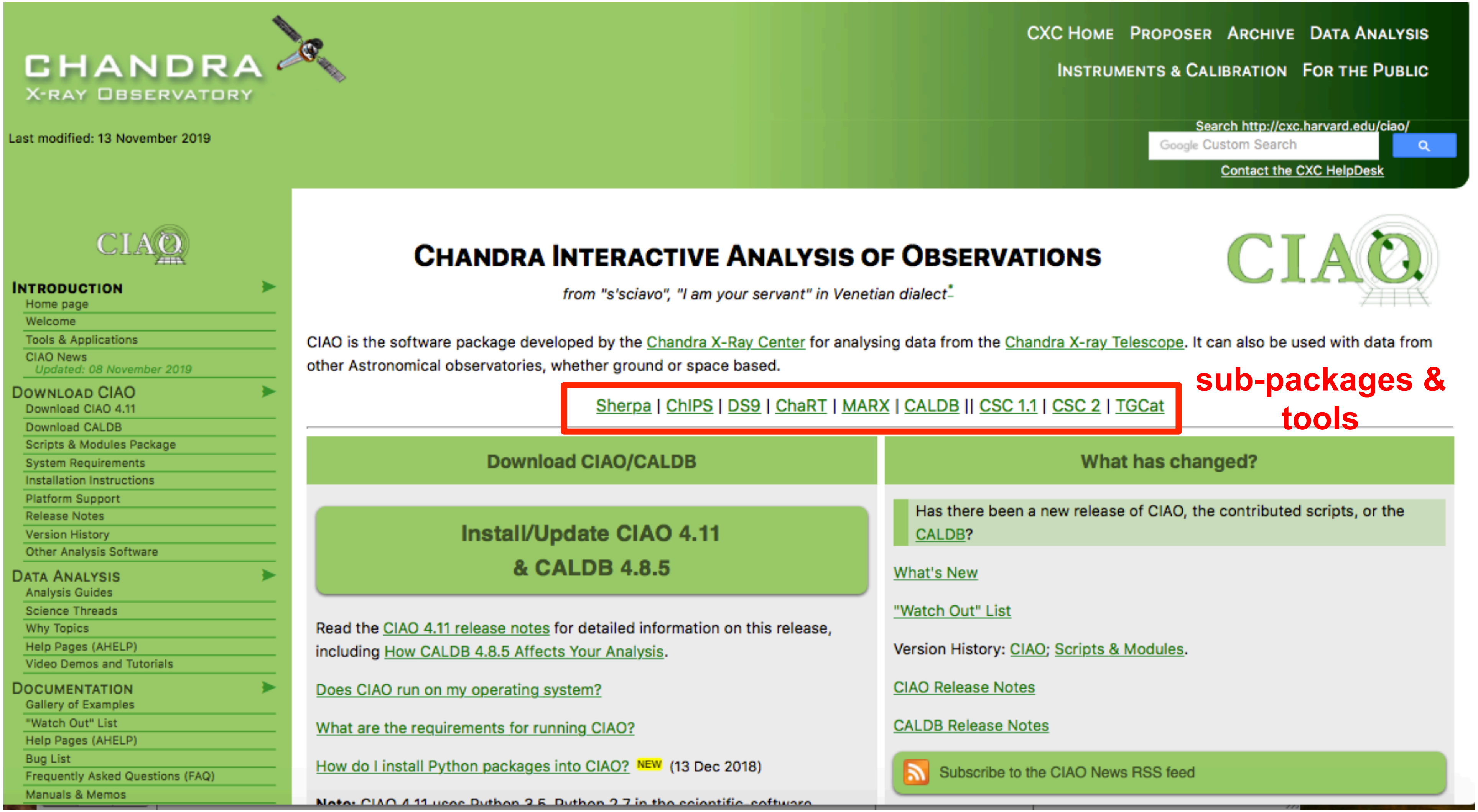
Chandra Tutorial

Eleonora Torresi 2010
+
Giorgio Lanzuisi 2011/2014/2015
+
Fabio Vito 2012
+
Cristian Vignali 2013, 2016, 2017
+
Giulia Migliori 2018

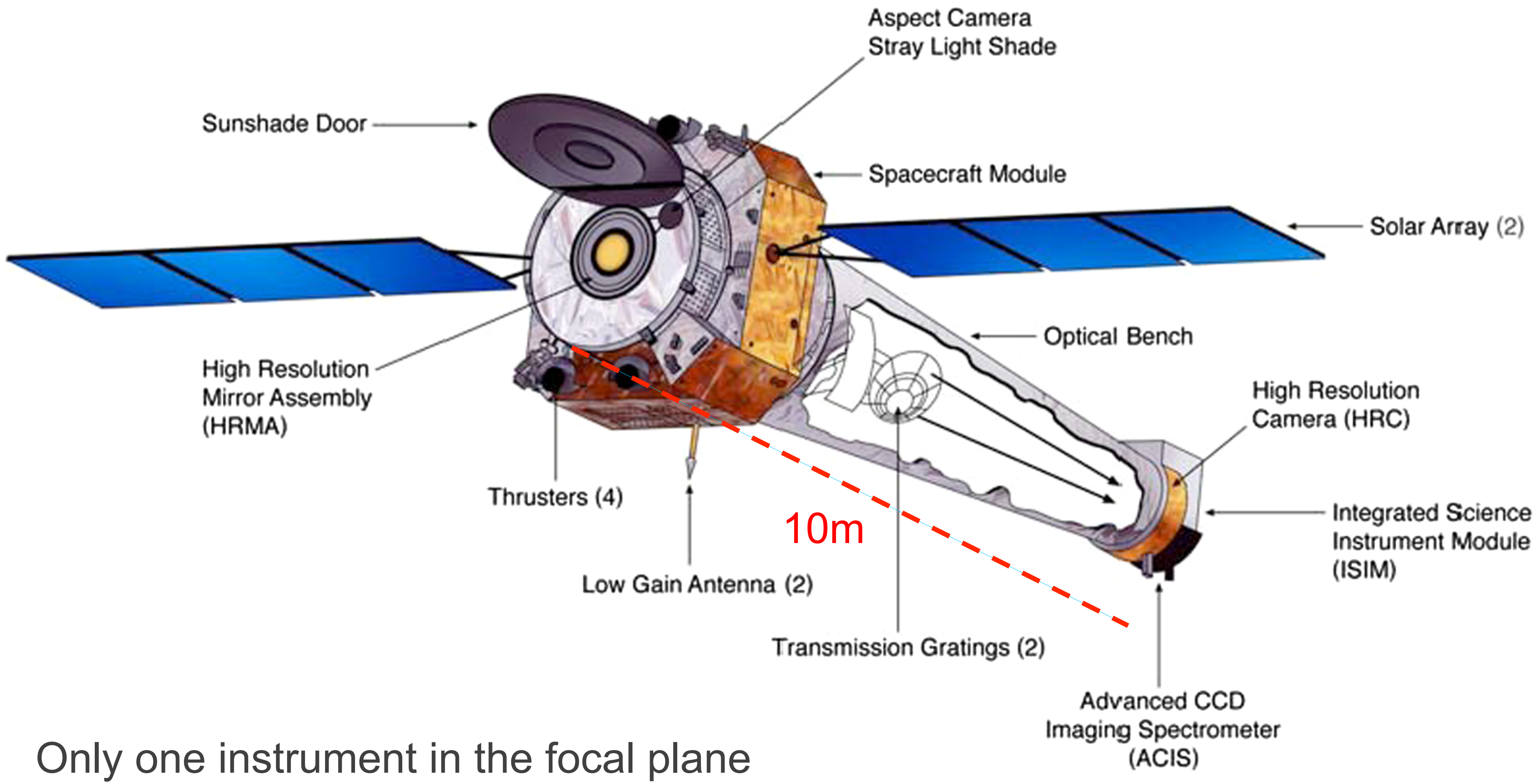
Astrophysics Lab - 2019

https://cxc.harvard.edu/ciao/



CIAO: software for *Chandra* data analysis

The spacecraft

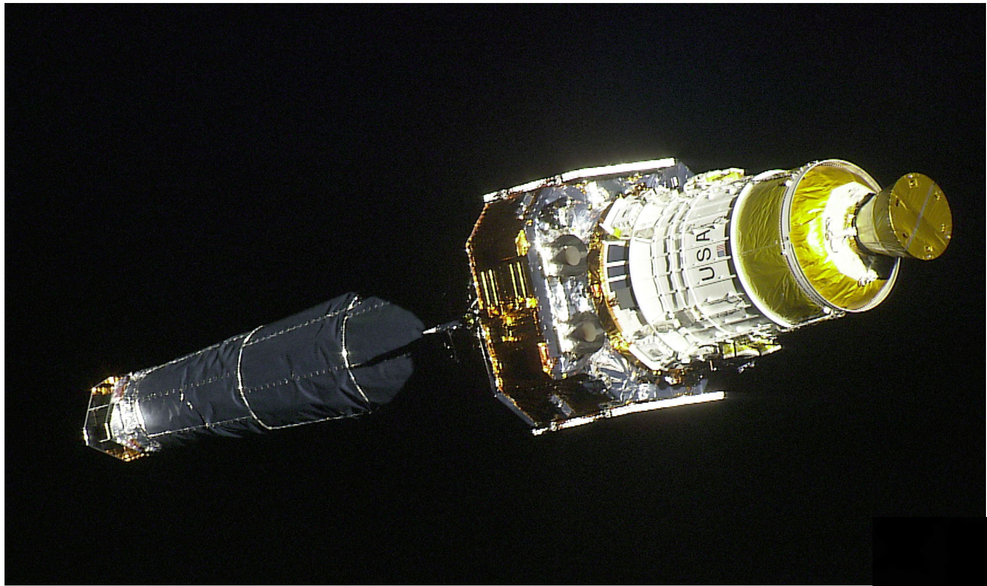


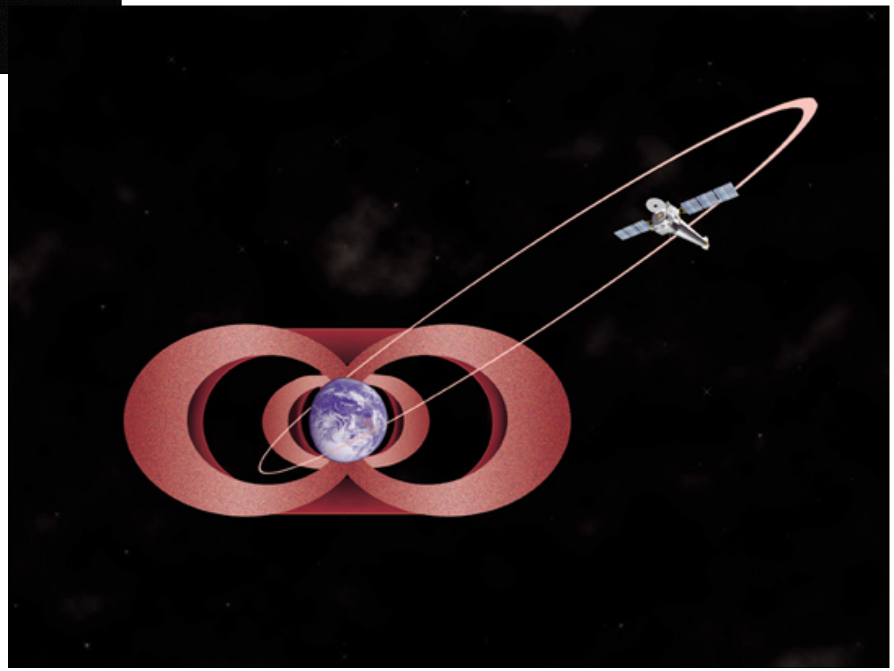
Only one instrument in the focal plane
"active" for each observation

The real spacecraft

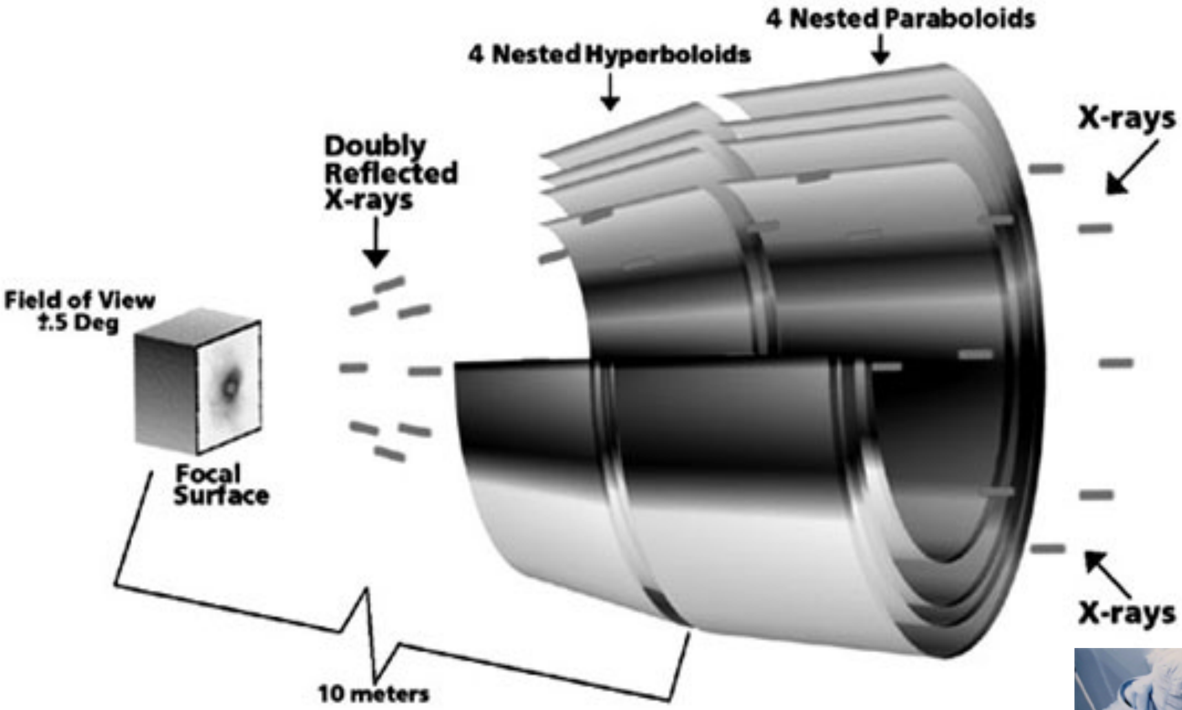
Launched:
July 23, 1999

The real spacecraft



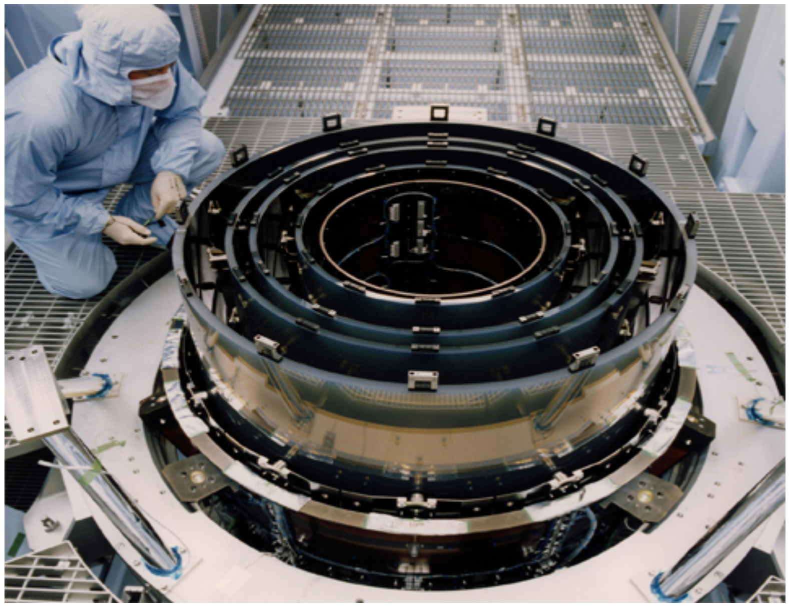


Mirrors



Mirror elements are 0.8 m long and from 0.6 m to 1.2 m diameter

4 mirrors only
Low effective area
but sharp PSF,
hence low
background



Strengths…

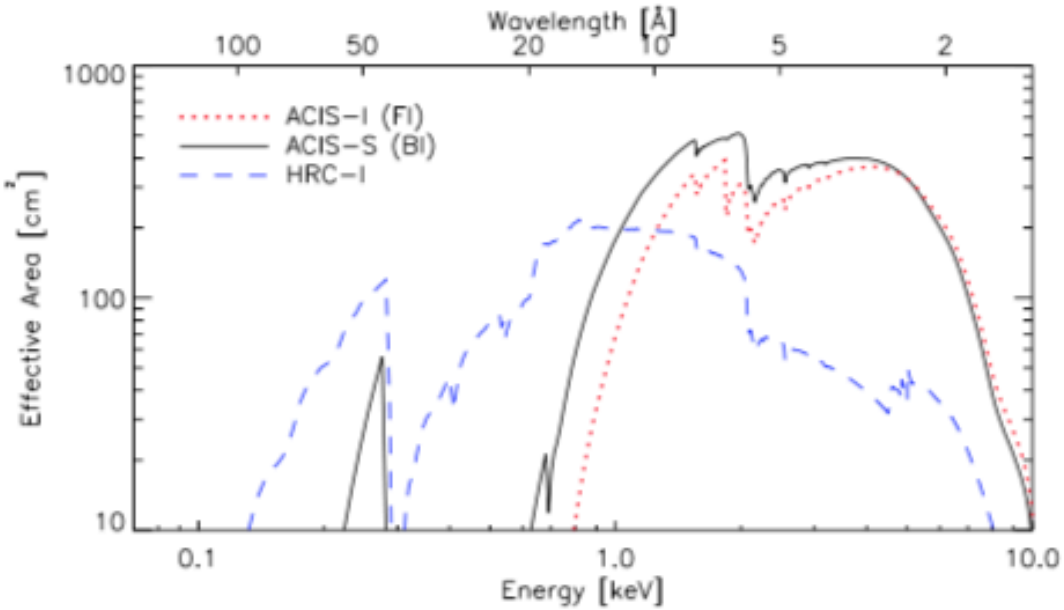
- Best spatial resolution of any X-ray satellite: ~1” (Hubble ~0.1”, next best X-ray satellite, XMM-Newton ~10”, ROSAT ~5”);
- good energy range (300 eV – 9 keV) & resolution (E/ΔE ~5 – 40);
- best energy resolution (Gratings) of any X-ray satellite: E/ΔE~1400 – 200 (Radio & Hubble ~20,000, next best X-ray satellite, XMM-Newton ~ 500 – 40);
- largest dynamic flux range of any satellite ever flown: 11 orders of magnitude; 10^{-18} – 10^{-7} erg cm^{-2} s^{-1}.

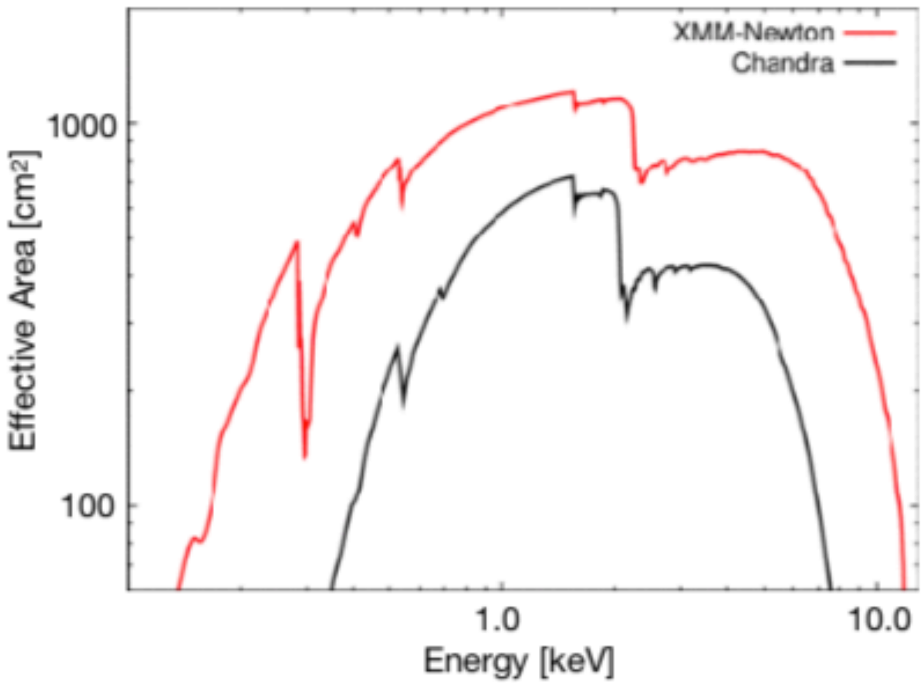
…and weaknesses

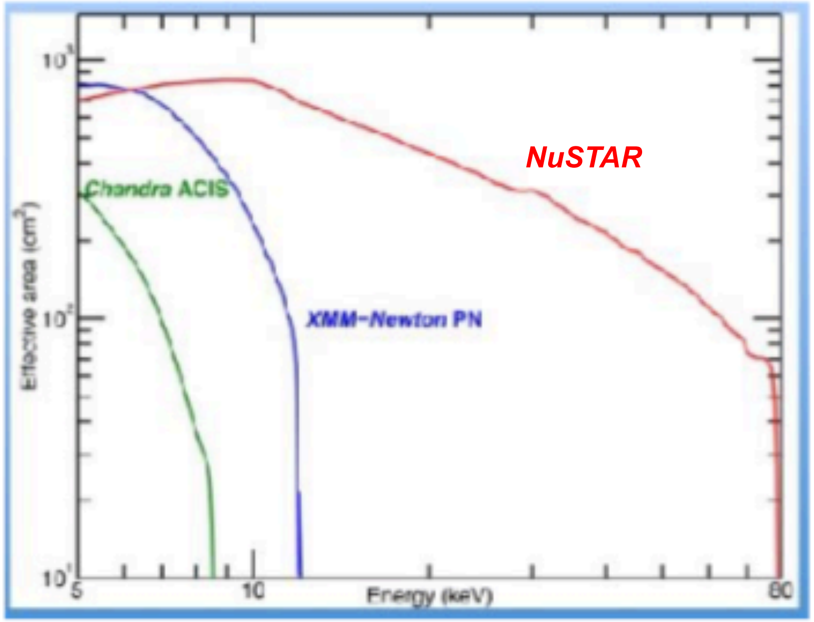
- small effective area:

@ 0.25 keV	800 cm^2
@ 5.0 keV	400 cm^2
@ 8.0 keV	100 cm^2

see Dadina's presentation
for further details



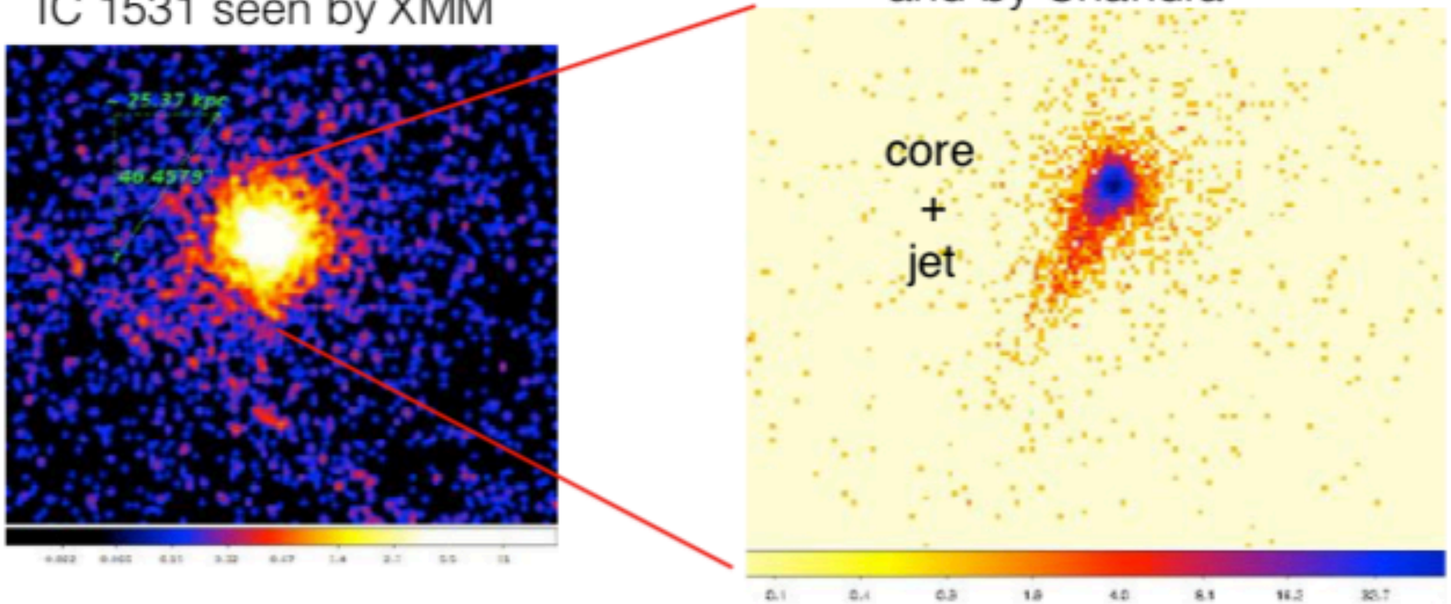


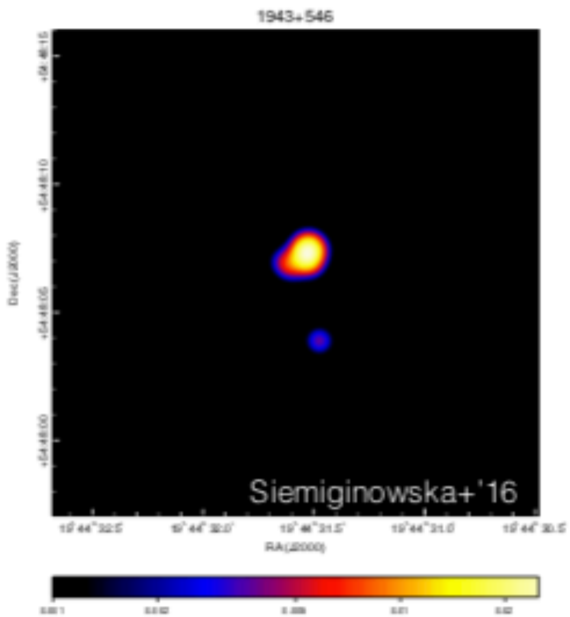


Ideal to study extended X-ray sources:

IC 1531 seen by XMM

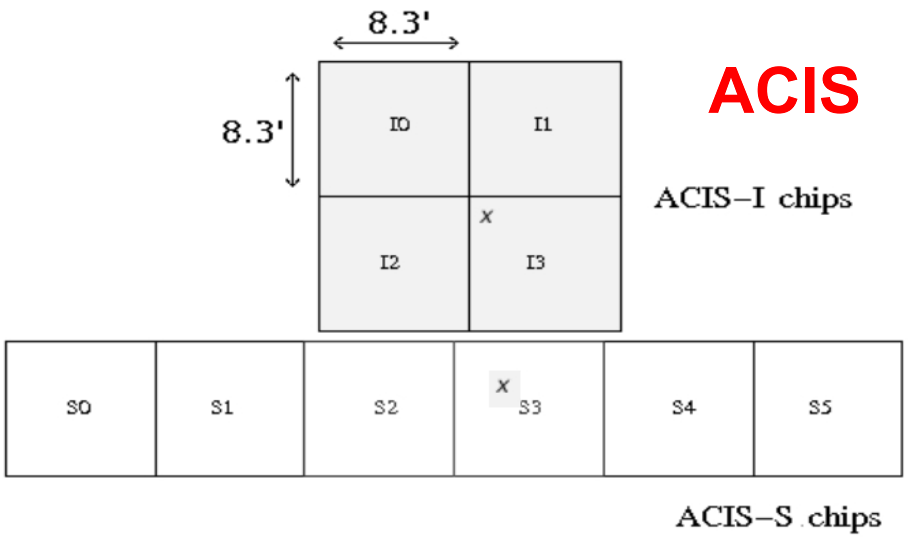
and by Chandra





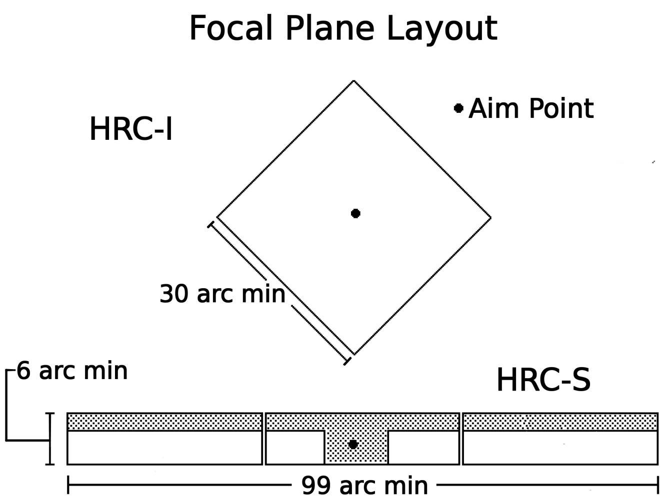
and to detect sources in very low-count regime: 5 counts may be a detection! (even less for point-like sources at on-axis position)

The detectors:



ACIS

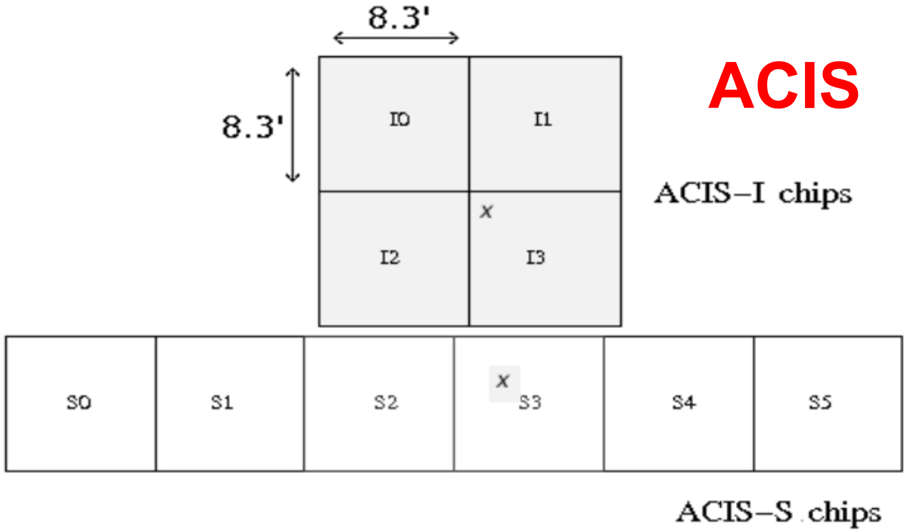
HRC



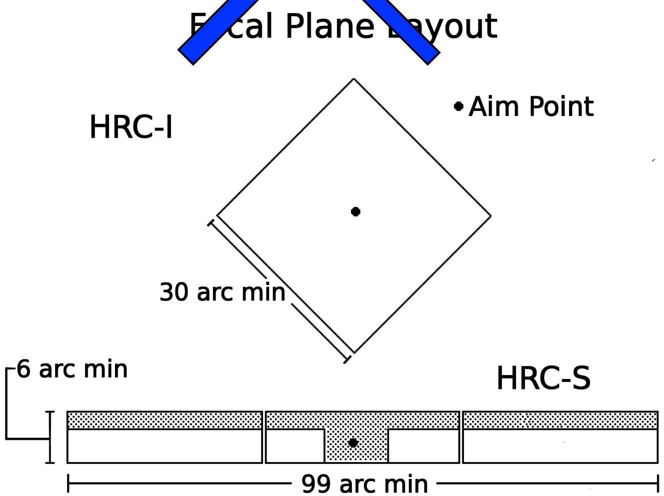
+HETG and LETG dispersive spec.

The detectors:

ACIS



HRC



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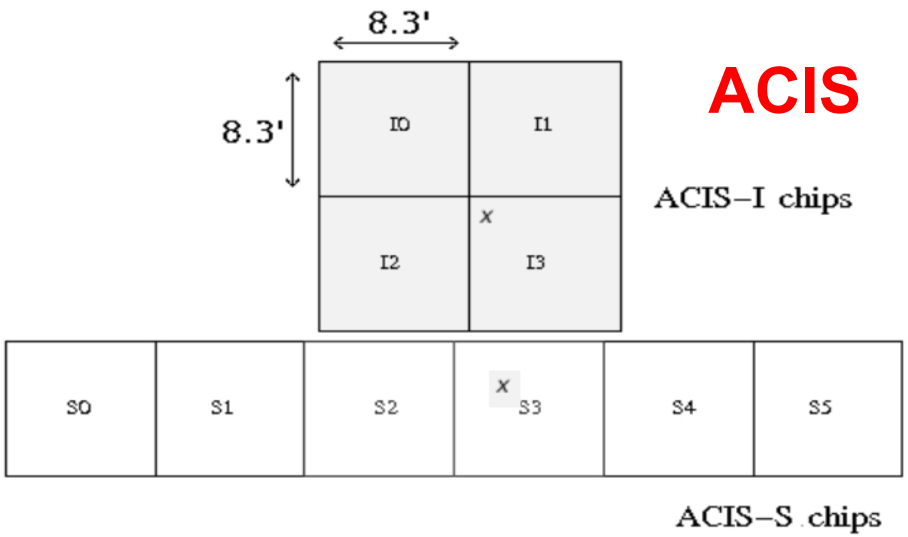
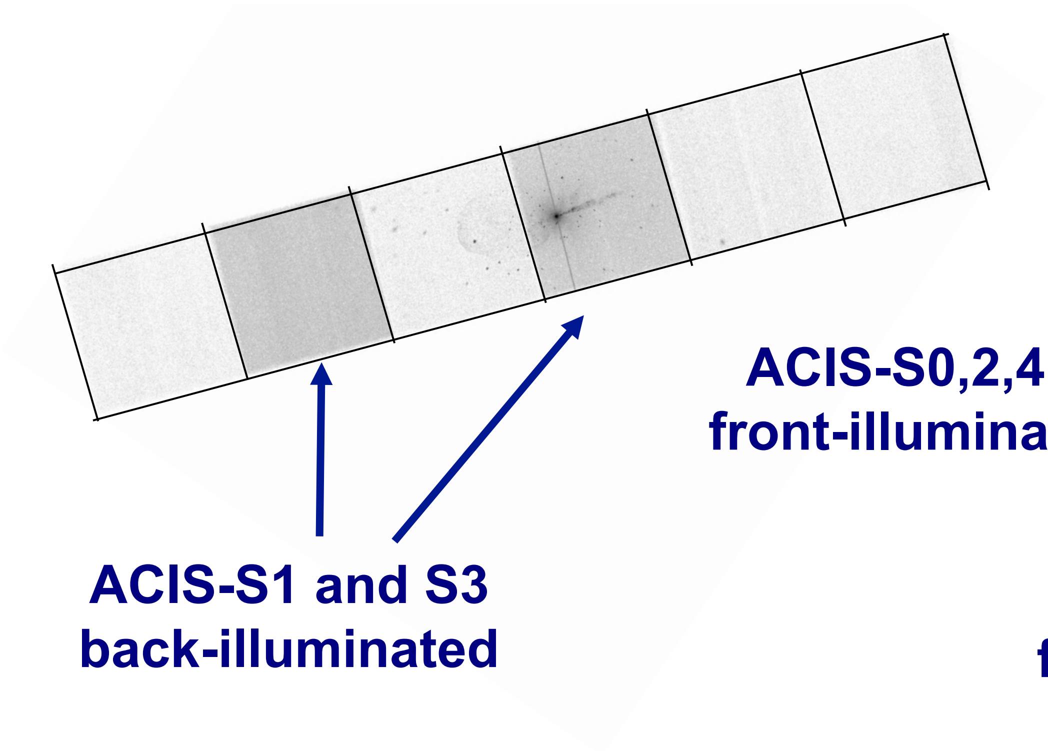
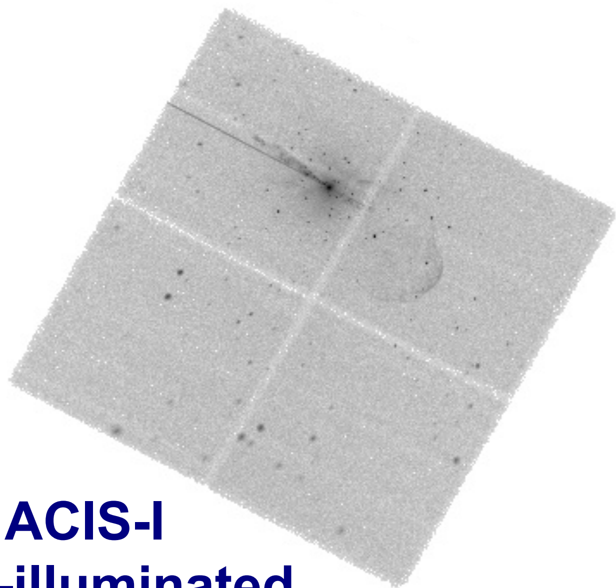




ACIS-S0,2,4,5
front-illuminated

ACIS-S1 and S3
back-illuminated



ACIS-I
front-illuminated

1. The fundamental rules to reduce X-ray data are the same in most of the cases BUT a good knowledge of the properties of X-ray satellites and their instruments is important to maximize the scientific output

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2. X-ray data from each satellite are usually accompained by specific software and tools to make a proper and easy data reduction and analysis

Chandra	→	CIAO
XMM-*Newton*	→	SAS

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Chandra	➔	CIAO
XMM-*Newton*	➔	SAS

3. How to get data: proposals of observations: if accepted

proprietary data for one year,
then archival data available to the community

Presentation available on the LabX2019 web page

Main steps in *Chandra* data analysis

- ❑ Download data from a public archive
- ❑ Visualize the X-ray data
- ❑ Reduce the X-ray (*Chandra*) data
- ❑ Specific applications: how to create a radio/X-ray contour for an extended source

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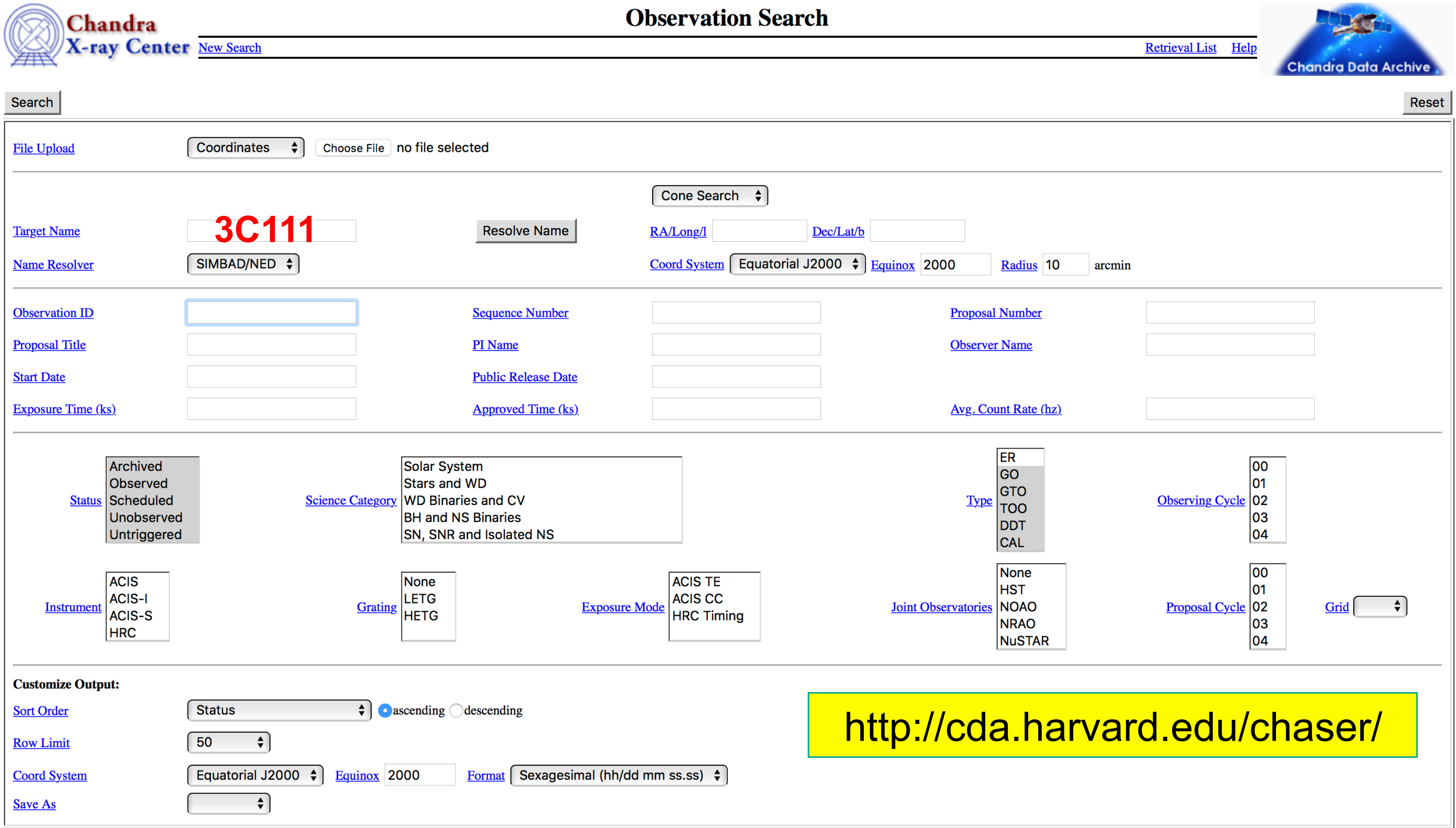
Where can I find X-ray data archives?

There are **multi-mission archives** (e.g., HEASARC, ASI) and **mission-related** (specific) **archives** (e.g., at the web pages of *Chandra*, XMM-*Newton*)

Chandra archive: webchaser



Selection possible on the basis of source name/coordinates/PI name/ObsID, etc you can view the details of each observation

Chandra X-ray Center

Search Results

New Search — Search Results — Retrieval List — Help

Chandra Data Archive

View Observation Information — Add Products to Retrieval List

- [x] Primary package
- [x] Secondary package
- [ ] Custom selection

Instrument

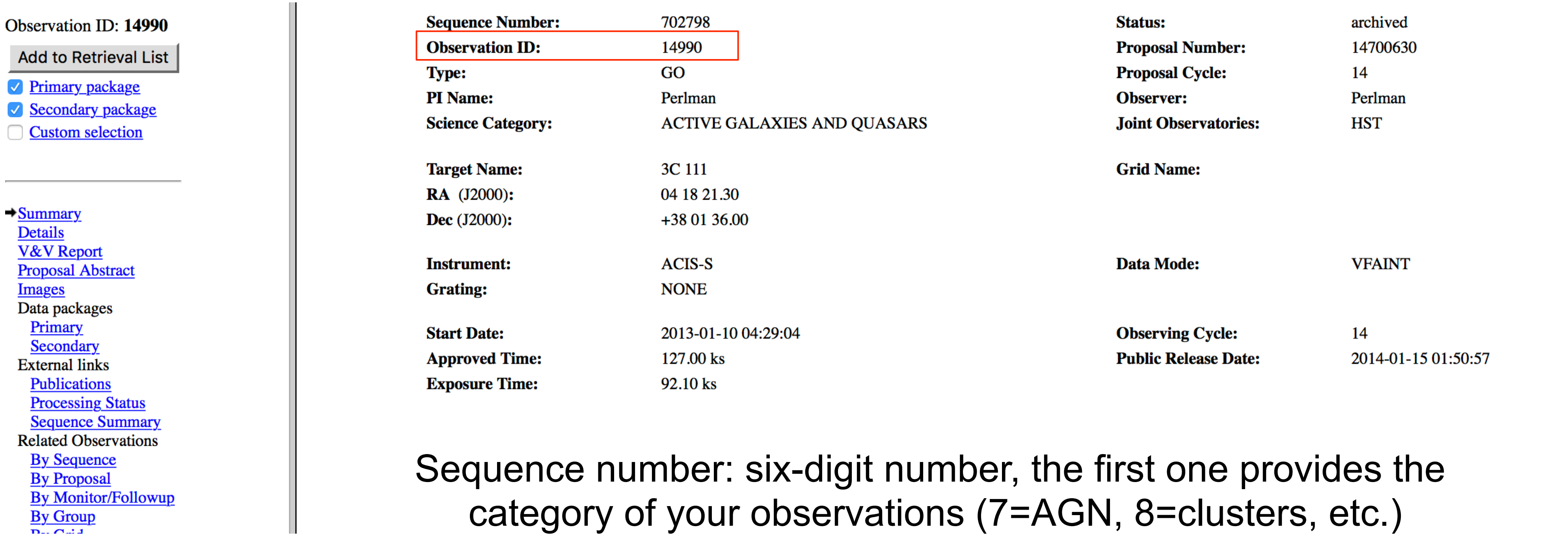
Select all | Unselect all

Select	Row	Seq Num	Obs ID	Instrument	Grating	Appr Exp	Exposure	Target Name	PI Name	RA	Dec	Status	Data Mode	Exp Mode	Avg Cnt Rate	Evt Cnt	Start Date	Public R
☐	1	702798	14990	ACIS-S	NONE	127.0	92.1	3C 111	Perlman	04 18 21.30	+38 01 36.00	archived	VFAINT	TE	5.65	520726	2013-01-10 04:29:04	2014-0
☐	2	703007	16219	ACIS-S	HETG	150.0	143.41	3C 111	Tombesi	04 18 21.30	+38 01 35.80	archived	FAINT	TE	7.63	1094231	2014-11-04 10:48:56	2015-1
☐	3	703412	19615	ACIS-S	NONE	26.0	22.54	3C 111	Perlman	04 18 21.30	+38 01 36.00	observed	VFAINT	TE	3.07	69154	2017-12-26 15:46:41	2019-0
☐	4	703412	20907	ACIS-S	NONE	32.0	28.16	3C 111	Perlman	04 18 21.30	+38 01 36.00	observed	VFAINT	TE	2.97	83648	2017-12-29 03:21:51	2019-0
☐	5	703412	20908	ACIS-S	NONE	32.0	27.23	3C 111	Perlman	04 18 21.30	+38 01 36.00	observed	VFAINT	TE	2.93	79812	2017-12-29 18:15:31	2019-0
☐	6	703413	19616	ACIS-S	NONE	90.0		3C 111	Perlman	04 18 21.30	+38 01 36.00	unobserved	VFAINT	TE			2018-12-25 00:00:00	
Totals						0.00	0.00									0		

Seq. # ObsID Expo

mark one (all) of these boxes to select the observations for the download.
An archive (.tar) file will be prepared for the download. This contains both primary and secondary datasets needed for immediate use for scientific purposes or complete reprocessing using the most up-to-date calibrations and CIAO tools

Details of the observation: instrument setup, CCDs in use, abstract of the proposal, pipeline-processed products, etc.



Observation ID: **14990**

Add to Retrieval List

- [x] Primary package
- [x] Secondary package
- [ ] Custom selection

→ Summary
Details
V&V Report
Proposal Abstract
Images
Data packages
  Primary
  Secondary
External links
  Publications
  Processing Status
  Sequence Summary
Related Observations
  By Sequence
  By Proposal
  By Monitor/Followup
  By Group

Sequence Number:	702798	**Status:**	archived
Observation ID:	14990	**Proposal Number:**	14700630
Type:	GO	**Proposal Cycle:**	14
PI Name:	Perlman	**Observer:**	Perlman
Science Category:	ACTIVE GALAXIES AND QUASARS	**Joint Observatories:**	HST
Target Name:	3C 111	**Grid Name:**	
RA (J2000):	04 18 21.30		
Dec (J2000):	+38 01 36.00		
Instrument:	ACIS-S	**Data Mode:**	VFAINT
Grating:	NONE		
Start Date:	2013-01-10 04:29:04	**Observing Cycle:**	14
Approved Time:	127.00 ks	**Public Release Date:**	2014-01-15 01:50:57
Exposure Time:	92.10 ks		

Sequence number: six-digit number, the first one provides the category of your observations (7=AGN, 8=clusters, etc.)

Alternatively (using a CIAO command-line)

- ➢ **download_chandra_obsid 14990** (once the obsid, 14990 in this case, is known)

otherwise

- ➢ **find_chandra_obsid 3C111**

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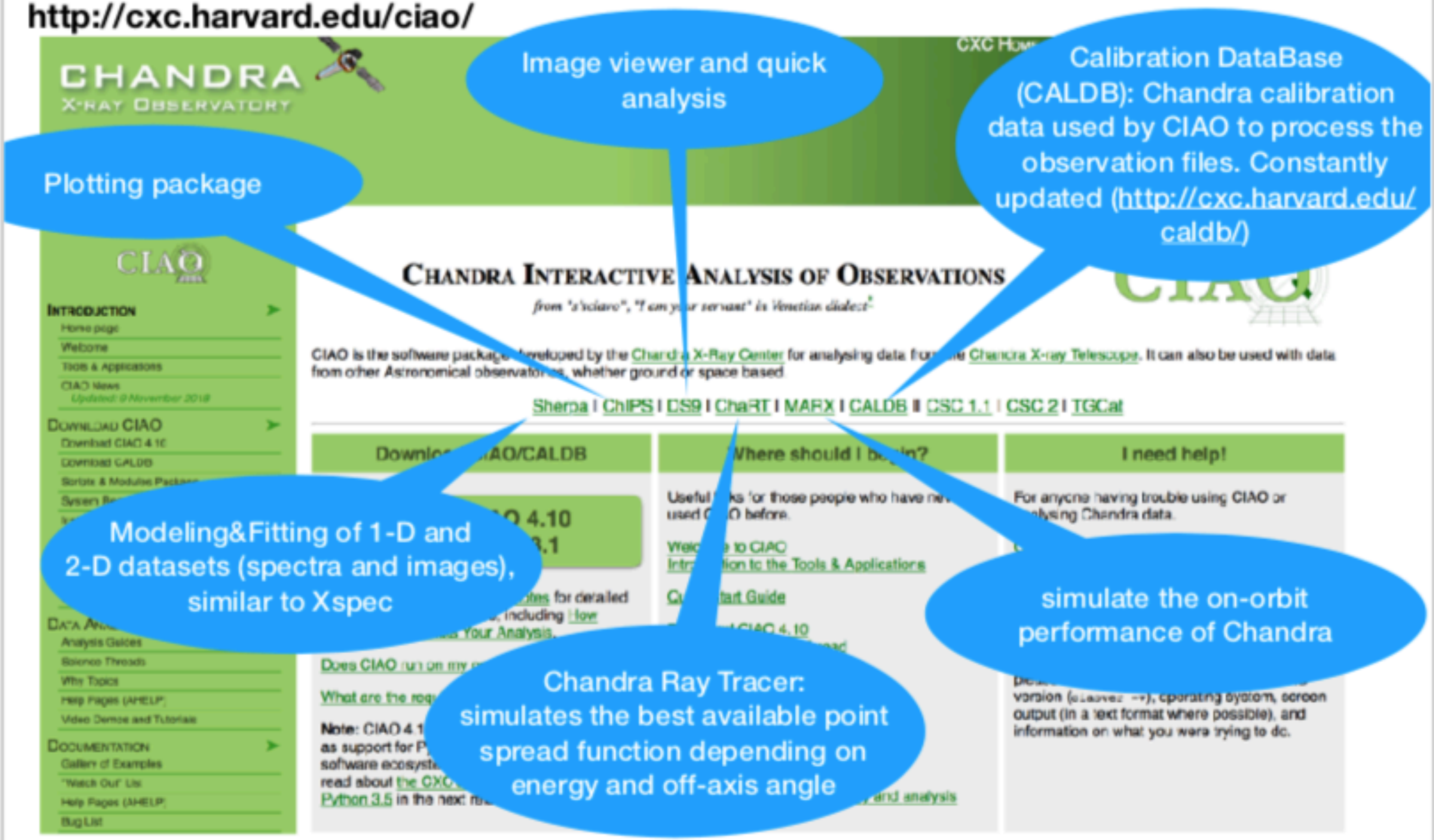
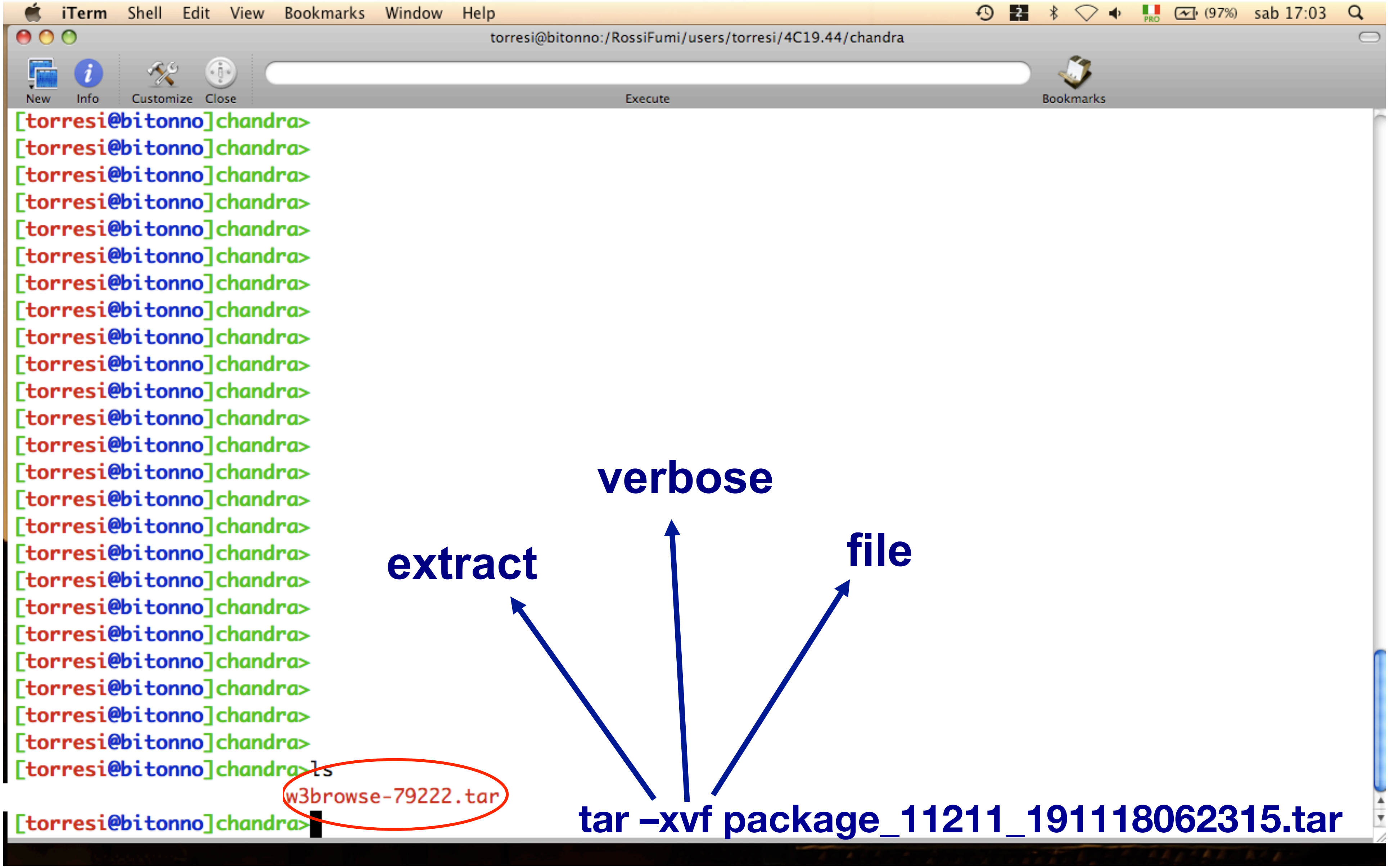
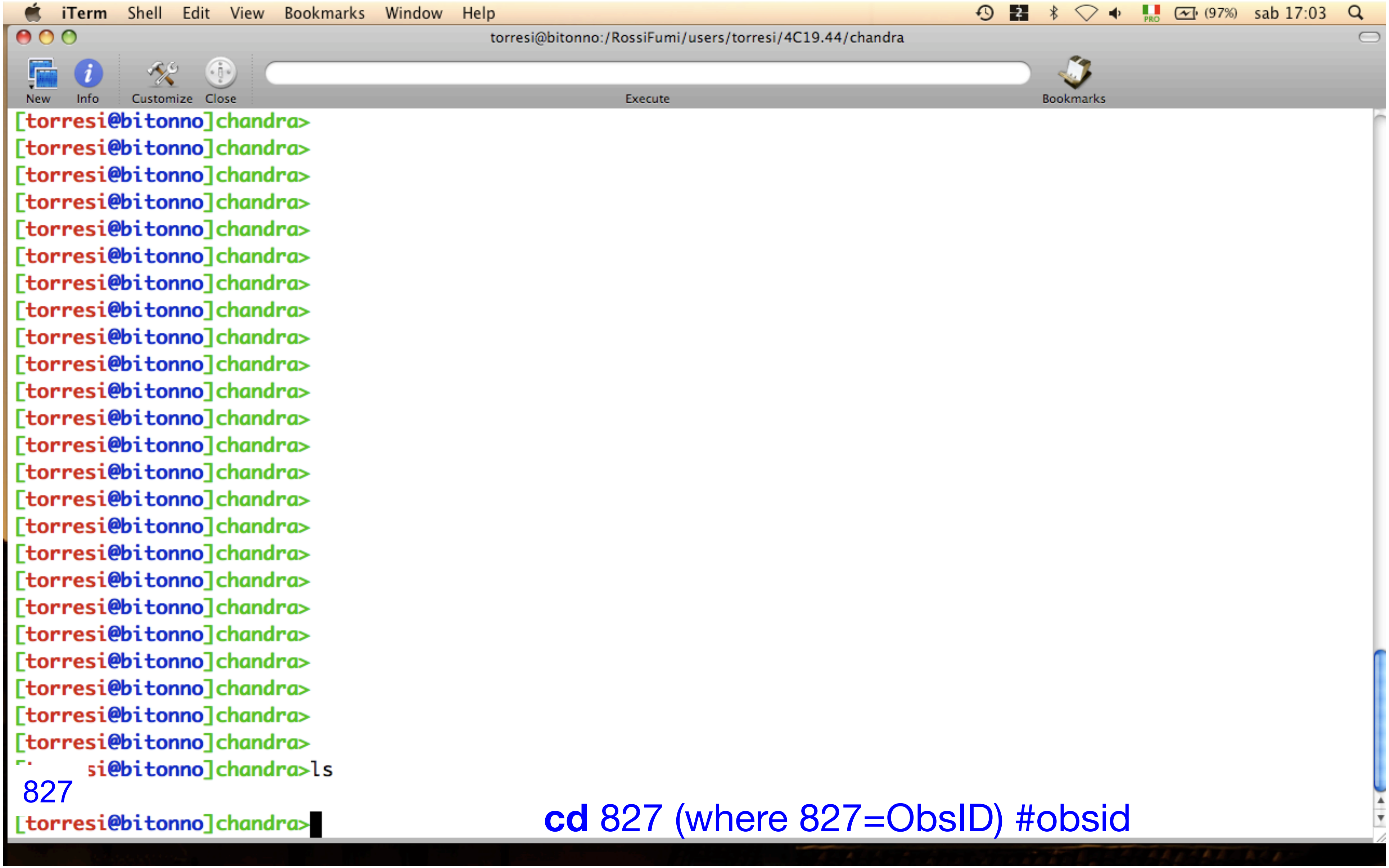
How to reduce and analyzed Chandra data: CIAO software

http://cxc.harvard.edu/ciao/




iTerm Shell Edit View Bookmarks Window Help
sab 17:03
torresi@bitonno:/RossiFumi/users/torresi/4C19.44/chandra
New Info Customize Close Execute Bookmarks
[torresi@bitonno]chandra>ls
w3browse-79222.tar
[torresi@bitonno]chandra>
verbose
extract
file
tar –xvf package_11211_191118062315.tar



827

cd 827 (where 827=ObsID) #obsid

http://cxc.cfa.harvard.edu/ciao/data_products_guide/

```
sapmcm127:3C219 gmiglior$ ls 827/
00README                        primary
axaff00827N002_VV001_vv2.pdf    secondary
oif.fits
```

data are stored in two directories: scientific & housekeeping files

```
sapmcm127:3C219 gmiglior$ ls 827/primary/
acisf00827N003_cntr_img2.fits.gz      acisf00827_000N003_bpix1.fits.gz
acisf00827N003_cntr_img2.jpg          acisf00827_000N003_fov1.fits.gz
acisf00827N003_evt2.fits.gz           orbitf087566700N001_eph1.fits.gz
acisf00827N003_full_img2.fits.gz      pcadf087648241N003_asol1.fits.gz
acisf00827N003_full_img2.jpg
```

primary:

evt2.fits : Level 2 event file, fully calibrated, fully filtered primary science product.

- asol1.fits : Level 1 aspect solution file(s). Time resolved pointing information.
- bpix1.fits : Level 1 bad pixel file
- fov1.fits : Level 1 field-of-view file.

```
sapmcm127:3C219 gmiglior$ ls 827/secondary/
acisf00827_000N003_evt1.fits.gz      acisf087647802N003_1_bias0.fits.gz
acisf00827_000N003_flt1.fits.gz      acisf087648408N003_pbk0.fits.gz
acisf00827_000N003_msk1.fits.gz      aspect
acisf00827_000N003_mtl1.fits.gz      axaff00827N002_VV001_vvref2.pdf.gz
acisf00827_000N003_stat1.fits.gz     ephem
```

secondary:

- evt1.fits : Event file, fully calibrated **unfiltered** event file. Used when reprocessing.
- msk1.fits : Mask file to identify active part of detector
- flt1.fits : Good time interval based on mission time line parameters
- mtl1.fits : Mission time line. Important science and engineering values vs time

FILE FORMAT

f=flight file revision format

`acisf00827N003_evt2.fits`

instrument Observation ID content (=event) & level

- The event file is in FITS (flexible image transport system) format;
- A single Chandra file can contain multiple “datasets” (e.g. data, Good Time Intervals, weight map, regions) which are stored in “blocks”.
- Blocks can contain image or table data.
- the event file can be though as a 4-D array which stores for each event the informations about energy, position and time;
- however in practice it is more complicate and there are more parameters (multiple coordinate systems, times, channels/energy);
- CIAO tools to explore FITS files (dmlist, dmstat..) or fv (an heasarc package)

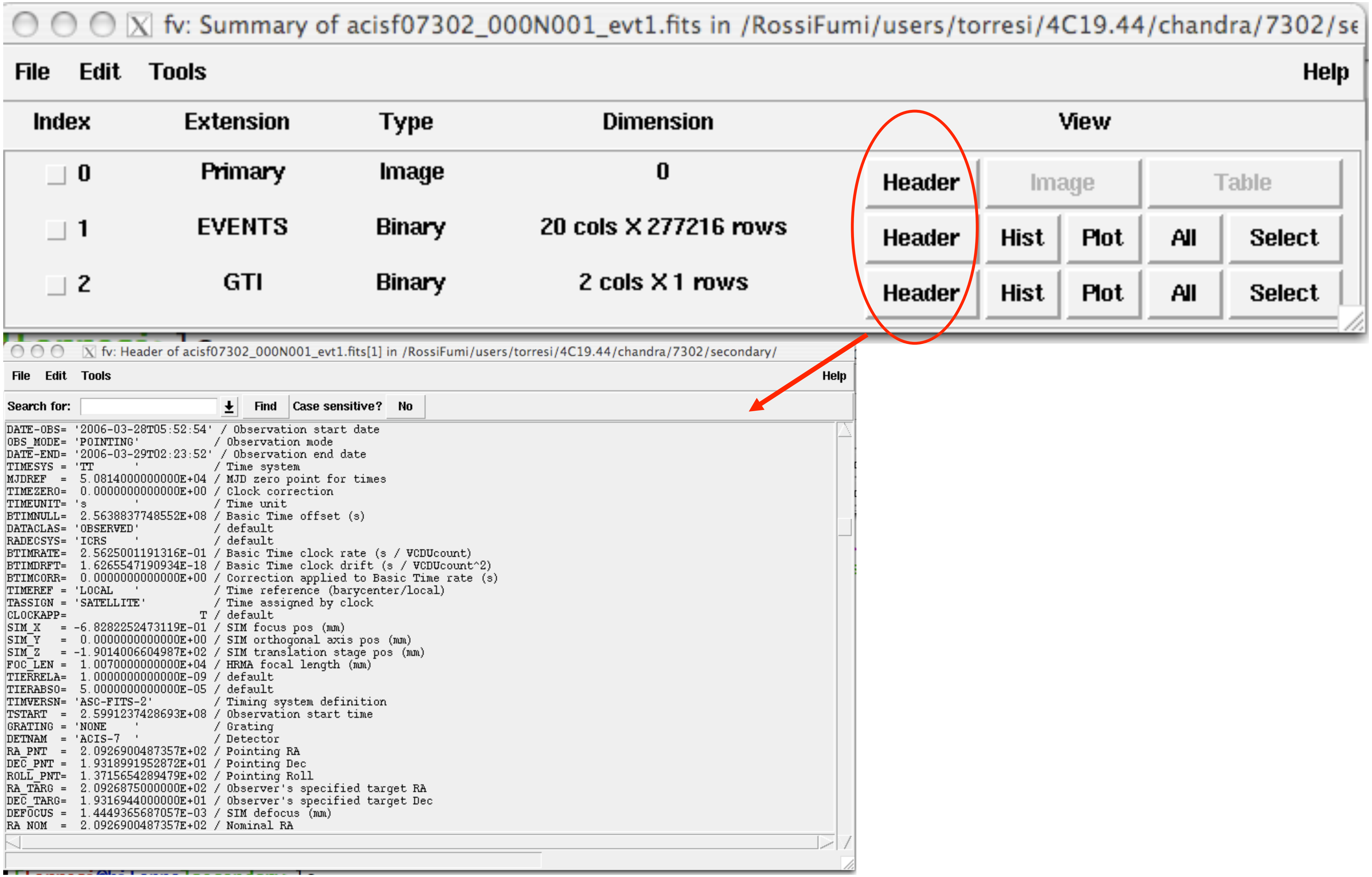
DATA REDUCTION & ANALYSIS WITH CIAO

dmlist event_file.evt   opt=subspace(/header/blocks/cols/data)

```
sapmcm127:repro gmiglior$ plist dmlist

Parameters for /Users/gmiglior/cxcds_param4/dmlist.par

        infile = acisf00827N003_evt2.fits Input dataset/block specification
           opt = header          Option
      (outfile = )               Output file (optional)
         (rows = )               Range of table rows to print (min:max)
        (cells = )               Range of array indices to print (min:max)
      (verbose = 0)              Debug Level(0-5)
         (mode = ql)
```

```
sapmcm127:primary gmiglior$ dmlist acisf00827N003_evt2.fits cols

--------------------------------------------------------------------------------
Columns for Table Block EVENTS
--------------------------------------------------------------------------------

ColNo  Name                 Unit        Type             Range
   1   time                 s            Real8          87647837.5706280023: 87667996.7588890046 S/C TT corresponding to mid-exposure
   2   ccd_id                            Int2           0:9                      CCD reporting event
   3   node_id                           Int2           0:3                      CCD serial readout amplifier node
   4   expno                             Int4           0:2147483647             Exposure number of CCD frame containing event
   5   chip(chipx,chipy)    pixel        Int2           1:1024                   Chip coords
   6   tdet(tdetx,tdety)    pixel        Int2           1:8192                   ACIS tiled detector coordinates
   7   det(detx,dety)       pixel        Real4          0.50:       8192.50      ACIS detector coordinates
   8   sky(x,y)             pixel        Real4          0.50:       8192.50      sky coordinates
   9   pha                  adu          Int4           0:36855                  total pulse height of event
  10   pha_ro               adu          Int4           0:36855                  total read-out pulse height of event
  11   energy               eV           Real4          0:  1000000.0            nominal energy of event (eV)
  12   pi                   chan         Int4           1:1024                   pulse invariant energy of event
  13   fltgrade                          Int2           0:255                    event grade, flight system
  14   grade                             Int2           0:7                      binned event grade
  15   status[4]                         Bit(4)                                  event status bits
```

All the information of your observation are contained in the header of the fits file. You can visualize it by using the FTOOL command *fv*



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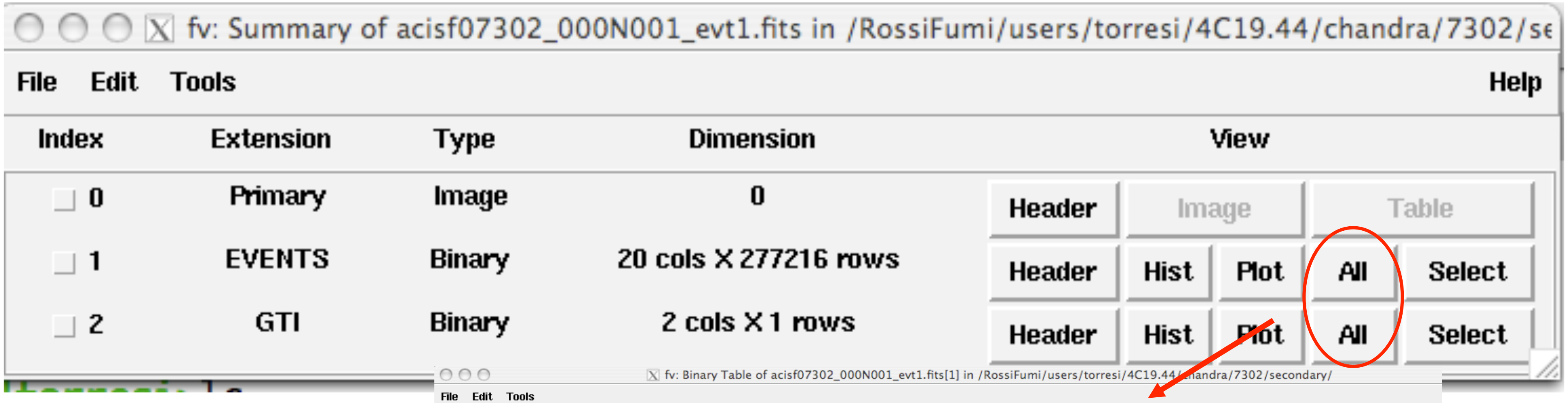
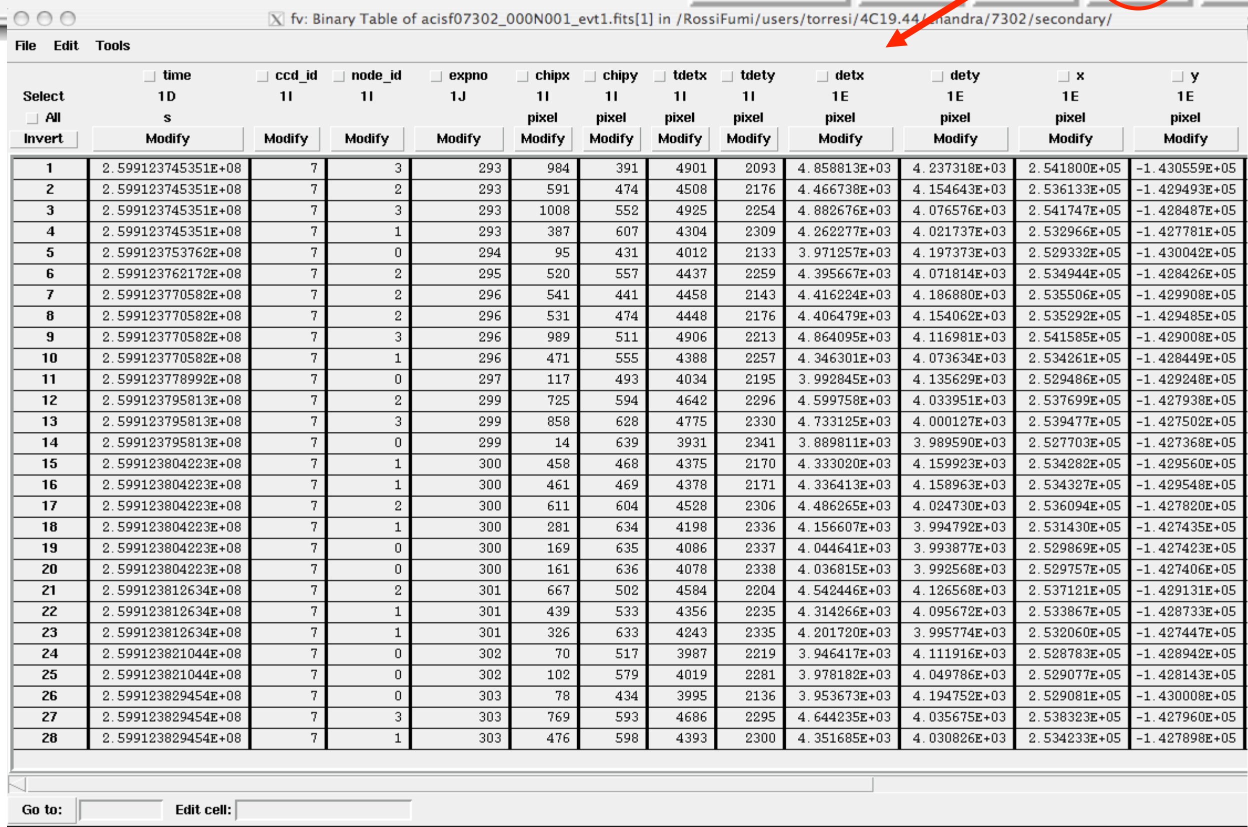




Select / All / Invert	time 1D s	ccd_id 1I	node_id 1I	expno 1J	chipx 1I pixel	chipy 1I pixel	tdetx 1I pixel	tdety 1I pixel	detx 1E pixel	dety 1E pixel	x 1E pixel	y 1E pixel
1	2.599123745351E+08	7	3	293	984	391	4901	2093	4.858813E+03	4.237318E+03	2.541800E+05	-1.430559E+05
2	2.599123745351E+08	7	2	293	591	474	4508	2176	4.466738E+03	4.154643E+03	2.536133E+05	-1.429493E+05
3	2.599123745351E+08	7	3	293	1008	552	4925	2254	4.882676E+03	4.076576E+03	2.541747E+05	-1.428487E+05
4	2.599123745351E+08	7	1	293	387	607	4304	2309	4.262277E+03	4.021737E+03	2.532966E+05	-1.427781E+05
5	2.599123753762E+08	7	0	294	95	431	4012	2133	3.971257E+03	4.197373E+03	2.529332E+05	-1.430042E+05
6	2.599123762172E+08	7	2	295	520	557	4437	2259	4.395667E+03	4.071814E+03	2.534944E+05	-1.428426E+05
7	2.599123770582E+08	7	2	296	541	441	4458	2143	4.416224E+03	4.186880E+03	2.535506E+05	-1.429908E+05
8	2.599123770582E+08	7	2	296	531	474	4448	2176	4.406479E+03	4.154062E+03	2.535292E+05	-1.429485E+05
9	2.599123770582E+08	7	3	296	989	511	4906	2213	4.864095E+03	4.116981E+03	2.541585E+05	-1.429008E+05
10	2.599123770582E+08	7	1	296	471	555	4388	2257	4.346301E+03	4.073634E+03	2.534261E+05	-1.428449E+05
11	2.599123778992E+08	7	0	297	117	493	4034	2195	3.992845E+03	4.135629E+03	2.529486E+05	-1.429248E+05
12	2.599123795813E+08	7	2	299	725	594	4642	2296	4.599758E+03	4.033951E+03	2.537699E+05	-1.427938E+05
13	2.599123795813E+08	7	3	299	858	628	4775	2330	4.733125E+03	4.000127E+03	2.539477E+05	-1.427502E+05
14	2.599123795813E+08	7	0	299	14	639	3931	2341	3.889811E+03	3.989590E+03	2.527703E+05	-1.427368E+05
15	2.599123804223E+08	7	1	300	458	468	4375	2170	4.333020E+03	4.159923E+03	2.534282E+05	-1.429560E+05
16	2.599123804223E+08	7	1	300	461	469	4378	2171	4.336413E+03	4.158963E+03	2.534327E+05	-1.429548E+05
17	2.599123804223E+08	7	2	300	611	604	4528	2306	4.486265E+03	4.024730E+03	2.536094E+05	-1.427820E+05
18	2.599123804223E+08	7	1	300	281	634	4198	2336	4.156607E+03	3.994792E+03	2.531430E+05	-1.427435E+05
19	2.599123804223E+08	7	0	300	169	635	4086	2337	4.044641E+03	3.993877E+03	2.529869E+05	-1.427423E+05
20	2.599123804223E+08	7	0	300	161	636	4078	2338	4.036815E+03	3.992568E+03	2.529757E+05	-1.427406E+05
21	2.599123812634E+08	7	2	301	667	502	4584	2204	4.542446E+03	4.126568E+03	2.537121E+05	-1.429131E+05
22	2.599123812634E+08	7	1	301	439	533	4356	2235	4.314266E+03	4.095672E+03	2.533867E+05	-1.428733E+05
23	2.599123812634E+08	7	1	301	326	633	4243	2335	4.201720E+03	3.995774E+03	2.532060E+05	-1.427447E+05
24	2.599123821044E+08	7	0	302	70	517	3987	2219	3.946417E+03	4.111916E+03	2.528783E+05	-1.428942E+05
25	2.599123821044E+08	7	0	302	102	579	4019	2281	3.978182E+03	4.049786E+03	2.529077E+05	-1.428143E+05
26	2.599123829454E+08	7	0	303	78	434	3995	2136	3.953673E+03	4.194752E+03	2.529081E+05	-1.430008E+05
27	2.599123829454E+08	7	3	303	769	593	4686	2295	4.644235E+03	4.035675E+03	2.538323E+05	-1.427960E+05
28	2.599123829454E+08	7	1	303	476	598	4393	2300	4.351685E+03	4.030826E+03	2.534233E+05	-1.427898E+05

Main steps in *Chandra* data analysis

- ❑ Download data from a public archive
- ❑ Visualize the X-ray data
- ❑ Reduce the X-ray (*Chandra*) data
- ❑ Specific applications: how to create a radio/X-ray contour for an extended source

Chandra data reduction

http://cxc.harvard.edu → Data Analysis → Threads

CIAO

- Introduction
- Download CIAO
- **Data Analysis**
- Documentation
- Sherpa (Modeling and Fitting)
- ChIPS (Plotting Package)
- Scripting in CIAO
- Data Products
- PSF Central NEW
- Workshops
- CXC Links
- CXC HelpDesk
- Site Map
- CIAO on social media

Science Threads

WHAT'S NEW | WATCH OUT

Top | All | Intro | Data Prep | Imag | Imag Spec | Grating | Timing | psf | TTT || ChIPS | Sherpa | Proposal | PSF Central

All threads

A list of all the threads on one page.

Introduction UPDATED

Beginners should start here. The Introductory threads provide an overview of the main components (GUI applications, parameter files) and concepts (the Data Model, filtering) in the CIAO data analysis software.

Data Preparation UPDATED

When Chandra data goes through Standard Data Processing (SDP), the most recently available calibration is applied to it. Since this calibration is continuously being improved, one should check whether there are newer files available. Similarly, some science decisions are made during SDP; every user has the option to reprocess the data with different parameters.

Imaging UPDATED

The Imaging threads cover a wide range of topics that include source detection, creating exposure maps and normalized images, and calculating image statistics. How to create color images for publication is addressed, as well as merging data from multiple observations.

Imaging Spectroscopy

After extracting source and background PI or PHA spectra from an imaging observation, the appropriate response files (ARF, RMF) are created so that the data may be modeled and fit. In the case of multiple or extended sources, a weighted ARF and RMF are built for the spectral analysis.

Scientific files
Housekeeping files

Scientific files
Housekeeping files

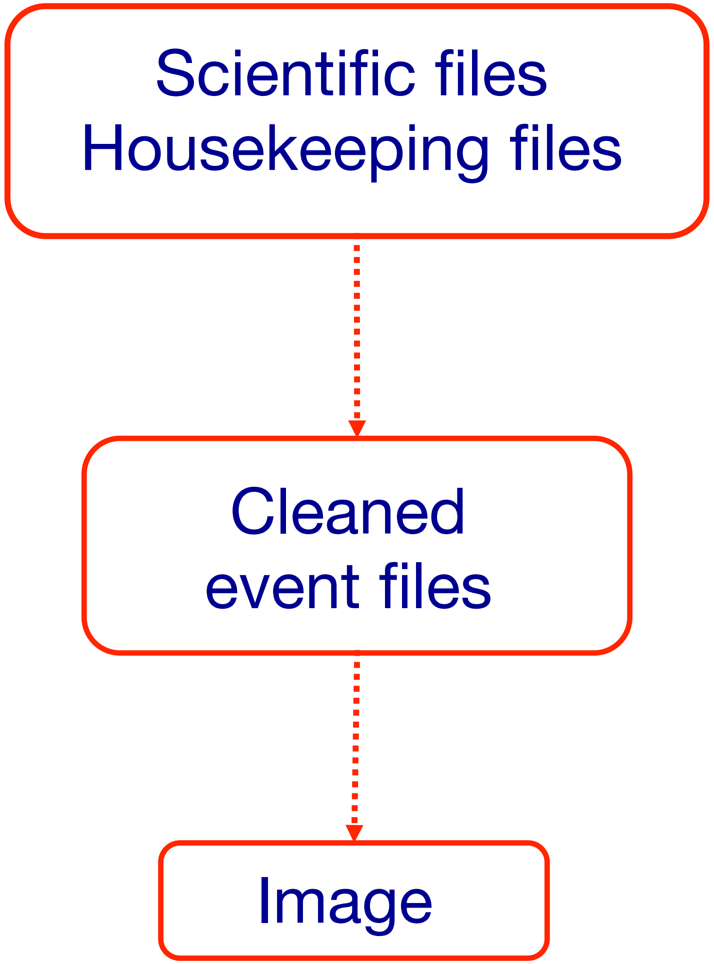
- removal of hot pixels or afterglows
  acis_run_hotpix
- creation of a new event file
  acis_process_events
- run *destreak* in case the ACIS-S4 chip (ccd_id=8) has been used
- filtering for bad grades and application of *Good Time Intervals (GTI)*
- creation of the background light curve

All steps needed to reprocess data in one command using the tool **chandra_repro**

- punlearn chandra_repro
- chandra_repro indir=14990 outdir=14990_new check_vf_pha=yes verbose=3

where check_fv_pha=yes if DATAMODE=vfaint, otherwise =no

Cleaned
event files



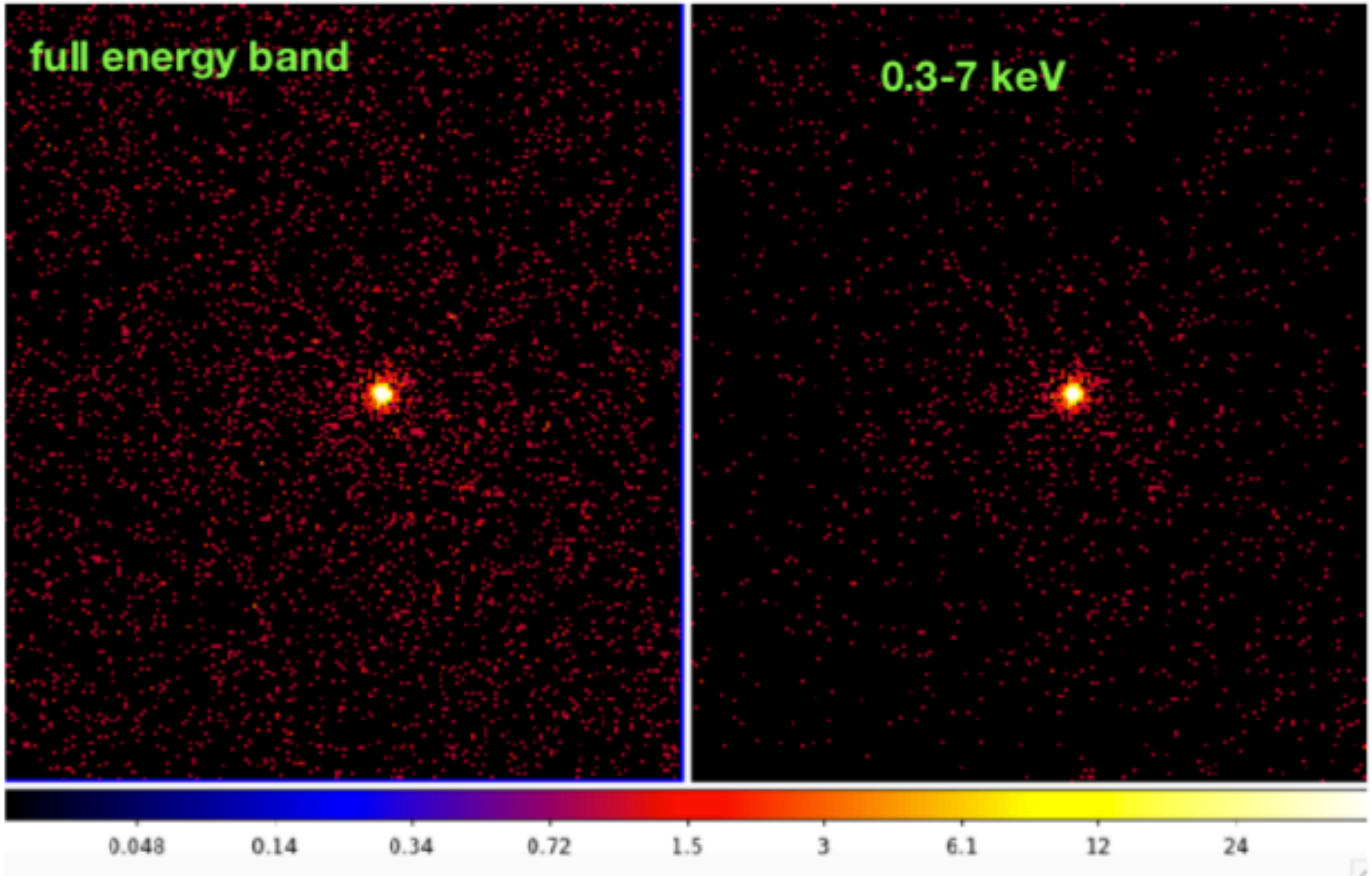
Create an image with binning=1 (original scale 1 pix=0.492”) in the 0.5−7 keV band (and selecting only good data)

- dmcopy ”14990_new/acisf14990_repro_evt2.fits[EVENTS][grade=0,2,3,4,6,status=0,energy=500:7000][bin X=1,Y=1]” 14990_new/obs14990_057keV_repro_evt2_bin1.fits clobber+

Filtering & Binning

Energy filter:

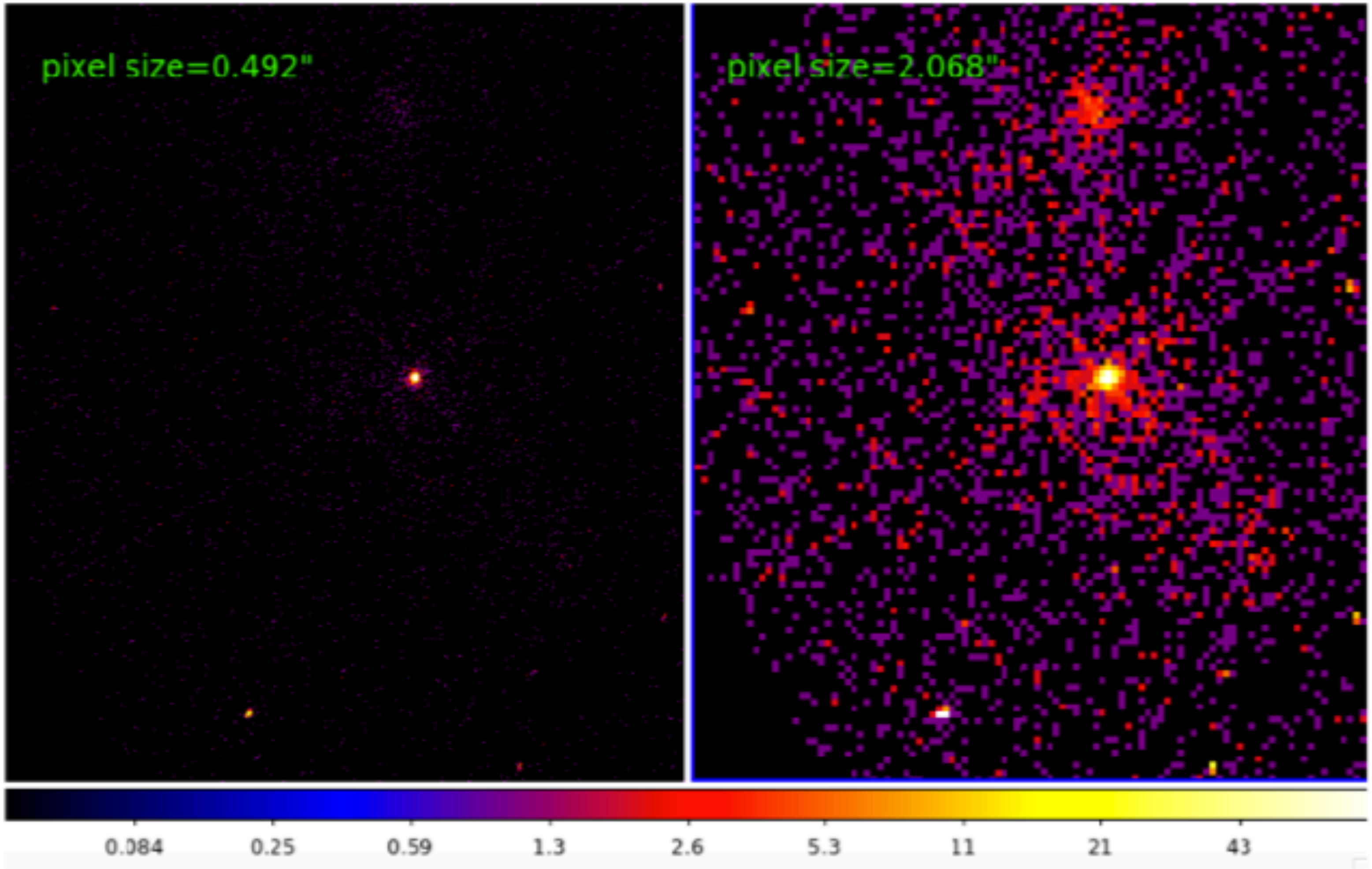
```
punlearn dmcopy
dmcopy "acisf00827_repro_evt2.fits[energy=300:7000]" evt_repro_0.3_7.0keV.fits
```



Filtering & Binning

Spatial binning:

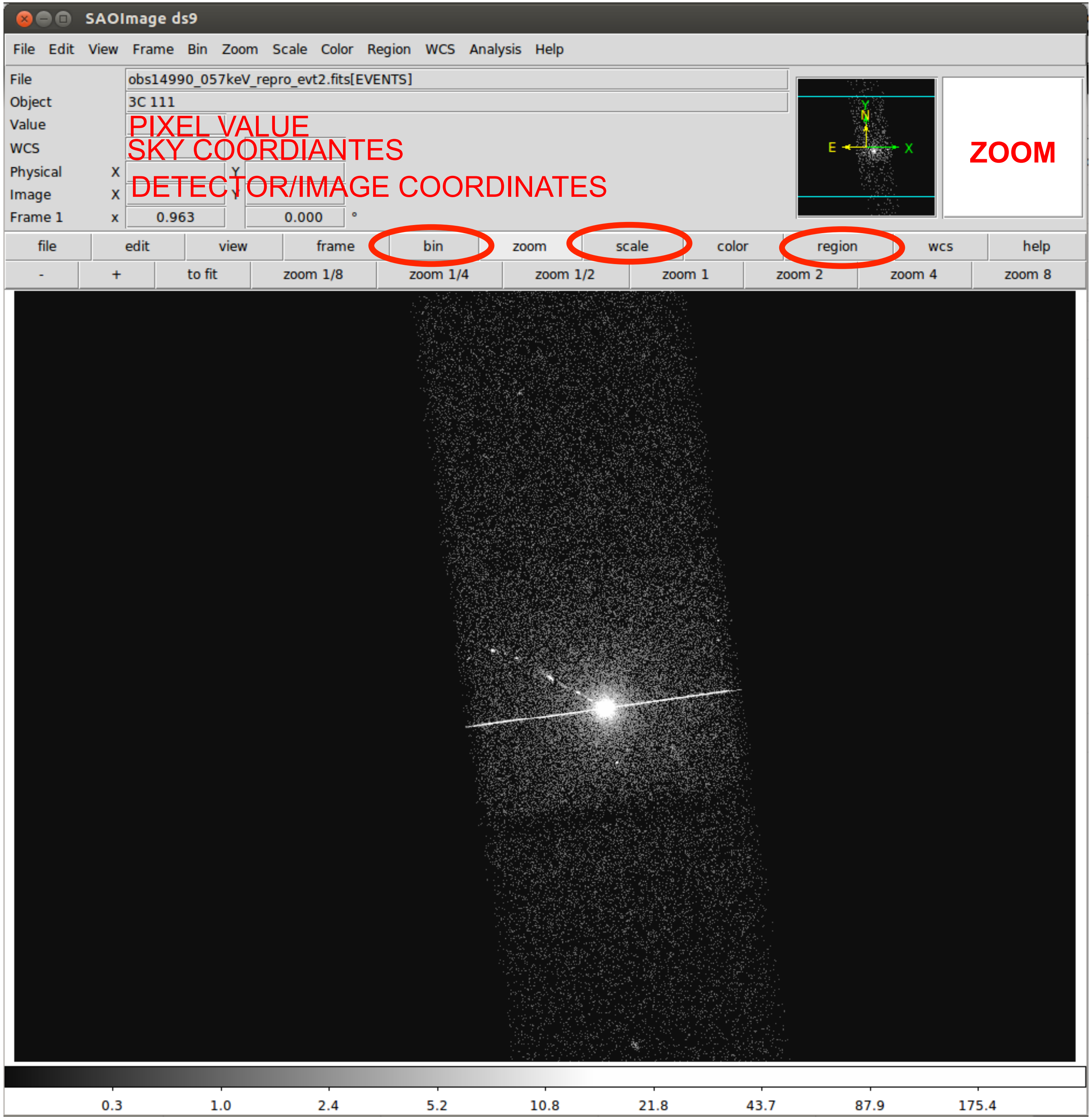
```
dmcopy "evt_repro_0.3_7.0keV.fits[bin x=::4,y=::4]" evt_repro_0.3_7.0keV_binsz4.img
```



DS9

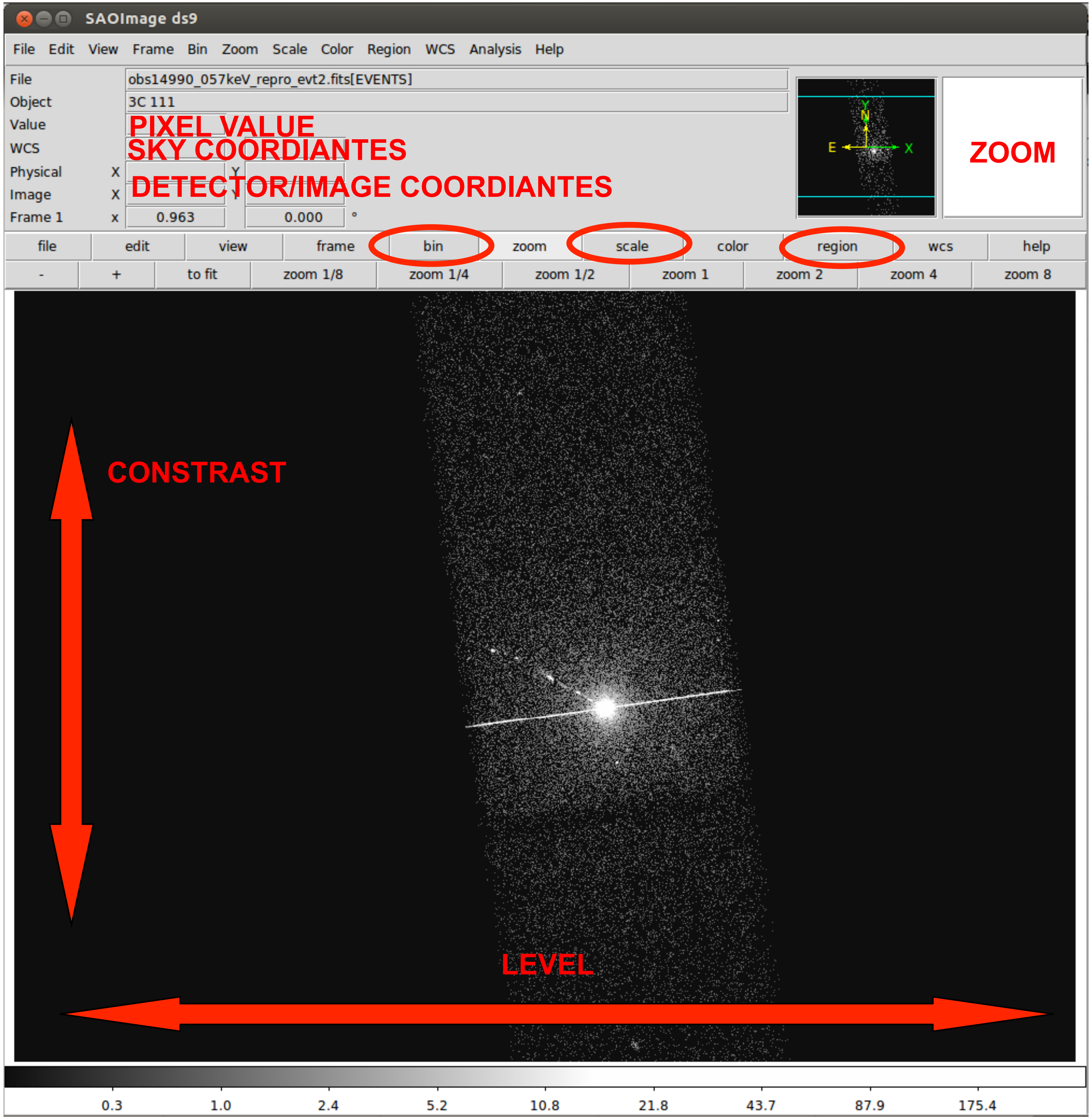
opens both event files (using the X,Y info)

and images



DS9

opens both event files (using the X,Y info) and images

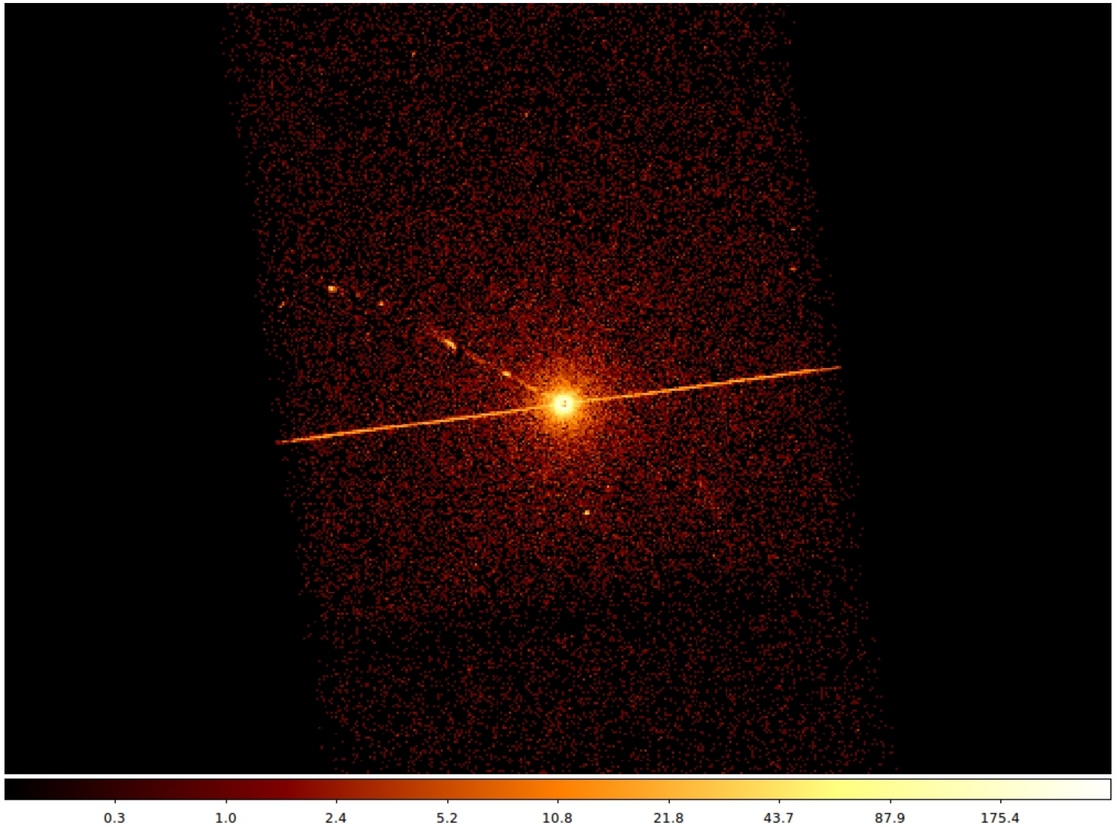


Most important information that can be obtained from an image:

- **Detection** (calculate the source counts and verify if this number is “in excess” with respect that of the background (alternatively: due to background fluctuations)

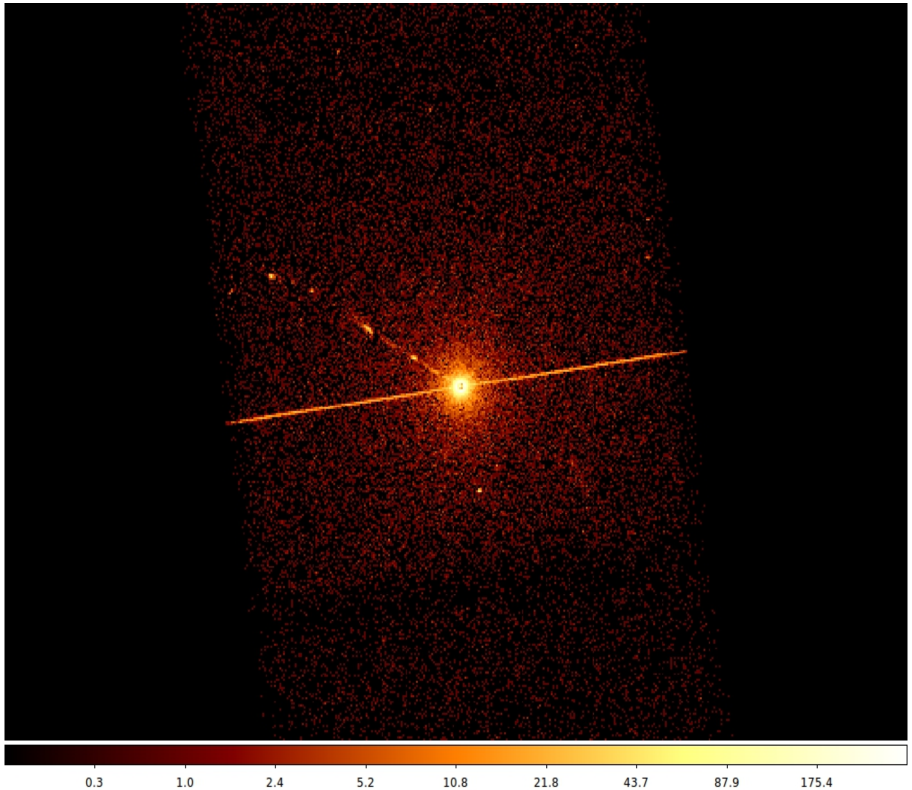
- **Morphology** (the source is pointlike or extended? obtain and fit a radial profile)

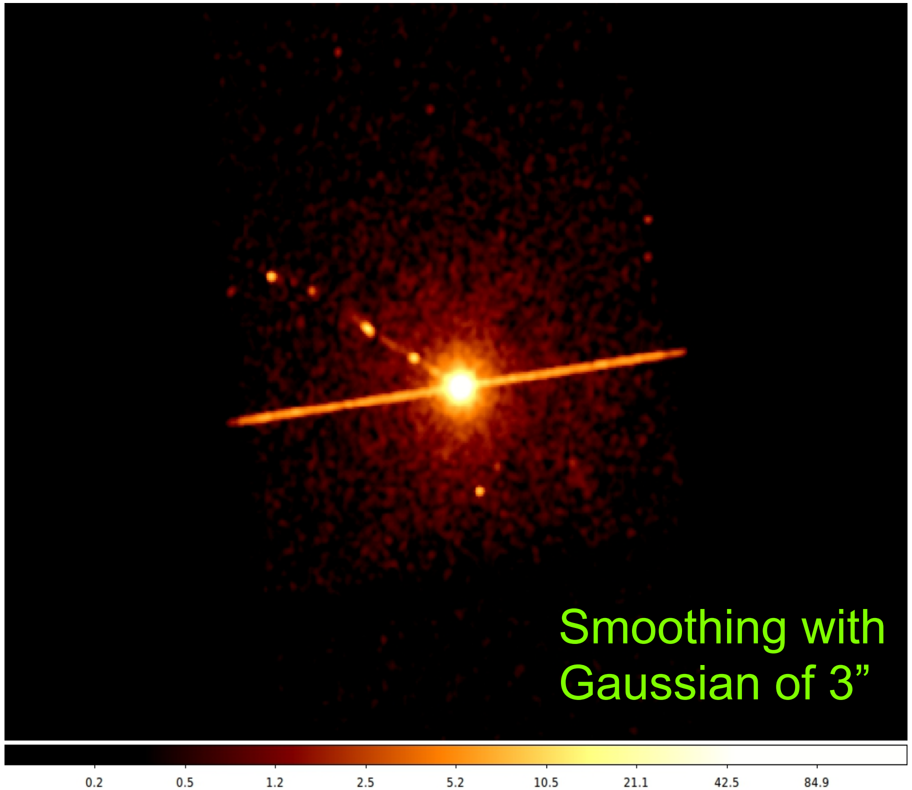
- X-ray **counterparts** of structures seen in other wavebands



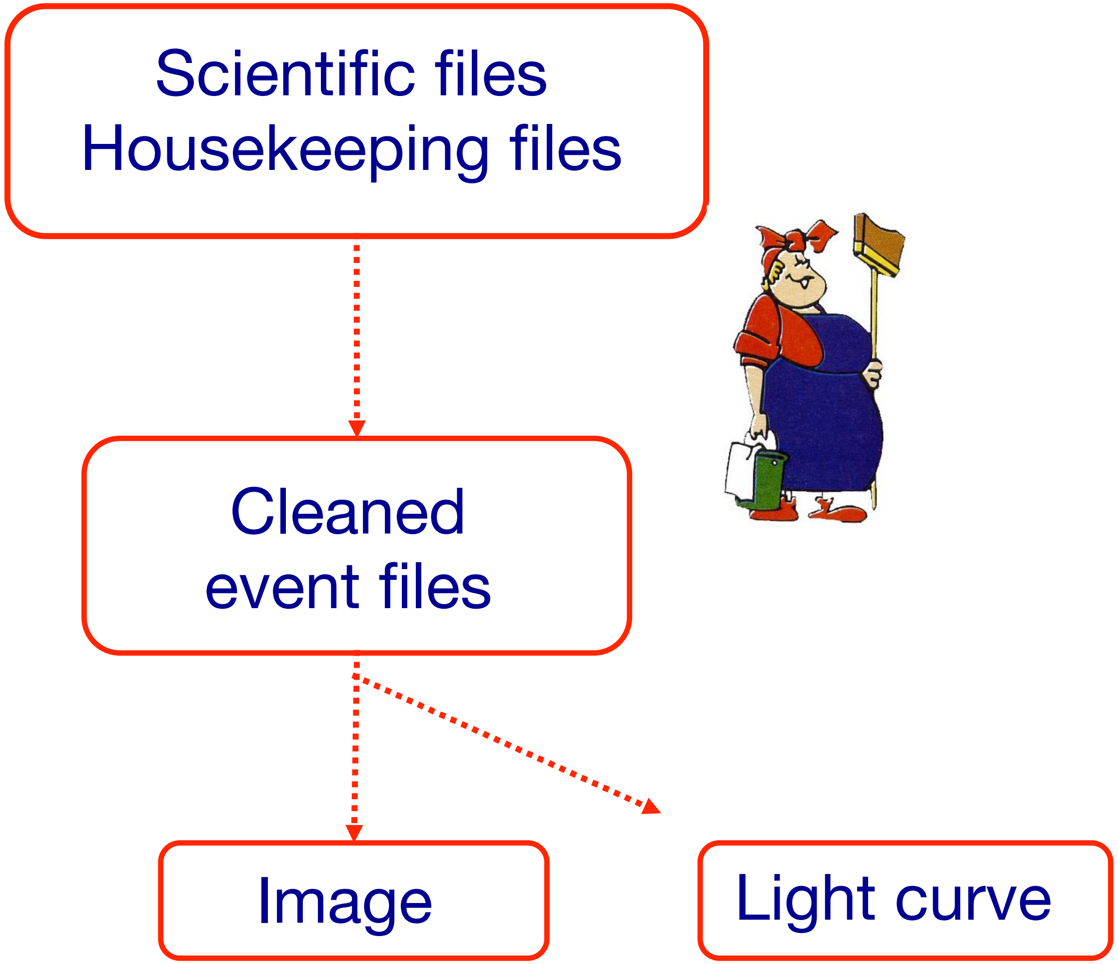
It is possible to improve the image look

smoothing



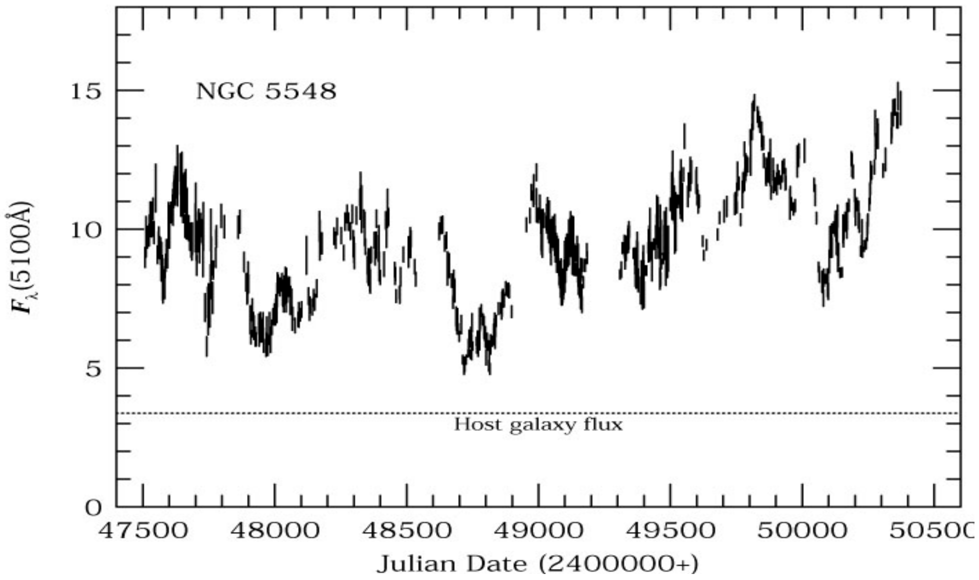


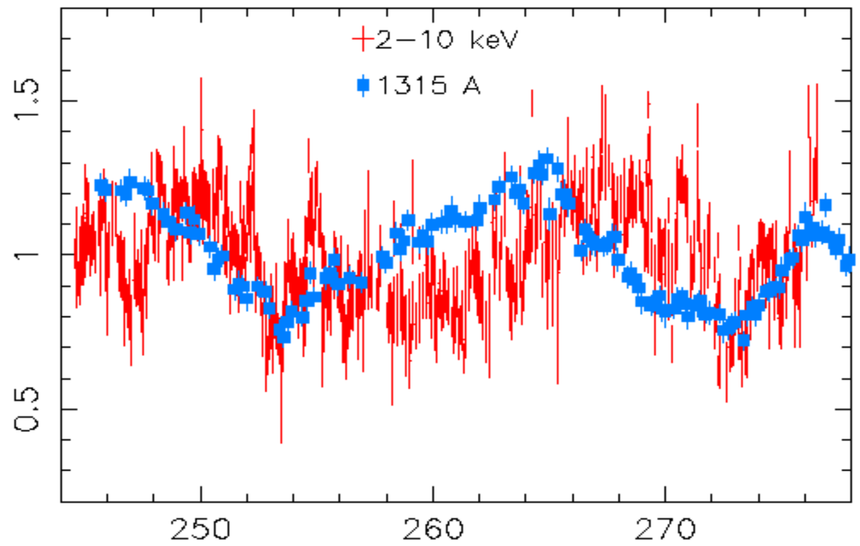
Smoothing an image means to substitute the value of each pixel for the value obtained by weighting the pixels nearby with a given function that generally is a Gaussian



see also XMM tutorial…

A light curve is the plot of the flux of a source versus time. It shows if and how the flux of the source varies during a certain time. The variability of a source can manifest on different time scales





How to extract a lightcurve

1) select a source and background region

2) identify the ccd

```
> punlearn dmstat
> dmstat "acisf00953N003_evt2.fits[sky=region(src1.reg)][cols ccd_id]"
```

3) extract the lightcurve (background subtracted)

```
>punlearn dmextract
>pset dmextract infile="acisf00953N003_evt2.fits
  [ccd_id=3,sky=region(src2.reg)][bin time= : : 2000]"
>pset dmextract outfile="src_sub_lc.fits"
>pset dmextract bkg="acisf00953N003_evt2.fits
  [ccd_id=3,sky=region(bkg.reg)]"
>pset dmextract opt="ltc1"
>dmextract
```

How to extract a lightcurve

1) select a source and background region

2) identify the ccd

```
> punlearn dmstat
> dmstat "acisf00953N003_evt2.fits[sky=region(src1.reg)][cols ccd_id]"
```

3) extract the lightcurve (background subtracted)

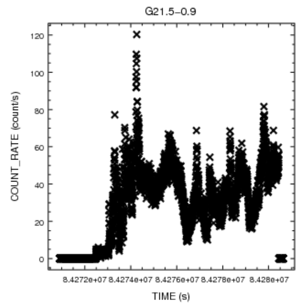
```
>punlearn dmextract
>pset dmextract infile="acisf00953N003_evt2.fits
  [ccd_id=3,sky=region(src2.reg)][bin time= : : 2000]"
>pset dmextract outfile="src_sub_lc.fits"
>pset dmextract bkg="acisf00953N003_evt2.fits
  [ccd_id=3,sky=region(bkg.reg)]"
>pset dmextract opt="ltc1"
>dmextract
```

MIN:MAX:STEP

There are several ways to visualize a light curve. Here are two examples:

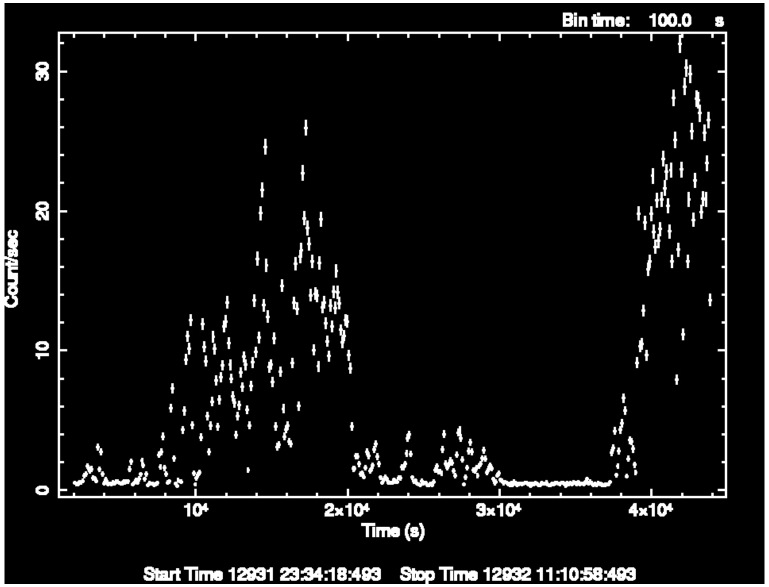
Chips provided by CIAO

```
unix% chips
-----------------------------------------
Welcome to ChIPS: CXC's Plotting Package
-----------------------------------------
CIAO 4.3 ChIPS version 1 Thursday, December 2, 2010

chips> make_figure("src2_sub_lc.fits[cols time,net_rate,err_rate]", "line.color=red")
```



The ftool ***lcurve***

```
eleonora:pn eleonora$ lcurve

lcurve 1.0 (xronos5.22)

Number of time series for this task[1]
Ser. 1 filename +options (or @file of filenames +options)[lcurve_sup10.lc]
 Series 1 file    1:lcurve_sup10.lc

 Selected FITS extensions: 1 - RATE TABLE;

 Source ............                    Start Time (d) .... 12931 23:33:28.493
 FITS Extension ....  1 - `RATE     `   Stop Time (d) ..... 12932 11:11:04.570
 No. of Rows .......          419       Bin Time (s) ......    100.0
 Right Ascension ...                    Internal time sys.. Converted to TJD
 Declination .......                    Experiment ........ XMM      EPN
 Filter ............ Medium
 Corrections applied: Vignetting - No ; Deadtime - No ; Bkgd - No ; Clock - Yes

 Selected Columns:  3- Time;  1- Y-axis;  2- Y-error;

 File contains binned data.

Name of the window file ('-' for default window)[-]

 Expected Start ... 12931.98157977479  (days)      23:33:28:493  (h:m:s:ms)
 Expected Stop .... 12932.46602511985  (days)      11:11: 4:570  (h:m:s:ms)

 Minimum Newbin Time     100.00000      (s)
 for Maximum Newbin No..              419

 Default Newbin Time is:   100.00000    (s) (to have 1 Intv. of      419 Newbins)
 Type INDEF to accept the default value
```



A light-curve can be built in different temporal bins, e.g. if the observation is 10^3s long, it is possible to extract a light-cuve with 10 bins of 100s, or 100 bins of 10s. The longer the bin the lower the temporal resolution but higher the S/N

To establish if a source varied during the observation we can apply the

χ^2 test

$$\chi^2_\nu = \frac{1}{\nu}\sum_{i=1}^{n}\frac{(c_i - < c >)^2}{\sigma_i^2}$$

c_i observed counts in every temporal bin I;

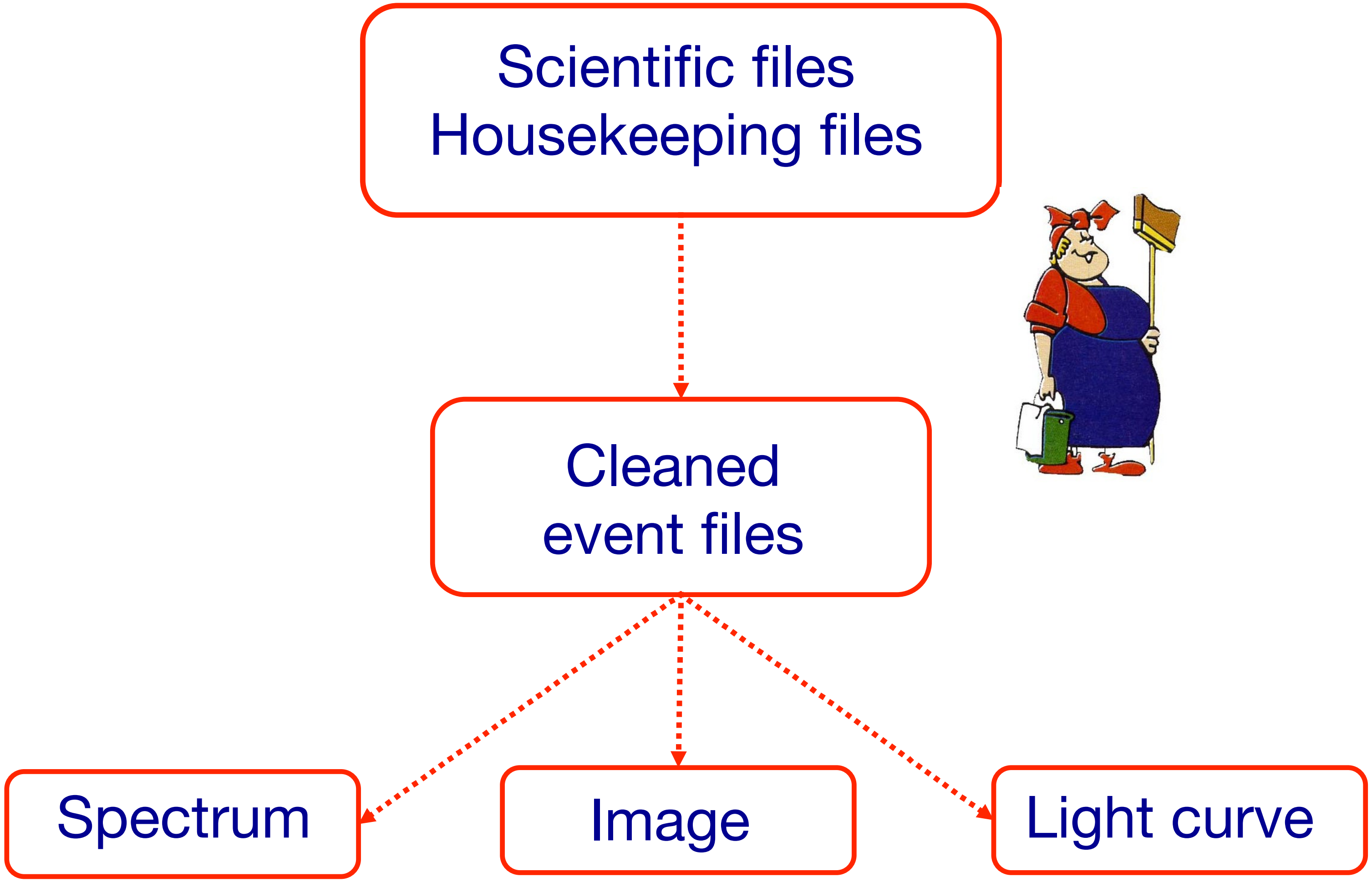
<c> average count during the observation;

σ_i Poissonian error;

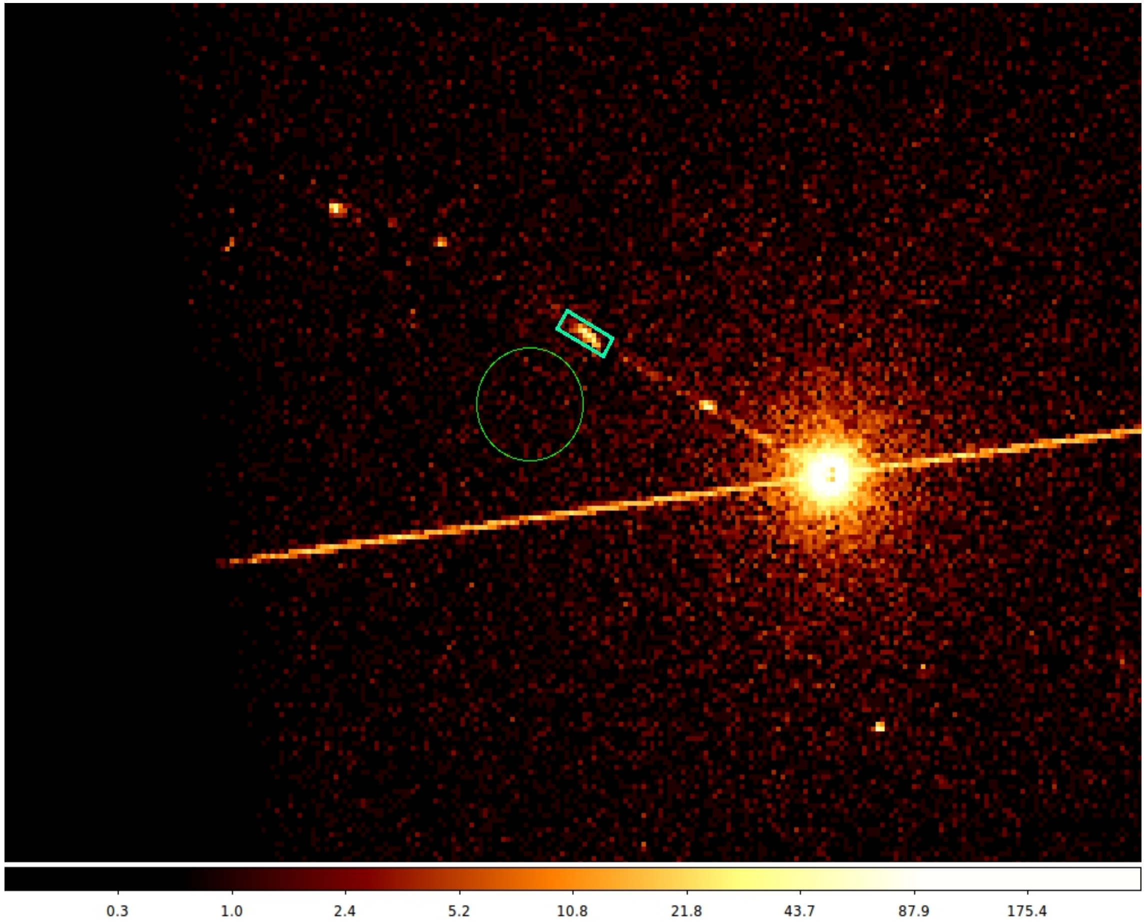
v = n-1 degrees of freedom.

Compute the null hypothesis probability that the source is not varied

this test should be repeated for several temporal bins


Scientific files
Housekeeping files
Cleaned
event files
Spectrum
Image
Light curve

Extract source and background spectra



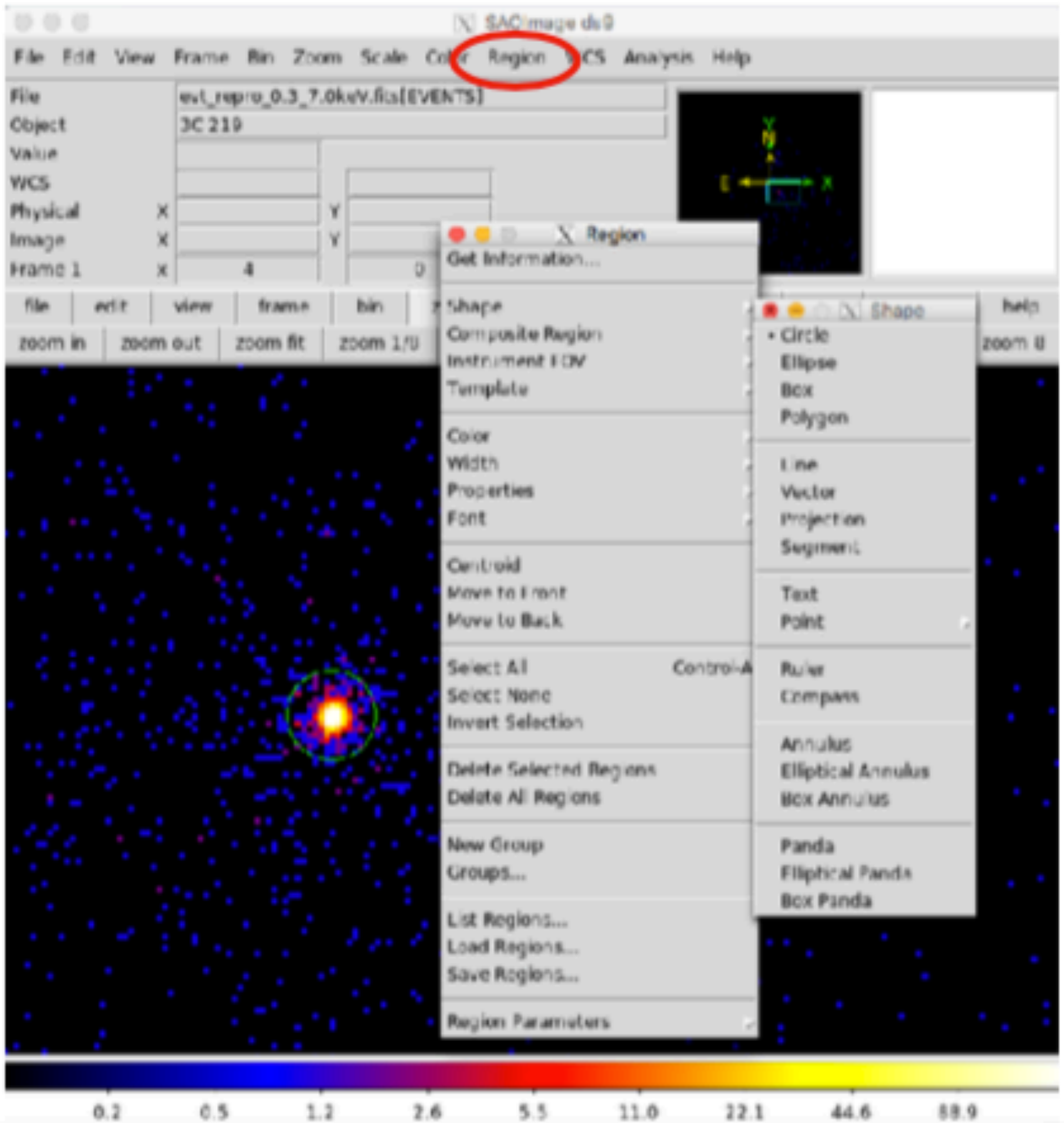
ds9 nomefile

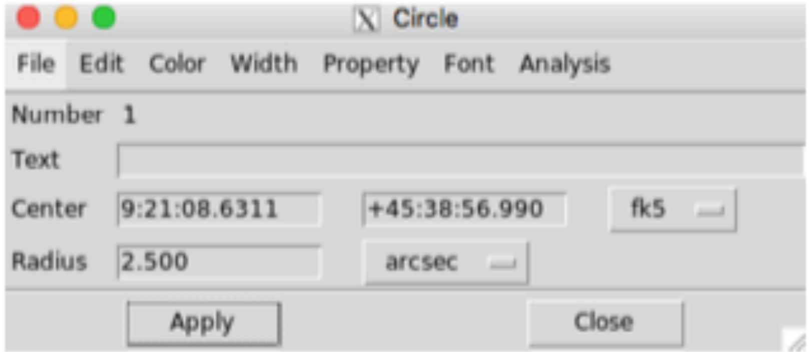
Region ➔
File Format ➔ **CIAO** ➔
File Coordinate system ➔
Physical

Choice of source and background region

Src: if pointlike source, based on the encircled energy fraction (EEF)
Back: source-free region, large enough to be representative of the 'real' background

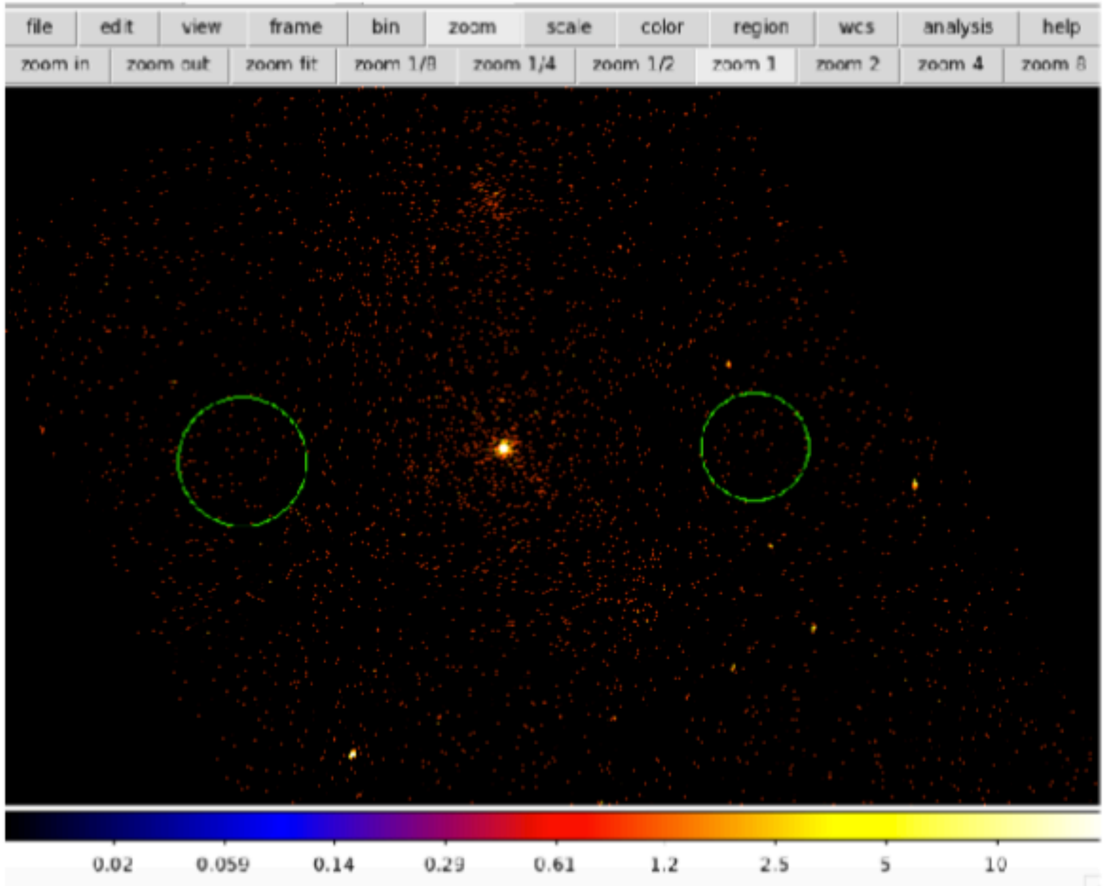
How to obtain the spectrum of the source (and background): selection of the extraction region



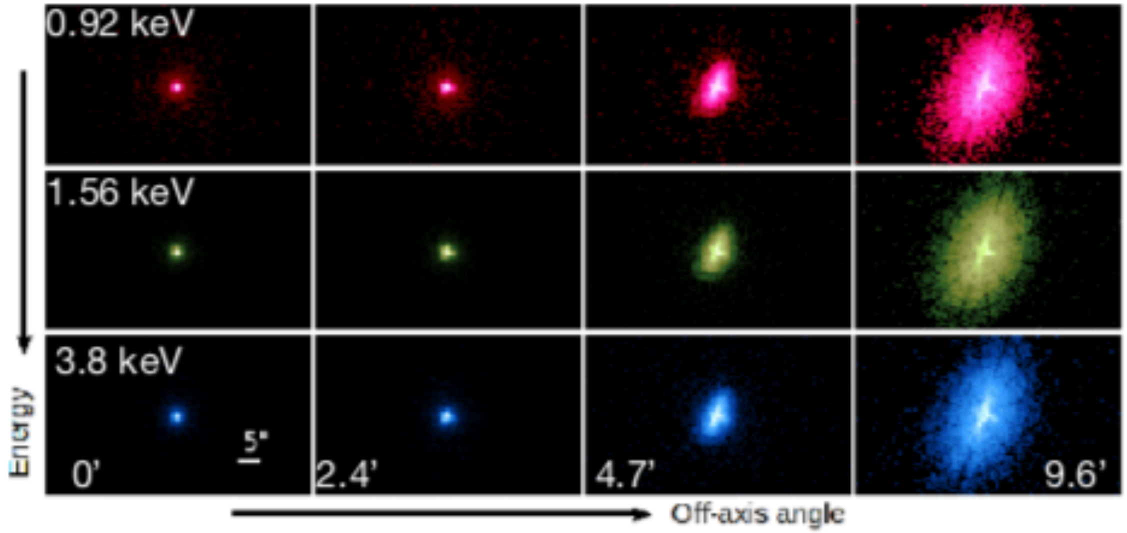


How to obtain the spectrum of the source (and background): bkg extraction region

- one or multiple region(s) in the field;
- on the same ccd;
- free from field sources;
- save it as bkg.reg (remember: format=CIAO; coord. system=physical)



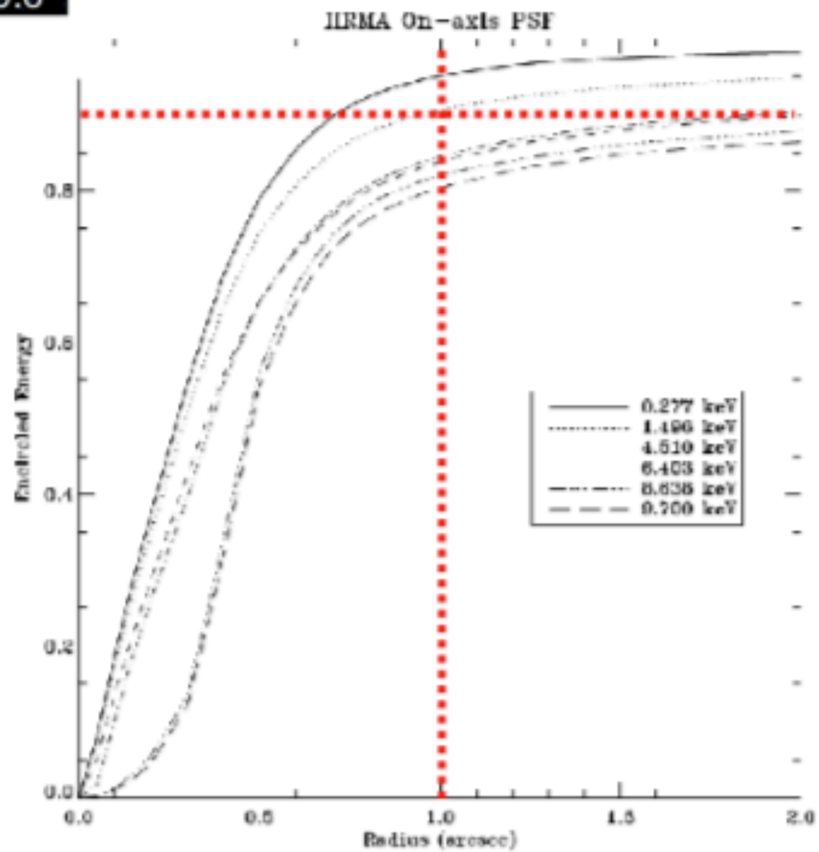
http://cxc.cfa.harvard.edu/ciao/PSFs/psf_central.html



The **Point Spread Function** varies with the source's spectral **energy** distribution and the **position** in the telescope field of view

Encircled Energy Fraction:

- the fraction of flux from a point source contained within a given radius at a given energy (~90% of photons of a point source fall within a 1" radius);
- gives an indication on the dimension of the source extraction region for a spectrum.



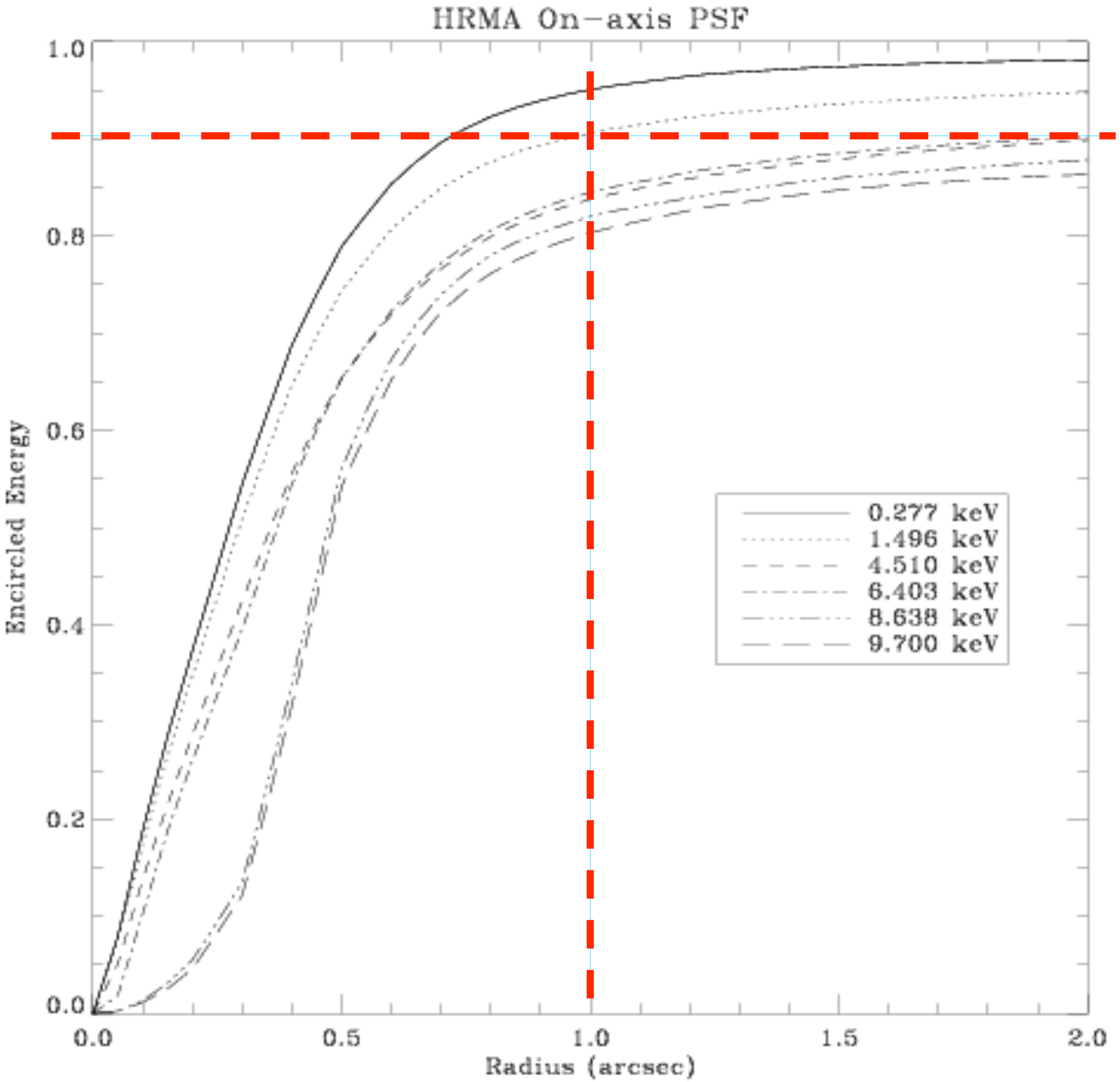
To extract the spectrum of a ***pointlike* source**…

```
-> punlearn specextract
-> pset specextract infile="acisf00547N002_evt2.fits[sky=region(src.reg)]"
-> pset specextract outroot=prova
-> pset specextract bkgfile="acisf00547N002_evt2.fits[sky=region(bkg.reg)]"
-> pset specextract weight=no
-> pset specextract correct=yes
-> pset specextract asp=pcadf089424455N002_asol1.fits
-> pset specextract mskfile=acisf00547_000N002_msk1.fits
-> pset specextract badpixfile=acisf00547_000N002_bpix1.fits
-> pset specextract grouptype=NUM_CTS binspec=15
-> pset specextract verbose=2
-> specextract
```

specextract runs the following CIAO tools

- dmextract: to extract source and (optionally) background spectra. This tool also creates the WMAP used as input to mkacisrmf.
- mkarf: to create ARF(s).
- arfcorr: to apply an energy-dependent point-source aperture correction to the source ARF file.
- mkrmf or mkacisrmf: to build the RMF(s), depending on which is appropriate for the data and the calibration; see the Creating ACIS RMFs why topic for details.
- dmgroup: to group the source spectrum and/or background spectrum.
- dmhedit: to update the BACKFILE, RESPFILE and ANCRFILE keys in the source and background spectrum files.

Encircled Energy Fraction (EEF)



About 90% of photons coming from a pointlike source fall within 1”@1.5 keV

…to extract the spectrum of an ***extended* source**

```
-> punlearn specextract
-> pset specextract infile="acisf00547N002_evt2.fits[sky=region(src.reg)]"
-> pset specextract outroot=prova
-> pset specextract bkgfile="acisf00547N002_evt2.fits[sky=region(bkg.reg)]"
-> pset specextract weight=yes
-> pset specextract correct=no
-> pset specextract asp=pcadf089424455N002_asol1.fits
-> pset specextract mskfile=acisf00547_000N002_msk1.fits
-> pset specextract badpixfile=acisf00547_000N002_bpix1.fits
-> pset specextract grouptype=NUM_CTS binspec=15
-> pset specextract verbose=2
-> specextract
```

The ARF should be averaged over the pixels used for the spectral extraction

specextract runs the following CIAO tools

- dmextract: to extract source and (optionally) background spectra. This tool also creates the WMAP used as input to mkacisrmf.
- sky2tdet: to create the WMAP input for mkwarf.
- mkwarf: to create weighted ARF(s).
- mkrmf or mkacisrmf: to build the RMF(s), depending on which is appropriate for the data and the calibration; see the Creating ACIS RMFs why topic for details.
- dmgroup: to group the source spectrum and/or background spectrum.
- dmhedit: to update the BACKFILE, RESPFILE and ANCRFILE keys in the source and background spectrum files.

The response matrix is composed by

1. The ***Redistribution Matrix File (RMF):*** associates to each instrument channel (I) the appropriate photon energy (E)

2. The ***Auxiliary Response File (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**

The quantum efficiency (QE) is the *fraction of incident photons registered by a detector.* For an ideal detector, this is 100%. In reality, however, no detector is 100% efficient. If, for instance, the detector is 70% efficient, then 100 arriving photons would result in 70 counts.

The combination of RMF and ARF produces the input spectrum, convolved with the telescope effective area and detector efficiencies versus energy

File Edit Tools **RMF** Help

Select	CHANNEL	E_MIN	E_MAX
	1E	1E	1E
All	channel	keV	keV
Invert	Modify	Modify	Modify
1	1.000000E+00	1.460000E-03	1.460000E-02
2	2.000000E+00	1.460000E-02	2.920000E-02
3	3.000000E+00	2.920000E-02	4.380000E-02
4	4.000000E+00	4.380000E-02	5.840000E-02
5	5.000000E+00	5.840000E-02	7.300000E-02
6	6.000000E+00	7.300000E-02	8.760000E-02
7	7.000000E+00	8.760000E-02	1.022000E-01
8	8.000000E+00	1.022000E-01	1.168000E-01
9	9.000000E+00	1.168000E-01	1.314000E-01
10	1.000000E+01	1.314000E-01	1.460000E-01
11	1.100000E+01	1.460000E-01	1.606000E-01
12	1.200000E+01	1.606000E-01	1.752000E-01
13	1.300000E+01	1.752000E-01	1.898000E-01
14	1.400000E+01	1.898000E-01	2.044000E-01
15	1.500000E+01	2.044000E-01	2.190000E-01
16	1.600000E+01	2.190000E-01	2.336000E-01
17	1.700000E+01	2.336000E-01	2.482000E-01
18	1.800000E+01	2.482000E-01	2.628000E-01
19	1.900000E+01	2.628000E-01	2.774000E-01
20	2.000000E+01	2.774000E-01	2.920000E-01

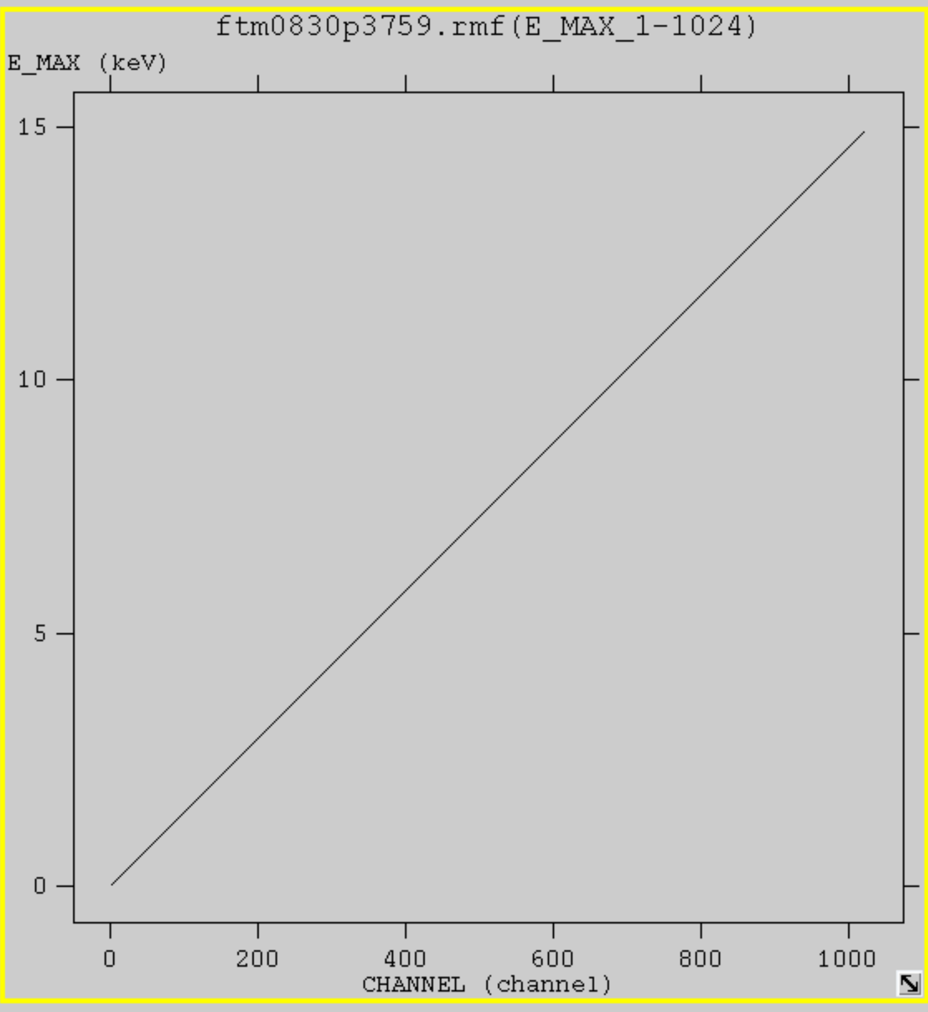
Go to: Edit cell: 0.219

File Edit Tools **ARF** Hel

Select	ENERG_LO	ENERG_HI	SPECRESP
	1E	1E	1E
All	keV	keV	cm**2
Invert	Modify	Modify	Modify
1	2.200000E-01	2.300000E-01	9.414584E+01
2	2.300000E-01	2.400000E-01	1.119709E+02
3	2.400000E-01	2.500000E-01	1.309653E+02
4	2.500000E-01	2.600000E-01	1.518642E+02
5	2.600000E-01	2.700000E-01	1.716482E+02
6	2.700000E-01	2.800000E-01	1.922011E+02
7	2.800000E-01	2.900000E-01	4.741680E+01
8	2.900000E-01	3.000000E-01	2.284590E+00
9	3.000000E-01	3.100000E-01	5.144246E+00
10	3.100000E-01	3.200000E-01	1.563580E+01
11	3.200000E-01	3.300000E-01	2.251595E+01
12	3.300000E-01	3.400000E-01	3.011008E+01
13	3.400000E-01	3.500000E-01	3.743014E+01
14	3.500000E-01	3.600000E-01	4.385400E+01
15	3.600000E-01	3.700000E-01	4.954287E+01
16	3.700000E-01	3.800000E-01	5.625348E+01
17	3.800000E-01	3.900000E-01	6.431229E+01
18	3.900000E-01	4.000000E-01	7.319862E+01
19	4.000000E-01	4.100000E-01	7.713167E+01
20	4.100000E-01	4.200000E-01	8.444775E+01

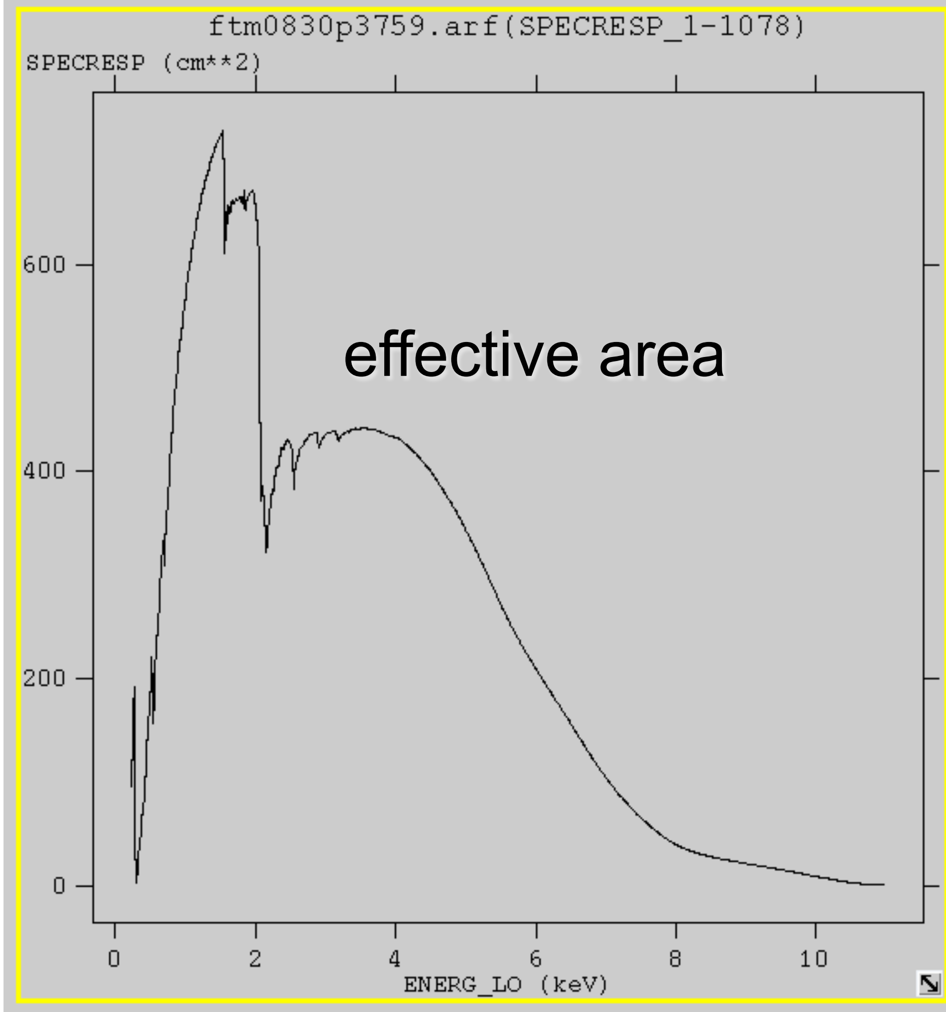
Go to: Edit cell: 0.42

RMF



ftm0830p3759.rmf(E_MAX_1-1024)
E_MAX (keV)
15
10
5
0
0
200
400
600
800
1000
CHANNEL (channel)

ARF



ftm0830p3759.arf(SPECRESP_1-1078)
SPECRESP (cm**2)
600
400
200
0
effective area
0
2
4
6
8
10
ENERG_LO (keV)

To combine spectra of the same source from different observations

-> punlearn combine_spectra
-> pset combine_spectra src_spectra=obs1843.pi,obs1842.pi
-> pset combine_spectra outroot=spec_combined
-> pset combine_spectra src_arfs=…
-> pset combine_spectra src_rmfs=...
-> pset combine_spectra bkg_spectra=...
-> pset combine_spectra bkg_arfs=… } optional
-> pset combine_spectra bkg_rmfs=...
-> pset combine_spectra bscale_method=… options: asca/time/counts
-> combine_spectra verbose 2

In case of long list of files to bu summed up: @namefile
Example: *pset combine_spectra src_spectra=@list_spectra*

Pileup

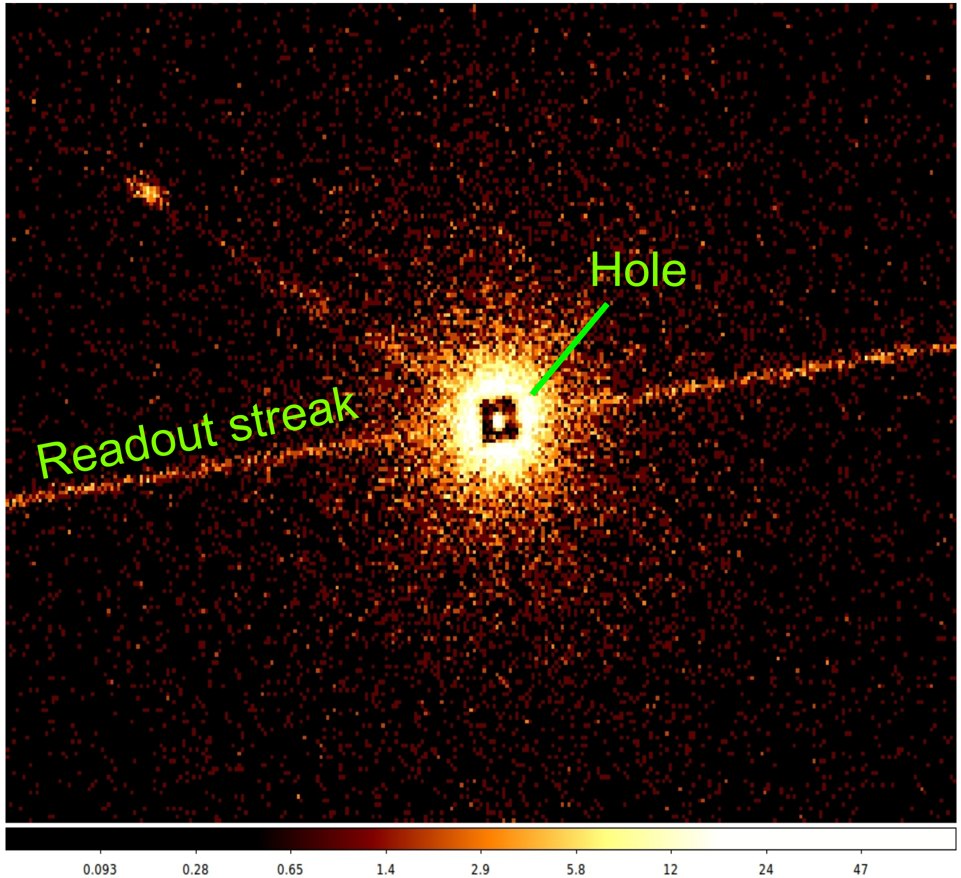
http://cxc.harvard.edu/ciao/download/doc/pileup_abc.pdf

Use webpimms to estimate the pileup of one observation
http://cxc.cfa.harvard.edu/toolkit/pimms.jsp

Two or more photon are collected during the same read-out in the same pixel, and are read as a single event (with higher energy)

→ loss of information from these events

→ distortion in the observed spectrum



Readout streak: the streak photons are clocked out in the wrong row, hence they are assigned the incorrect CHIPY value

Pileup two major effects are:

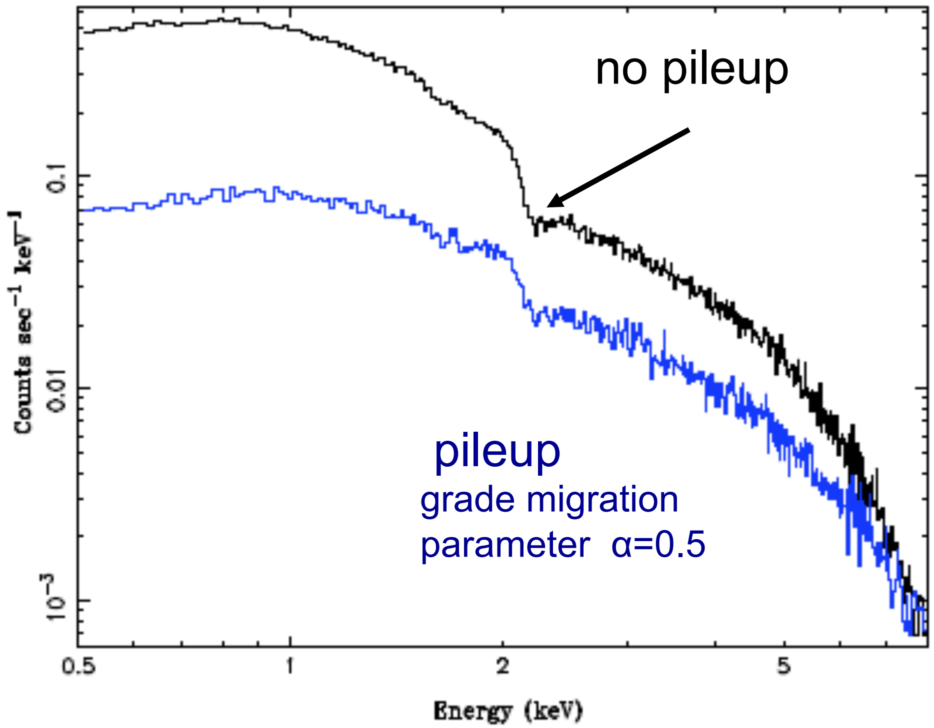
ENERGY MIGRATION photon energies sum to create a detected event with higher energy

GRADE MIGRATION event grades migrate towards values inconsistent with real photon events.

- net decrease of the observed count rate

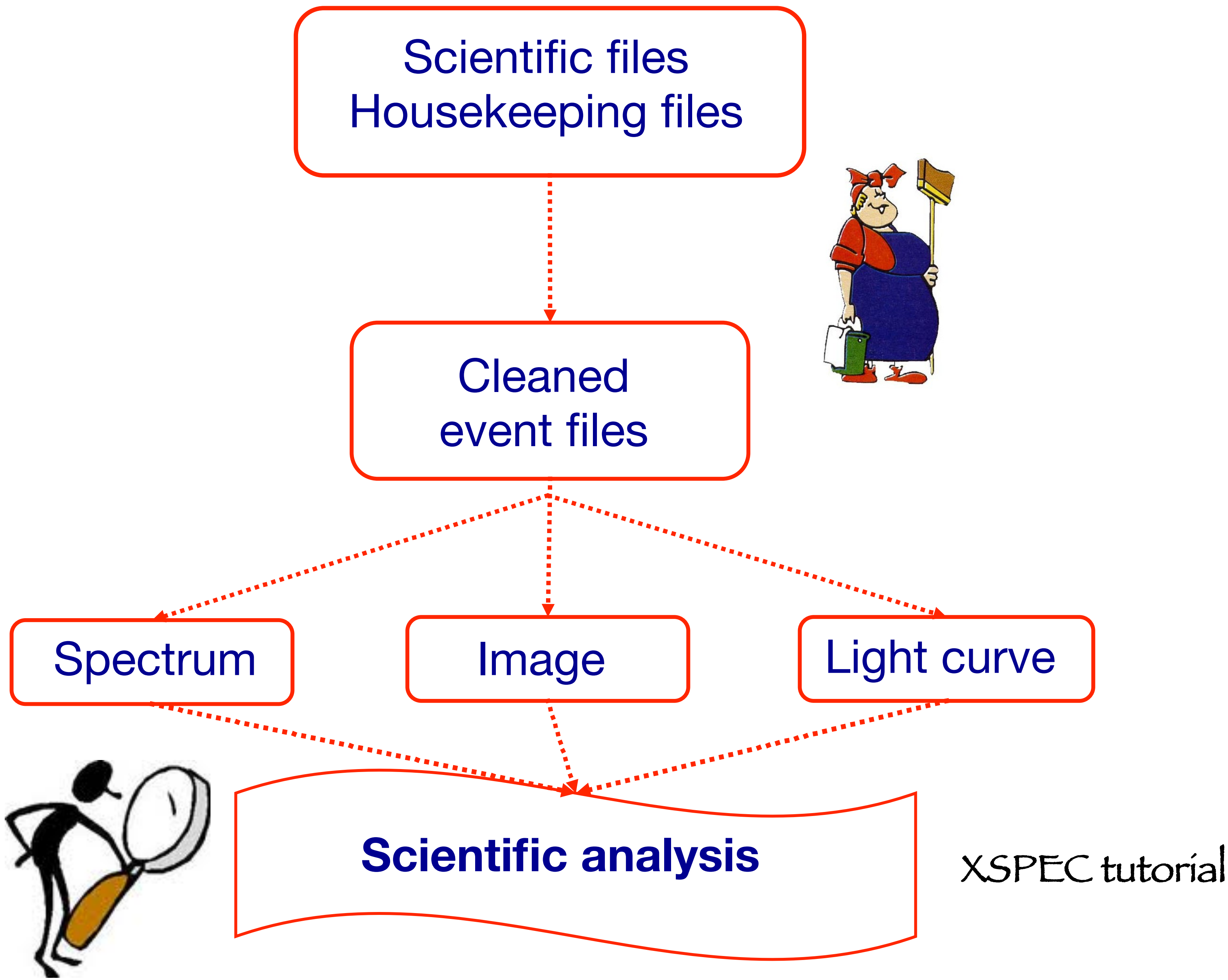
- net decrease in the fractional rms variability of the lightcurve

spectral shape of the source distorted



Avoid/limit pileup: (a) fasten the reading of the CCD (using the subarray option)
(b) extract the spectrum from an annulus centered on the source (hence removing the “inner part” of the source)

Pileup mitigation: use an XSPEC – pileup model

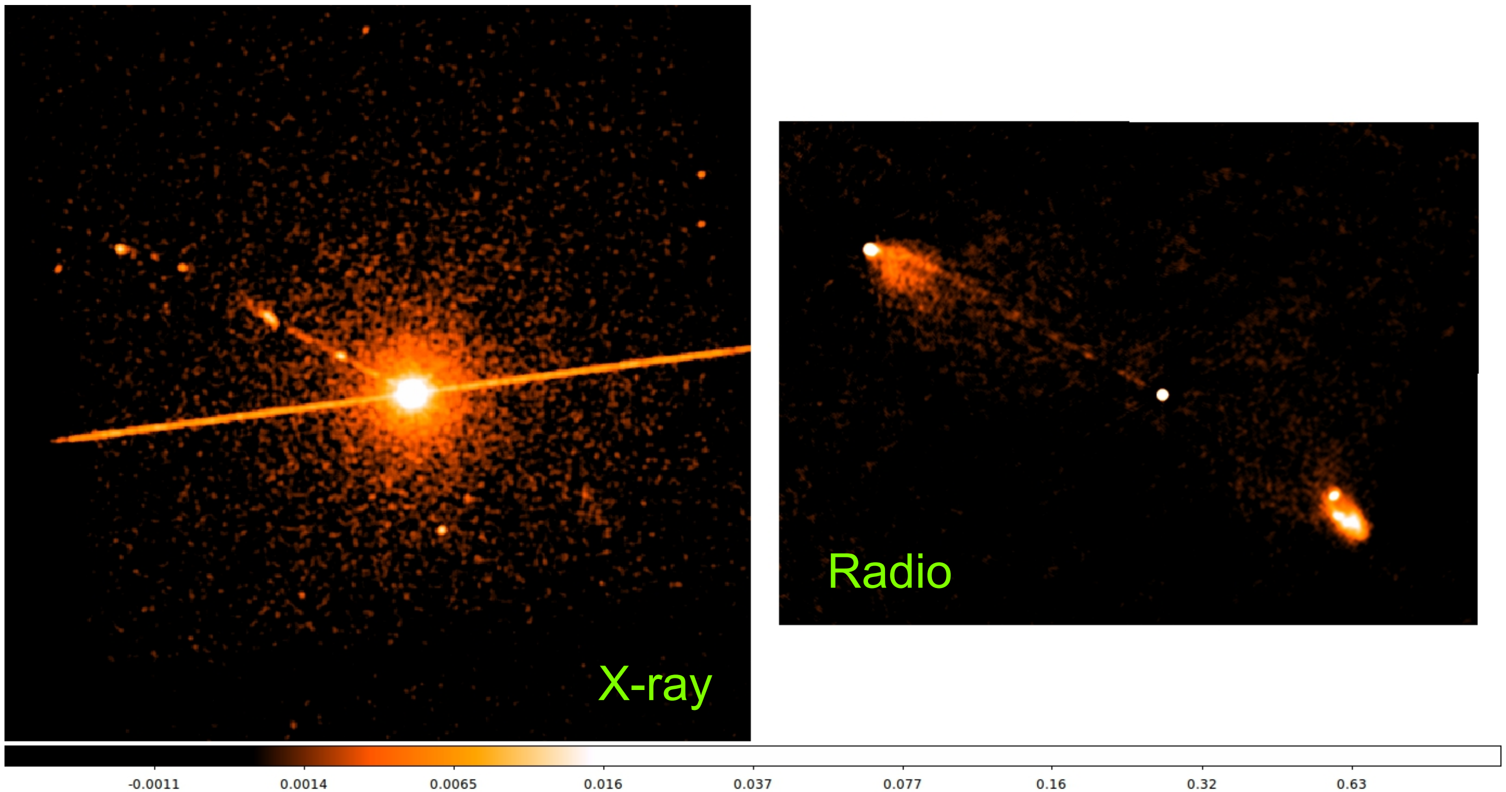

Scientific files
Housekeeping files
Cleaned
event files
Spectrum
Image
Light curve
Scientific analysis
XSPEC tutorial

Main steps in *Chandra* data analysis

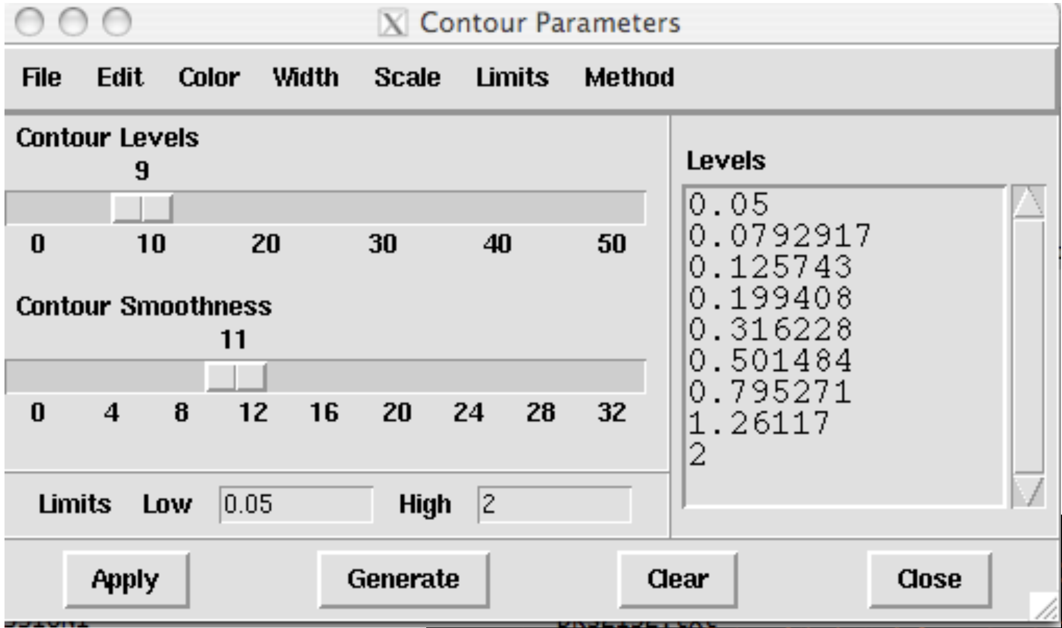
- Download data from a public archive
- Visualize the X-ray data
- Reduce the X-ray (*Chandra*) data
- Specific applications: how to create a radio/X-ray contour for an extended source

> ds9 X-ray_image radio_image

Frame ➔ match frames
➔ WCS

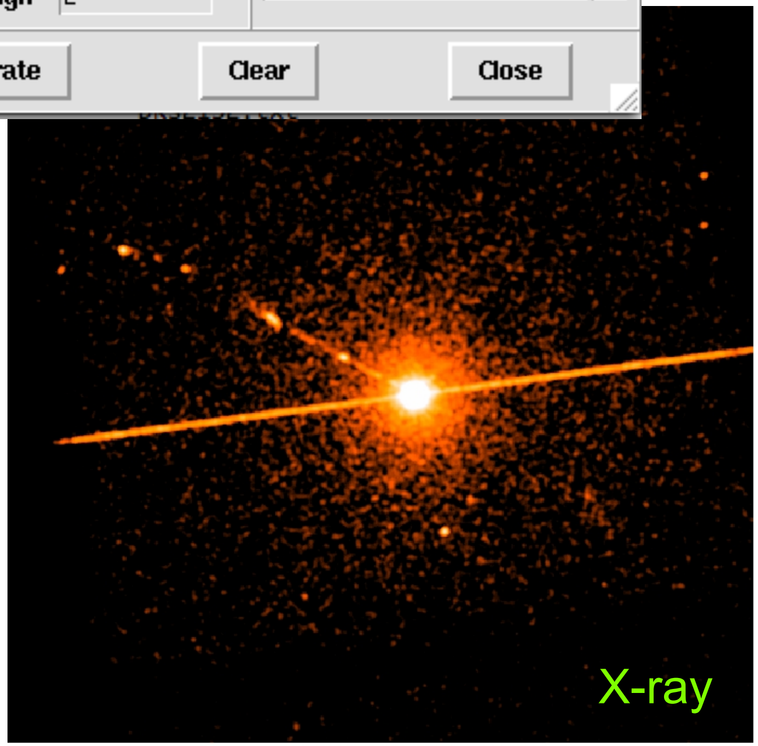


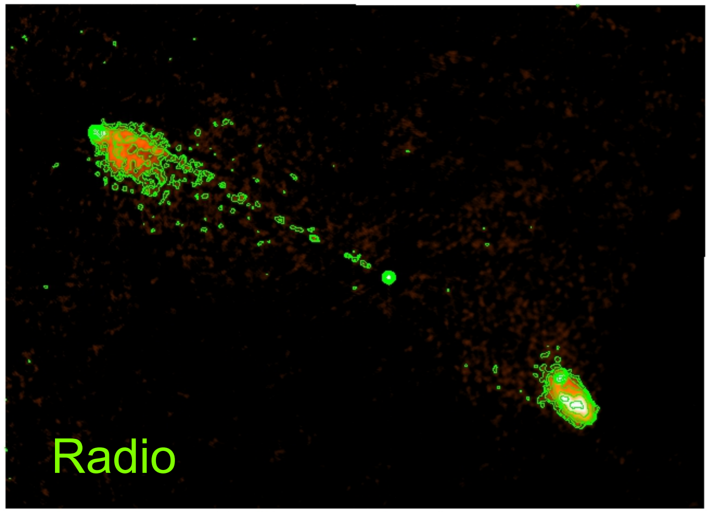
`> ds9 X-ray_image radio_image`

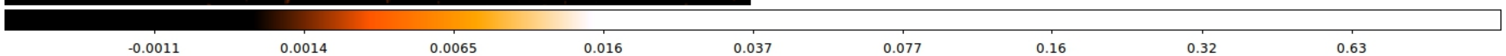


Analysis ➔ contours parameters

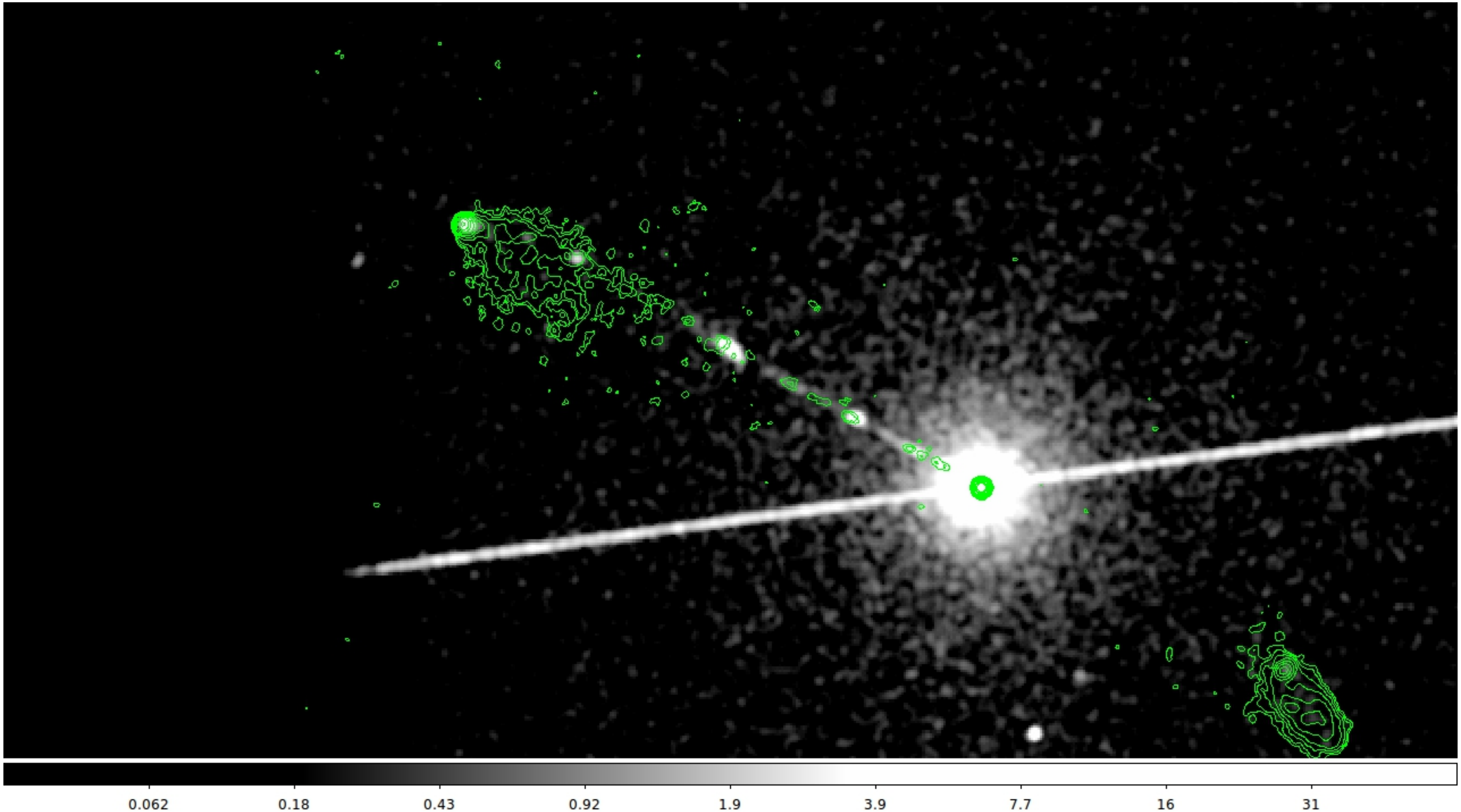
File ➔ save contours







Analysis → Contour parameters
→ File
→ Load contours



Not only radio/X…

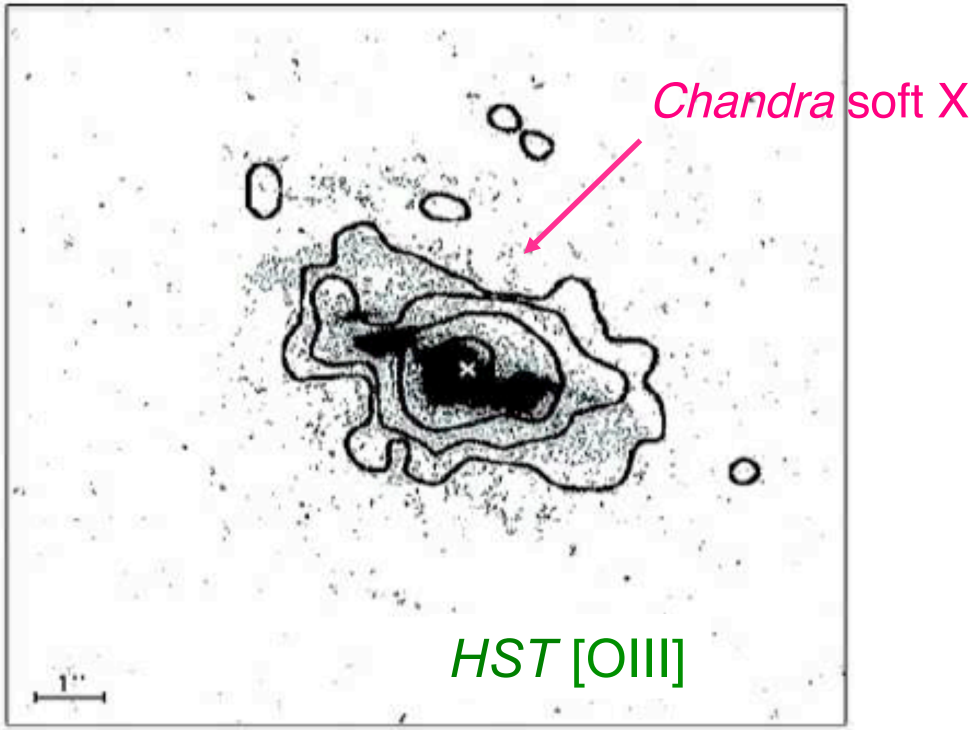


Fig. 4. Superposition of the *Chandra* soft X-ray (<2 keV) contours on an *HST* image taken through a linear ramp filter at redshifted [OIII]λ5007. The sign "**x**" indicates the centre of the hard X-ray source, north is up, east to the left. The X–ray image was smoothed with a Gaussian of FWHM ~ 6 pixels. The contours correspond to four logarithmic intervals in the range 1-60% of the peak flux.


THE END