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A New PROS Task for Calculating HRI Source Intensities or Upper Limits

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Abstract. The **srcinten** task provides PROS users with a tool to compute count rates for point sources in the *ROSAT* High Resolution Imager (HRI). Count rates are corrected for point response function, vignetting, and quantum efficiency effects. Corrected upper limits are cited at locations where the count rate falls below the source detection threshold.

1. Introduction

Approximate count rates for point sources observed with the *ROSAT* HRI can easily be calculated by using the IRAF/PROS **imcnts** task to accumulate X-ray events in a (usually) circular aperture about the source, with background derived from either a model background map or a region adjacent to the source. However, more accurate determinations require corrections for various instrumental effects, such as reduction in effective area for off-axis sources (vignetting), fraction of total source counts in the source aperture (encircled energy), and variations in detector quantum efficiency with event position on the detector. Although level-1 processing properly corrects for such effects, PROS users who wish to apply non-standard data screens, or who wish to study sources not detected in standard processing, are required to compute and apply such corrections by hand. The task is complicated by the fact that the correction factors include contributions from a range of off-axis angles or detector positions, due to the induced $\sim 3'$ satellite wobble present in most observations.

Srcinten is a new PROS task that computes and applies the above correction factors to the net counts in a user-specified aperture. If significance of the net counts is less than a user-specified threshold, an upper limit is calculated. As a pedagogical exercise, the task was designed to minimize additional coding and maximize the use of other existing tools in PROS and IRAF. It will be fully integrated into IRAF and available in the PROS **xray.xspatial** package in the next PROS release.

2. Calculation of Correction Factors

Both the vignetting and encircled energy corrections are primarily functions of source off-axis angle. The existing PROS task QPSPEC is used both to compute net counts in the source aperture and to compile an off-axis angle histogram, whose entries comprise the fraction, f_i, of counts in the aperture corresponding to off-axis angle θ_i.

For each angle θ_i, the vignetting correction $V(\theta_i)$ at 1 keV is evaluated using the function in Figure 1 (David et al. 1993). The average vignetting correction is then

$$< V > = \sum_i f_i V(\theta_i).$$

The encircled energy correction is simply the integral of the point response function (PRF) within the source aperture. Although in general the *ROSAT* HRI PRF exhibits significant azimuthal asymmetries for off-axis sources, the azimuthally-averaged function $P(r, \theta_i)$ may be used to estimate encircled energy (David et al. 1993). For each angle θ_i in the off-axis angle histogram, the encircled energy within aperture radius R is given by

$$E(R, \theta_i) = \int_0^R P(r, \theta_i) 2\pi r dr.$$

$E(R)$ for various off-axis angles θ is shown in Figure 1. The average encircled energy is given by

$$< E(R) > = \sum_i f_i E(R, \theta_i).$$

Relative quantum efficiency variations of approximately $\pm 10\%$ across the detector are present in the *ROSAT* HRI, and their correction requires knowledge of the event positions in detector coordinates (i.e., a coordinate system fixed to the detector). These coordinates are present in the event structure of QPOE files generated with PROS version 2.3, and may be added to earlier QPOE files using the PROS task **upqpoerdf**.

The PROS task **qpcopy** is used to generate an image of the events in the source aperture, blocked at a resolution equal to that of the calibration quantum efficiency map (QE). The average quantum efficiency correction is then

$$< QE > = \sum_{i,j} f_{i,j} QE_{i,j},$$

where $f_{i,j}$ is the fraction of total counts in binned detector pixel (i, j).

3. Structure Chart

Srcinten uses the IRAF CL script language and, as described above, takes advantage of a number of existing IRAF/PROS tools. The structure chart in Figure 2 shows all the tools used in **srcinten**, and a brief overview is given below.

qpspec extracts the total counts from the source and background regions and computes net counts and error. It also produces an off-axis angle histogram file in table format.

qpcopy copies one QPOE file to another through region filtering, to generate a source image in detector coordinates.

imcalc multiplies the source and QE images.

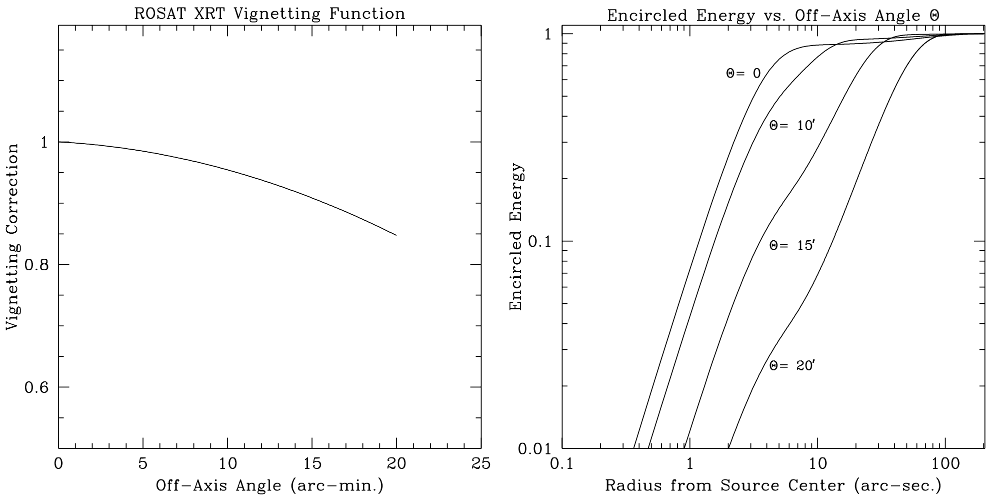

Figure 1. *ROSAT* XRT vignetting function at the energy 1 keV (*left*). *ROSAT* HRI encircled energy at various off-axis angles (*right*).

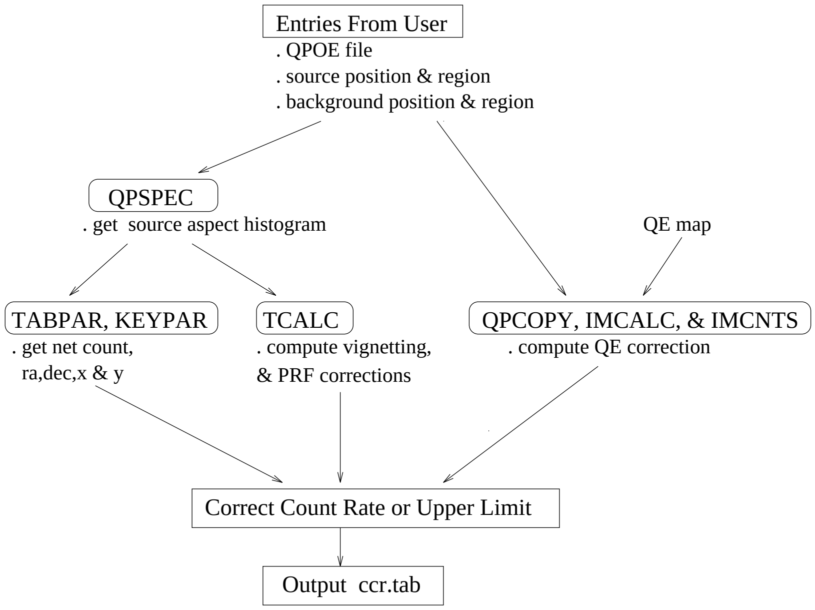

Figure 2. Structure Chart for **srcinten**.

imcnts computes the total counts in the source image.

tabpar, keypar, tinfo get keywords and values from tables, needed in computing correction factors.

tcalc performs arithmetic operations on columns to compute corrections.

4. Using srcinten in PROS

Before using **srcinten**, users are required to load the **xspectral**, **xspatial**, **ximages**, **images**, and TABLES packages. An example **srcinten** run is shown below, and the output table is displayed in Table 1. Both the count rate and upper limit columns are included in the output, but for sources above the user-specified significance threshold, only the count rate column is filled.

```
xs> srcinten
source qpoe file: xdata$rh110267n00.qp
source region descriptor: circle  2427.  2806.  82.
background qpoe file: xdata$rh110267n00.qp
bkgd region descriptor: annulus  2427.  2806.  82.  100.
output root name (_ccr.tab): src

-- Creating aspect histogram table from qpoe --
-- Computing vignetting correction factor --
-- Computing prf correction factor --
-- Computing qe correction factor --
-- SRCINTEN created Output table: src_ccr.tab --
```

ra	**dec**	**x**	**y**	**radius**	**cntrate**	**cntraterr**
deg	**deg**	**pix**	**pix**	**asec**	**c/ks**	**c/ks**
331.8	45.7	2427.	2806.	41.	83.1	10.7

uplrat	**totcnt**	**bkgcnt**	**exptim**	**prf**	**qe**	**vign**
c/ks	**c**	**c**	**sec**	**none**	**none**	**none**
INDEF	188.	43.	2124.4	0.96	0.93	0.92

Table 1. Output table src_ccr.tab

5. Conclusions

Although **srcinten** is a simple tool, it reproduces much of the functionality of its HRI level-1 processing counterpart and demonstrates the utility of assembling existing PROS tasks into CL scripts to address real analysis problems. Possible future enhancements include computing an energy-averaged vignetting function weighted by the source spectrum, allowing apertures of arbitrary shape, and correcting for spatially-varying exposure through an HRI exposure map.

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References

David, L. P., Harden, F. R., Kearns, K. E., & Zombeck, M. V. 1993, The *ROSAT* High Resolution Imager