RADIATION MEASUREMENTS IN THE STRATOSPHERE

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***Abstract*—We report a stratospheric balloon flight with the REXUS/BEXUS program in which we use a silicon diode based particles detector. We essentially detect protons and show that the number of detected protons is directly correlated with the altitude.**

***Index Terms*— Stratospheric balloons, real-time test, neutrons, protons, cosmic rays, REXUS-BEXUS**

1. INTRODUCTION

The Earth atmosphere is continuously crossed by cosmic particles and the atmosphere is then naturally a radiative environment. These cosmic rays and the secondary particles they generate in the atmosphere cause a major electronic reliability issue for very integrated devices [1][2][3][4]. The main issue for digital circuits is the Single Event Upset (SEU) which is a bit flip in a memory after the passage of a unique particle in the electronic device. This unique particle can be either neutron at ground and avionic levels or proton[5][6].

In order to prevent those issues, the particles fluxes have to be known at high altitude for avionic electronic purpose. The Hamlet project, which begun in 2007, focuses on real-time experiments using stratospheric balloons to measure the atmospheric natural radiative environment and its effects on memory chips. In this paper we focus on a silicon based detector that flew in the REXUS/BEXUS project.

REXUS/BEXUS is a project for students built on collaboration between ESA (European Space Agency), DLR (Deutsches Zentrum für Luft-und Raumfahrt) and SNSB (Swedish National Space Board). It offers the possibility for students' teams to fly experiments on rockets or balloons. After pre-selection and a selection workshop, students have about one year to build an experiment. During this whole year, they are surrounded by experts in many different domains. A specific and fully detailed documentation is the main link between students and experts. Some progress meetings are organized all along the year of work. To finish, a launch campaign takes place in Esrange space center near Kiruna (north Sweden). Our experiment took place in this student project, in the balloon part.

2. THE BALLOON RADIATION ENVIRONMENT

2.1 Kind of particles

Particles fluxes depend on latitude and altitude. The altitude dependence of pions, muons, protons, electrons neutrons and gammas is plotted in fig. 1.

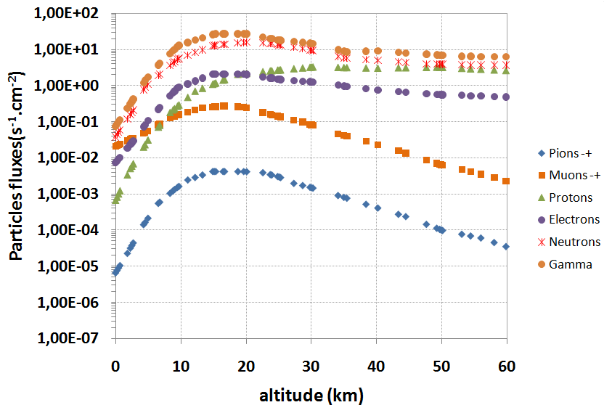

Figure 1 : Particles fluxes as a function of altitude [7].

Fig 1 shows gammas as particles that have the highest flux but as they deposit a low amount of energy, they are not considered in the electronic reliability issue for atmospheric applications. For the same reason, we can move electrons away from this study. Pions and muons have fluxes that are generally considered as too low to be involved in SEU rate. So we can just focus on protons and neutrons. Neutron flux at 20km is one order of magnitude higher than proton one. We can so expect, because their nuclear cross sections are nearly the same, that neutrons will be more important in the electronic issues. However, very integrated devices are sensitive to direct ionization of protons [5][6]. As every proton will ionize directly the device, we expect to measure hundred of events during a flight.

2.2 Flight profile

We present the BEXUS 11 flight launched from Esrange (Kiruna, Sweden) which is 67° latitude and 21° longitude.

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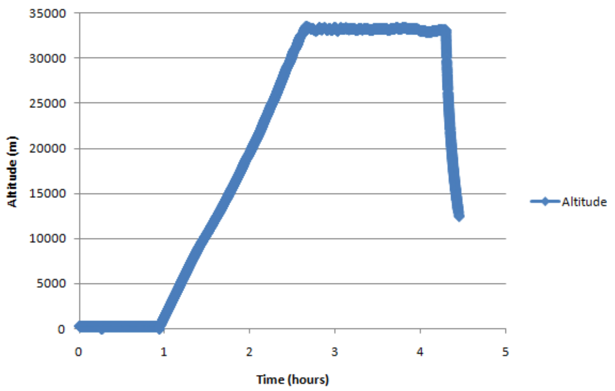

Figure 2 : Altitude profile of BEXUS 11 flight.

The balloon was launched the 11/23/2010. It took 1h30 to reach the ceiling at 34km altitude then stayed at 34km during nearly 2h and separate to land under parachute.

3. LAERTES

3.1 Principle of the experiment

LAERTES is a particle detector based on a silicon diode. The used diode is manufactured by ORTEC. The active area is 4.5cm² and 150µm thick.

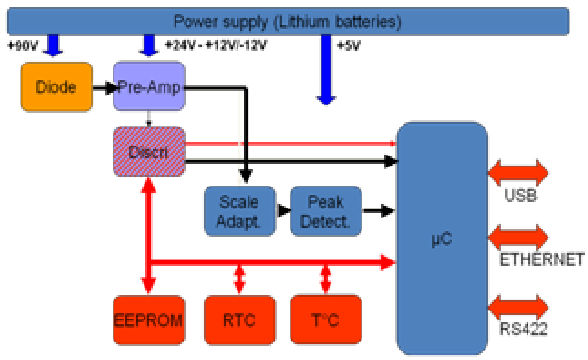

Figure 3 : LAERTES block diagram.

Figure 3 is the block diagram of LAERTES experiment. When a particle crosses the reverse biased diode, electron-hole pairs are directly or indirectly created. Due to the reverse bias voltage (90V), the electron-hole pairs are collected by the diode's electrodes. This collection creates a pulse in the current in the diode which charges a capacitor. The charge variation in the capacitor is then measured by a charge preamplifier. The amplitude of the signal that comes out of the preamplifier is then captured by a peak detector and measured by a microcontroller. To trig on every particle, a discriminator with an adjustable threshold is placed in parallel with the peak detector to force the microcontroller into an interruption. The experiment can communicate by the use of RS422 and USB for tests and by Ethernet using the UDP protocol for the communication with the gondola.

Power supply is performed by a DC/DC converter for +5V, +24V, +/-12V with a 9V battery. For the 90V, we use 30 button batteries which are 3V and 190mA.h, assuming that the diode is consuming only 0.3µA.

3.2 Experimental setup

LAERTES experiment is built in two identical aluminum boxes fixed together by aluminum angle brackets (see fig 4).

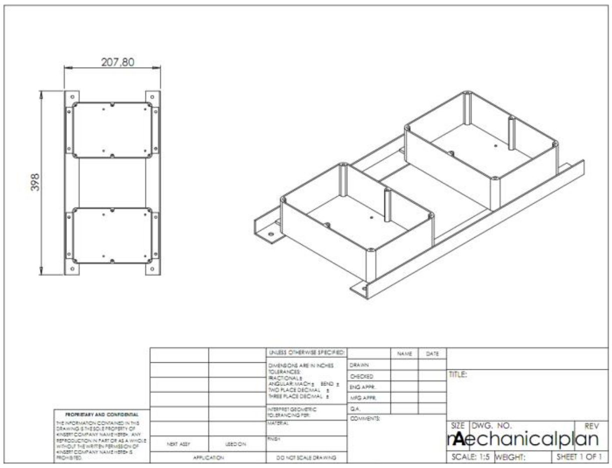

Figure 4 : LAERTES mechanical plan.

One box is used for the experiment board and the other one contains the supply board. The aim of using two boxes was to isolate the experiment from all the batteries, the DC/DC converters heat and electromagnetic compatibility.

MAIN FEATURES	
Experiment mass (in kg):	2 (including batteries)
Experiment dimensions (in m):	0.398x0.208x0.058
Deposited energy range	1 to 90 MeV
Operating temperature	-40 to 85°C

Table 1 : LAERTES main features

During the flight the diode was horizontal and polyurethane foam was used to block the diode and isolate from the outside cold. The threshold was at 1MeV at the beginning of the flight.

4. Tests

The environment at high altitude and due to the balloon (shocks at the take off, the separation and the landing) is aggressive, so it has been mandatory to do perform some tests.

4.1 Thermal test

Due to very low temperatures at high altitude (fig. 5) some tests and calculations had to be done.

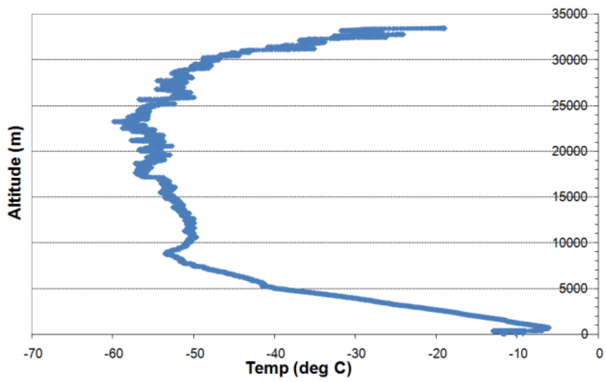

Figure 5 : Temperature profile as a function of altitude.

Fig. 5 plots the outside temperature measured by the balloon operating system during the BEXUS 11 flight. We use here the plot as a typical temperature profile for a stratospheric balloon. We can see that between 8 and 30km, the temperature is lower than -50°C.

For all our components, the temperature operating points are between -40°C and +85°C, it was mandatory to perform some thermal tests. As we only had a freezer and no climatic chambers, the test has been performed at only -15°C. We measured the time the experiment took to reach the external temperature.

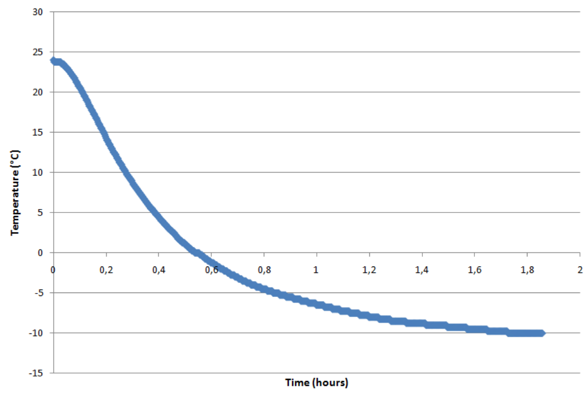

Figure 6 : Temperature measured by the experiment in a freezer as a function of time.

After 1h40 in the freezer at -15°C, we can see that the experiment is stabilizing near -10°C. After this test, we put more polyurethane foam between the boxes and the boards to better isolate from the cold. During a flight, the temperature is under -40°C between 5km and 30km altitude (see fig. 5), the flight profile gives us a time between those to temperature of about 1h (fig. 2). We have so considered the experiment as able to fly in good conditions.

4.2 Vibration test

The main risk, in vibration term, during a balloon flight is a 10g shock. In order to prevent a risk for the gondola and the other experiments on the same flight, we simulate the shock. Without any appropriate infrastructure, a mechanical test with 10 times the weight of the experiment put on it was necessary. The experiment weight 2kg. To perform this test, we putted 20kg on the experiment and wait half an hour to see if there were any problems with the mechanical design.

4.3 Vacuum test

Because it was expected that the balloon lifted up above 30km which is equivalent to a pressure as low as 4hPa we performed low pressure test. We used a vacuum chamber from our laboratory that uses alcatel pump. Tests were performed down to 0.1hPa during 2 hours and no dysfunctions were observed.

4.4 Calibration

As we store data on a microcontroller and measure the amplitudes using an analog to digital converter, the energies of the particles are stored as channel numbers. To know the equivalence between the channels and the energies, we needed a calibration. The first step is to measure and calculate the linearity law of the electronics. It is designed to have a test input from 0V to 2V and the ADC is 1024 bin long. The tests pulses are build with a pulse generator (fig. 7).

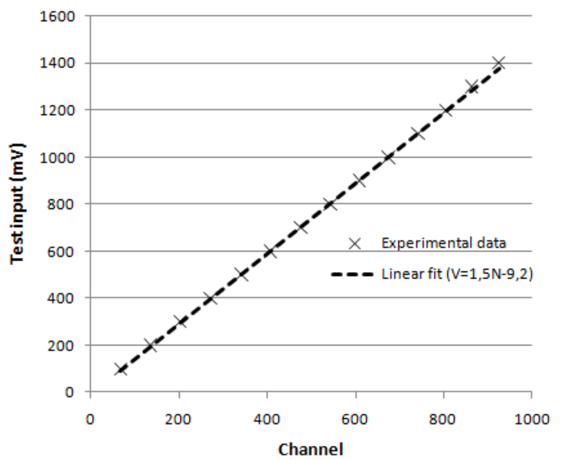

Figure 7 : Test input vs. Storage channel number

$$V\ (mV) = 1.5 \times N - 9.2 \qquad (1)$$

Equation (1) give the electronic linearity law which is the equivalence between a test input *V* and the channel *N* where the data is stored for a given input.

Once this equation is written, we needed a radiative source to have a point due to radiations. To perform this, we used a ^{252}Cf source (6.2MeV, alpha particles). All the measurements with this source are performed in vacuum and with the pulse generator plugged in parallel. During the calibration, the pulse generator is set at two different amplitudes (700mV, 1.2V). The calibration is plotted in fig. 7.

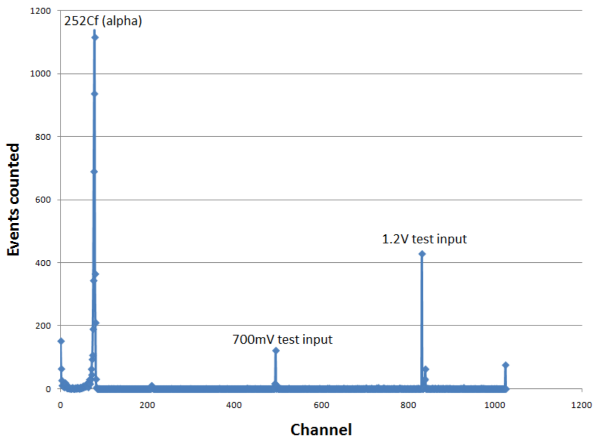

Figure 8 : Spectra obtained with a ^{252}Cf source in parallel to two test inputs 700mV and 1.2V.

From fig. 8, we find the channel equivalent with the ^{252}Cf alpha ray, which is here 79. We replace *N* by 79 in (1), which gives us:

$$V_{6.2MeV} = 127.7\ mV \qquad (2)$$

Assuming that the diode response is linear:

$$V = a\ E \qquad (3)$$

With 'a' a coefficient calculated by using the results of the alpha from the californium:

$$a = \frac{127.7}{6.2} = 20.6\ mV/MeV \qquad (4)$$

We can finally write the equation of the deposited energy E as a function of the channel:

$$E\ (MeV) = \ 0.0796\ N + 0.0709 \qquad (5)$$

5. Results

At the beginning of the flight, a problem with our experiment or communication link did not allow us to have any data below 9km. Above 9km, we detected 783 events. In order to see the evolution of the event rate with time, we have determined the number of detected events during a 1000 seconds period of time. We have then plotted (fig. 9) the event rate as well as the altitude on the same figure to compare and see if there was any correlation between altitude and particle flux.

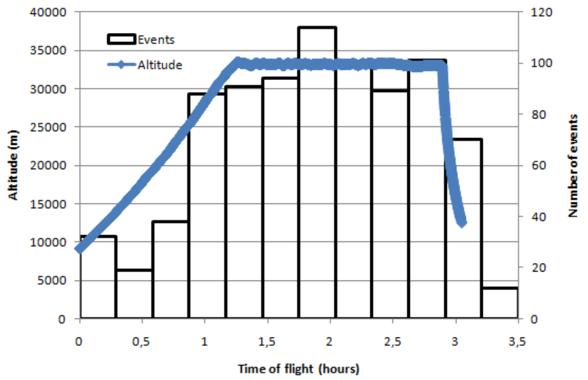

Figure 9 : Comparison between the evolution of the number of detected events as a function of time of flight and altitude profile.

We can clearly see in fig. 9 a strong correlation between the number of detected events and altitude above 25km. Between 9km and 25km altitude, there was still a problem that we can see because the measurements are very low. At the ceiling, the number of events every 1000seconds is quasi stable and it goes down during the descent. Once on the ground, as the experiment was still working, we still have measured some events.

6. Summary and Conclusion

We developed a light and small particle detector based on a silicon diode. We made it fly on a stratospheric balloon with the help of the BEXUS program. We detected particles after the balloon has reached 9km and then until the end of the flight. We compare the events rate and compare it to the altitude profile. We clearly showed a good correlation between the number of detected events and the altitude.

7. Acknowledgement

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8. REFERENCES

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