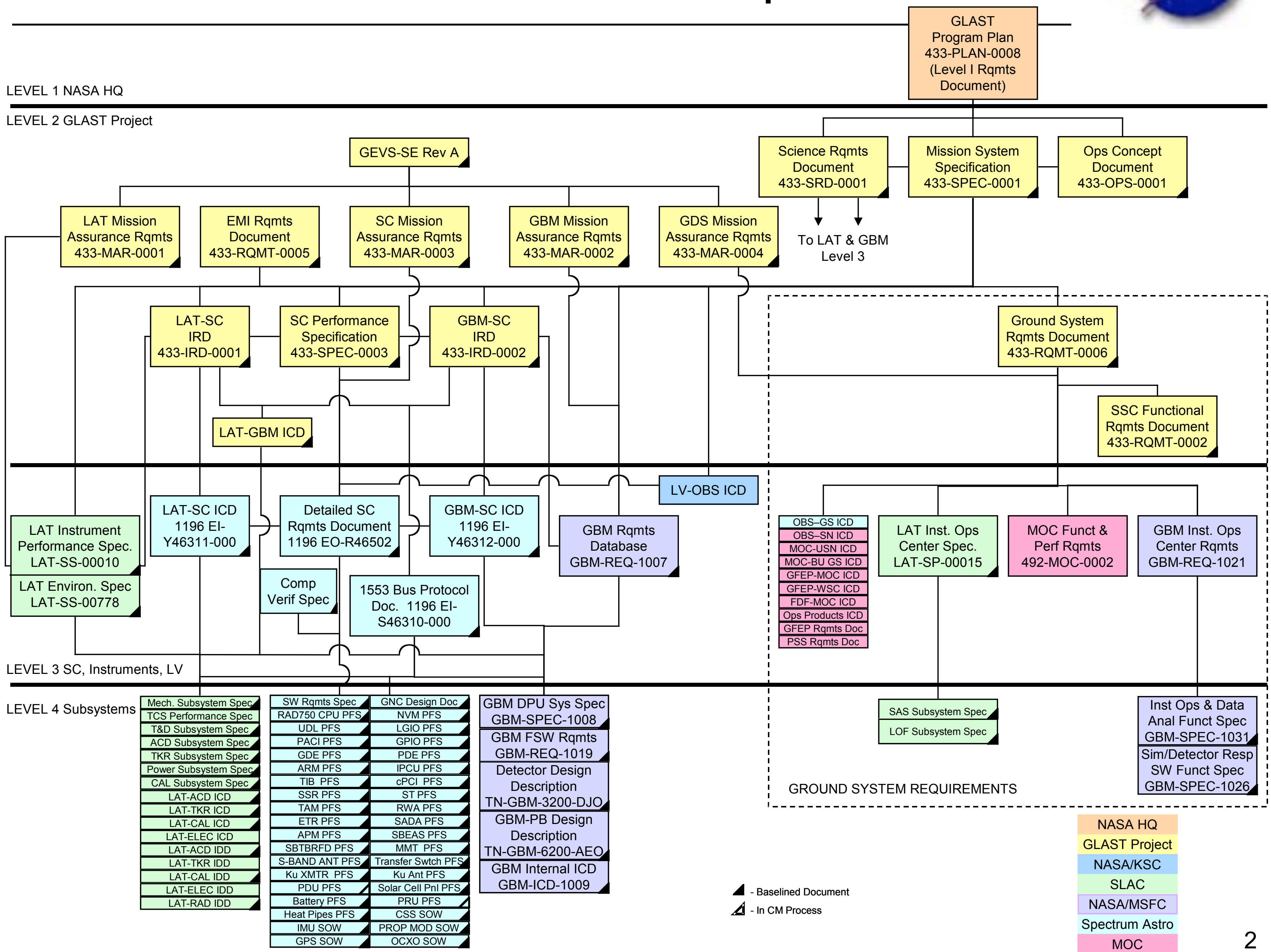
GLAST Project
Science Requirements Document (SRD)

Table 3.
Science Requirements on the GLAST Mission

Systems Engineering

Norman Rioux
Chris Connor
Julie McEnery

SRD In Context of Mission Requirements



Mission Verification Process

- ***End-To-End Mission System Verification is the responsibility of the GLAST Project Office and is led by Systems Engineering***
- ***Rigorous verification of engineering requirements is accomplished in the course of the integration and verification program and reported on at formal Project life cycle reviews***
  - *PER*
  - *PSR*
  - *ORR*
  - *FRR*
  - *LRR*
- ***Observatory Verification planning, execution, and coordination is contracted to General Dynamics***
  - *Includes Observatory I&T and On-Orbit Checkout*
- ***The GLAST Systems Verification Plan (SVP) documents the methodology planned to verify system functionality and compliance with mission requirements***
  - *433-PLAN-0005*
- ***Acceptable verification methods used on GLAST***
  - *Test, Analysis, Inspection, Demonstration*
- ***Verification Levels of Assembly***
  - *Component, Subsystem, Spacecraft, Observatory, On orbit*
- ***Objective For This Presentation: Status on verification process for SRD table 3***

SRD Table 3 Requirements Summary

Table 3. Science Requirements on the GLAST Mission	Requirement	Goal
3.28 Mission Lifetime (<20% degradation) 2 Footnote 2: 20% degradation = no more than 20% loss of LAT science return.	> 5 years	> 10 years
3.29 Telemetry Downlink Orbit Average	> 300 kbps	> 1 Mbps
3.30 Telemetry Downlink Realtime 3 Footnote 3: Uplink telemetry rate for at least 80% of time outside of SAA	> 1 kbps	> 2 kbps
3.31 Telemetry Uplink Realtime 3 Footnote 3: Uplink telemetry rate for at least 80% of time outside of SAA	> 1 kbps	> 2 kbps
3.32 Time to Respond to TOO's on Ground 4 Footnote 4: Response time for the SSC and MOC to plan and send a spacecraft repointing command after the decision is made to respond to a Target of Opportunity (TOO).	< 6 hours	< 4 hours
3.33 Spacecraft Repointing Times for Autonomous Slews 5 Footnote 5: Time for 75° slew, to be met 100% of the time under 4 reaction wheel (RWA) control and 75% of the time under 3 RWA control (single RWA failure) accounting for slew constraints (e.g. yaw flip).	< 10 min	< 5 min
3.34 GRB Notification Time to Ground by Spacecraft 6 Footnote 6: Time from spacecraft receipt of GRB notification from GBM or LAT to delivery to the Gamma-ray Coordinates Network (GCN) computer for 80% of all GRBs detected by the GBM or LAT.	< 7 sec	< 4 sec
3.35 Pointing Accuracy Absolute 7 Footnote 7: 1 sigma radius.	< 2 degrees	< 0.5 degrees
3.36 Pointing Knowledge 7 Footnote 7: 1 sigma radius	< 10 arcsec	< 5 arcsec

SRD Table 3 Requirements Summary

Continued

Table 3. Science Requirements on the GLAST Mission	Requirement	Goal
3.37 Observing Modes	- Rocking zenith pointing[15] - Pointed mode[8]	
3.38 Targeting No restrictions on Pointing 8 of axis normal to LAT Footnote 8: Pointing of axis normal to LAT to within 30 degrees of source. (No science constraint on roll axis.).		
3.39 Uniformity of Sky Coverage during All-sky Survey 9 Footnote 9: Sky coverage exposure uniformity integrating for 7 days, not including SAA effects	< ± 20%	< ± 10%
3.40 Observatory Time Accuracy 10 Footnote 10: Relative to Universal Time, 1 sigma r.m.s..	< 10μsec	< 3μsec
3.41 Observatory Absolute Position Accuracy	< 3.3 km	< 1 km
3.42 Observing Efficiency 11 Footnote 11: Fraction of time with data return, not including SAA effects.	> 90 %	> 95%
3.43 Data Loss 12 Footnote 12: Fraction of data taken by the instruments but not delivered to the IOC. Not including SAA data loss. Not including instrument deadtime.	< 2 %	< 1%
3.44 Data Corruption 13 Footnote 13: Fraction of undetected corrupted events.	$< 1 \times 10^{-10}$	$< 3 \times 10^{-11}$
3.45 Earth Avoidance 14 Axis normal to LAT shall be capable of remaining at an angle greater than this above the Earth's horizon during normal operations, with the possible exception of rapid slewing to acquire a GRB.	$> 30^{\circ}$ (adjustable)	N/A

Agenda

Presenter / SRD Requirements

Norman Rioux

- *3.28, 3.29, 3.30*
- *3.31, 3.40, 3.42*
- *3.34*
- *3.43*
- *3.44*

Chris Connor

- *3.33, 3.35, 3.37*
- *3.38, 3.41, 3.45*
- *3.36*

Julie McEnery

- *3.32*
- *3.39*

SRD Table 3 Requirements 3.28, 3.29, 3.30

3 Table 3. Science Requirements on the GLAST Mission	Performance Requirement	Performance Goal	Status
3.28 Mission Lifetime (<20% degradation) [2] Footnote 2: 20% degradation = no more than 20% loss of LAT science return.	> 5 years	> 10 years	Mission design requirement verified by analysis No consumables Single fault tolerant redundant design meeting 85% 5 year reliability requirement Redundancy supporting graceful degradation in LAT Tracker, Calorimeter and ACD
3.29 Telemetry Downlink Orbit Average	> 300 kbps	> 1 Mbps	Verified by analysis and test 40 Mbps Ku band science downlink 80 minutes of TDRSS downlink time scheduled per day Link verified in Compatibility Test Van (CTV) testing January 2007 Final verification conducted in end to end testing with flight IEM and SSR with Ku downlinks schedule through the MOC
3.30 Telemetry Downlink Realtime 3 Footnote 3: Uplink telemetry rate for at least 80% of time outside of SAA	> 1 kbps	> 2 kbps	Verified by test Ground Selectable 1 k, 2 k, 4 k bps Verified by CTV testing January 2007 Design provides commandable 8kbps data rate as a bonus if excess as-built margin permits Final verification conducted in end to end testing with flight IEM and SSR

SRD Table 3 Requirements
3.31, 3.40, 3.42

3 Table 3. Science Requirements on the GLAST Mission	Performance Requirement	Performance Goal	Status
3.31 Telemetry Uplink Realtime 3 Footnote 3: Uplink telemetry rate for at least 80% of time outside of SAA	> 1 kbps	> 2 kbps	Verified by test 4 kbps Verified by CTV testing January 2007 Final verification conducted in end to end testing with flight IEM and SSR
3.40 Observatory Time Accuracy 10 Footnote 10: Relative to Universal Time, 1 sigma r.m.s..	< 10μ sec	< 3μsec	To be verified at observatory level GPS receivers have been verifed to provide timing accurate to 1.5 micro seconds C&DH pulse per second interface has been functionally verified at component level of testing with EM IEM End to End LAT to Spacecraft test will verify observatory timing using Muon telescope EGSE. Muon telescope timing provided by independent GPS receiver
3.42 Observing Efficiency 11 Footnote 11: Fraction of time with data return, not including SAA effects.	> 90 %	> 95%	Mission design requirement verified by analysis Mission is designed to collect data at all times Routine operations enable continuous science data collection and return LAT resets under investigation

SRD Requirement 3.34

3.34 GRB Notification Time to Ground by Spacecraft [6]

< 7 sec

Footnote 6: Time from spacecraft receipt of GRB notification from GBM or LAT to delivery to the Gamma-ray Coordinates Network (GCN) computer for 80% of all GRBs detected by the GBM or LAT.

- ***To be verified during End to End Test***

- ***SC to MOC latency measured during Compatibility Test Van (CTV) testing for four trials using a state of health message***
  - *Averaging roughly 9 +/- 1 second SC to MOC*

- ***Contributing element: Lockup time of White Sands S-Band MA Demodulator unit (DMU)***
  - *Lockup time statistical in nature*
  - *Code 450 (TDRSS Space Network) is developing improved FPGA algorithms for use in the White Sands DMU at 1Kbps*
    - *May contribute reductions in latency on the order of 1 to 3 seconds*

SRD Requirement 3.34 (con't)

***3.34 GRB Notification Time to Ground by Spacecraft* [6]**

< 7 sec

Footnote 6: Time from spacecraft receipt of GRB notification from GBM or LAT to delivery to the Gamma-ray Coordinates Network (GCN) computer for 80% of all GRBs detected by the GBM or LAT.

	Pessimistic	**Nominal Estimate**	**Optimistic**
Instrument to SC Interface to SC antenna output	*3.4*	*1*	*1*
SC output to MOC ITOS	*10*	*9*	*8*
MOC ITOS to GCN	*2*	*1*	*.5*
Instrument to SC interface to GCN latency **Total:**	***15.4***	***11***	***9.5***
End to End Latency – GBM to GCN			
Margin against GBM first message to SC requirement	*-1.5*	*-1.5*	*-1.5*
Potential End to End latency without DMU improvement	***13.9***	***9.5***	***8***
Potential End to End latency with DMU improvement	***12.9***	***7.5***	***5***

SRD Requirement 3.43

3.43 Data Loss [12]

Requirement: < 2% Goal: <1%

Footnote 12: Fraction of data taken by the instruments but not delivered to the IOC. Not including SAA data loss. Not including instrument deadtime.

- ***Verified via analysis***
- ***SC Data System is being thoroughly tested at Subsystem and Observatory Levels.***
- ***SC System designed to allow multiple retransmission of data***
  - *SSR sized to provide 30 hours of science data and 36 hours of housekeeping data*
    - *Analysis shows that 24 hrs of recorded HSK and Science data may be played back in ~ 56 min at 40 Mbps.*
    - *TDRSS Loading analysis determined that ~300 min/day of TDRSS SA contact time available to support GLAST*
    - *The FOT plans to schedule 80 to 90 minutes of contact time per day at 40 Mbps.*

SRD Requirement 3.43 (con't)

FOT Data Retransmission Plan

- *While MOC is staffed:*
  - *FOT monitors frame statistics and will re-transmit to recover any lost frames*
  - *All missing/corrupted data will be retransmitted.*
- *During off hours and weekends:*
  - *FOT will be paged when automated monitoring at the MOC indicates frame loss above a settable threshold (currently 99%)*
  - *ISOC monitors event loss, and can also page FOT to request a re-transmit*
- *FOT will re-dump missing/corrupt data <u>twice</u> from the SSR to ensure complete data capture and lower any likelihood of error during re-dumps*

SRD Requirement 3.43 (con't)

- ***Ground System redundancy implemented to prevent data loss***
  - *Data captured on multiple Front-end Processors (GFEPs) at White Sands TDRSS ground terminal (WSC)*
    - *HSK and Science Data maintained on GFEPs for 7 days*
    - *GFEPs are redundant with hot backups*
    - *Use high reliability network connections between ground stations and MOC for transfer of science data.*
      - *Network availability is 99.50%*
      - *Network outage restored within 4 hrs*
  - *Data archived at MOC and backed-up on separate media*

SRD Requirement 3.44

3.44 Data Corruption [13]

Footnote 13: Fraction of undetected corrupted events.

Requirement: ***< 1 x*** 10^{-10}

Goal: ***< 3 x*** 10^{-11}

Verified via analysis

Four categories of data coming out of the data channel:

1. ***Data is actually good and detected as good.***
2. ***Data that is actually in error, detected as in error, and can be corrected based on coding.***
3. ***Data that is actually in error, detected as in error, but cannot be corrected with coding.***
4. ***Data that is actually in error, but detected as being good.***

This requirement is concerned with data in category 4.

Analysis of the science data return link performance including Reed Solomon coding and interleaving shows that this requirement is easily met with margin.

SRD Table 3 Requirements 3.33, 3.35, 3.37

Science Requirements extracted from SRD descriptive module	Performance Requirement	Performance Goal	Status
3 Table 3. Science Requirements on the GLAST Mission			
3.33 Spacecraft Repointing Times for Autonomous Slews 5 Footnote 5: Time for 75° slew, to be met 100% of the time under 4 reaction wheel (RWA) control and 75% of the time under 3 RWA control (single RWA failure) accounting for slew constraints (e.g. yaw flip).	< 10 min	< 5 min	Verified via analysis 4 RWAs: Maximum slew time is 9 min 3 RWAs: 84% of 75 degree slews are within 10 min RWA reliability information: Ps(15 yrs)=0.9555
3.35 Pointing Accuracy Absolute 7 Footnote 7: 1 sigma radius.	< 2 degrees	< 0.5 degrees	Verified via analysis 0.8 deg Driven by environmental disturbances and command latency
3.37 Observing Modes Observing Modes - Rocking zenith pointing 15 - Pointed mode 8 Footnote 8: Pointing of axis normal to LAT to within 30 degrees of source. (No science constraint on roll axis.). Footnote 15: The observatory shall be capable of scanning the LAT FOV (55° half-angle) over >90% of the celestial sphere repetitively on selectable timescales as short as every 2 orbits.			Verified via analysis Two primary observing modes provided are sky survey (zenith pointing with rocking angle) and pointed observation mode

SRD Table 3 Requirements 3.38, 3.41, 3.45

Science Requirements extracted from SRD descriptive module	Performance Requirement	Performance Goal	Status
3 Table 3. Science Requirements on the GLAST Mission			
3.38 Targeting No restrictions on Pointing [8] of axis normal to LAT Footnote 8: Pointing of axis normal to LAT to within 30 degrees of source. (No science constraint on roll axis.).			Verified via analysis Physical Constraints: Default is 30 deg Earth Avoidance, as per 3.18. 30 deg half-angle is the "sweet" spot of the LAT (55 deg FOV). GD provides PAPA (predict ahead planning algorithm) which utilizes ephemerides and operational constraints to compute slew profiles.
3.41 Observatory Absolute Position Accuracy	< 3.3 km	< 1 km	Verified via analysis 0.2 Km GPS design and supporting GNC software algorithms are heritage from previous GD programs.
3.45 Earth Avoidance 14 Axis normal to LAT shall be capable of remaining at an angle greater than this above the Earth's horizon during normal operations, with the possible exception of rapid slewing to acquire a GRB.	$> 30^{\circ}$ (adjustable)	N/A	Verified via analysis 30 deg Keep the earth out of the sweet spot. Will slew across earth if need be, taking into consideration the sun angle (maintain sun in X-Z plane).

SRD Requirement 3.36

- ***Observatory Pointing Knowledge Performance (1-sigma, radial)***
  - ***All BOL Sky Survey Cases:*** ***CBE < 10 arcsec***
  - ***All BOL Cases (Sky Survey & Pointed Obs):*** ***CBE < 15 arcsec***
  - *All Mission Cases (BOL & EOL):* *CBE < 30 arcsec*

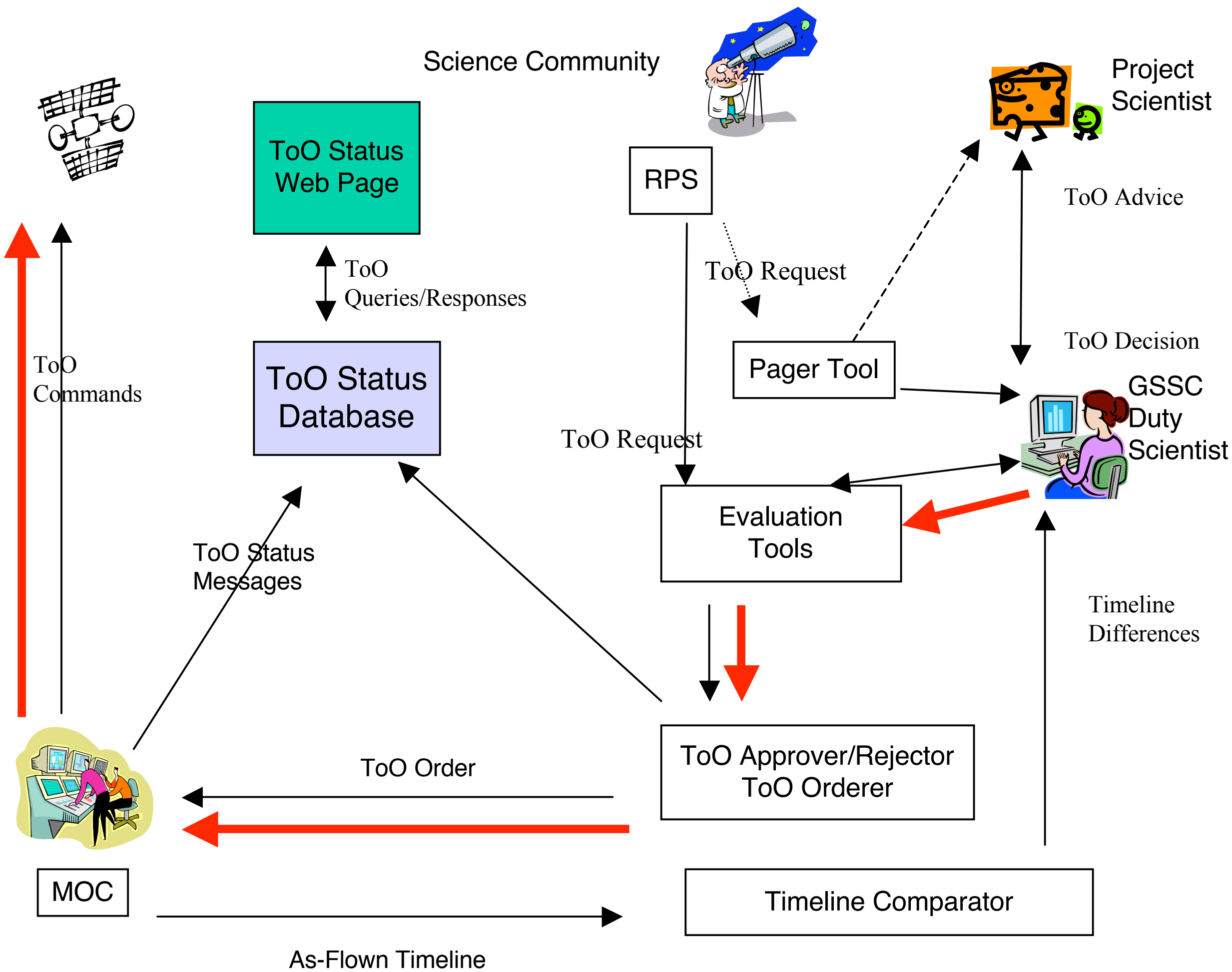
- ***All analysis performed with integrated, observatory-level thermal mechanical distortion models (spacecraft + science instruments)***
  - *Modeling uncertainty factors (MUFs) applied to distortion results*

SRD Requirement 3.36 (con't)

- ***Analysis efforts concentrated on identification of the primary distortion terms & overall review of model fidelity***
  - *Primary distortion sources are the optical bench skirt & star tracker to star tracker distortion on the optical bench reference*
  - *SC provider performed optical bench thermal test (Dec 2005) to help correlate models and refine predicted performance*
- ***LAT & SC thermal model correlation underway***
  - *Observatory TVAC scheduled for Summer 2007*
  - *Upon completion of these activities, we can reduce the MUFs*
- ***On-orbit GNC Kalman filter will help with some of the star tracker-to-star tracker distortion***
  - *Cyclic thermal distortion due to day/night transitions each orbit*

SRD Requirement 3.32

Response time for the GSSC and MOC to plan and send a repointing comand after the decision is made to respond to a ToO: 6 hours requirement, 4 hours goal, 12 hours minimum.



SRD Requirement 3.32

Target of Opportunity Handling

- ***Upon receiving authorization to proceed with the ToO, the GSSC constructs the ToO Order and forwards to the MOC***
  - *GSSC checks for constraint violations, occultation, availability, etc.*
  - *Approved ToO Order is sent to the MOC*
- ***MOC recognizes ToO Order and notifies appropriate FOT personnel for action***
  - *FOT processes ToO Order and evaluates impact to current TDRSS contact schedule*
  - *FOT schedules a forward link with TDRSS (if necessary)*
  - *MOC transmits the ToO commands to the spacecraft as soon as the TDRSS forward link is available*
- ***Receipt of ToOs orders do not absolutely necessitate weekly ATS replans by the FOT***
  - *Observatory autonomously returns to on-board observing schedule at completion of the ToO using check-pointed commands from the ATS*
  - *FOT will evaluate the affect of the ToO on scheduled TDRSS contacts and re-schedule additional contacts if necessary*
- ***GSSC will evaluate the affect of the ToO on current timeline and adjust accordingly with a re-planned timeline or adjust the upcoming planning week***

SRD Requirement 3.32

ToO Latency - Worst case scenario

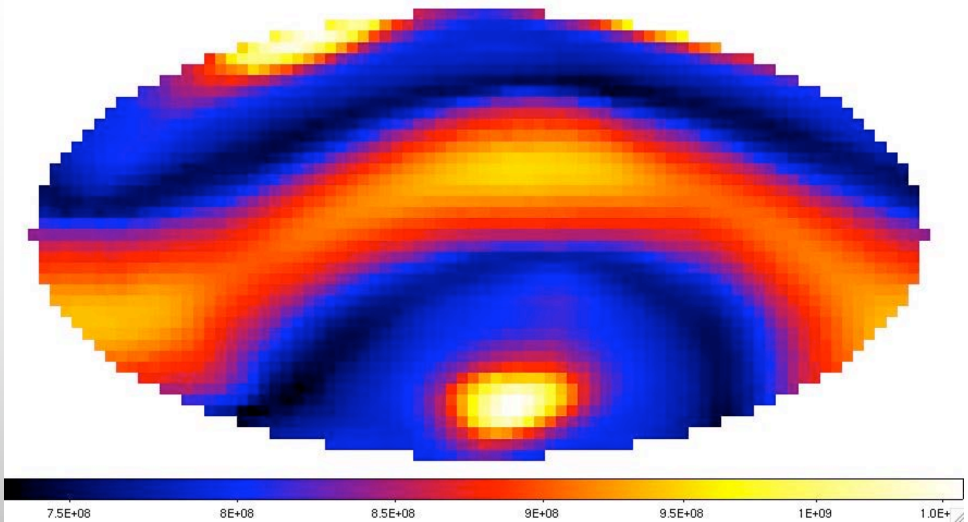
Action	**Time (min)**
GSSC duty scientist to perform evaluation and send mail	*60*
MOC to send email	*1*
FOT to receive email	*5*
FOT to travel to MOC	*90*
FOT to Schedule contact	*30*
SN to prep for contact	*30*
uplink command	*5*
Total	*221*

SRD Requirement 3.39

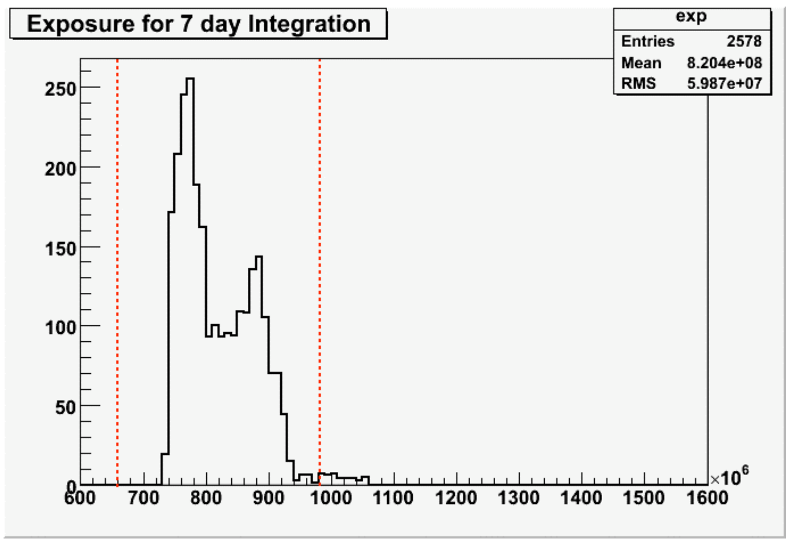
Uniformity of sky coverage during all sky survey: +-20% (req), +-10% (goal) integrated for 7 days not including effects of the SAA.

- ***Analysis:***
  - *Survey mode rocking 35 degrees north/south each orbit, orbit with 25.4 deg inclination.*
  - *Convolve the pointing history with the LAT effective area as a function of inclination to obtain the exposure over the sky.*
  - *The next two slides show the exposure from 100 MeV - 200 GeV for a 1 week and 55 day survey mode observation.*

Exposure Uniformity - 7 days

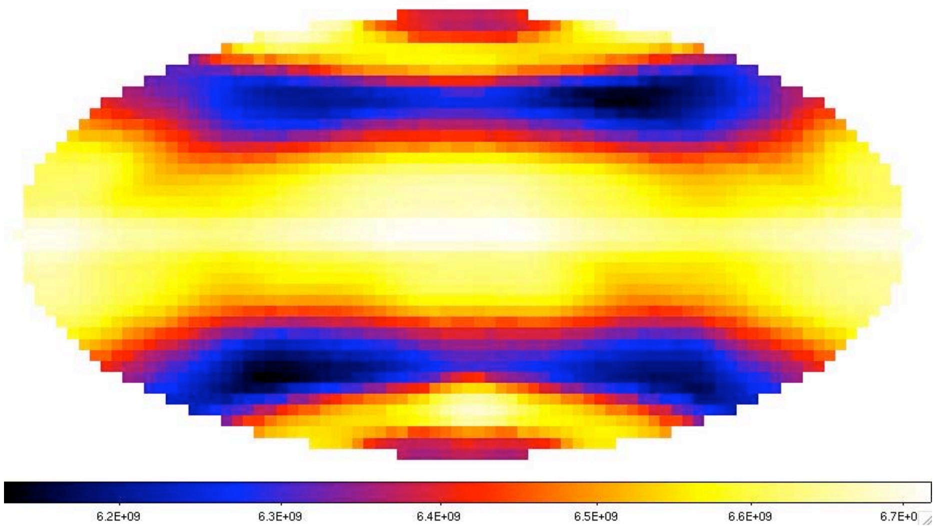


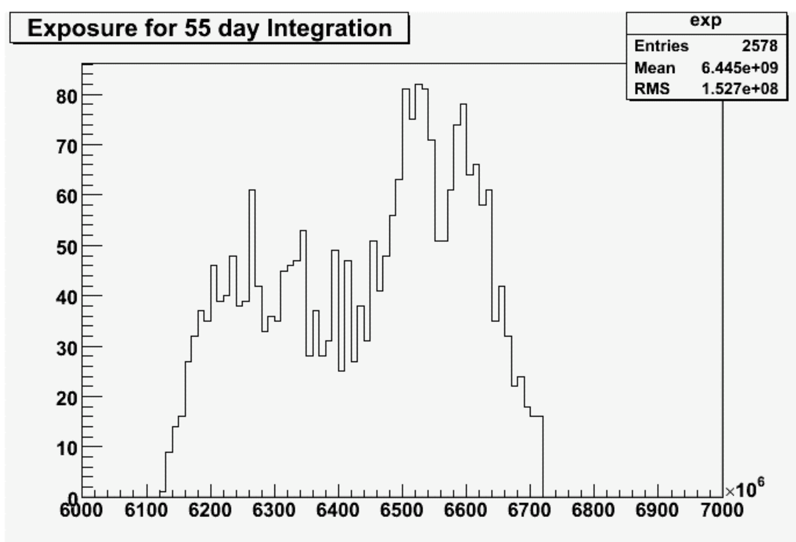
- *Colour scale is from max to min pixel value (so it is easy to see small structure)*



- *Histogram of exposure in bins of equal angular area on the sky.*
- *rms/mean = 7.3%, however there are some outliers.*
- *1.6% (41) of the bins lie further than 20% from the mean.*

Exposure Uniformity - 55 days

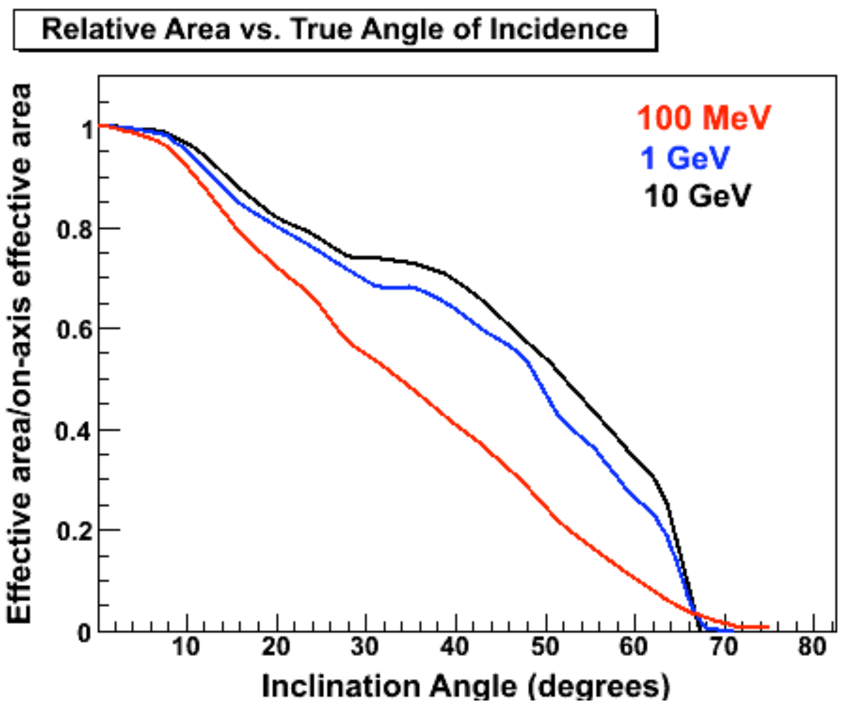




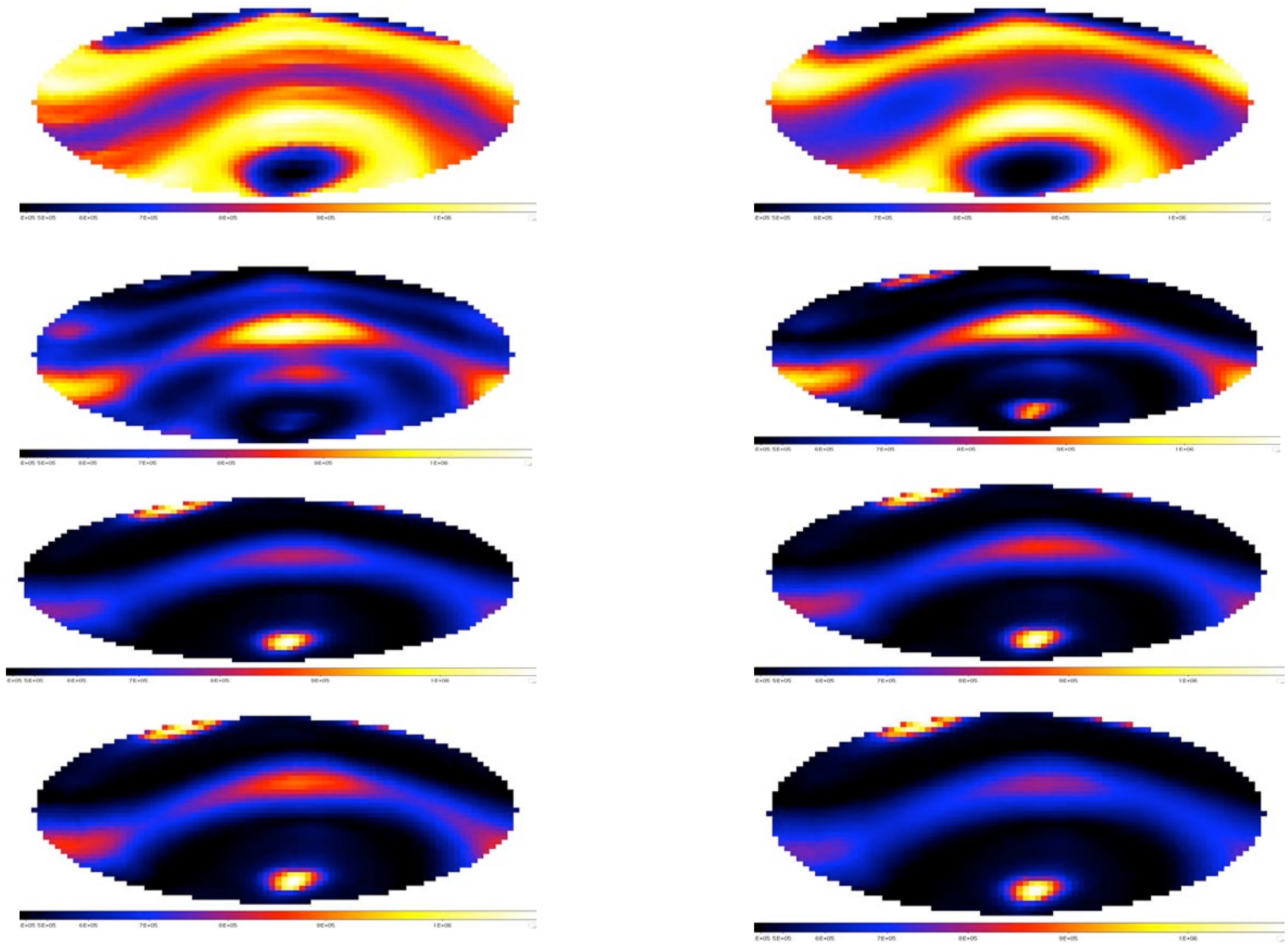
RMS/Mean = 2.3%, all bins lie within 20% of the mean. The lines +-20% of the mean lie off the scale of this plot!

A caveat

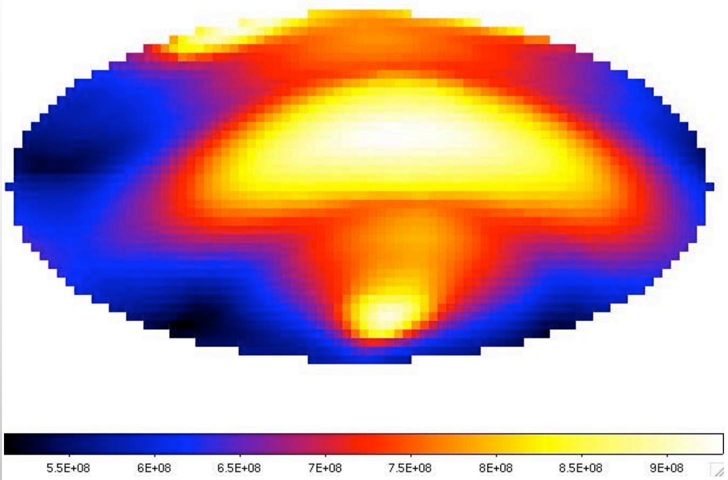
- ***The LAT Aeff vs inclination angle varies with energy, thus the exposure pattern on the sky also varies depending on the energy band being considered.***

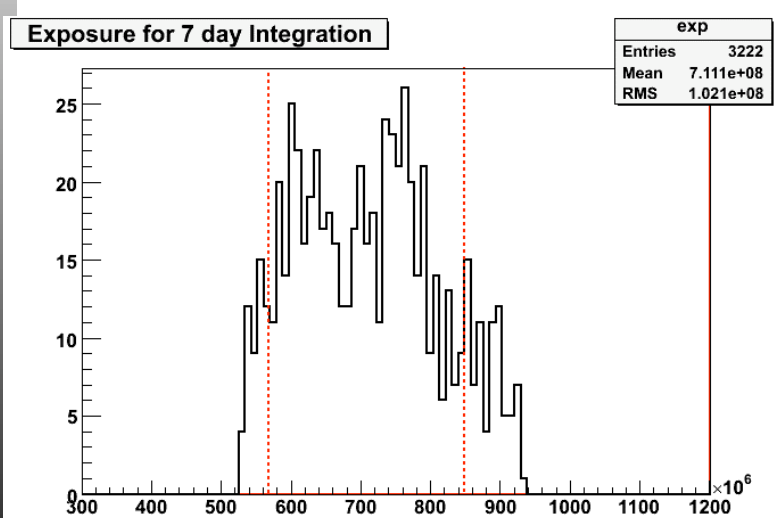


Exposure vs energy band



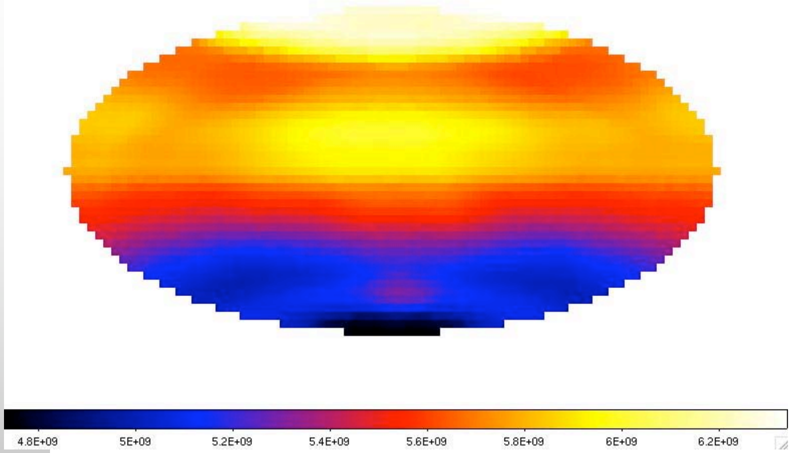
Effect of SAA - 1 week integration

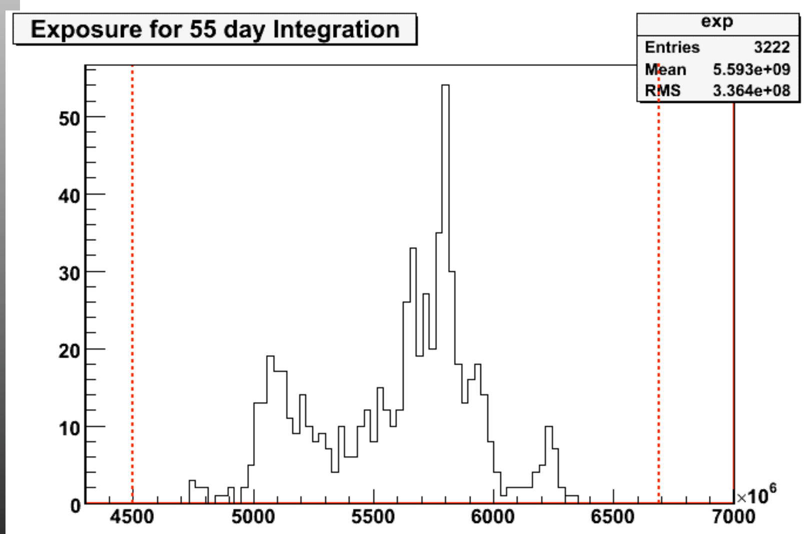




- ***The distribution of exposure on the sky has become significantly more non-uniform.***
- ***rms/mean = 14%***

Effect of SAA - 55 day integration





- *On longer timescales, the effect of SAA outages is to introduce a north/south asymmetry. However the overall magnitude of this is fairly small, all points on the sky remain within 20% of the mean.*

GLAST Mission Systems