X-ray Data Analysis of point sources, PART-II.

Extraction the spectrum of a point-source, count-to-flux conversion, extraction of physical properties, flux upper limits.

We have three goals:

(1) Learn how to extract a spectrum of a point source detected by Chandra. For this step we will use the *ciao* software, which is specific to Chandra.
(2) Fit the spectrum and extract the physical parameters, that will allow us to perform the spectral calibration (i.e. convert the count-rates into fluxes). We will use *Xspec*, which is a multi-mission software, useful to fit any X-ray/Gamma-ray spectrum.
(3) Compute flux upper limits in the case of non-detections.

We will continue our analysis of the X-ray emission from SN2014C, using the Chandra obs IDs 17569 and 21077.

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1. Extraction of Chandra spectral files with ciao

We will extract the X-ray spectrum of SN2014C as observed on two different epochs, one corresponds to ID 17569, and one corresponds to ID 21077. We will start from ID 17569. Start by downloading the data if you do not have the data.

Go into /17569/primary/. We will have to create a source region file and a background region file with optimal sizes and positions on your CCD. Load the evt2 file in ds9 and load the .reg file with the sources detected by wavedetect (if you followed my naming convention this file should be named evt_500_8000_src.reg; if you did not follow the suggested names, try to figure out which name you gave to the region file in wavedetect).

Check the size of the region around SN2014C, and create a **circular** region with radius that contains the entire region created by wavedetect around SN2014C, and centered exactly at the same position as the source created by wavedetect. Now open the PSF map that you created last time with mkpsfmap (evt_500_8000_psfmap.fits) and go with the cursor at the position of SN2014C and check the size of the PSF there. SN2014C is a point-source and the region that you are creating should not be smaller than the PSF! But not much larger than that either (why? Ask me if you do not find an obvious answer to this question). For Chandra on-axis a source region size around ~2" is standard for bright sources like this one. For faint sources, you would use a smaller region of ~1" to maximize the S/N ratio.

Save the source region with name: sou_Narcsec.reg (in fk5 coordinates, replace "N" with the arcsec radius that you used). Now save another version of the source region in physical coordinates with name: sou_Narcsec_physical.reg

For the background: Load the background region that you created last time in the ds9 and check if any of the sources found by wavedetect fall inside your background region. If yes, move the region around so that it does not contain any source. Then save a bk.reg (in fk5 coordinates) and one bk_physical.reg (in physical coordinates). Note: all the 4 region files above need to be in the /primary/ folder (or you will have to add paths to the line commands below).

Do a listing of your files in the /17569/primary/ folder and make sure that the four .reg files are there. Open the four region files with an editor of your choice and make sure that each file contains the one

region of interest, ONLY.

ONLY AFTER YOU INSPECTED THE REGION FILES as indicated above:
run the *ciao* routine s*pecextract.*[1] Make sure you loaded *ciao* in your terminal, then launch specextract as below. Specextract will extract a spectrum of the source using the photons in the source region and a spectrum of the background, using the photons in your background region.

Note1: all in one command line!
Note2: modify, if needed the names of the region files.
Note3: you need to use regions in physical units.
Note4: edit the coordinates below (in red) and use the coordinates of the X-ray source of interest (i.e. the one you are extracting a spectrum of). You can find the coordinates of your X-ray source by either double clicking on the source region, or by using *fv* on the region.fits file generated by wavdetect

specextract infile="acisf17569N001_evt2.fits.gz[sky=region(sou_Narcsec_physical.reg)]" outroot=spec17569 bkgfile="acisf17569N001_evt2.fits.gz[sky=region(bk_physical.reg)]" weight=no correct=yes asp="pcadf539017771N001_asol1.fits.gz" mskfile="./../secondary/acisf17569_000N001_msk1.fits.gz" grouptype=NUM_CTS binspec=1 refcoord="12:29:06.70 +02:03:08.60"

Input:

- evt2 file: you know what it is.
- Region files: the ones you just created, in physical units.
- Outroot: this will be the common name shared by all the output (so that it will be very easy to track the output from different spectra extraction, just by changing the outroot name, if needed).
- "asol1.fits" file: instrumental file that contains the **aspect solution** (i.e. The pointing position of the Chandra telescope vs. time). For each observation, the aspect information is stored in the aspect solution files, which are of the form pcad<TSTART>_asol1.fits. Aspect data is collected through three instruments of the Pointing Control and Attitude Determination (PCAD) system. Gyroscopes are used to measure the short-term changes in the aspect, while a 4.25 inch optical telescope images guide stars for long-term tracking on the celestial coordinate system. Star positions from **Hipparcos** and other astrometric surveys are used to put the aspect solution into a standard reference frame. Why is this information important?
- "msk1" file: instrumental mask file. The mask file records the valid part of the detector element - ACIS CCD in this case - used for the observation (i.e. the portion for which events can be telemetered). The active portion of an element may be smaller than the default regions if an observation was performed using subarrays or custom windows (i.e. if the user decided to use only a portion of the detector). This information is used when creating response files, such as ARFs (which is one of our data products, see below). Why would we use a smaller portion of the detector? Can you think about a situation when this is helpful?
- *Binspec=1* Means we do not want to apply any binning to the spectral data, which means that each bin in our spectrum will represent one photon. This option is useful as it will allow us to fit the spectra ALSO in the regime of low count statistics (i.e. at the time of fit we will not use Chi2 statistics, but instead we will use C-stat or Wstat). If your source is bright, you can decide

1 For the final data analysis of a scientific paper, you would first re-run the pipeline on the raw data and re-generate the files in the /primary/ folder using the script chandra_repro. This step will ensure that you are using the latest, most accurate info on the instrumental response. You can follow the steps here.

to bin the spectra with 20-30 counts minimum, and then fit the spectra using Chi2 statistics. It will be clear at the time of fitting.
- Refcoords: ensures that the correct PSF correction is applied to the final flux. What is a PSF correction?

Open the aspect solution file with *fv* and have a look at the structure and content.

Important note on **Mission Elapsed Time (MET)**: Chandra computes time as seconds since January 1, 1998, 00:00:00 TT. This is specific to Chandra. Each mission has its own reference time.

Output:
- **Spectral files (*.pi)**: for the source and for the background: spec2_21077.pi (source not grouped), spec2_21077_bkg.pi (background not grouped), **spec2_21077_grp.pi** (source, grouped). Note: grouped or binned is the same.
- **Ancillary Response Files (*.arf)**: spec_17569.arf (for the source, not corrected for PSF losses = the amount of flux that falls outside your source region), spec2_21077.corr.arf (for the source, corrected for PSF losses), spec2_21077_bkg.arf (for the background. Here the PSF correction never applies as the background is not a point source). ARF files contais the combined telescope/filter/detector areas ("effective area") and the quantum efficiency (QE) as a function of energy averaged over time (and therefore, aspect). The effective area is [cm^2] and the QE is [counts/photon]; they are multiplied together to create the ARF, resulting in [cm^2 counts/photon].
- **Redistribution Matrix Files (*.rmf)**: spec2_21077.rmf (for the source), spec2_21077_bkg.rmf (for the background). RMF files contain the maps from energy space into detector pulse height (or position) space. You can read this as: they contain the information to go from "channel" into "energy" of a photon. Each photon with a given energy has a probability to be recorded in a particular channel. These files contain this information. E.g. when you were filtering in energy your evt2 file with ds9, you were saying: "energy=500:8000". Channel 500 is ~0.5 keV and channel 8000 is ~8 keV. The RMF files contain the accurate info about which channel maps into what energy in keV.

You can find more info on the different Chandra data products here:
http://cxc.harvard.edu/ciao/threads/intro_data/

Now repeat each of the steps above for ID 21077, making sure to rename the output files accordingly (it will make your life way easier). Remember to work in the /primary/ folder.

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2. Spectral fitting with Xspec (one spectrum)

The Xspec manual can be found here:
https://heasarc.gsfc.nasa.gov/xanadu/xspec/manual/XspecManual.html

Go into the /17569/primary/ folder and launch Xspec by typing:
xspec <return>

Now this terminal is taken over by Xspec.

Load the spectral files:
data spec_17569_grp.pi <*return*> Note: load the *GROUPED* file.

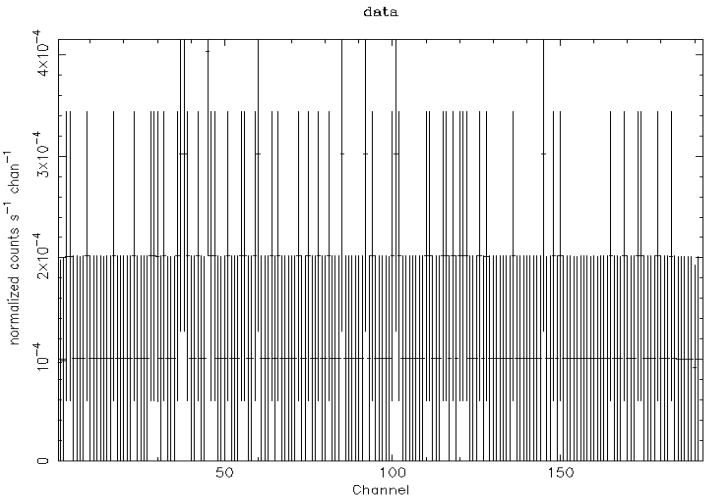
Xspec will return some valuable info about the content file, like the net count rate, exposure time etc. You will note that Xspec knows automatically that this file is associated with the bk files (.pi) and the rmf file and the .corr.arf file. This is because this info is stored in the header of the *spec_17569_grp.pi* file and Xspec is able to understand immediately which are the files to load, without having you typing in the information. This is very helpful and saves time. However, Xspec will not be able to find this info if launched from a place different from where you created the files. In that case, as we will see, we will have to type that info ourselves.

cpd /xw <*return*> Change plot device to XW (there are different options)/

A black window should appear. Go back to the terminal and display the data:

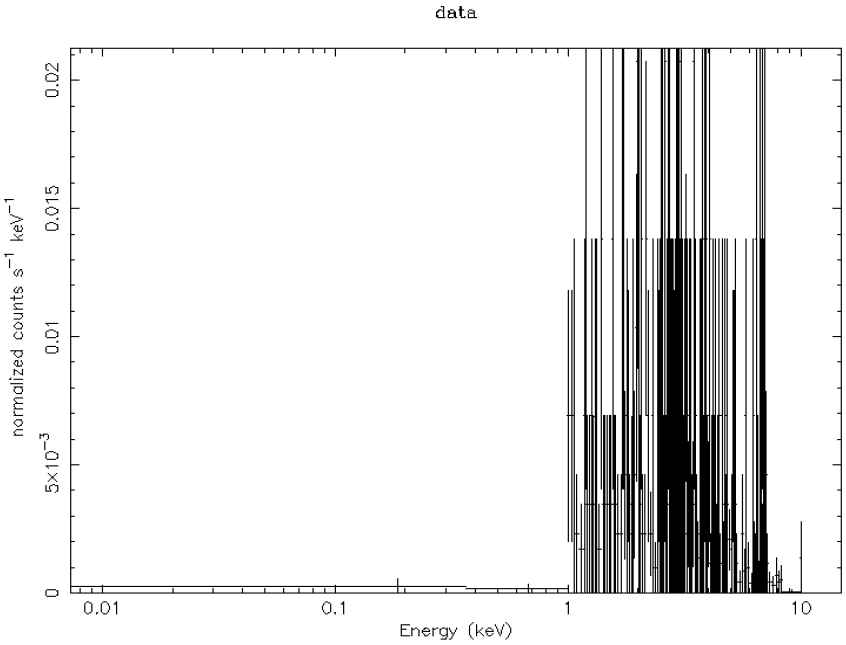
pl data <*return*>

This is a linear plot of the source data. You should see something similar to this plot:



Pay attention to the units of the x and y-axis. The x axis is in units of channels.

setpl ene <*return*> We go from channel into energy units for the x-axis
pl ldata <*return*> And here we re-plot but in log-log units. Note: we will always plot in LOG-LOG, never in linear! You should see something similar to the plot below:



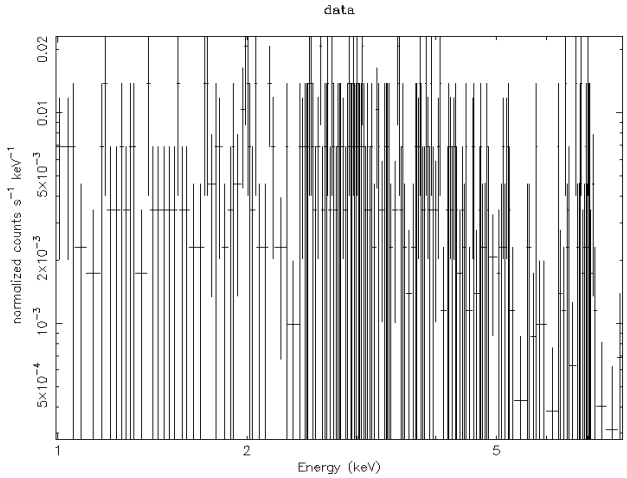
We will filter the "bad" events (e.g those that do not belong to the GTI- Good Time Intervals):

ignore bad <return>
pl ldata

Xspec will reject a few channels as a result of ignoring bad events.
Chandra is well calibrated between 0.5 and 8 keV. We will thus filter out events outside this energy range.

ignore 0.-0.5 <return>
ignore 8.-1000. <return>
pl ldata

Note: you need to put the "." after the number in ignore, or Xspec will understand you are speaking in channel units. Instead, with the "." Xspec understands you are speaking keV units. Here is the result: (note that there was no event with energy between 0.5 and 1 keV, so the plot starts at 1 keV)

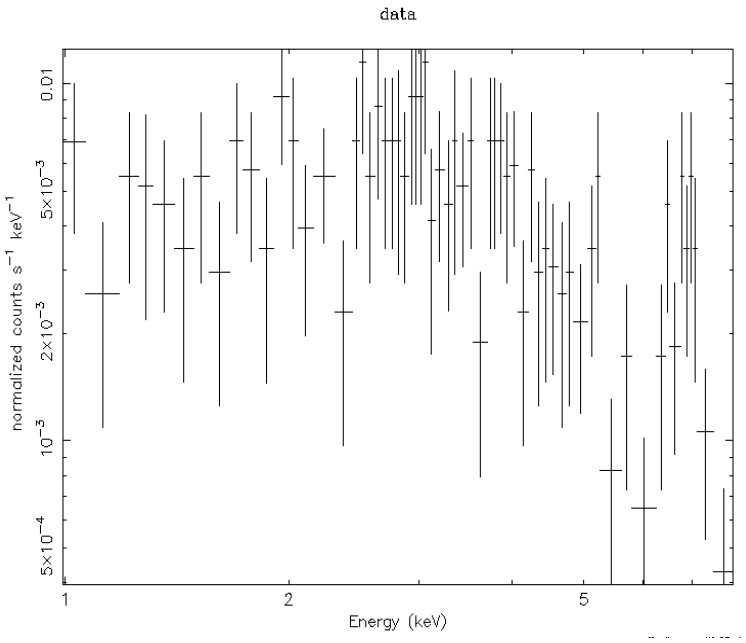


Here each bin represents one event. Now we will re-bin the spectrum for visualization purposes only (i.e. the plot looks different to help us doing the fitting, but the data that the software will fit are not re-binned). You should always keep in mind that re-binning means = loss of information. So, while it is ok to rebin for graphical purposes, the science must be done on not re-binned data. The motto is: "Account for every photon, make every photon count".

setpl rebin 5 3 <return>
pl ldata <return>

"5 and 3" are typical parameters that usually produce a good plot. Play around with both and you will see how things change in the plot. The goal is to have a plot where you can see the "shape" of the data better, **keeping in mind that you are not looking at the intrinsic spectral shape, but instead you are looking at the intrinsic spectral shape*instrumental response*intrinsic absorption*Milky Way absorption.** I.E. if the intrinsic spectral shape is a power-law you will not see a power-law. If this is not clear, stop and ask me.

Here is the result:



Load the most recent data about solar abudances:
abund aspl <return>

Since we quantify the absorption as equivalent amount of neutral hydrogen and we will use Solar abundances as a reference, we need to make sure we have the most updated data loaded. Forgetting to update the most recent solar abundances data would result in an inaccurate measurement of the absorption in our spectra.

ABSORBED SIMPLE POWER-LAW FIT

We will first try a fit with a simple power-law spectrum, where Flux_nu= norm*nu^(-Gamma). Gamma= photon index → as we are fitting the y axis in units of counts/s/keV. If we were to fit a y axis in units of energy/s/keV, then the index would be a spectral index beta, with Gamma=beta+1. There are many models already built into Xspec, like black-bodies, bremsstrahlung etc.

*mo tbabs*ztbabs*pow <return>*

Notes:

- pow= intrinsic model, which is built into Xspec already and is a simple power-law.
- tbabs= X-ray absorption component at redshift 0 (following the very same concept as what you read in the Morrison paper. Did you read it??). This will represent the absorption component of the Milky Way in the direction of SN2014C.
- ztbabs = X-ray absorption component at redshift z. This will represent the absorption component intrinsic to the host galaxy of SN2014C.

Here is how to put in your guesses for the parameters of the fit, step by step:

The NH from the Milky way in the direction of SN2014C is NH_MW=0.0614x10^22 cm-2 (do you remember how to calculate this number? Do you agree with this number?) This is an input parameter that will be frozen in our fit. Note: all the NH in Xspec are in units of 10^22 cm-2.

1:TBabs:nH> Type in: *0.0614 -1 <return>*
(-1 means: do not fit for this parameter, keep it frozen to the value that I tell you)

2:zTBabs:nH> This is the intrinsic NH. We will go with a first guess of 0.5. Type in:
0.5 <return>

3:zTBabs:Redshift> Our SN is at redshift 0, so we will type in:
0 <return>

4:powerlaw:PhoIndex> This is Gamma. We will go with 2 as first guess, so type in:
2 <return>

5:powerlaw:norm> This is the normalization of the power-law. Type in 1 as guess and then we renormalize the model.
1 <return>

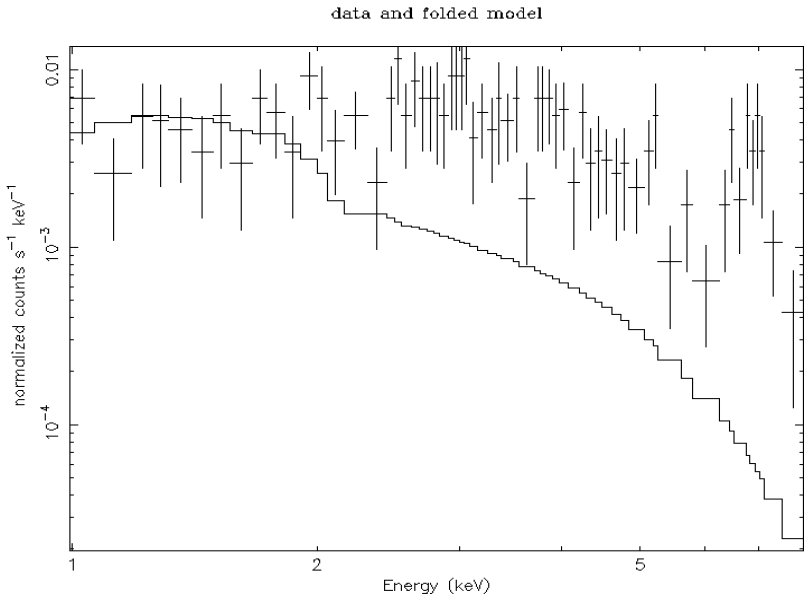
Xspec will return a summary of the input parameter of your fit. Before fitting, we have to renormalize the model and change the statistics from Chi2 to W-stat.

renorm <return>
statistic cstat <return>

With this command, Xspec will automatically know if there is a background file loaded or not and will know if it has to use the C-stat or W-stat for the fit (W-stat is a C-stat for cases with background, which means that we are effectively using Wstat here).

Let's have a look at the model and data BEFORE any attempt to fit (you always want your initial model parameter guesses to be reasonably close to the final values to avoid the risk of falling into local minima of the fitting statistics, as opposed to the absolute minimum, which identifies the best solution):

pl ldata



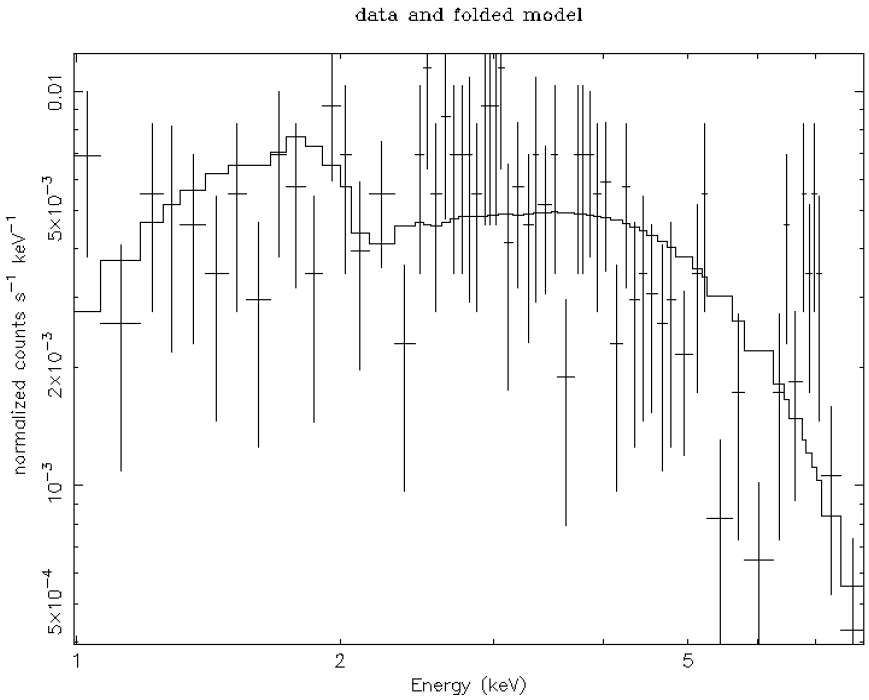
Now we fit:
fit 1000 <return> This is a simple fit and the fit should converge very soon to the final best solution, which will be reported in the parameter table as below:

```
========================================================================
Model TBabs<1>*zTBabs<2>*powerlaw<3> Source No.: 1   Active/On
Model Model Component  Parameter  Unit     Value
 par  comp
   1    1   TBabs      nH         10^22    6.14000E-02  frozen
   2    2   zTBabs     nH         10^22    0.566942     +/-  0.355537
   3    2   zTBabs     Redshift              0.0          frozen
   4    3   powerlaw   PhoIndex              0.206502     +/-  0.223015
   5    3   powerlaw   norm                  1.87724E-05  +/-  6.23359E-06
------------------------------------------------------------------------


Fit statistic : C-Statistic =         169.49 using 185 PHA bins and 182 degrees of freedom.

Test statistic : Chi-Squared =          208.26 using 185 PHA bins.
 Reduced chi-squared =         1.1443 for    182 degrees of freedom
 Null hypothesis probability =   8.856122e-02
XSPEC12>
```

IMPORTANT: do NOT trust the uncertainties reported in the table! The central value is accurate but the uncertainties are not. We will calculate uncertainties below.

To display your best fitting solution:
pl ldata <return>

Your plot should look similar to the plot below:



To calculate the model uncertainties on the best-fitting parameters, the syntax is:
unc confidence-level ##par

E.g. Uncertainties on intrinsic NH:
unc 1. 2 <*return*> This is the 1 sigma uncertainty on the intrinsic NH

```
XSPEC12>unc 1. 2
 Parameter   Confidence Range (1)
     2     0.153388     0.998276    (-0.410773,0.434115)
```

We will thus report the result of the fit as follows:
NH_intrinsic= 0.57 (-0.41, +0.43) in units of 10^22 cm-2 , 1 sigma c.l.
where the central value NH=0.57 was takes from the table above.

E.g. Uncertainties on Gamma:
unc 1. 4 <return>
We find: Gamma= 0.21 (-0.24, +0.25) 1 sigma c.l.

Absorbed Flux in a given energy band and its uncertainty, which I decided to be 0.3 -10 keV
flux 0.3 10. <return>

```
XSPEC12>flux 0.3 10.
Spectrum 1: Lower range bound          0.3 reset by matrix bound to          0.3
 Model Flux 0.00011511 photons (9.9444e-13 ergs/cm^2/s) range (0.30000 - 10.000 keV)
```

We find that the absorbed flux is ~9.9e-13 erg/s/cm2. These are physical units!! (i.e. the result is now in units that we can use to do science)

To compute the uncertainties on the flux, we will have to run simulations (i.e. a number of different

realization of the model, where the parameters will be allowed to vary in a range set by their error bars).

flux err 500 68. <return>

We are running 500 simulations, and I am asking to have as output the 68% confidence range for the flux.

```
XSPEC12>flux err 500 68.
Spectrum 1: Lower range bound          0.3 reset by matrix bound to          0.3
Parameter distribution is derived from fit covariance matrix.
 Model Flux 0.00011511 photons (9.9444e-13 ergs/cm^2/s) range (0.30000 - 10.000 keV)
     Error range 9.892e-05 - 0.0001205    (8.365e-13 - 1.055e-12)  (68.00% confidence)
```

From the output above, the final result that we will quote is:
Absorbed Flux (0.3-10 keV)= 9.94 (-1.58, +0.61)e-13 erg/s/cm2 (1 sigma c.l.)

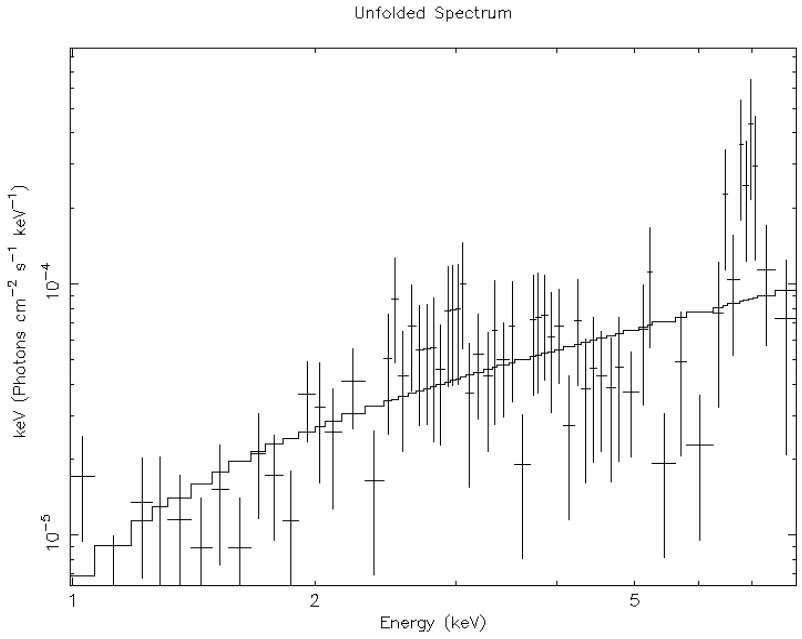
Very important 1: the X-ray flux depends on the energy band. In X-ray astronomy, quoting an X-ray flux without providing the energy range that was selected for the calculation of the flux has NO meaning. Every time you quote a flux in X-rays/ Gamma-rays you have to specify the energy range that you used.

Very important 2: the X-ray flux in a given energy band depends on the spectral shape assumed for the fit. This will become clear when later in the tutorial you will fit this very same spectrum with a bremsstrahlung spectrum.

To view the absorbed intrinsic spectrum, i.e. taking out the detector component
(which means: spectral shape*intrinsic absorption*Milky Way absorption):

pl eufspec <return>

This operation is called: unfolding the spectrum. It is possible to invert the matrix and solve for the intrinsic spectrum only after assuming a spectral shape. Note that in the plot below the y-axis is in units of energy/cm2/s/keV. The plot is thus Flux_nu~nu^-beta with beta=Gamma-1.
Above we found Gamma~0.2, so beta=-0.8 and the Flux~nu^0.8. Can you see the signature of absorption in the spectrum?



Unabsorbed Flux and its uncertainty:[2]
We will put to zero the Galactic and intrinsic NH and WITHOUT RE-FITTING we will compute the spectrum.

First we will put to 0 the Galactic NH:
newpar 1 0 <return>
Next we put to 0 the intrinsic NH:
newpar 2 0 <return>

To show the current model parameters, the initial info on the spectral files loaded:
show all <return>

Check if the two NH are 0 as in the table below:

```
========================================================================
Model TBabs<1>*zTBabs<2>*powerlaw<3> Source No.: 1   Active/On
Model Model Component  Parameter  Unit     Value
 par  comp
   1    1   TBabs      nH         10^22    0.0          frozen
   2    2   zTBabs     nH         10^22    0.0          +/-  0.355537
   3    2   zTBabs     Redshift              0.0          frozen
   4    3   powerlaw   PhoIndex              0.204766     +/-  0.223015
   5    3   powerlaw   norm                  1.87206E-05  +/-  6.23359E-06
------------------------------------------------------------------------
```

To calculate the unabsorbed flux in the 0.3 10 keV:
flux 0.3 10 <return>

2 This is the quick way to calculate the unabsorbed flux. The most accurate way to calculate the unabsorbed flux and its uncertainties is by specifying the model with cflux(). For the final analysis of your scientific papers, I recommend using cflux()

Which value do you find? Compare the unabsorbed to the absorbed flux (in the same energy band!). What do you find? Does it make sense?
To compute the uncertainties on the unabsorbed flux, we will assume that the **relative uncertainties** on the unabsorbed flux are the same as those that we derived for the absorbed flux. IMPORTANT: the relative uncertainties are the same, the absolute uncertainties will be different!!

Now repeat the same exercise with a thermal bremsstrahlung spectrum:

ABSORBED THERMAL BREMSSTRAHLUNG FIT

The value of the photon index that we found is "unusual". Synchrotron and Inverse Compton processes typically give Gamma=2. We found Gamma~0.2, which might suggest that the intrinsic spectrum is not a power-law. We will try to fit with an absorbed bremsstrahlung spectrum.

*mo tbabs*ztbabs*bremss <return>*

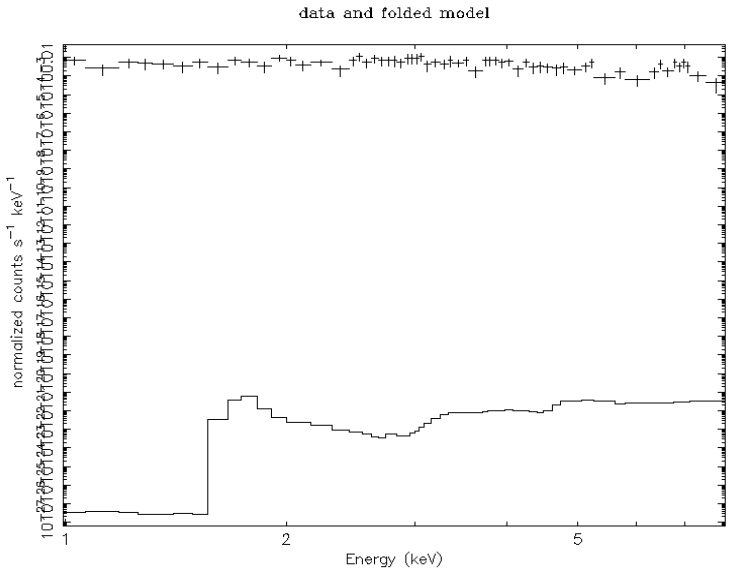
Use the same input parameters for the Galactic NH (frozen), a guess of 0.5 for the intrinsic NH (free to vary), redshift is 0. As best guess for the temperature (the units are keV), start with kT=20 keV. As before, renormalize with: *renorm <return>*

Your parameter table will like this before fitting:

```
========================================================================
Model TBabs<1>*zTBabs<2>*bremss<3> Source No.: 1   Active/On
Model Model Component  Parameter  Unit     Value
 par  comp
   1    1   TBabs      nH         10^22    6.14000E-02  frozen
   2    2   zTBabs     nH         10^22    0.500000     +/-  0.0
   3    2   zTBabs     Redshift              0.0          frozen
   4    3   bremss     kT         keV      20.0000      +/-  0.0
   5    3   bremss     norm                  1.00000      +/-  0.0
------------------------------------------------------------------------
```

pl ldata <return> Have a look at the plot.
fit 1000 <return>
pl ldata <return> Have a look at the data

You might end up with a situation like this one:



The fit did not converge and looking at the parameters below it is clear that the intrinsic NH exploded to unphysical values:

```
========================================================================
Model TBabs<1>*zTBabs<2>*bremss<3> Source No.: 1   Active/On
Model Model Component  Parameter  Unit     Value
 par  comp
   1    1   TBabs      nH         10^22    6.14000E-02  frozen
   2    2   zTBabs     nH         10^22    4960.49      +/-  4.18305E+43
   3    2   zTBabs     Redshift              0.0         frozen
   4    3   bremss     kT         keV      42.6499      +/-  2.88919E+45
   5    3   bremss     norm                8.11515E-02  +/-  3.57218E+41
------------------------------------------------------------------------
```

We will have to reset the initial parameter guesses. To help the fit converge, we will freeze one of the model parameters and fit the other ones:
newpar 2 0.5 -1 <return> In this way we are freezing the intrinsic NH to 0.5 (in units of 10^22 cm-2)
fit 1000 <return>
pl ldata

Which value of the T do you find?
Now thaw the intrinsic NH:
thaw 2 <return>
fit 1000 <return>
pl ldata <return>

How does the plot look now? The fit should now look better. However, try to compute the uncertainties on the intrinsic NH and T. What happens?

It seems that we are not able to constrain the uncertainties on the model parameters (and the parameter values). What you learned from this exercise is that the fit does not converge.

We will thus freeze T to 20 keV:
newpar 4 20 -1 <return>
fit 1000 <return>
pl ldata <return>

What is the best fitting intrinsic NH and 1 sigma error bars?
unc 1. 2 <return>

Calculate the 0.3 10 keV absorbed flux.
Calculate the 1 sigma uncertainty on the absorbed flux.

How does this value compare to the absorbed flux computed with a power-law model?

Compute the unabsorbed 0.3 10 keV flux.

Now repeat EVERYTHING for ID 21077: fit with a simple power-law first and then a thermal bremsstrahlung spectrum.

Now exit Xspec: *exit <return>*

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3. Joint fit of multiple spectra

It is often convenient to fit multiple spectra together (e.g. if you have reasons to believe that the same model applies to two spectra, and with a joint fit we will be able to constrain the parameters better). This will be the case for the gravitational wave source that you will analyze for the midterm, where we will have multiple spectra that are well fitted by a simple power law spectrum with the same photon index but different normalizations.

We will do a joint fit of the spectrum of SN2014C from ID 17569 and ID 21077.
We will load the two spectra into Xspec, and we will fit both spectra with an absorbed power-law

Inside the /21077/primary/ folder launch Xspec.
xspec <return>

We will start by loading the first data set:
data spec2_21077_grp.pi <return>
cpd /xw <return>
setpl ene <return>
pl ldata <return>
ignore bad <return>
ignore 0.-0.5 <return>
ignore 8.-1000. <return>
pl ldata <return> Check that you filtered out the events outside the 0.5-8 keV

abund aspl <return>
setpl rebin 5 3 <return>
pl ldata <return>

Now we load the second data set, making sure to edit the line below for the correct path and file name:
data 2:2 /Users/raffaellamargutti/SuperNovae/SN2014C/Chandra/17569/primary/spec1point5_grp.pi

Xspec will not be able to find the other files:

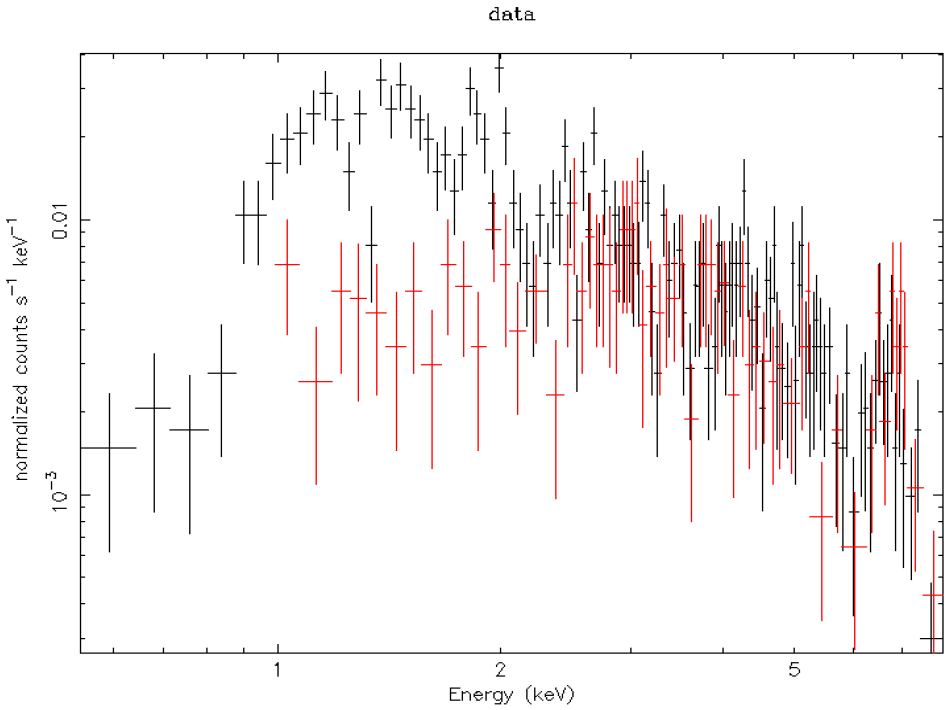
```
***XSPEC Error:  cannot open file named: spec1point5.rmf
Error: cannot read response file spec1point5.rmf
New filename ( "none" or "/*" to return to the XSPEC prompt):
```

We will have to tell Xspec the location of the file as below (edit the line below with your path and your .rmf file name):

/Users/raffaellamargutti/SuperNovae/SN2014C/Chandra/17569/primary/spec1point5.rmf

Do the same for the other files.
pl ldata <return>

We filter the bad events and the events outside the 0.5-8 keV in the second file as well.
ignore bad 2:2 <return>
ignore 2:2 0.-0.5 <return>
ignore 2:2 8.-100. <return>
pl ldata <return> Check that you have filtered out the events in the second file as well as below:



Now we fit the two data sets:
we will freeze the Gaalctic absorption to 0.0614e-22 cm-2. We will forces the power-law to have the same photon index in the two epochs, but different intrinsic absorption:

mo tbabs*ztbabs*pow <return>
0.0614 -1 <return> Galactic NH frozen to 0.0614

0.5 *<return>* This is the guess for the NH for the first data set
0 *<return>* Redshift frozen to 0
2. *<return>* Guess for the Photon Index in the first data set.
1. *<return>* Guess for the normalization of the power-law of the first data set.

We will tie the sixth parameter (which is the Galactic NH for the second dataset) to the same value of the first data set. To do that, just hit
<return>

For the intrinsic NH of the second dataset, we will start with a guess of 0.2:
0.2 *<return>*
We will tie the eight parameter (which is the redshift for the second dataset) to the same value of the first data set. To do that, just hit return. Same for the power-law index.

Put a guess of 1 for the normalization of the second parameter.

The current model list should look like this:

```
Current model list:

========================================================================
Model TBabs<1>*zTBabs<2>*powerlaw<3> Source No.: 1   Active/On
Model Model Component  Parameter  Unit     Value
 par  comp
                          Data group: 1
   1    1   TBabs      nH         10^22    6.14000E-02  frozen
   2    2   zTBabs     nH         10^22    0.500000     +/-  0.0
   3    2   zTBabs     Redshift            0.0          frozen
   4    3   powerlaw   PhoIndex            1.00000      +/-  0.0
   5    3   powerlaw   norm                1.00000      +/-  0.0
                          Data group: 2
   6    1   TBabs      nH         10^22    6.14000E-02  = p1
   7    2   zTBabs     nH         10^22    0.200000     +/-  0.0
   8    2   zTBabs     Redshift            0.0          = p3
   9    3   powerlaw   PhoIndex            1.00000      = p4
  10    3   powerlaw   norm                1.00000      +/-  0.0
------------------------------------------------------------------------
```

pl ldata *<return>* Have a look at the models before fitting
renorm *<return>*
pl ldata *<return>* Have a look at the models now before fitting.
fit 1000 *<return>*
pl ldata *<return>* Have a look at the fit and see how they compare to the data.

Calculate the 1 sigma uncertainties of the intrinsic NH of the first and second data set (i.e. parameter 2 and 7). How do the two intrinsic NH compare? Can you guess what might have happened to the source?

Calculate the uncertainty of the Photon Index (i.e. parameter 4. Note that parameter 9 is tied to parameter 4).

Calculate the absorbed 0.3-10 keV flux for the two spectra and its uncertainty (1 sigma c.l.).

Calculate the unabsorbed fluxes for the two epochs.

Plot the unfolded spectrum for the two spectra to better understand

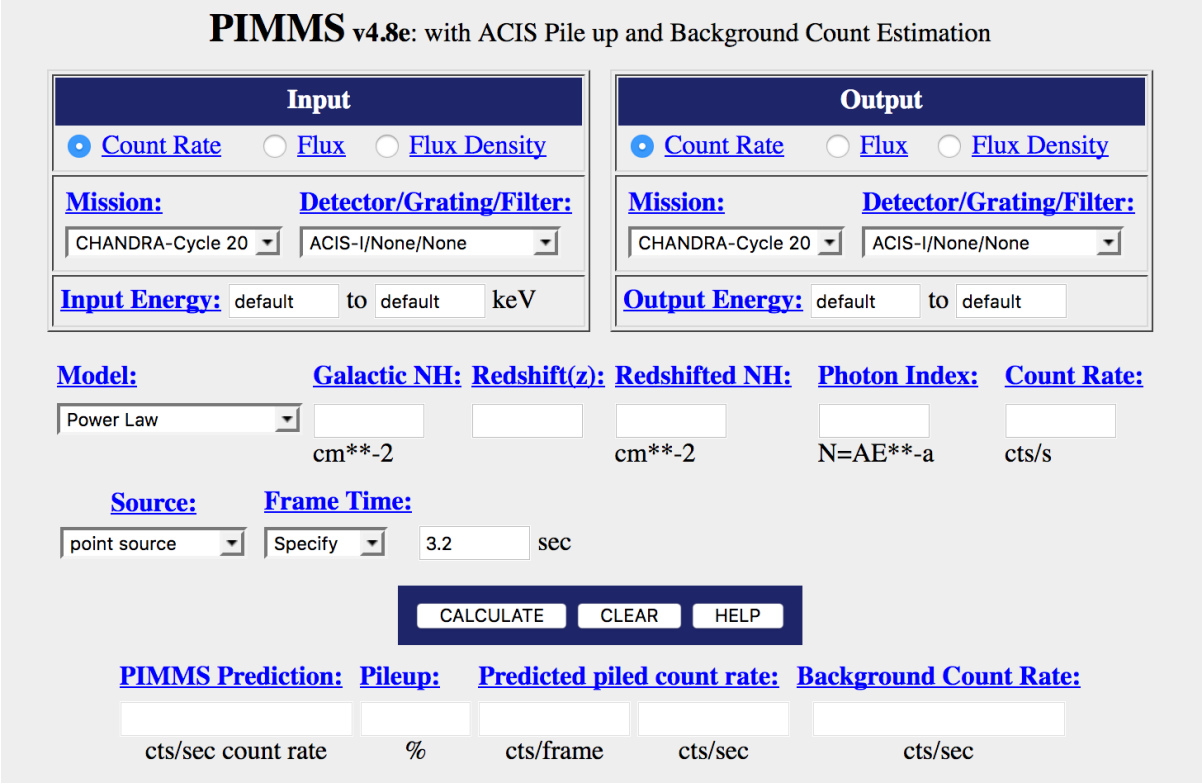
---

4. Turning count-rate upper limits into flux upper limits

Sometimes a source is not detected. Upper limits can however be very informative. Using Poissonian statistics we have learned how to compute count-rate upper limits. Now we want to go from count-rate to flux limits.

From the exercise above, now you know that to go from rates to flux you need to assume a spectral shape. If you have a detection then you can fit the spectrum and see if the data support a particular choice of spectral model or not. When we do not detect a source, the only thing we can do is to use our best guess for the spectral model and convert the rates into fluxes. We are thus introducing a systematic uncertainty in our calculations.

To go from rates to flux we will use a very simplified approach that is reasonably accurate and ok for ourpurposes. We will use the Chandra online PIMMS tool here:
http://cxc.harvard.edu/toolkit/pimms.jsp



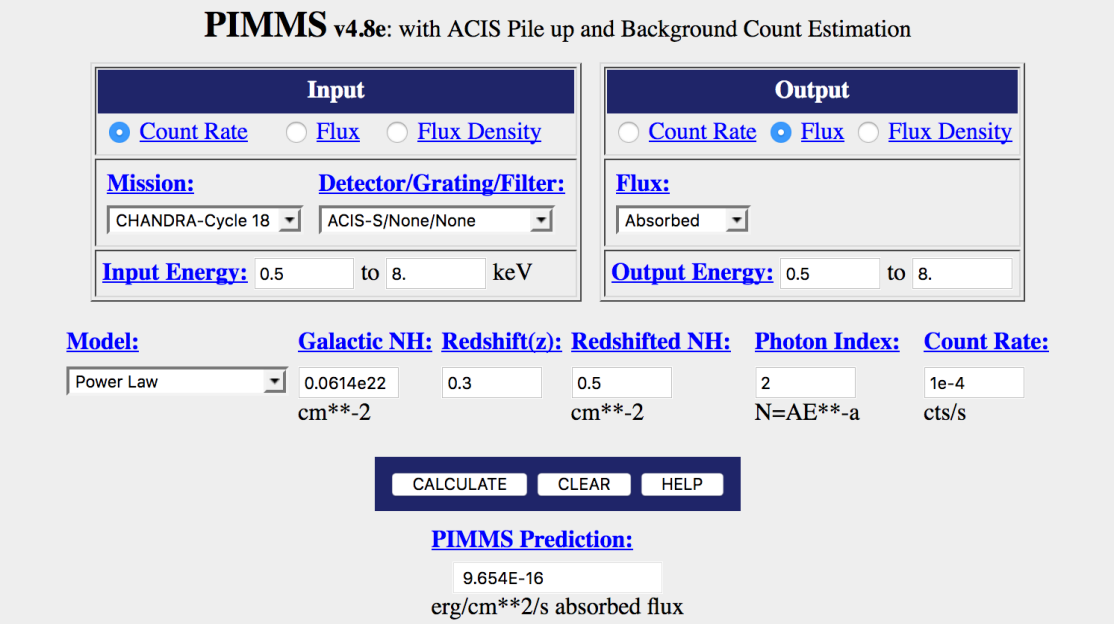
E.g. let's assume that we observed in 2017 with ACIS-S and we found a 0.5-8 keV count-rate upper

limit of 1e-4 c/s. We want to know what is the corresponding flux limit for an assumed power-law model with Index=2, Nhgalactic=0.0614e22 cm-2 and Nhintrinsic=0.5e22 cm-2 for a source at z=0.3.

INPUT: select count-rate
Mission: the Chandra response evolves with time, as we have seen in class. So we will have to select the "Chandra Cycle" during which the data have been taken. Chandra cycles corresponds to years, and 2018 is the 19th cycle. So we will select Cycle 18.
Detector: ACIS-S no grating
Input energy: 0.5 8 keV

OUTPUT: select flux, absorbed
Output energy: 0.5 8 keV

Model: power-law & fill up all the other fields accordingly, as below:



The corresponding flux limit is thus: 9.65e-16 erg/s/cm2
To compute the unabsorbed flux limit, select: Flux → unabsorbed.
What do you find?

Now you are ready to start doing science on your data!