Recent characterization results of LmAPDs: towards photon counting infrared arrays for HWO

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Introduction

Linear-mode avalanche photodiodes (LmAPDs) are intended for ultra-low flux NIR space astronomy with signals down to a few photons per pixel per hour. They must therefore meet extreme requirements in terms of detector noise, in particular dark currents (DC) << 1 e-/pixel/kilosecond.

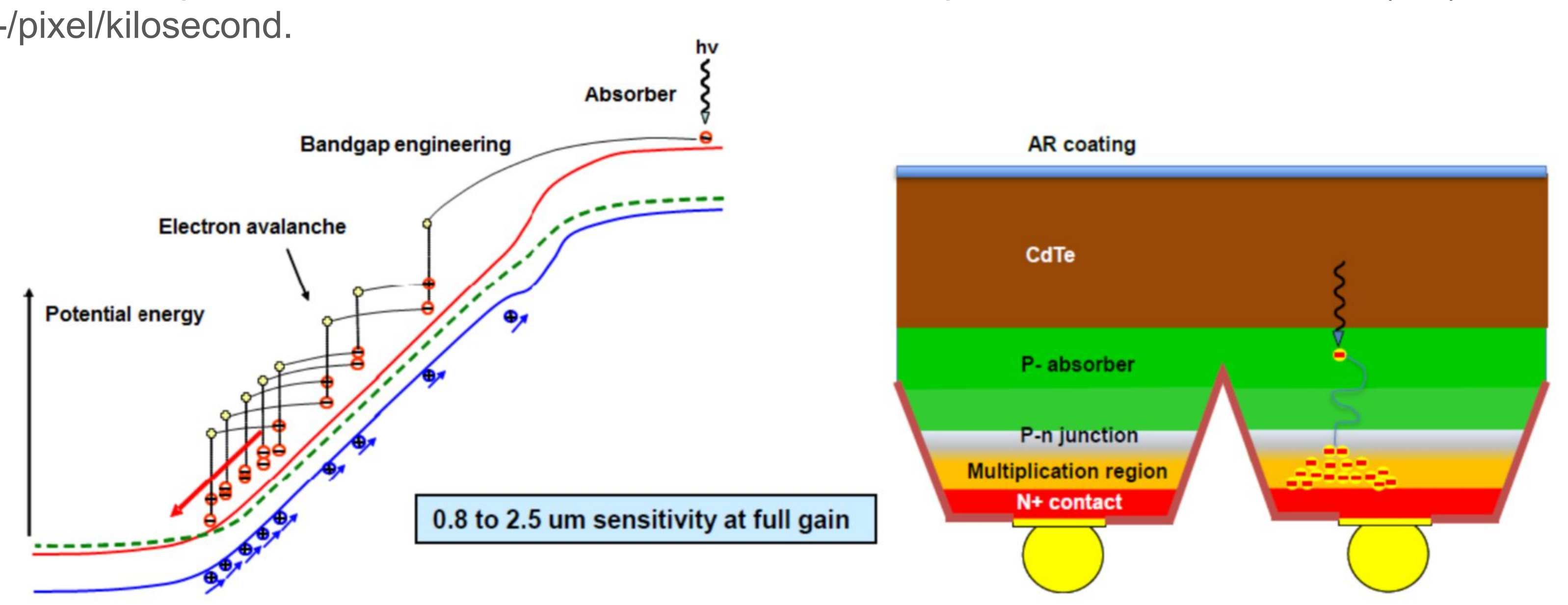

Fig.1: *(left) energy diagram of the the avalanche process used in the LmAPD; (right) diode architecture of a pixel.*

Our group at the Institute for Astronomy (University of Hawaiʻi) has partnered with Leonardo to develop this technology with the goal of bringing it to maturation for the future flagship mission of the Astro2020 Decadal Survey: the **Habitable World Observatory** (HWO). General updates can be found in Claveau et al. 2024 where our latest progress on these devices is described, including noise performance, on-sky results, and photon counting tests.

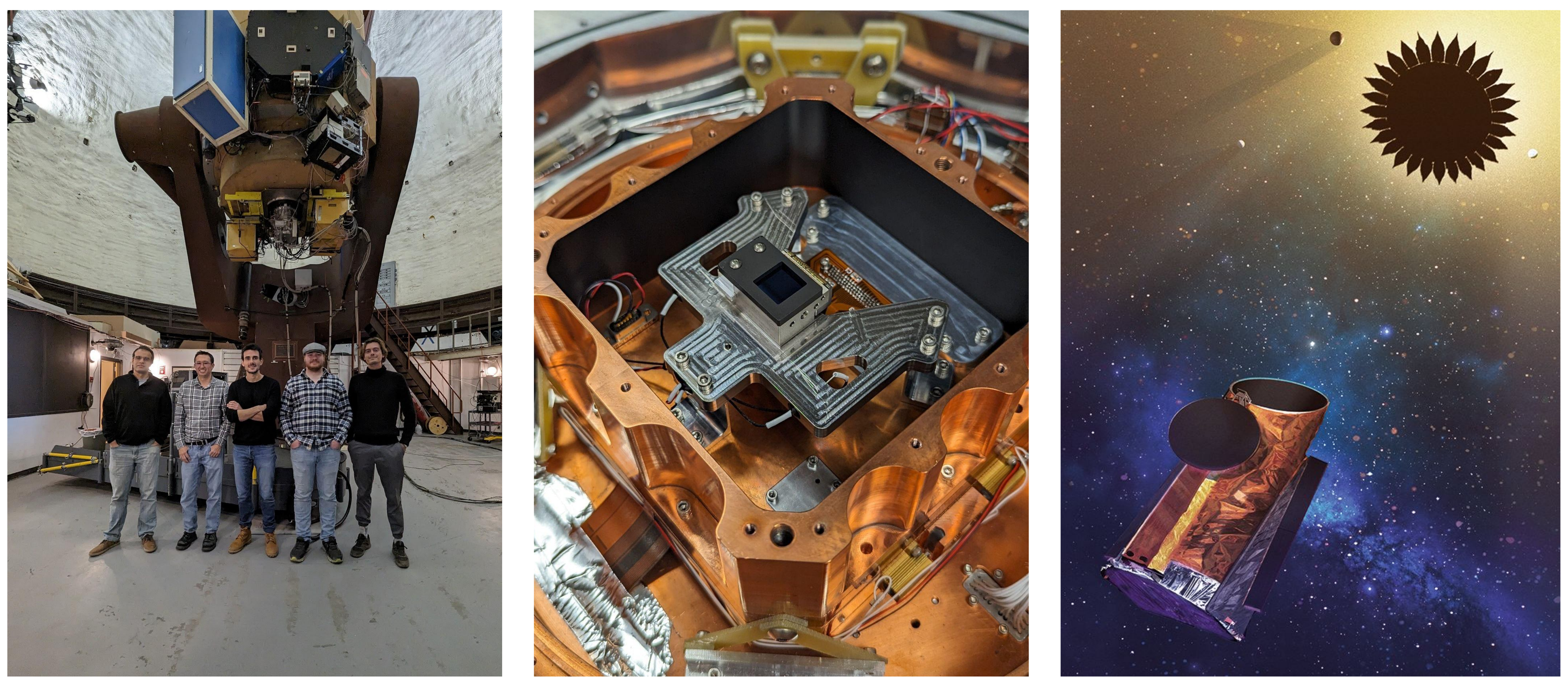

Fig.2: *(left) our team at the UH 88" observatory on Mauna Kea; (middle) the new LmAPD chip installed in its chamber; (right) HabEx, one of the HWO mission concepts.*

Glow and Dark-current

Recent characterizations of dark-current in infrared detectors have established the existence of a per-frame source of noise called **glow**. Similarly to conventional DC, it is attributed to thermal emission from the electronics within the spectral band of the device. In the case of the LmAPDs, we suspect the glow to originate from the read-out integrated circuit (ROIC), more particularly from the source-follower MOSFET.

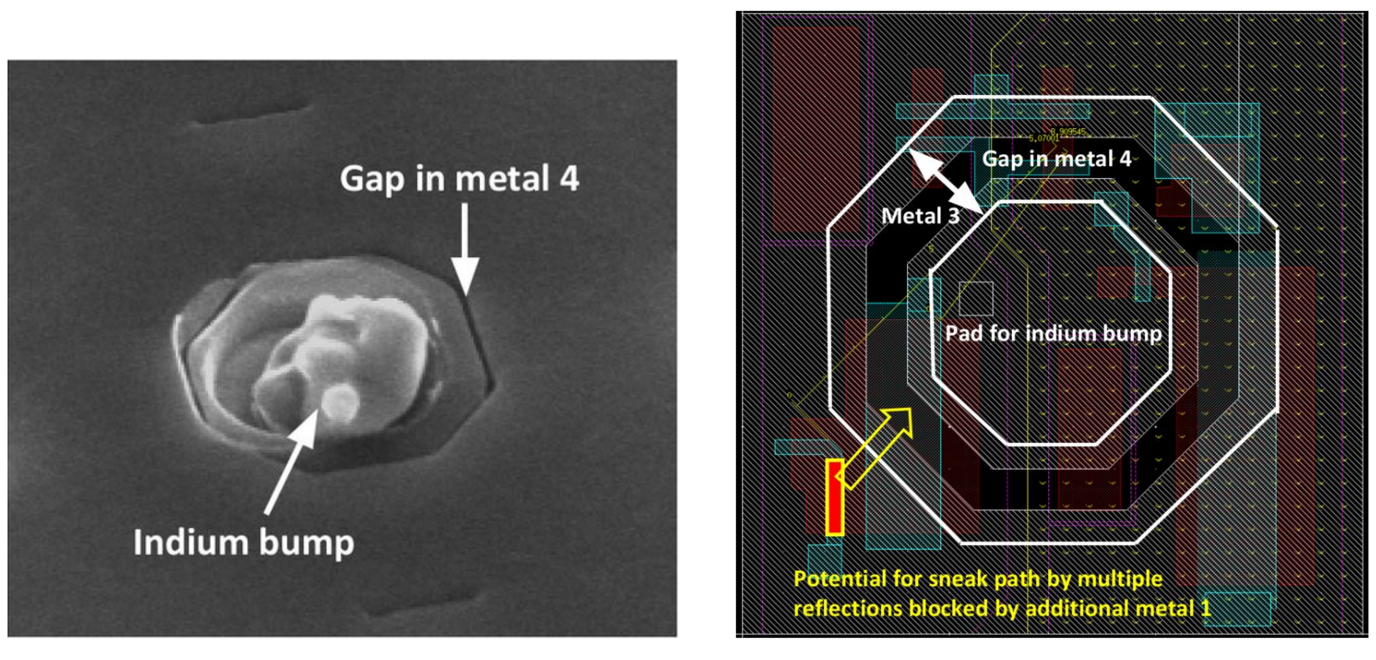

Fig.3: *Potential glow propagation path.*

To measure the glow and the DC separately, we take two Fowler-sampled datasets of equal, large exposure time:

- One without clocking (only intrinsic DC contributing)
- The other with clocking (intrinsic DC + glow integrating during the drop frames)

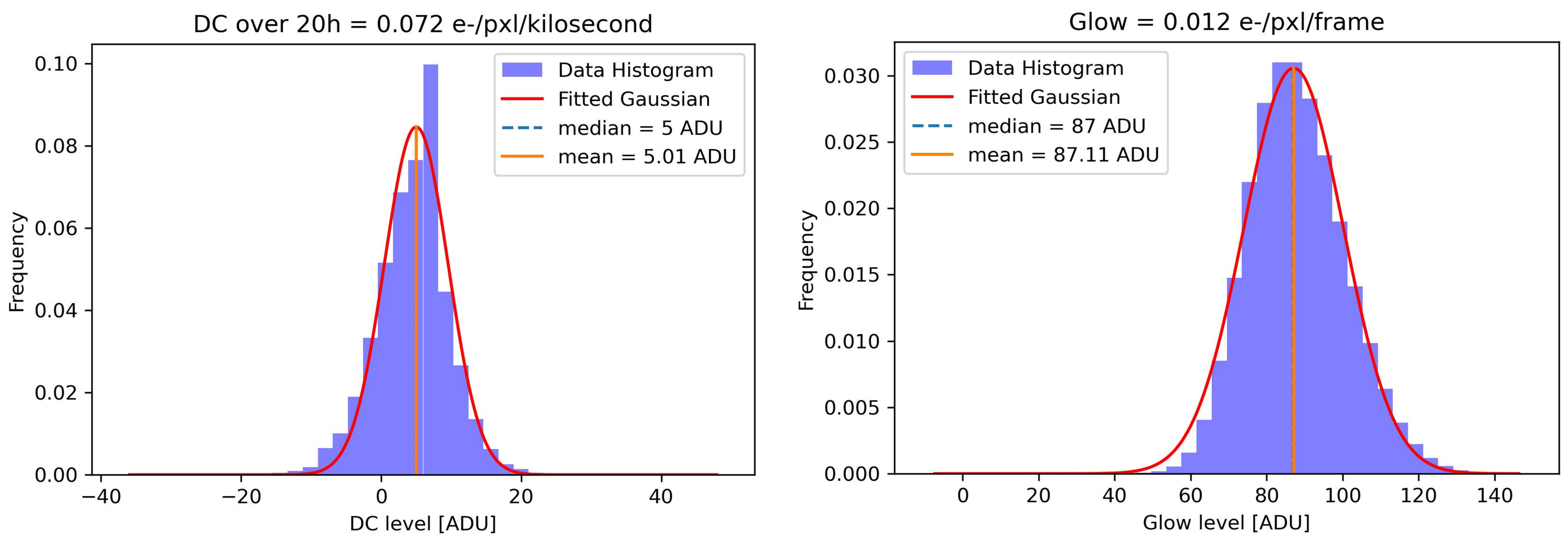

Fig.4: *histograms of the DC (left) and (glow) levels over the entire array. Test operated at 50K with a bias of 4V.*

In a previous study (Claveau et al. 2022), we report glow measurements of ~0.5e-/pxl/frame with a DC estimate of ~0.1 e-/pxl/ksec for tests at T=50K with a bias voltage of 4V. **The new chip characterized in this work shows a glow level of 0.012e-/pxl/frame, *ie.* a 4x decrease in glow, and a more accurate measurement of DC of 0.07 e-/pxl/ksec** in the same experimental conditions.

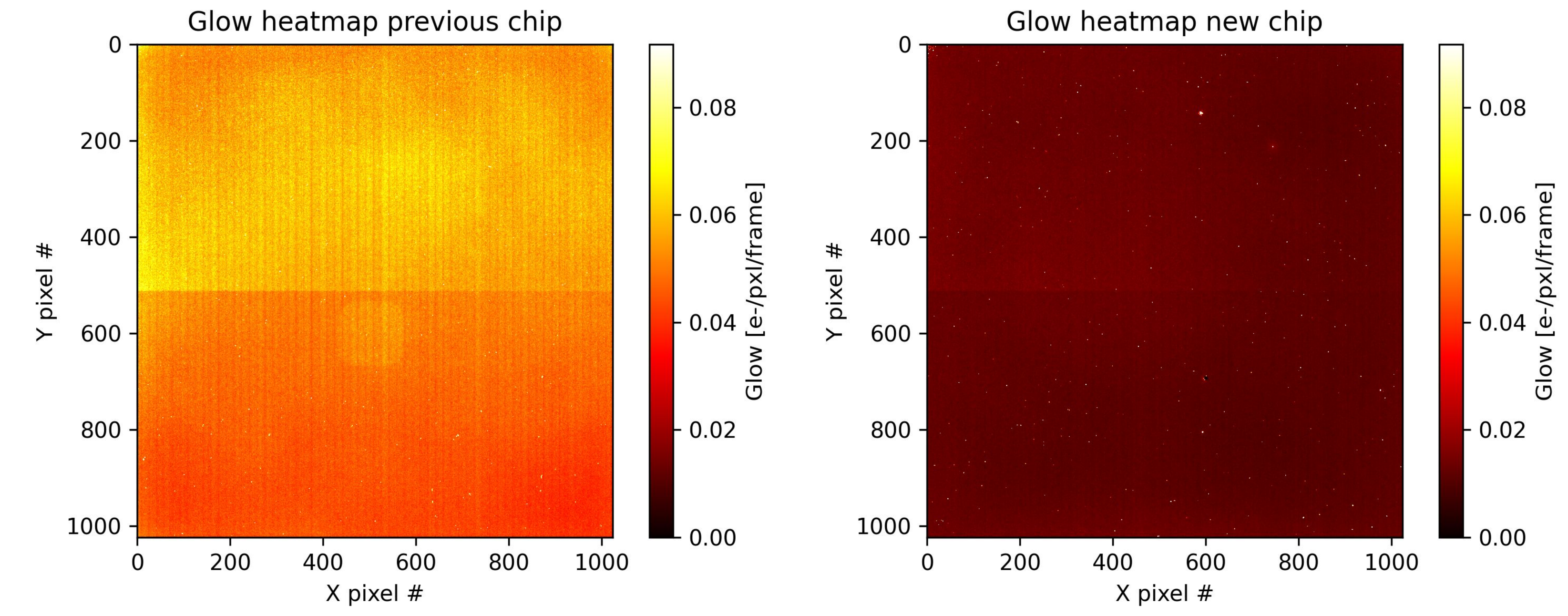

Fig.5: *glow heatmaps of the previous chip (left) and the new glow-corrected chip (right) showing the successful reduction on the new device.*

Towards photon counting detectors

The strength of the LmAPDs resides in their ability to amplify the photon signal before the readout noise penalty, thus decreasing the effective read noise.

At 10V bias, arguably the best bias for the device the read noise reaches a minimum of ~0.5 e-, and at 13V a minimum of <0.3 electrons. In the latter case, individual photon events are distinguishable. The dark current is indeed low enough that it manifests as a moderate slope in the photon detection tests.

Efficiently averaging down read noise is a crucial step towards "noise-free" photon counting devices.

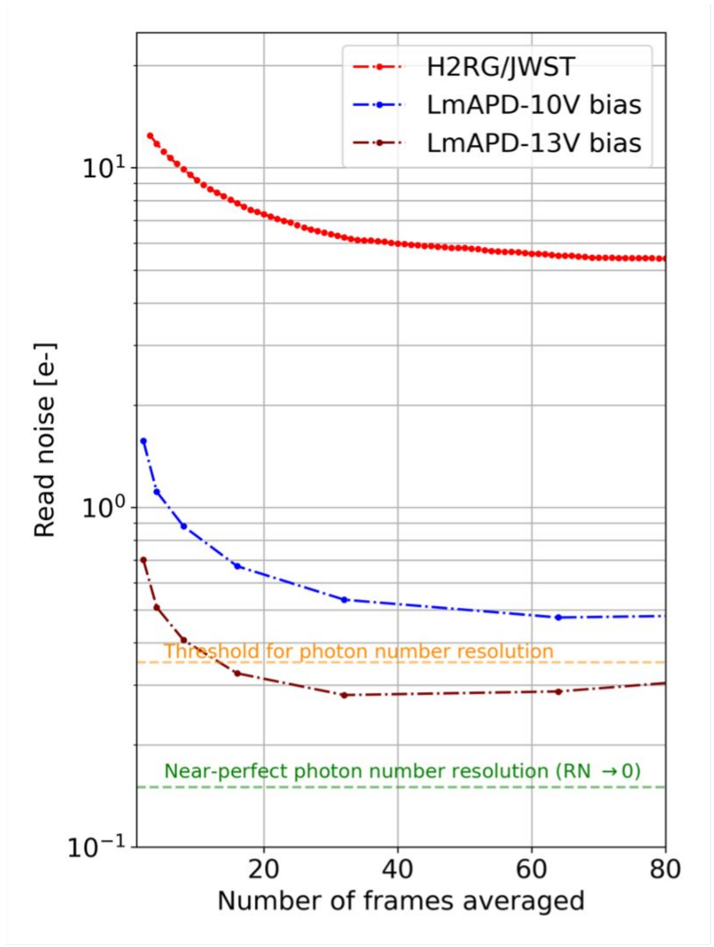

Fig.6: *read-noise averaging data comparing state-of-the-art H2RGs and LmAPDs.*

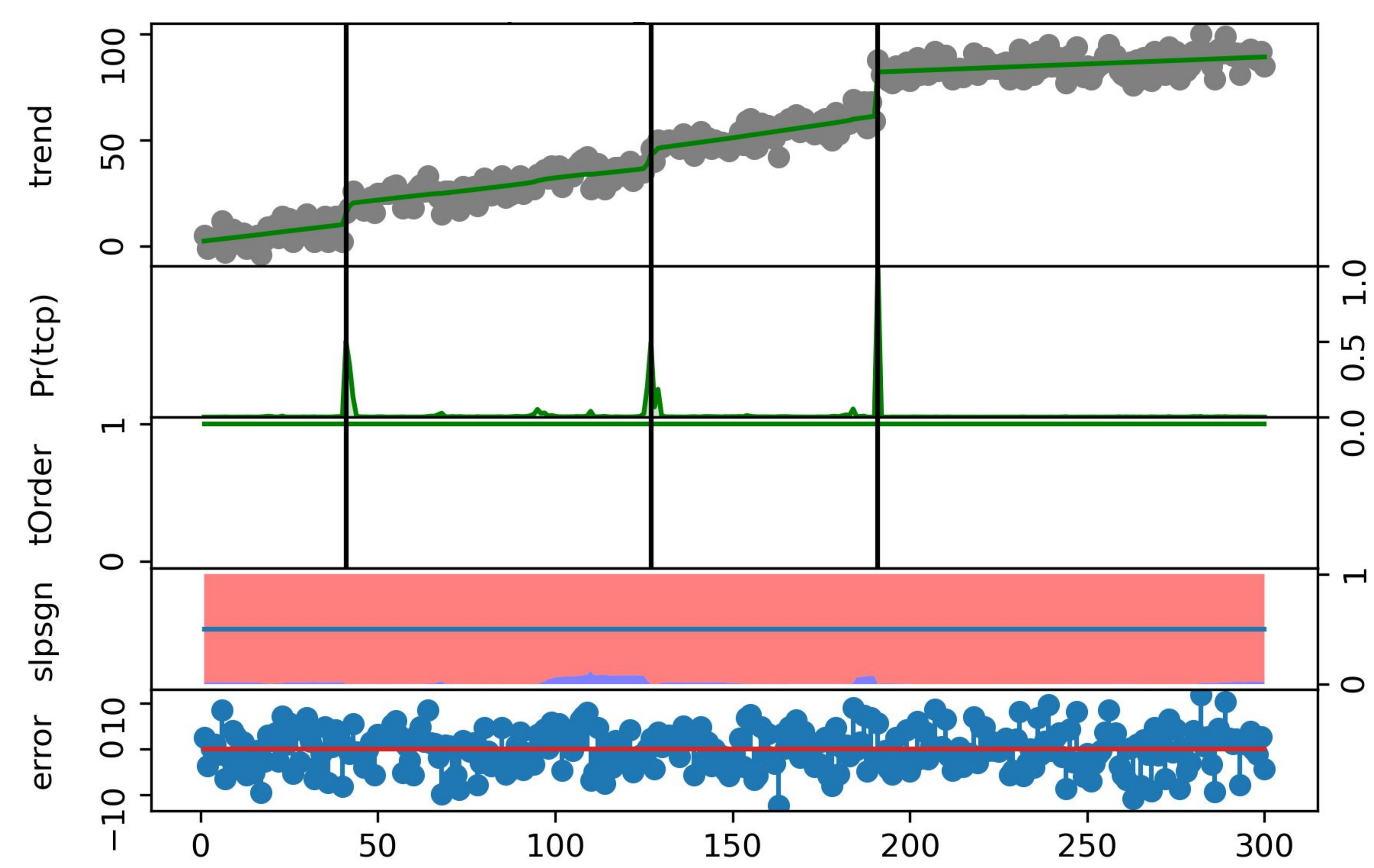

Fig.7: *Photon counting test. At high gain (BV=12V here), we can detect individual photons at under low fluxes conditions.*

CONCLUSIONS:

- Ultra low noise devices with photon counting capabilities
- Latest glow measurement ~0.01 e-/pxl/frame
- Operable outside the lab (on-sky tests)
- Future work: persistence characterization, radiation testing, excess noise factor…

REFERENCES:
(LmAPDs) Claveau et al. 2022 - Proc. SPIE Vol. 12191
(LmAPDs) Claveau et al. 2024 - SPIE talk, this conference
(ULBCam) Hall et al. 2004 - Proc. SPIE Vol. 5499