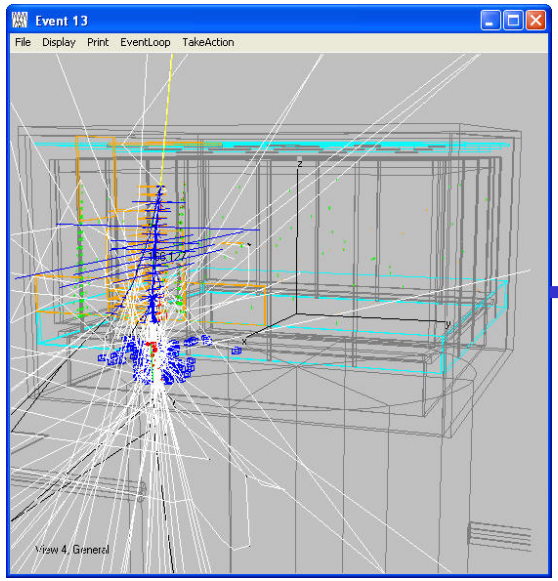
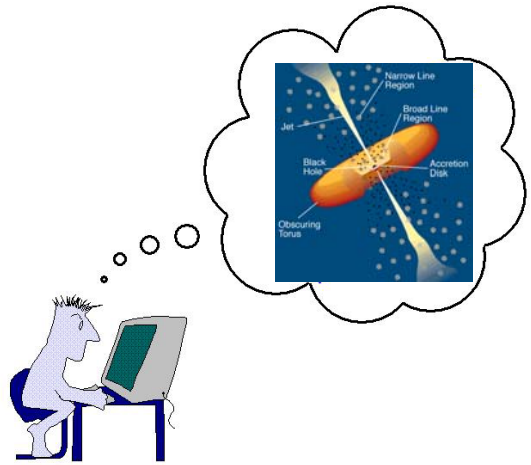
High-Level Analysis



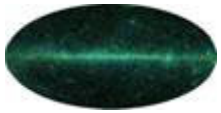
(T. Usher)

Science Tools



(Apologies to R. Dubois, D. Flath, M. Urry, P. Padovani)

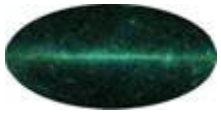
Seth Digel & Patrick Nolan
HEPL/Stanford Univ.



Outline

Reviewing what goes on inside the green box for DC1 and motivating the analysis topics that the DC1 science tools support using real results from EGRET

- **Introduction**
  - **More on scope & goals for DC1**
- **Science tools in DC1**
- **Analysis topics & examples from EGRET**
  - **Diffuse emission**
  - **Source detection**
  - **Spectral analysis**
  - **Extended sources**
  - **Isotropic emission**
  - **GRBs**



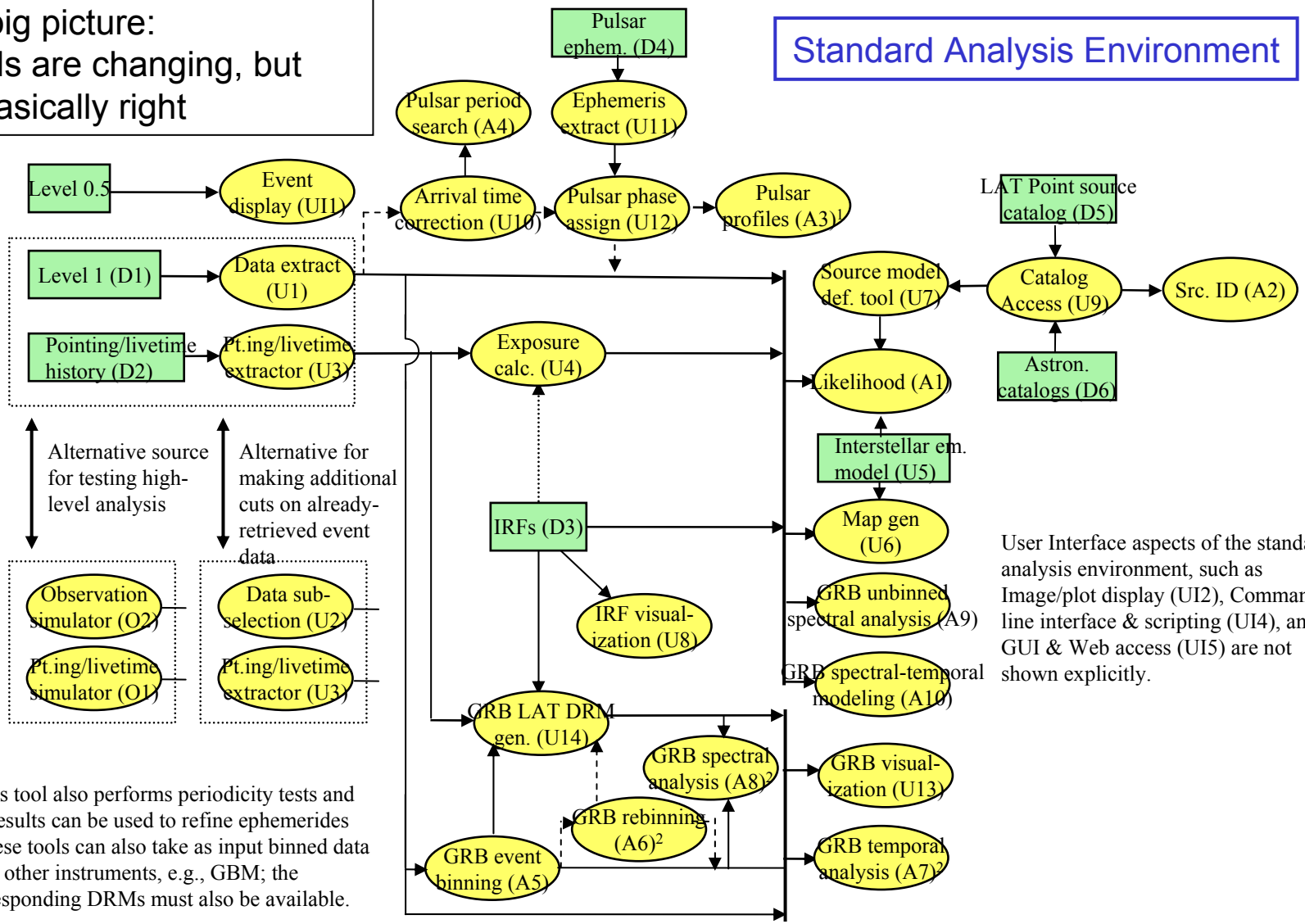
Introduction

- **Surprise! Data Challenge 1 is not about science**
  - **The emphasis is on the analysis techniques themselves (and the tools to implement them that are to be discussed this afternoon)**
- **What are the DC1 goals for the science tools?**
  - **Briefly, an end-to-end test of the system, going back to instrument simulation, event classification and generation of response functions, through high-level processing, and managing the flow of data in between**
  - **So we are at the high-level processing end of the chain now (more or less – will be some iteration, e.g., on event classes). We want to**
    - **shake test the science tools; actually they won't take a lot right now**
    - **introduce the analysis methods for gamma-ray astronomy with the LAT**
    - **get feedback on functionality – from you and from developers**
- **In this talk we want to motivate the analysis techniques with a selection of real, scientific results from EGRET; Pat Nolan will cover the analysis methods**
  - **Exercising the tools will include at least some of the kinds of analyses described here**

Science Tools in ~~DC1~~ DC3

The big picture:
Details are changing, but still basically right

Standard Analysis Environment

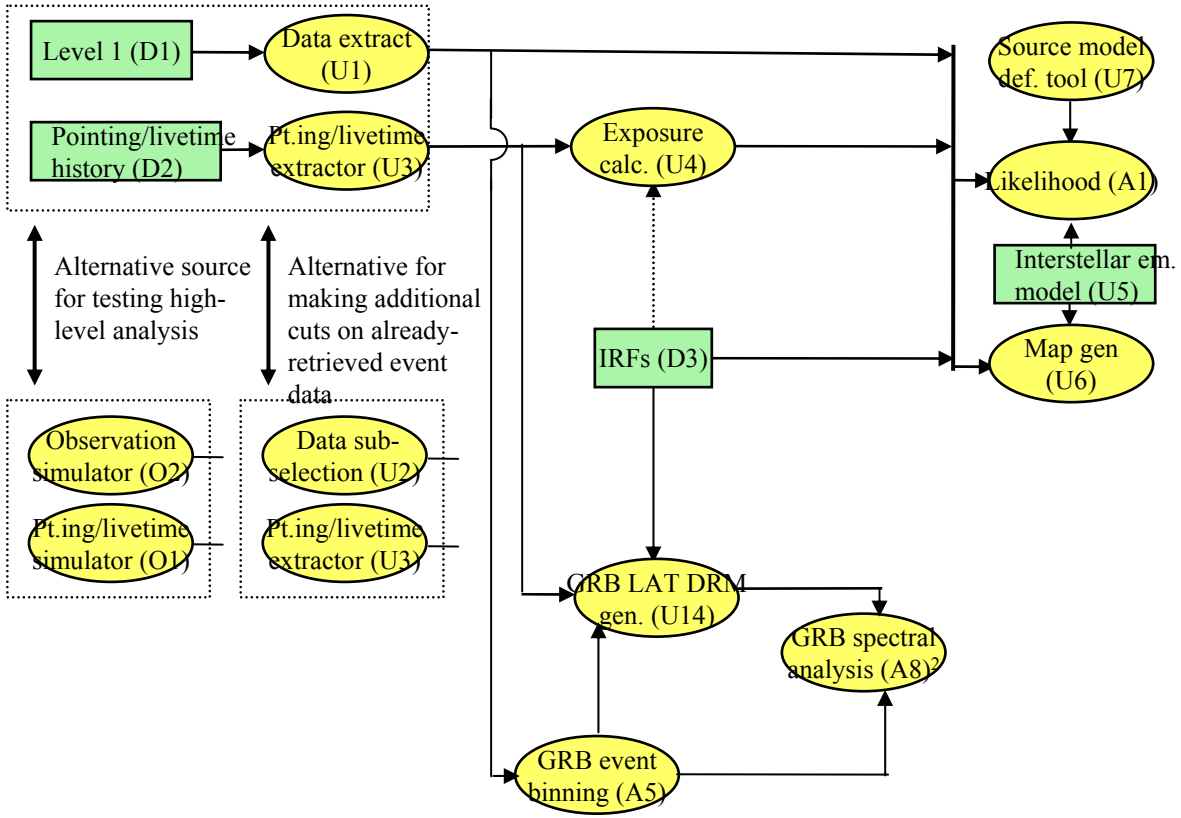


User Interface aspects of the standard analysis environment, such as Image/plot display (UI2), Command line interface & scripting (UI4), and GUI & Web access (UI5) are not shown explicitly.

[1] This tool also performs periodicity tests and the results can be used to refine ephemerides
[2] These tools can also take as input binned data from other instruments, e.g., GBM; the corresponding DRMs must also be available.

Science Tools in DC1

- **DC1 components of the science tools**
  - **Again, details have changed**
  - **Some other important details are not shown, like the machinery for loading the databases and serving the data**
- **All components are still prototypes**



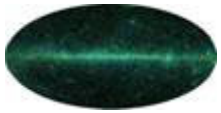
The DC1 functionality is
Data extraction
Limited visualization
Model definition
Model fitting
Observation simulation

Science Tools in DC1 (cont)

- Details of the contents of the event summaries are still converging
- The interstellar emission model is still the model used by EGRET team (Bertsch et al. 1993, Hunter et al. 1997)
- The instrument response functions are defined only for the events that pass the filters presented by Bill Atwood at the collaboration meeting in Rome
  - Eventually we expect to have more than one event class
  - PSF and energy resolution are being defined on a grid of energies and inclination angles, with a analytic function fit. No interpolation of the parameters between grid points is attempted
  - The IRFs are not yet in CALDB, although this switch should be completely transparent to the user
- The interface to EGRET data and pointing/livetime history is not complete (and was not planned for DC1)

Science Tools in DC1 (cont. 2)

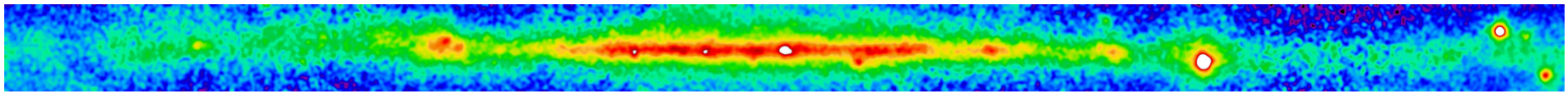
- The DRM generator RspGen understands only circular cutout regions so far; this is not a limitation at all for analyzing bright GRBs, but the intent is to make it understand custom shapes for crowded fields
- The map generation tool does not exist yet
  - EventBin (GRB event binning) can make counts maps
  - Exposure maps can be generated with [what]
- No visualization is integrated with the tools yet
- The orbit and attitude simulation is still idealized and not yet a standalone tool



Implementation of Science Tools

- Reminder: the tools are implemented as FTOOLS
  - HEASARC convention across missions
- You will notice that this defines much of the 'look and feel'
  - Provides a uniform interface
  - HOOPS for prompting at the command line
  - GUI is coming
- FITS files for data
  - More this afternoon

Analysis Topics



EGRET >300 MeV

- First a word about interstellar gamma-ray emission: Get used to it.
- Brightest at low latitudes, but detectable over the whole sky
- >60% of EGRET celestial gamma rays
- It fundamentally affects the approach to the analysis (as Pat will discuss)

Analysis Topics: Source detection

- **Source detection means at least 2 things:**
  - **Recognizing that you've detected a point source that you didn't know about (and defining its statistical significance and location on the sky)**
  - **Determining the significance of the detection of (or measuring an upper limit for) an already-known source**

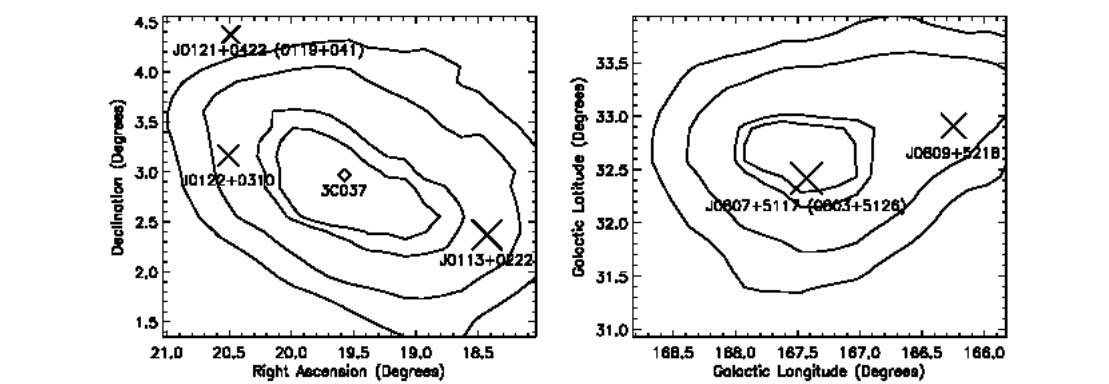


FIG. 3.—TS maps of possible composite 3EG sources. *Left*: 3EG J0118+0248. The 3EG identification 0119+041, the steep spectrum Mattox et al. (2001) counterpart 3C 037 (*diamond*), and our two new blazar counterparts (along the uncertainty region major axis) are shown. *Right*: 3EG J0808+5114. Again, two high-confidence identifications lie along the major axis.

Source location contours for two 3EG sources (Hartman et al. 1999). Potential (additional) counterparts, unresolved by EGRET, are indicated

Sowards-Emmerd, Romani, & Michelson (2003, ApJ, 590, 109)
http://adsabs.harvard.edu/cgi-bin/nph-bib_query?bibcode=2003ApJ...590..109S&db_key=AST

Analysis Topics: Spectral analysis

- **Well, this means measuring spectra**
  - **Mostly power laws resulting from shock acceleration, which is scale free**
  - **Spectral breaks occur for physics reasons and measuring them is diagnostic of the sources.**
- **For EGRET, the analysis of source spectra was a 2-step process**
  - **Fluxes were derived for fairly broad ranges of energy independently**
  - **Then a spectral model was fit**
- **The complication was that the exposure for a broad energy range depends on the source spectrum, so the fitting process was iterative.**

$$F_\gamma = (2.01 \pm 0.12) \times 10^{-6} (E/0.214\ \mathrm{GeV})^{-2.18 \pm 0.08}$$

photon $(\mathrm{cm}^2\ \mathrm{s}\ \mathrm{GeV})^{-1}$.

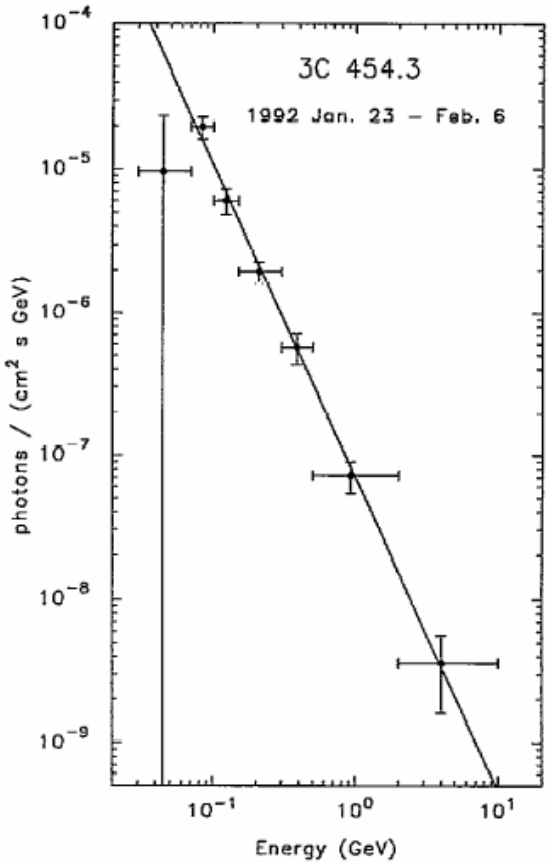
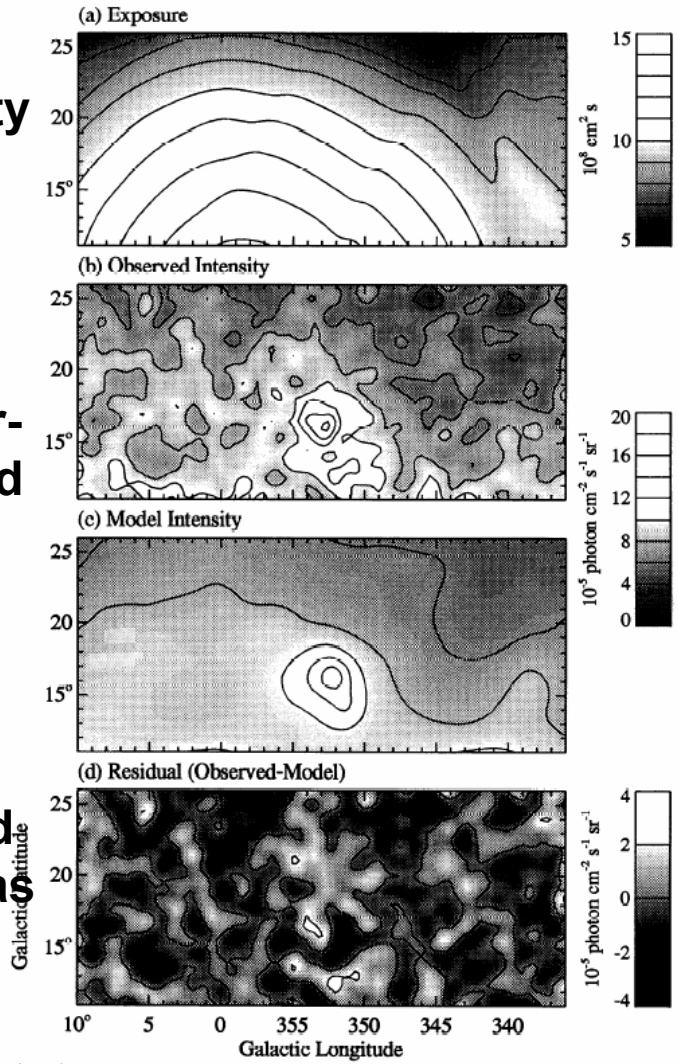


FIG. 3.—High-energy gamma ray spectrum of 3C 454.3 during the time interval 1992 January 23 to February 6. See text for comments on the 30–70 MeV point.

Hartman et al. 1993 (ApJ, 407,L41), http://adsabs.harvard.edu/cgi-bin/nph-bib_query?bibcode=1993ApJ...407L..41H&db_key=AST

Analysis Topics: Extended Sources

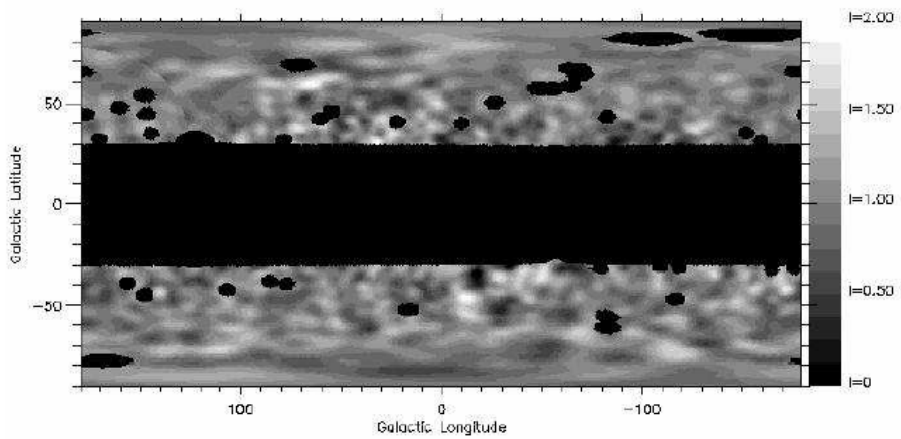
- Extended sources are more complicated to study, if you don't know their intrinsic intensity distributions
- For EGRET local molecular clouds were large enough (~15°) and bright enough to be resolved marginally
- A relatively bright source in Ophiuchus (a star-forming region ~100 pc distant with associated interstellar clouds) was detected by COS-B.
  - Based on the mass of interstellar gas, the inferred cosmic-ray density was 10×local and hard to understand
- With EGRET, the emission is marginally resolved. More importantly, the data indicated a variable source (i.e., not diffuse), identified as blazar PKS 1622-253, ~1° from the core of the main cloud



Hunter et al. (1994, ApJ, 436, 216) http://adsabs.harvard.edu/cgi-bin/nph-bib_query?bibcode=1994ApJ...436..216H

Analysis Topics: Isotropic Emission

- Detected by SAS-2 and EGRET
- This is not a topic of DC 1 per se, because the analysis really rests on beating down or carefully characterizing the residual charged particle and gamma-ray albedo backgrounds
- Where the LAT will advance the subject is in resolving the isotropic emission into (presumably) point source constituents that could not be detected with EGRET
- The blazar contribution to the isotropic background is not an answered question
  - 100% (Stecker & Salamon 1996)
  - 25% (Chiang & Mukherjee 1998)
  - maybe less (Willis 1996)



Willis (1996) Residual intensities, after MW and point sources were removed

Analysis Topics: GRBs

- **Light curves were not easy with EGRET, owing to the deadtime of the spark chamber; for the LAT they will be covered in the tutorial session this afternoon**
- **Other analyses can proceed as with point sources**

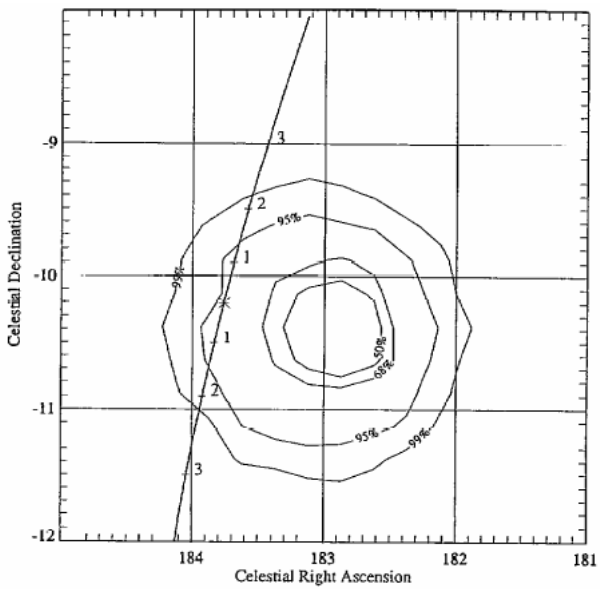


FIG. 3.—The most probable position as determined by the 16 gamma rays imaged in the spark chamber within 30 s after the burst began. The three circles represent the 50%, 68%, 95%, and 99% confidence intervals. The curved line depicts the 1.3 wide determination of the burst position from the Interplanetary Network. The most probable position along the arc is R.A. = 12^h15^m1, decl. = -10.2 J2000 and is shown by an asterisk, and the 1, 2, and 3 σ confidence positions along the arc are also labeled.

Superbowl Burst (GRB 930131)

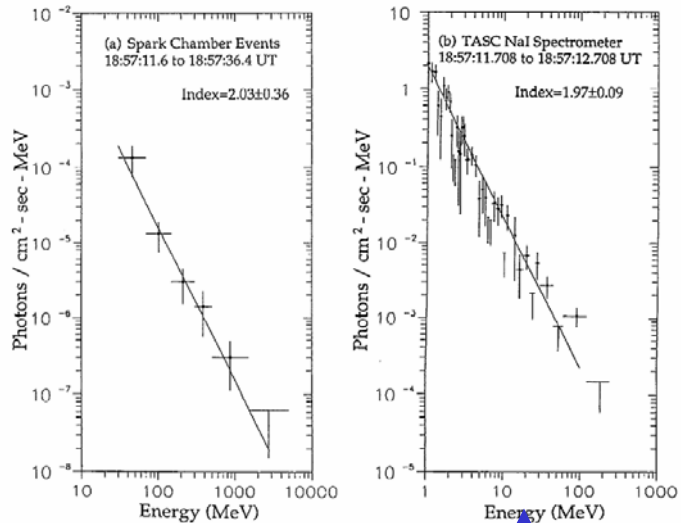
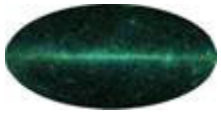


FIG. 2.—(*a*) Energy spectrum of the 16 gamma rays imaged in the spark chamber within 25 s after the burst began. The power-law fit and statistical errors are given by $(7.4 \pm 1.8) \times 10^{-4}(E/147\ \mathrm{MeV})^{-2.03\pm0.36}$ photons ($\mathrm{cm^2\ s\ MeV}$)$^{-1}$. The normalization energy is chosen so that the two errors are uncorrelated. (*b*) Background-subtracted energy spectrum from the Total Absorption Shower Counter for the 1 s time interval beginning at 18:57:11.708 UT. The power-law fit and statistical errors are given by $(1.90 \pm 0.26)(E/1\ \mathrm{MeV})^{-1.97\pm0.09}$ photons ($\mathrm{cm^2\ s\ MeV^{-1}}$).

From the EGRET TASC

Sommer et al. (1994, ApJ, 422, L63) http://adsabs.harvard.edu/cgi-bin/nph-bib_query?bibcode=1994ApJ...422L..63S&db_key=AST



Conclusions

- The DC1 science tools are prototypes, and at DC1 we are only partway through constructing the full Standard Analysis Environment
- Nevertheless, the analysis capabilities available for testing are sufficient for many scientific topics of central interest
- In fact the analyses presented here could in principle be undertaken with the DC1 science tools
- Next: Pat on the underpinnings of the analysis and the analysis algorithms