DE LA RECHERCHE À L'INDUSTRIE

MICROCHANNEL X-RAY TELESCOPE SCIENTIFIC PERFORMANCE

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WITH INPUTS AND ON BEHALF OF THE MXT SCIENCE TEAM

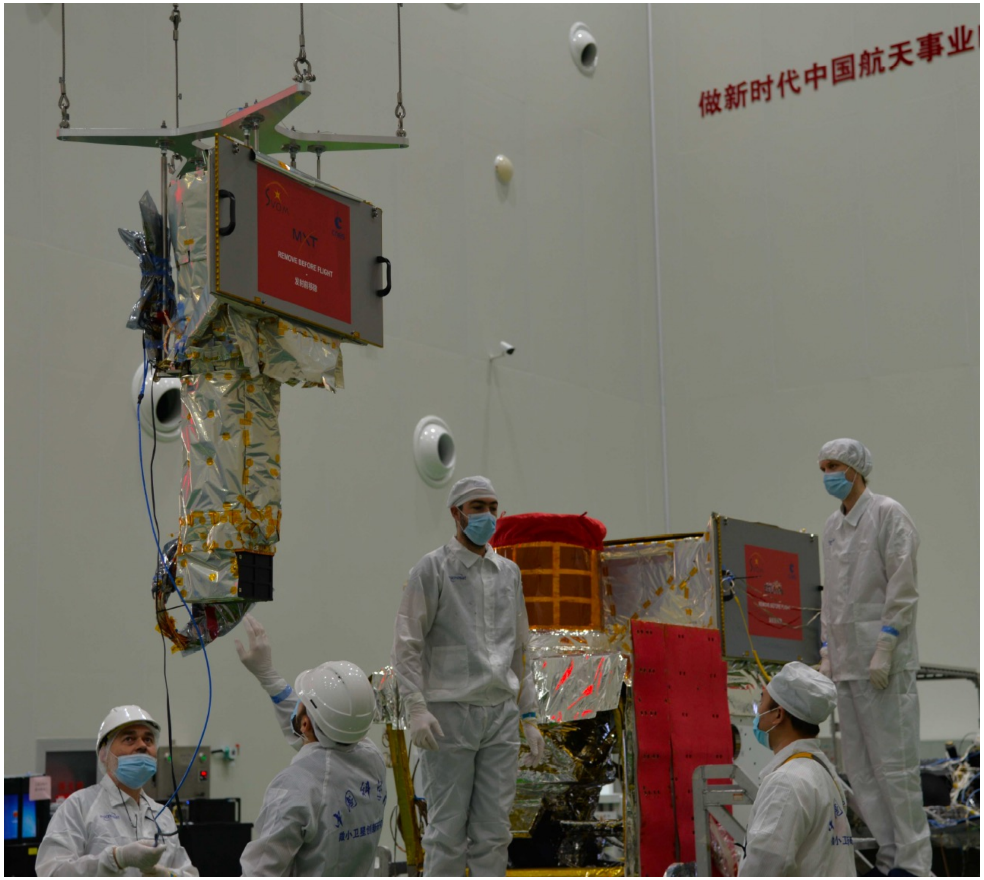
www.cea.fr

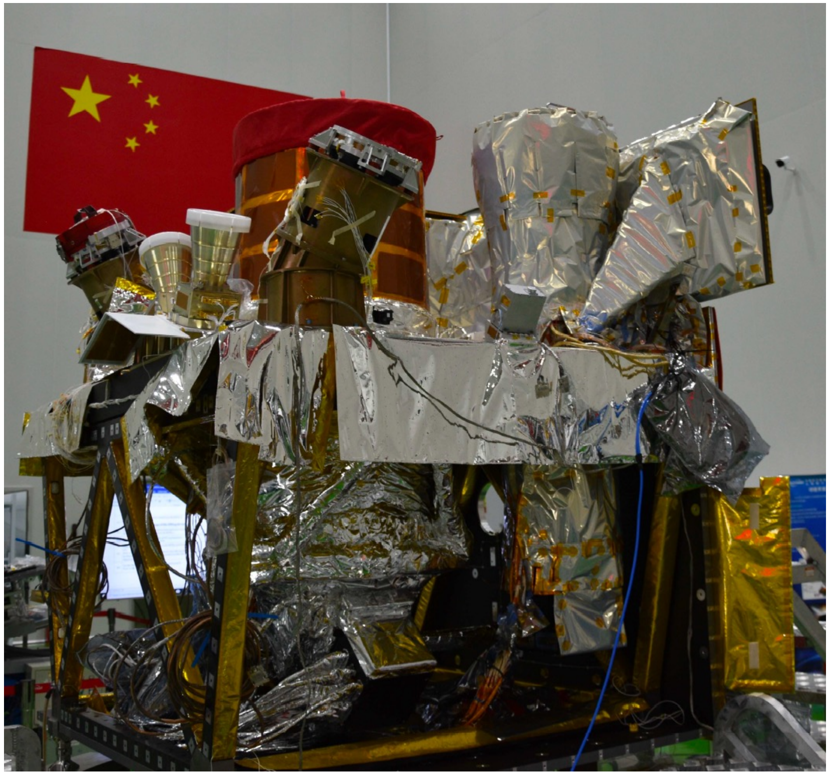
MXT FLIGHT MODEL

March 18th 2022 @ CNES

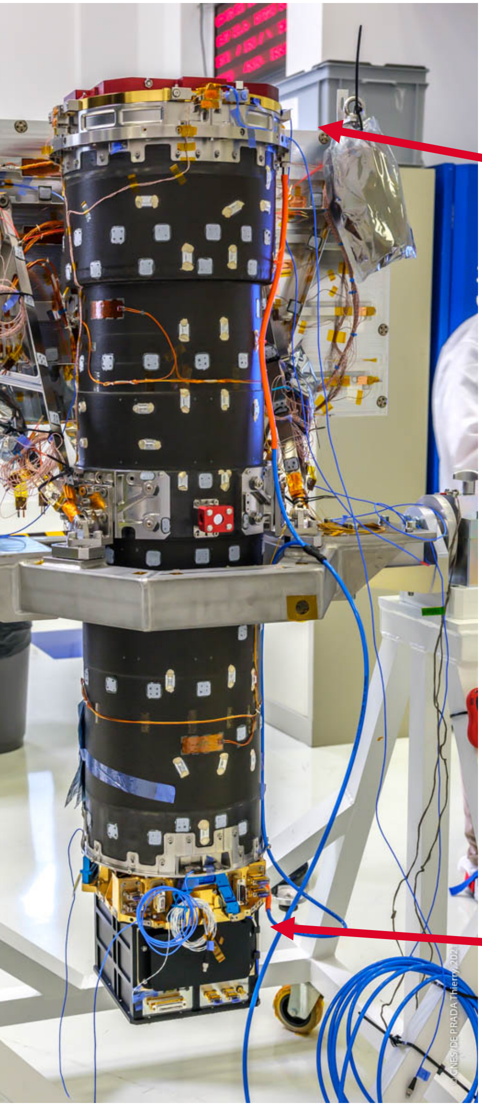
MXT HAS BEEN SHIPPED TO CHINA!

MECHANICAL INTEGRATION IN CHINA

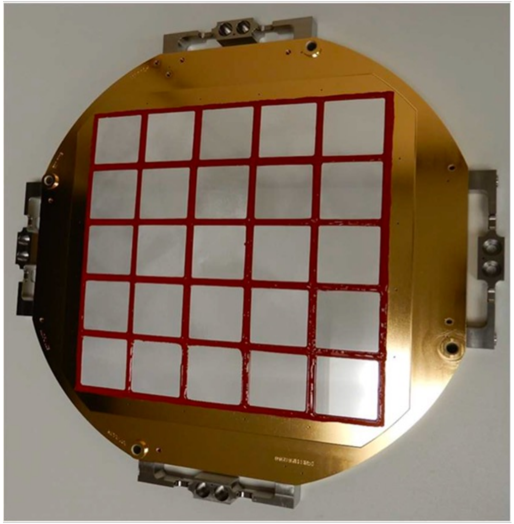


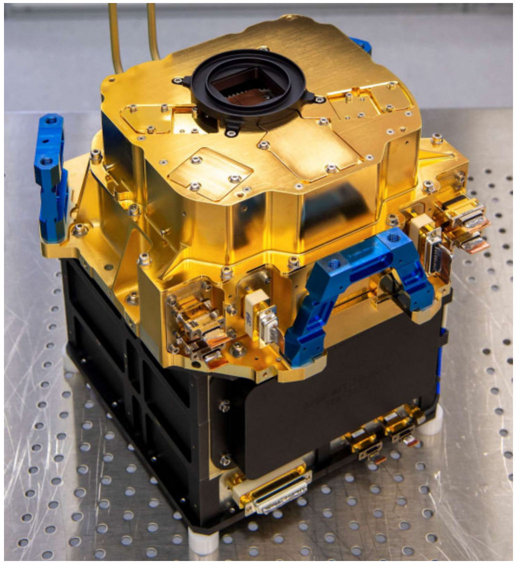


MXT FLIGHT MODEL & PERFORMANCE



Energy range	0.2 – 10 keV
Field of View	58 × 58 arcmin
Angular resolution	10 arcmin at 1.5 keV
Source location accuracy	$<$ 120 arcsec for 80 % GRBs
Effective area	$\sim$ 35 cm^2 at 1.5 keV
Sensitivity (5σ)	10 mCrab in 10 s 150 μCrab in 10 ks
Energy resolution	$<$ 80 eV at 1.5 keV
Time resolution	100 ms





MXT FLIGHT MODEL

MXT Data Processing Unit(s): implement the MXT control and scientific OBSW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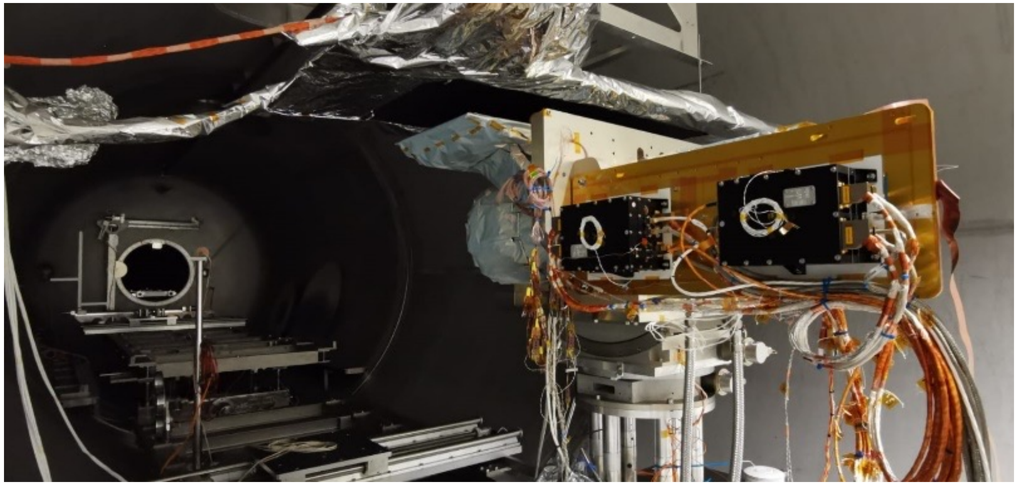
PANTER E2E CALIBRATION

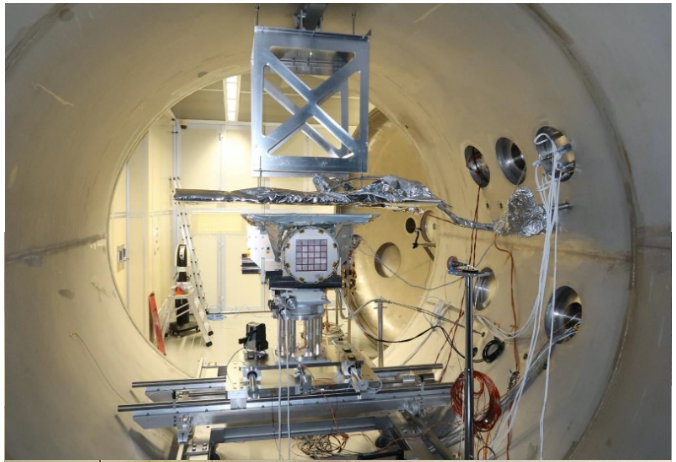
From October to November 5 2021, the MXT telescope in its final flight configuration was extensively tested at MPE Panter facility

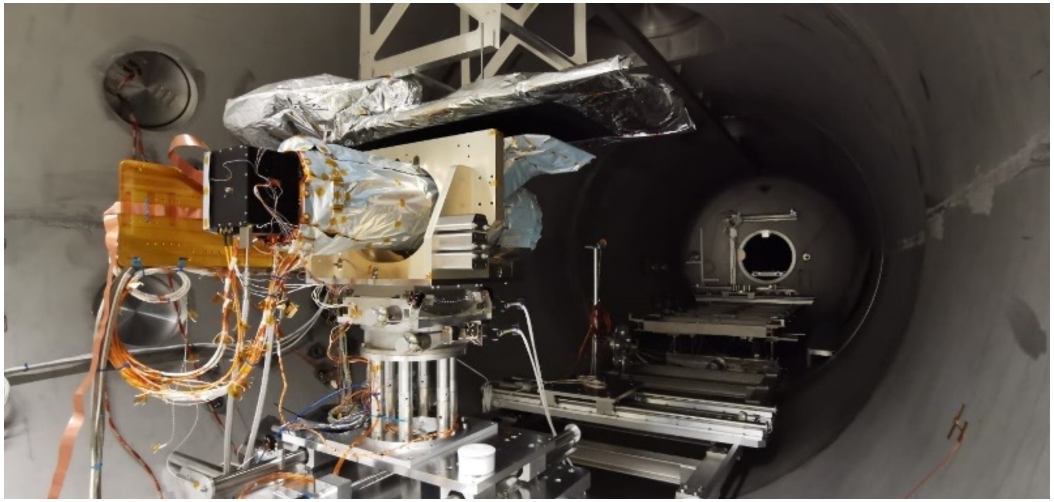
The main goals of the calibration campaign included :

- Measuring the telescope Point Spread Function (PSF) as a function of energy and position in the FOV
- Measuring the telescope Line of Sight (LOS)
- Measuring the telescope effective area
- Measuring the camera spectral response
- Testing the on board S/W scientific partition (real-time localization)
- Exploring different thermal regimes
- Measuring the impact of stray-light using lasers (impact of filter absence)

PANTER SETUP







PANTER (ET AL.) DATA ANALYSIS

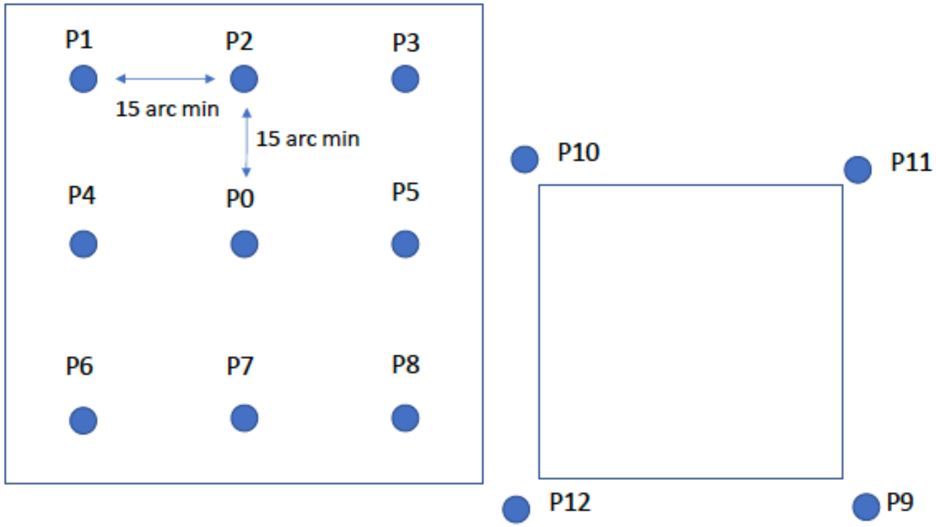
In 2022 we focused on the detailed analysis of Panter (and SOLEIL) data. This resulted in a set of papers that have been published lately

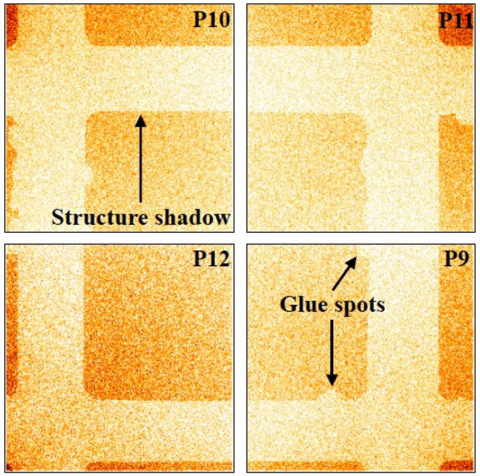
1) Spectral performance of the Microchannel X-ray Telescope on board the SVOM mission, by B. Schneider et al., ExpAstr (https://arxiv.org/abs/2212.09863)
2) The Scientific Performance of the Microchannel X-ray Telescope on board the SVOM Mission, by D. Götz et al., ExpAstr (https://arxiv.org/abs/2211.13489)
3) Analysis methods to localize and characterize X-ray sources with the Micro-channel X-ray Telescope on board the SVOM satellite, by S. Hussein et al., ApJ (https://arxiv.org/abs/2209.13330)
4) Design and performance of the camera of the Micro-channel X-ray Telescope on-board the SVOM mission, by A. Meuris et al., NIM-A
5) Characterization of the focal plane of the Microchannel X-ray Telescope at the Metrology beamline of SOLEIL synchrotron for the space astronomy mission SVOM, by A. Meuris et al., NIM-A
6) Stability and assembly precision of MXT line of sight, by J.M. Le Duigou et al., SPIE
7) Results of the development of the MXT X-ray telescope for the SVOM mission, by K. Mercier et al., SPIE
8) Calibration of the flight model lobster eye optic for SVOM, by C. Feldman et al., SPIE
9) SVOM-MXT Optic and Telescope Testing at PANTER, by V. Burwitz et al., ICSO

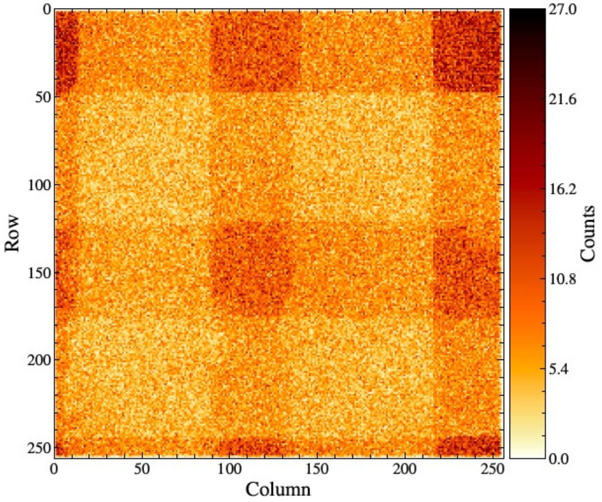
DATA TAKING

C-K 0.277 keV
O-K 0.525 keV
Cu-L 0.93 keV
Mg-K 1.253 keV
Al-K 1.486 keV
W-M 1.774 keV
Ag-L 2.98 keV

Ti-Ka 4.508 keV
Ti-Kb 4.93 keV
Cr-Ka 5.405 keV
Fe-Ka 6.398 keV
Fe-Kb 7.053 keV
Cu-Ka 8.047 keV







CAMERA PERFORMANCE

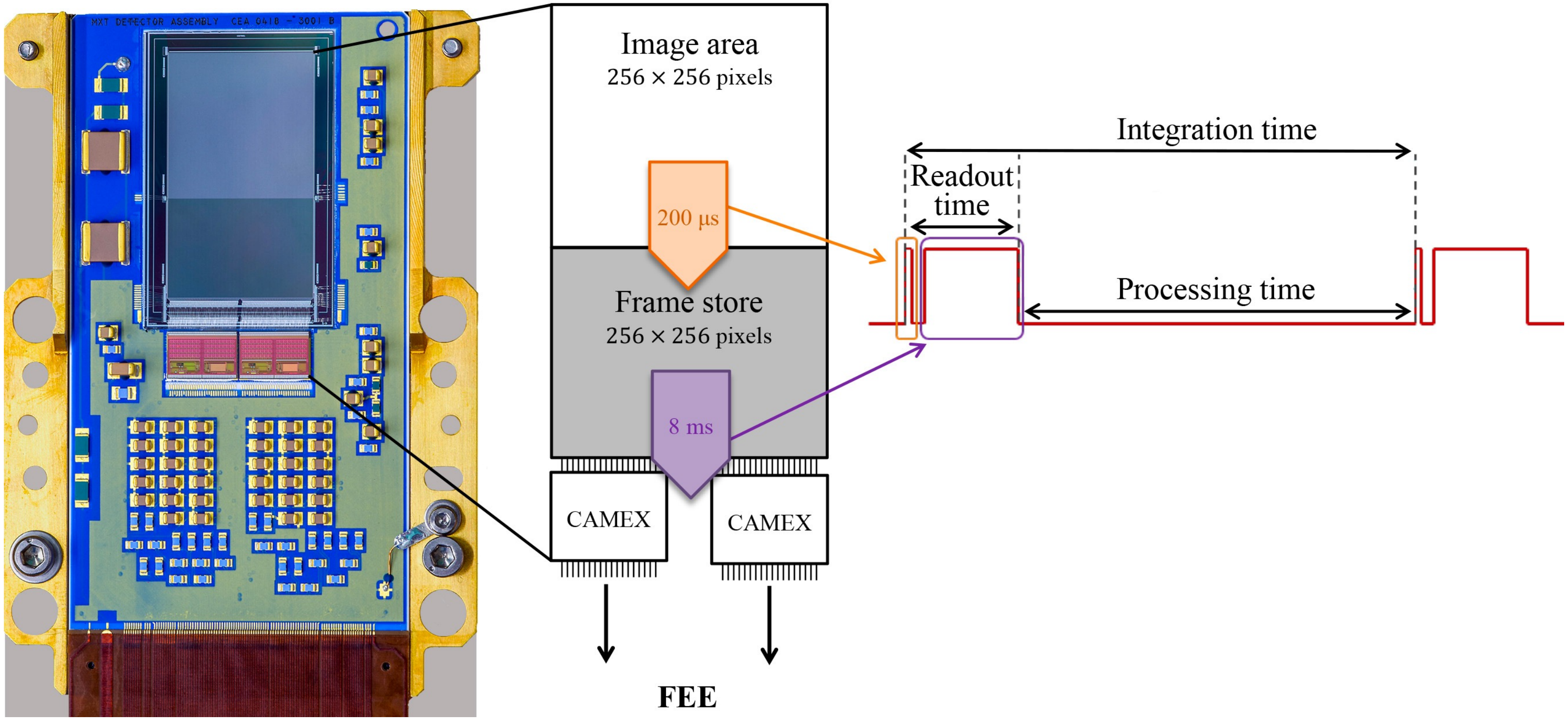


Image area
256 × 256 pixels

200 µs

Frame store
256 × 256 pixels

8 ms

CAMEX

CAMEX

FEE

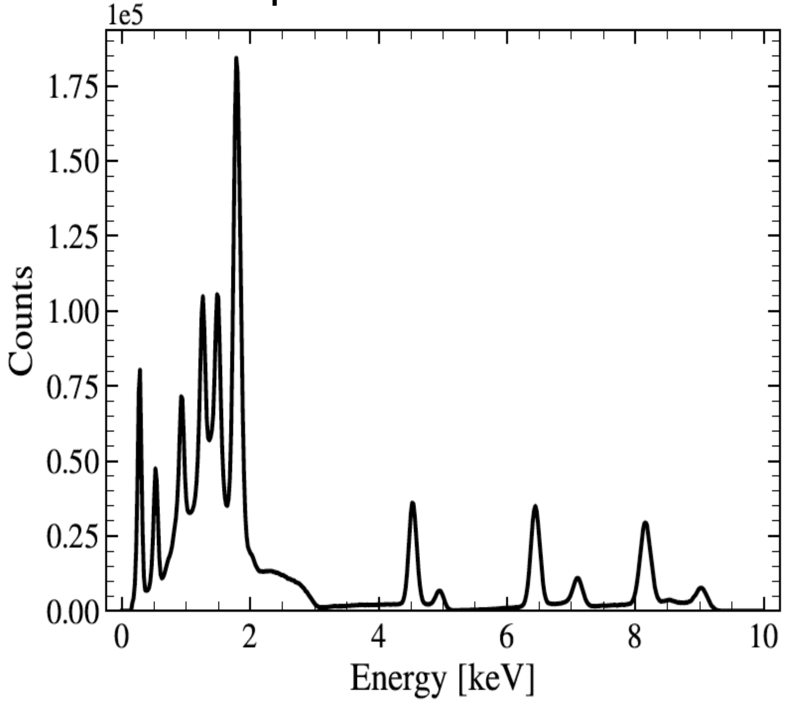
Integration time

Readout time

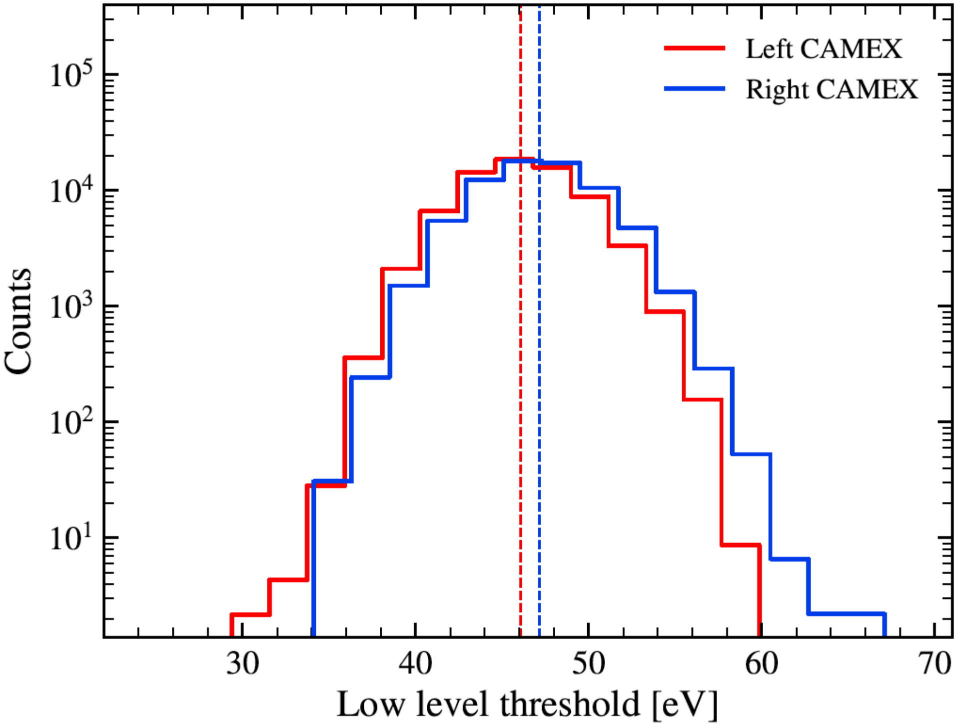
Processing time

CAMERA PERFORMANCE : LLT

Combined spectrum used for calibration

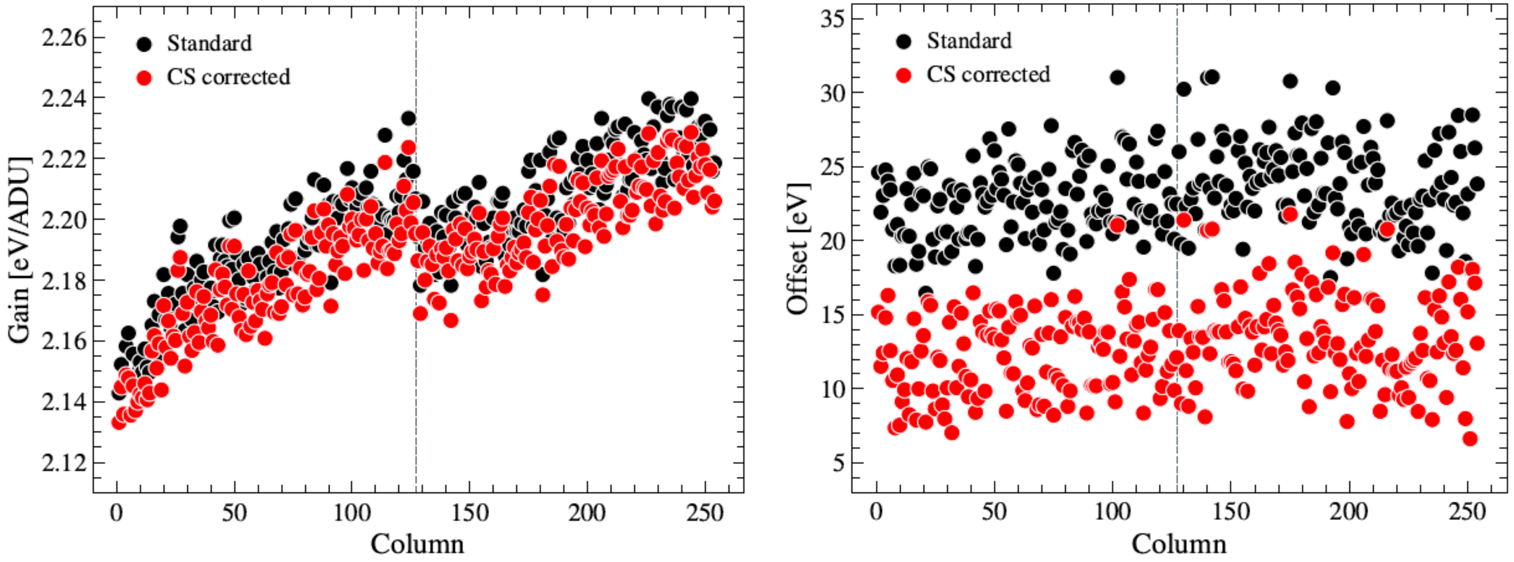


Requirement: 200 eV



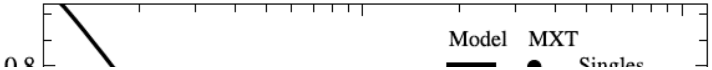
LLT is stable over the -75° to -65° C range

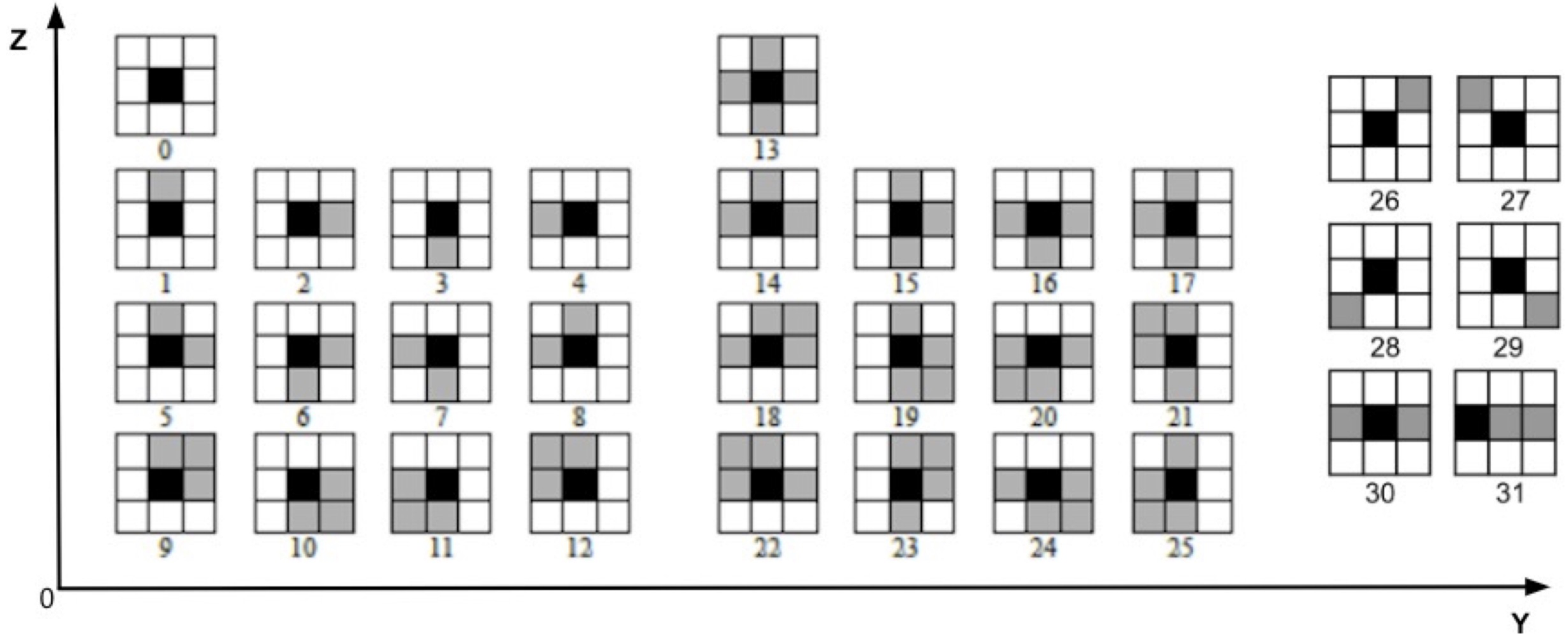
CAMERA PERFORMANCE : GAIN & OFFSET



At -65°C gain & offset are very regular over the entire detector

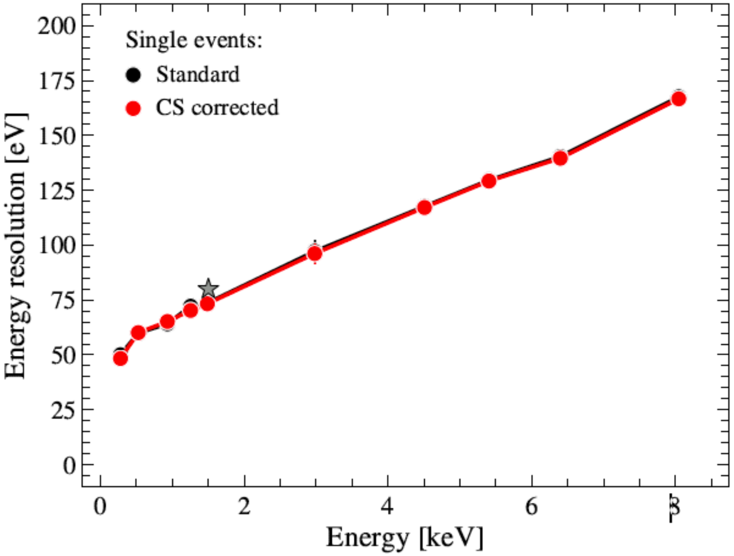
CAMERA PERFORMANCE : CHARGE SHARING

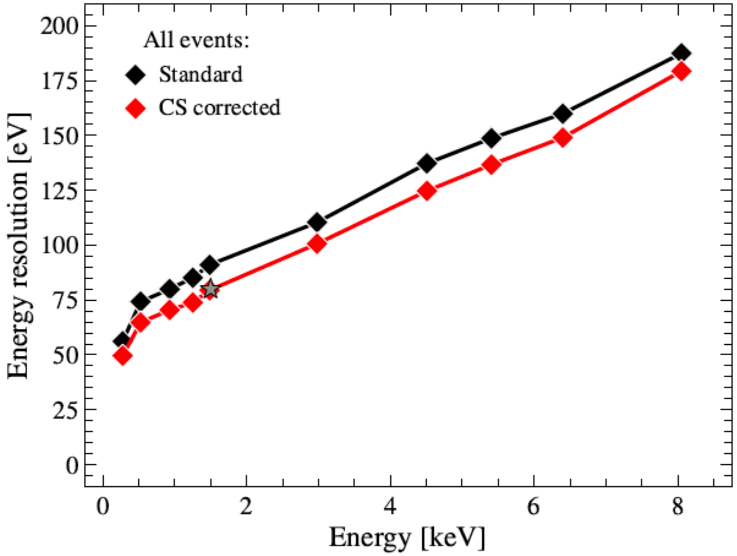


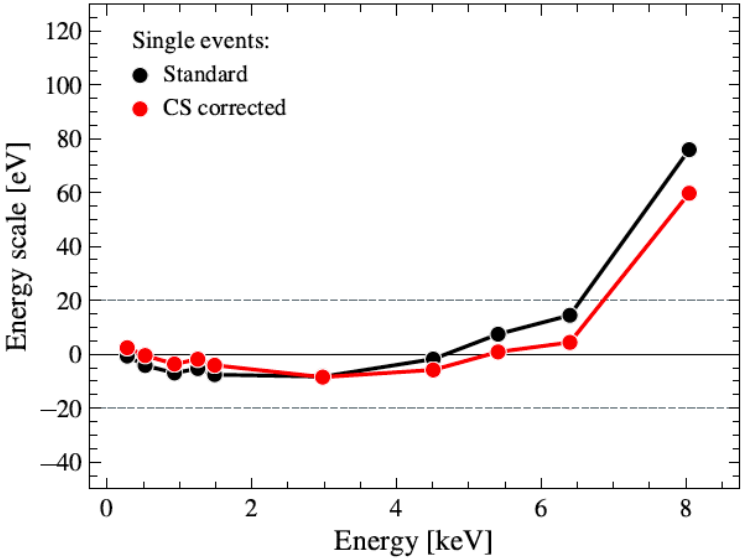


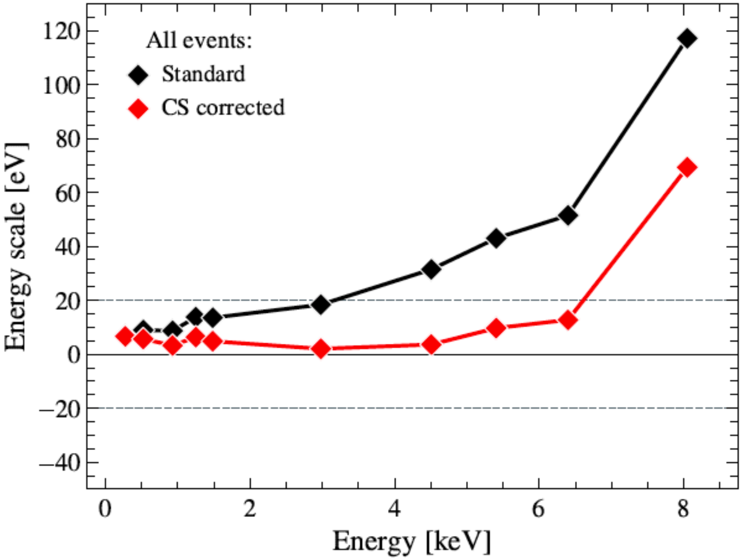
- threshold for suppressing noise events), a fraction of the photon energy gets lost and the recombined photon energy is thus slightly underestimated
- This produces a charge sharing (CS) energy effect, which on one side induces a shift of the line position to lower energy, and on the other side degrades the spectral performance of the instrument

ENERGY RESOLUTION AND ENERGY SCALE



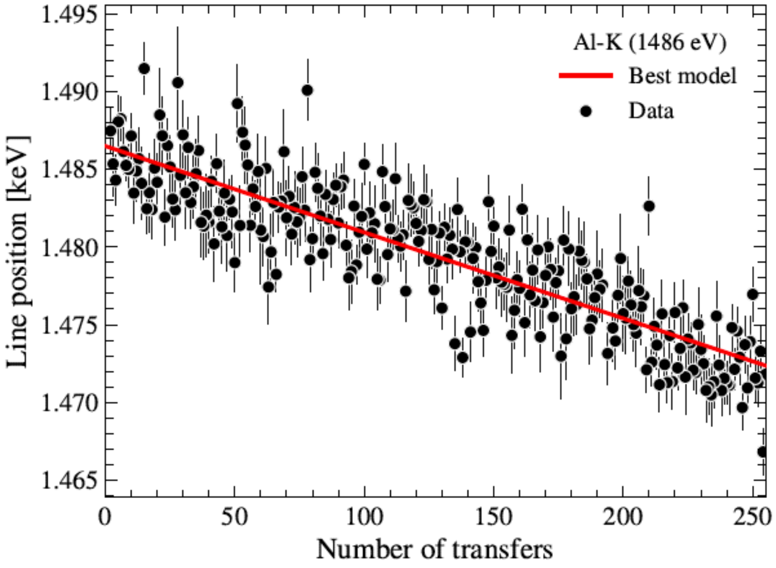


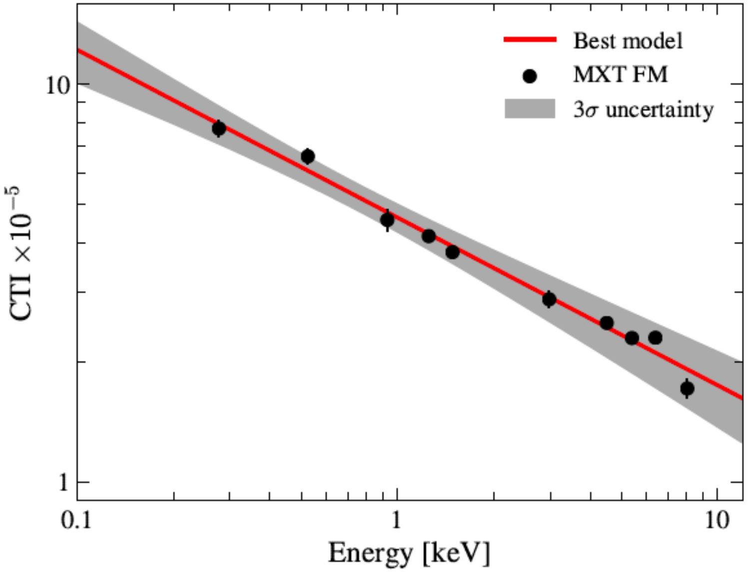




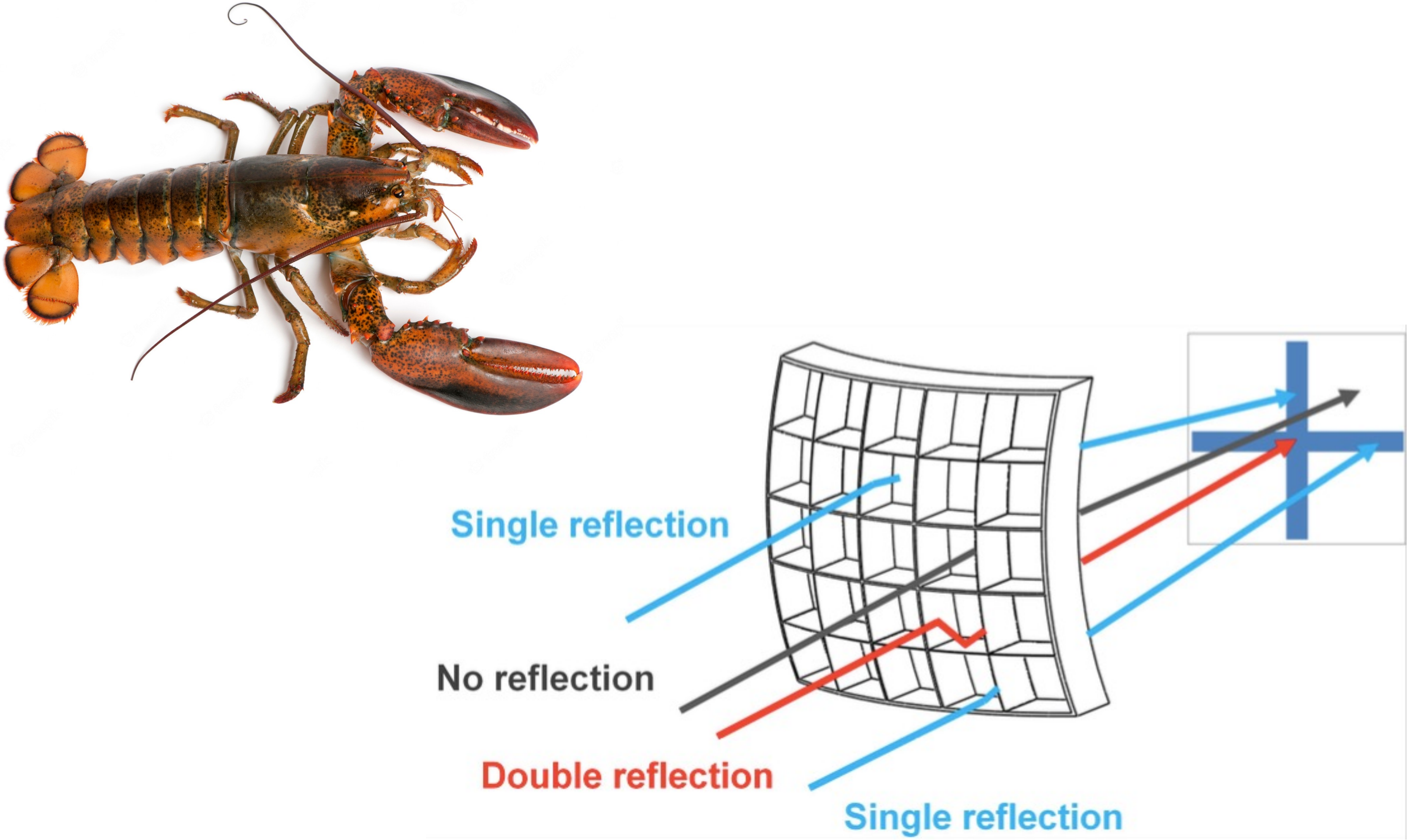
CHARGE TRANSFER INEFFICIENCY

The more lines the collected charge has travel to reach the CAMEX (i.e. the higher the number of transfers), the higher is the probability to lose some charge. This effect (CTI) can be characterized and corrected. The value measured corresponds well to the expected value for a new device. A degradation is expected in orbit due to irradiation (measurements with an irradiated device are on going, C. Plasse PHD)

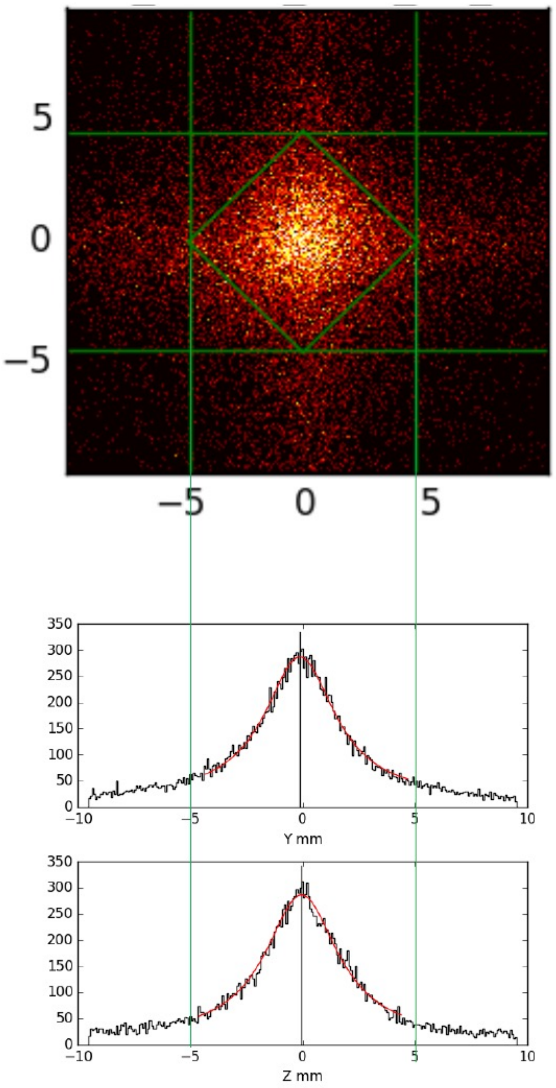




OPTICAL PERFORMANCE



OPTICAL PERFORMANCE



$$F(x,y) = \frac{A(f_1(x)+f_2(x))(f_1(y)+f_2(y))}{(1+\eta)^2}, \tag{2}$$

where

$$f_1(x) = \frac{1}{1+\left(\frac{2x}{G}\right)^2} \qquad f_2(x) = \eta\left(1-\left(\frac{x}{H}\right)^2\right) \tag{3}$$

$$f_1(y) = \frac{1}{1+\left(\frac{2y}{G}\right)^2} \qquad f_2(y) = \eta\left(1-\left(\frac{y}{H}\right)^2\right) \tag{4}$$

G: PSF Width (~FWHM)
eta: contribution of the arms

PSF models are available for simulation if needed

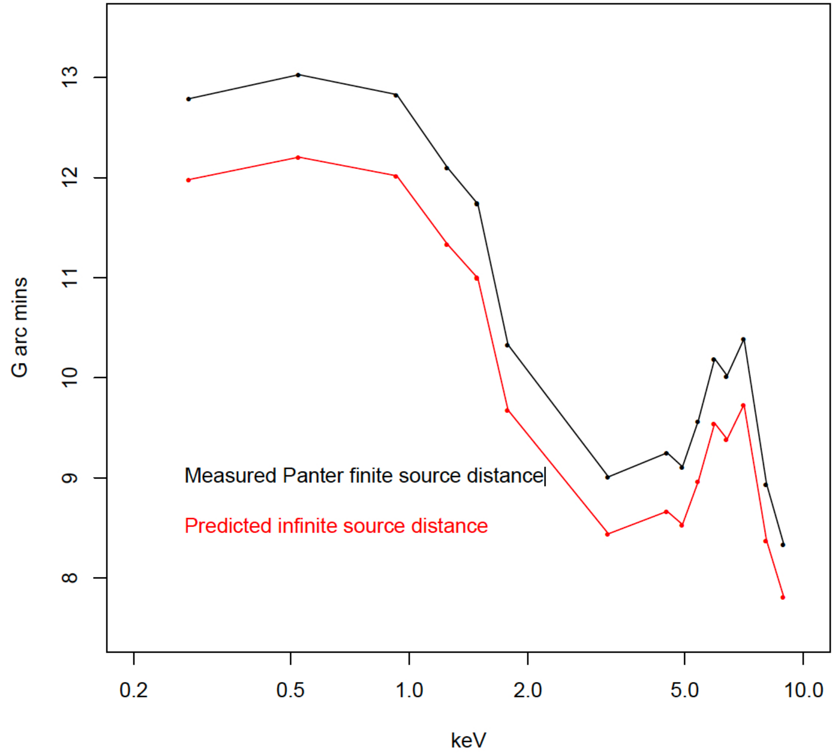
OPTICAL PERFORMANCE

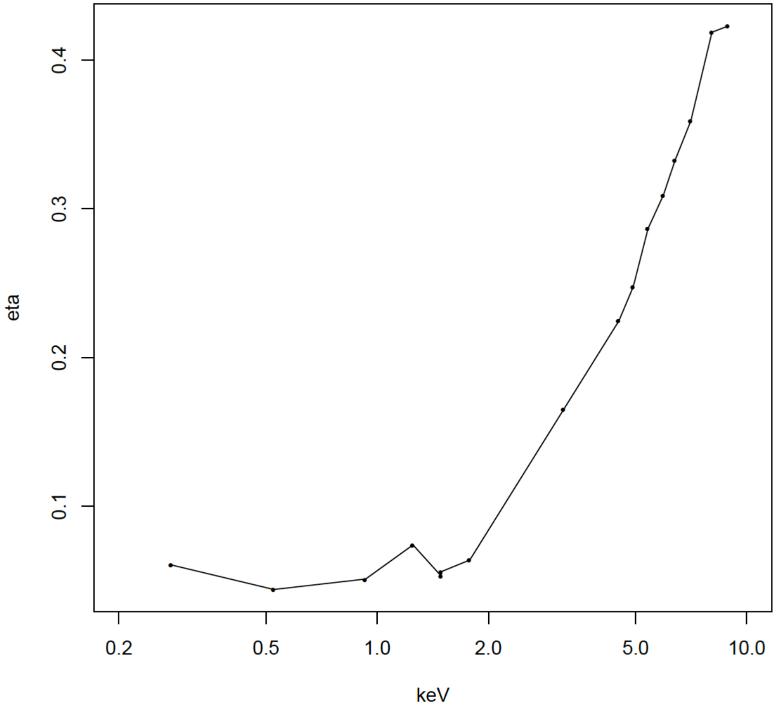
$$F(x,y) = \frac{A(f_1(x)+f_2(x))(f_1(y)+f_2(y))}{(1+\eta)^2}, \tag{2}$$

where

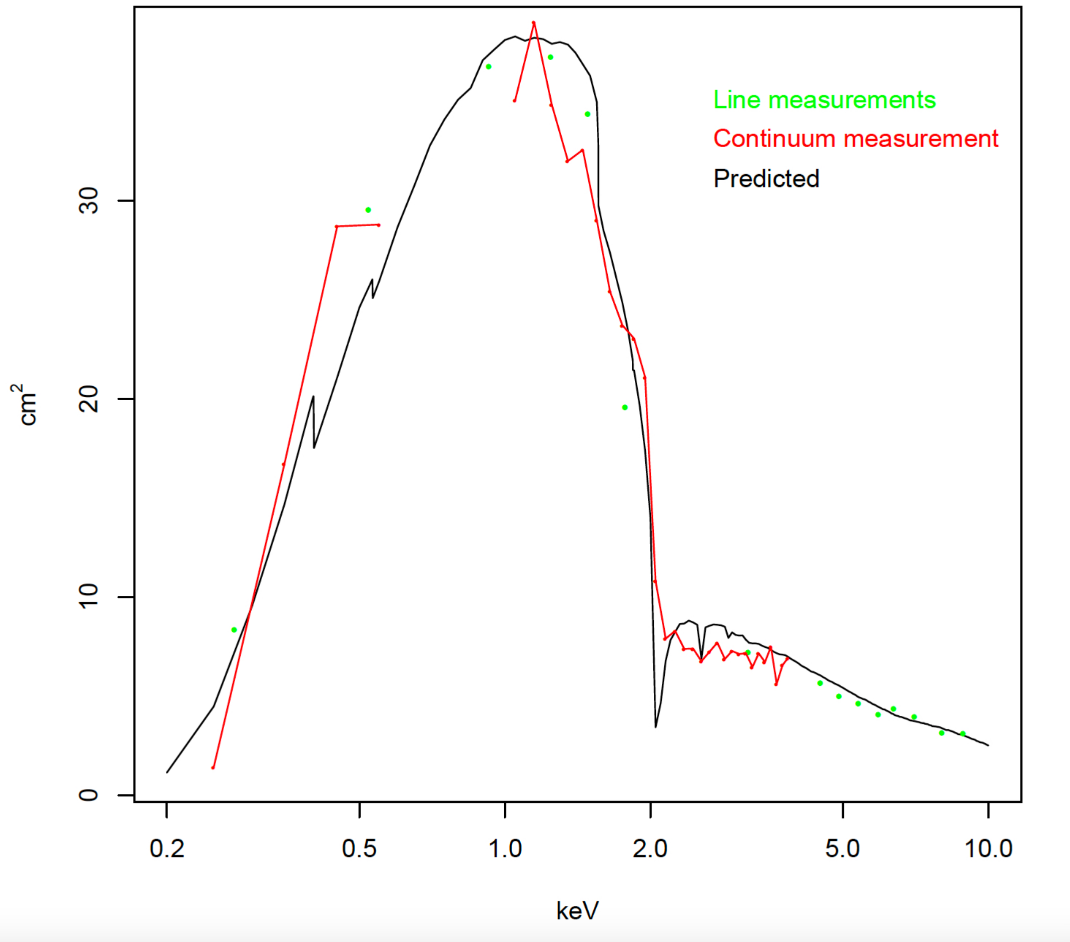
$$f_1(x) = \frac{1}{1+\left(\frac{2x}{G}\right)^2} \qquad f_2(x) = \eta\left(1-\left(\frac{x}{H}\right)^2\right) \tag{3}$$

$$f_1(y) = \frac{1}{1+\left(\frac{2y}{G}\right)^2} \qquad f_2(y) = \eta\left(1-\left(\frac{y}{H}\right)^2\right) \tag{4}$$





EFFECTIVE AREA



Quite good agreement between the data and the model. The residual discrepancies are probably due to the uncertain SDD reference detector calibration. May be improved by a dedicated calibration campaign in Soleil Synchrotron facility.

The effective area peaks at about 38 cm^2.

MXT SENSITIVITY

- More information about the MXT performance can be found here
  - https://arxiv.org/abs/2211.13489

- Using the MXT effective area derived above, one can estimate the expected counts for an astrophysical source in the MXT

- For example, if we consider a Crab-like spectrum with a photon index Γ =2.1, a normalization of 9 photons/cm^2/s/keV at 1 keV and an NH equivalent column density of 0.45×10^{22} atoms/cm^2, we obtain an expcted count rate of 121 cts/s in the MXT detector over the entire energy range in 1 ks.

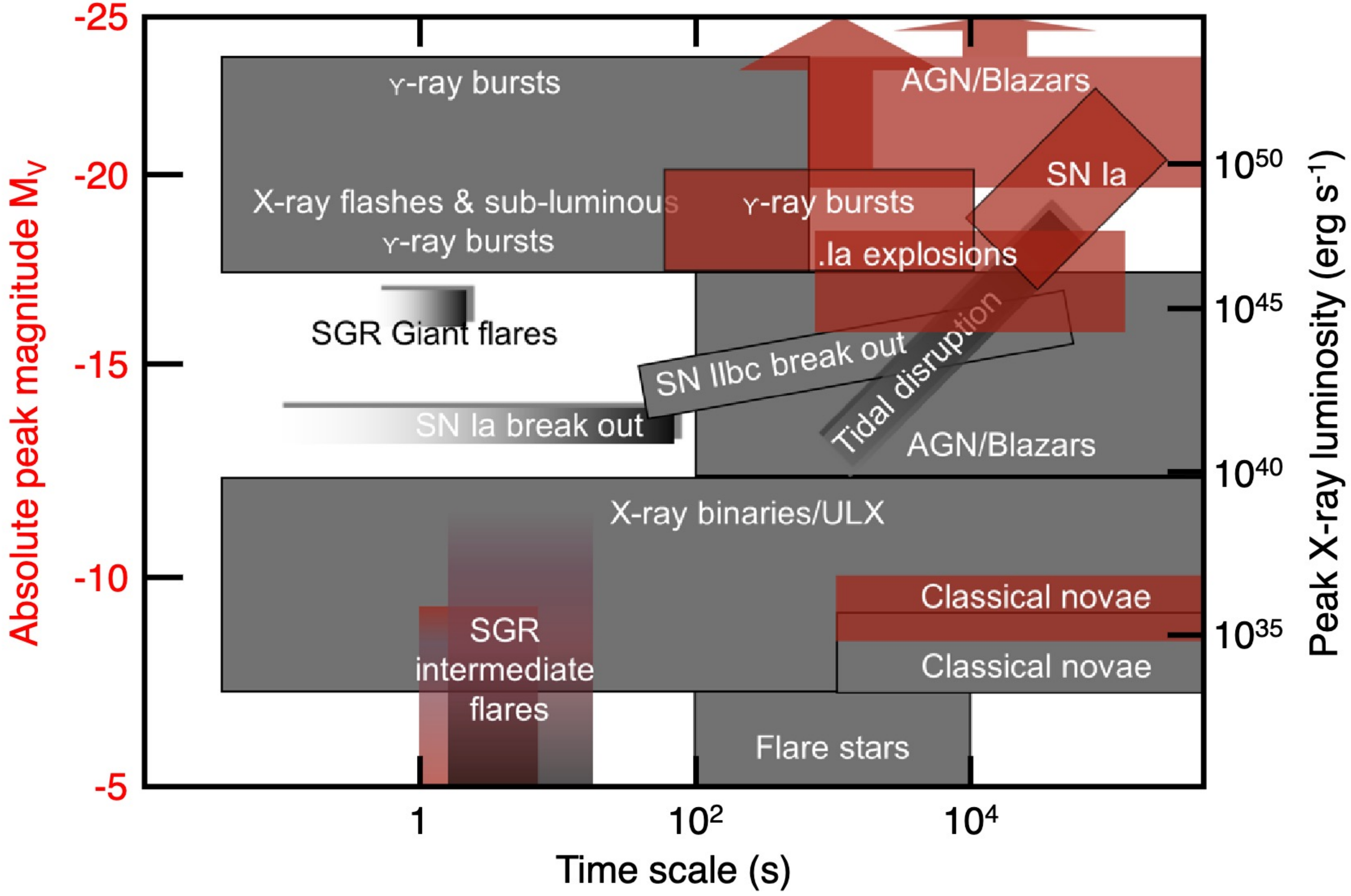
- The 5σ MXT sensitivity is hence
  - 1 mCrab in this case (1ks), 13 mCrab in 10 s, and 400 μCrab for a 10 ks observations.

- However, these values can are based on the simple comparison of the expected counts over the entire the detector and they do not consider the advantage of the imaging properties of the MXT, where> 50% of the counts are concentrated in the center of the PSF.
  - The latter is spread over an area of about 100×100 pixels^2, and the expected background within this area is about a 0.15 fraction of the one expected on the whole detector (~ 1 cts/s).
  - Taking this into account, the final sensitivity value is improved by a factor 30%.

MXT SIMULATION TOOLS

- MXT ARF and RMF derived from PANTER calibration data are available and can be used for simulating MXT spectra using XSPEC.
  - If you want to access them, they are available here
  - https://forge.in2p3.fr/projects/svom/dmsf?folder_id=3199
  - If you don’t have access to the SVOM redmine, please contact me by e-mail and I can send them to you
- APC colleagues (F. Cangemi & A. Coleiro) - in charge of SVOM GP observations in France- have developed and online simulation tool (jupyter notebook) to derive the exposure required for observing a given source with MXT. The tool can be found here
  - https://fcangemi.github.io/gp-tools-svom/exposure_time-book.html
    - Spectra can also be simulated (for people without XSPEC)
    - https://fcangemi.github.io/gp-tools-svom/exposure_time-book.html#simulate-your-spectra
  - In case of questions you can contact them directly at: cangemi@apc.in2p3.fr; coleiro@apc.in2p3.fr

MXT TRANSIENT SKY SCIENCE



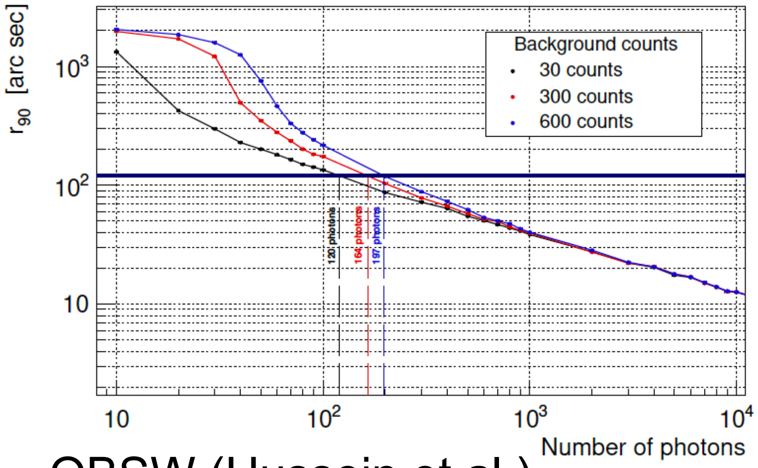
LOCALIZATION PERFORMANCE

- The data presented above have been used to estimate the in flight localization capabilities for the MXT
- In order to obtain this result, we performed a simulation process that needs as ingredients the PSF shape, the telescope effective area , the expected background in flight, and some hypotheses on the SVOM mission.
- Concerning the background, two main components need to be considered, the Cosmic X-ray Background (CXB) and the particle induced background.
- If we restrain ourselves to high galactic latitudes (which is compatible with the SVOM pointing law), there is a good agreement on the CXB measurement in the MXT energy range and one expects about 1 count/s over the entire detector for the CXB.
- The non X-ray background has been estimated using GEANT4 simulations of the SVOM space environment and the MXT mass model. The incident particles in the keV-MeV range were the CXB as measured by (in and out of the FOV), cosmic protons, SAA trapped protons, SAA trapped electrons. The average expected non-Xray background is 0.023 counts/s/cm^2 (i.e. 0.1 counts/s over the entire detector) dominating above 2 keV.

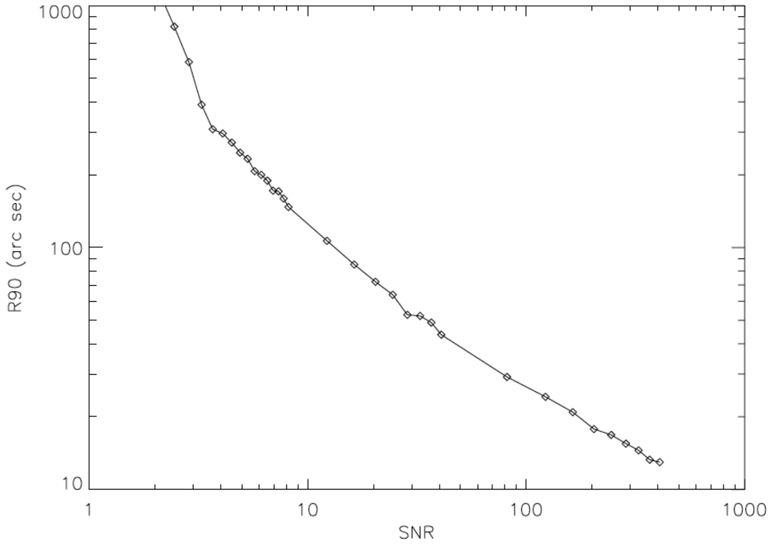
LOCALIZATION PERFORMANCE

- Using these background values we determined the R_{90} vs Signal-to-Noise Ratio curve. What we wanted to test is the ability for MXT to deliver GRB positions witha given accuracy 10 minutes after the end of the slew.
- This corresponds roughly to 600 counts of background integrated over the detector.

- Using the MXT PSF we simulated 1000 sources, distributed uniformly on the MXT FOV and with fluxes comprised between 10 and 10^4 counts, reconstructed their positions, and compared the latter to the injected positions.
- So we could define R90 as the radius within which 90% of the reconstructed positions fall.



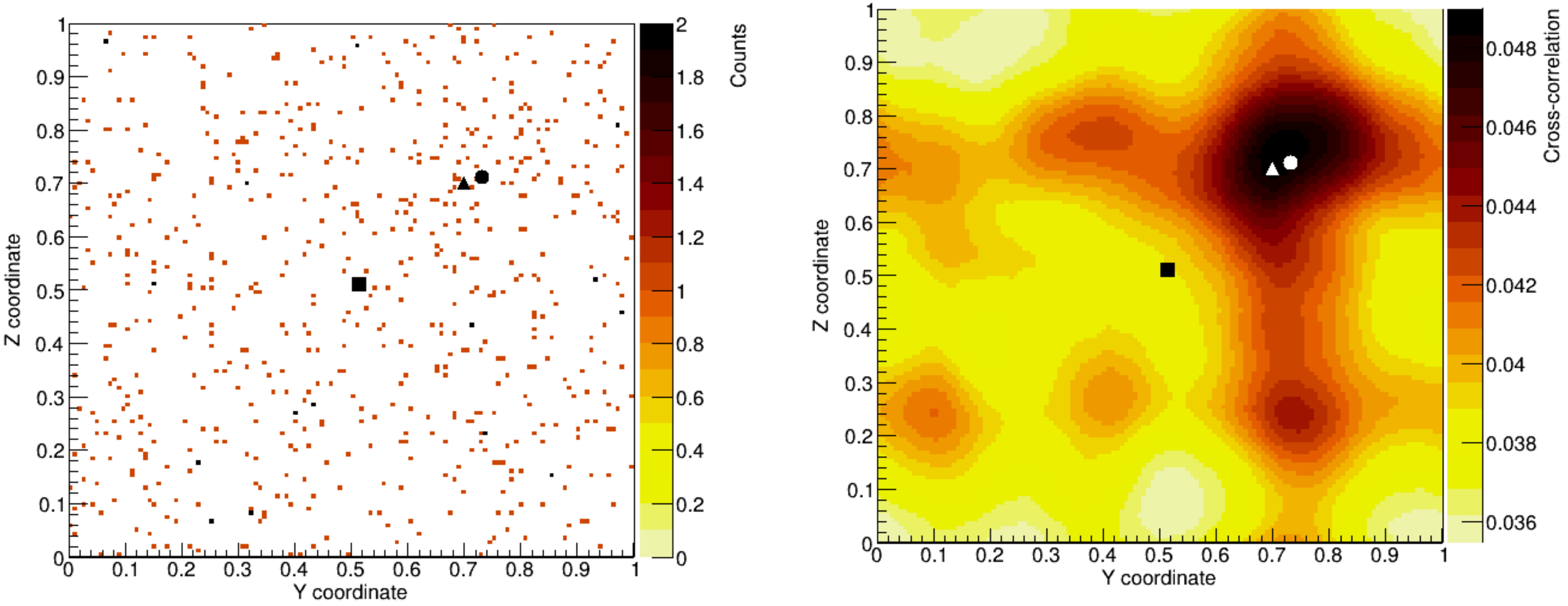
OBSW (Hussein et al.)



Simulation (Götz et al.)

LOCALIZATION PERFORMANCE

- In order to derive the MXT position we implemented the following method: we cross correlate the data with the MXT PSF, we look for the maximum in the correlated image, we define an area of ~35 pixels around the maximum, we select the pixels within this area which have at least 90% of the value of the maximum, and finally we barycenter those pixels.
- The method is very similar to the one implemented on board



BKG 600 counts; SRC 50 counts

LOCALIZATION PERFORMANCE

- Once we determined the relation between the localization accuracy and the MXT SNR, we downloaded from the public Swift/NGO archive the pre-processed XRT light curves for the GRBs detected between 2004 and 2017 (1128 GRBs).

- Among those GRBs we selected the ones for which BAT data and spectral parameters were available. This selection has been done because we needed to check which of the BAT GRBs, would have been detected by ECLAIRs

- ECLAIRs is less sensitive than BAT and we wanted to restrain our simulations to those GRBs that have at least 50% of probability to be detected by ECLAIRs at a SNR level that would trigger a SVOM slew.

- We then made the hypothesis that the SVOM and Swift slewing capabilities are similar, so that XRT and MXT are on source at the same time and that they experience the same Earth occultations (Swift and SVOM have similar orbital parameters).

- The MXT has a smaller effective area than XRT. Hence, in order to be able to use the XRT light curves, we computed for each GRB the ratio of the MXT expected counts by using the time average spectral parameters measured by XRT and performing XSPEC simulations for both instruments with the same parameters.

LOCALIZATION PERFORMANCE

- Once we determined the count rate conversion factor for all the GRBs afterglows, we integrated, for each light curve, the counts between the start of the observation and 10 minutes, and, using the R90 vs SNR curve, we could determine the expected localization uncertainty for the whole GRB sample.

- The results can be summarized as follows: for about 30% of the GRBs, the MXT will provide a localization accuracy better than 30 arcsec; about 50% of them will be localized to better than 1 arc minute and the vast majority of them (~80-85 %) will be localized to better than 2 arc minutes -> Compliant with the mission requirement!

CONCLUSIONS

- The MXT instrument is now mechanically and electrically integrated to the satellite! TVAC is starting today and next week we'll be able to test the MCAM status through the measurements of the internal ^{55}Fe source!

- The data taken at PANTER on October/November 2021 are of high quality and allowed us to reach all the calibration goals that have been presented in in detail in different papers. Spectral response matrices and PSF models are available on the redmine, exposure time calculator is available online.

- The performance requirements are globally met (even if with little margin for some items)

- We have proven that MXT is able to autonomously localize GRB afterglows in space!