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USER/005

ASTERIX Data Analysis
User Note 005

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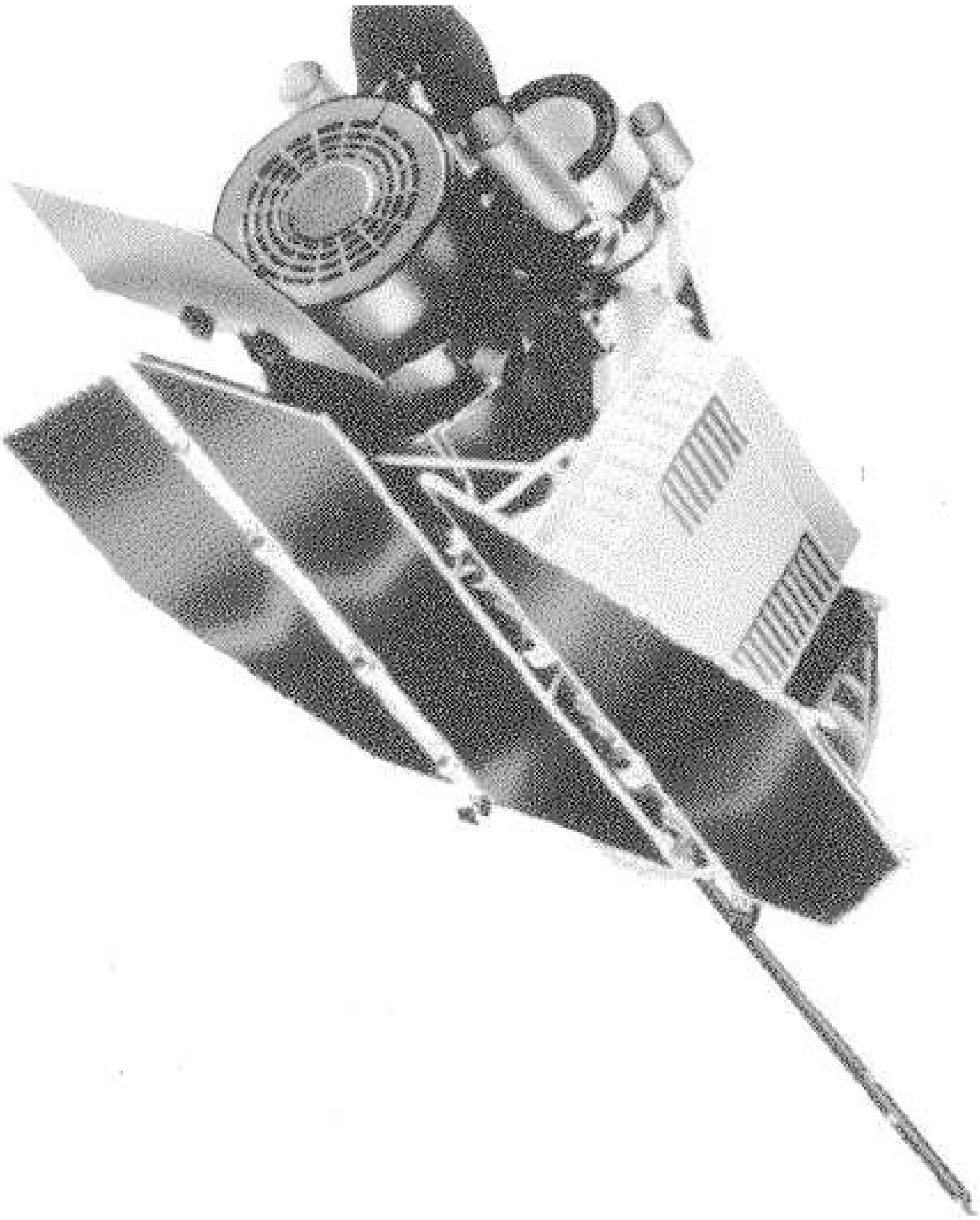
The ROSAT XRT interface in ASTERIX



Contents

1 Introduction

This guide is for people who want to reduce and analyse data from the ROSAT X-ray satellite using the Starlink multi-mission data analysis package ASTERIX. It describes how to get from observation datasets to high level data products such as spectra, point source lists, etc.

1.1 Software Version

This version of the user guide is associated with ASTERIX version 2.3, a beta version of which can be downloaded via the net.

```
http://sr.bham.ac.uk/asterix
```

No other formal release plans have yet been made. This version of ASTERIX is supported on Solaris, Digital Unix, and Linux.

1.2 ASTERIX Version 2.3

ASTERIX version 2.3 includes changes which allow the XRT interface to directly access FITS files. The development of full FITs compatibility throughout ASTERIX is also well underway.

1.3 Getting Started

All commands described in this document are available automatically as part of ASTERIX. If you have ASTERIX installed at your site, it can be started by typing

```
> aststart
```

Most ASTERIX commands can be run from the shell. The exception to this is the command driven version of image processing. This requires the user to start ICL (command: `icl`), although most of the same functions are available within Isys, the image processing GUI, which is invoked from the shell. All other ASTERIX commands will also run from ICL.

1.4 Getting Help

This document provides recipes for specific data analysis tasks, as well as descriptions of the data formats. It does not provide detailed help on individual ASTERIX ROSAT commands.

Such help is provided by the on-line help system, invoked by the command

```
> asthelp
```

`asthelp` attempts to provide complete information on all ASTERIX commands, as well as more general guidance on how to get started with ASTERIX, where to find documentation, information specific to the current ASTERIX release, etc..

With this release of ASTERIX, a hypertext version of `asthelp` is also available. This can be invoked with the command

```
> xasthelp
```

Or referenced on the WWW at

```
http://www.sr.bham.ac.uk/asterix
```

1.5 Related Documents

The international ROSAT project has also produced a number of useful documents, including individual calibration memos and the ROSAT Users Handbook. These are available from the US anonymous ftp site *legacy.gsfc.nasa.gov*. More specific references are provided in later section where appropriate.

News items, including the national ROSAT newsletters can be accessed via the Leicester ROSAT home page and the HEASARC ROSAT guest observer facility on the World Wide Web. Information about ASTERIX is available on Birmingham University's ASTERIX home page.

```
http://ledas-www.star.le.ac.uk/Forum/rosat-news
http://heasarc.gsfc.nasa.gov/docs/rosat/rosgof.html
http://www.sr.bham.ac.uk/asterix
```

1.6 Layout of this Guide

The following sections give information about the ROSAT satellite (section 2), the data that you get from ROSAT (section 3), how to read a data tape and how to get a quick idea of what your data contains (section 4), detailed descriptions of how to analyse ROSAT PSPC and HRI data (section 5), how to communicate with the ROSAT project and how to stay informed (section 6). Finally, there is a number of appendices describing the dataset formats, giving a full list of ASTERIX XRT commands.

2 ROSAT

The ROSAT X-ray astronomy satellite (Röntgen Satellite) was launched on June 1, 1990, and was switched off on Friday 12th February 1999. ROSAT is a German satellite,which also has scientific instrumentation supplied by the USA and the UK. There are scientific data centres at the Max Planck Institut für Extraterrestische Astrophysik (MPE) near Munich in Germany, the Goddard Space Flight Center (GSFC) near Washington DC in the US, and RAL/University of Leicester in the UK.

2.1 Project

Following a performance verification and calibration phase, the ROSAT satellite spent 6 months continuously scanning the sky to make an all-sky survey. This ended on Jan 25 1991, since then observations have consisted of pointings at individual targets. These targets are selected by peer-review committees from proposals made in response to annual announcements of opportunity in the three countries.

2.2 Satellite

The ROSAT satellite is in a 96 minute period, low earth orbit having an inclination of 53^o. It is a 3-axis stabilised spacecraft with two co-aligned telescope systems. The main telescope is the X-Ray Telescope (XRT), having at its focus a carousel which can place one of two Position Sensitive Proportional Counters (PSPC) or a micro channel plate High Resolution Imager (HRI) in the beam. There is also a Wide Field Camera (WFC) for EUV astronomy co-mounted with the XRT. This document deals only with the analysis of data from the XRT. SUN 62 describes the analysis of data from the WFC.

2.3 Attitude Measurement and Control System

The ROSAT XRT has two CCD star trackers (one of which failed early in the mission). The WFC has an independent star tracker. The data from this star tracker are being incorporated into XRT attitude solutions in the Rev 2 data re-processing.

During PSPC observations the ROSAT spacecraft is wobbled with an amplitude of typically $\pm$ 3 arcminutes at a period of around 400 seconds. This avoids having the sharply focussed X-ray image of a point source hitting a detector wire throughout the observation. HRI images are also wobbled, but with a lower amplitude of typically $\pm$ 1.5 arcminutes. Although the wobble is strictly periodic, the path of an image across the detector varies from cycle to cycle.

Attitude reconstruction has not met specification. This can manifest itself in distortion of the on-axis PSF seen with the HRI, and as offsets of up to 30 arcseconds between the positions of objects observed after an interval of months.

2.4 XRT Mirrors

The ROSAT XRT consists of four nested co-focal Wolter type 1 gold-coated Zerodur (glass) grazing incidence mirrors manufactured by Zeiss in Germany. The system has a field of view larger than the 2^o diameter of the PSPC (the HRI is smaller), although vignetting is significant at large off-axis angles, especially at high energies. The mirror system has a focal length of 240cm, a focal plane scale of 11.64 μ per arcsecond, and a geometric area of 1141 cm^2. The point spread function and effective area is described in the sections on the PSPC and HRI detectors.

2.5 PSPC

There are two (nominally identical) position sensitive proportional counters on ROSAT. PSPC C was in use up to Jan 25, 1991, after which PSPC B only was used.

The PSPC is a multiwire proportional counter which provides both spectral and spatial resolution. The counter gas is argon/methane/xenon, enclosed by a 1 μ polypropylene/carbon/lexan window supported by a grid with 72% transmission. A window support structure consists of 8 radial ribs meeting at a 20 arcminute diameter ring. The PSPC has a 2^o diameter. It has effective area between 0.1 and 2.2 keV, peaking at 330 cm^2 just below the carbon edge at 0.28 keV.

In general, both spectral and spatial resolution improve with increasing energy, but although the PSPC has 256 pha channels, it can make only $\sim$ 5 independent spectral measures. The spectral resolution varies as

$$FWHM/E = 0.43(E/0.93)^{-0.5}$$

The PSPC detector used for observations was swapped (from detector 'C' to detector 'B') on 25th January 1991, and the detector gain changed on 11th October 1991, so different combinations of response matrix and effective area file must be used for observations taken between these dates.

The recommended combinations are:

before 25th January 1991 - pspcc_eff.sdf and drm_06.sdf
25th January 1991 to 11th October 1991 - pspcb_eff.sdf and drm_06.sdf
after 11th October 1991 - pspcb_eff.sdf and drm_36.sdf

For further information on using these files, see the Leicester Database and Archive Services (LEDAS) User Guide or the ASTERIX documentation.

`http://ledas-www.star.le.ac.uk/info/user_guide/node24.html`

The PSPC PSF encloses 50% of counts at 1 keV in a radius of 0.22 arcminutes. A model describing the the PSF as a function of energy and off-axis angle (within the 20 arcminute ring) is a good fit to the data. However, at large off-axis angles the PSF can no longer be treated as circularly symmetric, and at the lowest energies electronic 'ghosting' occurs, significantly broadening the PSF below 0.19 keV. Neither of these extreme cases is covered by the PSF model.

The PSPC was occasionally used with a boron filter in the X-ray beam. This filter has little transmission between the boron edge (0.188 keV) and the carbon edge (0.28 keV), and thus can provide extra spectral information in the energy range where the intrinsic spectral resolution is poorest. The boron filter only covered the central part of the PSPC field of view.

Since the end of 1994, the gas supply to the PSPC has been exhausted. The HRI is now permanently at the focus. A typical PSPC image can be seen in Figure 1.

2.6 HRI

The ROSAT HRI is an enhanced version of the HRI flown on the Einstein satellite. It consists of two cascaded microchannel plates with a crossed grid readout system. The quantum efficiency of the HRI is maximised by use of a CsI coating on the front plate.

The HRI field of view is the intersection of a circle and a square, having an effective radius of $\sim$ 18 arcminutes. Unlike the PSPC, it is able to make full use of the very small mirror PSF, and has an on-axis 50% power radius of 3 arcseconds. However, point images also show a large diameter, low surface brightness halo

The effective area of the HRI is less than that of the PSPC at all energies, particularly so at the lowest energies. Like the PSPC, it has a strong carbon edge at 0.28 keV.

The HRI has 16 pha channels, and is easily able to distinguish UV photons from X-rays. Some X-ray spectral resolution may also be possible, however this would be very limited. Spatial gain variations have not been corrected in the HRI datasets. A typical HRI image can be seen in Figure 2.

3 The ROSAT Data

3.1 Overview and Origins

Data from the ROSAT XRT is processed by the SASS (Scientific Analysis Software System) before being converted to a FITS format and then distributed to the PI. This processing occurs at MPE for data belonging to German and UK PIs, and at GSFC for US PIs. Both the SASS and the FITS conversion software have evolved throughout the mission, but more fundamentally, the FITS conversion up until May 1994 was different at MPE from that at GSFC. (This corresponds to SASS versions earlier than 7_1.) Data distributed after that date was FITS converted using yet another form of the FITS standard, 'Rationalized Data Format' (RDF). This FITS conversion is now common between MPE and GSFC.

Starting at around the same time as the FITS software change, a re-processing of all data using the evolved SASS was started. This has become known as the 'Rev 2 re-processing'. The output from this re-processing are RDF files. Data in the Leicester public archives currently consist of a mix of RDF and pre-RDF FITS files. As of Feb 2000 around 3 percent of the old datasets remain. It is, however, anticipated that the database will be completely RDF within a matter of months.

ASTERIX 2.3-0 reads RDF FITS files directly. Earlier ASTERIX versions converted all FITS format files to HDS files using the program `xrtconv`. `xrtconv` has been withdraw in version 2.3-0.

3.2 The SASS

The Standard Analysis Software System converts the ROSAT telemetry into scientifically useful files. It performs standard scientific operations on these files, and generates postscript output summarising the observation. The data in the files that make up a ROSAT XRT observation dataset have all been through the SASS, however, the SASS does not make the FITS files that PIs and archive users receive, this is done by later software.

The SASS was written by MPE and SAO. Identical copies run at MPE and GSFC, although it has been continuously updated throughout the mission. A brief description of the SASS follows, however, the details of what specific versions of the SASS have done have proved difficult to uncover. What is clear is that later versions of the SASS produce significantly more reliable results than earlier versions. Confidence has risen to the point that with SASS version 7_1 the entire set of observations to date are being re-processed (the so-called 'Rev 2 re-processing').

The following modules make up the SASS.

SAV – copies telemetry tape to disk, deleting duplicate records, and separates PSPC from HRI data.

TEL – splits data into continuous observing intervals and identifies these with the timeline, assigns quality flags to detector and aspect data.

OBI – applies the aspect solution and screens out bad data. Determines components of background map.

SEQ (PSPC) – merges observation, makes images, performs source detection and identification, makes spectra and light curves and applies statistical tests to these.

SEQ (HRI) – as above, but no spectra or scientific light curves made.

3.3 FITS Conversions

The User's Guide to ROSAT Data in the Rationalized Data Format (RDF) is available to download from :

`http://ledas-www.star.le.ac.uk/rosat-goc/doc.html`

As the conversion of archive datasets into the RDF file format is soon to be completed the following section is now only useful as background.

3.3.1 The Background to FITS File Conversions

The ROSAT datasets have always been distributed as collections of FITS files, however there have been three different sets of file formats within the FITS convention. The MPE and GSFC FITS files represent the first generation data format. They were developed independently, and were read by the respective national analysis packages. Datasets from the two sites contained essentially the same information, although the GSFC datasets included files that had no equivalent in the MPE datasets. UK and German PIs had data in the MPE format, US PIs had data in the GSFC format.

The fact that there were two data formats, together with the deficiencies of the individual FITS styles, led to the definition of the a format common to both MPE and GSFC. This is the 'Rationalised Data Format' (RDF), which is described below. The switch between first generation FITS files and RDF FITS files took place in April 1994. In addition to current PI data, all prior data is being re-processed by the SASS and converted to RDF files.

Detailed descriptions of the files making up the datasets in the three formats are given for both the PSPC and HRI in appendix 1. This appendix also shows the correspondence between FITS files and HDS files.

4 Getting a Quick Look at your Data

In this section you will find a description of how to get from the your data tape or archive dataset useful images, spectra and light curves of point sources.

4.1 How to get your Data onto Disk

4.1.1 Reading a Data Tape

The UK ROSAT Data Centre sends out data tapes to PIs. Until May 1994, these tapes were always in VMS backup format. After that date, the default format became unix tar.

You can read the unix data tapes to disk with the command

```
> tar -xvf /dev/rmt0l
```

where /dev/rmt0l is the device filename for the tape drive. Extracted files will be placed in the current directory.

4.1.2 Accessing the On-line Public Archive

ROSAT data enters the public archive 1 year and 2 weeks after it was first sent to the PI. Rev 2 data enters the archive 6 months after distribution.

UK investigators can easily get archive datasets from the on-line service maintained by the Leicester Database and Archive Service (LEDAS). Access is described in detail in The LEDAS User Guide but will be describe very briefly here.

```
http://ledas-www.star.le.ac.uk/info/user_guide
```

The archive service is currently run from a DEC Alpha and is accessible via ssh (or telnet) and the WWW.

Connect to the LEDAS machine:

```
> ssh ledas.star.le.ac.uk
```

Use the username `xray`, no password is required. After giving your name, you will see a prompt. Type

```
ledas>  browse rospublic
```

You will then be using the Browse Database Management System, which has been described in a Users Guide (ESA TM-11, distributed to all Starlink sites as a MUD). The system is not described here, however, if you know the position or name of your target, or the original PI name, you can issue one of the following commands:

```
rospublic_total_dec> sc 10 20 30 +20 30 40
rospublic_total_dec> sn crab
rospublic_total_dec> sif pi smith
```

These perform searches, the results from which can be seen with the display sample command `ds`. Once the dataset required is identified, the command `request` will cause the dataset to be read from the CD jukebox to a staging area from which you can copy the data over the net to your home site. The system will mail you when the data is ready for copying, usually within 5 minutes of the `request` command being issued.

An alternative method using the WWW at Leicester and the *ARNIE* interface can be found at:

```
http://ledas-www.star.le.ac.uk/arnieV4
```

4.2 A Quick Look at the Data

With your data on a local disk you are now ready to run ASTERIX on it. Start ASTERIX with the command:

```
> aststart
```

If you are using a version of ASTERIX earlier than 2.3-0 you will need to convert your FITS data into HDS files using the command:

```
> xrtconv
```

Begin by getting a summary of the observation with the command `showxrt`.

ROSAT data is in the form of event tables, that is a logical record containing detection attributes such as position, time, etc. Most analysis cannot make use of the data in this form, but requires uniformly binned data. The ASTERIX command to bin data is `xrtsort`. With this you can make images, spectra, light curves, etc. It's probably best to make an image first. From this you can select regions for further study using `Isys`.

`Isys` or the command driven image processing can be used to inspect the image. Specific regions can then be resorted either by entering simple parameters into `xrtsort`, such as positions and radii of circles or annuli, or a regional description can be exported from `Isys` in ARD format (Askii Region Description) then entered into xrtsort. Subsequently the background can be extracted with `xrtsub`, calibrations and corrections applied with `xtrcorr`, and an energy response applied with `xrtresp`. ASTERIX spectral fitting can then be used directly, if you have it installed, or the command `ast2xsp` can be used to format the data to a form suitable for `xspec`.

More detailed guidance on data analysis techniques appears in subsequent sections of this guide.

5 Detailed Analysis

5.1 PSPC

The following is a brief overview of the basic reduction sequence, the details are shown in the later subsections.

ROSAT data may be obtained from a datatape or from the Leicester data archive (LEDAS). In either case the raw data should be copied into a single directory. It is important that this directory does not contain any raw datafiles from another observation as this can cause problems with the pre-processing.

- Users of ASTERIX earlier than version 2-3-0 will need to apply `xrtconv` to the raw dataset to convert it into ASTERIX format.
- `showxrt` will produce a summary of the observation, listing information such as target name, pointing direction and exposure time.
- The program `xrthk` may be used to "clean" the data by producing a file of times when the background was low.
- `xrtsort` can now be used to sort the data directly into an ASTERIX data file. Example 1 shows `xrtsort` being used to create an image. If a file of time slots has been created with `xrthk` this can be used in `xrtsort` when sorting the data (see Example 2).
- The data can be background subtracted with the program `xrtsub`. A background file should first be sorted from a blank area of sky with `xrtsort`.
- `xrtcorr` is used to exposure correct a dataset. This includes corrections for instrumental effects, such as vignetting, dead time as well as normalisation to on-axis counts/sec.
- A detector matrix needs to be produced with `xrtresp` before spectral fitting can be performed. To use `xspec` convert the files using `ast2xsp`.

5.2 Background Subtraction

This is a complex problem and needs to be thought about carefully before proceeding. The PSPC background consists of a cosmic X-ray background, a particle induced detector background, solar scattered X-rays, afterpulses, long and short term enhancements and auroral X-rays. A full description is given in Snowden et al, 1993.

The particles contribute $\sim 2-3\%$ of the background on average ($\sim 5\%$ for an observation with the boron filter), with their major effect being above 1 keV. The needs of background subtraction are as follows:

1. A representative region of background has to be selected from the observation using the `Isys` GUI or the command driven image processing commands. The background region should satisfy the following criteria:

- Large enough to give good statistics

- Free from sources
- Should not include the ribs or central ring
- As near to source as possible, to avoid ramps in the background

2. The background data need to be corrected for vignetting effects before subtraction. This is energy dependent and is complicated by the fact that the particles in the background have a different radial dependency to the photons (i.e. they are not vignetted).

3. The background has to be normalised for the area of the source and background boxes before subtraction.

`xrtsub` calculates: $SUB = SRC - BCK \times \frac{A\_s}{A\_b} \left[B\_phot \frac{V\_s}{V\_b} + B\_part \frac{P\_s}{P\_b} \right]$

where A is the area, *B_phot* the photon fraction of the background, *B_part* the particle fraction, V is the vignetting function and P is the position dependence of the particles. The subscripts 's' and 'b' refer to source and background respectively.

The program `xrtsub` caters for points 2 and 3, so the user only has to worry about point 1. The program ignores source or background pixels with bad quality and this feature may be used to create background regions with complicated shapes, which satisfy the requirements of point 1. e.g. an annulus at a large radius with sources and the ribs removed. See the section on subtracting extended sources for a recipe for creating such a background file.

The particles in the background are calculated using a model developed in Snowden et al. 1992 and updated by Plucinsky et al. 1993, which gives the particle flux as a function of energy, time and detector position. Over a single observation this model is entirely dependent on the housekeeping parameter master_veto_rate, which is contained in an array in the eventrate file. The model is well constrained for values between 0 and 170, and this constraint should be applied to the data using `xrthk` before attempting a difficult subtraction. The model parameters vary on a timescales of months. This effect is taken into account by providing a different set of model parameters depending on the date of the observation.

5.2.1 Point Source Subtraction

The background subtraction of point sources tends to be relatively easy because of the low intrinsic background of the PSPC. Use `Isys` to determine a suitable background area and then sort with `xrtsort`. This should be either an annulus around the source, with an inner radius of at least 3 arcminutes, or if source confusion makes this impossible, a circular box as near as possible to the source. The background box should be as large as possible without including any sources or intersecting the window support structure. If a spectrum or time series is being subtracted, the background datafile must have exactly the same range of spectral bins and time bins as the source file.

5.2.2 Extended Source Subtraction

This is a much trickier problem. The `asthelp` section "`xrtsub` advice extended_sources" gives up to date advice on the best subtraction method. The subtraction of an image provides a good illustration of the current best technique. Let's say a background subtracted image of the whole field between corrected pulse height channels 11 and 250 is required. First, `xrtsort` should be used to make a *spectral_image* over this channel range with about 6 spectral bins. A few spectral bins need to be used to adequately sample the vignetting function which is energy dependent. (It is unnecessary to use more than about 10 spectral bins because of the moderate energy resolution of the instrument. Indeed using a large number of energy bins can cause problems due to irregularities in the vignetting function).

The background area needs to be large but constrained within a narrow range of off-axis angles (so that a single vignetting correction may be applied to the data). The best shape to satisfy these criteria is an annulus at a reasonably large off-axis angle (e.g. $r = 0.6^o - 0.7^o$). To produce such an annulus with sources and window support structure removed, use the following procedure:

- Mask support structures using `xspokes` and `ardqual`.
- Select your background region using `iregion annulus`.
- Export the remaining areas using `iregion invert` and `iregion export`.
- Mask the un-selected regions using `ardqual`.

`xrtsub` may then be run on the source and background spectral images. The output spectral image can be compressed into an image using `project`. Alternatively it may be `project`ed into a spectrum for spectral work. *NB:* DO NOT compress the background spectral image into a spectrum before background subtraction as this will result in the spatial information being lost and the program will be unable to normalise for the box areas.

The above procedure is fairly robust against spatial variations in the background. One problem is that beyond the central ring, it becomes harder to resolve point sources from the background. This means that faint sources may be included in the background region when they would have been ignored in the middle. This can cause a slight over-subtraction and be a problem for very accurate work. No data should be used beyond a radius of 50 arcminutes due to inaccuracies in the vignetting function at these large radii.

5.2.3 Multiple Point Source Subtraction

The situation where there are a large number of point sources within the central ring, such as a 'deep survey' field, has many similarities to the case of the extended source. Choosing a nearby background region for each source is often impossible because of source confusion and anyway is time consuming. One method of subtracting these sources is to use an annulus at a large radius as described above. However, this method may cause over-subtraction and since many of the sources are likely to be faint, this can be a serious problem.

An alternative method is to use background from within the central ring. Although much of the area may be contaminated by sources, there is usually a reasonable amount of blank sky available. The method for producing such a background file is very similar to the annular background described in the 'Extended source' section.

- Produce a square spectral_image with sides just larger than the circle required*
- Select the regions to be excluded using `iregion`.
- Export the regions into an ARDFILE using `iregion export`.
- Use `ardqual` to remove the sources.

* Never `xrtsort` directly to a circular or annular spectral_image. The pixels at the edge of the circle will be only half filled and there is no way of subsequently correcting for this in the software.

An example of this method is shown in Figure 3.

A restriction of this method is that a single vignetting correction has to be applied to the whole background file. This means that the range of off-axis angles that can be used with this method is limited. A circular background region with off-axis angles 0–12 arcminutes or an annular box with angles 10–17 are acceptable.

When removing sources from the background region, careful consideration must be given to the point spread function of the instrument. Very high and very low energies are the most affected by photon scattering and so if sources are inadequately removed the spectral characteristics of the background will be strongly biased. A description of the PSPC PSF is given in Hasinger et al. 1992. Faint sources ($<$ 100 counts) can be adequately excluded with a circle of 1–2 arcminutes radius, centered on the source. Brighter sources should be treated individually. `Isys` can be used to obtain a radial profile to ascertain the distance from the source at which the source counts fall below the level of the background. Photons should be excluded from a circle of this radius centred on the source. Its often a good idea to smooth the image, before extracting the profile.

5.3 Instrument Corrections

5.3.1 Spatial/Temporal Gain Correction

The PSPC suffers from both spatial and temporal gain variations. An account of this can be found in *OGIP Calibration Memo CAL/ROS/95-003*. ASTERIX doesn't currently take these into account, however, there is an ftool, *pcpicor* which can be applied to the raw FITS data. This will only work for data in RDF format.

5.3.2 Exposure Correction

The program `xrtcorr` performs exposure correction on binned datasets. The effects listed in the following table are corrected for:

All these effects are applied directly to the *data* when exposure correcting a time series or an image, however, only the dead time correction is applied to a spectrum; in this case the energy dependent corrections and the effect of the wires are applied to the detector matrix. For a time series or an image, the energy dependent corrections, vignetting, PSF scattering and filter

Table 1: Correction factor dependencies

Correction	Energy	Time	Position
Vignetting	YES	NO	YES
PSF scattering	YES	NO	YES
Filter absorption	YES	NO	NO
Dead time	NO	YES	NO
Wires	NO	NO	NO

absorption, are applied assuming a mean energy. The default energy for this correction is 0.2 keV but it may be overridden on the command line, by :

```
> xrtcorr energy=1.0
```

The vignetting and filter corrections are read from the effective area and detector matrix files held in the $XRTCAL directory. The PSF correction is calculated from an analytical function and is a strong function of off-axis angle as well as energy. The wire correction is a single value (1.27) and dead time is calculated from count rate values stored in the eventrate file and is usually $\sim 2\%$.

The vignetting, PSF and filter corrections are *ENERGY* dependent and *NOT* pulse height dependent. This means that they cannot be directly applied to the data in a *spectrum* but rather must be applied to the detector matrix used in spectral fitting. The data in a spectrum are simply multiplied by the dead time factor and divided by the exposure time during exposure correction. The wire factor is not applied because this is also contained within the detector matrix.

Images and spectral_images are corrected for dead time and vignetting. The vignetting correction applied to an image assumes a mean energy and so is not accurate. The correction applied to a spectral_image, uses the approximate energy to pulse height bin mapping of $E = (Ch.No.)/100$ keV. This again is not accurate and under no circumstances should a spectral image be corrected with `xrtcorr` and then used for *spectral* work by `project`ing the file into a spectrum.

5.4 Spectral Analysis

PSPC spectra may be produced over the channel range 1-256. However the first 7 channels should be ignored in the spectral analysis of sources observed before 11th October 1991. On this date, the operating voltage of the detector was reduced in an attempt to lower the detector background. This led to the first 10 channels becoming useless and so analysis of observations post 11th October 1991 should ignore the first 10 channels.

5.4.1 Single Point Source

This is the simplest case, a circular box should be used in `xrtsort` to extract the source counts into a spectrum (BIN_AXIS=7). There is one subtlety which must be considered. The PSF of the PSPC is very energy dependent (Hasinger et al 1992), e,g, on-axis the 95% radius of a point source is 0.65 arcminutes at 0.5 keV, but 8.8 arcminutes at 1.7 keV. Below $\sim 0.3keV$ (channel 30), PSPC images suffer from an effect known as 'electronic ghost imaging'. This causes events to be recorded at the intersection of anode wires rather than at their true position and results in the image appearing like a rectangular grid rather than a point source. This effect varies from source to source and so is impossible to correct for in the software. It has been found that a source radius of 3 arcminutes usually includes most of the counts at all energies and produces good results as a rule. If low energies are not important and/or the source is very faint, this can be reduced to ~ 1 arcminute to improve the signal to noise. If very low energy counts are important for a particular source, e.g. if it is a very soft source, then the radius which includes most of the soft counts needs to be found. This may be done by displaying the *low energy* image with `idisplay`, centroiding on the source and producing a radial profile with `iradial`. The extraction radius should be set to the point where the source profile merges into the background.

Having produced the source spectrum, it should be background subtracted and exposure corrected as discussed earlier. After this a detector matrix needs to be created using the program `xrtresp`. The detector matrix is unique for each source, being a function of off-axis angle and source box radius. It is written directly into the spectral datafile. This file may be used directly in the ASTERIX spectral fitting package, `sfit`, or within `xspec` after format conversion by `ast2xsp`.

For weak or very soft sources, modelling the particle component of the background correctly is important. In this case the data should be "cleaned" before sorting by only using times when the Master Veto Rate parameter is between 0 and 170.

5.4.2 Extended Source Single Spectrum

Extended sources have higher background and so care needs to be taken when performing the background subtraction. To help reduce the background present in the data it is possible to "clean" the data using the Master Veto Rate parameter, contained in the eventrate file. The program `xrthk` may be used to generate a text file of time slots, for when the MVR value is between 0 and 170. This typically results in a reduction in exposure time of about 10 % but can significantly reduce the background. The particle model of Snowden et al 1991, used in the background subtraction assumes that the MVR is no greater than 170. The text file generated by `xrthk` can be used directly in `xrtsort` to specify the time ranges wanted (see Example 2). The same time ranges *must* be used when sorting the background file for the observation.

When analysing part or all of an extended source, e.g. the inner 0.1 degrees of a cluster of galaxies, there are no PSF considerations when choosing the source box. However, the source box must be small enough that a single vignetting correction (at a single off-axis angle) is appropriate for the file. A reasonable size source box would be a circle of radius 0.2 degrees within the inner ring, or an annulus of width 0.1 degrees outside the central ring. If a larger box is required, see the section on "radial_spectra".

It is not always obvious which off-axis angle to use for the vignetting correction of a large source box, centred on the optical axis. By default, the off-axis angle is set as the half radius of a circle or the mid-radius of an annulus. For a point source with a small source box this is not important, however, with a large source box this may not be appropriate. For instance, if a circular source box was used with a uniform distribution of photons, then the photon weighted mean off-axis angle would be $R/\sqrt{2}$, where R is the radius of the box. On the other hand if the photon distribution is strongly centrally peaked, then an off-axis angle less than the half radius would be appropriate. In general with a smooth decrease in the source radial profile, the half radius is the best value to use for the mean off-axis value, however this default can be overridden on the command line if necessary with:

```
> xrtcorr offax1=8.2
```

Where the off-axis value is in arcminutes.

5.4.3 Radial Spectra

To save time analysing different sections of an extended object, it is possible to produce a single file containing spectra at a number of different radii. For instance a circular cluster, centred on the optical axis, of extent 0.5 degrees, could be divided into 5 radial rings of width 0.1 degrees. To produce such a source file select a circular source box in `xrtsort` of radius 0.5 degrees, and select axes 7 and 8 at the BIN_AXIS prompt. As with extended sources, it is best to subset the data by restricting the Master Veto Rate range to 170.

The subtraction should be performed as for an extended source, e.g. an annular background region of radius 0.7–0.8 degrees might be appropriate. `xrtsub` and `xrtcorr` will then background subtract and exposure correct all the spectra in one go.

If `xspec` is used for spectral fitting, each spectrum may be converted individually with `ast2xsp`. The ASTERIX spectral fitting software will work directly on a radial set of spectra, the desired spectra may be selected with `sdata` before using `sfit`.

5.4.4 Spectral Analysis of the Background

To find the spectra of the cosmic background in a PSPC image, the following procedure may be adopted. It is probably best to just use data from within the central ring for this purpose to ensure uniform point source rejection to a well defined threshold.

1. Use `xrthk` to restrict the master veto rate to 170.

2. Use `xrtsort` to produce a square spectral_image which includes the inner ring. The spatial binsize should be about 15 arcseconds; any number of spectral channels may be used, but 32 or 64 is possibly best. A 256 by 256 by 32 spectral channel file should produce good results.

3. Use the `quality` setting programs to set pixels outside a radius of upto 17 arcminutes BAD and blank out the sources and window support structure from the spectral image (this procedure is described in the section on background subtracting multiple point sources).

4. The spectral_image can now be compressed into a spectrum using `project`.

5. Remove the particles (and detector noise) from the spectrum. This is accomplished by using `xrtsub` to produce a spectrum of the particle background by :

```
a) xrtsub spectrum spec_image part_file=parts

   This just uses xrtsub to generate the particle file, throw
   away the subtracted file that it produces. This assumes that the
   spectral file is called spectrum.sdf and the spectral image,
   spec_image.sdf

b) subtract spectrum parts

   Use to subtract the particles from the background spectrum
```

5. Exposure correct the spectrum with:

```
> xrtcorr offax1=n.n
```

`xrtcorr` will use an inappropriate default for the off-axis angle of this spectrum. It must be supplied with the area weighted mean off-axis angle of the photons, this is $R/\sqrt{2}$, where R is the radius of the circular region specified with the quality setting programs. OFFAX1 is in arcminutes.

6. `xrtresp` will attach a detector response structure using instrument information calculated by `xrtcorr`. The default matrix should be used with observations after mid 1991.

5.4.5 Spectra of many Sources

A common requirement in ROSAT analysis is to improve the signal to noise ratio by combining spectra from many similar sources in the same field, e.g. AGN in a deep exposure field. Strictly speaking this is incorrect because a separate detector matrix is required for each source, depending on the off-axis angle and the source extraction radius. However, if this point is born in mind and the analysis is restricted to sources within the central ring it is possible to use the technique.

Each source required should be extracted using a circular box with a fixed radius. If all the sources are faint then `xrtmspec` may be used to extract each spectrum. This procedure uses an extraction radius of 0.01 degrees which is too small for bright sources ($>$ 100 counts). If one or more bright sources are present, then `xrtmspec` should be modified to use a larger radius or each source should be extracted separately with `xrtsort`. Each source *must* be extracted with the same radius.

The spectra may be added together using:

```
> meandat average=no
```

This program adds the counts from each input spectrum. Subsequent programs will use the off-axis angle from the first file used in `meandat` to calculate the energy dependent corrections for the combined spectrum, so it is important that the first datafile is at an average off-axis angle for all the sources. The resultant datafile may be subtracted and corrected as described earlier.

5.5 Time Series Analysis

While we would fully expect the Time Series Analysis component of ASTERIX to function as described in this guide, the User should be aware that the use this software has now been superseded, and that there are no further plans for the development of Time Series software within ASTERIX.

ROSAT flies a near circular low earth orbit. The drawback of such an orbit is that periodically the satellite must stop observing while it passes through regions of high particle background such as the South Atlantic Anomaly. A *ROSAT* time series of greater than 30 minutes duration may have gaps in it due to this effect; this causes difficulties for traditional time series analysis routines. The ASTERIX document, USER_006, provides a summary of the routines within ASTERIX which have been designed to overcome this problem.

Analysis of PSPC data is further complicated by the window support structure. The detector is continually wobbled while observing to ensure that sources are not continuously hidden behind the fine wire mesh of the support structure. This means that a source will continually pass under wires and its flux will be modulated at the wobble period, (about six minutes). Sources outside the central ring are less prone to this effect because of the wide PSF at high off-axis angles.

A time series may be background subtracted if required in a similar manner to the spectral datasets mentioned earlier. It is likely that several of the time bins in the file will be only partly exposed and so it is important that the data is exposure corrected with `xrtcorr` before being analysed.

Due to the nature of ROSAT observations there can be very long gaps between data in a time series. To save disk space and processing time, the gaps in the time series may be removed with the program `streamline`.

The program `lombscar` provides a good technique for searching for peaks in the power spectrum of 'gappy' data.

5.5.1 Barycentric Correction

There is currently no way to correct for the motions of the satellite and the Earth from within ASTERIX. However there are two FTOOLS available `abc` and `bct`, wrapped up in a script `rosbary` which may be of some use. These programs will not work on old MPE style datasets.

5.6 Image Analysis

Images may be sorted over any energy range with `xrtsort`. Occasionally, observations are incorrectly processed by the SASS pre-processing software and aspect errors are introduced. This is often the result of a poor attitude solution from the star-trackers onboard ROSAT and results in photons appearing in a different part of the image from where they were recorded. A sign that this may have happened is if sources appear to be elongated along the wobble direction. If it is suspected that an observation contains aspect problems or if very accurate work, e.g. a search for source extension, is being undertaken, the problem can be reduced by subsetting the data on the aspect error (ASP_ERR) housekeeping parameter, contained in the attitude file. `xrthk` should be used to produce a file of times when the aspect error parameter was between 0 and 1. An image should then be produced with `xrtsort` between these times. At the same time, the Master Veto Rate parameter may be used to reduce the background in the image.

The image may be background subtracted using the methods outlined in the "Background subtraction" section.

`xrtcorr` may be used to exposure correct an image. This includes a vignetting correction, but it should be remembered that this correction when applied to an image is only approximate because vignetting is calibrated in terms of energy and not pulse height channel.

The image may be manipulated in a wide variety of ways using `Isys` and the command driven image processing, within ASTERIX. See "`asthelp` image" for details.

5.6.1 Energy Mapping

PSPC data contains energy as well as spatial information. It is possible to indicate this on an image by producing an *energy map*. This may be done in two ways :

1. Produce a spectral image, with 4-8 spectral channels.
2. Run `enmap` with a suitable threshold (See the help entry).
3. Plot the result with `idisplay`.

or by producing a 3-colour image,

1. Produce a low energy (chns: 8-40), medium energy (41-100) and high energy (101-200) image of the same region.
2. Combine these with `mkcolim`.
3. Display after using `icolour rgb`.

The first method is suitable for low signal to noise data whereas the 3-colour image method works well on bright objects.

5.6.2 Radial Profiling

A radial profile of a source may be produced with the `iradial` command. If the region of interest is contaminated by another source or intersects the window support structure, the image may be cleaned before starting the analysis. A typical procedure may be :

```
icl> idisplay im1          ! Display the image
icl> iregion               ! Choose the areas to set bad
icl> iexclude curr         ! Set these areas bad
icl> iradial               ! Produce the radial profile
icl> isave1d im1_radp      ! Save the radial profile
```

```
icl> exit
```

The saved radial profile may be analysed in detail with `qdp` if required after using the `astqdp` command.

The above example uses the command driven image processing commands. The same sequence, including the export to `qdp`, can be performed purely within `Isys`.

5.6.3 Test for Extension

A source may be tested for extension using the following procedure:

```
icl> idisplay
icl> icentroid              ! Find the centre of the source
icl> imode key              ! Switch to keyboard mode
icl> iradial                ! Produce a radial profile
icl> ipsf                   ! Compare with the expected PSF
```

`ipsf` allows several PSF functions to be compared against the radial profile. The PSPC options may be accessed by selecting XRT_PSPC. The best options at present are, ONAXIS_3 if the source is on axis or VARPROFILE if it is off axis. The routine gives a χ^2 value for the quality of the fit.

NB: if a source appears to be extended, the image should be sorted over times when the aspect error value was low, to minimise possible aspect errors, and the above procedure repeated.

5.7 Count Rates and Source Searching

Quick source counts and count rates may be extracted from a PSPC observation with the image processing system. e.g.

```
icl> xrtsort                ! Sort an image
icl> iload image xwin       ! Start the image processing system
icl> idisplay               ! Display the image
icl> icircstats             ! Find the counts in a source
```

To determine accurate source counts, the source searching routine, `pss` should be used. This routine provides a sensitive means of finding the sources in an XRT observation. Full details are given in the help and in the document, USER_004. It has a large number of operational modes but the following method works well for finding sources and obtaining count rates from a PSPC image.

1. Produce a background model image using `xrtsub`. This program creates a model of background by scaling the vignetting function as a function of energy using a *source free* portion of the input data and adding an estimate of the particle background (which is not vignetted). The simplest way to do this is to create a spectrum of a blank region using `xrtsort`. The lower and upper bounds in channels *must* be *exactly* the same as used to create the image to be searched by `pss`, and the spectrum should contain between 4 and 10 bins. For instance if the image was sorted over the corrected PH range 8-247, then the spectrum must be produced over the same 240 channels and may consist of 4,6,8, or 10 bins.

Invoke `xrtsub` giving it the image you want to search at the SOURCE prompt, your background spectrum at the BCKGND prompt, and supply it with a file name for the background model using the BGMODEL parameter. It will also output a background subtracted copy of the SOURCE image using the OUT parameter. `pss` can accept either the raw image or the background subtracted image.

2. Run `pss` using the XRT_PSPC VARPROFILE option in POLAR mode as the PSF and giving the background image generated above as the background (BGND) option. See Example 3. `pss` produces two outputs, a significance map and source list. The first of these is optional but useful in diagnosing problems. It is a map over the image region searched of the likelihood ratio of the two models *background only* and *background + point source*. `pss` searches for points in this map above a user supplied threshold, identifies these as sources and finds confidence intervals on the parameters describing the source, ie. flux, X and Y. The flux output is in raw counts and takes into account the fact that not all of the psf may be included in the search box.

3. The source list from `pss` may be displayed to the screen, file or printer using the `ssdump` command.

4. The source counts in the list produced by `pss` may be exposure corrected using `xpsscorr`.

`xpsscorr` can be used to convert the source counts calculated by `pss` into a count rate. This is the count rate which would have been observed had the source been on axis. It does this by dividing by the exposure time and by using calibration files to determine the vignetting. By default it also multiplies by a factor 1.0/0.79 to correct for the absorption by the fine wires in the support structure.

Alternatively the merged exposure map which is provided with each observation may be used to calculate the exposure time. This latter approach has the advantage of coping with sources which are partially obscured by the window support structure, however, it is only valid for images produced over the full time range and over the full pulse height channel range. Any subset of these quantities will invalidate the use of the exposure map.

With either method, the wire correction may be turned off by specifying "wires=no" on the command line. If the count rates are going to be subsequently converted into a flux using the effective area files or used within spectral fitting, the wire correction should NOT be applied as it is already included in the detector matrix.

5. Source positions can be marked on the displayed image using `imark`, or added as permanent annotations in the presentation graphics using `ssanot`.

6. Time series or spectra can be extracted for every source in a `pss` list using the `xrtmtime` and `xrtmspec` procedures respectively.

7. The whole process can be performed iteratively. To refine your background estimate those regions of the image input to `xrtsub` containing sources can be masked out using `iregion` and iexclude or Isys. This produces a background unbiased by the presence of point sources which can then be used in pss again.

5.8 HRI

Before starting to analyse HRI data you should obtain a copy of the calibration report :

```
ftp://legacy.gsfc.nasa.gov/pub/rosat/doc/hri/HRI_report
```

HRI data are sorted in an identical manner to PSPC data. The HRI has 16 pulse height channels, which give very limited energy resolution. It is not yet possible within ASTERIX to make use of this aspect of the data except to subset the data on PH channel within xrtsort.

Source spectra are significantly more peaked than background spectra and an improvement in signal to noise may result from restricting the channel range to 3–8, although the exact channel range will vary from one source to the next.

5.8.1 HRI_Aspect_Errors

An error in the SASS processing of aspect time has been recognised in Rosat HRI observations prior to 17 Jan 1997. The error in calculating aspect time causes the position of events to be offset by upto 3.5 pixels This causes the PSF to be blurred by the order of 3".

An approximate solution, using an FTOOLS script, has been developed which is accurate provided that the roll angle is not changing too rapidly. A detailed description of this problem is provided at :

```
http://ledas-www.star.le.ac.uk/rosat-goc/rosstatus178
http://hea-www.harvard.edu/rosat/rsdc_www/aspfix.html
```

5.9 Background Subtraction

Basic background subtraction may be performed with xrtsub. This will subtract the background after normalising for area. At present the software does not perform any correction for the different detector efficiencies at the source and background box positions.

Alternatively, since most of the background is due to particles, it would also be possible simply to subtract a flat background. Software to help determine the level of this may be obtained from:

```
ftp://legacy.gsfc.nasa.gov/ in directory /rosat/publications/diff_bkgrd/temp
```

5.10 Exposure Correction

The exposure correction program, `xrtcorr` performs dead-time corrections, correction for the mirror vignetting, and correction for the quantum efficiency of the detector. All corrections are carried out according to formulae given in the Calibration Report. The one slight exception to this is the quantum efficiency correction. The QE of the detector is provided as a 2-D map in detector coordinates. To apply this to data binned in world coordinates it is radially binned, and the averaged correction applied only as a function of radial offset from the centre of the FOV.

5.11 Source Searching

The source search program uses the point spread function as specified in the calibration report.

6 A Description of the PSF

The ROSAT PSF describes the spatial response of the instrument to a point source resulting from the scattering of photons due to mirror figuring and irregularities, and physical limitations of the detector. This response also varies with energy.

The PSF has to be considered to perform an optimal analysis of an observation.

The PSF results from a number of factors;

ON AXIS effects - see OGIP calibration memo. CAL/ROS/92-001.

- A scattering effect - caused by irregularities in the surface of the mirror.
- A penetration effect - due to the varying depth penetration of X-rays in the counter gas.
- A resolution effect - because of the manner in which electrons are generated.
- Image ghosting - in PHA channels less than channel 15.
- An ellipsoidal blur - due to the uncorrected attitude motion.

OFF AXIS effect - see OGIP calibration memo. CAL/ROS/93-015.

- A blur effect - the blur of the XMA.

6.1 ASTERIX PSF

6.1.1 ASTERIX Programs using the PSF System

- `pss` - in the point source searching program `pss` the PSF is used in conjunction with a background model to make comparisons with an input dataset. (See user˙004.)
- `imsim` - uses the PSF to help create simulated images.
- `spresp` - attaches a spatial response to an input dataset. (See the Respfile option below).
- `crepsf` - creates a tabular PSF dataset. (See the Tabular option below.)
- `spconvol` - is used in extended source searching to convolve the spatial response with a user supplied source model.
- `ipsf` - fits the PSF to a radial distribution produced by Iradial and displays the result.
- `xrad` - is a ROSAT PSPC only program which calculates the radius of a circle which encloses a certain fraction of counts.

6.1.2 PSF User Interface

Because ASTERIX is designed as a multi-mission program it facilitates the inclusion of instrument dependent code for the PSF by the use of a PSF data routines library which it accesses using PSF system routines. (See `Prog/011`)

The PSF system controls access to the numerous PSF options which are presented to the user in the ASTERIX PSF user interface as follows;

```
PSF system options :

ANALYTIC      ASCA          EXOLE         PWFC          RADIAL
RESPFILE      TABULAR       WFC           XRT_HRI       XRT_PSPC

CSPEC(PSF/model,spec[,nbin])
POLAR(PSF,rbin[,abin])      RECT(PSF,xbin[,ybin])

PSF - Choose PSF to use for source model /'XRT_PSPC'/ >
MASK - PSPC PSF option (LIST for descriptions) /'VARPROFILE'/ >
Loaded XRT PSF cube with 10 energy channels
AUX - Mean photon energy in KeV >
```

The reason for the large number of PSF options list above include: multiple missions and instruments, recalibrations, analytical options, searching for extended source, and techniques for improving the speed of PSF processing.

6.1.3 General Considerations

Although the options all provide a PSF to the ASTERIX programs in standard form it is important for the user to familiarise himself with the operation of the individual PSF which he is using, because there are variations in the behaviour of each option. Fortunately there are a number of general considerations which will hasten understanding of a particular PSF ;

- Does the PSF option derived from calibration data or an analytical form?
- Has the PSF been calculated from a generally applicable analytical function or is it instrument dependent?
- Which other PSF options are available?
- Is the PSF onaxis or offaxis?
- Does the PSF simply calculate and apply a single PSF array to a dataset?
- Is the PSF a variable option which attempts to account for the variation of the PSF with energy and variation of the PSF with off-axis angle? (see the Respfile Option below.)
- Is the option intended to be used when working with extended sources?
- Does the option include techniques to improve the speed of processing PSFs?

6.1.4 Improving PSF Processing Speeds

ASTERIX stores PSFs as 2D arrays of integrated probability. These arrays are pixel based. When applying the PSF the size of the PSF array determines the number of adjacent pixels which have to be visited. Because calculating a PSF for individual pixels, and then applying that PSF to each pixel in a dataset is computationally expensive, the PSF system includes strategies to speed up the process;

- `Reduce the PSF size`. The included energy fraction of the PSF, and hence pixel array size, can be reduced (as in `pss`).
- `Precalculate the PSF`. The spatial response can be pre-calculated and included in the dataset (see the Respfile Option below.)
- `Calculate the PSF on a grid`.The number of PSF calculations can be reduced by calculating PSFs, not at each pixel in the image, but over some coarser grid of positions. This method can be used either before applying the PSF (as in `spresp`) or on an 'as needed' basis (see the Model Option below.)

6.1.5 PSF and Extended Sources

The PSF system can also be used to search for or model extended point sources. The pss program has a variable EXTEN which measures the fit to an extended source using the PSF convolved with a Gaussian. Greater control of the process of modifying the PSF shape can be achieved using the `crepsf` and `spconvol` programs.

6.2 PSF Options and Masks

6.2.1 Other Satellites and ROSAT Instruments

The ASCA and EXOLE options refer to other satellite missions, while the WFC, XRT_HRI and XRT_PSPC are different ROSAT instruments which each require their own PSF.

```
PWFC*
- The WFC in pointed mode
WFC
- The WFC in survey mode
XRT_HRI
- The ROSAT XRT, HRI detector
XRT_PSPC*!
- The ROSAT XRT, PSPC 1 and 2 detectors

* These psf routines vary with position across the field of view
! These psf routines support energy modelling using the CSPEC model
```

6.2.2 Analytic Options

The ANALYTIC option provides single analytical descriptions which can be used as initial approximations to the PSF. These are useful pre-flight. They can also be used to help create models when dealing with extended sources

A number of analytical functions can be combined together and fit to calibration data to create a PSF model for a particular instrument (see the HRI Option below.)

6.2.3 Tabular and Respfile Options

The TABULAR and RESPFILE options do not create PSFs but are methods which allow access to PSFs which have been previously created.

The TABULAR option reads in a *single* PSF from a datafile which has been created by the `crepsf` application. This option is useful when working with extended sources.

The RESPFILE option is an attempt to increase the processing speed in a PSF program by allowing access to a SPATIAL RESPONSE which is attached to the datafile. The spatial response is an "array of PSF arrays." A spatial response is included in a datafile as a precomputed grid of point spread functions tailored to *both* the spatial and energy sub-space occupied by a dataset.

If a dataset repeatedly uses a PSF the program `spresp` can be used to create a PSF SPatial RESPonse and attach it to the dataset where it can be recalled as required. Because a SPATIAL RESPONSE is precalculated it also speeds processing time. This option is most useful in applications which make very intensive use of the PSF. Attaching a spatial response increase the size of a dataset.

6.2.4 PSF Models

The PSF MODELS are used to increase processing speed. The MODEL option places a grid over the dataset and subsequently computes a single PSF for each grid cell which is to be used for all the enclosed points. For each cell of the grid the PSF is calculated only once, and only if required.

There are three MODEL forms - POLAR(PSF,rbin[,abin]) and RECT(PSF,xbin[,ybin]) have spatial variations while CSPEC(PSF/model,spec[,nbin]) includes energy dependency.

MODEL selection *must* include a reference to a variable PSF option.

eg. PSF - Choose PSF to use for source model /'XRT˙PSPC'/ ¿ polar(xrt˙pspc,0.02)

In this example 'polar' is the model, 'xrt˙pspc' the variable PSF option and '0.02' the grid cell size.

6.2.5 XRT_PSPC - the Recommended Rosat Option and its Masks

The XRT_PSPC is the recommended option for the ROSAT PSPC and four MASKS are provided: VARPROFILE, VARGAUSSIAN, ONAXIS_2, ONAXIS_3

MASK is probably a slightly misleading term which is used by the PSF system for a sub-menu or sub-option.

ONAXIS_3 is a recommended MASK if the source is on axis.

The ONAXIS_3 mask returns a single on-axis PSF. It combines three functions which account for three of the factors which make up the composite on-axis PSF;

```
- primary electron generation is represented by a Gaussian function
- penetration of the counter gases which is an exponential function
- mirror scattering which is a Lorentzian function
```

At greater than 20 arc minutes off axis the off-axis blur becomes the dominant factor in the PSF and causes a noticeable asymmetry in the distribution of source counts. Because of the blur effect a PSF which varies with off-angle is a widely preferred option.

VARPROFILE is the recommended MASK if the source is off axis.

The VARPROFILE mask creates a variable PSF which contains *both* off-axis angle and energy dependence.

The VARPROFILE mask uses a 'data cube' - a file in which calibration data has been preprocessed and stored. The values of radius contained in US Rod Calibration Tables have been transformed into the 'data cube' with ENERGY, OFF AXIS and RADIAL BIN components. The 'data cube' applies to the whole ROSAT field of view and can be used to calculate an individual PSF for each data set. The comment 'Loaded XRT PSF cube with 10 energy channels' indicates that the data cube has been loaded.

```
THE CUBE'S DIMENSIONS

DATA CUBE   BINS    BIN SIZE

ENERGY      1-10    0.24keV
OFF AXIS    1-30    2 arcmin
RADIAL BIN  1-40    Variable @0.018 arcmin
```

With the VARPROFILE mask the user will also be prompted for a value of AUX.

The AUX value provides the program with a value of mean photon energy in keV. For typical source spectra 0.5keV is a recommended value for AUX. For very hard or soft sources other values may be required - look at a spectrum of the source to decide.

If the VARPROFILE option is being used with a MODEL the smallest recommended grid size is 0.02 (where axis values are in degrees).

6.3 HRI Option

The HRI model is an analytic fit to the in-flight response, performed by MPE/GSFC/SAO. The functional form of the on-axis HRI PSF is :

$$PSF(R) = A\_1e^{-0.5(\frac{R}{S1})^2} + A\_2e^{-0.5(\frac{R}{S2})^2} + e^{(\frac{-R}{S3})}$$

where the radial distance R from the psf centre is in arc seconds. The constants A and S have values :

A1 = 0.9638 S1 = 2.1858" A2 = 0.1798 S2 = 4.0419" A3 = 0.001168 S3 = 31.69"

The on-axis model provides a reasonable description of the PSF out to radii of 100 arcsec, but does not model the azimuthal asymmetry present within the PSF core [at a radii less than 12 arcsec] of the PSF.

The on-axis model does not vary with position in the field of view and consequently " ... the PSF starts to degrade beyond 5 arc minutes off axis. Beyond 12 arc minutes off axis, the images become very asymmetrical."

"A parametric representation of the azimuthally averaged off-axis HRI PSF has also been derived which is a simple extension of the on axis expression ... The best fit values of s2 are well parameterised by a cubic polynomial in the off-axis angle, and are given by

$$\mathrm{S2} = 3.3 + 0.019\theta - 0.016\theta^2 + 0.0044\theta^3$$

where T is the angle off-axis in arc minutes. Substituting this into the HRI PSF gives the general off-axis representation."

The ASTERIX XRT˙HRI option uses the off-axis HRI PSF parameterisation.

Documentation on HRI can be found at :

`http://hea-www.harvard.edu/rosat/rsdc_www/HRI_CAL_REPORT/node12.html. Feb-97`
`http://heasarc.gsfc.nasa.gov/docs/rosat/newsletters/hripsf10.html. Mar-96.`

7 Communicating with the ROSAT Project

7.1 Staying Informed

News items, including the national ROSAT newsletters can be accessed via the Leicester ROSAT home page and the HEASARC ROSAT guest observer facility on the World Wide Web.

```
http://www.star.le.ac.uk/Forum/rosat-news  and
http://heasarc.gsfc.nasa.gov/docs/rosat/rosgof.html
```

Documentation on ASTERIX can be found at:

```
http://www.sr.bham.ac.uk/asterix-docs/
```

7.2 Reporting Bugs

An interactive form can be found via the WWW which also lists known bugs, and the action being taken with regards to them, within ASTERIX project. This can be found from the main ASTERIX web page.

8 A Quick Guide

8.1 PSPC

This section gives brief details of the programs needed to process an XRT observation.

ROSAT data may be obtained from a data tape or from the Leicester data archive. In either case all the raw data files should be copied into a single directory. It is important that this directory does not contain any raw datafiles from another observation as this can cause problems with the pre-processing.

- Run `xrtconv` on the raw dataset to convert into ASTERIX format.
- Running program`showxrt` will produce a summary of the observation, listing information such as target name, pointing direction and exposure time.
- The program `xrthk` may be used to "clean" the data by producing a file of times when the background was low.
- `xrtsort` can now be used to sort the data directly into an ASTERIX data file. Example 1 shows `xrtsort` being used to create an image. If a file of time slots has been created with `xrthk` this can be used in `xrtsort` when sorting the data (see Example 2 below).
- The data can be background subtracted with the program `xrtsub`. A background file should first be sorted from a blank area of sky with `xrtsort`.
- `xrtcorr` is used to exposure correct a dataset. This includes corrections for instrumental effects, such as vignetting, dead time as well as normalisation to on-axis counts/sec.
- A detector matrix needs to be produced with `xrtresp` before spectral fitting can be performed. To use `xspec` convert the files using `ast2xsp`.

8.2 HRI

Processing of HRI data proceeds on an identical path to PSPC data, with the obvious omission of the spectral fitting.

9 Housekeeping and calibration data

9.1 Housekeeping Data

By thresholding on the values of different housekeeping parameters using the XRTHK program the User is able exclude unwanted times in the original dataset. XRTHK outputs a list of on/off MJD times which can then be passed into XRTSORT.

A list of the all housekeeping parameters are included later in this document (Appendix 4). The most commonly used parameters (and some suggested values) are :

- MV_ACO - the master veto rate (1-170).
- XACC - the accepted X-ray rate (1-30).
- ASP_QUAL - aspect quality (0-2).

The FTOOL program `fv` can be used to inspect the housekeeping parameters in the `evrate` and `aspect` extensions of the ancillary fits file. `fv` may subsequently be used to plot one array in a file against another.

For example - the `xspokes` program uses the satellite roll angle to determine the position of the window support structure on the image. This system can be flawed if an observation has been performed in two sections, with the satellite at different roll angles.

To check the roll angle, start FTOOL program fv and open your _anc.fits file. Select a plot on the aspect extension and use the time and roan_cas parameters as your axis.

9.2 Calibration Data

The effective area and detector response matrix information is currently read from SDF calibration files. `plotxy` can be used to plot SDF information.

eg. The approximate relationship between pulse height channel and energy for the PSPC is $E = (Ch.No.)/100$ keV, e.g. channel 100 is approximately 1.0 keV.

To plot the relative vignetting on-axis against that at 15 arcminutes:

```
plotxy $AST_ETC/pspcb_eff.effar_1 $AST_ETC/pspcb_eff.effar_4
```

Plots of the vignetting function are given in Figures 5 & 6. The vignetting function is defined at fourteen different off-axis angles from 0–60 arcminutes.

10 Examples

EXAMPLE 1: Sorting an image from PSPC data

```
XRTSORT
xunb> xrtsort
XSORT Version 2.0-0
The following header files are present:
 mrk33_hdr.sdf
ROOTNAME - Rootname of files to sort /'mrk33'/ >
TYPE - Output data type - Event(E) Binned(B) /'B'/ > B
Binned dataset selection
--------------------------
1 - XPIX
2 - YPIX
3 - XDET
4 - YDET
5 - Time
6 - PHA channel
7 - Corrected PHA channel
8 - Radial
AXES - Enter integer codes of axes required in data array /'12'/ > 1 2
SHAPE - Shape of source area [D,C,A,E,R] /'R'/ > R
RA - RA of the centre of the source region /'     158.13000488281'/ >
DEC - DEC of the centre of the source region /'     54.400001525879'/ >
SWIDTH - Width of source box /2.133333/ >
SHEIGHT - Height of source box /2.133333/ >
    Data array axes
  *******************
     3) XDET:      0 to    8192 (pixels)
     4) YDET:      0 to    8192 (pixels)
     5) Time:     147.000 to    87964.000 (seconds)
     6) PHA channel:      1 to     256 (chn.)
     7) Corr. PHA chan.      1 to     256 (chn.)
RANGES - Property ranges to change (enter numbers) /!/ >
 There are 15358 raw sky pixels within the X range selected
NXBIN - Number of output bins in the X axis /512/ >
There will be 512 X bins, each of 30 raw pixels, starting from -7680
 There are 15358 raw sky pixels within the Y range selected
NYBIN - Number of output bins in the Y axis /512/ >
There will be 512 Y bins, each of 30 raw pixels, starting from -7680
BACK - Is a background file wanted (Y/N) /FALSE/ > FALSE
OUT - Output source filename /'image1'/ > broad_image1
>
```

EXAMPLE 2: Sorting a spectrum from PSPC data with master veto rate between 0 and 170.

```
> xrthk
XRTHK - Version 1.7-0
RAWDIR - Raw data directory /'/data'/ >
Index/header file found on  /data
 Found 15 data files on  /data
 /data/mrk33.sdf
 /data/mrk33_att.sdf
 /data/mrk33_dif.sdf
 /data/mrk33_diffuse.sdf
 /data/mrk33_evr.sdf
 /data/mrk33_hdr.sdf
 /data/mrk33_imec.sdf
 /data/mrk33_mex.sdf
 /data/mrk33_orb.sdf
 /data/mrk33_overlay.sdf
 /data/mrk33_pl.sdf
 /data/mrk33_qua.sdf
 /data/mrk33_rz.sdf
 /data/broad_image1.sdf
 /data/aspec_10.sdf
ROOTNAME - Rootname of the calibration files /'mrk33'/ >
Typical parameters to sort on :
   Master veto rate : ee_mv
   Aspect error : asp_err
   Accepted event rate : ee_axe
HKPAR1 - Name of HK parameter (! to finish) /'ee_mv'/ >
ee_mv : ranges from 0 : 210
PMIN1 - Minimum value for this parameter /0/ >
PMAX1 - Maximum value for this parameter /210/ > 170
18 BAD windows - excluding 25.3 % of the data
HKPAR2 - Name of HK parameter (! to finish) /!/ >
Total exposure time now: 3063 seconds - excluded 25.35 % of the data
FNAME - Name of output time window file /'xrt_times.lis'/ >
xunb> xrtsort
XSORT Version 2.0-0
The following header files are present:
 mrk33_hdr.sdf
ROOTNAME - Rootname of files to sort /'mrk33'/ >
TYPE - Output data type - Event(E) Binned(B) /'B'/ >
Binned dataset selection
--------------------------
1 - XPIX
2 - YPIX
3 - XDET
4 - YDET
5 - Time
6 - PHA channel
```

```
7 - Corrected PHA channel
8 - Radial
AXES - Enter integer codes of axes required in data array /'7'/ > 7
SHAPE - Shape of source area [D,C,A,E,R] /'C'/ > C
RA - RA of the centre of the source region /'     158.13000488281'/ >
DEC - DEC of the centre of the source region /'     54.400001525879'/ >
RAD - Radius of source box (degrees) /1.066667/ > 0.16
    Data array axes
  *******************
     3) XDET:      0 to    8192 (pixels)
     4) YDET:      0 to    8192 (pixels)
     5) Time:     147.000 to    87964.000 (seconds)
     6) PHA channel:      1 to     256 (chn.)
     7) Corr. PHA chan.      1 to     256 (chn.)
RANGES - Property ranges to change (enter numbers) /!/ > 5
TIMRANGE - Time ranges /'147:87964'/ > xrt_times.lis
ENBIN - Bin width of corrected pulse height axis /1/ >
There will be 256 energy bins, each of 1 raw channels, starting from 1
BACK - Is a background file wanted (Y/N) /FALSE/ >
OUT - Output source filename /'aspec_10'/ > aspec_10
>
```

EXAMPLE 3: Source searching a PSPC image

```
> pss
PSS Version 2.0-1
INP - Dataset to be searched/tested for sources /'broad_srcsub'/ > broad_image1
EXPERT - Expert mode /TRUE/ >
PSF system options :
  ANALYTIC      ASCA          EXOLE         PWFC          RADIAL
  RESPFILE      TABULAR       WFC           XRT_HRI       XRT_PSPC
  CSPEC(psf/model,spec[,nbin])
  POLAR(psf,rbin[,abin])      RECT(psf,xbin[,ybin])
PSF - Choose PSF to use for source model /'XRT_PSPC'/ > polar(xrt_pspc,0.02)
MASK - PSPC psf option (LIST for descriptions) /'VARPROFILE'/ >
Loaded XRT psf cube with 10 energy channels
AUX - Mean photon energy in KeV > 0.9
PSFCON - Assume constant PSF across field /NO/ >
Energy fraction    Off-axis angle
                    0    32    64   arcmin
      50%         0.9   5.0  13.4   pixels
      68%         1.2   6.4  16.4   pixels
      90%         1.6   8.6  25.7   pixels
      95%         1.8   9.3  28.7   pixels
PSFPIX - Radius of PSF box in pixels /'68%'/ >
X position axis range is from 1.064584 to -1.064445 degrees
Y position axis range is from -1.064445 to 1.064583 degrees
SLICE - Section of dataset to search /'0.3:-0.3,-0.3:0.3'/ >
SOPT - Statistic option (CASH,GAUSSIAN) /'CASH'/ >
BGND - Background model /'broad_bgmodel'/ >
RESCALE - Re-scale background estimate /NO/ >
EXTEN - Fit for extension measure /NO/ >
SAMPLE - Oversampling factor for first pass /1/ >
First pass - grid spacing 1 pixels
MAP - Significance map /!/ > broad_sigmap
Significance varies from 0 to 12.07309
SIGMIN - Significance threshold /5/ > 4.5
 Src    X        Y     Signif
   1   0.19    -0.14    6.998
   2  -0.22    -0.01    4.528
   3   0.13     0.14    4.072
   4  -0.20     0.16    8.338
   5   0.00     0.00    4.507
   6  -0.07     0.22    8.857
   7  -0.14     0.23    4.872
   8   0.04    -0.19    5.617
   9   0.12     0.02    8.161
  10   0.06     0.06    3.657
  11  -0.14    -0.09   12.073
  12   0.04     0.16    5.764
  13   0.03     0.20    8.549
  14  -0.09    -0.11    4.844
```

```
  15  -0.09    -0.09    4.147
  16   0.05    -0.12    4.608
  17   0.04    -0.10    4.981
  18   0.22     0.10    5.942
  19   0.22     0.11    5.974
Second pass
ASYMMETRIC - Asymmetric source parameter errors /NO/ >
FERL - Flux error confidence level /'1 sigma'/ >
PERL - Positional error confidence levels /'90%'/ >
 Src      RA         DEC         X        Y     Signif    Flux
   1  10 31 01.5  +54 23 37    -0.22    -0.01    4.581    17.232
   2  10 31 09.0  +54 33 51    -0.20     0.16    8.362    40.788
   3  10 31 35.1  +54 37 30    -0.14     0.23    4.940    23.224
   4  10 31 35.7  +54 18 30    -0.13    -0.09   12.572    59.422
   5  10 31 54.0  +54 17 06    -0.09    -0.11    4.910    15.302
   6  10 32 03.8  +54 37 04    -0.07     0.22    9.039    48.550
   7  10 32 42.8  +54 35 46     0.03     0.20    8.767    39.222
   8  10 32 47.4  +54 17 50     0.04    -0.10    5.029    15.633
   9  10 32 47.6  +54 12 38     0.04    -0.19    5.624    20.476
  10  10 32 48.7  +54 33 57     0.04     0.17    6.040    23.733
  11  10 32 52.0  +54 16 38     0.05    -0.12    4.739    14.189
  12  10 33 21.5  +54 25 12     0.12     0.02    8.486    34.084
  13  10 33 47.6  +54 15 29     0.19    -0.14    7.144    34.381
  14  10 34 04.0  +54 30 52     0.22     0.11    6.077    30.701
  15  10 34 04.1  +54 30 57     0.22     0.12    6.172    31.177
OUT - Source search results file (! for none) /'srclist'/ > broad_srclist
SSUB - Source subtracted dataset /!/ > broad_srcsub
Creating source subtracted image...
```

11 Appendix 1: Dataset Filenames and Contents

The following is a list of files and contents, from dataset of different origins.

c1 = P if PSPC observation without the Boron filter
= FP if PSPC observation with the Boron filter
= H if HRI observation
= nnnnnn six digit ROSAT Observation Request (ROR) number.

Table 2: MPE PSPC files and naming conventions

Filename	Description
EVENTS.TFITS	Events
EVENTRATES.TFITS	Event rates
ATTITUDE.TFITS	Attitude
ORBIT.TFITS	Orbit
MEXMAP.IFITS	Exposure map
IMAGE1.IFITS	Broad band image
IMAGE2.IFITS	Hard band image
IMAGE3.IFITS	Soft band image
IMAGEEC.IFITS	Coded energy image
DIFEVENTS.TFITS	Differential events
QUALITY.TFITS	Quality
$RP\langle nnnnnn\rangle$.PUBLIC_CONTENTS	Public contents
MOIMP.IFITS	Modified instrument map
DRMPSPC.IFITS	Detector response
EFFAREA_PSPC.TFITS	Effective area

Table 3: GSFC PSPC files and naming conventions

Filename2	Description
$R\langle P/F\rangle\langle nnnnnn\rangle$.FITS	Events
$R\langle P/F\rangle\langle nnnnnn\rangle$.EVR	Event rates
$R\langle P/F\rangle\langle nnnnnn\rangle$.ASP	Aspect quality
$R\langle P/F\rangle\langle nnnnnn\rangle$.CAS	Corrected aspect
$R\langle P/F\rangle\langle nnnnnn\rangle$.HKB	Binned housekeeping
$R\langle P/F\rangle\langle nnnnnn\rangle$.MDS	Master data set
$R\langle P/F\rangle\langle nnnnnn\rangle$.PAR	Parameter set
$R\langle P/F\rangle\langle nnnnnn\rangle$.PUBLIC_CONTENTS	Public contents
$R\langle P/F\rangle\langle nnnnnn\rangle$*.REPORT	Processing report
$R\langle P/F\rangle\langle nnnnnn\rangle$.RCR	Radiation calibration
$R\langle P/F\rangle\langle nnnnnn\rangle$.SA	Split aspect
$R\langle P/F\rangle\langle nnnnnn\rangle$.SAS	Smoothed aspect
$R\langle P/F\rangle\langle nnnnnn\rangle$.SO	Split orbit
$R\langle P/F\rangle\langle nnnnnn\rangle$.STA	Housekeeping status
$R\langle P/F\rangle\langle nnnnnn\rangle$_IM1.FITS	Broad band image
$R\langle P/F\rangle\langle nnnnnn\rangle$_IM2.FITS	Hard band image
$R\langle P/F\rangle\langle nnnnnn\rangle$_IM3.FITS	Soft band image
$R\langle P/F\rangle\langle nnnnnn\rangle$_MEX.FITS	Exposure map
$R\langle P/F\rangle\langle nnnnnn\rangle$_SKY.FITS	Sky catalogue table
$R\langle P/F\rangle\langle nnnnnn\rangle$_SMX.ASC	Sky catalogue table
$R\langle P/F\rangle\langle nnnnnn\rangle$.MOI	Modified instrument map
$R\langle P/F\rangle\langle nnnnnn\rangle$.DMP	Detector response
$R\langle P/F\rangle\langle nnnnnn\rangle$.OAR	Effective area
$R\langle P/F\rangle\langle nnnnnn\rangle$*.PLT	Various Postscipt

Table 4: GSFC HRI files and naming conventions

Filename	Description
$RH\langle nnnnnn\rangle$.FITS	Events
$RH\langle nnnnnn\rangle$_IMG.FITS	Image
$RH\langle nnnnnn\rangle$.AH	Aspect histogram
$RH\langle nnnnnn\rangle$.ANP	Processing parameters
$RH\langle nnnnnn\rangle$.AO	Aspect offsets
$RH\langle nnnnnn\rangle$.CPB	Charged particle bgnd map
$RH\langle nnnnnn\rangle$.CPS	Complete photon store
$RH\langle nnnnnn\rangle$.DBM	Detector background map
$RH\langle nnnnnn\rangle$.DMS	Cts/pix**2/s histogram
$RH\langle nnnnnn\rangle$.HTL	Science frame qualitites
$RH\langle nnnnnn\rangle$.LTF	Live–time correction factors
$RH\langle nnnnnn\rangle$.MOB	Merged OBI TSH
$RH\langle nnnnnn\rangle$.OAN	Observation angles
$RH\langle nnnnnn\rangle$.OBI	Bright Earth intervals
$RH\langle nnnnnn\rangle$.OBT	Bright Earth TOE
$RH\langle nnnnnn\rangle$.OTS	TSH by OBI
$RH\langle nnnnnn\rangle$.PAR	Output parameter set
$RH\langle nnnnnn\rangle$.PUBLIC_CONTENTS	Public contents
$RH\langle nnnnnn\rangle$*.REPORT	Processing report
$RH\langle nnnnnn\rangle$.QEG	Quantum efficiency map
$RH\langle nnnnnn\rangle$.S1D	Sampling histogram
$RH\langle nnnnnn\rangle$.SAA	SAA rates
$RH\langle nnnnnn\rangle$.SGI	Standard good intervals
$RH\langle nnnnnn\rangle$.SO	Split orbit info
$RH\langle nnnnnn\rangle$.SPS	Science rates
$RH\langle nnnnnn\rangle$.SSC	Standard screen results
$RH\langle nnnnnn\rangle$.TSH	Temporal status history (TSH)
$RH\langle nnnnnn\rangle$._SKY.ASC	Sky catalogue table
$RH\langle nnnnnn\rangle$._SKY.FITS	Sky catalogue table
$RH\langle nnnnnn\rangle$._SKY.PLT	Postscript
$RH\langle nnnnnn\rangle$._STR.PLT	Postscript

Table 5: MPE & GSFC RDF FITS PSPC files

Filename	Description
$R\langle P/F\rangle\langle nnnnnn\rangle$_bas.fits	Events and good times
$R\langle P/F\rangle\langle nnnnnn\rangle$_anc.fits	Aspect and ancilliary data
$R\langle P/F\rangle\langle nnnnnn\rangle$_im1.fits	Broad band image
$R\langle P/F\rangle\langle nnnnnn\rangle$_im2.fits	Hard band image
$R\langle P/F\rangle\langle nnnnnn\rangle$_im3.fits	Soft band image
$R\langle P/F\rangle\langle nnnnnn\rangle$_bk1.fits	Broad band background
$R\langle P/F\rangle\langle nnnnnn\rangle$_bk2.fits	Hard band background
$R\langle P/F\rangle\langle nnnnnn\rangle$_bk3.fits	Soft band background
$R\langle P/F\rangle\langle nnnnnn\rangle$_mex.fits	Merged exposure map
$R\langle P/F\rangle\langle nnnnnn\rangle$_ime.fits	Energy coded image
$R\langle P/F\rangle\langle nnnnnn\rangle$_src.fits	Source extraction information
$R\langle P/F\rangle\langle nnnnnn\rangle$_his.fits	Processing parameter and log files
$R\langle P/F\rangle\langle nnnnnn\rangle$_prt.fits	Source lists and PostScript plots
$R\langle P/F\rangle\langle nnnnnn\rangle$_ltc.fits	Light curves (if extracted)
$R\langle P/F\rangle\langle nnnnnn\rangle$.public_contents	Public contents

Table 6: MPE & GSFC RDF FITS HRI files

Filename	Description
$RH\langle nnnnnn\rangle$_bas.fits	Events and good times
$RH\langle nnnnnn\rangle$_anc.fits	Aspect and ancilliary data
$RH\langle nnnnnn\rangle$_im1.fits	HRI image
$RH\langle nnnnnn\rangle$_bkg.fits	Background image
$RH\langle nnnnnn\rangle$_src.fits	Source extraction information
$RH\langle nnnnnn\rangle$_his.fits	Processing parameter and log files
$RH\langle nnnnnn\rangle$_prt.fits	Source lists and PostScript plots
$RH\langle nnnnnn\rangle$.public_contents	Public contents

Following the conversion of the first generation FITS files to the RDF data format most Users will find the information presented in Table 5 and Table 6 to be of most interest.

11.1 A Typical ASTERIX File

```
HARD_SPEC3  <UNKNOWN>

   TITLE          <_CHAR*80>       'GB2 1217+348'
   UNITS          <_CHAR*80>       'Counts'
   DATA_ARRAY(128,128,256)  <_REAL>   0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
                                      ... 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
   QUALITY        <QUALITY>        {structure}
      QUALITY(128,128,256)  <_UBYTE>   128,128,128,128,128,128,128,128,
                                       ... 128,128,128,128,128,128,128,128,128
      BADBITS        <_UBYTE>         *

   AXIS(3)        <AXIS>           {array of structures}

   Contents of AXIS(1)
      LABEL          <_CHAR*80>       'X position'
      UNITS          <_CHAR*80>       'degrees'
      NORMALISED     <_LOGICAL>       FALSE
      DATA_ARRAY     <ARRAY>          {structure}
         VARIANT        <_CHAR*6>        'SPACED'
         BASE           <_REAL>          1.058334
         SCALE          <_REAL>          -0.016666
         DIMENSION      <_INTEGER>       128

   MORE           <EXT>            {structure}
      ASTERIX        <EXT>            {structure}
         HEADER         <EXTENSION>      {structure}
            TARGET         <_CHAR*20>       'GB2 1298+348'
            OBSERVER       <_CHAR*20>       'WG700001P'
            OBSERVATORY    <_CHAR*5>        'ROSAT'
            INSTRUMENT     <_CHAR*3>        'XRT'
            AXIS_RA        <_DOUBLE>        185.029586791992
            AXIS_DEC       <_DOUBLE>        34.5200004577637
            FIELD_RA       <_DOUBLE>        185.02958679199
            FIELD_DEC      <_DOUBLE>        34.520000457764
            EQUINOX        <_INTEGER>       2000
            POSITION_ANGLE  <_DOUBLE>       0
            BASE_MJD       <_INTEGER>       49129
            BASE_DATE      <_CHAR*11>       '1993-May-22'
            BASE_UTC       <_DOUBLE>        26568.0000002263
            BASE_TAI       <_DOUBLE>        7812.30769675926
            OBS_LENGTH     <_REAL>          7970
            EXPOSURE_TIME  <_REAL>          4281

         INSTRUMENT     <EXTENSION>      {structure}
            PIXEL_SIZE     <_REAL>          0.5
            FILTER         <_CHAR*20>       'OFF'
            DETECTOR       <_CHAR*20>       'PSPCB'
            SC_BASE        <_DOUBLE>        93780976
            SC_CONV        <_DOUBLE>        0.99990789351471
            RAWDATA        <_CHAR*5>        'MPE'
            SASS_VERSION   <_CHAR*25>       '                         '
            SORT           <EXTN>           {structure}
               SPACE(1)       <SPACE>          {structure}
                  SHAPE          <_CHAR*1>        'R'
```

```
              PHI            <_REAL>         0
              XCENT          <_REAL>         0.000069
              YCENT          <_REAL>         0.000069
              XINNER         <_REAL>         0
              XOUTER         <_REAL>         1.066597
              YINNER         <_REAL>         0
              YOUTER         <_REAL>         1.066597

           XDET(1)        <XDET>          {structure}
              START          <_INTEGER>      0
              STOP           <_INTEGER>      8192

           YDET(1)        <YDET>          {structure}
              START          <_INTEGER>      0
              STOP           <_INTEGER>      8192

           TIME(1)        <TIME>          {structure}
              START          <_REAL>         2877
              STOP           <_REAL>         10847

           PH_CHANNEL(1)  <PH_CHANNEL>    {structure}
              START          <_INTEGER>      1
              STOP           <_INTEGER>      256

           ENERGY(1)      <ENERGY>        {structure}
              START          <_INTEGER>      1
              STOP           <_INTEGER>      256

     PSF            <EXTENSION>     {structure}
        LIBRARY_NAME   <_CHAR*6>       'PSFLIB'
        ROUTINE_NAME   <_CHAR*8>       'XRT_PSPC'

     PROCESSING     <EXTENSION>     {structure}
        BGND_SUBTRACTED  <_LOGICAL>    FALSE
        CORRECTED      <EXTENSION>     {structure}
           DEAD_TIME      <_LOGICAL>      FALSE
           VIGNETTING     <_LOGICAL>      FALSE

  HISTORY        <HISTORY>       {structure}
     CREATED        <_CHAR*18>      ' 9-Jul-96 14:35:25'
     UPDATE_MODE    <_CHAR*10>      'NORMAL'
     EXTEND_SIZE    <_INTEGER>      10
     CURRENT_RECORD  <_INTEGER>     2
     RECORDS(10)    <HIST_REC>      {array of structures}

     Contents of RECORDS(1)
        DATE           <_CHAR*30>      '    9-Jul-1996 14:35:25'
        COMMAND        <_CHAR*30>      'XSORT Version 1.7-1'
        HOST           <_CHAR*30>      'xra1'

End of Trace.
```

12 Appendix 2: ASTERIX XRT Command List

12.1 Preprocessing

fits2hds - Convert US, MPE and RDF FITS files into ASTERIX format.

12.2 Data Analysis

showxrt - Display details of an XRT observation.
xpsscorr - Exposure correct a PSS source file.
xrad - Calculate the PSF of a PSPC source.
xrtcorr - Perform instrument corrections.
xrthk - Produce a file of times when the housekeeping parameters are within a certain range.
xrtresp - Calculate the detector matrix for a source.
xrtsub - Perform background subtraction.
xrtsort - Sort raw data into a binned dataset, e.g. image, spectrum.
xspokes - Produce an ARD file to describe the position of the PSPC support structure on the image.

12.3 ICL Procedures

xpsf - Draw the PSF circle on an image.
xrtbox - Interactively define a source region for data sorting.
xrtbckbox - Define a source and background region for data sorting.
xrtmspec - Produce a spectrum for each source found with `pss`.
xrtmtime - Produce a time series for each source found with `pss`.

12.4 Associated Commands

ardqual - Set pixels GOOD/BAD using an ARD file.
arithmetic - Basic arithmetic on 2 files.
ast2xsp - Convert an ASTERIX spectral file into `xspec` format.
enmap - Creates an energy map.
evbin - Bin up an EVENT dataset.
meandat - Average several datafiles.
mkcolim - Produce a 3-colour image.
project - Reduce file dimensions.
Isys - Image processing GUI.

13 Appendix 3: Photon Characteristics

Table 7: PSPC and HRI Photon characteristics

Property	PSPC		HRI	
	MPE	US	MPE	US
XDET[a]	0–8192	1–8192	0–4096	1–4096
YDET[a]	0–8192	1–8192	0–4096	1–4096
XPIX[b]	$-7680 \rightarrow +7680$	1–15360	$-4095 \rightarrow +4097$	1–8192
YPIX[b]	$-7680 \rightarrow +7680$	1–15360	$-4095 \rightarrow +4097$	1–8192
Time	S/C time	S/C time	S/C time	S/C time
Raw PHA	1–256	1–256	0–15	0–15
Corr. PHA[c]	1–256	0–255	1–1	1–1

[a] Pixel position on the detector.
[b] Pixel position on the sky. i.e. directly related to RA/DEC.
[c] The raw pulse height from the PSPC is corrected for gain effects during the SASS pre-processing. This corrected PHA is related to the energy of the incident photon.

The sky pixels are defined and numbered differently in the US and MPE datafiles. US data increases from bottom to top, so for the PSPC, the bottom left hand corner pixel is 1,1. MPE pixel numbers decrease with increasing Y value, so the bottom left hand pixel is -7680,7680 and the top left hand corner pixel is -7680,-7680. Corrected PH channels have the same meaning in the two datasets, but the US supply channels 0–255 for PSPC data whereas the MPE data ranges from 1–256. The channel 0 PSPC data in the US files may not be used within ASTERIX.

14 Appendix 4: Important Housekeeping Parameters

By setting the values of different housekeeping parameters using the XRTHK program the User is able exclude unwanted times in the original dataset. XRTHK produces a list of on/off MJD's times which are passed in to XRTSORT.

The following list of parameters upon which the user is able to search in XRTHK has been compiled from the ASPECT and EVRATE extension of the ANCILLARY RDF data file

```
EVRATE FITS EXTENSION

PARAMETER           DESCRIPTION
TIME                / Spacecraft time of event
MV_ACO              / MV anticoincidence rate
XTRANSM             / Transmitted X-ray rate
A1_AL               / Events in anode A1 above low level threshold
A2_AL               / Events in veto anode A2 above low level thresho
A1AL_MV             / Events in A1 above low level thresh in antico.
XACC                / Accepted X-ray rate
SA_RATE             / SA-RATE
SAADA_RT            / SAA detector A rate
SAADB_RT            / SAA detector B rate
A1_AH               / Events in anode A1 above high level threshold
A2_AH               / Events in veto anode A2 above high level thresh
|K1_EDGE            / Rate of events in edge strips of front cathode
K2_EDGE             / Rate of events in edge strips of back cathode K
K1_PASS             / Rate of events in K1 passing event selection
K2_PASS             / Rate of events in K2 passing event selection
MV_CNT              / MV anticoincidence counter
XTR_CNT             / Transmitted X-ray events counter
A1AL_CNT            / Counter of events in A1 above low level threshold
A2AL_CNT            / Counter of events in A2 above low level threshold
XACC_CNT            / Accepted X-ray events
PING_CNT            / Ping counter
A1AH_CNT            / Events in A1 above high level
A2AH_CNT            / Events in A2 above high level
K1ED_CNT            / Events in edge strips of K1
K2ED_CNT            / Events in edge strips of K2
K1PA_CNT            / Events in K1 passing event selection logic
K2PA_CNT            / Events in K2 passing event selection logic

ASPECT FITS EXTENSION

PARAMETER           DESCRIPTION
TIME                / Spacecraft time of corrected aspect (sec)
MJD_INT             / Integer portion of UT in MJD
MJD_FRAC            / Fractional portion of UT in MJD
RA_CAS              / Corrected right ascension (offset from RA_NOM)
DEC_CAS             / Corrected declination (offset from DEC_NOM)
ROAN_CAS            / Corrected roll angle (offset from ROLL_NOM)
ASP_QUAL            / Aspect quality
STT_QUAL            / Star tracker flag
RA_SC               / Right ascension of spacecraft pointing
DEC_SC              / Declination of spacecraft pointing
```

```
ROAN_SC            / Roll angle of spacecraft pointing
RA_ERR             / 1-sigma error of RA_SC
DEC_ERR            / 1-sigma error of DEC_SC
ROAN_ERR           / 1-sigma error of ROAN_SC
STATUS             / Aspect status
```

15 Glossary

ARD - Ascii Region Description. A method of describing a spatial region in a text file.
GUI - Graphical User Interface.
HRI - High Resolution Imager.
LEDAS - Leicester Database and Archive Service.
MPE - Max-Planck institute at Garching bei Munchen.
PSF - Point spread function. The scattering of photons from a source due to mirror irregularities and detector response.
PSPC - Position Sensitive Proportional Counter.
RDAC - *ROSAT* Data Archive Centre.
ROD - *ROSAT* Observation Dataset.
US - United States of America.
Vignetting - The decline in detection efficiency with increasing off-axis angle. Primarily due to XRT mirror reflectivity.

15.1 Useful WWW References

Hypertex version of asthelp:
http://www.sr.bham.ac.uk/asterix

ROSAT news items:
http://ledas-www.star.le.ac.uk/rosat-goc.html
http://heasarc.gsfc.nasa.gov/
http://www.sr/bham.ac.uk/asterix

LEDAS user guide:
http://ledas-www.star.le.ac.uk/rosat-goc/doc.html

Calibration report:
ftp://legacy.gsfc.nasa.gov/rosat/doc/hri/hri_report

15.2 Caption List

The following figures can be found in $AST_DOCS as postscript files.

figure 1. "PSPC image" user_005_impspc.ps_tex

figure 2. "HRI image" user_005_imhri.ps_tex

figure 3. "Background extraction technique" user_005_srcblk.ps_tex

figure 4. "HRI detector efficiency" user_005_hriqeff.ps_tex

figure 5. "Vignetting curves at 0,15,30,45 arcminutes of-axis" user_005_angvig.ps_tex

figure 6. "Vignetting at diff. energies" user_005_envig.ps_tex

16 References & Bibliography

16.1 User Guides

"The UK ROSAT Data Archive Centre User Guide", Sembay, S., Watson, M.G., Osborne, J.P.

"The EXSAS users guide", EXSAS development group, ROSAT Scientific Data Center, MPE, 8046 Garching, Giessenstrasse, Germany.

"ROSAT Data Products Guide", Downes, R., White, R., Reichert, G., Dennerl, K., Englehauser, J., Rosso, C., Voges, W.

16.2 Instrumentation

David, L.P., Harnden Jr., F.R., Kearns, K.E., Zombeck, M.V., "The ROSAT High Resolution Imager (HRI)", *U.S. ROSAT Science Data Center /SAO*

Plucinsky, P.P., Snowden, S.L., Briel, U.G., Hasinger, B. & Pfefferman, E., 1993, *Astrophys.J., submitted.*

Snowden, S.L., Plucinsky, P.P, Briel, U., Hasinger, G. & Pfeffermann, E. 1992, *Astrophys.J.,* **393**, *819*

Snowden, S.L., McCammon, D., Burrows, D.N. & Mendenhall, J.A, 1993, *Astrophys.J., submitted.*

Hasinger, G., Turner, J.T., George, I.M., Boese, G., 1992, OGIP calibration memo. CAL/ROS/92-001, published in 'Legacy II'.

Hasinger, G., Turner, J.T., George, I.M., Boese, G., 1992, OGIP calibration memo. CAL/ROS/92-001a.

Hasinger, G., Boese, G., Predehl, P., 1993, OGIP calibration memo. CAL/ROS/93-015.

16.3 ASTERIX documents

APP_001, "PSS manual", Allan, D.J, Ponman, T.J.

PROG_002, "Data structures: specification and conventions: ", Ponman, T.J.

USER_006, "A guide to time series analysis within ASTERIX", Saxton, R.D.

SUN98, "ASTERIX - X-ray Data Processing System", Saxton, R.D.