ASO-S/HXI software User Guide

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Doc.V0.95_20230601

Software version：V1.24 beta

Content

1 Software Change History

Table 1 Major changes

Next update In Jun or July 2023	Will use calibrated grids for imaging; Will add MEM_GE and HXI_FF for imaging; Will add options for selecting background for all the imaging detectors;
01-**Jun-2023** **V1.24 beta**	Add more functions; fixed a few bugs; many improvements. (1) Now HXI GUI should work correctly in SSW (the main reason ware the conflict with HXIS and the path setting); (2) Add interactive selection of time intervals with mouse; (3) Add back the function to save light curves into a 'SAV'; (4) The code to get GOES data is improved; (5) Selection of detectors by groups is now working correctly; (6) Add plot for detector counts and BKG counts; (7) The beamsize in HXI_clean is changed from res. (the highest resolution of the selected subcollimators) to res./sqrt(2).
17-Apr-2023 V1.21 beta	Some minor changes; allow the software to run on IDL 8.2.
11-Apr-2023 V1.2 beta	First released beta version; (1) The software is still under test. (2) A few functions are not available, including flarelist, interactive selection of time intervals, background selection. (3) Vis_clean and Vis_bp are working but the visitibilities are not fully calibrated. (4) MEM_GE, HXI_FFitting, VIS_FF should not be used for this version.
30-July-2022 V0.9 beta	Test version for internal users. The software provides basic functions for analysis of HXI light curves, imaging, and spectra.

2 Background

2.1 Content

This document is the user guide for HXI analysis software for the HXI payload on board the ASO-S.
This document can be found in the HXI software package or the ASO-S website (http://aso-s.pmo.ac.cn/).

2.2 A brief introduction of HXI

The Hard X-ray Imager (HXI) is one of the three payloads onboard the ASO-S mission. Its scientific objective is to investigate magnetic reconnection, particle acceleration, and plasma heating in solar flares.
HXI observes hard X-ray fluxes, spectra, and images of solar flares in the energy range from ~10 keV to 300 keV. The images are reconstructed on ground from spatially modulated signals based on Fourier transform imaging technology. The highest spatial resolution is ~3.1 arcsec.

Table 2 HXI specifications

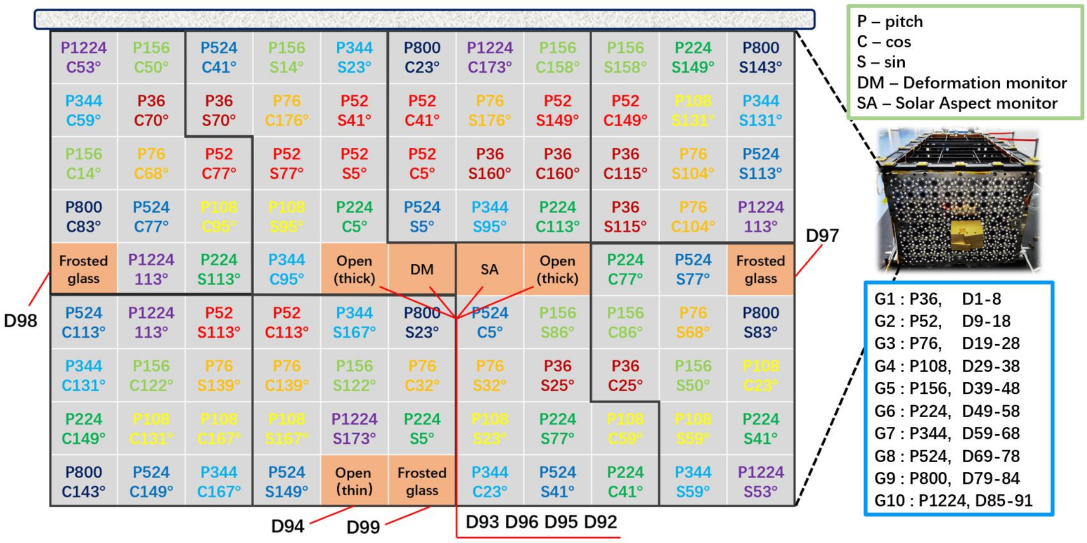
Energy range	Spectra: ~10 – 300 keV Imaging: ~15 – 284 keV
Spatial resolution:	~ 3.1 arcsec
Temporal resolution:	regular mode: 4 s burst mode: 0.125 s, 0.25 s, 0.5 s, 1 s
Energy resolution:	~ 22%@32keV
Grid pitch:	10 groups from 36 to 1224 μm
Detectors:	99; detector ID: D1-D99; 91 for imaging:
total flux monitors:	3 (one with high sensitivity) Detector ID: D92-D94 D92: thick1 D93: thick2 D94: thin (provides trigger for LST)
background monitors:	5; Detector ID: D95-D99
Relative twist	~1 arcsec (latest measurement)

Temperature difference of grids	< 1°C
Pointing accuracy (SAS system)	Better than 0.3 arcsec Time resolution: 0.25 s
Wavelength (SAS)	565-585 nm

HXI has three major components, Collimator (HXI-C), Spectrometer (HXI-S), and Electronics Control Box (HXI-E).

HXI collimator consists of 91 sub-collimators which are used to modulate hard X-rays. It also has a Solar Aspect System (SAS) that contains two sets of cameras, DM and SA. DM monitors the relative shift and twist between front and rear panels by obtaining the centroids of the images of the three frosted glasses on the front panel. It also images the Sun at the same time. SA takes images of the Sun in white light to provide high-precision locations of solar disk center (or pointing of HXI). Both DM and SA data are used to remove the components due to the pointing change of DM itself from the measured shifts.

HXI has in total 99 detectors, including 91 behind each sub-collimator, three open detectors that monitor total fluxes, and five that monitor background. One of the open detectors has thin Al front window and is therefore more sensitive at low energy X-rays.



2.3 Terms and acronyms

3 HXI data products

3.1 HXI data overview

HXI data products include:

- **Level 0C (0.0) data**

  This data is not released.

  - Science data
    - Detector data FITS
    - SAS data FITS
  - Engineering data FITS

- **Level 0.5 data**

  This data is not released. But users may request for the data if the calibration results (Level 1.0 and Q1) are questionable.

  The binary tables in Level 0.0 data are read out, decoded, and then saved as level 0.5 FITS. The background spectra during the time windows of non-flaring and low particle rate are identified, accumulated, and saved in a corresponding .SAV file for each hour (FITS). These spectra are used for energy calibration in the next step. The calibration data are now separately stored.

  - Detector data FITS

    The detector data contains three types of data,

    ADC spectra, which has 1024 uncalibrated ADC channels;

    four-channel data, which has only four energy ranges but is useful for recording extremely high-rate flux;

    event data, the data records individual events. However, the number of events is very limited, and the data is mostly used for energy calibration.
  - Background spectra data (.SAV)
  - SAS data FITS
  - Calibration data
    - Electronics calibration data FITS
    - SAS calibration data FITS
  - Engineering data FITS

- **Level 1.0 data (main scientific data product)**

Level 1.0 detector data are calibrated spectra data rebinned into 80 energy bins in the range of 10 to 300 keV. These spectra are energy-calibrated and corrected for differential non-linearity (DNL). The calibration results are also

Level 1.0 SAS data include the centroids of three frosted glasses, centroid of solar disk (DM), locations of solar disk center derived from the least square method (LSM, circular limb fitting) and the four-quadrant method (FQM), taken four times per second.

- Detector spectra data FITS
- SAS data FITS
- Calibration results and auxiliary data

Level Q1 data

Q1 data provide quicklook data and plots for light curves, monitor data, pointing, etc. The data are also stored by hour. Daily FITS are also generated for detection of flare events.

- Q1 data FITS （hourly and daily）
- Quicklook plots PNG （hourly light curves, dynamic spectra, and monitor data, daily light curves, quicklook of pointing data）
- HXI flare list
  - Ongoing work
  - The flare list will present the list of automatically detected HXI flare events and key parameters. The flare id can be used in the HXI GUI to get the flare time range and flare location (under development).
- Data production status in PNG (DPS)
  - This data is plotted as PNG image to show the latest production status and current version of all HXI data products. In the future, users can also check whether the data FITS they have is the latest through HXI GUI.

Level Q2 data

Q2 data provide quicklook light curves and images of flare events. The corresponding FITS are not released. Only quicklook plots can be viewed from the ASO-S website, which shows light curves, location of the flare on solar disk, Clean images in different energy ranges at peak time. The images and spectra are usually made for two peak times instead of one single peak time, one detected at low energies and one at high energies.

Note: (1) These plots are only for quick look of the flare events and should not be used for scientific purposes. (2) The semi-calibrated spectra are calibrated only with the diagonal elements of response matrix and shall not be used for science.

- Quicklook imagecube FITS and spectra FITS (not released)
- Quicklook plots PNG (quicklook images and spectra)

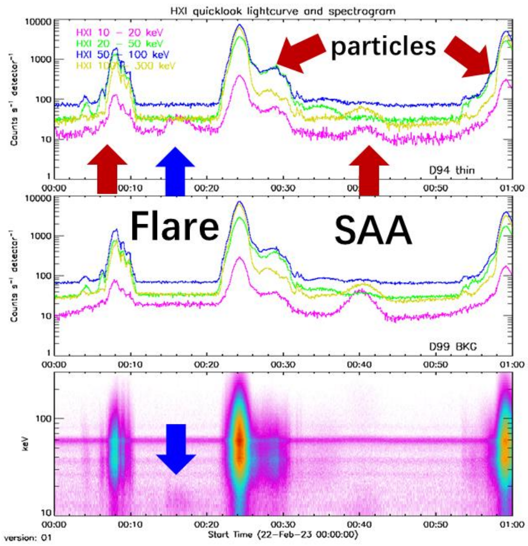
3.2 Level 1.0 data

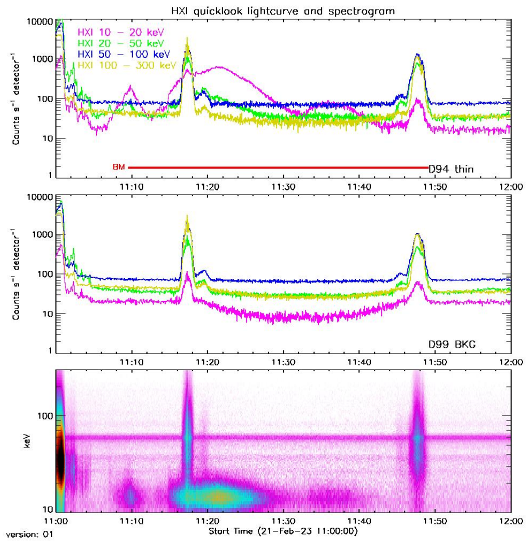
HXI Level 1 FITS		
Primary	Main header	
EXT1	INFO	HXI info data
EXT2	EBOUNDS	80 energy bands for HXI level 1 data
EXT3	HXI_MODU	HXI modulation data
EXT4	HXI_SPEC	HXI spectra data
EXT5	HXI_MODU_4CHAN	HXI four-channel modulation data
EXT6	HXI_SPEC_4CHAN	HXI four-channel spectrum data
EXT7	HXI_pointing	SAS pointing results
EXT8	HXI_ene_calib	Energy calibration results

3.3 Level Q1 data

HXI Level Q1 FITS		
Primary		
EXT1	HXI QL INFO	HXI level Q1 quciklook info
EXT2	EBOUNDS	HXI QL standard energy bands
EXT3	CRATE	HXI Q1 count rate data
EXT4	MONITOR	HXI QL monitor data

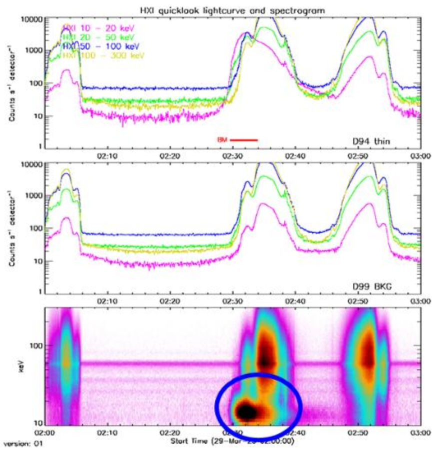
EXT5	Flags	HXI QL flags

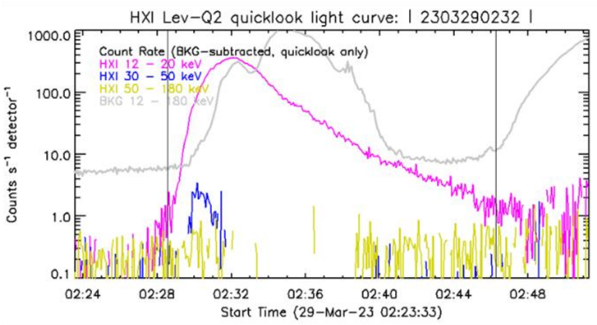




3.4 Flare list

Work in progress.





HXI flares are automatically detected from the 2D spectrogram, instead of 1D light curves. The list will be released soon.

3.5 Accessing HXI Data

Users can browse the quicklook products in the 'Image Browser' to have an overview of the flare and determine the time range of the data:

http://aso-s.pmo.ac.cn/sodc/imageBrowser.jsp

Currently there are three types of quicklook images:

- **HXI light curve**: light curves and spectrogram of detectors with thin and thick front window, as well as those from background detectors. Another plot will be added to show the SAS data.
- **HXI data production status** (dps): These plots are produced to show the status and current version of HXI data products. Users can check whether they need download the latest version.
- **HXI HKD quicklook**: these are used to monitor some of the housekeeping data, such as total flux, high voltage, temperatures and position angles of the platform.
- **HXI SAS pointing data**: ongoing work. These are produced to show the pointing changes and rotational angle of the platform.

To download data, users can go to this page:
http://aso-s.pmo.ac.cn/sodc/dataArchive.jsp
There are two types of data for download:

- **Level Q1**
  - Hourly Fits
  - Hourly Png
  - DPS Png
- **Level 1** : detector data (FITS)

3.6 Installation guide

HXI software, as part of the ASO-S software written in IDL, is now integrated in the SolarSoftWare system (SSW). You can also download the package from the website to use it as an independent software (you still need SSW).

Method 1:

After installing IDL and SSW, users shall customize the SSW setup and HXI setup for HXI analysis.

(1) Copy setup.hxi_env to ssw\site\setup, and change the following setting:
setenv HXI_DATA_USER E:\HXI\data, (point to the folder where you save the downloaded HXI data);

or you can

(2) Change the current working folder to the data folder.

Method 2:

Currently, users can download the software from the website. In SSW, change the working folder to the folder of the software. Then run 'HXI_env_set.pro'. It will add data path of the 'data' folder in the software package.
Then, type 'hxi' in the IDL command line to start the GUI.

3.7 Know Issues

(1) Background removal

Background selection is very important for spectral analysis and imaging. But for some flares, it could be very complicated and difficult.

There are in general three ways of selecting background. (We are still working on these problem)

(a) For spectral analysis

- Fluxes before and after flares; can be used when the background profile is simple and constant.
- Use background from nearby BKG detector; can be used when the particle rate is low and the flare has no strong emission above 150 keV.
- 48h+10s ahead or -48h-10s behind; may be used for some cases when other method is not available.

(b) For imaging

The background fluxes of the 91 detectors are different, especially when the particle rate is high. Background selection is a difficult job and may be case by case.

- Fluxes before and after flares; can be used when the background profile is simple and constant.
- Use average background of all BKG detectors; can be used when the particle rate is low, and the flare has no strong emission above 150 keV, and the background profile is simple.
- 48h+10s ahead or -48h-10s behind; may be used for some cases when other method is not available.

(2) High energy photons of flares can penetrate the material and the front window of background detectors, causing solar fluxes in the background data. For these cases, their data cannot be used directly as background.

(3) The full imaging calibration has not been done, which including the aspect calibration and grid calibration.

(4) HXI software is still under development and tests. Please send us email about your suggestions and the bugs you find.

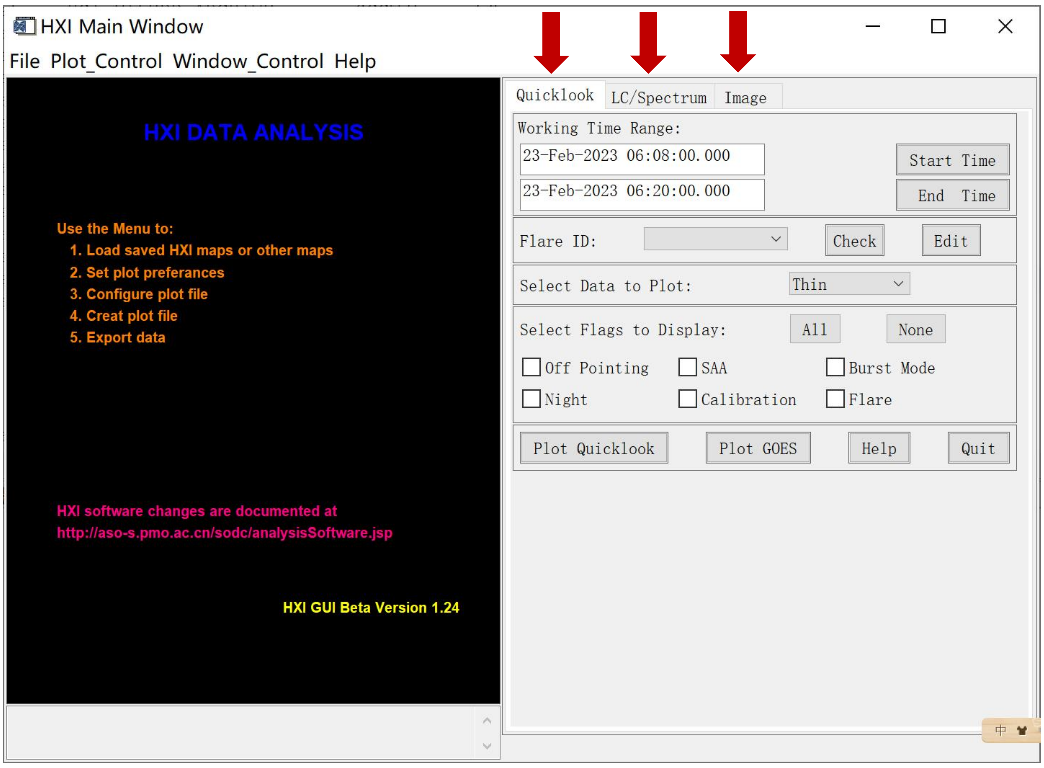
(5) At current stage, please contact the team for assistance if you want to use the data for science.

4 HXI software

4.1 HXI software overview

HXI GUI is developed by Fanxiaoyu Xia, Fu Yu, Changxue Chen, Wei Chen (spectra-related procedures), Yang Su (imaging-related procedures).

The goal of HXI analysis software is to provide a user-friendly interface for X-ray imaging and analysis with HXI data. To keep consistency of interface with the previous high-energy solar mission RHESSI and minimize users' adaptation time, we adopted some components in the RHESSI software and developed a new interface.



HXI GUI is integration of the interface framework, objects, and plotman (developed by the RHESSI team). Like RHESSI software, HXI software is also object-oriented. It includes a GUI and over 65 procedures/functions, which provide three major functions with three tags:

(1) **quicklook**

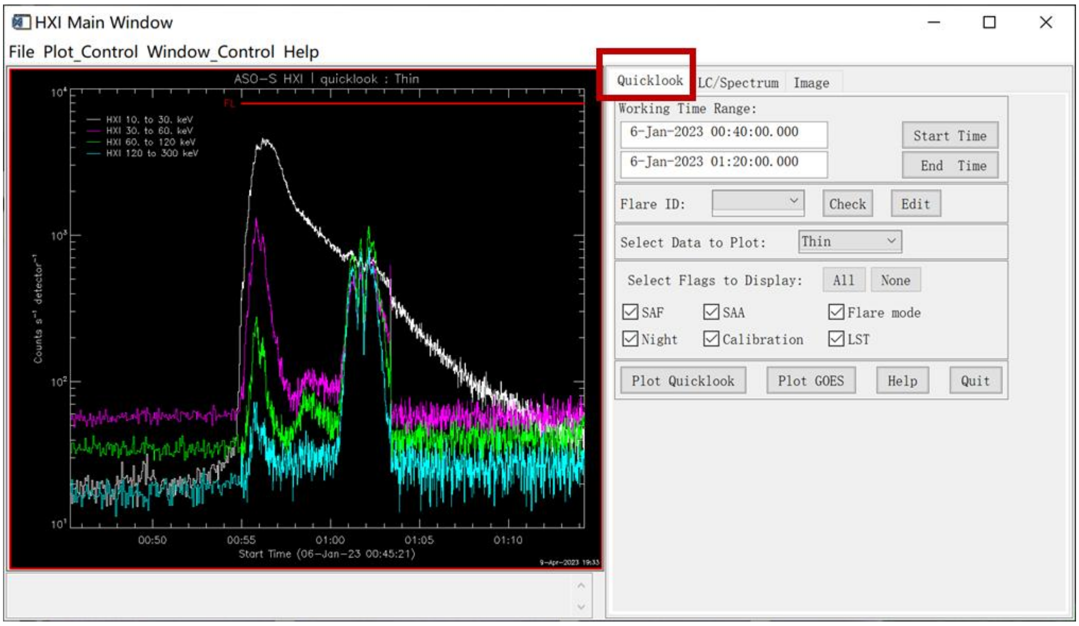
(2) **light curve and spectrum**

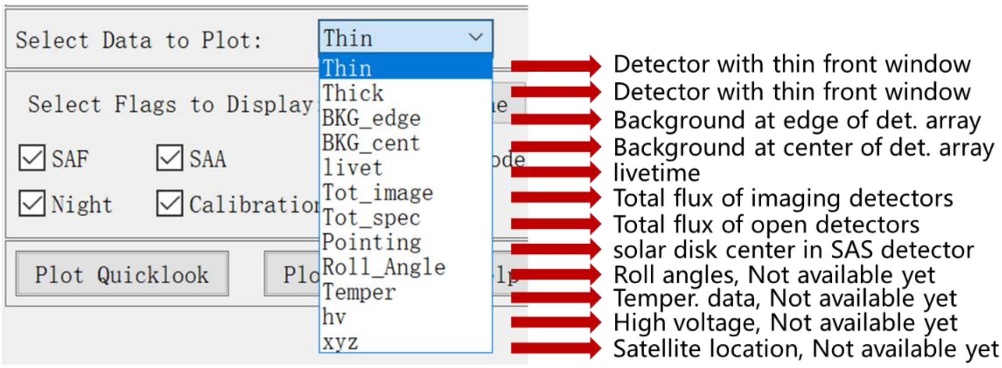
(3) **imaging**

4.2 Quicklook

Quicklook Tag provides a function zone for quicklook plots of flare X-ray light curves (total fluxes and background fluxes), monitor data (high voltage, temperatures, etc.), and pointing data.

This function reads the given **Level Q1 FITS** (through 'Open' in the main manu) or searches for the corresponding Level Q1 FITS files according to the time range

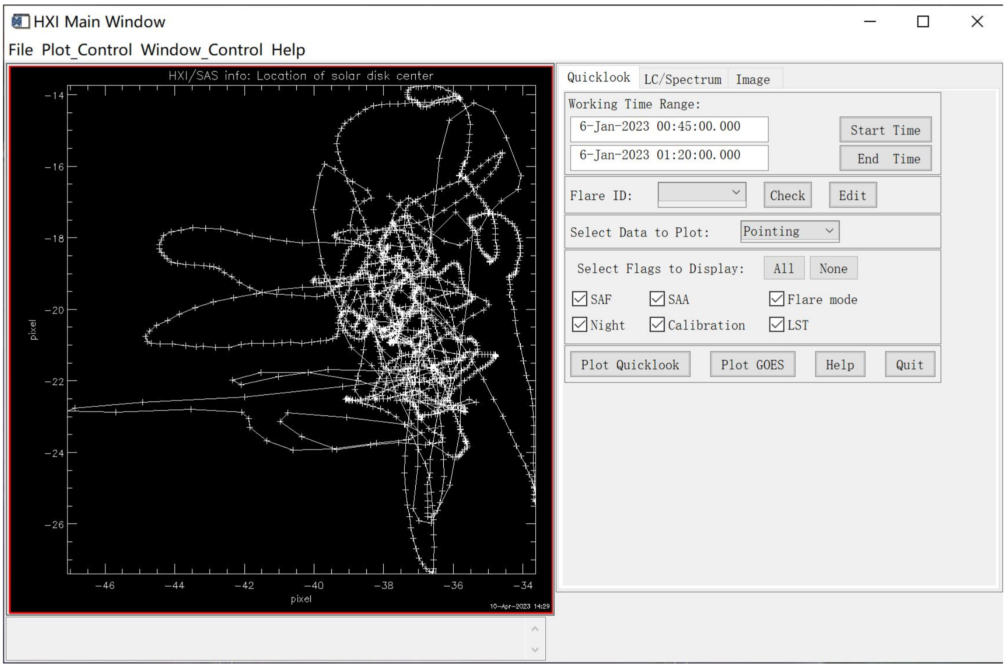




users defined and then reads the data, combines the data, plots the time profiles of the selected parameter.

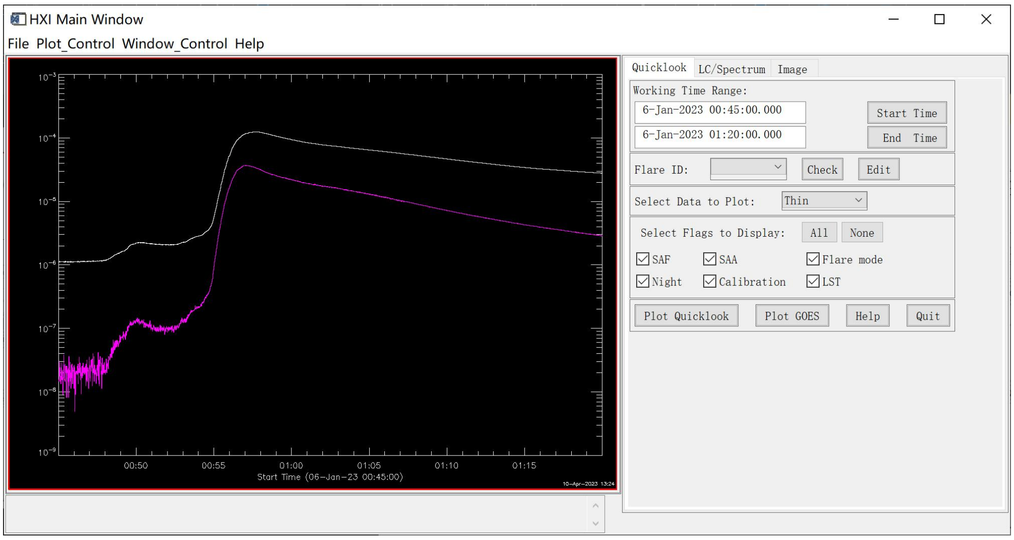
Users can quickly set a time range by inputting the time in the time boxes, or selecting the time in the popup time widget, or by inputting an HXI flare ID (ongoing work).

The time range set here is used as the time limits for the observation in the current analysis and is displayed at the top of the other zones as a reminder. Further analysis of spectra and images shall be done within this range. To change



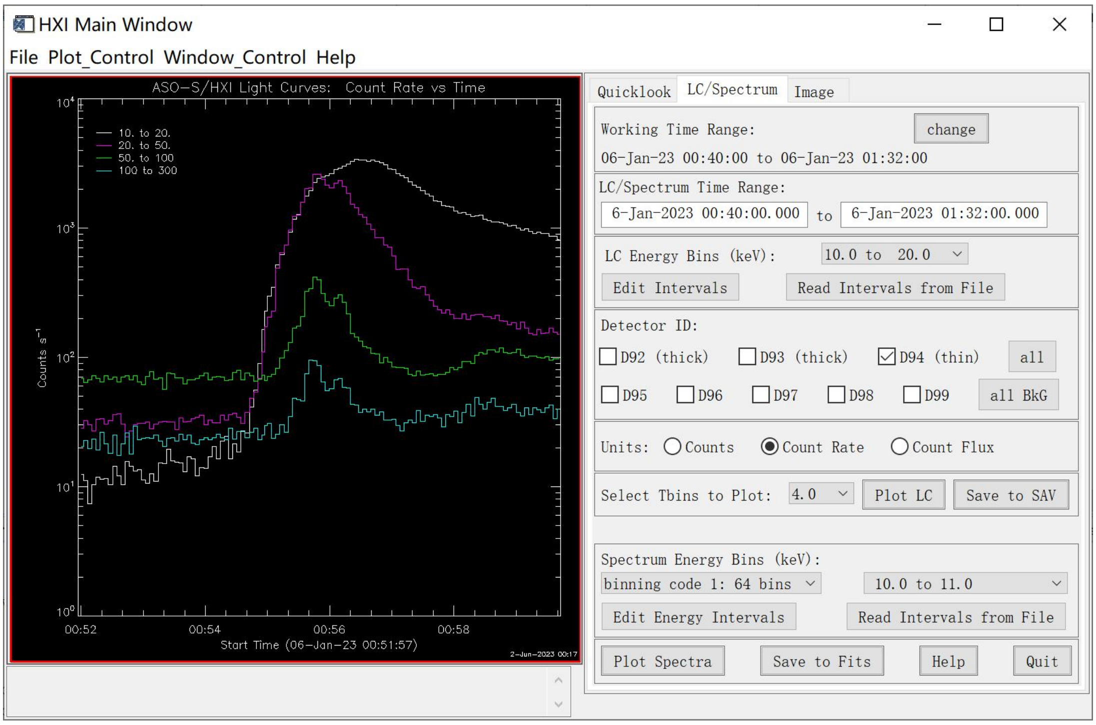
this range, users can always switch back to this Quicklook Tag and change the time range through a click on the Quicklook Tag or the 'Change' button in the other two tag zones.

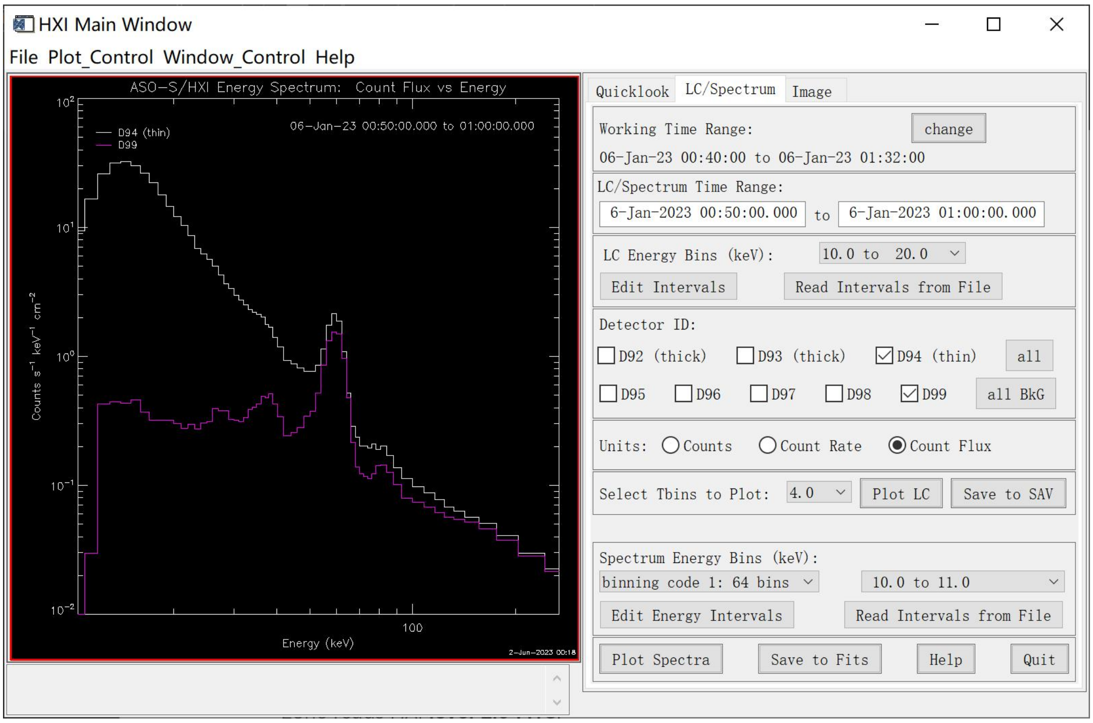
The flags include: SAF (safe mode), SAA (SAA passage), Flare mode (FL, burst mode), Night (NT, night time), Calibration (Cal, calibration mode), LST (trigger signal for LST, not used).



4.3 Light curve and spectra

Light curve/spectra Tag allows users plot light curves and spectra for



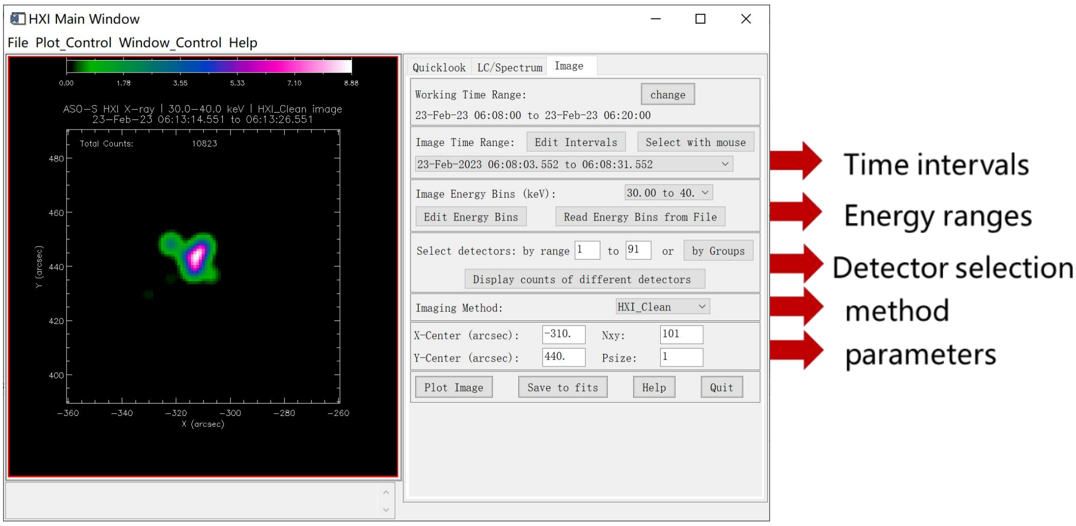


user-defined energy ranges and save the data into SAV or FITS files. This function zone reads HXI **level 1.0 FITS**.

Users can select different detectors for making light curves and spectra. Note that D92 and D93 are the total flux monitors with thick front window and D94 is the total flux monitor with thin front window. D95 to D99 are background detectors. The result can be saved as a FITS file, which can be used for spectral analysis in OPSEX.

Note that D92 and D95, D93 and D96, D94 and D99 are neighboring detectors, respectively. Therefore, the three pairs sometimes can be used together for background removal. However, there are limitations of such applications.

The time range here defines the start and end time for the spectra data and FITS file. Users can choose the time bin size for making light curves and spectra FITS. For spectral studies, we recommend that users make and save the spectra fits for detectors D94 and D99. The saved spectra FITS and DRM file can be analyzed in OSPEX, with the help of hxi_data.pro and hxi_drm.pro (see below).



4.4 imaging

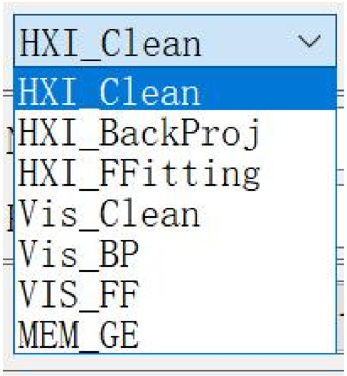
Imaging Tag provides an interface for making images with HXI data. Users can change and add more time intervals and energy ranges.

The detector range defines the detectors used in imaging. Users can directly input the ID range of detectors or select the boxes representing grid group 1 through 10, with increasing pitch or spatial resolution.

Imaging methods include HXI_BP (Su+ RAA 2019), HXI_Clean (Su+ RAA 2019), HXI_FF, VIS_BP, VIS_Clean, VIS_FF, etc.

Currently, Vis_FF, HXI_FFitting, MEM_GE are not available. Visibilities are not fully calibrated yet. The full imaging calibration is still ongoing work.

X-center, Y-center are the coordinates of the map center, usually defined as the flare location. 'Nxy' defines the number of pixels along X or Y, and 'psize' is the size of individual pixel in arcsec.



If flare location is unknown, users can make a full disk image first to determine the flare location and then change Xcen and Ycen to the correct flare cite to make a new image of the flare. HXI_BP or VIS_BP is suggested to make the full disk image, with a detector range of D39-D91, a psize of 4 or 5 arcsec, nxy of 501 or 401. In the future, the flare location (Xcen and Ycen) will be obtained from HXI flare list automatically.

Suggestions:

Psize: we suggest users to set its value according to the purpose of the imaging and the selection of detectors (the finest grids). For a small region around the flare site, psize of 1-2 arcsec is suggested. 3-5 arcsec can be also used. A psize smaller than 1 arcsec is not helpful in improving reconstruction quality.

FOV: The field of view (nxy*psize) should not be too large to avoid possible sidelobes, unless users want to make a full-disk image. 100 – 200 arcsec is suggested.

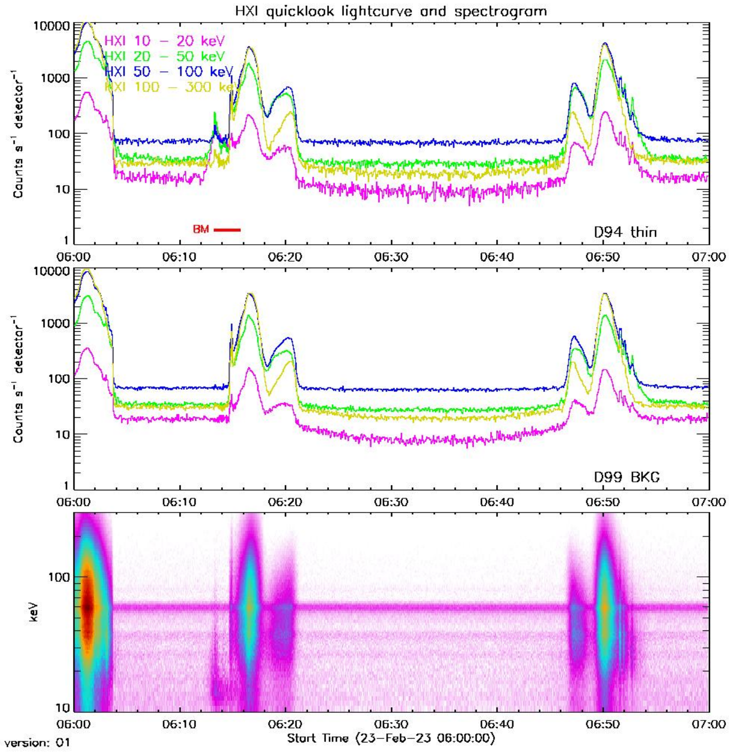
Duration: should not be too long which may cause long imaging time; should not be too short to ensure that there are enough counts. 5s -40 s duration time is suggested.

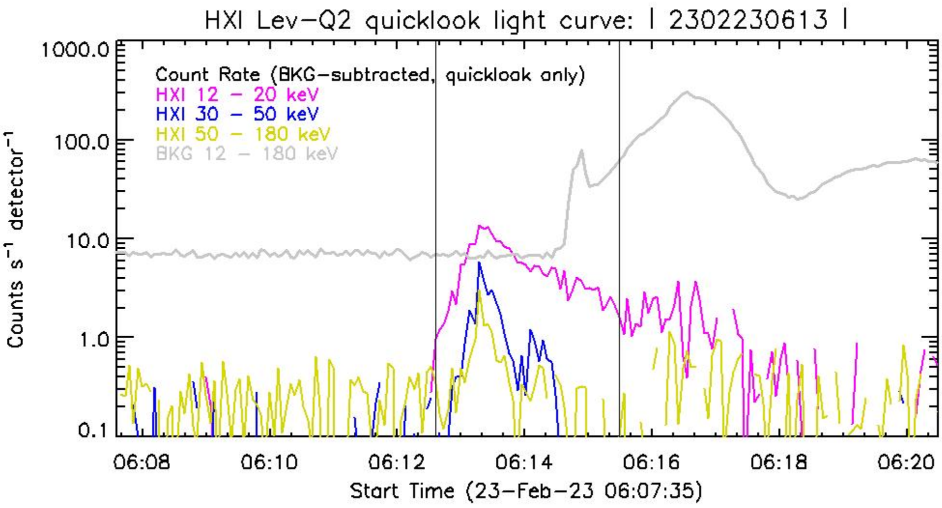
Energy bins: Bin size should be larger than at least 3 keV. Otherwise, the SNR will be low and bin size will be significantly smaller than the energy resolution. A bin size of 4-10 keV is suggested. 20 keV is also acceptable in some cases.

5 Guide for HXI data analysis

Here we use the flare observed on Feb-23 2023 as an example.

5.1 Analysis of Feb-23 2023 flare





5.1.1 First step: Browse and download data

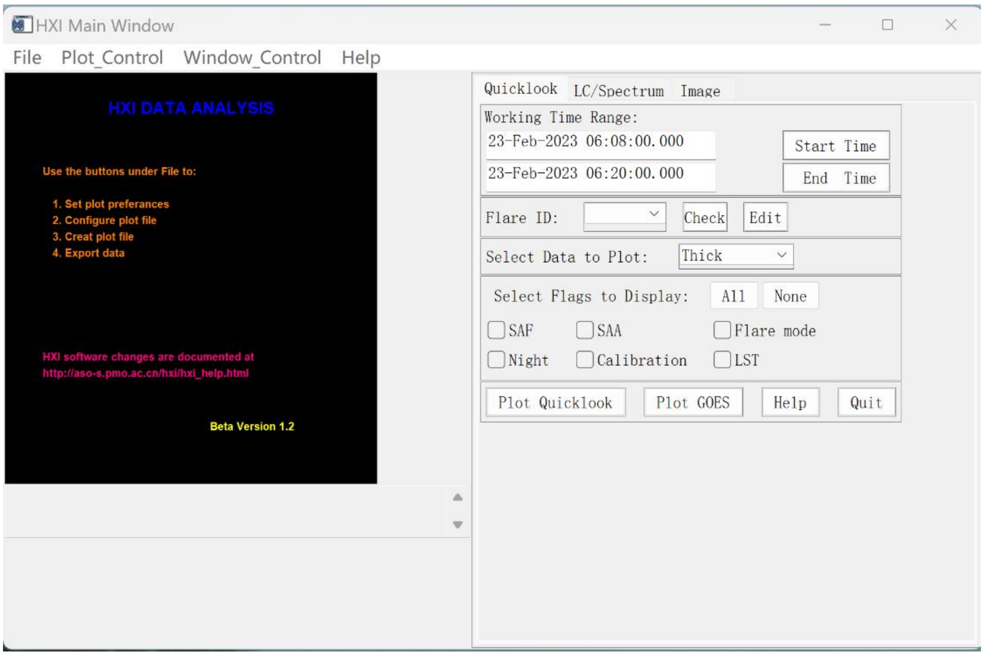
This is the quicklook plots for this flare. The first panel: total fluxes from D94 open detectors; the second panel: the background detector next to D94; the bottom panel: spectrogram of D94. ‘BM’ means burst mode, which is automatically triggered in-orbit.

5.1.2 Quicklook with HXI GUI

To start HXI GUI, type 'hxi' in the command line.

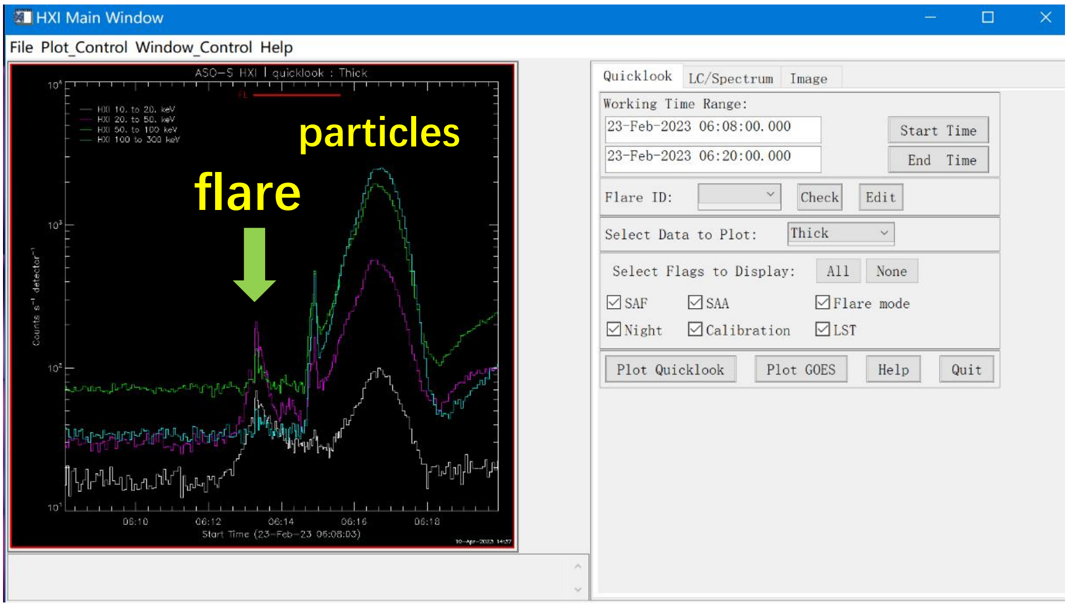
Example:

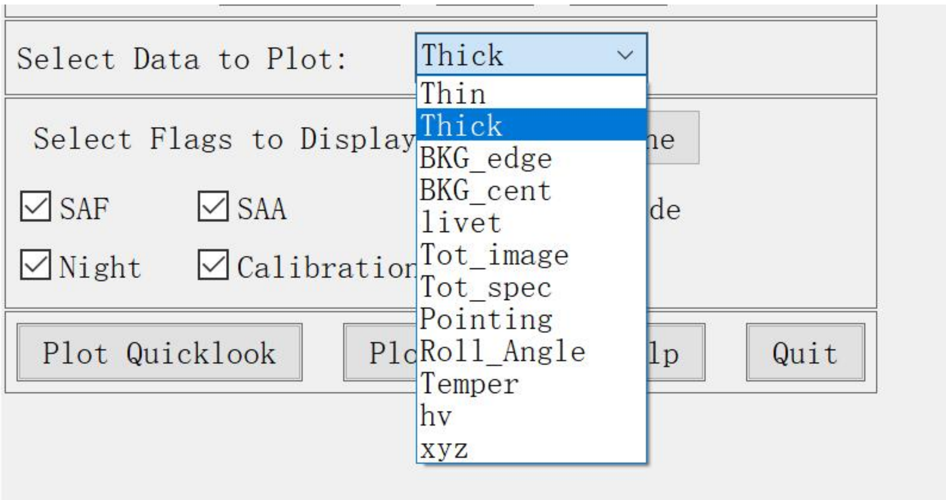
```
IDL> hxi
% ASTROLIB: Astronomy Library system variables have been added
% DEVICELIB: Added system variable !BCOLOR
% DEVICELIB: Added system variable !ASPECT

Beta Version 1.2

IDL>
```



(1) Click 'Start time' and 'End time' to set a time range, and then click 'Plot Quicklook' to show X-ray light curves observed by HXI, while click 'Plot GOES' to display GOES fluxes.

(2) 'Flare ID' is given by the HXI team, click 'check' to seek the flare during the time range you have set, or inputting a flare ID if you have known.





(3) In the tag of "Select Data to Plot", you can choose quicklook light curves to display. The combobox includes: Thick, Thin, BKG_edge, BKG_center, livet, Tot_image, Tot_spec, monitor pointing, Roll_angle, Temper, hv, and xyz.

(4) In the tag of 'Select Flags to Display', you can choose the Flags to show, i.e., SAF (safe mode), SAA (SAA passage), Flare mode (FL, burst mode), Night (NT, night time), Calibration (Cal, calibration mode), LST (trigger signal for LST).

5.1.3 Spectral analysis

(1) Input the start and end time in 'LC/Spectrum Time Range'.

(2) In the tag of 'LC Energy Bins (keV)', you can set the energy bin for the light curve to display.

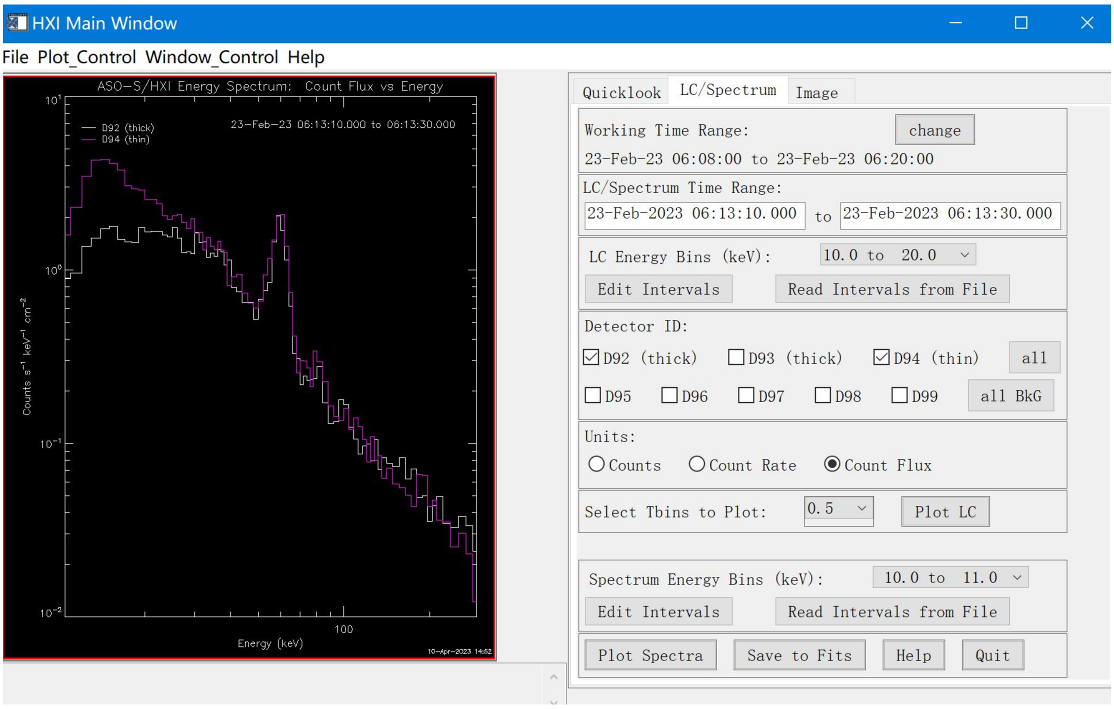
(3) In the tag of ‘Detector ID’, you can choose the detector you wanted.

(4) In the tag of ‘Units’, you can change the units to display.

(5) In the tag of ‘Select Tbins to Plot’, you can choose the time bin for the light curve.

(6) In the tag of ‘Spectrum Energy Bins (keV)’, you can change the energy bins by click ‘Edit Intervals’, or by ‘Read Intervals from File’ if you have one.

(7) When all tags are set, you can display the spectrum by clicking ‘Plot Spectrum’, and save it by ‘Save to Fits’, which can be used for spectral analysis in OPSEX.



5.1.4 Imaging

(1) Input the start and end time in ‘Image Time Range’.

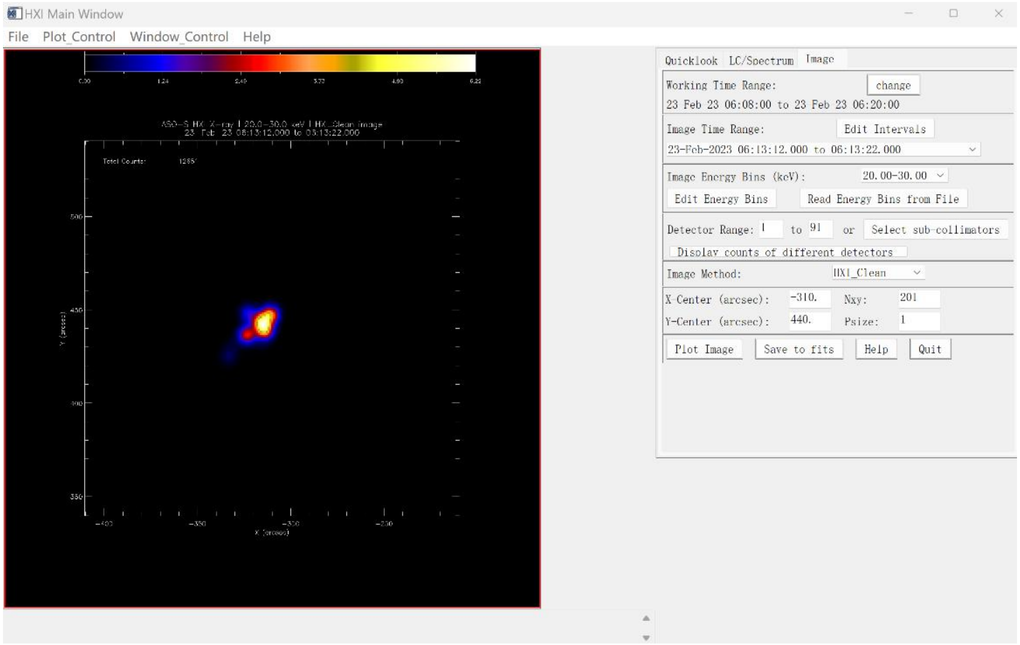
(2) In the tag of ‘Image Energy Bins (keV)’, you can change the energy bins by clicking ‘Edit Energy Bins’, or by ‘Read Energy Bins from File’ if you have one.

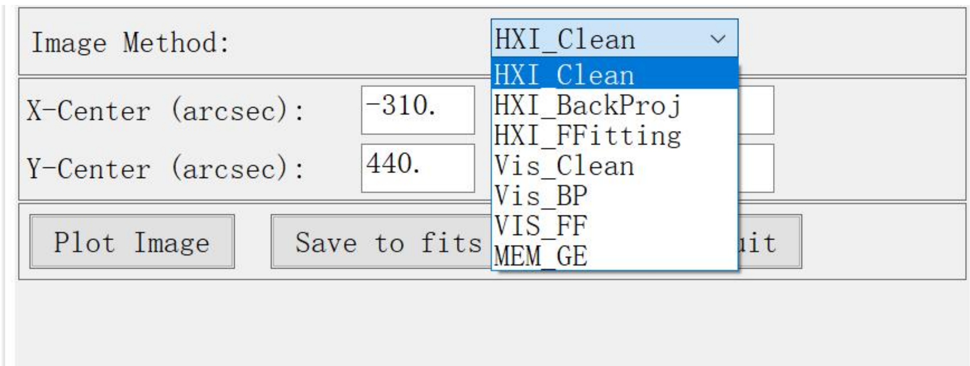
(3) In the tag of ‘Detector Range’, you can directly input the Detector ID number, or you may click ‘g1-g10’ in ‘Select sub-collimators’.

(4) In the tag of ‘Image method’, you can select one imaging algorithm to generate the HXI image, which includes HXI_Clean, HXI_BackProj, HXI_FFitting, VIS_Clean, VIS_BP, VIS_FF, and MEM_GE.

(5) X-center, Y-center are the coordinates of the map center, usually defined as the flare location. ‘Nxy’ defines the number of pixels along X or Y, and ‘Psize’ is the size of individual pixel in arcsec.

(6) When all tags are set, you can generate and display the image by clicking ‘Plot Image’, and save it by ‘Save to Fits’.





Note: background selection and removal are very important for HXI spectral analysis and imaging. But it is quite difficult for some of the flares. There are in general three ways to do it:

We are still working on the problem and will give a more detailed solution.

6 Spectra analysis with HXI data in OSPEX

The saved spectra and drm FITS can be used in OSPEX for spectral analysis.

Step1:

```
o=ospex()
o->set, spex_file_reader='hxi'
```

Step2:

Select the saved spectra FITS as input data. The drm FITS will be automatically added.

Step3: Background selection

If the flare has a rather flat background, then users can use OSPEX to select the background as they do it for RHESSI data.

If the background during flare time is gradually increasing or decreasing, then users can use the high energy profile and apply it to the low-energy light curves to get the background with same profile, a function provided by OSPEX. In this cases, the high energy fluxes should be all background flux, meaning that the flare should not emit at the high energies. Or do not use or fit the time range where flare emit at high energies.

For more complicated cases, users may need replace the background with either background data from the nearby BKG detector or the data recorded 48h before or ahead of the flare time.

TBC

Step4: selection of time intervals and spectral fitting

7 Contacts

Table 3 Contacts

For all questions related to HXI, data, and software	Yang Su yang.su@pmo.ac.cn
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