High-Level Analysis of LAT Data: Use Cases

S. W. Digel (SU/HEPL) for the SSC-LAT Working Group

SSC-LAT Science Tools Workshop

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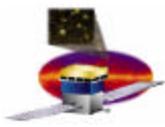
Plan of the talk

- **Introduce the tools and databases of the standard analysis environment**

- **Show how they fit together into a sensible environment for high-level analysis**

- **Make the case for completeness with Use Cases**
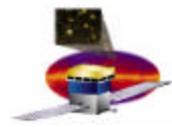
Who put the T in LAT?

- **The design of the high-level analysis environment that is the subject of this meeting treats the LAT as an astronomical instrument**

- **Implicit in this assumption is that the high-level analysis can proceed with the instrument response functions**
  - **IRFs are defined from beam tests and MC instrument simulations and monitored in flight**

- **Also implicit is that background rejection is well in hand (i.e., meets performance requirements)**
  - **Routine scientific analysis will not require modeling the charged particle background or making cuts to select 'good times' by geomagnetic quantities**

Standard Analysis Environment

- **Flow is generally left to right, from Level ~1 to Level 2+**
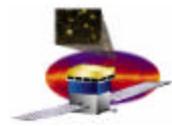
Walk through

- **Event display**
    - **to be inherited from instrument simulation**
    - **no path to higher-level analysis**
    - **reference by event ID, useful for sanity check**

```
┌──────────────┐          ╭────────────────╮
│  Level 0.5   │──────────│  Event display │
└──────────────┘          ╰────────────────╯
```
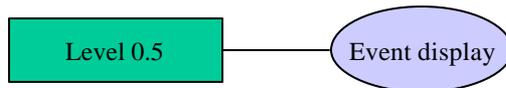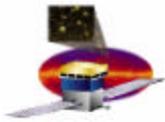
Walk through (2)

- **Connection to Level 1 processing**
  - **intermediate utilities stand between the Level 1 data and the analysis tools**
  - **exposure calculation is separate as well; it doesn't care about the source of the pointing/livetime information**
  - **exposure calculation must match Level 1 extraction parameters**
  - **U1 can work on previously-extracted gamma rays**

| Level 1 (D1)[1] |———| Data extract (U1) |——————|

| Pointing/livetime history (D2)[1] |——| Pt.ing/livetime extractor (U2) |——| Exposure calc. (U3) |
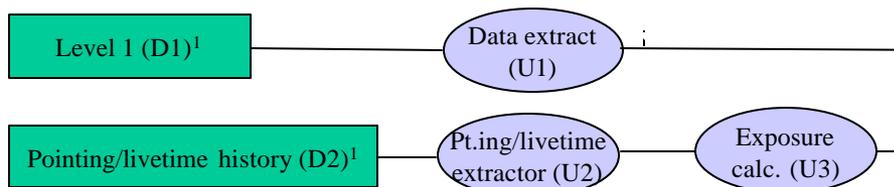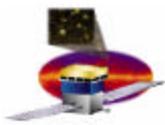
Walk through (3)

- **Known pulsars**
  - **D5 represents timing information (radio) maintained during the mission**
  - **after phase assignment, analysis can proceed as usual, or periodicity tests applied**

```
        ┌──────────────────────┐
        │  Pulsar ephem (D5)    │
        └──────────┬───────────┘
                   │
              ╭────┴────╮
    ┌────────►│ Pulsar   │─ ─ ─ ─┐
    │         │phase assign (A3)│ │
    │         ╰─────────╯        ▼
    └─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─┘
```
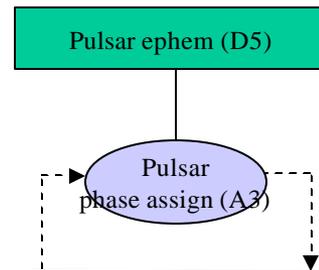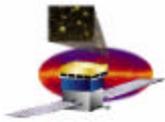
Walk through (4)

- **Other databases as input to high-level analysis**
  - **Instrument response functions – PSF, Aeff, Eng. res. (RMF)**
  - **Interstellar emission model (tool or database?) is unavoidable**

IRFs (D6)

Interstellar emission model (A8)
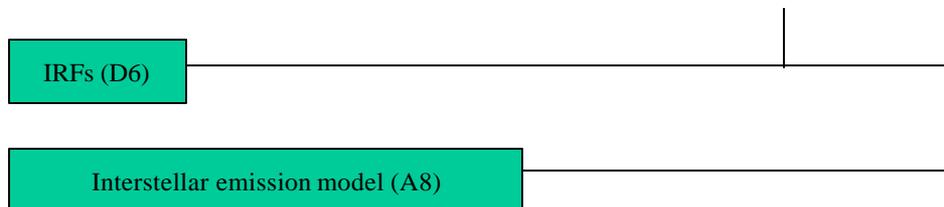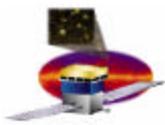
Walk through (5)

- **Image/plot display**
  - **Not actually free floating, resource for analysis tools**
  - **Interstellar emission model (tool or database?) is unavoidable**

Image/plot display (U8)
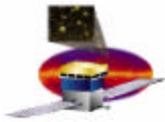
Walk through (6)

- **Source model definition tool**
  - **specification of models (point sources, extended sources, diffuse) for likelihood analysis *and* for observation simulation (not shown)**
  - **probably should indicate that the source model definitions can be written in files**
  - **also uses A8**

Source model
def. tool (U7)
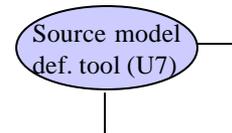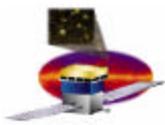
Walk through (7)

- **Core analysis tools**
  - **likelihood analysis – characterization of point and extended sources**
  - **map generation for visualization, export; any binning required for likelihood analysis will be internal to**

Likelihood (A1)

GRB spectral/temporal analysis (A6)

GRB physical modeling (A7)

Map gen (U4)

Pulsar profiles (A4)

Pulsar period search (A5)
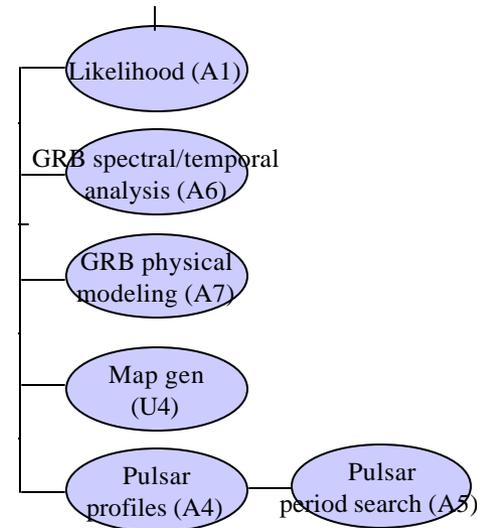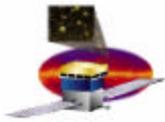
Walk through (8)

- **Beyond Level 2**
  - **LAT source catalog is related to likelihood analysis, but not connected by a standard analysis tool**
  - **astronomical catalogs may be external resources**

```
                    ┌──────────────────────────┐
                    │  Point source catalog (D3) │
                    └──────────────────────────┘
         ┌───────(  Catalog     )───( Src. ID (A2) )
         │       (  Access (U5)  )
                    ┌──────────────────────────────────┐
                    │ Astronomical catalogs (incl. D4)  │
                    └──────────────────────────────────┘
```
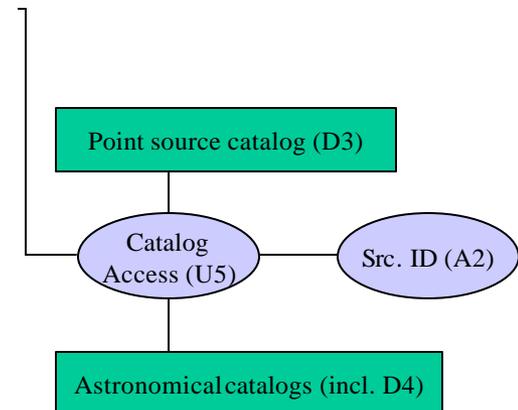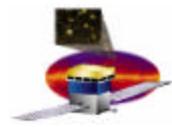
Use case 1

- **Contributed by D. Band, J. Chiang, S. D., P. Nolan, J. P. Norris**

- **<u>Determine the average spectrum of 3C 273 for a particular one-month period</u>**

  1. **Extract the gamma-ray data from the Level 1 database using U1, selecting a large enough region of the sky, and making standard cuts on zenith angle**

  2. **Generate the corresponding exposure using U3 after using U2 to extract the pointing/livetime history**

  3. **Define a model for the region of the sky using U7, which should be nearly automatic but allow for interactive editing; U7 uses U5 and A8**

  4. **Use U4 to generate maps of the region using the data and the model as a sanity check; display tool uses U8.**

  5. **Then iteratively use A1 to optimize the positions and fluxes of the point sources, pruning any that do not belong for this time range, adding any not already cataloged. A1 uses IRFs in D6**

  6. **With other parameters fixed, rerun A1 with various spectral models for 3C 273, or run A1 sucessively for narrow energy ranges to define the fluxes and uncertainties**

  D1, D2, D6, U1, U2, U3, U4, U5, U7, U8, A1, A8 ← **Elements of standard analysis environment referenced here**
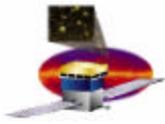
Use case 2

- **Determine the light curve of 3C 273 for a particular one-month period**

   Steps 1–5 for this analysis are the same as for the spectral analysis

   6. Based on the detection significance of 3C 273 in the whole month interval, decide what time interval will be used for evaluating the flux.

   7. Extract gamma-ray data sets (U1), generate corresponding exposures (U3) for each of these intervals, and reoptimize the model parameters for each time interval (A1) to determine the flux and confidence interval (or upper limit). *Note that this process of extracting data, generating exposure, and applying a common model in the likelihood analysis, can be automated.*

   8. If desired, time intervals can be lengthened or shortened based on the findings in step 7, and the analysis re-run.

   D1, D2, D6, U1, U2, U3, U4, U5, U7, U8, A1, A8
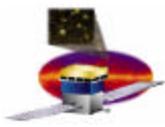
Use case 3

- **<u>Study gamma-ray emission from a known pulsar</u>**

    1. **Extract the gamma-ray data (U1) for a region of the sky around the pulsar, for the time and energy ranges of interest.**

    2. **Assign phases to these gamma rays using A3 by specifying either the name of the pulsar (if it is known in D5) or the timing parameters.**

    Periodicity tests:

    3. **To enhance the detectability of periodicity in the LAT data, the gamma-ray data need to be passed through A4, which selects the gamma rays within a certain (energy and inclination angle dependent) radius of the position of the pulsar. This cut discriminates against the diffuse gamma-ray emission. The position of the pulsar may be specified either via its name (if the pulsar is in D5) or explicitly.**

    4. **A4 can also generate phase binned histograms and apply periodicity tests.**

    Phase-binned analysis:

    5. **Use U3 to calculate the exposure corresponding to the gamma rays extracted by U1. U3 can automatically generate the exposure matrices**

    with the same cuts as used for a dataset produced by U1.

    6. **The rest of the analysis proceeds as in use case #1, with the exception that A1 can be told what phase range to include.**

    D1, D2, D5, D6, U1, U2, U3, U4, U5, U7, U8, A1, A3, A4, A8
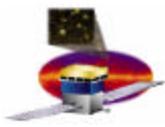
Use case 4

- **<u>Gamma-ray burst analysis</u>**

  Decompose GRB time profile into intervals, analyze temporal and spectral behavior as a function of energy and time.

  1. **Apply steps 1-5 from Case 1 to extract the relevant LAT data for the region around the GRB, and to create a model of the surrounding sources.**

  2. **Extract the relevant GBM data [using GBM tool TBD].**

  3. **Use A6 to divide the GBM + LAT time profile of the GRB into subintervals, possibly automatically**

  4. **Utilizing data from the full energy range extracted in 1+2, fit pulses to the subintervals specified in 3 with A6.**

  5. **Data from (all, or subset of) fitted pulse intervals are sent to GRB physical model fitting program A7, which requires exposure**

  D1, D2, D5, D6, U1, U2, U3, U4, U5, U7, U8, A1, A3, A4, A6, A7, A8
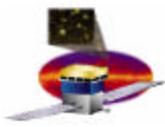
Use case 5

- **<u>Make a sky map image</u>**

  1. **Extract the gamma-ray data for the desired time range, energy range, region of the sky, event type, etc. using U1.**

  2. **Generate the corresponding exposure using U3.**

  3. **Use the map generator (U4) to bin and grid the gamma rays in the desired projection**

  4. **Do the same with the exposure using U4. A gamma-ray spectrum must be assumed at this step**

  5. **Display the resulting counts, exposure, and intensity (counts/exposure) maps using the image display tool U8.**

  6. **U8 and the catalog access tool U5 (which uses D3 & D4) can be used to plot overlays of sources extracted from astronomical catalogs if desired.**

D1, D2, D3, D4, D5, D6, U1, U2, U3, U4, U5, U7, U8, A1, A3, A4, A6, A7
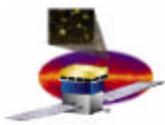
Use case 6

- **Search for pulsations in a suspected gamma-ray pulsar**

  1. **Extract the gamma-ray data for the desired time range, energy range, region of the sky, event type, etc.**

  2. **Use A4 to select gamma rays near the position of the prospective pulsar**

  3. **Use A5 to search for periodicity. This assumes that standard point source analysis has already been performed to derive the most accurate position possible for the source.**

D1, D2, D3, D4, D5, D6, U1, U2, U3, U4, U5, U7, U8, A1, A3, A4, A5, A6, A7
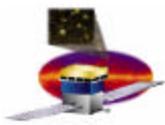
Use case 7

- ## Search for counterpart to a detected point source

  This use case starts after a point source has been detected and characterized with A1.

  1. Identify potential counterparts using A2 to quantitatively assign confidence levels based on the size and shape of the confidence region for the source and the properties of the astronomical catalogs available (e.g., their *log N-log S* relations).

  [What's left? U6, the utility for event display]

  D1, D2, D3, D4, D5, D6, U1, U2, U3, U4, U5, U7, U8, A1, A2, A3, A4, A5, A6, A7
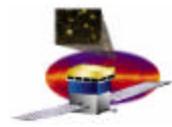
Other use cases in preparation

- **Chiang – characterization of gamma-ray blazars**
- **Ozaki – study of small extended sources**