eROSITA in-flight: commissioning and calibration: following the changes

eROSITA post-launch schedule (baseline)

- Ground calibration, delivery to NPOL, integration, testing, launch
- Baseline: use ~ 105 d (15 wk) transfer phase (to L2, and into halo orbit around L2) for initial measurements, then start survey phase ...
- after ~ 7 weeks at "about L2"
- external constraints on eROSITA schedule by SRG:
  major orbit correction maneuvers on the way to L2:
  on days 10, 20, and (if needed) 40
- external constraints on eROSITA schedule by ART-XC:
  is starting operations significantly later than originally anticipated
  and interferes with original eROSITA planning of Commissioning Phase:
  $\rightarrow$ ART-XC CalPV programme extends now into eROSITA camera commissioning phase

eROSITA post-launch schedule (baseline)

- **Launch delayed from April 1/2 or April 10/11 2019 to June 21/22 or July 12/13 2019 !**
- **complementary visibility windows to previously assumed (preferred) March/April or September/October launch windows**
- **n wk outgassing (telescope cover, filter wheel, cooling)**
- **4 wk commissioning (1 + 2 + 2 + 2 cameras per week),**
- **4 wk calibration (Cal) phase interleaved with 3 wk performance verification (PV) phase,**
- **4 yr survey(s) ($90°/\mathrm{h}$ like XMM-Newton Slew Survey) interleaved with monitoring,**
- **3+ yr pointed programme (GO)**

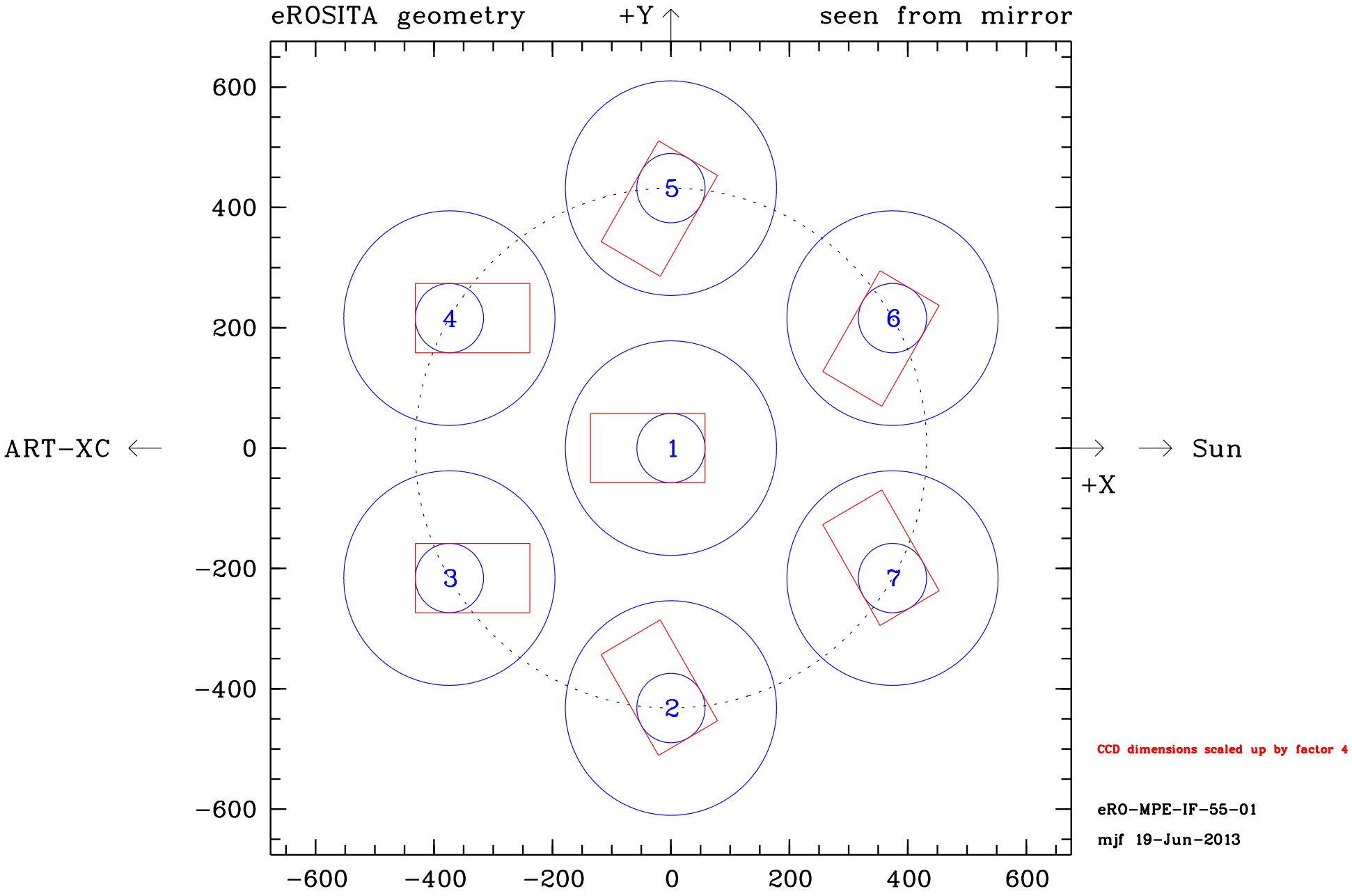
eROSITA post-launch schedule (to be finalized) (D. Coutinho)

- **Launch of SRG at T_0 (baseline: $\sim$ June/July 2019) from Baikonur with Proton-M/Block DM-03**
- **L2 transfer trajectory start ($T_0 + 1.6\,h$)**
- **start of post-separation phase: power system switch on**
- **satellite check-out: on-board service system test and set-up, test of the BKU program, test of the solar panel rotation by BKU commands, ...**
- **$T_0 + 3.6\,h$: eROSITA: ITC switch on, ITC and thermal control verification, check software, optimize temperatures**
- **$T_0 + 3\,d$: in-orbit mode transition completed: ITC software verification, ...**
- **$T_0 + 10\,d$: first trajectory correction burn to L2: 30 kg**

eROSITA post-launch schedule (to be finalized)

- $T_0 + 11\,d$: **eROSITA (and ART-XC): cover open (during communication session), outgassing, switch on of CEs, health test and test data mode**
- $T_0 + 20\,d$: **second trajectory correction burn to L2: 15 kg**
- $T_0 + 21\,d$: **eROSITA: check filter wheels, test calibration procedure, test time tagged commands, software updates to CE (if needed)**
- $T_0 + 40\,d$: **third trajectory correction burn to L2: optional, eROSITA filter wheel closed (etc.) via spacecraft command**
- $T_0 + 41\,d$: **commissioning phase with CCD cooling**
- $T_0 + 66\,d$: **CalPV phase (27-AUG – 14 OCT, 17-SEP – 4-NOV)**
- $T_0 + 115\,d$: **survey phase**
- `https://www.hs.uni-hamburg.de/hserosita/viscal`

eROSITA geometry: mirror modules and cameras



eROSITA post-launch schedule (to be finalized)

- **eROSITA: cool CCD detectors, settle time $\sim$ 2d**
- **switch on CCD camera # 1 (on-chip filter, TM6)**
  health check, on-board calibration source, thresholds, fix set-up,
  "Commissioning Light", if needed: adjust set-up
- **switch on CCD camera # 2 (off-chip filter, TM5)**
  health check, on-board calibration source, thresholds, fix set-up,
  "Commissioning Light", if needed: adjust set-up
- **switch on CCD cameras # 3 – # 7 (TM 2,4,7,1,3)**
  health check, on-board calibration source, thresholds, fix set-up,
- **Software updates, table uploads (if needed)**
- **"Commissioning Light" with all 7 cameras**
- **End-of-Commissioning Review**
- $T_0 + 66\,d$**: CalPV phase (27-AUG – 14 OCT, 17-SEP – 4-NOV)**
- $T_0 + 115\,d$**: survey phase**

eROSITA post-launch schedule (to be finalized)

- eROSITA: start calibration and performance verification observations, interleaved (enhance visibility), according to time-line,
  In-flight calibration (+PV) plan documents:
  `https://wiki.mpe.mpg.de/eRosita/PvPhase`
- make use of communication sessions during ground contacts
- reach quasi-periodic orbit around L2
- End-of-CalPV Review
- start survey operations
- complete calibration (if needed)
- monitoring observations (Fe-55/Closed and celestial sources)
- orbit corrections (station keeping) every 40 – 70 days
  (eROSITA mode to be finalized), survey rotation has to be stopped,
  use this occasion for pointed monitoring observations (RXJ 1856, 1E 0102)
- reaction wheel unloading (eROSITA observing, attitude may be worse)

In-orbit calibration subjects

- Commissioning
- Background (graded shield, calibration and monitoring, "Closed", etc.)

- Plate scale and boresight of the 7 modules (star-trackers vs. mirror assembly)
- Filter integrity (launch, micrometeorites)
- Soft X-ray (and XUV) response and contamination monitoring
- Gain and CTI (calibration and monitoring, "CalClosed" Fe-55), RMF
- PSF (on-axis, off-axis, survey)
- Effective area, QE, flat-fielding, and vignetting
- Optical loading by point sources (energy shift, spurious sources)
- X-ray baffle (Sco X-1 visible until 22-SEP, use still surveys?)
- Absolute and relative timing (and operational tests e.g., ROSAT-like "mini-survey" for time-delays between star tracker and X-ray cameras, attitude reconstruction)
- Power-law type spectrum (high-energy cross-calibration)
- clusters of galaxies (general cross-calibration, IACHEC)

- Monitoring every 6 months: RXJ1856 (contamination), 1E0102 (low-energy gain): highly recommended by IACHEC

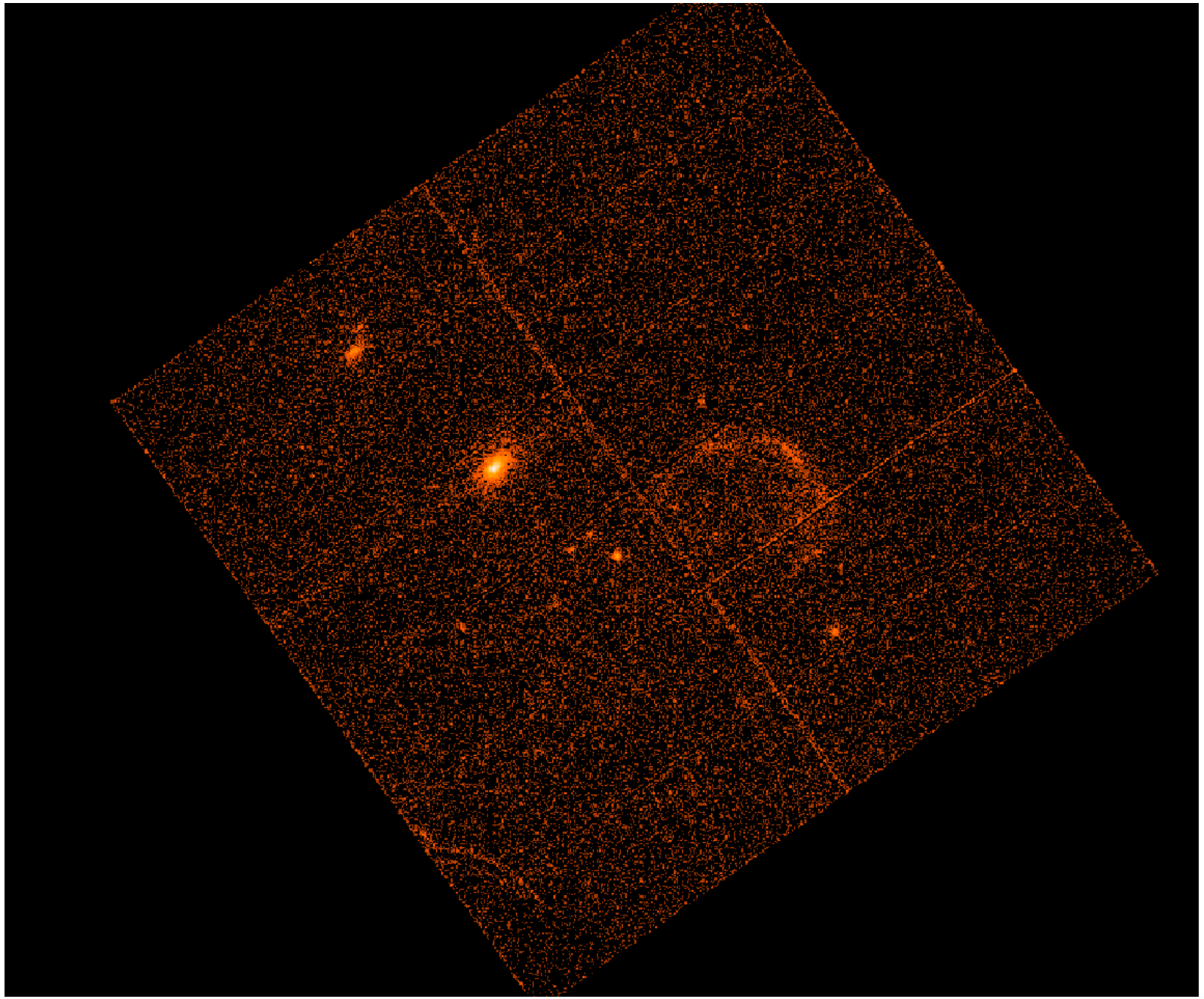
Commissioning: 4wk

- During/after commissioning of camera:
  closed (4 mm Al), calclosed (Fe-55), (low-gain mode like for EPIC-pn not implemented), "open" (i.e., filter): "Commissioning Light"
- Why as soon as possible: immediate quicklook of :
  background from sky (soft protons !)
  filter integrity, optical loading,
  mirror module health, PSF,
  baffle performance, single-reflections, bore-sight, ...
- helps to optimize set-up for following "open" (filter) scientific CalPV observations (save weeks of time to possibly adapt on-board software, but also eSASS)
- Preferred target: LMC: 30 Dor region / SN1987A (observable "at any time")

Target name	RA (2000)	Dec (2000)	l (deg)	β (deg)	Remark	Duration (ks)
LMC (30 Dor)	05 38 42.4	−69 01 02	279.37	−86.827	for each camera	40

- Minimum:
  – after commissioning of first camera (on-chip, TM6)
  – after commissioning of second camera (off-chip, TM5)
  – after commissioning of all cameras
- Commissioning phase determines and fixes set-up for CalPV (and survey) phase

"XMM-Newton First / Commissioning Light" (0022_0115740201_PNU014)



Background: 1d

- During/after commissioning of all cameras
- as predefined set of commands (macro)
- similar to calibration source: one after another CLOSED filter during survey
- baseline: once per week (e.g., camera 1 on day 1, camera 2 on day 2, ...)
- joint SRG background study for L2: eROSITA + ART-XC

Clusters of galaxies: 2d

- Are more subject of cross-calibration with other missions
  than actual eROSITA calibration (scientific like cluster T, not gain/CTI)
- eROSITA advantage: no chip gaps, large FOV!
- Preferred targets (1 low-T, 1 high-T): IACHEC recommendation
  A1795 + A2029, both not visible for June/July launch, A1835, A2052, A2199
- work to be expected, e.g.: derive T for eROSITA
  (7 temperatures should be the same within errors), XMM, Chandra
  determine differences and re-iterate (effective area, vignetting, EEF, RMF),...
  contribute to calibration parameters

Filter integrity (launch): 1d

- objects with extended optical emission
- Preferred targets: the more extended the better (others as back-up):

Target name	RA (2000)	Dec (2000)	l (deg)	β (deg)	Remark	Duration (ks)
Omega Cen	13 26 47.2	−47 28 46	309.103	−35.228	d=10' V=3.7	80
M4 (NGC 6121)	16 23 35.2	−26 31 32	350.974	−4.869	d=8.5' V=5.6	80
M22 (NGC 6656)	18 36 23.9	−23 54 17	9.893	−0.728	d=6.5' V=5.1	80
47 Tuc (NGC 104)	00 24 05.6	−72 04 52	305.896	−62.353	d=6' V=4	80
NGC 6752	19 10 52.1	−59 59 04	336.494	−37.221	d=3.8' V=5.4	80
M5 (NGC 5904)	15 18 33.2	+02 04 51	3.860	+19.646	d=3.5' V=5.7	80
M71 (NGC 6838)	19 53 46.4	+18 46 45	56.747	+38.792	d=3.3' V=8.2	80
M2 (NGC 7089)	21 33 27.0	−00 49 23	55.045	+14.509	d=2' V=6.5	80
NGC 1261	03 12 16.2	−55 12 58	270.540	−67.273	d=1.4' V=8.3	80
(total)						80

- Omega Cen only visible for 1 day (28-AUG)!
- "Commissioning Light" may be even more important

Boresight (and plate scale) of the 7 modules

Target name	RA (2000)	Dec (2000)	l (deg)	β (deg)	Remark	Duration (ks)
NGC 2516	07 58 20.0	−60 52 13	273.940	−75.890	**mosaic** $\pm 25'$	4×20
Hyades	04 31 60.0	+18 10 00	178.972	−3.691	**mosaic** $\pm 25'$	4×20
Pleiades	03 47 00.0	+24 07 00	166.572	+4.086	**mosaic** $\pm 25'$	4×20
NGC 6475	17 53 30.0	−34 49 12	355.802	−11.388	**mosaic** $\pm 25'$	4×20
NGC 752	01 57 41.0	+37 47 06	137.126	+24.061	**mosaic** $\pm 25'$	4×20
(Cal I)						**80**
(Cal II)						**80**
(survey)						**80**

Observe one field with all 7 cameras simultaneously, in 4 positions (square with length 25').
Coordination with ART-XC could be checked (would however require different targets)

Run (full) pipeline. Perform source detection for each camera separately. Identify the detected sources by position correlation with other source catalogues. Determine the centers of the FOVs and relative pointing offsets for each camera, and update the corresponding calibration file entries.

Determine the plate scale for each camera (and update the corresponding calibration file entries). For the brightest point sources also a PSF analysis (as function of off-axis angle) shall be performed.

Boresight (and plate scale) of the 7 modules: 2d + 1d + 1d

- 2 star trackers attached to eROSITA, 1 to ART-XC
- Fields with many sources with well-known positions
- Preferred targets (repeat once in CalPV + after 1/2 yr):
  NGC 2516 (Hyades, Pleiades, NGC 6475, NGC 7520)

Gain and CTI: 4d

- line positions and line widths
- Preferred targets:
  1ES 0102-72 (repeat every 6 months !),
  Vela SNR (visible after 18-OCT), 3C 58 (visible before 22-SEP),
  back-up: Puppis-A, SNR G021.5-00.9, LHA 120-N 132D
- in addition: CalClosed (Fe-55): cameras one by one (also during survey)

Soft X-ray response and contamination monitoring:
2d + 1d

Target name	RA (2000)	Dec (2000)	l (deg)	β (deg)	Remark	Duration (ks)
1RXS J185635.1-375433	18 56 35.1	−37 54 33	358.600	−15.033	**visible!**	**80**
1RXS J214303.7+065419	21 43 03.7	+06 54 19	62.658	+19.419	**invisible!**	**80**
1RXS J080623.0-412233	08 06 23.0	−41 22 33	257.427	−59.394		**80**
1RXS J160518.8+324907	16 05 18.8	+32 49 07	52.877	+52.238		**80**
(Cal I)					**RXJ2143**	**80**
(Cal II)					**RXJ2143**	**80**
(survey I)					**RXJ1856**	**80**
(survey II)					**RXJ1856**	**80**
(survey III)					**RXJ1856**	**80**
(survey IV)					**RXJ1856**	**80**
(survey V)					**RXJ1856**	**80**
(survey VI)					**RXJ1856**	**80**
(survey VII)					**RXJ1856**	**80**
(survey VIII)					**RXJ1856**	**80**

Soft X-ray response and contamination monitoring:
2d + 1d

Target name	Abs.feature	Visibility	
1RXS J185635.1-375433	–	Sep 13 - Oct 25	Mar 11 - Apr 22
1RXS J214303.7+065419	700 eV	Nov 01 - Dec 14	Apr 30 - Jun 13
1RXS J080623.0-412233	460 eV	Oct 01 - Dec 24	Mar 29 - Jun 24
1RXS J160518.8+324907	450 eV	Jul 07 - Sep 15	Jan 05 - Mar 13

- Verify filter transmission in soft X-rays, constant source, time dependent
- repeat the one selected target every 6 months !

XUV response and contamination monitoring: 1d

- White dwarfs, supersoft sources, counts below lower threshold:
- Preferred targets:
  HZ 43, GD 153, PG 1658+441 (visible until 23-OCT), PG 0136+251, ...

Power-law type spectrum: 1d

- Preferred targets (one or two): 1ES 1553+11.3, Mkn 3,
  PKS 0558−304, MS0419.3+1943, MS0317.0+1834, MS0737.9+7441, ...
  (pile-up: 3C 273, PKS 2155−304, Mkn 421)

Effective area, vignetting, flatfield: 4d

- Preferred targets: supernova remnants, clusters of galaxies
- Out-of-focus not possible in-orbit (to avoid pile-up)

PSF (core and wings): 7d

- Use ground calibration and few verification observations:
- Preferred targets: point-like 3XMM 3-10 cts/s (pile-up limit!)
- Actual PSF in-orbit calibration: stacked data from first all-sky survey
- Use point-like sources from first eROSITA catalog

Stars (optical loading): 1d

- Bright optical stars will move through FOV during survey
- will shift X-ray energies and cause spurious events
- Calibrate effect by observing bright optical X-ray dark stars
- Preferred targets: single A-type stars (ROSAT non-detections)
- Procedure: offset map calculation + short exposure)

Discussion/on-going work:

- coordination of mission planning of Cal-PV with IKI (e.g., regular video-cons)
- interface between MPE, IKI, and NPOL during commissioning and CalPV (dry-run)?
- new/revised ART-XC observing programme ($\rightarrow$ eROSITA commissioning)
- new/revised eROSITA in-flight calibration programme
- CAL coordination with ART-XC: possible joint target list + schedule
- new/revised eROSITA performance verification programme (DE + RU)
- new/revised mock time-line: (commissioning and) CalPV phase
- CAL coordination with eROSITA working groups:
  – update target lists in WG (esp. Clusters of Galaxies!)
  – is $\sim 2\%$ of calibration/monitoring time sufficient (compared to 5% for XMM)?
- CAL coordination with XMM-Newton and NuSTAR:
  frequent launch delays caused severe problems