Evaluation of the pointing accuracy of the X-Ray Imaging and Spectroscopy Mission (XRISM) during the first year

(13 May 2025, IACHEC)

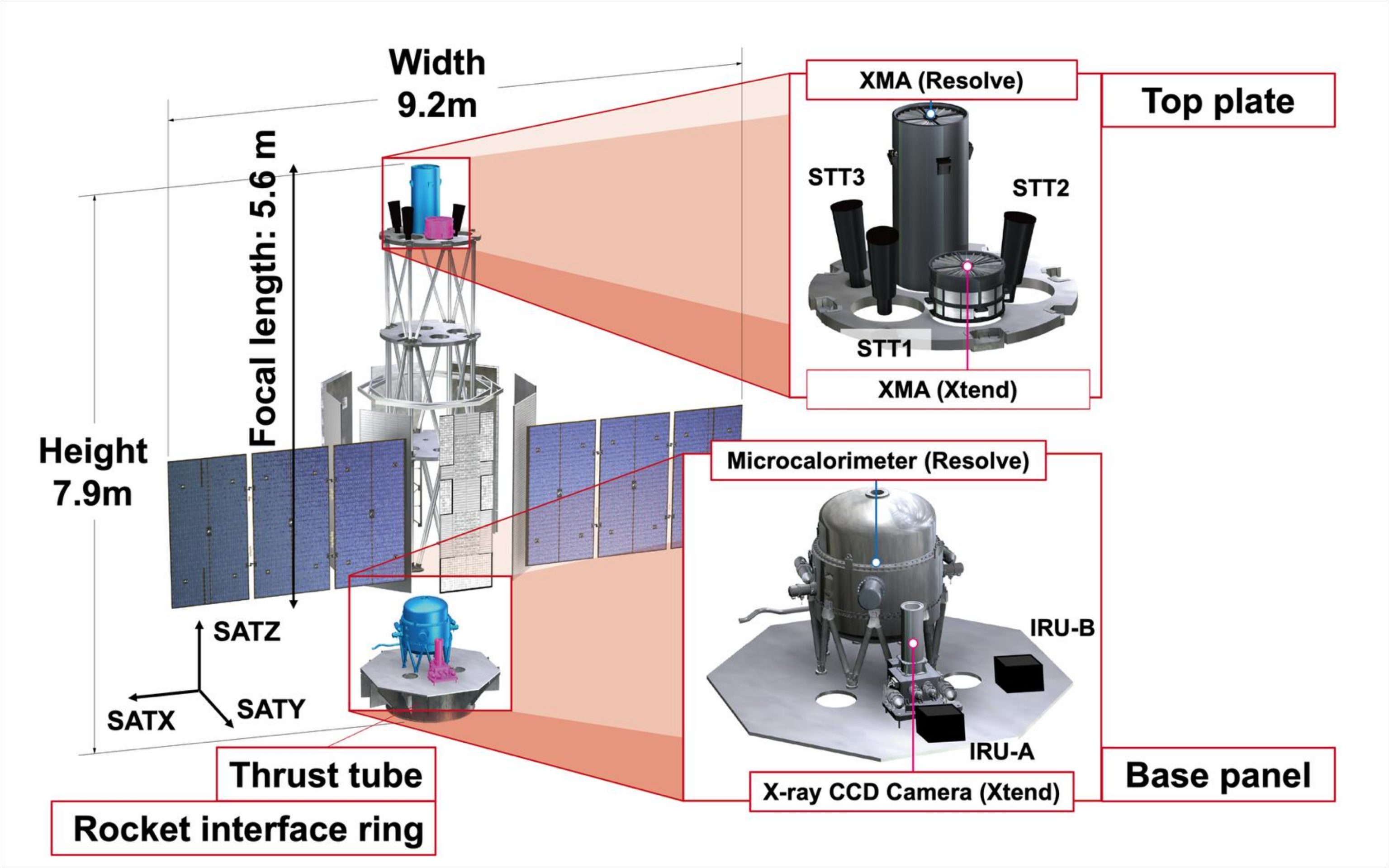
Yoshiaki Kanemaru[1],
Ryo Iizuka[1], Yoshitomo Maeda[1], Kazuhiro Kiyokane[2], Takashi Kominato[2], Yuto Nihei[2],
Chikara Natsukari[1], Shin Watanabe [1], Manabu Ishida [1],
Takashi Okajima [3], Takayuki Hayashi[3], Kosuke Sato[4], Yukikatsu Terada[1, 4],
and SOT members

([1]: ISAS/JAXA, [2] NEC, [3] GSFC/NASA, [4] Saitama University)

Contents

X-Ray Imaging and Spectroscopy Mission

Exploded schematic view of XRISM



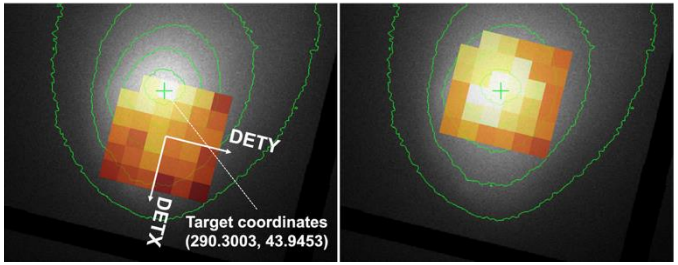
- XRISM carries three star trackers (STTs) on the top panel and two inertial reference units (IRUs) on the base plate. These components are mainly used for pointing determination.
- In the normal mode, the attitude is controlled using two STTs as long as there is no earth occultation blocking their FOV. If this condition isn't met, IRUs take over the attitude control.

Status of pointing accuracy evaluation

2023/9/6
Critical
Commissioning

Aimpoint search Step 1
(2023/10/14)

Alignment matrix update #1
(2023/10/17)



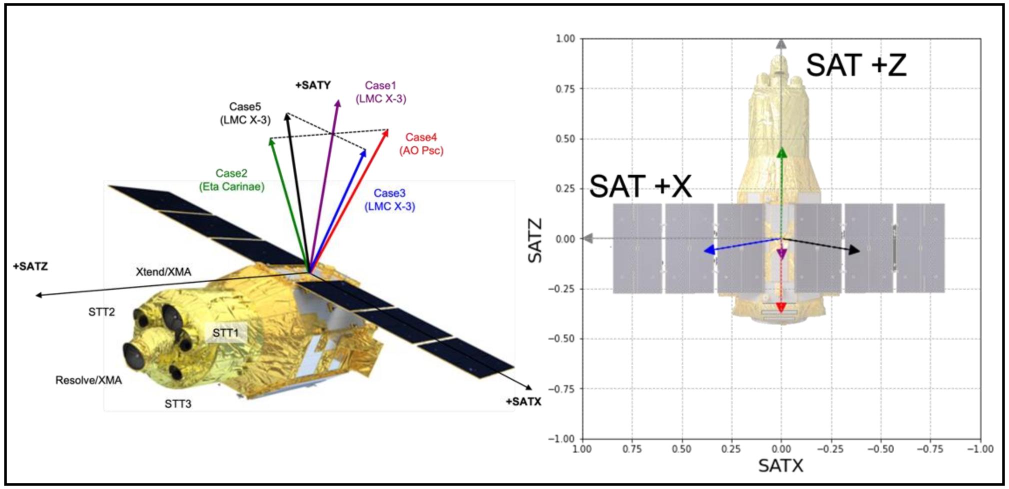
Aimpoint search Step 2
(2023/11/16-18, 21-24)

Alignment matrix update #2
(2023/11/30)

PV Cal
2024/2/8

Verification of pointing requirements

- absolute determination accuracy: 20”
- …



2024/8/31

- **Commissioning phase:**
  - The onboard alignment matrix has been updated.
  - The Xtend nominal aimpoint has been updated as the CALDB parameters.
  - Pointing requirements were met under a conservative evaluation.

- Verification was based on < 1 month of data, mainly observed before the second alignment-matrix update.
  → **Long-term performance was evaluated with the PV data** (> 2 Ms)

Observations

X-Ray Imaging and Spectroscopy Mission

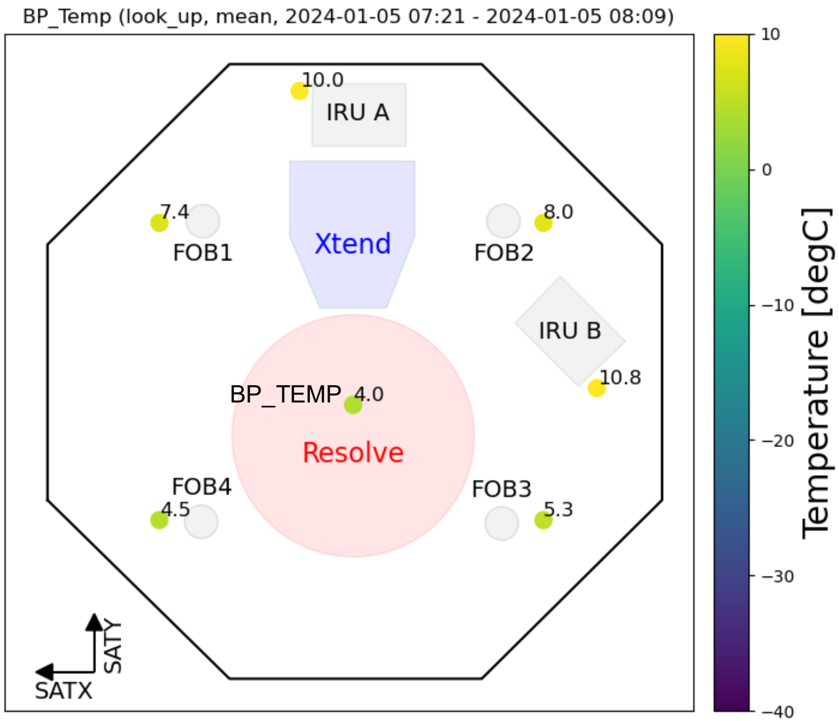
Target	Obs-ID	Nominal attitude (RA, Dec, Roll)	[1]$(\theta_{\rm SunX}, \theta_{\rm SunZ})$	Z-sun angle	Note
Abell2319	000101000	[2](290.2999, 43.9232, 256.2165)	(-6.1, -8.0)	96.1	[3]
Abell2319_Cor1	000102000	[2](290.2972, 43.9447, 256.2140)	(-4.8, 5.2)	94.8	[3](Verification)
Abell2319	000103000	[2](290.2972, 43.9446, 256.2134)	(-3.4, -2.2)	93.4	[3](Verification)
LMC_X-3_Case5	000115000	[2](84.7376, -64.0857, 168.8675)	(-3.5, 20.0)	93.3	[4](Case 5)
AO_Psc	000116000	[2](343.8229, -3.1782, 248.6630)	(-18.7, 0.0)	108.7	[4](Case 4)
LMC_X-3_Case3	000119000	[2](84.7384, -64.0850, 133.4133)	(-3.4, -20.0)	93.2	[4](Case 3)
LMC_X-3_Case1	000120000	[2](84.7380, -64.0853, 154.4243)	(-3.2, -0.0)	93.2	[4](Case 1)
Eta_Carinae	000121000	[2](161.2671, -59.6845, 89.7839)	(23.8, -0.0)	66.2	[4](Case 2)
LMC_X-3_Case1	000124000	(84.7360, -64.0836, 163.2029)	(-3.1, -0.1)	93.1	[4 5] (Verification)
NGC4151	000125000	(182.6349, 39.4065, 121.1046)	(3.1, -0.9)	86.9	[5]
PKS2155-304	000127000	(329.7174, -30.2250, 256.5119)	(23.2, 0.1)	66.8	[5]
NGC4151	000137000	(182.6345, 39.4065, 106.6398)	(-16.6, -0.2)	106.6	[5]
Vela_X-1_1	000139000	(135.5275, -40.5538, 149.4804)	(-20.2, 0.3)	110.2	[5]
Vela_X-1_2	000140000	(135.5274, -40.5540, 151.4797)	(-20.4, 2.0)	110.4	[5]
Vela_X-1_3	000141000	(135.5279, -40.5544, 147.4799)	(-20.6, -2.3)	110.6	[5]
Vela_X-1_4	000142000	(135.5276, -40.5541, 150.4202)	(-20.7, 0.3)	110.7	[5]
Vela_X-1_5	000143000	(135.5276, -40.5541, 152.4203)	(-20.9, 2.0)	110.9	[5]
Vela_X-1_6	000144000	(135.5281, -40.5545, 148.4201)	(-21.1, -2.3)	111.1	[5]
3C273	000145000	(187.2764, 2.0529, 112.4320)	(-10.2, -0.0)	100.2	[5]
MCG-6-30-15	000161000	(203.9737, -34.2951, 118.1216)	(-11.4, 0.1)	101.4	[5]
Cen_X-3	300003010	(170.3127, -60.6239, 156.7998)	(-13.7, 0.3)	103.7	[5]
Circinus_X-1	300028010	(230.1706, -57.1665, 103.9934)	(6.4, 0.2)	83.6	[5]
4U1630-472	900001010	(248.5066, -47.3929, 91.7899)	(15.3, -0.1)	74.7	[5]
GX13+1	300036010	(273.6305, -17.1567, 91.3903)[6]	(27.2, -0.4)	62.8	[5]
Cyg_X-3	300065010	(308.1071, 40.9586, 112.2588)	(26.3, -0.2)	63.7	[5]
4U1624-490	300040010	(247.0120, -49.1981, 126.9970)	(-24.2, 14.1)	113.5	[5]
4U1624-490	300040020	(247.0103, -49.1985, 115.9971)	(-27.9, 0.2)	117.9	[5]
CYGNUS_X-1	300049010	(299.5897, 35.2012, 89.7827)	(13.9, -0.6)	76.1	[5]
4U1916-053	300039010	(289.6984, -5.2380, 79.9732)	(-6.2, -0.1)	96.2	[5]
SS_CYGNI	300042020	(325.6775, 43.5860, 76.8692)	(14.6, -0.3)	75.4	[5]
NGC4151	300047020	(182.6352, 39.4063, 308.8715)	(-12.4, -0.2)	102.4	[5]
SS_CYGNI	300042010	(325.6780, 43.5857, 60.4388)	(2.6, -0.2)	87.4	[5]
NGC4151	300047030	(182.6359, 39.4058, 292.3487)	(9.4, -0.3)	80.6	[5]
NGC4151	300047040	(182.6356, 39.4059, 292.3480)	(14.5, 3.7)	75.5	[5]
NGC3783	300050010	(174.7575, -37.7390, 310.1910)	(14.1, 0.2)	75.9	[5]
GT_MUS	300000010	(174.8730, -65.3978, 331.1673)	(7.5, 0.4)	82.5	[5]

- **Observation used in the analysis**
  - Point sources were observed as on-axis targets.
- Total net exposure:
  - Resolve: ~2.8 Msec
  - Xtend: ~2.5 Msec

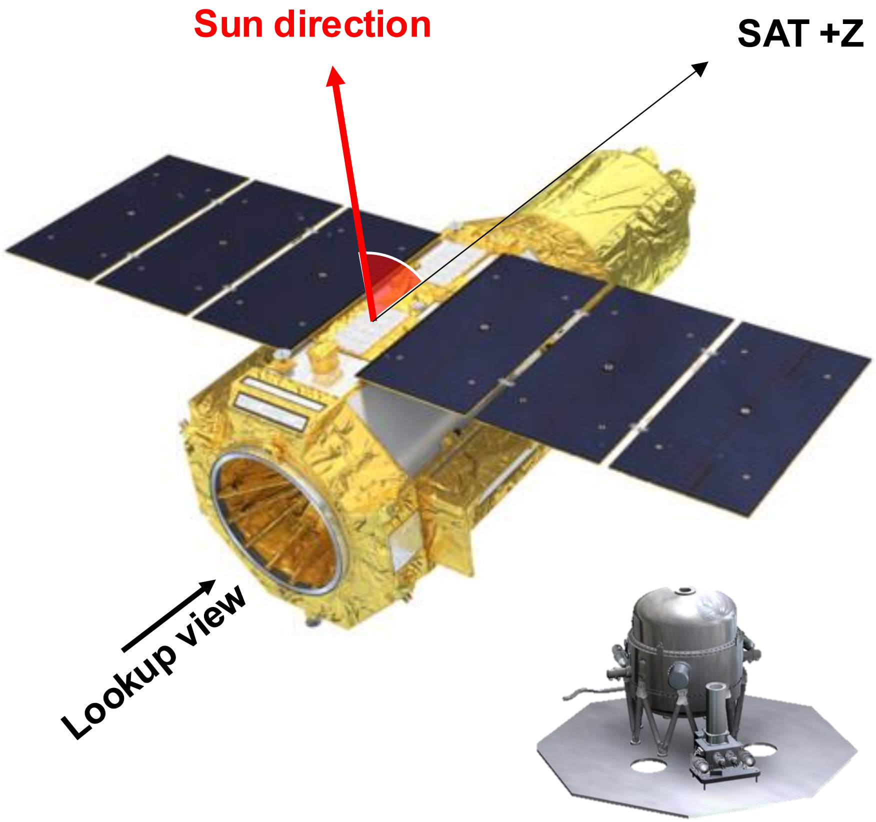
[1] Nominal sun direction expressed by the rotation angles about the SATX and SATZ axes, following the right-hand rule.
[2] Attitude corrected according to the aimpoint search results.
[3] Aimpoint search Step 1 observation.
[4] Aimpoint search Step 2 observation.
[5] Referred to as the one-year data.
[6] Including an offset of about +5 arcseconds in RA, caused by a discrepancy between the direction registered in the AOCS and the actual source position.
8

Aimpoint shift

Z-sun angle and BP temperature

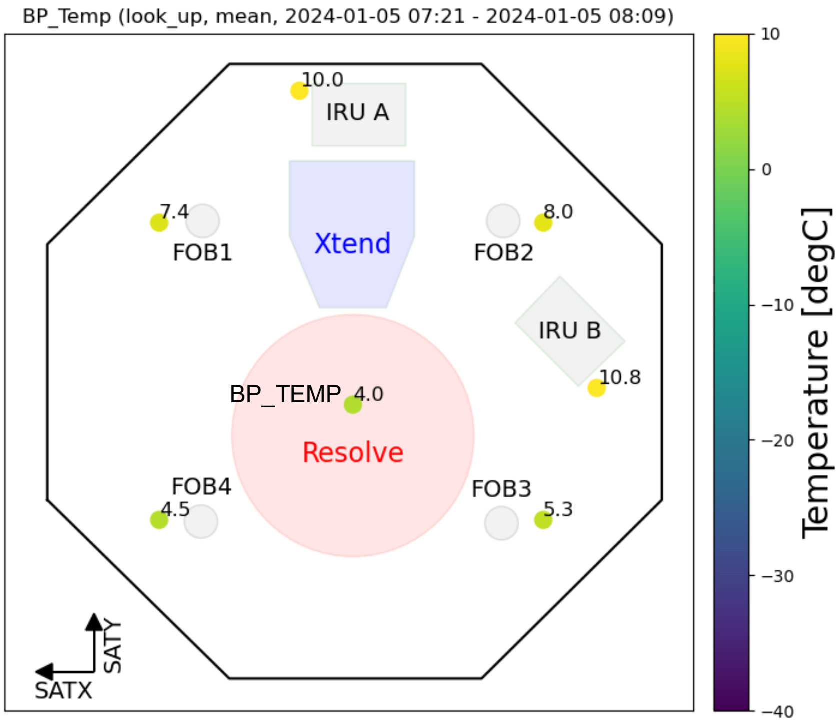


Lookup view of base panel (BP) and temperature measurement point

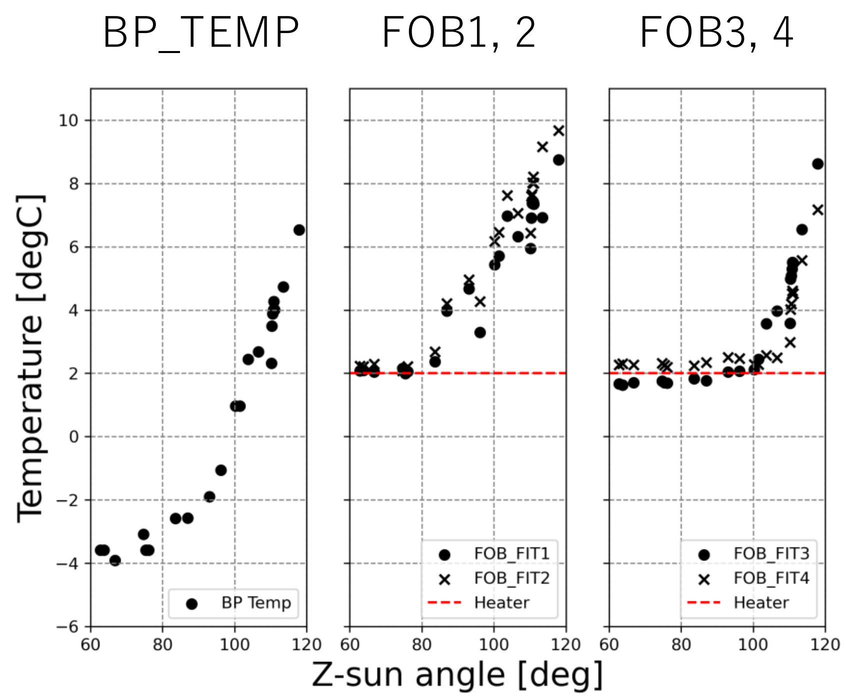


- **Base panel (BP) temperature and its dependence on Z-sun angle**
  - Z-sun angle: angular separation between the spacecraft boresight (SAT +Z) and the Sun direction.
  - Z-sun angle shows a clear correlation with the temperature of the lower spacecraft structure.
  - **BP_TEMP** (temp. sensor at the center of the base panel) is an indicator for the BP temperature.

Z-sun angle and BP temperature



Lookup view of base panel (BP) and temperature measurement point



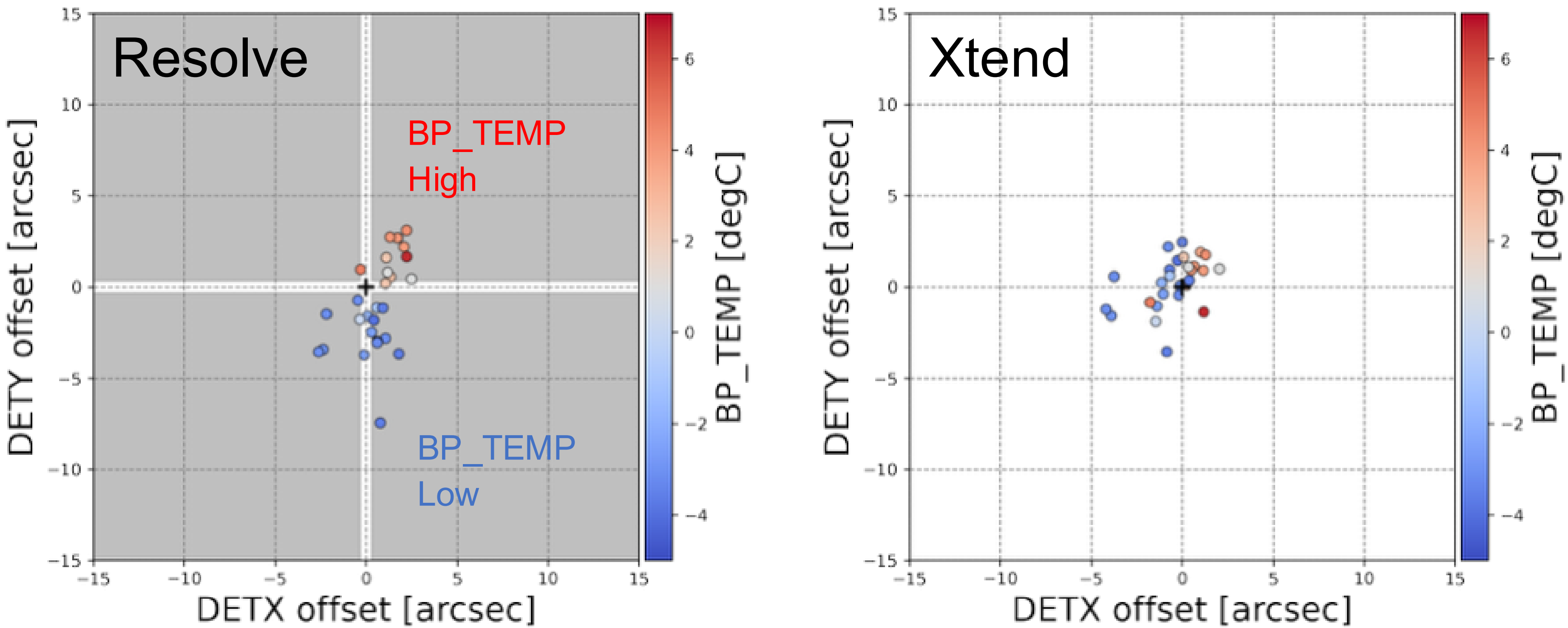
Correlation between temperature measurement points and the Z-sun angle

- **Base panel (BP) temperature and its dependence on Z-sun angle**
  - Z-sun angle: angular separation between the spacecraft boresight (SAT +Z) and the Sun direction.
  - Z-sun angle shows a clear correlation with the temperature of the lower spacecraft structure.
  - **BP_TEMP** (temp. sensor at the center of the base panel) is an indicator for the BP temperature.

Observational aimpoints

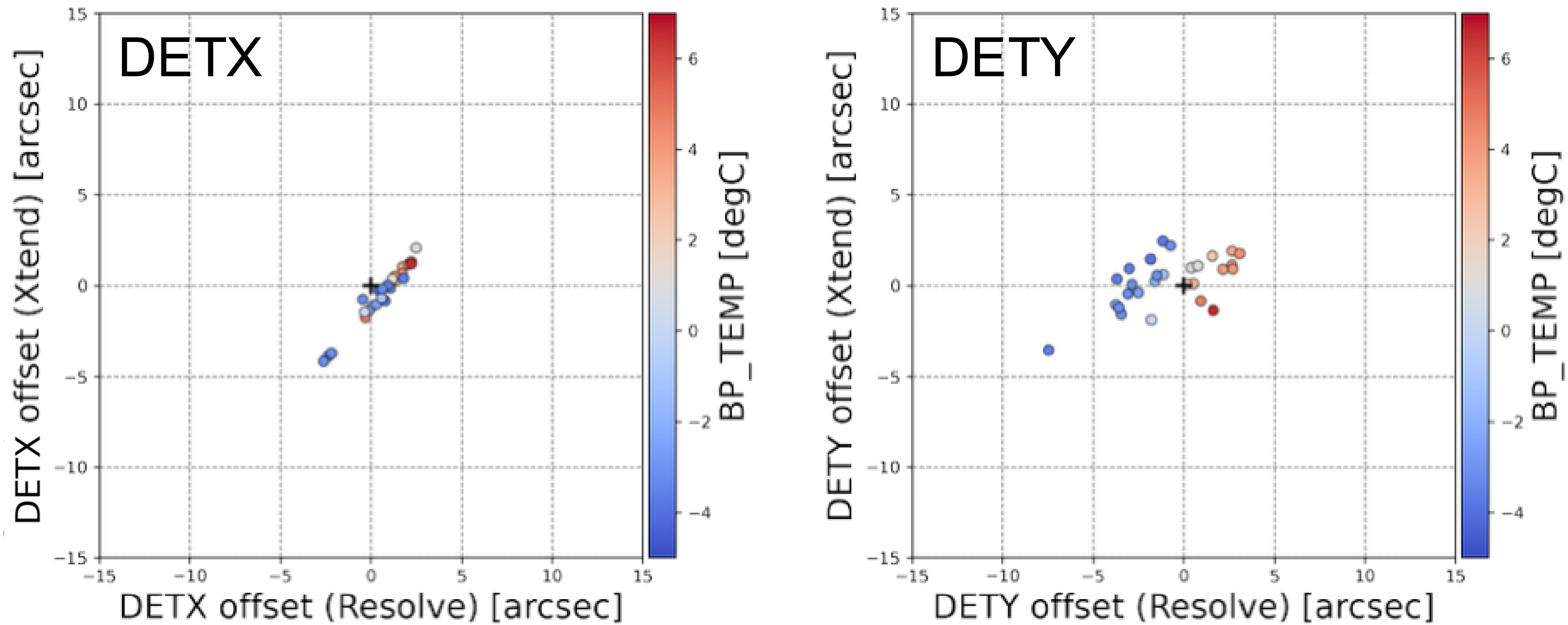
XRISM X-Ray Imaging and Spectroscopy Mission

Observational aimpoints from each observation



- **Observational aimpoints derived from on-axis point-source observations**
  - For both Resolve and Xtend, the aimpoints scatter around the nominal aimpoint.
    - No irreversible significant shift has been observed, including during the gate-valve opening operation.
    - The nominal aimpoints and alignment matrices remain appropriate.
  - The aimpoints of Resolve show a correlation with the BP_TEMP.

Correlations of aimpoints for Resolve and Xtend



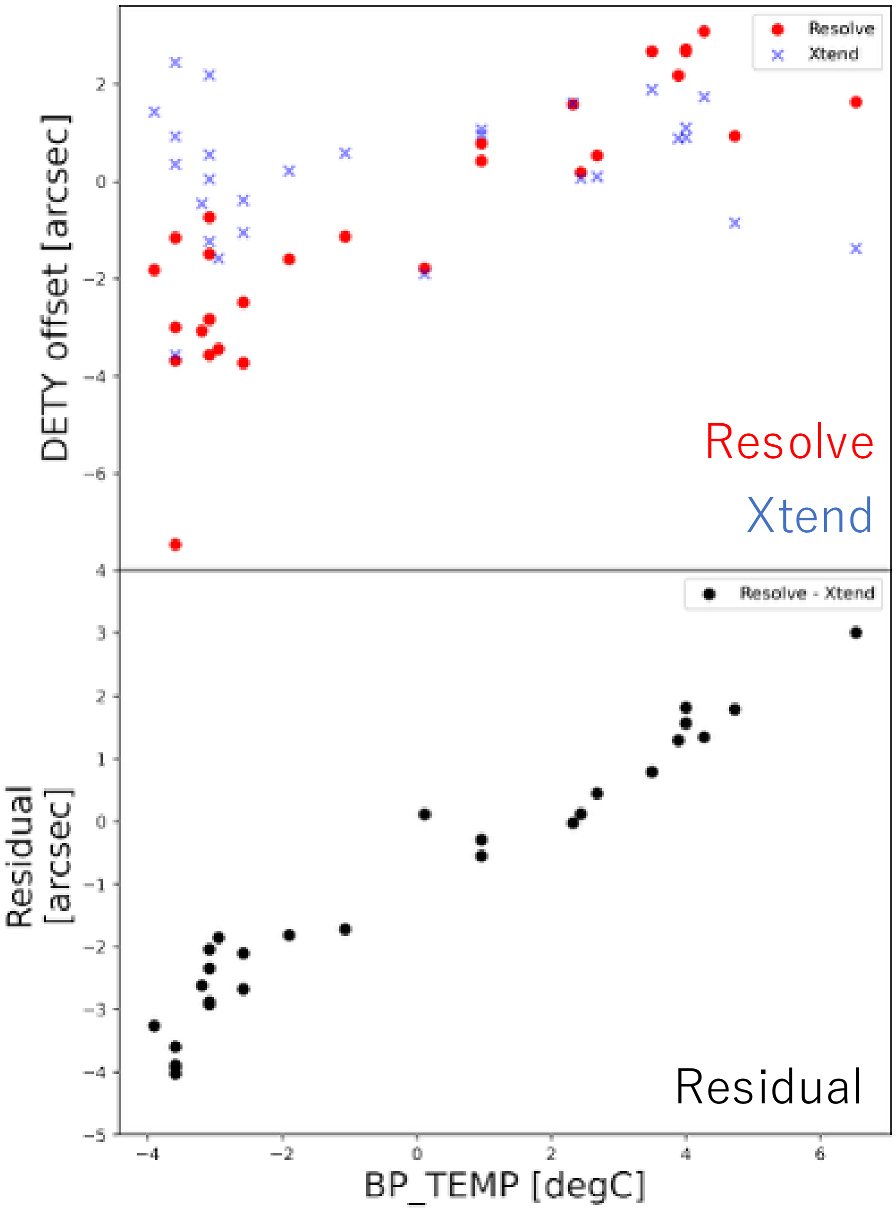
DETX direction

- Resolve and Xtend aimpoints shift **together in the same direction,** likely from attitude-control error.

DETY direction

- Resolve and Xtend aimpoints shift **differently** from one another.

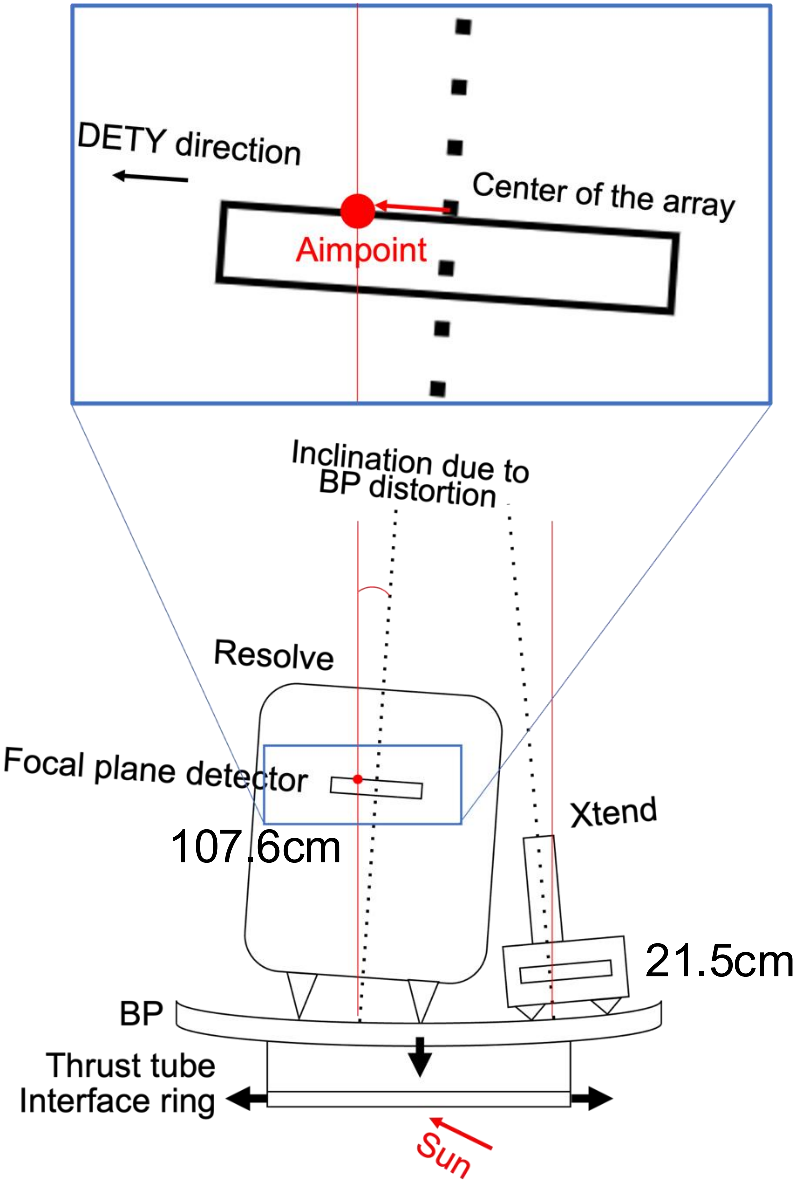
DETY shift



DETY Offsets vs. BP_TEMP

- Upper panel: individual offsets
  - Resolve: clear correlation with BP_TEMP
  - Xtend: little to no correlation
- Lower panel: Resolve − Xtend difference
  - Differencing removes common-mode shifts mainly caused by attitude-control errors
  - There is a clear temperature dependence.
  - Assuming Xtend as temperature-independent gives the BP_TEMP dependence is ~0.65″/℃ for Resolve.
  - Consistent with thermal-distortion simulations (<1”/℃).

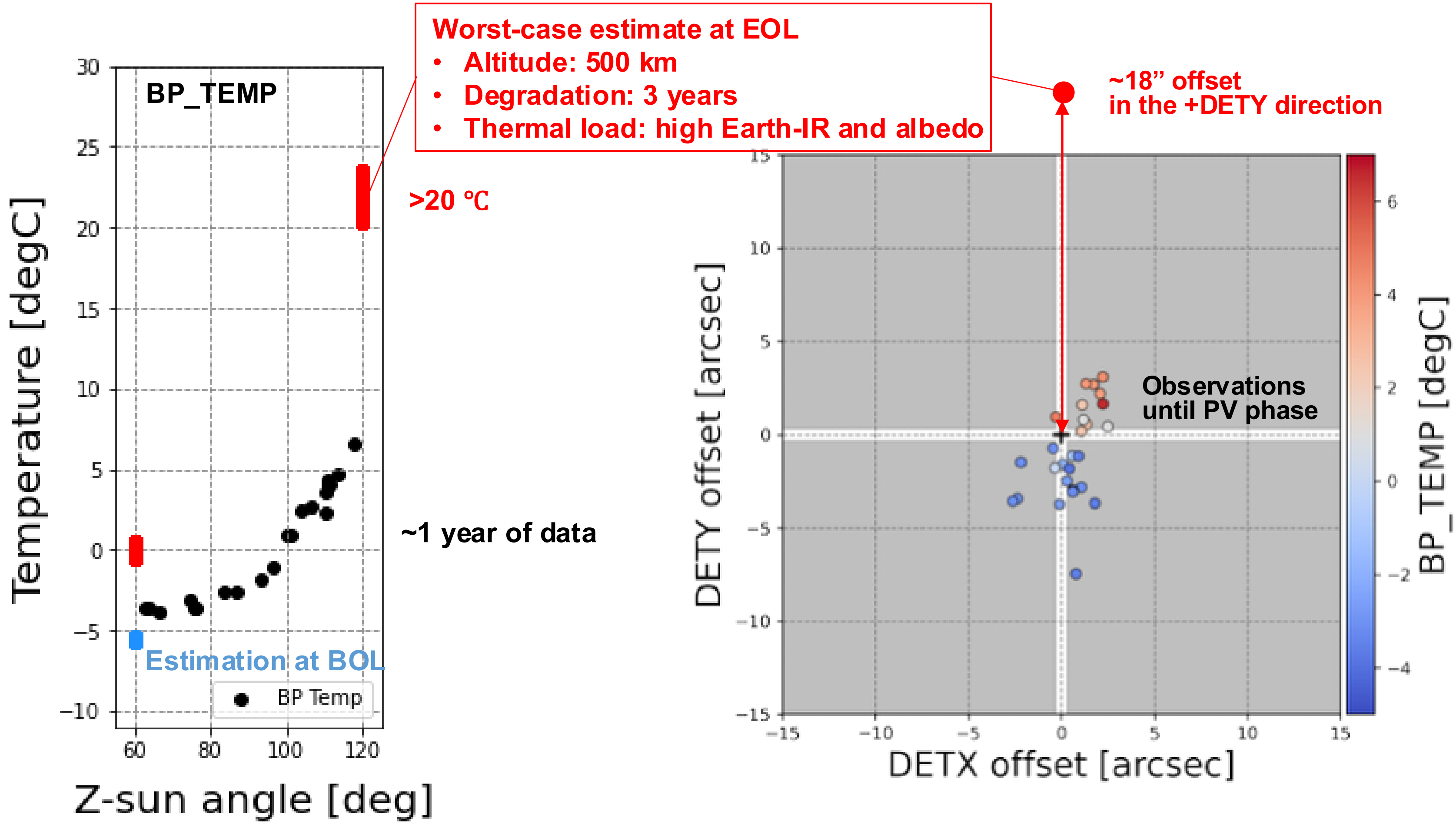
DETY shift



Schematic drawing of the BP and detectors

- Ground tests for Hitomi demonstrated that thermal expansion of the aluminum rocket interface ring can cause BP distortion.
- The heat expansion of the ring causes the base panel to distort into a downwardly concave shape.
- The focal planes of Resolve and Xtend are approximately 108 cm and 22 cm away from the BP surface. The difference in these distances may account for the different offset amounts in the DETY direction between Resolve and Xtend.
- After one year in orbit, thermal distortion introduces only a few-arcsec offset for Resolve.
  - The resulting photon loss is < 1 %, which is negligible.

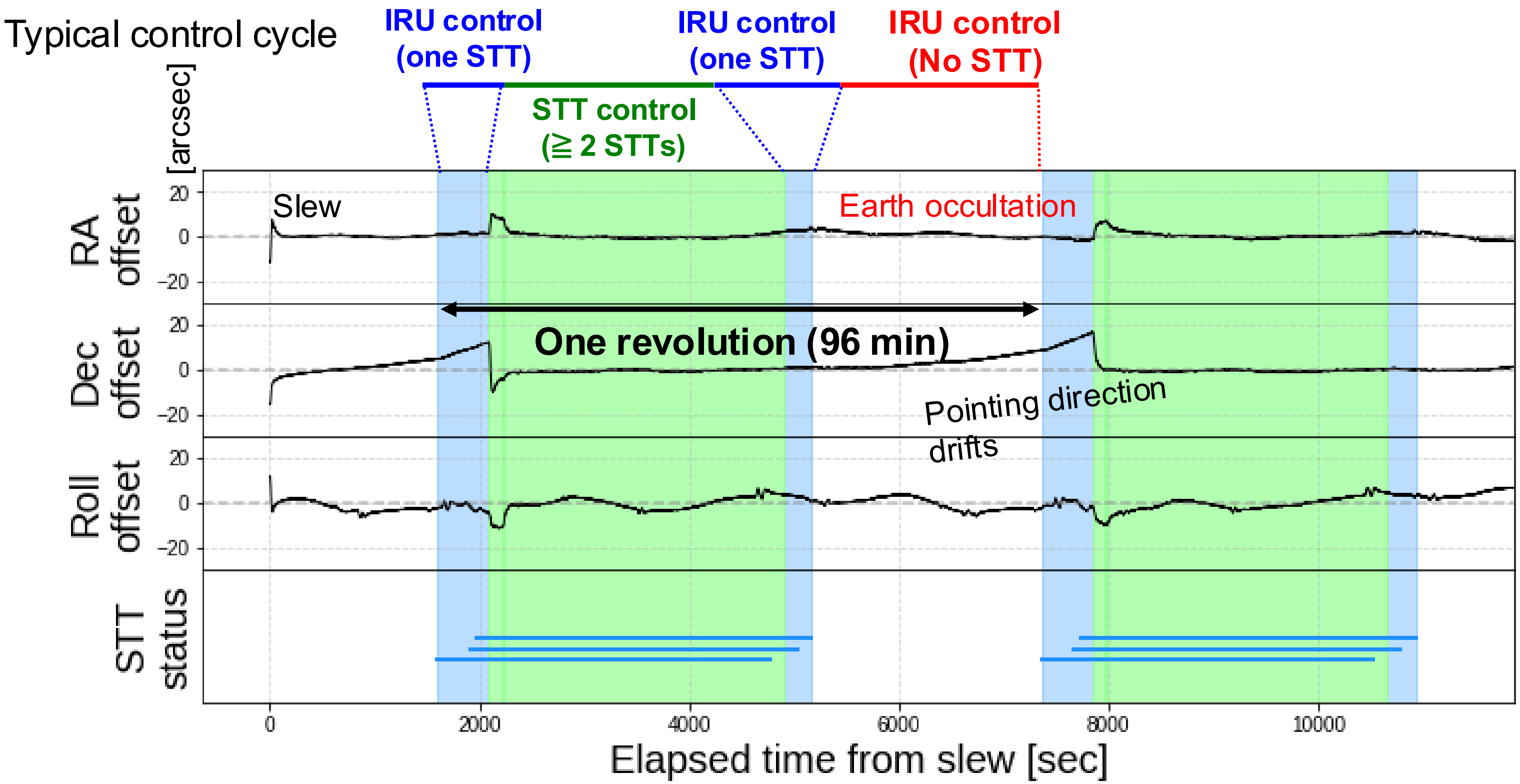
Worst-case estimation at EOL



- Pre-launch worst-case estimate predicted an offset up to 18″.
  - One year after launch, BP_TEMP and the other thermal measurement points remain stable. <u>No clear evidence of degradation has been detected.</u>
    - The spacecraft body is designed to meet the performance requirements for five years after launch.

Control and Determination accuracies

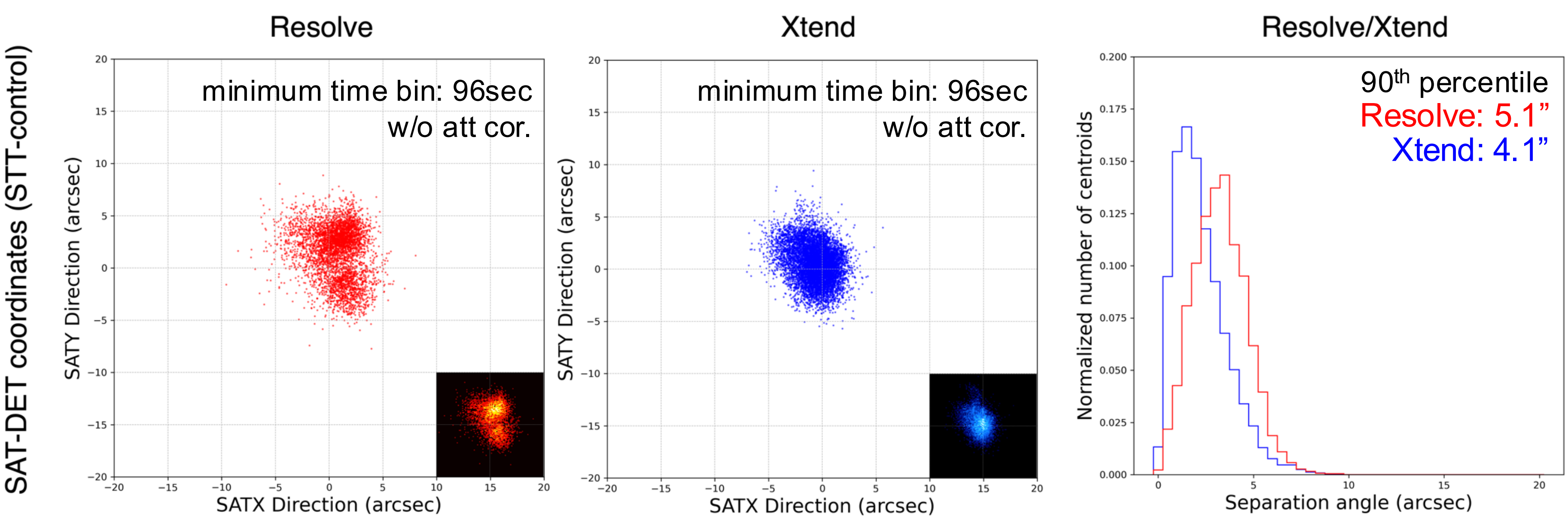
Attitude control cycle



- **Example history of the angular offset of the satellite attitude from the aimed target attitude.**
  - During target observations, at least one STT remains active, allowing attitude determination on the ground.
  - Control accuracy was evaluated during the STT-controlled period, whereas determination accuracy was evaluated during the STT-active period.

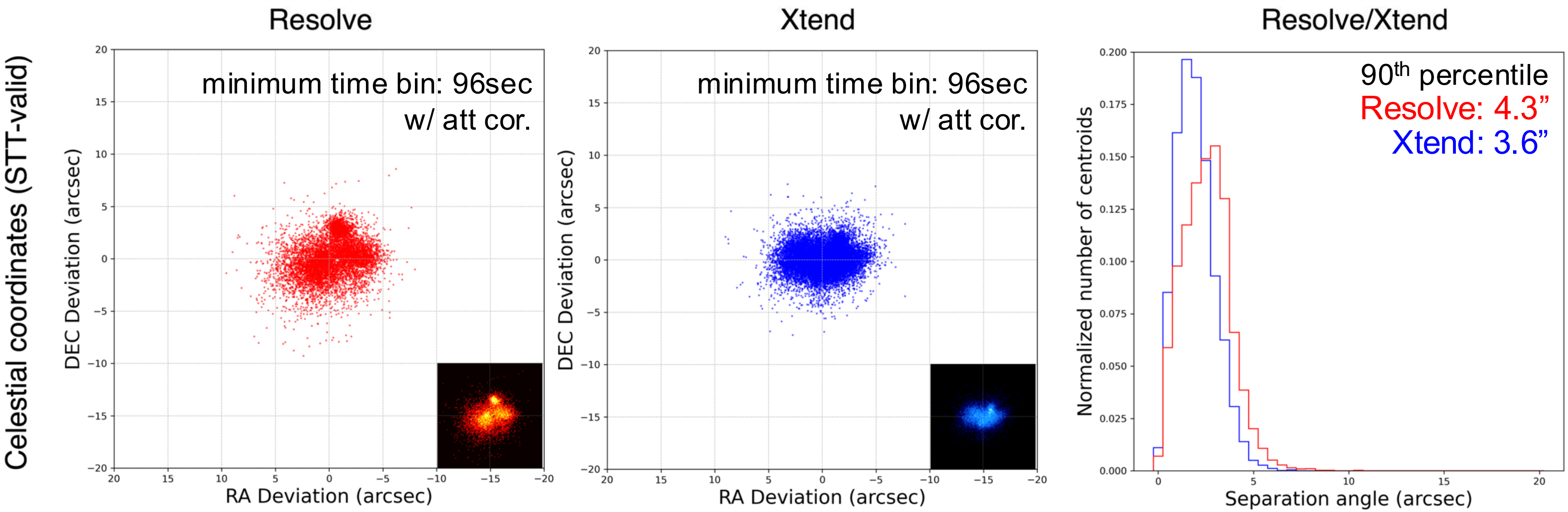
Absolute control accuracy

XRISM X-Ray Imaging and Spectroscopy Mission



- **Absolute control accuracy**
  - defined as the deviation between the target direction and the telescope’s boresight direction during the onboard attitude control
  - Resolve: 9.5″ ± 1.8″ (3σ)
  - Xtend: 7.6″ ± 1.0″ (3σ)
    - *(derived from the mean and standard deviations of aimpoints for each observation, then statistically combined)*
    - Although Resolve aimpoints spread along the DETY direction due to thermal distortion, the shifts are minor, and the resulting absolute control accuracy remains well within the mission requirement (55″).

Absolute determination accuracy



- **Absolute determination accuracy**
  - defined as the angular distance between the target’s celestial coordinates and its measured coordinates
  - Resolve: 5.8″ ± 0.9″ (3σ)
  - Xtend: 5.5″ ± 0.7″ (3σ)
    - *(derived from the mean and standard deviations of aimpoints for each observation, then statistically combined)*
    - ASCA SIS and Suzaku XIS/HXI required temperature-dependent corrections, yet their 90 % error circles still lay in the ten-arcsecond range. XRISM achieves much higher absolute determination accuracy without any post-correction.

Summary

- **Nominal parameters**:
  - The nominal aimpoints and alignment matrices remain valid.

- **Aimpoint shift**:
  - Thermal distortion produces a few-arcsecond shift in the DETY direction, resulting in a negligible photon loss of < 1 %.
  - Pre-launch worst-case simulations allowed offsets up to 18″ in the DETY direction, yet no evidence of thermal-control degradation has been observed.

- **Absolute determination accuracy**:
  - Resolve and Xtend achieve 5–6″, a clear improvement over the ≥ 10″ error circles of ASCA and Suzaku.