Progress of ASO-S/HXI and Tutorial on HXI data analysis

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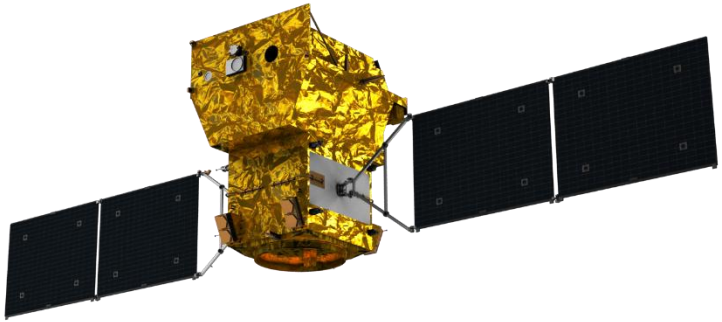
& ASO-S/HXI team

April 11, 2023

- **ASO-S/HXI:**
  - Overview and status
  - Data products
  - Observations
- **Tutorial on data analysis**
  - HXI GUI
  - Example
  - Known issues

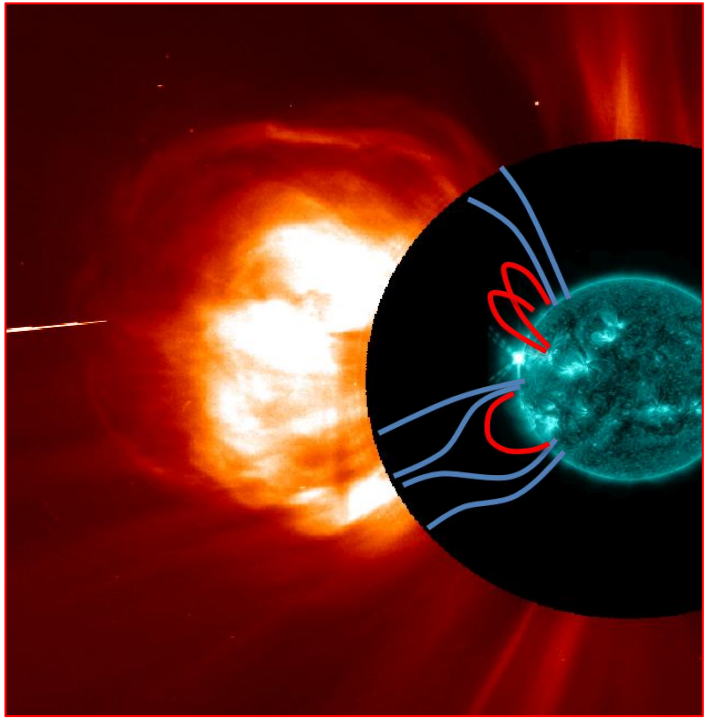


ASO-S/HXI：overview

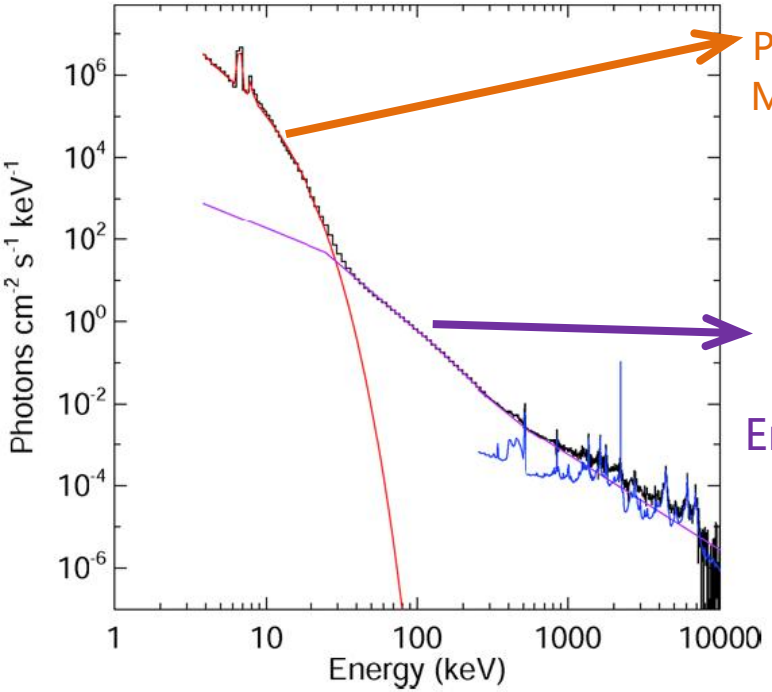
ASO-S: Scientific objectives

‘1M2B’

- **Relationship between flares and magnetic field:** how does solar magnetic field can result in the occurrence of solar flares?
- **Relationship between CMEs and magnetic field:** how does solar magnetic field can result in the occurrence of CMEs?
- **Relationship between flares and CMEs**



ASO-S/HXI：overview



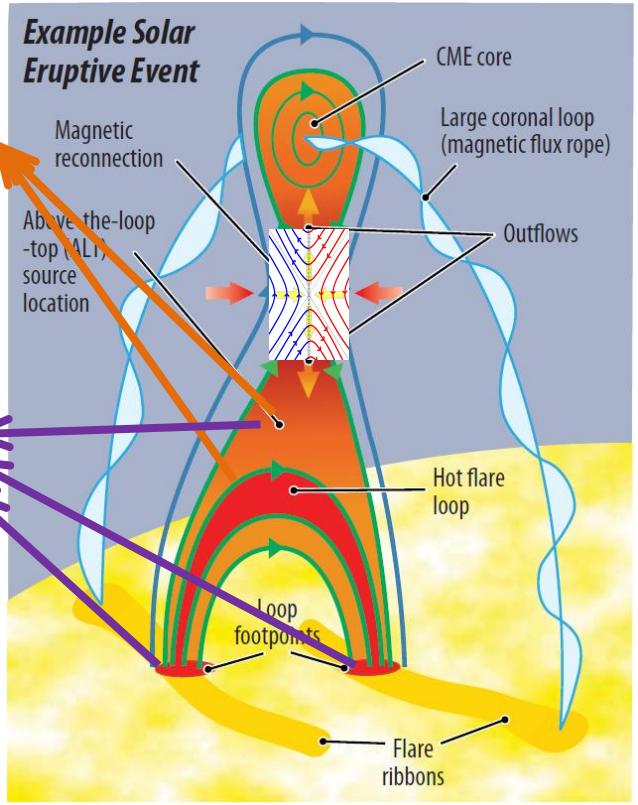
John C. Raymond et al. 2012, Lin 2011

Thermal emissions：

Plasma heated to a few MK to a few tens of MK

Non-thermal Bremsstrahlung emission：

Energetic electrons



ASO-S/HXI：overview

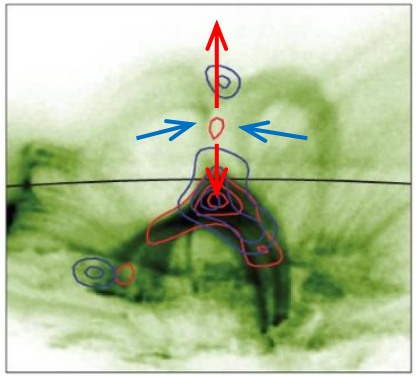
1960s 1970s 1980s 1990s 2000s 2010s 2020s

ASO-S/HXI：overview

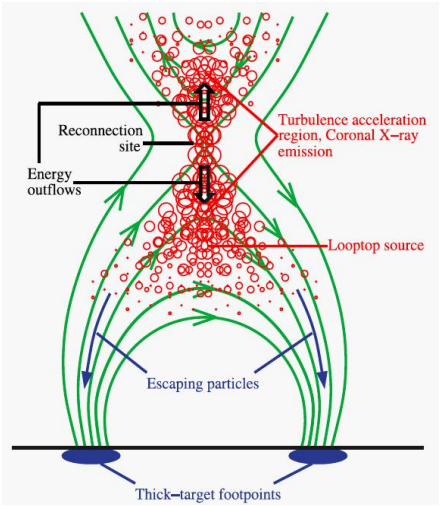
HXI: To observe hard X-ray spectra and images

Krucker and Battaglia, 2014

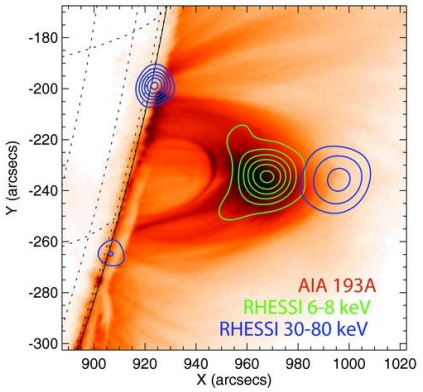
- Solar X-ray Bursts
- Energy release and Plasma heating
- Energetic particles
- Magnetic reconnection

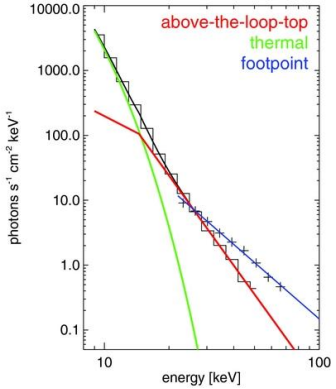


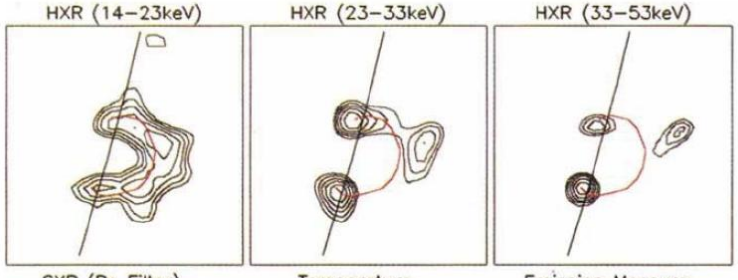
Su + 2013, Nature Physics



Liu et al. 2013

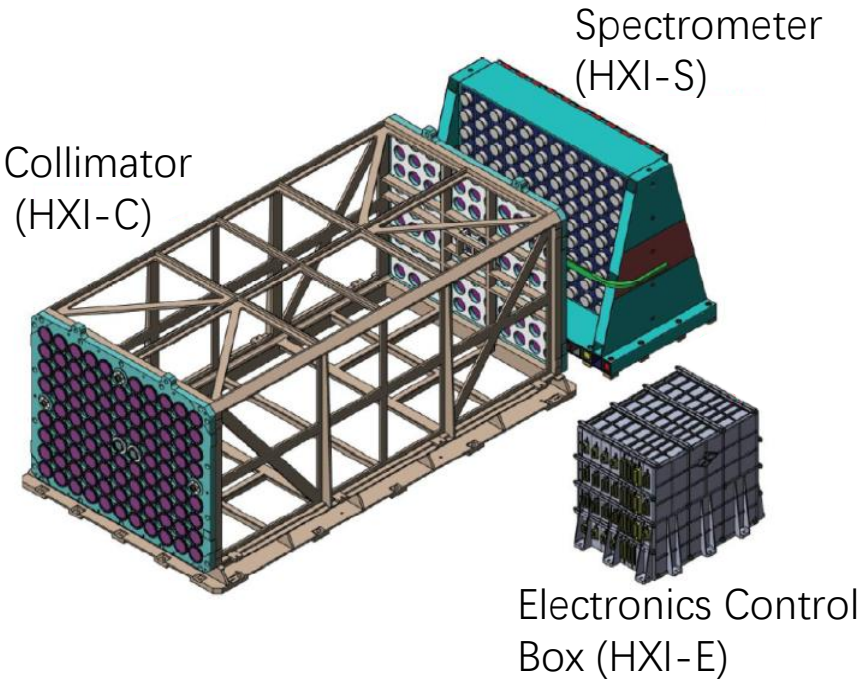


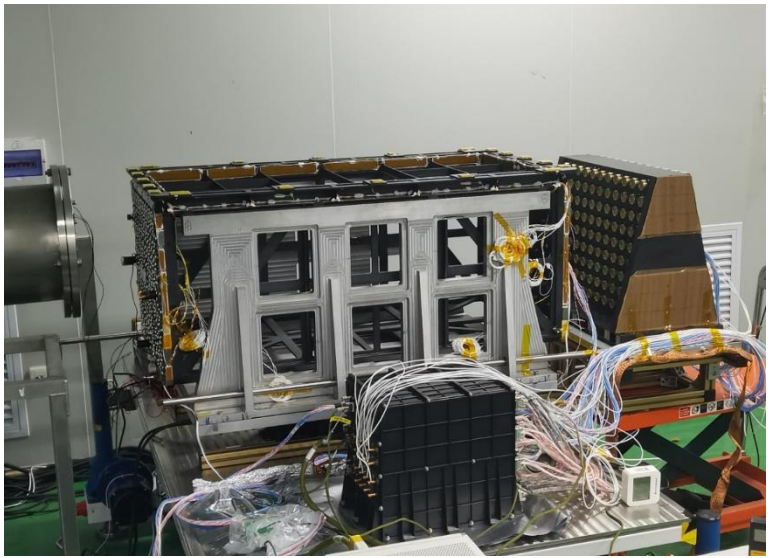




Masuda et al. 1994, Nature

ASO-S/HXI：overview

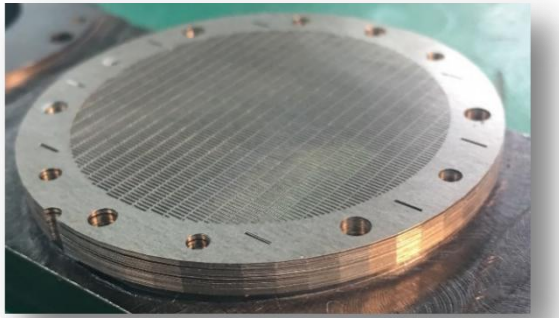


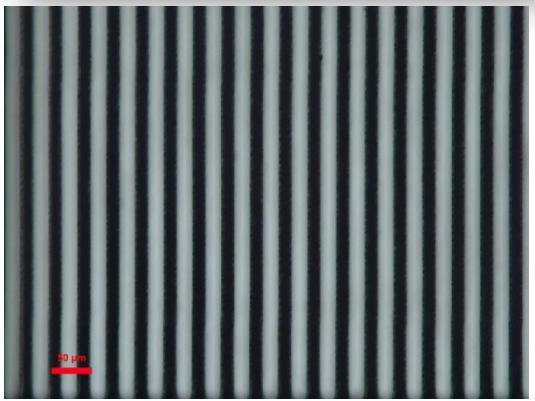


ASO-S/HXI：overview

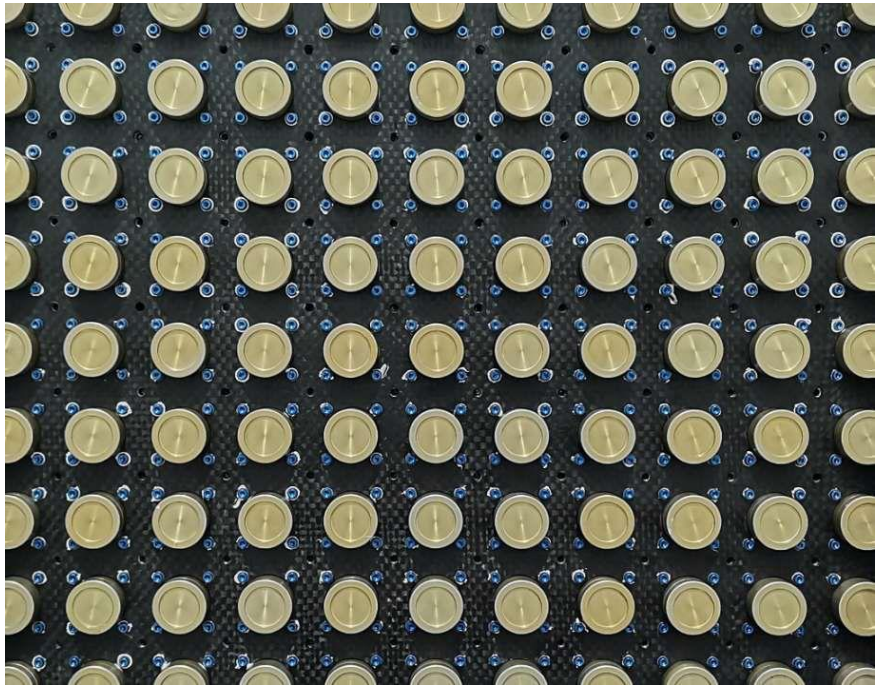
HXI specifications	
energy range	~ 10 -300 keV (spectra) ~ 15 -284 keV (imaging)
Spatial resolution	~ 3.1 arcsec
Energy resolution	better than 22%@32keV
Time resolution	0.125 – 4s
Grid pitch	10 groups from 36 to 1224 μm
subcollimators	91
Detectors	99 $LaBr_3$ detectors
	imaging: 91/ BKG: 5 / Total flux: 3
Twist	~1 arcsec
Temperature diff.	< 1°C
Pointing accuracy:	Better than 0.3 arcsec Time resolution: 0.25 s

Tungsten grid layers:
10 groups, 32 types, ~3400 layers





ASO-S/HXI：overview



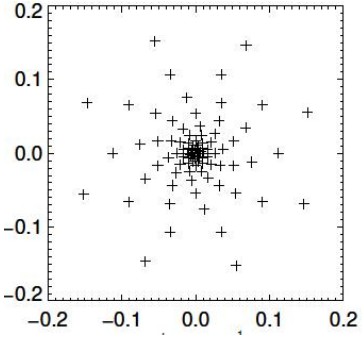
$LaBr_3$ Detector:

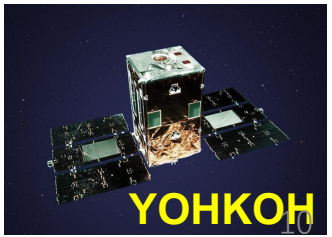
ASO-S/HXI：overview

- We learned a lot from YOHKOH, RHESSI, and the two teams.

Table 2 HXI grid configuration for the present design

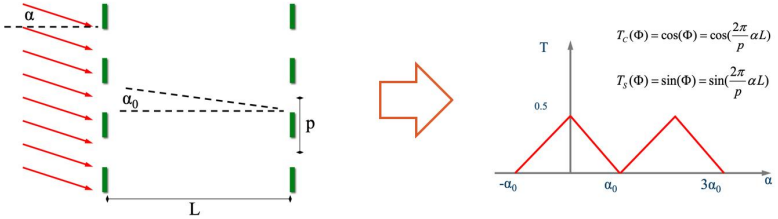
Grid index	1	2	3	4	5	6	7	8	9	10
Pitch/μm	36	52	76	108	156	224	344	524	800	1224
Spatial resolution/″	3.1	4.5	6.5	9.3	13.4	19.3	29.6	45.0	68.8	105.2
Grid numbers	4×2	5×2	5×2	5×2	5×2	5×2	5×2	5×2	3×2	2×2+1×3[a]
	20	0	27	18	9	0	18	0	18	48
	65	36	63	54	45	36	54	36	78	108
Placement angle/°	110	72	99	90	81	72	90	72	138	168
	155	108	135	126	117	108	126	108		
		144	171	162	153	144	162	144		



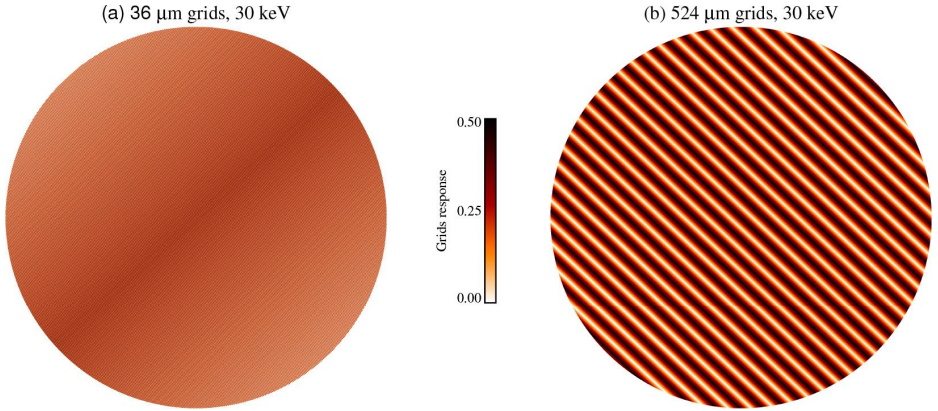


ASO-S/HXI：overview

HXI Grid



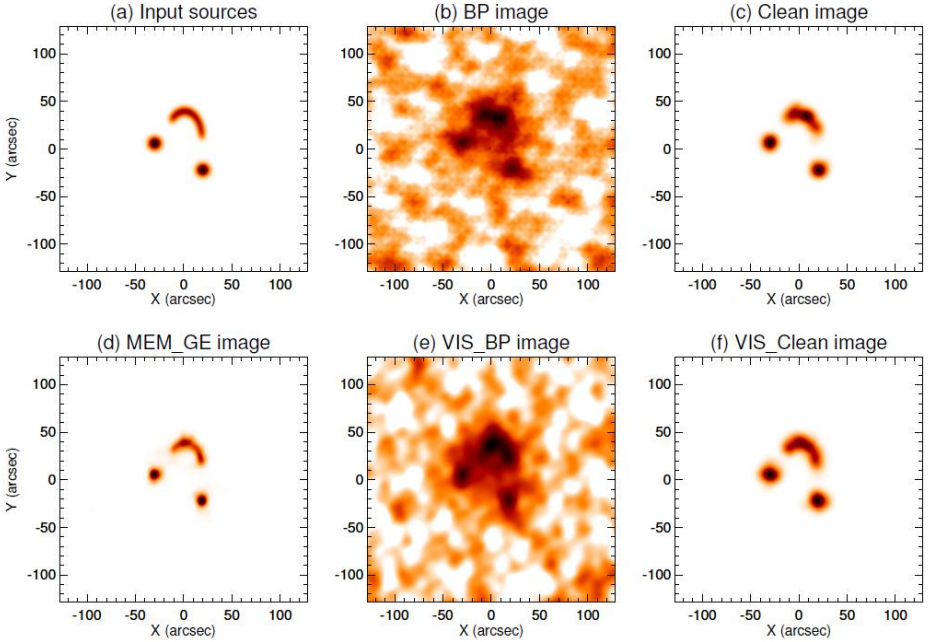
Calculated Pattern (gird response, Su+2019)



ASO-S/HXI：overview

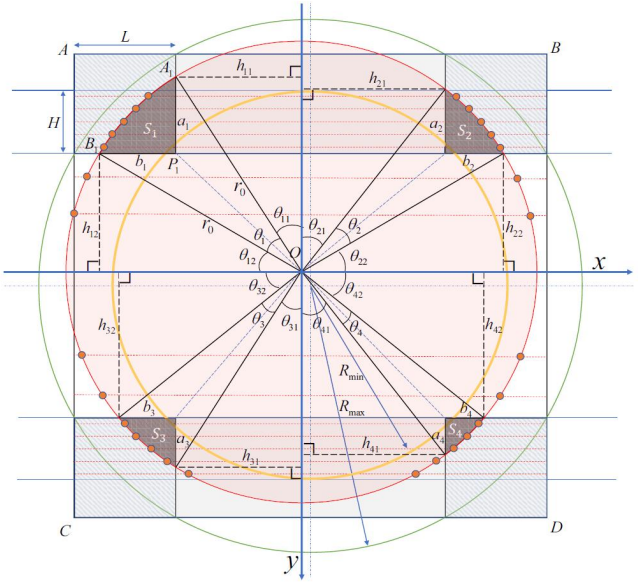
Imaging test (ideal case):

Reconstructed HXI images （Su et al. 2019）

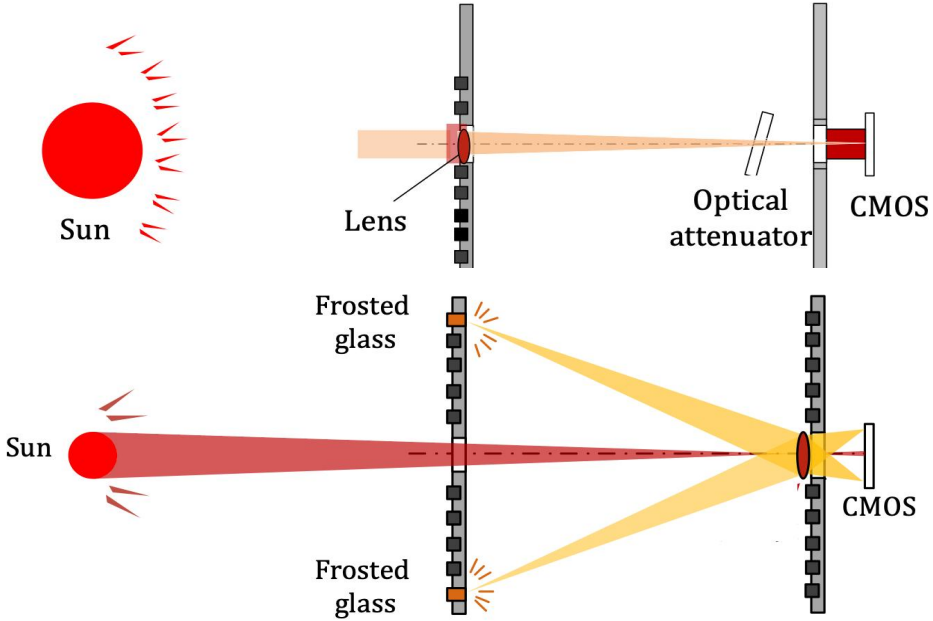


ASO-S/HXI：overview

- Two methods for determining solar disk center (Yu et al. 2020)

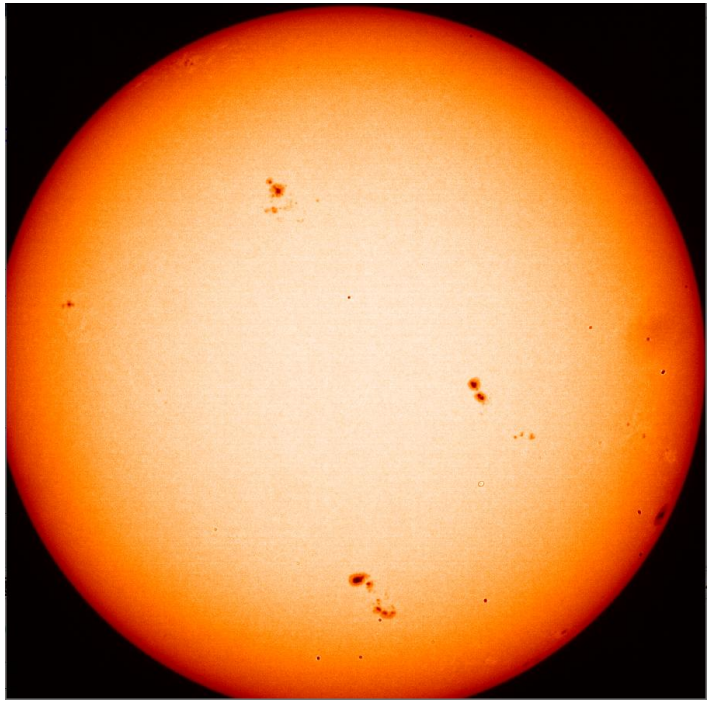


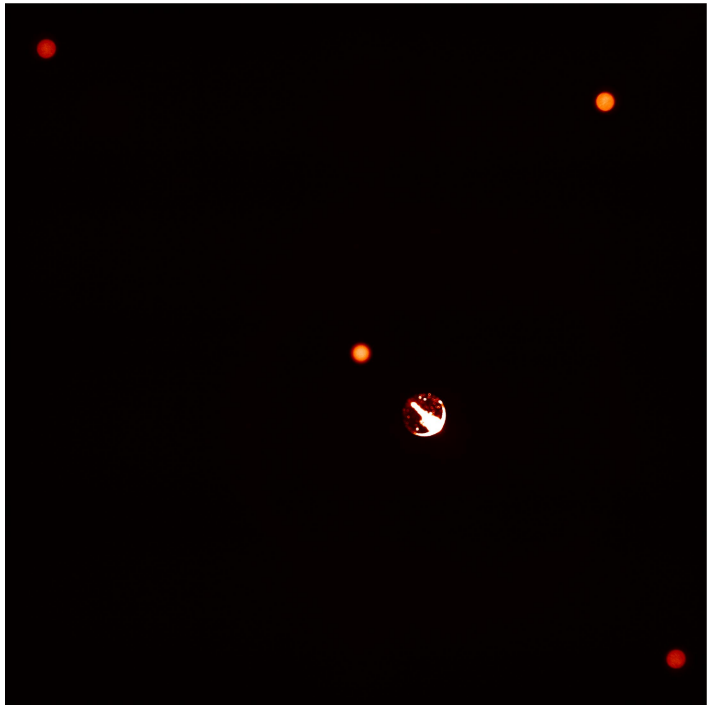
Solar Aspect system (SAS)



ASO-S/HXI：overview

SAS calibration images





ASO-S/HXI：overview

HXI instrument team

Zhe Zhang, Jian Wu, +

- HXI instrument
  - Grids and collimator
  - Detectors
  - Control box
  - SAS system
- Ground tests and calibration
- Beam tests
- Geant4 simulation

HXI science team

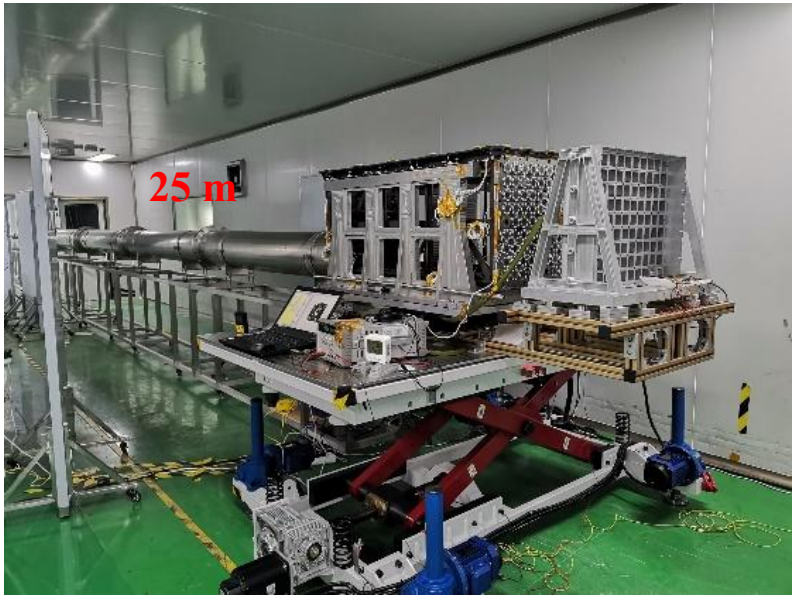
Yang Su, Wei Chen, +

- Data products and processing
- Production and Analysis software
- Energy calibration
- Grid calibration
- Simulated flare data
- Imaging algorithms
- Imaging simulation

- HXI design
- Grid parameters
- Detector response matrix
- Analysis for Beam tests
- SAS calibration
- In-orbit Calibration
- Performance analysis

ASO-S/HXI：overview

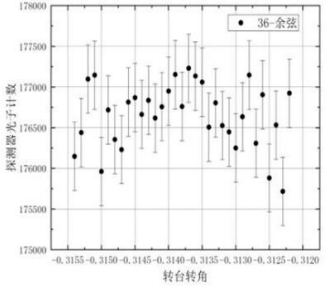
Beam test for modulation curves with New X-ray generator and new facilities



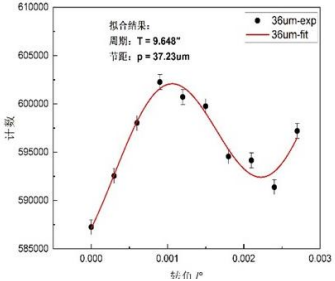
beam test (2021)

36μm

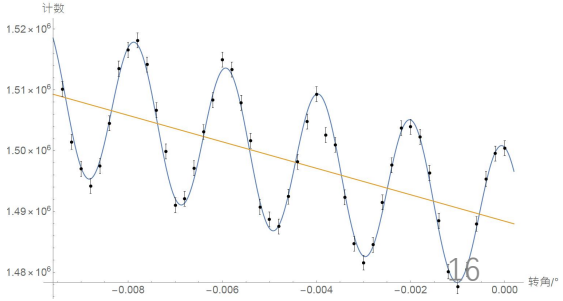
2020



2021.03



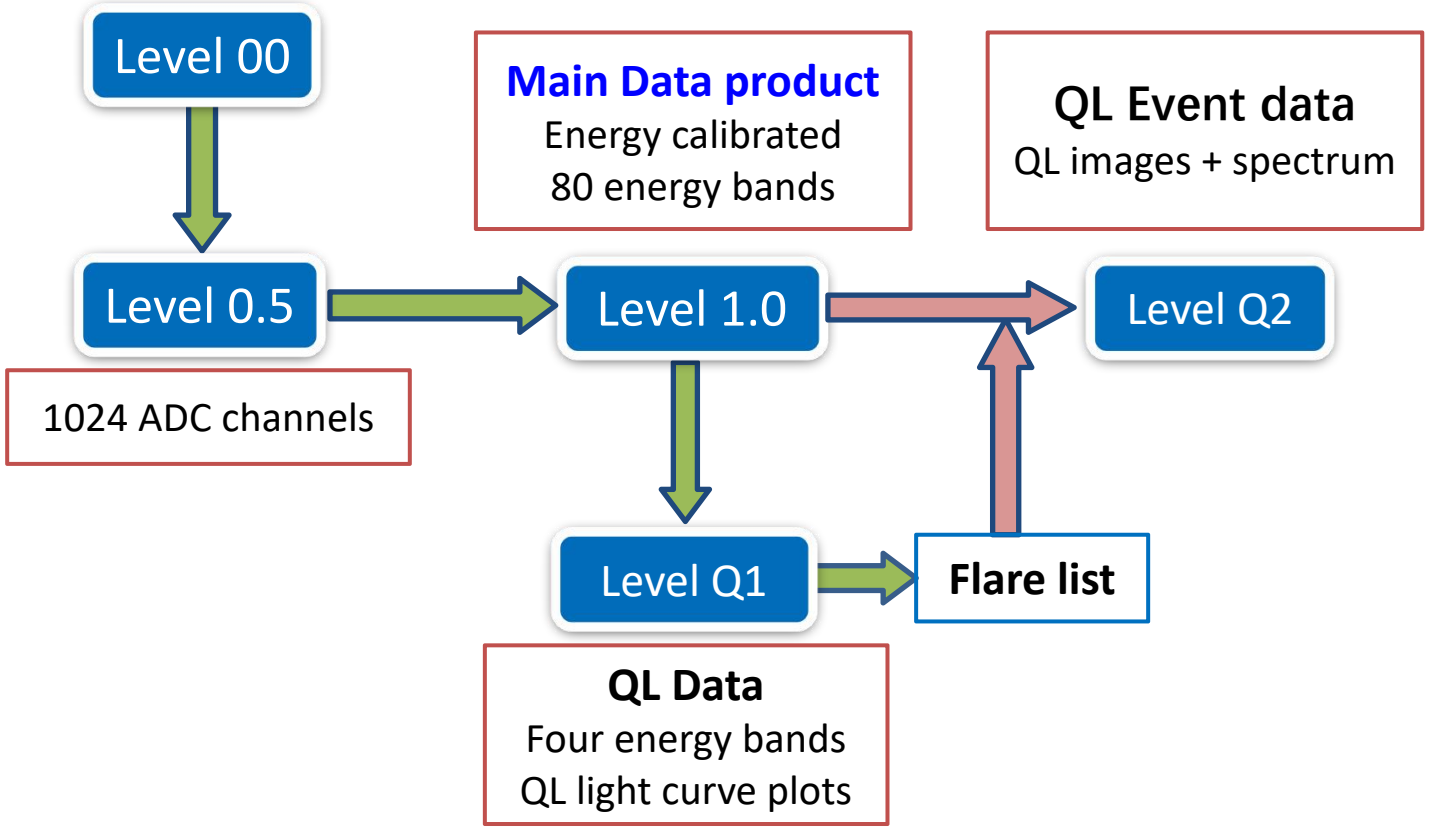
2021.10



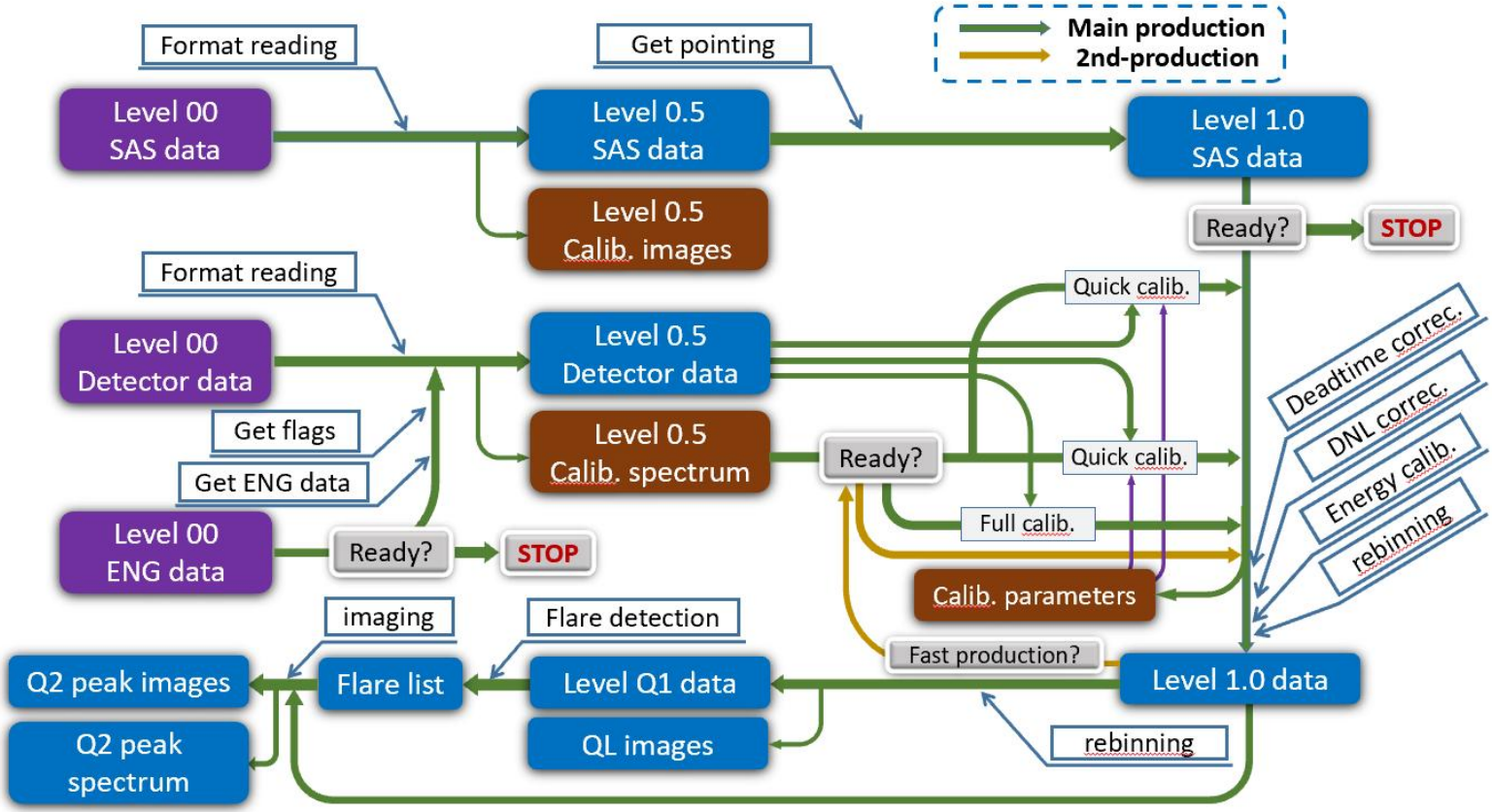
ASO-S/HXI：overview

- 2022.10.09 launch of ASO-S
- 2022.10.17 HXI was powered up
- 2022.11.21 HXI released first image
- 2022.12.12 ASO-S released first images
- 2023.01.18 in-orbit testing and optimization is done
- 2023.04 working on imaging calibration；
  recorded more than 200 flares;
  including three X-class flares

ASO-S/HXI：data products



ASO-S/HXI：data products



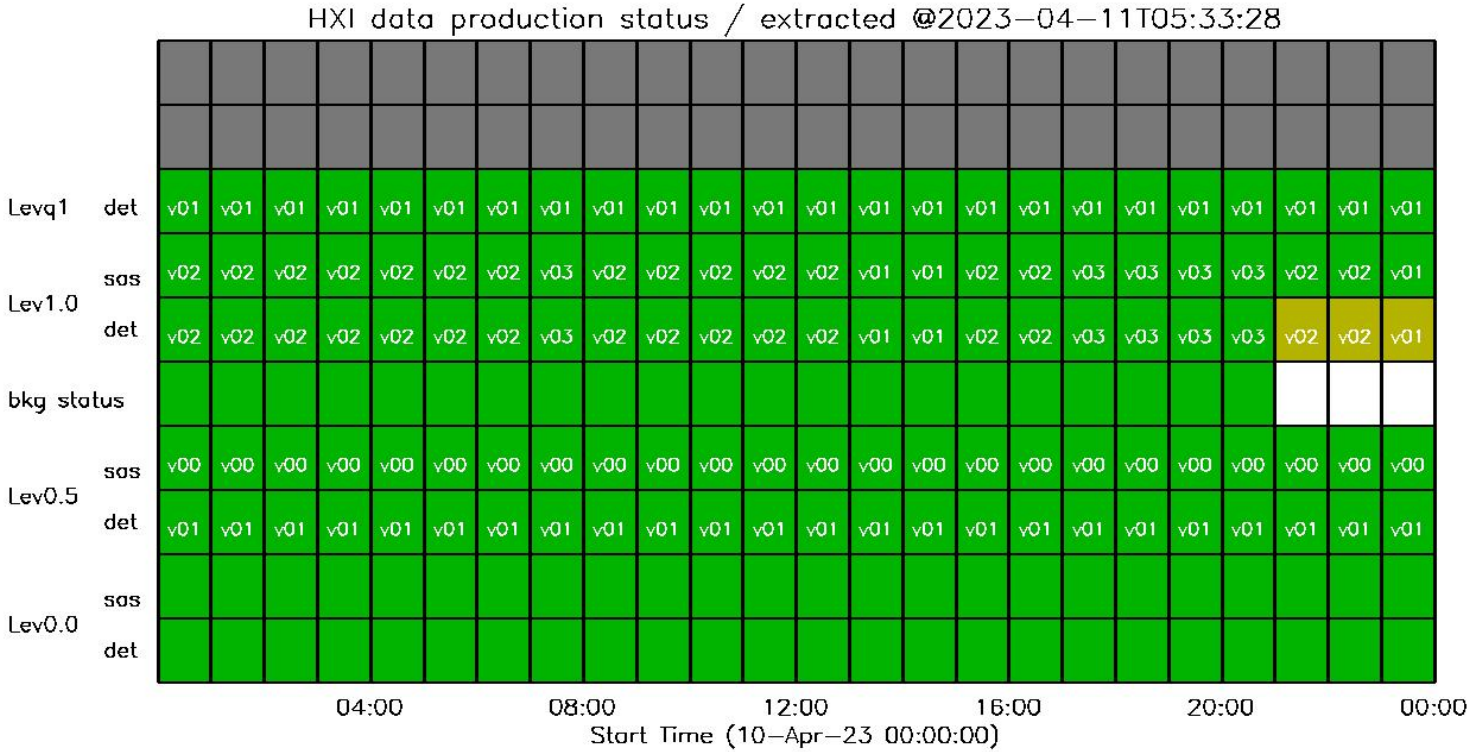
ASO-S/HXI：data products

HXI Level 1 FITS		
Primary		
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

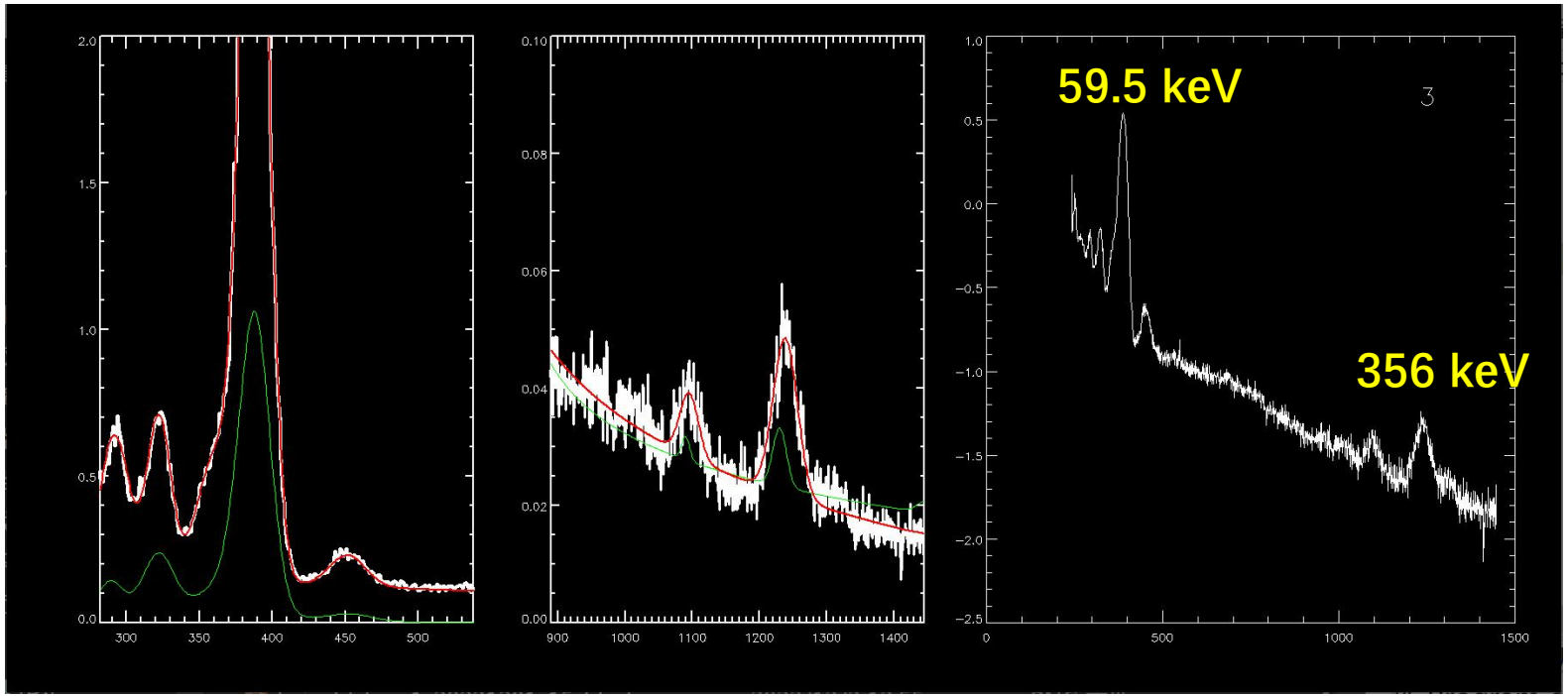
ASO-S/HXI：data products

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

ASO-S/HXI：data products



ASO-S/HXI：data products



ASO-S/HXI：data products

P1224 C53°	P156 C50°	P524 C41°	P156 S14°	P344 S23°	P800 C23°	P1224 C173°	P156 C158°	P156 S158°	P224 S149°	P800 S143°
P344 C59°	P36 C70°	P36 S70°	P76 C176°	P52 S41°	P52 C41°	P76 S176°	P52 S149°	P52 C149°	P108 S131°	P344 S131°
P156 C14°	P76 C68°	P52 C77°	P52 S77°	P52 S5°	P52 C5°	P36 S160°	P36 C160°	P36 C115°	P76 S104°	P524 S113°
P800 C83°	P524 C77°	P108 C95°	P108 S95°	P224 C5°	P524 S5°	P344 S95°	P224 C113°	P36 S115°	P76 C104°	P1224 113°
Frosted glass	P1224 113°	P224 S113°	P344 C95°	Open (thick)	DM	SA	Open (thick)	P224 C77°	P524 S77°	Frosted glass
P524 C113°	P1224 113°	P52 S113°	P52 C113°	P344 S167°	P800 S23°	P524 C5°	P156 S86°	P156 C86°	P76 S68°	P800 S83°
P344 C131°	P156 C122°	P76 S139°	P76 C139°	P156 S122°	P76 C32°	P76 S32°	P36 S25°	P36 C25°	P156 S50°	P108 C23°
P224 C149°	P108 C131°	P108 C167°	P108 S167°	P1224 S173°	P224 S5°	P108 S23°	P224 S77°	P108 C59°	P108 S59°	P224 S41°
P800 C143°	P524 C149°	P344 C167°	P524 S149°	Open (thin)	Frosted glass	P344 C23°	P524 S41°	P224 C41°	P344 S59°	P1224 S53°

D98

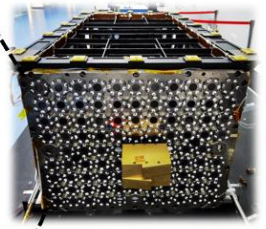
D97

D94

D99

D93 D96 D95 D92

P – pitch
C – cos
S – sin
DM – Deformation monitor
SA – Solar Aspect monitor

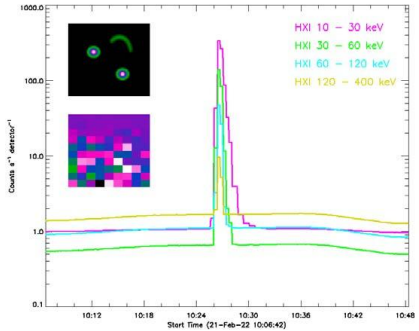


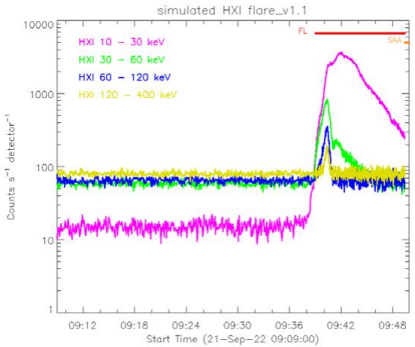
G1 : P36, D1-8
G2 : P52, D9-18
G3 : P76, D19-28
G4 : P108, D29-38
G5 : P156, D39-48
G6 : P224, D49-58
G7 : P344, D59-68
G8 : P524, D69-78
G9 : P800, D79-84
G10 : P1224, D85-91

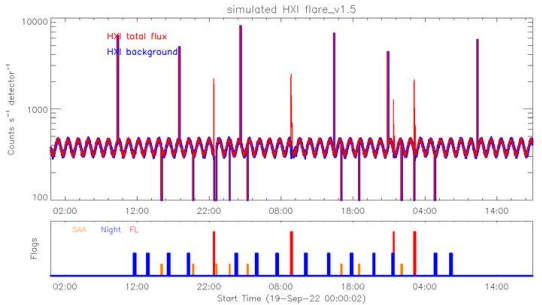
ASO-S/HXI：data products

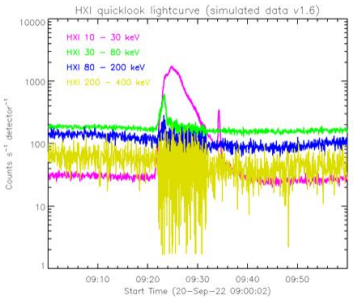
Created simulated data, as realistic as possible:

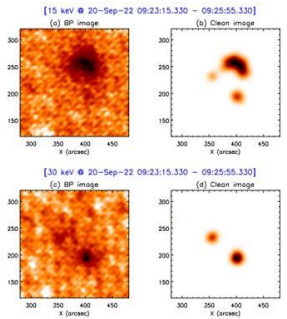
202006			202010			202106			202206
Simu. Data V0.7	V0.8	V0.9	**V1.0**	V1.1	V1.3	**V1.5**	V1.6	V1.8	**V2.0**

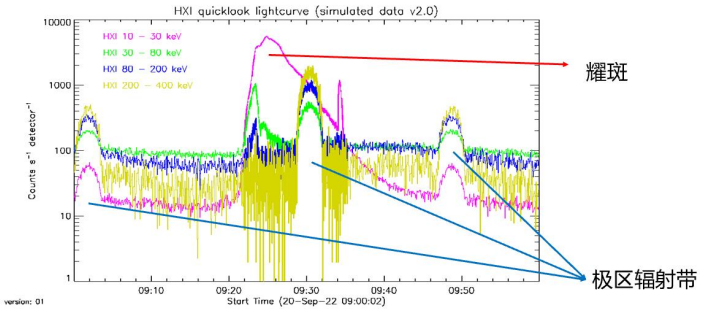






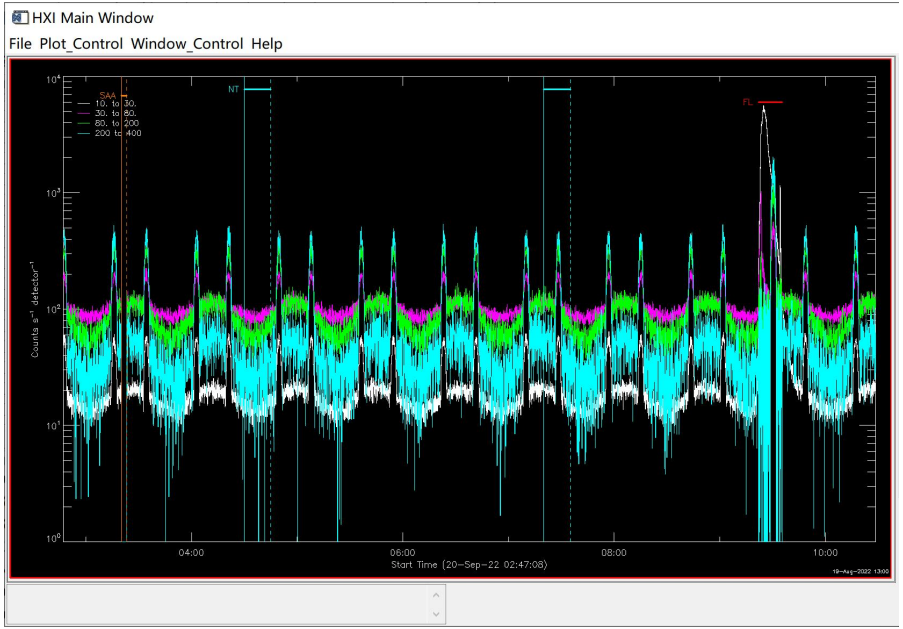




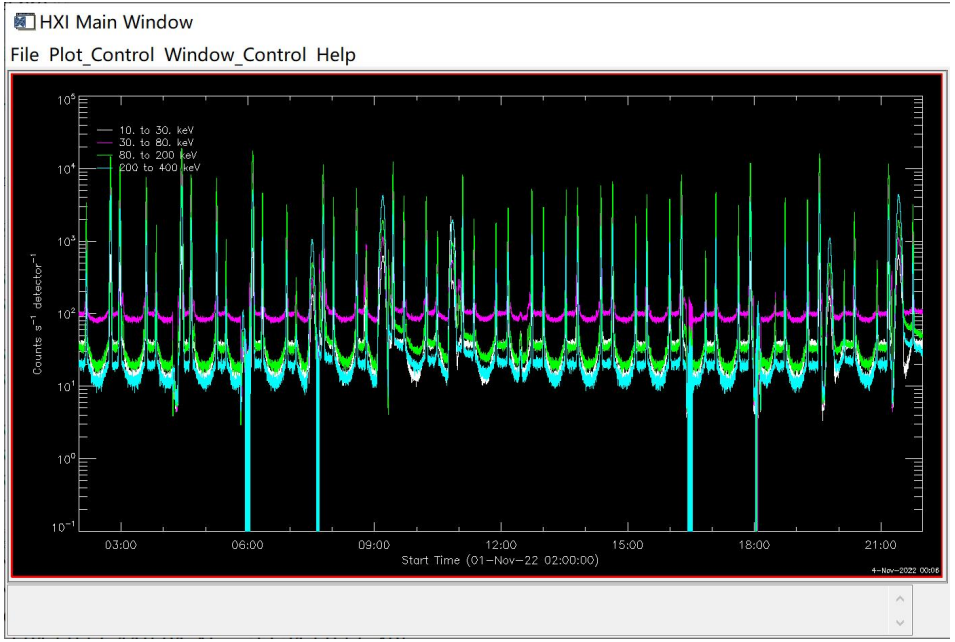


ASO-S/HXI：data products

Simulated data

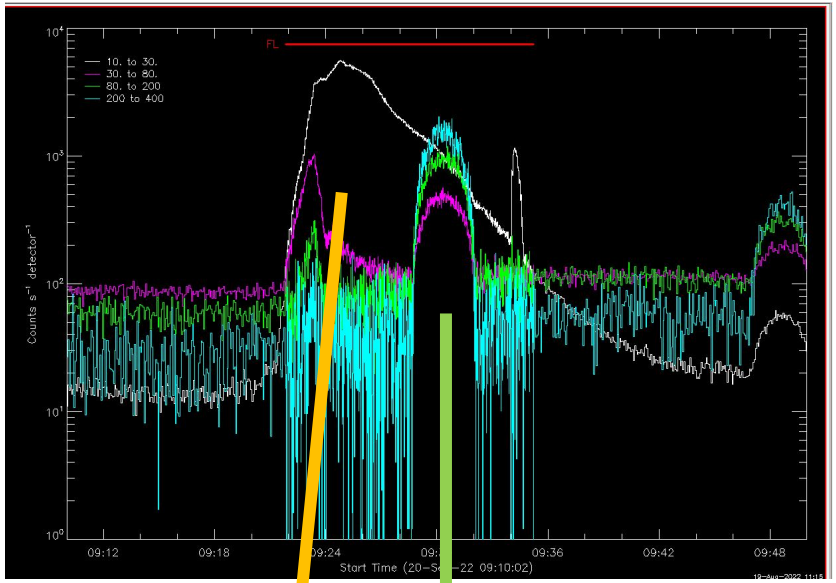


Observation data



ASO-S/HXI：data products

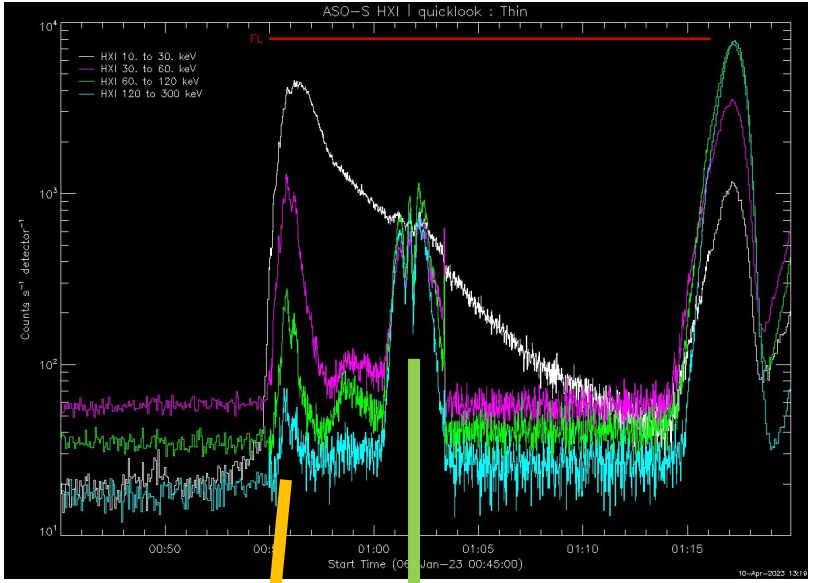
Simulated data



flare

particles

2023-Jan-06 X-class flare

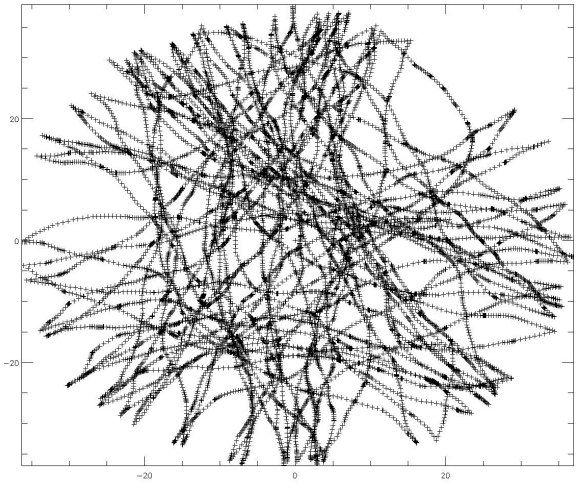


flare

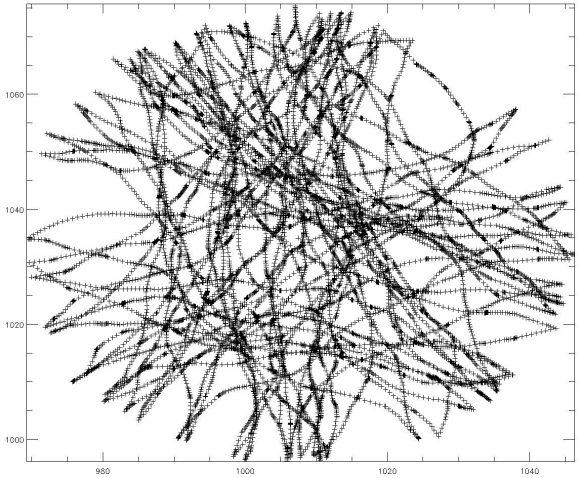
particles

ASO-S/HXI：data products

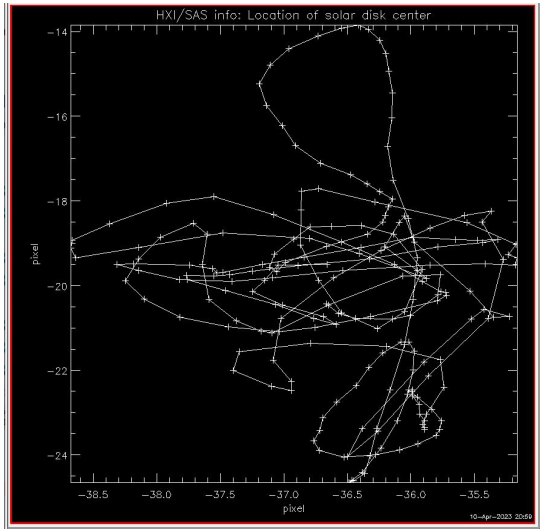
simulated pointing shifts/drifts: input



simulated pointing shifts: SAS measurements



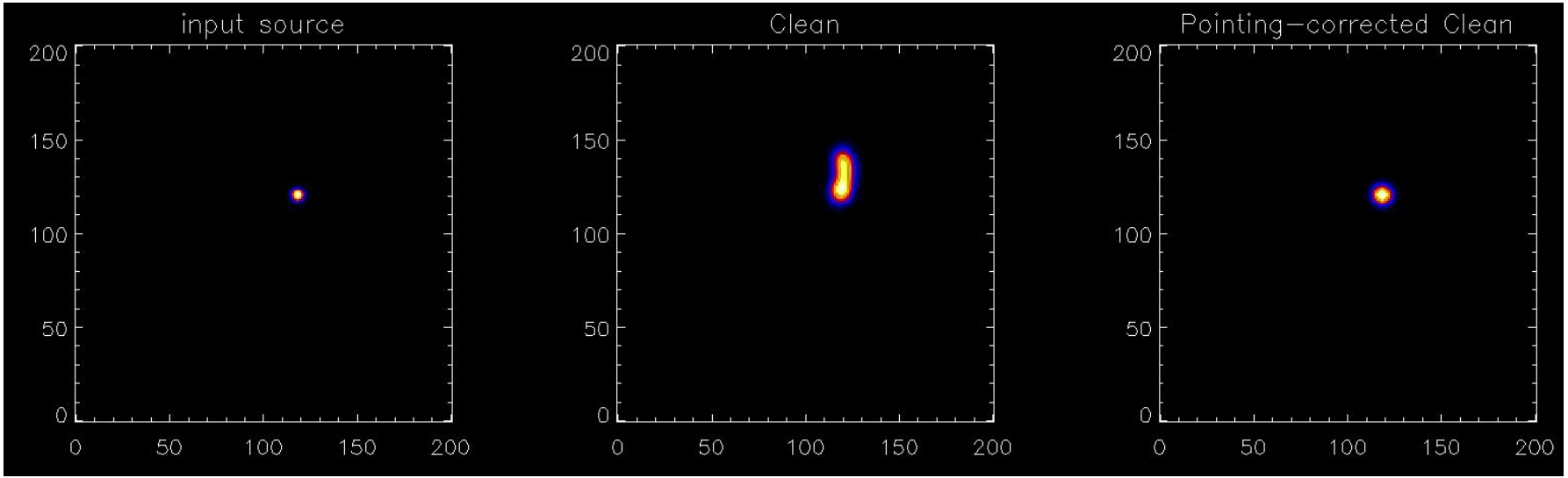
Observed data



ASO-S/HXI：data products

Correction for pointing shifts within duration time

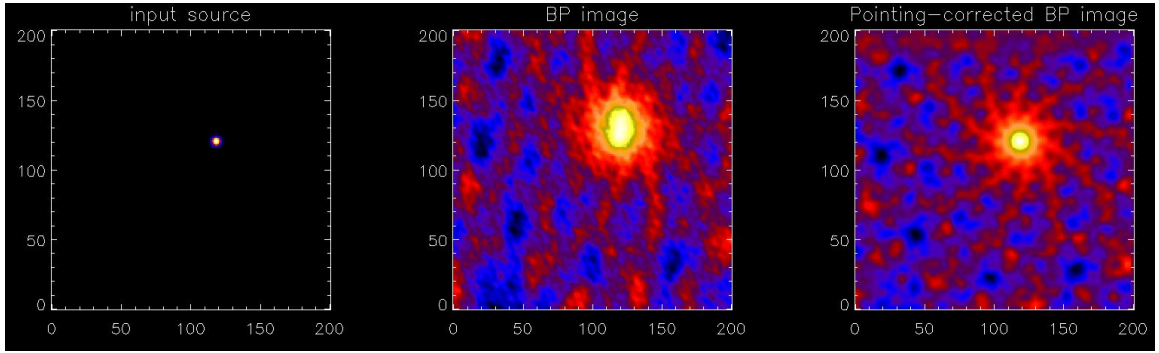
Input | Clean | Corrected Clean



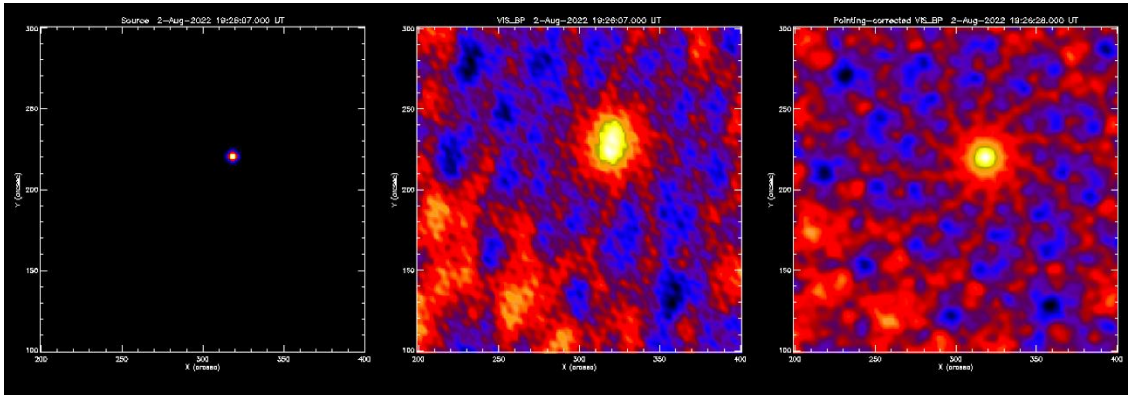
ASO-S/HXI：data products

Input image　　without correction　　corrected

HXI_BP

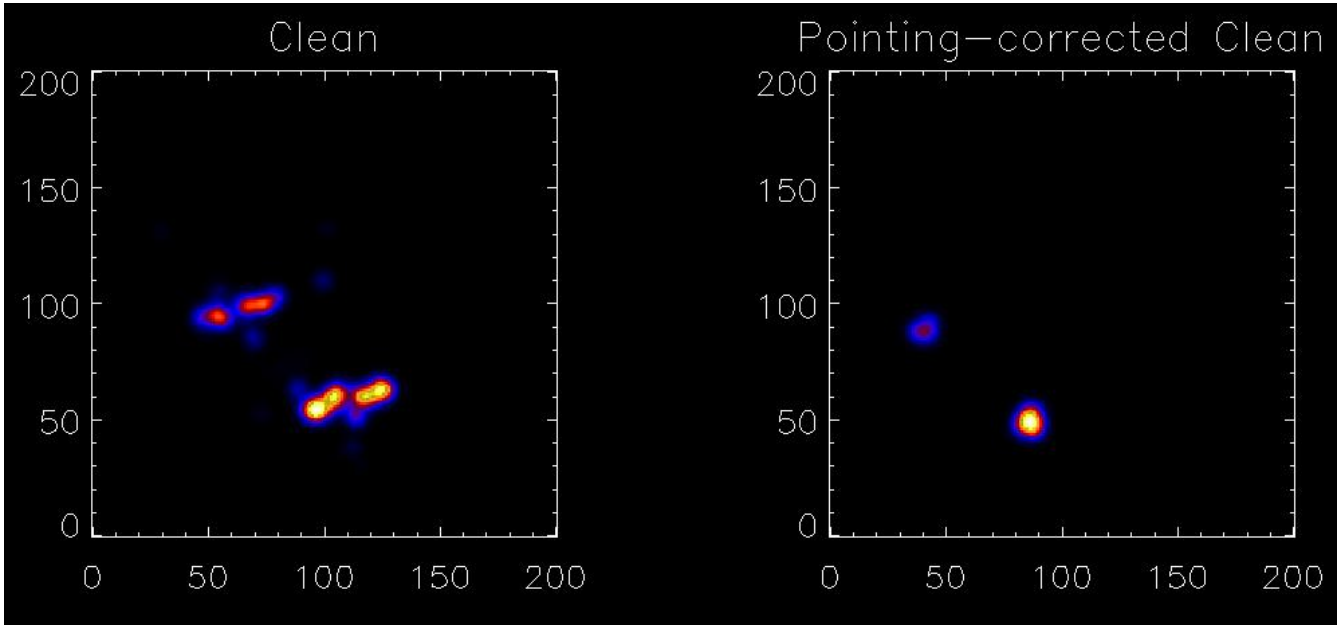


VIS_BP



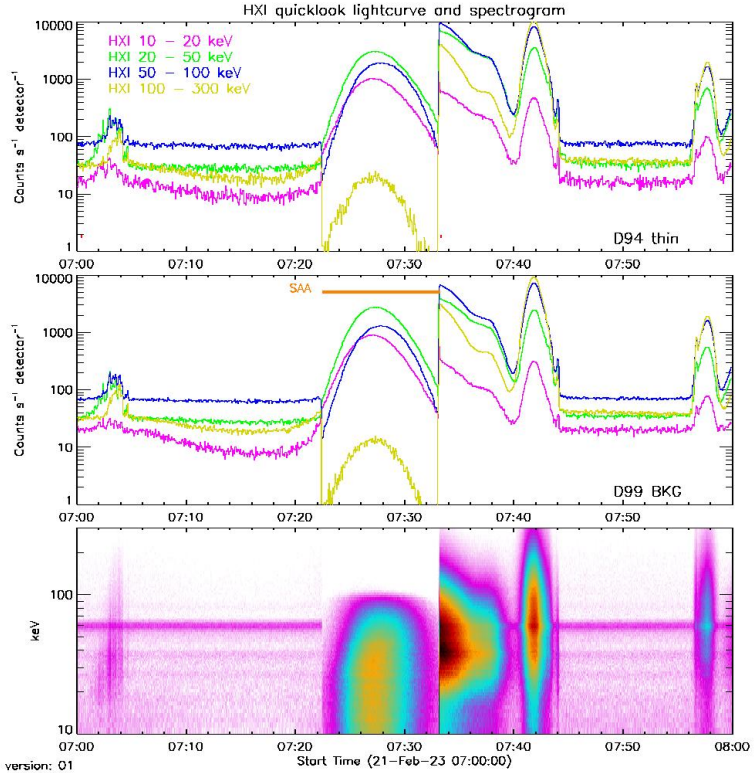
ASO-S/HXI：data products

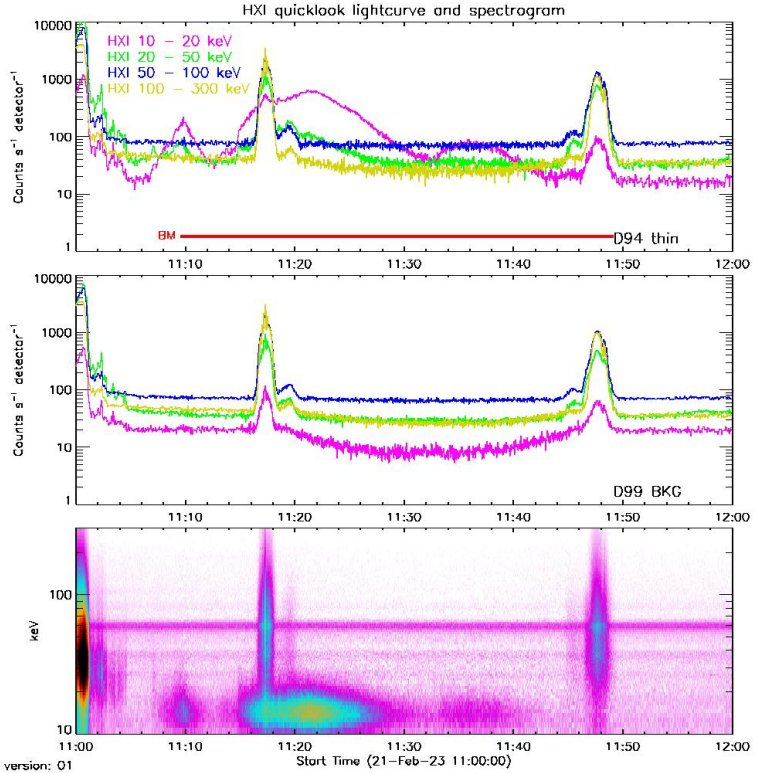
Correction for pointing shifts during imaging
Based on simulated data v2.0



ASO-S/HXI：observations

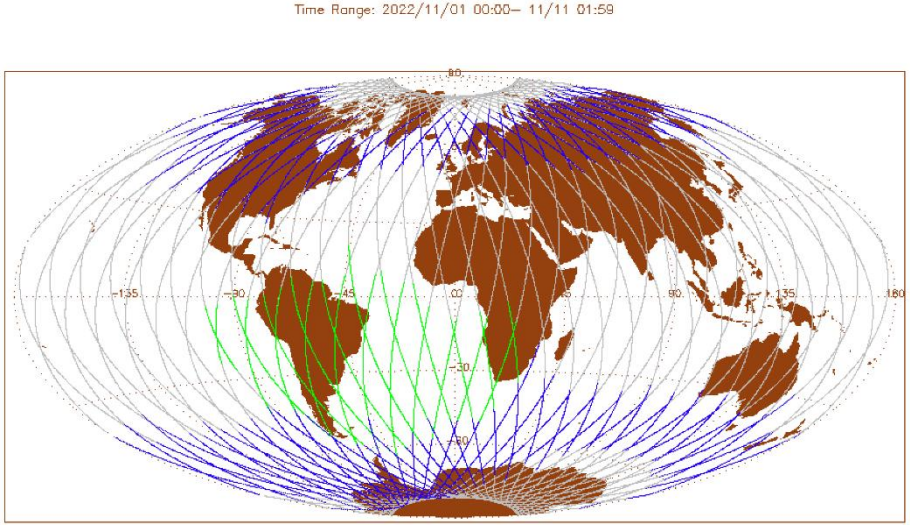
First, we need understand HXI quicklook data



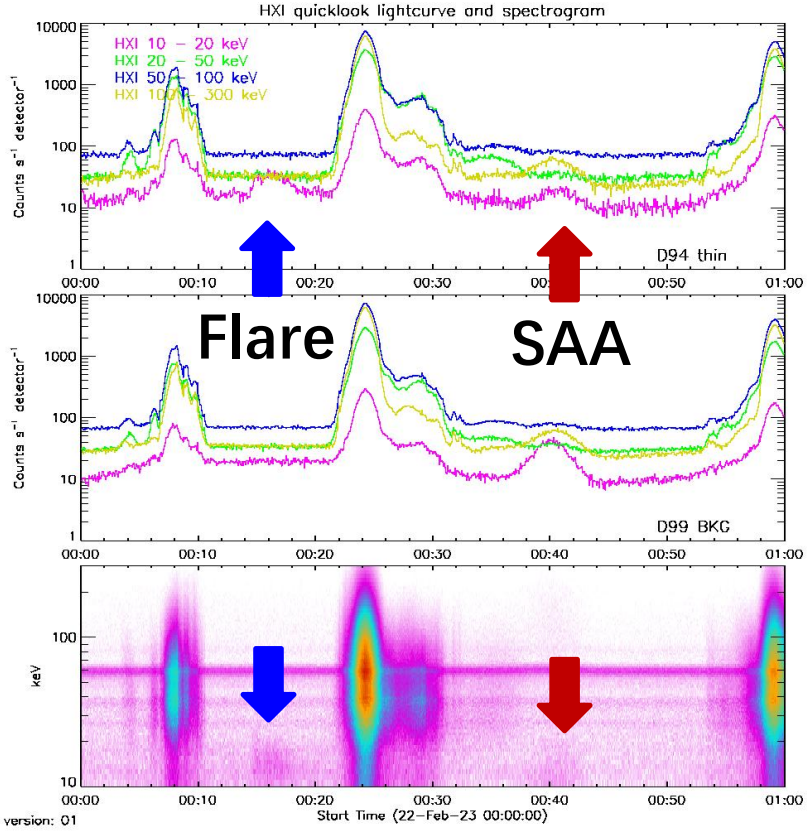


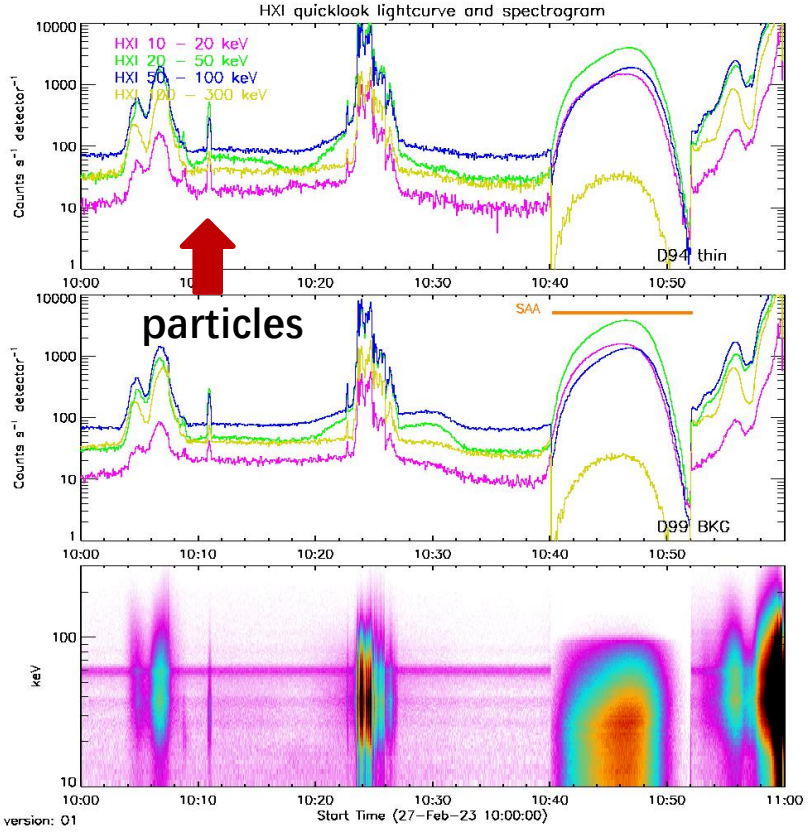
ASO-S/HXI：observations

SAA and radiation belt (Wei Chen, Zhe Zhang)



ASO-S/HXI：observations





ASO-S/HXI：observations

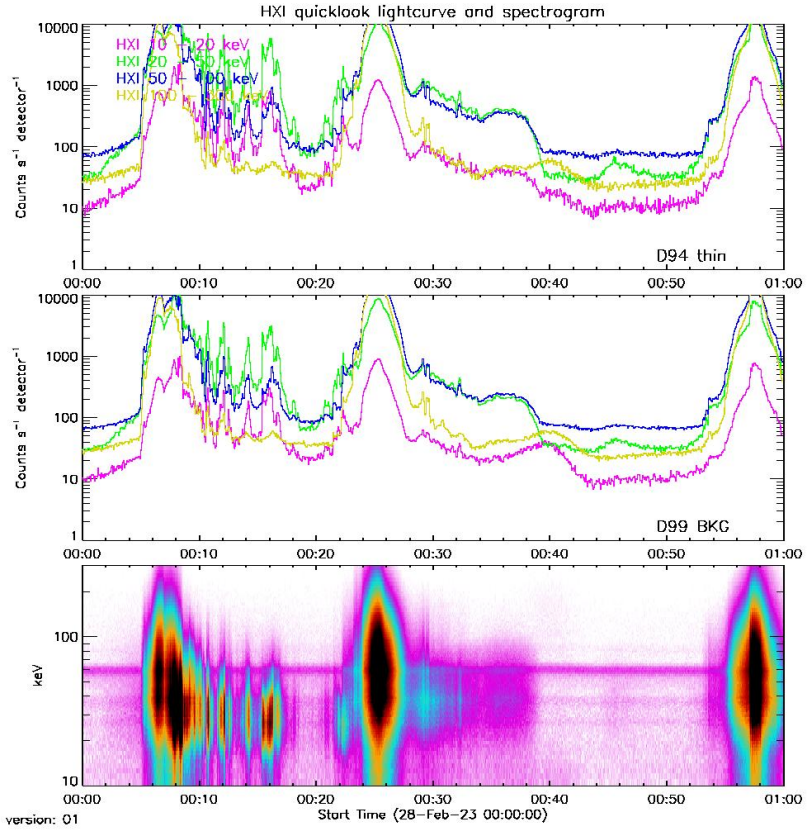
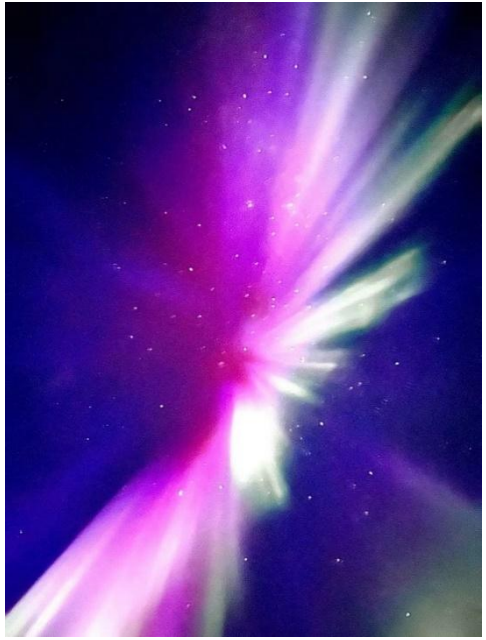
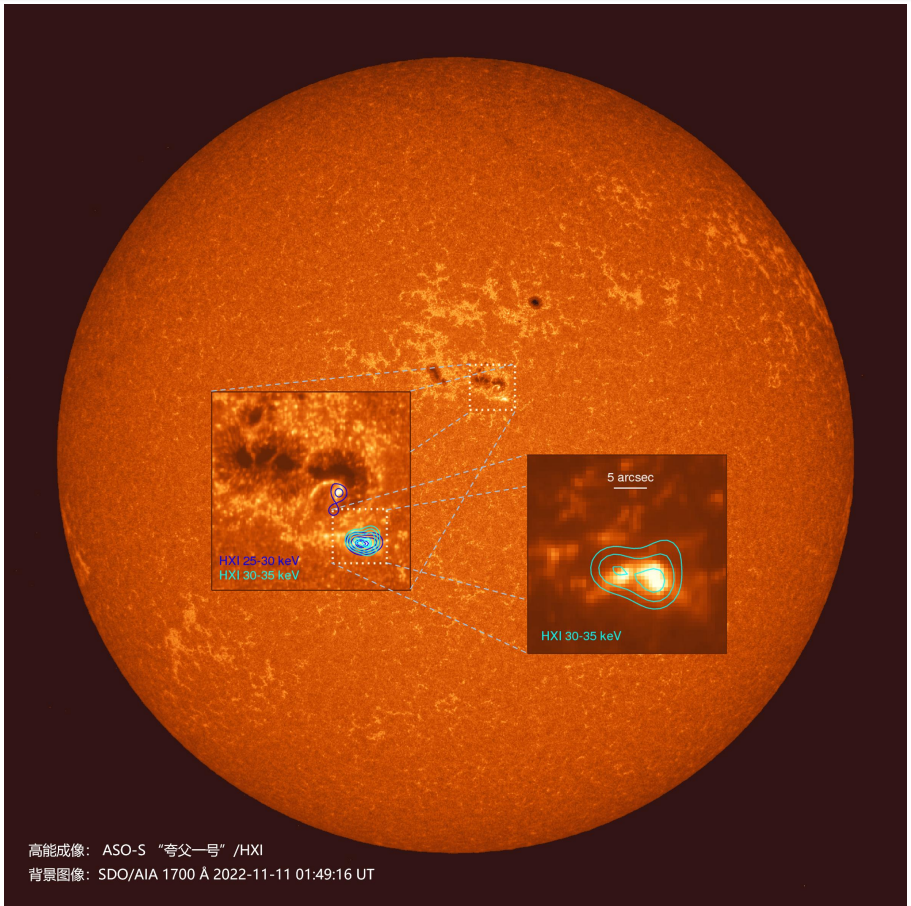


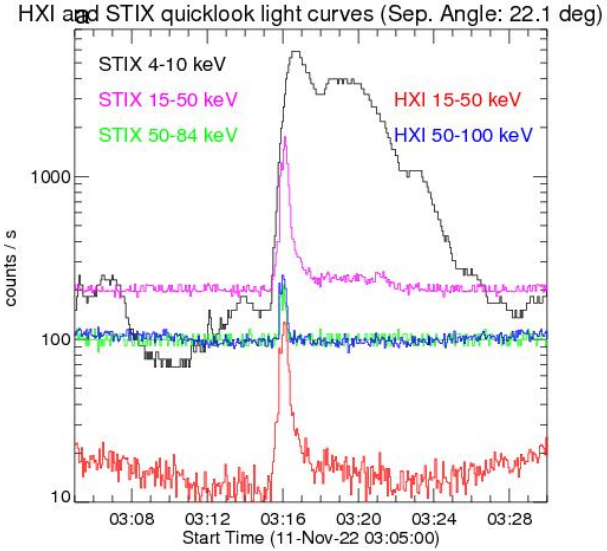
Photo of aurora: Yuan Ren (Antarctica)

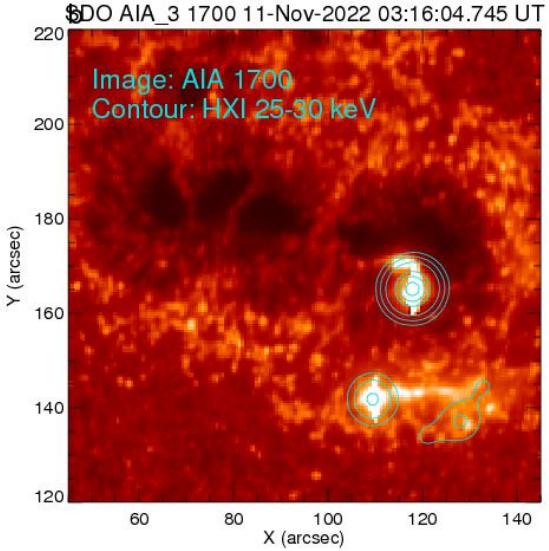


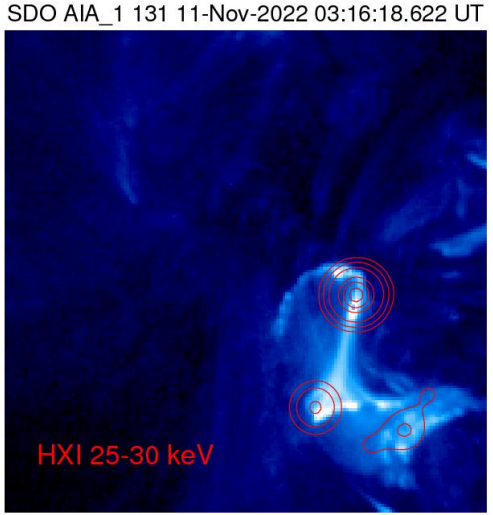
ASO-S/HXI：observations



ASO-S/HXI：observations

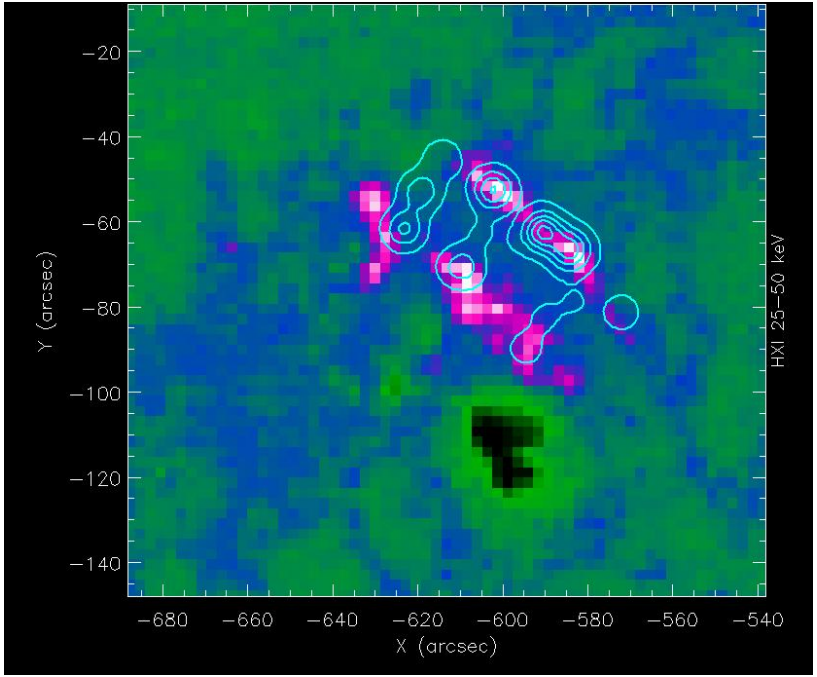


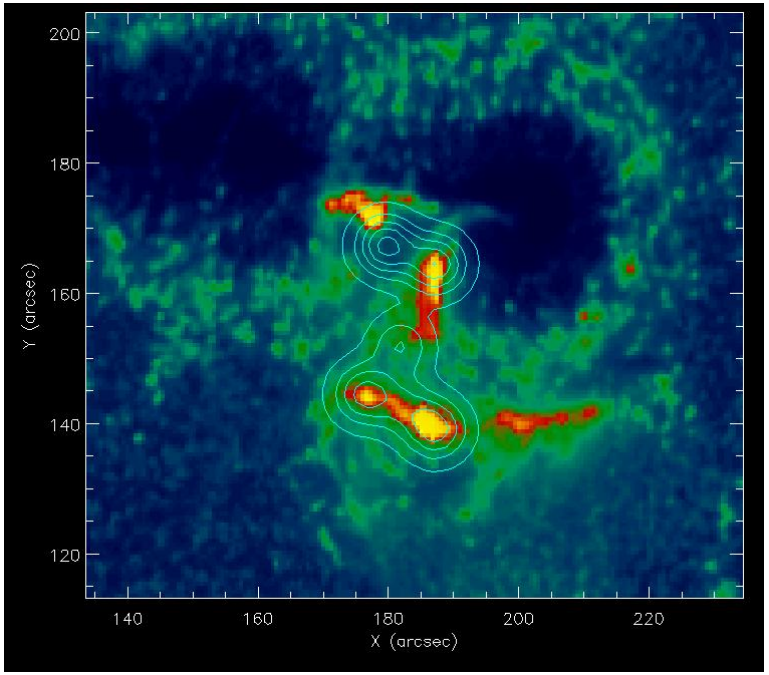




ASO-S/HXI：observations

Complex structures in Flare Ribbons (often seen in HXI data)

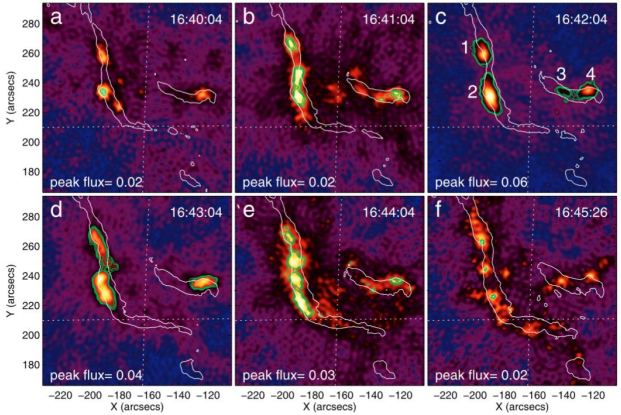


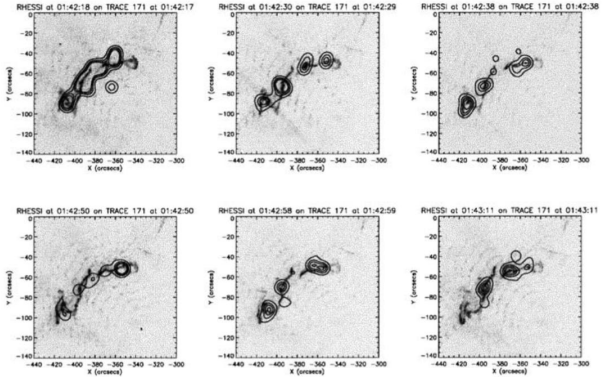


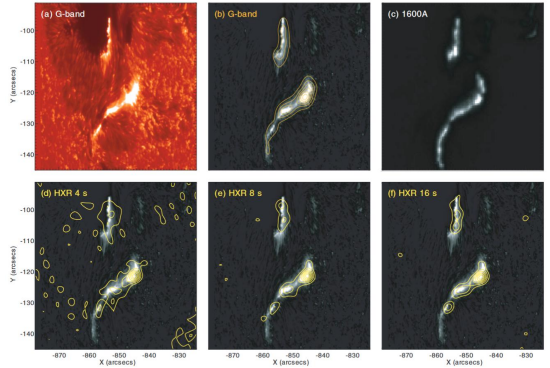
ASO-S/HXI：observations

HXR Flare Ribbons from RHESSI (rarely seen)

Fletcher & Hudson 2002
Liu et al. 2007
Dennis & Pernak 2009
Krucker et al. 2011

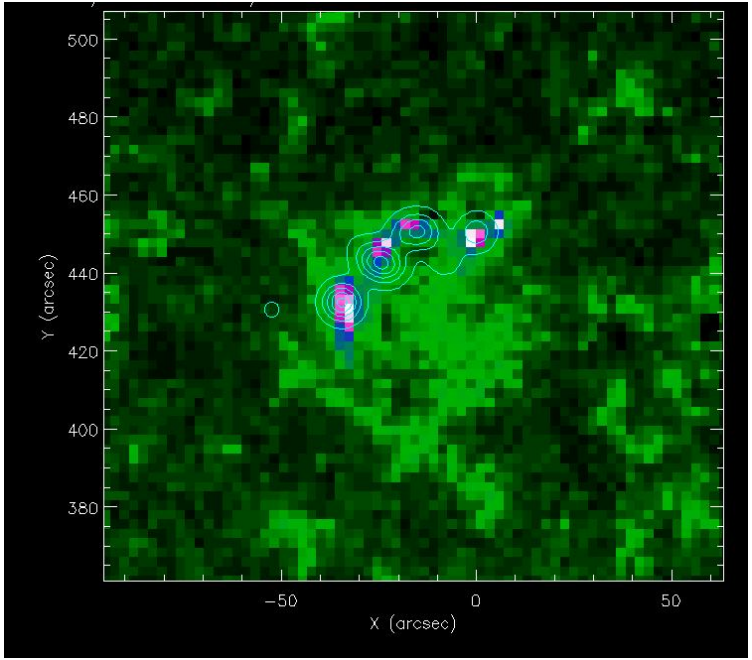


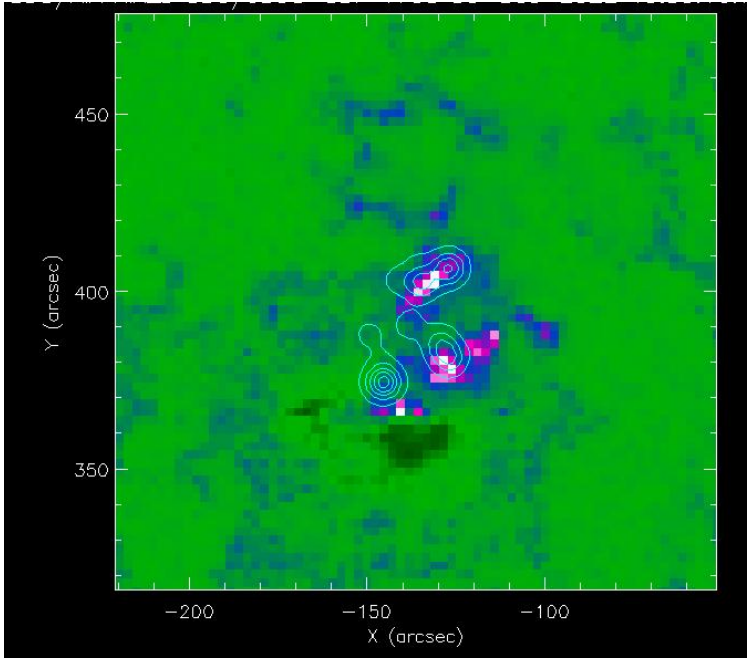




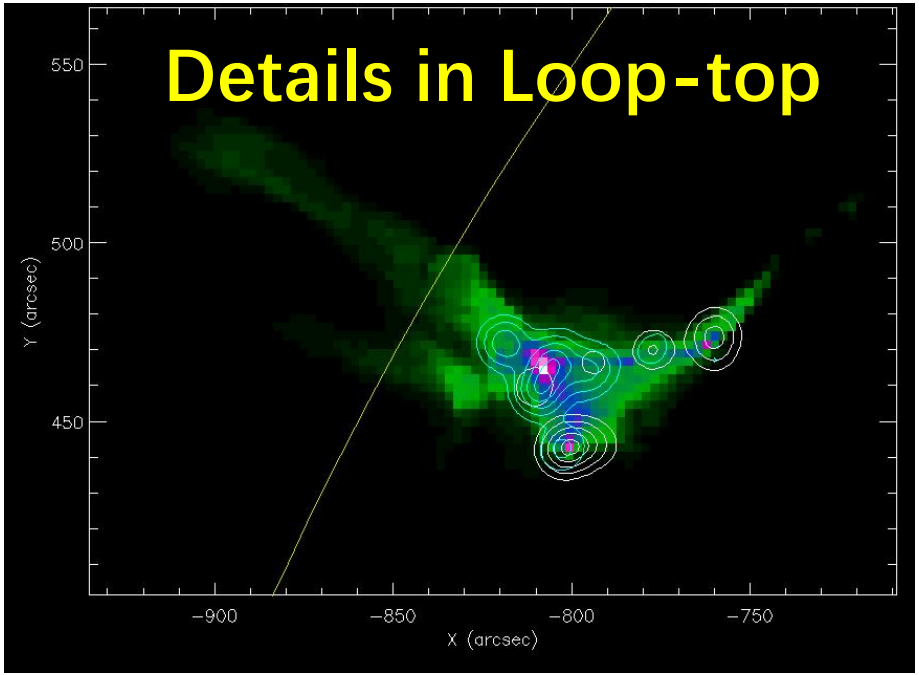
ASO-S/HXI：observations

More examples of complex HXR ribbons

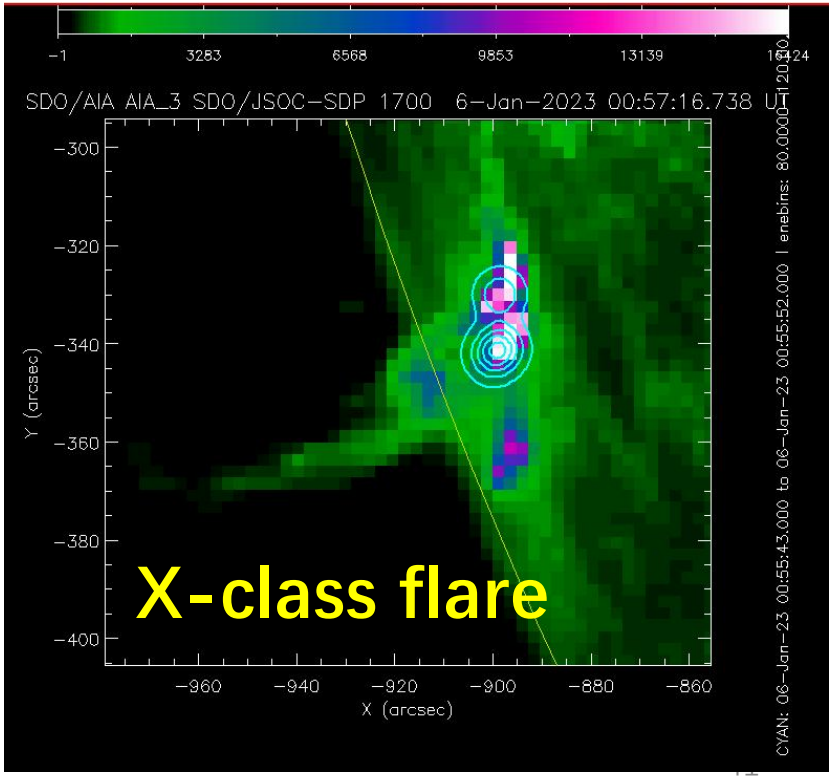




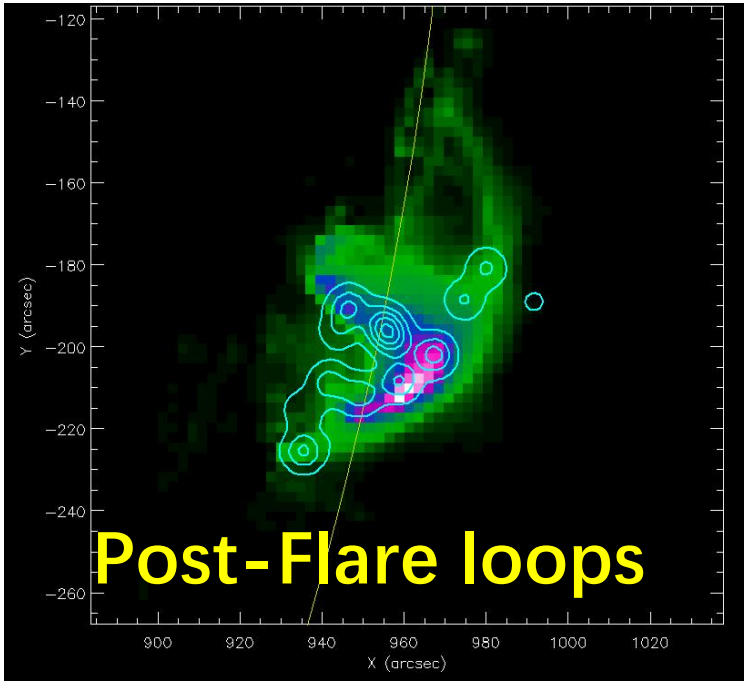
ASO-S/HXI：observations

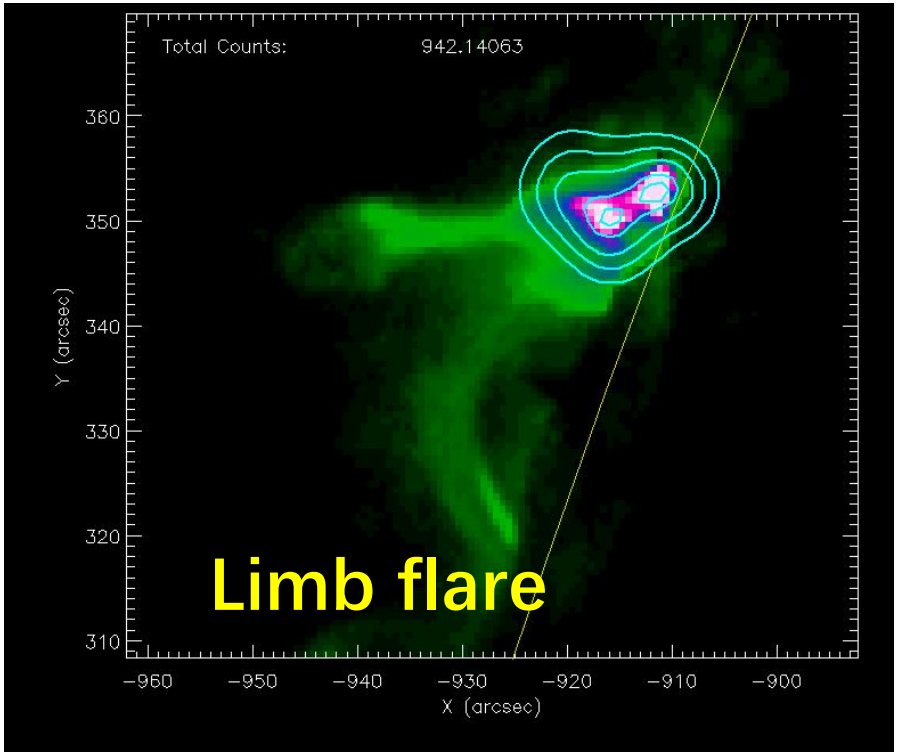


80-120 keV

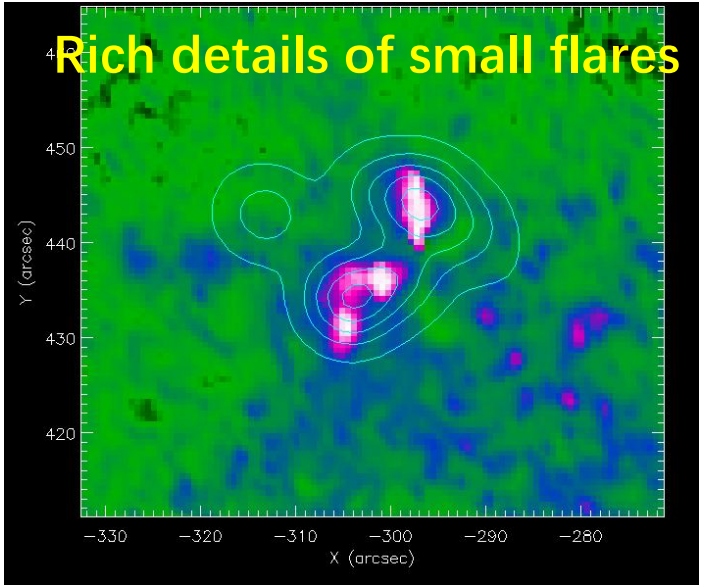


ASO-S/HXI：observations



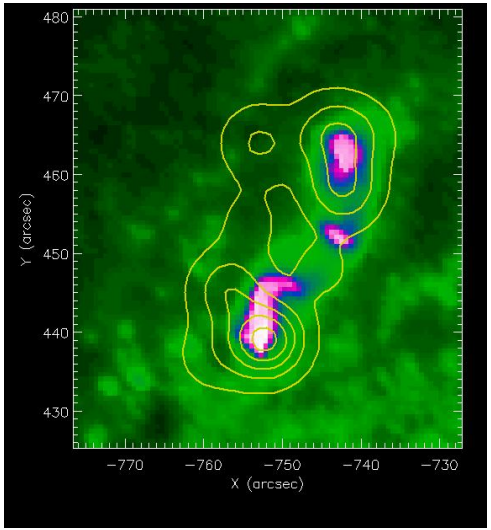


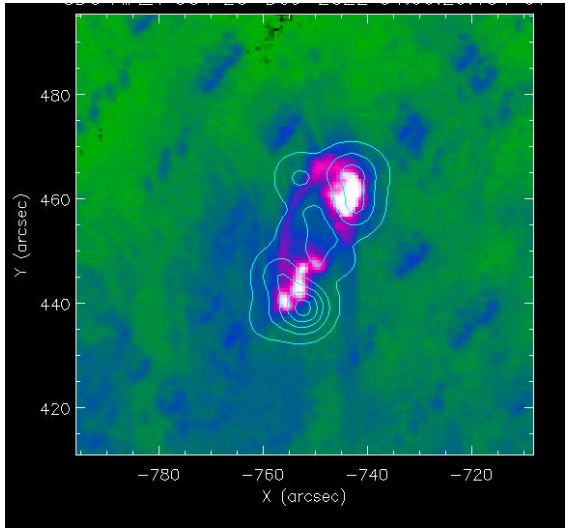
ASO-S/HXI：observations

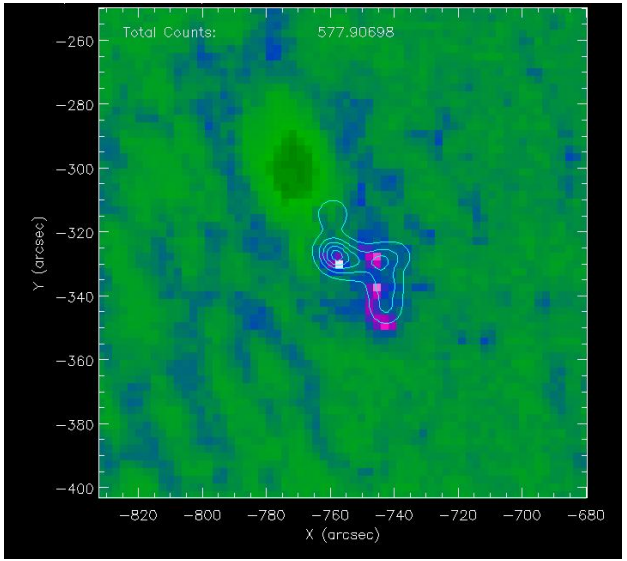


ASO-S/HXI：observations

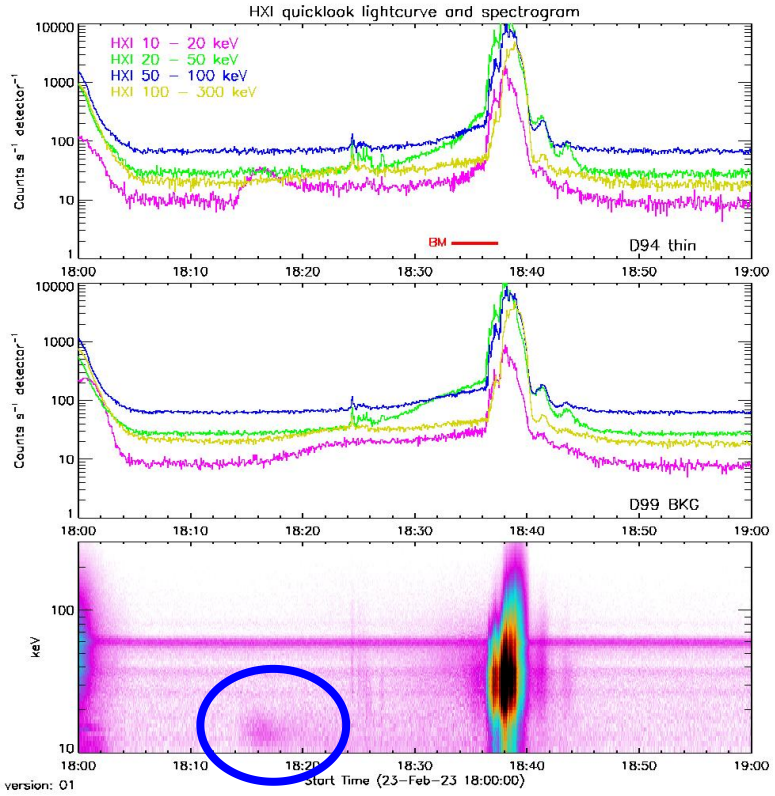
High energy HXRs in two GOES C2 class flares



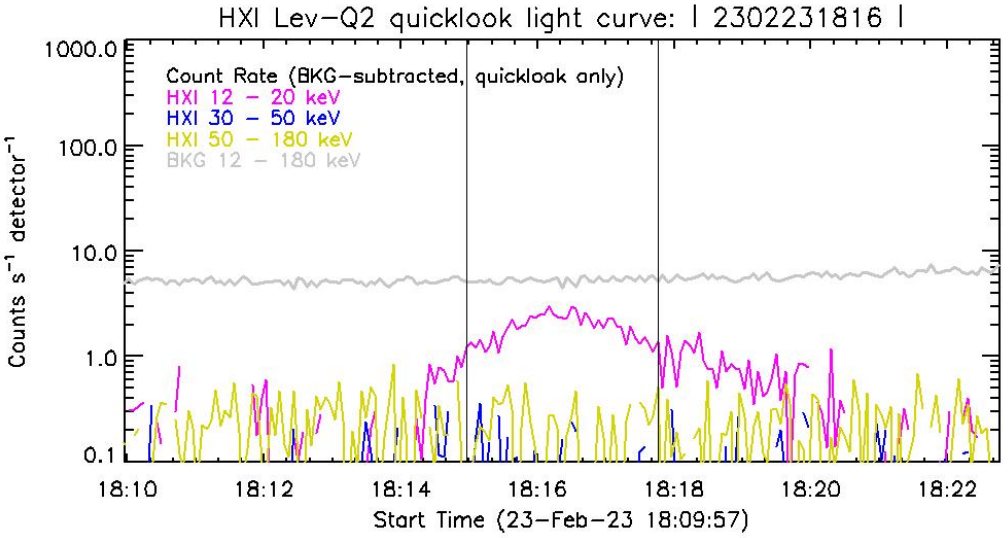




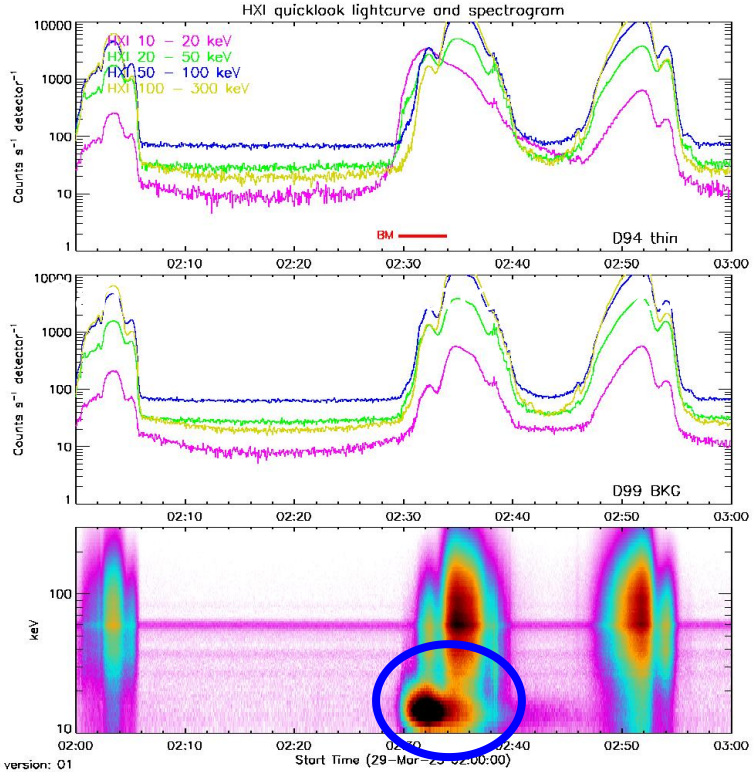
ASO-S/HXI：observations

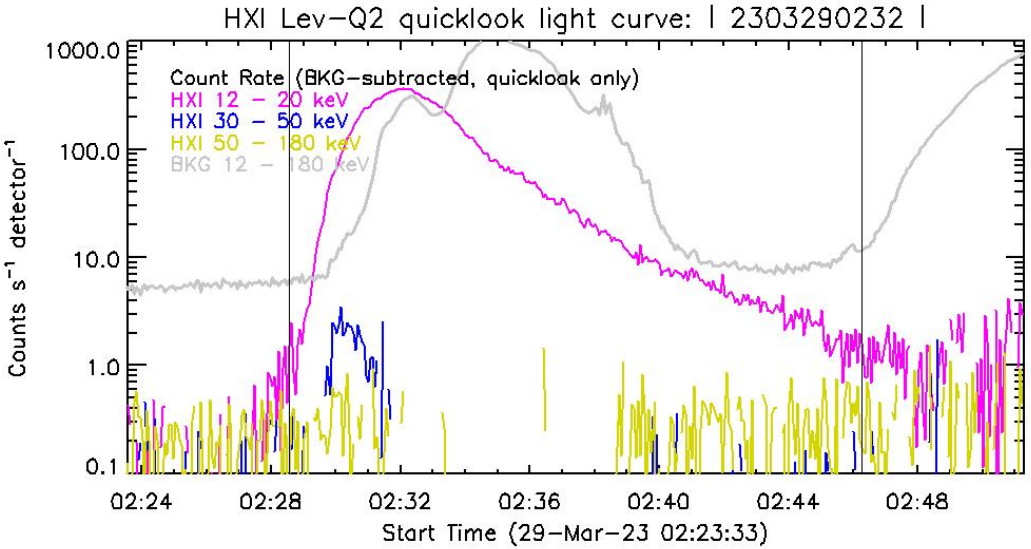


HXI Flare list: ongoing work



ASO-S/HXI：observations



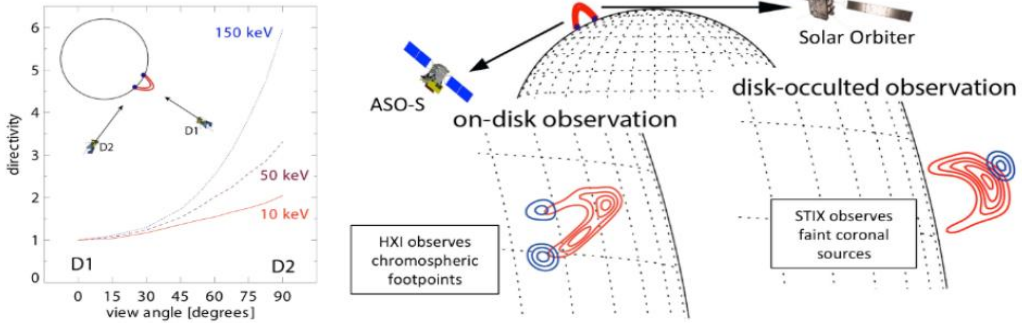


ASO-S/HXI：Summary

HXI:

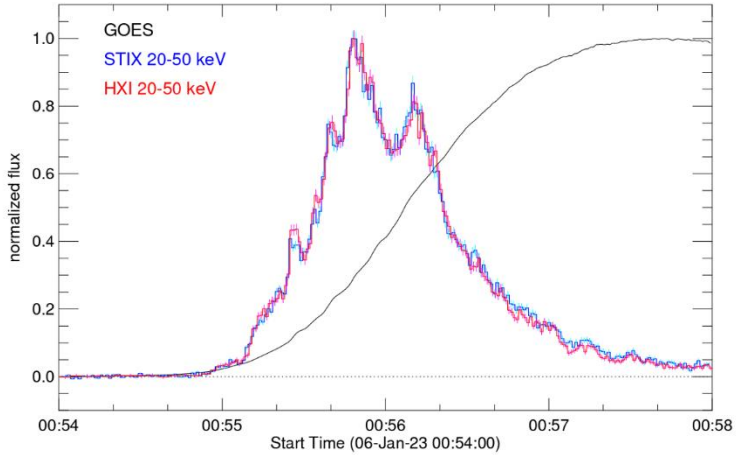
- **China's First HXR solar imager**
- **improvements**: more subcollimators; more visibilities?; independent total flux and background monitors
- Currently the only HXR solar imager from Earth's point of view (NuSTAR is not solar- dedicated)
- **(HXI+STIX) First stereoscopic imaging observation in HXR (important for directivity studies)**

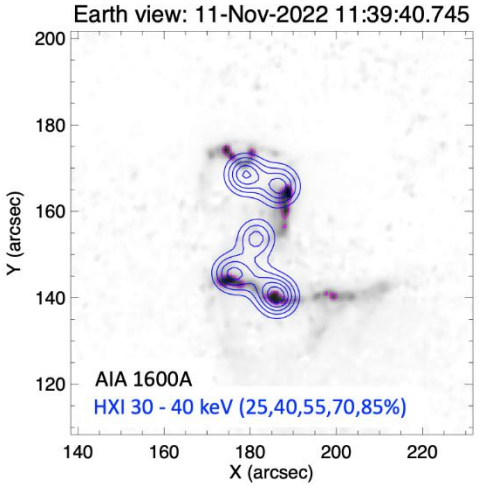
Solar Orbiter/STIX+ASO-S/HXI, Krucker et al. 2019

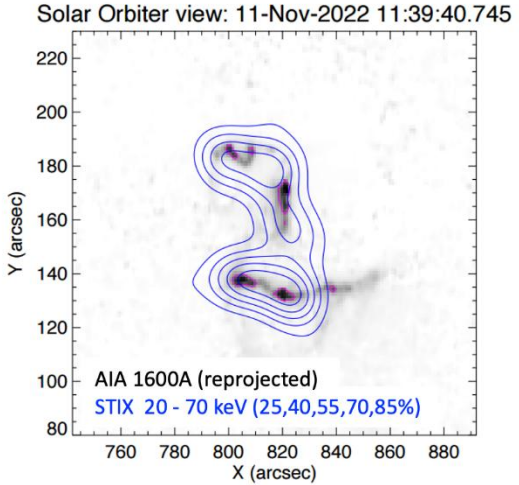


ASO-S/HXI：Summary

By Säm Krucker and Yang Su

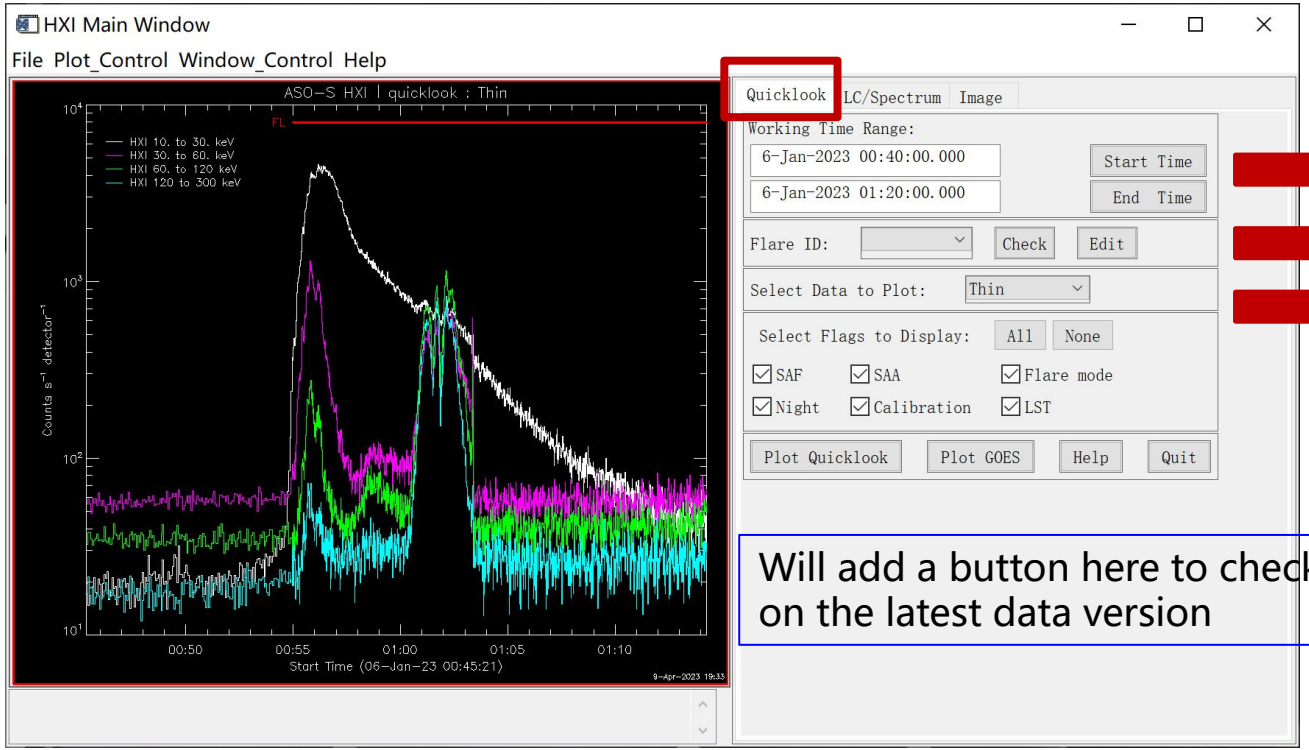






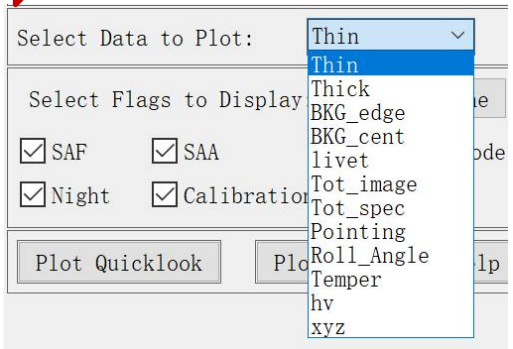
Tutorial：HXI GUI

HXI analysis software: HXI GUI
(objects + GUI + plotman, by Fanxiaoyu Xia, Fu Yu, Changxue Chen, Wei Chen, Yang Su)

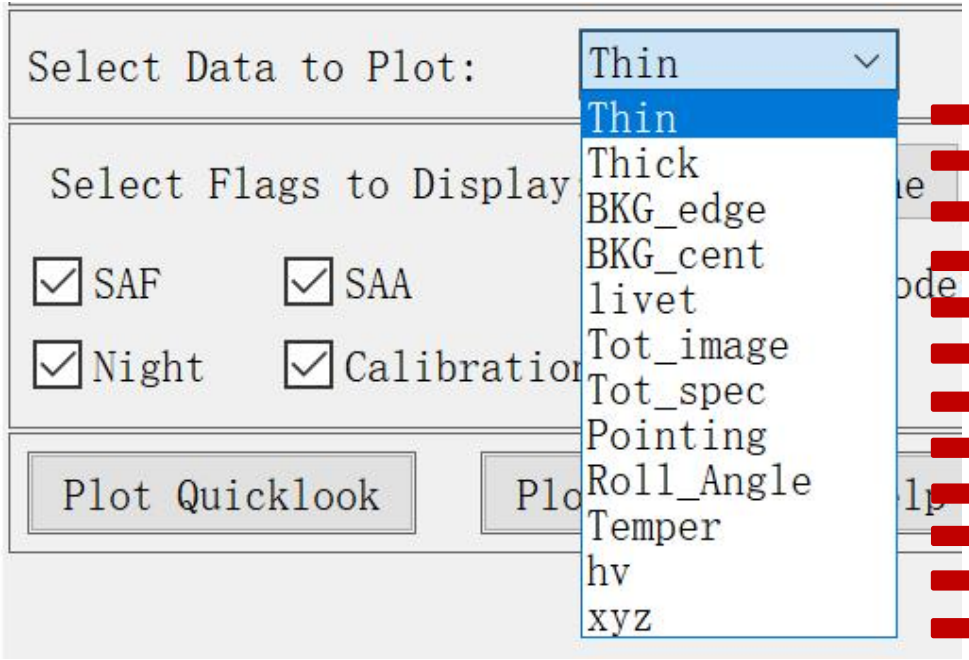


Time range

Flare info (not used)

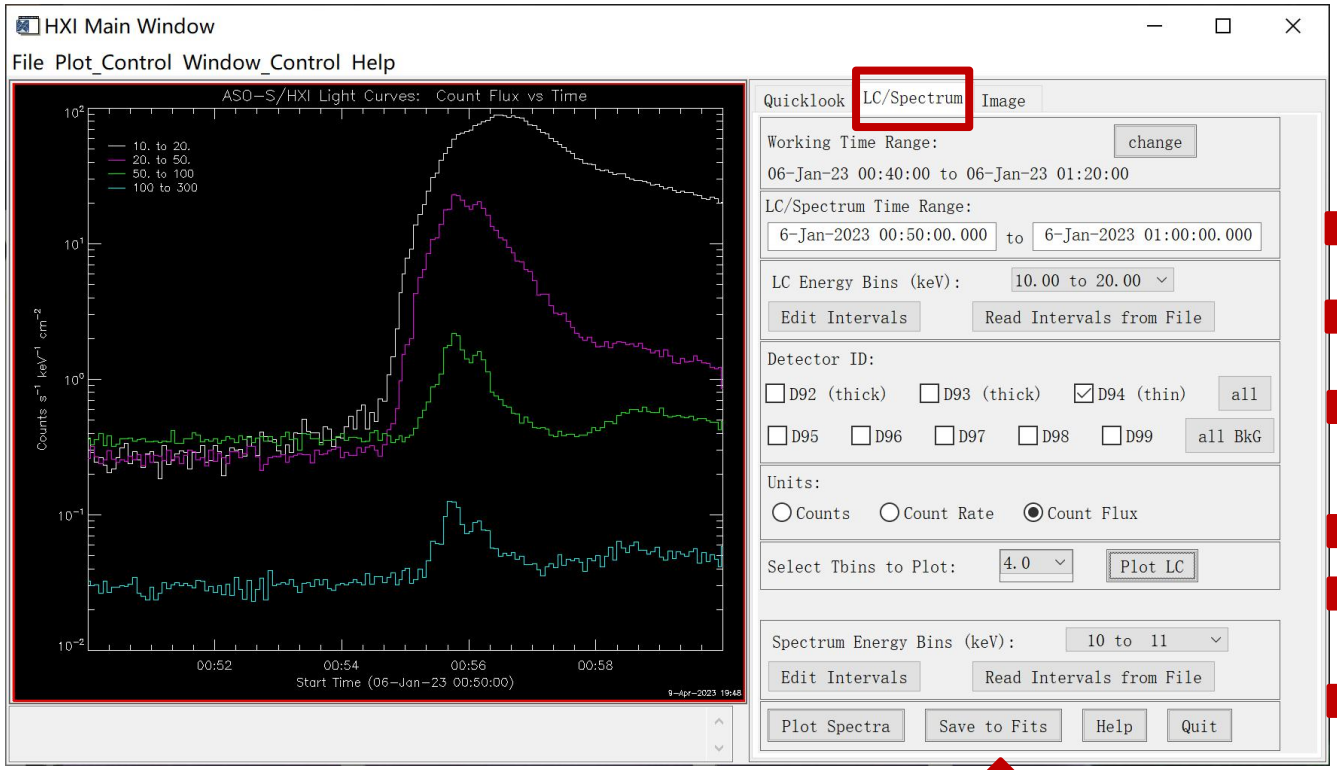


Tutorial：HXI GUI



- Detector with thin front window
- Detector with thin front window
- Background at edge of det. array
- Background at center of det. array
- livetime
- Total flux of imaging detectors
- Total flux of open detectors
- solar disk center in SAS detector
- Roll angles, Not available yet
- Temper. data, Not available yet
- High voltage, Not available yet
- Satellite location, Not available yet

Tutorial：HXI GUI



Time intervals

Energy ranges

Detectors

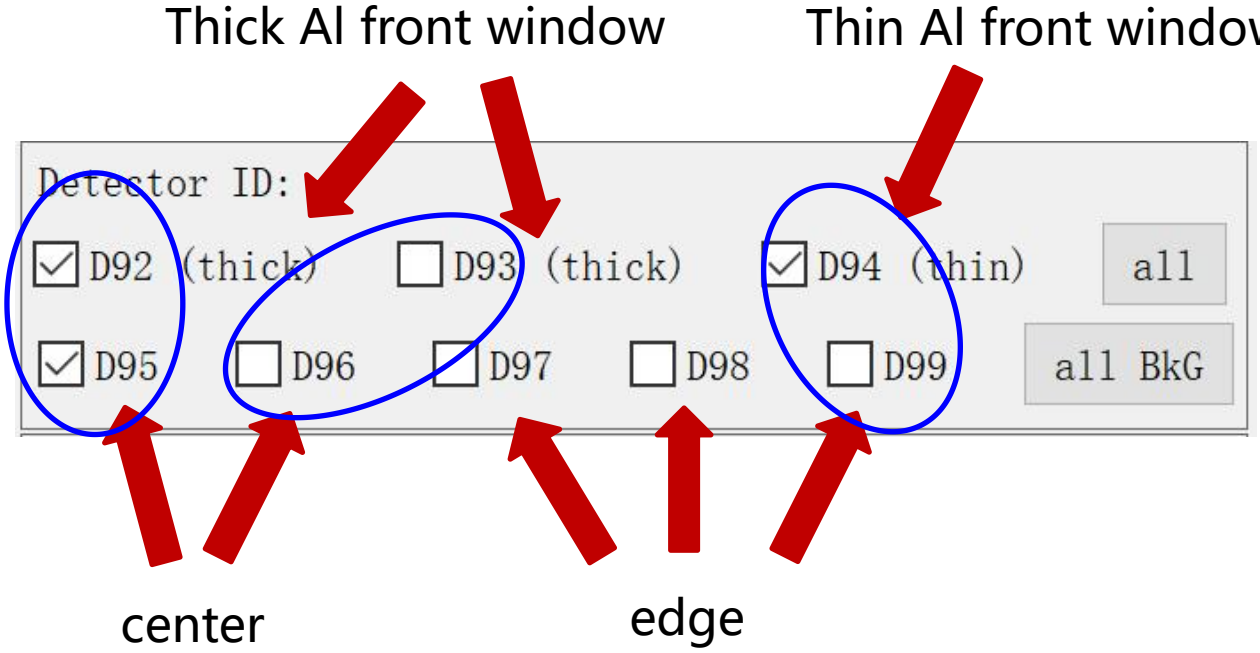
unit

Time binsize

En binning

Save FITS -> OSPEX

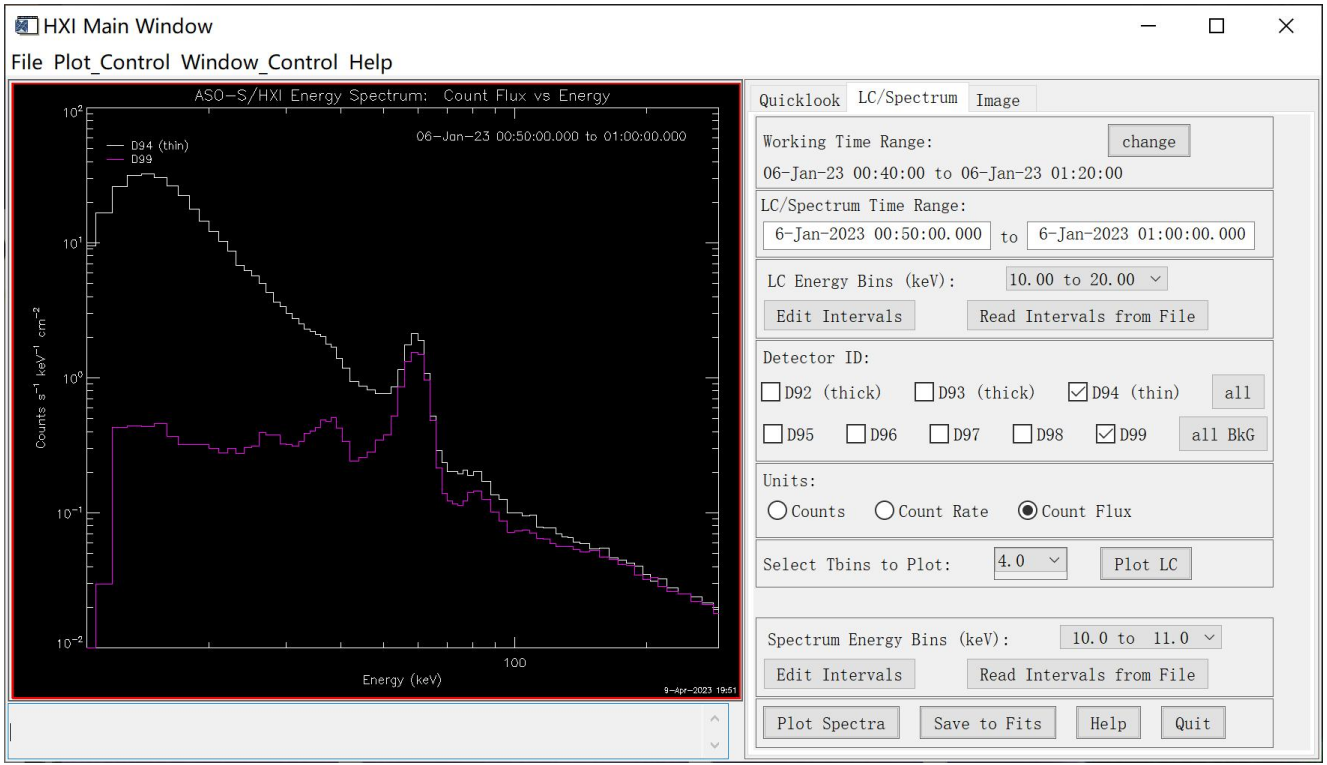
Tutorial：HXI GUI



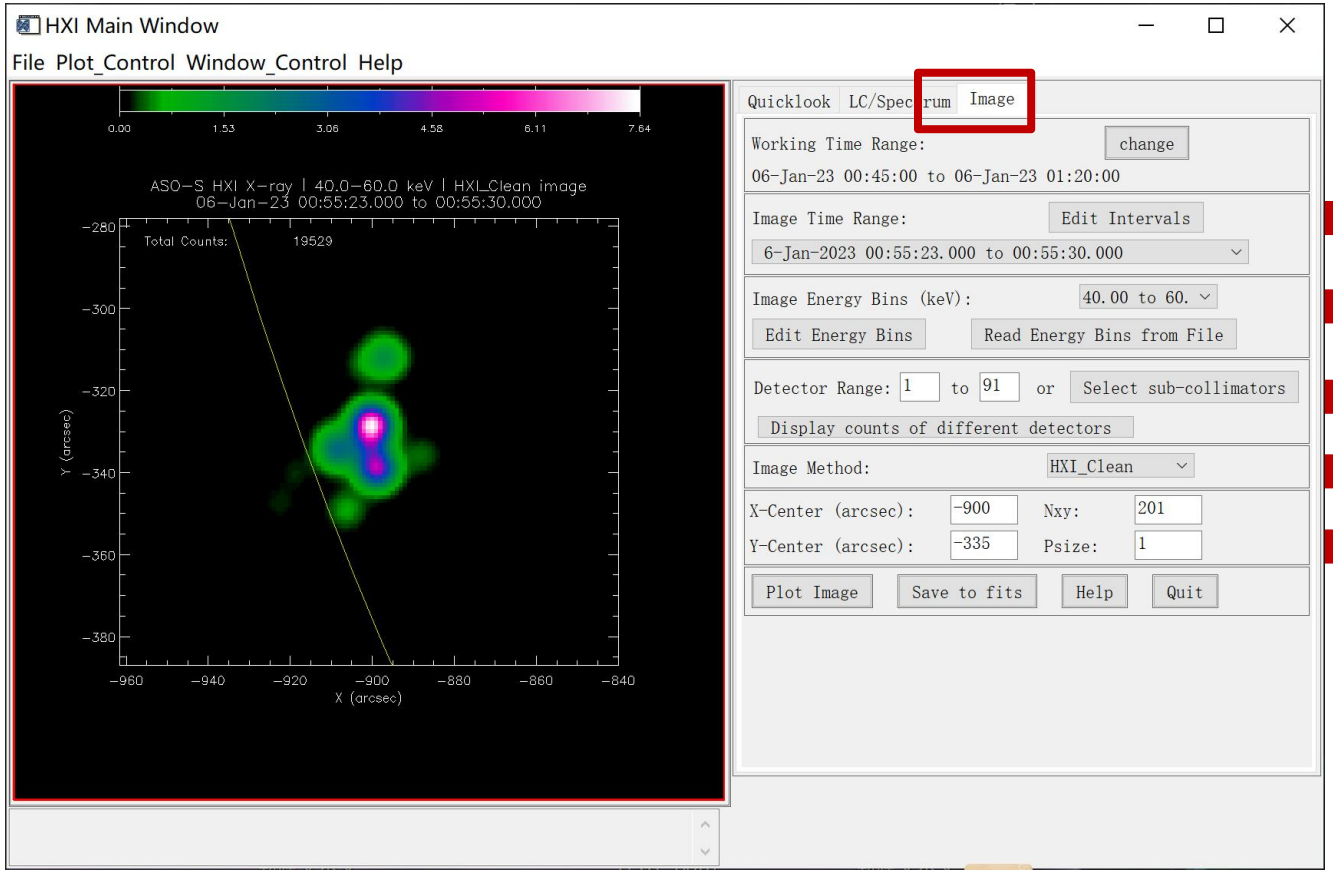
Total flux monitors

BKG monitors

Tutorial：HXI GUI



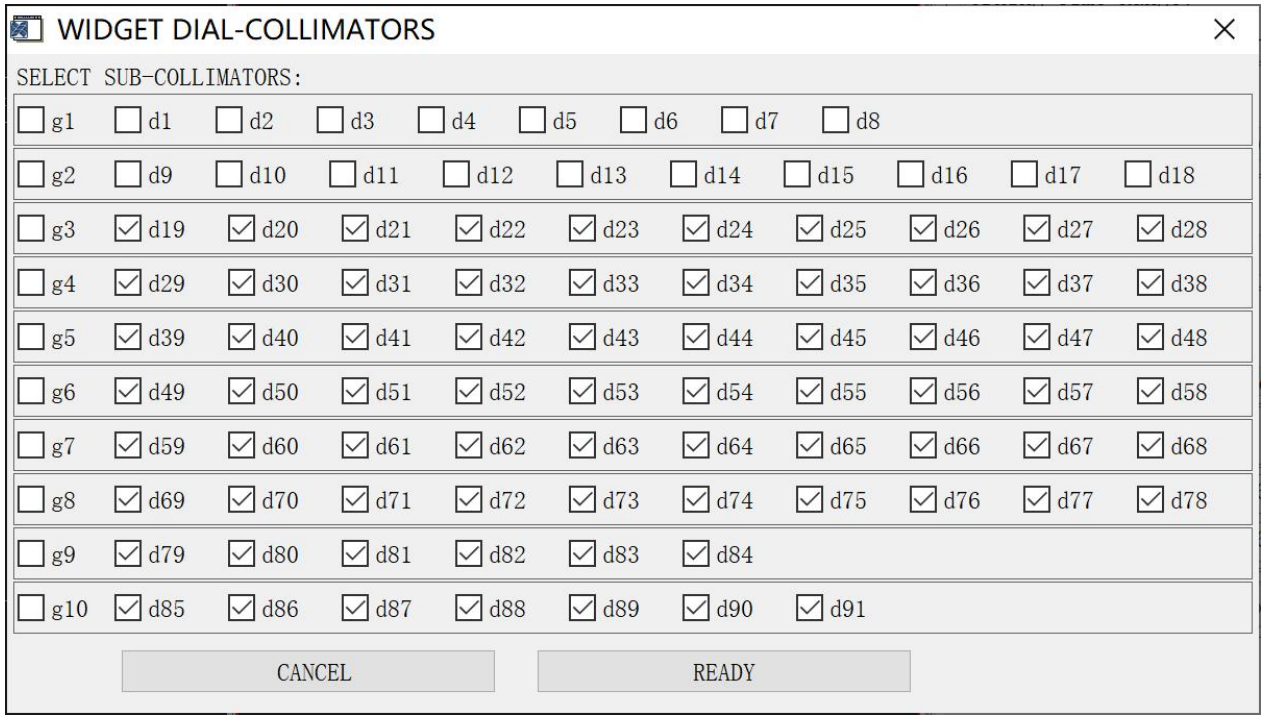
Tutorial：HXI GUI



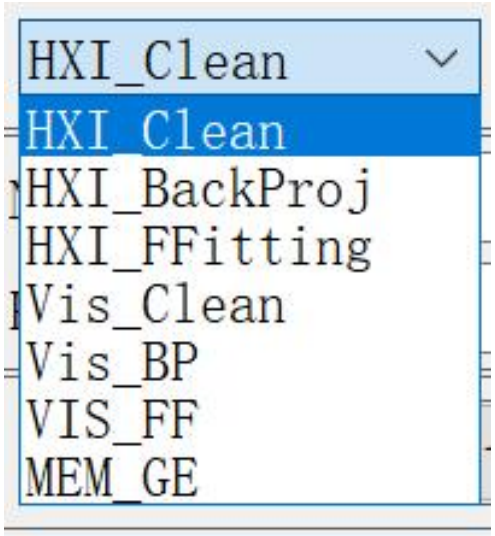
- Time intervals
- Energy ranges
- Detector selection method
- parameters

Tutorial：HXI GUI

At current stage (grid calibration is not done yet), you may try to start from g3 or above



Tutorial：HXI GUI



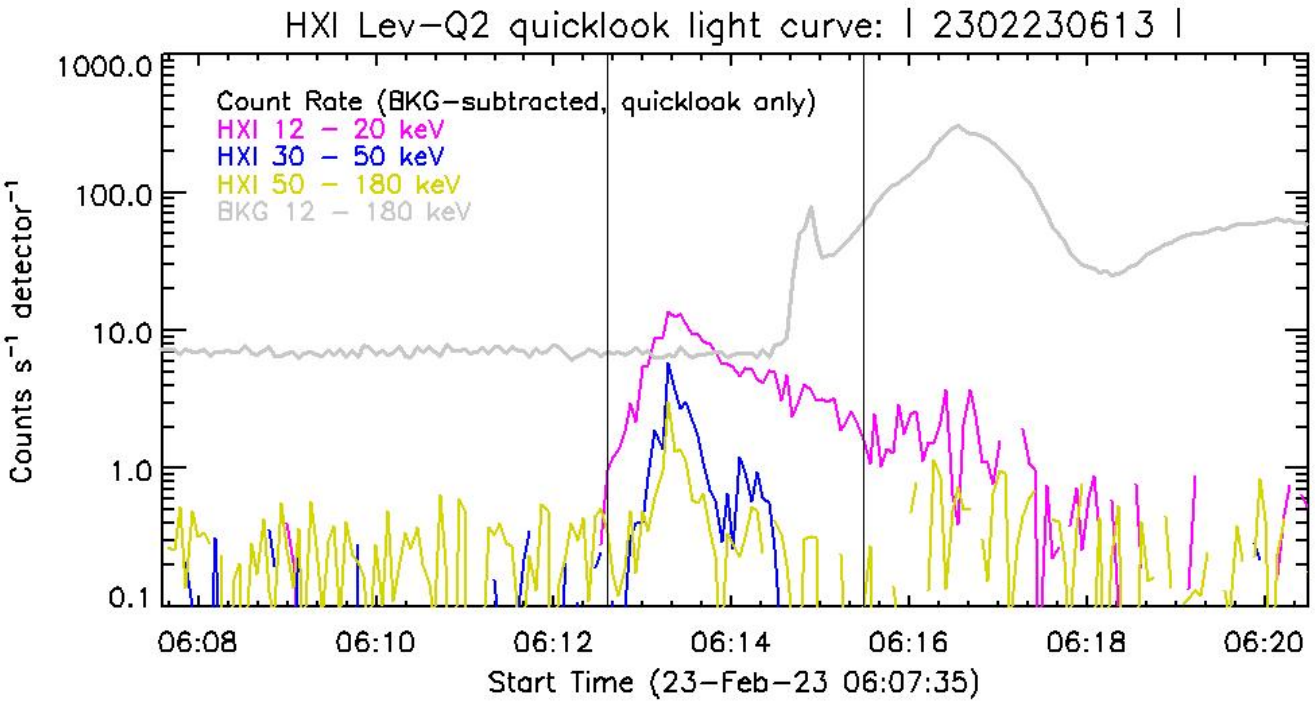
Currently available:
HXI_Clean
HXI_BP

VIS_Clean
VIS_BP

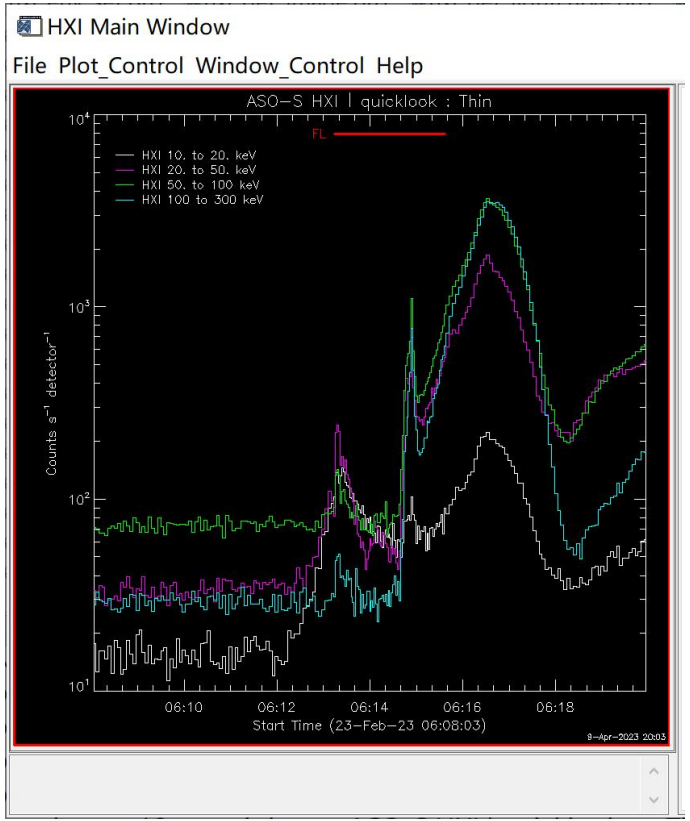
Note that vis-based methods are not perfect yet. For limb flares and fine grids, visibilities still need corrections.

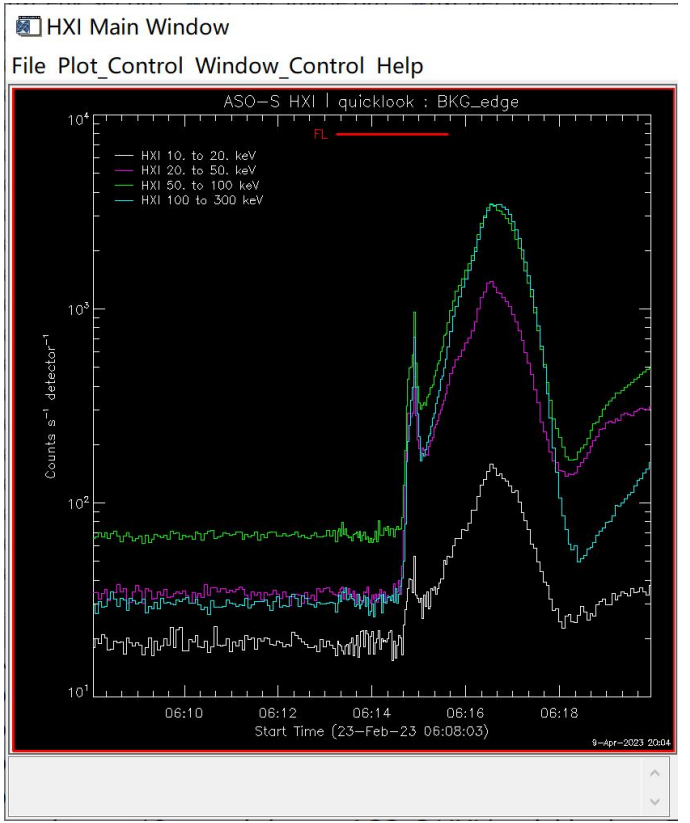
Note that HXI_clean and HXI_BP are quite slow in calculating patterns and corrections of pointing shifts. An update is on the way which can reduce the time for imaging.

Tutorial：Example

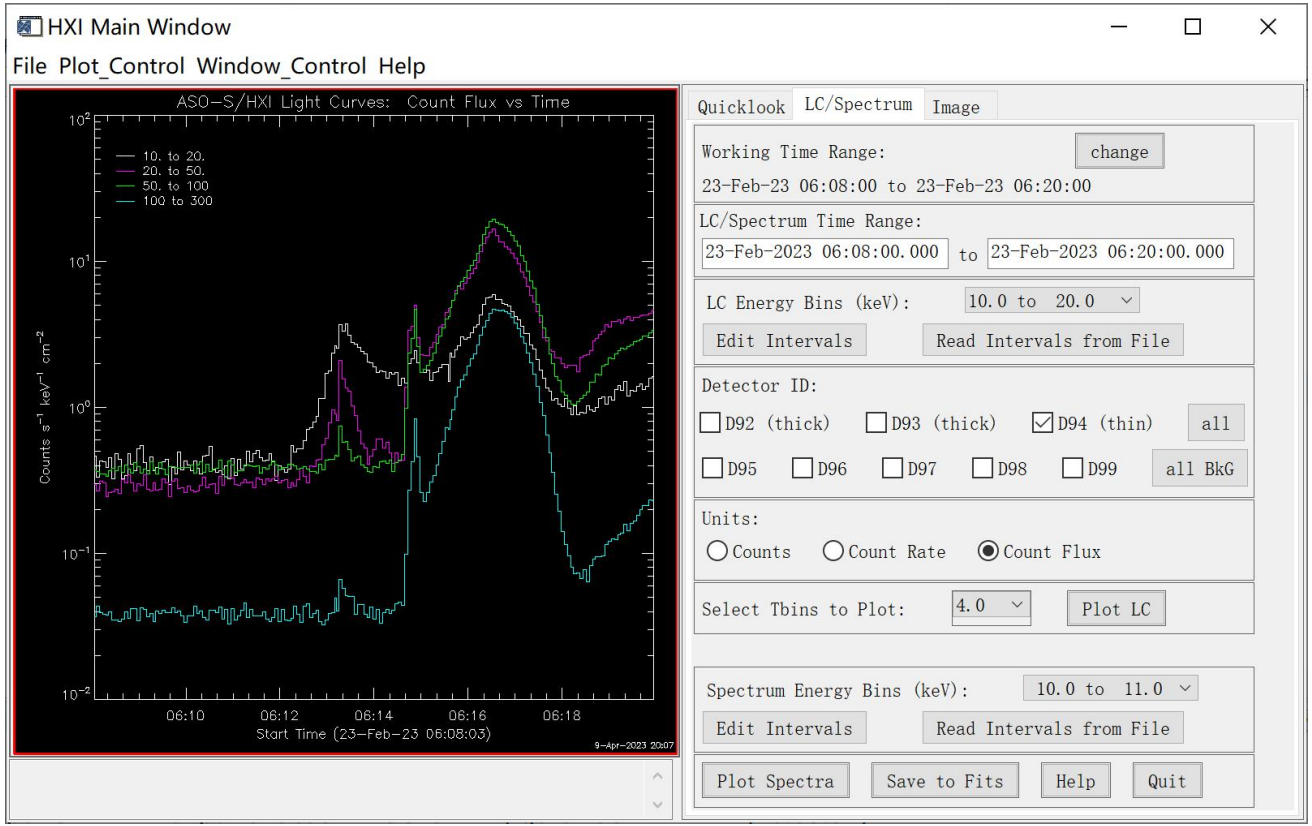


Tutorial：Example

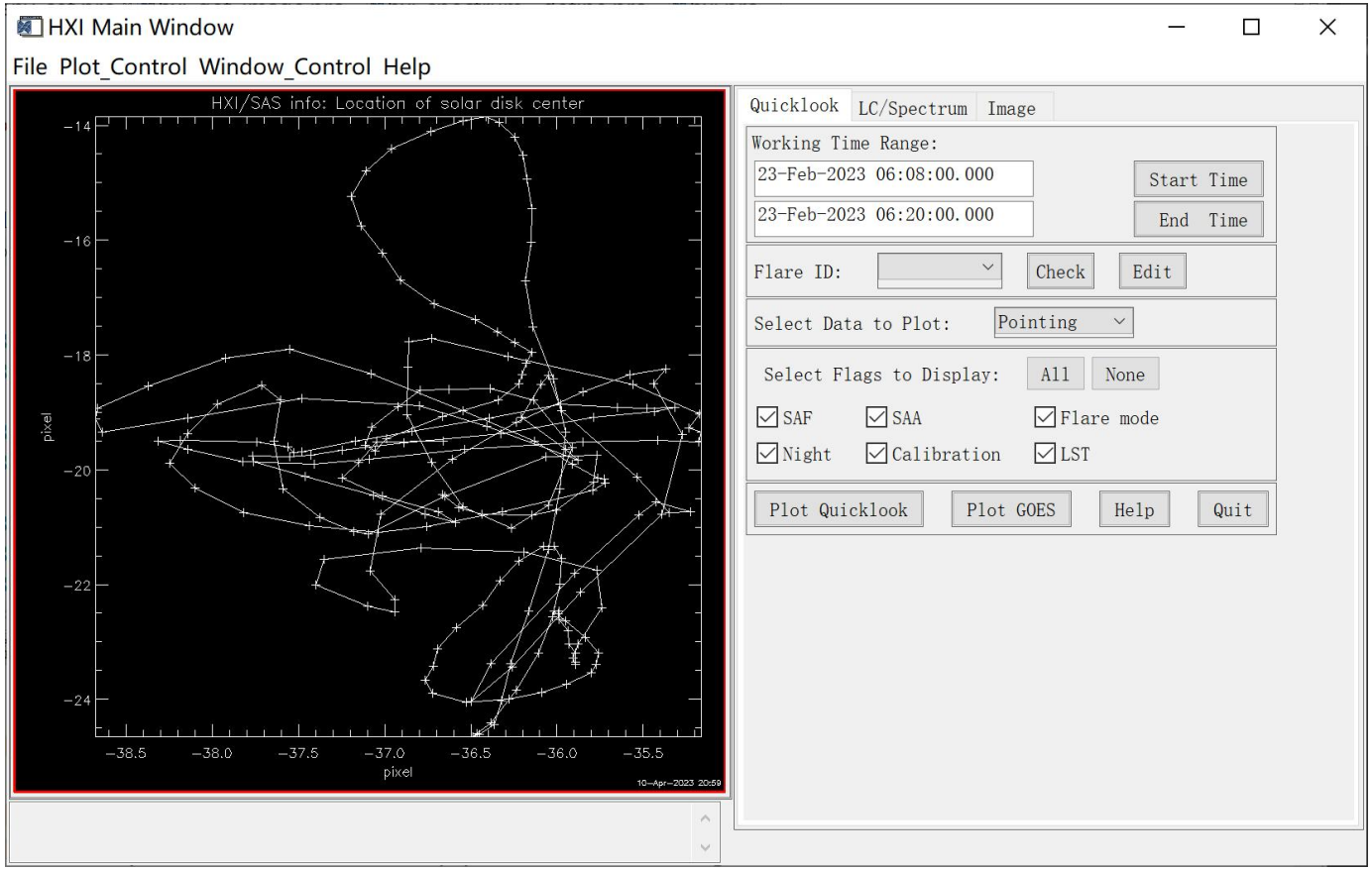




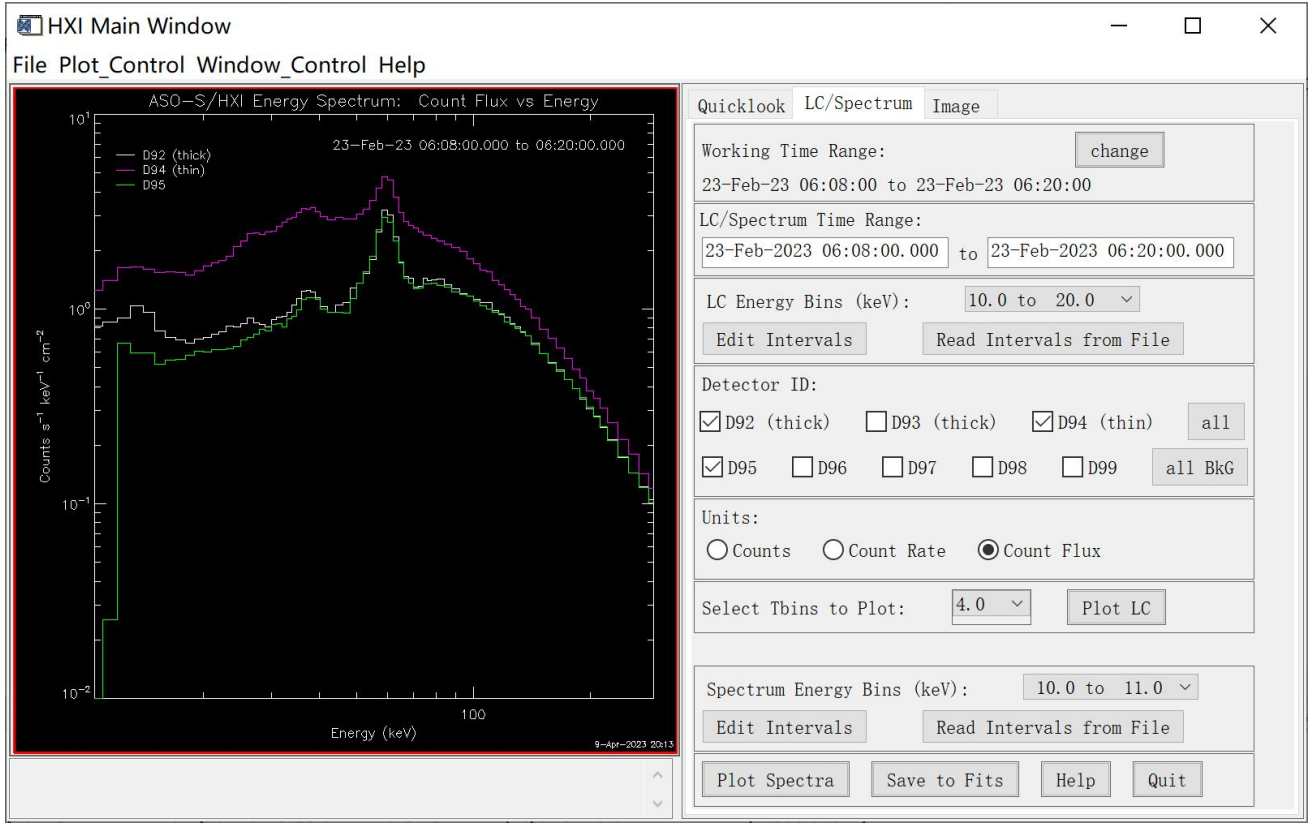
Tutorial：Example



Tutorial：Example



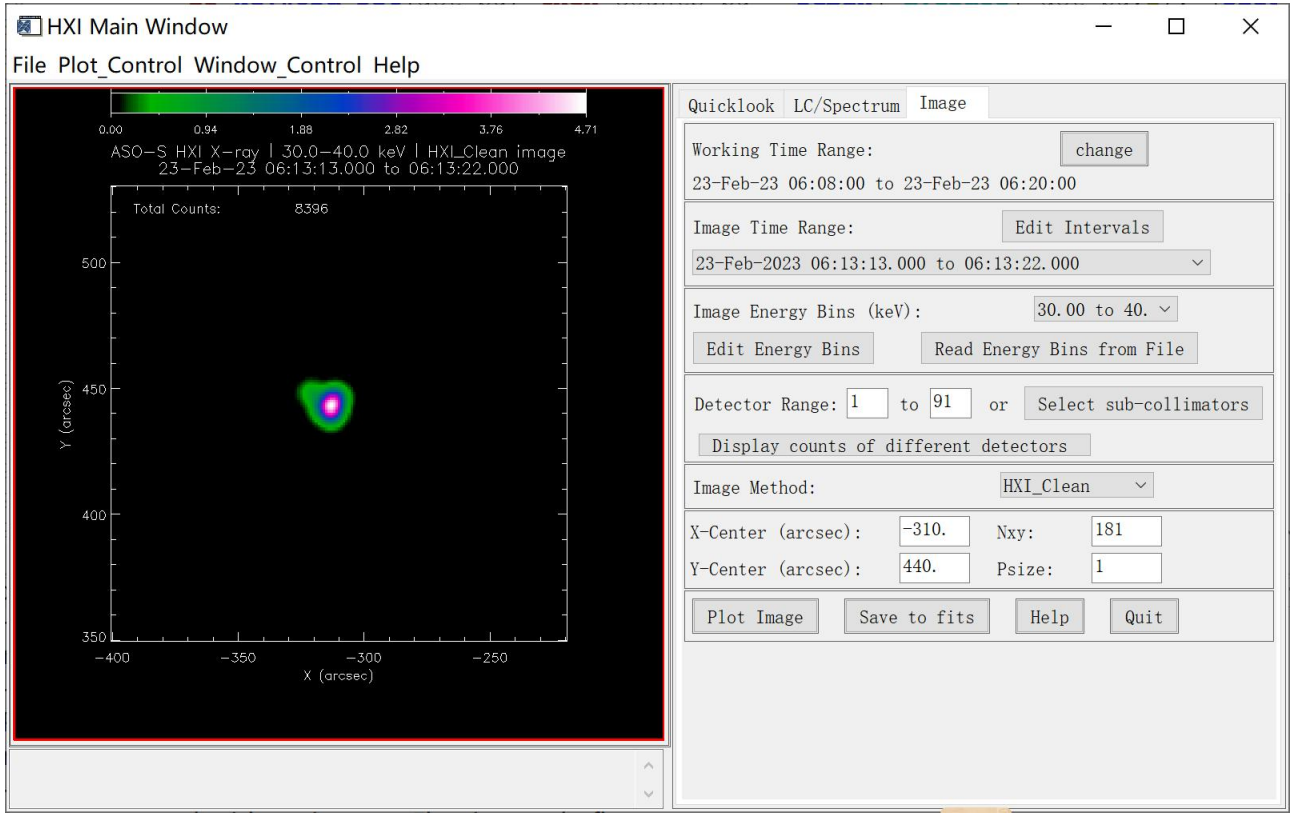
Tutorial：Example



The saved spectra FITS and DRM file can be analyzed in OSPEX

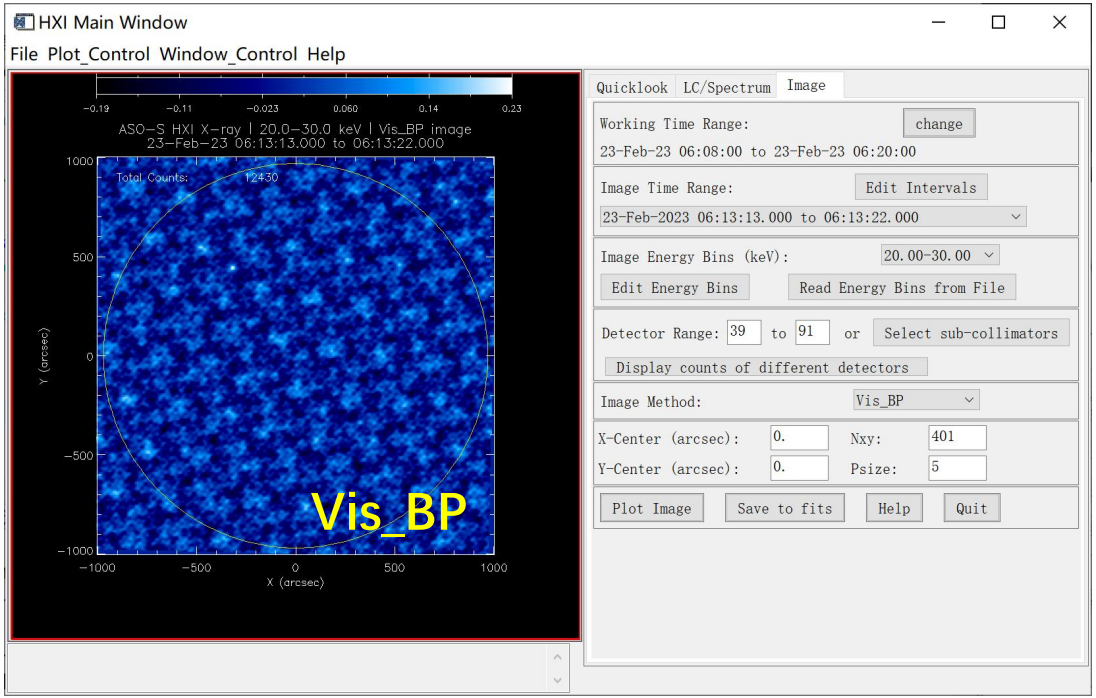
```
o=ospex()
o->set,
spex_file_reader='hxi'
```

Tutorial：Example



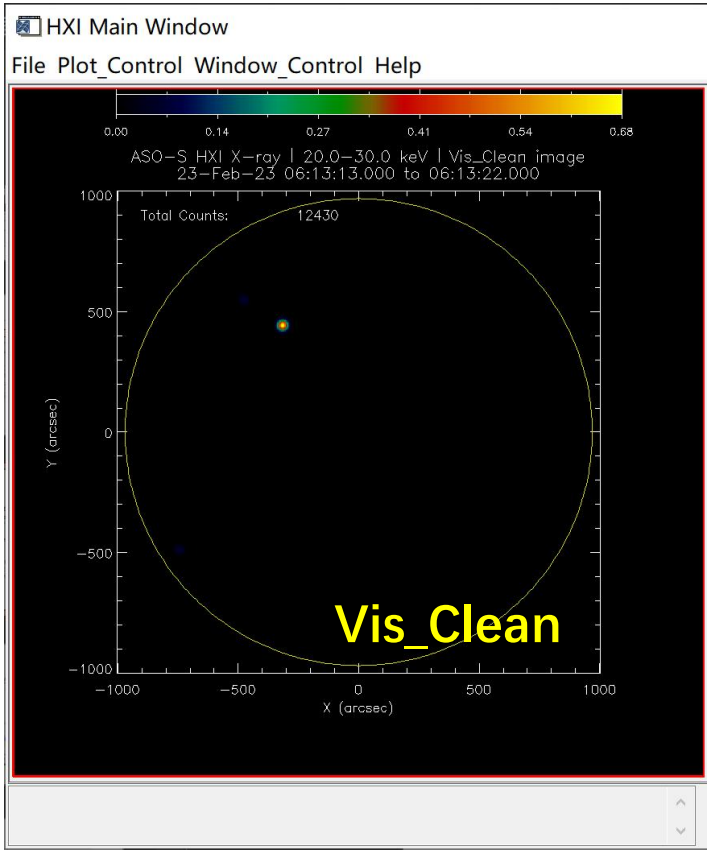
Tutorial：Example

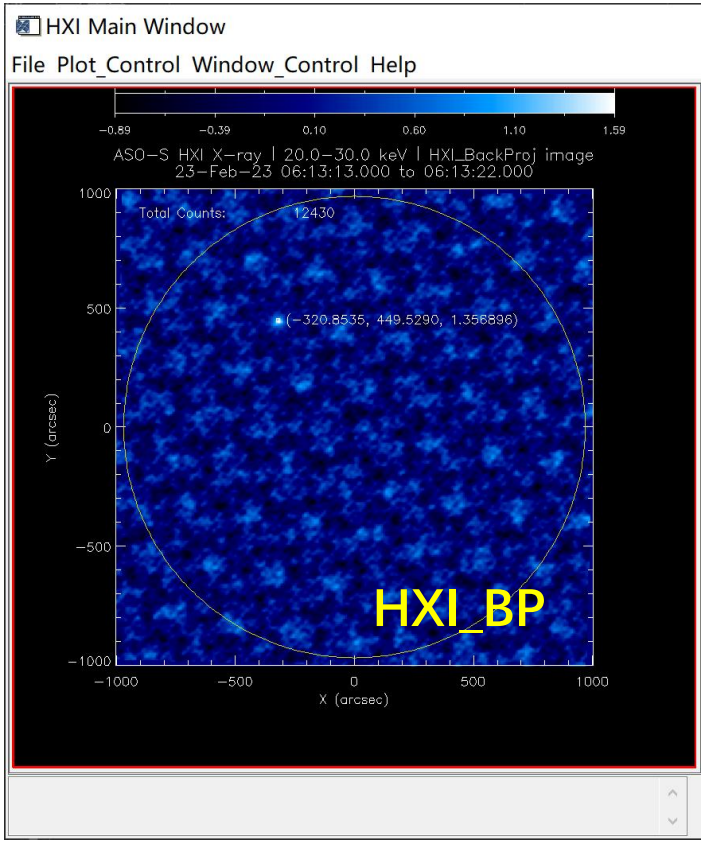
If flare location is unknown, then users can make a full disk image first.
Xcen: 0.
Ycen: 0.
Nxy: 401
Psize: 5
Detectors: D39-D91
Method: VIS_BP or HXI_BP



Flare location will be obtained automatically from Flare list.

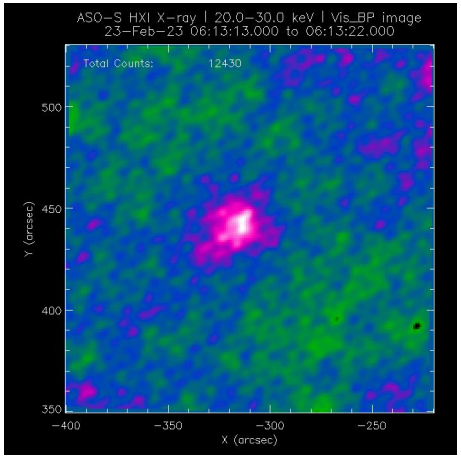
Tutorial：Example



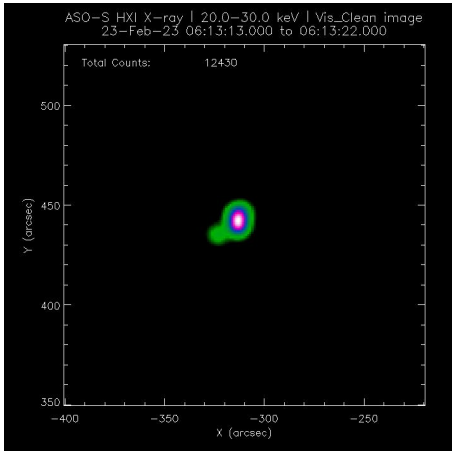


Tutorial：Example

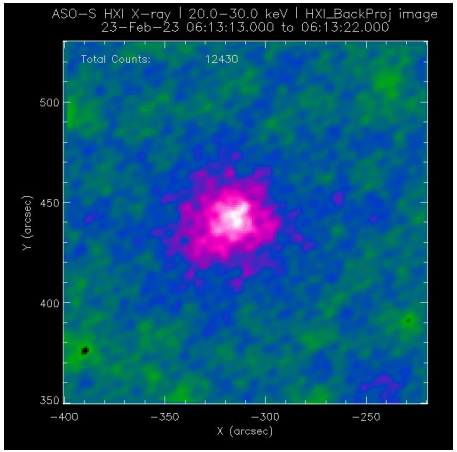
Vis_BP



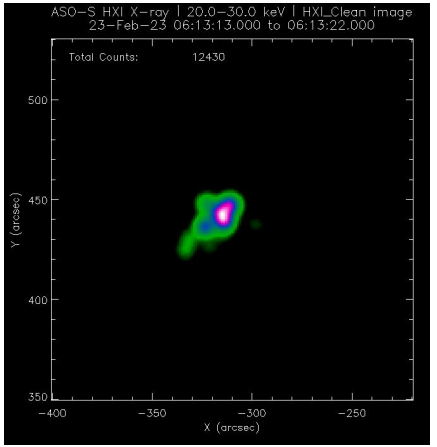
Vis_Clean



HXI_BP

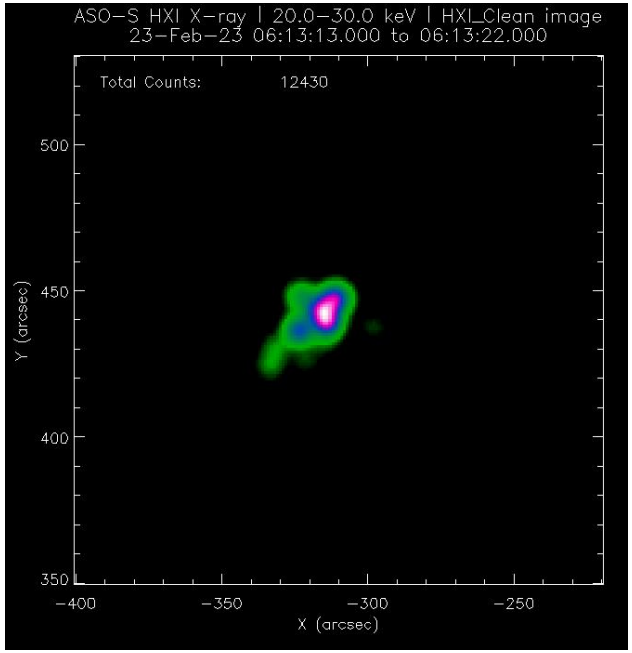


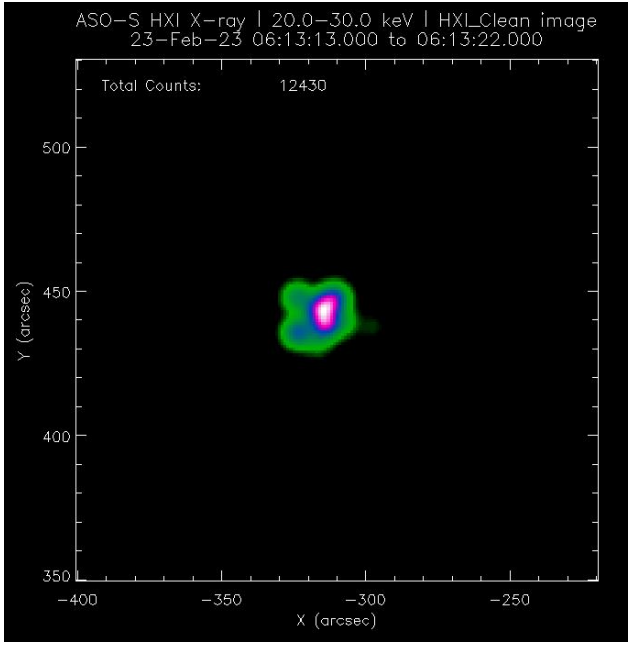
HXI_Clean



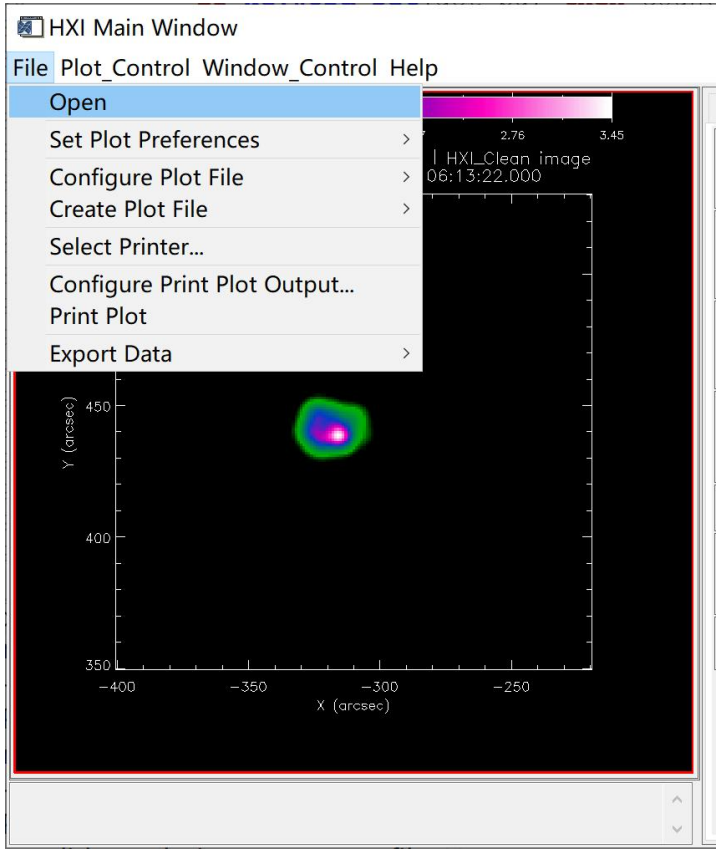
Tutorial：Example

New background (-48 h -10s)



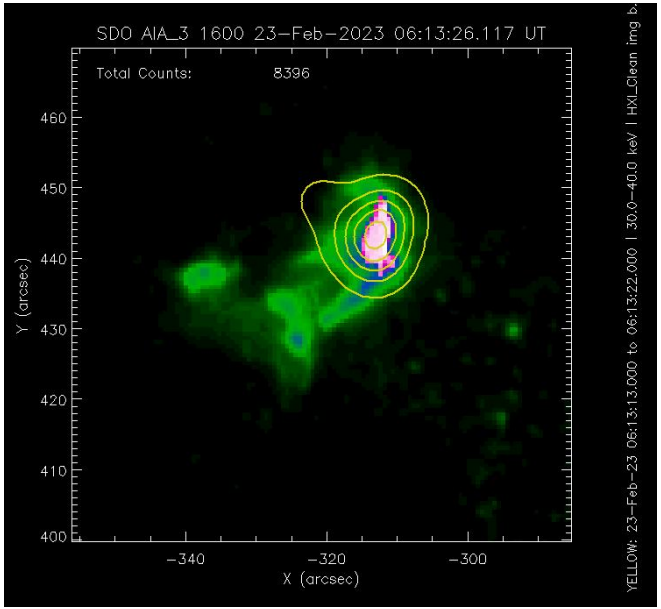


Tutorial：Example



OPEN:

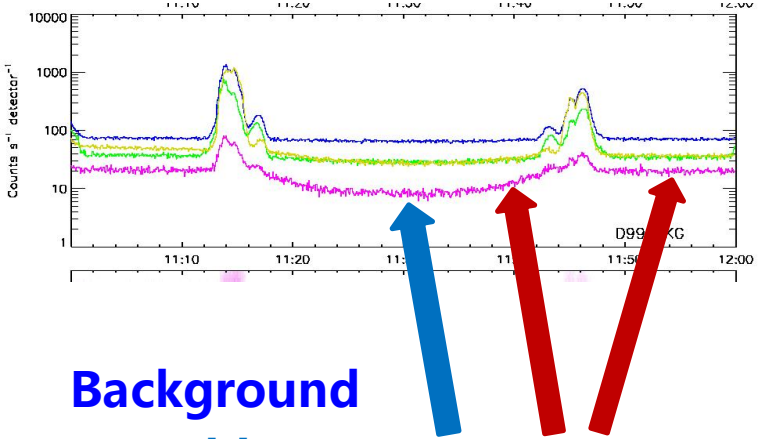
- Can load saved HXI maps
- Can load AIA maps and other maps (through fits2map.pro)



Tutorial：Known issues

Known issues: Background removal is very complicated

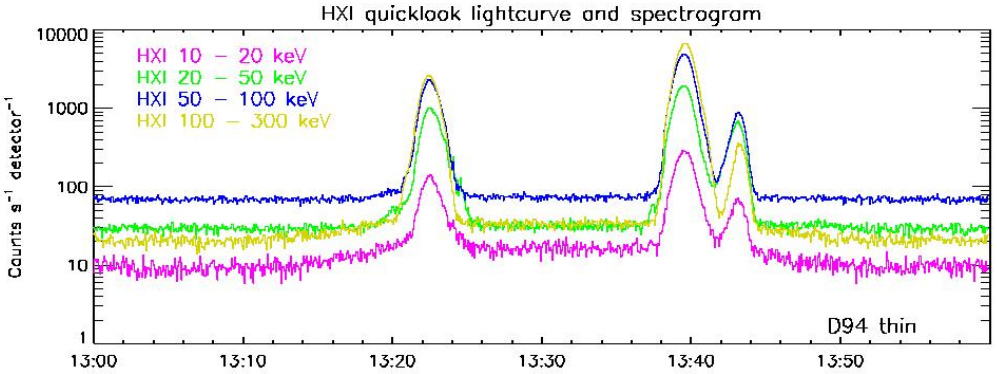
- **Background removal for spectral analysis**
  - Three choices (case by case):
  - before and after flares;
  - nearby BKG detector;
  - 48h+10s ahead or -48h-10s behind
- **Background selection for imaging**
  - Three choices (case by case):
  - before and after flares;
  - BKG detectors;
  - 48h+10s ahead or -48h-10s behind



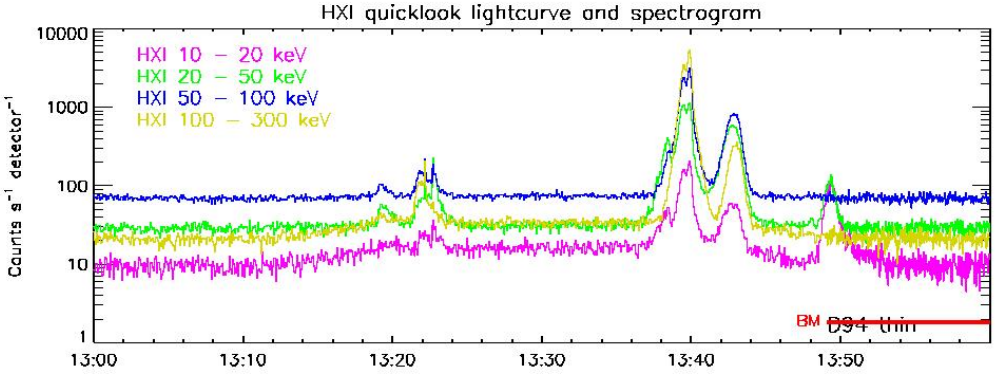
Background

- **Stable component**
- **Particles**
  - **vary with orbit**
  - **Vary in detector array**

Tutorial：Example



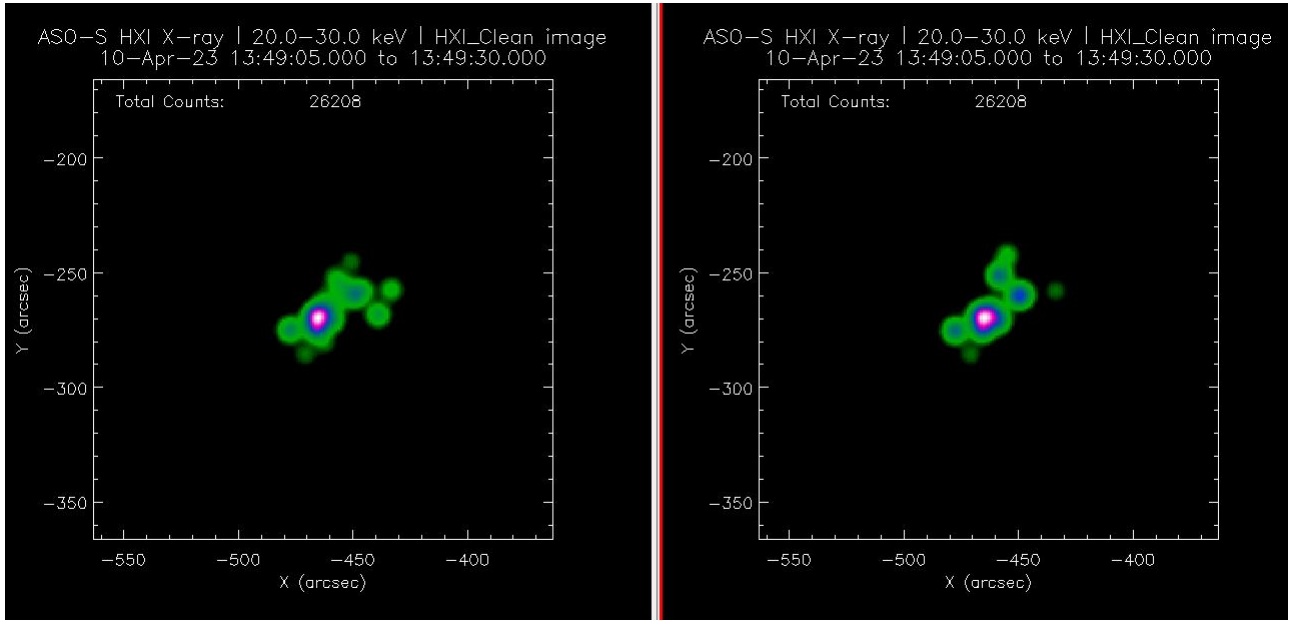
April 08 2023



April 10 2023

Tutorial：Example

New background (-48 h -10s)

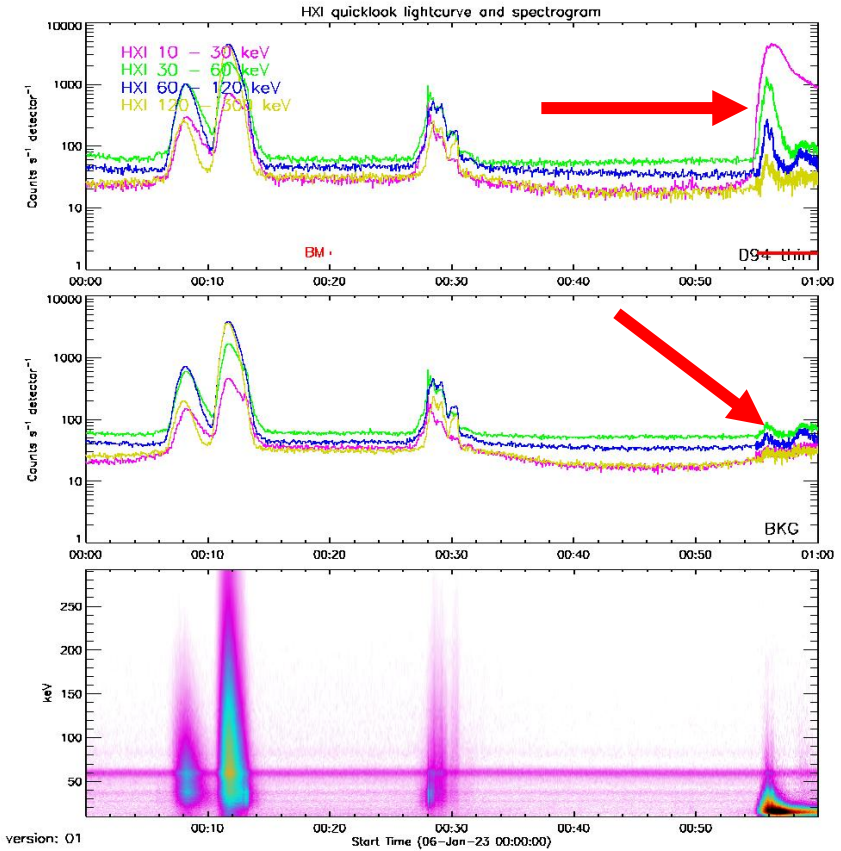


Tutorial：Known issues

An X-class flare detected by HXI

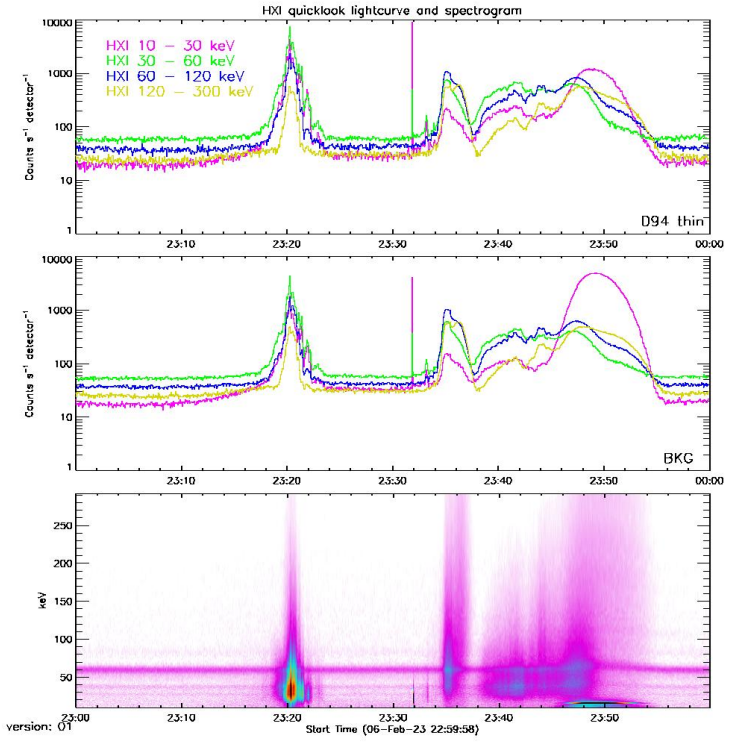
High energy solar X-rays can cause increase of flux in background detector.

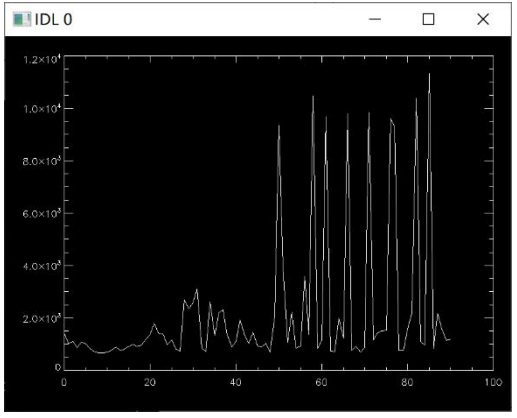
In this case, the fluxes in the BKG detectors can not be used as background.

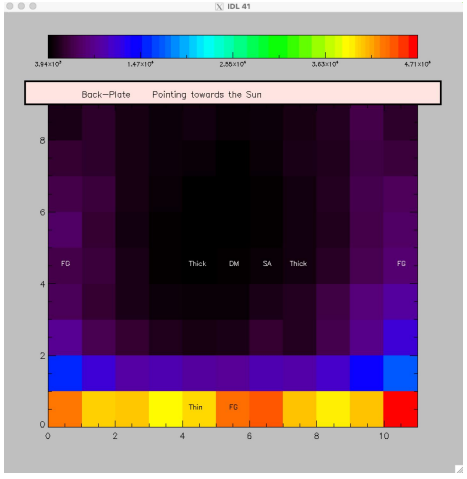


Tutorial：Known issues

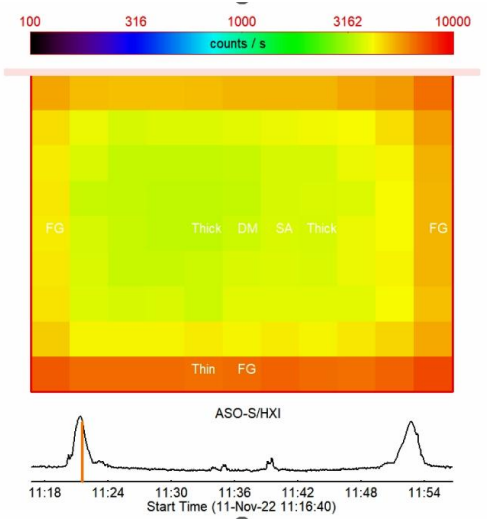
Short but very strong signals







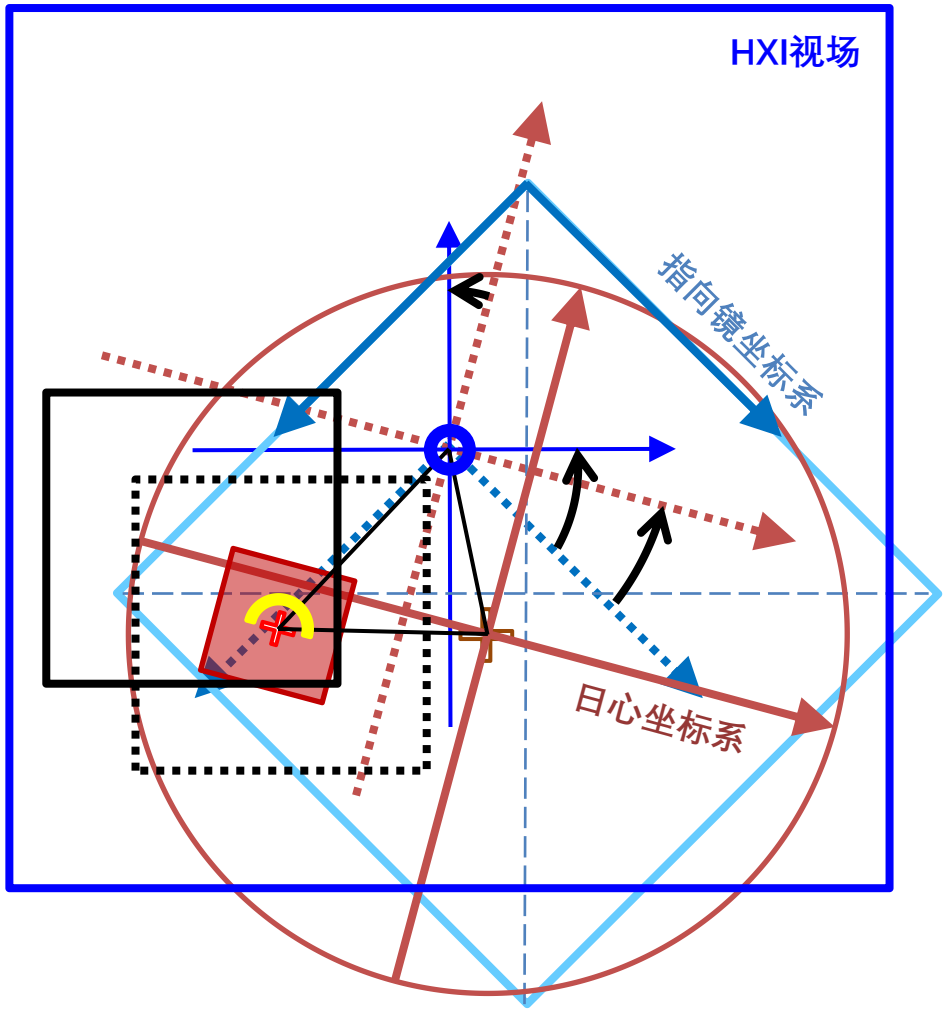
(Wei Chen)

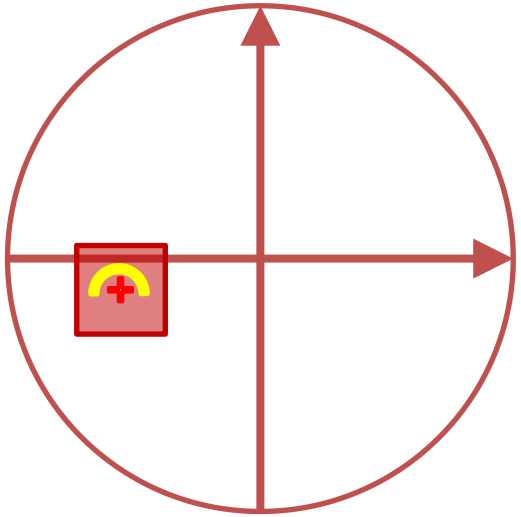


Tutorial：Known issues

Known issues: Calibrations

- Energy calibration and correction of DNL: done
- Imaging calibration: ongoing work
  - Locations and pointing: almost done
  - Grid calibration (phase): work in progress
- Cross calibrations: HXI-STIX, HXI-Fermi, work in progress





HXI光轴/成像中心（角秒）

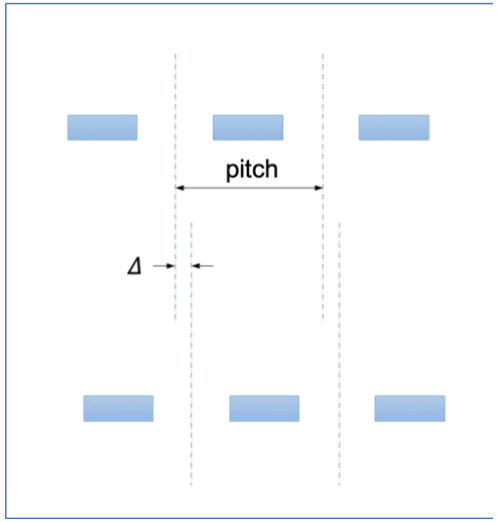
太阳镜光轴（像素）

图像中心 [xc, yc] (太阳坐标系，角秒)

太阳镜太阳像中心 [cen_x, cen_y]（像素）

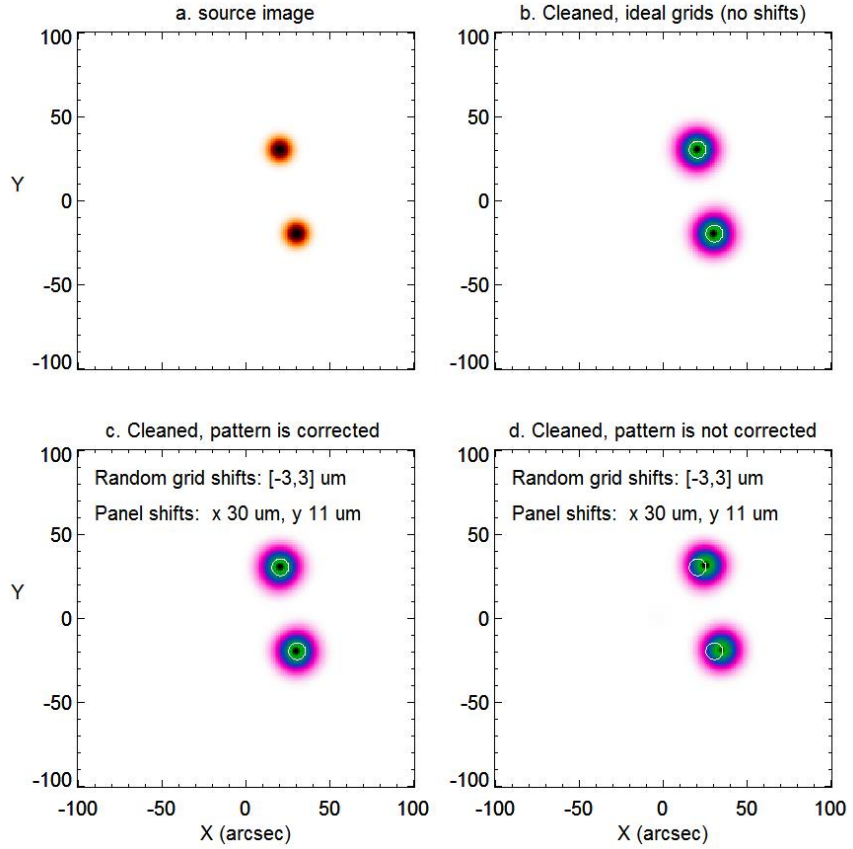
Tutorial：Known issues

Known issues: Grid Calibrations



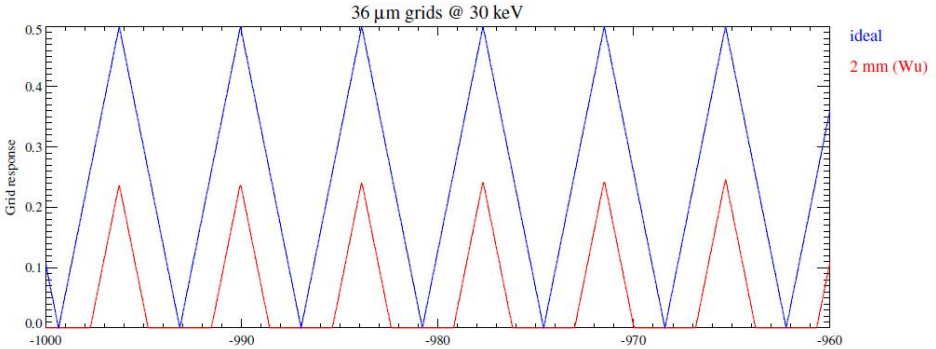
Cos: Δ=0

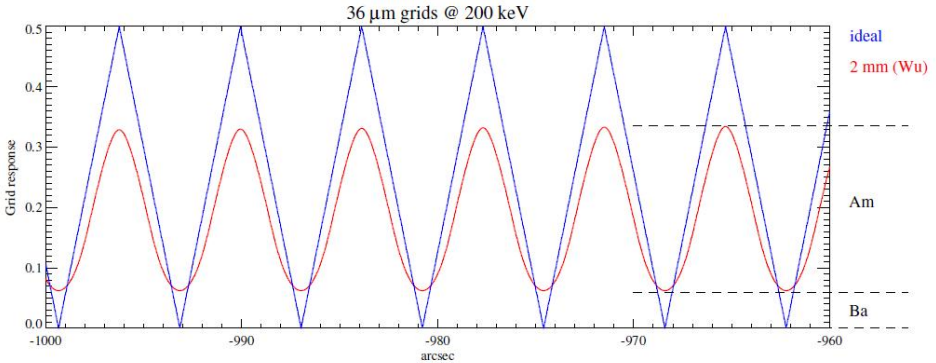
Sin: Δ=pitch/4



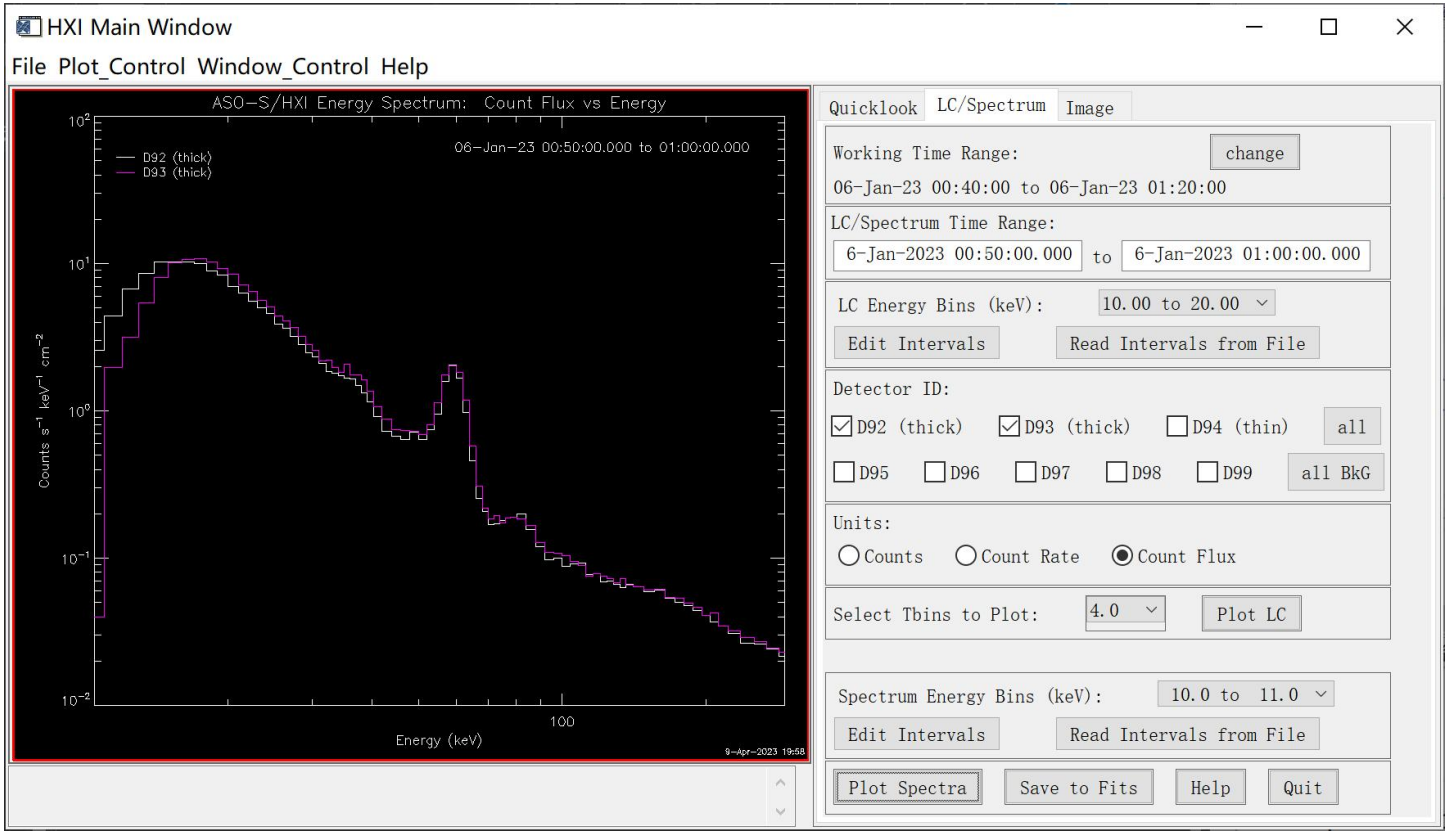
Tutorial：Known issues

Known issues: Grid Calibrations





Tutorial：Known issues



Thank You!