Guide for X-ray imaging and spectroscopy of clusters of galaxies using XMM-Newton EPIC instruments and **clusteranalysis** software

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Chapter 1

General

The **clusteranalysis** software can be used to perform X-ray imaging and spatially resolved spectroscopy of clusters of galaxies. Using the tools, starting from the imaging and spectral products from XMM-Newton reduction, one can construct and model the profiles of the surface brightness and temperature and derive the density and mass profiles of the gas and dark matter.

Chapter 2

Setup

In order to run the analysis, you must have FTOOLS, ds9, IDL and XSPEC working. Create a directory /wrk/*yourname*/clusteranalysis in sky9 machine and go there. Copy a file /data/jnevalai/clusteranalysis/repository/kurssi/setup.script there and set the keywords OBJNAME and OBSID to match your data, INSTRUMENT to PN and clustanaldir to /wrk/*yourname*/clusteranalysis . Execute the script by typing “source setup.script” This should be done only once, when you install the software. The procedure produces directory structure compatible with the current software and analysis target and copies relevant parameter files into your data directory. Later on, you run the analysis while staying at directory **/wrk/*yourname*/clusteranalysis/data/OBJNAME/INSTRUMENT/OBSID**.

Chapter 3

Imaging

The starting point are the image products resulting from XMM-Newton analysis (see the notes xmm_reduction1.pdf, xmm_reduction2.pdf and xmm_reduction3.pdf):
"*raw*.im" (an image containing uncorrected raw counts per pixel)
"*.exp" (exposure map) and
"*rate.im" (vignetting-corrected, particle background-subtracted surface brightness map).
Put these files into directory **/wrk/***yourname***/clusteranalysis/data/OBJNAME/INSTRUMENT/OBSID**.

3.1 Constructing the surface brightness profile

Here we will be using IDL programs for analysing the data. Go to
/wrk/*yourname***/clusteranalysis/data/OBJNAME/INSTRUMENT/OBSID**. Edit the **idl_imaging_setup.pro** to correspond to the analysis at hand. Start IDL and type **.run idl_imaging_setup**.

!!! DO ".run idl_imaging_setup" EACH TIME YOU START IDL IMAGING SESSION !!!.

3.1.1 Mask

Looking at the image (using e.g. ds9 of fv tools) you see that there are (most probably) some unwanted point sources projected in the line-of-sight. Also, there may be some asymmetries in the brightness distribution which complicate the modeling. You have to exclude these regions from the analysis. This is done by creating a mask containing the info on the point source locations and sizes. This mask will be used later when extracting the surface brightness profile. The program **mask.pro** will create such a mask, whose name is defined by a parameter **maskimage** in a file **mask_par.pro**. You should create a file **pointsrc.list** file in directory
/wrk/*yourname***/clusteranalysis/data/OBJNAME/INSTRUMENT/OBSID** where each line contains info for one source, in format
x y r
, where x and y are the X and Y coordinates and r is the radius in "image" coordinate system.

Set the parameter "n_pointsrc" to the number of your point sources and "imagesize" into the size of the image in pixels (use fv to find the value). Then, execute commands **.run mask_par.pro** and **run mask.pro**. The resulting pixel values of the output mask image should be 1.0 in the allowed regions and 0.0 in the point source regions, forbidden sectors and CCD gap regions.

3.1.2 Surface brightness accumulation details

The surface brightness (in a given band, region and instrument) is defined as the count rate (counts s^{-1}) per the area ($arcmin^2$) used to accumulate the counts, i.e. the units are [counts s^{-1} $arcmin^{-2}$]. The counts are accumulated from the final count rate image (*rate.im) in concentric annuli around the cluster center, excluding the pixels with value zero in the mask. The number of useful pixels is also recorded, and these will be used to divide the count rates in the annuli, to yield the surface brightness profile. This can be done with the program "make_surf.pro" which is controlled by the parameter file **make_surf_par.pro**.

Set the keyword **maskimage** to the name of the mask image created in the previous step. Examine the *rate.im* image and its header using ds9 and fv tools to find the values for the **imagesize** (the size of the image in pixels), **cntr_x** (x coordinate of the cluster center) , **cntr_y** (y coordinate of the cluster center), The units are in the "image" system. Set the keyword **pixel_in_arcmin** to the size of a pixel in arcmin, using the information that the original XMM_Newton PN pixel size is 0.000833333 arcmin, and noting that you used some binning factor when producing the *rate.im* image earlier.

Set the keyword **testplotfile** to the name of the surface brightness profile plot file and change the range of values of the x and y axis by keywords **xran**, **yran** and **yran2**. Set the keyword **datafile** to the name of the file where the program saves all information.

3.1.3 Radial regions

Before extracting the surface brightness profile, you have to make a choice how to divide the image into annuli where to accumulate the counts. In practice, you need to define the radial boundaries of the annuli in arcmin. A good criterion for choosing the boundaries is that within each annulus there should be a same minimal number of counts. This ensures similar statistical uncertainties in each bin. In Gaussian statistics, $\sigma = \sqrt{N}$, where N is the number of counts and σ is the statistical uncertainty. This binning can be done with a program **grprad.pro**, controlled by a parameter file **grprad_par.pro**. Set the keyword **mincounts** to above N, e.g. 400 so that the statistical uncertainty is $\sqrt{N}$/N = 20/400 = 5%. Set the keyword **picsize** to a maximum value of the radius used for binning (in case of XMM-Newton PN, the maximum distance covered from the FOV center is 15 arcmin). When executing **grprad.pro** to a given data set (see below), a vector called **rad_bound_arcmin** is created into IDL memory, containing the radial boundaries with your choise of binning.

3.1.4 Run the programs

After having set the above parameters in files **make_surf_par.pro** and **grprad_par.pro**, you can run the relevant programs **make_surf_par.pro, grprad_par.pro, grprad.pro and make_surf.pro** using a script command **@surf-brightmake** (after executing the **idl_imaging_setup.pro** command). Have a look at the plot with gv or ggv to make sure the above choises make sense.