Latest characterization results of 1kx1k LmAPDs for ultra-low noise NIR astronomy

Guillaume Huber[a], Michael Bottom[a], Charles-Antoine Claveau[b], Shane Jacobson[a], Pavaman Bilgi[a]
[a]Institute for Astronomy, University of Hawai‘i; [b]University of California, Berkeley

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. In these conditions, every photon matters and detectors must therefore meet extreme requirements in terms of signal to noise performance. In particular dark currents (DC) need to be << 1 e-/pixel/kilosecond, and read-out-noise should be at the sub-electron level.

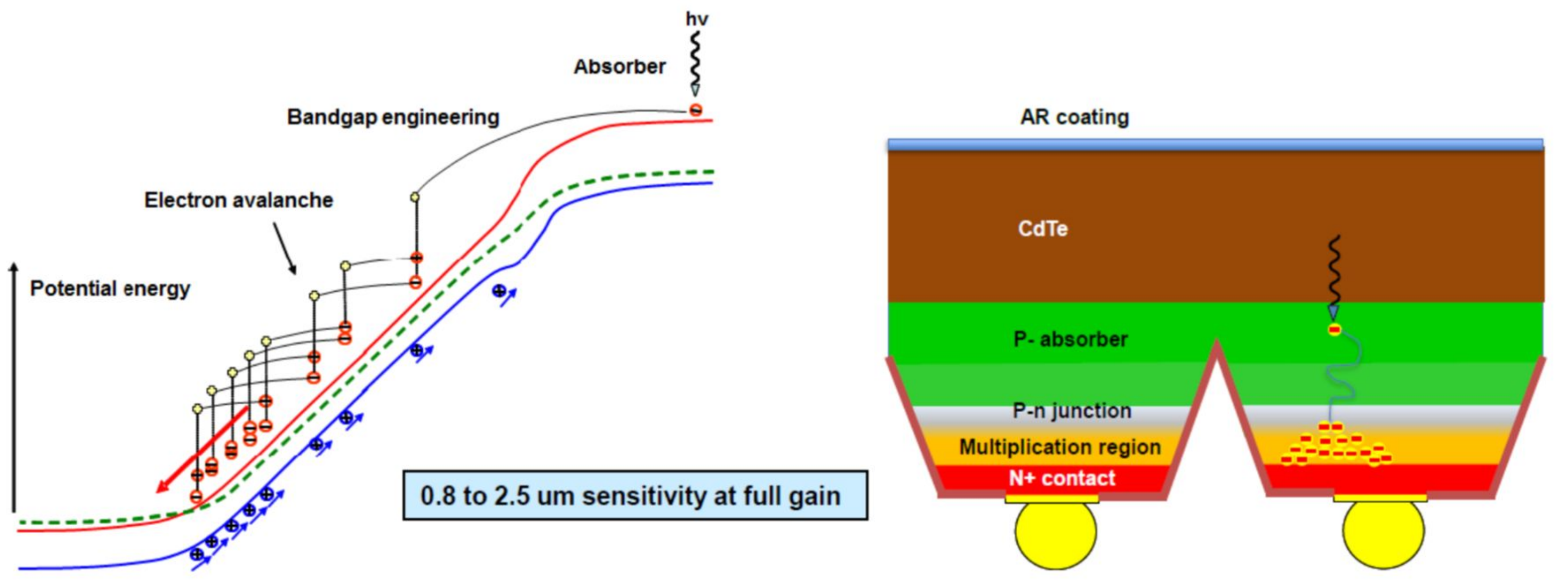

Fig.1: *energy diagram of the the avalanche process and pixel architecture of the LmAPD*

Our group at the Institute for Astronomy (University of Hawai‘i) 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). Current tests are operated on 1k x 1k pixel arrays, soon to be upgraded to 2k x 2k.

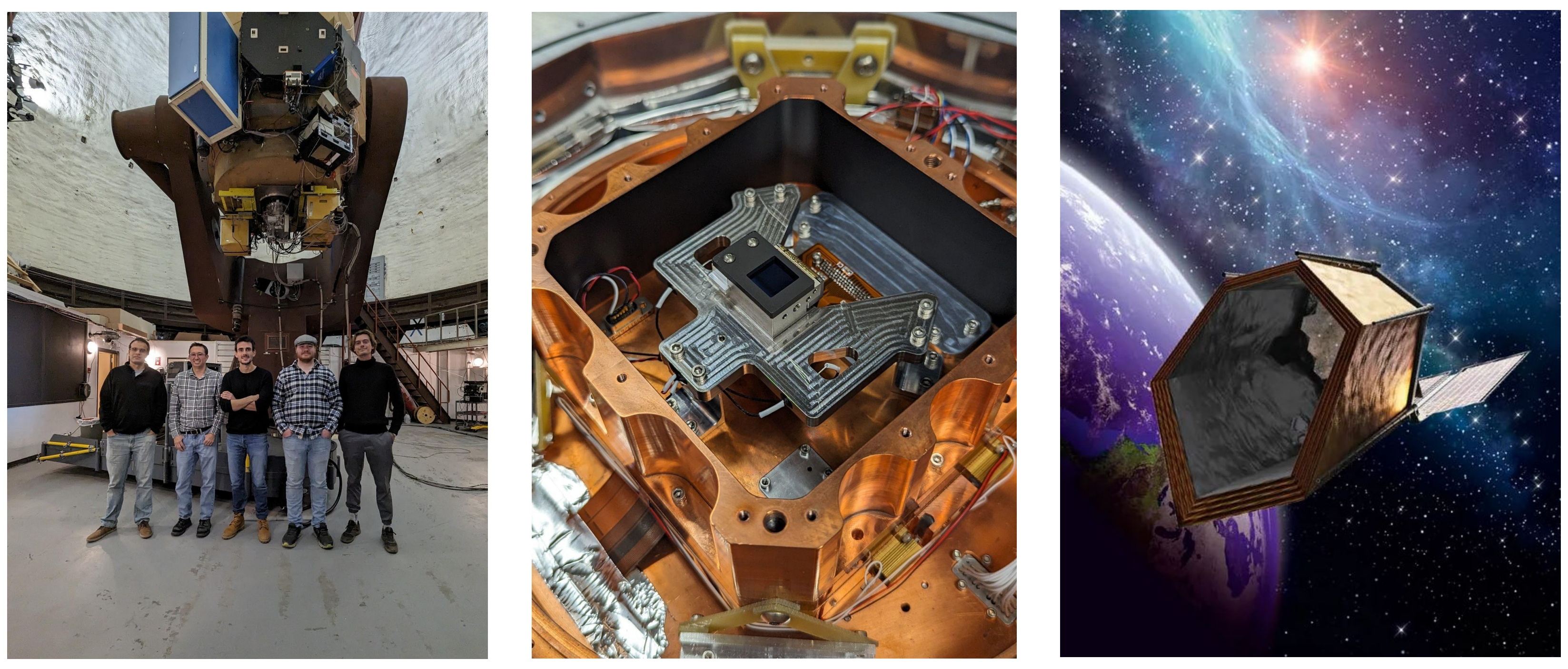

Fig.2: *(left) our team at the UH 88" observatory on Mauna Kea; (middle) 1kx1k LmAPD installed in its cryo-chamber; (right) artist view of the HWO mission concept.*

Towards photon counting detectors

At the low levels of dark-current and glow, the main impediment to single photon detection is **readout noise**. Conveniently, LmAPDs amplify the photon signal before the read noise penalty via the avalanche process, thus decreasing the effective read noise. Efficiently averaging down read noise is a crucial step towards “noise-free” photon counting devices.

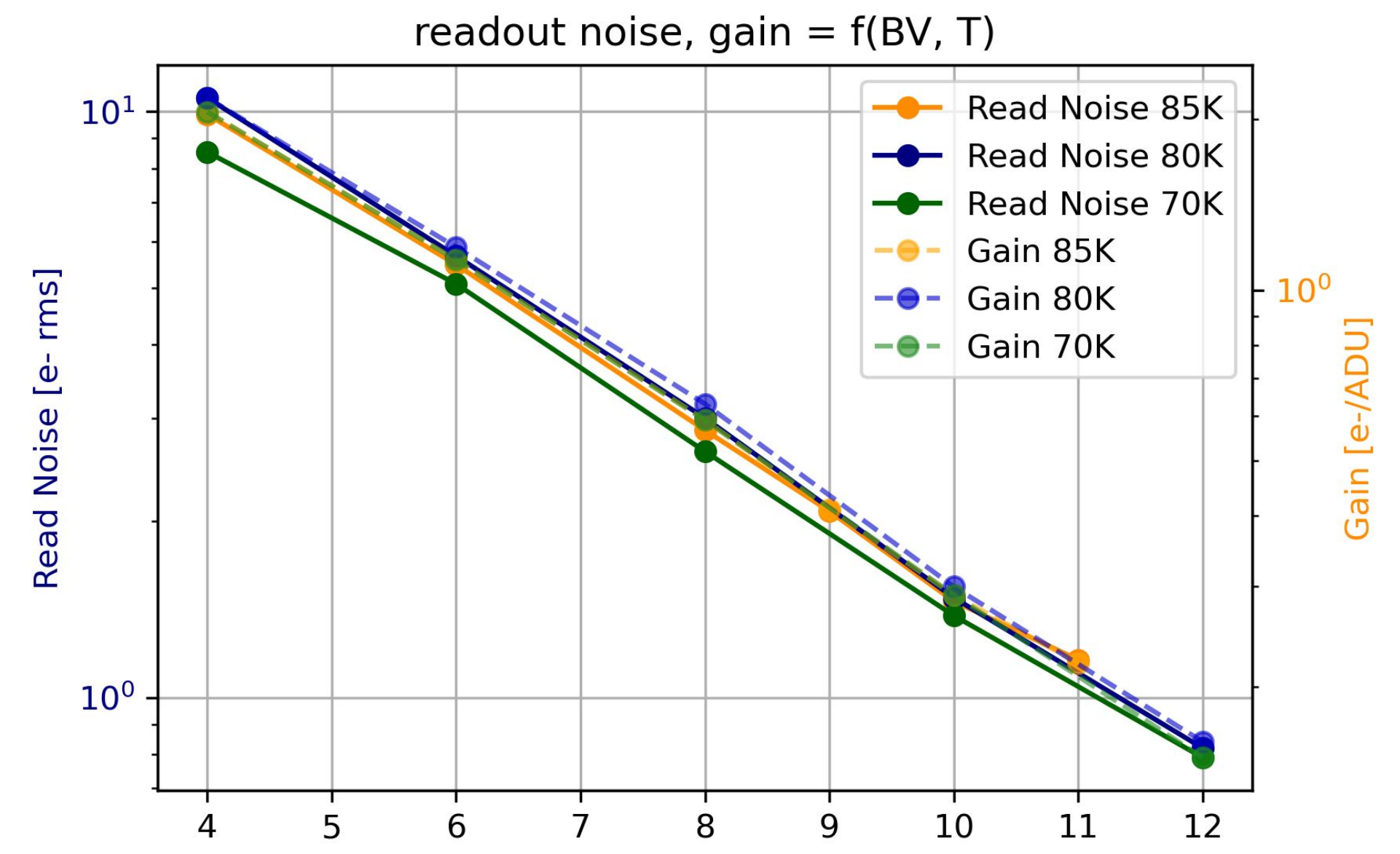

Fig.3: *effective read-noise as a function of APD gain.*

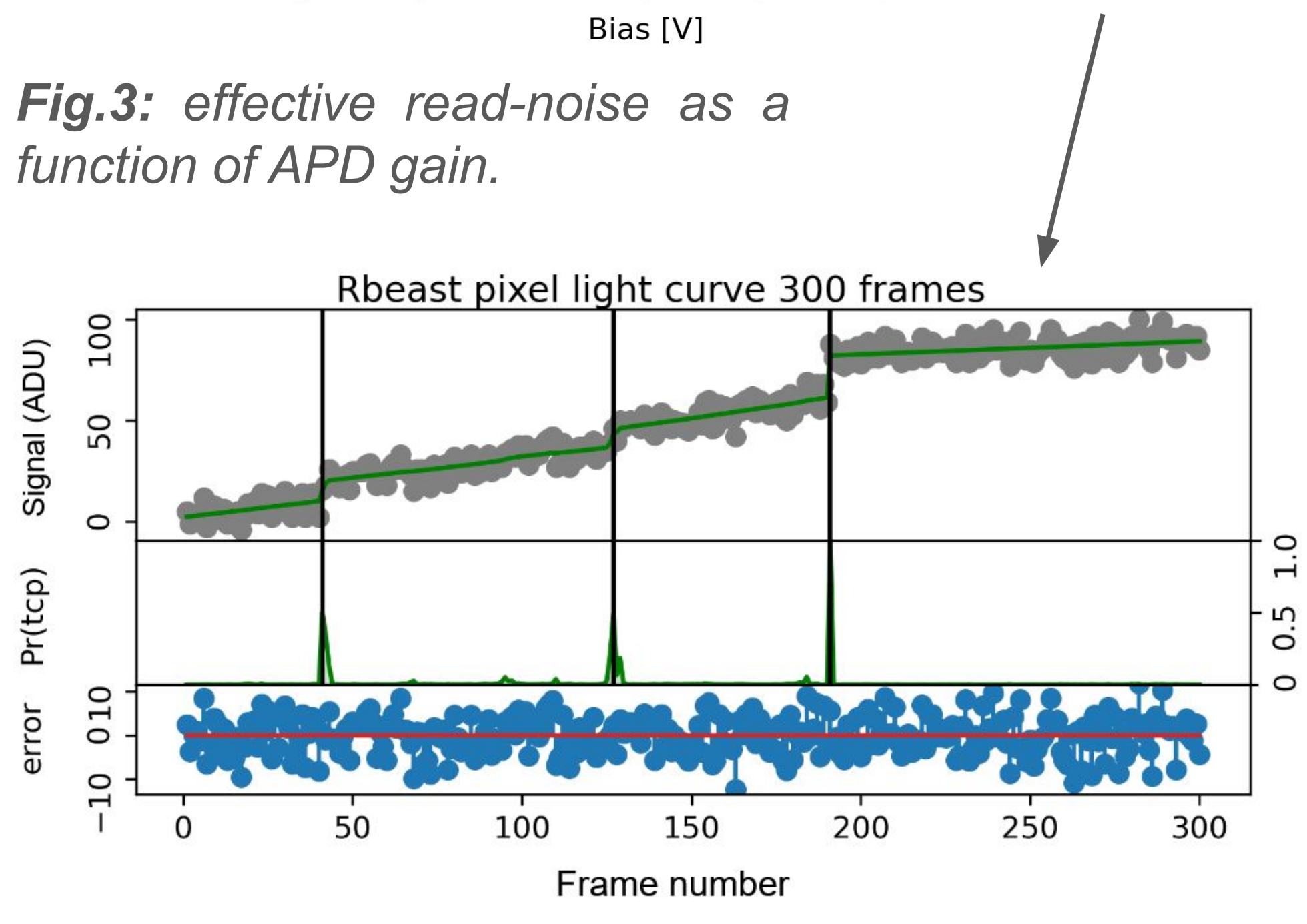

Fig.5: *A way of detecting single photons is simply by integrating a very low flux up-the-ramp. At high gain (BV=12V here), we see “photon jumps”.*

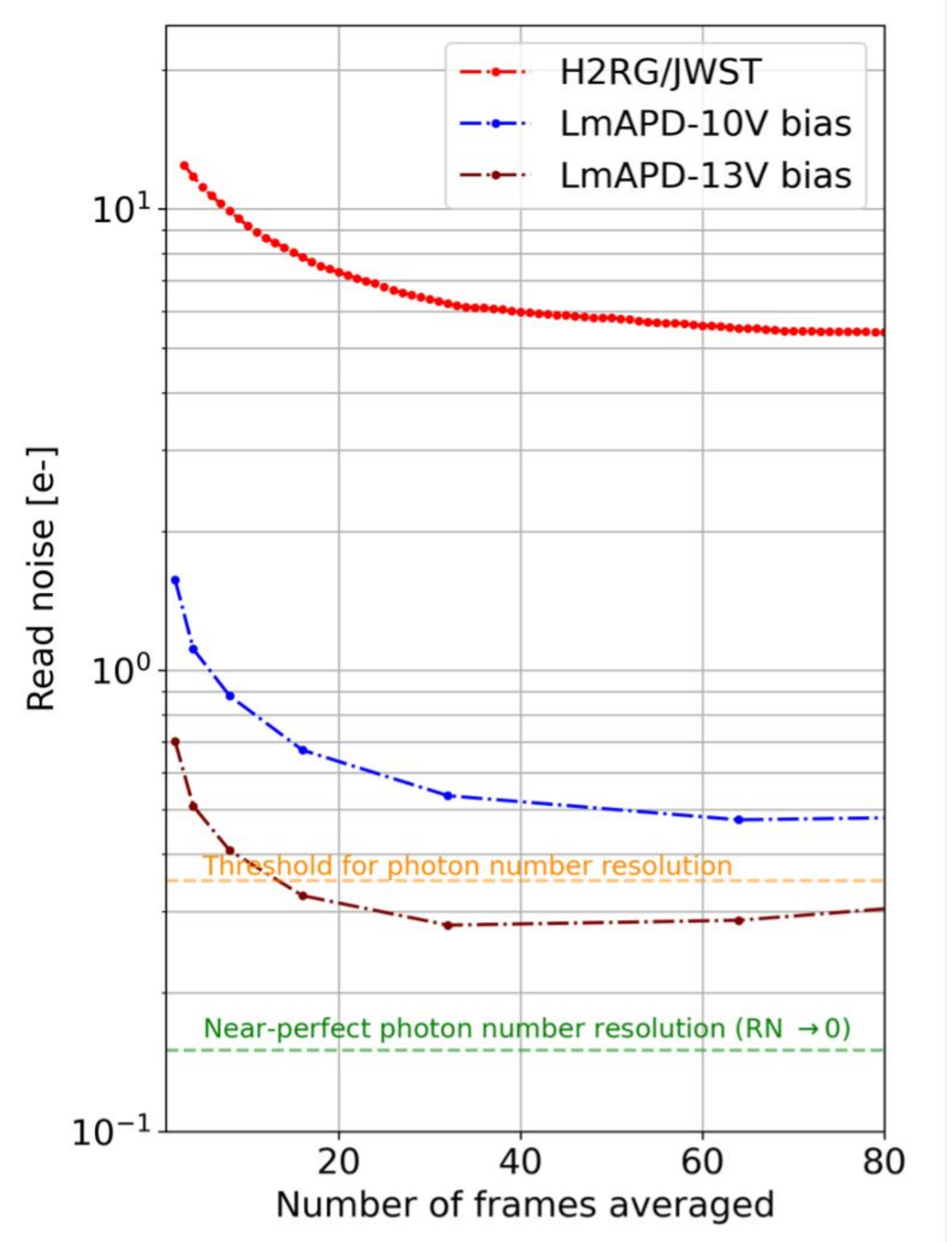

Fig.4: *read-noise averaging data comparing state-of-the-art H2RGs and LmAPDs.*

At 12V bias, arguably the best bias for the device, the read noise reaches sub-electron values. In this 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.

Dark-current and glow

Multiplexer glow is a per-frame component of noise inherent to infrared arrays. In the case of LmAPDs, it is one of the major impediments to photon counting and is driving current R&D progress. Recently, we recently measured a **0.01 e-/pxl/frame level of glow**, bringing down the **overall dark-current to neglectable values** (<0.1 e-/pxl/kilosecond).

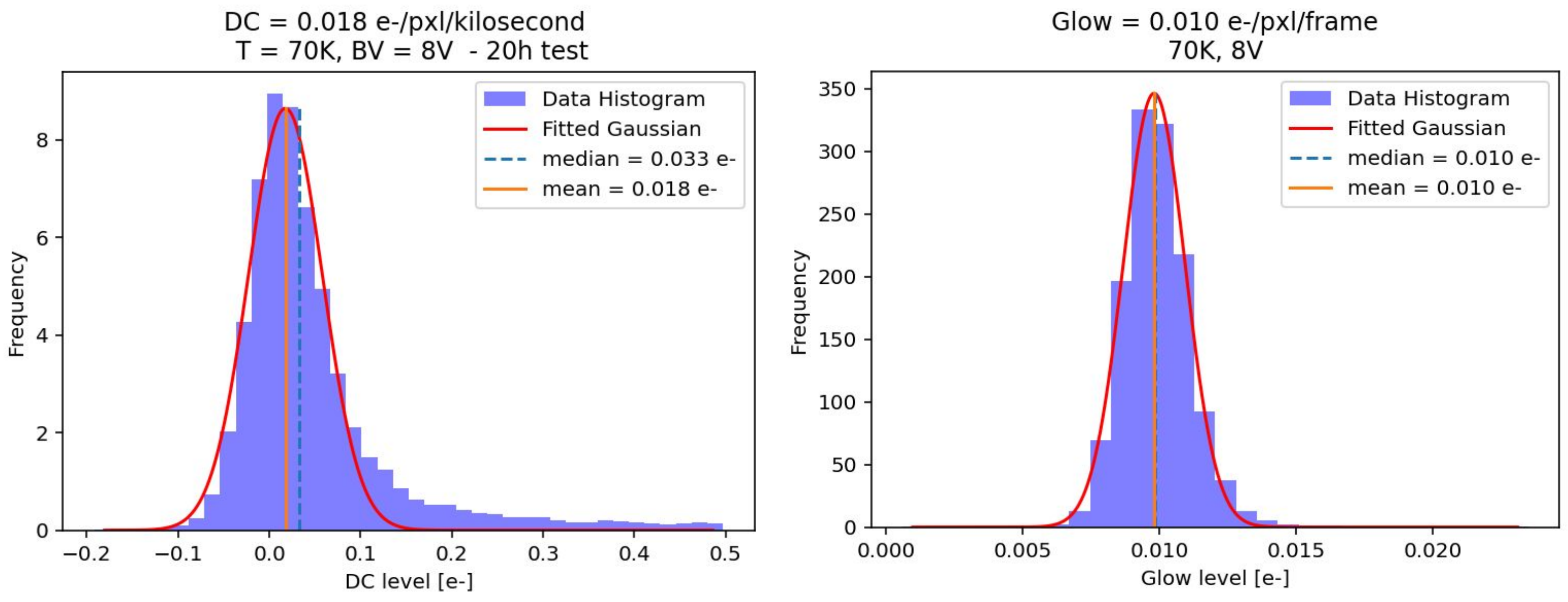

Fig.6: *histograms of the DC (left) and (glow) levels over the entire array. Test operated at 70K with a bias of 8V.*

In recent work, we find that output dark-current is independent of the gain. Which means that it is not amplified and that operating at high gain reduces the effective DC. At high bias however, tunnel-DC kicks in and increases in an exponential way, setting a hard limit on the operating range of gain.

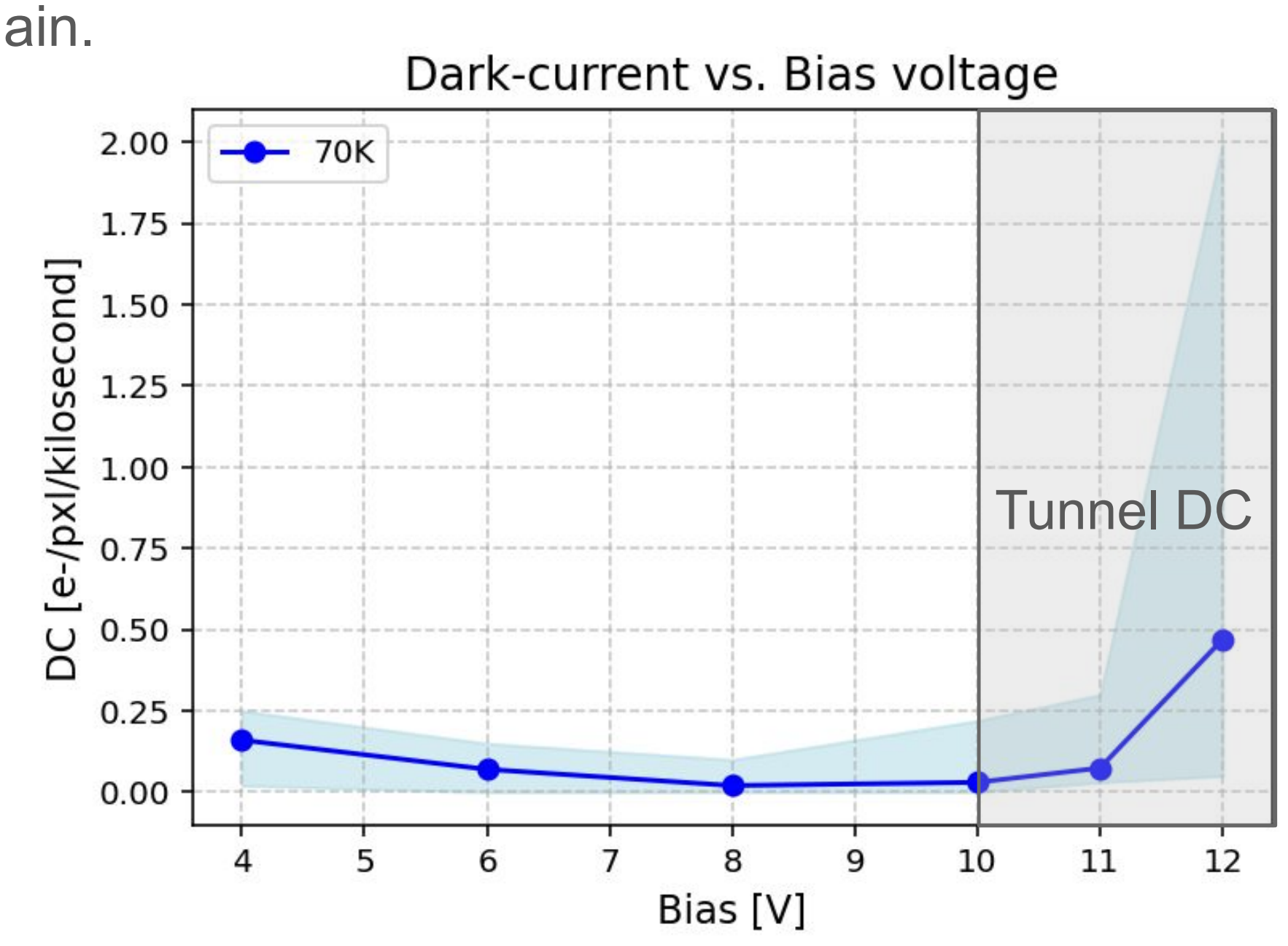

Fig.7: *Dark-current vs. bias voltage. At 70K, DC remains under 1 e-/kilosecond, but tunnel-induced DC manifests at high bias.*

Another concern is the amplification of glow. We find that glow is amplified by the APD but it is still unclear if it is getting the full multiplication gain, in which case it would be impossible to distinguish glow photons from true astrophysical ones.

Persistence

Like most HgCdTe detectors, LmAPDs have persistence which is essentially a transient increase in dark signal after illumination. Although its amplitude is less that 1% of the light received, it can remain for extended periods of time and is amplified as the **traps are located in or near the absorber and get avalanched**.

Current efforts focus on reducing the persistence at its root, by redesigning the mesa slots, believed to be hosting the persistence traps.

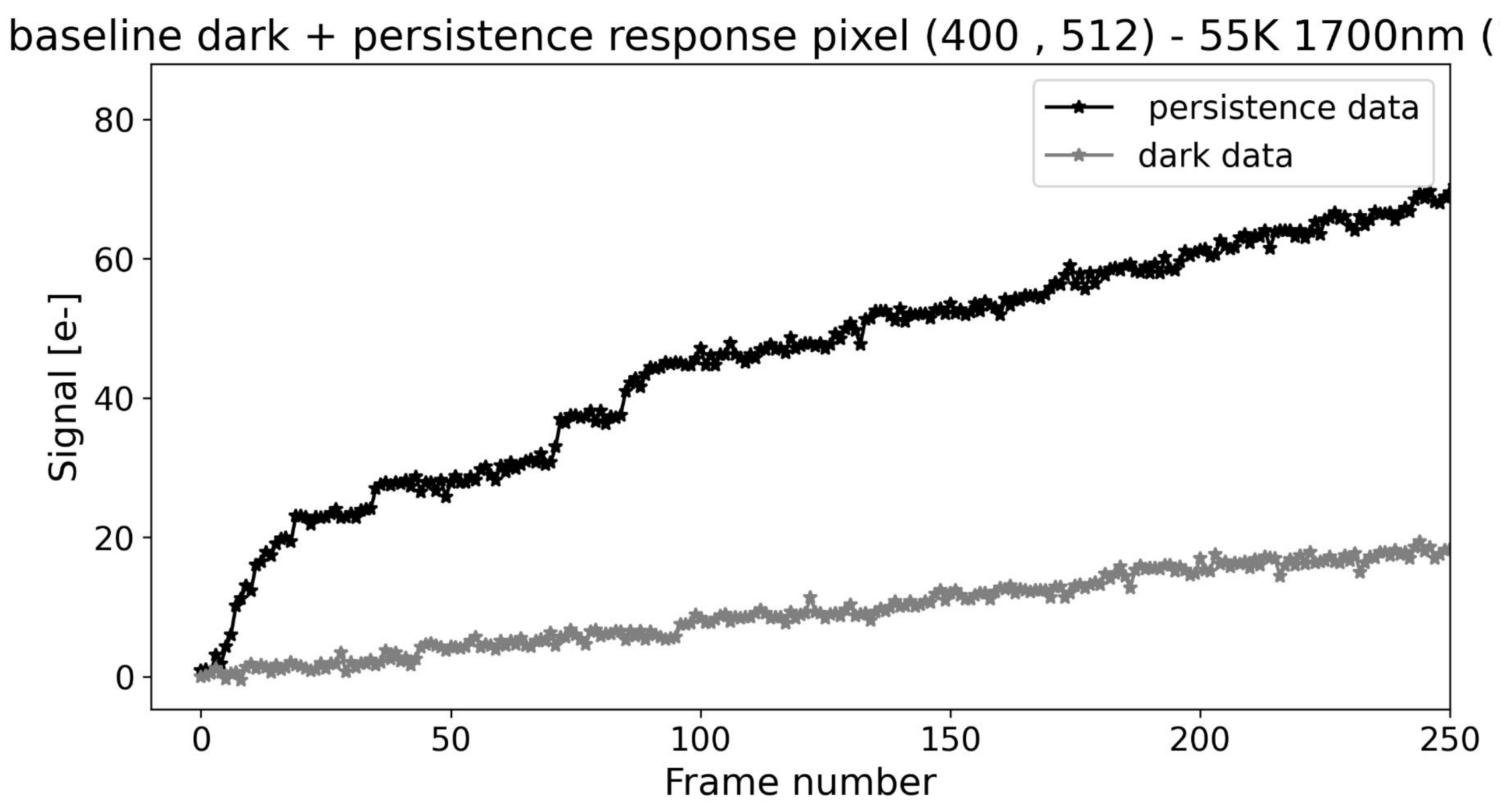

Fig.7: *At high gain, we can see “photon-like jumps” in individual pixel persistence ramps, confirming the theorized idea that persistence originates from trapped charges within the APD. If the persistence jumps are the same amplitude as photon jumps, this will potentially cause issues to distinguish low signals from persistence.*

CONCLUSIONS:

- Ultra-low noise devices with photon counting capabilities
- Latest glow measurement ~0.01 e-/pxl/frame but glow is amplified, so is persistence…
- 1kx1k Operable outside the lab (on-sky tests), 2kx2k under development at Leonardo
- Future work: radiation testing, PNR, excess noise factor…

REFERENCES:

(LmAPDs) Claveau et al. 2022 - SPIE talk / proc.
(LmAPDs) Claveau et al. 2024 - SPIE talk / proc.
(LmAPDs) Huber et al. 2024 - SPIE talk / proc.
(ULBCam) Hall et al. 2004 - Proc. SPIE Vol. 5499

email me:
ghuber@hawaii.edu