evigweight

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Abstract

Weight EPIC events with inverse effective area over one exposure

1 Instruments/Modes

Instrument	Mode
EPIC MOS	IMAGING
EPIC PN	IMAGING

2 Use

pipeline processing	no
interactive analysis	yes

3 Description

3.1 Introduction

evigweight applies to inhomogeneous extended sources. The source spectrum (shape and flux) depends on the region considered (ie on the sky coordinates). The instrument (telescope+detector) response is not flat, ie the effective area at a given energy depends on the position in the focal plane, defined by *detx*, *dety* the detector coordinates (`DETX`,`DETY` columns).

evigweight sets the stage for an alternative method to building an exposure map (via **eexpmap**) adapted to the spectral selection or an effective area (via **arfgen**) adapted to the spatial selection, in parallel to images and spectra. The idea is to 'correct' each photon so that the derived event list is equivalent to what one would get for a flat instrument.

Because the weight is computed for each event on the basis of its own detector coordinates, the method is not sensitive to pointing variations of the telescope. Because the event's own energy is used, it makes no assumption about the spatial or spectral repartition of the source.

3.2 Definitions

The spectroscopic model of the source gives $s_{\alpha,\delta}(E)$, the number of photons received per cm^2 and per second at the earth, from sky position α, δ and at energy E (differential per solid angle and energy).

The number of photons, $m_{detx,dety}(I)$, detected (per second) in pixel $detx, dety$ and in PI energy bin I centered at E_I is obtained by multiplying by the effective area and applying the response matrix:

$$m_{detx,dety}(I) \;=\; \int_e R_{detx,dety}(e,I)\; A_{detx,dety}(e)\; s_{\alpha,\delta}(e)\; \mathrm{d}e\; \Delta\Omega \tag{1}$$

$A_{detx,dety}(E)$ is the effective area at position $detx, dety$ for energy E and includes all instrumental effects (telescope, RGA, filter, detector). $R_{detx,dety}(E,I)$ is the redistribution of photons of energy E at position $detx, dety$ into PI bin I. The correspondence between sky position and detector coordinates depends on the telescope's pointing. In theory this correspondence is not direct, but via a convolution with the Point Spread Function. This complication is ignored here (see Sect.3.7).

3.3 Event processing

evigweight computes a weight for each photon j falling at detector coordinates $(detx_j, dety_j)$ and of energy (PI) E_j by the inverse of the ratio of the effective area at that position to the central effective area (at the same energy):

$$w_j \;=\; \frac{A_{0,0}(E_j)}{A_{detx_j,dety_j}(E_j)} \tag{2}$$

This weight is stored by default as column `WEIGHT` (the name can be changed setting `weightcolname`).

3.4 Spectral analysis

One can then define (via **evselect** called with `withzcolumn`=Y `withzerrorcolumn`=N) a 'corrected' spectrum $O'(I)$ within region Reg (usually in sky coordinates) and its associated error $\sigma(O'(I))$:

$$O'(I) \;=\; \sum_j \frac{w_j}{T_{exp}(CCD_j)} \qquad (\alpha_j,\delta_j) \in Reg;\; E_I - \Delta E_I/2 \;<\; E_j \;<\; E_I + \Delta E_I/2 \tag{3}$$

$$\sigma^2(O'(I)) \;=\; \sum_j \frac{w_j^2}{T_{exp}^2(CCD_j)} \tag{4}$$

where $T_{exp}(CCD_j)$ is the exposure time for the CCD/node where the event was detected and ΔE_I the width of bin I. If the region Reg extends over a single CCD, the exposure time may be taken out of the sums. $O'(I)$ is an estimate of the spectrum one would get if the detector was flat.

In terms of the usual 'uncorrected' spectrum:

$$O'(I) \;=\; \langle w_j \rangle(I)\; O(I) \tag{5}$$

$$\sigma^2(O'(I)) \;=\; \langle w_j^2 \rangle(I)\; O(I) \tag{6}$$

where the $\langle\rangle$ denote the average over the $O(I)$ photons in bin I.

The corresponding source spectrum $S(E)$ is also obtained by summing over the region, and the model spectrum $M'(I)$ (to be compared to the data) by multiplying with the central effective area and applying

the response matrix.

$$S(E) = \sum_{\alpha,\delta \in Reg} s_{\alpha,\delta}(E) \quad (7)$$

$$M'(I) = \int_e R_{Reg}(e,I)\, A_{0,0}(e)\, S(e)\, \mathrm{d}e \quad (8)$$

Of course the response matrix should be taken (via **rmfgen**) in the true detector region (not at the center) associated with the sky region *Reg*. The central effective area may be obtained by calling **arfgen** with special settings:

```
arfgen arfset=your_arf spectrumset=your_spectrum withbadpixcorr=N modelee=N  \
       withdetbounds=Y filterdss=N detmaptype=flat detxbins=1 detybins=1  \
       withsourcepos=Y sourcecoords=tel sourcex=0 sourcey=0
```

Model fitting may be performed via XSPEC, entering $O'(I)$ as `RATE`, and $\sigma(O'(I))$ as `STAT_ERR`, with $A_{0,0}(e)$ and $R_{Reg}(e,I)$ in the Ancillary Response File and Redistribution Matrix File, respectively.

Note that the weighting procedure is incompatible with using the Poisson model (C-statistic) in XSPEC (the χ^2 formula must be used). This means that care must be taken to have enough counts per spectral bin.

3.5 Spatial analysis

In the same way, constructing an image $D'(\alpha,\delta)$ of the source within the energy band E_1, E_2 may be done by calling **evselect** (with `withzcolumn`=Y `withzerrorcolumn`=N) :

$$D'(\alpha,\delta) = \sum_{E_1<E_j<E_2} w_j \,/\, T_{exp} \quad (9)$$

$$\sigma(D'(\alpha,\delta)) = \sqrt{\sum_j w_j^2} \,/\, T_{exp} \quad (10)$$

This is directly proportional to the source brightness (no need to divide by the exposure map), except for bad pixels and CCD gaps (see Sect.3.9).

3.6 Pros and cons

Advantages: exact, easy to use (only one ARF), can deal with any complex spatial variation of the source.

Drawbacks: degradation of the statistical quality:

$$\Delta O'(I)/O'(I) = \sqrt{\langle w_j^2\rangle}/\langle w_j\rangle \; \Delta O(I)/O(I) \quad (11)$$

from Eq.5 and 6. This is not a problem if the effective area is not varying much in the region considered ($\sqrt{\langle w_j^2\rangle}/\langle w_j\rangle \sim 1$).

3.7 Assumptions

- The method outlined above is valid, if the vignetting effect is constant within one PSF (this is OK for XMM) and remains the same for energies differing by the order of ΔE (this is OK for XMM except at the very lowest energies).

- The current version ignores the PATTERN value. This results in vignetting being computed for PATTERN=0. This is all right since the pattern distribution is approximately the same for all CCDs.

3.8 Background correction

One important issue for the spectral analysis with X-ray detectors is the treatment of background for extended sources. In order to subtract the background properly, one needs the background spectrum with precisely the same detector characteristics as the extracted source spectrum. The **backcorr** task should not be used on spectra obtained with the weighting procedure (because it corrects for differential vignetting between the source and background areas).

To deal with the particle background (more or less constant outside proton flares), one should assign weights to the reference event list and extract images or spectra using the same spectral or spatial (in detector coordinates) selection as the source. The original spatial selection (on the source) is usually applied to sky coordinates (not detector coordinates). As XMM's pointing is very stable, the conversion from a region in sky coordinates (X,Y) to one in detector coordinates (DETX,DETY) is just a rotation-translation. A scale factor obtained by comparing event rates outside the field of view or at very high energy should generally be applied to the reference images or spectra. The difference should then be particle free. This operation subtracts some astrophysical background as well, but not necessarily the right one for the current field.

In addition to the particle background, the residual astrophysical component (positive or negative) may be subtracted if it can be assumed to be uniform over the field of view (can be checked on the image), and the source does not cover the entire field of view. Selecting an area outside the source for *Reg*, one may use Sect.3.4 to build the 'on-axis' background spectrum, which can be directly subtracted from the source spectrum (accounting for the different region sizes via **backscale**). Integrating that spectrum within a band (and dividing by the region's area) results in a constant which may be subtracted from images.

3.9 Correction for gaps and dead pixels

evigweight does not offer an automatic way to deal with gaps, dead/hot pixels and columns in the detector.

An easy and simple approach is to assume that the source in the extracted region emits homogeneously. In this case one can directly compute the BACKSCAL keyword and add it to the spectral file via **backscale**. For images one may get the corresponding exposure map via **eexpmap**, switching off all the vignetting corrections (mirror, filter, quantum efficiency) in **eexpmap** except the gaps and bad pixels. This is done by calling **eexpmap** with withvignetting=N and withpatterns=N.

4 Parameters

This section documents the parameters recognized by this task (if any).

Parameter	Mand	Type	Default	Constraints
ineventset	yes	dataset	' '	none

name of input events file

newoutput	no	boolean	no	yes/no

Create output events file (no for overwriting input)

outeventset	no	dataset	'events.out'	none

name of output events file. If this parameter is set, then `newoutput`=Y is automatic

weightcolname	no	string	'WEIGHT'	none

name of output (weight) column

witheffectivearea	no	boolean	yes	yes/no

factor the mirror's effective area (and gratings absorption for MOS) into vignetting weight

withfiltertransmission	no	boolean	yes	yes/no

factor the filter's transmission into vignetting weight

withquantumefficiency	no	boolean	yes	yes/no

factor the CCD's quantum efficiency into vignetting weight

5 Errors

This section documents warnings and errors generated by this task (if any). Note that warnings and errors can also be generated in the SAS infrastructure libraries, in which case they would not be documented here. Refer to the index of all errors and warnings available in the HTML version of the SAS documentation.

copyData01 *(error)*
PI is neither Integer16 (as in merged events lists) nor Real32 (as in CCD-specific events lists)

6 Input Files

1. Either an events file (from **emenergy** or **epevents**) with `EVENTS` extension containing `PI`, `DETX`, `DETY`, `RAWX`, `RAWY`
2. Or an events file (from **evlistcomb**) with `EVENTS` extension containing `CCDNR`, `PI`, `DETX`, `DETY`, `RAWX`, `RAWY`

7 Output Files

1. events file with additional items:
   - new column, name taken from `weightcolname` (for **evselect**)
   - keywords detailing which subroutines were activated
   - keywords propagated to the `EXPOSURE` extension (for **evlistcomb**)

8 Algorithm

```
MODULE em_events_module

   Read the parameters
   Open events file
   If newoutput then  clone events file
   Read columns PI, DETX, DETY, RAWX, RAWY, CCDNR (if it exists)
   Create column WEIGHT (or enable modifications if it already exists)

   Set CAL state to central CCD
   call CAL_telCoordToCamCoord2(0,0,xmm2,ymm2,zmm2)
   call CAL_camCoord2ToCamCoord1(xmm2,ymm2,zmm2,xmm1,ymm1,zmm1)
   call CAL_camCoord1ToChipCoord(xmm1,ymm1,zmm1,RAWX0,RAWY0)
   Loop over PI
      eff0 = effarea(PI,0,0,RAWX0,RAWY0)
   end loop

   Set CAL state to current CCD
   call CAL_getMiscellaneousData('FOCAL_LENGTH',focalLength)
   step = 1. / realAttribute(detx_col,'TCDLT')
   conv = step * 180.d0 / pi / focalLength
   Loop over events
      if CCDNR exists and CCDNR changed then  set CAL state to new CCD
      if not (OUT_OF_FOV or OUT_OF_CCD_WINDOW or OUTSIDE_THRESHOLDS) then
         call CAL_camCoord2ToTelCoord(DETX/conv,DETY/conv,0,theta,phi)
         WEIGHT = eff0(PI) / effarea(PI,theta,phi,RAWX,RAWY)
      endif
   end loop

   Close events file

FUNCTION effarea(PI,DETX,DETY,RAWX,RAWY)

   effarea = 1.
   E0 = min(max(PI,100),14000)
   if witheffectivearea then
      effarea = effarea * CAL_getEffectiveArea(E0, theta, phi)
   if withfiltertransmission then
      effarea = effarea * CAL_getFilterTransmission(E0, theta, phi)
   if withquantumefficiency then
      effarea = effarea * CAL_getQuantumEfficiency(E0, RAWX, RAWY)

end module
```

9 Comments

- The principle of **evigweight** ignores the Point Spread Function. It should never be used for analysing point sources.
- Events outside the field of view (flagged as `OUT_OF_FOV`), outside the CCD (flagged as

OUT_OF_CCD_WINDOW), or outside the energy range (flagged as OUTSIDE_THRESHOLDS), get WEIGHT=0. As a result they are automatically ignored when creating images or spectra.

References