# Lab 9
# Data Analysis II: High Energy

In this lab exercise you will use **Ftools** and **Xselect** to extract and process a *Suzaku* X-ray Observatory image of the NGC 4406 galaxy. Specifically, you will correct the image for variations in exposure time and telescope efficiency across the field-of-view.

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 ("lecture9-data.tar.gz") for this lab into your data directory, unzipping and untarring the file as usual. You will now have the following three new files: the observation event file, *ngc4406_suzaku_evt.fits*, a simulated flat field file, *flat_field_evt.fits*, and an exposure map image file, *exposure_map_img.fits*. Using the construction "ftlist <fitsfilename> H", make a note of the number of extensions (HDU's) and their names for these files **to be handed in at the end of the lab**.

The ftool "fkeyprint"may be used to print out the values of keywords in fits headers. Find the total time interval from start-to-finish of the NGC 4406 observation, and how long the actual exposure time was (when data was actually taken), as follows:

fkeyprint infile=ngc4406_suzaku_evt.fits keynam=EXPOSURE outfile=STDOUT
fkeyprint infile=ngc4406_suzaku_evt.fits keynam=TELAPSE outfile=STDOUT

**Make a note of (and hand in) these numbers. What does this tell us about the *Suzaku* observing efficiency?** Most of this difference is due occultation by the Earth: *Suzaku* is in a relatively low altitude orbit, which reduces the number of background events due to charged particles entering the detector thanks to the Earth's magnetic field.

Use **Xselect** to read the *Suzaku* event file, and extract and plot (in **ds9**) a binned image of NGC 4406, as follows.

1) Type **Xselect** on the command line.
   At the prompt (probably something like "xsel:SUZAKU >")…
2) read events ngc4406_suzaku_evt.fits
3) extract image
4) plot image
5) save image ngc4406_suzaku_8bin_img.fits
6) exit

Note that the image is binned by a factor of 8 by default. You can check this (and other keyword values, as well as data information) by typing "show status."

Run the ftool "fimgstat" on the binned image, and **record the minimum, maximum, sum, and mean in the table on the homework assignment. In obtaining the mean here, and in later applications of fimgstat, set lower threshold value so as to exclude 0-value pixels.**

The exposure map, *exposure_map_img.fits*, considers the detector field of view and the spacecraft attitude, to calculate exposure time per sky pixel. **Record the minimum, maximum, and mean exposure times in the table on the homework assignment**.

However, the exposure map does not account for the fact that the fraction of X-ray photons entering the telescope that reaches the focal plane decreases with increasing off-axis angle, an effect called ***vignetting***. To account for this, one may simulate an observation of a **flat field** with constant intensity on the sky, given the calibrated telescope optical performance and the conditions at the time of the observation of interest. This was how *flat_field_evt.fits* was constructed. It gives a much truer picture of how the efficiency of the telescope to collects X-rays depends on detector position.

As you did above, use **Xselect** to extract a binned image, *flat_field_img.fits,* from *flat_field_evt.fits*. Smooth the image in **ds9**, using a smoothing kernel of 15 pixels, and save the smoothed image (*using "save frame as fits", not "save image"*) as *flat_field_ds9smo15_img.fits*. Using fimgstat, **record the minimun, maximum, and mean of this fits image in the table on the homework assignment**.

We will use the exposure map, but only to construct a *mask* to smooth out the rough edges in the flat field. The mask will have the value of **0** when the exposure is below some threshold (we will use 1000 seconds), and **1** when the exposure is above the same threshold. We shall call the mask image *skymaskmap_1k_img.fits*:

fimgtrim infile=exposure_map_img.fits threshlo=1000 threshup=1000 const_lo=0 const_up=1 \
outfile=skymaskmap_1k_img.fits

(Note that the backslash is the Unix continuation character; alternatively one may type this command entirely on one line). Now, we apply the mask, multiplying the flat field image by the mask image. This done with the ftool "farith" that performs binary mathematical operations (such as multiplication, "*", or division, "/") between fits files:

farith flat_field_ds9smo15_img.fits skymaskmap_1k_img.fits flat_field_smo_trim_img.fits "*"

Fortunately, the exposure has the same binning as the flat field image – otherwise we would need to rebin it. We now have a sharper flat field image, *flat_field_smo_trim_img.fits*. Using fimgstat, **record the minimum, maximum, and mean of this fits image in the table on the homework assignment**.

Because the flat field was derived from simulated data, its scale is arbitrary relative to our real observation. This should be apparent from the table entries that you have been making. We will normalize by dividing by the maximum value (substitute it for FFMAX in the expression below) you just derived using "fcarith" -- an ftool that performs mathematical operations of constants on fits files:

fcarith flat_field_smo_trim_img.fits <FFMAX> flat_field_smo_trim_norm_img.fits "/"

Now multiply by the true exposure time, either from fkeyprint on *ngc4406_suzaku_evt.fits* (see above) or the maximum value of *exposure_map_img.fits* (see the table). Substitute this for EXPTIME in:

fcarith flat_field_smo_trim_norm_img.fits <EXPTIME> flat_field_expmap_img.fits "*"

The file *flat_field_expmap_img.fits* is the final vignetting-corrected exposure map. Using fimgstat, **record the minimum, maximum, and mean of this fits image in the table on the homework assignment**.
Dividing the NGC 4406 image by this yields the vignetting-corrected count rate image:

farith ngc4406_suzaku_8bin_img.fits flat_field_expmap_img.fits ngc4406_suzaku_8bin_vigcor_rate_img.fits "/"

When we applied the masked exposure map, there were pixels with 0 exposure time. When we divided this out, the divide-by-zero produces a bunch of pixels that are assigned the value -999.

We can trim these out as follows:

fimgtrim infile=ngc4406_suzaku_8bin_vigcor_rate_img.fits threshlo=0 threshup=INDEF const_lo=0 \
outfile=ngc4406_suzaku_8bin_vigcor_rate_trimg.fits

**One last time, record the minimum, maximum, sum, and mean in the table on the homework assignment. Compare the product of the sum and the exposure time (the "effective" number of counts, if the telescope/detector was at its maximum efficiency everywhere) with the total number of counts in the original image.**