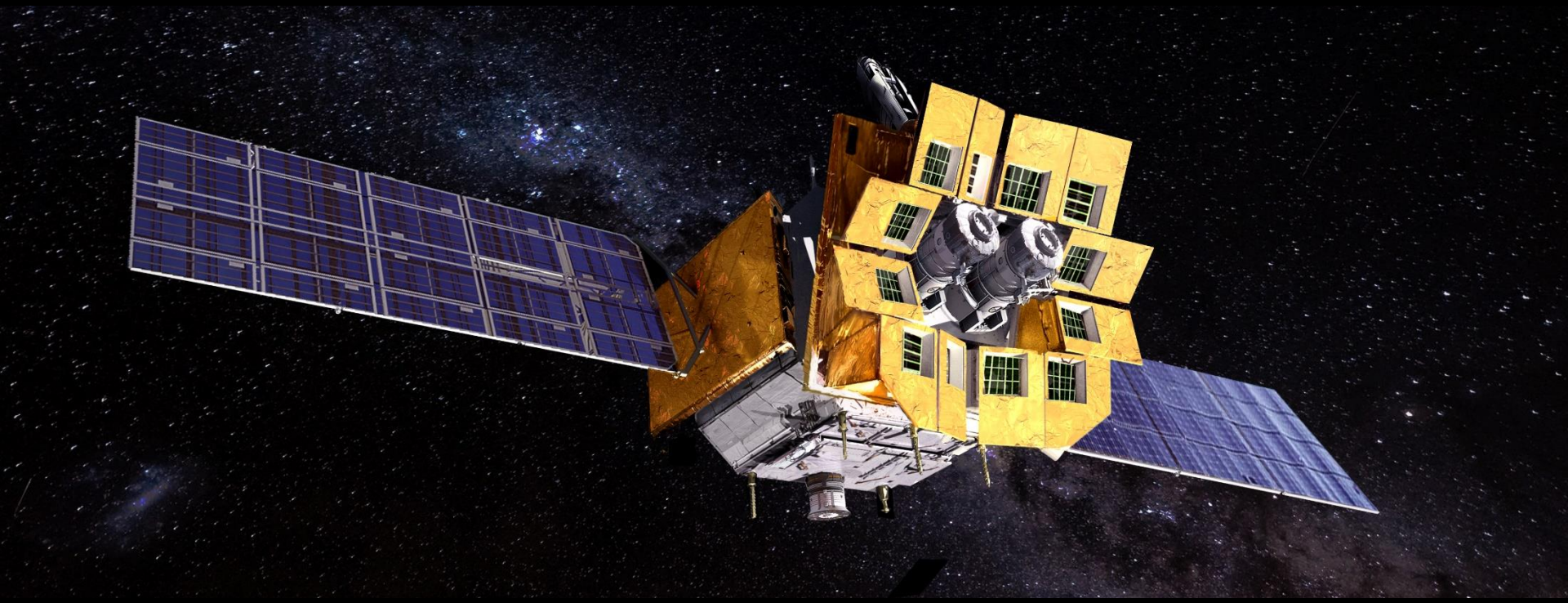
Einstein Probe

Exploring the dynamic x-ray universe

CALDB design and preliminary plan of in-flight calibration for EP-FXT



Chengkui Li on behalf of FXT Data center & FXT Payload Team

2023-04-25 15th IACHEC meeting at Seeblick Pelham

Overview

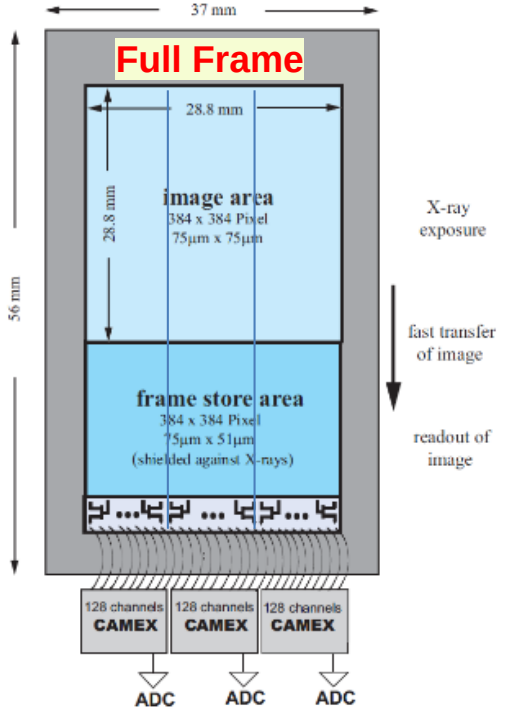
1. FXT and FXT-CalDB
2. Launch Window of EP
3. FXT In-orbit Calibration Plan
   - Phases and Subjects
   - Targets and Visibility
   - Commissioning Light
   - Preliminary Plan

1. FXT and FXT-CalDB

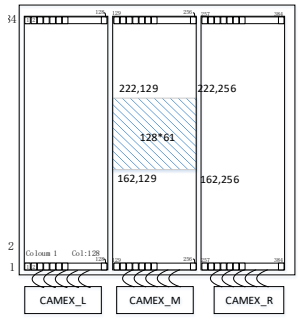
FXT: 2 modules

Modes: Full Frame (ff) // Partial Window (pw) // Timing Mode (tm)

Filters : open // thin // medium // hole // closed // calclosed(Fe55)

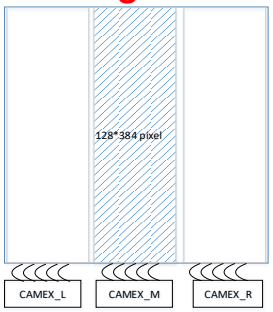


ff: 384*384 pixels
~50 ms



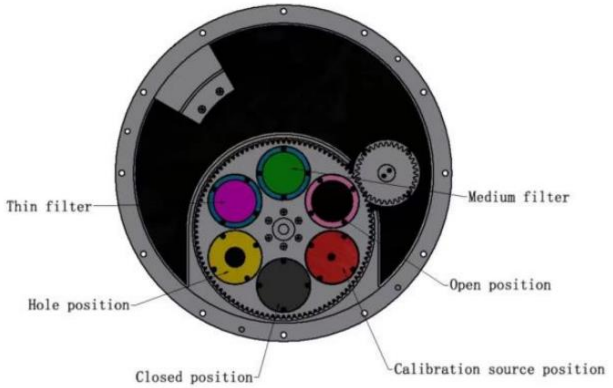
pw:

128*61 pixels
~2 ms



tm:

128*384 pixels
~23.68 us

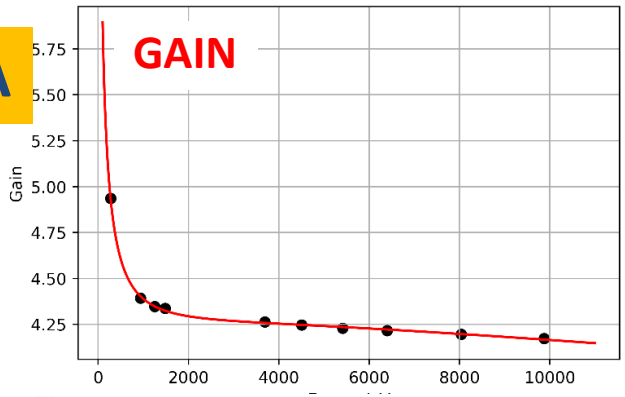


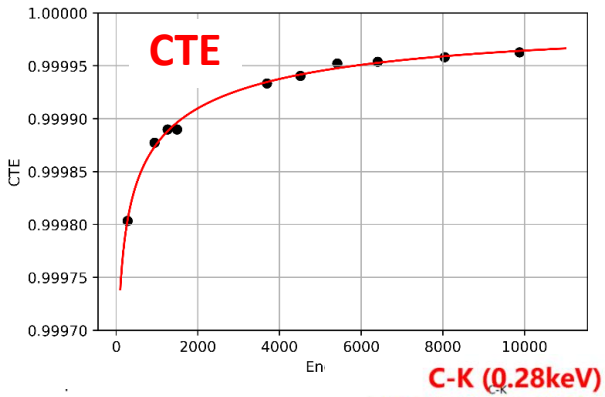
Filter: Six Positions
open /thin /medium /hole

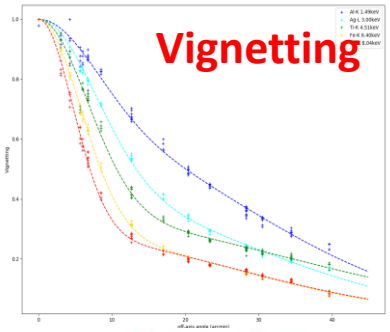
FXT-CalDB: 2 modules * 3 modes * 4 filters

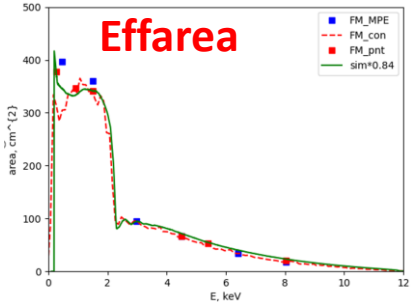
1. FXT on-ground calibration

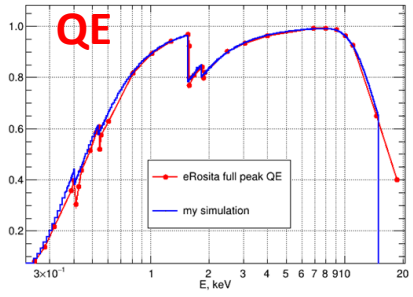
FXT-A

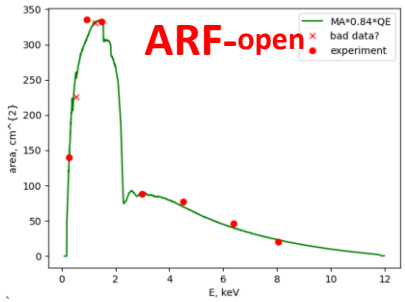


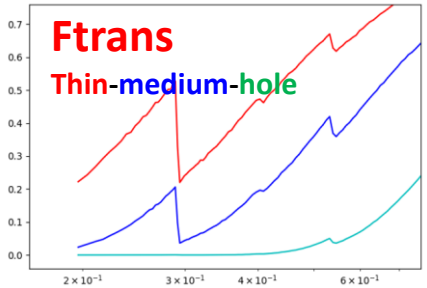


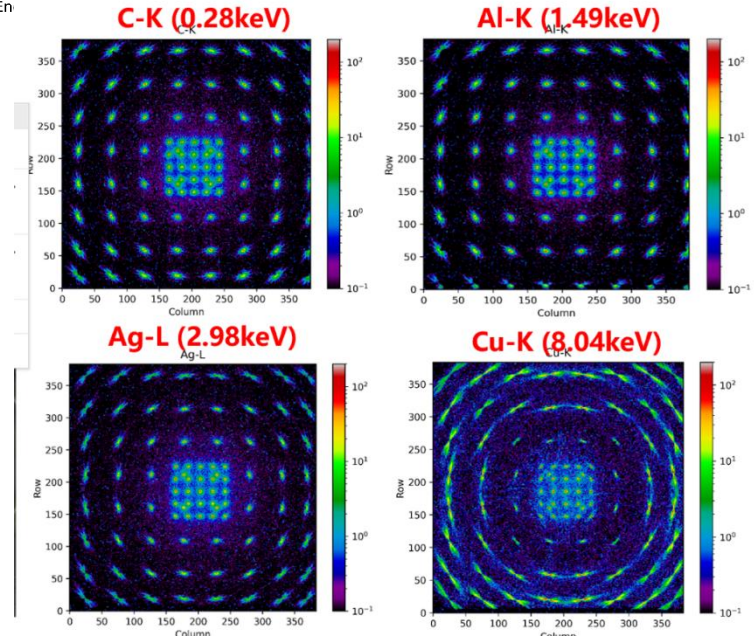












Calibrations of FXT-A and B are completed, and integral experiment will be completed in April.

See Yusa & Juan's talk

1. FXT and FXT-CalDB

Based on FXT on-ground calibration

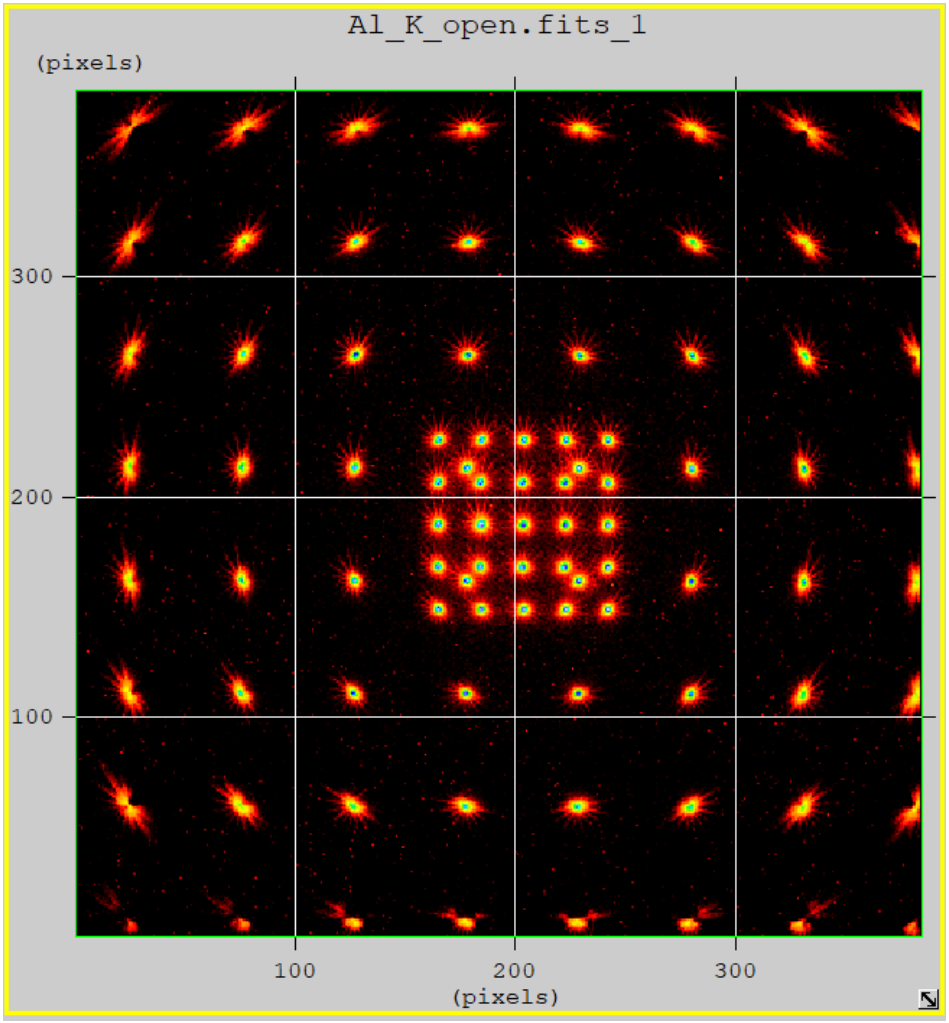
Telescope	Instrument	Directory	Calibration File		Number
$CALDB/EP/	FXT/	index/	1	index file	
		bcf/	2	Teldef	2
			3	Instrument	1
			4	Badpixel	4
			5	E-C	6
			6	frac_grade	2
			7	Effarea	2
			8	QE	6
			9	Ftrans	2
		cpf/	10	ARF	18
			11	RMF	18
			12	PSF	24
			13	Vignetting	4

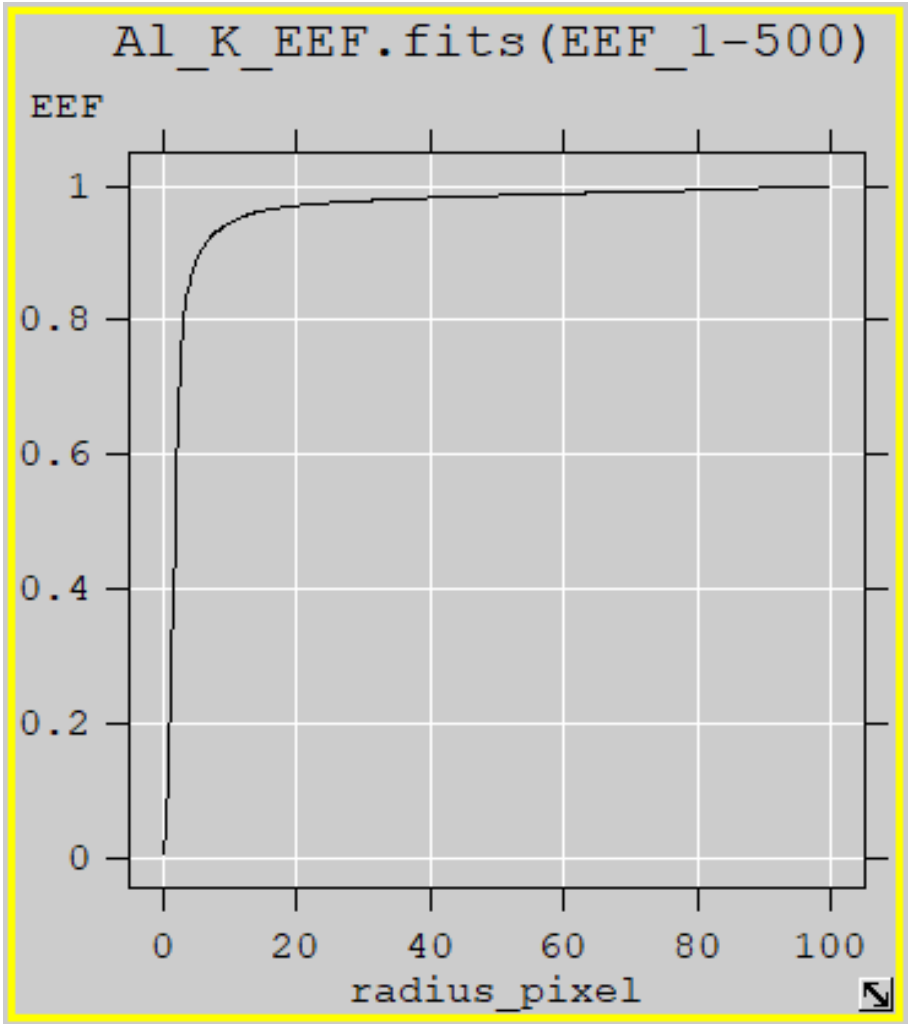
CALDB file system based on HEASARC

In data analysis: fxtpical, fxtexpogen, fxtarfgen, fxtrmfgen

1. CALDB--PSF and EEF

FXT-A Al-K PSF





1. CALDB—GAIN and CTI

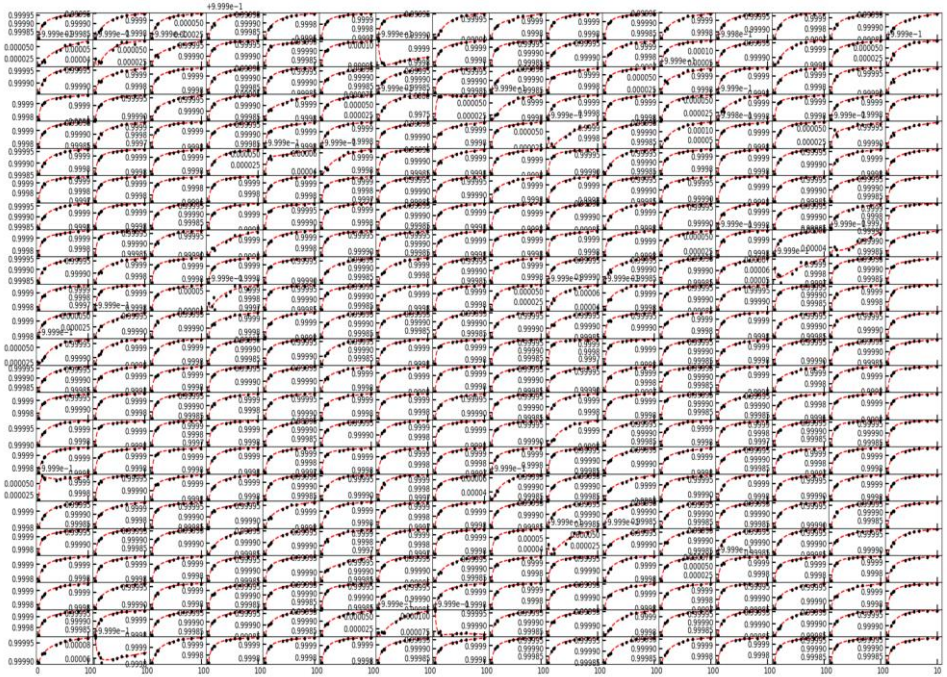
384 Columns

$$\text{GAIN} = A_0 + \text{A}_1\text{LogE} + A_2 LogE^2 + A_3 LogE^3$$

$$\text{CTI} = B_0 + B_1\text{LogE} + B_2 LogE^2 + B_3 LogE^3$$

$$\text{E} = GAIN \times Channel/(1 - CTI)^{RAWY}$$

GAINS



CTE

1. CALDB—GAIN and CTI

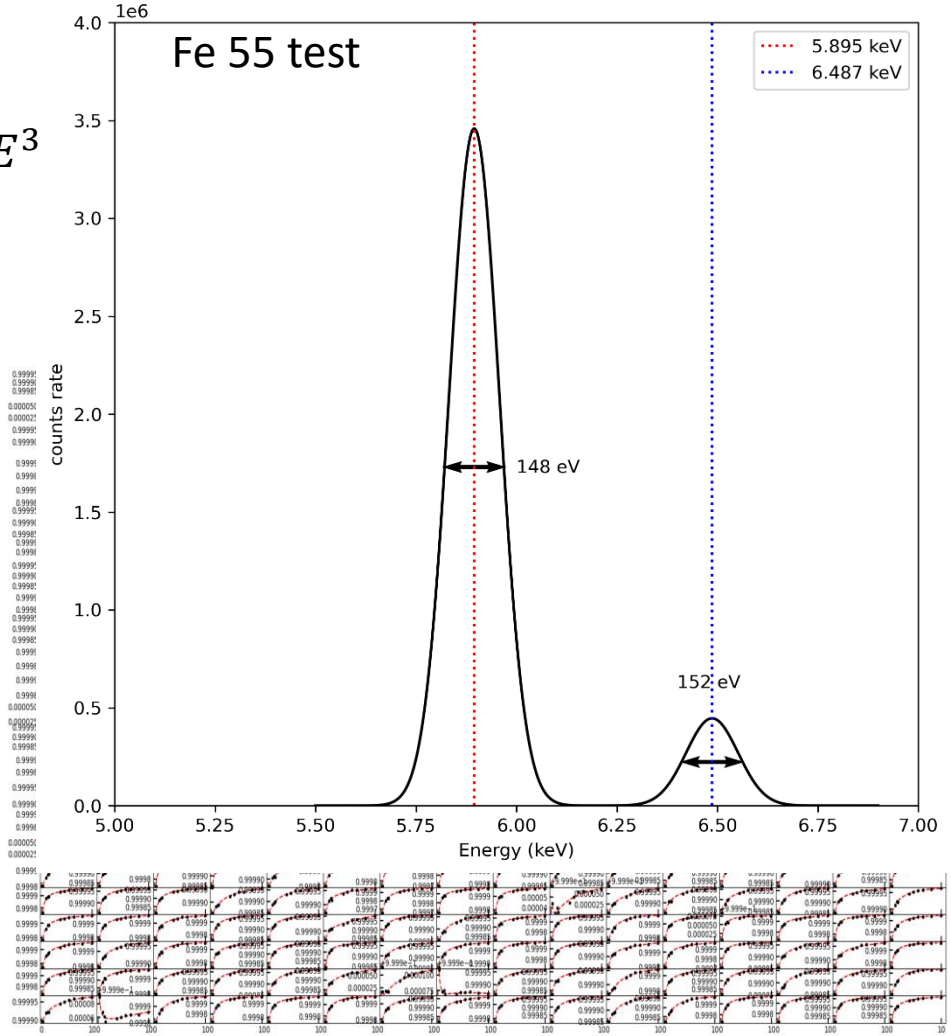
384 Columns

$$\text{GAIN} = A_0 + \text{A}_1\text{LogE} + A_2 LogE^2 + A_3 LogE^3$$

$$\text{CTI} = B_0 + B_1\text{LogE} + B_2 LogE^2 + B_3 LogE^3$$

$$\text{E} = GAIN \times Channel/(1 - CTI)^{RAWY}$$

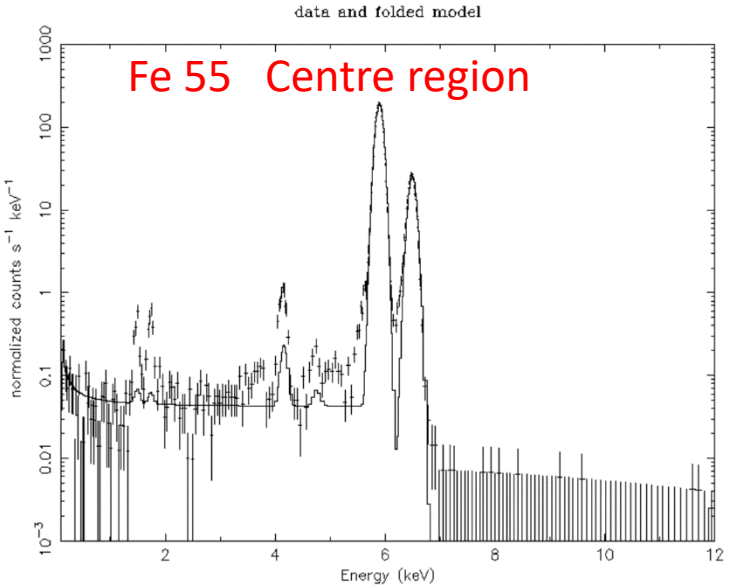
GAINS

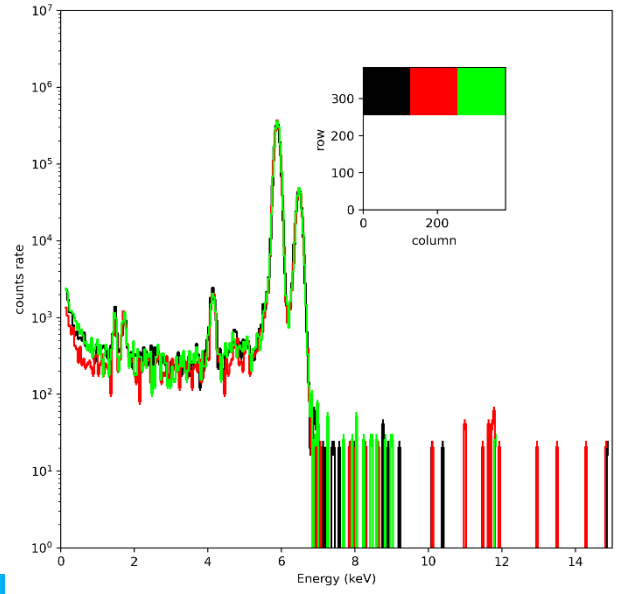


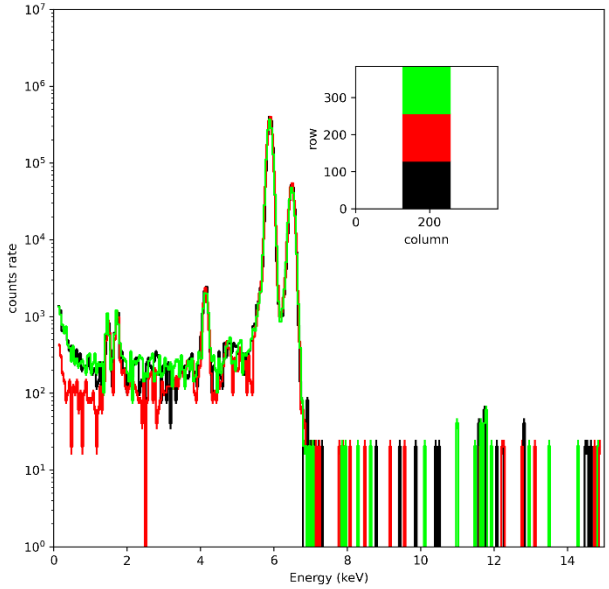
CTE

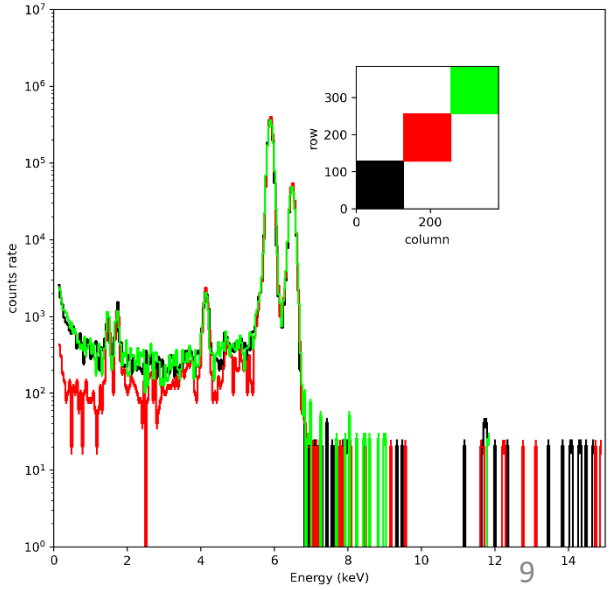
1. CALDB — RMF

- No on-ground calibration yet
- CCD region
- Threshold
- Grade



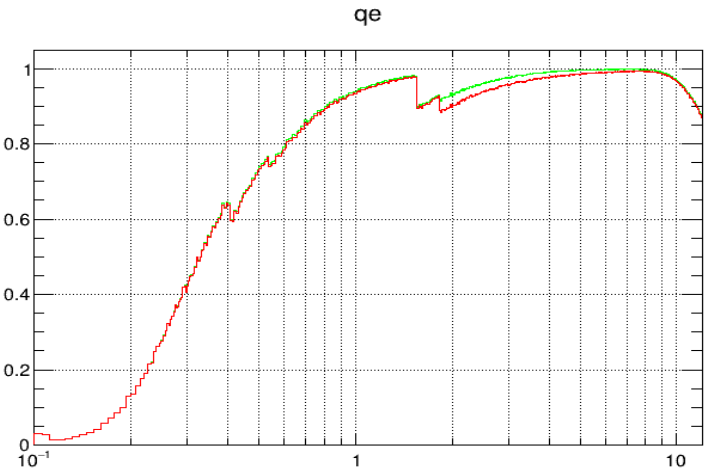


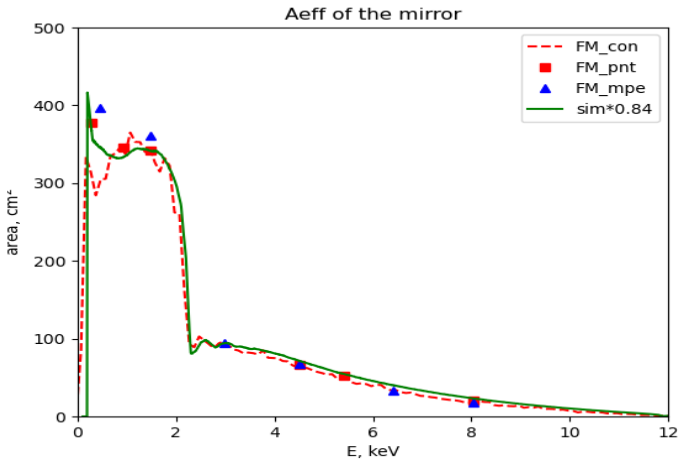


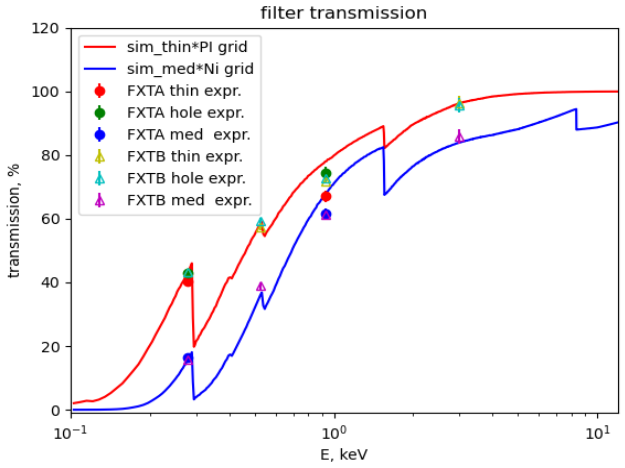


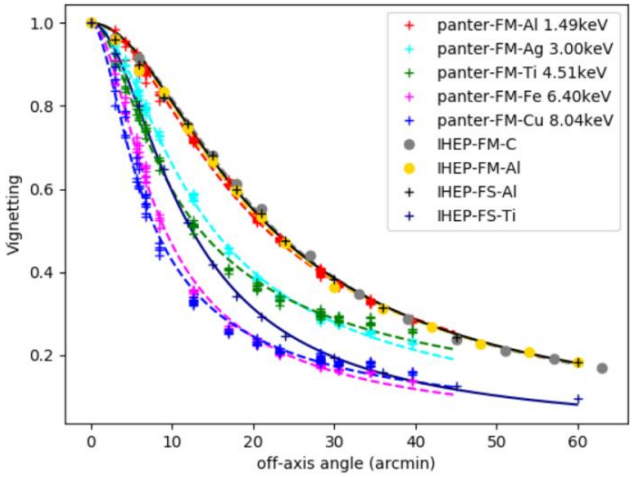
1. CALDB---ARF

- QE
- Filter
- Mirror
- Vignetting
- PSF







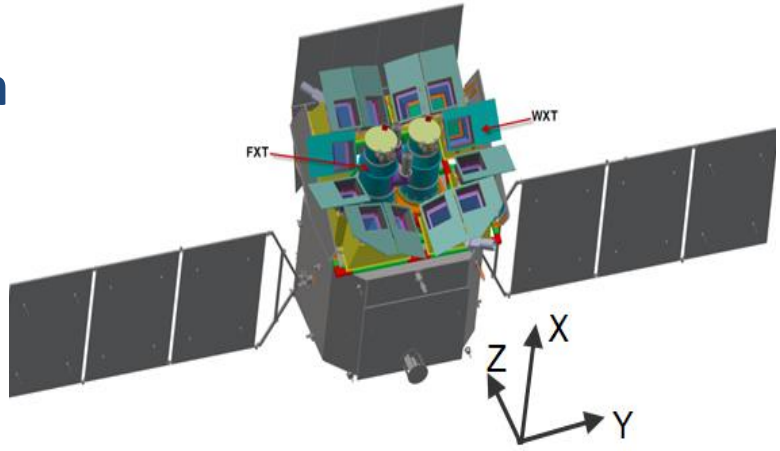


2. Launch Window of EP

- **Launch:** Nov. 5, 2023 at Xichang Satellite Launch Center

  Orbit : circle, 600 km, inclination: 29°

- **Changes of the on-ground calibration**
  - finite source distance
  - radiation damage
  - contamination
  - micrometeoroid impact



- **In-orbit calibration ➔ update FXT-CalDB**

  Internal: Closed & CalClosed, not recommended to use in the early stage of in-orbit

  Targets :
  - Visibility (solar avoidance angle > 90 °)
  - X-ray bright (statistics) but not too bright (pile-up), optical not too bright
  - **Recommended by eROSITA:** Michael Freyberg eRO-MPE-PL-55-01 01

3.1 In-orbit Calibration Phases & Subjects

- **Initial Phase: Critical Operation (Launch T0: ~2 weeks)** — **Spacecraft team**
  - FXT Outgassing
  - Front cover open (Filter: medium)
  - Spacecraft: power/thermal control, communication, attitude control
- **Commissioning Phase: Function Check (~1 week)** — **Payload team**
  - Switch-on of the cameras
  - First Light (Mode: full frame; Filter: medium)
  - Parameter tuning (fine-tuned)
- **Instrument Calibration Phase: (~90 days)** — **Payload team + FXT Data Center**
  - Filter integrity (launch and micrometeorites)
  - Contamination (Soft X-ray and XUV response)
  - X-ray baffle (mosaic)
  - Plate scale and boresight
  - Gain and CTI, RMF
  - Effective area, Vignetting
  - PSF
  - Timing
- **Performance Verification (PV) Phase: (~2 weeks)** — **Payload team + Ground segment + Science team**
  - Spectrum for cross-calibration (Power-law type, galaxy cluster)
  - Simultaneous observations of FXT 2 modules, or with other Satellites
- **Guest Observation Phase: (~4 years)**
  - Monitoring Calibration

Refer to: Michael Freyberg eRO-MPE-PL-55-01 01

3.2 Calibration Targets and Visibility

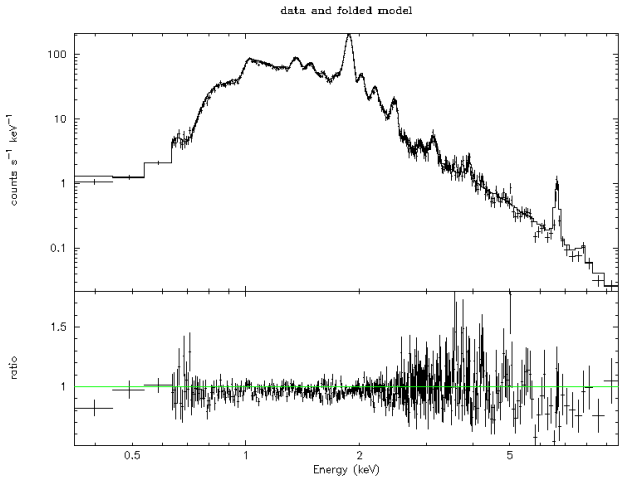
Candidate targets of eROSITA: Michael Freyberg eRO-MPE-PL-55-01 01

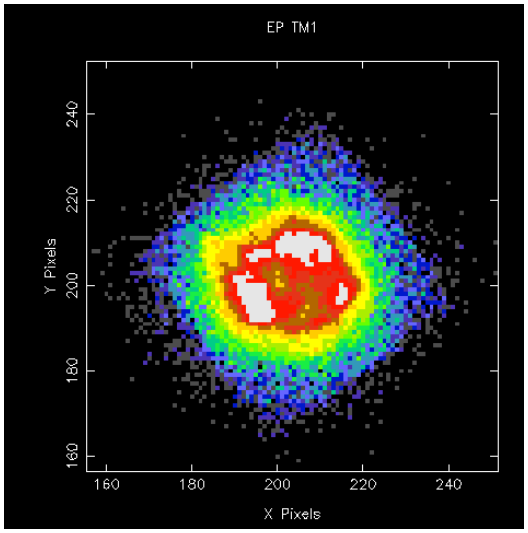
Target	RA(2000)	DEC(2000)	Type	Galon	Galat
Commissioning:					
LMC (30 Dor)	05 38 42.4	-69 01 02	always visible	279.368	-86.827
Plate scale and boresight of the 7 modules:					
Hyades	04 31 60.00	+18 10 00.0	open cluster	178.972	-3.691
Pleiades	03 47 00.00	+24 07 00.0	open cluster	166.572	4.086
NGC 2516	07 58 20.00	-60 52 13.0	open cluster	273.940	-75.890
NGC 6475	17 53 30.00	-34 49 12.0	open cluster	355.802	-11.388
NGC 752	01 57 41.00	+37 47 06.0	open cluster	137.126	24.061
Gain and CTI:					
1ES 0102-72	01 04 02.00	-72 01 55.0	SNR	301.558	-65.036
LHA 120-N 132D	05 25 15.23	-69 38 12.8	SNR	280.295	-85.540
Vela SNR	08 48 45.75	-45 36 51.4	SNR	265.347	-59.522
Puppis A	08 22 00	-42 55 00	SNR		
3C58	02 05 38.00	64 49 26.0	SNR	130.722	47.914
SNR G021.5-00.9	18 33 33.57	-10 34 07.5	SNR/pulsar	21.502	12.625
Filter integrity (launch and micrometeorites):					
omega Cen (NGC 5139)	13 26 47.24	-47 28 46.5	GC d=10' V=3.7	309.103	-35.228
M4 (NGC 6121)	16 23 35.22	-26 31 32.7	GC d=8.5' V=5.6	350.974	-4.869
M22 (NGC 6656)	18 36 23.94	-23 54 17.1	GC d=6.5' V=5.1	9.893	-0.728
47 Tuc (NGC 104)	00 24 05.67	-72 04 52.6	GC d=6' V=4	305.896	-62.353
NGC 6752	19 10 52.11	-59 59 04.4	GC d=3.8' V=5.4	336.494	-37.221
M5 (NGC 5904)	15 18 33.22	+02 04 51.7	GC d=3.5' V=5.7	3.860	19.646
M71 (NGC 6838)	19 53 46.49	+18 46 45.1	GC d=3.3' V=8.2	56.747	38.792
M2 (NGC 7089)	21 33 27.02	-00 49 23.7	GC d=2' V=6.5	55.045	14.509
M15 (NGC 7078)	21 29 58.33	+12 10 01.2	GC d=2' V=6.2	65.014	25.475
NGC 1261	03 12 16.21	-55 12 58.4	GC d=1.4' V=8.3	270.540	-67.273
Soft X-ray response and contamination monitoring:					
1RXS J185635.1-375433	18 56 35.11	-37 54 30.5	INS	358.600	-15.033
1RXS J160518.8+324907	16 05 18.9	+32 49 07	INS	52.877	52.238
1RXS J130848.6+212708	13 08 48.7	+21 27 08	INS	338.748	26.426
1RXS J080623.0-412233	08 06 23.0	-41 22 33	INS	257.427	-59.394
1RXS J042003.1-502300	04 20 02.2	-50 22 46	INS	258.136	-69.494
1RXS J214303.7+065419	21 43 03.8	+06 54 20	INS	62.658	19.419
1RXS J072025.1-312554	07 20 24.961	-31 25 50.21	INS:var	244.159	-52.860
XUV response and contamination monitoring:					
HZ 43	13 16 21.853	+29 05 55.38	WD V=12.7	54.108	34.047
GD 153	12 57 02.337	+22 01 56.68	WD V=13.4	317.261	25.785
PG 1658+441	16 59 48.44	+44 01 03.9	WD V=14.6	69.124	66.033
PG 0136+251	01 38 53.02	25 23 22.8	WD V=16	136.246	14.070
CAL 83	05 43 34.5	-68 22 18	XRB	278.564	-87.602
Power-law type spectrum:					
Mkn 421	11 04 27.314	+38 12 31.80	BL Lac	179.832	29.504
PKS 2155-304	21 58 52.065	-30 13 32.12	BL Lac	17.731	-16.771
MS0737.9+7441	07 44 05.1	+74 33 59	BL Lac	140.266	52.117
MS0317.0+1834	03 19 51.789	+18 45 33.84	BL Lac	165.108	0.382
MS0419.3+1943	04 22 18.0	+19 50 54	BL Lac	176.028	-1.670
PKS 0558-504	05 59 47.4	-50 26 51	Sy1	257.963	-73.887
Mkn 3	06 15 36.458	+71 02 15.24	Sy2	143.297	47.624
Effective area and vignetting:					
1ES 0102-72	01 04 02.00	-72 01 55.0	SNR	301.558	-65.036
LHA 120-N 132D	05 25 15.23	-69 38 12.8	SNR	280.295	-85.540
Vela SNR	08 48 45.75	-45 36 51.4	SNR	265.347	-59.522
Puppis A	08 22 00	-42 55 00	SNR		
3C58	02 05 38.00	64 49 26.0	SNR	130.722	47.914
SNR G021.5-00.9	18 33 33.57	-10 34 07.5	SNR/pulsar	21.502	12.625
4U 1722-30	17 27 33.2	-30 48 07	LMXB in GC	356.321	-7.560
Flatfield and vignetting:					
A1795	13 49 00.5	+26 35 07	ClG:clu	33.790	34.994
A2029	15 10 58.7	+05 45 42	ClG:clu	6.506	22.646
A2256	17 03 43.5	+78 43 05	ClG:lar	111.097	77.224
A754	09 08 50.1	-09 38 12	ClG:lar	239.253	-24.834
A2142	15 58 20.00	+27 14 00.3	ClG:lar	44.232	46.457
A3571	13 47 28.9	-32 51 57	ClG:clu	316.318	-20.297
A2052	15 16 45.5	+07 00 01	ClG:clu	9.395	24.245
A2199	16 28 37.0	+39 31 28	ClG:clu	62.898	60.072
A262	01 52 50.4	+36 08 46	ClG:clu		
A3112	03 17 52.4	-44 14 35	ClG:clu	252.953	-58.950
A85	00 41 37.8	-09 20 33	ClG:clu	115.054	-12.700
A780 (Hydra A Cluster)	09 18 10	-12 05 00	ClG:clu	243.138	-26.529
MKW 3s	15 21 50.7	+07 42 18	ClG:clu	11.392	25.278
A2204	16 32 45.7	+05 34 43	ClG:clu	21.091	27.177
A1835	14 01 02.07	+02 52 43.2	ClG:clu	340.386	14.257
A496	04 33 35.00	-13 14 46.0	ClG:clu	209.564	-34.766
A1060	10 36 51.3	-27 31 35	ClG:clu	269.631	-33.312
A3827	22 01 49.1	-59 57 15	ClG:clu	332.227	-44.106
PSF:					
Cen X-3	11 21 15.78	-60 37 22.7	HMXB	292.092	-56.339
Mkn 766	12 18 26.484	+29 48 46.15	Sy1	190.681	28.939
Mkn 205	12 21 44.967	+75 18 37.99	Sy1	125.446	63.773
PKS 0312-770	03 11 55.233	-76 51 50.87	Sy1	293.441	-73.870
3C 273	12 29 06.695	+02 03 08.66	Quasar	289.952	4.774
QSO B0836+71	08 41 24.365	+70 53 42.17	Quasar	143.542	50.150
SMC X-1	01 17 05.146	-73 26 36.03	HMXB	300.416	-66.470
PKS 0558-504	05 59 47.4	-50 26 51	Sy1	257.963	-73.887
PG 1634+706	16 34 28.990	+70 31 32.42	Quasar	102.842	81.295
X-ray baffle (mosaic or mini-survey):					
Sco X-1 (offset)	16 19 55.00	-15 38 24.0	LMXB	359.095	5.725
Crab (offset)	05 34 31.938	+22 00 52.18	Pulsar+SNR	184.558	-1.294
LMC X-2 (offset)	05 20 28.04	-71 57 53.3	LMXB	283.100	-83.579
LMC X-3 (offset)	05 38 56.299	-64 05 03.00	HMXB	273.577	-86.691
Masked mode:					
GX 13+1	18 14 31.55	-17 09 26.7	LMXB	13.517	6.238
GX 17+2	18 16 01.389	-14 02 10.62	LMXB	16.433	9.348
Timing:					
PSR B0540-69	05 40 11.221	-69 19 54.98	50ms	279.718	-86.665
PSR B1929+10	19 32 13.950	+10 59 32.42	226ms	47.383	32.291
PSR J1210-5226	12 10 00.91	-52 26 28.4	424ms	296.546	-45.784
Cen X-3	11 21 15.78	-60 37 22.7	4.84s	292.092	-56.339
1E 1048.1-5937	10 50 08.93	-59 53 19.9	6.4s	288.261	-58.601
PSR J1930+1852	19 30 30.13	+18 52 14.1	136ms	54.097	40.104
PSR J1119-6127	11 19 14.30	-61 27 49.5	408ms	292.152	-57.102
Miscellaneous:					
3C 382	18 35 03.390	+32 41 46.86	Sy1	61.306	55.736
Ark 564	22 42 39.309	+29 43 31.55	Sy1	92.139	34.702
1H 1426+428	14 28 32.600	+42 40 21.08	BL Lac	260.170	-70.866
Performance verification:					
zeta Ori field offset	05 40 45.00	-01 56 30.0		206.451	-25.292
WW Hor	02 36 12.00	-52 19 12.0	CV: AM Her	272.227	-61.559
Tycho	00 25 22.00	+64 08 24.0		120.094	53.750
M31	00 42 43.00	+41 16 12.0	diffuse+point	121.171	33.352
NGC 253	00 47 34.00	-25 17 24.0	soft diffuse	97.435	-27.779
A 189	01 25 25.00	+01 44 28.0		140.105	-6.713
Virgo M87	12 30 50.00	+12 23 24.0		283.789	14.417
Coma Cluster	12 59 46.7	+27 57 00		57.378	31.375
Perseus Cluster	03 19 47.2	+41 30 47		150.573	22.340
Cygnus Loop SW	20 49 00	+30 15 00		73.381	45.771
Galactic Center Sgr A*	17 45 40.041	-29 00 28.12		359.945	-5.608

3.2 Calibration Targets and Visibility

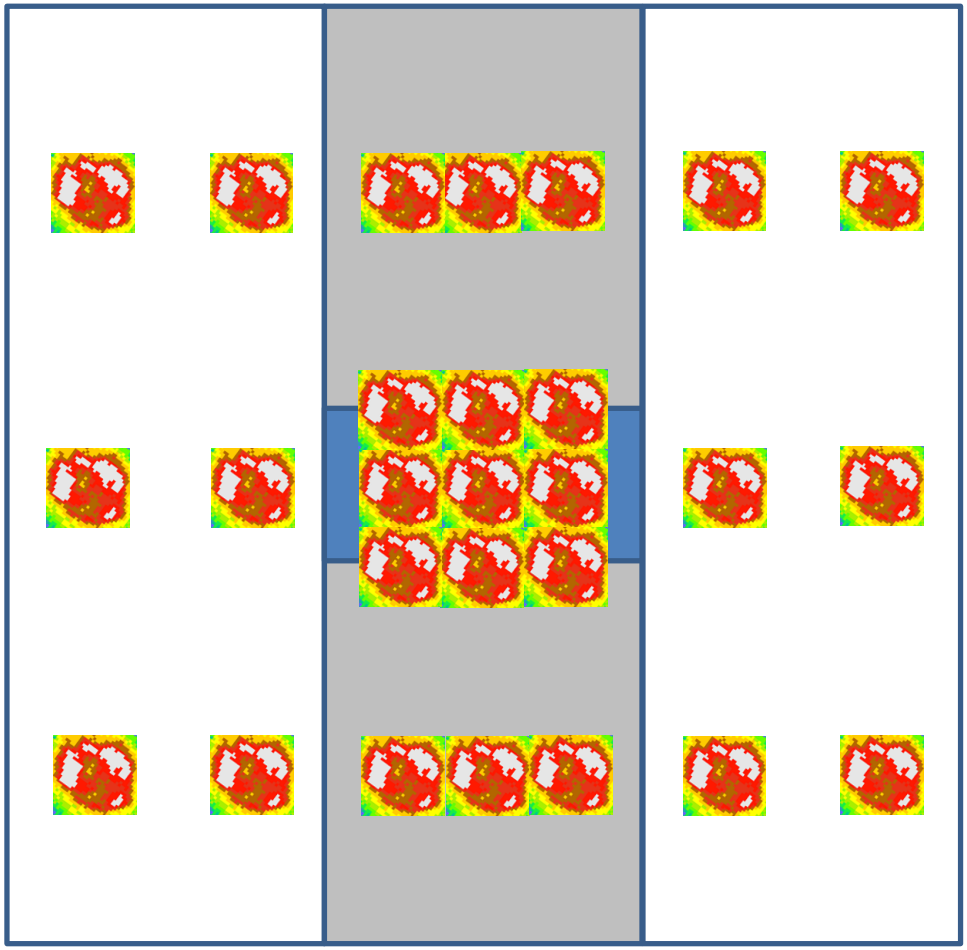
	Calibration subjects		Type	Target	Visibility
1	**Commissioning**	first light	~Cluster of galaxies	PKS 0745-191 ★	
2	**Plate scale and boresight**		open cluster	NGC 752	0805-0130
				Pleiades	0824-0219
				Hyades	**0902-0227**
3	**Gain and CTI**		SNR	**Cas A**	**0721-0118**
				3C 58	0822-0216
				Puppis A	1121-0519
				Vela SNR	**1127-0524**
				A1795	0106-0706
4	**Filter integrity**	bright diffuse optical source	GC	**NGC 1261**	**0702-1230**
5	**Contamination**	soft X-ray response	INS	1RXS J042003.1-502300	0803-0130
				1RXS J072025.1-312554	**1024-0419**
				1RXS J080623.0-412233	1114-0530
		XUV response	WD	PG 0136+251	0726-0122
				GD153	1227-0625
				HZ 43	1228-0626
6	**Effective area and vignetting**		SNR	**3C 58**	**0822-0216**
				Vela SNR	1127-0524
				Puppis A	1121-0519
7	**PSF**	point-like source	Sy1	PKS 0558-504	0924-0321
			Quasar	QSO B0836+71	1014-0409
			Sy1	Mkn 205	1029-0425
			Quasar	**PG 1634+706**	**1118-0508**
			Sy1	Mkn 766	1214-0612
8	**X-ray baffle**		Pulsar+SNR	**Crab**	**0918-0315**
			HMXB	LMC X-3	0810-0120
9	**Timing**		8.7 s	**4U 0142+61**	**0815-0211**
			33 ms	Crab	0918-0315
			6.4 s	1E 1048.1-5937	0115-0715
			4.84 s	Cen X-3	0121-0721
			408 ms	**PSR J1119-6127**	**0122-0722**
10	**Performance verification**	FXT 2 modules X-ray satellite	Power-law type		
			Custer of Galaxies		

CTI: Cas A + Vela SNR



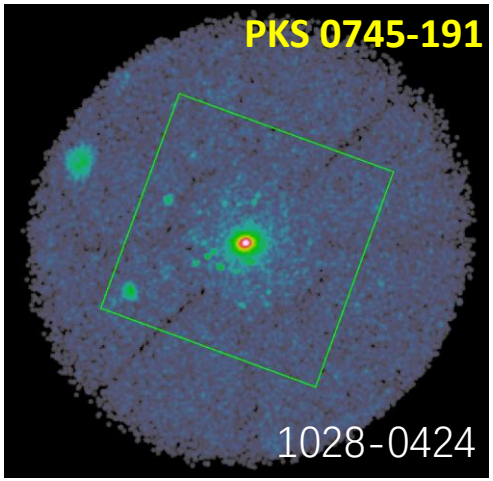


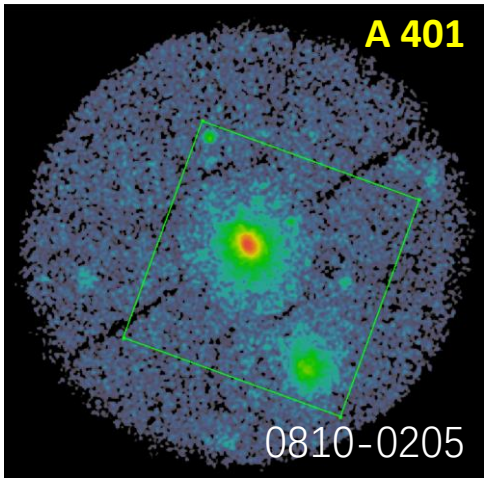
Simulated observation of Cas A by FXT; Obs. Time=1500s



3.3 “Commissioning Light” candidates

Preferred target (Cluster of Galaxies): PKS 0745-191





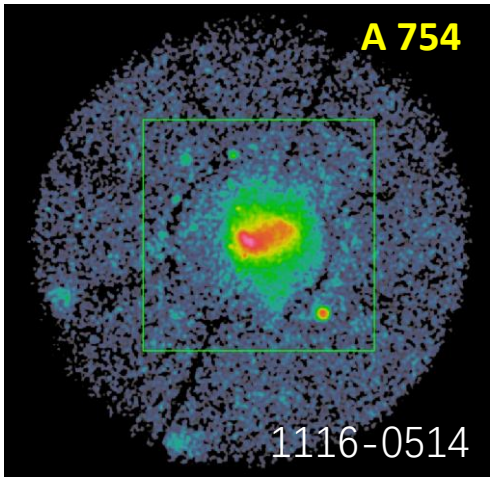


Image: ROSAT survey; Green square: FoV of FXT, 1°*1°

Target	RA	DEC	z	nH(10^20)	flux (10^-11) (0.1-2.4 keV)	Visibility
PKS 0745-191	116.88	-19.29	0.1028	43.49	6.155	1028-0424
A401	44.737	13.573	0.0739	10.6	4.28	0810-0205
A754	137.256	-9.655	0.0542	4.7	6.41	1116-0514

3.4 Preliminary Plan

Target	Calibration issue	Exposure time		
	Launch	T_0: 2023-11-05		
	outgassing	2023-11-06	+14 days	
PKS 0745-191	comissioning	2023-11-20	+7 days	
Preliminary Plan of FXT Instrument Calibration				
Hyades	boresight	T_{start}: 2023-11-27	+2 days	20ks*4
NGC 1261 (d=12.9', m=8.4)	filter integrity	2023-11-29	+2 days	20ks*4po(thin)
		2023-12-01	+2 days	20ks*4po(medium)
		2023-12-03	+2 days	20ks*4po(hole)
4U 0142+61 (P=8.69s)	timing	2023-12-05	+1 days	40ks(ff)
1RXS J072025.1-312554	contamination	2023-12-06	+1 days	50ks
Crab	X-ray baffle	2023-12-07	+2 days	10ks*8po
Vela SNR	Gain, CTI, RMF, ARF (center, thin)	2023-12-09	+1 days	50ks(ff)
Cas A		2023-12-10	+4 days	20ks*9po(ff)
Vela SNR		2023-12-14	+1 days	50ks(pw)
Cas A		2023-12-15	+4 days	20ks*9po(pw)
Vela SNR		2023-12-19	+1 days	50ks(tm)
Cas A		2023-12-20	+4 days	20ks*9po(tm)
PG 1634+706	PSF	2023-12-24	+13 days	50ks*13po(norm)
		2024-01-06	+13 days	50ks*13po(hole)
3C 58	vignetting	2024-01-19	+4 days	50ks*4po(norm)
		2024-01-23	+4 days	50ks*4po(hole)
Mkn 3 (Power law)	ARF	2024-01-27	+1 days	50ks(pw, thin)
		2024-01-28	+1 days	50ks(ff, thin)
		2024-01-29	+1 days	50ks(ff, medium)
		2024-01-30	+1 days	50ks(hole)
EXO 0422-086 (Cluster)	ARF	2024-01-31	+1 days	50ks(pw, thin)
		2024-02-01	+1 days	50ks(ff, thin)
		2024-02-02	+1 days	50ks(ff, medium)
		2024-02-03	+1 days	50ks(ff, hole)
PSR J1119-6127 (P=408 ms)	timing	2024-02-04	+0.5 days	20ks(pw)
		2024-02-04	+0.5 days	20ks(tm)
1RXS J072025.1-312554	contamination	2024-02-05	+1 days	50ks
Vela SNR	Gain, CTI, RMF, ARF (outer, thin)	2024-02-06	+1 days	50ks(ff)
Cas A		2024-02-07	+12 days	20ks*24(ff)
		2024-02-19	+6 days	20ks*12(tm)
Total time	T_{end}: 2024-02-25 90 days			

Instrument Calibration Phase:

(learn from eROSITA Calibration plan)

- **Start :** 2023-11-27
- **Mode:** ff, pw, tm
  Filter : thin, medium
  hole (open)
- **End :** 2024-02-25
- **Total :** 90 days
- **Next :** optimize FXT calibration plan to meet EP project

Monitoring (EP lifetime)		
1E 0102-72	0323-0923	Gain, CTI, RMF, ARF
Vela SNR	1127-0524	
Cas A	0721-0118	
1RXS J072025.1-312554	1024-0419	Contamination
RX J1856.5-3754	0402-1004	

Thank you!