

X-ray Lab

What are our Goals for the next week(s)?

- Learn about X-ray observatories and data we collect.
- Make an introduction about the tools we use in X-ray astronomy.
- Perform (on your own) some basic tasks with X-ray data.
- Measure fundamental parameters of an Astrophysical Object.

Before we start ...

We will use **Linux** OS in LAB, and whatever you like at home

We will work on **Bash** terminal

Most data will be stored in **fits** files

You may manipulate files on your own using **Python**, **Topcat** and **HEASOFT** tools

For teamwork/questions we will communicate via **SLACK** channel

Getting started with work on your laptop:

Linux: recommend **Ubuntu** for starters, see also PoP OS!, Fedora, Manjaro, Arch

Also, in Windows 10: install Windows subsystem for linux (WSL)

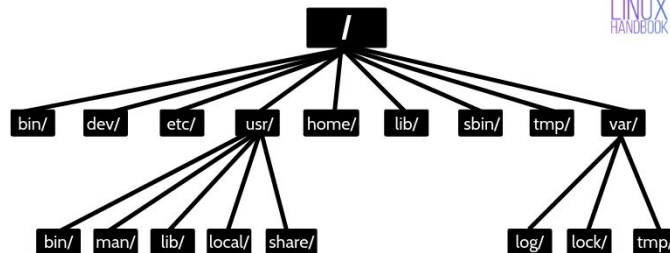
Python: install Anaconda distribution

Editor: studio code, **Atom**, vim, **gedit**, kate, **Jupyter**

X-ray software: Provided by NASA, ESA etc...

We will use **HEASoft** (High Energy Astrophysics ...)

BASH, short intro



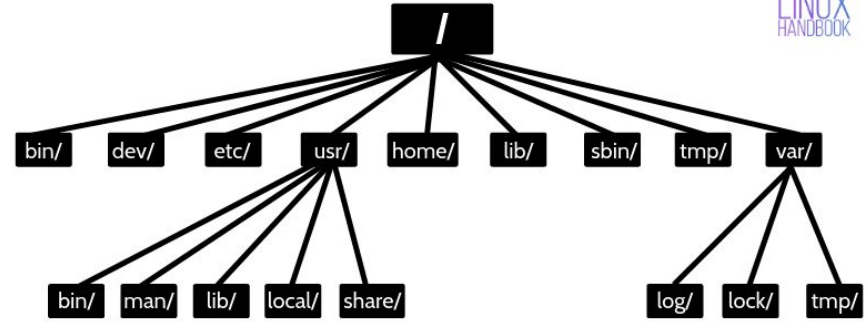
Unix (Linux) filesystem is structured in terms of Directories and a tree structure

HOME: each user has a “starting point”, usually only you have access

- Present working directory: **pwd** , this is also known as ‘.’
- List directory contents: **ls**
- Change directory: **cd**
- Directories higher in the chain are referred as ‘..’
- Make directory: **mkdir /**
- Delete file or Directory: **rm** or **rmdir**, Be very careful!!
- Copying: **cp**

An example

```
File Edit View Bookmarks Settings Help
(base) vasilopoulos@obas-rech-gv:~$ pwd
/home/vasilopoulos
(base) vasilopoulos@obas-rech-gv:~$ mkdir TEST_RUN
(base) vasilopoulos@obas-rech-gv:~$ mkdir TEST_RUN/foo
(base) vasilopoulos@obas-rech-gv:~$ cd TEST_RUN/foo/
(base) vasilopoulos@obas-rech-gv:~/TEST_RUN/foo$ pwd
/home/vasilopoulos/TEST_RUN/foo
(base) vasilopoulos@obas-rech-gv:~/TEST_RUN/foo$ cd ..
(base) vasilopoulos@obas-rech-gv:~/TEST_RUN$ pwd
/home/vasilopoulos/TEST_RUN
(base) vasilopoulos@obas-rech-gv:~/TEST_RUN$ ls
foo
(base) vasilopoulos@obas-rech-gv:~/TEST_RUN$ cd foo/
(base) vasilopoulos@obas-rech-gv:~/TEST_RUN/foo$ pwd
/home/vasilopoulos/TEST_RUN/foo
(base) vasilopoulos@obas-rech-gv:~/TEST_RUN/foo$ cd ../../
(base) vasilopoulos@obas-rech-gv:~$ pwd
/home/vasilopoulos
(base) vasilopoulos@obas-rech-gv:~$ rmdir TEST_RUN/foo
(base) vasilopoulos@obas-rech-gv:~$ rmdir TEST_RUN
(base) vasilopoulos@obas-rech-gv:~$
```



man

- man stands for manual (i.e. RTFM)
- 'man <command>' for details on usage:
- e.g. >**man ls**

- Output a list '-l'
- Short by date '-d'
- Size in human units '-h'
- e.g.

'ls -l' , 'ls -d' , 'ls -lhd'

```
LS(1) User Commands LS(1)
NAME
  ls - list directory contents
SYNOPSIS
  ls [OPTION]... [FILE]...
DESCRIPTION
  List information about the FILES (the current directory by default). Sort entries alphabetically if none of -cftuvSUX nor --sort is specified.

  Mandatory arguments to long options are mandatory for short options too.

  -a, --all
      do not ignore entries starting with .

  -A, --almost-all
      do not list implied . and ..

  --author
      with -l, print the author of each file

  -b, --escape
      print C-style escapes for nongraphic characters

  --block-size=SIZE
      with -l, scale sizes by SIZE when printing them; e.g., '--block-size=M'; see SIZE format below

  -B, --ignore-backups
      do not list implied entries ending with ~

  -c
      with -lt: sort by, and show, ctime (time of last modification of file status information); with -lt: sort by, and show, other time; with -lt: sort by, and show, first
```



John Kallimanis 4:31 PM

Καλό και πλήρες bash tutorial:

<https://tldp.org/LDP/Bash-Beginners-Guide/html/Bash-Beginners-Guide.html>

Πιο εισαγωγικό αρα πιο χρησιμο:

<https://www.freecodecamp.org/news/linux-command-line-bash-tutorial/>

Wildcards

- Frequently used “*”
 - Search for all files that have a specific extension (btw, extensions are hidden in Windows)

```
(base) vasilopoulos@obas-rech-gv:~/Dropbox/EKPA_ASTRO_LAB$ ls
data.pco                pnbackground_spectrum.fits  sngrouped_pn_full.fits      xselect.log
data.qdp                pnclean.fits                sngrouped_pn_NO_OVERSAMPLE_full.fits
DRAFT_BB.xcm           pn_full.arf                 src_clean_bary.fits
heasoft-6.29src.tar.gz pn_full.rmfile              src.reg
(base) vasilopoulos@obas-rech-gv:~/Dropbox/EKPA_ASTRO_LAB$ ls *fits
pnbackground_spectrum.fits  sngrouped_pn_full.fits      src_clean_bary.fits
pnclean.fits               sngrouped_pn_NO_OVERSAMPLE_full.fits
(base) vasilopoulos@obas-rech-gv:~/Dropbox/EKPA_ASTRO_LAB$ ls *full*
pn_full.arf  pn_full.rmfile  sngrouped_pn_full.fits  sngrouped_pn_NO_OVERSAMPLE_full.fits
(base) vasilopoulos@obas-rech-gv:~/Dropbox/EKPA_ASTRO_LAB$ ls -lth *fits
-rw-r--r-- 1 vasilopoulos vasilopoulos 135K Apr  9 2020 sngrouped_pn_full.fits
-rw-r--r-- 1 vasilopoulos vasilopoulos 135K Apr  9 2020 sngrouped_pn_NO_OVERSAMPLE_full.fits
-rw-r--r-- 1 vasilopoulos vasilopoulos 18M Feb  7 2020 src_clean_bary.fits
-rw-r--r-- 1 vasilopoulos vasilopoulos 158M Feb  6 2020 pnclean.fits
-rw-r--r-- 1 vasilopoulos vasilopoulos 119K Jan 30 2019 pnbackground_spectrum.fits
(base) vasilopoulos@obas-rech-gv:~/Dropbox/EKPA_ASTRO_LAB$
```

Main part

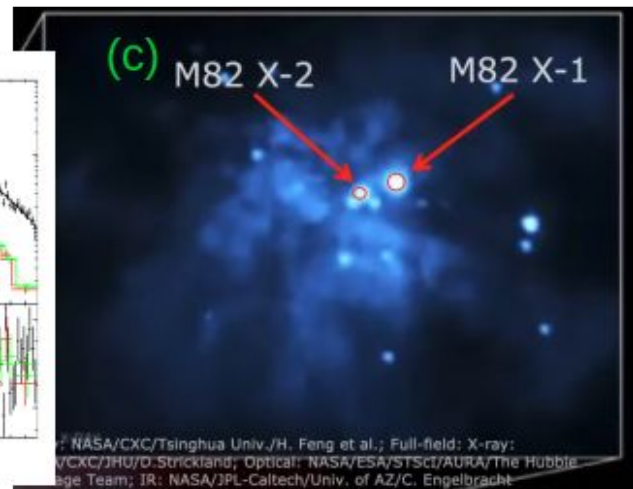
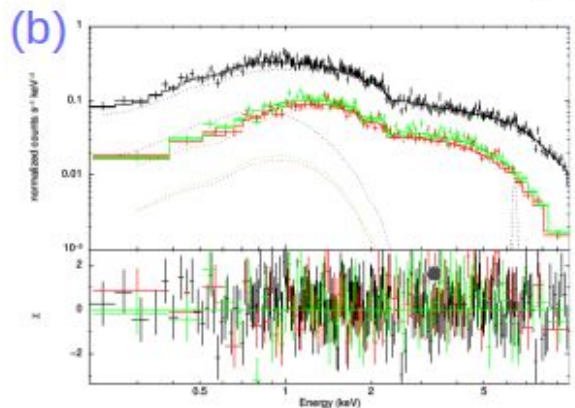
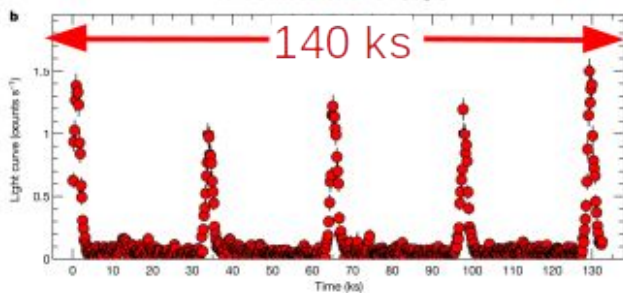
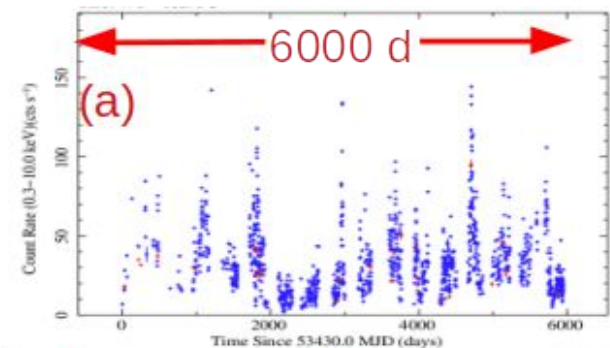
- X-ray observatories
- How do X-ray data look (usually)

- Spectral analysis and modeling (with examples in xspec)
We will use sciserver and jupyter notebooks

Photons

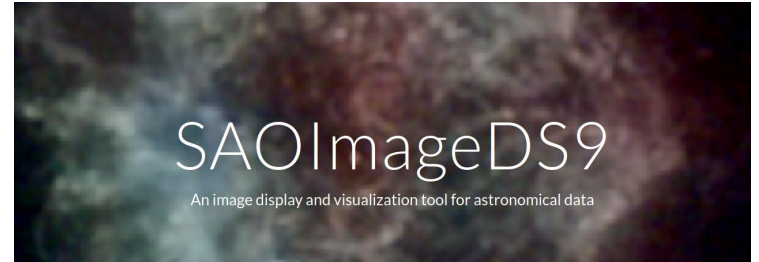
Time of arrival - Energy - position

- (a) time series (300 nsec)
- (b) spectra (0.3-70.0 keV)
- (c) morphology (0.5 arcsec)



X-ray data

Do it yourself - at home



- saoDS9 (not Deep Space 9)

<https://sites.google.com/cfa.harvard.edu/saoimageds9>

- Topcat

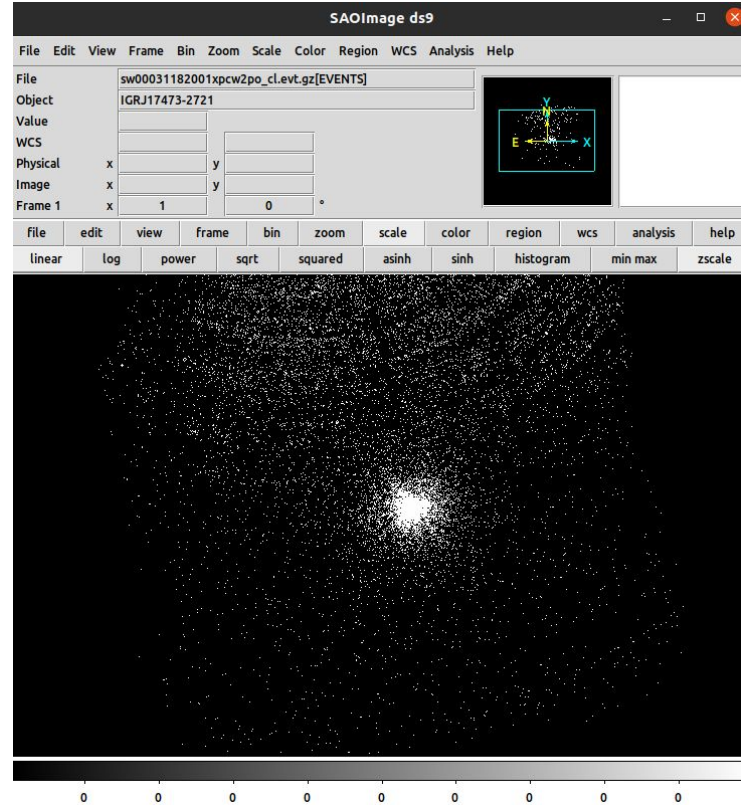
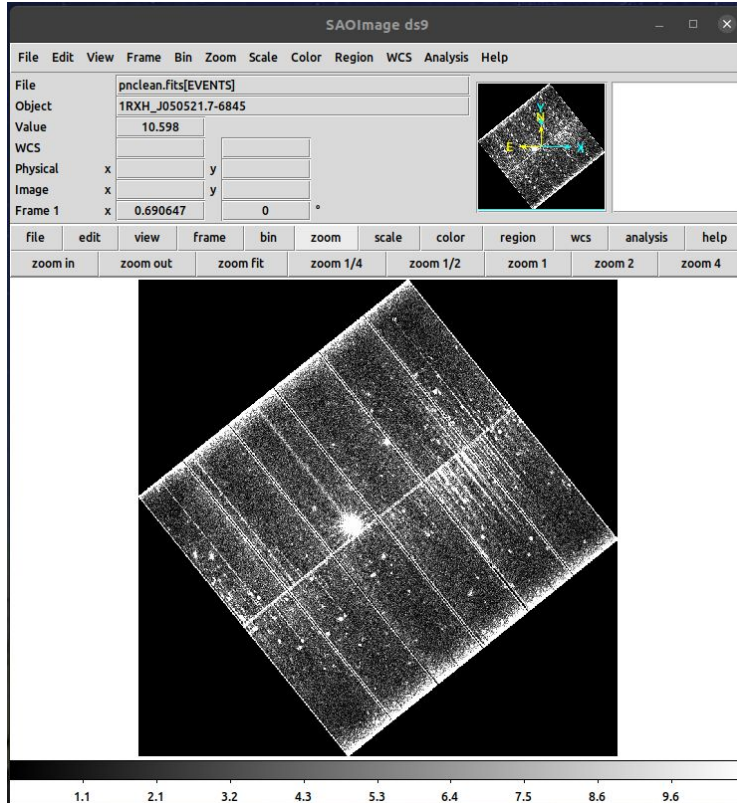
<http://www.star.bristol.ac.uk/~mbt/topcat/>



TOPCAT

Tool for Operations on Catalogues And Tables

ds9



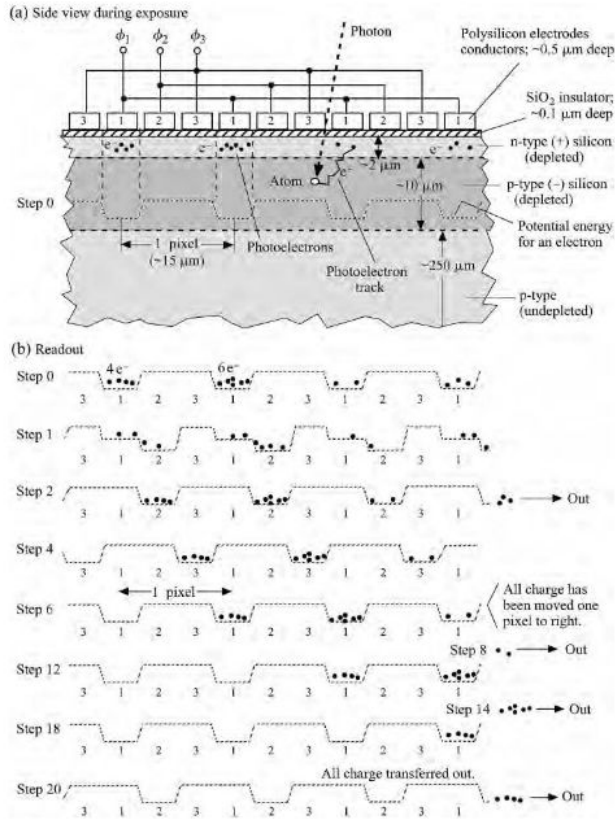


Figure 6.3. Principle of operation of a charge-coupled device (CCD) for visible light. (a) Cross section view. A photon creates a photoelectron in the silicon which is then collected in a low-potential-energy region for each pixel. (b) Readout scheme. After sufficient exposure and the detection of numerous photons, the charges are read out by manipulation of the voltages on the three sets of electrodes.

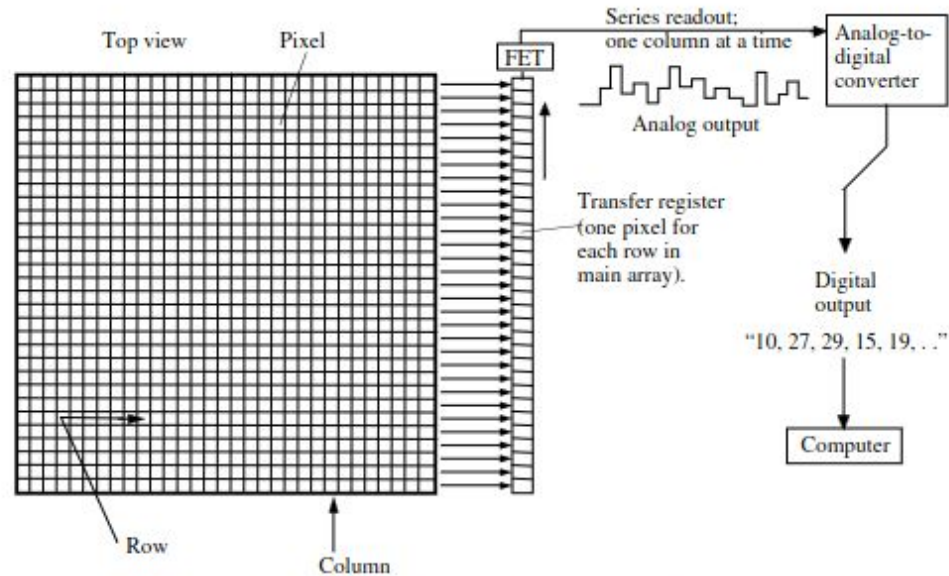


Figure 6.4. Readout method for the entire array. The charges in the pixels of the array are all shifted to the right by one pixel. The charges in the rightmost column are thereby moved into a transfer register and are then read out in the upward direction to a field-effect transistor (FET). This yields an analog signal with amplitude proportional to the charge in the pixel being read out. These analog numbers are converted to digital form with an analog-to-digital converter.

File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help

File sw00031182001xwtw2po_cl.evt.gz[EVENTS]

Object IGRJ17473-2721

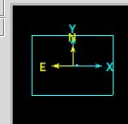
Value

WCS

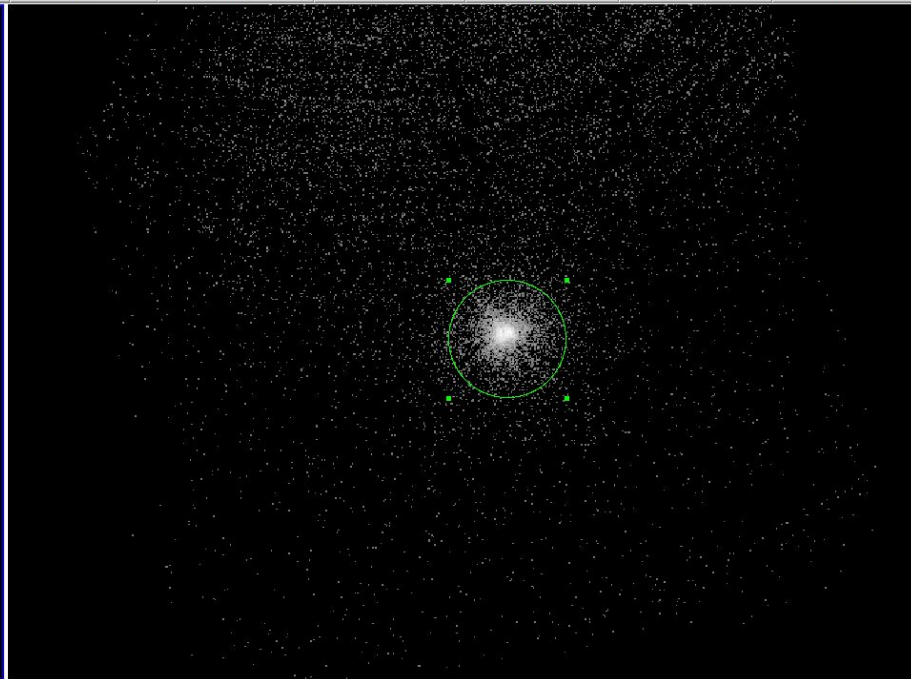
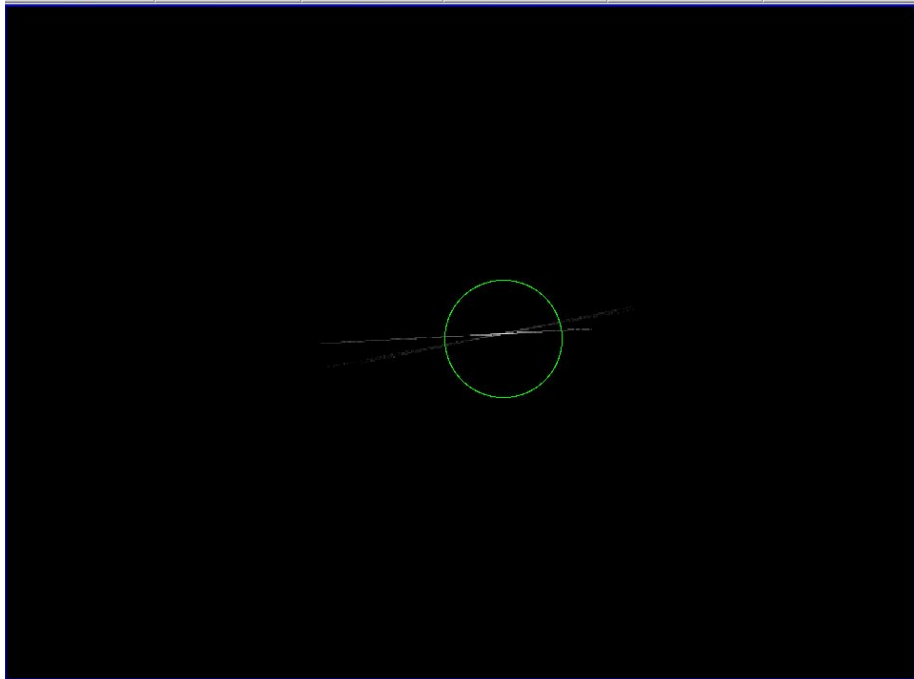
Physical x y

Image x y

Frame 1 x 1.44 y 0 *



| file | edit | view | frame | bin | zoom | scale | color | region | wcs | analysis | help |
|------|------|------|--------|-------|--------|-------|-------|--------|------|----------|------|
| new | rgb | 3d | delete | clear | single | tile | blink | first | prev | next | last |



2

5

13

27

56

113

227

457

913

File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help

File sw00031182001xwtw2po_cl.evt.gz[EVENTS]

Object IGRJ17473-2721

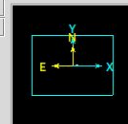
Value

WCS

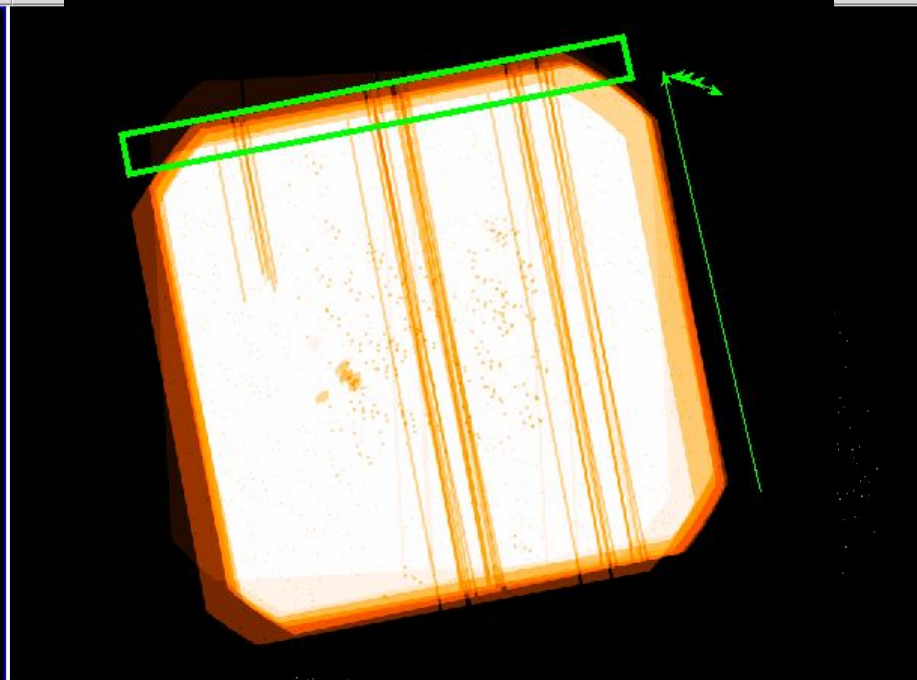
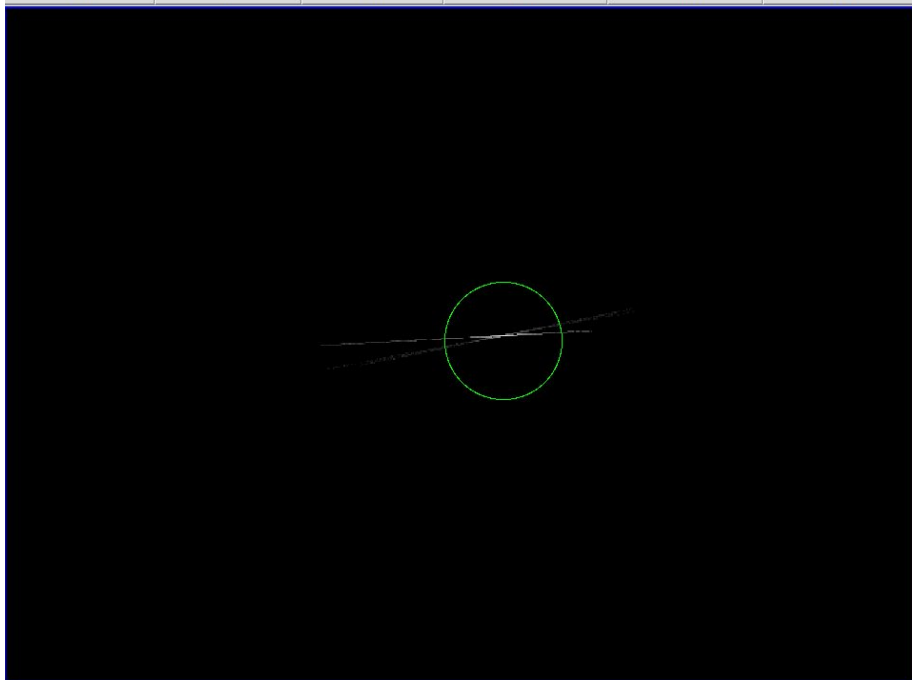
Physical x y

Image x y

Frame 1 x 1.44 0 *



| file | edit | view | frame | bin | zoom | scale | color | region | wcs | analysis | help |
|------|------|------|--------|-------|--------|-------|-------|--------|------|----------|------|
| new | rgb | 3d | delete | clear | single | tile | blink | first | prev | next | last |



2

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113

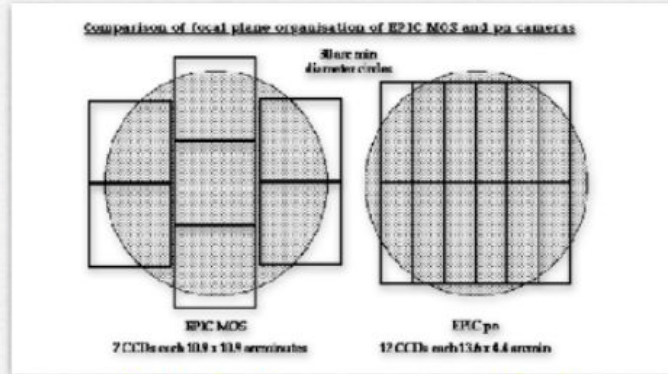
227

457

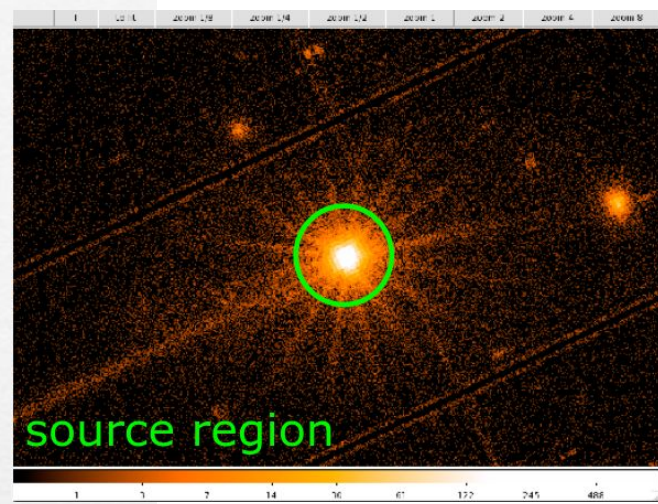
913

EPIC SCIENCE MODES

MOS



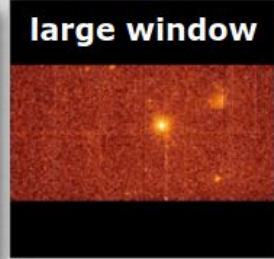
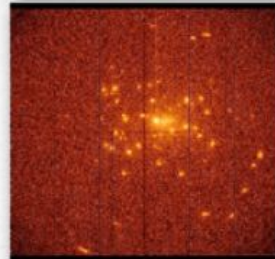
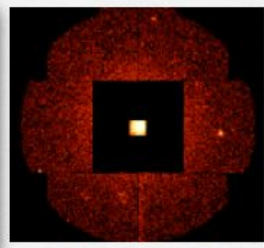
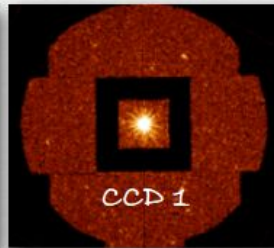
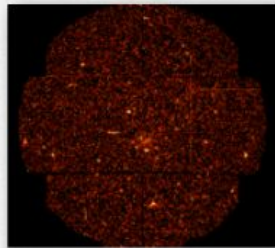
pn



full frame

partial window

timing mode



MOS

pn

SADImage v0.9

File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help

File: pinnewed[EVENTS]

Object: FACTOR A

Value: []

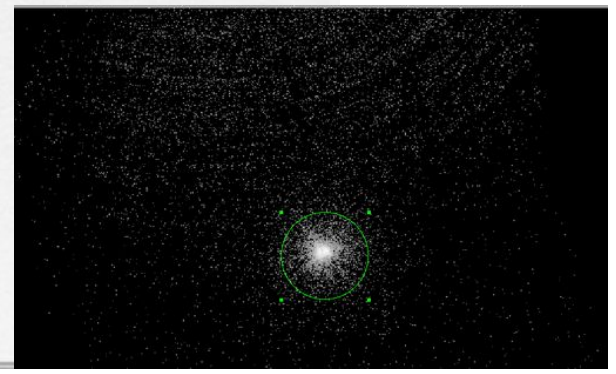
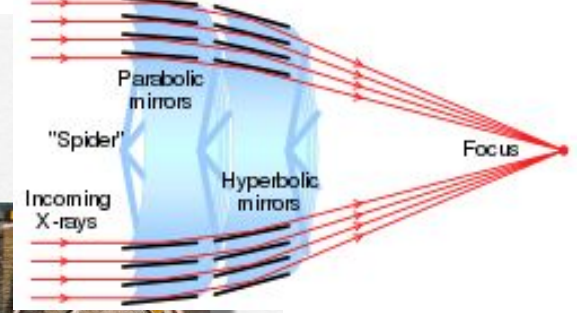
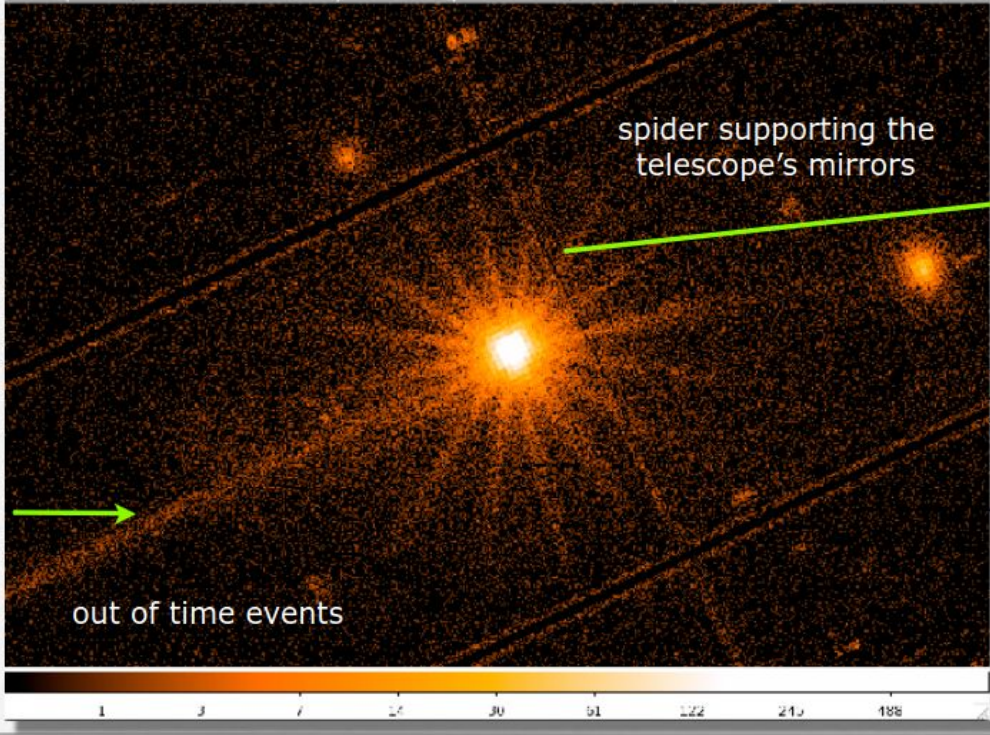
WCS: [] []

Physical Image: X [] Y []

Frame 1: X 1244 Y 0.000 *

file edit view frame bin zoom scale color region wcs help

- - to fit zoom 1/8 zoom 1/4 zoom 1/2 zoom 1 zoom 2 zoom 4 zoom 8



The term '*pattern*' indicates the distribution of pixels over which a charge cloud spreads (= '*grade*' in Chandra/ACIS)

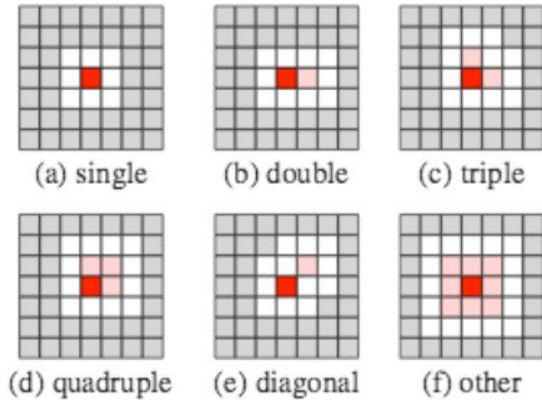
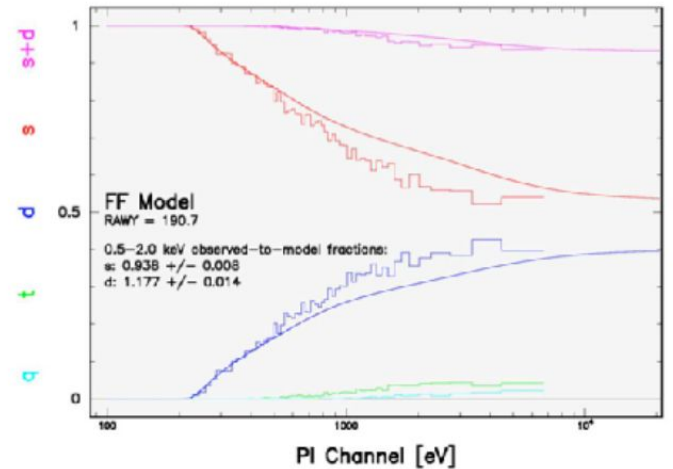


Fig. 1. Examples of EPIC pattern classifications. In each case the dark red pixel contains maximum charge, light red pixels have charge above a threshold value whereas white pixels are necessarily below this threshold. Grey pixels do not influence the pattern classification of the event.

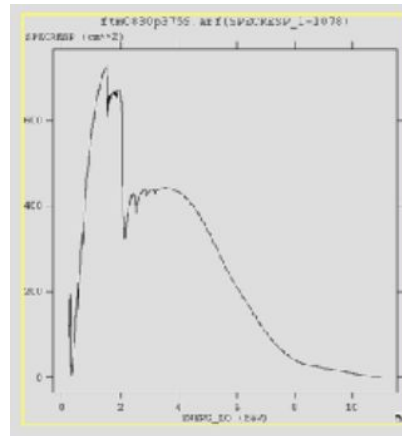
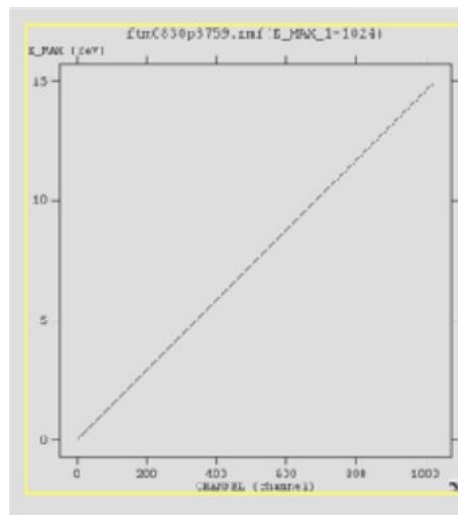
fraction of the four valid event types



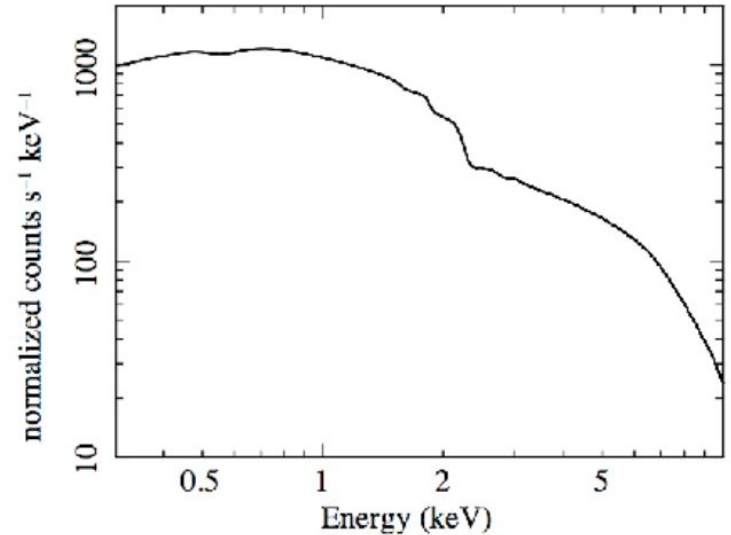
An X-ray photon can generate a variety of patterns. The probability of each pattern is a function of the photon's energy.

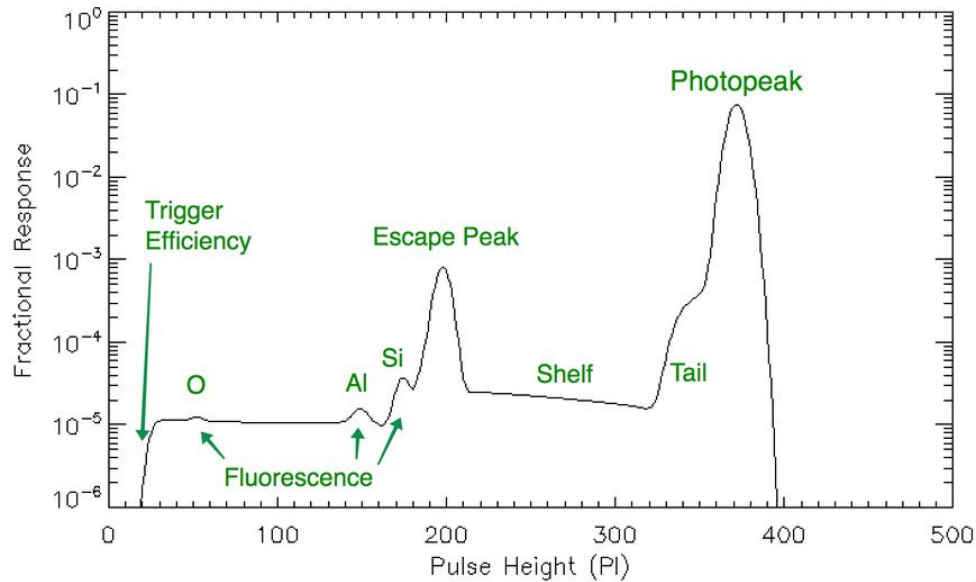
The RMF
associates to each
instrument channel
(I) the appropriate
photon energy (E)

The ARF includes
information on the
effective area, filter
transmission and any
additional energy-
dependent
efficiencies, i.e. the
efficiency of the
instrument in
revealing photons



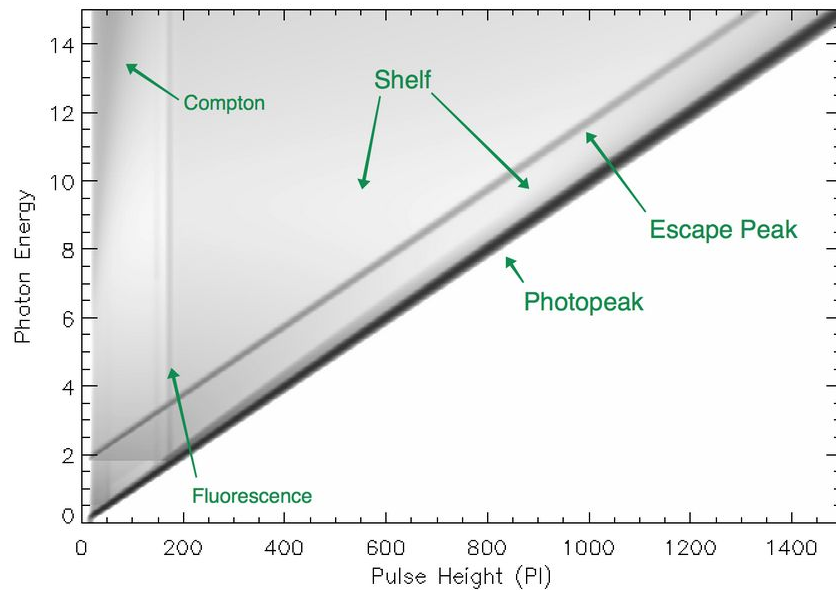
This is a PL !!!

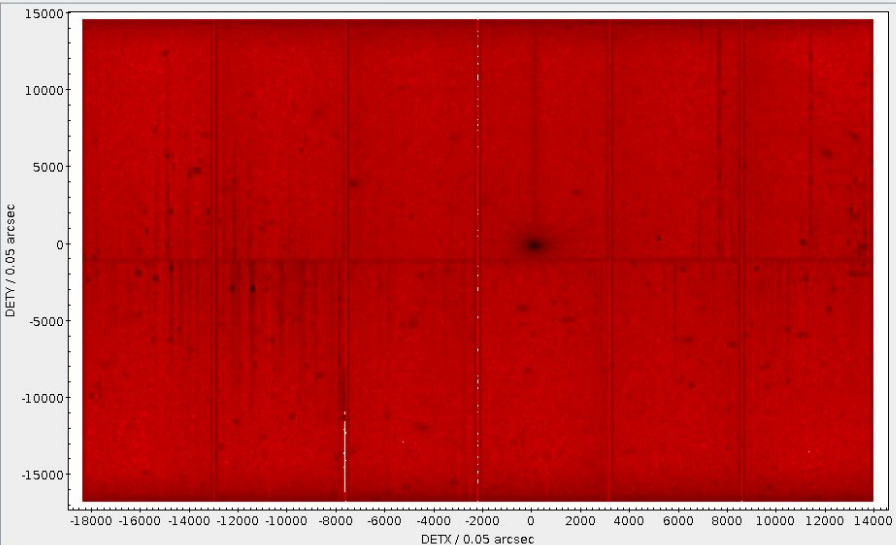




single incident photon energy of 3.75 keV. This would be the spectrum that NICER would record if the astrophysical target emitted a single narrow line at 3.75 keV

And in 2D





Position Subsets Form

Table: 1: pnclean.fits

X: DETX

Y: DETY

X ↔ Y

Position: Count: 1,280,452 / 1,280,452

Select



Table Browser for 1: pnclean.fits

| | TIME | RAWX | RAWY | DETX | DETY | X | Y | PHA | PI | FLAG | PATTERN | PAT_ID | PAT_SEQ | CCDNF |
|----|------------|------|------|-------|-------|-------|-------|------|-------|------|---------|--------|---------|-------|
| 1 | 6.247749E8 | 61 | 140 | -7259 | 3918 | 29244 | 31720 | 32 | 178 | 0 | 0 | 0 | 0 | 1 |
| 2 | 6.247749E8 | 1 | 55 | -2293 | 10983 | 20944 | 34105 | 179 | 908 | 4 | 0 | 0 | 0 | 1 |
| 3 | 6.247749E8 | 19 | 13 | -3793 | 14380 | 19981 | 37691 | 37 | 232 | 40 | 0 | 0 | 0 | 1 |
| 4 | 6.247749E8 | 59 | 142 | -7100 | 3765 | 29216 | 31501 | 32 | 1081 | 1 | 98 | 1 | 0 | 1 |
| 5 | 6.247749E8 | 20 | 39 | -3840 | 12247 | 21356 | 36060 | 2530 | 19793 | 16 | 1 | 5121 | 0 | 1 |
| 6 | 6.247749E8 | 32 | 180 | -4839 | 606 | 29438 | 27622 | 1704 | 9024 | 0 | 0 | 0 | 70 | 1 |
| 7 | 6.247749E8 | 61 | 83 | -7218 | 8663 | 26235 | 35389 | 1162 | 8260 | 0 | 4 | 5121 | 0 | 1 |
| 8 | 6.247749E8 | 54 | 13 | -6681 | 14415 | 22208 | 39530 | 44 | 1890 | 1 | 232 | 1 | 0 | 1 |
| 9 | 6.247749E8 | 62 | 142 | -7366 | 3785 | 29411 | 31683 | 40 | 226 | 0 | 0 | 0 | 0 | 1 |
| 10 | 6.247749E8 | 42 | 159 | -5650 | 2344 | 28979 | 29484 | 197 | 1086 | 0 | 0 | 0 | 0 | 1 |
| 11 | 6.247749E8 | 5 | 200 | -2604 | -1025 | 28721 | 24950 | 210 | 1190 | 4 | 0 | 0 | 0 | 1 |
| 12 | 6.247749E8 | 57 | 114 | -6909 | 6109 | 27597 | 33206 | 91 | 886 | 0 | 3 | 5121 | 1 | 1 |
| 13 | 6.247749E8 | 57 | 122 | -6899 | 5404 | 28031 | 32651 | 36 | 200 | 0 | 0 | 0 | 0 | 1 |
| 14 | 6.247749E8 | 64 | 122 | -7488 | 5424 | 28477 | 33036 | 55 | 538 | 5 | 4 | 1 | 0 | 1 |
| 15 | 6.247749E8 | 1 | 91 | -2319 | 7978 | 22850 | 31781 | 2832 | 26398 | 5 | 206 | 1 | 1 | 1 |
| 16 | 6.247749E8 | 39 | 98 | -5402 | 7397 | 25615 | 33263 | 2770 | 14492 | 0 | 0 | 0 | 0 | 1 |
| 17 | 6.247749E8 | 60 | 124 | -7138 | 5255 | 28311 | 32685 | 21 | 341 | 1 | 78 | 1 | 0 | 1 |
| 18 | 6.247749E8 | 64 | 125 | -7503 | 5144 | 28665 | 32827 | 23 | 258 | 5 | 4 | 2 | 0 | 1 |
| 19 | 6.247749E8 | 7 | 15 | -6131 | 14286 | 21860 | 39085 | 22 | 208 | 0 | 1 | 5121 | 0 | 1 |
| 20 | 6.247749E8 | 84 | 13 | -7490 | 14452 | 22814 | 40067 | 137 | 794 | 5 | 1 | 1 | 0 | 1 |
| 21 | 6.247749E8 | 59 | 180 | -7093 | 613 | 31188 | 29042 | 2660 | 14670 | 0 | 0 | 0 | 0 | 1 |
| 22 | 6.247749E8 | 1 | 173 | -2286 | 1218 | 27066 | 26497 | 98 | 547 | 4 | 0 | 0 | 0 | 1 |
| 23 | 6.247749E8 | 6 | 138 | -2748 | 4075 | 25633 | 29011 | 50 | 267 | 0 | 0 | 0 | 0 | 1 |

TOPCAT

File Views Graphics Joins Windows VO Interactions Help

Table List

- 1: pnclean.fits
- 2: pnclean.fits-2
- 3: pnclean.fits-3
- 4: pnclean.fits-4
- 5: pnclean.fits-5
- 6: pnclean.fits-6
- 7: pnclean.fits-7
- 8: pnclean.fits-8
- 9: pnclean.fits-9
- 10: pnclean.fits-10
- 11: pnclean.fits-11

Current Table Properties

Label: pnclean.fits

Location: pnclean.fits

Name: EVENTS

Rows: 1,280,452

Columns: 15

Sort Order:

Row Subset: All

Activation Actions: 0 / 1

SAMP

Messages:

Clients:

610 / 7924 M

Total: 1,280,452 Visible: 1,280,452 Selected: 0