



Fermi

Gamma-ray Space Telescope



Multiwavelength Transient Analyses

Judy Racusin
NASA/GSFC

Fermi Summer School, June 2023



- **Astrophysical context**
 - **Source association**
 - **Emission mechanisms**
- ***Fermi* data probe a region of the spectrum that**
 - **Can be the high energy anchor for your model**
 - **Or bridge lower energy regimes and TeV**
- **How you fit/extrapolate/interpolate over many decades can strongly influence the physical models you walk away with, and correctly accounting for errors over those decades is really important**

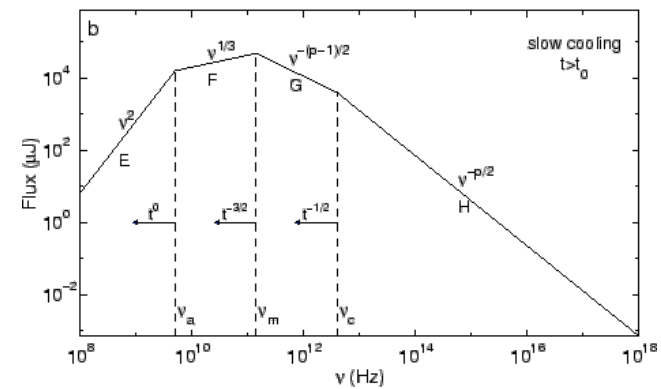
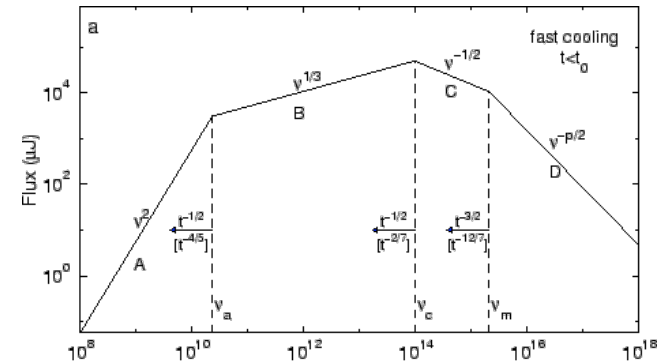
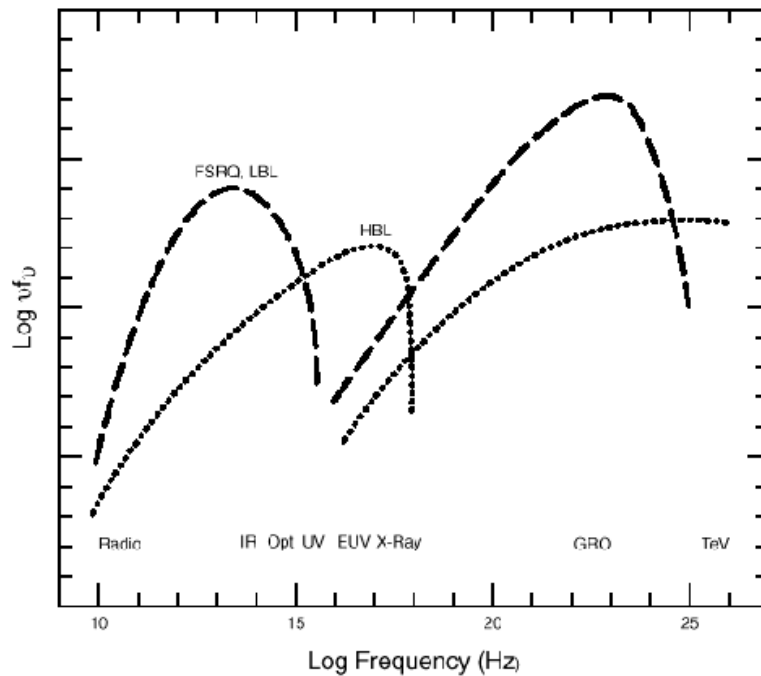


- I ~~stole~~ borrowed some of this material from Alan Marscher's 2012 Fermi Summer School Talk and reworked from my 2017 talk
 - See Alan's talk for a more blazar focused discussion
- I will use a GRB as an example, but most of this is relevant/applicable to other source types
- 2 primary ways to build an SED
 - Input ~raw data, response functions, etc. and fit the whole spectrum together
 - Collect individually fit datasets and combine them fitting more complex physical models around already fit model dependent data (will come back to this issue)
- There are lots and lots of ways to do this
 - Software (XSPEC, RMFIT, Sherpa, likelihood, 3ML, custom software ...)
 - Units (energy, frequency, wavelength, ...)



- **Radio/mm/microwave**
 - temperature -> flux density
 - In frequency
- **IR/Optical/UV**
 - magnitudes in different filters
 - $F_v = 10^{k-0.4m}$ mJy where k depends on filter used
 - Must account for extinction in UV/blue
 - In wavelength
- **X-ray**
 - counting photons -> flux
 - Must account for N_H absorption <1 keV
 - Conversion depends on shape of spectrum
- **Gamma-ray**
 - counting photons -> flux
 - Likelihood often used to fit spectrum, background, etc.

Broadband Spectral Energy Distributions (SEDs)



Sari, Piran, Narayan (1998)

Spectral Energy Distributions

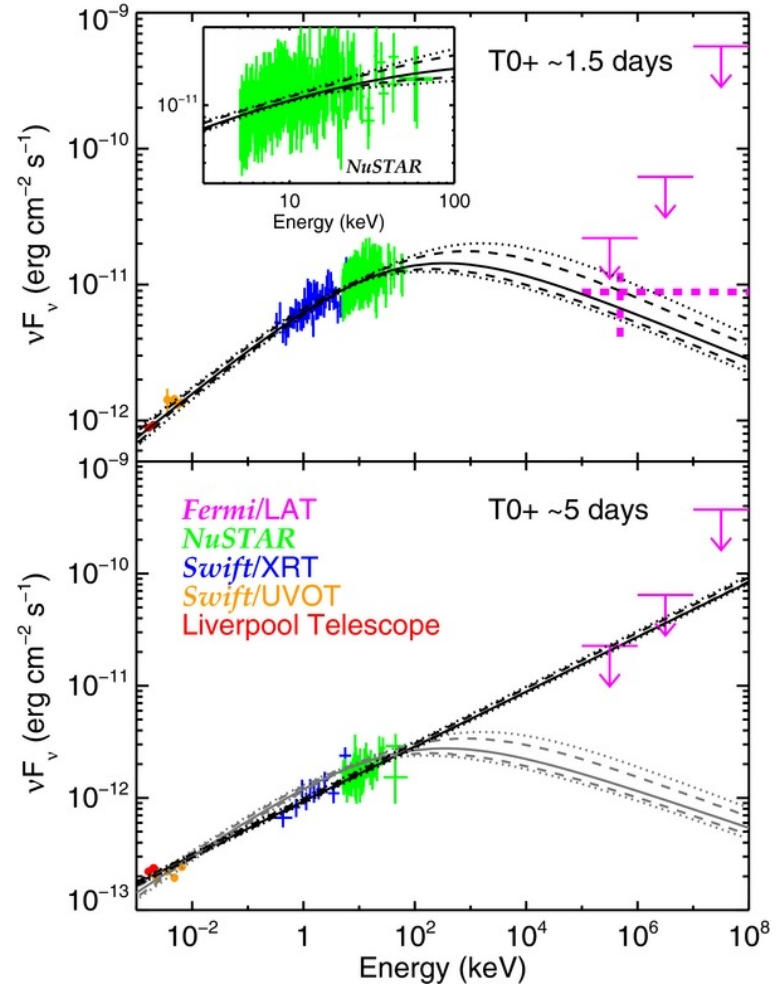
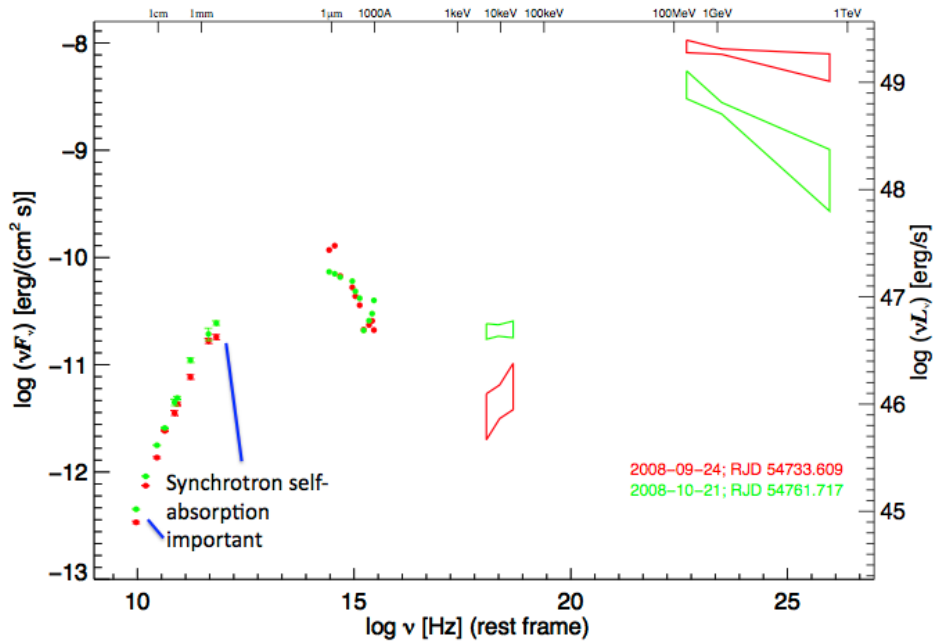


- We want to plot of $\log_{10} \nu F_\nu$ vs $\log_{10} \nu$
- How is this measured?

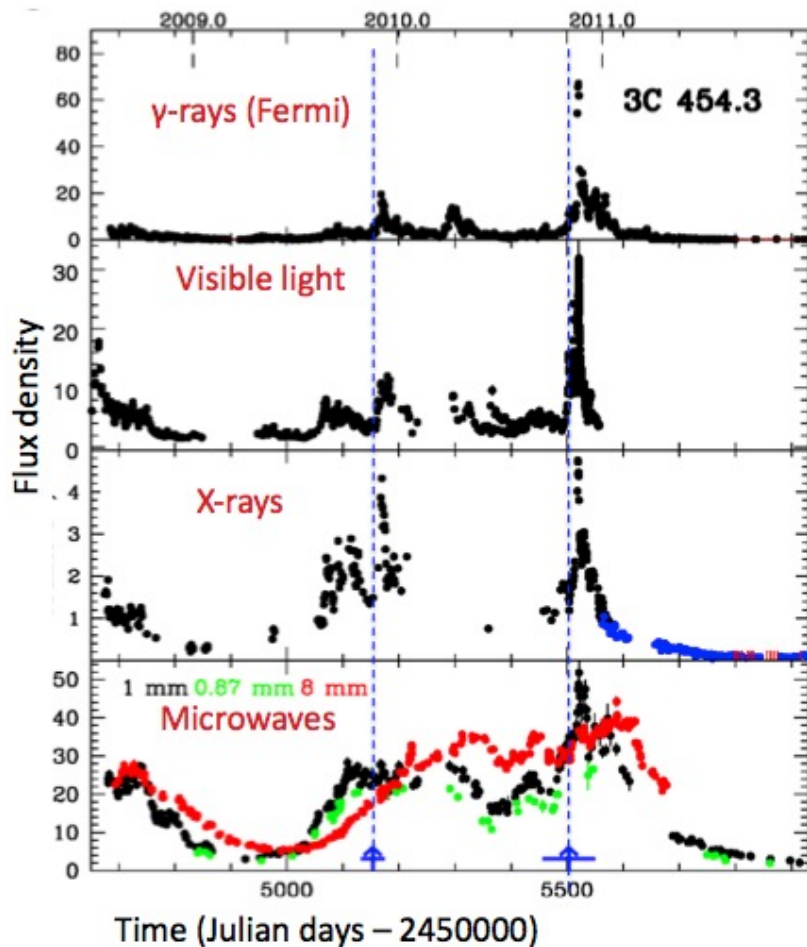
Measure known as	Unit	Formula	Measured where?	Details
Photon Flux Density*	ph cm ⁻² s ⁻¹ keV ⁻¹	$N(E)=AE^{-\Gamma}$ (example)	X-ray, γ -ray	Instrument dependent
Spectral Flux Density or Energy Flux*	erg cm ⁻² s ⁻¹ keV ⁻¹ or Jy or mag	$f_\nu = E N(E) = B E^{-\alpha}$	X-ray, γ Optical, radio	Specific energy $\alpha=\Gamma-1$ 1 keV = 1.602x10 ⁻⁹ erg
Luminosity*	erg s ⁻¹ keV ⁻¹	$L=f_\nu 4\pi D^2 k$	X-ray, γ	k=k-correction, D=distance
Spectral Energy density	erg cm ⁻² s ⁻¹	$\nu f_\nu=E^2 N(E)$	Combined broadband spectrum	

*Integrate from E_1 - E_2 to get flux measurement in specific band for light curves

Broadband Spectral Energy Distributions (SEDs)

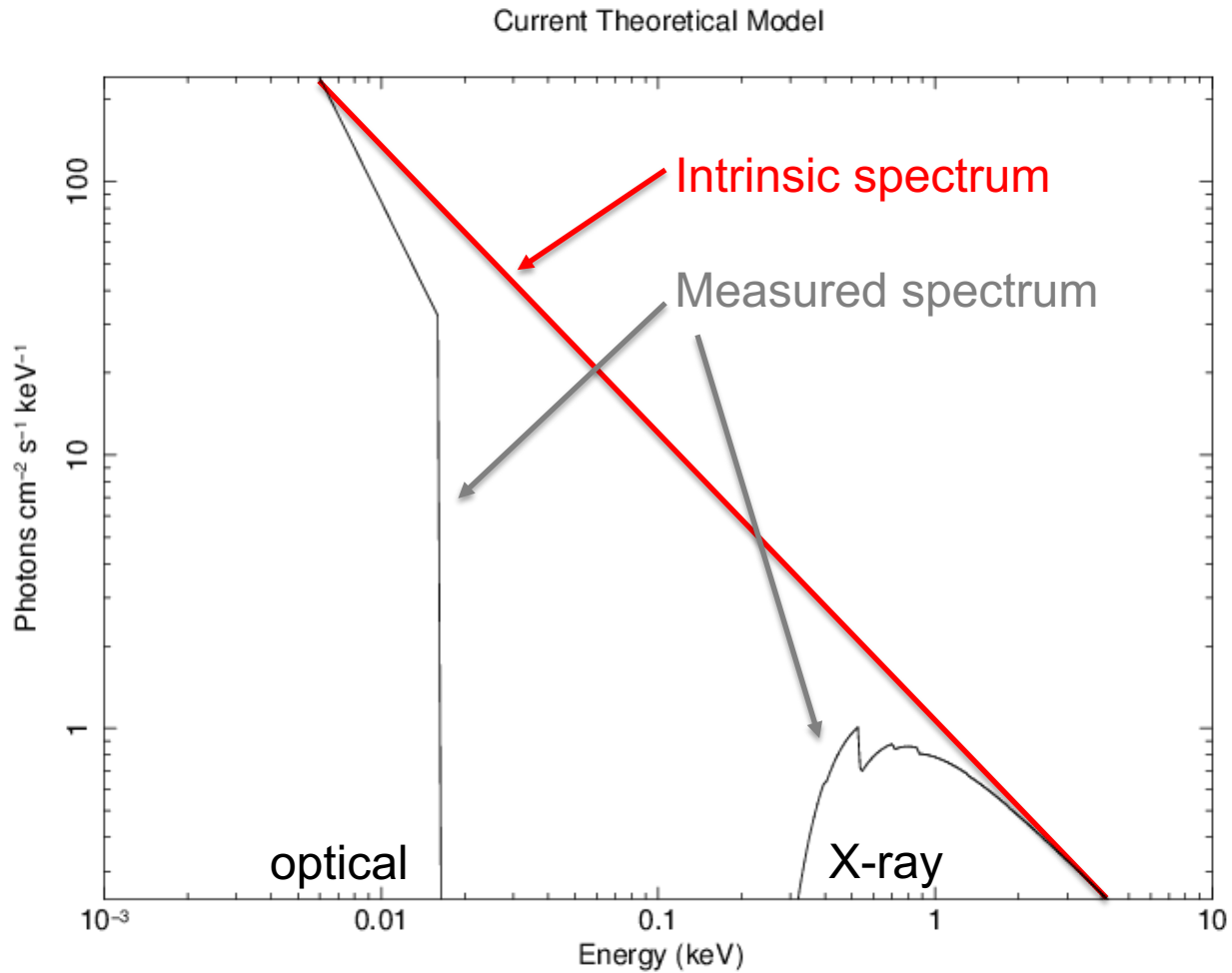


Kouveliotou et al. (2013)



- Flux variations in different wavebands may or may not be correlated, or have delays
- Evidence of variation of different components
- Already messy, therefore simultaneous data at least constrains the same things at the same time (or different things at the same time)
- Talk by Manel last week

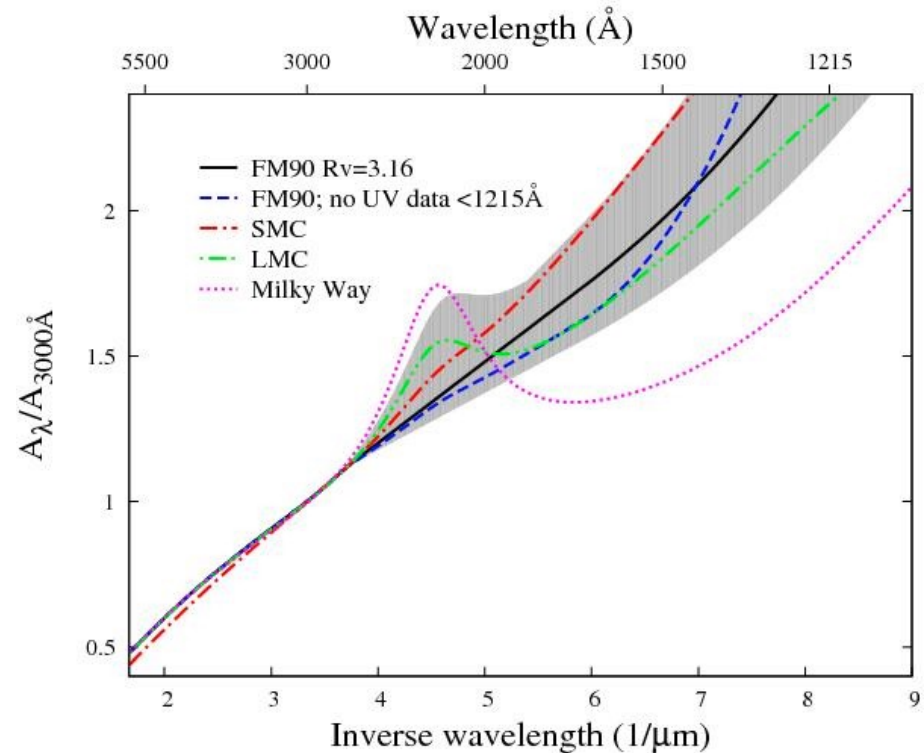
Extinction and Absorption





- Interstellar dust absorbs and scatters some of the IR, optical, UV light
- Different dust composition or grain size impacts absorption & scattering
- Well-mapped for Milky Way, LMC, SMC
- $A_V = E(B-V) \times R_V$
 - R_V set specifically for MW, LMC, SMC
 - Fit $E(B-V)$ or A_V
 - Get it from NED
 - Get it from literature where someone else has already fit it for the same object
- Cardelli et al. 1989 provides relations between A_V and other wavelengths, though depends on extinction curves
- XSPEC models (z)dust

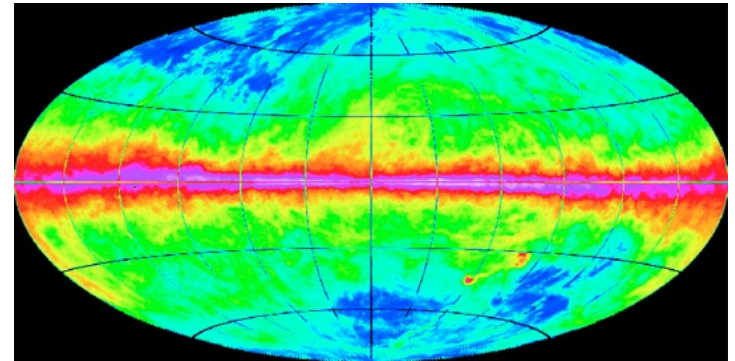
<http://heasarc.gsfc.nasa.gov/xanadu/xspec/manual/XSmodelZdust.html>



Schady et al. 2012
Pei 1992

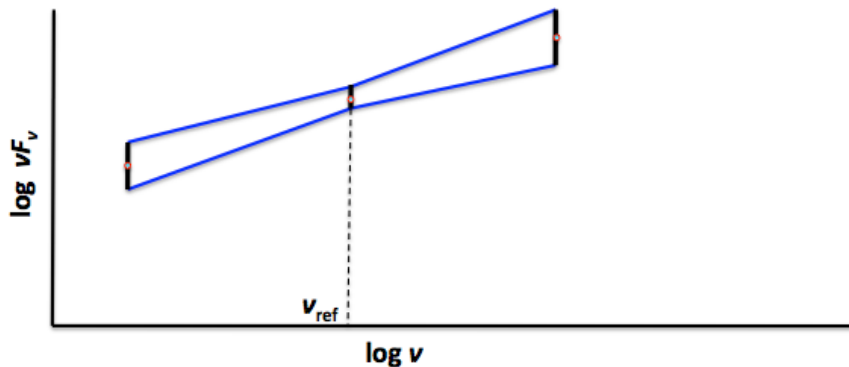


- **Interstellar neutral hydrogen gas absorbs soft X-rays**
 - **Photo-electric absorption using some set of photo-ionization cross-sections**
- **2 sources of absorption for extragalactic sources (N_H – hydrogen column density)**
 - **Galactic – well mapped by Kalberla et al. 2005**
 - **ftool NH**
 - <http://heasarc.gsfc.nasa.gov/cgi-bin/Tools/w3nh/w3nh.pl>
 - **Intrinsic absorption should be fit, can account for redshift (if known)**
- **XSPEC models (z)wabs, (z)phabs**





- Likelihood analysis needed to determine contribution of source and background components (fit/assume spectral model)
- If γ -ray source well characterized (bright), and the shape can be constrained (e.g. powerlaw) independently, you can just use results of likelihood over-plotted with broadband SED
 - Use bowtie shape to represent uncertainties centered at ν_{ref}
 - $\sigma_F(\nu) = (\nu/\nu_{\text{ref}})^{-\alpha} [\ln(\nu/\nu_{\text{ref}})^2 \sigma_\alpha^2 + \sigma_F^2(\nu_{\text{ref}})]^{1/2}$
 - usually $\nu_{\text{ref}} = 2.42 \times 10^{17} \text{ Hz} = 1 \text{ keV}$



Taking into account error on both normalization (flux) and slope

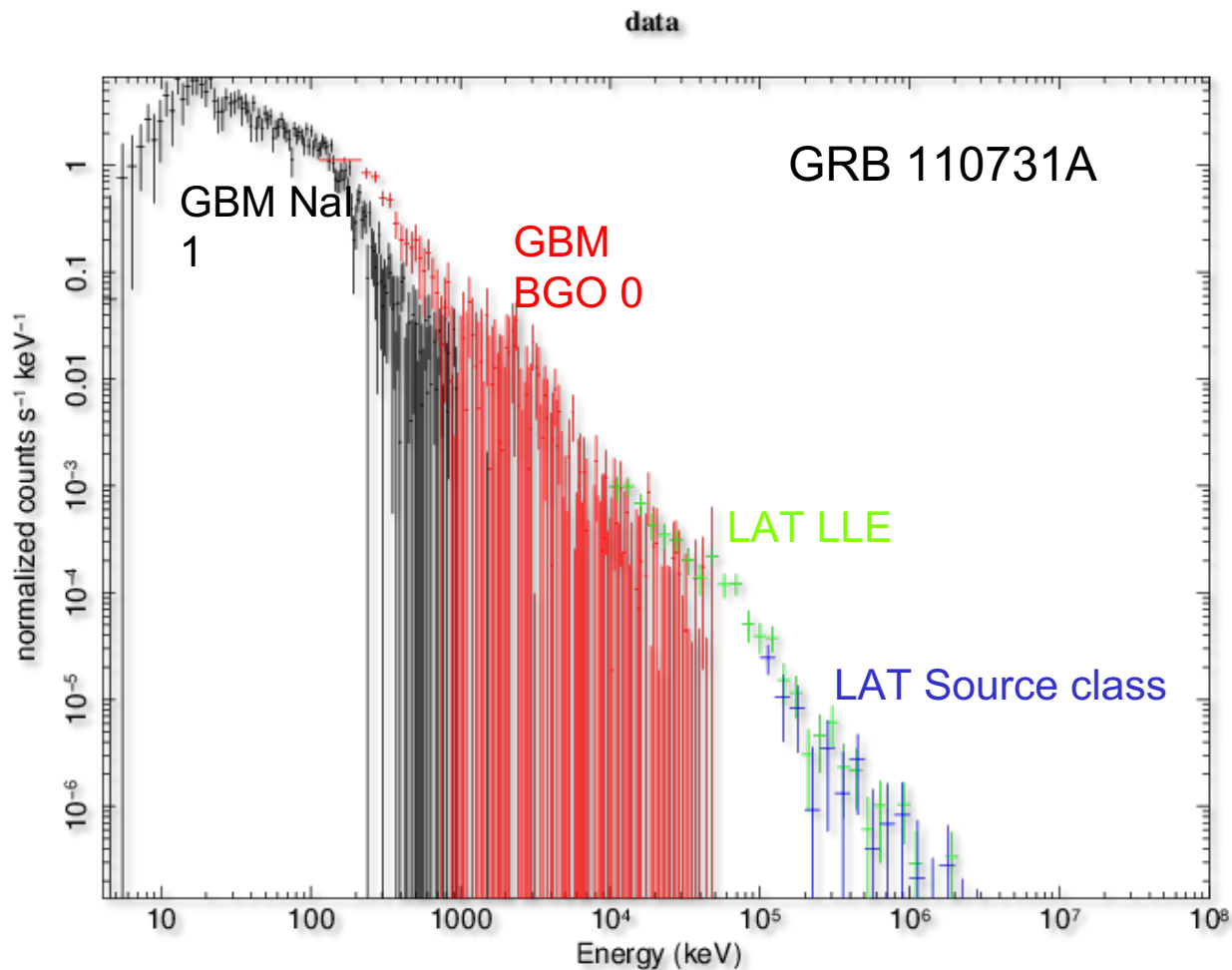
- However, if shape of γ -ray spectrum affected by data in nearby parts of the spectrum (breaks, curvature, cutoffs, etc.), you should do joint fits given a spectral model, and solve for free parameters

vFv Spectra are Model Dependent



- In order to take data from raw (counts, magnitudes etc.), you must **assume**
 - Instrumental response function - which can depend on event class (LAT), readout mode (X-ray), filter (optical/IR/UV)
 - Background
 - Instrumental can depend on temperature of detector, hot pixels/strips
 - Particle background – depends on proximity to SAA, orbit, solar activity
 - Real sources – earth, moon, sun, astrophysical sources, Galaxy, etc.
 - Things getting in the way
 - Extinction, absorption, emission lines, EBL
- To get to flux, you fit a model to your spectrum
- vFv is your unfolded (remove model and all of above) spectrum
 - So fitting a model to your vFv spectrum is kind of cheating ...

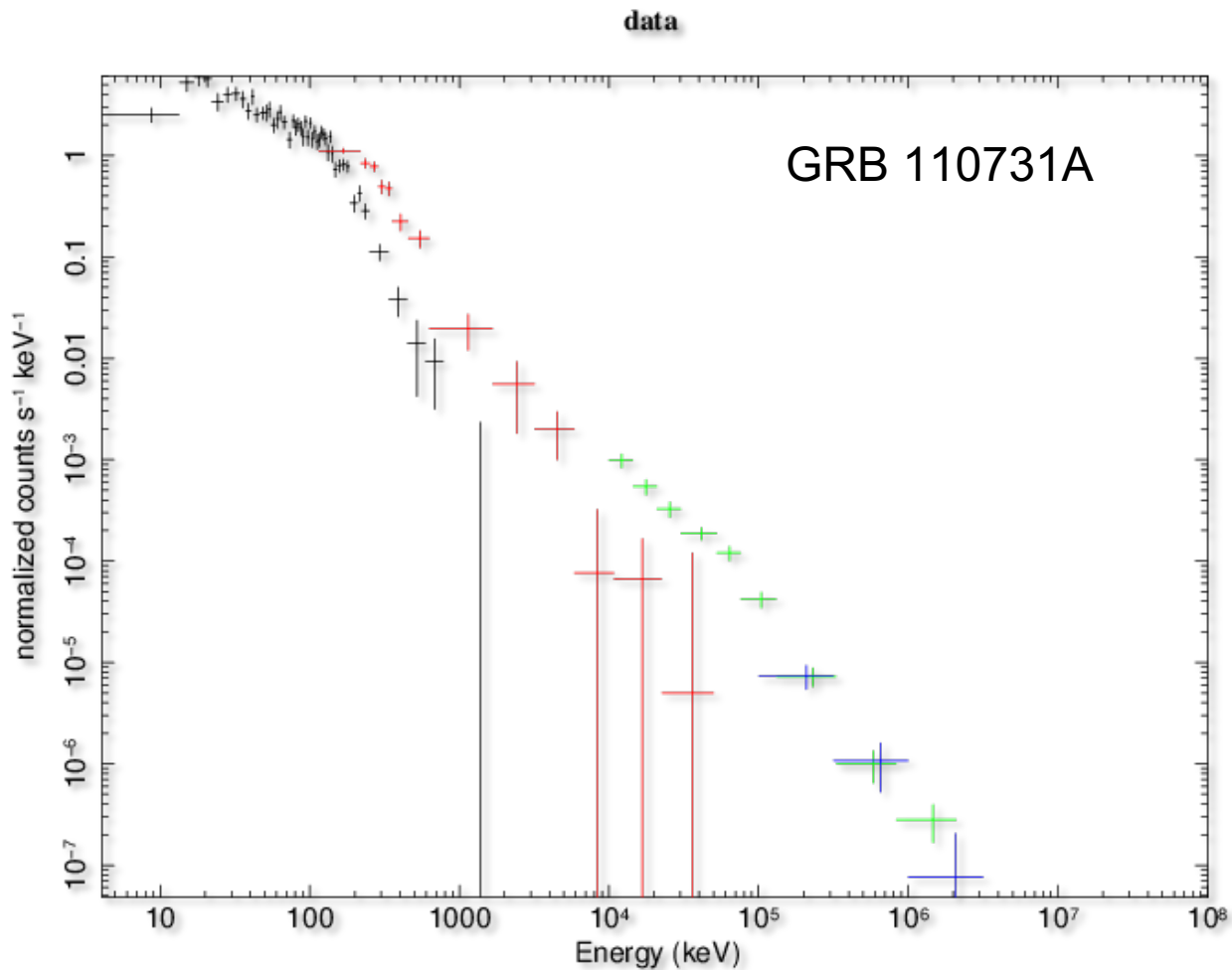
vFv Spectra are Model Dependent



jracusin 29-May-2014 11:50

Unbinned (poorly binned) counts spectrum

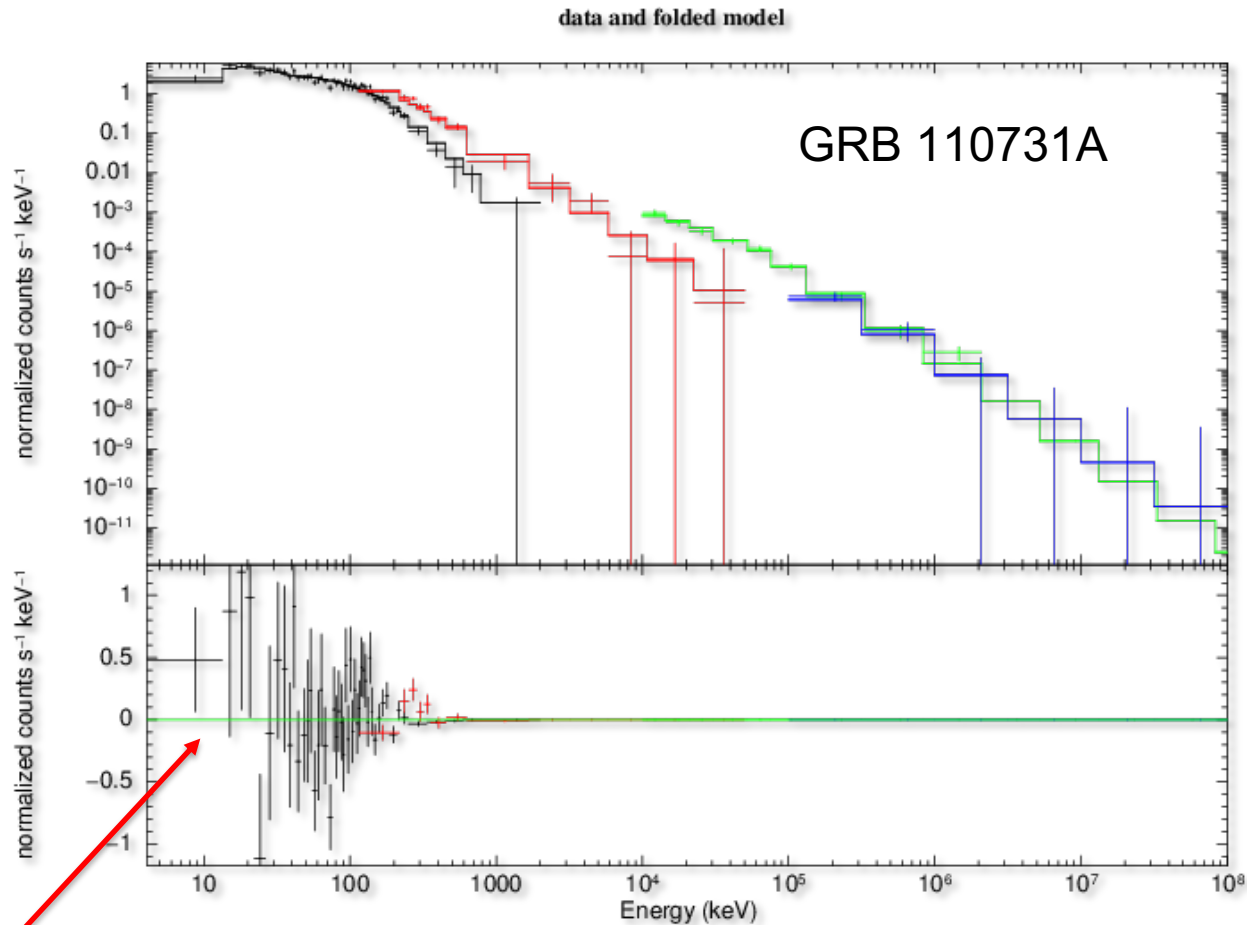
vFv Spectra are Model Dependent



jracusin 29-May-2014 11:51

Binned counts spectrum
(only binned for plotting purposes)

vFv Spectra are Model Dependent



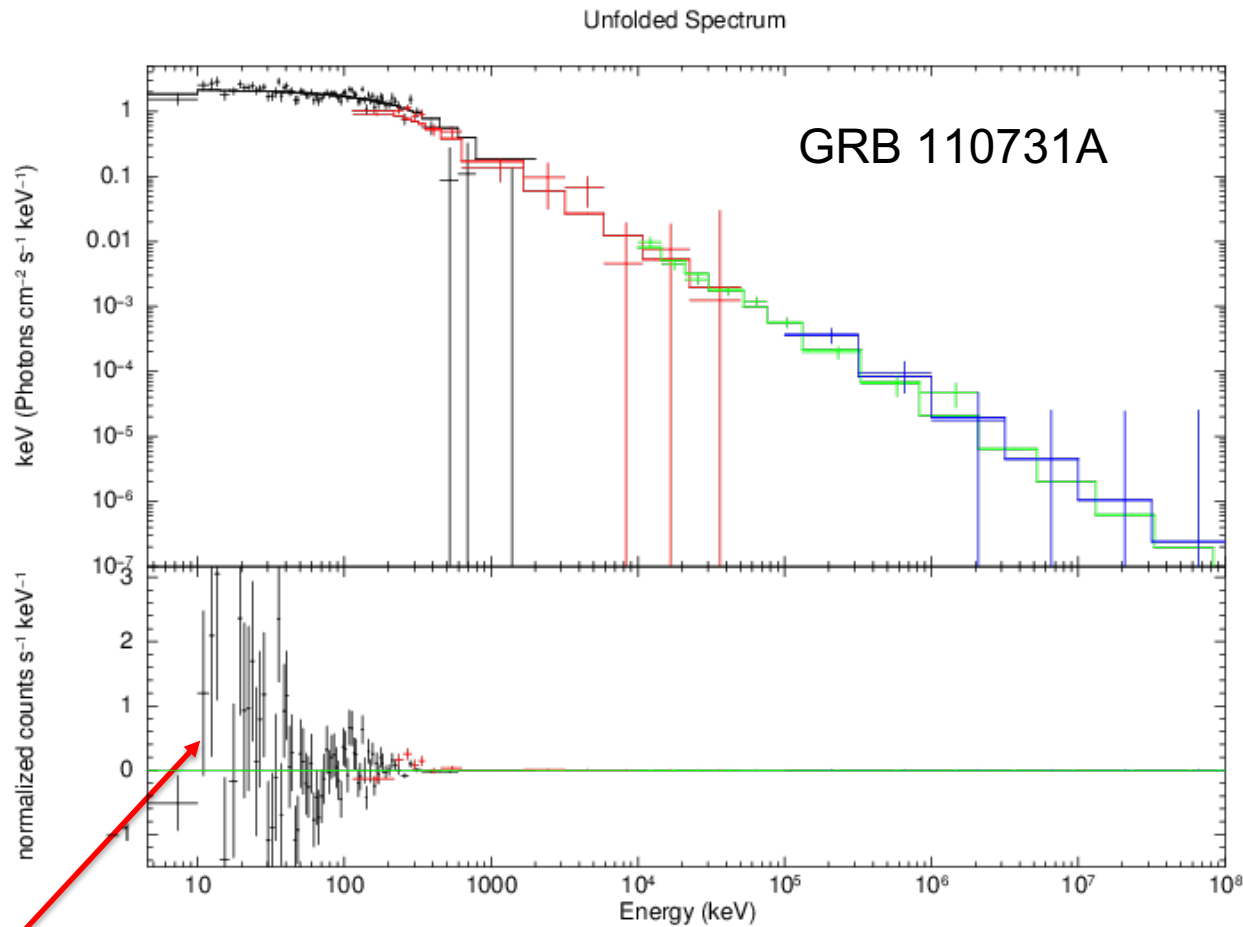
jracusin 29-May-2014 11:31

residuals

Binned counts spectrum
Fit to Band function (grbm in XSPEC)

$$A(E) = \begin{cases} K(E/100)^{\alpha_1} \exp(-E/E_c) & E < (\alpha_1 - \alpha_2)E_c \\ K[(\alpha_1 - \alpha_2)E_c/100]^{\alpha_1 - \alpha_2} (E/100)^{\alpha_2} \exp[-(\alpha_1 - \alpha_2)] & E > (\alpha_1 - \alpha_2)E_c \end{cases}$$

vFv Spectra are Model Dependent

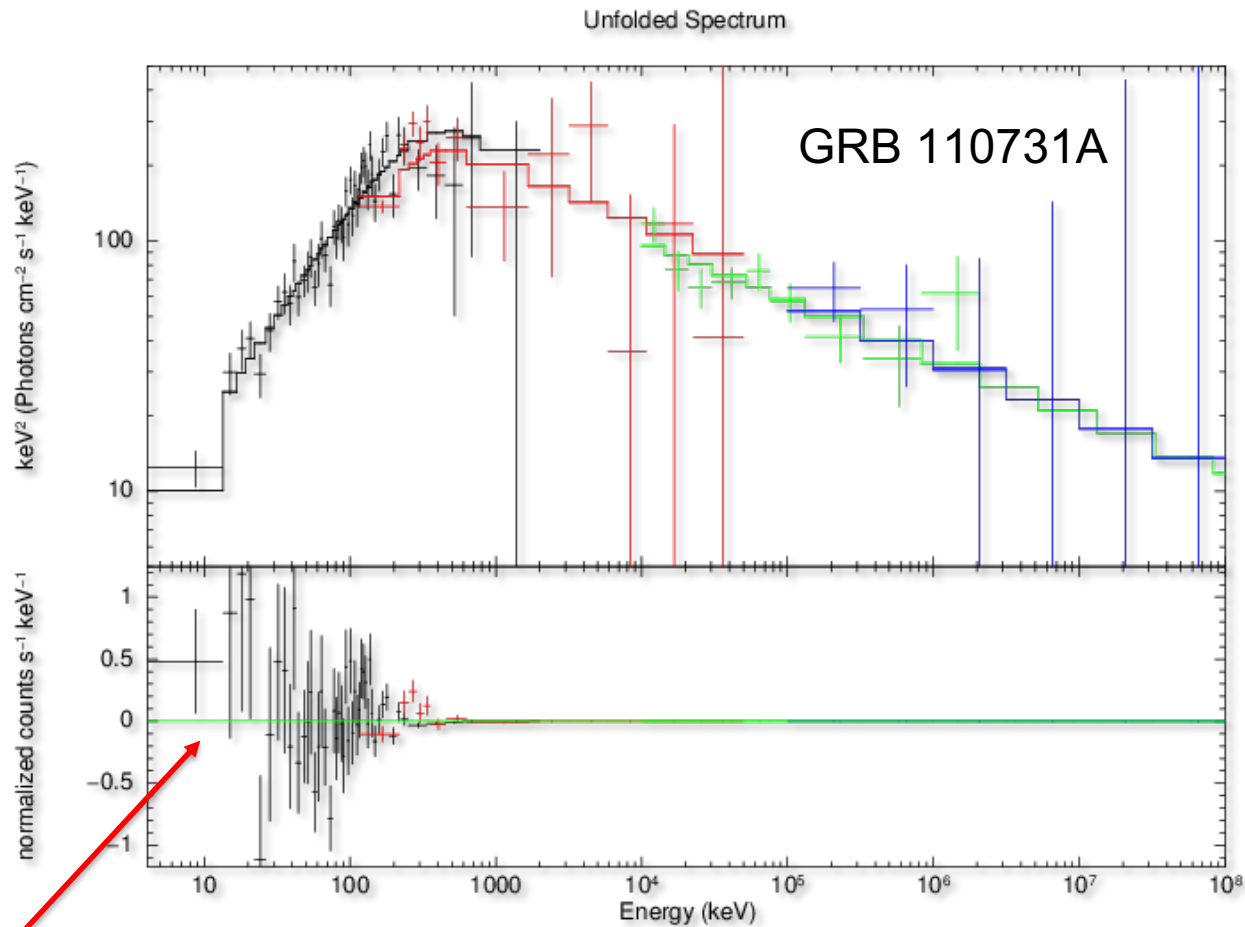


residuals

jracusin 30-May-2014 16:02

Binned unfolded F_{ν} spectrum
Fit to Band function (grbm in XSPEC)

vFv Spectra are Model Dependent



residuals

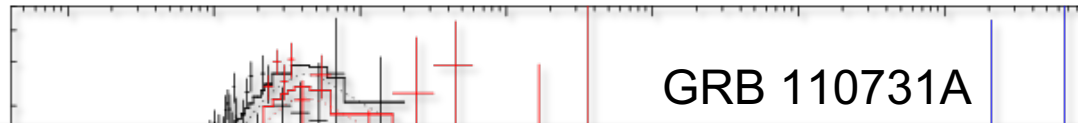
jracusin 29-May-2014 11:36

$vF_v = E^2 N(E)$ spectrum
 Fit to Band function (grbm in XSPEC)

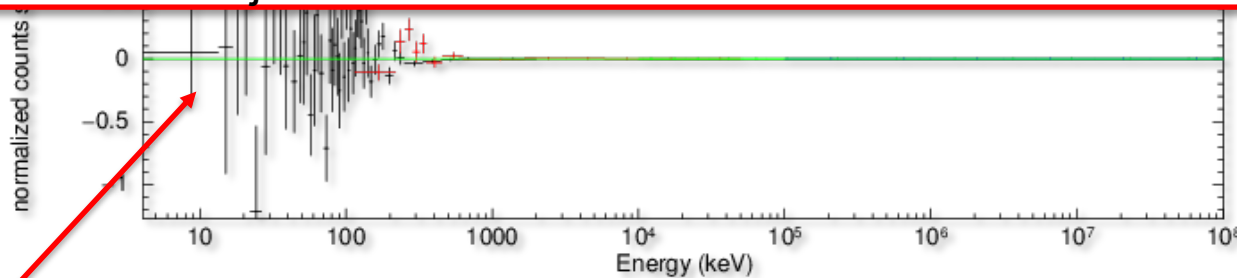
vFv Spectra are Model Dependent



Unfolded Spectrum



- Therefore, vFv SEDs are not model-independent
- Residuals and fit statistics, are a better way to judge how well the data fit the model
- Plotting data with best fit model can bias the reader towards the validity of your model
 - Used inconsistently in different fields
 - LAT team generally plots model + residuals
- This is all just a note of caution!

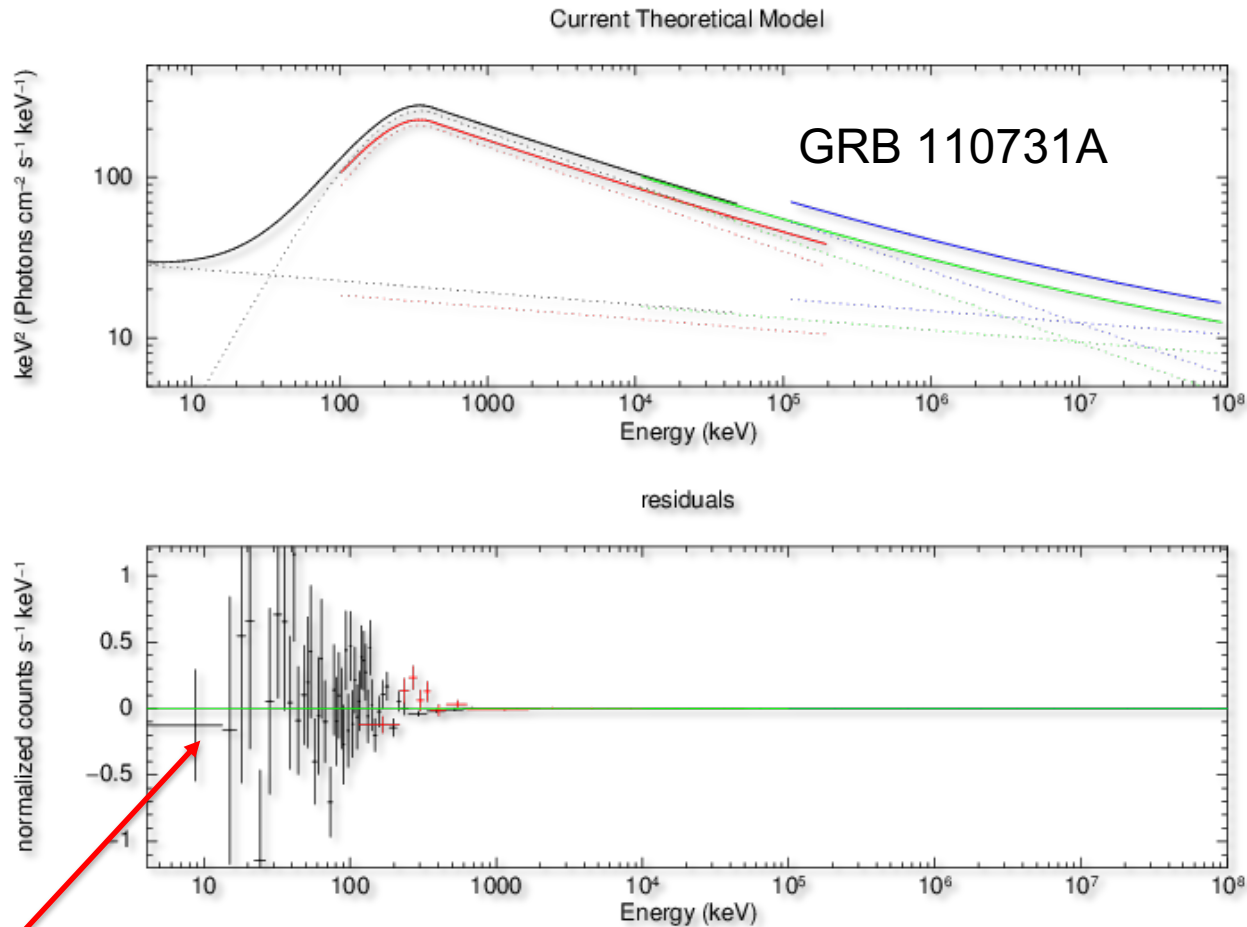


residuals

$vF_v = E^2N(E)$ spectrum

Fit to Pow+Band function (pow+grbm in XSPEC)

vFv Spectra are Model Dependent



residuals

$vF_v = E^2 N(E)$ spectrum
Fit to Pow+Band function (pow+grbm in XSPEC)

Let's build a really simple SED



- **Extract LAT Spectra**
 - **Standard Science Tools Method**
 - **gtmktime**
 - **gtselect**
 - **gtltcube**
 - **gtexpmap**
 - **gtdiffrsp**
 - **gtlike**
 - **(gtfindsrc)**
 - **gtbin**
 - **gtrspgen**
 - **gtbkg**
 - **http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/lat_grb_analysis.html**
 - **Shortcut/Wrapper Method**
 - **gtburst**
 - **<https://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/gtburst.html>**



- **LAT Low Energy (LLE)**
 - really loose event classification that can be used down to ~30 MeV, useful during brightest part of bright bursts when source is really bright compared to background
- **Transient class**
 - Useful during bright prompt burst itself, while source in counts limited
- **Source class**
 - Useful over longer intervals like long extended emission (100's-1000's of seconds)

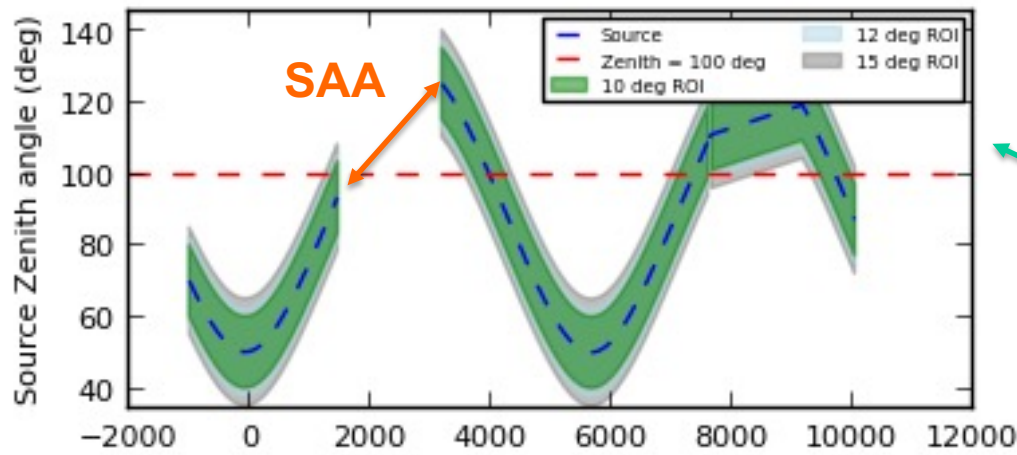


- **gtburst**
 - Python GUI interface for
 - downloading GBM/LLE/LAT data
 - selecting background and source intervals (GBM, LLE)
 - likelihood analysis of LAT data
 - Localizing LAT GRBs
 - Also useful for other short transients (e.g. Solar Flares)
 - Is part of the science tools, but updates via git separately
 - It is on your VM now
 - Written by Giacomo Vianello & Nicola Omodei (LAT team)
- **rmfit**
 - IDL GUI for selecting background and source intervals
 - Spectral fitting of GBM data
 - Available on FSSC user contributed tools
 - Written by Rob Preece, Adam Goldstein (GBM team)
- **GBM Data Tools (Gamma-ray Data Tools)**
 - Python tools for downloading, extracting, and fitting GBM data
 - Available on FSSC and github
 - Written by Adam Goldstein and others
- **XSPEC**
 - Standard tool in X-ray astronomy
 - Written by Keith Arnaud (NASA/GSFC)

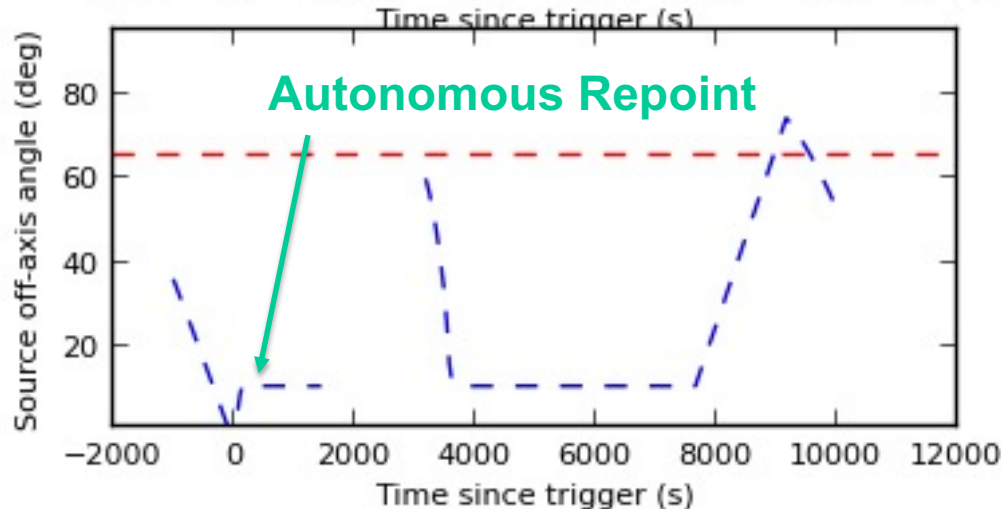
Common Time Interval



Navigation plots



Too close to earth limb



Outside FoV

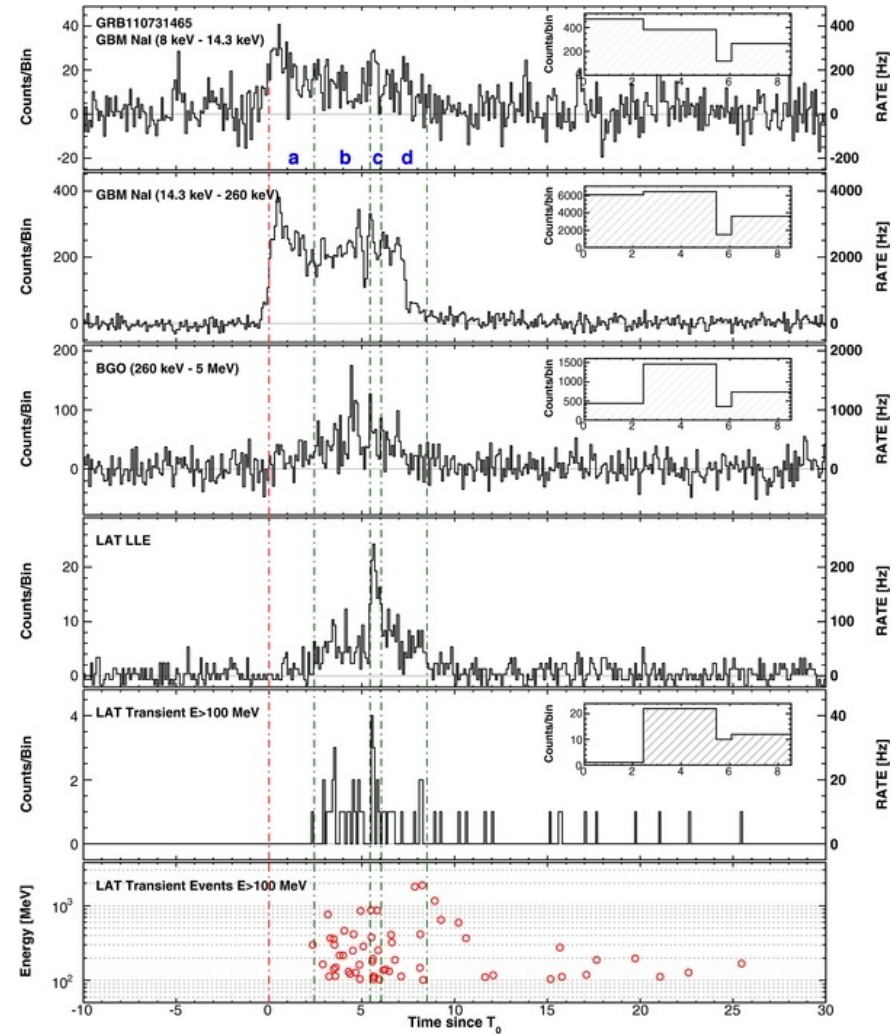
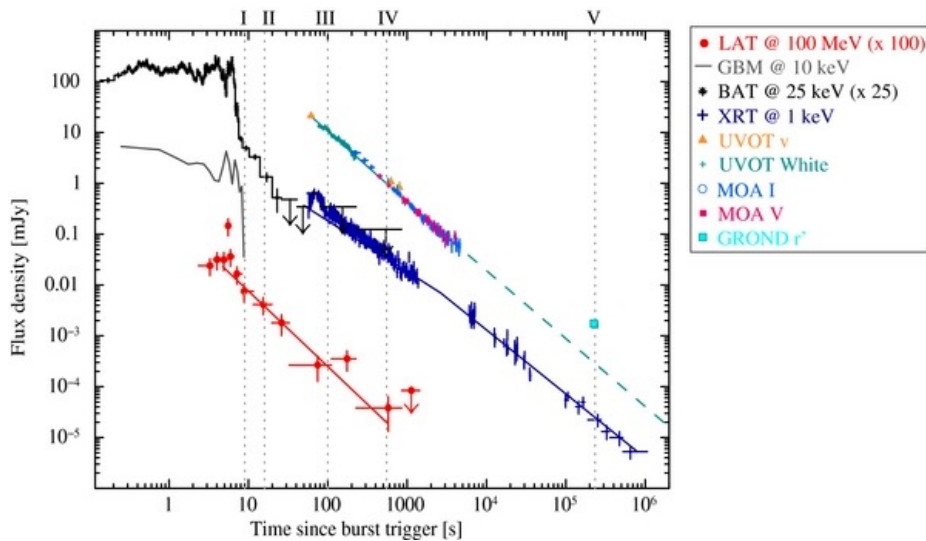
LAT GTIs:
 $T_0 + -973 - 1331$ s
 $T_0 + 4290 - 7050$ s

**You can recreate all of this from the FT2 file
 Or from the gtmktime output GTI extension**

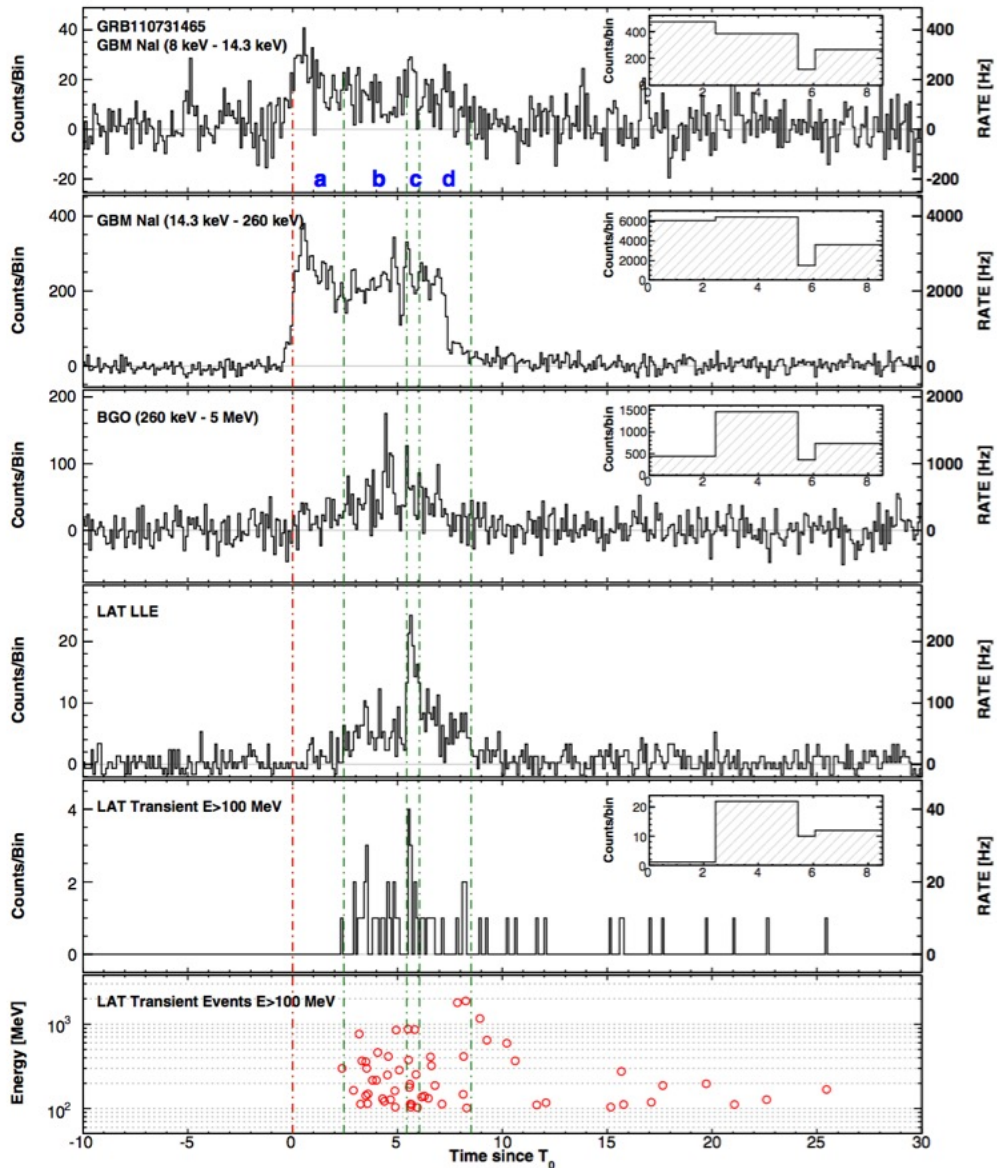
Example: GRB 110731A



- Simultaneously detected by Swift & Fermi
 - GBM, LAT clearly detected
 - BAT, XRT, UVOT + ground-based observations
- Ackermann et al. 2012
 - *Multiwavelength Observations of GRB 110731A: GeV Emission from Onset to Afterglow*



Common Time Interval



GBM $T_{90} = 14.3$ s

LAT detection for ~1000 s

**Let's use joint GBM+LAT interval:
 $T_0 + 0-20$ s**



- **Extract Data for GBM & LAT**
- **Likelihood analysis of LAT data using gtburst**
 - **Get simple fit to LAT spectrum, and contribution from background**
- **Get both GBM & LAT data in XSPEC**
 - **Joint band function fit**
 - **Different statistics for different instruments**
 - **GBM - C-stat**
 - **LAT - pgstat (Poisson data with Gaussian background)**



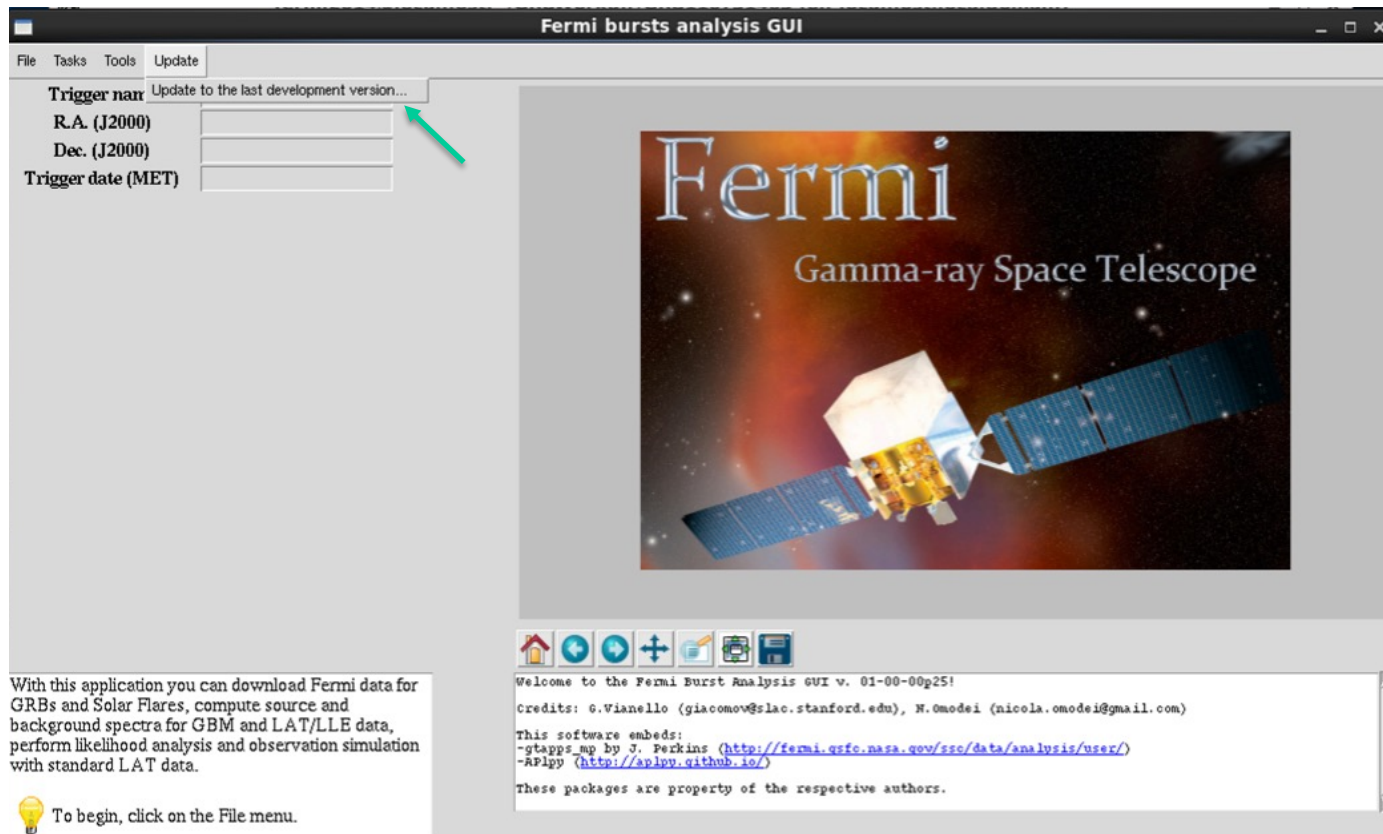
- **Data for tutorial**
 - **Extract it yourself**
 - **gtburst – we'll walk through it**
 - **Or grab data I already extracted**
 - <https://confluence.slac.stanford.edu/download/attachments/382927547/NotesOnLightCurves.pptx?version=1&modificationDate=1685826922000&api=v2>
 - put grb110731a_xspec.tar.gz in shared directory
 - in your docker image home directory, type:
 - mkdir grb110731a
 - cd grb110731a
 - mv /data/grb110731a_xspec.tar.gz .
 - tar xvfz grb110731a_xspec.tar.gz



- **Option 1 – skip to XSPEC**
- **Option 2 – walk through LAT GRB analysis with Gtburst**
- **Caveat**
 - You should be able to also select time intervals for GBM data in Gtburst, but I couldn't get it to work last night
 - You can select GBM intervals and spectral files with the gbm data tools, which I did
 - All of these files are in the tar file



- **gtburst**
 - **Update** - always a good idea



Fermi bursts analysis GUI

File Tasks Tools Update

Trigger name Update to the last development version...

R.A. (J2000)

Dec. (J2000)

Trigger date (MET)

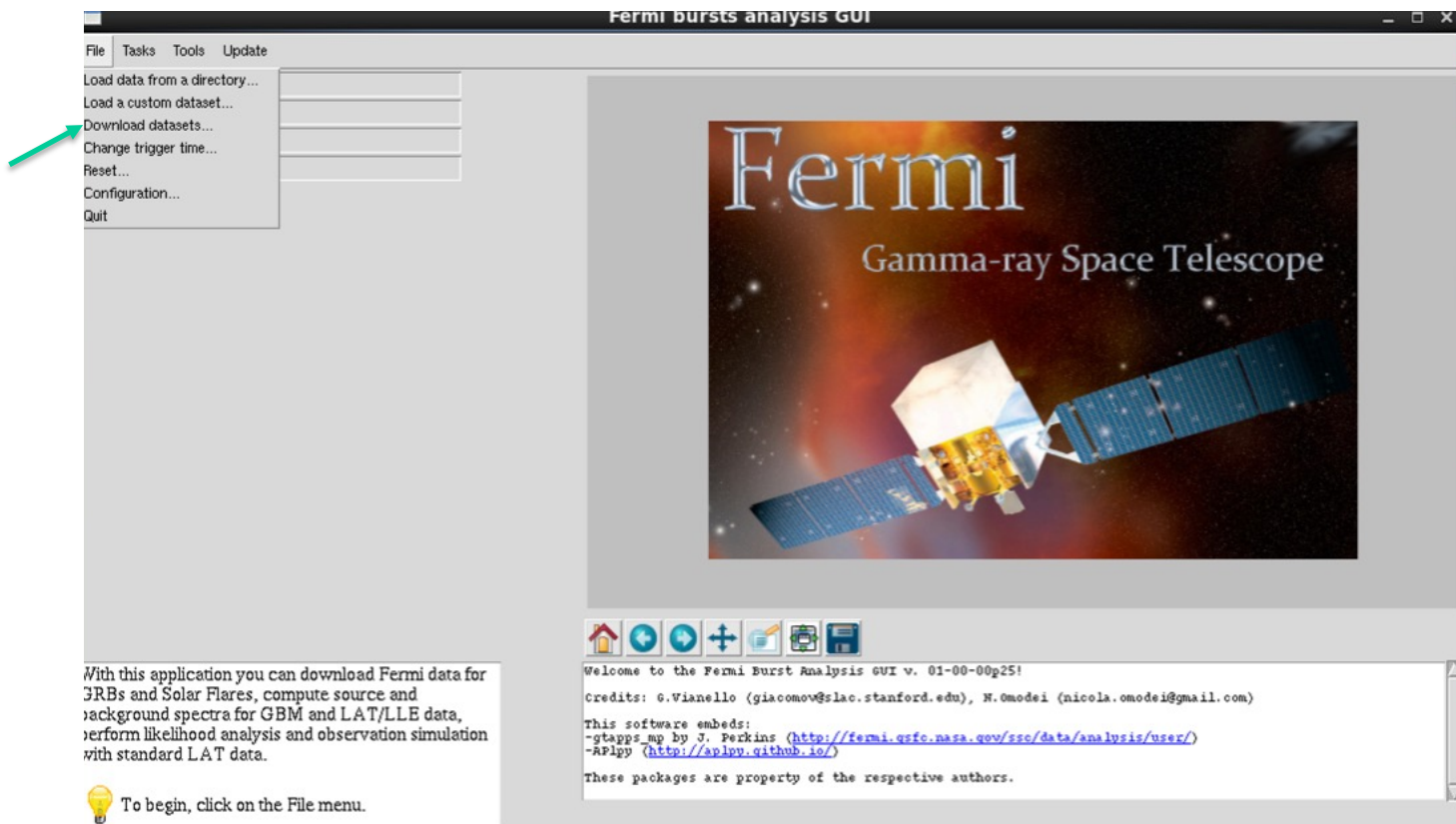
Fermi
Gamma-ray Space Telescope

Welcome to the Fermi Burst Analysis GUI v. 01-00-00p25!
credits: G.Vianello (giacomov@slac.stanford.edu), N.Omodei (nicola.omodei@gmail.com)
This software embeds:
-gtapps by J. Perkins (<http://fermi.gsfc.nasa.gov/ssc/data/analysis/user/>)
-APipy (<http://apipy.github.io/>)
These packages are property of the respective authors.

To begin, click on the File menu.



- **gtburst**
 - **Download LAT dataset**



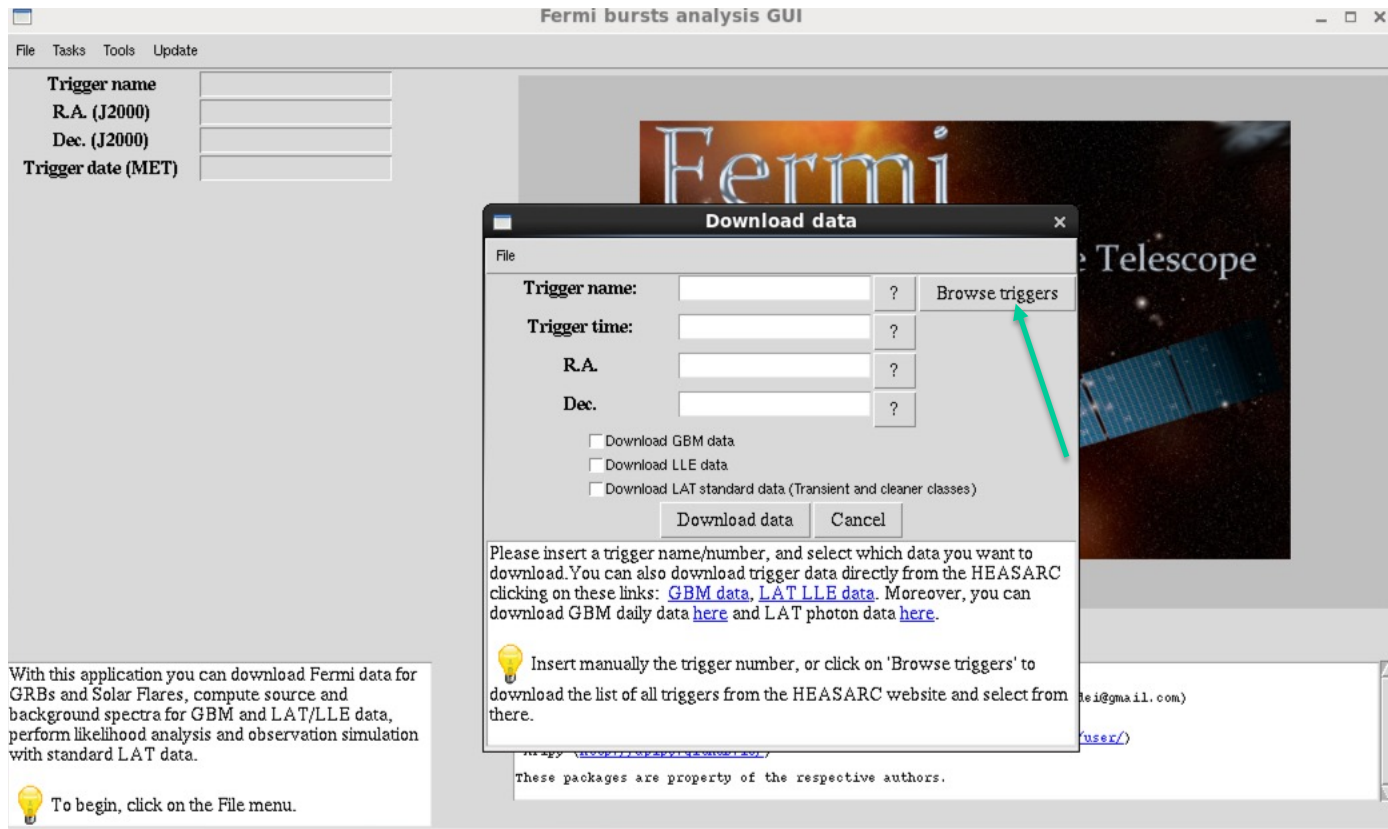
With this application you can download Fermi data for GRBs and Solar Flares, compute source and background spectra for GBM and LAT/LLE data, perform likelihood analysis and observation simulation with standard LAT data.

To begin, click on the File menu.

Welcome to the Fermi Burst Analysis GUI v. 01-00-00p25!
Credits: G.Vianello (giacomov@slac.stanford.edu), N. Omodei (nicola.omodei@gmail.com)
This software embeds:
-gtapps_mp by J. Perkins (<http://fermi.gsfc.nasa.gov/ssc/data/analysis/user/>)
-APLpy (<http://aplpy.github.io/>)
These packages are property of the respective authors.



- **gtburst**
 - **Browse GBM/Swift triggers, or enter manual info**



The screenshot shows the 'Fermi bursts analysis GUI' window. On the left, there are input fields for 'Trigger name', 'R.A. (J2000)', 'Dec. (J2000)', and 'Trigger date (MET)'. A 'Download data' dialog box is open in the center, containing fields for 'Trigger name', 'Trigger time', 'R.A.', and 'Dec.', each with a question mark icon. A 'Browse triggers' button is located to the right of the 'Trigger name' field, and a red arrow points to it. Below the input fields are three checkboxes: 'Download GBM data', 'Download LLE data', and 'Download LAT standard data (Transient and cleaner classes)'. At the bottom of the dialog are 'Download data' and 'Cancel' buttons. Below the dialog, there is a text box with instructions: 'Please insert a trigger name/number, and select which data you want to download. You can also download trigger data directly from the HEASARC clicking on these links: [GBM data](#), [LAT LLE data](#). Moreover, you can download GBM daily data [here](#) and LAT photon data [here](#).' A lightbulb icon is next to the text: 'Insert manually the trigger number, or click on 'Browse triggers' to download the list of all triggers from the HEASARC website and select from there.'

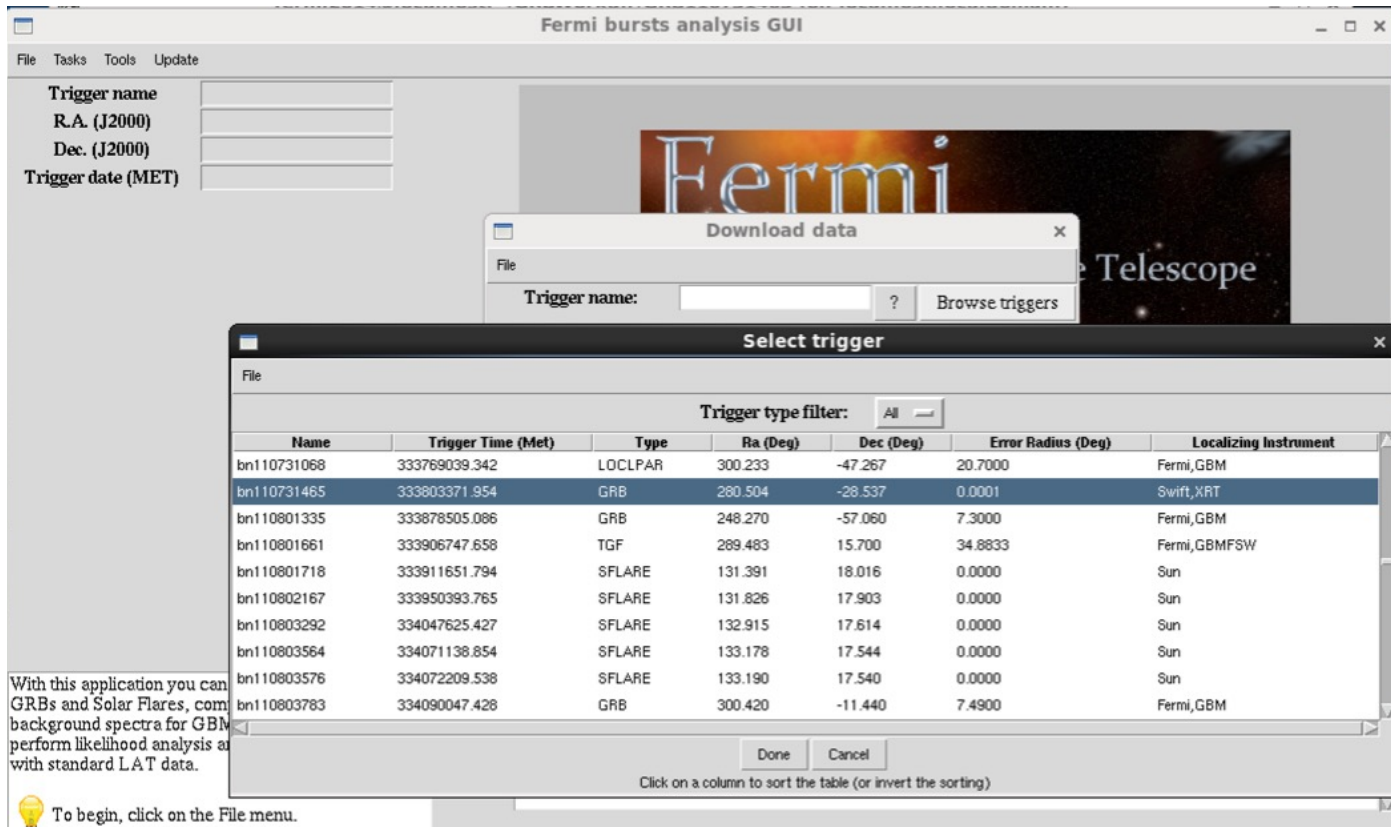
With this application you can download Fermi data for GRBs and Solar Flares, compute source and background spectra for GBM and LAT/LLE data, perform likelihood analysis and observation simulation with standard LAT data.

To begin, click on the File menu.

These packages are property of the respective authors.



- **gtburst**
 - **Choose your trigger**



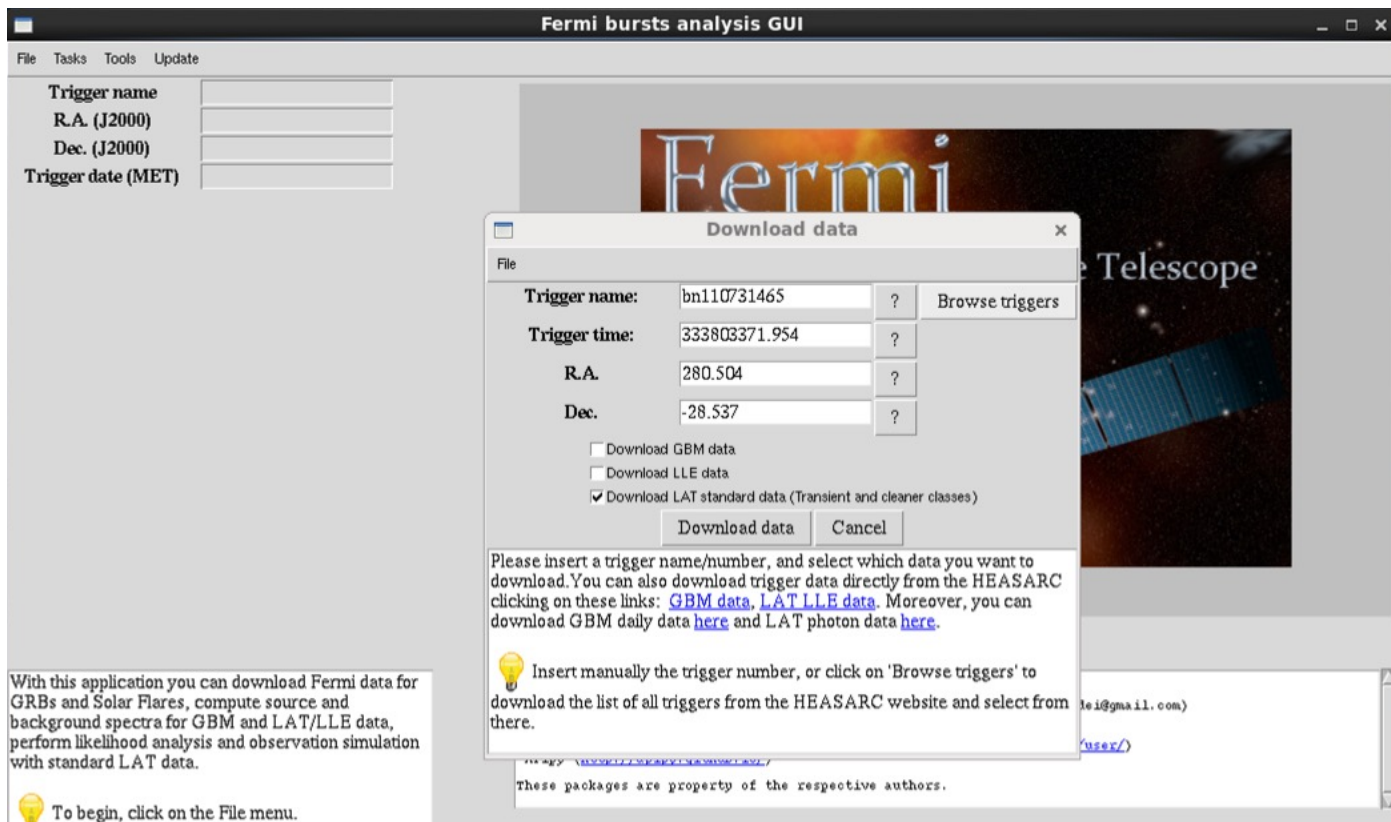
The screenshot shows the 'Fermi bursts analysis GUI' window. In the foreground, the 'Select trigger' dialog box is open, displaying a table of triggers. The table has columns for Name, Trigger Time (Met), Type, Ra (Deg), Dec (Deg), Error Radius (Deg), and Localizing Instrument. The 'Trigger type filter' is set to 'All'. Below the table, there are 'Done' and 'Cancel' buttons, and a note: 'Click on a column to sort the table (or invert the sorting)'. A lightbulb icon and text at the bottom left of the dialog box state: 'To begin, click on the File menu.'

With this application you can
GRBs and Solar Flares, com
background spectra for GBM
perform likelihood analysis at
with standard LAT data.

Name	Trigger Time (Met)	Type	Ra (Deg)	Dec (Deg)	Error Radius (Deg)	Localizing Instrument
bn110731068	333769039.342	LOCLPAR	300.233	-47.267	20.7000	Fermi,GBM
bn110731465	333803371.954	GRB	280.504	-28.537	0.0001	Swift,XRT
bn110801335	333878505.086	GRB	248.270	-57.080	7.3000	Fermi,GBM
bn110801661	333906747.658	TGF	289.483	15.700	34.8833	Fermi,GBMFSW
bn110801718	333911651.794	SFLARE	131.391	18.016	0.0000	Sun
bn110802167	333950393.765	SFLARE	131.826	17.903	0.0000	Sun
bn110803292	334047625.427	SFLARE	132.915	17.614	0.0000	Sun
bn110803564	334071138.854	SFLARE	133.178	17.544	0.0000	Sun
bn110803576	334072209.538	SFLARE	133.190	17.540	0.0000	Sun
bn110803783	334090047.428	GRB	300.420	-11.440	7.4900	Fermi,GBM



- **gtburst**
 - Choose the dataset
 - 10000 is standard interval to search



The screenshot shows the 'Fermi bursts analysis GUI' window. On the left, there are input fields for 'Trigger name', 'R.A. (J2000)', 'Dec. (J2000)', and 'Trigger date (MET)'. A central 'Download data' dialog box is open, containing the following fields and options:

Field	Value	Action
Trigger name:	bn110731465	? Browse triggers
Trigger time:	333803371.954	?
R.A.	280.504	?
Dec.	-28.537	?

Below the fields are three checkboxes:

- Download GBM data
- Download LLE data
- Download LAT standard data (Transient and cleaner classes)

Buttons: Download data, Cancel

Please insert a trigger name/number, and select which data you want to download. You can also download trigger data directly from the HEASARC clicking on these links: [GBM data](#), [LAT LLE data](#). Moreover, you can download GBM daily data [here](#) and LAT photon data [here](#).

💡 Insert manually the trigger number, or click on 'Browse triggers' to download the list of all triggers from the HEASARC website and select from there.

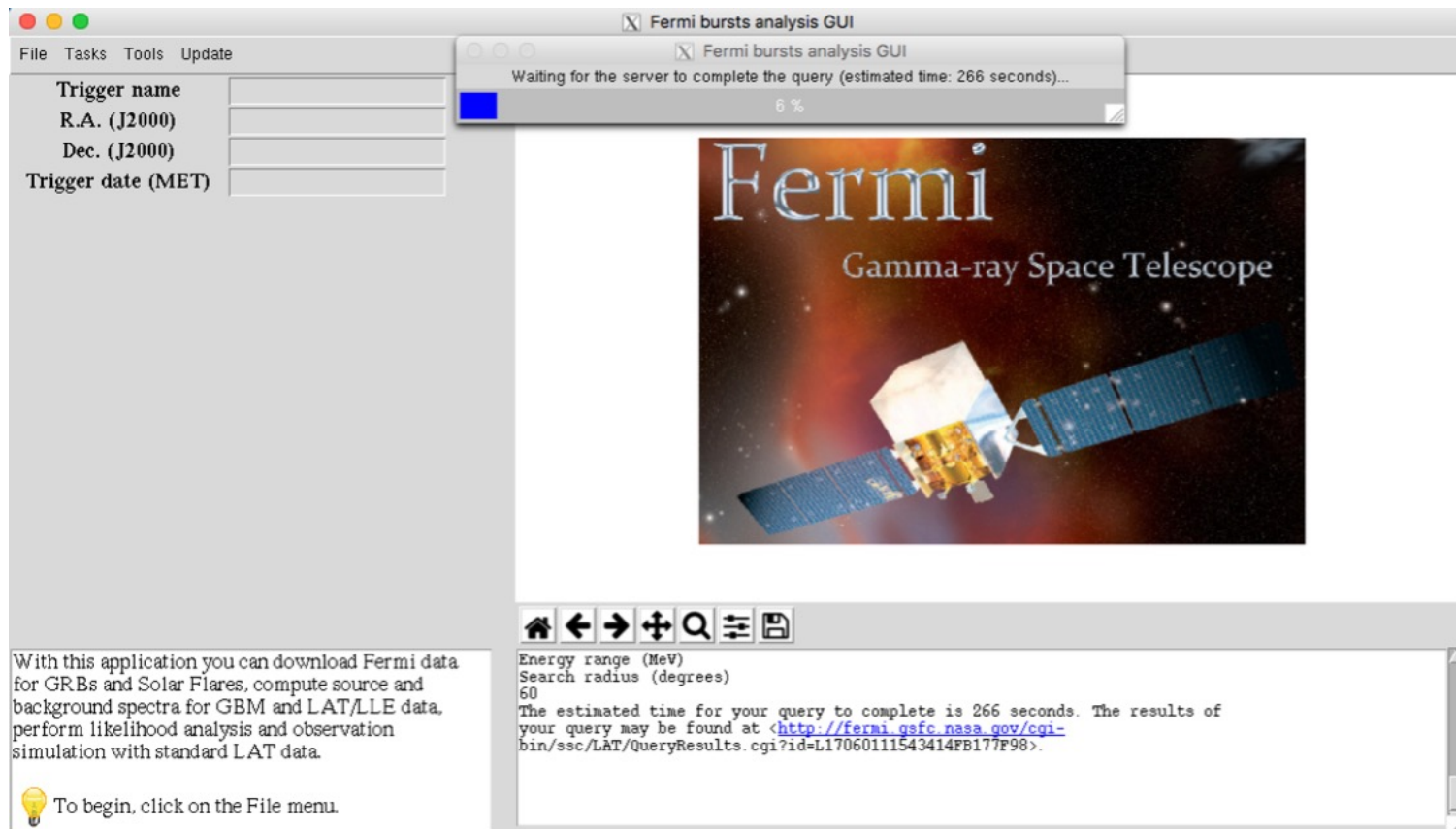
These packages are property of the respective authors.

With this application you can download Fermi data for GRBs and Solar Flares, compute source and background spectra for GBM and LAT/LLE data, perform likelihood analysis and observation simulation with standard LAT data.

💡 To begin, click on the File menu.



- **gtburst**
 - **wait ...**



The screenshot shows a graphical user interface for the Fermi bursts analysis. A progress dialog box is open, indicating that the server is completing a query, with an estimated time of 266 seconds and a progress bar at 6%. The main window features a menu bar (File, Tasks, Tools, Update), input fields for Trigger name, R.A. (J2000), Dec. (J2000), and Trigger date (MET), and a large image of the Fermi Gamma-ray Space Telescope. Below the image is a toolbar with navigation icons and a text area containing instructions and a URL for query results.

File Tasks Tools Update

Trigger name
R.A. (J2000)
Dec. (J2000)
Trigger date (MET)

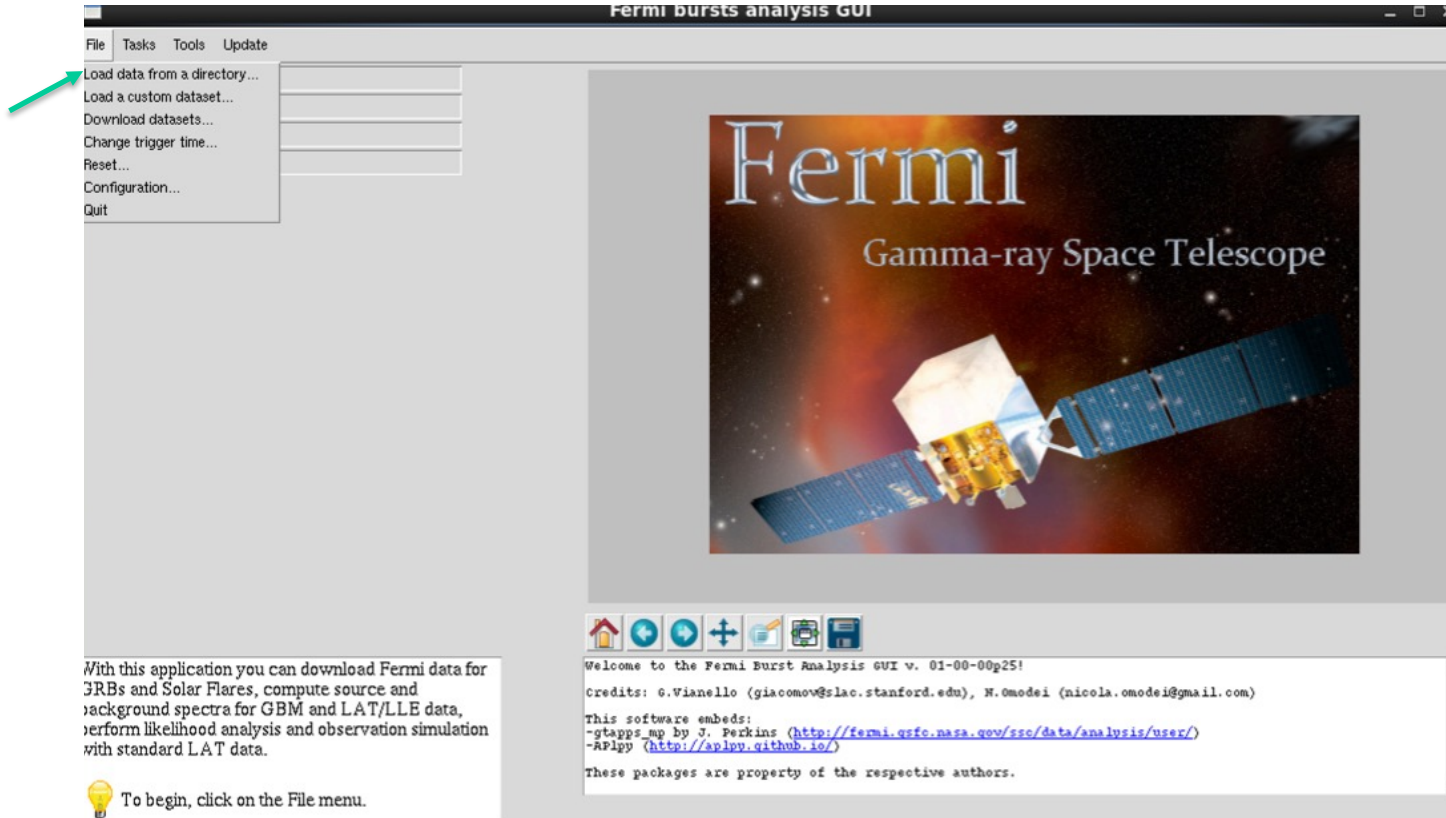
Fermi
Gamma-ray Space Telescope

Energy range (MeV)
Search radius (degrees)
60
The estimated time for your query to complete is 266 seconds. The results of your query may be found at <http://fermi.gsfc.nasa.gov/cgi-bin/ssc/LAT/QueryResults.cgi?id=L17060111543414FB177F98>.

To begin, click on the File menu.



- **gtburst**
 - or grab data from directory



Fermi bursts analysis GUI

File Tasks Tools Update

Load data from a directory...
Load a custom dataset...
Download datasets...
Change trigger time...
Reset...
Configuration...
Quit

Fermi
Gamma-ray Space Telescope

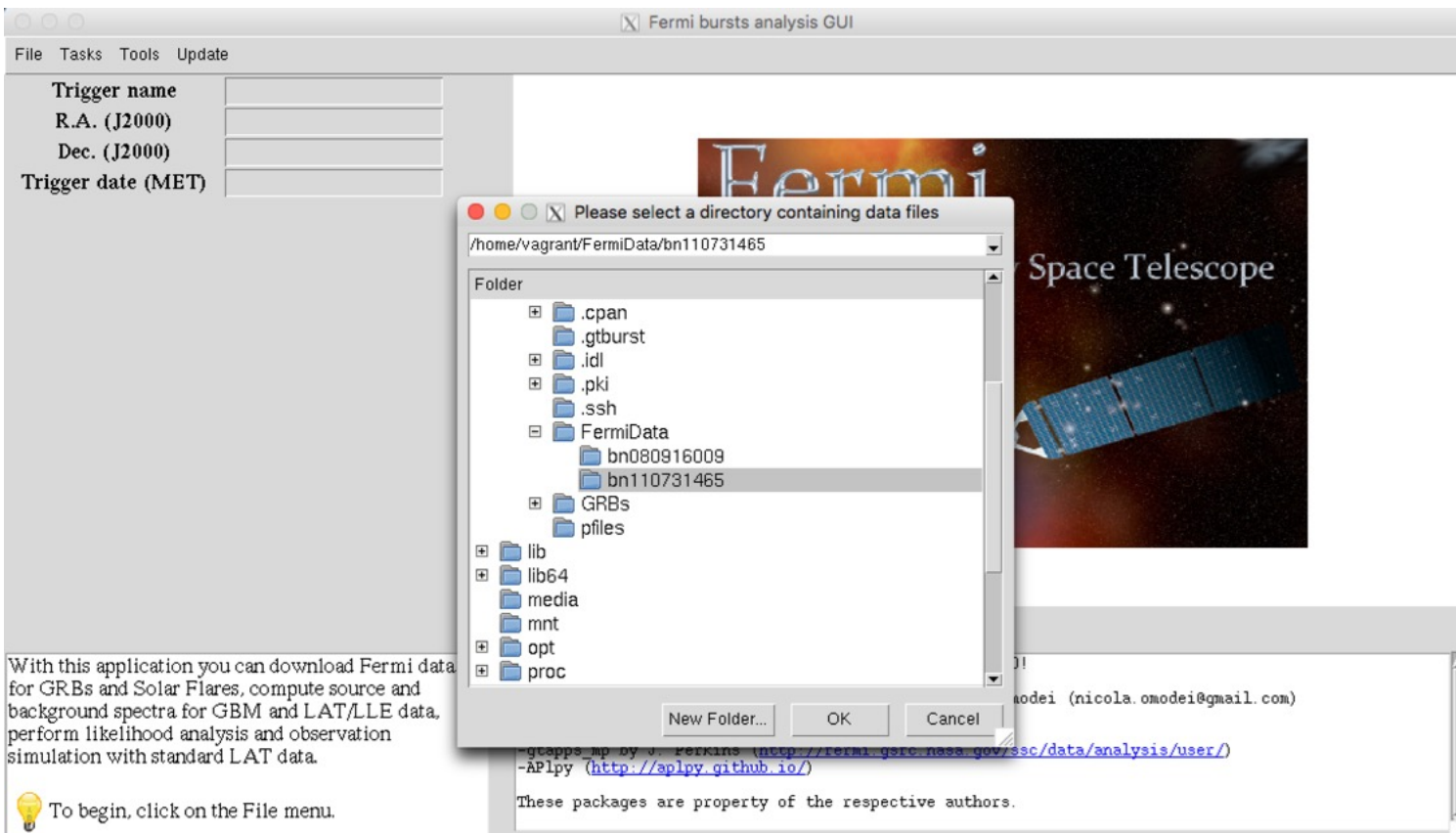
With this application you can download Fermi data for GRBs and Solar Flares, compute source and background spectra for GBM and LAT/LLE data, perform likelihood analysis and observation simulation with standard LAT data.

To begin, click on the File menu.

Welcome to the Fermi Burst Analysis GUI v. 01-00-00p25!
Credits: G.Vianello (giacomov@slac.stanford.edu), N. Omodei (nicola.omodei@gmail.com)
This software embeds:
-gtapps_mp by J. Perkins (<http://fermi.gsfc.nasa.gov/ssc/data/analysis/user/>)
-APLpy (<http://aplpy.github.io/>)
These packages are property of the respective authors.



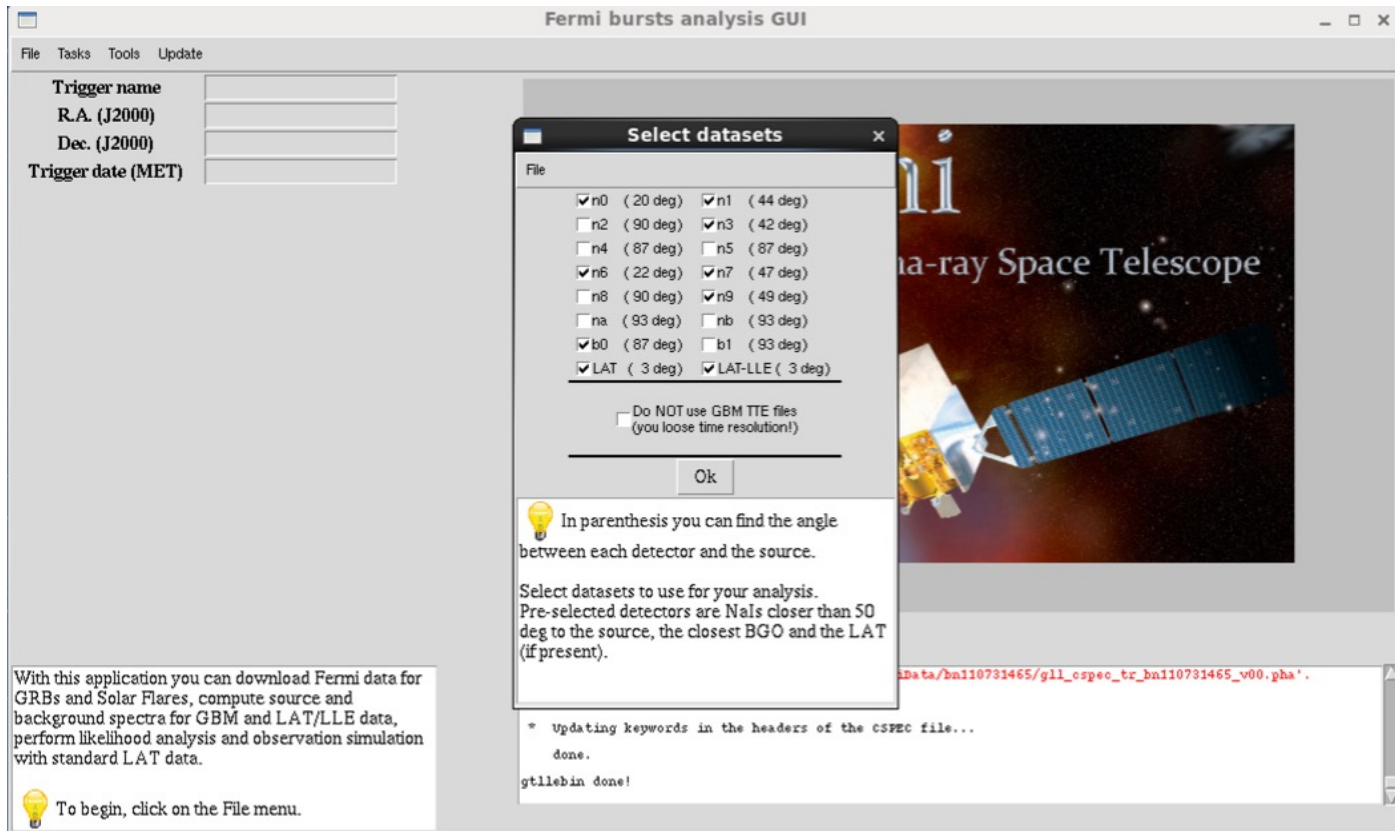
- **gtburst**
 - **or grab data from directory**



The screenshot shows the 'Fermi bursts analysis GUI' window. On the left, there are input fields for 'Trigger name', 'R.A. (J2000)', 'Dec. (J2000)', and 'Trigger date (MET)'. A central dialog box titled 'Please select a directory containing data files' is open, showing a file tree with the path '/home/vagrant/FermiData/bn110731465'. The 'FermiData' folder is expanded, and the subfolder 'bn110731465' is selected. Below the dialog, there is a text area with instructions: 'With this application you can download Fermi data for GRBs and Solar Flares, compute source and background spectra for GBM and LAT/LLE data, perform likelihood analysis and observation simulation with standard LAT data.' and a lightbulb icon with the text 'To begin, click on the File menu.' The bottom of the window shows a terminal window with the command 'git clone https://github.com/fermi-gamma-ray-space-telescope/fermi_data_analysis.git' and the output 'Cloning into 'fermi_data_analysis'...



- **gtburst**
 - **Choose the dataset**

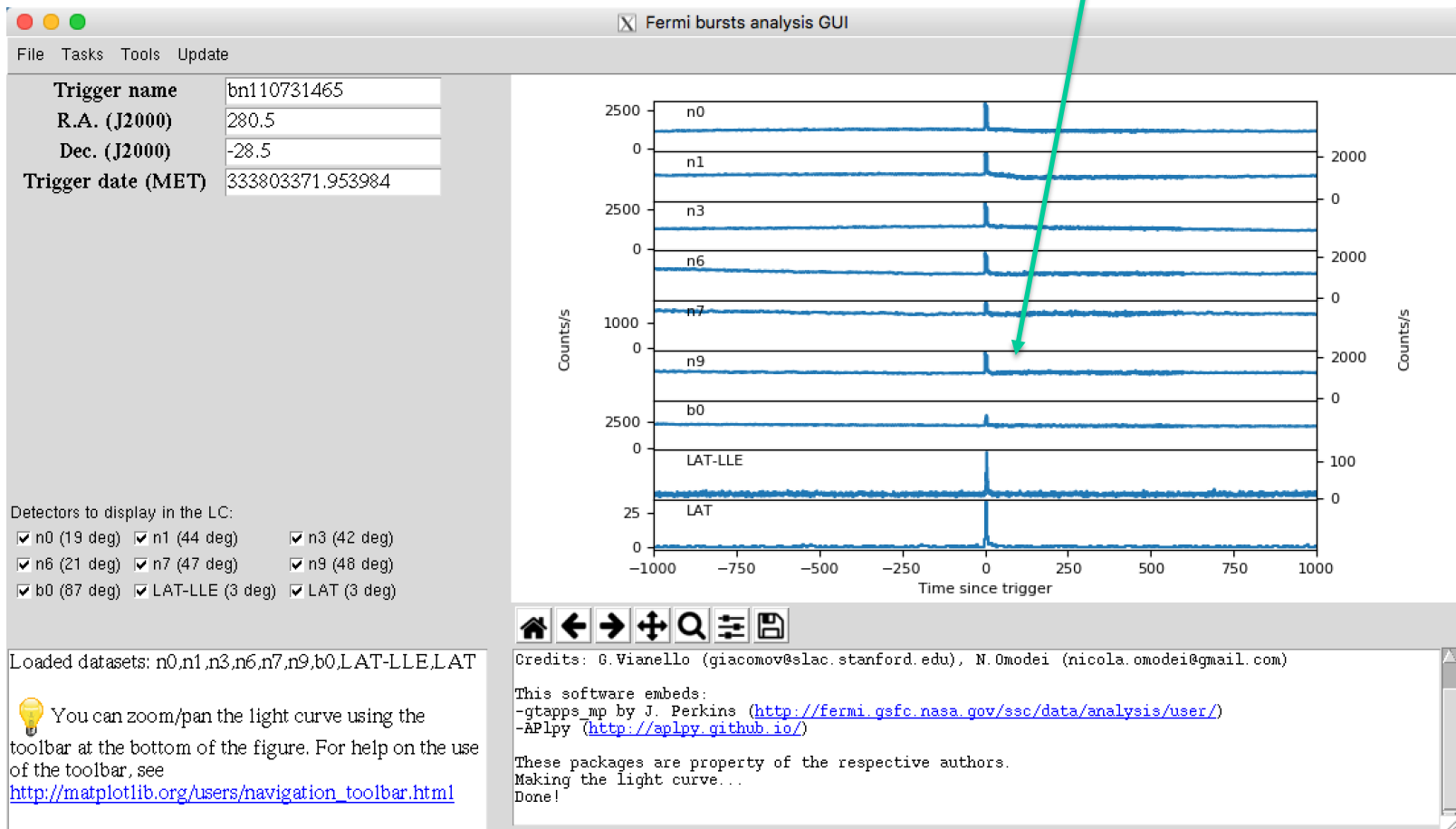


The screenshot shows the 'Fermi bursts analysis GUI' window. On the left, there are input fields for 'Trigger name', 'R.A. (J2000)', 'Dec. (J2000)', and 'Trigger date (MET)'. A central dialog box titled 'Select datasets' is open, displaying a list of detectors with their respective angles in degrees. The detectors and their angles are: n0 (20 deg), n1 (44 deg), n2 (90 deg), n3 (42 deg), n4 (87 deg), n5 (87 deg), n6 (22 deg), n7 (47 deg), n8 (90 deg), n9 (49 deg), na (93 deg), nb (93 deg), b0 (87 deg), b1 (93 deg), LAT (3 deg), and LAT-LLE (3 deg). A checkbox labeled 'Do NOT use GBM TTE files (you loose time resolution!)' is present and unchecked. An 'Ok' button is at the bottom of the dialog. Below the dialog, a lightbulb icon indicates a tip: 'In parenthesis you can find the angle between each detector and the source. Select datasets to use for your analysis. Pre-selected detectors are Nals closer than 50 deg to the source, the closest BGO and the LAT (if present).' At the bottom of the GUI, a status bar shows the message: '* Updating keywords in the headers of the CSPEC file... done. gtlllebin done!'. A text box at the bottom left explains the application's capabilities: 'With this application you can download Fermi data for GRBs and Solar Flares, compute source and background spectra for GBM and LAT/LLE data, perform likelihood analysis and observation simulation with standard LAT data.' A lightbulb icon next to it says 'To begin, click on the File menu.'



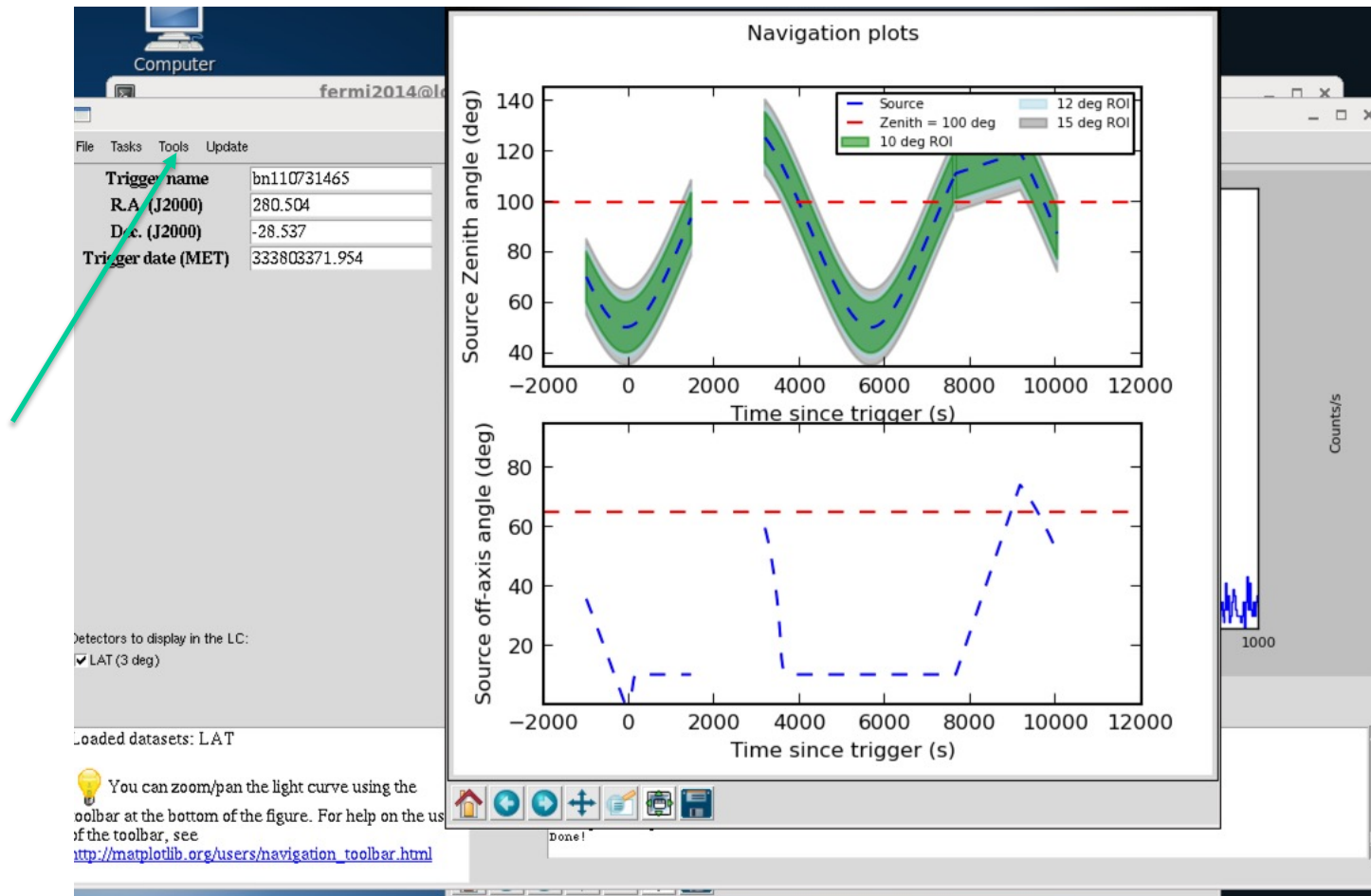
- gtburst

Clearly a burst!





- **gtburst**





- **gtburst**

File Tasks Tools Update
X Fermi bursts analysis GUI

Make likelihood analysis 0731465

Find source with TS map interactively recenter ROI

Make spectra for XSPEC


Trigger date (MET) 333803371.953984

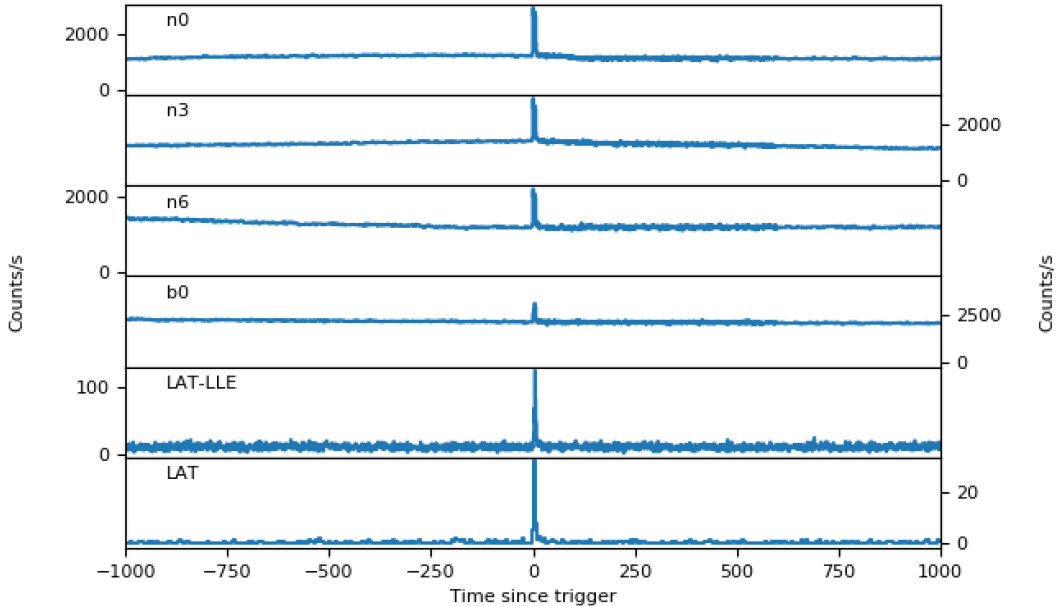
Detectors to display in the LC:

n0 (19 deg) n3 (42 deg) n6 (21 deg)

b0 (87 deg) LAT-LLE (3 deg) LAT (3 deg)

Loaded datasets: n0,n3,n6,b0,LAT-LLE,LAT

 You can zoom/pan the light curve using the toolbar at the bottom of the figure. For help on the use of the toolbar, see http://matplotlib.org/users/navigation_toolbar.html



Time since trigger

Home Back Forward Zoom Fit Save

Credits: G.Vianello (giacomov@slac.stanford.edu), N.Omodei (nicola.omodei@gmail.com)

This software embeds:
 -gtapps_mp by J. Perkins (<http://fermi.gsfc.nasa.gov/ssc/data/analysis/user/>)
 -APLpy (<http://aplpy.github.io/>)

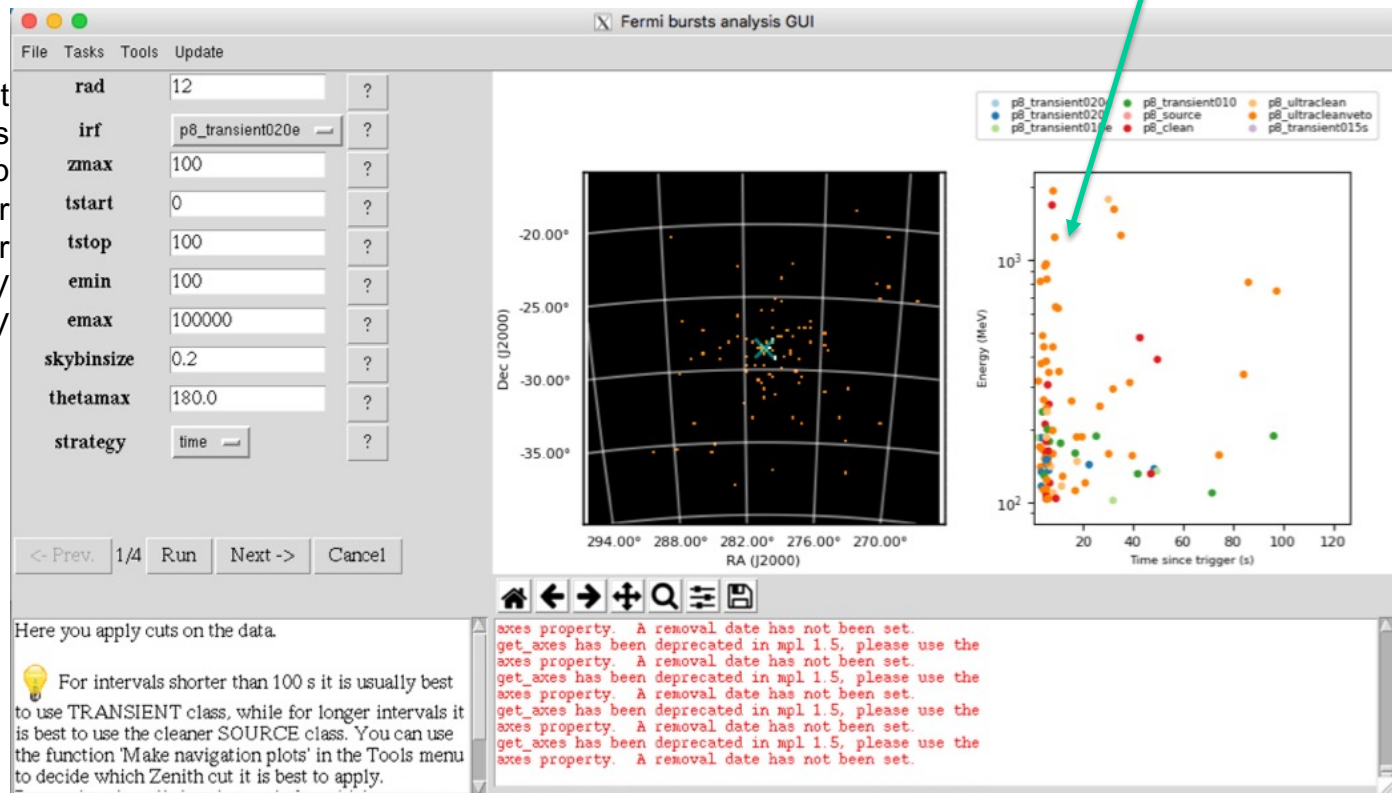
These packages are property of the respective authors.
 Making the light curve...
 Done!



- gtburst


- Radius of interest
- Event class
- Limit earth limb
- Start time relative to trigger
- Stop time relative to trigger
- Min energy in MeV
- Max energy in MeV

Click here



The screenshot shows the 'Fermi bursts analysis GUI' with a control panel on the left and two plots on the right. The control panel includes parameters for 'rad', 'irf', 'zmax', 'tstart', 'tstop', 'emin', 'emax', 'skybinsize', 'thetamax', and 'strategy'. The sky map plot shows a grid of RA (J2000) and Dec (J2000) with colored data points. The energy-time plot shows Energy (MeV) on a logarithmic scale versus Time since trigger (s) on a linear scale. A legend identifies various event classes like 'p8_transient020', 'p8_transient010', 'p8_ultraclean', etc. A green arrow points to a specific data point in the energy-time plot.

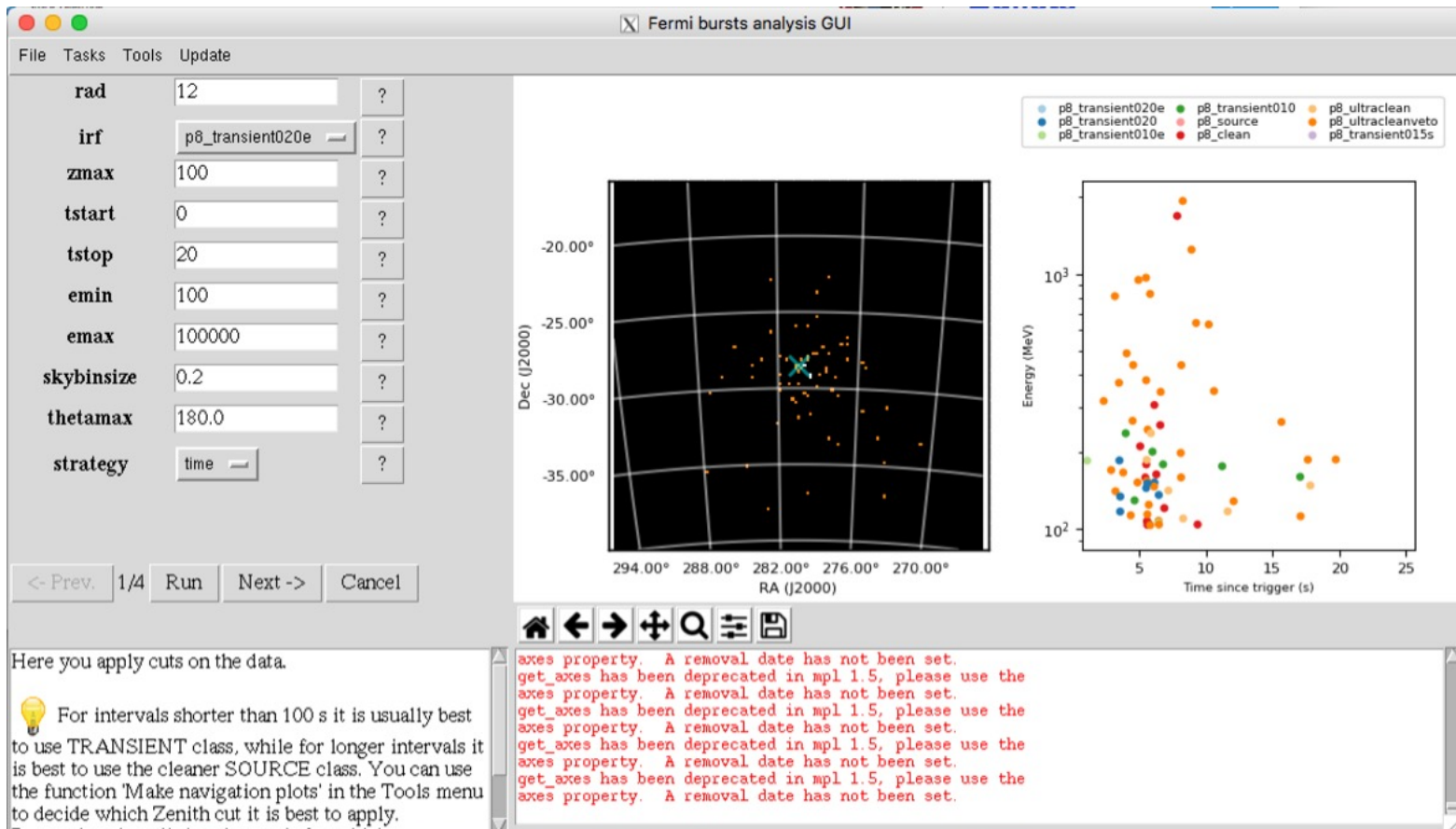
Here you apply cuts on the data.

 For intervals shorter than 100 s it is usually best to use TRANSIENT class, while for longer intervals it is best to use the cleaner SOURCE class. You can use the function 'Make navigation plots' in the Tools menu to decide which Zenith cut it is best to apply.

axes property. A removal date has not been set.
 get_axes has been deprecated in mpl 1.5, please use the axes property. A removal date has not been set.
 axes property. A removal date has not been set.
 get_axes has been deprecated in mpl 1.5, please use the axes property. A removal date has not been set.
 axes property. A removal date has not been set.
 get_axes has been deprecated in mpl 1.5, please use the axes property. A removal date has not been set.
 axes property. A removal date has not been set.
 get_axes has been deprecated in mpl 1.5, please use the axes property. A removal date has not been set.

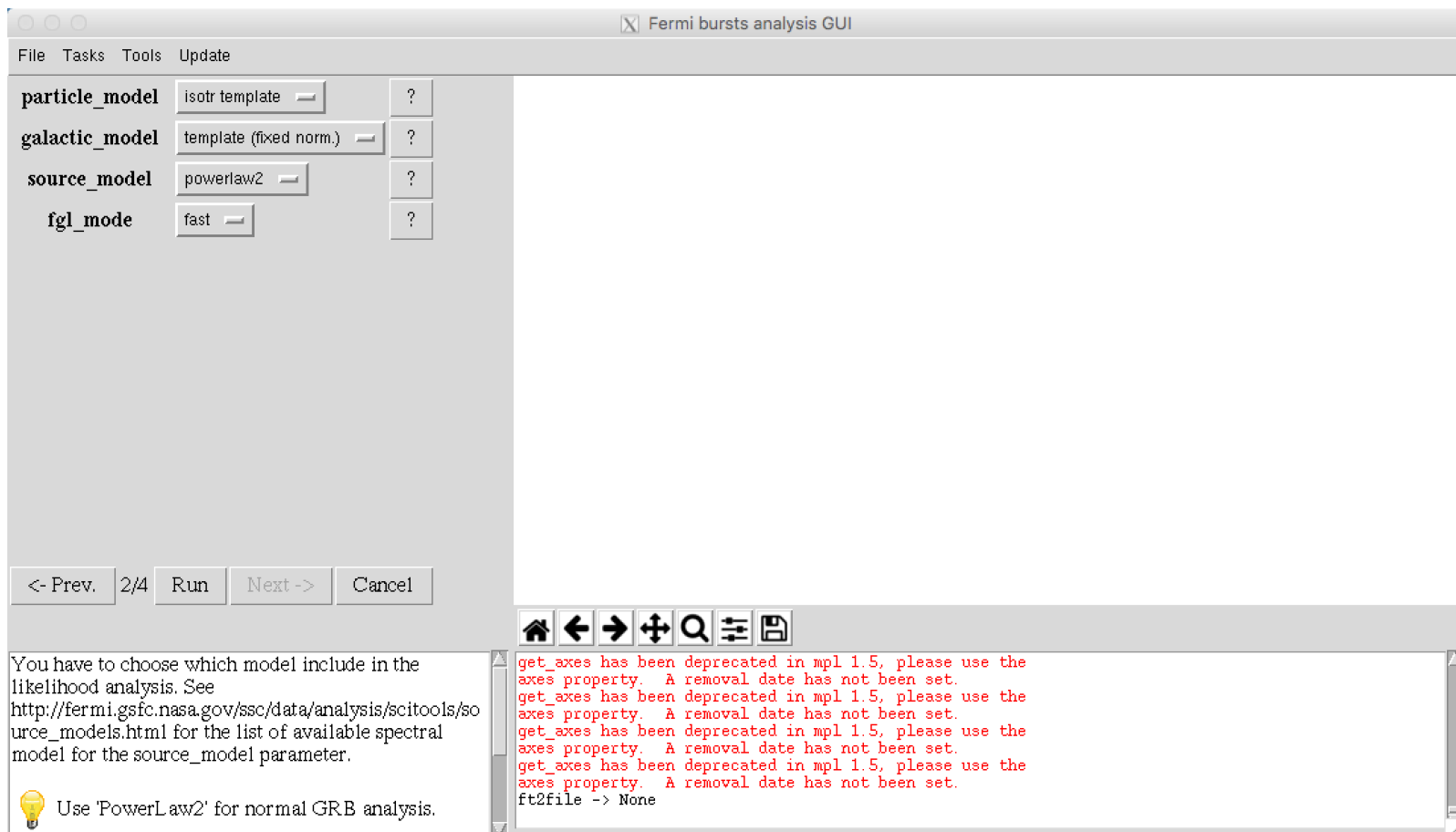


- **gtburst**
 - Limit data selection to SED interval
 - Relevant event class (Transient20e)





- **gtburst**
 - **Setting up background models for likelihood**
 - **next-run-next**



The screenshot shows the 'Fermi bursts analysis GUI' window. The title bar reads 'Fermi bursts analysis GUI'. The menu bar includes 'File', 'Tasks', 'Tools', and 'Update'. The main panel contains four rows of model selection controls:

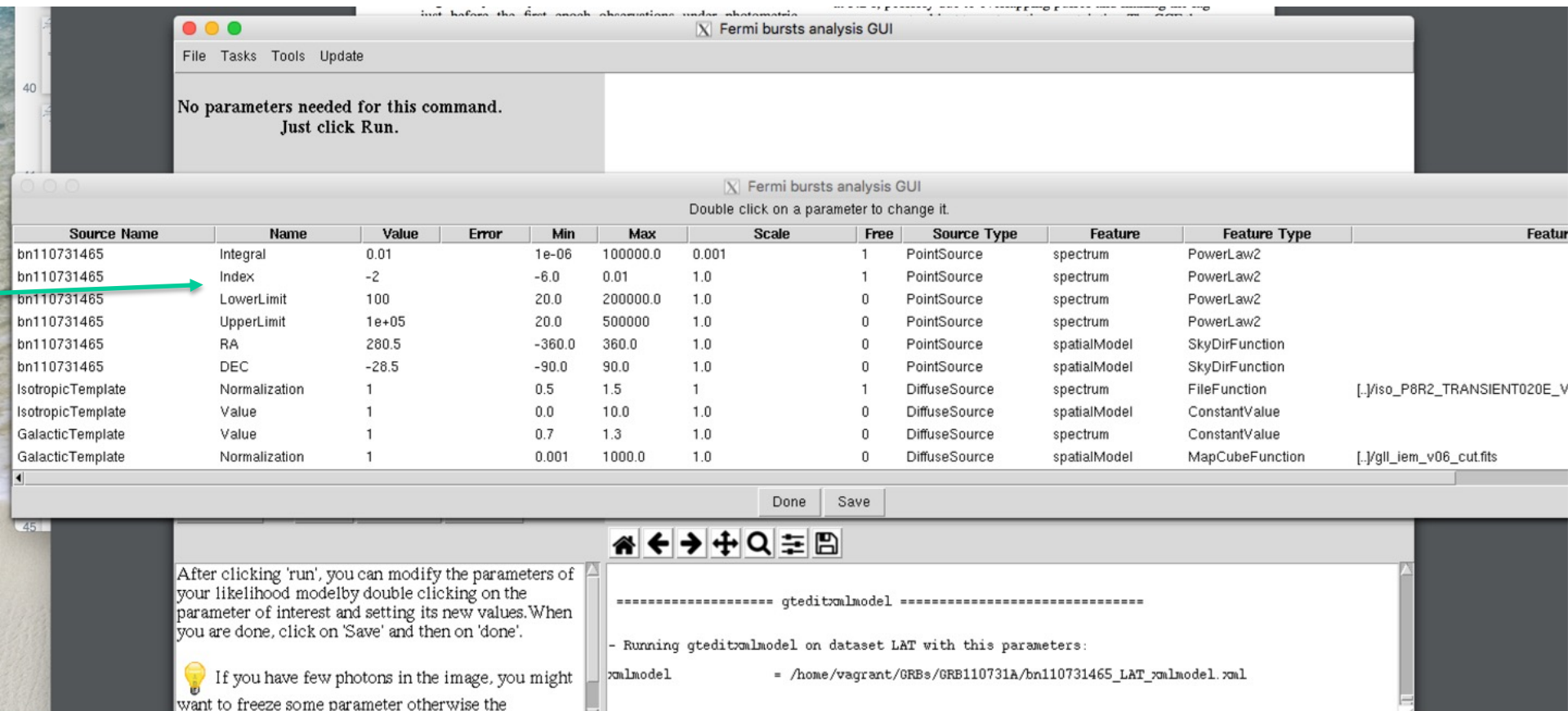
particle_model	isotr template	?
galactic_model	template (fixed norm.)	?
source_model	powerlaw2	?
fgl_mode	fast	?

Below these controls are navigation buttons: '<- Prev.', '2/4', 'Run', 'Next ->', and 'Cancel'. At the bottom left, a text box provides instructions: 'You have to choose which model include in the likelihood analysis. See http://fermi.gsfc.nasa.gov/ssc/data/analysis/scitools/source_models.html for the list of available spectral model for the source_model parameter. Use 'PowerLaw2' for normal GRB analysis.'

At the bottom right, a terminal window displays a series of red error messages: 'get_axes has been deprecated in mpl 1.5, please use the axes property. A removal date has not been set.' This message is repeated five times. The terminal prompt is 'ft2file -> None'.



- **gtburst**
 - XML file, default fits power-law with index=2



just before the first epoch observations under photomodels

40

File Tasks Tools Update

No parameters needed for this command.
Just click Run.

41

Double click on a parameter to change it.

Source Name	Name	Value	Error	Min	Max	Scale	Free	Source Type	Feature	Feature Type	Feature
bn110731465	Integral	0.01		1e-06	100000.0	0.001	1	PointSource	spectrum	PowerLaw2	
bn110731465	Index	-2		-6.0	0.01	1.0	1	PointSource	spectrum	PowerLaw2	
bn110731465	LowerLimit	100		20.0	200000.0	1.0	0	PointSource	spectrum	PowerLaw2	
bn110731465	UpperLimit	1e+05		20.0	500000	1.0	0	PointSource	spectrum	PowerLaw2	
bn110731465	RA	280.5		-360.0	360.0	1.0	0	PointSource	spatialModel	SkyDirFunction	
bn110731465	DEC	-28.5		-90.0	90.0	1.0	0	PointSource	spatialModel	SkyDirFunction	
IsotropicTemplate	Normalization	1		0.5	1.5	1	1	DiffuseSource	spectrum	FileFunction	[./iso_P8R2_TRANSIENT020E_V
IsotropicTemplate	Value	1		0.0	10.0	1.0	0	DiffuseSource	spatialModel	ConstantValue	
GalacticTemplate	Value	1		0.7	1.3	1.0	0	DiffuseSource	spectrum	ConstantValue	
GalacticTemplate	Normalization	1		0.001	1000.0	1.0	0	DiffuseSource	spatialModel	MapCubeFunction	[./gll_iem_v06_cut.fits

Done Save

45

After clicking 'run', you can modify the parameters of your likelihood model by double clicking on the parameter of interest and setting its new values. When you are done, click on 'Save' and then on 'done'.

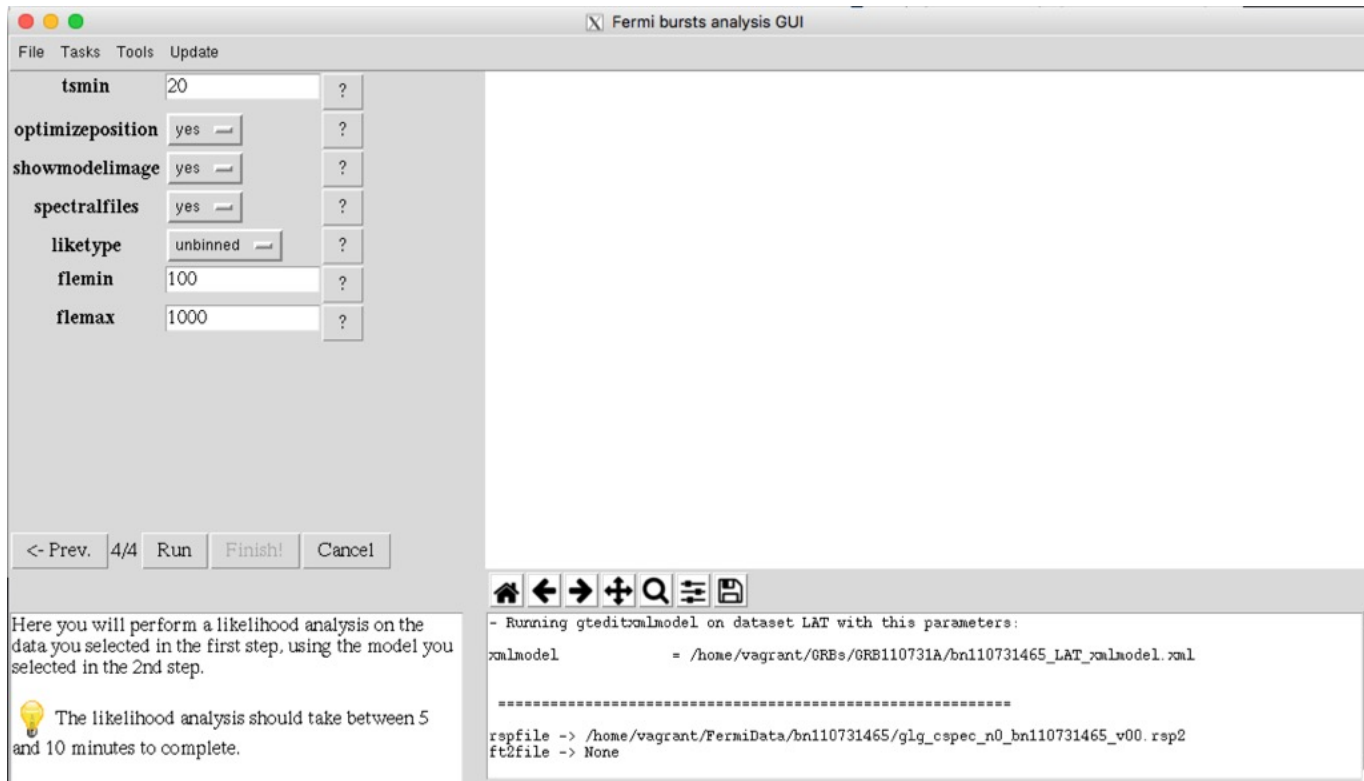
💡 If you have few photons in the image, you might want to freeze some parameter otherwise the

```

===== gtditxmlmodel =====
- Running gtditxmlmodel on dataset LAT with this parameters:
xmlmodel = /home/vagrant/GRBs/GRB110731A/bn110731465_LAT_xmlmodel.xml
  
```



- **gtburst**
 - **Optimizing position** – runs **gtfindsrc** after **gtlike**
 - **Show model image** – makes **TS map**
 - **Spectral files** – makes **XSPEC** ready files
 - **Run -> wait ...**



The screenshot shows the 'Fermi bursts analysis GUI' window. The left panel contains several configuration options:

- tmin**: 20
- optimizeposition**: yes
- showmodelimage**: yes
- spectralfiles**: yes
- liketype**: unbinned
- flemin**: 100
- flemax**: 1000

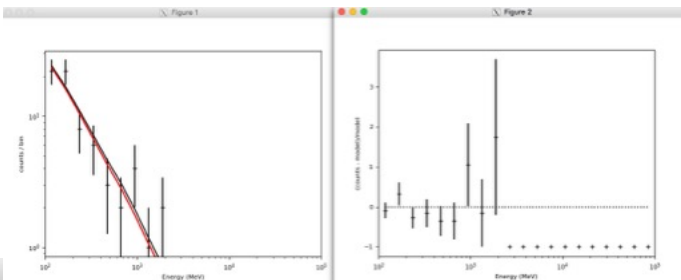
At the bottom of the left panel, there are buttons for '<- Prev.', '4/4', 'Run', 'Finish!', and 'Cancel'. Below these buttons is a text box with a lightbulb icon and the text: 'The likelihood analysis should take between 5 and 10 minutes to complete.'

The right panel shows a terminal window with the following output:

```
- Running gtditvmlmodel on dataset LAT with this parameters:  
xalmodel = /home/vagrant/GRBs/GRB110731A/bn110731465_LAT_xalmodel.xml  
  
-----  
rspfile -> /home/vagrant/FermiData/bn110731465/glg_cspec_n0_bn110731465_v00.rsp2  
ft2file -> None
```



- **gtburst**
 - LAT Likelihood results
 - Finish



Likelihood results

Source name	Par. Name	Value	Error	Units	TS
GalacticTemplate	Value	1	n. a. (fixed)	-	0
	Energy flux	5.19e-08	0	erg/cm2/s	
	Photon flux	0.00011	0	ph./cm2/s	
IsotropicTemplate	Normalization	1.5	0.173	-	1
	Energy flux	1.67e-07	1.93e-08	erg/cm2/s	
	Photon flux	0.00047	5.42e-05	ph./cm2/s	
bn110731465	Integral	0.000495	6.14e-05	ph./cm2/s	569
	Index	-2.43	0.164	-	
	LowerLimit	100	n. a. (fixed)	MeV	
	UpperLimit	1e+05	n. a. (fixed)	MeV	
	Photon flux	1.66e-07	2.09e-08	erg/cm2/s	
	Photon flux	0.000476	6.04e-05	ph./cm2/s	

*** plus 3 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 % c. l.
 Log(Likelihood) = 206.751059003

New localization from gtfindsrc:

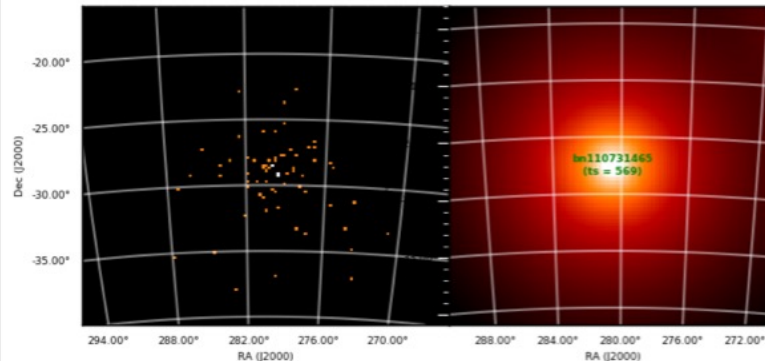
(R. A. , Dec) = (280.344, -28.664)
 68 % containment radius = 0.188
 90 % containment radius = 0.265

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

File Tasks Tools

tmin 20 ?
 optimizeposition yes ?
 showmodelimage yes ?
 spectralfiles yes ?
 liketype unbinned ?
 flemin 100 ?
 flemax 1000 ?

<- Prev. 4/4 Run Finish! Cancel



Here you will perform a likelihood analysis on the data you selected in the first step, using the model you selected in the 2nd step.

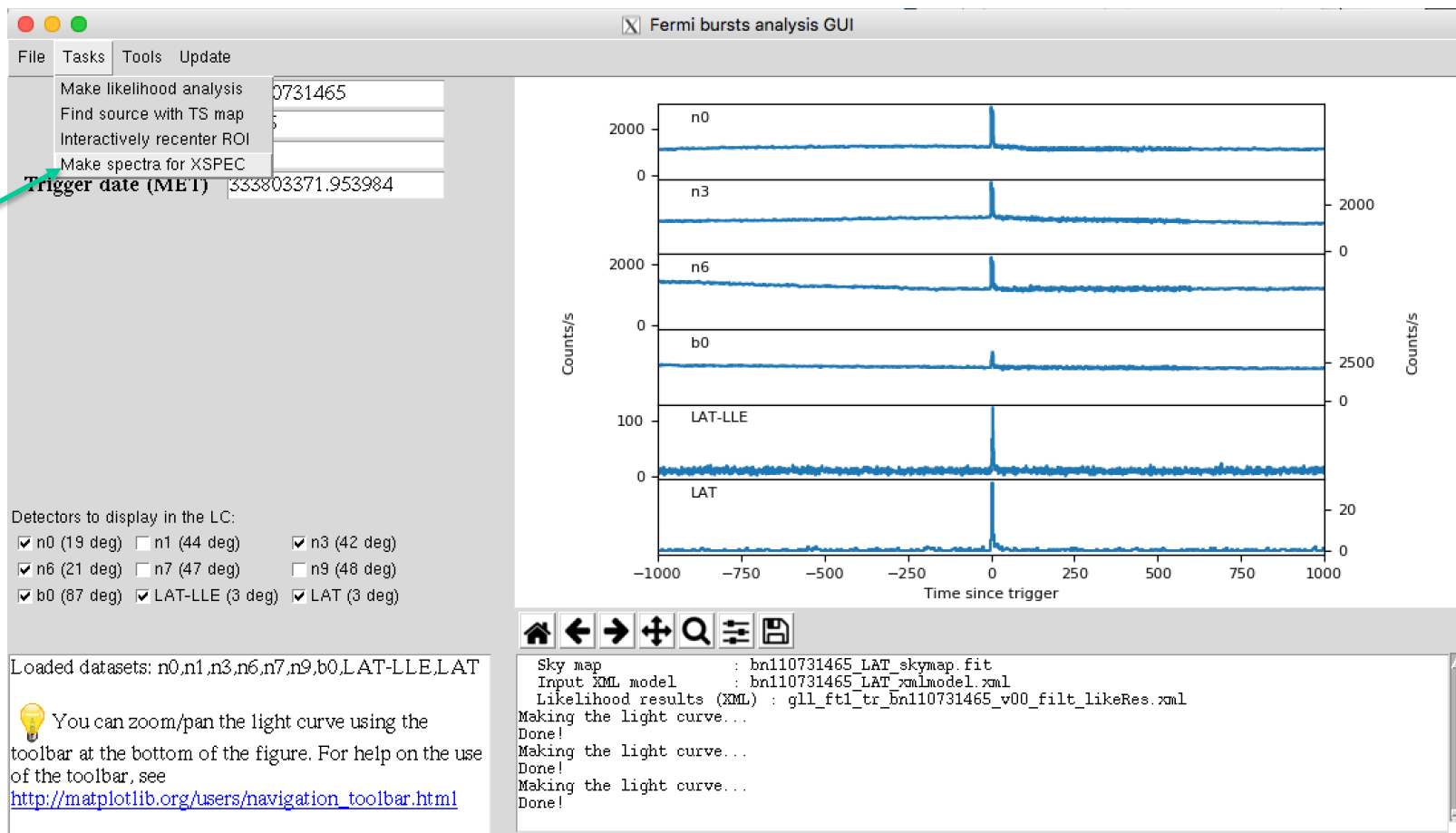
The likelihood analysis should take between 5 and 10 minutes to complete.

90 % containment radius = 0.265
 Distance from initial position = 0.214

NOTE: this new localization WILL NOT be used by default. If you judge it is a better localization than the one you started with, update the coordinates yourself and re-run the likelihood

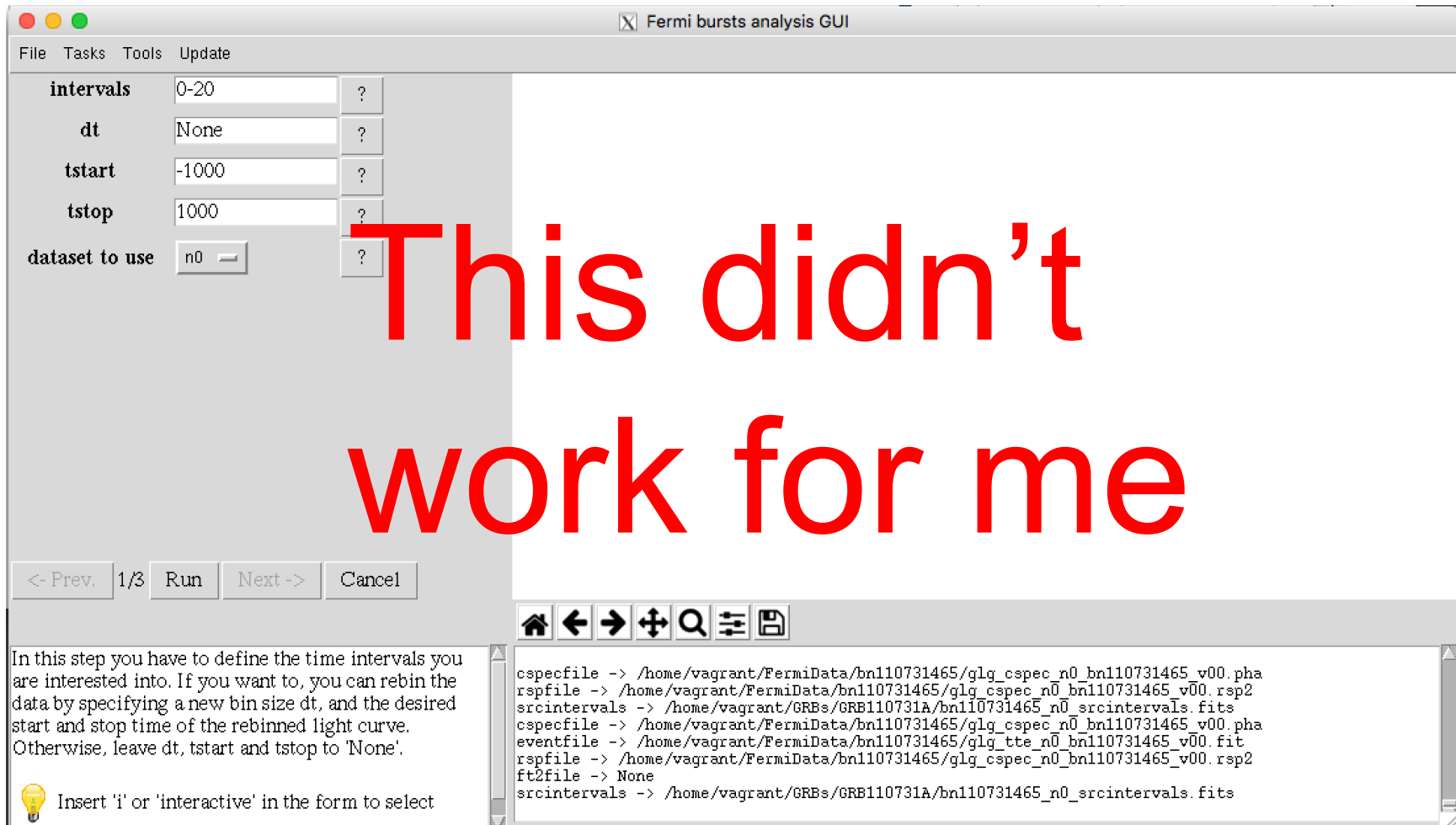


- **gtburst**
 - Turn off some of the GBM detectors, only need 2 or 3 Nals (with smallest angle) & 1 BGO





- **interactive or manual interval input**



This didn't work for me

In this step you have to define the time intervals you are interested into. If you want to, you can rebin the data by specifying a new bin size dt, and the desired start and stop time of the rebinned light curve. Otherwise, leave dt, tstart and tstop to 'None'.

Insert 'i' or 'interactive' in the form to select

```
cspecfile -> /home/vagrant/FermiData/bn110731465/glg_cspec_n0_bn110731465_v00.pha
rspfile -> /home/vagrant/FermiData/bn110731465/glg_cspec_n0_bn110731465_v00.rsp2
srcintervals -> /home/vagrant/GRBs/GRB110731A/bn110731465_n0_srcintervals.fits
cspecfile -> /home/vagrant/FermiData/bn110731465/glg_cspec_n0_bn110731465_v00.pha
eventfile -> /home/vagrant/FermiData/bn110731465/glg_tte_n0_bn110731465_v00.fit
rspfile -> /home/vagrant/FermiData/bn110731465/glg_cspec_n0_bn110731465_v00.rsp2
ft2file -> None
srcintervals -> /home/vagrant/GRBs/GRB110731A/bn110731465_n0_srcintervals.fits
```



- interactively zoom

File Tasks Tools Update
☒ Fermi bursts analysis GUI

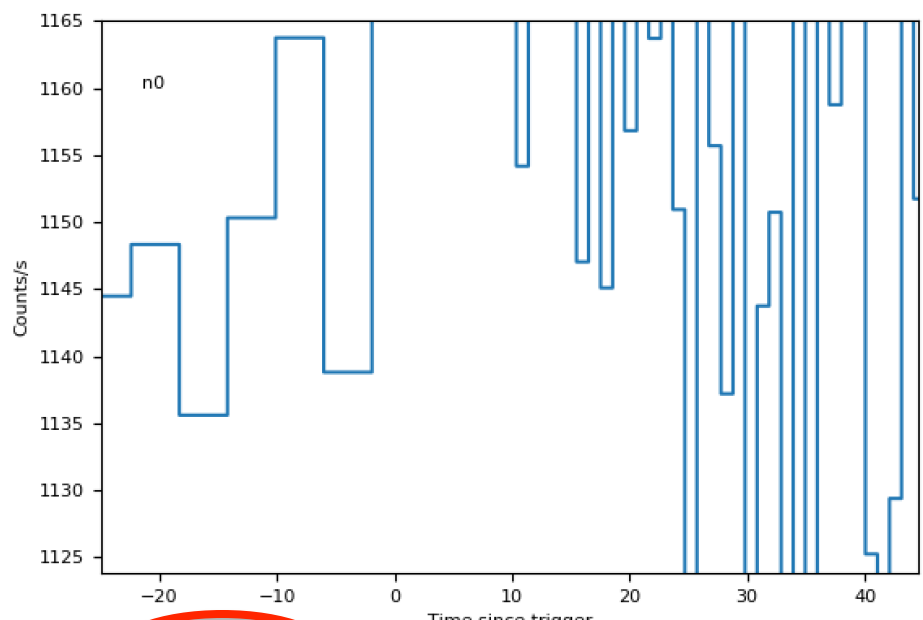
intervals ?

dt ?

tstart ?

tstop ?

dataset to use ?



Counts/s

Time since trigger

Clear

Done

<- Prev. 1/3 Run Next -> Cancel

In this step you have to define the time intervals you are interested into. If you want to, you can rebin the data by specifying a new bin size dt, and the desired start and stop time of the rebinned light curve. Otherwise, leave dt, tstart and tstop to 'None'.

Insert 'i' or 'interactive' in the form to select

```

ft2file      = None
tstart      = -1000
tstop       = 1000
dt          = None
srcintervals = /home/vagrant/GRBs/GRB110731A/bn110731465_n0_srcintervals.fits
cspecfile   = /home/vagrant/FermiData/bn110731465/glg_cspec_n0_bn110731465_v00.pha

* Get time intervals interactively...
Using default event loop until function specific to this GUI is implemented
        
```



- interactively choose source interval

File Tasks Tools Update
☒ Fermi bursts analysis GUI

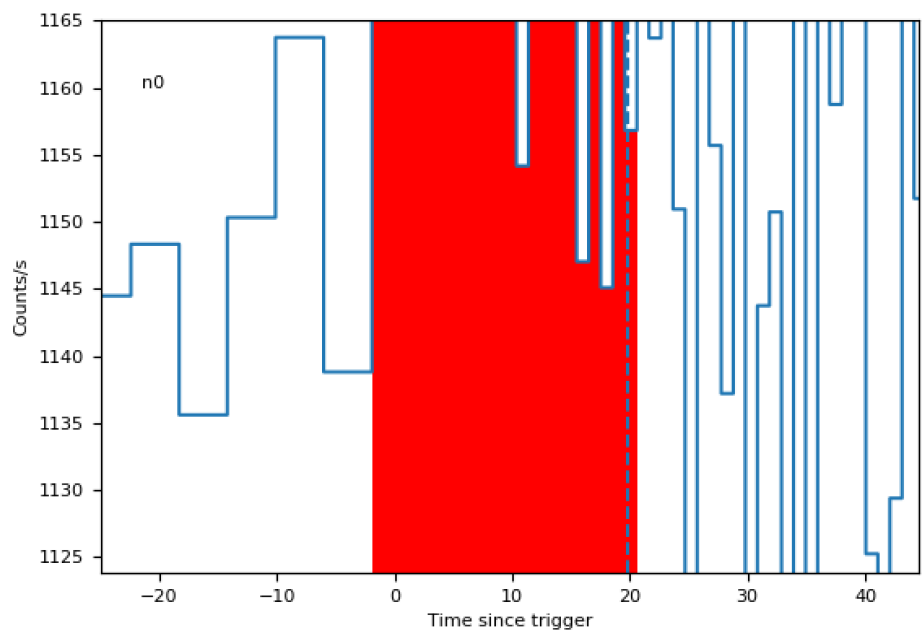
intervals ?

dt ?

tstart ?

tstop ?

dataset to use ?



Counts/s

Time since trigger

Clear

Done

<- Prev. 1/3 Run Next -> Cancel

🏠
⬅️
➡️
📏
🔍
📄

x=19.8182 y=1137.05

```

ft2file           = None
tstart            = -1000
tstop             = 1000
dt                = None
srcintervals      = /home/vagrant/GRBs/GRB110731A/bn110731465_n0_srcintervals.fits
cspecfile         = /home/vagrant/FermiData/bn110731465/glg_cspec_n0_bn110731465_v00.pha

* Get time intervals interactively...
Using default event loop until function specific to this GUI is implemented
        
```

💡 In this step you have to define the time intervals you are interested into. If you want to, you can rebin the data by specifying a new bin size dt, and the desired start and stop time of the rebinned light curve. Otherwise, leave dt, tstart and tstop to 'None'.

Insert 'i' or 'interactive' in the form to select

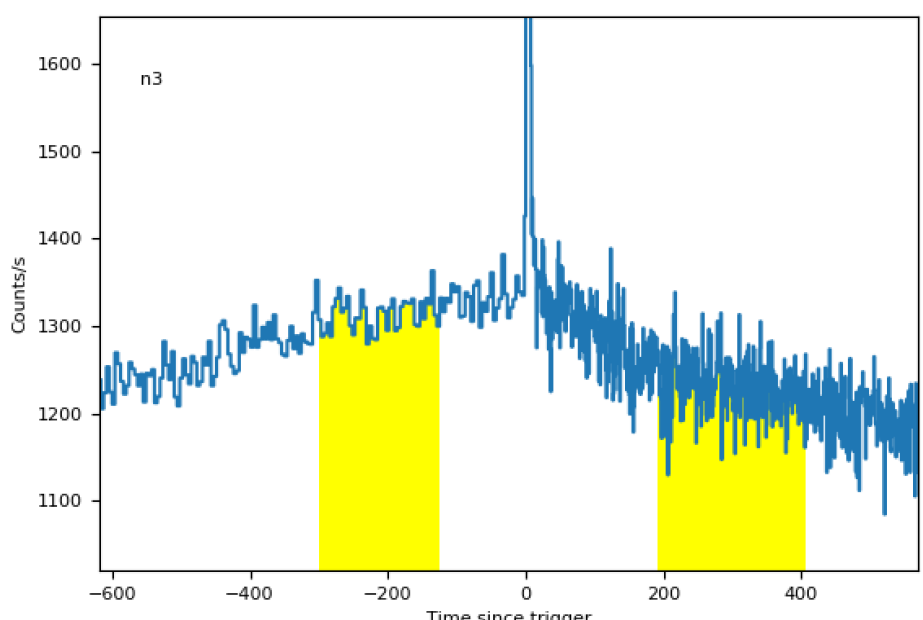


- interactively choose background for each detector

Fermi bursts analysis GUI
File Tasks Tools Update

intervals ?

<- Prev.
2/3
Run
Next ->
Cancel



Counts/s

n3

Time since trigger


Clear
Done

Home
Back
Forward
Zoom
Search
Print

```

bkgspectra      = /home/vagrant/GRBs/GRB110731A/bn110731465_n3_bkgspectra.bak
rspfile         = /home/vagrant/FermiData/bn110731465/glg_cspect_n3_bn110731465_v00.rsp2
intervals       = interactive
bkgintervals    = /home/vagrant/GRBs/GRB110731A/bn110731465_n3_bkgintervals.fits
srcintervals    = /home/vagrant/GRBs/GRB110731A/bn110731465_n0_srcintervals.fits
cspecfile       = /home/vagrant/FermiData/bn110731465/glg_cspect_n3_bn110731465_v00.pha

* Get time intervals interactively...
Using default event loop until function specific to this GUI is implemented
        
```

 Select two time intervals, one before and one



- resulting fit, retry if it doesn't look right

X Fermi bursts analysis GUI

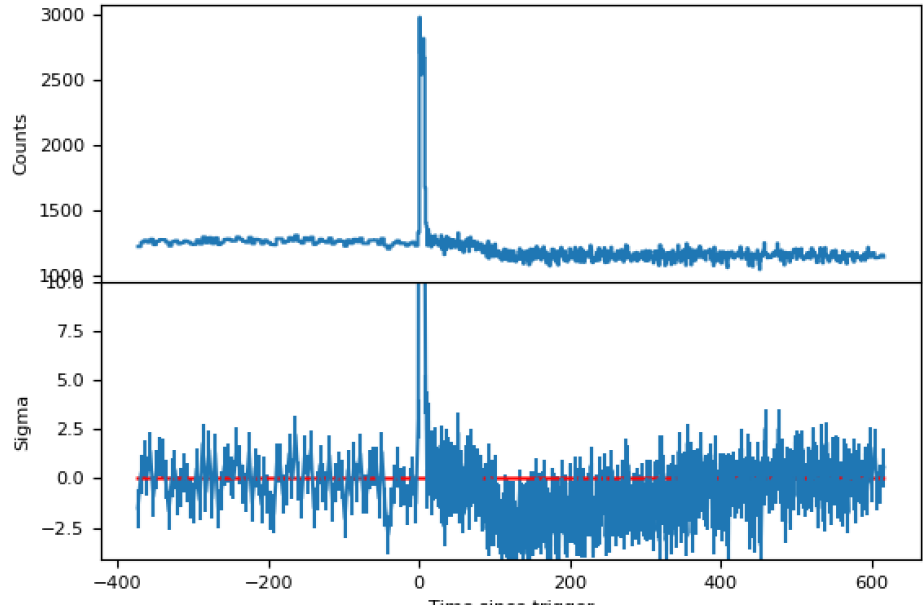
File Tasks Tools Update

intervals
interactive
?

<- Prev.
2/3
Run
Next ->
Cancel

In this step you will produce the background spectra. You have to select off-pulse intervals. The program will then fit a different polynomial for each channel of the detector, and it will interpolate such polynomials in the pulse interval(s) to compute the background spectrum.

Select two time intervals, one before and one



Retry
Ok

Home
Back
Forward
Zoom In
Zoom Out
Print

```

gtllebkg done!
gtllebkgGUI done!
Computing residuals...
Done
Using default event loop until function specific to this GUI is implemented
          
```



- resulting files

```
[vagrant@host-10-0-2-15 GRB110731A]$ ls *pha *rsp *bak
bn110731465_b0_bkgspectra.bak      bn110731465_n3_weightedrsp.rsp
bn110731465_b0_srcspectra.pha     bn110731465_n6_bkgspectra.bak
bn110731465_b0_weightedrsp.rsp    bn110731465_n6_srcspectra.pha
bn110731465_LAT-LLE_bkgspectra.bak bn110731465_n6_weightedrsp.rsp
bn110731465_LAT-LLE_srcspectra.pha bn110731465_n7_bkgspectra.bak
bn110731465_LAT-LLE_weightedrsp.rsp bn110731465_n7_srcspectra.pha
bn110731465_n0_bkgspectra.bak     bn110731465_n7_weightedrsp.rsp
bn110731465_n0_srcspectra.pha     bn110731465_n9_bkgspectra.bak
bn110731465_n0_weightedrsp.rsp    bn110731465_n9_srcspectra.pha
bn110731465_n1_bkgspectra.bak     bn110731465_n9_weightedrsp.rsp
bn110731465_n1_srcspectra.pha     gll_ft1_tr_bn110731465_v00_filt_spec_0.000_20.000.bak
bn110731465_n1_weightedrsp.rsp    gll_ft1_tr_bn110731465_v00_filt_spec_0.000_20.000.pha
bn110731465_n3_bkgspectra.bak     gll_ft1_tr_bn110731465_v00_filt_spec_0.000_20.000.rsp
bn110731465_n3_srcspectra.pha
[vagrant@host-10-0-2-15 GRB110731A]$ █
```



- **XSPEC**
 - <http://heasarc.gsfc.nasa.gov/xanadu/xspec/manual/manual.html>
 - Standard spectral model fitting package, developed in X-ray community, so a bit X-ray centric (units default in keV)
 - **Inputs:**
 - **counts/channel spectra**
 - **Background files**
 - **Response files**
 - **Outputs:**
 - **Fit parameters**
 - **Model fit to data in counts space, F_ν , νF_ν in energy, frequency, etc.**
- **Other spectral fitting packages**
 - **RMFIT**
 - **SHERPA**



data 1:1 bn110731465_n3.pha
res 1:1 glg_cspect_n3_bn110731465_v00.rsp2

data 1:2 bn110731465_n0.pha
res 1:2 glg_cspect_n0_bn110731465_v00.rsp2

data 2:3 bn110731465_b0.pha
res 3 glg_cspect_b0_bn110731465_v00.rsp2

data 4:4
gll_ft1_tr_bn110731465_v00_filt_spec_0.000_
20.000.pha

Setting up 3 data groups

- NaI
- BGO
- LAT

This allows us to do things like free parameters (e.g. normalization constant) in each group from each other



- Let's set things up

`cpd /xw`

`setplot en`

`ignore 1:**-8.0`

`ignore 1:1000.-**`

`ignore 3:**-200.`

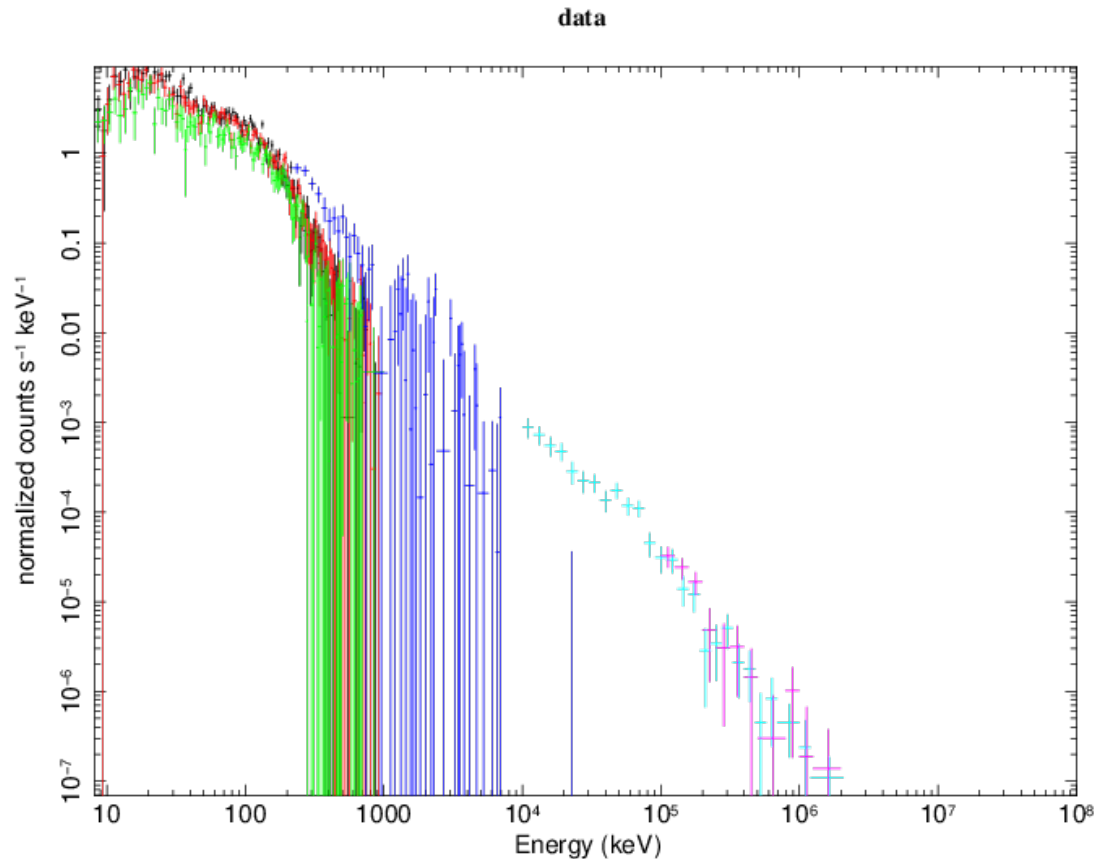
`ignore 3:40e3-**`

`ignore bad`

`statistic cstat`

`statistic pgstat 4`

- Let's plot our data
 - plot ldata



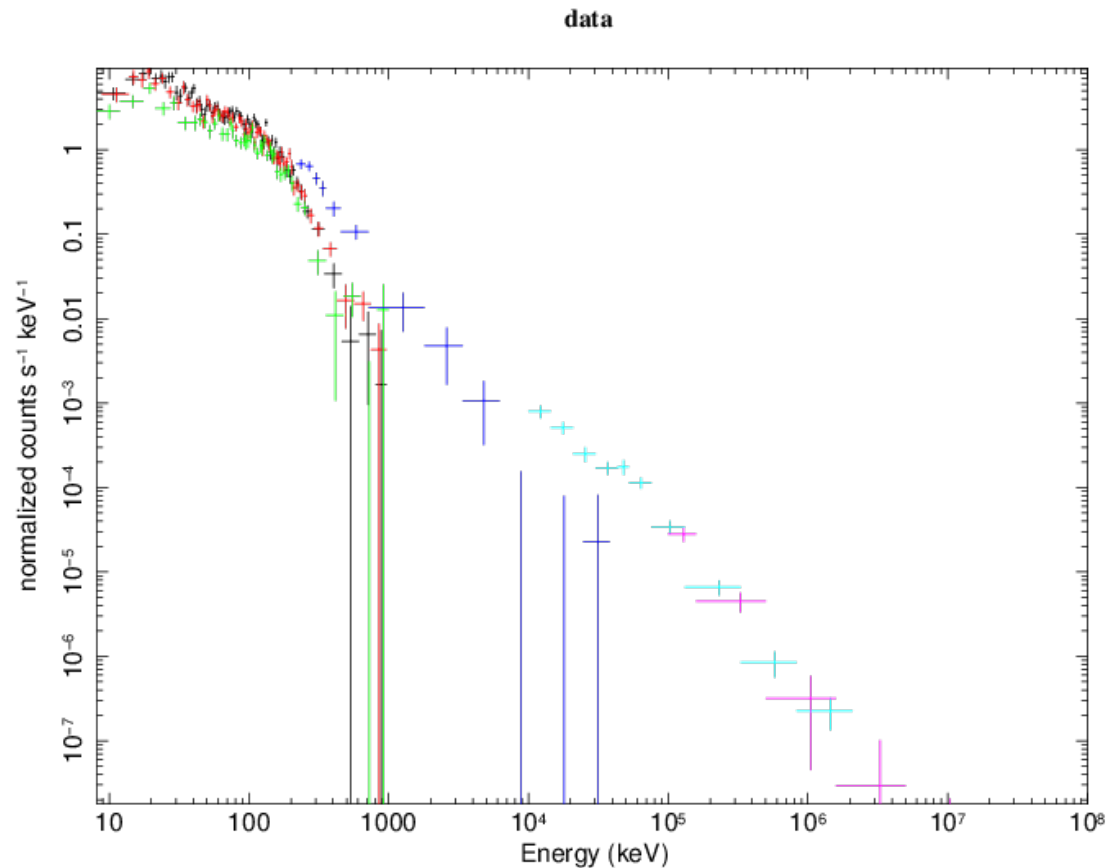
cstat = Cash Statistic, pgstat = poisson signal with gaussian noise



- Let's bin our data (for plotting purposes only)
 - `setplot rebin <min significance><max # bins><plot group>`

- `setplot rebin 5 10 1`
- `setplot rebin 5 10 2`
- `setplot rebin 5 10 3`
- `setplot rebin 5 20 4`
- `setplot rebin 5 5 5`
- `plot ldata`

feel free to play with these numbers to make nicer looking plots, it won't affect the fits





- Let's fit the data to some simple models

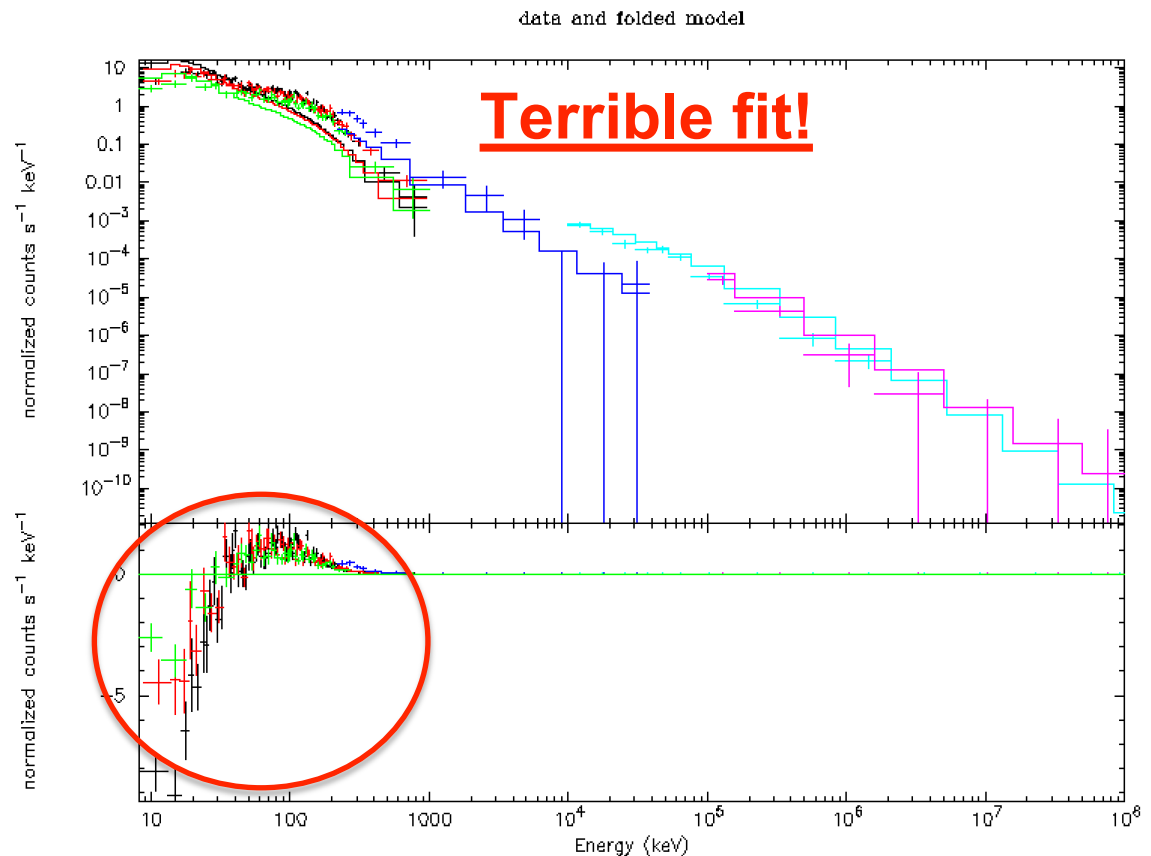
- model pow
- [press enter to use default parameters
- fit 1000

- Let's plot fit with residuals

- plot ldata res

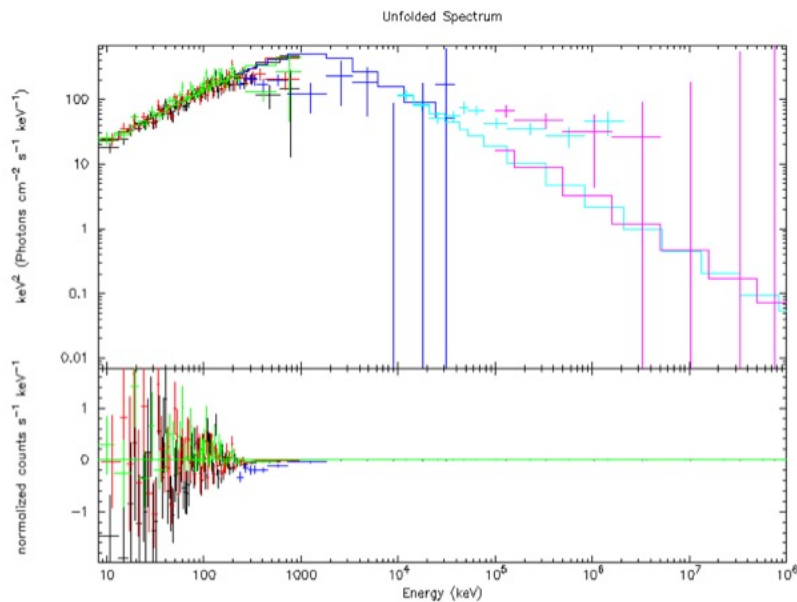
```
Model powerlaw<1> Source No.: 1 Active/On
Model Model Component Parameter Unit Value
par comp
```

Data group: 1

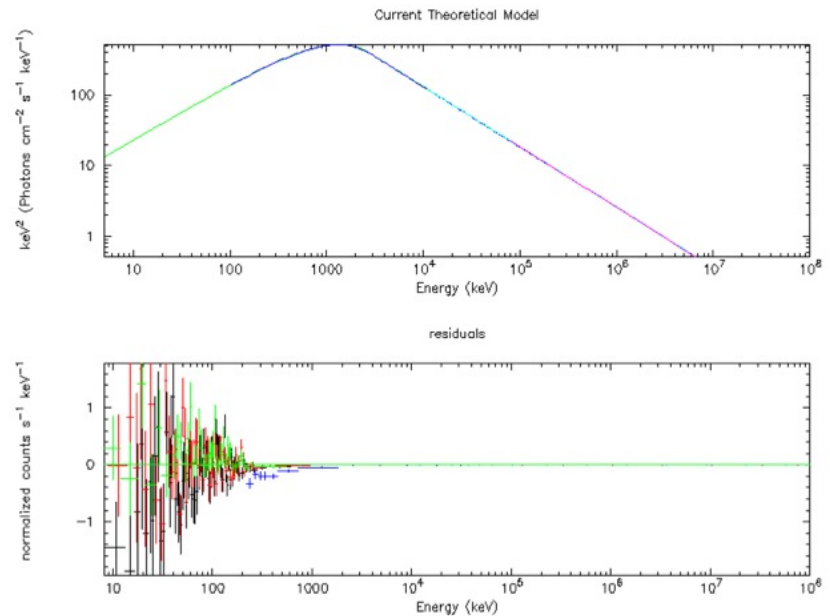




- **Let's look at the plot like a SED plotting νF_ν to unfold the data using the response functions & model. This makes your spectrum plot model dependent, caution when interpreting physical models!**
 - plot eeuf res
 - plot eemo res



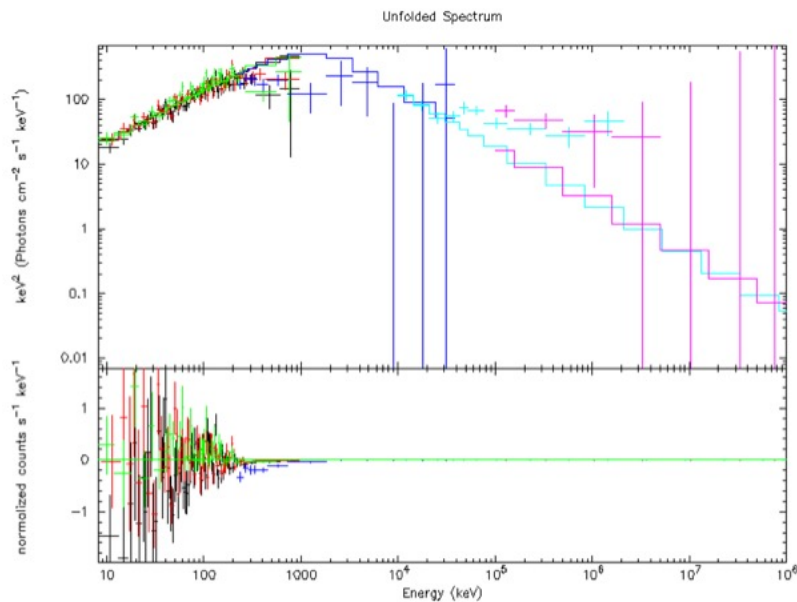
[rscah] 1-Jun-2017 18:09



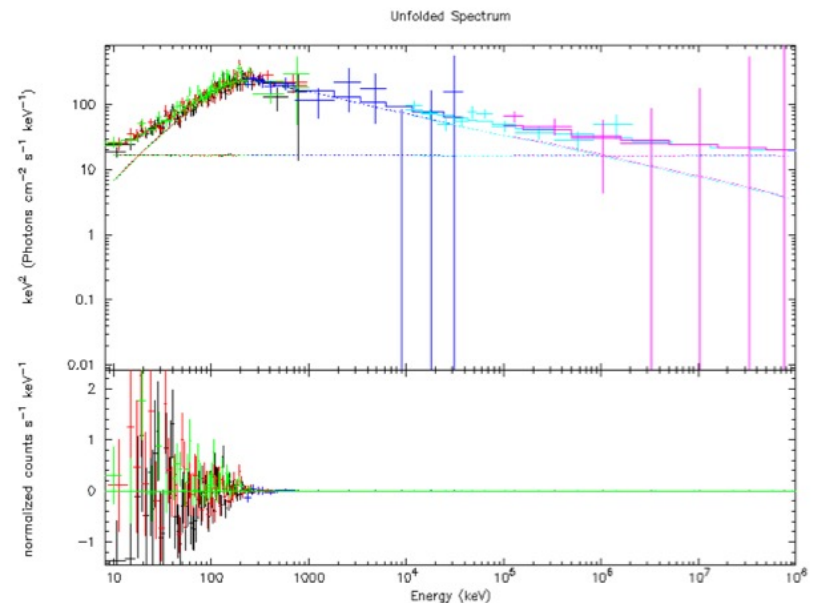
[rscah] 1-Jun-2017 18:16



- Let's to a better fit to the data. Try these models
 - model grbm
 - model grbm+pow
 - model grbm+pow+bb
 - model const(grbm+pow+bb)
 - freeze 1
 - untie 19



[reueh 1--Jun--2017 18:09



[reueh 1--Jun--2017 18:10



- **Fit the data**
 - **fit 1000**
 - **May have to do this several times**
- **Tricks to refine the fit, get out of local minima**
 - **method migrad**
 - **Minuit2 migrad method, useful for getting into the right ballpark with wider parameter space**
 - **method leven**
 - **Default minimization method, useful for refining fit**
 - **Sometimes useful to go back and forth setting method, fitting, trying other method**
- **All these commands are documented here**
 - **<https://heasarc.gsfc.nasa.gov/xanadu/xspec/manual/manual.html>**



- You have a fit
 - But don't believe the results just yet ...

```

=====
Model constant<1>(grbm<2> + powerlaw<3> + bbody<4>) Source No.: 1 Active/On
Model Model Component Parameter Unit Value
par comp
-----
Data group: 1
  1 1 constant factor 6.98173E-02 +/- 5.40843E+04
  2 2 grbm alpha -2.25451E-03 +/- 0.154769
  3 2 grbm beta -1.82868 +/- 3.99082E-02
  4 2 grbm tem keV 88.9897 +/- 14.6841
  5 2 grbm norm 6.66711E-02 +/- 5.16470E+04
  6 3 powerlaw PhoIndex 5.84980 +/- 2.35146E+06
  7 3 powerlaw norm 1.08363 +/- 2.21283E+06
  8 4 bbody kT keV 2.83379E-02 +/- -1.00000
  9 4 bbody norm 0.102170 +/- -1.00000
Data group: 2
 10 1 constant factor 6.98173E-02 = p1
 11 2 grbm alpha -2.25451E-03 = p2
 12 2 grbm beta -1.82868 = p3
 13 2 grbm tem keV 88.9897 = p4
 14 2 grbm norm 6.66711E-02 = p5
 15 3 powerlaw PhoIndex 5.84980 = p6
 16 3 powerlaw norm 1.08363 = p7
 17 4 bbody kT keV 2.83379E-02 = p8
 18 4 bbody norm 0.102170 = p9
Data group: 3
 19 1 constant factor 6.59656E-02 +/- 5.11005E+04
 20 2 grbm alpha -2.25451E-03 = p2
 21 2 grbm beta -1.82868 = p3
 22 2 grbm tem keV 88.9897 = p4
 23 2 grbm norm 6.66711E-02 = p5
 24 3 powerlaw PhoIndex 5.84980 = p6
 25 3 powerlaw norm 1.08363 = p7
 26 4 bbody kT keV 2.83379E-02 = p8
 27 4 bbody norm 0.102170 = p9
=====

```

Never believe these errors, ever!

```

Fit statistic : C-Statistic          297.43    using 121 bins, spectrum 1, group 1.

Warning: cstat statistic is only valid for Poisson data.
Background file is not Poisson for spectrum 1

C-Statistic          38.18    using 53 bins, spectrum 2, group 1.

Warning: cstat statistic is only valid for Poisson data.
Background file is not Poisson for spectrum 2

PG-Statistic         318.19    using 123 bins, spectrum 3, group 1.
C-Statistic          84.40    using 119 bins, spectrum 4, group 2.

Warning: cstat statistic is only valid for Poisson data.
Background file is not Poisson for spectrum 4

C-Statistic          46.81    using 30 bins, spectrum 5, group 3.

Warning: cstat statistic is only valid for Poisson data.
Source file is not Poisson for spectrum 5
Background file is not Poisson for spectrum 5

Total fit statistic   785.02    with 436 d.o.f.

```

Goodness of fit



- **Errors on parameters and local minima**
 - Sometime will find new better fit, and you can start over
 - Confidence interval default = 90%, can change

```
XSPEC12>error 1-6
Parameter   Confidence Range (2.706)
Number of trials exceeded: continue fitting?
Number of trials exceeded: continue fitting?
Number of trials exceeded: continue fitting?
      1   -0.744889   -0.193892   (-0.260579,0.290418)
Apparent non-monotonicity in statistic space detected.
Current bracket values -2.25746, -2.25356
and delta stat 2.69048, 3.31576
but latest trial -2.25736 gives 2.685
Suggest that you check this result using the steppar command.
      2   -2.40369   -2.25551   (-0.0739512,0.0742339)
      3    127.898    232.325   (-41.8045,62.6225)
      4    0.0214608   0.0303339   (-0.00350109,0.00537204)
      5     1.93526     2.45999   (-0.0674719,0.457264)
      6     7.96772     39.5745   (-8.86897,22.7378)
```




- **XSPEC can do lots of other useful things**
 - **Many spectral models**
 - **<http://heasarc.gsfc.nasa.gov/xanadu/xspec/manual/Models.html>**
 - **Calculate fluxes over energy range**
 - **If you want de-absorbed X-ray fluxes (true emitted flux), you can set the $nH=0$ after fitting**
 - **Can even simulate data using fakeit command**
 - **Can fit offsets for different datasets if cross-calibration is uncertain**
 - **different fit parameters (e.g. normalizations) for different instruments**
 - **Plot data in counts, F_v , vF_v**



- **Do this in time-resolved analysis**
 - **measure evolution of parameters**
 - **are all components seen in every interval**
 - **f_ttest for nested models**
 - **more sophisticated simulations potentially required**
- **Rmfit can also do these joint fits**