# ANNEX 19

# SPI INSTRUMENT SPECIFIC SOFTWARE

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# - PART OF SPI USER MANUAL -

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## Scope

This document assembles high-level user introduction to the SPI instument-specific software as part of the software system for INTEGRAL data analysis at ISDC.

## Document History

- 01 Mar 2002 Issue 1 create from SPI and ISDC ISSW documents

## Overview

The processing and standard analysis of the telemetry data from the SPI instrument occurs through the INTEGRAL Science Data Center (ISDC) in Ecogia / CH. Instrument-specific parts of the software to do this are called the Instrument Specific Software (ISSW), and are provided by the SPI Team through its delegated team members to the ISDC for integration into the ISDC software system. Here we describe how this ISSW is designed and incorporated into the ISDC software system, and how it may be used. We distinguish as categories of the ISSW, from the user's point of view:

1. ISSW tools for data decomposition and preprocessing
2. ISSW tools for instrument performance analysis
3. ISSW tools for near-realtime analysis of bursts and transients
4. ISSW tools for instrument calibration and response determination
5. ISSW tools for background analysis and modelling
6. ISSW tools for preparation of data for astrophysical analysis
7. ISSW tools for astrophysical analyses, in the areas of imaging, spectra, timing, and model fitting

Preprocessing and routine monitoring parts of this system is ISDC-specific, and response/calibration- and performance analysis parts are specific to project-related sites and the ISDC, while science analysis parts of this software may be distributed to the community with the data.

## ISSW Functions

### *ISSW tools for data decomposition and preprocessing*

The SPI-specific telemetry aspects have been encoded into ISDC's 'Preprocessing' software, based on the SPI Science Data Format Description (SPI-ST-0-2911-CNES). A description of the instrument-specific data formats (raw and decoded/FITS) is found in the SPI ISSW ICD.

No parameters are foreseen in this software, nor any parameter definition files which need maintenance. On the other hand, any telemetry anomaly or change will incur software changes on the ISDC side, advised by CESR.

### *ISSW tools for instrument performance analysis*

The SPI instrument health is monitored at ESOC, through limit checking as defined in the SPI instrument database file provided to ISOC from the SPI Team. For performance monitoring of the SPI instrument at ISDC, this same definition file is used to define parameter names, locations, and units. The limit checking part is overwritten, however, to define limits which apply to scientific performance rather than health checks. The corresponding ISDC system is names "OSM" (observation status monitoring); this is a root-based package, with an "automatic" and an "interactive" implementation. Interactively, a variety of user-specific displays can be built and saved for later usage. This "interactive OSM" is also used by SPI experts for their deep science performance analysis work at ISDC and remotely. Specific OSM displays are provided for the SPI hardware subsystems, such as the Anticoincidence System (ACS).

For subsequent science analysis, the results of performance analysis are condensed into "good time intervals" datafiles. The ISDC package SPIGTI includes algorithms to translate SPI mode transitions into corresponding entries; algorithm adaption occurs through software changes.

### *ISSW tools for near-realtime analysis of bursts and transients*

In order to monitor incoming data in near-realtime for the detection of gamma-ray bursts and transients, special ISSW has been tailored for the ISDC of the IBAS (for realtime burst detection) and QLA (for daily quick-look analyses to search for transient sources). The IBAS ISSW features a branch for monitoring the ACS detector rates, and a branch to monitor Ge camera detector rates. Glitches exceeding a significance threshold above a running average are used to signify a burst. The QLA software for SPI is a tailored derivative of the SPIROS imaging/source search algorithm (see below), optimized for performance and catalogue interfacing. It processes a reference catalogue of expected sources with their characteristica, and outputs a list of discrepant/new sources.

### *ISSW tools for instrument calibration and response determination*

The raw Ge detector event messages are pre-processed into calibrated event messages, based on gain correction factors derived through instrumental-line fitting analysis. For this, incoming raw events are histogrammed (ISSW module SPIHISTO), line fitting (ISSW module SPILINE) then determines the gain correction factors (ISSW module SPICALI). Similarly, from Performance Analysis a set of assessed PSD calibration libraries is maintained, from which the PSD classification criteria are derived. Both the gain correction and PSD classifications are applied (ISSW module SPICOR) when the events are read/used for science analysis, e.g. when binned into spectra for later analysis (ISSW module SPIHIST).

The instrument response of SPI is determined solely from Monte Carlo simulations of the physics interactions within instrument and detectors. The MGEANT software package is used to handle the physics details and produce physical interaction events. The SPI response is determined as a function of incidence direction and energy. The different variabilities of response aspects with angle and energy is accounted for by decomposition into different matrices (L, D), one addressing the detailed energy response of detectors, the other addressing the attenuation of gamma-rays from all incidence directions on their way to the Ge detectors. The ISSW module RSPGEN composes these matrices to assemble a response function representation as needed for different purposes, i.e., for spectral analysis or for imaging analysis. The basic response matrices L and D are provided to ISDC by GSFC of the SPI Team. The RSPGEN module uses these and makes the necessary interpolations, instrumental-preformance adjustments, and formatting to provide imaging response matrices (IRF) for the SPIROS/SKYMAX/DIFIT imaging analysis modules, and spectral response matrices (ARF, RMF) for XSPEC spectral fitting.

### *ISSW tools for background analysis and modelling*

Instrumental background is large for any instrument in the MeV regime, from cosmic-ray activation of spacecraft material. Basic/standard spectral analysis software (e.g. from CERN packages as part of the ISDC ROOT scripting language; but also modules have been provided as part of the ISSW, such as SPILINE, or GASPAN) is used to identify characteristic spectral lines and thus explore the background types. Fit results must be digested interactively by instrument scientists to derive background parameters; no direct interface to background modelling is foreseen (see below).

For detailed Monte Carlo simulations of background, both the MGEANT package (used also for the response simulation) and the TIMMS implementation of GEANT with enhancements are available. External particle radiation environments are specified by the user, the detailed mass models and response functions included in these packages then generate the simulated Ge detector event messages as expected from such background. Studies performed at CESR (Pierre Jean) and CEA (Nene Diallo) constitute a baseline for SPI instrumental background. More must be learned during the mission from comparisons of background explorations with simulations.

Background handling in the science analysis software occurs through fitting of the amplitudes of background model tremplates prepared from above knowledge. The ISSW module BGDGEN includes several analytical background model representations, as well as an interface to a simulated or otherwise obtained background template; also, correlations to auxilliary parameters from the INTEGRAL housekeeping database (e.g. radiation monitor countrate) can be used in BGDGEN. The output of BGDGEN is a background model for imaging analysis, whose amplitude should be determined however within imaging analysis to account for correlation of source signal and background in the actual measurement.

No special ISSW is provided for background modelling in spectral and timing domains; this is addressed by spectral and timing analysis software directly.

### *ISSW tools for preparation of data for astrophysical analysis*

Before astrophysical analyses, the measured data together with auxilliary data and responses must be collected and prepared as a data group. Beyond interactive identification of the relevant data intervals, and using ISDC general utilities such as OG_CREATE, several ISSW modules are involved here.

The instrument pointings on the sky are assembled by ISSW module SPIPOINT. Instrument deadtimes for the time intervals in question are derived from housekeeping rates of the instrument through ISSW module SPIDEAD. Proper uncontaminated data intervals are derived with SPIGTI (see performance analysis). Imaging responses and background models are tailored to the analysis data sets with ISSW modules SPIBOUNDS (define binning constraints in general terms), BIN-I (define the binning used in analysis), IMG-I (prepare the response matrices in appropriate binning), and BGK-I (prepare relevant background model). The measured data themselves are binned into histograms for science analysis, using ISSW module SPIHIST.

Utilities for interfacing to previous knowledge about the gamma-ray sky are provided for diffuse emission (skymap convolution, ISSW module SKYCNV, with preparation of the sky parameters in module GENSKY) and for source calalogues (ISSW module CAT-I).

### *ISSW tools for astrophysical analyses, in the areas of imaging, spectra, timing, and model fitting*

The most general and theoretically also most sensitive analysis would make use of the full data in unbinned form (to retain measured resolutions), and use the instrument response in full spectral and spatial detail to deconvolve the appearance of the sky. Response information would be too complex and big to be handled, however, so that compromises are necessary. For imaging analyses, one assumes the separation in wide energy bands is adequate to not distort results from adjacent energy bands. For spectral analyses, one either attempts to separate a source direction through a first round of imaging which generates "selected source spectral data", or else assumes that spatial data selection and subtraction can be made to isolate the spectral signal from the source of interest. For timing analyses, similar considerations apply; here often one isolates the source signal only through its unique signature in the timing domain, and empirically defines the flat timing signature as the background from the rest of the sky and the instrument.

#### Imaging Analysis

Two methods for generation of images are provided: Iterative removal of sources from high to low significance (ISSW module SPIROS), and sky deconvolution with account for image entropy (ISSW module SKYMAX). SPIROS determines parameters (flux, significance, spectrum) for each identified source, hence aims at point-like sources primarily. SKYMAX treats the sky as pixelized intensity map, hence aims at diffuse emission primarily. Both packages are capable of imaging the sky with point-like and diffuse emission together, within these constraints/compromises.

SPIROS: The package searches for a sky correlation of the instrument response with a strong point source. Upon finding it, the corresponding expected signal from this strongest source is subtracted from the measured dataset, and then the search is continued for the next-strongest source. At the end, a list of identified sources exists, which, in the final analysis step, is used as input to fit their intensities in combination through a maximum-likelihood method. The user may start with an "expected" sky which may be composed of diffuse emission and point sources; also, background model templates can be provided and are used in all search and fitting steps. Diffuse emission and source patterns can be controlled through choices of coordinate systems / spline functions.

SKYMAX: The package iteratively modifies the inputs sky such as to improve the data fit after convolving with the instrument response, using the entropy of the inputs sky as a second criterion in order to damp fitting of the noise. The gradient search

method is complex due to the large number of free parameters (each sky pixel). Iterations are terminated once noise is found to dominate, which I detected through internal Monte Carlo simulations. The user controls search method details, but most importantly the entropy reference, through provision of the input / starting map. Results are provided in the form of image and image projections.

Model Fitting: Two ISSW modules/packages are provided to determine intensity parameters of sky intensity models from SPI measurements: a Maximum Likelihood fitting method, and a Markov Chain Monte Carlo method source model fitting. In these modules, fitting methods and fit parameter constraints are controlled by the user, in addition to the variety of spatial intensity model formats which can be provided/used.

### Spectral Analysis

Basic spectral analysis is supported through the tools mentioned above, for performance analysis and inflight calibration/gain analysis, and background exploration.

Astrophysical spectral models are fitted to data by the X-ray community through the XSPEC software package. This package, also part of the ISDC tools, is enhanced (XSPEC Version-12) to support the more complex inclusion of imaging and spectral responses simultaneously. With this, the response to each source in the field of view can be used to fold its expected spectrum into dataspace, so that for the source in question astrophysical model spectra can be fitted/tested in dataspace through forward folding and iteration of its parameters. - Before XSPEC12 is available, a compromise is supported in a two-step analysis: In a first step of imaging analysis, SPIROS is used to fit the celestial sources of the measurement, and to then extract a spectrum of measured events which are attributed to the source in question. In a second step, these "extracted source counts" are then fitted to astrophysical source models with XSPEC, using SPI's spectral response matrices as provied by RSGEN.

Note that the imaging and spatial model fitting tools can be applied in narrow energy bins. This will treat the instrument response properly within each spectral bin, and thus derive a proper result for each spectral bin. If crosstalk among spectral bands is small (as can be expected for the high-spectral resolution SPI instrument in many cases), therefore spectral information also is derived from imaging analysis tools.

### Timing Analysis

No special ISSW has been provided for source timing analysis. XCHRONOS application on lists of event time tags is the ISDC standard. A special imaging preselection analysis (as described for spectral analysis) is being worked on.

## ISSW Interfaces and Embedding

All ISSW software modules are provided as FTOOL units. This implies that their user parameters are specified in a unique ASCII parameter control file, and all I/O is handled through FITS I/O library calls. The preparation of the control parameters, and specifically the locations and identifiers of the datasets to be read and written, can be a complex enterprise. For this purpose, ISDC "scripts" are built and provided, which facilitate parameter passing between ISSW modules which are run routinely or in predefined sequences. Such scripts may also feature user-friendly interfaces with parameter menues and semi-automatic parameter generation assistance (GUIs). These scripts and GUIs are described elsewhere and not considered ISSW.