Particle background for Equatorial Low Earth Orbit (ELEO)

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1 Introduction

An important consideration for X-ray and Gamma ray missions is the particle background environment. Focusing telescopes with lower effective area are only background limited at the fainter end of sensitivity. On the other hand, collimators and concentrators have larger effective area hence there primary concern is to both limit and model the background to get better sensitivity. It can be achieved through employing shielding systems and careful modeling of radiation environment (see figure **??** for state of the art simulation efforts) and choosing the orbit in accordance with science objectives and background limitations.

Low Earth Orbit (LEO) is the most commonly used orbit for imaging satellites, communication satellites (network) and many different space telescopes (Hubble, AGILE, ASTROSAT, etc.) and space stations (ISS, Tiangong-2). It is defined to be less than 2000 km in altitude or with less than 128 minutes period and with eccentricity within 0.25. Thus, it requires less energy for satellite placement (although does require frequent orbital corrections due to orbital decay), provides good bandwidth and low latency for communication (although the window for communication is short due to smaller orbits) and is more easily accessible for servicing of space stations and satellites. Moreover, it is between the Earth's upper atmosphere and inner Van Allen radiation belt to keep the high energy particle background to the minimum.

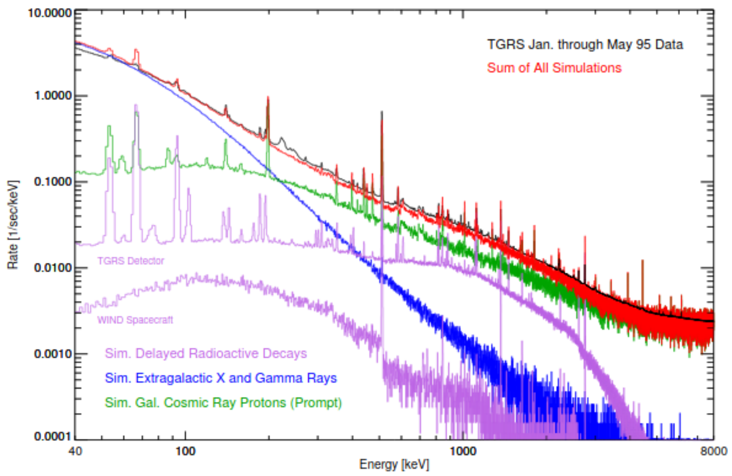

Figure 21.5: State-of-the-art *a priori* modelling of γ-ray instrumental background: data from *Wind*/TGRS and a simulation of all important background components using MGGPOD (Weidenspointner et al 2005).

Figure 1: Simulated background environment using MGGPOD

2 Particle Background for ELEO missions

The particle background for an unshielded detector in LEO is primarily made up of cosmic diffuse radiation (below 150 keV) and albedo glow of Earth from interaction of cosmic rays with atmosphere (above 150 keV). Natural and induced radioactivity (summarized in Kishalay's report) are important at 0.1 to few MeVs. The background fluctuations can either be prompt (interaction causing a nuclear reaction within 1 μs) or delayed (excited particles in detector material decay later) and thus can build up during the lifetime of a mission. To suppress this, the materials chosen for the spacecraft and instrument should be less susceptible to induced radioactivity. Passive shielding is useful below 100 keV in which the instrument is encased below a moderate thickness (few mm) of high Z material (like lead and tungsten) in a "graded" configuration followed by lower Z material. For $\tilde{\text{M}}$ev energies a thick passive layer is required but it would generate even more background by reprocessing cosmic rays into neutrons, gamma rays and other charged particles. In that case active shielding is used where scintillators like NaI and CsI act as anti-coincidence detectors to veto cosmic rays and daughter particles. A combination of passive and active shielding is successful in limiting most of this background. Another important background consideration is the South Atlantic Anomaly (SAA) (see Figure 2) which is a region over Brazil of trapped highly charged particles where inner Van Allen belt is closest to the atmosphere. LEO orbits and inclinations are chosen such as to minimize the time that the satellite spends in this region.

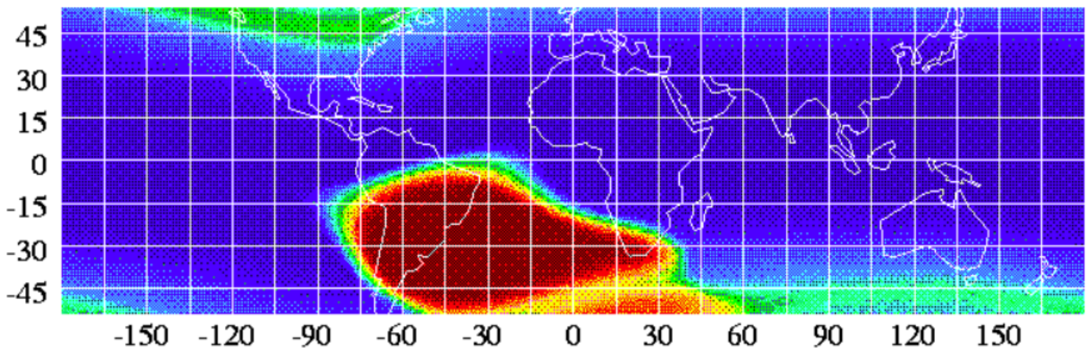

Figure 2: Map of South Atlantic Anomaly

Some examples of missions in ELEO orbits are EXIST (500 km, 5° inclination), AGILE (535 km, 2.47° inclination) and ASTROSAT (600 km, 6° inclination). The Energetic X-ray Imaging Survey Telescop (EXIST) [III et al., 2006] has a High Energy Telescope on board consisting of CZT (Cadmium Zinc Telluride) detectors and NaI anti coincidence (veto) detectors covered in a graded Z passive shield of lead, tantalum, tin and copper. Figure 3 shows the simulated total background rate for EXIST HET modeled using MGGPOD [Weidenspointner et al., 2007] and contribution of different background components as a function of energy. Diffuse photons are the highest contributor.

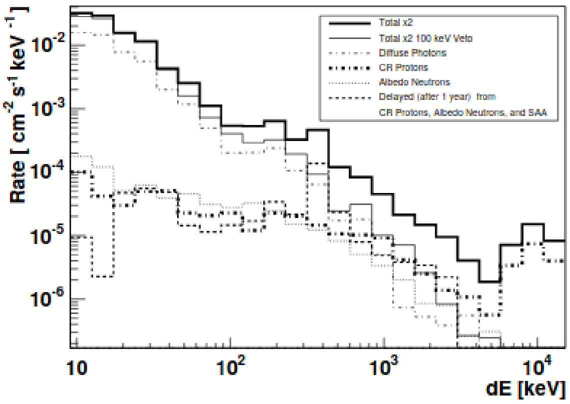

Figure 3. Total Background (prompt+delayed) before and after applying a shield-veto whenever an event deposits >100 keV in any one of the shields (fully active configuration). The relative contribution from different environmental components are also shown (before veto). We assumed an in-orbit time of 1 year with activation by primary CR protons, albedo neutrons, SAA particles, and secondary particles produced by interactions of the primary particles with the satellite. The figure assumes that 5 min passed since the last SAA passage.

Figure 3: Simulated background environment for EXIST HET

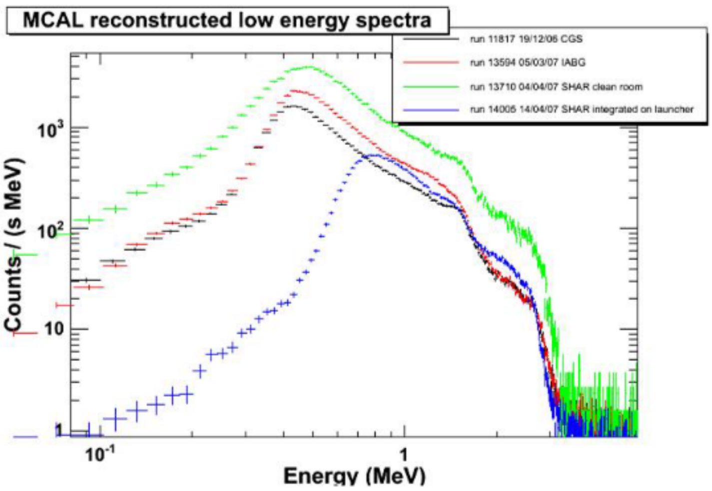

Fig. 21. *An example of the AGILE pre-launch scientific measurements carried out before and during the AGILE launch campaign. The plot shows a sequence of spectral measurements obtained with the AGILE MCAL for different environmental and testing conditions. Black data points: data obtained during the satellite integration at the CGS facility in Tortona (Italy). Red data points: data obtained during the satellite qualification at the IABG facility in Munich (Germany). Green data points: data obtained during the satellite launcher pre-integration tests at the Sriharikota facility. Blue data points: data obtained during the final pre-launch tests with the satellite completely integrated with the PSLV-C8 at a height of about 50 meters above ground. In this case, the MCAL threshold was set near 600 keV. Note the difference of the pre- and post-integration spectra interpreted as caused by different natural radioactive background conditions.*

Figure 4: Measured background environment during launch operations of AGILE

The space program AGILE (Astro-rivelatore Gamma aImmagini LEggero) is an Italian Space Agency mission dedicated to gamma ray astrophysics. The main detector (GRID) is a Silicon-Tungsten tracker with CsI calorimetry and anti-coincidence system. It is fully active shielded. Figure 4 shows the pre and post launch background environment count rate versus energy. Note the difference in background due to change in natural radioactivity. Figure 5 shows the background count rate in one orbit where the peak corresponds to SAA region.

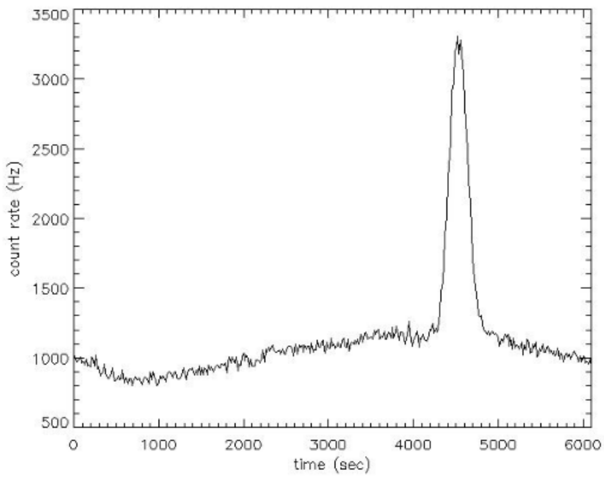

Fig. 22. *AGILE AC count rate throughout the whole orbit for one of the 12 lateral Anticoincidence panels. The count rate peak occurs in coincidence with the passage over the South Atlantic Anomaly.*

Figure 5: Single orbit count rate for AGILE

ASTROSAT's CZT Imager [Bhalerao et al., 2017] is also similar to EXIST with wide FOV, coded aperture masked CZT detectors with CsI anti-coincidence veto detectors. Since CZTI has pixellated detectors, the secondary showers produced from CR interactions were being detected in each pixel as separate events but very closely spaced (bunched) in time. The team developed a bunch cleaning algorithm to eliminate the background in post processing. Figure 6 shows the raw and bunch cleaned count rates [Vadawale et al., 2016].

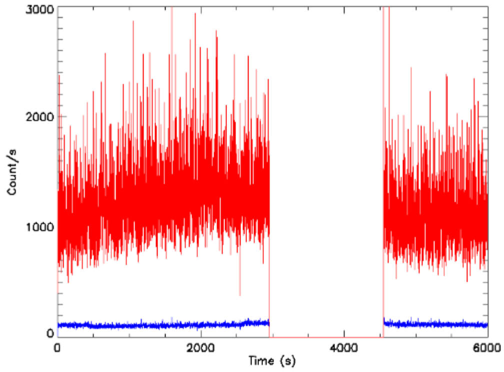

Figure 4. Raw count rate observed by CZTI (red) and the count rate after 'bunch-cleaning' (blue) demonstrating the effect of the 'bunched' events and effectiveness of the cleaning algorithm.

Figure 6: Raw background count rate and bunch cleaned count rate for CZTI aboard ASTROSAT

3 SAA simulations

ESA's tool SPENVIS (SPace ENVironment Information System) simulations [Cumani et al., 2019] of trapped particle flux in SAA at different altitudes and inclination can be seen in figure 7. The simulation results show that altitude of 550 km has a factor of 2 less particle flux compared to 600 km and time spent in SAA is less by 20%. Moreover, low inclination orbits (less than 5°) are favorable.

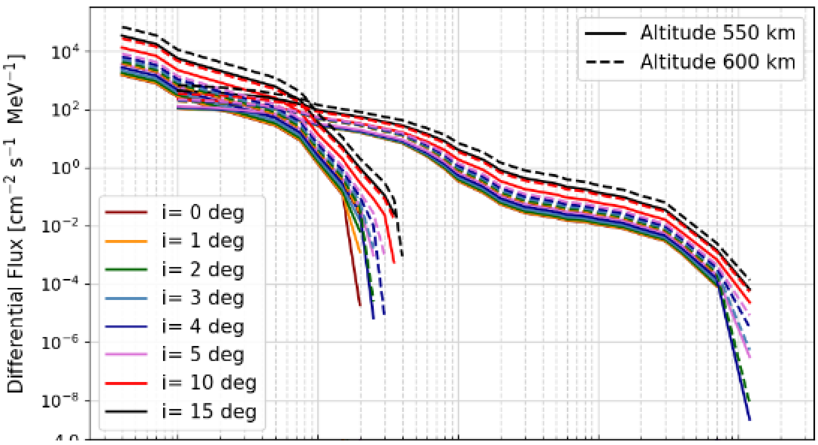

Figure 7: SPENVIS simulation for different inclination angles and two LEO altitudes

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