SLAC-TN-06-026
August 2006

MONITORING DISPLAYS FOR GLAST

Building ISOC Status Displays for the Large Area Telescope aboard the Gamma Ray Large Area Space Telescope (GLAST) Observatory

Christina Ketchum

Office of Science, SULI Program

Stanford University, California

Stanford Linear Accelerator Center

Menlo Park, California

August 2, 2006

Prepared in partial fulfillment of the requirements of the Office of Science, U.S. Department of Energy Science Undergraduate Laboratory Internship (SULI) Program under the direction of Rob Cameron in the Kavli Institute for Particle Astrophysics and Cosmology Division of the Stanford Linear Accelerator Center.

Participant: ____

Signature

Research Advisor: ____

Signature

Work supported in part by Department of Energy contract DE-AC02-76SF00515

Table of Contents

ABSTRACT

Building ISOC Status Displays for the Large Area Telescope aboard the Gamma Ray Large Area Space Telescope (GLAST) Observatory. CHRISTINA KETCHUM (Lewis and Clark College, Portland, OR 97219) ROB CAMERON (Stanford Linear Accelerator Center, Menlo Park, CA 94025).

In September 2007 the Gamma Ray Large Area Space Telescope (GLAST) is scheduled to launch aboard a Delta II rocket in order to put two high-energy gamma-ray detectors, the Large Area Telescope (LAT) and the GLAST Burst Monitor (GBM) into low earth orbit. The Instrument Science Operations Center (ISOC) at SLAC is responsible for the LAT operations for the duration of the mission, and will therefore build an operations center including a monitoring station at SLAC to inform operations staff and visitors of the status of the LAT instrument and GLAST. This monitoring station is to include sky maps showing the location of GLAST in its orbit as well as the LAT's projected field of view on the sky containing known gamma-ray sources. The display also requires a world map showing the locations of GLAST and three Tracking and Data Relay Satellites (TDRS) relative to the ground, their trail lines, and "footprint" circles indicating the range of communications for each satellite. The final display will also include a space view showing the orbiting and pointing information of GLAST and the TDRS satellites.

In order to build the displays the astronomy programs Xephem, DS9, SatTrack, and STK were employed to model the position of GLAST and pointing information of the LAT instrument, and the programming utilities Python and Cron were used in Unix to obtain updated

information from database and load them into the programs at regular intervals. Through these methods the indicated displays were created and combined to produce a monitoring display for the LAT and GLAST.

INTRODUCTION

Gamma-rays are the most energetic rays in the electromagnetic energy spectrum, with energies beginning at 40keV. Because of the amount of energy required to produce such photons, gamma-rays are necessarily created in some of the most extreme conditions in the universe. Energetic phenomena such as pulsars, collapsing binary neutron stars, hypernovae, and active galactic nuclei have the capability of accelerating charged particles to relativistic speeds. The radiation emitted from these particles is Doppler boosted into the gamma-ray energy spectrum, which effectively beams gamma-rays across the universe. There are two classifications of gamma-ray emission. The first of which are called gamma-ray bursts (GRBs), which last from 1 to 100 seconds. An average of one GRB is detected every day, indicating that they are a fairly common event. The second type is long-term variable gamma-ray emission, which last from days to weeks. These features of the sky are constantly changing as new cosmic events trigger gamma-ray production. Currently catalogs of gamma ray sources, such as the 3EG catalog that was produced from data taken by the EGRET (Energetic Gamma-ray Experiment Telescope) have relatively few objects. The 3EG catalog has only 271 sources and of these, 170 are unidentified. It is predicted that with the use of the next generation instruments such as the LAT on GLAST these sources can be identified, and perhaps as many as 10,000 new gamma-ray sources will be discovered. More information can also be gathered about the extreme conditions necessary to produce gamma-rays by detecting and cataloging gamma-ray emission in the universe.

The Gamma-ray Large Area Space Telescope (GLAST) satellite houses two different forms of gamma-ray detectors, the Large Area Telescope (LAT) shown in Figure 1, and the GLAST Burst Monitor (GBM) to detect high energy gamma-ray emission and short powerful bursts of lower energy gamma-rays respectively. SLAC has managed the construction of the LAT and will be responsible for the operations of the LAT while it is in orbit and will therefore require status displays on the position, attitude, contact times and durations, and potential gamma-ray sources that the LAT will be viewing.

In order to communicate this information to the staff working with the LAT as well as visitors, two maps must be developed to track GLAST through its 96 minute orbit around the Earth and to plot its field of view of the sky. The main objective is to control such programs with the Unix timing application “cron” so that the information used to construct the map will be obtained weekly and updated daily on each display with positional information distributed by NASA (National Aeronautics and Space Administration). These processes will be automated so that no user input is required and so run continuously for the duration of the GLAST mission (from 5 to 10 years). GLAST orbital ephemerides and contact schedules will also be regularly obtained from NASA distributions, interpreted, and fed into a usable display. Many different satellite tracking programs can be used to create the Earth view with a satellite overlay and the sky field of view map. It is necessary to select which satellite tracking programs provide the most accessible and accurate displays and to combine these individual maps into a coherent operations display.

MATERIALS AND METHODS

In order to identify the most useful satellite tracking and astronomy programs for the display, a number of different programs were investigated. After some preliminary research on the capabilities of software programs there were three that seemed to be helpful. Xephem, which is software available for free on the internet at http://www.clearskyinstitute.com/xephem/, has numerous capabilities, including that of a sky visualization, complete with ground station masks (simulated horizon lines), constellation projections, and the ability to load external data catalogs. Accordingly Xephem was used for simulating a local sky view and tracking GLAST as it passes overhead. The program STK was used for the ground tracking map based on the quality of its maps and images, and the ease with which satellites can be added to the display and modified. SatTrack was selected to create a world view display with LAT pointing information because of its ability to produce detailed space visualizations. And finally the program DS9 was used to create an Aitoff projection all sky view map with the LAT field of view.

The next step was to enable these four programs to use external data. STK and Xephem require satellite information in Two Line Element (TLE) [1] format and use their own propagators to extract orbital information from those elements. However, the positional information that ISOC receives from NASA is in the form of Ephemerides, which includes the x, y, and z coordinates at one minute time intervals of the satellite on an earth centered inertial (ECI) coordinate system. Due to a difference in coordinate systems between the provided data and the STK required format it was necessary to use TLEs in order to plot the orbits of satellites in STK. The information regarding GLAST satellite pointing is also provided by NASA in a file called the Preliminary Science Timeline. This file contains extraneous data that was not required for the pointing location of the satellite, so the file had to be parsed using a program written in Python to extract the slewing positions of GLAST. Then the resulting pointing information was saved as an attitude file as a part of SatTrack. Two other SatTrack files, the object data catalog and the defaults data catalog, had to be altered as well to direct SatTrack to read the attitude data from file. The Tracking and Data Relay Satellite System (TDRSS) which is a network of geostationary communications satellites will be relaying data transmitted from GLAST to the ground stations. The TDRSS Forecast Schedule was used to obtain a list of predicted ground station contact times for GLAST.

The GLAST and TDRSS Ephemerides files and the TDRSS Forecast Schedule are uploaded weekly to a database kept on the SLAC server, while the Preliminary Science Timeline is also updated weekly but remains in file format. The program Cron was used to automate their retrieval, formatting, and usage, so that every week at a regular time of night all the required information regarding GLAST and TDRSS would be updated and then loaded into STK, Xephem, SatTrack, and DS9.

To create the full sky map the program DS9 was used. First the program ‘gtbin’ was used to produce a Flexible Image Transport System (FITS) file that simulates what the gamma-ray sky would look like as a background sky map or after launch, load actual GLAST data into the image. This image was loaded into DS9 then overlaid with a galactic coordinate system in an Aitoff style projection. The gamma-ray source data obtained by EGRET aboard the Compton satellite was also run through “gtbin” in order to create a region file for DS9. The resulting file was then loaded into DS9 to create small circles surrounding each known gamma-ray source in the sky. Then the program ‘gtorbsim’ was used to model real-time satellite pointing information with the Right Ascension (RA) and Declination (Dec) position of the boresight of the LAT. To define the LAT field of view a program function called “Region” of DS9 was utilized. The RA and Dec of the boresight were then run through a program created by Mr. James Chiang to output an array of points defining the circle of the field of view. These points, when placed on an Aitoff projection map resulted in circles that deformed as the coordinate system stretched at the edges of the map to represent the field of view. A python program was then written to smooth out the shape as it approached the edges of the map and eliminate extraneous line creation that resulted when the field of view was wrapped from the left to the right side of the map. The image including the simulated gamma-ray sky, known gamma-ray sources, and the field of view of the LAT was then driven through the XPA interface so that DS9 commands can be issued from the command line of the Unix machine and eventually regulated by Cron.

RESULTS

The final product achieved through the use of Xephem, SatTrack, STK, and DS9 was very similar to the goal initially set. Through STK a ground map as in Figure 2 was produced that displays the real-time locations of GLAST, TDRS-East, TDRS-West, and TDRS-Z in addition to outlining the South Atlantic Anomaly Region (SAAR). The SAAR is the area above the Earth that the ionic particles trapped in the Van Allen radiation belt come closest to the Earth's surface. The interference that this causes with the LAT is so great that no data will be taken during the time that GLAST is in the SAAR. [2] All satellites have "footprints" of their available contact ranges as well as leading and following sub-satellite position trails. In SatTrack a real-time pointing and location representation shown in Figure 3 was developed. The satellites are represented as wire cubes with different colored lines extending from their bodies to indicate their x, y, and z axis. The z-axis or boresight of GLAST, indicated by a red line, moves according to the slewing information provided by NASA. In Xephem a sky view as in Figure 4 was created to indicate the position of GLAST with respect to an observer at SLAC. The path of GLAST is tracked across the sky and there are time stamps at the beginning and end points of the current pass. In DS9 a display was created represented in Figure 5 showing the field of view of the LAT on the gamma-ray sky, as well as indicating which known gamma-ray sources are within the field of view.

DISCUSSION AND CONCLUSION

The final step of the project was to combine the displays created with Xephem, STK, SatTrack, and DS9 on to one monitor for easy accessibility. The four displays cover enough view points for the location and attitude of the LAT to be clearly represented.

Throughout the development of the displays for GLAST and the LAT, many requirements had to be changed. Some early goals were discarded due to limitations of the software. Initially the ground display on STK was to incorporate contact times as well as satellite positions, trails and footprints. The portions of GLAST's trail that were available for communications link to one of the TDRSS satellites would be highlighted. However, with only the free version of STK the feature that allowed such a function was disenabled although available in the full version of STK. The world view supplied by SatTrack is only available in the purchased version. For future satellite tracking projects STK in its full purchased version would be useful. STK is technically and computationally less capable than SatTrack, but the degree of ease with which it can be used is far superior. The graphics supplied by the program STK are also of a better quality than those possessed by SatTrack. STK has many different options with which to represent the world map including an image of the Earth created from actual photos taken from space, while SatTrack only represents the Earth with continent outlines and an optional latitude and longitude grid.

Other boundaries imposed on this project were temporal in nature. All of the utilized data currently supplied to ISOC about GLAST is only modeled data because GLAST is not currently in orbit. Specifically the Preliminary Science Timeline is only available currently as an example file, which contains no actual attitude information, only the correct formatting for such a document. Any inaccuracies which may arise in the parsing and application of this file can only be remedied once GLAST is in orbit and actual data is being supplied.

A future possibility for improvement of the display would be to include another Aitoff sky view map. With the second map the actual gamma-ray data taken by LAT over the last 24 hours could be displayed and compiled into an accelerated movie of the previous day's gamma-ray detection. This would provide a way for visitors to the LAT operations center to directly view the product of the GLAST project and have a physical sense of what the project is actually accomplishing.

ACKNOWLEDGEMENTS

This research was conducted at the Stanford Linear Accelerator Center. I thank the U. S. Department of Energy, Office of Science for giving me the opportunity to participate in the SULI program and the chance to have an incredible learning experience. Special thanks go to my mentor Rob Cameron for his knowledge, patience, and humor. I would also like to thank Steve Culp for making sure I had access to all the data I needed, Rodney Wong for handling numerous computer issues, and James Chiang for being a constant support in developing the Aitoff projections.

REFERENCES

[1] Dr. T.S. Kelso, CelesTrak, {http://www.celestrak.com}, May 2006.

[2] “Space Flight Questions and Answers”, NASA, {http://www.hq.nasa.gov/osf/qanda2.html}, June 2004.

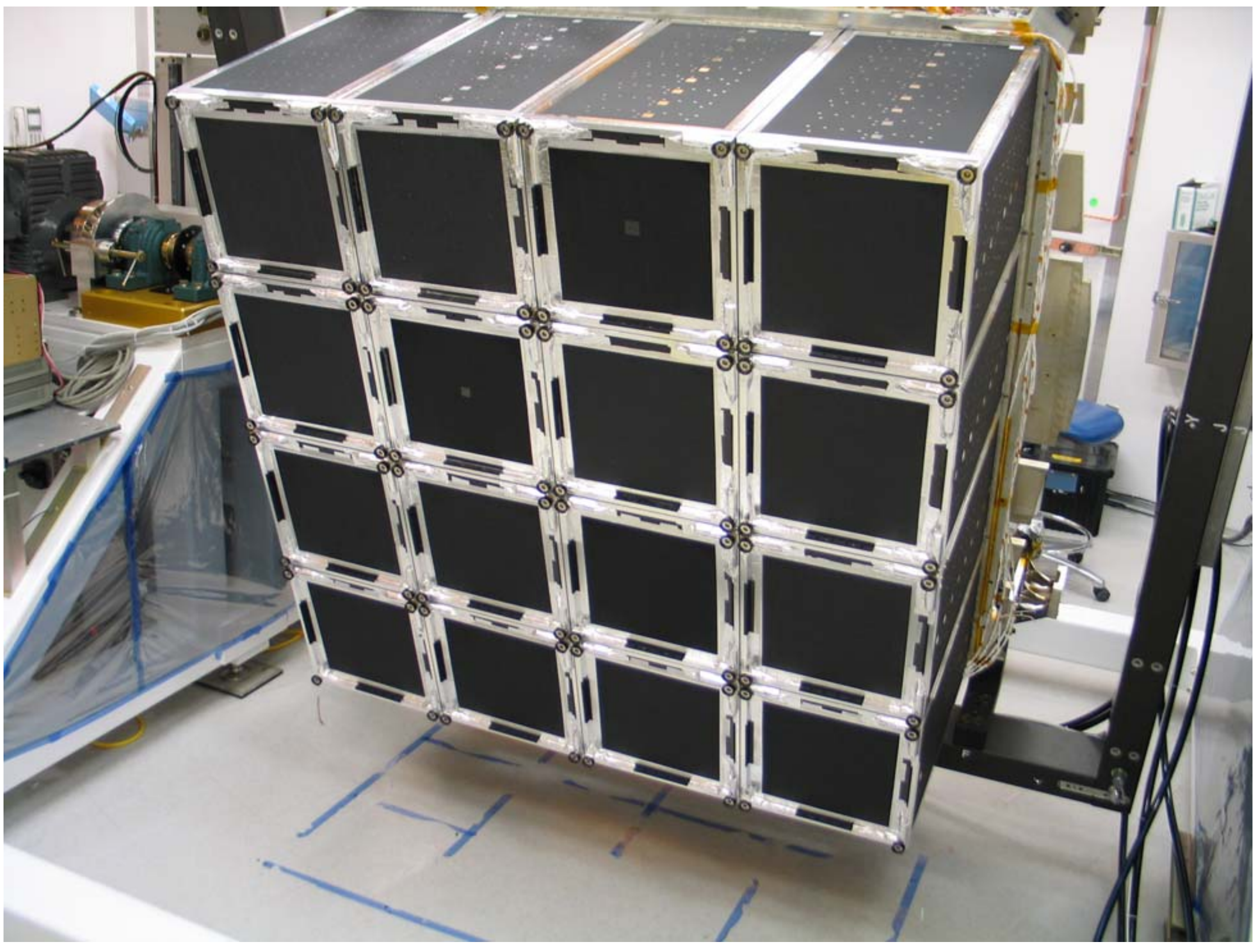

Figure 1. A photo of the Large Area Telescope (LAT) after being built at SLAC.

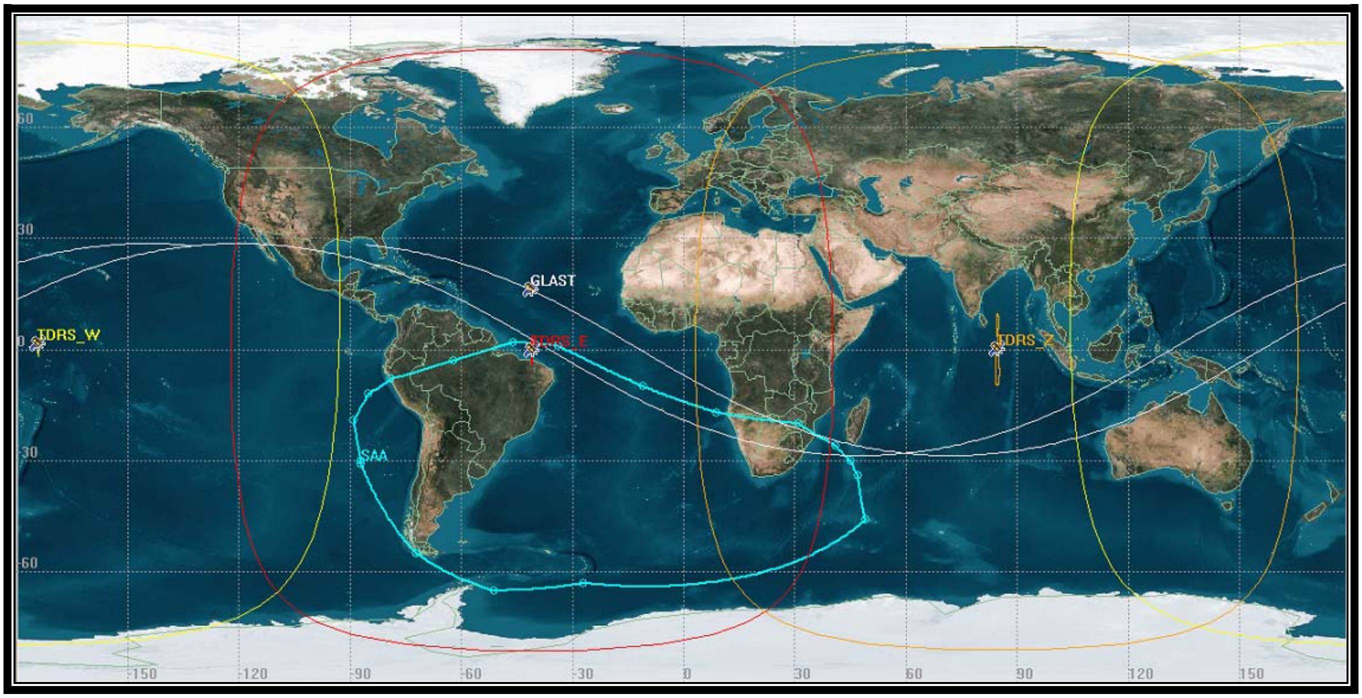

Figure 2. Ground view map of Earth including the GLAST, TDRS-East, TDRS-West, and TDRS-Z satellites, and the South Atlantic Anomaly (SAA) Region created with STK.

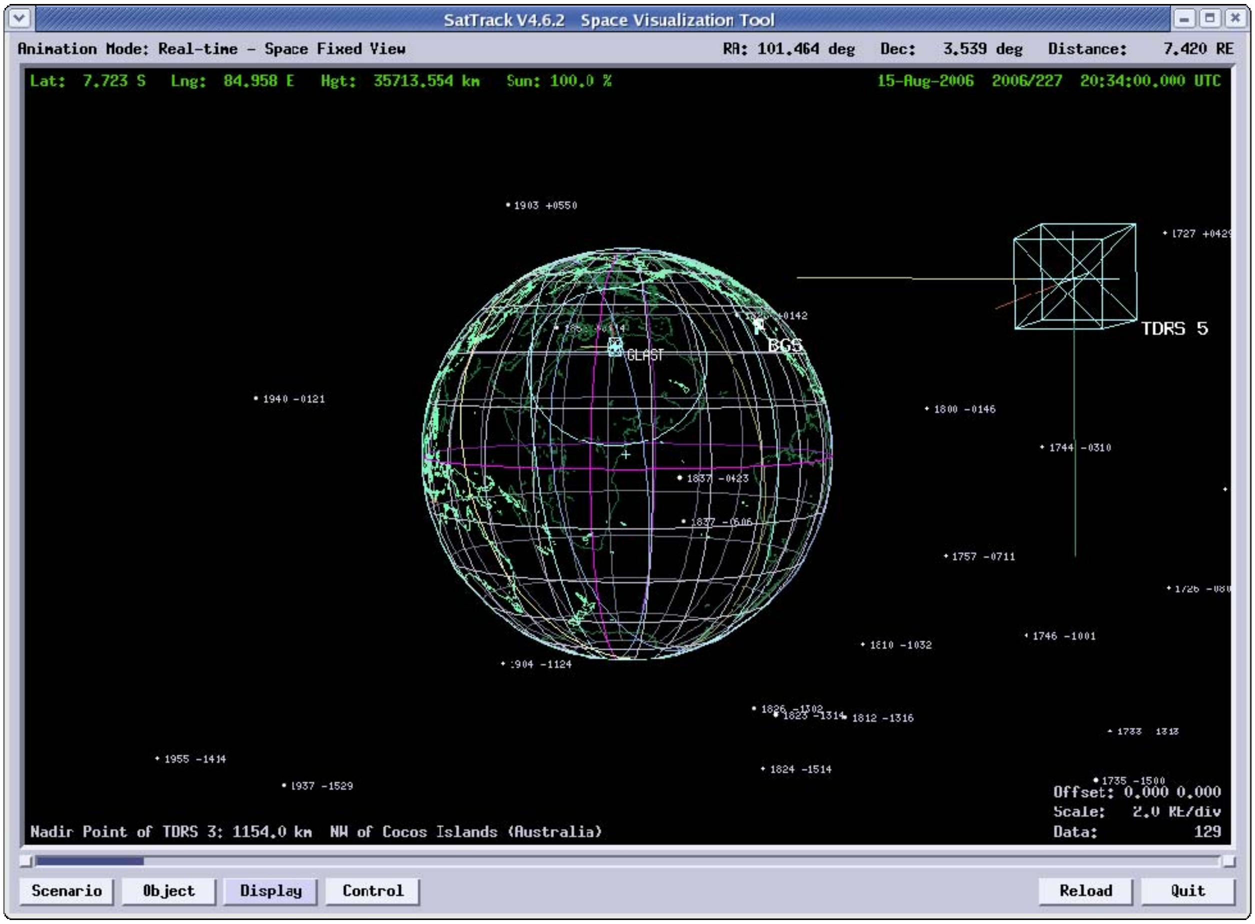

Figure 3. Display created in SatTrack showing the Earth with GLAST orbiting close above it, the TDRS 5 satellite in the foreground, and a number of gamma-ray sources in the sky.

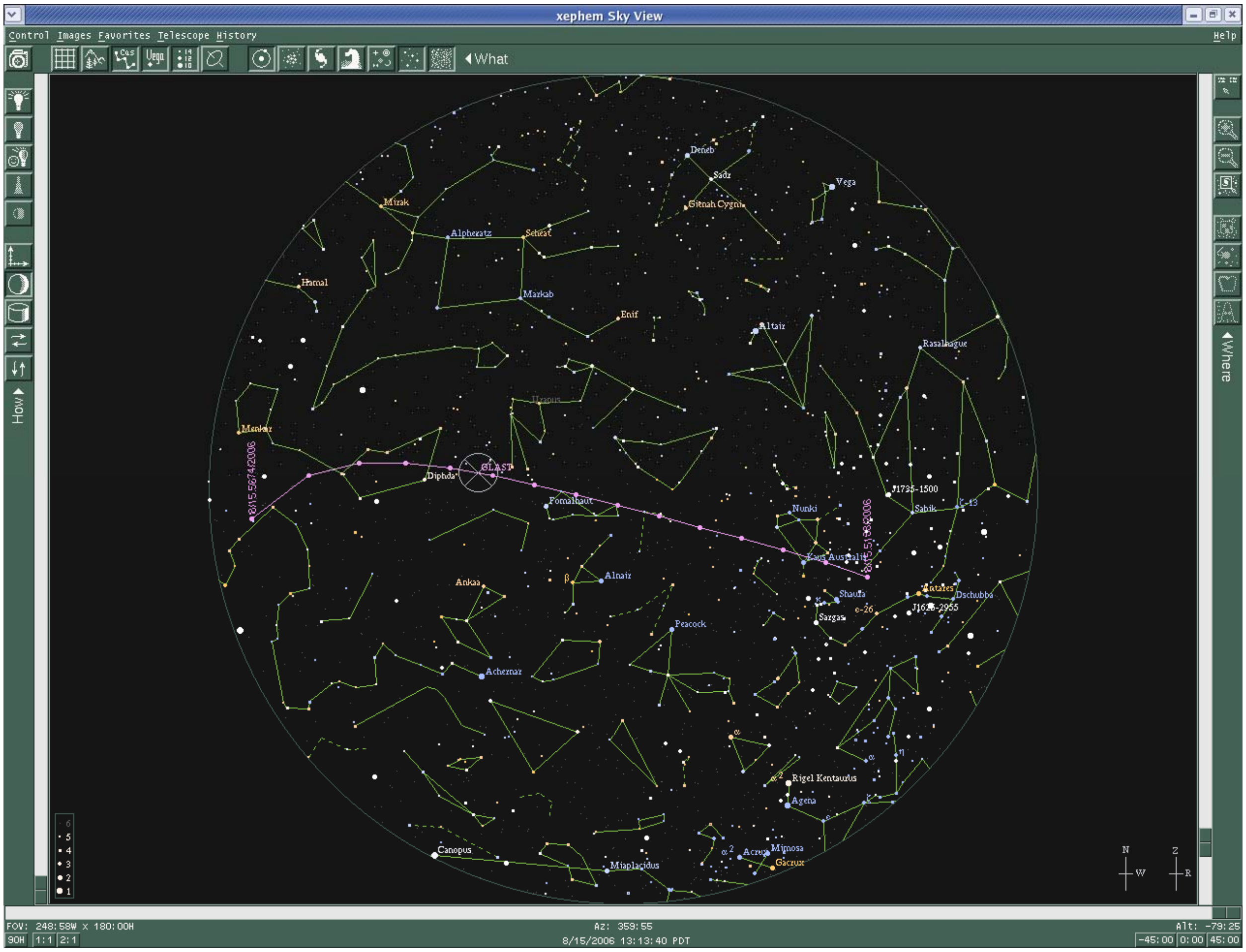

Figure 4. Sky view map showing the local stars and constellations with the path of the GLAST satellite created in Xephem.

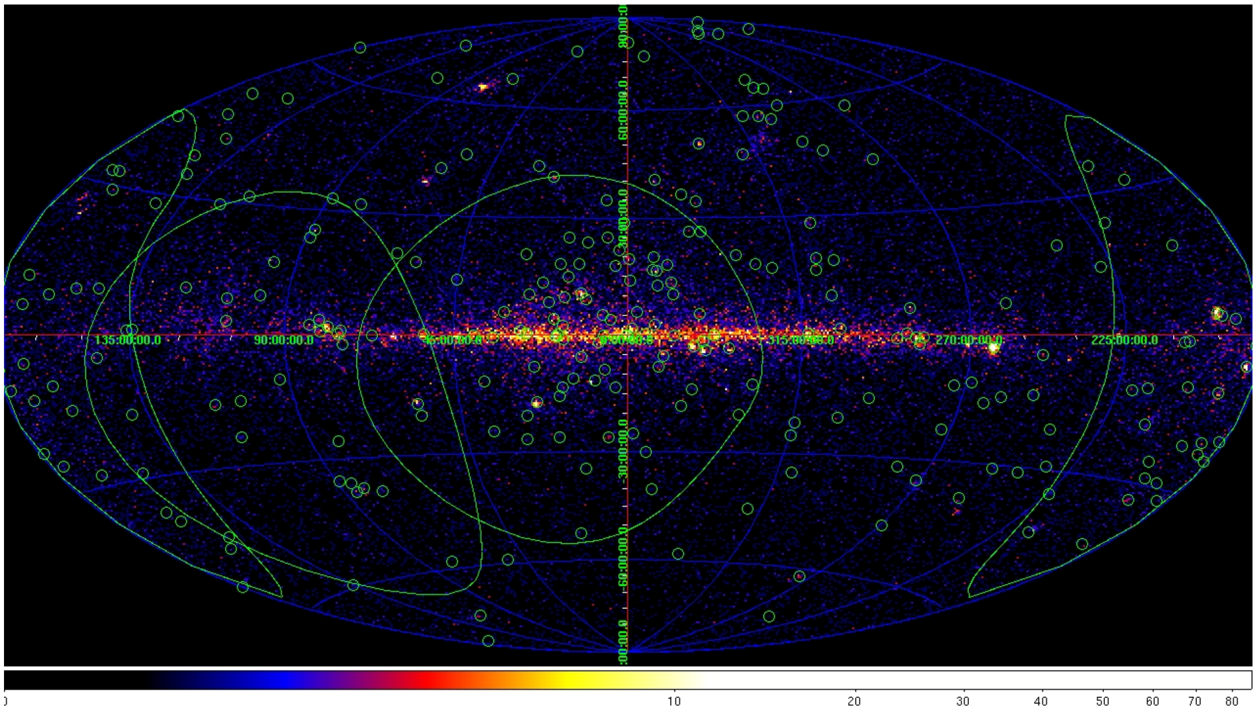

Figure 5. An Aitoff style projection of the simulated gamma-ray sky with circle indicators of known gamma-ray sources and deformed circles indicating the LAT's projected field of view.