Euclid H2RG detectors: Impact of crosshatch patterns on photometric and centroid errors

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ABSTRACT

In the framework of ESA's Science programme, the Euclid mission [1] has the objective to map the geometry of the Dark Universe. For the Near Infrared Spectrometer and Photometer (NISP) instrument, the state-of-the-art HAWAII-2RG detectors (cut-off at 2.3 µm) from Teledyne Imaging Systems will be used in association with the SIDECAR ASIC readout electronics. A dedicated test bench has been developed at ESA/ESTEC to test these detectors. This publication will show the impact of crosshatch patterns on photometric and centroid errors after flat field correction.

Keywords: Detector, infrared, HAWAII-2RG, photometry

1. INTRODUCTION

The focal plan of the NISP instrument on the Euclid mission contains sixteen HAWAII-2RG detectors. The performances of these detectors play a key role in the final performances of the instruments

A dedicated test bench has been designed, developed and validated at ESTEC to perform tests on these detectors. This test bench is equipped with a spot projector system allowing projecting a Euclid like PSF onto the detector. The detector under test shows crosshatch patterns that may correspond to sub-pixel variations in quantum efficiency or charge collection. The goal of the tests was to evaluate the impact of crosshatches patterns on the Euclid photometric performance and centroid calculation after flat field correction. The Euclid requirement on the impact of crosshatch patterns is defined as the following: assuming integration over the perfect PSF of an F/10 beam (Airy function), the root-mean-square variation of photometric response due to response non-uniformity inside a pixel on one single exposure shall be less than 0.55%, at every wavelength between 920 and 2000nm.

2. TEST SET UP DESCRIPTION

The test set up was described in [2] and consists of a Quartz Tungsten Halogen (QTH) lamp at 40W, a monochromator and a spot projector (see Figure 1). This spot projector system contains 6 lenses and has been originally designed to project a spot smaller than the pixel size for a measurement of intra-pixel variation on CCD detectors [3].

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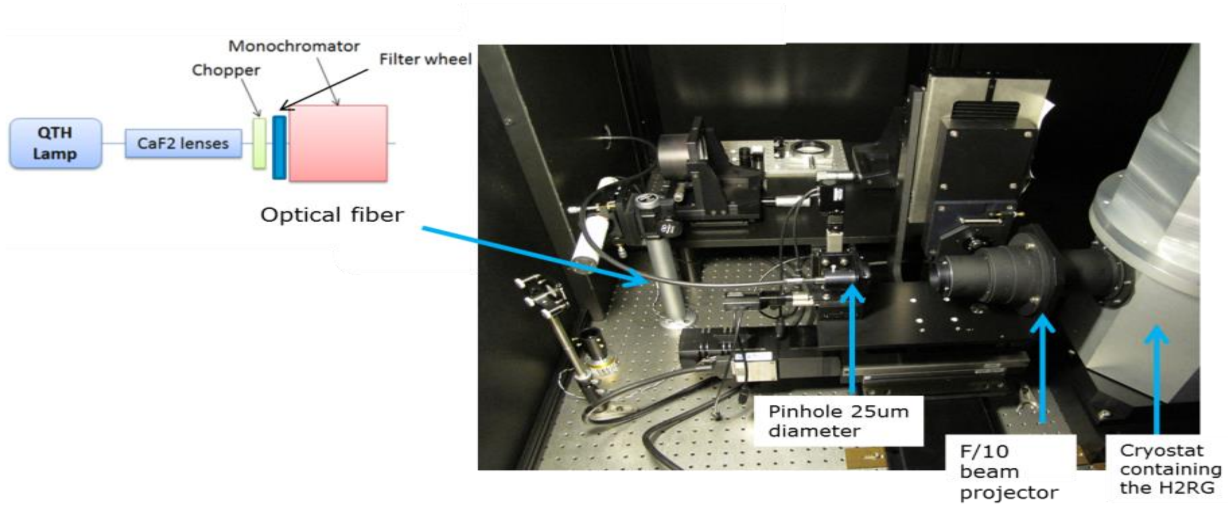


Figure 1 Drawing and picture of the test bench with the spot projector system mounted on 3 axis translation stage and the cryostat containing the H2RG or HAWAII-2RG detector

A 25 µm diameter pinhole has been inserted in the spot projector to create a Euclid-like F#10 beam. The spot projector is mounted on a tip/tilt plate for alignment as well as on a separate micrometer-driven alignment stage for the pinhole.

The spot projector system is mounted on a 3 axis Newport precision motor translation stage allowing step in the optical axis direction as well as scanning a pixel with a 2µm step in the plane perpendicular to the optical axis. The scan in the optical axis direction was used to find the best focus position and was kept constant for the rest of the test. An automatized data acquisition system developed in Python allows recording frames for each spot projector position and for each wavelength coming out from the monochromator (see Figure 1). The tests were performed at 1950 nm and at focus, the full width half maximum of the spot is around 1.6 pixels or 28.8 µm. The entire setup is mounted on a vibration controlled optical table inside a dark enclosure.

3. DETECTOR UNDER TEST

The tested detector is an engineering grade Euclid infrared detector, SCA18281. It contains some crosshatches patterns on the top right of the array. The crosshatches patterns seem to be surface features on the detector visible by eye. Investigations about crosshatch features on HgCdTe are published and according to [4] the “atomic force microscopy confirmed there were morphological features on the Hg1-xCdxTe surface corresponding to $[\bar{2}31][\bar{2}13][01\bar{1}]$ directions with depth variations of 5Å to 10Å ”. The Figure 2 shows the crosshatch pattern as appearing on a quantum efficiency map at 2000nm of the tested detector. Isolated crosshatches show a decrease of quantum efficiency (QE) of about 5% to 10% compare to the adjacent pixels, at 2000nm. Nevertheless this QE drop is wavelength dependent, with a variation of the quantum efficiency drop between 800nm and 2000nm of about 6%.

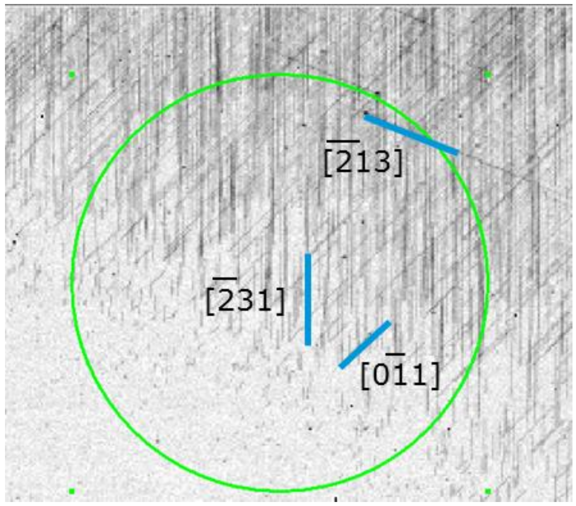


Figure 2 Crosshatches on a quantum efficiency map at 2000nm wavelength. The green circle show the area accessible with the spot projector.

4. SCAN OF VERTICAL CROSSHATCHES

During this test, three different vertical crosshatches, e.g. along the direction [$\bar{2}$31], were scanned. They were selected to be isolated (only one crosshatch direction inside the pixel and no other crosshatched pixels in the surroundings). Another study is needed to evaluate the impact of the other two diagonal crosshatch directions.

The scanned areas are listed as:

- Area 1: containing a vertical crosshatched pixel with quantum efficiency (QE) of 92% while the surrounding area is at 97%
- Area 2: containing a vertical crosshatched pixel with a QE=88% (surrounding area at 94%)
- Area 3: containing a vertical crosshatched pixel with a QE=84% (surrounding area at 96%)

The QE map cut-outs of the areas containing the scanned pixels are shown in Figure 3. It has been difficult to find isolated and at the same time crosshatched pixels with a low QE. Any other overlapping crosshatch in the same pixel will make the intra-pixel geometry more complex and will certainly complicate the conclusions on the photometry.

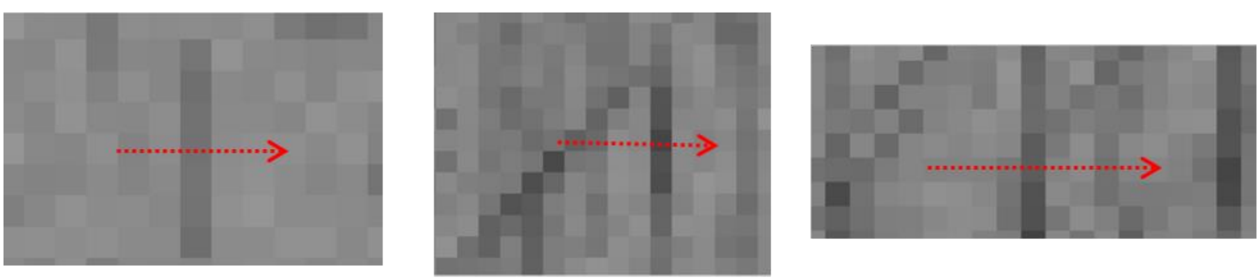


Figure 3 Selected areas with vertical crosshatches. Left: Area 1, middle: Area 2 and right: Area 3. The arrow shows the scanning direction and also marks all pixels scanned with the spot projector in each area.

The impact of the vertical crosshatches will be measured as centroid displacements when scanning the spot over the pixels in the indicated areas and with respect to photometry as change of fluence within a given photometric window.

Each scan is horizontal and therefore perpendicular to the vertical crosshatch line (see Figure 3). The 2 µm step size between two spot positions is roughly a 10th of a pixel (1.8 µm).

For each spot position, 10 Correlated Double Sampling (CDS) frames with shutter open and then 10 CDS shutter closed are recorded with the HAWAII-2RG detector, and the difference of the averaged CDS image with shutter open and with

shutter closed is computed, in order to remove the background. The centroid of the projected spot in the x and y directions (see Figure 4) is computed by fitting a 2D Gaussian after flat field correction. A total of 6 scans over the 9 pixels were recorded (2 days of automated measurements). Each spot position is then averaged over the 6 scans.
An example of the result of the centroid computations in the x and y direction over the 6 scans is shown in Figure 4. In the x direction, the spot moved effectively between the pixel 954 and the pixel 962 passing over the crosshatched pixel located at x=958. In the y direction the spot stayed within 0.3 pixels (or 5.4 µm), during the 6 horizontal scans.

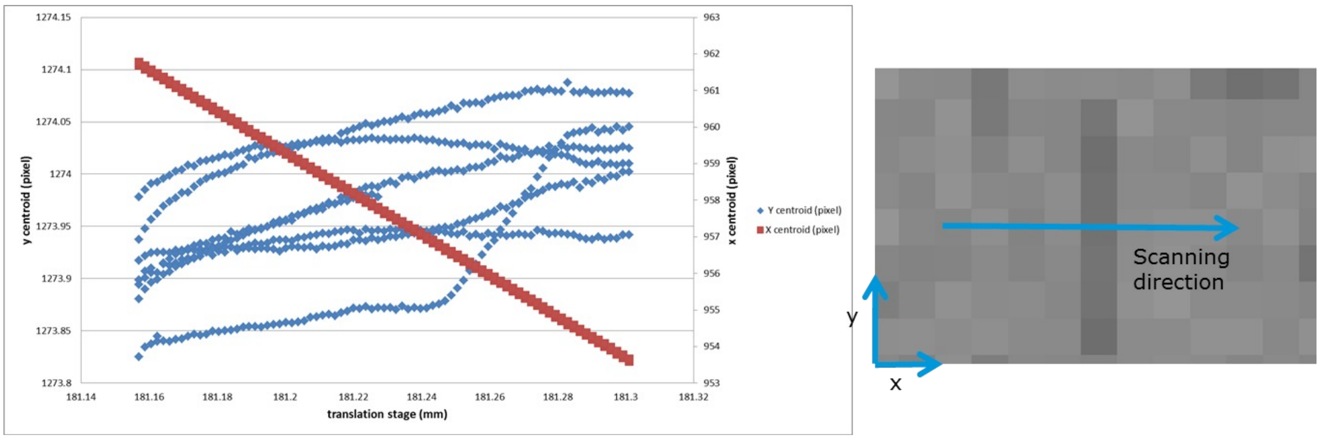
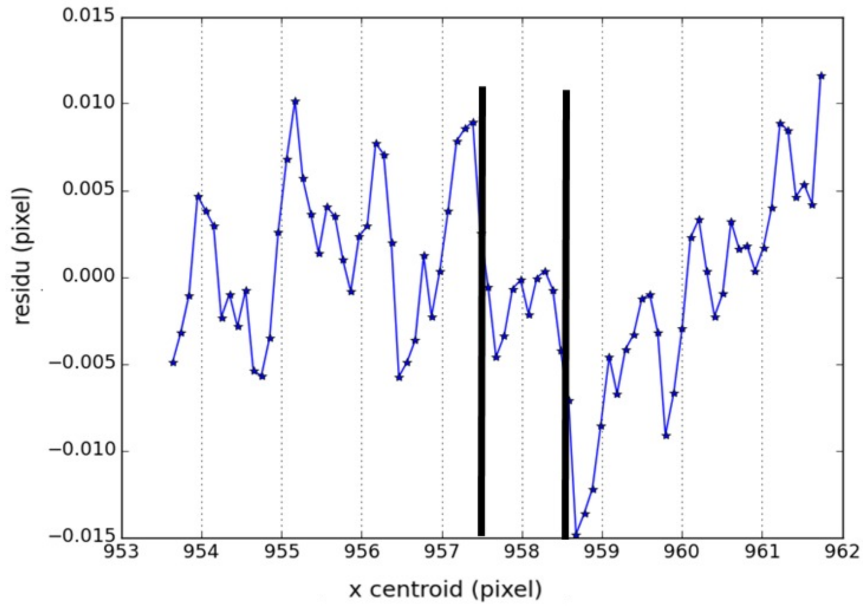


Figure 4 Left: position of the centroid of the spot in x and y detector pixel coordinates. Right: scanning direction of the vertically crosshatched pixel.

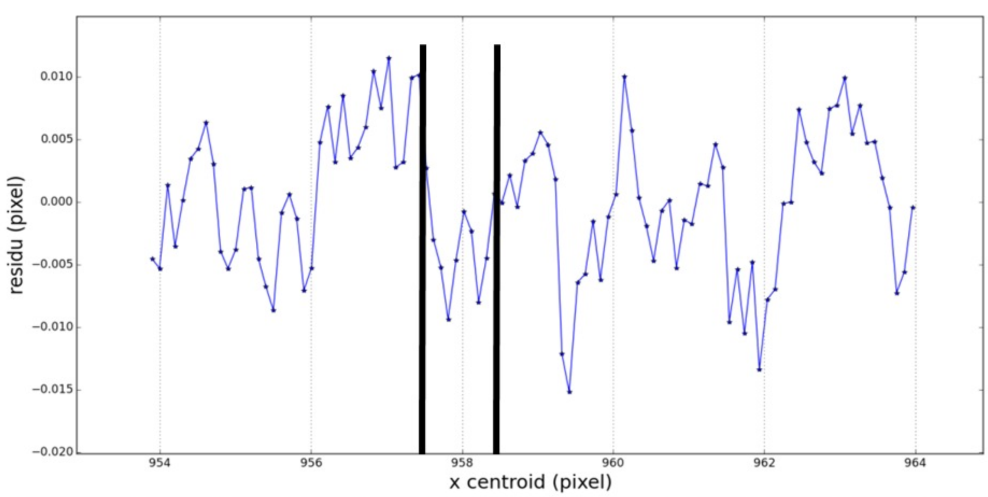
5. IMPACT ON CENTROID

The impact on the centroid in the x direction is measured by computing the residues between the computed and expected centroid spot position. The expected centroid value is computed using a linear fit over the entire scanned area (x centroid line in the Figure 4).
For the 3 scanned areas the residues stayed within 0.3µm (see Figure 5, Figure 6, Figure 7). No clear impact of the crosshatches is noticeable within this level of measurement accuracy. On each plot the boundary of the crosshatched pixel is marked with vertical black lines.



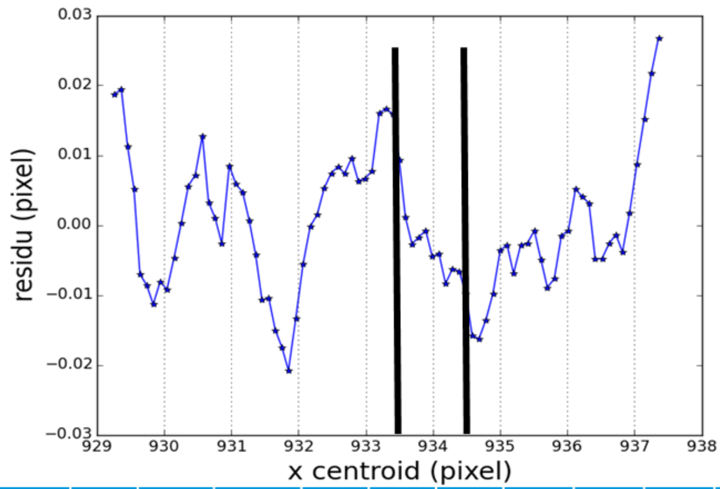
pixel	954	955	956	957	958	959	960	961	962
QE (%)	96	97	95	97	92	97	97	97	96

Figure 5 Residues to the linear fit for the Area 1



pixel	954	955	956	957	958	959	960	961	962	963	964
QE (%)	95	95	95	93	88	95	96	92	95	96	95

Figure 6 Residues to the linear fit for the Area 2



pixel	929	930	931	932	933	934	935	936	937	938
QE (%)	92	88	90	97	96	84	96	95	96	92

Figure 7 Residues to the linear fit for the Area 3.

6. IMPACT ON THE PHOTOMETRY

The photometric impact of the crosshatches is measured by summing the signal within a given photometric window when the spot is located in the pixel at the center of the window, e.g. the photometric window is moving along when the spot moves from one pixel to another.

The sum of the signal for different window size has been computed for different spot location (see Figure 8). If the size of the window is too small, part of the signal is lost outside the window when the spot is moving to the side of the pixel (see sum of 3*3 pixels in the Figure 8). If the window size is too big, background noise will be added to the spot signal (see sum 15*15 pixels in the Figure 8). The optimum size of the photometric window was determined to be 5*5 pixels and therefore was used for the rest of the study.

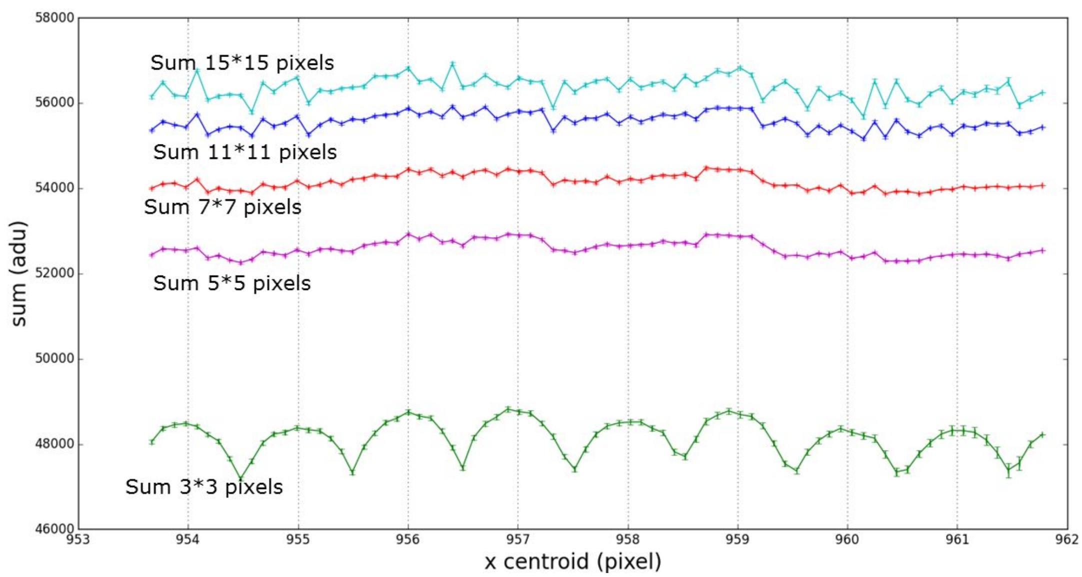
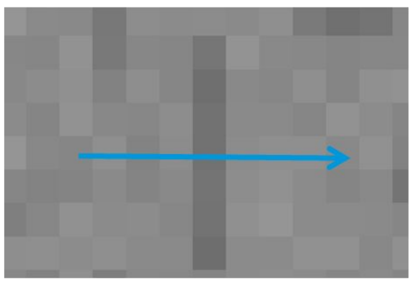


Figure 8 Variation of the sum of the signal during the scan for different photometric window sizes

6.1 AREA 1

The first scanned area contains a vertically crosshatched pixel with an associated QE of 92% while the directly adjacent pixels have a QE of 97%. One can notice that the pixels on either side of the vertical crosshatch seem not affected by any other crosshatches and exhibit the expected average QE. It can therefore be assumed that the crosshatch is isolated and its impact can be clearly measured.

The standard deviation of the photometry over the scanned pixels is 0.3% and no major effect is noticeable when the spot is passing over the vertically crosshatched pixel (see Figure 9). The standard deviation is computed over the photometric signal recorded for each spot projector position for the 9 scanned pixels. The recorded images were corrected using the flat field map of quantum efficiency therefore only the crosshatch impact are visible.



pixel	954	955	956	957	958	959	960	961	962
QE (%)	96	97	95	97	92	97	97	97	96

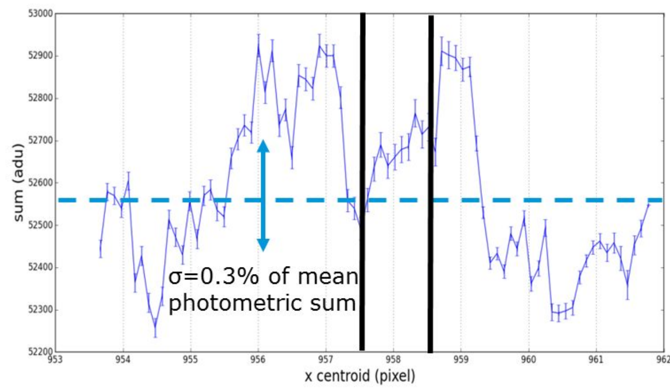
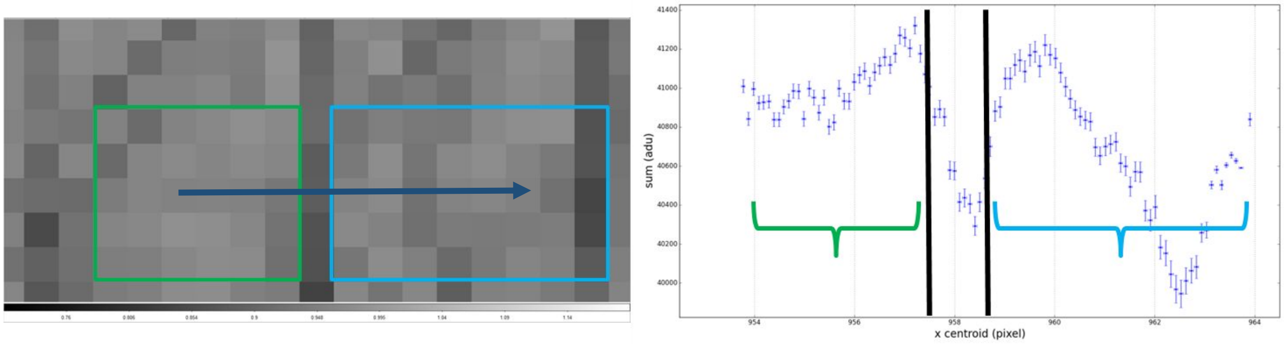


Figure 9 Left: The arrow represents the scanned pixel with reference to the associated QE map. Right: Variation of the sum of the signal in the photometric window with respect to the x centroid of the spot. The boundary of the crosshatched pixel is marked with vertical black lines.

6.2 AREA 2

The scanned area contains this time a vertical crosshatch resulting in a QE of 88% on pixel 958, while the directly adjacent pixels have a QE of 93% and 95%. Once can notice that the left side of the vertical cross-hatch (in green in Figure 10) shows less QE variation than the right side of the vertical cross hatch (in blue in Figure 10). The right side of the vertical crosshatch patterns seems more disturbed and containing pixels with other crosshatches. The green and blue box on the left picture in Figure 10 represents the pixels included in the photometric window during the scans. The presence of other crosshatches affects the photometry resulting in a dip at pixel 963 on the Figure 10. The standard deviation of the photometric sum is 0.8% over the scanned pixels.

However, other crosshatched structure present in the photometric window of the scanned pixels prevent to conclude properly on the impact of this crosshatch.

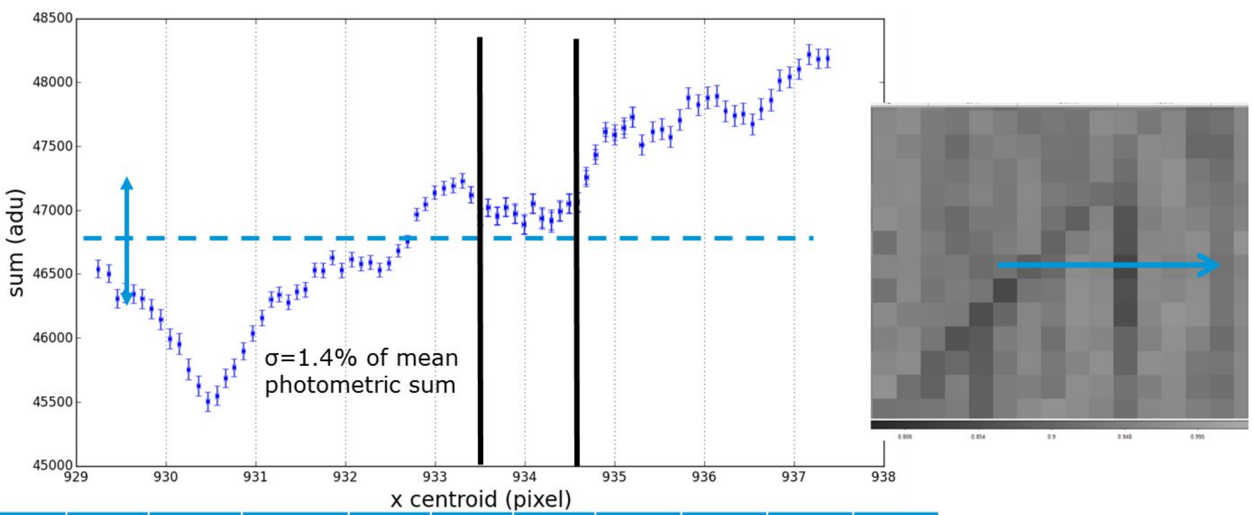


pixel	954	955	956	957	958	959	960	961	962	963	964
QE (%)	95	95	95	93	88	95	96	92	95	96	95

Figure 10 Left: The arrow represents the scanned pixel with reference to the associated QE map. Right: Variation of the sum of the signal in the photometric window with respect to the x centroid of the spot. The boundary of the crosshatched pixel is marked with vertical black lines.

6.3 AREA 3

For this scanned area, the crosshatched pixel (pixel 934) has a QE of 84% while the direct neighbors (right and left) have a QE of 96% each. However, other crosshatches seem as well present in the photometric window (pixel 930 and pixel 938). The variation of the photometric signal during the scan as summed within the photometric window is shown on the left of Figure 11. The standard deviation of the photometric sum is 1.4% over the scanned pixels. However, the shape of the photometry curve seem to point to a systematic drift in the measurements, which is being investigated.



pixel	929	930	931	932	933	934	935	936	937	938
QE (%)	92	88	90	97	96	84	96	95	96	92

Figure 11 Left: The arrow represents the scanned pixel with reference to the associated QE map. Right: Variation of the sum of the signal in the photometric window with respect to the x centroid of the spot. The boundary of the crosshatched pixel is marked with vertical black lines.

7. CONCLUSIONS

A spot projector test bench dedicated to measure the photometric and centroiding impact of crosshatch patterns on a H2RG detector has been installed at ESTEC to support the Euclid mission. The impact of crosshatches on the centroid is within 0.3 µm for a crosshatched pixel with QE of 84% with neighbor pixels with a QE of 96%.

The impact of vertical crosshatch pattern on the photometry has been measured to be:

- σ=0.3% for a crosshatched pixels of a quantum efficiency of 92% (surrounding area at 97%)
- σ=0.8% for a crosshatched pixels of a quantum efficiency of 88% (surrounding area at 94%)
- σ=1.4 % for a crosshatched pixels of a quantum efficiency of 84% (surrounding area at 96%)

Regarding the last two measurements, it was not possible to provide a proper conclusion because of the suspected presence of other crosshatches in the same pixels that make the interpretation of the analysis results considerably more difficult.

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