“Watching the Violent Universe”
The COSMAX project

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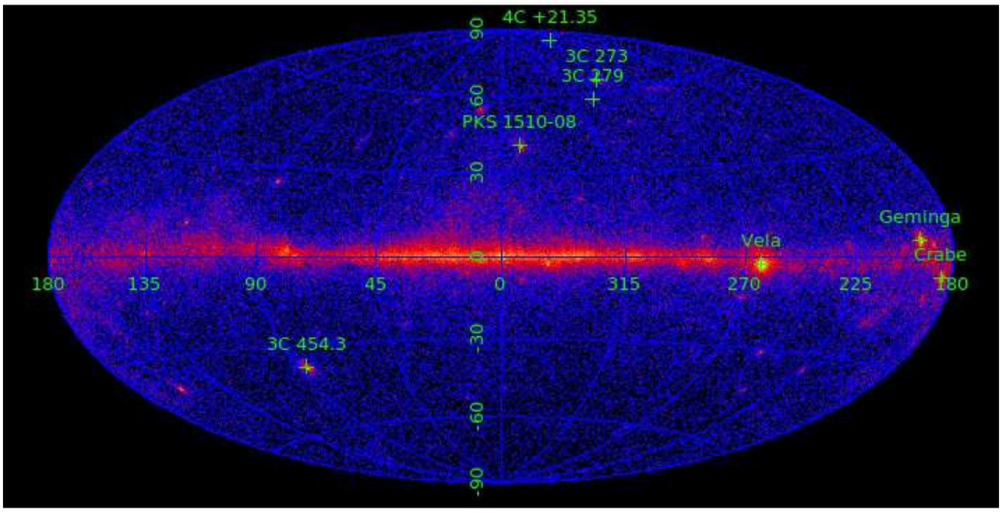
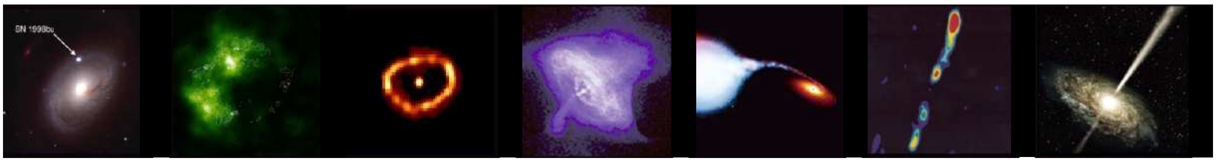


Introduction

The Cosmax project aims at allowing anyone interested to have a glimpse at the ever-changing gamma-ray sky. Periods where particularly interesting and spectacular events (solar outburts, gamma-ray bursts, flaring actrive galactic nuclei, novas….) took place can be selected, or alternatively the sky can be watched « live ». The project makes use of the publicly-available data of the Large Area Telescope (LAT) aboard the NASA Fermi satellite. The goal is to increase the awareness of the general public towards violent phenomena of the Universe, all exhibiting extraordinary properties, with some of them showing strong temporal variability (or a transient character) contrasting with the seemingly steadiness of the sky.

Cosmic rays detected at Earth are direct (and historically the earliest one, since the 100th anniversary of their discovery was celebrated in 2012) evidence for the existence of cosmic accelerators in the Universe. The nature of these accelerators long remained a mystery, mainly because cosmic rays are randomly deflected in the magnetic fields permeating the cosmos. The information related to their direction is thus lost.

Gamma rays are a privileged means to study gamma cosmic accelerators, whether they are the sources of cosmic rays or otherwise : gamma-rays are only produced by high-energy particles interacting with matter, magnetic fields or low-energy electromagnetic radiations (like visible light) and are immune to magnetic deflexion. Different accelerator classes including pulsars, supernova remnants, X-ray binaries, novae, active galactic nuclei, gamma-ray bursts… have been detected in gamma rays. Thanks to its exceptional data, the Fermi-LAT (Large Area Telescope) has allowed a major leap forward in our knowledge of these objects. The possibility of exploring the Fermi-LAT data in a simple fashion rests on several unique properties shown by these data: they are public (as are all analysis tools), span the entire sky (the sky is surveyed every 3 hours), quite easy to comprehend (consisting of a simple list of photon parameters: sky coordinates, energy, detection time...) and quickly available (less than 12 hours elapsed between the detection and the posting on the internet). It is thus possible for non-experts to generate full sky maps (or restricted to user-defined regions) similar to those illustrating most of the LAT press releases. Many of these press releases report interesting transient events (e.g., spectacular flares experienced by different sources). The sky can also be watched "live" by using the very latest data (bright flaring sources detected at any given moment are listed on the Fermi blog at http://fermisky.blogspot.co.at/). The brightness variations can be followed as a function of time as well.



Tutorial of the LAT data exploration

Context

- The Fermi satellite orbits Earth at an altitude of 565 km, corresponding to an orbital period of 96.5 min. It was launched by NASA on June 11th, 2008 (ther mission was the called GLAST) and should continue to take data at least till 2016. Its principal instrument, the LAT (Large Area Telescope), detects gamma-rays with energies greater than 30 MeV. The LAT field-of-view spans 20% of the whole sky. In survey mode, its rocks every second orbit to survey alternatively the two sky hemispheres and thus scan the whole sky every 3 hours. The sky coverage is uniform within 30% .
- Gamma-ray photons are detected one at a time, using particle-physics techniques. photons are rare: with a 1 square-meter collecting area the LAT detects only 3 photons per second on average, while cosmic rays detected over the same time period are about 1000 times more abundant.
- When the enter the detector, most photons materialize into a electron-positron pairs (following Einstein famous formula $E=mc^2$). The initial direction as well as the photon energy are « reconstructed » thanks to sophisticated algorithms from the signals generated by electrons and positrons within the LAT principal elements, called the tracker and the calorimeter respectively. A third element, the anticoincidence shield allows us to tell whether the particle entering the LAT is charged or neutral, et thus to discriminate between cosmic rays (charged) and gamma rays (neutral).
- The LAT accuracy to measure the photon sky direction, i.e., angular resolution, strongly depends on the photon energy. It ranges from 0.2° at high energy (above 10 GeV) to 5° at 100 MeV. This is the reason why even point sources appear as extended blobs in the gamma-ray sky maps.
- The LAT data can be downloaded for each mission week (starting at week 9, corresponding to the beginning of LAT scientific operations in August 2008) from the URL: http://heasarc.gsfc.nasa.gov/FTP/fermi/data/lat/weekly/photon/[1]
  For information, files including the corresponding satellite parametrers like its position, its orientation…, as a function of time (optional in the following) can be downloaded at the following URL:
  http://heasarc.gsfc.nasa.gov/FTP/fermi/data/lat/weekly/spacecraft/[2].
- The photon detection time is expressed in «mission elapsed time » (MET), the time in seconds elapsed since an arbitrary reference time set to 00:00 January 1st, 2001[3].
- The photon sky direction is expressed in celestial coordinates: right ascension (noted RA), declination (noted DEC) which are equivalent to the earth-based longitude and latitude respectively, as they share the same reference plan (the equator) or in galactic coordinates : galactic longitude, noted L, and galactic latitude, noted B (the reference plan being the Galactic plan (aka Milky Way plan) in that case.

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[1] Use the "fetch" command to download the data for the week of choice automatically.
[2] Use the " fetch_sat" command to dowload these data for the week of choice.
[3] The commands Date_to_MET and MET_to_Date enable the user to convert the date (in Universal Time) into MET and vice-versa.

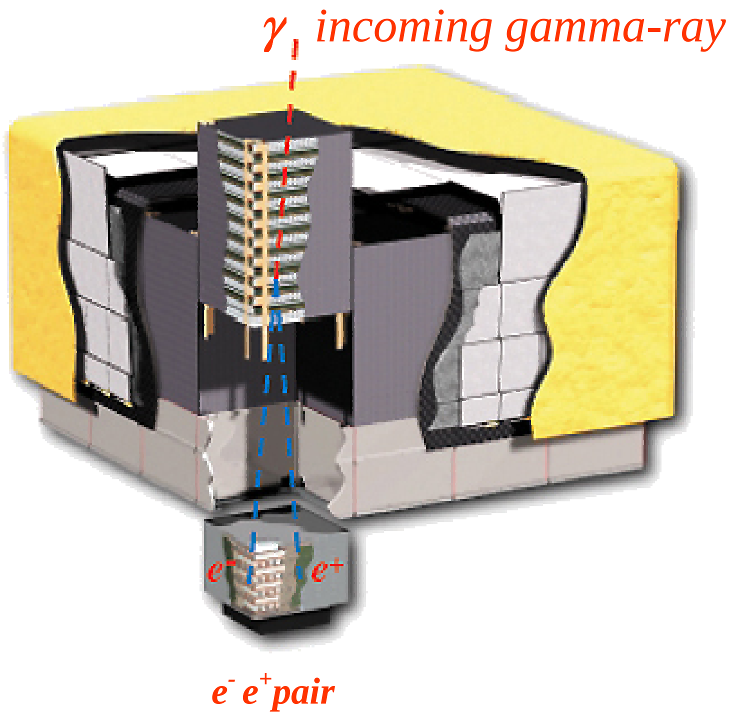

Figure 1 Sketch of the Fermi-LAT. The telescope comprises 16 towers, composed each of a tracker (upper part) and a colarimeter (lower part). An anticoincidence system (tiles in light gray) encloses the upper part and is covered with a micrometeorite shield (in yellow).

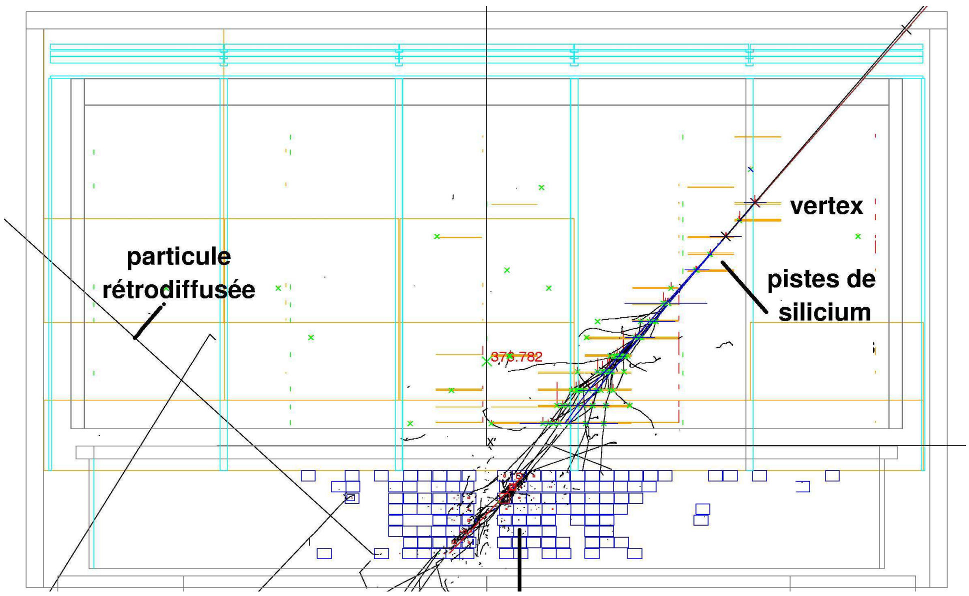

Figure 2 Result of a simulation showing the detection of a 5 GeV photon detected by the LAT.

If you already have a Linux machine running,
the set of tools can be downloaded from:
ftp://www.cenbg.in2p3.fr/astropart/VM/cosmax_linux.tar.gz
and instructions can be found at:
ftp://www.cenbg.in2p3.fr/astropart/VM/README.txt

Installation of the Linux VMWare virtual machine on a Windows PC

Required configuration
- Windows XP or more recent version with an internet connection.[4]
- version VmWare Player-5.x or more recent (free for Windows and Linux), http://www.vmware.com
- at least 1Go RAM for the virtual machine (the memory can be changed through the menu « Virtual Machine » then « Virtual MachineSettings », « Memory » see figure below)
- at least 10 Go of disk space available
- a display resolution of at least 1280x1024 (can be changed with « root » privileges)

Download
- download the zipped file ftp://www.cenbg.in2p3.fr/astropart/VM/sl5.7z
- unzip the file with 7Zip (free: http://www.7-zip.org/)
- download the latest version of VMwarePlayer for Windows PC

Installation
- Install VmwarePlayer
- Uncompress the file .zip in a dedicated directory
- The .zip file can then be deleted.

Usage
- Execute VMware Player to open the virtual machine (alternatively double click on the SL5.7.vmx file). The very first time, if the message « Copied or Moved machine ?» shows up, click on « Copied ».
- Once the machine is on, you have access to a full SL5 system, with internet access if your Windows machine is connected.
- Open a predefined session, username: local1, password :local1
- The analysis can start.

Some practical information:
- The session setup is defined in /home/local1/.ucshrc.
- The "root" password is 'scilinux5.7'.
- One can switch from the virtual machine to Windows by clicking in the respective windows.
- It is possible to set up an exchange directory between Windows and the Linux virtual machine as follows:
In the menu of the Linux virtual machine , select "Virtual Machine Settings" (or alternatively type CTRL-D), then "Options", "Shared Folders", ensure that the option "Always enabled" is checked, then select "Add" and choose a directory path under Windows with a name like

[4] - On some old PCs, the « Virtualization Technology » function might not be allowed. See http://www.sysprobs.com/disable-enable-virtualization-technology-bios to fix this problem.

« Exchange » then « Finish ». The directory path appears in "Host Path". Click on « OK » (see figure below).
- In your Linux session, the exchange directory is /mnt/hgfs/Exchange (in this example)

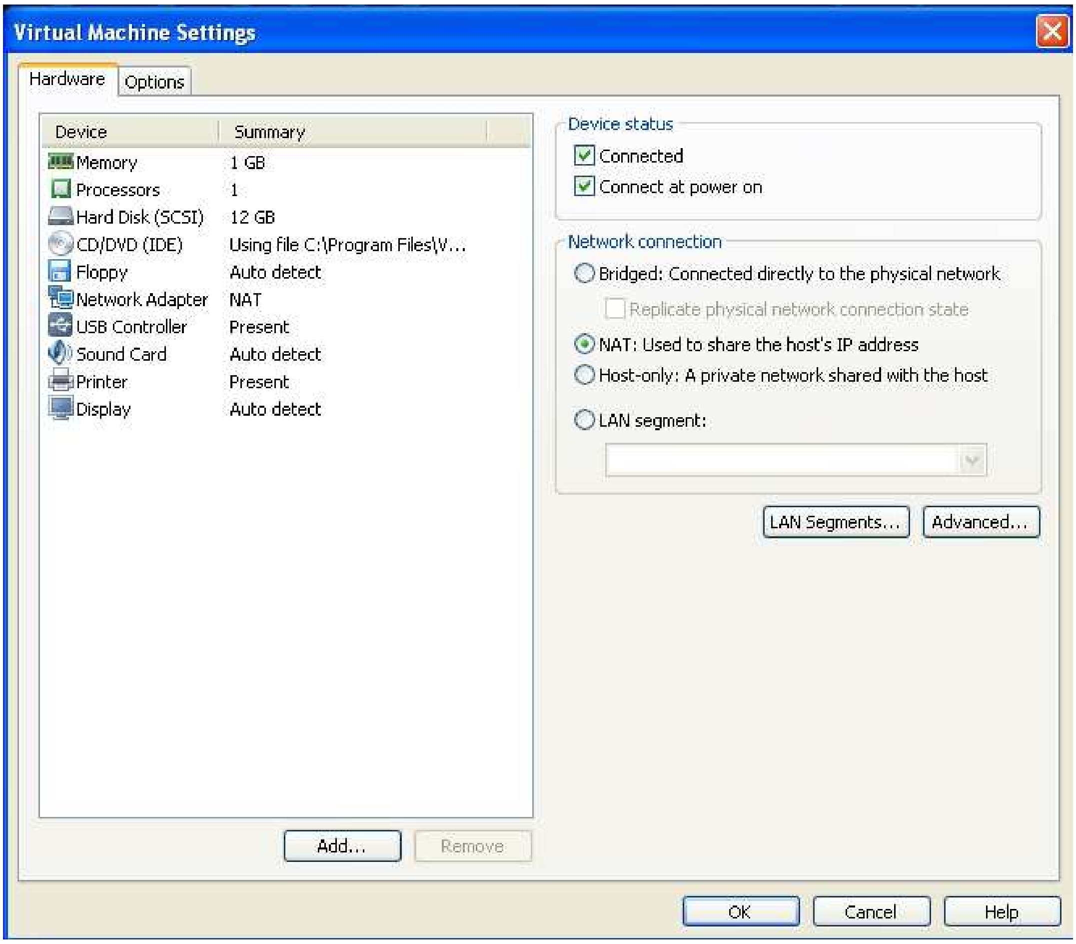

Figure 3. Virtual Machine Settings (« Options » page)

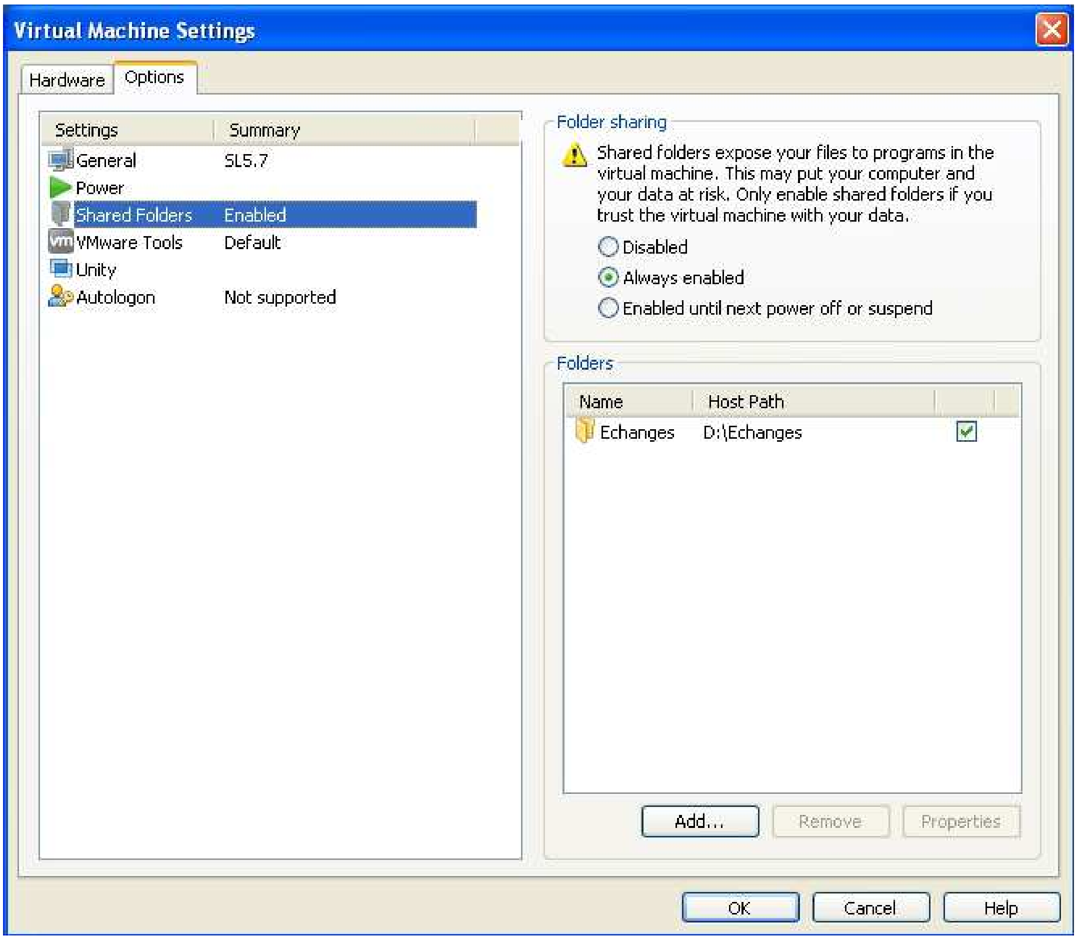

Figure 4. Virtual Machine Settings (« Options » page)

Installation of the Linux VirtualBox virtual machine on a Windows PC or a Mac

Required configuration

- A working internet connection.
- at least 1Go RAM for the virtual machine (the memory can be changed through the menu « Configuration » then « System »)
- at least 12 Go of disk space available
- a display resolution of at least 1280x1024

Download

- download the file cosmax_VB.ova (ftp://www.cenbg.in2p3.fr/astropart/VM/cosmax_VB.ova)
- download the latest version of VirtualBox (https://www.virtualbox.org/) for your machine.

Installation

- Install VirtualBox
- Execute VirtualBox
- In the menu Machine, click on "Add"
- Enter the path to the cosmax_VB.ova file

Usage

- Turn on the cosmax_VB virtual machine by clicking on the ON-OFF button.
- Once the machine is up, you have access to a full SL5 system, with internet access if your host machine is connected.
- Open a predefined session, username: local1, password :local1
- The analysis can start.

Some practical information:

- The session setup is defined in /home/local1/.ucshrc.
- The "root" password is 'scilinux5.7'.
- One can switch from the virtual machine to your host machine by clicking in the respective windows.
- It is possible to set up an exchange directory between your host machine and the Linux virtual machine as follows:

In the Configuration menu of the Linux virtual machine , select "Shared Folders", then select "Add" in "Permanent Files" . Choose a directory path in your host machine with a directory name like « Exchange » and check the boxes "Automatic mount" and "Permanent setting"
(see figure below, in French sorry!)

- In your Linux session, the exchange directory is /media/sf_Exchange (in this example).

The directory name is sf_xxxx where xxxx is the shared-folder directory name on your host.

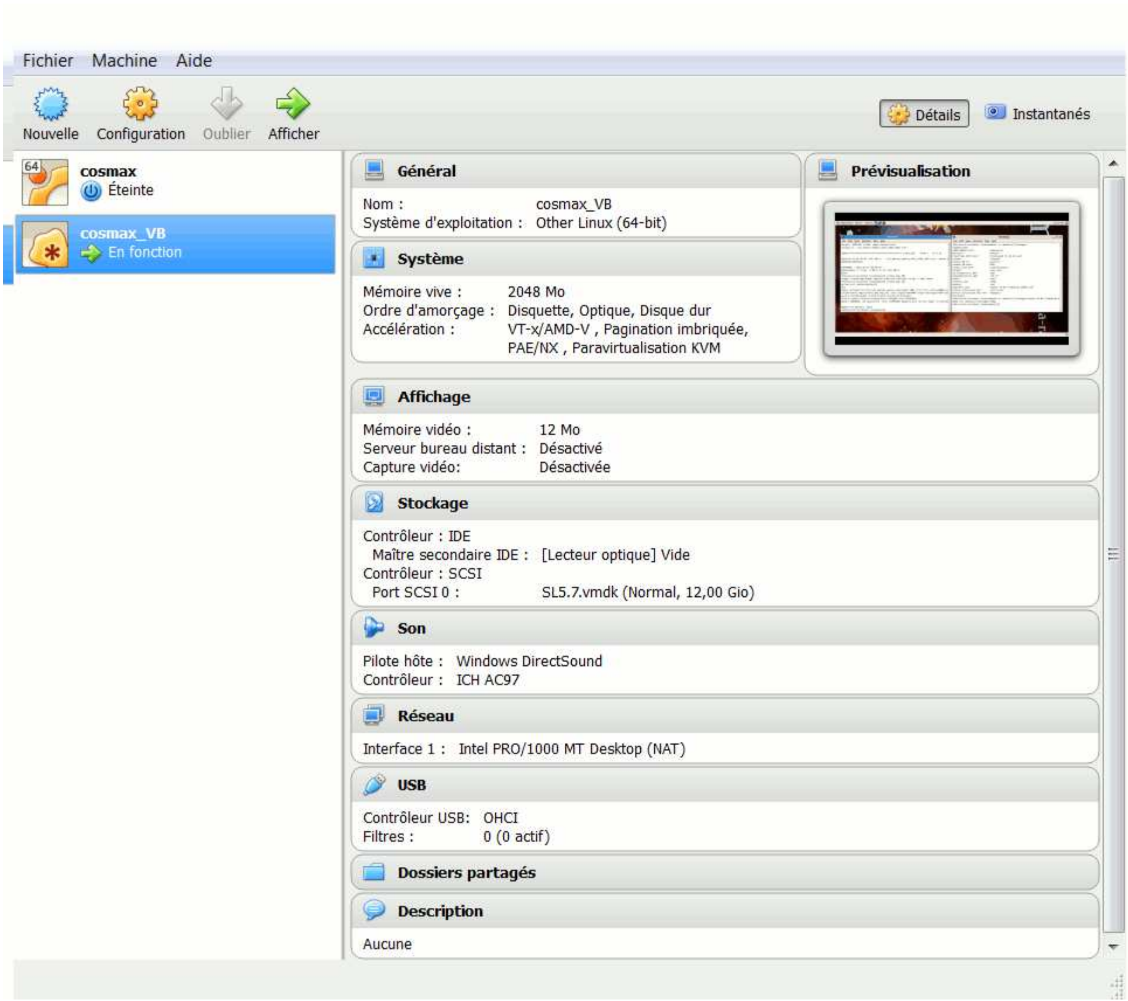

Figure 5. VirtualBox Configuration Settings

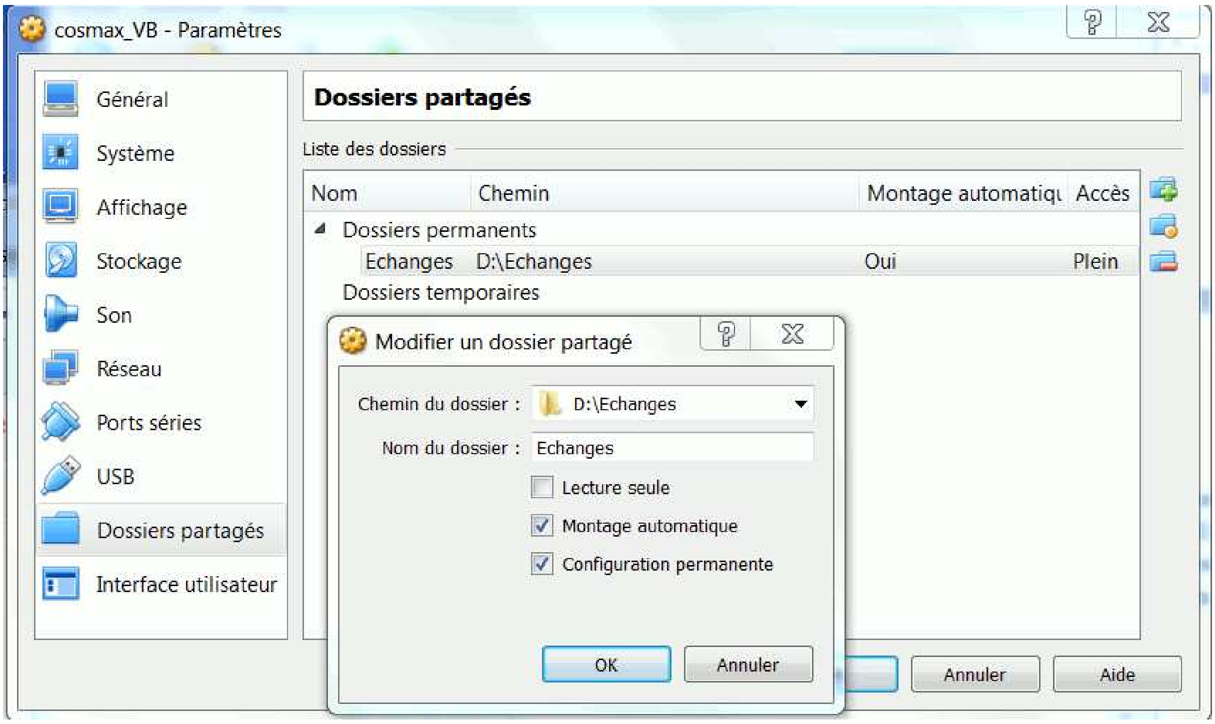

Figure 6. VirtualBox shared-folder settings.

Preamble

It is not necessary to master linux (or UNIX) for this project, but knowledge of basic commands like cd (change the current directory), ls (list the directory files), cp (copy a file into another), mv (rename or move a file), rm (delete a file)… will make the user life simpler.
IMPORTANT : if some of the functions described below don't work, the installation may not be up-to-date. To correct this problem, type in the following command :

- ➢ update

If the problem persists or in case of an error message, do :

- ➢ rm –f update.py

```
> wget ftp://www.cenbg.in2p3.fr/astropart/VM/update/update.py
```

- ➢ update

If the latter command is unknown (message: command not found), do:

- ➢ python update.py

Data

The LAT data files use the fits format. The downloaded weekly files (see below) are stored in the directory named fits_file (the satellite data are placed in the directory fits_file_sat). Their file names are:
lat_photon_weekly_wxxx_p130_v001.fits (or lat_photon_weekly_wxxx_p130_v001_filt.fits) where xxx is the week number.

Dowload a weekly file for a given date

Convert the date into MET, which returns the corresponding mission week as well.

- ➢ Date_to_MET hour minute second day month year

Example

- ➢ Date_to_MET 0 0 0 16 9 2008

2008-09-16 00:00:00
MET: 243216000 week: 15
In this example, the date is in mission week 15.
The data file can be dowloaded (if the internet connection is functionning) thanks to the following command:

- ➢ fetch 15

In a first setp, this command downloads the file lat_photon_weekly_wxxx_p130_v001.fits onto the directory fits_file and then delete the data of some photons with high probability of arising from the interaction of cosmic rays with the Earth atmosphere (condition « zenith_angle>100 », for the experts). The resulting file is called lat_photon_weekly_wxxx_p130_v001_filt.fits and is that used in the following. The original file lat_photon_weekly_wxxx_p130_v001.fits is removed to save disk space.
The syntax to download the data for the current week (latest delivery) is:

- ➢ fetch current

Data exploration

Open one of the weekly data files (thereafter for week 15) with the command fv[5] (« fits viewer ») :

[5] http://heasarc.gsfc.nasa.gov/ftools/fv/tutorial/fv_guide.html

➢ fv fits_file/lat_photon_weekly_w015_p130_v001_filt.fits

The two gray panels shown aside pop up. The horizontal panel corresponds to the data contents of the open file. On the line showing Index=1 (Extension=EVENTS), click on « All ».

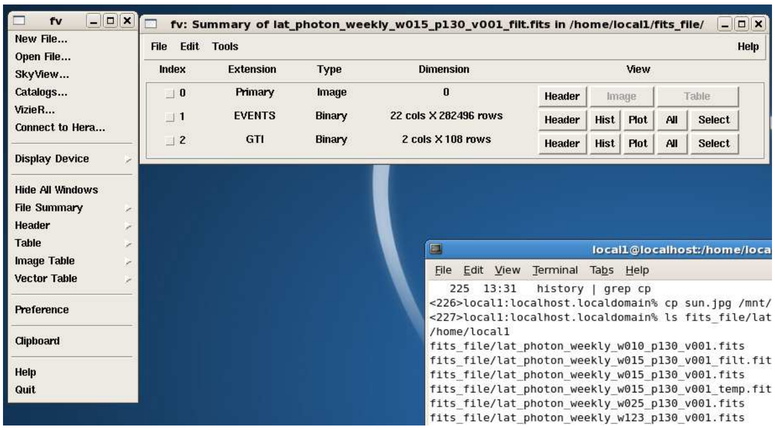

Figure 7. Panels brought up with the fv command

The data are listed as a table, where each line corresponds to one photon, and the différent columns to the photon parameters. All parameters are described in the « Header » tab: Energy (in MeV), RA (right ascension), DEC (declination), L (galactic longitude), B (galactic latitude), …, TIME (detection time in MET),…, as well as other secondary parameters which are only required for a detailled analysis outside the scope of this project. It is possible to create histograms for these different parameters by clicking on Hist, then selecting the chosen parameter.

The simple analyses discussed in the following only involve the parameters Energy, RA, DEC (or alternatively L and B) and TIME.

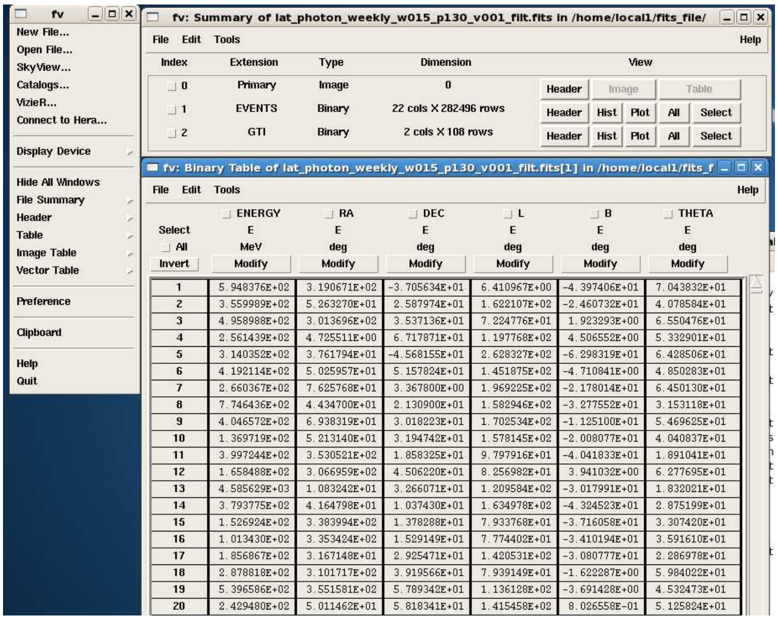

Figure 8. Menus and « EVENTS » table, as displayed with fv

Generation of a weekly sky map

The command :

- ➢ create_map #week (option)

creates a sky map (stored in the file counts_map_#week_option.fits) for the entire selected week (noted '#week') for a given projection (noted 'option') among three possible ones: cel, gal and ait (see below).

These maps can be displayed with the command ds9[6]

- ➢ ds9 -cmap b -scale log -zoom to fit counts_map_#week_option.fits

Option 'cel'

The map (an example of which is given below) is in celestial coordinates and in Cartesian projection. The ordinate (declination) ranges from -90° to +90°. The abscissa (right ascencion) ranges from 180° to -180°, such the point RA=0, DEC=0 (the vernal point, which is the position of the Sun at the Spring equinox) is lying at the center of the figure. The galactic plan shows up as a bell-shaped curve. This projection distorts areas, the regions located near the poles being considerably expanded as compared to those close to the equator.

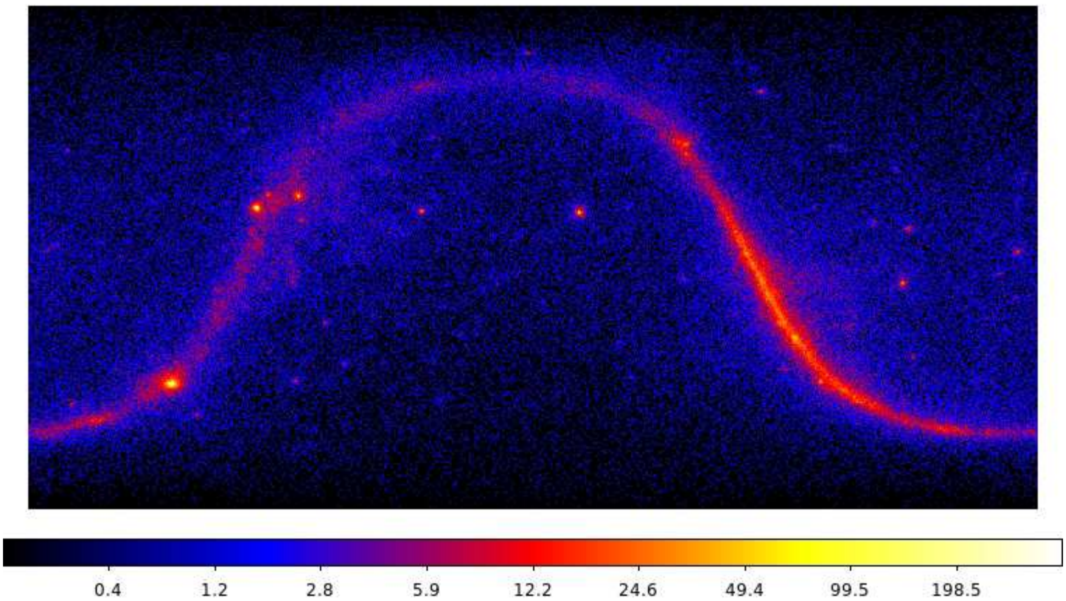

Figure 9. Map in celestial coordinates and in Cartesian projection.

Option 'gal'

The map (an example of which is given below) is in galactic coordinates and in Cartesian projection. The ordinate (galactic longitude B) ranges from -90° to +90°. The abscissa (galactic latitude L) ranges from 180° to -180°, such the point L=0, B=0 (the galactic center) is lying at the center of the figure. The galactic plan lies along the ordinate (B=0). This projection distorts areas, the regions located near the poles being considerably expanded as compared to those close to the equator.

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[6] http://hea-www.harvard.edu/RD/ds9/ref/

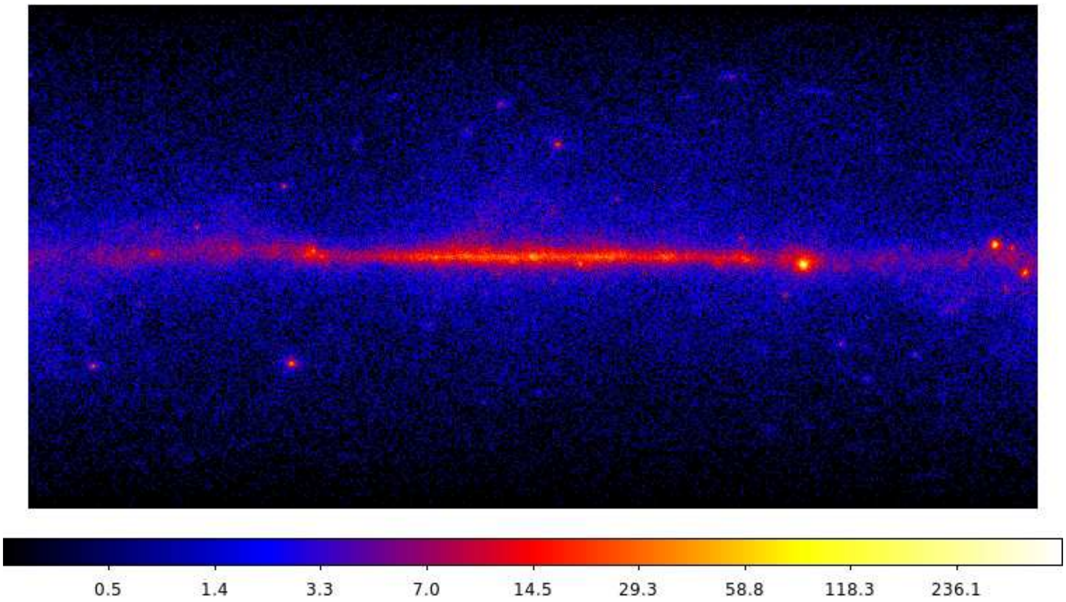


Figure 10. Map in galactic coordinates and in Cartesian projection.

Option 'ait'

The map (an example is given below) is in galactic coordinates and in Hammer-Aitoff projection. Some curves with constant L or B are displayed. This projection conservs areas, and is thus very commonly used in Astronomy.

Le following command was used :

- ds9 -cmap b -scale log -zoom to fit -grid yes -grid view axes tickmarks no -grid skyformat degrees -grid format1 d.0 -grid format2 d.0 -wcs galactic -file counts_map_015_ait.fits -regions load all bright_sources.reg

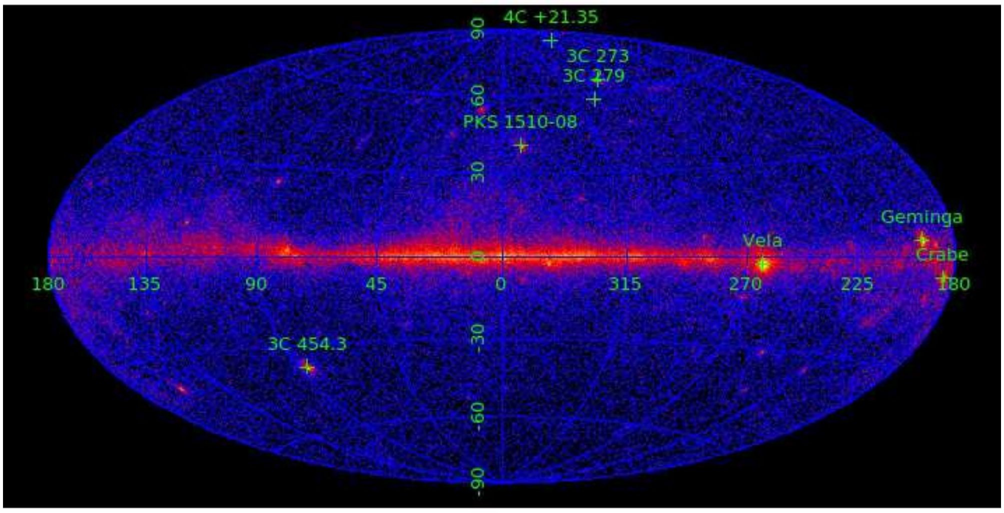


Figure 11. Map in Hammer-Aitoff projection and in galactic coordinates. The location of 8 bright sources (3 pulsars in the Galactic plan and 5 blazars out of it) is given.

Creation of a skymap with selection
The command:

- ➢ create_map #semaine option time_min time_max ra dec r emin emax

allows the creation of a map where photons can be selected:

- in detection time, ranging between time_min et time_max, expressed in MET (these limits must be comprised within the selected week; Note : entering time_min=0 and time_max=0 allows all photons to be used).
- in position, in a circular sky region centered at point (RA, DEC) and with radius r.
- in energy between emin et emax, expressed in MeV.

In addition to creating the file counts_map_#week.fits visuable with ds9, a fits file including the so-selected photons is created under the name lat_photon_weekly_w#week_pyyy_vzzz temp.fits

Ex : *create_map 256 ait 388727100 388799100 173.1 27.7 15*
creates a map for the week 256 between MET=388727100 et MET=388799100 of a 15 degrees-in-radius sky region centered at a point of coordinates RA=173.1, DEC=27.7, (gamma-ray burst GRB 130427A).

Creating an animated gif illustrating the temporal behavior of a cosmic source

The command :

- ➢ *create_movie #week option time_min time_max delta_t (ra dec r emin emax delay)*

allows the user to create an animation

- where the time of photon detection is between time_min and time_max, expressed in MET (these times must be comprised in the bounds of the considered week; note : entering time_min=0 and time_max=0 allows the selection of all photons in the weekly file) and delta_t is the time covered by each image (en seconde). The parameter delay is the delay between two images in the animation (default : 0.05 s).

Note : Several consecutive weeks can be merged by replacing #week for #initial_week-#final_week.
Optional selections can be applied :

- in position, in a circular sky area centered at a point of coordonnates (RA, DEC) , r-degrees in radius;
- in energy between emin and emax, expressed in MeV.

Ex : create_movie 256 ait 388727100 388799100 3600 173.1 27.7 15
The resulting file, in animated-gif format, is created under movie/mov_#week.gif (or movie/mov_#initial_week-#final_week.gif). It can be visualized for instance with firefox :

- ➢ *firefox movie/mov_#week.gif*

Examples are given below for a GRB and a solar eruption sursaut gamma.

Creating a light curve illustrating the temporal evolution of a source
The command :

- ➢ *create_light_curve #week output_file time_min time_max delta_t (ra dec r emin emax)*

allows the user to create a lightcurve (flux variation vs. time)

- where the time of photon detection is between time_min and time_max, expressed in MET (these times must be comprised in the bounds of the considered week; note : entering time_min=0 and time_max=0 allows the selection of all photons in the weekly file) and delta_t is the time bin.

- The resulting file (output_file) is in text format : time, time bin, flux, flux uncertainty.

Note : Several consecutive weeks can be merged by replacing #week for #initial_week-#final_week.
Important : the satellite files for all considered weeks must have been downloaded (obtained with fetch_sat #week), in order to compute the exposure and provide the photon flux from the photon number.
Optional selections can be applied :

- in position, in a circular sky area centered at a point of coordinates (RA, DEC) , r-degrees in radius;
- in energy between emin and emax, expressed in MeV.

Description of the map

The detected particles comprise four components :

- The Galactic diffuse emission, due to the interaction of cosmic rays with matter in the galaxy (gas, dust); this emission makes the outline of the Galactic plane so visible;
- The isotropic (that is to say, spatially uniform) diffuse background, whose origin is uncertain; it may be made up of different components, some being known (unresolved active galactic nuclei), others being more hypothetical (e.g., associated with annihilating dark matter).
- A residual instrumental background, corresponding to particles different from cosmic gamma-rays misidentified by (passed "through the cracks" of) the rejection procedure. This background is more or less uniform, like the previous one. For most practical purposes they are considered as a single component rather than separately;
- Point sources either galactic: pulsars, pulsar nebulae and supernova remnants, X-ray binaries, globular clusters, or extragalactic: active galactic nuclei and gamma ray bursts. The most recent catalog, published in 2012 and established with 2 years of data sources lists 1873 sources. The three brightest sources, which have a constant brightness (or almost constant) are pulsars: they are the Vela, Geminga and Crab pulsars. They produce a pulsed emission with periods of 89 ms, 237 ms and 33 ms, respectively, with very few photons with energies above 10 GeV (10000 MeV), as shown in the map where a selection beyond this threshold has been performed.

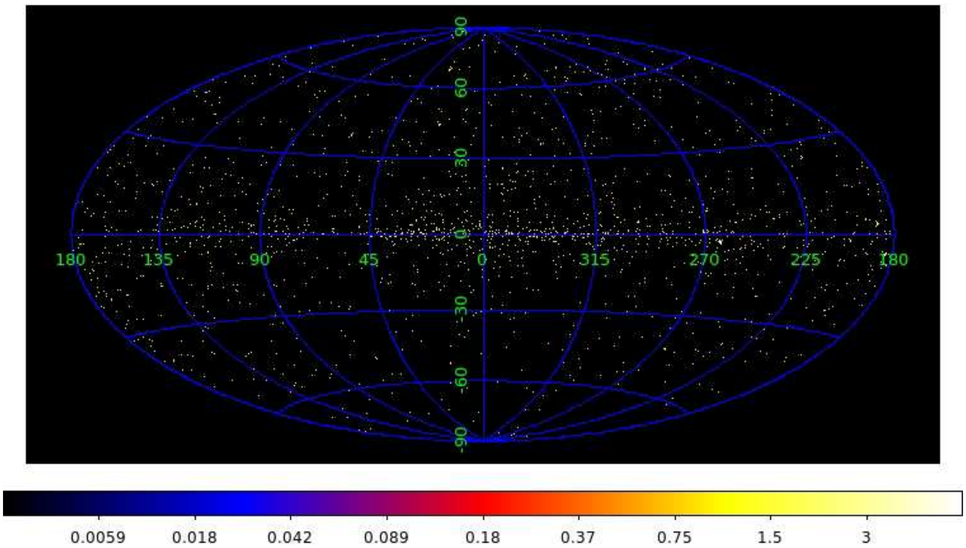


Figure 12. Map in Hammer-Aitoff projection and in galactic coordinates, for photons with energies greater than 10 GeV.

Major flare of 3C 454.3

3C 454.3 is the brightest blazar among the thousand detected by LAT. Blazars are radio galaxies (belonging to the class of active galaxies) exhibiting a relativistic jet emanating from the regions near a central supermassive black hole (with a mass exceeding 100 milion solar masses) and directed straight to the Earth. This feature makes the source very bright and leads to very variable emission within the cone spanned by the jet. Located 7.2 billion light years away, 3C 454.3 showed several major eruptions since the commissioning of Fermi in August 2008, the most spectacular one took place between 17 and 22 November 2010 (week 128). The source, with galactic coordinates L = 86.1, B = -38.2, was the brightest object in the sky in that period.

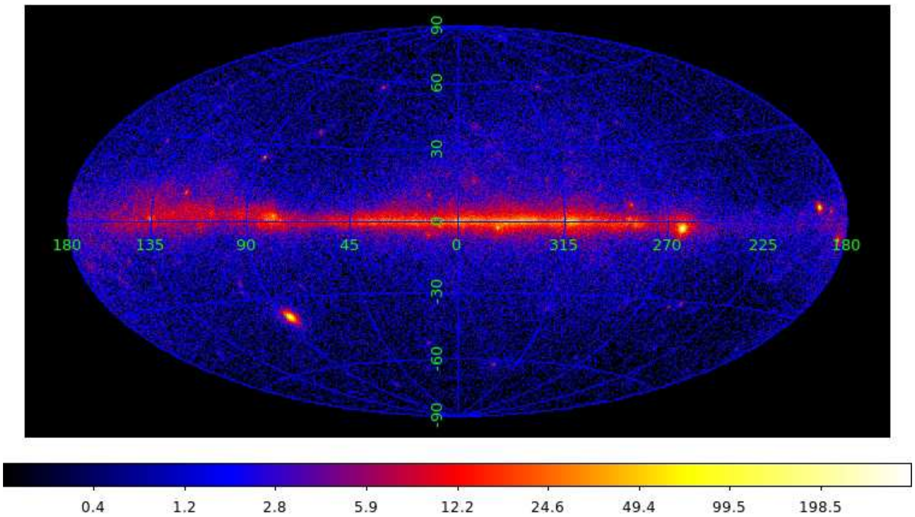


Figure 13. Map for week 128. The blazar 3C 454.3 is visible at (L,B)= (86.1, 38.2)

The spectacular brightness variation of this blazar is shown in the figure below (spanning the period from August 2008 to December 2010). The flux of Vela, which is usually the brightest source in the sky is depicted by the dashed line. Every time the flux of 3C 454.3 exceeds this limit, it dominates the gamma-ray sky.

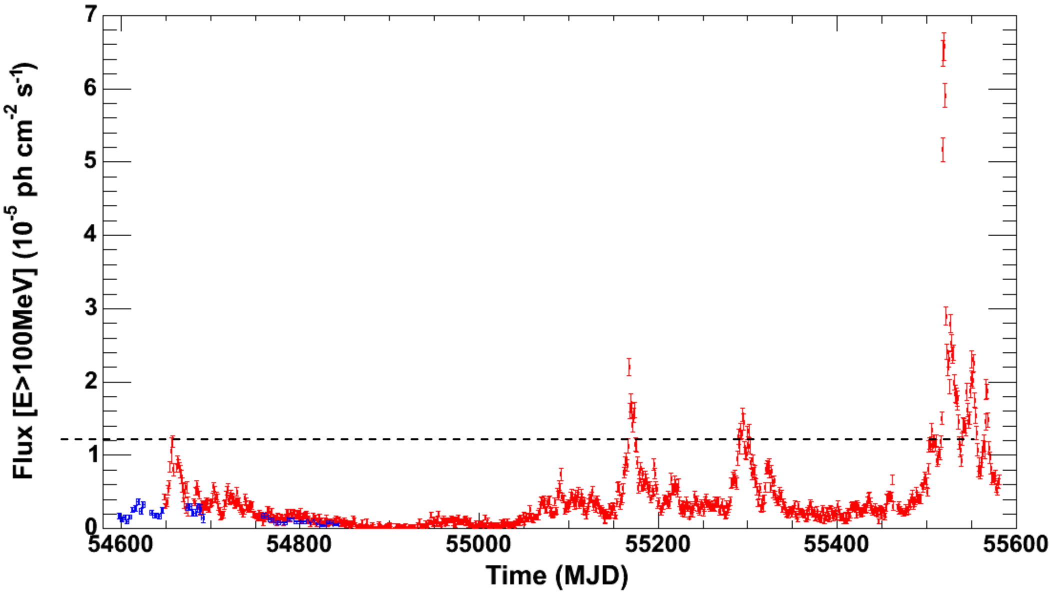


Figure 14. Temporal flux variations ("lightcurve") for the blazar 3C 454.3

An exceptional gamma-ray burst

The gamma-ray burst GRB 080916C, probably related to the explosion marking the death of very massive star, was detected on Septembre 16, 2008 at 00:13 UT. It lasted 23 minutes. The estimated distance of the event was 12.2 billion light years. Its exceptional power corresponded to that of 9000 supernovae**.**
http://www.nasa.gov/mission_pages/GLAST/news/high_grb.html
http://en.wikipedia.org/wiki/GRB_080916C
http://www.science20.com/news_releases/grb_080916c_most_extreme_gammaray_blast_ever_we_know_about
The following map (created with > create_map 15 ait 243216000 243219600 120 -56 15) illustrates the detection of this event in the LAT .

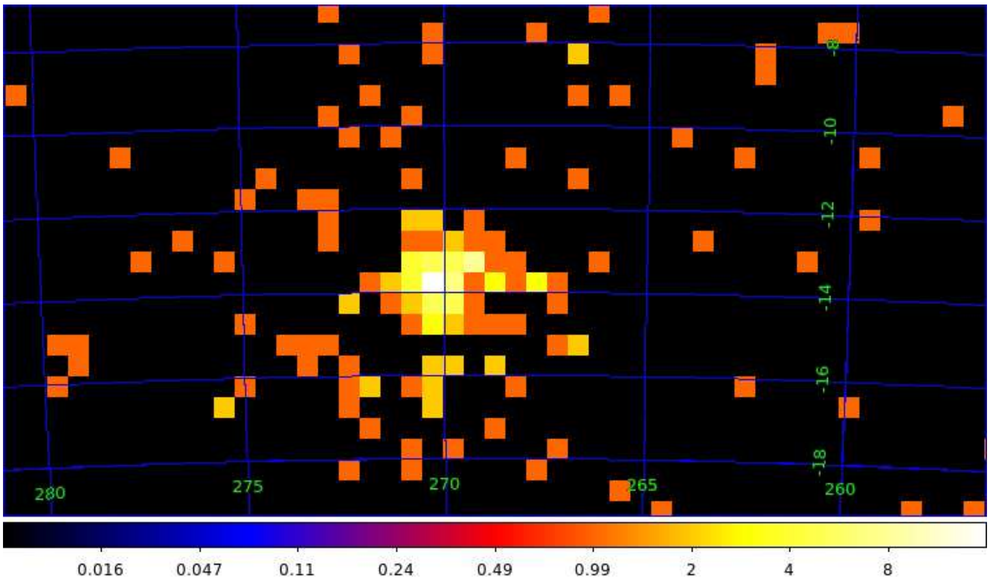


Figure 15. Map of the region around GRB090916C

One can explore the temporal properties of this rare event:

- fv fits_file/lat_photon_weekly_w015_p130_v001_temp.fits

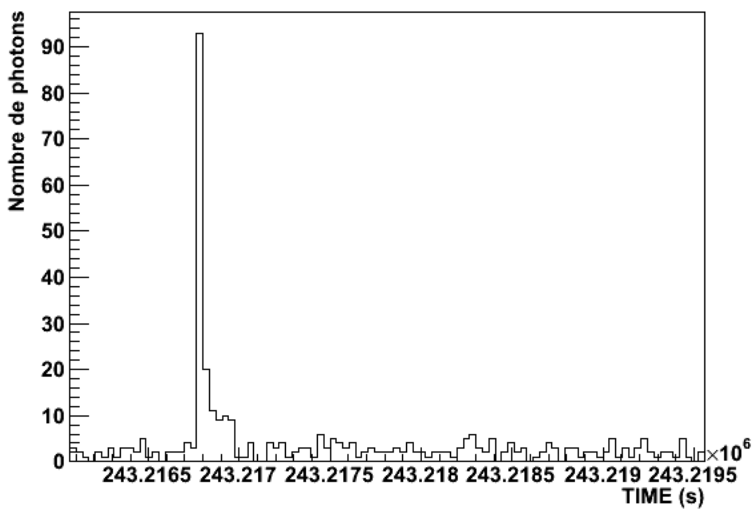
  then click on Hist, parameter X: TIME, limits Min=243216000 Max=243219600 Bin Size=50

  ou

- hist #file_name TIME (#number_of_bins)

  where #number_of_bins is an optional parametre (default is 100) defining the histogram size.

Figure 16. Distribution of the photon arrival time during one hour including GRB090916C.



A major solar eruption

This eruption, the most violent one ever dtected in gamma-rays took place on March 6, 2012 (week 196). The map below displays how the Sun looked like at that time (L~80°,B~-60°).

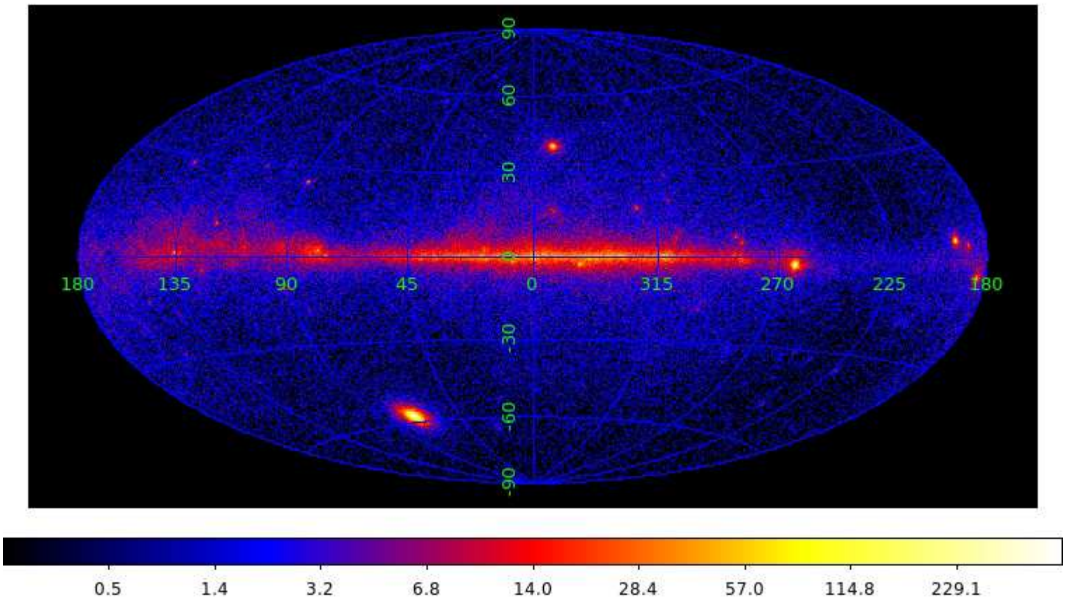


Figure 17. Sky map showing the brightest solar eruption recorded by the Fermi LAT.

The flaring Crab nebula

The Crab nebula (M1) is a supernova remnant housing a pulsar. This pulsar produces a wind of high-energy particles energetizing the surrounding nebula, resulting from the interaction of the matter ejected in the explosion with the interstellar medium. The explosion took place on July 4th, 1054 and was reported by chinese astronomers. Both the pulsar and the nebula shine in gamma-rays. It is not possible to resolve them separately with the Fermi-LAT data, although the nebula is spatially extended(6’x 4’). The pulsar emission is (quasi-)periodic with a period of 33 ms, wheareas that from the nebula is essentially steady. It was long believed that the nebula emission only varied over long timescales (tens of years), to such an extent that it was considered as the “standard candle” of gamma-ray astronomy. It was a shock to the community to discover in 2009 that this emission could vary over much shorter timescales, less than one day. Properties of the emitting zone (much smaller that the whole nebula) and the processes responsible for the flaring activity remain largely unknown. The figures below show a sky region centered at the nebula location (left panels) at two different epochs (weeks 196 and 248). The flaring episode correspond to the lower panels. The source on the left hand side is the Geminga pulsar, serving as a reference. Usually brighter than the Crab nebula (upper panels), it is outshine by the nebula during the flaring episode (lower panels). The projections onto the horizontal axis (galactic longitude L) are given in the right panels. Note: the axis direction is reversed w.r.t. the left panels, Geminga is showing up on the right-hand side of Crab..

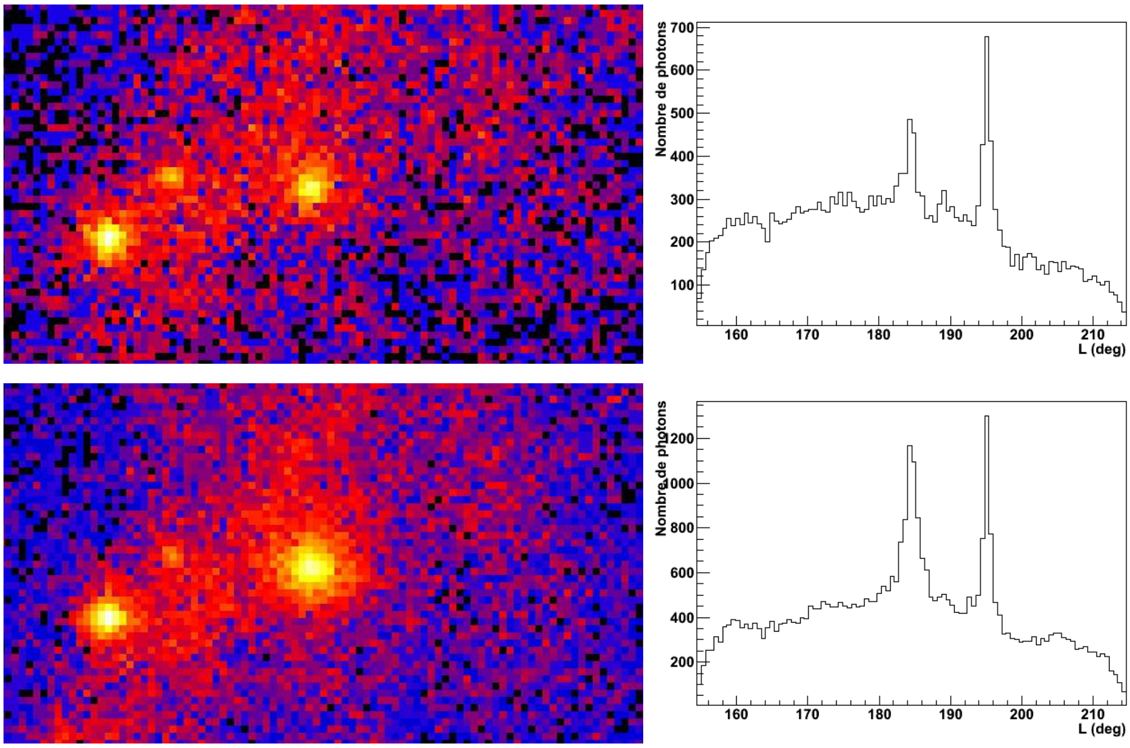


Figure 18. Left: Sky maps showing the Crab region at two different epochs (week 196: top and 248: bottom). Right: Galactic longitude projections of the left-hand maps (the axis directions are reversed).

Using the « Fermi blog»

For (almost) every week, it is possible to check out what variable sources were particularly active or what new transient event was recorded thanks to the « Fermi blog». This blog, which is intended as a service to the scientific community, is updated by members of the LAT collaboration called « Flare advocates ». For a given week, type in:

- blog #week

to display the blog for the selected week. with Firefox. An example is given below for week 196.

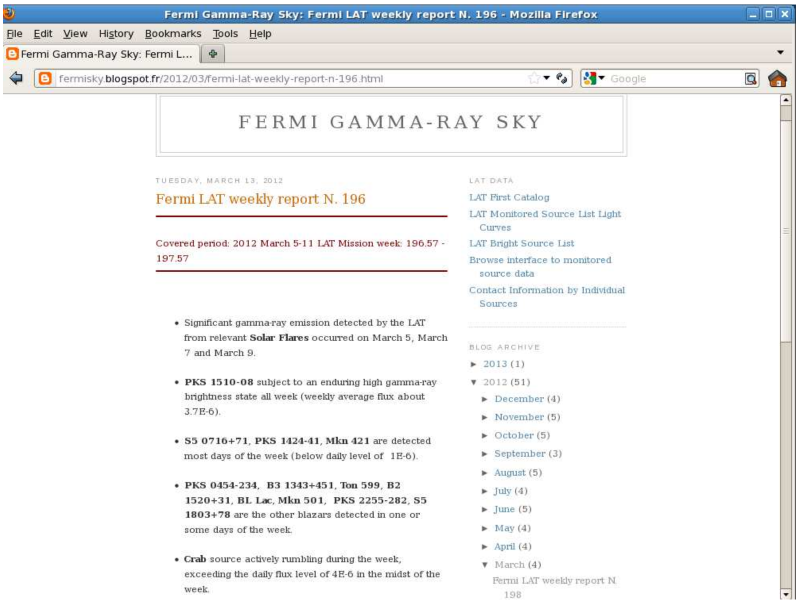


Figure 19. Screenshot of the Fermi blog.

The « blog » command generates a file including the positions of the sources mentioned in the blog. These positions will be automatically overlaid on maps subsequently created with « create_map » as described above (only with the ‘ait’ option) for the selected week.

For those who want more…

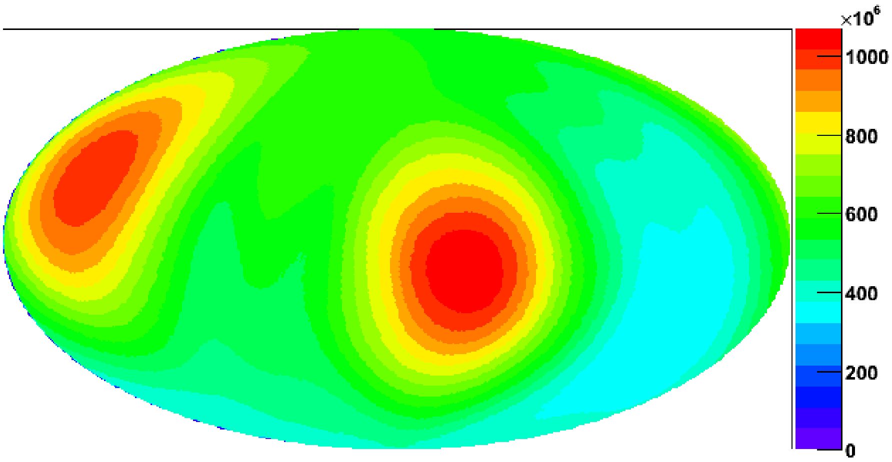
Exposure correction

The sky maps presented above are based on photon counting. The physical parameters characterizing a source that one is looking for are the photon flux (unit: photons/cm^2/s), the energy flux (unit: erg/cm^2/s) and energy distribution (called spectrum) of the photons emitted by the source. The gamma-ray spectrum is used in conjunction with the spectra obtained in other parts of the electromagnetic spectrum (radio, microwave, infrared, optical, ultraviolet, X-rays, low- or high-energy gamma-rays) to be compared with model predictions and thus establish what are the emission processes, the properties of the emitting particles and those of the environment (including matter, radiation, magnetic field ...) from the emission site.

Simply speaking, the number of collected photons, N, is equal to N: N = F x S x T where F is the source flux, S the collection area (called effective area) and T is the duration of the collection. In the case of the Fermi-LAT, S depends on the energy and is not constant over time, since the instrument scans the sky continuously: S varies greatly with the angle between the axis θ instrument and the source direction in the sky. The exposure, A, is the product S x T (more precisely A = $A = \int S(\theta(t))dt$, where the angle varies with time). This is the same concept that applies to photography, the exposure of a photograph depending on the aperture, which is the area of the opening through which the light passes, and the shutter speed.

An exposure map (for photons having an energy of 1 GeV) can be created (only after the commands and fetch fetch_sat have been executed for the week of interest) with the command:
>create_exposure #week

The map is stored in the file: figures/expo_aitoff_#week.gif
An example is given below. The unit is cm^2 s.



In reality, the flux and exposure both are dependent on the photon energy. The *differential number* of photons per energy unit is : *N(E)= F(E) x A(E)* and the expected number of detected photons is: $N = \int F(E)A(E)dE$. In the standard analysis of Fermi-LAT data, a sky region with a typical radius of 10 degrees is selected and the parameters of a model including all sources in the region as well as the diffuse emission components contributing photons to that region are adjusted. The analysis takes into account the spread in the measured photon resulting from the finite capability of the LAT to resolve sources (« angular resolution angulaire », which is strongly energy dependent), leading to an overlap of neighboring sources in the maps. When analyzing very bright sources, performing a simplified analysis will provide good results. This analysis allows the parameters K and Γ, called normalization factor and spectral index respectively, assuming that the differential flux function is a power-law function $F(E) = KE^{-\Gamma}$, to be derived from the energy distribution of photons selected in a region centered in the source direction and including 90% of the source photons considering the actual angular resolution[7]. The figure below shows the energy distribution of so-selected photons. The red curve represents the result of the analysis where the power-law function F(E) (in blue) was multiplied by the exposure function A(E) (shown in green), then integrated over the same energy bins as those of the photon energy histogram, to get comparable quantities. The contribution of the diffuse emission background is often negligible in the case of a bright source.

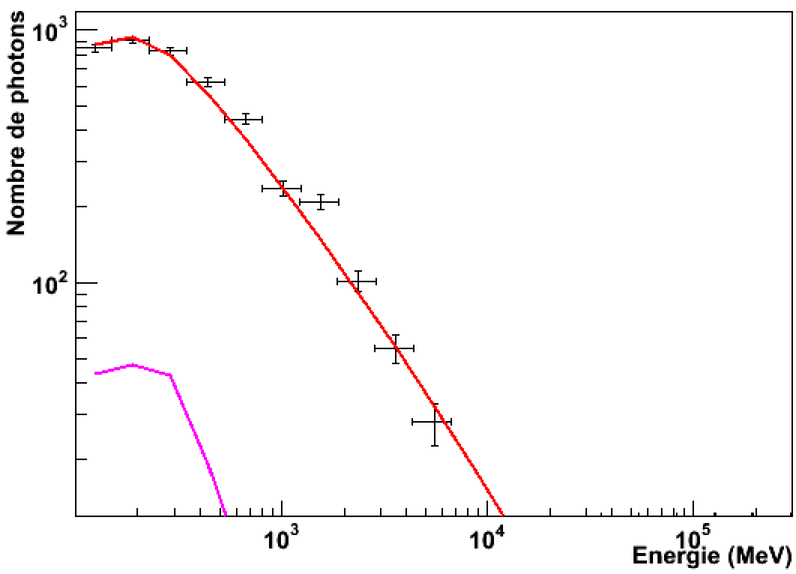
The command fit_spectrum allows the user to manually search for a pair (*F*,*Γ*) that correctly matches the data via a comparison such as that displayed in the figure below. It makes use of a data file created by the create_map command for a10°-in-radius region centered in the source location and a satellite data file downloaded with fetch_sat for the week of interest.

- fit_spectrum #week

  Enter flux, index (type -1 to exit) : *1.7e-5, 2.3*

In the above example, #week=128, one has entered *F*=1.7x10^{-5} photons cm^{-2} s^{-1} (integral flux above 100 MeV) and a spectral index *Γ* of 2.3. *F* typically lies in the range 10^{-6} -10^{-5} ph cm^{-2} s^{-1} for a bright source, and *Γ* is usually in the range 1.5 to 3. In scientific jargon, a spectrum with low *Γ* value (< 2) is called « hard », while a spectrum with a high value of *Γ*, it is called « hard ».

Figure 18. Energy distribution of photons selected with a direction close to that of 3C 454.3. (black crosses). The red curve correspond to the prediction of a model whose parameters have been manually adjusted to match the data. The magenta curve corresponds to the contribution of the diffuse emission background.



[7] The integral flux F above a lower-bound energy E_0 is often favored over a differential flux K as it has more physical meaning. It can easily be derived from K, E_0 and Γ: $F = \int_{E_0}^{+\infty} F(E)dE = KE_0^{-\Gamma+1}/(\Gamma-1)$.

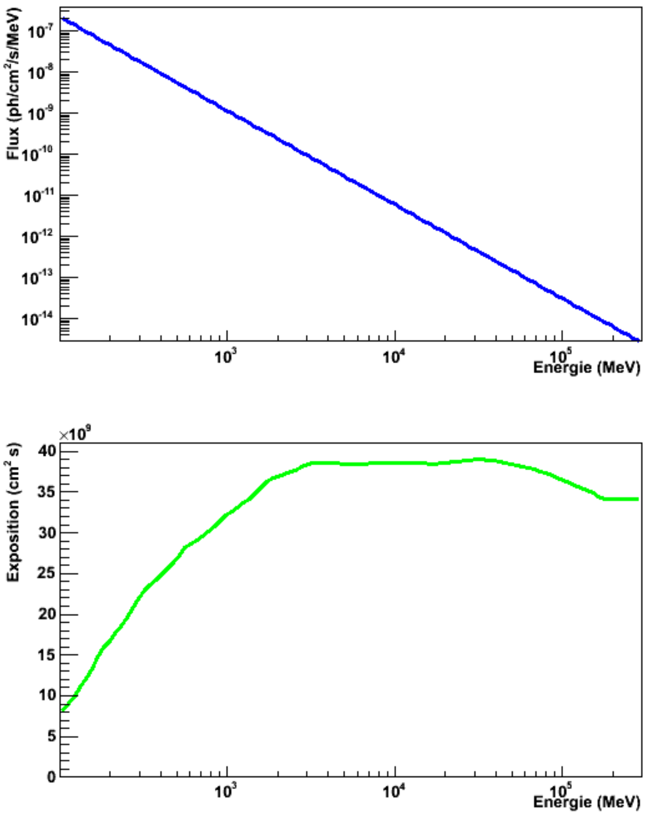


Figure 19. Top panel : Power-law distribution in the model used. Bottom panel: Exposure function as a function of the photon energy for 3C 454.3 in the week 196.

Events of particular interest

Name	Type	Time start/end	week	Date	RA	Dec	z/D	Reference
GRB 130427A	GRB	07:47:06/20h	256	27/04/13	173,15	27,71	z=0.34	http://arxiv.org/pdf/1311.5623v2.pdf
GRB 080916C	GRB	00:12:45/23’	15	16/09/08	119,85	-56,64	z=4.35	http://arxiv.org/pdf/0907.0714v1.pdf
GRB 090510	GRB	00:22:59	49	10/05/09	333,55	-26,6	z=0.90	http://arxiv.org/pdf/1005.2141v1.pdf
GRB 090902B	GRB	11:05:08	65	02/09/09	264,94	27,32	z=1.82	http://arxiv.org/pdf/0909.2470v2.pdf
GRB 090926A	GRB	04:20:26	69	26/09/09	353,4	-66,32	z=2.11	http://arxiv.org/pdf/1111.4129v1.pdf
Sun	Flare	0h00/8h00	196	06/03/12	348	-5	1 UA	
M1 (Crab)	Flare	6 days	149	12/04/11	82,71	13,55	1,9 kpc	http://arxiv.org/pdf/1105.5028.pdf
V407 Cyg	Novae	19 days	93	11/03/10	315,54	45,78	2,7 kpc	http://arxiv.org/pdf/0912.4029v2.pdf
PKS 1502+106	Blazar		196		226,1	10,49	z=1.84	http://arxiv.org/pdf/1004.5099v1.pdf
4C +71.07	Blazar	7 days	148		143,54	34,43	z=2.21	http://arxiv.org/pdf/1005.2141v1.pdf
3C 454.3	Blazar	5 days	128-129	17-22/11/10	343,5	16,15	z=0.86	http://arxiv.org/pdf/0909.2470v2.pdf