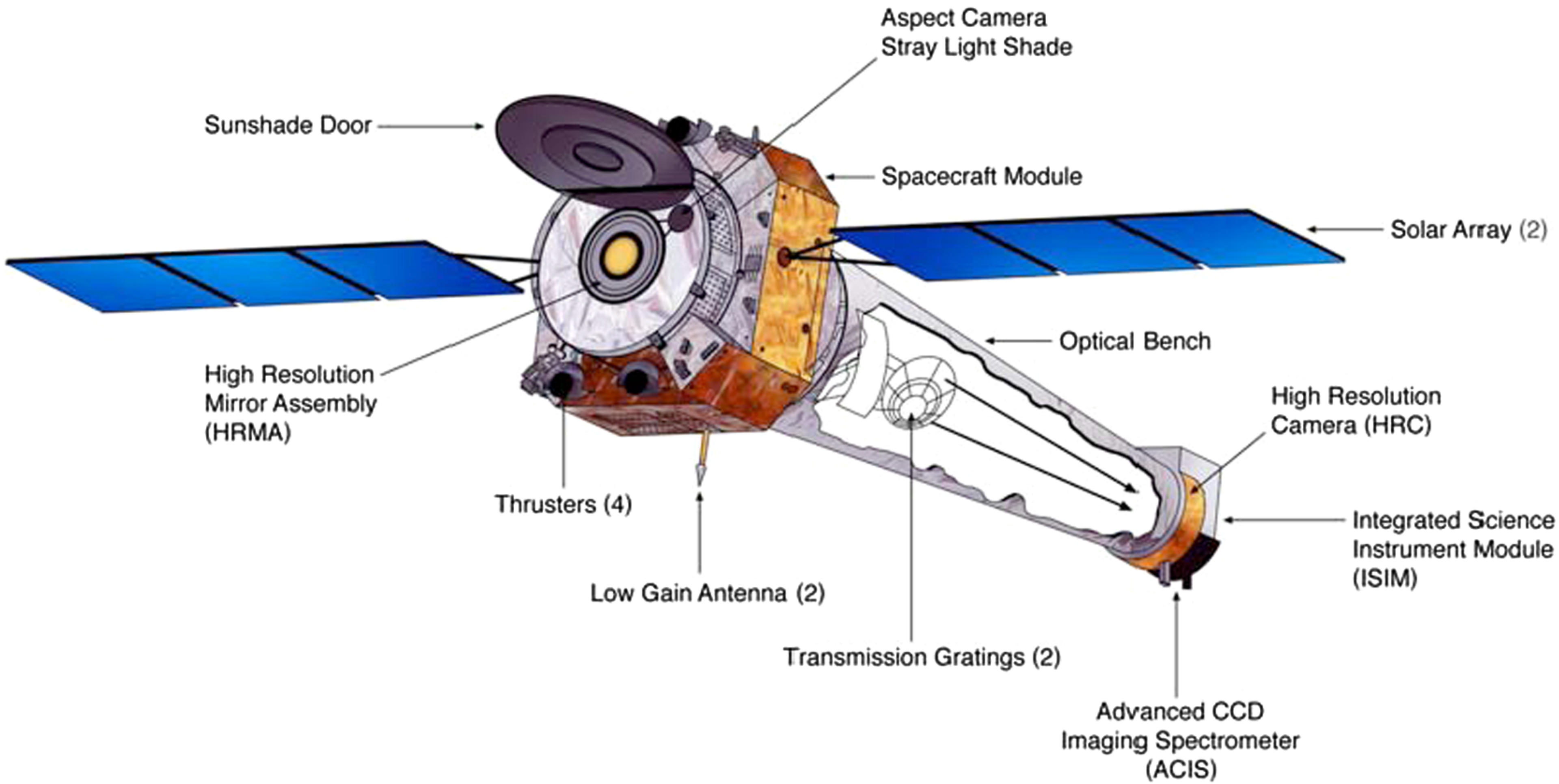
Chandra Tutorial

Laboratorio di Astrofisica 2014

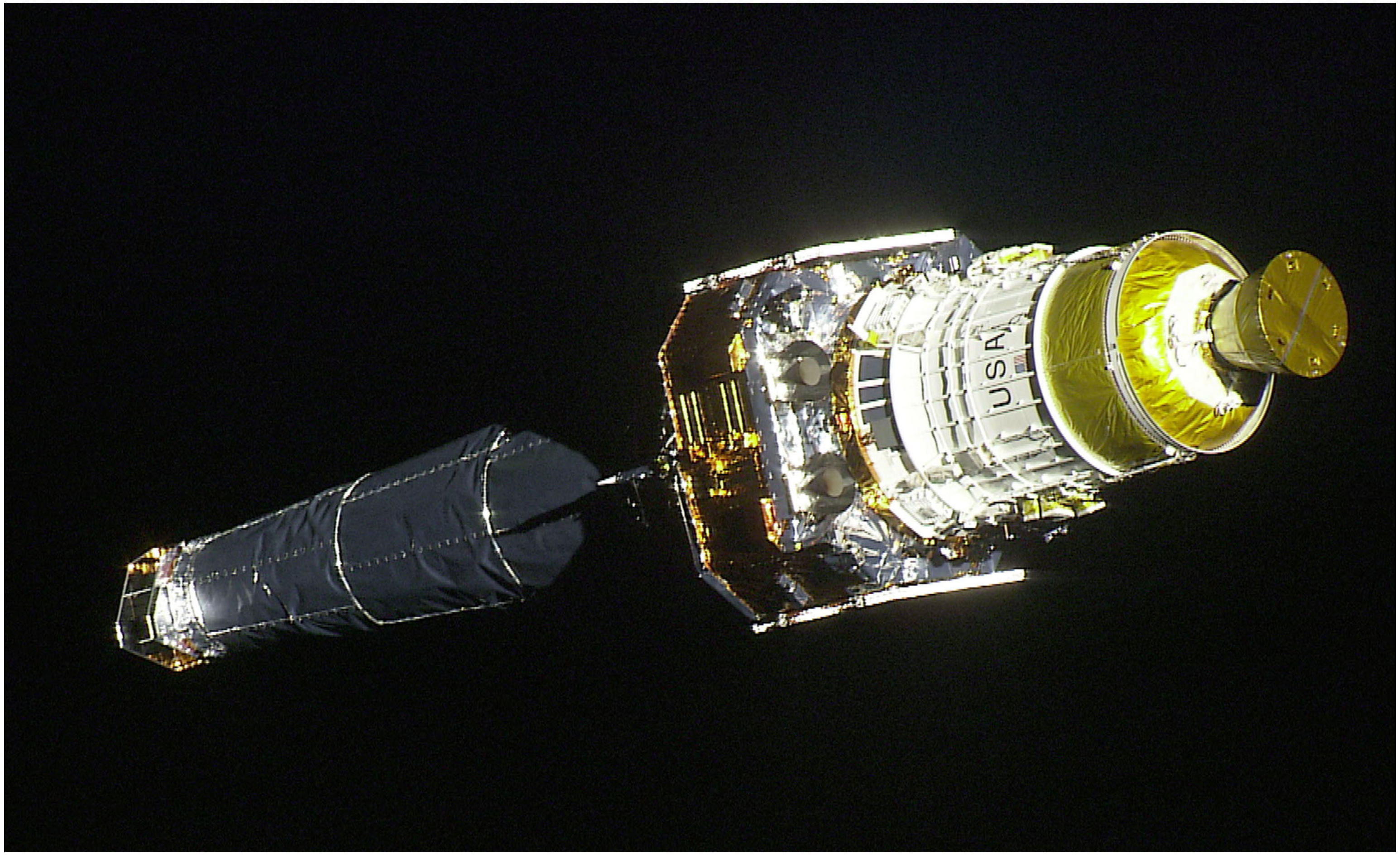
The spacecraft



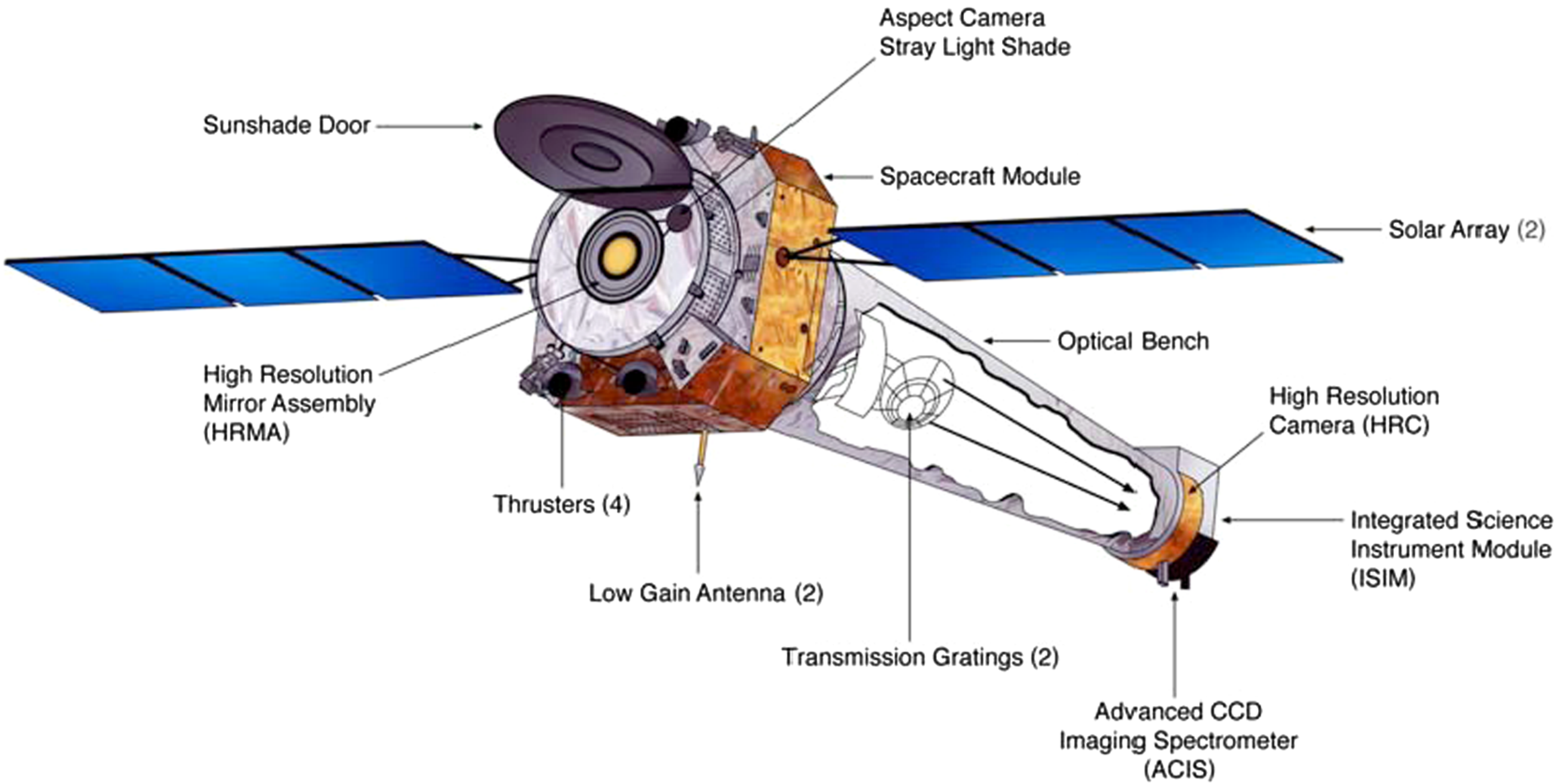
The real spacecraft

Launched:
July 23, 1999

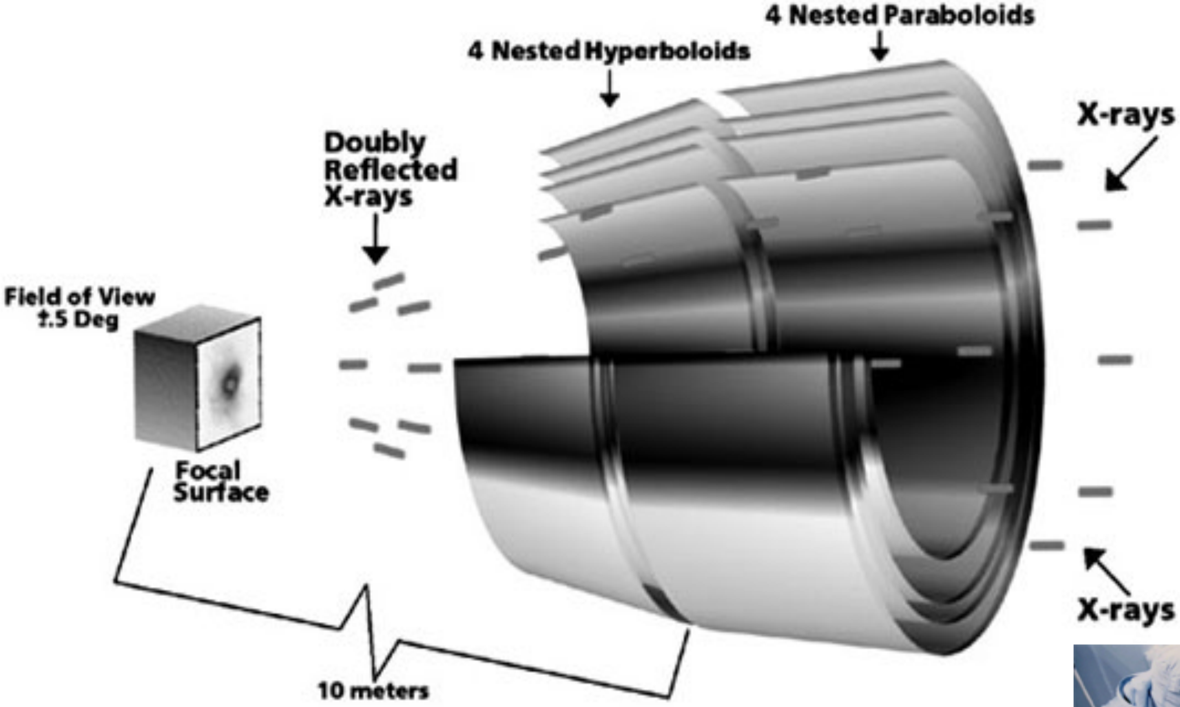
The real spacecraft



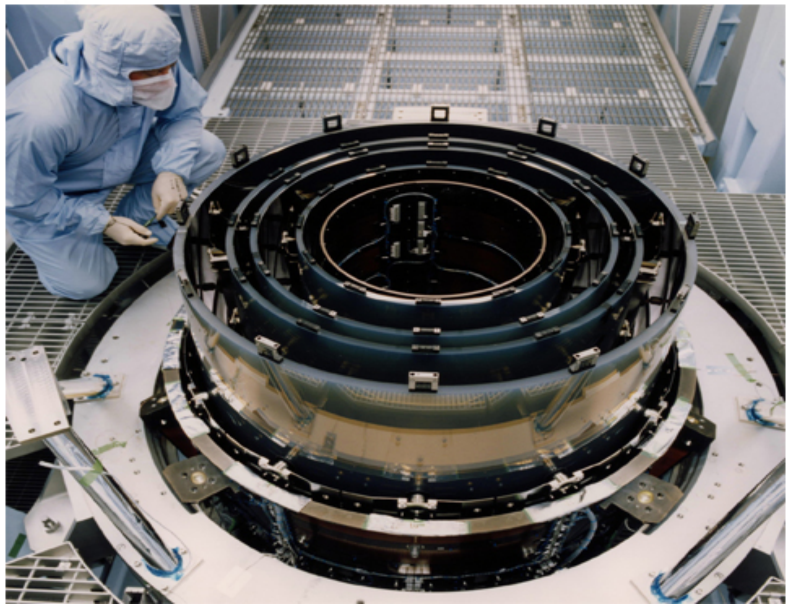
The spacecraft



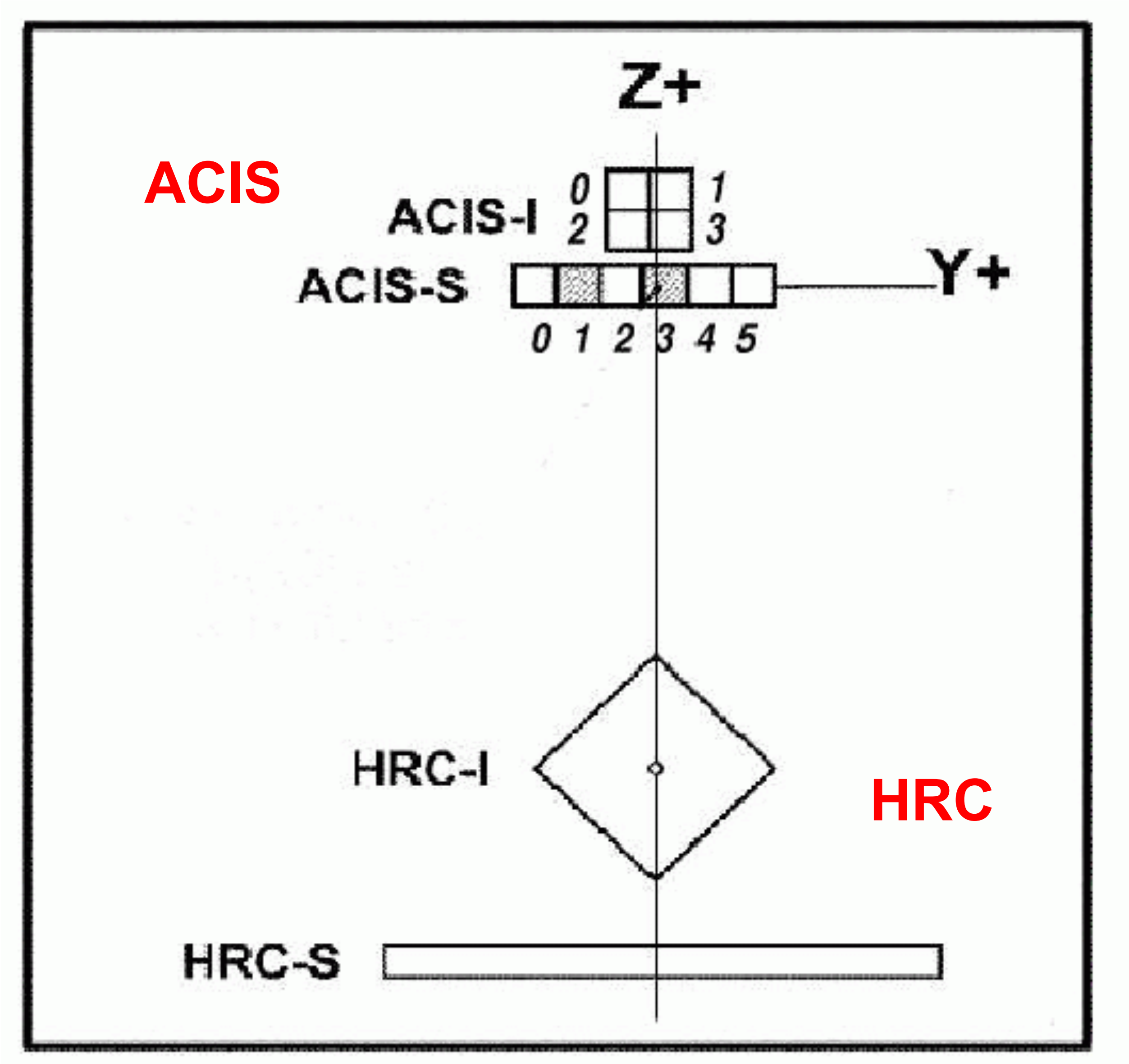
Mirrors



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

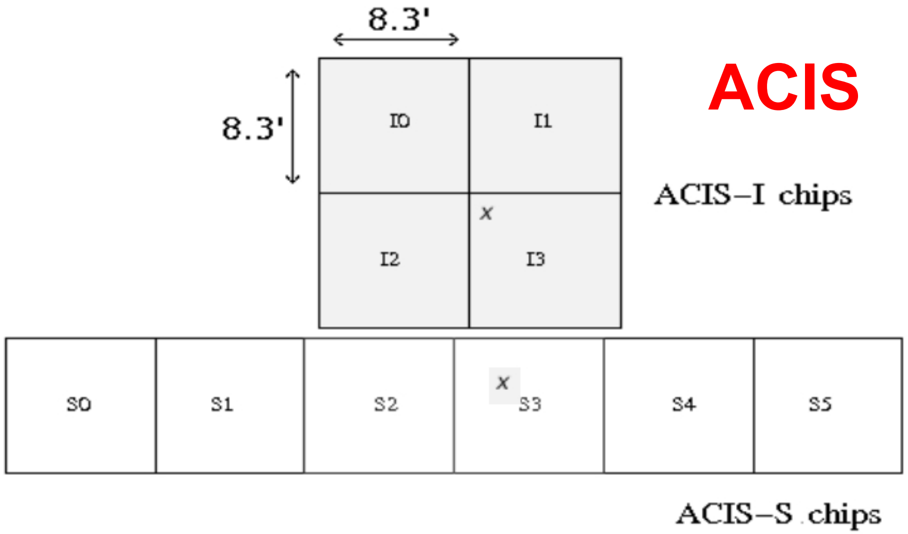


The detectors:

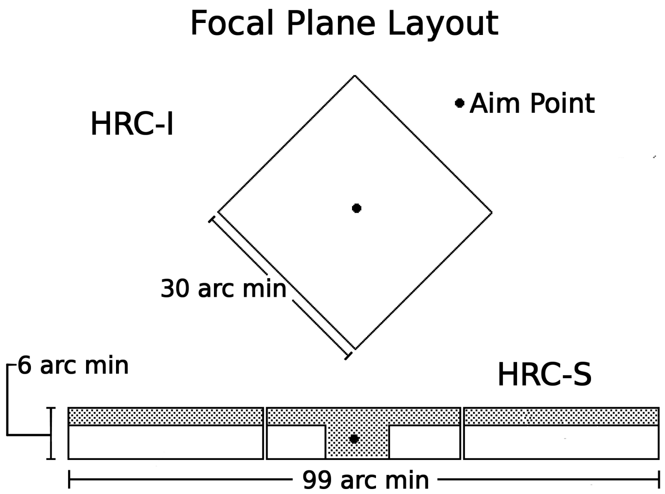


The detectors:

ACIS

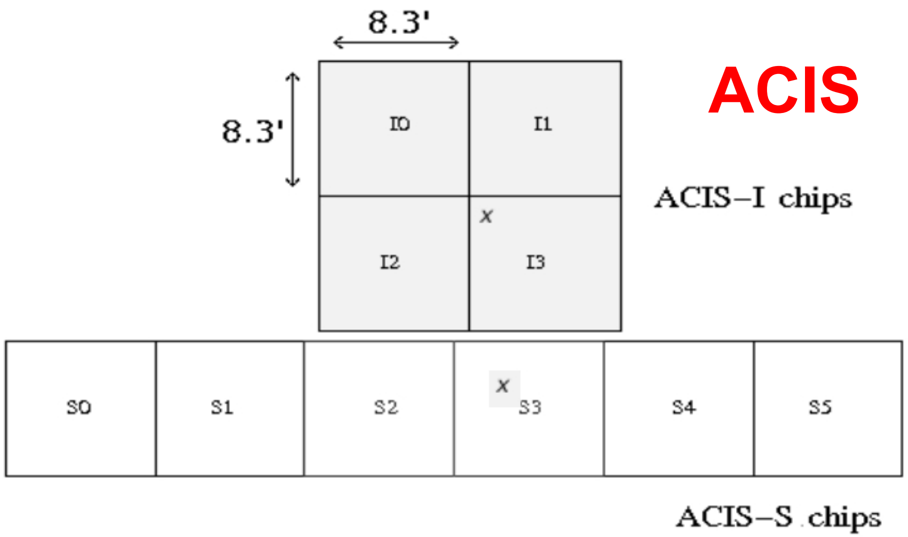


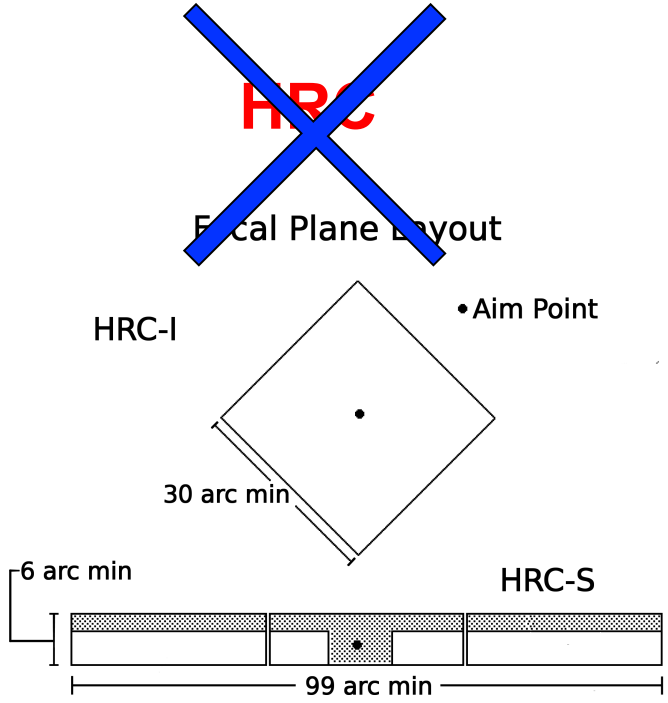
HRC



+HETG and LETG dispersive spec.

The detectors:

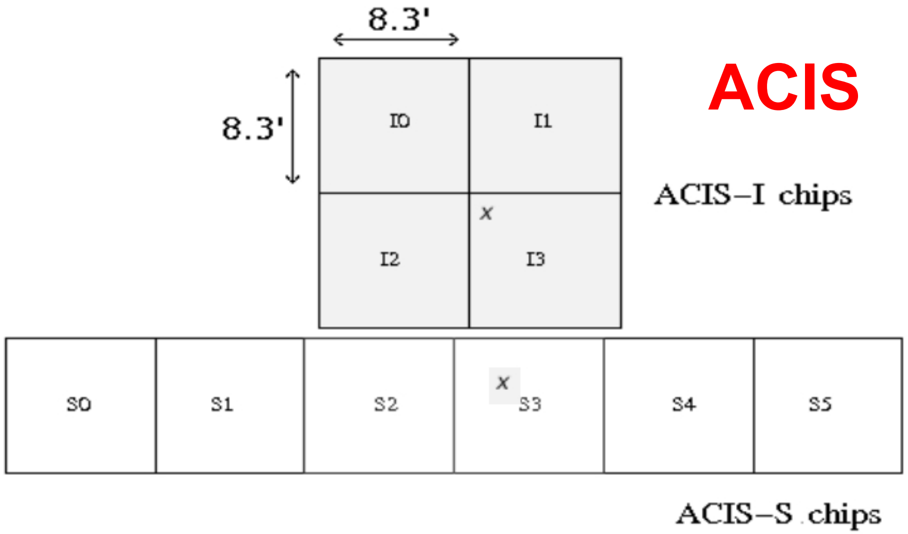


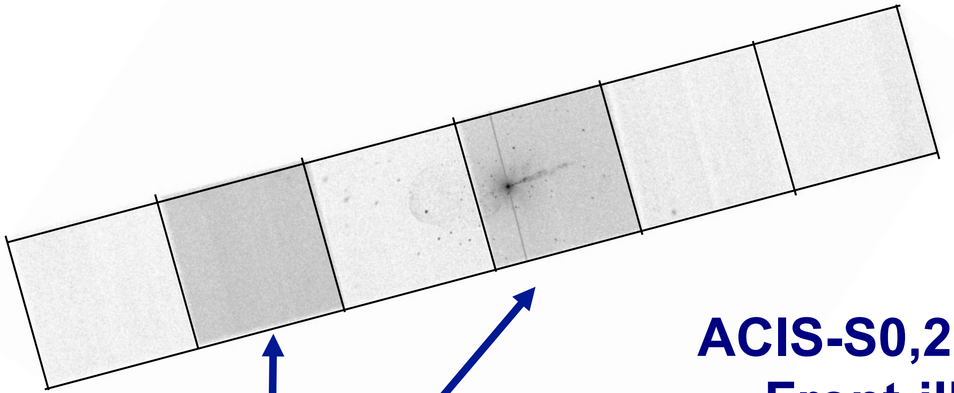


+HETG and LETG dispersive spec.

The detectors:

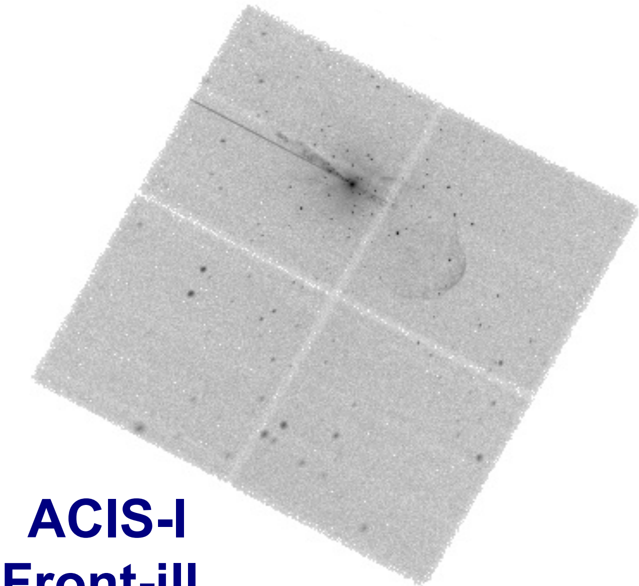
ACIS





ACIS-S0,2,4,5
Front-ill.

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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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 → SAS

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3. How to get data: Chandra → CIAO; XMM → SAS

proposals of observations

↓

proprietary data for one year

↓

archival data available to the community

→ How to download X-ray data from a public archive

→ How the downloaded files look like

→ How to reduce X-ray (*Chandra*) data

→ How to create the 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

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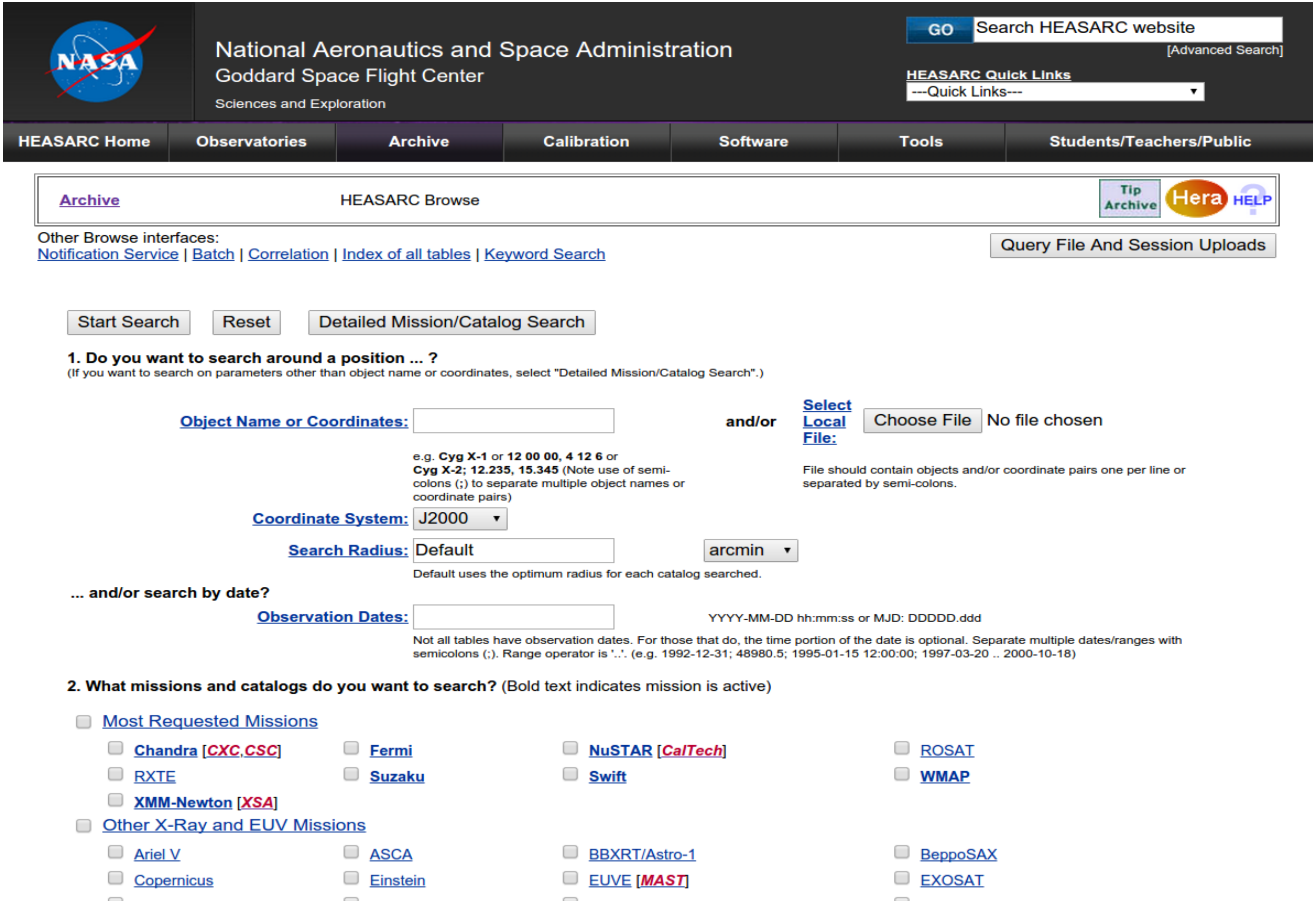
http://heasarc.nasa.gov/ → Archive → Browse


GO Search HEASARC website
[Advanced Search]
HEASARC Quick Links
---Quick Links---

National Aeronautics and Space Administration
Goddard Space Flight Center
Sciences and Exploration

HEASARC Home | Observatories | Archive | Calibration | Software | Tools | Students/Teachers/Public

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

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 chosen

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)

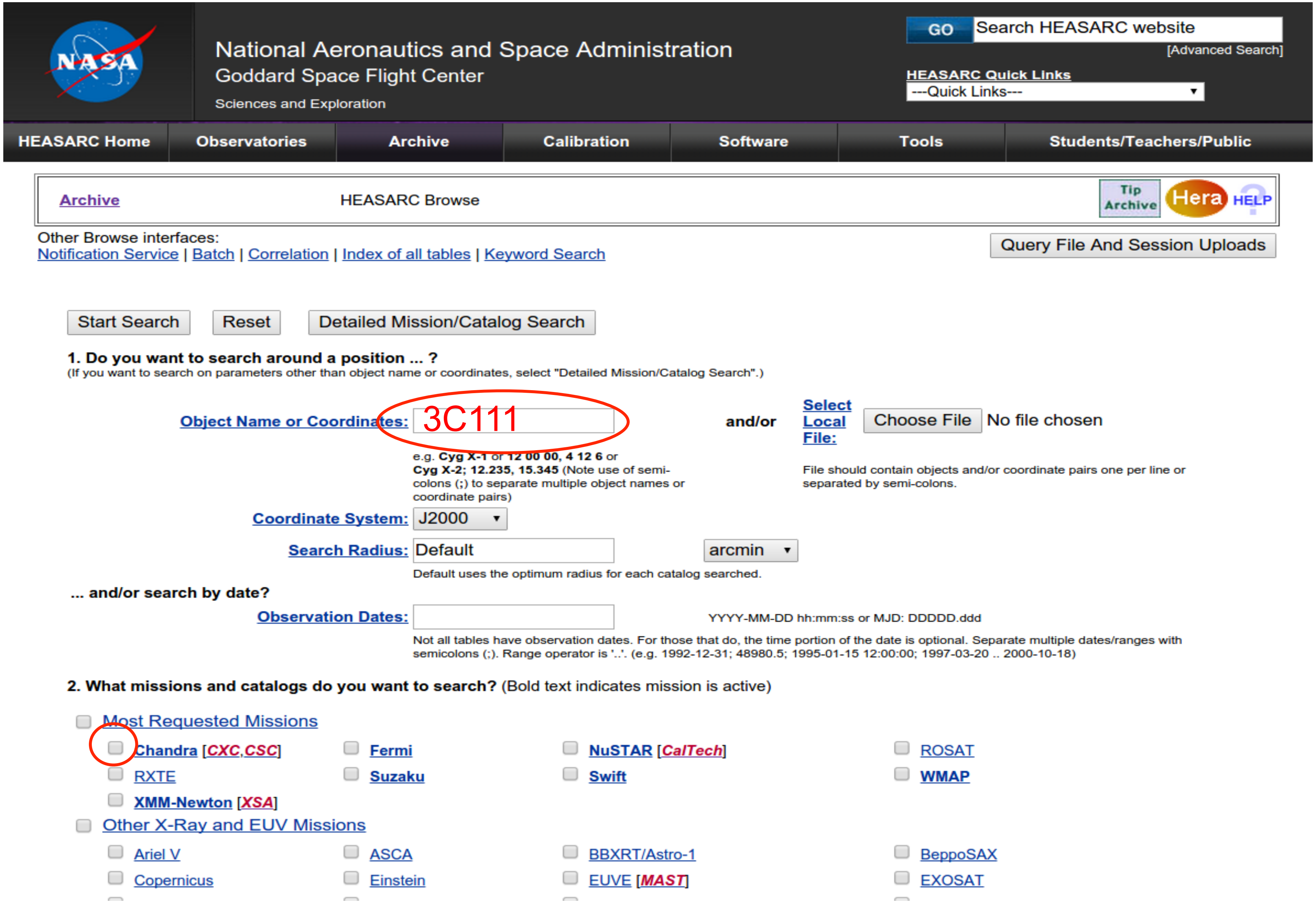
2. What missions and catalogs do you want to search? (Bold text indicates mission is active)

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

Other X-Ray and EUV Missions
- Ariel V
- ASCA
- BBXRT/Astro-1
- BeppoSAX
- Copernicus
- Einstein
- EUVE [*MAST*]
- EXOSAT

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

Main Search Form | Browse Query Results | Tip Archive | Hera | HELP

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, 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	16219	unobserved	3C 111	04 18 21.30	+38 01 35.8	2014-11-12	ACIS-S	HETG	150000	GO	Tombesi		0.004 (3c111)
	ASCA ROSAT RXTE XMM	O R N S D F	14990	archived	3C 111	04 18 21.30	+38 01 36.0	2013-01-10 04:29:04	ACIS-S	NONE	122250	GO	Perlman	2014-01-15	0.006 (3c111)
	ASCA ROSAT RXTE XMM	O R N S D B F	9279	archived	0415+379	04 18 21.30	+38 01 35.8	2008-12-08 06:04:09	ACIS-S	NONE	10140	GO	Lister	2009-12-08	0.004 (3c111)

3 rows retrieved from chanmaster

Data Product Retrieval

- **Select the checkboxes for the rows of interest above,**
- **Un-check any data products below you are not interested in**
- **Select the Data Product Retrieval tab for retrieval options**

Data Products **available for chanmaster**

- **All**
- Chandra Proposal Abstracts (abstracts)
- Events Lists (events)
- FITS and JPEG Images (images)
- Miscellaneous Files (misc)

Further Actions:

Do you want to **plot** your chanmaster results using Java Plot (help) or Xamin (notes)?

Do you want to Cross-correlate your chanmaster results with another catalog or table? (help)

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

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

Archive	Data Products for selected row in Chandra Observations

- 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.

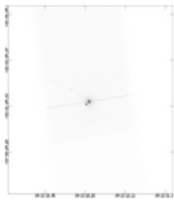
✓ Select all products for all rows

Chandra Observations (chanmaster) FTOOLS

obsid	status	name	ra	dec	time	detector	grating	exposure	type	pi	public_date
14990	archived	3C 111	04 18 21.30	+38 01 36.0	2013-01-10 04:29:04	ACIS-S	NONE	122250	GO	Perlman	2014-01-15

Select all products in this row

FITS and JPEG Images

Center Image (acisf14990N001_e1_cntr_img2.fits.gz)	FITS	837 kB		updated: 2013/01/12 00:00:00
Center Image (acisf14990N001_e2_cntr_img2.fits.gz)	FITS	945 kB		updated: 2013/01/12 00:00:00
Center Image (acisf14990N001_e1_cntr_img2.jpg)	JPEG	85 kB		updated: 2013/01/12 00:00:00
Center Image (acisf14990N001_e2_cntr_img2.jpg)	JPEG	223 kB		updated: 2013/01/12 00:00:00
Full Image (acisf14990N001_e1_full_img2.fits.gz)	FITS	828 kB		updated: 2013/01/12 00:00:00
Full Image (acisf14990N001_e2_full_img2.fits.gz)	FITS	844 kB		updated: 2013/01/12 00:00:00

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

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

Aspect Quality (pcadf474179932N001_aqual1.fits.gz)	FITS	1809 kB	updated: 2013/01/12 00:00:00
Aspect Solution (pcadf474179932N001_asol1.fits.gz)	FITS	30450 kB	updated: 2013/01/12 00:00:00
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OBC Aspect Solution (pcadf474201724N001_osol1.fits.gz)	FITS	252 kB	updated: 2013/01/11 00:00:00
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Orbit Ephemeris (orbitf474120303N001_eph1.fits.gz)	FITS	310 kB	updated: 2013/02/08 00:00:00
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Events List (acisf14990N001_e2_evt2.fits.gz)	FITS	21138 kB	updated: 2013/01/12 00:00:00
Miscellaneous Files			
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Bad Pixel List (acisf14990_000N001_e2_bpix1.fits.gz)	FITS	29 kB	updated: 2013/01/12 00:00:00
Observation Index File (oif.fits)	FITS	31 kB	updated: 2014/01/15 15:18:00
Secondary Products (secondary)	DIRECTORY	263085 kB	updated: 2014/01/15 22:26:39

TAR selected products | Create Download Script | Reset

Save to Hera | What is Hera?

Page maintainer: Browse Feedback

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

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

Archive	Retrieve Data Products

Estimated size of TAR file: 314 MB

Your TAR file is being created now. When finished you may retrieve it via the following link

http://heasarc.gsfc.nasa.gov/FTP/retrieve/w3browse/w3browse-164971.tar.

Please wait until the "TAR complete" message appears below before retrieving.

Below are data products included in the TAR file: (filenames ending in '.gz' or '.Z' have been compressed for faster downloading.)

Tarred: /FTP/chandra/data/science/ao14/cat7//14990/primary/acisf14990N001_e2_full_img2.fits.gz
Tarred: /FTP/chandra/data/science/ao14/cat7//14990/primary/acisf14990N001_e2_evt2.fits.gz
Tarred: /FTP/chandra/data/science/ao14/cat7//14990/primary/acisf14990_000N001_e1_bpix1.fits.gz
Tarred: /FTP/chandra/data/science/ao14/cat7//14990/primary/acisf14990N001_e2_full_img2.jpg
Tarred: /FTP/chandra/data/science/ao14/cat7//14990/primary/acisf14990N001_e1_evt2.fits.gz
Tarred: /FTP/chandra/data/science/ao14/cat7//14990/oif.fits
Tarred: /FTP/chandra/data/science/ao14/cat7//14990/primary/acisf14990N001_e1_full_img2.jpg
Tarred: /FTP/chandra/data/science/ao14/cat7//14990/primary/pcadf474179932N001_asol1.fits.gz
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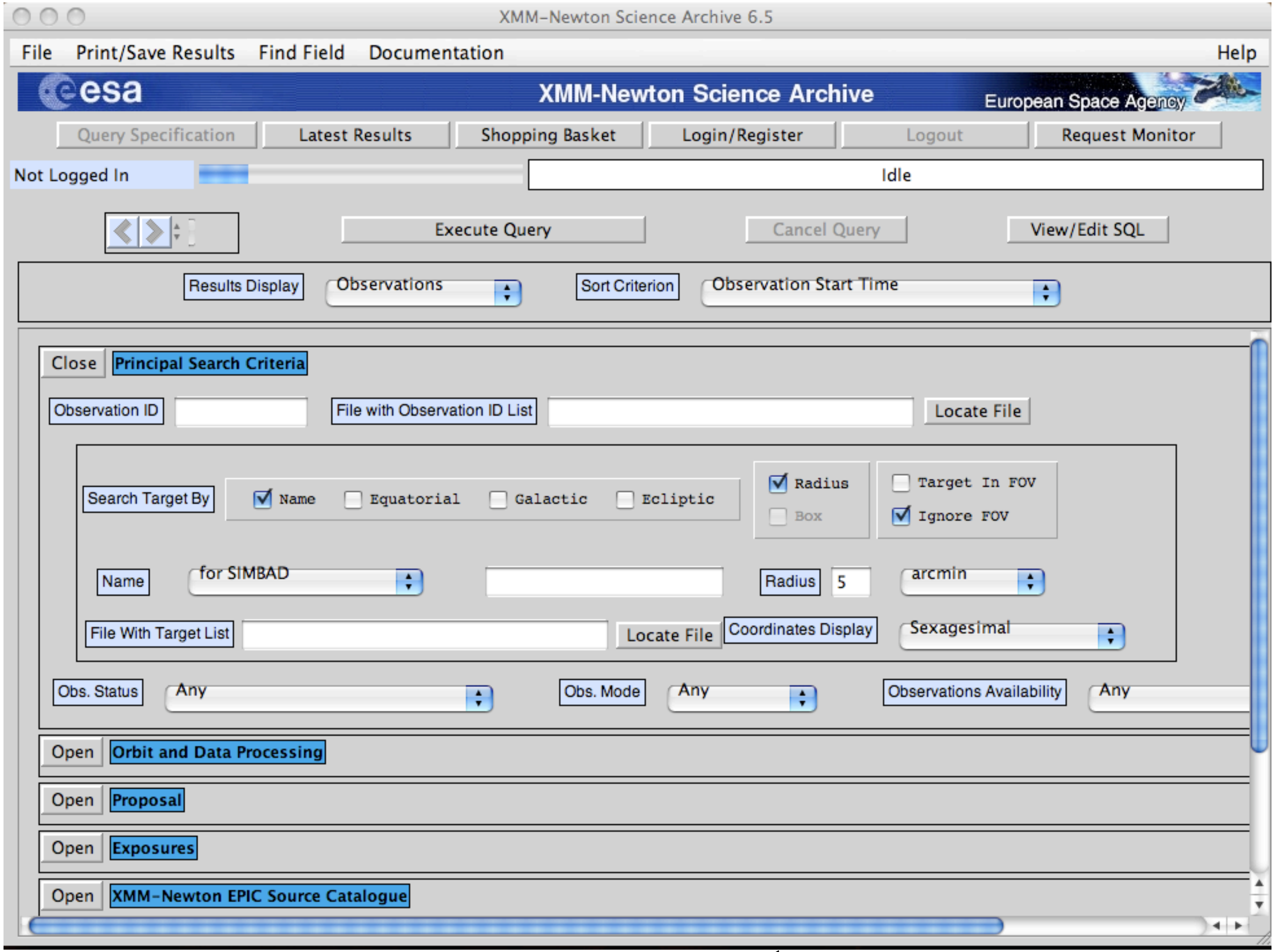
Tarred: /FTP/chandra/data/science/ao14/cat7//14990/primary/orbitf474120303N001_eph1.fits.gz
Tarred: /FTP/chandra/data/science/ao14/cat7//14990/secondary

TAR complete: Actual size: 314 MB.

Remote files are not included in the tar file. Use the **Create Download Script** option to retrieve remote files.

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

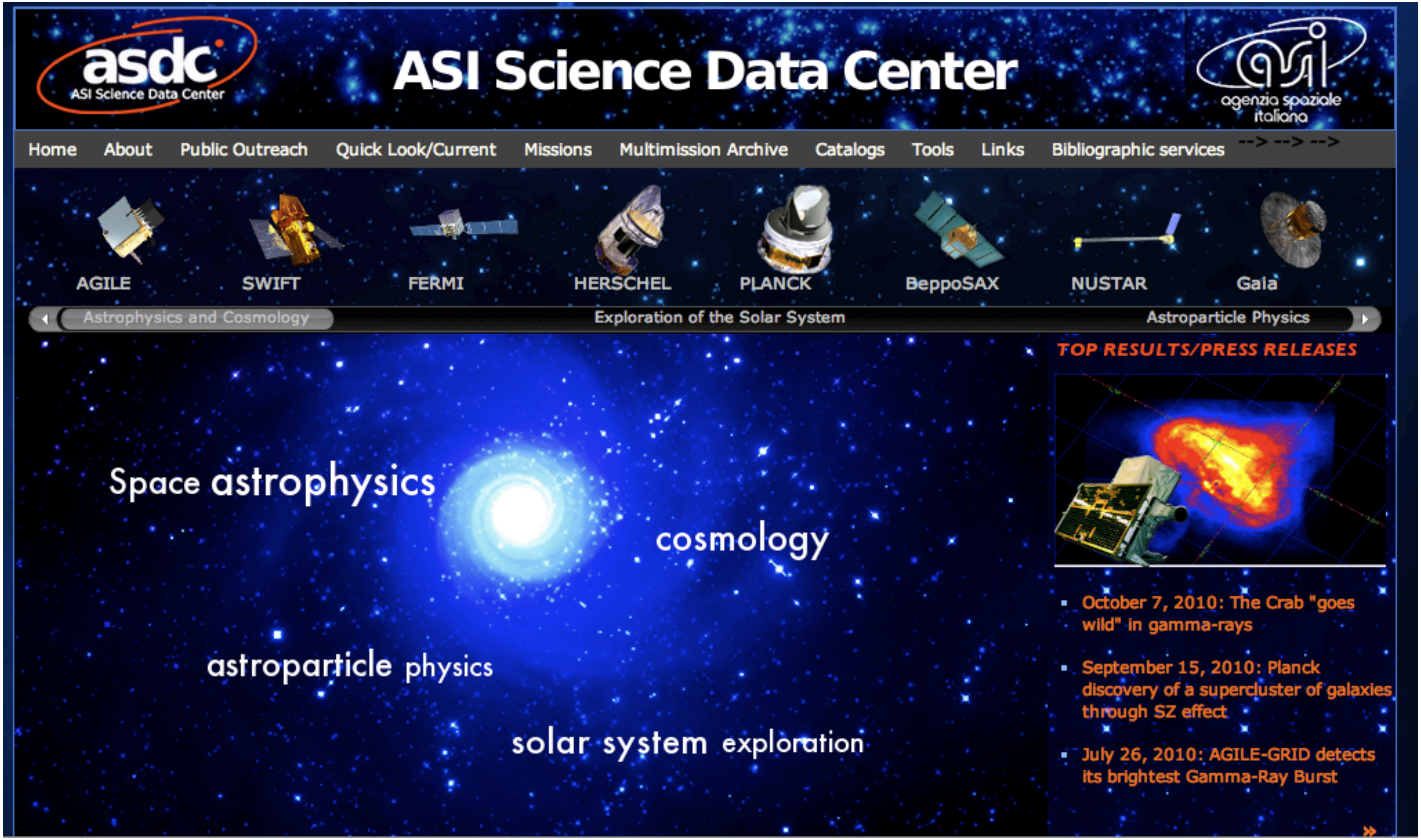
http://xmm.esac.esa.int/xsa/



see XMM tutorial...

ASI Scientific Data Center (ASDC- Frascati, Roma)

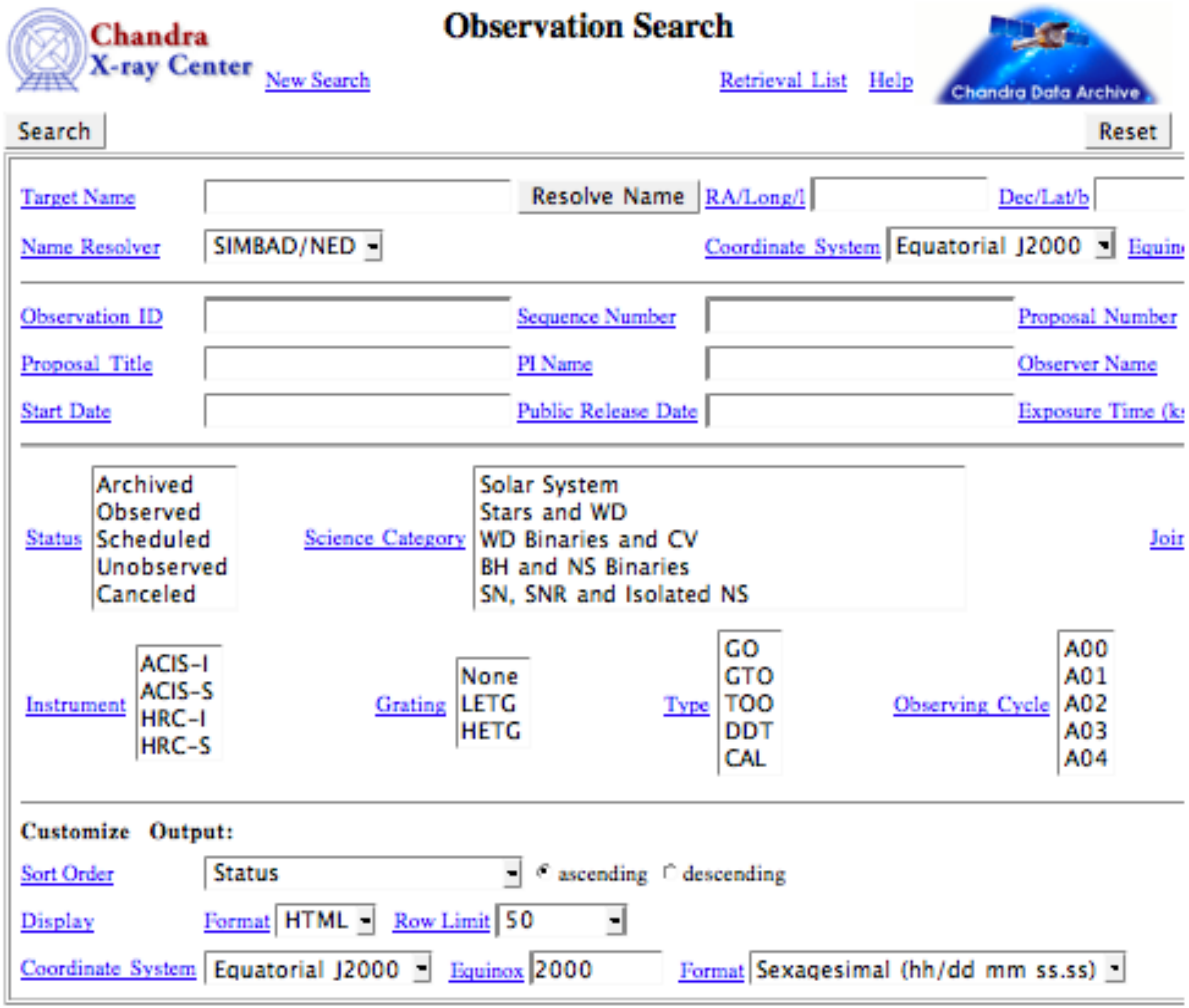
http://www.asdc.asi.it/



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

http://cxc.harvard.edu/cda/

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



Chandra X-ray Center

Search Results

New Search Retrieval List Help

Chandra Data Archive

View Observation Information | Add to Retrieval List

☑ Primary products
☑ Secondary products

Select all | Unselect all

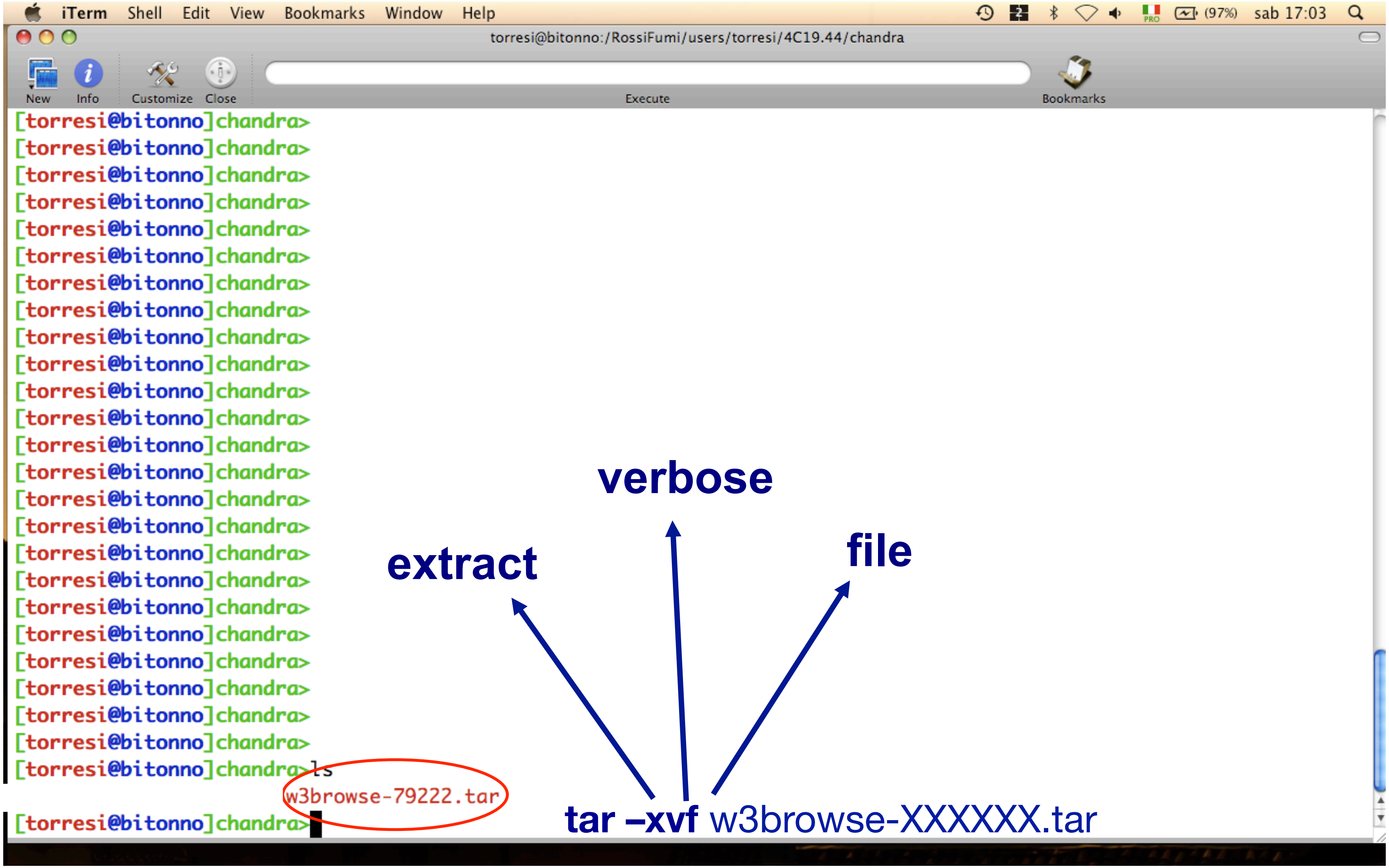
Select	Row	Seq Num	Obs ID	Instrument	Grating	Appr Exp (ks)	Exposure (ks)	Target
☐	1	700743	4064	ACIS-S	NONE	5.0	4.73	BR 0331-1622
☐	2	700744	4065	ACIS-S	NONE	4.0	4.12	BR 0353-3820
☐	3	700745	4066	ACIS-S	NONE	4.0	4.04	BR 0418-5723
☐	4	700746	4067	ACIS-S	NONE	5.0	4.73	BR 0424-2209
☐	5	700747	4068	ACIS-S	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

→ How to download X-ray data from a public archive

→ **How the downloaded files look like**

→ How to reduce X-ray (*Chandra*) data

→ How to create the radio and/or X-ray contours for an extended object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New Info Customize Close Execute Bookmarks
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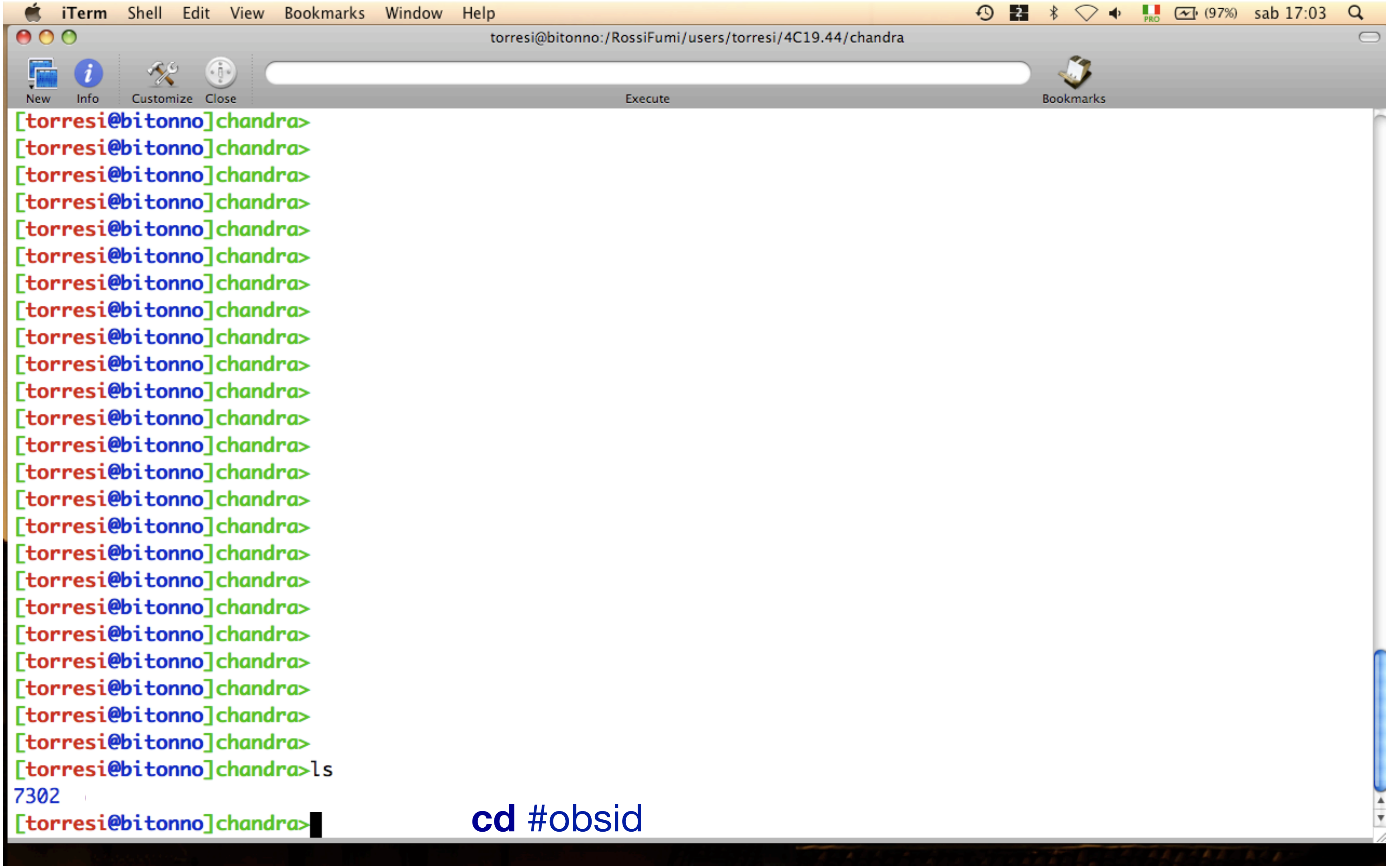
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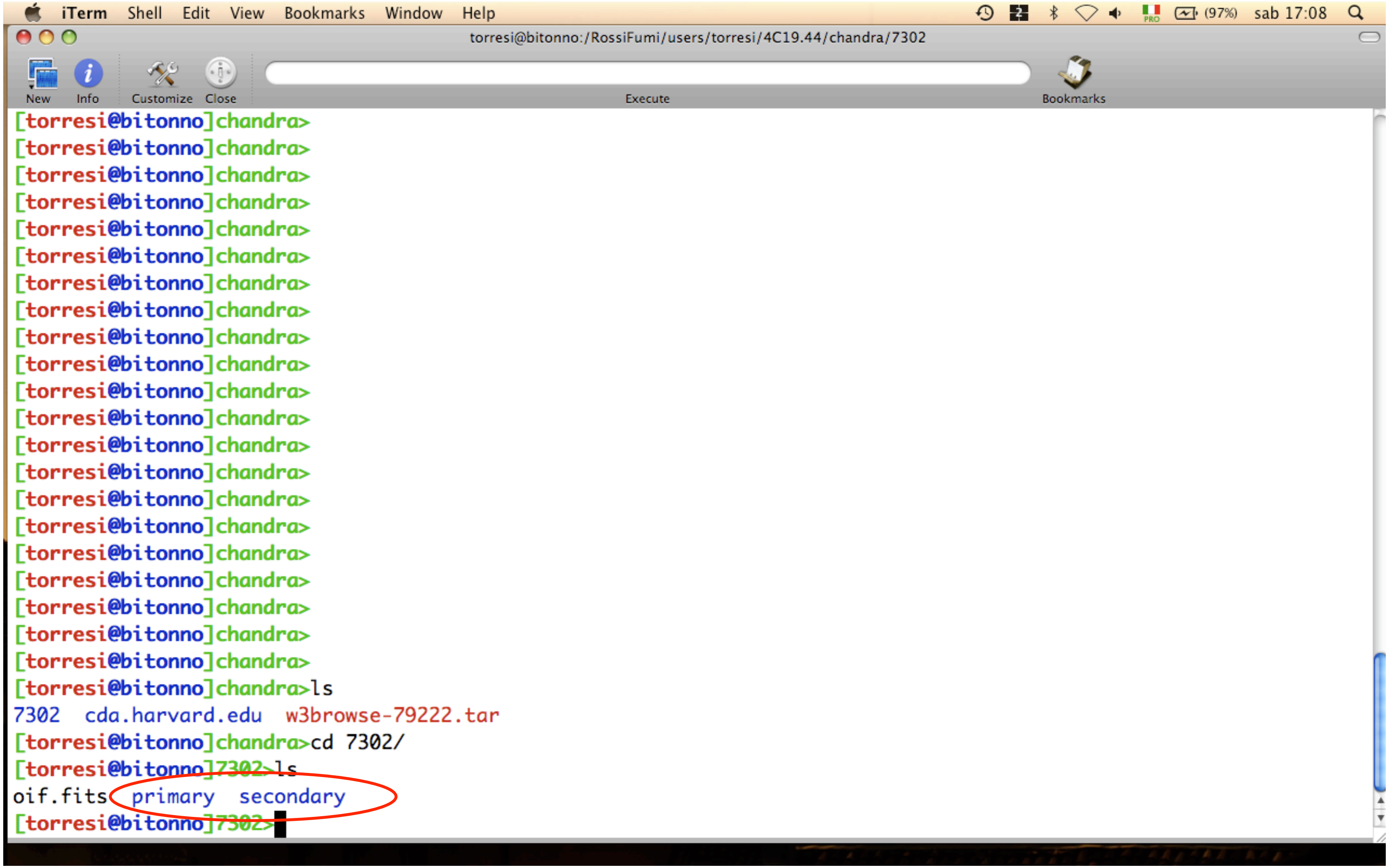
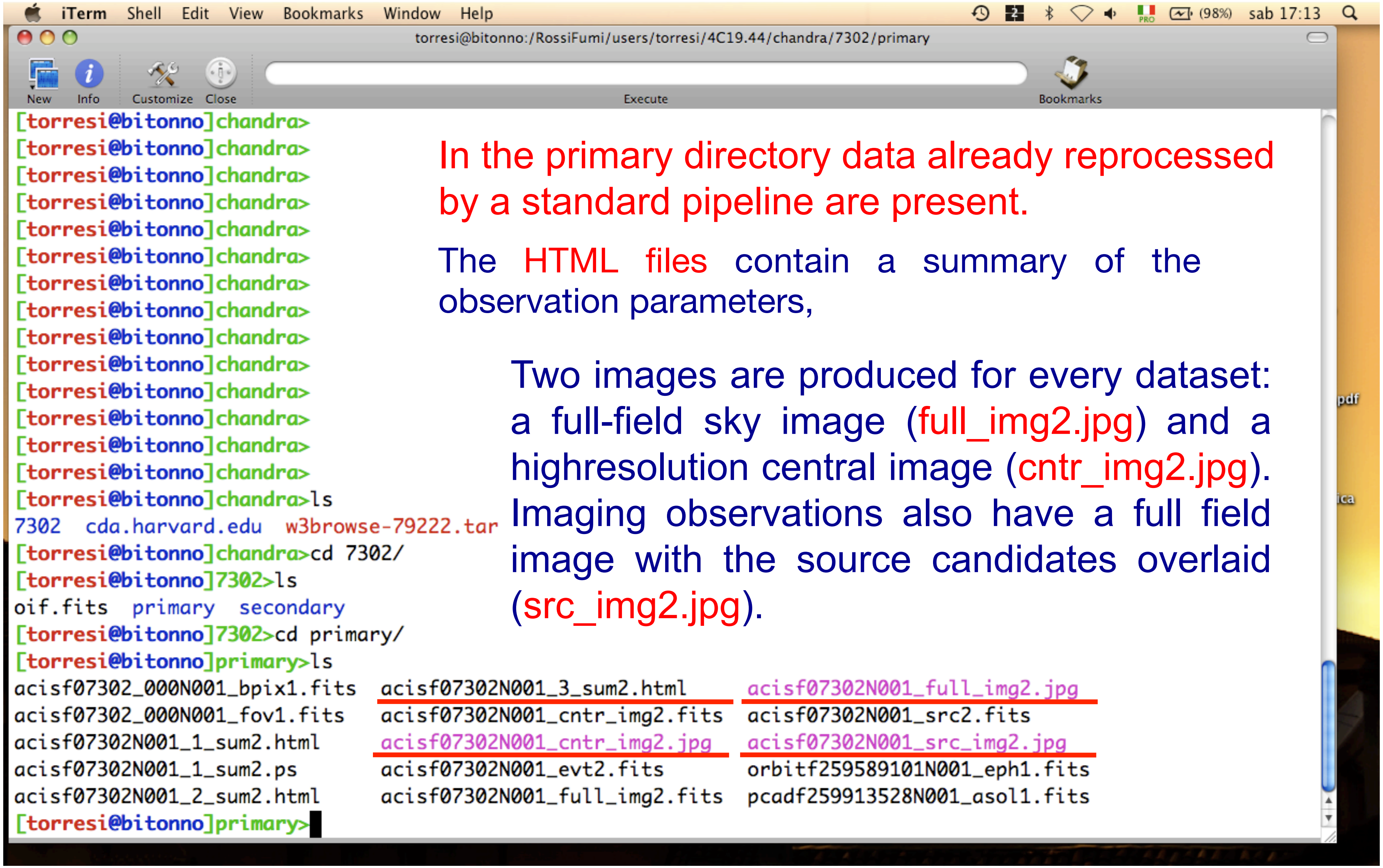
[torresi@bitonno]chandra>ls
7302
[torresi@bitonno]chandra>
cd #obsid


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>ls
7302 cda.harvard.edu w3browse-79222.tar
[torresi@bitonno]chandra>cd 7302/
[torresi@bitonno]7302>ls
oif.fits primary secondary
[torresi@bitonno]7302>



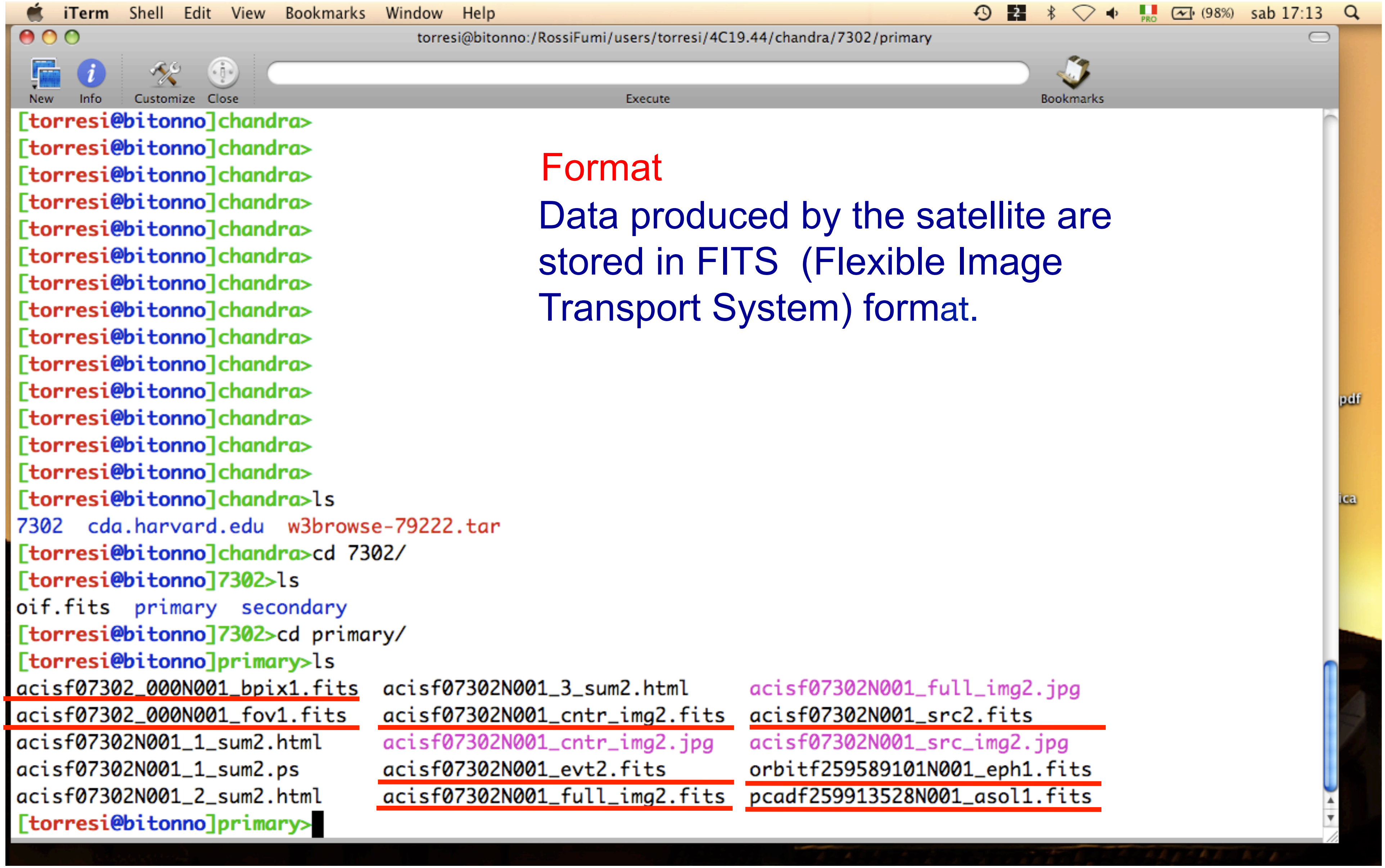
In the primary directory data already reprocessed by a standard pipeline are present.

The HTML files contain a summary of the observation parameters,

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

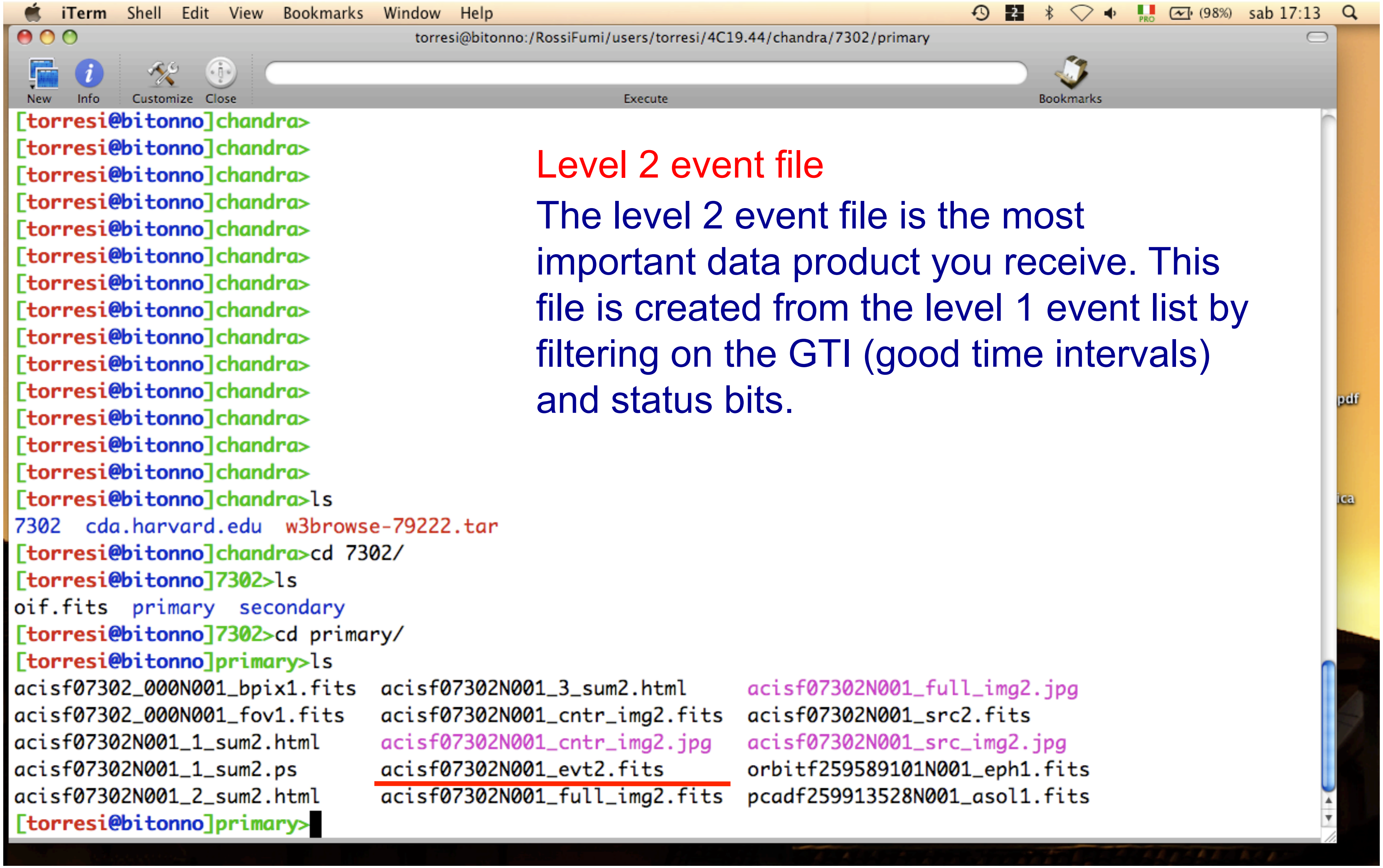
Format

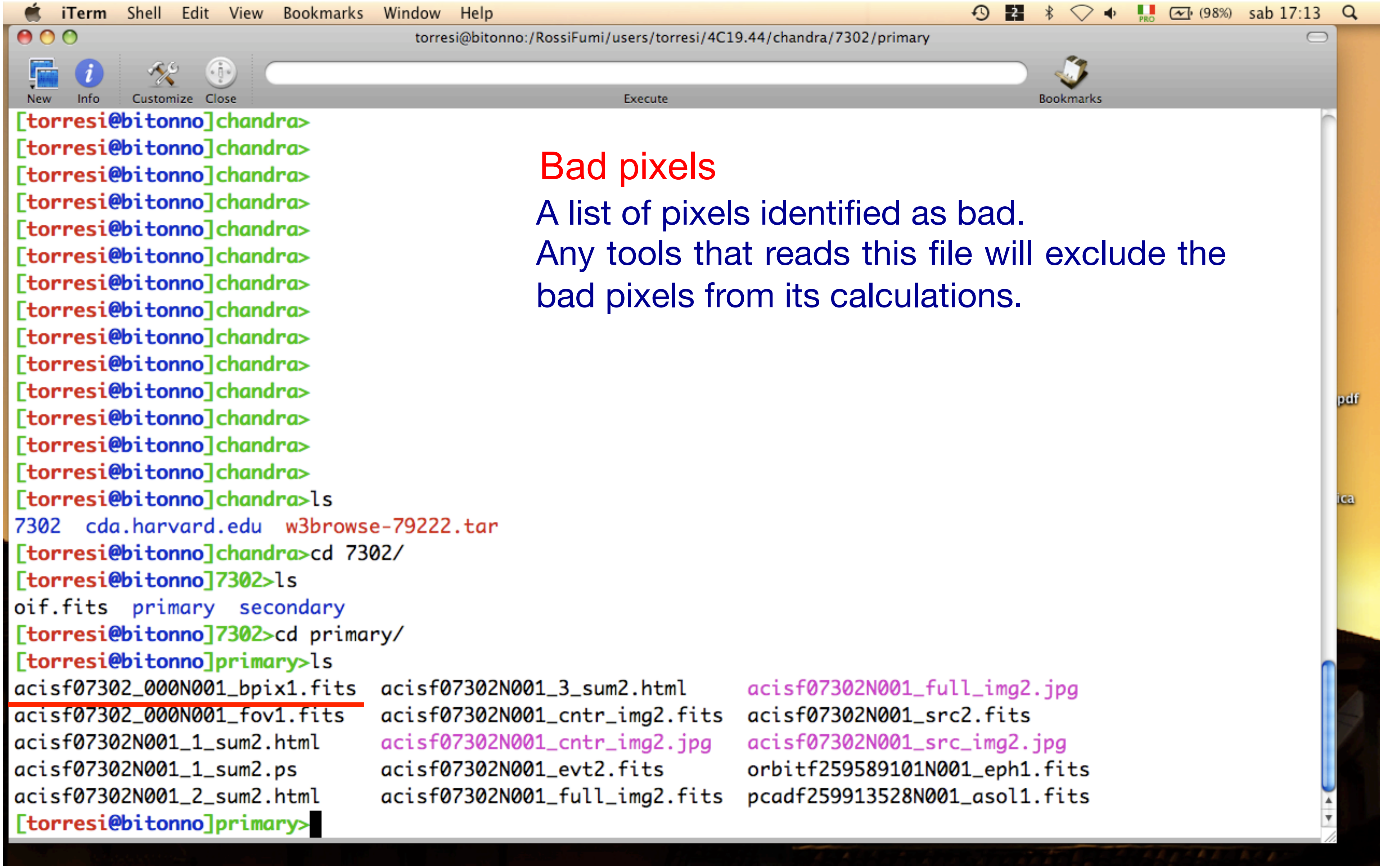
Data produced by the satellite are stored in FITS (Flexible Image Transport System) format.



Level 2 event file

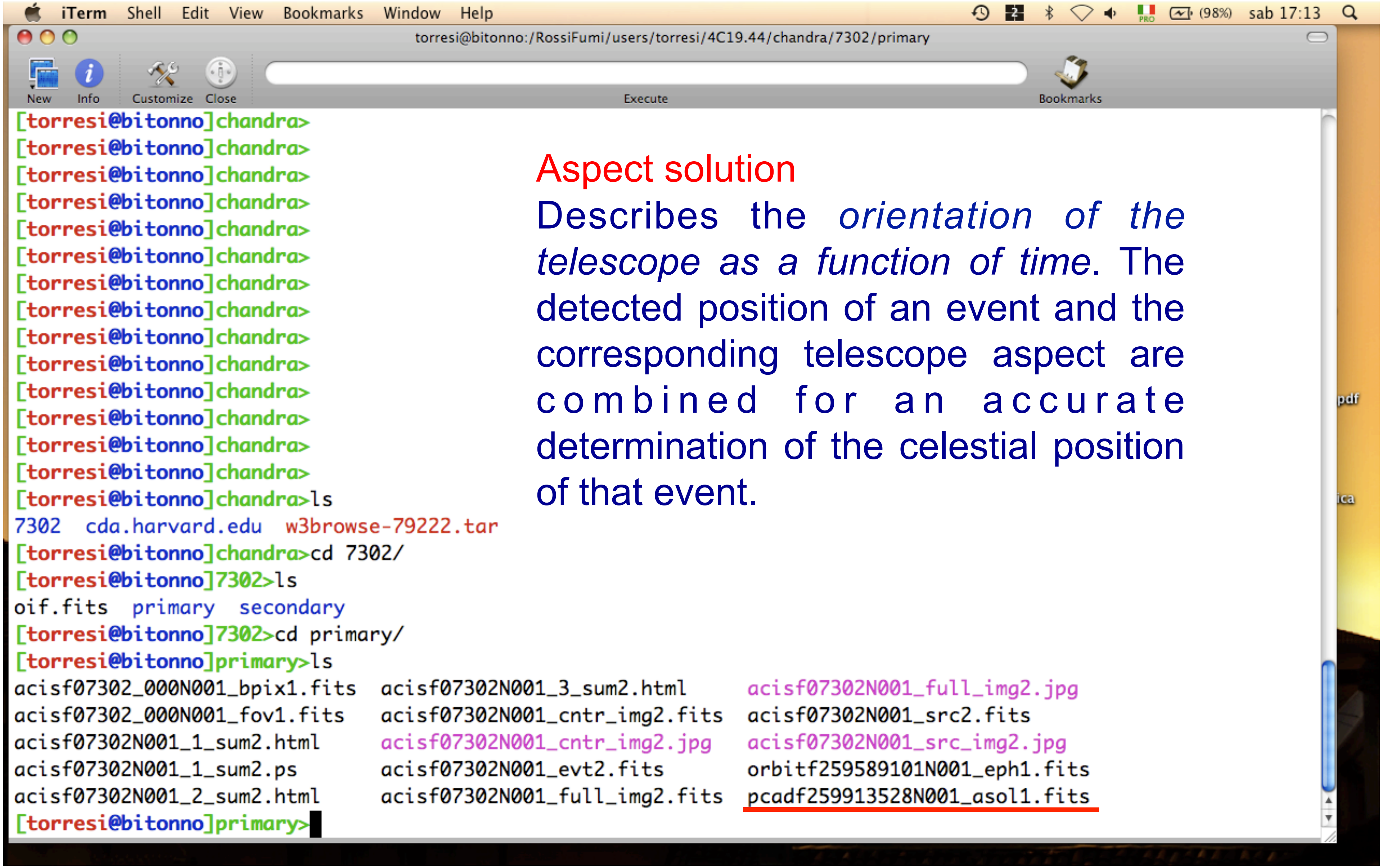
The level 2 event file is the most important data product you receive. This file is created from the level 1 event list by filtering on the GTI (good time intervals) and status bits.





Bad pixels

A list of pixels identified as bad.
Any tools that reads this file will exclude the bad pixels from its calculations.



Aspect solution

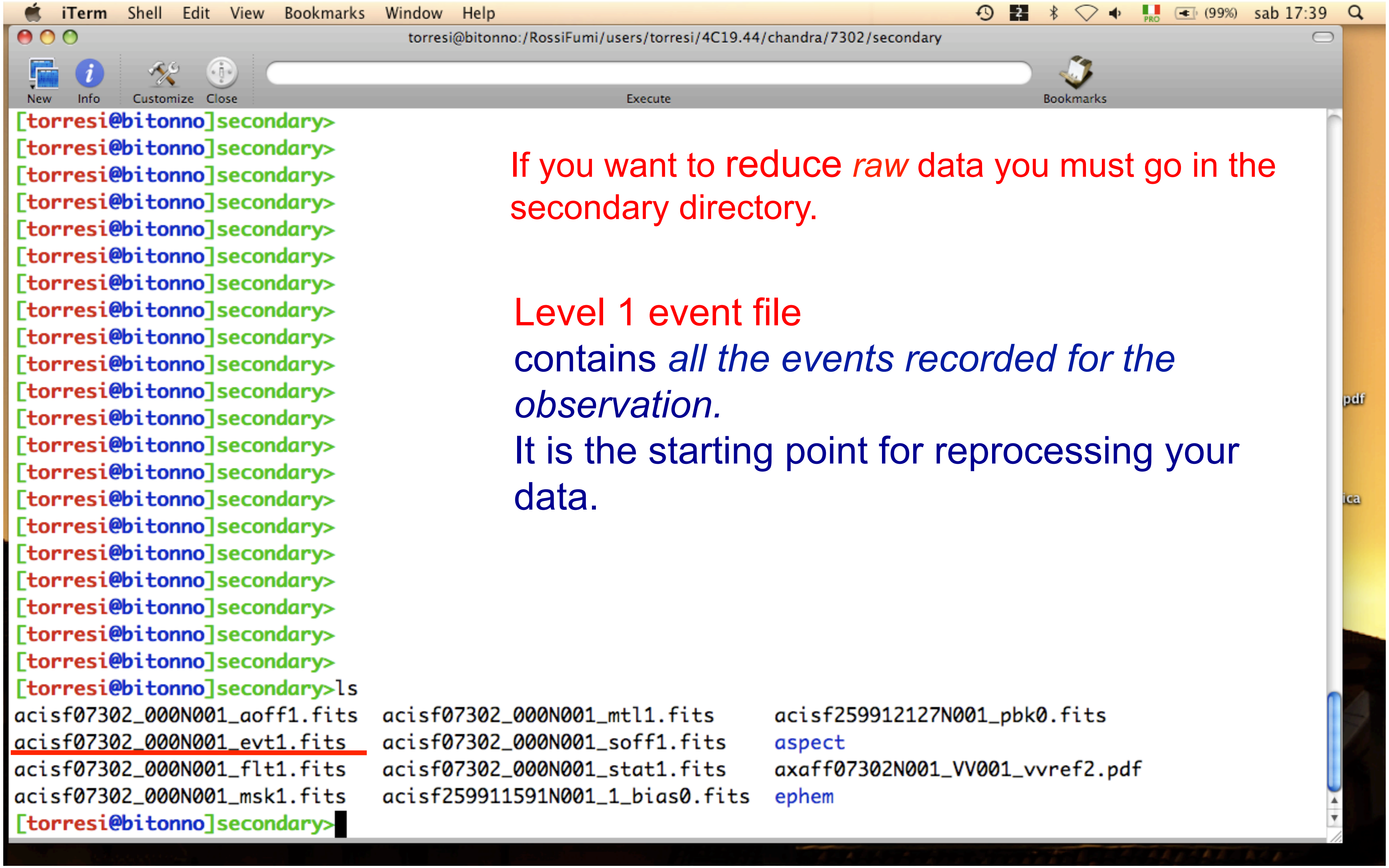
Describes the *orientation of the telescope as a function of time*. The detected position of an event and the corresponding telescope aspect are combined for an accurate determination of the celestial position of that event.

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

Level 1 event file

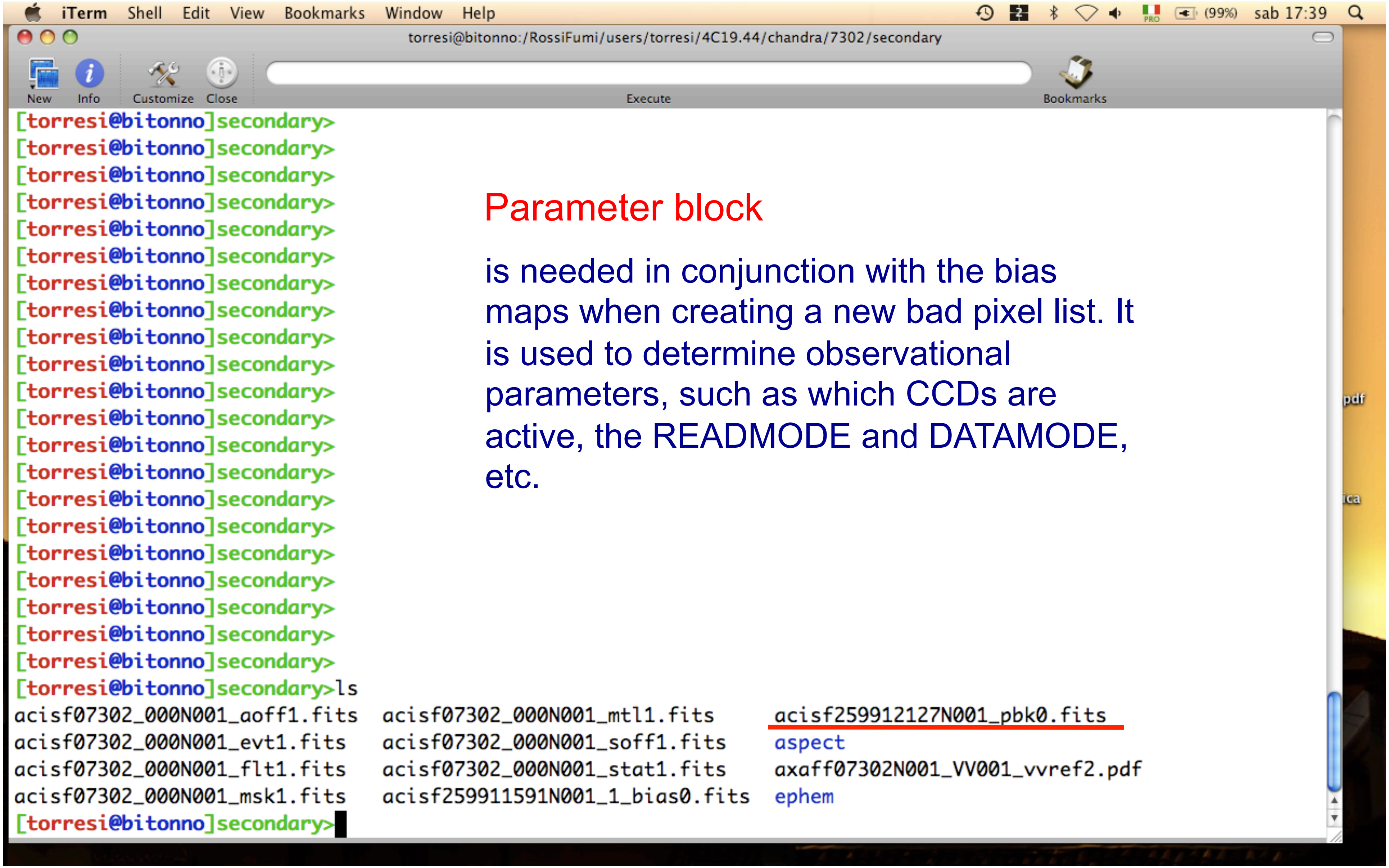
contains *all the events recorded for the observation.*

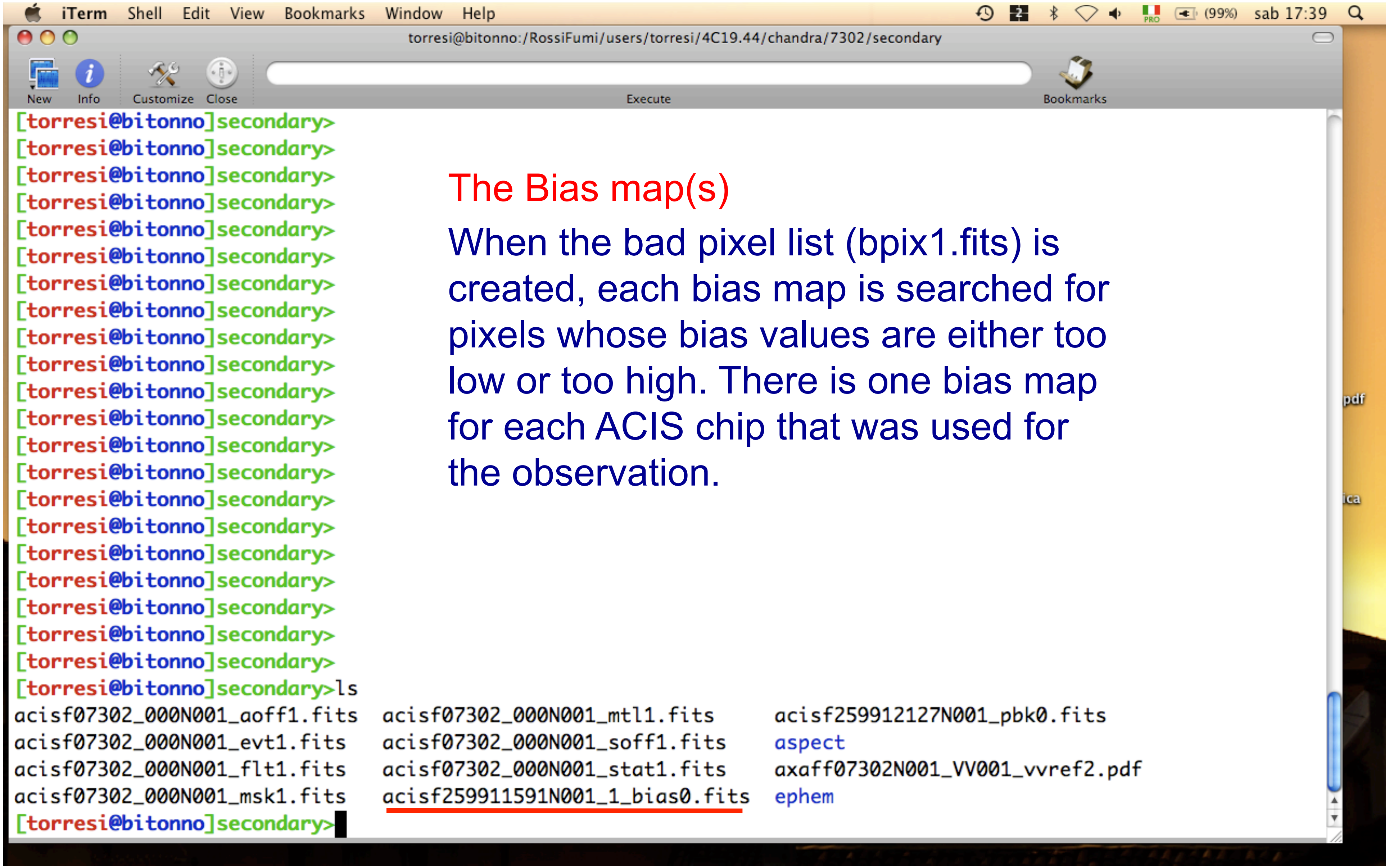
It is the starting point for reprocessing your data.



Parameter block

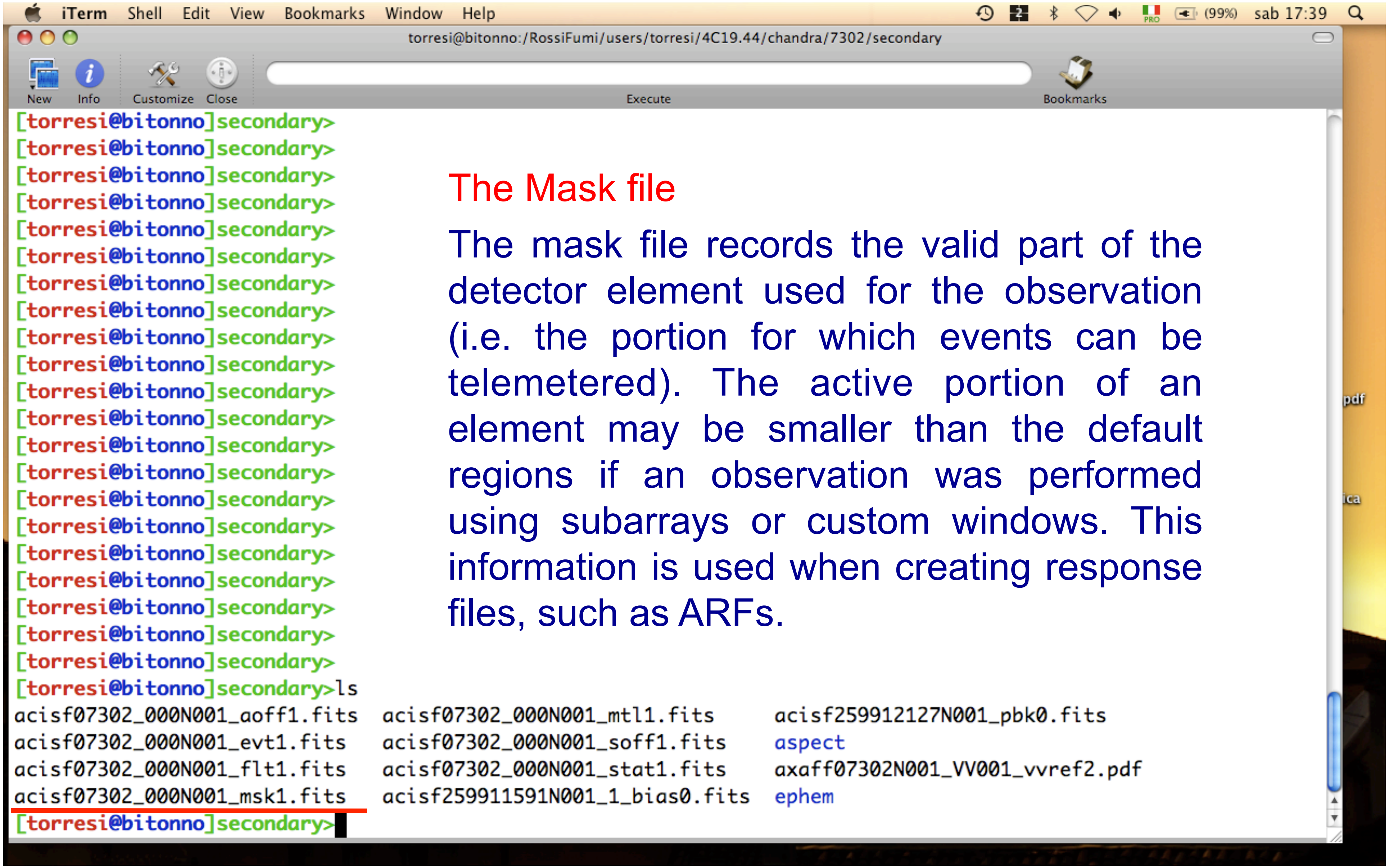
is needed in conjunction with the bias maps when creating a new bad pixel list. It is used to determine observational parameters, such as which CCDs are active, the READMODE and DATAMODE, etc.





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 record of the time filters applied to the data.

```
torresi@bitonno:/RossiFumi/users/torresi/4C19.44/chandra/7302/secondary
[torresi@bitonno]secondary>
[torresi@bitonno]secondary>
[torresi@bitonno]secondary>
[torresi@bitonno]secondary>
[torresi@bitonno]secondary>
[torresi@bitonno]secondary>
[torresi@bitonno]secondary>
[torresi@bitonno]secondary>
[torresi@bitonno]secondary>
[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>
```
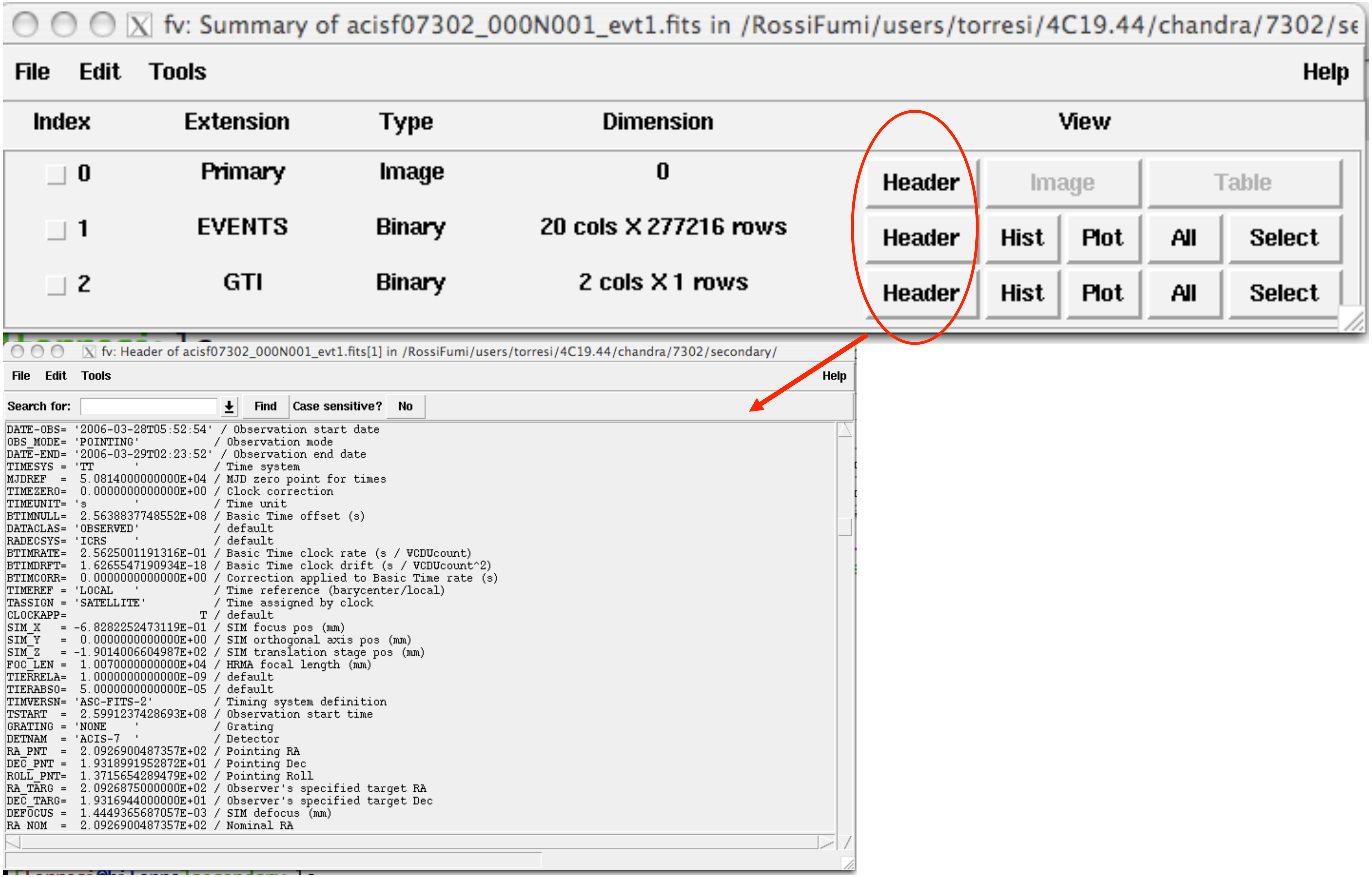
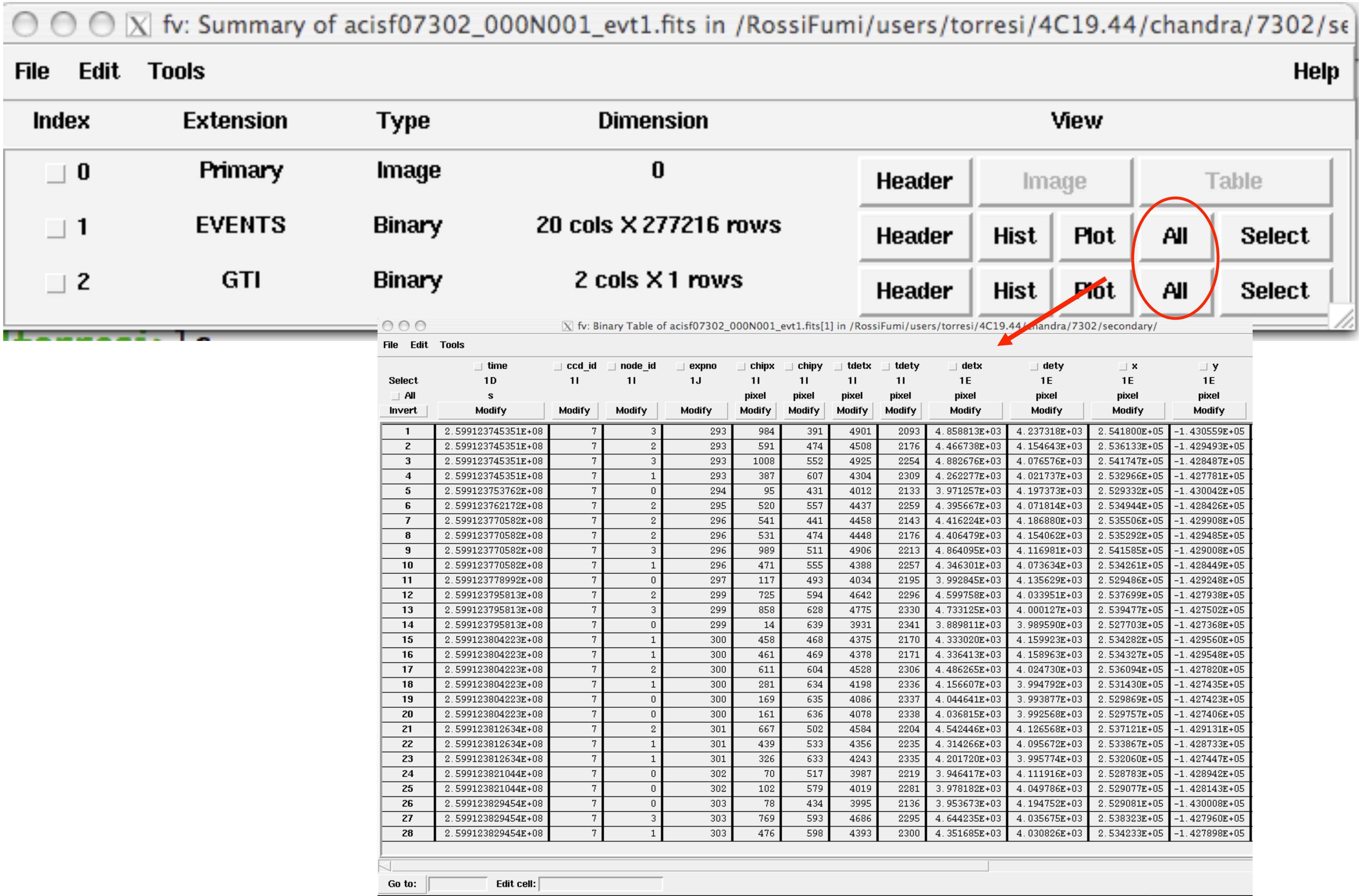

All the information of your observation are contained in the header of the fits file. You can visualize it by using the FTOOL command *fv*



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



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

→ How to download X-ray data from a public archive

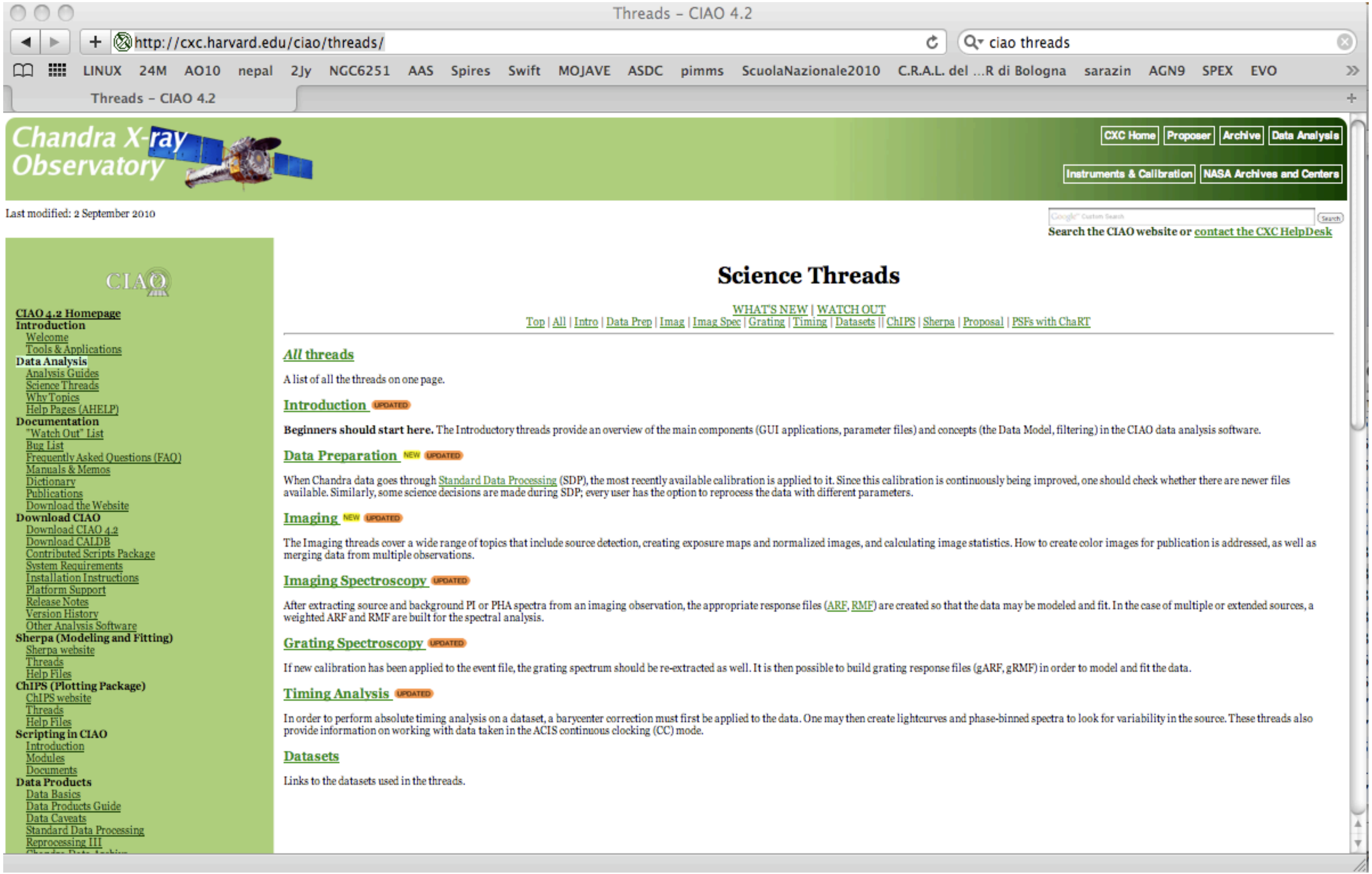
→ How the downloaded files look like

→ How to reduce X-ray (*Chandra*) data

→ How to create the radio and/or X-ray contours for an extended object

Chandra data reduction

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



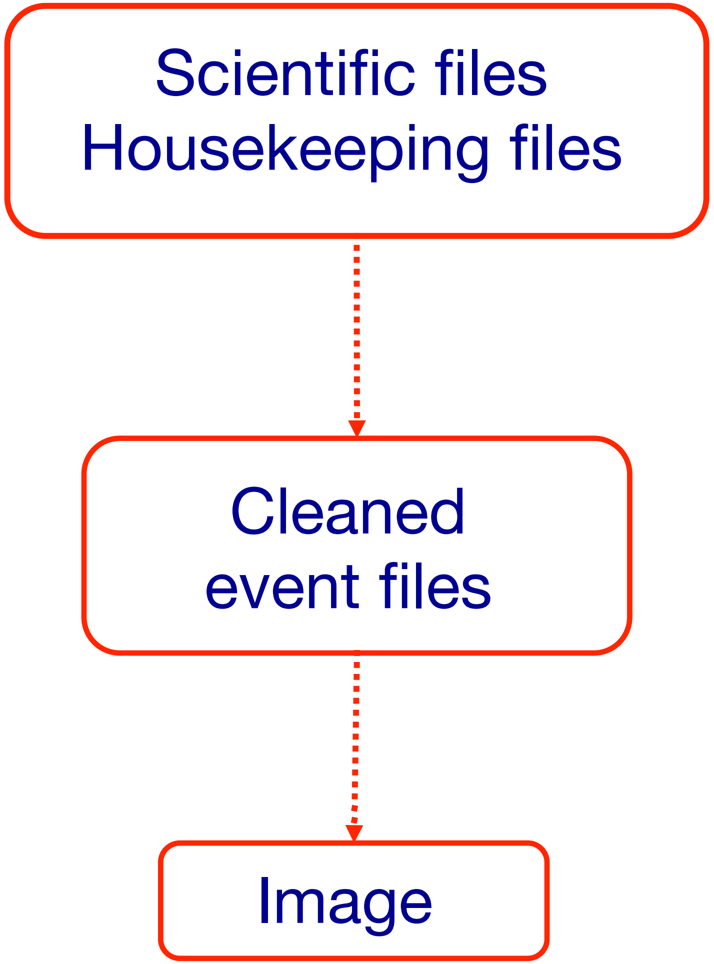
Scientific files
Housekeeping files

Scientific files
Housekeeping files

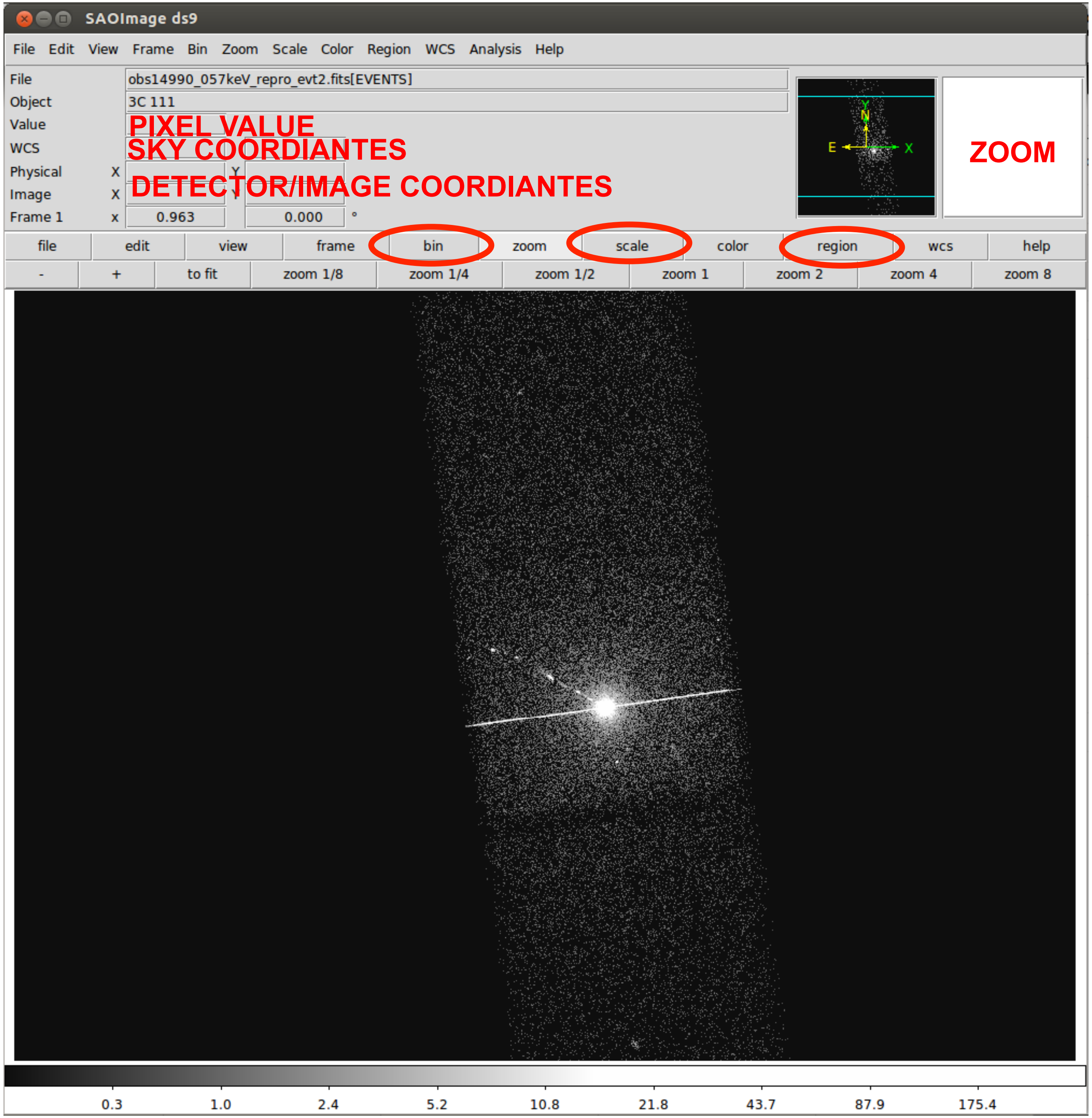
- removal of hot pixels or afterglows
  acis_run_hotpix
- creation of a new event file
  acis_process_events
- run *destreak* in case the ACIS-S4 chip (ccd_id=8) has been used
- filtering for bad grades and application of *Good Time Intervals (GTI)*
- creation of the background light curve

↓

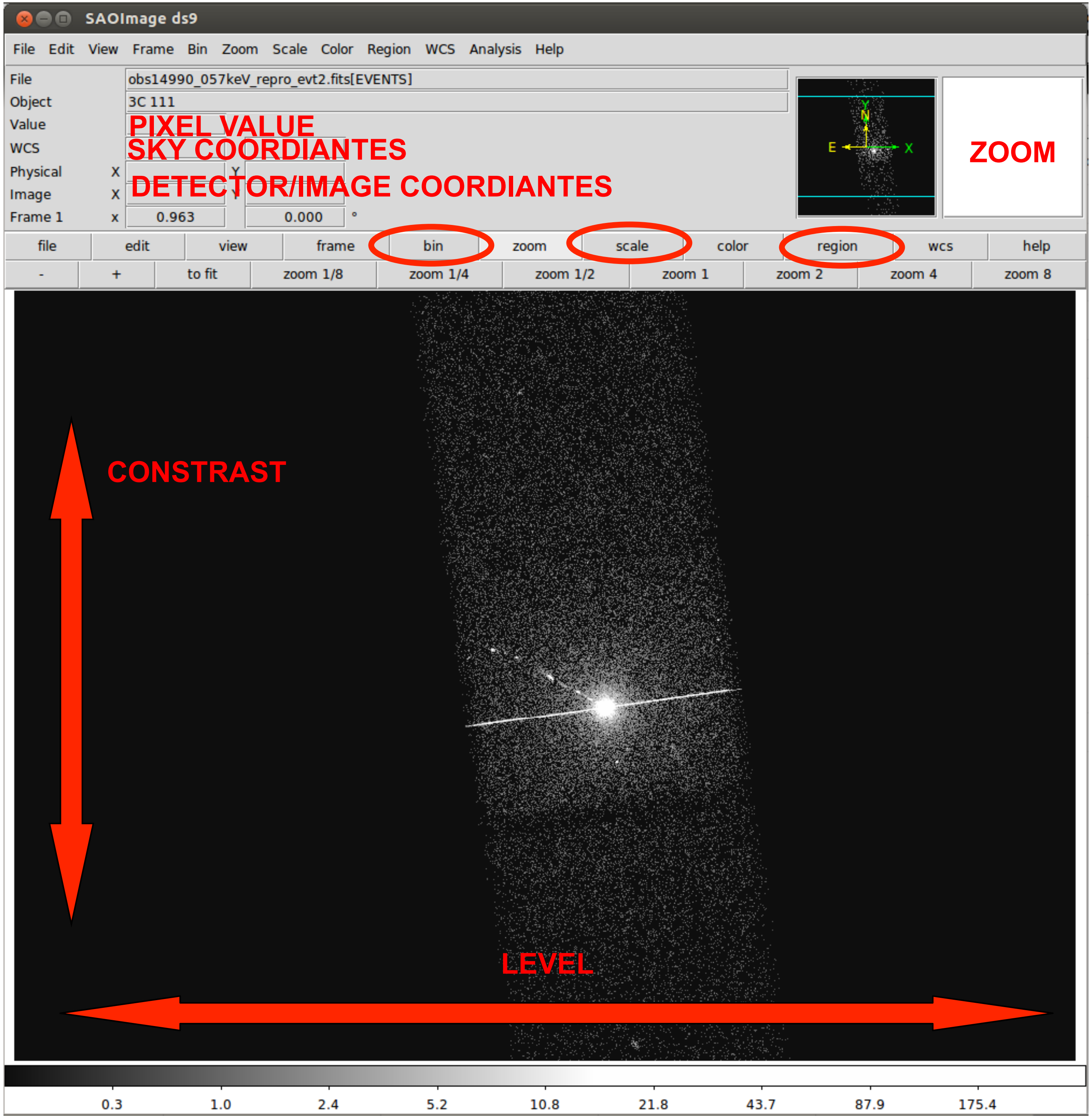
Cleaned event files


Scientific files
Housekeeping files
Cleaned
event files
Image

DS9:


SAOImage ds9
File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help
File obs14990_057keV_repro_evt2.fits[EVENTS]
Object 3C 111
Value
WCS
Physical X Y
Image X Y
Frame 1 x 0.963 0.000 °
PIXEL VALUE
SKY COORDIANTES
DETECTOR/IMAGE COORDIANTES
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
0.3 1.0 2.4 5.2 10.8 21.8 43.7 87.9 175.4

DS9:

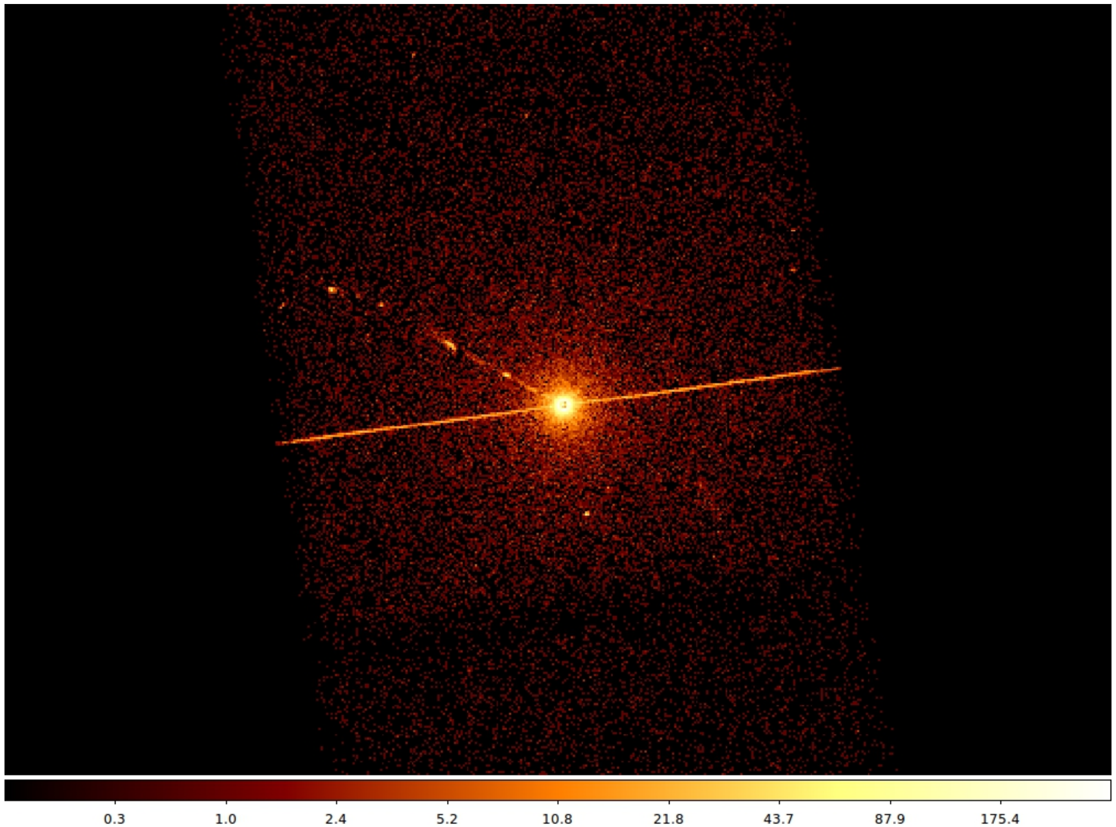

SAOImage ds9
File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help
File obs14990_057keV_repro_evt2.fits[EVENTS]
Object 3C 111
Value
WCS
Physical
Image
Frame 1 x 0.963 0.000 °
PIXEL VALUE
SKY COORDIANTES
DETECTOR/IMAGE COORDIANTES
ZOOM
file edit view frame bin zoom scale color region wcs help
- + to fit zoom 1/8 zoom 1/4 zoom 1/2 zoom 1 zoom 2 zoom 4 zoom 8
CONSTRAST
LEVEL
0.3 1.0 2.4 5.2 10.8 21.8 43.7 87.9 175.4

Most important information deducible from an image:

- Detection (calculate the source counts and verify if the observed excess is real or due to background fluctuations)

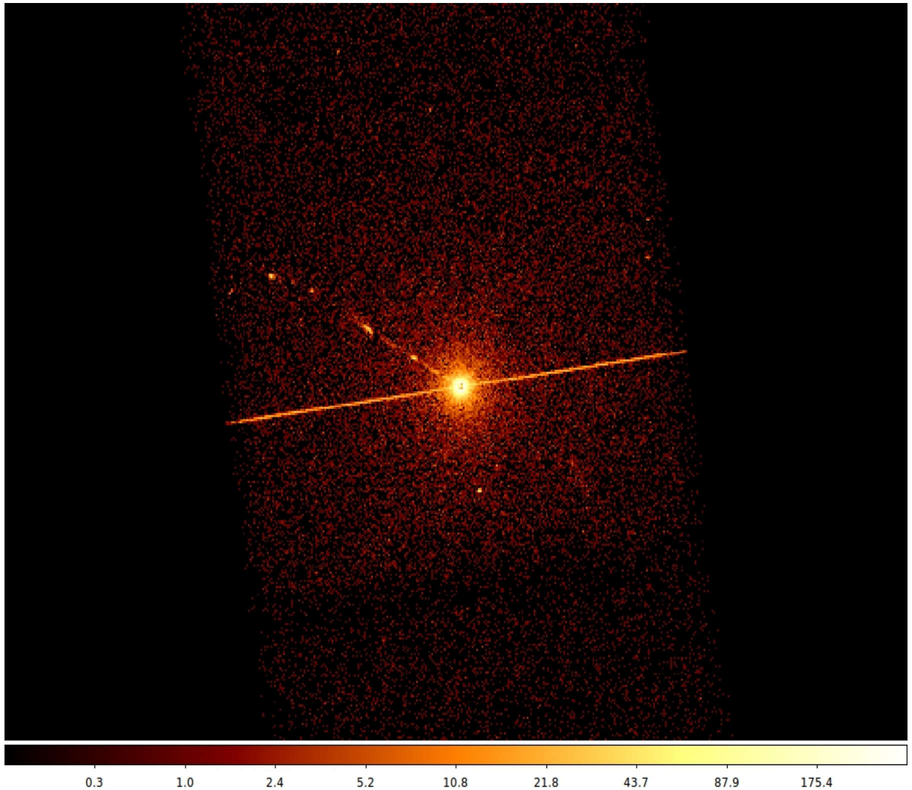
- Morphology (the source is pointlike or extended? obtain and fit a radial profile);

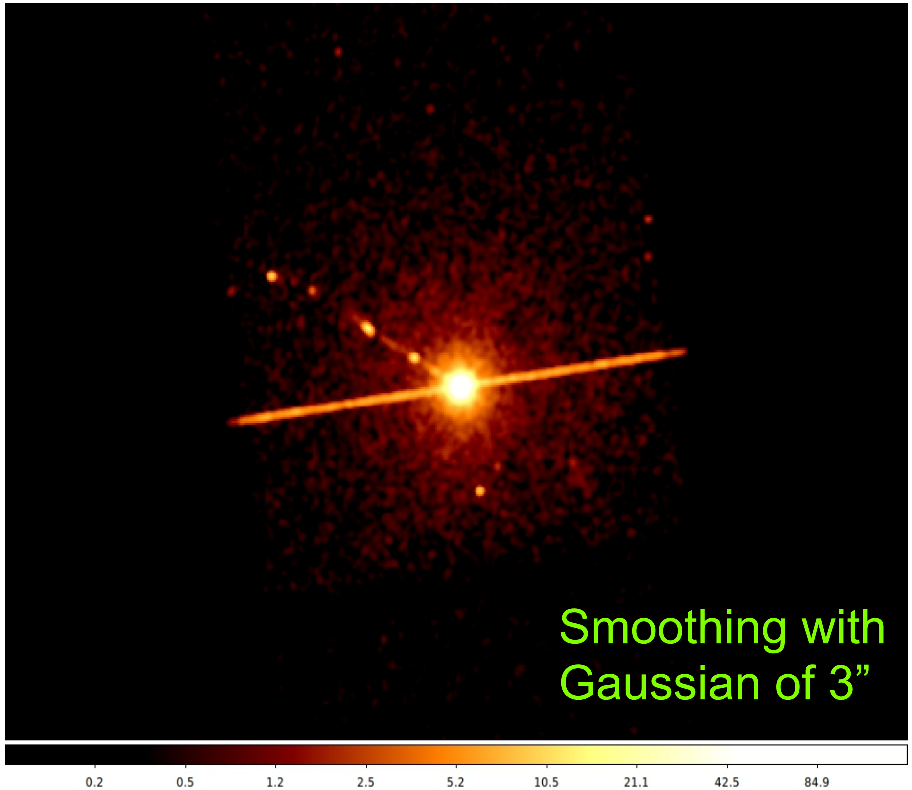
- X-ray counterparts of structures seen in other wavebands.



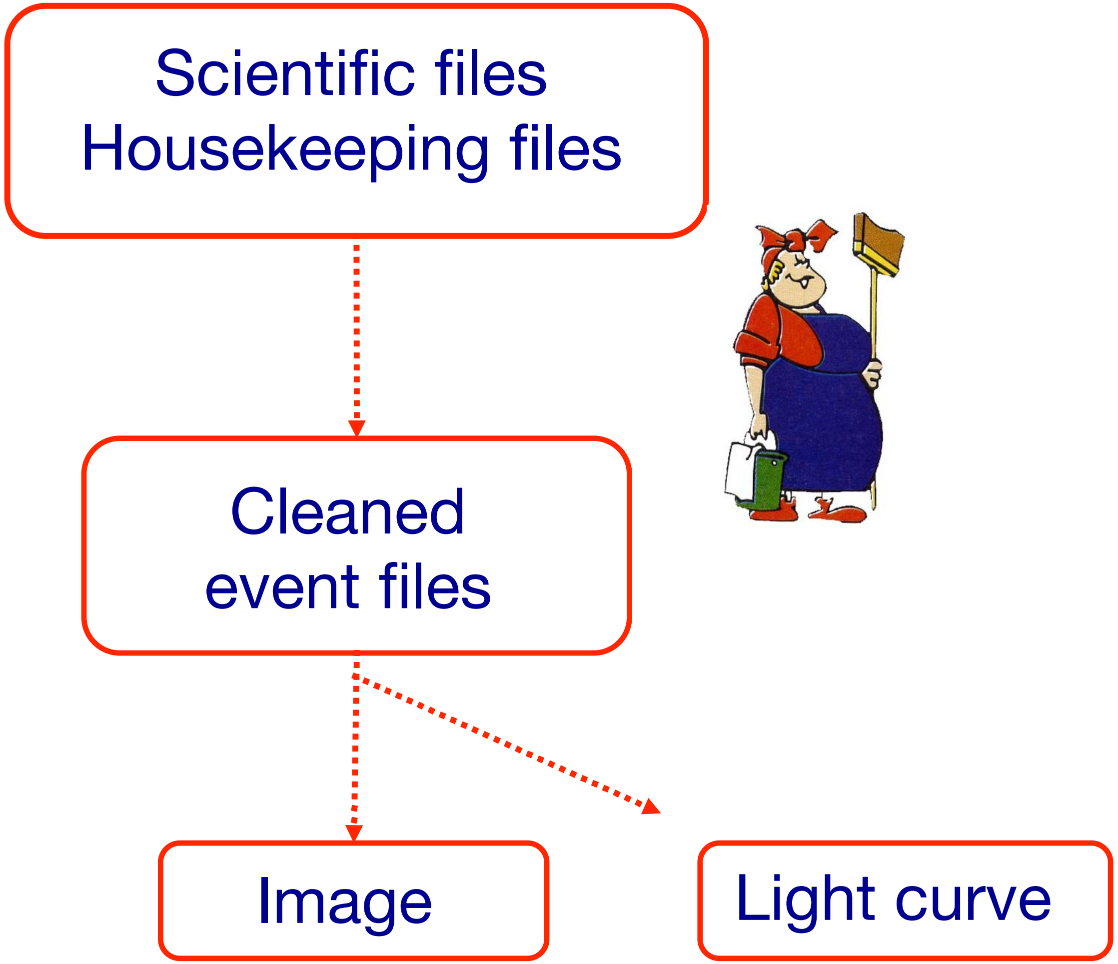
It is possible to improve the image look

smoothing





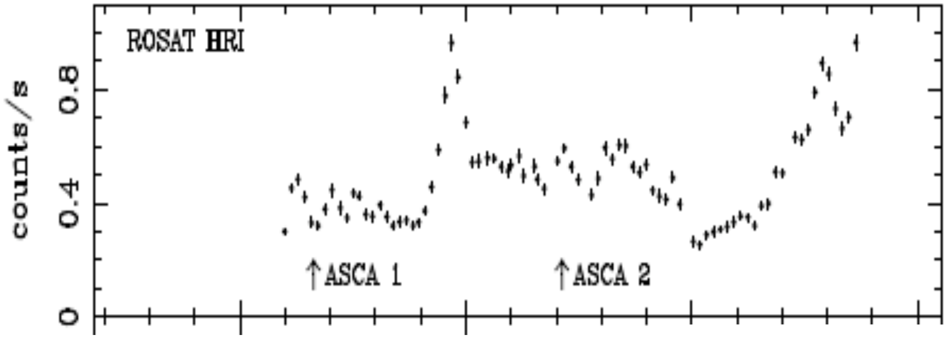
To **smooth an image** means to substitute the value of each pixel for the value obtained by weighting the pixels nearby with a certain function, that generally is a Gaussian.

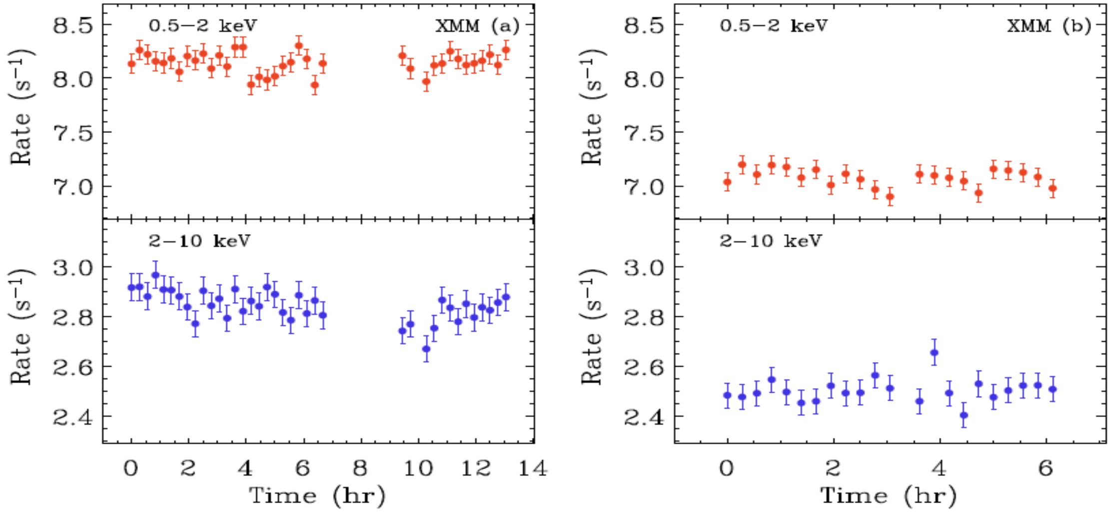


see XMM tutorial...

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.

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.





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)

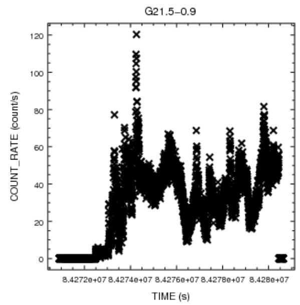
```
>punlearn dmextract
>pset dmextract infile="acisf00953N003_evt2.fits
  [ccd_id=3,sky=region(src2.reg)][bin time= : : 2000]"
>pset dmextract outfile="src_sub_lc.fits"
>pset dmextract bkg="acisf00953N003_evt2.fits
  [ccd_id=3,sky=region(bkg.reg)]"
>pset dmextract opt="ltc1"
>dmextract
```

MIN:MAX:STEP

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

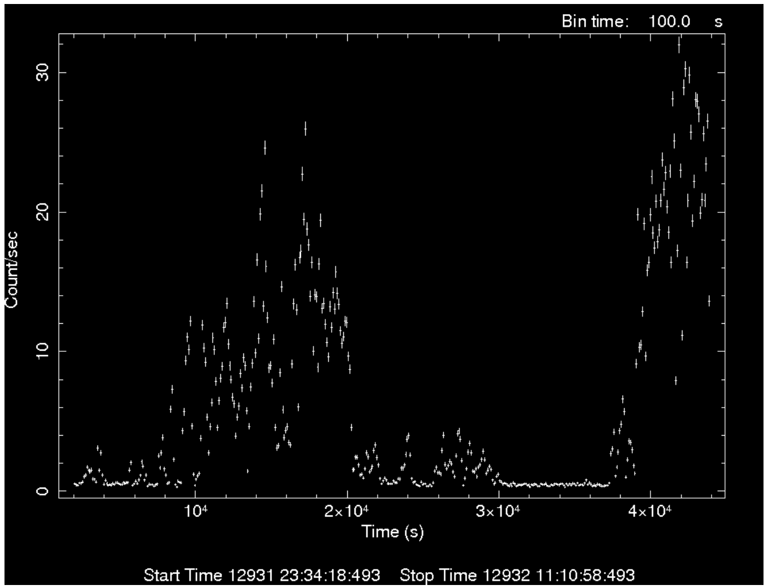
Chips provided by CIAO

```
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 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;

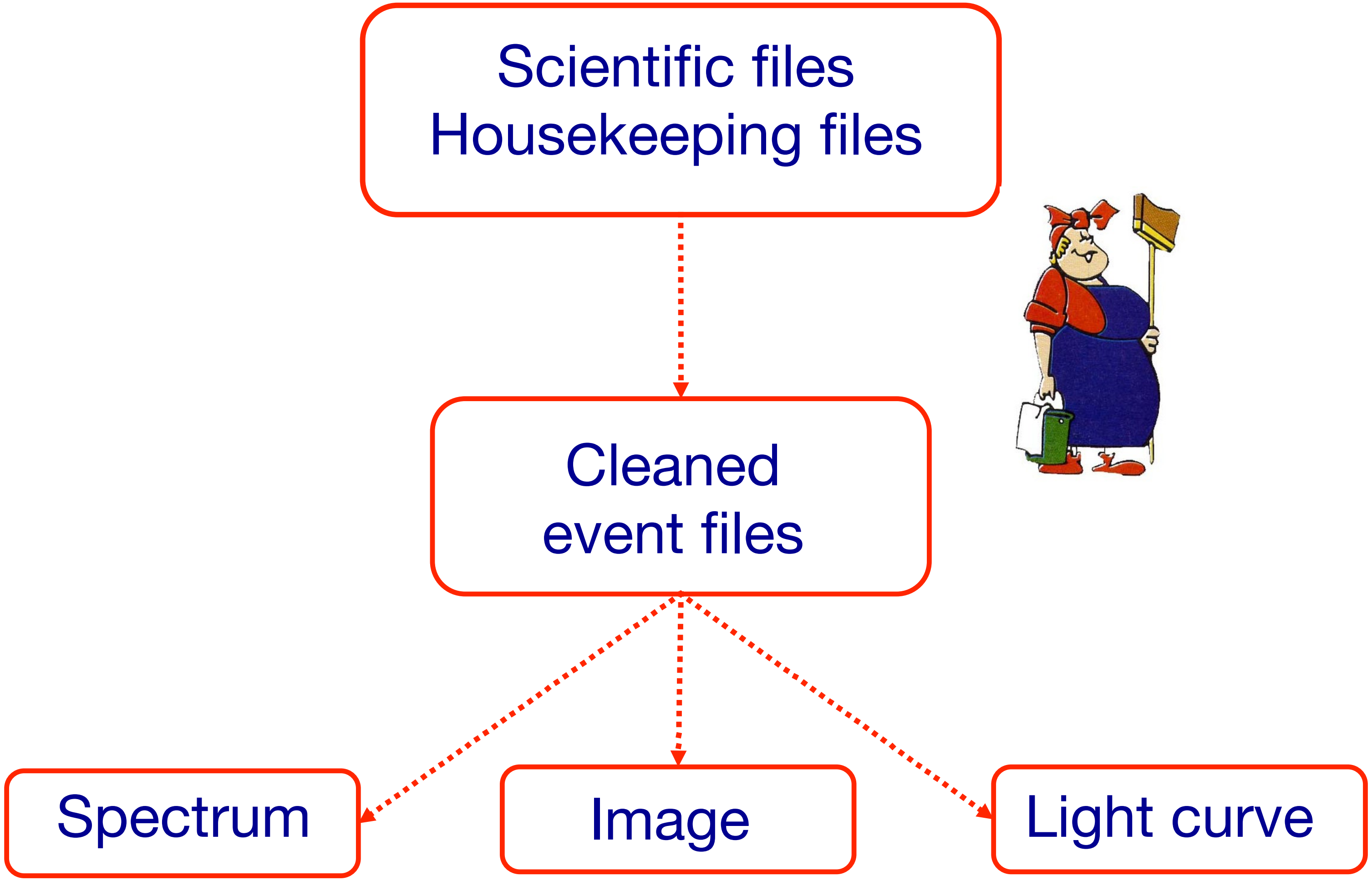
σ_i Poissonian erro;

v = n-1 degrees of freedom;

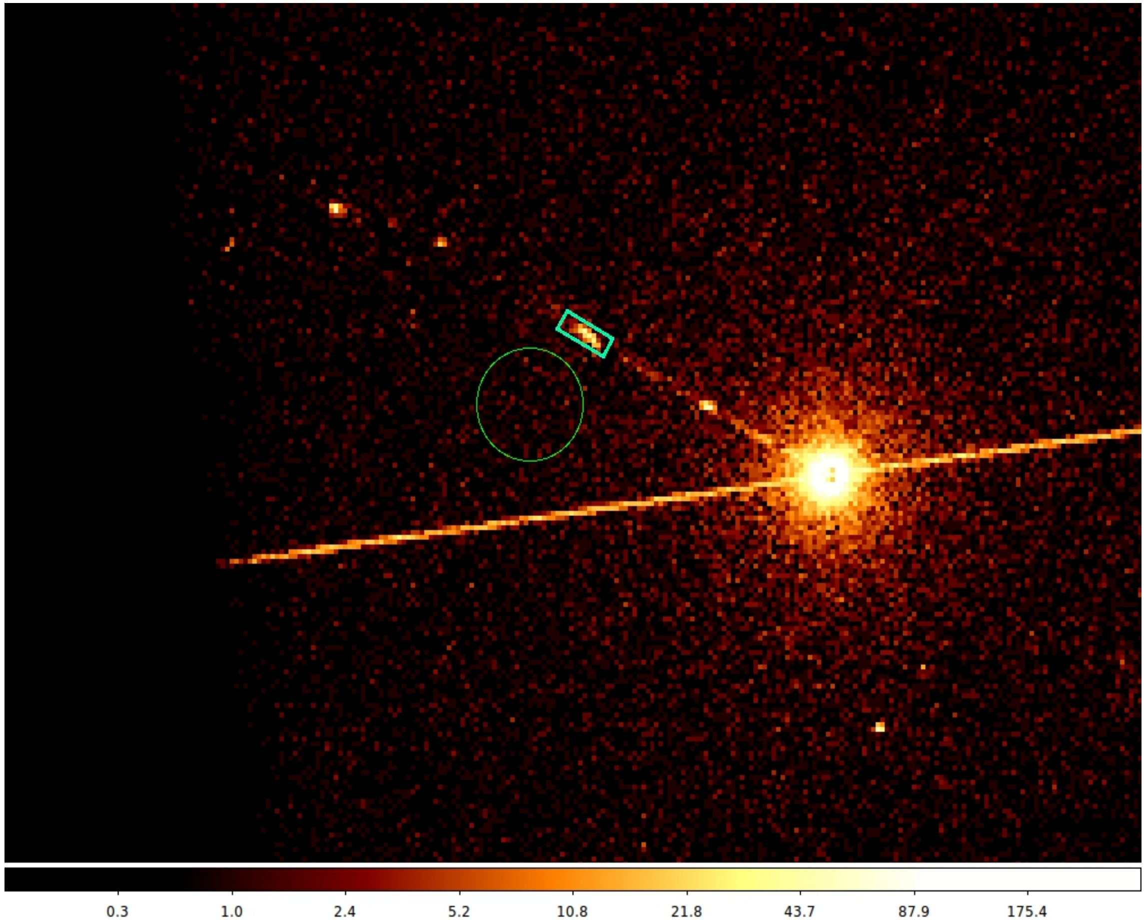
Compute the null hypothesis probability that the source is not varied

this test should be repeated for several temporal bins.

See the IDL tutorial...


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

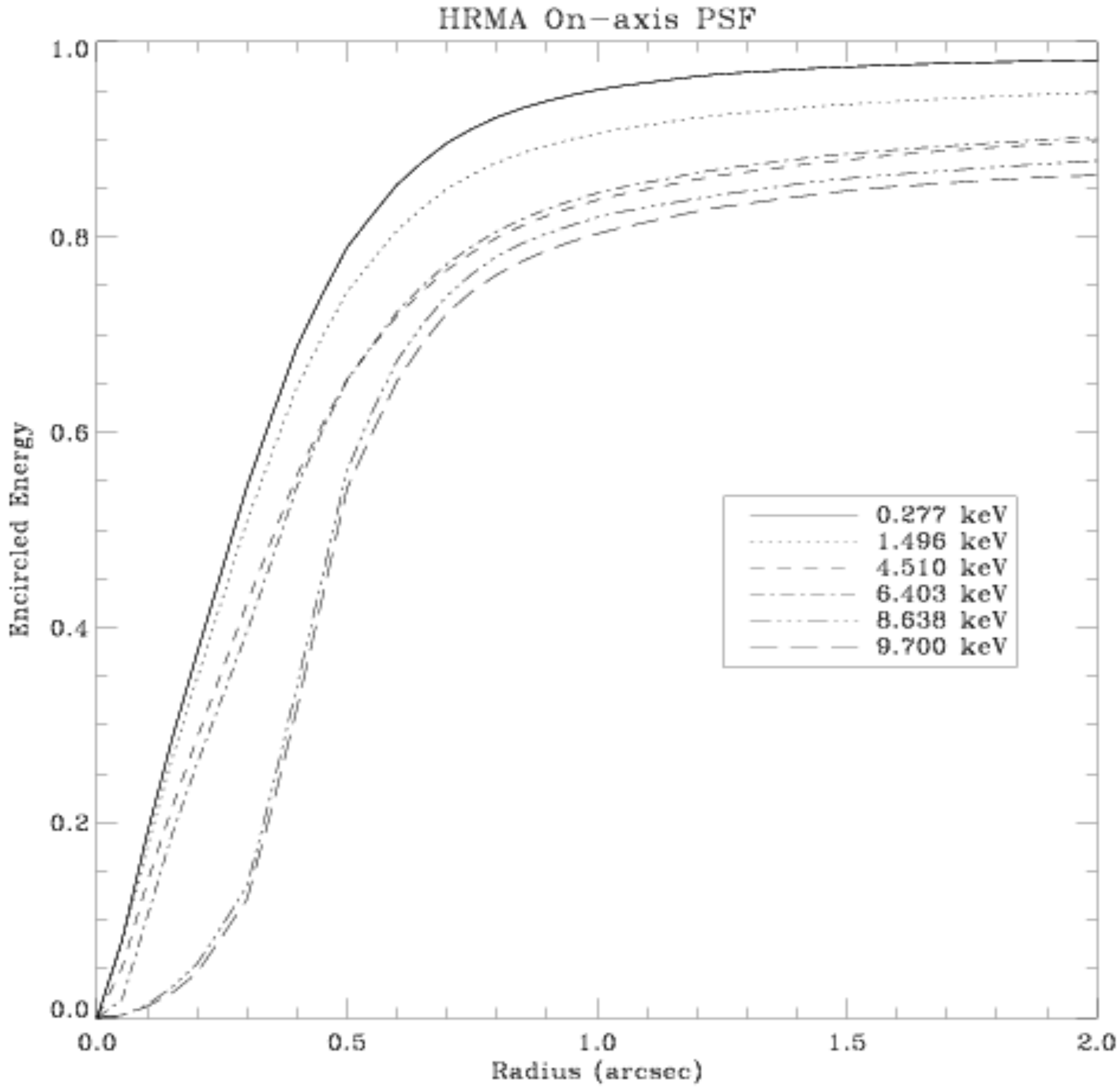
To extract the spectrum of a *pointlike* source…

```
-> 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 pbkfile=acisf089424366N002_pbk0.fits
-> pset specextract grouptype=NUM_CTS binspec=15
-> 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.

Fractional encircled energy



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 pbkfile=acisf089424366N002_pbk0.fits
-> pset specextract grouptype=NUM_CTS binspec=15
-> 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.

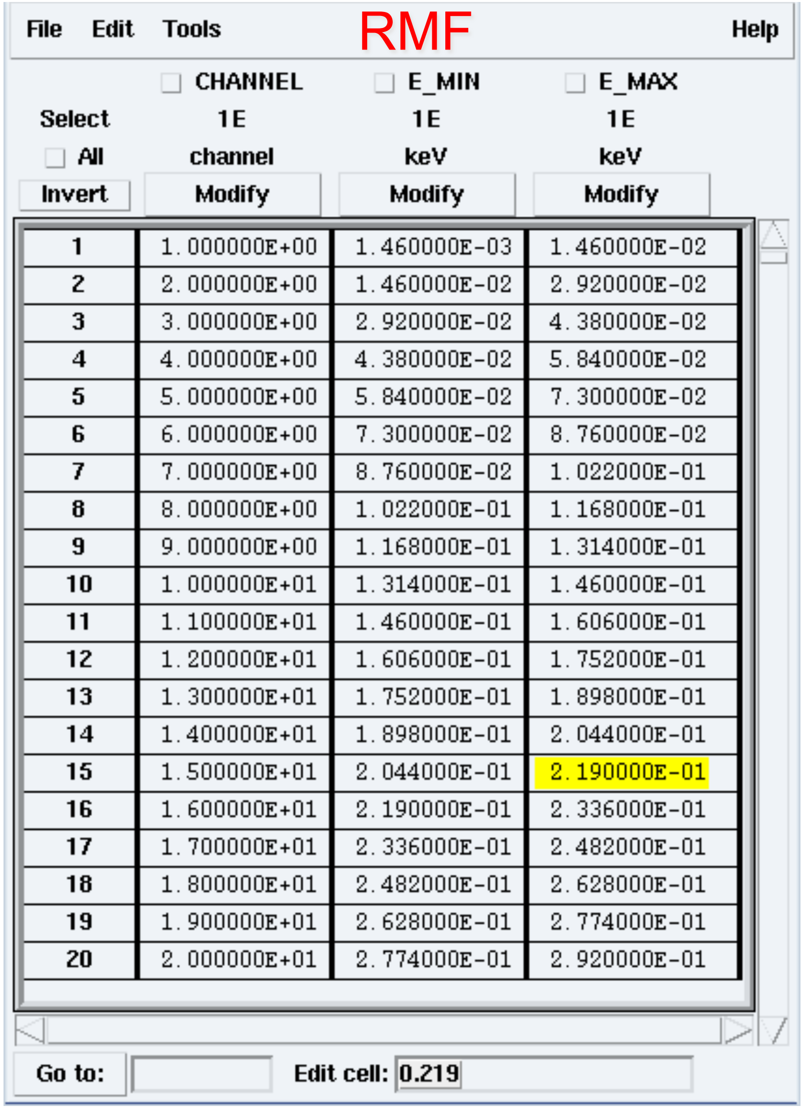
The response matrix is composed by

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

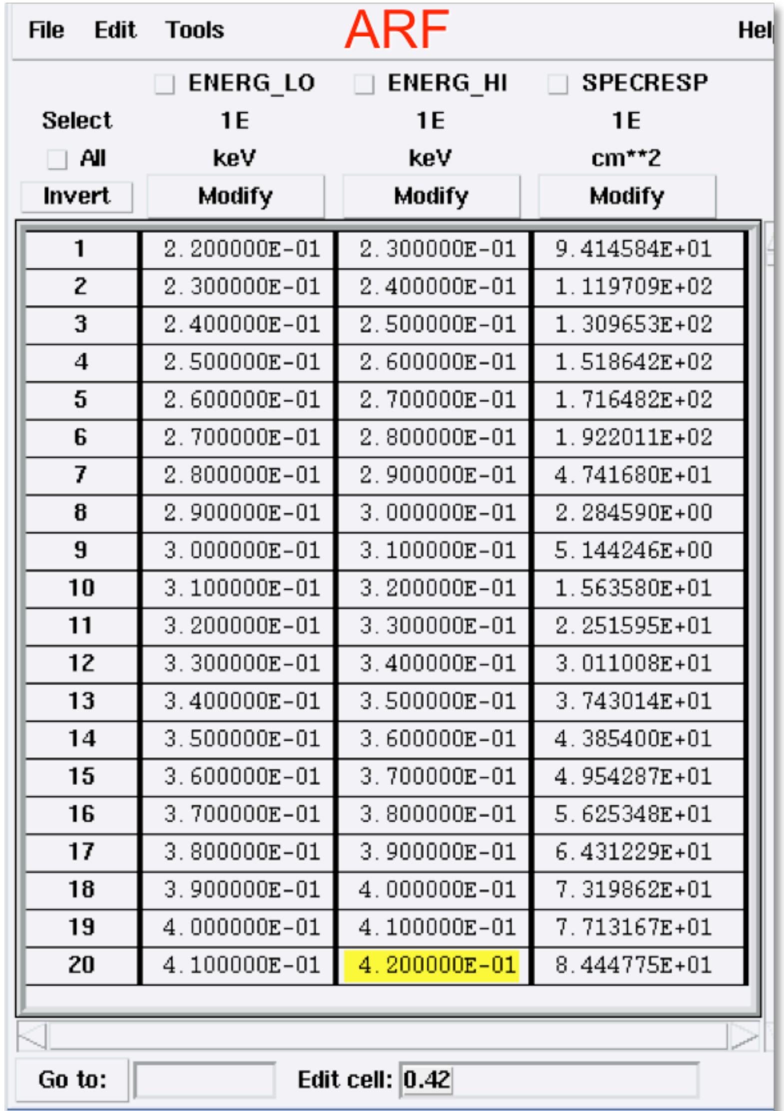
2. The ***Auxiliary Response File (ARF):*** includes information on the effective area, filter transmission and any additional energy-dependent efficiencies, i.e. **the efficiency of the instrument in revealing photons.**

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.

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

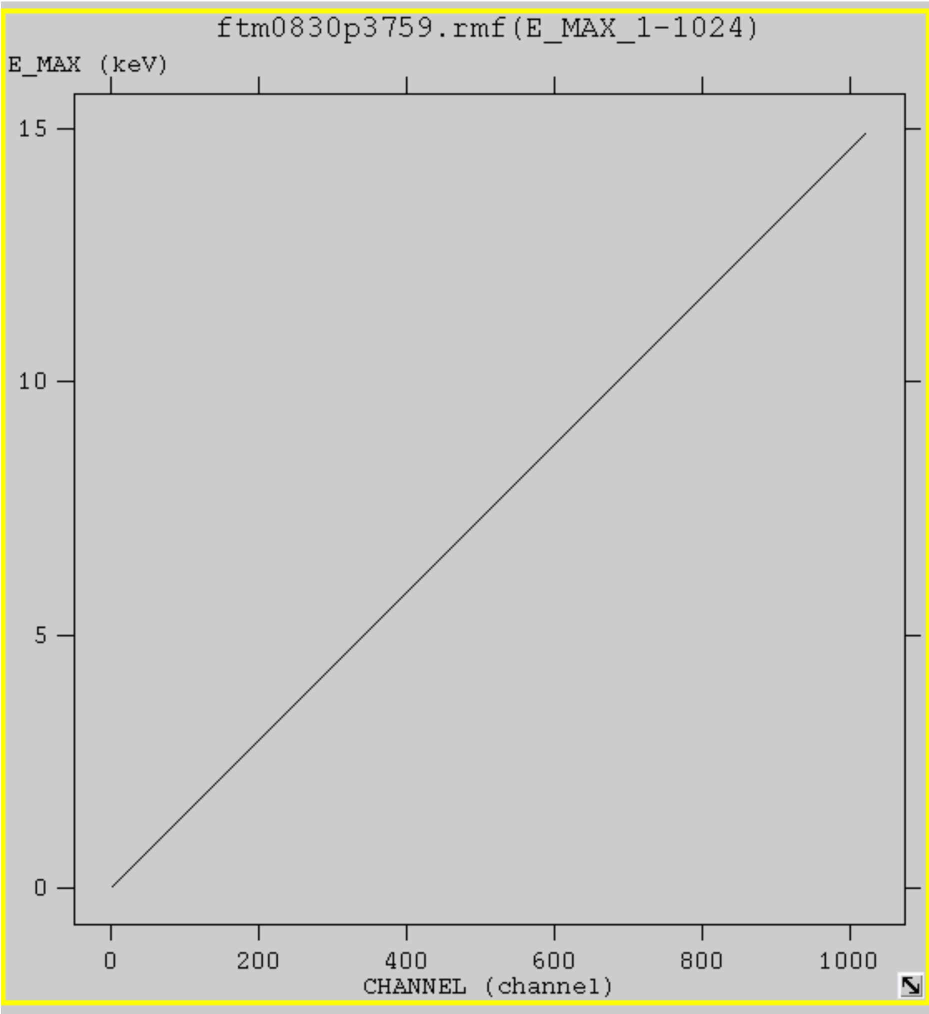


Select	CHANNEL	E_MIN	E_MAX
	1E	1E	1E
All	channel	keV	keV
Invert	Modify	Modify	Modify
1	1.000000E+00	1.460000E-03	1.460000E-02
2	2.000000E+00	1.460000E-02	2.920000E-02
3	3.000000E+00	2.920000E-02	4.380000E-02
4	4.000000E+00	4.380000E-02	5.840000E-02
5	5.000000E+00	5.840000E-02	7.300000E-02
6	6.000000E+00	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



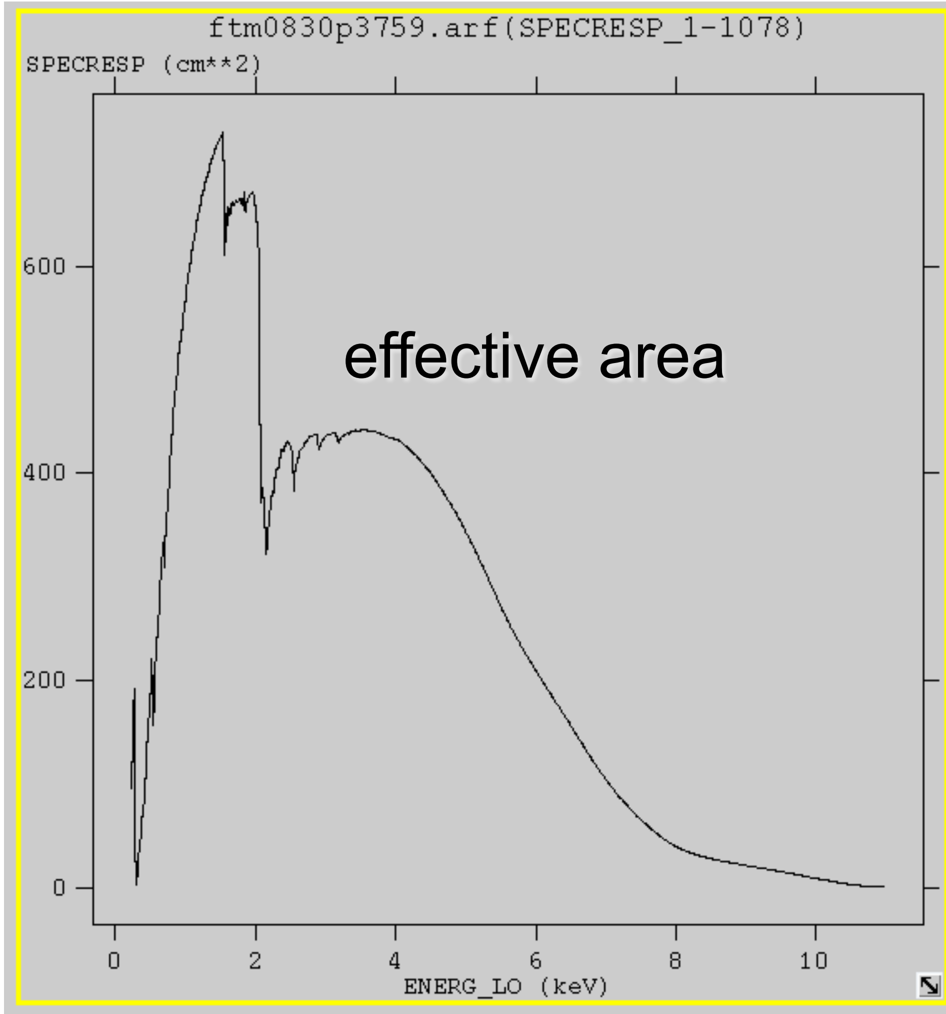
Select	ENERG_LO	ENERG_HI	SPECRESP
	1E	1E	1E
All	keV	keV	cm**2
Invert	Modify	Modify	Modify
1	2.200000E-01	2.300000E-01	9.414584E+01
2	2.300000E-01	2.400000E-01	1.119709E+02
3	2.400000E-01	2.500000E-01	1.309653E+02
4	2.500000E-01	2.600000E-01	1.518642E+02
5	2.600000E-01	2.700000E-01	1.716482E+02
6	2.700000E-01	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

RMF



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

ARF



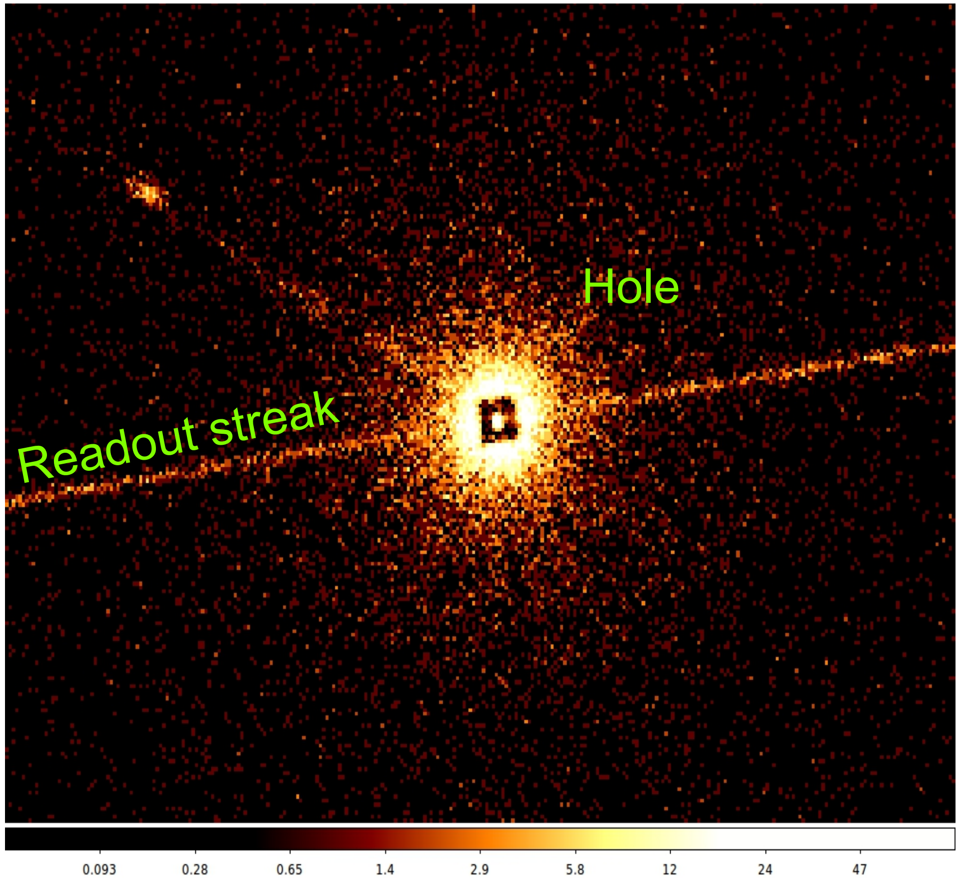
ftm0830p3759.arf(SPECRESP_1-1078)
SPECRESP (cm**2)
600
400
200
0
effective area
0
2
4
6
8
10
ENERG_LO (keV)

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 informatio from these events

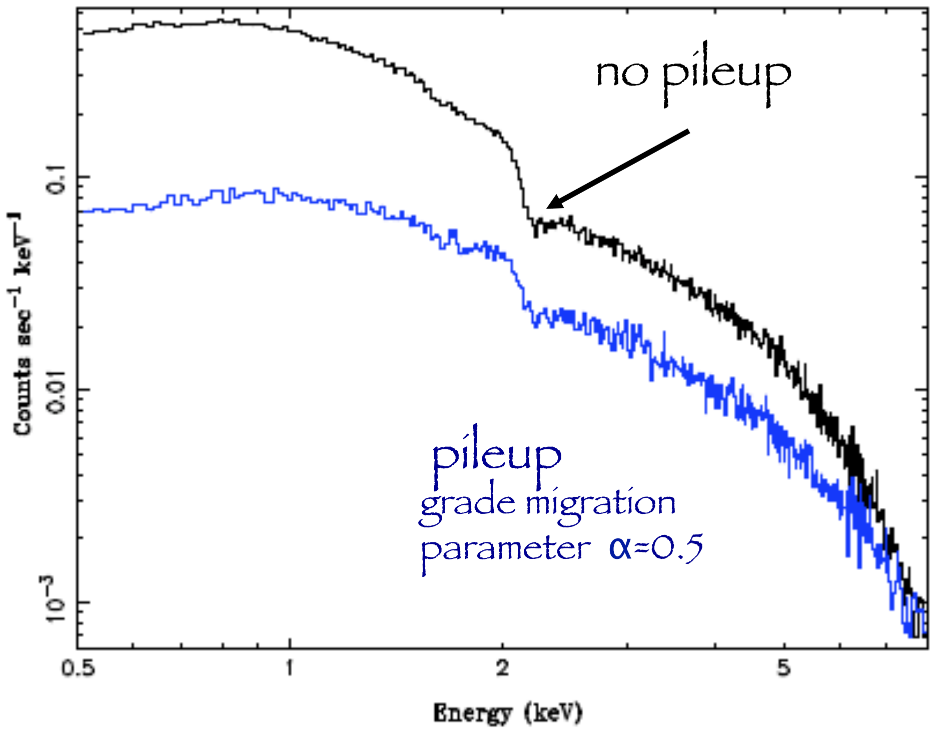


Pileup two major effects are:
ENERGY MIGRATION photon energies sum to create a detected event with higher energy;
GRADE MIGRATION event grades migrate towards values inconsistent with real photon events.

- net decrease of the observed count rate

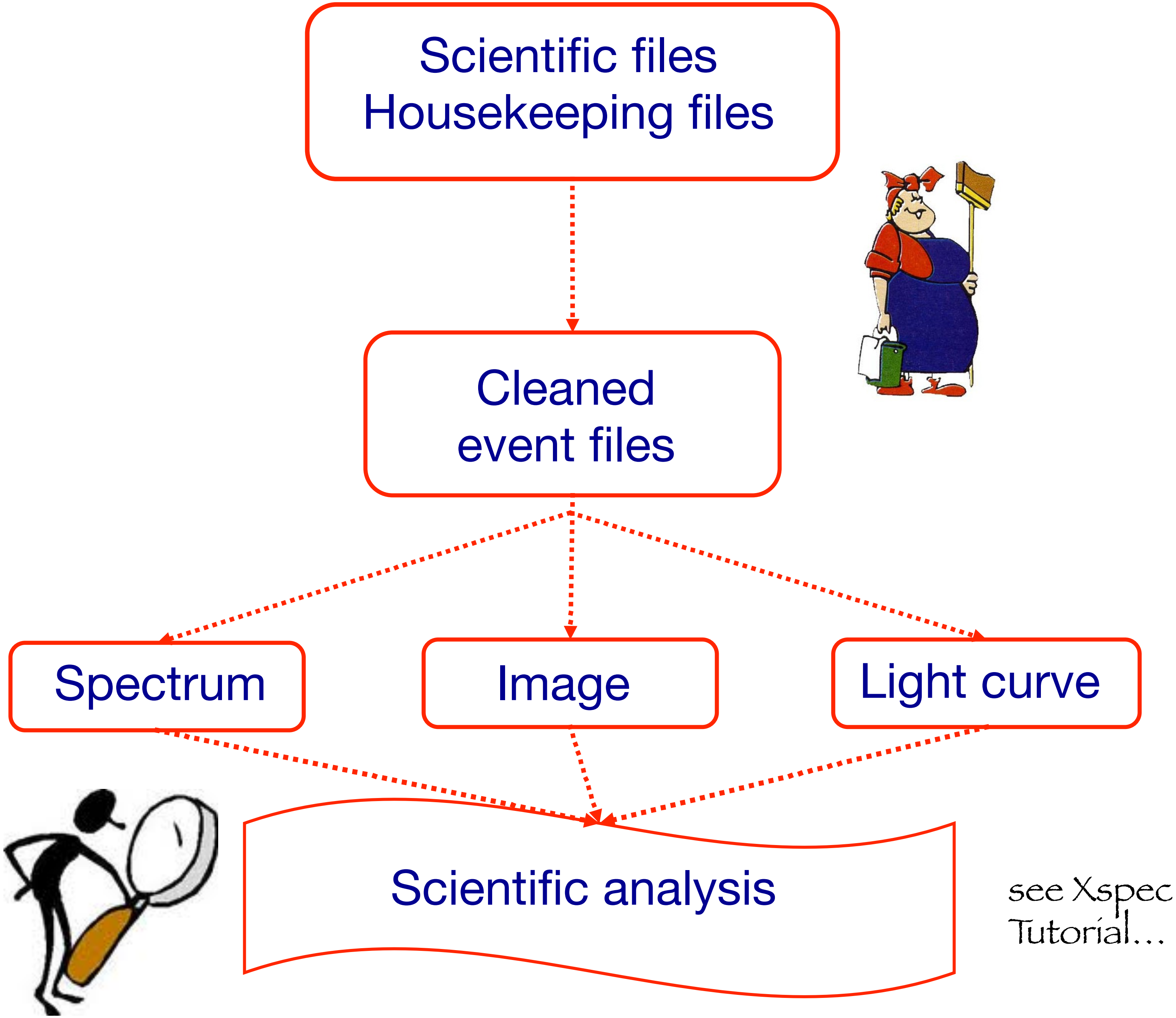
- net decrease in the fractional rms variability of the lightcurve

detected spectral shape of the source distorted



Avoid pileup: reduce the counts per frame pixels (PIMMS)

Pileup mitigation: use an XSPEC – pileup model


Scientific files
Housekeeping files
Cleaned
event files
Spectrum
Image
Light curve
Scientific analysis
see Xspec
Tutorial...

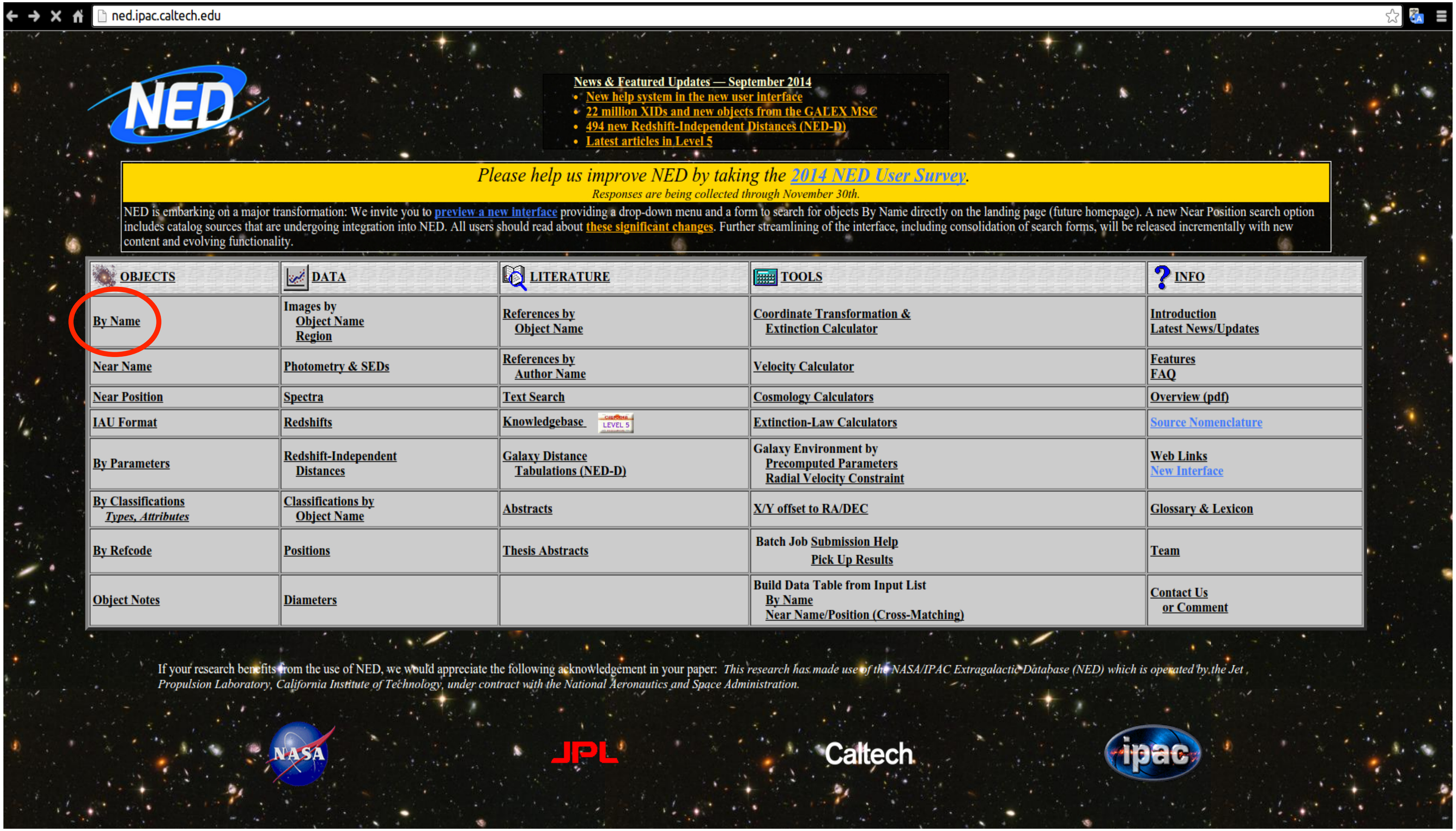
→ How to download X-ray data from a public archive

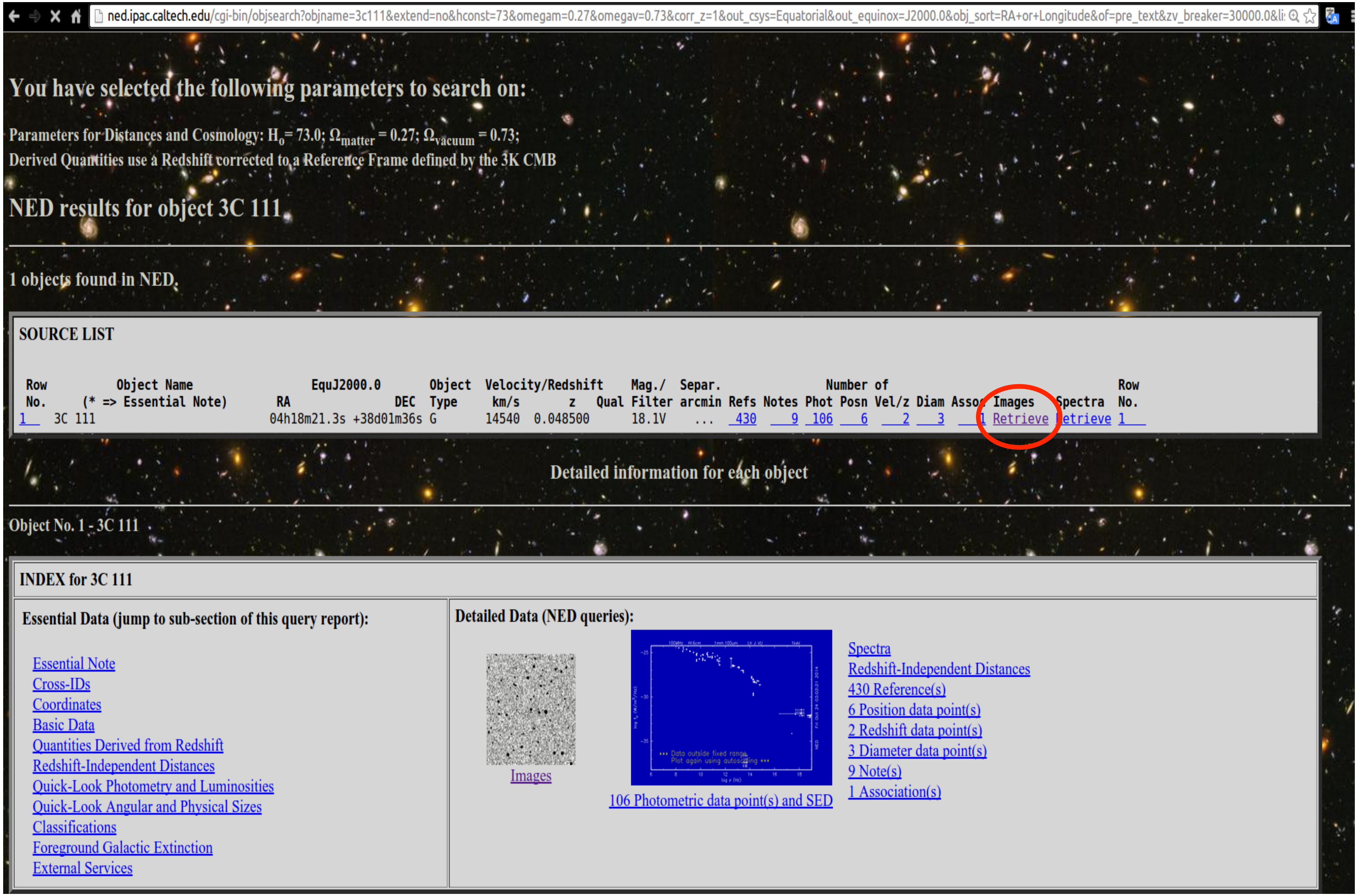
→ How the downloaded files look like

→ How to reduce X-ray (*Chandra*) data

→ How to create the radio and/or X-ray contours for an extended object

http://ned.ipac.caltech.edu/





ned.ipac.caltech.edu/cgi-bin/objsearch?objname=3c111&extend=no&hconst=73&omegam=0.27&omegav=0.73&corr_z=1&out_csys=Equatorial&out_equinox=J2000.0&obj_sort=RA+or+Longitude&of=pre_text&zv_breaker=30000.0&li

You have selected the following parameters to search on:

Parameters for Distances and Cosmology: H_o = 73.0; Ω_{matter} = 0.27; Ω_{vacuum} = 0.73;
Derived Quantities use a Redshift corrected to a Reference Frame defined by the 3K CMB

NED results for object 3C 111

1 objects found in NED.

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	Row No.
1	3C 111	04h18m21.3s	+38d01m36s	G	14540	0.048500		18.1V	...	430	9	106	6	2	3	1	Retrieve	Retrieve	1

Detailed information for each object

Object No. 1 - 3C 111

INDEX for 3C 111

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

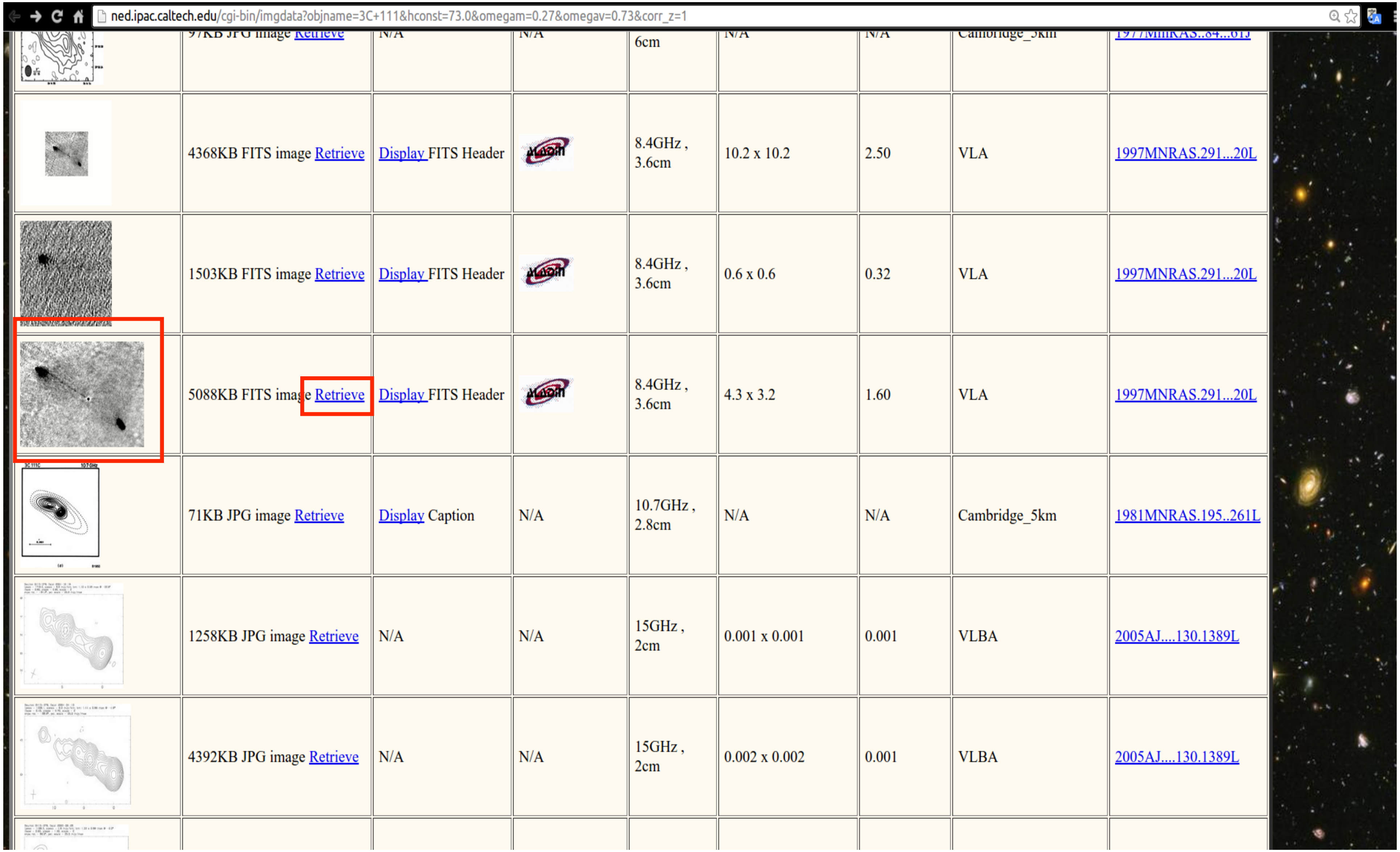
- Essential Note
- Cross-IDs
- Coordinates
- Basic Data
- Quantities Derived from Redshift
- Redshift-Independent Distances
- Quick-Look Photometry and Luminosities
- Quick-Look Angular and Physical Sizes
- Classifications
- Foreground Galactic Extinction
- External Services

Detailed Data (NED queries):

Images

106 Photometric data point(s) and SED

- Spectra
- Redshift-Independent Distances
- 430 Reference(s)
- 6 Position data point(s)
- 2 Redshift data point(s)
- 3 Diameter data point(s)
- 9 Note(s)
- 1 Association(s)



ned.ipac.caltech.edu/cgi-bin/imgdata?objname=3C+111&hconst=73.0&omegam=0.27&omegav=0.73&corr_z=1

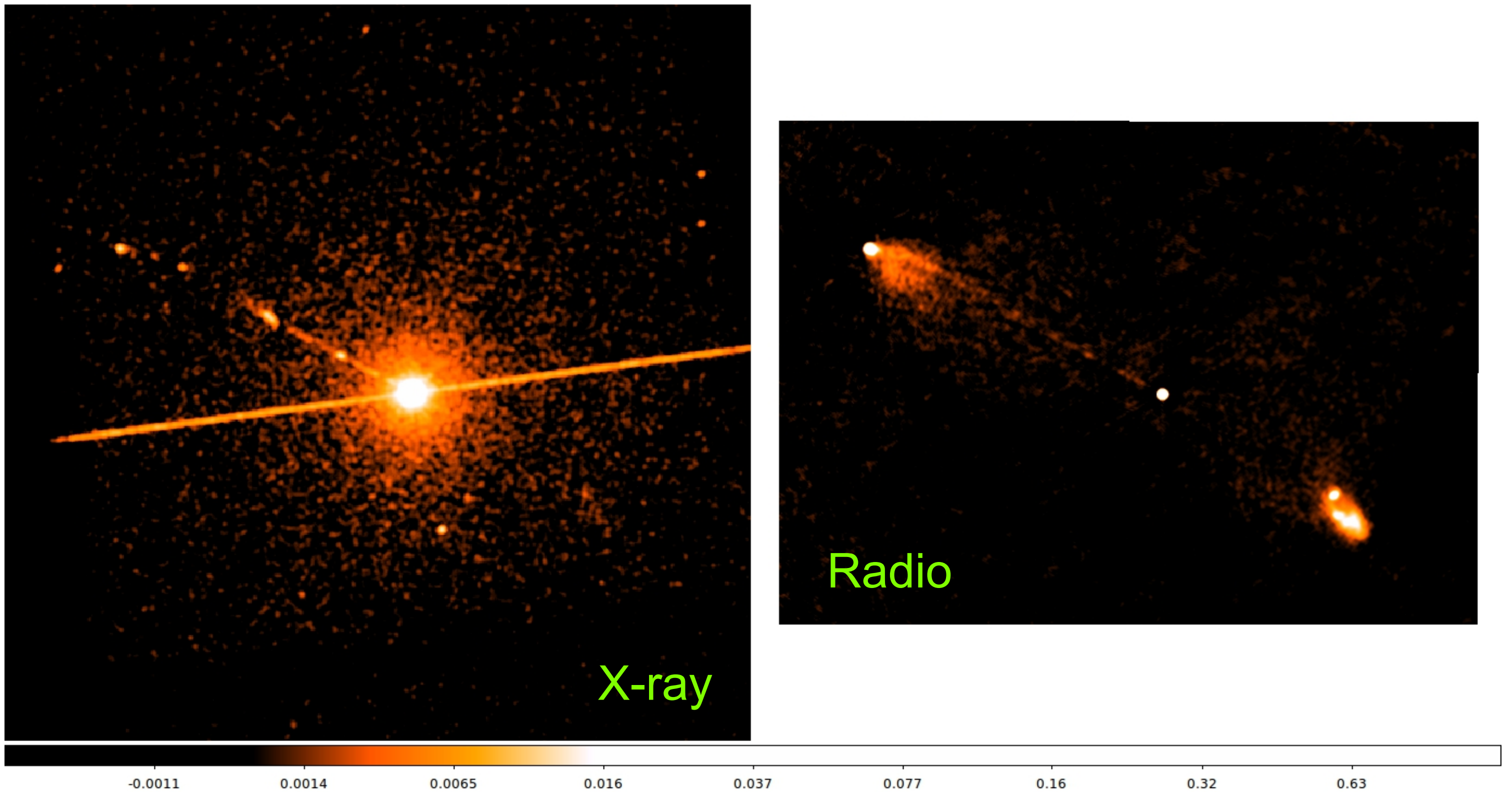
	97KB JPG image Retrieve	N/A	N/A	6cm	N/A	N/A	Cambridge_5km	1977MNRAS..84...61J
	4368KB FITS image Retrieve	Display FITS Header		8.4GHz , 3.6cm	10.2 x 10.2	2.50	VLA	1997MNRAS.291...20L
	1503KB FITS image Retrieve	Display FITS Header		8.4GHz , 3.6cm	0.6 x 0.6	0.32	VLA	1997MNRAS.291...20L
	5088KB FITS image Retrieve	Display FITS Header		8.4GHz , 3.6cm	4.3 x 3.2	1.60	VLA	1997MNRAS.291...20L
	71KB JPG image Retrieve	Display Caption	N/A	10.7GHz , 2.8cm	N/A	N/A	Cambridge_5km	1981MNRAS.195..261L
	1258KB JPG image Retrieve	N/A	N/A	15GHz , 2cm	0.001 x 0.001	0.001	VLBA	2005AJ....130.1389L
	4392KB JPG image Retrieve	N/A	N/A	15GHz , 2cm	0.002 x 0.002	0.001	VLBA	2005AJ....130.1389L

Other useful links

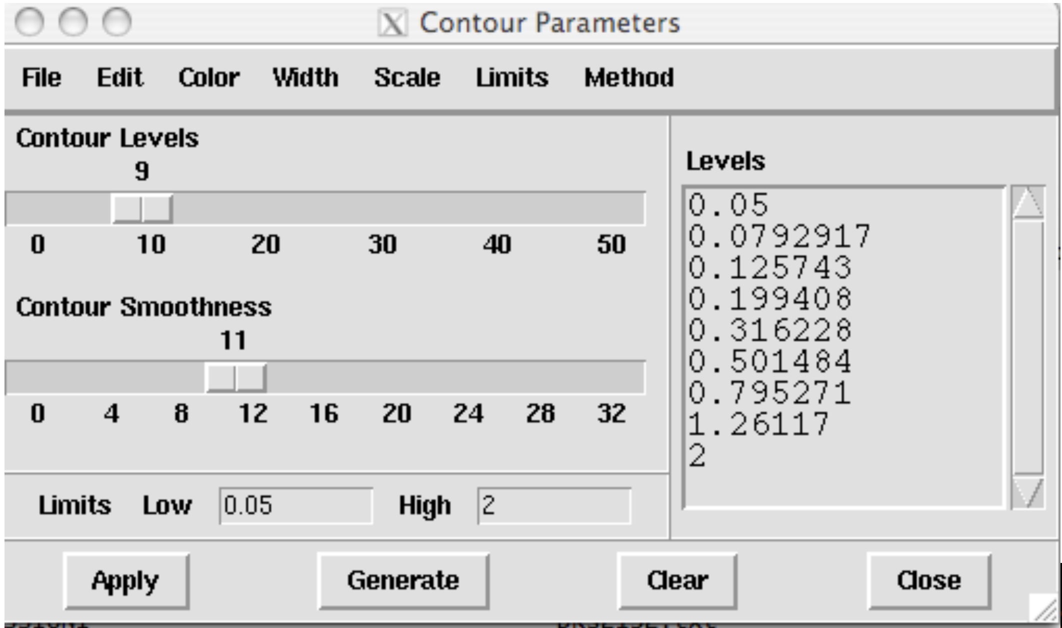
- http://www.jb.man.ac.uk/atlas/icon.html
- http://2jy.extragalactic.info/2Jy_home_page.html
- http://www.jb.man.ac.uk/atlas/dragns.html

> ds9 X-ray_image radio_image

Frame → match frames
→ WCS

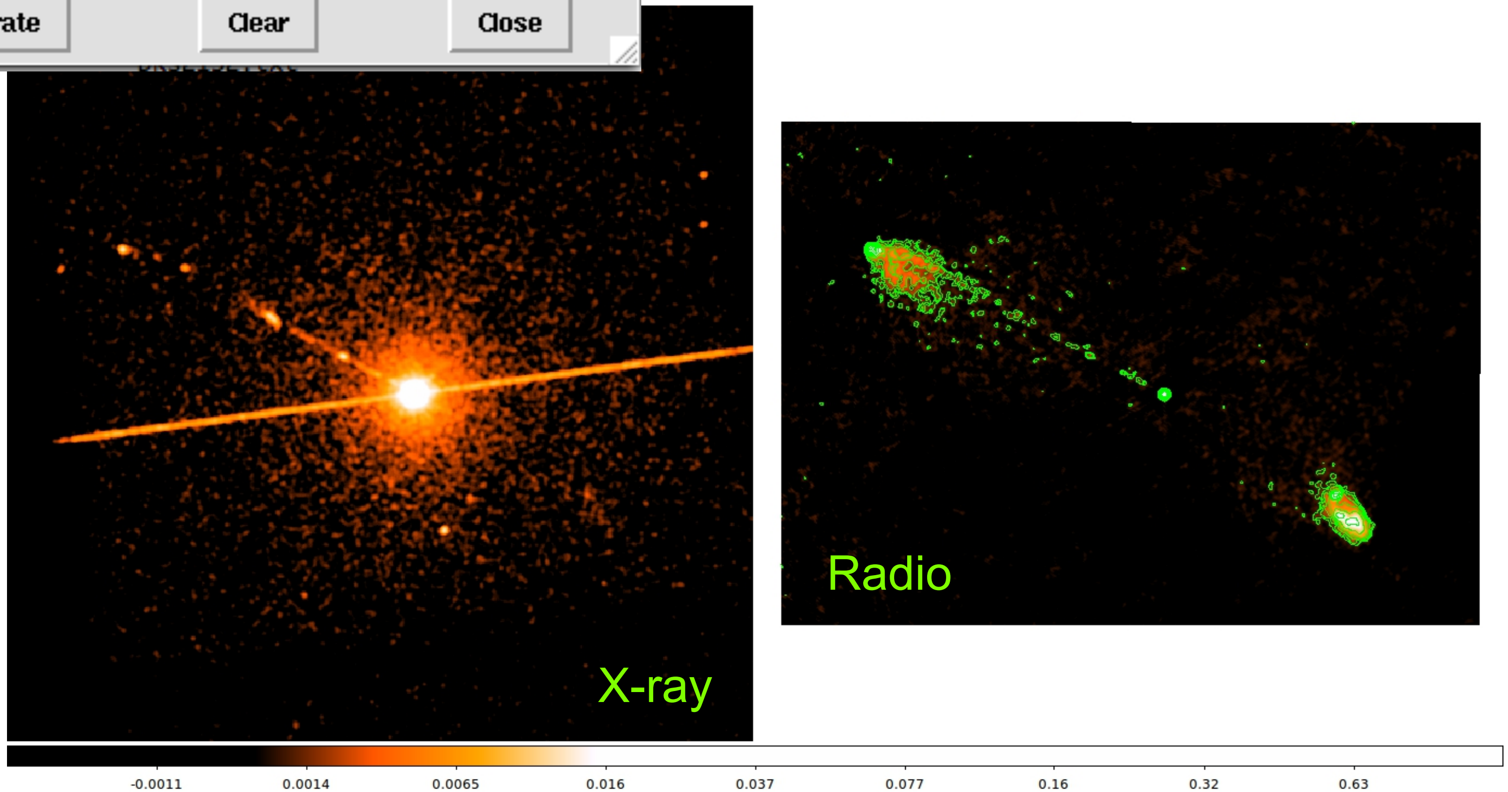


> ds9 X-ray_image radio_image

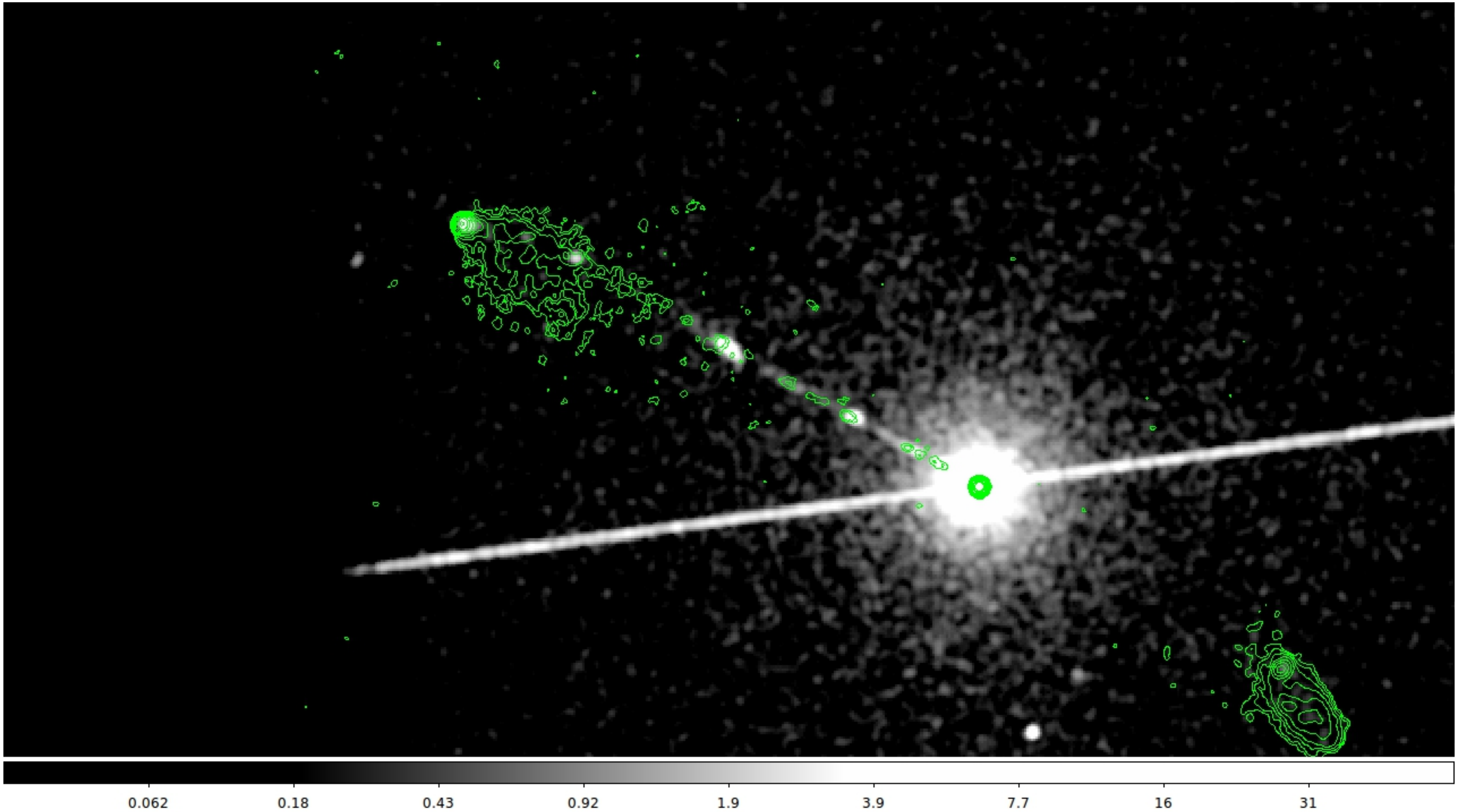


Analysis -> contours parameters

File -> save contours



Analysis → Contour parameters
→ File
→ Load contours



Not only radio/X...

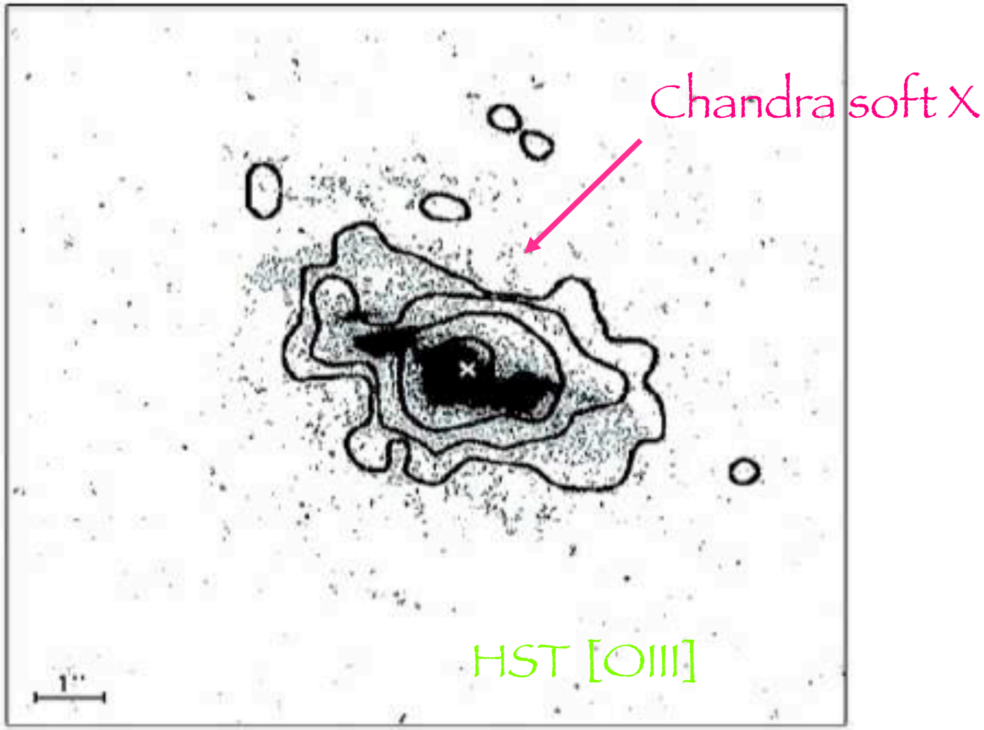


Fig. 4. Superposition of the *Chandra* soft X-ray (<2 keV) contours on an *HST* image taken through a linear ramp filter at redshifted [OIII]λ5007. The sign "**x**" indicates the centre of the hard X-ray source, north is up, east to the left. The X–ray image was smoothed with a Gaussian of FWHM ~ 6 pixels.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


THE END