



Fermi
Gamma-ray Space Telescope



GRB Data Analysis

Judy Racusin
NASA/GSFC



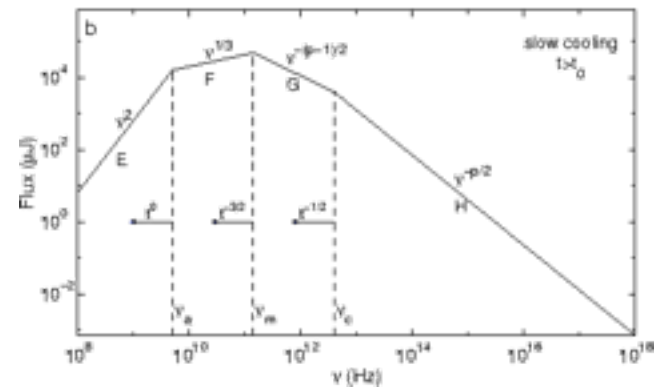
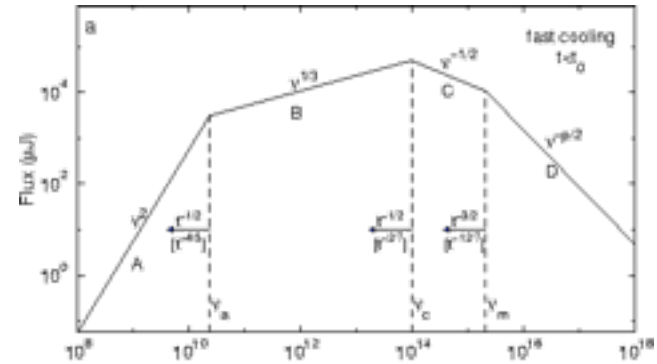
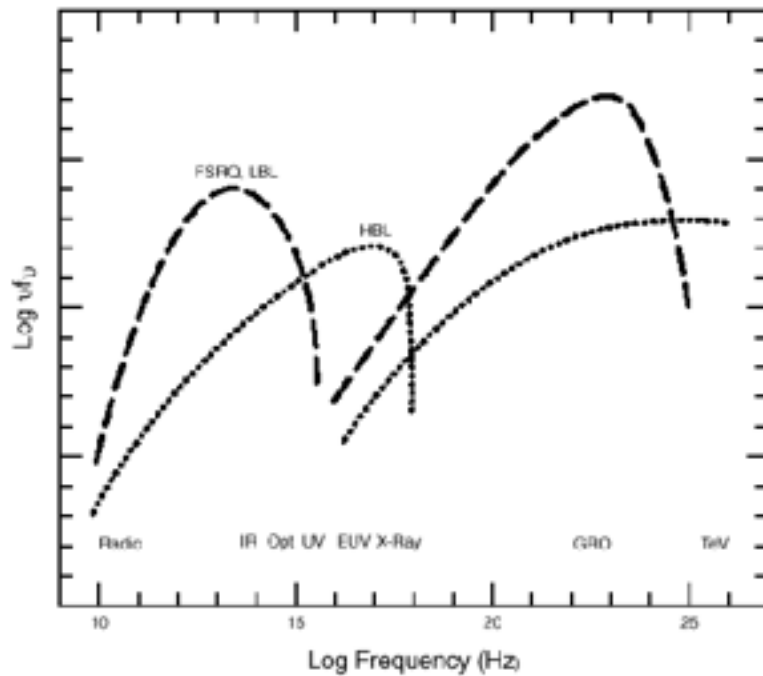
- **Astrophysical context**
 - **Source association**
 - **Emission mechanisms**
- ***Fermi* data probe a region of the spectrum that**
 - **Can be the high energy anchor for your model**
 - **Or bridge lower energy regimes and TeV**
- **How you fit/extrapolate/interpolate over many decades can strongly 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
 - See that 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, custom software ...)
 - Units (energy, frequency, wavelength, ...)



- **Radio/mm/microwave**
 - temperature -> flux density
 - In frequency
- **IR/Optical/UV**
 - magnitudes in different filters
 - $F_{\nu} = 10^{k-0.4m}$ mJy where k depends on filter used
 - In wavelength
- **X-ray**
 - counting photons -> flux
 - Conversion depends on shape of spectrum
- **Gamma-ray**
 - counting photons -> flux
 - Likelihood often used to fit spectrum, background, etc.



Sari, Piran, Narayan (1998)

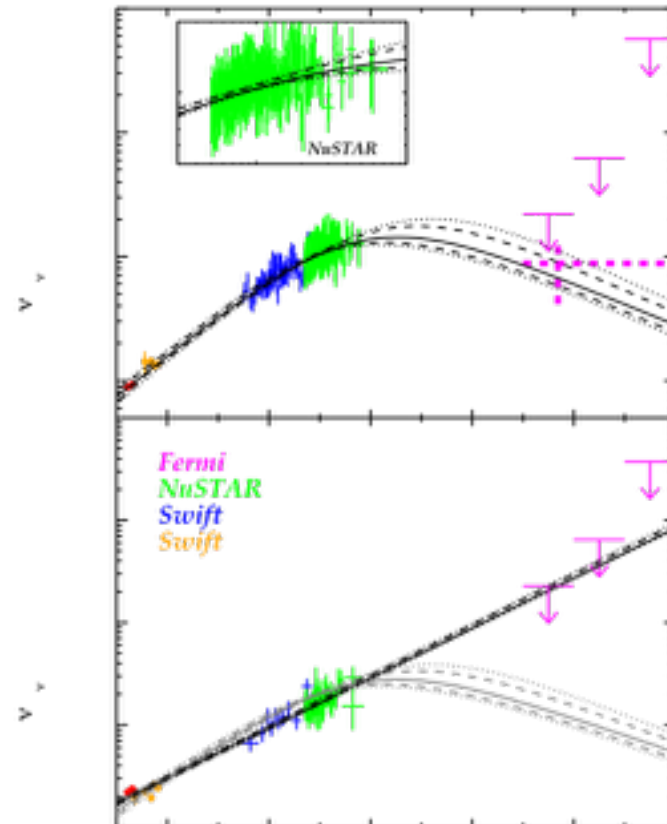
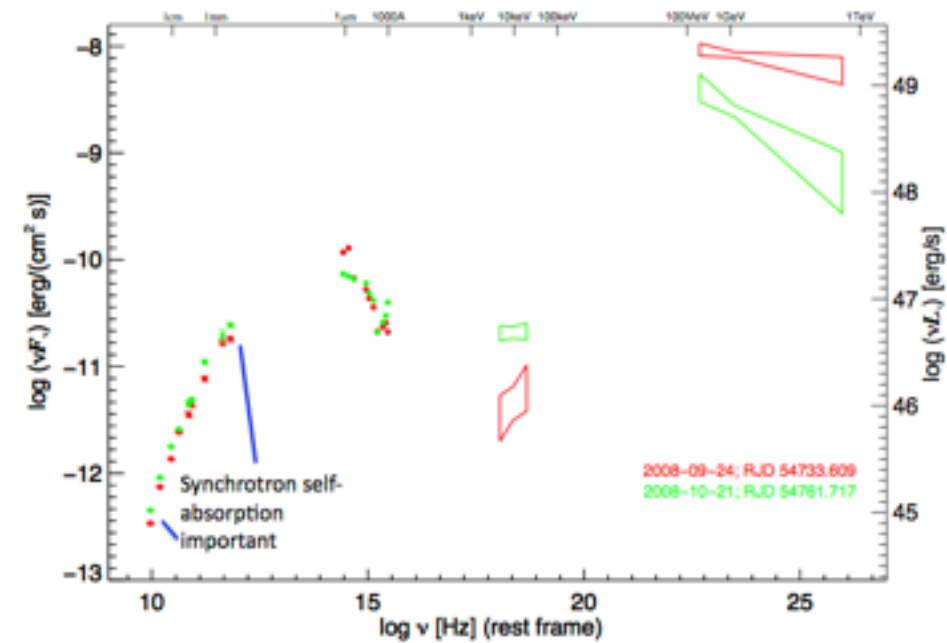
Spectral Energy Distributions



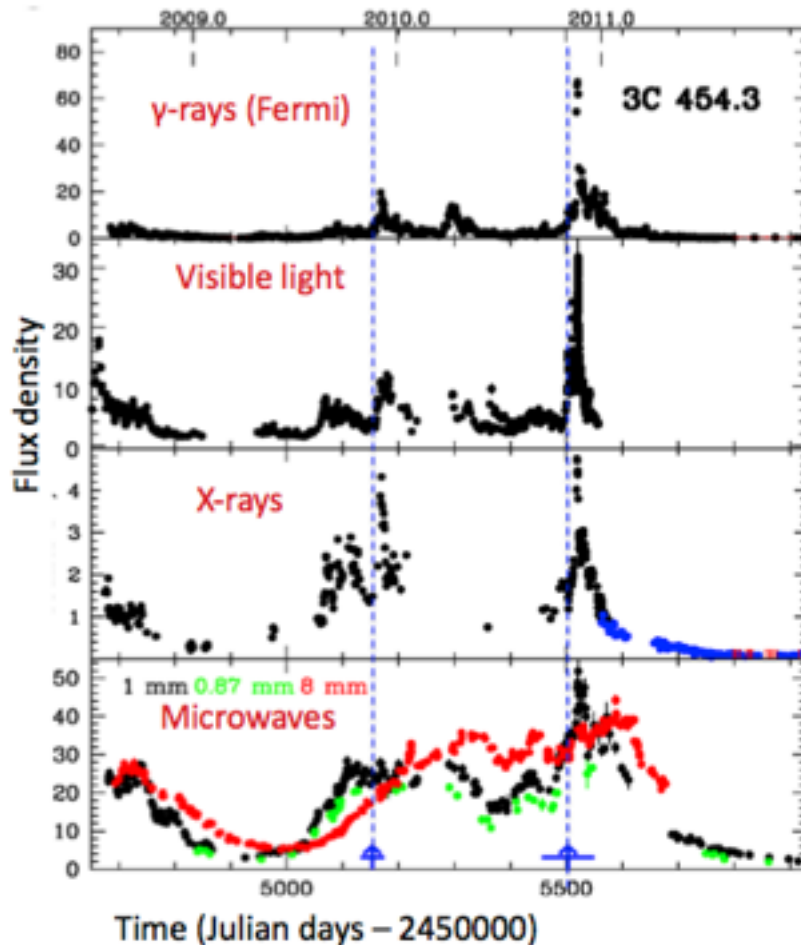
- We want to plot of $\log_{10} \nu F_\nu$ vs $\log_{10} \nu$
- How is this measured?

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

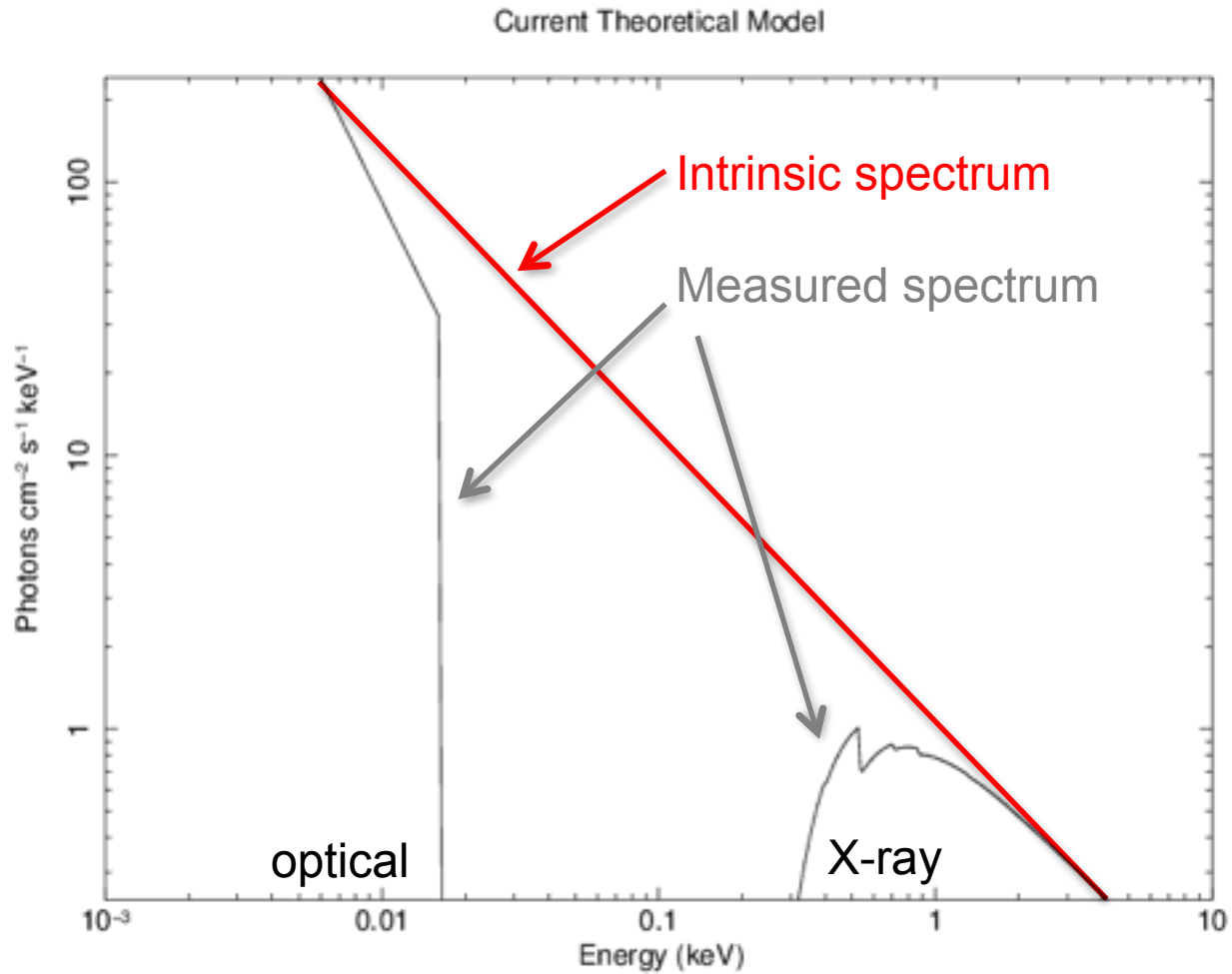


Kouveliotou et al. (2013)



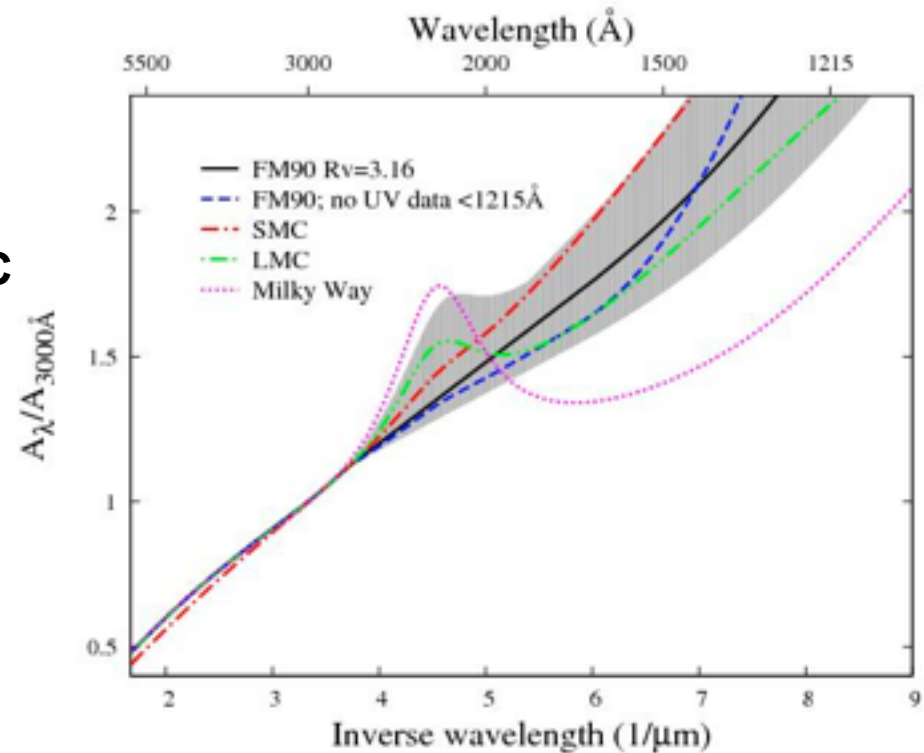
- Flux variations in different wavebands may or may not be correlated, or have delays
- Evidence of variation of different components
- Already messy, therefore simultaneous data at least constrains the same things at the same time (or different things at the same time)
- Talk by Betta next week

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

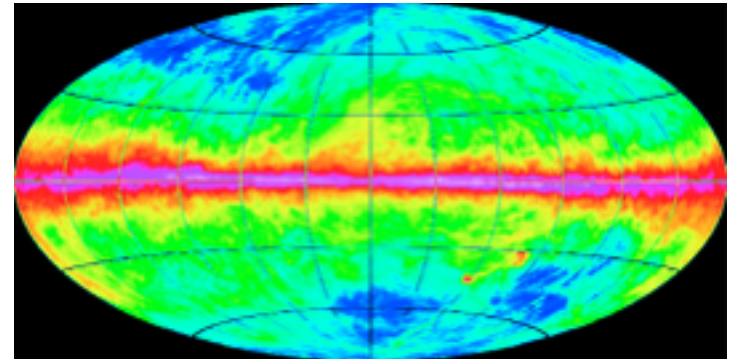


Schady et al. 2012
Pei 1992

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



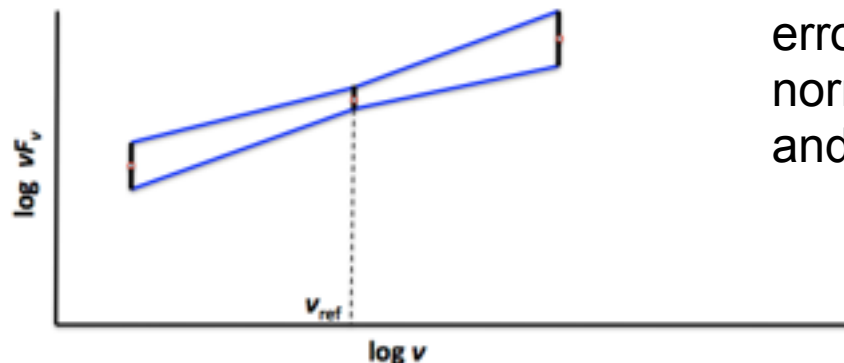
- **Interstellar neutral hydrogen gas absorbs soft X-rays**
 - **Photo-electric absorption using some set of photo-ionization cross-sections**
- **2 sources of absorption for extragalactic sources (N_{H} – hydrogen column density)**
 - **Galactic – well mapped by Kalberla et al. 2005**
 - **ftool NH**
 - <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

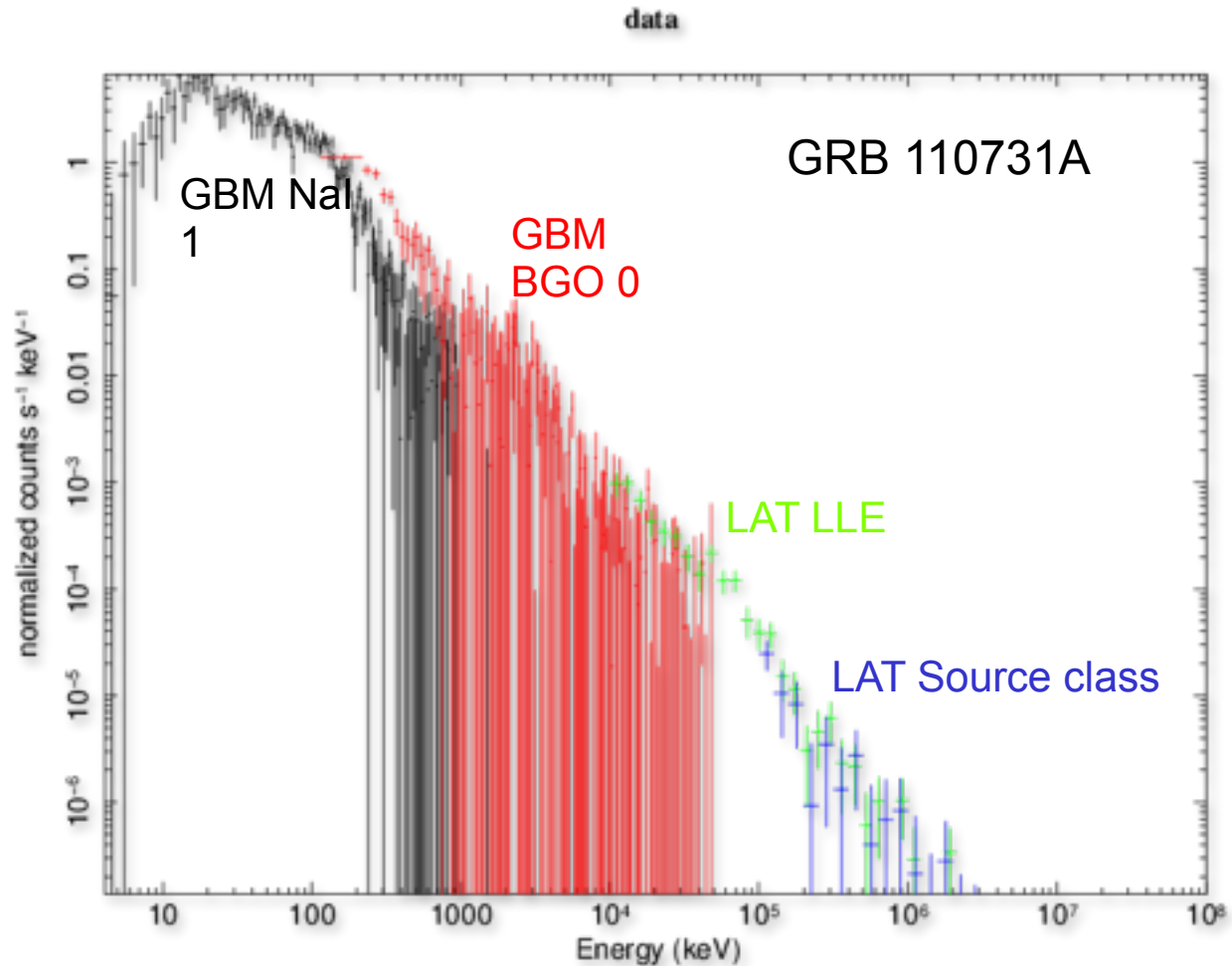
- However, if shape of γ -ray spectrum affected by data in nearby parts of the spectrum (breaks, curvature, cutoffs, etc.), you should do joint fits given a spectral model, and solve for free parameters

vFv Spectra are Model Dependent



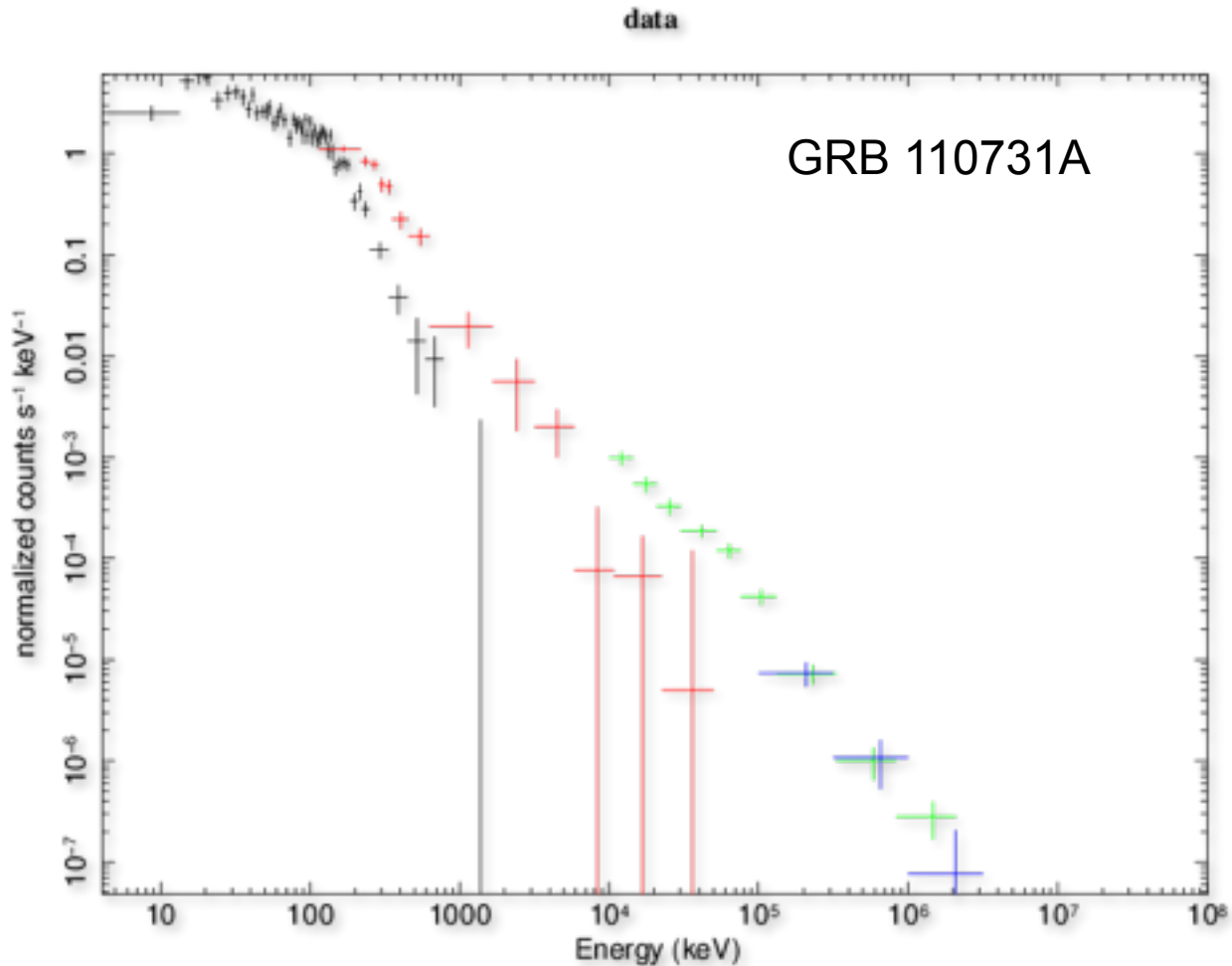
- In order to take data from raw (counts, magnitudes etc.), you must assume
 - Instrumental response function - which can depend on event class (LAT), readout mode (X-ray), filter (optical/IR/UV)
 - Background
 - Instrumental can depend on temperature of detector, hot pixels/ strips
 - Particle background – 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
- 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



jacusin 29-May-2014 11:50

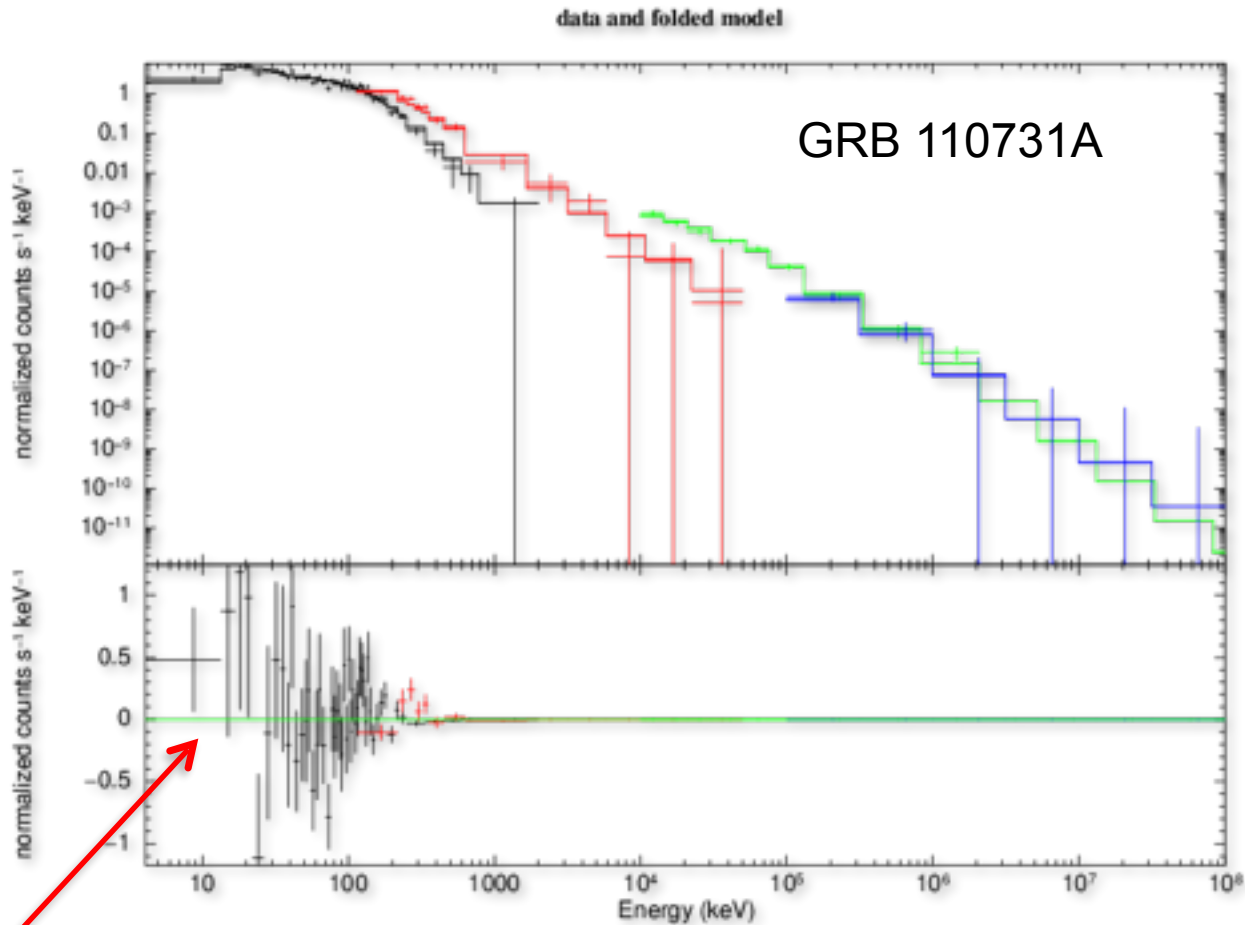
Unbinned (poorly binned) counts spectrum



jracusin 29-May-2014 11:51

Binned counts spectrum
(only binned for plotting purposes)

vFv Spectra are Model Dependent



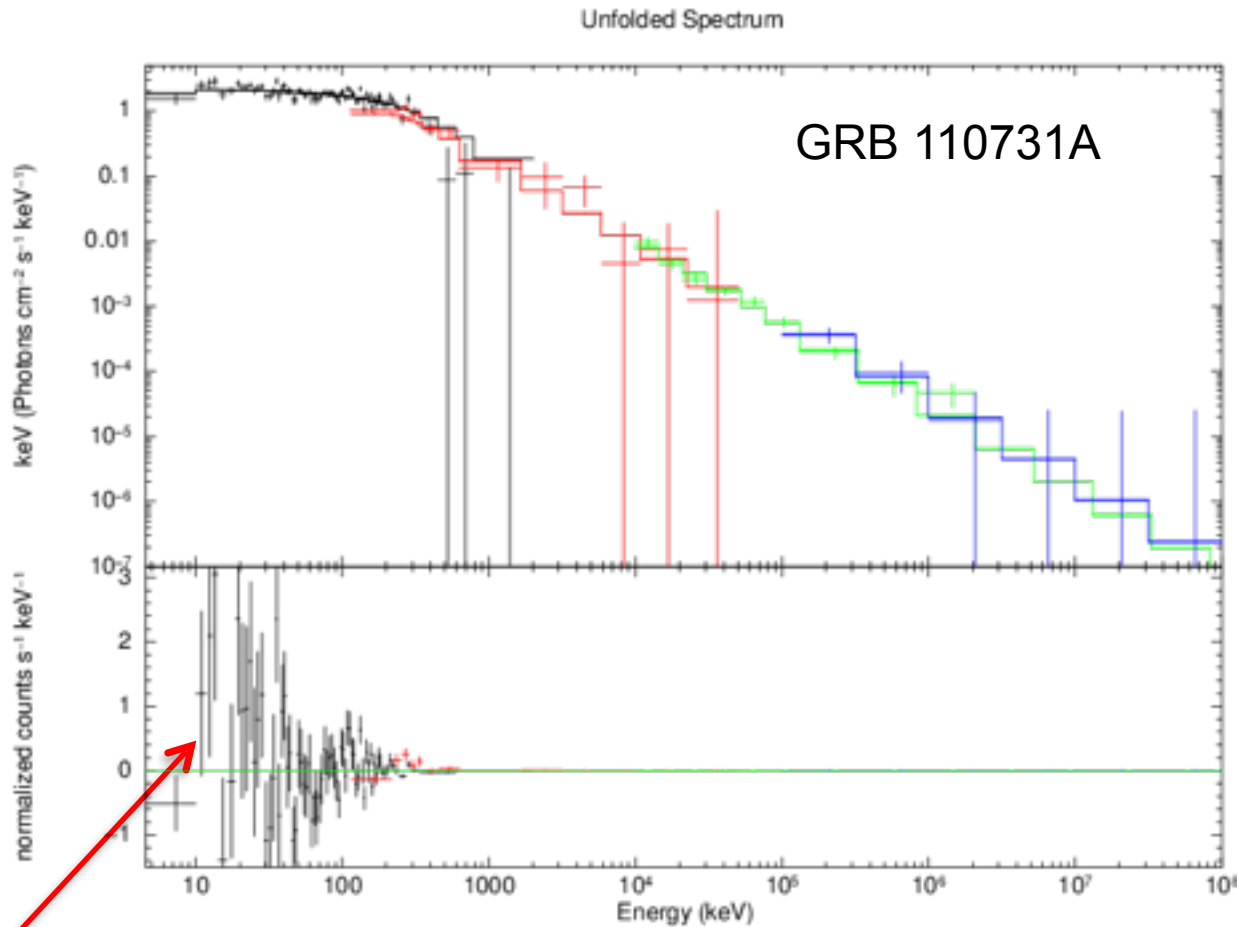
jacush 29-May-2014 11:31

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

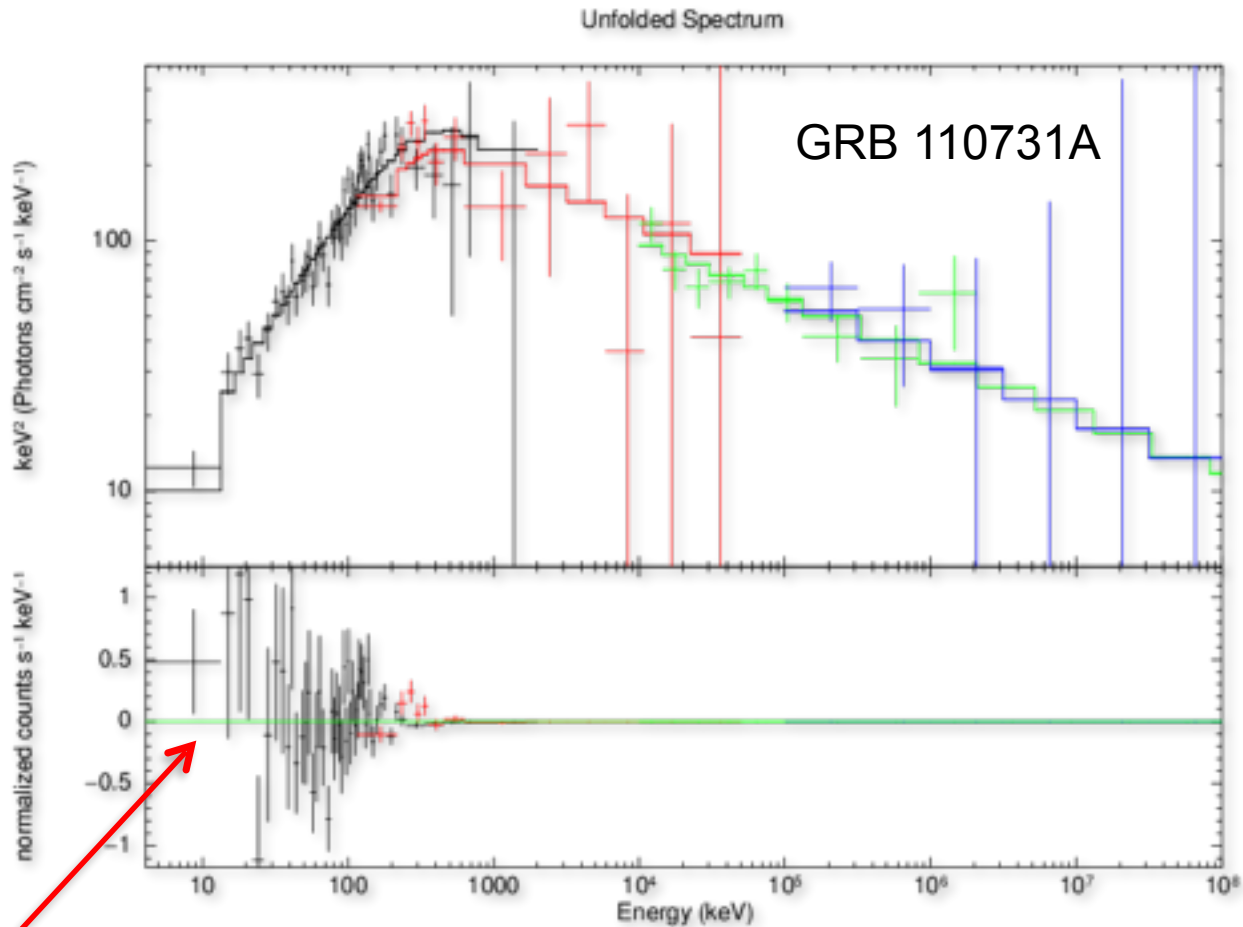


residuals

jacusin 30-May-2014 16:02

Binned unfolded F_ν spectrum
Fit to Band function (grbm in XSPEC)

vFv Spectra are Model Dependent



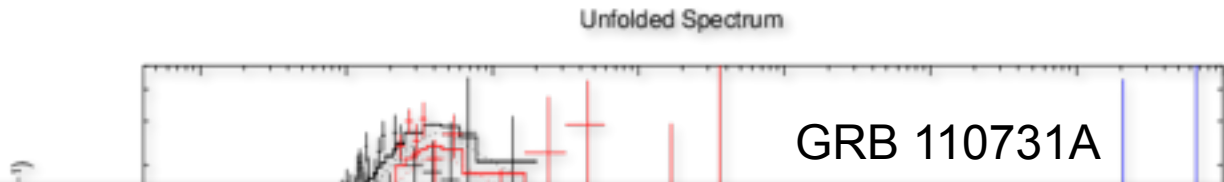
residuals

jacusin 29-May-2014 11:36

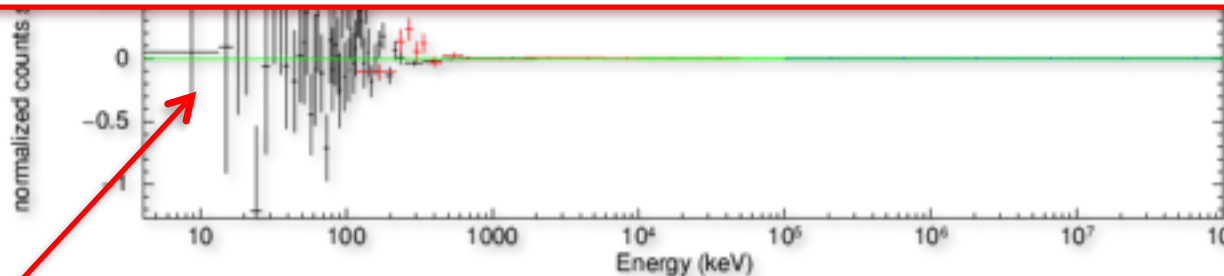
$vF_v = E^2 N(E)$ spectrum

Fit to Band function (grbm in XSPEC)

vFv Spectra are Model Dependent



- 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!

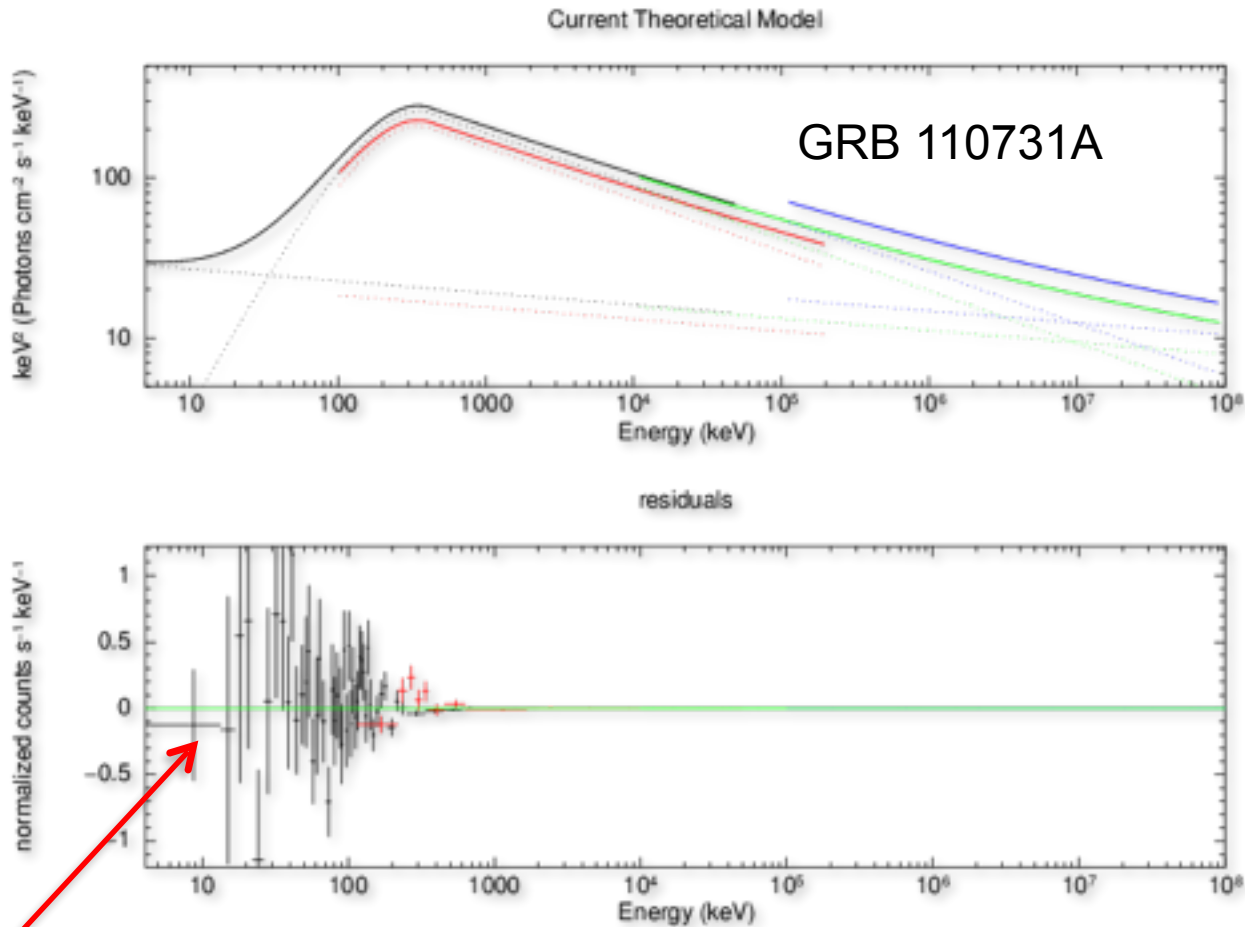


residuals

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

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

vFv Spectra are Model Dependent



residuals

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

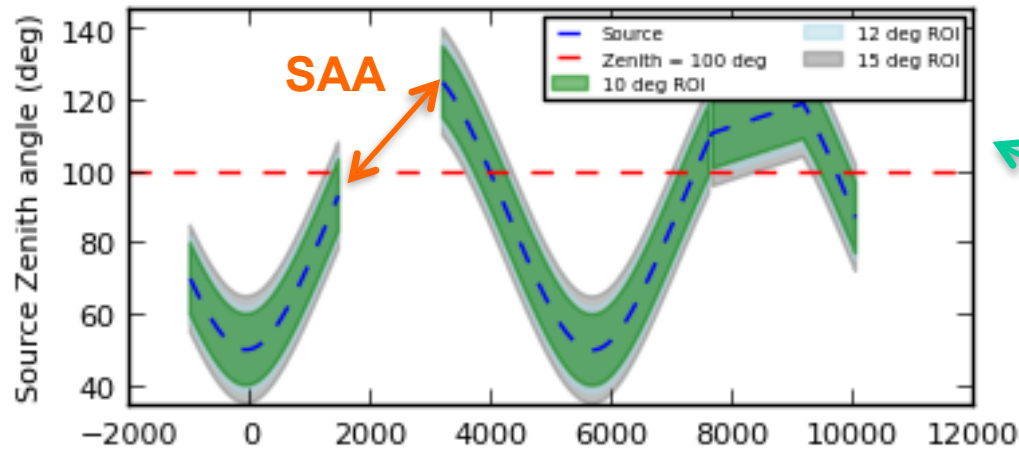


- **gtburst**
 - Python GUI interface for
 - downloading GBM/LLE/LAT data
 - selecting background and source intervals (GBM, LLE)
 - likelihood analysis of LAT data
 - Localizing LAT GRBs
 - Also useful for other short transients (e.g. Solar Flares)
 - Is part of the science tools, but updates via git 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)
- **XSPEC**
 - Standard tool in X-ray astronomy
 - Written by Keith Arnaud (NASA/GSFC)

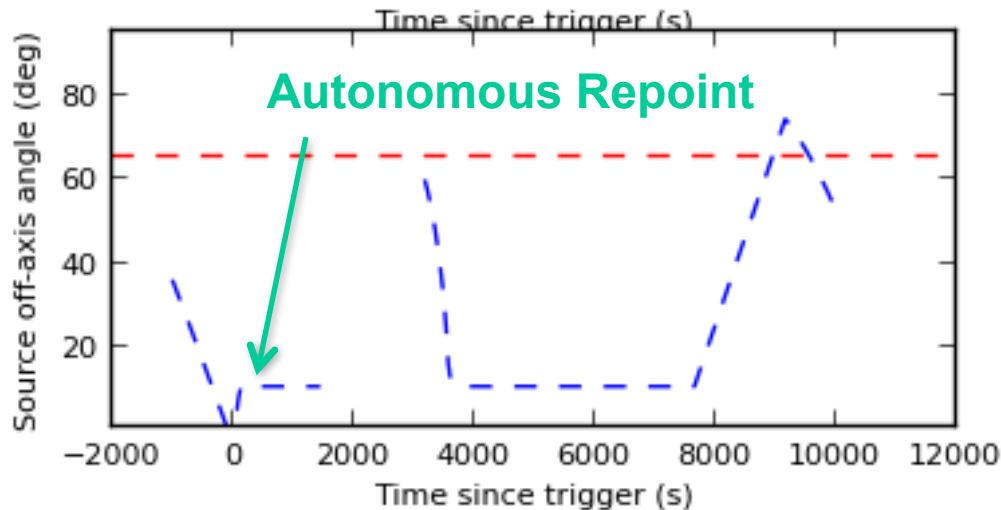
Common Time Interval



Navigation plots



Too close to earth limb



Outside FoV

LAT GTIs:

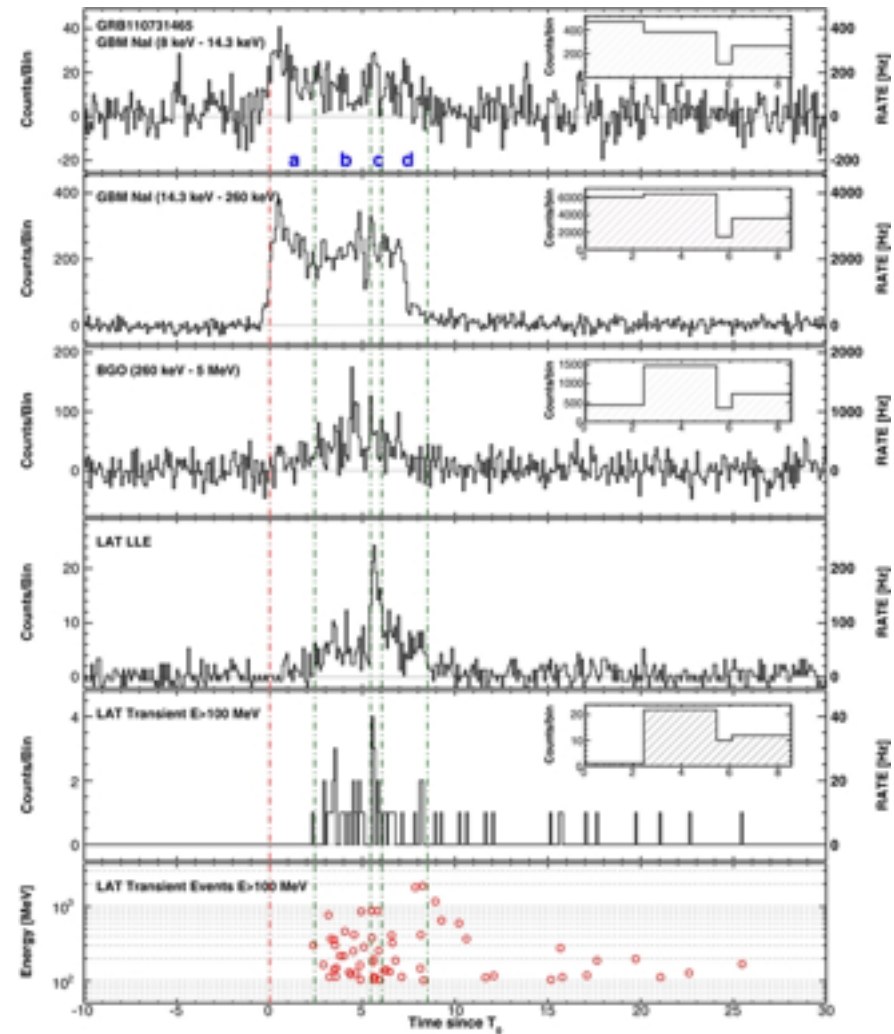
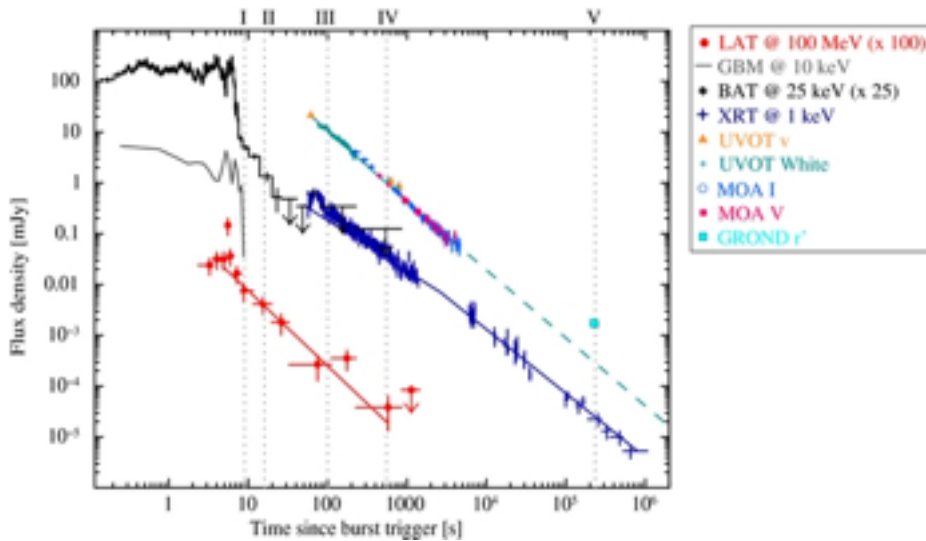
$T_0 + -973 - 1331$ s

$T_0 + 4290 - 7050$ s

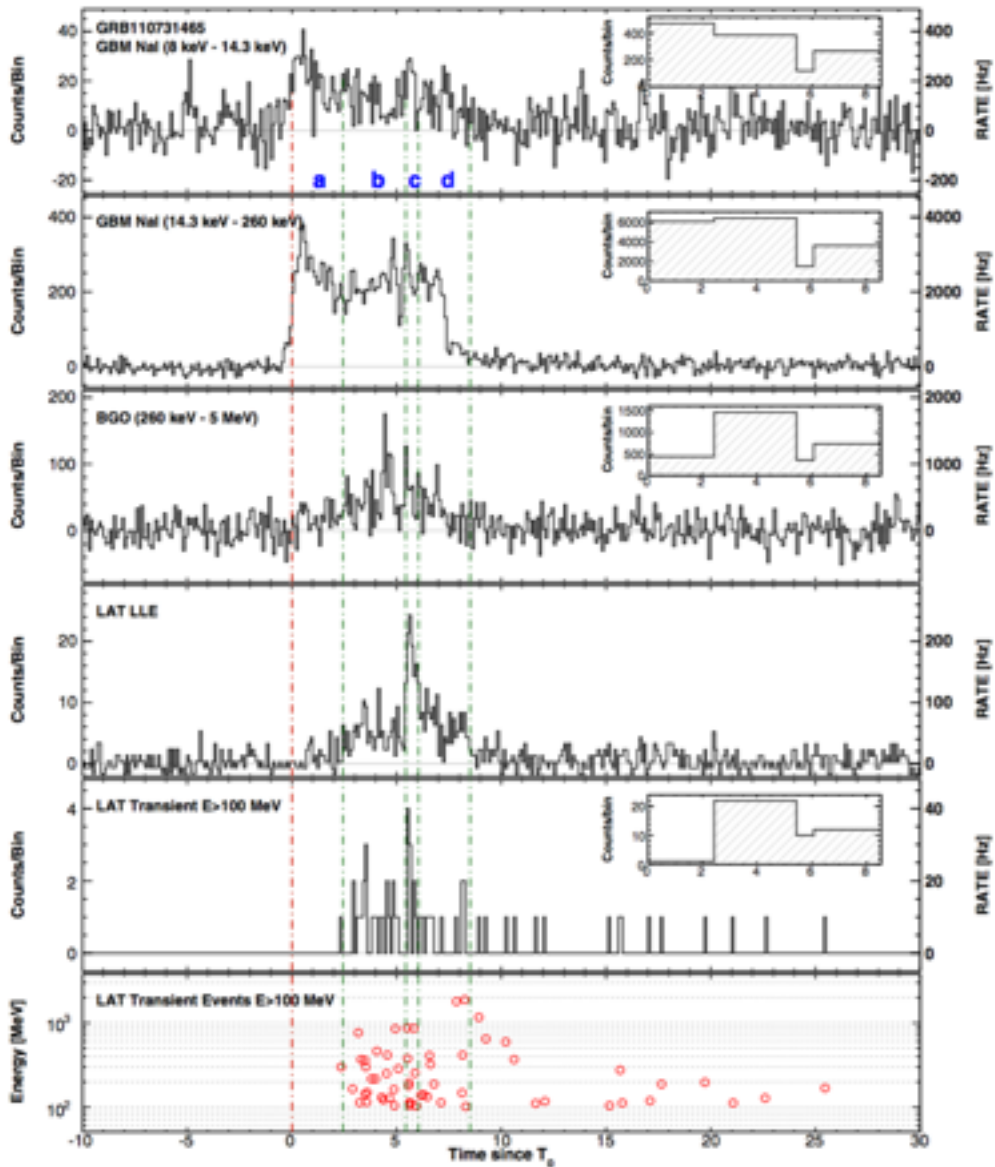
**You can recreate all of this from the FT2 file
Or from the gtmktime output GTI extension**



- 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**



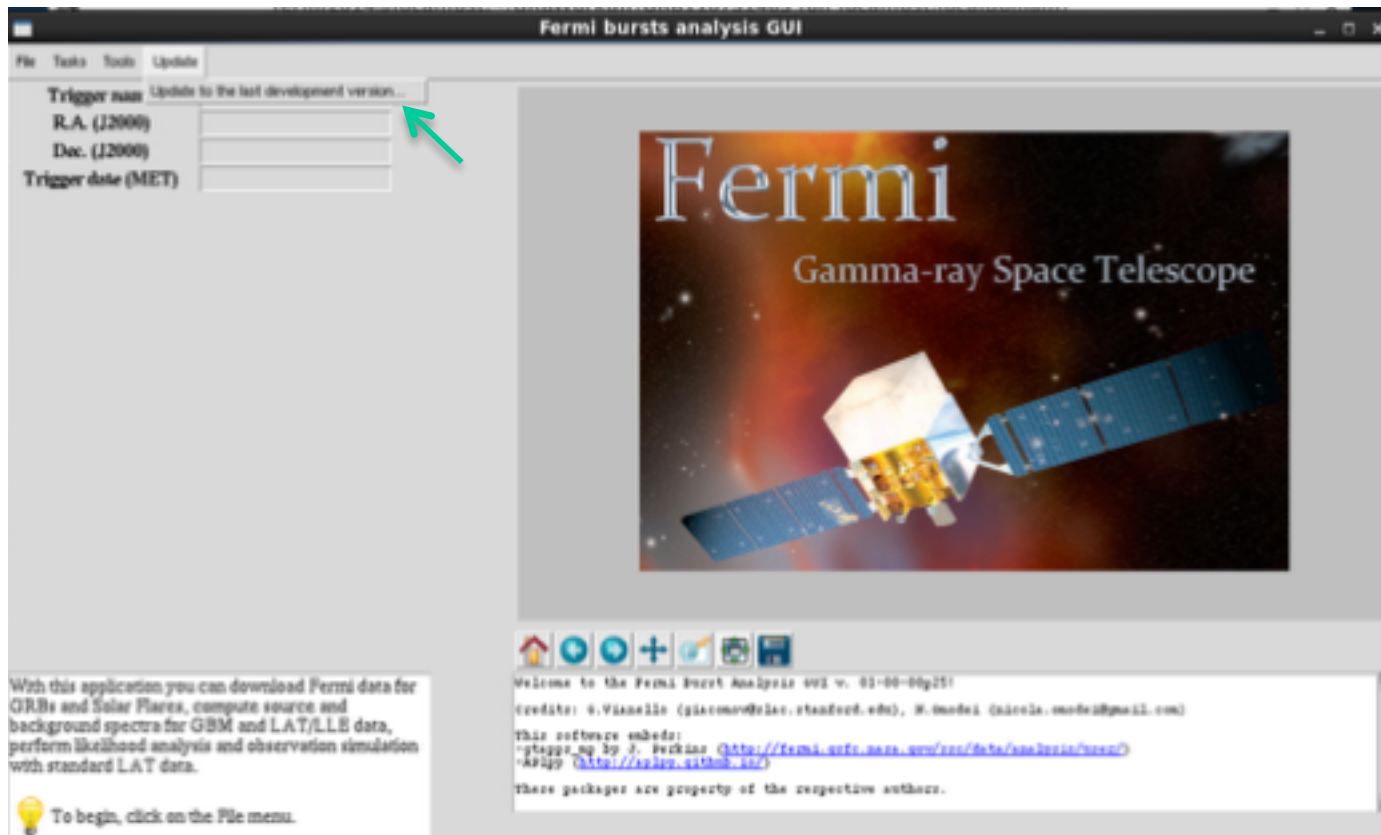
- **Extract Data for GBM & LAT**
- **Likelihood analysis of LAT data using gtburst**
 - **Get simple fit to LAT spectrum, and contribution from background**
- **Get both GBM & LAT data in XSPEC**
 - **Joint band function fit**
 - **Different statistics for different instruments**
 - **GBM - C-stat**
 - **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/223229391/grb110731a.tar.gz?version=1&modificationDate=1496332971347&api=v2>
 - **put grb110731a.tar.gz in ssvm directory**
 - **in your VM home directory (/home/vagrant), type:**
 - **mv /vagrant/grb110731a.tar.gz ~/**
 - **tar xvfz grb110731a.tar.gz**
 - **it will create FermiData directory**
 - **mkdir /home/vagrant/grb110731a**



- `cd /home/vagrant/grb110731a`
- `gtburst`
 - **Update** - always a good idea



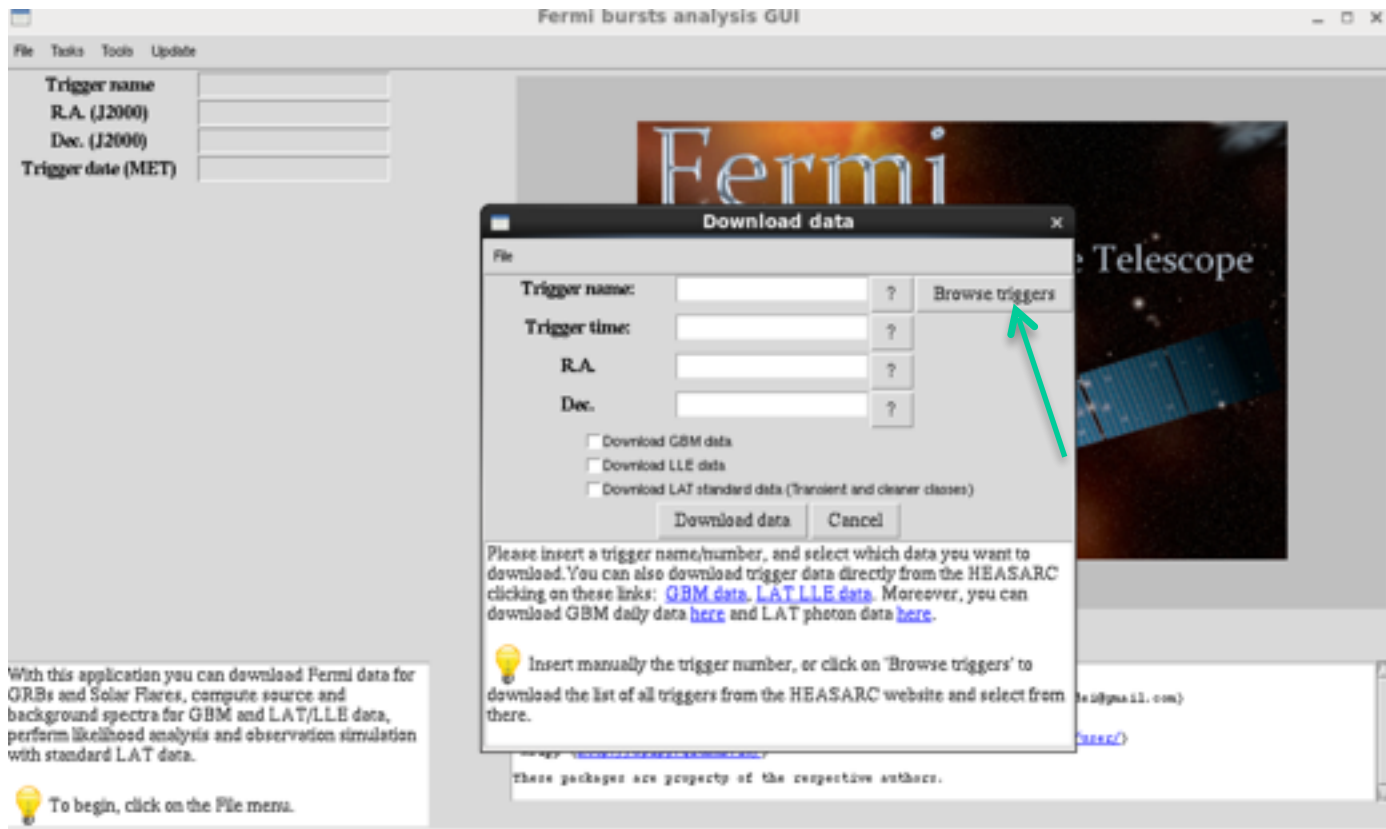


- **gtburst**
 - **Download LAT dataset**



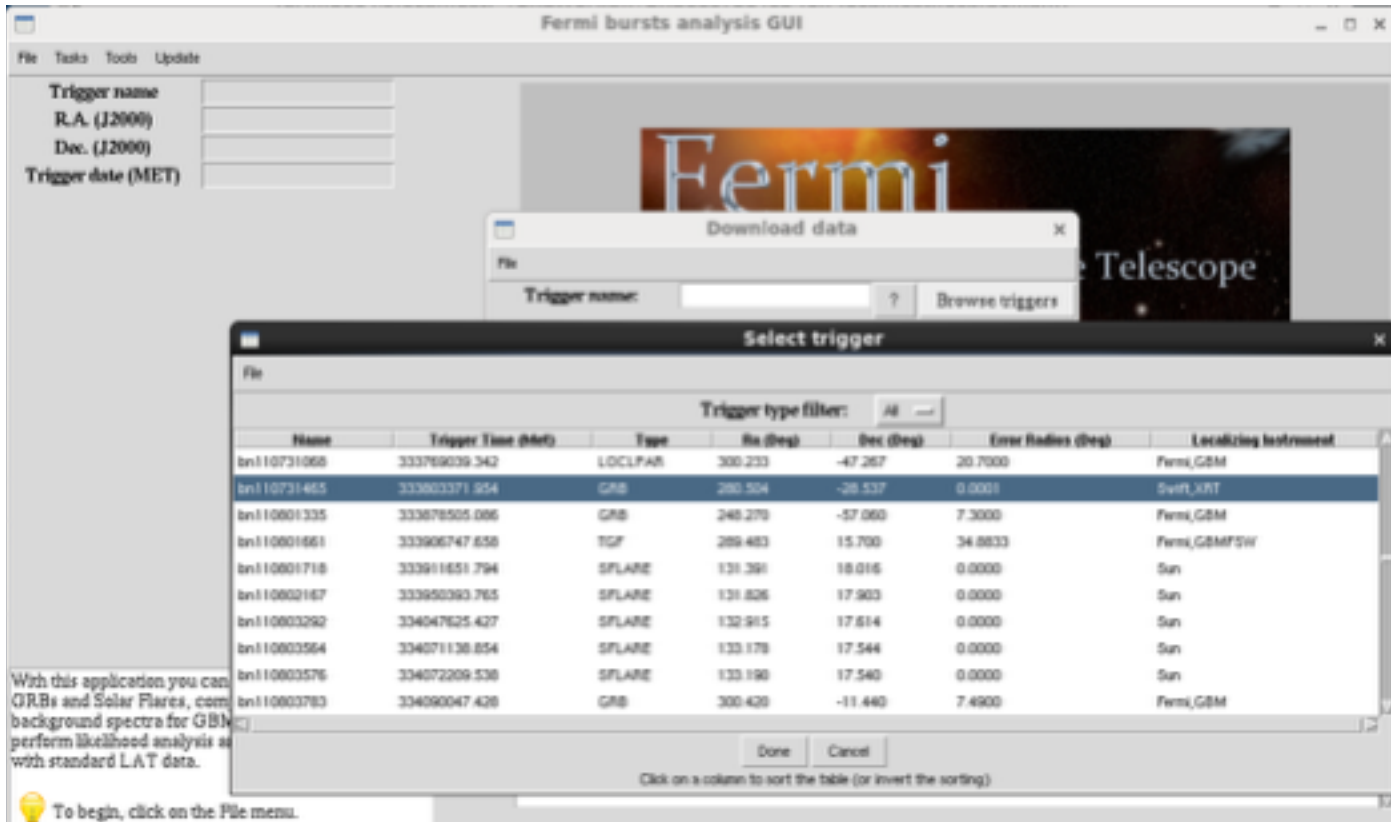


- **gtburst**
 - Browse GBM/Swift triggers, or enter manual info





- **gtburst**
 - Choose your trigger



The screenshot shows the 'Fermi bursts analysis GUI' with a 'Select trigger' dialog box open. The dialog box contains a table of triggers with the following columns: Name, Trigger Time (MET), Type, Ra (Deg), Dec (Deg), Error Radius (Deg), and Localizing Instrument. The table lists several triggers, including GRBs and Solar Flares.

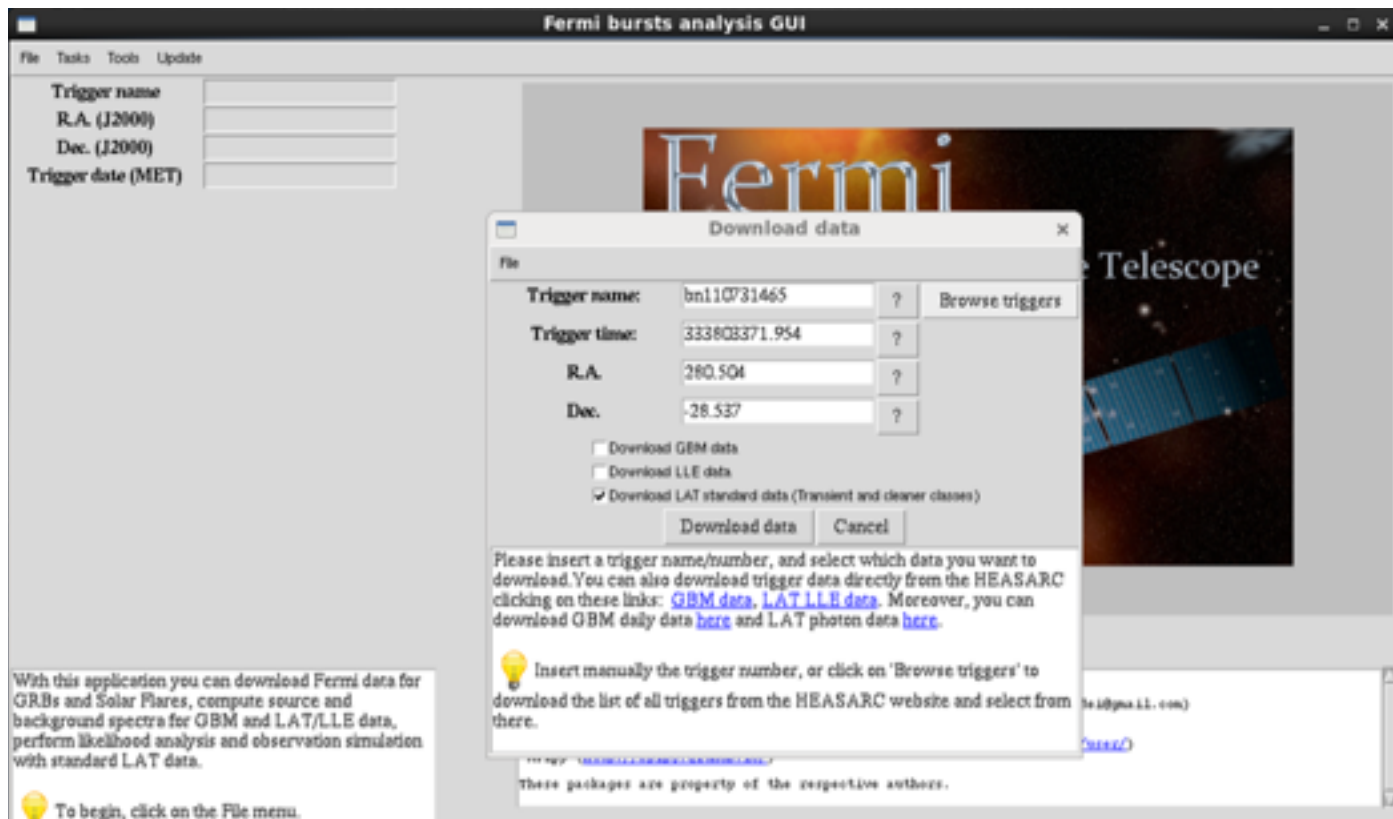
Name	Trigger Time (MET)	Type	Ra (Deg)	Dec (Deg)	Error Radius (Deg)	Localizing Instrument
bn110731060	333769039.342	LOCLPAR	300.233	-47.267	20.7000	Fermi,GBM
bn110731465	333802371.954	GRB	280.504	-28.537	0.0001	Swift_XRT
bn110801335	333878505.086	GRB	248.270	-57.060	7.3000	Fermi,GBM
bn110801661	333906747.658	TGF	289.483	15.700	34.8833	Fermi,GBMFSW
bn110801718	333911651.794	SFLARE	131.381	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

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

To begin, click on the File menu.



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



The screenshot shows the 'Fermi bursts analysis GUI' window. A 'Download data' dialog box is open, allowing the user to specify parameters for data retrieval. The dialog includes fields for Trigger name, Trigger time, R.A., and Dec., each with a question mark icon and a 'Browse triggers' button. Below these fields are three checkboxes: 'Download GBM data', 'Download LLE data', and 'Download LAT standard data (Transient and cleaner classes)'. The 'Download data' button is highlighted. A help message at the bottom of the dialog explains that users can insert a trigger name/number or click 'Browse triggers' to download a list of triggers from the HEASARC website. It also provides links for GBM data, LAT LLE data, GBM daily data, and LAT photon data. A note at the bottom of the dialog states that the packages are property of the respective authors.

File Tasks Tools Update

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

Fermi
Gamma-ray Space Telescope

Download data

File

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

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

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 the 'Fermi bursts analysis GUI' window. A progress dialog box is open, displaying 'Waiting for the server to complete the query (estimated time: 266 seconds)...' and a progress bar at 6%. The main window contains a form with the following fields:

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

Below the form is a large image of the Fermi Gamma-ray Space Telescope satellite in space. At the bottom of the window, there is a text area with the following content:

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.

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=L17060111543414PB177F98>.

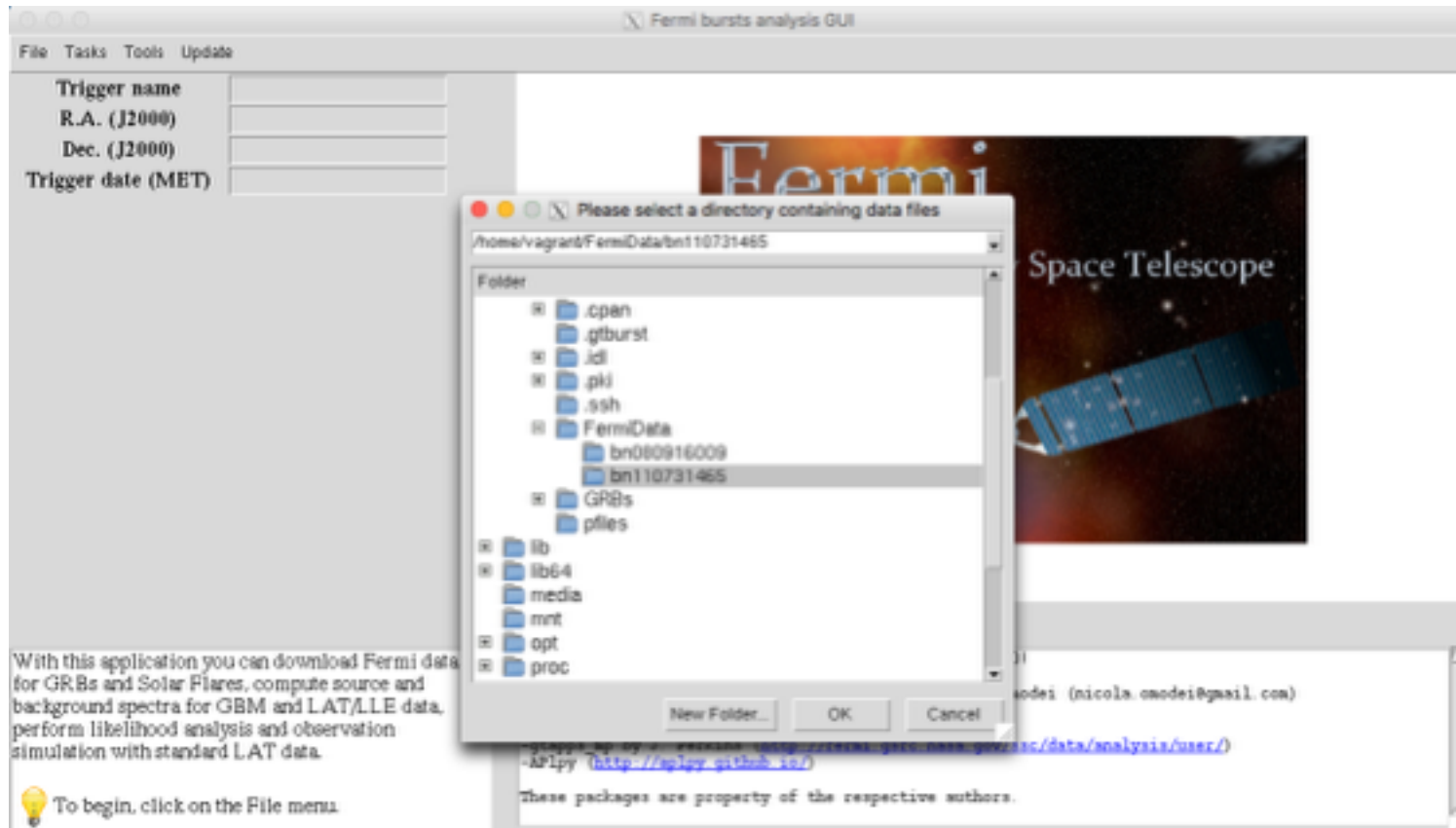


- **gtburst**
 - or grab data from directory





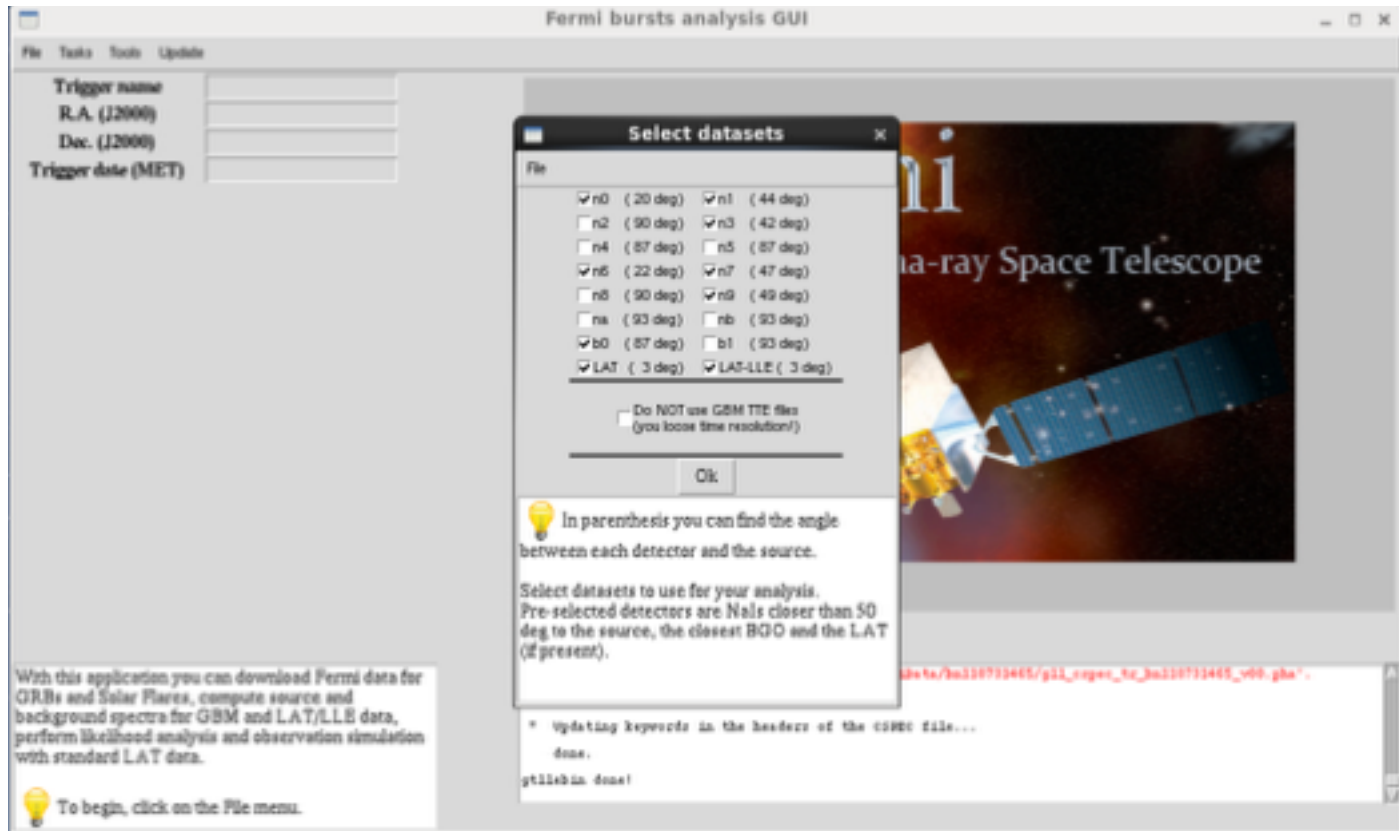
- **gtburst**
 - or grab data from directory



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 'gburst' folder is highlighted. 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.'



- **gtburst**
 - Choose the dataset

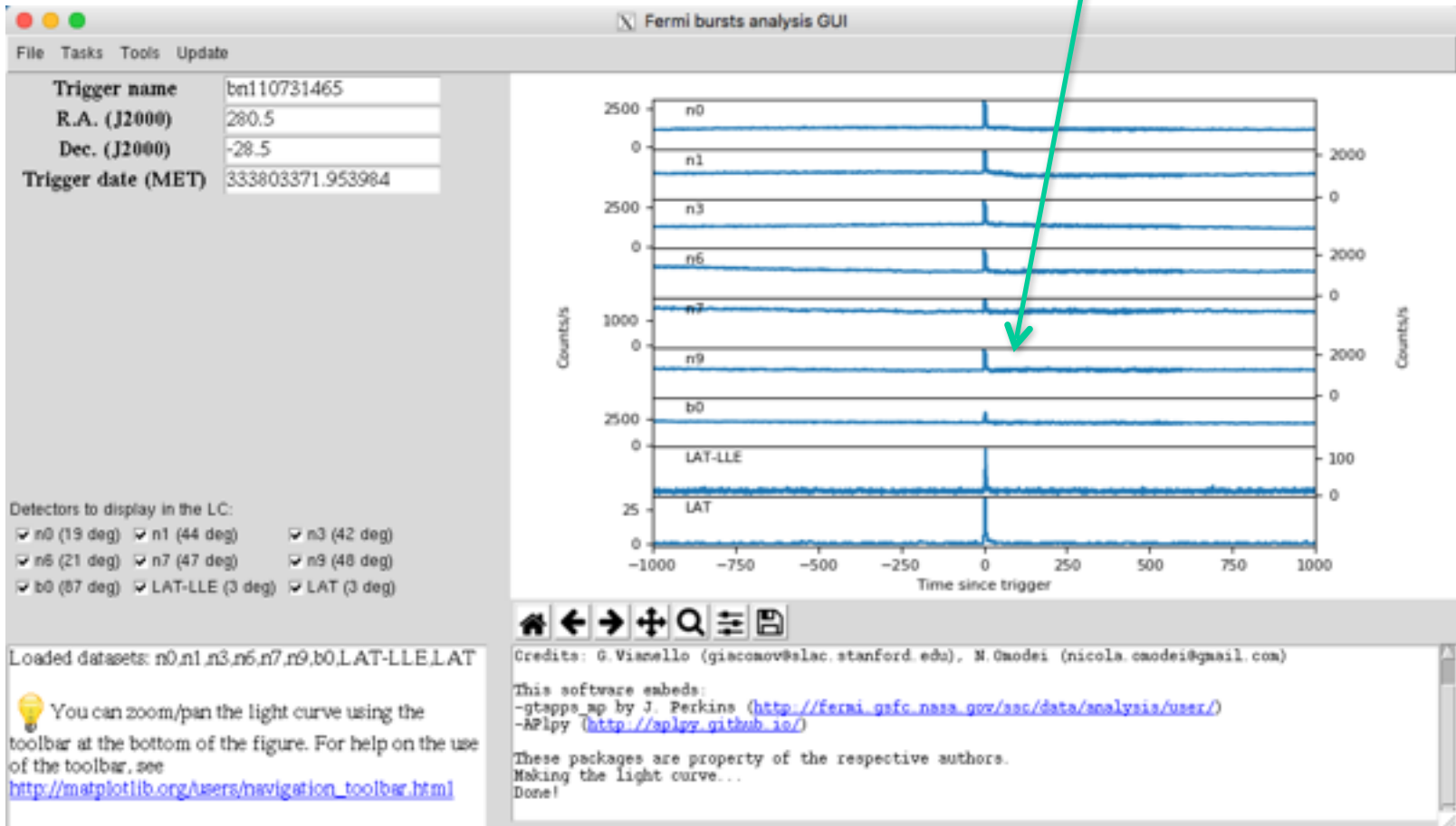


The screenshot shows the 'Fermi bursts analysis GUI' window. On the left, there are input fields for 'Trigger name', 'R.A. (J2000)', 'Dec. (J2000)', and 'Trigger date (MET)'. The main area displays a 'Select datasets' dialog box with a list of detectors and their angles in degrees. The detectors listed 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. Below the list, there is a lightbulb icon and text: '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 dialog, there is a 'Ok' button and a status bar showing 'Updating keywords in the headers of the CSPO file... done.' and 'gtburst done!'. In the background, a banner for the Fermi Gamma-ray Space Telescope is visible.



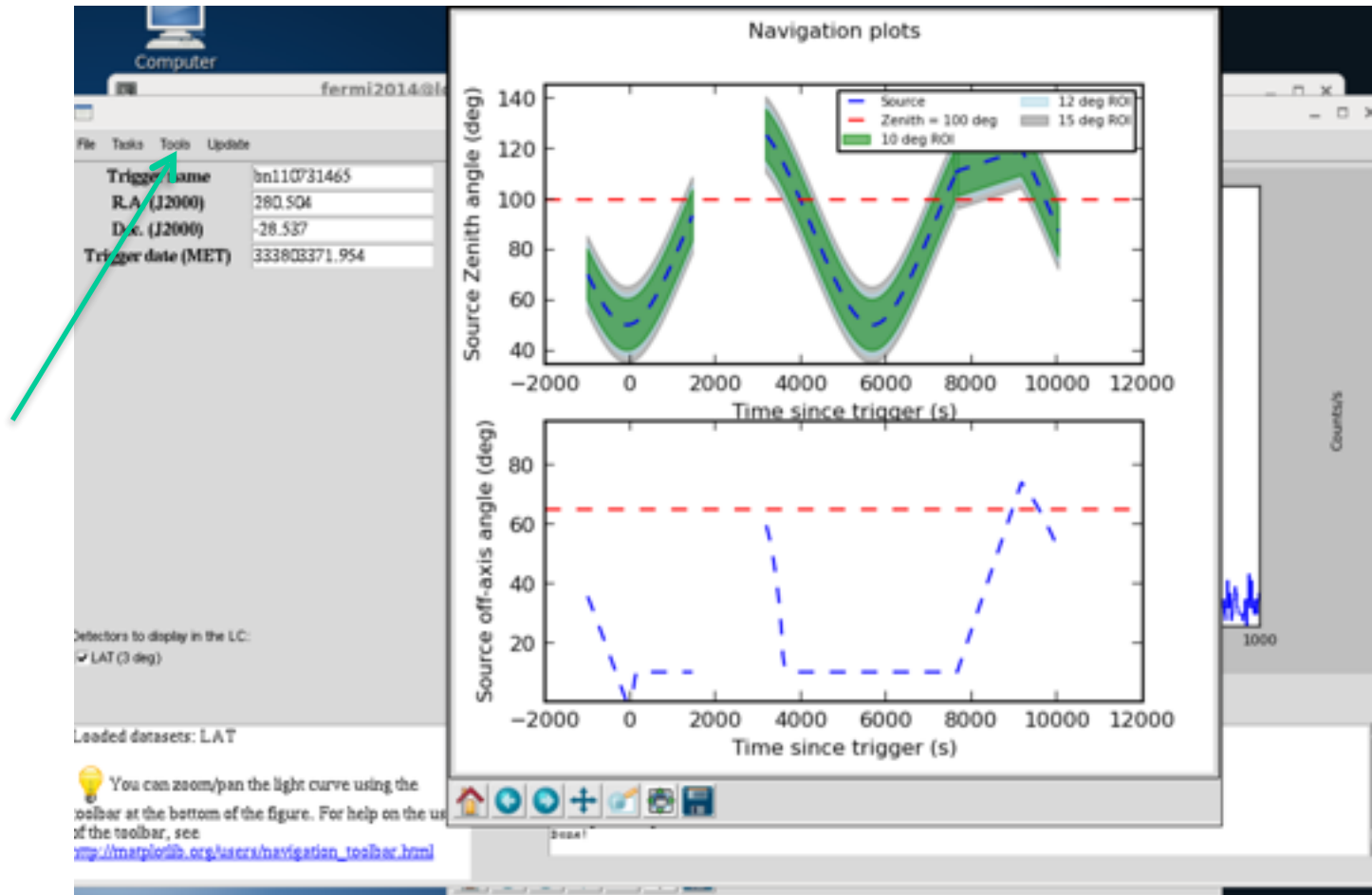
- **gtburst**

Clearly a burst!



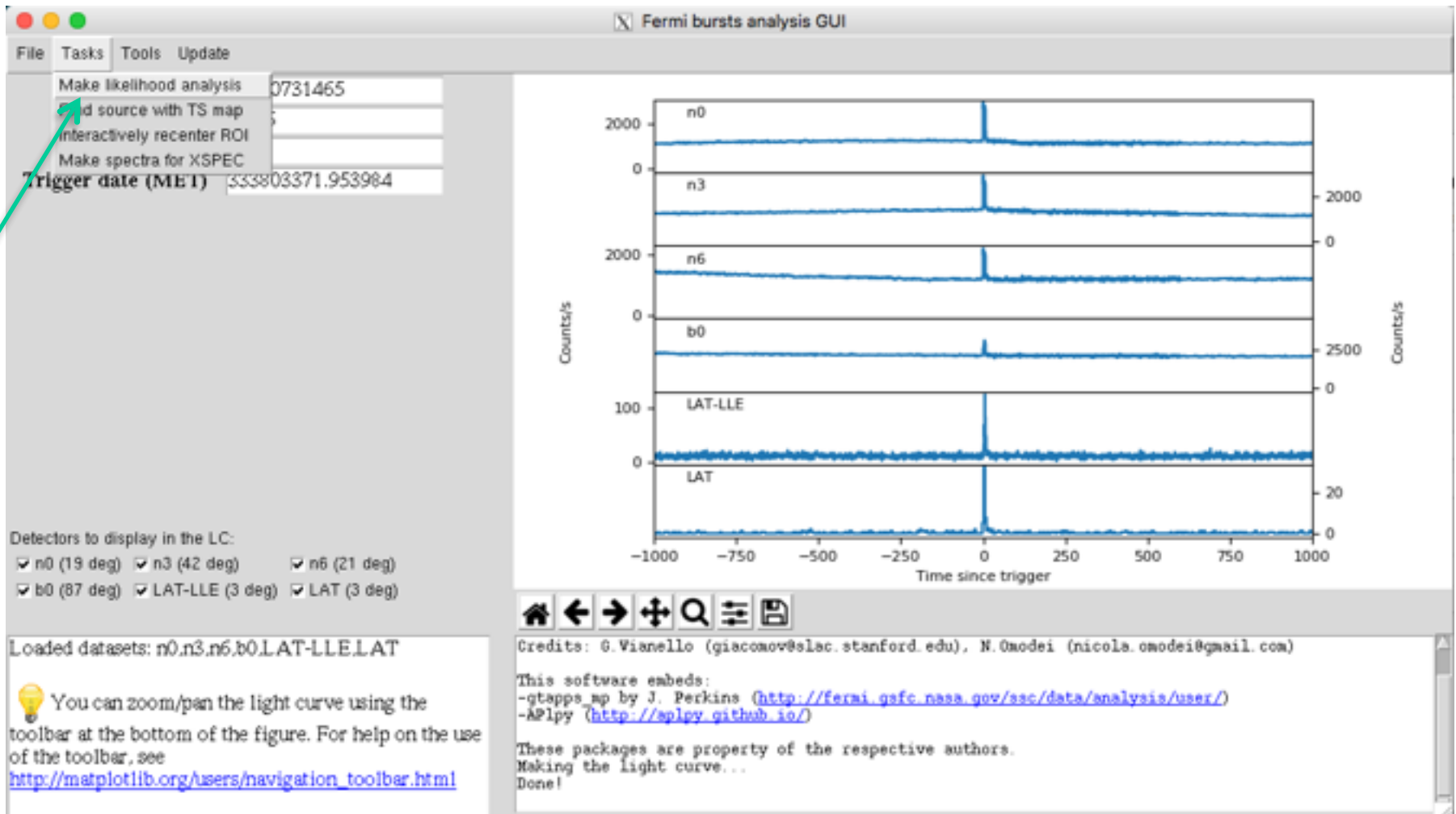


- **gtburst**





- **gtburst**



The screenshot shows the 'Fermi bursts analysis GUI' window. On the left, a 'Tasks' menu is open, listing options like 'Make likelihood analysis', 'Add source with TS map', and 'Make spectra for XSPEC'. A green arrow points to the 'Add source with TS map' option. Below the menu, the 'Trigger date (MJD)' is displayed as 553803371.953984.

The main panel displays a light curve plot with six stacked panels. The x-axis is 'Time since trigger' ranging from -1000 to 1000. The y-axis is 'Counts/s'. The panels are labeled: n0, n3, n6, b0, LAT-LLE, and LAT. Each panel shows a sharp peak at time 0. The y-axis scales are 2000 for n0, n3, and n6; 2500 for b0; and 100 for LAT-LLE and LAT.

Below the plot is a toolbar with icons for home, back, forward, zoom, pan, and save. At the bottom, there is a credits section and a note about software dependencies.

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

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/>)

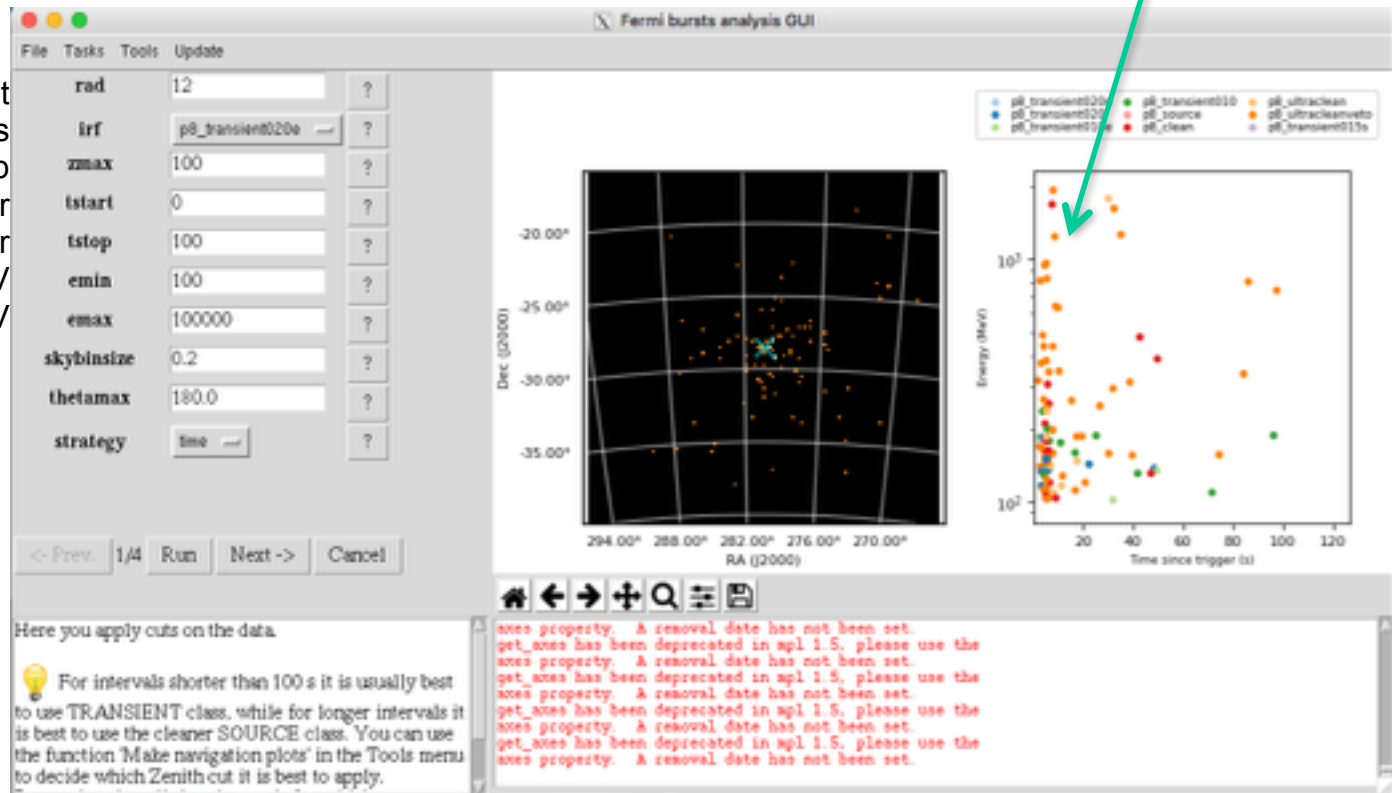
These packages are property of the respective authors.
 Making the light curve...
 Done!



- **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

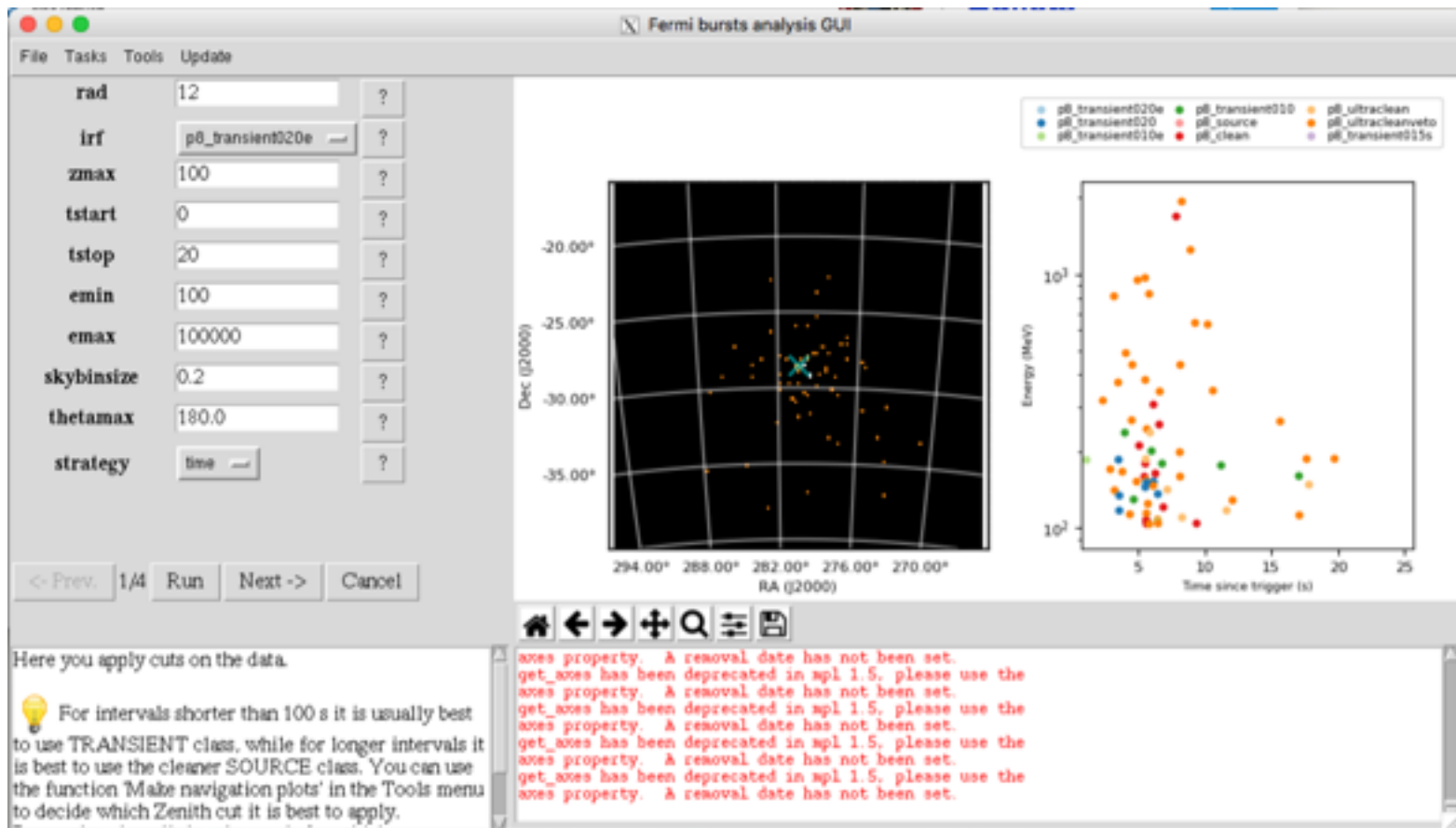
Click here



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 radius (rad), event class (irf), earth limb limit (zmax), start/stop times (tstart, tstop), energy range (emin, emax), skybin size (skybinsize), theta max (thetamax), and strategy. The sky map plot shows Dec (J2000) vs RA (J2000) with a grid and colored event markers. The energy-time plot shows Energy (MeV) vs Time since trigger (s) on a log scale. A legend at the top right identifies event classes like 'gb_transient020', 'gb_transient010', 'gb_ultraclean', etc. A red arrow points from the text 'Click here' to a specific data point in the energy-time plot. At the bottom, there is a text area with instructions on applying cuts and a warning about deprecated 'get_axes' property.

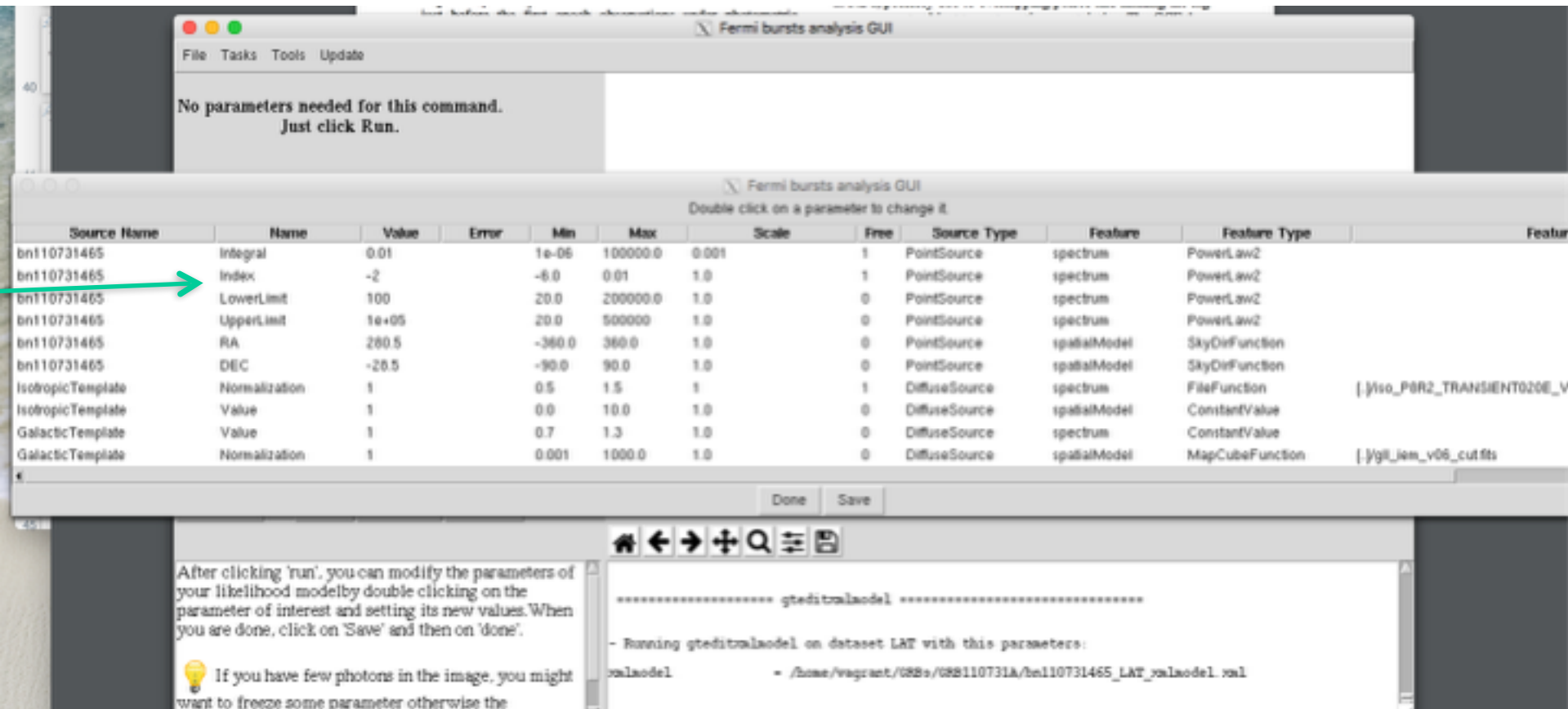


- **gtburst**
 - Limit data selection to SED interval
 - Relevant event class (Transient20e)





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



The screenshot shows the Fermi bursts analysis GUI. At the top, a message box says "No parameters needed for this command. Just click Run." Below this is a table of parameters for source bn110731465. A green arrow points to the 'Index' parameter. At the bottom, a command window shows the execution of 'gtditralmodel' on the dataset LAT.

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	500000.0	1.0	0	PointSource	spectrum	PowerLaw2	
bn110731465	RA	280.5		-360.0	360.0	1.0	0	PointSource	spatialModel	SkyDirFunction	
bn110731465	DEC	-26.5		-90.0	90.0	1.0	0	PointSource	spatialModel	SkyDirFunction	
IsotropicTemplate	Normalization	1		0.5	1.5	1	1	DiffuseSource	spectrum	FileFunction	/iso_P0R2_TRANSIENT0206_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_jem_v06_cut.fits

```

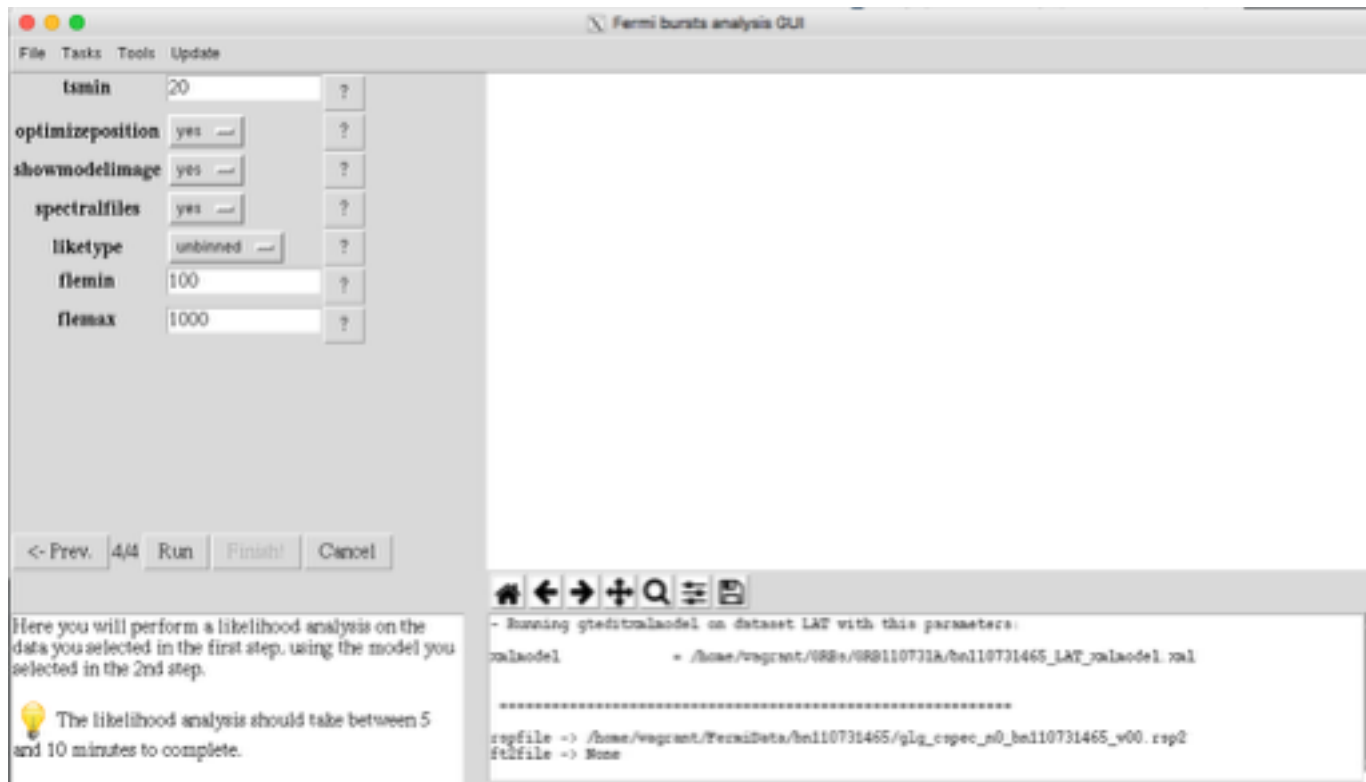
***** gtditralmodel *****
- Running gtditralmodel on dataset LAT with this parameters:
gtditralmodel - /home/vagrant/GRBs/GRB110731A/bn110731465_LAT_xalmodel.xml
  
```

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

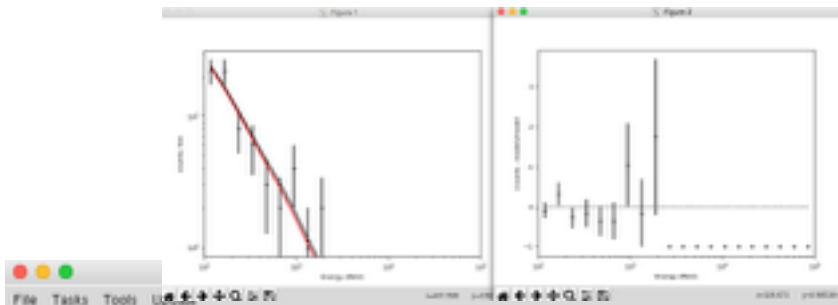


- **gtburst**
 - Optimizing position – runs gtfndsrc after gtlike
 - Show model image – makes TS map
 - Spectral files – makes XSPEC ready files
 - Run -> wait ...





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



Likelihood results

Source name	Par. Name	Value	Error	Units	TS
GalacticTemplate	Index	1.8 ± (fixed)		-	0
	Energy flux	5.19e-08	0	erg/cm2/s	
	Photon flux	0.00011	0	ph./cm2/s	
IsotropicTemplate	Normalization	1.5	0.177	-	1
	Energy flux	1.67e-07	1.93e-08	erg/cm2/s	
	Photon flux	0.00047	5.42e-05	ph./cm2/s	
J0510731465	Integral	0.000495	6.34e-05	ph./cm2/s	569
	Index	-2.43	0.164	-	
	LowerLimit	109	± (fixed)	MeV	
	UpperLimit	1e-05	± (fixed)	MeV	
	Energy flux	1.66e-07	2.19e-08	erg/cm2/s	
	Photon flux	0.000474	6.04e-05	ph./cm2/s	

*** plus 3 PML sources with TS<1 (not printed to save space)
 *** All fluxes and upper limits have been computed on 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) = 106.751050003

New localization from gtfindarc:

(R.A., Dec) = (283.344, -28.664)
 68 % containment radius = 0.188
 90 % containment radius = 0.255

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

File Tasks Tools

tsmin 20 ?

optimizeposition yes ?

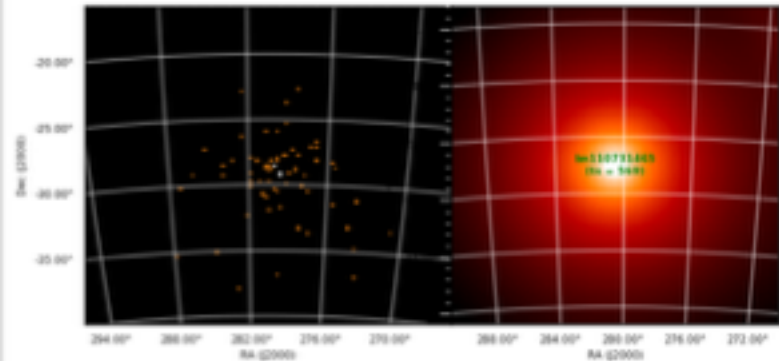
showmodelimage yes ?

spectralfiles yes ?

liketype unbinned ?

flimit 100 ?

flimax 1000 ?



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.

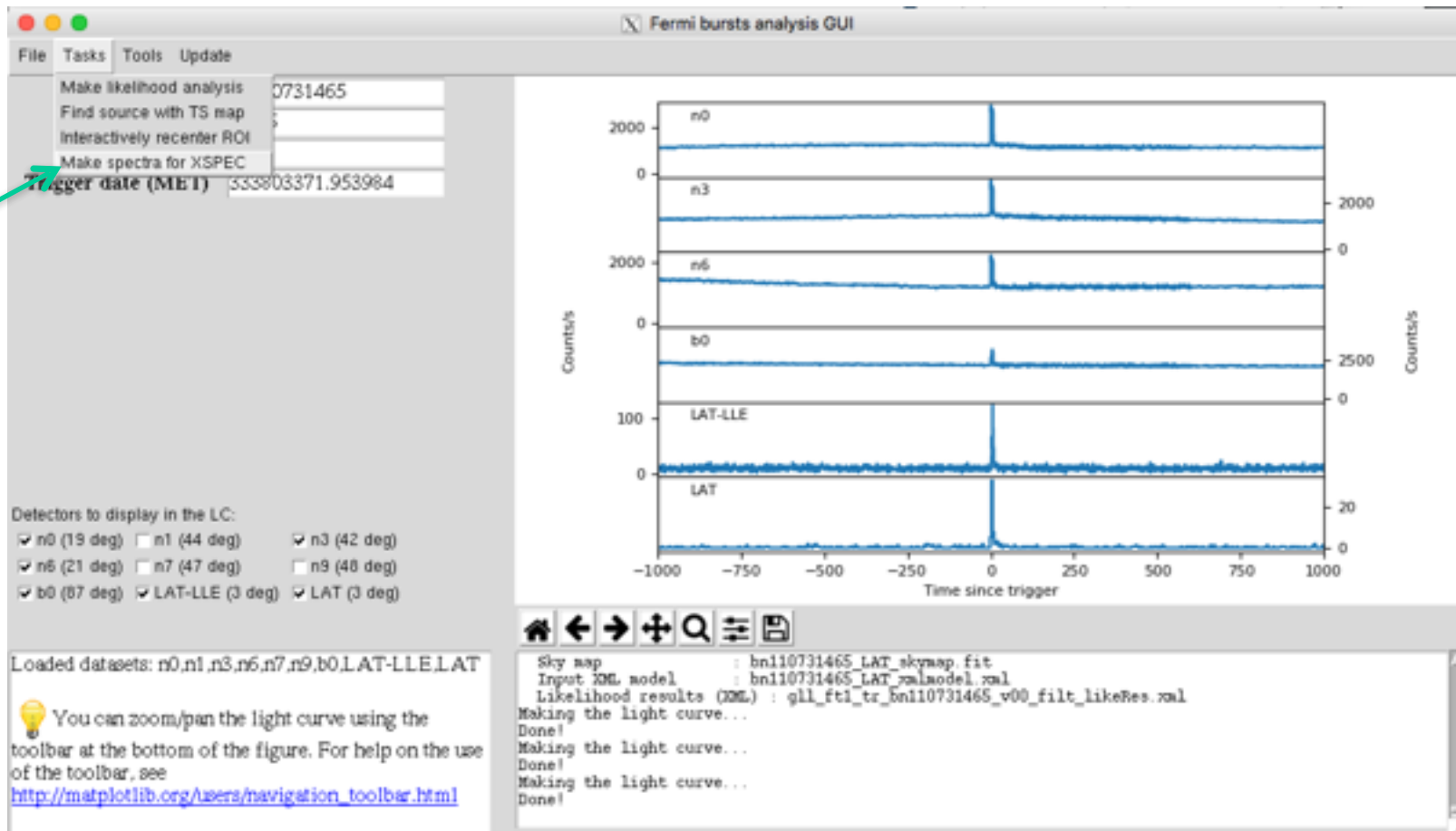
The likelihood analysis should take between 5 and 10 minutes to complete.

90 % containment radius = 0.255
 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

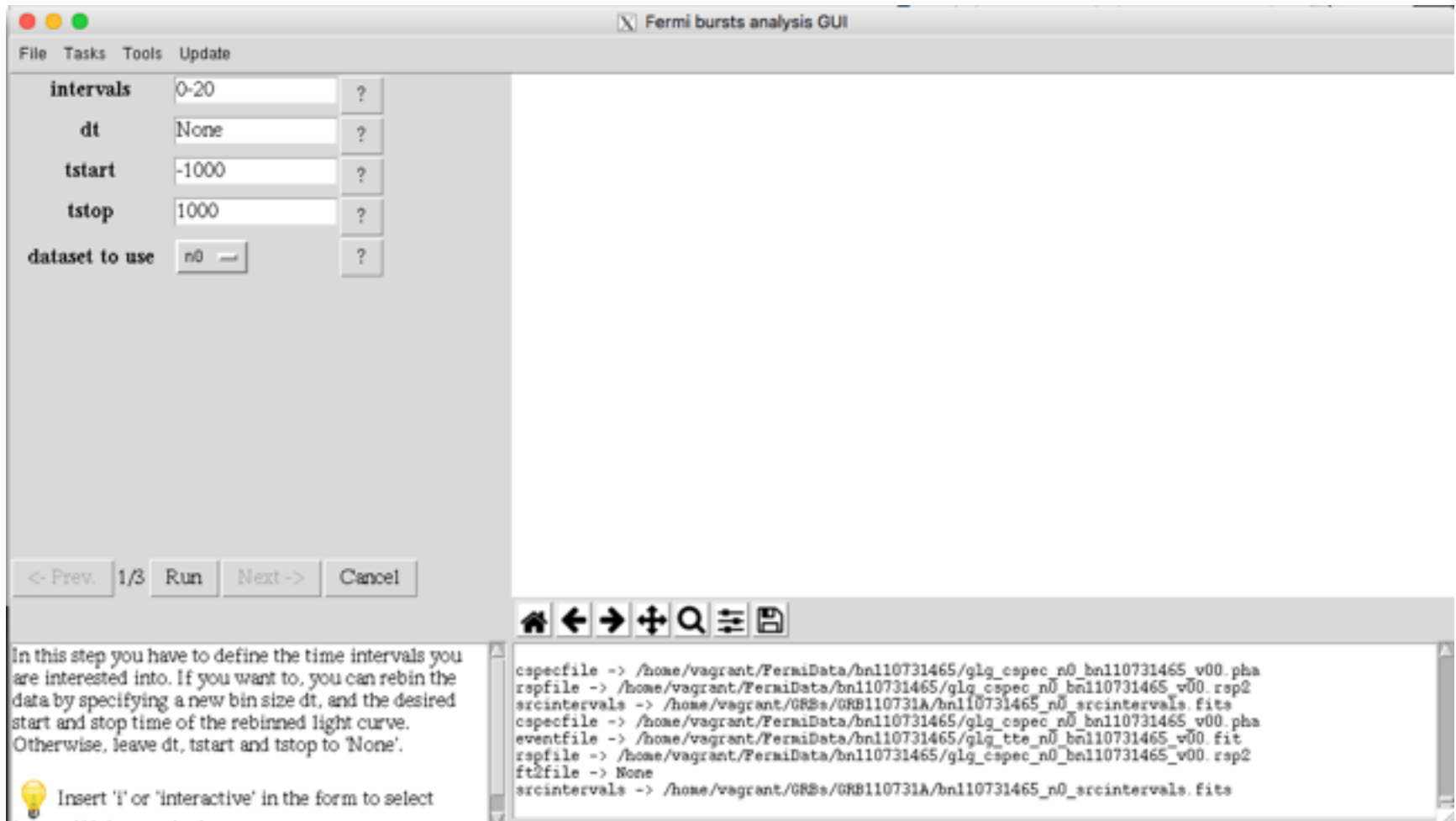


- **gtburst**
 - Turn off some of the GBM detectors, only need 2 or 3 Nals (with smallest angle) & 1 BGO





- **interactive or manual interval input**



The screenshot shows the 'Fermi bursts analysis GUI' window. The main panel contains several input fields for defining time intervals:

intervals	0-20	?
dt	None	?
tstart	-1000	?
tstop	1000	?
dataset to use	n0	?

Navigation buttons at the bottom include '< Prev.', '1/3', 'Run', 'Next ->', and 'Cancel'.

A terminal window at the bottom right shows the following commands and their outputs:

```
cspecfile -> /home/vagrant/FermiData/bn110731465/qlg_cspec_n0_bn110731465_v00.pha
repfile -> /home/vagrant/FermiData/bn110731465/qlg_cspec_n0_bn110731465_v00.rep2
srcintervals -> /home/vagrant/GRBs/GRB110731A/bn110731465_n0_srcintervals.fits
cspecfile -> /home/vagrant/FermiData/bn110731465/qlg_cspec_n0_bn110731465_v00.pha
eventfile -> /home/vagrant/FermiData/bn110731465/qlg_tte_n0_bn110731465_v00.fit
repfile -> /home/vagrant/FermiData/bn110731465/qlg_cspec_n0_bn110731465_v00.rep2
ft2file -> None
srcintervals -> /home/vagrant/GRBs/GRB110731A/bn110731465_n0_srcintervals.fits
```

Below the terminal, a lightbulb icon is followed by the text: 'Insert 'i' or 'interactive' in the form to select'.



- interactively zoom

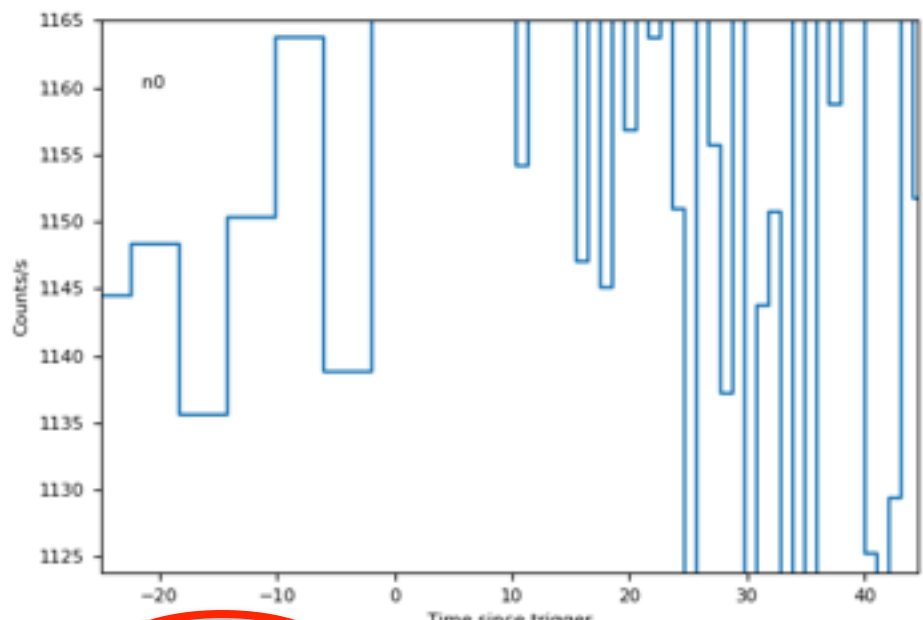
Fermi bursts analysis GUI

File Tasks Tools Update

intervals: interactive ?
 dt: None ?
 tstart: -1000 ?
 tstop: 1000 ?
 dataset to use: n0 ?

<- 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



Counts/s

Time since trigger

Clear Done

Zoom to rectangle

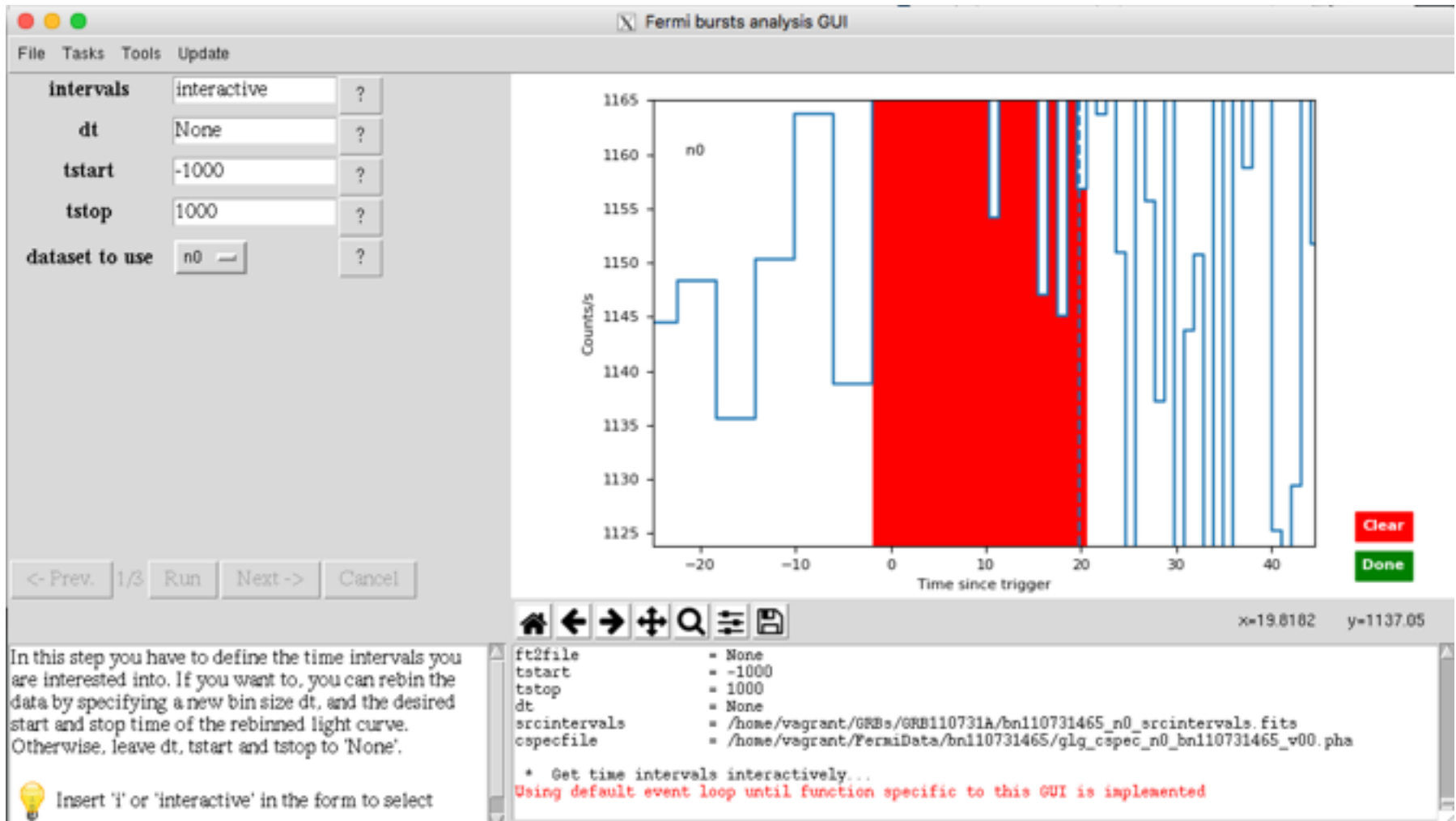
```

ft2file      = None
tstart      = -1000
tstop       = 1000
dt          = None
srcintervals = /home/vagrant/GRBs/GRB110731A/bn11073146S_n0_srcintervals.fits
cspecfile   = /home/vagrant/FermiData/bn11073146S/qlq_cspec_n0_bn11073146S_v00.pha

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



- interactively choose source interval



The screenshot shows the 'Fermi bursts analysis GUI' window. On the left, there are configuration options for intervals, dt, tstart, tstop, and dataset to use. The main plot shows 'Counts/s' vs 'Time since trigger' with a red shaded region from t=0 to t=20. Below the plot is a toolbar and a status bar. At the bottom, there is a text box with instructions and a terminal window showing the current configuration.

GUI Configuration:

- intervals: interactive
- dt: None
- tstart: -1000
- tstop: 1000
- dataset to use: n0

Plot Data:

Time since trigger	Counts/s
-20	1144
-18	1148
-15	1136
-12	1150
-10	1163
-5	1139
0	1165 (start of red region)
10	1154
15	1146
18	1145
20	1165 (end of red region)
22	1165
25	1151
28	1138
32	1144
35	1151
38	1159
40	1125
42	1129
44	1137

Terminal Output:

```
ft2file          = None
tstart           = -1000
tstop            = 1000
dt               = None
srcintervals     = /home/vagrant/GRBs/GRB110731A/bn110731465_n0_srcintervals.fits
cspecfile        = /home/vagrant/FermiData/bn110731465/qlg_cspec_n0_bn110731465_v00.pha

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

Instructions: 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'.

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

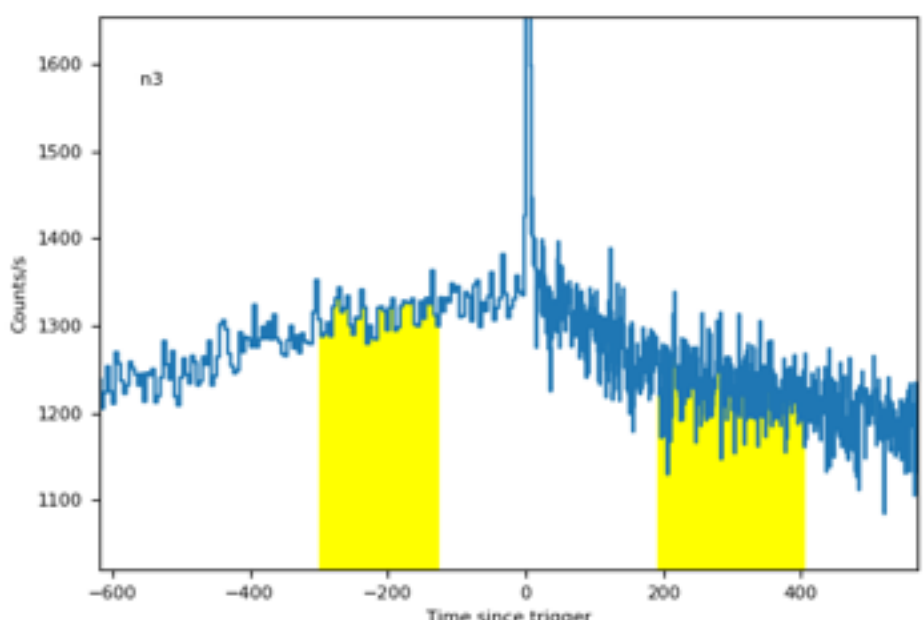


- interactively choose background for each detector

Fermi bursts analysis GUI

File Tasks Tools Update

intervals ?



Counts/s

Time since trigger

Clear Done

<- 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

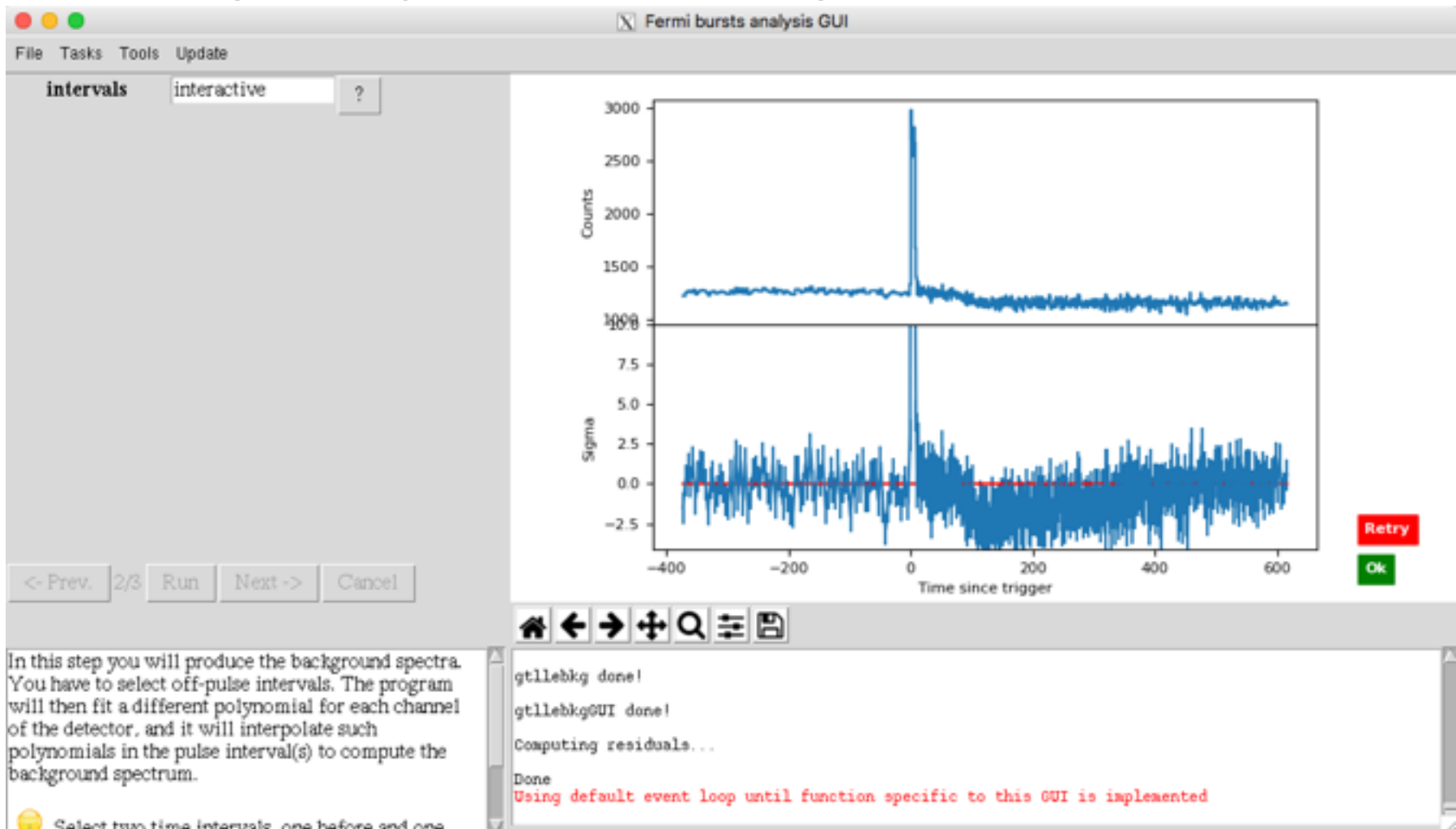
```

bkgspectra      = /home/vagrant/GRBs/GRB110731A/bn110731465_n3_bkgspectra.bak
rspfile         = /home/vagrant/FermiData/bn110731465/qlq_cspeg_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/qlq_cspeg_n3_bn110731465_v00.pha

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



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



The screenshot shows the 'Fermi bursts analysis GUI' window. The main plot area contains two vertically stacked plots. The top plot shows 'Counts' on the y-axis (ranging from 1000 to 3000) against 'Time since trigger' on the x-axis (ranging from -400 to 600). A sharp peak is visible at time 0, reaching approximately 3000 counts. The bottom plot shows 'Sigma' on the y-axis (ranging from -2.5 to 7.5) against the same x-axis. A red dashed horizontal line is drawn at Sigma = 0.0. A 'Retry' button (red) and an 'Ok' button (green) are located to the right of the plots. Below the plots is a toolbar with navigation icons. At the bottom left, there is a text box with instructions: '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.' Below this is a yellow smiley icon and the text 'Select two time intervals: one before and one'. At the bottom right, a status window displays the following text: 'gtllebkg done!', 'gtllebkgGUI done!', 'Computing residuals...', 'Done', and '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.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



- Download example_prompt.xcm
 - data 1:1
bn110731465_n0_srcspectra.pha{*}
 - data 2:2
bn110731465_n3_srcspectra.pha{*}
 - data 3:3
bn110731465_n6_srcspectra.pha{*}
 - data 4:4
bn110731465_b0_srcspectra.pha{*}
 - data 5:5 bn110731465_LAT-
LLE_srcspectra.pha{*}
 - data 6:6
gll_ft1_tr_bn110731465_v00_filt_sp
ec_0.000_20.000.pha

Setting up 4 data groups

- NaI
- BGO
- LLE
- LAT

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

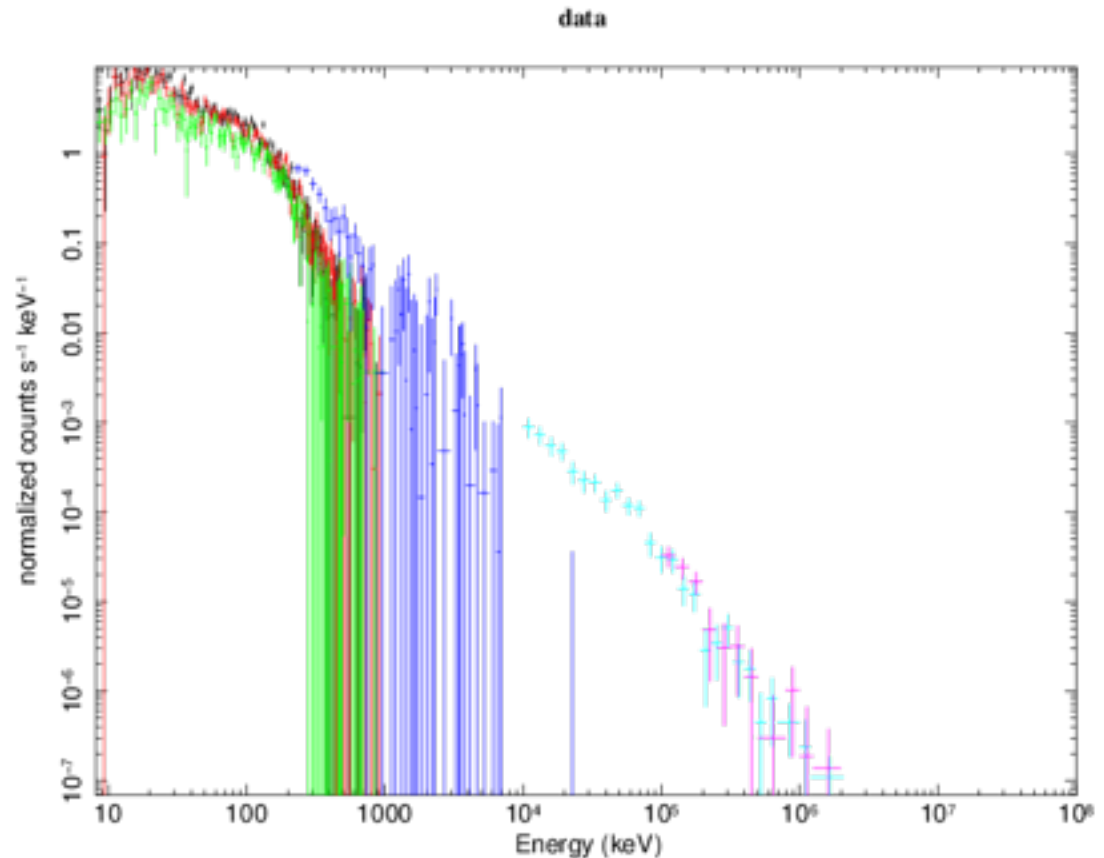


- Let's set things up

- cpd /xw
- setplot en
- ignore 1-3:**-8.0
- ignore 1-3:1000.-**
- ignore 4:**-200.
- ignore 4:40e3-**
- ignore 6:**-20e3
- ignore bad

- statistic cstat
- statistic pgstat 5
- statistic pgstat 6

- Let's plot our data
 - plot ldata



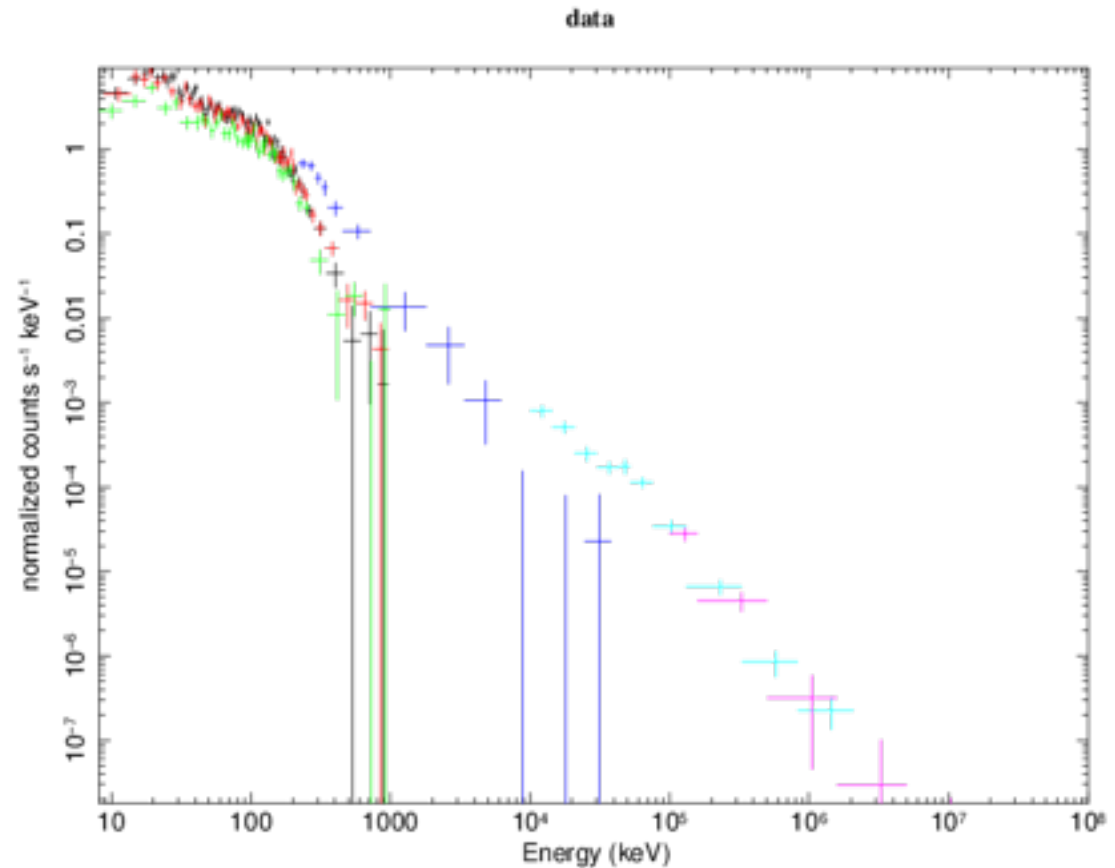
cstat = Cash Statistic, pgstat = poisson signal with gaussian noise



- 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`
- `setplot rebin 5 5 6`
- `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

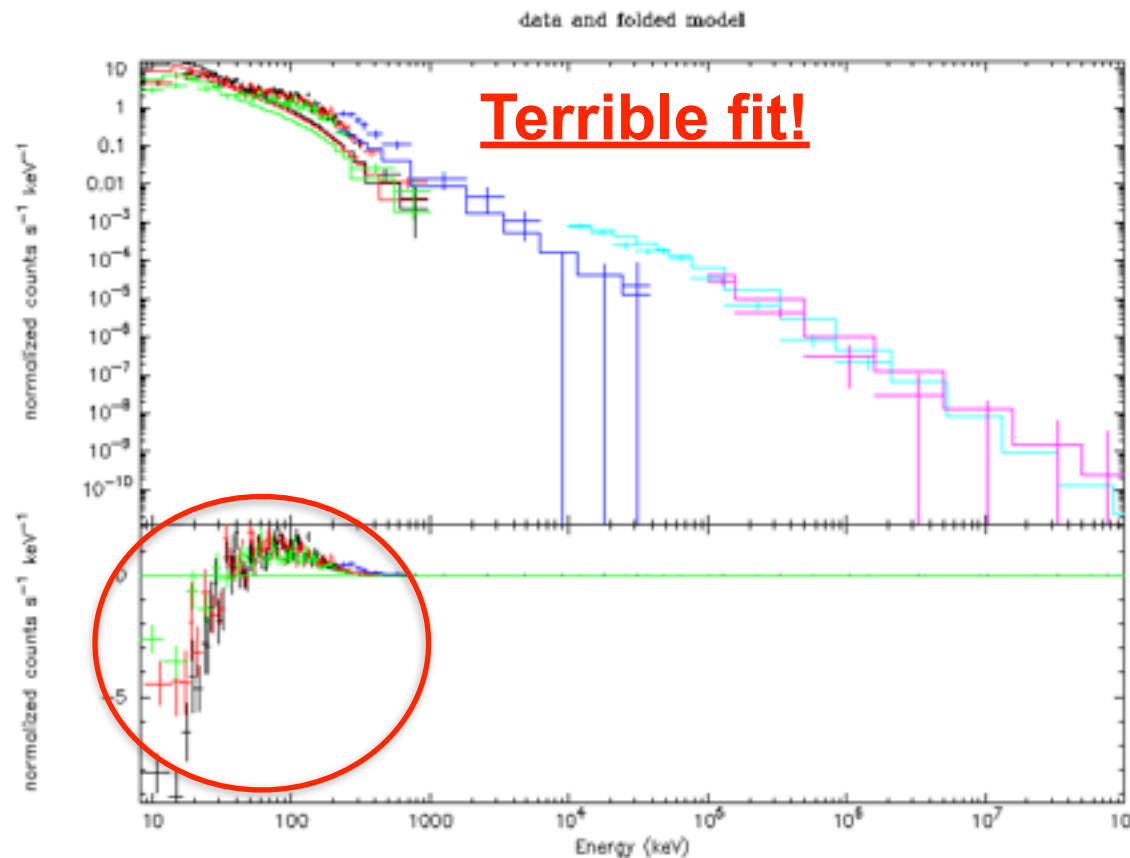
- mode
- [press default]
- fit 100

- Let's plot residuals
- plot residuals

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

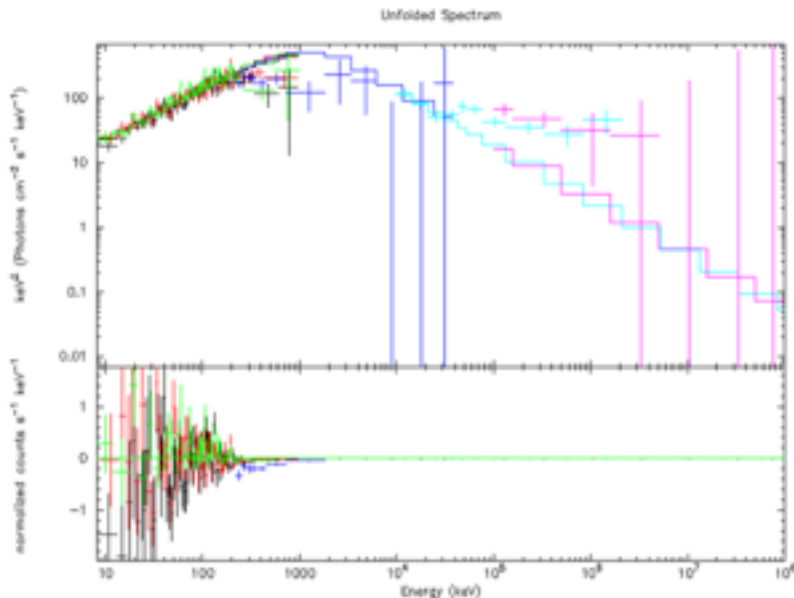
Data group: 1

E-03

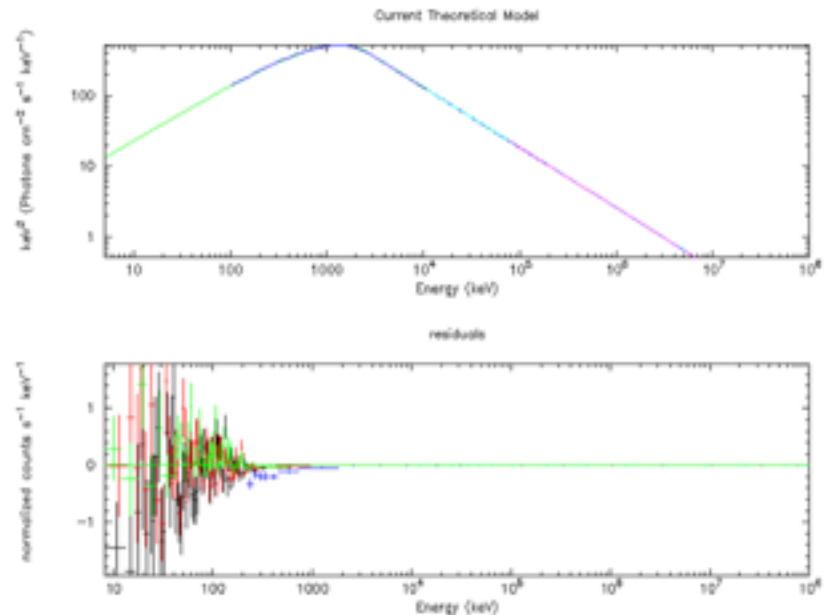




- Let's look at the plot like a SED plotting νF_ν to unfold the data using the response functions & model. This makes your spectrum plot model dependent, caution when interpreting physical models!
 - plot eeuf res
 - plot eemo res



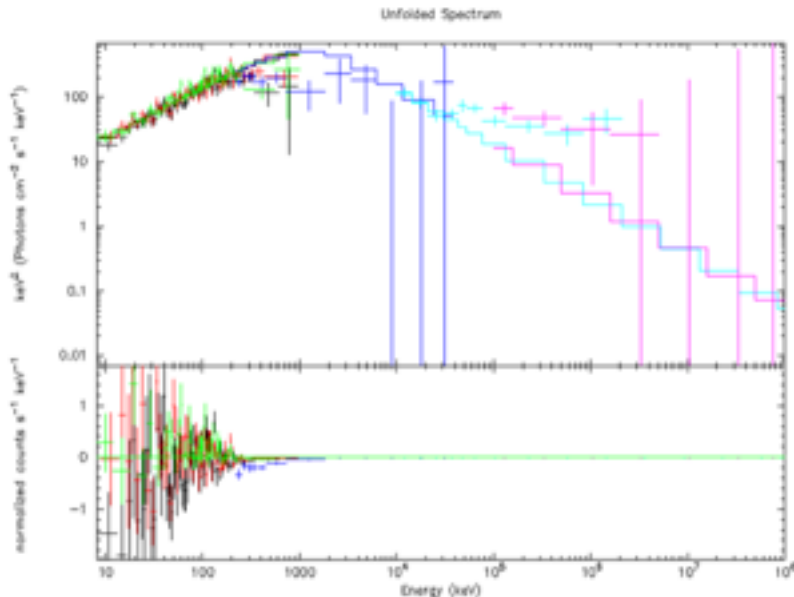
[Smith 1-Jan-2017 18:08]



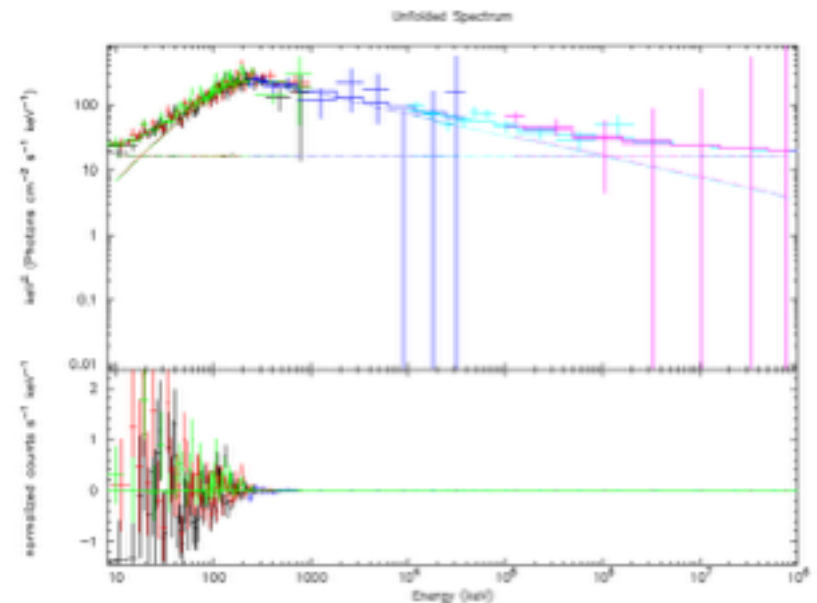
[Smith 1-Jan-2017 18:18]



- 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
 - newer 28=19



[result: 1-Jan-2017 18:08



[result: 1-Jan-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**
 - **<http://heasarc.nasa.gov/xanadu/xspec/manual/XScommandSummary.html>**



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

```

Model: grbm1> + powerlaw2> Source No.: 1 Active/On
Model Model Component Parameter Unit Value
par comp
Data group: 1
 1 1 grbm alpha -0.483338 +/- 0.153824
 2 1 grbm beta -2.33086 +/- 2.70428E-02
 3 1 grbm tau keV 169.501 +/- 20.4815
 4 1 grbm norm 2.49647E-02 +/- 2.58057E-03
 5 2 powerlaw PhoIndex 2.00173 +/- 4.51806E-02
 6 2 powerlaw norm 16.8186 +/- 5.03555
Data group: 2
 7 1 grbm alpha -0.483338 = 1
 8 1 grbm beta -2.33086 = 2
 9 1 grbm tau keV 169.501 = 3
10 1 grbm norm 2.49647E-02 = 4
11 2 powerlaw PhoIndex 2.00173 = 5
12 2 powerlaw norm 16.8186 = 6
Data group: 3
13 1 grbm alpha -0.483338 = 1
14 1 grbm beta -2.33086 = 2
15 1 grbm tau keV 169.501 = 3
16 1 grbm norm 2.49647E-02 = 4
17 2 powerlaw PhoIndex 2.00173 = 5
18 2 powerlaw norm 16.8186 = 6
Data group: 4
19 1 grbm alpha -0.483338 = 1
20 1 grbm beta -2.33086 = 2
21 1 grbm tau keV 169.501 = 3
22 1 grbm norm 2.49647E-02 = 4
23 2 powerlaw PhoIndex 2.00173 = 5
24 2 powerlaw norm 16.8186 = 6
    
```



Never believe these errors, ever!

Fit statistic : C-Statistic = 379.18 using 490 PHA bins.

Warning: cstat statistic is only valid for Poisson data.
Background File is not Poisson.

PG-Statistic = 52.67 using 80 PHA bins.

Warning: pgsat statistic is only valid for Poisson data.
Source File is not Poisson.
Background File is not Poisson.

Total Statistic = 431.78 with 564 degrees of freedom.

Test statistic : Chi-Squared = 498.83 using 570 PHA bins.
Reduced chi-squared = 0.88304 for 564 degrees of freedom
Null hypothesis probability = 9.786258E-05

***Warning: Chi-square may not be valid due to bins with zero variance
in spectrum number(s): 5

nTotal Test Statistic = 498.83 with 564 degrees of freedom.



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.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_ν , νF_ν**



- **Do this in time-resolved analysis**
 - **measure evolution of parameters**
 - **are all components seen in every interval**
 - **f-test for nested models**
 - **more sophisticated simulations potentially required**
- **Rmfit also does these joint fits**
 - **Colleen will demonstrate rmfit next week**