Characterization of a Room Temperature Photon Number Resolving Detector for Quantum Information Science and Astrophysics

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ABSTRACT

We report characterization results for a room temperature photon number resolving detector. Dartmouth designed and initially characterized the detector, and Gigajot Technology made the camera [1, 2]. It is configured as an imaging array detector with one million pixels. Unlike other single photon sensing detector arrays, such as those based on avalanche photodiodes, its pixels have high fill factor and can distinguish photon number. It also operates at room temperature, unlike superconducting single photon sensing detectors. We present measurements of read noise and demonstrate the photon number resolving capability. We compare the results to requirements of astrophysics and quantum information science experiments.

INTRODUCTION

The Quanta Image Sensor (QIS) has low noise and scalable architecture that is well-suited for low light level imaging applications. In particular, it enables whole new classes of science, such as exoplanet characterization and life finding in the Universe. It is also well-suited for quantum information science, where one must detect individual photons with very high quantum efficiency. With these applications in mind, we acquired a one megapixel QIS-based camera from Gigajot Technology in order to characterize the detector's performance and compare it to requirements for future NASA exoplanet missions and bi-photon entanglement verification quantum experiments.

CAMERA SYSTEM

The camera consists of 20 packaged megapixel detectors mounted on a PCB inside of a 3D-printed body with a C-lens mount (Figure 1) and a lens. The software has a GUI and provides control for setting read modes. For the purposes of this project, we used a full-frame read mode and eight reads at the beginning and end of each exposure.

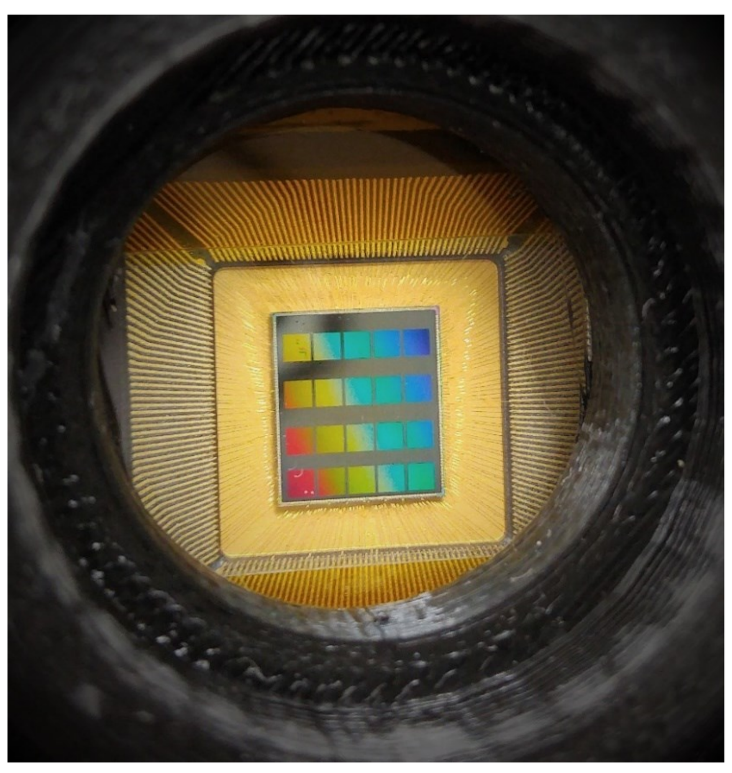

Figure 1. The picture shows 20 packaged megapixel detectors in the RIT Center for Detectors.

CHARACTERIZATION

We measured performance in the Rochester Imaging Detector Laboratory at RIT, based on methods developed for testing astronomical detectors. The noise is the standard deviation of reads measured in a large stack of images. The conversion gain is the average spacing, in analog-to-digital units, between peaks in a histogram of pixel values obtained with the detector under illumination. We measured pixel size using a microscope.

Table 1. Detector Performance Goals

Parameter	Measured	Goal
Format	1K×1K	1K×1K
Pixel Size	1.1 μm	1.1 μm
Read Noise (mean)	0.32 e^-	<0.17 e^-
Dark Current (@200 K)	not tested	<0.001 e^-/s/pix
QE	not tested	>85%
Latent Image (@200 K)	not tested	<1 e^-/pix
Charge Rate Capacity	not tested	>10^4 e^-/s/pix
Operating Temperature	300 K	120 K – 300 K
Fill Factor	not measured	100%
Susceptibility to Radiation Damage	not tested	immeasurable
Susceptibility to Radiation Transients	not tested	immeasurable
Power (@1000 fps at 5 bits/pixel)	not tested	<12.5 nW/pixel
Power (@0.1 fps at 5 bits/pixel)	not tested	<1.25 pW/pixel

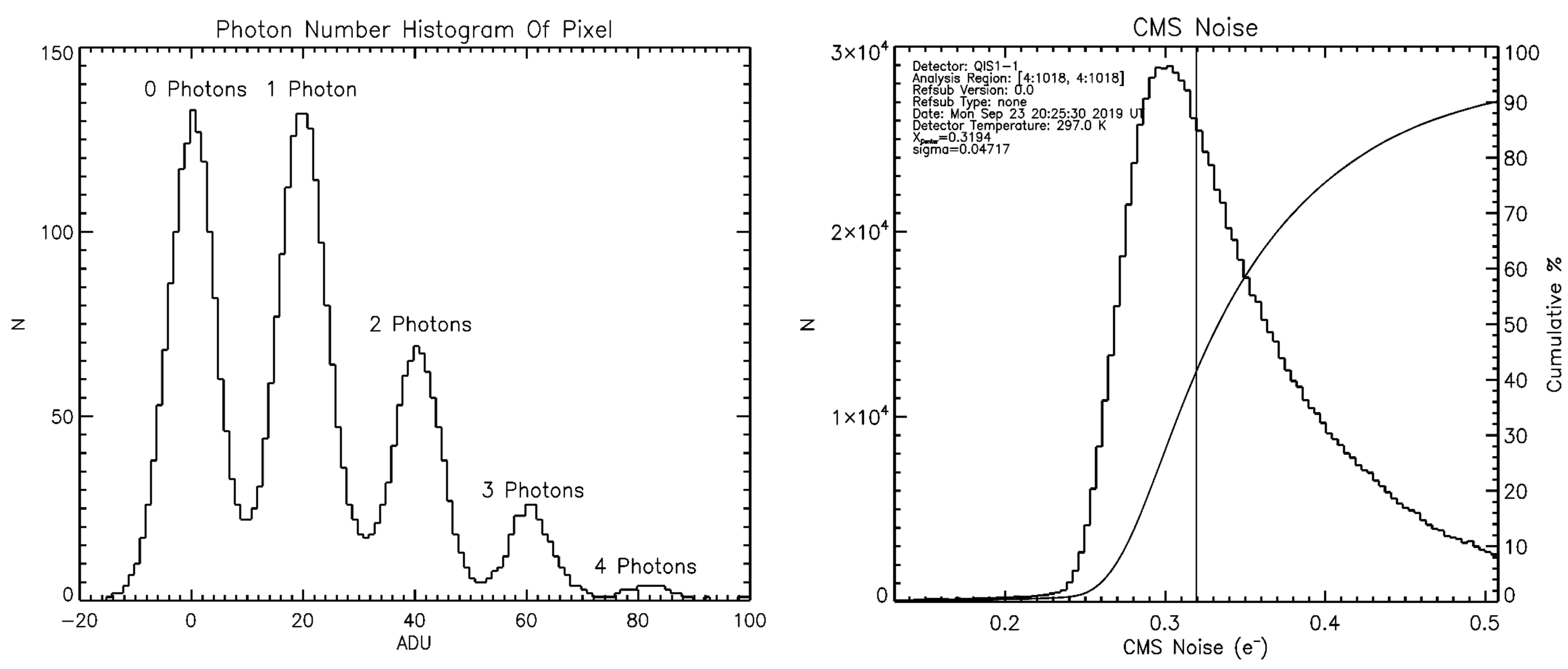

Figure 2. (*left*) The histogram of pixel values demonstrates photon number resolution and is used to calculate analog-to-digital conversion gain. (*right*) The mean CMS read noise is ~0.32 e^-.

EXOPLANET FINDING

Table 2 shows the diameter required for a space telescope in order to generate SNR=3 for a faint object, as a function of read noise and quantum efficiency at visible wavelengths.

Telescope Diameter (meters) for SNR = 3						
FOM		Quantum Efficiency				
		60%	70%	80%	90%	100%
read noise	0	9.5	8.8	8.3	7.8	7.4
	1	10.5	9.7	9.1	8.6	8.1
	2	12.2	11.3	10.5	9.9	9.4
	3	13.8	12.8	12.0	11.3	10.7
	4	15.4	14.3	13.3	12.6	11.9
	5	16.8	15.6	14.6	13.7	13.0
	6	18.2	16.8	15.7	14.8	14.1
	7	19.4	18.0	16.8	15.8	15.0
mag_star=26, V band, R=20000, i_dark=0.0001 e-/s/pixel						

Table 2. Red is for a typical CCD and green is for QIS.

PHOTON ENTANGLEMENT VERIFICATION

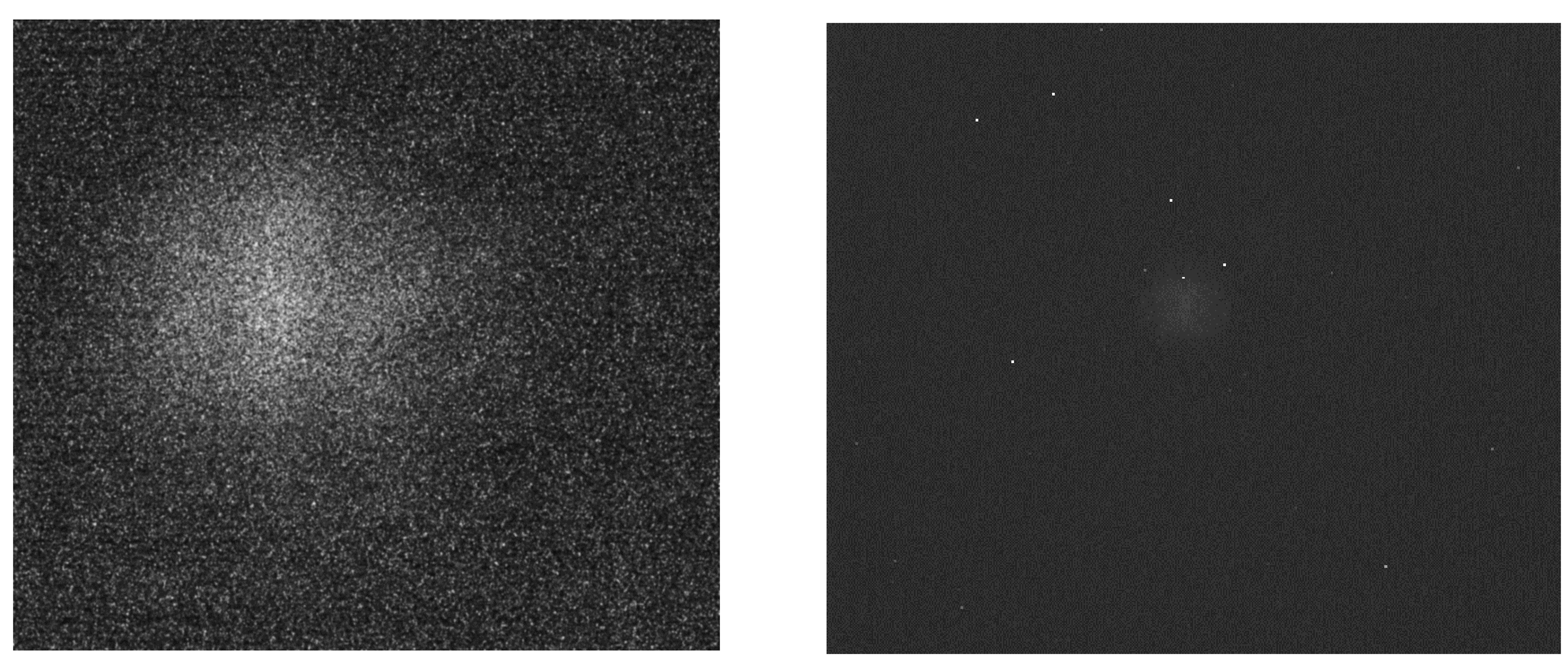

Figure 3. Photon pair generation sites in a non-linear crystal are imaged using the QIS (left) with an integration time of 74 μs and a PCO Pixelfly CCD (right) with an integration time of 25 ms.

ACKNOWLEDGMENTS

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REFERENCES

1. https://www.gigajot.tech/
2. Ma, J., Masoodian, S., Starkey, D.A., and Fossum, E.R. 2017, "Photon-Number-Resolving Megapixel Image Sensor at Room Temperature without Avalanche Gain," Optica, Vol. 4, Issue 12, pp. 1474-1481