Planning contents of [DC2] LAT source catalog

What is this?

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Outline

- Mandate – catalog is a deliverable from the LAT team
- History
  - What was done for COS-B & EGRET
  - What we imagined some time ago as the contents (DPWG)
- Walk before get run over
  - Summary of desirable contents
  - Sensible goals for DC2
  - Proposed DC2-era source catalog contents – for discussion
    - Should know better than to plan in public in real time

** Distribution and/or online access to catalog are not considered here; neither is the L2 pipeline processing **

What the Collaboration signed up to do

- **What the AO said:**

> "It is anticipated that the team will develop a catalog of high-energy gamma-ray sources and carry out other science investigations as detailed in their IPI proposal." (§4.2.3)

> ***Conduct all-sky survey.*** This task includes producing all-sky intensity maps, diffuse emission models, source catalogs, and residual maps and analyses. The catalog and maps will be produced and published after 1, 2, and 5 years. (§1.0)

- **What our AO response said:**

(§2.1.5.1)

> The most important goal of the survey is the production of a reliable point source catalog. This requires a well-calibrated, stable instrument. We are committed to producing and maintaining a comprehensive source catalog at the earliest possible stage, and to keeping this catalog up-to-date throughout the mission. We will draw on the experience of our team members who were part of the EGRET catalog efforts. Two keys to producing an optimal catalog are (1) modeling the interstellar and extragalactic diffuse radiation and (2) determining the source locations accurately enough to avoid source confusion. We recognize the criti-

Catalogs in high-energy γ-ray astronomy

- The *entire* COS-B catalog: a 6-page paper

TABLE 1

THE 2CG CATALOG OF GAMMA-RAY SOURCES

SOURCE NAME	NO. OF OBSERVATIONS	POSITION l (degrees)	POSITION b (degrees)	ERROR RADIUS (degrees)	FLUX[a] $E>100$ MeV (10^{-6} photons cm^{-2} s^{-1})	SPECTRAL[b] PARAMETER	COMMENTS	CG SOURCE (Hermsen *et al.* 1977)	IDENTIFICATION	REFERENCES
2CG 006−00.....	3	6.7	−0.5	1.0	2.4	0.39±0.08		...	...	...
2CG 010−31.....	1	10.5	−31.5	1.5	1.2	...		...	...	...
2CG 013+00.....	4	13.7	+0.6	1.0	1.0	0.68±0.14		...	...	...
2CG 036+01.....	3	36.5	+1.5	1.0	1.9	0.27±0.07		...	...	...
2CG 054+01.....	3	54.2	+1.7	1.0	1.3	0.20±0.09		...	...	...
2CG 065+00.....	4	65.7	0.0	0.8	1.2	0.24±0.09		CG 64+0	...	...
2CG 075+00.....	5	75.0	0.0	1.0	1.3	...	could be an extended feature	CG 75−0	...	...
2CG 078+01.....	5	78.0	+1.5	1.0	2.5	...		CG 78+1	...	...
2CG 095+04.....	3	95.5	+4.2	1.5	1.1	...		...	...	...
2CG 121+04.....	3	121.0	+4.0	1.0	1.0	0.43±0.12		CG 121+3		
2CG 135+01.....	3	135.0	+1.5	1.0	1.0	0.31±0.10		CG 135+1	...	...
2CG 184−05.....	4	184.5	−5.8	0.4	3.7	0.18±0.04		CG 185−5	PSR 0531+21	Kniffen *et al.* (1974)
2CG 195+04.....	3	195.1	+4.5	0.4	4.8	0.33+0.04	γ195+5	CG 195−4	...	Thompson *et al.*(1977)
2CG 218−00.....	3	218.5	−0.5	1.3	1.0	0.20±0.08		...	...	...
2CG 235−01.....	2	235.5	−1.0	1.5	1.0	...		...	...	...
2CG 263−02.....	4	263.6	−2.5	0.3	13.2	0.36±0.02		CG 263−2	PSR 0833−45	Thompson *et al.*(1975)
2CG 284−00.....	1	284.3	−0.5	1.0	2.7	...	could be an extended feature	...	...	...
2CG 288−00.....	1	288.3	−0.7	1.3	1.6	...		...	...	...
2CG 289+64.....	2	289.3	+64.6	0.8	0.6	0.15±0.07		CG 291+65	3C 273	Swanenburg *et al.*(1978) Bignami *et al.* (1980)
2CG 311−01.....	2	311.5	−1.3	1.0	2.1	...		CG 312−1	...	...
2CG 333+01.....	3	333.5	+1.0	1.0	3.8	...		CG 333+0	...	...
2CG 342−02.....	5	342.9	−2.5	1.0	2.0	0.36±0.09		...	...	...
2CG 353+16.....	4	353.3	+16.0	1.5	1.1	0.24±0.09		...	ρ Oph	Mayer-Hasselwander *et al.* (1980)
2CG 356+00.....	1	356.5	+0.3	1.0	2.6	0.46±0.12	prob. variable	...	...	...
2CG 359−00.....	3	359.5	−0.7	1.0	1.8	...		...	...	...

[a] Assuming E^{-2} spectra.

[b] Intensity ($E > 300$ MeV)/Intensity ($E > 100$ MeV), assuming E^{-2} spectra calculating both intensities.

Swanenburg et al. (1981)

Catalogs (2)

- **The 3rd EGRET catalog: A 124 page paper, with spectra and source location maps available via ftp**

TABLE 4

THIRD EGRET SOURCE CATALOG

Name	R.A. (deg)	Decl. (deg)	l	b	θ_{95}	F	ΔF	γ	Counts	$(TS)^{1/2}$	VP	ID	Other Name	Note	Reference	z
3EG J0010+7309.....	2.56	73.17	119.92	10.54	0.24	42.3	5.5	1.85	243	9.3	P1234		2EG J0008+7307	@	1,2	
						65.9	12.0	±0.10	99	7.1	34.0		GEV J0008+7304	em		
						34.4	9.8		63	4.1	211.0		SNR CTA 1?			
						<51.7			<23	0.9	319.0		Pulsar in CTA 1?			
						<75.1			<23	1.4	319.5					
						<42.4			<32	1.3	319.+					
						35.2	10.1		55	4.1	401.0					
						<96.8			<73	0.0	P3					
						51.8	7.6		172	8.5	P12					
						26.5	7.7		64	4.0	P34					
3EG J0038−0949.....	9.74	−9.82	112.69	−72.44	0.59	12.0	3.7	2.70	40	4.1	P1234					
						<19.0		±0.44	<16	0.7	9.1					
						21.6	9.0		15	3.4	13.2					
						<11.8			<4	0.0	327.0					
						<26.2			<14	1.0	404.0					
						37.7	16.0		11	3.5	425.0					
						<33.2			<18	1.7	428.0					
						15.4	5.9		24	3.4	P1					
						17.9	6.3		25	3.7	P4					
						11.0	4.9		20	2.8	P34					
3EG J0118+0248.....	19.60	2.81	136.23	−59.36	1.16	20.3	5.8	2.63	35	4.5	21.0	a	2EG J0119+0312	C	1	0.637
						<23.6		±0.66	<10	0.0	28.0		0119+041?			
						<17.8			<13	0.0	26.+					
						<9.3			<12	0.0	317.0					
						<12.8			<13	0.0	425.0					
						13.4	4.3		37	3.7	P1					
						<6.6			<16	0.0	P34					
						5.1	2.7		26	2.1	P1234					
3EG J0130−1758.....	22.70	−17.97	169.71	−77.11	0.97	11.6	3.0	2.50	56	4.9	P1234	a	2EG J0129−1748		1	1.022
						13.8	6.8	±0.29	13	2.6	13.2		0130−171?			
						13.3	5.9		19	2.9	21.0					
						11.8	3.7		40	4.0	P1					
						9.2	5.2		13	2.2	P4					
3EG J0159−3603.....	29.84	−36.06	248.89	−73.04	0.79	9.8	2.8	2.89	47	4.3	P1234		2EG J0159−3557		1	
						<22.8		±0.51	<24	2.0	9.1					
						11.8	6.5		13	2.3	10.0					
						17.4	7.4		16	3.1	13.2					
						<12.7			<5	0.0	404.0					
						<19.1			<27	1.9	428.0					
						12.2	3.8		37	4.1	P1					
						<13.9			<25	1.3	P4					
3EG J0204+1458.....	31.11	14.97	147.95	−44.32	0.97	23.6	5.6	2.23	61	5.3	P1	A	2EG J0204+1512	C	1,3,4	0.405
						24.3	6.2	±0.28	52	4.9	21.0		0202+149			
						52.8	26.4		10	2.8	26.0		4C+15.05			
						<38.3			<11	0.5	28.0					
						24.5	13.1		12	2.4	26.+					
						<9.1			<22	0.4	317.0					

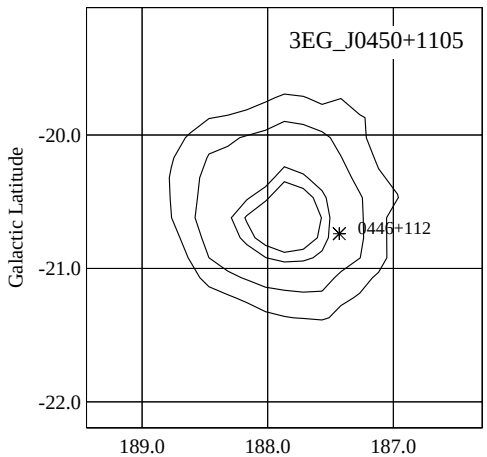
Includes spectral index and flux history where possible

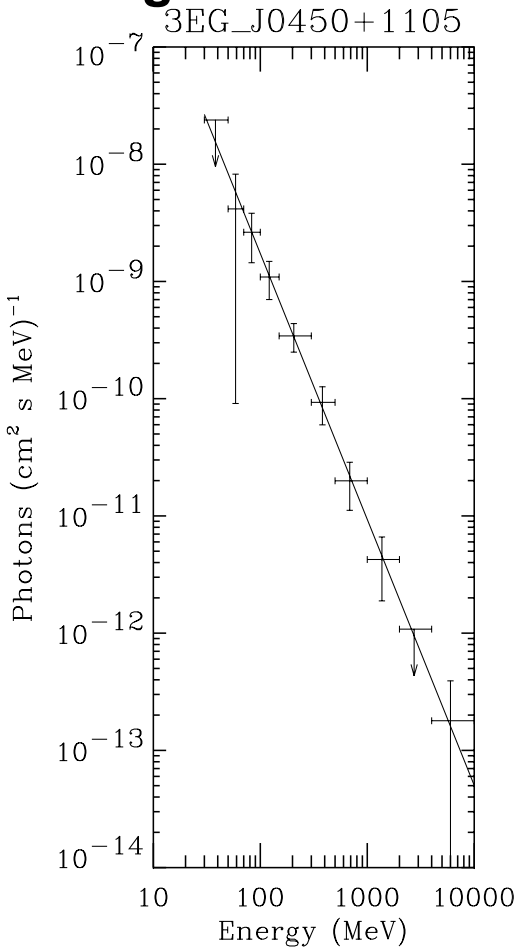
271 sources

Hartman et al. (1999)

Catalogs (3)

- **Ancillary information for 3EG catalog**





From ftp://gamma.gsfc.nasa.gov/pub/THIRD_CATALOG

Data Products Working Group

- **Epoch: 2001-early 2002**
- **Who**

  D. Band, J. Bonnell, C. Meetre, J. Norris (SSC)
  C. Meegan, W. Paciesas, R. Preece (GBM)
  S. Digel, E. do Couto e Silva, P. Nolan, T. Schalk, S. Williams (LAT)
  D. Small (GLAST Mission Operations manager)

- **Invited by the Project to define the science data products that would be exchanged between the MOC, IOCs, and GSSC**
  - **To standardize where possible and sensible, e.g., agree with GBM on representation of time**
  - **To define what depends on what else**

DPWG's guess: 3EG without the VPs

Column Number	Column Name	Units
1	**source name ("telephone number")**	dimensionless
2	**RA**	deg
3	**Dec**	deg
4	**th68 semimajor, semiminor axis, and position angle**	deg
5	**th95 semimajor, semiminor axis, and position angle**	deg
6	**flux (>100 MeV, avg. for the time interval of the catalog)**	cm-2 s-1
7	**flux uncertainty, 1 sigma (as above)**	cm-2 s-1
8	**photon spectral index (avg)**	dimensionless
9	**variability index**	dimensionless
10	**significance (avg)**	dimensionless
11	**significance (peak)**	dimensionless
12	**peak flux (for time interval above?)**	cm-2 s-1
13	**peak flux uncertainty**	cm-2 s-1
14	**time of peak flux (wrt MJDREF)**	s
15	**interval of time**	s
16	**flux history**	cm-2 s-1
17	**flux uncertainty, 1 sigma (as above)**	cm-2 s-1
18	**start times of flux history entries**	s
19	**end times of flux history entries**	s
20	**candidate counterparts**	dimensionless
21	**degrees of confidence for the counterparts**	dimensionless
22	**flags (confusion, low latitude,…)**	dimensionless

Where it is

Average flux & spectral index

Detection significances

Flux history-related quantities

Prospective counterparts

Flags

Approaching reality

- The source catalog is not our attempt to 'do all the science'
  - Include only what can be automated and run in finite time
  - For example, this rules out detailed spectral fits (e.g., searches for spectral breaks); most of the catalog sources will be faint on average anyway
- Clearly, source location information, flux, significance, and spectral index are important basic info, as is a name
- Variability is such a key characteristic of blazars that this is worth careful consideration
  - Regarding variability, an overall index value can be provided
  - Flux histories? I think so, but this could be implemented in many ways [and provided as 'ancillary' information]
- Potential counterparts at other wavelengths
  - E.g., Mattox et al. 2001, Sowards-Emmerd et al. 2003, 2004
  - Counterpart ID is clearly desirable, but raises challenging statistical issues

Approaching reality

- So far, I have been careful to refer to this as the LAT source catalog and not the LAT *point* source catalog
  - Small extended sources will be detected in a search for point sources, and tests for 'extendedness' could be applied at least for simple template sources – like disk or possibly ellipse
  - At some point, not for DC2, we need to decide whether pursuing this is feasible and desirable for the source catalog

Regarding the variability index

- **For EGRET, examples include**

$$\mu = 100 \times \sigma_{\rm sd} \times \langle F \rangle^{-1}$$

Torres et al. (2001)

dispersion of flux measurements

$$\delta \equiv \frac{\sigma}{\mu}$$

Nolan et al. (2003)

average flux

- **Some technical differences, but basically both are dispersion of flux relative to the average**
  - **Careful treatment of upper limits is essential**
  - **Also, the variability index was for the time scale relevant for EGRET viewing periods (~weeks)**
- **For the LAT, sampling of each source will be much better**
  - **Timescale/sensitivity tradeoff needs to be investigated, or perhaps variability indices calculated for a range of time scales**

Proposed catalog contents for DC2

- **Starting point for discussion**

Name

Location & error ellipse

Flux, flux uncertainty

Significance [peak?]

Spectral index [hardness ratio?]

Variability index

Counterparts ranked by positional coincidence relative to error ellipse