eROSITA: on the in-orbit calibration strategy and plan

From the ground to the science

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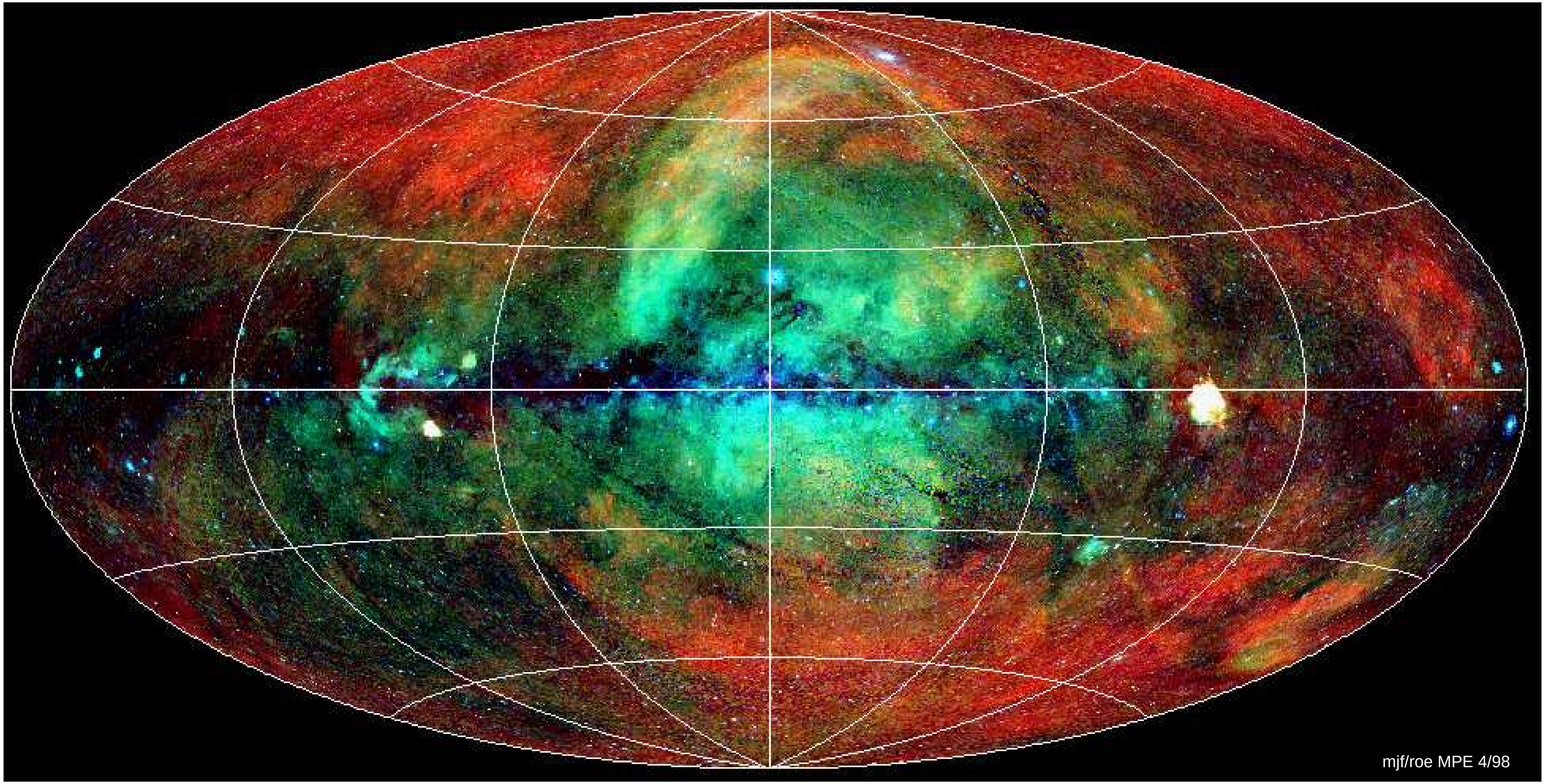


ROSAT all-sky survey: $\longrightarrow$ **energy range, resolution, sensitivity, time, camera, ...**

Spectrum-Roentgen-Gamma (SRG): eROSITA + ART-XC

Launch @ Baikonur 2014/Q4

Zenit/Fregat + Navigator

Mission duration > 7 yr

X band, 512 (380) kb/s

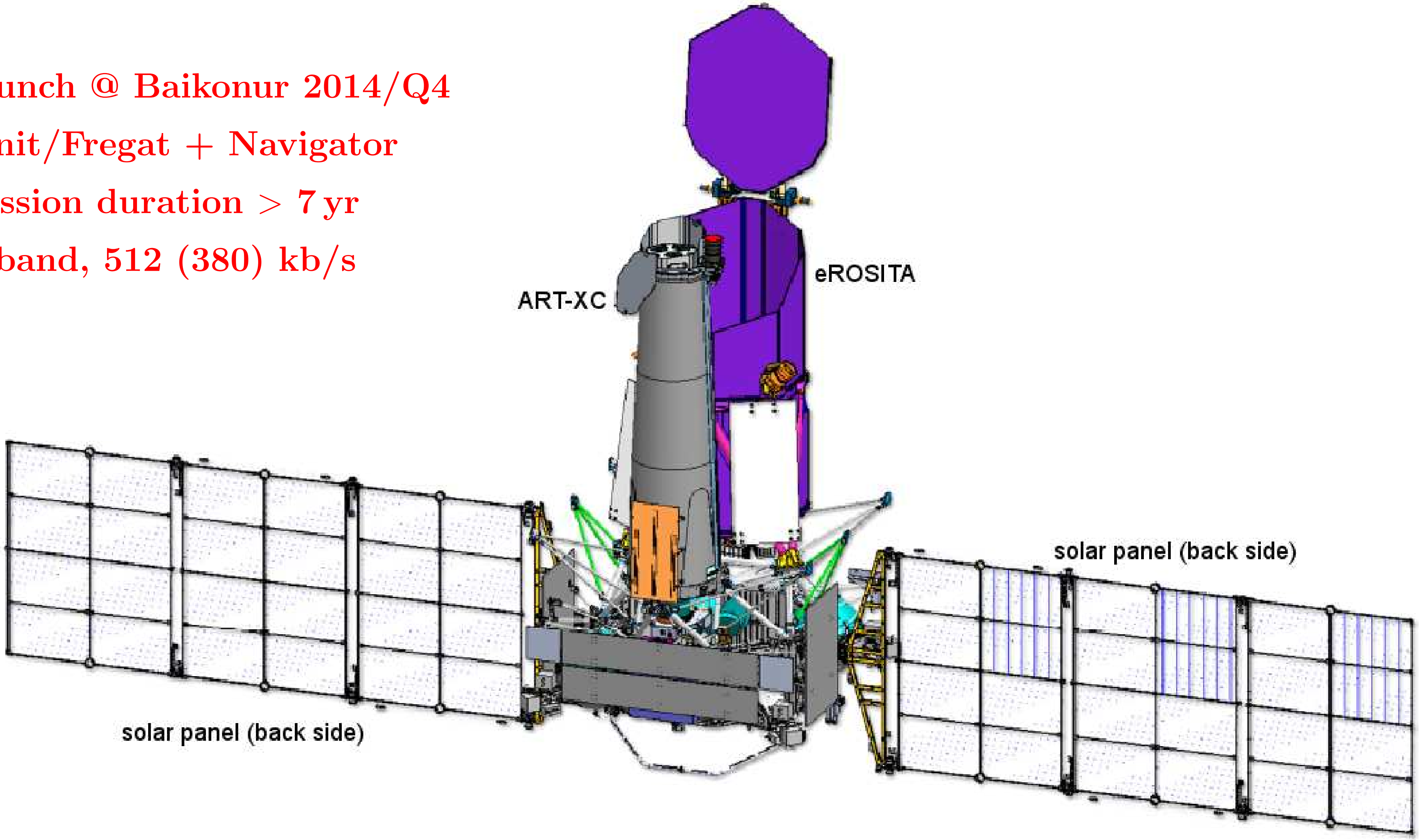
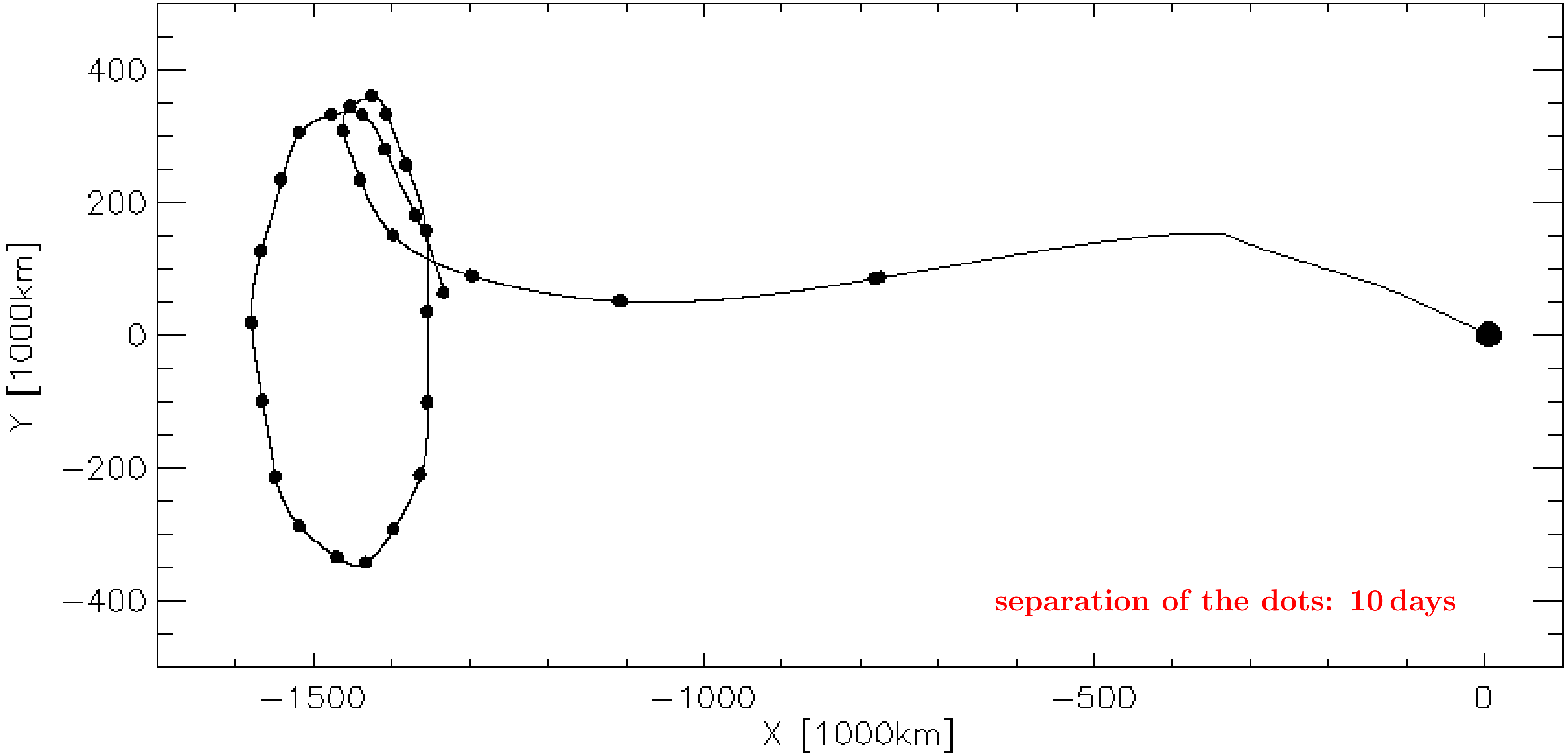


Figure 1: The Russian Spectrum-Roentgen-Gamma (SRG) satellite with the German soft X-ray telescope eROSITA (in purple, with front cover opened toward the Sun) and the Russian hard X-ray instrument ART-XC (in grey), with deployed solar panels, mounted onto the Navigator platform (adapted from Pavlinsky et al. 2011).

Mission scenario: L2



cannot be serviced (etc.) anymore at L2

→ needs careful work on-ground

development, EM, QM, FM, calibration, end-to-end test, check-out

outgassing, commissioning, calibration, performance verification, monitoring

Key features related to in-flight calibration

- Mission scenario: 4 yr all-sky survey(s), 3 yr pointed follow-up
- Detectability of 100.000 Clusters of Galaxies, $z < 1.5$: PSF, background
- Readout vs. scan speed (CCD: 50 ms frame time, 75 μm pixels; 360° per 4h, 6 scans)
- Prototype camera (TRoPIC) operational since 2007 (!) at PANTER: sub-pixel
- only 1 mode (FF), "standard candles" too bright !
- Fe-55 source: on filter wheel, strong enough for later mission phases
- Sky division (D/RUS) not relevant for calibration
- Schedule: use ~100 d transfer phase for initial measurements, then start survey phase ...
- Lauch, satellite checkout,
  3 wk outgassing, 4 wk commissioning (1, 2, 2, 2 cameras),
  calibration and performance verification, 4yr survey

The issues of in-orbit calibration

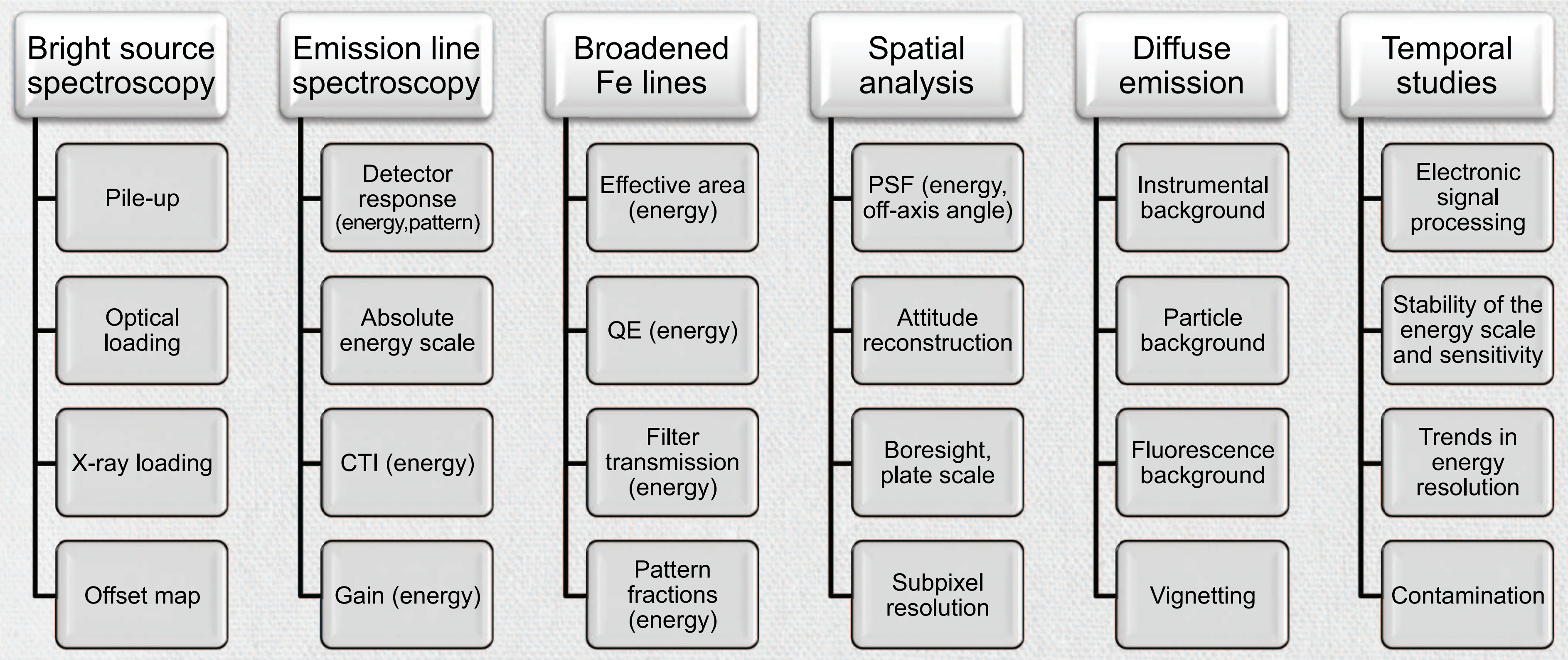
Changes of the on-ground calibration (performed at PUMA + PANTER)

- expected due to finite source distance
- expected due to radiation damage
- possible due to launch
- possible due to contamination
- possible due to micrometeoroid impact
- possible due to yet unknown effects

Instrumentation parts:

- optical light blocking filters
- mirror shells, X-ray baffle
- mirror module orientation (with respect to star tracker and other modules)
- “PSF”, contamination, etc.

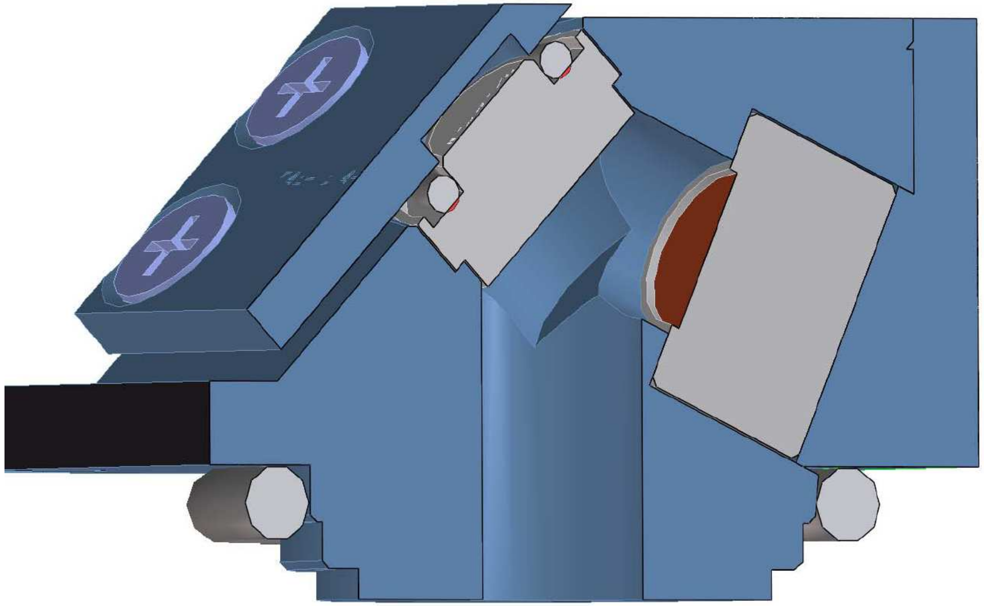
Science subjects and their relevance for calibration subjects

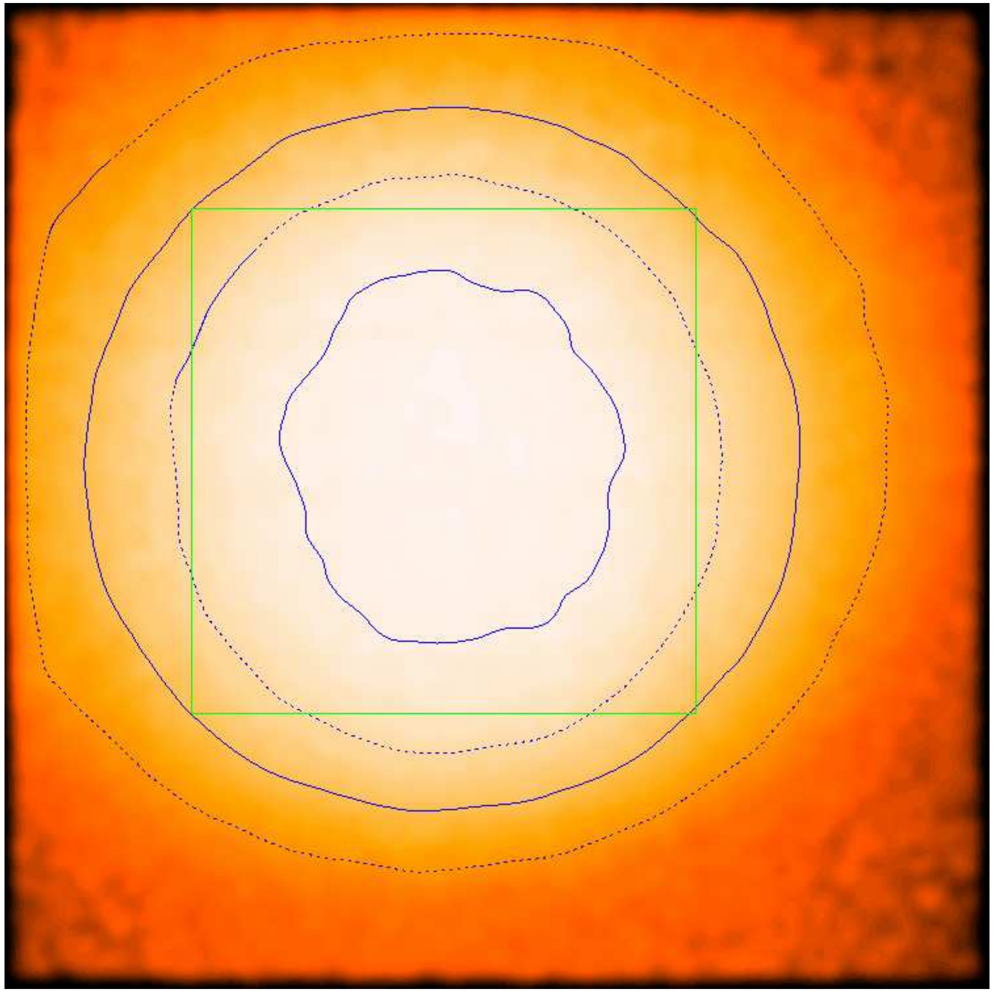


Calibration: from photons to bits: the fate of X-rays

device	*process*	*signal*	*characteristic properties*	
telescope	reflection (scattering)	*photon [eV]*	effective area (E,φ) point spread function (E,φ) field of view (FOV) boresight	collecting area, reflectivity, vignetting mirror quality focal length, detector geometry, plate scale alignment
filter	absorption		transmission (E) contamination (E,t)	filter thickness, spatial homogeneity temporal behaviour
CCD	charge release	*charge [e⁻]*	charge splitting low energy threshold	**patterns** (singles, doubles, triples, quadruples, invalid..)
			contaminating effects	**pile-up** (single pixel, pattern) **photon background** (fluorescence, optical loading) **particle induced background** (soft protons, MIPs) **detector induced background** (noise, bright pixels)
			quantum efficiency (QE) energy resolution (ΔE)	
	charge transfer		charge transfer loss (CTI) pattern migration	**trap saturation** due to photons and particles **charge transfer noise** **threshold induced charge loss** reemission, charge diffusion, charge splitting
	charge readout	*pulse height amplitude [adu]*	readout noise amplification ('gain')	non-linear gain, also dependence of the "apparent" gain on threshold(!) dependence on energy, temperature, time
on-board data processor	signal processing	*event [bit]*	energy offsets (offset map) common mode correction signal extraction MIP suppression	**restrictions likely due to limitations in on-board computing power and telemetry** (low energy threshold, MIPS..)

Internal calibration source: based on Fe-55





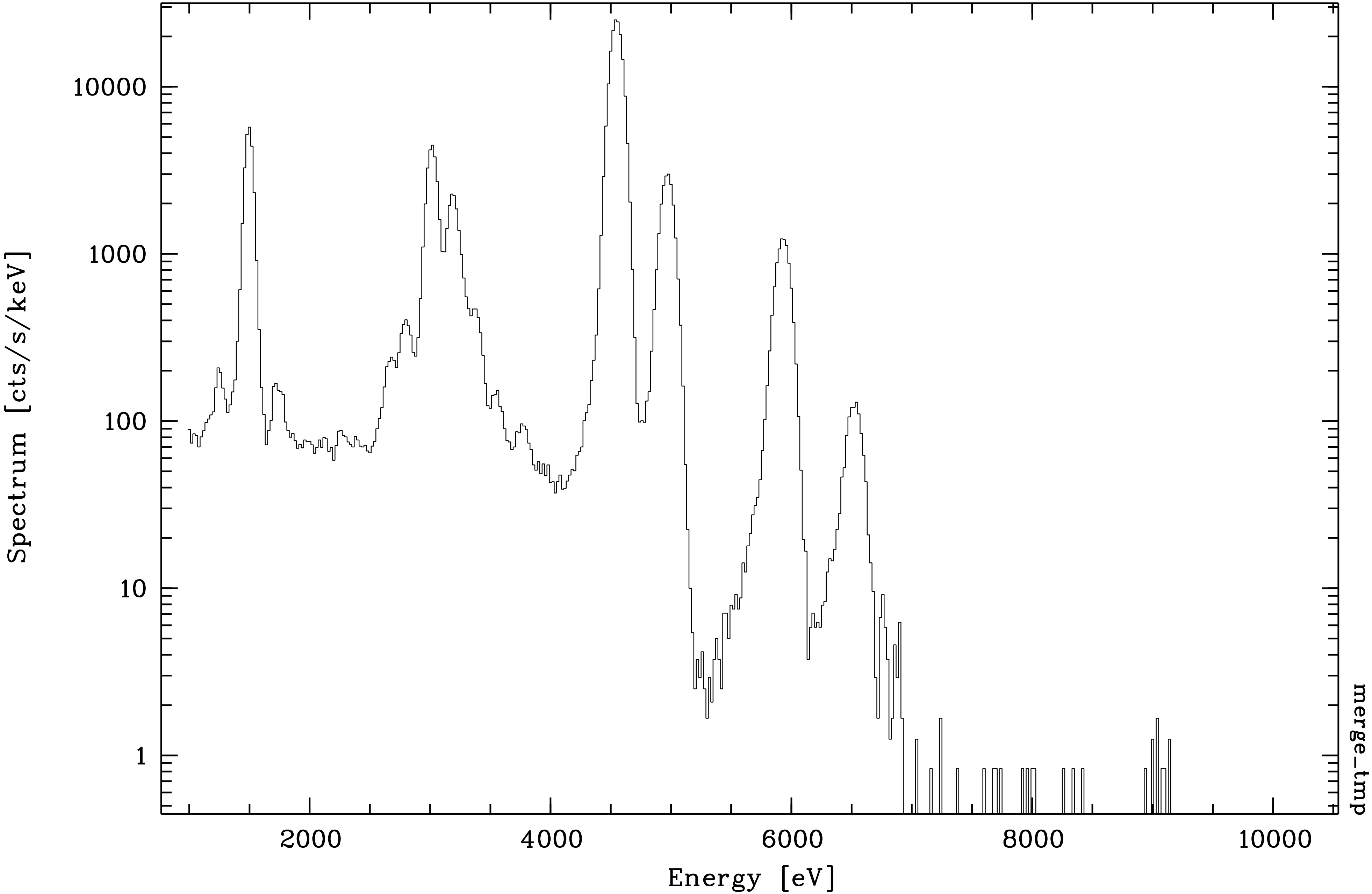
source: Fe-55 → Mn-55 (EC), $T_{1/2} = 2.7\,\mathrm{yr}$

target Al + Ti → 1.49, 4.51, 4.93, 5.89, 6.49 keV

mounted on filter wheel with 4 positions

eROSITA CCD 28.4×28.4 mm^2 (image 64 mm), 50 % at FOV edges

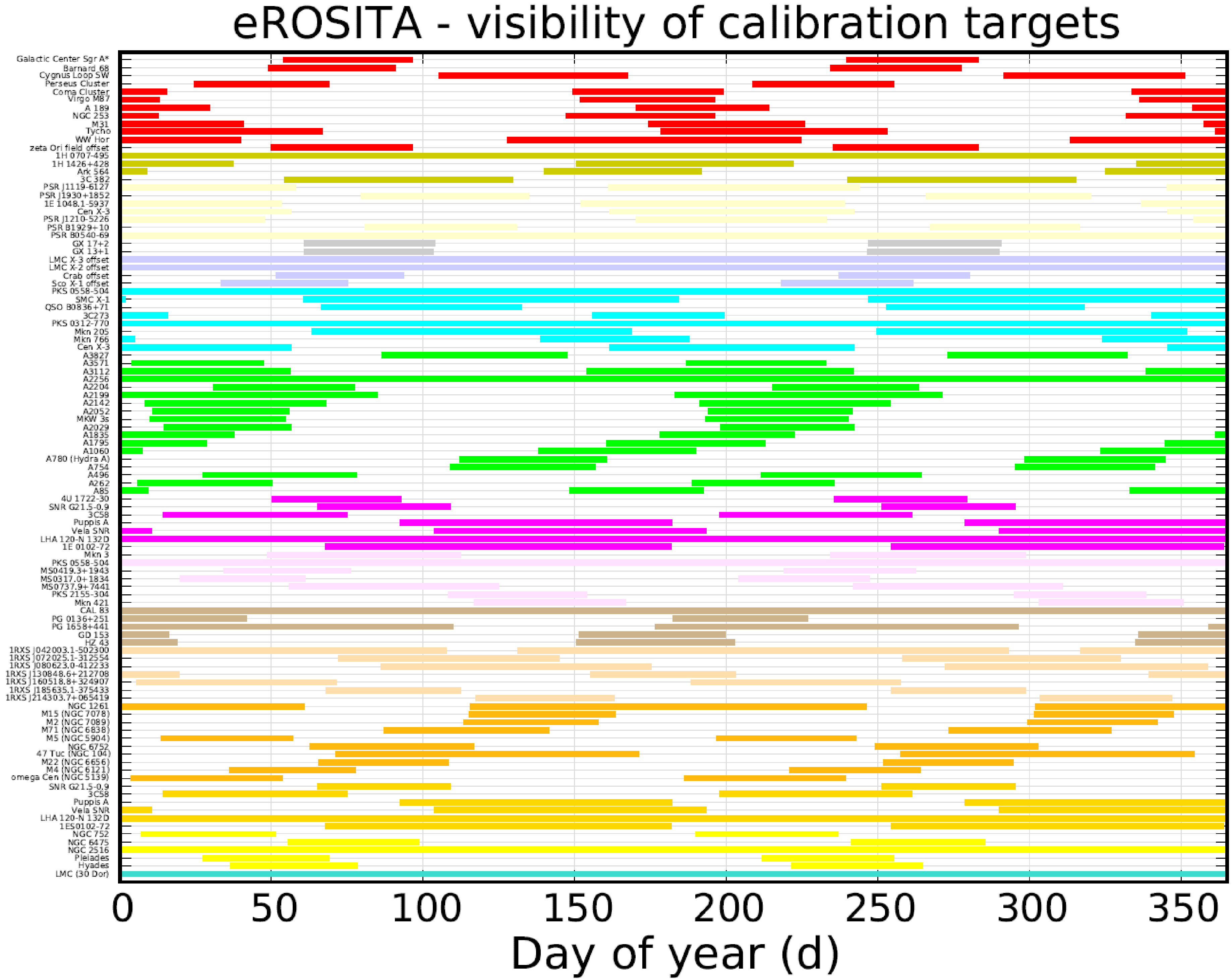
Internal calibration source: spectrum mono-pixel events



In-orbit calibration subjects:

During transfer phase to L2: outgassing, check-out (3 wk), commissioning (one camera after another, 4 wk), and in-flight calibration:

Calibration subject:
Commissioning
Plate scale and boresight of the 7 modules
Gain and CTI
Filter integrity (launch and micrometeorites)
Soft X-ray response and contamination monitoring
XUV response and contamination monitoring
Power-law type spectrum
Effective area and vignetting
Flatfield and vignetting
PSF
X-ray baffle (mosaic or mini-survey)
Masked mode
Timing
Miscellaneous
Performance verification



eROSITA - visibility of calibration targets
Galactic Center Sgr A*
Barnard 68
Cygnus Loop SW
Perseus Cluster
Coma Cluster
Virgo M87
A 189
NGC 253
M31
Tycho
WW Hor
zeta Ori field offset
1H 0707-495
1H 1426+428
Ark 564
3C 382
PSR J1119-6127
PSR J1930+1852
1E 1048.1-5937
Cen X-3
PSR J1210-5226
PSR B1929+10
PSR B0540-69
GX 17+2
GX 13+1
LMC X-3 offset
LMC X-2 offset
Crab offset
Sco X-1 offset
PKS 0558-504
SMC X-1
QSO B0836+71
3C273
PKS 0312-770
Mkn 205
Mkn 766
Cen X-3
A3827
A3571
A3112
A2256
A2204
A2199
A2142
A2052
MKW 3s
A2029
A1835
A1795
A1060
A780 (Hydra A)
A754
A496
A262
A85
4U 1722-30
SNR G21.5-0.9
3C58
Puppis A
Vela SNR
LHA 120-N 132D
1E 0102-72
Mkn 3
PKS 0558-504
MS0419.3+1943
MS0317.0+1834
MS0737.9+7441
PKS 2155-304
Mkn 421
CAL 83
PG 0136+251
PG 1658+441
GD 153
HZ 43
1RXS J042003.1-502300
1RXS J072025.1-312554
1RXS J080623.0-412233
1RXS J130848.6+212708
1RXS J160518.8+324907
1RXS J185635.1-375433
1RXS J214303.7+065419
NGC 1261
M15 (NGC 7078)
M2 (NGC 7089)
M71 (NGC 6838)
M5 (NGC 5904)
NGC 6752
47 Tuc (NGC 104)
M22 (NGC 6656)
M4 (NGC 6121)
omega Cen (NGC 5139)
SNR G21.5-0.9
3C58
Puppis A
Vela SNR
LHA 120-N 132D
1ES0102-72
NGC 752
NGC 6475
NGC 2516
Pleiades
Hyades
LMC (30 Dor)
0
50
100
150
200
250
300
350
Day of year (d)

Calibration target selection (I):

- Dedicated for specific calibration subject (only celestial sources for mirrors etc.)
- non-variable sources preferred (monitoring)
- Visibility (ecliptic coordinates), e.g. LMC targets preferred, depends on launch date
- Bright (statistics) but not too bright (pile-up, telemetry)
- Optically not too bright (filter, PSF!)
- Attitude reconstruction and relative timing of cameras and star tracker: several great-circles ("mini-survey") over stellar clusters, pulsars, etc.
- Stray light (X-ray baffle relative to mirror): "mini-survey" or mosaic close to Sco X-1 (out-of-FOV: 30' – 190' off-axis)
- Background: filter wheel in closed position (4 mm Al), CCD corners, no radiation monitor onboard SRG
- Closed/CalClosed: only 1 at a time, at high $|\beta|$
- Idea: after each all-sky survey (6 months): 1 day Cal/monitoring campaign
- 7 (almost) identical cameras → natural simultaneous (!) cross-calibration
- cross-calibration with other operational X-ray missions (TBD)

Calibration target selection (II)

- filter integrity: on-chip, external
  bright diffuse optical source, e.g. Omega Cen
- contamination: on CCD or mirror:
  soft sources, e.g. isolated neutron stars ("Magnificent Seven")
  RX J1856.5-3754 (INS), or GD 153 (WD)
- PSF: point-like sources, not too bright on-axis, may be brighter off-axis:
  ground-cal, stacking of point sources of first survey
- effective area and vignetting:
  non-variable source, maybe slightly extended or very extended (e.g., Coma cluster)
- gain (energy scale):
  featureless source spectrum (e.g. power-law): use instrumental edges, e.g., 3C 273
  moderately line-rich spectrum: e.g., SNR: 1E 0102-72, A1795, ...
- CTI: Fe-55 ("CalClosed" filter wheel position), Vela SNR (O VII, O VIII),
  can also be used for event pattern
- spectral response function: width, shelf (partial events):
  highly absorbed sources, low intrinsic continuum
- plate scale, boresight: field with many sources (known locations)
  stellar clusters: e.g., NGC 2516, NGC 6475 (M 7), NGC 752, Hyades
- stray light (X-ray baffle relative to mirror): scans close to Sco X-1

Targets with multi-wavelength information, visibility, ...

Back Forward www.mpe.mpg.de/~mjf/CalPV/ Reload Stop Print Hon

Most Visited

Target candidates

The following table contains a list of candidate celestial targets to be used for eROSITA commissioning and in-orbit calibration (maybe also/instead for performance verification).
The images were extracted from various archives using the skyview tool.
The overview is a 6.3 degree field in galactic coordinates from the ROSAT PSPC all-sky survey, with a 30.5 arcmin inner ring indicating the eROSITA FOV, a ring with radius 110 arcmin where single reflection arcs at the edge of the FOV may occur from bright sources therein, and with 190 arcmin radius where faint arcs at the center of the FOV may occur.
All other images are of 61 arcmin size and in equatorial coordinates:

- RASS: ROSAT PSPC all-sky survey
- PSPC: ROSAT PSPC pointed observations
- HRI: ROSAT HRI pointed observations
- DSSr: Digitized Sky Survey 2, red
- Wise-3.4: Wide-field Infrared Survey Explorer, 3.4 micron
- Wise-4.6: Wide-field Infrared Survey Explorer, 4.6 micron
- 2MASS-J: Two Micron All Sky Survey, 1.25 micron
- 2MASS-K: Two Micron All Sky Survey, 2.2 micron

The visiblity has been computed assuming an allowed solar aspect angle range of 90 ± 20 degrees, for the period 01-JUL-2014 to 30-JUN-2015 (launch, commissioning, calibration, performance verification, first survey, re-calibration).

Target	RA DEC	Equatorial	Galactic	Ecliptic	Overview	RASS	PSPC	HRI	DSSr	Wise-3.4	Wise-4.6	2Mass-J	2Mass-K	Visibility
LMC (30 Dor)	05 38 42.4 -69 01 02.0	84.67667 -69.01722	279.36835 -31.68118	306.88098 -86.82674	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	Observable throughout the specified period.
Hyades	04 32 00.0 18 10 00.0	68.0 +18.16667	178.97173 -19.94772	69.10395 -3.69091	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	2014 Aug 12 - 2014 Sep 22 2015 Feb 08 - 2015 Mar 20
Pleiades	03 47 00.0 24 07 00.0	56.75 +24.11667	166.57167 -23.52119	59.88673 +4.08635	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	2014 Aug 02 - 2014 Sep 13 2015 Jan 30 - 2015 Mar 11
NGC 2516	07 58 20.0 -60 52 13.0	119.58333 -60.87028	273.94009 -15.88099	170.33417 -75.89008	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	Observable throughout the specified period.
NGC 6475	17 53 30.0 -34 49 12.0	268.375 -34.82	355.80228 -4.45189	268.63922 -11.38838	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	2014 Aug 31 - 2014 Oct 12 2015 Feb 27 - 2015 Apr 09
NGC 752	01 57 41.0 37 47 06.0	29.42083 +37.785	137.1261 -23.25428	41.07064 +24.06148	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	2014 Jul 11 - 2014 Aug 26 2015 Jan 09 - 2015 Feb 22
1ES 0102-72	01 04 02.0 -72 01 55.0	16.00833 -72.03194	301.55807 -45.06253	314.63528 -65.03632	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	2014 Sep 13 - 2014 Dec 30 2015 Mar 11 - 2015 Jul 01
LHA 120-N 132D	05 25 15.23 -69 38 12.8	81.31346 -69.63689	280.29541 -32.76654	312.51297 -85.53964	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	Observable throughout the specified period.
Vela SNR	08 48 45.75 -45 36 51.4	132.19063 -45.61428	265.3472 -1.19826	157.85107 -59.52238	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	2014 Oct 19 - 2015 Jan 11 2015 Apr 15 - 2015 Jul 13
Puppis A	08 22 00.0 -42 55 00.0	125.5 -42.91667	260.31445 -3.41632	147.00206 -59.53112	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	2014 Oct 08 - 2014 Dec 31 2015 Apr 04 - 2015 Jul 01
3C58	02 05 38.0 64 49 26.0	31.40833 +64.82389	130.72165 +3.07997	57.20063 +47.91417	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	2014 Jul 19 - 2014 Sep 21 2015 Jan 17 - 2015 Mar 19
SNR G021.5-00.9	18 33 33.57 -10 34 07.5	278.38989 -10.56875	21.50155 -0.88559	278.45236 +12.62471	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	2014 Sep 10 - 2014 Oct 22 2015 Mar 09 - 2015 Apr 19
omega Cen (NGC 5139)	13 26 47.24 -47 28 46.5	201.69682 -47.47958	309.10284 +14.96838	219.75755 -35.22784	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	2014 Jul 07 - 2014 Aug 28 2015 Jan 05 - 2015 Feb 23

Targets: as basis for discussion ...

		+41.51306	-13.26181	+22.34018	FITS	FITS	FITS	FITS	FITS	FITS	FITS	FITS	FITS	2015 Jan 27 - 2015 Mar 11
Cygnus Loop SW	20 49 00.0 30 15 00.0	312.25 +30.25	73.3814 -8.48718	326.37396 +45.77061	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	2014 Oct 20 - 2014 Dec 17 2015 Apr 17 - 2015 Jun 17
Barnard 68	17 22 38.2 -23 49 34.0	260.65918 -23.82611	1.5259 +7.08943	261.46091 -0.66328	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	2014 Aug 24 - 2014 Oct 04 2015 Feb 20 - 2015 Apr 01
Galactic Center Sgr A*	17 45 40.04 -29 00 28.12	266.41684 -29.00781	359.94519 -0.04619	266.85175 -5.60767	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	2014 Aug 30 - 2014 Oct 10 2015 Feb 25 - 2015 Apr 07
Coalsack Nebula	12 33 19.0 -63 44 36.0	188.32916 -63.74333	300.93008 -0.94192	223.50995 -52.87549	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	2014 Jul 01 - 2014 Sep 11 2014 Dec 30 - 2015 Mar 09
Barnard 59	17 12 18.0 -27 22 00.0	258.07501 -27.36667	357.25644 +6.99167	259.39487 -4.36533	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	2014 Aug 22 - 2014 Oct 02 2015 Feb 18 - 2015 Mar 30
FeSt 1-457	17 35 45.0 -25 33 12.0	263.9375 -25.55333	1.71107 +3.65141	264.52826 -2.22912	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	2014 Aug 28 - 2014 Oct 08 2015 Feb 23 - 2015 Apr 04
TGU H2171 P5	16 40 51.0 -24 16 35.0	250.21249 -24.27639	355.37762 +14.48854	252.01321 -2.06422	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	JPG FITS	2014 Aug 15 - 2014 Sep 25 2015 Feb 11 - 2015 Mar 23

The strategy and plan for commissioning and in-orbit calibration is described in document eRO-MPE-PL-55-01.
An overview of the visibility is available in PDF format (prepared by J.Robrade).
The colour coding of the target name indicates the calibration subject :

Calibration subject:
Commissioning
Plate scale and boresight of the 7 modules
Gain and CTI
Filter integrity (launch and micrometeorites)
Soft X-ray response and contamination monitoring
XUV response and contamination monitoring
Power-law type spectrum
Effective area and vignetting
Flatfield and vignetting
PSF
X-ray baffle (mosaic or mini-survey)
Masked mode
Timing
Miscellaneous
Performance verification

This page makes use of NASA's SkyView facility (http://skyview.gsfc.nasa.gov) located at NASA Goddard Space Flight Center.
This page makes use of the ROSAT Data Archive of the Max-Planck-Institut fur extraterrestrische Physik (MPE) at Garching, Germany.
This page makes use of data products from the DSS2 red survey. The Digitized Sky Surveys were produced at the Space Telescope Science Institute under U.S. Government grant NAG W-2166. The images of these surveys are based on photographic data obtained using the Oschin Schmidt Telescope on Palomar Mountain and the UK Schmidt Telescope.

Cross-calibration within eROSITA/SRG and with others

- **7 (almost) identical cameras → natural simultaneous (!) cross-calibration**
- **commissioning one after another, initial checks pair-wise (telemetry)**
- **cross-calibration with ART-XC (TBD)**
- **cross-calibration with other operational X-ray missions (TBC): XMM-Newton, Chandra, Astro-H, Suzaku, NuSTAR, Swift, ...**

- **Create test timeline for lauch 15-JAN-2015 (visibility, order, ...)**

- **Candidate targets and documentation:** `http://www.mpe.mpg.de/~mjf/CalPV/`