# How to analyse compact sources with SPI in complex cases
# IUG action 01/05



| Prepared by: | Signature: |
|---|---|
| **Jean-Pierre ROQUES**<br>**Elisabeth JOURDAIN** | |
| Accepted by: | Signature: |
| | |
| Approved and Application authorized by: | |
| | |



Number of pages: 21

Secretariat of origin: CESR - Pascale Ramon

Host system: PC

Host software:

| Word Processing | Drawings |
|---|---|
| Word 2000 | / |

| C.E.S.R. | EXTERNAL DISTRIBUTION |
|---|---|
| Jourdain E.<br>Roques J.P. | Courvoisier T. (ISDC PI)<br>Integral User Group |

# DOCUMENT CHANGE RECORD

| Edition | Revision | Date | Modified pages | Observations |
|---|---|---|---|---|
| 1 | 0 | 05/09/05 | / | **First issue** |
| **1** | **1** | 08/09/05 | All | Main modifications are indicated by a vertical bar in the right margin |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

## - TABLE OF CONTENTS -

## 1. INTRODUCTION

This document presents some guidelines for SPI data analysis of point sources using SPIROS software. It is far to be complete and alternatives can be discussed. However, the recommendations given here follow our basic approach and should produce reliable results.

## 2. SPI DATA ANALYSIS PRINCIPLES

The SPI data rely on a sky image seen through a coded mask by 19 detectors. From that, it follows that each source projects on the detection plan a shadow specific to its direction (relative to the SPI axis pointing). Conversely, a given detector can receive the contribution of several sources, the counts being mixed in the data.The SPI transfer function is complex and cannot be inverted. The reconstruction procedure is based on a model-fitting method, which attributes, to a given incident angle, the flux contained in the corresponding expected pattern (through an energy matrix response).

The SPI data for a given energy bin, integrated during a time interval within a pointing p can be expressed as:

$$D_p = \sum_{s=1,m} \alpha_{s,p} \, x \, M_{p,s} + B_p \tag{1}$$

Where D, M, B are 19 elements vectors (one element per detector), and represent respectively:

- D : data (number of counts) measured on the detector plane
- $a_S$ : source intensity
- $M_{p,\,s}$ : SPI response for the source s for the pointing direction p
- $B_p$ : background on the detector plane for the pointing p

The small number of detectors is the strongest limitation of SPI. Indeed, we have only 19 data to reconstruct a sky region which can contain several sources plus a detector background.
This strongly limits the number of parameters that can be determined in the right side of the equation.

The dithering strategy has thus been adopted as it allows to accumulate data on a limited sky region. With the usual 5X5 dithering pattern, the sky region intercepted by the mask covers 24° x 24° (instead of 16°x16° for one pointing or staring mode), ie ~ 2.25 more but with an amount of data 25 times larger (or event more as the same dithering pattern is repeated up to 4 times in one orbit).

The consequence is to increase the number of equations, which implies:

- increase the number of parameters that can be determined
- and/or give better constraints to the parameters

The set of equations then obtained (p set of 19 eq.) can be solved by a "standard" minimisation procedure eg. $\chi^2$ minimisation.

The "art" of such a model fitting process is to:

- extract the maximum of information
- minimize the error on the parameters.

These two points are in contradiction and the challenge is to find the best compromise between these two requirements.

The optimisation can be done observing the following rules:

- introduce as much as possible extra-knowledge on the parameters
- search for the "minimal" sky model (minimum number of $\alpha_{s,\,p}$ parameters to be searched).

We will see how this can be done in the next sections.

### 2.1. Minimisation of the number of free parameters: Background determination

The background determination is a key point from a mathematical and physical point of view. Mathematically, it represents “basically” 19 unknowns by pointing and thus, if no prior is introduced, prevents any solution. In order to solve eq. (1), we will see how to minimize the number of free parameters for the background, under the constraint to have a "correct" background determination.

#### 2.1.1. Determining one background per detector : SPIROS mode 2

The background in eq. (1) for p pointings is a matrix BB of 19 (detectors) x p (pointings) elements.

We assume that:

1. For each detector, the background variation with p follows a known-law (for instance it can be constant)

2. The background absolute normalisation has to be determined.

Then:

$BB\,(p,d) = \beta_d \times b_d\,(p)$ where $b_d\,(p)$ is known

We have then 19 values (vector $\beta$) to determine, instead of 19 x p.

This can be generalized if $b_d$ is a linear combination of n components. In this case we have to derive 19 x n values for $\beta$. In particular, this allows to determine a background normalisation by time interval. This is what is done with the background mode 2 in SPIROS.

Method characteristics:

- n background components per detector are derived i.e. 19 x n parameters. The risk is that this determination can be influenced by the modulation of the sources in the field-of-view.
- The background variation for each of the 19 x n components has to be known.

### 2.1.2. Determining the overall background rate : SPIROS mode 3

It has been shown that, for a given energy bin, the background pattern on the detector plane (uniformity map) can be considered as constant.

This assumption can be considered valid:

- If the background rate variation is reasonable: solar flare, high solar activity, radiations belts should be excluded.
- If we consider on a reasonable period of time (some months).

In this case: BB (p,d) = $\beta$ U(d) where U(d) is the uniformity map also named empty-field reference.
$\beta$ is the background normalisation that has to be determined. This can be generalized by allowing the background normalisation $\beta$ to vary in n time intervals. Then we have n values to determine.

This is what is done in SPIROS Mode 3.

Method Characteristics:

- n parameters have to be determined $1 \leq n \leq p$
- the background pattern is known.

Limitations:

The background (spatial) pattern has to be constant and known.

A variant of this method is the MCM implemented in SPIROS: background mode 5, where U(d) is automatically determined.
This should be reserved to experienced users as U(d) can be poorly determined is some cases.

### 2.1.3. Recommendations for background handling

Our preferred method is background mode 3 since it reduces the number of free parameters and produces reasonable description of the data.

The background normalisation should be kept constant unless its variation is assessed. This assessment can be done looking at the various counting rates in the science HK data.

If the background variation is required, be careful to determine the minimal number of free parameters.

The introduction of un-needed background variation can mask/compensate an imperfection of the sky model and increases the number of free parameters.

The choice of the empty-field reference should be made carefully. At CESR we use mainly :

- Revolution 72 for revolutions up to 140 (19 det)
- Revolution 158 for revolutions 142 - 214 (18 det)
- Revolution 220 after revolution 215 (17 det)

Note that Revolution 220 is not public; a solution should be found in agreement with the Project Scientist. It is mandatory that some private data can be used as background reference.

### 2.2. Sky model determination

#### 2.2.1. Source position search

SPIROS-IMAGING works both with known and unknown sources. If an input catalogue is given, SPIROS will first build a sky model with the proposed sources then looks for a (parametrable) number of new ones required by the data. One must take care of the influence of the source position errors on the image generation. If the source position introduced in SPIROS is different from the true position (even slightly), the iterative removal of sources algorithm leads to subsequent artefacts in the image. This problem may become important for strong sources or when a large number of sources are in inaccurate positions. Thus, whenever possible, the exact source positions should be introduced in SPIROS as *a-priori* knowledge (input catalogue) in order to avoid these cumulative errors. But, a contrario, to use an input catalogue with too many (non-emitting) sources also leads to an unstable solution.

Thus in practice we recommend to try to find the minimal sky model able to explain the data. Concerning the input source catalogue we then recommend to use a progressive introduction of the a-priori knowledge:

1. Run SPIROS without input catalogue
2. Identify the sources (at first iteration, the strongest ones) ; create an input catalogue with them
3. Run SPIROS with this input catalogue and search for new sources
4. Go to step 2 and stop if the catalogue is unchanged.

The user should look carefully at the SPIROS output log.
Among a lot of useful data the user should look at:
- the final reduced $\chi^2$
- the $\chi^2$ per science windows

A high reduced $\chi^2$ or some high $\chi^2$ in some science windows can indicate:

- an incomplete sky model: Some sources can be missing or strongly vary (SPIROS - IMAGING keeps the sources constant).

- a wrong background model: In many cases users remove some "bad" science windows under some "background problem" arguments. In the majority of the cases this argument is wrong and a background variation is not the reason of this bad $\chi^2$.

**Recommendation to users:**

- Introduce progressively an a-priori knowledge in SPIROS for source positions.
- Don't declare science windows as "bad" without justification. This very often masks an incomplete sky model: the introduction of source variability (SPIROS mode TIMING) will often clarify the situation.
- Sources search should be done in a few energy bands to catch all sources. Some sources are very soft and should be searched in the first energy channels.

A new SPIROS mode TIMING-IMAGING has been developed but has not been tested for the present version of this document. It will allow to search for sources together with an input catalogue where time variability has been introduced.

2.2.2. Determination of sources fluxes and spectra

Coming back to eq. (1), the detector pattern M for a given source varies with p, the pointing direction. Thus if a source is assumed to be constant $\alpha_s(p)$ = cste, no satisfactory solution can be found if the source is truly significantly variable.
At the opposite if all sources are supposed significantly to vary on the p timescale, the number of free parameters will increase. There again the user should find the best compromise.
SPIROS TIMING mode allows the introduction of source time variability. The variability timescale that will be used in SPIROS is introduced in the input catalogue.

SPIROS in TIMING mode then produces a light curve of sources within the defined time bins.
In presence of strong variable source i.e. 4U1700-377 you will immediately note a decrease of $\chi^2$ values when you introduce the 4U1700 variability.

We recommend to progressively introduce the minimal needed source variability.

SPIROS in TIMING mode also produces the spectra for each source: 1 spectrum per time bin plus its mean spectrum.

## 3. A COMPLEX CASE : GX339-4 FIELD

We have chosen an observation pointed on GX339-4 (rev 166) as an example of complex analysis as this field contains a dozen of potentially hard X-ray emitting sources and at least one of them highly variable (4U1700-377) at the field border.

We propose here a procedure which can be used as a basic and reliable analysis. The data analysis should however remain an empirical practice and the user is not to be afraid to test several configurations to get his/her own idea.

### 3.1. Data preparation: Choice of good data + background construction

First, the periods corresponding to the radiation belts entries are to be suppressed in the Science windows (Scw) list. If not, these pointings (the few last Scw) give awful chi2 values (> 1000) in the SPIROS output. Beyond that, it could be necessary to exclude Scws corrupted by solar activity. The diagnostics can be made, for example, with the SPI ACS count rates.
In our example, we use the Scw 1 to 70.
We use systematically a flat-field background built from a revolution without source (here rev 158) and the mode 3 background method. As the ACS count rates are very stable, the background will be considered as constant in our analysis.

### 3.2. Catalogue construction

The light curves and spectra are built by model fitting method. It is thus crucial to introduce a sky model as clean as possible i.e. with all the emitting sources (up to a given significance) and no more. Too less or too much sources can both lead to unreliable results. This is easy to do by running SPIROS in IMAGING mode to detect and localise the sources. Note that the sources fluxes being kept constant, chi2 values can be high when strong variable sources are present (like in the chosen revolution). The final test will be done in TIMING mode to check whether the sky model is close enough to the data ( again by the chi2 values).

*General philosophy* :

Let SPIROS to find a reasonable number of sources (5, in the most common cases, 10-15 in a complex region) without input catalogue. Then, introduce prior progressively: the brightest (identified) sources are introduced in an input catalogue with their positions **fixed** (to theoretical ones if identified). SPIROS is re-run with this input catalogue + still 5-10 sources to be searched for. Update catalogue with new strong or identified sources. Iterate up to get no significant (i.e. > ~ 3-4 $\sigma$) new excesses

Spiros parameters:

| | |
|---|---|
| **Mode** | IMAGING |
| **Background mode**: | 3 |
| **Energy bands**: | 20-27 keV (to search for soft sources).<br>23-50 keV (Maximal sensibility of SPI) |
| **Image-fov**: | POINTING-ZFCOV (all the sources present in the total field of view (16° by 16°) are to be considered as they can light detectors. Here, 4U1700-377 is between 7° and 15.6°, a particularly sensitive case due to its intensity.) |

The recommended procedure (illustrated with our example):

- Step 1: Spiros Imaging **without input catalogue**,
  **nofsources** =10 (number of sources searched for)

Results: Output catalogue with detected excesses positions, proposed identifications and the distance between them.

Output Catalogue 1:

Erange (keV) [ 23.4 - 51.0]

SOURCE-1 256.20068 -37.89108
Mcrab is 191.7057 +/- 2.3115
Possible identification
255.98654 -37.84414 **4U 1700-377** 0.18

*****************************************************

SOURCE-2 248.22607 -47.54560
Mcrab is 69.5346 +/- 1.9081
Possible identification
248.00792 -47.87472 IGR J16320-4751 0.36
248.21666 -47.76833 AX J1632.8-4746 0.22
248.46829 -48.11125 AX J1633.8-4807 0.59
248.50166 -47.39417 **4U 1630-47** 0.24
248.85417 -47.47333 AX J1635.4-4728 0.43
248.96600 -47.58981 SGR 1627-41 0.50
248.97417 -47.42808 IGR J16358-4726 0.52
248.97917 -47.33167 AX J1635.9-4719 0.55
249.11667 -47.82694 KS 1632-477 0.66

*****************************************************

SOURCE-3 256.99121 -44.05267
Mcrab is 108.3533 +/- 1.9861
Possible identification
257.22751 -44.10056 **H 1705-440** 0.18
257.42813 -44.48517 PSR B1706-44 0.53
*****************************************************

SOURCE-4 263.06683 -34.27795
Mcrab is 145.3585 +/- 5.2682
Possible identification
262.98917 -33.83472 **GX 354-0** 0.45
263.35040 -33.38778 4U 1730-335 0.92
*****************************************************

SOURCE-5 249.25262 -53.34265
Mcrab is 83.7677 +/- 2.0617
Possible identification
250.23125 -53.75139 **H 1636-536** 0.71
*****************************************************

SOURCE-6 243.14325 -42.28708
Erange (keV) [ 23.4 - 51.0]
Flux is 0.0049+/- 0.0004
Mcrab is 28.0322 +/- 2.3175
Possible identification
*****************************************************

SOURCE-7 258.64221 -29.42226
Mcrab is 507.9479 +/- 27.2824
Possible identification
*****************************************************

SOURCE-8 237.93375 -37.70143
Mcrab is 111.1090 +/- 5.9175
Possible identification
*****************************************************

SOURCE-9 243.28569 -53.98683
Mcrab is 35.0349 +/- 2.0538
Possible identification
*****************************************************

SOURCE-10 266.81223 -34.24802
Erange (keV) [ 23.4 - 51.0]
Flux is 0.0155+/- 0.0011
Mcrab is 89.4627 +/- 6.1782
Possible identification
267.20001 -32.90000 IGR J17488-3253 1.39
267.46085 -33.19861 SLX 1746-331 1.18
*****************************************************

The associated mean chi2 is 13.03. This high value is unavoidable due to the 4U 1700 variability, not taken into account in the IMAGING Mode.

- Step 2: We used the first result to fix the positions of the most intense sources in **input _catalogue.fits** and re-run Spiros (IMAGING) WITH this catalogue (5 sources) in input + **nofsources** = 7 sources to be searched for in addition.

Output Catalogue 2:

Erange (keV) [ 23.4 - 51.0]

4U1700-377 255.98666 -37.84977
Mcrab is 185.0008 +/- 2.4685
Possible identification
255.98654 -37.84414 **4U 1700-377** 0.01
*****************************************************

4U1630-47/GX337-00 248.50165 -47.39418
Mcrab is 71.6173 +/- 2.0133
Possible identification
248.00792 -47.87472 IGR J16320-4751 0.58
248.21666 -47.76833 AX J1632.8-4746 0.42

248.46829 -48.11125 AX J1633.8-4807 0.72
248.50166 -47.39417 **4U 1630-47** 0.00
248.85417 -47.47333 AX J1635.4-4728 0.25
248.96600 -47.58981 SGR 1627-41 0.37
248.97417 -47.42808 IGR J16358-4726 0.32
248.97917 -47.33167 AX J1635.9-4719 0.33
249.11667 -47.82694 KS 1632-477 0.60
*****************************************************

H1705-440 257.22702 -44.11553
Mcrab is 94.5932 +/- 1.9174
Possible identification
257.22751 -44.10056 **H 1705-440** 0.01
257.42813 -44.48517 PSR B1706-44 0.40
*****************************************************

GX354-0 262.99417 -33.82812
Mcrab is 130.0836 +/- 5.0994
Possible identification
262.98917 -33.83472 **GX 354-0** 0.01
263.35040 -33.38778 4U 1730-335 0.53
*****************************************************

V*V801Ara/H1636-536 250.21408 -53.73570
Mcrab is 66.9946 +/- 1.8963
Possible identification
250.23125 -53.75139 **H 1636-536** 0.02
*****************************************************

SOURCE-6 255.45692 -49.16973
Mcrab is 44.4948 +/- 1.8235
Possible identification
255.70625 -48.78972 **GX 339-4** 0.41
*****************************************************
SOURCE-7 247.24854 -40.72343
Mcrab is 40.9782 +/- 2.1634
Possible identification
247.75000 -40.60000 3EG J1631-4033 0.40
247.89999 -40.46667 **IGR J16316-4028** 0.56
*****************************************************
SOURCE-8 256.58627 -28.00217
Mcrab is 478.5385 +/- 37.5503
Possible identification
257.55124 -28.13167 XTE J1710-281 0.86
*****************************************************

SOURCE-9 251.69943 -44.65913
Mcrab is 27.6022 +/- 1.9099
Possible identification
251.44875 -45.61111 **GX 340+0** 0.97
251.64792 -45.11778 IGR J16465-4507 0.46
252.02499 -45.23333 IGR J16479-4514 0.62
252.38333 -43.83556 PSR J1649-4349 0.96
*****************************************************

SOURCE-10 259.84250 -38.40267
Mcrab is 37.9553 +/- 2.3985
Possible identification
259.00000 -38.90000 XTE J1716-389 0.82
259.52084 -37.44833 AX J1718.0-3726 0.99
259.59583 -39.35167 4U 1715-39 0.97
260.27499 -37.44833 AX J1721.0-3726 1.01
****************************************************

SOURCE-11 243.69208 -45.06185
Mcrab is 31.4981 +/- 2.3688
Possible identification
****************************************************

SOURCE-12 258.71341 -29.57037
Mcrab is 227.7756 +/- 27.3221
Possible identification

The associated mean chi2 is 12.80, but here too, this value is not very conclusive.
The most striking result is that fixing the intense sources (particularly 4U1700) allows to detect GX339-4, IGR J16316-4028 and GX 340+0. The 8$^{th}$ source is not considered due to it big flux errors (related to an off-axis position).

The output catalogue obtained in the low energy band (20-27 keV) lead us to add OAO 1657-415 to our 2nd catalogue for a total of 9 sources.

- Step 3: A last run of SPIROS/IMAGING with this updated catalogue shows that any other interesting excess appears in the low energy band while something around the SAX J1712.6-3739 can be considered as plausible source with ~ 50 mCrab (23-50 keV ) and a significance of 15 σ.

| IMAGING MODE : Fluxes are only indicative |
|---|

**RECOMMENDATIONS** for the catalogue construction:

BACKGROUND Mode 3
Use **Image-fov** = POINTING-ZCFOV
Begin without input catalogue but a reasonable number of sources to be searched (5 for “normal” fields, 10-15 for crowded ones).
Iterate a few times with SPIROS by updating the input catalogue with strongest identified excesses.
Check to chi2 values in **TIMING** mode to confirm the detection of the weakest sources.

### 3.3. TIMING Mode: Light curves extraction

When the catalogue is completed (or thought to be), a variability timescale is to be chosen for the detected sources and SPIROS runs in TIMING mode.

We have to :

- change SPIROS mode: **Mode** TIMING
- fill the Input_catalogue with timescale parameters:

*General philosophy*:

The Input source catalogue is crucial for the results reliability. As already explained, the number of considered sources and the associated variability timescales have to be as close as possible to the "data reality", i.e. the best compromise between the reality (which has rigorously a infinite complexity) and the statistics reflected in the data. To add free parameters (a source or a smaller temporal binning) has to be a-posteriori justified by a significant chi2 decrease. A good way is to run SPIROS/TIMING with the strongest sources let to be variable one after the other and check how the chi2 (individual Scw and global) vary. The timescale could be of 1 to 5-6 Scw following the count rates. 4U1700-377 is an extreme case as its influence on the chi2 is such that it must be kept variable on a 1 Scw timescale even during the other sources tests.

In our example:

For the TIMING mode, the input catalogue has to be filled with Name, RA_OBJ, DEC_OBJ(position), VAR_MODL (whatever a string), VAR_PARS (see below ) and SEL_FLAG for the asked for sources.

For this observation, we have fill it by:

| NAME | RA_OBJ | DEC_OBJ | VAR_MODL | VAR_PARS | SEL_FLAG |
|---|---|---|---|---|---|
| 20A | 1E | 1E | 128A | 8E | 1I |
| | deg | deg | | **to expand** | |
| 4U1700-377 | 2.559867E+02 | -3.784977E+01 | CONSTANT | 0.000000E+00 | 2 |
| 4U1630-47 | 2.485282E+02 | -4.742179E+01 | CONSTANT | 0.000000E+00 | 2 |
| GX339-4 | 2.557108E+02 | -4.879122E+01 | CONSTANT | 0.000000E+00 | 1 |
| H1705-440 | 2.572270E+02 | -4.411554E+01 | CONSTANT | 0.000000E+00 | 2 |
| GX354-0 | 2.629942E+02 | -3.382812E+01 | CONSTANT | 0.000000E+00 | 1 |
| GX340+0 | 2.514527E+02 | -4.562418E+01 | CONSTANT | 0.000000E+00 | 1 |
| IGRJ16316-4028 | 2.479010E+02 | -4.046674E+01 | CONSTANT | 0.000000E+00 | 1 |
| OAO1657-415 | 2.552141E+02 | -4.166098E+01 | CONSTANT | 0.000000E+00 | 1 |
| H 1636-536 | 2.502141E+02 | -5.373570E+01 | CONSTANT | 0.000000E+00 | 1 |
| SAXJ1712.6-3739 | 2.581607E+02 | -3.73538E+01 | CONSTANT | 0.000000E+00 | 1 |

The SEL_FLAG can take 3 values:

- 0 : SPIROS does not consider the source
- 1 : SPIROS considers the source as constant , so does not read anything more
- 2 : SPIROS considers this source as variable and reads VAR_MODL and (IF VAR_MODL contains a string, whatever it is) VAR_PARS columns.

The VAR_PARS column consists of 8 sub_columns describing the variability parameters for each source. The sub_column N° 5 contains the required timescales.

We have chosen

- 4U1700-377 : 0.0 (corresponds to 1scw timescale. Note that the **source-timing-scale** keyword has to be set to 0.0 also)
- 4U1630-47 : 0.1259 day (3 H, ~ 3-4 Scws)
- H1705-440 : 0.1259 day
- GX339-4, GX340+0, GX354-0, IGR16316-4028, OAO1657-415, XTEJ1710-281, H1636-536, SAXJ1712.6 : no needed as SEL_FLAG = 1

After running SPIROS in TIMING mode, we get a mean reduced $\chi 2$ value equal to 1.92 and the following mean significance for each source:

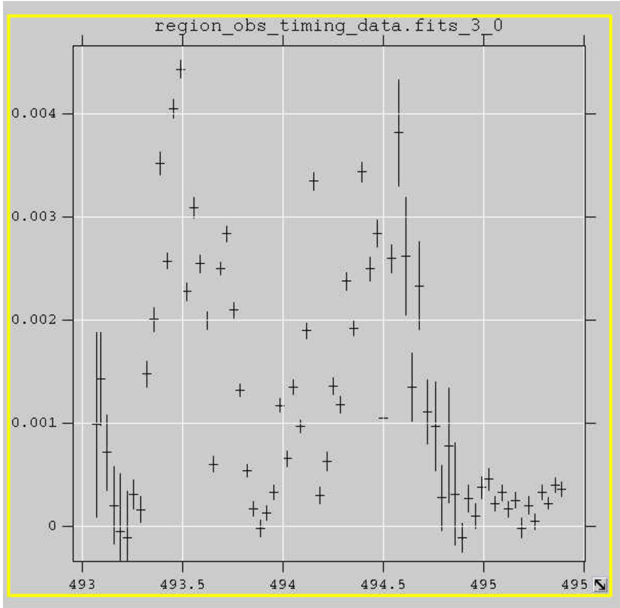
| | | |
|---|---|---|
| 1 | 4U1700-377 | 44.2 |
| 2 | 4U1630-47/GX337-00 | 52.1 |
| 3 | GX339-4 | 23.3 |
| 4 | H1705-440 | 50.6 |
| 5 | GX354-0 | 28.9 |
| 6 | GX340+0 | 16.2 |
| 7 | IGRJ16316-4028 | 12.1 |
| 8 | OAO1657-415 | 10.6 |
| 9 | V*V801Ara/H1636-53 | 21.2 |
| 10 | SAXJ1712.6-3739 | 6.1 |

The last source, SAXJ1712.6-3739, has a low significance and may be removed from the minimal sky model.
A run with only 9 sources gives a mean $\chi 2$ = 1.95 and only slight changes in the other sources significances.
Other configurations can be tested. For instance, to consider H1705-440 as constant leads the mean reduced $\chi 2$ value to increase to 2.08. If we then "forget" GX340-0, this value further increases to 2.27.

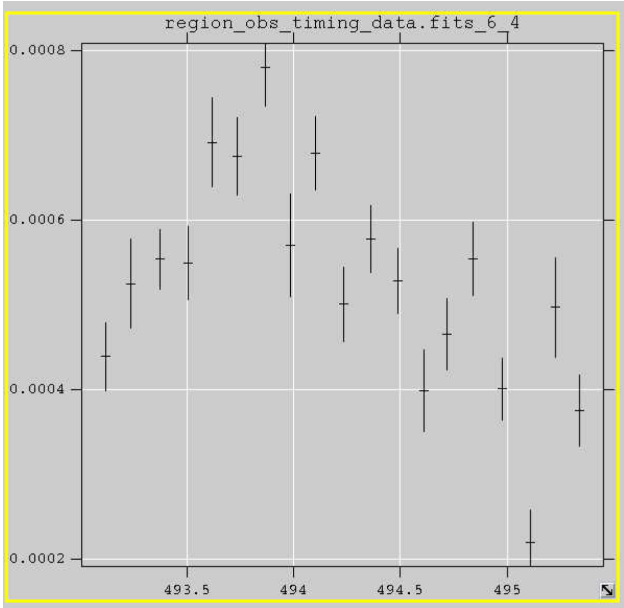
Looking at individual $\chi 2$ values by Scw, we note that some of them are still rather high (up to 3.5 in the 23-51 keV energy range), proving that the proposed sky model is incomplete, probably in its temporal variability. Nevertheless, the main characteristics are well determined.

We get in output (filename given by the **source-timing** keyword), the light curves of background (row index 2) and of each source (in the same order as in the input catalogue).

We show here the light curves of 4U100-377 on the 1 Scw timescale and H1705-440 in the 3 H timescale in the 23-50 keV energy band.




4U 1700-377




H1705-440

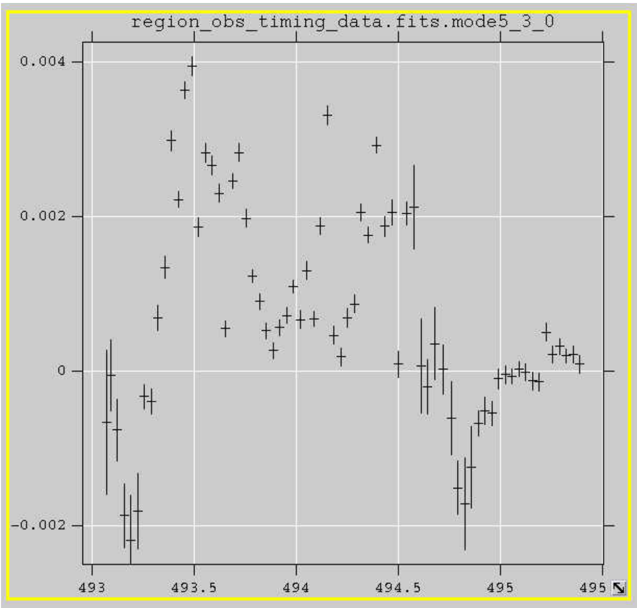
* To illustrate how the chi2 values help to do a diagnostic, we present below the SPIROS outputs obtained when the soft source GX340-0 is respectively missing and included in the 20-23 keV energy band:

.

| | | without GX340-0 | With GX340-0 | | | without GX340-0 | With GX340-0 |
|---|---|---|---|---|---|---|---|
| 166 | 1 | 0.54 | 0.67 | 166 | 36 | 1.50 | 1.41 |
| 166 | 2 | 2.06 | 1.74 | 166 | 37 | 2.03 | 1.73 |
| 166 | 3 | 1.13 | 0.80 | 166 | 38 | 1.31 | 0.94 |
| 166 | 4 | 0.57 | 0.50 | 166 | 39 | 0.82 | 0.79 |
| 166 | 5 | 0.75 | 0.71 | 166 | 40 | 1.38 | 1.19 |
| 166 | 6 | 1.17 | 1.68 | 166 | 41 | **2.27** | **1.45** |
| 166 | 7 | **1.70** | **1.01** | 166 | 42 | 0.97 | 0.78 |
| 166 | 8 | 2.00 | 1.79 | 166 | 43 | 1.35 | 1.18 |
| 166 | 9 | 1.04 | 0.69 | 166 | 44 | 1.10 | 1.11 |
| 166 | 10 | 1.04 | 0.83 | 166 | 45 | 0.70 | 0.54 |
| 166 | 11 | 1.55 | 1.27 | 166 | 46 | 1.27 | 1.12 |
| 166 | 12 | **1.67** | **1.25** | 166 | 47 | 1.02 | 1.16 |
| 166 | 13 | 1.94 | 1.64 | 166 | 48 | 0.98 | 0.88 |
| 166 | 14 | 0.91 | 0.99 | 166 | 49 | 1.91 | 1.56 |
| 166 | 15 | 0.99 | 1.26 | 166 | 50 | **2.26** | **1.42** |
| 166 | 16 | 1.42 | 1.43 | 166 | 51 | 1.07 | 0.85 |
| 166 | 17 | **2.10** | **1.59** | 166 | 52 | 1.41 | 1.54 |
| 166 | 18 | 1.47 | 1.29 | 166 | 53 | 0.56 | 0.97 |
| 166 | 19 | 1.04 | 0.88 | 166 | 54 | 1.21 | 1.11 |
| 166 | 20 | 1.16 | 1.00 | 166 | 55 | 1.19 | 1.08 |
| 166 | 21 | 1.84 | 1.61 | 166 | 56 | 1.28 | 1.18 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 166 | 22 | **2.69** | **2.18** | 166 | 57 | 1.63 | 1.40 |
| 166 | 23 | 1.13 | 1.23 | 166 | 58 | 1.31 | 0.89 |
| 166 | 24 | 1.35 | 1.22 | 166 | 59 | **2.68** | **2.10** |
| 166 | 25 | **2.88** | **2.27** | 166 | 60 | 1.57 | 1.54 |
| 166 | 26 | 0.77 | 1.18 | 166 | 61 | 0.98 | 0.89 |
| 166 | 27 | 0.90 | 0.54 | 166 | 62 | 1.18 | 1.16 |
| 166 | 28 | **2.24** | **1.75** | 166 | 63 | 1.93 | 1.80 |
| 166 | 29 | 2.68 | 2.47 | 166 | 64 | 1.34 | 1.19 |
| 166 | 30 | 1.56 | 1.29 | 166 | 65 | 1.11 | 0.90 |
| 166 | 31 | 1.16 | 0.99 | 166 | 66 | 1.49 | 1.39 |
| 166 | 32 | 0.54 | 0.32 | 166 | 67 | 1.59 | 1.54 |
| 166 | 33 | 1.18 | 0.98 | 166 | 68 | 1.25 | 1.02 |
| 166 | 34 | 1.42 | 1.18 | 166 | 69 | **1.38** | **0.87** |
| 166 | 35 | 1.04 | 0.73 | 166 | 70 | **2.09** | **1.63** |

* As an example of potential problem with bad background mode choice, we present here the 4U1700-377 light curve obtained with the background parameter put to 5.




This light curve presents points with significantly negative fluxes when the source is far from the SPI axis. Indeed, as 4U1700-377 lights only a small fraction of the detector, it perturbs the background estimation in this specific mode and thus the sources fluxes determination.

**RECOMMENDATIONS** for the timing analysis:
BACKGROUND mode 3

***How to choose the time scales***:

Goal: They have to be as long as possible without degrading the $\chi 2$.
Method: To adapt to take into account:

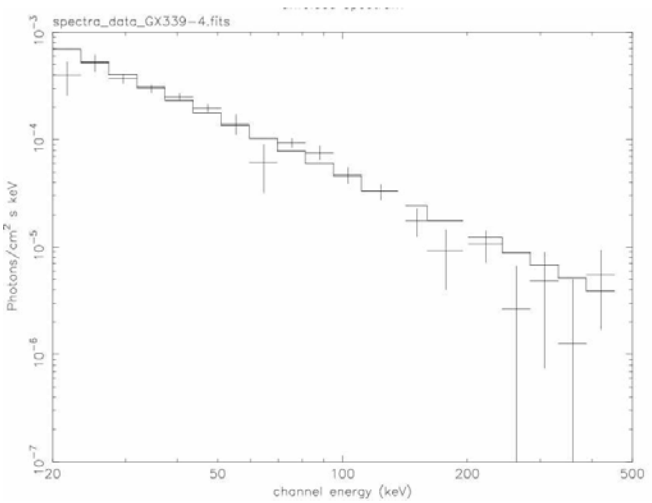
- The source intensity (for each binning contains a statistically significant counts number)
- An a priori variability information (periodicity ?, flaring ?, X-ray temporal behavior,….)
- Results obtained with a short timescale showing the global evolution.
- The chi2 improvement (or not) brought by any additional parameter (see SPIROS log file).

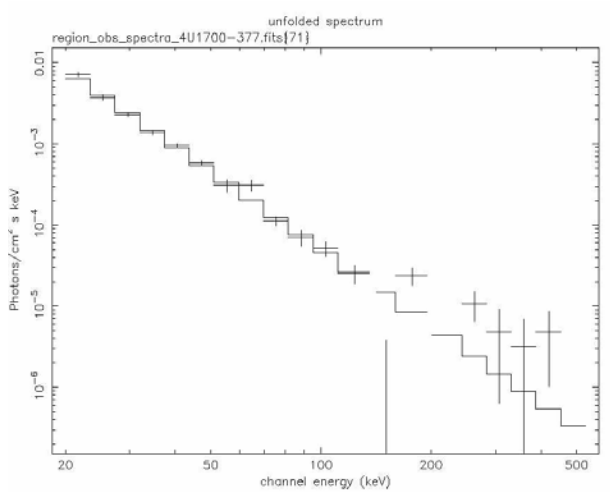
A temporal bin should contain 3-4 $\sigma$, in average.

### 3.4. TIMING Mode: Spectra extraction

The best way to obtain spectra when sources are variable is to use here too the TIMING mode, with the only change that we ask for ALL energy bins to be treated (**srclocbins** keyword), to have more than 1 channel. The variability timescales as defined above will then be taken into account and a spectrum by time bin will be built for each source of the input_catalogue. Moreover, a mean spectrum is built when the number of time bins in greater than 1. These data are stored in the output files used in the SPECTRAL mode (**source-spec-idx** and **source-spec** keywords).
In our case, keeping the same timescales than above, we get the spectra of GX339-4 and 4U1700 shown below.

However, as the sources variability is less crucial in the spectral analysis, we can suggest to chose longer timescales in the input_catalogue. In our example, all sources but 4U1700 can be taken as constant. We have even checked that to consider 4U1700-377 as constant does not change its mean spectrum nor the GX339-4 spectrum significantly.



# 4. POINT SOURCES AND DIFFUSE EMISSION

## 4.1. Diffuse emission due to Cosmic rays Interactions

IBIS and SPI have demonstrated that this emission integrated over the Central Galactic radian is less than 10% of the total discrete source emission. It is clear that, except when SPI data are integrated over very long period (years), we don't expect major data analysis problem if this emission is neglected.

## 4.2. Narrow line 511 keV study

SPIROS offers through its input catalogue the possibility to include extended sources, with fixed size. Then the 511 keV distribution can be included as a source with a 8° x 8° Gaussian shape and located at l = 0°, b = 0°. We have tested the influence of this component on the 511 keV image generation of the Galactic Centre region. We have used a selection of 2252 Scws between revolution 47 and 123, which represents 5.7 Ms. The energy range is 505-516 keV. The background method is mode 3 with a timescale variation of 1 day.

### 4.2.1. <u>Image reconstruction without diffuse 511 keV emission</u>

We have run SPIROS in IMAGING mode without input catalogue and found 6 sources above 6 $\sigma$ within a 16° circle around the Galactic Centre.

### 4.2.2. <u>Image reconstruction with diffuse 511 keV emission</u>

We have run SPIROS in IMAGING mode with an input catalogue containing the diffuse component and asked SPIROS to search for sources. The diffuse component has been detected at 18 $\sigma$, with a flux of ~ 10-3 ph cm-2 s-1. No source above 3 $\sigma$ has been detected within a 16° circle around the Galactic Centre.

## 4.3. Point source flux in the 300 – 500 keV domain

In the Galactic Centre Region, this energy range can be disturbed by the positronium emission when long integration duration has been chosen. We have used the same SPIROS features as for the 511 keV tests and the same data set. We have tried to determine the flux of 6 point sources: 4 are detected in the 300 – 600 keV domain and 2 are added for test purpose.

### 4.3.1. <u>Results without positronium component</u>

| Source name | Cnts /cm2 s | significance |
|---|---|---|
| CenA | 0.1655E-02 | 3.3 |
| IGRJ17464-3213 | 0.5796E-03 | 5.8 |
| 1E1740.7-2943 | 0.9645E-03 | 9.4 |
| GRS1758-258 | 0.7186E-03 | 7.3 |
| GS1826-24 | 0.6521E-03 | 6.4 |
| 4U1700-377 | 0.8155E-04 | 0.7 |

#### 4.3.2. Results with positronium component

| Source name | Cnts /cm2 s | significance |
|---|---|---|
| CenA | 0.1 8765E-02 | 3.7 |
| IGRJ17464-3213 | 0.1347E-03 | 1.2 |
| 1E1740.7-2943 | 0.4600E-03 | 4.0 |
| GRS1758-258 | 0.3732E-03 | 3.5 |
| GS1826-24 | 0.4716E-03 | 4.6 |
| 4U1700-377 | - 0.19E-04 | -0.2 |
| Positronium | 0.35e-03 | 9.7 |

#### 4.3.3. Discussion

One should note that the fluxes of all sources have decreased except Cen A and 4U1700-377 which are out of the region affected by the positronium emission. Moreover, 4U1700-377 does not emit in this energy range. The emission of IGRJ17464-3213 vanishes.
Using this simple recipe, the user can take into account any **known** diffuse emission but should be aware of the limitations of such an analysis. For instance, to ask for the flux of a large number of sources may produce unreliable results.

## 5. DISCUSSION AND CONCLUSION

The approach described here shows how to conduct SPI data analysis in order to extract reliable scientific information. However it is worth noting that this implies a proper set-up of the data reduction environment.

The GUI proposed by ISDC is adapted to simple cases but does not allow to conduct such an analysis in a blind and automatic way. However it is possible to run SPIROS analysis out of the GUI and then set the proper parameter values.

The main improvements that could be implemented in the ISDC scripts are:

- Mode 3 can be selected in the GUI, but does not work as the reference background files are not produced.
- Default SPIROS parameter values are not the best i.e. we recommend the use of the zero-coded-field of view.
- Timing mode through the GUI should be proved: the integration time scale is the same for all sources while SPIROS can handle more configurations.
- Access to the background visualisation (science HK data) should be proposed.
- A source identification assistant is needed.

The implementation of mode 3 is straight forward; it consists in a renormalisation of a reference empty field data file. To ease this process we propose a simple executable to the ISDC.

A detailed procedure for the analysis of GX339-4 field-of-view within the ISDC system will be issued soon, this should help ISDC to tune their system and should give an example to the users.

The analysis of the GX339-4 field-of-view is a rather complex case as this region contains several variable sources. In particular the presence and the temporal behaviour of 4U1700-77 require attention. We have shown that, thanks to P. Connell, SPIROS software handles all these difficulties and allows to derive spectra and light curves. We hope that the example given here will help to solve the majority of the cases. We again propose to any user our help and expertise for specific cases.