eROSITA commissioning and calibration plans: getting closer to launch

eROSITA post-launch schedule (under discussion)

- **Ground calibration, delivery to NPOL, integration, 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"**

- n **wk outgassing,**
- **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°/h like XMM-Newton Slew Survey) interleaved with monitoring,**
- **3+ yr pointed programme (GO)**

eROSITA post-launch schedule (under discussion) (D. Coutinho)

- Launch of SRG at T_0 (baseline: $\sim$ April 2019) from Baikonur Site 81/Area 24, with Proton-M/Block DM-03 No. 4L (TBC)
- L2 transfer trajectory start ($T_0 + 1.6\,h$)
- the following items based on document from IKI ("ART-XC Flight to L2 plan", by R. Krivonos)
- start of post-separation phase (PSP): 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 rootation by BKU commands, transition to in-orbit mode
- $T_0 + 3.6\,h$: eROSITA: ITC switch on, ITC and thermal control verification, check software, optimize temperatures (when and how exactly: time-tagged or during communication session – with low speed !)
- $T_0 + 3\,d$: in-orbit mode transition completed: ITC software verification, RadioComplex interface verification ?
- $T_0 + 10\,d$: first trajectory correction burn to L2: 30 kg

eROSITA post-launch schedule (under discussion)

- $T_0 + 11\,d$: **any target coordinates are now possible (within visibility constraints)**
- $T_0 + 11\,d$: **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**
- $T_0 + 20\,d$: **eROSITA (and ART-XC): no operations**
- $T_0 + 21\,d$: **ART-XC: detector switch-on with high voltage, selected observations**
- $T_0 + 21\,d$: **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 (when need clear?)**

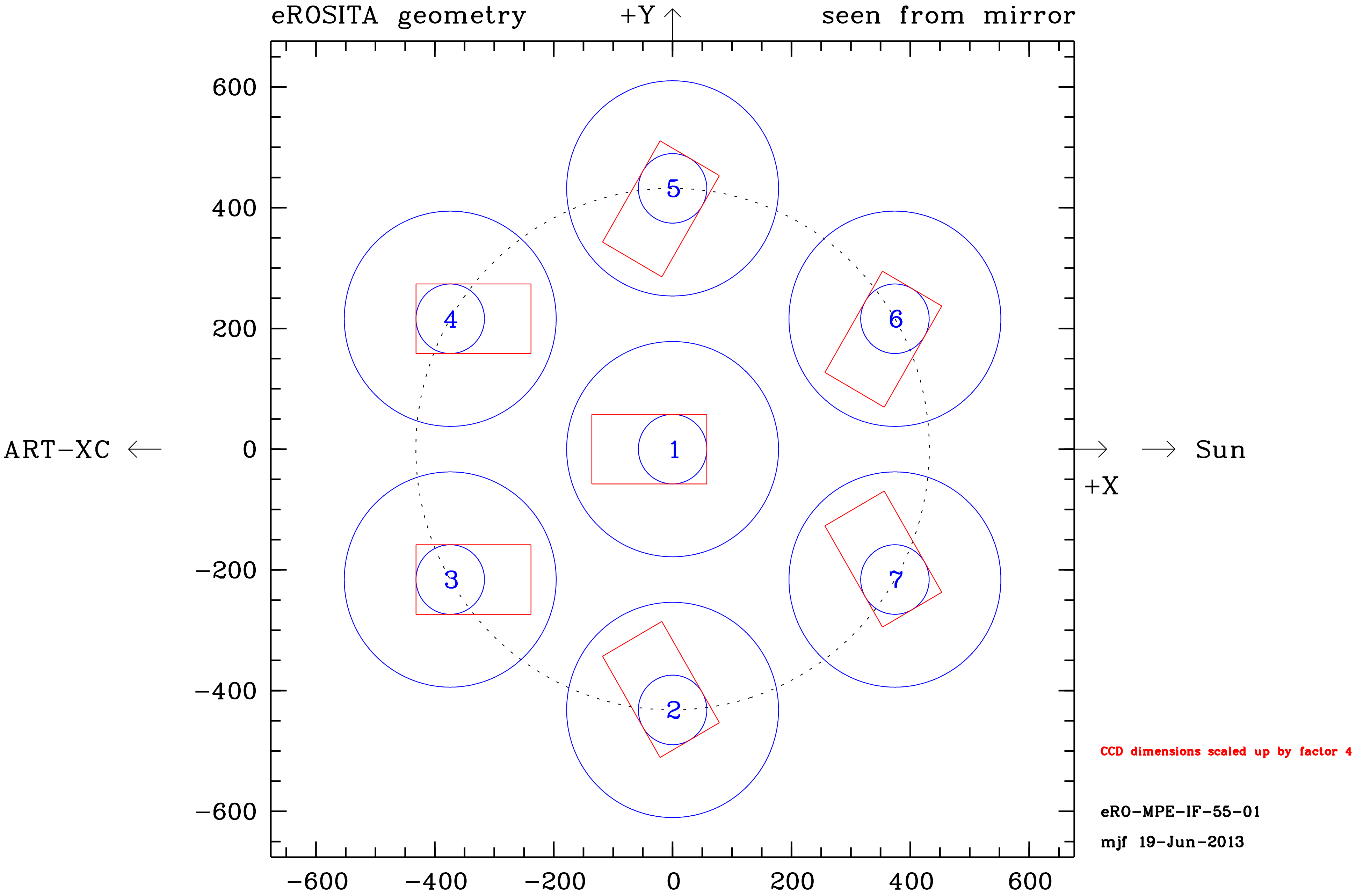
eROSITA post-launch schedule (under discussion)

- **eROSITA: cool CCD detectors,**
- **switch on CCD camera # 1 (on-chip filter)**
  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)**
  health check, on-board calibration source, thresholds, fix set-up,
  "Commissioning Light", if needed: adjust set-up
- **switch on CCD cameras # 3 – # 7**
  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**

eROSITA post-launch schedule (under discussion)

- **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 and celestial sources)**
- **orbit corrections (station keeping) every 40 – 70 days (eROSITA safe mode)**
- **reaction wheel unloading (eROSITA observing)**

eROSITA geometry: mirror modules and cameras



eROSITA geometry: FM Assembly and Position

Telescope Module (pos.)	1	2	3	4	5	6	7
Mirror Assembly (FM)	2	3	5	4	6	7	1
Camera Assembly (FM)	3	2	7	4	5	6	1
ext. Filter (frame #)	23	10	7	24	20	1	19
ext. Filter (PI) [nm]	205.0	207.7	209.9	204.5	219.5	212.5	203.1
ext. Filter (Al) [nm]	(200)	(200)	(200)	(200)	103.3	(200)	102.3

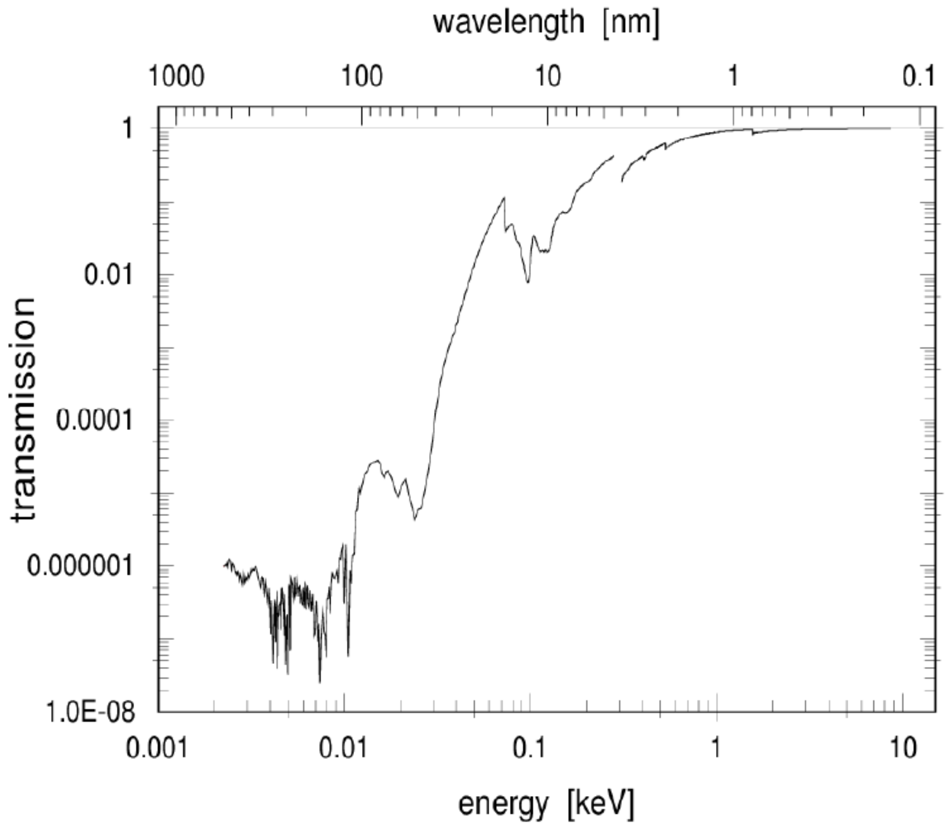
On-chip filter: 200 nm Al + external 200 nm PI (nominal)
Off-chip filter: external 200 nm PI + 100 nm Al (nominal)

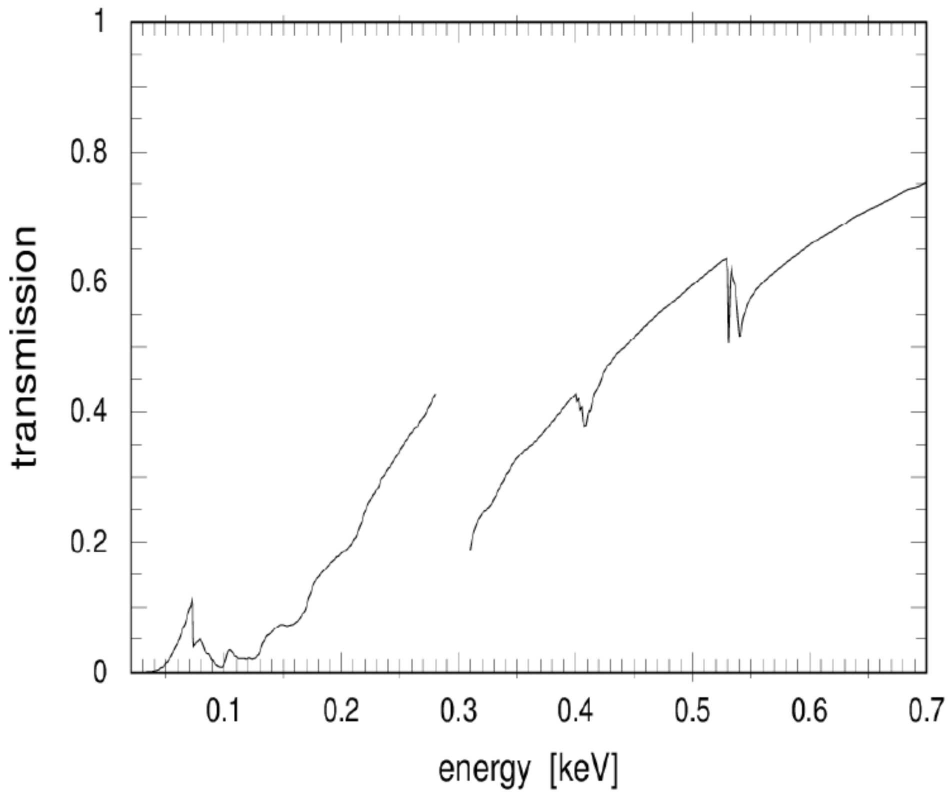
baseline: always use external filter (CalPV + surveys)

filters measured at BESSY in 2015: 5, 11, 16, 21 (A.v Kienlin)

problems at BESSY around C-edge
model gap with extrapolation from EPIC thin/medium filters

Optical light blocking filter transmission recovery (K. Dennerl)

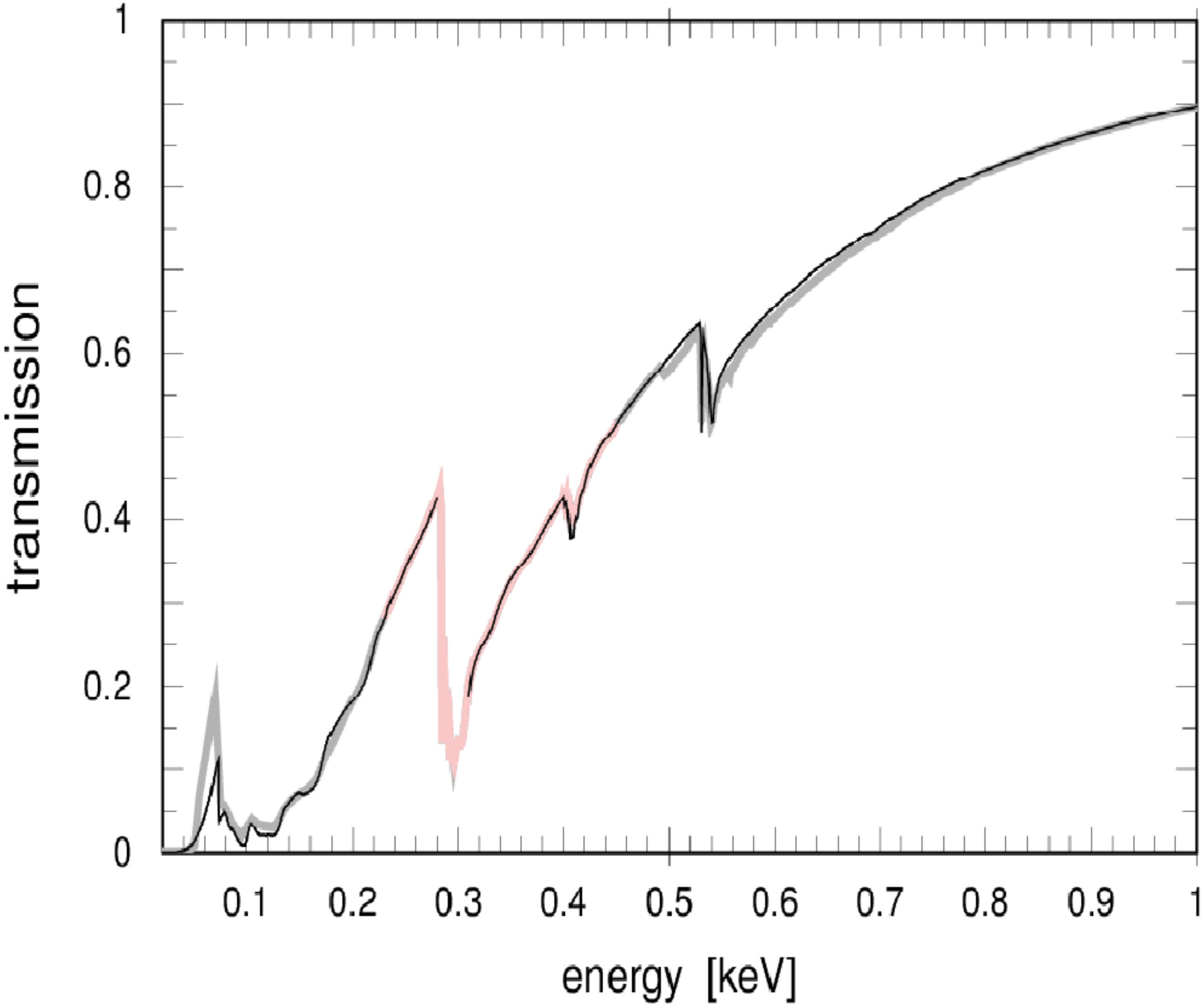




BESSY measurements:

degraded performance suspected around C-K edge

Optical light blocking filter transmission recovery (K. Dennerl)



→ fill the gap by rescaling EPIC Thin/Medium filter transmission

eROSITA quantum efficiency measurements (St. Granato)

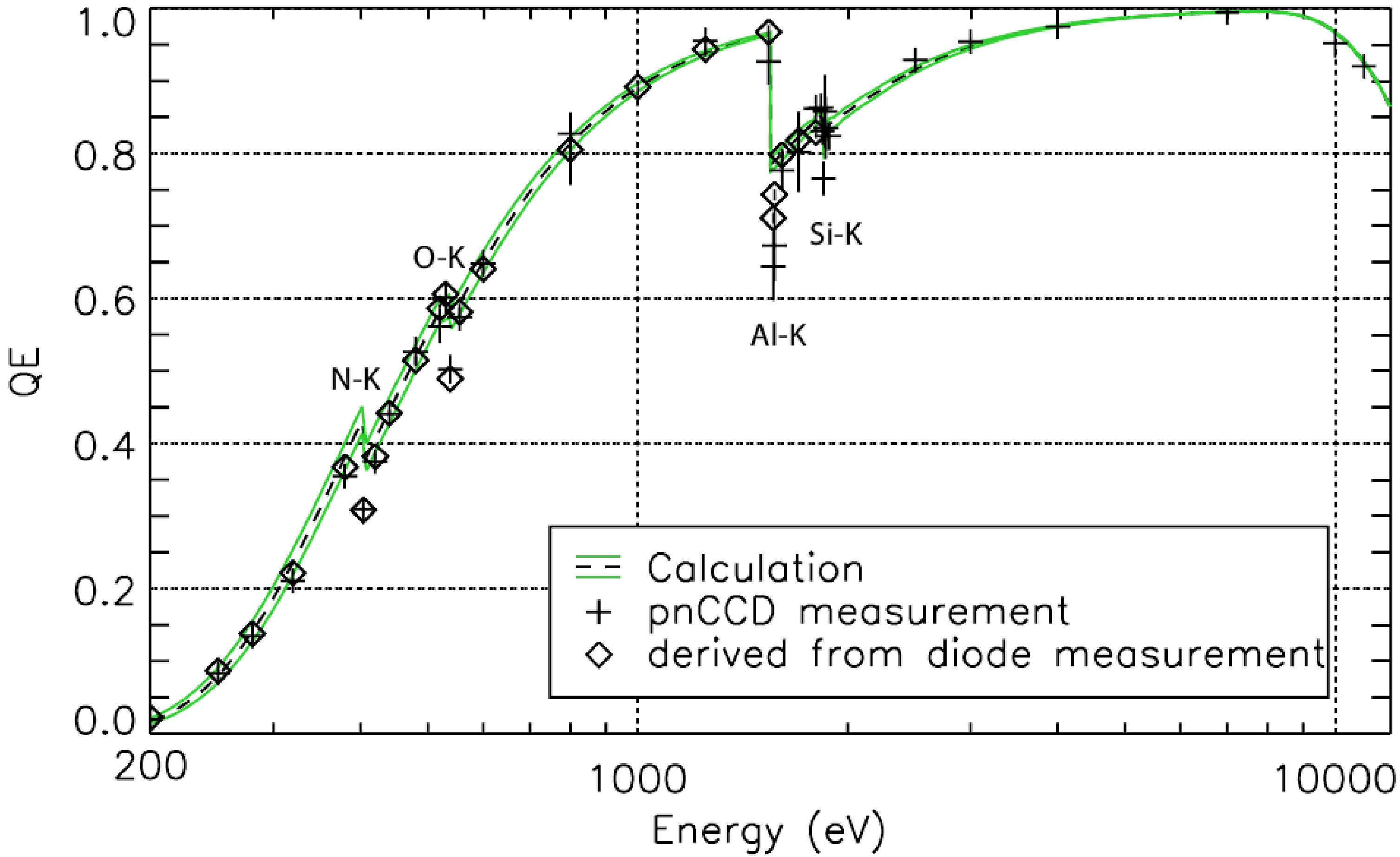
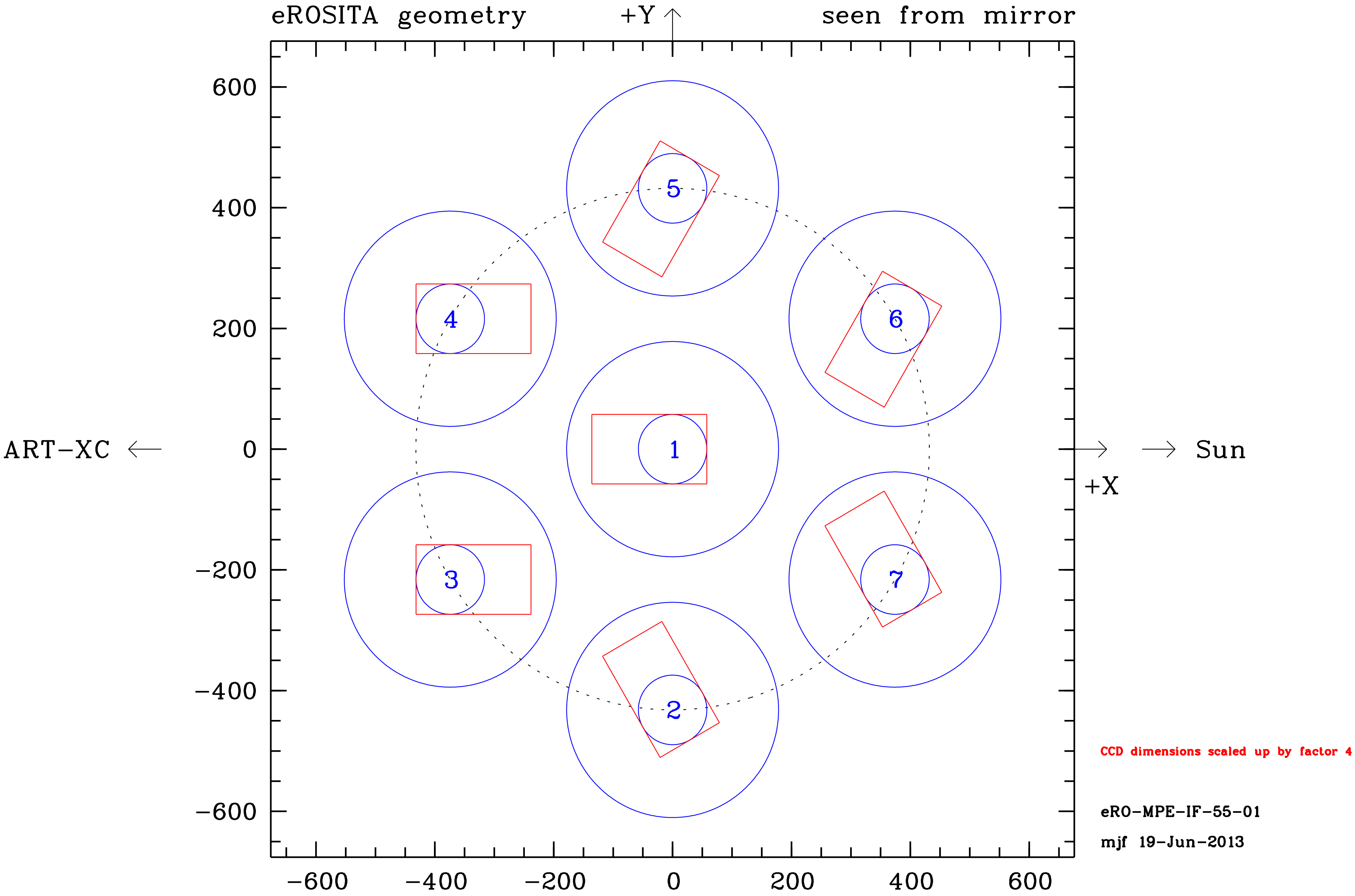


Figure 8.2.: Measured and calculated QE of detectors with eROSITA entrance window including aluminum on-chip filter. The dashed line shows the calculation according to eq. 8.1. The maximum variation of this calculation due to the uncertainty of layer thicknesses is shown by green solid lines. The shown measurement data points are gained from monochromator measurements with a PNCCD and a photodiode of the same entrance window. Apart from the absorption edges, already shown in fig. 8.1, measurement and calculation show high agreement.

eROSITA geometry: mirror modules and cameras



eROSITA ground calibration and position (CALDB)

Telescope Module (position)	1	2	3	4	5	6	7
Mirror Assembly (FM)	2	3	5	4	6	7	1
HEW @ Al-Kα (1.49 keV) [arcsec]	16.0	15.5	16.5	15.9	16.1	15.6	17.0
HEW @ Cu-Kα (8.04 keV) [arcsec]	14.5	15.1	15.6	16.3	15.1	16.2	14.7
Effective area @ Al-Kα [cm^2]	391	393	388	369	378	392	392
Effective area @ Cu-Kα [cm^2]	24.8	25.1	24.1	23.8	25.1	25.0	24.8
Scattering @ Cu-Kα [%]	11.1	11.0	13.2	12.1	11.2	12.8	10.2
Camera Assembly (FM)	3	2	7	4	5	6	1
FWHM @ C-Kα (0.277 keV) [eV]	58	58	58	58	50	59	49
FWHM @ O-Kα (0.525 keV) [eV]	64	65	66	64	57	69	56
FWHM @ Cu-L (0.93 keV) [eV]	70	74	72	70	68	71	68
FWHM @ Al-Kα (1.49 keV) [eV]	77	82	72	77	75	77	77
FWHM @ Ti-Kα (4.51 keV) [eV]	118	125	122	118	116	120	117
FWHM @ Fe-Kα (6.40 keV) [eV]	138	145	142	138	135	141	136
FWHM @ Cu-Kα (8.04 keV) [eV]	158	167	163	158	155	159	156
FWHM @ Ge-Kα (9.89 keV) [eV]	178	204	182	173	170	180	175
ext. Filter (frame #)	23	10	7	24	20	1	19
ext. Filter (PI) [nm]	205.0	207.7	209.9	204.5	219.5	212.5	203.1
ext. Filter (Al) [nm]	(200)	(200)	(200)	(200)	103.3	(200)	102.3

In-orbit calibration subjects

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

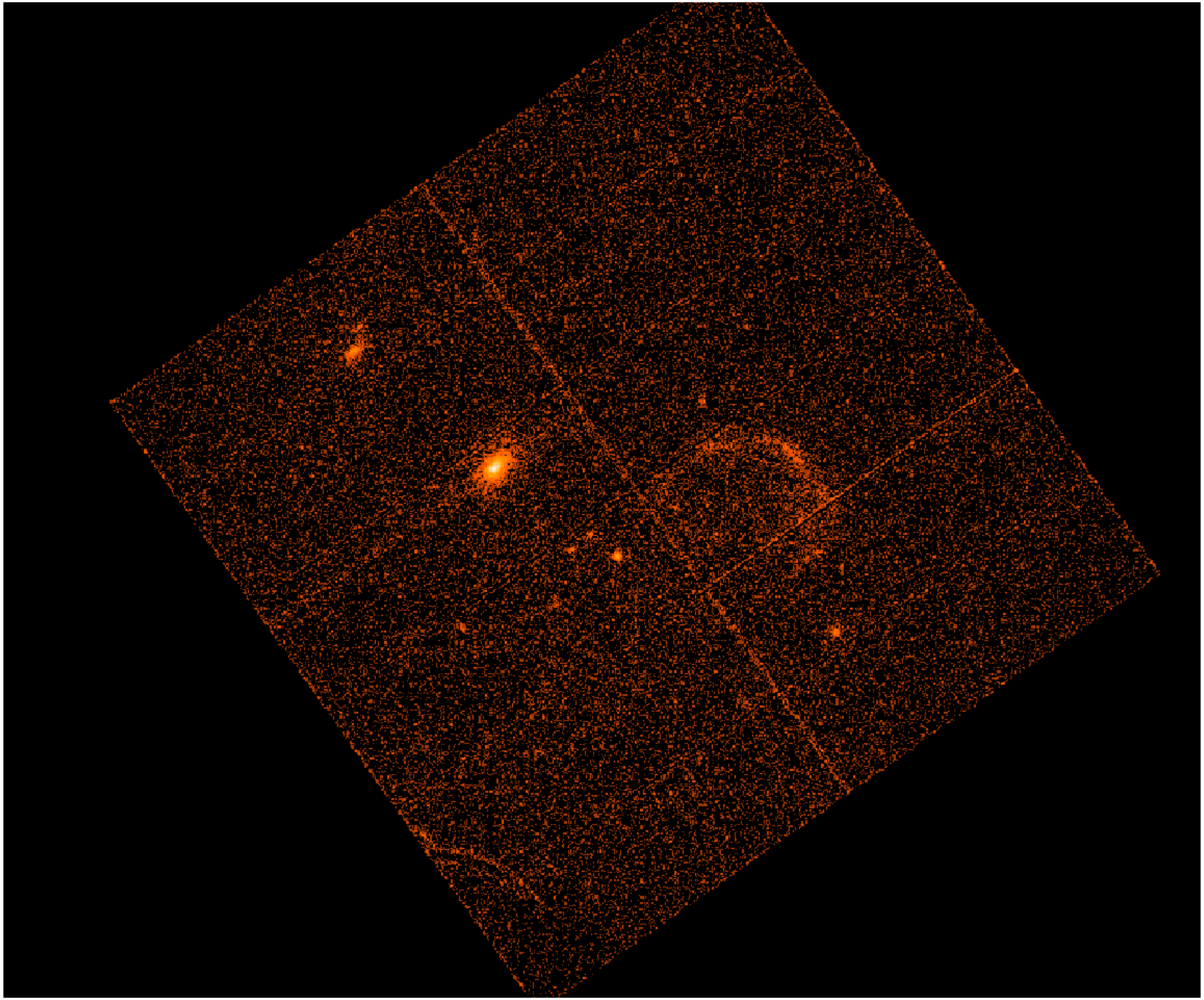
- Plate scale and boresight of the 7 modules (star-trackers vs. mirror assembly)
- Filter integrity (launch, micrometeorites)
- Soft X-ray (and XUV) response and contamination monitoring
- Gain and CTI (calibration and monitoring, "CalClosed" Fe-55)
- PSF (on-axis, off-axis, survey)
- Effective area, flat-fielding, and vignetting
- Optical loading by point sources (energy shift, spurious sources)
- X-ray baffle (Sco X-1 not visible, use 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

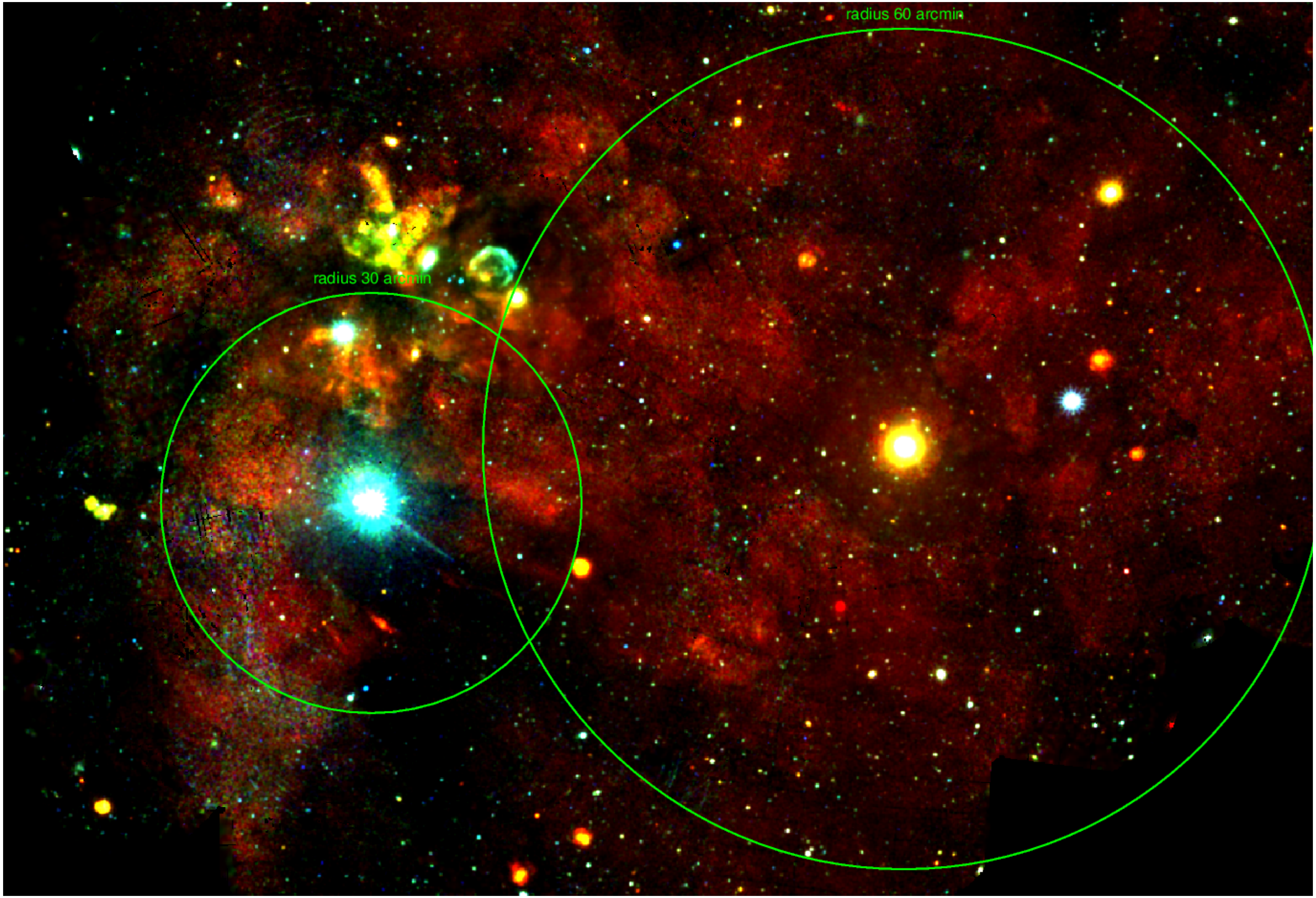
Operational constraints:

- Data handling rate inside camera (buffers)
- Data downlink rate limited
- Only short commanding period during ground contacts
- Number of time-tagged commands to be stored very limited
- response time of manual commanding to L2: $\sim$12 s
- Pile-up and pseudo-MIPs (for bright sources, see below)
- Visibility (ecliptic coordinates), depends on launch date and switch-on date
- Closed/CalClosed: only 1 module at a time
  (i.e., 6/7 of exposure to avoid dark regions)
- Monitor health and calibration validity regularly, but do not stop surveys too long:
  after each all-sky survey (6 months): 1 day Cal/monitoring campaign:
  1E0102 and RXJ1856
- cross-calibration with other operational X-ray missions,
  depends then also on other (external) constraints,
  e.g. for 3C 273 (XMM-Newton, Chandra, NuSTAR: June)

“XMM-Newton First / Commissioning Light” (0022_0115740201_PNU014)



“Commissioning Light” (XMM-Newton EPIC image courtesy F.Haberl)



Commissioning: 4wk

- During/after commissioning of camera:
  closed (4 mm Al), calclosed (Fe-55), low-gain closed (TBC), low-gain open (TBC), "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 (observable at any time)
- Minimum:
  - after commissioning of first camera (on-chip)
  - after commissioning of second camera (off-chip)
  - after commissioning of all cameras
- Details TBD: what shall be observed during commissioning of other cameras?
  all the time "Commissioning Light", same or different position ?
  follow ART-XC and return to "Commissioning Light" with next camera ??
- Commissioning phase determines and fixes set-up for CalPV (and survey) phase

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 (ARF), large FOV (BKG)!
- Preferred targets (1 low-T, 1 high-T): IACHEC recommendation
  A1795, A2029 (Coma (center to be defined), 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

PSF (core and wings): 7d

- Use ground calibration and few verification observations:
- Preferred targets: point-like 3XMM_dr8 sources with 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

In-orbit Calibration Plan (see CalPlan document)

- **Commissioning**

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**

- **Filter integrity**

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**

In-orbit Calibration Plan (see CalPlan document)

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.

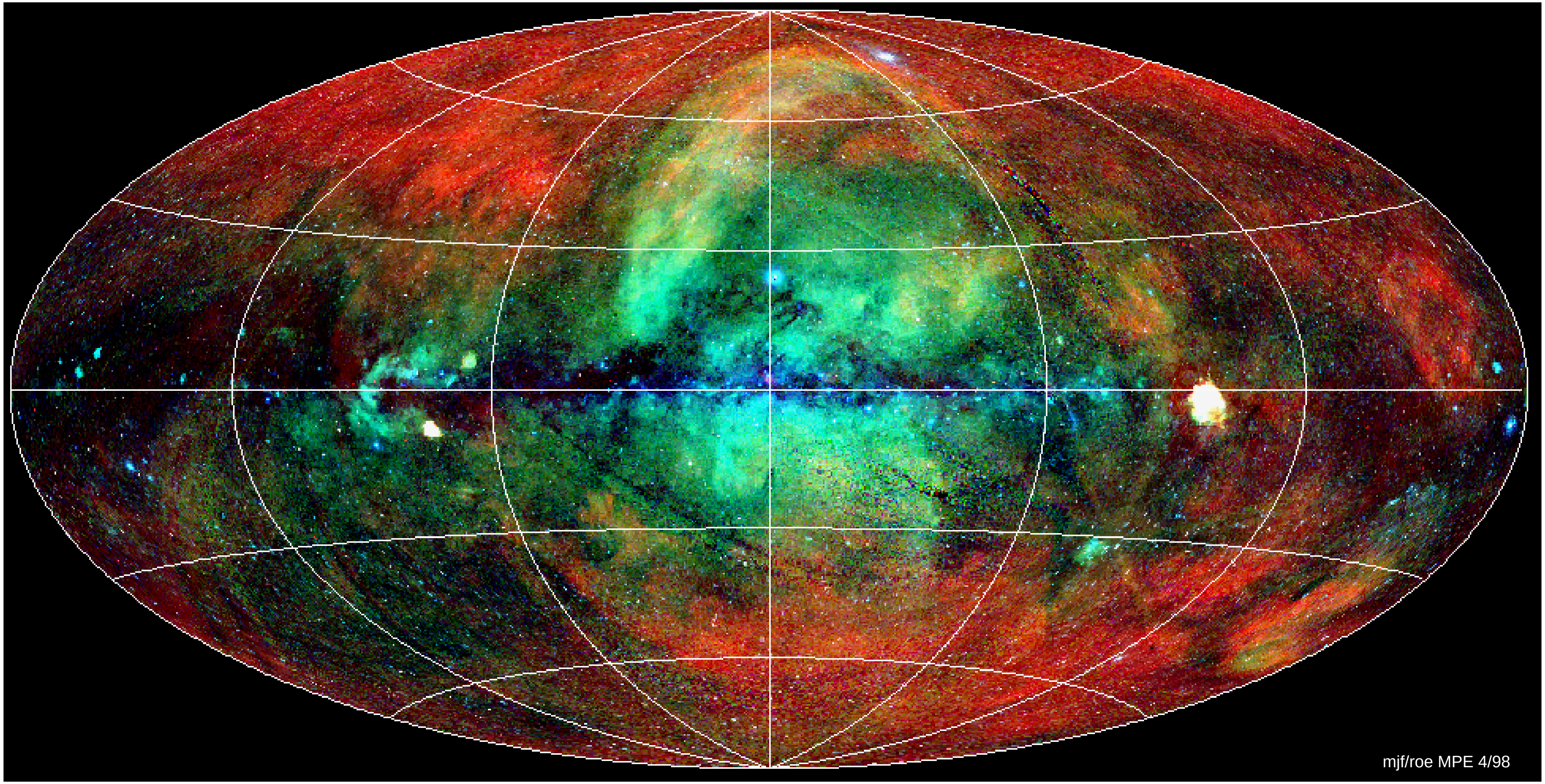
Determine the plate scale for each camera (and update the corresponding calibration file entries). For the brightest point sources also a PSF analysis (as function of off-axis angle) shall be performed.

Performance Verification vs. Calibration: 21d + 28d

- visibility of certain targets during Cal-PV:
  depends on launch date + successful commissioning + ART-XC + ...
- full calibration may not be available at the time of PV observation
- PV requires Cal, but can in turn also improve in-flight Cal (e.g., PSF)

Discussion/on-going work:

- coordination of mission planning of Cal-PV with IKI (e.g., regular video-cons)
- mock time-line: (commissioning and) CalPV phase
- CAL coordination with ART-XC: selected joint target list + schedule
- interface between MPE, IKI, and NPOL during commissioning and CalPV (dry-run)?
- joint SRG background study for L2: eROSITA + ART-XC
- CAL coordination with eROSITA working groups:
  is $\sim 2\%$ of calibration/monitoring time sufficient (compared to 5% for XMM)?
- revive ESO/MIDAS + EXSAS software for ROSAT analysis:
  work to port to "modern systems" started, mailing list created
  `https://lists.mpe.mpg.de/cgi-bin/mailman/listinfo/exsas`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