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BROWSING FITS FILES AND SOURCE IDENTIFICATION

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This cookbook describes (1) how to view (and optionally modify) FITS files and how to make simple plots using the HEASOFT tool `fv`, (2) how to perform source identifications by querying the *Simbad* database.

Introduction

In order to use FV you need to initialize the HEASOFT environment keywords (see the README/STARTUP file). In order to avoid conflicts with other analysis software, it is recommended to work in a separate window, dedicated to HEASOFT tools only.

To start an FV session type `fv filename.fits` on the terminal. Two windows will open on your terminal, a small one with general commands, and a larger one displaying the content of the FITS file you have opened.

Here we will describe briefly how to use FV for selecting X-ray sources from a table produced by the wavelet detection algorithm (`pwdetect` for Chandra or `pwxdetect` for XMM-Newton) and to view and plot X-ray light curves produced by specific CIAO (for Chandra) or SAS (for XMM-Newton) data analysis software. In both cases, the relevant FITS files contain no image but one or more "estensions" with data arrays (tables).

Browsing the list of detected sources

Open the FITS table contained in the file *det_src.fits* produced by the wavelet detection algorithm.

Click the button **View/All** to see the whole content of the table. In particular, you will find source coordinates and errors (undertainties), the off-axis angle, the detection scale and statistical significance, source and background total counts and count rates, among other quantities (one in each column).

To sort the rows by any chosen parameter, open the **Tools** menu and select **Sort Rows...**. A new window will open, where you can select the desired column (e.g. *Src_cnt* for the number of total source counts) and click on the **Primary Column** button. By default the data will be sort in ascending order, and you have to de-select the square button if you prefer a descending order. Finally, click on **Sort**.

To select rows with a giver criterion, open the **Edit** menu and select **Select Rows From Expr**. In the new window, click on the desired column name and choose an arithmetic operator: in this way you will end up with a **condition** like $Src\_cnt > 1000$, where the number needs to be added by hand. Then, click on **Select** and **Close**.

In order to write a file with the coordinates of selected sources, first select the coordinate columns by clicking on the square button adjacent to the column name (e.g. *RA* and *Dec*). Then open the **File** menu and select **Export as text...**. In the new window choose a File Name and click on

Save. Another window will open, where you can click on both the **Selection** flags, for the Rows and for the Columns. In this way you will save only the selected quantities (e.g. coordinates) for the selected X-ray sources. Choose the **Fixed Width Columns** output format, and **Save**.

Now you can edit the ASCII output file and check the content is what you expect. In order to use this list of coordinates for source identification with Simbad remember to delete the first three rows (header) in the file.

Finally, if you want to identify the selected source in your image, note the source numbers in the last column of the sorted source list, open the region file created by the wavelet detection algorithm, and add the string "color=yellow" at the end of each entry with source number corresponding to those you have just selected. Delete all regions in the current image and reload the region file you have modified. Now, the selected sources will be marked by a yellow circle and number.

Source Identification

Open the Web browser and connect to the Simbad database server at

http://simbad.u-strasbg.fr/

There you can choose different kinds of query. In particular,

- If you have a file with a list of coordinates you may want to perform a **Query by coordinates**. In this case, you need to **Browse...** the ASCII file produced above, define a *search radius* ($3''$ for Chandra and $5''$ for XMM-Newton is the suggested minimum value), and click on **submit file** (at the bottom of the page).

  You wil get a list of optical identifications for each X-ray source. By clicking on the *Identifier* name of the optical counterpart in the list, you can access other useful information (spectral type, colors, other IDs, bibliography, and more).

- If you have been provided with the name of an optical counterpart, you can perform a **Query by identifier**. Put the name in the *Identifier:* field and click on **submit id**.

  In this case you can use the FK5 (J2000) coordinates to look for the corresponding X-ray source in the image viewed with `SAOimage ds9`, where you have overlayed the source regions.

  Once you have identified your source, click on the green circle, open the **Region** menu, select **Invert selection**, and then click on the **delete** button on the main window. Only the region of the selected source will be left on the image. Now you can click again on the source circle, open again the **Region** menu, and select **Save regions...** to write an ASCII file with the coordinates of the X-ray source in the image.

X-ray light curves and Time screening

To plot source or background X-ray light curves you can use the HEASOFT tool FV.

Open the FITS file with the X-ray light source generated by the proper CIAO (for Chandra) or SAS (for XMM-Newton) command:

`$ fv` **source_lc.fits**

You can view the full content of the table containing the count rate and statistical error for each time bin by clicking on the **View/All** button corresponding to the first extension (usually called RATE) of the FITS file.

If you click on **Plot** instead, you can select *TIME* on the *X* axis, *RATE* (for XMM, or *COUNT_RATE* for Chandra) on the *Y* axis, and *ERROR* as the *Y error*. Finally you can click on **Plot**.

If you want to select a time interval (i.e. a time range in which the background was low or the source was quiescent/flaring), you can open the **Tools** menu, choose **Select X range**, and then drag the left mouse button on the plot window (see **Mouse Button Functions Hints** in the small window). The time range values will be displayed and can be used for further selection of photon events for the analysis. These values can be saved in an ASCII file by clicking on **Save...**

Creating plots of hardness ratios

A lightcurve of an hardness ratio, i.e. ratio of count rates in two different energy bands, can be created with HEASOFT tools and displayed with FV, in a way analogous to what is described above for typical X-ray lightcurves. Before plotting, of course, the hardness ratio has to be calculated for each time bin. This can be done by creating a FITS file with two *RATE* columns for two different energy bands, and subsequently writing the ratio of their values in a new column of the same file, also containing the time intervals. The following instructions assume XMM data; in the case of Chandra data remember that the column *RATE* is called *COUNT_RATE*. Specifically, the steps to be done are as follows.

- Following the tutorial for the data analysis, create two FITS files with light-curves in two different energy bands. Let's call them **soft_lc.fits** and **hard_lc.fits** (read hints in some of the exercises).
- Copy the FITS file with the light-curve in the soft X-ray band to another file called, e.g., **twobands_lc.fits**

  `$ cp` **soft_lc.fits twobands_lc.fits**

- Open the new file with FV, click on the button **View/All**, click on the button **Modify** of the column *RATE*, select from the menu **Parameters...** and edit the name of the column to rename it, e.g., *RATE_SOFT*. Save the file and exit FV.
- Add the *RATE* column of the hard-band lightcurve to the new file, using the command

  `$ faddcol` **twobands_lc.fits hard_lc.fits RATE**.

- Calculate the hardness ratio with

  `$ fcalc` **twobands_lc.fits HR_lc.fits HR "RATE / RATE_SOFT"**

- Plot the new column *HR* vs. *TIME* with FV.