SEP Protons in GEO with the ESA MultiFunctional Spectrometer

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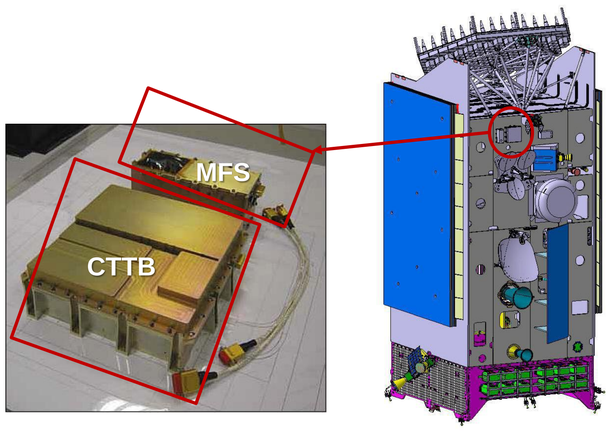
1. MFS and Alphasat

AlphaSat is a large telecomunication satellite primarily designed to expand Immarsat's existing global mobile telecomunication network, launched in July 2013. It was built by Airbus DS through a public-private partnership (PPP) between the European Space Agency (ESA) and Immarsat. Alphasat is based on Alphabus [1], the large European telecom plataform developed by Airbus DS and Thales Alenia Space under a joint contract with ESA and France's CNES Space Agency.

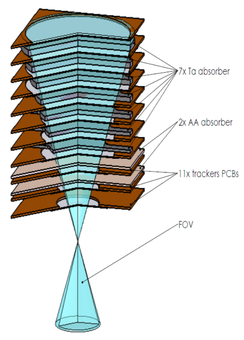


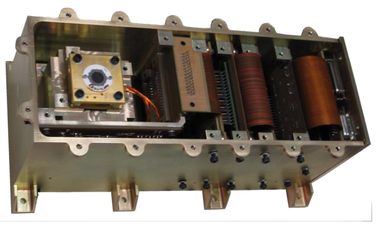
✓ Alphabus is at geosynchronus (**GEO**) orbit carrying the ESA Alphasat Environment and Effects Facility (**AEEF**) (a.k.a. **TDP8** - Technology Demostration Payload 8).
✓ AEEF includes two experiments: Component Technology Test Bed (**CTTB**) and a MultiFunctional Spectrometer (**MFS**) whose development was led by EFACEC SA , Portugal.
✓ The two units are installed on X-panel of the AlphaSat.
✓ TDP8 goal is to study radiation effects on components by employing several technology experiments in conjunction with radiation monitoring at GEO orbit.

2. MFS Technical Overview

MFS requirements:

Electron detector	*Spectral range 450 (goal 300 KeV) – 7 MeV* *ΔE/E< 20%*
Proton detector	*Spectral range 1 MeV – 200 MeV* *ΔE/E< 10%*
Alphas detector	*Spectral range 5 MeV – 200 MeV* *ΔE/E< 20%*
Heavy Ions detector	*Spectral range 5 MeV/nuc – 50 MeV/nuc* *Particle Separation: 1 amu up to Z=8*
Count rate	*10^7/cm^2/s for e$^-$ an p E>1MeV (integral mode)*
Field of View	*40º*
Accumulation time	*60s to 600s in 60s steps*
Power consuption	*5W*
Mission Lifetime	*≥3 years*
Weight	*2.914 kg*
Dimensions	*257 x 120 x 117mm^3*

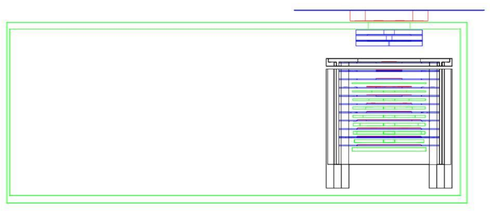




Particle detection principle: dE/dx measurement in a stack of **11 silicon** (300 μm each) detectors interleaved by layers of absorber material (**aluminium** and **tantalum**)
Stack is surrounded by an aluminium structure to shield events out from FOV.
Collimator disks with different appertures placed on top of the stack.

3. MFS Geant4 Simulation

A detailed Monte Carlo simulation of MFS was implemented using Geant4 version 4.9.4.p02 with the complete detectector's geometry and materials.
The simulation output is a ROOT file with a tree of events storing all relevant variables.

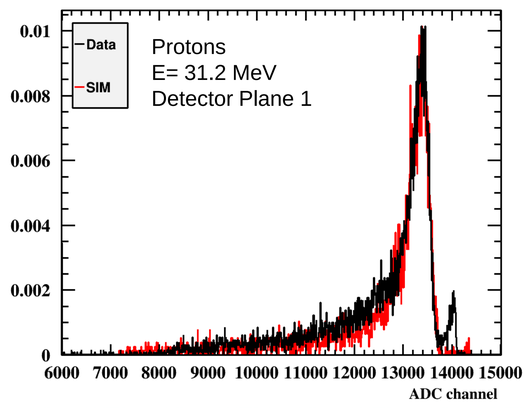


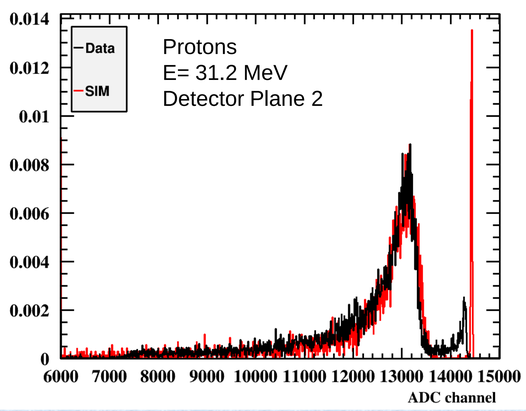
A set of ROOT macros were built to perform analysis and produce histograms. The deposited energy in each detector was converted in ADC channel output according to the result of detector's calibration. Calibration and FE electronics response was simulated and added at analysis level.

4. MFS Ground Test Data Analysis

The MFS ProtoFlight Model (PFM) was tested at Paul Scherrer Institute (PSI), in 2010, at the Proton Irradiation Facility (PIF) and with the monochromator chamber using ^{90}Sr to provide a monoenergetic electron beam [2]. The goals were the following:
✓ verification and calibration of the equipment subject to radiation.
✓ approval of the PFM design.

Simulation results were in very good agreement with test beam data





5. Particle Identification and Energy Reconstruction with MFS

The MFS particle identification algorithm uses a Look-Up Table (LUT), which was built based on the analysis of MC MFS response to simulated protons, electrons, alpha particles and heavier nuclei. LUT stores:
✓ Thresholds for deposited energies by each species in ADC channels;
✓ Maximum energy deposited together with energy left in the previous detector.
Energy reconstruction is possible based on information about the detector with maximum energy and on the deposited energy in the previous detector.

6. MFS Flux Spectra Reconstruction Method

6.1 Derivation of MFS response functions

The response funtions $RF_{i,q}(E)$ for each MFS channel have been derived by the simulations of omnidirectional fluxes of electrons and protons using the Geant4 MFS simulation. Background was also evaluated.
Aspects to consider:

✓ MFS samples the spectra in broad and overlapping energy bands;
✓ an improved definition of the MFS energy channels is foreseen and already established.

6.2 Unfolding MFS data

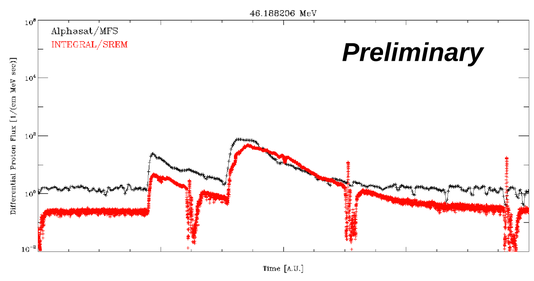
The measurements of the MFS unit are provided in terms of count-rates C_i $i=1...,17$, given by the sum

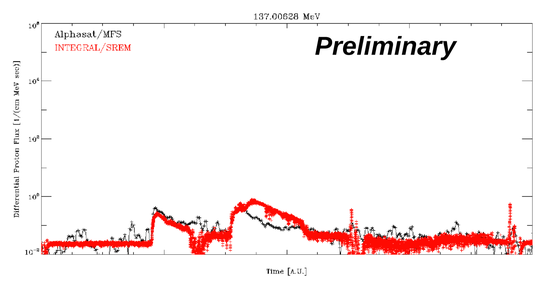
$$C_i = \sum_{q=p,e} C_{i,q} = \sum_{q=p,e} \left[\int_0^\infty f_q(E) RF_{i,q}(E) dE \right] \qquad (6.1)$$

Each term is attributed to measurements of the incident proton and electron fluxes. Here $f_q(E)$ denotes the differential omni-differential fluxes in units of [cm^{-2}MeV^{-1}s^{-1}] while $RF_{i,q}(E)$ describes the corresponding response functions for $q=p,e$. The calculation of proton and electron differential fluxes $f_q(E)$ requires the solution of previous equation which is a Fredholm integral equation of first kind [3].
The Single Value Desconvolution (SVD) technique was applied as an efficient unfolding technique over different proton and electron energy ranges.
This method does not require any assumption on the spectral shapes and it was initially developed for the unfolding of ESA/SREM measurements. The results extracted have been successfully used for the estimation of solar proton fluxes and energetic trapped particles in the radiation belts.

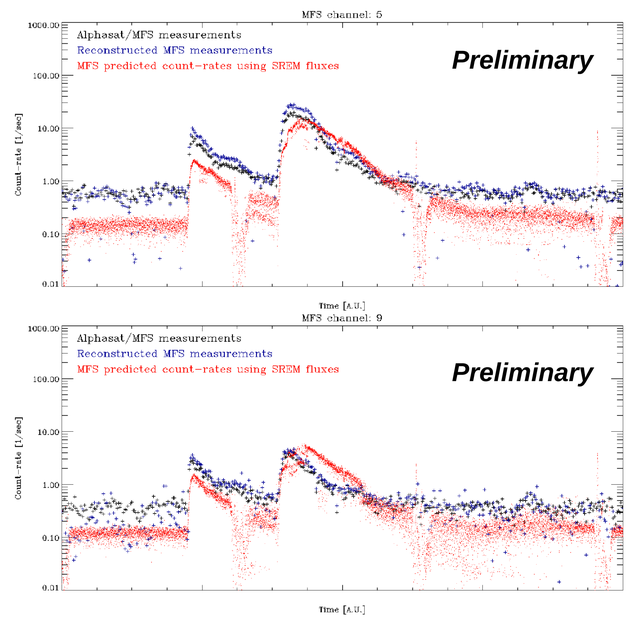
7. Results

Results based on the measurements of MFS during the moderate SEP of January 2014 [4] are presented. For the determination of the numerical solution of Eq. (6.1) the proton response functions were binned in 20 logarithmically spaced bins within Ep=4-150 MeV and the electron response functions in 7 logarithmically spaced bins within Ep=1-8 MeV in order to apply the SVD unfolding method.
The derived results show that the unfolding of MFS data in a proton dominated environment using the SVD approach provides consistent differential proton flux results for E> 40 MeV. The pictures below introduce differential proton flux series based on Alphasat/MFS and INTEGRAL/SREM measurements at GEO for E=46 and 137 MeV. Despite the different orbital characteristics of the considered missions, and the different characteristics of the considered monitors, the derived fluxes are in good agreement within an order or two.





Measurements of Alphasat/MFS P5 and P9 channels compared with MFS reconstructed count-rates derived by folding the differential proton flux series of Alphasat/MFS and INTEGRAL/SREM with MFS proton response functions. The comparison shows that the Alphasat/MFS measurements and those derived from response function of P5-P9 channels are consistent with INTEGRAL/SREM proton fluxes.



References

[1]. "Alphabus, a successful European Public Private Partnership", Cussac, T. *et al.*, Proceedings of the 61st International Astronautical Congress, Prague, Czech Republic, Sept. 27- Oct 1, 2010, IAC-10.B2.1.7 [2] ESA Contract No. 4000110640/14/NL/AK [3] "Unfolding and Validation of SREM Fluxes", Sandberg, I. *et al.*, IEEE Trans. Nuc,Sci,Vol.59, Issue:4, (2012) pp 1105. [4] HTTP://WWW.SWPC.NOAA.GOV/PRODUCTS/GOES-PROTON-FLUX