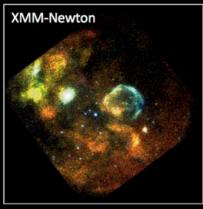
eROSITA Calibration and First Results

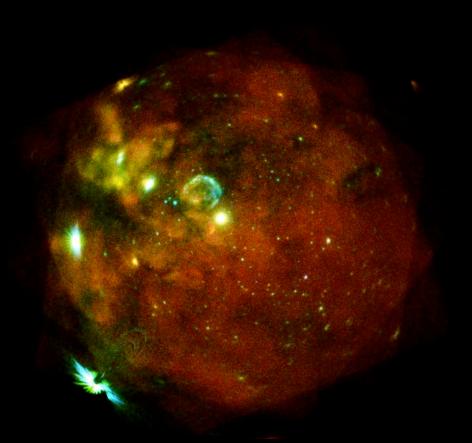


IACHEC, 2021 April 23

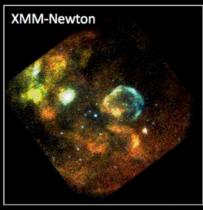
Konrad Dennerl, MPE



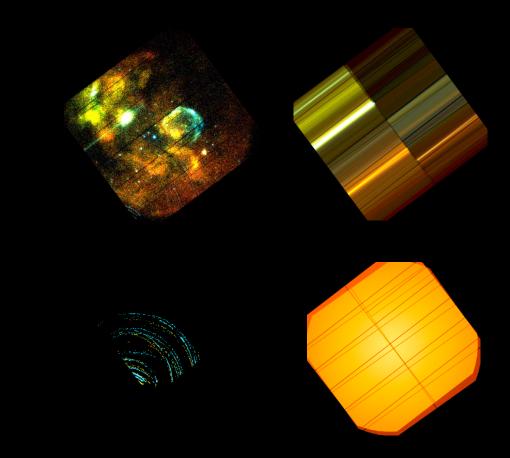
EPIC-PN FL Dennerl et al. 2001



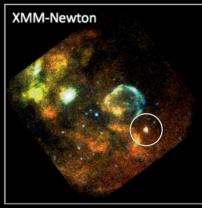
Credit: F. Haberl, M. Freyberg, C. Maitra



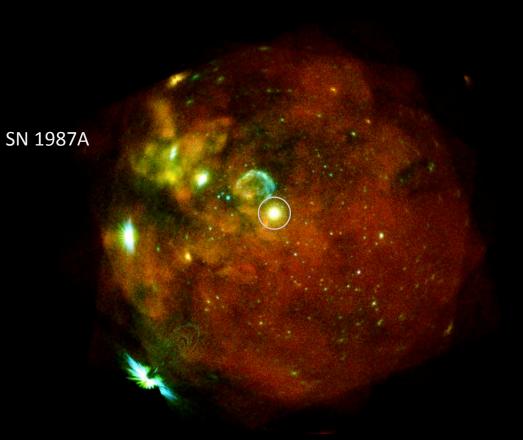
EPIC-PN FL Dennerl et al. 2001



Dennerl et al. 2001

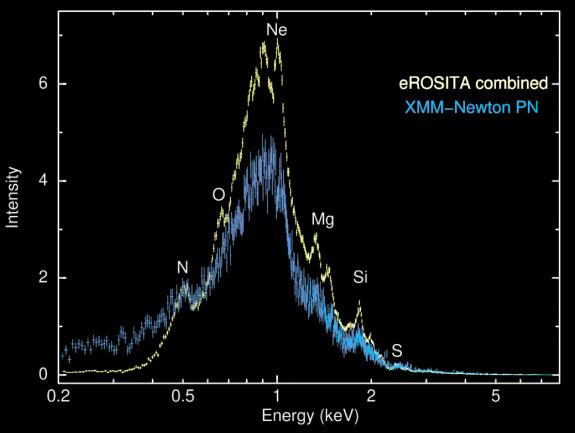


EPIC-PN FL Dennerl et al. 2001

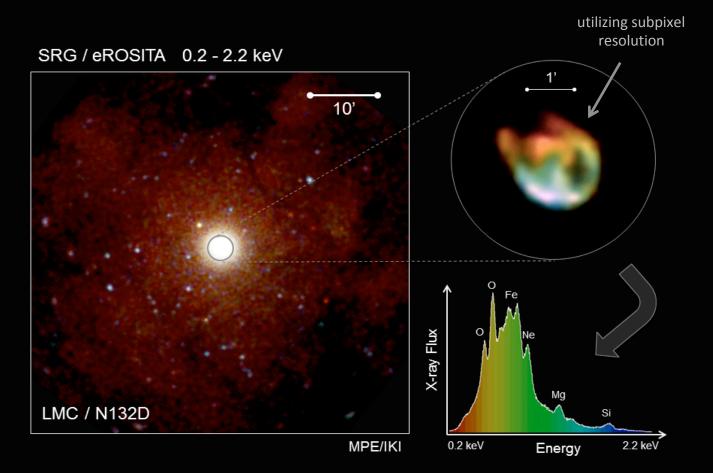


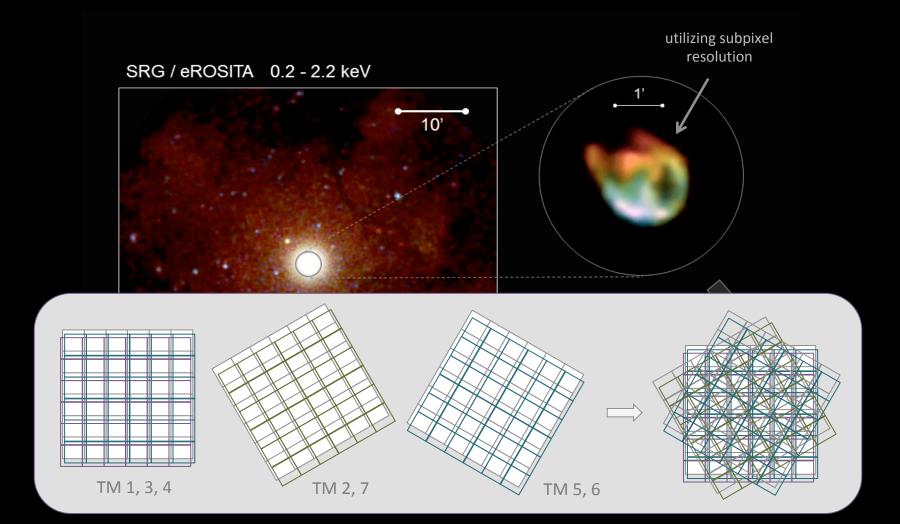
Credit: F. Haberl, M. Freyberg, C. Maitra

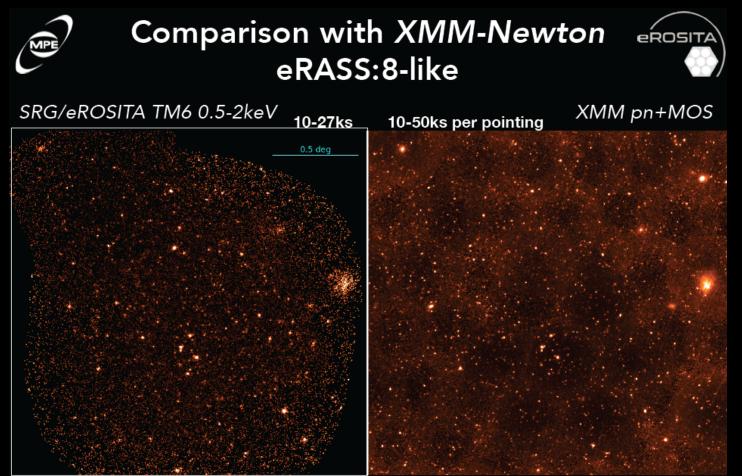
SN 1987A in the LMC



C. Maitra, F. Haberl, MPE/IKI







MPE/IKI

XXL North Survey field Image Credit: M. Ramos (MPE)

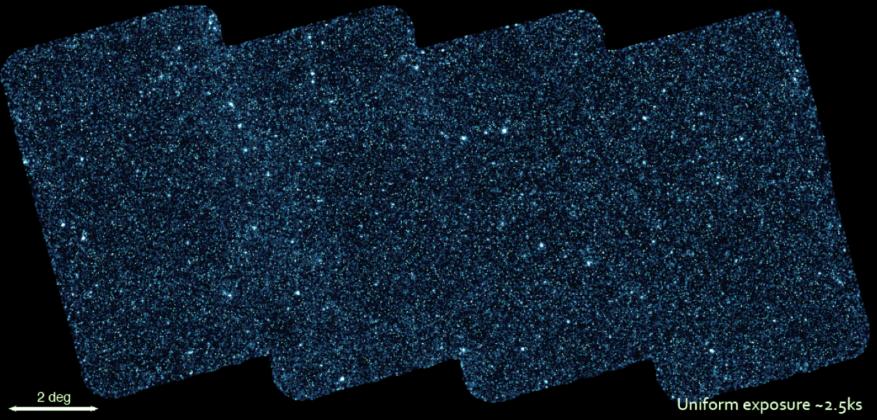


3 observing modes:

- pointing
- field scan
- survey



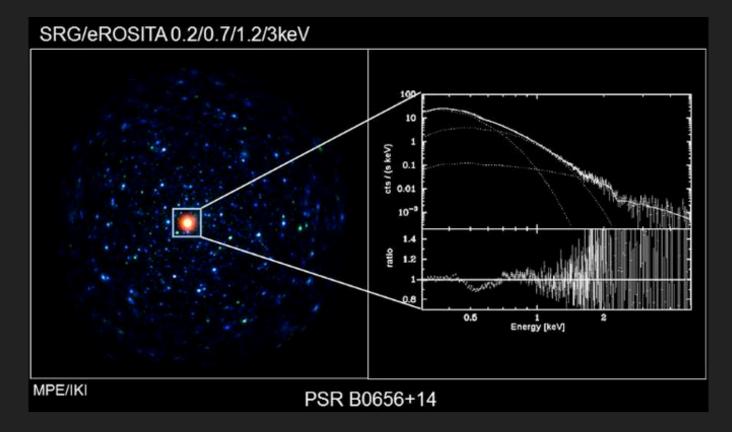
eFEDS: a preview of eRASS:8



Exposure corrected image in the 0.5 – 2.0 keV band

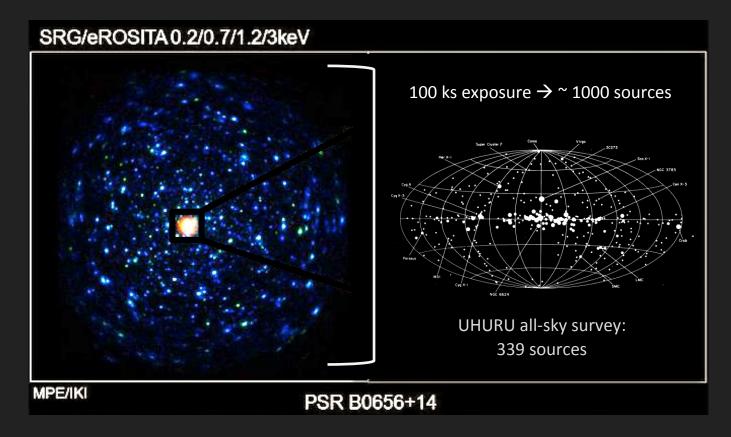
Credit: H. Brunner, M. Ramos-Ceja

Isolated neutron star PSR B0656+14



385 ms pulsar, 50 ms time resolution

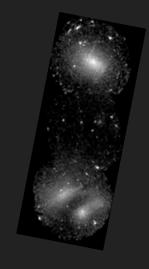
Isolated neutron star PSR B0656+14



385 ms pulsar, 50 ms time resolution

Abell 3391/3395

XMM-Newton 0.4 – 1.25 keV



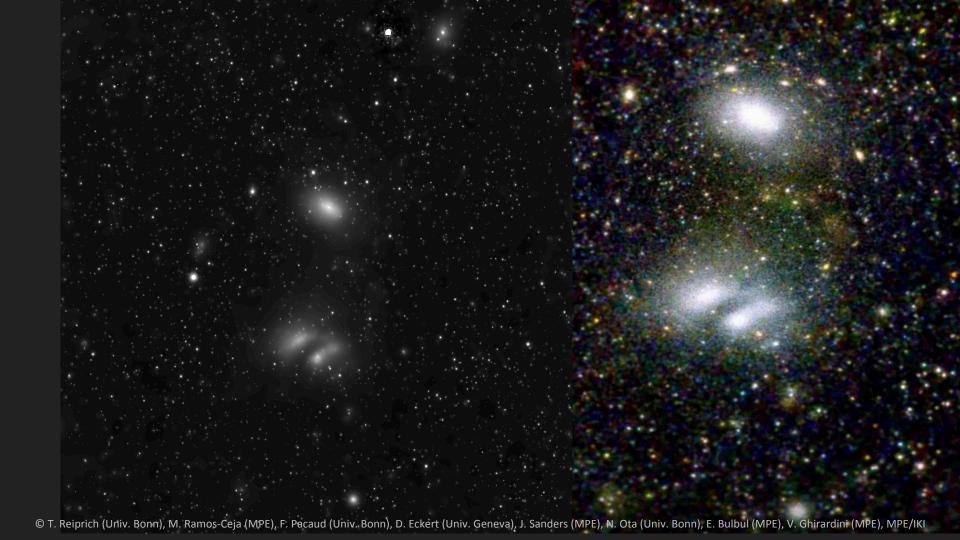


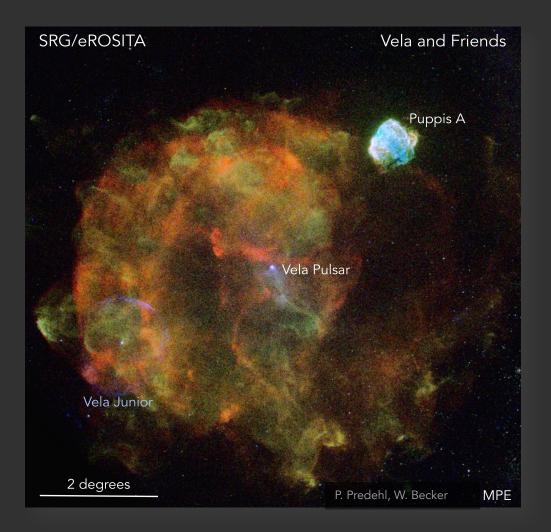
Abell 3391/3395

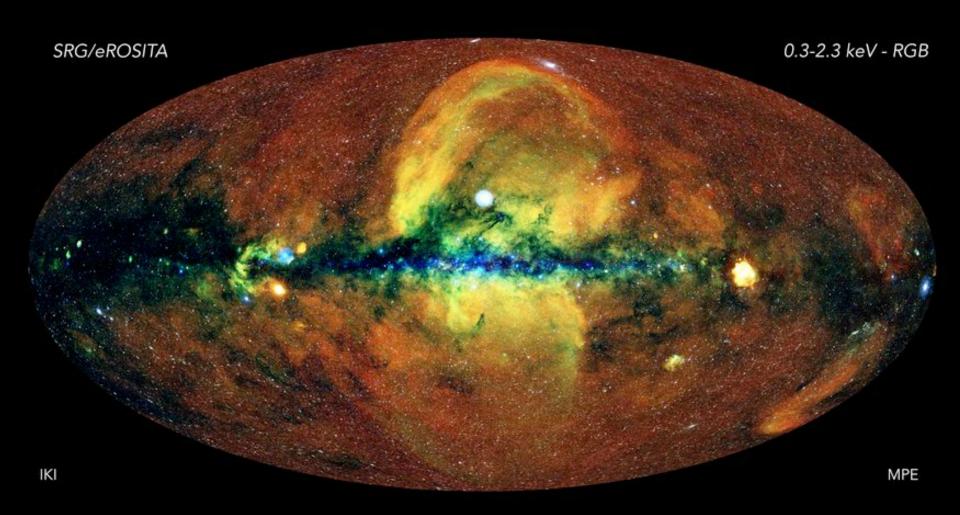
SRG/eROSITA 0.2-2.0 keV

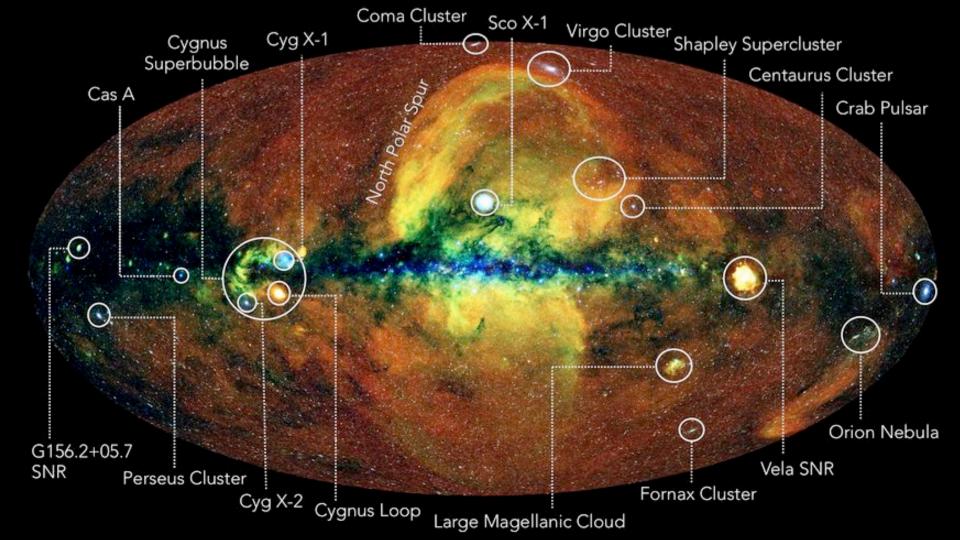
eROSITA PV phase

T. Reiprich (Univ. Bonn), M. Ramos-Ceja (MPE), F. Pacaud (Univ. Bonn), D. Eckert (Univ. Geneva), J. Sanders (MPE), N. Ota (Univ. Bonn), E. Bulbul (MPE), V. Ghirardini (MPE)









ROSAT + XMM / EPIC-pn \rightarrow eROSITA

(extended ROentgen Survey with an Imaging Telescope Array)

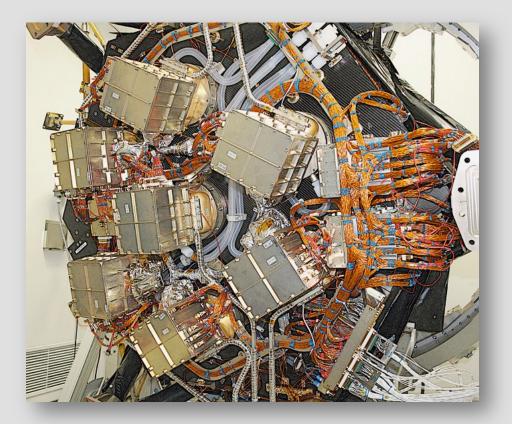


eROSITA on SRG (Spectrum-Roentgen-Gamma): Mirror Side



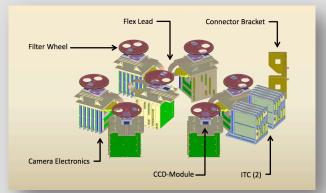
- 7 telescope modules (TM)
- 54 nested gold-coated nickel mirror shells
- focal length: 1600 mm
- field of view: 1 deg diameter
- on-axis HEW: 16"

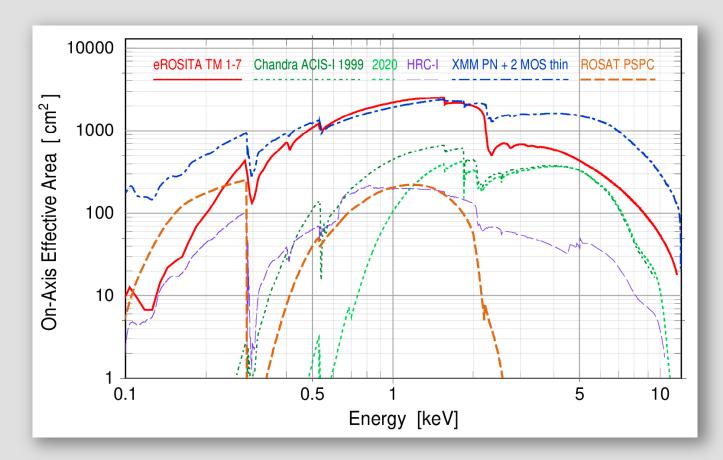
eROSITA on SRG (Spectrum-Roentgen-Gamma): Detector Side



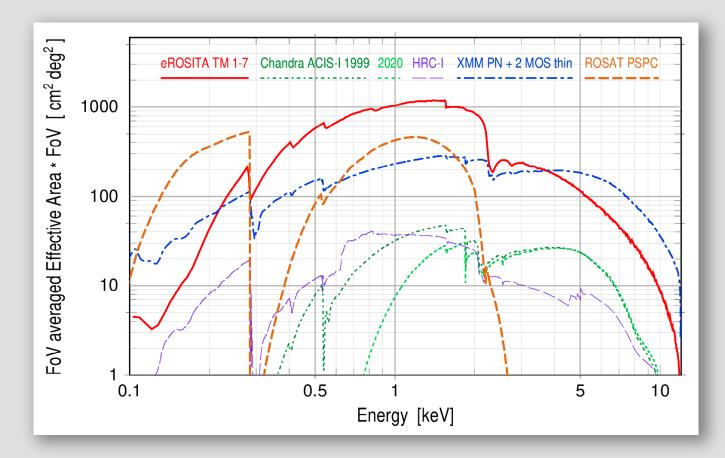
- 7 pn-CCDs with framestore
- 5 CCDs with 200 nm Al filter, 2 without
- 384 x 384 pixels of 75μm x 75 μm
- 50 ms cycle time
- 7 filter wheels with four positions: open, closed, ⁵⁵Fe cal, filter

filter: 5 x 200 nm Pl, 2 x 200 nm Pl + 100 nm Al





On-Axis Effective Area of eROSITA comparable to XMM-Newton



Grasp of eROSITA about 5 times higher than that of XMM-Newton

eROSITA Calibration:

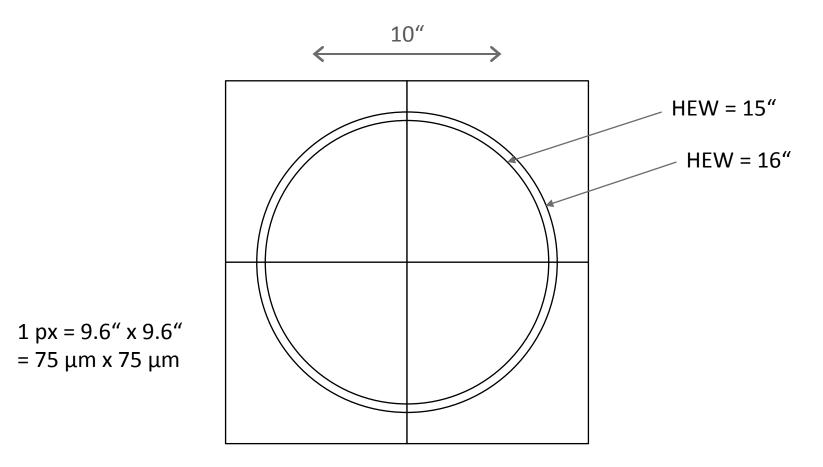
Mirror

Point Spread Function (PSF)

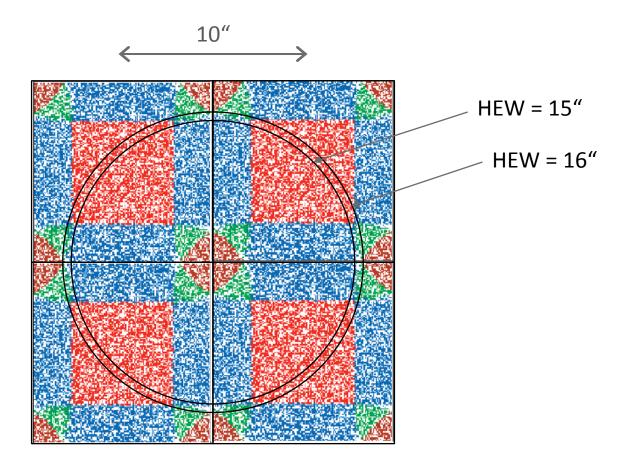
Vignetting



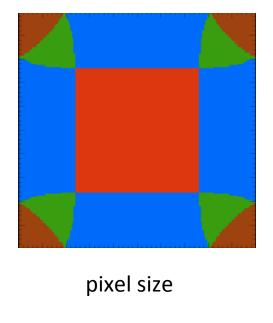
Determination of the eROSITA on-axis PSF

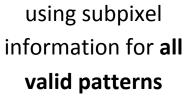


Determination of the eROSITA on-axis PSF

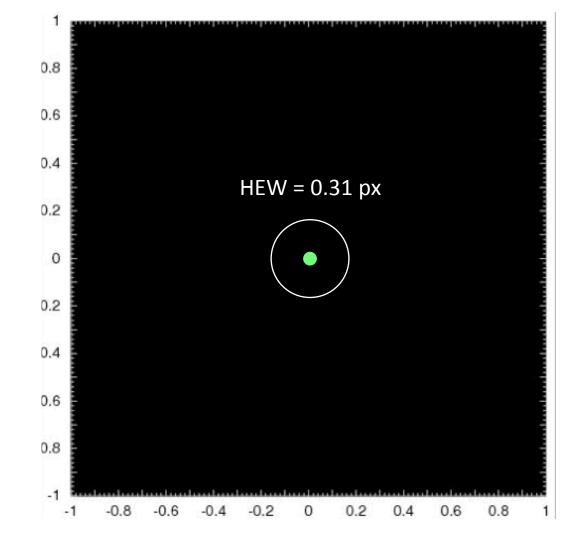


1 px = 9.6" x 9.6" = 75 μm x 75 μm

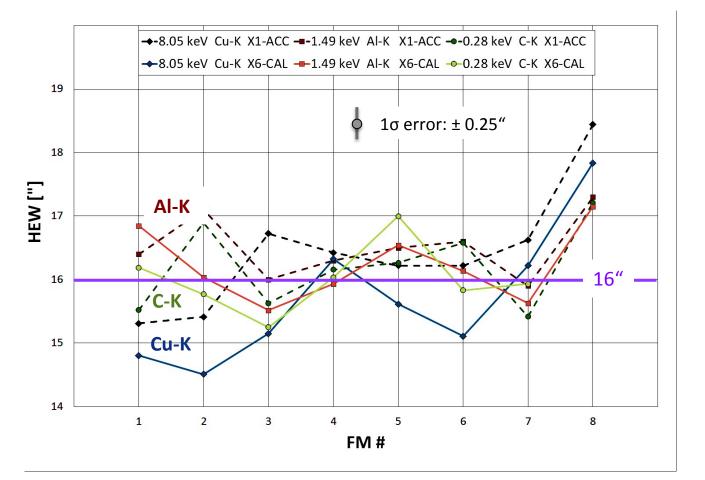




Al-K 12 x 12 raster

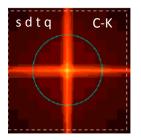


Determination of the eROSITA on-axis PSF

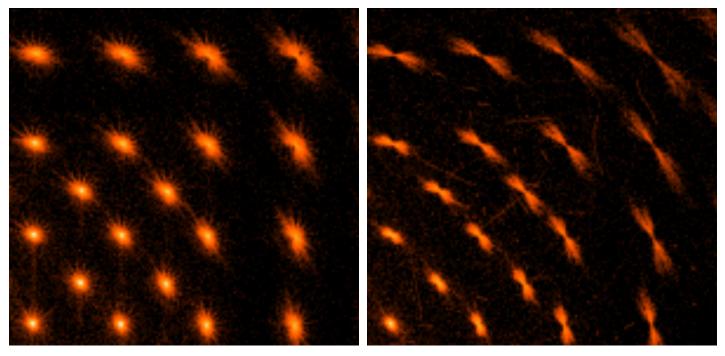








Determination of the eROSITA off-axis PSF



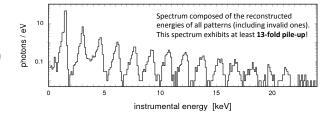
1.5 keV

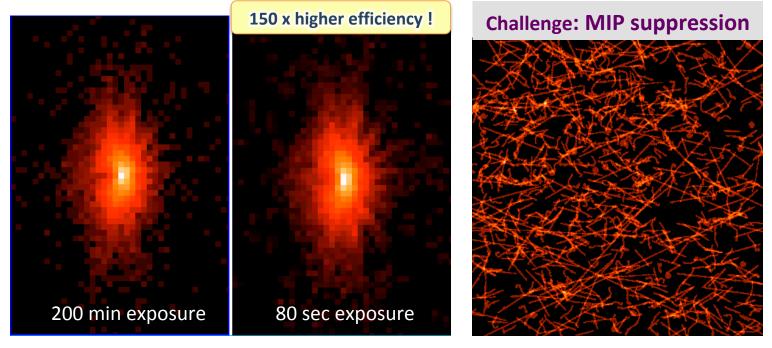


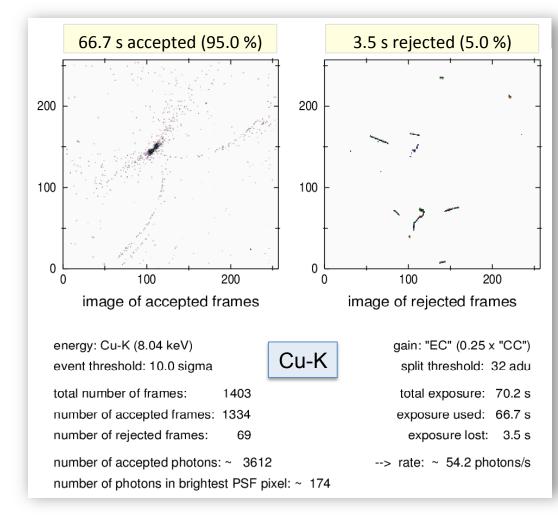
1 pixel scan takes ~ 6-8 hours: how can we shorten the exposure time ?

Method : operate the CCD in "charge accumulation mode"

- 1) utilize the fact that the dominant photon energy is known
- 2) analyse the accumulated charges (challenge: MIP suppression)
- 3) abandon subpixel resolution (not required for off-axis PSF)





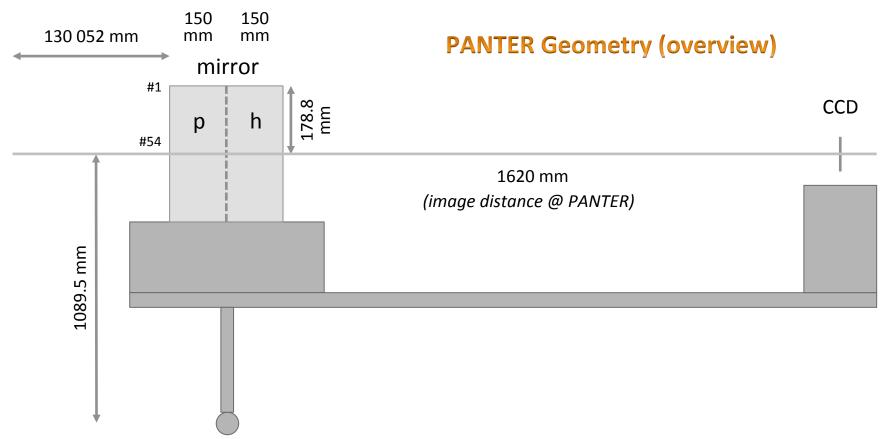


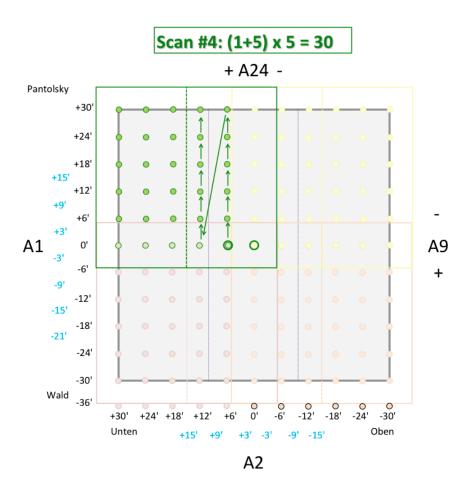
Operating the CCD in "charge accumulation mode"

Challenge: Suppression of MIPs in the case of extreme pile-up

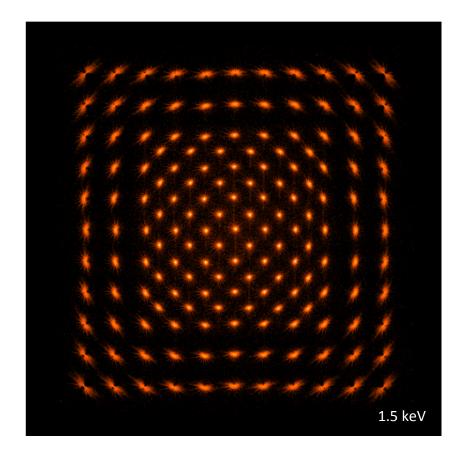
Solution: reject all frames which contain ,suspicious' features

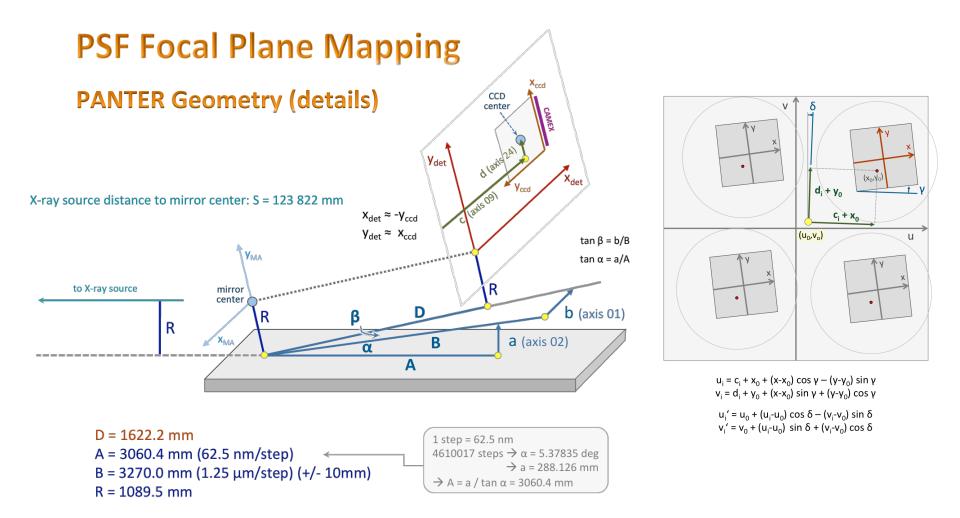
PSF Focal Plane Mapping

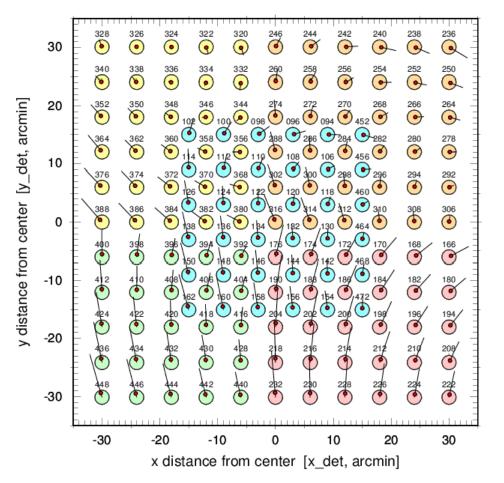




PSF Focal Plane Mapping







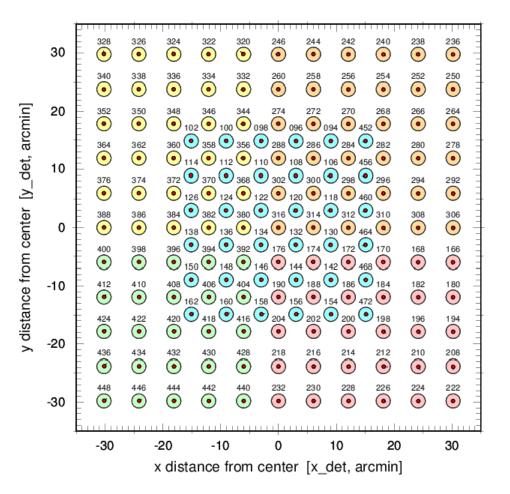
PSF Focal Plane Mapping

without geometric correction

large circles: predicted PSF centers small circles: corr. measured PSF centers displacement lines enlarged by factor 10.0

A = 3060.4 mm, B = 3270.0 mm, C = 1621.0 mm gamma = 0.0 arcmin, delta = 0.0 arcmin x = (128.0 - y_ccd), y = (x_ccd - 128.0)

mean positional 1o deviation: 20.6"



PSF Focal Plane Mapping

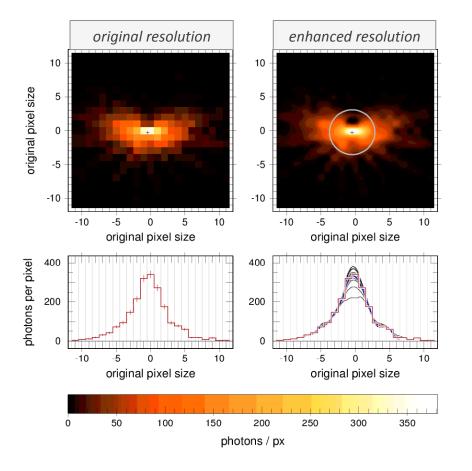
Result of geometrical fit with 7 parameters: A, B, D, γ, δ, x₀, y₀

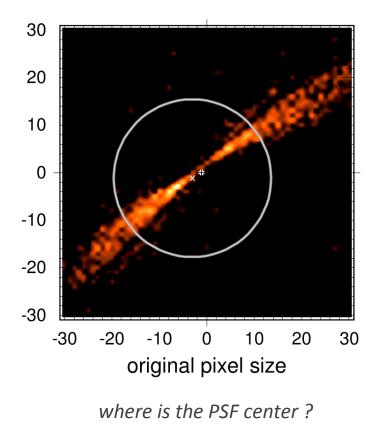
large circles: predicted PSF centers small circles: corr. measured PSF centers displacement lines enlarged by factor 10.0

A = 3095.3 mm, B = 3252.7 mm, D = 1622.2 mm gamma = 46.4 arcmin, delta = -9.9 arcmin x = (127.8 - y_ccd), y = (x_ccd - 129.7)

mean positional 1o deviation: 2.1"

PSF Focal Plane Mapping: additional challenges





30 y distance from center [y_det, arcmin] 20 10 0 -10 -20 -30 -30 -10 -20 x distance from center [x_det, arcmin]

alk

agl

c-k

PSF Focal Plane Mapping: **RGB** images

eROSITA FoV

121 PSFs from scans 1 - 4, each composed of 3 energies

brightest pixel of all PSFs at each energy normalized to 1.0

transfer function: $f(z) = z^{0.4}$, zoomed to [0.0, 0.4]

30

cuk

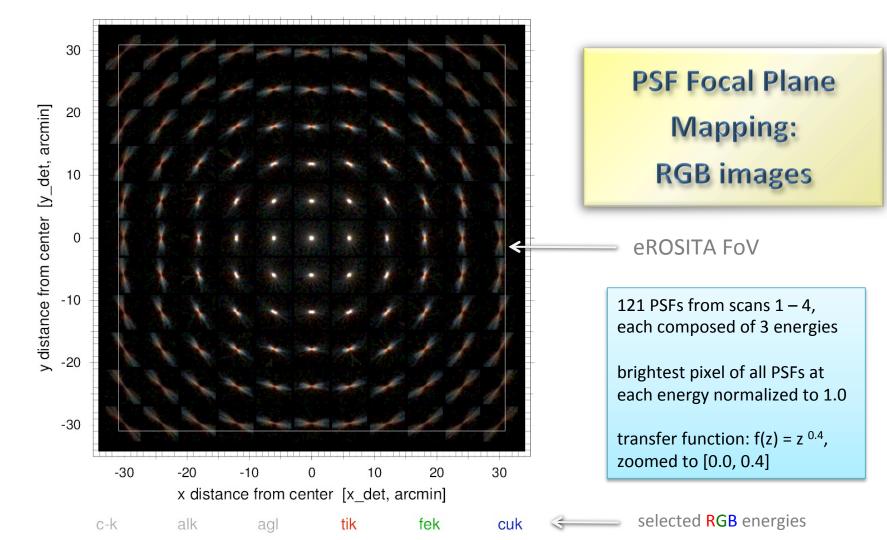
20

fek

10

tik

selected **RGB** energies



30 y distance from center [y_det, arcmin] 20 10 0 -10 -20 -30 -30 -20 -10 x distance from center [x_det, arcmin]

c-k

alk

agl

PSF Focal Plane Mapping: **RGB** images

eROSITA FoV

121 PSFs from scans 1 - 4, each composed of 6 energies

brightest pixel of all PSFs at each energy normalized to 1.0

transfer function: $f(z) = z^{0.4}$, zoomed to [0.0, 0.4]

30

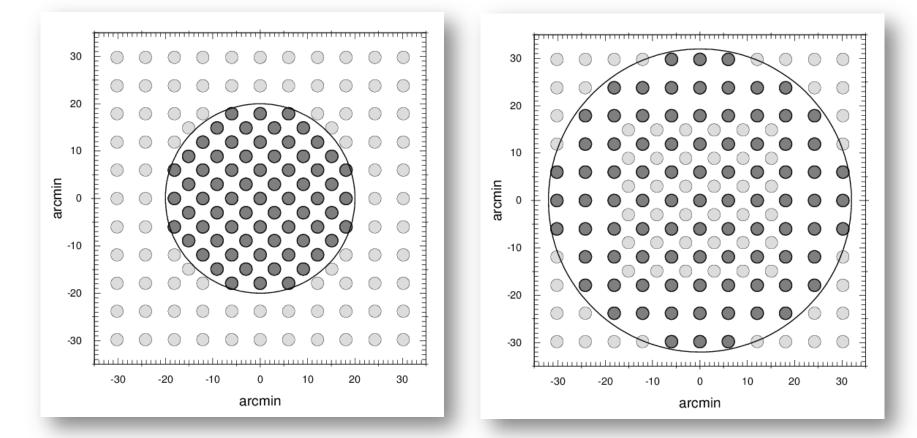
cuk

20

fek

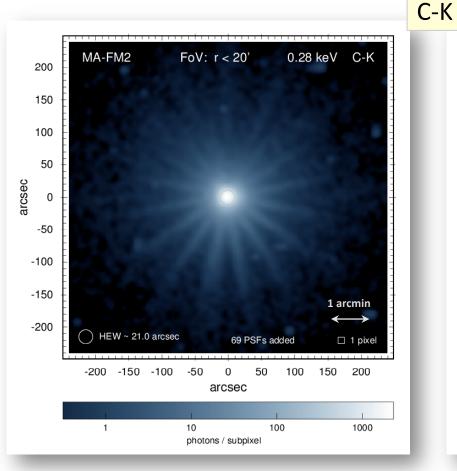
10

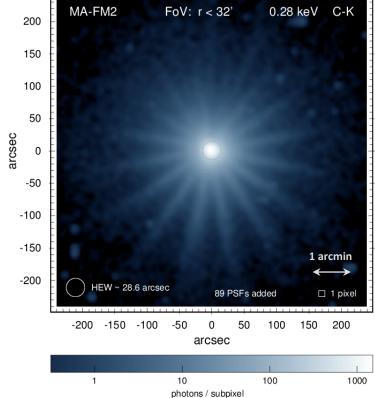
tik



full FoV (60 arcmin diameter)

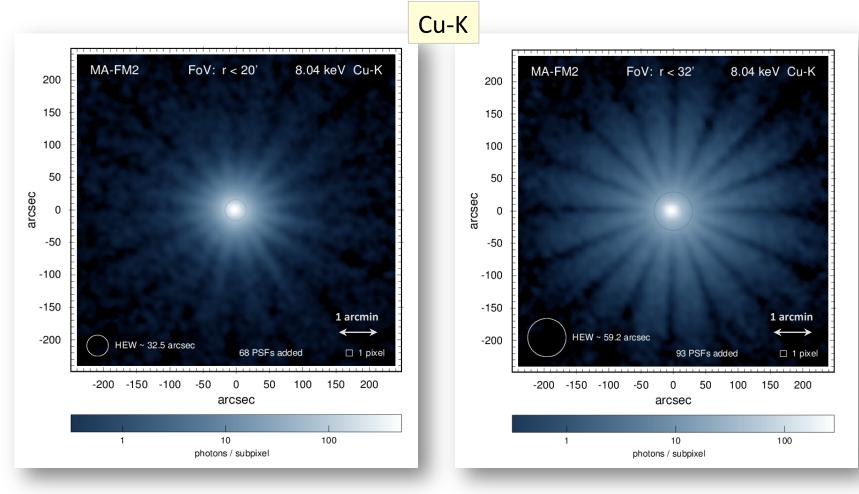
inner FoV (40 arcmin diameter)





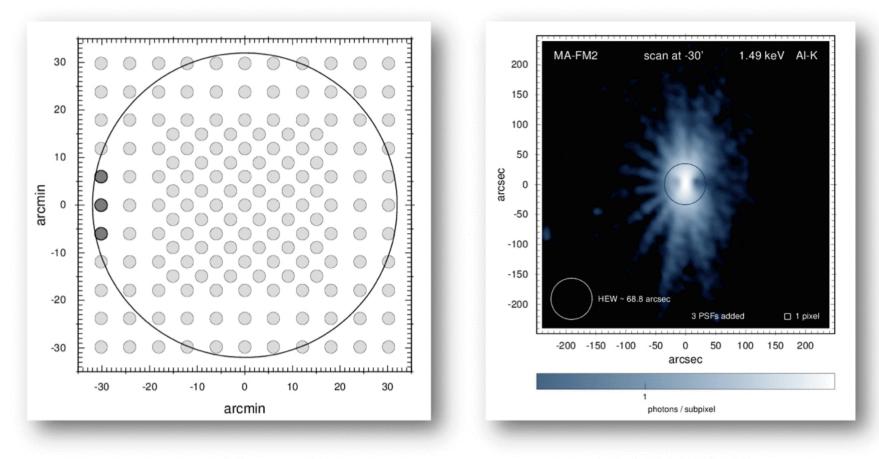
full FoV (60 arcmin diameter)

inner FoV (40 arcmin diameter)



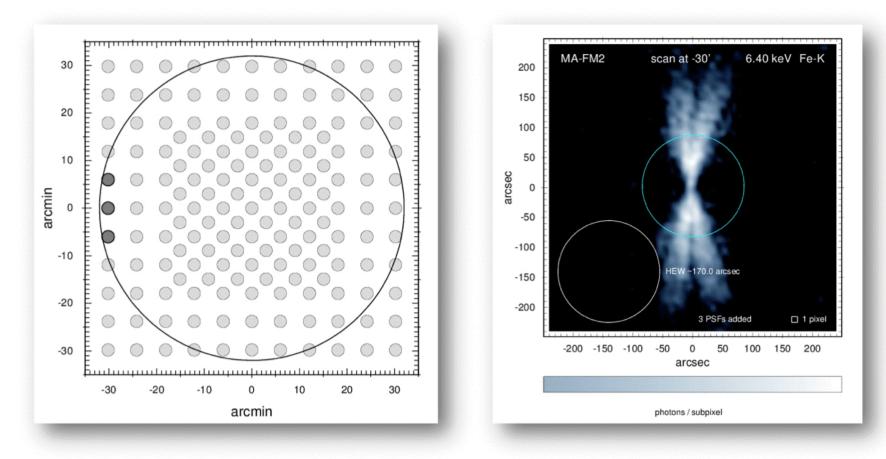
inner FoV (40 arcmin diameter)

full FoV (60 arcmin diameter)



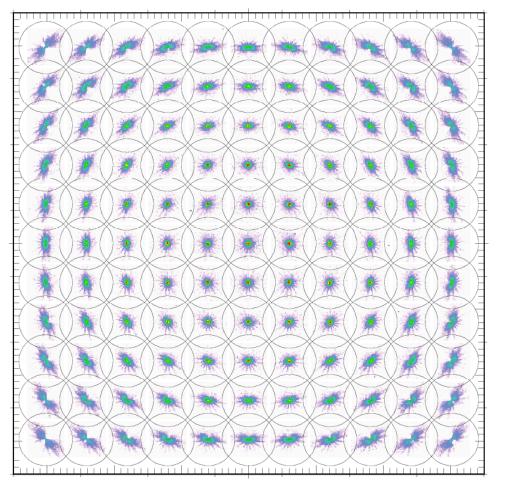
Al-K, 1.49 keV

scan at -30 arcmin



Fe-K, 6.40 keV

scan at -30 arcmin



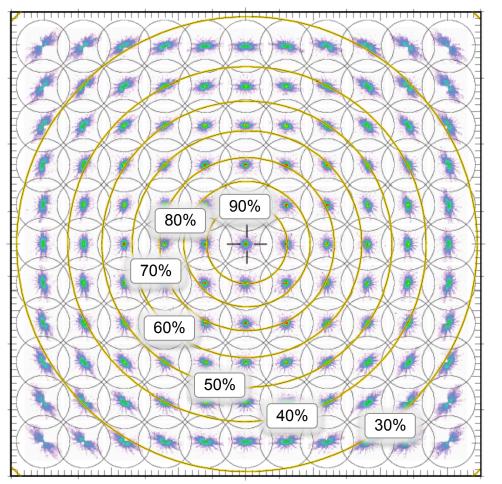
PSF Focal Plane Mapping

after geometry correction

extraction radius: 4 arcmin

\rightarrow vignetting

FM2, Al-K



PSF Focal Plane Mapping

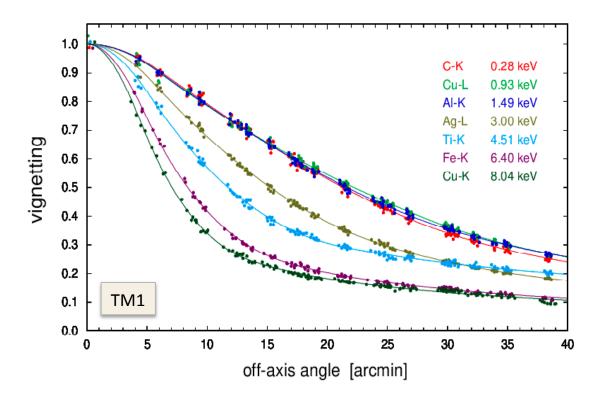
after geometry correction

extraction radius: 4 arcmin

\rightarrow vignetting

FM2, Al-K

PSF Focal Plane Mapping: vignetting curves



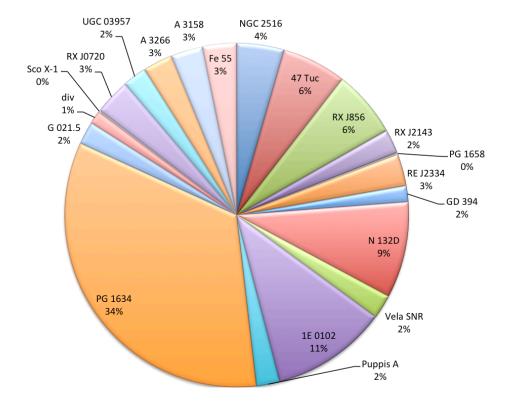
vignetting defined here as the relative encircled flux within r = 4.0 arcmin for a point source

derived from **1073 PSFs** covering the focal plane

empirical curves were determined together with the vignetting center

only assumption: azimuthal symmetry in vignetting

Calibration observations during the CalPV phase



The segments scale with the average exposure time per TM

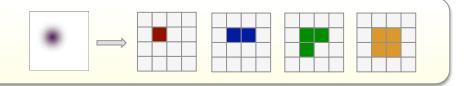
eROSITA Calibration:

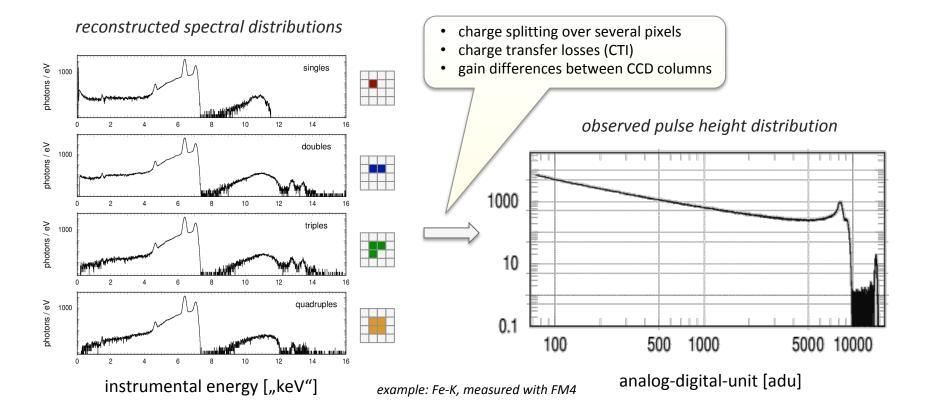
Detector

Charge Transfer Inefficiency (CTI),

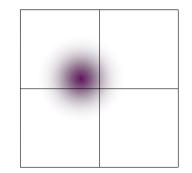
Gain

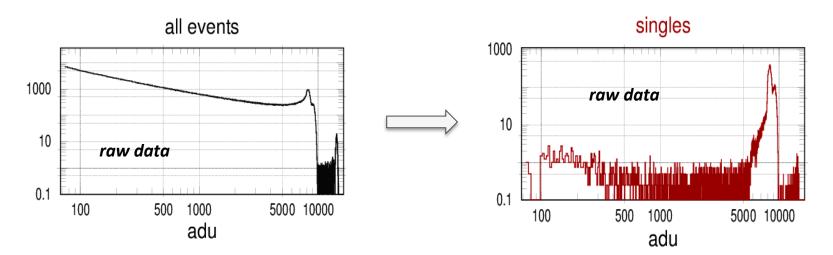
extent of charge cloud & 75 μ m pixel size → 4 pattern types





- pattern recognition
- correction for gain variations between CCD channels
- correction for charge transfer loss (CTI)



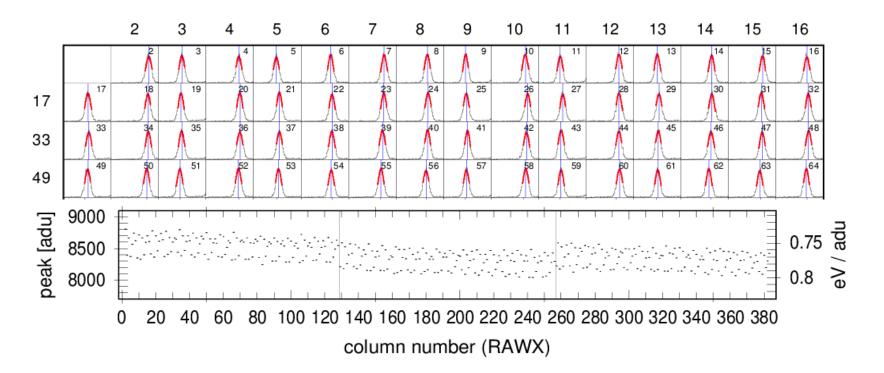


pattern recognition

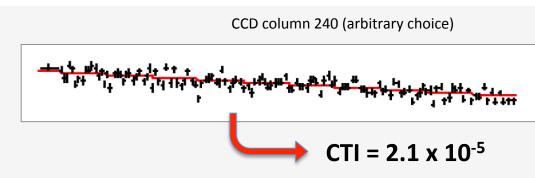
- pattern recognition
- correction for gain variations between CCD channels
- correction for charge transfer loss (CTI)

gain determination

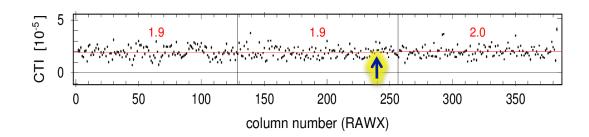
example: Fe-K, measured with FM4



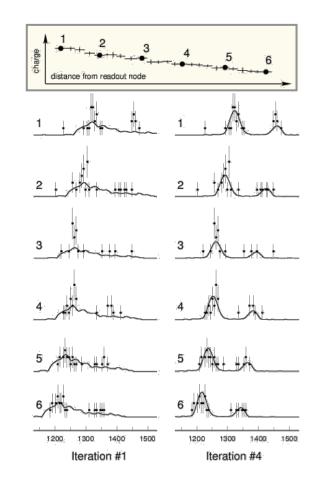
- pattern recognition
- correction for gain variations between CCD channels
- correction for charge transfer loss (CTI)



emission line determined in 130 (adaptively computed) macro pixels containing a minimum of 30 first singles around the line



CTI determination



97	مهامه والمراجع والمراجع والمالية والمحاصل معارفة والمراجع	2.7 161 🕆			1.3 225 🠳		- south and a fight of the property of the property of the stand group	CTI determination			
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110	- to a find the set of the set of the first first for the set of t	1.8 17	'4	- and in the start of the grant of and start and start and starting the starting the start and starting the	2.4	238	- with what is the share for proper product in the property	1.8	302	- Managara a sa ing panana na ang panana sa ang panana sa	1.5
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113	- Minterior and a state of the second state of the second state	1.0 17	7	- West and a state of the second state of the	2.4	241	- Milesindeninin praiser the presentation	2.1	305	<u>مەر ئەر ئەر ئەر ئەر ئەر ئەر ئەر ئەر ئەر ئ</u>	1.9
114	- Contracting and the second	1.9 17	'8	- and the state of	1.7	242	- and a start of the start of t	2.8	306	-and the state of the	1.8
115	- interesting and a second of the second sec	1.2 17	'9	٣٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠٠	1.4	243	- in the second and in the second and the	1.9	307	- and the second state of the second state	1.9
116	- interest and a second second second second second	1.0 18	80		1.8	244	<u></u>	2.2	308	<u>~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~</u>	1.7
117	- Sand and a start of a start of a start and a second	1.8 18	31	were a first for the first of the	2.1	245	and a second	2.0	309	- the addition of the second	2.0
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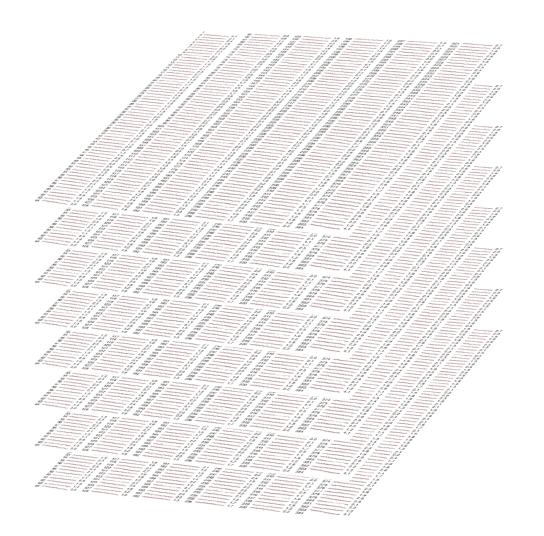
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CTI determination

example: Fe-K, measured with FM4

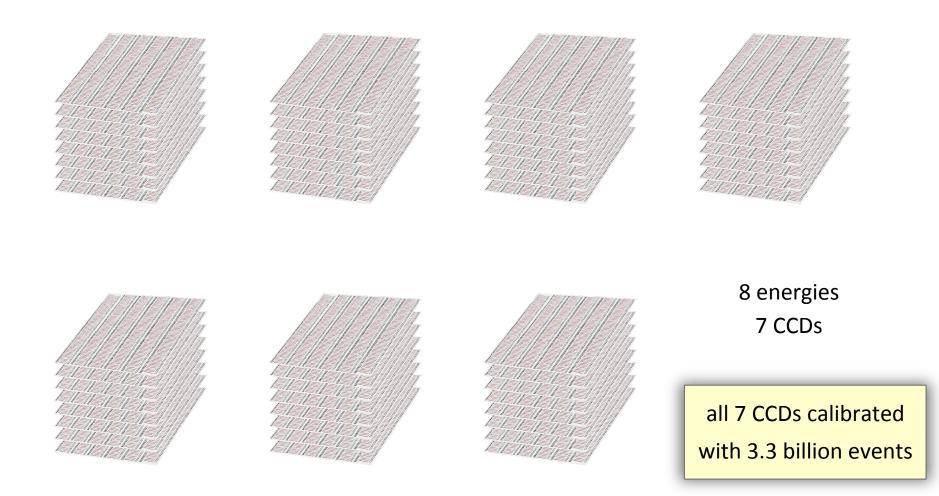
plot contains 47267 data points

each data point is the result of several iterative template fits



CTI determination

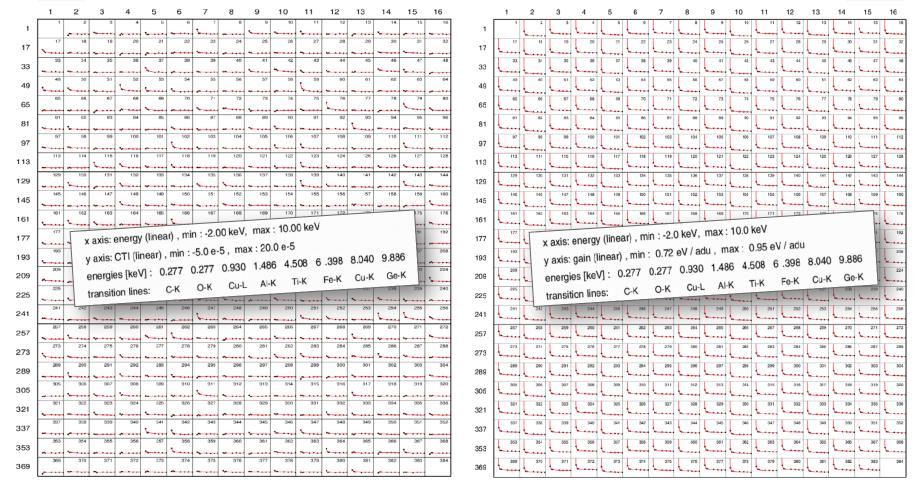
8 calibration energies



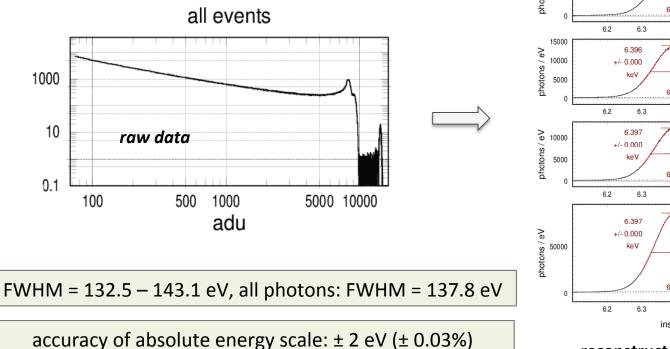
CTI

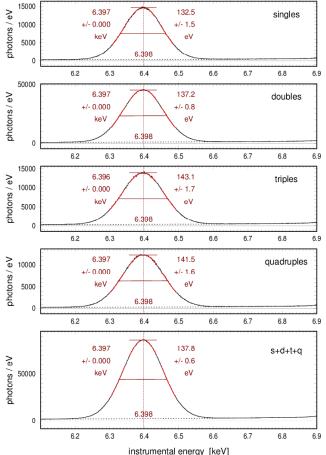
Energy interpolation of the CTI and gain





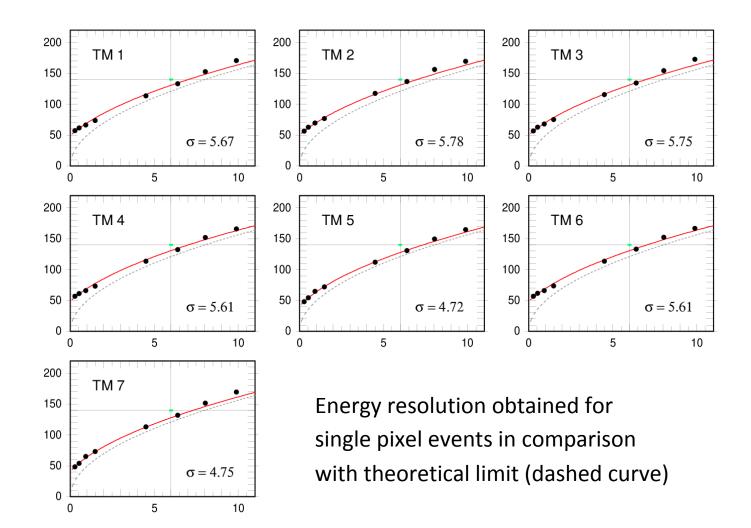
- pattern recognition
- correction for **gain** variations between CCD channels
- correction for charge transfer loss (CTI)

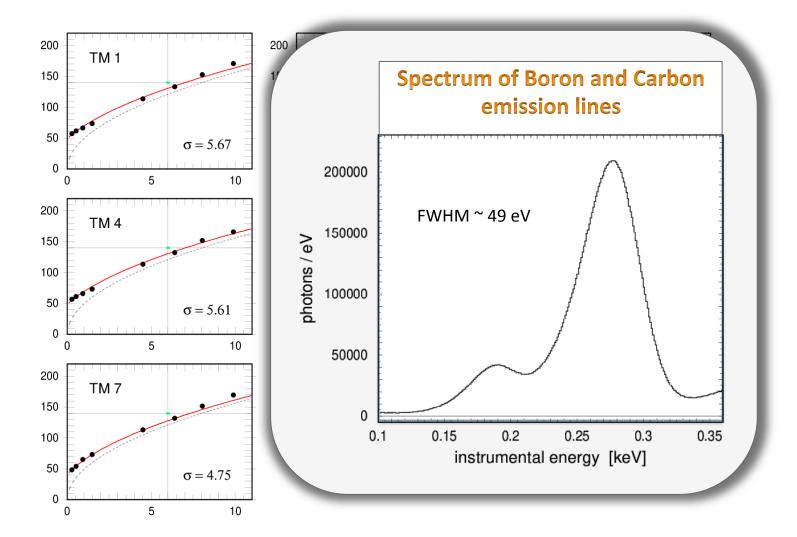




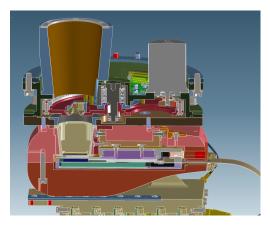
example: Fe-K, measured with FM4

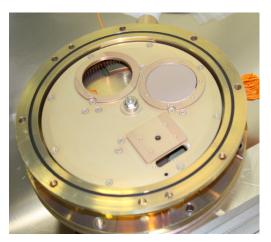
reconstructed spectral distribution

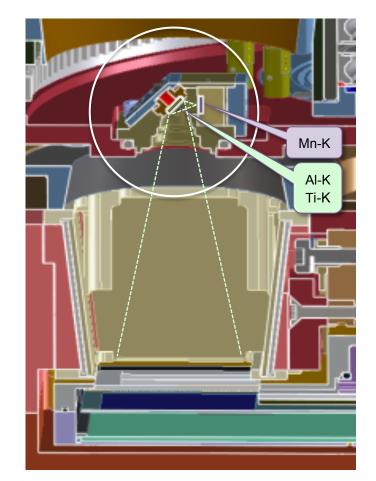




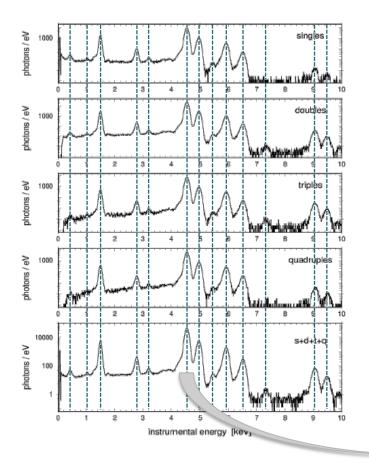
Energy calibration with the internal ⁵⁵Fe source

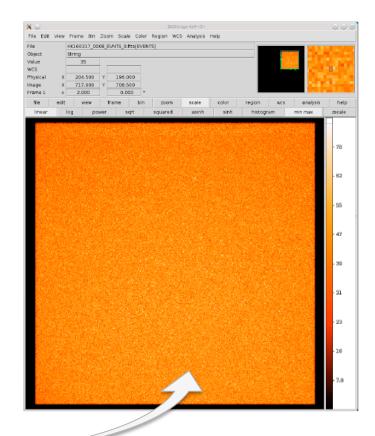


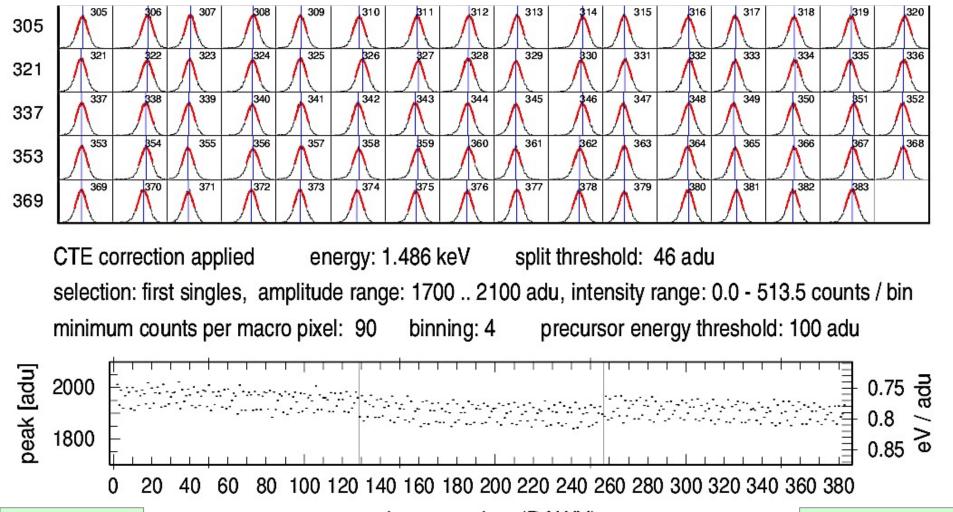




Energy Calibration: internal calibration source



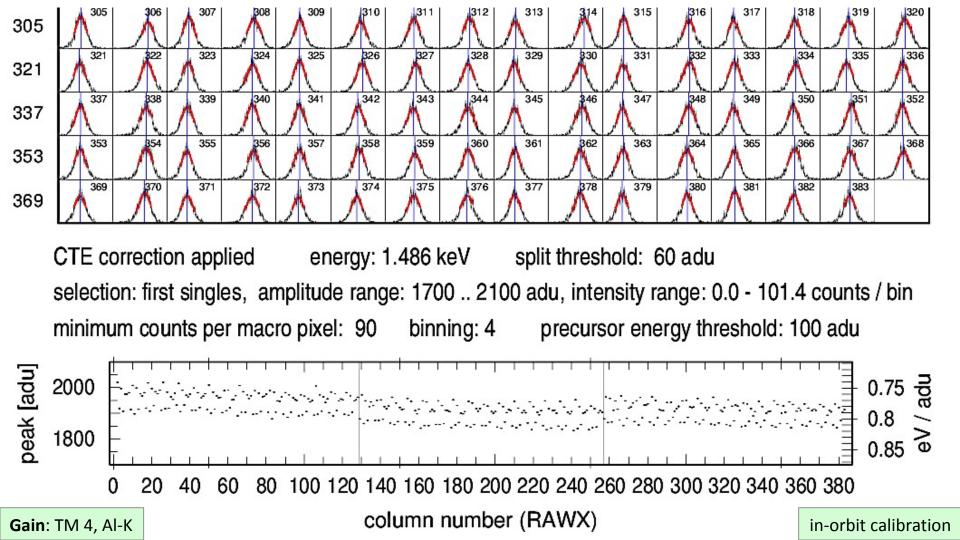


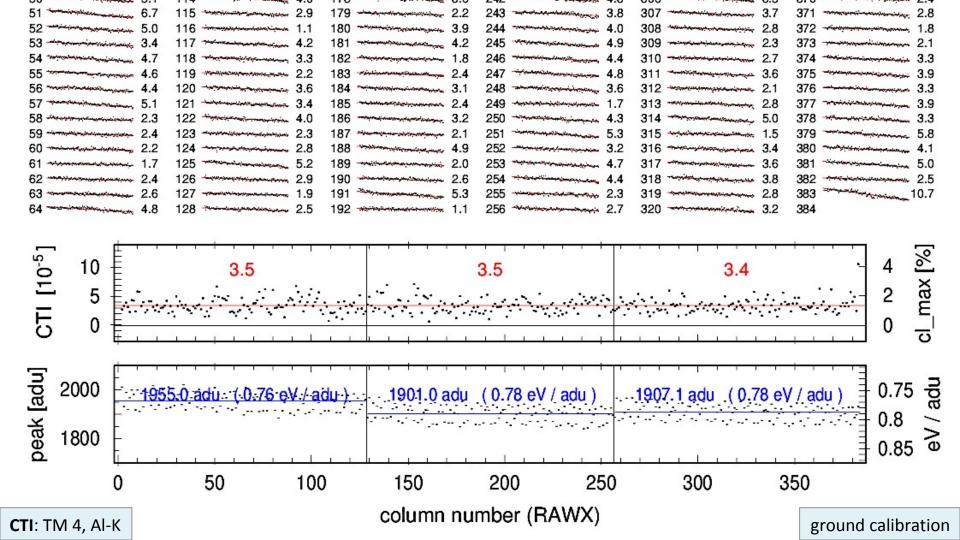


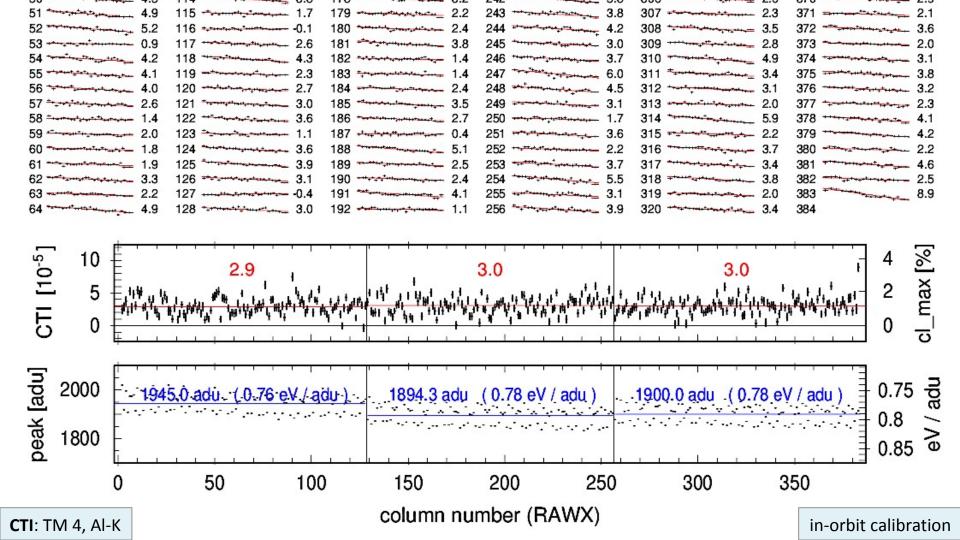
Gain: TM 4, Al-K

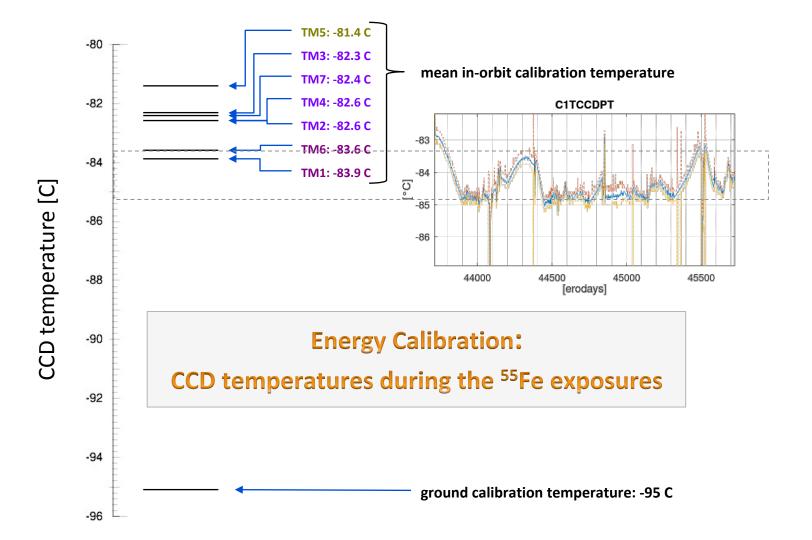
column number (RAWX)

ground calibration

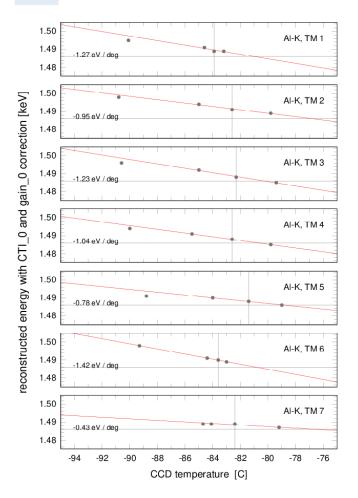


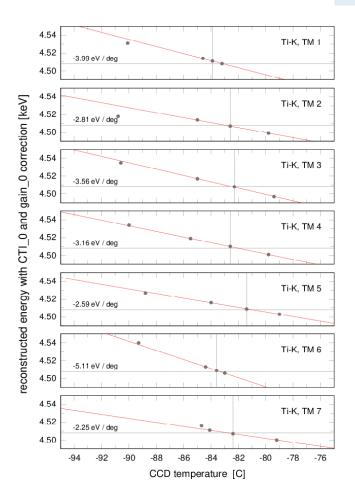




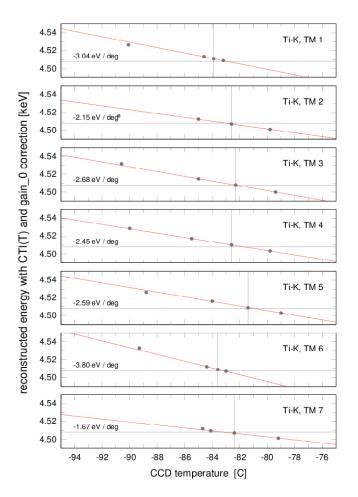


CCD temperature induced energy drifts

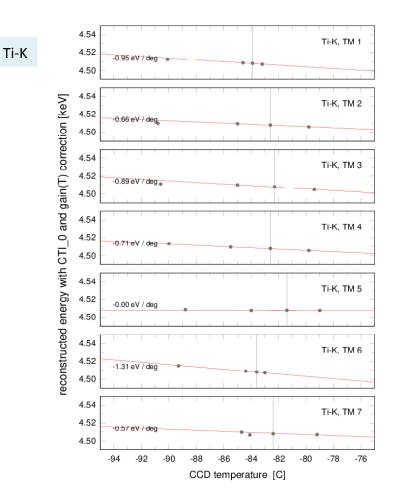




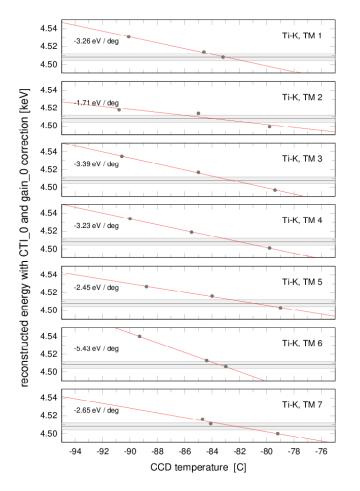
Effect of the temperature dependent gain



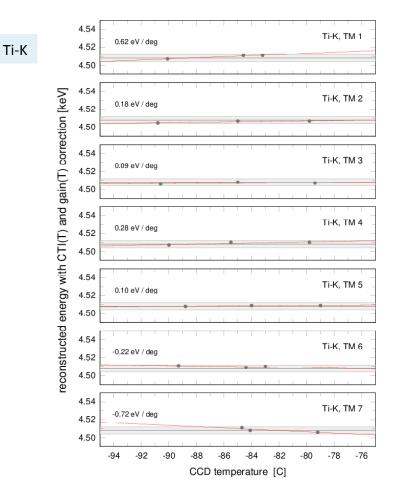
Effect of the temperature dependent CTI

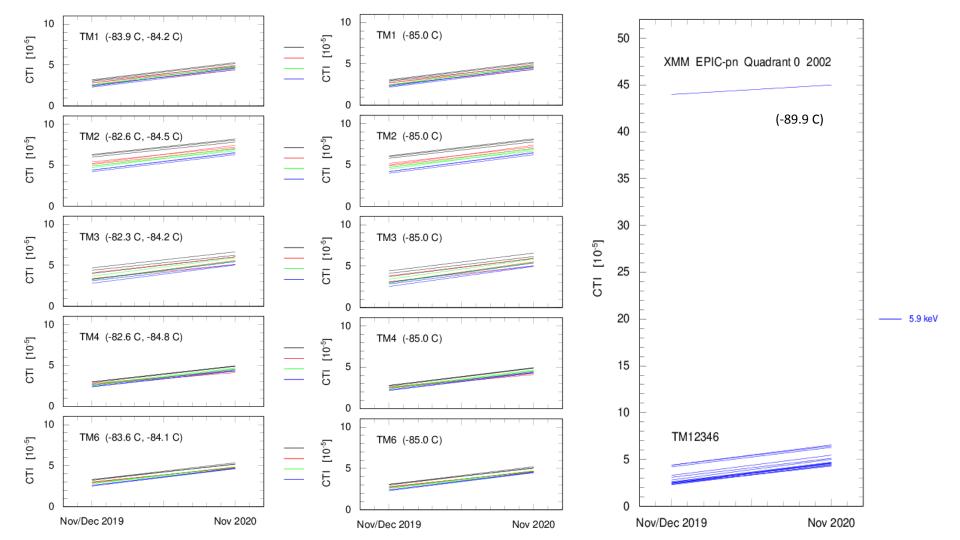


without temperature dependent energy correction

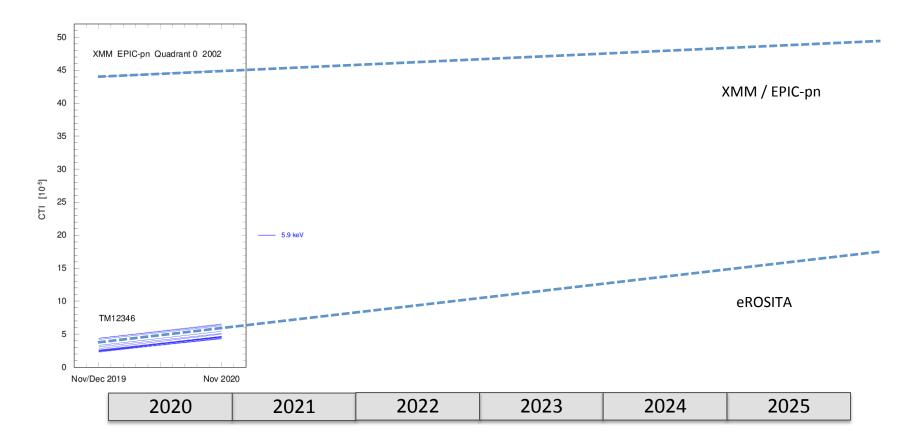


with temperature dependent energy correction

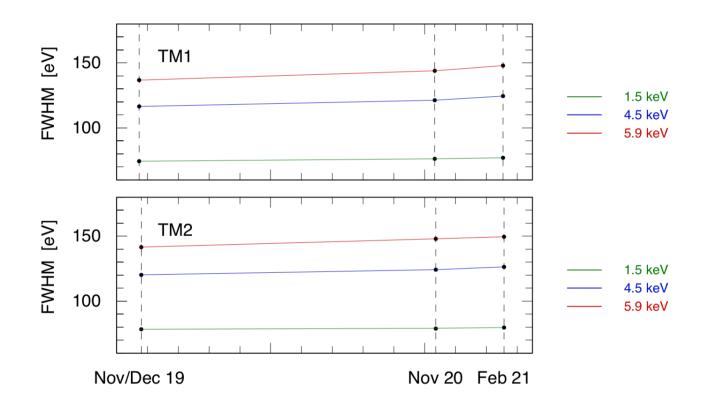




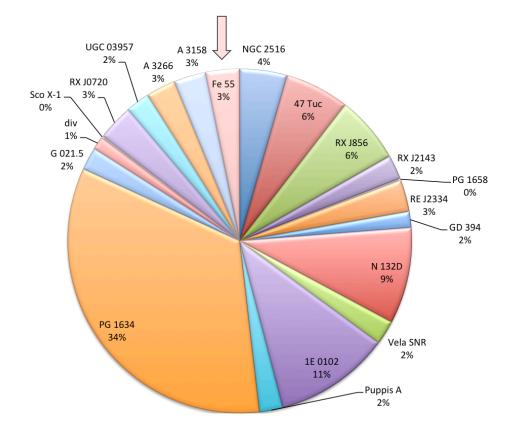
Expected CTI increase



FWHM evolution (with long-term correction)



Calibration observations during the CalPV phase



The segments scale with the average exposure time per TM





From Munich to Moscow





Transport in Moscow from SVO airport to NPOL

> 10 years of development and > 90 Million €

From Moscow to Baikonur



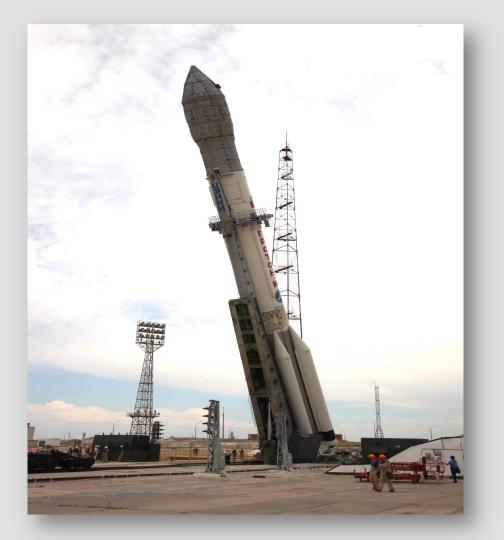






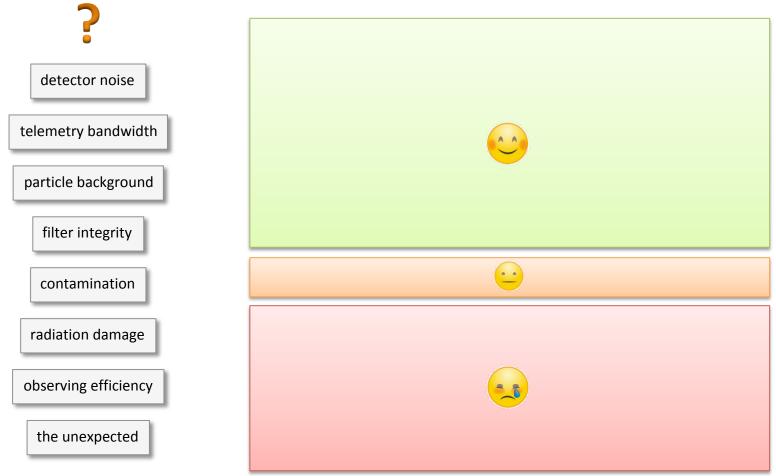


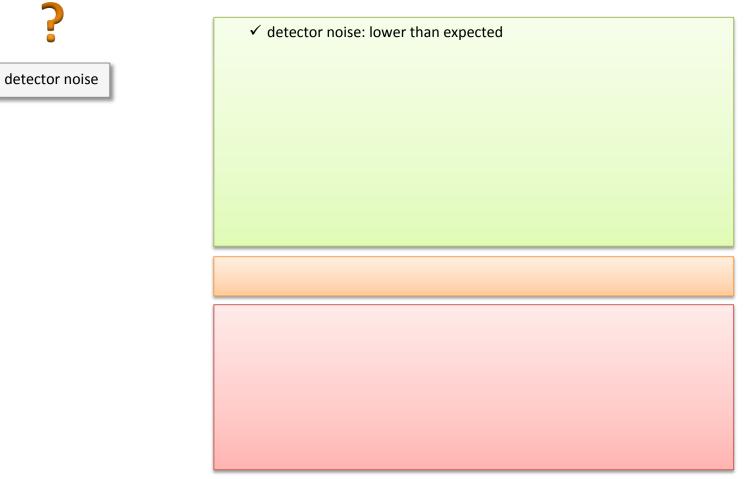






Baikonur, Kazakhstan, 2019 July 13





✓ detector noise: lower than expected

✓ telemetry bandwidth: sufficient

- ✓ efficient onboard data compression
- ✓ more telemetry available than expected

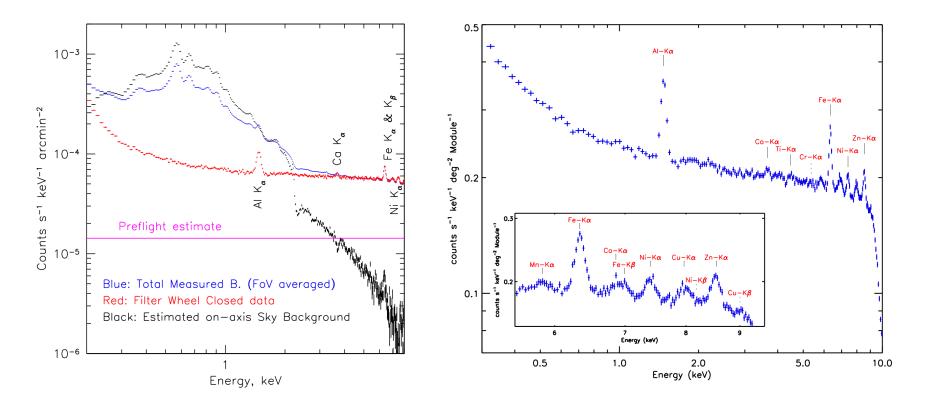
telemetry bandwidth

- ✓ detector noise: lower than expected
- ✓ telemetry bandwidth: sufficient
 - ✓ efficient onboard data compression
 - ✓ more telemetry available than expected
- ✓ particle background: less variable than expected

particle background

- particle background: higher than expected

Background



- ✓ detector noise: lower than expected
- ✓ telemetry bandwidth: sufficient
 - ✓ efficient onboard data compression
 - ✓ more telemetry available than expected
- ✓ particle background: less variable than expected
- ✓ filters ok

filter integrity

- particle background: higher than expected

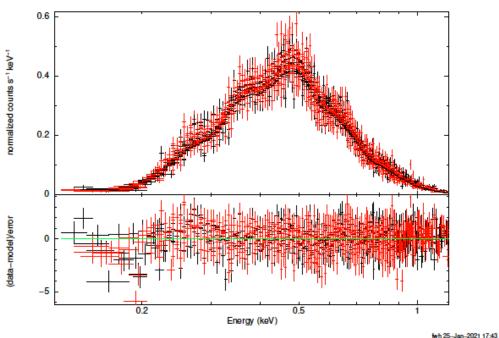
- ✓ detector noise: lower than expected
- ✓ telemetry bandwidth: sufficient
 - ✓ efficient onboard data compression
 - ✓ more telemetry available than expected
- ✓ particle background: less variable than expected
- ✓ filters ok
- ✓ contamination: no indication seen yet (!)

contamination

- particle background: higher than expected

Contamination Monitoring

RXJ2143 eROSITA TM12346 PAT=1 bbody*edge



RXJ2143:



Simultaneous fit to the 10 spectra (5 TMs at 2 occasions) with common n_H and C-K edge depth \rightarrow no evidence of contamination (!)

Analysis of eROSITA spectra from isolated neutron stars for contamination monitoring

F. Haberl, M. Freyberg, K. Dennerl, H. Brunner

January 27, 2021

- ✓ detector noise: lower than expected
- ✓ telemetry bandwidth: sufficient
 - ✓ efficient onboard data compression
 - ✓ more telemetry available than expected
- ✓ particle background: less variable than expected
- ✓ filters ok
- ✓ contamination: no indication seen yet (!)

radiation damage: CTI increase slightly higher than expected

- particle background: higher than expected

radiation damage

- ✓ detector noise: lower than expected
- ✓ telemetry bandwidth: sufficient
 - ✓ efficient onboard data compression
 - ✓ more telemetry available than expected
- ✓ particle background: less variable than expected
- ✓ filters ok
- ✓ contamination: no indication seen yet (!)

o radiation damage: CTI increase slightly higher than expected

- particle background: higher than expected
- micrometeoroid damages

"radiation" damage

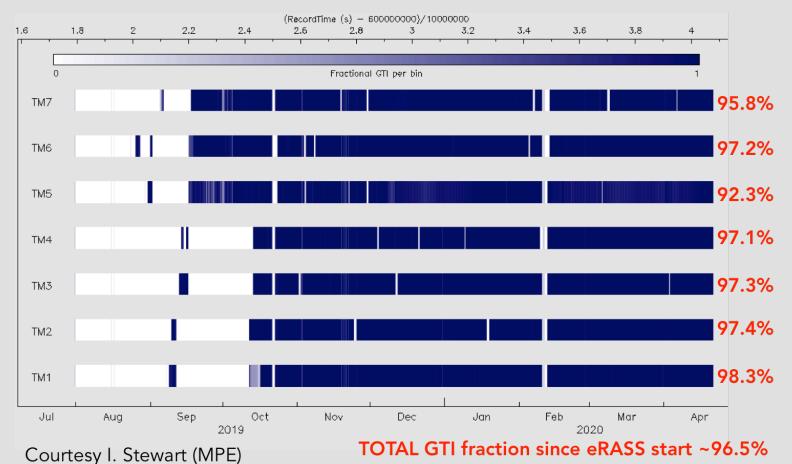
- ✓ detector noise: lower than expected
- ✓ telemetry bandwidth: sufficient
 - ✓ efficient onboard data compression
 - \checkmark more telemetry available than expected
- ✓ particle background: less variable than expected
- ✓ filters ok
- ✓ contamination: no indication seen yet (!)
- ✓ satellite platform: very stable and reliable
- ✓ observing efficiency: very high

o radiation damage: CTI increase slightly higher than expected

- particle background: higher than expected
- micrometeoroid damages

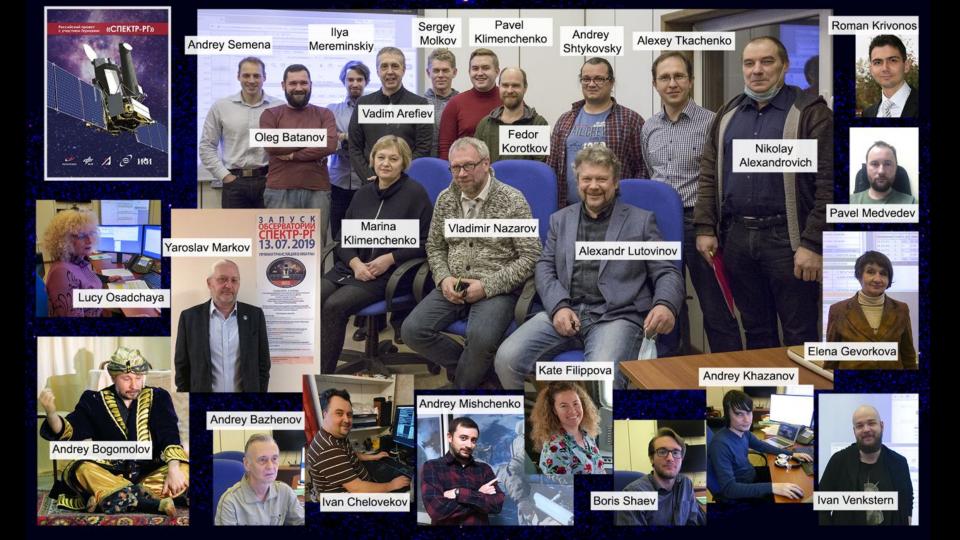
observing efficiency

Observing Efficiency



Operations Team at MPE





- ✓ detector noise: lower than expected
- ✓ telemetry bandwidth: sufficient
 - ✓ efficient onboard data compression
 - ✓ more telemetry available than expected
- ✓ particle background: less variable than expected
- ✓ filters ok
- ✓ contamination: no indication seen yet (!)
- ✓ satellite platform: very stable and reliable
- ✓ observing efficiency: very high

o radiation damage: CTI increase slightly higher than expected

- particle background: higher than expected
- micrometeoroid damages
- CCD temperatures: higher and more variable than expected

the unexpected

- ✓ detector noise: lower than expected
- ✓ telemetry bandwidth: sufficient
 - ✓ efficient onboard data compression
 - \checkmark more telemetry available than expected
- ✓ particle background: less variable than expected
- ✓ filters ok
- ✓ contamination: no indication seen yet (!)
- ✓ satellite platform: very stable and reliable
- ✓ observing efficiency: very high

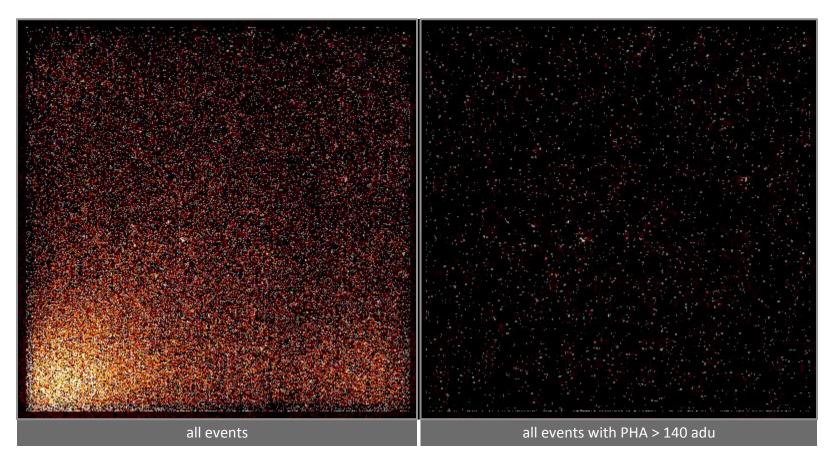
o radiation damage: CTI increase slightly higher than expected

- particle background: higher than expected
- micrometeoroid damages
- CCD temperatures: higher and more variable than expected
- severe optical light leak problem in two cameras

the unexpected

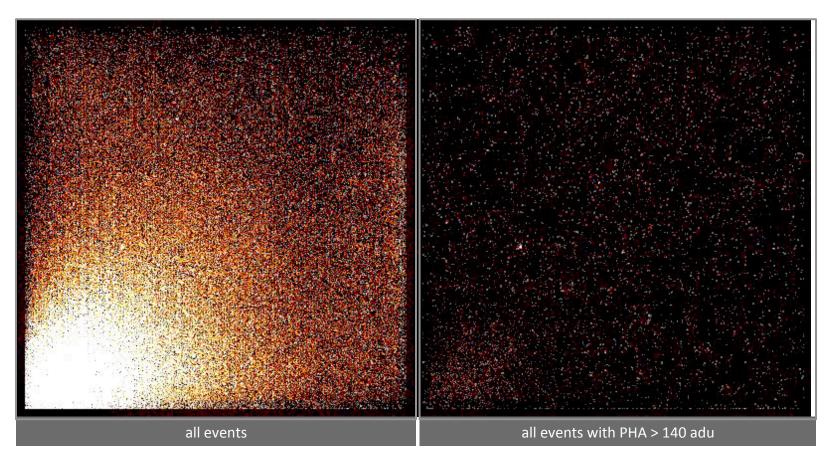
optical light leak

10 min time bins

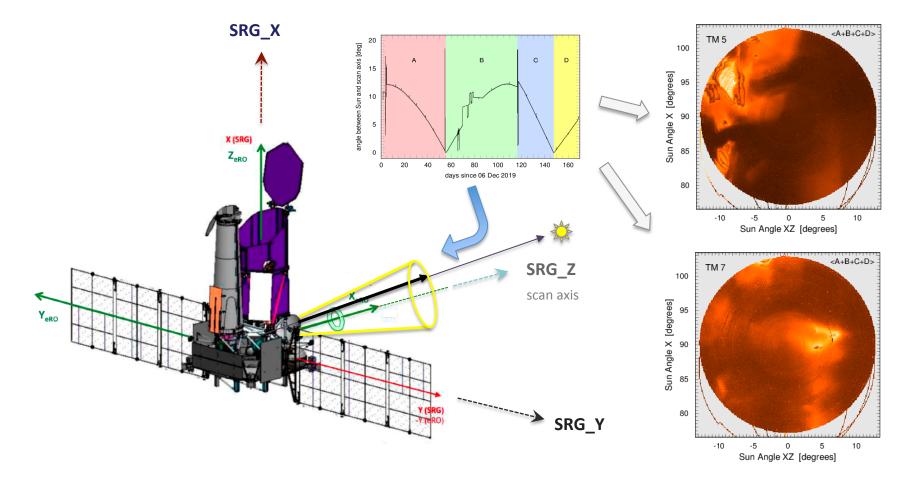


optical light leak

10 min time bins

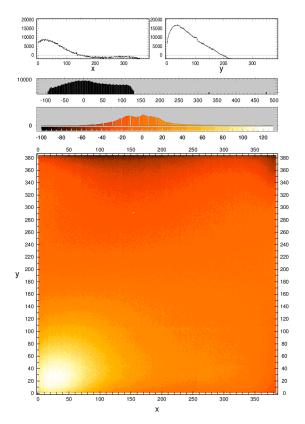


Energy Calibration: optical light leak in TM5 and TM7

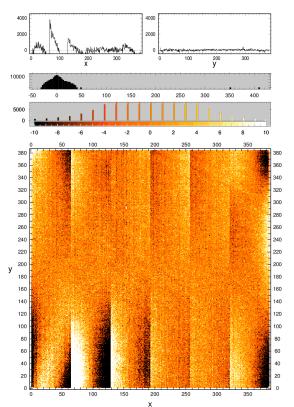


Energy Calibration: optical light leak in TM5 and TM7

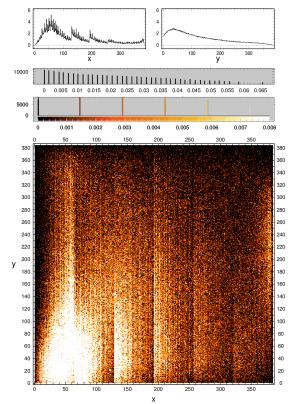
residual offset map caused by optical light



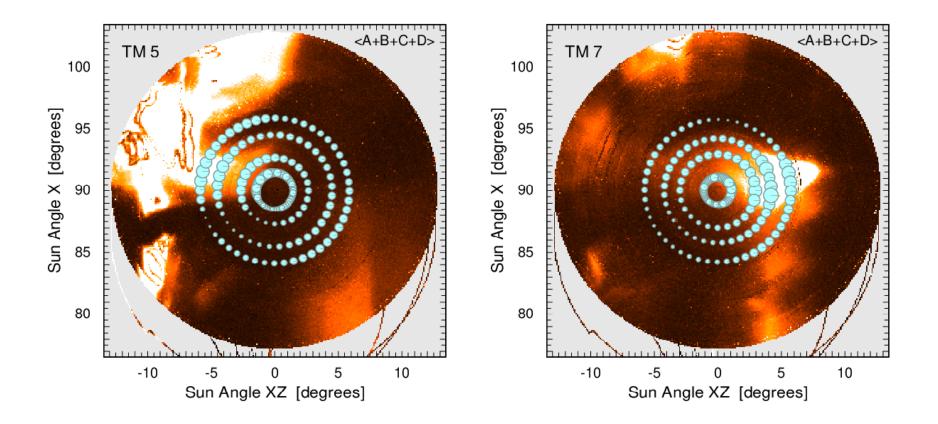
after common mode subtraction



observed event rate (TM7)



Energy Calibration: optical light leak in TM5 and TM7

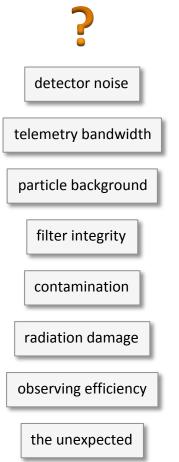


- ✓ detector noise: lower than expected
- ✓ telemetry bandwidth: sufficient
 - ✓ efficient onboard data compression
 - ✓ more telemetry available than expected
- ✓ particle background: less variable than expected
- ✓ filters ok
- ✓ contamination: no indication seen yet (!)
- ✓ satellite platform: very stable and reliable
- ✓ observing efficiency: very high

radiation damage: CTI increase slightly higher than expected

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- micrometeoroid damages
- CCD temperatures: higher and more variable than expected
- severe optical light leak problem in two cameras
- frequent camera resets required, may result in time shifts
- some CCD frames not usable due to artefacts, data cleaning required

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eROSITA Calibration and First Results



IACHEC, 2021 April 23

Konrad Dennerl, MPE