SIMULATING THE PERFORMANCE OF THE SVOM/CAGIRE CAMERA FOR FOLLOW-UP OF SVOM

ALIX NOUVEL DE LA FLÈCHE

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Abstract

The spatial mission SVOM aims to perform multi-wavelength observations of the transient sky from high energies to the visible and near infra-red (NIR) wavelengths. Thanks to its onboard and ground instruments, it will be able to detect and follow the more violent phenomena of the universe from their first moment.

In order to follow-up SVOM alerts, France develops a NIR camera that will be located at the focus of a robotic telescope in Mexico. This camera will be equipped with a 2k×2k detector developed by the French company Lynred.

One of the goals of my PhD is to characterize the detector performances, and to get a better understanding of its performance.

Description of the detector

The detector is composed of a CMOS sensor onto which a detection layer is hybridized. It is composed of 2048×2048 pixels of different types. [Fièque et al. 2018]

The 2040×2040 purple pixels at the centre are active pixels. The green ones are reference pixels, they are not sensitive to light but deliver a signal linked to the detector electronics and are used as a reference. The other pixels are used for more precise detector calibration.

The detector is divided into 32 outputs which can be read simultaneously.

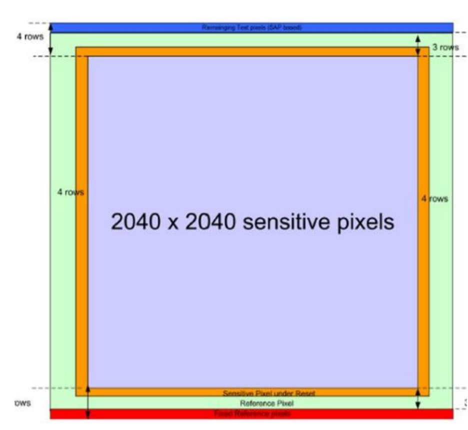

Figure 1 : Map of the different types of pixels.

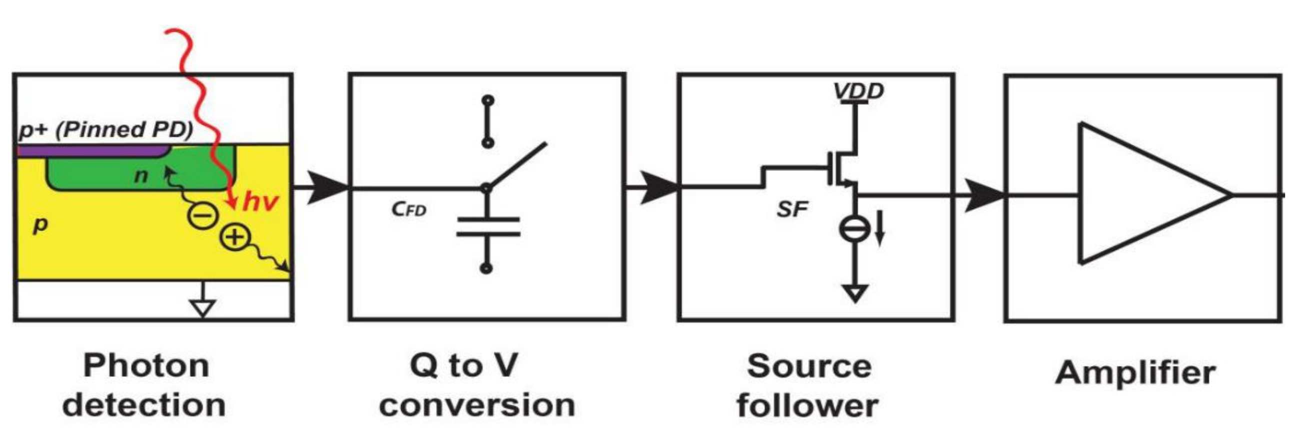

Figure 2 : Steps of charge to voltage conversion by a CMOS detector.
(credit : Linearity analysis of a CMOS image sensor Fei Wang , Albert Theuwissen)

As photons impinges the detector in the p-n junction of the photodiode, electrons move through the junction. The accumulated charges are converted to voltage by an integration capacitance and read by a source follower transistor. The signal is then amplified and converted into ADU.

Ideally, the output signal is proportional to the impinging flux of photon. But in reality, the integration capacitance, and other parameters, introduce non-linearities.

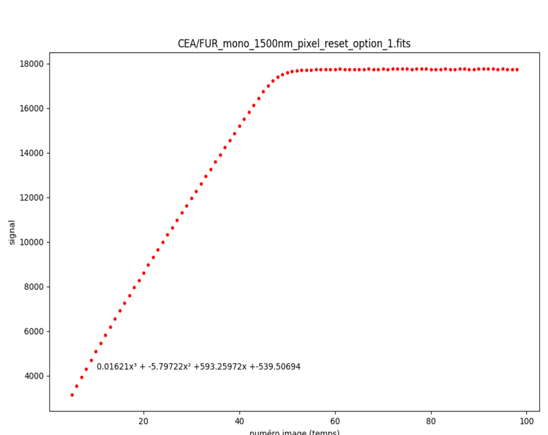

Figure 3 : ramp reaching saturation

The detector works in an UpTheRamp mode, which means we obtain a ramp containing the signal accumulated all along the exposure. At some point, the signal reaches saturation and is no more exploitable. The charge is accumulated between two resets of the detector. A complete lecture of the array lasts about 1,33s.

In an ideal situation, the signal returned before saturation would be proportional to time and it would be easy to determine the flux by computing the slope of the ramp. But as we have seen before, non linearities affect the shape of the ramp.

Conclusion

We are now able to reduce the noise of our images and to fit our ramps in a reliable way. We are able to get the flux thanks to the 1st order parameter of the 3rd order polynomial fit. These are the first steps to create a pre-processing pipeline of the images at the detector level.

References

B.KUBIK et al. , "High and low flux nonlinearity correction of NIR H2RG 2k × 2k arrays", journal of Low temperature Physics.

Gene P. WECKLER. "Operation of p-n junction Photodetectors in a Photon Flux Integrating Mode", IEEE Journal of solid-state circuits, Vol. sc-2, n°3, 1967

G. FINGER et al. " Interpixel capacitance in large format CMOS hybrid arrays" Proc.SPIE 6276, High Energy, Optical, and Infrared Detectors for astronomy il, June 2006

FIEQUE et al., " Development of astronomy large focal plane array "ALFA" at Sofradir and CEA", SPIE Vol. 10709 , 2018.

Reference pixel correction.

In order to subtract the noise from the pixel, we use the signal from the reference pixels to correct the active ones. For each output, we select the reference pixels (green ones in Fig. 1) from top and bottom of the detector, and we compute the median of their signal. This result is then subtracted to the signal of each pixel of the corresponding output. We compute as well the median signal of right and left reference pixels and subtract it to each line. This correction process allows us to reduce the CDS noise by nearly 10%.

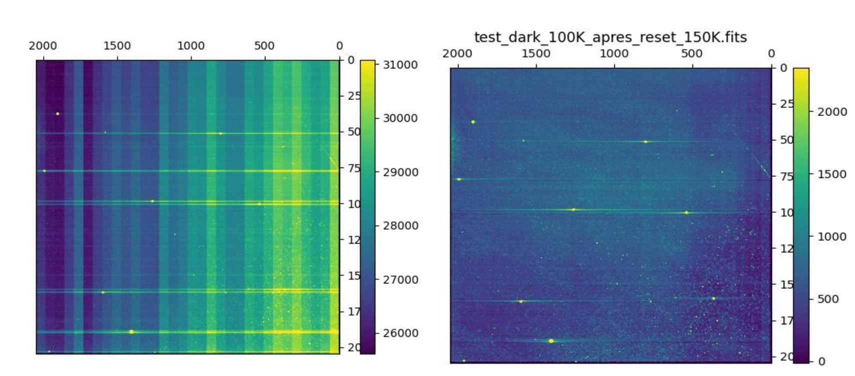

Figure 4 : Map of output signal before (left) and after (right) correction by reference pixels

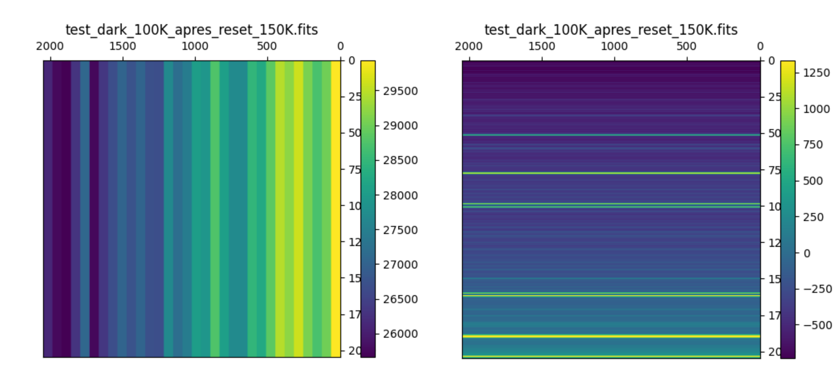

Figure 5 : Maps of the correction applied on each output (left) and on each lines (right)

Signal fitting and non linearity

We aim to fit our ramps with the more suitable function and to determine the flux. We tried two different ways : an empirical one with polynomial fits and a physical one trying to find the equations related to the detector.

Polynomials : We fitted our ramps with 1st , 2nd, 3rd and 4th order polynomials and with the same orders with Legendre polynomials. We compared the quality of all the polynomials fits thanks to the χ² method.

$$\chi^2 = \sum_i \frac{(f(x_i) - y_i)^2}{\sigma_i^2}$$

$f(x_i) - y_i$: Difference between the true value and the theoretical one.

σ_i^2: Variance of the signal at each point i of the ramp.

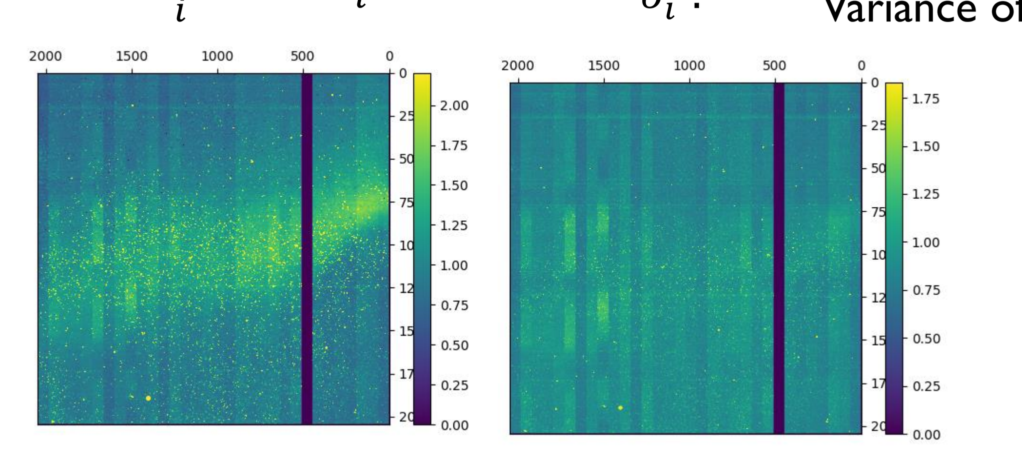

Figure 6 : Maps of χ² for fits by a 2nd order polynomial and 3rd order polynomial.

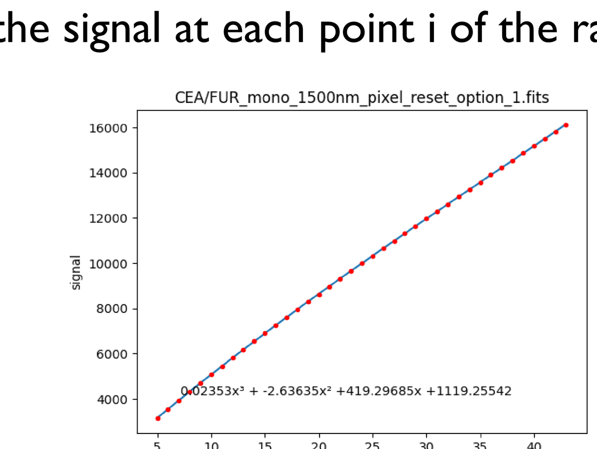

Figure 7 : Fit of a ramp by a 3rd order polynomial

We conclude to use a 3rd order polynomial to fit our ramp. The flux is defined as the 1st order coefficient of the 3rd order polynomial .

Physical approach : We used the equations of a p-n junction and a variable capacitance to take into account the non linearity of the signal. The resulting equation of the output signal versus time is given as follow,

$$V_s = G_{ADU} \times g_{amplification} \times \frac{q}{C_G + \sqrt{\frac{b}{\left[V_0^{\frac{1}{2}} - \frac{I_p \times t}{M}\right]^2}}}$$

p-n junction Voltage

Variable capacitance

V_0 = initial bias

a = reset voltage

I_p, M, b = parameters of the junction

q = elementary charge

C_G = fix capacitance of the diode

G_{ADU} = Volt to ADU conversion

$g_{amplification}$= amplifying gain

The model is not optimal yet to fit our ramps and does not take into account all physical parameters. However, the physical approach allows us to have a better understanding of the non linearities.