Data processing of X-ray and UV/optical observations from the SWIFT Observatory

Nandita Das
University of Belgrade
Master in Astrophysics and Space Science (MASS)
Advisor: Prof. Dragana Ilić, University of Belgrade

Abstract

Gamma-Ray Bursts (GRBs) are among the most luminous electromagnetic events in the universe, releasing immense energy within seconds. The NASA-led *Swift* satellite, launched in 2004, was designed to detect these bursts and observe their afterglows in X-ray and UV/optical wavelengths with high temporal resolution. *Swift* carries three instruments: the Burst Alert Telescope (BAT) for GRB detection, and two narrow-field instruments—the X-Ray Telescope (XRT) and the Ultraviolet/Optical Telescope (UVOT)—for rapid follow-up observations.

This report presents the process of extracting and analyzing GRB afterglow data from *Swift* observations, focusing on the construction and modeling of the spectral energy distribution (SED) using data from the XRT and UVOT instruments.

Introduction

This report focuses on GRB 130427A, which is associated with the Type Ic supernova SN 2013cq. This GRB was chosen from (GRB List) and is notable for being one of the brightest bursts ever observed by *Swift*, with extensive follow-up across wavelengths. Key parameters of the event are:

GRB/Supernova name: 2013cq
- Host galaxy - none
- Discovery **date** - 2013/04/27.713
- RA: 11:32:32.81
- **Dec**: +27:41:56.1
- offset: 0.0
- **Last** mag: 19.7
- **Last date**: 2013/05/02
- **Max** Mag: 12.0
- **Max Date**: 2013/04/27 Ic
- z: 0.340000
- z host: n/a
- Reference: CBET 3531
- Discover: SWIFT burst alert
- Alternate **names**: GRB 130427A, CSS130502:113233+274156

Downloading Data

Using the Swift data search tool, we search for the images of this event:

Query the Swift swiftmastr catalogue

Querying the swiftmastr catalogue. About this catalogue. Change catalogue. About this interface.

Search type: Simple | **Advanced**.

Show filters for which columns? All Columns to select Basic Include distance and download columns?

Name or position: GRB 130427A Radius: 12 arcmin System: J2000

Output: Coordinate format: Sexagesimal System: J2000 Output Format: HTML Show in: Inline

Sort direction ↑

Search

☑	○	xrt_expo_pc	>	0	More	Effective Exposure on Source Photon Counting XRT Mode
		UVOT parameters				
☑	○	uvot_expo_uu	>	0	More	Effective Exposure on Source U UVOT Filter
☑	○	uvot_expo_bb	>	0	More	Effective Exposure on Source B UVOT Filter
☑	○	uvot_expo_vv	>	0	More	Effective Exposure on Source V UVOT Filter
☑	○	uvot_expo_w1	>	0	More	Effective Exposure on Source UVW1 UVOT Filter
☑	○	uvot_expo_w2	>	0	More	Effective Exposure on Source UVW2 UVOT Filter
☑	○	uvot_expo_m2	>	0	More	Effective Exposure on Source UVM2 UVOT Filter

Resolved 'GRB 130427A' as (173.1347411881, 27.6984570988)

Searching around RA=11^h 32^m 32.34^s, Dec=+27° 41′ 54.4″ (173.1347, 27.6985), radius=12.0′.

Permanent link to this search.

Retrieved 2 datasets.

Advanced search results

Download	_r	name	target_id	ra	decl	roll_angle	start_time	s
Obs | Object	124′′	GRB130427a	554620	11h 32m 32.11s	+27° 39′ 50.0″	319.445674	2013-04-29T20:58:48	2013-
Obs | Object	37′′	GRB130427a	554620	11h 32m 32.53s	+27° 42′ 32.0″	140.989679	2013-10-22T00:29:59	2013-

After submitting the 'Search', we obtain different observations of the same GRB, and select the one with highest exposure time in most filters. This requirement is purely statistical, aiming for the most accurate flux measurements.

Clicking 'Obs' will take us to the observation data which we can select and download from. We select the data from the UVOT instrument of the image type. These images have the following naming scheme:

```
sw[id observation]u[filter]\_sk.img
```

where: u- denotes UVOT observations; [filter]- indicates which filter (U- uu, B- bb, V- vv, UW1-w1, UW2-w2, UM2-m2); sk- denotes images calibrated to based on the object equatorial coordinates for epoch J2000. For each filter, we have one image like this.

uvot

hk

☐	sw00554620153uac.hk	FITS 60.0 kB	(level 1) Housekeeping data
☐	sw00554620153uaf.hk	FITS 799.0 kB	(level 1) Housekeeping data
☐	sw00554620153uct.hk	FITS 60.0 kB	(level 1) Housekeeping data
☐	sw00554620153uen.hk	FITS 2.5 MB	(level 1) instrument engineering data
☐	sw00554620153uer.hk	FITS 40.0 kB	(level 1) Housekeeping data
☐	sw00554620153ues.hk	FITS 31.0 kB	(level 1) Housekeeping data

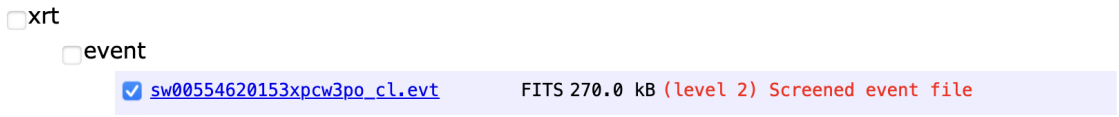
image

☐	sw00554620153ubb_ex.img	FITS 5.1 MB	(level 2) Uvot filter exp images
☐	sw00554620153ubb_rw.img	FITS 4.0 MB	(level 1) Raw coordinate images
☑	sw00554620153ubb_sk.img	FITS 5.0 MB	(level 2) Uvot filter sky images
☐	sw00554620153um2_ex.img	FITS 5.1 MB	(level 2) Uvot filter exp images
☐	sw00554620153um2_rw.img	FITS 4.0 MB	(level 1) Raw coordinate images
☑	sw00554620153um2_sk.img	FITS 5.0 MB	(level 2) Uvot filter sky images
☐	sw00554620153uuu_ex.img	FITS 5.1 MB	(level 2) Uvot filter exp images
☐	sw00554620153uuu_rw.img	FITS 4.0 MB	(level 1) Raw coordinate images
☑	sw00554620153uuu_sk.img	FITS 5.0 MB	(level 2) Uvot filter sky images
☐	sw00554620153uvv_ex.img	FITS 5.1 MB	(level 2) Uvot filter exp images
☐	sw00554620153uvv_rw.img	FITS 4.0 MB	(level 1) Raw coordinate images
☑	sw00554620153uvv_sk.img	FITS 5.0 MB	(level 2) Uvot filter sky images
☐	sw00554620153uw1_ex.img	FITS 75.6 MB	(level 2) Uvot filter exp images
☐	sw00554620153uw1_rw.img	FITS 60.2 MB	(level 1) Raw coordinate images
☑	sw00554620153uw1_sk.img	FITS 75.5 MB	(level 2) Uvot filter sky images
☐	sw00554620153uw2_ex.img	FITS 5.1 MB	(level 2) Uvot filter exp images
☐	sw00554620153uw2_rw.img	FITS 4.0 MB	(level 1) Raw coordinate images
☑	sw00554620153uw2_sk.img	FITS 5.1 MB	(level 2) Uvot filter sky images

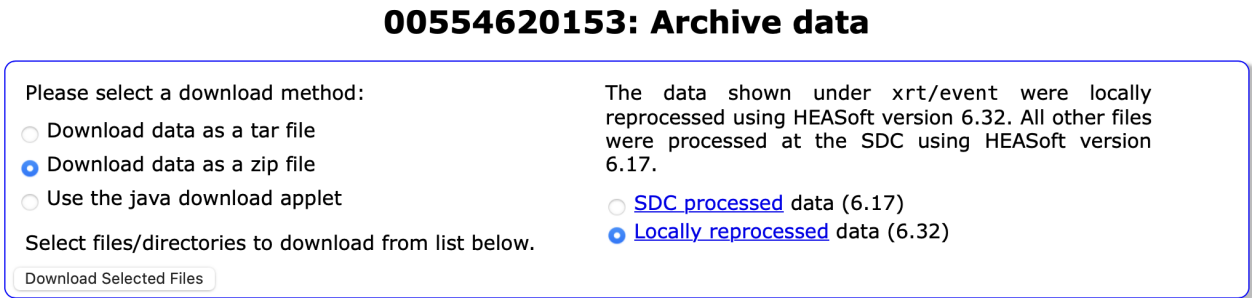
Next, we find event images obtained with the XRT instrument which have names following the scheme:

where: x- indicates that the XRT observations; pc- denotes detection in PC mode; po- telescope was pointing directly to the object; cl- data are reduced and ready for the extraction of the spectrum, image, light curve, etc. (depending on the detection mode); .evt- indicates that this is the event type of image. We select the corresponding image.

```
sw[id observation]xpcw[some number]po_cl.evt
```



Finally, we downloaded all the files as a zip file:



Extracting Xray Spectra

After extracting the event file $sw00568849001xpcw3po\_cl.evt$ from xrt/event, we load it into SAO Image ds9, where we select circular regions of radius 47" around the source and some background region, and save them accordingly (in physical coordinates). The background reflects the background signal in the vicinity of the source, which is why we take this region not too far from the source.

While extracting regions for source and background, there was 2 very bright spot, for further analysis extract coordinate for both, central one is more closer to our expected GRB and using coordinate of other spot searching on SIMBAD it's clear that bright spot basaically from AGN.

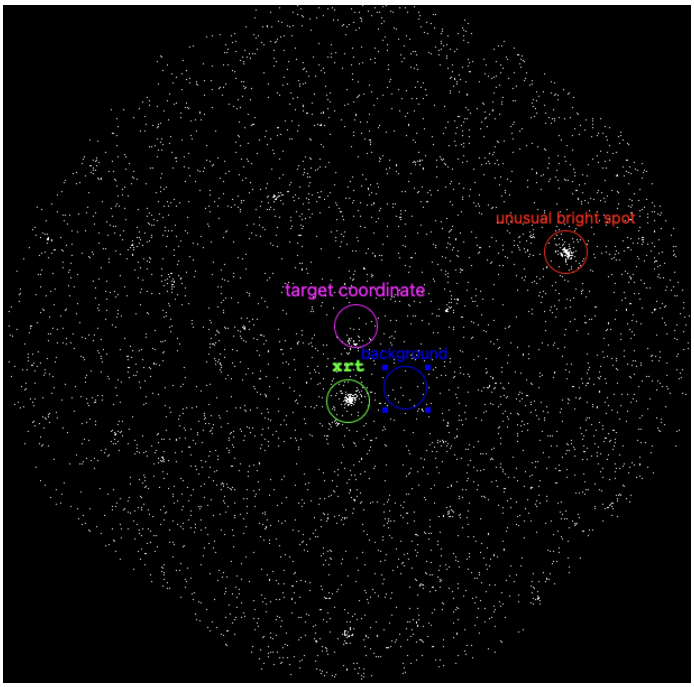
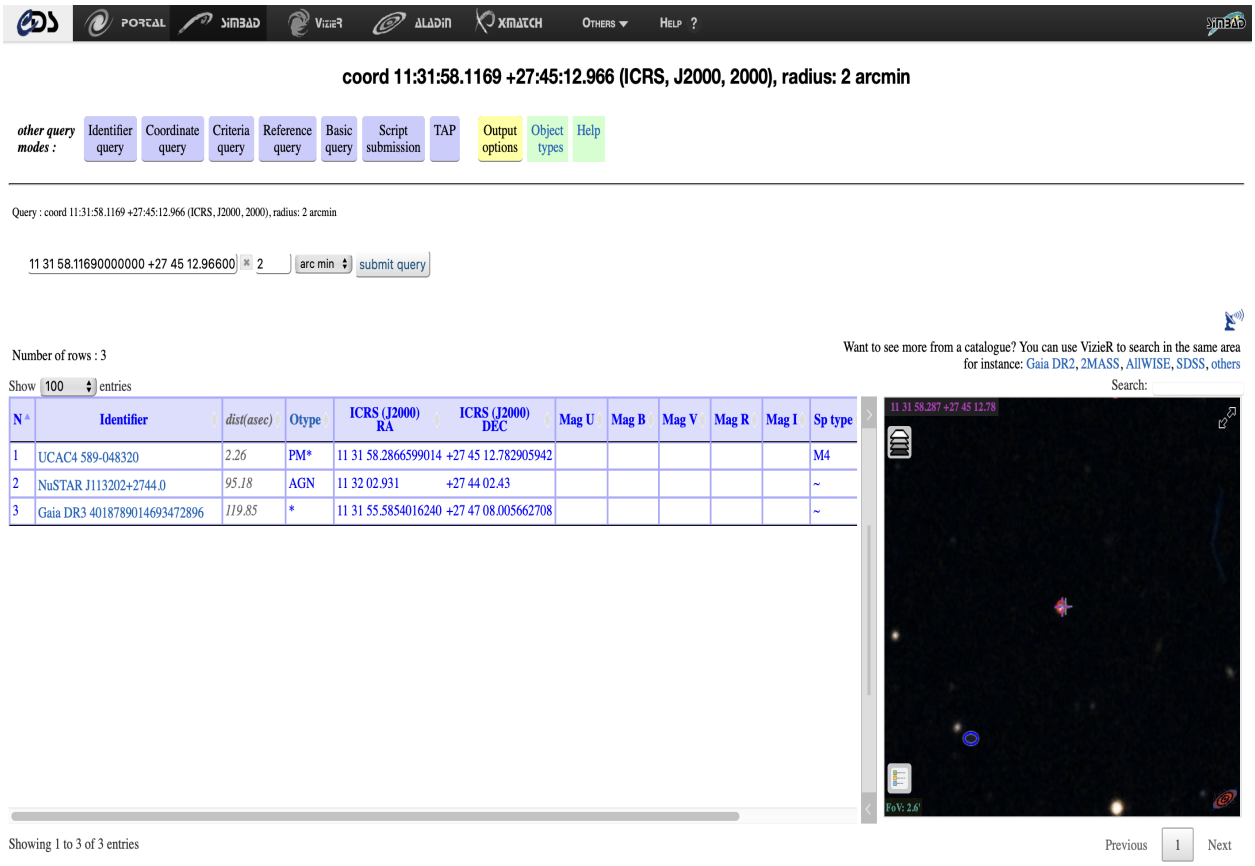
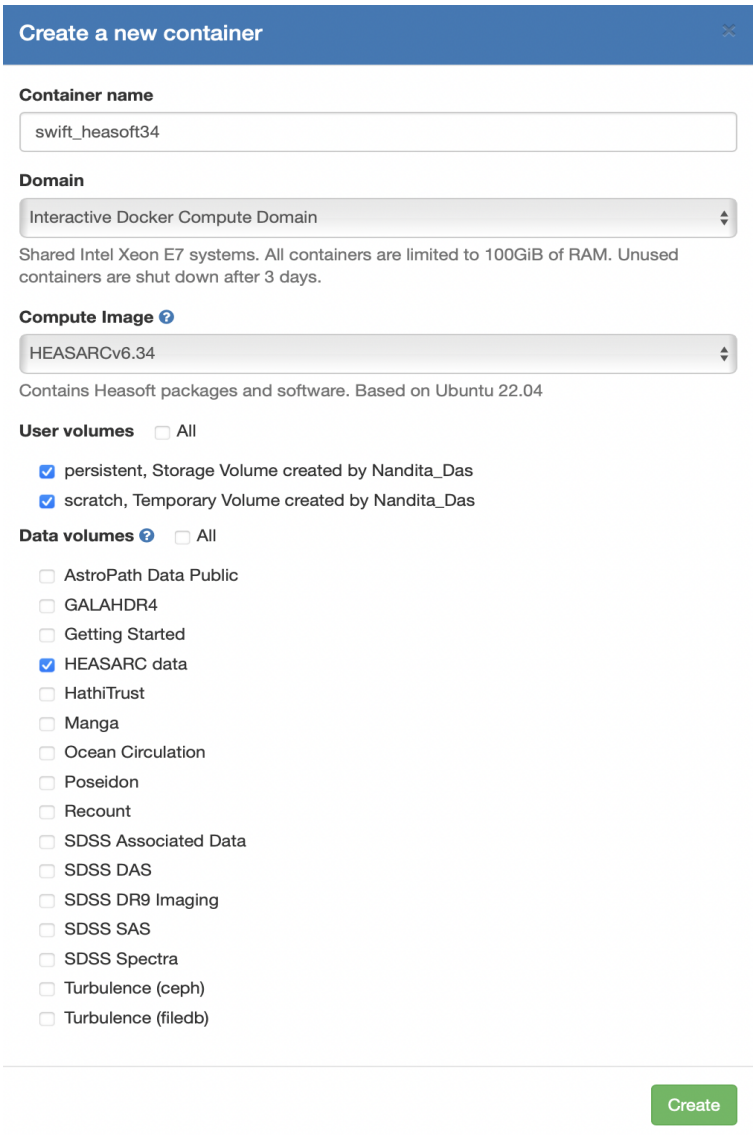


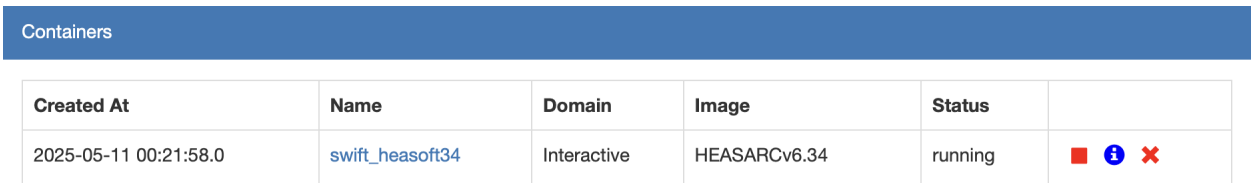
Fig. 1.— Source and background regions selected for X-ray spectra.



Heasoft on SciServer

First we have to create a container to using Heasoft on SciServer.: I created a container named - $swift\_heasoft34$ using interactive docker mode, select latest heasoft $HEASARCv6.34$, create persistent user volume to save data, and also HEASARC data from Data volumes.





After clicking $swift\_heasoft$ link, a jupyter notebook opened including tutorials.

Open a terminal clicking (+) sign and under 'other'. Already uploaded the swift data in the 'persistent' directory. Now to go to directory where the files are and run 'xselect'.

```
xselect

read event sw...po_cl.evt

set image sky
filter region ... .reg
extract spectrum
save spectrum ... .pha

clear region

filter region background_region_xray.reg
extract spectrum
save spectrum xrt_bkg.pha

exit
```

```
                    **  XSELECT V2.5b  **

> Enter session name >[exper]
exper:SUZAKU > read event sw00554620153xpcw3po_cl.evt
> Enter the Event file dir >[/home/idies/workspace/Storage/Nandita_Das/persistent]
Got new mission: SWIFT
> Reset the mission ? >[yes]

 Notes: XSELECT set up for      SWIFT
 Time keyword is TIME       in units of s
 Default timing binsize =   5.0000

Setting...
 Image  keywords   = X          Y           with binning =    1
 WMAP   keywords   = X          Y           with binning =    1
 Energy keyword    = PI                    with binning =    1

Getting Min and Max for Energy Column...
Got min and max for PI:     0   1023

Got the minimum time resolution of the read data:   2.5073
MJDREF =  5.1910000742870E+04 with TIMESYS = TT
 Number of files read in:           1

******************** Observation Catalogue ********************

Data Directory is: /home/idies/workspace/Storage/Nandita_Das/persistent/
HK Directory is: /home/idies/workspace/Storage/Nandita_Das/persistent/


        OBJECT      OBS_ID      DATE-OBS            DATAMODE
      1 GRB130427A  00554620153 2013-10-22T00:33:17 PHOTON

exper:SWIFT-XRT-PHOTON >
```

```
exper:SWIFT-XRT-PHOTON > set image sky
exper:SWIFT-XRT-PHOTON > filter region source.reg
exper:SWIFT-XRT-PHOTON > extract spectrum
extractor v6.11    12 Dec 2023
 Getting FITS WCS Keywords
 Doing file: /home/idies/workspace/Storage/Nandita_Das/persistent/sw00554620153xpcw3po_cl.evt
[regfilter("exper_region.xsl",X,Y)]
100% completed
          Total      Good    Bad: Time     Phase     Grade       Cut
            185       185            0         0         0         0
================================================================================
    Grand Total      Good    Bad: Time     Phase     Grade       Cut
            185       185            0         0         0         0
   in  25424.     seconds
 Spectrum         has       185 counts for  7.2766E-03 counts/sec
Keyword TLM2FITS has two values: 'V6.4' and 'V6.4    '
Keyword OBJECT has two values: 'GRB130427a' and 'GRB130427A'
 ... wrote the PHA data Extension
exper:SWIFT-XRT-PHOTON > save spectrum source.pha
Wrote spectrum to source.pha
exper:SWIFT-XRT-PHOTON >
```

```
exper:SWIFT-XRT-PHOTON > clear region
exper:SWIFT-XRT-PHOTON > filter region background.reg
exper:SWIFT-XRT-PHOTON > extract spectrum
extractor v6.11    12 Dec 2023
 Getting FITS WCS Keywords
 Doing file: /home/idies/workspace/Storage/Nandita_Das/persistent/sw00554620153xpcw3po_cl.evt
[regfilter("exper_region.xsl",X,Y)]
100% completed
          Total      Good    Bad: Time     Phase     Grade       Cut
             12        12            0         0         0         0
================================================================================
    Grand Total      Good    Bad: Time     Phase     Grade       Cut
             12        12            0         0         0         0
   in  25424.     seconds
 Spectrum         has        12 counts for  4.7199E-04 counts/sec
Keyword TLM2FITS has two values: 'V6.4' and 'V6.4    '
Keyword OBJECT has two values: 'GRB130427a' and 'GRB130427A'
 ... wrote the PHA data Extension
exper:SWIFT-XRT-PHOTON > save spectrum background.pha
Wrote spectrum to background.pha
exper:SWIFT-XRT-PHOTON > exit
> Save this session? >[no]
```

Now, we have to extract source and background spectra. The next step is downloading calibration files $swxpc0to12s6_{20130101v014.rmf}$ and $swxs6_{20010101v001.arf}$ from (Swift Responses) to obtain a realistic source spectrum.

XRT	Windowed Timing grade 0-2	swxs6_20010101v001.arf, swxwt0to2s6_20131212v015.rmf
	Photon counting grade 0-12	swxs6_20010101v001.arf, swxpc0to12s6_20130101v014.rmf

```
 ** grppha 3.1.0
 ..... using pha_gp   Ver 1.1.1
Please enter PHA filename[ ] source.pha
Please enter output filename[ ] source.pi

  -------------------------
  MANDATORY KEYWORDS/VALUES
  -------------------------
  ------------------------------------------------------------------------
  ------------------------------------------------------------------------
  EXTNAME   - SPECTRUM        Name of this BINTABLE
  TELESCOP  - SWIFT           Mission/Satellite name
  INSTRUME  - XRT             Instrument/Detector
  FILTER    - NONE            Instrument filter in use
  EXPOSURE  - 25322.          Integration time (in secs) of PHA data
  AREASCAL  - 1.0000          Area scaling factor
  BACKSCAL  - 1.25000E-03     Background scaling factor
  BACKFILE  - none            Associated background file
  CORRSCAL  - 1.0000          Correlation scaling factor
  CORRFILE  - none            Associated correlation file
  RESPFILE  - none            Associated redistribution matrix file
  ANCRFILE  - none            Associated ancillary response file
  POISSERR  - TRUE            Whether Poissonian errors apply
  CHANTYPE  - PI              Whether channels have been corrected
  TLMIN1    - 0               First legal Detector channel
  DETCHANS  - 1024            No. of legal detector channels
  NCHAN     - 1024            No. of detector channels in dataset
  PHAVERSN  - 1.2.0           OGIP FITS version number
  STAT_ERR  - FALSE           Statistical Error
  SYS_ERR   - FALSE           Fractional Systematic Error
  QUALITY   - TRUE            Quality Flag
  GROUPING  - FALSE           Grouping Flag
  ------------------------------------------------------------------------
  ------------------------------------------------------------------------
GRPPHA[]
```

```
GRPPHA[] bad 0-29
GRPPHA[] group min 20
GRPPHA[group min 20] chkey BACKFILE background.pha
GRPPHA[chkey BACKFILE background.pha] chkey RESPFILE swxpc0to12s6_20130101v014.rmf
GRPPHA[chkey RESPFILE swxpc0to12s6_20130101v014.rmf] chkey ANCRFILE swxs6_20010101v001.arf
GRPPHA[chkey ANCRFILE swxs6_20010101v001.arf] exit
 ... written the PHA data Extension
 ...... exiting, changes written to file : source.pi
 ** grppha 3.1.0 completed successfully
```

UV/Optical Photometry of GRB

Since we aim to obtain the SED of the GRB, we are interested in finding out how many photons are detected per second (object flux). To calculate this, we will sum all exposures, which also reduces the uncertainty. However, note that typically the image will rotate or slightly shift between two exposures, thus the object on two exposures will not be in the same position.

To start, find and extract the GRB images in the aforementioned filters (folder uvot/image). HEASOFT contains packages that will sum all exposures and correct for the object position shift between two exposures. This package is uvotimsum, which we use as follows:

uvotimsum sw[id observation]u[filter] sk.img u[filter] sum.fits chatter6=1

In the end, this package will return a summed GRB image in the given filter in the .fits format. The same procedure should be repeated for each of the filters.

```
** HEASARC data Volume was not mounted. Please do that when creating the container. **
(heasoft) idies@df736f00ea38:~/workspace/Storage/Nandita_Das/persistent/uvot$ uvotimsum
Name of input image file(s)[sw00554620153ubb_sk.img]
Output file name[ubb_sum.fits]
uvotimsum: HDU [0] is on the exclude list ASPCORR:NONE
uvotimsum: shell uvotimsum1 "infile=sw00554620153ubb_sk.img" "outfile=xout.1010.3" "ra=173.144378" "dec=27.698517" "pixs
ize=0.00027888888381462" "width=1169" "height=1129" "datatype=COUNT" "exclude=0" "clobber=no" "history=yes" "chatter=3"
uvotimsum:
--- begin uvotimsum1
status: parameters loaded
status: HDU [0] is on the exclude list
status: assimilating HDU 1+1
status: selected output units [deg]
status: set output system FK5/2.000000e+03
status: created file xout.1010.3
status: created output image
--- end uvotimsum1
uvotimsum: shell fthedit "infile=xout.1010.3" "keyword=@template.1010.2" "operation=ADD" "history=NO" "longstring=NO" "p
rotect=YES" "chatter=1"
uvotimsum: --- begin/end fthedit
uvotimsum: shell ftemplate "template=template.1010.2" "outfile=normal.1010.4"
uvotimsum: --- begin/end ftemplate
uvotimsum: shell ftappend "infile=output.1010.1+0[col #EXTNAME='B'; #FILTER='B';#EXPOSURE=144.456047144888;#TSTART=40417
5834.54084;#TSTOP=404175981.31176;#FRAMTIME=0.0110322;]" "outfile=normal.1010.4" "chatter=1" "history=NO"
uvotimsum: --- begin/end ftappend
uvotimsum: shell ftchecksum "infile=output.1010.1" "update=yes" "chatter=2" "datasum=Yes" "allok=No"
uvotimsum:
--- begin ftchecksum
File: output.1010.1
  HDU CHECKSUM  DATASUM
   1:  updated  updated
   2:  updated  correct
   OK, all checksums are valid.
--- end ftchecksum
```

```
(heasoft) idies@df736f00ea38:~/workspace/Storage/Nandita_Das/persistent/uvot$ uvotimsum
Name of input image file(s)[sw00554620153ubb_sk.img] sw00554620153um2_sk.img
Output file name[ubb_sum.fits] um2_sum.fits
uvotimsum: HDU [0] is on the exclude list ASPCORR:NONE
uvotimsum: shell uvotimsum1 "infile=sw00554620153um2_sk.img" "outfile=xout.1040.3" "ra=173.144325" "dec=27.698178" "pixs
ize=0.00027888888888381462" "width=1169" "height=1129" "datatype=COUNT" "exclude=0" "clobber=no" "history=yes" "chatter=3"
uvotimsum:
--- begin uvotimsum1
status: parameters loaded
status: HDU [0] is on the exclude list
status: assimilating HDU 1+1
status: selected output units [deg]
status: set output system FK5/2.000000e+03
status: created file xout.1040.3
status: created output image
--- end uvotimsum1
uvotimsum: shell fthedit "infile=xout.1040.3" "keyword=@template.1040.2" "operation=ADD" "chatter=1" "longstring=NO" "pr
otect=YES" "history=NO"
uvotimsum: --- begin/end fthedit
uvotimsum: shell ftemplate "template=template.1040.2" "outfile=normal.1040.4"
uvotimsum: --- begin/end ftemplate
uvotimsum: shell ftappend "infile=output.1040.1+0[col #EXTNAME='UVM2'; #FILTER='UVM2';#EXPOSURE=423.052172406317;#TSTART
=404176731.1972;#TSTOP=404177161.02868;#FRAMTIME=0.0110322;]" "outfile=normal.1040.4" "history=NO" "chatter=1"
uvotimsum: --- begin/end ftappend
uvotimsum: shell ftchecksum "infile=output.1040.1" "update=yes" "datasum=Yes" "allok=No" "chatter=2"
uvotimsum:
--- begin ftchecksum
File: output.1040.1
  HDU CHECKSUM  DATASUM
   1:  updated  updated
   2:  updated  correct
   OK, all checksums are valid.
--- end ftchecksum
(heasoft) idies@df736f00ea38:~/workspace/Storage/Nandita_Das/persistent/uvot$ uvotimsum
Name of input image file(s)[sw00554620153um2_sk.img] sw00554620153uuu_sk.img
Output file name[um2_sum.fits] uuu_sum.fits
uvotimsum: HDU [0] is on the exclude list ASPCORR:NONE
uvotimsum: shell uvotimsum1 "infile=sw00554620153uuu_sk.img" "outfile=xout.1064.3" "ra=173.143889" "dec=27.699255" "pixs
ize=0.00027888888888381462" "width=1169" "height=1129" "datatype=COUNT" "exclude=0" "clobber=no" "history=yes" "chatter=3"
uvotimsum:
--- begin uvotimsum1
status: parameters loaded
status: HDU [0] is on the exclude list
status: assimilating HDU 1+1
status: selected output units [deg]
status: set output system FK5/2.000000e+03
status: created file xout.1064.3
status: created output image
--- end uvotimsum1
uvotimsum: shell fthedit "infile=xout.1064.3" "keyword=@template.1064.2" "operation=ADD" "protect=YES" "chatter=1" "long
string=NO" "history=NO"
uvotimsum: --- begin/end fthedit
uvotimsum: shell ftemplate "template=template.1064.2" "outfile=normal.1064.4"
uvotimsum: --- begin/end ftemplate
uvotimsum: shell ftappend "infile=output.1064.1+0[col #EXTNAME='U'; #FILTER='U';#EXPOSURE=144.456047144888;#TSTART=40417
5682.51826;#TSTOP=404175829.28918;#FRAMTIME=0.0110322;]" "outfile=normal.1064.4" "history=NO" "chatter=1"
uvotimsum: --- begin/end ftappend
uvotimsum: shell ftchecksum "infile=output.1064.1" "update=yes" "allok=No" "datasum=Yes" "chatter=2"
uvotimsum:
--- begin ftchecksum
File: output.1064.1
  HDU CHECKSUM  DATASUM
   1:  updated  updated
   2:  updated  correct
   OK, all checksums are valid.
--- end ftchecksum
```

```
(heasoft) idies@df736f00ea38:~/workspace/Storage/Nandita_Das/persistent/uvot$ uvotimsum
Name of input image file(s)[sw00554620153um2_sk.img] sw00554620153uuu_sk.img
Output file name[um2_sum.fits] uuu_sum.fits
uvotimsum: HDU [0] is on the exclude list ASPCORR:NONE
uvotimsum: shell uvotimsum1 "infile=sw00554620153uuu_sk.img" "outfile=xout.1064.3" "ra=173.143889" "dec=27.699255" "pixs
ize=0.00027888888888381462" "width=1169" "height=1129" "datatype=COUNT" "exclude=0" "clobber=no" "history=yes" "chatter=3"
uvotimsum:
--- begin uvotimsum1
status: parameters loaded
status: HDU [0] is on the exclude list
status: assimilating HDU 1+1
status: selected output units [deg]
status: set output system FK5/2.000000e+03
status: created file xout.1064.3
status: created output image
--- end uvotimsum1
uvotimsum: shell fthedit "infile=xout.1064.3" "keyword=@template.1064.2" "operation=ADD" "protect=YES" "chatter=1" "long
string=NO" "history=NO"
uvotimsum: --- begin/end fthedit
uvotimsum: shell ftemplate "template=template.1064.2" "outfile=normal.1064.4"
uvotimsum: --- begin/end ftemplate
uvotimsum: shell ftappend "infile=output.1064.1+0[col #EXTNAME='U'; #FILTER='U';#EXPOSURE=144.456047144888;#TSTART=40417
5682.51826;#TSTOP=404175829.28918;#FRAMTIME=0.0110322;]" "outfile=normal.1064.4" "history=NO" "chatter=1"
uvotimsum: --- begin/end ftappend
uvotimsum: shell ftchecksum "infile=output.1064.1" "update=yes" "allok=No" "datasum=Yes" "chatter=2"
uvotimsum:
--- begin ftchecksum
File: output.1064.1
  HDU CHECKSUM  DATASUM
   1:  updated  updated
   2:  updated  correct
   OK, all checksums are valid.
--- end ftchecksum
(heasoft) idies@df736f00ea38:~/workspace/Storage/Nandita_Das/persistent/uvot$ uvotimsum
Name of input image file(s)[sw00554620153uuu_sk.img] sw00554620153uvv_sk.img
Output file name[uuu_sum.fits] uvv_sum.fits
uvotimsum: HDU [0] is on the exclude list ASPCORR:NONE
uvotimsum: shell uvotimsum1 "infile=sw00554620153uvv_sk.img" "outfile=xout.1088.3" "ra=173.144337" "dec=27.698042" "pixs
ize=0.00027888888888381462" "width=1169" "height=1129" "datatype=COUNT" "exclude=0" "clobber=no" "history=yes" "chatter=3"
uvotimsum:
--- begin uvotimsum1
status: parameters loaded
status: HDU [0] is on the exclude list
status: assimilating HDU 1+1
status: selected output units [deg]
status: set output system FK5/2.000000e+03
status: created file xout.1088.3
status: created output image
--- end uvotimsum1
uvotimsum: shell fthedit "infile=xout.1088.3" "keyword=@template.1088.2" "operation=ADD" "history=NO" "protect=YES" "lon
gstring=NO" "chatter=1"
uvotimsum: --- begin/end fthedit
uvotimsum: shell ftemplate "template=template.1088.2" "outfile=normal.1088.4"
uvotimsum: --- begin/end ftemplate
uvotimsum: shell ftappend "infile=output.1088.1+0[col #EXTNAME='V'; #FILTER='V';#EXPOSURE=144.466893341981;#TSTART=40417
6580.01312;#TSTOP=404176726.79506;#FRAMTIME=0.0110322;]" "outfile=normal.1088.4" "history=NO" "chatter=1"
uvotimsum: --- begin/end ftappend
uvotimsum: shell ftchecksum "infile=output.1088.1" "update=yes" "chatter=2" "datasum=Yes" "allok=No"
uvotimsum:
--- begin ftchecksum
File: output.1088.1
  HDU CHECKSUM  DATASUM
   1:  updated  updated
   2:  updated  correct
   OK, all checksums are valid.
--- end ftchecksum
```

```
(heasoft) idies@df736f00ea38:~/workspace/Storage/Nandita_Das/persistent/uvot$ uvotimsum
Name of input image file(s)[sw00554620153uuu_sk.img] sw00554620153uvv_sk.img
Output file name[uuu_sum.fits] uvv_sum.fits
uvotimsum: HDU [0] is on the exclude list ASPCORR:NONE
uvotimsum: shell uvotimsum1 "infile=sw00554620153uvv_sk.img" "outfile=xout.1088.3" "ra=173.144337" "dec=27.698042" "pixs
ize=0.00027888888381462" "width=1169" "height=1129" "datatype=COUNT" "exclude=0" "clobber=no" "history=yes" "chatter=3"
uvotimsum:
--- begin uvotimsum1
status: parameters loaded
status: HDU [0] is on the exclude list
status: assimilating HDU 1+1
status: selected output units [deg]
status: set output system FK5/2.000000e+03
status: created file xout.1088.3
status: created output image
--- end uvotimsum1
uvotimsum: shell fthedit "infile=xout.1088.3" "keyword=@template.1088.2" "operation=ADD" "history=NO" "protect=YES" "lon
gstring=NO" "chatter=1"
uvotimsum: --- begin/end fthedit
uvotimsum: shell ftemplate "template=template.1088.2" "outfile=normal.1088.4"
uvotimsum: --- begin/end ftemplate
uvotimsum: shell ftappend "infile=output.1088.1+0[col #EXTNAME='V'; #FILTER='V';#EXPOSURE=144.466893341981;#TSTART=40417
6580.01312;#TSTOP=404176726.79506;#FRAMTIME=0.0110322;]" "outfile=normal.1088.4" "history=NO" "chatter=1"
uvotimsum: --- begin/end ftappend
uvotimsum: shell ftchecksum "infile=output.1088.1" "update=yes" "chatter=2" "datasum=Yes" "allok=No"
uvotimsum:
--- begin ftchecksum
File: output.1088.1
  HDU CHECKSUM  DATASUM
   1:  updated  updated
   2:  updated  correct
   OK, all checksums are valid.
--- end ftchecksum
(heasoft) idies@df736f00ea38:~/workspace/Storage/Nandita_Das/persistent/uvot$ uvotimsum
Name of input image file(s)[sw00554620153uvv_sk.img] sw00554620153uw1_sk.img
Output file name[uvv_sum.fits] uw1_sum.fits
uvotimsum: HDU [0] is on the exclude list ASPCORR:NONE
uvotimsum: shell uvotimsum1 "infile=sw00554620153uw1_sk.img" "outfile=xout.1112.3" "ra=173.141840" "dec=27.696947" "pixs
ize=0.00027888888381462" "width=1185" "height=1144" "datatype=COUNT" "exclude=0" "clobber=no" "history=yes" "chatter=3"
uvotimsum:
--- begin uvotimsum1
status: parameters loaded
status: HDU [0] is on the exclude list
status: assimilating HDU 1+1
status: selected output units [deg]
status: set output system FK5/2.000000e+03
status: assimilating HDU 2+1
status: assimilating HDU 3+1
status: assimilating HDU 4+1
status: assimilating HDU 5+1
status: assimilating HDU 6+1
status: assimilating HDU 7+1
status: assimilating HDU 8+1
status: assimilating HDU 9+1
status: assimilating HDU 10+1
status: assimilating HDU 11+1
status: assimilating HDU 12+1
status: assimilating HDU 13+1
status: assimilating HDU 14+1
status: assimilating HDU 15+1
status: created file xout.1112.3
status: created output image
--- end uvotimsum1
uvotimsum: shell fthedit "infile=xout.1112.3" "keyword=@template.1112.2" "operation=ADD" "chatter=1" "longstring=NO" "hi
story=NO" "protect=YES"
uvotimsum: --- begin/end fthedit
uvotimsum: shell ftemplate "template=template.1112.2" "outfile=normal.1112.4"
uvotimsum: --- begin/end ftemplate
uvotimsum: shell ftappend "infile=output.1112.1+0[col #EXTNAME='UVW1'; #FILTER='UVW1';#EXPOSURE=23711.4122759876;#TSTART
=404094684.51004;#TSTOP=404175677.50932;#FRAMTIME=0.0110322;]" "outfile=normal.1112.4" "history=NO" "chatter=1"
uvotimsum: --- begin/end ftappend
uvotimsum: shell ftchecksum "infile=output.1112.1" "update=yes" "datasum=Yes" "chatter=2" "allok=No"
uvotimsum:
--- begin ftchecksum
File: output.1112.1
  HDU CHECKSUM  DATASUM
   1:  updated  updated
   2:  updated  correct
   OK, all checksums are valid.
--- end ftchecksum
```

```
(heasoft) idies@df736f00ea38:~/workspace/Storage/Nandita_Das/persistent/uvot$ uvotimsum
Name of input image file(s)[sw00554620153uw1_sk.img] sw00554620153uw2_sk.img
Output file name[uw1_sum.fits] uw2_sum.fits
uvotimsum: HDU [0] is on the exclude list ASPCORR:NONE
uvotimsum: shell uvotimsum1 "infile=sw00554620153uw2_sk.img" "outfile=xout.1357.3" "ra=173.144512" "dec=27.698458" "pixs
ize=0.00027888888381462" "width=1174" "height=1134" "datatype=COUNT" "exclude=0" "clobber=no" "history=yes" "chatter=3"
uvotimsum:
--- begin uvotimsum1
status: parameters loaded
status: HDU [0] is on the exclude list
status: assimilating HDU 1+1
status: selected output units [deg]
status: set output system FK5/2.000000e+03
status: created file xout.1357.3
status: created output image
--- end uvotimsum1
uvotimsum: shell fthedit "infile=xout.1357.3" "keyword=@template.1357.2" "operation=ADD" "protect=YES" "longstring=NO" "
chatter=1" "history=NO"
uvotimsum: --- begin/end fthedit
uvotimsum: shell ftemplate "template=template.1357.2" "outfile=normal.1357.4"
uvotimsum: --- begin/end ftemplate
uvotimsum: shell ftappend "infile=output.1357.1+0[col #EXTNAME='UVW2'; #FILTER='UVW2';#EXPOSURE=578.508325580053;#TSTART
=404175987.01578;#TSTOP=404176574.79456;#FRAMTIME=0.0110322;]" "outfile=normal.1357.4" "chatter=1" "history=NO"
uvotimsum: --- begin/end ftappend
uvotimsum: shell ftchecksum "infile=output.1357.1" "update=yes" "chatter=2" "allok=No" "datasum=Yes"
uvotimsum:
--- begin ftchecksum
File: output.1357.1
  HDU CHECKSUM  DATASUM
   1:  updated  updated
   2:  updated  correct
   OK, all checksums are valid.
--- end ftchecksum
```

To use the summed images in the XSPEC package, we need to convert them to the .pha format. Before doing that, we need to create .reg files for the source and background separately using the ds9 program (as we did in the case of processing X-ray images). One tip for ds9 is to change the scale to logarithmic instead of linear to see the sources more clearly. Locate the source in the UV/optical images based on the known equatorial coordinates of the source.

Since we have 6 filters, be careful with the file naming. One suggestion is the following notation u[filter] src.reg for the source (and similar for the background).

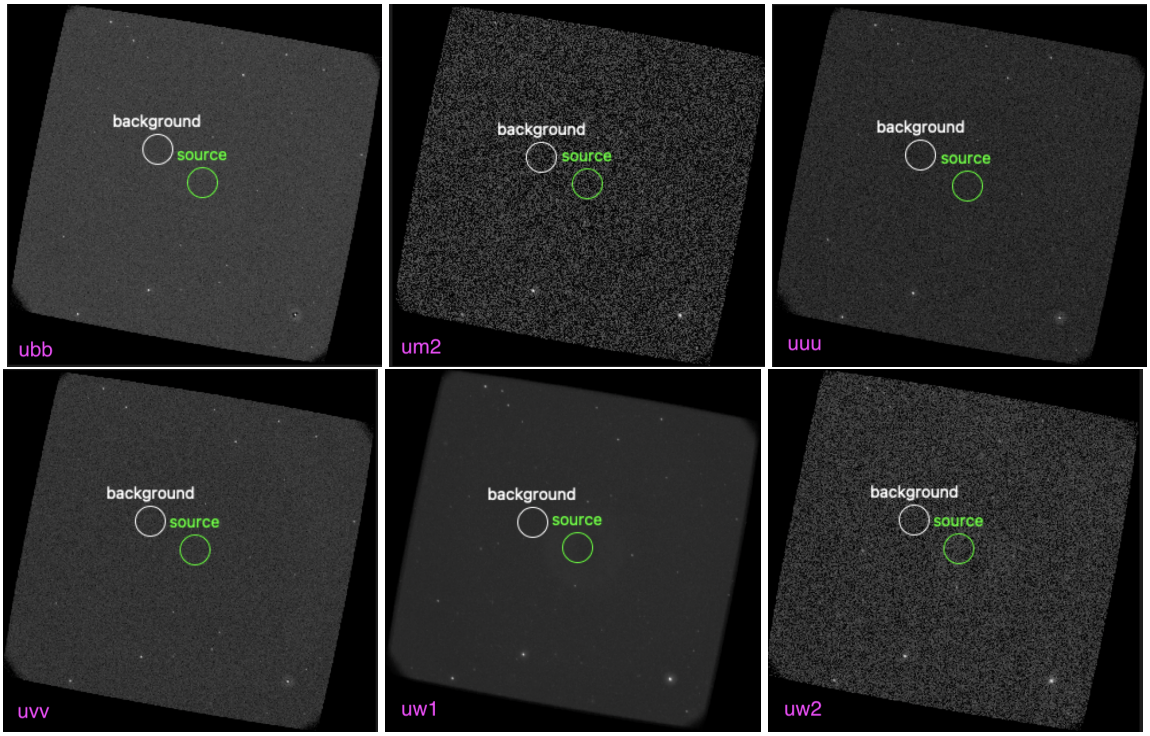


Fig. 2.— Source and Backgroun region for uvot filter.

Before converting the summed images into .pha files, we need to download calibration files from the link https: (Swift Responses). For each filter, we will have one .rsp file.

UVOT	UV Grism	ugrism.rsp
	Optical Grism	vgrism.rsp
	White	swuwh_20041120v105.rsp
	U	swuuu_20041120v105.rsp
	B	swubb_20041120v105.rsp
	V	swuvv_20041120v105.rsp
	UVW1	swuw1_20041120v106.rsp
	UVM2	swum2_20041120v106.rsp
	UVW2	swuw2_20041120v106.rsp

Now we can write in the terminal:

```
uvot2pha infile=u[filter]_sum.fits srcpha=[filter].pha bkgpha=[filter]
bkg.pha srcreg=u[filter] src.reg bkgreg=u[filter] bkg.reg resp
file=[filter].rsp clobber7=y chatter=1
```

```
(heasoft) idies@5a4939538e8e:~/workspace/Storage/Nandita_Das/persistent/uvot$ uvot2pha
 infile=uuu_sum.fits srcpha=uuu.pha bkgpha=uuu_bkg.pha srcreg=uuu_src.reg bkgreg=uuu_b
kg.reg respfile=swuuu_20041120v105.rsp clobber=yes chatter=1
uvot2pha infile=ubb_sum.fits srcpha=ubb.pha bkgpha=ubb_bkg.pha srcreg=ubb_src.reg bkgr
eg=ubb_bkg.reg respfile=swubb_20041120v105.rsp clobber=yes chatter=1
uvot2pha infile=uvv_sum.fits srcpha=uvv.pha bkgpha=uvv_bkg.pha srcreg=uvv_src.reg bkgr
eg=uvv_bkg.reg respfile=swuvv_20041120v105.rsp clobber=yes chatter=1
uvot2pha infile=uw1_sum.fits srcpha=uw1.pha bkgpha=uw1_bkg.pha srcreg=uw1_src.reg bkgr
eg=uw1_bkg.reg respfile=swuw1_20041120v106.rsp clobber=yes chatter=1
uvot2pha infile=uw2_sum.fits srcpha=uw2.pha bkgpha=uw2_bkg.pha srcreg=uw2_src.reg bkgr
eg=uw2_bkg.reg respfile=swuw2_20041120v106.rsp clobber=yes chatter=1
uvot2pha infile=um2_sum.fits srcpha=um2.pha bkgpha=um2_bkg.pha srcreg=um2_src.reg bkgr
eg=um2_bkg.reg respfile=swum2_20041120v106.rsp clobber=yes chatter=1
```

Wonderful! You have successfully created the files that you can use to plot the SED curve of the GRB.

SED of GRB

Spectral Modeling in XSPEC

In XSPEC, spectral modeling is performed by assuming a theoretical shape for the intrinsic spectrum of the source, denoted as $f(E)$. This spectrum is then folded through the instrument's response function, $\mathcal{R}(E, I)$, which gives the probability that a photon of energy E is detected in detector channel I. The modeled count rate in each channel, $C(I)$, is calculated using the integral:

$$C(I) = \int f(E)\, \mathcal{R}(E, I)\, dE$$

This result is then compared with the observed data, and a χ^2-minimization algorithm is applied to determine the best-fit parameters of the chosen model.

The system response function $\mathcal{R}(E, I)$ is continuous in energy, but for numerical modeling it must be discretized. This leads to the construction of a response matrix—stored in a file with the `.rsp` extension for UVOT filters—which maps photon energies to detector channels. In the case of XRT observations (specifically in Photon Counting (PC) mode), the response is described by two separate calibration files: an RMF file (`.rmf`) containing the normalized redistribution matrix, and an ARF file (`.arf`) containing effective area information. When combined, they define the full system response, enabling the comparison between modeled and observed spectra across the X-ray energy range.

Accurate use of these response matrices is crucial for fitting spectral models and deriving physical properties of the GRB afterglow emission in both X-ray and optical/UV domains.

Fitting the SED of GRB

We now load the data extracted from X and UV/optical images into XSPEC to plot the SED and fit the model.

```
(heasoft) idies@5a4939538e8e:~/workspace/Storage/Nandita_Das/persistent$ xspec

                XSPEC version: 12.14.1
        Build Date/Time: Thu Aug 22 22:23:14 2024

XSPEC12>data 1:1 uuu.pha 1:2 ubb.pha 1:3 uvv.pha 1:4 uw1.pha 1:5 uw2.pha 1:6 um2.pha 2:7 xrt.pi
Number of spectra read ..... 6***Warning: Detected response matrix energy bin value = 0 (or neg).
     XSPEC will instead use small finite value (response file will not be altered).
Number of spectra read ..... 7
7 spectra  in use
```

```
data 1:1 uuu.pha 1:2 ubb.pha 1:3 uvv.pha 1:4 uw1.pha 1:5 uw2.pha 1:6
um2.pha 2:7xrt.pi
```

```
Spectral Data File: uuu.pha  Spectrum 1
Net count rate (cts/s) for Spectrum:1  4.469e+00 +/- 4.855e+00 (3.2 % total)
 Assigned to Data Group 1 and Plot Group 1
  Noticed Channels:  1
  Telescope: SWIFT Instrument: UVOTA  Channel Type: PHA
  Exposure Time: 144.5 sec
 Using fit statistic: chi
 Using Background File                uuu_bkg.pha
  Background Exposure Time: 144.5 sec
 Using Response (RMF) File            swuuu_20041120v105.rsp for Source 1
Spectral Data File: ubb.pha  Spectrum 2
Net count rate (cts/s) for Spectrum:2  6.379e+00 +/- 7.055e+00 (1.8 % total)
 Assigned to Data Group 1 and Plot Group 2
  Noticed Channels:  1
  Telescope: SWIFT Instrument: UVOTA  Channel Type: PHA
  Exposure Time: 144.5 sec
 Using fit statistic: chi
 Using Background File                ubb_bkg.pha
  Background Exposure Time: 144.5 sec
 Using Response (RMF) File            swubb_20041120v105.rsp for Source 1
Spectral Data File: uvv.pha  Spectrum 3
Net count rate (cts/s) for Spectrum:3  9.245e+00 +/- 9.595e+00 (3.7 % total)
 Assigned to Data Group 1 and Plot Group 3
  Noticed Channels:  1
  Telescope: SWIFT Instrument: UVOTA  Channel Type: PHA
  Exposure Time: 144.5 sec
 Using fit statistic: chi
 Using Background File                uvv_bkg.pha
  Background Exposure Time: 144.5 sec
 Using Response (RMF) File            swuvv_20041120v105.rsp for Source 1
```

```
Spectral Data File: uw1.pha  Spectrum 4
Net count rate (cts/s) for Spectrum:4  1.665e+00 +/- 1.666e+00 (6.2 % total)
 Assigned to Data Group 1 and Plot Group 4
  Noticed Channels:  1
  Telescope: SWIFT Instrument: UVOTA  Channel Type: PHA
  Exposure Time: 2.371e+04 sec
 Using fit statistic: chi
 Using Background File                uw1_bkg.pha
  Background Exposure Time: 2.371e+04 sec
 Using Response (RMF) File            swuw1_20041120v106.rsp for Source 1

Spectral Data File: uw2.pha  Spectrum 5
Net count rate (cts/s) for Spectrum:5  1.290e+00 +/- 1.313e+00 (13.9 % total
 Assigned to Data Group 1 and Plot Group 5
  Noticed Channels:  1
  Telescope: SWIFT Instrument: UVOTA  Channel Type: PHA
  Exposure Time: 578.5 sec
 Using fit statistic: chi
 Using Background File                uw2_bkg.pha
  Background Exposure Time: 578.5 sec
 Using Response (RMF) File            swuw2_20041120v106.rsp for Source 1

Spectral Data File: um2.pha  Spectrum 6
Net count rate (cts/s) for Spectrum:6  6.208e-02 +/- 2.292e-01 (1.1 % total)
 Assigned to Data Group 1 and Plot Group 6
  Noticed Channels:  1
  Telescope: SWIFT Instrument: UVOTA  Channel Type: PHA
  Exposure Time: 423.1 sec
 Using fit statistic: chi
 Using Background File                um2_bkg.pha
  Background Exposure Time: 423.1 sec
 Using Response (RMF) File            swum2_20041120v106.rsp for Source 1

Spectral Data File: xrt.pi  Spectrum 7
Net count rate (cts/s) for Spectrum:7  6.832e-03 +/- 5.543e-04 (93.5 % total)
 Assigned to Data Group 2 and Plot Group 7
  Noticed Channels:  1-694
  Telescope: SWIFT Instrument: XRT  Channel Type: PI
  Exposure Time: 2.532e+04 sec
 Using fit statistic: chi
 Using Background File               background.pha
  Background Exposure Time: 2.532e+04 sec
 Using Response (RMF) File           swxpc0to12s6_20130101v014.rmf for Source 1
 Using Auxiliary Response (ARF) File  swxs6_20010101v001.arf



> cpd/ png
> setplot en
> plot ldata
```

```
XSPEC12>cpd /png
XSPEC12>setplot en
XSPEC12>plot ldata
XSPEC12>ignore bad

ignore:     0 channels ignored from  source number 2
ignore:     0 channels ignored from  source number 6
ignore:     0 channels ignored from  source number 1
ignore:     0 channels ignored from  source number 3
ignore:     0 channels ignored from  source number 4
ignore:     0 channels ignored from  source number 5
ignore:   686 channels ignored from  source number 7
XSPEC12>plot
```

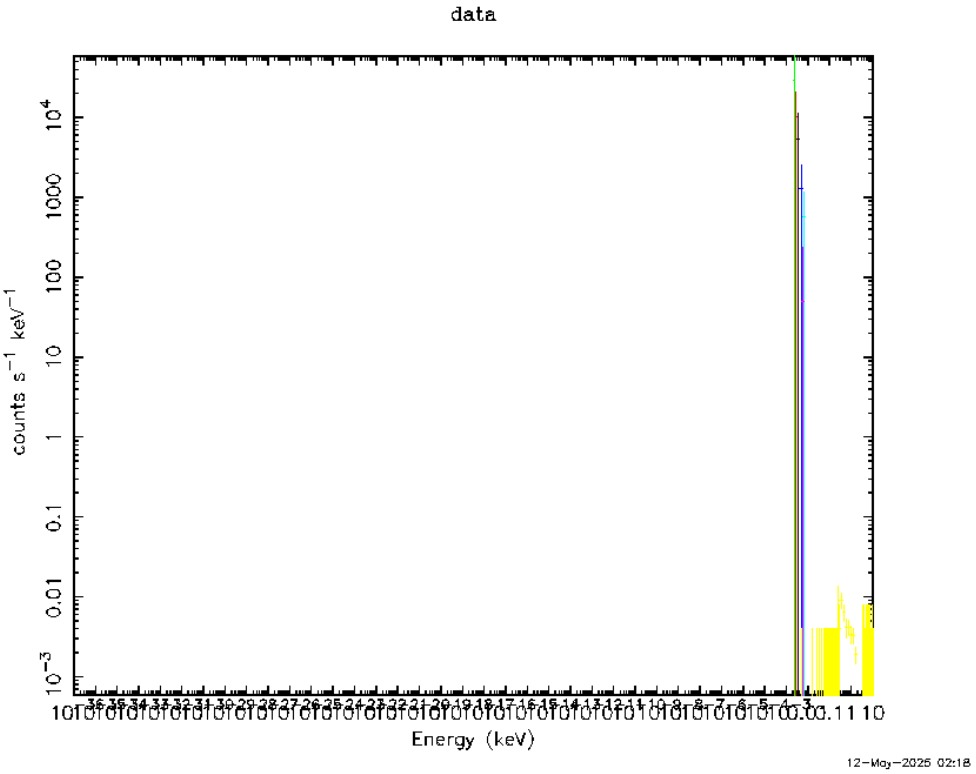


Fig. 3.— SED of afterglow

To ignore the channels previously marked as bad and 'zoom in' on the lines on the bottom-right side of the plot:

```
> ignore bad
> ignore 5.4-**
> plot ldata
```

```
XSPEC12>cpd /png
XSPEC12>setplot en
XSPEC12>ignore 5.4-**
      No channels ignored (no channels in specified range)
      No channels ignored (no channels in specified range)
      No channels ignored (no channels in specified range)
      No channels ignored (no channels in specified range)
      No channels ignored (no channels in specified range)
      No channels ignored (no channels in specified range)
   485 channels (210-694) ignored in spectrum #     7
```

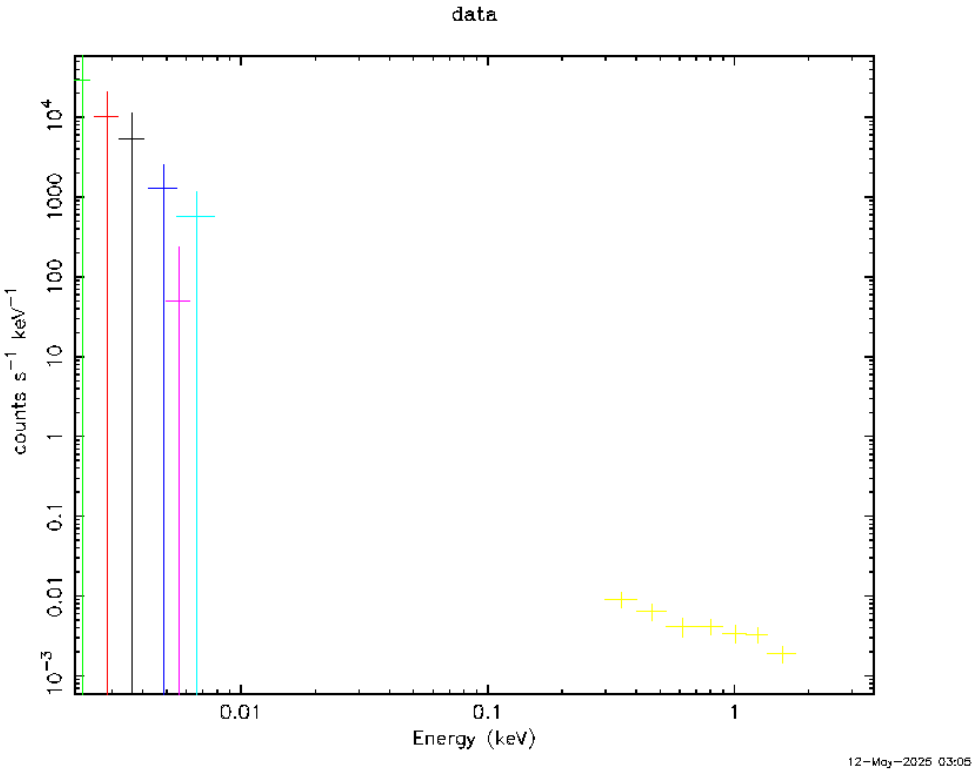


Fig. 4.— Better version of SED after discarding data above 5.4 keV.

Now that we have a nice and clean SED, we can proceed to the fitting. To start, we need to specify the model used for fitting. We will use the standard power-law model with absorption, which can be set as follows:

To perform fitting we ran:

```
> model phabs*powerlaw
1:data group 1::phabs:nH>1
2:data group 1::powerlaw:PhoIndex>
3:data group 1::powerlaw:norm>
4:data group 2::phabs:nH>2
5:data group 2::powerlaw:PhoIndex>1.5
6:data group 2::powerlaw:norm>1e4
```

We then run 'renorm' to synchronize the normalization parameter across both data groups and optimize the initial parameter guesses, which helps reduce the chi-squared value.

```
XSPEC12>model phabs*powerlaw

Input parameter value, delta, min, bot, top, and max values for ...
              1      0.001(      0.01)          0          0     100000      1e+06
1:data group 1::phabs:nH>1
              1       0.01(      0.01)         -3         -2          9         10
2:data group 1::powerlaw:PhoIndex>
              1       0.01(      0.01)          0          0      1e+20      1e+24
3:data group 1::powerlaw:norm>

Input parameter value, delta, min, bot, top, and max values for ...
              1      0.001(      0.01)          0          0     100000      1e+06
4:data group 2::phabs:nH>2
              1       0.01(      0.01)         -3         -2          9         10
5:data group 2::powerlaw:PhoIndex>1.5
              1       0.01(      0.01)          0          0      1e+20      1e+24
6:data group 2::powerlaw:norm>1e4

========================================================================
Model phabs<1>*powerlaw<2> Source No.: 1   Active/On
Model Model Component  Parameter  Unit     Value
 par  comp
                           Data group: 1
   1    1   phabs      nH         10^22    1.00000      +/-  0.0
   2    2   powerlaw   PhoIndex            1.00000      +/-  0.0
   3    2   powerlaw   norm                1.00000      +/-  0.0
                           Data group: 2
   4    1   phabs      nH         10^22    2.00000      +/-  0.0
   5    2   powerlaw   PhoIndex            1.50000      +/-  0.0
   6    2   powerlaw   norm                1.00000E+04  +/-  0.0
------------------------------------------------------------------------


Fit statistic  : Chi-Squared                    1.34     using 1 bins, spectrum 1, gr
oup 1.
                 Chi-Squared                    0.01     using 1 bins, spectrum 2, gr
oup 1.
                 Chi-Squared                    0.48     using 1 bins, spectrum 3, gr
oup 1.
                 Chi-Squared                   10.08     using 1 bins, spectrum 4, gr
oup 1.
                 Chi-Squared                   26.53     using 1 bins, spectrum 5, gr
oup 1.
                 Chi-Squared                  417.16     using 1 bins, spectrum 6, gr
oup 1.
                 Chi-Squared              2.310261e+18     using 8 bins, spectrum 7,
group 2.
Total fit statistic                       2.310261e+18     with 8 d.o.f.

Test statistic : Chi-Squared              2.310261e+18     using 14 bins.
 Null hypothesis probability of 0.000000e+00 with 8 degrees of freedom
 Current data and model not fit yet.
```

Next plot the model with the initial parameters by typing plot. The plot will noe display, in addition to the observed data points, a curve corresponding to the model for the given parameters (it will be a curve for X-ray spectra and points for UV/optical data). Of course, it will not follow perfectly the data, so next run the fitting in the following way:

```
> fit 100
```

```
XSPEC12>fit 100
                                  Parameters
Chi-Squared  |beta|/N    Lvl          1:nH    2:PhoIndex        3:norm          4:nH
   5:PhoIndex        6:norm
***Warning: Zero alpha-matrix diagonal element for parameter 1
 Parameter 1 is pegged at 1 due to zero or negative pivot element, likely
 caused by the fit being insensitive to the parameter.
126.358      3.90295       5       1.00000       3.11505   4.22367e-08       2.00000
      1.50000   3.57235e-05
126.358      299887        4       1.00000       3.11509   4.22446e-08       1.99998
      1.50000   3.57235e-05
***Warning: Zero alpha-matrix diagonal element for parameter 1
 Parameter 1 is pegged at 1 due to zero or negative pivot element, likely
 caused by the fit being insensitive to the parameter.
124.046      299941        0       1.00000       3.42104   1.07557e-07       1.86239
      1.51331   3.56455e-05
105.804      653100        0       1.00000       3.46864   1.27955e-07      0.817737
      1.68152   3.33143e-05
90.2986      159293       -1       1.00000       3.51695   1.07053e-07      0.306822
      2.20855   2.38533e-05
24.0798      193234       -1       1.00000       3.55648   8.72719e-08     0.0218364
      2.31635   2.72311e-05
10.3347      245986       -2       1.00000       3.90976   6.40777e-09    0.00341116
      2.13145   3.33911e-05
6.18781      1.39611e+07  -1       1.00000       4.10826   7.58100e-09   0.000202154
      2.24256   3.49883e-05
5.20468      3.35518e+07  -1       1.00000       4.10737   5.48778e-09   8.25564e-05
      2.26454   3.55860e-05
5.0095       3.15012e+06  -1       1.00000       4.13989   4.40999e-09   2.90383e-05
      2.27157   3.57730e-05
4.92728      877717       -1       1.00000       4.17844   3.61391e-09   3.24112e-06
      2.27375   3.58315e-05
4.88215      1.10471e+06  -1       1.00000       4.21672   2.96615e-09   1.32693e-08
      2.27427   3.58496e-05
4.73163      1.33541e+06  -2       1.00000       4.53866   4.18685e-10   5.17597e-09
      2.26420   3.61356e-05
4.56372      2.11509e+08  -2       1.00000       4.94203   3.10571e-11   1.45373e-09
      2.29465   3.66794e-05
3.95245      4.30144e+09  -1       1.00000       5.09358   3.93498e-11   2.48058e-10
      2.29297   3.69435e-05
***Warning: Zero alpha-matrix diagonal element for parameter 4
 Parameter 4 is pegged at 2.48058e-10 due to zero or negative pivot element, likely
 caused by the fit being insensitive to the parameter.
```

```
3.30779      8.05079e+09  -1       1.00000       5.08994   3.10465e-11   2.48058e-10
      2.35612   3.77008e-05
3.28748      8.17268e+08  -1       1.00000       5.10965   2.69716e-11   2.48058e-10
      2.36123   3.77245e-05
3.27016      4.00858e+06  -1       1.00000       5.13255   2.38165e-11   2.48058e-10
      2.36179   3.77242e-05
3.25338      1.35106e+07  -1       1.00000       5.15504   2.10904e-11   2.48058e-10
      2.36185   3.77240e-05
3.23718      8.6563e+06   -1       1.00000       5.17705   1.87225e-11   2.48058e-10
      2.36186   3.77239e-05
3.22156      2.31529e+06  -1       1.00000       5.19857   1.66610e-11   2.48058e-10
      2.36186   3.77239e-05
3.20649      5.396e+06    -1       1.00000       5.21963   1.48619e-11   2.48058e-10
      2.36186   3.77239e-05
3.19197      1.46078e+07  -1       1.00000       5.24023   1.32882e-11   2.48058e-10
      2.36186   3.77239e-05
3.17797      2.54551e+07  -1       1.00000       5.26037   1.19085e-11   2.48058e-10
      2.36186   3.77239e-05
3.16448      3.80738e+07  -1       1.00000       5.28008   1.06963e-11   2.48058e-10
      2.36186   3.77239e-05
3.15149      5.25997e+07  -1       1.00000       5.29935   9.62872e-12   2.48058e-10
      2.36186   3.77239e-05
3.13898      6.91676e+07  -1       1.00000       5.31820   8.68657e-12   2.48058e-10
      2.36186   3.77239e-05
3.12693      8.79104e+07  -1       1.00000       5.33665   7.85330e-12   2.48058e-10
      2.36186   3.77239e-05
3.11533      1.08958e+08  -1       1.00000       5.35468   7.11478e-12   2.48058e-10
      2.36186   3.77239e-05
3.10417      1.32438e+08  -1       1.00000       5.37233   6.45887e-12   2.48058e-10
      2.36186   3.77239e-05
3.09343      1.58471e+08  -1       1.00000       5.38959   5.87515e-12   2.48058e-10
      2.36186   3.77239e-05
3.08309      1.87175e+08  -1       1.00000       5.40648   5.35463e-12   2.48058e-10
      2.36186   3.77239e-05
3.07314      2.18661e+08  -1       1.00000       5.42300   4.88957e-12   2.48058e-10
      2.36186   3.77239e-05



***Warning: Zero alpha-matrix diagonal element for parameter 1
***Warning: Zero alpha-matrix diagonal element for parameter 4
 Parameter 1 is pegged at 1 due to zero or negative pivot element, likely
 caused by the fit being insensitive to the parameter.
 Parameter 4 is pegged at 2.48058e-10 due to zero or negative pivot element, likely
 caused by the fit being insensitive to the parameter.
3.06357      2.53032e+08  -1       1.00000       5.43916   4.47325e-12   2.48058e-10
      2.36186   3.77239e-05
================================================
```

```
 Variances and Principal Axes
                 2        3        5        6
 7.8645E-24|  0.0000   1.0000   0.0000   0.0000
 9.4956E-12|  0.0000   0.0000   0.0000   1.0000
 2.0630E-02|  0.0000   0.0000   1.0000  -0.0000
 2.8540E+00|  1.0000  -0.0000   0.0000   0.0000
------------------------------------------------

================================================
  Covariance Matrix
        1           2           3           4
   2.854e+00  -7.945e-11   0.000e+00   0.000e+00
  -7.945e-11   2.220e-21   0.000e+00   0.000e+00
   0.000e+00   0.000e+00   2.063e-02  -9.446e-08
   0.000e+00   0.000e+00  -9.446e-08   9.928e-12
------------------------------------------------

======================================================================
Model phabs<1>*powerlaw<2> Source No.: 1   Active/On
Model Model Component  Parameter  Unit     Value
 par  comp
                           Data group: 1
   1    1   phabs      nH         10^22    1.00000      +/-  -1.00000
   2    2   powerlaw   PhoIndex            5.43916      +/-  1.68937
   3    2   powerlaw   norm                4.47325E-12  +/-  4.71154E-11
                           Data group: 2
   4    1   phabs      nH         10^22    2.48058E-10  +/-  -1.00000
   5    2   powerlaw   PhoIndex            2.36186      +/-  0.143632
   6    2   powerlaw   norm                3.77239E-05  +/-  3.15090E-06
----------------------------------------------------------------------

Fit statistic  : Chi-Squared                    0.05     using 1 bins, spectrum 1, gr
oup 1.
                 Chi-Squared                  0.0005     using 1 bins, spectrum 2, gr
oup 1.
                 Chi-Squared                    0.10     using 1 bins, spectrum 3, gr
oup 1.
                 Chi-Squared                    0.32     using 1 bins, spectrum 4, gr
oup 1.
                 Chi-Squared                    0.55     using 1 bins, spectrum 5, gr
oup 1.
                 Chi-Squared                    0.57     using 1 bins, spectrum 6, gr
oup 1.
                 Chi-Squared                    1.47     using 8 bins, spectrum 7, gr
oup 2.
Total fit statistic                             3.06     with 8 d.o.f.

Test statistic : Chi-Squared                    3.06     using 14 bins.
 Null hypothesis probability of 9.30e-01 with 8 degrees of freedom
```

Next, redraw the model and visually compare the fitting quality. Note that, in addition to the SED and the corresponding model, we will also plot their difference, with the following command:

```
> plot ldata residual
XSPEC12 > iplot
PLT > la x Energy (keV)
> la y Counts s-1 keV-1
> la top SED of GRB 130427A
> time off
> plot
> hardcopy grb_sed.ps/cps
```

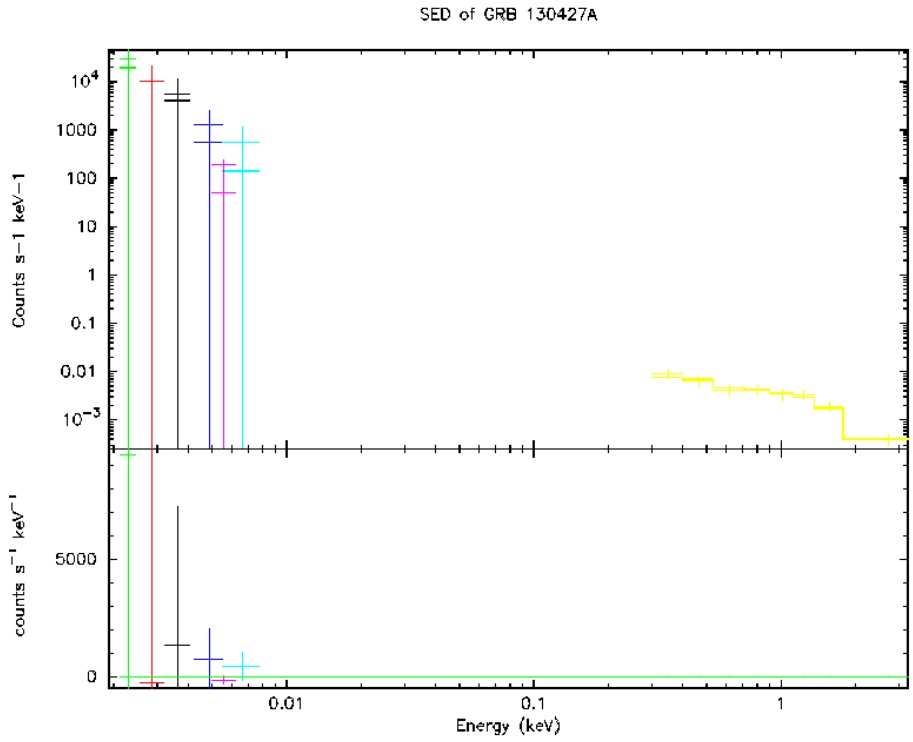


Fig. 5.— Comparison of observed data and fitting model.

To change the color of the X-ray spectrum and its corresponding model for a start (this is the most obvious example to see the change) type the following:

```
> color 1 on 13
> color 2 on 14
> plot
```

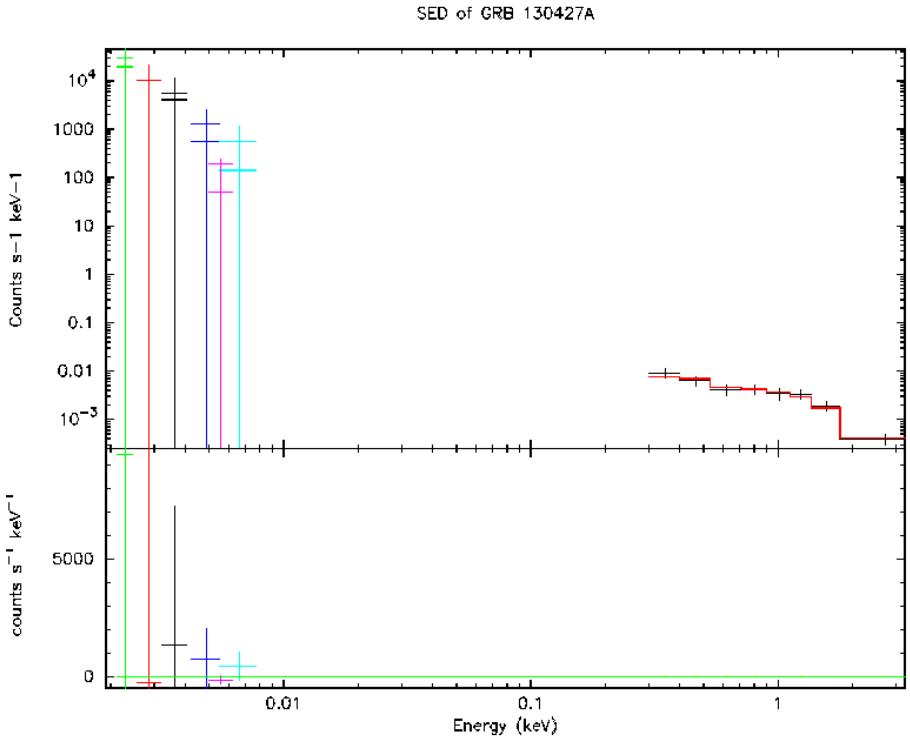


Fig. 6.— Comparison of observed data and fitting model with color corresponding.

References

GRB List: https://www.rochesterastronomy.org/snimages/grblist.html
Swift Search: https://www.swift.ac.uk/swift_live/index.php#advanced
Swift GRB Responses: https://swift.gsfc.nasa.gov/proposals/swift_responses.html