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Modeling the e-APD SAPHIRA/C-RED ONE camera at a low flux level

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We implemented an electron avalanche photodiode (e-APD) in the MIRC-X instrument, which is an upgrade of the six-telescope near-infrared imager MIRC, at the CHARA array. This technology improves the sensitivity of near-infrared interferometry.

We aim to characterize a near-infrared C-RED ONE camera from First Light Imaging (FLI) using an e-APD from Leonardo (previously SELEX).

We first used the classical mean-variance analysis to measure the system gain and the amplification gain. We then developed a physical model of the statistical distribution of the camera output signal. This model is based on multiple convolutions of the Poisson statistic, the intrinsic avalanche gain distribution, and the observed distribution of the background signal. At a low flux level, this model independently constrains the incident illumination level, the total gain, and the excess noise factor of the amplification.

We measure a total transmission of $48 \pm 3\%$ including the cold filter and the Quantum Efficiency.
We measure a system gain of 0.49 ADU/e, a readout noise of 10 ADU, and amplification gains as high as 200. These results are consistent between the two methods and therefore validate our modeling approach. The measured excess noise factor based on the modeling is 1.47 ± 0.03, with no obvious dependency with flux level or amplification gain.

The presented model allows the characteristics of the e-APD array to be measured at a low flux level independently of a preexisting calibration. With < 0.3\,electron equivalent readout noise at kilohertz frame rates, we confirm the revolutionary performances of the camera with respect to the PICNIC or HAWAII technologies. However, the measured excess noise factor is significantly higher than what is claimed in the literature (<1.25), and explains why counting multiple photons remains challenging with this camera.

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