First LAT Observations during GLAST L&EO

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https://confluence.slac.stanford.edu/display/ISOC/First+Pointed+Observation
https://confluence.slac.stanford.edu/display/ISOC/Launch+and+Early+Ops+Planning

Abstract

This note aims to develop a detailed strategy for scanned and/or pointed observations after LAT power-on during Launch & Early Operations (L&EO). As a prerequisite, we define the gamma-related instrument measurements, verifications, and validations necessary with the first observations, including their relative priorities. We also aim to identify the persons who will develop the analyses and who will assume responsibility for performing them during L&EO.

1 First Light

After the solar panels are deployed and the spacecraft (S/C) has been checked out, the LAT will be turned on, and a series of charge injection runs will show us that the LAT is alive and that its interfaces are working. The first LAT events will start to reveal the trigger and background rates, and we will begin to accumulate cosmic rays for calibrations. A relatively complete overview of this process is in the ISOC Ops Plan (1), which draws on the SVAC calibration plan (2). Steve Ritz summarized the LAT Activation Plan at the ISOC technical review in August 2006 (3), where Jon Pineau then gave a detailed draft timeline. A more recent summary was made by Eric Grove at the opening of the April 2007 ISOC Workshop (4). The *Launch+and+Early+Ops+Planning* confluence page cited as a subtitle to this note will be increasingly up-to-date as launch approaches. As of May 22 the main milestones are the following:

- On-orbit activation (3 days) – power on LAT, initial SAA high voltage tests.
- Initial Science Checkout (4 days) – rate & threshold studies, nadir scan, subsystem timing-in.
- Filler time, for analysis and/or STRs[1] (2-3 days) – background and filter efficiency studies. A ToO pointed test could occur here, **as could first Vela or Crab observations**.

[1] STR = Special Test Request, typically for troubleshooting.

- Subsystem Calibration (TBD days) – charge injection, possibly ACD CNO.
- Filler time, for analysis and/or STRs (2-3 days) – in addition to filter & background tests, GRB handling test, etc. **ToO and pointed observations could occur here**.
- Subsystem Calibration, cont'd (TBD days) – load constants derived from previous data collection and analysis. First GCR calibrations [2] .
- Filler time, for analysis and/or STRs (2-3 days) – as above.
- Subsystem Calibration, cont'd (1.5 days) and Analysis (1 day) – validate calibration constants, iterate if needed, tune sky survey mode and establish science operations. **LAT calibration complete**.
- Final Science Checkout (TBD days) – verify timing-in, background rates, filter efficiencies, SAA boundaries in large part via **pointed and scanned observations**.
- Normal science (remainder of L&EO days) – Sky survey with occasional pointed observations.

Assuming 2 days for the calibration TBD's gives 20 to 23 days before the Final Science Checkout. Since spacecraft on-orbit activation and checkout should take 11 days, and taking a total of 61 days of L&EO, we can hope for $(61 - 22 - 11) = 28$ days for those last two phases, *two weeks of which would be pointed observations*. Sounds great, inch'Allah.

This note addresses the first gamma ray observations. Specifically, what is the right mixture of scanned versus pointed observations and, when we point, *where* should we point. In addition, plans for pointed observations need to include *earth avoidance stratgies*: if you slew to a different target, should you pass through the zenith, or twist around the horizon? To answer these, we need to state clearly just *what* do we want to measure with these first pointings. The above list makes apparent that our first pointings will come in bits and spurts, presumably concurrent with changing filter & threshold settings. We thus want to think about targets that will let us make progress even with balkanized data sets. Pulsar timing is an example of a study that doesn't suffer from changing trigger biases. Quite possibly, event reconstruction cuts will smooth such biases enough for studies requiring known Instrument Response Functions (IRFs). Table 1 is intended to define the list of goals and data sets to attain them.

2 A few things about orbital mechanics

The satellite orbital period is $P = 2\pi/\omega_0 = 2\pi/\sqrt{GM/a^3}$, where $GM = 3.98 \times 10^{14}$ m^3/s and a is the orbit semi-major axis. Our orbit is circular, with radius $r_o = a(1 - e^2)$ where the eccentricity is $e \simeq 0$, and $r_o \simeq a \simeq R + h$

[2] GCR = Galactic Cosmic Rays

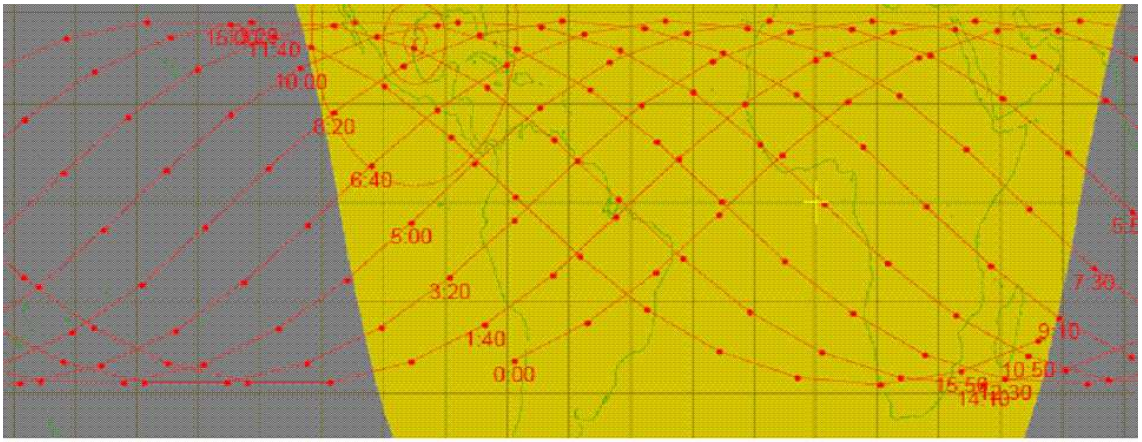

Fig. 1. GLAST's path for typical sequence of orbits (GLAST-like orbital elements were fed to XEphem to make this plot). The $\sim 25^o$ shift in longitude per orbit is due mainly to the Earth's rotation during a ~ 90 minute orbit, not to the slower orbital precession.

where h is the height of the orbit above the earth (e.g. 565 km), and $R = 6378$ km is the radius of the Earth. These numbers give $P = 96$ minutes.

Figure 1 shows a sequence of orbits for AGILE, with an orbit quite similar to GLAST's. The inclination i of the orbit relative to plane of the Earth's equator makes the satellite pass over north latitude $\lambda_{s/c} = +i$ and then swoop south to $\lambda_{s/c} = -i$ once per revolution. At the next pass, the earth will have turned $360\frac{96}{24 \cdot 60} = 24$ degrees, neglecting precession and other effects, shown in the figure as a westward shift in longitude.

2.1 Orbital Precession & Earth Occulation

Orbital precession is such that the (R.A, δ) of the orbit poles trace an $i = 28.5°$ radius circle on the sky in 55 days. To first order, this nodal regression is due to the Earth's bulge, via a quantity $J_2 = 1082.63 \times 10^{-6}$. The period depends on i and on h. Julie posted a formula at (6) for $\frac{d\omega}{d\theta}$, the fractional shift per orbit, which then gives the number of degrees per day:

$$d\omega/day = \frac{d\omega}{d\theta}\omega_0 \frac{180}{\pi} 86400 \, (deg/day) \tag{1}$$

$$\frac{d\omega}{d\theta} = -\frac{3}{2} J_2 (R/r_o)^2 \cos i \tag{2}$$

It is for the rate of change of the longitude of the ascending node of the orbit - the longitude (in earth-centerd inertial coordinates) at which the spacecraft crosses the equator on its way north. The definitive orbital inclination i is still under discussion at the few degree level and is a trade-off between constraints (satellite weight and fuel load) and optimizations (e.g. SAA avoidance). Using $i = 25.4°$ and h as above, $\frac{d\omega}{d\theta}$ becomes 1.25×10^{-3}, whence $\frac{d\omega}{d\theta} = 6.7^o$ per day, for a 53.4 day precession period.

The above discussion neglects higher-order effects: the Earth's shape is more complex than an oblate sphere, there is some atmospheric drag, the moon, and so forth. GLAST MOC planning for e.g. TDRSS contacts etc. are considered to be reliable for at most three weeks in advance, using much more complete calculations.

Above we mentioned the satellite's Earth longitude, but now consider its Right Ascension, that is, its place in the celestial rather than the terrestial sphere. Precession means that for fixed R.A., the spacecraft latitude $\lambda_{s/c}$ (e.g., sideview A in figure 2) inverts to $-\lambda_{s/c}$ after about a month (half a precession period, neglecting the Earth's travel around the Sun). Sources at high declination thus suffer Earth occulation as a function of precessional phase, as shown in sideview B. This has been discussed in (7; 8; 10).

Vela is our brightest standard candle, with declination $\delta = -45°$. The ratio of pointed exposure compared to exposure in survey mode varies between 2 and 6 depending on the precession phase. We'll call this the *"pointed enhancement"*. Hence, it really matters *when* you decide to point at Vela. Figure 3 illustrates this point. It comes from preparatory studies for A_{eff} validation as a function of gamma ray angle on the detector. An additional effect is that of the South Atlantic Anomaly (SAA), illustrated in figure 4: a southern source like Vela will receive less exposure than a northern source with the same absolute declination, such as the blazar Mrk 421.

The initial phase of the orbital precession depends essentially on the time of day of launch! That is, if Cape Canaveral is "behind" the Earth or "in front of it" at lift off (in the sense of figure 2), then the initial precession phase will be different by a month. Operations at Cape Canaveral are such that GLAST lift-off is likely to be "mid-day", with *some* flexibility. GLAST may want to tweak the launch hour so as to initially synchronize the orbits to overlap our field-of-view with Swift's as much as possible (the beat period of the two orbits' precessions is ~ 6 years, longer than the Swift mission lifetime) [3]. Naysayers argue that the higher order orbital drifts mentioned above mean that GLAST and Swift will overlap anyway.

In any case, the LAT collaboration will have little control over the launch time, and hence over the initial precessional phase, and hence over which week number after launch will be most favorable for pointed observations of a given source. It behooves us to have a plan "A" and a plan "B", and also

[3] Orbit info and more at http://en.wikipedia.org/wiki/Swift_Gamma-Ray_Burst_Mission

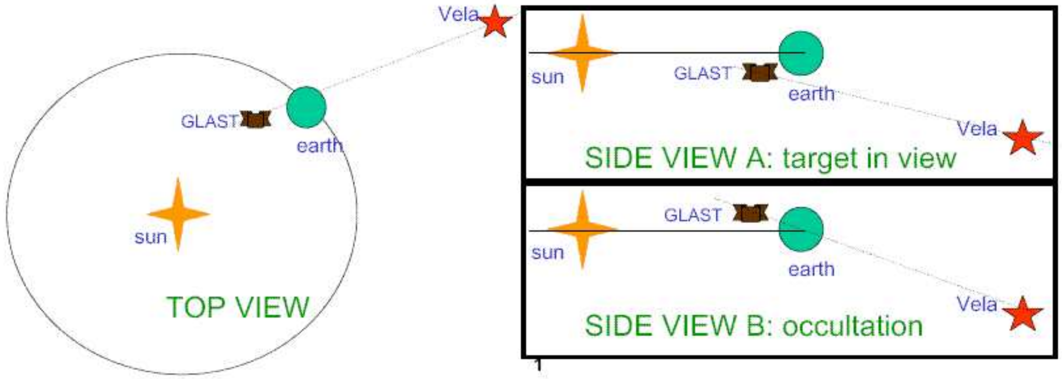

Fig. 2. Sketch of how orbital precession affects exposure time for a high declination source. Top view: in this projection, the Earth is between GLAST and a given source once per satellite orbit. Side view: (A) if GLAST is at a southern latitude when "behind" the Earth then it will still see a southern source, but (B) not if GLAST is at a northern latitude at that point.

to not bet too strongly on being able to pick the most favorable "pointed enhancement" for our initial gamma ray studies. We may want to pick A and B targets such that δ is large and of the same sign as $\lambda_{s/c}$ when GLAST is "behind" the Earth relative to the target.

Finally, we will also want to simulate FT2 files using true orbital elements immediately after launch and to update our simulations accordingly, to allow detailed calculations of candidate target exposures. Note that most currently available FT2 files start at midnight UTC, i.e. early evening in Florida...

2.2 Earth Avoidance

This paragraph is from (9) :

For scanning/rocking observations, occultation by the earth is not an issue because the horizon is far from the edge of the field of view. However, during pointed observations when no secondary target is defined, the Earth will come into the field of view. GLAST will track the direction of the target until the z-axis of the LAT reaches some specified minimum offset from the horizon (30 degrees in the obssim2 simulations). Then instead of slewing back through the zenith, GLAST will slew around the horizon at constant zenith angle to meet the target as it rises again on the other side of the earth. During these slews, typically a large part of the FOV is occulted by the earth. The expectation is that GLAST will execute typically 1 ARR per week[4]. (...) About 2.6% of the time the earth will be partially in the field of view, using a conservative definition of occultation as source zenith angle $> (113-66) = 47$ degrees, where 113^o is the approximate zenith angle of the horizon and 66 is the approximate half angle of the LAT FOV.

Earth avoidance entails a choice: slew through the zenith to another target? Or slide around the horizon. It is an issue of signal-to-noise, because not only does the integrated signal vary in the two cases, but the rate of earth albedo background gammas is larger when a source is close to the horizon. Metaphorically speaking, the view of sources close to zenith is cleaner & crisper than the view through the gamma haze towards the horizon. Data volumes and event rates will also be larger when the LAT axis is closer to the Earth limb. Pre-launch Monte Carlo studies should address this, but L&EO pointed observations will be necessary to confirm the conclusions, since detailed modeling of this is surely delicate.

We can also define the "orbital latitude" of a source as $\lambda_{orb} = \delta - \lambda_{s/c}$ then Vela ranges between $-70° < \lambda_{orb} < -20°$. At the extreme, Vela ($\delta = 45^o$) will rise only 43° above the horizon. In the scheme where you have two targets and you slew through the zenith, it is better to pick targets where $|\delta + \lambda_{s/c}|$ is large when behind the Earth.

2.3 Orbit & Attitude Simulators, and FT2 files

The accuracy of predicted gamma statistics, possibly broken down into angle bins as in figure 3, for different targets and pointing scenarios, depends on the realism of the satellite orbits used in the simulations. Trading off compromises between the different goals further means comparing apples with apples. The confluence page (6) aims to make sure that we use that same tools as much as possible.

Generation of pointing/location history, and creation of an FT2 file containing that history, are two separate functions. Here are the different tools:

(1) **gtorbsim** makes FT2 files for user-specified rocking angles parameters. It assigns a constant livetime fraction to the intervals in the FT2 file. The orbit propagation and the rocking are idealized - like instantaneous rocking. (We're fairly sure that) it does not include earth avoidance in its pointing strategy. The altitude and inclination are not user-specifiable

[4] ARR = Autonomous Repoint Request. It's one possible follow-up for a bright burst, autonomously chosen by LAT and executed by the spacecraft.

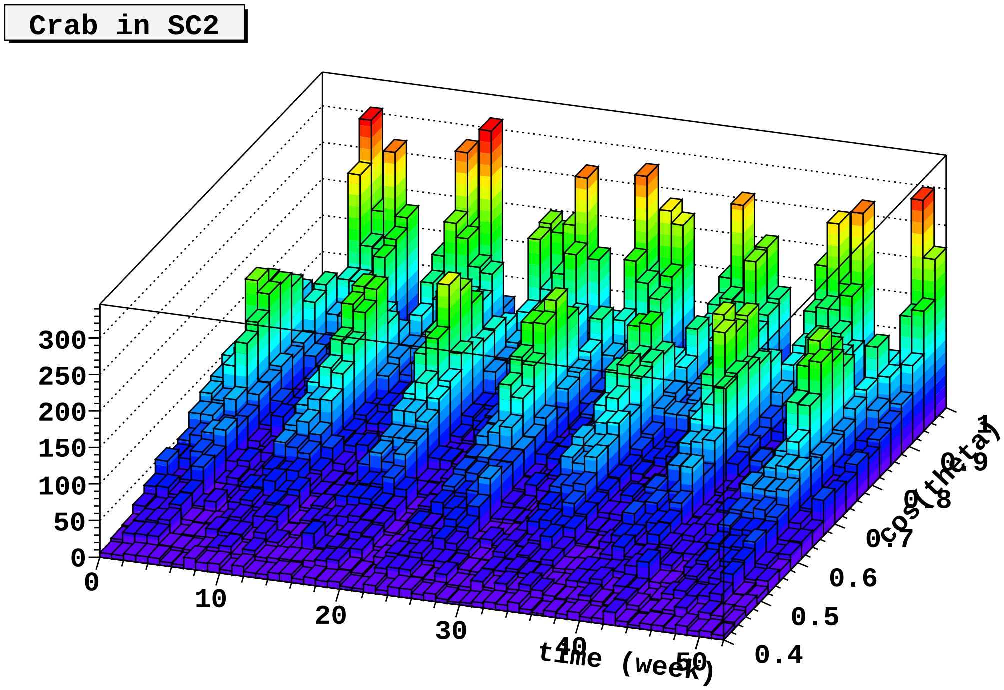

Fig. 3. Gamma ray rates from the Crab, week by week for one year of *gtobbsim* SC2 data. The y-axis is $\cos\theta$, the incident angle of the gamma relative to the LAT axis. Orbital precession causes three week periods with very low rates close to the axis, but the highest rates in the 30 to 40 degree interval. The same plots for Vela and Geminga are qualitatively similar, whereas for '1760-44 the phase is shifted by a few weeks (credit: T. Reposeur).

but are whatever we are currently using. Pointing has been disabled in recent versions of the code.

(2) **GLEAM** can read an FT2 file, ignoring the livetime column, or an ASCII pointing history. If not fed an input it will compute its own *but* scanning is alleged to be unreliable. It outputs the pointing history as a ROOT file that can be converted with makeFT2.

(3) **Guiseppe Romeo's** simulator reads orbital elements (provided by Flight Dynamics to the MOC) for accurate short-term prediction of the orbit, for example to plan TDRSS contacts. It includes earth avoidance in its pointed observations and slews at finite rate, but otherwise the slewing is not particularly realistic, with instantanous accelerations and no overshoots. This simulator should be made available as a Science Tool by the GSSC before Summer '07.

(4) **Eric Stoneking's** simulator has realistic attitude control, although the control parameters and important quantities like torques and rotational inertias were based on Stoneking's best guesses rather than (probably controlled) information from General Dynamics. Advantage – accurate. Disadvantage – slow. Julie uses an older version with fewer features that is faster.

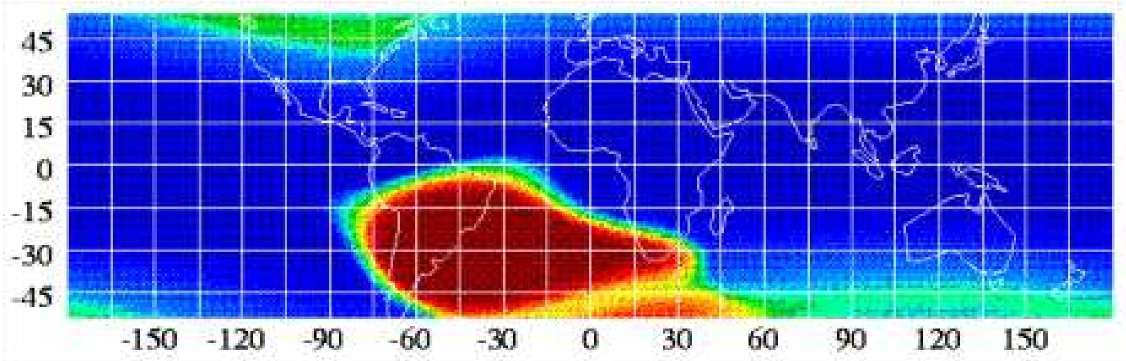

Fig. 4. The Van Allen radiation belts touch closest to Earth between South America and South Africa, mainly due to the tilt of the Earth's magnetic axis relative to the rotation axis, creating the South Atlantic Anomaly (SAA). At south latitude 25^o, near the extreme of GLAST's orbit, the SAA covers more than 20% of Earth's longitude.

(5) **Offline S/C FSW** Julie says that the simulator run by S/C FSW is being ported to become an offline standalone tool.
(6) **Real data** In (5) Seth discusses differences of real-life FT2's with idealized ones. Planned observations need to take real-life constraints into account.

We should try to converge towards the same simulator as the MOC uses. The confluence page lists mainly Stoneking simulations. Situation evolving?

3 Statement of goals

The key instrument verifications that we need to do with gamma rays from point sources very early in the mission boil down to essentially three (table 1). They are:

(1) **Validate the Instrument Response Functions (IRFs)**, more specifically, the effective area A_{eff} and the Point Spread Function (PSF). This comes at the very end of the event reconstruction chain and thus tests a whole lot all at once. The CERN testbeam work has already explored a lot of this space. If we quickly find that the experimental A_{eff} and PSF fairly resemble the Monte Carlo predictions, we'll be happy and move on. If they don't... well, we'll still have to move on, but will have to burrow into the black box.
(2) **Alignment of the LAT and Celestial reference frames**, which also depends on reliable event reconstruction, and on reasonable internal instrument alignment.
(3) **Validate the absolute event timestamps**, mainly using pulsar phases.

How can we quantify success? Science requirements can't be more than a guideline, because adequate statistics and mastery of systematic biases will extend beyond the L&EO timeframe. Here's a suggestion for a different paradigm: let's determine the precision that can be obtained in some optimistic scenario (e.g.: two weeks of pointing). Then, as we juggle the advantages for one study of pointing here with the advantages of another study to scan there, we can look at the relative degradation for each study. We'll likely find that compromise does not qualitatively spoil the results.

Julie McEnery spells out pointing modes in (7), and started to explore cost and benefit of pointing versus scan for some applications, e.g. alignment, or what GRB follow-up costs in terms of sky survey uniformity.

Before re-hashing these topics in greater detail, here's an issue: point dead-on, or look askance? If you look straight at e.g. Vela, then you'll have gammas going down cracks sometimes. If you put Vela 45^o off-center then a) longer paths in the TKR and CAL, b) almost as much effective area and c) you can have Geminga and Crab in the same field-of-view (see figure 5.

3.1 Pointing precision

In (11), Toby Burnett uses 24 DC2 sources with fluxes $> 10^{-6}/\mathrm{cm}^2/\mathrm{s}$ over the 55 days of DC2 to demonstrate that he obtains the required 0.5 arcmin radius error circles. In (12) he discusses the 4 arcsecond requirement for LAT absolute pointing. He finds 20 arc second alignment, with some caveats, for 90 days of data in survey mode, using Crab, Vela, and Geminga. Pointing for 10 days at Vela, or at a point intermediate between Vela and the anticenter, gives worse results. The short-term goal is to attain alignment small enough to be negligeable for source localisation, limited by early PSF and statistics.

Julie reports that thermal distortions (twists) lead to a half-degree difference in celestial alignment for pointing versus survey data [5]. We can use L&EO to validate that, in order to be able to take it into account for ARR's during the mission lifetime.

3.2 Timestamp validation

Denis Dumora & Lucas Guillemot have worked out algorithms to derive a possible clock offset from Crab, Vela, and Geminga phase offsets, assuming that we'll have accurate ephemerides for Geminga. Crab ephemerides are likely to

[5] Toby asks – could you rotate 180^o from time to time to mitigate the distortion?

be available from Nançay, Jodrell, and Parkes during L&EO, and Simon Johnston has requested daily Parkes time for Vela during this period. In pointed mode, from Toby's work, we see (1360,460,220) gammas per day from Vela, Geminga, and Crab, respectively, *without* a clear statement about the phase of the orbital precession. Study to be hashed out.

Simon Johnston has suggested that daily Vela observations be made during this critical check-out phase. The Parkes schedule is finalized 60 days in advance, and we don't know when launch will be! So making this happen is, so far, a problem. The Crab can be observed daily by Nançay and Jodrell – it's better if the same radiotelescope is making all the observations if the goal is to get phases lined up neatly. In progress...

3.3 A_{eff} and PSF verification

Marianne Lemoine-Goumard, working with Damien Parent, has developed algorithms and code to a) validate a set of IRFs (mainly the effective area, A_{eff}) by reconstructing spectra for some reference sources, and b) monitoring the evolution of those spectra (and hence the IRF validation) over time. This code is in CVS, and is going into the ISOC L1 processing.

A coordinated parallel effort by Claudia Cecchi et al to validate and monitor the PSF's is also well underway. Presumably Claudia's and Toby's efforts are mutually supportive?

Marianne breaks her tests into angle and energy intervals. The mean angle θ of gamma rays from a given source (she focusses on the same bright pulsars as above) tracks the orbital precession.

See https://confluence.slac.stanford.edu/display/ISOC/IRF+Monitoring for further information.

3.4 Secondary goals

Beyond the primary objectives just discussed, here we recall other important goals:

First Light Science result for Outreach AGILE recently posted a first picture of Vela, at http://www.asdc.asi.it/news.php#2007-04-23-3:45-pm, and we saw a pulsar light curve at the June 26 pulsar VRVS. We in GLAST of course want to send something flashy to the NY Times a.s.a.p. and is a colored blob called Vela good enough? This is a question for Ritz & Michelson. A 2-

week sky survey map will be pretty cool looking, about half as many photons as the entire EGRET mission. With a zoom on a blazar spectrum and the light curve of the first new pulsar, maybe '2229+6114 ($l, b = 106.65, 2.95$) or something.

Demonstrating Pointing Costs & Benefits An AAR for a burst or an AGN flare will allow the LAT to generate more (but not completely) continuous light curves. Pointing degrades the uniformity of sky surveys during that period (7). L&EO is the right time to demonstrate how it all really works, especially if we want to explore choices between e.g. Earth avoidance schemes.

High latitude targets When I asked Benoit whether the AGN group had strong feelings about a place to point during L&EO he said "survey mode is great for blazars" and then he said "what we're really waiting to see is the residual background rate at high latitude". I would think that survey mode would be fine for that. We can add that the residual background will be different depending on the zenith angle of the high latitude patch in question, due to Earth albedo.

Do other Science Working Groups have opinions about targets for L& EO pointing? Maybe the Dark Matter people could get excited about a long hard look at the galactic center?

4 Survey and/or Pointed Observations during L&EO

Figure 5 shows the pulsar sky. Table 2 will list targets and data rates.

On the *ISOC/First+Pointed+Observation* confluence page there is a template of things we need to spell out, such as detector prerequisites and configuration. As this write-up evolves we will address those points.

References

[1] L. Bator, W. Craig, S. Digel, D. Lung, J. Martin, LAT-SS-01378-03 "ISOC Operations Plan"

[2] E. do Couto e Silva & S. Ritz, LAT-MD-00446-06 "GLAST LAT SVAC Plan"

[3] *https://confluence.slac.stanford.edu/display/ISOC/ISOC+Technical+Review*

[4] *https://confluence.slac.stanford.edu/display/ISOC/ISOC+Workshop+Apr+2007+Agenda*

[5] *"Thinking inside the box"*, dark joke initiated by Anders Borgland, and evolved by Seth Digel in his Pointing & Live Time summary at *https://confluence.slac.stanford.edu/display/ISOC/Pointing+and+Livetime+History+and+the+*

Topic	Constraint	"2 week best"	Folks
Pointing precision			Burnett
Timestamp validation	some stats from 3 pulsars		Smith, Guillemot, Borgland et al
A_{eff} verification			Lemoine et al (Chiang, Atwood?)
PSF verification			Cecchi et al (Atwood?)

Table 1. Goals for L&EO gamma ray observations, more or less by order of importance. "2 week best" means the best precision that can be obtained in two weeks if you could have the observation scheme you wanted most – real life will be compared to that figure-of-merit.

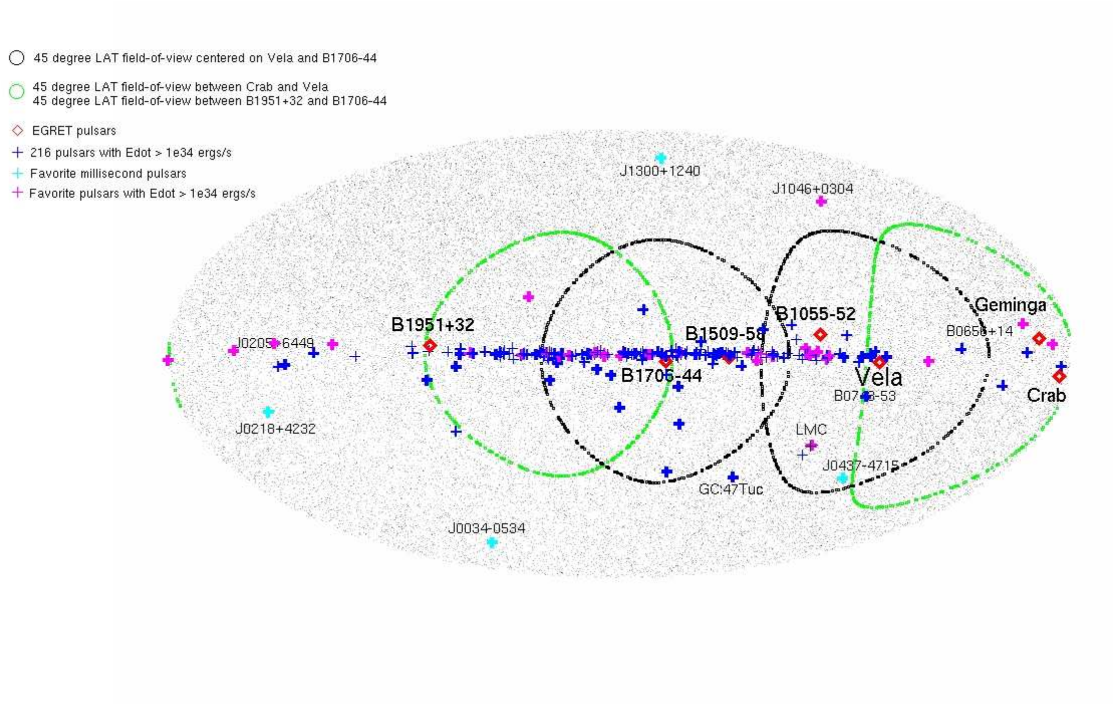

Fig. 5. Pointing: here are some 45° radius fields-of-view and the ~ 200 high Edot pulsars (credit: D. Parent).

Target	Vela γ/day	Crab γ/day	Geminga γ/day	Mrk 421 γ/day
Vela				
Half-way Vela-Crab				
Galactic Center				
Half-way '1706-'1951				

Table 2
Things you could point at and what you'd get.

[6] https://confluence.slac.stanford.edu/display/DC2/orbit+and+attitude+profiles For the nodal regression formula see also *http://iss-transit.sourceforge.net/IssVenusTransit-archive.html*
[7] J. McEnery, "To point or not to point", document in progress – better reference?
[8] Seth described Earth occulation versus orbital precession in a presentation in 2002 or so that we'll refer to here except that I can't find it anymore.
[9] *http://confluence.slac.stanford.edu/display/DC2/2007/06/18/Filtering+for+times+when+the+*
[10] T. Reposeur et al, First GLAST Symposium.
[11] T. Burnett, "Localization of Gamma-ray point sources with the LAT", First GLAST Symposium.
[12] T. Burnett, "Aligning the LAT with the S/C star tracker", C&A meeting 21 May 07,

http://d0.phys.washington.edu/∼burnett/glast/anagroup/alignment_status.html