

SPIDAI – SPI Data Analysis Interface

User manual

1. Overview

SPIDAI is a simple IDL (<http://www.itvis.com/ProductServices/IDL.aspx>) program designed to ease the process of SPI data reduction and analysis. It consists of a basic graphical interface featuring buttons, text fields and visualization tools. These enable a quick setup of the parameters of the reduction process as well as instant monitoring of the quality indicators and output products of the treatment.

2. SPI data reduction with SPIDAI

General remarks about the instrument and its observational strategy can be found in the Appendix. Here we briefly guide the reader on how to use the SPIDAI software to produce scientifically exploitable material. Even though the presented software executes the different steps in a row (“pipeline”) and produces the output products (i.e. light curves and spectra) quite quickly, the user still owns an important (and irreplaceable) part in the process. Indeed, he or she is requested to carefully monitor the quality indicators of the ongoing treatment.

Basically, there are three indicators which enable to assess if the obtained results may be trusted. The first and most important indicator is the quality of the fit between the original counts distribution recorded by the detector plane and the counts distribution that has been reconstructed from the sky model convolved with the instrument response. This quality is determined from a χ^2 test, the values of which are automatically plotted at the end of each run, such that the user is brought to give them full consideration. χ^2 values greater than 3.0 clearly indicate that there is a problem and that the parameters of the current run need to be revised.

In this case, there is a secondary indicator that very often gives additional information: the reconstructed background count rate as a function of time. Strong peaks in this curve are due to background flaring and the concerned pointings (often occurring at the beginning/end of a revolution) need to be excluded from the analysis. A first cleaning has been performed in a previous step in order to propose a set of data ready for a scientific analysis¹. If the background count rate is stable (<5%) but still there are bad χ^2 occurrences, this may then indicate that the variability time scale of the background and/or of the main (strong) sources is not appropriate, i.e. not short enough. If the time scales are at minimum already (i.e. at the science-window time scale), then there is probably one or more sources missing in the sky model.

¹ See Appendix for more information

Finally, it often proves useful to consider the reconstructed light curves of the sources, which thus represent a third quality indicator. Indeed, some sources for which a short time scale was specified may turn out to be less variable than expected, in which case a longer time sampling is sufficient to describe their physical properties; in turn, this will reduce the free parameters of the fitting process, and hence provide more accurate results. So we strongly recommend to take time to adjust properly the sky model and the corresponding timescales to be sure that the obtained results are robust.

3. Getting started

To run SPIDAI, the user may simply hit the command *spidai* in a terminal and the front window (titled “*SPIDAI – Front Window*”) opens immediately. It contains four strips, laid out in a column: “*Basic setup*”, “*Sky model setup*” and “*Output path*” control the parameterization of the reduction process while “*Run*”, the main strip on the bottom, controls the execution and monitoring of the treatment. All strips will be further detailed in the following sections.

4. Basic setup

This strip features two buttons: “*Keep previous parameters*” and “*New run*”. The first time SPIDAI is used, the user should select “*New run*”, causing a secondary window to open; this window, entitled “*Main parameter setup*”, enables the user to specify the main parameters for the current data extraction run.

4.1. Choose an optional name for the run

The user can fill the upper text field. This name will be used to mark the output files, for example the name “test” will lead to output files called “..._test_..._out”.

4.2. Choose a target source

The user has to click in the featured source catalogue (Bouchet et al. 2008), or to directly enter the coordinates (α, δ) of a sky region to observe.

4.3. Choose an energy binning mode

The user may choose between three energy binning modes, labeled (1), (2) and (3).

Mode (1) is the standard/default light curve (broad band) mode, intended to study the flux evolution with time of the source(s) that is(are) observed. The energy bands are large, with a standard binning of [25-50],[50-150],[150-450] and [450-650] keV.

Mode (2) is the standard/default (narrow band) spectral mode, designed to study the spectrum(a) of the source(s) in the field of view. It features 50 logarithmic energy bins from 20 keV to 650 keV.

Mode (3) enables the user to freely choose the energy bins for the flux extraction; for this purpose a tertiary window opens entitled “*Energy bins*”. The user can create a new energy bin file by entering manually the bounds of the energy bins in the designated text fields or open a previous one. Note that the energy domain is restricted to 20 keV - 650 keV for the moment due to a specific treatment required above this energy and not yet implemented in this automatic procedure.

4.4. Select the maximum offset angle

Since SPI has a large field of view, pointings that are offset by less than 16° still capture a contribution from the target source flux and may thus be included in the analysis. However, we recommend to reduce the offset angle in order to exclude the pointings for which the target source illuminates less than 50% of the detector plane ($<12^\circ$; default configuration). In some cases it may be useful to consider only the pointings for which the source flux is fully coded on the detector plane ($<8^\circ$).

Note that source spectra will not be calculated if the source angle value is higher than 16° ,

4.5. Select revolutions or pointing file

The user may choose observations which are to be analyzed or a saved pointing file.

The revolutions may be treated individually by simply entering the corresponding number in the text field, or analyzed group-wise, by using the operators “+” (add revolution(s) to the analysis) and “-“ (consider all revolutions between the operands in the treatment). Example: 44+46-49+52 will include the revolutions 44,46,47,48,49 and 52 in the current run. **Due to memory allocation limit, the user cannot analyze a period covering more than 120 revolutions in a single run.**

Pointing files saved in a previous study with “*Save pointing file*” can be read by the software.

The revolutions are available from revolution 38 to revolution 981 for the first delivery. The data set will be increased according to the data public release.

5. Sky model setup

This strip is dedicated to the setup of the sky model. For each component in the sky model, flux values are extracted along a user specified time scale, a process that is called “deconvolution” (cf. manual of the program *SPI.deconv.image*). The sky model needs to be defined with care, since too few components (or time steps) as well as too many components (or time steps) may lead to flawed/unreliable results.

5.1. Sources

First, the user is invited to specify the sources in the sky model. This may be done by either keeping the previously defined model (“*Keep current setup*”) or by creating a new one² (“*Create new model*”). In order to create a new sky model file, a secondary window opens, filled with the target source chosen in basic set up. Source variability is automatically set according to energy binning mode but the user can change it by clicking on “*Modify*”. Similarly, the source may be deleted from the catalog by selecting clicking on the “*Delete*” button.

The user can add source by selecting it with the mouse. Automatically its name and coordinates appear in the text boxes on the left; it may then be included in the catalog below by clicking on the “*Add*” button. Then the user may choose variability between formatted tags. **The source number is limited to 15.**

Please note that some sources are notoriously variable³ and hence they must be allowed to vary on the pointing (= science-window) time scale (i.e. they are considered to be ‘constant per pointing’). Examples of the formatted tags that need to be entered to specify different variabilities are given in Table 1.

Table 1 – Variability Tags

<i>cst</i>	Constant, i.e. no variability
<i>scw:2,10,4,5</i>	2 intervals of 10 science-windows followed by 4 intervals of 5 science-windows
<i>sec:3,5000,10,3000</i>	3 intervals of 5000 seconds followed by 10 intervals of 3000 seconds
<i>fix:scw,3</i>	All intervals are 3 science-window long; one science-window being the minimum time unit, the standard tag for a very variable source is thus <i>fix:scw,1</i>
<i>fix:rev,1</i>	Constant per revolution; this is the standard time tag for non-variable sources when several revolutions are treated at once
<i>fix/rev:scw,10</i>	All intervals are 10 science-window long except (eventually) at the end of a revolution, where a break is forced to the next revolution
<i>fix/rev:sec,4000</i>	All intervals are 4000 seconds long except (eventually) at the end of a revolution, where a break is forced to the next revolution

We strongly recommend to the user to take time to define properly its sky model: missing sources or too many (unnecessary) free parameters (ie too short variability timescale) may introduce some biases or lead to large error bars. Several tests has to be done to ensure a result, particularly in crowded regions.

² In a first run, the user should create a new file.

³ We have tentatively identified with an * in the source catalogue

5.2. Background

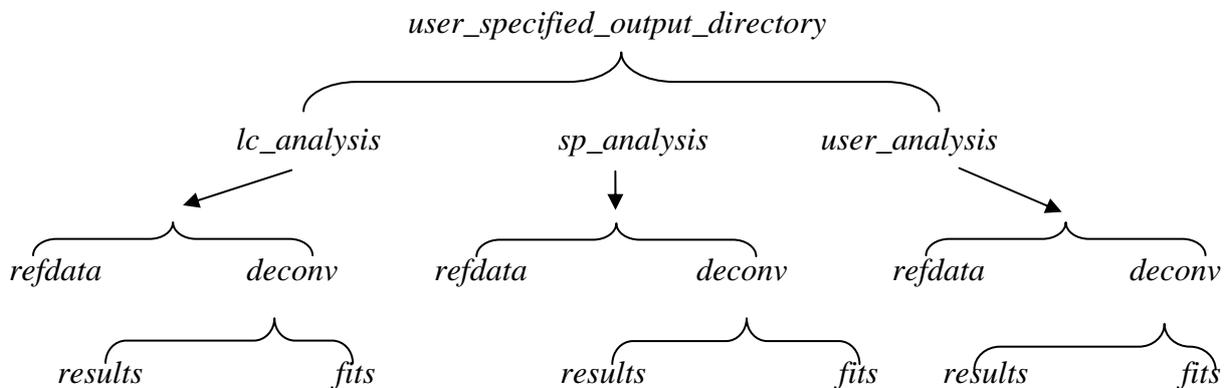
Next, the user is invited to specify the properties of the background model⁴.

The background component is considered to have similar properties than the sources, and the pattern that is used is automatically determined to best match the revolutions that are to be treated. Therefore, when creating a new background file, the user is only invited to specify the variability timescale of the normalization of the background pattern. The tags that are used are the same as for the sources, but the standard options may be selected more quickly due to dedicated buttons. The “Customize” button yet enables the user to manually enter the appropriate variability tag, for which the template formats can be found in Table 1.

As a general rule, the background normalization needs to be set at least as variable as the main source that the user wants to study. For instance, if the user wants to extract the average spectrum of Cygnus X-1 on a pointing time scale, he should not specify a background normalization that varies on a significantly longer scale (like the revolution time scale), since this would lead to erroneous results. Indeed, the average spectrum is calculated from the sum of the pointing spectra, but the background estimation being the same for different pointings, the error bar is calculated from dependent variables and will hence be incorrect.

6. Output path

This strip enables the user to specify the output directory to which the products of the analysis are written on the disk. The default is the directory in which SPIDAI is being executed, but it may prove useful to add the source name and/or the observations identifier as an additional subdirectory. After hitting the “ok” button, the directory is checked, validated if the user has writing permission and created if needed. From there, several subdirectories are automatically created in order to better separate the output products. The following example illustrates the directory policy:



⁴ See Appendix for more information about the method used to estimate the background patterns.

The directories *lc_analysis* (1), *sp_analysis* (2) and *user_analysis* (3) are determined according to the energy binning mode (cf. “*Basic setup*”) and stand for light curve analysis, spectral analysis and analysis with a user specified energy binning, respectively. The directory *refdata* contains the standard pre-deconvolution *.fits* files (*counts.fits*, *livetime.fits*, *back_group.fits* etc.) while the directory *deconv* contains the products of the deconvolution algorithm. These are separated in *results* and *fits*, the former containing some ascii output files⁵ and the latter containing formatted *.fits* files of the spectra and response (rmf) matrices (one by source and its associated time bins plus the averaged ones) for use in fitting software like *Xspec* or *ISIS*.

7. Run

The main strip on the bottom of the SPIDAI window controls several tasks at the time.

7.1. Run Data Extraction

This button is the launcher of the pipeline. It successively runs the different steps of the SPI data reduction, from the creation of the directory tree and parameter files to the visualization of the quality indicators (χ^2) of the deconvolution process. In this last step, a window is opened which shows two plots, the upper one being the χ^2 values (color scale) per energy bin (y axis) for each pointing (x axis) and the lower one being the χ^2 values per energy bin for each detector.

Once the treatment is finished, a series of buttons is activated, enabling to control/visualize the output products of the treatment.

7.2. Pointing management

The χ^2 plots described above can put in bright some unacceptable values which have to be investigated⁶ or removed.

Indeed, some pointings may be flawed by high solar activity, radiation belt entry or any other non-normal incident and must be removed manually. “Bad” pointings can be identified from unusual high χ^2 values or from strong peaks in the reconstructed counts curve of the background (See “*Plot Residuals*”).

The user may select some pointings to be removed after entering an energy bin number. This number should be chosen thanks to the color scale plot.

Note that to ease this selection, pointings have been treated in a previous processing⁷ and some of them removed automatically. Thanks to the pointing manager, the user may decide to reintroduce them in the study.

⁵ See the user manual of *SPI.deconv.image* for the details.

⁶ See section 2 for advices about the sky model

7.3. Save pointing file

The user may save the present pointing management to use it in a later study. An extension (“*.pntg*”) will be automatically added as the software will be able to read this file secondly.

7.4. Plot Chi2

The user may again plot color scales of χ^2 values.

7.5. Plot Residuals

This button plots the count rate of the reconstructed background contribution as a function of time along with the residuals of this reconstruction. Such a plot proves useful to identify flares of the background, which may for instance occur at the beginning/end of a revolution (due to radiation belt exit/entry) and must be excluded from the analysis since they flaw the obtained results.

7.6. Plot Light Curves

This button plots the light curve of a given source in a given energy bin. This feature is useful to check if the specified variability is indeed needed or if a longer time scale would have been more appropriate, since it would reduce the number of free parameters in the deconvolution process.

Please note that the very first and very last energy bin of the hereby produced spectra should be systematically excluded from the scientific analysis, since the count rates in these channels are not fully reliable.

8. Appendix

8.1. INTEGRAL/SPI and its observational strategy

SPI is a high resolution γ -ray spectrometer (Vedrenne et al. 2003) aboard the INTEGRAL observatory. The observational strategy of the INTEGRAL mission is based on approximately 3-day long revolutions around the Earth during which one (or several) sky region(s) is(are) sampled by means of 30 – 40 minute long fixed pointings (or science-windows), separated generally by a 2° angular distance each. As the number of SPI pixels is small (among the initial 19 detectors, four broke down over 8 years of operation, reducing the detector plane to only 15 pixels in 2011), this so-called ‘dithering’ scheme (see Jensen et al. 2003 for details) is essential for SPI image reconstruction; indeed, combining the information obtained from a set of dithered pointings is crucial for obtaining a good precision of the flux extraction algorithm (see e.g. Joinet et al. 2005). Therefore, we recommend not analyzing observations consisting of less than 10 – 20 pointings, depending on the complexity of the field of view/sky model.

⁷ See Appendix for more information

8.2. Background pattern determination

The background pattern corresponds to the non-uniformity map of the detector plane, due to intrinsic differences between each individual detector and their localization inside the detector plane (centre or closer from the ACS). It is determined through “empty field” observations. We have checked that the while not perfectly stable, its time evolution is very small and we propose a set of one “empty field” per six months. They are part of the default configuration and can not be modified by the user. Only the timescale evolution of the background normalization over the analyzed period has to be defined (see Section 5.2).

8.3. Pointing pre-cleaning

The purpose is to clean as much as possible ‘bad’ pointings, that is to say, we identify with unacceptable variabilities in the background count-rate (generally related to exit/entry in the radiation belts or strong solar activity).

We resolved the equation $D = \lambda * B$

With D , the data and B , the background pattern (see Section 8.2), both being 19 elements vectors.

This analysis is performed on 2 energy bins ([145-192] keV and [200-300] keV). Pointings for which $\chi^2 > 6.8$ and/or $\lambda > 1.5$ are excluded a priori.