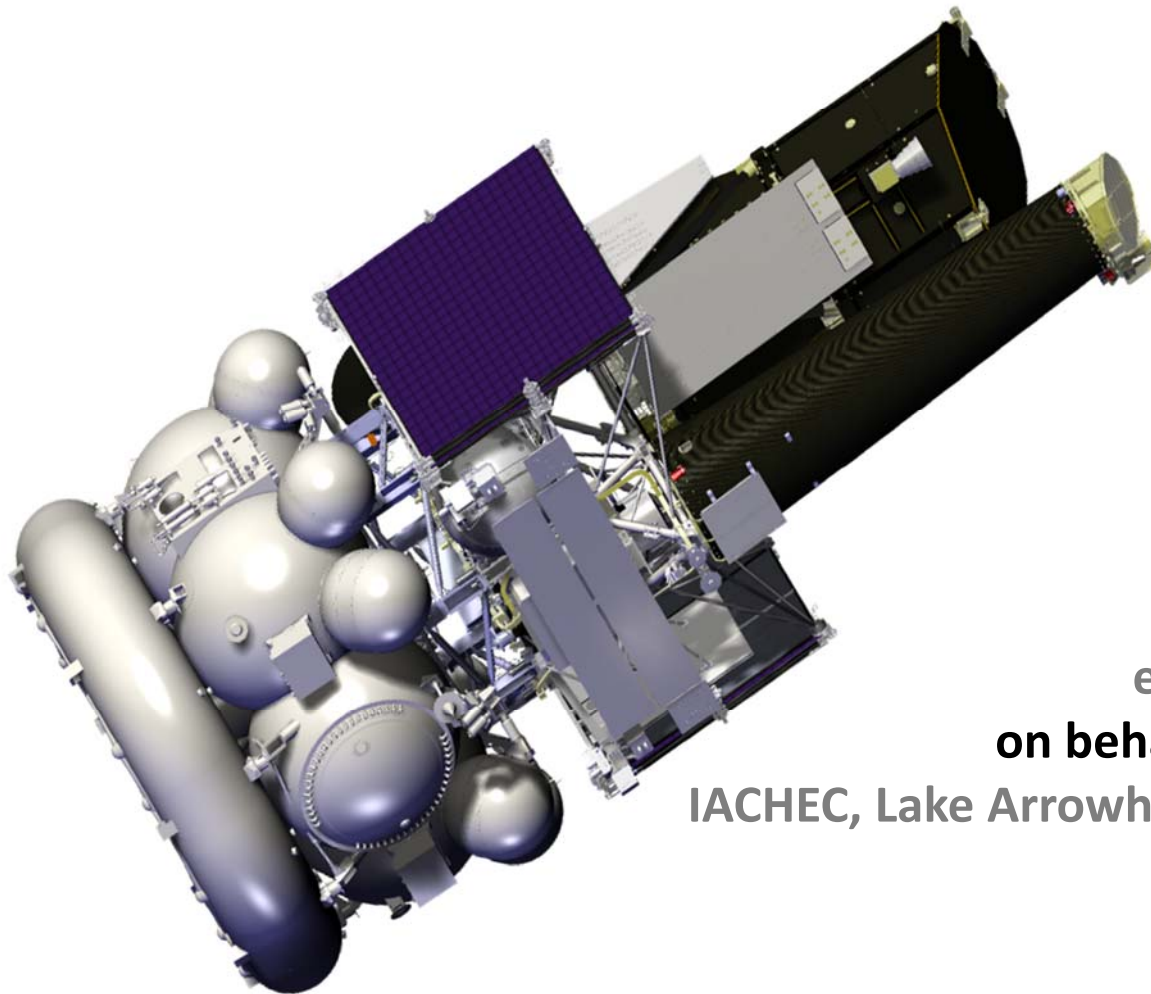


Status and Calibration of the eROSITA X-ray Telescope



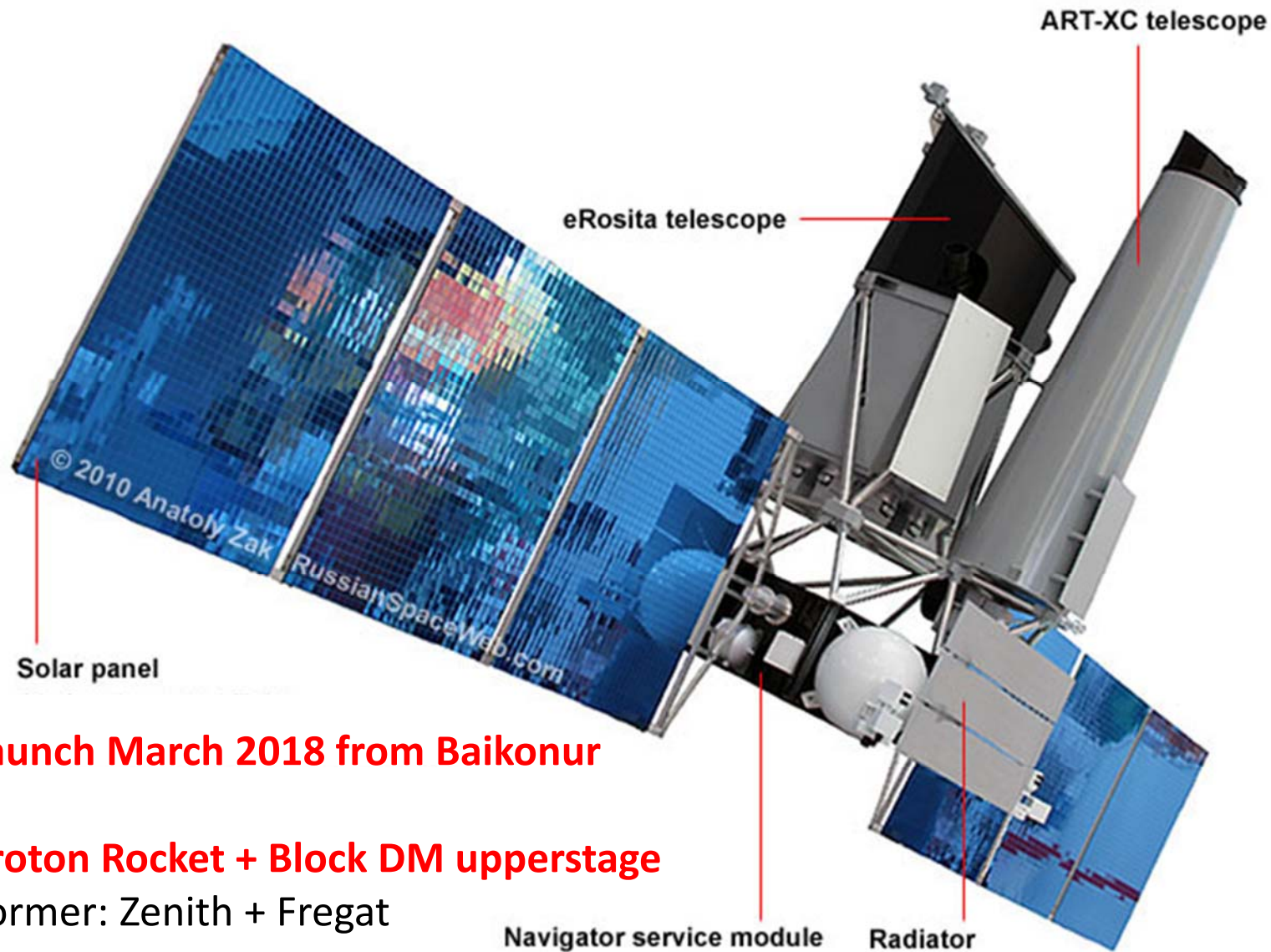
Vadim Burwitz

Max-Planck Institut für
extraterrestrische Physik

on behalf of the eROSITA Team

IACHEC, Lake Arrowhead, USA, 29-Mar-2017

Spektr-Rentgen-Gamma (SRG)



Launch March 2018 from Baikonur

Proton Rocket + Block DM upperstage

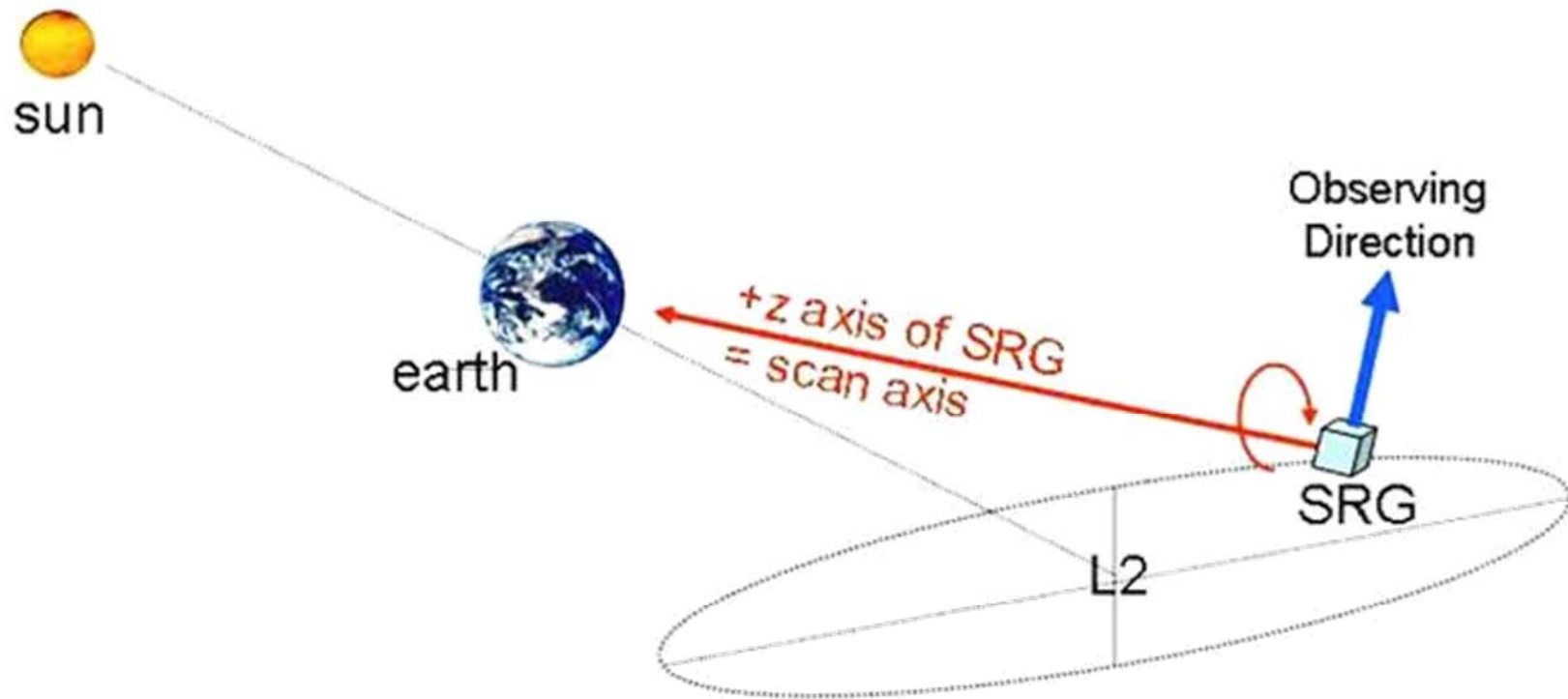
Former: Zenith + Fregat



IACHEC, Lake Arrowhead, USA, March 29, 2017



Spektr-RG Mission Profile



Orbit around L2

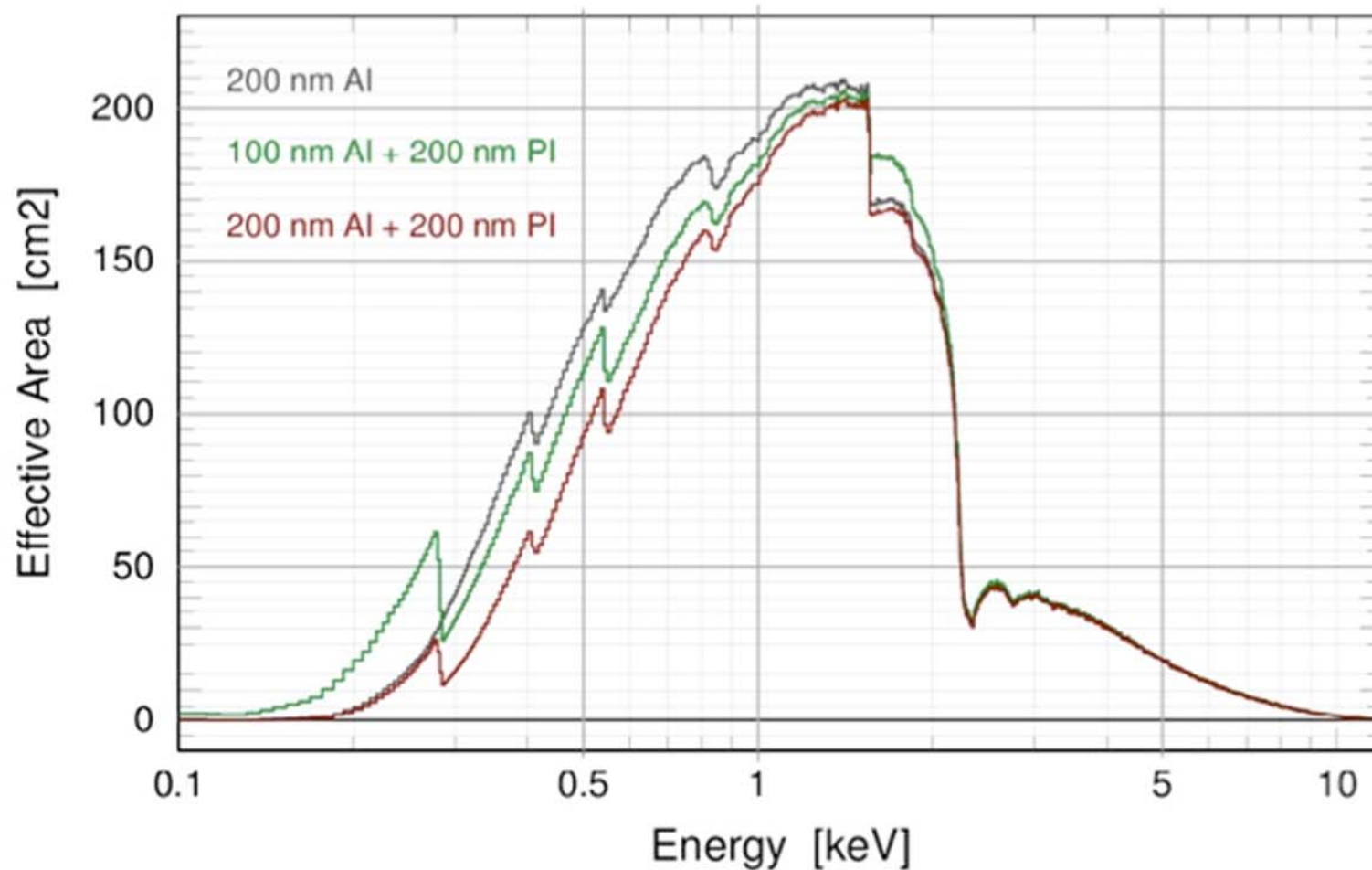
Permanent Rotation of S/C, ~ 4 hours / revolution

4 years all-sky survey

3 years pointed observations



Expected Telescope Survey Effective Area

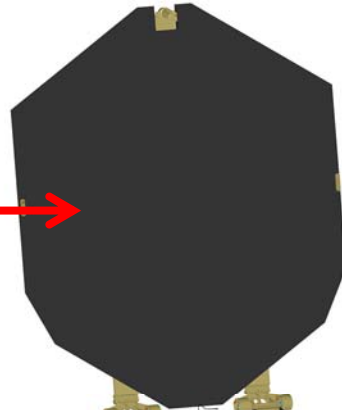


Effective areas of the three filter combinations for one eROSITA camera, composed of the expected effective area of one mirror assembly (averaged over the FoV), the filter transmissions, and the CCD quantum efficiency. All values are preliminary.



eROSITA

Front Cover



X-ray Baffles (7)

Mirror Modules (7)

Sun Sensors (2)

Electronics Radiators (2)

Star Trackers (2)

Electron Deflectors(7)

Camera Radiators (2)

Cameras (7), Electronics(7)
Cooling System (7)

IACHEC, Lake Arrowhead, USA, March 29, 2017



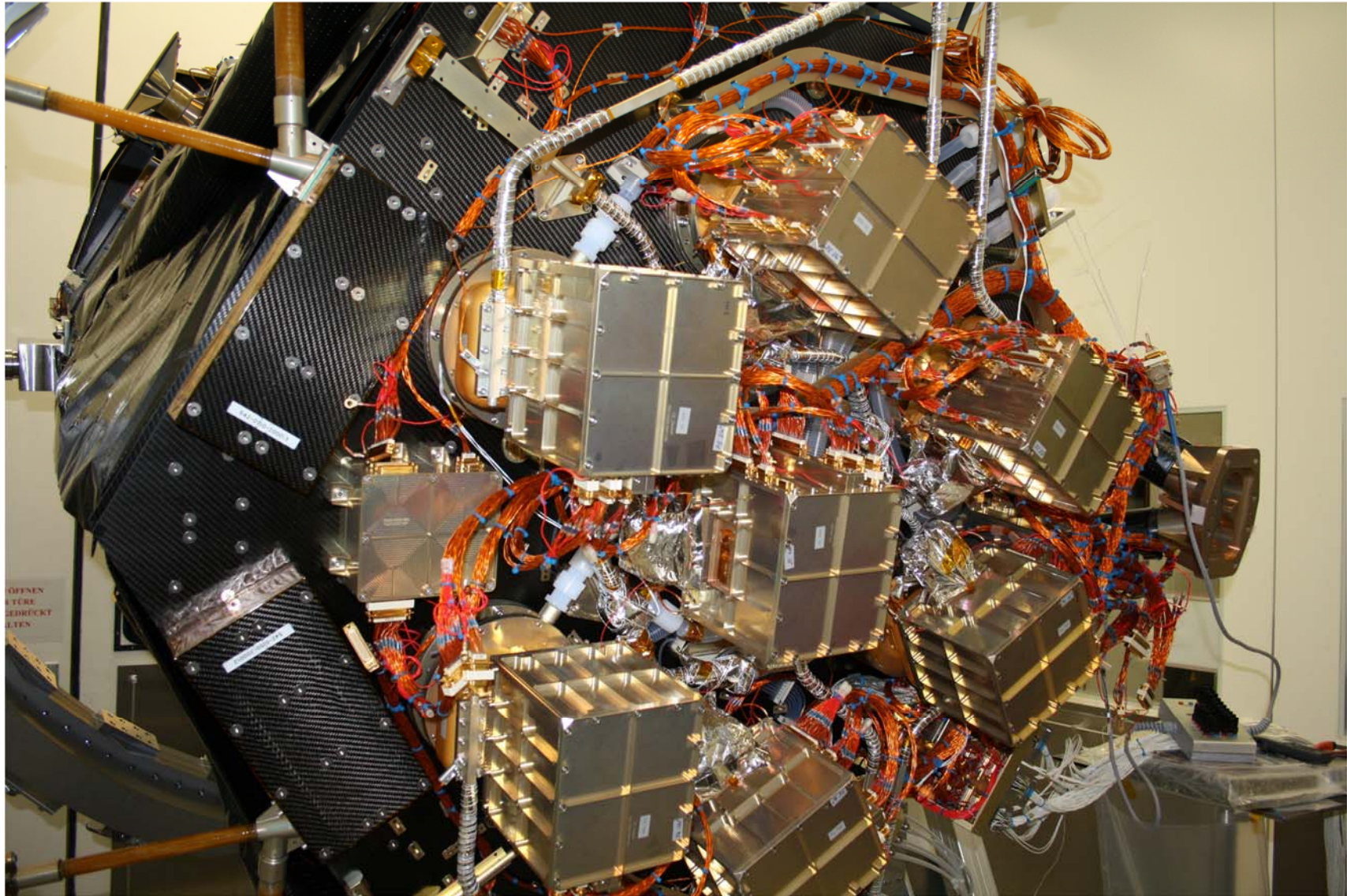
FM Hardware Status → Complete

	March 2017
Mirror Modules (8)	ready
X-ray Baffles (8)	ready
Electron Deflectors (8)	ready
Filterwheels (8)	ready
Camera Mechanics (8)	ready
Electronics Boxes (10 FM)	ready
Electronics Heatpipes (9)	ready
Harness	ready
MLI	ready
Heatpipe System Camera	ready
Telescope Structure	ready
Radiators (4)	ready
CCD-Modules (11)	ready
Electronics	ready

IACHEC, Lake Arrowhead, USA, March 29, 2017



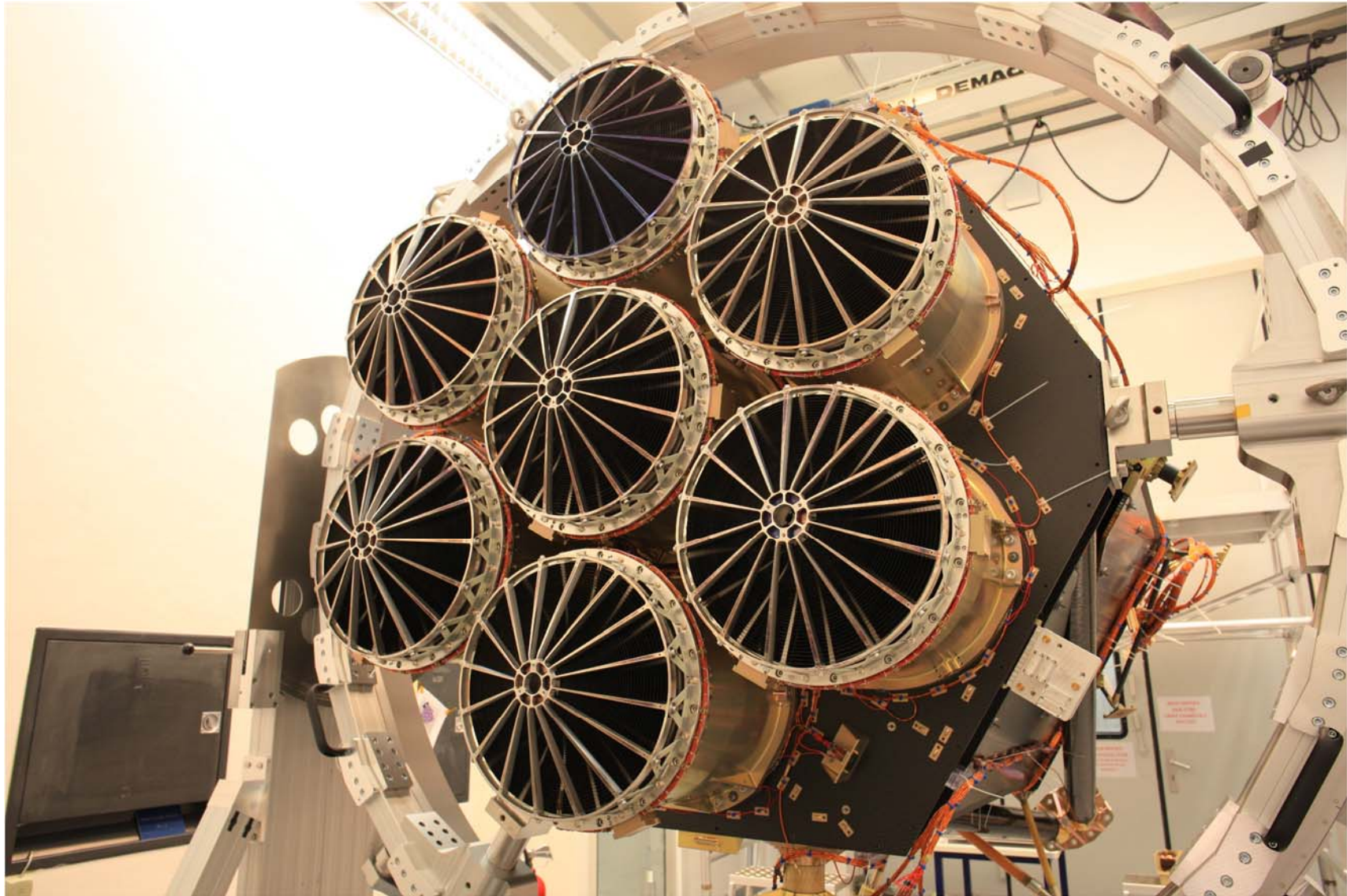
Completed Telescope Cameras



IACHEC, Lake Arrowhead, USA, March 29, 2017



Completed Telescope: Mirrors



IACHEC, Lake Arrowhead, USA, March 29, 2017



Completed Telescope: PANTER Final Test



IACHEC, Lake Arrowhead, USA, March 29, 2017



Completed Telescope: PANTER Final Test



IACHEC, Lake Arrowhead, USA, March 29, 2017



eROSITA Departure from PANTER

Dec. 5th 2017



Transport to Moscow



IACHEC, Lake Arrowhead, USA, March 29, 2017



eROSITA at Lavochkin, Moscow



IACHEC, Lake Arrowhead, USA, March 29, 2017

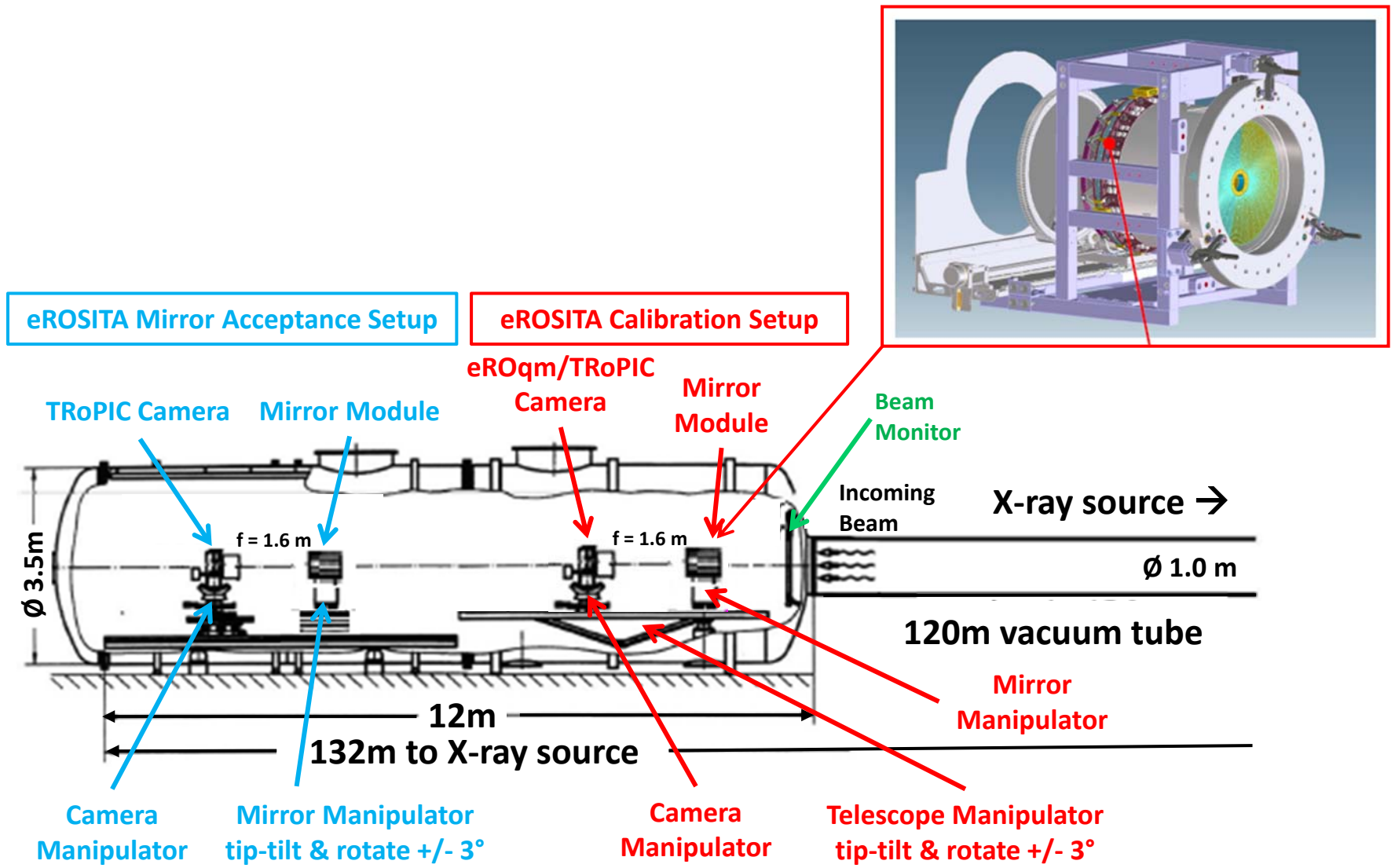


Qualification Tests & Calibration

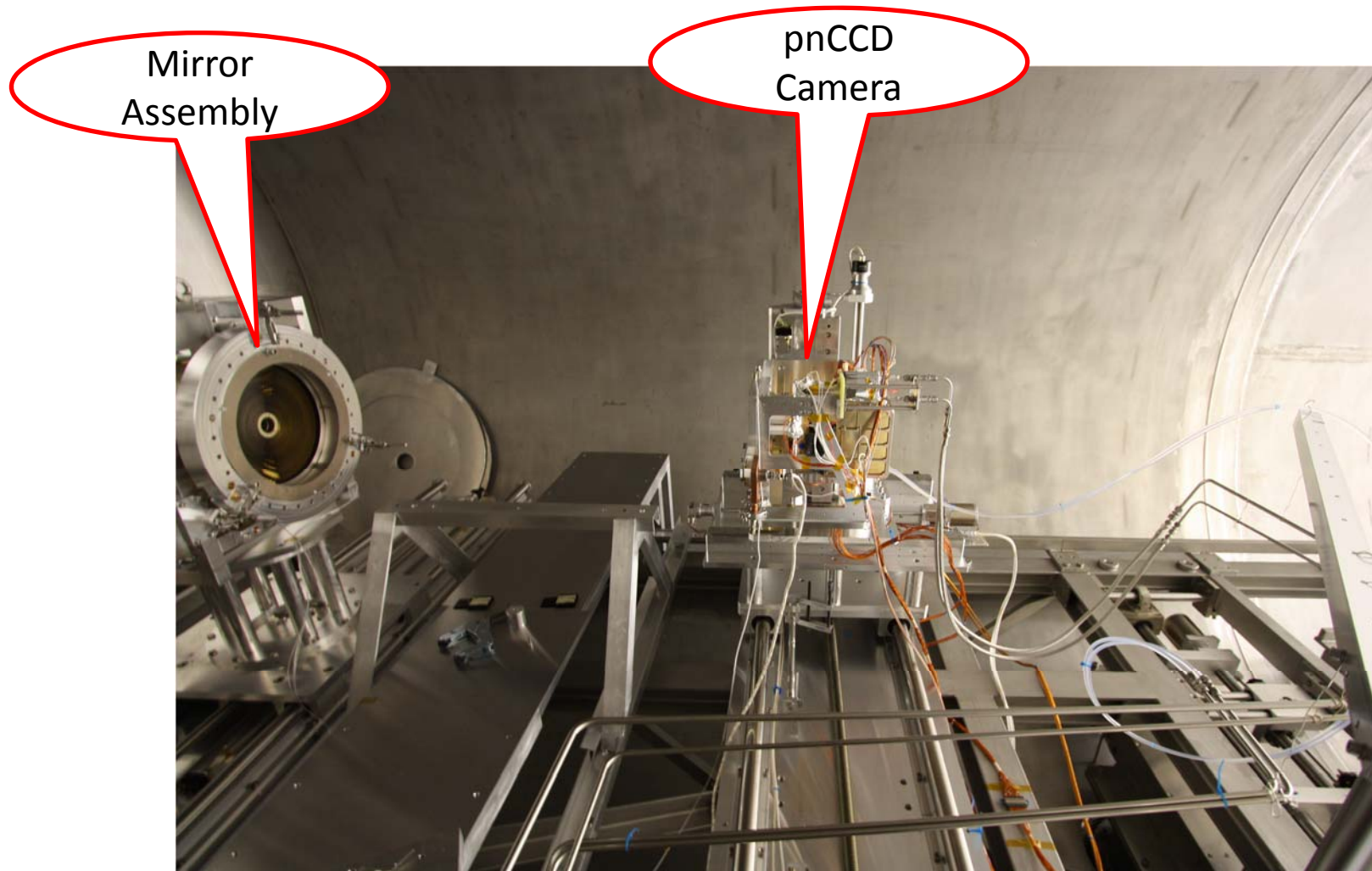
Vibration	MPE Shaker, IABG
Acoustic Noise	IABG
EMC	MPE, IABG
Thermal Vacuum	MPE: TVK2,4,5, PUMA, PANTER, IABG
Calibration	MPE: GEPARD, PUMA, PANTER



eROSITA Mirror Tests at the PANTER test Facility



Calibrating the eROSITA X-ray Optics at PANTER



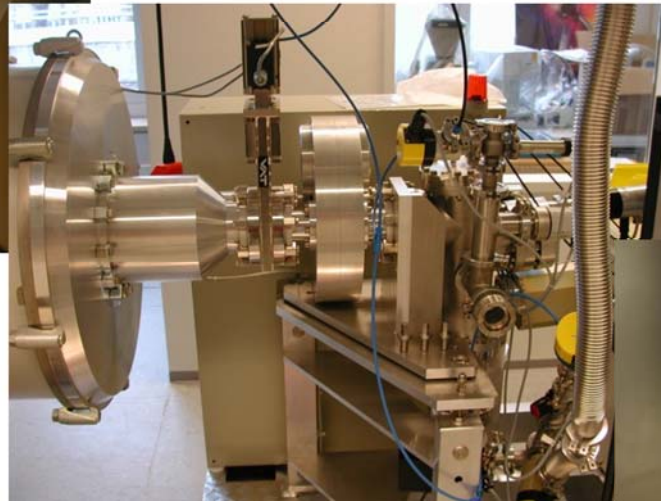
IACHEC, Lake Arrowhead, USA, March 29, 2017



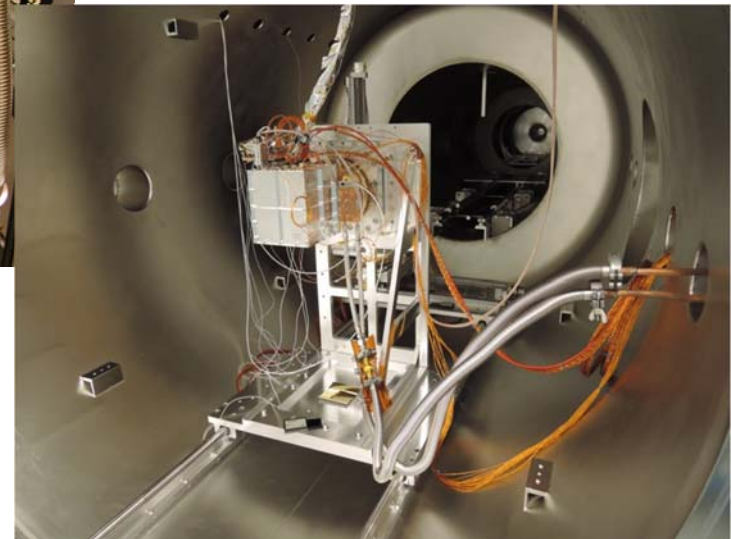
PUMA Facility



Vacuum: $p = 2 \times 10^{-7}$ mbar
StirlingCooler: $T < -120^\circ\text{C}$
2nd cooler for electronics



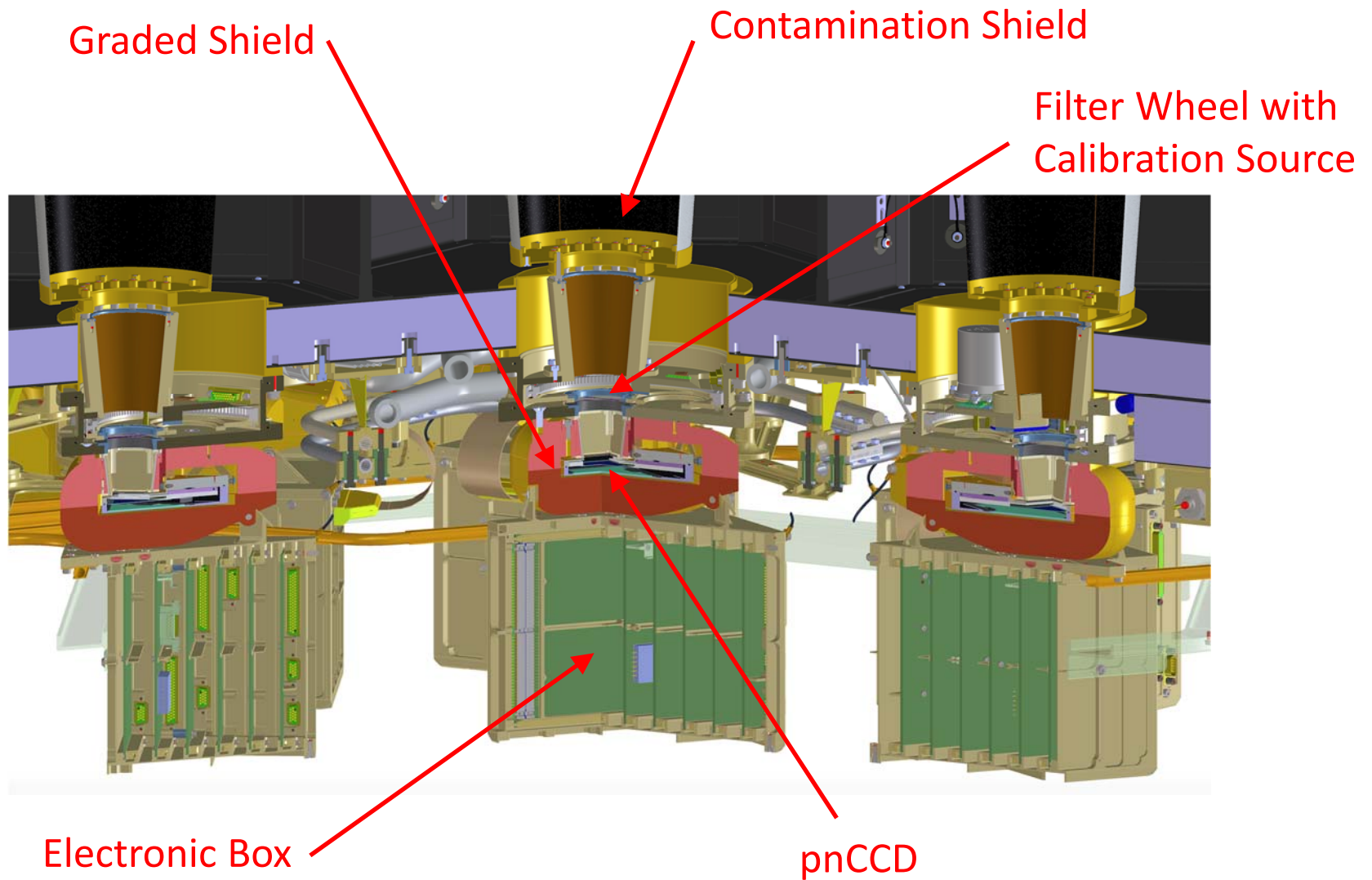
Multitarget X-ray Source
Double Filterwheel
charact. lines 0.3keV – 10keV



eROSITA FM camera in PUMA



The eROSITA Cameras



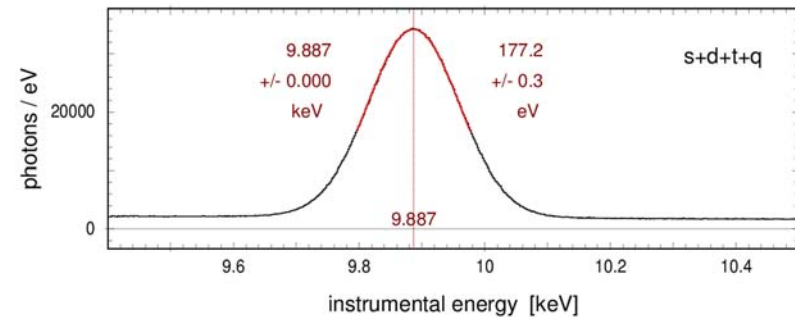
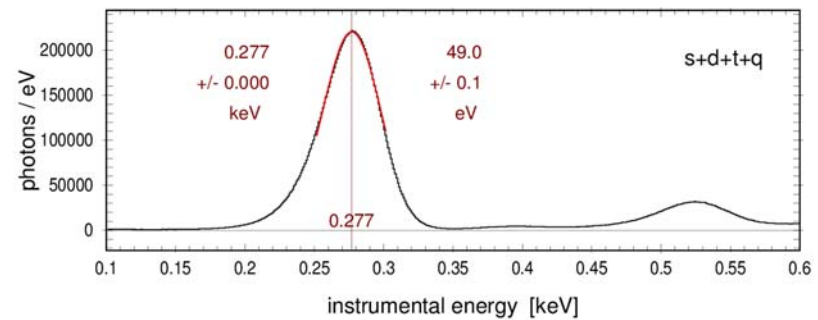
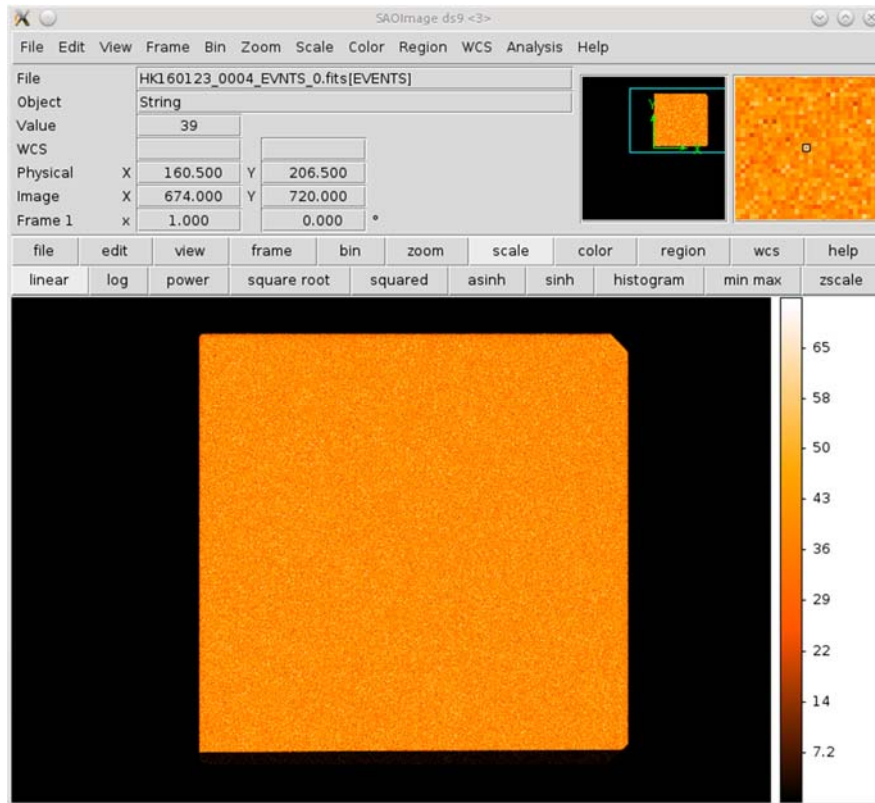
The eROSITA Cameras

- 7 framestore pn CCDs developed at MPE
- 50 ms frame time
- Sensitive in the 0.2-10 keV
- 5 CCDs with on chip Al-filter 2 without
- Filterwheel with Al, PI filters and
Fe55 calibration source
- Energy Resolution 50eV@0.3keV 157eV@6.4keV



FM Camera Calibration

- Spectral resolution at all 9 measured energies well within specification
- Extremely good uniformity
- Only weak dependence on temperature of CCD and electronics (unlike XMM-EPIC!)

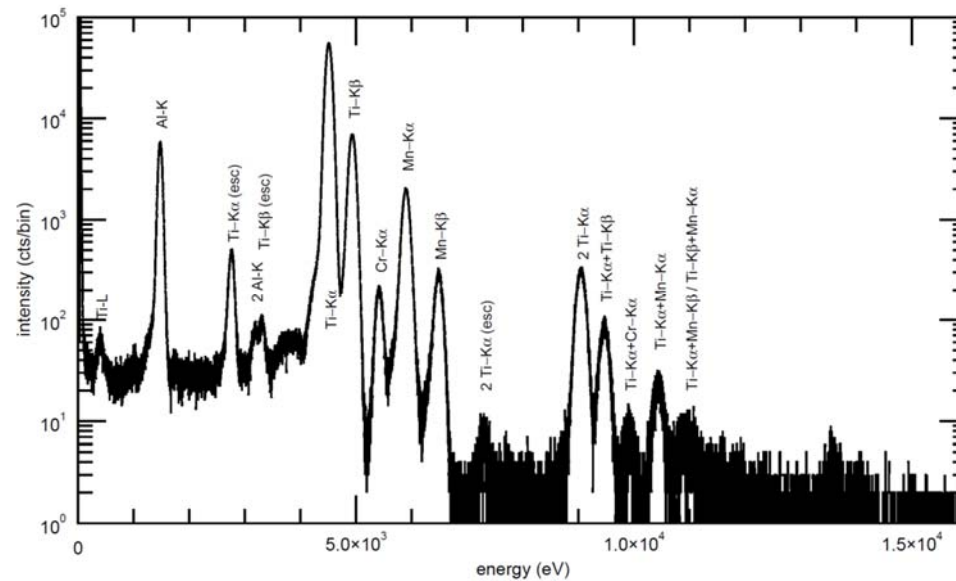
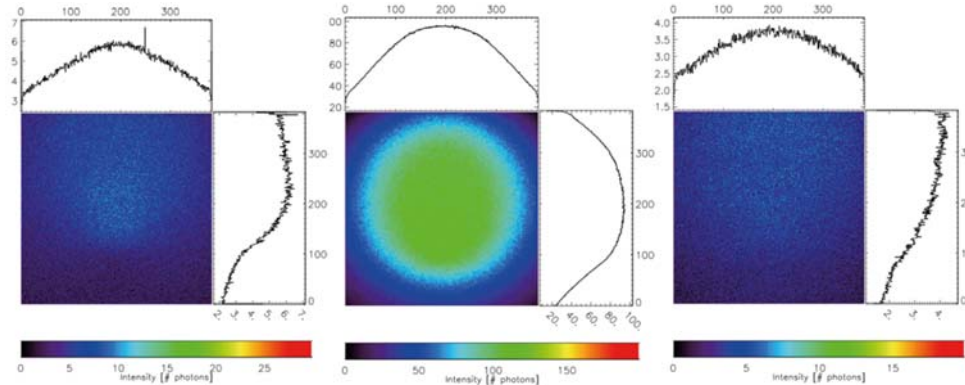


Onboard Fe 55 Calibration Source

Al K α

Ti K α

Mn K α



Summary of detector calibration measurements

- At least 1 energies from C-K to Ge-K have to be measured
- ~30 million events per energy with
 - no pile-up
 - enough first singles (~10/pixel)
 - low continuum
- In total about one week of measurements per camera is needed at PUMA



The eROSITA Mirror Modules

Stray-light as driver for baffle design

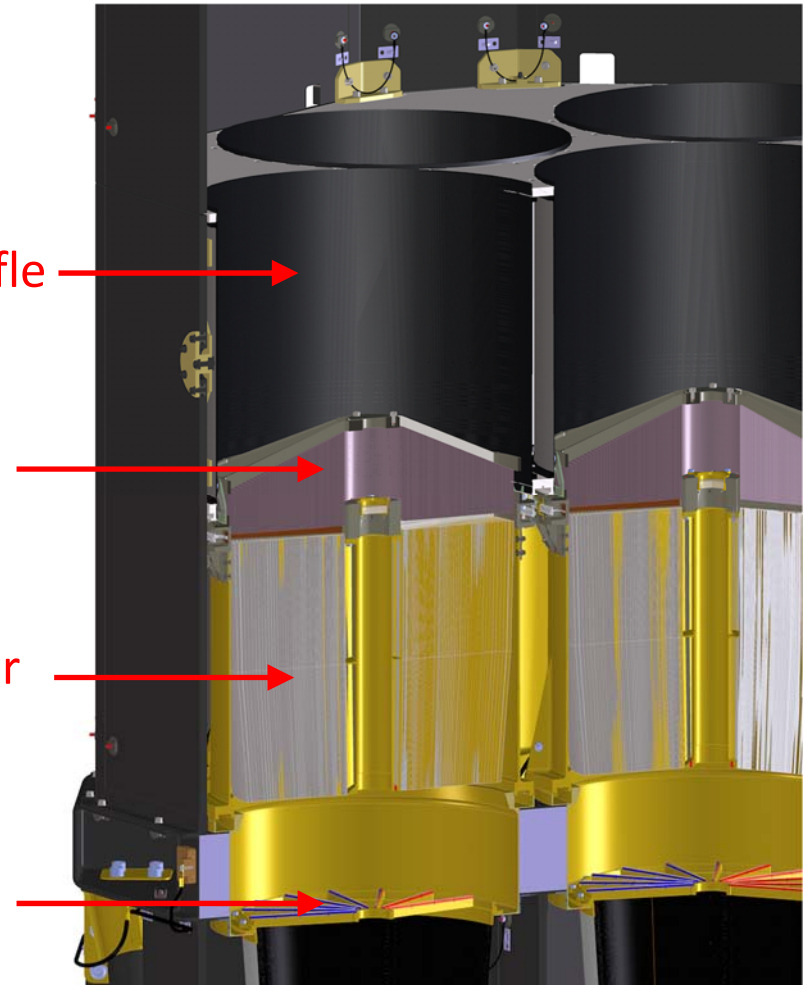
- Optical stray-light
 - Sun shield
 - Baffle (against Earth radiation)
 - Mirror backsides
 - Filter
- X-ray stray-light
 - Baffle (against off-axis single reflections)
 - Mirror backsides

Thermal baffle

X-ray baffle

X-ray Mirror

Electron
deflector



eROSITA Mirror Calibration

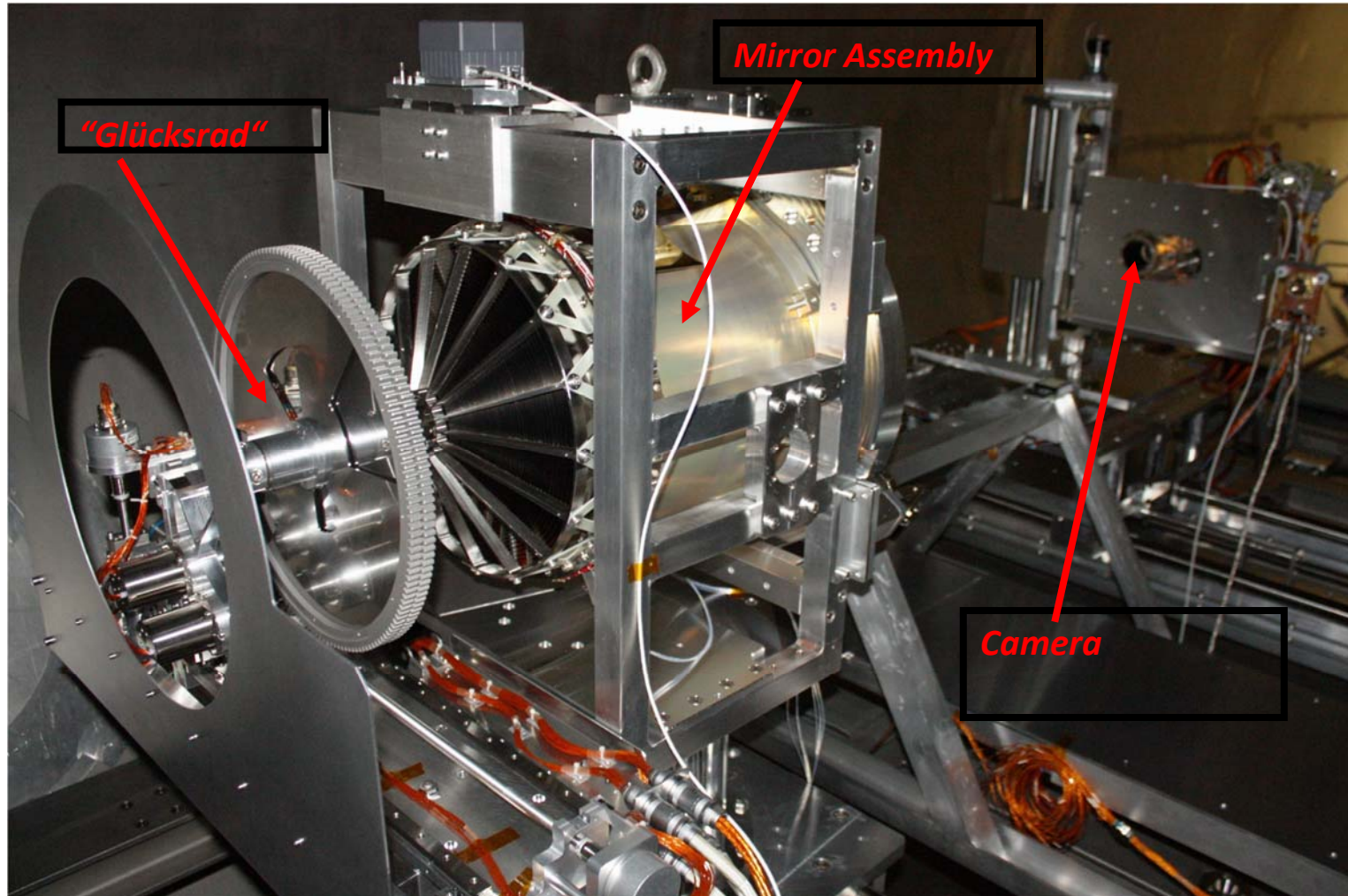
Each of the 8 Mirror Modules
(7 FMs and 1 spare)
will have gone through the following
procedure:

- an X-ray acceptance test
 - HEW and effective area
- Integration of the baffle unit
- X-ray test after baffle integration
 - HEW and effective area
- Environmental tests (thermal cycling and vibration)
- Final calibration tests to measure the:
 - PSF on-axis / off-axis in the energy range 0.28 – 8.04 keV
 - effective area in the energy range 0.28 – 8.04 keV
 - contribution of scattering
 - Focal length measurement in X-rays and physically

Mirror Assembly	FM 1	FM 2	FM 3	FM 4	FM 5	FM 6	FM 7	FM 8 (FS)
Acceptance Test	Green	Green	Green	Green	Green	Green	Green	Green
X-Ray Baffle Mounting	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green
X-Ray Test	Green	Light Blue	Light Blue	Light Blue	Light Blue	Light Blue	Light Blue	Light Blue
Vibration	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green
X-Ray Test	Green	Light Blue	Light Blue	Light Blue	Light Blue	Light Blue	Light Blue	Light Blue
TV	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green	Light Green
X-Ray Test	Green	Light Blue	Light Blue	Light Blue	Light Blue	Light Blue	Light Blue	Light Blue
Telescope Module Test	Green	Light Blue	Light Blue	Light Blue	Light Blue	Light Blue	Light Blue	Light Blue
Calibration	Green	Green	Green	Green	Green	Green	Green	Green



Mirror Assembly in PANTER



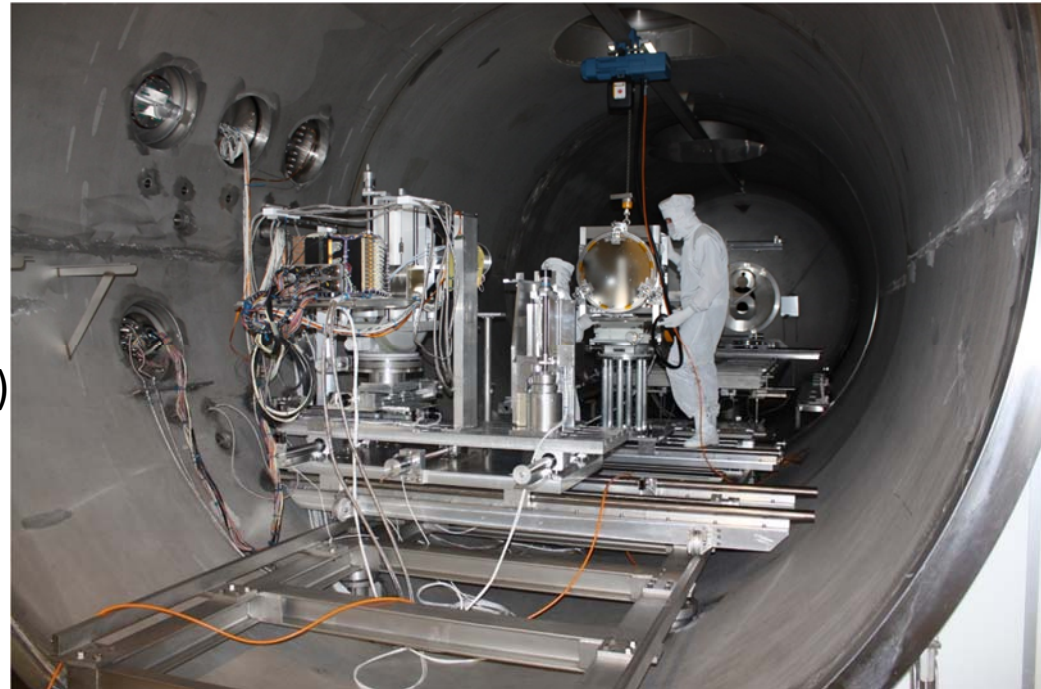
IACHEC, Lake Arrowhead, USA, March 29, 2017



FM Mirror Calibration Overview

Calibration Activities:

- Alignment (pitch, yaw)
 - Optical
 - X-ray (Al-K)
- **Focus search (Al-K)**
- Deep in-focus, on axis (HEW)
- Focal plane mapping (C-K .. Cu-K)
 - PSF on-/off-axis
 - Eff. Area on-/off-axis
 - Vignetting
- Effective Area (C-K to Ge-K)
 - Direct on-/off-axis
 - „Glücksrad“ quasi parallel illumination
 - Continuum
- Focal length
 - X-ray
 - mechanical gage

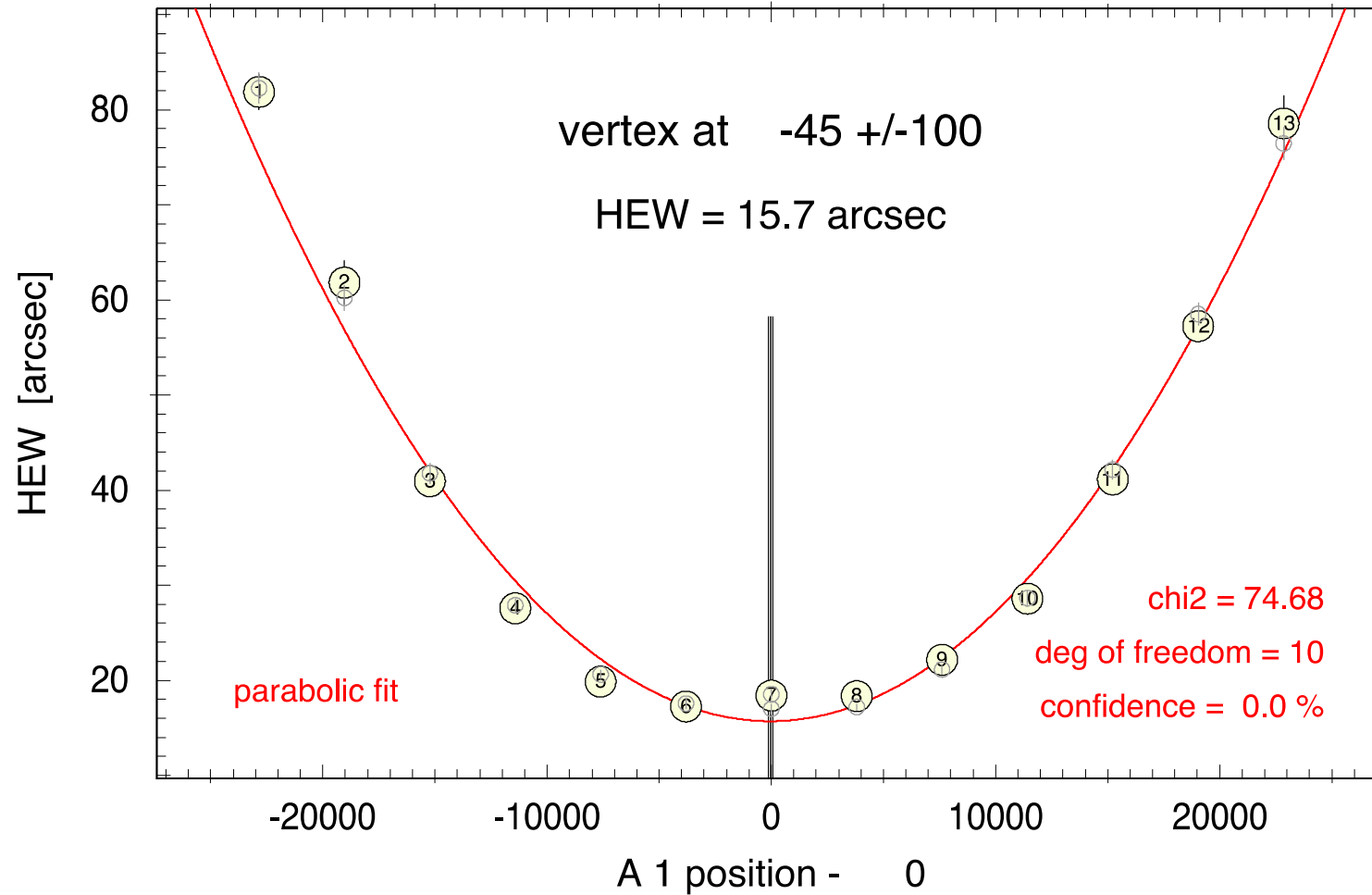


**Calibration of all 8 Mirrors
7 FM + 1 Flight spare
Completed end of May 2016**

~ 2 weeks / mirror at PANTER



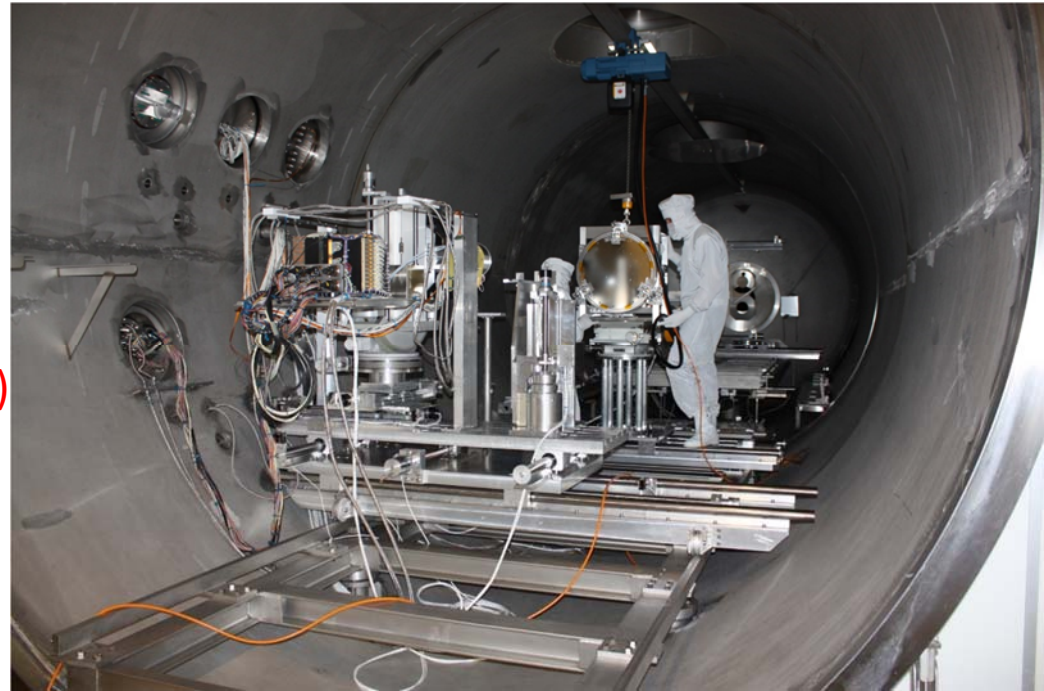
Focus Search



FM Mirror Calibration Overview

Calibration Activities:

- Alignment (pitch, yaw)
 - Optical
 - X-ray (Al-K)
- Focus search (Al-K)
- Deep in-focus, on axis (HEW)
- Focal plane mapping (C-K .. Cu-K)
 - PSF on-/off-axis
 - Eff. Area on-/off-axis
 - Vignetting
- Effective Area (C-K to Ge-K)
 - Direct on-/off-axis
 - „Glücksrad“ quasi parallel illumination
 - Continuum
- Focal length
 - X-ray
 - mechanical gage

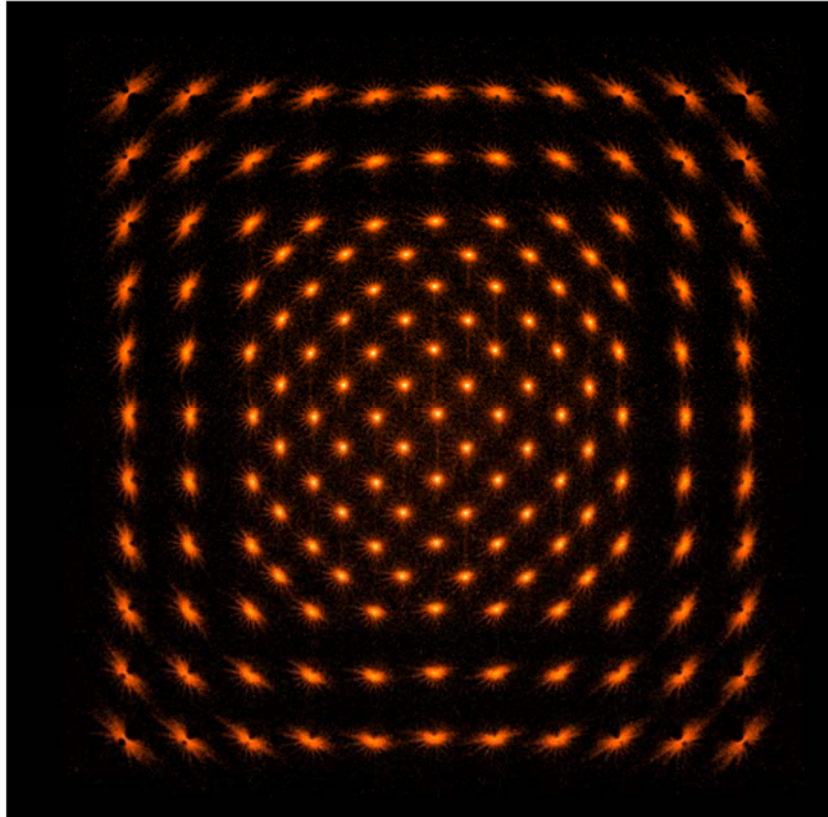


Calibration of all 8 Mirrors
7 FM + 1 Flight spare
Completed end of May 2016

~ 2 weeks / mirror at PANTER

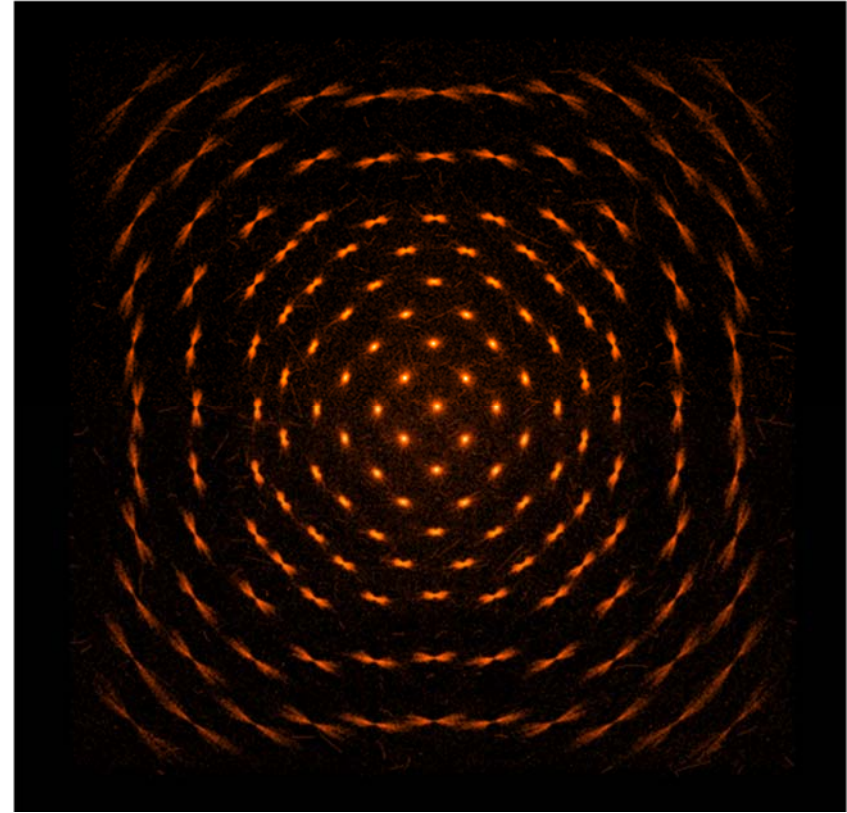


Focal Plane Mapping



Al $K\alpha$

HEW = 16,3 arcsec



Cu $K\alpha$

HEW = 14,7 arcsec

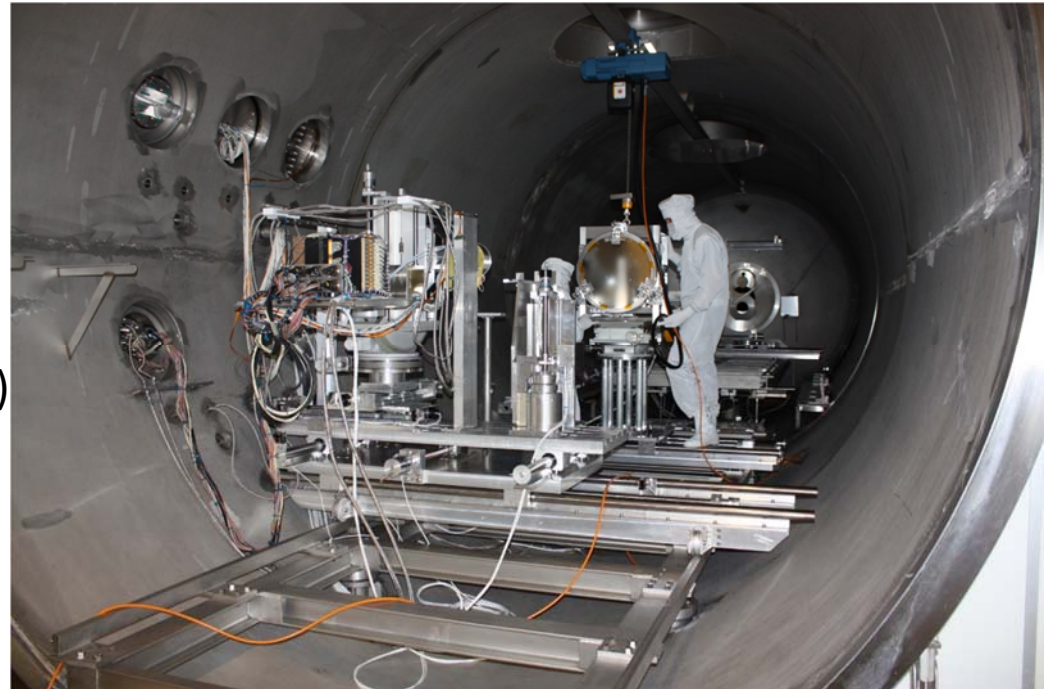
images shown in log scale



FM Mirror Calibration Overview

Calibration Activities:

- Alignment (pitch, yaw)
 - Optical
 - X-ray (Al-K)
- Focus search (Al-K)
- Deep in-focus, on axis (HEW)
- Focal plane mapping (C-K .. Cu-K)
 - PSF on-/off-axis
 - Eff. Area on-/off-axis
 - Vignetting
- **Effective Area (C-K to Ge-K)**
 - **Direct on-/off-axis**
 - **„Glücksrad“ quasi parallel illumination**
 - **Continuum**
- Focal length
 - X-ray
 - mechanical gage

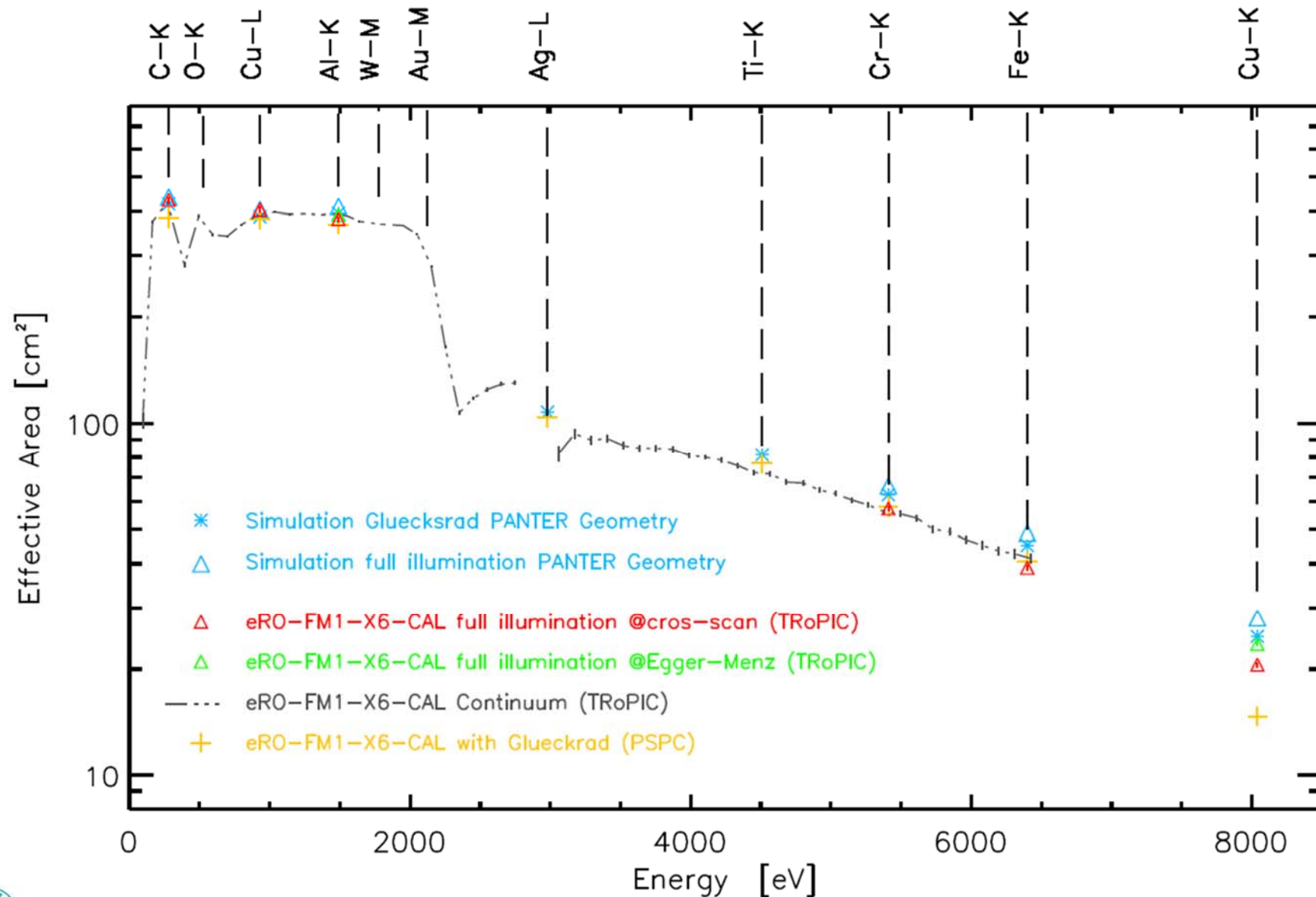


Calibration of all 8 Mirrors
7 FM + 1 Flight spare
Completed end of May 2016

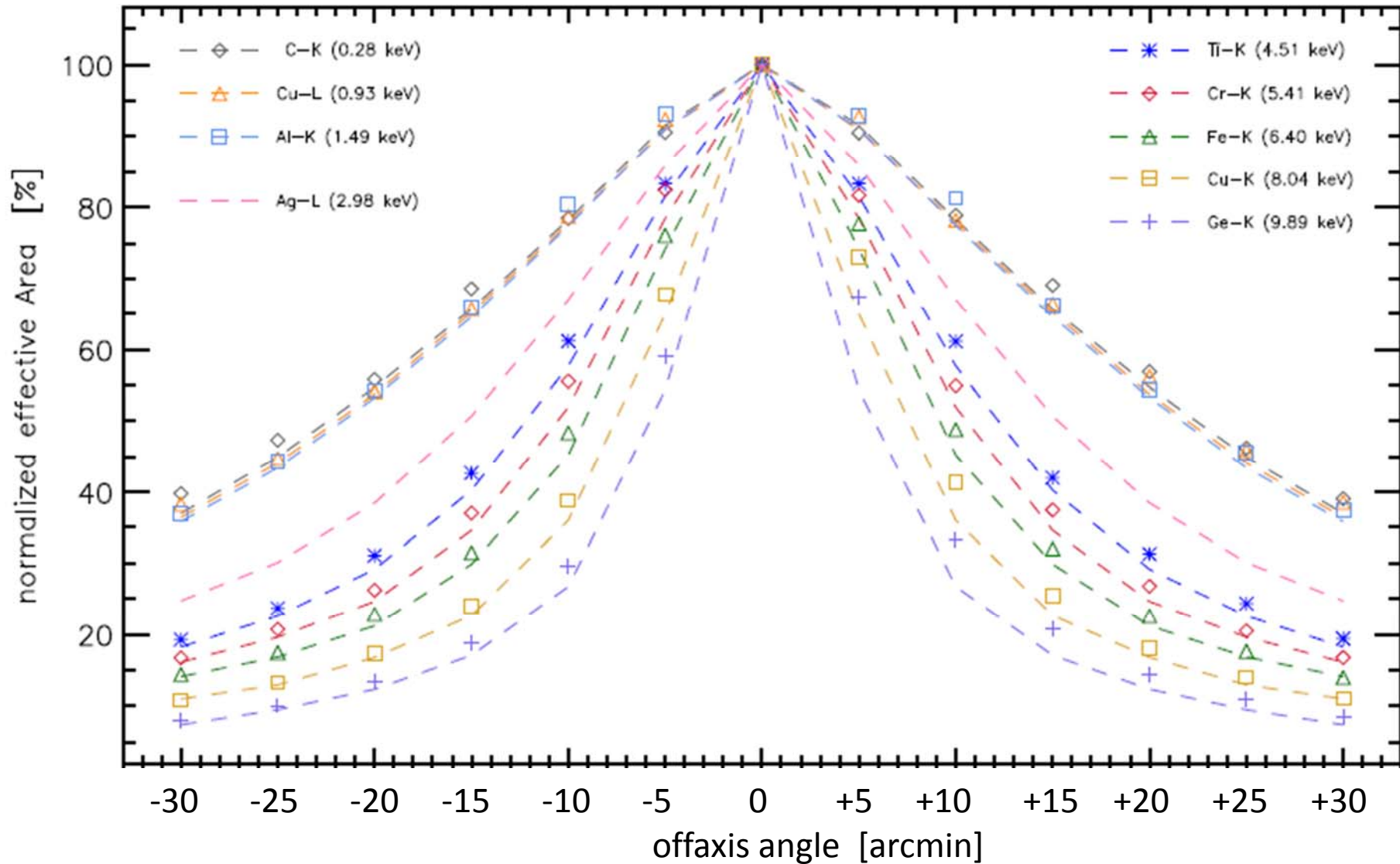
~ 2 weeks / mirror at PANTER



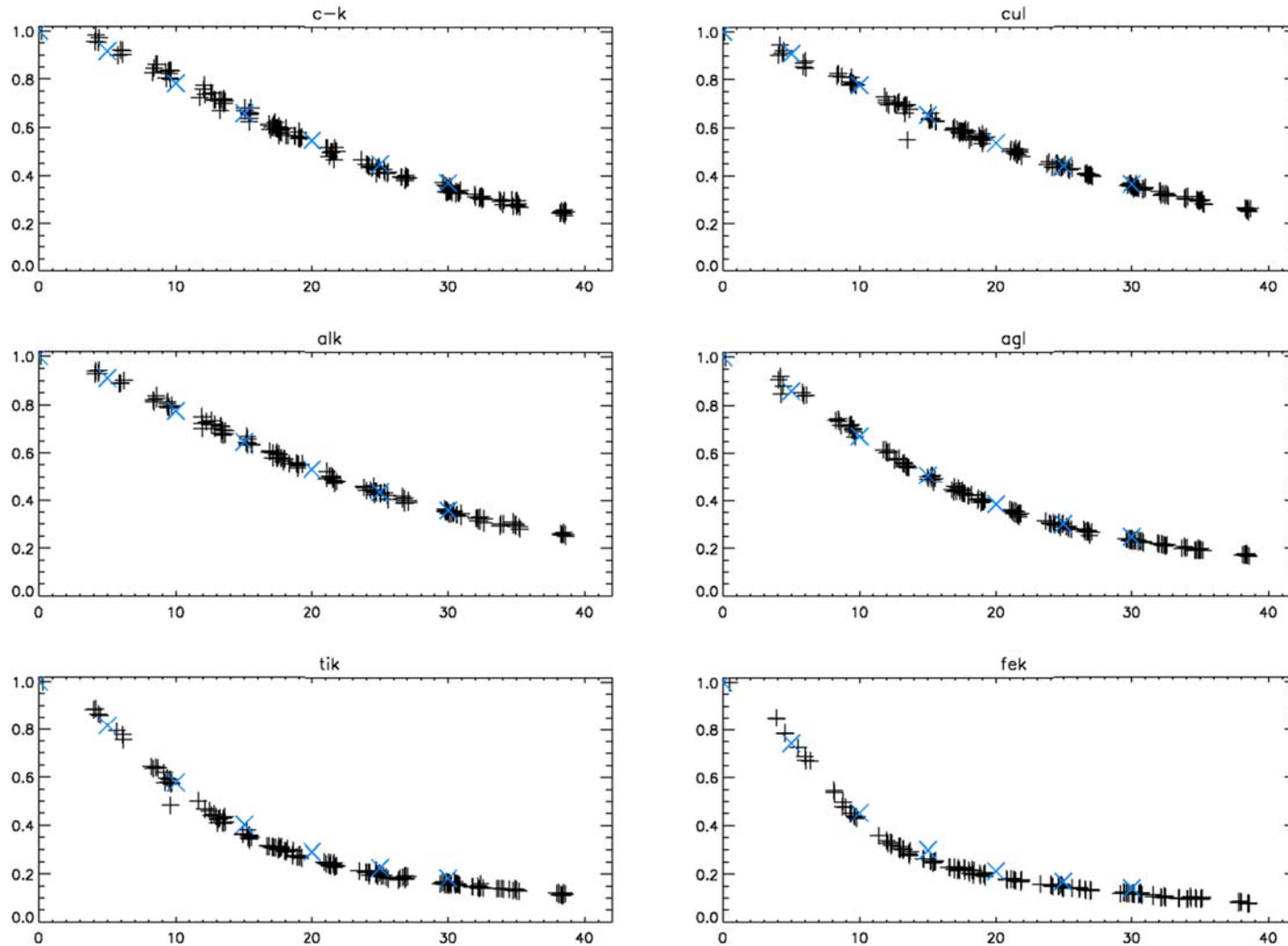
Effective Area Measurements



On-/off-axis Effective Area: Vignetting



Focal Plane Mapping → Vignetting



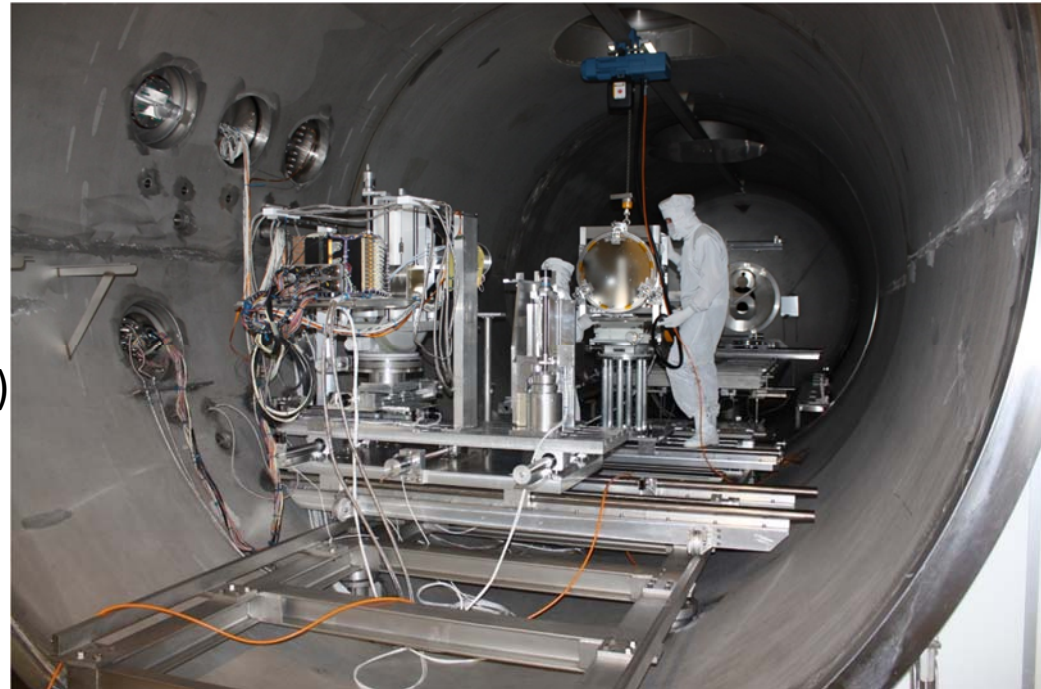
data from off-axis eff. area and focal plane mapping combined



FM Mirror Calibration Overview

Calibration Activities:

- Alignment (pitch, yaw)
 - Optical
 - X-ray (Al-K)
- Focus search (Al-K)
- Deep in-focus, on axis (HEW)
- Focal plane mapping (C-K .. Cu-K)
 - PSF on-/off-axis
 - Eff. Area on-/off-axis
 - Vignetting
- Effective Area (C-K to Ge-K)
 - Direct on-/off-axis
 - „Glücksrad“ quasi parallel illumination
 - Continuum
- Focal length
 - X-ray
 - mechanical gage



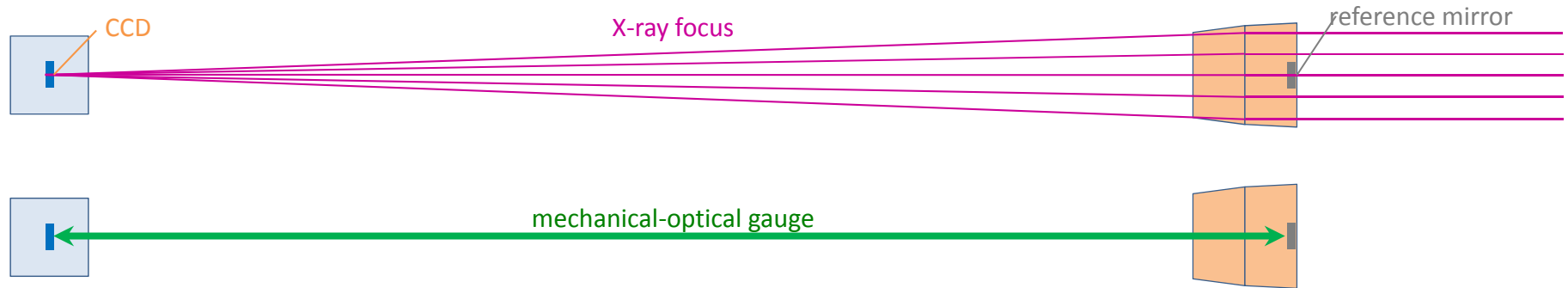
Calibration of all 8 Mirrors
7 FM + 1 Flight spare
Completed end of May 2016

~ 2 weeks / mirror at PANTER

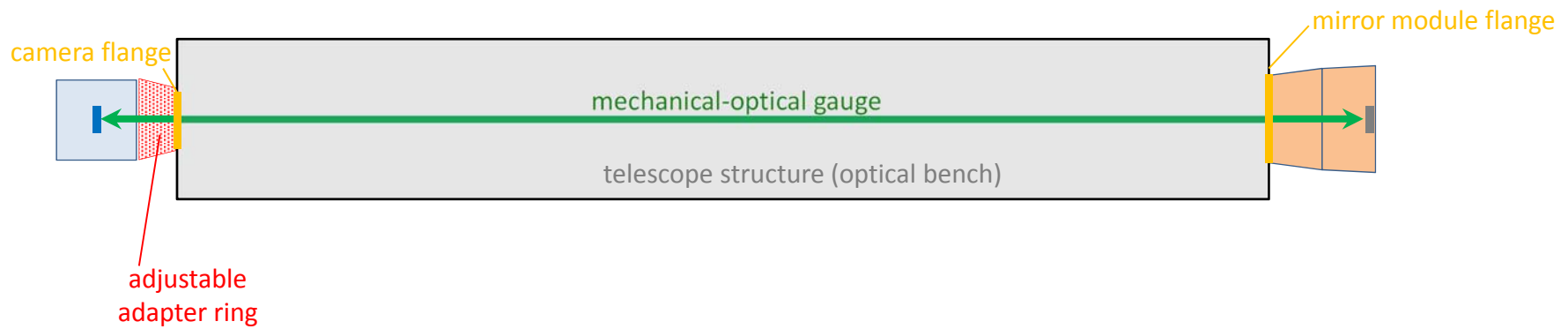


Focal Length

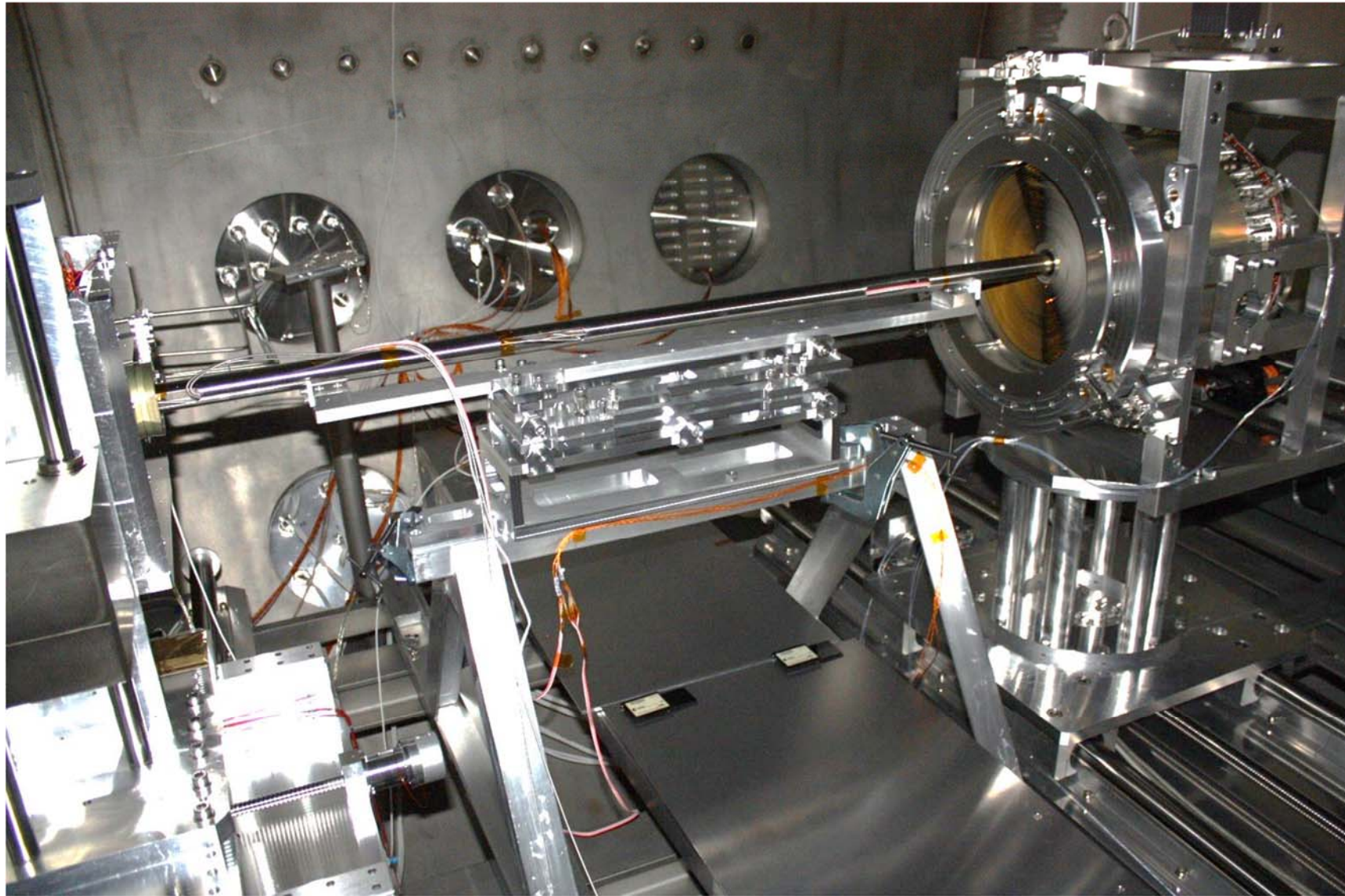
(1) X-Ray Calibration



(2) Mounting into Telescope Structure



Focal Length Gauge (Vacuum Proof)



IACHEC, Lake Arrowhead, USA, March 29, 2017



Summary of the eROSITA Calibration

Mirror Assembly Results

	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	
HEW Al-K α @ 1.49 keV	17.0	16.0	15.5	15.9	16.5	16.1	15.6	17.1	[''
HEW Cu-K α @ 8.04 keV	14.7	14.5	15.1	16.3	15.6	15.1	16.2	17.8	[''
Eff. Area @ Al-K α	392	391	393	369	388	378	392	390	[cm ²
Eff. Area @ Cu-K α	24.8	24.8	25.1	23.8	24.1	25.1	25.0	24.2	[cm ²
Scattering @ Cu-K α	10.2	11.1	11.0	12.1	13.2	11.2	12.8	12.3	[%]

Camera Calibration Results for Spectral Resolution [eV]

	FM1	FM2	FM3	FM4	FM5	FM6	FM7	QE
C-K α @ 0.277 keV	49	58	58	58	50	59	58	16%
O-K α @ 0.525 keV	56	65	64	64	57	69	66	53%
Cu-L @ 0.93 keV	68	74	70	70	68	71	72	89%
Al-K α @ 1.49 keV	77	82	77	77	75	77	72	85%
Ti-K α @ 4.51 keV	117	125	118	118	116	120	122	98%
Fe-K α @ 6.40 keV	136	145	138	138	135	141	142	99%
Cu-K α @ 8.04 keV	156	167	158	158	155	159	163	100%
Ge-K α @ 9.89 keV	175	204	178	173	170	180	182	98%



eROSITA Status

Jan – Jun 2016 PANTER / PUMA

The 7 FM Mirrors Assemblies and 7 Cameras have all been calibrated
→ the calibration results are currently being fed into the SASS

Jun - Aug 2016 MPE

all 7 Mirrors and 7 Cameras

→ Integrated into the telescope structure.

Sep – Nov 2016

the complete eROSITA with all 7 Telescope was tested

→ Camera cooling, Thermal control, Communication, Electronics, CCDs

Dec 2016 IABG

last environmental tests (vibration, EMC)

Jan 2017 → delivery to Russia, post transport tests → all ok

2017 → integration and testing of eROSITA on satellite platform

2018 → Launch from Baikonur

2018 → Commissioning and Cal Perf. Verif. → thereafter survey begin



Ground Based Telescope Cross Calibration of Spectr-XG (eROSITA and ART-XC)

In the spirit of simplifying in-orbit cross-calibration

A plan is being setup for a ground based cross-calibration of the eROSITA and ART-XC spare mirror and spare detector units at PANTER. This will be done to ensure that the calibration of overlapping 6-10 keV spectral region is well understood.

In PANTER it will be possible to automatically switch between mirrors and detectors in the beam.

This is taking the IACHEC philosophy to the pre-launch phase of a new mission

