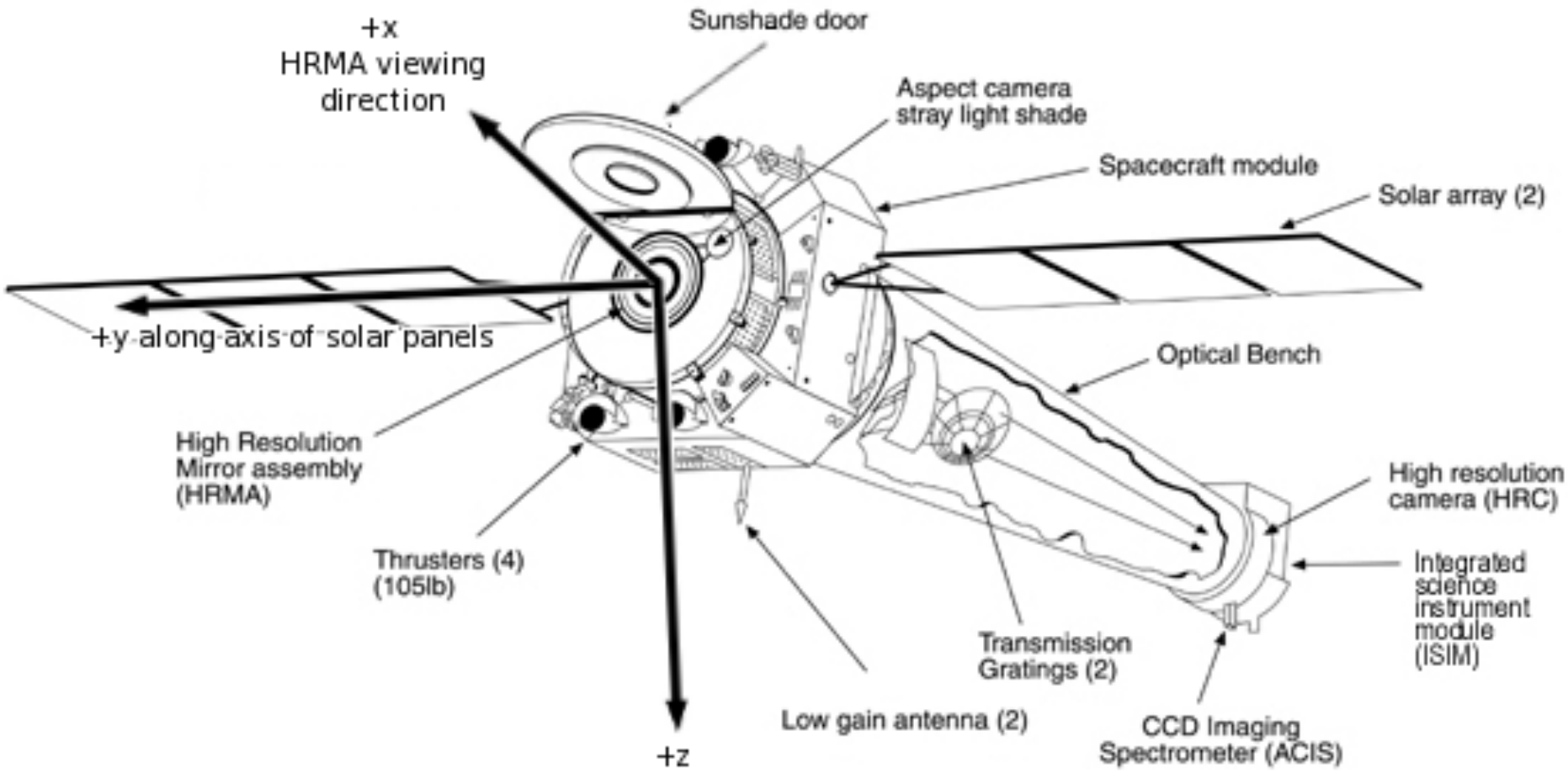
Chandra Tutorial

C. Vignali - Laboratorio di Astrofisica 2013

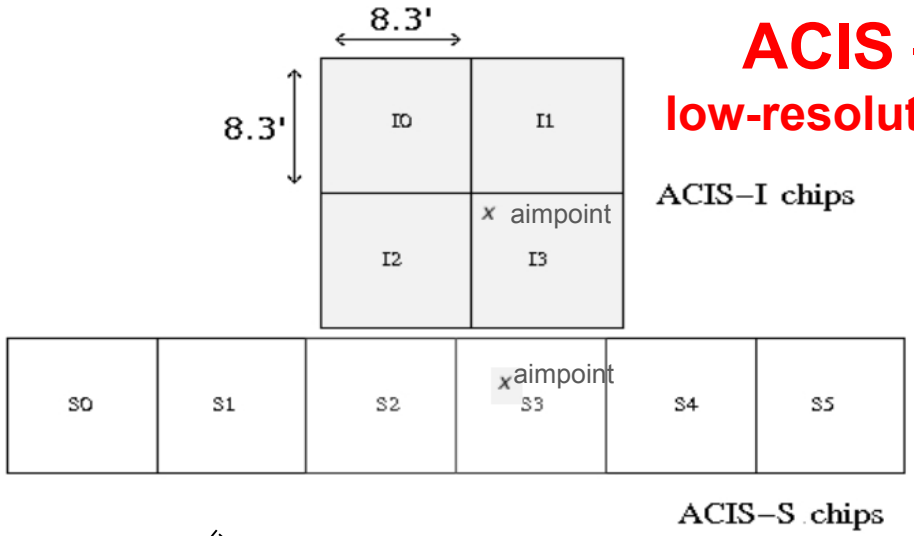
The spacecraft



ACIS

The detectors

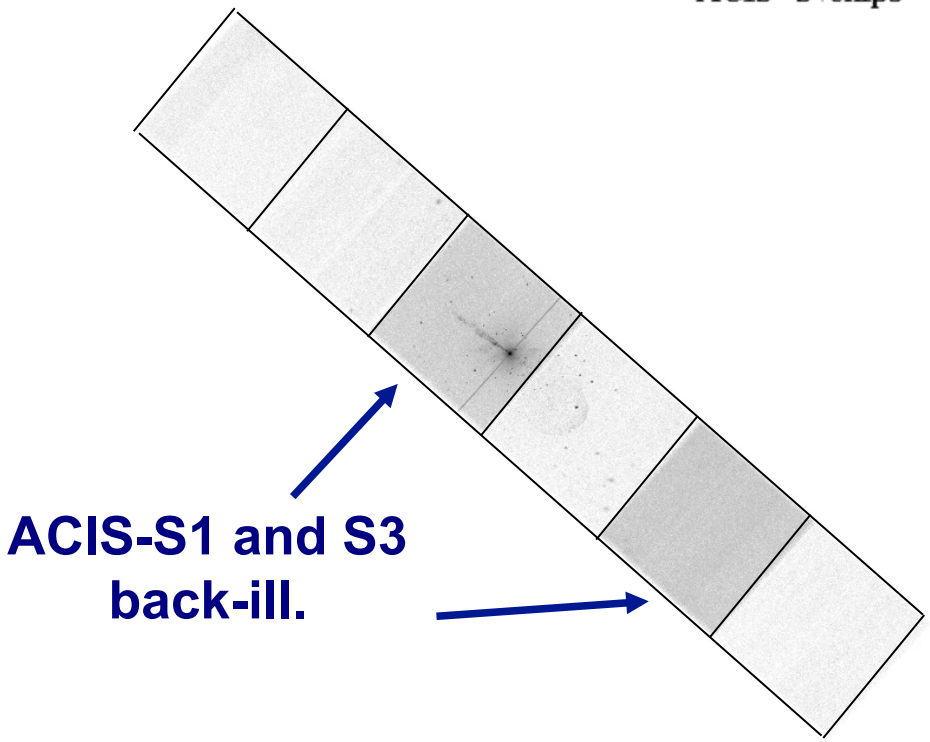
ACIS – imaging and low-resolution spectroscopy



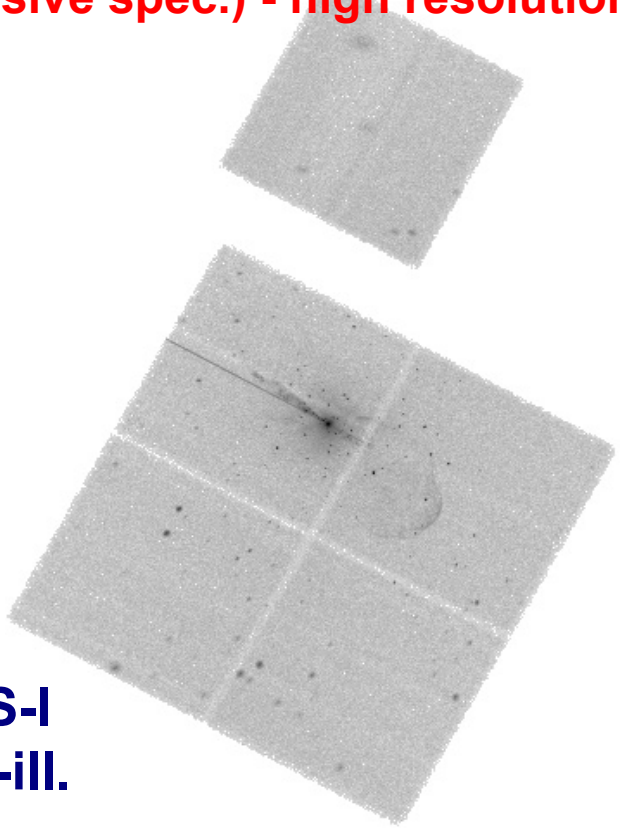
HRC – high-resolution camera

HETG and LETG

(dispersive spec.) - high resolution



ACIS-S1 and S3 back-ill.



ACIS-I front-ill.

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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Chandra ➔ *CIAO*

XMM-*Newton* ➔ *SAS*

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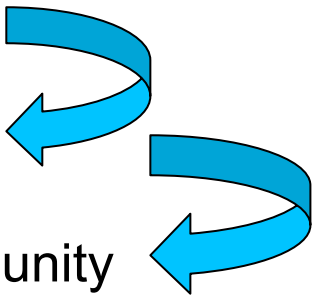
Chandra ➔ *CIAO*
XMM-*Newton* ➔ *SAS*

3. How to get X-ray data:

proposals of observations

proprietary data for one year

archival data available to the community



- ✓ Downloading of X-ray data from a public archive
- ✓ How do the downloaded files look like?
- ✓ Steps to reduce X-ray (*Chandra*) data
- ✓ Creation of radio and/or X-ray contours for an extended object
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Where can I find X-ray data archives?

High Energy Astrophysics Science Archive Research Center (HEASARC) - NASA

http://heasarc.nasa.gov/ → Archive → Browse

Archive

HEASARC Browse

Tip Archive | Hera | HELP

Other Browse interfaces:
Notification Service | Batch | Correlation | Index of all tables | Keyword Search

Query File And Session Uploads

Main Search Form > Search Results > Choose Data Products

Start Search | Reset | Detailed Mission/Catalog Search

1. Do you want to search around a position ... ?
(If you want to search on parameters other than object name or coordinates, select "Detailed Mission/Catalog Search".)

Object Name Or Coordinates: [ ] **and/or** Select Local File: [Choose File] no file selected

e.g. **Cyg X-1** or **12 00 00, 4 12 6** or **Cyg X-2; 12.235, 15.345** (Note use of semi-colons (;) to separate multiple object names or coordinate pairs)

File should contain objects and/or coordinate pairs one per line or separated by semi-colons.

Coordinate System: J2000

Search Radius: Default arcmin

Default uses the optimum radius for each catalog searched.

... and/or search by date?

Observation Dates: [ ] YYYY-MM-DD hh:mm:ss or MJD: DDDDD.ddd

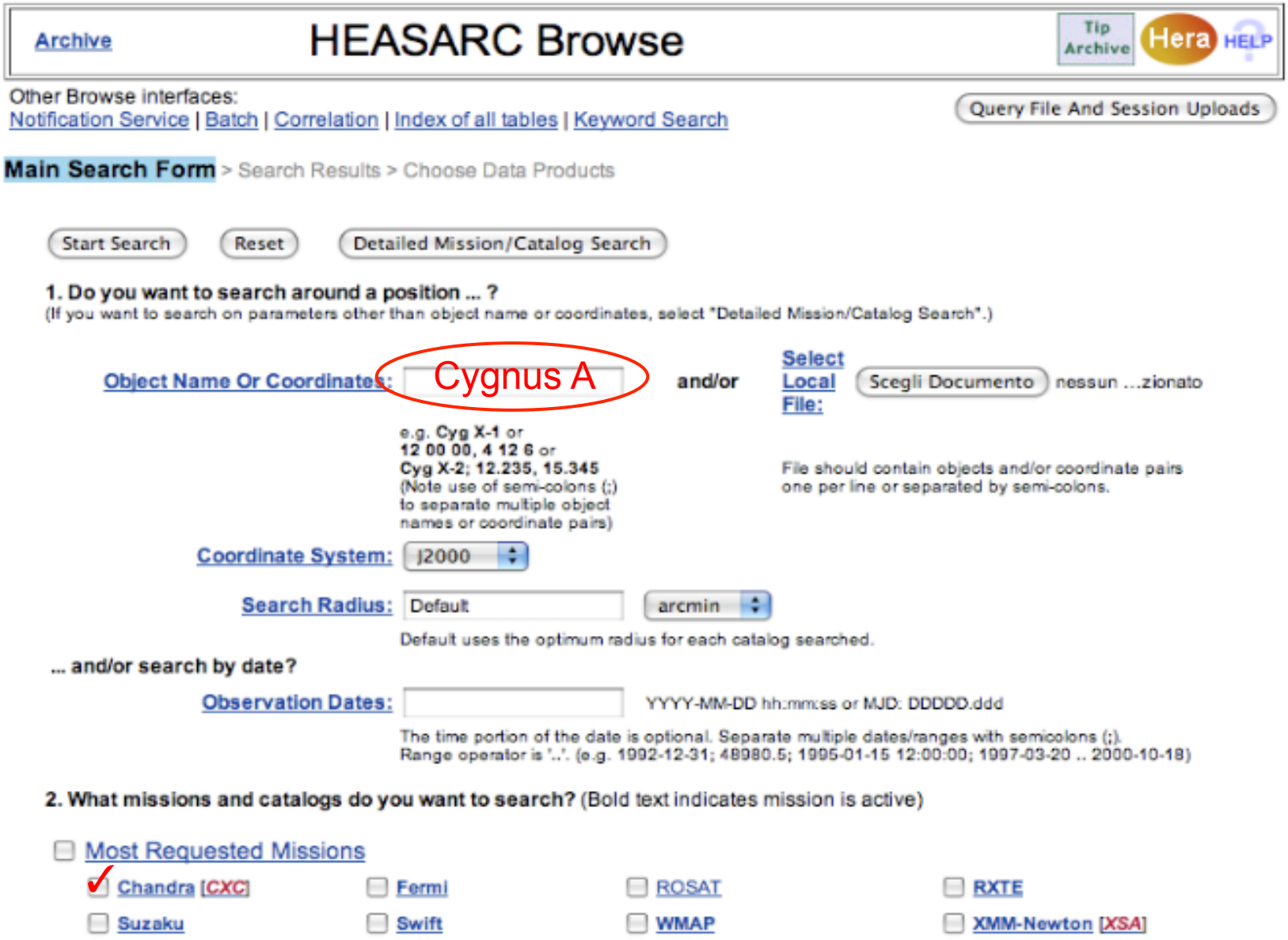
Not all tables have observation dates. For those that do, the time portion of the date is optional. Separate multiple dates/ranges with semicolons (;). Range operator is '..'. (e.g. 1992-12-31; 48980.5; 1995-01-15 12:00:00; 1997-03-20 .. 2000-10-18)

2. What missions and catalogs do you want to search? (Bold text indicates mission is active)

- [ ] Most Requested Missions
  - [ ] **Chandra** [*CXC*,*CSC*]
  - [ ] **Fermi**
  - [ ] **NuSTAR** [*CalTech*]
  - [ ] ROSAT
  - [ ] RXTE
  - [ ] **Suzaku**
  - [ ] **Swift**
  - [ ] **WMAP**
  - [ ] **XMM-Newton** [*XSA*]

High Energy Astrophysics Science Archive Research Center (HEASARC) - NASA

http://heasarc.nasa.gov/ → Archive → Browse



High Energy Astrophysics Science Archive Research Center (HEASARC) - NASA

http://heasarc.nasa.gov/ → Archive → Browse

Query Information | Query Results | Data Products Retrieval | Help

chandra

chanmaster | cxoxassist

Click mission tabs (middle tab level) to display table tabs. Move cursor over tabs to see more information.

Table Legend:

Display all parameters for a row

Sort by a column in order: 1,2,3 Sort by column in reverse order: 3,2,1 Current table sort

Services links: O: Digitized Sky Survey image, R: ROSAT All-Sky Survey image, N: NED objects near coordinates, S: SIMBAD objects near coordinates, D: get list of data products, H: analyze data products using Hera, B: ADS bibliography holdings, F: FOV plot for observation

Data Products: Click checkbox to add row to Data Product Retrieval List

---

Chandra Observations (chanmaster) Bulletin Note

Search radius used: 21.00 '

Select All	Related Links	Services	obsid	status	name	ra	dec	time	detector	grating	exposure [s]	type	pi	public date	Search Offset ['] from (target)
	ASCA ROSAT RXTE XMM	O R N S D H B F	5831	archived	Cygnus A	19 59 28.30	+40 44 02.0	2005-02-16 13:00:09	ACIS-I	NONE	51770	GO	Young	2006-02-27	0.011 (cygnus a)
	ASCA ROSAT RXTE XMM	O R N S D H B F	360	archived	CYGNUS A	19 59 28.30	+40 44 02.0	2000-05-21 03:12:26	ACIS-S	NONE	35160	GTO	Wilson	2001-06-06	0.011 (cygnus a)
	ASCA ROSAT RXTE XMM	O R N S D H B F	6252	archived	Cygnus A	19 59 28.30	+40 44 02.0	2005-09-07 04:47:32	ACIS-I	NONE	30050	GO	Young	2006-02-27	0.011 (cygnus a)
	ASCA ROSAT RXTE XMM	O R N S D H B F	6225	archived	Cygnus A	19 59 28.30	+40 44 02.0	2005-02-15 15:25:05	ACIS-I	NONE	24630	GO	Young	2006-02-27	0.011 (cygnus a)
	ASCA ROSAT RXTE XMM	O R N S D H B F	6226	archived	Cygnus A	19 59 28.30	+40 44 02.0	2005-02-19 05:09:29	ACIS-I	NONE	24150	GO	Young	2006-02-27	0.011 (cygnus a)

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High Energy Astrophysics Science Archive Research Center (HEASARC) - NASA

http://heasarc.nasa.gov/ → Archive → Browse

Archive Data Products for selected row in Chandra Observations

Choose Tables > Choose Data Products > Retrieve Data Products

- Do you want to view a data product? Click on its hyperlinked data format.
- Do you want to retrieve data products in a tarfile? Check the boxes beside each product and click one of the buttons at the bottom of the page.

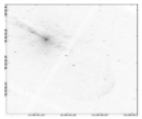
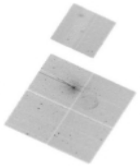
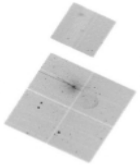
Select all products for all rows

Chandra Observations (chanmaster) FTOOLS

obsid	status	name	ra	dec	time	detector	grating	exposure	type	pi
7797	archived	Centaurus A Jet	13 25 19.15	-43 02 42.4	2007-03-22 08:59:51	ACIS-I	NONE	98170	GO	Kraft

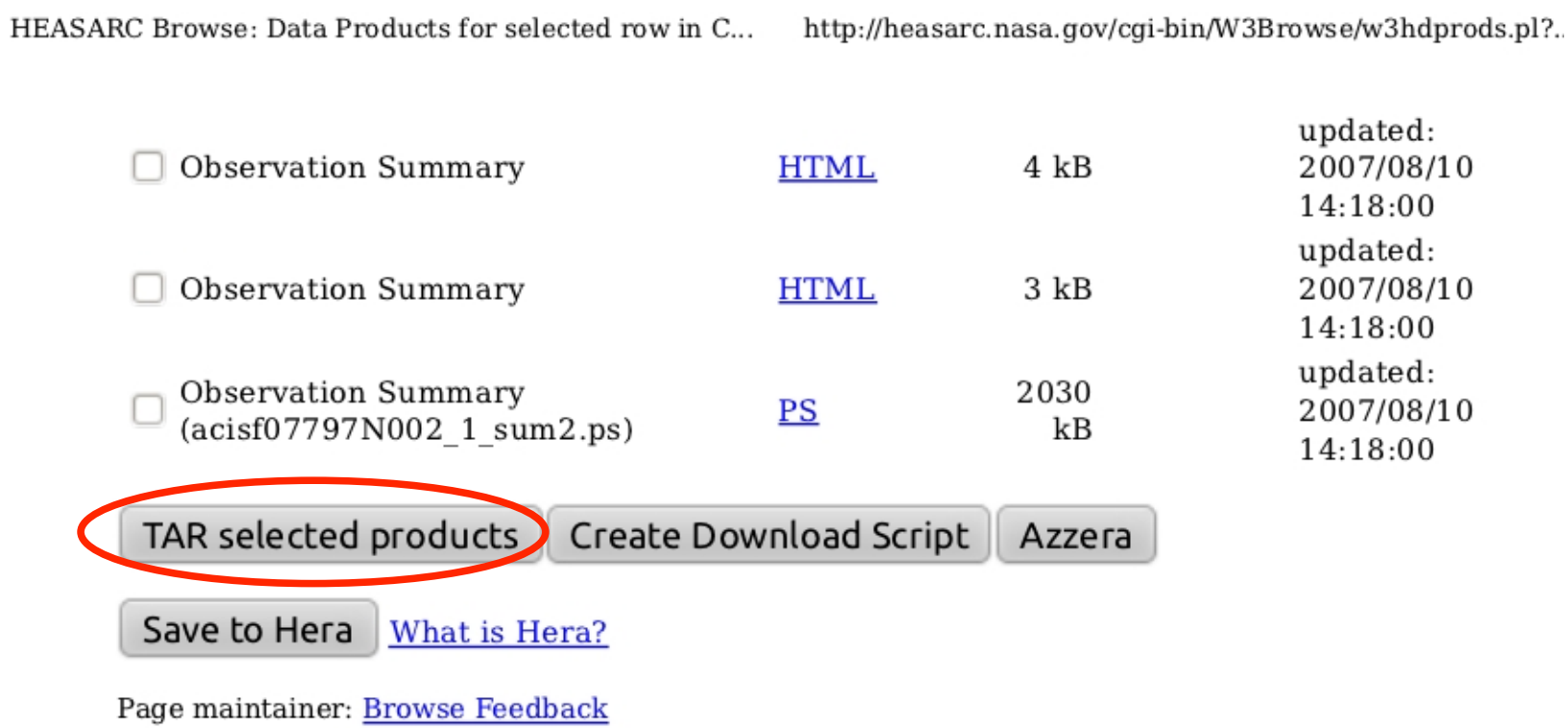
Select all products in this row

FITS and JPEG Images

Center Image (acisf07797N002_cntr_img2.fits.gz)	FITS	210 kB		updated: 2007/08/10 14:16:00
Center Image (acisf07797N002_cntr_img2.jpg)	JPEG	615 kB		updated: 2007/08/10 14:16:00
Full Image (acisf07797N002_full_img2.fits.gz)	FITS	82 kB		updated: 2007/08/10 14:18:00
Full Image (acisf07797N002_full_img2.jpg)	JPEG	47 kB		updated: 2007/08/10 14:18:00
Source Image (acisf07797N002_src_img2.jpg)	JPEG	47 kB		updated: 2007/08/10 14:18:00

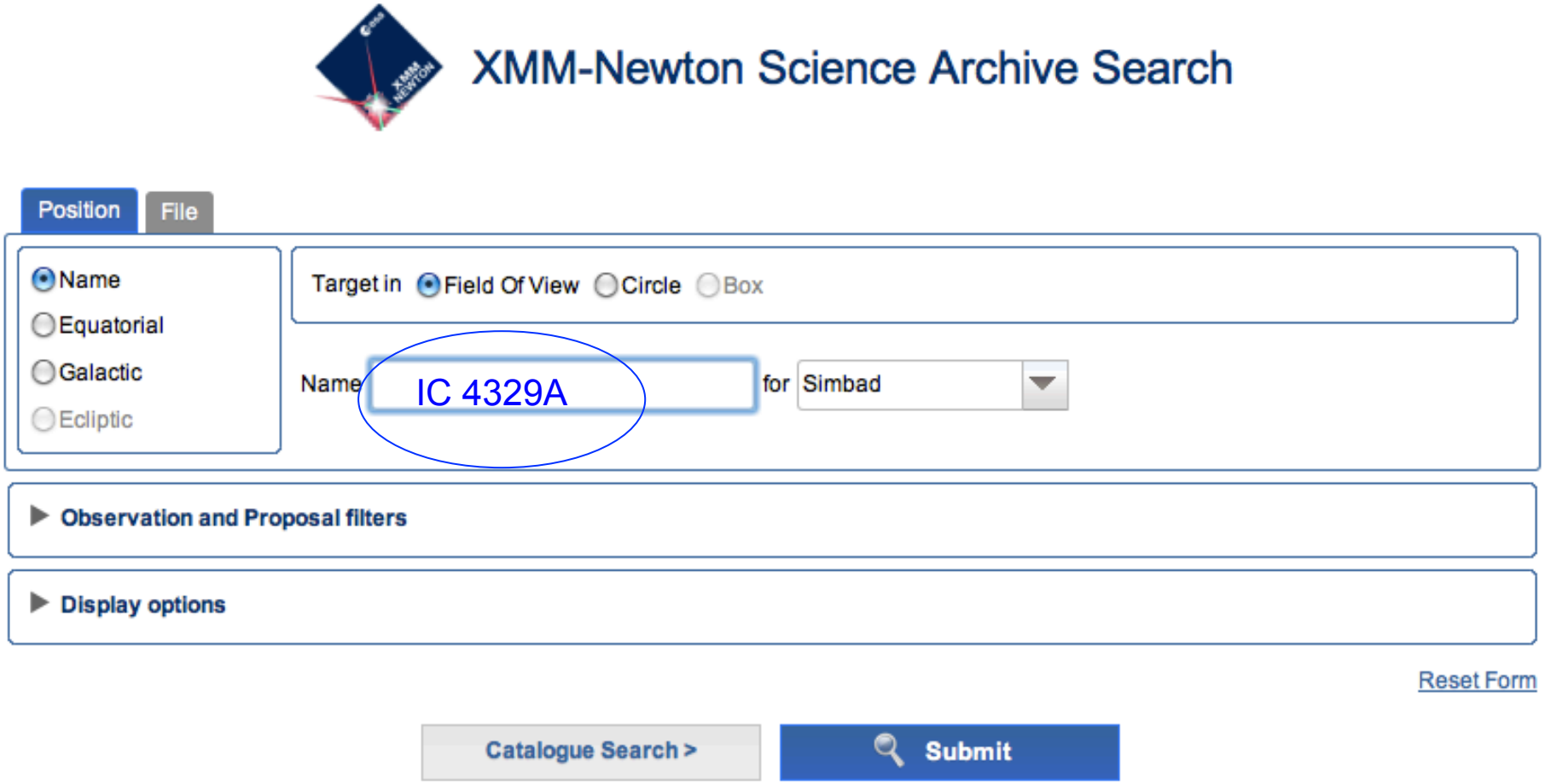
High Energy Astrophysics Science Archive Research Center (HEASARC) - NASA

http://heasarc.nasa.gov/ → Archive → Browse



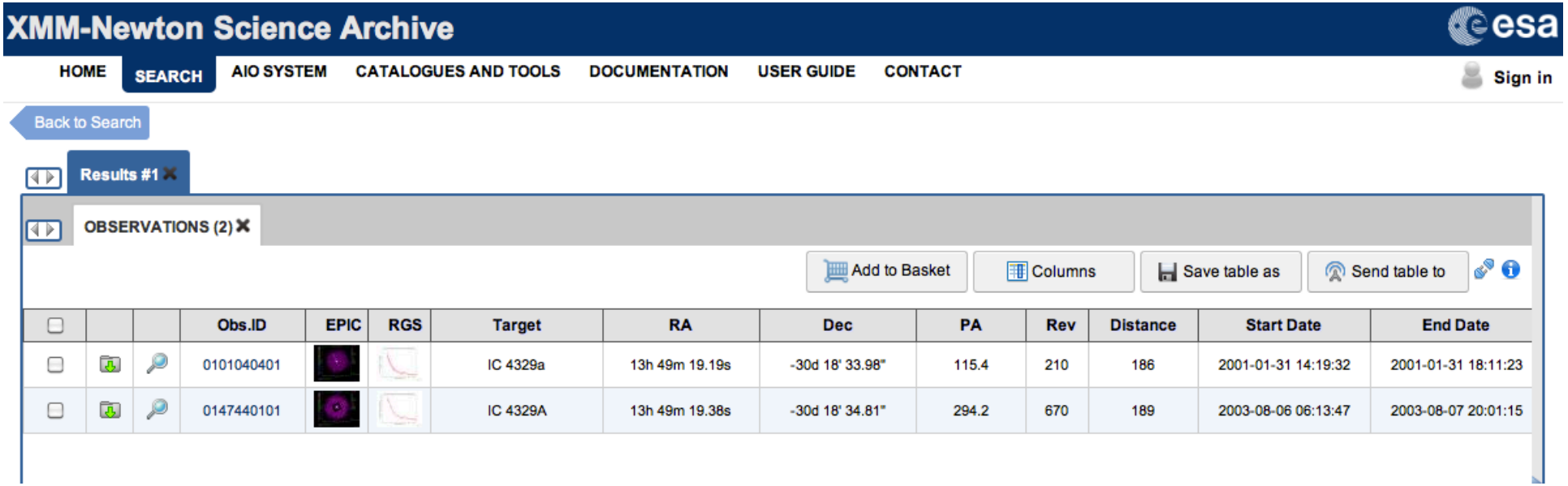
XMM-*Newton* Science Operations Centre (ESA-Vilspa, Spain) – I

http://xmm.esac.esa.int/xsa/



XMM-*Newton* Science Operations Centre (ESA-Vilspa, Spain) – I

http://xmm.esac.esa.int/xsa/

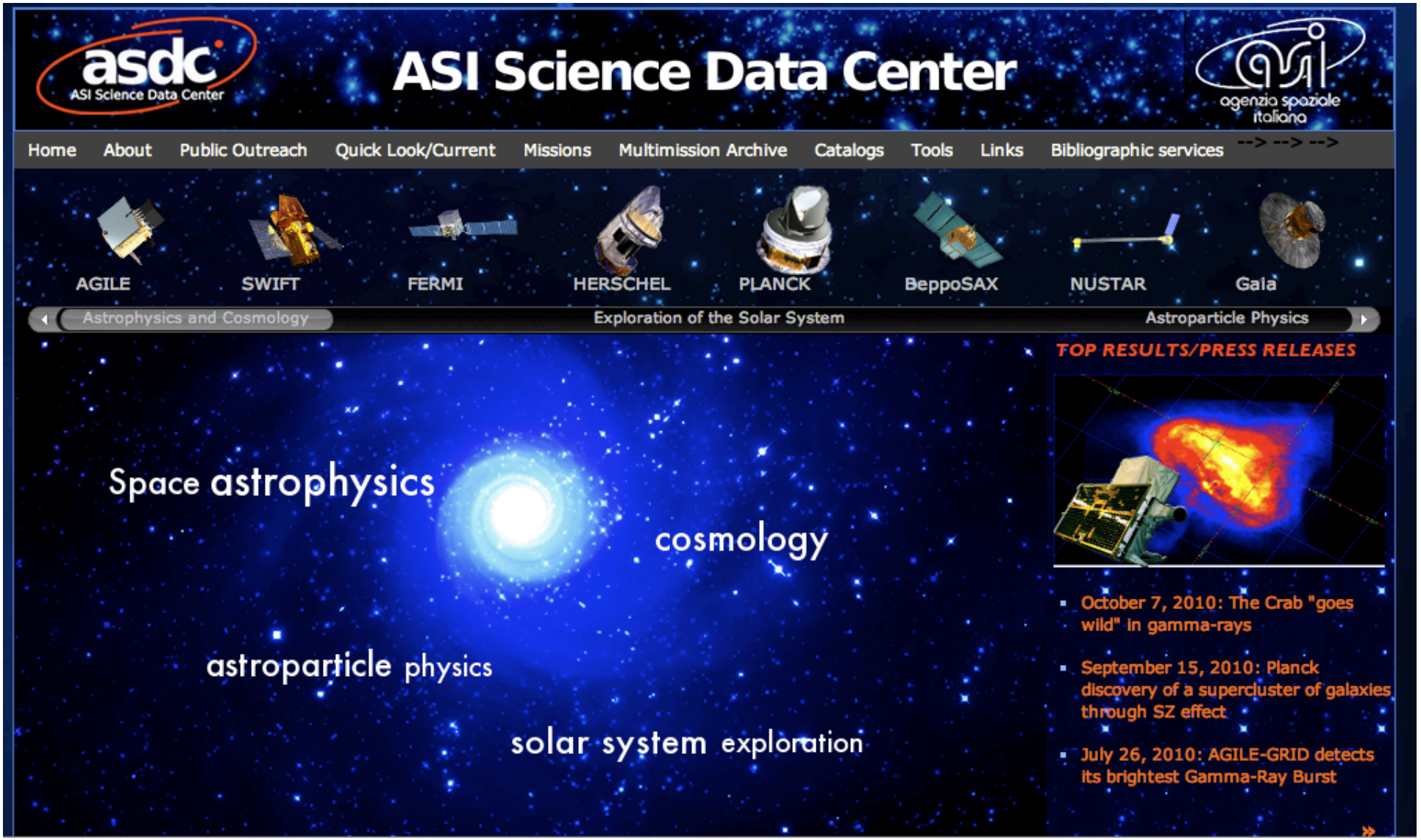


Preview of data (images/extracted spectra) is possible as well as interactive analysis of X-ray images

More details on the XMM-*Newton* tutorial…

ASI Scientific Data Center (ASDC- Frascati, Roma)

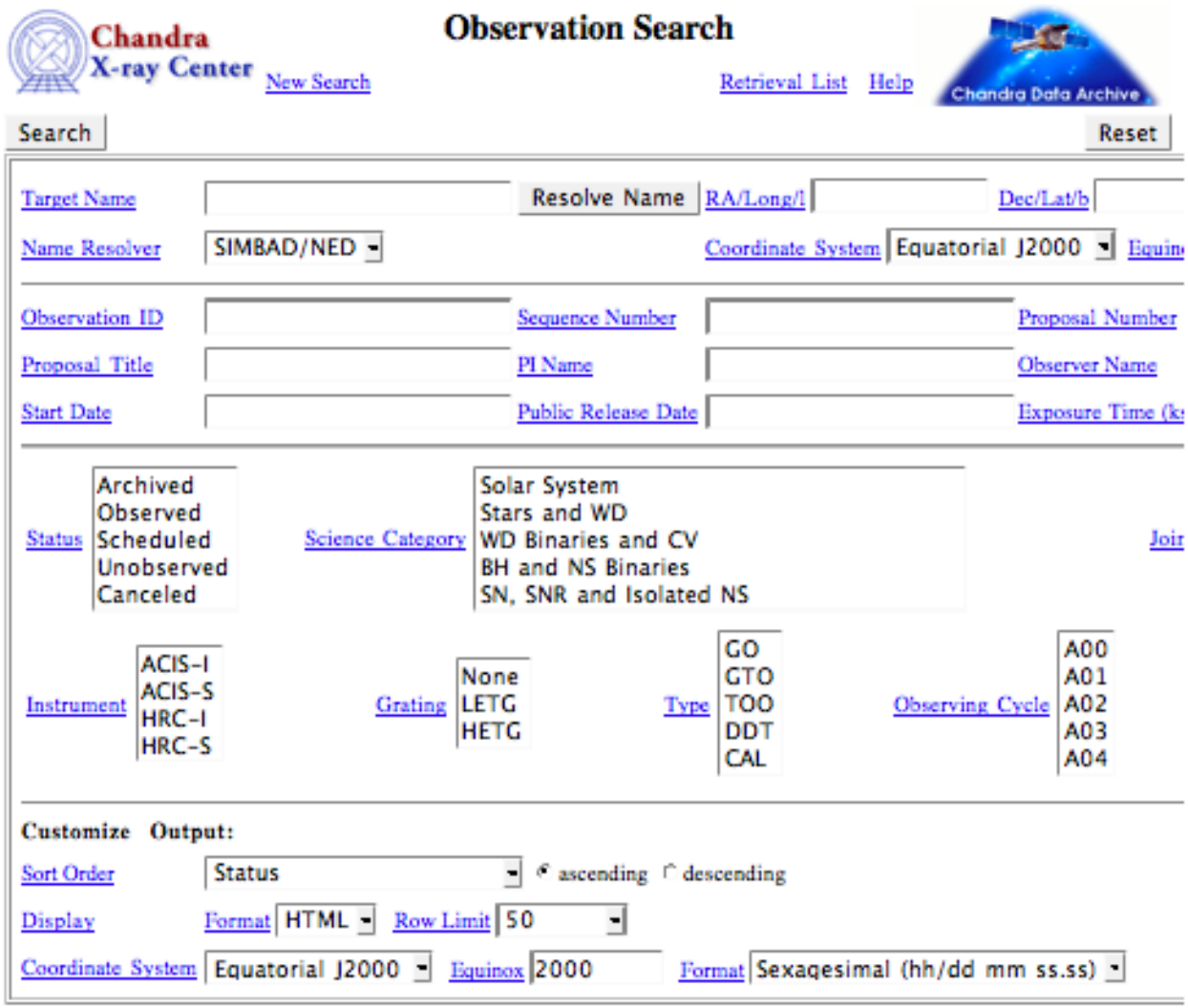
http://www.asdc.asi.it/



Chandra X-ray Center (CXC-CFA, Cambridge-Boston)

http://cda.harvard.edu/chaser/

Chandra Data Archive: Observation Search **webchaser** http://cda.harvard.edu/chaser/



View Observation Information | Add to Retrieval List | Primary products | Secondary products

Select all | Unselect all

Select	Row	Seq_Num	Obs_ID	Instrument	Grating	Appr_Exp_(ks)	Exposure_(ks)	Target
☐	1	700743	4064	ACIS-S	NONE	5.0	4.73	BR 0331-1622
☐	2	700744	4065	ACIS-S	NONE	4.0	4.12	BR 0353-3820
☐	3	700745	4066	ACIS-S	NONE	4.0	4.04	BR 0418-5723
☐	4	700746	4067	ACIS-S	NONE	5.0	4.73	BR 0424-2209
☐	5	700747	4068	ACIS-S	NONE	5.0	4.59	PSS 0747+4434
☐	6	700748	4069	ACIS-S	NONE	5.0	5.12	PSS 1058+1245
☐	7	700749	4070	ACIS-S	NONE	5.0	4.76	BRI 1117-1330
☐	8	700750	4071	ACIS-S	NONE	5.0	4.92	PSS 1506+5220
☐	9	700751	4072	ACIS-S	NONE	5.0	4.91	PSS 1646+5514
☐	10	700752	4073	ACIS-S	NONE	5.0	4.96	BR 2213-6729

Now all in one command:

download_chandra_obsid Obs_ID

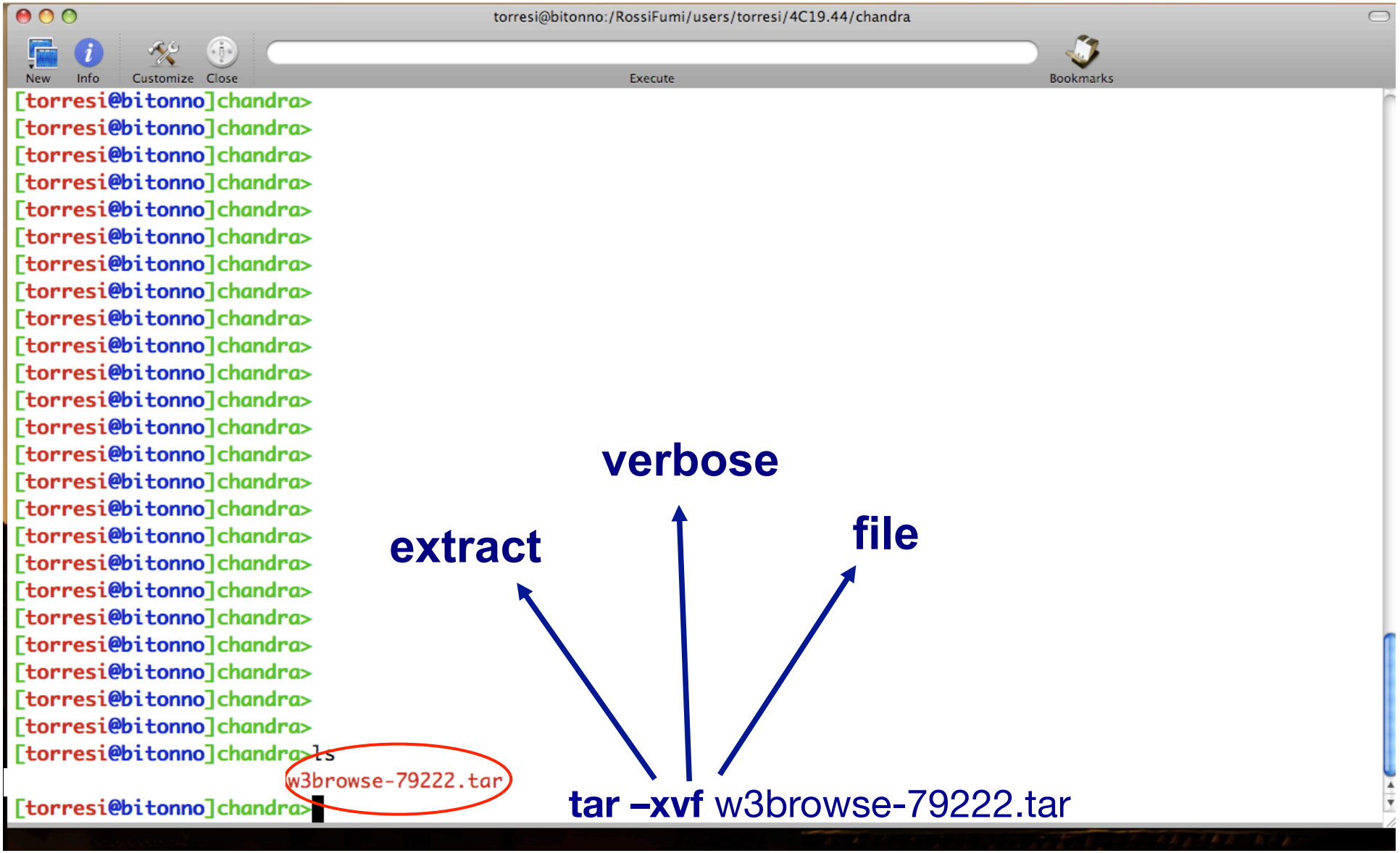
✓ Downloading of X-ray data from a public archive

✓ How do the downloaded files look like?

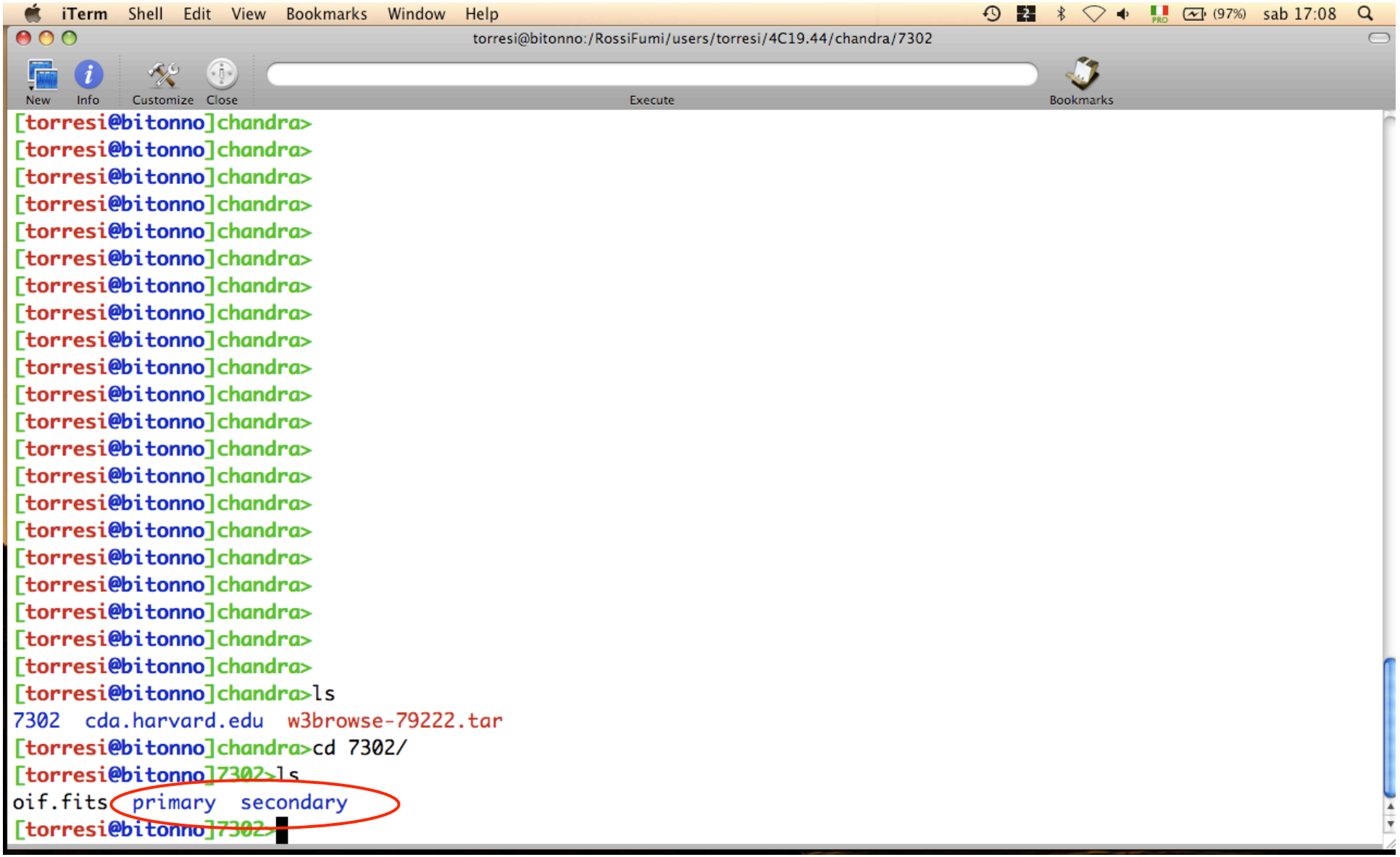
✓ Steps to reduce X-ray (*Chandra*) data

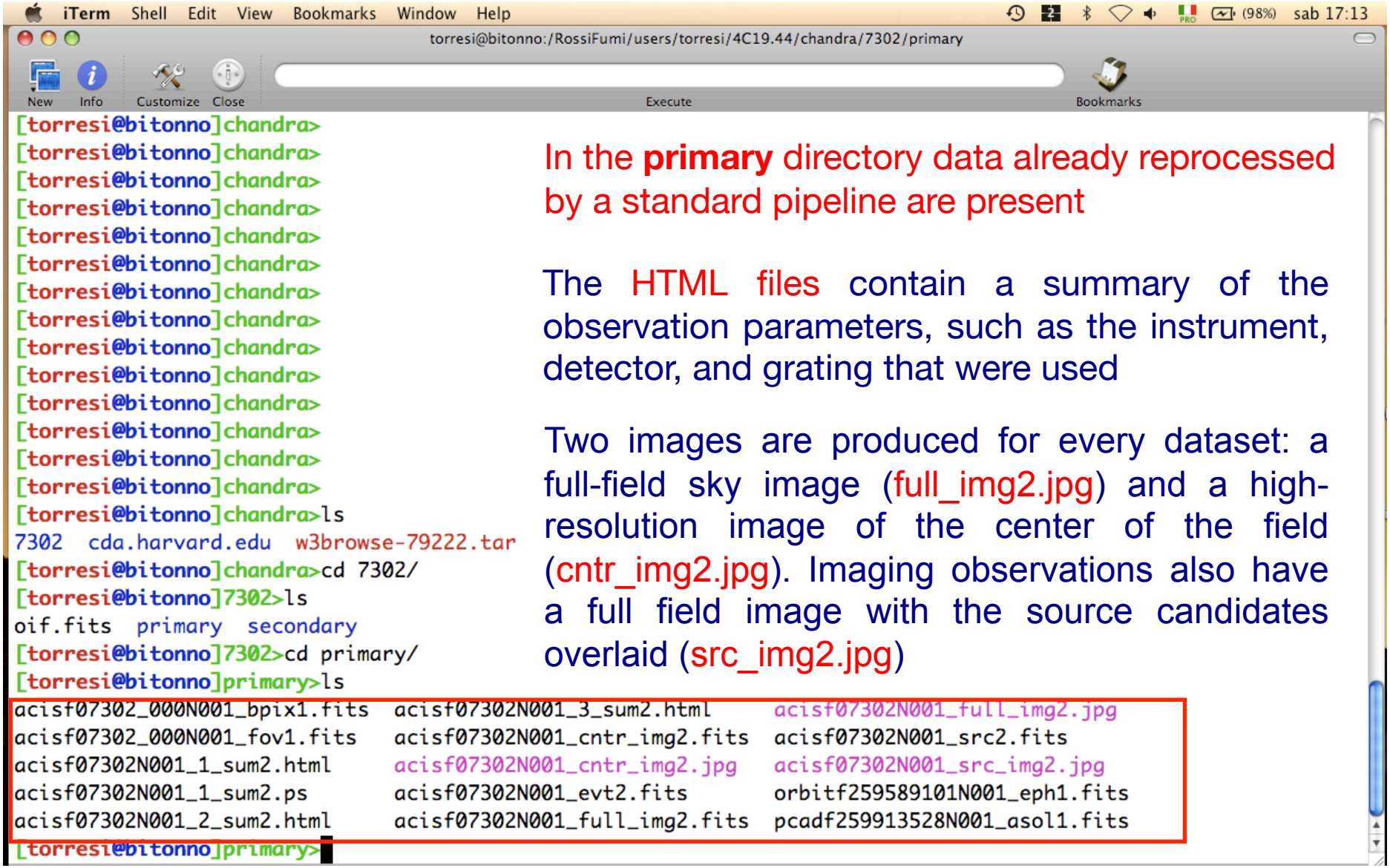
✓ Creation of radio and/or X-ray contours for an extended object

✓ How to create a radio/X-ray contour superposition image


torresi@bitonno:/RossiFumi/users/torresi/4C19.44/chandra
New
Info
Customize
Close
Execute
Bookmarks
[torresi@bitonno]chandra>
[torresi@bitonno]chandra>ls
w3browse-79222.tar
[torresi@bitonno]chandra>
verbose
extract
file
tar –xvf w3browse-79222.tar

cd 7302 → obs id

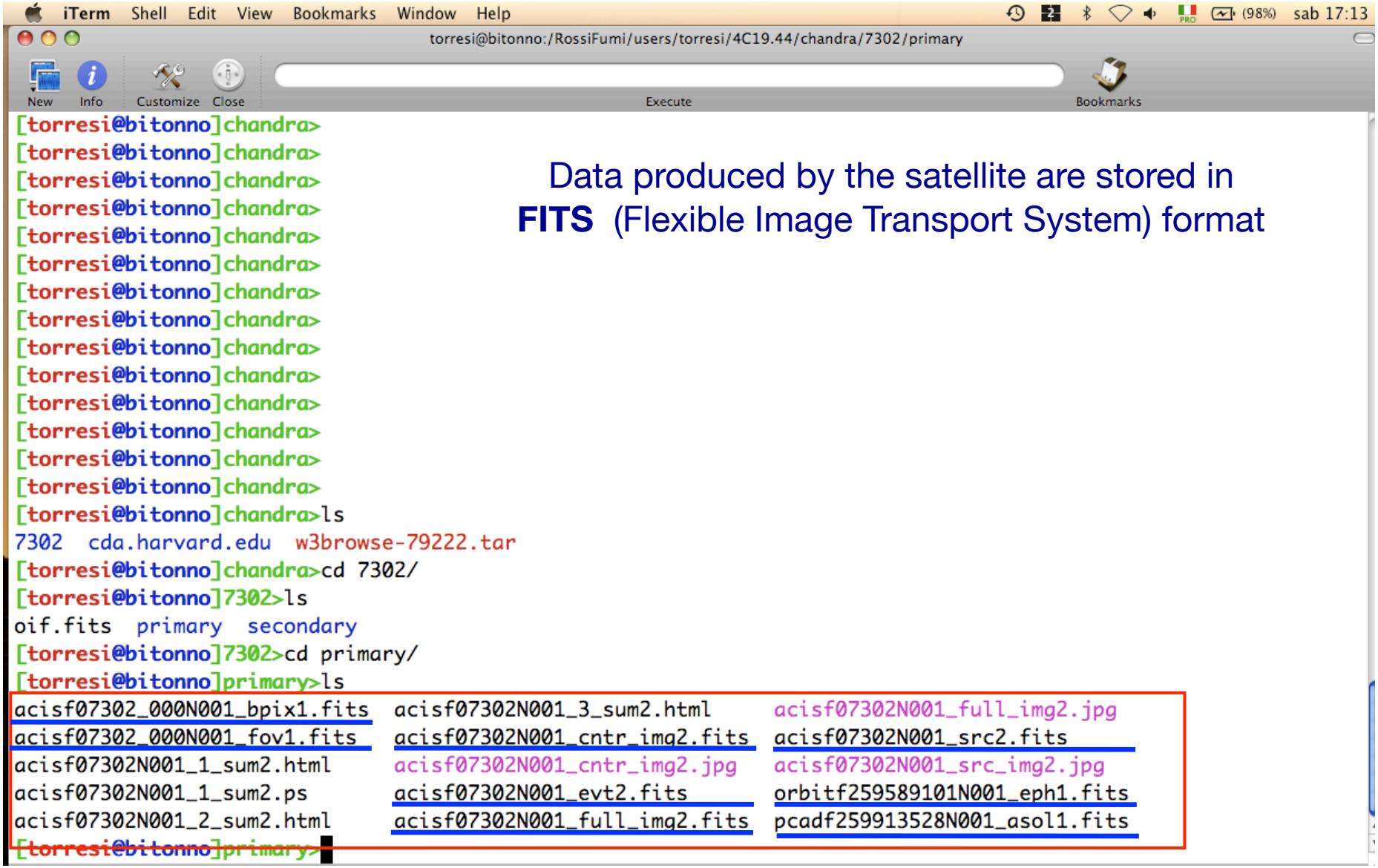

iTerm Shell Edit View Bookmarks Window Help
(97%) sab 17:08
torresi@bitonno:/RossiFumi/users/torresi/4C19.44/chandra/7302
New Info Customize Close
Execute
Bookmarks
[torresi@bitonno]chandra>
[torresi@bitonno]chandra>ls
7302 cda.harvard.edu w3browse-79222.tar
[torresi@bitonno]chandra>cd 7302/
[torresi@bitonno]7302>ls
oif.fits primary secondary
[torresi@bitonno]7302>



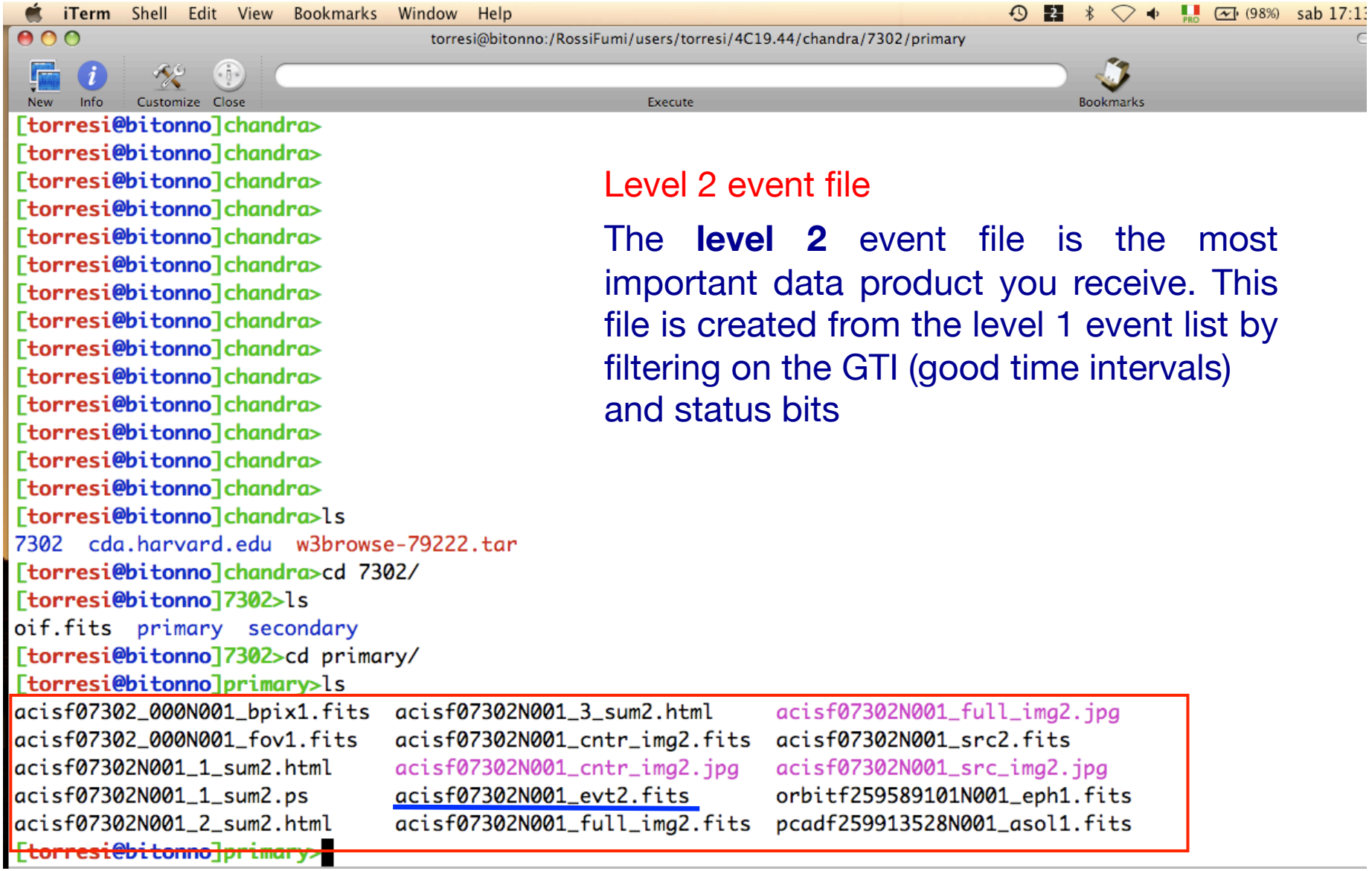
In the **primary** directory data already reprocessed by a standard pipeline are present

The HTML files contain a summary of the observation parameters, such as the instrument, detector, and grating that were used

Two images are produced for every dataset: a full-field sky image (full_img2.jpg) and a high-resolution image of the center of the field (cntr_img2.jpg). Imaging observations also have a full field image with the source candidates overlaid (src_img2.jpg)

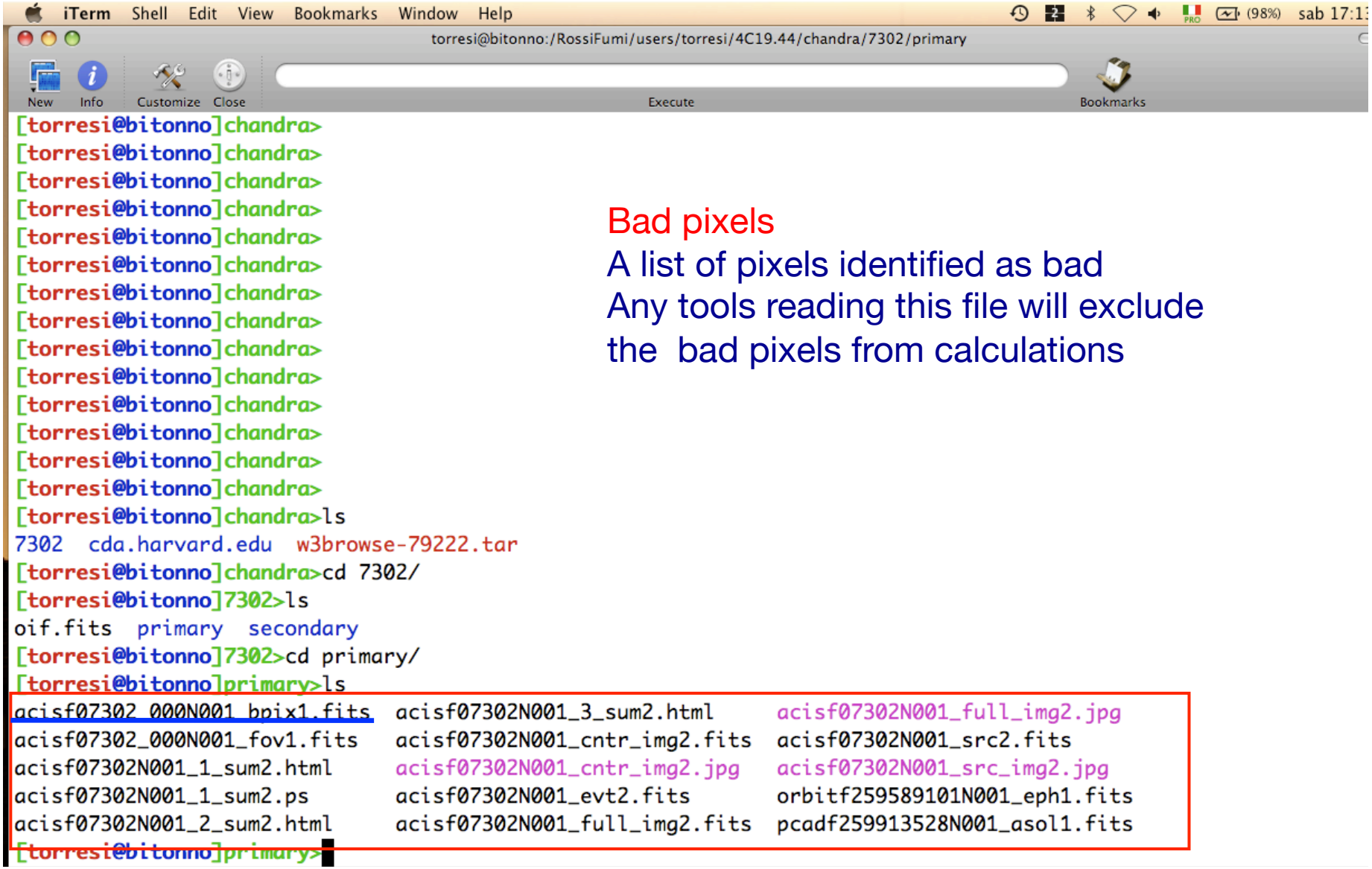


Data produced by the satellite are stored in
FITS (Flexible Image Transport System) format



Level 2 event file

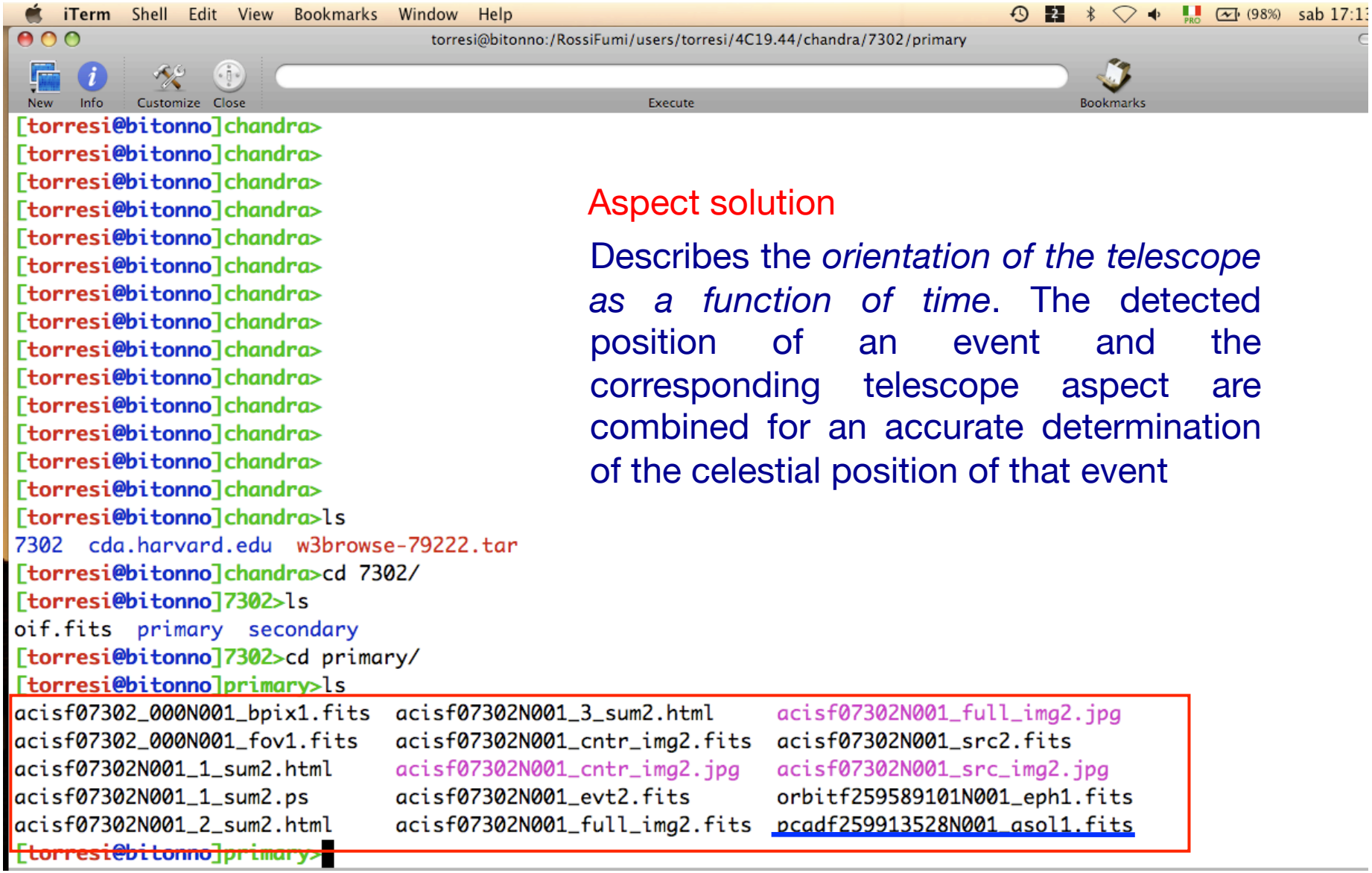
The **level 2** event file is the most important data product you receive. This file is created from the level 1 event list by filtering on the GTI (good time intervals) and status bits



Bad pixels

A list of pixels identified as bad

Any tools reading this file will exclude the bad pixels from calculations



Aspect solution

Describes the *orientation of the telescope as a function of time*. The detected position of an event and the corresponding telescope aspect are combined for an accurate determination of the celestial position of that event

iTerm Shell Edit View Bookmarks Window Help (99%) sab 17:39

torresi@bitonno:/RossiFumi/users/torresi/4C19.44/chandra/7302/secondary

New Info Customize Close Execute Bookmarks

```
[torresi@bitonno]secondary>
[torresi@bitonno]secondary>
[torresi@bitonno]secondary>
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[torresi@bitonno]secondary>
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[torresi@bitonno]secondary>
[torresi@bitonno]secondary>
[torresi@bitonno]secondary>
[torresi@bitonno]secondary>
[torresi@bitonno]secondary>ls
acisf07302_000N001_aoff1.fits  acisf07302_000N001_mtl1.fits      acisf259912127N001_pbk0.fits
acisf07302_000N001_evt1.fits   acisf07302_000N001_soff1.fits     aspect
acisf07302_000N001_flt1.fits   acisf07302_000N001_stat1.fits     axaff07302N001_VV001_vvref2.pdf
acisf07302_000N001_msk1.fits   acisf259911591N001_1_bias0.fits   ephem
[torresi@bitonno]secondary>
```
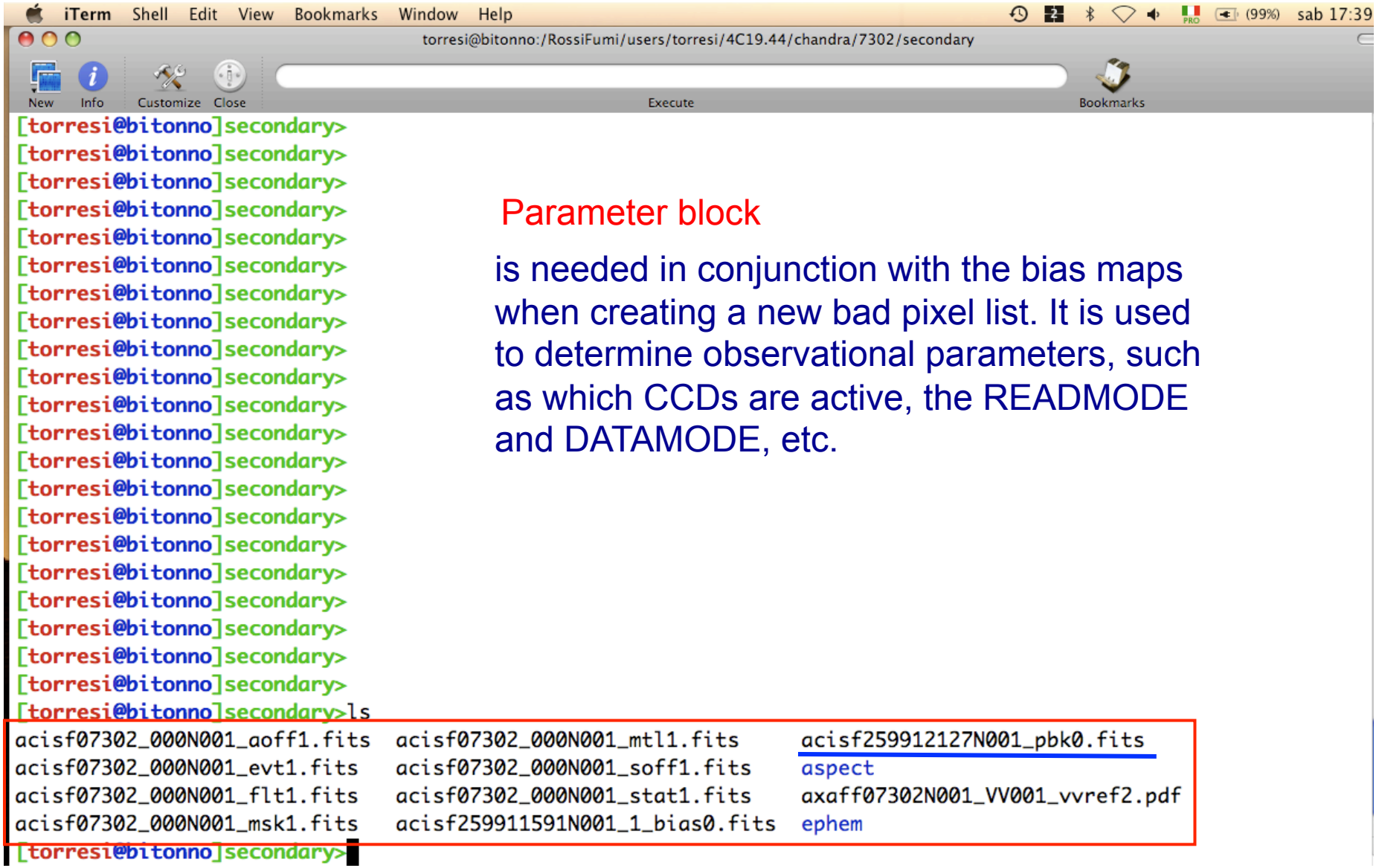

If you want to reduce *raw* data you must go in the **secondary** directory.

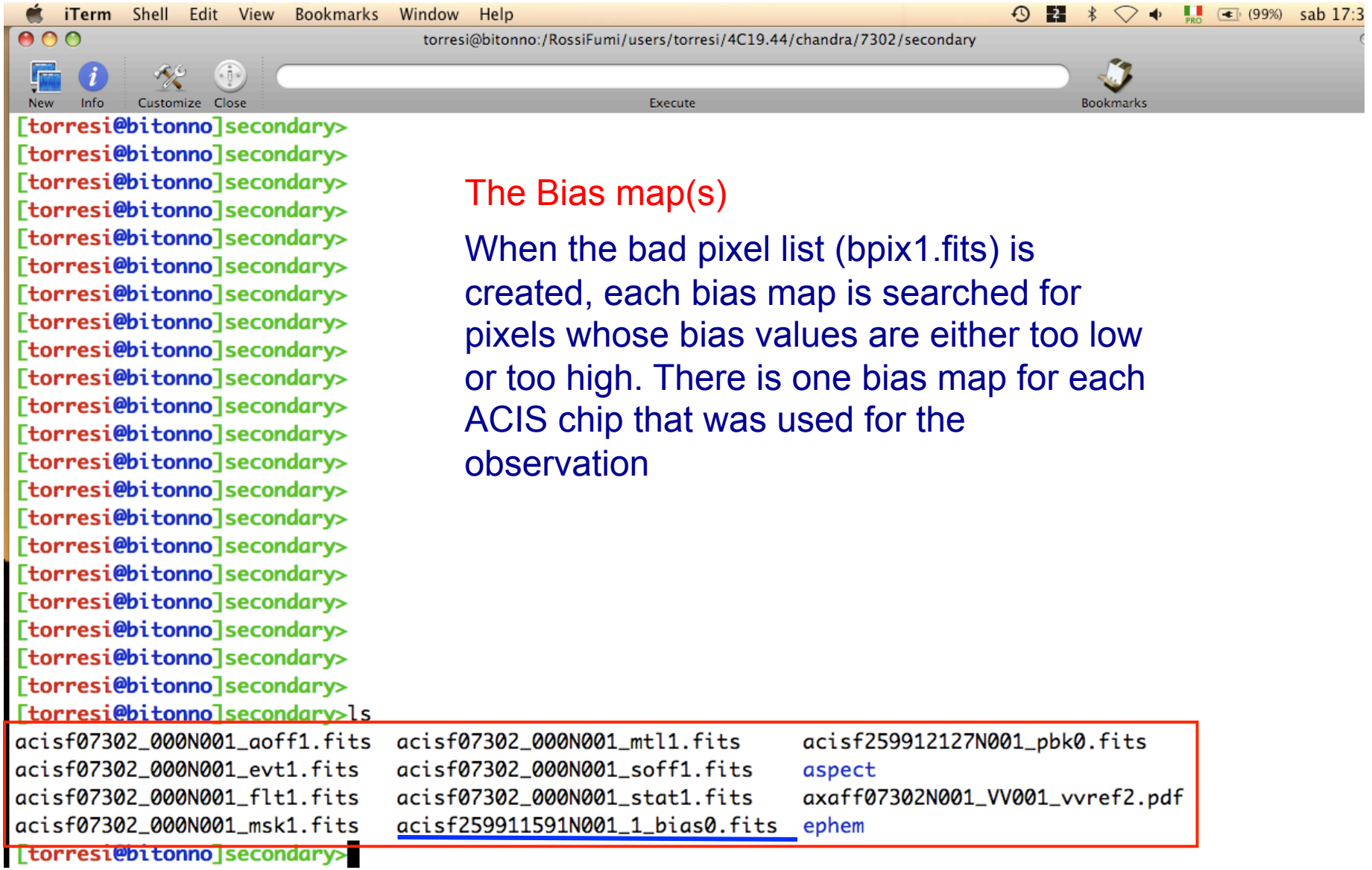
Here you find:

Level 1 event file contains *all the events recorded for the observation.* It is the starting point for reprocessing your data



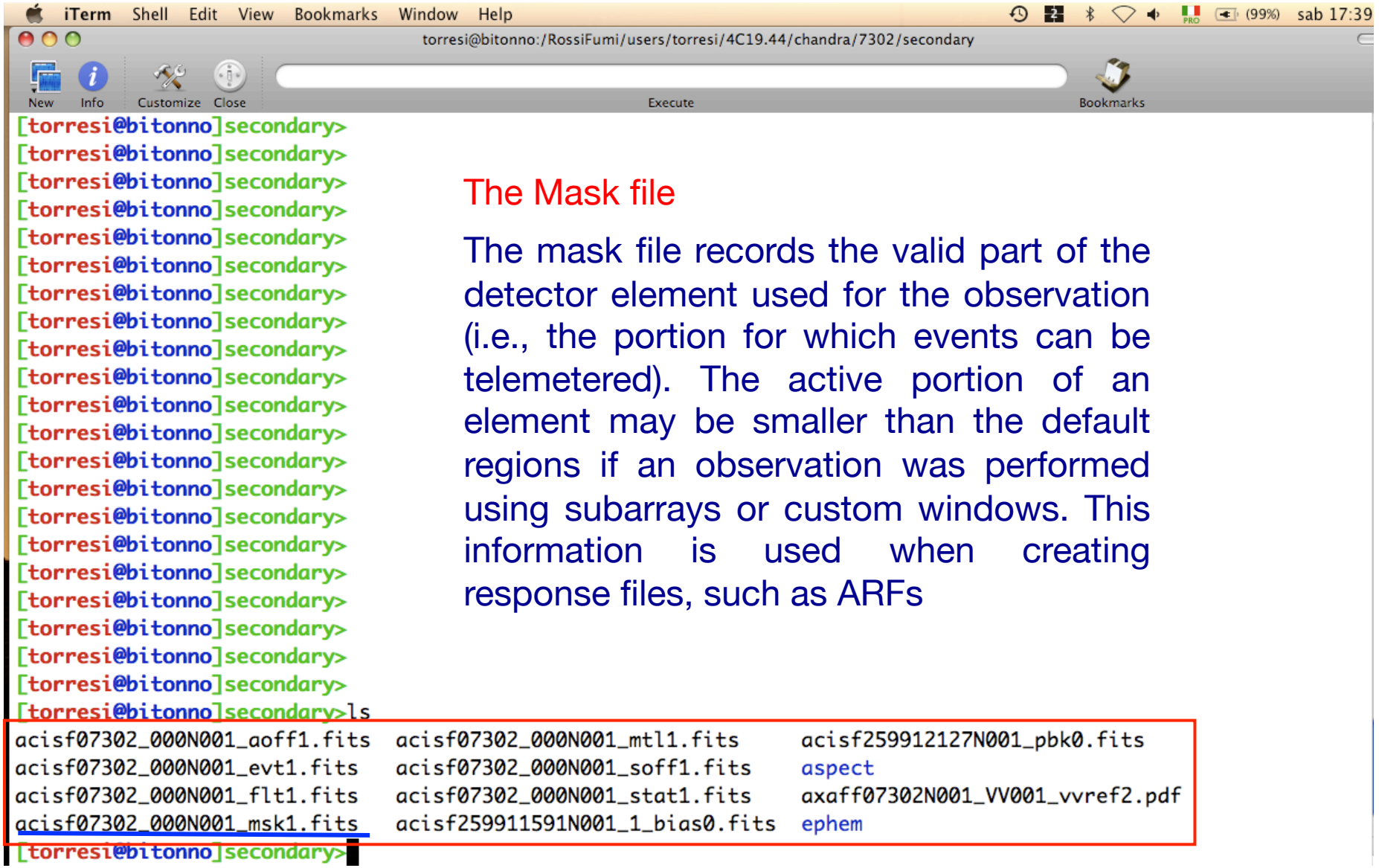
Parameter block

is needed in conjunction with the bias maps when creating a new bad pixel list. It is used to determine observational parameters, such as which CCDs are active, the READMODE and DATAMODE, etc.



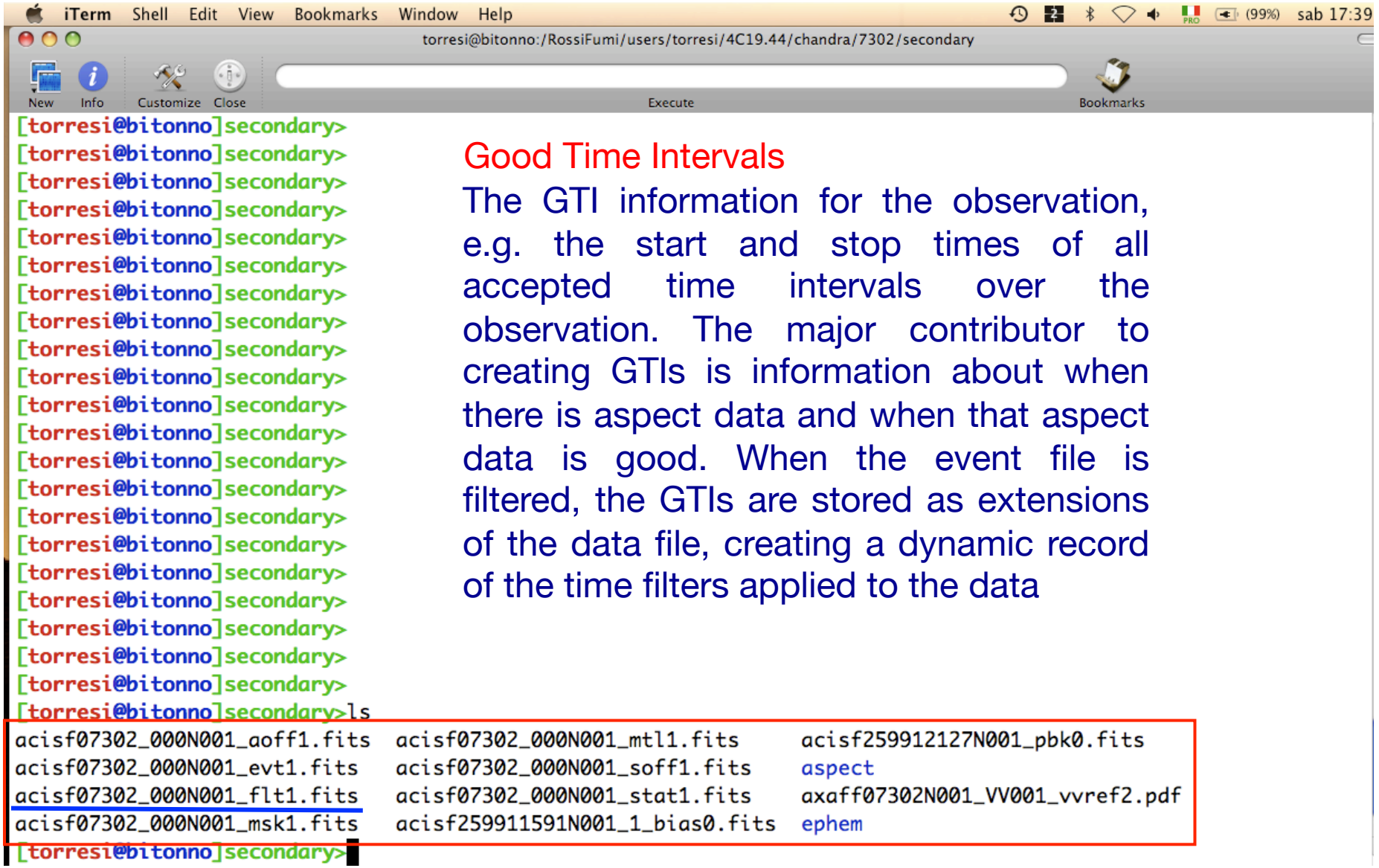
The Bias map(s)

When the bad pixel list (bpix1.fits) is created, each bias map is searched for pixels whose bias values are either too low or too high. There is one bias map for each ACIS chip that was used for the observation



The Mask file

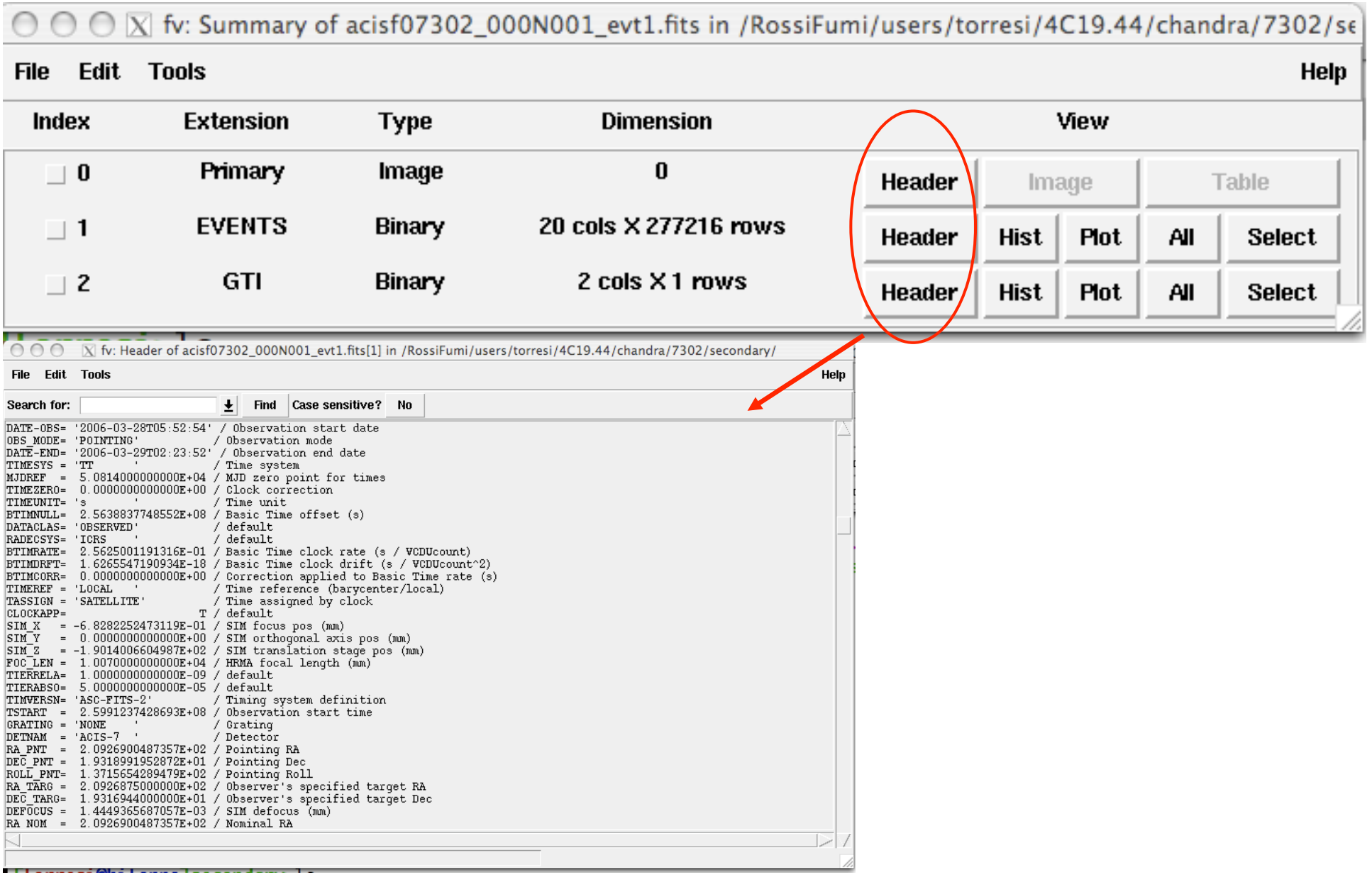
The mask file records the valid part of the detector element used for the observation (i.e., the portion for which events can be telemetered). The active portion of an element may be smaller than the default regions if an observation was performed using subarrays or custom windows. This information is used when creating response files, such as ARFs



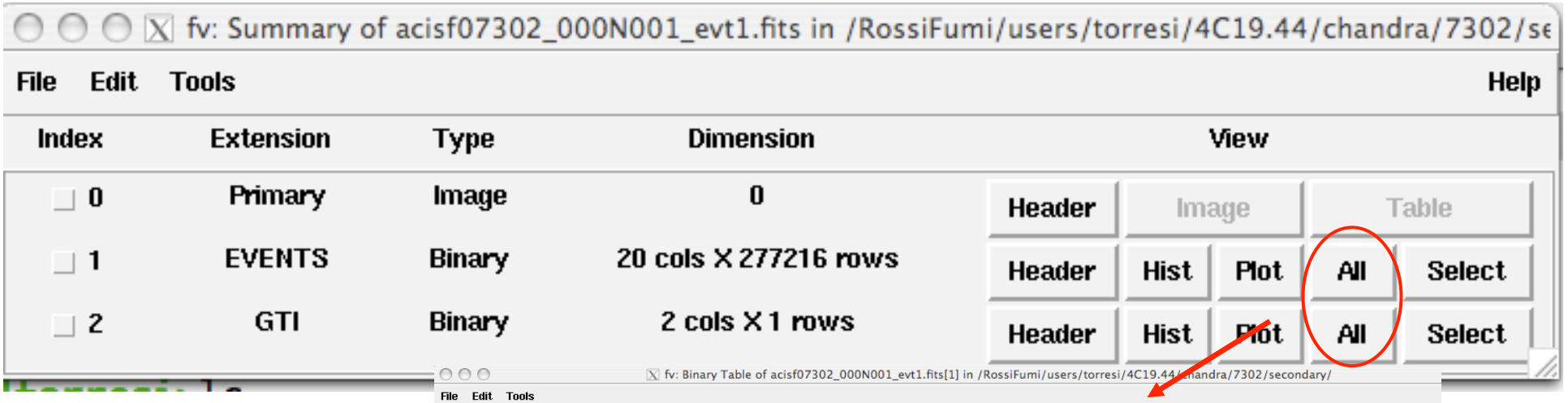
Good Time Intervals

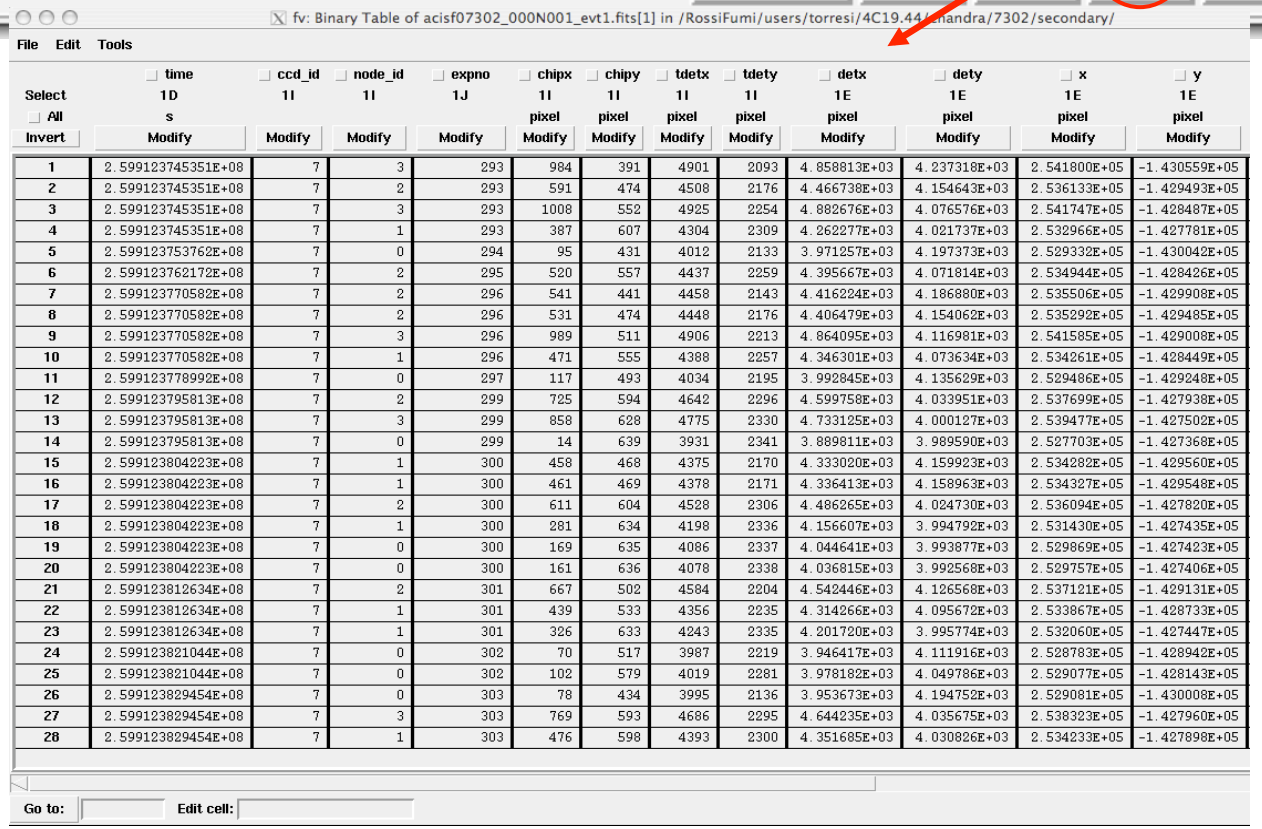
The GTI information for the observation, e.g. the start and stop times of all accepted time intervals over the observation. The major contributor to creating GTIs is information about when there is aspect data and when that aspect data is good. When the event file is filtered, the GTIs are stored as extensions of the data file, creating a dynamic record of the time filters applied to the data

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*



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





	time 1D s Modify	ccd_id 1I Modify	node_id 1I Modify	expno 1J Modify	chipx 1I pixel Modify	chipy 1I pixel Modify	tdetx 1I pixel Modify	tdety 1I pixel Modify	detx 1E pixel Modify	dety 1E pixel Modify	x 1E pixel Modify	y 1E pixel Modify
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

✓ Downloading of X-ray data from a public archive

✓ How do the downloaded files look like?

✓ Steps to reduce X-ray (*Chandra*) data

✓ Creation of radio and/or X-ray contours for an extended object

✓ How to create a radio/X-ray contour superposition image

Chandra data reduction

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

Science Threads

All threads

A list of all the threads on one page.

Introduction NEW 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 NEW 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 NEW UPDATED

After extracting source and background PI or PHA spectra from an imaging observation, the appropriate

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

Now all in one command:
chandra_repro

Cleaned
event files

Scientific files
Housekeeping files

Cleaned
event files

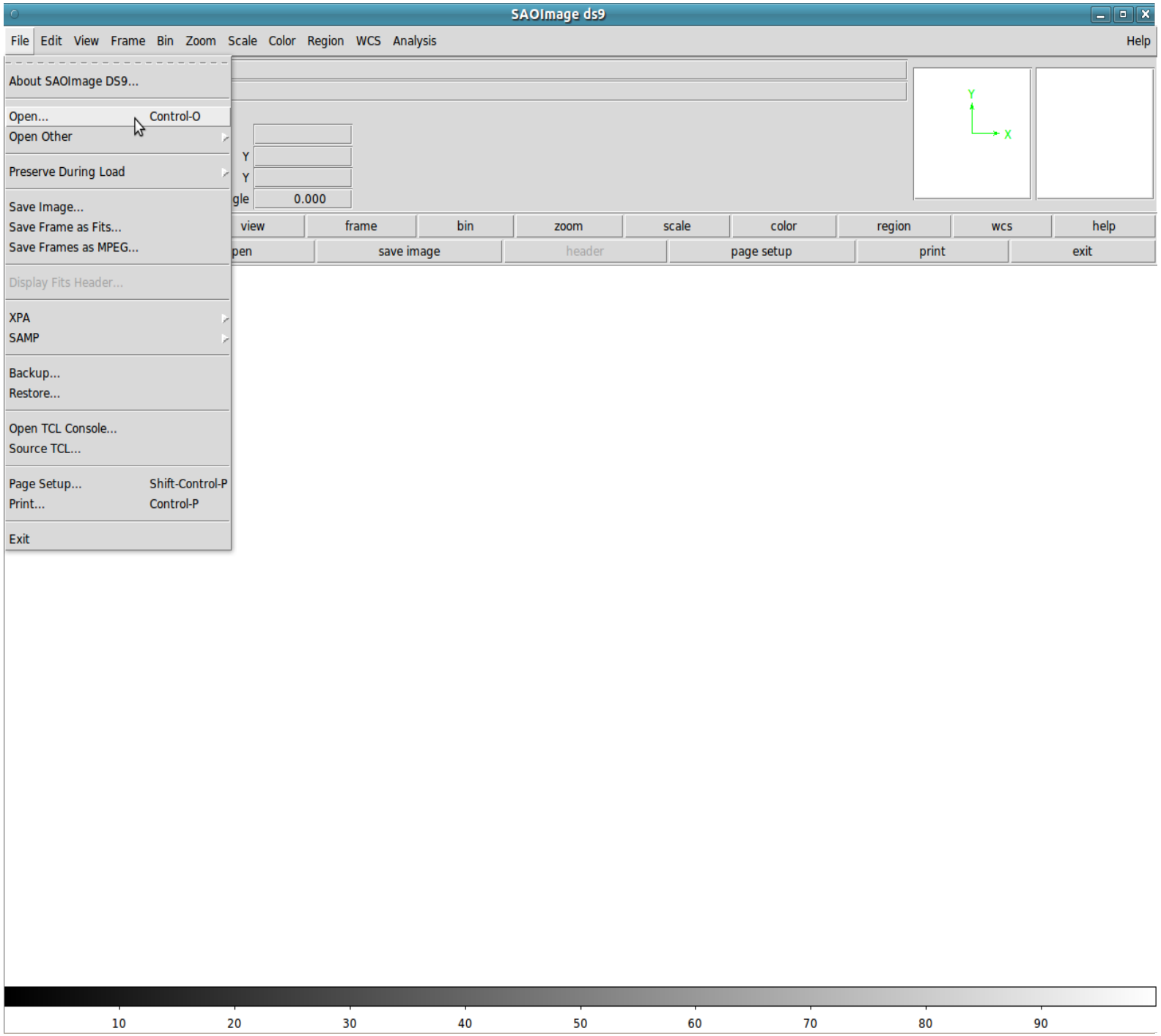
Image

DS9:

File

↓

Open



DS9:

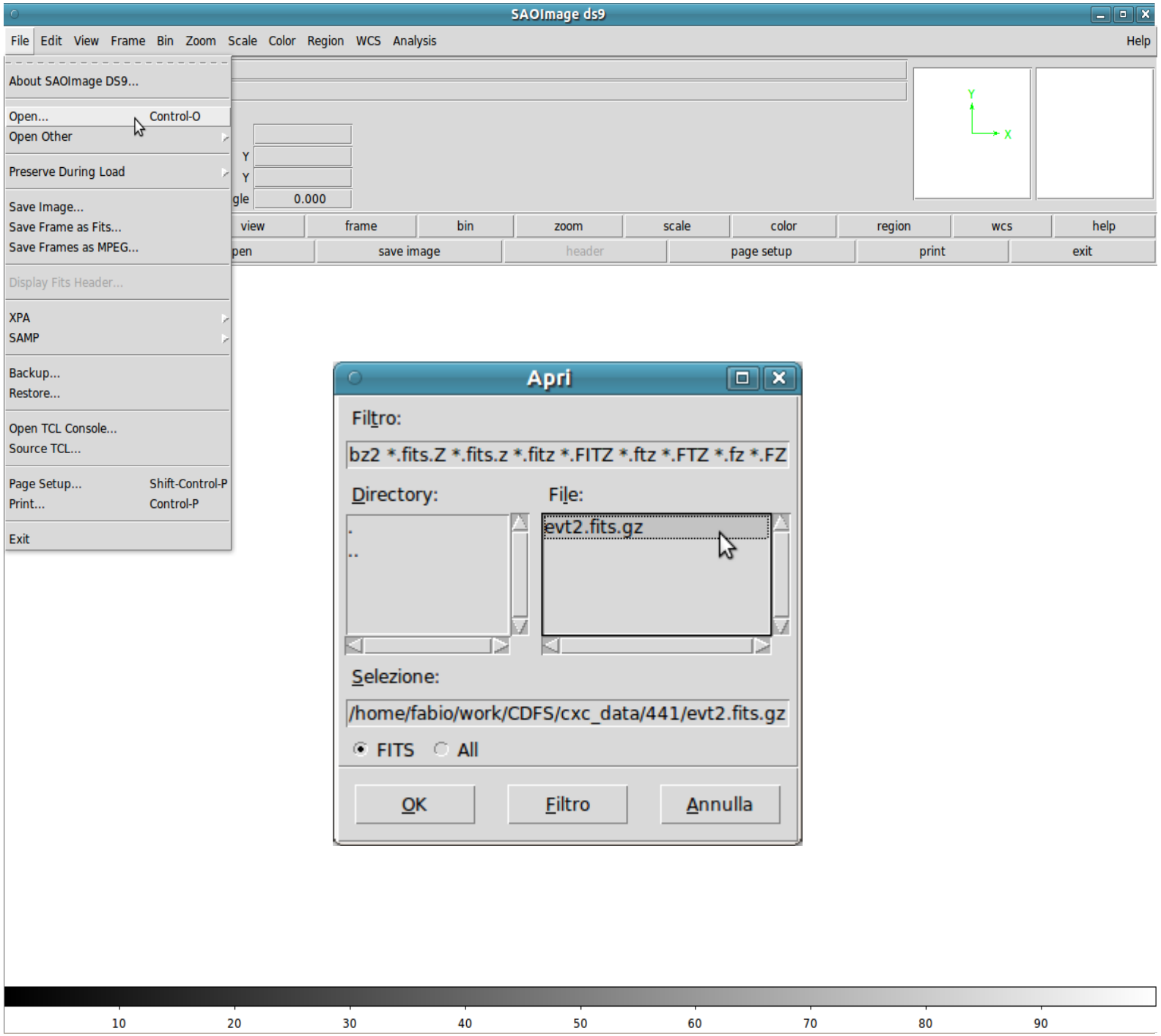
File

↓

Open

↓

Evt2 file

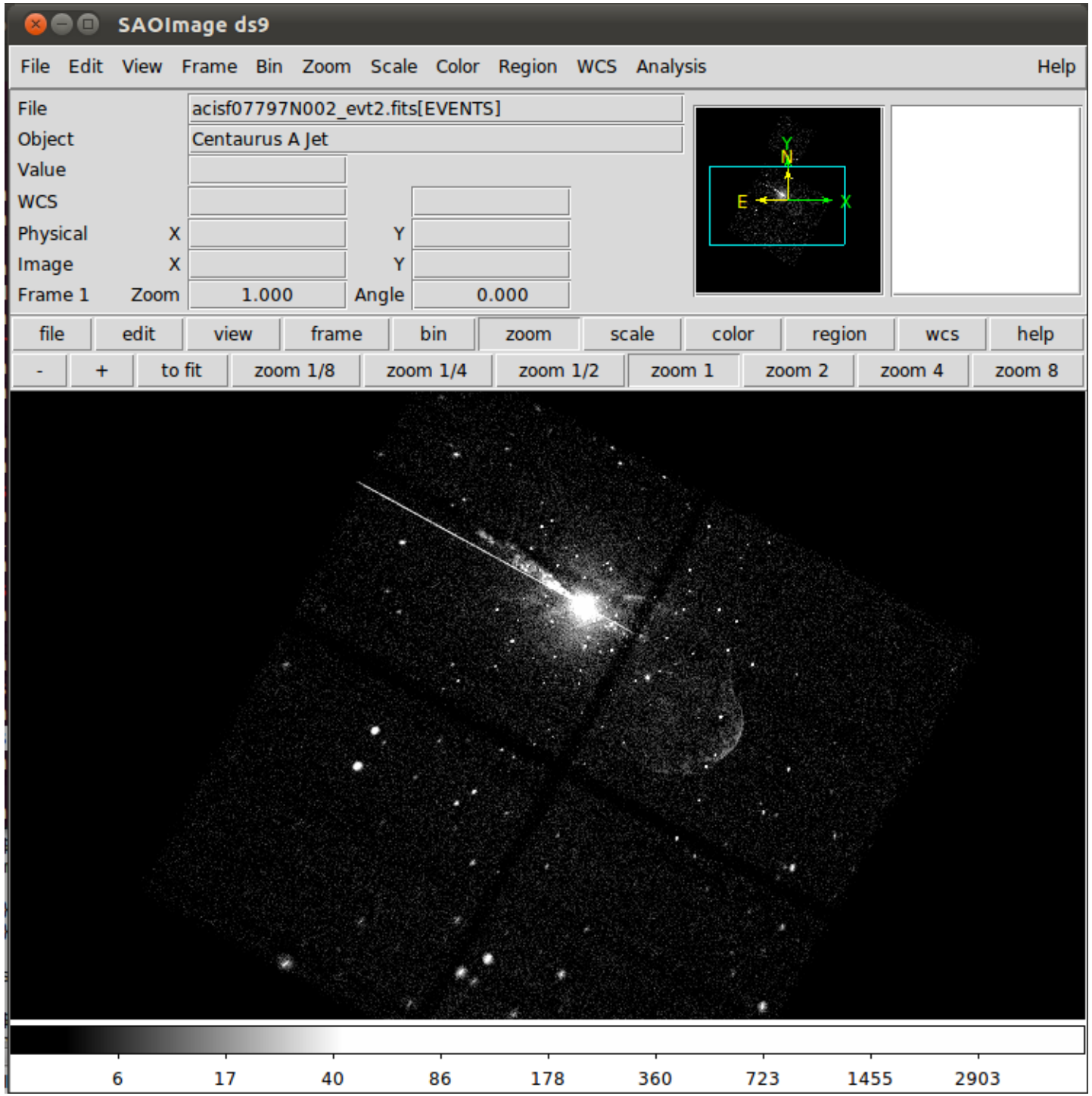


DS9:

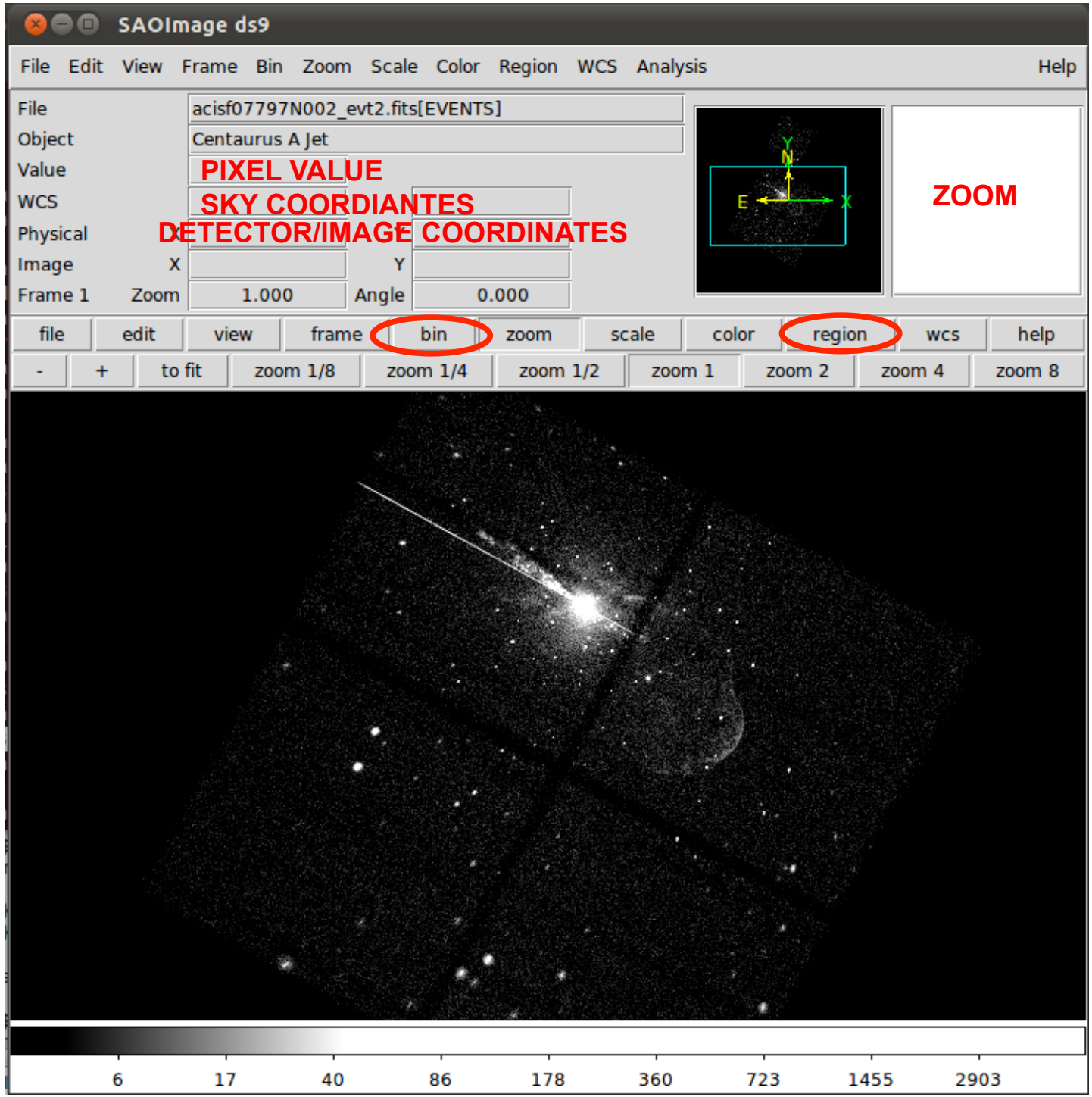
Scale

↓

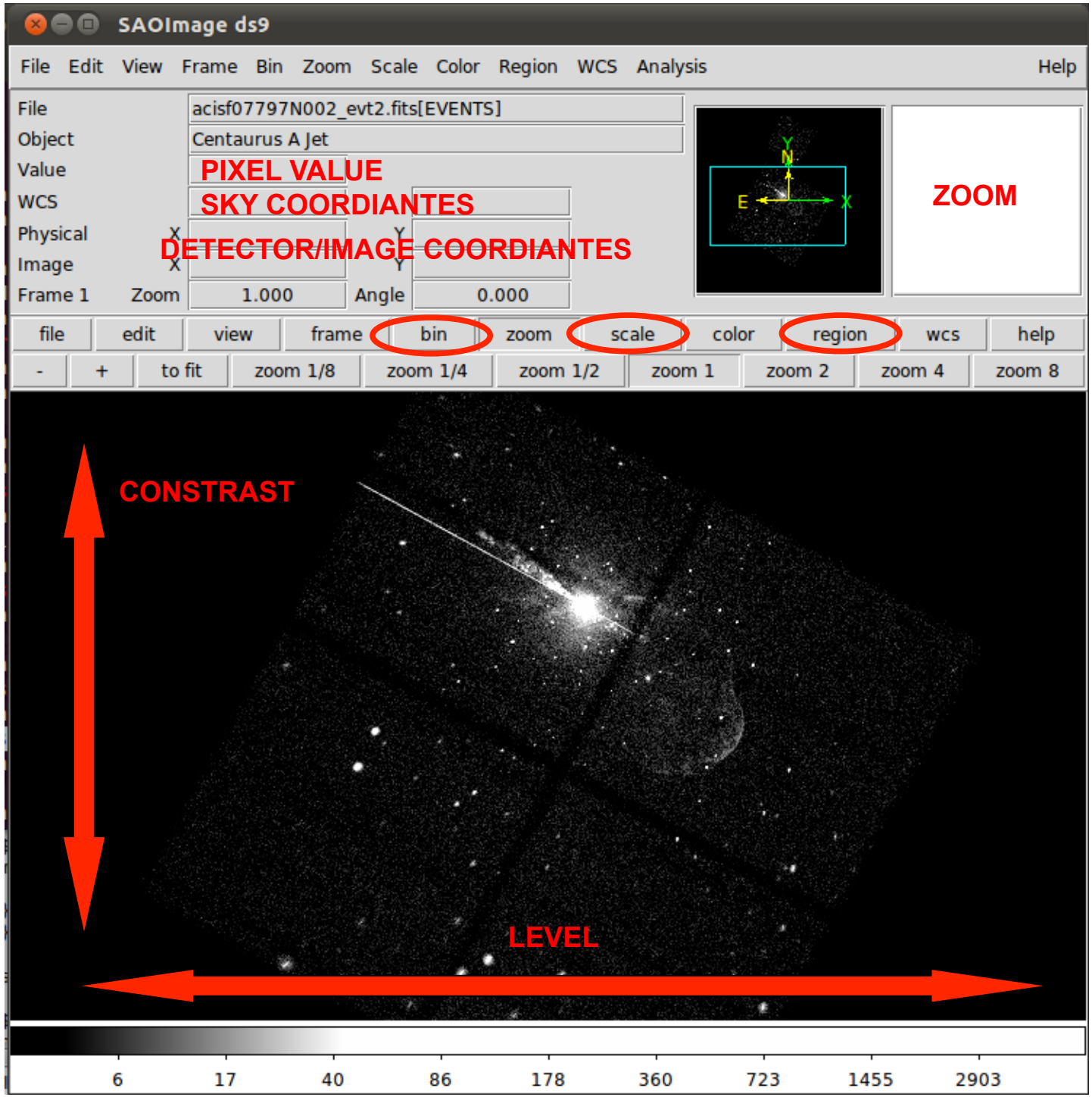
Log



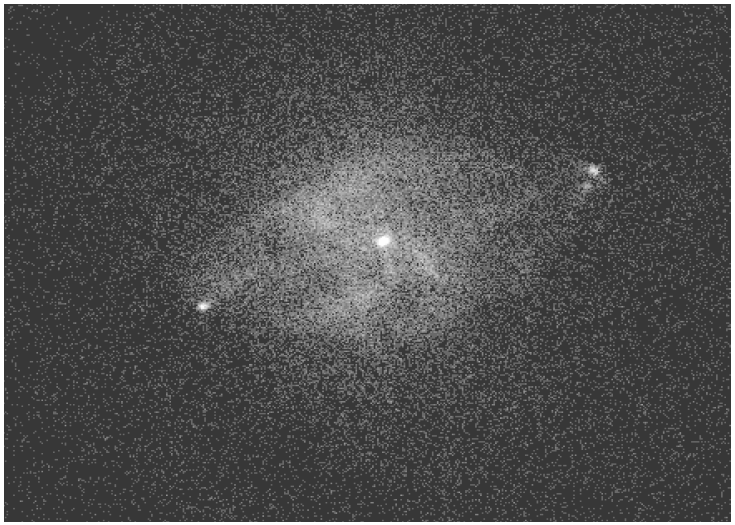
DS9:


SAOImage ds9
File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help
File acisf07797N002_evt2.fits[EVENTS]
Object Centaurus A Jet
Value
WCS
Physical
Image X Y
Frame 1 Zoom 1.000 Angle 0.000
PIXEL VALUE
SKY COORDIANTES
DETECTOR/IMAGE COORDINATES
ZOOM
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
6 17 40 86 178 360 723 1455 2903

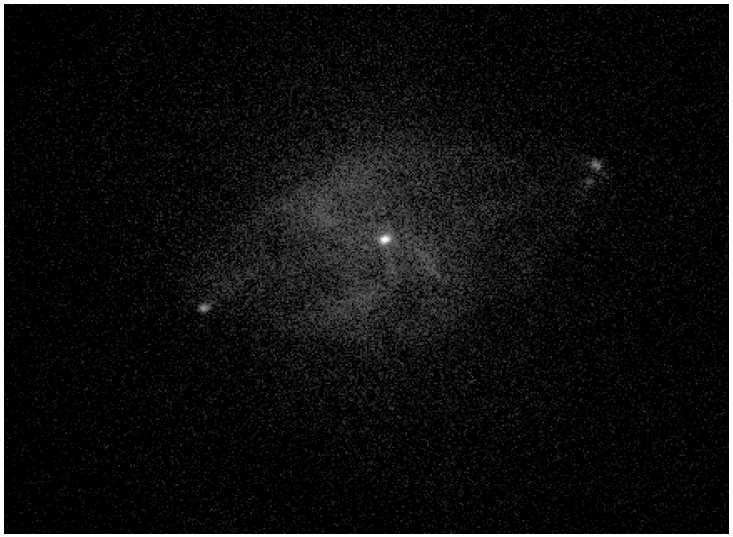
DS9:



Hold right button down and move left/right and/or up/down

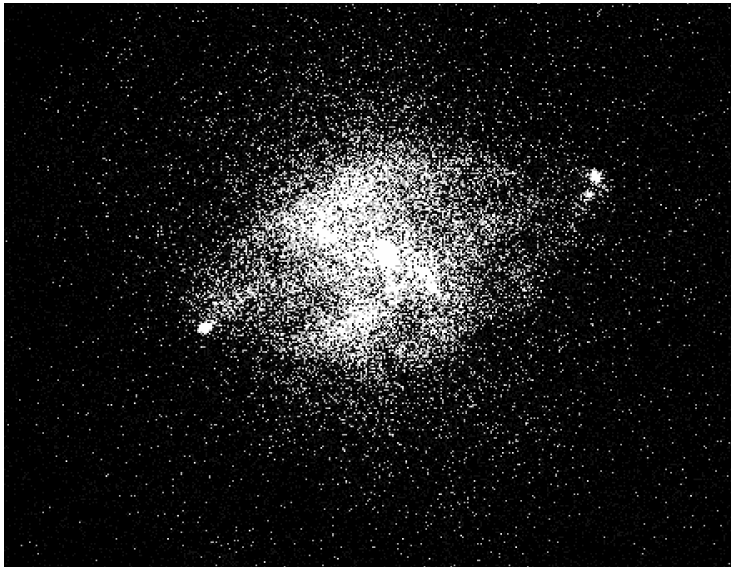


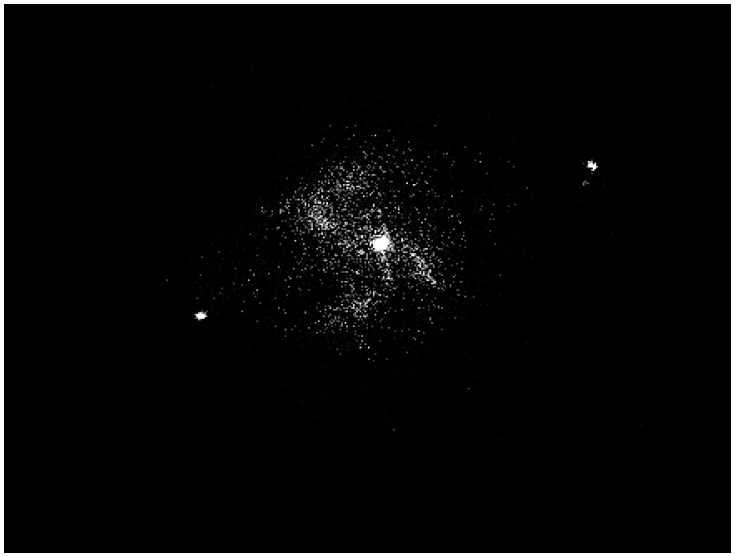
Level



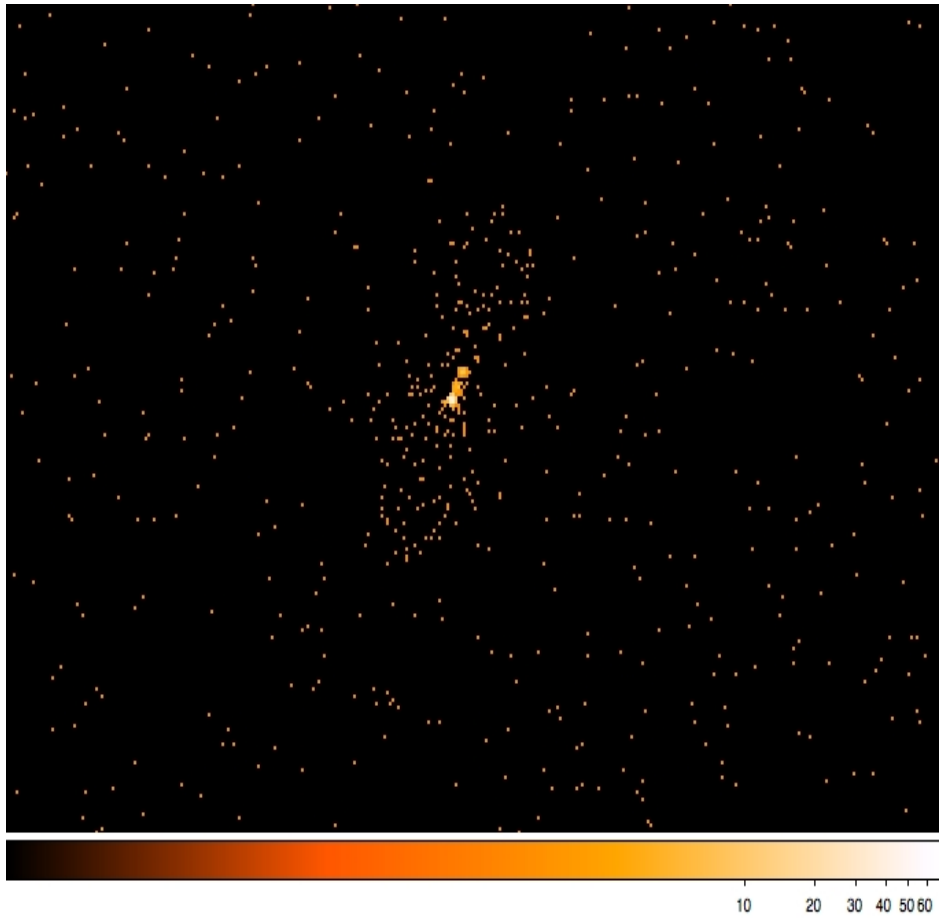
Contrast

Contrast + Level





Most important information deducible from an image:
- the source is pointlike or extended;
- obtain and fit a radial profile;
- calculate the source counts and verify if the observed excess is real or due to background fluctuations;
- X-ray counterparts of structures seen in other wavebands.

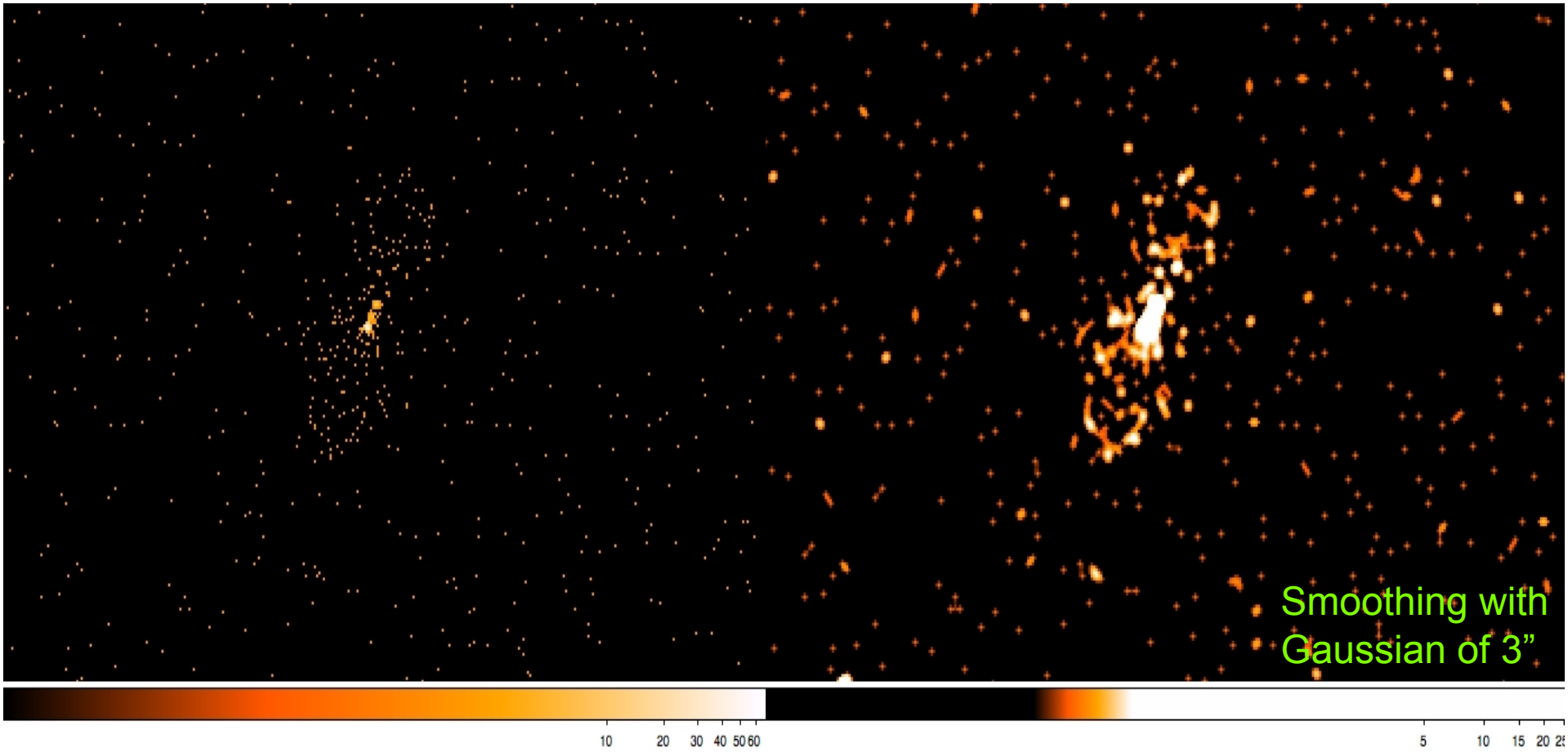


It is possible to improve the image look

$$Y(t) = \int K(t,s)\, X(s)\, ds$$

X=input; Y=output; K=kernel

smoothing →



To **smooth an image** means to substitute the value of each pixel for the value obtained by weighting the pixels nearby with a certain function (e.g., a Gaussian)

Scientific files
Housekeeping files

Cleaned
event files

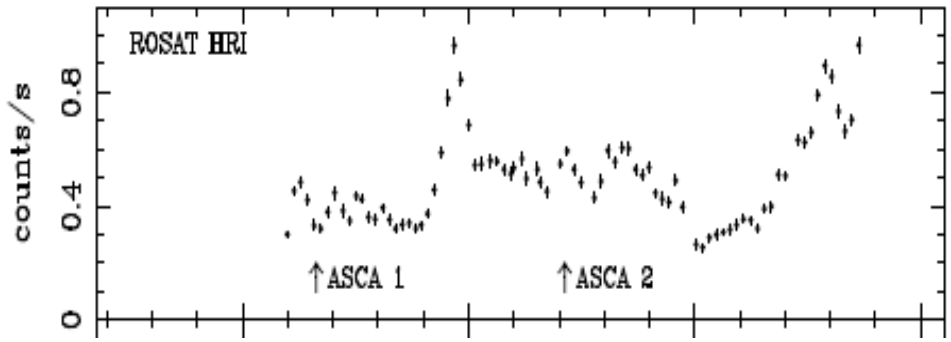
Image

Light curve

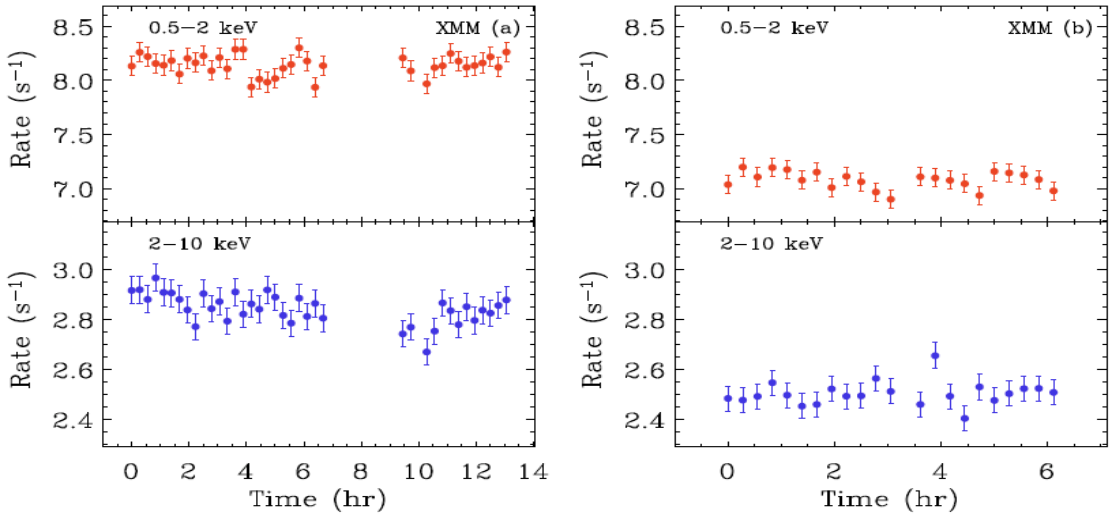
A light curve is the plot of the flux of a source versus time. It shows if and how the flux of the source varies during a certain time.

The variability of a source can manifest on different time scales.

The light curve of a source is the sum of all the events at every time t, independently from the energy of a single event, that fall within a fixed spatial region.



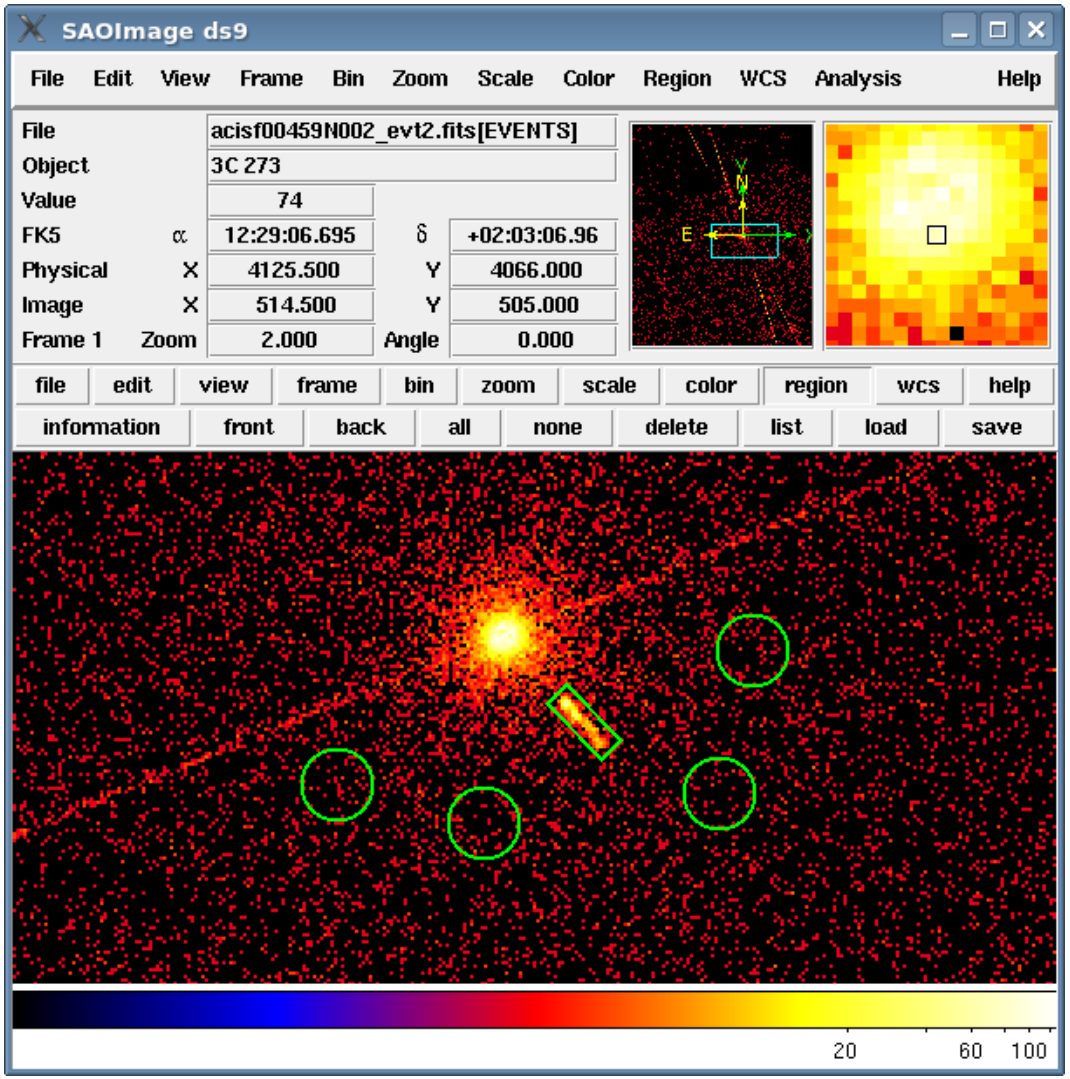
time



How to extract a lightcurve

1) select a source and background region

see later



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]"
```

dmstat → compute statistics for images and columns in tables

http://cxc.harvard.edu/ciao/ahelp/dmstat.html
ahelp dmstat

Notes: punlearn dmstat (or other tools) ➔ to restore default parameter values
plist dmstat (or other tools) ➔ to verify the parameter values for a tool

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

3) extract the lightcurve (background subtracted)

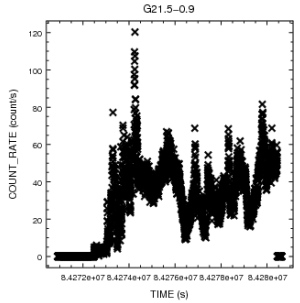
```
>punlearn dmextract
>pset dmextract infile="acisf00953N003_evt2.fits
  [ccd_id=3,sky=region(src2.reg)][bin time= : : 2000]"
>pset dmextract outfile="src_sub_lc.fits"
>pset dmextract bkg="acisf00953N003_evt2.fits
  [ccd_id=3,sky=region(bkg.reg)]"
>pset dmextract opt="ltc1"
>dmextract
```

pset → Set parameter values on the command line

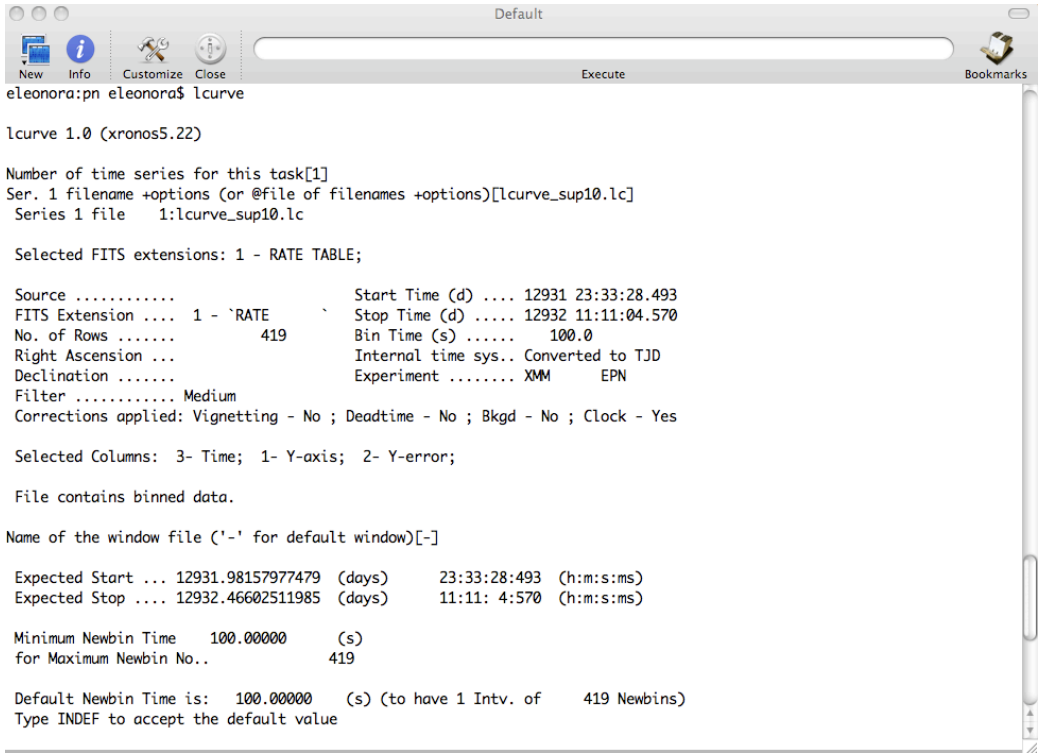
There are several ways to visualize a light curve. Here are two examples:

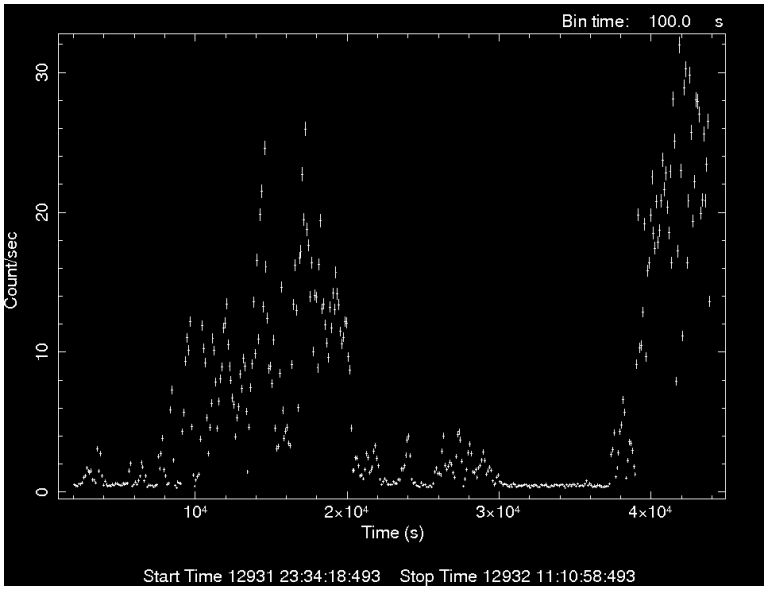
Chips provided by CIAO

```
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***





A light curve can be build in different temporal bins, e.g. if the observation is

1000 s long it is possible to extract light curves of 10 s and 100 s.

The longer is the temporal bin the lower is the resolution but the higher is the S/N.

To establish if a source varied during the observation we can apply the χ^2 **test**: considering the light curve constant we calculate

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

$\mathbf{c_i}$ observed counts in every temporal bin I;

σ_i Poissonian error;

<c> average count during the observation;

ν **=n-1** degrees of freedom;

Compute the null hypothesis probability $P(\chi^2,\nu)$ i.e. P that the source is not varied**;**

this test should be repeated for several temporal bins.

see the Statistics Tutorial

Scientific files
Housekeeping files

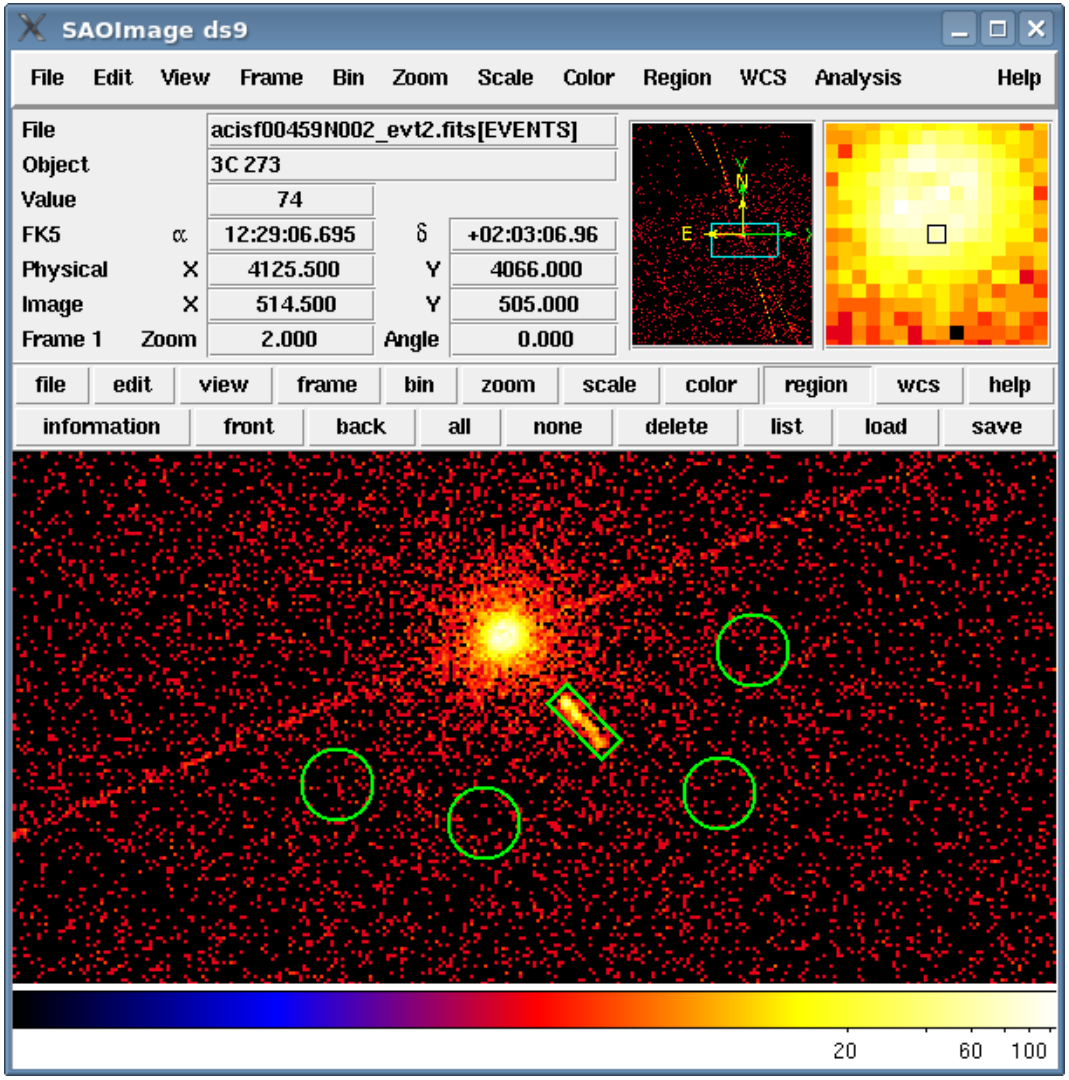
Cleaned
event files

Spectrum

Image

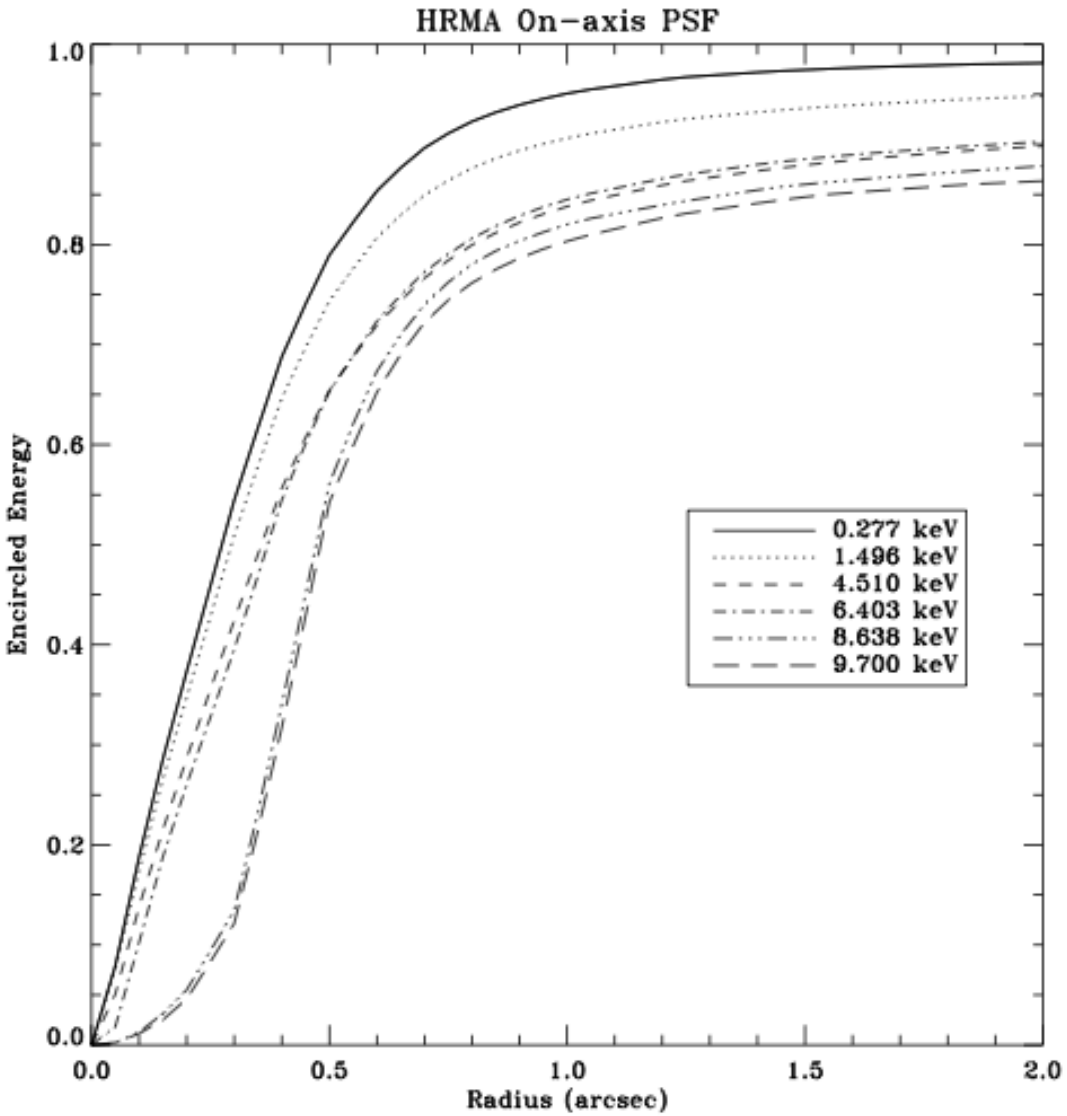
Light curve

Extract source and background regions



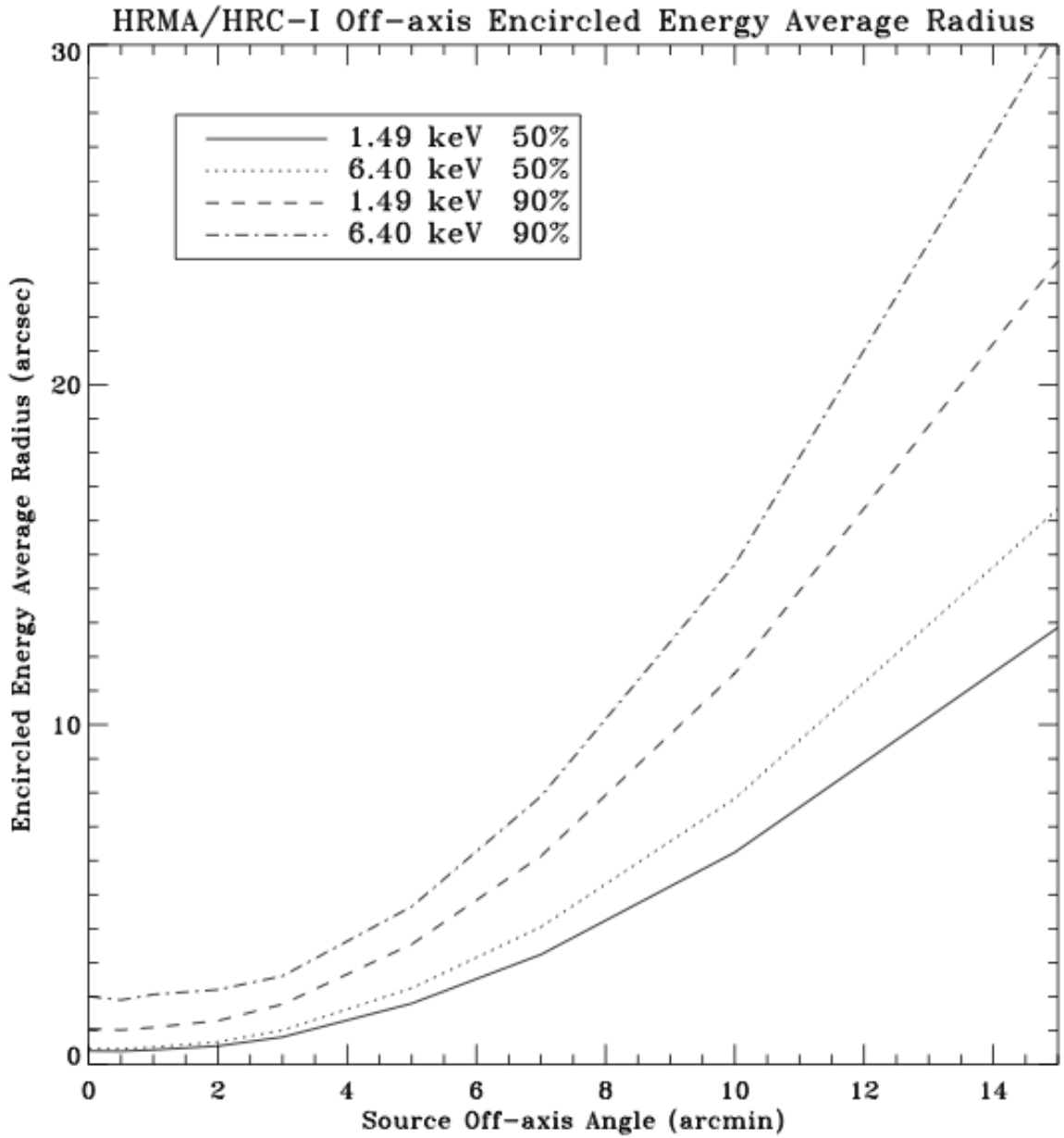

```
ds9 nomefile

Region ->
File Format ->
CIAO          ->
File Coordinate
system -> Physical
```

Fractional encircled energy



About 90% of photons coming from a pointlike source fall within 4 pixel≅2” @ 1.5 keV

Encircled Energy Fraction vs Off-Axis Angle



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

```
-> punlearn specextract
-> pset specextract infile="acisf00547N002_evt2.fits[sky=region
(src.reg)]"
-> pset specextract outroot=spectrum
-> 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 pbkfile=acisf089424366N002_pbk0.fits
-> specextract verbose 2
```

specextract runs the following 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.

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

```
-> punlearn specextract
-> pset specextract infile="acisf00547N002_evt2.fits[sky=region
(src.reg)]"
-> pset specextract outroot=spectrum
-> 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 pbkfile=acisf089424366N002_pbk0.fits
-> specextract verbose 2
```

specextract runs the following 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.

Grouping spectra with *grppha*

To have a given number of counts per bin, i.e., enough counts per bin to apply X^2 statistics

```
punlearn grppha
pset grppha infile=spectrum.pha
pset grppha outfile=spectrum_gr25.pha
pset grppha comm="chkey BACKFILE spectrum_bkg.pha &
chkey ANCRFILE spectrum.arf & chkey RESPFILE
spectrum.rmf & group min 15 & exit"
```

See Statistics/Fitting/xspec Tutorials

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% (every incoming photon results in a single count). In reality, however, no detector is 100% efficient. If, for instance, the detector is 70% efficient, then every 100 photons would result in 70 counts.

When the input spectrum is "multiplied" by the ARF, the result is the distribution of counts that would be seen by a detector with perfect (i.e. infinite) energy resolution.

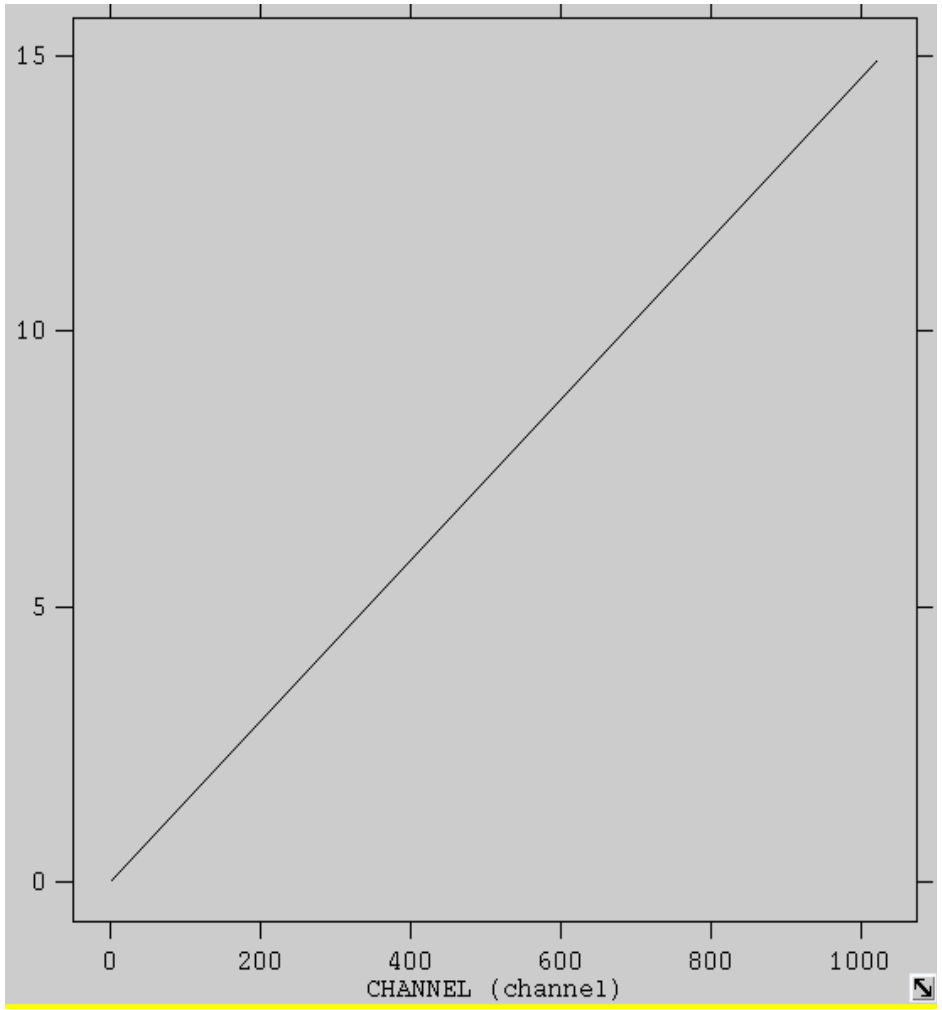
The RMF is then needed to produce the final observed spectrum.

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

RMF

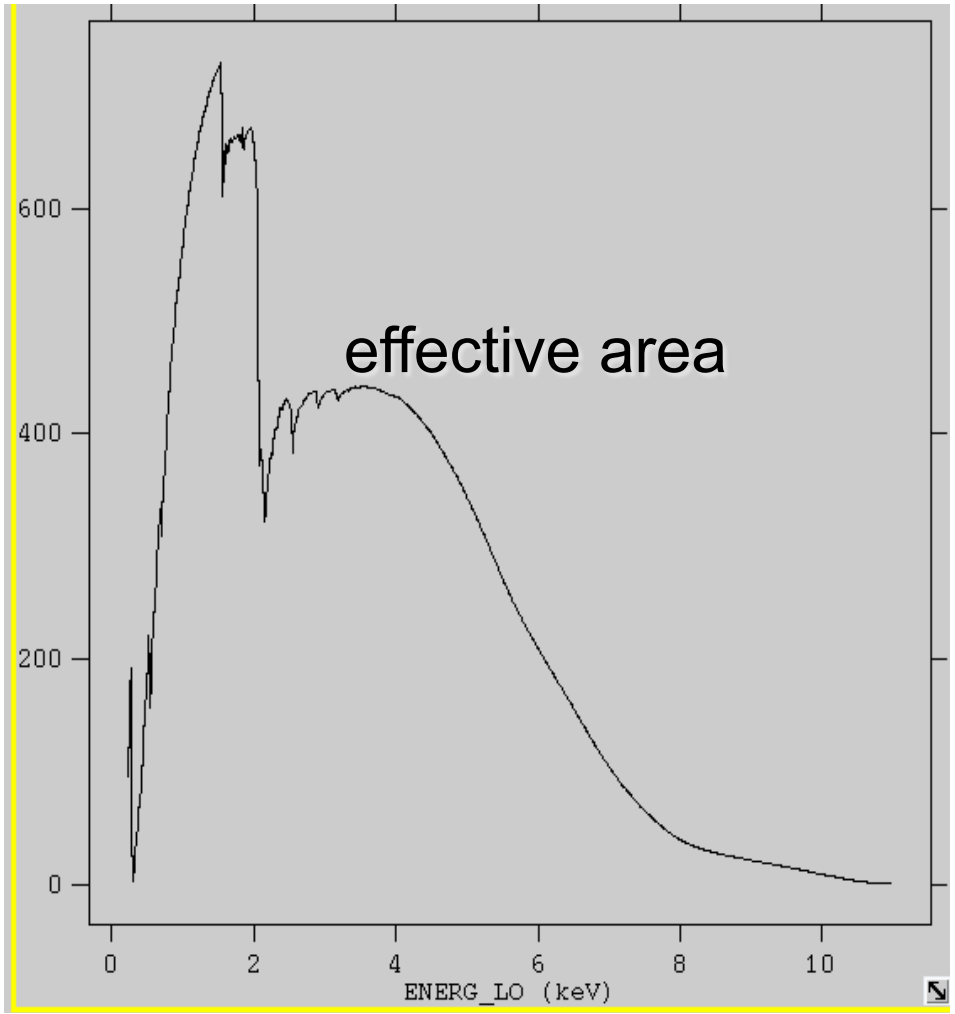


File Edit Tools ARF Hel

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

ARF

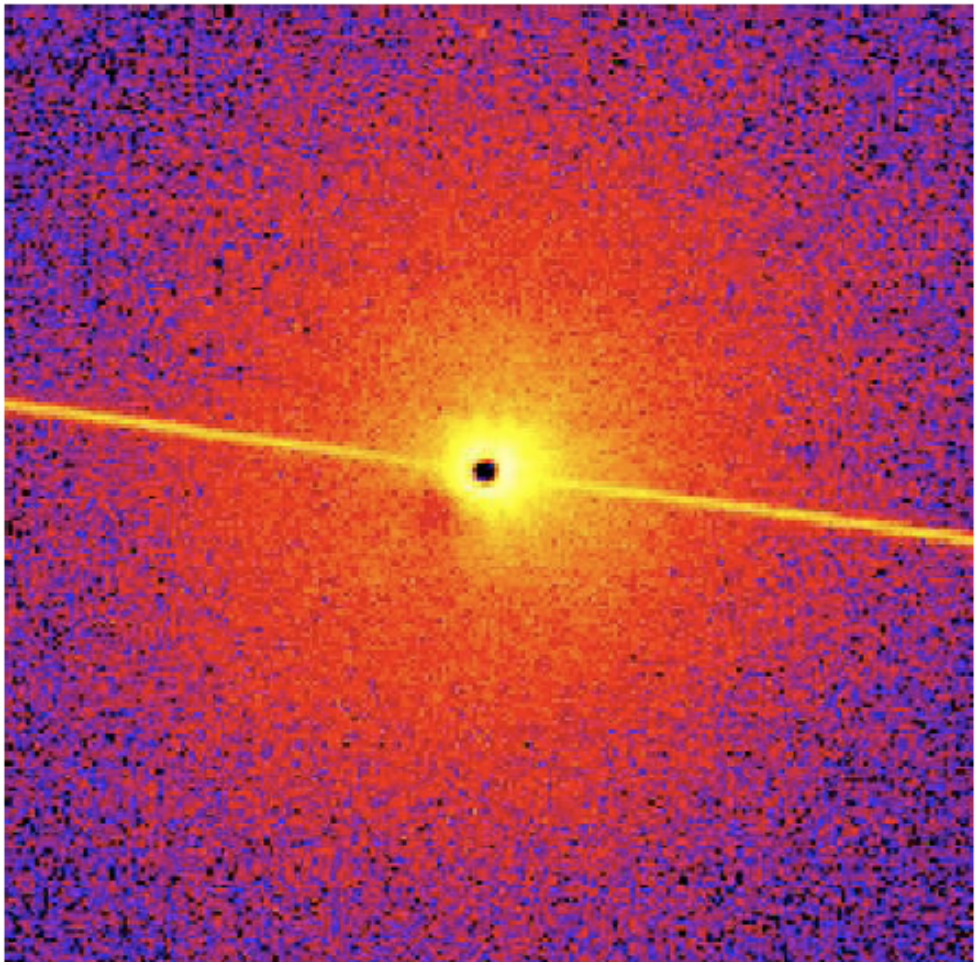


Pileup

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

Two or more photon events overlapping in a single detector frame and being read as a single event

➔ loss of information from these events, and hardening of the X-ray spectrum



Pileup' s two major effects are:

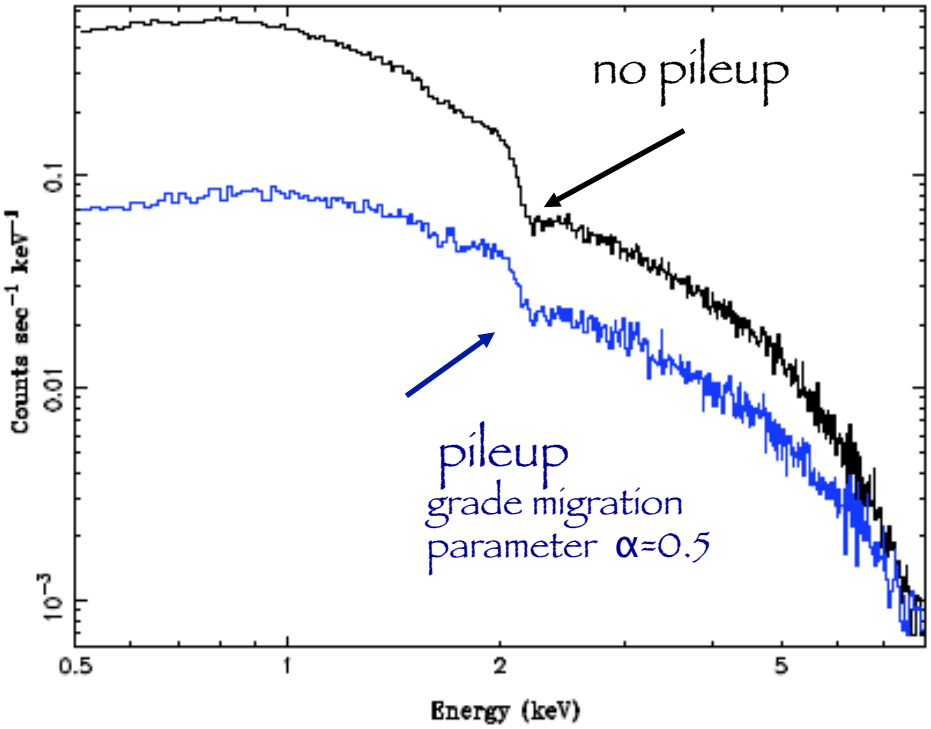
•ENERGY MIGRATION photon energies sum to create a detected event with higher energy;

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

- net decrease of the total observed count rate

- net decrease in the fractional rms (root mean square) variability of the lightcurve

detected spectral shape of the source distorted

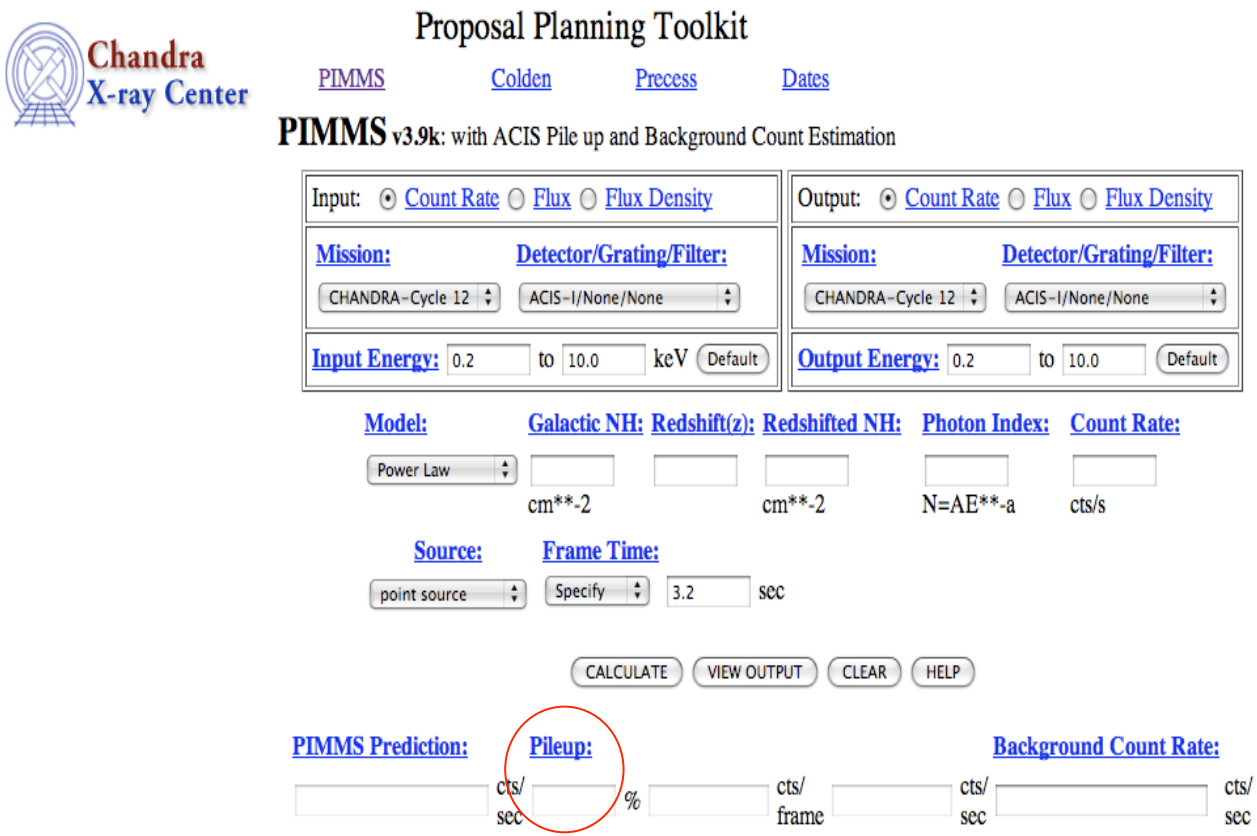


How to avoid pileup ➔ reduce the counts per frame per pixels (…)

How to avoid pileup ➔ by reducing the counts per frame per pixels (…)

Pileup estimation ➔ several ways. One is **PIMMS**

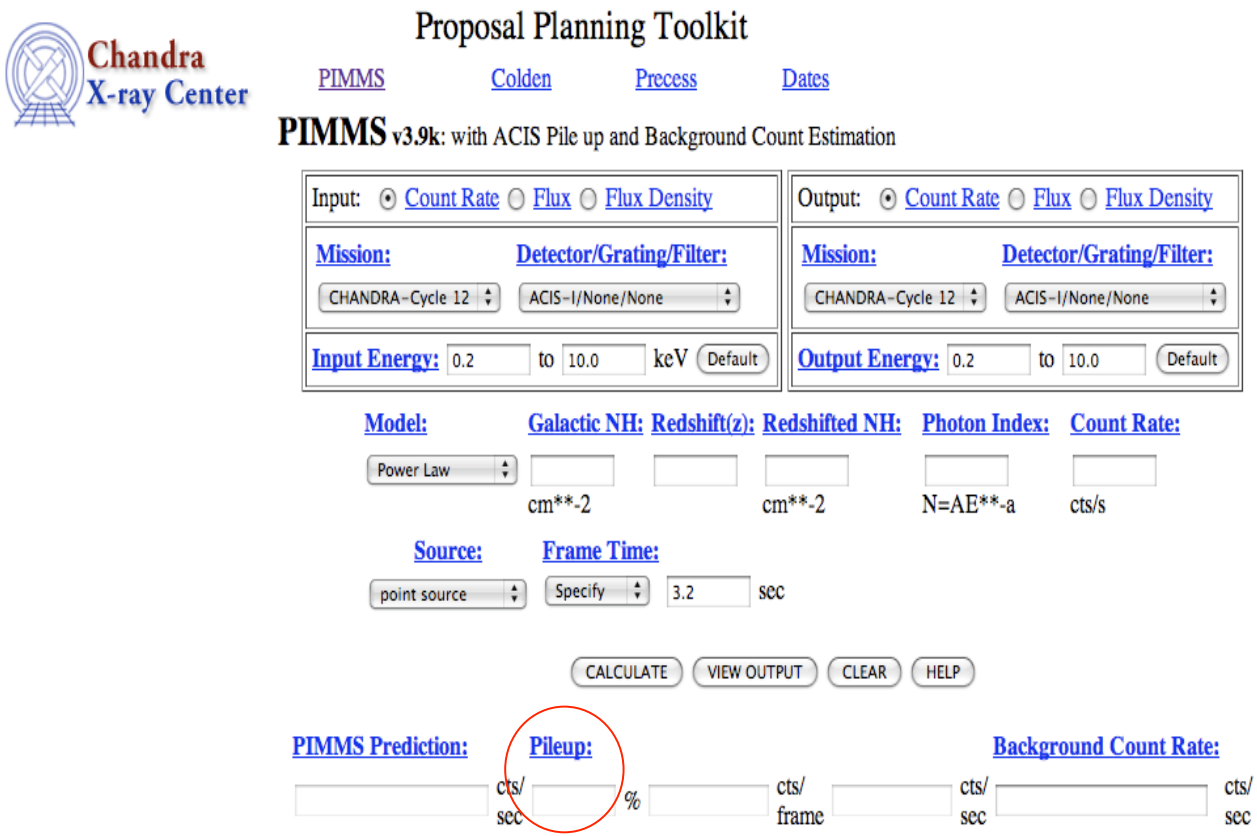
heasarc → tools → webpimms



How to avoid pileup ➔ by reducing the counts per frame per pixels (…)

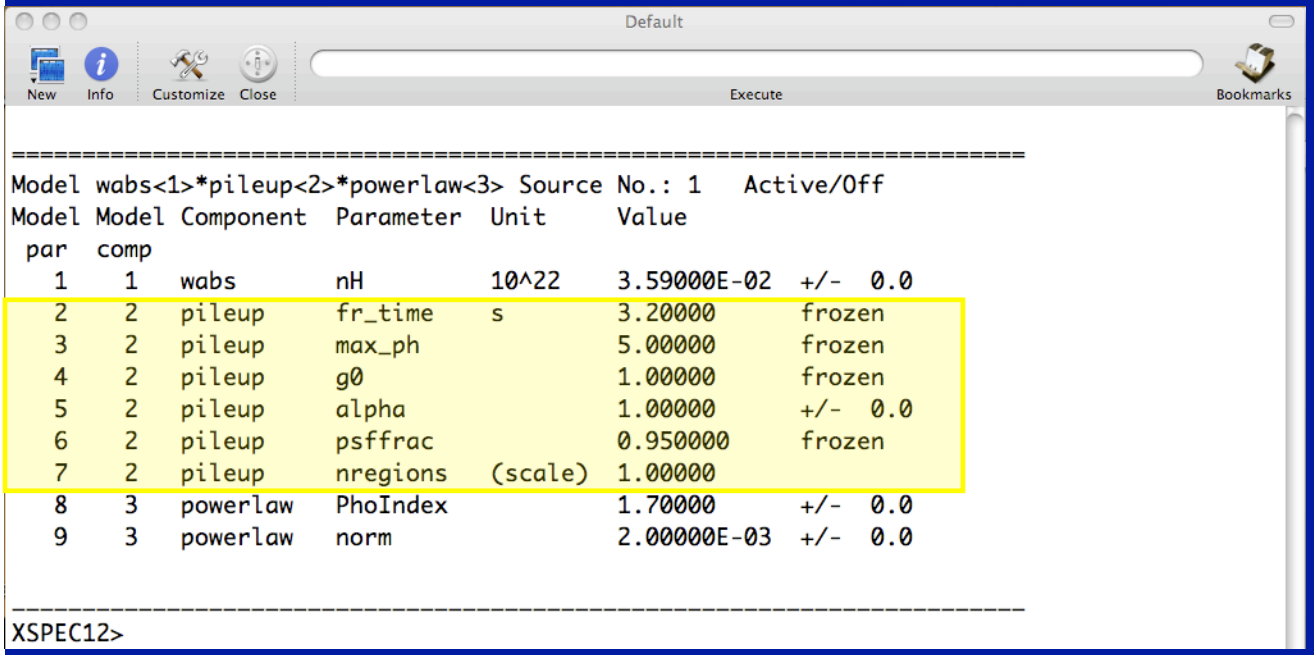
Pileup estimation ➔ several ways. One is **PIMMS**

heasarc → tools → webpimms



Pileup migration ➔ application to spectral data (pileup model in XSPEC)

The pileup model




```
========================================================================
Model wabs<1>*pileup<2>*powerlaw<3> Source No.: 1   Active/Off
Model Model Component  Parameter  Unit     Value
 par  comp
   1    1   wabs       nH         10^22    3.59000E-02  +/-  0.0
   2    2   pileup     fr_time    s        3.20000      frozen
   3    2   pileup     max_ph              5.00000      frozen
   4    2   pileup     g0                  1.00000      frozen
   5    2   pileup     alpha               1.00000      +/-  0.0
   6    2   pileup     psffrac             0.950000     frozen
   7    2   pileup     nregions   (scale)  1.00000
   8    3   powerlaw   PhoIndex            1.70000      +/-  0.0
   9    3   powerlaw   norm                2.00000E-03  +/-  0.0

------------------------------------------------------------------------
XSPEC12>
```

fr_time -> parameter equal to the good exposure time per frame
divided by the fractional exposure . Default value 3.2 s.

max_ph -> this is the maximum number of photons considered for pileup in a single frame.

g0 -> grade correction for single photon detection. I.e., a fraction g0 of single photon events will be retained as good grades. Default value g0=1.

alpha -> the grade migration parameter, such that the probability of n events piled together in a single frame being retained as a 'good grade' is alpha^{n-1}. This parameter can range from 0 to 1.

psffrac -> the fraction of the spectrum that is within the central piled portion of the PSF is 95%. This value is appropriate for an extraction radius of 2" (≈4 pixels).

nregions -> divide the model counts among nregions regions, to which the pileup model will be applied independently. For point sources =1. It should remain frozen.

Scientific files
Housekeeping files

Cleaned
event files

Spectrum

Image

Light curve

Scientific analysis

see XMM
Tutorial…

✓ Downloading of X-ray data from a public archive

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NED Database

NED results for object NGC 6251

1 objects found in NED. Skyplot(first 100)

SOURCE LIST

Row No.	Object Name (* => Essential Note)	EquJ2000.0 RA	DEC	Object Type	Velocity/Redshift km/s	z	Qual	Mag./ Filter	Separ. arcmin	Number of Refs	Notes	Phot	Posn	Vel/z	Diam	Assoc	Images	Spectra
1	NGC 6251	16h32m32.0s	+82d32m16s	G	7408	0.024710		13.64	...	306	8	45	5	7	6	0	Retrieve	Retriev

Detailed information for each object

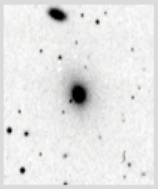
Object No. 1 - NGC 6251

INDEX for NGC 6251

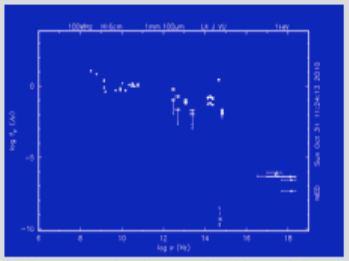
Essential Data (jump to sub-section of this query report):

- Essential Note
- Cross-IDs
- Coordinates
- Basic Data
- Quantities Derived from Redshift
- Redshift-Independent Distances NEW
- Classifications NEW
- Foreground Galactic Extinction
- External Services

Detailed Data (NED queries):

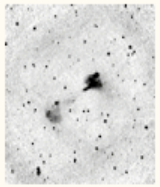
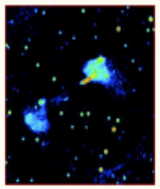
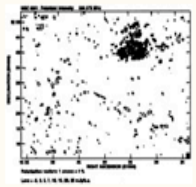
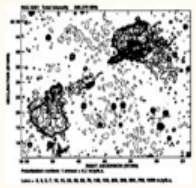
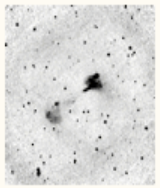
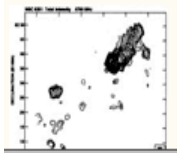


Images



45 Photometric data point(s) and SED

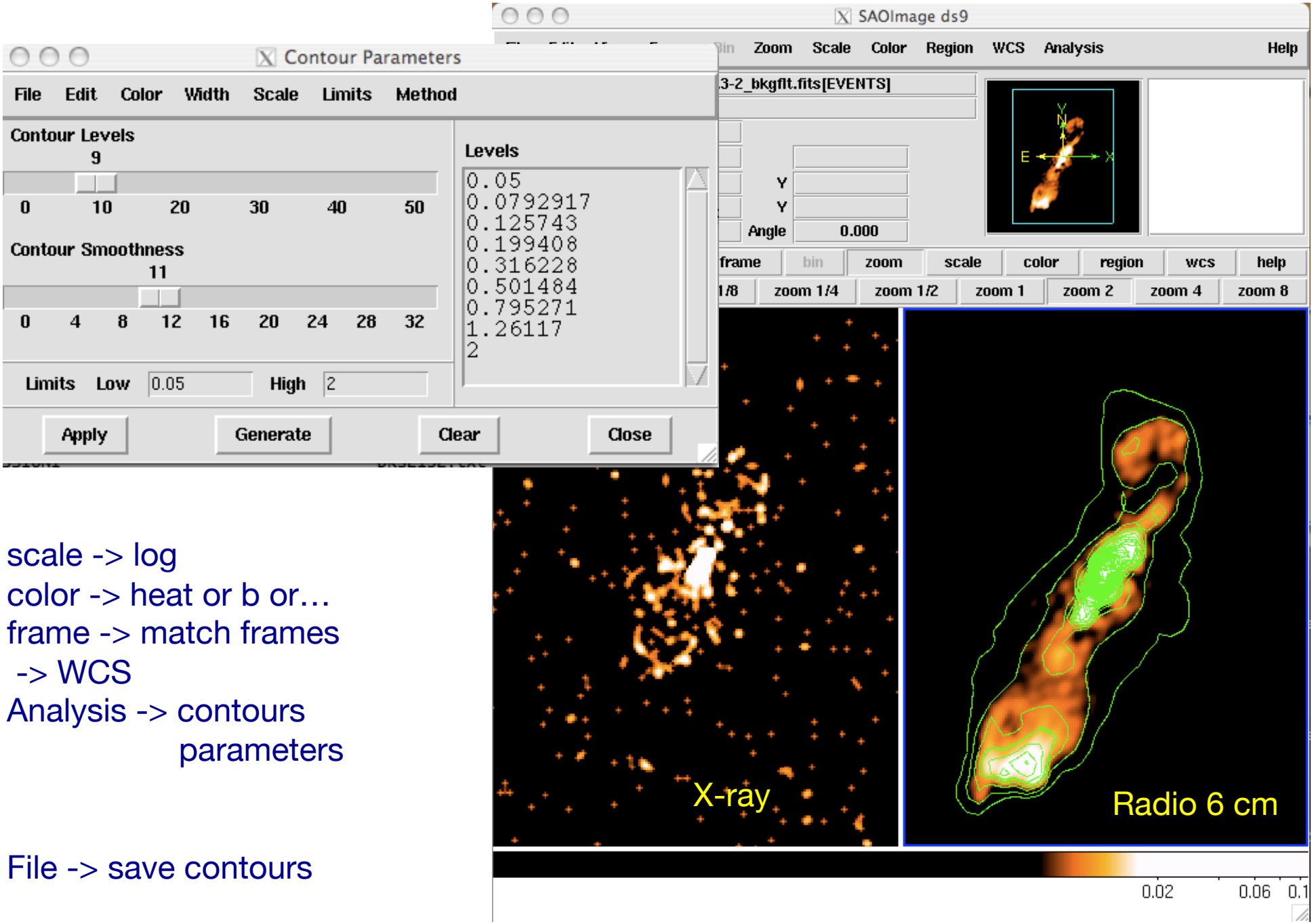
- Spectra
- Redshift-Independent Distances
- 306 Reference(s)
- 5 Position data point(s)
- 7 Redshift data point(s)
- 6 diameter data point(s)
- 8 Note(s)
- UGC data
- RC3 data

	1062KB FITS image Retrieve	Display FITS Header		0.3GHz , 100cm	85.0 x 85.0	55.00	WSRT	1997A&AS..123..423M
	15KB JPG image Retrieve	N/A	N/A	327MHz , 92cm	85.0 x 85.0	55.00	WSRT	2003DRAGN.C.....:
	104KB JPG image Retrieve	Display Caption	N/A	326MHz , 92cm	N/A	55.00	WSRT	1997A&AS..123..423M
	202KB JPG image Retrieve	Display Caption	N/A	326MHz , 92cm	N/A	55.00	WSRT	1997A&AS..123..423M
	3162KB FITS image Retrieve	Display FITS Header		326MHz , 92cm	128.0 x 128.0	55.00	WSRT	1997A&AS..123..423M
	99KB JPG image Retrieve	Display Caption	N/A	4.8GHz , 6.3cm	N/A	150.00	Effelsberg	1997A&AS..123..423M

Other useful links

- http://www.jb.man.ac.uk/atlas/icon.html
- http://2jy.extragalactic.info/2Jy_home_page.html
- http://www.jb.man.ac.uk/atlas/dragns.html

ds9 X-ray image radio image



scale -> log
color -> heat or b or…
frame -> match frames
-> WCS
Analysis -> contours
parameters

File -> save contours

✓ Downloading of X-ray data from a public archive

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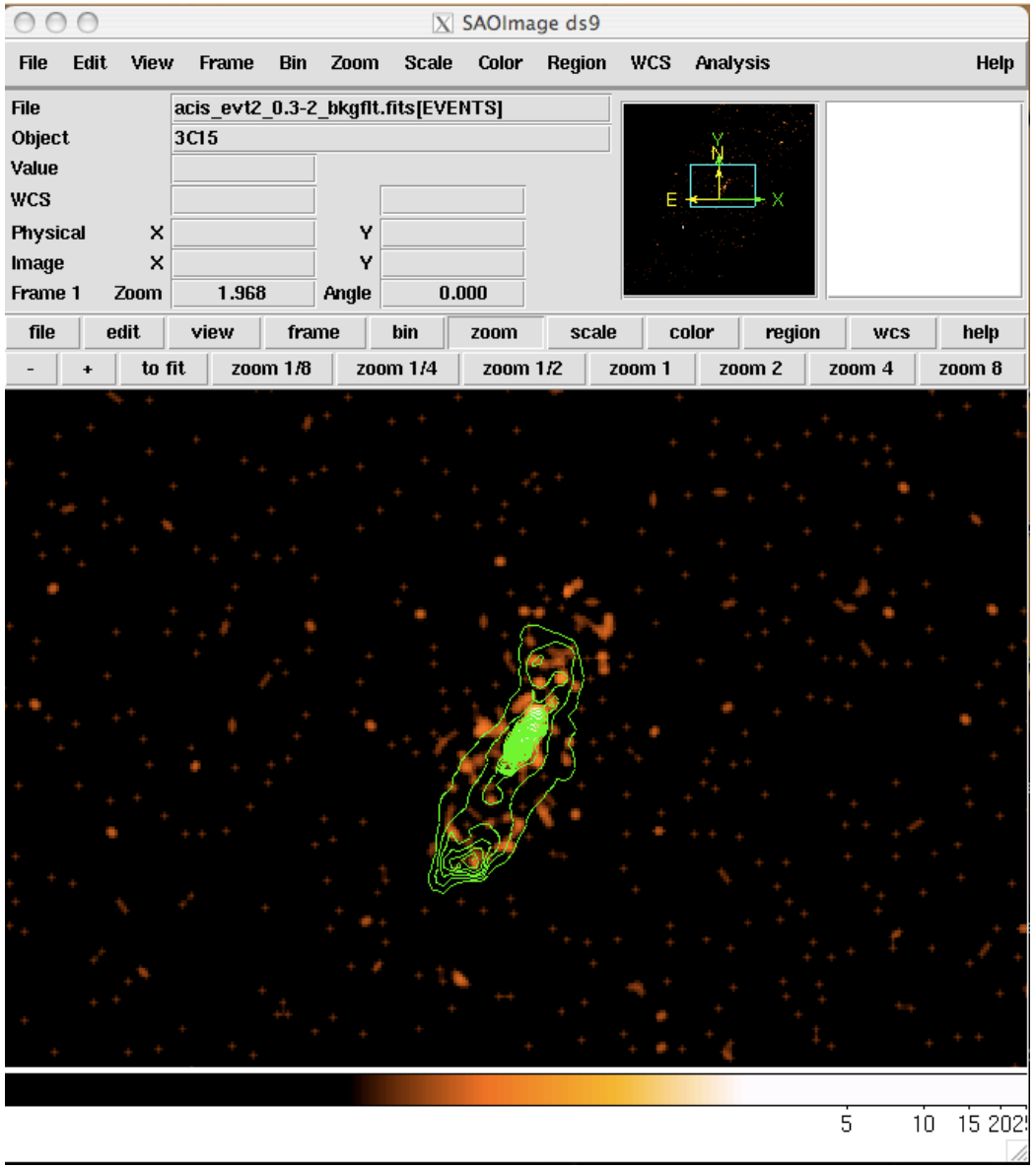
✓ How to create a radio/X-ray contour superposition image

Analysis ->
Contours parameters ->
File ->
Load contours



From the terminal (command-line):
ds9 IMAGE –scale log –contour load FILE_CONTOURS &

Not only radio/X...

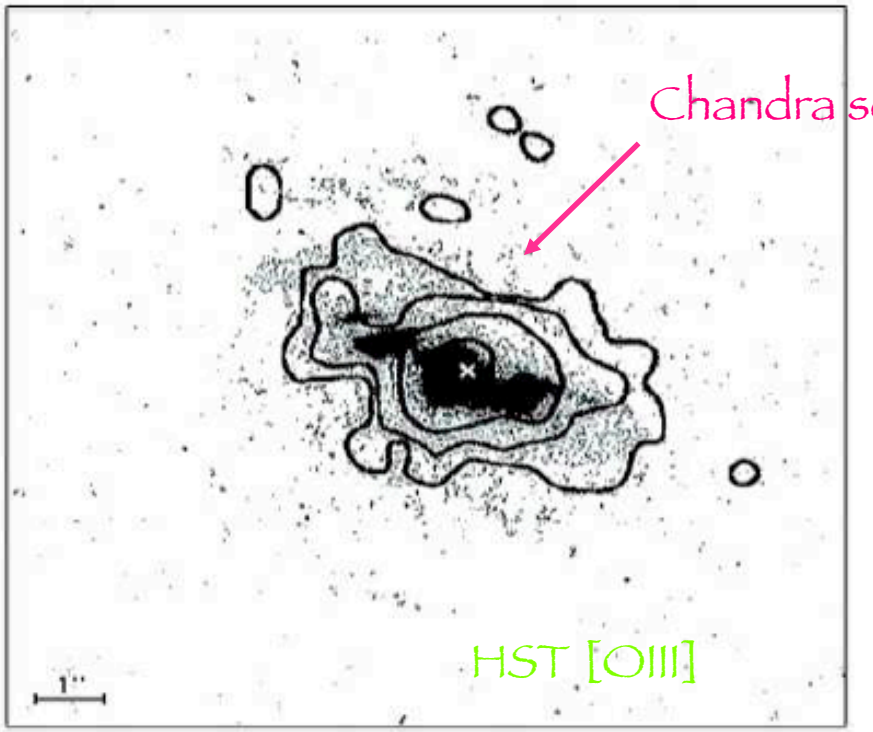
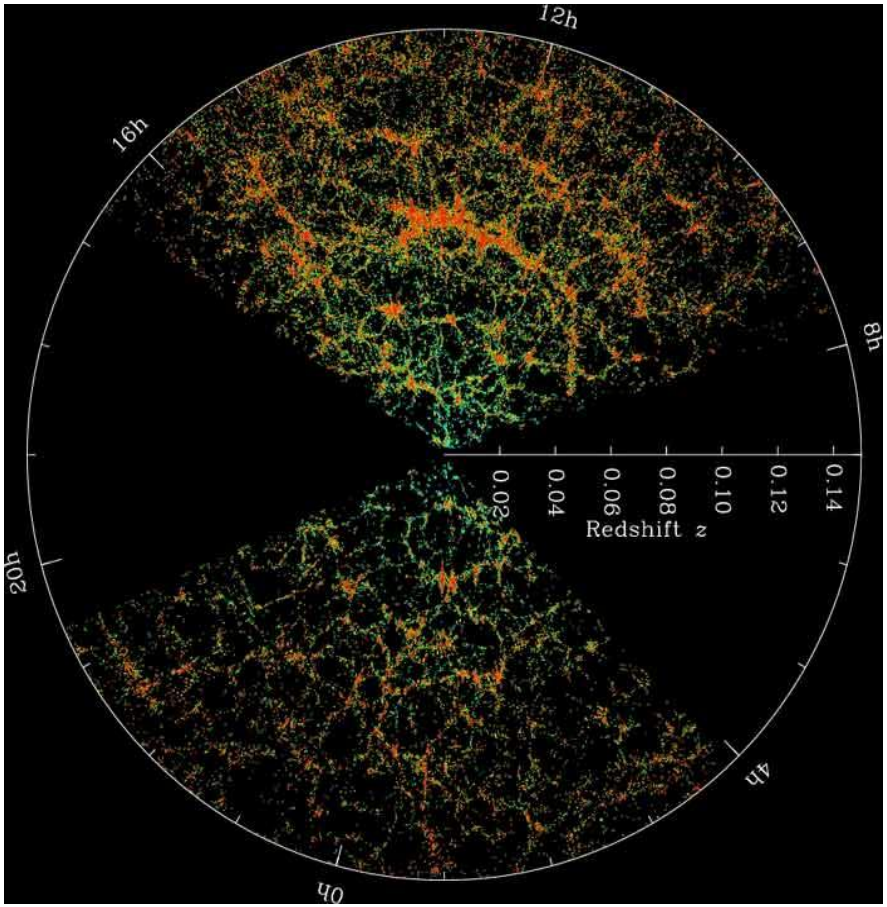


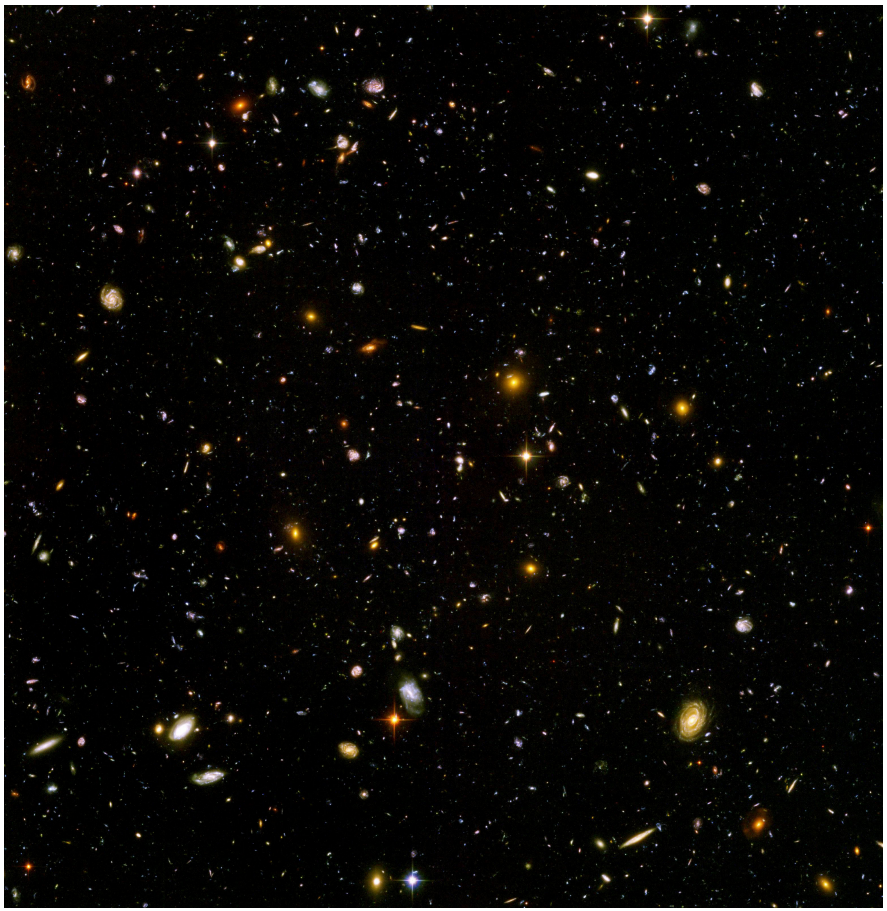
Fig. 4. Superposition of the *Chandra* soft X-ray (<2 keV) contours on an *HST* image taken through a linear ramp filter at redshifted [OIII]λ5007. The sign "x" indicates the centre of the hard X-ray source, north is up, east to the left. The X–ray image was smoothed with a Gaussian of FWHM ~ 6 pixels.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

Surveys

Sloan Digital Sku Survey
8,400 square degrees
>1 Milion object up to z=0.15



Hubble Ultra Deep Field
11 square arcmin
10000 galaxies up to z=10

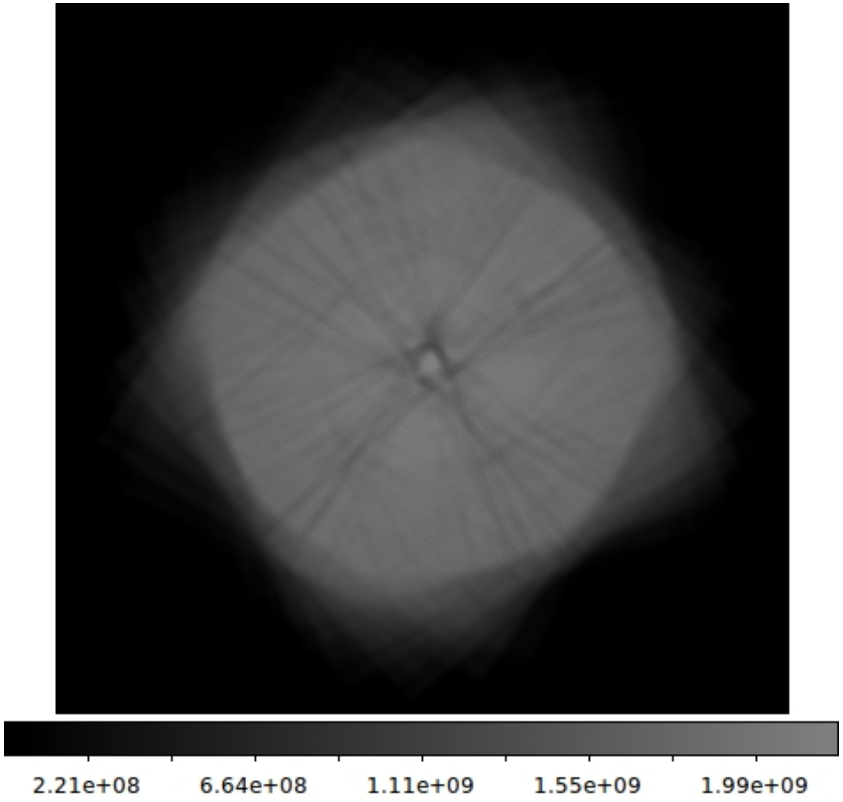


X-ray Surveys

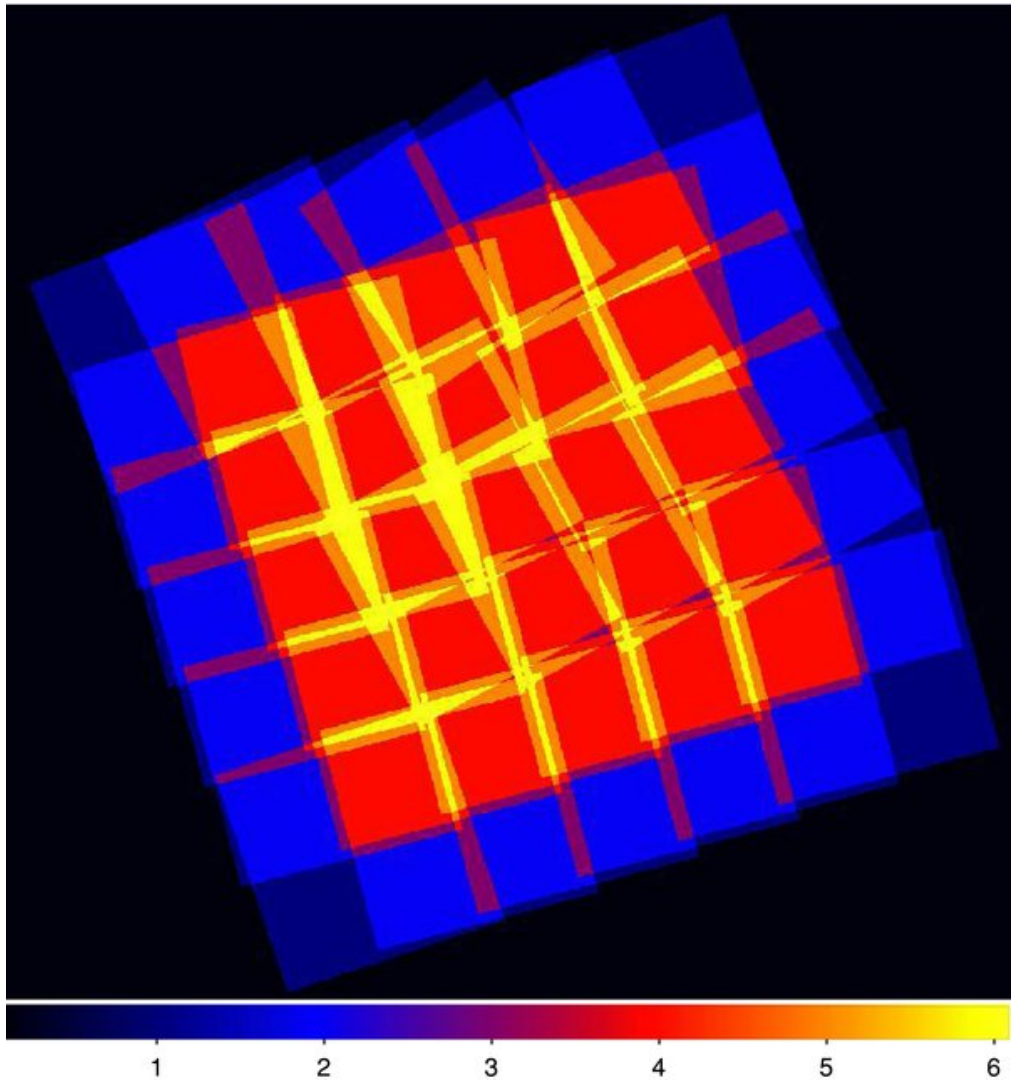
Chandra Deep Field South
0.11 square degree

52 observations
taken in 2000, 2007, 2010

Tot 4 Msec



Chandra COSMOS ~1 square degree
36 pointings

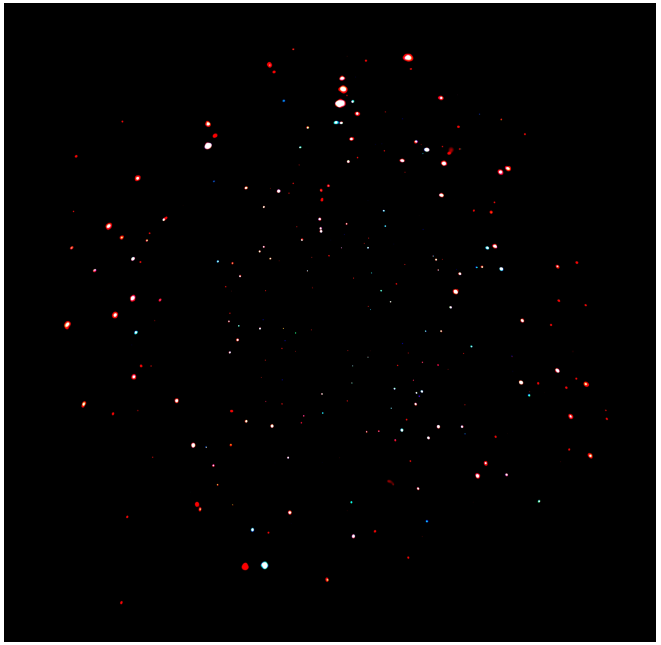


X-ray Surveys

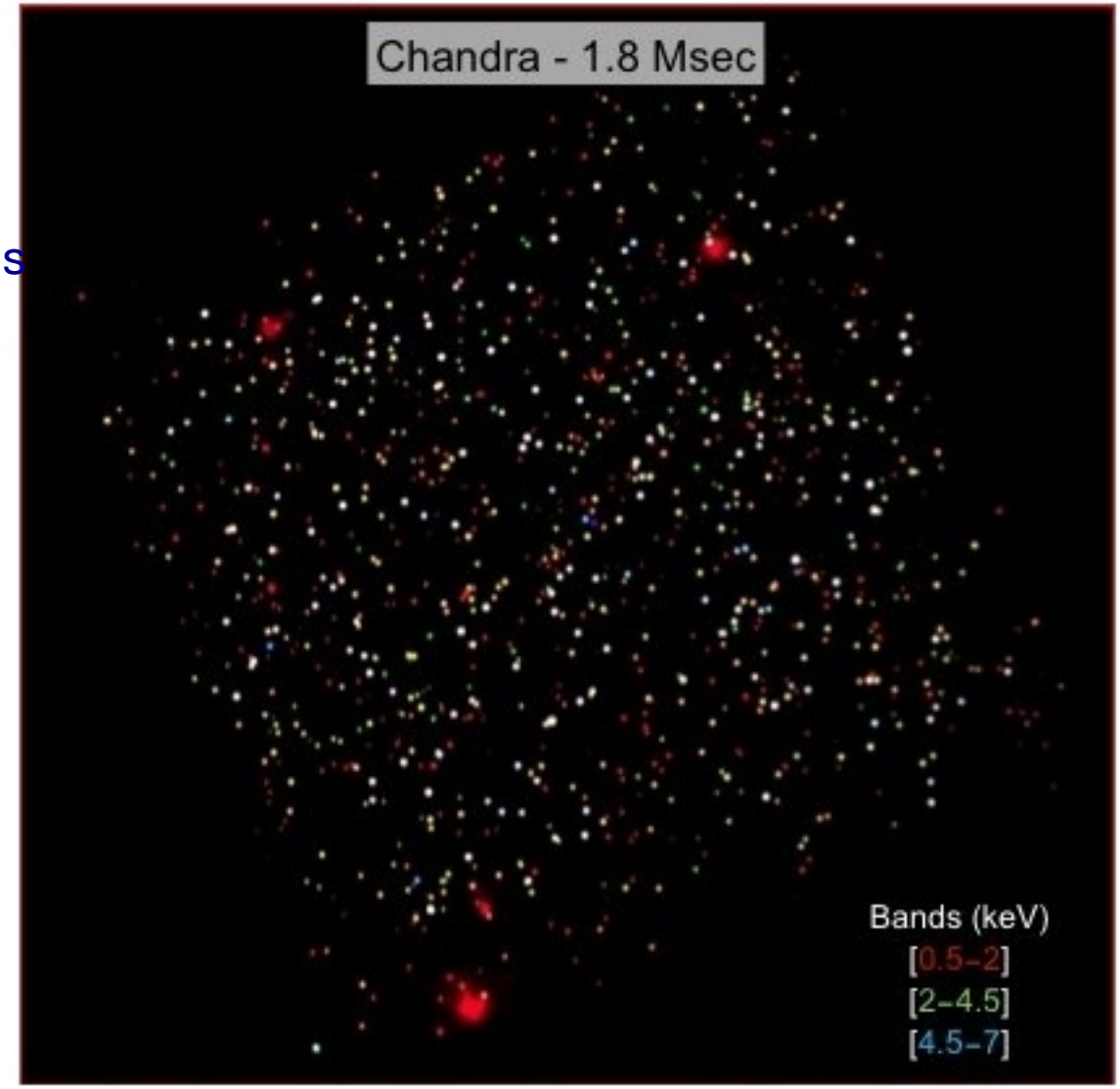
Chandra Deep Field South
0.11 square degree

53 observations
taken in 2000, 2007, 2010

Tot 4 Ms (to be extended to 7Ms in 2014)



Chandra COSMOS ~1 square degree
36 pointings (to be extended to 2 deg^2)




THE END