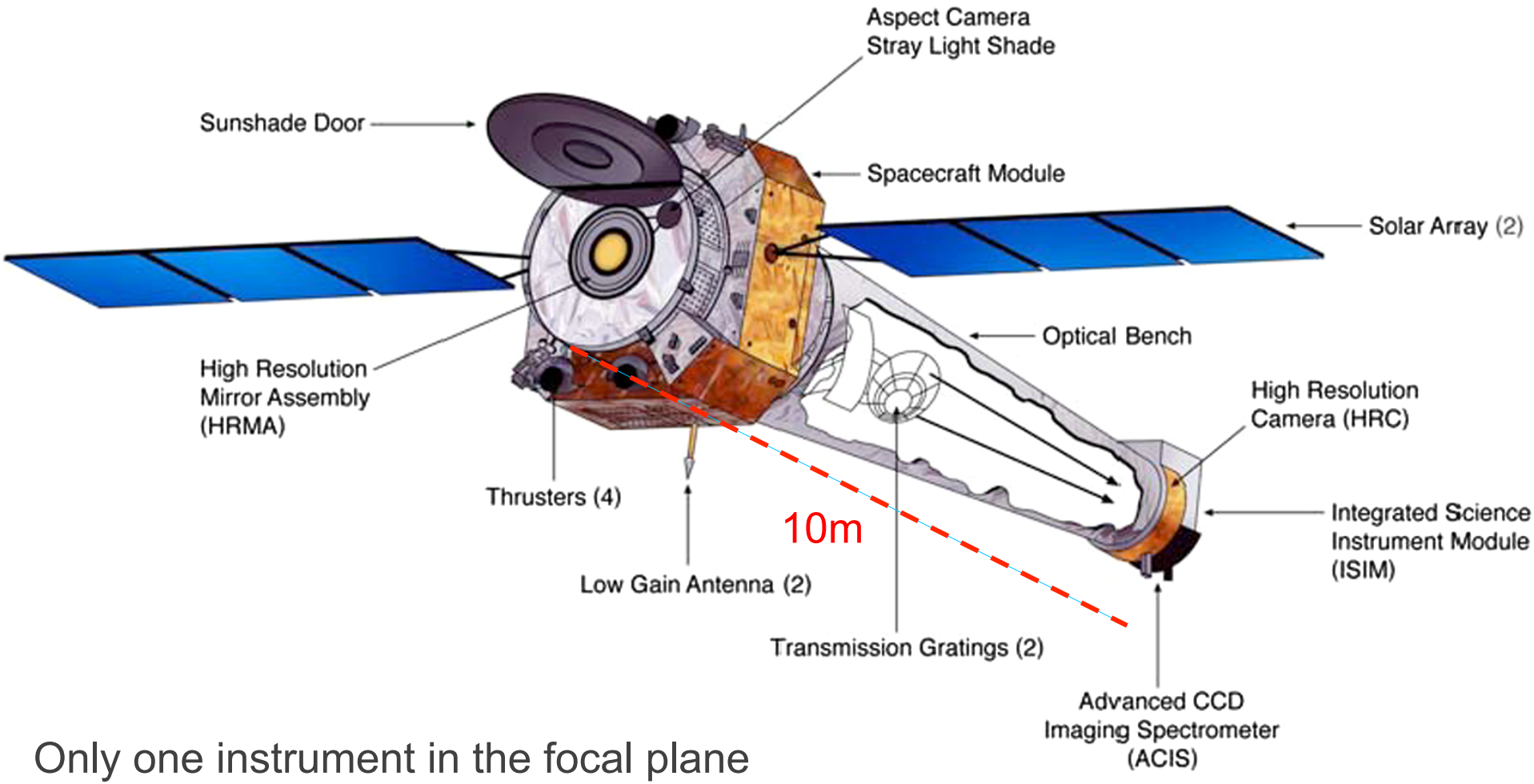
Chandra Tutorial

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

Laboratorio di Astrofisica 2017

The spacecraft

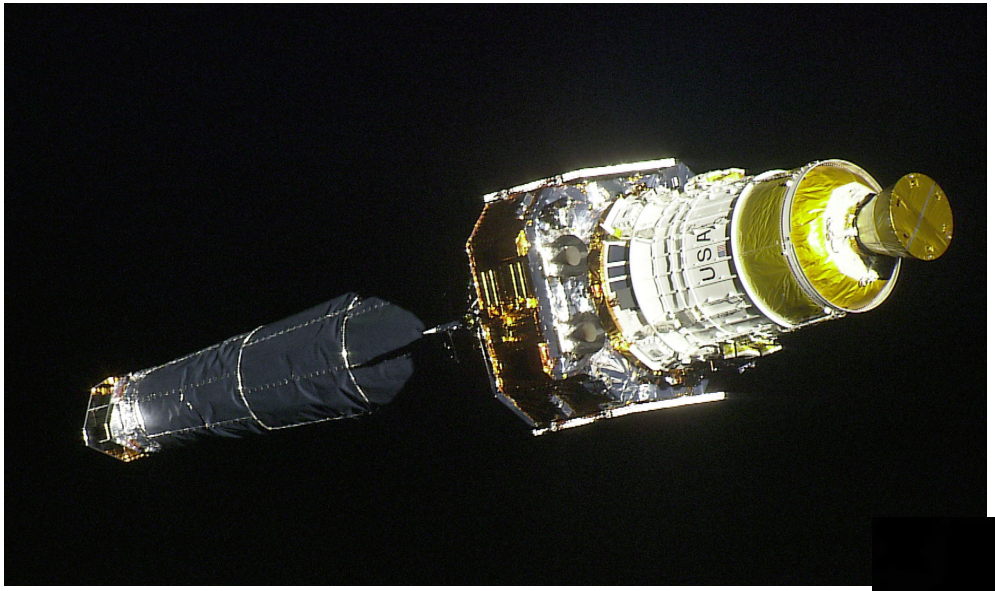


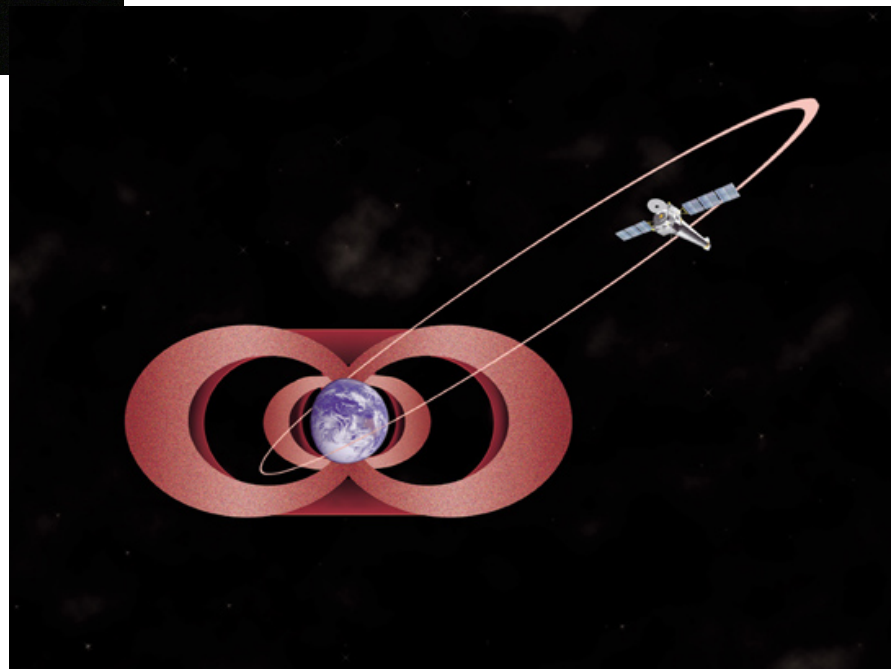
Only one instrument in the focal plane
"active" for each observation

The real spacecraft

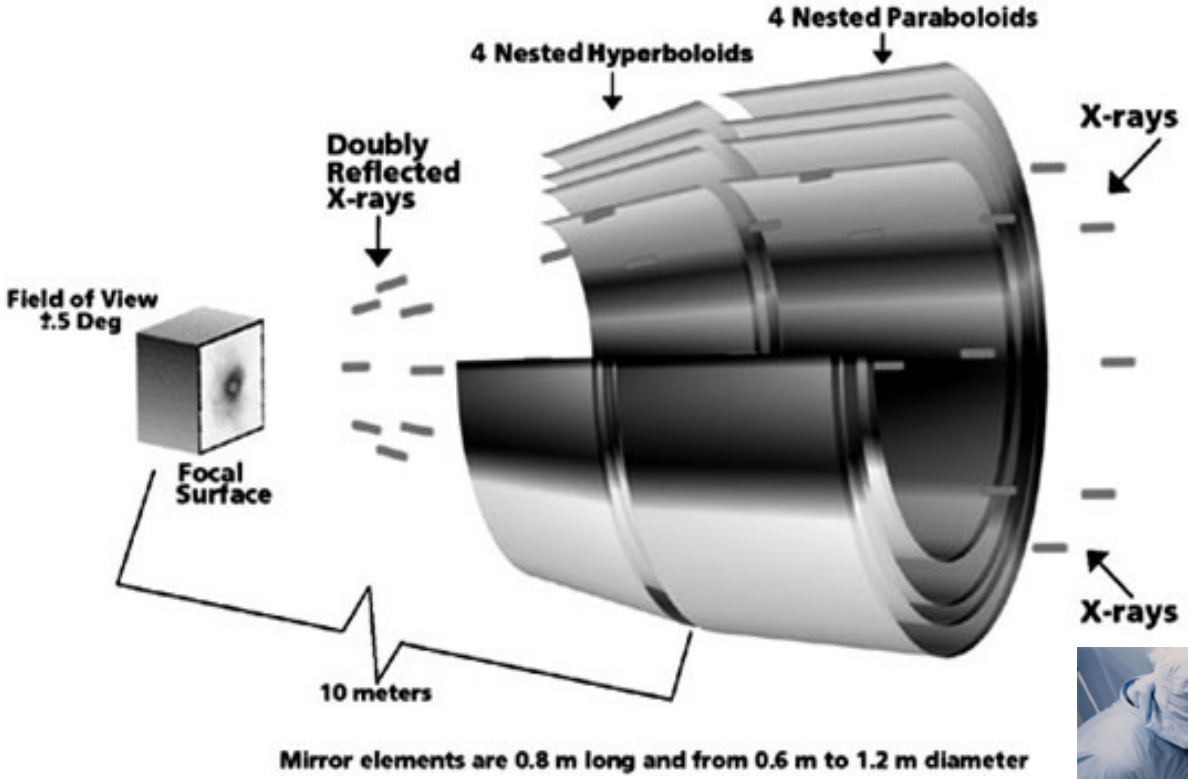
Launched:
July 23, 1999

The real spacecraft



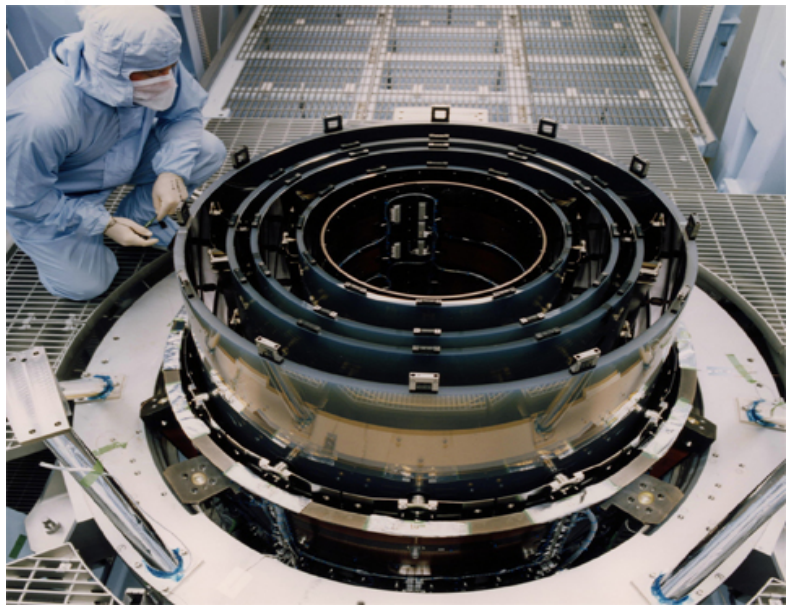


Mirrors



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

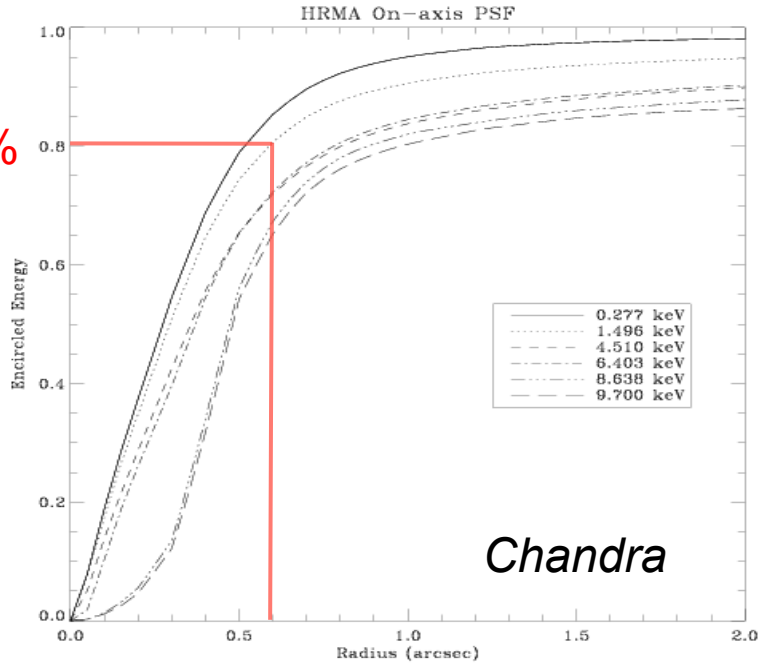
4 mirrors only
Low effective area
but sharp PSF,
hence low
background



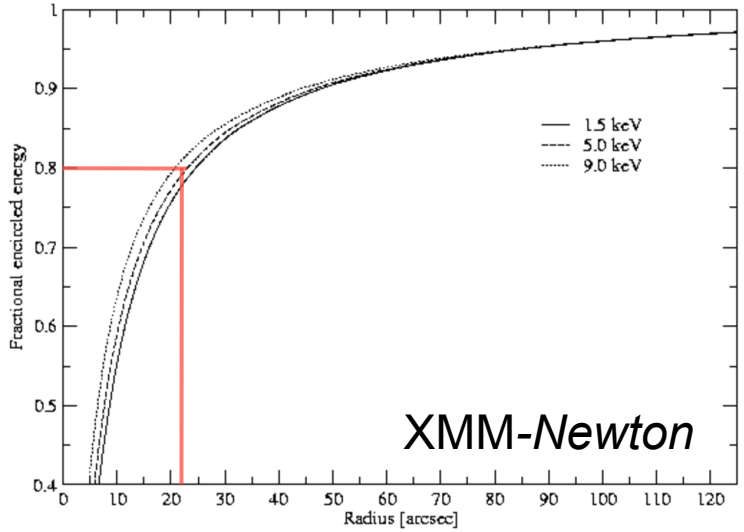
Chandra vs. XMM

PSF

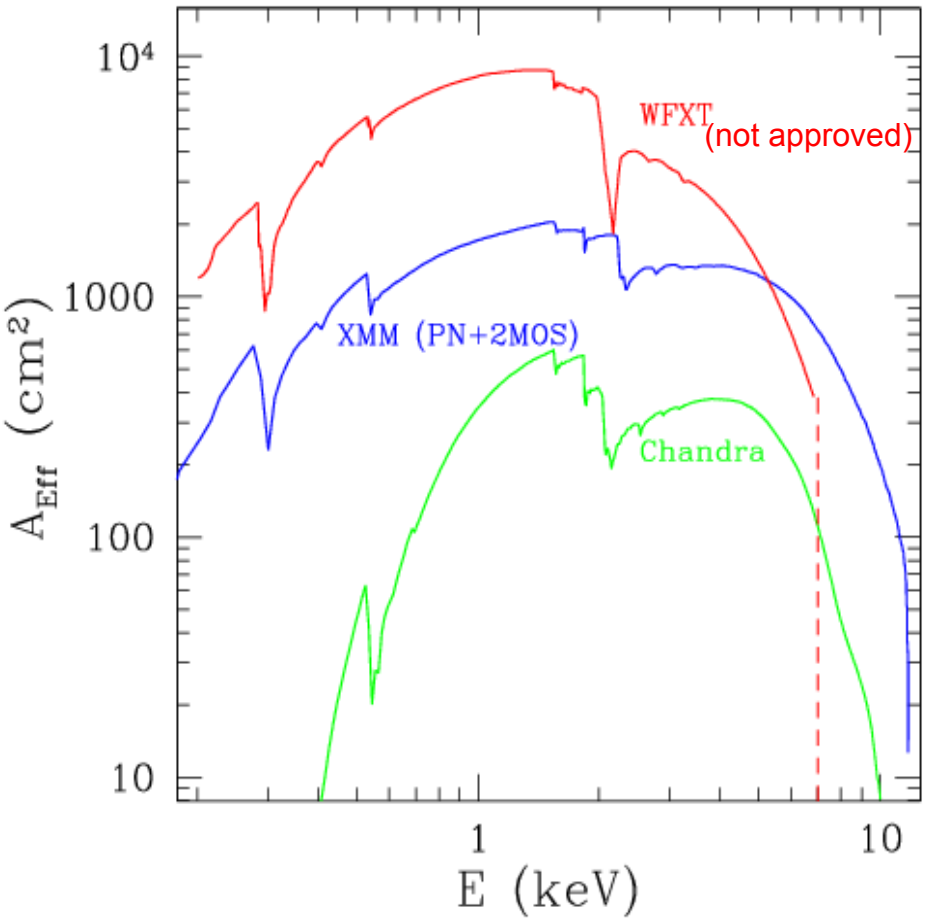
80%



80%

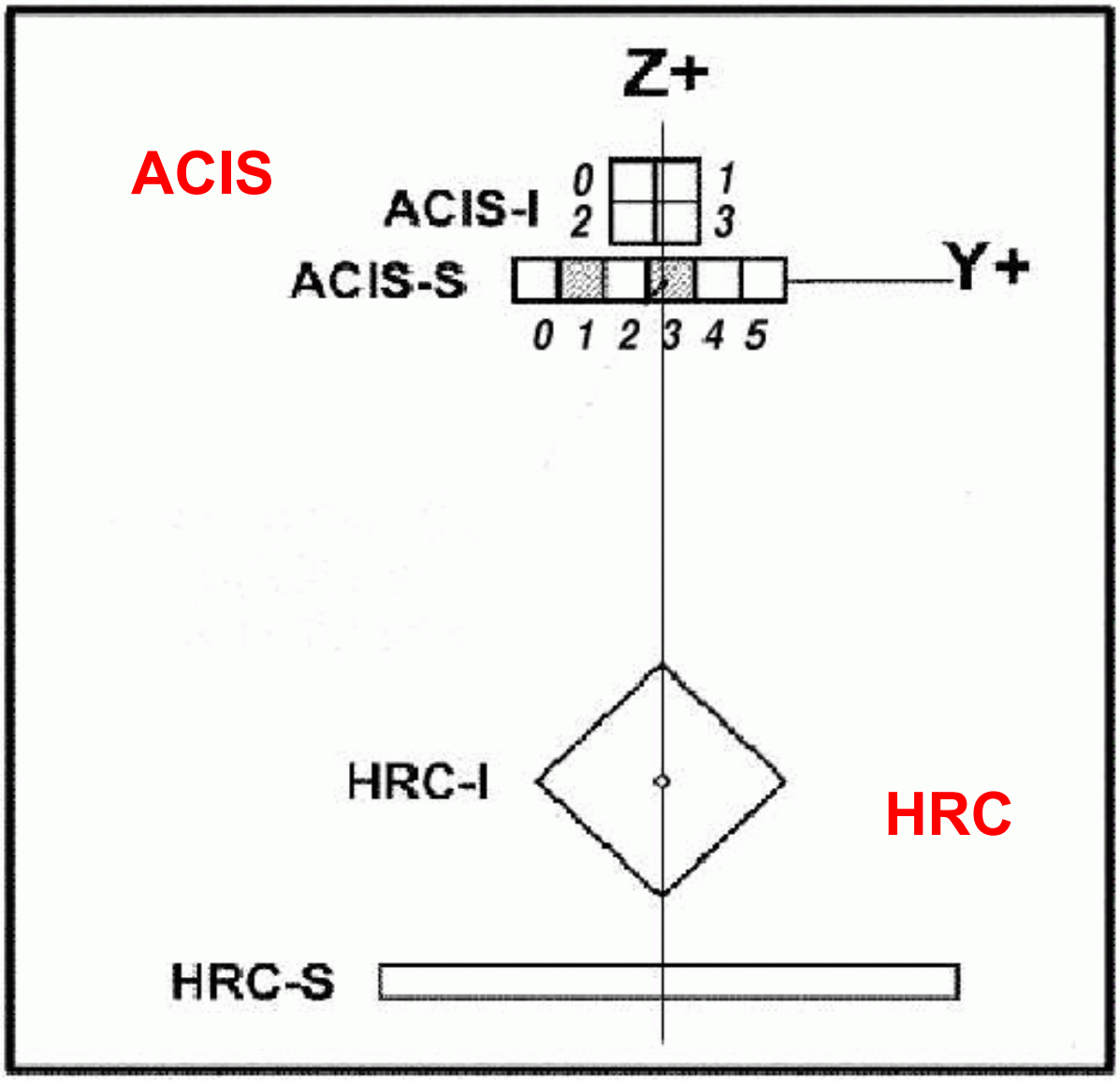


Effective Area

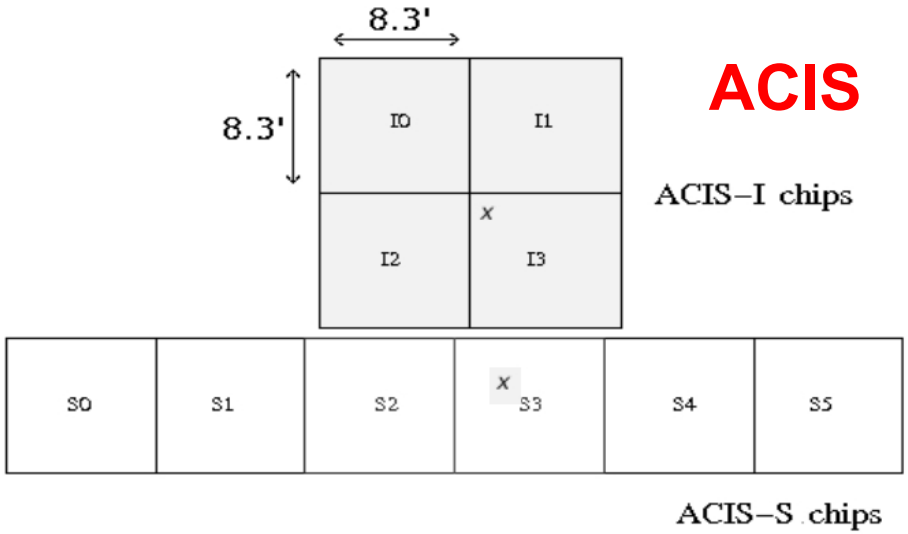


see Dadina's presentation

The detectors:

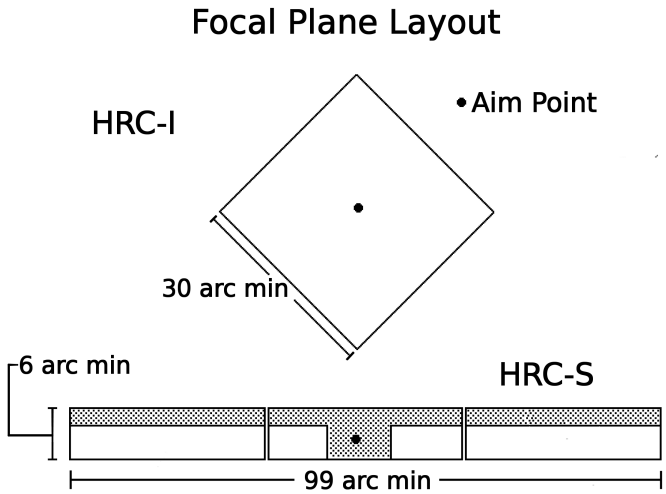


The detectors:



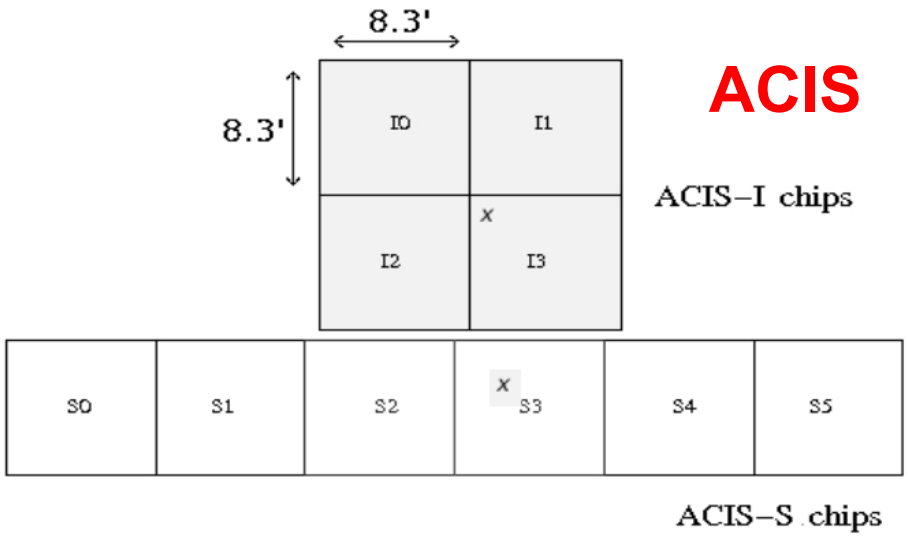
ACIS

HRC



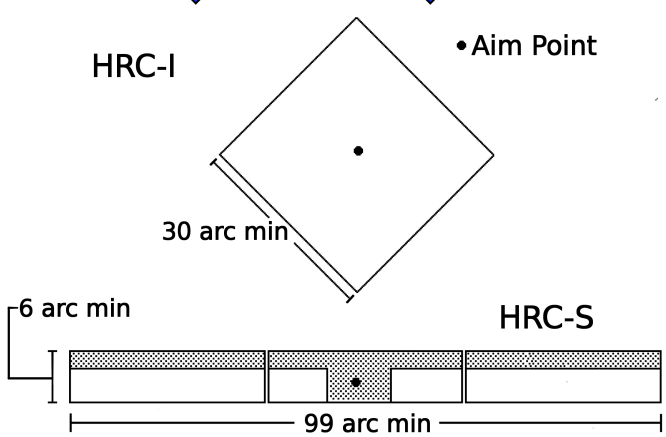
+HETG and LETG dispersive spec.

The detectors:



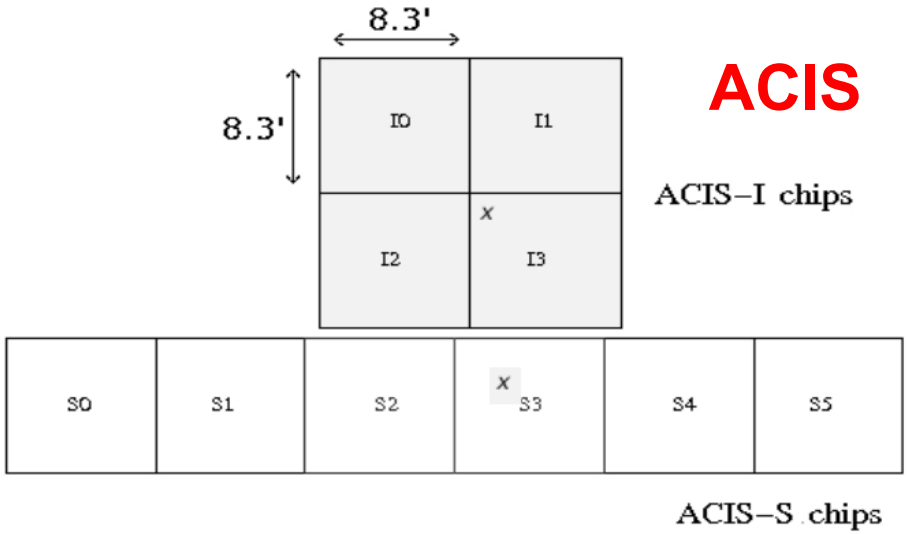
ACIS

~~HRC~~

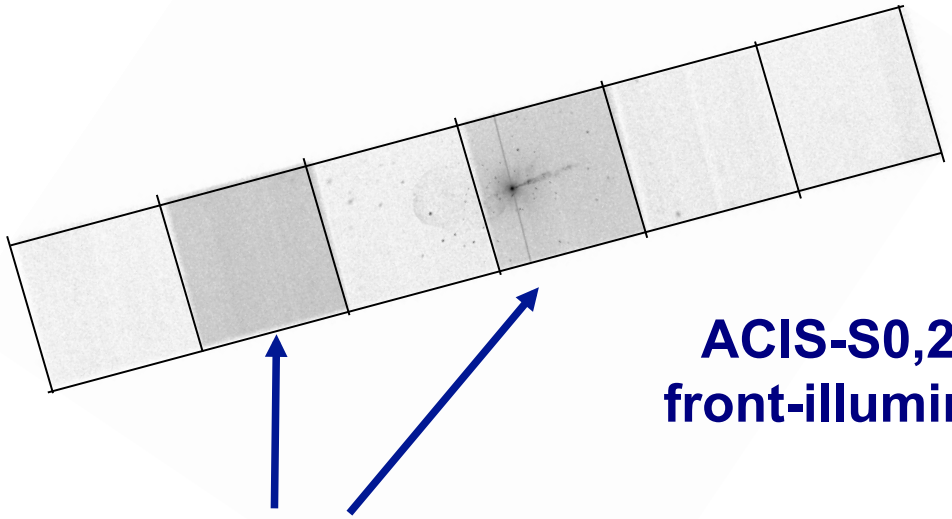


~~+HETG and LETG dispersive spec.~~

The detectors:

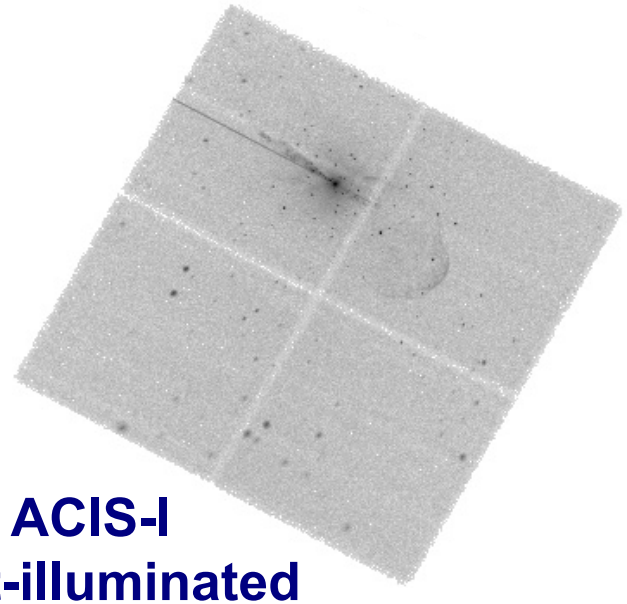


ACIS



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

ACIS-S1 and S3
back-illuminated



ACIS-I
front-illuminated

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

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Chandra	➔	CIAO
XMM-*Newton*	➔	SAS

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Chandra	➔	CIAO
XMM-*Newton*	➔	SAS

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

proprietary data for one year

then archival data available to the community

Main steps in *Chandra* data analysis

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

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Where can I find X-ray data archives?

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

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

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

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

High Energy Astrophysics Science Archive Research Center (HEASARC) - NASA
http://heasarc.nasa.gov → Archive → Browse

High Energy Astrophysics Science Archive Research Center

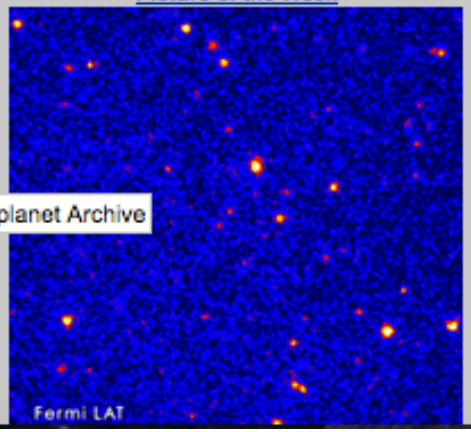
About the HEASARC | Resources for Scientists | FAQ/Help | Site Map | Other Archives

Guest Observer Facilities & Science Centers	
AGILE	ASCA
BeppoSAX	COBE
CGRO	Chandra
EUVE	Fermi
GALEX	HETE-2
Hitomi	INTEGRAL
MAXI	NICER
NuSTAR	ROSAT
RXTE	Suzaku
Swift	TESS
WMAP	XMM-Newton
NASA Archives	
ADS	AstroGravS
EOSDIS	ExoArchive
HORIZONS	IRSA
KOA	LAMBDA
MAST	NExScI
NED	NSSDC
PDS	SDAC

NASA Exoplanet Archive

The High Energy Astrophysics Science Archive Research Center (HEASARC) is the primary archive for NASA's (and other space agencies') missions studying electromagnetic radiation from extremely energetic cosmic phenomena ranging from black holes to the Big Bang. Since its merger with the Legacy Archive for Microwave Background Data Analysis (LAMBDA) in 2008, the HEASARC archive contains data obtained by high-energy astronomy missions observing in the extreme-ultraviolet (EUV), X-ray, and gamma-ray bands, as well as data from space missions, balloons, and ground-based facilities that have studied the relic cosmic microwave background (CMB) radiation in the sub-mm, mm and cm bands.

HEASARC Picture of the Week



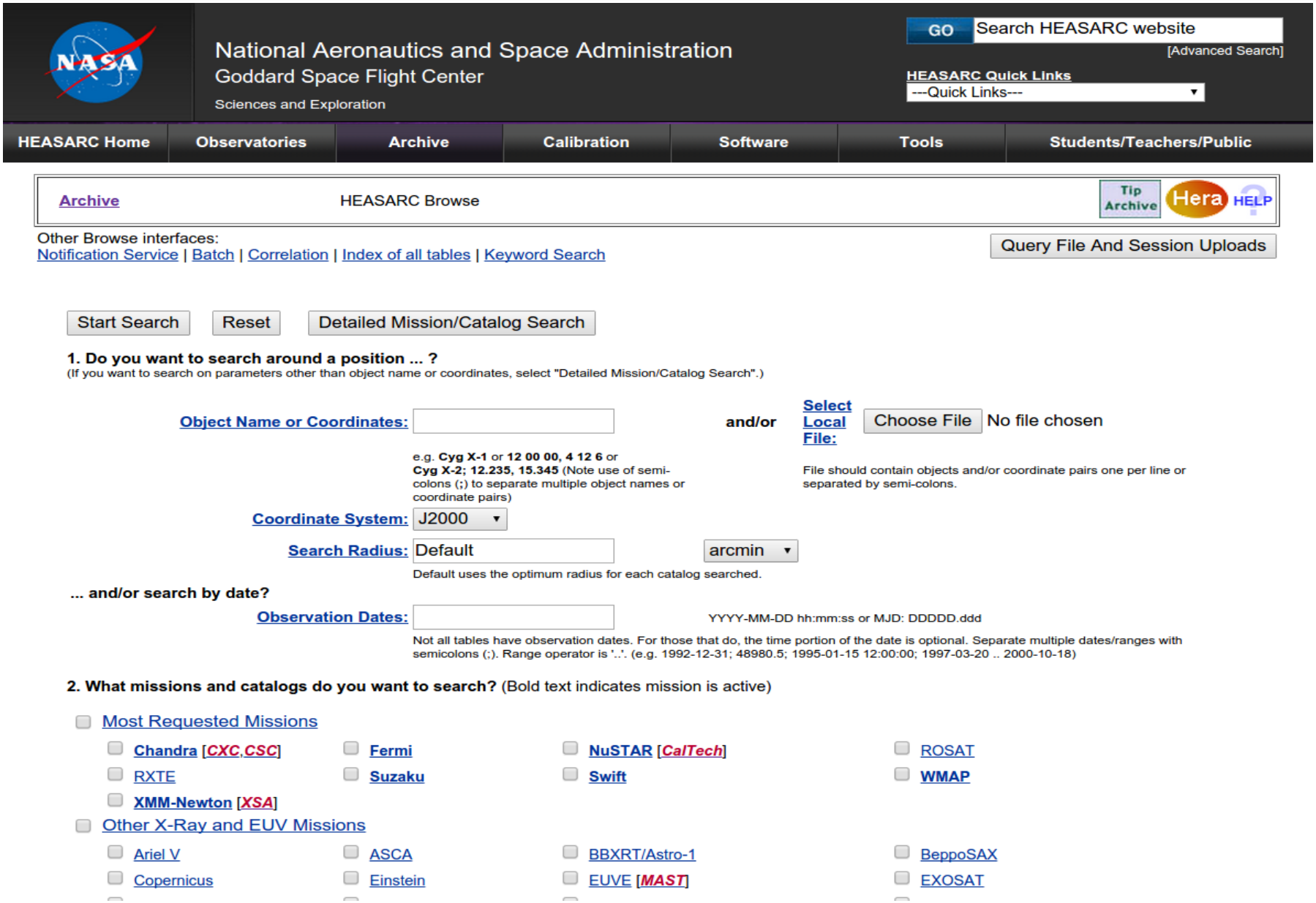
APOD: Astronomy Picture of the Day

Latest News

- NASA Space Telescopes Pinpoint Elusive Brown Dwarf
(16 Nov 2016)
In a first-of-its-kind collaboration, NASA's Spitzer and Swift space telescopes joined forces to observe a microlensing event, when a distant star brightens due to the gravitational field of at least one foreground cosmic object. This technique is useful for finding low-mass bodies orbiting stars, such as planets. In this case, the observations revealed a brown dwarf. This study by Shvartzvald et al. has just appeared in ApJ (2016, 831, 183).
- Starvation Diet for Black Hole Dims Brilliant Galaxy
(10 Nov 2016)
Astronomers may have solved the mystery of the peculiarly volatile behavior of a supermassive black hole (SMBH) at the center of the active galaxy Mkn 1018. Combined data from Chandra and other observatories suggest that this SMBH is no longer being fed enough fuel to make its surroundings shine brightly. After discovering the AGN's fickle nature during a survey project using ESO's Very Large Telescope (VLT), astronomers observed it with both Chandra and Hubble. Other observatories used in this study include NuSTAR and Swift. Two

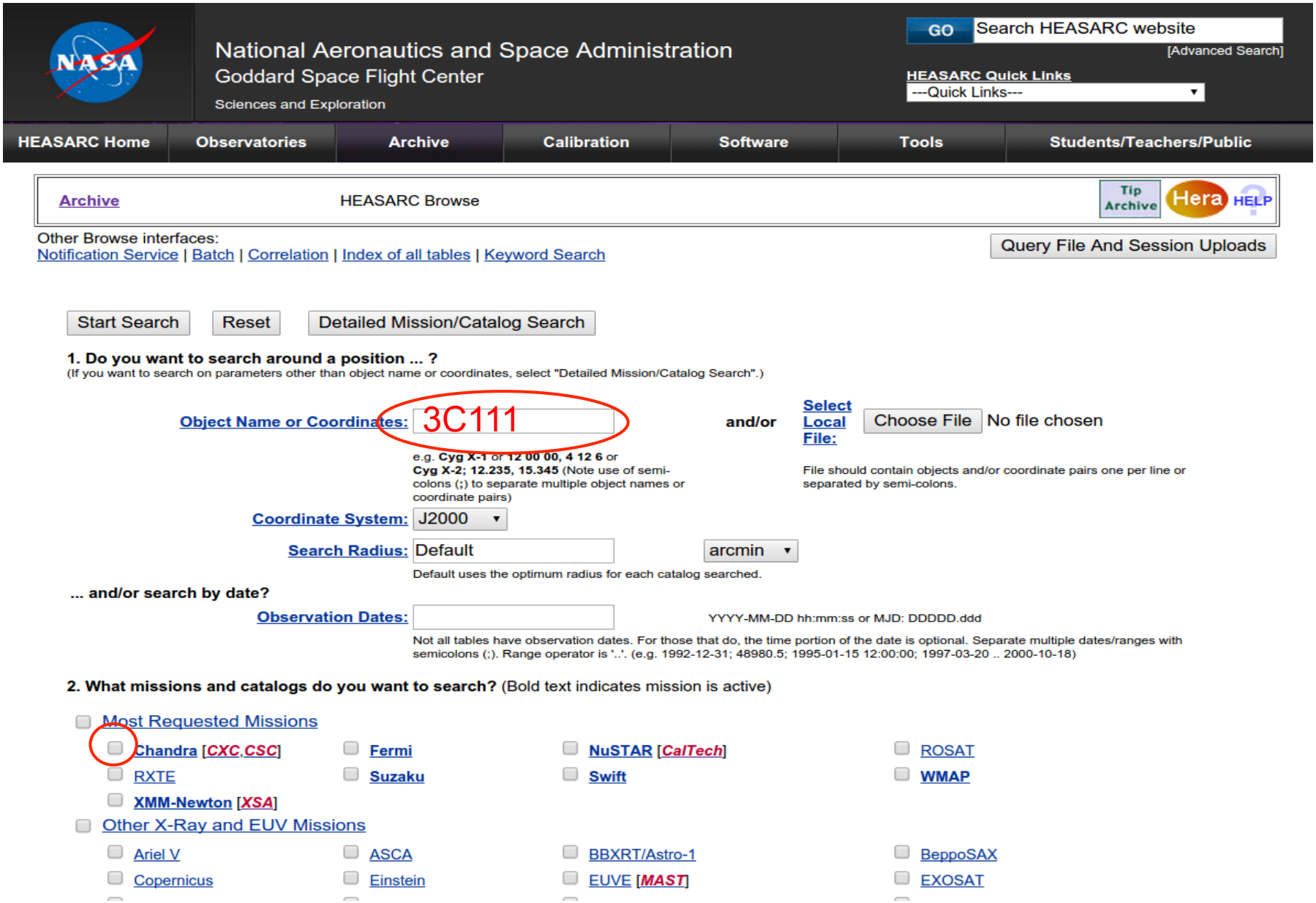
High Energy Astrophysics Science Archive Research Center (HEASARC) - NASA

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



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

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



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

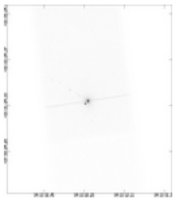
Chandra Observations (chanmaster) FTOOLS

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

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Aspect Solution (pcadf474179932N001_asol1.fits.gz)	FITS	30450 kB	updated: 2013/01/12 00:00:00
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Bad Pixel List (acisf14990_000N001_e2_bpix1.fits.gz)	FITS	29 kB	updated: 2013/01/12 00:00:00
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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?

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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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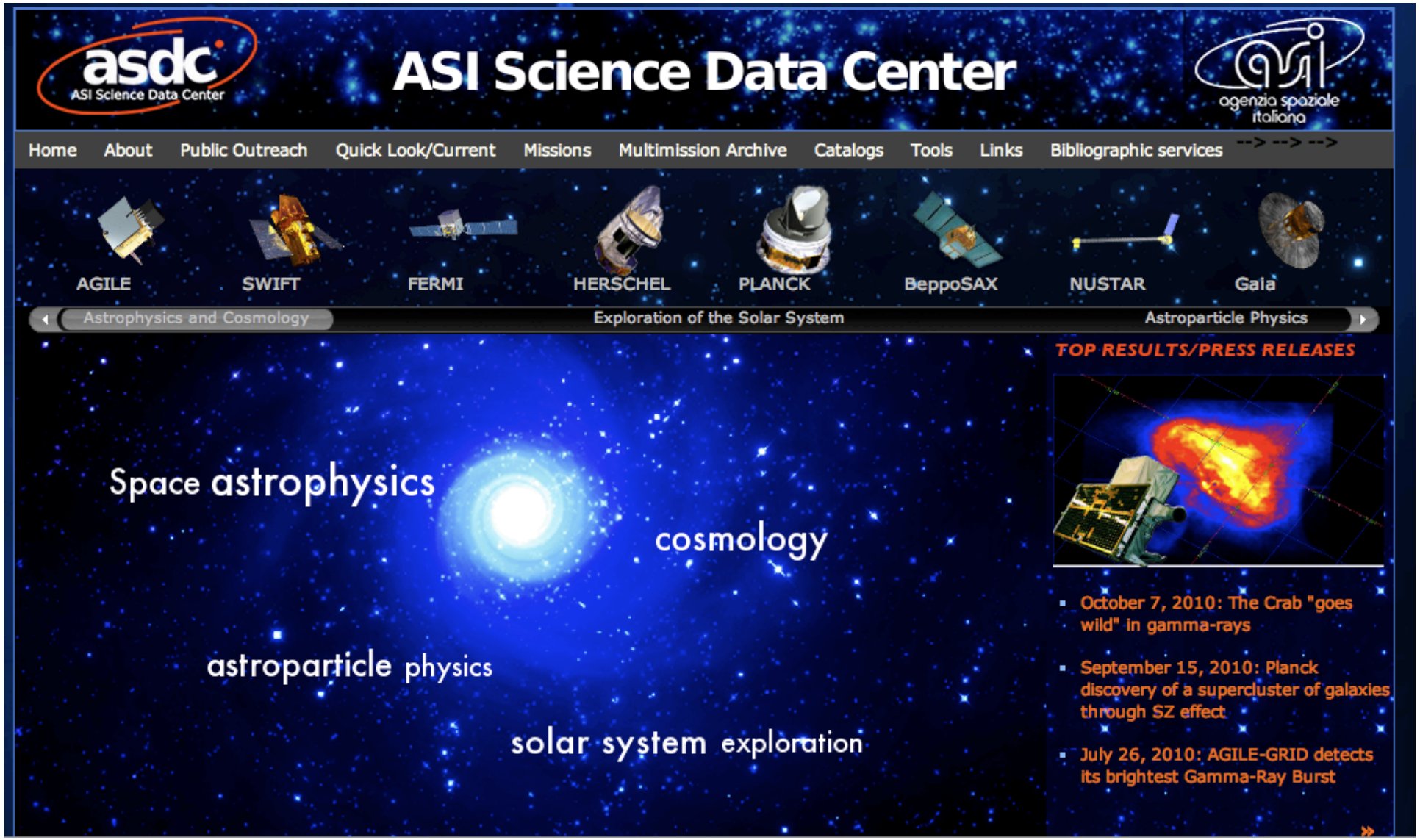
Tarred: /FTP/chandra/data/science/ao14/cat7//14990/primary/orbitf474120303N001_eph1.fits.gz
Tarred: /FTP/chandra/data/science/ao14/cat7//14990/secondary

TAR complete: Actual size: 314 MB.

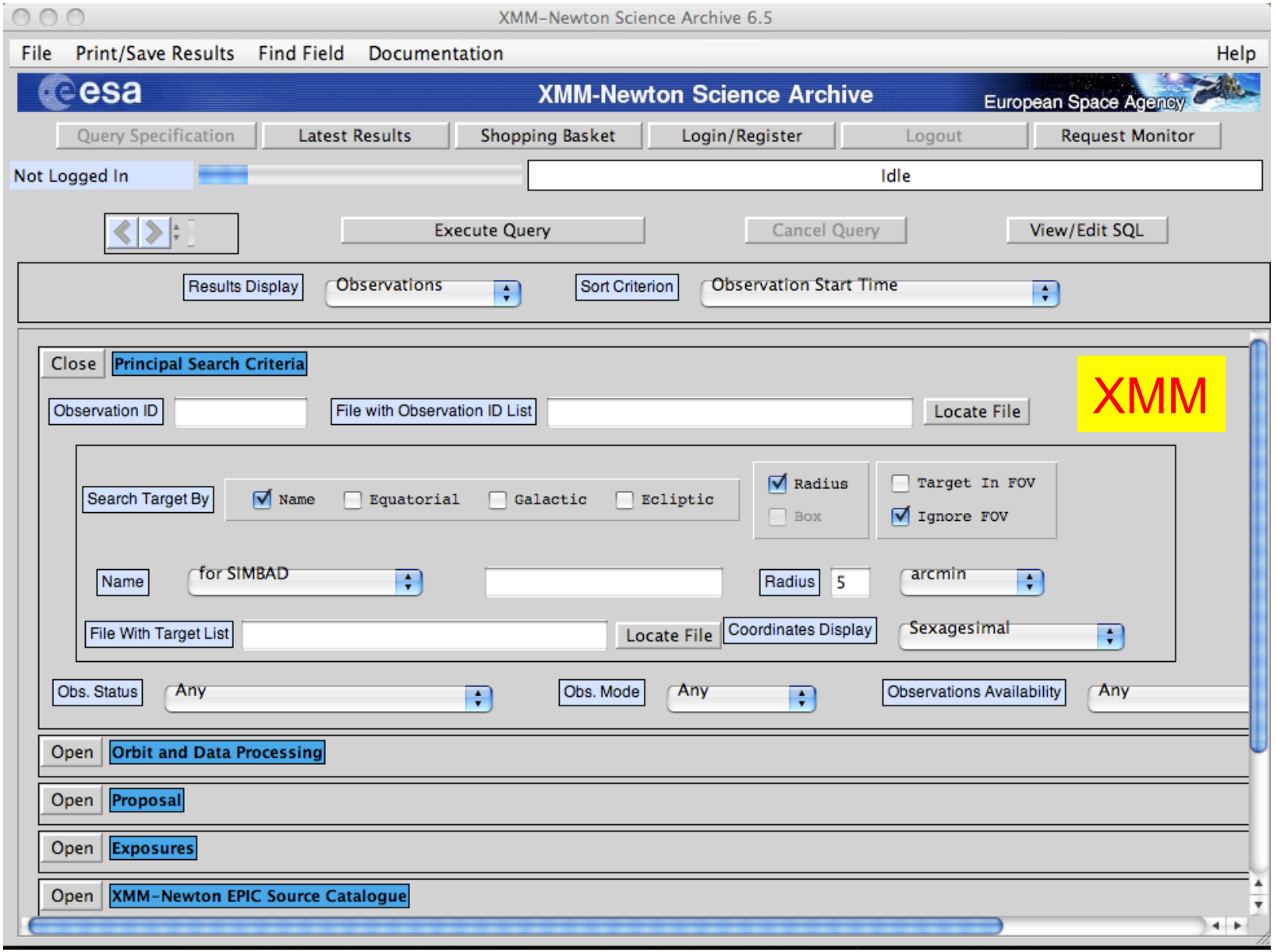
Remote files are not included in the tar file. Use the **Create Download Script** option to retrieve remote files.

ASI Scientific Data Center (ASDC- Frascati, Roma)
http://www.asdc.asi.it/



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

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



see XMM tutorial…

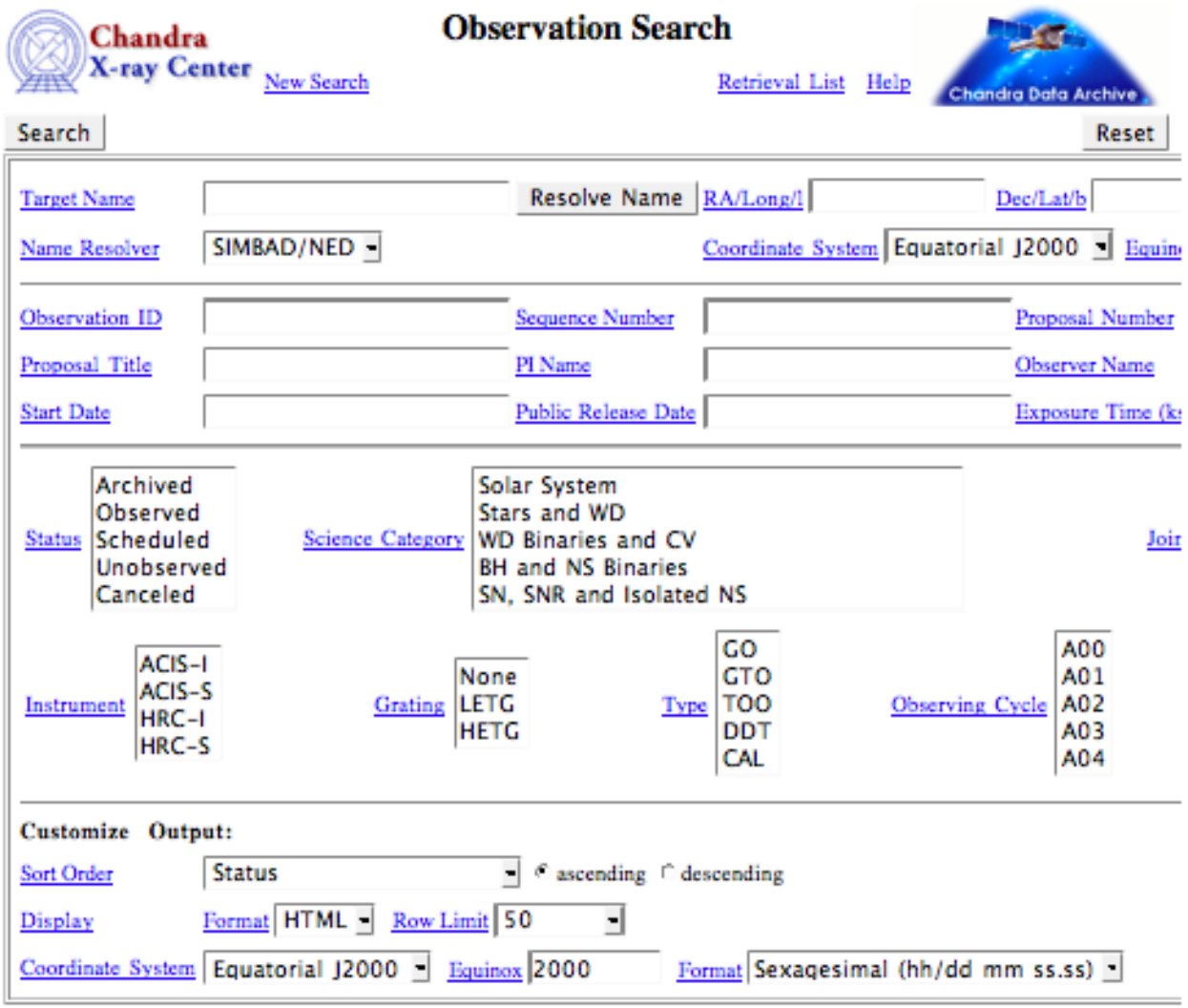
Chandra X-ray Center (CXC-CFA, Cambridge-Boston)

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

Chandra Data Archive: Observation Search

Chandra webchaser

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



View Observation Information | Add to Retrieval List

Primary products

Secondary products

Select all | Unselect all

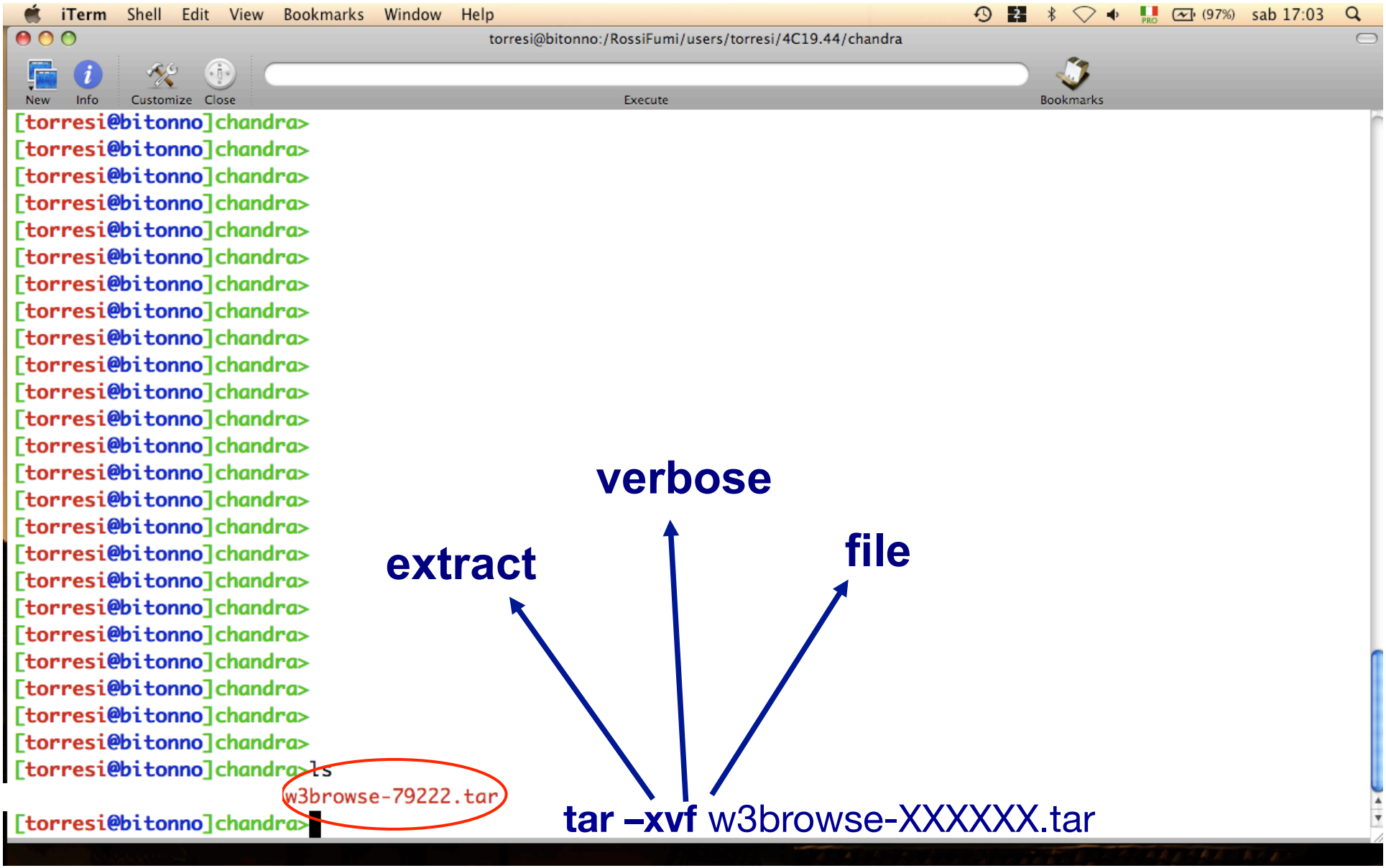
Select	Row	Seq_Num	Obs_ID	Instrument	Grating	Appr_Exp_(ks)	Exposure_(ks)	Target
☐	1	700743	4064	ACIS-S	NONE	5.0	4.73	BR 0331-1622
☐	2	700744	4065	ACIS-S	NONE	4.0	4.12	BR 0353-3820
☐	3	700745	4066	ACIS-S	NONE	4.0	4.04	BR 0418-5723
☐	4	700746	4067	ACIS-S	NONE	5.0	4.73	BR 0424-2209
☐	5	700747	4068	ACIS-S	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

Alternatively (using a CIAO command-line)

> download_chandra_obsid 7302 (once the obsid, 7302 in this case, is known)

Main steps in *Chandra* data analysis

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


iTerm Shell Edit View Bookmarks Window Help
(97%) sab 17:03
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-XXXXXX.tar


iTerm Shell Edit View Bookmarks Window Help
(97%) sab 17:03
torresi@bitonno:/RossiFumi/users/torresi/4C19.44/chandra
New
Info
Customize
Close
Execute
Bookmarks
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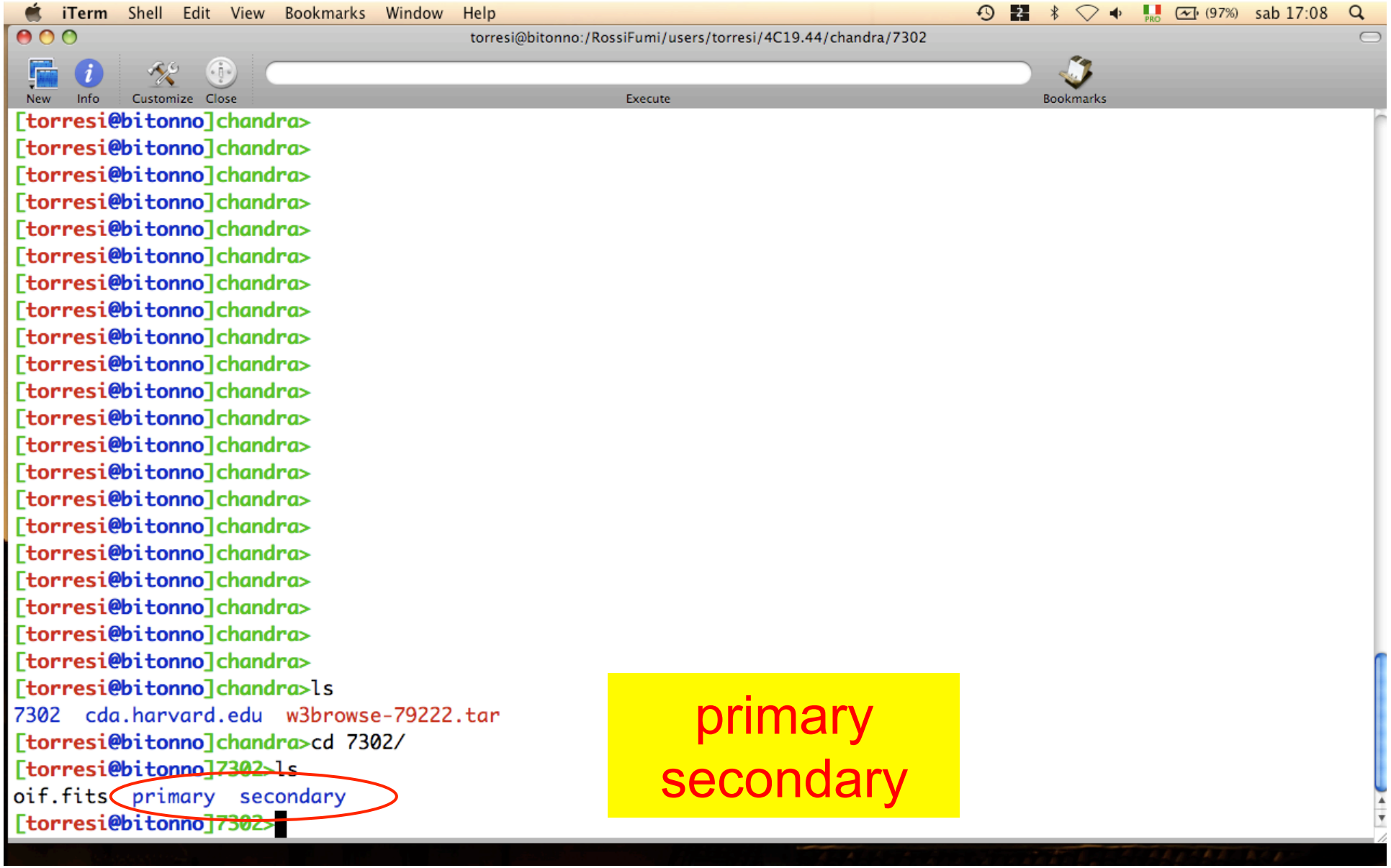
[torresi@bitonno]chandra>ls
7302
[torresi@bitonno]chandra>
cd #obsid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New Info Customize Close Execute Bookmarks
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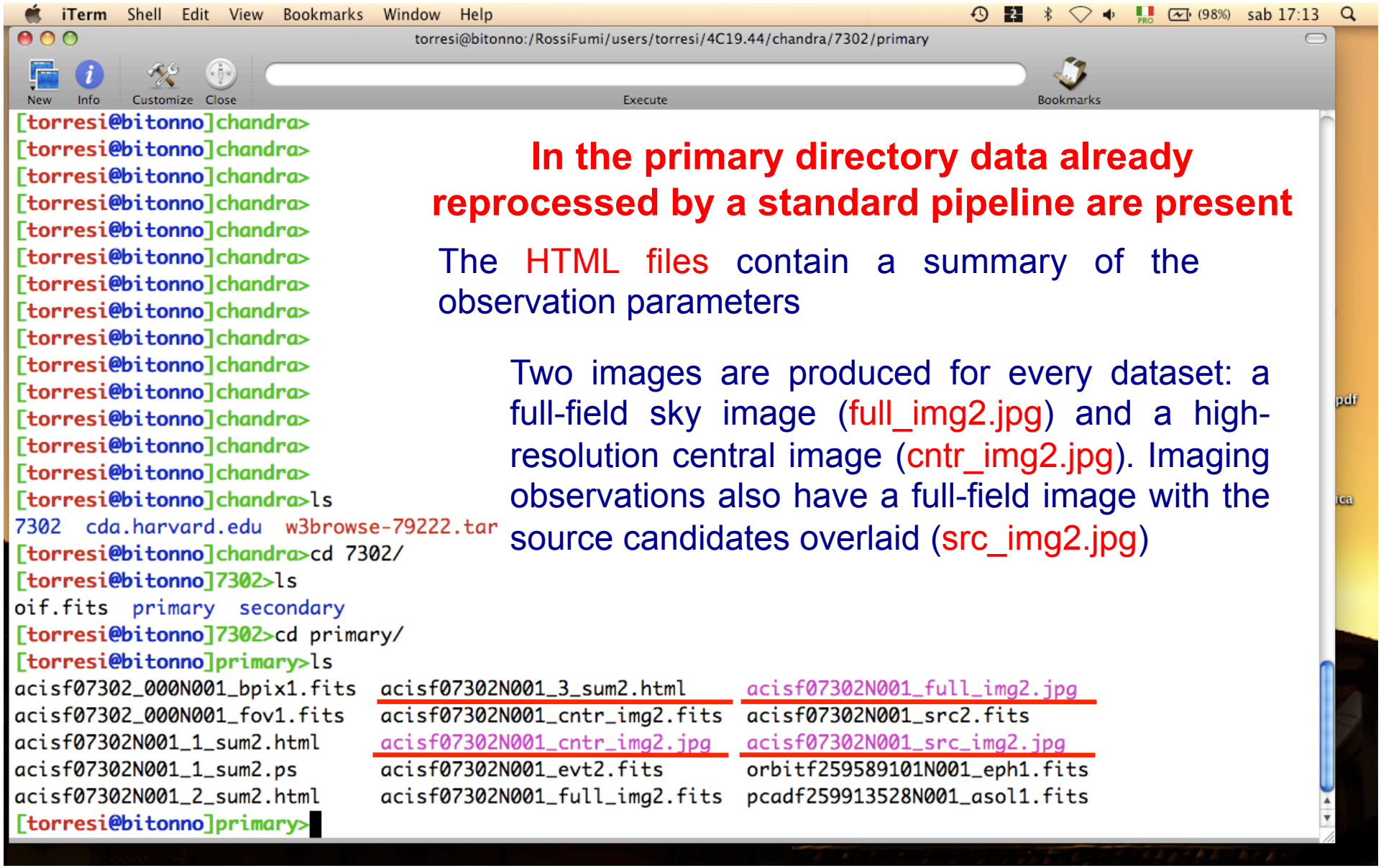
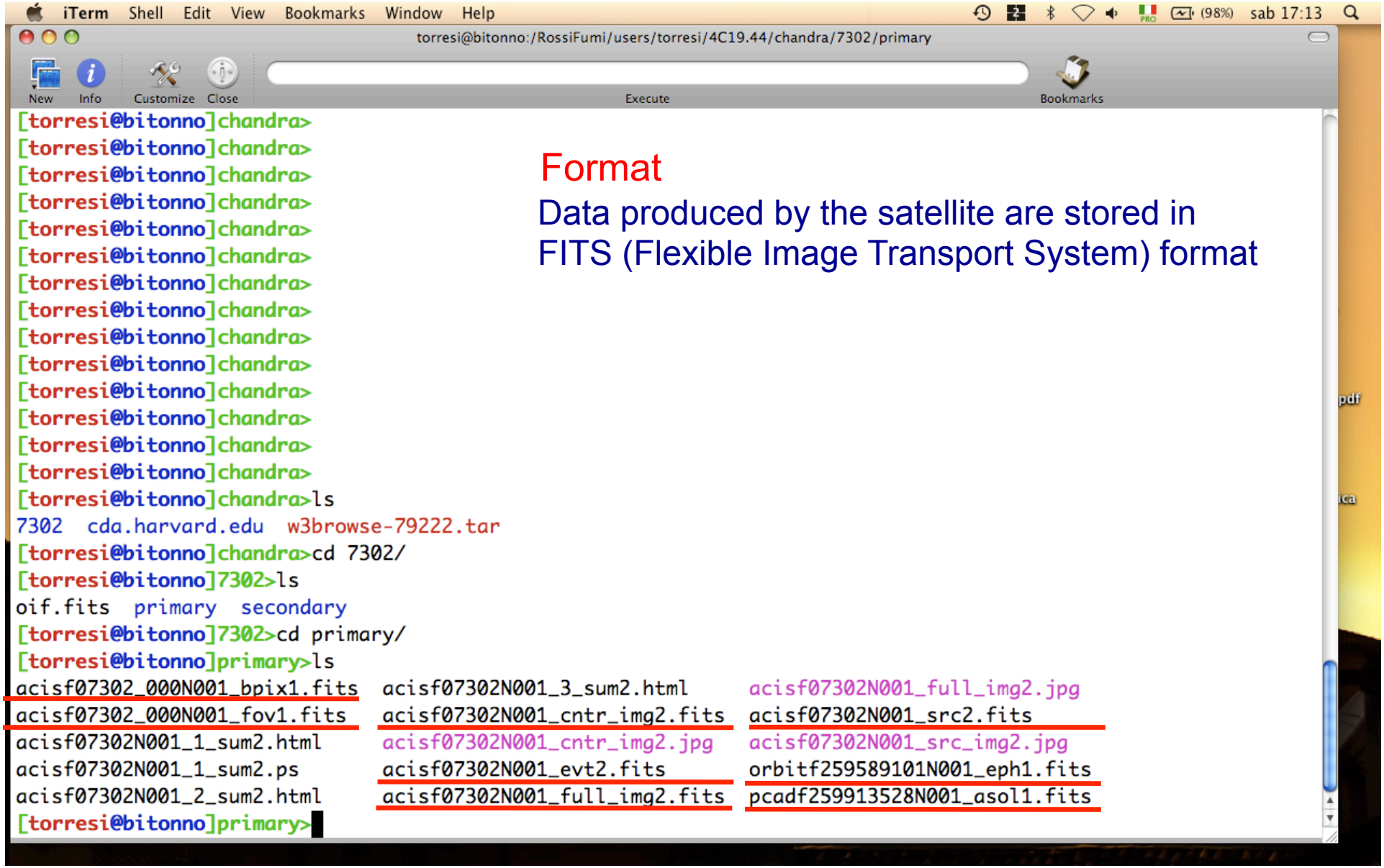
7302 cda.harvard.edu w3browse-79222.tar
[torresi@bitonno]chandra>cd 7302/
[torresi@bitonno]7302>ls
oif.fits primary secondary
[torresi@bitonno]7302>
primary
secondary



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 high-resolution central image (cntr_img2.jpg). Imaging observations also have a full-field image with the source candidates overlaid (src_img2.jpg)


iTerm Shell Edit View Bookmarks Window Help
(98%) sab 17:13
torresi@bitonno:/RossiFumi/users/torresi/4C19.44/chandra/7302/primary
New Info Customize Close
Execute
Bookmarks
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[torresi@bitonno]chandra>
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[torresi@bitonno]chandra>ls
7302 cda.harvard.edu w3browse-79222.tar
[torresi@bitonno]chandra>cd 7302/
[torresi@bitonno]7302>ls
oif.fits primary secondary
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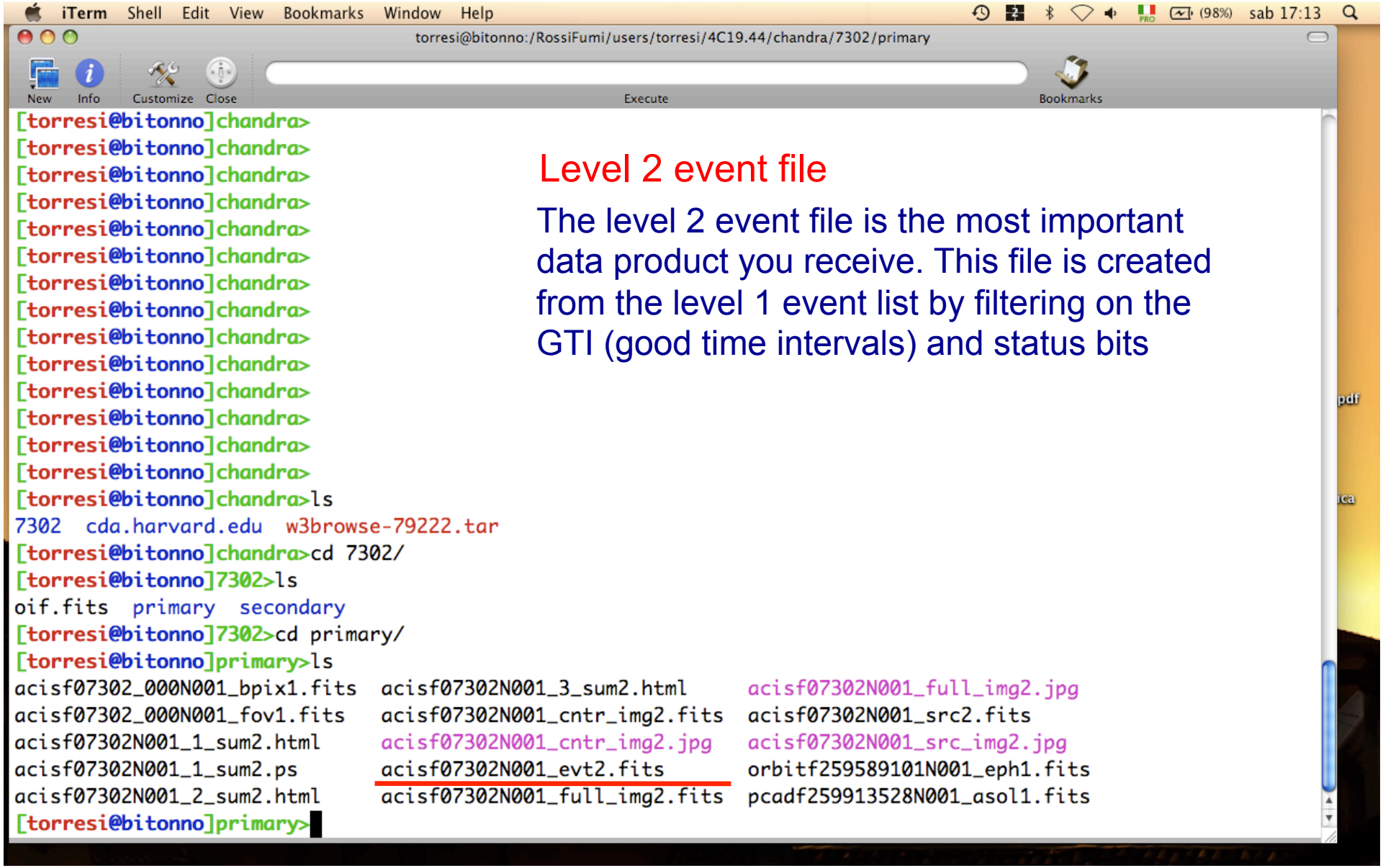
acisf07302_000N001_bpix1.fits acisf07302N001_3_sum2.html acisf07302N001_full_img2.jpg
acisf07302_000N001_fov1.fits acisf07302N001_cntr_img2.fits acisf07302N001_src2.fits
acisf07302N001_1_sum2.html acisf07302N001_cntr_img2.jpg acisf07302N001_src_img2.jpg
acisf07302N001_1_sum2.ps acisf07302N001_evt2.fits orbitf259589101N001_eph1.fits
acisf07302N001_2_sum2.html acisf07302N001_full_img2.fits pcadf259913528N001_asol1.fits
[torresi@bitonno]primary>
Format
Data produced by the satellite are stored in
FITS (Flexible Image Transport System) format


iTerm Shell Edit View Bookmarks Window Help
(98%) sab 17:13
torresi@bitonno:/RossiFumi/users/torresi/4C19.44/chandra/7302/primary
New Info Customize Close
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Bookmarks
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oif.fits primary secondary
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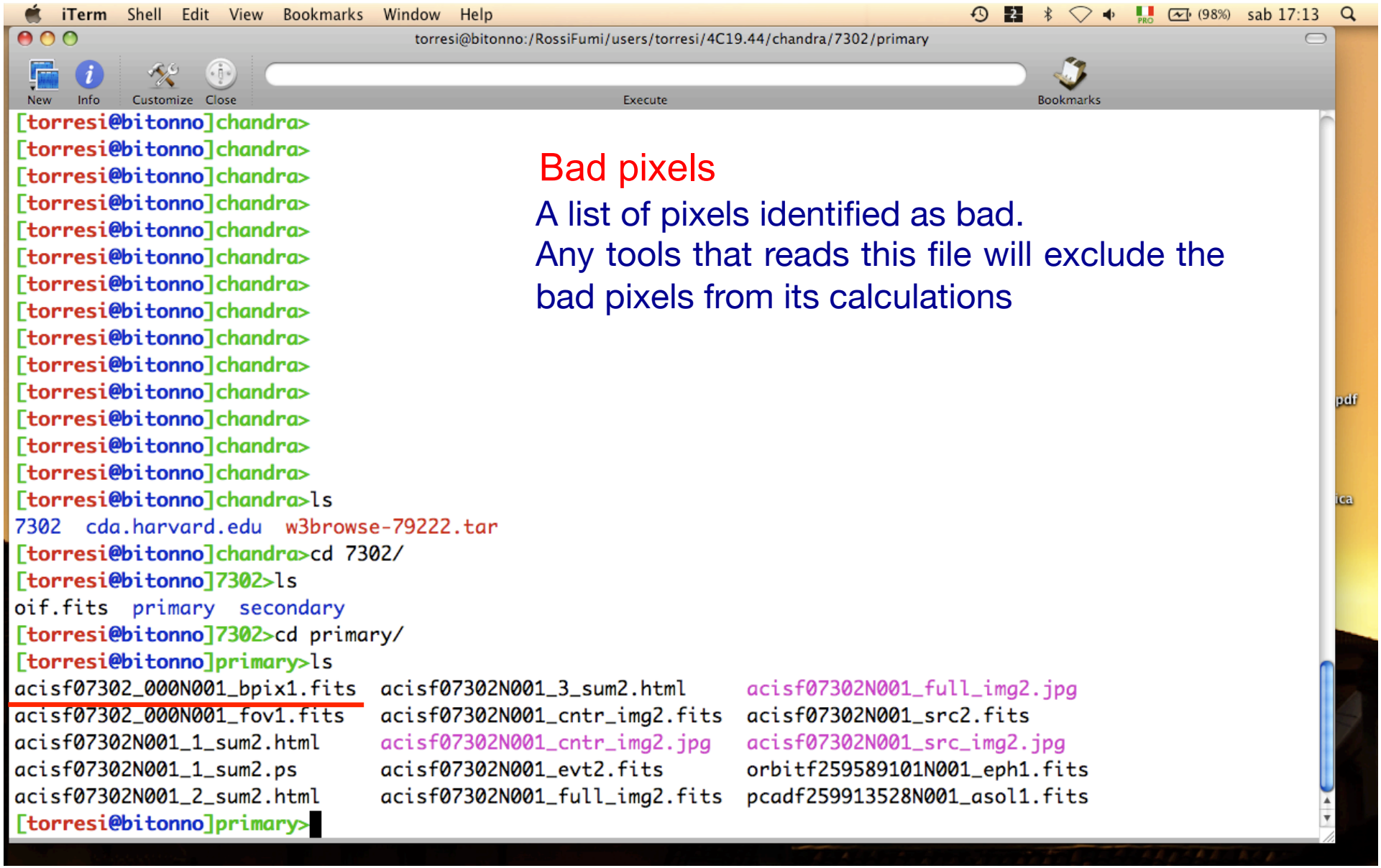
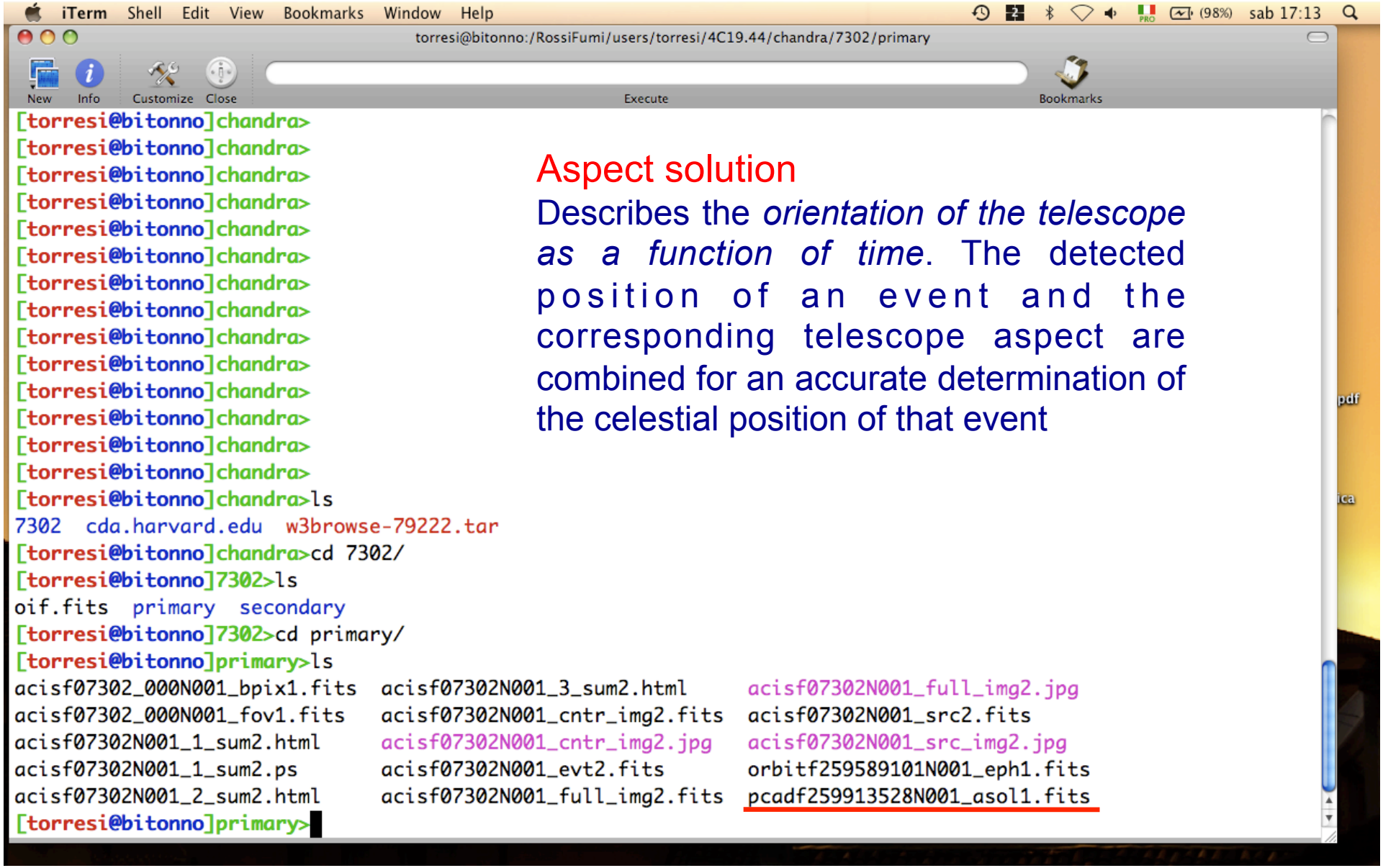
acisf07302_000N001_bpix1.fits acisf07302N001_3_sum2.html acisf07302N001_full_img2.jpg
acisf07302_000N001_fov1.fits acisf07302N001_cntr_img2.fits acisf07302N001_src2.fits
acisf07302N001_1_sum2.html acisf07302N001_cntr_img2.jpg acisf07302N001_src_img2.jpg
acisf07302N001_1_sum2.ps acisf07302N001_evt2.fits orbitf259589101N001_eph1.fits
acisf07302N001_2_sum2.html acisf07302N001_full_img2.fits pcadf259913528N001_asol1.fits
[torresi@bitonno]primary>
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


iTerm Shell Edit View Bookmarks Window Help
sab 17:13
torresi@bitonno:/RossiFumi/users/torresi/4C19.44/chandra/7302/primary
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>cd primary/
[torresi@bitonno]primary>ls
acisf07302_000N001_bpix1.fits acisf07302N001_3_sum2.html acisf07302N001_full_img2.jpg
acisf07302_000N001_fov1.fits acisf07302N001_cntr_img2.fits acisf07302N001_src2.fits
acisf07302N001_1_sum2.html acisf07302N001_cntr_img2.jpg acisf07302N001_src_img2.jpg
acisf07302N001_1_sum2.ps acisf07302N001_evt2.fits orbitf259589101N001_eph1.fits
acisf07302N001_2_sum2.html acisf07302N001_full_img2.fits pcadf259913528N001_asol1.fits
[torresi@bitonno]primary>
Bad pixels
A list of pixels identified as bad.
Any tools that reads this file will exclude the bad pixels from its calculations


iTerm Shell Edit View Bookmarks Window Help
(98%) sab 17:13
torresi@bitonno:/RossiFumi/users/torresi/4C19.44/chandra/7302/primary
New Info Customize Close
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Bookmarks
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7302 cda.harvard.edu w3browse-79222.tar
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oif.fits primary secondary
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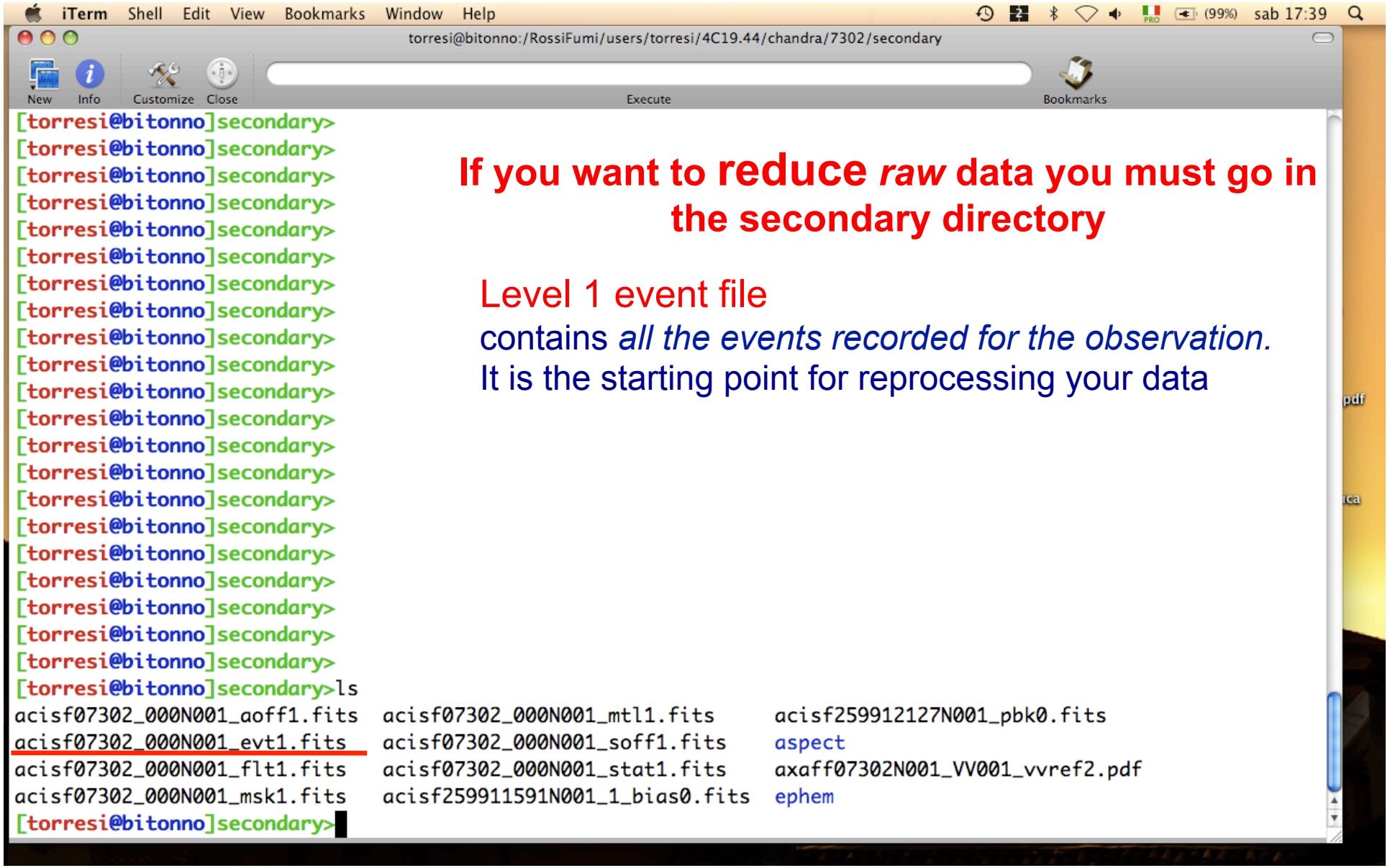
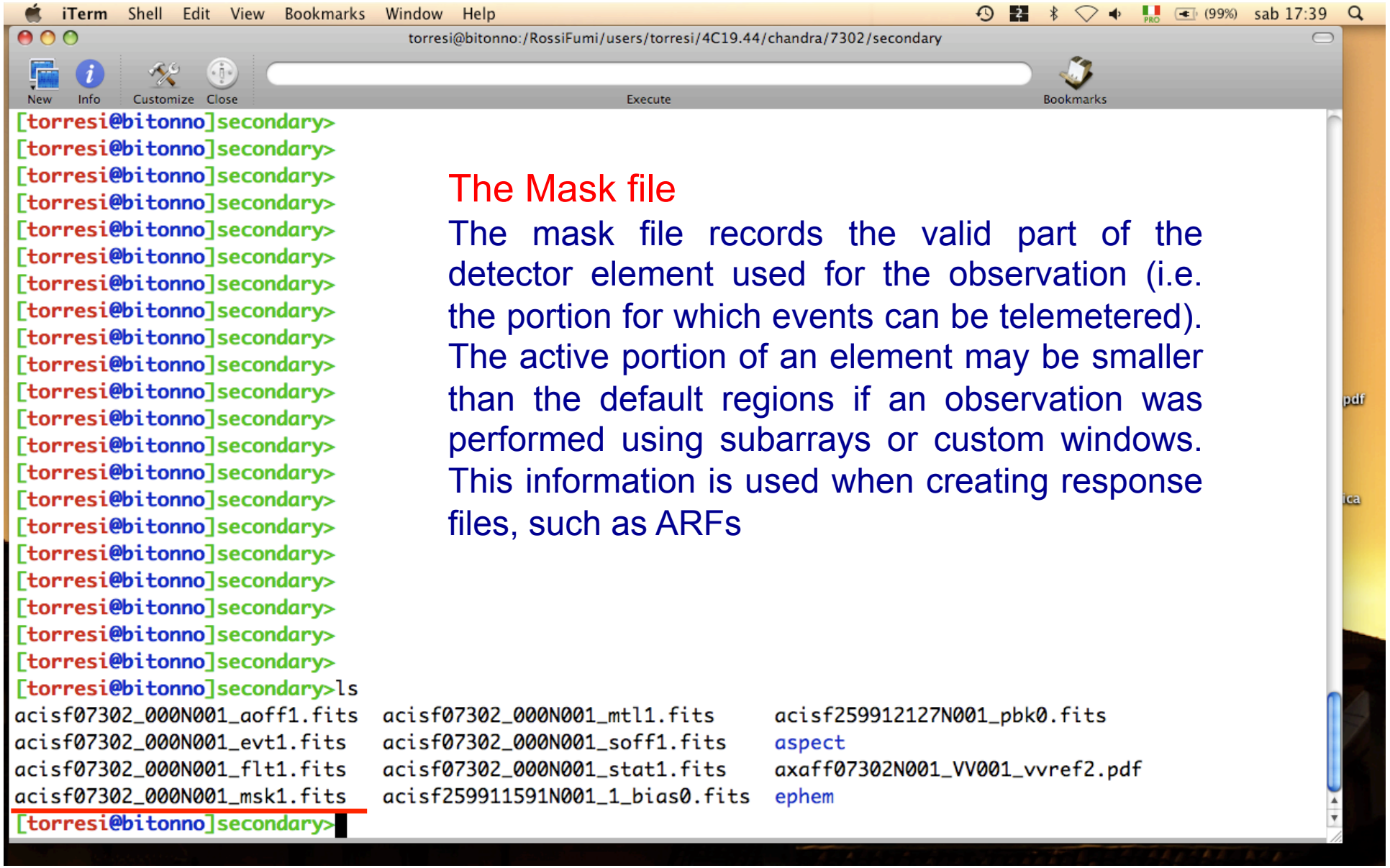
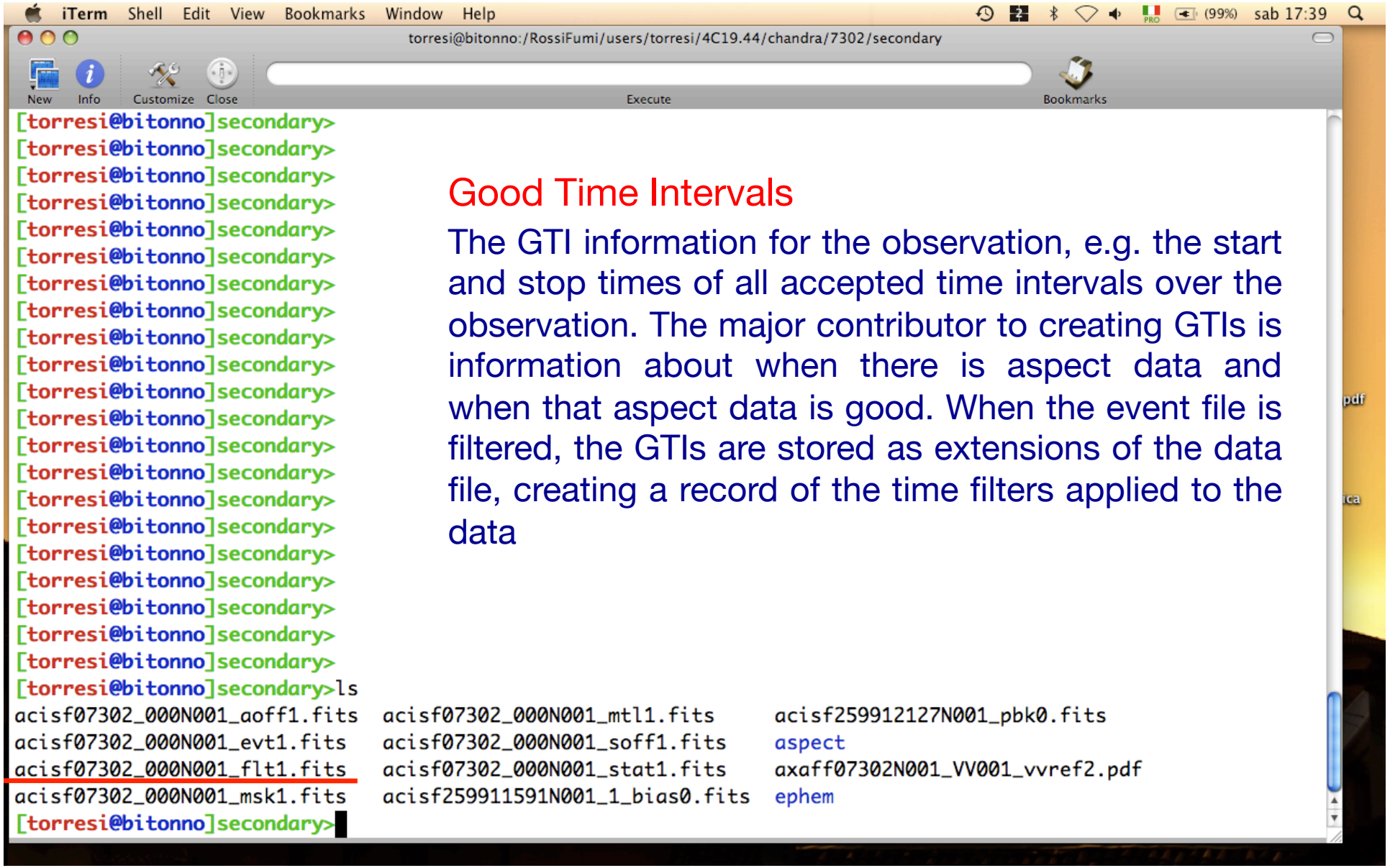
acisf07302_000N001_bpix1.fits acisf07302N001_3_sum2.html acisf07302N001_full_img2.jpg
acisf07302_000N001_fov1.fits acisf07302N001_cntr_img2.fits acisf07302N001_src2.fits
acisf07302N001_1_sum2.html acisf07302N001_cntr_img2.jpg acisf07302N001_src_img2.jpg
acisf07302N001_1_sum2.ps acisf07302N001_evt2.fits orbitf259589101N001_eph1.fits
acisf07302N001_2_sum2.html acisf07302N001_full_img2.fits pcadf259913528N001_asol1.fits
[torresi@bitonno]primary>
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>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
Level 1 event file
contains all the events recorded for the observation.
It is the starting point for reprocessing your data



The Mask file

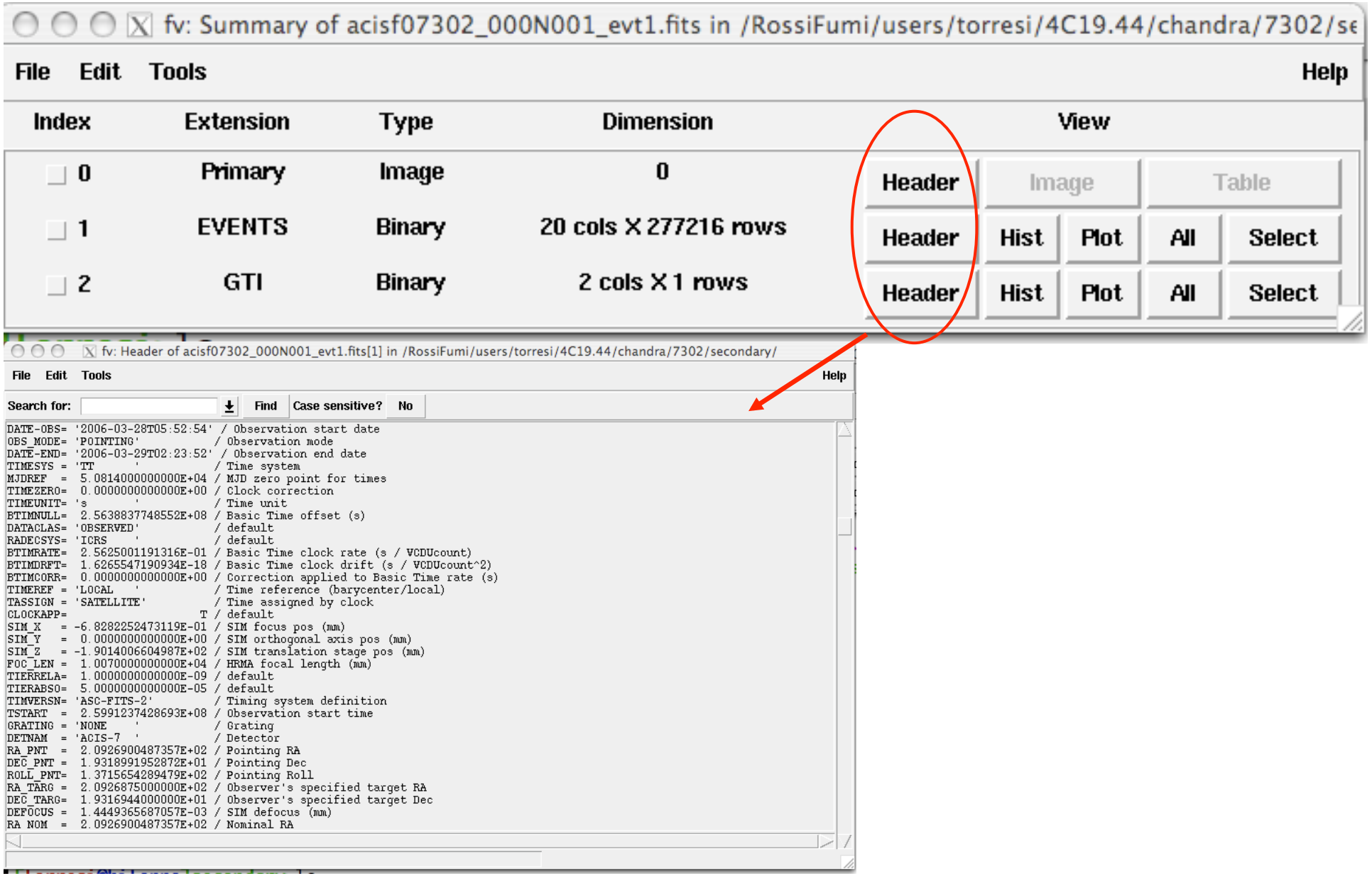
The mask file records the valid part of the detector element used for the observation (i.e. the portion for which events can be telemetered). The active portion of an element may be smaller than the default regions if an observation was performed using subarrays or custom windows. This information is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



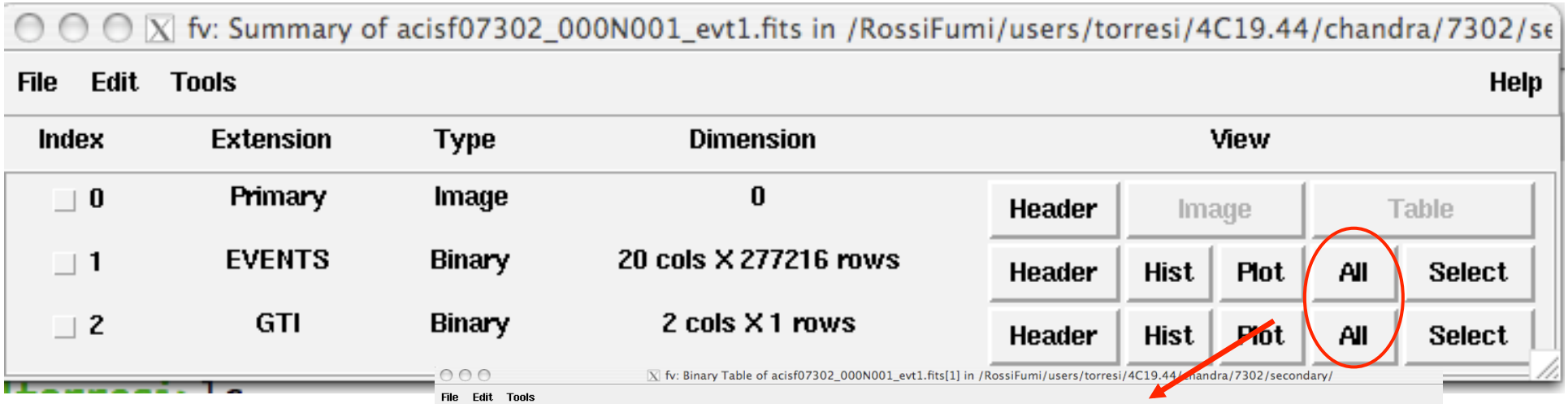
Good Time Intervals

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

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*



fv: Binary Table of acisf07302_000N001_evt1.fits[1] in /RossiFumi/users/torresi/4C19.44/chandra/7302/secondary/

File Edit Tools

Select All Invert

	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

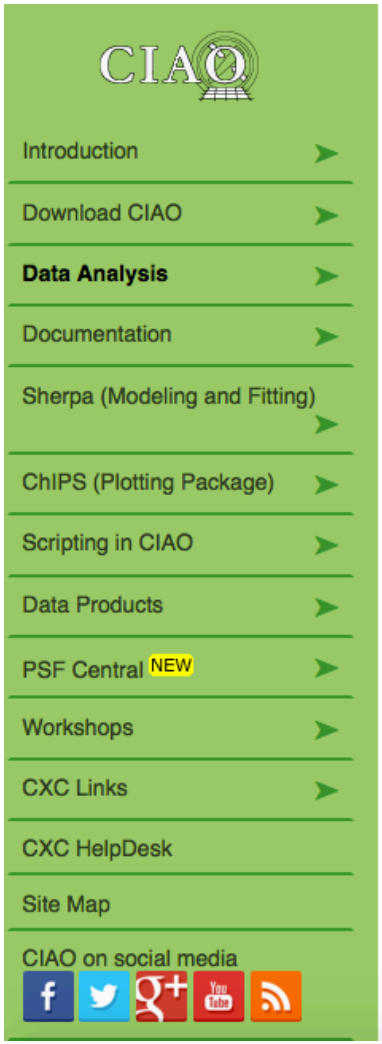
Go to: Edit cell:

Main steps in *Chandra* data analysis

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

Chandra data reduction

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



Science Threads

WHAT'S NEW | WATCH OUT

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

All threads

A list of all the threads on one page.

Introduction UPDATED

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

Data Preparation UPDATED

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

Imaging UPDATED

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

Imaging Spectroscopy

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

Scientific files
Housekeeping files

Scientific files
Housekeeping files

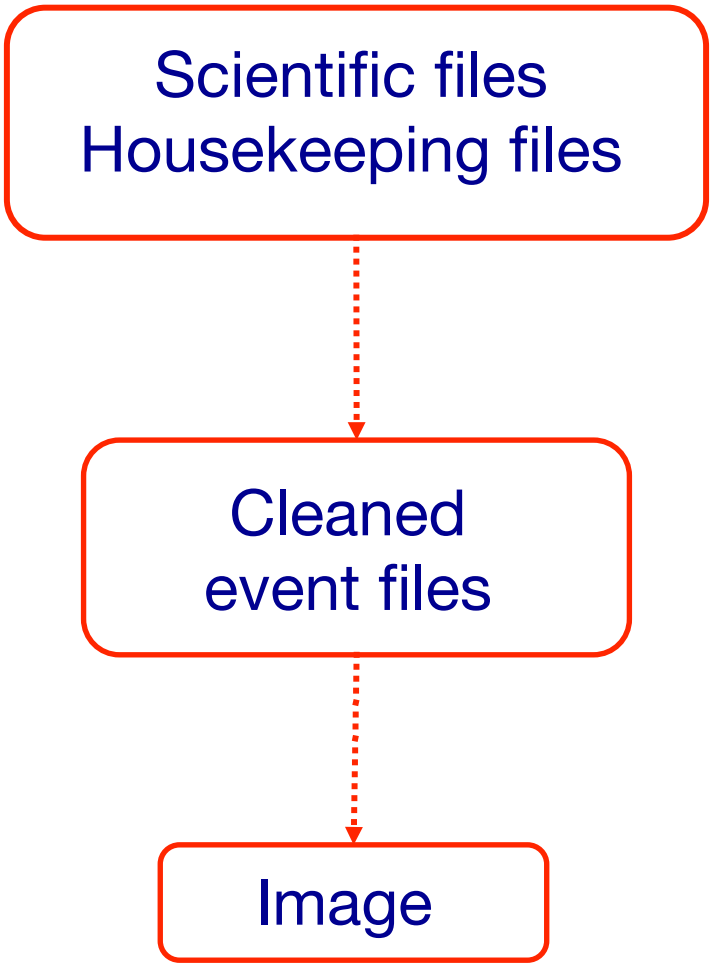
- removal of hot pixels or afterglows
  acis_run_hotpix
- creation of a new event file
  acis_process_events
- run *destreak* in case the ACIS-S4 chip (ccd_id=8) has been used
- filtering for bad grades and application of *Good Time Intervals (GTI)*
- creation of the background light curve

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

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

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

Cleaned
event files

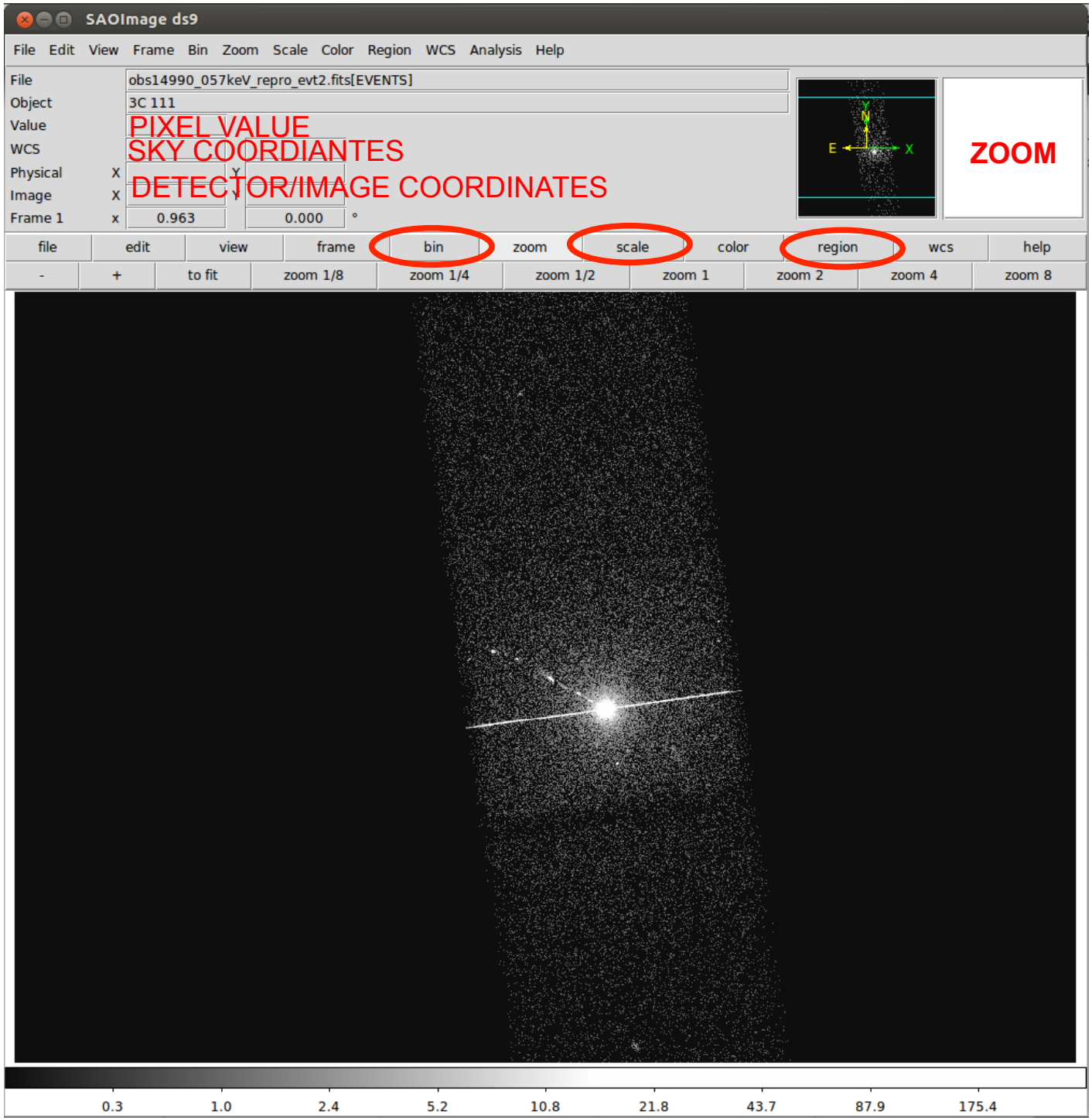


Create an image with binning=1 (original scale 1 pix=0.492”) in the 0.5−7 keV band (and selecting only good data)

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

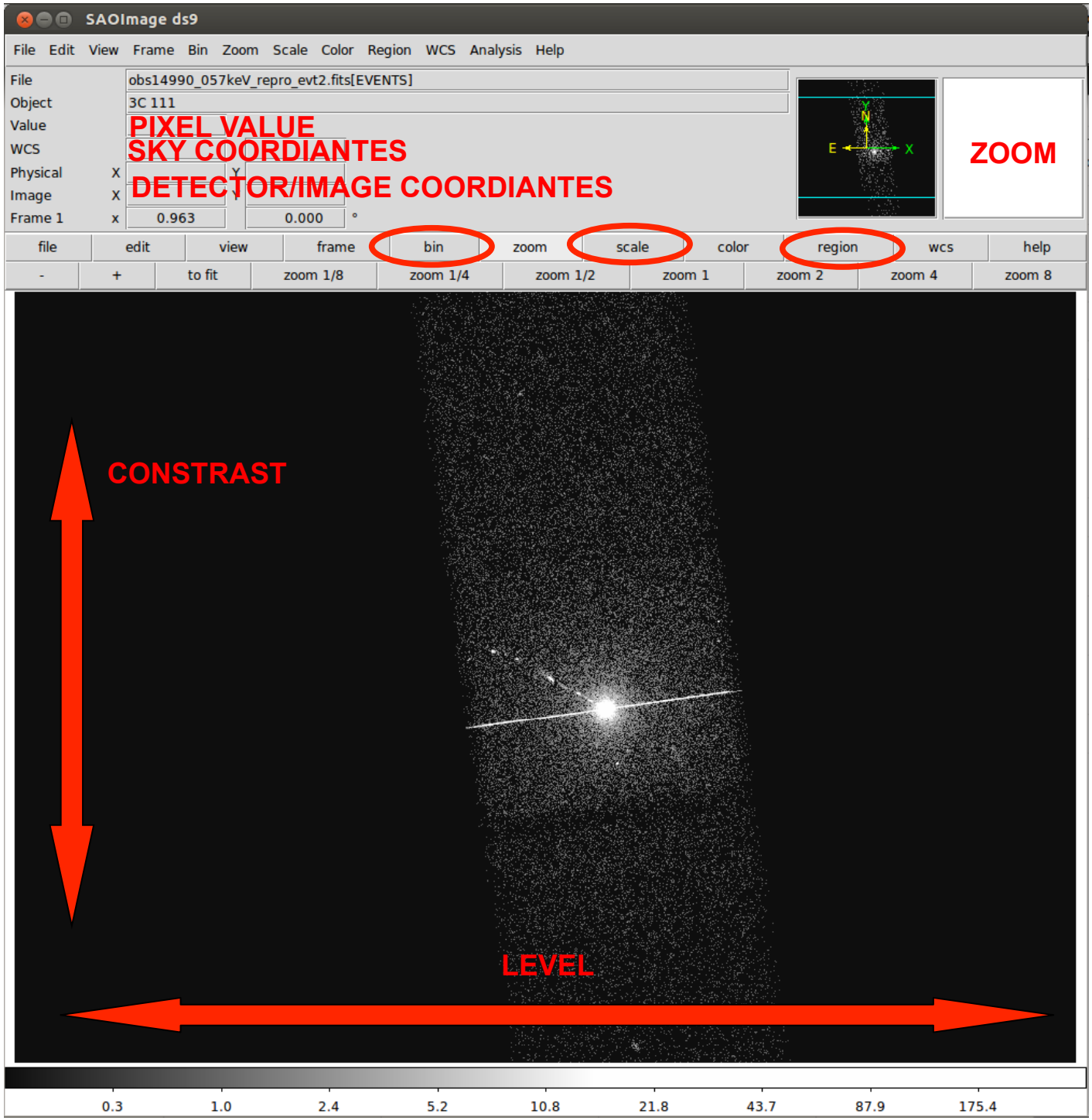
DS9

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



DS9

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

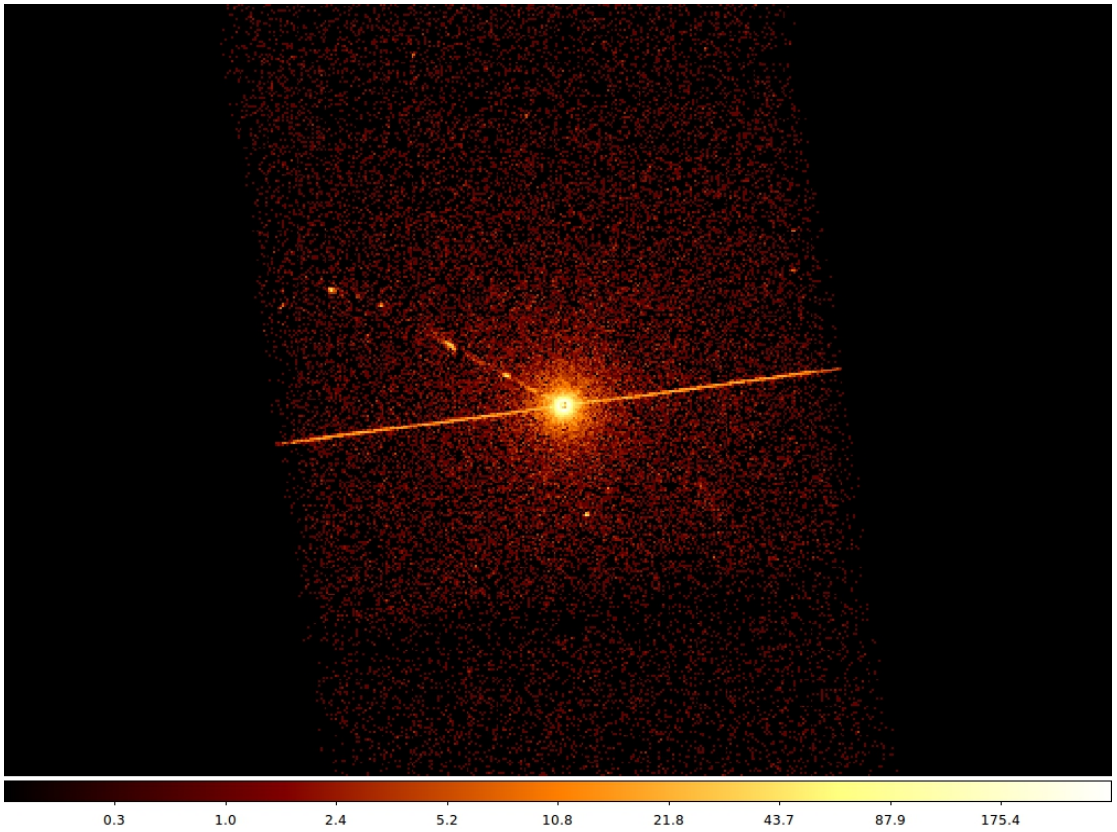


Most important information that can be obtained from an image:

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

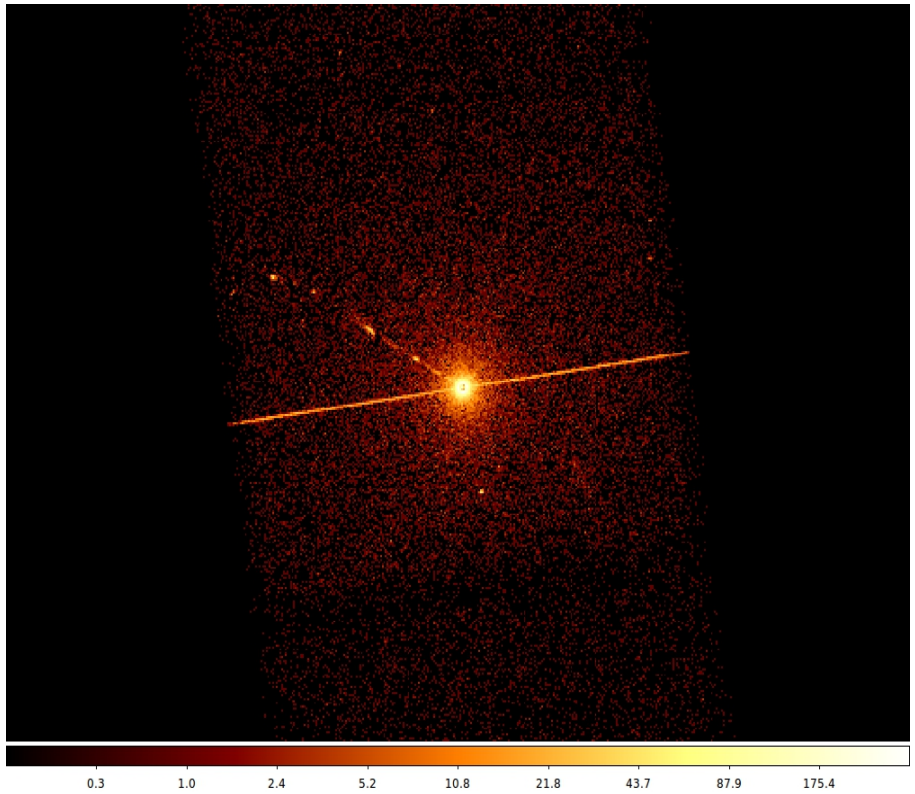
- **Morphology** (the source is pointlike or extended? obtain and fit a radial profile)

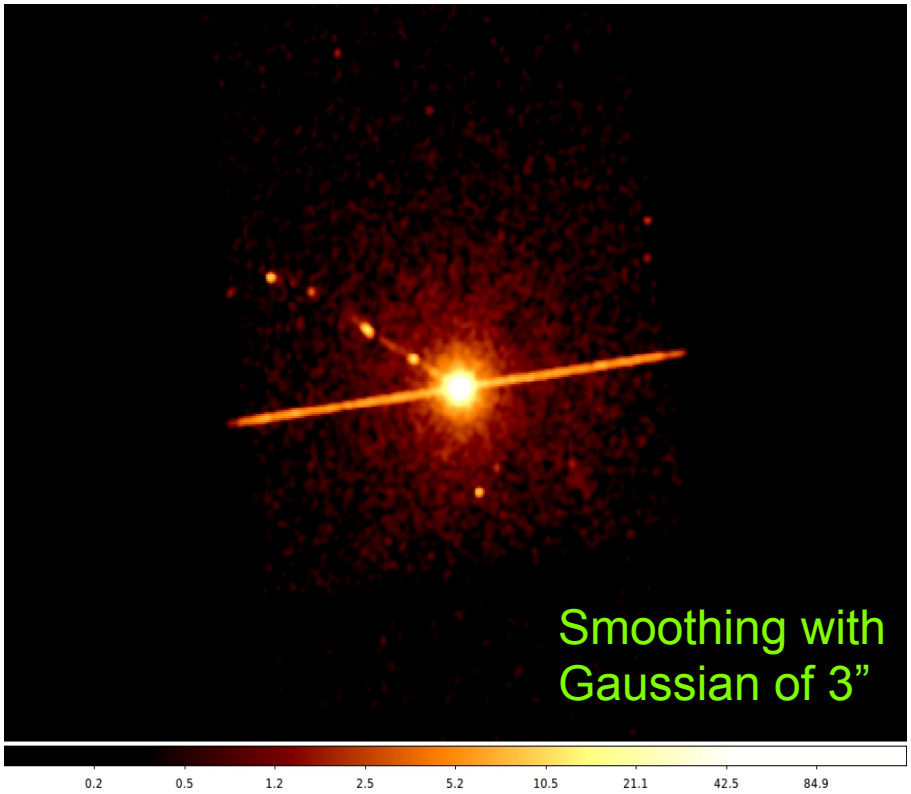
- X-ray **counterparts** of structures seen in other wavebands



It is possible to improve the image look

smoothing





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

Scientific files
Housekeeping files

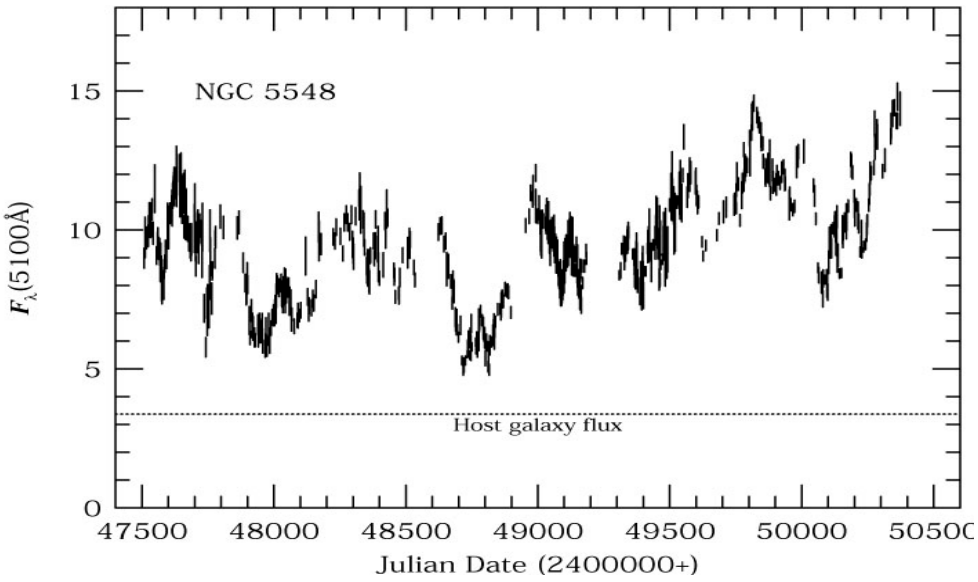
Cleaned
event files

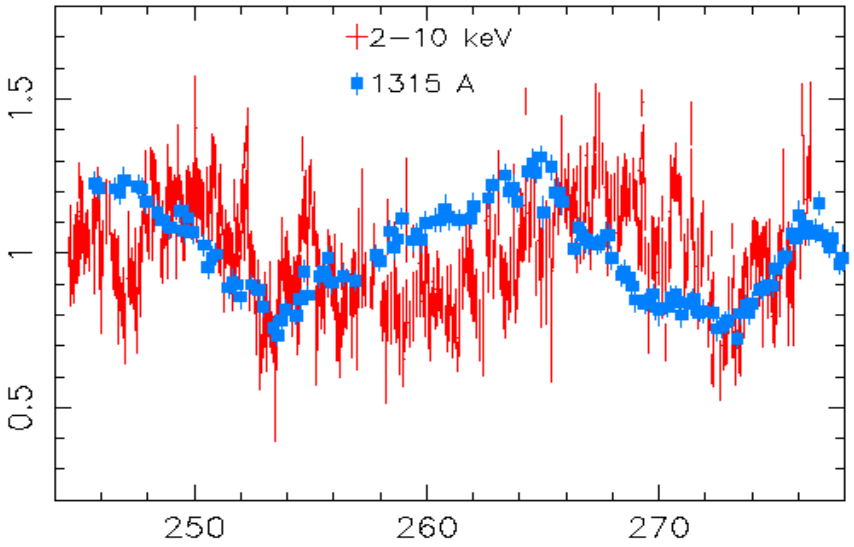
Image

Light curve

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





How to extract a lightcurve

1) select a source and background region

2) identify the ccd

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

3) extract the lightcurve (background subtracted)

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

How to extract a lightcurve

1) select a source and background region

2) identify the ccd

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

3) extract the lightcurve (background subtracted)

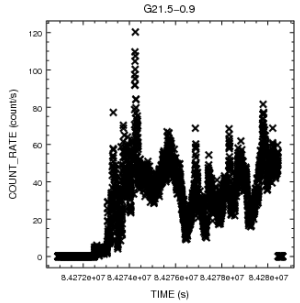
```
>punlearn dmextract
>pset dmextract infile="acisf00953N003_evt2.fits
  [ccd_id=3,sky=region(src2.reg)][bin time= : : 2000]"
>pset dmextract outfile="src_sub_lc.fits"
>pset dmextract bkg="acisf00953N003_evt2.fits
  [ccd_id=3,sky=region(bkg.reg)]"
>pset dmextract opt="ltc1"
>dmextract
```

MIN:MAX:STEP

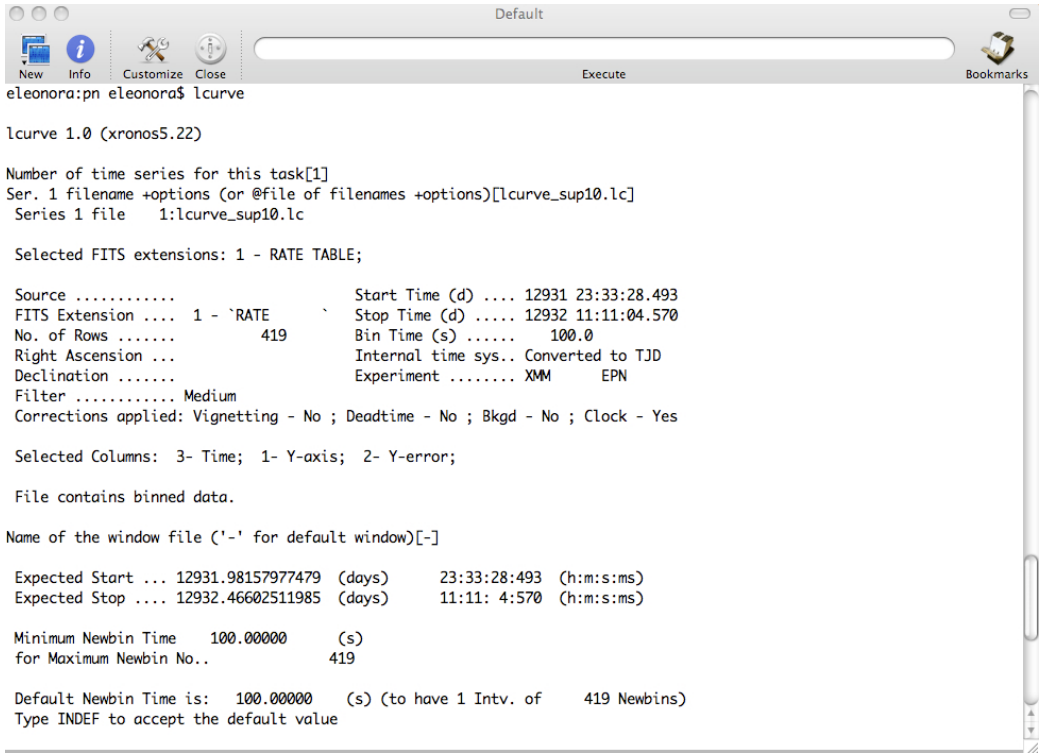
There are several ways to visualize a light curve. Here are two examples:

Chips provided by CIAO

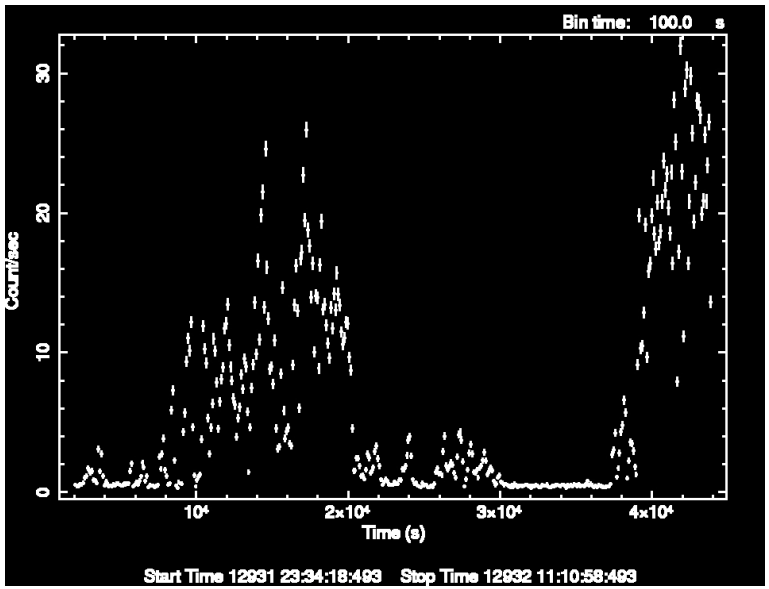
```
unix% chips
-----------------------------------------
Welcome to ChIPS: CXC's Plotting Package
-----------------------------------------
CIAO 4.3 ChIPS version 1 Thursday, December 2, 2010

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



The ftool ***lcurve***




```
eleonora:pn eleonora$ lcurve

lcurve 1.0 (xronos5.22)

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

 Selected FITS extensions: 1 - RATE TABLE;

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

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

 File contains binned data.

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

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

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

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



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

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

χ^2 test

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

c_i observed counts in every temporal bin I;

<c> average count during the observation;

σ_i Poissonian error;

v = n-1 degrees of freedom.

Compute the null hypothesis probability that the source is not varied

this test should be repeated for several temporal bins

Scientific files
Housekeeping files

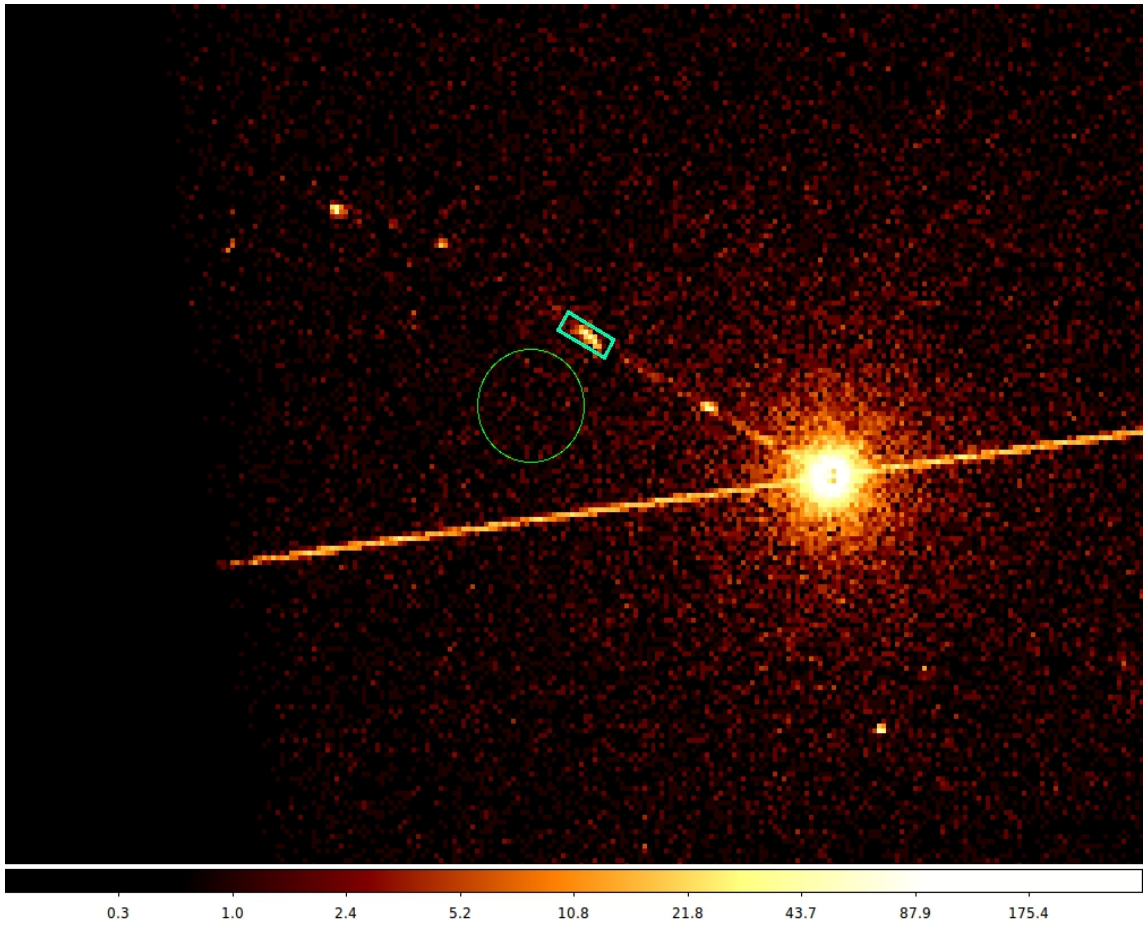
Cleaned
event files

Spectrum

Image

Light curve

Extract source and background spectra



ds9 nomefile

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

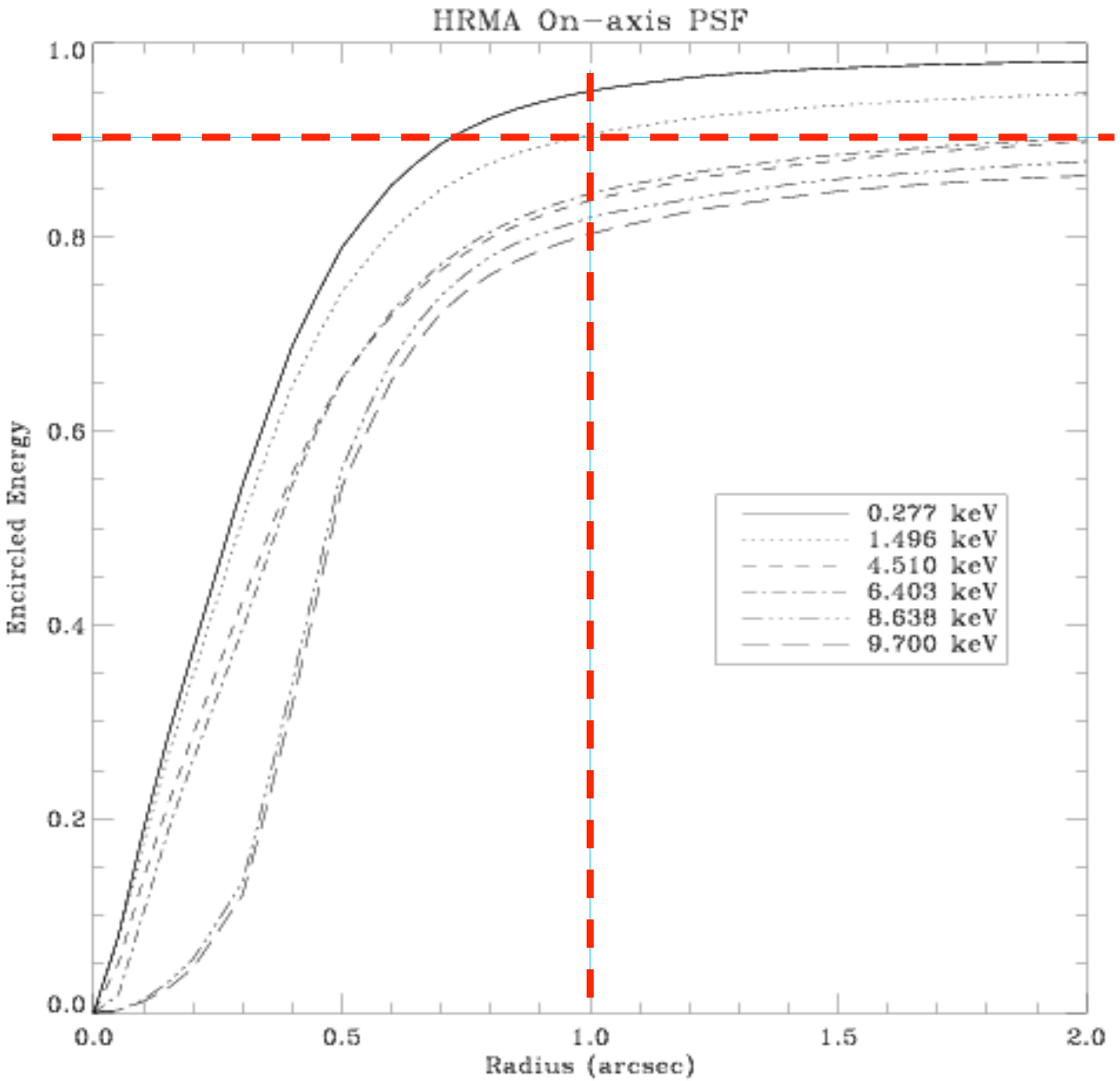
To extract the spectrum of a ***pointlike* source**…

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

specextract runs the following CIAO tools

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

Encircled Energy Fraction (EEF)



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

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

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

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

specextract runs the following CIAO tools

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

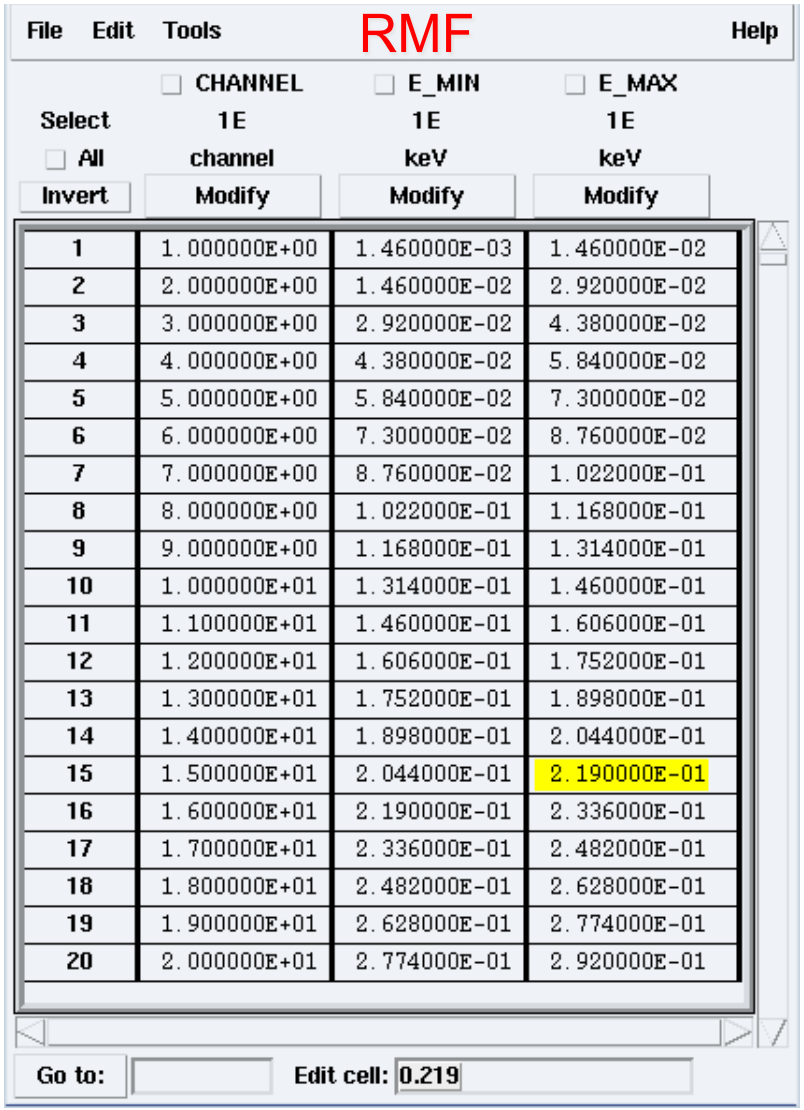
The response matrix is composed by

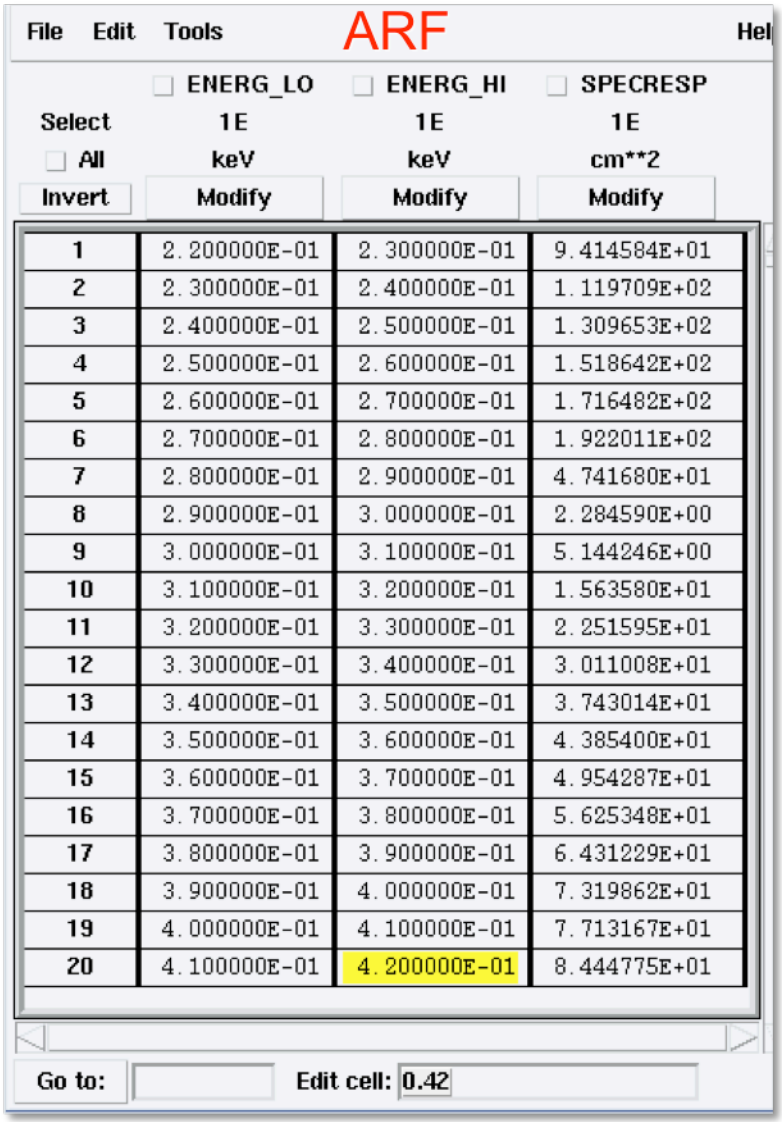
1. The ***Redistribution Matrix File (RMF):*** associates to each instrument channel (I) the appropriate photon energy (E)

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

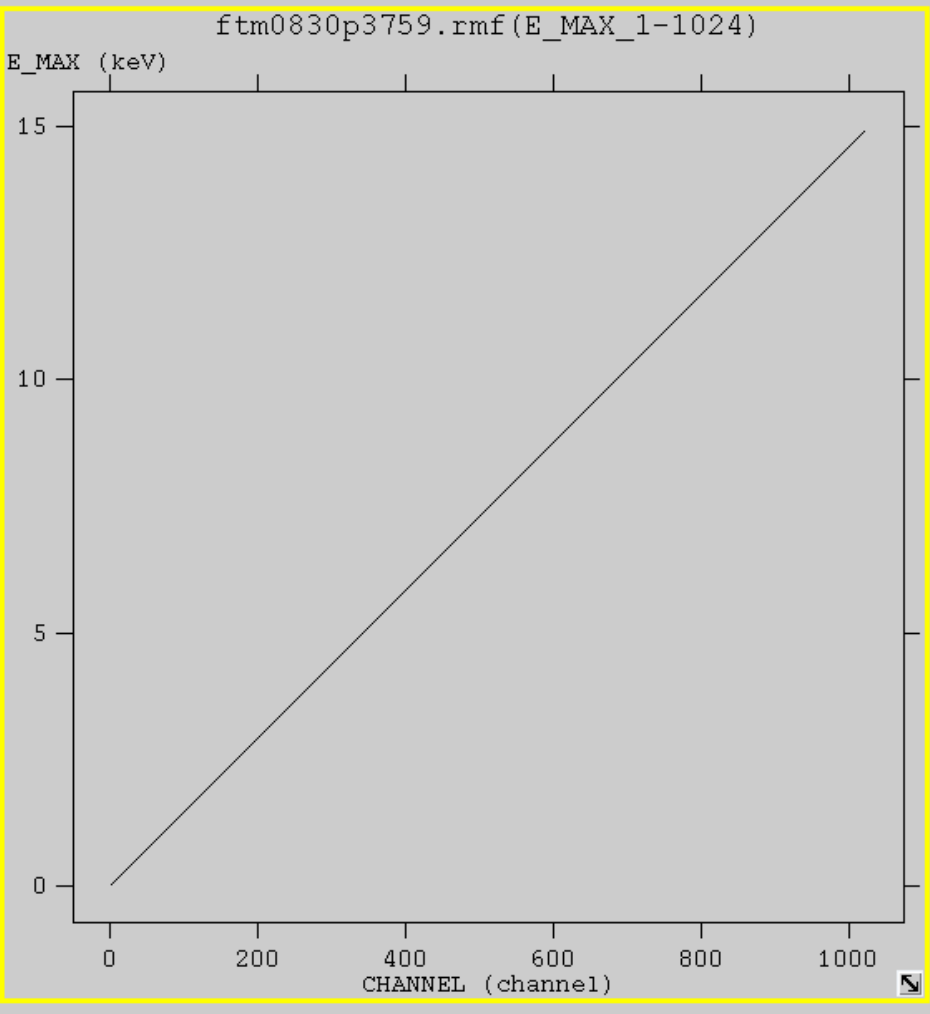
The quantum efficiency (QE) is the *fraction of incident photons registered by a detector.* For an ideal detector, this is 100%. In reality, however, no detector is 100% efficient. If, for instance, the detector is 70% efficient, then 100 arriving photons would result in 70 counts.

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

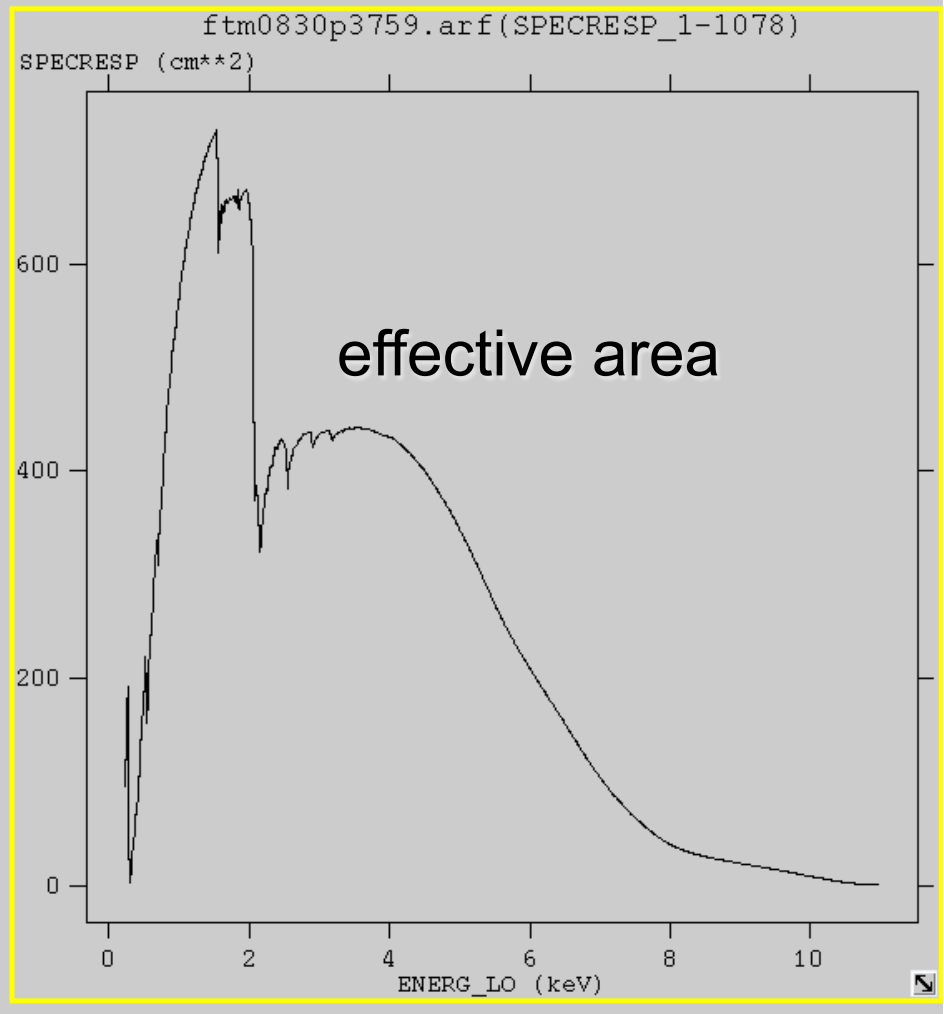

File Edit Tools
RMF
Help
CHANNEL
E_MIN
E_MAX
Select
1E
1E
1E
All
channel
keV
keV
Invert
Modify
Modify
Modify
1 1.000000E+00 1.460000E-03 1.460000E-02
2 2.000000E+00 1.460000E-02 2.920000E-02
3 3.000000E+00 2.920000E-02 4.380000E-02
4 4.000000E+00 4.380000E-02 5.840000E-02
5 5.000000E+00 5.840000E-02 7.300000E-02
6 6.000000E+00 7.300000E-02 8.760000E-02
7 7.000000E+00 8.760000E-02 1.022000E-01
8 8.000000E+00 1.022000E-01 1.168000E-01
9 9.000000E+00 1.168000E-01 1.314000E-01
10 1.000000E+01 1.314000E-01 1.460000E-01
11 1.100000E+01 1.460000E-01 1.606000E-01
12 1.200000E+01 1.606000E-01 1.752000E-01
13 1.300000E+01 1.752000E-01 1.898000E-01
14 1.400000E+01 1.898000E-01 2.044000E-01
15 1.500000E+01 2.044000E-01 2.190000E-01
16 1.600000E+01 2.190000E-01 2.336000E-01
17 1.700000E+01 2.336000E-01 2.482000E-01
18 1.800000E+01 2.482000E-01 2.628000E-01
19 1.900000E+01 2.628000E-01 2.774000E-01
20 2.000000E+01 2.774000E-01 2.920000E-01
Go to:
Edit cell: 0.219


File Edit Tools
ARF
Hel
ENERG_LO
ENERG_HI
SPECRESP
Select
1E
1E
1E
All
keV
keV
cm**2
Invert
Modify
Modify
Modify
1 2.200000E-01 2.300000E-01 9.414584E+01
2 2.300000E-01 2.400000E-01 1.119709E+02
3 2.400000E-01 2.500000E-01 1.309653E+02
4 2.500000E-01 2.600000E-01 1.518642E+02
5 2.600000E-01 2.700000E-01 1.716482E+02
6 2.700000E-01 2.800000E-01 1.922011E+02
7 2.800000E-01 2.900000E-01 4.741680E+01
8 2.900000E-01 3.000000E-01 2.284590E+00
9 3.000000E-01 3.100000E-01 5.144246E+00
10 3.100000E-01 3.200000E-01 1.563580E+01
11 3.200000E-01 3.300000E-01 2.251595E+01
12 3.300000E-01 3.400000E-01 3.011008E+01
13 3.400000E-01 3.500000E-01 3.743014E+01
14 3.500000E-01 3.600000E-01 4.385400E+01
15 3.600000E-01 3.700000E-01 4.954287E+01
16 3.700000E-01 3.800000E-01 5.625348E+01
17 3.800000E-01 3.900000E-01 6.431229E+01
18 3.900000E-01 4.000000E-01 7.319862E+01
19 4.000000E-01 4.100000E-01 7.713167E+01
20 4.100000E-01 4.200000E-01 8.444775E+01
Go to:
Edit cell: 0.42

RMF


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

ARF


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

To combine spectra of the same source from different observations

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

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

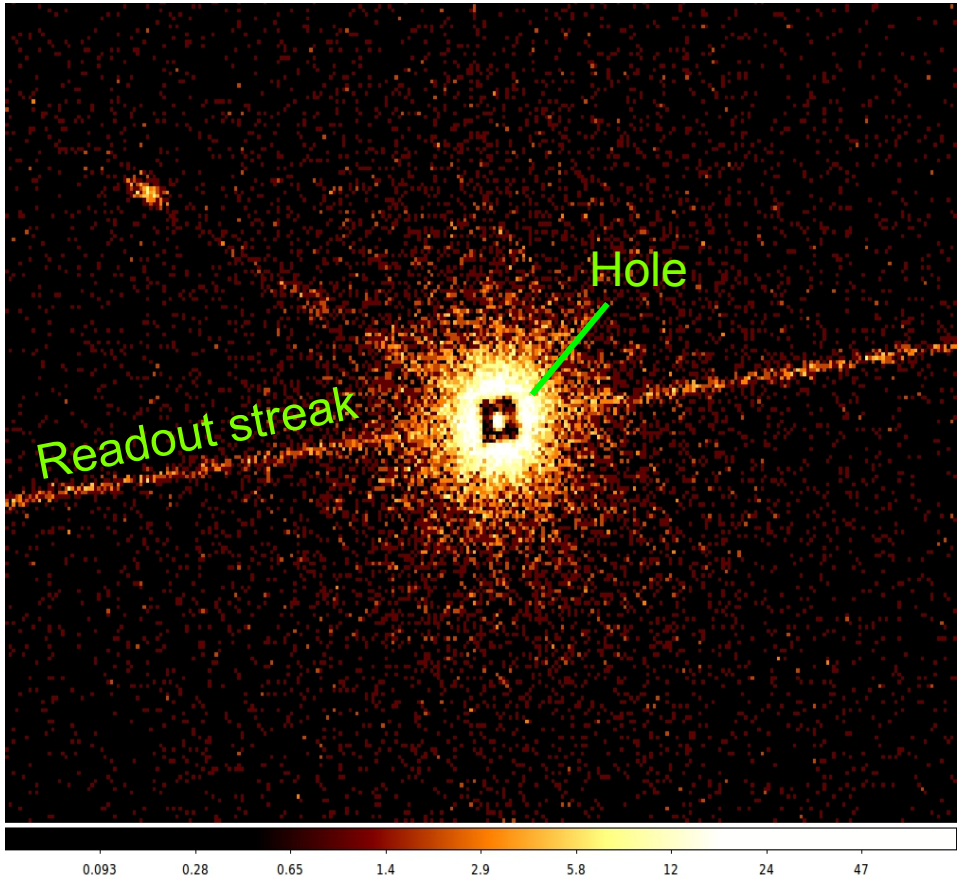
Pileup

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

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

→ loss of information from these events

→ distortion in the observed spectrum



Pileup two major effects are:

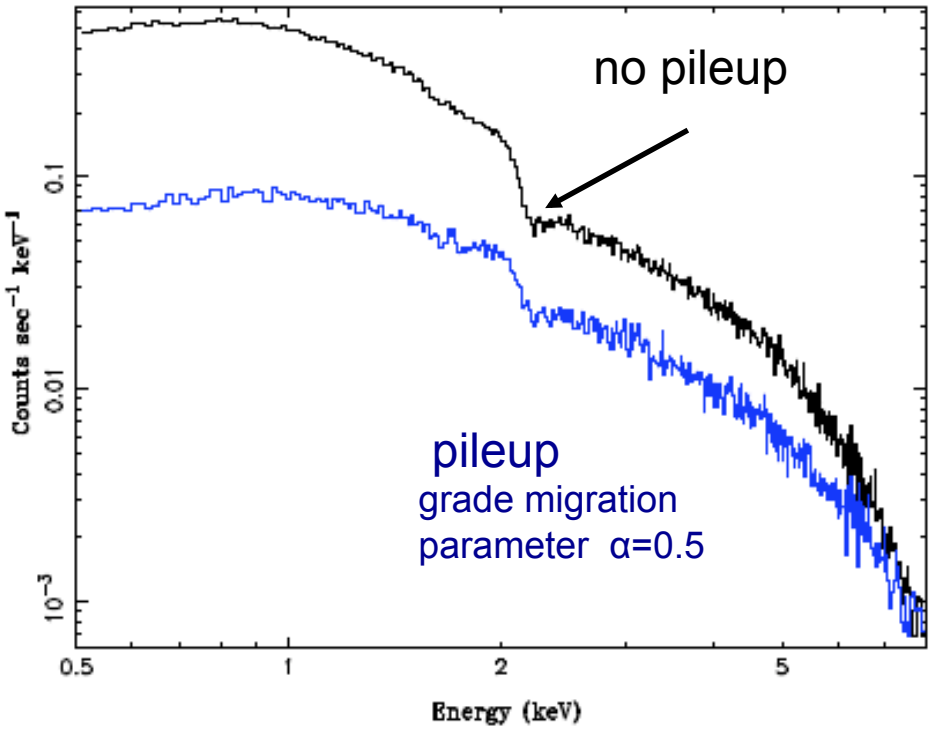
ENERGY MIGRATION photon energies sum to create a detected event with higher energy

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

- net decrease of the observed count rate

- net decrease in the fractional rms variability of the lightcurve

spectral shape of the source distorted



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

Pileup mitigation: use an XSPEC – pileup model

Scientific files
Housekeeping files

Cleaned
event files

Spectrum

Image

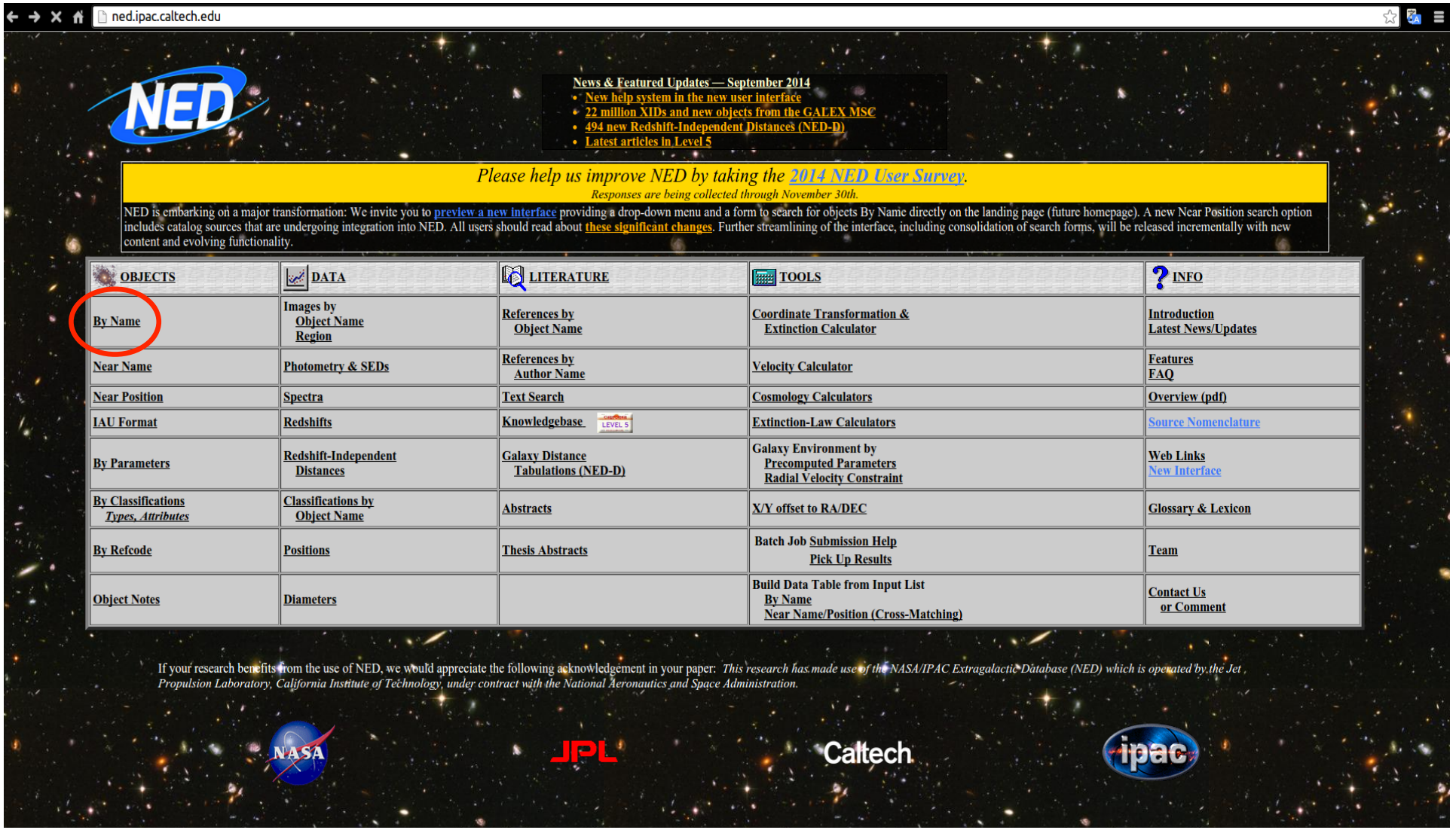
Light curve

Scientific analysis

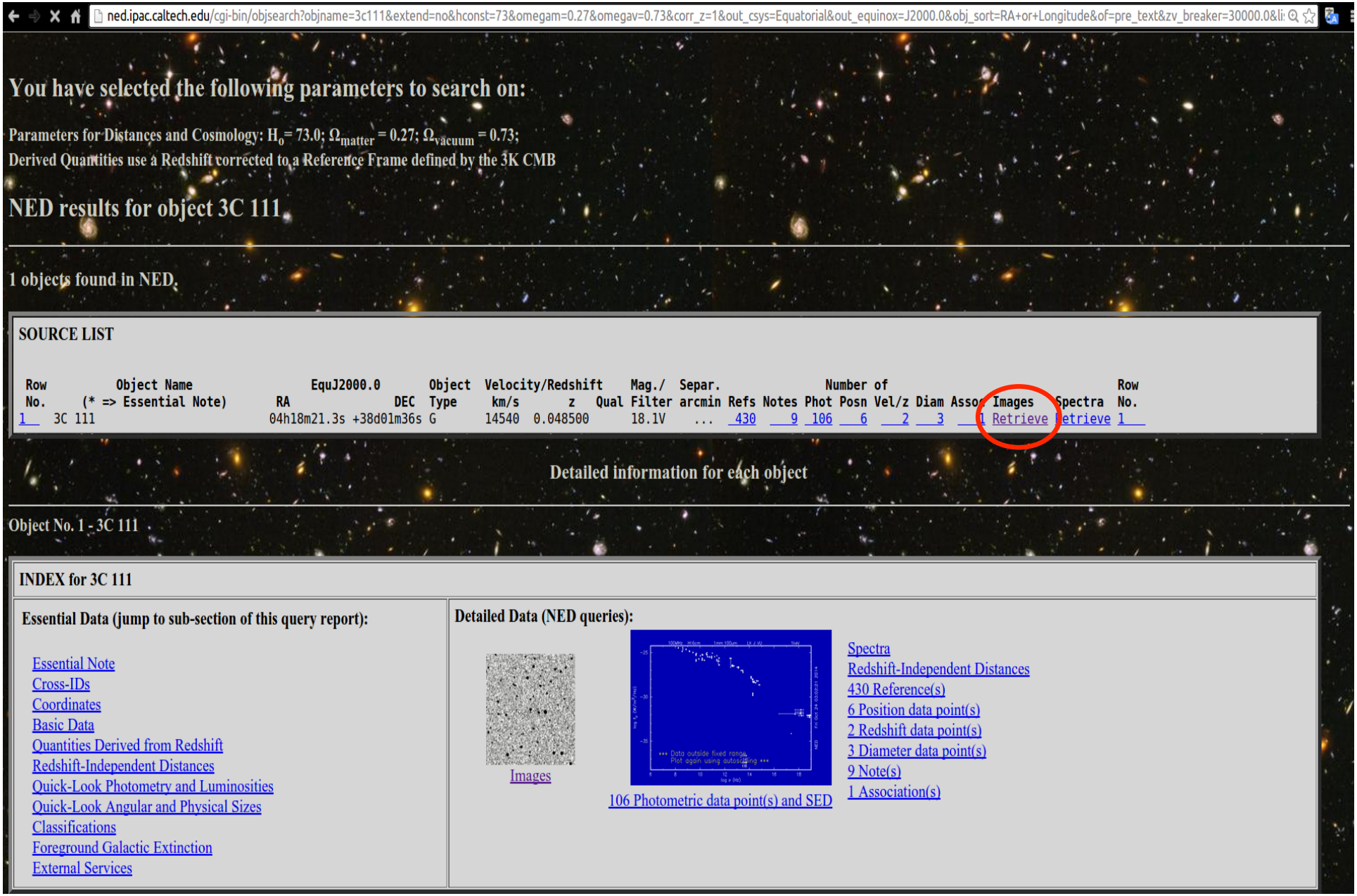
Main steps in *Chandra* data analysis

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

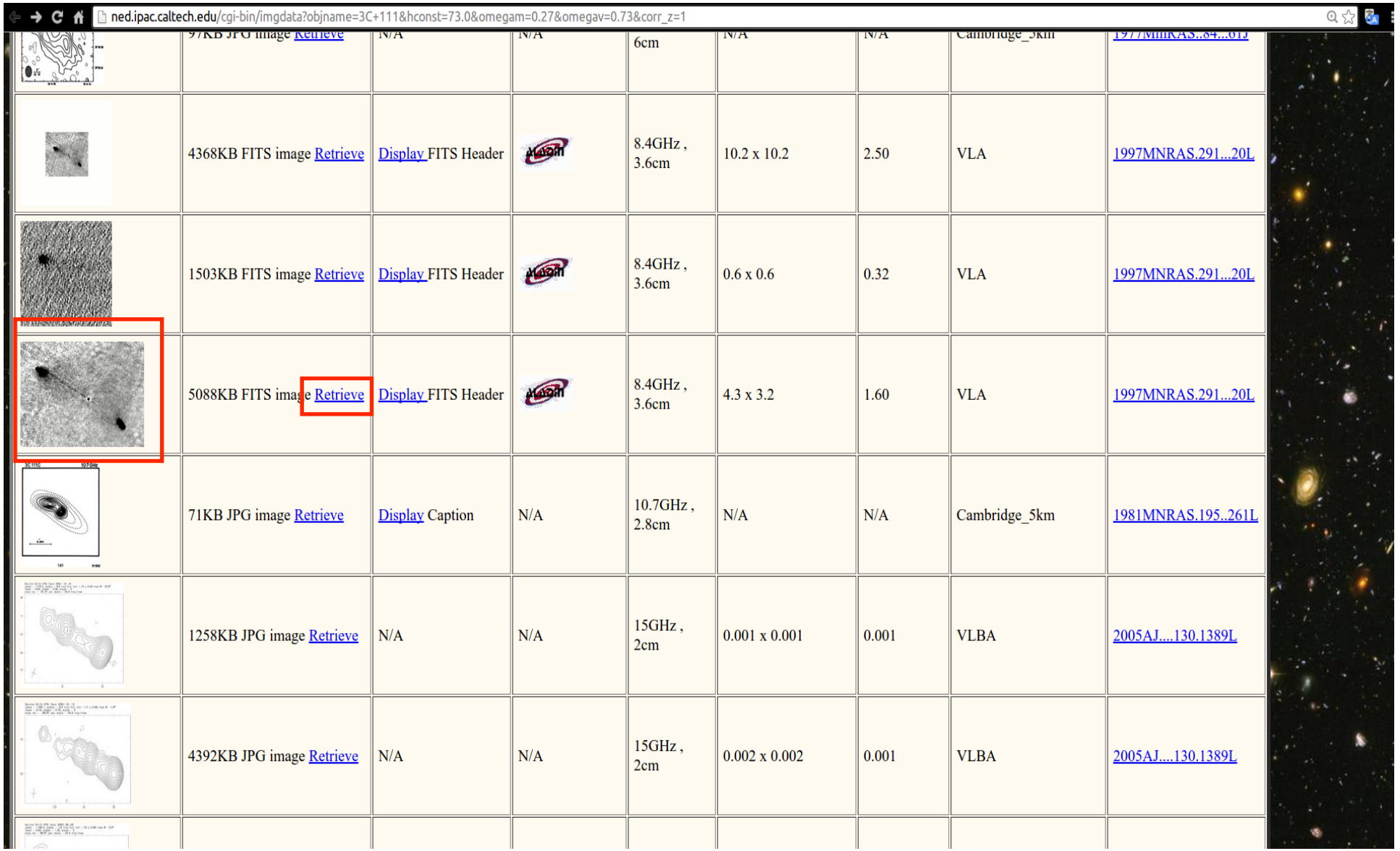
http://ned.ipac.caltech.edu/



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



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



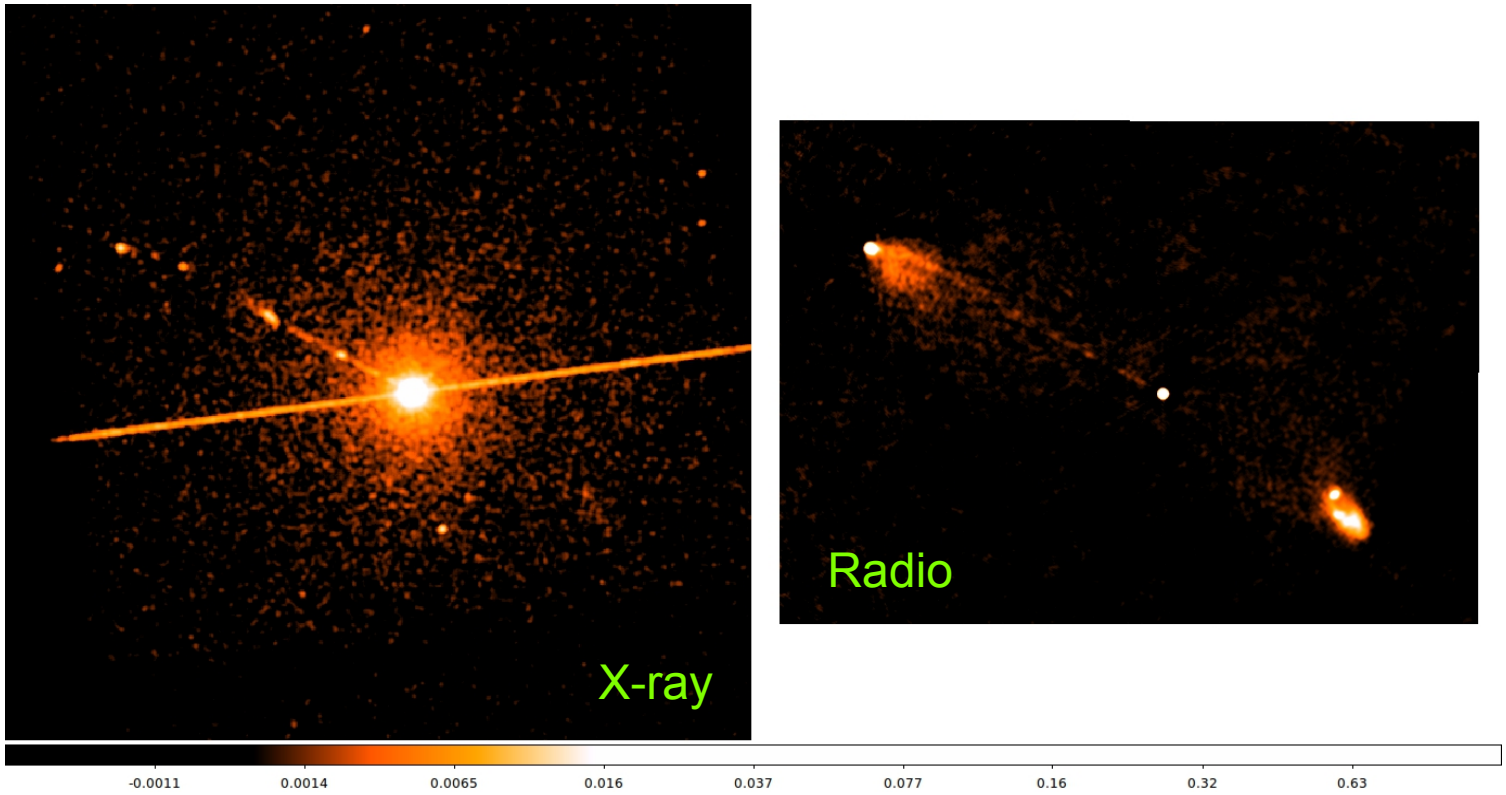
	97KB JPG image Retrieve	N/A	N/A	6cm	N/A	N/A	Cambridge_5km	1977MNRAS..84...61J
	4368KB FITS image Retrieve	Display FITS Header		8.4GHz , 3.6cm	10.2 x 10.2	2.50	VLA	1997MNRAS.291...20L
	1503KB FITS image Retrieve	Display FITS Header		8.4GHz , 3.6cm	0.6 x 0.6	0.32	VLA	1997MNRAS.291...20L
	5088KB FITS image 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

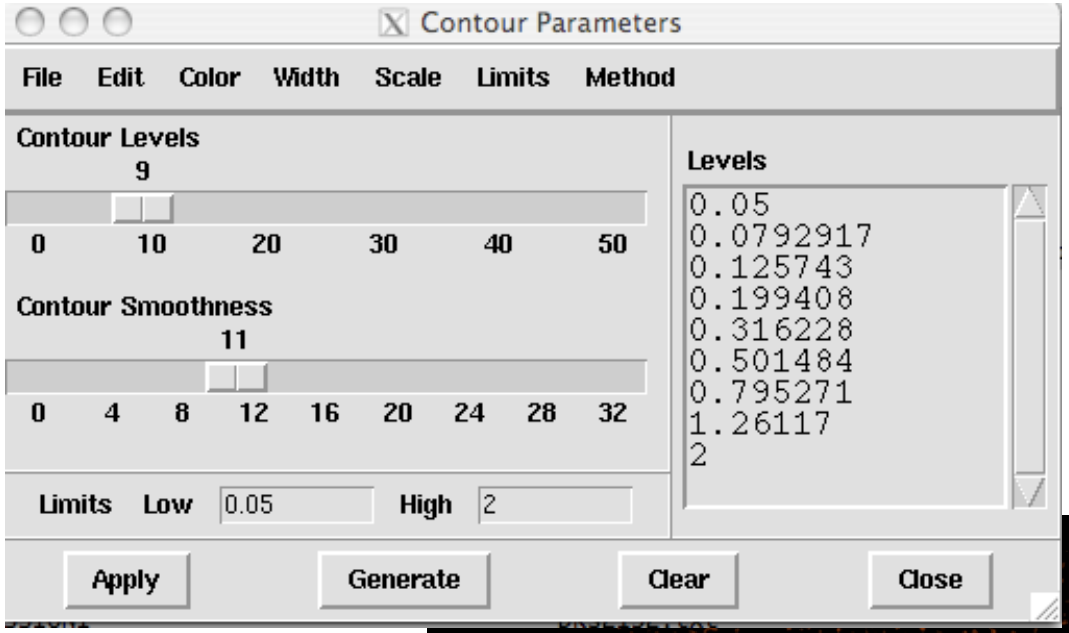
- http://www.jb.man.ac.uk/atlas/icon.html
- http://2jy.extragalactic.info/2Jy_home_page.html
- http://www.jb.man.ac.uk/atlas/dragns.html

> ds9 X-ray_image radio_image

Frame ➔ match frames
➔ WCS

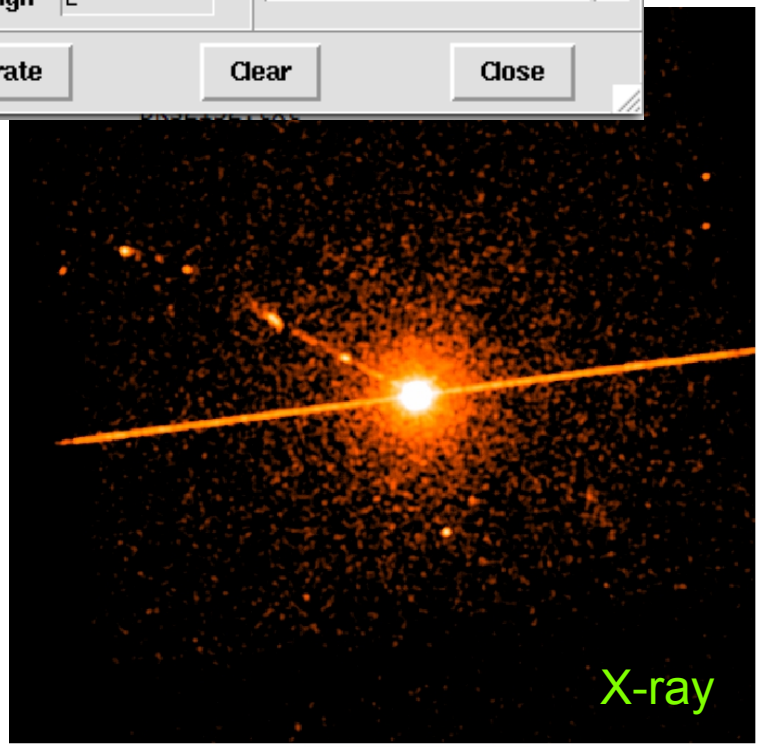


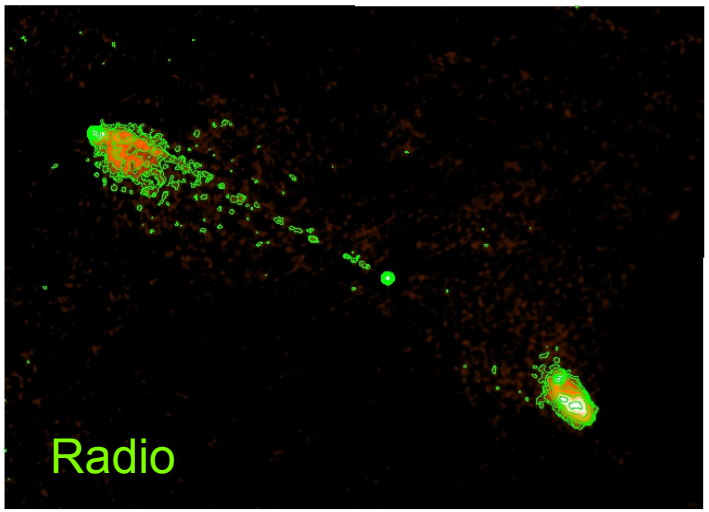
> ds9 X-ray_image radio_image

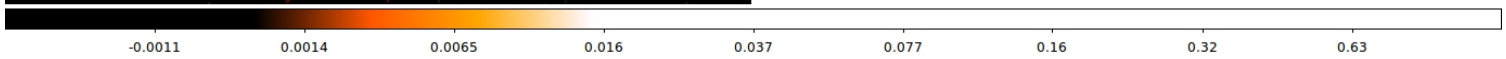


Analysis ➔ contours parameters

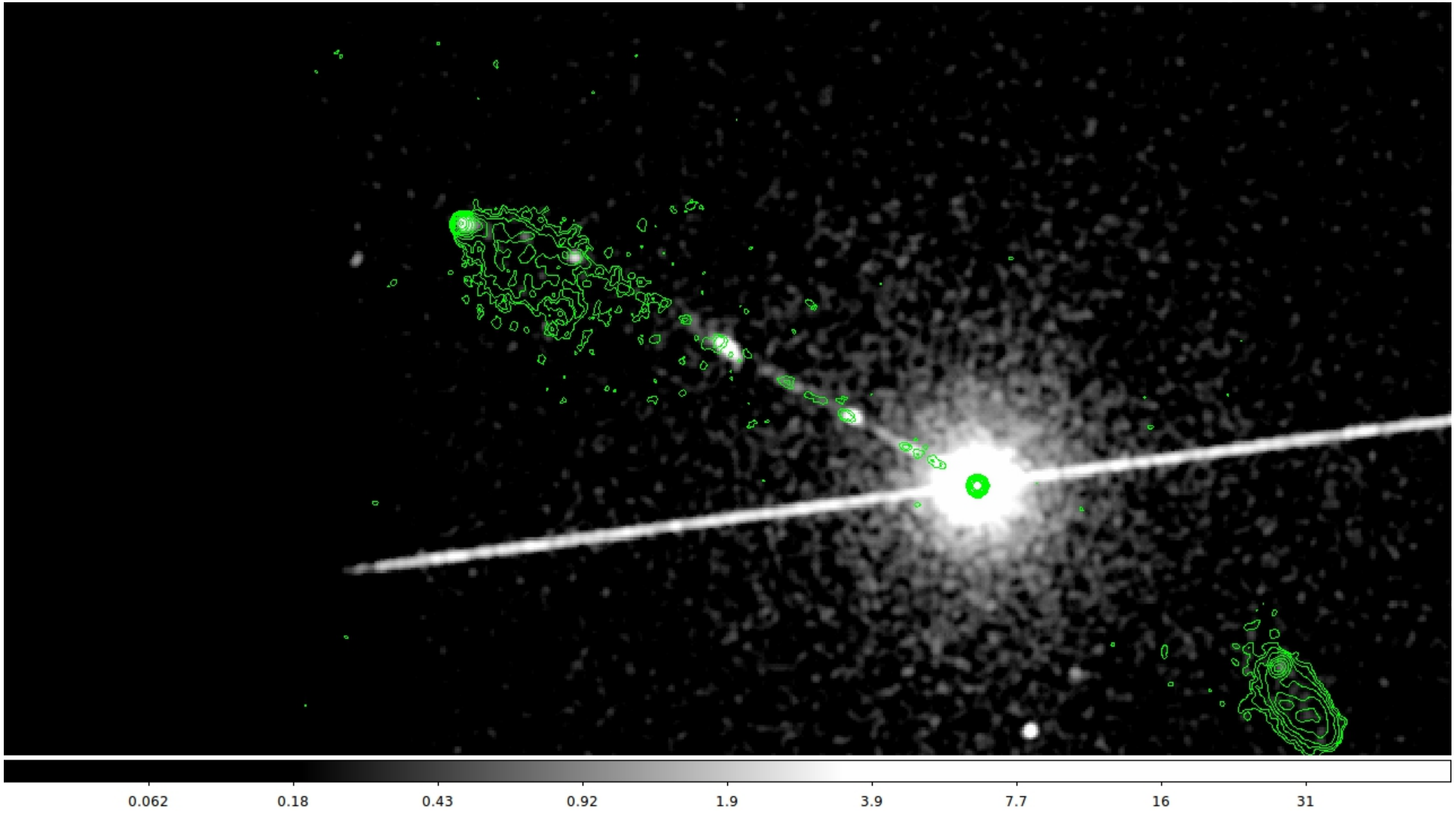
File ➔ save contours







Analysis → Contour parameters
→ File
→ Load contours



Not only radio/X…

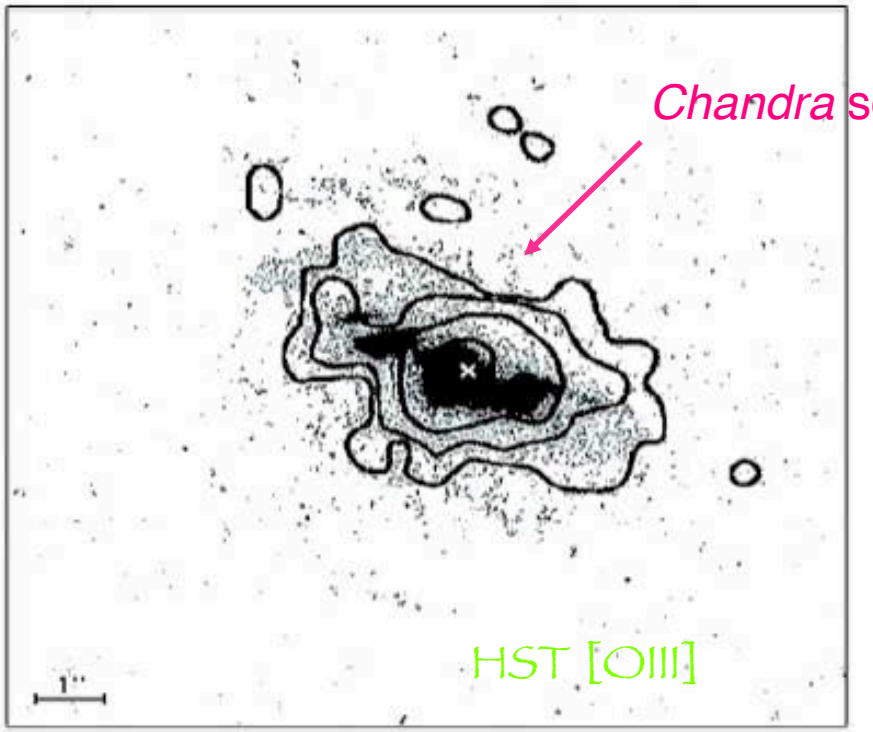


Fig. 4. Superposition of the *Chandra* soft X-ray (<2 keV) contours on an *HST* image taken through a linear ramp filter at redshifted [OIII]λ5007. The sign "x" indicates the centre of the hard X-ray source, north is up, east to the left. The X–ray image was smoothed with a Gaussian of FWHM ~ 6 pixels.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


THE END