spi_obs_back

User Manual

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Note to the user

This software has been written to analyse data of the SPI telescope onboard INTEGRAL. Particular care has been taken in making the software user friendly and well documented. If you appreciated this effort, and if this software and User Manual were useful for your scientific work, the author would appreciate a corresponding acknowledgment in your published work.

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1 Introduction

The executable `spi_obs_back` is part of the SPI scientific analysis preparation software component (SAP). It generates background models for a given observation group using a variety of different methods. Up to five different components may be included in a background model which will be grouped using a `SPI.-BMOD-DSP-IDX` index structure. The model components will be stored in `SPI.-BMOD-DSP` data structures.

A background model component is defined by its type and normalisation method. The type describes the time variability of the instrumental background. Section 5 describes all types that have been implemented in the current version of `spi_obs_back`. The normalisation method describes how the absolute number of predicted background counts is obtained. In particular, a background model may be normalised to an OFF observation that is scaled by an absolute activity tracer (such as the Veto saturated count rate). Section 6 describes all normalisation methods that have been implemented in `spi_obs_back`.

Of course, not all background model types and normalisation methods provide a satisfactory description of the instrumental background, yet the multitude of options allows for deep studies and eventually for the selection of an optimum method. The following combinations are recommened:

- `Continuum point source analysis` : TBD
- `Continuum diffuse source analysis` : TBD
- `511 keV diffuse gamma-ray line analysis` :

```
nmodel, i,q,                   2,1,5,"Number of background model components"
model01,s,q,               "GEDSAT",,,"Component 1 model type"
mpar01, s,q,                    " ",,,"Component 1 model parameters"
norm01, s,q,                 "CONT",,,"Component 1 normalisation type"
npar01, s,q,"490-495,523-545 keV",,,"Component 1 normalisation parameters"
scale01,r,q,                    1.0,,,"Component 1 scaling factor"
model02,s,q,               "GEDSAT",,,"Component 2 model type"
mpar02, s,q,                     "",,,"Component 2 model parameters"
norm02, s,q,              "OFFLINE",,,"Component 2 normalisation type"
npar02, s,q,"490-495,523-545 keV",,,"Component 2 normalisation parameters"
scale02,r,q,                    1.0,,,"Component 2 scaling factor"
```

- ^{26}`Al (1809 keV) diffuse gamma-ray line analysis` :

```
nmodel, i,q,                       2,1,5,"Number of background model components"
model01,s,q,                   "GEDSAT",,,"Component 1 model type"
mpar01, s,q,                        " ",,,"Component 1 model parameters"
norm01, s,q,                     "CONT",,,"Component 1 normalisation type"
npar01, s,q,"1786-1802,1815-1828 keV",,,"Component 1 normalisation parameters"
scale01,r,q,                        1.0,,,"Component 1 scaling factor"
model02,s,q,                   "GEDSAT",,,"Component 2 model type"
mpar02, s,q,                         "",,,"Component 2 model parameters"
norm02, s,q,                  "OFFLINE",,,"Component 2 normalisation type"
npar02, s,q,"1786-1802,1815-1828 keV",,,"Component 2 normalisation parameters"
scale02,r,q,                        1.0,,,"Component 2 scaling factor"
```

- ^{44}`Ti (1157 keV) point source gamma-ray line analysis` : TBD

`spi_obs_back` is written in the ANSI C++ language and has been developped under ISDC support platform 6.3. It requires `spi_toolslib` version 4.2.0 or higher.

2 Getting started

Before installing `spi_obs_back`, make sure that the ISDC support platform 6.3 or higher is installed on your system, and that you have installed the library `spi_toolslib` version 4.2.0 or higher.

After downloading the `spi_obs_back.tar.gz` file, step into a directory that should hold the distribution, move the `spi_obs_back.tar.gz` file into this directory and type after the UNIX prompt `$` (don't type this prompt):

```
$ gunzip spi_obs_back.tar.gz
$ tar xvf spi_obs_back.tar
```

The first command uncompresses the distribution file, the second unpacks the files.

Before configuration, the distribution needs to be reset to a clean state. To do this, type

```
$ make distclean
```

Then, configure the distribution. It is assumed here that you have previously installed the ISDC support platform, thus you should type

```
$ ~/bin/ac_stuff/configure
```

Finally, build the distribution by typing

```
$ make global_install
```

To perform a unit test, type

```
$ make test
```

Make sure that the test data `spi_test_data-1.0.tar.gz` are available at your site (they should reside in a directory whose name is defined by the `ISDC_TEST_DATA_DIR` environment variable).

3 Parameter file

```
#######################################################################
#                                                                     #
#               Centre d'Etude Spatiale des Rayonnements              #
#                     (in collaboration with ISDC)                    #
#                                                                     #
#                       SPI background modelling                      #
#                                                                     #
# ------------------------------------------------------------------- #
#                                                                     #
#  File:      spi_obs_back.par                                        #
#  Version:   2.9.2                                                   #
#  Component: SAP                                                     #
#                                                                     #
#  Author:    Juergen Knoedlseder                                     #
#             knodlseder@cesr.fr                                      #
#             CESR                                                    #
#                                                                     #
#  Purpose:   Parameter file for the SPI background modelling task    #
#                                                                     #
#######################################################################
#
# The input DOLs/filenames
#========================
ingrpDOL, s,q,    "og_spi.fits",,,"Input Observation Group DOL or filename"
inebdsDOL,s,q,               "",,,"Energy boundary DOL or filename"
ingtiDOL, s,q,               "",,,"Good Time Interval DOL or filename"
indspDOL, s,q,               "",,,"Event Spectrum DOL or filename"
indtiDOL, s,q,               "",,,"Deadtime DOL or filename"
offgrpDOL,s,q,"og_spi_off.fits",,,"Off-data Observation Group DOL or filename"
#
# The output DOLs/filenames
#=========================
outgrpDOL,   s,q,          "og_spi.fits",,,"Output Observation Group DOL or filename"
outidxDOL,   s,q,"back_model_index.fits",,,"Background model index DOL or filename"
outbgmDOL,   s,q,      "back_model.fits",,,"Background model DOL or filename"
detachSwgIdx,b,q,                  "yes",,,"Detach SwG index ?"
#
# Background model parameters
#===========================
nmodel, i,q,                     2,1,20,"Number of background model components"
#
model01,s,q,                "GEDSAT",,,"Component 1 model type"
mpar01, s,q,                      "",,,"Component 1 model parameters"
norm01, s,q,                 "CONT2",,,"Component 1 normalisation type"
npar01, s,q,"1163-1169,1177-1183 keV",,,"Component 1 normalisation parameters"
scale01,r,q,                    1.0,,,"Component 1 scaling factor"
#
model02,s,q,                "GEDSAT",,,"Component 2 model type"
mpar02, s,q,                      "",,,"Component 2 model parameters"
norm02, s,q,              "OFFLINE2",,,"Component 2 normalisation type"
npar02, s,q,"1163-1169,1177-1183 keV",,,"Component 2 normalisation parameters"
```

```
scale02,r,q,                      1.0,,,"Component 2 scaling factor"
#
model03,s,q,                       "",,,"Component 3 model type"
mpar03, s,q,                       "",,,"Component 3 model parameters"
norm03, s,q,                       "",,,"Component 3 normalisation type"
npar03, s,q,                       "",,,"Component 3 normalisation parameters"
scale03,r,q,                      0.0,,,"Component 3 scaling factor"
#
model04,s,q,                       "",,,"Component 4 model type"
mpar04, s,q,                       "",,,"Component 4 model parameters"
norm04, s,q,                       "",,,"Component 4 normalisation type"
npar04, s,q,                       "",,,"Component 4 normalisation parameters"
scale04,r,q,                      0.0,,,"Component 4 scaling factor"
#
model05,s,q,                       "",,,"Component 5 model type"
mpar05, s,q,                       "",,,"Component 5 model parameters"
norm05, s,q,                       "",,,"Component 5 normalisation type"
npar05, s,q,                       "",,,"Component 5 normalisation parameters"
scale05,r,q,                      0.0,,,"Component 5 scaling factor"
#
model06,s,q,                       "",,,"Component 6 model type"
mpar06, s,q,                       "",,,"Component 6 model parameters"
norm06, s,q,                       "",,,"Component 6 normalisation type"
npar06, s,q,                       "",,,"Component 6 normalisation parameters"
scale06,r,q,                      0.0,,,"Component 6 scaling factor"
#
model07,s,q,                       "",,,"Component 7 model type"
mpar07, s,q,                       "",,,"Component 7 model parameters"
norm07, s,q,                       "",,,"Component 7 normalisation type"
npar07, s,q,                       "",,,"Component 7 normalisation parameters"
scale07,r,q,                      0.0,,,"Component 7 scaling factor"
#
model08,s,q,                       "",,,"Component 8 model type"
mpar08, s,q,                       "",,,"Component 8 model parameters"
norm08, s,q,                       "",,,"Component 8 normalisation type"
npar08, s,q,                       "",,,"Component 8 normalisation parameters"
scale08,r,q,                      0.0,,,"Component 8 scaling factor"
#
model09,s,q,                       "",,,"Component 9 model type"
mpar09, s,q,                       "",,,"Component 9 model parameters"
norm09, s,q,                       "",,,"Component 9 normalisation type"
npar09, s,q,                       "",,,"Component 9 normalisation parameters"
scale09,r,q,                      0.0,,,"Component 9 scaling factor"
#
model10,s,q,                       "",,,"Component 10 model type"
mpar10, s,q,                       "",,,"Component 10 model parameters"
norm10, s,q,                       "",,,"Component 10 normalisation type"
npar10, s,q,                       "",,,"Component 10 normalisation parameters"
scale10,r,q,                      0.0,,,"Component 10 scaling factor"
#
model11,s,q,                       "",,,"Component 11 model type"
mpar11, s,q,                       "",,,"Component 11 model parameters"
norm11, s,q,                       "",,,"Component 11 normalisation type"
```

```
npar11, s,q,                       "",,,"Component 11 normalisation parameters"
scale11,r,q,                     0.0,,,"Component 11 scaling factor"
#
model12,s,q,                       "",,,"Component 12 model type"
mpar12, s,q,                       "",,,"Component 12 model parameters"
norm12, s,q,                       "",,,"Component 12 normalisation type"
npar12, s,q,                       "",,,"Component 12 normalisation parameters"
scale12,r,q,                     0.0,,,"Component 12 scaling factor"
#
model13,s,q,                       "",,,"Component 13 model type"
mpar13, s,q,                       "",,,"Component 13 model parameters"
norm13, s,q,                       "",,,"Component 13 normalisation type"
npar13, s,q,                       "",,,"Component 13 normalisation parameters"
scale13,r,q,                     0.0,,,"Component 13 scaling factor"
#
model14,s,q,                       "",,,"Component 14 model type"
mpar14, s,q,                       "",,,"Component 14 model parameters"
norm14, s,q,                       "",,,"Component 14 normalisation type"
npar14, s,q,                       "",,,"Component 14 normalisation parameters"
scale14,r,q,                     0.0,,,"Component 14 scaling factor"
#
model15,s,q,                       "",,,"Component 15 model type"
mpar15, s,q,                       "",,,"Component 15 model parameters"
norm15, s,q,                       "",,,"Component 15 normalisation type"
npar15, s,q,                       "",,,"Component 15 normalisation parameters"
scale15,r,q,                     0.0,,,"Component 15 scaling factor"
#
model16,s,q,                       "",,,"Component 16 model type"
mpar16, s,q,                       "",,,"Component 16 model parameters"
norm16, s,q,                       "",,,"Component 16 normalisation type"
npar16, s,q,                       "",,,"Component 16 normalisation parameters"
scale16,r,q,                     0.0,,,"Component 16 scaling factor"
#
model17,s,q,                       "",,,"Component 17 model type"
mpar17, s,q,                       "",,,"Component 17 model parameters"
norm17, s,q,                       "",,,"Component 17 normalisation type"
npar17, s,q,                       "",,,"Component 17 normalisation parameters"
scale17,r,q,                     0.0,,,"Component 17 scaling factor"
#
model18,s,q,                       "",,,"Component 18 model type"
mpar18, s,q,                       "",,,"Component 18 model parameters"
norm18, s,q,                       "",,,"Component 18 normalisation type"
npar18, s,q,                       "",,,"Component 18 normalisation parameters"
scale18,r,q,                     0.0,,,"Component 18 scaling factor"
#
model19,s,q,                       "",,,"Component 19 model type"
mpar19, s,q,                       "",,,"Component 19 model parameters"
norm19, s,q,                       "",,,"Component 19 normalisation type"
npar19, s,q,                       "",,,"Component 19 normalisation parameters"
scale19,r,q,                     0.0,,,"Component 19 scaling factor"
#
model20,s,q,                       "",,,"Component 20 model type"
mpar20, s,q,                       "",,,"Component 20 model parameters"
```

```
norm20, s,q,                          "",,,"Component 20 normalisation type"
npar20, s,q,                          "",,,"Component 20 normalisation parameters"
scale20,r,q,                         0.0,,,"Component 20 scaling factor"
#
# Other parameters
#=================
bgmFilter,b,h,yes,,,"Zero invalid pointings ?"
#
# Standard parameters
#====================
clobber,b,h,yes,,,"Overwrite existing output data ?"
verbose,i,h,3,0,4,"Information logging level"
```

Instead of specifying complete DOLs (Data Object Locations), which are composed of a filename plus the data structure extension (HDU), `spi_obs_back` accepts also simple filenames and adds the appropriate data structure extensions. This means that **specified data structure extensions are ignored**.

The parameters have the following meaning:

- `ingrpDOL` (optional) specifies the DOL or filename of the input Observation Group (HDU `[GROUPING]`) for which a background model should be derived. The input group has to be of level `BIN_I`.

  If an output Observation Group has been specified (parameter `outgrpDOL`), the specification of this parameter is optional. If the parameter is left blank, the output Observation Group will then be used as input Observation Group. Otherwise, the input Observation Group will be copied into the output Observation Group.

- `inebdsDOL` (optional) specifies the DOL or filename of an energy boundary definition (HDU `[SPI.-EBDS-SET]`). This data structure specifies the energy boundaries of the binned data.

  If a `[SPI.-EBDS-SET]` element exists already in the input Observation Group, this element will be replaced by the specified DOL in the output Observation Group. Otherwise, the specified DOL will be attached to the output Observation Group. If left blank, it is assumed that a `[SPI.-EBDS-SET]` element exists already in the input Observation Group. If no such element is found, however, the task execution is aborted with an error message.

- `ingtiDOL` (optional) specifies the DOL or filename of a Good Time Interval definition (HDU `[SPI.-OBS.-GTI]`). This data structure specifies the time intervals that have been used for data taking.

  If a `[SPI.-OBS.-GTI]` element exists already in the input Observation Group, this element will be replaced by the specified DOL in the output Observation Group. Otherwise, the specified DOL will be attached to the output Observation Group. If left blank, it is assumed that a `[SPI.-OBS.-GTI]` element exists already in the input Observation Group. If no such element is found, however, the task execution is aborted with an error message.

- `indspDOL` (optional) specifies the DOL or filename of an Event Spectra (HDU `[SPI.-OBS.-DSP]`). This data structure contains the binned event data. It is needed for the normalisation of the background model.

  If a `[SPI.-OBS.-DSP]` element exists already in the input Observation Group, this element will be replaced by the specified DOL in the output Observation Group. Otherwise, the specified DOL will be attached to the output Observation Group. If left blank, it is assumed that a `[SPI.-OBS.-DSP]` element exists already in the input Observation Group. If no such element is found, however, the task execution is aborted with an error message.

- `indtiDOL` (optional) specifies the DOL or filename of a Deadtime data structure (HDU `[SPI.-OBS.-DTI]`). This data structure contains the livetime and the deadtime ratio for the binned data.

If a [SPI.-OBS.-DTI] element exists already in the input Observation Group, this element will be replaced by the specified DOL in the output Observation Group. Otherwise, the specified DOL will be attached to the output Observation Group. If left blank, it is assumed that a [SPI.-OBS.-DTI] element exists already in the input Observation Group. If no such element is found, however, the task execution is aborted with an error message.

- `offgrpDOL` (optional) specifies the DOL or filename of an Observation Group that defines an OFF observation (HDU [GROUPING]). This Observation Group is only needed if one of the background model components has the normalisation methods `OFFLINE` or `OFFCONT`. Otherwise this parameter may be left blank.

  Note that the pseudo-detector definition of the OFF Observation Group has to be identical to the pseudo-detector definition of the ON Observation Group. In contrast, the energy bin definition not to be identical (yet it is recommended to use at least identical energy bin sizes).

- `outgrpDOL` (optional) specifies the DOL or filename of the output Observation Group (HDU [GROUPING]). The output Observation Group will be a copy of the input Observation Group plus the resulting Background Model Index data structure [SPI.-BMOD-DSP-IDX] attached.

  If an input Observation Group has been specified (parameter `ingrpDOL`), the specification of this parameter is optional. If the parameter is left blank, the input Observation Group will then be used as output Observation Group.

- `outidxDOL` specifies the DOL or filename of the Background Model Index (HDU [SPI.-BMOD-DSP-IDX]). After execution of the task, this index will contain pointers to the various components of the background model.

  This index will be attached to the output Observation Group. Any index of the same type that may already exist in the output Observation Group will be detached before. If the specified DOL is identical to an already existing DOL, this DOL will be deleted if the `clobber` parameter is `yes` (otherwise the task will abort with an error).

- `outbgmDOL` specifies the filename of the Background Model data structure (HDU [SPI.-BMOD-DSP]). **Note that this filename is relative to the Background Model Index (parameter `outidxDOL`), and that no HDU extension should be provided for this parameter.** After execution of the task, this file will contain all background model components.

- `detachSwgIdx` specifies if an science window group index that may have existed in the input observation group should be detached in the output observation group. Normally, in the analysis steps after background modelling, the science window group index is not required anymore. Since the presence of a science window group index may considerable slow down the file access, it is preferably to detach the index at this step of the analysis. Hence specify `yes` as default. Only if for some reason the science window group index is still needed (which allows access to housekeeping information), specify `no`.

- `nmodel` specifies the number of background model components that should be derived. This number has to be comprised between 1 and 20.

- `model`***nn*** specifies the type of the background model component *nn*. The following types are available (see section 5 for a more detailed description): `CONST`, `ONTIME`, `DEADTIME`, `DEADLIVE`, `ADJACENT`, `ADJACENT2`, `VETOGATE`, `VETONONSAT`, `VETOSAT`, `GEDRATE`, `GEDSAT`, and `TEMPLATE`.

- `mpar`***nn*** specifies parameters for the background model component *nn*. The model `ADJACENT` has parameters that specify the energy bins that should be used as adjacent energy bins. One may either specify directly the bin indices (starting from 1 as given in the `SPI.-EBDS-SET` data structure) or energies in units of keV (in the latter case the parameter string has to be terminated by the acronym `keV`). A comma separated list has to be specified, where either individual bins or bin ranges should be specified. Examples are: `1,3-5,9,10-20` or `1800.0-1805.0,1813-1818 keV`. Note that at least one energy bin or bin range is required. The model `ADJACENT2` is similar to `ADJACENT`, yet it requires exactly two energy bands, where the first one should be on the left side and the second one on the right side of the line. The model `TEMPLATE` requires a DOL or filename for a template file (HDU `[SPI.-BVAR-MOD]`).

- `norm`*nn* specifies the background model normalisation method for component *nn*. The following methods are available (see section 6 for a more detailed description): `NO`, `GLOBAL`, `DETE`, `LINE`, `CONT`, `CONT2`, `OFFLINE`, `OFFLINE2`, and `OFFCONT`.

- `mpar`*nn* specifies parameters for the background model normalisation method for component *nn*. The following normalisation methods need parameters:

  `LINE`: requires at least 2 energy intervals. The first interval specifies an interval that encloses a gamma-ray line that should be used for normalisation. The second and all subsequent energy intervals specify adjacent energy intervals that define the level of the underlying continuum background. In a standard case, two adjacent energy intervals will be specified (one to the left and one to the right side of the line), hence a total of three intervals will be given.

  `CONT`: requires at least 1 energy interval. The background level in all specified intervals will be averaged and used for normalisation of the background model.

  `CONT2`: requires exactly two distinct energy intervals. The number of counts in both intervals will be averaged and used to adjust a linear function that models the energy dependence of the background normalisation.

  `OFFLINE`: does not require energy intervals, yet normally for gamma-ray lines, at least one interval should be specified. The background continuum level beneath the gamma-ray line in the OFF data will be determined by averaging the count rates over the specified intervals. Typically, two energy intervals adjacent to the gamma-ray line of interest should be specified. In contrast to `LINE` no line energy interval is needed since the background model normalisation will be performed automatically for all data-space bins (hence each data-space bin defines a separate line energy interval).

  If no energy interval is specified, the background continuum level will be assumed to be zero. This option may be useful to predict background models for continuum emission from OFF observation.

  `OFFLINE2`: requires exactly two distinct energy intervals. The background continuum level beneath the gamma-ray line in the OFF data will be determined by averaging the count rates over the specified intervals. A linear energy dependence is assumed for the normalisation. (in contrast, `OFFLINE` assumes no energy dependence, i.e. the background is assumed constant with energy).

  `OFFCONT`: requires at least 1 energy interval. The background level in the OFF data for all specified intervals will be averaged and used for normalisation of the background model.

- `scale`*nn* specifies a global scaling factor that is applied to each background model component. By default this parameter should be set to unity.

- `bgmFilter` specifies if pointings for which the background model values are either partially zero or partially negative should be all set to background model values of zero. This situation may arise if for example the `ADJACENT` background model is used, yet the number of counts in the adjacent bands is not sufficient to allow for an adequate determination of the background level. **Note that in this case, also the event data should be zeroed for these pointings.** Thus, better make sure that no invalid pointings occur (they are flagged by warnings in the log-file).

- `clobber` specifies if existing output data structures should be overwritten or not. If `yes` is specified, the executable will notify the user about the deletion of any file. If `no` is specified and the executable attempts to overwrite existing data (e.g. an existing output Observation Group or background model index), the task will exit with an error message.

- `verbose` specifies the verbose level of the executable. For `verbose=0`, no information will be logged in case of an error. For `verbose=1`, only errors will be logged, while for `verbose=2` also actions (such as DOL detachments and attachments and DOL deletion) will be logged. `verbose=3` provides a detailed report about the background model generation. `verbose=4` dumps all input data in a log file that is used for background model generation.

4 Interface definition

`spi_obs_back` attaches a background model index of type `SPI.-BMOD-DSP-IDX` to the observation group. This index points on the individual components of the background model that are stored as separate data structures of type `SPI.-BMOD-DSP`.

Each background model component consists of two columns `COUNTS` and `STAT_ERR`. `COUNTS` contains the predicted background level in units of counts. `STAT_ERR` contains the associated statistical error that has be derived using error propagation. Note that background models that are based on time (such as `CONST`, `ONTIME`, `DEADTIME`, and `DEADLIVE` have no associated statistical error.

Eventually, a background model template (i.e. a file describing the variation of the background with time) will be specified. The background template has to be of type `SPI.-BVAR-MOD`. This file contains two columns `OB_TIME` and `RATE`. `OB_TIME` specifies the time at which a given rate is measured, while `RATE` specifies the rate (in units of counts/sec) for each of the 19 Germanium detectors. Rates for multiple detectors will be built by multiplying the rates for the individual detectors.

5 Background model types

The following sections describe the algorithms that are implemented in `spi_obs_back` to model the **time dependence** of the instrumental background. The scaling of this time dependence is arbitrary, hence a background model normalisation has been implemented to provide the predicted number of counts in each data-space bin (see section 6 for details about the different normalisation possibilities).

5.1 CONST

The constant background model assumes that the background level is proportional to the livetime of the detectors.

The background model for pointing p, pseudo-detector d, and energy bin e is given by

$$\mathtt{BGM}_{p,d,e} = \Delta_e \times \mathtt{LIVETIME}_{p,d} \tag{1}$$

where Δ_e is the binsize of the energy bin e in keV, and $\mathtt{LIVETIME}_{p,d}$ is the livetime for pointing p and pseudo-detector d in seconds.

5.2 ONTIME

The `ONTIME` background model assumes that the background level is proportional to the ontime of the detectors.

The background model for pointing p, pseudo-detector d, and energy bin e is given by

$$\mathtt{BGM}_{p,d,e} = \Delta_e \times \mathtt{ONTIME}_{p,d} \tag{2}$$

where Δ_e is the binsize of the energy bin e in keV, and $\mathtt{ONTIME}_{(p,d)}$ is the ontime for pointing p and pseudo-detector d in seconds.

5.3 DEADTIME

The DEADTIME background model assumes that the background level is proportional to the deadtime of the detectors. The deadtime is here defined as DEADTIME = ONTIME − LIVETIME. The model considers the fact that a high background rate produces are larger deadtime, and hence the deadtime should be a measure of the background rate.

The background model for pointing p, pseudo-detector d, and energy bin e is given by

$$\mathtt{BGM}_{p,d,e} = \Delta_e \times \mathtt{DEADTIME}_{p,d} \tag{3}$$

where Δ_e is the binsize of the energy bin e in keV, and $\mathtt{DEADTIME}_{(p,d)}$ is the deadtime for pointing p and pseudo-detector d in seconds.

5.4 DEADLIVE

The DEADLIVE background model assumes that the background level is proportional to the product of the fractional deadtime (i.e. the fraction of a second during which the detectors are dead) and the livetime. The first term considers the fact that a high background rate produces are larger deadtime, and hence the deadtime should be a measure of the background rate. The second term introduces a self background rate reduction, since a higher background rate also leads to a smaller livetime.

The background model for pointing p, pseudo-detector d, and energy bin e is given by

$$\mathtt{BGM}_{p,d,e} = \Delta_e \times \frac{\mathtt{ONTIME_{p,d}} - \mathtt{LIVETIME_{p,d}}}{\mathtt{ONTIME_{p,d}}} \times \mathtt{LIVETIME}_{p,d} \tag{4}$$

where Δ_e is the binsize of the energy bin e in keV, $\mathtt{LIVETIME}_{p,d}$ is the livetime, and $\mathtt{ONTIME}_{p,d}$ is the ontime for pointing p and pseudo-detector d in seconds.

5.5 ADJACENT

The ADJACENT background model uses adjacent energy bins of the event spectra to determine the level of the instrumental background.

The background model for pointing p, pseudo-detector d, and energy bin e is given by

$$\mathtt{BGM}_{p,d,e} = \Delta_e \times \sum_{e' \in \mathtt{ADJ}} \frac{\mathtt{DSP}_{p,d,e'}}{\Delta_{e'}} \tag{5}$$

where Δ_e is the binsize of the energy bin e in keV, $\mathtt{DSP}_{p,d,e}$ is the event rate for pointing p, pseudo-detector d, and energy bin e, and ADJ is the set of adjacent energies that should be used (typically, these are bins to the left and the right of the gamma-ray line of interest). Equation 5 is equivalent to performing a maximum likelihood estimation of a constant (as function of energy) background level over the adjacent energy intervals.

Note that by definition, the ADJACENT background model has already a meaningful scaling, hence one may select the normalisation option NO to suppress any additional background model normalisation (see section 6).

5.6 ADJACENT2

TBW

5.7 VETOGATE

The `VETOGATE` background model assumes that the background level is proportional to the product of DFEE Veto gate rate and livetime.

The background model for pointing p, pseudo-detector d, and energy bin e is given by

$$\texttt{BGM}_{p,d,e} = \Delta_e \times \texttt{P\_\_DF\_\_NVTGT\_\_L}_p \times \texttt{LIVETIME}_{p,d} \tag{6}$$

where Δ_e is the binsize of the energy bin e in keV, $\texttt{P\_\_DF\_\_NVTGT\_\_L}_p$ is the average number of DFEE Veto Gate triggers per second for pointing p, and $\texttt{LIVETIME}_{p,d}$ is the livetime for pointing p and pseudo-detector d in seconds.

5.8 VETONONSAT

The `VETONONSAT` background model assumes that the background level is proportional to the product of DFEE non-saturated Veto gate rate and livetime.

The background model for pointing p, pseudo-detector d, and energy bin e is given by

$$\texttt{BGM}_{p,d,e} = \Delta_e \times \texttt{P\_\_DF\_\_CNVT\_MBW\_\_L}_p \times \texttt{LIVETIME}_{p,d} \tag{7}$$

where Δ_e is the binsize of the energy bin e in keV, $\texttt{P\_\_DF\_\_CNVT\_MBW\_\_L}_p$ is the average number of DFEE non-saturated Veto Gate triggers per second for pointing p, and $\texttt{LIVETIME}_{p,d}$ is the livetime for pointing p and pseudo-detector d in seconds.

5.9 VETOSAT

The `VETOSAT` background model assumes that the background level is proportional to the product of DFEE saturated Veto gate rate and livetime.

The background model for pointing p, pseudo-detector d, and energy bin e is given by

$$\texttt{BGM}_{p,d,e} = \Delta_e \times \texttt{P\_\_DF\_\_CNVT\_MAB\_\_L}_p \times \texttt{LIVETIME}_{p,d} \tag{8}$$

where Δ_e is the binsize of the energy bin e in keV, $\texttt{P\_\_DF\_\_CNVT\_MAB\_\_L}_p$ is the average number of DFEE saturated Veto Gate triggers per second for pointing p, and $\texttt{LIVETIME}_{p,d}$ is the livetime for pointing p and pseudo-detector d in seconds.

5.10 GEDRATE

The `GEDRATE` background model assumes that the background level is proportional to the product of DFEE non-saturated detector trigger rate and livetime.

The background model for pointing p, pseudo-detector d, and energy bin e is given by

$$\texttt{BGM}_{p,d,e} = \Delta_e \times \texttt{P\_\_DF\_\_CAFTT\_\_L}_{p,d} \times \texttt{LIVETIME}_{p,d} \tag{9}$$

where Δ_e is the binsize of the energy bin e in keV, $\texttt{P\_\_DF\_\_CAFTT\_\_L}_{p,d}$ is the average number of DFEE non-saturated detector triggers per second, and $\texttt{LIVETIME}_{p,d}$ is the livetime for pointing p and pseudo-detector d in seconds.

For double- and tripple-detector event pseudo-detectors, the DFEE non-saturated detector trigger rate is the mean trigger rate for the hit Germanium detectors.

5.11 GEDSAT

The `GEDSAT` background model assumes that the background level is proportional to the product of DFEE saturated detector trigger rate and livetime.

The background model for pointing p, pseudo-detector d, and energy bin e is given by

$$\mathtt{BGM}_{p,d,e} = \Delta_e \times \mathtt{P\_DF\_CAFTS\_L}_{p,d} \times \mathtt{LIVETIME}_{p,d} \tag{10}$$

where Δ_e is the binsize of the energy bin e in keV, $\mathtt{P\_DF\_CAFTS\_L}_{p,d}$ is the average number of DFEE saturated detector per second, and $\mathtt{LIVETIME}_{p,d}$ is the livetime for pointing p and pseudo-detector d in seconds.

For double- and tripple-detector event pseudo-detectors, the DFEE saturated detector trigger rate is the mean trigger rate for the hit Germanium detectors.

5.12 TEMPLATE

The `TEMPLATE` background model assumes that the background level is given by the rate specified in a template file of HDU type `[SPI.-BVAR-MOD]`.

The background model for pointing p, pseudo-detector d, and energy bin e is given by

$$\mathtt{BGM}_{p,d,e} = \Delta_e \times \mathtt{TEMPLATE}_{p,d} \times \mathtt{LIVETIME}_{p,d} \tag{11}$$

where Δ_e is the binsize of the energy bin e in keV, $\mathtt{TEMPLATE}_{p,d}$ is the average template rate, and $\mathtt{LIVETIME}_{p,d}$ is the livetime for pointing p and pseudo-detector d in seconds.

For double- and tripple-detector event pseudo-detectors, the assumed template rate is the product of the template rates of the individual detectors that participated in the interaction.

6 Background model normalisation

The background models derived using the equations in section 5 mainly describe the time dependence of the instrumental background variations. Any pseudo-detector variation may only result from deadtime differences and/or missing onboard spectra for individual detectors.

An exception is the `ADJACENT` background model type, which results from a direct normalisation on the measured data. For this model, equation 5 provides directly meaningful background count predictions, hence it may be directly applied to analyse the data. For all other models, a background model normalisation is required.

Therefore, in a second step, a background model normalisation is performed using

$$\mathtt{BGM}^{\mathrm{norm}}_{p,d,e} = \mathtt{norm}_{d,e} \times \mathtt{BGM}_{p,d,e} \tag{12}$$

where $\mathtt{BGM}^{\mathrm{norm}}_{p,d,e}$ is the output background model created by `spi_obs_back`, $\mathtt{BGM}_{p,d,e}$ is the background model as derived following the equations in section 5, and $\mathtt{norm}_{d,e}$ is a pointing averaged normalisation factor for each pseudo-detector d and energy bin e. Since the normalisation factor is averaged over all pointings, the normalisation is assumed independent of time.

The following sections describe the possible normalisation methods.

6.1 NO

No background model normalisation is performed, i.e.

$$\mathtt{norm} = 1.0 \tag{13}$$

This option may be chosen if the user either is not interested in absolute background levels (e.g. because they will be fitted later), or if the background model component is of type ADJACENT (this is the only type that provides a meaningful normalisation itself).

6.2 GLOBAL

The background model is scaled globally for each energy bin e to the input data using a single scaling factor $\texttt{norm}_e$, given by the equation

$$\texttt{norm}_e = \frac{\sum_{p,d} \texttt{DSP}_{p,d,e}}{\sum_{p,d} \texttt{BGM}_{p,d,e}} \tag{14}$$

where $\texttt{BGM}_{p,d,e}$ is the background model and $\texttt{DSP}_{p,d,e}$ are the event spectra for pointing p, pseudo-detector d, and energy bin e. This method preserves the relative counting rates between pseudo-detectors.

This option may be useful for background model types GEDRATE and GEDSAT which provide meaningful individual background model levels for each Germanium detector using the count rates in each individual detector. Note, however, that if double or tripple pseudo-detectors are used, the relative counting rate between pseudo-detectors is not correctly determined for the GEDRATE and GEDSAT models, hence the GLOBAL option may lead to unreliable results.

6.3 DETE

The background model is scaled for each energy bin e and pseudo-detector d to the input data using the normalisation

$$\texttt{norm}_{d,e} = \frac{\sum_{p} \texttt{DSP}_{p,d,e}}{\sum_{p} \texttt{BGM}_{p,d,e}} \tag{15}$$

where $\texttt{BGM}_{p,d,e}$ is the background model and $\texttt{DSP}_{p,d,e}$ are the event spectra for pointing p, pseudo-detector d, and energy bin e.

This option provides reasonable relative counting rate between detectors (yet is formally only correct for an empty field observation).

6.4 LINE

This method allows to normalise a background model component on the level of a gamma-ray line. The normalisation is performed using

$$\texttt{norm}_{d,e} = \Delta_e \times \frac{\sum_p \left(\frac{\sum_{e' \in \texttt{LINE}} \texttt{DSP}_{p,d,e'}}{\sum_{e' \in \texttt{LINE}} \Delta_{e'}} - \frac{\sum_{e' \in \texttt{ADJ}} \texttt{DSP}_{p,d,e'}}{\sum_{e' \in \texttt{ADJ}} \Delta_{e'}} \right)}{\sum_p \texttt{BGM}_{p,d,e}} \tag{16}$$

where $\texttt{BGM}_{p,d,e}$ is the background model and $\texttt{DSP}_{p,d,e}$ are the event spectra for pointing p, pseudo-detector d, and energy bin e. The notation $e' \in \texttt{LINE}$ signifies that the sum is taken over all energy bins that fall in the specified line energy interval, while the notation $e' \in \texttt{ADJ}$ selects all energy bins that fall in the specified adjacent energy intervals.

6.5 CONT

This method allows to normalise a background model component on the level of continuum energy bands. The normalisation is performed using

$$\texttt{norm}_{d,e} = \Delta_e \times \frac{\sum_p \frac{\sum_{e' \in \texttt{CONT}} \texttt{DSP}_{p,d,e'}}{\sum_{e' \in \texttt{CONT}} \Delta_{e'}}}{\sum_p \texttt{BGM}_{p,d,e}} \tag{17}$$

where $\texttt{BGM}_{p,d,e}$ is the background model and $\texttt{DSP}_{p,d,e}$ are the event spectra for pointing p, pseudo-detector d, and energy bin e. The notation $e' \in \texttt{CONT}$ signifies that the sum is taken over all energy bins that fall in the specified continuum energy intervals.

6.6 CONT2

TBW

6.7 OFFLINE

This background model normalisation aims in predicting absolute levels of instrumental background lines for each pseudo-detector d and energy bin e by using an OFF observation, which typically is a long observation of an empty field. It has been mainly developped for generating background models for diffuse gamma-ray line emission.

The normalisation is performed using

$$\texttt{norm}_{d,e} = \frac{\texttt{rate}^{\rm off}_{d,e}}{\texttt{rate}^{\rm on}_{d,e}} \tag{18}$$

where $\texttt{rate}^{\rm on}_{d,e}$ and $\texttt{rate}^{\rm off}_{d,e}$ are the pointing averaged background model counting rates for the ON observation and the OFF observation respectively for each pseudo-detector d and energy bin e (the ON observation is the observation for which the background model should be derived).

The pointing averaged background model counting rates for the ON observation are given by

$$\texttt{rate}^{\rm on}_{d,e} = \frac{\sum_{p'} \texttt{BGM}_{p',d,e}}{\Delta_e \times \sum_{p'} \texttt{LIVETIME}_{p',d}} \tag{19}$$

where Δ_e is the binsize of the energy bin e in keV, and $\texttt{LIVETIME}_{p,d}$ is the livetime for pointing p and pseudo-detector d in seconds. Consequently, $\texttt{rate}^{\rm on}_{d,e}$ is given in units of counts s^{-1} keV^{-1}.

The pointing averaged background model counting rates for the OFF observation are derived using

$$\texttt{rate}^{\rm off}_{d,e} = \frac{\sum_{p'} \texttt{BGM}_{p',d}\texttt{LIVETIME}^{\rm off}_{p',d}}{\sum_{p'} \texttt{BGM}^{\rm off}_{p',d}\texttt{LIVETIME}_{p',d}} \times \sum_p \frac{1}{\texttt{LIVETIME}^{\rm off}_{p,d}} \left(\frac{\sum_{e' \in e} \texttt{DSP}^{\rm off}_{p,d,e'}}{\sum_{e' \in e} \Delta_{e'}} - \frac{\sum_{e' \in \texttt{ADJ}} \texttt{DSP}^{\rm off}_{p,d,e'}}{\sum_{e' \in \texttt{ADJ}} \Delta_{e'}} \right) \tag{20}$$

The first term is a *global* scaling factor which accounts for global background counting rate differences between the ON and the OFF observation for each pseudo-detector. $\texttt{BGM}_{p',d}$ and $\texttt{BGM}^{\rm off}_{p',d}$ are calculated using the formulae given in section 5 where the Δ_e term has been dropped (i.e. the scaling factor is energy independent). Generally, this term varies only slightly between pseudo-detectors, hence it indeed provides a global model scaling. Small variations may result from deadtime differences and/or missing onboard spectra among individual detectors.

The second term provides the pointing averaged excess counting rates in the OFF observation over some *adjacent* energy bands (defined by the energy intervals ADJ). The notation $e' \in \texttt{ADJ}$ in equation 20 signifies that the sum is taken over all OFF data energy bins that fall in the adjacent energy intervals that have been defined using the normalisation parameter. The notation $e' \in e$ in equation 20 signifies that the sum is taken over all OFF data energy bins that enclose the ON data bin e (even if the OFF data energy bins are larger than the ON data bins). Typically, ADJ comprise two energy bands on both sides of an instrumental background line, yet more or less than two bands are possible. **If no adjacent energy interval is selected, no underlying continuum is subtracted from the line. This mode may be of interest to predict the instrumental background model for continuum sources.**

The background model normalisation is only performed for the energy bins e of the ON data that are fully enclosed in the energy bins of the OFF data (i.e. if the lower or upper energy boundary of an energy bin e of the ON data falls outside the range covered by the OFF data, the corresponding background model normalisation becomes zero). Generally, one should provide an OFF observation with the same energy binning as the ON observation, yet this is not required by `spi_obs_back`. However, the pseudo-detector definiton has to be identical for the ON and the OFF observation.

6.8 OFFLINE2

TBW

6.9 OFFCONT

This normalisation method is similar to `OFFLINE`, yet instead of normalising on gamma-ray line count rates the normalisation is performed on specific continuum energy intervals. For this method, Eq. 20 is replaced by

$$\mathtt{rate}^{\rm off}_{d,e} = \frac{\sum_{p'} \mathtt{BGM}_{p',d}\mathtt{LIVETIME}^{\rm off}_{p',d}}{\sum_{p'} \mathtt{BGM}^{\rm off}_{p',d}\mathtt{LIVETIME}_{p',d}} \times \sum_{p} \frac{1}{\mathtt{LIVETIME}^{\rm off}_{p,d}} \left(\frac{\sum_{e' \in \mathtt{ADJ}} \mathtt{DSP}^{\rm off}_{p,d,e'}}{\sum_{e' \in \mathtt{ADJ}} \Delta_{e'}} \right) \quad (21)$$

7 Error codes

The executable `spi_obs_back` may stop with the following error codes:

SPI_OBS_BACK_ERROR_MEM_ALLOC	-233300
SPI_OBS_BACK_ERROR_BAD_PARAMETER	-233301
SPI_OBS_BACK_ERROR_NO_MINIMUM	-233302
SPI_OBS_BACK_ERROR_NO_MAXIMUM	-233303
SPI_OBS_BACK_ERROR_DATA_SPACE_EMPTY	-233304
SPI_OBS_BACK_ERROR_BAD_EBDS_NUM	-233305
SPI_OBS_BACK_ERROR_NO_MODEL	-233306
SPI_OBS_BACK_ERROR_GTI_EMPTY	-233310
SPI_OBS_BACK_ERROR_BAD_GTI_SIZE	-233311
SPI_OBS_BACK_ERROR_BAD_GTI_COLUMN_DIM	-233312
SPI_OBS_BACK_ERROR_DTI_EMPTY	-233320
SPI_OBS_BACK_ERROR_BAD_DTI_SIZE	-233321
SPI_OBS_BACK_ERROR_BAD_DSP_SIZE	-233330
SPI_OBS_BACK_ERROR_BAD_SCHK_SIZE	-233340
SPI_OBS_BACK_ERROR_BAD_OFF_DATA	-233350
SPI_OBS_BACK_ERROR_TPL_EMPTY	-233360
SPI_OBS_BACK_ERROR_BAD_TPL_OBT	-233361
SPI_OBS_BACK_ERROR_BAD_TPL_COLUMN_DIM	-233362

They have the following meaning:

- `SPI_OBS_BACK_ERROR_MEM_ALLOC` : the allocation of dynamical memory has failed. Probable your system resources are too limited to run this task.
- `SPI_OBS_BACK_ERROR_BAD_PARAMETER` : an invalid task parameter has been specified. More information is found in the log file.
- `SPI_OBS_BACK_ERROR_NO_MINIMUM` : in the specification of adjacent energy intervals, no minimum has been found in an interval definition. Please verify the task parameters.
- `SPI_OBS_BACK_ERROR_NO_MAXIMUM` : in the specification of adjacent energy intervals, no maximum has been found in an interval definition. Please verify the task parameters.
- `SPI_OBS_BACK_ERROR_DATA_SPACE_EMPTY` : the data-space in the input observation group is empty, i.e. on of the dimensions `PT_NUM`, `DET_NUM` and `EBIN_NUM` is smaller than 1.
- `SPI_OBS_BACK_ERROR_BAD_EBDS_NUM` : the number of energy boundaries that is found in the `SPI.-EBDS-SET` data structure mismatches the `EBIN_NUM` keyword. The input data are corrupted and/or inconsistent. Please provide valid and consistent input data.
- `SPI_OBS_BACK_ERROR_NO_MODEL` : the number of specified background model components is smaller than 1 and no models will be generated by **`spi_obs_back`**.
- `SPI_OBS_BACK_ERROR_GTI_EMPTY` : the data structure `SPI.-OBS.-GTI` is empty or the OBT column has a dimension of zero.
- `SPI_OBS_BACK_ERROR_BAD_GTI_SIZE` : the `SPI.-OBS.-GTI` table size is incompatible with the data-space dimensions.
- `SPI_OBS_BACK_ERROR_BAD_GTI_COLUMN_DIM` : the `OBT_START` and `OBT_END` columns of the `SPI.-OBS.-GTI` data structure have incompatible vector dimensions.
- `SPI_OBS_BACK_ERROR_DTI_EMPTY` : the data structure `SPI.-OBS.-DTI` is empty.
- `SPI_OBS_BACK_ERROR_BAD_DTI_SIZE` : the `SPI.-OBS.-DTI` table size is incompatible with the data-space dimensions.
- `SPI_OBS_BACK_ERROR_BAD_DSP_SIZE` : the `SPI.-OBS.-DSP` table size is incompatible with the data-space dimensions.
- `SPI_OBS_BACK_ERROR_BAD_SCHK_SIZE` : the `SPI.-SCHK-HRW` table size is incompatible with the `SPI.-SCHK-CNV` table size.
- `SPI_OBS_BACK_ERROR_BAD_OFF_DATA` : the number of pseudo-detectors in the OFF data does not correspond to the number of pseudo-detectors in the ON data. Please provide a compatible OFF observation group.
- `SPI_OBS_BACK_ERROR_TPL_EMPTY` : the specified background variation template of HDU type `SPI.-BVAR-MOD` is empty. At least one row is required in the data structure.
- `SPI_OBS_BACK_ERROR_BAD_TPL_OBT` : the specified background variation template of HDU type `SPI.-BVAR-MOD` has OBT values that are not in a strictly monotonic order. Please assure that the OBT values are given in monotonic order.
- `SPI_OBS_BACK_ERROR_BAD_TPL_COLUMN_DIM` : the `RATE` column has not the correct dimension. The vector has to contain either 19, 61 or 85 elements.

In addition, all errors that may occur in calls to ISDC support functions (such as for example DAL, RIL or PIL) are forwarded. Please consult the ISDC web pages for getting information about these error codes.