Aditya-L1

SOLAR LOW ENERGY X-RAY SPECTROMETER (SoLEXS)

Data Analysis Guide

Version 1.0

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Change History

Version number	Date	Affected section, Figure, Table	Nature of change	Description
1.0	January 2025	-	-	First Release

* A: Addition, M: Modification, D: Deletion

Contents

1 Introduction

Aditya-L1 is India's first space-based solar mission developed by the Indian Space Research Organisation (ISRO). Launched on 2 September 2023, the spacecraft was inserted in a halo orbit around Lagrangian point 1 (L1) of the Sun-Earth system on 6 January 2024. Solar Low Energy X-ray Spectrometer (SoLEXS), one of the payloads on Aditya-L1, is a sun-as-a-star spectrometer in the energy range of 2 keV to 22 keV. It employs Silicon Drift Detector (SDD) as sensor element to detect energy. SDD is particularly suited for solar soft X-ray flux monitoring because of its high-event rate handling capability ($\sim 10^5$ counts/second) and low noise performance with energy FWHM of ∼170 eV at 5.9 keV. The on-board processing unit histograms the recorded energies of the X-ray events to build a spectrum every second to capture the impulsive solar activity. To cover an extensive dynamic range from A class to X class flares, the payload has two apertures with geometric areas of 7.1 and 0.1 mm^2. The detailed specifications of the payload are provided in Table 1.

This document serves as a data analysis guide for working with SoLEXS data. It introduces the SoLEXS data products, calibration database, and a python package named SoLEXS_Tools. It also outlines a workflow for preparing and analyzing SoLEXS data using spectral fitting tools, along with an example case study of a solar flare. By following the instructions in this document, users will be able to derive important plasma parameters such as temperature, emission measure, and elemental abundances from SoLEXS data.

Table 1: Specifications of SoLEXS

Parameter	Specification
Energy Range	2 – 22 keV (2.8 – 22 keV for spectral fitting)[1]
Energy Resolution	∼ 170 eV @ 5.9 keV
Time Cadence	Spectral Channel: 1 second Temporal Channel: 1 second
Detector	
Type Number Active Area Thickness Entrance Window	Silicon Drift Detector (SDD) 2 (named SDD1 & SDD2) 30 mm^2 450 ± 20 μm 8 μm thick Be
Aperture Area	SDD1: 7.106 mm^2 SDD2: 0.106 mm^2
Field of View	SDD1: ± 1.8° SDD2: ± 1.3°
Calibration Source	Fe-55 with Ti foil
Digital Pulse Processing parameters	
Pulse peaking time (triangular pulse)	Spectral Channel: 2 μs Temporal Channel: 0.35 μs
Number of channels in the spectrum	340
Channel Width	1 - 168 channel: ∼ 47.6 eV 169 - 340 channel: ∼ 95.2 eV

[1] The instrument response between 2 to 2.8 keV is currently uncertain, and efforts are underway to optimize and verify it. Users are advised to use spectral data above 2.8 keV for modeling. This will be updated in the next release.

2 SoLEXS Data Products

SoLEXS data is hosted on the PRADAN website[2], where it is made available in a day-wise format. Users can select and download the required files using various options provided on the website.

2.1 Level-1 Data Products

SoLEXS Level-1 (L1) data files are provided in FITS (Flexible Image Transport System) format, compressed using the gzip algorithm. Additionally, all L1 data files conform to the OGIP standards, ensuring compatibility with standard astronomical data analysis tools like XSPEC[3] and Sherpa[4].

2.1.1 Good Time Intervals (GTI) File

The level-1 GTI file lists the time intervals during which the detector was collecting valid data. These intervals are determined based on several criteria:

1. The Sun was within the field of view of the instrument.
2. The specific detector (`SDD1` or `SDD2`) was operational.
3. The health parameters of the instrument were within the recommended ranges.

2.1.2 Light Curve (LC) File

The level-1 LC file provides a time series of counts detected in the energy range 2–22 keV at a cadence of one second for a given day.

The `RATE` extension includes the following columns:

1. `TIME`: Unix Time.
2. `COUNTS`: Counts per second in the energy range 2–22 keV .

2.1.3 Pulse Invariant (PI) Spectral File

The level-1 PI file is a Type-II Pulse Invariant (PI) spectral file containing energy-resolved calibrated spectra recorded at a cadence of one second for a given day. Each row in the `SPECTRUM` extension corresponds to a spectrum recorded with a one second integration time. The `SPECTRUM` extension includes the following columns:

1. `TSTART`: The start time of the integration interval.
2. `TELAPSE`: The integration time for the spectrum. For SoLEXS data, this is one second.
3. `SPEC_NUM`: A unique identifier for the spectrum within the file.
4. `CHANNEL`: The energy channel index.
5. `COUNTS`: The spectral counts detected in each energy channel during the integration interval.
6. `EXPOSURE`: The effective integration time after applying deadtime correction. (Note: Deadtime correction is not currently applied, so `EXPOSURE` is equal to `TELAPSE`.)

[2] `https://pradan.issdc.gov.in/pradan/al1`
[3] `https://heasarc.gsfc.nasa.gov/xanadu/xspec/`
[4] `https://sherpa.readthedocs.io`

2.2 Time in SoLEXS Data Products

All time-related data in SoLEXS files is recorded in Unix time, which represents the number of seconds elapsed since January 1, 1970, 00:00:00 UTC. Unix time is widely adopted in computing beyond its original application as the system time for Unix. Unix time is available in almost all system programming APIs. SoLEXS_Tools also provides utilities to perform such conversions described in section 3.3.1.

2.3 L1 Data Naming Convention

The naming convention for a SoLEXS Level-1 (L1) data file downloaded from PRADAN is as follows:

```
AL1_SLX_L1_YYYYMMDD_vM.n.zip
```

Where:

- **YYYYMMDD**: Represents the year, month, and day of the observation.
- **vM.n**: Represents the version of the data product

After downloading and unzipping the `.zip` file, a directory is created with the same name as the zip file. For example:

```
AL1_SLX_L1_YYYYMMDD_vM.n/
```

This directory contains subdirectories for each detector `SDD1` and `SDD2`. Each detector-wise directory contains the respective L1 files for that detector. The naming convention of L1 data products will be as follows:

- **GTI File:** `AL1_SOLEXS_YYYYMMDD_SDDn_L1.gti.gz`
- **LC File:** `AL1_SOLEXS_YYYYMMDD_SDDn_L1.lc.gz`
- **PI File:** `AL1_SOLEXS_YYYYMMDD_SDDn_L1.pi.gz`

After unzipping the downloaded zip file, the file will generate following directory strucutre:

```
AL1_SLX_L1_YYYYMMDD_vM.n/
    SDD1/
        AL1_SOLEXS_YYYYMMDD_SDD1_L1.gti.gz
        AL1_SOLEXS_YYYYMMDD_SDD1_L1.lc.gz
        AL1_SOLEXS_YYYYMMDD_SDD1_L1.pi.gz
    SDD2/
        AL1_SOLEXS_YYYYMMDD_SDD2_L1.gti.gz
        AL1_SOLEXS_YYYYMMDD_SDD2_L1.lc.gz
        AL1_SOLEXS_YYYYMMDD_SDD2_L1.pi.gz
```

Note: If a particular detector has no valid observations on a given day, the LC and PI files for that detector will not be generated.

2.4 Calibration Database (CALDB)

The Calibration Database (CALDB) for SoLEXS provides essential files that describe the instrument's response characteristics. These files are crucial for converting raw photon counts into meaningful physical parameters during spectral analysis. The CALDB is organized to include:

- Auxiliary Response File (ARF)
- Redistribution Matrix File (RMF)

The CALDB files are stored within the directory structure of the SoLEXS_Tools package, and their paths are automatically resolved during the installation.

3 SoLEXS_Tools

SoLEXS_Tools is a Python package developed to facilitate the processing and preparation of the SoLEXS data. It provides essential tools and utilities generating and managing spectral data and calibration files, enabling users to perform spectral analysis using specialized tools such as XSPEC or Sherpa. The package includes SoLEXS calibration database (CALDB), which provides essential calibration files such as Auxiliary Response File (ARF) and Redistribution Matrix File (RMF).

3.1 Requirements

Before installing SoLEXS_Tools, ensure that the following dependencies are met:

1. Python 3.6 or Higher

   Check Python Version

   ```
   python3 --version
   ```

2. External Python Packages

   NumPy, Astropy

   Install the dependencies using pip:

   ```
   pip install numpy astropy
   ```

3.2 Installation

Download the SoLEXS_Tools package from Pradan website and follow the instructions given below:

```
tar xvf solexs_tools-m.n.tar.gz
cd solexs_tools
python setup.py build
python setup.py install
```

3.3 Command Line Tools

SoLEXS_Tools, when installed, creates several command-line tools automatically. These tools simplify common data processing tasks. Once installed, these commands can be directly accessed from the terminal.

3.3.1 `solexs-time2utc`

Convert a Unix timestamp to UTC in ISO 8601 format.
Usage:

```
solexs-time2utc <unix_time>
```

Arguments:

- `<unix_time>`: Unix timestamp to convert.

Example:

```
solexs-time2utc 1707715800
# Output: UTC Time: 2024-02-12T11:00:00
```

3.3.2 `solexs-utc2time`

Convert UTC in ISO 8601 format to a Unix timestamp.
Usage:

```
solexs-utc2time <utc_time>
```

Arguments:

- `<utc_time>`: UTC time in ISO 8601 format.

Example:

```
solexs-utc2time 2024-02-12T11:00:00
# Output: Unix Timestamp: 1707715800
```

3.3.3 `solexs-genlc`

Generate a light curve file from Level 1 PI spectrogram file (Type II) for a specified energy range.
Usage:

```
    solexs-genlc -i <l1_pi_file> -elo <ene_low> -ehi <ene_high> \
    [-tbin <time_bin>] [-o <outfile>] [--clobber <True/False>]
```

Arguments:

- `<l1_pi_file>`: Path to the Level 1 PI spectrogram file (Type II)
- `<ene_low>`: Lower energy limit in keV
- `<ene_high>`: Higher energy limit in keV
- `<time_bin>`: Time bin size in seconds (Default set to one second)

Example:

```
solexs-genlc -i AL1_SOLEXS_20240212/L1/SDD2/AL1_SOLEXS_20240212_SDD2_L1.pi.gz \
-elo 2 -ehi 22 -tbin 60
```

3.3.4 `solexs-genspec`

Generate a type-I PI spectral file from Level 1 PI spectrogram file (Type II) for a specified time range.
Usage:

```
solexs-genspec -i <l1_pi_file> -tstart <tstart> -tstop <tstop> \
-gti <l1_gti_file> [-o <outfile>] [--clobber <True/False>]
```

Arguments:

- `<l1_pi_file>`: Path to the Level 1 PI spectrogram file (Type II)
- `<tstart>`: Start time in Unix seconds
- `<tstop>`: Stop time in Unix seconds
- `<l1_gti_file>`: Path to the Level 1 Good Time Interval File

Example:

```
solexs-genspec -i AL1_SOLEXS_20240212_SDD2_L1.pi.gz \
-tstart 1707715800 -tstop 1707715860 \
-gti AL1_SOLEXS_20240212_SDD2_L1.gti.gz
```

3.3.5 `solexs-genmultispec`

Generate multiple type-I PI spectral files from Level 1 PI spectrogram file (Type II) for a specified time range and time binning.
Usage:

```
solexs-genspec -i <l1_pi_file> -tstart <tstart> -tstop <tstop> -tbin <tme_bin>\
-gti <l1_gti_file> [-o <outdir>] [--clobber <True/False>]
```

Arguments:

- `<l1_pi_file>`: Path to the Level 1 PI spectrogram file (Type II)
- `<tstart>`: Start time in Unix seconds
- `<tstop>`: Stop time in Unix seconds
- `<time_bin>`: Time bin size in seconds
- `<l1_gti_file>`: Path to the Level 1 Good Time Interval File

Example:

```
solexs-genspec -i AL1_SOLEXS_20240212_SDD2_L1.pi.gz \
-tstart 1707715800 -tstop 1707715860 -tbin 10\
-gti AL1_SOLEXS_20240212_SDD2_L1.gti.gz
```

4 Spectral Analysis with SoLEXS Data

The most important radiation mechanism producing X-ray emission in SoLEXS's energy range are thermal bremsstrahlung continuum and line emission from highly ionized atoms of various elements in the solar corona. SoLEXS data can be used for diagnosis of physical parameters, such as plasma temperature, emission measure, and elemental abundances. This process requires spectral fitting of the data from Type-I Pulse Invariant (PI) spectral files and the calibration files (ARF and RMF). Tools such as XSPEC, Sherpa, or OSPEX can used for spectral fitting.

4.1 Detector Selection for Spectral Analysis

While downloading the data from the PRADAN website, users can apply the quality filter criteria to check which detector (SDD1 or SDD2) is recommended for spectral analysis. The quallity filter values are as follows:

- 1: Neither SDD1 nor SDD2 is suitable for spectral analysis.
- 2: SDD1 is recommended for spectral analysis.
- 3: SDD2 is recommended for spectral analysis.
- 4: Both SDD1 and SDD2 are suitable for spectral analysis.

4.2 Type-I Pulse Invariant (PI) Spectral File

The `solexs-genspec` and `solexs-genmultispec` commands in SoLEXS_Tools generate Type-I PI spectral file(s) from the input L1 Type-II PI spectral file. The `SPECTRUM` extension of the Type-I PI file contains a single spectrum integrated over the user-specified time range, unlike Type-II PI file, which contains multiple spectra at one second cadence for the entire day. The Type-I PI spectral file is OGIP complaint and includes all the necessary preprocessing to make it ready for spectral analysis.

The header of the `SPECTRUM` extension includes metadata such as the observation time start (`TSTART`), observation time end (`TSTOP`), exposure time (`EXPOSURE`), and calibration file paths (`RESPFILE` for RMF and `ANCRFILE` for ARF). The `SPECTRUM` extension also includes following columns:

1. `CHANNEL`: Energy channel numbers.
2. `COUNTS`: Counts in each energy channel.
3. `STAT_ERR`: Statistical errors for the counts (assumed Poissonian).
4. `SYS_ERR`: Systematic errors for the counts.
5. `QUALITY`: Quality flag, where 1 indicates bad quality and 0 indicates good quality.

4.3 Workflow for Spectral Analysis

The following steps outline the typical workflow for performing spectral analysis with SoLEXS data:

1. **Select a Solar Flare:**
   - Plot the light curve using L1 LC file using visualization tools such as xronos, fv, or python's matplotlib.
   - Identify the phase of the flare for spectral analysis. Ensure that the selected integration time provides a reliable signal-to-noise ratio for the spectrum.
   - Note the start and end times of the selected phase.
2. **Generate Type-I PI File:**
   - Use the `solexs-genspec/solexs-genmultispec` command to generate Type-I PI file(s) for the selected time range.
   - The output will be OGIP-compliant Type-I PI spectral file(s), to be used in spectral fitting tools like XSPEC or Sherpa.
3. **Load the Data in a Spectral Analysis Tool:**
   - Import the Type-I PI file into XSPEC or Sherpa.
   - Ensure the response files (ARF and RMF) are correctly loaded with correct paths. The names and location of the files are written in the header.
   - Ensure appropriate errors on the spectrum are loaded. The statistical (Poissonian) error is availabele in `STAT_ERR` column.
   - The systematic error (`SYS_ERR` column) is currently set to zeros. Add systematic error if necessary. We recommend using systematic error of 4%.
4. **Choose a Spectral Model:**
   - SoLEXS spectrum, during solar flares, can be modeled with thermal emission model (continuum and lines) characterized by temperature, emission measure, and abundances of various elements.
   - Following thermal emission models are available for spectral fitting.
     - chspec [5]: Local model in XSPEC with CHIANTI atmoic database
     - vvapec [6]: XSPEC model with AtomDB atomic database
     - vth_abun [7]: OSPEX model with CHIANTI atmoic database

   We recommend using chspec for SoLEXS spectral modelling.

[5] `https://github.com/xastprl/chspec`
[6] `https://heasarc.gsfc.nasa.gov/xanadu/xspec/manual/node134.html`
[7] `https://hesperia.gsfc.nasa.gov/ssw/packages/xray/idl/f_vth_abun.pro`

5. **Fit the Model to the Data:**

   - Provide the inital guesses and bounds for the model parameters.
   - Select the spectral enery range for fitting. The lower limit should be not be less than 2.8 keV (Refer section 4.5.2). The upper limit should be determined based on the signal-to-noise ratio.
   - Perform fitting to minimize the fit statistic (χ^2).
   - Obtain corresponding best-fit model parameters and their error estimates.
   - Evaluate the goodness-of-fit using statistical measures (reduced χ^2) and residuals.

4.4 Using XSPEC for Spectral Analysis

This example demonstrates the analysis of an M6 solar flare observed by SoLEXS on February 12, 2024, starting at 03:23 UT and peaking at 03:48 UT. The analysis focuses on a 30-second interval near the flare's peak.

4.4.1 Select a Solar Flare

- Use the Level-1 LC file to visualize the light curve data for the given day as illustrated in Figure 1.

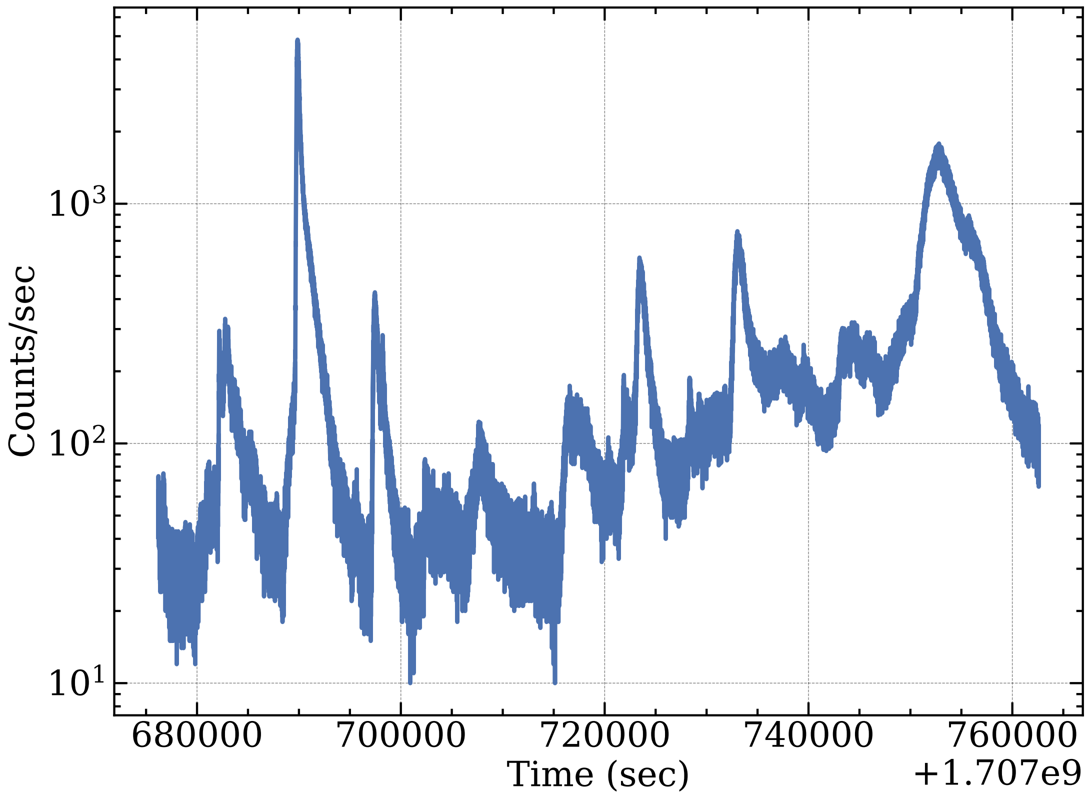

Figure 1: Light Curve data for February 12, 2024

- Select a flare for spectral analysis. For example, an M6 solar flare, biggest flare of the selected day, is used. Note down the start and stop time of the flare.

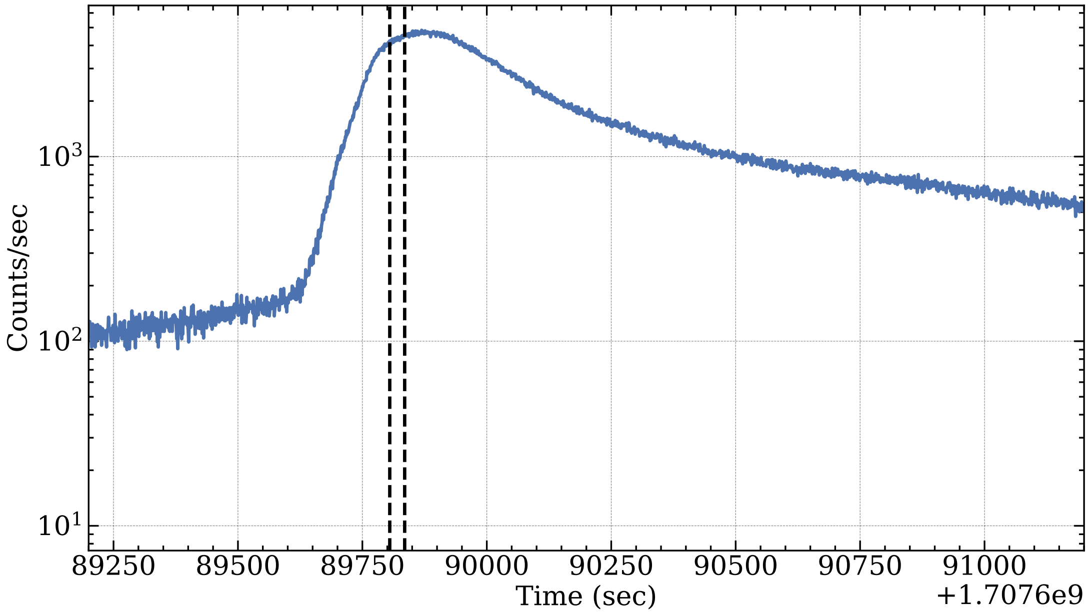

Figure 2: Light Curve data for M6 solar flare starting at 03:23 UT, peaking at 03:48 UT, and ending at 04:10 UT

4.4.2 Generate Type-I PI Files

Use the `solexs-genmultispec` command to create Type-I PI files for the selected start time of 03:23:15 UT (1707688395), stop time of 04:10:15 UT (1707691215), and time binning (30 seconds).

```
solexs-genmultispec -i AL1_SOLEXS_20240212/L1/SDD2/AL1_SOLEXS_20240212_SDD2_L1.pi.gz \
-tstart 1707688395 -tstop 1707691215 -tbin 30 \
-gti AL1_SOLEXS_20240212/L1/SDD2/AL1_SOLEXS_20240212_SDD2_L1.gti.gz
```

4.4.3 Load the Spectrum in XSPEC

For example, an integration of 30-seconds during peak of the selected flare, with start time 03:46:45 UT and stop time 03:47:15 UT (Figure 2) will be used for spectral fitting. Start XSPEC and load the generated PI file.

```
xspec

    XSPEC version: 12.14.1
Build Date/Time: Thu Sep  5 15:37:06 2024

XSPEC12>data AL1_SOLEXS_20240212_SDD2_L1_034645_034715.pi

1 spectrum  in use

Spectral Data File: AL1_SOLEXS_20240212_SDD2_L1_034645_034715.pi  Spectrum 1
Net count rate (cts/s) for Spectrum:1  5.752e+03 +/- 1.385e+01
Assigned to Data Group 1 and Plot Group 1
Noticed Channels:  1-340
Telescope: AL1 Instrument: SoLEXS  Channel Type: PI
Exposure Time: 30 sec
Using fit statistic: chi
Using Response (RMF) File            /path/to/solexs_gaussian_SDD2_512.rmf
Using Auxiliary Response (ARF) File  /path/to/solexs_arf_SDD2.fits
```

4.4.4 Choose a Spectral Model

```
XSPEC12>lmod chspec /path/to/chspec/
Model package chspec successfully loaded.
XSPEC12>model chisoth

Model chisoth<1> Source No.: 1   Active/On
Model Model Component  Parameter  Unit     Value
 par  comp
   1    1   chisoth    logT       K        7.00000      frozen
   2    1   chisoth    He                  10.9000      frozen
   3    1   chisoth    Li                  1.64000      frozen
   4    1   chisoth    Be                  1.94000      frozen
   5    1   chisoth    B                   3.09000      frozen
   6    1   chisoth    C                   8.59000      frozen
   7    1   chisoth    N                   8.00000      frozen
   8    1   chisoth    O                   8.89000      frozen
   9    1   chisoth    F                   4.56000      frozen
  10    1   chisoth    Ne                  8.08000      frozen
  11    1   chisoth    Na                  6.93000      frozen
  12    1   chisoth    Mg                  8.15000      frozen
  13    1   chisoth    Al                  7.04000      frozen
  14    1   chisoth    Si                  8.10000      frozen
```

```
  15    1   chisoth    P                    5.45000      frozen
  16    1   chisoth    S                    7.27000      frozen
  17    1   chisoth    Cl                   5.50000      frozen
  18    1   chisoth    Ar                   6.58000      frozen
  19    1   chisoth    K                    5.67000      frozen
  20    1   chisoth    Ca                   6.93000      frozen
  21    1   chisoth    Sc                   3.71000      frozen
  22    1   chisoth    Ti                   5.56000      frozen
  23    1   chisoth    V                    4.54000      frozen
  24    1   chisoth    Cr                   6.21000      frozen
  25    1   chisoth    Mn                   5.93000      frozen
  26    1   chisoth    Fe                   8.10000      frozen
  27    1   chisoth    Co                   5.46000      frozen
  28    1   chisoth    Ni                   6.84000      frozen
  29    1   chisoth    Cu                   4.75000      frozen
  30    1   chisoth    Zn                   5.14000      frozen
  31    1   chisoth    norm                 1.00000      +/-  0.0
------------------------------------------------------------------------

Rebinning table to response energy bins: NEW NBINS 2250 OLD NBINS 0

Fit statistic  : Chi-Squared               57919.79     using 151 bins.

Test statistic : Chi-Squared               57919.79     using 151 bins.
 Null hypothesis probability of 0.00e+00 with 149 degrees of freedom
 Current data and model not fit yet.
```

4.4.5 Fit the Model to the Data

- Provide the inital guesses and bounds for the model parameters. Thaw temperature, norm, abundances of Ar, Ca, Fe, and Ni. Keep rest of the model parameters frozen.

```
XSPEC12>thaw 18 20 26 28

Fit statistic  : Chi-Squared               57919.79     using 151 bins.

Test statistic : Chi-Squared               57919.79     using 151 bins.
    Null hypothesis probability of 0.00e+00 with 145 degrees of freedom
    Current data and model not fit yet.
```

- Select the spectral enery range of 2.8 to 12 keV for fitting.

```
XSPEC12>ignore **-2.8 12.0-**
58 channels (1-58) ignored in spectrum #     1
131 channels (210-340) ignored in spectrum #     1
```

- Perform fitting to minimize the fit statistic (χ^2). Obtain corresponding best-fit model parameters and their error estimates.

```
XSPEC12>fit

Model chisoth<1> Source No.: 1   Active/On
Model Model Component  Parameter  Unit     Value
par  comp
1    1   chisoth    logT       K        7.23437      +/-  3.17094E-03
2    1   chisoth    He                  10.9000      frozen
3    1   chisoth    Li                  1.64000      frozen
4    1   chisoth    Be                  1.94000      frozen
5    1   chisoth    B                   3.09000      frozen
6    1   chisoth    C                   8.59000      frozen
7    1   chisoth    N                   8.00000      frozen
8    1   chisoth    O                   8.89000      frozen
9    1   chisoth    F                   4.56000      frozen
10    1   chisoth    Ne                  8.08000      frozen
11    1   chisoth    Na                  6.93000      frozen
12    1   chisoth    Mg                  8.15000      frozen
13    1   chisoth    Al                  7.04000      frozen
14    1   chisoth    Si                  8.10000      frozen
15    1   chisoth    P                   5.45000      frozen
16    1   chisoth    S                   7.27000      frozen
17    1   chisoth    Cl                  5.50000      frozen
18    1   chisoth    Ar                  6.38420      +/-  4.01372E-02
19    1   chisoth    K                   5.67000      frozen
20    1   chisoth    Ca                  6.72087      +/-  2.24401E-02
21    1   chisoth    Sc                  3.71000      frozen
22    1   chisoth    Ti                  5.56000      frozen
23    1   chisoth    V                   4.54000      frozen
24    1   chisoth    Cr                  6.21000      frozen
25    1   chisoth    Mn                  5.93000      frozen
26    1   chisoth    Fe                  7.90129      +/-  1.80268E-02
27    1   chisoth    Co                  5.46000      frozen
28    1   chisoth    Ni                  7.59931      +/-  7.74566E-02
29    1   chisoth    Cu                  4.75000      frozen
30    1   chisoth    Zn                  5.14000      frozen
31    1   chisoth    norm                1401.19      +/-  16.1127
________________________________________________________________________


Fit statistic  : Chi-Squared                 472.19     using 151 bins.

Test statistic : Chi-Squared                 472.19     using 151 bins.
Null hypothesis probability of 2.74e-36 with 145 degrees of freedom
```

- Evaluate goodness-of-fit by calculating reduced χ^2 and plot fitted model with residuls (Figure 3).

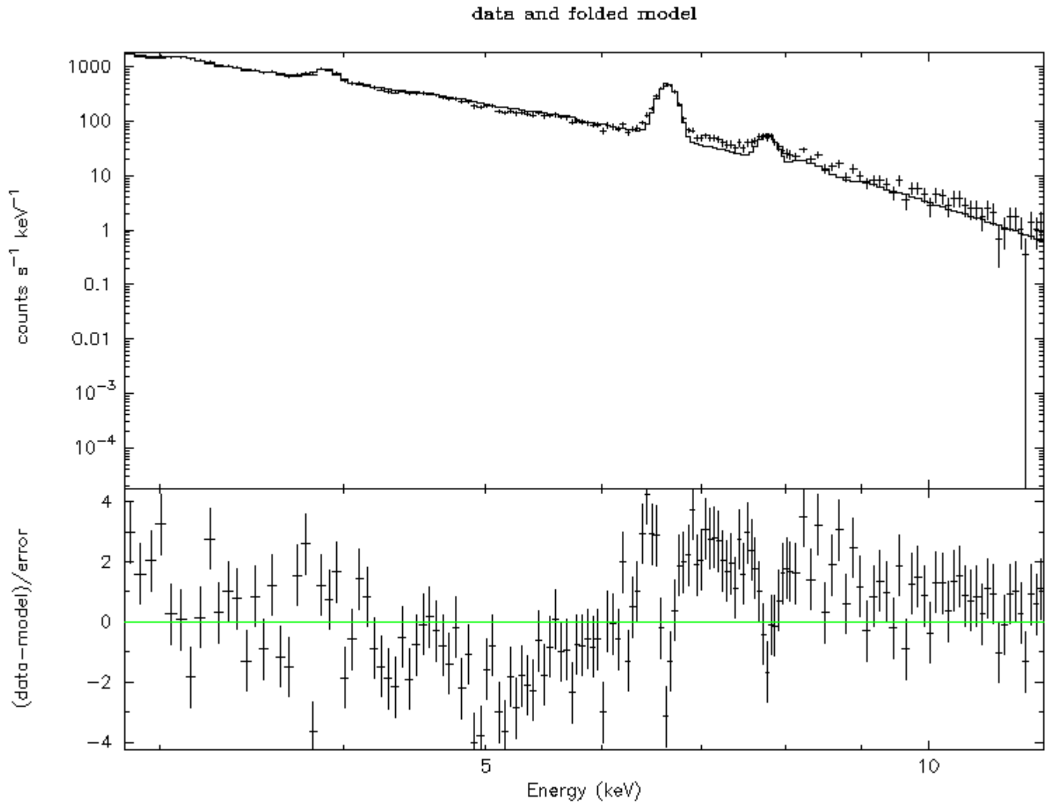

Figure 3: CHIANTI isothermal plasma model fit to observed SoLEXS spectrum.

4.5 Notes on SoLEXS Spectral Analysis

This section provides important notes and clarifications regarding the characteristics of SoLEXS data and its use in spectral analysis.

4.5.1 Channel Binning in SoLEXS

The SoLEXS detector uses a Digital Pulse Processing (DPP) system to digitize photon energies into Pulse Height Analysis (PHA) channels. While the 9-bit digitization allows for 512 potential channels, to save on the data rate, DPP uses following design:

- Channels 1 to 168 are recorded individually, maintaining full energy channel bin width.
- Beyond the 168th channel, channels are grouped into pairs, effectively doubling the energy channel bin width.
- As a result, the total number of channels is reduced to 340 (Figure 4).

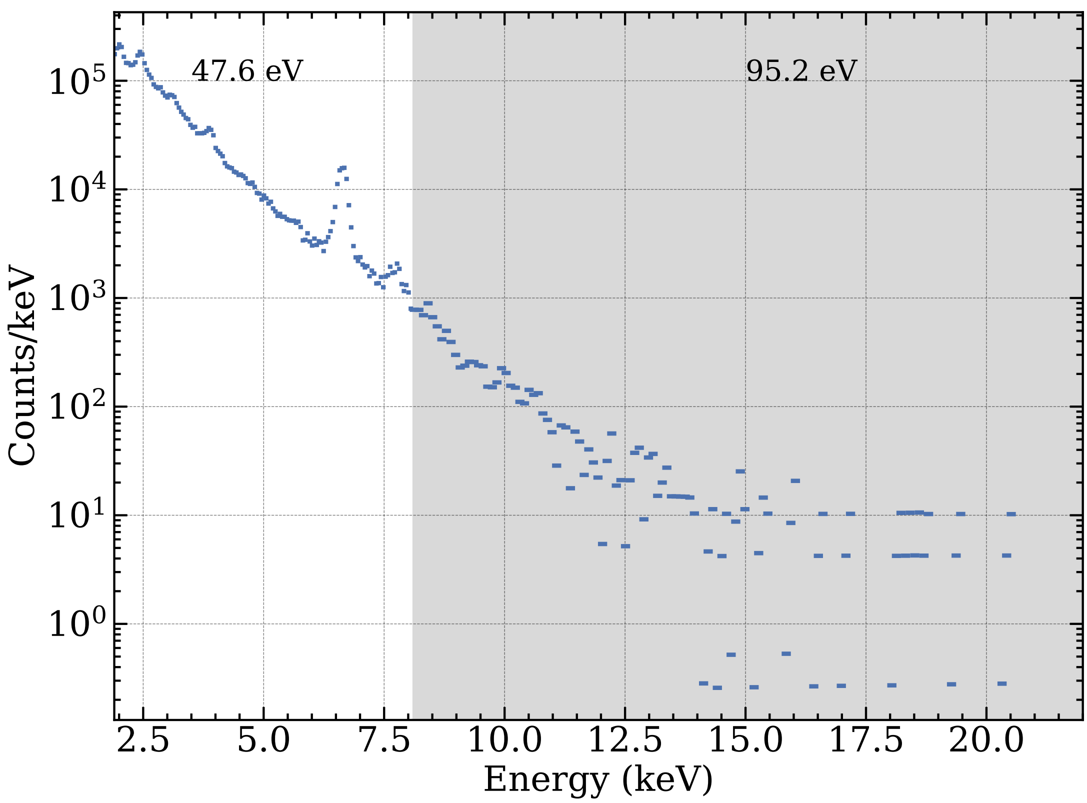

Figure 4: Energy binnging in the spectral data

The instrument response stored in the RMF file is also grouped into pairs beyond the 168th channel. This maintains consistency between the spectral data andd the response matrix.

4.5.2 Response Calibration Below 2.8 keV

Although the lower energy limit for SoLEXS is 2 keV, the current calibration database files (ARF and RMF) are not optimized for energies below 2.8 keV. The response in the energy range 2 to 2.8 keV may not be accurate, and users are advised to exclude channels corresponding to these energies during spectral analysis. When fitting the spectrum, set the lower energy limit to 2.8 keV or higher to ensure reliable results.

4.5.3 Detector Selection for Spectral Analysis

During the peak phase of the solar maximum in 2024, the SDD1 detector frequently experienced saturation due to high photon flux levels. As a result, data from SDD1 may not be available for spectral analysis during this period. We recommend using data from the SDD2 detector for spectral analysis, as it remained operational without saturation.

4.5.4 Errors on Spectral Data

There are two sources of uncertainty in the spectral data:

- Statistical Uncertainty: This stems from the photon counting process and is assumed to follow Poissonian statistics.

- Systematic Uncertainty: This stems from uncertainties in the calibration of the instrument.

Currently, the systematic uncertainty in each energy bin is under analysis and is set to zero in the Type-I PI file. Users are advised to apply a model systematic error of 4% during spectral fitting to account for these uncertainties.

4.5.5 Resolution Degradation at High Count Rates

The resolution of the SDDs is observed to degrade at high count rates, typically above 10^5 counts per second. Users should exercise caution when fitting spectral data recorded at such high count rates, as the degraded resolution may impact the accuracy of the fit. For reference, such high count rates are typically observed during high X-class flares for SDD2 and M-class flares for SDD1.