General requirements on all analysis software (Patrick Nolan)

- The software must be usable by an end user who is not an expert in the GLAST instrument or its database. This means that it must fetch its data in a way which is transparent to the user. Selections must be based on concepts and units which are comprehensible to an astronomer.

- The user interface should be through a GUI window which can be displayed on the common computers which will be selected for this sort of thing.

A. Point Sources

1. Detection of transients - onboard and on the ground

(Arache Djannati-Atai & Regis Terrier, 16 Dec 1999)

** Dedicated CAL(only) trigger at VHE, and subsequent analysis?

2. Significances (vs. spurious source rate) and confidence regions

(Y. C. Lin, 14 Dec 1999)

This is an area that EGRET did not do too well. The cutline is set at sqrt(TS)=4.0. But there are no detailed studies to indicate what is the chance that the detection is the result of statistical fluctuations of the background events. Tom Willis did some Monte Carlo calculations of the accidental detection rate. But his results are probably too brief and have not been taken too seriously. GLAST should be able to answer the question of the accidental detection rate precisely. There is an issue of trade-off between missing real detections if cut too hard vs. accepting accident detections if cut too loose.

3. Variability

Periodicity Searches (John Mattox, 3 Jan 2000)

We can easily do this now with supercomputers (which provide enough memory for a giga-point FFT without swapping to disk). This should be possible by 2005 with a standard scientific work station. The requirements should be specified soon, but I don't think we should invest effort in coding until ~1 year before launch.

4. Spectra (Patrick Nolan, 4 January 2000)

1. The basic inputs for a run of the program will include
   - The position of the point source, in a selectable coordinate system.
   - The time interval of interest.
   - The energy range.
   - Energy binning; either a standard set or customized.
   - The spectrum model form: power law, broken power law, sum of two power laws, power law + line, etc.
   - Constraints to be placed on parameters in the fitting, including acceptable ranges and fixed values.
   - Background parameters, analogous to EGRET's gmult and gbias.
   - Quality criteria to be used for data selection, if the user knows how.

2. If the chosen point source is a pulsar, then it should be possible to obtain a spectrum of a chosen phase range. The "background" to be subtracted should be obtained either from another phase range or from off-source data.

3. Standard outputs should include
   - A human-readable report containing the quality of the fit, the best-fit parameters, and confidence intervals.
   - A table which shows the measured and fitted flux in each energy channel.
   - A FITS file containing the above information.
   - A figure showing the measured and fitted flux.

- A figure showing the confidence regions of subsets of the fitting parameters.

4. The activity of the program should be logged so that a user can go back at a later time and reproduce the same analysis. The log should be readily accessible to the user, but not easy to delete.

5. For sources in confused regions of the sky, there should be a facility which allows data from certain portions of the sky to be excluded from the analysis.

6. For advanced users, there should be a batch mode in which many source positions will be specified in a file. The program should analyze them all without user interaction.

Issues to be studied:

• Models. For EGRET, it was possible to fit all but the brightest sources with a simple power-law spectrum model. More complex models were used for the three bright pulsars. It is likely that we will see some statistically significant departures from power laws for several bright sources. However, there are no well-established models of the sort that are used for X-ray analysis (thermal plasma, Sunyaev-Titarchuk, etc.) which would be relevant in our energy range. I believe that users will want to specify their own models. We will need a clean method for allowing that to happen. That opens the door to a host of technical issues, such as differentiability.

• Flux algorithm. The best way to establish the flux in each energy band is through a likelihood analysis, as with LIKE. Is this too burdensome to put into this program? Should there be a separate program as with EGRET? Should we allow nearby sources to be specified so we can remove their influence? Everything is connected!

• Fitting algorithm. I am tempted to specify that we use forward-folding with maximum likelihood. (EGRET used minimum chi-squared.) However, I am not sure that the effort is justified. The point of folding/iterating is that the response matrix isnon-diagonal. We need to see just how non-diagonal it will be. If it is close to diagonal, then a simple non-iterative method will work. Perhaps there could be two methods, a fast one for the many weak sources and a "correct" one for a few strong sources.

• X-ray packages. Could we piggy-back on someone else's work? The X-ray community has one or two standard analysis packages which seem to be portable from one instrument to another. Could we make use of one of those?

(Arache Djannati-Atai & Regis Terrier, 16 Dec 1999)
** Which hypotheses? Power law, and more generally brocken power laws, Curved shapes (parabola in nufnu, or powerlaw*exp...)
** Index variability searches==> also hardness-ratio studies

5. Identifications (John Mattox, 3 Jan 2000)

I suggest that we create a program to evaluate potential GLAST identifications with the method I described in 1997 (ApJ, 481, 95). A catalog of possible GLAST blazars will need to be assembled. With ~5000 GLAST blazar detections expected, this is not trivial. Radio surveys should be the primary source (as the objective search for EGRET/blazar identifications described in the article sited above). The NVSS survey (done with the VLA) can also be used. Optical studies can also be done prior to the GLAST mission to characterize the optical variability of the sources, and to obtain photometry of potential reference stars for differential photometry in the GLAST era. Similar catalogs will need to be assembled for other types of AGN, and potential galactic gamma-ray sources.

6. Catalog (Arache Djannati-Atai & Regis Terrier, 16 Dec 1999)

** Grouping sources per type (galactic, extra-galactic,unknown) or per characteristic (variable/steady, pulsed/semi-periodic/unpulsed...), or all in the same basket?

(Seth Digel, 10 Jan 2000)

1. Detecting sources and generating the catalog are different functions; the catalog generator must have access to the source detection database and the source identification software.

2. The catalog must be well integrated with a database for searching.

3. Regions of potential source confusion or marginally-resolved diffuse emission must be handled specifically.

What should the catalog contain?

Positions, fluxes, and their uncertainties (average over some time interval)
significances
flux & spectral histories
confidence limit for variability
identifications (with confidence levels)
confusion flag
catalog version or analysis version.

Other Issues

• Upper limits (likely to be an important component of flux histories), may be generated for a specific direction and time range; or (as for EGRET), maps of upper limits for various standard time ranges could be precomputed.

• Appropriate time ranges for source detection need to be investigated. Spurious source rate must be investigated.

B. Extended Emission

1. Distinguishing from point sources (Arache Djannati-Atai & Regis Terrier, 16 Dec 1999)
** possibility to fit different spatial patterns to extended emission regions (SNR shells...)

** spatial variability (long term)??

2. Interstellar emission and cosmic rays in the Milky Way and halo
(Seth Digel, 20 Dec 1999)

1. The model must be available for arbitrary energy ranges within GLAST's limits (30 MeV-100 GeV?). This allows for unbinned analysis and flexibility in selecting bins for GLAST's analysis.

2. The model likewise must be available with arbitrary gridding in a range of standard coordinate systems.

3. Even if preconvolved model intensity maps or maps with intensity integrated on the assumption of some spectral index are ultimately used in the point source analysis, requirements 1 and 2 still stand. This will allow flexibility in selecting energy bands and spectra.

4. Depending on how the likelihood analysis software is ultimately implemented, model maps, or 3-dimensional arrays of intensity maps vs. energy, can be generated on the fly for the analysis. However, the software must be able to export diffuse emission maps as FITS files. This is to support non-standard analyses and to allow visualization of the interstellar emission model.

3. Spectroscopy of the π^0 bump
4. Extragalactic residual diffuse

C. Gamma-Ray Bursts

1. Detection onboard (Arache Djannati-Atai, 16 Dec 1999)

** dedicated CAL(only) trigger at high energy and analysis.

2. Pulse profiles

3. Spectroscopy

4. Delayed emission

D. Pulsars

1. Phase folding

2. Periodicity searches

3. Spectroscopy

E. Special Analyses

1. Multi-gamma events

2. Polarization (John Mattox, 3 Jan 2000)

I have an interest in this area, but feel that it is premature to consider developing software for it until the instrument team makes a commitment to an instrument design which provides useful polarization sensitivity.

3. WIMP line search

F. Calibration

1. Ground-based

2. In-flight (Arache Djannati-Atai & Regis Terrier, 16 Dec 1999, 7 Jan 2000)

**dedicated trigger mode. Easily reloadable code from ground.

Filters to isolate interesting non-interacting cosmics, to be sorted per species (H, HE, CNO, Fe)...

Many other things to think of (inter-calibration between energy ranges, between Xtals, towers...):

- test modes for the readout electronics ASICs
- using simply the cosmic ray groups : P, He, CNO and Fe groups.

Unfortunately one does not expect well defined lines, but rather broad energy deposition patterns to be fitted using the simulations. So one would need to have rather complete information (like energy in each xtal) about the High Z events (and also P, He, but I don’t know if there's a possible trigger mode forseen for them).

Stability: The same way using cosmic rays. We forsee for the CAL a few percent efficiency drop per year, mainly due to radiations giving rise to an efficiency loss in light yield of the Xtals and the quantum efficiency of the PIN diodes (much less than the Xtal effect); electronics being made in the DMILL technology (for the CAL), they are expected to be very, very stable...

G. Science Databases

1. Events

2. Photons (Stan Hunter, 5 Jan 2000)

Coordinate transformations between instrument, spacecraft, and sky need to be defined and verified.

3. Exposure timeline

4. Calibration (instrument response functions)

(Arache Djannati-Atai & Regis Terrier, 7 Jan 2000)

It depends on the nature of the calibration file we are talking about. Let's focus on the calibration files which provide the instrument response function. A preliminary step should be a clear definition of event classes, e.g.,

(*a*) those fully contained in one tower (TKR+CAL),
(*b*) those contained in the TKR but partly missed in the CAL (e.g., one of the pair particles in a crack or out of the side of the instrument)
(*c*) those seen only in the TKR (depends also on the energy)
(*d*) those seen only in the CAL (CAL-only) high energy trigger.
(*e*) those passing through 2 towers etc... (events close to the walls/sides)
(*f*) and we are certainly forgetting cases.

Classes (*a*), (*b*), (*c*) (*e*) go into 2 sub-classes :

1- events converted in the upper TKR (2.5% Pb sheets)
2- "   "   "   lower TKR (25 % sheets)

This is just a first attempt, we could really make a clear definition of classes basing ourselves on the populations of events having different angular and energy resolutions.

Next, for each class we need the PSF, the $\Delta E/E$ and the Aeff, for given energies, zenith angles and probably azimuth angles. One should be able to generate new calibration files for different failures which could happen, partial efficiency or total loss of a xtal, strips, a tower! (hopefully not...!)

Also: Analytical model of the instrument: kind of multiparameter (energy, zenith angle, azimuth (?),...) interpolation of the calibration files, which would be used in the final analysis algorithms (likelihood, etc.), instead of histograms, or one dimensional calibration files.

5. Source catalog

6. Other astronomical catalogs

Other Charges to the Working Group

A.3 Point Source Variability

a. What is the time profile of the gamma-ray flux of a typical AGN. Is quiescent emission expected, or will most of the detections be made for ~day or week timescales?

A.6 Point Source Catalog

a. What information should the source catalog contain?

position, position uncertainty, average flux, flux uncertainty, flux history, spectrum, possible identifications,

B.2 Interstellar Emission Model

a. To what extent is one needed for the point source analysis?

b. What angular resolution is required?

C.1 GRB Onboard Detection

a. Spatial map of the diffuse gamma-ray background

b. Variation of CR residual background

c. Requirements implied for on-board Level 3 trigger

D. Pulsars

a. Do we need to select candidates for radio timing so that contemporaneous ephemerides will be available?

E.1 Multi-gamma Events

a. What rate of these events might be expected?

b. Can they be flagged, distinguished from background events, with automated processing?

E.2 Polarization

a. Is special analysis required, or can measurement of plane of pair be part of the automatic reconstruction?

E.3 WIMP Line Search

a. Will this be via large-angle calorimeter-only events?

F.2 In-flight Calibration

a. How should calibration be monitored in-flight for the instrument subsystems?

b. How should provision be made for reprocessing event data?

G. Science Databases

a. How will they need to interface with instrument team and guest investigator analysis software?

c. For extraction of maps of exposure & photons, what coordinate systems should be supported? Moving systems, e.g., for solar system?

d. Are specific data products derived from the databases needed for guest investigator support?