eupper

January 27, 2025

Abstract

A routine to calculate the count rate upper limit at a position within an image

1 Instruments/Modes

Instrument	Mode
EPIC	IMAGING

2 Use

pipeline processing	no
interactive analysis	yes

3 Description

This task is designed to analyse a circular region within an image, specified in celestial coordinates, and calculate the upper limit at that position. It has been designed to run as quickly as possible and to that end avoids using any calibration quantities. The input image should be in sky coordinates and WCS keywords in the header are used to find the required position within the image. The task should run on any sky image regardless of the instrument.

A more flexible but slower result for XMM-Newton EPIC images, using the full XMM-Newton calibration, can be obtained from the **eregionanalyse** task.

3.1 Encircled energy function

The point spread function (PSF) is a function of off-axis angle and photon energy for all X-ray cameras. The correct calculation of this value is time consuming. In practise, the XMM-Newton EPIC cameras have been designed to minimise the variation of the PSF, and hence the encircled energy fraction (EEF), across the field of view and across the range of observed photon energies. For this reason, a good approximation to the EEF, for fixed radii, can be tabulated within the code for each camera. The tabulated values,

Extraction radius	Camera			
(arcsec)	MOS-1	MOS2	EPN pointed	EPN slew
15	0.68	0.69	0.71	0.65
30	0.83	0.83	0.88	0.85
45	0.89	0.89	0.93	0.91
60	0.92	0.93	0.95	0.94

used within the program, are shown below but may be overridden on the command line. They should be accurate to about 5%.

3.2 Input

3.2.1 Source image

The source image shoule be input in sky (X/Y) or celestial (RA/DEC) coordinates. The task expects to find astrometry keywords in a certain part of the primary header and will exit with an error if the keywords are not found. Standard images produced by evselect and xmmselect and the pipeline will process ok. Specifically images need to have the coordinate transformation (CTYPE1 keyword) as "RA—TAN" or "EQU–CAR".

A set of source images containing the required RA/DEC position may be used.

3.2.2 Source region

The upper limit will be found from a circular region within the input image, centred on the celestial (RA, DEC, FK4 2000) position defined by the parameters `srcra` and `srcdec` with radius given by `srcradius`.

3.2.3 Background

Background is taken from an annular region within the source image via the `bgdra`, `bgdra`, `bgdrinner` and `bgdrouter` parameters.

3.2.4 Exposure

By default the exposure time used for converting counts to count rate is read from the EXPOSURE keyword in the header of the source image. An exposure map may be introduced by the `exposuremap` parameter in which case the exposure time is taken as the value at the central pixel of the source region within the exposure map. A set of exposure maps containing the required RA/DEC position may be used.

3.3 Output

3.3.1 Statistical upper limit

By default this gives the 2-sigma upper limit on the background subtracted source count rate. If the number of counts is small, i.e. there are less than 80 counts in the source region then the Bayesian upper limit is returned (see Kraft, Burrows and Nousek, 1991, ApJ 374, 344). For larger numbers of counts the returned count rate upper limit is given by:

$$U = (max((S - B * area\_ratio), 0) + 2 * \sqrt{S + B \times area\_ratio^2})/exp\_tim/eef \quad (1)$$

where

S = TOTAL counts in source extraction region

B = Counts in background region

$area\_ratio$ = area_src_region / area_bgd_region

exp_tim is exposure time at centre of source region

eef is the encircled energy fraction in the source region

The significance level of the upper limit may be changed using the `ulsig` parameter.

3.3.2 Other details

If the parameter `details` is true then the following information is also output:

```
Source/back counts: number of photons in the source and backgnd regions

Area ratio: the ratio of the source to background region areas

Exposure: The exposure time at the centre of the source region

EEF: The encircled energy factor used in the calculation

Obsid: The identifier for the observation

Dates: The start and end date of the observation

Bckgnd subtracted source c/r: The source count rate and error after background
subtraction and correction for the EEF.
```

3.4 Output format

The output format shown below is dependent on the value of the `details` keyword. The strings shown may be searched for in a script and every effort will be made to keep them constant between versions of this task.

`details` = true

```
eupper:- Source/back counts: 1554 4599
Area ratio: 0.253
Exposure: 11980.7
EEF:0.95
Obsid:   0791581001
Dates: 2016-04-26T21:16:29 2016-04-27T05:47:26
Bckgnd subtracted source c/r: 0.046725479 +/- 0.020185693 c/s
eupper:-  Statistical upper limit c/r: 0.081501066 c/s
```

`details` = false

```
eupper:-  Statistical upper limit c/r: 0.041501066 c/s
```

3.5 Examples

3.5.1 Find an upper limit using an annular background region

```
eupper imageset=imagepnew.ds srcra=187.912 srcdec=64.2 srcradius=0.00833 bgdra=187.912 bgddec=64.2
bgdrinner=0.01666 bgdrouter=0.03333
```

This will find the upper limit from a 30 arcsecond circle about the sky position, ra=187.912 degs, dec=64.2 degs, using a background annulus about the source circle of inner radius, 1 and outer radius 2 arcminutes. The exposure time will be taken from the primary header of the file imagepnew.ds and the result will be a 2-sigma upper limit.

3.5.2 Use an exposure map

```
eupper imageset=emosimage.ds exposuremap=emosexpos.ds srcra=187.912 srcdec=64.2
```

Takes the exposure value from the pixel in the file emosexpos.ds which contains the position ra=187.912 degs, dec=64.2 degs.

3.5.3 Find a 3-sigma upper limit

```
eupper imageset=emosimage.ds ulsig=0.9973
```

By default the task finds the 2-sigma (95.4% confidence upper limit. Here ulsig is set to 0.9973, the 3-sigma confidence value.

3.5.4 Use own value of the encircled energy factor

```
eupper imageset=emosimage.ds eef=0.9
```

Tells the program that the source region contains 90% of the counts.

3.5.5 Get the combined upper limit from two observations

```
eupper imageset='OBS0791581001\_image.ds,OBS0801621001\_image.ds'
       exposuremap='OBS0791581001\_expmap.ds,OBS0801621001\_expmap.ds'
       srcra=187.912 srcdec=64.2 expmode=add
```

Calculates the upper limit from the combined data in the two observations.

3.5.6 Get the combined upper limit from two energy ranges

```
eupper imageset='P0791581001M1S002IMAGE\_4000.FTZ P0791581001M1S002IMAGE\_5000.FTZ'
       exposuremap='P0791581001M1S002EXPMAP4000.FTZ P0791581001M1S002EXPMAP5000.FTZ'
       srcra=187.912 srcdec=64.2 expmode=average
```

Calculates the upper limit from the combined energy bands (4000 and 5000). The `expmode`=average tells the code to use the average exposure time from the two maps (energy bands).

4 Parameters

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

Parameter	Mand	Type	Default	Constraints

imageset	yes	string	image	

The name of the input image.

exposuremap	no	string	NotSet	

The name of the exposure map

srcra	yes	double		

The right ascencion of the upper limit position in degrees.

srcdec	yes	double		

The declination of the upper limit position in degrees.

srcradius	yes	double		

The radius of the source area (degrees)

bgdra	yes	double		

The right ascencion of the background area in degrees.

bgddec	yes	double		

The declination of the background area in degrees.

bgdrinner	no	double	0.0	

The inner radius of the background area (degrees). Deafulted to 0 in the case of a circular region

bgdrouter	yes	double		

The outer radius of the background area (degrees).

ulsig	no	double	0.954	

The significance for the upper limit calculation. The default is two-sigma (0.954). Set the value to 0.68 for one sigma or 0.997 for three sigma etc.

witheef	no	boolean	no	

Whether the encircled energy factor has been specified as a parameter

eef	no	double	1.0	

If `witheef`=true then the encircled energy factor is set by this parameter.

expmode	no	double	add	

If `expmode`=add then the code uses the summed exposure time from all of the input exposure maps. If `expmode`=average, it uses the mean exposure time from the maps.

details	yes	boolean	no	

Output details of the calculation including number of counts etc.

withoutputfile	yes	boolean	no	

Write the output result to a text file ?

output	no	string	output.txt	

Name of output text file

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.

DataNotSupported *(error)*
The instrument is not recognised.

invalidArraySize *(error)*
The image is not two dimensional.

InvalidWCSType *(error)*
The image axes specified in the CTYPE1 and CTYPE2 keywords are not compatible.

InvalidPosWCSInfo *(warning)*
The REFerence keywords in the image header, e.g. REFXCRPX, REFXCRVL, REFXCDLT are incomplete. Defaults are chosen but there is likely to be a problem later.
corrective action:

6 Input Files

- a sky coordinate image containing WCS keywords allowing a translation between celestial coordinates and image pixel. Coordinate systems RA—TAN and EQU–CAR are currently supported.
- optionally an exposure map containing WCS keywords allowing a translation between celestial coordinates and image pixel..

7 Output Files

8 Algorithm

9 Comments

References