フェルミガンマ線望遠鏡データの見方

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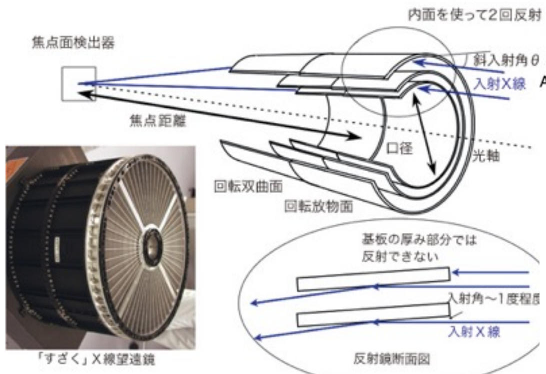
多波長データ使い方研究会

Introduction

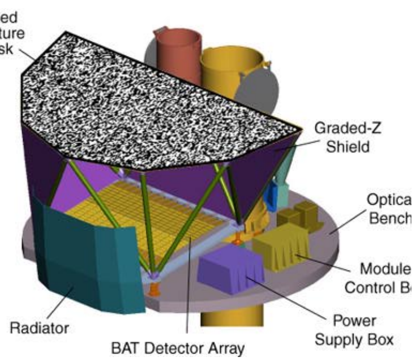
- X線ガンマ線観測では、撮像、分光、測光を一度に行う
- 光子ひとつひとつのエネルギー、到来方向を計測できる
- 波長域によって様々な光子の相互作用過程を利用し、感度向上

keV　　MeV　　GeV

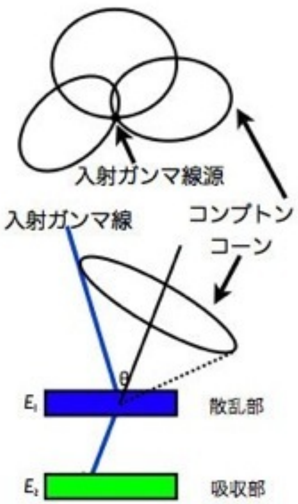
光電吸収　　コンプトン散乱　　対生成



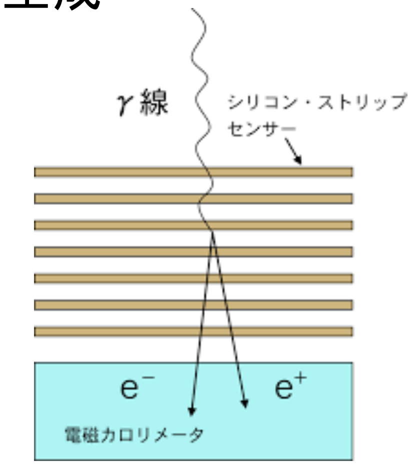
X線の全反射を利用し、集光
CCDなどで光電吸収させ、
測光分光



鏡では集光できない硬X線
や軟ガンマ線は
符号化マスクなどで作った
パターンを光電吸収で
測光分光



コンプトン散乱を利用し
、その運動学から
到来方向を制限



対生成反応で生じた電
子用電子のトラックから
到来方向を制限
カロリメータで測光分光

Switf/XRT, すざくXRTなど　Swift-BAT, INTEGRAL-IBISなど　ひとみ SGD など　CGRO-EGRET, AGILE, Fermi-LAT など

1.1 Fermi Gamma-ray Space Telescope

LAT

Silicon-Strip detectors
- Identification &direction measurement of γ-rays

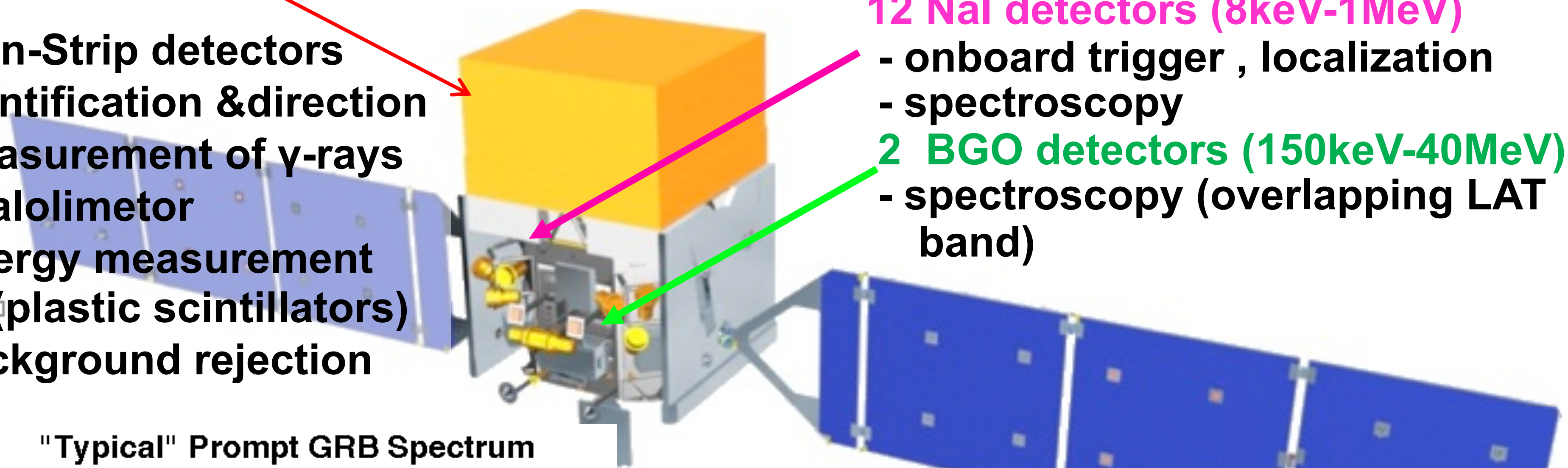
CsI calolimetor
- Energy measurement

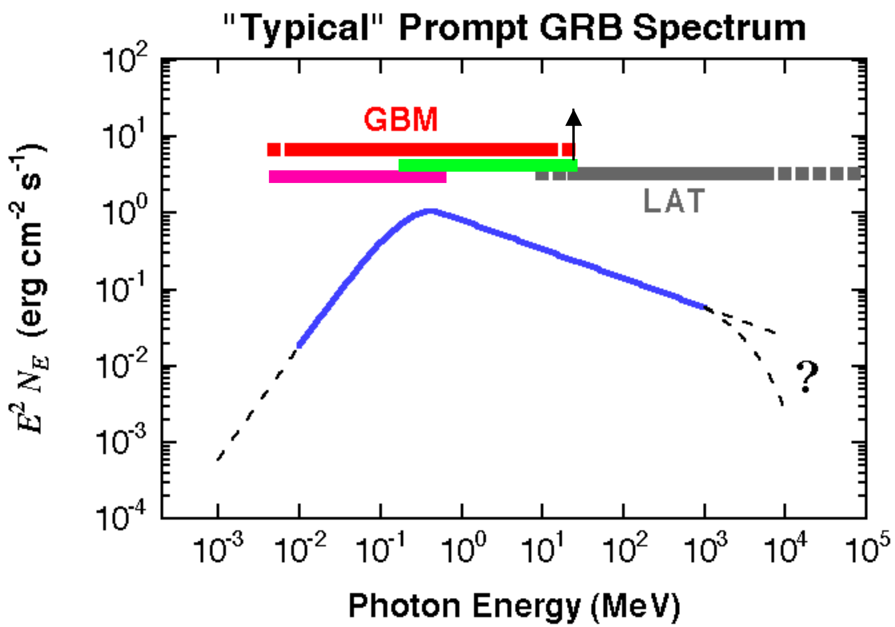
ACD (plastic scintillators)
- background rejection

Gamma-ray Burst Monitor (GBM)

12 NaI detectors (8keV-1MeV)
- onboard trigger , localization
- spectroscopy

2 BGO detectors (150keV-40MeV)
- spectroscopy (overlapping LAT band)





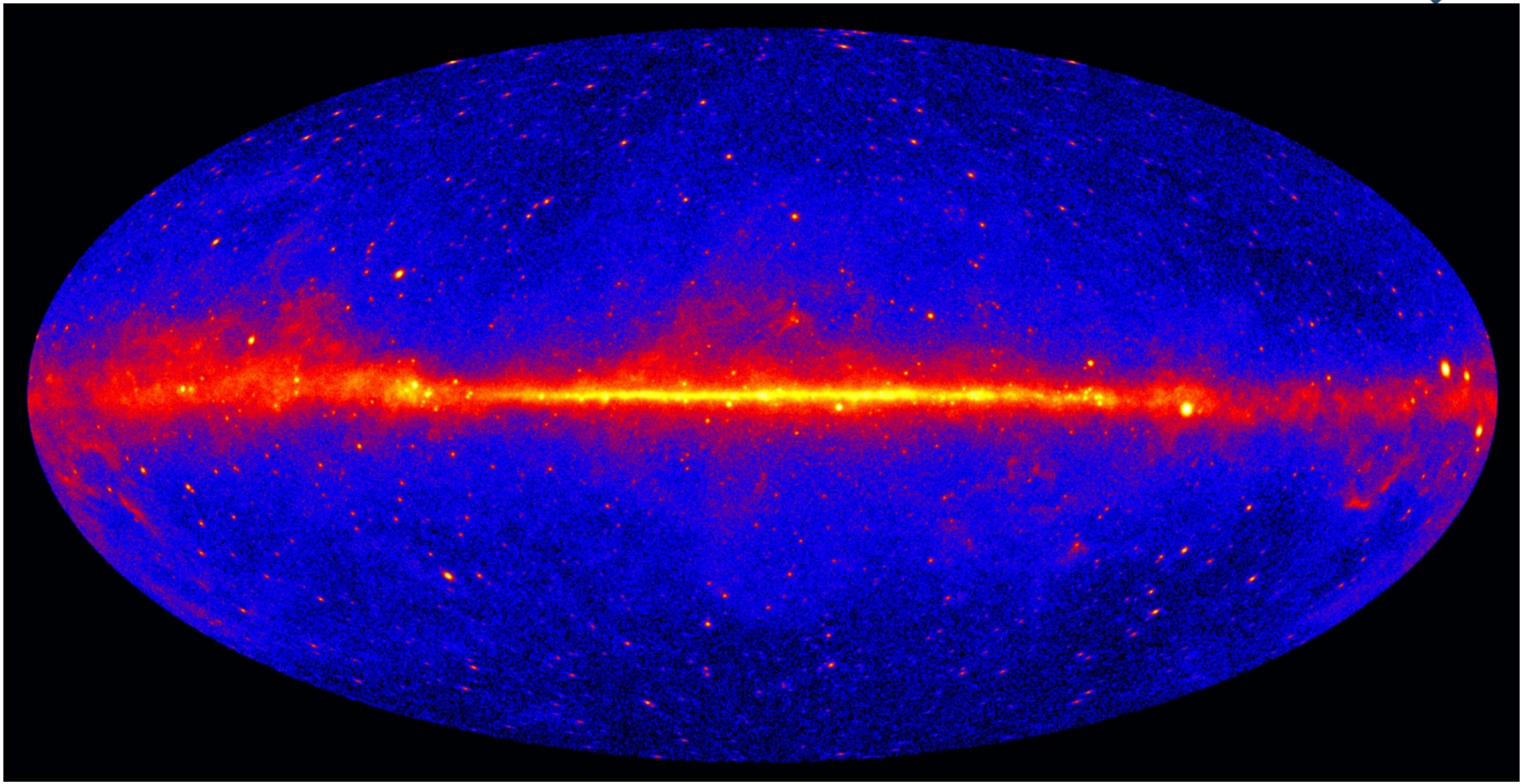
- -Efficient observing mode
- -Wide FoV
- -Low deadtime
- -Large effective area
- -Good angular resolution
- -Energy coverage

LAT specification and performance

Quantity	LAT (Minimim Spec.)	EGRET
Energy Range	20 MeV - 300 GeV	20 MeV - 30 GeV
Peak Effective Area [1]	> 8000 cm^2	1500 cm^2
Field of View	> 2 sr	0.5 sr
Angular Resolution [2]	< 3.5° (100 MeV) < 0.15° (>10 GeV)	5.8° (100 MeV)
Energy Resolution [3]	< 10%	10%
Deadtime per Event	< 100 μs	100 ms
Source Location Determination [4]	< 0.5'	15'
Point Source Sensitivity [5]	$< 6 \times 10^{-9}$ cm^{-2} s^{-1}	$\sim 10^{-7}$ cm^{-2} s^{-1}

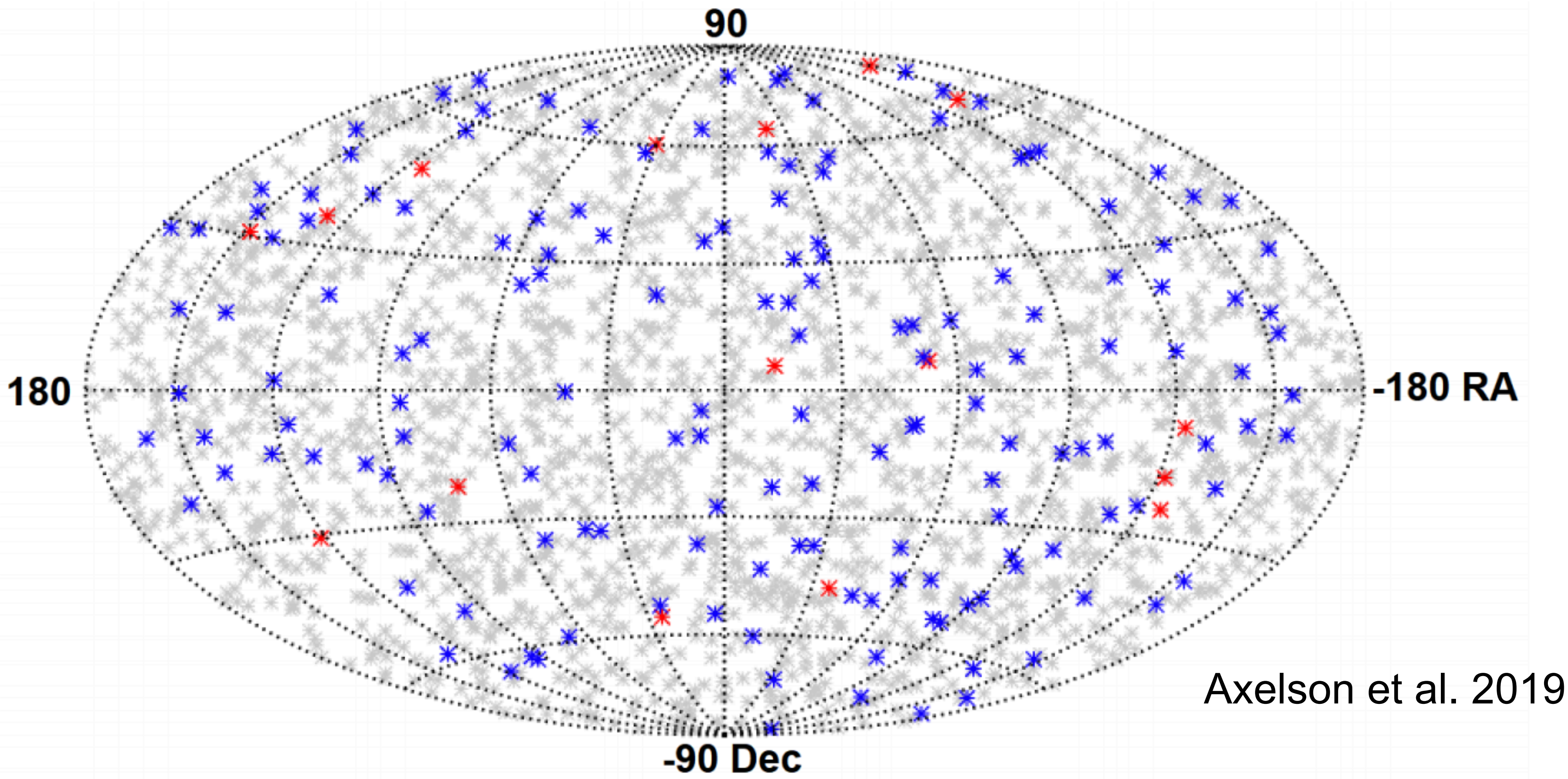
✓ およそ90分で全天をスキャン観測
(2018年3月の太陽パネル異常により、運用に制限。全天スキャンに最速3時間
https://fermi.gsfc.nasa.gov/ssc/observations/types/post_anomaly/)
✓ 1世代前のEGRET検出器(CGRO)に比べて、高感度、広視野、高位置分解能により多数のガンマ線天体を検出

LAT all-sky survey



10年の観測でおよそ5000のガンマ線点源を検出。うちおよそ3000がAGN(ほぼブレーザー)
Abdllahi et al. 2019

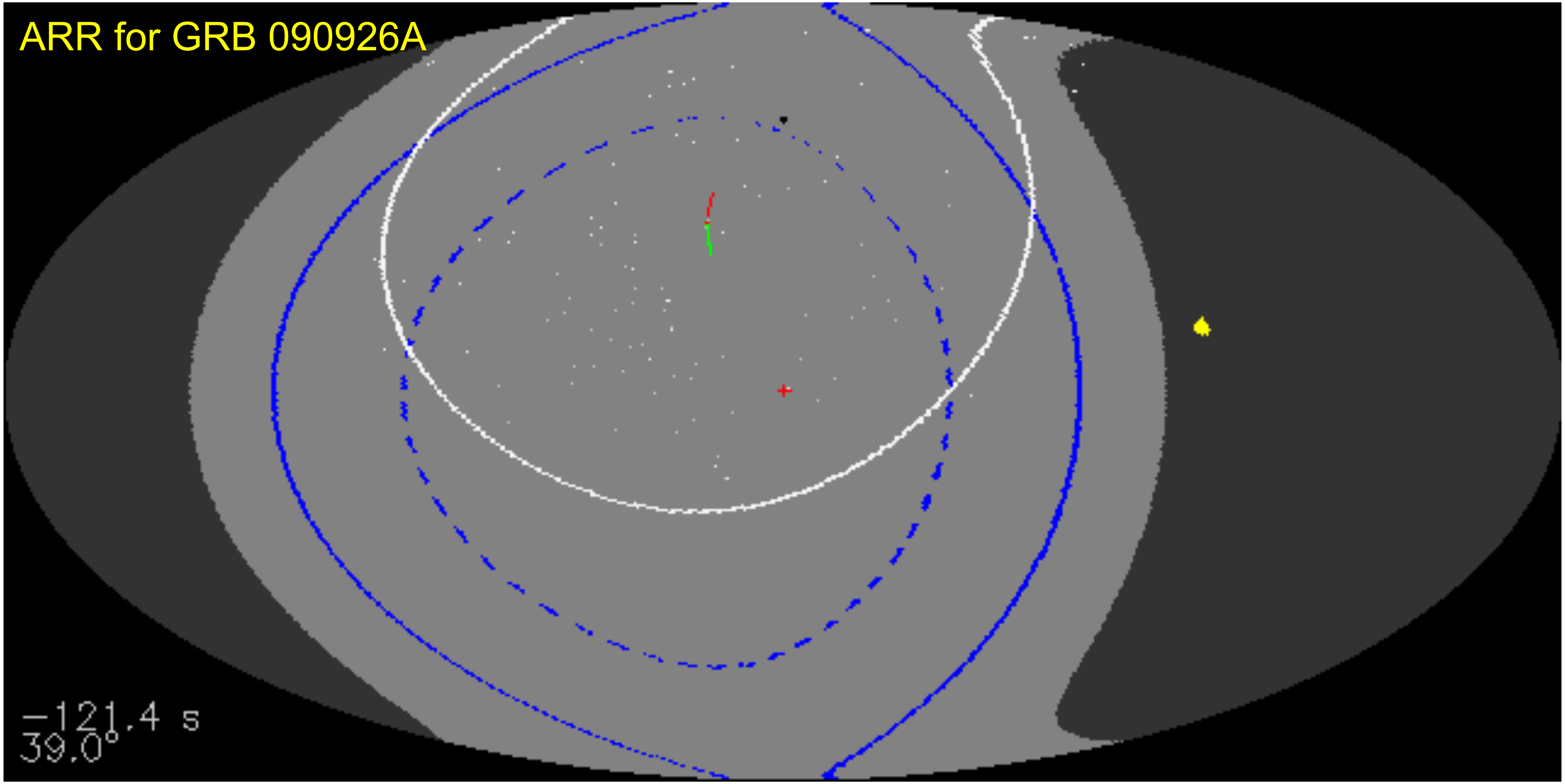
Fermi GRB observations



- The LAT detected 186 GRBs up to 2018 Aug. (1~2 per month)
  - ~Half with more accurate follow-up localisations by Swift and ground-based observatories (GROND, Gemini-S, Gemini-N, VLT)
  - 27 redshift measurements, from z=1.406 (GRB 160625B) to z=4.35 (GRB 080916C)

1.3.2 Autonomous Repoint Request (ARR)

GBM FSW triggers Autonomous Repoint Request (ARR)
S/C slew to the GBM position up to 2.5 hours subject to earth-limb constraint



ARR triggered for almost a half of LAT events ➔ helpful for extended emission search
2018年3月のトラブル以降disable中。。

Fermi data for MM transients

- フェルミは GeV sky を常時モニタ (3時間でおよそ全天をカバー)
- 多数のブレーザーを検出
- ガンマ線バーストからのプロンプト放射、残光放射をGeV領域で観測
- データは即時公開 (タイミングによっては3-4時間ぐらいでサーバーに置かれる)

ブレーザーやGRBといった突発現象における多波長観測で重要な役割
- ブレーザーフレアのメカニズム
- GRBの多波長ガンマ線スペクトルから探る放射機構やジェットの物理
- ニュートリノや重力波の電磁波対応天体探査

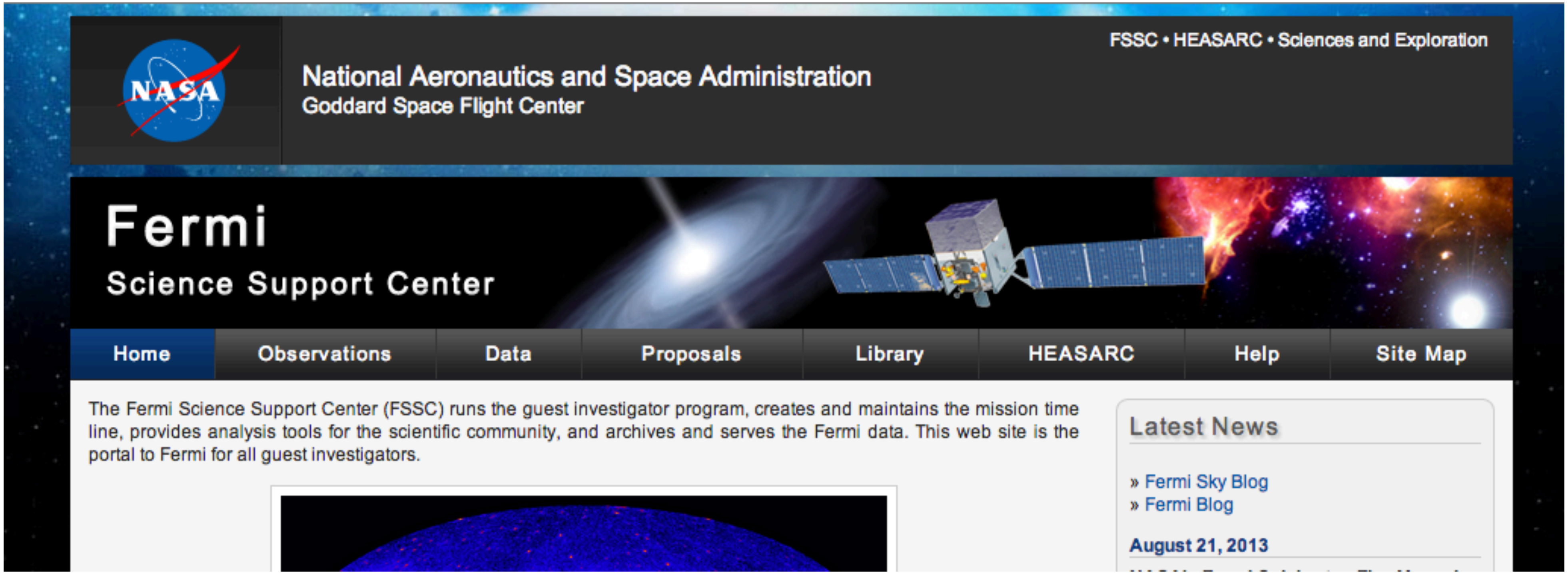
➢ フェルミチームで用意してるQLプロダクトの入手
➢ 簡単なデータ解析により、自分で興味ある天体がガンマ線で増光しているかどうかチェック

ぐらいができるとよいのではないかと思います。
(残念ながら、昨日みたいな on-demand なシステムはない(と思う)
ので頑張って手を動かします)

2. Fermi のデータはどうやって解析するの?
～クイックルックデータ編

すべてのはじまりはFSSCから

Fermi Science Support Center (FSSC) : 全てはここから始まる!
http://fermi.gsfc.nasa.gov/ssc/



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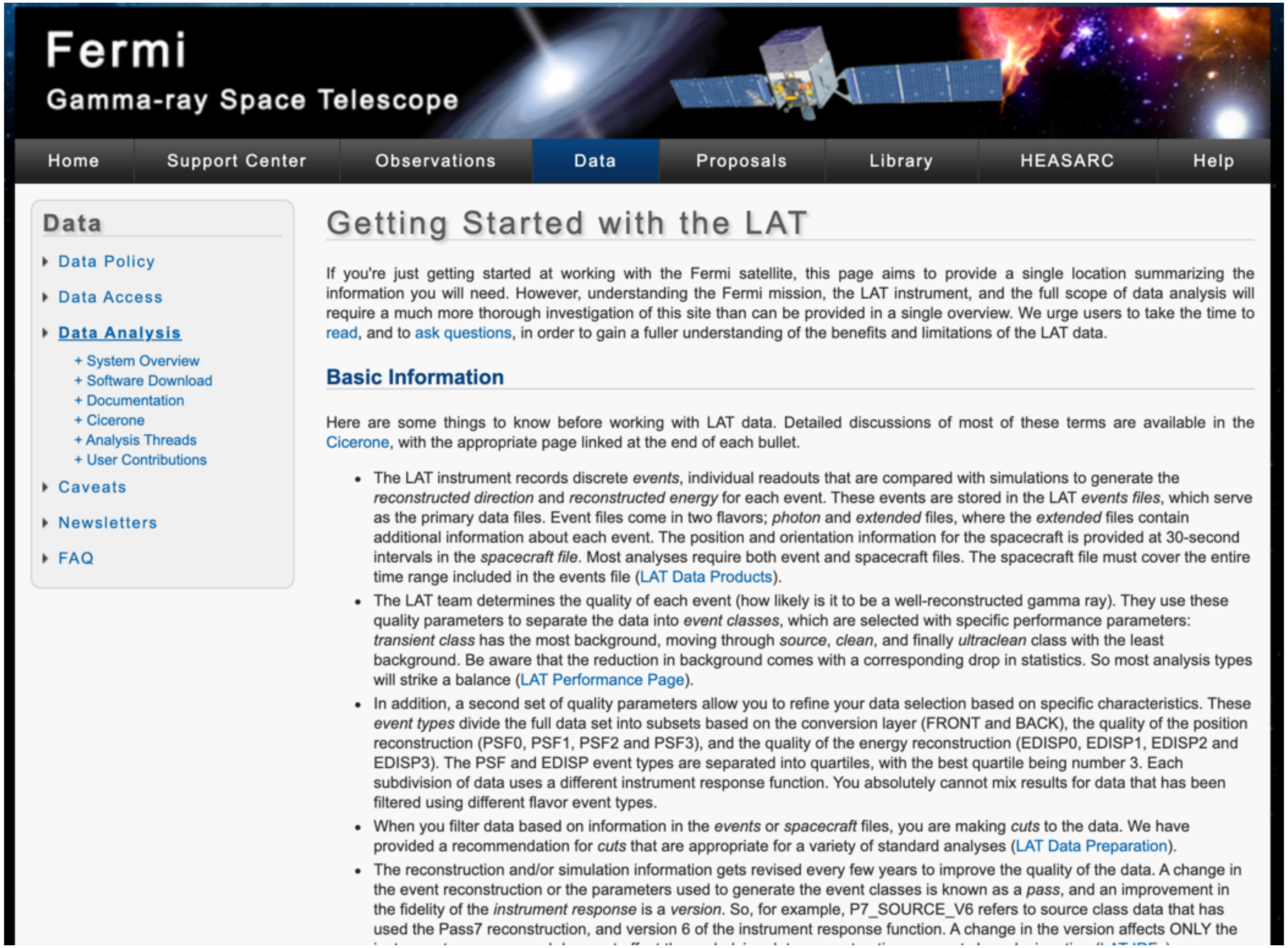
https://fermi.gsfc.nasa.gov/ssc/data/analysis/LAT_essentials.html



Fermi
Gamma-ray Space Telescope

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- Caveats
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Getting Started with the LAT

If you're just getting started at working with the Fermi satellite, this page aims to provide a single location summarizing the information you will need. However, understanding the Fermi mission, the LAT instrument, and the full scope of data analysis will require a much more thorough investigation of this site than can be provided in a single overview. We urge users to take the time to read, and to ask questions, in order to gain a fuller understanding of the benefits and limitations of the LAT data.

Basic Information

Here are some things to know before working with LAT data. Detailed discussions of most of these terms are available in the Cicerone, with the appropriate page linked at the end of each bullet.

- The LAT instrument records discrete *events*, individual readouts that are compared with simulations to generate the *reconstructed direction* and *reconstructed energy* for each event. These events are stored in the LAT *events files*, which serve as the primary data files. Event files come in two flavors; *photon* and *extended* files, where the *extended* files contain additional information about each event. The position and orientation information for the spacecraft is provided at 30-second intervals in the *spacecraft file*. Most analyses require both event and spacecraft files. The spacecraft file must cover the entire time range included in the events file (LAT Data Products).
- The LAT team determines the quality of each event (how likely is it to be a well-reconstructed gamma ray). They use these quality parameters to separate the data into *event classes*, which are selected with specific performance parameters: *transient class* has the most background, moving through *source*, *clean*, and finally *ultraclean* class with the least background. Be aware that the reduction in background comes with a corresponding drop in statistics. So most analysis types will strike a balance (LAT Performance Page).
- In addition, a second set of quality parameters allow you to refine your data selection based on specific characteristics. These *event types* divide the full data set into subsets based on the conversion layer (FRONT and BACK), the quality of the position reconstruction (PSF0, PSF1, PSF2 and PSF3), and the quality of the energy reconstruction (EDISP0, EDISP1, EDISP2 and EDISP3). The PSF and EDISP event types are separated into quartiles, with the best quartile being number 3. Each subdivision of data uses a different instrument response function. You absolutely cannot mix results for data that has been filtered using different flavor event types.
- When you filter data based on information in the *events* or *spacecraft* files, you are making *cuts* to the data. We have provided a recommendation for *cuts* that are appropriate for a variety of standard analyses (LAT Data Preparation).
- The reconstruction and/or simulation information gets revised every few years to improve the quality of the data. A change in the event reconstruction or the parameters used to generate the event classes is known as a *pass*, and an improvement in the fidelity of the *instrument response* is a *version*. So, for example, P7_SOURCE_V6 refers to source class data that has used the Pass7 reconstruction, and version 6 of the instrument response function. A change in the version affects ONLY the

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https://fermi.gsfc.nasa.gov/ssc/data/analysis/LAT_essentials.html

High-level Information

There is an abundance of information available to you, including documentation and high-level data products. Here are some items that may be useful for you, and are worth reviewing before diving into the data analysis:

さまざまなカタログデータ

- Most Recent Source Catalogs:
  - Fourth Point Source Catalog (aka 4FGL-DR2)
  - Second Pulsar Catalog
  - First Catalog of LAT GRBs
  - Third Catalog of High-Energy (>10 GeV) Sources (aka 3FHL)

クイックルックデータ

- Quick-Look Data Products:
  - Bright Monitored Sources — Daily and Weekly light curves for sources that have flared above 1×10^{-6} ph cm^{-2} s^{-1} during the lifetime of the mission.
  - Aperture Photometry Light Curves — For all sources in the 3FGL catalog.
  - List of LAT GRBs
- Available documentation:
  - Cicerone — In-depth discussion of the mission, the instruments, the data and the analysis methods.
  - Analysis Overview — High-level description of the individual Fermitools and their use in standard analyses.
  - Reference Manual — Online versions of the fhelp (man page) for each tool.
  - Analysis Threads — Cookbook-like examples of various analyses designed to walk you through the process step-by-step.
  - The talks and tutorials from the Fermi Summer Schools are an excellent resource. See the github repository.

例えば、4FGL-DR2

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Data

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  - + LAT Catalog
  - + LAT Data Queries
  - + LAT Query Results
  - + LAT Weekly Files
  - + GBM Data
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LAT 10-year Source Catalog (4FGL-DR2)

The Large Area Telescope (LAT) on board NASA's *Fermi* Gamma-ray Space Telescope (launched June 11, 2008) surveys the entire sky each day. This web page presents an incremental version (4FGL-DR2, for Data Release 2) of the fourth full catalog of LAT sources, based on 10 years of survey data in the 50 MeV-1 TeV energy range. For a full explanation about the catalog and its construction see the DR2 document. The data analysis is identical to 4FGL, so the reference is still the 4FGL paper . Please cite both documents when you use this data release.

The source designation is the same as 4FGL, 4FGL JHHMM.m+DDMM(c,e,i,s) where the 4 refers to the fourth catalog (1FGL was released at 1 year, 2FGL at 2 years, and 3FGL at 4 years) and FGL represents Fermi Gamma-ray LAT. In 4FGL-DR2, the "DataRelease" column set to either 1 or 2 allows telling new sources from original 4FGL sources. The optional "e", "i" and "s" designators are explained in the caveats below. The 4FGL-DR2 does not include 2-month light curves that were in the 4FGL catalog.

LAT Catalog Data Products

The LAT 10-year Source Catalog is currently available as a FITS file to be used for data analysis within the Fermitools. A BROWSE table containing a searchable version of the catalog is also available. Supporting tools and documentation have been provided and are linked below.

- LAT 10-year Source Catalog (4FGL-DR2 in FITS format)
- LAT 10-year Source Catalog (BROWSE table - Ongoing update)
- LAT 10-year Source Catalog (XML format)
- LAT 10-year Source Catalog Document
- Map of the 10-year LAT Detection Threshold (in FITS format)
- Python script (and instructions) to convert the 4FGL-DR2 source list into an XML file.
- DS9 Region Files:
  - 4FGL-DR2 positions (as crosses) and source names
  - 4FGL-DR2 95% error ellipses (no source names)
  - 4FGL-DR2 association positions (as crosses) and names
- Extended Source template archive – Gzipped archive of extended source templates used in the catalog analysis.
- Sun/Moon template model files: Only for use with the 10-year data set!
  - Sun/Moon spatial template (Inverse Compton) for the time period included in the 10-year catalog
  - Sun/Moon spatial template (Disk Component) for the time period included in the 10-year catalog
- Plots of spectral fits for 4FGL-DR2 sources: Gzipped file
- Plots of 1-year light curves for 4FGL-DR2 sources: Gzipped file
- Aperture photometry light curves and power spectra

We emphasize several important points and caveats regarding use of the 4FGL-DR2 catalog:

例えば、4FGL-DR2

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fv: Binary Table of gll_psc_v26.fit[1] in /Users/ohno/Downloads/

File Edit Tools Help

Select	Source_Name	DataRelease	RAJ2000	DEJ2000	GLON	GLAT	Conf_68_SemiMajor	Conf_68_SemiMinor	Conf_68_PosAng	Conf_95_SemiMajor	Conf_95_SemiMinor	Conf_95_PosAng
	18A	I	E	E	E	E	E	E	E	E	E	E
All			deg	deg	deg	deg	deg	deg	deg	deg	deg	deg
Invert	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify	Modify
1	4FGL J0000.3-7355	1	0.0983	-73.9220	307.7090	-42.7295	0.0324	0.0315	-62.700	0.0525	0.0510	-62.700
2	4FGL J0000.5+0743	2	0.1375	7.7273	101.6565	-53.0295	0.0945	0.0700	-10.220	0.1533	0.1135	-10.220
3	4FGL J0001.2+4741	1	0.3126	47.6859	114.2502	-14.3381	0.0369	0.0332	-45.900	0.0598	0.0538	-45.900
4	4FGL J0001.2-0747	1	0.3151	-7.7971	89.0327	-67.3050	0.0184	0.0176	64.100	0.0299	0.0285	64.100
5	4FGL J0001.5+2113	1	0.3815	21.2183	107.6494	-40.1677	0.0260	0.0240	-60.520	0.0422	0.0389	-60.520
6	4FGL J0001.6-4156	1	0.4165	-41.9425	334.2263	-72.0285	0.0427	0.0324	44.090	0.0692	0.0525	44.090
7	4FGL J0002.1-6728	1	0.5378	-67.4746	310.0849	-48.9635	0.0217	0.0192	52.510	0.0352	0.0311	52.510
8	4FGL J0002.1+6721c	1	0.5419	67.3578	118.2035	4.9395	0.0956	0.0685	-82.100	0.1550	0.1111	-82.100
9	4FGL J0002.3-0815	2	0.5937	-8.2652	89.0435	-67.8483	0.0418	0.0334	56.690	0.0677	0.0541	56.690
10	4FGL J0002.4-5156	2	0.6131	-51.9355	319.9995	-63.5390	0.0965	0.0598	15.000	0.1564	0.0970	15.000
11	4FGL J0002.7+7220	2	0.6786	72.3479	119.2088	9.8293	0.0686	0.0493	27.570	0.1112	0.0799	27.570
12	4FGL J0002.8+6217	1	0.7201	62.2905	117.3204	-0.0510	0.0212	0.0202	3.840	0.0343	0.0328	3.840
13	4FGL J0003.1-5248	1	0.7817	-52.8071	318.9899	-62.7889	0.0205	0.0188	-41.610	0.0333	0.0305	-41.610
14	4FGL J0003.2+2207	1	0.8058	22.1302	108.4385	-39.3808	0.0601	0.0533	-75.210	0.0974	0.0864	-75.210
15	4FGL J0003.3+2511	1	0.8323	25.1912	109.3816	-36.4115	0.0630	0.0556	63.580	0.1021	0.0901	63.580
16	4FGL J0003.3-1928	1	0.8465	-19.4676	65.1978	-76.5810	0.0437	0.0379	-51.750	0.0708	0.0614	-51.750
17	4FGL J0003.3-5905	1	0.8483	-59.0952	314.2390	-56.9659	0.0796	0.0479	25.980	0.1291	0.0776	25.980
18	4FGL J0003.6+3059	1	0.9045	30.9898	111.0045	-30.7720	0.0500	0.0440	-83.550	0.0810	0.0714	-83.550
19	4FGL J0003.9-1149	1	0.9986	-11.8251	84.5954	-71.0751	0.0323	0.0308	-31.930	0.0524	0.0499	-31.930

Go to: Edit cell:

- 4FGL-DR2 positions (as crosses) and source names
  - 4FGL-DR2 95% error ellipses (no source names)
  - 4FGL-DR2 association positions (as crosses) and names
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We emphasize several important points and caveats regarding use of the 4FGL-DR2 catalog:

QLライトカーブ

過去に明るくなったソースに着目し
Day/weekスケールでライトカーブを提供

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Monitored Source List Light Curves

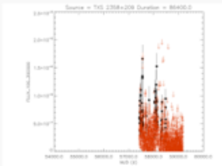
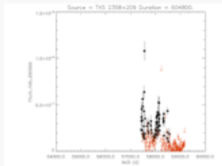
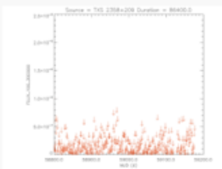
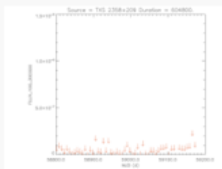
The LAT team monitors flux values for a number of bright sources and transient sources that have shown flares during the mission. (See up-to-date weekly reports on flaring sources at the Fermi-LAT Flare Advocate Blog.) As sources cross the monitoring flux threshold of 1×10^{-6} cm^{-2}s^{-1}, they are added to the monitored source list. (The initial flux threshold was 2×10^{-6} cm^{-2}s^{-1}, but this value was lowered in June 2009.) In addition to the light curves below, the flux values in several bands are available via Browse. This list will continue to grow as the mission progresses.

PLEASE NOTE: The tabulated fluxes are derived at the LAT Instrument Science Operations center in an automated analysis to produce results quickly to facilitate follow-up multiwavelength observations of flaring sources. The table of released fluxes will be updated as analysis and calibrations improve.

These early flux estimates **do not include systematic uncertainties and do not have an absolute flux calibration.** Use of these data as absolute flux measurements for constraining models or for comparison to other data is strongly discouraged at this time. In addition to overall normalization uncertainties, source fluxes may have variations of up to 10% due to currently-uncorrected dependencies of the gamma-ray detection efficiency on variations of the particle background in orbit. Please note that these results are produced using preliminary instrument response functions and calibrations. The quality and stability of these results will improve when updated calibrations become available over the coming months.

Note: Due to a software error, flux upper limits are not available for dates between approximately 2010-09-14 to 2011-02-21.

A detailed description of the data included in these files can be found here.

Source	Daily LC	Weekly LC
TXS 2358+209 (RA = 0.385000, Dec = 21.2270) • Daily Light Curve • Daily Light Curve (1yr) • Daily Light Curve Fits File • Weekly Light Curve • Weekly Light Curve (1yr) • Weekly Light Curve Fits File		
	 (most recent 1-year data segment)	 (most recent 1-year data segment)

解析に用いるレスポンスが簡易版

解析時間スケールは限られるが
全ての点源をモニタ

LAT 3FGL Catalog Aperture Photometry Lightcurves

We provide here aperture photometry light curves of all sources in the Fermi Large Area Telescope Third Source Catalog (3FGL) with 30 day time resolution. The light curves and plots will generally be updated weekly. We also plot power spectra of the light curves for periods between 65 days and the length of the light curve, with a frequency oversampling of a factor of 5.

Some caveats:

- These light curves are intended to provide a quick way to inspect gross features in the long-term light curves. They are unlikely to be directly useful for detailed scientific analysis.
- They are not background subtracted.
- The apertures will contain photons from nearby sources.

A thread describing the steps involved in aperture photometry of LAT data can be found here. A script to perform aperture photometry (aperture.pl) is available here.

The columns in the data files are:

1. Time of center of bin (MJD)
2. Count rate in the aperture in photons cm^-2 s^-1
3. Count rate error based on the observed number of photons. This is used in the plots
4. Half-width of the time bin in days.
5. Count rate error based on the relative exposure of the time bin.
6. Exposure in cm^2 s.
7. Line number. This will not be present in later versions of these files.

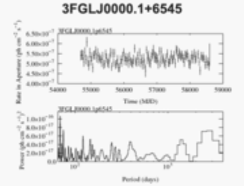
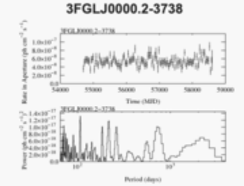
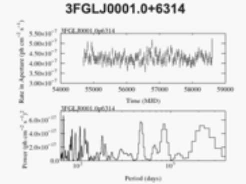
The aperture photometry used:

- 1 degree radius apertures
- 100 MeV to 200 GeV
- Data are P8 Source class (evclass=128), front+back (evtype=3)
- A zenith limit of 105 degrees.
- A rock limit of 90 degrees. (i.e. no filtering on this.)
- A bore-sight limit of 180 degrees. (i.e. no filtering on this.)
- Times when a source was closer than 5 degrees from the Sun are excluded.

For caveats on period detection in LAT light curves please see here.

Flaring Sources in the Aperture Photometry Lightcurves

RA Range:
00-01 | 02-03 | 04-05 | 06-07 | 08-09 | 10-11 | 12-13 | 14-15 | 16-17 | 18-19 | 20-21 | 22-23

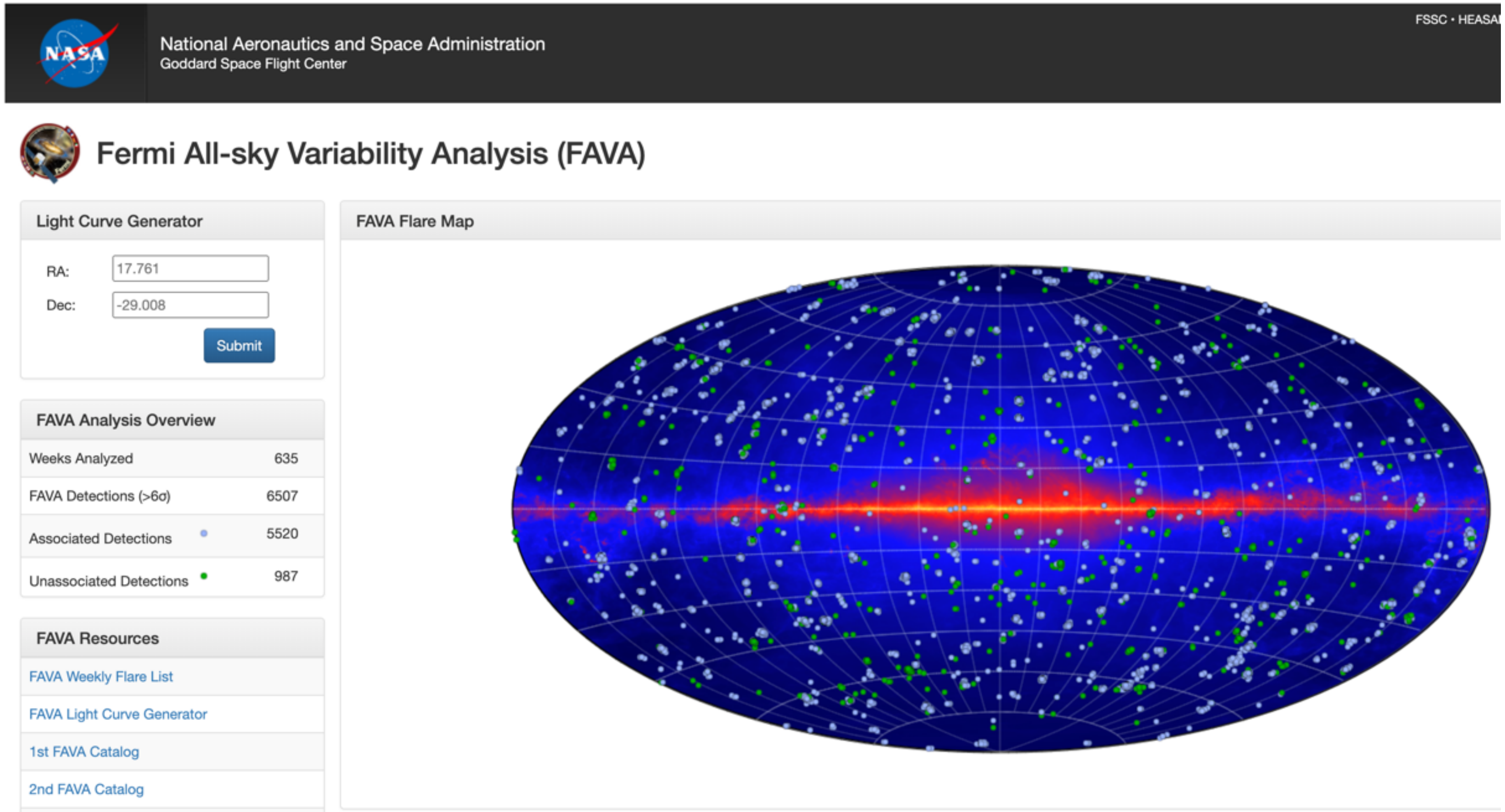
3FGLJ0000.1+6545	3FGLJ0000.2-3738	3FGLJ0001.0+6314
		

Aperture photometry (となりのソースからの混入など不定性あり)

Fermi All-sky Variability Analysis (FAVA)

全天データを総解析し、一週間ごとに変動天体が現れないか監視 (Abdollahi et al. 2017)

https://fermi.gsfc.nasa.gov/ssc/data/access/lat/FAVA/index.php



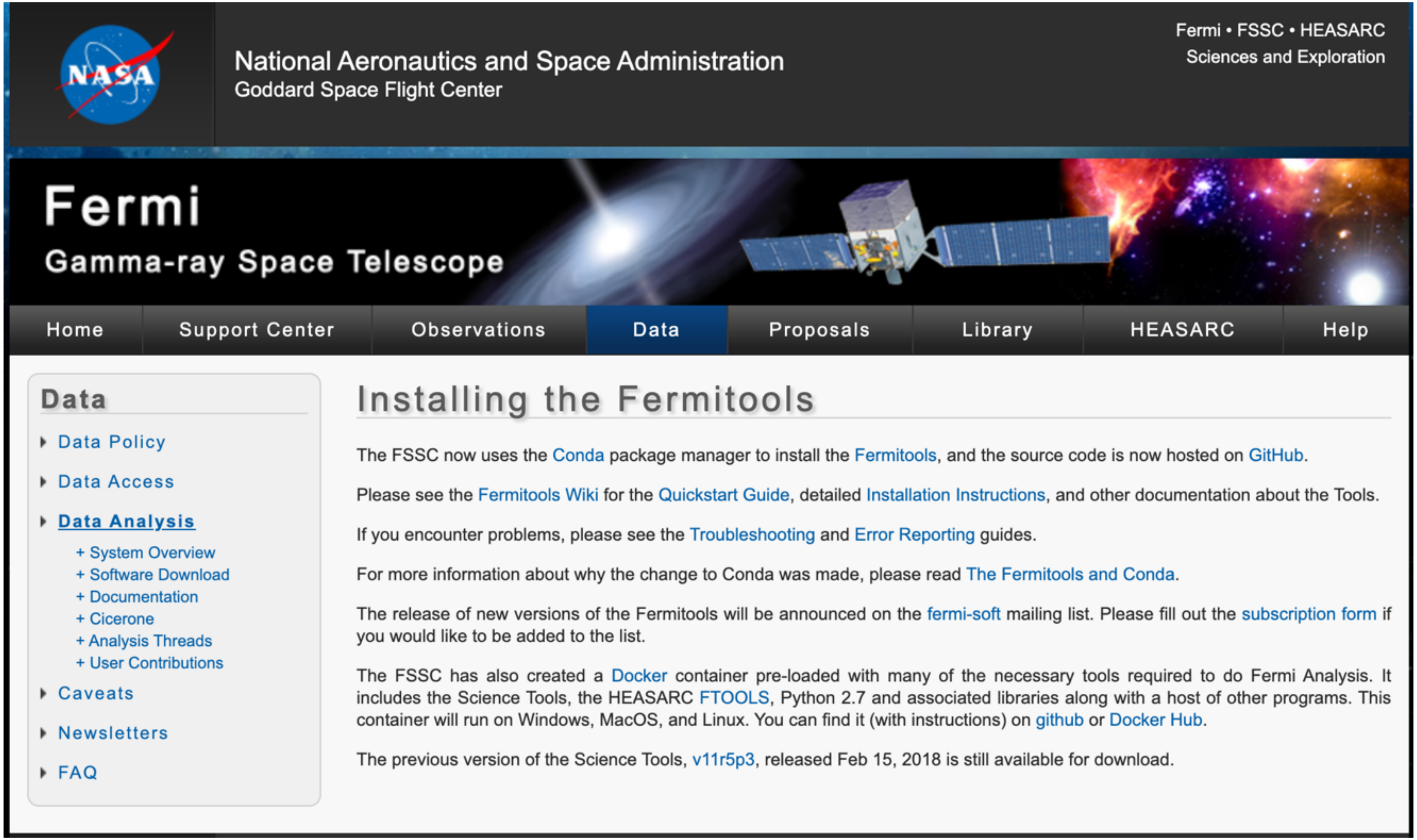
自分で任意の領域のライトカーブを作ることもできる
(やはり preliminary であることに注意)

突発天体との対応などは、急ぎでなければ
フェルミチームの提供するクイックルックデータ
でもできそう。
ただ、急ぎの場合や、それで論文を書きたい場合は
やはり真面目に解析をしないといけない
(公開カタログのデータも論文に使えるが、情報は
限られる)

2. Fermi のデータはどうやって解析するの?
〜データ解析編

2.1 Fermitools

Fermi (特にLAT)の基本的な解析ツールパッケージ。これがないと始まらない
FSSC -> Data -> Data Analysis -> Software Download


National Aeronautics and Space Administration
Goddard Space Flight Center

Fermi • FSSC • HEASARC
Sciences and Exploration

Fermi
Gamma-ray Space Telescope

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Data

- Data Policy
- Data Access
- Data Analysis
  - + System Overview
  - + Software Download
  - + Documentation
  - + Cicerone
  - + Analysis Threads
  - + User Contributions
- Caveats
- Newsletters
- FAQ

Installing the Fermitools

The FSSC now uses the Conda package manager to install the Fermitools, and the source code is now hosted on GitHub.

Please see the Fermitools Wiki for the Quickstart Guide, detailed Installation Instructions, and other documentation about the Tools.

If you encounter problems, please see the Troubleshooting and Error Reporting guides.

For more information about why the change to Conda was made, please read The Fermitools and Conda.

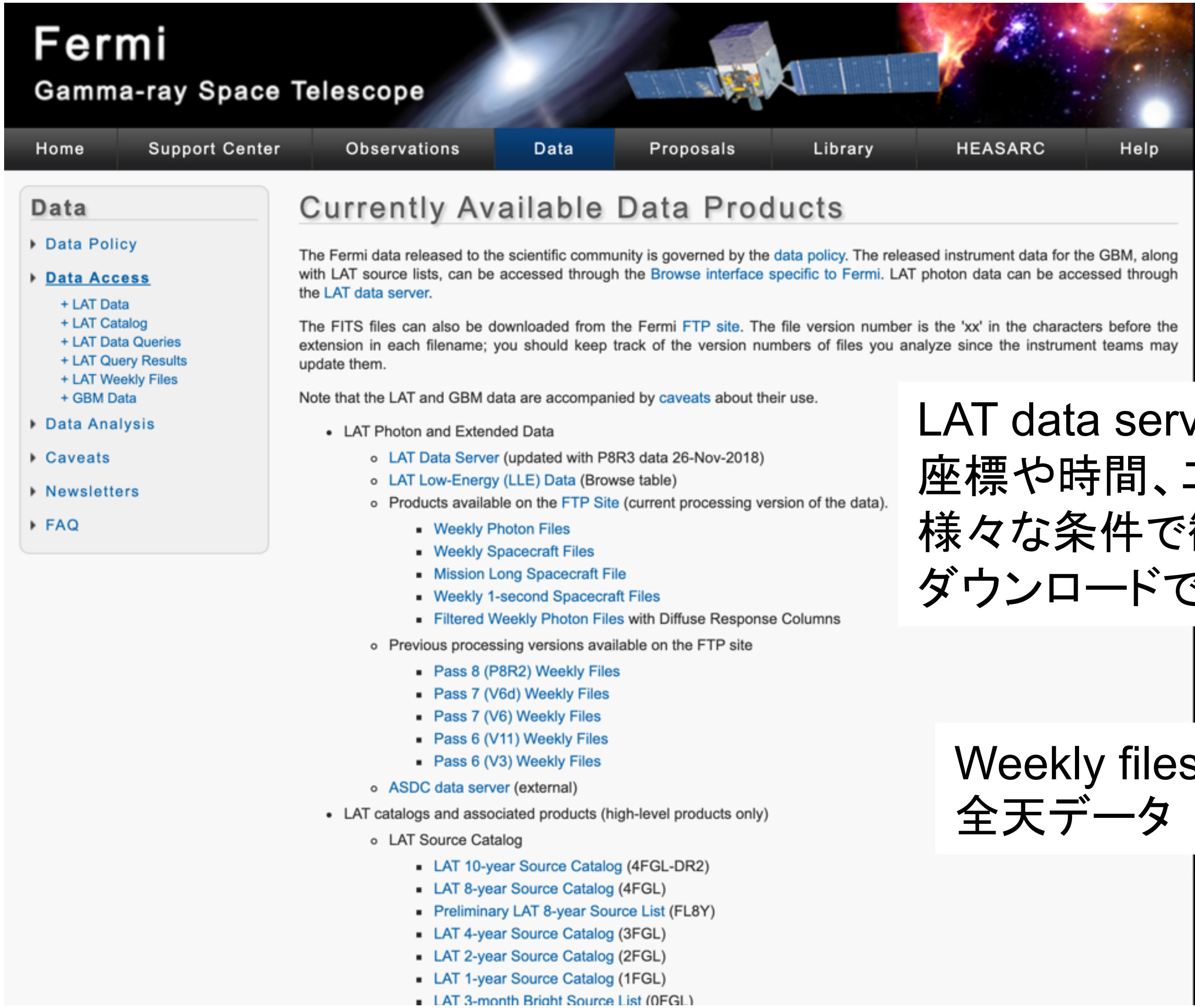
The release of new versions of the Fermitools will be announced on the fermi-soft mailing list. Please fill out the subscription form if you would like to be added to the list.

The FSSC has also created a Docker container pre-loaded with many of the necessary tools required to do Fermi Analysis. It includes the Science Tools, the HEASARC FTOOLS, Python 2.7 and associated libraries along with a host of other programs. This container will run on Windows, MacOS, and Linux. You can find it (with instructions) on github or Docker Hub.

The previous version of the Science Tools, v11r5p3, released Feb 15, 2018 is still available for download.

Download LAT data

LAT データ は、FSSC Data server からアクセスできる

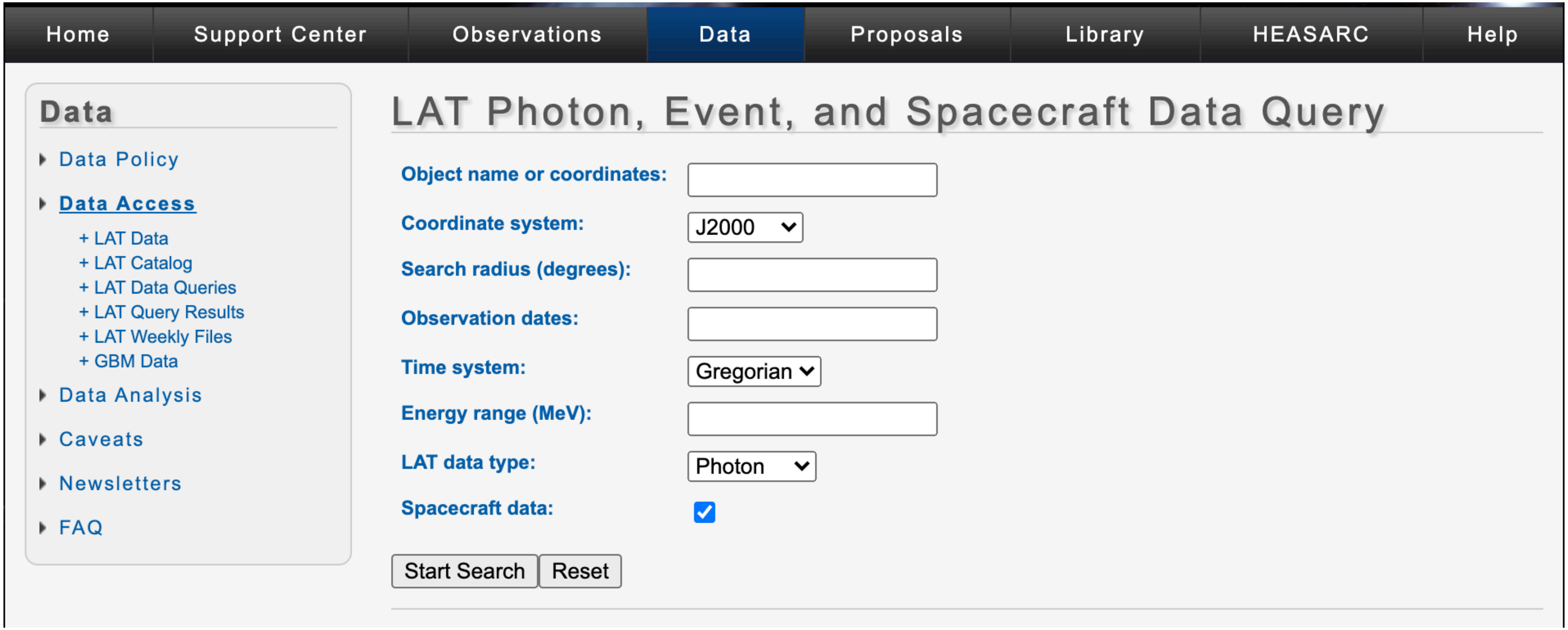


LAT data server
座標や時間、エネルギーバンドなど
様々な条件で観測データをセレクションし、
ダウンロードできる

Weekly files は、週ごとにパッケージされた
全天データ

3.1 Download LAT data

LAT データ は、FSSC Data server からアクセスできる



3.1 Download LAT data

LAT データ は、FSSC Data server からアクセスできる

Start Search Reset

Object name or coordinates:	193.98, -5.82
Coordinate system:	J2000
Search radius (degrees):	20
Observation dates:	START, 255398400
Time system:	MET
Energy range (MeV):	100, 100000
LAT data type:	Photon
Spacecraft data:	☑

Search was for 3C 279

Results for query L1203211445197365007F88

Your search criteria were:

Equatorial coordinates (degrees)	(193.98,-5.82)
Time range (MET)	(239557417,255398400)
Time range (Gregorian)	(2008-08-04 15:43:37,2009-02-04 00:00:00)
Energy range (MeV)	(100,100000)
Search radius (degrees)	20

Save this information for future reference

The state of your query is 2 (Query complete)

Server	Position in Queue	Estimated Time Remaining (sec)
Photon Server	Query complete	N/A
Spacecraft Server	Query complete	N/A

なんか２種類でてきたけど
なんだこれ？

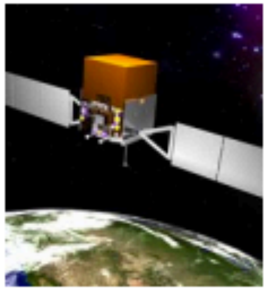
Filename	Number of Entries	Size (MB)	Status
L1203211445197365007F88_PH00.fits	183137	16.48	Available
L1203211445197365007F88_SC00.fits	445088	62.85	Available

For long exposures and/or large extraction area, there will be 2 or more photon files (PH00, PH01, …)

4.2 LAT Photon data

片桐ゼミ'08

- ガンマ線のイベントリスト
  i.e. 1photon毎のエネルギー、到来方向、時間等を羅列したFITS file(FT1とも呼ばれる)
- どのように得られる？



機上でのイベントセレクション(on-board fitering)

- Si stripが3つ列になっている
- 対応するACDがヒットしていない
- Etc.

Level0 data
(生データ)
on the ground

加工(processing)

- 軌跡を再構成
  (reconstruction
- EventをID
  ガンマ線？荷電粒子？
- 物理量の決定
  エネルギー、到来方向、時間、etc.
- 緩いカット

Level1データ

⑩ さらに必要なパラメータを絞り込む
⑩ FITSに変換

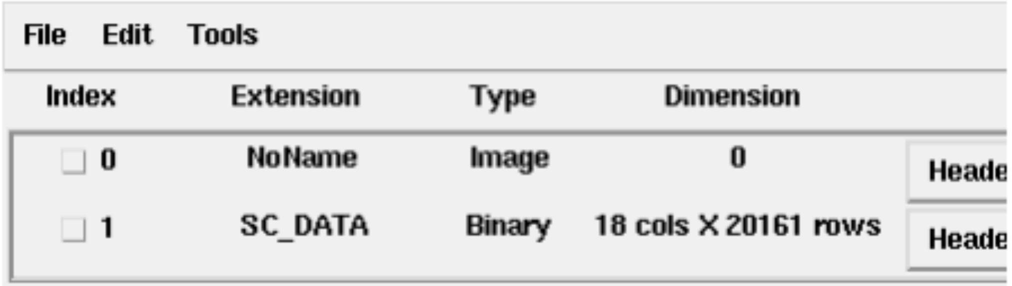
photon summary data

4.3 LAT spacecraft (SC) data

片桐ゼミ'08

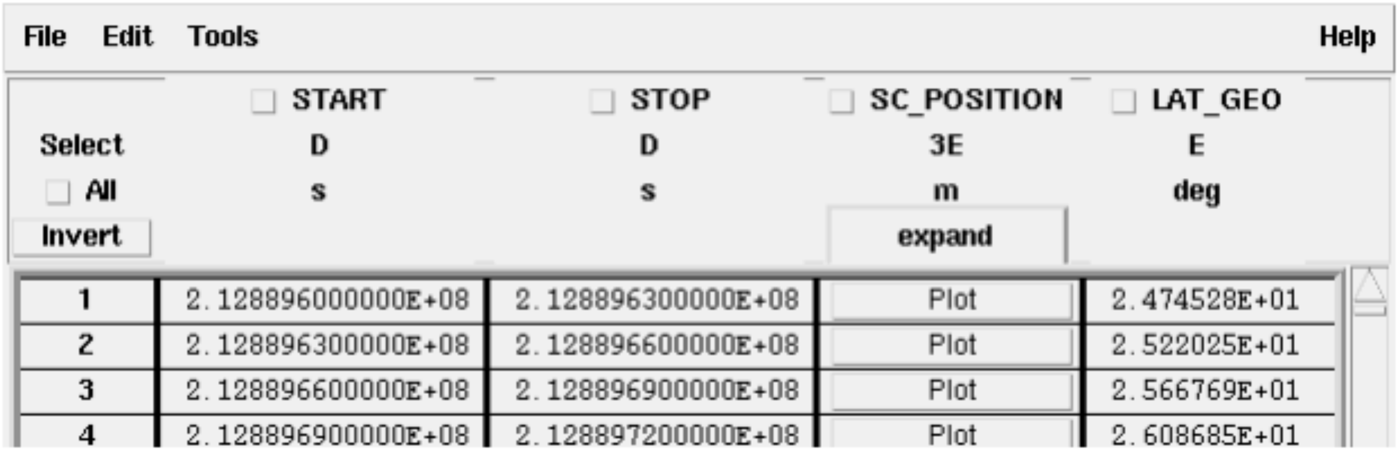
名前の通り
- **衛星の位置や向き**
- Livetime
- SAAに入っているか、地磁気の大きさ、etc.

を時系列に並べたファイル。



File Edit Tools

Index	Extension	Type	Dimension	
0	NoName	Image	0	Heade
1	SC_DATA	Binary	18 cols X 20161 rows	Heade



File Edit Tools Help

Select	START	STOP	SC_POSITION	LAT_GEO
	D	D	3E	E
All	s	s	m	deg
Invert			expand	
1	2.128896000000E+08	2.128896300000E+08	Plot	2.474528E+01
2	2.128896300000E+08	2.128896600000E+08	Plot	2.522025E+01
3	2.128896600000E+08	2.128896900000E+08	Plot	2.566769E+01
4	2.128896900000E+08	2.128897200000E+08	Plot	2.608685E+01

3.4 LAT Instrument Response Function (IRFs)

Photon data をプロセスする際、どれぐらい厳しくバックグラウンドをカットするか等のイベントセレクションの種類により、複数のデータタイプと対応する応答関数が用意されている

カット厳しい

P8R2 IRF name	Event Class (evclass)	Class Hierarchy	Photon File	Extended File
P8R2_ULTRACLEANVETO_V6	1024	Standard	X	X
P8R2_ULTRACLEAN_V6	512	Standard	X	X
P8R2_CLEAN_V6	256	Standard	X	X
P8R2_SOURCE_V6	128	Standard	X	X
P8R2_TRANSIENT010_V6	64	Standard		X
P8R2_TRANSIENT020_V6	16	Standard		X
P8R2_TRANSIENT010E_V6	64	Extended		X
P8R2_TRANSIENT020E_V6	8	Extended		X
P8R2_TRANSIENT015S_V6	65536	No-ACD		X

http://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Cicerone/Cicerone_LAT_IRFs/IRF_overview.html

カット緩い

4.4 LAT Instrument Response Function (IRFs)

Photon data をプロセスする際、どれぐらい厳しくバックグラウンドをカットするか等のイベントセレクションの種類により、複数のデータタイプと対応する応答関数が用意されている

カット厳しい

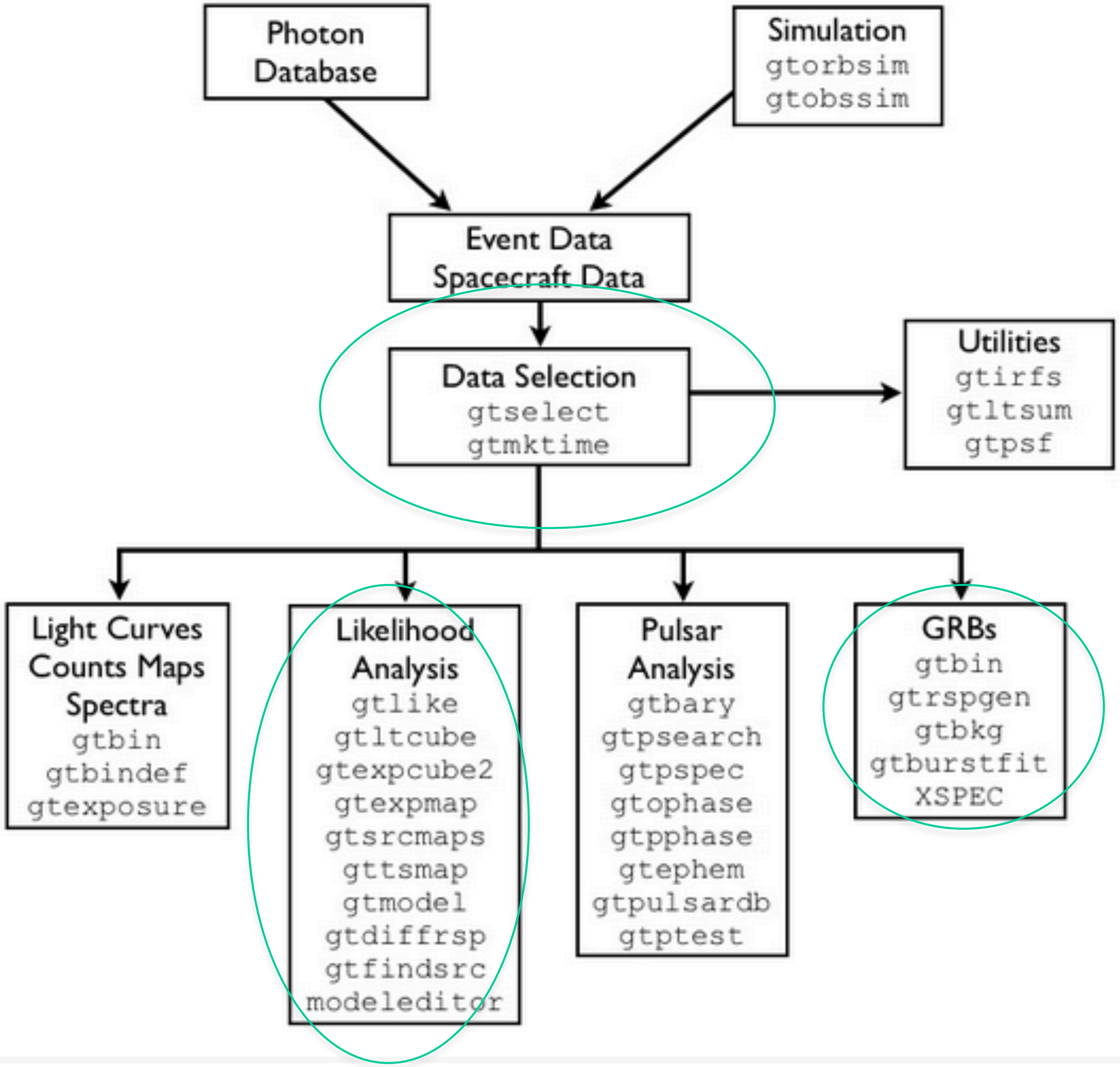
P8R2 IRF name	Event Class (evclass)	Class Hierarchy	Photon File	Extended File
P8R2_				
P8R2_				
P8R2_				
P8R2_				
P8R2_				
P8R2_				
P8R2_				
P8R2_				
P8R2_				

カットが緩いと、有効面積が増えるが、
バックグラウンドの混入が増える。
ブレーザーの長期解析や、マルチメッセンジャー対応天体など
を長時間にわたって探査をする際はバックグラウンド混入が問題になるので、SOURCE class 以上を使うのが推奨

GRB の場合は、プロンプト放射は継続時間が短いので”ほとんど”
バックグラウンドフリー, TRANSIENT class でも良い
(TRANSIENT020 が推奨されている)
それぞれの応答関数は Science Tools に含まれている

カット緩い

3.5 LAT data analysis structure



Gtselect, gtmktime で
データセレクション
(時間、領域)

プロンプト放射:
Gtbin でライトカーブ
スペクトル、マップを書く

Afterglow:
Gtlike で likelihood 解析

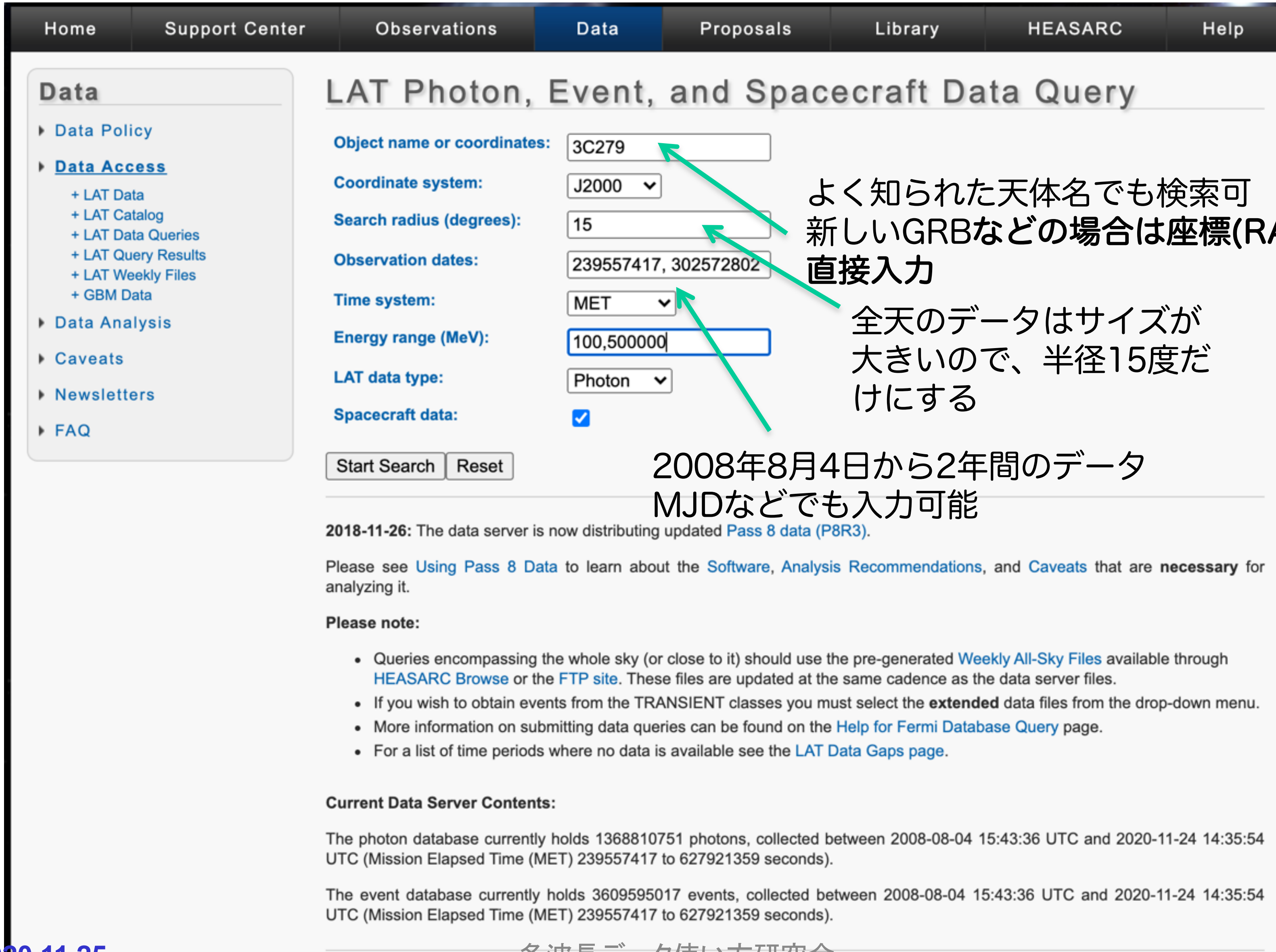
というのが基本的な流れ

4. LAT データ解析
（実際に解析してみよう編）

参考リンク: https://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/binned_likelihood_tutorial.html
他にも
https://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/
に多数の cookbook がある

3.6 データダウンロード

例題として、以下のデータをダウンロード　(ブレーザー天体3C279)



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  - + LAT Query Results
  - + LAT Weekly Files
  - + GBM Data
- Data Analysis
- Caveats
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- FAQ

LAT Photon, Event, and Spacecraft Data Query

Object name or coordinates:	3C279
Coordinate system:	J2000
Search radius (degrees):	15
Observation dates:	239557417, 302572802
Time system:	MET
Energy range (MeV):	100,500000
LAT data type:	Photon
Spacecraft data:	☑

Start Search　Reset

2018-11-26: The data server is now distributing updated Pass 8 data (P8R3).

Please see Using Pass 8 Data to learn about the Software, Analysis Recommendations, and Caveats that are **necessary** for analyzing it.

Please note:

- Queries encompassing the whole sky (or close to it) should use the pre-generated Weekly All-Sky Files available through HEASARC Browse or the FTP site. These files are updated at the same cadence as the data server files.
- If you wish to obtain events from the TRANSIENT classes you must select the **extended** data files from the drop-down menu.
- More information on submitting data queries can be found on the Help for Fermi Database Query page.
- For a list of time periods where no data is available see the LAT Data Gaps page.

Current Data Server Contents:

The photon database currently holds 1368810751 photons, collected between 2008-08-04 15:43:36 UTC and 2020-11-24 14:35:54 UTC (Mission Elapsed Time (MET) 239557417 to 627921359 seconds).

The event database currently holds 3609595017 events, collected between 2008-08-04 15:43:36 UTC and 2020-11-24 14:35:54 UTC (Mission Elapsed Time (MET) 239557417 to 627921359 seconds).

よく知られた天体名でも検索可
新しいGRBなどの場合は座標(RA,Dec)を直接入力

全天のデータはサイズが大きいので、半径15度だけにする

2008年8月4日から2年間のデータ
MJDなどでも入力可能

3.6 データダウンロード

例題として、以下のデータをダウンロード　(3C279)

しばらく（20秒ぐらい）待つと
データが ready になり、
リンクのクリック、もしくは
Wget のスクリプトでダウンロード
できるようになる。

Data

- Data Policy
- Data Access
  - + LAT Data
  - + LAT Catalog
  - + LAT Data Queries
  - + LAT Query Results
  - + LAT Weekly Files
  - + GBM Data
- Data Analysis
- Caveats
- Newsletters
- FAQ

Results for query L20112416190721F9E93E99

Your search criteria were:

Equatorial coordinates (degrees)	(194.047,-5.78931)
Time range (MET)	(239557417,302572802)
Time range (Gregorian)	(2008-08-04 15:43:36,2010-08-04 00:00:00)
Energy range (MeV)	(100,500000)
Search radius (degrees)	15

The state of your query is 2 (Query complete)

Server	Position in Queue	Estimated Time Remaining (sec)
Photon Server	Query complete	NA
Spacecraft Server	Query complete	NA

The filenames of the result files consist of the query ID string with an identifier appended to indicate which database the file came from. The identifiers are of the form: _DDNN where DD indicates the database and NN is the file number. The file number will generally be '00' unless the query resulted in a large data volume. In that case the data is broken up into multiple files. The values of the database field are:

- PH - Photon Database
- SC - Spacecraft Pointing, Livetime, and History Database
- EV - Extended Database

In the event that you do not see any files with the data type you requested listed below, you should try resubmitting your query as there may have been a problem.

Filename	Number of Entries	Size (MB)	Status
L20112416190721F9E93E99_SC00.fits	1763993	255.73	Available
L20112416190721F9E93E99_PH00.fits	52400	4.95	Available
L20112416190721F9E93E99_PH01.fits	111594	10.48	Available
L20112416190721F9E93E99_PH03.fits	98142	9.23	Available
L20112416190721F9E93E99_PH04.fits	78911	7.43	Available
L20112416190721F9E93E99_PH06.fits	47854	4.52	Available
L20112416190721F9E93E99_PH02.fits	68813	6.48	Available
L20112416190721F9E93E99_PH05.fits	65664	6.19	Available

If you would like to download the files via wget, simply copy the following commands and paste them into a terminal window. The files will be downloaded to the current directory in the terminal window.

```
wget https://fermi.gsfc.nasa.gov/FTP/fermi/data/lat/queries/L20112416190721F9E93E99_SC00.fits
wget https://fermi.gsfc.nasa.gov/FTP/fermi/data/lat/queries/L20112416190721F9E93E99_PH00.fits
wget https://fermi.gsfc.nasa.gov/FTP/fermi/data/lat/queries/L20112416190721F9E93E99_PH01.fits
wget https://fermi.gsfc.nasa.gov/FTP/fermi/data/lat/queries/L20112416190721F9E93E99_PH03.fits
wget https://fermi.gsfc.nasa.gov/FTP/fermi/data/lat/queries/L20112416190721F9E93E99_PH04.fits
wget https://fermi.gsfc.nasa.gov/FTP/fermi/data/lat/queries/L20112416190721F9E93E99_PH06.fits
wget https://fermi.gsfc.nasa.gov/FTP/fermi/data/lat/queries/L20112416190721F9E93E99_PH02.fits
wget https://fermi.gsfc.nasa.gov/FTP/fermi/data/lat/queries/L20112416190721F9E93E99_PH05.fits
```

4.6 データ準備 (gtselect)

まず、gtselect でイベントセレクション、解析領域、時間や
地球大気からの放射の影響をカットする

今回は SOURCE class を使うので “evclass=128, evtype=3” を指定

```
(fermi) [ohno@massalia3 6:22 3c279]$ gtselect evclass=128 evtype=3

 WARNING: version mismatch between CFITSIO header (v3.43) and linked library (v3.41).

Input FT1 file[@ft1.lst]
Output FT1 file[3c279_binned_filtered.fits]
RA for new search center (degrees) (0:360) [INDEF]
Dec for new search center (degrees) (-90:90) [INDEF]
radius of new search region (degrees) (0:180) [INDEF]
start time (MET in s) (0:) [239557417]
end time (MET in s) (0:) [239957417]
lower energy limit (MeV) (0:) [100]
upper energy limit (MeV) (0:) [500000]
maximum zenith angle value (degrees) (0:180) [90]
```

2日分の解析は長いので、この例では4.6日寛らいを解析

地球大気の放射の混入をさけるたm、zenith angle cut する

```
(fermi) [ohno@massalia3 6:26 3c279]$ gtmktime

WARNING: version mismatch between CFITSIO header (v3.43) and linked library (v3.41).

Spacecraft data file[L181126210218F4F0ED2738_SC00.fits]
Filter expression[(DATA_QUAL>0)&&(LAT_CONFIG==1)]
Apply ROI-based zenith angle cut[no]
Event data file[3C279_binned_filtered.fits]
Output event file name[3C279_binned_gti.fits]
```

観測条件の悪い時間帯を除外

LAT angle

The Earth limb

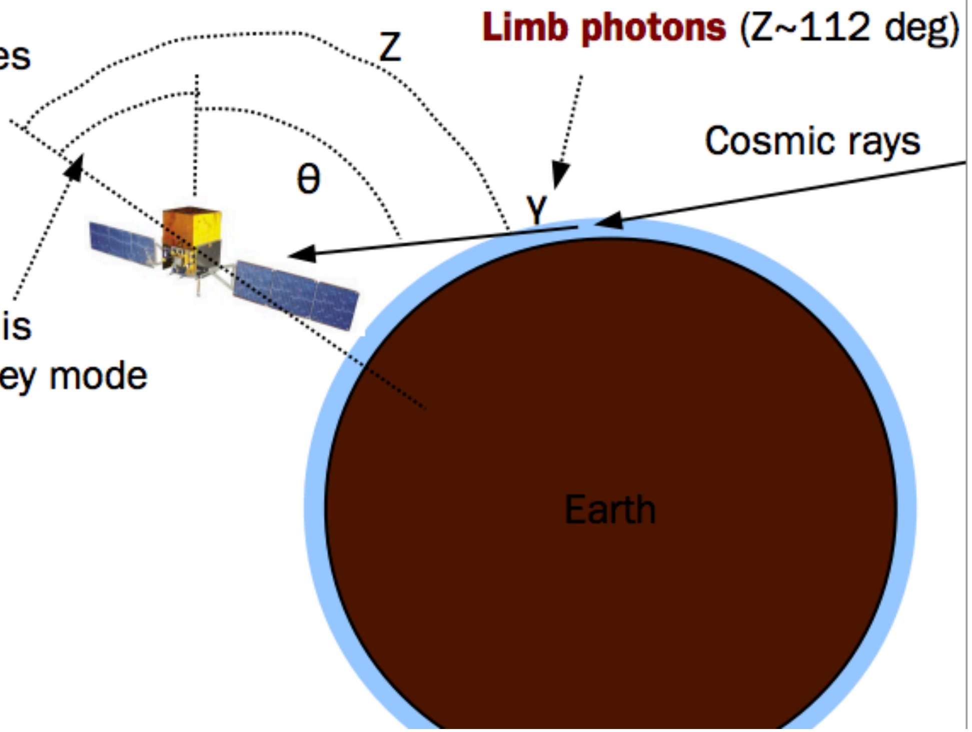
<u>Parameters:</u>

- Θ (incience angle): Polar coordinate of event in instrumental frame (w.r.t. LAT boresight)
- Z (zenith angle): angle between event and LAT zenith axis
- Rocking angle: angle between LAT boresight and zenith of LAT

LAT視野方向と天体位置
= incident angle
LAT天頂角と天体位置
= zenith angle
LAT視野方向と天頂角
= rocking angle

<u>Earth Limb:</u>

- Photons from cosmic-ray - atmosphere interaction have Z~112 deg, which implies θ >~ 112 deg – 50 deg ~ 62 deg in standard survey mode
- Θ<60 deg possible during ToO observations with larger rocking angle



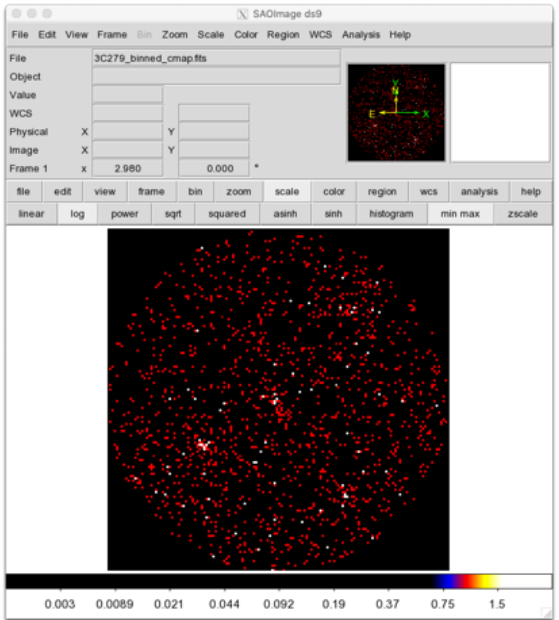
Zenith angle が大きいと
大気ガンマ線の影響が大きいとして
カットする必要がある。

Weigner 2013

カウントマップを書く (gtbin)

```
(fermi) [ohno@massalia3 6:27 3c279]$ gtbin

WARNING: version mismatch between CFITSIO header (v3.43) and linked library (v3.41).

This is gtbin version HEAD
Type of output file (CCUBE|CMAP|LC|PHA1|PHA2|HEALPIX) [CMAP]
Event data file name[3C279_binned_gti.fits]
Output file name[3C279_binned_cmap.fits]
Spacecraft data file name[NONE]
Size of the X axis in pixels[150]
Size of the Y axis in pixels[150]
Image scale (in degrees/pixel)[0.2]
Coordinate system (CEL - celestial, GAL -galactic) (CEL|GAL) [CEL]
First coordinate of image center in degrees (RA or galactic l)[193.88]
Second coordinate of image center in degrees (DEC or galactic b)[-5.82]
Rotation angle of image axis, in degrees[0]
Projection method e.g. AIT|ARC|CAR|GLS|MER|NCP|SIN|STG|TAN:[AIT]
gtbin: WARNING: No spacecraft file: EXPOSURE keyword will be set equal to ontime.
```

CMAP でカウントマップ



4日分なので分かりにくいが、
中心に少しclusteringしてるようにも見える
(これをこれからlikelihood解析で調べる)

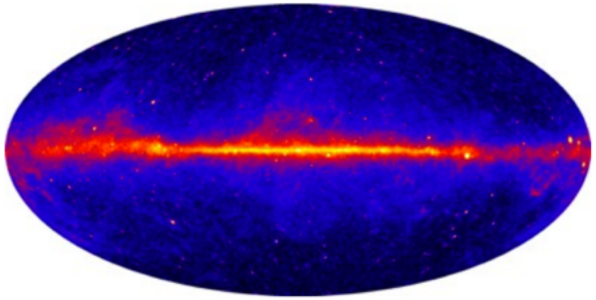
5. LAT データ解析
(likelihood analysis 編)

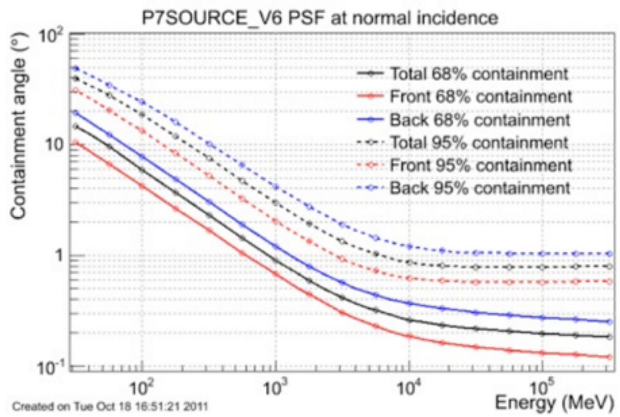
Why likelihood analysis？

Jeremy S. Parkins 2012 Fermi Summer School
http://fermi.gsfc.nasa.gov/science/mtgs/summerschool/2012/week1/Adv_Likelihood_Perkins.pdf

Why Model Fitting?

- We use the Likelihood method because the LAT data are limited by statistics, a bright diffuse background and a broad PSF.
- The model construction defines the questions we want to ask which means:
    - It will not answer a question you are not asking (ie. unknown parameters).

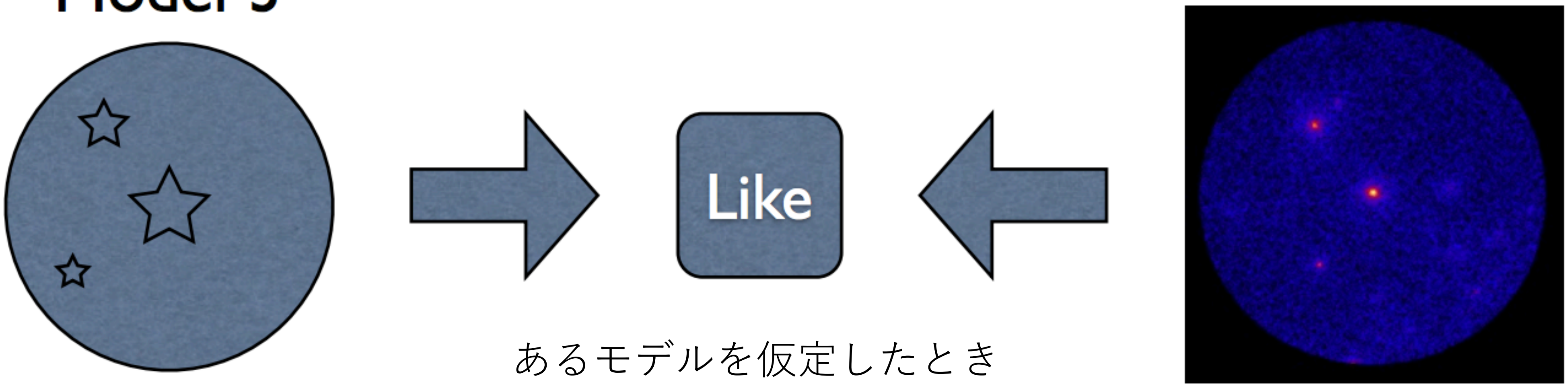




LAT は、photon 数が少ない
バックグラウンドの影響、エネルギーに
依存したPSFの影響を考慮して
最適なモデルを決める必要がある。
➔ Maximum likelihood

A Graphical Example

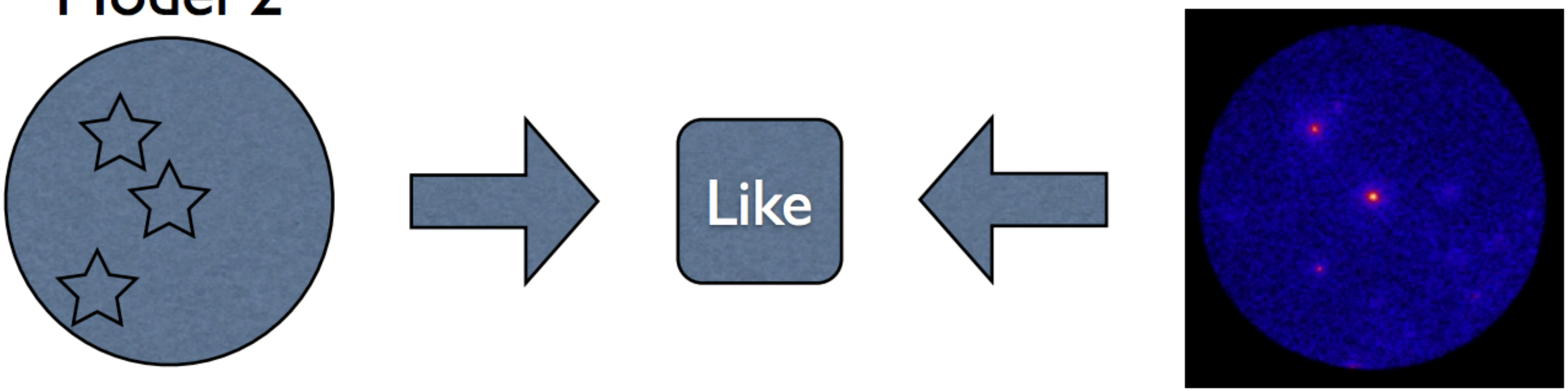
Model 3



あるモデルを仮定したとき
各場所で検出された photon 数に
なる確率が最大になるようにする

Our Data

Model 2



Like Likelihood Analysis: basics (2)

- The number of counts in each bin is small and thus is characterized by the Poisson distribution.
- $\mathcal{L}$ is the product of the probabilities of observing n_k counts in each bin when the number of counts predicted by the model is m_k

$$\mathcal{L} = \prod_k \frac{m_k^{n_k} e^{-m_k}}{n_k!}$$

あるモデル m_k のとき、
観測値が n_k である確率
を全てのk (ROI)で掛け合わせる

- $\mathcal{L}$ can be rewritten as

$$\mathcal{L} = \prod_k e^{-m_k} \prod_k \frac{m_k^{n_k}}{n_k!} = e^{-N_{pred}} \prod_k \frac{m_k^{n_k}}{n_k!}$$

Like Likelihood Analysis: basics (3)

- If we let the bin sizes get infinitesimally small, then n_k = (0 or 1) and we are left with a product running over the number of photons:

$$\mathcal{L} = e^{-N_{pred}} \prod_i m_i$$

- (This is the *unbinned* likelihood method).

Nk = 0 or 1 になるほど、
K を細かく設定する
➔ Unbinned likelihood
ROI が有限
➔ Binned likelihood

- It's easier to handle the logarithm of $\mathcal{L}$ so we usually maximize:

$$\log\mathcal{L} = \sum_i \log(m_i) - N_{pred}$$

Log を取ると計算が
簡単になる

これを最大にするようにしたい！

Like Likelihood Analysis: basics (5)

では、モデル(predicted count)
はどのようにして決めるか？

- The source model considered is

$$S(E,\hat{p},t) = \underbrace{\sum_i s_i(E,t)\delta(\hat{p}-\hat{p}_i)}_{\text{Point Sources}} + \underbrace{S_G(E,\hat{p}) + S_{eg}(E,\hat{p})}_{\text{Galactic \& EG Diffuse Sources}} + \underbrace{\sum_l S_l(E,\hat{p},t)}_{\text{Other Sources}},$$

このモデルを
定義しないといけない

- This model is folded with the Instrument Response Functions (IRFs) to obtain the predicted number of counts in the measured quantity space (E’, p’, t’):

$$M(E',\hat{p}',t) = \int_{\mathrm{SR}} dE\,d\hat{p}\,R(E',\hat{p}',t;E,\hat{p})S(E,\hat{p},t)$$

レスポンスを掛け合わせて
観測量に焼き直す

Like Likelihood Analysis: basics (9)

- The function to maximize is:

$$\log \mathcal{L} = \sum_j \log M(E'_j, \hat{p}'_j, t_j) - N_{\rm pred}$$

logL を source model とレスポンスを掛け合わせた量で表現

- where the sum is performed over photons in the ROI.
- The predicted number of counts is:

$$N_{\rm pred} = \int_{\rm ROI} dE' d\hat{p}'\, dt M(E', \hat{p}', t)$$

Npred も source model から計算する

- To save CPU time, a model-independent quantity called the exposure map (or cube) is precomputed:

$$\varepsilon(E, \hat{p}) \equiv \int_{\rm ROI} dE'\, d\hat{p}'\, dt\, R(E', \hat{p}', t; E, \hat{p})$$

Exposureを掛け合わせて観測量と比較

- Then:

$$N_{\rm pred} = \int_{\rm SR} dE d\hat{p}\, S(E, \hat{p})\, \varepsilon(E, \hat{p})$$

Likelihoodにおける天体の有意度

- X^2は使えない
- Test statistics

$$T_s = 2(\log \mathcal{L} - \log \mathcal{L}_0)$$

L：目標とする天体を含んだモデルでのlikelihood
L0：目標とする天体を除いたモデルでのlikelihood

- 統計が多い場合のX^2に等しい
- 特に感度ぎりぎりの天体の検出には必須

- As a basic rule of thumb, the square root of the TS is approximately equal to the detection significance for a given source.

Likelihood解析: まとめ

$$\log\mathcal{L} = \sum_i \log(m_i) - N_{pred}$$

これを最大化するモデルを探したい。しかし、モデルとデータを
比較するには、モデルを検出器のレスポンスで畳み込む必要がある。

つまり、Likelihood 解析には以下が必要

-観測データ (photon data)
-Exposure map (=検出器のレスポンス)
-モデルの定義
-バックグラウンドモデル

ということに注意して解析をはじめてみましょう。

a) イベントセレクション (gtselect, gtmktime)

イベントクラス、時刻、ROIの切り出し(gtselect)

```
(fermi) [ohno@massalia3 6:22 3c279]$ gtselect evclass=128 evtype=3

 WARNING: version mismatch between CFITSIO header (v3.43) and linked library (v3.41).

Input FT1 file[@ft1.lst]
Output FT1 file[3c279_binned_filtered.fits]
RA for new search center (degrees) (0:360) [INDEF]
Dec for new search center (degrees) (-90:90) [INDEF]
radius of new search region (degrees) (0:180) [INDEF]
start time (MET in s) (0:) [239557417]
end time (MET in s) (0:) [239957417]
lower energy limit (MeV) (0:) [100]
upper energy limit (MeV) (0:) [500000]
maximum zenith angle value (degrees) (0:180) [90]
```

GTI の定義 (gtmktime)

```
(fermi) [ohno@massalia3 6:26 3c279]$ gtmktime

WARNING: version mismatch between CFITSIO header (v3.43) and linked library (v3.41).

Spacecraft data file[L181126210218F4F0ED2738_SC00.fits]
Filter expression[(DATA_QUAL>0)&&(LAT_CONFIG==1)]
Apply ROI-based zenith angle cut[no]
Event data file[3C279_binned_filtered.fits]
Output event file name[3C279_binned_gti.fits]
```

データ準備で行ったのと同じ手順。すでにファイル作成済みなら不要

b) Exposure 作成 (gtltcuve/gtexpcube2)

Live time 計算

```
(fermi) [ohno@massalia3 6:52 3c279]$ gtltcube

WARNING: version mismatch between CFITSIO header (v3.43) and linked library (v3.41).

Event data file[3C279_binned_gti.fits]
Spacecraft data file[L181126210218F4F0ED2738_SC00.fits]
Output file[3C279_binned_ltcube.fits]
Step size in cos(theta) (0.:1.) [0.025]
Pixel size (degrees)[1]
Working on file L181126210218F4F0ED2738_SC00.fits
```

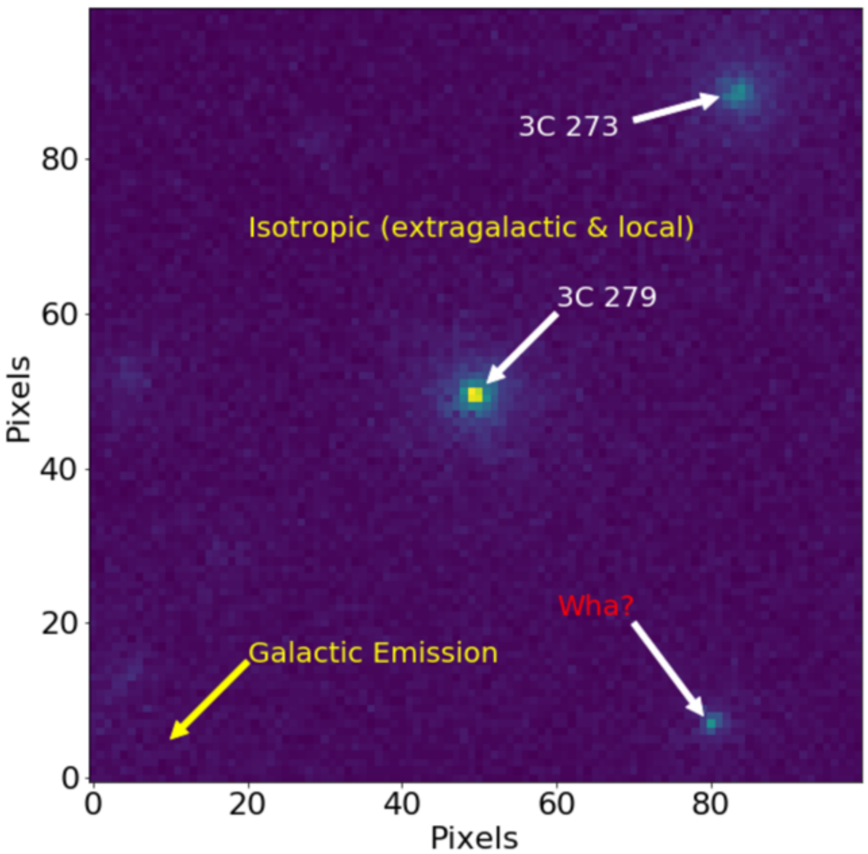
Exposure 計算

```
(fermi) [ohno@massalia3 6:59 3c279]$ gtexpcube2

WARNING: version mismatch between CFITSIO header (v3.43) and linked library (v3.41).

Livetime cube file[3C279_binned_ltcube.fits]
Counts map file[3C279_binned_ccube.fits]
Output file name[3C279_binned_expcube.fits]
Response functions to use[P8R3_SOURCE_V2]
```

これで exposure (レスポンス) の用意はできた。あとは、モデルを構築する

Source model の準備

Source + background モデルを xml ファイルで記述する

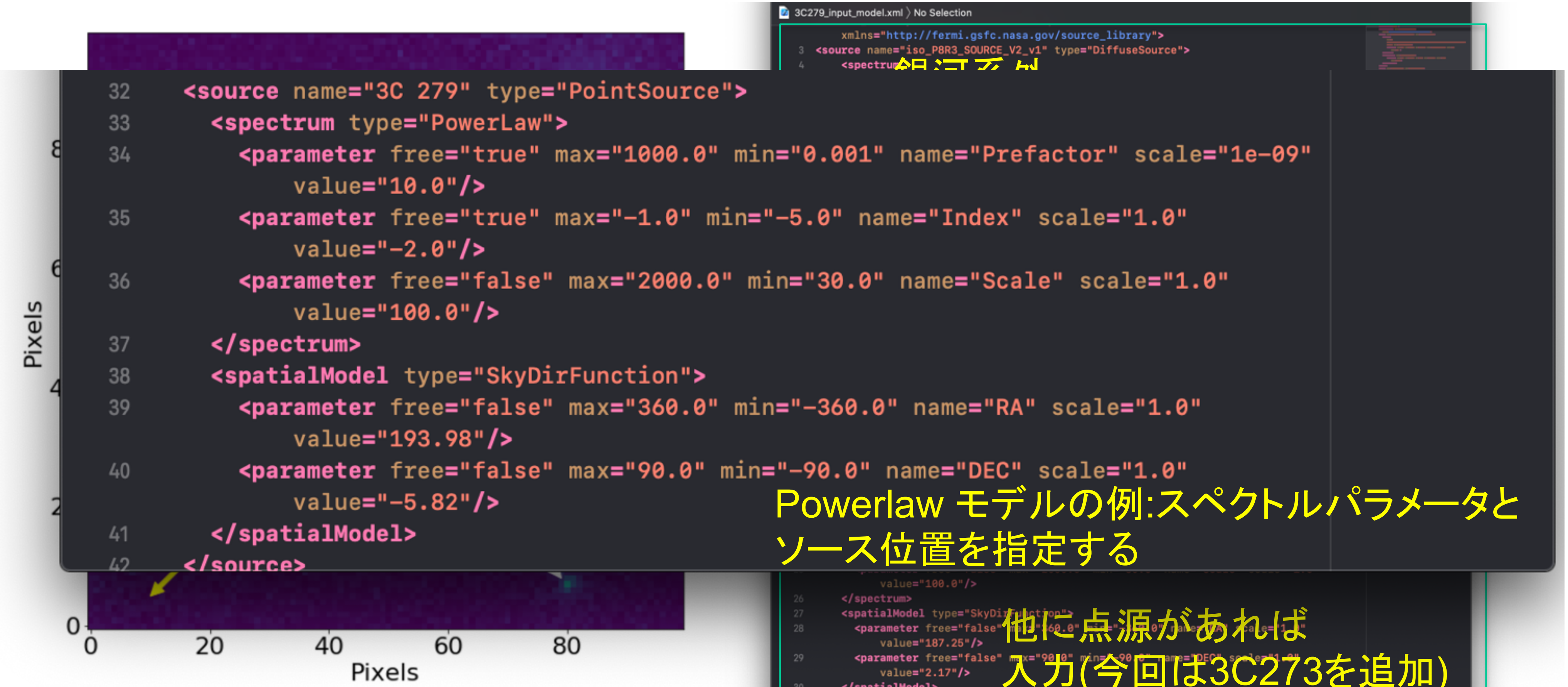



```xml
    xmlns="http://fermi.gsfc.nasa.gov/source_library">
<source name="iso_P8R3_SOURCE_V2_v1" type="DiffuseSource">
    <spectrum [illegible]
        file=[illegible]
        (CONDA_PREFIX)/share/fermitools/refdata/fermi/galdiffuse/iso_P8R3_SOURCE_V2_v
        1.txt" [illegible]
        <parameter [illegible]
            value="1" />
    </spectrum>
    <spatialModel type="ConstantValue">
        <parameter free="0" max="10.0" min="0.0" name="Value" scale="1.0"
            value="1.0"/>
    </spatialModel>
</source>
<source name="gll_iem_v07" type="DiffuseSource">
    <spectrum type="PowerLaw">
      <parameter free="0" max="1.0" min="-1.0" name="Index" scale="-1.0"
        value="0.0"/>
      <parameter free="0" max="1000.0" min="1000.0" name="Scale" scale="1.0"
        value="1000.0"/>
      <parameter free="0" max="10.0" min="0.1" name="Prefactor" scale="1.0"
        value="1.0"/>
    </spectrum>
    <spatialModel
        file="$(CONDA_PREFIX)/share/fermitools/refdata/fermi/galdiffuse/gll_iem_v07
        .fits" type="MapCubeFunction">
        <parameter free="0" max="1000.0" min="0.001" name="Normalization" scale=
          "1.0" value="1.0"/>
    </spatialModel>
</source>
  <source name="3C 273" type="PointSource">
    <spectrum type="PowerLaw">
      <parameter free="true" max="1000.0" min="0.001" name="Prefactor" scale="1e-09"
        value="10.0"/>
      <parameter free="true" max="-1.0" min="-5.0" name="Index" scale="1.0"
        value="-2.1"/>
      <parameter free="false" max="2000.0" min="30.0" name="Scale" scale="1.0"
        value="100.0"/>
    </spectrum>
    <spatialModel type="SkyDir[illegible]">
      <parameter free="false"[illegible]
        value="187.25"/>
      <parameter free="false" [illegible]
        value="2.17"/>
    </spatialModel>
  </source>
  <source name="3C 279" type="PointSource">
    <spectrum type="PowerLaw">
      <parameter free="true" max="1000.0" min="0.001" name="Prefactor" scale="1e-09"
        value="10.0"/>
      <parameter free="true" max="-1.0" min="-5.0" name="Index" scale="1.0"
        value="-2.0"/>
      <parameter free="false" max="2000.0" min="30.0" name="Scale" scale="1.0"
        value="100.0"/>
    </spectrum>
    <spatialModel type="SkyDirFunction">
      <parameter free="false" max="360.0" min="-360.0" name="RA" scale="1.0"
        value="193.98"/>
      <parameter free="false" max="90.0" min="[illegible]
        value="-5.82"/>
    </spatialModel>
  </source>
```

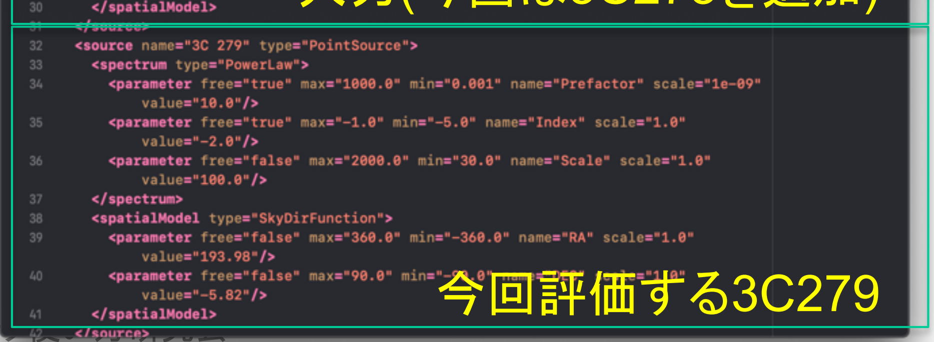
ROI 内に他の点源がある場合は
Xml ファイルに追記していく
本来は、カタログファイルをチェックして
影響のありそうな点源を逐次追加する。
カタログファイルからモデルファイルを
作成するスクリプトは提供されている

Source model の準備

Source + background モデルを xml ファイルで記述する




```xml
<source name="3C 279" type="PointSource">
  <spectrum type="PowerLaw">
    <parameter free="true" max="1000.0" min="0.001" name="Prefactor" scale="1e-09"
        value="10.0"/>
    <parameter free="true" max="-1.0" min="-5.0" name="Index" scale="1.0"
        value="-2.0"/>
    <parameter free="false" max="2000.0" min="30.0" name="Scale" scale="1.0"
        value="100.0"/>
  </spectrum>
  <spatialModel type="SkyDirFunction">
    <parameter free="false" max="360.0" min="-360.0" name="RA" scale="1.0"
        value="193.98"/>
    <parameter free="false" max="90.0" min="-90.0" name="DEC" scale="1.0"
        value="-5.82"/>
  </spatialModel>
</source>
```



ROI 内に他の点源がある場合は
Xml ファイルに追記していく
本来は、カタログファイルをチェックして
影響のありそうな点源を逐次追加する。
カタログファイルからモデルファイルを
作成するスクリプトは提供されている

Background model

http://fermi.gsfc.nasa.gov/ssc/data/access/lat/BackgroundModels.html

Galactic interstellar emission model	Event Selection/ IRF Name	Isotropic spectral template
gll_iem_v07.fits (see below for P8R3 usage notes)	Pass 8 Source (front+back, allPSF, allEDISP) P8R3_SOURCE_V3	iso_P8R3_SOURCE_V3_v1.txt
	Pass 8 Source (front only) P8R3_SOURCE_V3::FRONT	iso_P8R3_SOURCE_V3_FRONT_v1.txt
	Pass 8 Source (back only) P8R3_SOURCE_V3::BACK	iso_P8R3_SOURCE_V3_BACK_v1.txt
	Pass 8 Clean (front+back, allPSF, allEDISP) P8R3_CLEAN_V3	iso_P8R3_CLEAN_V3_v1.txt
	Pass 8 Clean (PSF0) P8R3_CLEAN_V3::PSF0	iso_P8R3_CLEAN_V3_PSF0_v1.txt
	Pass 8 Clean (PSF1) P8R3_CLEAN_V3::PSF1	iso_P8R3_CLEAN_V3_PSF1_v1.txt
	Pass 8 Clean (PSF2) P8R3_CLEAN_V3::PSF2	iso_P8R3_CLEAN_V3_PSF2_v1.txt
	Pass 8 Clean (PSF3) P8R3_CLEAN_V3::PSF3	iso_P8R3_CLEAN_V3_PSF3_v1.txt
	Pass 8 Ultraclean (front+back, allPSF, allEDISP) P8R3_ULTRACLEAN_V3	iso_P8R3_ULTRACLEAN_V3_v1.txt
	Pass 8 Ultraclean (EDISP0) P8R3_ULTRACLEAN_V3::EDISP0	iso_P8R3_ULTRACLEAN_V3_EDISP0_v1.txt
	Pass 8 Ultraclean (EDISP1) P8R3_ULTRACLEAN_V3::EDISP1	iso_P8R3_ULTRACLEAN_V3_EDISP1_v1.txt
	Pass 8 Ultraclean (EDISP2) P8R3_ULTRACLEAN_V3::EDISP2	iso_P8R3_ULTRACLEAN_V3_EDISP2_v1.txt
	Pass 8 Ultraclean (EDISP3) P8R3_ULTRACLEAN_V3::EDISP3	iso_P8R3_ULTRACLEAN_V3_EDISP3_v1.txt
	Pass 8 Ultracleanveto (front+back, allPSF, allEDISP) P8R3_ULTRACLEANVETO_V3	iso_P8R3_ULTRACLEANVETO_V3_v1.txt
	Pass 8 Sourceveto (front+back, allPSF, allEDISP) P8R3_SOURCEVETO_V3	iso_P8R3_SOURCEVETO_V3_v1.txt

今回はこの二つを
使う。
IRF によって使い分ける
必要有り。
詳しくは同ページを
参照

4 FGL source xml

狙った天体以外に、点源のバックグラウンドがいないかどうかは、
カタログのリストを調べるのがよい。

http://fermi.gsfc.nasa.gov/ssc/data/access/lat/4yr_catalog/

LAT Catalog Data Products

The LAT 4-year Point Source Catalog is currently available as a FITS file and as an XML model file to be used for data analysis within the Fermi Science Tools. A BROWSE table containing a searchable version of the catalog will be made available soon Supporting tools and documentation have been provided and are linked below.

It is important that all users of this catalog review the caveats listed below the catalog links. These describe the content of the catalog at a high level, as well as some cautions for the user.

- LAT 4-year Point Source Catalog (3FGL in FITS format)
- LAT 4-year Point Source Catalog (BROWSE table)
- LAT 4-year Point Source Catalog Paper
- Column descriptions for the LAT 4-year Point Source Catalog are provided in Appendix B of the paper
  - Full content of Table 4 (Main source table)
  - Full content of Table 8 (Fluxes in bands)
  - Full content of Table 11 (2FGL sources not in 3FGL)
- XML Model File for LAT 4-year Point Source Catalog
- DS9 Region Files:
  - 3FGL positions (as crosses) and source names
  - 3FGL positions (as crosses) and association names
  - 3FGL 95% error ellipses (no source names)
- Visualization Tools:
  - 3FGL Interactive Table
  - 3FGL source map with mouse-over information
  - 3FGL variability versus curvature plot
  - Aperture photometry light curves and power spectra
  - Map of the 4-year LAT Detection Threshold (in FITS format)

Xml file や、ds9 のregion fileとしても
あるので、p.59 の xml file にすぐに
追加可能、カウントマップに重ねることも
できる。

Source map計算 (gtsrcmaps)

```
(fermi) [ohno@massalia3 7:16 3c279]$ gtsrcmaps

WARNING: version mismatch between CFITSIO header (v3.43) and linked library (v3.41).

Exposure hypercube file[3C279_binned_ltcube.fits]
Counts map file[3C279_binned_ccube.fits]
Source model file[3C279_input_model.xml]
Binned exposure map[3C279_binned_expcube.fits]
Source maps output file[3C279_binned_srcmaps.fits]
Response functions[CALDB]
Generating SourceMap for 3C 273 38....................!
Generating SourceMap for 3C 279 38....................!
Generating SourceMap for gll_iem_v07 38....................!
Generating SourceMap for iso_P8R3_SOURCE_V2_v1 38....................!
```

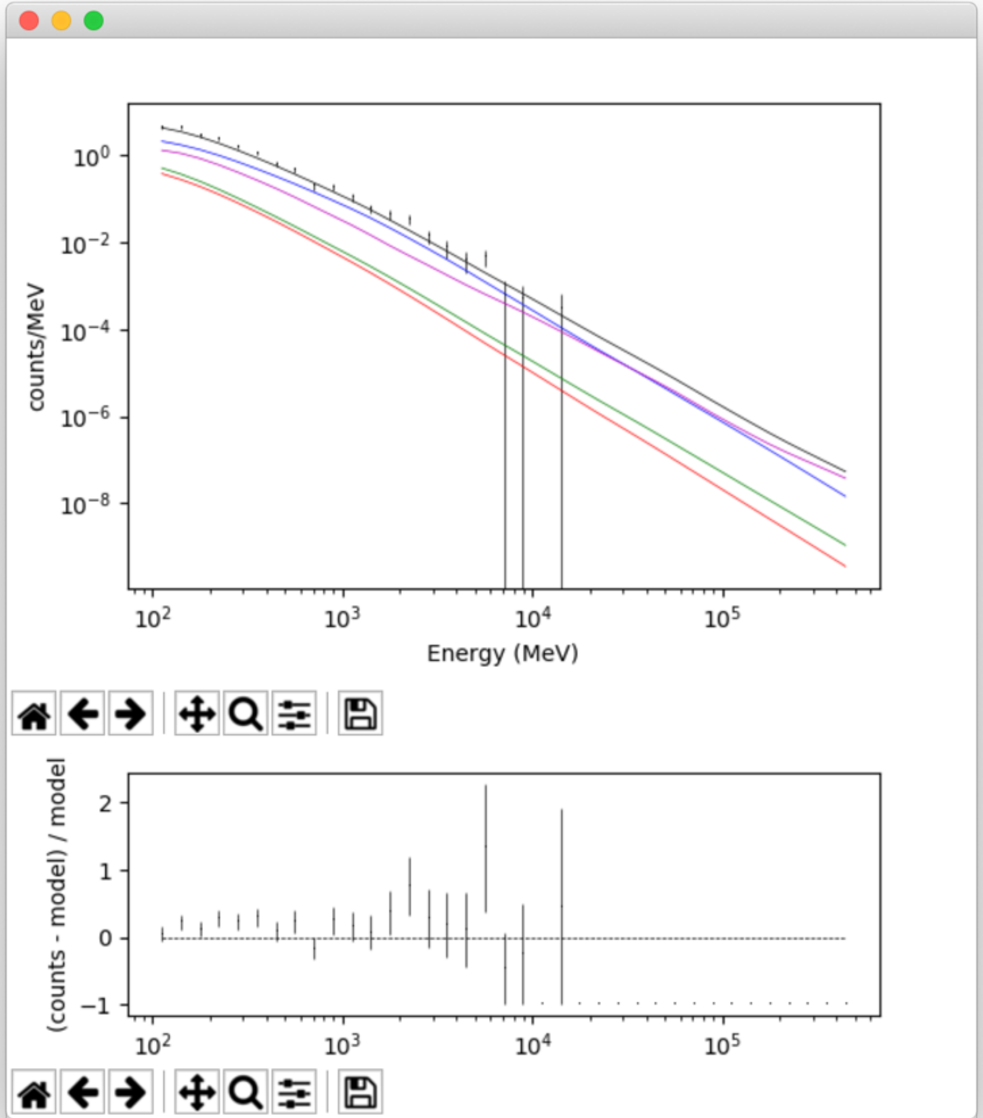
ここまでで用意した exposure, レスポンス、モデルに基づいて、モデルで定義した各ソースのカウントマップをエネルギー毎に計算。

Likelihood 解析 (gtlike)

```
(fermi) [ohno@massalia3 7:53 3c279]$ gtlike

 WARNING: version mismatch between CFITSIO header (v3.43) and linked library (v3.41).

Statistic to use (BINNED|UNBINNED) [BINNED]
Counts map file[3C279_binned_srcmaps.fits]
Binned exposure map[3C279_binned_allsky_expcube.fits]
Exposure hypercube file[3C279_binned_ltcube.fits]
Source model file[3C279_input_model.xml]
Response functions to use[CALDB]
Optimizer (DRMNFB|NEWMINUIT|MINUIT|DRMNGB|LBFGS) [NEWMINUIT]
```

…. 解析がすすむ。。

Likelihood 解析 (gtlike)



解析結果

```
Computing TS values for each source (4 total)
....!

Photon fluxes are computed for the energy range 100 to 500000 MeV

3C 273:
Prefactor: 6.11614 +/- 1.98941
Index: -2.69982 +/- 0.245313
Scale: 100
TS value: 54.6827
Flux: 3.60453e-07 +/- 8.22487e-08 photons/cm^2/s

3C 279:
Prefactor: 5.76287 +/- 1.68615
Index: -2.56243 +/- 0.21013
Scale: 100
TS value: 69.0614
Flux: 3.69395e-07 +/- 7.59162e-08 photons/cm^2/s
```

同様の解析を time-resolve で
行うことで fluxの
ライトカーブや、index の変化など
を得る。

TS map (gttsmap)

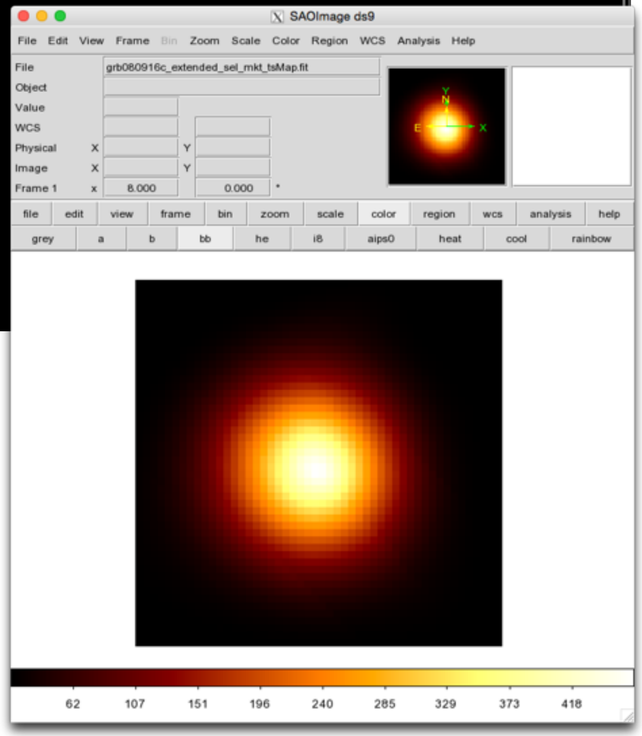
・バックグラウンドに対して、点源モデルをスキャンすることで、各ピクセル位置における点源モデルの有意度(TS)を計算する。
・"点源モデルをスキャンする"、ということが決まっているので、モデルファイルは点源を除いた物を使う。

```
[ohno@massalia3 18:47 Tutorial]$ cat LAT_likelihoodmodel_P8_template_tsMap.xml
<?xml version="1.0" standalone="no"?>
<source_library title="source library">

  <source name="GalacticTemplate" type="DiffuseSource">
    <spectrum type="ConstantValue">
      <parameter free="1" max="10" min="0" name="Value" scale="1" value="2.103967643" />
    </spectrum>
    <spatialModel file="$(FERMI_DIR)/refdata/fermi/galdiffuse/gll_iem_v06.fits" type="MapCubeFunctio
n">
      <parameter free="0" max="1000" min="0.001" name="Normalization" scale="1" value="1" />
    </spatialModel>
  </source>
  <source name="IsotropicTemplate" type="DiffuseSource">
    <spectrum file="$(FERMI_DIR)/refdata/fermi/galdiffuse/iso_P8R2_SOURCE_V6_v06.txt" type="FileFunc
tion">
      <parameter free="1" max="1000" min="1e-05" name="Normalization" scale="1" value="1.000000022e-
05" />
    </spectrum>
    <spatialModel type="ConstantValue">
      <parameter free="0" max="10" min="0" name="Value" scale="1" value="1" />
    </spatialModel>
  </source>
</source_library>
```

バックグラウンドモデルしか記述しない(今回は diffuse のみ。点源bgdがある場合は随時追加)

TS map (gttsmap)

```
(fermi) [ohno@massalia3 12:10 grb080916c]$ gttsmap

WARNING: version mismatch between CFITSIO header (v3.43) and linked library (v3.41).

Statistic to use (BINNED|UNBINNED) [BINNED]
Counts map file[GRB080916C_binned_srcmaps.fits]
Binned exposure map[GRB080916C_binned_allsky_expcube.fits]
Exposure hypercube file[GRB080916C_binned_ltcube.fits]
Source model file[GRB080916C_input_model_gtlike.xml] GRB080916C_input_model_tsmap.xml
Response functions to use[P8R3_SOURCE_V2]
Optimizer (DRMNFB|NEWMINUIT|MINUIT|DRMNGB|LBFGS) [NEWMINUIT]
TS map file name[GRB080916C_binned_tsmap.fits]
Number of X axis pixels[30]
Number of Y axis pixels[30]
Image scale (in degrees/pixel)[0.8]
Coordinate system (CEL|GAL) [CEL]
X-coordinate of image center in degrees (RA or l)[193.98] 119.847
Y-coordinate of image center in degrees (Dec or b)[-5.82] -56.638
Projection method (AIT|ARC|CAR|GLS|MER|NCP|SIN|STG|TAN) [AIT]
```



未同定ソースの検出有意度の評価、位置決定精度
広がっているか否か、などに用いられる。
GRBなど突発天体探査などの場合はこれが大事かも

LAT 解析　まとめ

- LAT データは、FSSC の LAT data server からダウンロード
- Photon data / spacecraft data の２種類が必要
- 解析の流れは

  1) gtselect でイベントセレクション
  2) gtbin でカウントマップを書いてソース位置などを確認
  3) exposure map の計算
  4) モデルファイルを用意
  5) gtlike でスペクトルフィット
     - SED
     - 興味のある期間でflux計算 => ライトカーブ
       など
  6) 未同定天体(GRBなど)の場合は gttsmap などで位置決定
-

様々な解析インターフェース

- Gtburst (GRB解析に有用なGUIベースの解析ツール)

https://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/gtburst.html

(Fermi-LAT GRBチームのGCN報告はほぼこの結果に基いてます)

- Python モジュール (gt_apps, pylikelihood)

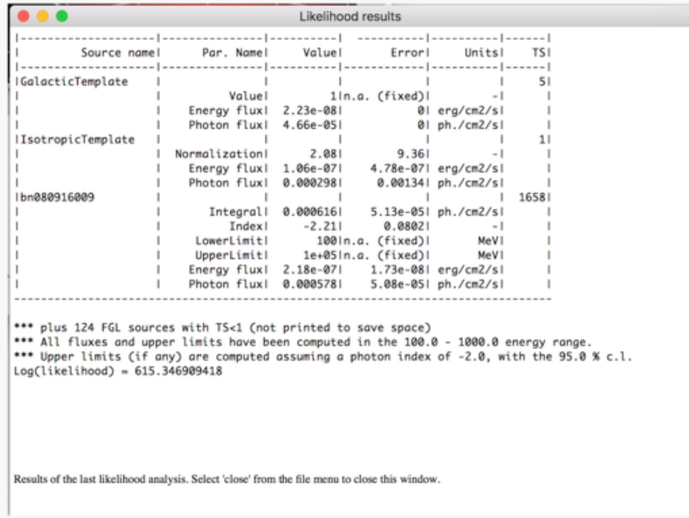
https://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/python_tutorial.html

https://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/upper_limits.html

- Fermipy

https://fermipy.readthedocs.io/en/latest/index.html

などなど



Likelihood results

Source name	Par. Name	Value	Error	Units	TS
GalacticTemplate					5
	Value	1	n.a. (fixed)	-	
	Energy flux	2.23e-08	0	erg/cm2/s	
	Photon flux	4.66e-05	0	ph./cm2/s	
IsotropicTemplate					1
	Normalization	2.08	9.36	-	
	Energy flux	1.06e-07	4.78e-07	erg/cm2/s	
	Photon flux	0.000298	0.00134	ph./cm2/s	
bn080916009					1658
	Integral	0.000616	5.13e-05	ph./cm2/s	
	Index	-2.21	0.0802	-	
	LowerLimit	100	n.a. (fixed)	MeV	
	UpperLimit	1e+05	n.a. (fixed)	MeV	
	Energy flux	2.18e-07	1.73e-08	erg/cm2/s	
	Photon flux	0.000578	5.08e-05	ph./cm2/s	

*** plus 124 FGL sources with TS<1 (not printed to save space)
*** All fluxes and upper limits have been computed in the 100.0 - 1000.0 energy range.
*** Upper limits (if any) are computed assuming a photon index of -2.0, with the 95.0 % c.l.
Log(likelihood) = 615.346909418

Results of the last likelihood analysis. Select 'close' from the file menu to close this window.

Resulting count map and likelihood model image. GRB 080916C is well detected!