esensmap

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Abstract

Calculate EPIC sensitivity map

1 Instruments/Modes

Instrument	Mode
EPIC MOS:	IMAGING
EPIC PN:	IMAGING

2 Use

pipeline processing	yes
interactive analysis	yes

3 Description

esensmap creates a sensitivity map, providing upper limits to detect a point source over given background. In each image pixel, it includes the vignetting corrected source count rate ($\mathrm{cts\,s^{-1}}$) that corresponds to the minimum detection likelihood as specified in the parameter `mlmin`. From version 4.0 on, energy conversion factors (ECFs[1] in units of $10^{11}\,\mathrm{cts\,cm^2\,erg^{-1}}$) are accepted via the parameter `ecf` to produce sensitivity maps in flux units ($\mathrm{erg\,cm^{-2}\,s^{-1}}$). The task parameter `outunit` determines whether to write count-rate maps (`outunit`=rate), flux maps (`outunit`=flux), or both (`outunit`=both).

eboxdetect-like Poisson mode

The task may either be called for individual energy bands or combinations of energy bands and instruments. The upper limits are derived by assuming Poissonian count statistics in each 3×3 pixel detection cell, using the exposure and background values read from the input images. It is assumed that 30 % of the PSF fall into the detection cell. Likelihoods are calculated as a function of raw source and background counts via the incomplete gamma function as described for **eboxdetect**. This simple upper limit

[1]The default ECFs used to convert count rates to fluxes in the XMM-Newton catalogues are given for example at https://xmmssc.aip.de/cms/users-guide/catalogue-construction/catalogue-organisation/#ECFs

calculation is meant as a reference point for a more detailed assessment of the sensitivity of the detection process to be determined through Monte Carlo simulations.

In the case of multiple input energy bands, the upper limits are calculated for the combined images. I.e. they refer to the detection sensitivity which would be achieved by adding up the photons observed in the individual bands (not identical to the sensitivity in a combined source-detection fit). Pixels outside of the detection mask as well as pixels with zero exposure time are assigned a sensitivity value of –1.0. This also holds for pixels where – potentially arising from a failure of the spline fit in the esplinemap backgound task – zero or negative values occur in the input background maps.

emldetect-like DeltaC mode

Version 4.0 introduces a DeltaC approach that is based on **emldetect**-like Cash statistic. It can be activated via the task parameter `statistic`=deltac and employs a likelihood test comparing the detection likelihood of background plus source emission with pure background emission. The log-likelihood ratio can be expressed via the Cash statistic C as $\Delta C = C(\text{background}) - C(\text{background} + \text{source})$. This quantity, which follows a χ^2 distribution approximately, is minimised in the **emldetect** source fit. Free parameters of this fit are the count rate in each input image, the source position, and, optionally, the source extent. The total detection likelihood is derived from the sum of the individual ΔC values (for more details, see for example Rosen et al. 2016, A&A 590, A1; Traulsen et al. 2019, A&A 624, A77).

The new esensmap mode adapts a simplified version of this **emldetect** approach, which was developed in the EU funded ARCHES[2] project. It uses background and exposure map(s) of an observation to determine the limiting count rate at a given total detection likelihood (parameter `mlmin`) in each of the exposed pixels, which are supplied as detection mask(s). If data of several instruments and/or energy bands are provided, the output sensitivity map gives the combined all-EPIC broad-band limits for n degrees of freedom, where n is the number of input images plus 3 (for source position and extent), similar to the combined fit performed by **emldetect**. To compute ΔC, the point-spread function (PSF) in each image pixel is interpolated from a grid of PSFs spanning different off-axis angles across the field of view. The parameter `doff` controls the off-axis steps. It defaults to 12 arcsec. Mid-band energies, at which the PSFs are obtained, are to be provided via the parameter `energies`. Parameter `ecut` controls the half size of the box within the PSF is evaluated, by default 15 arcsec (cf. the **emldetect** parameter `ecut`).

Since the EPIC PSFs are essentially rotationally symmetric, the azimuthal dependence of the PSF shapes (i.e., their orientation angle) is ignored for the sake of computational efficiency. This approximation leads to deviations from the true sensitivity of the order of several percent at the detector edges, where the PSFs are not covered completely (i.e. where the mask fraction is significantly smaller than one). Sensitivity values in these areas come with larger uncertainties anyway, as the source detection process itself.

4 Parameters

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

Parameter	Mand	Type	Default	Constraints
detmasksets	yes	(list of) file name(s)	detmask.fits	

Names of detection masks

[2] Astronomical Resource Cross-matching for High Energy Studies, http://www.arches-fp7.eu

expimagesets	yes	(list of) file name(s)	expimage.fits	

Names of exposure images

bkgimagesets	yes	(list of) file name(s)	bkgimage.fits	

Names of background maps

sensimageset	yes	(list of) file name(s)	sensimage.fits	

Name of sensitivity image(s). One for `outunit`=rate or flux, two for `outunit`=both

outunit	no	string	rate	rate | flux | both

Produce sensitivity maps in rate units (cts s^{-1}) and/or flux units (erg cm^{-2} s^{-1})

ecf	no	list of floats	1.0	0.00001<ecf<1 000.0

Energy conversion factors in units of 10^{11} cts cm^2 erg^{-1} to be used for sensitivity maps in flux units

mlmin	no	float	10.0	[1.0<param<20.0]

Detection likelihood for which the upper limit of the source counts is calculated. Corresponds to the parameters likemin of **eboxdetect** and mlmin of **emldetect**

statistic	no	string	poisson	poisson | deltac

Switch between eboxdetect-like Poissonian statistic (faster) and emldetect-like DeltaC-statistic and PSF reading (slower)

energies	no	list of floats	1000	1<param<30 000

DeltaC statistic: Mid-band energies to read the PSF, one per input image

doff	no	float	12	1<doff<1 200

DeltaC statistic: Step size of the PSF off-axis angles in arcsec

ecut	no	float	15	5<ecut<55

DeltaC statistic: Half side length of the area in which the PSF is evaluated (image pixels)

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.

WrongInst *(error)*
Unknown instrument ID

MissingParameter *(error)*
Missing input file name

FileMismatch *(error)*
Inconsistent number of input images

FileMismatch *(error)*
Inconsistent instruments or bands

FileMismatch *(error)*
Number of detector masks not equal number of instruments

FileMismatch *(error)*
Inconsistent image coordinates

FileMismatch *(error)*
Inconsistent number of output file names

FileMismatch *(warning)*
More output file names provided than needed
corrective action: Only the first file name(s) will be used

MissingAttribute *(warning)*
Keyword not found in the header of an input file
corrective action: Keyword will not be copied to output file

SingleECF *(warning)*
Several ECFs provided for a Poisson map that needs only one
corrective action: First ECF will be used

noConvergence *(warning)*
A fit ended without reaching convergence
corrective action: Fit value is copied to the output map anyway

6 Input Files

PPS products:

1. from task **eexpmap**: EPIC exposure image(s)
2. from task **esplinemap**: background map(s)
3. from task **emask**: Detection mask(s) (one per instrument)

7 Output Files

1. PPS product : EPIC sensitivity image

8 Algorithm

```
   subroutine esensmap
     Loop over image pixels:
       Loop over input images:
         IF detection mask == 1
           Accumulate background in 3 x 3 pixel detection cell
           Determine exposure in detection cell
         END IF
       END Loop

       Evaluate cumulative Poissonian distribution
       Subtract background and divide by exposure
       Correct for fraction of PSF outside of the detection cell

       IF exposure in pixel /= 0: Write result to output sensitivity map
     END Loop
 end subroutine  esensmap
```

9 Comments

10 Future developments

References