Summary after 6th lecture:

Statistics, basic:

Poisson distribution:

- **discrete, independent events**
- **for small mean numbers**
- **asymmetric**
- **normalized to unity.**

Normal (Gaussian) distribution.:

- **differential probability**
- **normalized to unity**
- **symmetric around mean**
- **describes the random events for large m.**

Significance of measurement:

- **FWHM, “3 sigma” error**
- **standard deviation, variance**
- **propagation of errors.**

Background substraction:

- **signal-to-noise ratio**
- **low-B and high-B limits**
- **bright and faint sources.**

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- bright and faint sources.

Theoretical variance:

$$\sigma^2 = \frac{1}{n} \sum_{i=1}^{i=n} (x_i - m)^2$$

Practical variance:

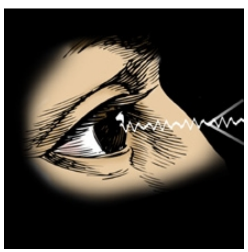
$$\sigma^2 = \frac{1}{n-1} \sum_{i=1}^{i=n} (x_i - x_{av})^2$$

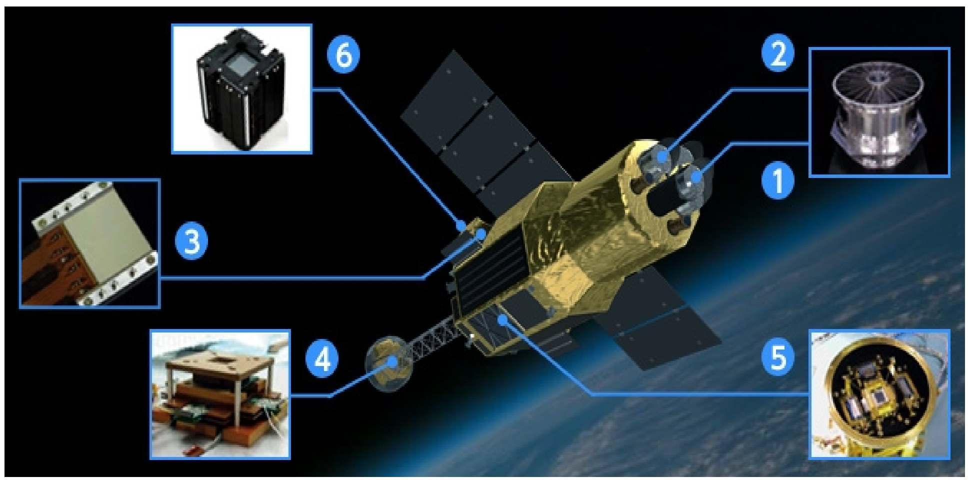
$$\left(x_{av} = \sum_{j=1}^{j=n} \frac{x_j}{n} \right)$$

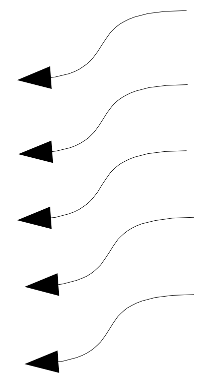
Lecture 7: Data reduction and calibration

X-ray photons have relatively large energies, so single ones can be easily detected, but have relatively low fluxes, so they are easy to count.

(Handbook for X-ray astronomy, 2011)







Observer | Satellite, ASTRO-H | Photons | Source

1.Soft X-ray telescope
2.Hard X-ray telescope } **focusing X-ray**
3.Soft X-ray imager
4.Hard X-ray imager } **imaging CCD**
5.Soft X-ray spectrometer
6. Soft γ- ray detector

The event file – list of detected events, with a set of attributes: position, time of arrival, some attributes related to the energy of the photon, quantities to discriminate good events from bkgr.

Data stored in FITS format: Flexible Image Transport System

- binary table extension with event list,
- extensions required for analysis of the event list:

Table 4.1 *Attributes for each X-ray in a Chandra ACIS event file*

Column name	Min	Max	Description
TIME			Spacecraft time (s)
CCD_ID	0	9	CCD chip
NODE_ID	0	3	Section of chip
EXPNO			Readout number
CHIPX	1	1024	Chip position
CHIPY	1	1024	Chip position
TDETX	1	8192	Detector position
TDETY	1	8192	Detector position
DETX	0	8192	Detector position
DETY	0	8192	Detector position
X	0	8192	Sky position
Y	0	8192	Sky position
PHAS	−4096	4095	Vector of PHA for grade
PHA	0	36855	Total PHA for event
ENERGY	0	1000000	Estimated event energy
PI	1	1024	Gain-corrected PHA
FLTGRADE	0	255	Event Grade
GRADE	0	7	Event Grade
STATUS			Status flags

Informations about the status of the detector and satellite are stored in housekeeping files, usually at a fixed cadence:

Table 4.2 *Example housekeeping attributes for the Suzaku XIS*

Column name	Description
TIME	Spacecraft time (s)
AOCU_HK_CNT3_NML_P	Whether attitude control is in pointing mode
ANG_DIST	Angle between instantaneous pointing and the mean
Sn_DRATE	Telemetry rate for sensor n
SAA_HXD	Whether satellite is in SAA
T_SAA_HXD	Time since last SAA passage
ELV	Angle between pointing direction and Earth's limb
DYE_ELV	Angle between pointing direction and the sunlit limb of the Earth

The raw event attributes are processed to create refine attributes, This is normally done in an automated pipeline by data center.

1) Calculation of sky position:

- convert the raw detector position to one in a coordinate system fixed in the focal plane, DETX, DETY (constant in time),

- converting to sky coordinates, requires a knowledge of the direction that the focal plane was pointing, AUXILIARY STAR-TRACKER TELESCOPE, (time variable – satellite may dither about location),

- the positions X,Y recorded in the event file are in units of pixels and can be converted to right ascension and declination using World Coordinate System (WCS)

In Chandra the detector pixel sizes are comparable to the spatial resolution.

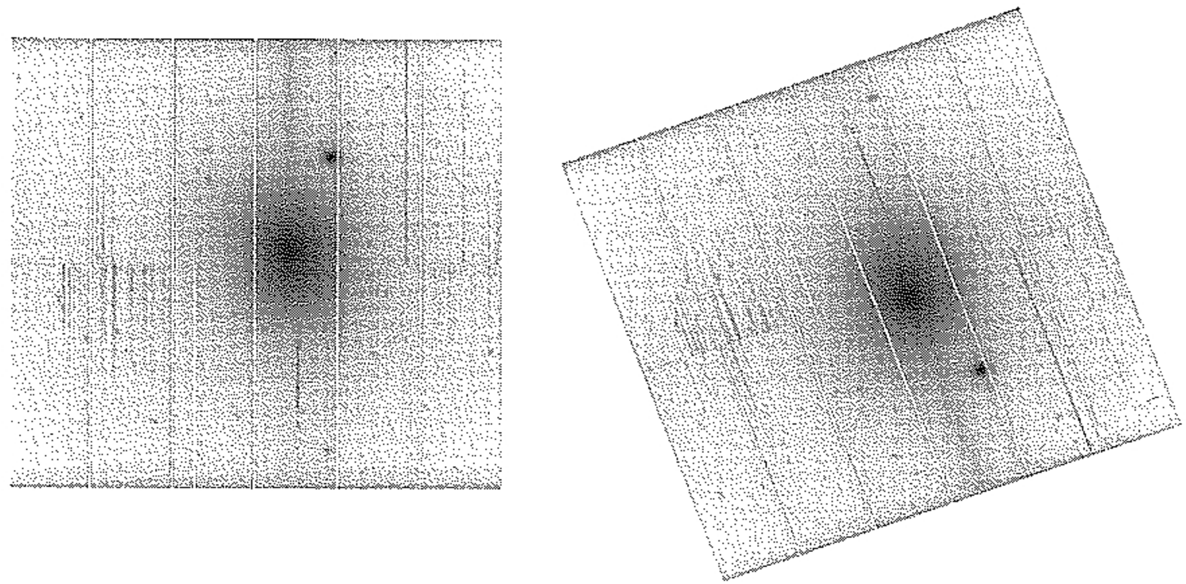


Fig. 4.1 The cluster Abell 1795 observed with the XMM–Newton EPIC-pn detector (ObsID 0097820101) in detector (left) and sky (right) coordinates

2) Calculation of grade:

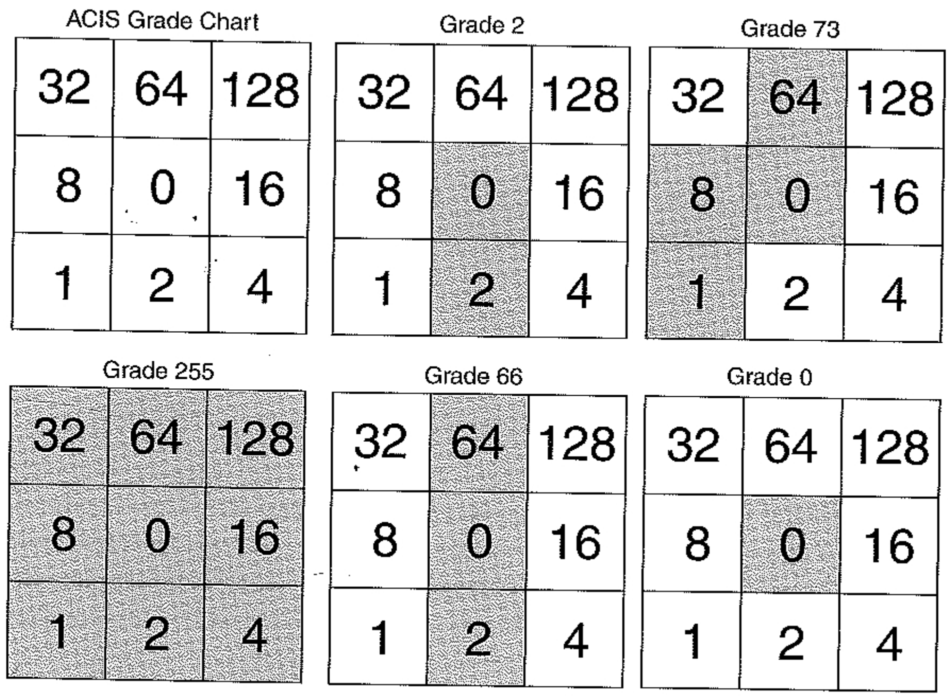


Fig. 4.2 Illustration of different CCD grades, using the Chandra ACIS grade system. A single event is defined as all contiguous pixels in a frame with charge above some minimum value. The event center (pixel "0") is taken to be the pixel with largest charge. Gray boxes indicate pixels with charge above the minimum. The grade is calculated by summing the numbers in each gray box. Some grades, such as 255, are automatically rejected as being almost certainly due to particle impact rather than an X-ray photon. Grade 0 events, also known as single-pixel events, have the best energy resolution, although double- and triple-pixel events are usually not much worse

3) Calculation of energy or wavelength:

- CCDs accumulate charge for each X-ray
  PHA (Pulse Height Amplitude – total for event),

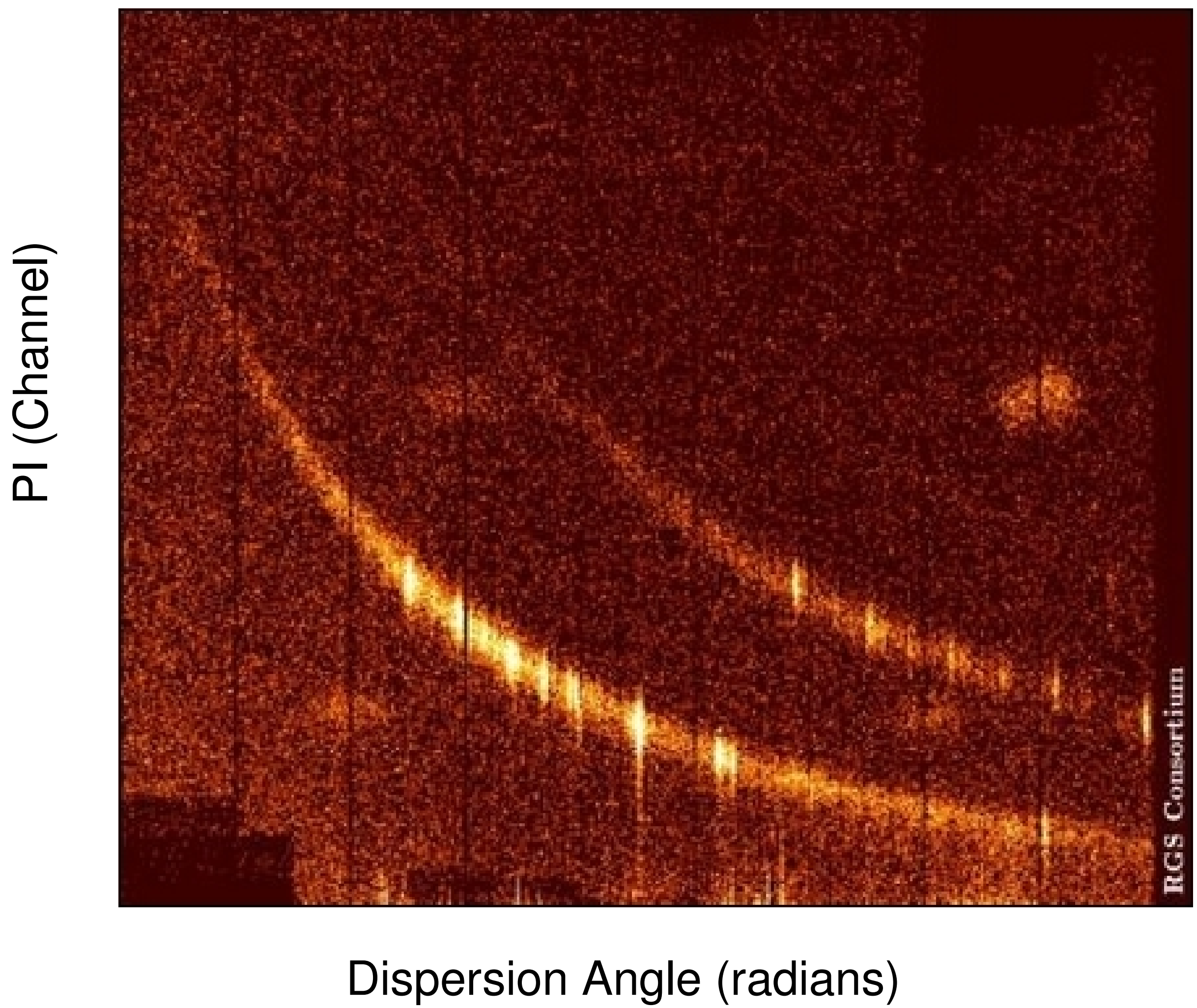
- the conversion between PHA and energy may not be strictly linear and can vary with time or position of the detector,

- any time or position variability is corrected and stored as PI (for PHA invariant),

- the relationship between PI and the energy of the photon is encoded in the response matrix,

- PHAS – vector of PHA for grade, 3 x 3 or 5 x 5 pixel regions.

- overlap between diffraction orders can be broken since each event can be placed on a two – dimensional plot.



4) Calculation of time:

- the event time is recorded on board, relative to the spacecraft clock,

- then converted to a time at Earth and recorded in seconds relative to the modified Julian date MJD,

- sources with high variability or precise ephemerides the time should be converted to Solar System barycenter to eliminate effects due to the Earth's orbit,

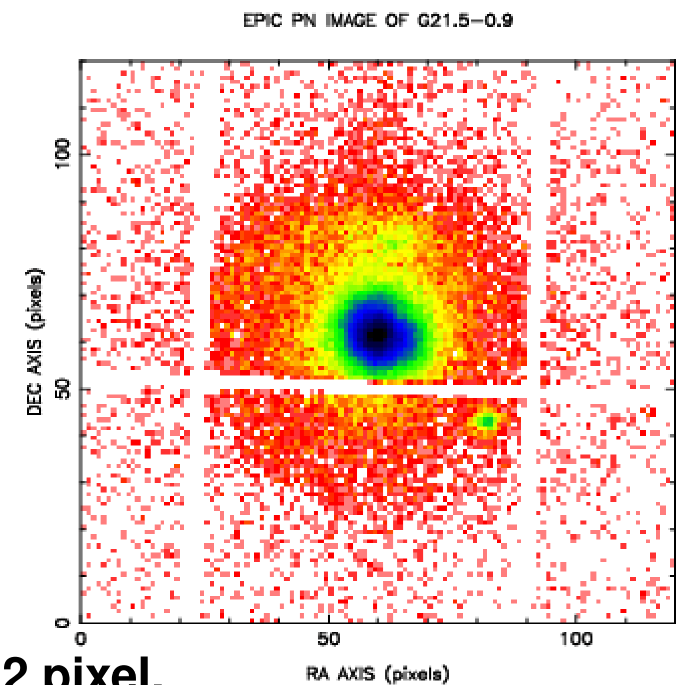
- this is not done in automatic processing, since precise information about the satellite orbit is typically available several weeks after the observation.

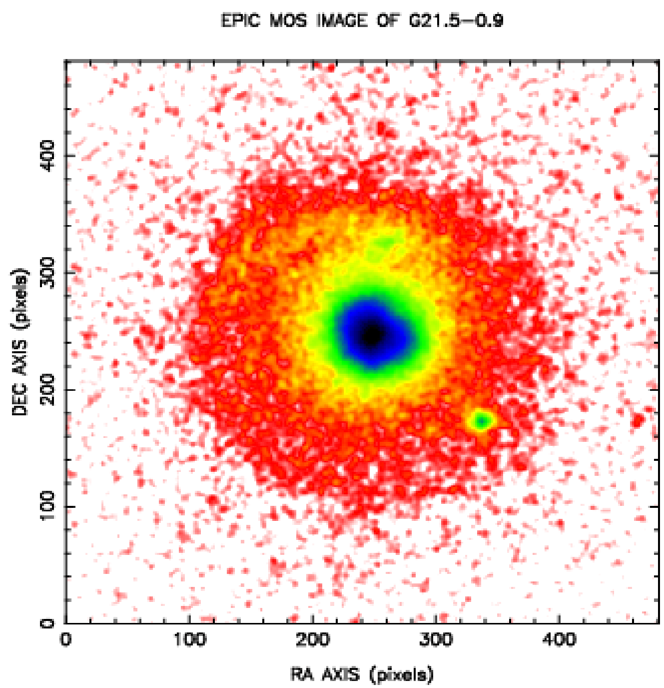
5) Non – X – ray background rejection:

- signal due to cosmic rays (energetic particles) often differs in some way from that due to X-rays,
- different instruments have different definitions of grades and choices about which can be assume d to be bkgr,
- the signal-to-noise ratio can be improved by rejecting events which are likely to be bkgr,
- processing systems leaves the opinion to researcher about farther removing of bkgr at the cost of rejecting true X-rays,

Left
The raw XMM PN image
SNR G21.5-0.9
Pixel size 4'', image – 8'

Right
The XMM MOS image
Pixel size 1'', image – 8'
Gaussian smoothing
mask with width sigma=2 pixel.





Looking at the data:

Do not assume that the automated processing has worked correctly, look at it in as many ways as possible.

(Handbook for X-ray astronomy, 2011)

1) Hot spots, bad rows, flickering pixels, and afterglows:

- electronic hot spots or bad rows – are neither X-ray nor bkgr events, may be excluded on-board the spacecraft in order to reduce the telemetry load,

- flickering pixels (CCDs) depends on the temperature

- statistical cleaning is performed by the HEAsoft program: *cleansis,* *X*MM-Newton SAS program: *emevents,*

- cosmic ray interaction with CCD - “afterglow” - CIAO tools.

2) Pileup:

- significantly impacts imaging, spectral and timing analysis,

- the best strategy is to plan the observation to reduce its importance by choosing instrument and operating modes appropriately,

- it can be explicitly modelled in spectral analysis.

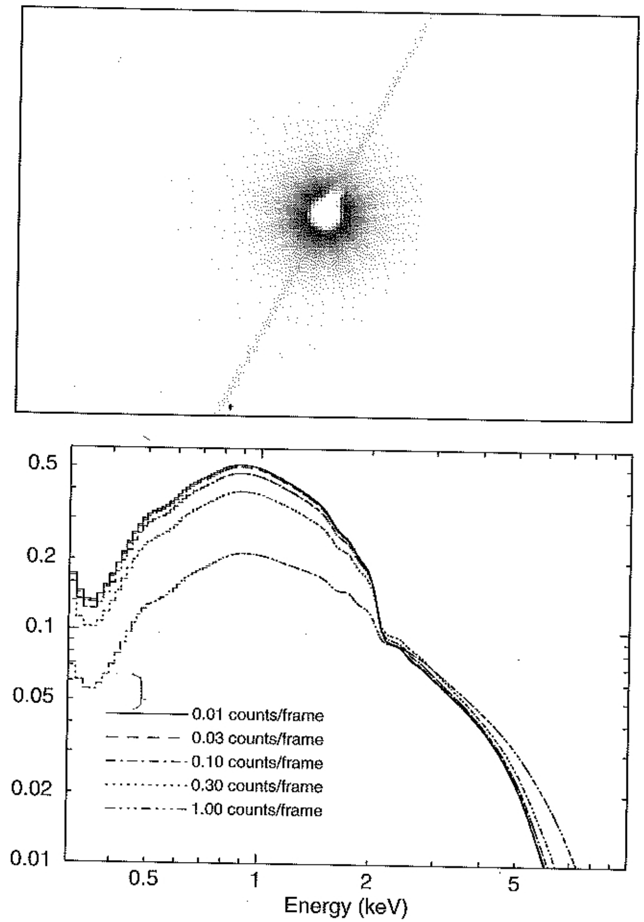


Fig. 4.5 [Top] Chandra ACIS observation of the bright source Hercules X-1. The hole in the center of the source is due to piled-up events which are rejected because of bad grades. Also visible are the streaks due to events detected while the detector is being read out and the shadows of the mirror support structure. [Bottom] Chandra ACIS simulated spectra showing the effect of increasing pileup. As the input count rate, and hence pileup, is increased the observed spectrum decreases at low energy while increasing at higher energies

Selecting events of interest:

Any instrument with spatial resolution will likely require filtering to select the region of interest.

(Handbook for X-ray astronomy, 2011)

1) By region:

- region filters consist of a combination of individual shapes.

Table 4.5 *Region shapes*

Shape	Arguments	Description	HEAsoft	CIAO	SAS
Point	(X,Y)	One-pixel square region	√	√	√
Line	$(X1,Y1,\ X2,Y2)$	One-pixel-wide rectangle from $(X1,Y1)$ to $(X2,Y2)$	√	X	√
Polygon	$(X1,Y1,\ X2,Y2,\ \ldots)$	Polygon with vertices $(X1,Y1)$, $(X2,Y2)$, ...	√	√	√
Rectangle	$(X1,Y1,\ X2,Y2,\ A)$	Box with corners $(X1,Y1)$, $(X2,Y2)$ rotated by A	√	√	√
Box	$(X,Y,W,\ H,\ A)$	Box with center (X,Y) width W, height H and rotation A	√	√	√
Diamond	$(X,Y,W,\ H,A)$	Diamond with center (X,Y) width W, height H and rotation A	√	X	√
Circle	$(X,Y,\ R)$	Circle with center (X,Y) and radius R	√	X	√
Annulus	$(X,Y,\ Ri,\ Ro)$	Annulus between Ri and Ro centered on (X,Y)	√	√	√
Ellipse	$(X,Y,\ Rx,\ Ry,\ A)$	Ellipse center (X,Y) semi-major axes Rx, Ry and rotation A	√	√	√
Elliptannulus	$(X,Y,\ Rix,\ Riy,\ Rox,\ Roy,\ Ai,\ Ao)$	Like Annulus region but with ellipses	√	√	√
Boxannulus	$(X,Y,W1,\ H1,W2,\ H2,\ A)$	Like Annulus region but with boxes	√	√	√
Sector	$(X,Y,\ A1,\ A2)$	Region center (Xc,Yc) between angles $A1$ and $A2$	√	√	√
Pie	$(X,Y,\ Ri,\ Ro,\ A1,\ A2)$	Region center (Xc,Yc) between radii Ri, Ro and angles $A1$, $A2$	√	√	X
Panda	$(X,Y,\ A1,\ A2,1,\ Ri,\ Ro,\ 1)$	Same as Pie region	X	√	√
Epanda	$(X,Y,\ A1,\ A2,\ 1,\ Rix,\ Riy,\ Rox,\ Roy,\ 1,\ A)$	Like Panda region but with ellipses	√	X	X
Bpanda	$(X,Y,\ A1,\ A2,1,\ Wi,\ Hi,\ Wo,\ Ho,\ 1,\ A)$	Like Panda region but with boxes	√	X	X

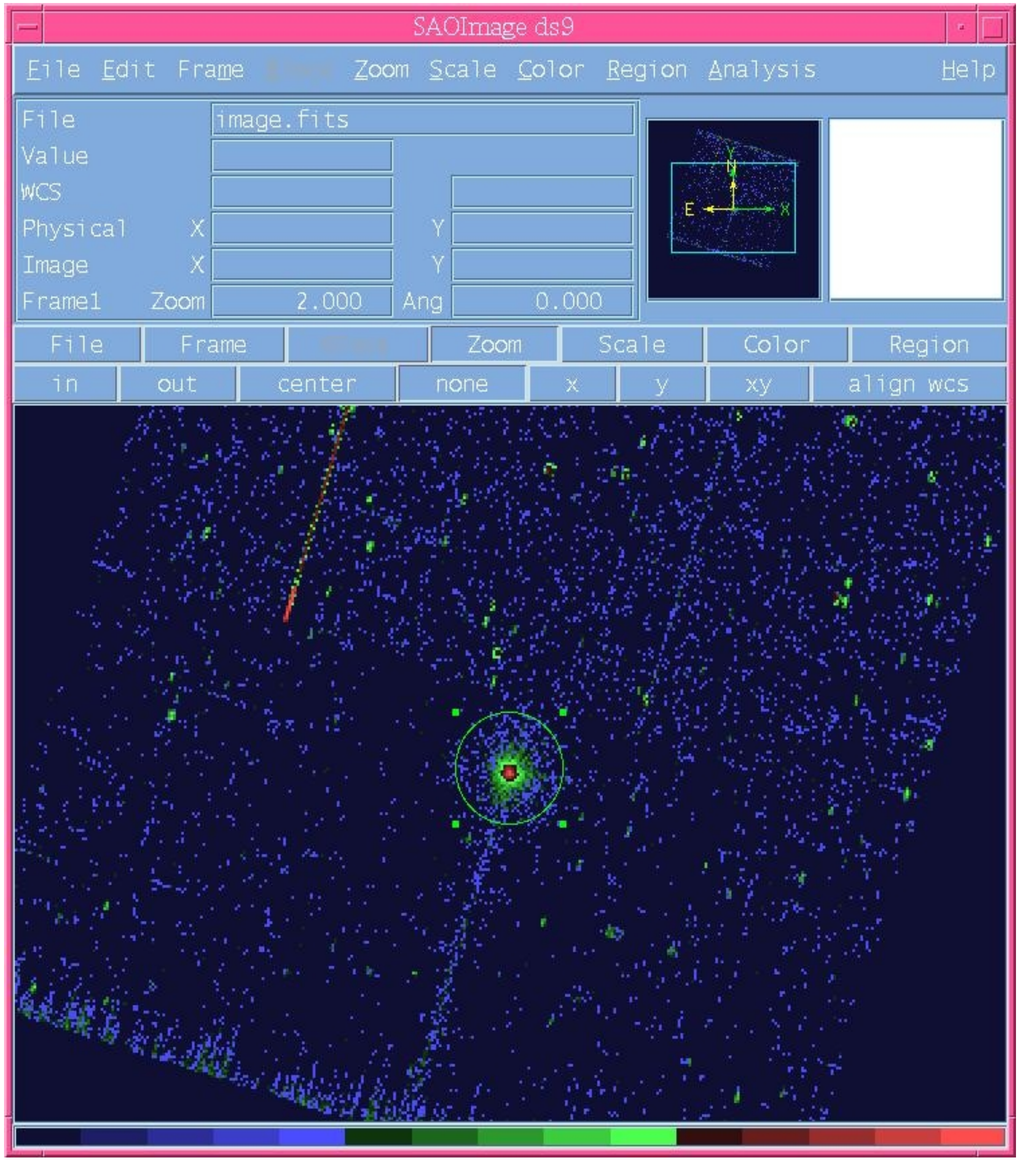
All angles are measured in degrees anti-clockwise from the x-axis.
HEAsoft uses Pie as a synonym for Sector while SAS uses Sector as a synonym for Pie.
SAS defines W and H as the half-width and half-height in contrast to HEAsoft and CIAO where they are the full width and height.

- can be defined in a text file, FITS file, or directly as an argument of software,

- several different text formats in use, the two main are : DS9/FUNTOOLS , CIAO,

- both can be produced by the image and data visualization program SAOImage DS9.

DS9 window with marked circle around the source.



- coordinate system in which the regions are specified: three possibilities: *image, physical, WCS,*

- *image* – not recommended since they will vary if the pixel binning is changed,

- *physical* – actual values in the event file, X, Y for the sky, DETX, DETY for detector,

- the FITS file format allows complex regions to be done,

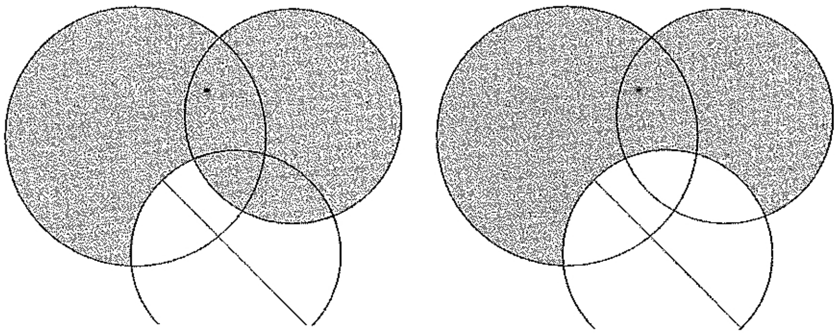


Fig. 4.6 Selected area when the bottom exclude circle is listed second (region 1 – left) or third (region 2 – right)

Region 1	Region 2
circle(3968.5, 3921.5, 288.2)	circle(3968.5, 3921.5, 288.2)
−circle(4192.5, 3661.5, 231.2)	circle(4316.5, 3969.5, 238.8)
circle(4316.5, 3969.5, 238.8)	−circle(4192.5, 3661.5, 231.2)

2) By time interval:

- good time intervals (GTIs) during which events are accumulated,

- GTIs for an observation are listed in their own files with extension typically: STDGTI, GTI#

- it contains the lists of start and stop times, in units of spacecraft time, users are required to convert....!!!!

3) By phase:

- for sources with known periods it may be useful to extract events from a particular phase,

- create a new column in the FITS file called PHASE,

- Chandra dithers in a Lissajous patter with 1000 s period.

4) By intensity/rate:

- it is often useful to select events based on the source (or bkgr.) event rate at time of the event, such as the source is bright or when the bkgr. rate is law.

- subsequent calibration tools can automatically calculate the total good time using informations stored in FITS event file, example:

  > extract curve

  > filter intensity 1.0-2.0

  > extract events

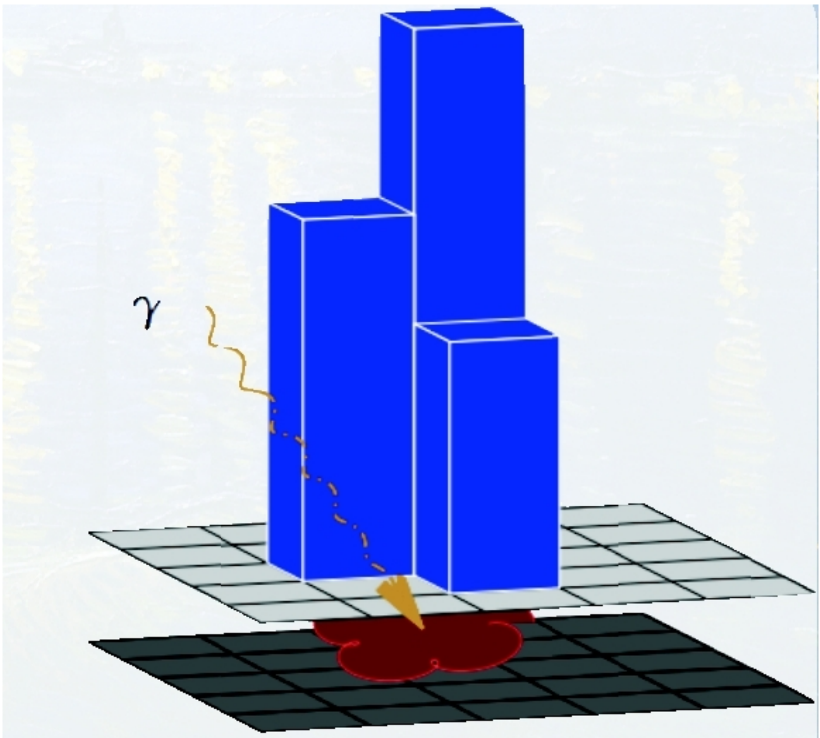
- first command creates lightcurve, second generates a list of GTIs for when the count rate between 1.0-2.0, and the third makes a new event file using these GTIs.

5) By spectral channels:

- it is often use when creating images or lightcurves, to select energy band or to improve signal-to-noise ratio,

6) By grade:

- bkgr. removed during standard processing,
- additional most common filter is to select only events with all the charge in a single pixel,
- be careful – not all choices may be calibrated.



From J.Davis, "Pileup Modeling"
http://www.jedsoft.org/fun/slxfig/pileup2008.pdf

6) By auxiliary criteria :

Table 4.6 *Common filters on auxiliary criteria*

Filter	Reason
Angle between pointing direction and Earth's limb	The extended atmosphere can absorb lower-energy X-rays.
Angle between pointing direction and Earth's day–night terminator	The sunlit Earth is visible in X-rays due to scattering of solar emission and fluorescence of the atmosphere. Also, some detectors are sensitive to optical contamination.
Angle between pointing direction and Sun	Solar X-rays may be able to scatter into the detector at small angles. In practice, the angle is usually determined by operational constraints on the orientation of solar panels to the Sun.
Cut-off rigidity (or McIlwain L)	The Earth's magnetosphere shields the spacecraft from high-energy particles. The cut-off rigidity and McIlwain L are measures of this protection.
SAA flag	The SAA is a region of the Earth's atmosphere above the South Atlantic that has intense particle bombardment. Some instruments are turned off in the SAA; others continue operating but the data are often not useful.
Time since last SAA passage	The SAA particle bombardment can generate short-lived radioactives which themselves provide background as they decay.

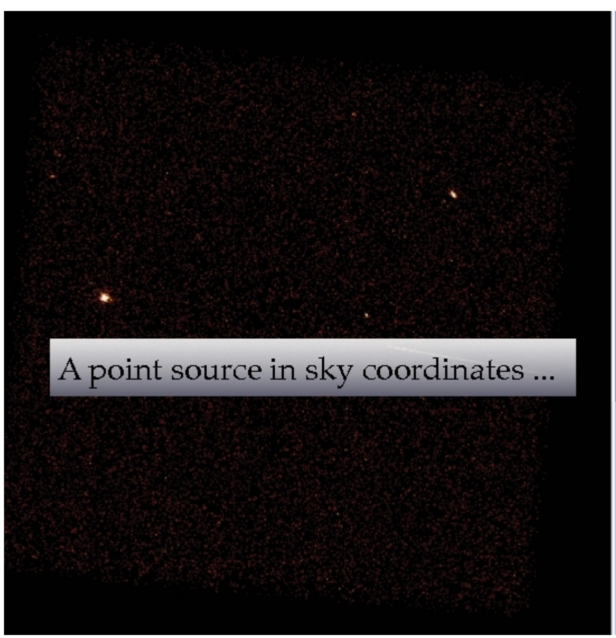
Extracting analysis products:

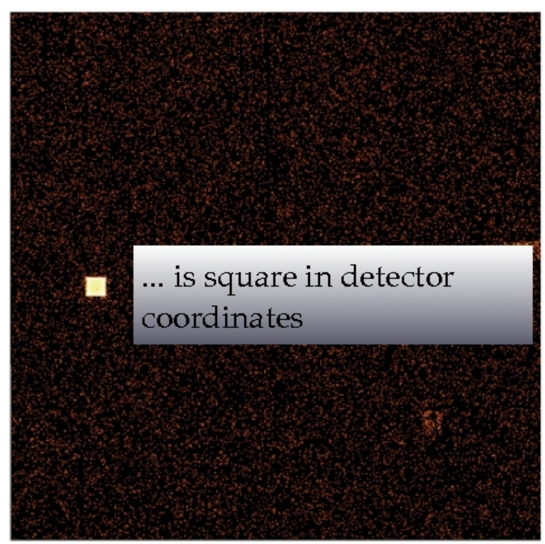
Most data analysis tools do not work directly with the event file. Multi-dimensional event space (energy, time, position), is projecting onto one or two dimensions, then binning: we get histogram of counts in one or two dimensions.

(Handbook for X-ray astronomy, 2011)

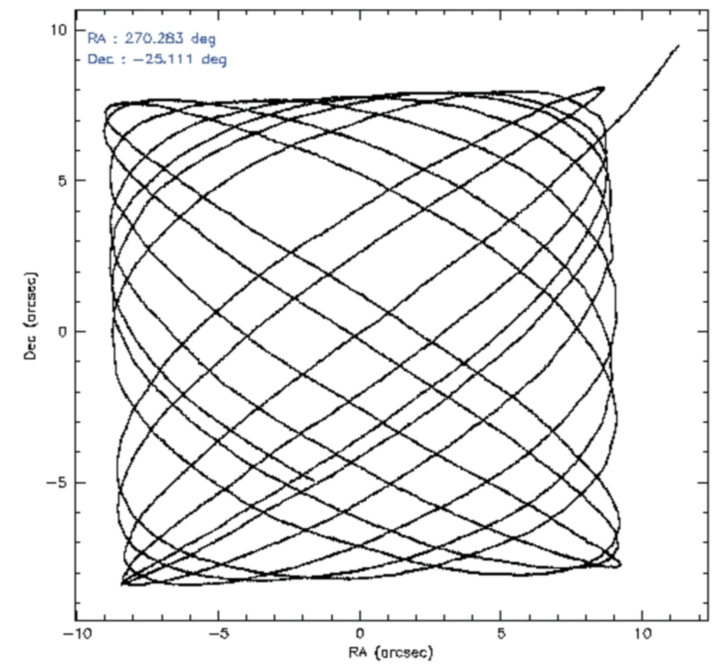
1) Image:

- useful to check for detector artifacts: Chandra dithering:





Davis + 2011



- some instruments have a pixel size much smaller than the telescope spatial resolution, and the image should be binned up, a rule of thumb is to choose:

  bin size $\sim$ 1/3 FWHM of spacial resolution.

- for high signal-to-noise data – TIME and PI images.

2) Spectrum:

- the columns in event file with energy information are: PHA and PI,

- CCD usually also have a vector column PHAS that record charge at each pixel,

- standard processing: PHAS $\Rightarrow$ PHA $\Rightarrow$ PI

- ENERGY column should not be used....!!!!!

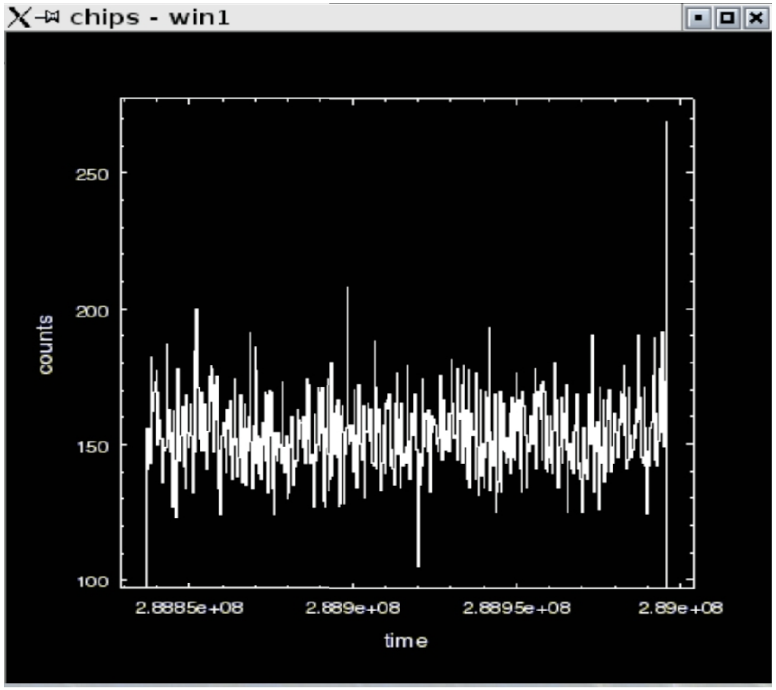
3) Light curve:

- time series using the TIME column in the events file,

- be careful with data from instruments as CCD with periodic readouts,

- bkgr. can be variable and should be examined,

- look at the light curve of all events in the region with no bright source:



<u>Calibration:</u>

Standard processing in X-ray astronomy does not usually make products in physical units, free of all detector characteristics.

(Handbook for X-ray astronomy, 2011)

One essential feature we want to determine is the source intensity:

$$S(X_S, Y_S, E, t) \qquad [\mathrm{photons/cm^2/s/keV/sr}]$$

Calibration:

Standard processing in X-ray astronomy does not usually make products in physical units, free of all detector characteristics.

(Handbook for X-ray astronomy, 2011)

One essential feature we want to determine is the source intensity:

$$S(X_S, Y_S, E, t) \qquad [\text{photons/cm}^2\text{/s/keV/sr}]$$

Observed counts C(X,Y,PI) in a given pixel and PI bin, come from the source flux with fundamental response equation:

$$C(X, Y, PI) = \int\int\int\int R(X, Y, PI, X_S, Y_S, E, t) \cdot S(X_S, Y_S, E, t) \cdot dX_S \cdot dY_S \cdot dE \cdot dt$$

R – instrumental response [cm^2].

1) For imaging:

- is created by summing over the PI bins:

$$C(X,Y,PI)=\sum_{PI} C(X,Y,PI)$$

$$=\int\int\int\int\left(\sum_{PI} R(X,Y,PI,X_S,Y_S,E,t)\right)$$

$$\cdot S(X_S,Y_S,E,t)\cdot dX_S\cdot dY_S\cdot dE\cdot dt$$

$$=\int\int\int\int R_{image}(X,Y,PI,X_S,Y_S,E,t)$$

$$\cdot S(X_S,Y_S,E,t)\cdot dX_S\cdot dY_S\cdot dE\cdot dt$$

- usually the instrumental response for images is split into point spread function (PSF) and the effective area EA , often called Exposure Map.

$$R_{image}(X, Y, PI, X_S, Y_S, E, t) = PSF(r, \theta, X_S, Y_S, E) \cdot EA(X_S, Y_S, E, t)$$

$$r^2 = (X - X_S)^2 + (Y - Y_S)^2$$
$$\theta = \arctan((Y - Y_S)/(X - X_S))$$

- PSF – information about spatial resolution, position on the detector from a point source,
  PSF – energy and position dependent,

- effective area or exposure mat is the telescope area at X_S, Y_S given an X-ray of energy E at time t – time dependent, can be calculated using the telescope “aspect history”, provided as one of the auxiliary files,

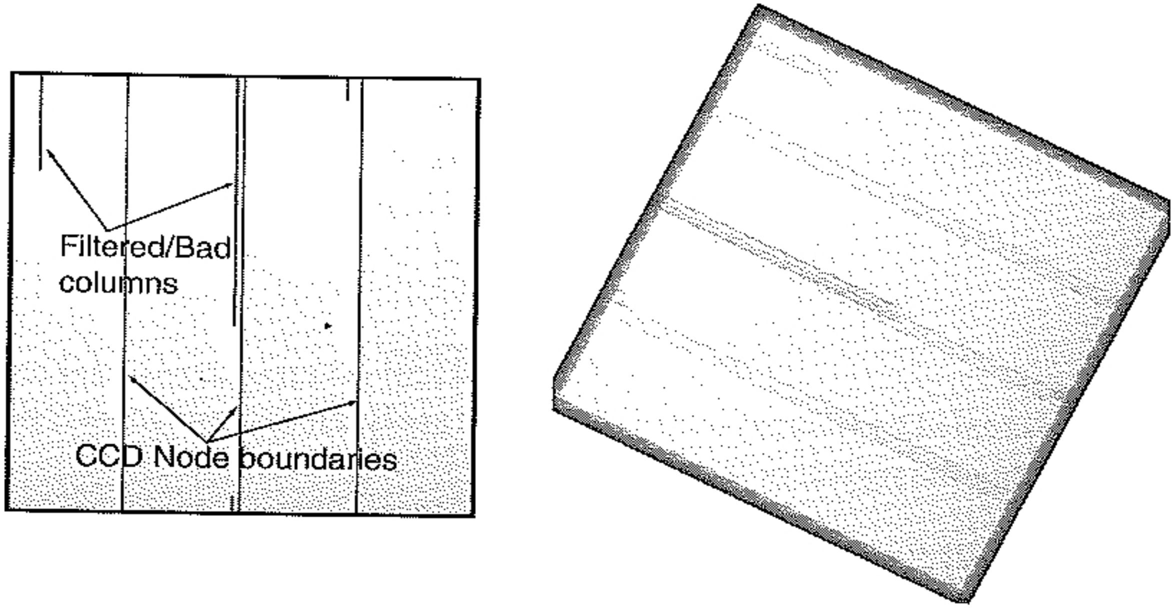


Fig. 4.10 [Left] Chandra ACIS instrumental effective area (exposure) map (at 1.5 keV) in detector coordinates, showing the node boundaries on the CCD and undesirable or bad columns that have been filtered. [Right] Same, after converting to sky coordinates and including the ACIS dither that smears out the bad columns

2) For spectroscopy:

- binning over the region and assuming that S does not vary within the region and with time:

$$C(PI)=\int \left\{\int\int\int\int\int R(X,Y,PI,X_S,Y_S,E,t)\cdot dX_S\cdot dY_S\cdot dX\cdot dY\cdot dt\right\}\cdot S_{spec}(E)\cdot dE$$

- response usually split between: ancillary response file: ARF, in units of [cm^2], and matrix RMF, which is unitless.

$$RMF(PI,E)=\int\int\int R_{RMF}(X,Y,PI,E,t)\cdot dX\cdot dY\cdot dt$$

$$ARF(E)=\int\int\int\int\int R_{ARF}(X,Y,X_S,Y_S,E,t)\cdot dX_S\cdot dY_S\cdot dX\cdot dY\cdot dt$$

2) For spectroscopy:

- binning over the region and assuming that S does not vary within the region and with time:

$$C(PI)=\int\{\int\int\int\int\int R(X,Y,PI,X_S,Y_S,E,t)\cdot dX_S\cdot dY_S\cdot dX\cdot dY\cdot dt\}\cdot S_{spec}(E)\cdot dE$$

- response usually split between: ancillary response file: ARF, in units of [cm^2], and matrix RMF, which is unitless.

$$RMF(PI,E)=\int\int\int R_{RMF}(X,Y,PI,E,t)\cdot dX\cdot dY\cdot dt$$

$$ARF(E)=\int\int\int\int\int R_{ARF}(X,Y,X_S,Y_S,E,t)\cdot dX_S\cdot dY_S\cdot dX\cdot dY\cdot dt$$

- the equation above is reduced to:

$$C(PI)=T\int RMF(PI,E)\cdot ARF(E)\cdot S_{spec}(E)\cdot dE$$

- for theoretical perfect detector RMF would be a diagonal matrix as each energy would be mapped to a single channal in the detector,

- in reality detectors have some spread in their response, X-rays with energy E ending in channel *I* or even *I+500*,

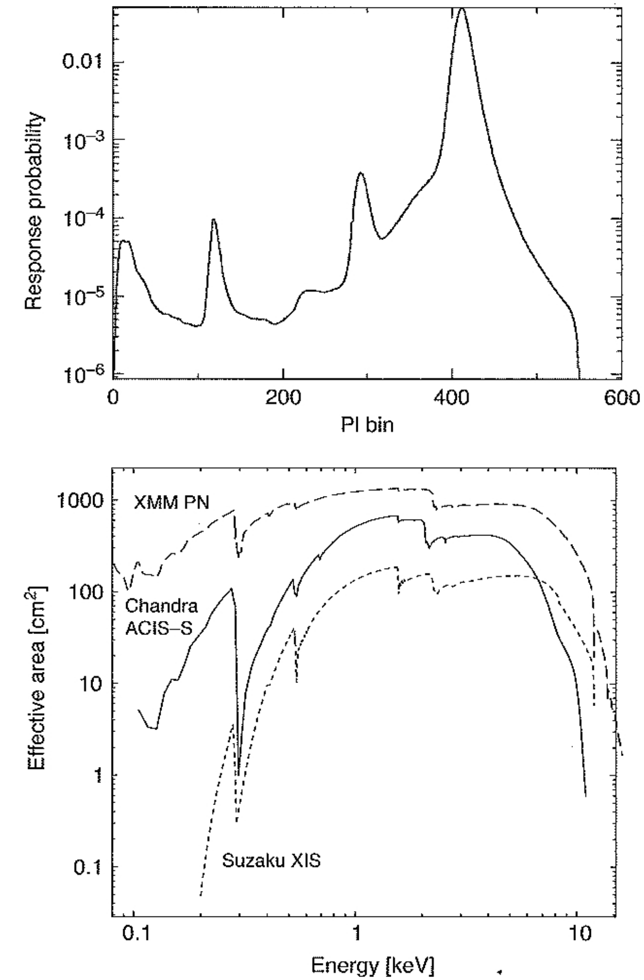


Fig. 4.11 [Top] One row of the ACIS-I response matrix showing the probability of a 6 keV input X-ray falling in each PI bin. [Bottom] Effective area curves for the three X-ray missions: XMM–Newton EPIC-pn detector (dashed line), Chandra ACIS-S (solid line), and Suzaku XIS-BI (dotted line). The effective-area curves were obtained from PIMMS 4.1 at http://heasarc.gsfc.nasa.gov/Tools/w3pimms.html

- for theoretical perfect detector RMF would be a diagonal matrix as each energy would be mapped to a single channal in the detector,

- in reality detectors have some spread in their response, X-rays with energy E ending in channel I or even I+500,

- the total spectral response for energy E is:

$$ARF(E) \cdot \int RMF(PI, E) \cdot dPI$$

- some instrument teams define the RMF so that:

$$\int RMF(PI, E) \cdot dPI = 1.0$$

3) For light curves:

- there are no calibration files specifically used in timing analysis, but we have to remember:

- aspect dither can move source on and off the detector,

- “dead time correction” due to an instrumental recovery time,

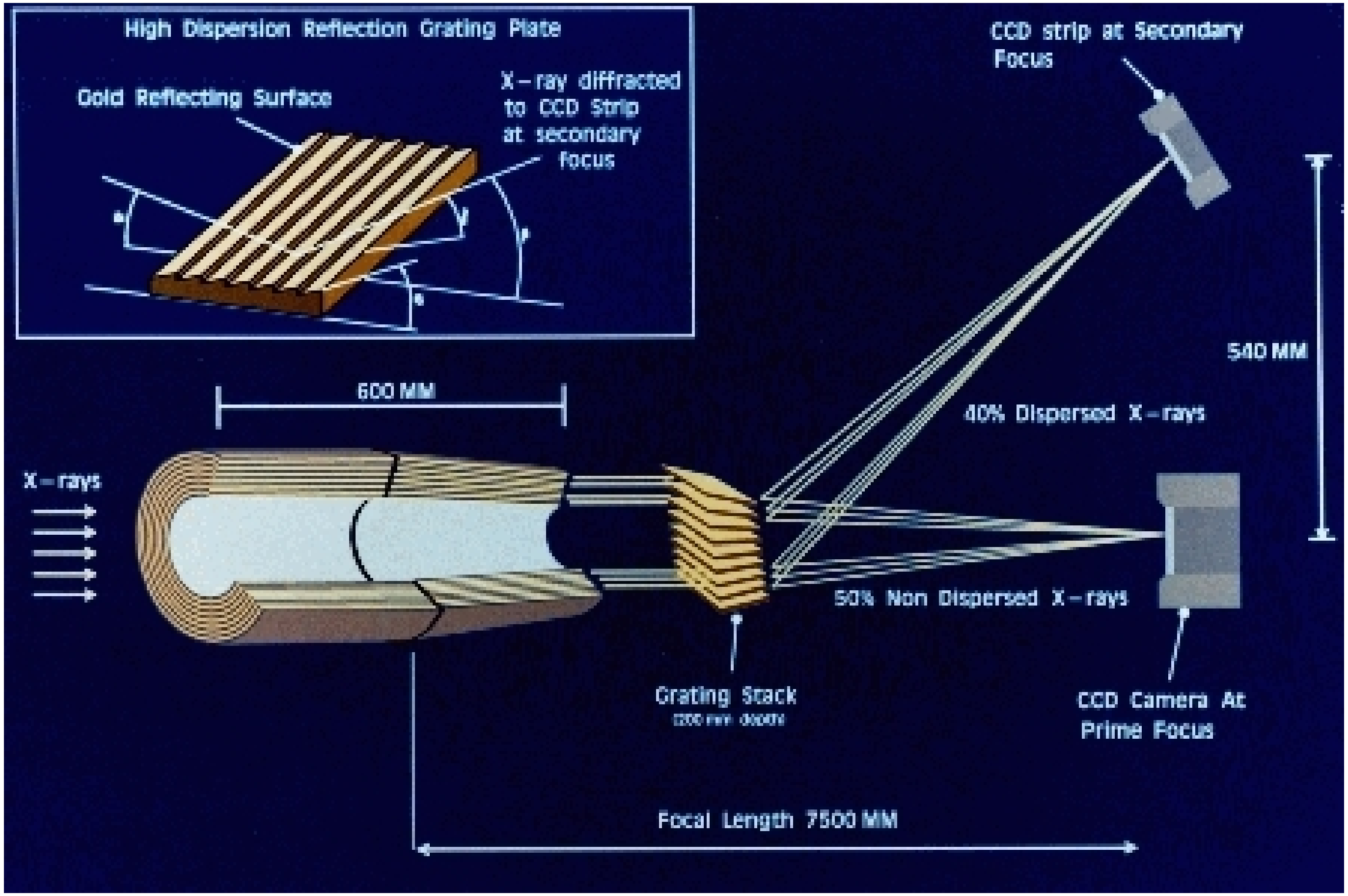
- “dead time” is automatically calculated, but not explicitly used when making light curve plots.

- counts from bright sources limited by telemetry saturation

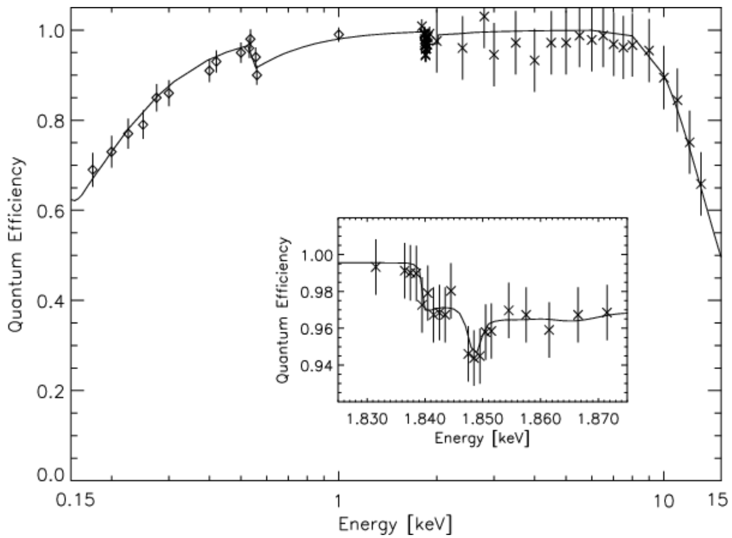
  .... check documentation for the mission.......

Homework: find A_{eff} (E), A_{eff} (off-axis angle), PSF
for following gratings + mirrors + detector:

EINSTAIN, EXOSAT, ASCA, CHANDRA (LEG, HEG), XMM RGS, SUZAKU.



CCD



EINSTEIN

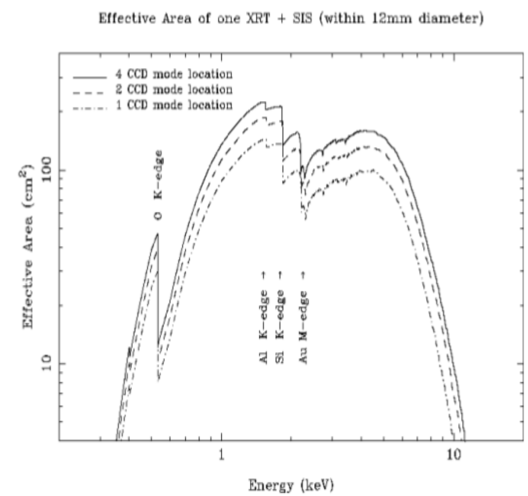
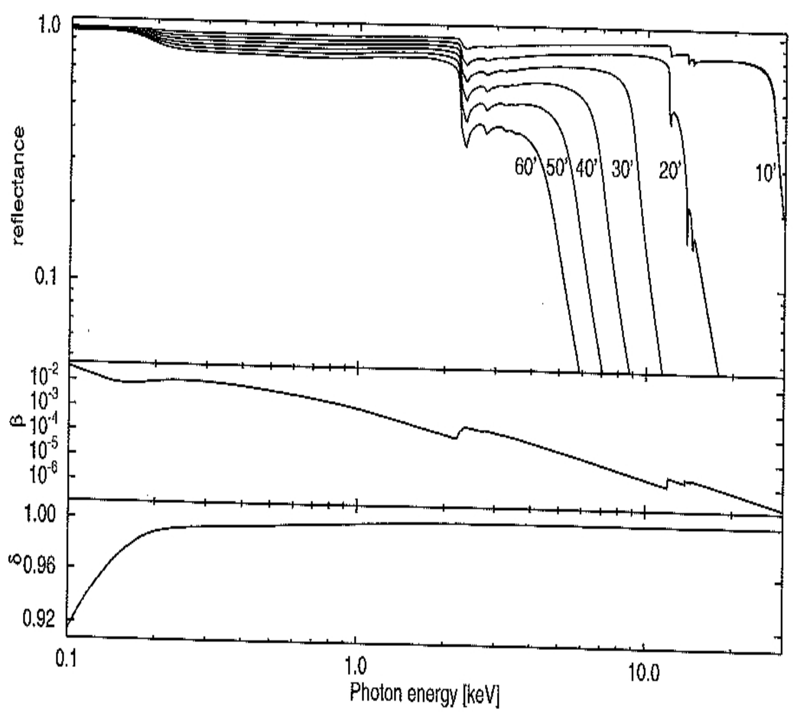


Figure 3.10: Dependence on energy of the effective area of a single SIS combined with an XRT. Dependence on the source locations is also shown.

Mirrors



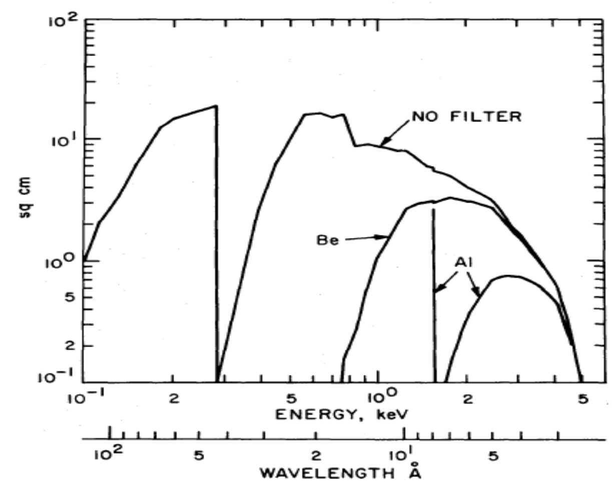
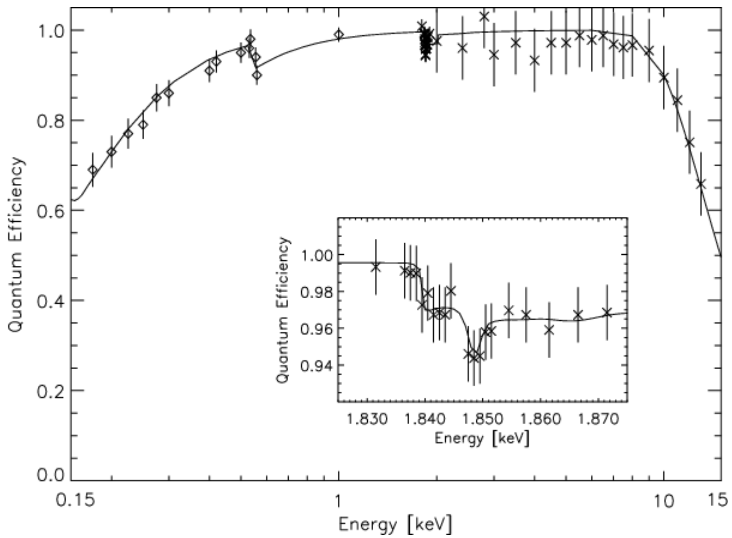
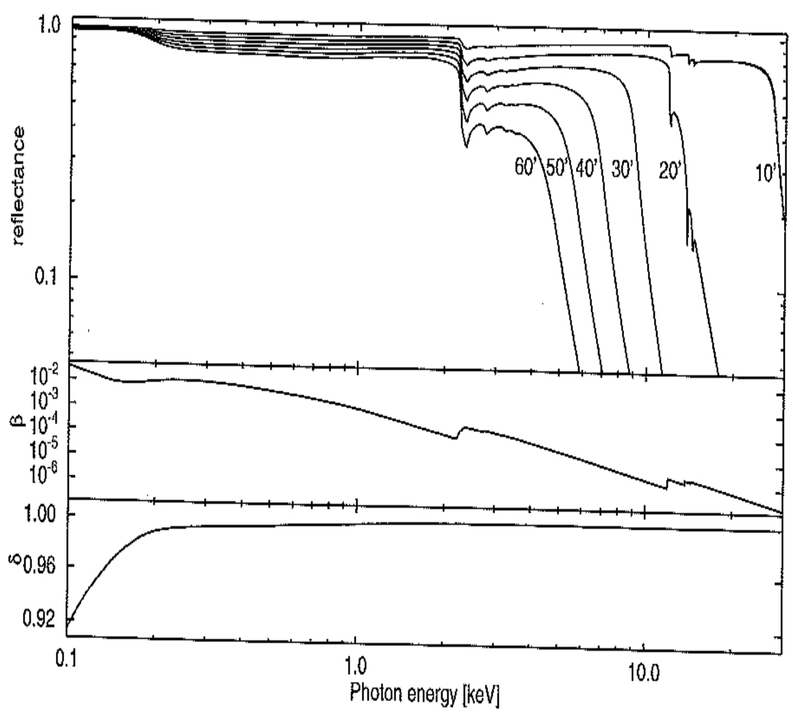


Fig. 5.—Effective area HRI No. 2 with no filters, with Be filter, and with Al filter. Photons which scatter from the mirror with angles greater than 6″ have not been included; thus this efficiency is for 12″ pixels.

CCD



Mirrors



ASCA

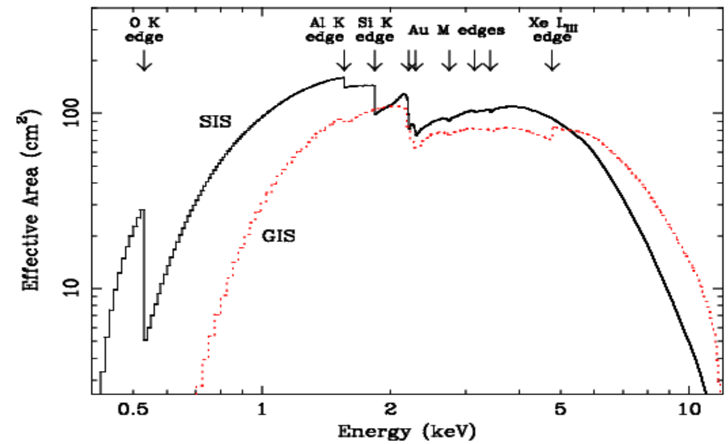


Figure 2.3 Effective area curves for the SIS (solid line) and GIS (dotted line) when the pairs of like detectors are averaged together. In practice, the effective area is a function of position in the field of view, and also time dependent in the case of the SIS, but these curves (for NGC 5548, *ASCA* sequence number 76029010) are typical. The sharp features correspond to absorption arising in either the mirrors or the detectors; the associated atomic shells are labeled.

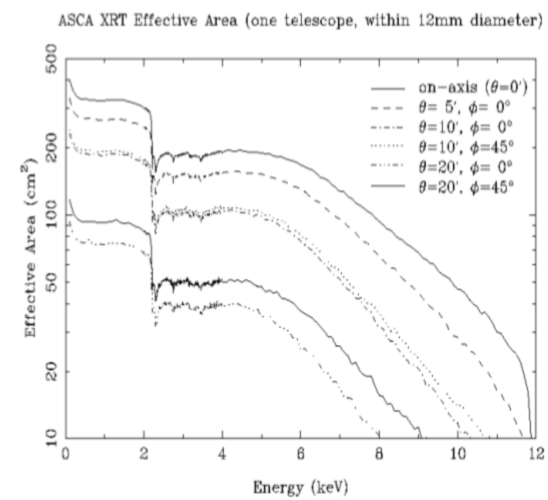
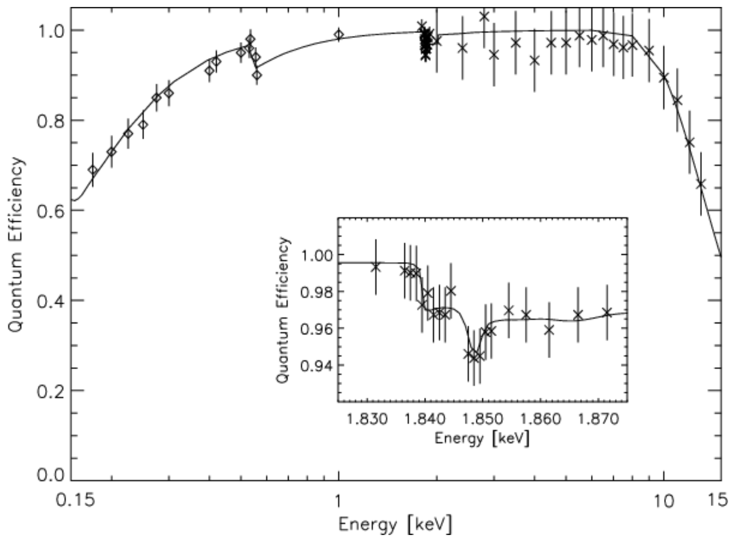
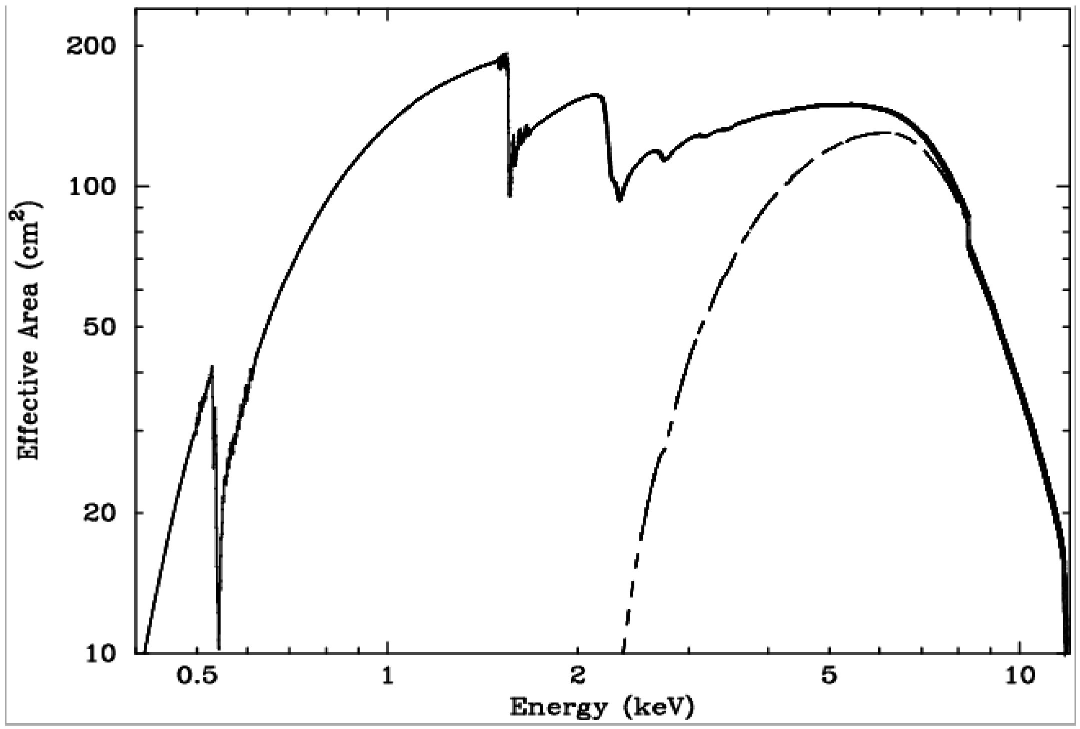


Figure 3.3: Effective area of a single XRT as a function of the energy of the incident X-ray. Dependence on the off-axis angle θ and azimuthal angle ϕ is also shown.

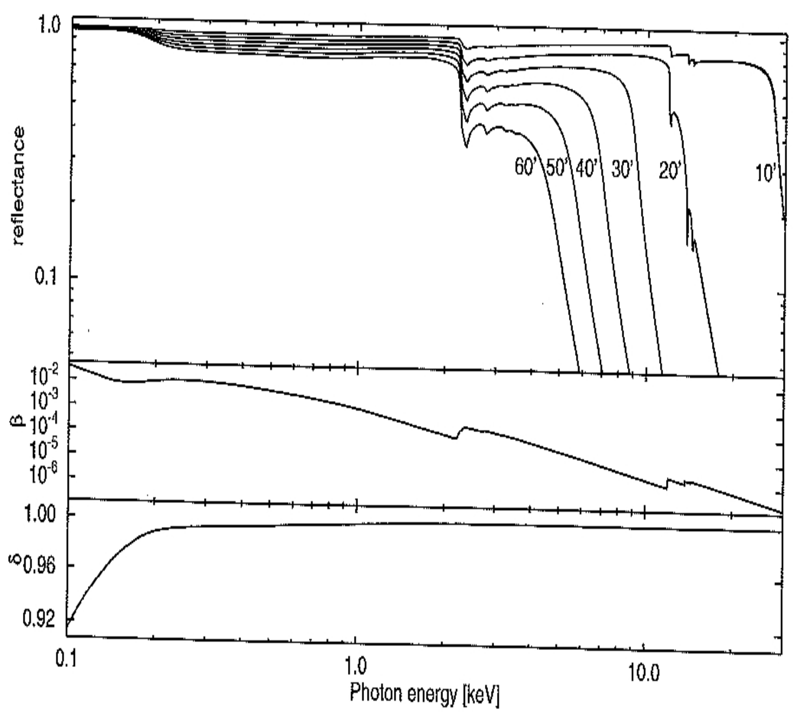
CCD



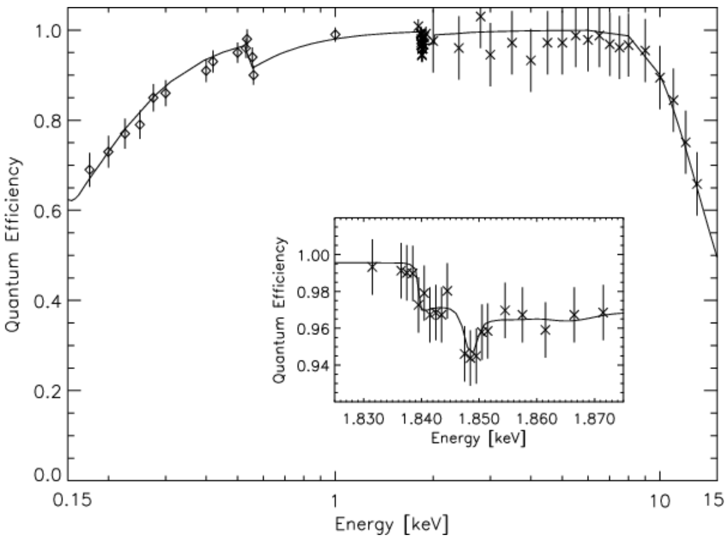
SUZAKU



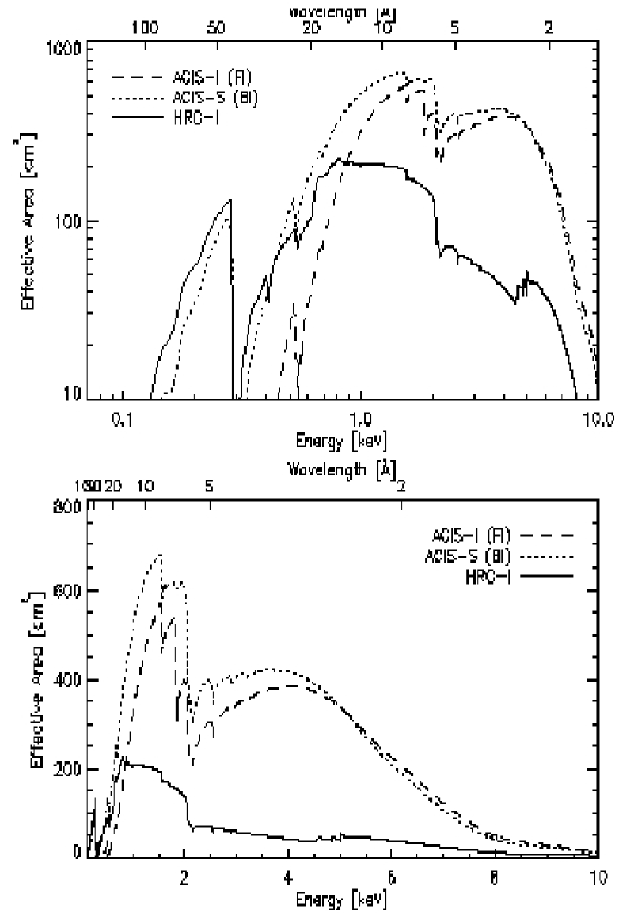
Mirrors



CCD



CHANDRA



Mirrors

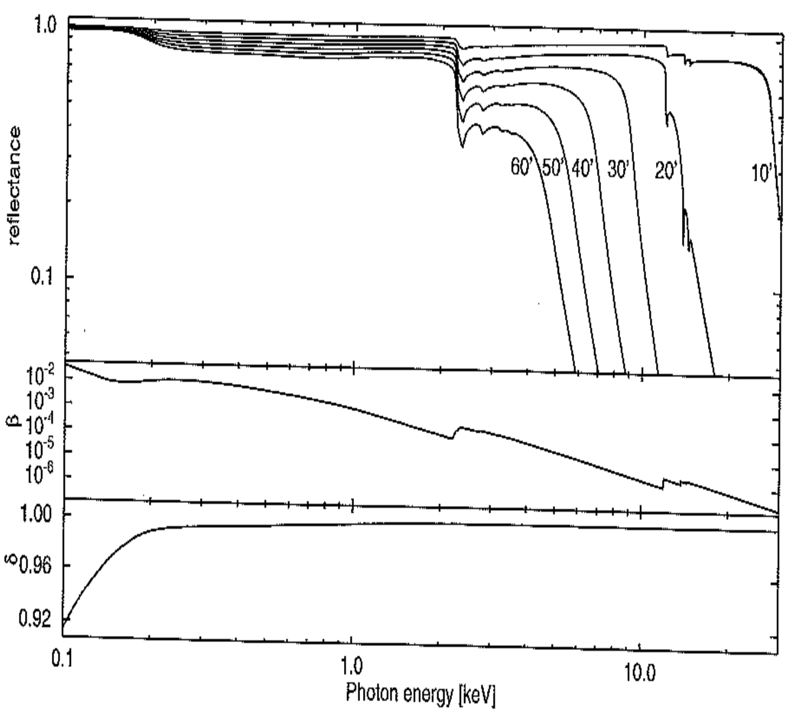
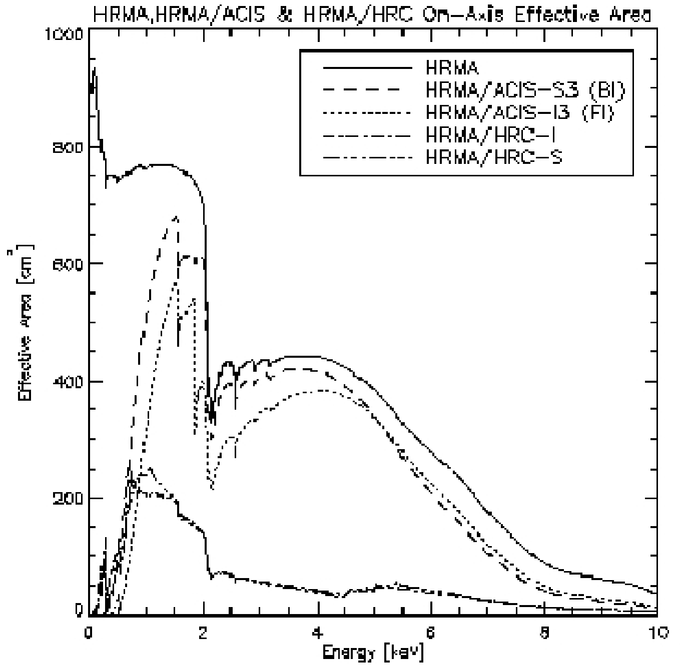
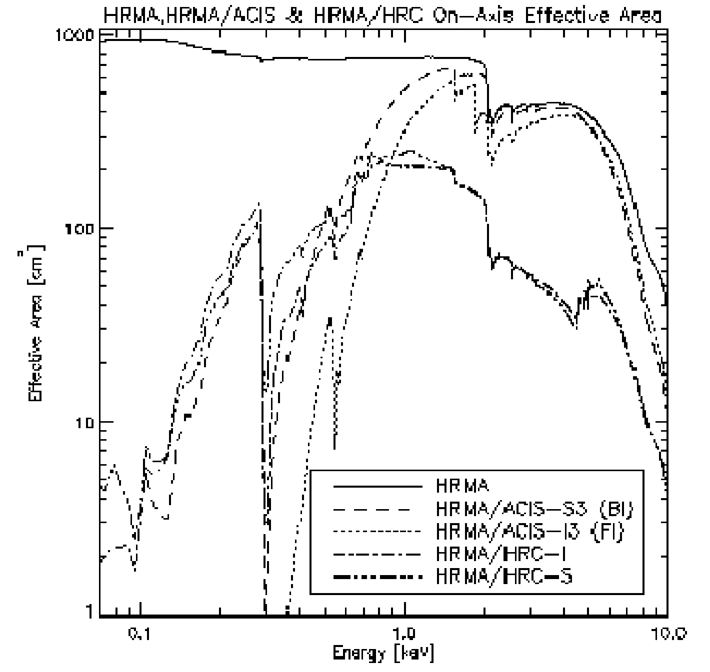


Figure 1.3: Comparison of the on-axis effective areas for observing a point sourc(integrated over the PSF) of the HRMA HRC-I, the HRMA/ACIS(FI), and the HRMA/ACIS(BI) combinations. The ACIS curves show the predicted values for the middle of Cycle 13.

CHANDRA





The HRMA/ACIS and HRMA/HRC effective areas versus X-ray energy in linear-linear (top) and log-log (bottom) scales. The structure near 2 keV is due to the iridium M-edge. The HRMA effective area is calculated by the raytrace simulation based on the HRMA model and scaled by the XRCF calibration data. The HRMA/ACIS effective area is the product of the HRMA effective area and the Quantum Efficiency (QE) of ACIS-I3 (front illuminated) or ACIS-S3 (back illuminated). The HRMA/HRC effective area is the product of HRMA effective area and the QE of HRC-I or HRC-S at their aimpoints, including the effect of UV/Ion Shields (UVIS).

Hands – on sessions:

```
> ssh -X  libra
> exec tcsh
> source /work/agata/doktor_wyklad/init.csh
```

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

Hands-on exercise:

Viewing header or data (as text):

- `dmlist` (ciao)
- `fdump` (ftools)
- `fitsdump` (marx)
- `fv` (ftools)
- `prism` (ciao)

Plotting / imaging the data:

- `chips` (ciao)
- `ds9` (sao)
- `IDL` (custom)
- `ISIS` (cfitsio, pgplot)
- `prism` (ciao)
- `vwhere` (ISIS module)

Davis + 2011

A radial temperature profile of the cluster A1835 with Chandra

Basic Steps:

1. In the Chandra archive, find non-gratings observation of A1835 performed after 2000-01-29 (ACIS temperature −120C). Obsid:
2. What mode was Chandra observing in:
3. Do data need to be reprocessed? Why or why not? (Hint: check what processing is applied to the respective background file)
4. Check light curve for background flares.
5. Create image of the cluster, subtracting the backgrounds (blank-sky and readout artifact) and dividing by the exposure map.
6. Extract cluster spectrum within $r = 1$ Mpc and determine mean cluster temperature and bolometric luminosity. (Hint: at this step, the excess Galactic background can be ignored)

Advanced Topics:

1. Extract spectra in several annular regions.
2. Extract spectrum from a region far from the cluster (e.g., $r > 2.5$ Mpc, using chips I2, I3, S2). Do you see the excess soft background?
3. Fit cluster spectra in annuli (hint: take excess background into account by adding a model component normalized by the ratio of region areas). Is there a cool core in this cluster?
4. At what radii the Galactic excess background becomes important?

Suggested reading: 1. "On the discrepancy between Chandra and XMM temperature profiles for A1835", Markevitch 2002, astro-ph/0205333 (beware some steps there are outdated). 2. Background cookbook, `cxc.harvard.edu/cal/Acis/Cal_prods/bkgrnd/acisbg/COOKBOOK`

Principles of ranking the lecture:

- to be here

- to participate into discussions

- to make a homework

- hand – on sessions with the use of the computer.....

- exam – very simple :::)))

wi-fi password: a w sercu maj