# rgsspectrum

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**Abstract**

Generates source and background spectra for a single RGS exposure. For convenience, the option to background-correct the source spectrum is also supported. The spectrum includes, for each channel, the number of counts, a correction to the exposure time, and the effective size of the extraction region.

## 1 Instruments/Modes

| Instrument | Mode |
|---|---|
| RGS | Spectroscopy |
| RGS | High Time Resolution |

## 2 Use

| | |
|---|---|
| pipeline processing | yes |
| interactive analysis | yes |

# 3 Description

**rgsspectrum** creates an OGIP-compliant spectrum of counts for a single RGS exposure. The histogramming of events in this task is the same as in the instrument non-specific tasks, **xmmselect** and **evselect**, but **rgsspectrum** utilizes the RGS exposure maps found in the input event list file to produce a more sophisticated spectrum than is possible for those tasks. However, due to its alternative approach, this task is unable to benefit from a number of low-level SAS facilities. For instance, the user is limited to a single, hard-coded expression for selecting the events to be included in the spectrum: the "canonical" spectrum for a given source and reflection order. Further, no attempt is made to document the selections as a data sub-space within the output file. In these respects **rgsspectrum** is inferior to **xmmselect** and **evselect**. There is some possibility that these deficiencies will be addressed as the SAS continues to evolve. Nevertheless, **rgsspectrum** is the preferred spectrum-generator for RGS, and must be used for compatibility with **rgsrmfgen** and **rgsfluxer**.

Three types of spectrum are available, indicated by the value of the header attribute, `HDUCLAS2`:

| | |
|---|---|
| NET | background-corrected source spectrum |
| TOTAL | the source spectrum without background-correction |
| BKG | the background spectrum |

Note that although the spatial selection region for the background spectrum is not source-specific, the energy selection region is source-specific, and for this reason the background spectrum is technically source-specific. By default the TOTAL and BKG spectra are produced together as a pair. These two have the same format, which includes the new `AREASCAL` and `BACKSCAL` columns as specified under HDU Version 1.2.0 of the OGIP Spectral File Format (OGIP Memo OGIP/92-007). This format is supported as of LHEASOFT Version 5.1 (XSPEC Version 11.1). The background-corrected spectrum omits the `BACKSCAL` column, which is not needed (nor well-defined in that case), and instead provides the `STAT_ERR` column. In High Time Resolution (HTR) mode the entire cross-dispersion dimension is collapsed into one row, inextricably mixing source and background events together. In this mode the background region is not spatial; rather it is source and order specific in the plane of energy versus dispersion. The consequences of this detail are noted throughout this document.

In addition to the standard columns, `AREASCAL` and `BACKSCAL`, **rgsspectrum** will optionally include a non-standard column, `FRAC_EXP`. The differences between these three columns bears some explaining. `AREASCAL` is a channel-specific correction factor to the global `EXPOSURE` value recorded in the spectrum header. The product of `EXPOSURE` times `AREASCAL` is the exposure duration for any fully exposed pixels in each channel. Bad CCD elements and bad events reduce the realized exposure duration in the affected pixels from this full exposure value. Because of this the average realized exposure duration within the selection region at each channel may be less than the full exposure. `FRAC_EXP` records this average exposure duration as a correction factor to the full exposure at each channel; it represents the source selection region in NET and TOTAL spectra and the background selection region in BKG spectra. Note that in HTR mode the background selection region is not spatial, and so this column always refers to the source selection region. Finally, `BACKSCAL` records the effective number of fully exposed pixels in the selection region (source for TOTAL spectra and background for BKG spectra).

The above description of the `BACKSCAL` column applies only to Spectroscopy mode data; in HTR mode this column has nothing to do with exposure. The true meaning of the `BACKSCAL` column derives from its role in the formula for background correction:

$$\mathrm{COUNTS_{NET}} = \mathrm{COUNTS_{TOTAL}} - \frac{\mathrm{BACKSCAL_{TOTAL}}}{\mathrm{BACKSCAL_{BKG}}}\mathrm{COUNTS_{BKG}}$$

The `BACKSCAL` column exists so that a scaling ratio can be constructed to normalize the background count histogram to the effective width of the source selection region. In HTR mode `BACKSCAL` records the model background distribution, obtained from the CCF, integrated over the energy selection region (source or background) at each channel.

# 4 Parameters

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

| Parameter | Mand | Type | Default | Constraints |
|---|---|---|---|---|
| **evlist** | yes | dataset | evlist.ds | |

The input filtered event dataset. It must contain the `EVENTS` table and exposure map extensions. Not modified. All other file names required by this task are inferred by default from this one.

| | | | | |
|---|---|---|---|---|
| **srclist** | no | dataset | | |

The input source definition dataset. It must contain the `SRCLIST` table and the relevant selection region extensions. Not modified. The default file name is inferred from the input `evlist` name as: `*SRCLI_????.*` if there are ten characters before the suffix, and otherwise just `srclist.*`.

| | | | | |
|---|---|---|---|---|
| **source** | no | integer | 0 | non-negative |

The `INDEX` number of an entry in the `SRCLIST` table. This determines the incidence angle and selection regions. The default value, zero, indicates the `SOURCEID` attribute of the `EVENTS` table.

| | | | | |
|---|---|---|---|---|
| **order** | no | integer | 1 | positive |

The reflection order number. This determines the energy selection region.

| | | | | |
|---|---|---|---|---|
| **withspectrum** | no | boolean | yes | |

Enables output of the source spectrum (parameter `spectrumset`). The type of this spectrum is controlled by parameter `bkgcorrect`.

| | | | | |
|---|---|---|---|---|
| **bkgcorrect** | no | boolean | no | |

Enables background-correction of the source spectrum.

| | | | | |
|---|---|---|---|---|
| **spectrumset** | no | dataset | | |

The output source spectrum dataset (OGIP-compliant format). The default file name is inferred from the input `evlist` name as: `*SRSPEC`<*order*>`<`*source*`>.*` if there are ten characters before the suffix, and otherwise just `src`<*source*>`o`<*order*>`.pha`.

| | | | | |
|---|---|---|---|---|
| **withbkgset** | no | boolean | yes | |

Enables output of the background spectrum (parameter `bkgset`).

| | | | | |
|---|---|---|---|---|
| **bkgset** | no | dataset | | |

The output background spectrum dataset (OGIP-compliant format). The default file name is inferred

from the input `evlist` name as: `*BGSPEC<`*order*`><`*source*`>.*` if there are ten characters before the suffix, and otherwise just `bkg<`*source*`>o<`*order*`>.pha`.

| **rebin** | no | integer | 1 | positive |
|---|---|---|---|---|

The channel rebinning factor. The events and exposure are rebinned going into the histogram, which gives a more stable result than if the full-resolution spectrum is rebinned later (a very minor point).

| **edgechannels** | no | integer | 2 | non-negative |
|---|---|---|---|---|

The number of channels at the edges of each chip to be marked as bad in the output `QUALITY` column. For reasons not well understood at this time, the two channels at either edge of every chip do not seem to be properly calibrated.

| **exposed** | no | real | 0.1 | 0-1 |
|---|---|---|---|---|

Channels with less than this fraction of full exposure are marked as bad in the output `QUALITY` column.

| **withfracexp** | no | boolean | no | |
|---|---|---|---|---|

Enables addition of the non-standard (but harmless) `FRAC_EXP` column to the output spectra. This is the fraction of full exposure in each channel.

| **badquality** | no | integer | 1 | 0-5 |
|---|---|---|---|---|

The `QUALITY` column value used to indicate a bad channel. The default causes bad channels to be discarded automatically by XSPEC. Advanced users of XSPEC may prefer to change this for diagnostic purposes.

# 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.

**SourceNotFound** *(error)*
The `SRCLIST` table has no entry with the specified source `INDEX` number.

**ZeroExposure** *(error)*
Either the input event dataset contains no exposure map extensions at all, or none of the exposure maps enclose a non-zero area, which indicates that no frames passed through the filter.

**NothingRequested** *(warning)*
It is permissible, but pointless, to set parameters `withspectrum` and `withbkgset` both to

false.
*corrective action:* The task does nothing and completes without error.

**InvalidExposureMap** *(warning)*
The channel definitions in the EVENTS table must align with the channel definitions in the exposure map extensions. In the case of a null exposure map (see **rgsfilter**) this merely indicates that for this chip no frames passed through the filter, which may be cause for concern.
*corrective action:* The exposure map is discarded and the spectrum may not be correct.

# 6 Input Files

The following input files are never modified by this task.

- `evlist` — filtered event dataset (**rgsfilter**)

  Attributes: TELESCOP, INSTRUME, FILTER, OBJECT, OBS_ID, EXP_ID, EXPIDSTR, DATE-OBS, DATE-END, EQUINOX, RADECSYS.

  Extensions:

  - EVENTS

    Attributes:

    | | | |
    |---|---|---|
    | SOURCEID | int | aspect correction target source index |
    | RA_OBJ DEC_OBJ | | |

    Columns:

    | | | |
    |---|---|---|
    | PI | short | calibrated energy |
    | BETA_CHANNEL XDSP_CHANNEL | short | channel coordinates |

    These WCS attributes of the channel columns are also required: TCDLT, TCRPX, TCRVL, TLMIN and TLMAX.

  - EXPMAPnn

    At least one valid exposure map extension is required. To be considered valid an exposure map must cover a non-zero area on a channel grid commensurate with the channel grid of the EVENTS table.

    Attributes:

    | | | |
    |---|---|---|
    | CCDNODE | int | readout node identifier |
    | DATAMAX | real | maximum duration of exposure |
    | CTYPE1 CUNIT1 CRPIX1 CRVAL1 CDELT1 | WCS | dispersion axis |
    | CTYPE2 CUNIT2 CRPIX2 CRVAL2 CDELT2 | WCS | cross-dispersion axis |

- `srclist` — source definition dataset (**rgsregions**)

  Extensions:

  - SRCLIST

    Attributes:

    | | | |
    |---|---|---|
    | INSTRUME | string | instrument |

    Columns:

    | | | |
    |---|---|---|
    | INDEX | int | source identifier |
    | DELTA_DISP | real | grating dispersion angle |

  - <*instrument*>_BACKGROUND

    FITS region in RGS angular coordinates: defines the background spatial selection region. This region is never required in HTR mode, and in Spectroscopy mode it is not required for a TOTAL spectrum.

– <*instrument*>_SRC<*source*>_SPATIAL
FITS region in RGS angular coordinates: defines the source spatial selection region. This region is always required in HTR mode, but in Spectroscopy mode it is not required for a BKG spectrum.

– <*instrument*>_SRC<*source*>_ORDER_<*order*>
FITS region in RGS dispersion and energy (PI): defines the source energy selection region. This region is always required in Spectroscopy mode, but in HTR mode it is not required for a BKG spectrum.

– <*instrument*>_SRC<*source*>_ORD<*order*>_BKG
FITS region in RGS dispersion and energy (PI): defines the background energy selection region. This region is never required in Spectroscopy mode, and in HTR mode it is not required for a TOTAL spectrum.

# 7 Output Files

The output files are spectra in OGIP-compliant format (OGIP Memo OGIP/92-007). In addition to the mandatory attributes, the following non-standard attributes are provided for use by **rgsfluxer** and **rgsrmfgen**:

| | | |
|---|---|---|
| `SOURCEID` | int | source identifier |
| `RFLORDER` | int | reflection order |
| `LINE_SEP` | real | [Angstroms] grating line spacing |
| `RGSALPHA` | real | [radians] grating incidence angle |

These columns are provided for all spectra, regardless of type:

| | | |
|---|---|---|
| `CHANNEL` | short | dispersion channel number |
| `COUNTS` | int | number of selected photons |
| `QUALITY` | short | data quality flag |
| `AREASCAL` | real | full exposure correction factor |
| `FRAC_EXP` | real | average exposure correction factor (optional) |

In addition to these, for TOTAL and BKG spectra only the `BACKSCAL` column is provided, and for NET spectra only the `STAT_ERR` column is provided:

| | | |
|---|---|---|
| `BACKSCAL` | real | background scaling factor |
| `STAT_ERR` | real | statistical error |

- `spectrumset`
  Source spectrum (TOTAL or NET), produced only if enabled by parameter `withspectrum`.
- `bkgset`
  Background spectrum (BKG), produced only if enabled by parameter `withbkgset`.

# 8 Algorithm

The following three fragments of pseudo-code summarize the computation of the spectrum at any given channel. fg and bg refer to source and background respectively, though these qualifiers are omitted where it may be understood that a TOTAL spectrum refers to fg and a BKG spectrum refers to bg. The first fragment is the formula for histogramming the events.

```
IF ( mode == HTR )
  IF ( XDSP_CHANNEL in SpatialSourceRegion )
    IF ( PI in EnergySourceRegion ) ++fg.counts
    IF ( PI in EnergyBackgroundRegion ) ++bg.counts
ELSE
  IF ( PI in EnergySourceRegion )
    IF ( XDSP_CHANNEL in SpatialSourceRegion ) ++fg.counts
    IF ( XDSP_CHANNEL in SpatialBackgroundRegion ) ++bg.counts
```

The next fragment computes the backscal and frac_exp statistics from the accumulated exposure, which is just the sum over all exposure map pixels that lie within the spatial selection region at the given channel. The fullExposure statistic is simply the DATAMAX attribute of the exposure map associated with the channel. Note that this association is not guaranteed to be unique (particularly at the trans-node boundary), and when the fullExposure value for a channel is not well defined the statistics are flagged as having been corrupted.

```
IF ( mode == HTR )
  fg.backscal = background distribution integrated over EnergySourceRegion
  bg.backscal = background distribution integrated over EnergyBackgroundRegion
  normalizer = $rebin * extent( SpatialSourceRegion ) * fullExposure
  frac_exp = normalizer ? fg.exposure / normalizer : 0
ELSE
  backscal = fullExposure ? exposure / fullExposure : 0
  normalizer = $rebin * extent( SpatialRegion ) * fullExposure
  frac_exp = normalizer ? exposure / normalizer : 0
```

The last fragment shows how each output column is defined. The dubious flag indicates corrupted statistics as explained above, and it is also set in accordance with the edgechannels parameter.

```
AREASCAL = fullExposure / EXPOSURE
QUALITY = dubious ? $badquality : 0

IF ( HDUCLAS2 == NET )
  scale = bg.backscal ? fg.backscal / bg.backscal : 0
  COUNTS = fg.counts - round( scale * bg.counts )
  STAT_ERR = max( 1, sqrt( fg.counts + scale * scale * bg.counts ) )
  FRAC_EXP = fg.frac_exp
  IF ( !bg.backscal OR fg.frac_exp < $exposed OR bg.frac_exp < $exposed )
    QUALITY = $badquality
ELSE
  COUNTS = counts
  BACKSCAL = backscal
  FRAC_EXP = frac_exp
  IF ( frac_exp < $exposed )
    QUALITY = $badquality
```

# 9 Comments

In Spectroscopy mode the two channels at the trans-node boundary of each chip are marked as bad, for reasons explained above. For completely unrelated reasons, these channels are likely to contain spurious events and it is therefore well, in general, that they are discarded. Still the user might reasonably prefer to use these channels when conditions are favorable, and this task should not be getting in the way.

# References