HXI collimator onboard ASO-S mission & its ground characterization

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on behalf of HXI team

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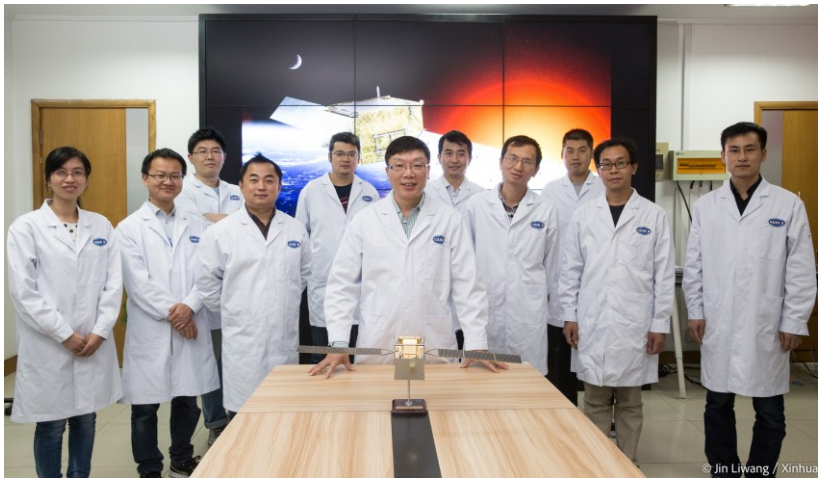
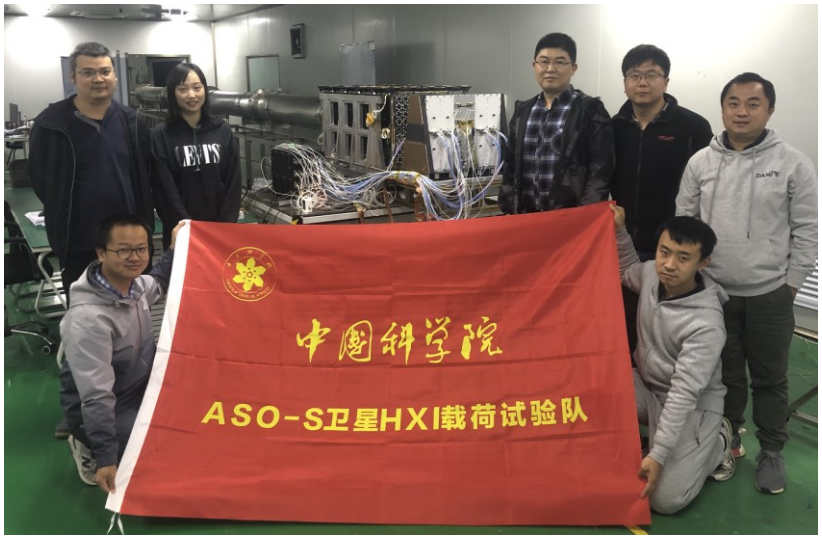
Key laboratory of dark matter and space astronomy, CAS

2023.11.22

Our Team



DAMPE and HXI/ASO-S team



陈灯意：
这个团队让人感觉很温暖

暗物质卫星发射成功的那一天，我是流泪的。因为我觉得这个团队走过来真的是很不容易。那天我没有看发射的现场，我在酒泉发射中心值班大厅里面值班，那天我特别想找一个人抱一下，但是有点腼腆。我能参与这个事情，真的感觉特别荣幸，是一件非常值得纪念和书写的经历。

我的日常工作就是结构设计，包括出工程图，还有具体的加工、工艺方面的工作。我们这个团队让人感觉很温暖，没有说谁和谁斤斤计较，大家都会相互帮助。

比如说结构方面出现了一些问题，大家不会袖手旁观，都会想办法一起解决。还有就是在工作上大家齐心协力，不管是春节还是什么节日，大家都在一起工作，让人感到温暖，这是我最大的感受。

暗物质卫星发射成功的那一天，我是流泪的。因为我觉得这个团队走过来真的是很不容易。

Outlines

1 ASO-S introduction

2 Detailed design of HXI-C

3 Ground characterization (2021.09)

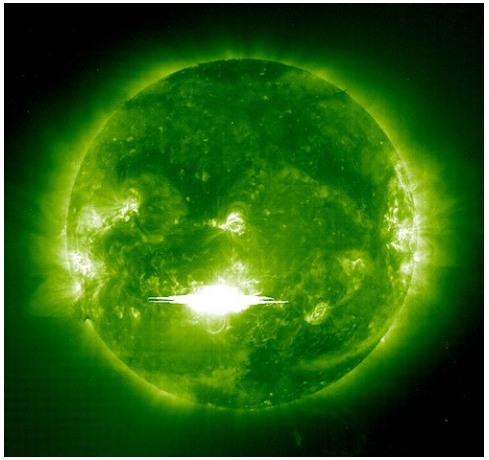
4 On orbit calibration

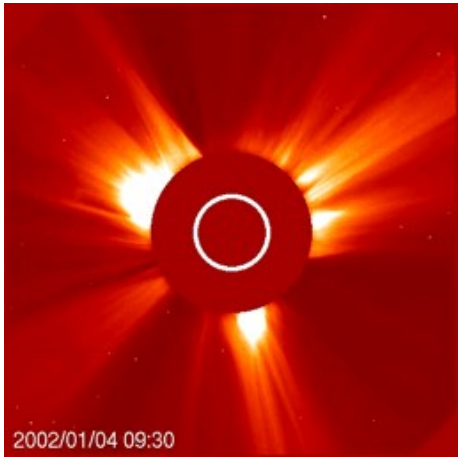
5 Ground characterization (2023.07)

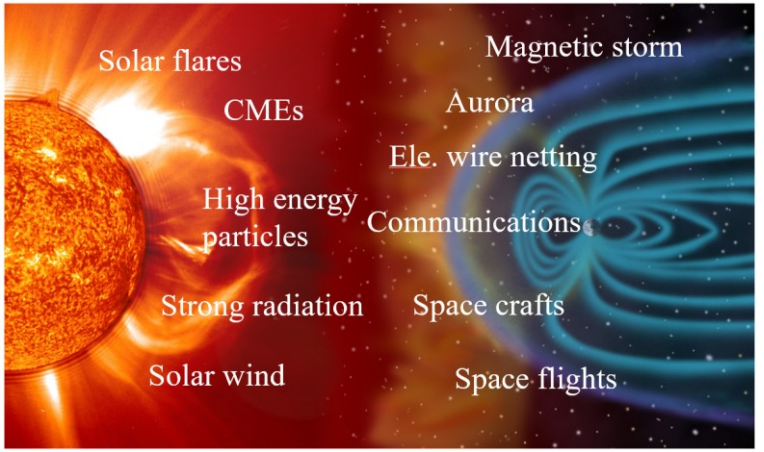
6 Summary

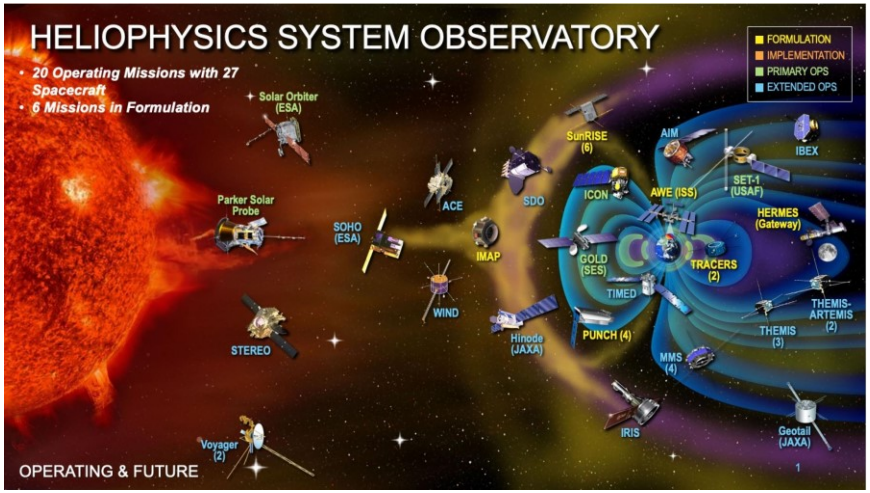
1 ASO-S introduction

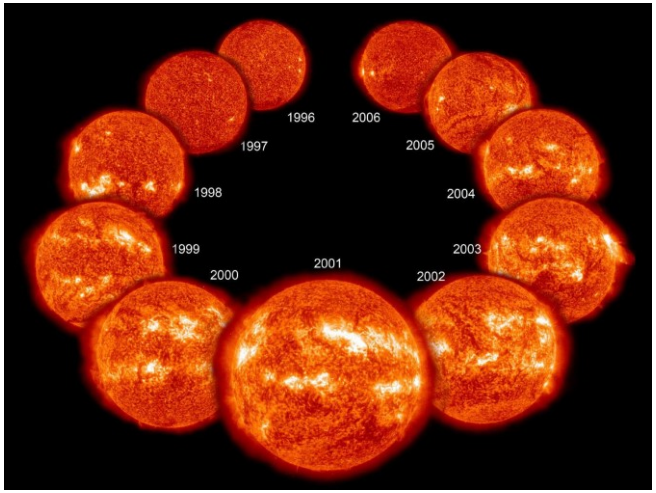
Solar eruptions and affects





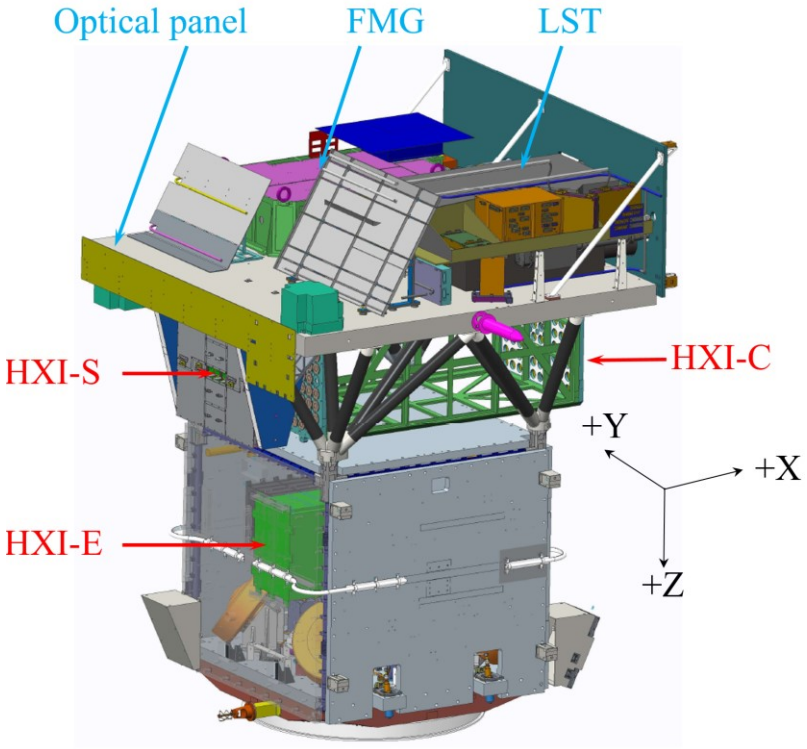






Solar missions and activity cycles

1 ASO-S introduction



- **FMG:** measuring solar field
- **LST:** observations of CMEs
- **HXI:** solar flares study

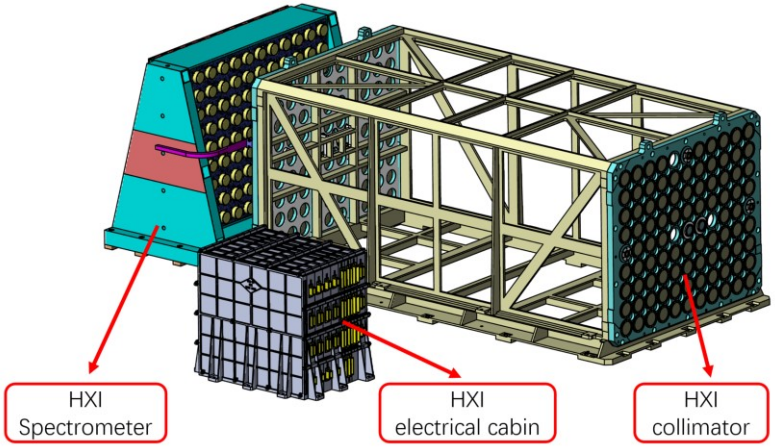
Science objective

- **Relationships** between flares and CMEs
- **Causality** among flares, CMEs and solar magnetic field
- **Mechanisms** of energy release and transportation
- **Clues** for forecasting space weather

Mission Information

- **Orbit** 720 km SSO
- **Attitude Control** 3-axis stability
- **Mission duration** >4 years
- **Launch** By CZ-2D Rocket 09/10/2022

1 ASO-S/HXI introduction

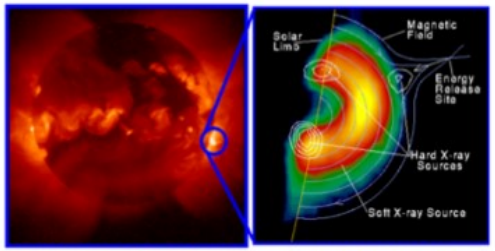


Science objective

- **Exploring** mechanisms of particle acceleration and explosive energy release in solar flares
- **Observing** hard x-ray images and spectra

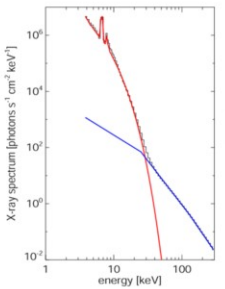
- **HXI-C:** indirect modulation of solar hard x-rays
- **HXI-S:** recorder the modulated x-rays from HXI-C
- **HXI-E:** power supply and data manager

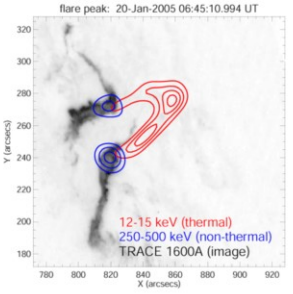
Yohkoh/HXT



Yohkoh X-ray Image of a Solar Flare, Combined Image in Soft X-rays (left) and Soft X-rays with Hard X-ray Contours (right). Jan 13, 1992.

RHESSI





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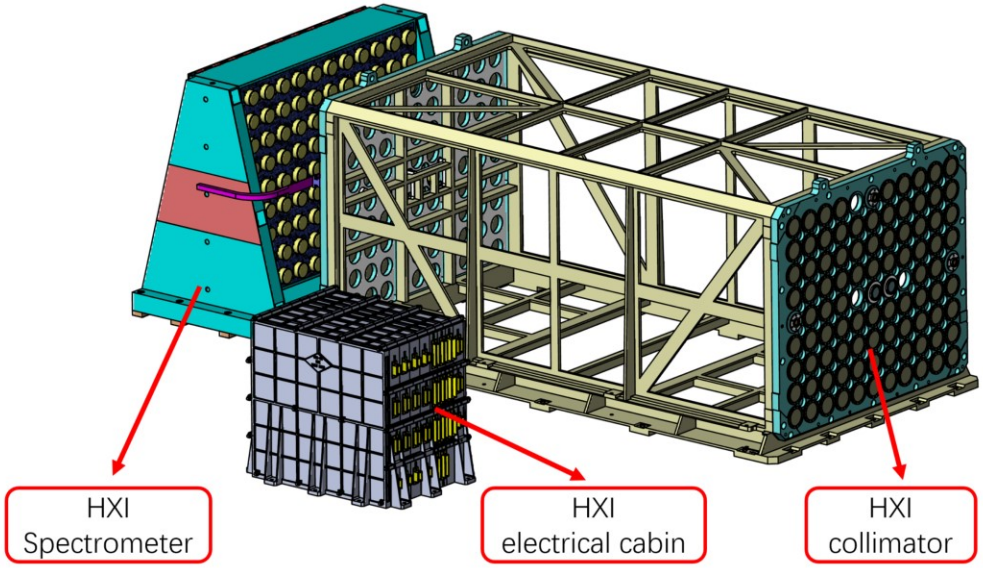
2 Detailed design of HXI-C

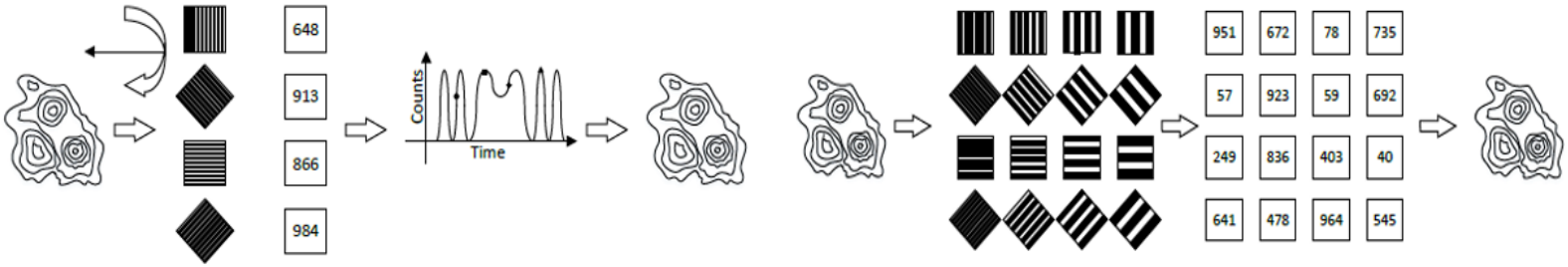


- **HXI-C:** *X-ray optics, providing 91 independent sub-collimators, solar aspect system and deformation monitor;*
- HXI-S: *LaBr3 detector modules coupled with R1924A PMT, X-ray recorder.*
- HXI-E: *power supply (DC-DC and high voltage power) and data manager*

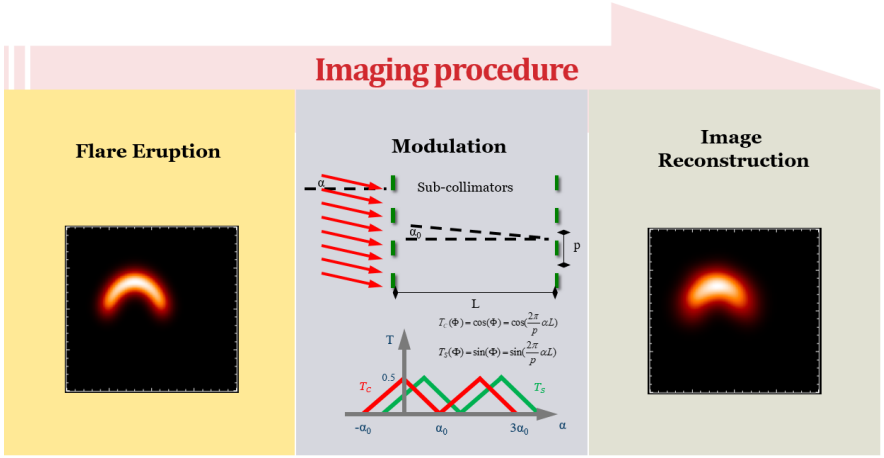
Zhang et al. (2019, RAA)
Chen et al. (2020, JINST)

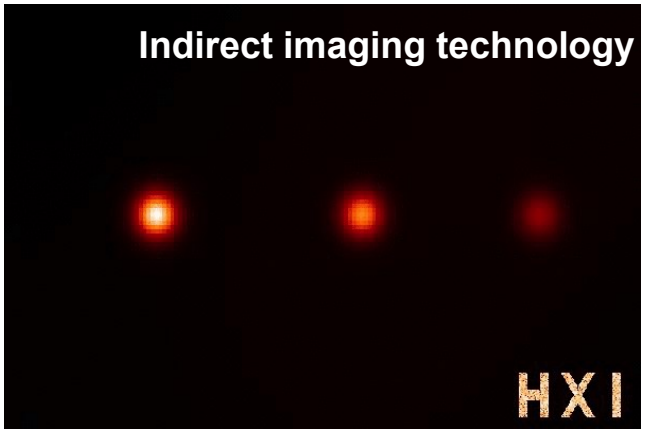
2 Detailed design of HXI-C

Basic Principle



K. Makishima et al. (1977, Plenary Meeting)

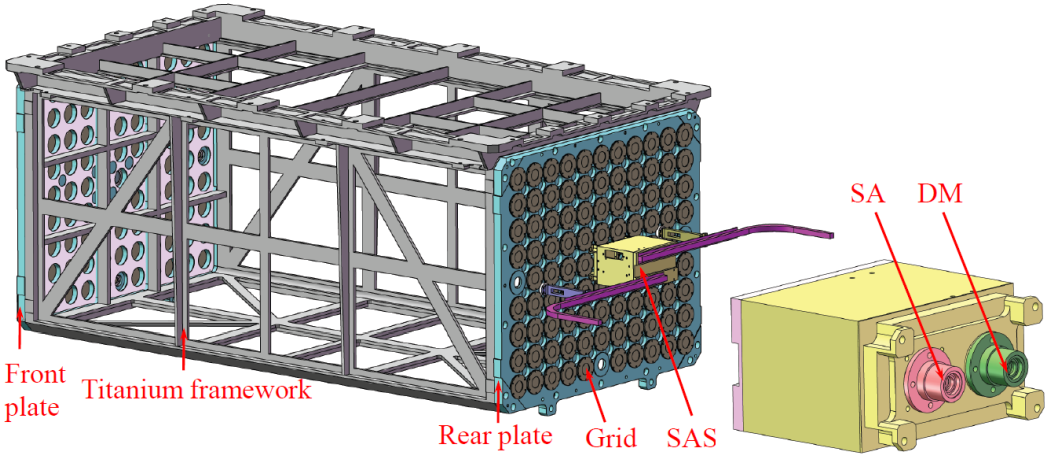


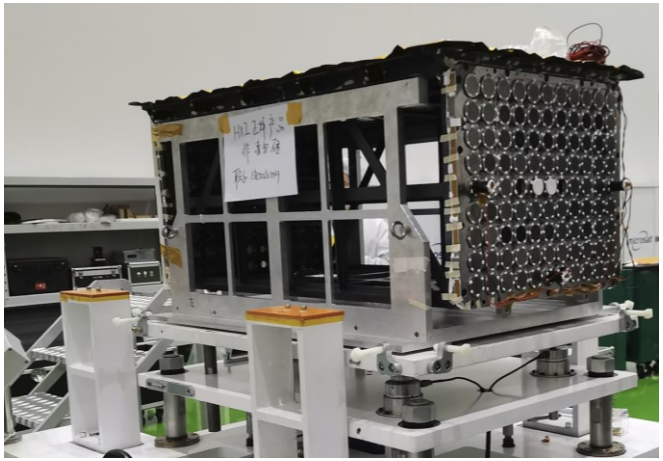


Su et al. (2019, RAA)

2 Detailed design of HXI-C

Composition of HXI collimator

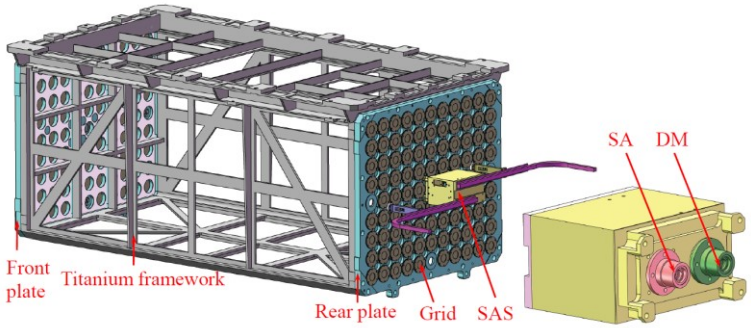


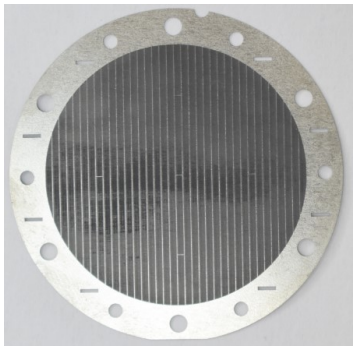


Components	Function	Notes
Grids	Used for x-ray modulation	91 pairs grids
Tungsten plates	Scattered background shielding	2 pieces with total thickness 2mm
Solar aspect system	Measurement of solar center	**SA** (Solar Aspect)
	Relative deformation monitor	**DM** (Deformation System)
Framework support	Structure stability	A whole titanium framework;
Thermal control	Thermal homogenous holding	Front and rear titanium base plate; Active TC: heaters were used by closed loop control Passive TC: multi-layers and insulation were used

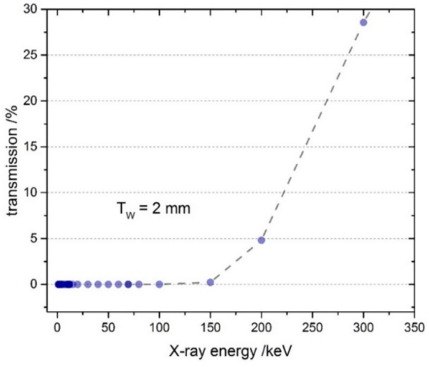
2 Detailed design of HXI-C

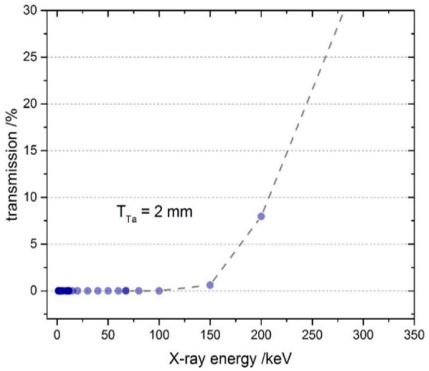
1 Grids material and thickness





Pitch:36μm (left: front grid; right: rear grid)

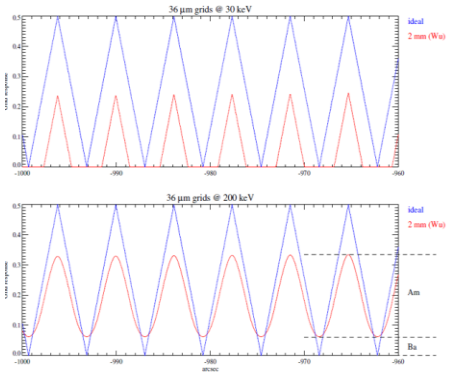


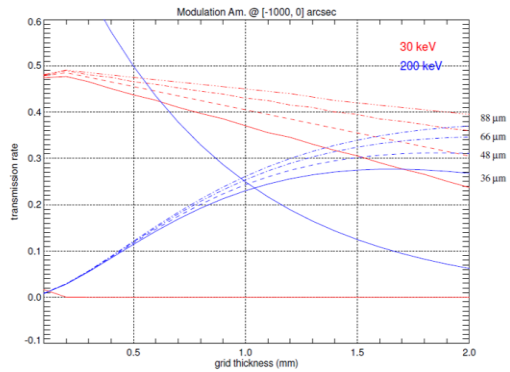


杂质元素	Al	Ca	Fe	Mg	Mo	Ni	Si	C	N	O
含量（w%）	0.002	0.005	0.005	0.003	0.01	0.003	0.005	0.008	0.003	0.005

www.atm-tungten.com

Su et al. (2019, RAA)



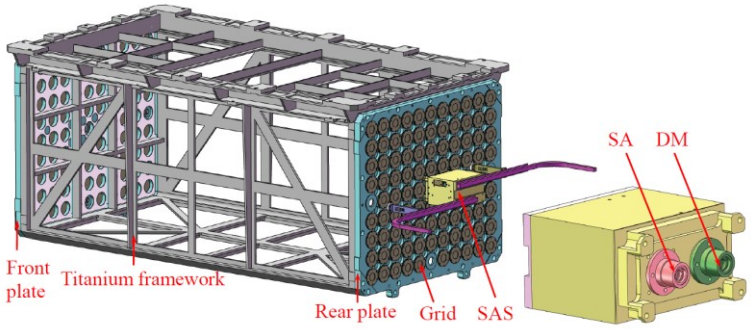


▪光栅节距	36μm	52μm	76μm	108/156/224/344/524/800/1224
厚度	1.0mm	1.4mm	1.7mm	2.0mm

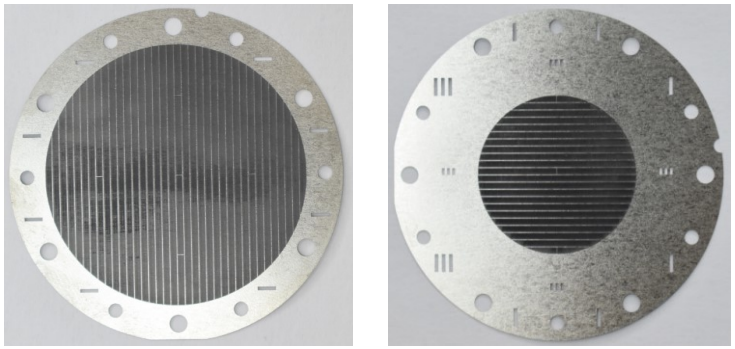
Compromise between grids transmission and modulation amplitude

2 Detailed design of HXI-C

2 Grids Pitch distribution



Definition: FWHM=p/2L



Pitch:36μm (left: front grid; right: rear grid)

- **Arithmetic sequence：$p_n=p_{max}/n$ ， n=1,2,… (Yohkoh/HXT)**
- **Log. spacing distribution：$p_n=p_{max}.\alpha^{-(n-1)}$ ， n=1,2,… α∈(0,1) (RHESSI & STIX/Solar Orbiter)**

1 Science objective guarantee---smallest pitch 36 μm;
2 Experience from RHESSI，aptly increase grids of large pitch may expand detection range
3 Lower cost---reduce small pitch gratings scale

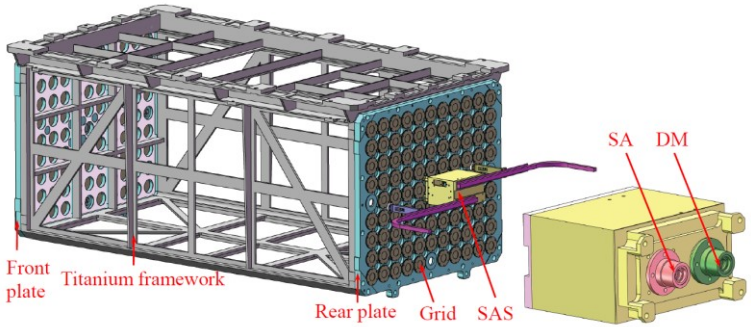
pitch/μm	36	52	76	108	156	224	344	524	800	1224

Chen et al. (2021, RAA)

Isometric sequence distribution | logarithmic distribution

2 Detailed design of HXI-C

3 Grids configuration and distribution



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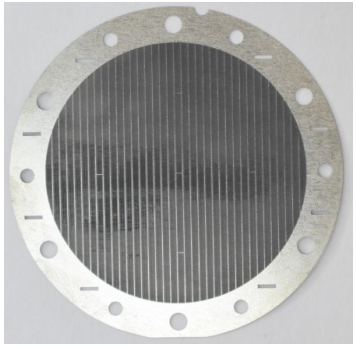
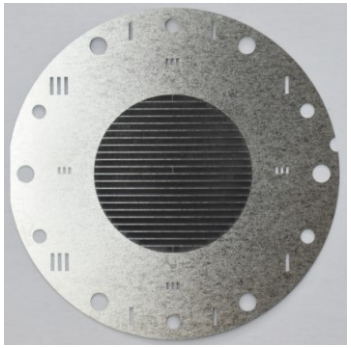




Pitch:36μm (left: front grid; right: rear grid)

Interface plate: front view of rear plate(from HXI-S to the solar)

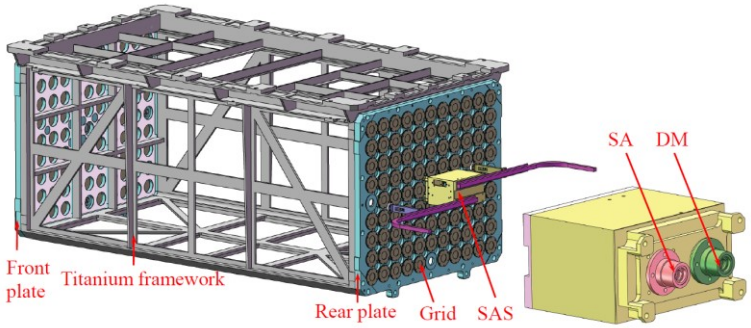
1224 53°	156 50°	524 41°	156 14°	344 23°	800 23°	1224 173°	156 158°	156 158°	224 149°	800 143°
344 59°	36 70°	36 70°	76 176°	52 41°	52 41°	76 176°	52 149°	52 149°	108 131°	344 131°
156 14°	76 68°	52 77°	52 77°	52 5°	52 5°	36 160°	36 160°	36 115°	76 104°	524 113°
800 83°	524 77°	108 95°	108 95°	224 5°	524 5°	344 95°	224 113°	36 115°	76 104°	1224 113°
frosted glass	1224 113°	344 95°	344 95°	OPEN	DM	SA	OPEN	224 77°	524 77°	frosted glass
524 113°	1224 113°	52 113°	52 113°	344 167°	800 23°	524 5°	156 86°	156 86°	76 68°	800 83°
344 131°	156 122°	76 139°	76 139°	156 122°	76 32°	76 32°	36 25°	36 25°	156 50°	108 23°
224 149°	108 131°	108 167°	108 167°	1224 173°	224 5°	108 23°	224 77°	108 59°	108 59°	224 41°
800 143°	524 149°	524 149°	524 149°	OPEN	frosted glass	344 23°	524 41°	224 41°	344 59°	1224 53°

Chen et al. (2021, RAA)

1 Instrument mechanical characteristic; 2 Instrument thermal (deformation) property;
3 Spatial instrument reliability; 4 Imaging optimization;

2 Detailed design of HXI-C

4 Grids manufacture



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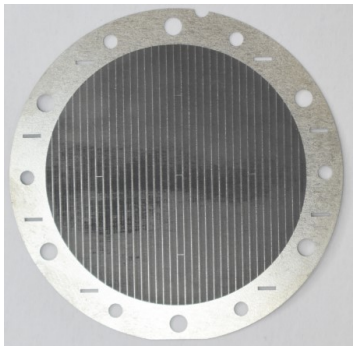

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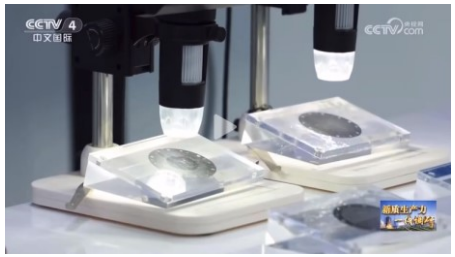
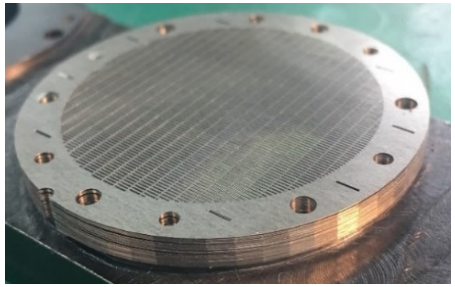




Difficulties in fabrication technology

1 Material: hard metal, tungsten;

2 Finest pitch: 36μm, slit width 18~20μm;

3 High depth-width ratio: ＞5;

4 Large area: grinding scale φ36mm;

5 Stability and consistency: over 3500 pcs production;

thousands of slits for single grid

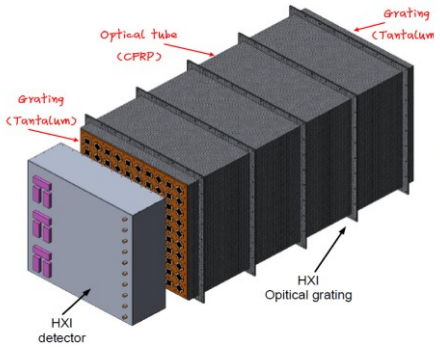
A key technical breakthrough against foreign blockade in fine processing field

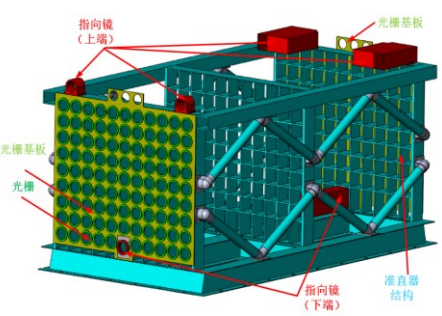
2 Detailed design of HXI-C

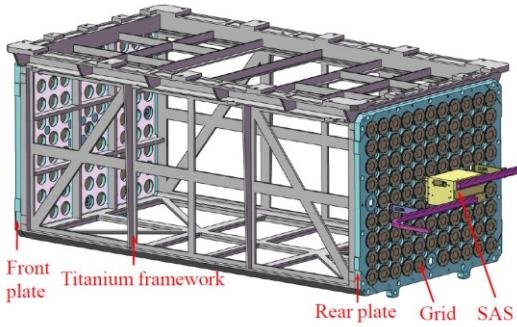
5 Mechanical and thermal design

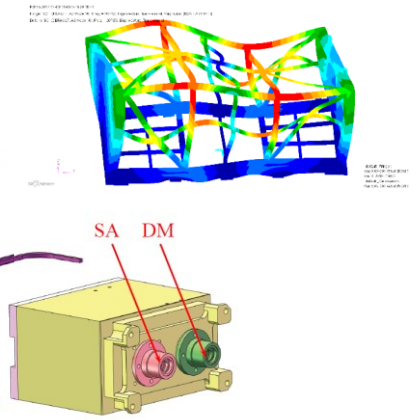
Requirement

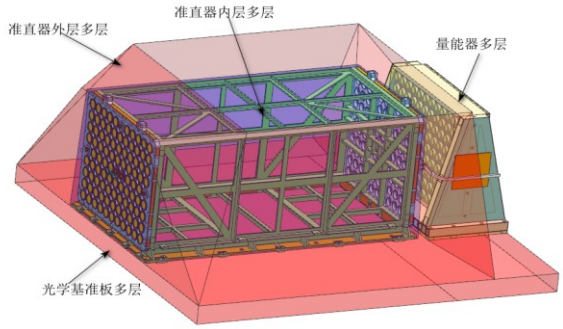
•**Mechanical stability;** **Temperature homogenous;** **Mass budget limit;**

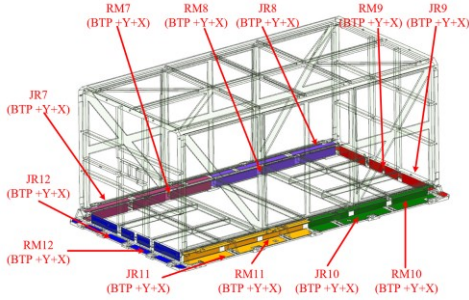


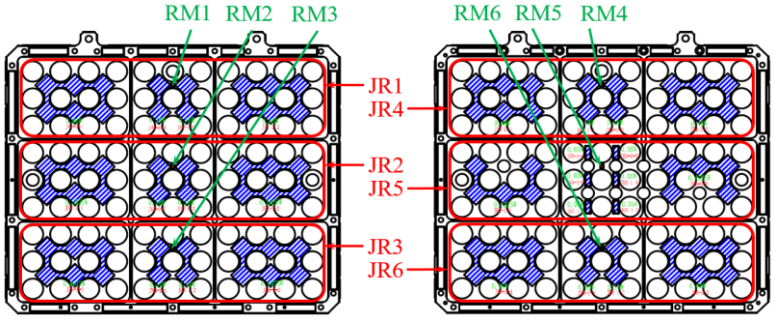












Chen et al. (2021, RAA)

2 Detailed design of HXI-C

6 Solar Aspect System

Requirement

- **Measurement of solar center ;**
- **Relative deformation monitor for HXI-C framework;**

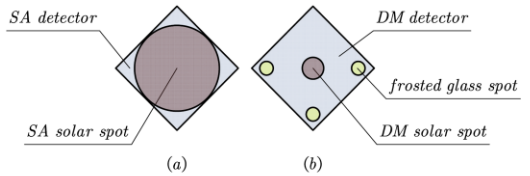


Fig. 2 Light spots morphological characteristics on the detectors in orbit use.

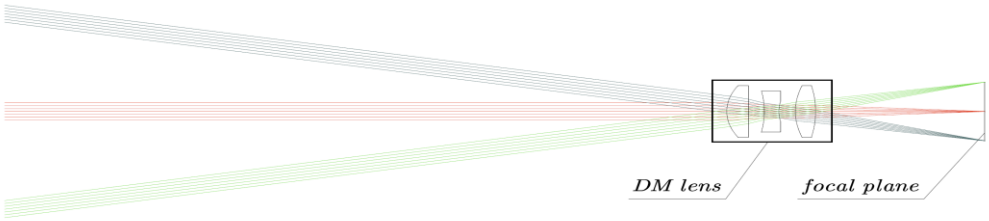


Fig. 4 The optical design of the DM

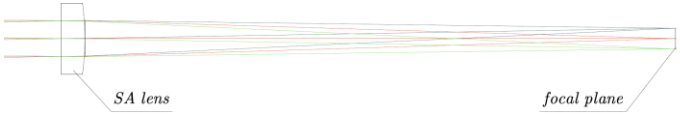
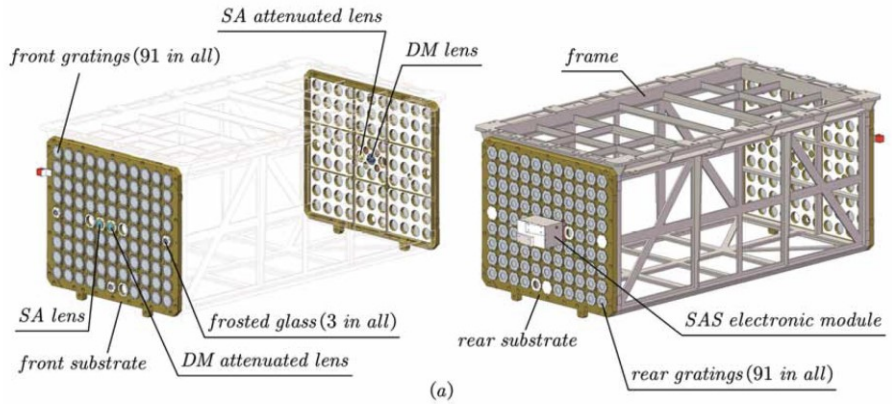
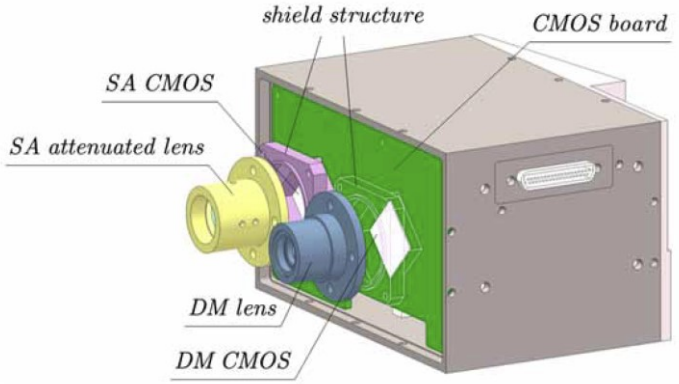


Fig. 3 The optical design of the SA





Yu et al. (2023, Sol. Phys., submitted)

2 Detailed design of HXI-C

A short summary for HXI-C

Characteristics	Design value	In orbit results
Energy range	30~200keV	~ 10 -300 keV (spectra) ~ 15 -284 keV (imaging)
Spatial res.	Better than 6″	~ 3.1 arcsec
Energy res.	Better than 27%	Better than 22%@32keV
Time res.	Better than 0.5s	0.125 – 4s
Modulation grid	10 kinds	10 kinds from 36 to 1224 μm
Sub-collimators	91 pairs	91
Detector modules	99	99 $LaBr_3$ detectors
		Image: 91/ Background: 5 / Total flux: 3
Point meas. acc.	Better than 2″	Better than 0.3 arcsec

Outlines

1 ASO-S introduction

2 Detailed design of HXI-C

3 Ground characterization (2021.09)

4 On orbit calibration

5 Ground characterization (2023.07)

6 Summary

3 Ground characterization and tests

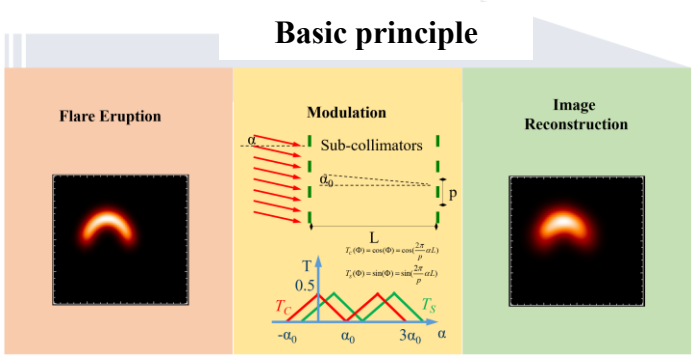
1 Modulation characterization

Requirement

- **Modulation function test;**
- **Modulation parameters characterized;**

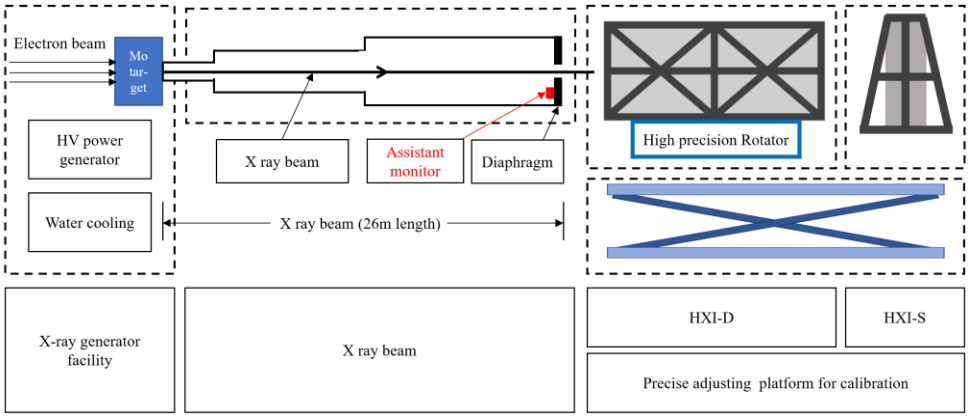
Method

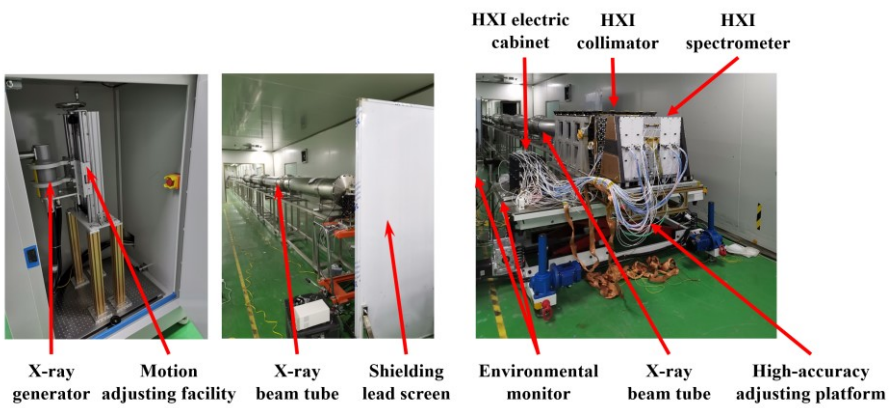
- **Test with a set of X-ray Modulation Characterization System;**



Facility

- **Integrated in Dong-yi, Yantai; Test from Sept. 23 to Nov. 8; All 91 sub-collimator was tested;**

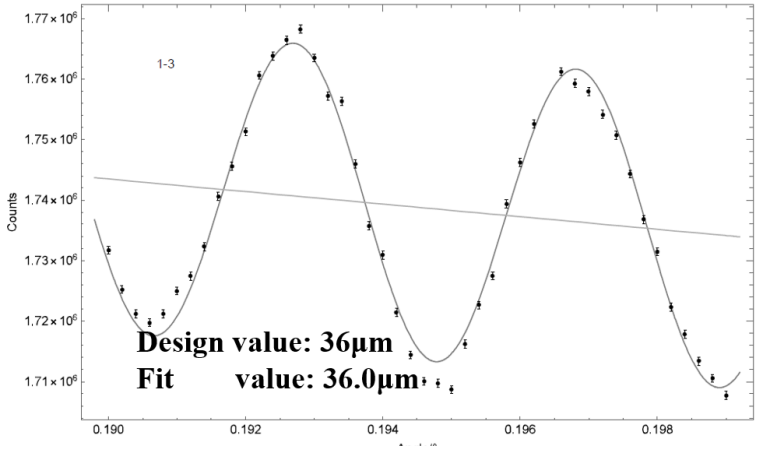




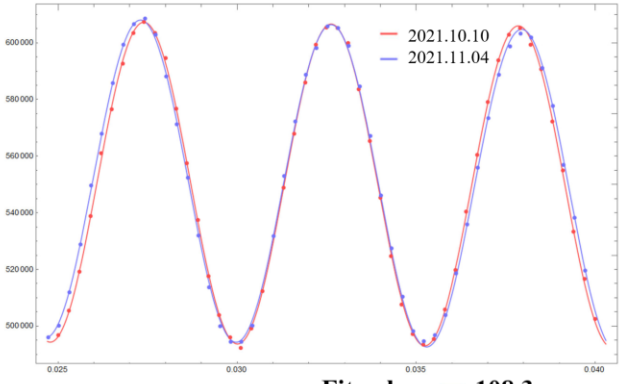
3 Ground characterization and tests

1 Modulation characterization

Modulation curve for p36



Modulation curve for p108



Design value: 108μm

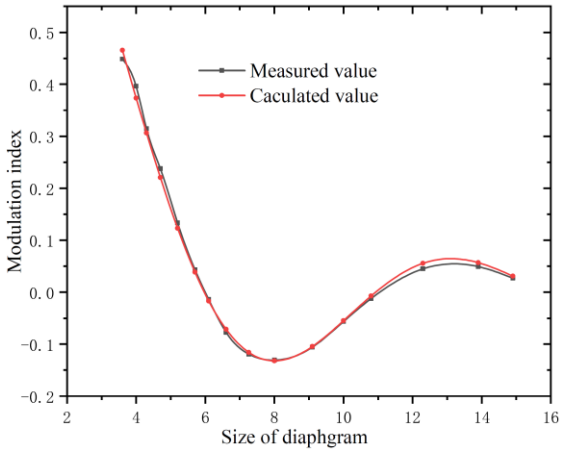
Fit value: 108.3μm

Fit value: 110.1μm

Chen et al. (2022, Chin. J. Space. Sci.)

Jiang et al. (2022, RAA)

Modulation index curve for p224

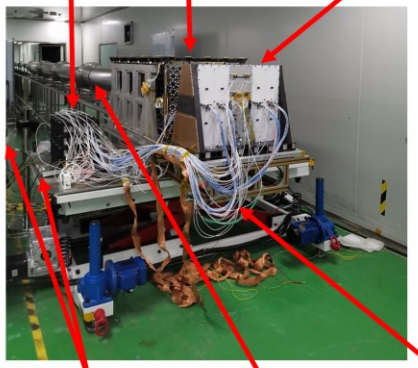


X-ray generator

Motion adjusting facility

X-ray beam tube

Shielding lead screen



HXI electric cabinet

HXI collimator

HXI spectrometer

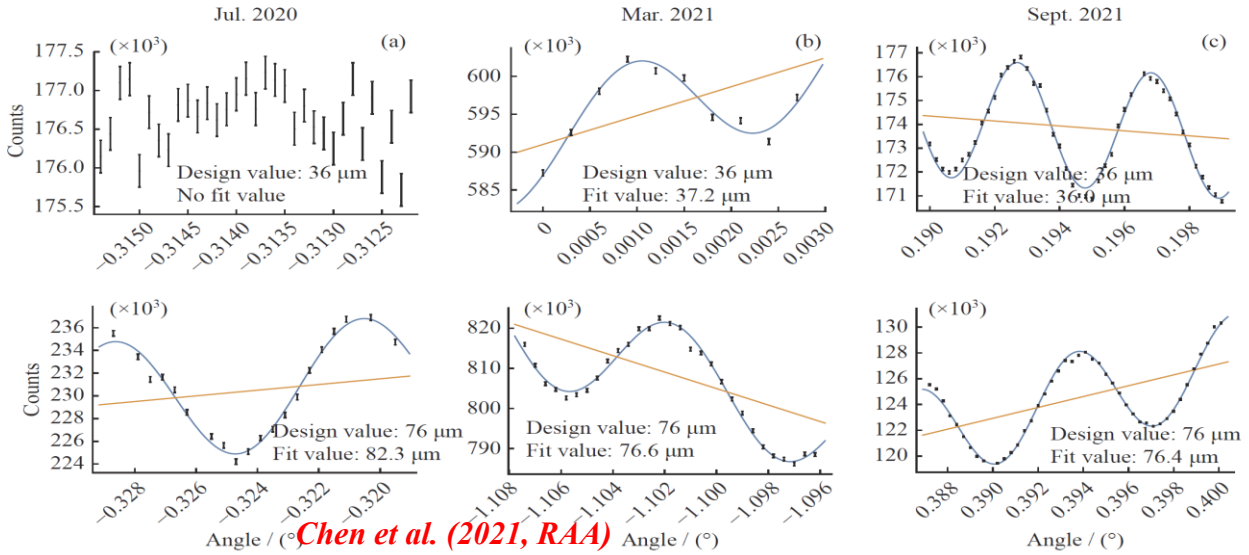
Environmental monitor

X-ray beam tube

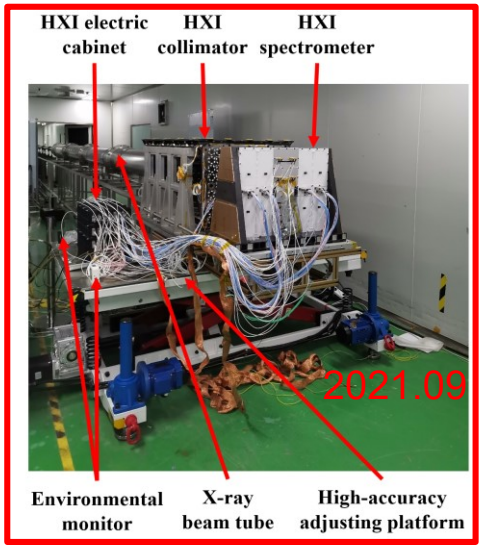
High-accuracy adjusting platform

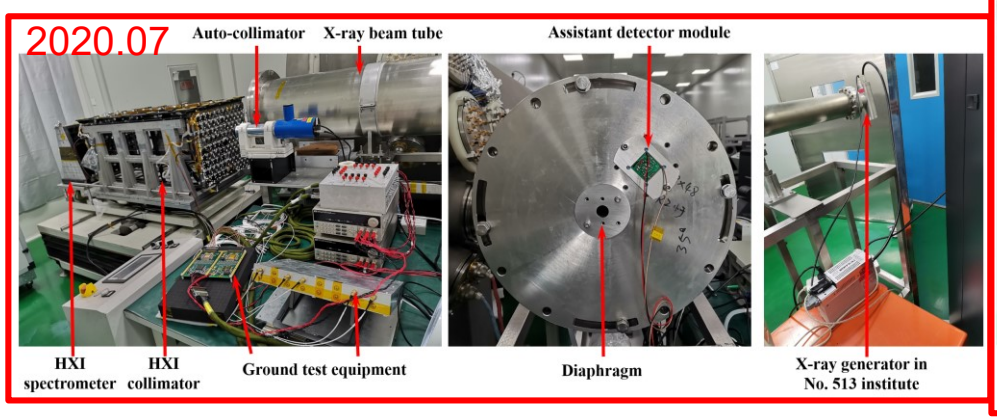
3 Ground characterization and tests

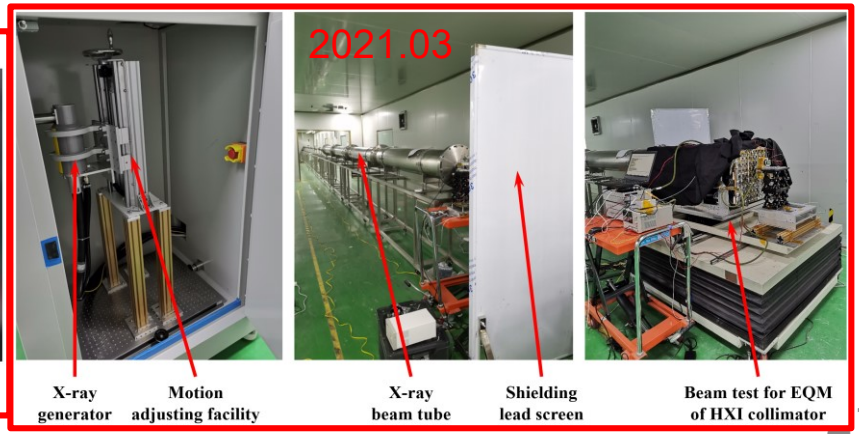
1 Modulation characterization



Chen et al. (2021, RAA)
Jiang et al.(2023, NIM-A)







3 Ground characterization and tests

2 Deformation monitoring for HXI-C

Requirement

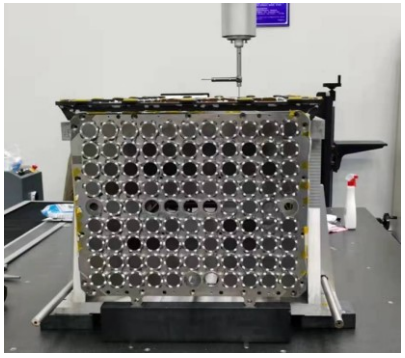
- **Relative displacement measurement for front and rear base-plate;**

Method

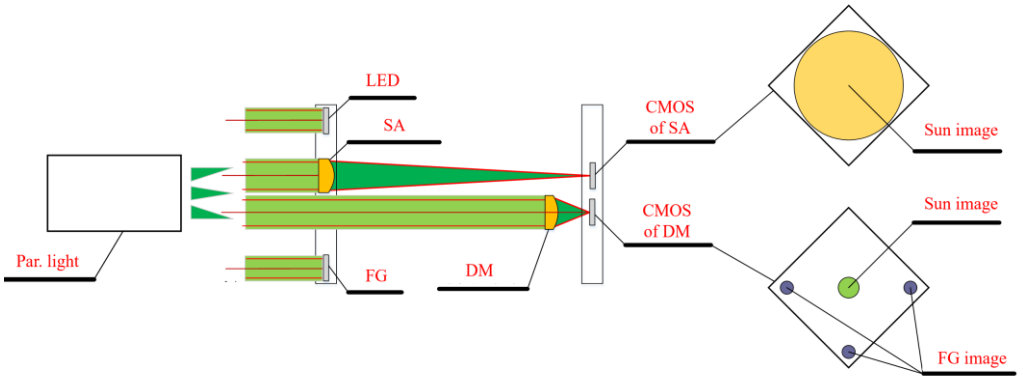
- **Direct measurement by CMM;**
- **Zero point calibration measurement by SAS (SA & DM)**

Facility

- **Ground test until its launch; On orbit calibration on scheduled time;**



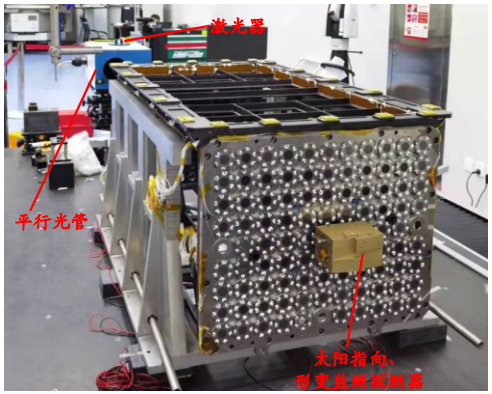
CMM measuring



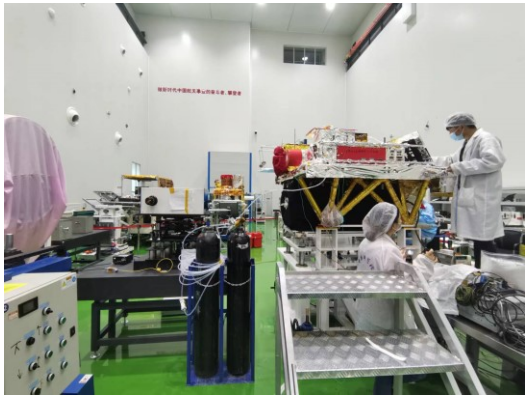
Zero point calibration

3 Ground characterization and tests

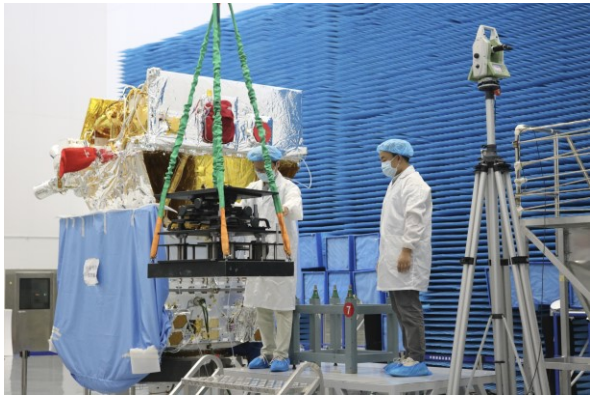
2 Deformation monitoring for HXI-C



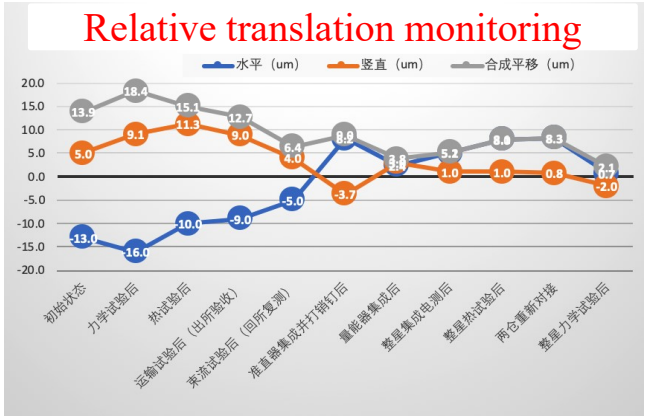
2021.11 Xi'an



2022.03 Shanghai



2022.09 Jiuquan



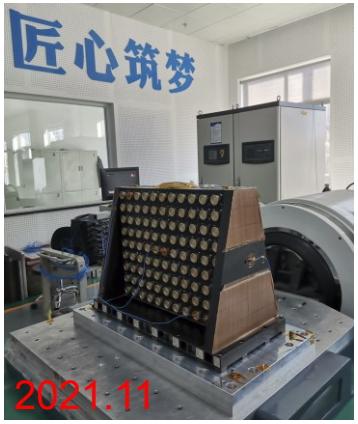
•Relative twist: ~2.9″

•Relative translation： ~7.3 μm

Before launch!

3 Ground characterization and tests

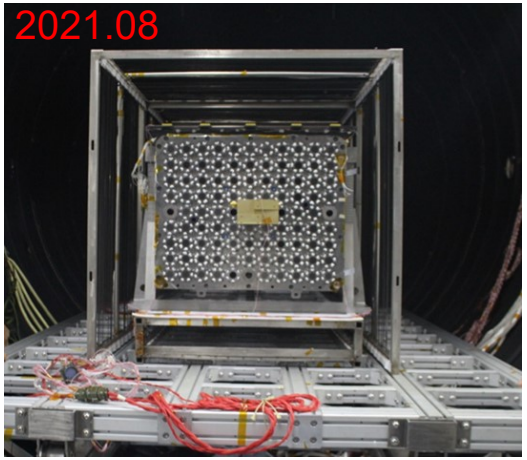
3 Spatial environmental tests for HXI



HXI-S vibration and TV test

HXI-C vibration test

HXI-S EMC test



HXI-C TC test

3 Ground characterization and tests

4 Integration and tests in IAM/CAS

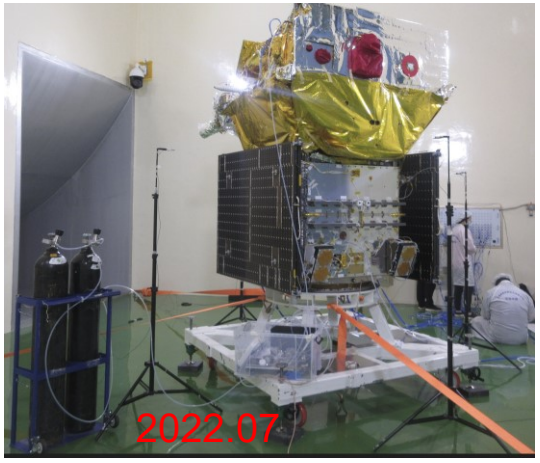
Sleep in Conference room

HXI-C installation

HXI-S installation

TV and TB test

Vibration test



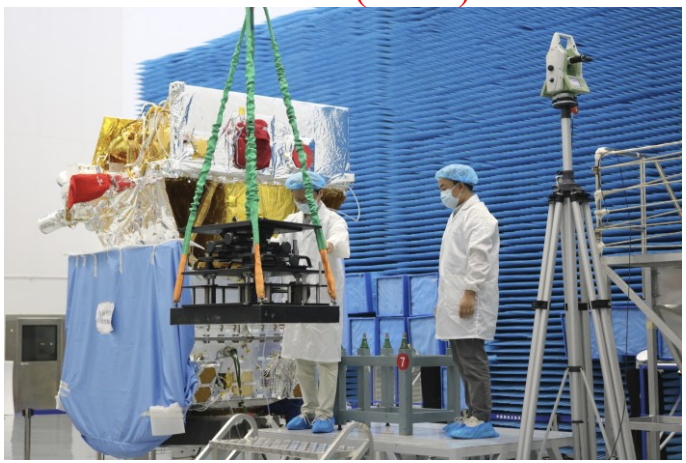
Noise test

3 Ground characterization and tests

5 Integration and tests in Jiuquan Launch center

2022.08

2022.09 (23:00)



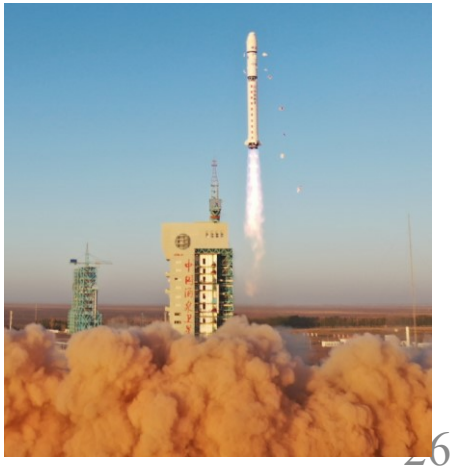
2022.09 08:30

2022.09

2022.09

Half an hour before launch

2022.10.07 Launch



Outlines

1 ASO-S introduction

2 Detailed design of HXI-C

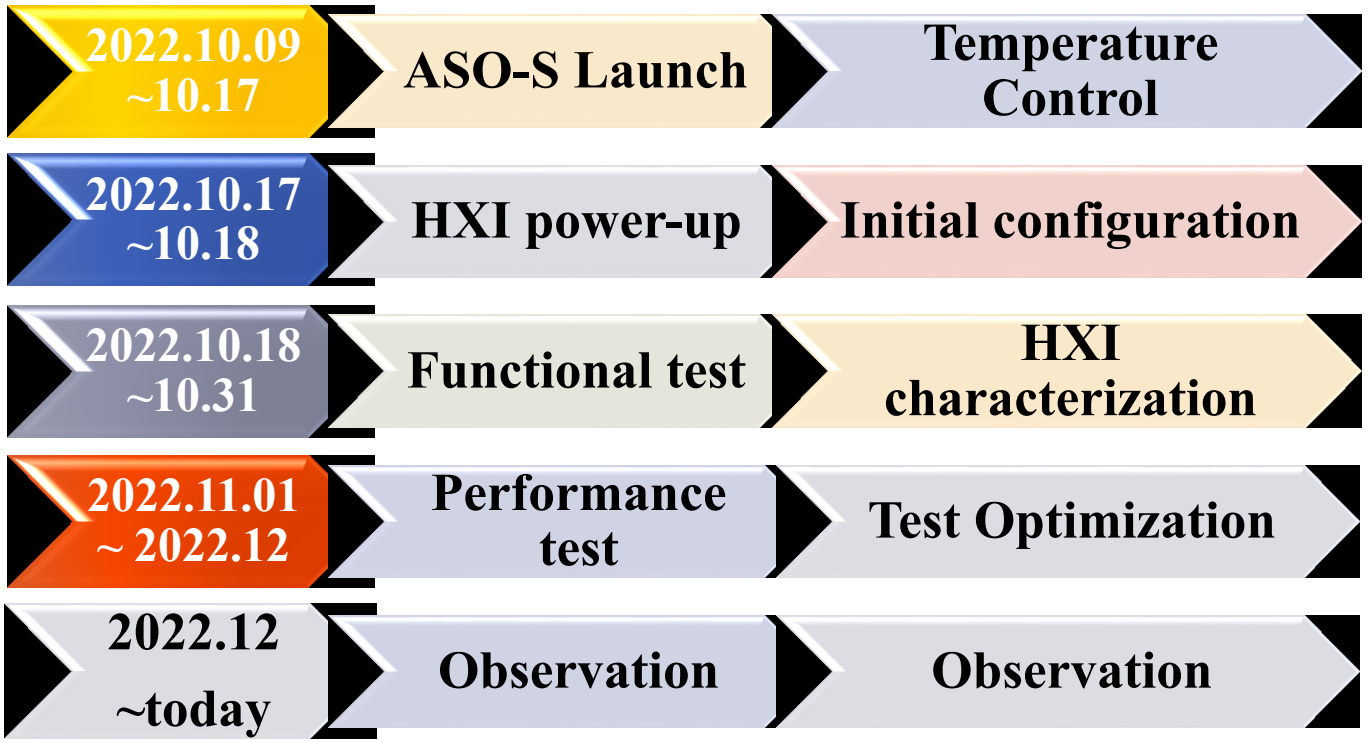
3 Ground characterization (2021.09)

4 On orbit calibration

5 Ground characterization (2023.07)

6 Summary

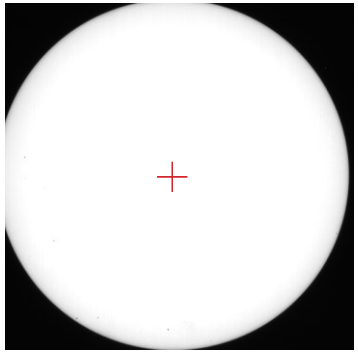
4 On orbit calibration

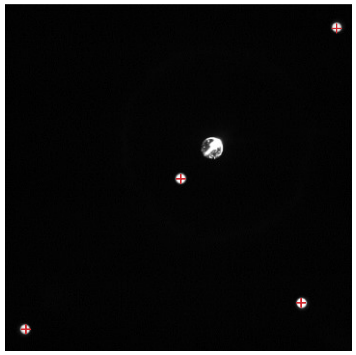


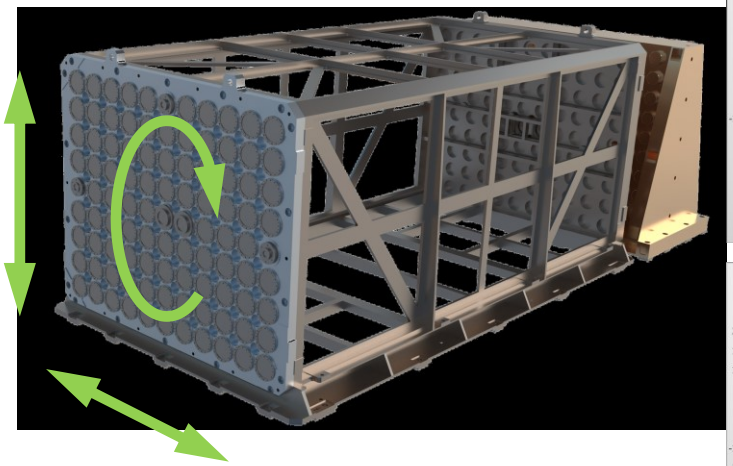
On orbit test procedure

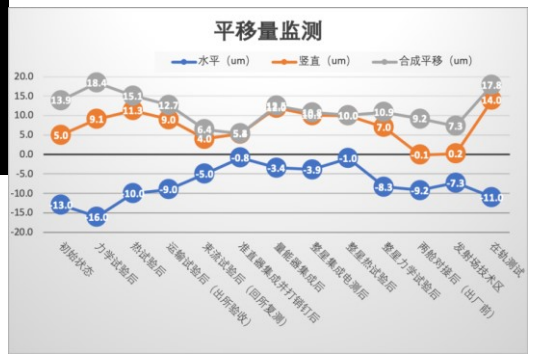
4 On orbit calibration and tests

1 characterization for HXI-C (SAS ZERO CALI.)

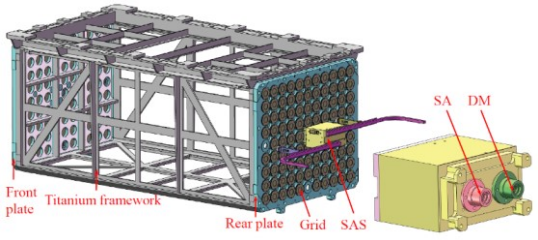




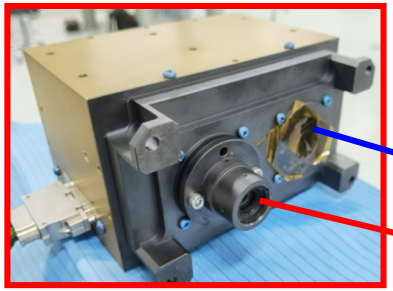




- **Relative twist: ~0.7″**
- **Relative translation： ~17.8 μm**

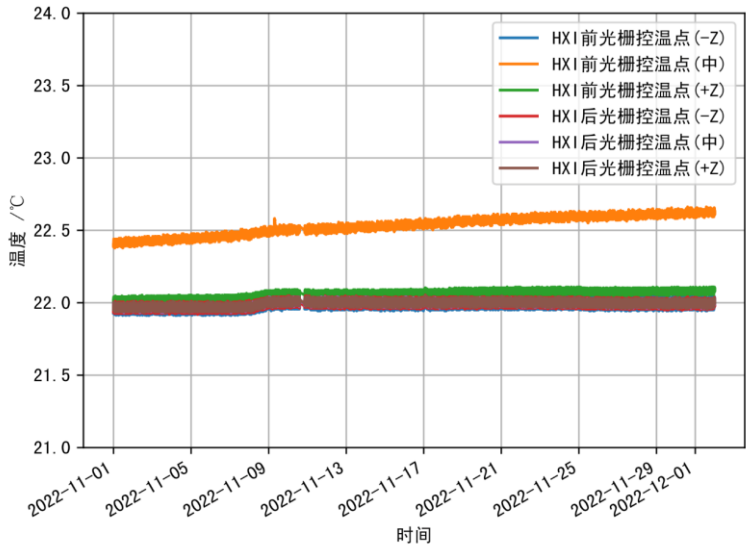


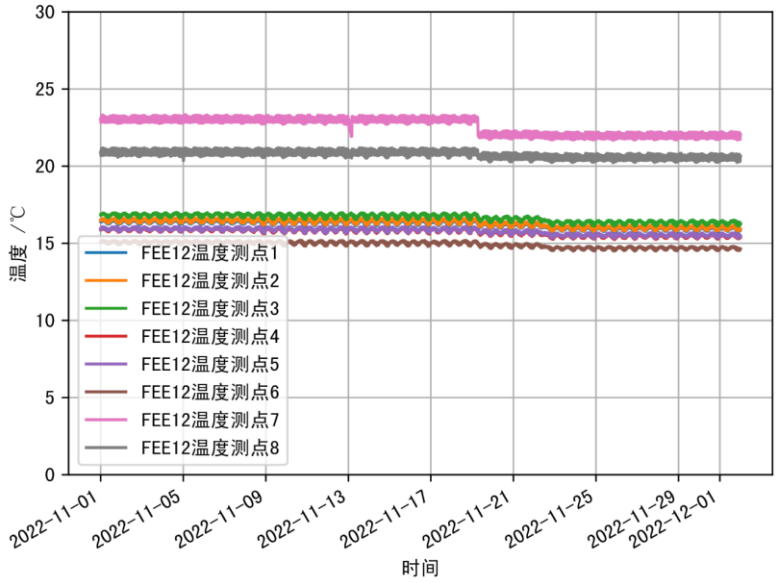
- *SA measuring center of the Sun*
- *DM deformation monitor*



4 On orbit characterization

2 Temperature homogenous and stability



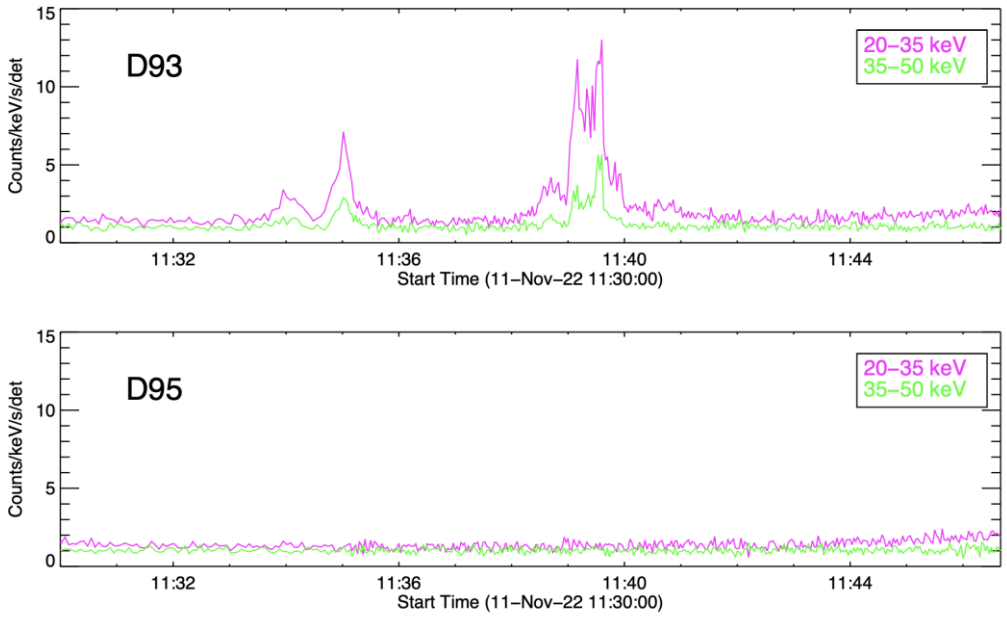


•Temperature difference: ~0.6 ℃ for HXI-C and 2 ℃ for HXI-S;

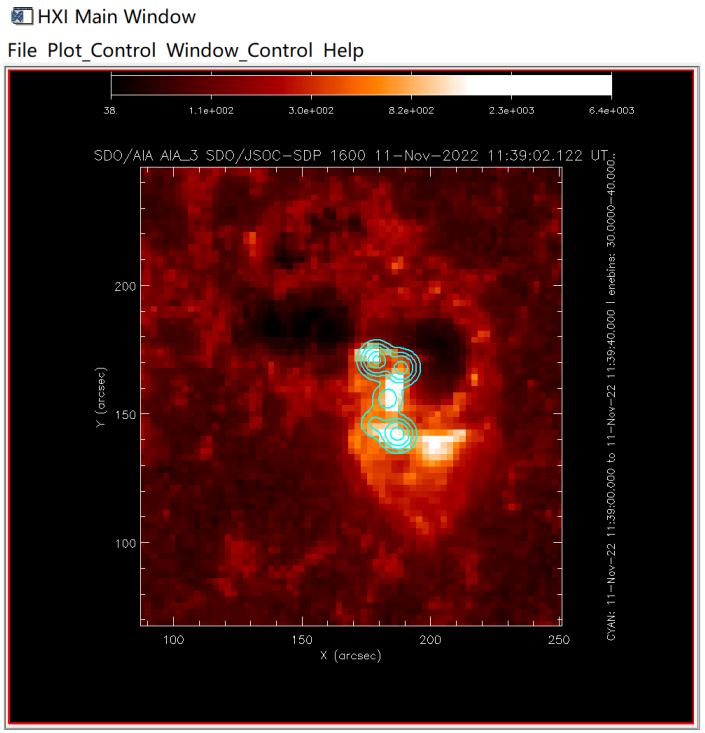
•Temperature stability：~0.1℃ in 30 days (in Nov. 2022)

4 On orbit characterization

3 Hard X-ray image on 11/11/2022



Light curve on UTC 2022-11-11 11:38:00



•Very nice image property!

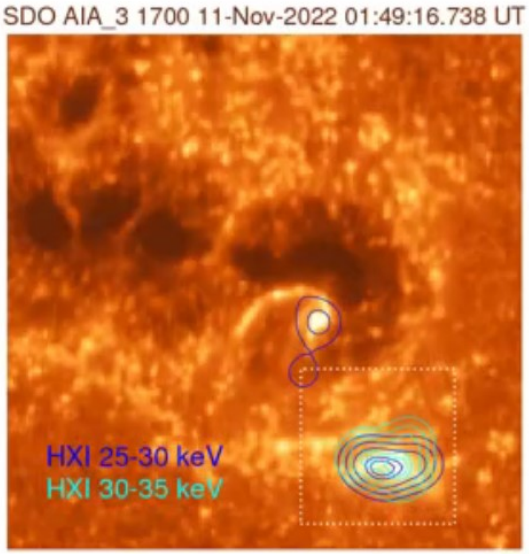
(make HXI-team very confident!)

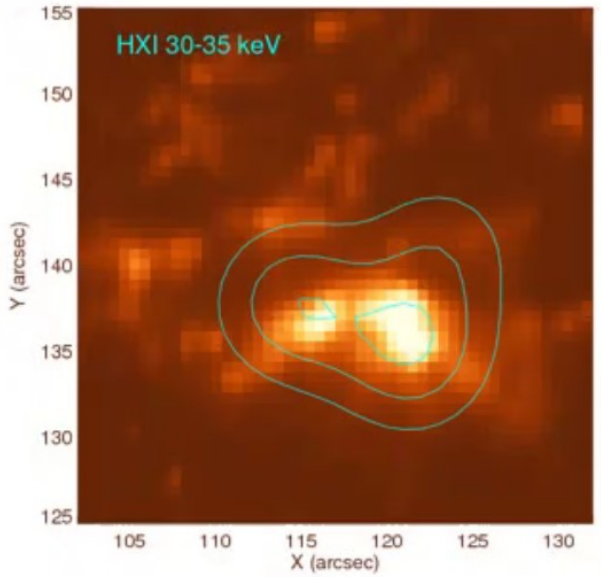
4 On orbit characterization

3 Hard X-ray image on 11/11/2022

我国首次获得太阳硬X射线图像

央视网 2022-11-23 16:50:38 63208次观看



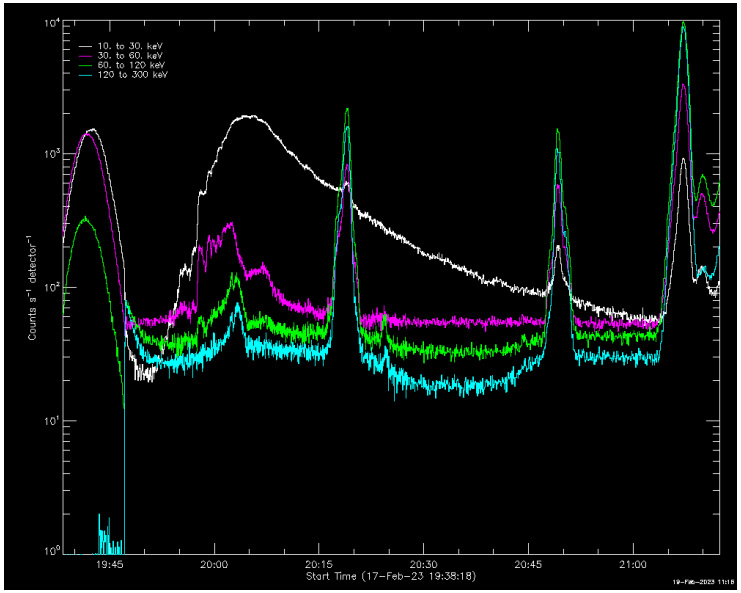


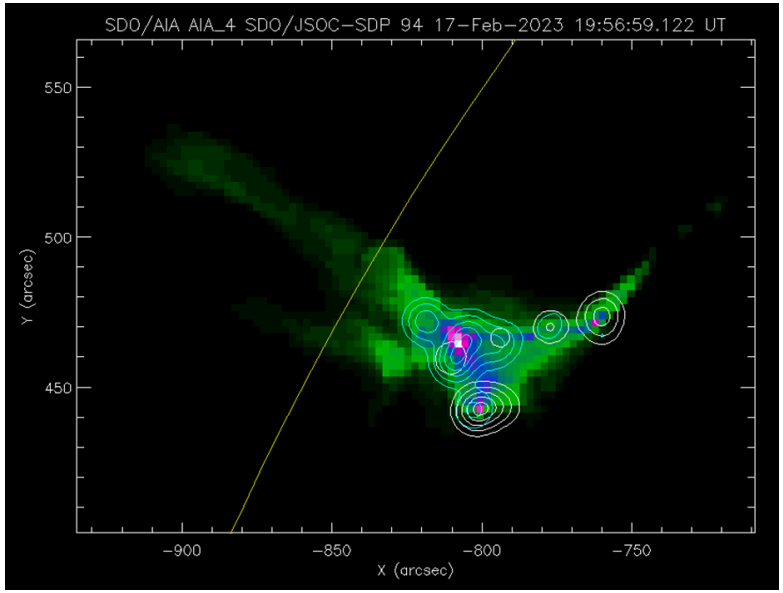
•Double foot print X-ray source

•Very perfect hard X-ray image, even better than expected!

4 On orbit characterization

3 Hard X-ray image on 17/02/2022





•Multiple foot print X-ray source

•Delicate structure (different from past results), advance our knowledge in solar flares !

Outlines

1 ASO-S introduction

2 Detailed design of HXI-C

3 Ground characterization (2021.09)

4 On orbit calibration

5 Ground characterization (2023.07)

6 Summary

5 Ground characterization after launch

After launch beam tests background

Motivation

- **Too long time used for modulation test (last about 45d)**

$$P(\theta,\varphi) \approx g_0^2(\theta_g) + \frac{g_1^2(\theta_g)}{2} F_1\left(2\pi\frac{L}{p\,l}R\right) F_1\left(2\pi\frac{L}{p\,l}r_s\right) \cos\left(2\pi\frac{L}{p}\theta_g + \theta_0\right)$$

Modulation factor — Source factor

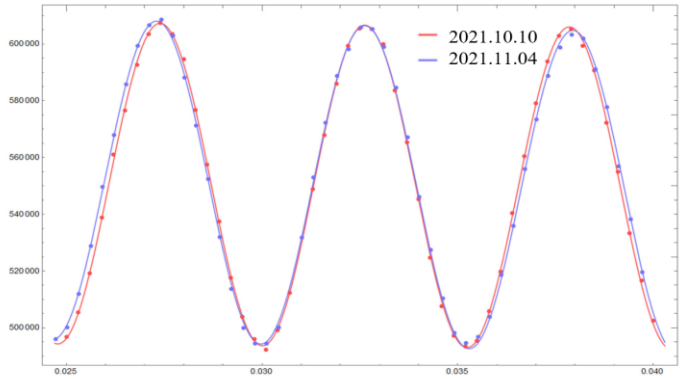
More simplified term under assumption that low energy photons totally transmitting or not when facing our grids

$$P = P_{0t}P_{0b} + \frac{2F\sin(\pi P_{0t})\sin(\pi P_{0b})}{\pi^2}\cos\left(\frac{2n\pi L}{p}\theta + n\theta_0\right)$$

P_{0t} transmission ratio for the front grid and P_{0b} for the rear

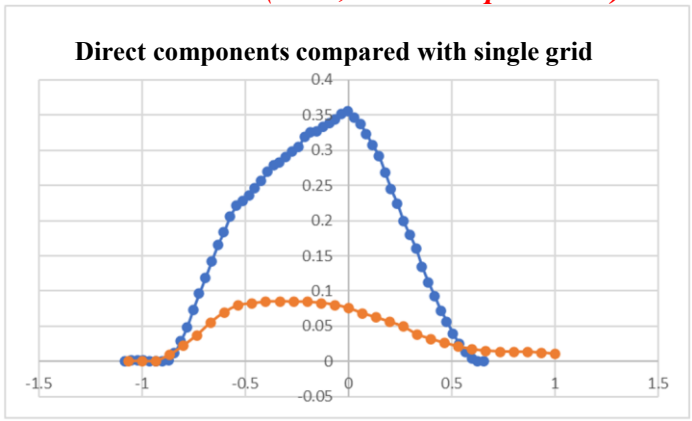
- Acquisition modulation amplitude by **testing P_{0t} and P_{0b}**, which will **save a lot of time**;
- Quick evaluation for stack grids;
- Service for future potential missions;

Testing time: 2023.07 for HXI EQM



Design value: 108μm **Fit value: 108.3μm** **Fit value: 110.1μm**

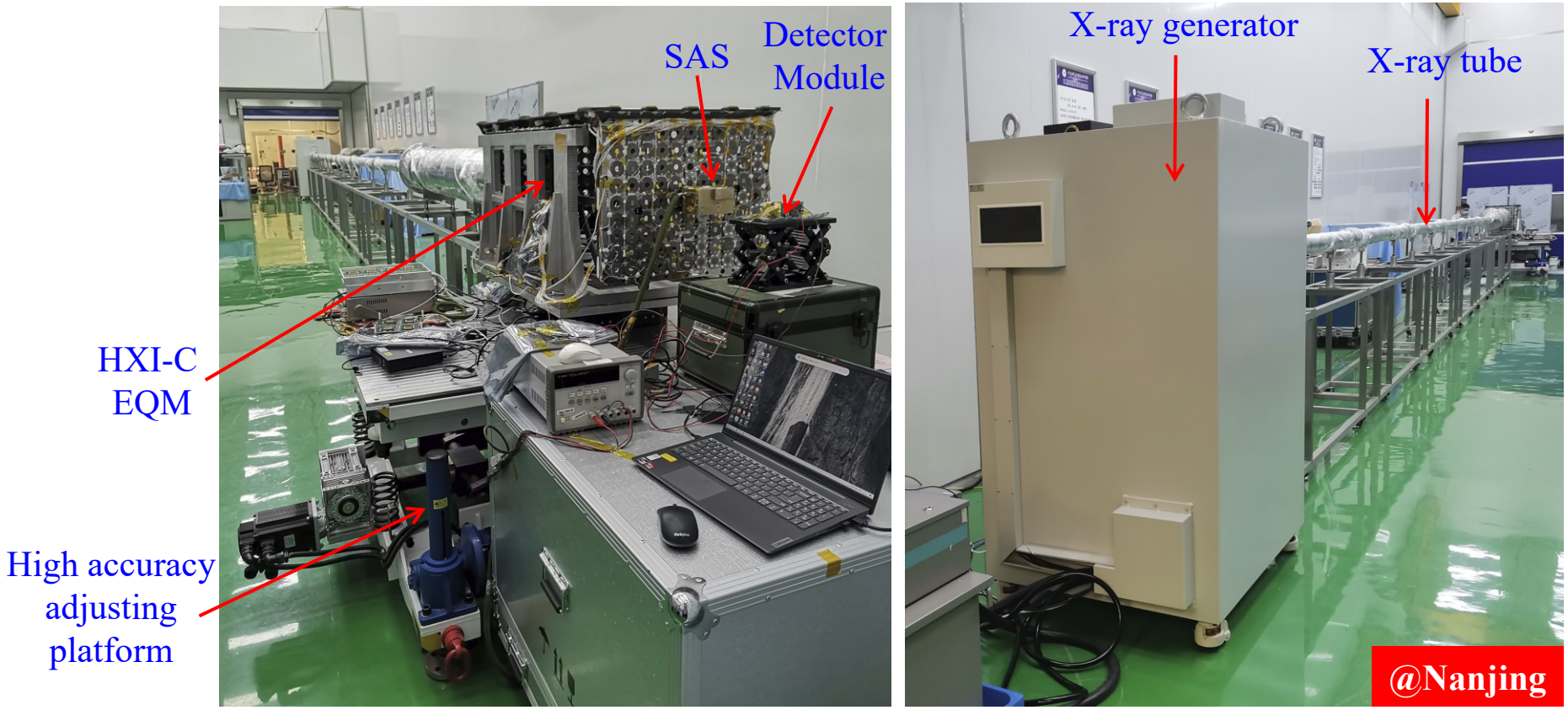
Chen et al. (2022, Chin. J. Space. Sci.)



Chen et al. (2022, Internal BT report)

5 Ground characterization after launch

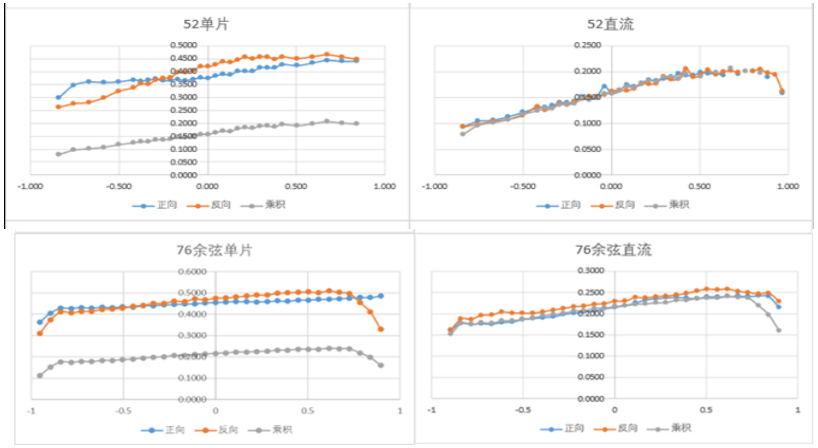
X-ray beam tests simplified proposal verification

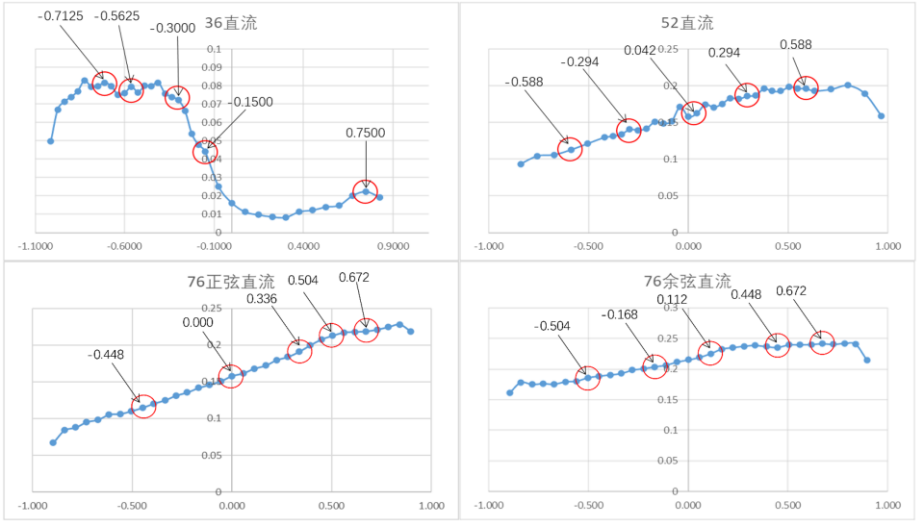


- **The same config. with HXI FM, except tube length(18.5m), accurate diaph. and sufficient time;**
- **Test serval cases including backgrounds, transmission of single and a pair grid et al.**

5 Ground characterization after launch

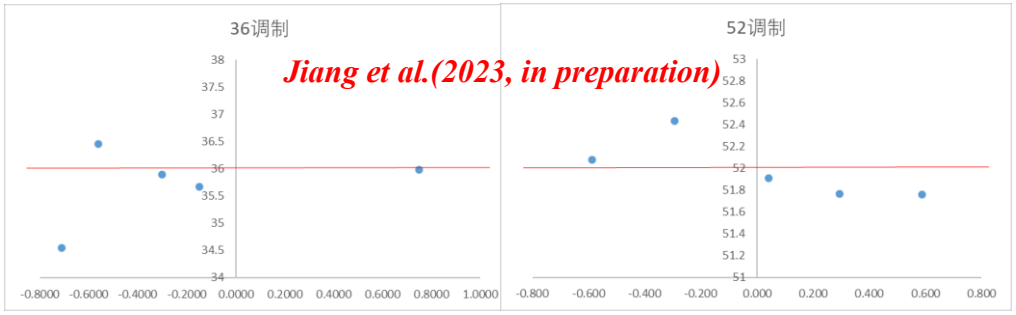
X-ray beam tests simplified proposal verification





Verified results consistent with expectations

Transmissions ranged with selected testing points



Jiang et al.(2023, in preparation)

•Modulation curves and fitted pitch of grids presents well status for HXI-C EQM .

6 Summary

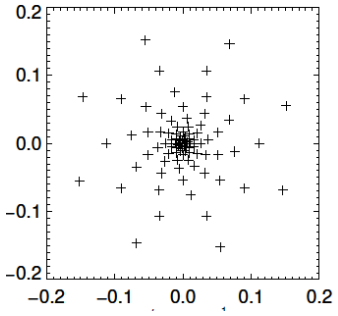
ASO-S was successfully sent to space on 09/10/2022. HXI has basically finished its on orbit calibration with perfect performance. Series of solar hard X-ray images was reconstructed with high spatial resolution.

We wish more wonderful results in the near future! Cooperation are warmly welcome and scientific data is open onsite.

Thank you!

Backup for grids configuration

- 等间距分布：$p_n=p_{max}/n$，n=1,2,…（Yohkoh/HXT采用）
- 对数间距分布：$p_n=p_{max}.\alpha^{-(n-1)}$，n=1,2,… 且α∈（0,1）（RHESSI与Solar Orbiter/STIX采用）；



等间距分布	p /μm	360	180	120	90	72	60	51	45	40	36
	角分辨/″	31	15	10	7.5	6	5	4.3	3.75	3.3	3.1
光栅摆放角/°	9	0	1	1	0	0	1	0	0	1	1
	27	1	1	1	1	0	1	0	0	0	0
	45	0	1	0	1	0	0	1	1	0	1
	63	1	1	0	0	1	0	1	1	0	0
	81	0	1	0	0	1	1	0	0	1	1
	99	1	0	1	0	1	0	1	0	1	0
	117	0	0	0	1	1	0	0	1	1	1
	135	1	0	1	0	1	0	1	1	0	0
	153	0	0	0	1	0	1	1	1	0	1
	171	1	0	1	1	0	1	0	0	1	0

对数间距分布	p /μm	800	398	294	218	160	120	88	66	48	36
	角分辨/″	68.8	34.2	25.3	18.8	13.8	10.3	7.5	5.7	4.1	3.1
光栅摆放角/°	9	0	1	0	1	0	1	0	1	0	1
	27	1	0	1	0	1	0	1	0	1	0
	45	0	1	0	1	0	1	0	1	0	0
	63	0	0	1	0	1	0	1	0	1	0
	81	0	1	0	1	0	1	0	1	0	1
	99	1	0	1	0	1	0	1	0	1	0
	117	0	1	0	1	0	1	0	1	0	0
	135	0	0	1	0	1	0	1	0	1	0
	153	0	1	0	1	0	1	0	1	0	1
	171	1	0	1	0	1	0	1	0	1	0

Backup

3 Deformation monitoring for HXI-C