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The LAT tracker performance and first results after launch

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The FERMI (former GLAST) Gamma-Ray Large Area Space Telescope is a satellite-based observatory that will study the gamma-ray sky in a wide energy range from a few keV to 300 GeV, allowing the investigation of many fields of the gamma ray astrophysics. FERMI will open a new and important window on a wide variety of phenomena, including black holes and active galactic nuclei, gamma-ray bursts, the origin of cosmic rays and supernova remnants and searches for hypothetical new phenomena such as supersymmetric dark matter annihilations. The primary instrument is the Large Area Telescope (LAT), which measures gamma-ray flux and spectra from 20 MeV to > 300 GeV and is a successor to the highly successful EGRET experiment on CGRO. The LAT has better angular resolution, greater effective area, wider field of view and broader energy coverage than any previous experiment in this energy range.
FERMI was integrated with a spacecraft in December 2006 and was launched in June 2008 from Kennedy Space Flight Centre (NASA). This paper is related to the commissioning experience with the LAT tracker.

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1.Introduction

The Large Area Telescope (LAT) [1][2][3] of the Gamma-ray Large-Area Space Telescope (FERMI) mission is a pair-conversion gamma-ray detector similar in concept to the previous NASA high-energy gamma-ray mission EGRET on the Compton Gamma-Ray Observatory [4].
With respect to previous gamma ray missions it has a very large field of view that allows monitoring 20% of the sky at any instant and a very wide energy range from 30MeV up to 300GeV. FERMI-LAT will allow to dramatically change the high energy gamma ray catalog by increasing of an order of magnitude the number of point sources, by increasing the timing resolution for variable phenomena (Gamma ray burst, pulsars, …) and increasing the spatial localization of know sources.
High energy (20 MeV–300 GeV) gamma-rays convert into electron-positron pairs in one of 16 layers of tungsten foils. The charged particles pass through up to 36 layers of position-sensitive detectors interleaved with the tungsten, the "tracker," leaving behind tracks pointing back toward the origin of the gamma ray. After passing through the last tracking layer they enter a calorimeter composed of bars of cesium-iodide crystals read out by PIN diodes. The calorimeter furnishes the energy measurement of the incident gamma ray. A third detector system, the anti-coincidence detector (ACD), surrounds the top and sides of the tracking instrument. It consists of panels of plastic scintillators read out by wave-shifting fibers and photo-multiplier tubes and is used to veto charged cosmic-ray events such as electrons, protons or heavier nuclei.
In the LAT the tracker and calorimeter are segmented into 16 "towers," which are covered by the ACD and a thermal blanket and meteor shield. An aluminum grid supports the detector modules and the data acquisition system and computers, which are located below the calorimeter modules. The LAT is designed to improve upon EGRET's sensitivity to astrophysical gamma-ray sources by well over a factor of 10. That is accomplished partly by sheer size, but also by use of state-of-the-art particle detection technology, such as the silicon-strip detectors [5] used in the tracker system.

2.Tracker design

Each of the 16 tracker modules is composed of a stack of 19 "trays," as shown in Figure 1. A tray is a stiff, lightweight carbon-composite panel with silicon-strip detectors (SSDs) bonded on both sides, with the strips on top parallel to those on the bottom. Also bonded to the bottom surface of all but the 3 lowest trays, between the panel and the detectors, is an array of tungsten foils, one to match the active area of each detector wafer. The thickness of the tungsten foil is 2.7% radiation length for the upper 12 trays (light-converter trays), 18% radiation length for the next 4 trays (thick-converter trays). The last 3 trays do not have tungsten foils. Each tray is rotated 90° with respect to the one above or below. The detectors on the bottom of a tray combine with those on the top of the tray below to form a 90° stereo x,y pair with a 2 mm gap between them, and with the tungsten converter foils located just above. Each front-end electronics multi-chip module (MCM) supports the readout of 1536 silicon strips. It consists of a single printed wiring board (PWB) upon which are mounted 24 64-channel amplifier-discriminator ASICs (GTFE), two digital readout-controller ASICs (GTRC), the right angle interconnect, bias and termination resistors, decoupling capacitors, resettable fuses, and two nano-connectors. Each nano-connector plugs into a long flex-circuit cable, each of which interfaces 9 MCMs to the data-acquisition electronics located below the calorimeter in the Tower Electronics Module (TEM). Thus on each of the 4 sides of a tracker module one finds 9 readout boards to support 9 layers of silicon-strip detectors, which send their data to the TEM via two flex-circuit cables. Each channel in the GTFE has a preamplifier, shaping amplifier, and discriminator similar, although not identical, to the prototype circuits described in [6]. The amplified detector signals are discriminated by a single threshold per GTFE chip; no other measurement of the signal size is made within the GTFE. The GTFE chips are arranged on the MCM in 4 groups of 6. Each group reads out one SSD “ladder,” which consists of 4 SSDs connected in series to yield strips of about 36 cm effective length. All communication with the TEM passes through the GTRC chips, which in turn relay commands and data to and from the GTFE chips. Event data and trigger primitives flow from the GTFE chips into one or the other of the GTRC chips by passing through one GTFE chip after another. This scheme was chosen over the use of a common bus in order to avoid the possibility of a single malfunctioning chip pulling down the entire bus (Figure 2). Concern that in the chosen scheme a single bad chip could block the flow of data is mitigated by the left-right redundancy described below. Each GTFE chip has two command decoders, one that listens to the left-hand GTRC, and a second that listens to the right-hand GTRC. Each GTFE also has two output data shift registers, one that moves data to the left, and a second that moves data to the right. Trigger information is formed within each GTFE chip from a logical OR of the 64 channels, of which any arbitrary set can be masked. The OR signal is passed to the left or right, depending on the setting of the chip, and combined with the OR of the neighbor, and so on down the line, until the GTRC receives a logical OR of all non-masked channels in those chips that it controls. This “layer-OR” trigger primitive initiates in the GTRC a one-shot pulse of adjustable length, which is sent down as a “trigger request” to the TEM for trigger processing. In addition, a counter in the GTRC measures the length of the layer-OR signal (time-over-threshold) and buffers the result for inclusion in the event data stream. Upon receipt of a “trigger acknowledge”, each GTFE chip latches the status of all 64 channels into one of 4 internal event buffers, as specified by the 2-bit trigger code. A 64-bit mask, which is separate from the trigger mask mentioned above, can be used to mask any subset of channels from contributing data, as may be necessary in case of noisy channels.

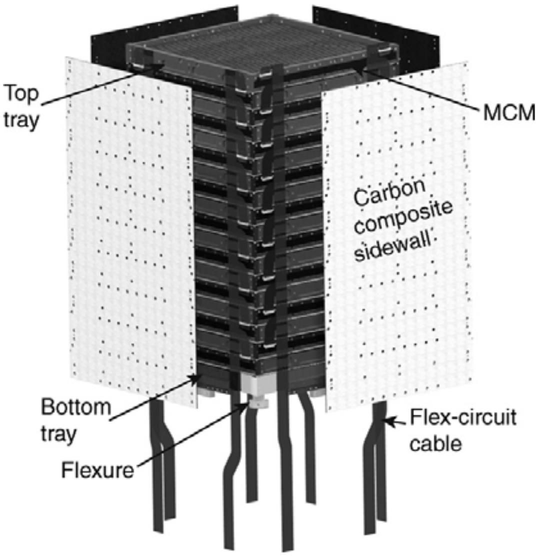

Figure 1 Exploded view of a Tracker tower module.

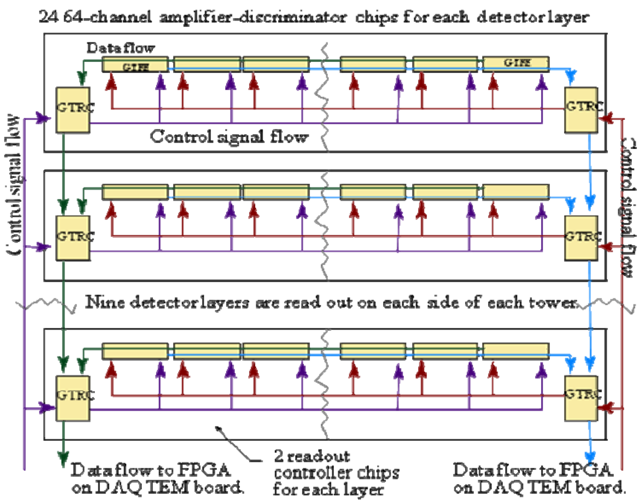

Figure 2 Schema of read out electronics

The Tracker was designed to satisfy the FERMI science requirements [7] on effective area, angular resolution, and field-of-view. In addition, it was designed to provide the primary trigger of the LAT instrument. A particular challenge was to optimize the angular resolution on incoming photons over a broad range of photon energies from 20 MeV to above 300 GeV with a limited number of detector layers. The ultimate design relied on extensive Monte Carlo simulation to evaluate trade-offs between the number and spacing of the silicon layers, the SSD strip pitch, and the tungsten converter thickness. In general, the design requires a compromise between very thin converter foils, good for angular resolution, versus thick foils, good for effective area.

The design has been fully verified and qualified during an intense beam test campaign in the 2006 at CERN PS and SPS [8]. In Figure 3 is shown the hit multiplicity for incoming electrons of different energies (single tower event and 0° beam angle). The hit multiplicity increases as the electromagnetic cascade develops inside the tracker: it is evident the effect of the thicker layers (18% X_0) on the shower profile. For comparison also the results obtained with protons are shown.

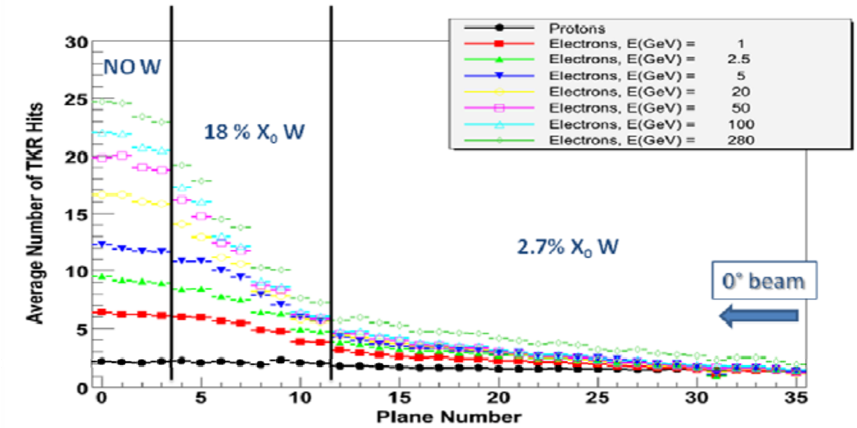

Figure 3 Hit multiplicity for electrons of different energies

Unlike silicon trackers for ground based experiments the LAT tracker isn't light but it still has a very good angular resolution for gammas. We have measured the angular resolution with gammas produced by bremsstrahlung between beam electrons and the upstream materials: it has been evaluated with respect to the nominal beam direction. The results are in Figure 4 , the Monte Carlo simulation is shown for comparison

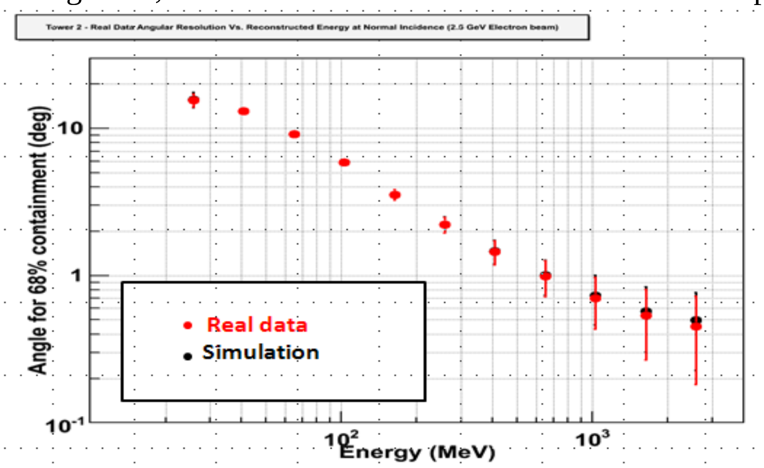

Figure 4 Angular resolution for gammas (0° incidence)

3. Launch and early orbits – Commissioning phase

FERMI has been successfully launched from Cape Canaveral on the 11th of June 2008. It is now in a circular orbit around the earth at an altitude of 565km and an inclination of 25.6°: it takes 96 minutes to make a revolution around the earth. After 12 days from the launch all the detectors have been turned on at conservative value of voltage and general settings and after other 7 days of testing and studies of the performances, all the detectors were set to the nominal settings. In particular for the tracker we have worked for the first 7 days at 80V checking noise occupancy and trigger efficiency and rates and then set the voltage to the nominal value of 105V. Changing from conservative value to nominal values of voltage and threshold gives just a small increase in the trigger efficiency.

3.1Thermal control

The thermal control of all the parts of a satellite is crucial for any space experiment. One of the main aspects that has been monitored during the commissioning is the thermal behavior of the tracker. The heat produced by the electronics is driven away by means of heat pipes and ultimately dissipated by radiation into space. The temperature of all the towers is monitored by means of thermistors located at different heights along the flex-circuit cable. In Figure 5 is shown the thermal trend of a tower during the first week after the turn on. The tracker has reached a stable thermal configuration in a couple of days after the turn on and then keeps steady with fluctuations smaller than 0.5°C. The tracker performances aren't effect at all by this small fluctuations: the only requirement is to keep the overall temperature lower than 25°C in order to avoid some strips to flare (less than 0.05% on average).

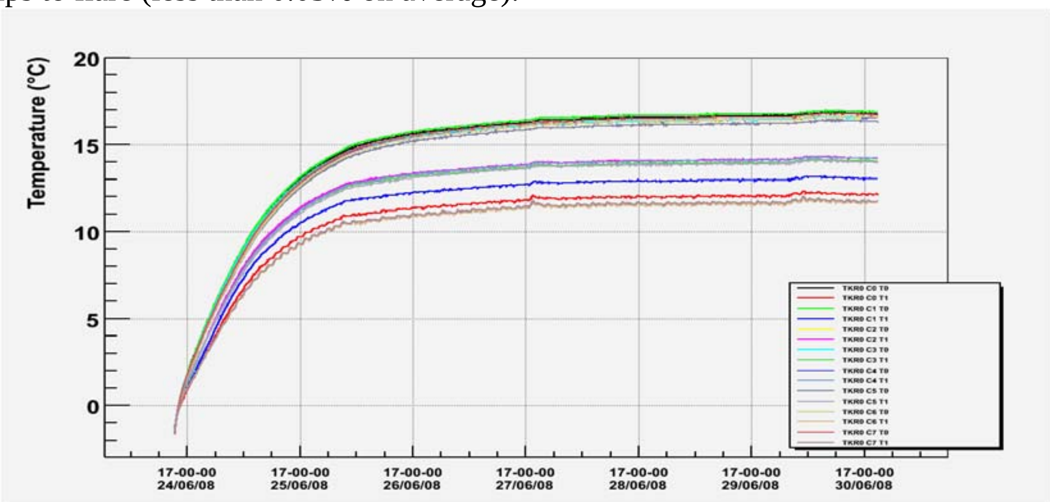

Figure 5 Thermal trend of a tower in a week after the turn on

3.2 Noise Occupancy

The noise occupancy is a crucial parameter to monitor in order to grantee long term operations: it is required in average to be less than 5×10^{-5} to suppress useless data from using up the downlink between satellite and ground. In each tracker module, the highest occupancy channels are identified as hot and masked from data collection until the average occupancy is below the above requirement. In order to monitor the noise occupancy the onboard periodic trigger is used: the noise occupancy is defined as the average fraction of channels above threshold at any snapshot in time when a periodic trigger is asserted. During the commissioning the noise occupancy was on average at 3×10^{-6}, an order of magnitude lower than required which is very good for long term operations. We have observed just a slight increase in noise occupancy of a couple of towers but the problem has been solved masking one hot strip per tower.

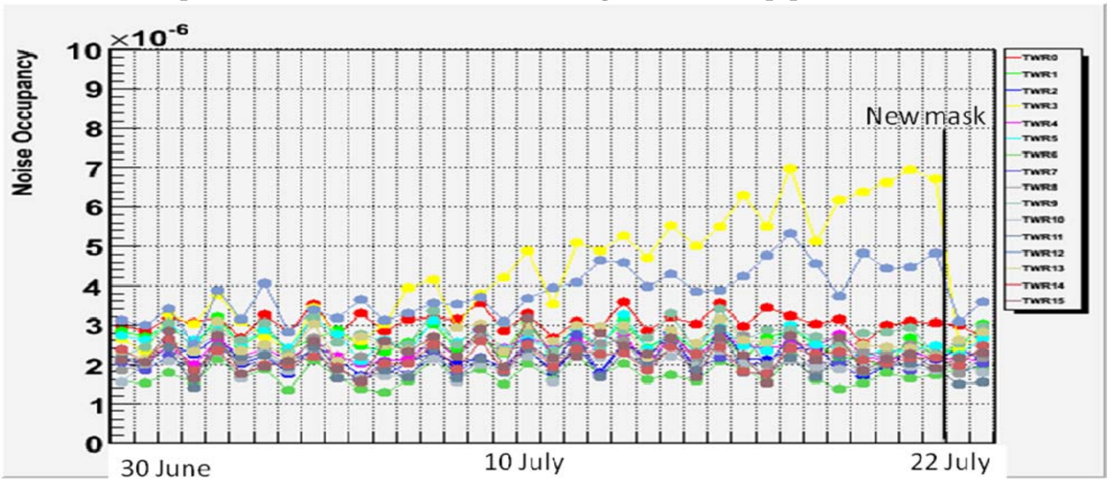

Figure 6 Noise occupancy trend during the commissioning

3.3 Hit efficiency

At low photon energy, around 100 MeV, most of the information on the photon direction comes from the first two space points measured on the track of the higher energy particle, so it is crucial that those two measurements be made close to the photon-conversion vertex, to minimize the effects of multiple scattering in the following layers of tungsten and support material. Therefore, the efficiency of each detection layer should be nearly 100%, and the inevitable inefficiencies should be localized in known regions that can be isolated at the analysis stage.

The hit efficiency is evaluated looking for missing hits along the reconstructed track in a ±3.0mm confidential zone. In the analysis the geometrical inefficiency (≈4%) has been taken into account: the hit efficiency is very high for all towers (>98%) and the inefficiency is due only to dead strips. By performing a layer by layer analysis it results that only 24 layers (4% of the total) have a hit inefficiency greater than 1%

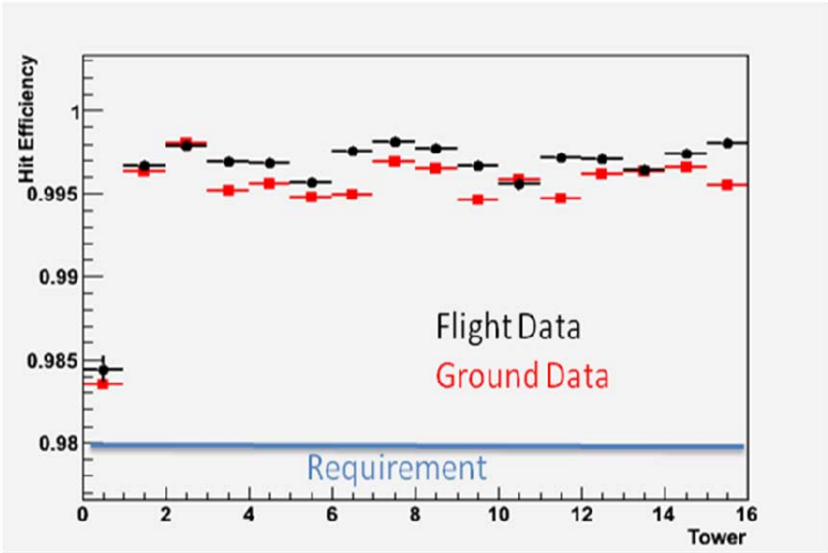

Figure 7 Hit efficiency (ground data reported for reference)

3.4 Trigger efficiency

Since the tracker is one of the two main instruments of the LAT, its trigger efficiency is a crucial parameter for the overall performance of the LAT. In particular it is fundamental for triggering low energy gammas that don't reach the calorimeter.

A tracker trigger is asserted from a tower when there are 6 signals above threshold in consecutive layers (3x + 3y). To study the trigger efficiency a set of events are selected in which a charged particle cross two towers and hits at least 6 consecutive layers in each tower. If the first tower sends a trigger request then we search for a trigger request in the second tower, in this way the trigger efficiency is evaluated tower by tower. As shown in Figure 8 the efficiency is 98% for almost all the towers, which is greater than the requested value of 90%. The lower value for tower 0 is due to a higher number of dead strips.

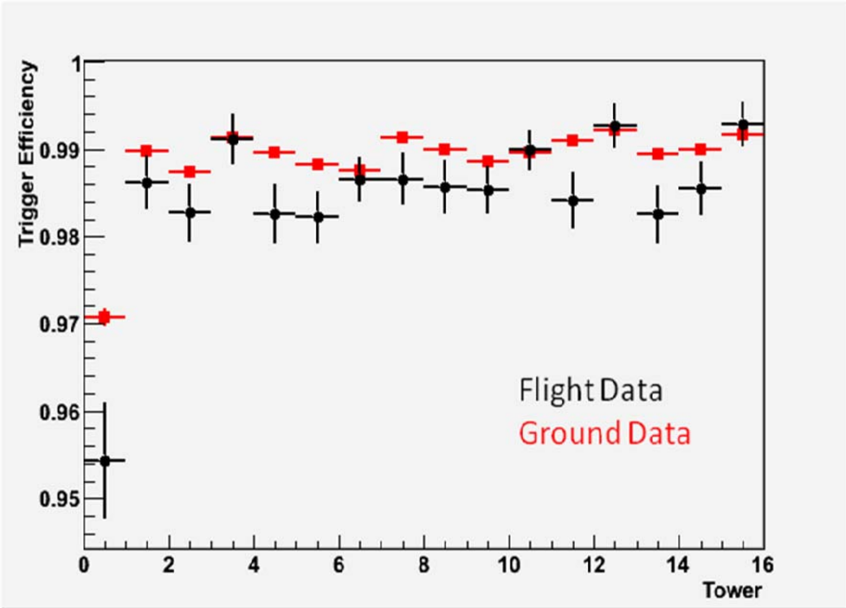

Figure 8 Trigger efficiency (Ground data for reference)

4. South Atlantic Anomaly boundaries

The South Atlantic Anomaly (or SAA) is the region where Earth's inner van Allen radiation belt makes its closest approach to the planet's surface. Thus, for a given altitude, the radiation intensity is greater within this region than elsewhere. When in the SAA the supply voltage of the ACD photomultipliers is reduced to avoid damages and the FERMI-LAT doesn't take, moreover the rate of charged particles is too high to be efficiently filtered away on board and so it will saturate the bandwidth of the link with the ground based station with useless data. For these reason it is very important to measure the exact boundaries of the SAA in order to reduce the inactive time of the LAT. Each of the 16 towers has 4 counters that count the number of triggers in a set of layers: all these counters are used to build a count map of the area, reported in Figure 9 where the averaged measured rate from all the counters is shown: the decrease of the measured rate at the center of the SAA is due to a saturation effect in GTFE preamplifier stage of the readout electronics. The blue line shows the boundaries of the SAA as measured from previous missions: with these boundaries the inactive time is 18%.

Using the collected data during the commissioning we have reduced redefined the boundaries and reduced the inactive time to 13% (magenta line in Figure 9) . The SAA will be monitored during the mission live time since its boundaries can change in relation to the solar activity.

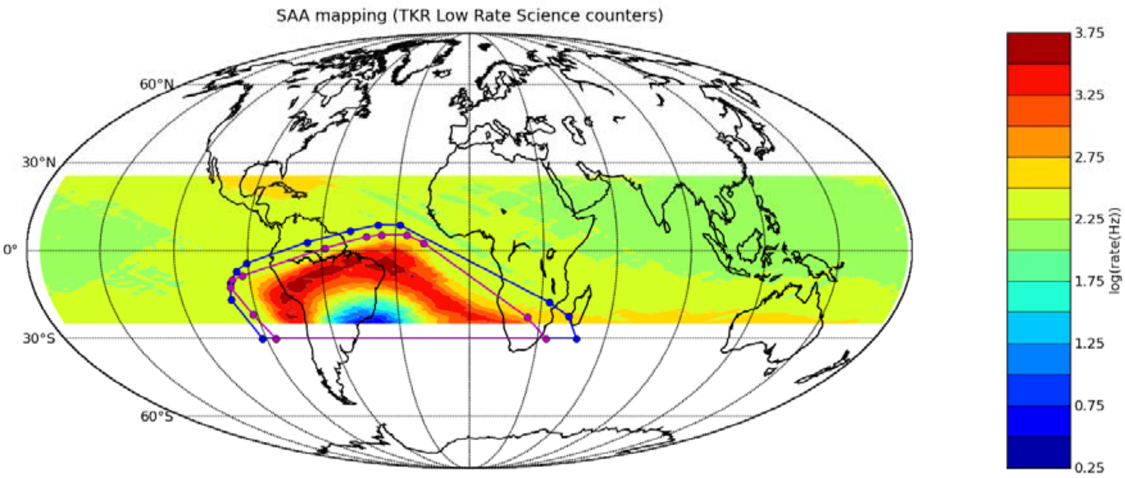

Figure 9 SAA maps from tracker counters

4.1 Conclusions

FERMI has been launched in space on the 11th of June 2008 and fully turned on the 23rd of June 2008. The LAT tracker underwent 4g acceleration and now it is working in vacuum (the pressure in thermosphere at 565km is lower than 10^{-5} Torr) at a steady temperature of 15°C. All the main parameters have been monitored during the commissioning phase and everything is working as expected. During the commissioning phase a new map of the SAA has been measured and the inactive mission time has been reduced to 13%.

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