



# emenergy

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## Abstract

Assign energy and quality flag to events for one node of one EPIC-MOS CCD over one exposure.

## 1 Instruments/Modes

Instrument	Mode
EPIC MOS	IMAGING, TIMING

## 2 Use

pipeline processing	yes
interactive analysis	yes

## 3 Description

**emenergy** is the task which prepares the spectral analysis of EPIC-MOS data. It adds a quality flag to all events, prepares the (optical) background map, computes the best PHA energy from all information available, corrects for charge transfer losses and translates it into PI. The CCDBKG subroutine cannot be applied to slew data.

**emenergy** calls (in order) the following subroutines, all of which can be individually switched off:

- EVFLAG flags all events whose pattern could not be fully recognized on-board because of the proximity of:
  - 1- a border of the CCD (`CLOSE_TO_CCD_BORDER`)
  - 2- the left or lower border of the current window (`CLOSE_TO_CCD_WINDOW`). In window mode, the right and upper borders are analysed including the lines/columns next to them.
  - 3- a pixel declared as bad in the on-board library (`CLOSE_TO_ONBOARD_BADPIX`)
  - 4- a line (`CLOSE_TO_BADROW`) or column (`CLOSE_TO_BADCOL`) deactivated through a large offset (voluntarily or not)
  - 5- a dead pixel/line/column (`CLOSE_TO_DEADPIX`)
  - 6- a bright pixel not declared in the on-board library (`CLOSE_TO_BRIGHTPIX`)



Only bad pixels immediately next to the main pixel of the event (not diagonal) justify flagging. If the CCD is read through both nodes (known from the window keywords) then the limit between nodes must be flagged as well (`CLOSE_TO_NODE_BOUNDARY`).

In case 5 (missing data) of dead pixels at distance 2, then `PERIPIX` should be incremented for the `CCDBKG` task. Single events in that case would not be flagged at all. Similarly in case 4 (wrong data) at distance 2, then `PERIPIX` should be incremented by 8 (to deactivate the event for `CCDBKG`).

In `TIMING` mode there are no bad pixels, only bad columns. In Compressed Timing mode, events for which `RAWX` and `PATTERN` were not known are flagged as `UNKNOWN_RAWX_PATTERN`. The flag value allows to identify the reason for flagging (using binary coding as described in `evatt`, explicited in the `XMMEA_nn` keywords). The flags set by `EVFLAG` are informative (contrary to those set in `emevents` which are mostly rejection flags). The flagged events should be used or not depending on the type of study. For spectral applications aiming at the best resolution and most reliable energies it is safer to reject them. The effective area should then reflect that. For detection purposes they can be included to improve the statistics.

Finally, the events outside the field of view are flagged (`OUT_OF_FOV`) to allow easily removing them from sky maps. They are useful to estimate the particle background, though.

- `CCDBKG` prepares the CCD background map used by `MAKE_E` to correct the energies. By default (no outside information required) a map of the CCD background can be formed by averaging  $E_4/(16-\text{PERIPIX})$  for all events encompassing a pixel in their 5x5 area. Only unflagged events should be considered. Large events ( $> 2$  pixels) are not suitable because the charge leakage into  $E_4$  is usually non-negligible. Events at distance 1 or less from the borders include under/over-scans in the outer corona and should not be used. Events with `PERIPIX`  $>$  `maxperipix` are not used either. The default (`maxperipix=0`, no other event in the outer corona) is rather strict to ensure the best quality, and may be relaxed in the case of a piled-up source to `maxperipix=2`. Events with  $E_1 <$  `minenergy` are also not used. This is because a fraction of low energy events are noise events with a wrong value of  $E_4$  (rejected by `REJECT_E3E4` down the line).

The map is built in `RAWX/RAWY` coordinates. To check for possible time variations `CCDBKG` outputs  $E_4$  averaged over the CCD (or window) as a function of time.

If `fillccdbkg=yes` then the off-source areas of the CCD (where less than `fillminnumber` good events contribute) are replaced by the sum of averages over the current line and current column (off-source), minus the full average. This is equivalent to replacing the integer offsets onboard by real (higher precision) ones. This filling procedure is applied separately to the areas of the CCD within the field of view and outside the field of view.

To make the background determination more robust, `REJECT_E3E4` is called a first time (with no background map) before `CCDBKG` to remove the most obvious noise events, and a 3 sigma clipping is applied to  $E_4$  locally (with respect to a first estimate of the background). This procedure does not apply in `REDUCED IMAGING` mode (no  $E_4$  information), nor in `TIMING` mode.

In parallel (`useccfdarkframe` parameter) one can use the background map from the average dark frame in the CCF (of better spatial resolution). All the  $E_i$  are then corrected for the difference between the dark map and the local offset, before building the internal background map (as described above) and building the `PHA` energy (in `MAKE_E`). This allows to correct CCD defects at the pixel scale (whereas  $E_4$  is an average over 16 pixels around the X-ray hit).

Another option is to use a specific background map instead if data in `DIAGNOSTIC` mode have been recorded prior to the scientific exposures (not `PPS`). The decimal digits of the reference background (in `ADU`) are subtracted from `PHA` and `PI` correctly, but not from the  $E_i$  (integers). Consequently if the `PHA` column is regenerated later from the same events list it will lose the decimal precision.

- `REJECT_E3E4` (`IMAGING` mode, not reduced `IMAGING`). Some instrumental effects result in wrong events associated with pathological charge values next to it. This information is



known through the  $E_3$  and  $E_4$  data. The REJECT\_E3 procedure in **emevents** rejected part of that noise. An additional way to reject it is to reject all events whose  $E_3/E_1$  and  $E_4/E_1$  (after CCD background subtraction) lie outside the normal cloud, specified as an ellipse in that plane (the ellipse parameters are in the E3E4ELLIPSE\_n fields of the XMM\_MISCDATA CCF file). This is done with flag BAD\_E3E4, and has little effect on true X-rays (10% loss at 100 eV, < 1% above 150 eV).

This test cannot be applied directly next to rows or columns with a large offset (taken from the OFFSETS extension). In that case  $E_3$  is first corrected for the large offset.  $E_4$  can be corrected as well if the offset is not too large (such that  $E_4$  was truncated at -16384) and PERIPIX=0 (otherwise one cannot know how many pixels of the bad row/column were counted in  $E_4$ ). If  $E_4$  cannot be corrected it is set to 0 for the test (*i.e.* the test bears only on  $E_3/E_1$ ).

- MAKE\_E computes a single energy PHA (in ADU) for each event from a weighted sum of the  $E_i$ , and the residual background  $Bkg(x, y)$  computed in CCDBKG, assumed not to vary with time (*i.e.* the time series output from CCDBKG is not used). This is performed via CAL\_mosPhaBuild, described in **calmosalgo**. If large offsets (from the OFFSETS extension) exist next to the event,  $E_1$  and  $E_2$  are corrected for that before being sent to CAL\_mosPhaBuild.

Events with reconstructed PHA above the upper EMDH threshold are flagged as OUTSIDE\_THRESHOLDS.

MAKE\_E adds TLMIN/TLMAX keywords to the PHA column. By default, randomisation over 1 ADU is performed on  $E_1$  before building PHA. Randomisation may be switched off using **randomizeenergy**.

In Timing and compressed timing mode, given that the ADU channels are not uniform in size, a spectral redistribution can be applied (control by **ontimepha**) to smear out this effect. In TIMING mode MAKE\_E does nothing but the randomisation (the sum was already performed in flight).

- CTLCORR. Charge transfer losses will inevitably appear at some level over time due to radiation damage. They occur as the lines are transferred, first to the frame store area, then to the reading register, and as the pixels are transferred along the reading register. Knowledge will undoubtedly accumulate with time on this phenomenon. In theory, charge losses could be local, could depend on energy and on count rate. This is performed via CAL\_mosCtiCorrect. The result is written into PI, so that PHA always remains uncorrected for CTI.

In Timing mode RAWY does not correspond to the vertical position on the CCD, but to time. The CTI correction should be called assuming the source position, given by the SRC\_RAWY keyword. In Compressed Timing mode, the source position should be taken from the SRC\_RAWX keyword when RAWX is unknown (events flagged as UNKNOWN\_RAWX\_PATTERN).

- ENERGY. The energy of each event in ADU units (from MAKE\_E or CTLCORR) is converted into pulse invariant (PI) units. This is performed via CAL\_mosGainCorrect. Events with reconstructed PI above the upper EMDH threshold (converted into PI) are flagged as OUTSIDE\_THRESHOLDS. ENERGY adds TLMIN/TLMAX keywords to the PI column.

## 4 Parameters

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

Parameter	Mand	Type	Default	Constraints
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<b>ineventset</b>	yes	dataset	' '	none
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name of input events file



<b>newoutput</b>	no	boolean	no	yes/no
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Create output events file (no for overwriting input)

<b>outeventset</b>	no	dataset	'events.out'	none
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name of output events file. If this parameter is set, then **newoutput**=Y is automatic

<b>flagevents</b>	no	boolean	yes	yes/no
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activate EVFLAG

<b>correctcti</b>	no	boolean	yes	yes/no
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activate CTI\_CORR

<b>getccdbkg</b>	no	boolean	yes	yes/no
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activate CCDBKG

<b>minenergy</b>	no	integer	100	$\geq 0$
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Minimum PHA energy (in ADU) for CCDBKG

<b>maxperipix</b>	no	integer	0	$\geq 0, \leq 7$
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Maximum PERIPIX for CCDBKG

<b>fillccdbkg</b>	no	boolean	yes	yes/no
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Fill the empty areas of CCD background map

<b>useccfdarkframe</b>	no	boolean	no	yes/no
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Use dark frame in CCF

<b>fillminnumber</b>	no	integer	10	$\geq 0$
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Number of events below which filling is applied

<b>maskedccdset</b>	no	dataset	' '	none
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name of CCD masked image file from emdiag (for CCD background)

<b>rejectbade3e4</b>	no	boolean	yes	yes/no
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Reject events with bad E3/E4

<b>makepha</b>	no	boolean	yes	yes/no
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activate MAKE\_E

<b>randomizeenergy</b>	no	boolean	yes	yes/no
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randomize PHA over 1 ADU

<b>correctgain</b>	no	boolean	yes	yes/no
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activate ENERGY

<b>writebackgroundset</b>	no	boolean	no	yes/no
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Create output file for optical background image and time series

<b>backgroundset</b>	no	dataset	'bkgccd.map'	none
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name of output file for optical background image and time series

<b>timebin</b>	no	real	100	$> 0$
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time bin for E4 time-series

<b>ontimepha</b>	no	boolean	no	yes/no
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activate spectral redistribution (only timing and compressed timing)

## 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.

**getParamvalues01** (*error*)

blank input event file name

**getParamvalues03** (*error*)

PUT\_XY not run before

**getParamvalues06** (*error*)

MAKE.E not run and correctgain=Y

**readBkg01** (*error*)

unexpected data type in diagnostic background map

**readBkg02** (*error*)

array too small in diagnostic background map

**readBkg03** (*error*)

not 2-D array in diagnostic background map

**readBkg04** (*error*)

diagnostic background map not compatible with event file

**readBkg05** (*error*)

useccfdarkframe=yes and missing offset/variance extension

**evflagImage13** (*warning*)

flagevents=yes and a bad pixel has invalid coordinates in IMAGING mode. It will be ignored

*corrective action:* inform SOC (this is probably an error in the CCF)

**evflagTime13** (*warning*)

flagevents=yes and a bad pixel has invalid coordinates in TIMING mode. It will be ignored

*corrective action:* inform SOC (this is probably an error in the CCF)

**subDark10** (*warning*)

background subtraction from the CCF or an external file modifies the energies. It cannot be run twice on the same data

*corrective action:* restart from the output of **emevents** if you want the full precision of the background subtraction

**readBkg12** (*warning*)

dimensions of the diagnostic background map larger than CCD size. Use anyway

*corrective action:* check this is not a mistake in the input image file

**getparamvalues10** (*warning*)

no **EXPOSURE** extension. The CCD-specific keywords will be forgotten after merging the CCDs

*corrective action:* restart with **emevents** if you want the **EXPOSURE** extension

**getparamvalues11** (*warning*)

**flagevents=yes** and **EVFLAG** already done before. Not repeated

*corrective action:* restart from the output of **emevents** if you really want **EVFLAG** to run anew

**getparamvalues12** (*warning*)

**useccfdarkframe=Y** or **maskedccdset** set in Timing mode. Not done

*corrective action:* these options cannot be used in Timing mode

**getparamvalues13** (*warning*)

Reduced Imaging data and **getccdbkg=Y**. Not done

*corrective action:* this option cannot be used on Reduced Imaging data

**getparamvalues19** (*warning*)

**makepha=Y** and background subtraction from the CCF or an external file already done before. Decimal digits will be lost

*corrective action:* restart from the output of **emevents** if you want the full precision of the background subtraction

**getparamvalues20** (*warning*)

the event file is empty. Nothing done

*corrective action:* check this is normal

**getparamvalues22** (*warning*)

not Imaging data and **rejectbade3e4=Y**. Not done

*corrective action:* this option can be used only in full Imaging mode

**getparamvalues26** (*warning*)

slew data and **getccdbkg=Y**. Not done

*corrective action:* this option cannot be used on slew data

## 6 Input Files

1. event file (from **emevents**) with bad pixels (**BADPIX**), offset/variance (**OFFSETS0**), bad offsets (**OFFSETS**) and **EXPOSURE** extension.
2. optical background map from Diagnostic mode in **emdiag** format (interactive only)

## 7 Output Files

1. event file with modified/additional items:
  - filled in columns **FLAG**, **PHA** and **PI** (for **PRODUCT: EPIC** event list)
  - modified columns **ENERGYE1**, **ENERGYE2**, **ENERGYE3** and **ENERGYE4** if **useccfdarkframe=Y**
  - **XMMEA\_nn** keywords detailing which flags were set
  - **XMMEA\_EA** keyword defining selection for spectra
  - keywords detailing which subroutines were activated



- comment lines with names of input files
  - keywords propagated to the EXPOSURE extension (for **evlistcomb**)
2. optical background map and time-series over the CCD from E<sub>4</sub> (for calibration purposes) as a separate FITS file with:
- the background map (real, 600x600) with the offsets added back in, stored in the primary.
  - an array (integer, 600x600) extension (CCD\_WGHT) storing the weight (number of pixels contributing) of each pixel
  - a binary table extension (CCD\_VAR) for the time-series, with two columns BKGCHARGE (real: average background per time bin, offsets subtracted) and BKGWEIGHT (integer: number of pixels contributing to each time bin).
  - an OFFSETS0 extension propagated from the events file, with the same structure as the offsets file in the ODF ([1]).

## 8 Algorithm

```
subroutine emenergy

Read the file names among parameters

Opening of input file event
Copy of input file event on output file event if need be

parameters read : choice of sub_tasks to execute
Loop over input task parameters
    Read the task parameter / 1 to perform the procedure,
                        0 not to perform it /
End loop

Get the values of files columns in memory

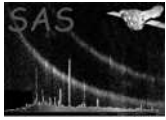
call EVFLAG

call REJECT_E3E4 with no background
call CCDBKG
call CLIPE4
call CCDBKG
discard flags applied by intermediate calls to REJECT_E3E4 and CLIPE4

call REJECT_E3E4
call MAKE_E
call CTI_CORR
call ENERGY

Close files

SUBROUTINE EVFLAG
if evflag requested then
    Loop over events
        flag events using binary coding for different reasons
    end loop
```



```
endif

SUBROUTINE CCDBKG
  if useccfdarkframe then read dark frame map
  else if maskedccdset is set then read DIAGNOSTIC map
  Subtract the offsets
  Correct the Ei columns by the contents of the reference map
    integrated over the area associated to each Ei
  if ccdbkg requested then
    Loop over events
      except for flagged events, events with peripix > 0, pattern > 4,
        E1 < minenergy
      calculation of sigmae4 = summation of energy E4
      calculation of sigmaper = summation of (16-peripix)
    end loop
    divide sigmae4 by sigmaper to obtain BKG value
    if fillccdbkg then
      Loop over positions where less than fillminnumber events contribute
        Average E4 over rows rowav and columns colav
        Replace BKG by rowav + colav - full average
      end loop
    endif
    if bkgfile NE ' ' then
      save of the arrays sigmae4 and sigmaper in a new fits file
      keywords are recopied
    endif
  endif

SUBROUTINE CLIPE4
  Get variance on E4 - BKG(x,y) after applying same selection as in CCDBKG
  Flag events where E4 is more than 3 sigma away from BKG(x,y)

SUBROUTINE REJECT_E3E4
  if reject_e3e4 requested then
    Read e3cen,e4cen,e3rad,e4rad,e3ang from CAL
    Loop over events rows
      loce3 = E3
      loce4 = E4
      if bad offsets nearby then
        loce3 = loce3 + projection of additional offsets onto pixels in E3
        offe4 = sum of additional offsets in outer corona
        if peripix==0 and offe4 < 16000 loce4 = loce4 + offe4
      endif
      loce3 = (loce3 - BKG * (8- number of pixels in E2)) / (E1-BKG) - e3cen
      loce4 = (loce4 - BKG * (16-PERIPPIX)) / (E1-BKG) - e4cen
      dist2 = (loce3*cos(e3ang)+loce4*sin(e3ang))/e3rad**2 +
        (loce4*cos(e3ang)-loce3*sin(e3ang))/e4rad**2
      Flag events with dist2 > 1
    end loop
  endif

SUBROUTINE MAKE_E
  if make_e requested
    call CAL_integerToReal(ener1,e1rand)
    edum = E2
    if bad offsets nearby then
```





```
        e1rand = e1rand + additional offsets on central pixel
        edum = edum + projection of additional offsets onto pixels in E2
    endif
    call CAL_mosPhaBuild(e1rand,edum,pattern,pha,BKG,E3,E4,peripix,flag)
endif
```

```
SUBROUTINE CTI_CORR
    if cti_corr requested call CAL_mosCTIcorrection
```

```
SUBROUTINE ENERGY
    if energy requested call CAL_mosGainCorrect

    end subroutine emenergy
```

## 9 Comments

- The flag map built by EVFLAG could be of interest to **eexpmap** and **arfgem**. To that end it would need to be supplemented with small 5x5 maps (one per pattern) describing the effective extension of a bad pixel. Computing the area lost to bright pixels declared on-board is another matter. It depends on energy, through the bright pixel level.
- If the telescope's attitude were to vary significantly (more than the PSF) with time, then it should be considered using X,Y (attitude corrected) as coordinates for CCDBKG, since the optical background from stars would follow the attitude variations. Note that this would need accumulating the map over a larger area than the current window to accommodate pointing excursions. The large scale optical background (*e.g.* stray light from the earth) does not come through the telescope's optics and therefore has no reason to follow the attitude variations. On the other hand it would be expected to vary along the orbit. The way to deal with that would be to model the large scales (*e.g.* by a quadratic shape) separately in several time bins and then model the parameters' variations with time (quadratic).
- The subroutines CTI\_CORR and ENERGY only call the CAL routines CAL\_mosCTIcorrection and CAL\_gainCorrection.
- The scheme does not allow for the possibility of measuring the gain in one observation (with the calibration source) and passing this on to **emenergy** (to supplement or replace the CAL).
- The baseline is to perform the ENERGY subroutine at the end. It could also be considered performing ENERGY (converting all  $E_i$  into PI) before CTI\_CORR. This would be the best option if the ADU to PI conversion were significantly non linear. On the other hand it is somewhat more difficult to calibrate and may induce some additional error.

## 10 Future developments

- It should be considered scanning the  $E_4$  time-series to warn the user if significant variations are detected.



## References

- [1] ESA. XMM Interface Control Document: Observation and Slew Data Files (XSCS to SSC) (SciSIM to SOCSIM). Technical Report XMM-SOC-ICD-0004-SSD Issue 2.5, ESA/SSD, June 2000. Found at the URL: [ftp://astro.estec.esa.nl/pub/XMM/documents/odf\\_icd.ps.gz](ftp://astro.estec.esa.nl/pub/XMM/documents/odf_icd.ps.gz).