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STUDY OF COSMIC RAYS AND LIGHT FLASHES ON BOARD SPACE STATION MIR: THE SILEYE EXPERIMENT

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ABSTRACT

The SilEye experiment aims to study the cause and processes related to the anomalous Light Flashes (LF) perceived by astronauts in orbit and their relation with Cosmic Rays. These observations will be also useful in the study of the long duration manned space flight environment. Two PC-driven silicon detector telescopes have been built and placed aboard Space Station MIR. SilEye-1 was launched in 1995 and provided particles track and LF information; the data gathered indicate a linear dependence of $F_{LF}(Hz)$ (4 2) 10^3 5.3 1.7 10^4 $F_{part}(Hz)$ if South Atlantic Anomaly fluxes are not included. Even though higher statistic is required, this is an indication that heavy ion interactions with the eye are the main LF cause. To improve quality and quantity of measurements, a second apparatus, SilEye-2, was placed on MIR in 1997, and started work from August 1998. This instrument provides energetic information, which allows nuclear identification in selected energy ranges; we present preliminary measurements of the radiation field inside MIR performed with SilEye-2 detector in June 1998.

INTRODUCTION

The possibility of visual stimula due to an ionizing radiation (*Light Flash*) was originally foreseen by Tobias (1952) and first reported in 1969 by astronaut Edwin Aldrin, on board Apollo-11. Subsequently other crews reported similar experiences. "Light Flashes" (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 (Malachowski, 1978, Tobias, 1981, Horneck, 1992, McNulty, 1996) and, more recently, on MIR Space Station; ground based accelerator experiments to reproduce this effect were also performed (Budinger, 1971, Tobias, 1975). 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 which has granted the use of the Space Station and the collaboration of its crews.

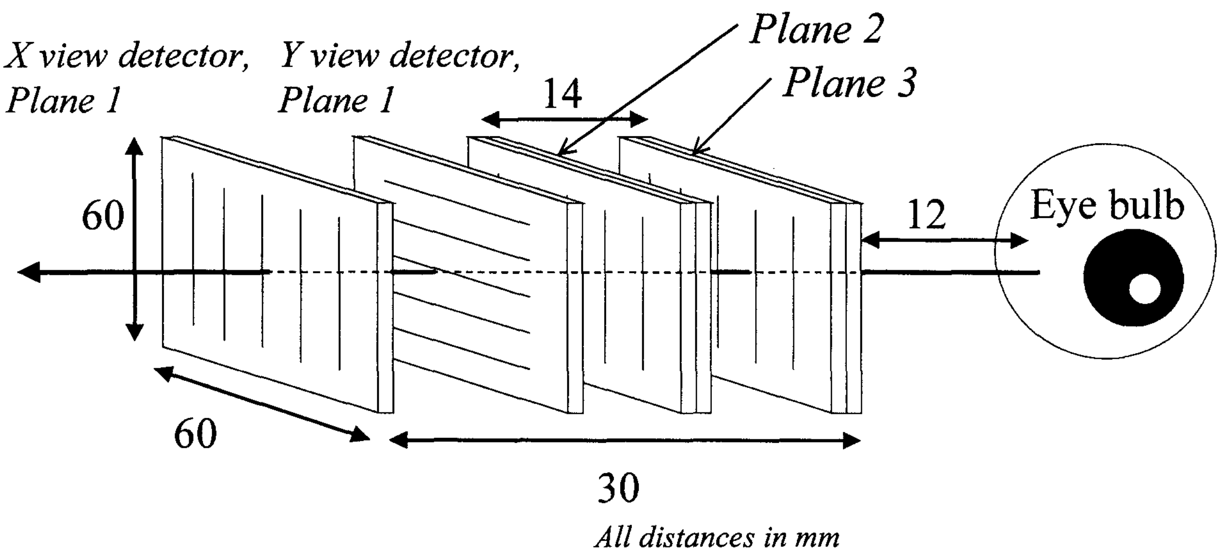

Fig. 1. Silicon detector setup scheme for SilEye-2. Passive Iron absorbers of 1 mm interposed between planes are not shown.

The objective of the experiment is the study of biophysical effects related to the radiation environment inside MIR with particular attention to the phenomenon of "Light Flashes". Although the cause of LF is still not known, the most probable mechanism involves the passage of a cosmic charged particle through the cosmonaut's visual system. Therefore, it is extremely important to determine simultaneously time, nature, energy and trajectory of the particle passing through the cosmonaut's eyes, as well as the cosmonaut's LF perception time. These conditions were not fulfilled by all the previous experiments in space. The first prototype of the detector SilEye (SilEye-1) was placed on the Station MIR in October 1995.

In the years 1996-97 25-measurement sessions involving 6 cosmonauts have been performed and almost 90 LFs have been recorded. Following this mission, a new detector (SilEye-2) has been developed and constructed in order to characterize more accurately the radiation flux. It was sent to MIR in October 1997. A complete description of the experiment SilEye was given by Galper, (1996) and Picozza, (1997): calibration results obtained with accelerated proton beams were presented by Bidoli, (1997). Here we show SilEye-1 data on LF correlation with particle flux and SilEye-2 results on radiation environment inside MIR Space Station.

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 (Bakaldin, 1997) 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 49 mm in SilEye-1 and 14 mm in SilEye-2: a scheme of the detector configuration is shown in Figure 1. 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 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 40-200 MeV/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). SilEye-2 detector was put on side in order to place the detectors as close as possible to the eye thus maximizing angular coverage. Data acquisition is performed by a portable PC with PCMCIA acquisition card which is also linked to a joystick with a button (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 provide a check on correct position of the detector, the dark adaptation of the observer and his reaction time. These LEDs are used to normalize astronaut responses to obtain a more uniform data set.

RESULTS

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. The different shielding of the station may cause variations in the LF perception; however, low statistics of SilEye-1 data did not show this effect which is being studied with SilEye-2 runs.

In Figure 2a are shown two typical result topologies. 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 orders of magnitude above the maximum acquisition rate (SilEye-1 maximum acquisition rate was about 25 Hz 1500 ev/min); the triangles on the time axis represent the LF observed by the astronaut during the sessions (in total about 90 flashes were observed). To 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 2b: we can observe a proportionality relation between frequency of LF observation and particle flux of

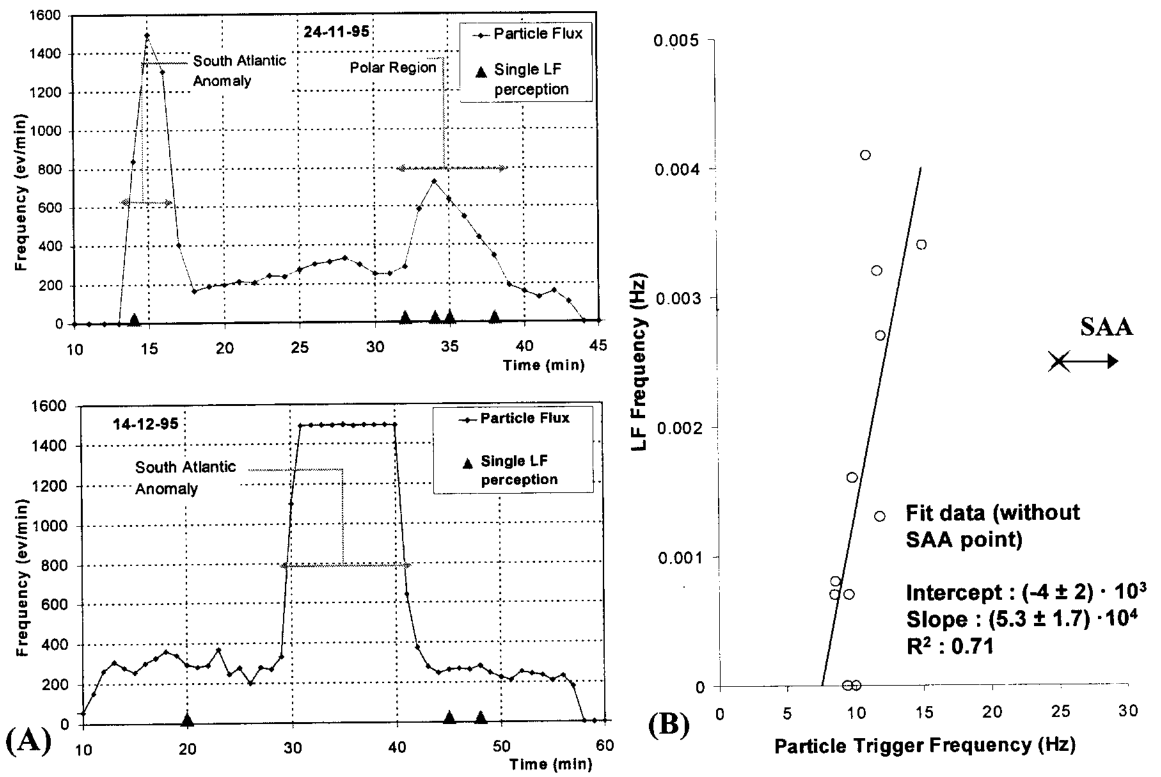

Fig. 2. a) Two of the 25 LF sessions showing particle flux and LF observation as function of time. b) Observed Light Flashes frequency as a function of Particle flux. SAA observed flux is well above the fluxes relative to other latitudes. The arrow indicates that the real SAA flux is higher than the measured one.

$F_{LF}(Hz)$ (4 2) 10^3 5.3 1.7 10^4 $F_{part}(Hz)$ (the probability of a chance correlation is $p<0.02$) except in the SAA region. Care must be taken in the interpretation of these results, since the low statistics and the indirect measurement of the particle nature do not allow for any definitive results. From this plot it is possible to see how protons (which are the majority of observed particles and make up for almost all particles in the SAA) could be ruled out as the main cause of LF in favor of heavier particles which are therefore the most probable cause for LF. A direct identification involving particle nature and energetic data acquisition awaits analysis of SilEye-2 data.

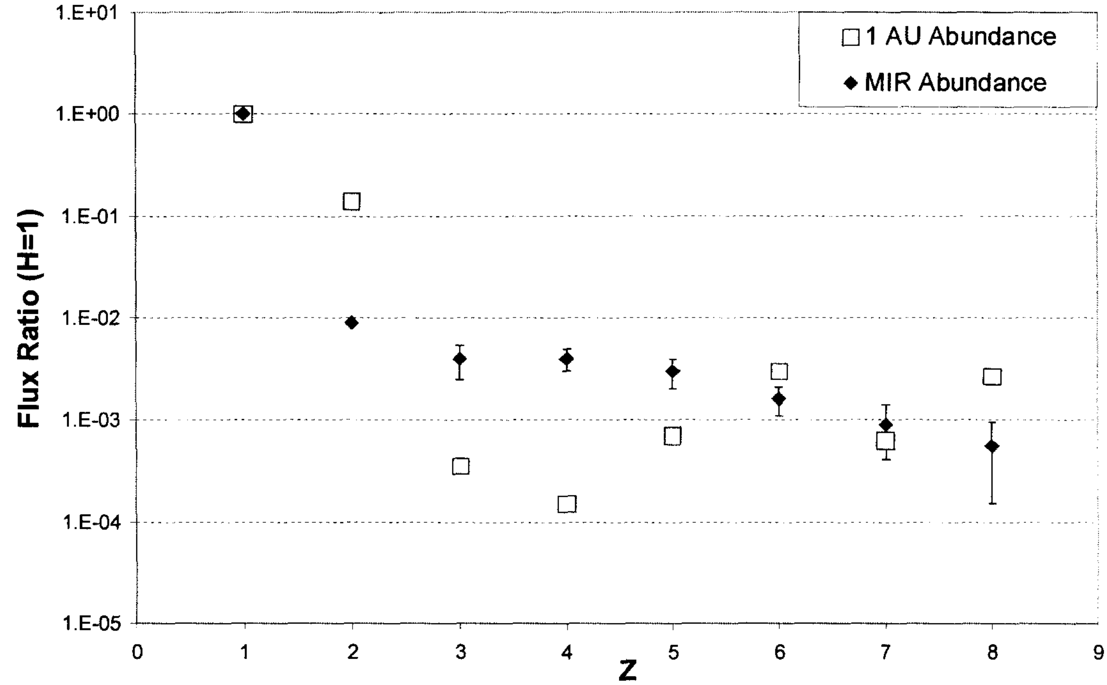

Fig. 3. Relative abundance of elements as measured by SilEye-2 detector, compared with 1 AU abundance.

MIR Space Station Nuclear Abundance With SilEye-2

In the first three sessions with the SilEye-2 instrument on MIR station, in three hours of work, about 19000 particle tracks have been collected. Figure 3 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 (Simpson, 1983), 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 (Reitz, 1996).

Data analysis of a first part of SilEye-2 LF data is in progress (at this time several sessions with astronauts have been performed) although most of the data have been sent to Earth in March 1999 with the latest MIR crew shift. The construction (Casolino, 1997) 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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