Multiplexer Glow on H1RG 8um cut-off detector

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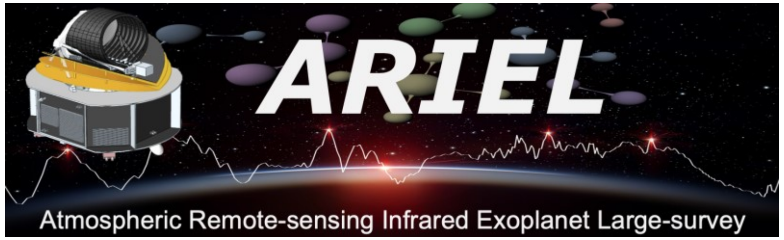
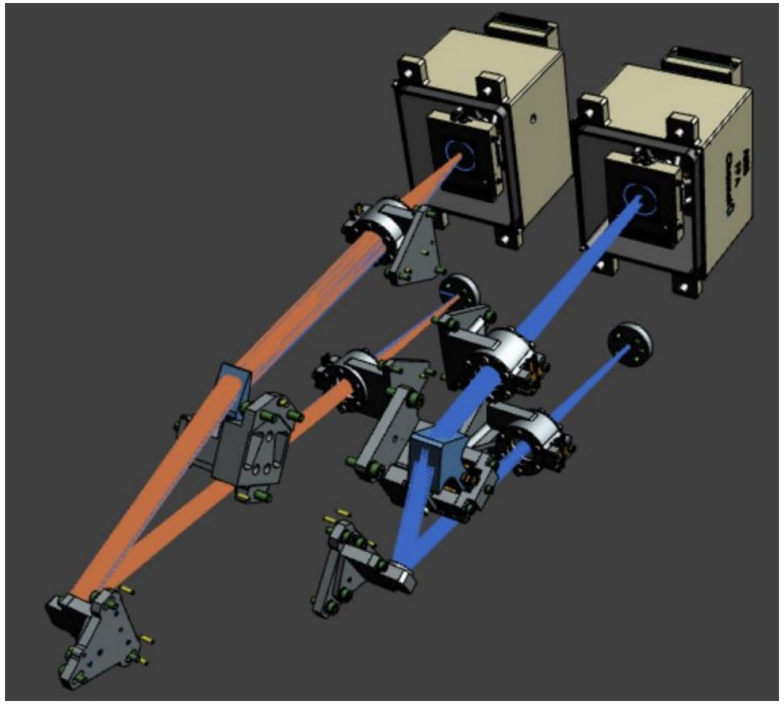
ARIEL MISSION and AIRS INSTRUMENT

ARIEL (Atmospheric Remote sensing Infrared Exoplanet Large survey):

- ESA M-class mission to study what exoplanets are made of by doing spectroscopy of their atmosphere
- The payload is made of 2 instruments:
  - FGS: Fine Guiding Sensor (H2RG + Sidecar)
  - AIRS (Ariel InfraRed Spectrometer)
    - NIR band spectrometer: 4.5um cut-off (H1RG + custom electronics)
    - LWIR band spectrometer: 8um cut-off (H1RG + custom electronics)
- **AIRS images the spectrograph on a small ROI (~128*64 pixels)**
- Early 8um cut-off Engineering Models procured during the Study Phase at TIS (non standard cut-off)
- CEA Saclay (IRFU) and ESA (ESTEC SCI-FIV) benches for competitive EO characterization (derisking)



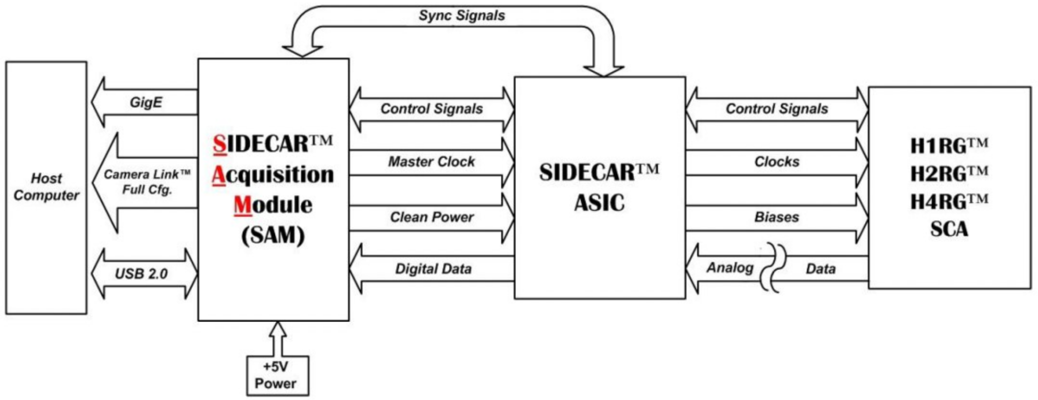


AIRS Optomechanical early design (Amiaux 2020)

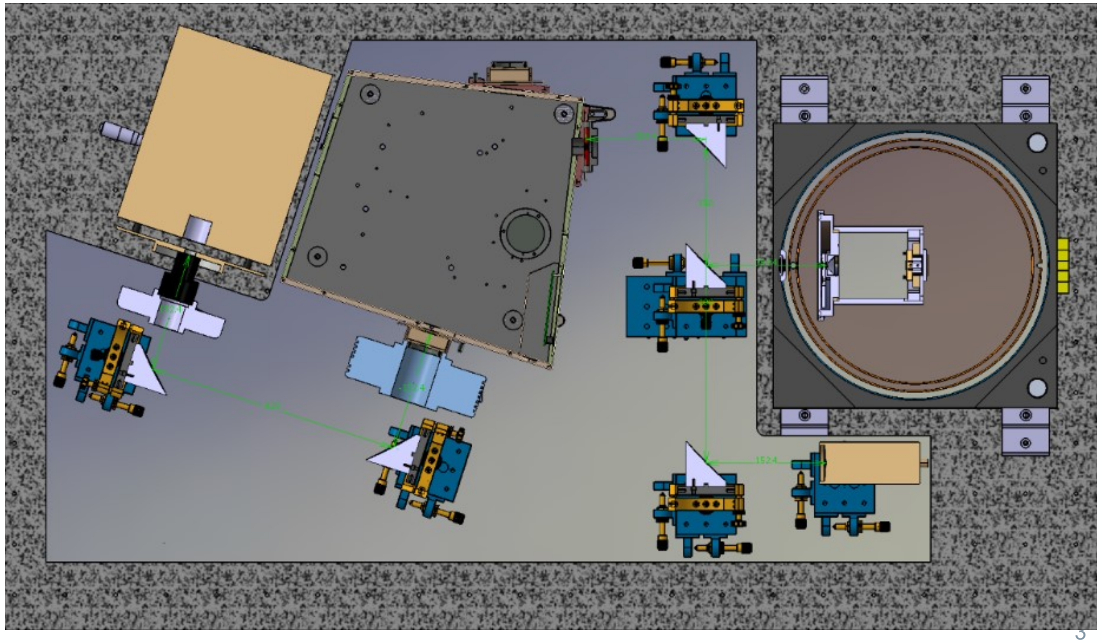
TEST SETUPS

- ESA MWIR BENCH:
  - Cryostat + CC He cryocooler:
    - H1RG @ 42K
    - SIDECAR ASIC @ 100K
    - Filter Wheel (ND, 4um, 6um, 8um) @ 35K
    - Thermal shields, pinhole
  - Cavity BlackBody
  - Monochromator
  - Offner Relays

- CEA Detection chain is custom:
  - CFEE: cryogenic preamp (discrete OPAMPS)
  - DCU: Detector Control Unit



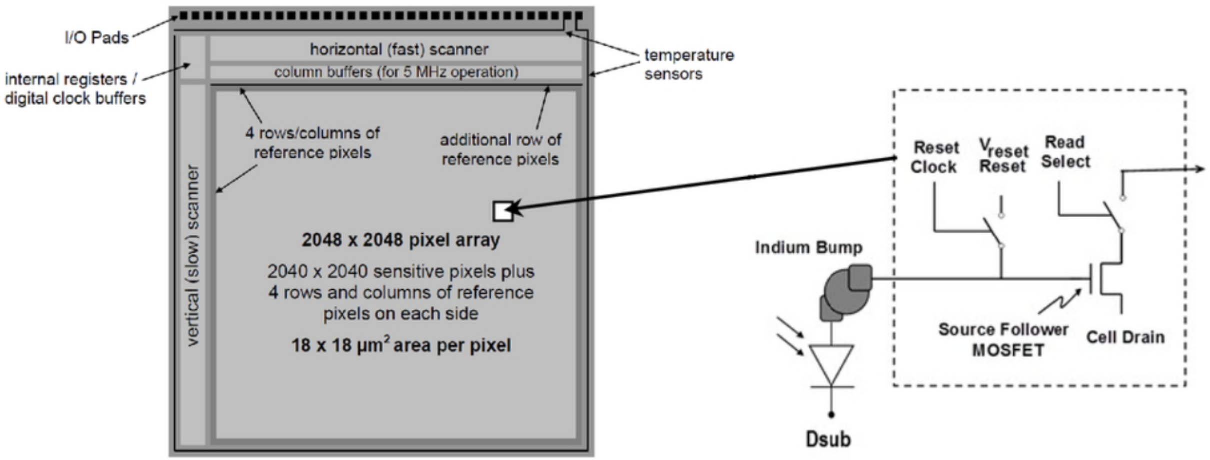
SCI-FIV detection chain: (SIDECAR cryo + H1RG) +SAM



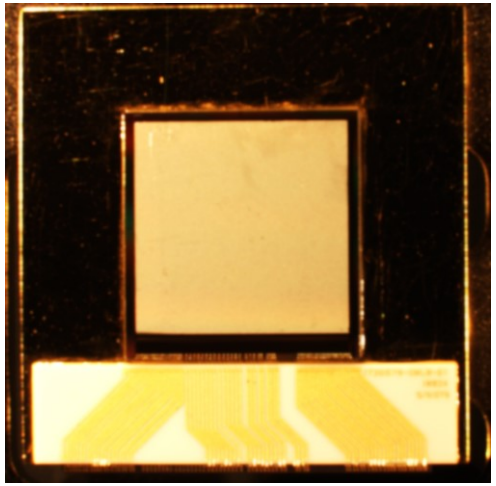
HxRG detectors

- MCT hybridized PV layer (P on N) on CMOS ROIC
- 18um pixel pitch
- Standard cut-offs:
    - Visible (400-700 nm)
    - Near Infrared (700-1000 nm)
    - Short-Wave Infrared (1000-3000 nm)
    - Medium-Wave Infrared (3000-5000 nm)
- X=1/2/4 for 1k x 1k / 2k*2k / 4k*4k image areas
- R is for reference pixels
- G is for guiding mode (interleaved window mode)
- Flexible ROIC (reset modes, buffering, ROIs, clocking options)
- SFD pixel cell (low noise, low FWC, low power dissipation)
- Molybdenum package

- Widely used in astronomy / scientific imaging



H2RG ROIC and pixel cell architecture

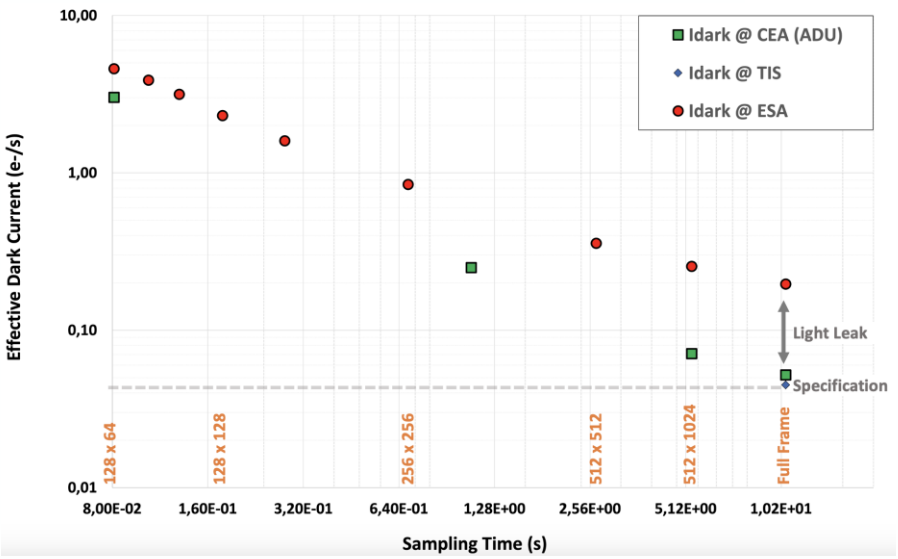


H1RG bare ROIC processed at ESA

GLOW IS THE NEW DARK

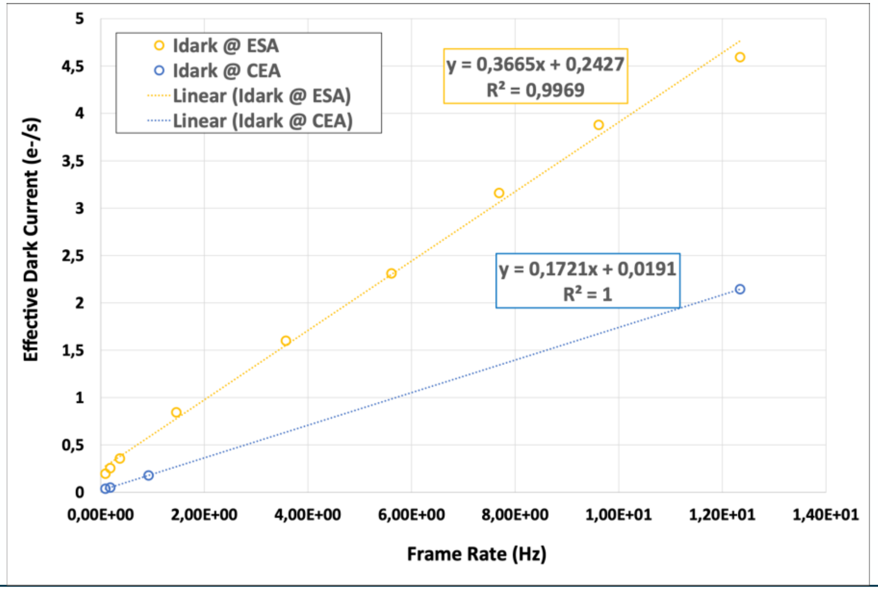
Impact of the readout timing – Per Frame Glow factor

- Early Dark current measurement in window mode revealed a drastic increase of I_{DARK}
- Sampling Time is adjusted by reading out different ROIs or including non clocked drop frames in the UTR acquisition



- Measured Dark Current (Effective Dark Current S_{DARK}) is a combination of True Dark Current (I_{DARK}) and Glow induced signal:

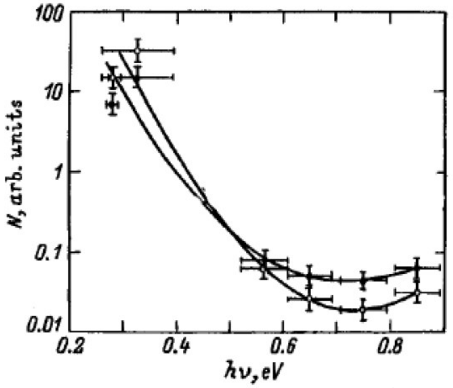
$$S_{DARK} = I_{DARK} + F/dt$$



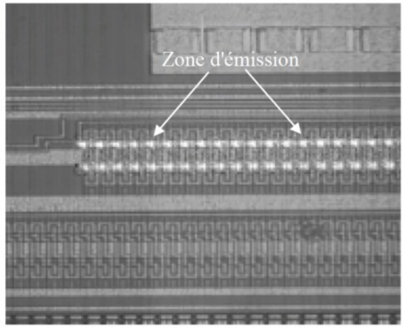
- F: per frame Glow factor
- dt: sampling time

Evidence of glow (short litterature review)

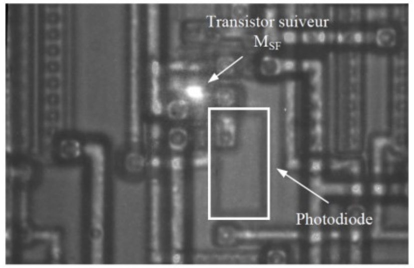
- Electroluminescence of MOS tranistsors identified in the early 80s
- Proposed as a failure analysis technique for CMOS manufacturing (stare at silicon dies with lowlight cameras to spot electroluminescnece areas)
- Observed on memory circuits and visible image sensors (APS)
- Observed on hybridised IR image sensors (Output buffers and pixel cell)
- Glow mitigation (shielding) at TIS was done with the newest generation of the ROIC (RG generation)
- BUT IT IS STILL THERE (TIS, Leonardo,…)



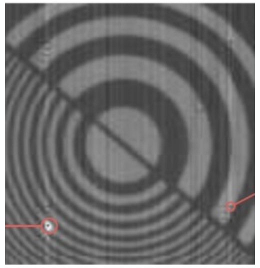
From Kosyachenko and Mazur (1999)

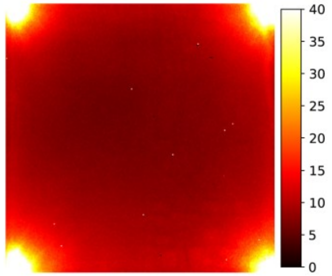


Ring Oscillator
From Maestre (2003)

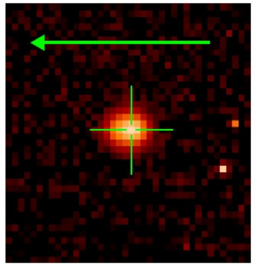


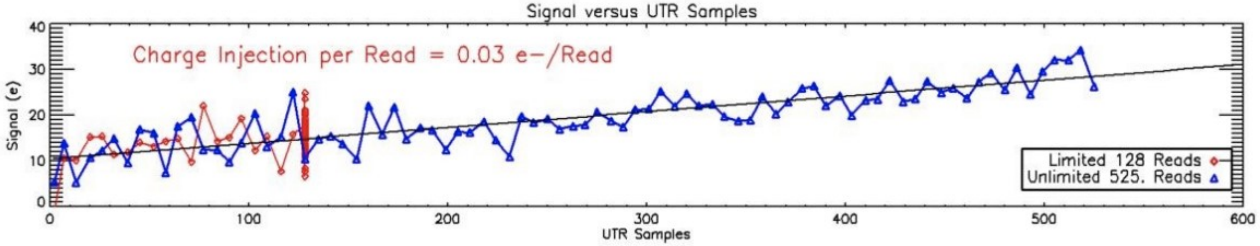
Test Pixel
From Maestre (2003)


Test APS
From Boucher (2007)



HST-NICMOS
From Bergeron et al (2020)


NIRSPEC Detector ROI sequence
From Bergeron et al (2020)



MOONS H4RG (ESO)
From Ives et al (2020)

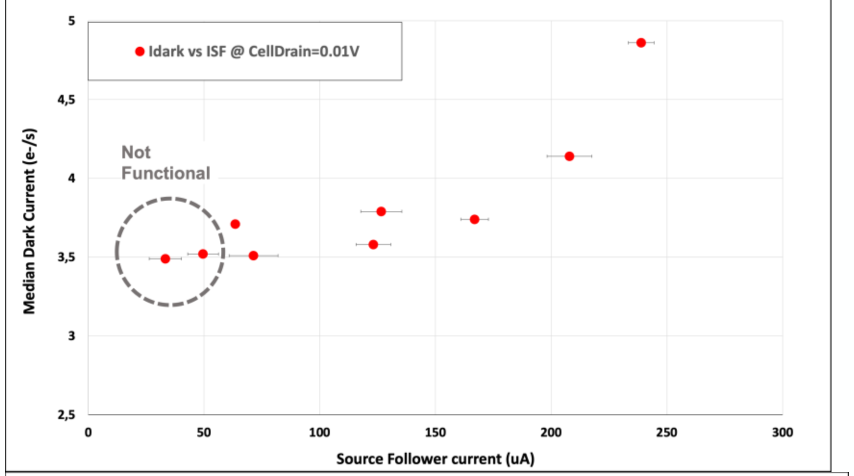
Parameters of influence – experimental results

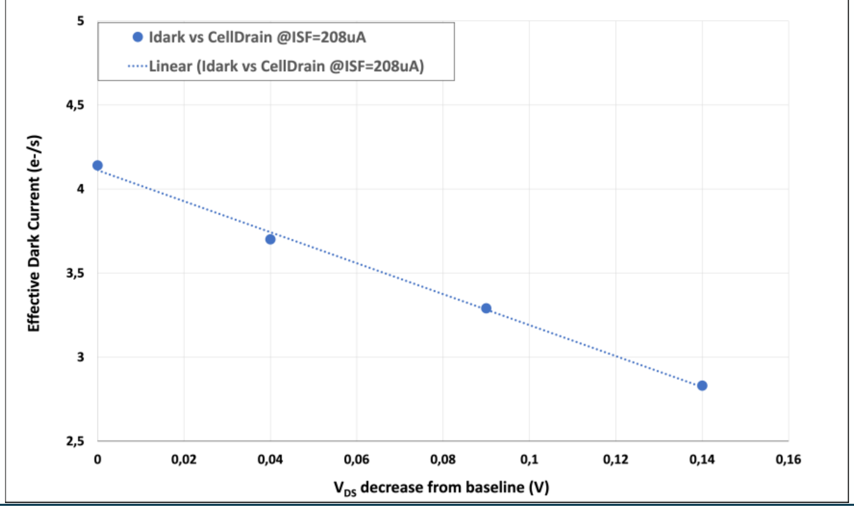
- The rate of photoemission is related to substrate current of the MOSFET
- We observe a decrase of effective dark current with decrease of SF current:
  - Adjusting column current and SIECAR telemetry
  - Consistent with higher PFG found at ESA (unbuffered) compared to CEA (buffered)
- We observe a decrease of effective dark current with decrease of the Drain to Source voltage
- As we saw earlier the readout timing is also of importance see next slides for pixel selection time

$$N_{ph} = \frac{A I_{bias}}{q}(V_{DS} - V_{DSsat}) \exp -(\frac{B}{V_{DS} - V_{DS\ sat}})$$

From Stellari et al (1999)

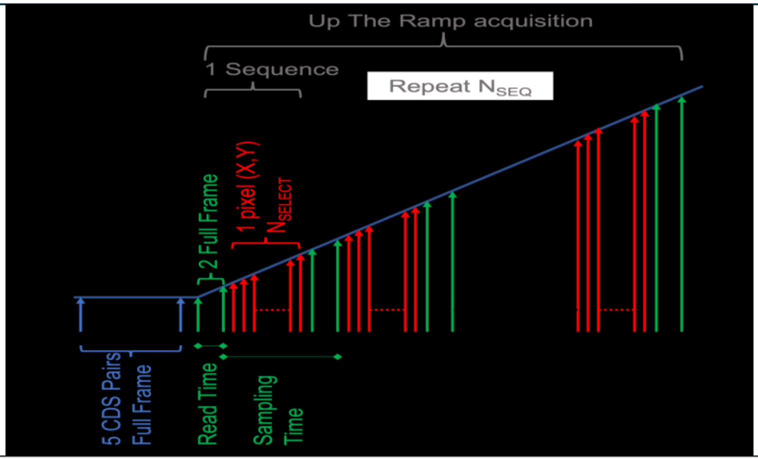
MITIGATION APPROACH IDENTIFIED
VDS BIASING

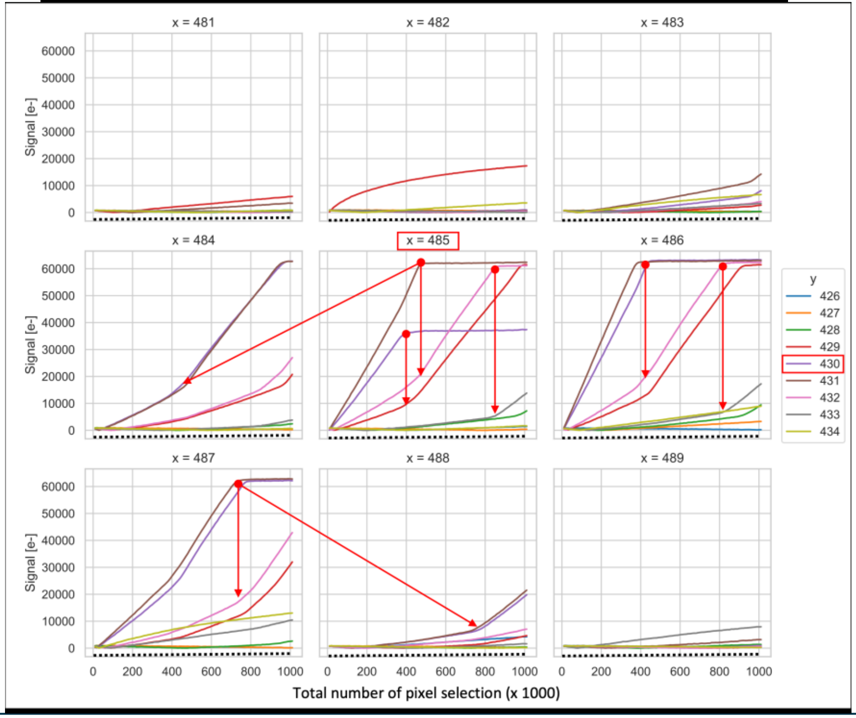




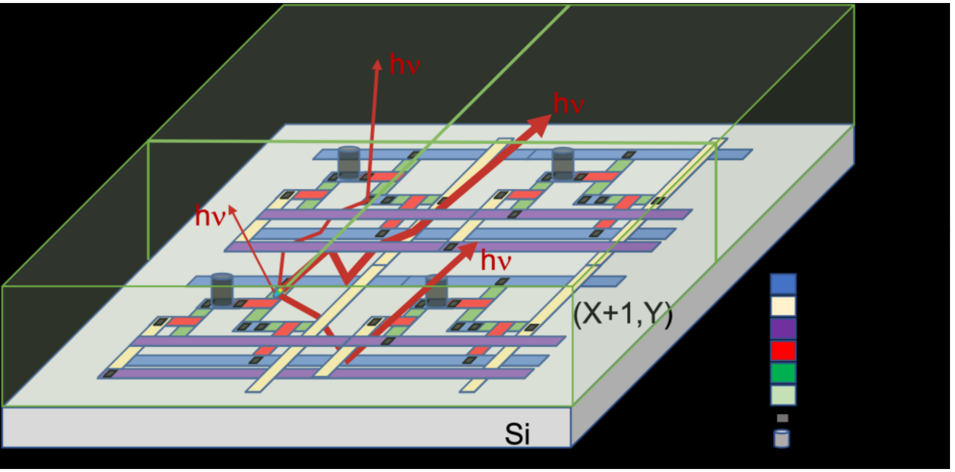
Glow generated by 1 Pixel Cell (1)

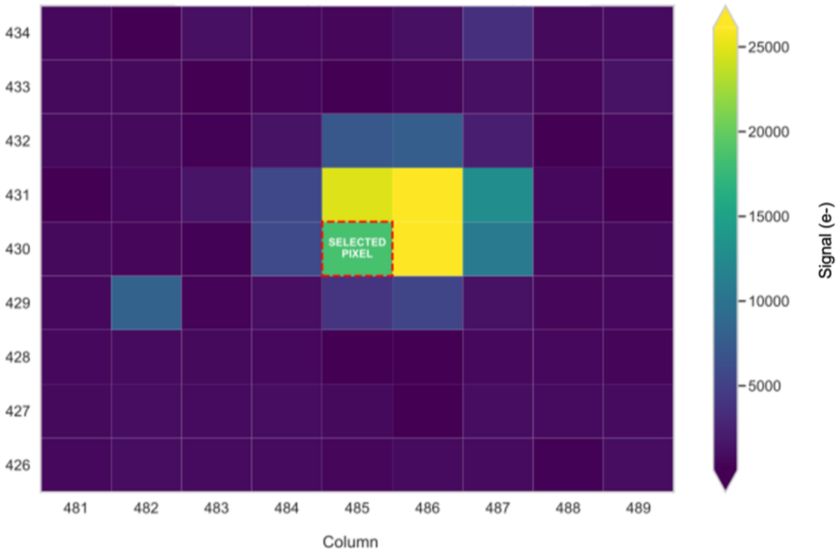
- Dedicated acquisition sequence to generate glow on a given pixel cell and analyse the impact on surrounding pixels
- Monitoring the signal on the full frame allows control on the data quality and analyse the dyanmics of the glow generation:
  - The signal collected is proportional to the number of selections of the pixel
  - The selected pixel does not collect the maximum amount of glow (slopes)
  - Neighbouring pixels are collecting electroluminescent photons
  - Inflexion points originates from the saturation of neighbouring pixels

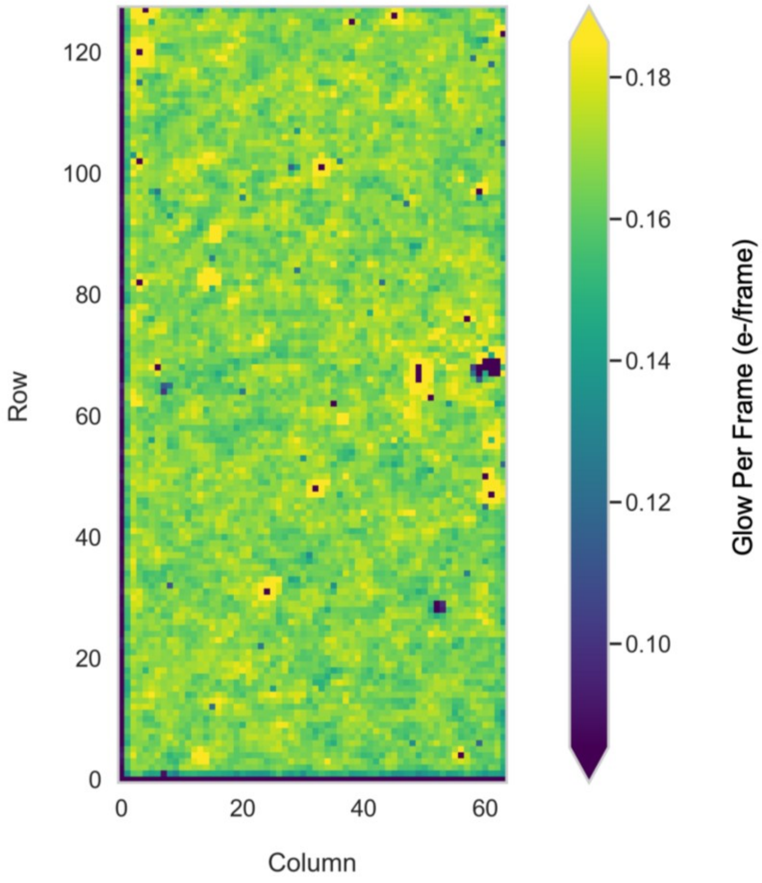




Glow generated by 1 Pixel Cell (2)







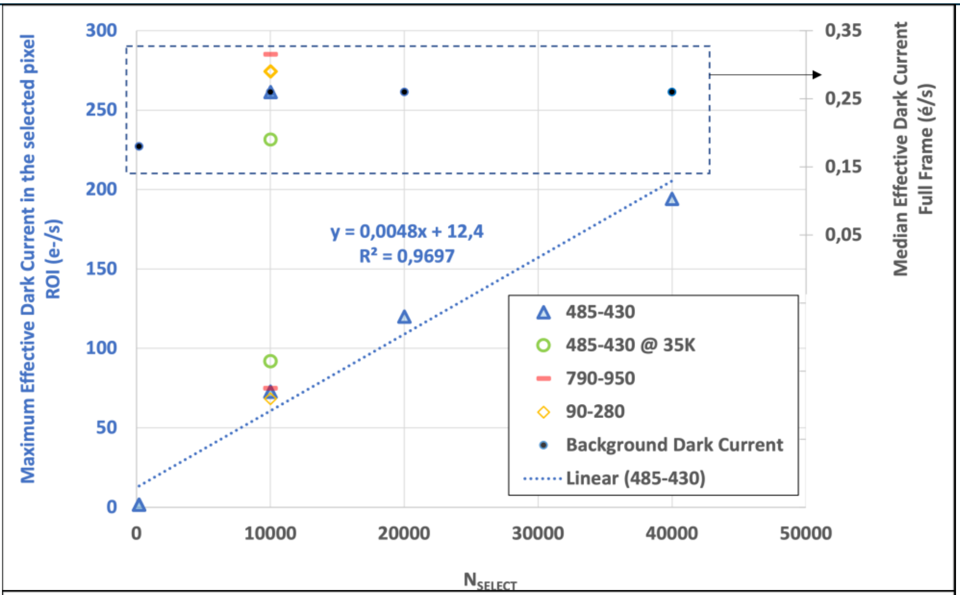
- The spatial signature of the glow of the unit cell is independent of the readout direction and consistent across the whole image area
- We speculate that this spatial pattern is induced by multiple reflections of the photons within the metal layers of the ROIC before readhing the MCT layer
- The glow at ROI level is the sum of individual pixel cell contributions following the pattern identified at the pixel cell level (IPC, Crosstal may also contribute)

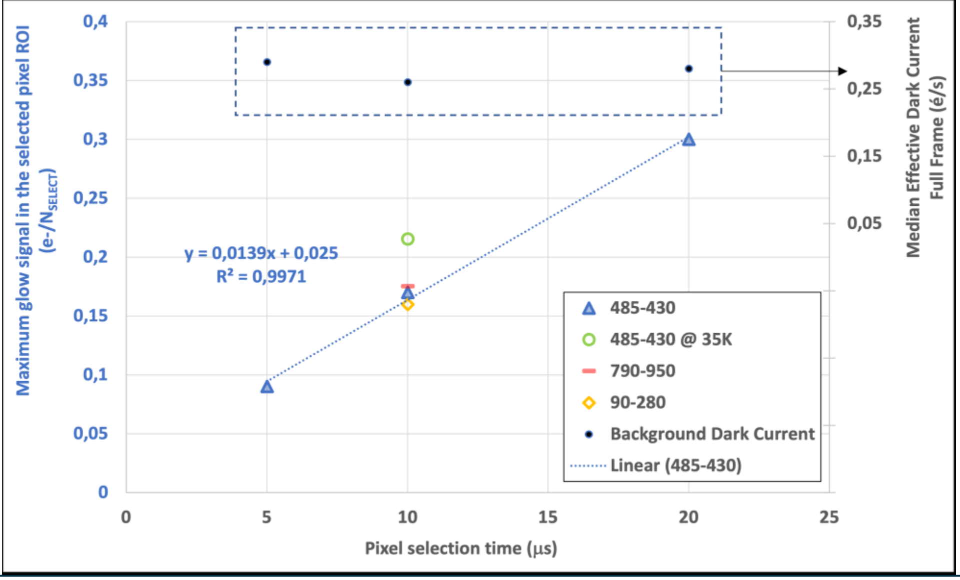
Glow generated by 1 Pixel Cell (3)

- The effective dark current is proportional to the Number of selection between each full frame
- The result is consistent for 3 ROIs
- Impact of temperature is not clear

- The glow generation increases with the pixel selection time (tweaked by changin the masterclock frequency)
- The GPF can be estimated by the single pixel selection experiment: maximum glow < GPF < cumulated glow
- Monitoring of the full frame confirms the quality of the data

GLOW GENERATION MECHANISM CONFIRMED
SPATIAL SIGNATURE IDENTIFIED





CONCLUSION

- The selection of individual pixel generates photons (most likely in the IR) that propagate towards the MCT layer following a preferred optical path (ROIC interconnects) and are collected by the neighbouring pixels (at least 3x3) thus creating a parasitic signal that superimposes to the observed scene
- Parameter of influcence:
  - The effective dark current increases with the frame rate
  - The glow per frame increases with the pixel selection time
  - The glow per frame increases with the Source Follower current (in favour of HxRG buffered mode)
  - The glow per frame increases with the Source Follower Drain to Source voltage (easy way to mitigate glow)
- Impact on instrument performances:
  - Mostly for faint targets (long UTR acquisitions) :SNR driven by the number of reads done during the UTR sequence: trade-off between theoritical reduction of RON and generation of photon noise by the glow.
  - IDARK plateau at sufficently low temperature most likely caused by the ROIC glow
- **Call to the community** ➔ let's gather data on glow across detector manufacturers, cut-off wavelength, pixel pitch, ROIC architecture (we're happy to process your data ☺)