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Fermi Large Area Telescope Operations: Progress Over 4 Years

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ABSTRACT

The Fermi Gamma-ray Space Telescope was launched into orbit in June 2008, and is conducting a multi-year gamma-ray all-sky survey, using the main instrument on *Fermi*, the Large Area Telescope (LAT). *Fermi* began its science mission in August 2008, and has now been operating for almost 4 years. The SLAC National Accelerator Laboratory hosts the LAT Instrument Science Operations Center (ISOC), which supports the operation of the LAT in conjunction with the Mission Operations Center (MOC) and the Fermi Science Support Center (FSSC), both at NASA's Goddard Space Flight Center. The LAT has a continuous output data rate of about 1.5 Mbits per second, and data from the LAT are stored on *Fermi* and transmitted to the ground through TDRS and the MOC to the ISOC about 10 times per day. Several hundred computers at SLAC are used to process LAT data to perform event reconstruction, and gamma-ray photon data are subsequently delivered to the FSSC for public release with a few hours of being detected by the LAT. We summarize the current status of the LAT, and the evolution of the data processing and monitoring performed by the ISOC during the first 4 years of the Fermi mission, together with future plans for further changes to detected event data processing and instrument operations and monitoring.

Keywords: Fermi Gamma-ray Space Telescope, gamma rays, operations

1. INTRODUCTION

The operations of the Large Area Telescope (LAT) detector on the Fermi Gamma-ray Space Telescope (*Fermi*) is performed by the LAT Instrument Science Operations Center (ISOC) located at the SLAC National Accelerator Center at Stanford University in California, in conjunction with the *Fermi* Mission Operations Center (MOC) and the *Fermi* Science Support Center (FSSC) at NASA's Goddard Space Flight Center in Maryland[1]. The main functions of the ISOC are:

- Command planning and command sequence construction for the LAT, and the transmission of the LAT commands to the MOC for uplink to *Fermi* and the LAT
- Monitoring the health and safety of the LAT
- Maintaining and upgrading the LAT on-board flight software (FSW) executed on the LAT flight computers
- Science performance monitoring, verification and optimization of the LAT
- Receipt and archiving and processing of LAT event data to perform event reconstruction and classification, and delivery of reconstructed photon event data to the FSSC for public release, and develop and provide to the FSSC science analysis software tools and instrument calibrations for the analysis of LAT data
- Host LAT event data for the use of the LAT Collaboration, and provide computing facilities for use by the Collaboration

As shown by the above functions, the ISOC supports both the *Fermi* mission with NASA, and the international LAT Collaboration. The LAT instrument construction was managed and performed at SLAC, in cooperation with the international partners of the LAT Collaboration, and SLAC is the core site for the LAT Collaboration through its hosting of the ISOC.

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A detailed description of the LAT instrument is available elsewhere[2], but in summary, the LAT is a gamma-ray detector, using pair-production measurement techniques to detect gamma-rays. The LAT (Figure 1) has 3 detector sub-systems: a 4x4 array of tracker (TKR) towers, with each tower having 36 layers of Si strip detectors interleaved with Tungsten conversion foils, in which electron-positron secondary particles produced by incoming gamma-ray photons are tracked, to provide direction data on the primary gamma-ray photons; plus a 4x4 array of Calorimeter (CAL) modules for photon energy measurement, with each CAL module consisting of 8 layers of alternating X and Y oriented CsI scintillating crystal logs, with large and small PIN photo-diodes at both ends of each crystal. The TKR and CAL towers are surrounded by an Anti-Coincidence Detector (ACD), which uses plastic scintillator tiles and ribbons attached to photo-multiplier tube light detectors, to detect and discriminate against charged cosmic ray particles hitting the LAT. Signals from the LAT detector sub-systems are readout into the LAT Trigger and Data Flow electronics system, which triggers on detected gamma-ray photons and other events, and which provides some further realtime event filtering and data packaging and instrument control.

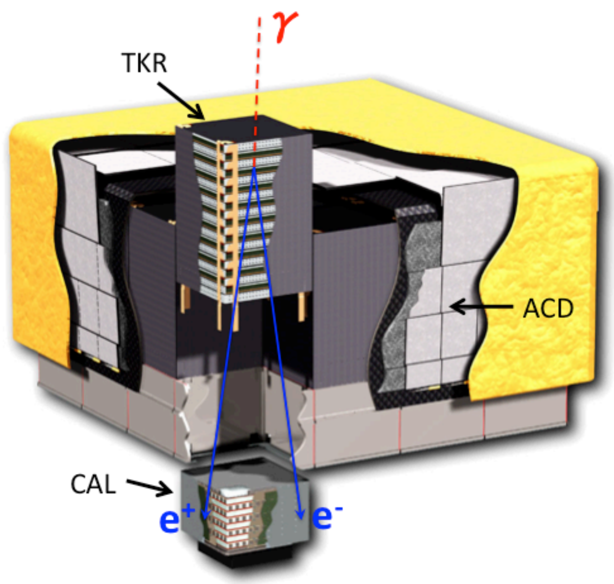

Figure 1. A schematic diagram of the Large Area Telescope with cutaway, showing the 3 detector sub-systems.

The LAT is primarily a sky-survey telescope, having and large field of view (2.2 steradians), with the primary observation mode of Fermi and the LAT being a continuous sky-survey, in which the entire sky is observed every 2 orbits, about 190 minutes. In the first year of the *Fermi* mission, the LAT data were proprietary to the LAT Collaboration. During this first year, the Collaboration, in cooperation with the ISOC, refined the processing and analysis of LAT data and measured the LAT's science performance for detecting celestial gamma-ray photons in the presence of real on-orbit charged particle backgrounds. At the end of the first year, the year of LAT photon data was publicly released through the FSSC and photon data processed by the ISOC and then delivered to the FSSC are now immediately publicly released by the FSSC.

Fermi and the LAT have been operating for almost 4 years, and several improvements to the LAT have been made, together with improvements to ground operations in the ISOC. In section 2, we briefly describe the pre-launch operations testing in the ISOC and its benefits. In section 3 we summarize some highlights of LAT operations since the start of the *Fermi* routine science mission. In section 4 we describe the major updates to LAT data processing already done and being planned for the near future. Section 5 offers insights and conclusions from the mission so far.

2. PRE-LAUNCH ACTIVITIES

In preparation for the launch of Fermi, the ISOC team members participated in 3 broad areas of operations and science analysis development and testing, in conjunction with the LAT Collaboration and the other Fermi mission elements in NASA. These 3 areas were LAT science performance modeling and science analysis tests involving the entire LAT Collaboration in three Data Challenges; Fermi and LAT integration and test and flight operations development and testing, centered on the joint US Department of Energy and NASA project to integrate and test the LAT instrument, and the subsequent NASA-coordinated activities to integrate and test the *Fermi* satellite observatory and test the NASA-centric *Fermi* ground operations elements; and LAT science operations rehearsals centered on the ISOC but involving the entire LAT Collaboration in two LAT Operations Simulations. Details of these three areas are given below. Through the combination of these disparate types of testing, both computer software and systems and also technical staff and scientists in the ISOC and the broader LAT Collaboration were thoroughly tested and rehearsed before launch. As a result, the initial on-orbit 60 day commissioning period for Fermi and the LAT, and the subsequent transition to the routine science mission in early August 2008 were accomplished with remarkably few problems.

2.1 Data Challenges

Following the model of experiment development and testing in the particle physics scientific community, from which the LAT instrument and Collaboration derive much of their technical and scientific heritage, the LAT Collaboration conducted a series of 3 Data Challenges to develop and test the science analysis tools and computing infrastructure needed to support the processing and analysis of LAT data. These Data Challenges began almost 5 years before the launch of *Fermi,* and made use of increasingly realistic and extensive simulations of expected gamma-ray photon data and charged particle background data to test the processing and analysis systems and tools needed for the LAT. The Data Challenges served as rehearsals of the scientific analysis activities of the LAT Collaboration, but also aided the testing of the computational infrastructure needed for the ISOC and the Fermi mission.

The first Data Challenge was 6 months in duration, from September 2003 until February 2004. The LAT Collaboration developed and used a Monte Carlo simulation of 1 full day of LAT event data, both gamma-ray photons and charged particles. The full gamma-ray sky was simulated, including discrete celestial gamma-ray sources such as active galaxies, including source flux variability and galactic pulsars, plus diffuse emission (both from the Galaxy, plus extra-galactic diffuse emission). To generate the 400 million events needed for the simulation, a processing pipeline was developed for the large computer “farm” at SLAC. In addition, several science analysis software tools were developed and bundled into an analysis toolkit by members of the ISOC and the LAT Collaboration. Except for a core group of test developers, the Collaboration performed a “blind” analysis of the simulated data, with several modest goals established for the Challenge. The results of the Challenge were reviewed at a closeout meeting in February 2004. This initial Challenge successfully initiated the use of key processing elements such as the processing pipeline and analysis toolkit, plus the initial development of analysis documentation and user tutorial guides, and allowed many problems to be discovered and fixed during the Challenge.

The second Data Challenge started in March 2006 and ended in June 2006, although planning and preparation started in June 2005. It used a Monte Carlo simulation of 55 days of LAT event data, where 55 days corresponds to the precession period for the nominal pre-launch orbit of Fermi, being a circular orbit at an altitude of 565 km, with an inclination of 28.5 degrees. About 200,000 CPU hours were used on the SLAC computer farm to produce the simulated data, which served to further develop and test the data processing pipeline for the ISOC at SLAC. The pipeline was also exercised by jobs for analysis of the simulated data. Data servers were populated with the data at the ISOC, to serve the LAT Collaboration, and at the FSSC. This data challenge also included the simulation of data from the smaller Gamma-ray Burst Monitor (GBM) instrument on *Fermi*, and the joint analysis of LAT and GBM data on simulated gamma-ray bursts. The simulated data were also used to test and develop ISOC software tools for data display and reporting. Again, this Data Challenge was a “blind” test for the LAT Collaboration, with predefined requirements and goals for the analyses performed on the data.

The third Data Challenge started in December 2006 and ended in February 2008. It was labeled as a “Service Challenge”, because of its fundamental aim to test the robustness and reliability of data processing, data serving and data analysis systems and tools for the LAT and ISOC. It also expanded the scope of the previous Data Challenges, by including the production of 4 separate datasets: another 55 day dataset which was used to rehearse daily analysis tasks; a 1-year dataset to rehearse long-term analysis which would be needed during the mission for the production of a 1-year source catalog; and the generation and flight-like packaging of a 1-day dataset and a 1-week dataset, to be used for the ISOC Science Operations Simulations described in Section 2.3. This Challenge again stress-tested the processing pipeline at SLAC, to drive the percentage of failed processing jobs on the SLAC computer farm to well below 1%. It tested realistic use of data servers at the ISOC and the FSSC, plus testing of web-based monitoring and trending of LAT and ISOC performance diagnostics.

2.2 Instrument Engineering and Operations Testing

Test planning and execution of ISOC operations software elements began in mid-2005, in cooperation with the NASA *Fermi* operations elements at the MOC and the FSSC. This testing aimed at verifying data exchange interfaces and formats between the ground operations elements, and unit testing of specific functions to support *Fermi* flight operations. Individual functional requirements for the ISOC were tested and approved in this way.

Late in 2005, the integration and test of the LAT instrument progressed from the construction and testing of individual detector or electronics units to the functional and performance testing of the integrated instrument. Adhering to the "test as you fly" maxim for complex missions, some elements of ISOC data collection, transmission and processing were integrated into the LAT instrument tests, so that ISOC software systems for archiving, transmitting and processing real LAT data could be tested and exercised, both for engineering commanding and telemetry and for detected event data. Software and web applications for trending of LAT telemetry were tested this way, which also allowed ISOC operations staff to gain familiarity with the tools and provide important feedback to the developers on problems and improvements.

In mid-2007, ISOC operations staff began participating in NASA-coordinated mission operations simulations, which involved some ISOC staff and LAT Collaboration members being located at the MOC during rehearsals of the 60-day Launch and Early Orbit activation and commissioning period for *Fermi*. These simulations also rehearsed the necessary close coordination of LAT operations staff and activities based at SLAC with the LAT team based at the MOC for the activation and thorough check of the LAT in this post-launch phase.

2.3 LAT ISOC Operations Simulations

The ISOC led two Operations Simulations within the LAT Collaboration. Their objective was to rehearse the members of the ISOC and the scientists of the LAT Collaboration to be ready to support the on-orbit commissioning of the LAT, and the transition to the routine science mission for *Fermi*. These Operations Simulations were a successor and extension to the Data Challenges described in Section 2.1.

The first Operations Simulation was 4 days in duration, held in October 2007. It rehearsed the activities associated with the delivery, ingest and processing of 1 day (15 orbits) of LAT data. 79 LAT scientists and engineers participated, mostly at SLAC but with some remote participation in Europe and Japan. Simulated realistic LAT event datasets were used, with flight-like delivery of the data by several discrete deliveries across the test. Realistic real-time activities were performed including receipt and archiving of raw LAT data, dispatch to event processing, subsequent automated science processing, with web-based monitoring and reporting tools being used. Staffing functions were also rehearsed, with on-console shifts of ISOC operations staff and duty scientists and shift changes. Some limited anomalies were also included in the data to check the required detection, reporting and response processes.

The second Operations Simulation was also 4 days in duration, held in March 2008. It was based on the delivery, ingest and processing of 1 week (100 orbits) of LAT data, and included simulated instrument anomalies and transient gamma-ray events. 75 LAT scientists and engineers participated, again mostly at SLAC but with some remote participation from Europe and Japan. In addition to rehearsing the on-shift activities, this rehearsal also involved more detailed analysis of the LAT data by off-shift scientists.

3. CURRENT OPERATIONS ACTIVITIES

3.1 Routine Operations

The LAT has been operational and performing routine data collection for 99.6% of the time since the start of the routine science mission on August 4, 2008. On average, about 15% of possible data-collection time is not used when the LAT stops collecting data as *Fermi* transits the South Atlantic Anomaly (SAA) region of high charged particle background. About 18 hours of the mission time has been used for performing occasional charge injection calibrations on the LAT detector units. The LAT has been powered down once during the science mission, in March 2009, by a safing action by the Fermi satellite, but other time has also been lost for data-taking due to some other safing actions by the satellite platform which have stopped LAT data-taking. LAT data-taking has also been interrupted several times during LAT flight software updates which are discussed in Section 3.2.

The readout of the LAT detectors has been triggered 240 billion times in the science mission, caused by charged particles and gamma-ray photon events detected in the instrument. Internal event filtering in the LAT is applied to these events, to discriminate between photons and charged particles, reducing the event rate by about a factor of 5. About 48 billion LAT events have been delivered to the ground for further processing and event discrimination and filtering. These output events are compressed in the LAT and then temporarily stored in data storage on the satellite, which is played back for transmission through geostationary TDRS data-relay satellites to the ground, about 10 times per day. The continuous time-averaged data rate from the LAT is about 1.5 Mbps, equivalent to about 130 Gbits/day. Figure 2 shows the history over the science mission of the daily volume of data sent from the LAT for delivery to the ground.

Several times per day, downlinked *Fermi* data are transmitted from the TDRS White Sands ground terminal to the MOC, where the LAT data are separated from other data and then transmitted to the ISOC for processing. ISOC data handling is automated, and received data are archived, checked for data gaps, and then dispatched for processing on the SLAC computer farm, with the data deliveries being split into segments for parallelized processing on hundreds of CPU cores. Each LAT readout event analyzed to reconstruct the incoming time, direction and energy of the gamma-ray photon or charged particle which triggered the instrument readout. Filters are applied to the reconstructed events to select the gamma-ray photons, with several levels of photon likelihood being applied to each event. The identified photons are then automatically delivered to the FSSC for immediate public release.

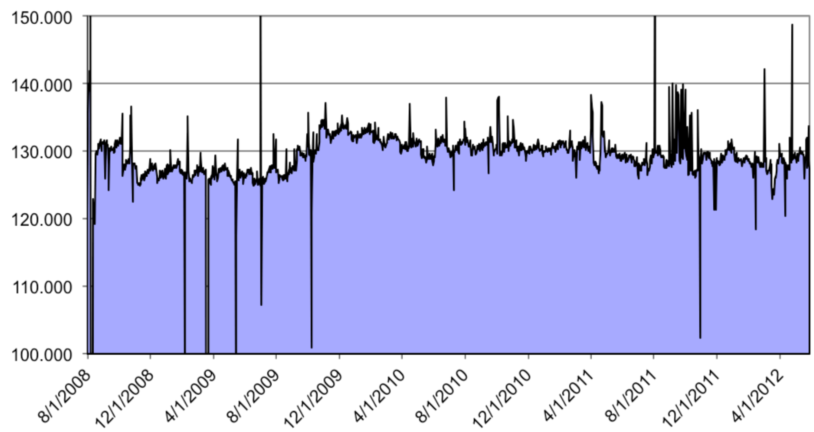

Figure 2. Daily data volume from the LAT (Gbits/day), since the start of the *Fermi* science mission. A 53-day modulation of the data volume corresponding to the *Fermi* precession period can be seen. Other short-term changes in the data volume caused by Targets of Opportunity and autonomous inertial pointings for the satellite, plus calibration activities and other instrument outages, and solar activity. The overall LAT data rate was increased by an instrument configuration change in October 2009.

Figure 3 shows histograms of the time taken for each orbit of LAT data to be delivered from the LAT by NASA, and then processed and released by the ISOC at SLAC. It can be seen that most data are available within 10 hours, and that processing time at SLAC is typically less than 3 hours.

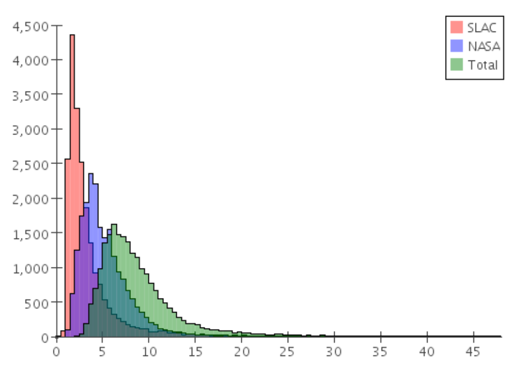

Figure 3. Histograms of data transmission and processing times for LAT data, with 1 count per orbit of data. The leftmost histogram peaking at 2 hours is the time spent handling and processing the data in the ISOC at SLAC. The middle histogram is the time NASA takes to downlink and deliver the data to SLAC. The rightmost histogram shows the total of the times in the first two histograms.

The ISOC has delivered over 190 million high-confidence photons to the FSSC for public release, and has also provided data on 1.36 billion events of lower confidence to the FSSC.

3.2 LAT Flight Software Updates

A major function of the ISOC is to maintain the flight software (FSW), which runs on the 3 operational and 2 standby computers in the LAT, and upgrade the FSW as needed. Since launch, the ISOC has performed 15 upgrades of the LAT FSW. Several of these upgrades were in the first year of the mission, and were to provide all the needed on-board FSW functions and also to identify a bug that had caused infrequent resets to the LAT processors, initially discovered in pre-launch testing. This bug was eventually traced to an undocumented data pre-fetch in the direct memory access circuit in the CPUs, which was worked around in 2009 and finally fixed in 2010. Table 1 shows the history of the FSW updates so far.

Table 1. LAT flight software updates since launch.

FSW Build	Start Date	Days Used	Principal Reason for Update
B1-0-8	24-Jun-2008	37	FSW Build at launch
B1-1-0	31-Jul-2008	61	Install GRB detection
B1-1-3	30-Sep-2008	120	Update photon filter, update GRB detection
B2-0-0	28-Jan-2009	94	Install turbo-reset capability for LAT
B2-0-1	2-May-2009	27	Improve LAT register reads; CPU reset mitigations
B2-0-2	29-May-2009	111	Interim fix for LAT CPU resets
B2-1-0	7-Sep-2009	14	Add compression of LAT event diagnostic data
B2-0-2*	1-Oct-2009	7	Revert to B2-0-2, to avoid CPU resets from bug revealed by B2-1-0 use
B2-1-2	8-Oct-2009	21	Fix calculation of event checksum
B2-2-0	29-Oct-2009	166	Further mitigation of CPU resets; updated detector configuration control
LCFG/RIM	13-Apr-2010	30	Begin use of updated detector configuration control
B2-2-1	13-May-2010	76	Final fix for LAT CPU resets
B2-2-2	28-Jul-2010	64	Fix CAL 4-range readout event compression
B2-3-0	30-Sep-2010	54	Speedup of detector charge injection calibrations
B2-3-1	23-Nov-2010	323	Reduce duration of GRB autonomous repoint requests to 2.5 hours
B2-3-2	12-Oct-2011	236	Correct 30 second LAT data checking after GRB alert from GBM

Only one FSW update has been performed in the past year, but the ISOC is currently preparing to install FSW build B3-0-0 on the LAT later this year. This major update is being done to ensure the ISOC's FSW development and maintenance computer systems at SLAC are maintainable for the expected remainder of the mission, within the Red Hat Enterprise 5 and 6 operating systems, and also to simplify the ground installation and use of the FSW photon and charged particle filters. No functional changes have been included in B3-0-0, but two further builds are being planned: B3-1-0 will support correct event data compression for a new detector readout buffering scheme being planned (see Section 4), and B3-1-1 which will fix a small number of known remaining minor FSW issues. No further FSW updates are planned beyond B3-1-1, which we expect to install in the fifth year of LAT orbital operations.

3.3 LAT Performance

The LAT is a complex instrument, having 3 separate detector subsystems and close to 1 million detection channels, connected to an extremely configurable trigger and data flow system having 2 million bits of configuration data. The performance of the LAT depends on the correct functioning of all of these elements. The performance of the LAT is carefully monitored, with the ISOC producing plots of about 120,000 measurements for each orbit of data collected, and with over 4000 monitored quantities having automated alarms for out-of-range values. These plots and any alarms are accessible through web pages, and the ISOC enlists the services of the world-wide distribution of scientists in the LAT Collaboration, to take week-long shifts to continuously monitor the LAT and also monitor the automated processing of the LAT data, and report any significant issues back to the ISOC staff.

Despite its complexity, the LAT has generally shown very stable behavior over the lifetime of the mission, with no major component failures so far. There have been some failures of a very small fraction of the detector elements. Of 6,144 light detection diodes in the CAL, 3 show incorrect response since the start of the mission, although the CAL CsI crystal logs have shown a few percent decrease in light emission, which is in agreement with expected yellowing of the crystals due to cumulative radiation damage in orbit. Of the 884,736 Si strip detectors in the TKR, 510 strips are excessively noisy and so have been electronically masked off from contributing to event triggers. Of these 510 strips, 203 strips were identified as being excessively noisy prior to launch and were electronically masked off before launch. Since launch, another 307 Si strips have become excessively noisy and have also been electronically masked. Of these 307 noisy strips, 111 are in the first manufactured TKR detector tower, and became noisy in the first year of operation, and can be attributed to early manufacturing issues. Another 170 noisy strips are in a single Si wafer ladder in 1 TKR tower, which started becoming generally noisy about 1 year after launch and continues to slowly get more noisy. There is no evidence of similar large-scale noise increases in any of the other 2303 Si wafer ladders in the LAT.

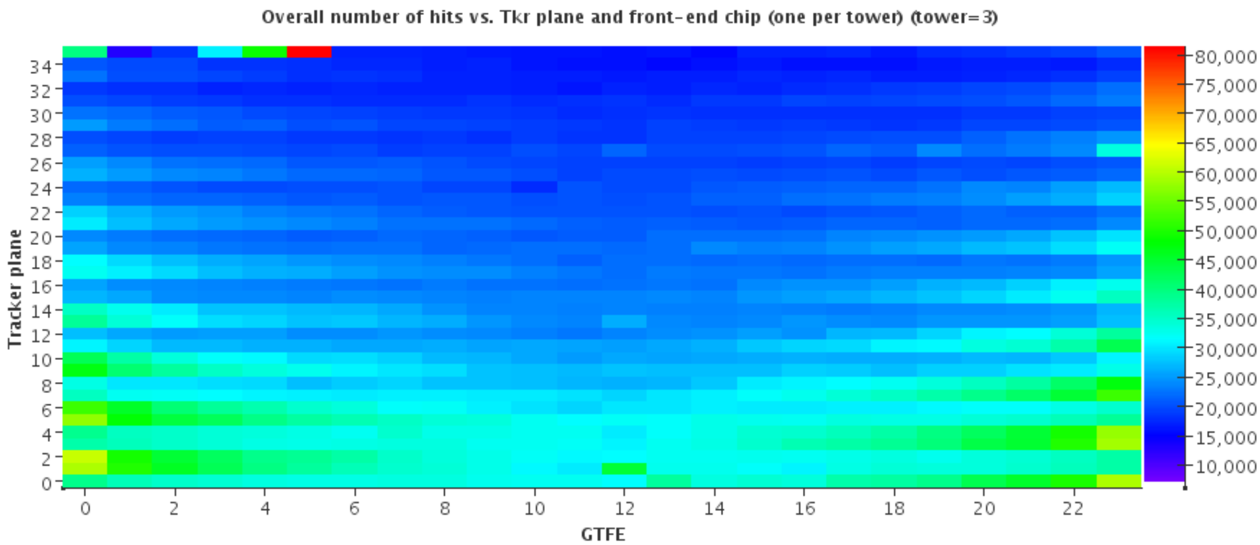

Figure 4. An example of one of the monitoring plots generated for each orbit of LAT data collection. This shows the number of hits recorded in TKR tower 3 of the LAT, for an orbit in June 2012. There are 36 layers of Si detectors in the tower, where layer 0 is nearest the LAT Calorimeter and is the layer most shielded from radiation and showing relatively few hits, and layer 35 is the layer least shielded from radiation and showing relatively many hits. Each Si layer is constructed of 4 ladders of Si wafers, with the 384 Si strips in each ladder readout by 6 Tracker Front Ends (GTFEs). The first Si wafer ladder of layer 35 in this tower shows excessive noise.

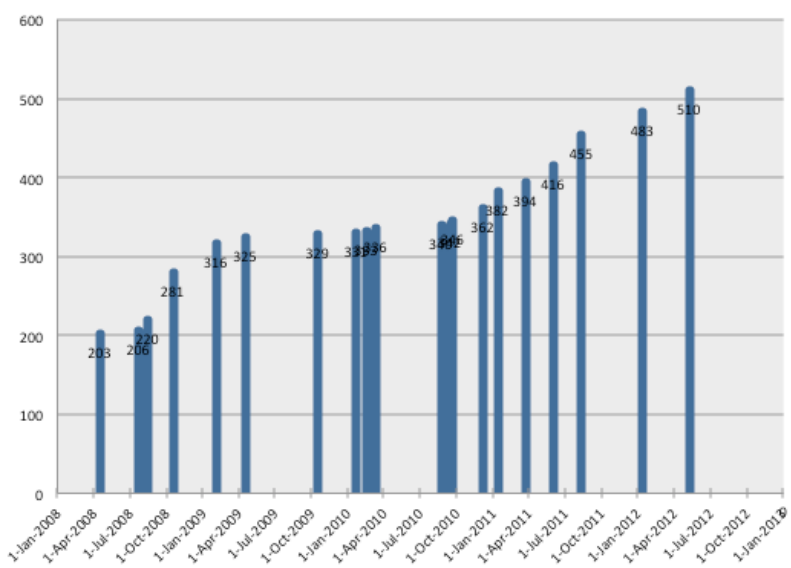

Figure 5. The time history of the cumulative number of noisy TKR Si detector strips that are electronically masked in the LAT. 208 strips were masked at the time of launch, and another 307 strips have been masked since launch. The recently masked strips are mostly in layer 35 of TKR tower 3.

3.4 Automated Science Processing

After event reconstruction and event filtering, the ISOC further processes the LAT photon data to perform Automated Science Processing (ASP), and provides ASP data products to the LAT Collaboration and the FSSC. In ASP, the ISOC monitors flux values for a number of bright sources and transient sources that have shown flares during the mission. As sources cross the monitoring flux threshold of 1×10^{-6} photons $cm^{-2}s^{-1}$, they are added to the monitored source list. The initial flux threshold was 2×10^{-6} photons $cm^{-2}s^{-1}$, but this value was lowered in June 2009. A list of 19 sources to be monitored daily and weekly was established at the start of the mission. This list has now grown to 92 sources, and will continue to grow as the mission progresses.

In addition, ASP is used to refine the positions and fluences of GRBs detected by the LAT and GBM instruments, and also perform blind searches for previously undetected GRBs. The ASP searches for spatial and temporal clustering of LAT gamma-ray photons, with significance thresholds set to give a small but acceptable number of false detections. ASP transmits automated GRB Notices to GCN for immediate release, to provide refined GRB positions as quickly as possible to the astronomical community for follow-up observations.

3.5 ISOC Computing Resources at SLAC

To rapidly perform the event reconstruction processing and automated science processing on the LAT event data, the ISOC makes use of SLAC's large computer "farm", which contains several thousand CPU cores operated through the LSF batch control system. Roughly 1600 CPU cores are identified in the SLAC computer farm for Fermi LAT data processing and other LAT science activities. Routine Level 1 processing of LAT event data requires about 10 CPU-years per calendar month, using on average more than 100 cores. Figure 6 shows a typical 1-day time history of batch jobs dispatched to the computer farm, showing an episodic time structure, tied to the deliveries of LAT data to SLAC from the Fermi observatory through the MOC. Figure 6 demonstrates that LAT event data processing is typically completed in about 1 to 2 hours, which is consistent with the histogram of SLAC processing times shown in Figure 3.

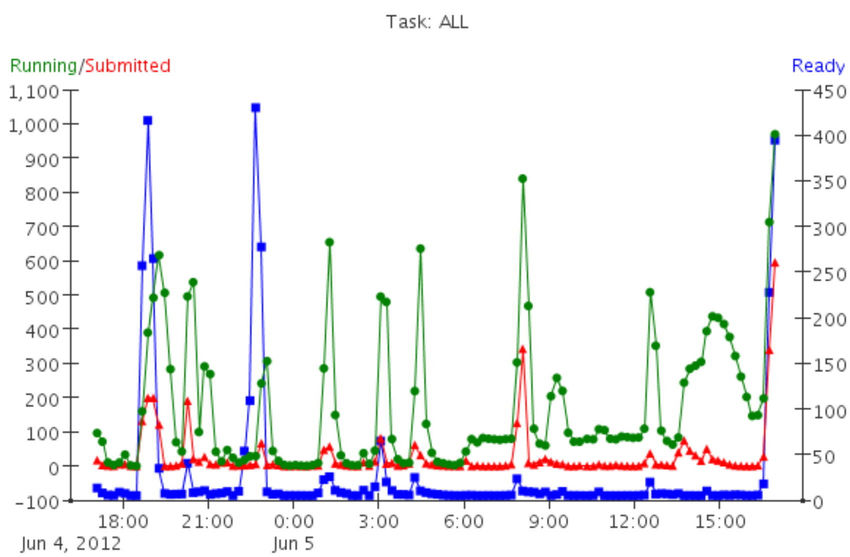

Figure 6. A typical day of batch jobs submitted to SLAC's computer farm, for event reconstruction processing and filtering of LAT event data. The episodic time structure is driven by the times of LAT data deliveries from NASA.

The ISOC archives all raw and processed data from the LAT on disk and tape at SLAC. About 1.1 PB of LAT event data have been accumulated since the start of the mission, including both photon data and charged particle data. Figure 7 shows the growth in the total disk-based data storage capacity for LAT data at SLAC, which is currently about 1.8 PB. Figure 7 also shows the amount of free disk storage capacity, over the time of the mission, indicating that disk storage is added as needed. Tape storage is also used for backup of 2 copies of the LAT data. Also stored is a significant amount of Monte-Carlo simulation data, which is generated to model and characterize the LAT performance.

4. PAST AND FUTURE UPDATES

There have been several updates to photon data and associated data that the ISOC routinely produces and delivers to the FSSC for public release. After each LAT readout event is reconstructed, selection cuts on event reconstruction parameters are applied to select gamma-ray photons from the much larger rate of charged particle events. A few different nested classes of photon events are created for differing scientific analyses, ranging from severe cuts with the least contamination of charged particles, where the LAT detects about 1 to 2 photons per second, to looser cuts having more photons but also having more contaminating charged particles.

One significant update to LAT event classes occurred in mid-2011. The event classes at the time of launch were labeled "Pass 6" (indicating that the development and refinement of LAT event classification went through 5 significant revisions prior to launch), and the ISOC switched to delivering "Pass 7" event classes on 1 August 2011, where the revised event classes were based on analyses performed after launch using data collected in orbit.

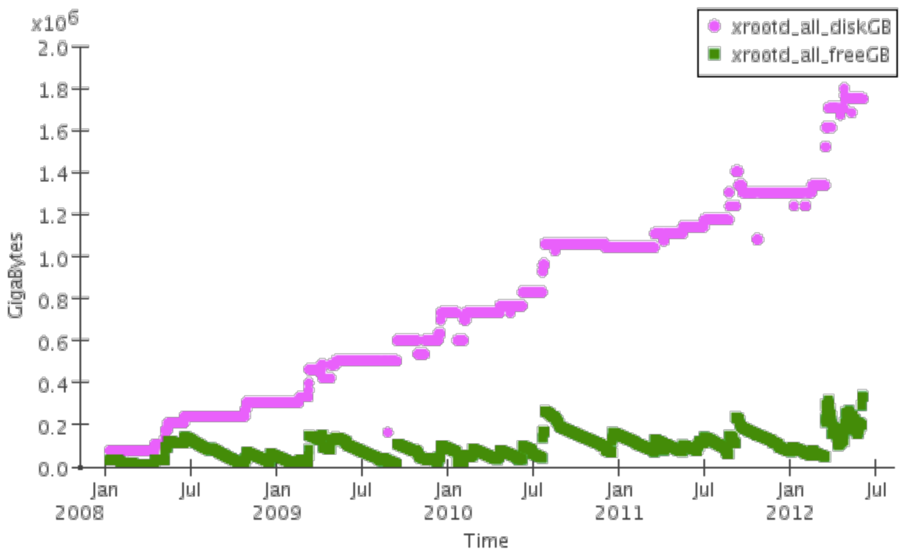

Figure 7. The history of cumulative total disk storage for LAT data at SLAC (light curve), and the total free disk storage at SLAC (dark curve), in PB. About 1.1 PB of LAT event data have been accumulated since the start of the *Fermi* mission.

Following extensive checks of the new event classes, the entire mission event dataset was reprocessed through the new selections for the new event classes and pre-delivered to the FSSC, so that both archival LAT Pass 7 data and current LAT Pass 7 data were made publicly available simultaneously through the FSSC. New instrument performance measures for LAT effective area, angular resolution and energy resolution were also released through the FSSC at the same time, plus revised science tools to select and analyze the new photon classes. It is expected that another Pass7 data update will again occur within the next year, using new detector calibrations applied, but using the same Pass 7 event classifications.

Finally, development of "Pass 8" event analysis is underway within the LAT Collaboration. Pass 8 will make use of improved event track finding and energy estimation methods for LAT events, which are making use of the accumulated knowledge of LAT detector performance gathered from 4 years of mission data. Pass 8 should provide marked improvement in LAT performance. But careful checks will be performed by the Collaboration before Pass 8 data are publicly released.

5. SUMMARY

The LAT detector on *Fermi* has performed exceedingly well since launch in June 2008, with very few, short timescale disruptions to continuous data collection of gamma-ray and charged particle data. The activation of the LAT and the subsequent commissioning and transition to the routine science mission have been remarkably problem-free. This can largely be attributed to the combination of the program preparation and support methods of the space astrophysics community and the particle physics community. The space astrophysics community contributes carefully managed testing and operating procedures, and the particle physics community contributes extensive instrument performance modeling and data processing and analysis preparation. In addition, the LAT instrument itself is largely problem-free after nearly 4 years of in-orbit operation, and with no evidence of future problems and with the added promise of future performance improvements.

In early 2012, *Fermi* went through its first NASA Senior Review, which recommended a 2-year extension to the original 5-year baseline mission, for which the DoE and international partner agencies funding the LAT Collaboration have also expressed support.

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