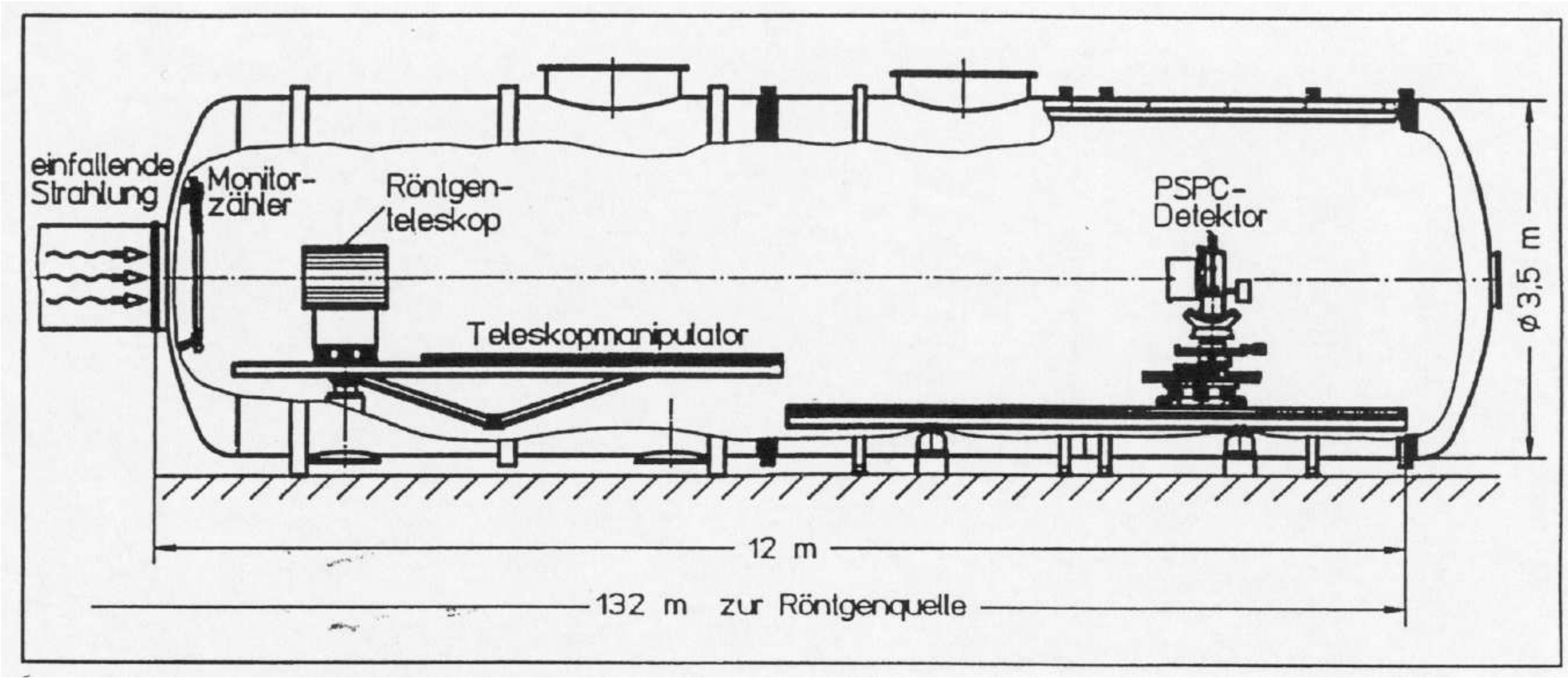
eROSITA mirror calibration:

First measurements and future concept



PANTER instrument chamber set-up for XMM mirror calibration:

12 m length, 3.5 m diameter: 8m to focal plane instrumentation

now: f = 1.6 m; cameras = PSPC, EPIC-pn, TRoPIC

eROSITA product tree of telescope FM

- telescope = 7 modules with 54 shells each + 7 cameras
  - telescope infrastructure
    - optical bench
    - cover and mechanism
    - thermal control system
    - baffle
  - mirror system
    - mirrors
    - structure
  - cameras
    - camera housing
    - CCD module
    - electronics box
    - electronics and software

eROSITA optics at PANTER: test objects

- telescope = 7 modules with 54 shells each + 7 cameras

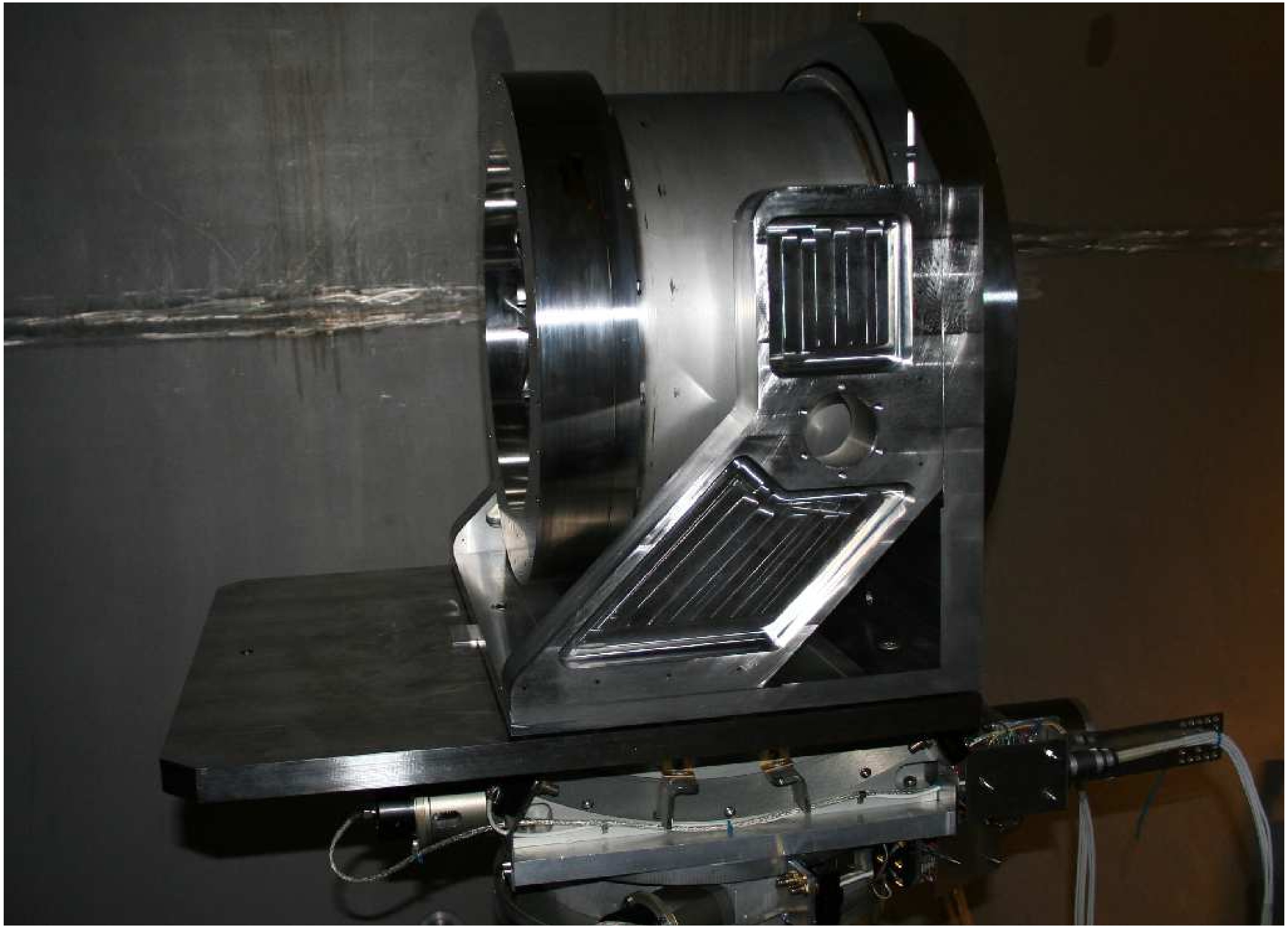
- single shell 44/3 (ABRIXAS mandrel), ...
- single shell 46/1, 46/2, 46/8 (ABRIXAS mandrel)
- single shell 27/4 (MLT mandrel), ...

- single shell 1 (MLT mandrel): to be installed tomorrow
- single shell 2 (Zeiss mandrel): to be installed tomorrow
- DM (QM): shells 1 + 27
- FM1
- FM2, ..., FM7 (incl. cameras)
- end-to-end test

eROSITA optics at PANTER: test subjects (on-axis)

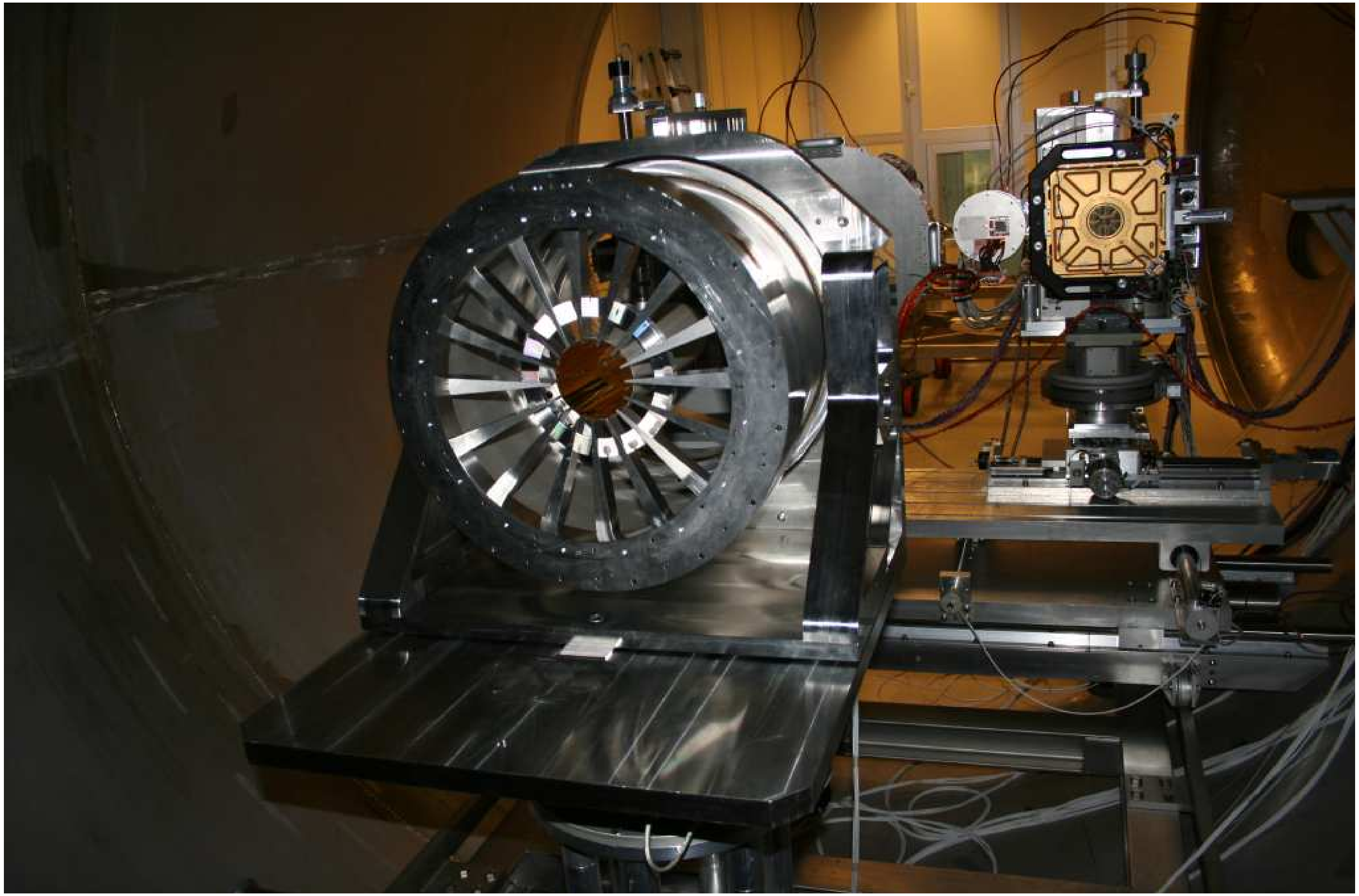
- **delivery, visual inspection, installation**
- **optical alignment (laser)**
- **X-ray alignment (Burkert test)**
- **point spread function (HEW, W90) at various energies:**
  - **large-scale (PSPC, e.g. scattering, micro-roughness)**
  - **small-scale (TRoPIC): "pixel scan":**
    20×20 **(**$3.75\,\mu$m **step) raster over 1 pixel to avoid split bias**
    re-shift coordinates and merge exposures
    sub-pixel resolution via split event statistics
- **single reflections: parabola entrance (mounting at spider), hyperbola entrance (close to mid-plane)**
- **out-of-focus rings (position, width, "pseudo-Hartmann" test)**
- **effective area at various energies (full illumination, "Glücksrad")**
- **gold edge, off-axis behaviour, contamination control, ...**

eROSITA: mechanical interface (GSE)

→  →

Mounted onto rotate-tilt-stage for X-ray alignment and dedicated off-axis exposures

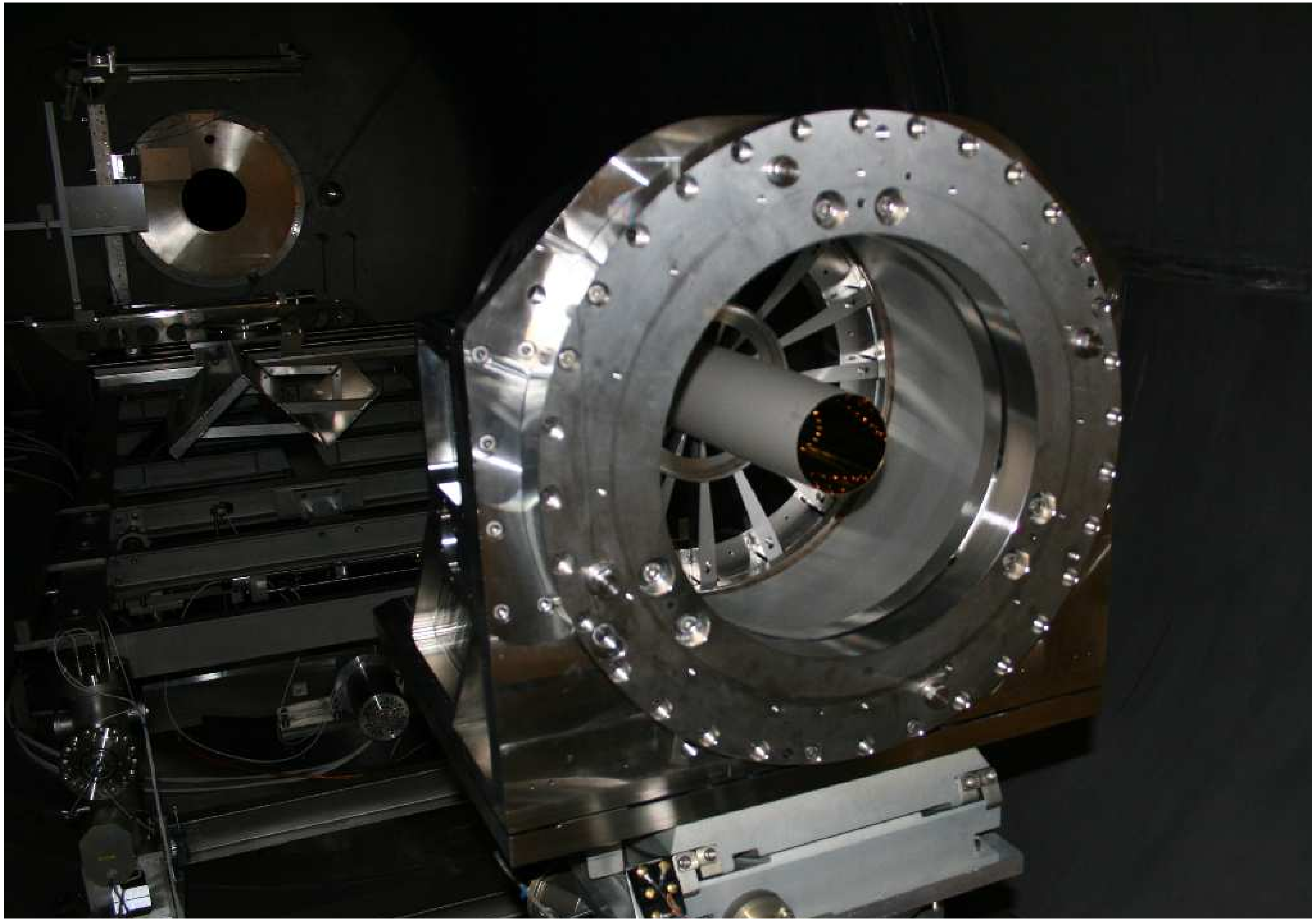
Set-up at PANTER



Shell and finger spider before mounting of entrance aperture

In the back: PSPC (right), TRoPIC (middle), EPIC-pn (partially covered)

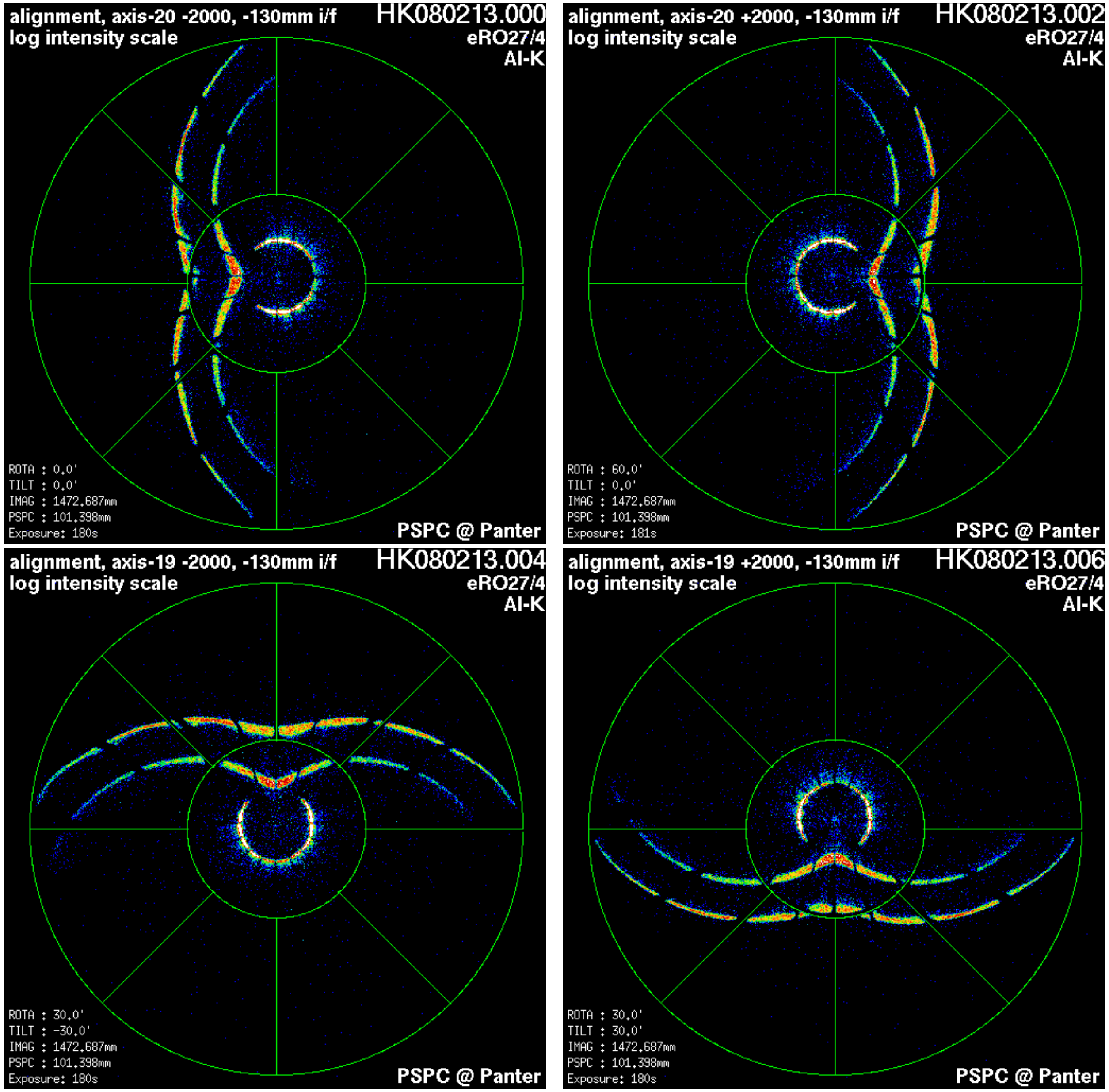
Tube exit



In the back: exit of 123 m tube, with various aperture stops

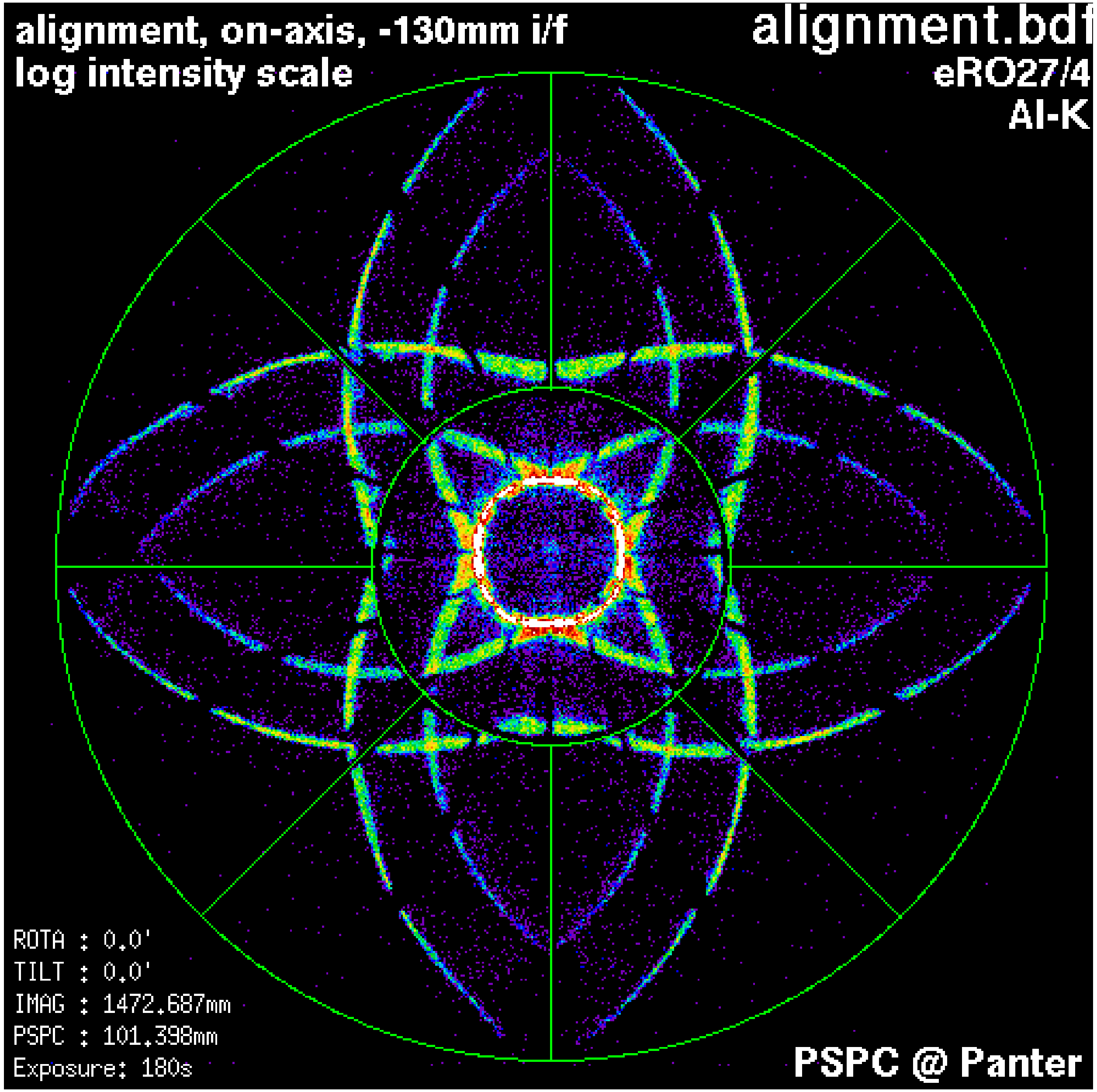
Distance source - mirror midplane: 130 m: maximum (full) divergence angle 9.5'

eRO-27/4: alignment (PSPC)



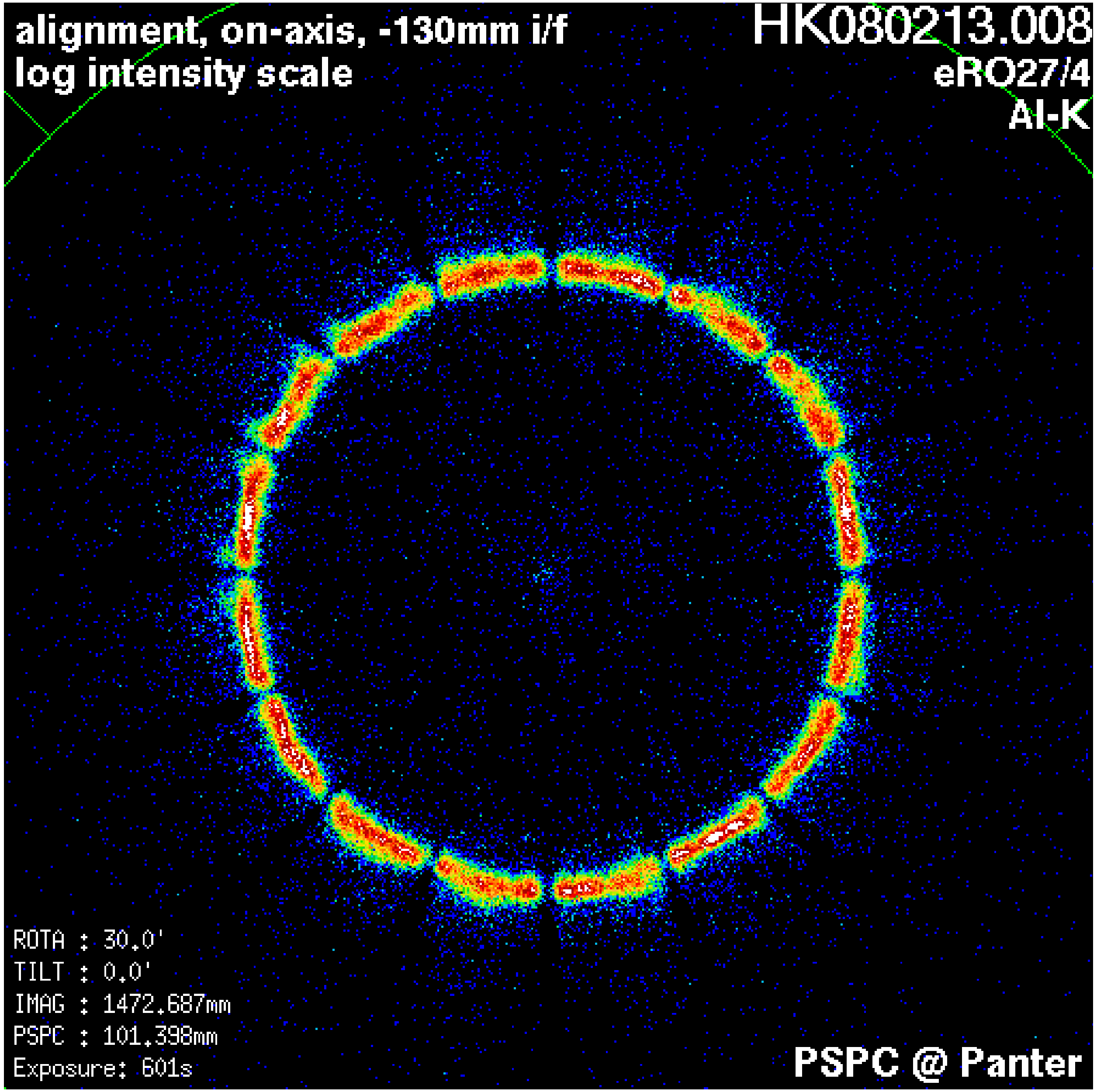
out-of-focus off-axis single reflections (hyperbola, parabola)

eRO-27/4: alignment (PSPC): "on-axis" (combined image)



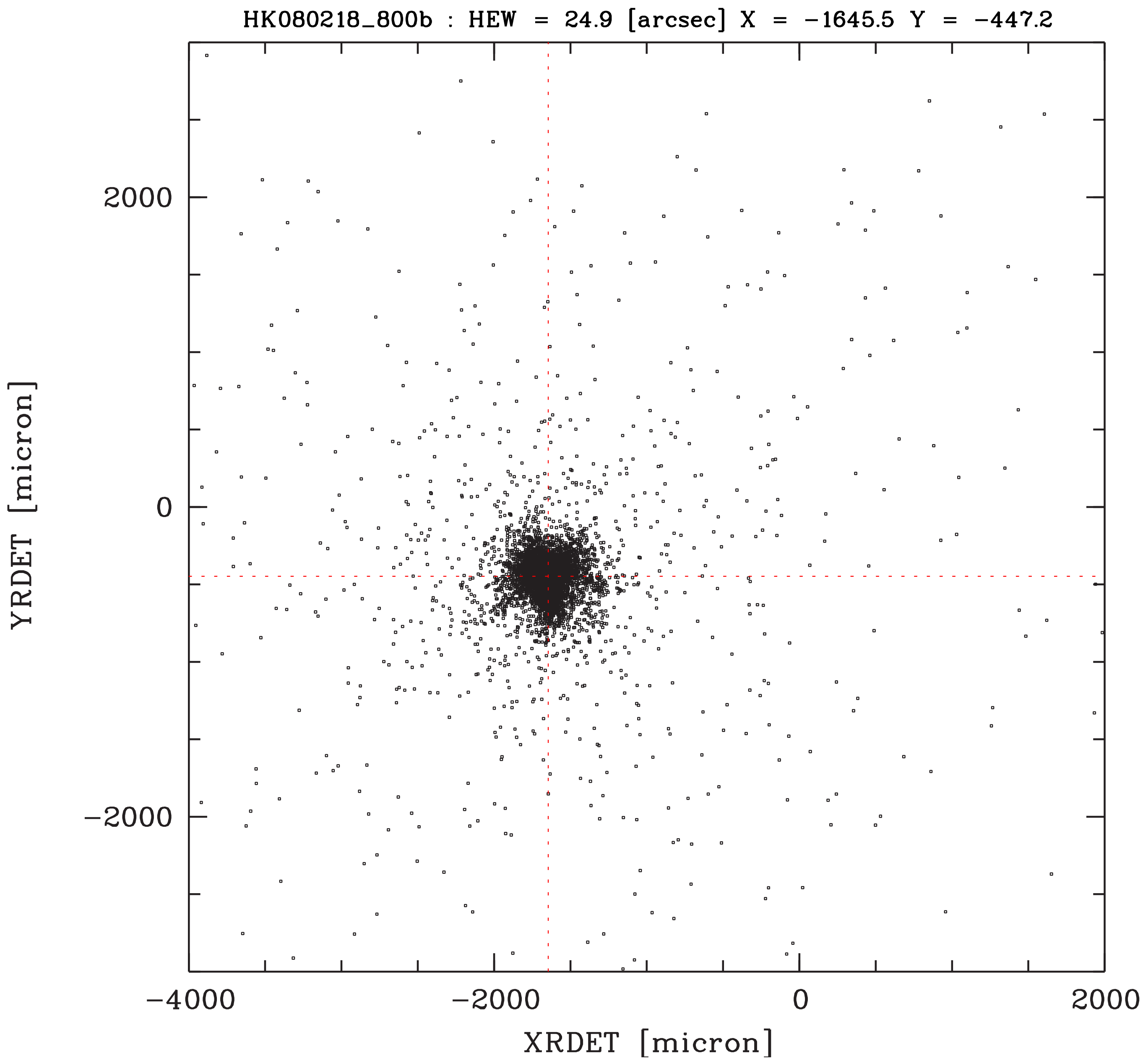
combined image: symmetric

eRO-27/4: out-of-focus (PSPC): on-axis

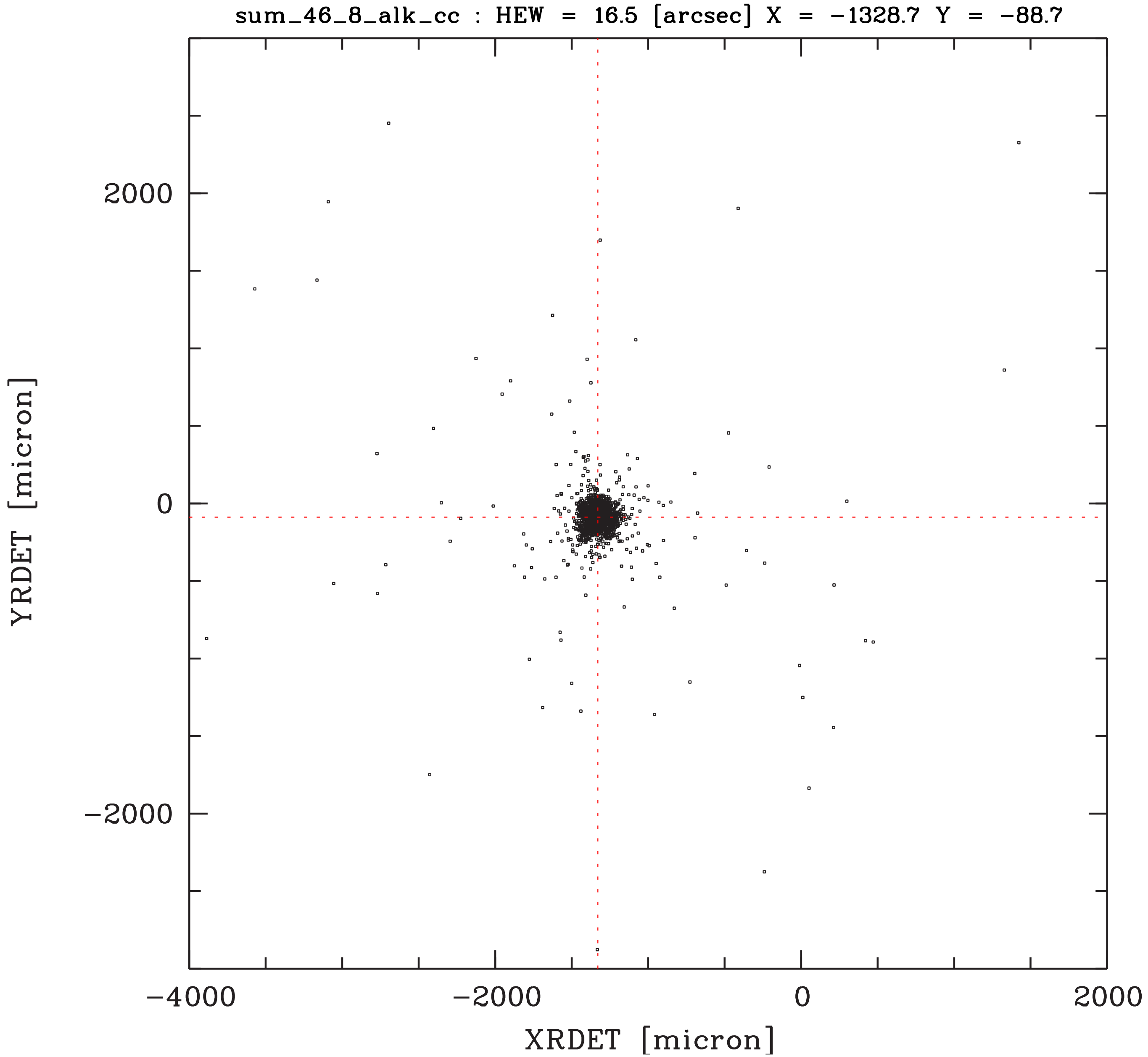


16 fingers of spider, zoomed image

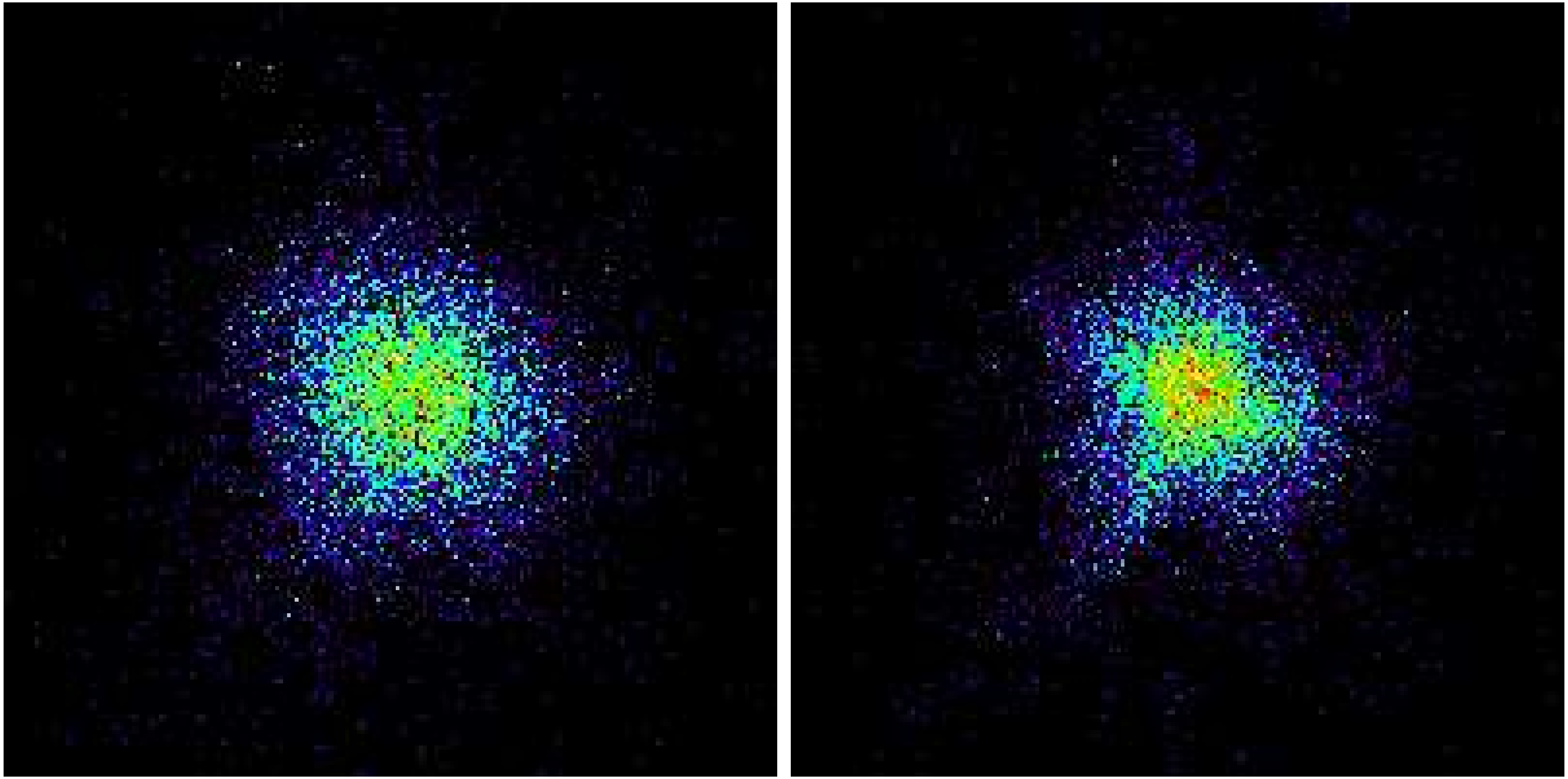
eRO-27/4 PSF: TRoPIC: HEW = 25 (22.5) arcsec (Al-K)



eRO-46/8 PSF: TRoPIC: HEW = 17 (14.7) arcsec (Al-K)



eRO-46/8: towards sub-pixel resolution

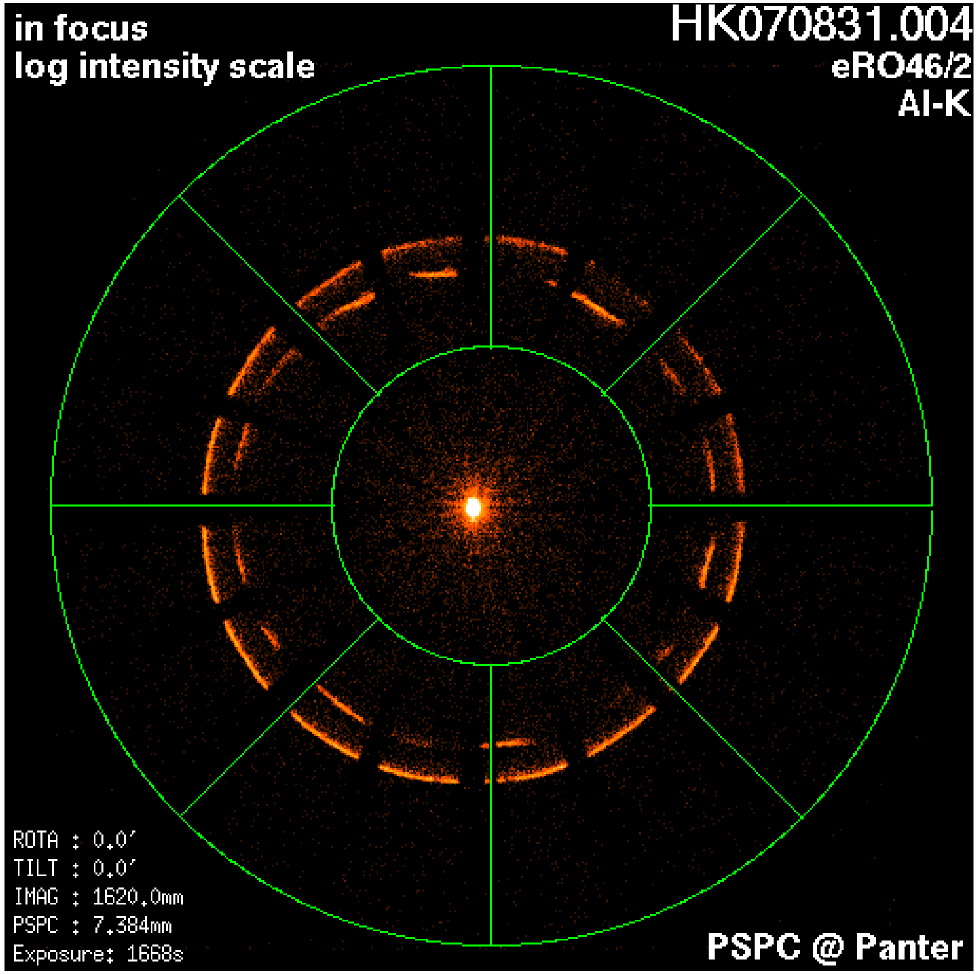


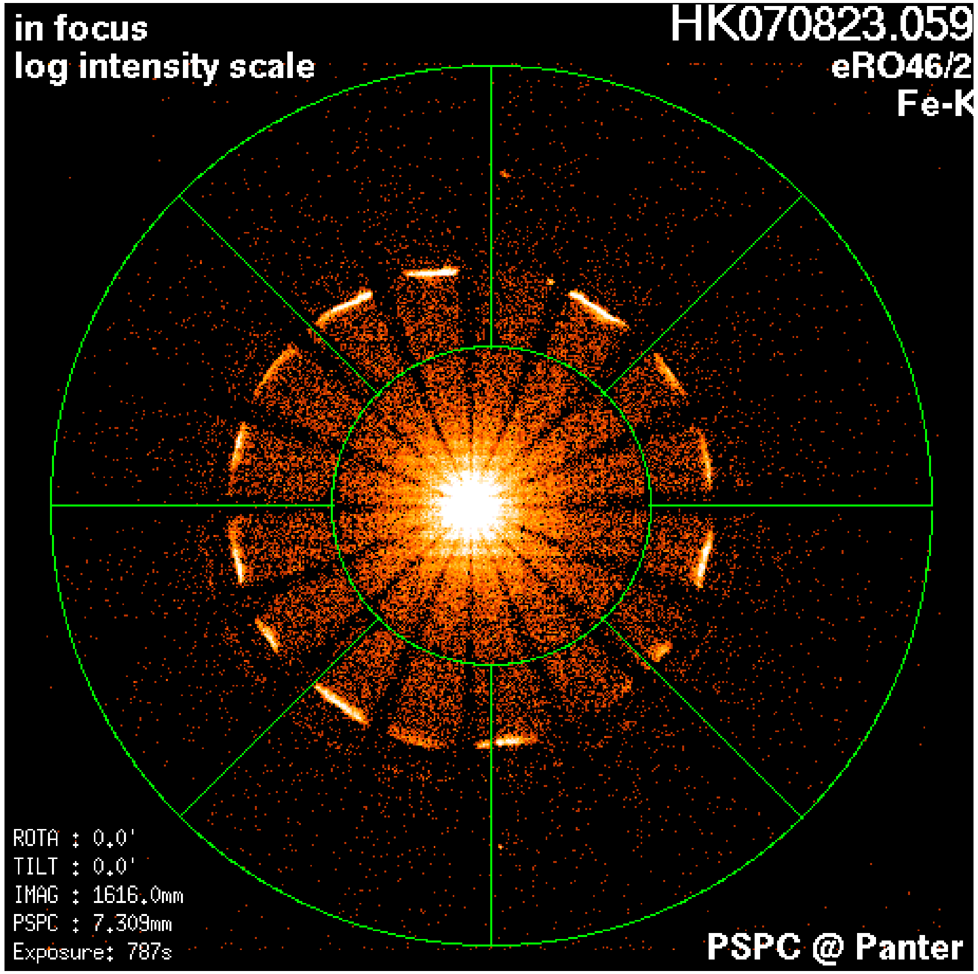
randomize events within split area (i.e. where doubles, tripels etc. are generated)

instead of within full pixel (like in XMM-SAS),

this improves spatial resolution: HEW 17 arcsec → 14.7 arcsec

eRO-46/2: single reflections (PSPC)



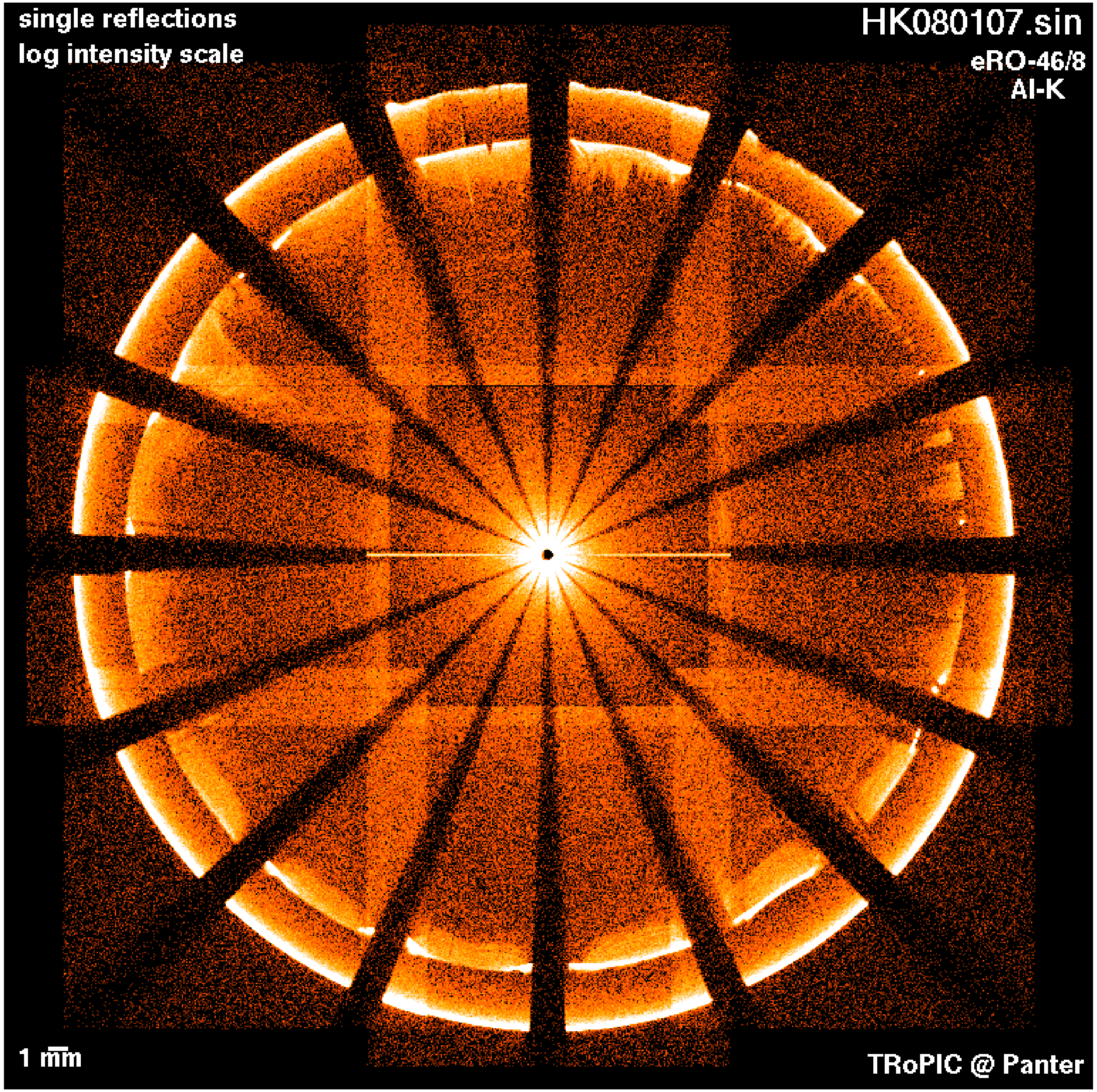


outer ring: hyperbola close to mid-plane

inner ring: parabola close to entrance

at higher energies: outer ring disappears due to large incidence angles

eRO-46/8: single reflections (TRoPIC mosaic)

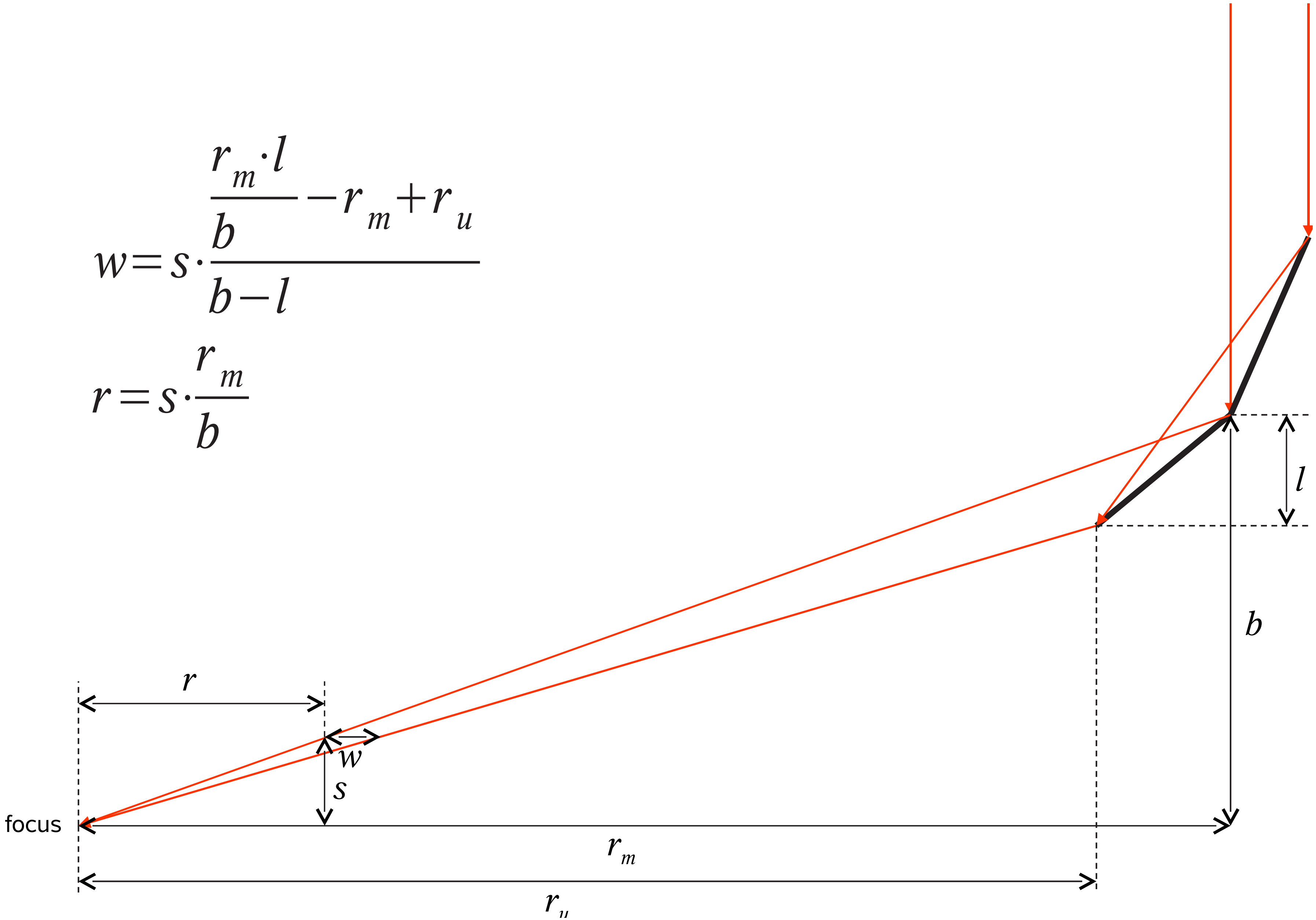


single reflection rings, out-of-time events, pile-up in PSF core

Out-of-focus rings: position and width

$$w = s \cdot \frac{\frac{r_m \cdot l}{b} - r_m + r_u}{b - l}$$

$$r = s \cdot \frac{r_m}{b}$$



Out-of-focus ring geometry: position and width

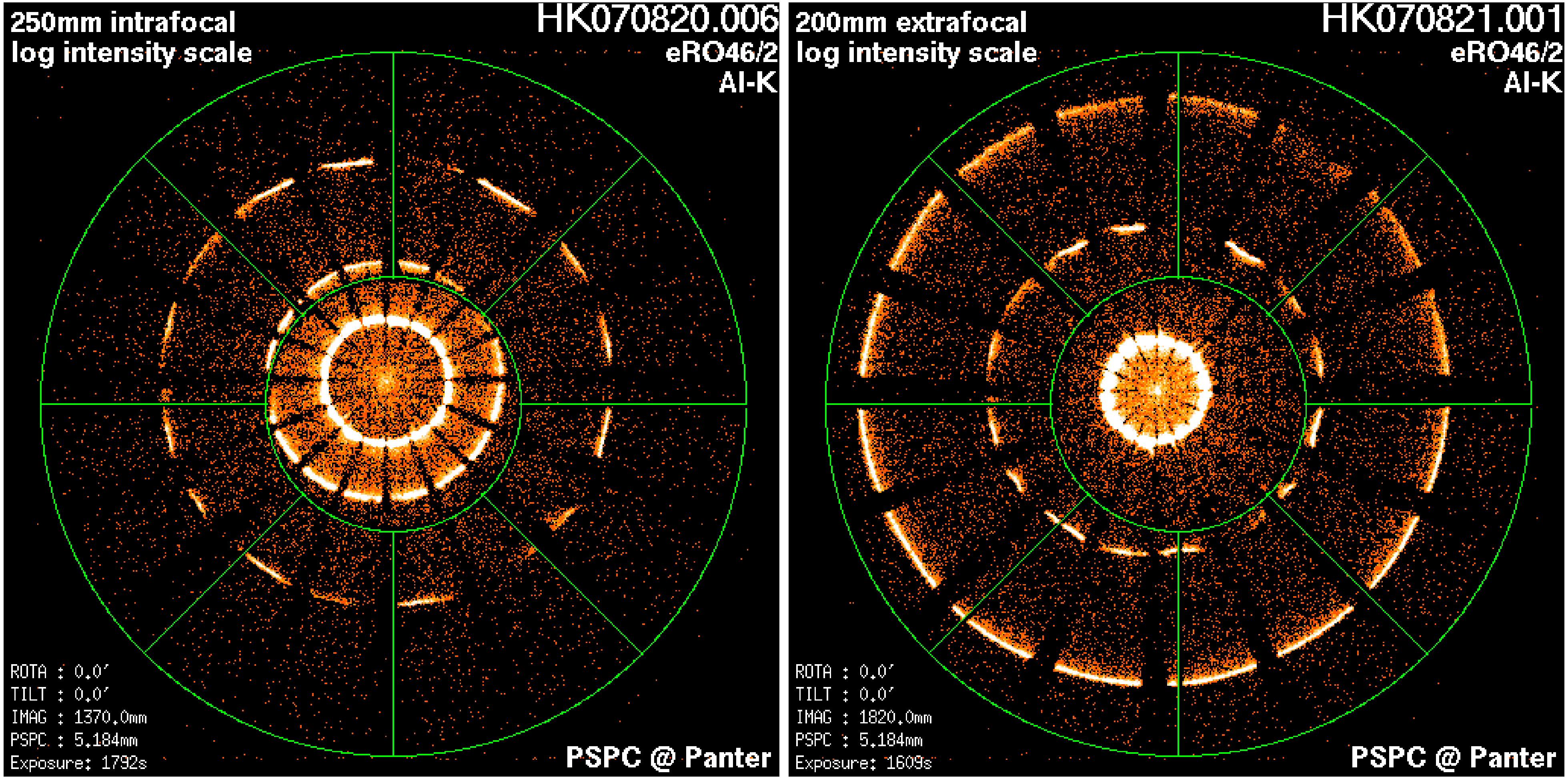
Shell #	mid-plane radius r_m [mm]	exit radius r_u [mm]	distance s [mm]	ring center r_c [mm]	ring width w [mm]
46	47.202	43.870	40	1.180	0.028
			125	3.686	0.088
			175	5.161	0.124
			200	5.898	0.141
			250	7.373	0.177
			400	11.796	0.283
27	81.943	76.160	40	2.048	0.049
			144.02	7.373	0.177
			250	12.799	0.307
1	174.184	161.906	40	4.353	0.105
			67.75	7.373	0.177
			250	27.208	0.655

focal plane instrumentation at PANTER: along optical axis: $\pm$250 mm

highest spatial resolution: TRoPIC: FOV 19.2 mm squared

out-of-focus rings allow spatial location of "features"

eRO-46/2: out-of-focus rings + single reflections (PSPC)

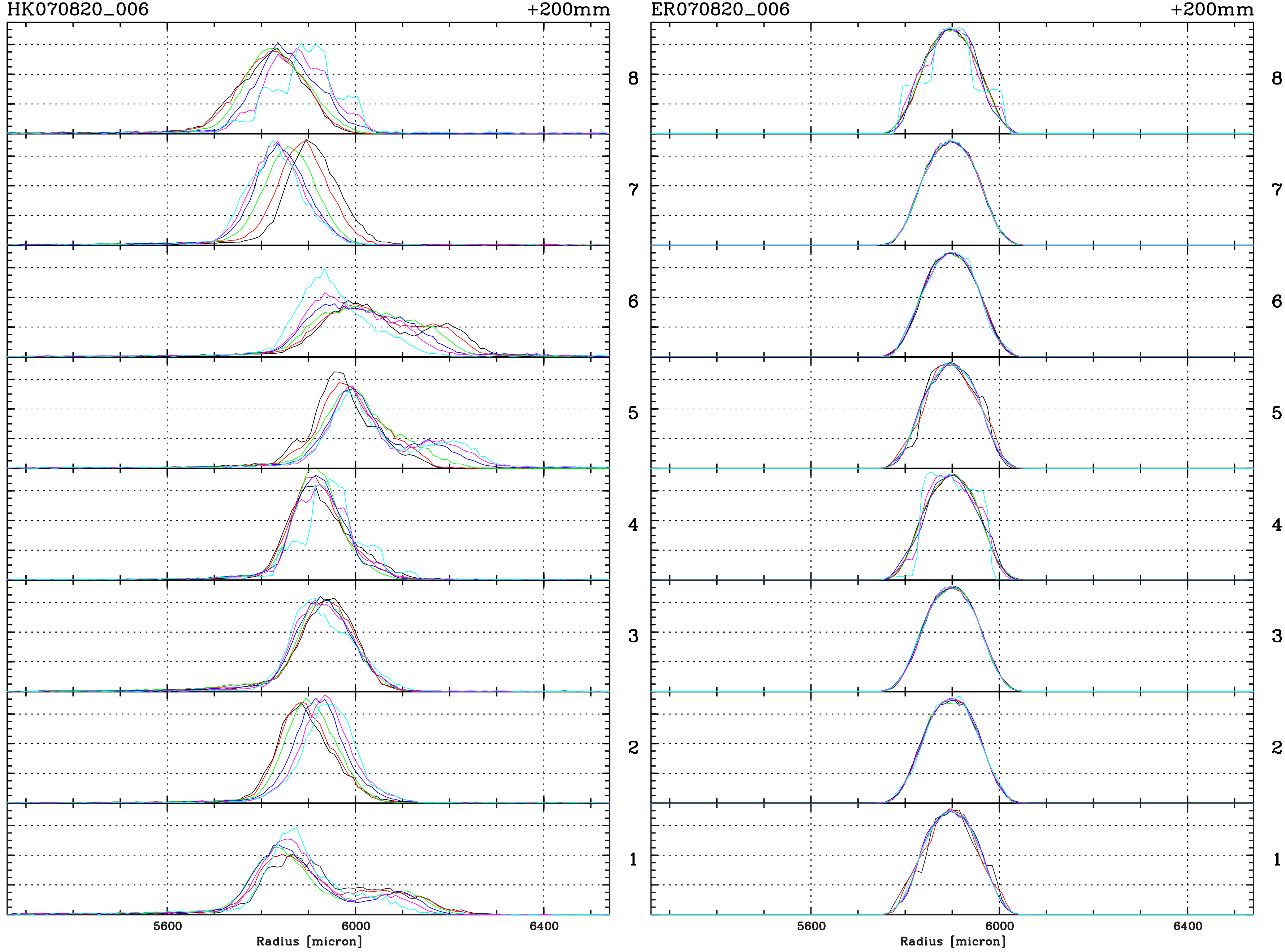


intrafocal: parabola and hyperbola single reflections, double-reflection ring

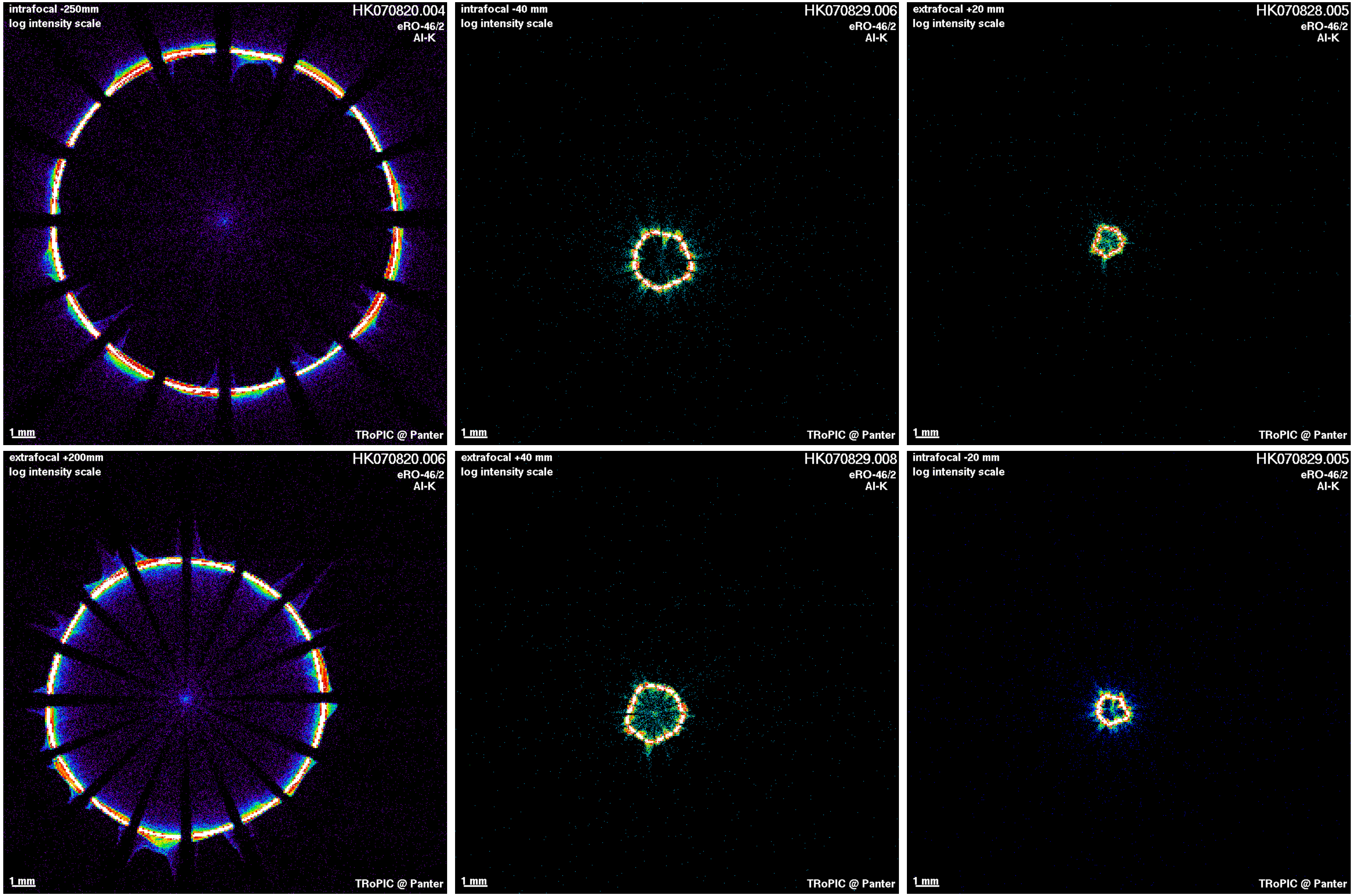
extrafocal: hyperbola and parabola and single reflections, double-reflection ring

cross-sections of double-reflection ring, if sufficient spatial resolution: →

eRO-46/2: out-of-focus rings (TRoPIC): data + theory

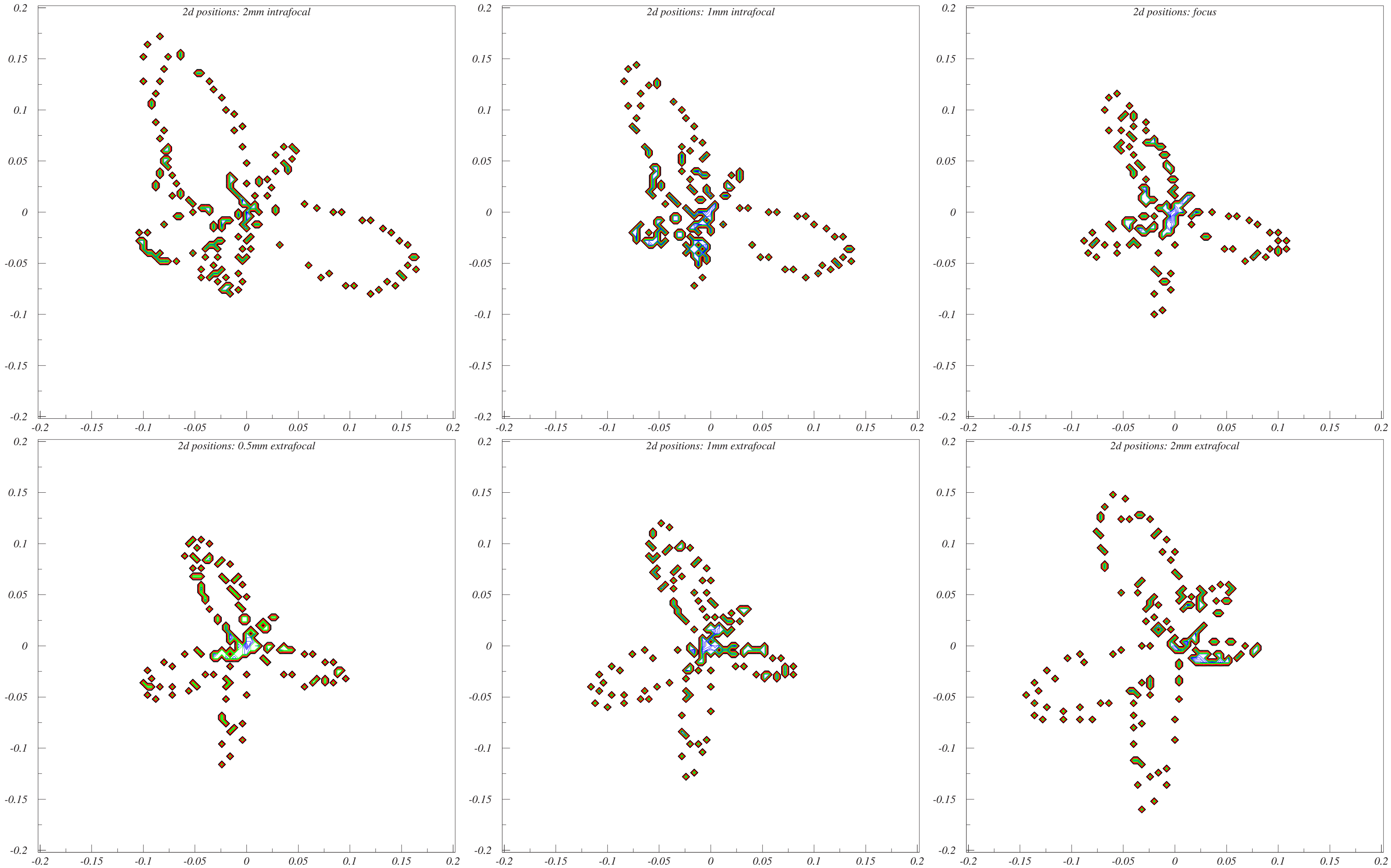


eRO-46/2: -250, +200, -40, +40, -20, +20 mm out-of-focus



mirrored rings from intra-focal to extra-focal

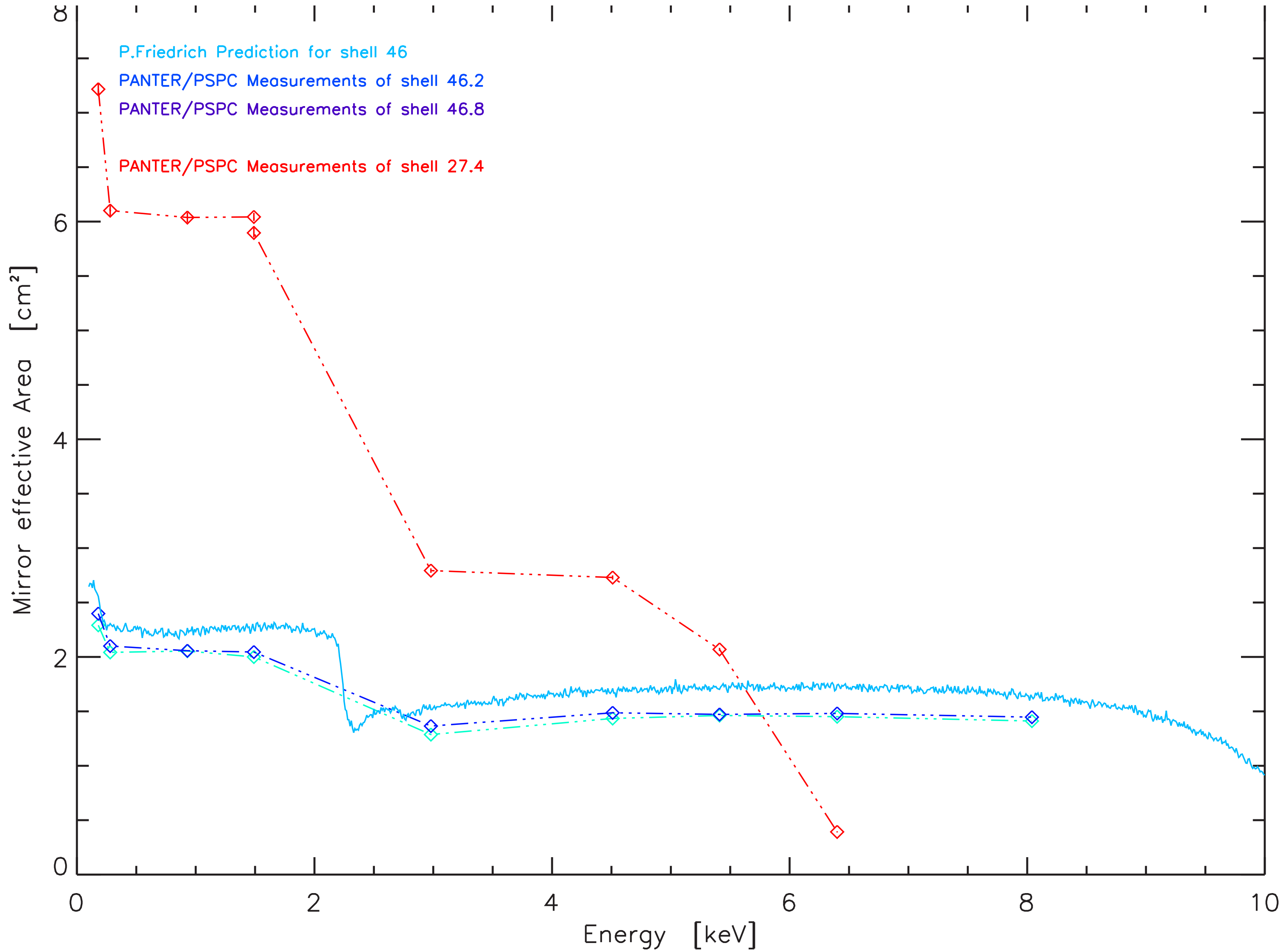
eRO-46/2: Pseudo-Hartmann test: in-focus prediction



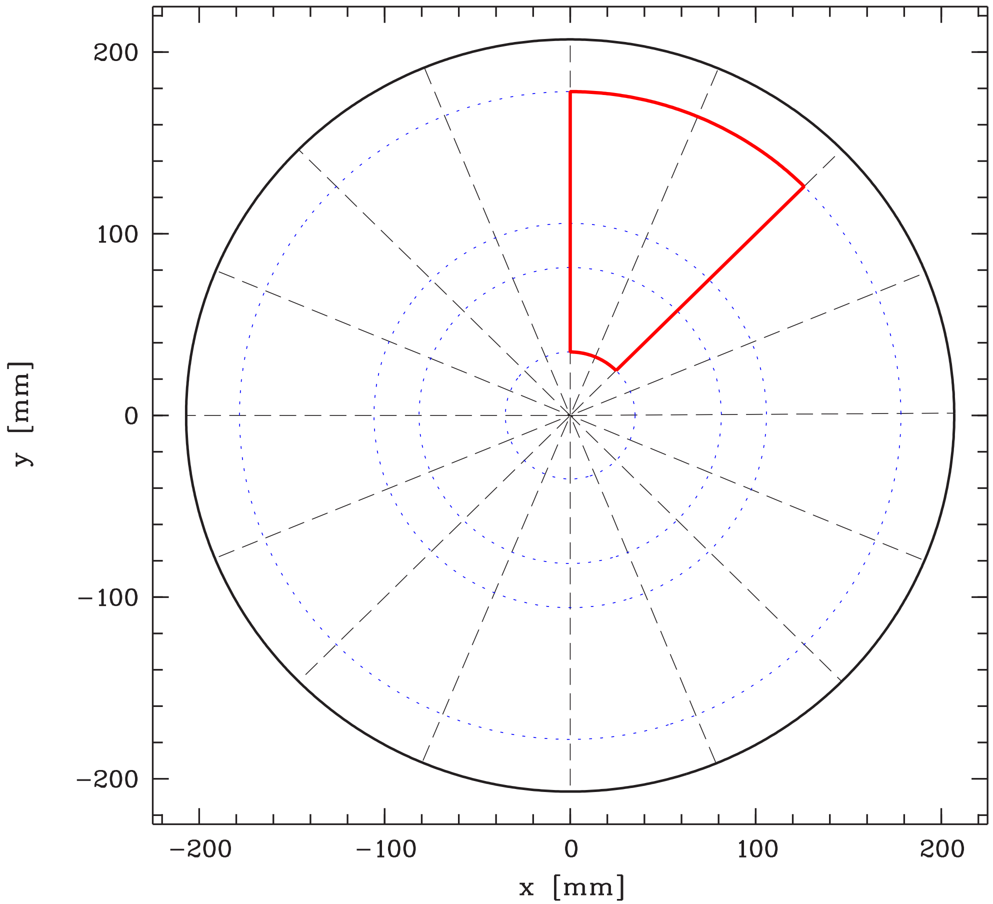
interpolation of -250mm intrafocal and +200mm extrafocal images to focus position:

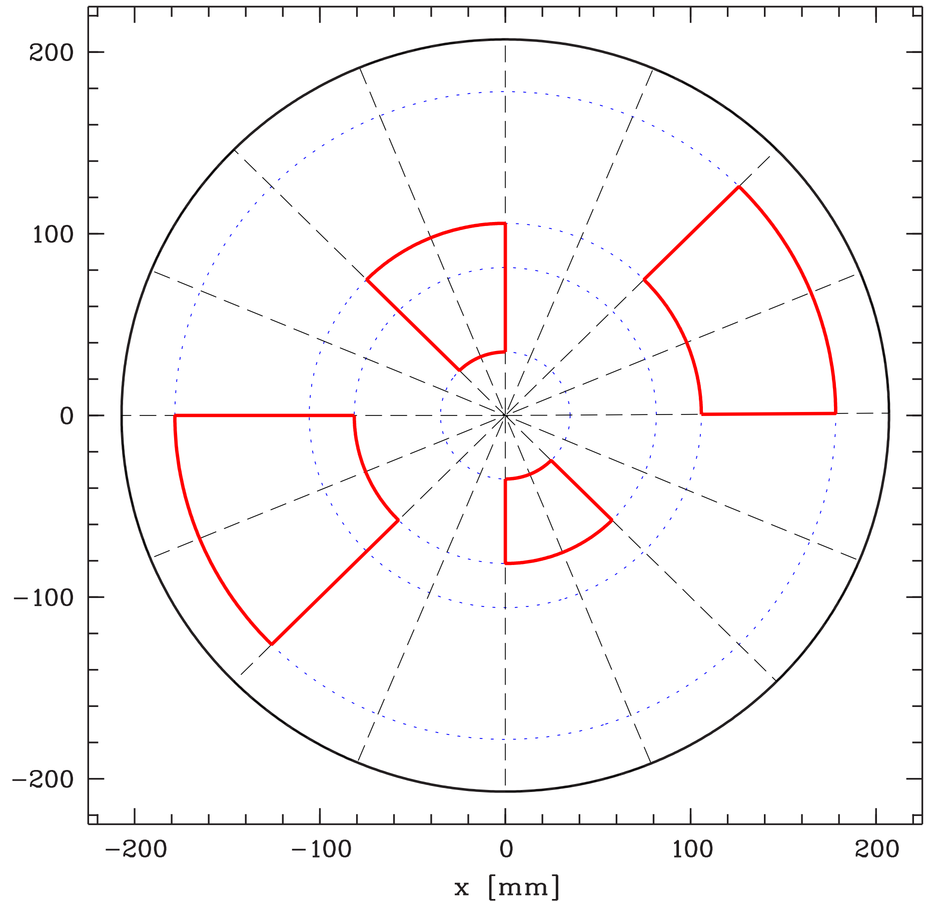
-2mm, -1mm intrafocal, 0mm, +0.5mm, +1mm, +2mm extrafocal

eRO-27/4: effective areas



eROSITA: effective areas via “Glücksrad”





put open mirror aperture parallel to incident beam

any aperture from 0° to 45° (2 sectors)

sum of sectors gives parallel beam effective area

eROSITA flight models

- **FM1: according to schedule will be delivered prior to first camera FM**
- **FM1: calibrate extensively with TRoPIC**
- **FM1: mount X-ray baffle**
- **FM1: double crystal monochromator for gold edge (2.1 – 3 keV)**
- **FM1: calibrate afterwards with corresponding camera FM1**
- **focal length, determine effects of camera**
- **→ pile-up, stray-light, ...**
- **FM2, ..., FM7 (incl. cameras)**
- **end-to-end test: only 1 – 3 modules in beam**

eROSITA in-orbit calibration with cosmic sources: comments

- bright sources may saturate telemetry ("disk quota") (1 event per readout-cycle per camera): these limits depend on other payload and calibration agreements
- standard sources: N132D, Mkn421, PKS2155, 1E0102, Crab, Vela: XMM: 40 - 10000 cts/s
- background in LEO: fluorescent O-K line (532 eV) from scattered solar X-rays

eROSITA in-orbit calibration with cosmic sources: strategy ?

- observe source only with one (or more) camera active at the same time, and use other cameras with closed filter position
- give more (all ?) telemetry to eROSITA during calibration observations
- split telemetry for S-X-G cross-calibration observations
- calibration observations in survey mode
- surveys could be interrupted for pointed calibration observations (every 6 months for e.g. 2 days, dependent on target visibility)