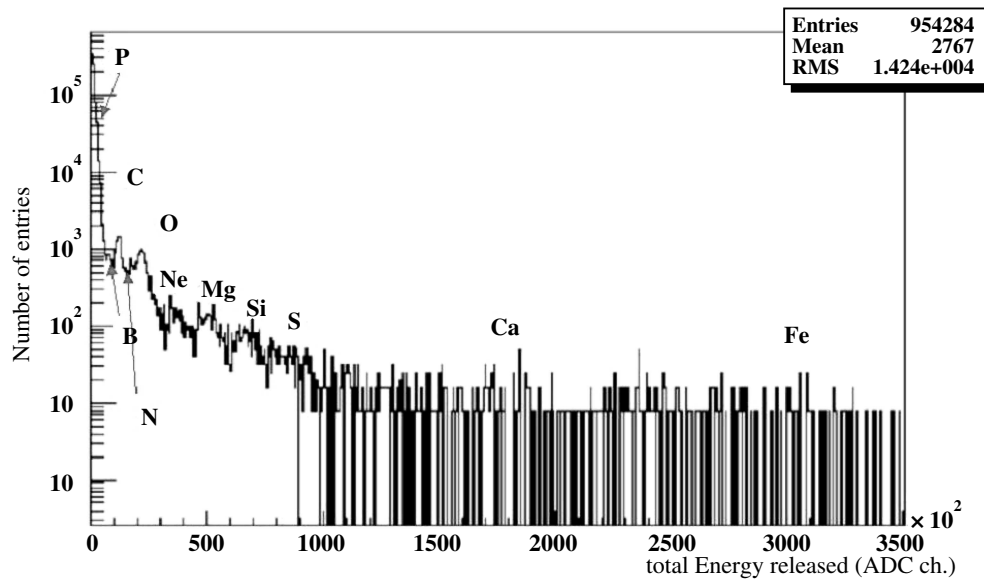


Fig. 4. Histogram of the nuclear abundance measurements inside ISS. On the X axis is plotted the total energy released in the detector (in ADC channels). Particles selected have a kinetic energy above 100 MeV. The Ca and Fe peaks are limited by statistics.

performing a linear fit as a function of the square of the charge Z^2 of the detector, to calibrate its response and measure its linearity: the results of the fit $P_{\text{adc}}=345 \times Z^2 - 112$ with a correlation coefficient $R=0.992$ show the excellent linearity of the device. From the peak area it is possible to evaluate relative nuclear composition inside ISS: normalizing to 1 the abundances to the BCNO group we obtain that the F-S ($9 \leq Z \leq 16$) group amounts to 0.4 ± 0.1 , the Ca ($17 \leq Z \leq 24$) group to 0.094 ± 0.09 and the Fe group ($Z \geq 25$) to 0.077 ± 0.09 . An orbit dependent data analysis is currently in progress and will be used to evaluate the differences with the external cosmic ray flux and tune Montecarlo and analytical calculations which propagate the external flux inside the ISS and estimate the dose absorbed and equivalent by the astronauts in different points of the station. In addition, a precise measurement of the high Z component is important to have a detailed estimate of the inactivation of human cells exposed to protons and heavy nuclei^{19,20}.

CONCLUSIONS

We have presented the characteristics and aims of the Sileye-3 experiment on the International Space Station and reported the first results on LF observations and nuclear abundances inside ISS. The observation of LFs on board the ISS confirms the presence of this phenomenon; possible relations with brain activity and cosmic ray flux will help understand the mechanisms involved. Future work includes the realization of a large area silicon detector telescope to

cover all the solid angle of the astronaut's head and directly correlate each cosmic ray with LF perception and brain activity. This facility, Sileye-4/Altea²¹) will be placed on board the ISS by the end of 2003.

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