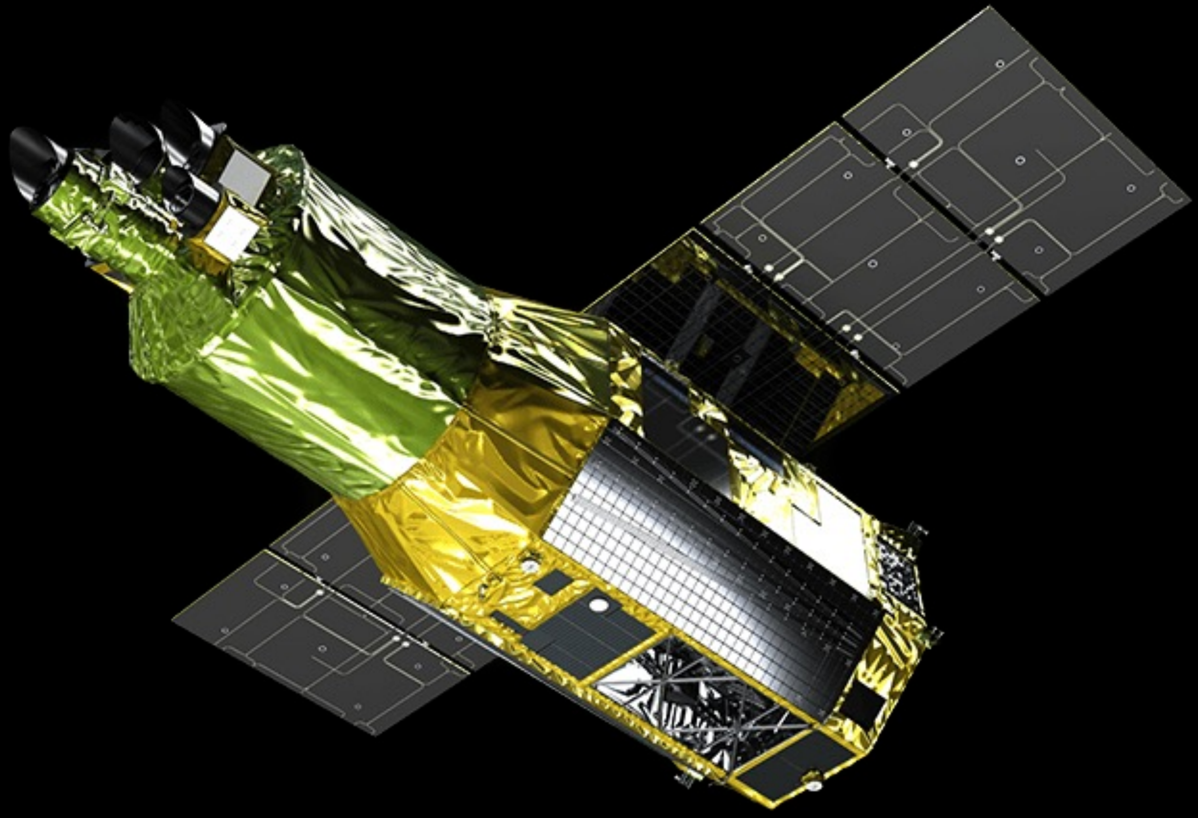
Planning in-flight calibration for XRISM



Eric D. Miller (MIT) for the XRISM Team

IACHEC CoObs WG, 10 February 2023

XRISM IFCP Team

XRISM X-Ray Imaging and Spectroscopy Mission

Chair	Eric Miller *
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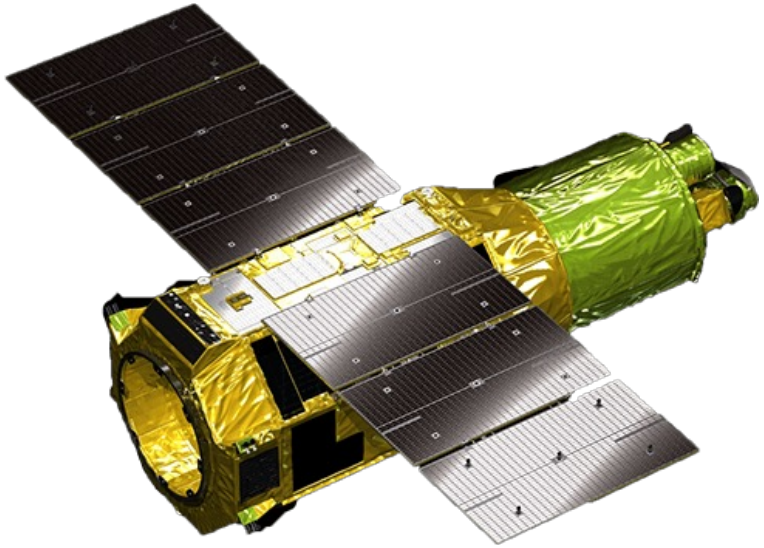
* IFCP sub-group lead.

Mission

- XRISM is led by JAXA, with contributions from NASA and ESA
- 3-year nominal mission + cryogen-free mode
- Low Earth orbit, i = 31°
- Launch in ~ May 2023
  - 0–3 months: initial phase (commissioning)
  - 3–9 months: calibration + PV phase
  - 9+ months: GO phase



Instrument	FOV	PSF (HPD)	ΔE (FWHM @6 keV)	Energy band
Resolve	3′ × 3′ (6 × 6 pixels)	<1.7′	7 eV (goal 5 eV)	0.3–12 keV
Xtend	38′ × 38′	<1.7′	< 250 eV at EOL (< 200 eV at BOL)	0.4–13 keV

Resolve performance requirements

XRISM X-Ray Imaging and Spectroscopy Mission

Parameter	Requirement	Hitomi Values
Energy resolution	7 eV (FWHM)	5.0 eV
Energy scale accuracy	± 2 eV	± 0.5 eV
Residual Background	2×10^{-3} counts/s/keV	0.8×10^{-3} counts/s/keV
Field of view	2.9 x 2.9 arcmin	same, by design
Angular resolution	1.7 arcmin (HPD)	1.2 arcmin
Effective area (1 keV)	> 160 cm^2	250 cm^2
Effective area (6 keV)	> 210 cm^2	312 cm^2
Cryogen-mode Lifetime	3 years	4.2 years (projected)
Operational Efficiency	> 90%	> 98%

XRISM calibration requirements

Requirement	Resolve	Xtend
Energy scale	2 eV for each pixel [1 eV (0.05–12 keV), 3 eV (12–25 keV)]	5% (1 keV) 0.3% (6 keV)
Energy resolution (FWHM)	1 [0.5] eV for each pixel[b] [2 eV (12–25 keV)]	10% (1 keV)[c] 5% (6 keV)[c]
Abs. eff. area on-axis[d]	10% [5%]	10% [5%]
Abs. eff. area off-axis[d]	10% [5%] within $5'$	15% [10%] within $10'$
Rel. eff. area on-axis[d]	5% [3%] [5% (12–25 keV)]	5% [2%]
Rel. eff. area $< 2'$ off-axis[d]	5% [3%] [5% (12–25 keV)]	10% [5%]
Rel. eff. area $2'$–$5'$ off-axis[d]	10% [10% (12–25 keV)]	10% [5%]
Rel. eff. area $> 5'$ off-axis[d]	N/A	10% [5%]
Rel. eff. area fine structure[d]	5% in 1 eV bins around C, N, O K edges[e]	15% at Si K edge
PSF on-axis[f]	5% [3% (0.3–25 keV)]	10%
PSF off-axis[g]	5% [5% (12–25 keV)]	[10%]
Absolute timing[h]	1.0 ms	10 ms
Relative timing[h]	0.5 ms	TBD
Aimpoint	Difference in the aimpoint and optical axis known to $30''$	

XRISM calibration requirements (cont'd)

XRISM X-Ray Imaging and Spectroscopy Mission

[a] Unless otherwise noted, requirements are $1\,\sigma$ uncertainties over 0.3–12 keV. Values given in [] are goals.

[b] Knowledge of the Gaussian peak width for hi- and mid-res primary events. Off-peak redistribution components have additional requirements for ground calibration and will be spot-checked if feasible in flight.

[c] Knowledge of the full redistribution width on the on-axis CCD. Off-axis CCDs have no current response calibration requirements.

[d] All effective area requirements apply to all allowed Resolve filter and gate valve combinations. The effective area knowledge in the gate valve closed configuration can be relaxed by 5% precision compared to the requirements in the nominal configuration, and is only applicable to energies above 1.8 keV. The fine structure effective area in these configurations must be calibrated for appropriate K edges (edges of the primary materials and known contaminants) and other known features (e.g., Bragg diffraction features).

[e] Additional requirements apply to ground calibration of filter transmission edges at higher energies. Those shown are relevant to on-orbit monitoring of molecular contamination.

[f] For Resolve, the point spread function (PSF) requirement is defined as the uncertainty in the fraction of photons on each pixel for a source at the aimpoint.

[g] For Resolve, this is defined as the uncertainty in the fraction of photons on each pixel for a source within $2'$ of the aimpoint; or in 3×3 corner pixel groups for a source $2'$–$4'$ off-axis.

[h] Timing requirements are defined for the end-to-end satellite timing system; i.e., values include allocations for both the instrument time tagging uncertainty and the spacecraft time coordinate uncertainty. The uncertainty interval that defines the Xtend absolute timing requirement is TBD.

Timing calibration targets

XRISM X-Ray Imaging and Spectroscopy Mission

M. Sawada

- Timing requirement (1 ms at 1 sigma) is applicable only to events of the H and Mp grades.
- Absolute timing is not strongly required for PV targets, but relative timing is required to be calibrated for extracting appropriate pulse profiles.
- Coordinated observations with NICER
  - T. Enoto and K. Pottschmidt agreed to be PoCs for coordinating XRISM + NICER calibration observations (more later).
  - PoC to collect information on possible limitations on NICER observation conditions.
  - Goal of this coordinated observation is to derive the absolute timing and jitter from the cross-correlation analyses of the light curve and/or pulse profile, using the NICER data as a template.
- Targets
  - PSR B0540 is not suitable as calibration source due to broad pulse peak (M. Sakama report).
  - Reorganized the candidates as one primary (Crab), three secondaries (PSR B1821, J1937, and J0218), and backup (B0540) sources.
  - Since calibration is not time-sensitive, we can wait for the Crab, although early observation of secondary source still under consideration.

On-axis effective area calibration

L. Brenneman

- 3C273, PKS2155, 1ES0033, Mrk 421 and 1ES0229 are all good calibration targets for Resolve; G21.5, 1ES0033 and 1ES0229 are good for Xtend.
  - Would recommend ~50 ks exposures for each to ensure <5% precision across 0.3- 12 keV and in most individual energy bins.
  - Resolve calibration will be challenging for high energies (>8 keV), especially for filters. Very challenging >12 keV for both Resolve and Xtend.
- Care must be taken when evaluating Resolve spectra for very bright sources such as Mrk 421: a significant fraction of events will be graded as low-res and/or secondaries.
  - This seems to impact spectral flux in a uniform way across the bandpass, but not slope.
  - Consequence is that there will be discrepancies between measured flux and input model flux (i.e., accuracy), but precision of flux measurements is still excellent.
    - This will make it challenging to tell whether differences in flux seen on-orbit vs. in our models are attributable to intrinsic changes or instrumentation characteristics (i.e., event grading).
    - Need to consider how to handle event filtering in on-orbit calibration work.
    - Simultaneous observations with other telescopes will help.

Resolve PSF verification

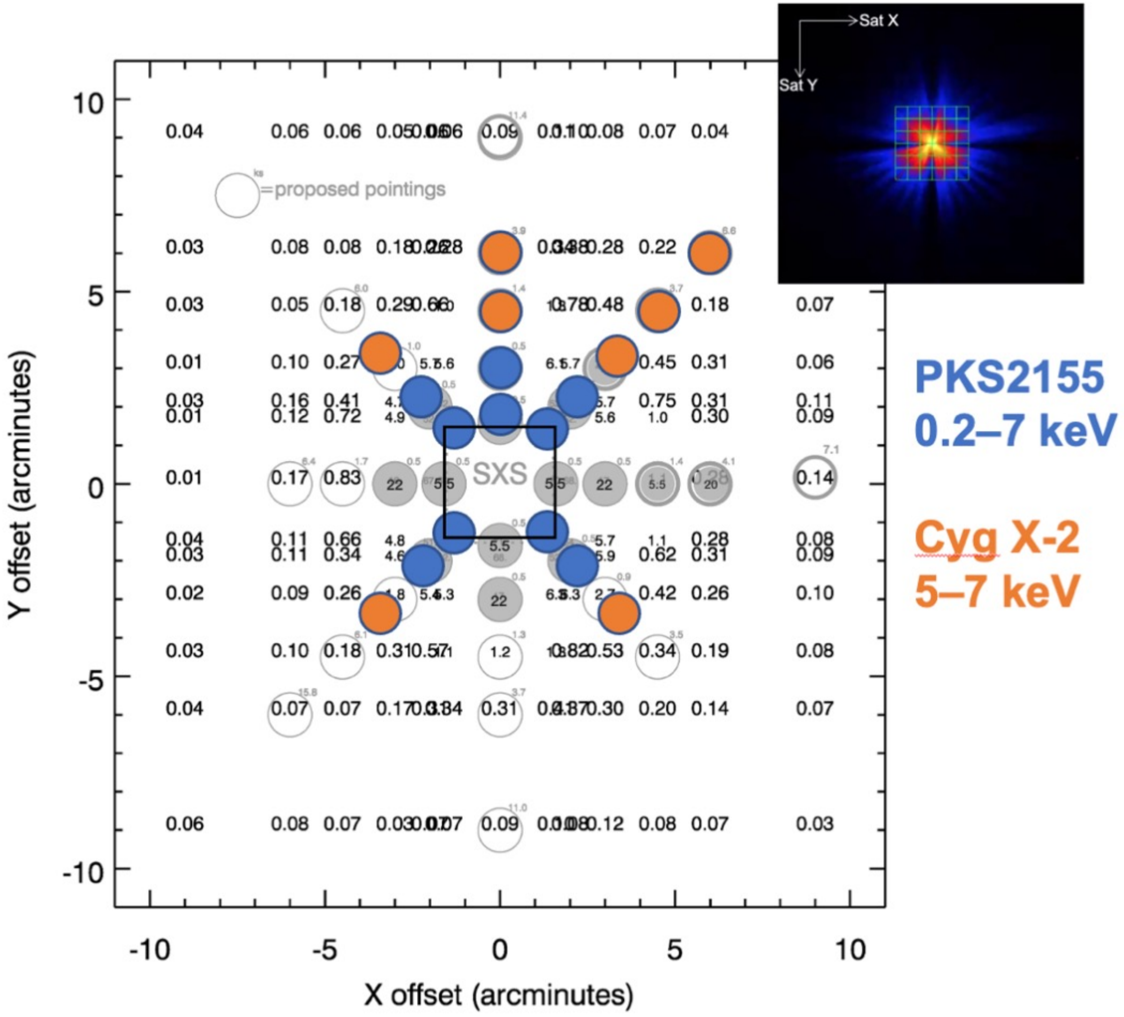


Table 2.4.1: Plan for verifying the Resolve PSF ground calibration in flight.

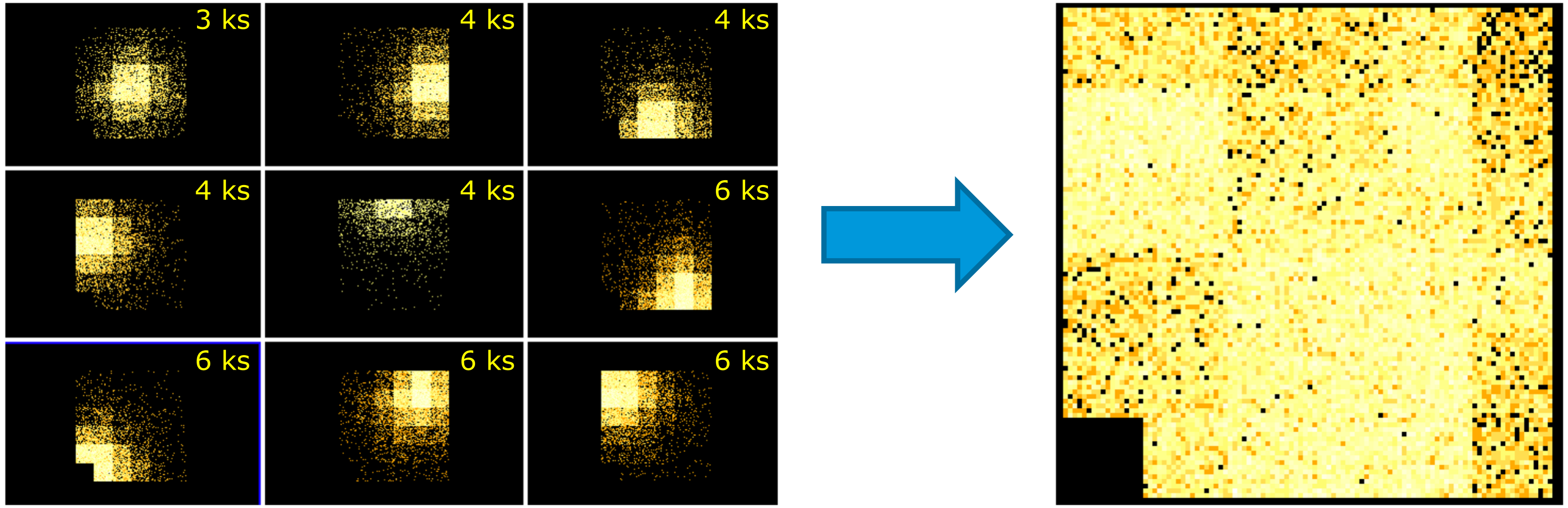
Target	Energy band	Roll angle	Offset (arcmin)	Total t_{exp} (ks)
PKS 2155-304	0.2–7 keV	4 quadrants (x)	1.8, 3	20(?), 32
PKS 2155-304	0.2–7 keV	XMA shadow*	1.8, 3	10(?), 22
Cyg X-2	5–7 keV	4 quadrants (x)	4.5	4
Cyg X-2	5–7 keV	1 quadrant (x)	6, 9	4, 9
Cyg X-2	5–7 keV	XMA shadow*	4.5, 6	2, 5
Total			18 pointings	108

Resolve energy scale and spectral response

XRISM X-Ray Imaging and Spectroscopy Mission

Simulations by M. Guainazzi

- Capella raster scan to uniformly illuminate all Resolve pixels.
- Obtain >1000 counts in two Fe L lines (0.72 and 0.82 keV).
- Two modes (normal/forced mid-res) × three operating temperatures.
- Simultaneous observation? Orbital velocity is well known. Relative X-ray fluxes of the binary stars may be one concern. Don’t need strict GTI overlap.
  - Suggestion for deeper central pointing (~30 ks).
  - Bootstrap/bracket the off-axis raster scan observations with on-axis “truth” observations.
  - Confer with Chandra HETG team, IACHEC high-resolution WG.



Total time allocation 43 ks x 5 = 215 ks (+ on-axis 50 ks)

IFCP Points of Contact (PoC)

XRiSM X-Ray Imaging and Spectroscopy Mission

- Useful to have “informal” discussion with calibration scientists from other missions as we plan coordinated ***calibration*** observations.
- IFCP PoCs will:
  - Communicate with counterpart(s) from designated mission.
  - Discuss operational constraints, calibration requirements and goals, instrument settings, other elements to ensure appropriate data is acquired by each mission.
  - Do *not* make operational or programmatic decisions.
- IFCP PoCs:
  - T. Enoto (NICER)
  - K. Pottschmidt (NuSTAR)
  - M. Guainazzi (XMM)
  - P. Plucinsky (Chandra)
  - TBD (Swift)
  - E. Miller (IACHEC)
- Scheduling PoCs: Chris (XRISM) -> other missions

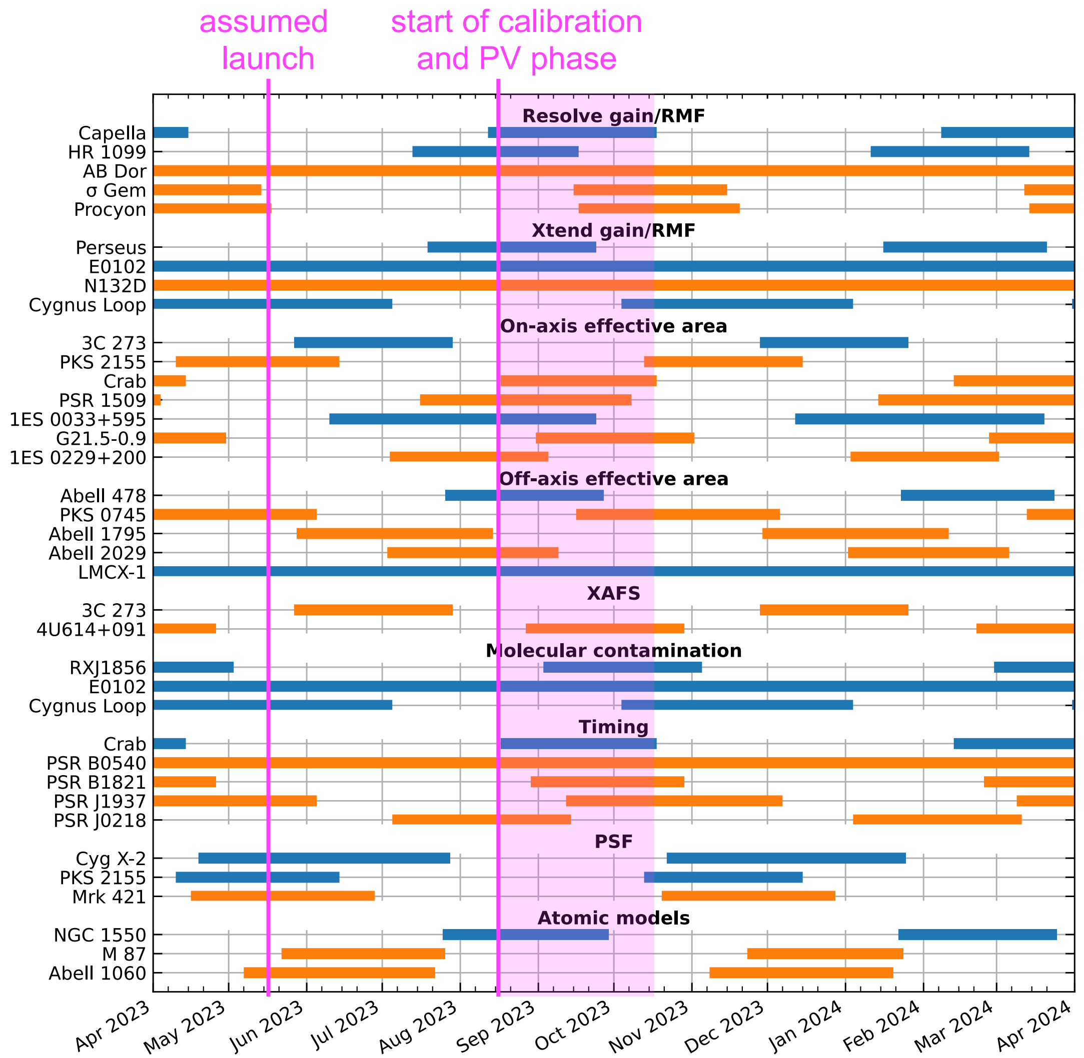
In-flight Calibration Targets

XRiSM X-Ray Imaging and Spectroscopy Mission

Table 3.2.1: Calibration targets listed by calibration element.

Calibration element	Resolve GV closed	Resolve GV open	Xtend
Energy scale (on-axis)	HR1099(50), ABDor(50), CP, FW, MXS	Capella(50), HR1099(50), ABDor(50), Procyon, σGem, CP, FW, MXS	Perseus(2x40=80), Cygnus Loop(2x30=60), 1E0102-72(30), any Resolve source with lines
Energy scale (pixel-to-pixel, off-axis)	CP, FW, MXS	Capella (2x3x40=240), CP, FW, MXS	See Energy scale (on-axis)
Gain (short-term stability)	CP, MXS	CP, MXS	CS
LSF/RMF	See Energy scale (on-axis)	See Energy scale (on-axis)	See Energy scale (on-axis)
Effective area (on-axis) (absolute and relative)	3C273(50), PKS2155-304(50), Crab(10)	3C273(50), PKS2155-304(50), G21.5-0.9(50), 1ES0229+200(TBD), Mrk421, PSR1509-58, Abell clusters, PV	1ES0033+595(75), G21.5-0.9(50), 1ES0229+200(TBD), Abell clusters, PV
Effective area (off-axis)	NA	See PSF (calibrating vignetting x PSF)	Abell 478(40), PKS 0745-191(TBD), Abell 1795(TBD), Abell 2029(TBD)
Effective area (fine structure) (ISM baseline)	NA	3C273(75), 4U0614+091(75)	NA
Contamination (on-axis)	NA	RXJ1856-3754(40), 1E0102-72(30)	RXJ1856-3754(40), 1E0102-72(30)
Contamination (off-axis)	NA	NA	See Energy scale (on-axis) Vela SNR(60)
Timing	NA	Crab(10), PSR0540-69(50), PSRB1821-24(50), PSRJ1937+21(50), PSRJ0218+4232(50) (exposure times for abs, relative requires more time, or MXS; TBD)	Crab(10)
Optical axis	NA	LMCX-1(6x5=30), Capella (See Energy scale off-axis)	See Effective area (off-axis) 1E0102-72(8x3=24), G21.5-0.9(8x7.5=60)
PSF on-axis	NA	Capella, PV targets (See Energy scale off-axis)	PV targets, V1223Sgr
PSF off-axis (wings)	NA	Cyg X-2+PKS2155(200), 3C273, Mrk 421 Total exposure less if first obs. confirm that ground cal. is applicable	Rely on ground cal.
Astrometry	NA	Capella, 1ES0033 (energy scale Resolve raster, Xtend eff. area)	Capella, 1ES0033 (see Xtend eff. area)
Stray light	NA	Crab(45)	Crab(45)
Atomic Models	NA	NGC1550(100), M87(100), Abell 1060(100)	NA

Notes: Exposure times in ks are given in parentheses. Primary targets are shown in blue, secondary targets in orange, and possible alternate targets in black. CP=calibration pixel, FW=filter wheel ^{55}Fe source, MXS=direct Modulated X-ray Source, CS=^{55}Fe calibration source.



In-flight Calibration Targets

XRiSM X-Ray Imaging and Spectroscopy Mission

Table 3.2.2: List of primary calibration targets with total exposure time and observing strategies.

Target name	t_{exp} (ks)	RA	Dec	Purpose	Coo.	Notes
1ES0033+595	75	8.9690	+59.8345	Xtend on-axis Aeff	a	
3c273	150	187.2779	+2.0524	Resolve on-axis Aeff	a	50 ks each with Resolve open filter, Be filter, and ND filter. Xtend operated in 1/8 window or burst mode
Abell 478	40	63.3363	+10.4764	Xtend optical axis	N/A	4 pointings of 10 ks each, separated by 10 arcmin
Capella	50	79.1723	+45.9980	Resolve gain/LSF on-axis	b	
Capella raster	258	79.1723	+45.9980	Resolve gain/LSF pixel-by-pixel	N/A	6x9 pointing raster scan (see Figure 2.2 7); 3 ks on-axis, 4 ks at edges, 6 ks at corners, times 3 temps and 2 modes (Hi-Res and forced Mid-Res)
Crab	10	83.6331	+22.0145	Timing	c	Observed off Resolve field. Xtend in "Crab" mode.
Crab stray light	45	83.6331	+22.0145	Stray light	N/A	Observe at 1° offset [TBD]
Cygnus Loop	60	313.9091	+31.0038	Xtend gain/LSF	N/A	30 ks full window, 30 ks 1/8 window; roll constraints TBD
Cyg X-2	24	326.1715	+38.3214	Resolve off-axis PSF	d	Xtend operated in 1/8 window or burst mode
E0102	60	16.0050	-72.0312	Xtend energy scale, Resolve and Xtend contamination monitoring	N/A	One 30-ks observation soon after GV and Xtend door open, then another 30-ks observation one month later.
HR 1099	50	54.1970	+0.5878	Resolve gain/LSF on-axis	b	
LMCX-1	30	84.9118	-69.7432	Resolve optical axis	a	6x 5-ks observations w/ target just outside Resolve FOV [Capella may be sufficient]
NGC 1550	100	64.9080	+02.4099	Astrophysical models	N/A	
North Polar Spur	100	X	X	Galactic foreground	N/A	[needs discussion; do we want this, Lockman Hole, or neither?]
Perseus Cluster	80	49.9467	+41.5131	Xtend energy scale	N/A	40 ks full window, 40 ks 1/8 window; roll constraints TBD
PKS2155	84	329.7169	-30.2256	Resolve off-axis PSF	d	Xtend operated in 1/8 window or burst mode
RXJ 1856	40	284.1463	-37.9085	Resolve and Xtend contamination monitoring	N/A	Observe soon after GV and Xtend door open.

Coo. = coordination with other mission required. Key:
a: NuSTAR required; at least one of XMM or Swift or Chandra required. Observations should be overlapping but exact GTI are not required (i.e., we will use the analysis strategy in Madsen et al. 2017[12]
b: Chandra/HETG or XMM/RGS. [TBD if this is required; archival data or short anchor observation may be sufficient]
c: NICER recommended.
d: One of Swift, NICER, or XMM required, with as strict GTI overlap as possible.

Table 3.2.3: Decision tree for selecting a secondary target if the primary is unavailable.

Target name	t_{exp} (ks)	RA	Dec	Purpose	Coo.	Notes
1ES0033+595						
PKS2155-304	50			Xtend on-axis Aeff	a	Xtend: 1/8 window or burst
G21.5-0.9	50				N/A	Xtend: full window
1ES0229+200	TBD				a	Xtend: TBD
3c273						
PKS2155-304	50			Resolve on-axis Aeff	a	Xtend: 1/8 win or burst
G21.5-0.9	50				N/A	Xtend: full window
1ES0229+200	TBD				a	Xtend: TBD
Abell 478						
PKS0745-191	TBD			Xtend optical axis	N/A	
Abell 1795	TBD				N/A	
Abell 2029	TBD				N/A	
Capella						
ABDor	50			Resolve gain/LSF on-axis	b	
Capella raster						
none	. . .			Resolve gain/LSF pixel-by-pixel	N/A	Use FW, indirect MXS
Crab						
PSR0540-69	50			Timing	c	Secondary always visible
Crab stray light						
none	. . .			Stray light	N/A	Observe when visible
Cygnus Loop						
none	. . .			Xtend gain/LSF	N/A	Observe when visible
Cyg X-2						
3C273	TBD			Resolve off-axis PSF	a	Xtend: 1/8 window or burst
Mrk 421	TBD				a	
E0102						
N132D	30			Xtend energy scale, Resolve and Xtend contamination monitoring	N/A	Primary always visible. N132D is an optional calibration target.
HR 1099						
ABDor	50			Resolve gain/LSF on-axis	b	
LMCX-1						
Capella	. . .			Resolve optical axis	a	Capella raster scan can be used instead
NGC 1550						
M87	100			Atomic models	N/A	Can wait until primary is visible.
Abell 1060	100					
North Polar Spur						
none	. . .			Galactic foreground	N/A	Observe when visible
Perseus Cluster						
none	. . .			Xtend energy scale	N/A	Observe when visible
PKS2155						
none	. . .			Resolve off-axis PSF	a	Observe when visible
RXJ 1856						
none	. . .			Resolve and Xtend contamination monitoring	N/A	E0102 can be used, always visible

Coo. = coordination with other mission required. Key:
a: NuSTAR required; at least one of XMM or Swift or Chandra required. Observations should be overlapping but exact GTI are not required (i.e., we will use the analysis strategy in Madsen et al. 2017[12]
b: Chandra/HETG or XMM/RGS. [TBD if this is required; archival data or short anchor observation may be sufficient]
c: NICER recommended.
d: One of Swift, NICER, or XMM required, with as strict GTI overlap as possible.

Draft calibration observing schedule

XRiSM X-Ray Imaging and Spectroscopy Mission

Case study XRISM calibration-and-PV-phase observing schedule, assuming launch in the middle of May 2023. Only calibration targets are shown, Performance Verification (PV) science targets have been redacted. Calibration targets, exposure times, and schedule are unofficial, and only a case study plan. Compiled 2022-10-21.

TARGET	START_DATE	END_DATE	TEXP
E0102 #1	8/12/23 0:00	8/13/23 6:30	30
1ES0033+595	8/13/23 6:41	8/14/23 23:22	75
Capella raster	8/14/23 23:44	8/21/23 3:41	258
Crab	8/21/23 4:00	8/21/23 9:11	10
Abell 478 #1	8/21/23 9:29	8/21/23 14:36	10
Abell 478 #2	8/21/23 14:49	8/21/23 20:00	10
Abell 478 #3	8/21/23 20:13	8/22/23 1:23	10
Abell 478 #4	8/22/23 1:36	8/22/23 6:51	10
HR 1099	8/22/23 7:07	8/23/23 9:43	50
Perseus Cluster	8/23/23 10:05	8/24/23 7:31	40
Perseus Cluster	8/24/23 7:44	8/25/23 6:14	40
NGC 1550	8/25/23 6:36	8/27/23 15:03	100
Capella	8/27/23 15:26	8/28/23 21:18	50
E0102 #2	8/28/23 21:58	8/29/23 14:30	30
Crab stray ligh	8/29/23 15:06	8/30/23 20:32	45
LMCX-1 #1	8/30/23 21:05	8/31/23 0:41	5
LMCX-1 #2	8/31/23 0:54	8/31/23 3:08	5
LMCX-1 #3	8/31/23 3:21	8/31/23 5:28	5
LMCX-1 #4	8/31/23 5:41	8/31/23 7:49	5
LMCX-1 #5	8/31/23 8:02	8/31/23 10:10	5
LMCX-1 #6	8/31/23 10:23	8/31/23 14:22	5
RXJ 1856	9/3/23 2:45	9/4/23 14:39	40
Cygnus Loop Ful	10/8/23 23:35	10/9/23 23:26	30
Cygnus Loop Ful	10/9/23 23:40	10/10/23 17:02	30
PKS2155	10/16/23 13:43	10/18/23 22:23	84
Cyg X-2	10/31/23 10:48	10/31/23 23:42	24
3c273 Open filt	1/18/23 13:52	1/19/23 18:20	50
3c273 Be Filter	1/19/23 18:33	1/20/23 22:54	50