Lab 11
Data Analysis IV: X-ray Spectroscopy

In this lab exercise you will utilize **IDL**, **Xselect,** and **Xspec** to extract and analyze the composite spectrum of the brightest point sources in a (for all practical purposes) blank field observed with the *Chandra* X-ray Observatory for an exposure time of about 100 ksec.

Log into your department unix account and start X Windows using the "startx" command. Open a browser and download the zipped and tarred data file ("lecture11-data.tar.gz") for this lab into your data directory, unzipping and untarring the file as usual. The file **acisf10534_evt2_c0123t_clean.fits** is a cleaned event list file in *fits* format. Such a file corresponds to a table of events recorded by the detector with each event tagged by its arrival time, position on the detector and on the sky, "pulse height" (essentially how strong a signal the event induced in the detector), and various quality flags and such. A raw events file was processed so that only events that correspond to actual X-ray photons are retained, and others (e.g. charged particles in space interacting with the telescope and detector) were screened out. As you did in Lab 9, use **Xselect** to read the event file, and extract and plot (in **ds9**) a binned image. Recall that the appropriate sequence of commands in **Xselect** is *read events, extract image, plot image, save image*. I will refer to this image fits file in what follows as **acis_img.fits**.

1) 101 sources were detected in this field, and **srcs.lst** is a table of the 13 brightest with right ascension, declination, and the statistical significance listed in columns 1, 2, and 3, respectively. Our initial step is to construct a **ds9** region file with 10 arcsec circular regions for only those sources within 6 arcmin of the nominal pointing direction of the telescope, because of variations in the spectral response with off-axis angle. 10 arcsec is a reasonable radius for *Chandra* spectral extraction of a (not-too-far-off-axis) point source. The **IDL** program **xregions.pro** makes this region file, and also constructs two auxiliary region files – one that corresponds to the 6 arcmin "acceptance circle" and another that includes all 13 sources. It calls a generalized version of **myregions.pro** from last week's lab that allows one to specify the radii (measured in degrees) in the region file:

```
pro myregions, raARRAY, decARRAY, radsec
nsources = n_elements(raARRAY)
openw, 1, "radec.tbl"
for i = 0, nsources-1 do begin
printf, 1, raARRAY(i), decARRAY(i)
endfor
close, 1
make_regions, "radec.tbl", inds=[0,1],rad=radsec/3600.0
spawn, "mv regions.reg myregions.reg"
end
```

Your first task is to copy (using the unix **cp** command) the old version to **myregions_old.pro**, and then edit **myregions.pro** so that it is in line with the above (i.e., change the first line and the call to **make_regions.pro** that otherwise assumes a default of 3 arcsec). Note that **xregions.pro** calls the **gcirc** function from idlastro to compute the distance in arcsec between the nominal pointing direction and each source (Lecture 1). Compile and run this program in **IDL**, using the appropriate arguments. Load the image into **ds9** twice into separate frames, superimposing the regions file for all bright sources in one frame, and the one for only those inside 6 arcmin in the other. Also superimpose the 6 arcmin acceptance circle region file on the image in both frames. Save this image by selecting the **Save Image** option from the **File** menu. **Email this image to the instructors before leaving the lab today.**

2) We now use **Xselect** to extract a composite spectrum from this multiple-source region file. Unfortunately the format of region files created with **make_regions.pro** is unsuitable for **Xselect**. To fix this, load the region file of the bright sources within 6 arcmin into **ds9** and then save it (either in wcs, or in physical, coordinates) -- giving it some other name like *composite.reg*. Extracting a spectrum using **Xselect** is similar to extracting an image with the additional step that we must filter the event file so that only events in our desired region are extracted: Type **Xselect** on the command line; once in **Xselect**...

a) read the event file
b) type *filter region composite.reg* (or whatever you called it)
c) extract the spectrum
d) save the spectrum, calling it (e.g.) *composite_spec.fits*
e) exit **Xselect**

3) Next, we group the spectrum to have a minimum of 20 counts per bin so that we may use Gaussian statistics, using the program **grppha**: Type *grppha composite_spec.fits composite_grp20_spec.fits* on the command line and then, within **grppha...**

a) type *group min 20*
b) *exit* (not *quit*) **grppha**

4) Finally, we will analyze the grouped composite spectrum using **Xspec** as follows. First type *xspec* on the command line.

a) Now that you're in, we will first set the plotting window and also some other commands for cosmetic reasons:

```
XSPEC12>setplot dev /xw
XSPEC12>setplot energy
XSPEC12>setplot rebin 3 5
XSPEC12>setplot command lweight 3
XSPEC12>setplot command csize 1.3
```

b) Next, read in the data and the response files, and ignore energies where *Chandra* is not very efficient and/or well-calibrated:

```
XSPEC12>data composite_grp20_spec.fits
XSPEC12>response acisi_aimpt_cy12.rmf
XSPEC12>arf acisi_aimpt_cy12.arf
XSPEC12>ignore 0.0-0.5
XSPEC12>ignore 5.0-**
```

c) Fit the spectra, **recording your results in the table below as you go**. Apply the **model** and **fit** commands to fit the data with power-law (called *powerlaw* in **Xspec**), thermal bremsstrahlung (*bremss*), and blackbody (*bbody*) models. Include absorption by the Galactic column density in this direction (1.2×10^{20} cm^{-2}) by using the *wabs* multiplicative model. For example,

```
XSPEC12>mo wa*pow

Input parameter value, delta, min, bot, top, and max values for ...
        1     0.001        0        0    100000     1e+06
1:wabs:nH>.012,-1
        1      0.01       -3       -2        9       10
2:powerlaw:PhoIndex>2
```

```
        1      0.01        0        0     1e+24     1e+24
3:powerlaw:norm>

========================================================================
Model wabs<1>*powerlaw<2> Source No.: 1   Active/On
Model Model Component  Parameter  Unit     Value
par  comp
1    1   wabs      nH       10^22    1.20000E-02  frozen
2    2   powerlaw  PhoIndex          2.00000     +/-  0.0
3    2   powerlaw  norm              1.00000     +/-  0.0
------------------------------------------------------------------------


Chi-Squared =   6.294435e+11 using 118 PHA bins.
Reduced chi-squared =   5.426237e+09 for    116 degrees of freedom
Null hypothesis probability =   0.000000e+00
Current data and model not fit yet.
XSPEC12>fit
```

…

Note (1) the use of abbrevations (*pow* for *powerlaw*, *wa* for *wabs*), and (2) that the column density is in units of 10^{22} cm^{-2}. (3) Between fits, save the commands in files, e.g.

```
XSPEC12>save all plaw_best-fit_all.xcm
```

etc.

model	**index or kT**	**chi-squared, χ^2**	**degrees of freedom, ν**	**χ^2/ν**
power law				
bremsstrahlung				
blackbody				

d) Restore the best of the best-fits – the model with the lowest reduced chi-squared (χ^2/ν) using

```
XSPEC12>@<BESTMODEL>.xcm
```

and use the **error** and **flux** commands to fill in the following table, recording the flux in erg cm^{-2} s^{-1}:

best-fit model name	**Index or kT**	**$\Delta\chi^2$=2.706 confidence range**	**(0.5-1.5 keV) flux**	**(1.5-5 keV) flux**	**(0.5-5 keV) flux**

e) Finally, plot the data, best-fit model, and residuals to the best-fit model as follows, printing out a hardcopy **to be handed in at the end of the lab.**

```
XSPEC12>iplot ldata residuals
PLT> hardcopy
PLT> quit
XSPEC12>mv pgplot.ps composite.ps
XSPEC12>gv composite.ps
```