# Astro Skipper-CCD Detector

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## Introduction

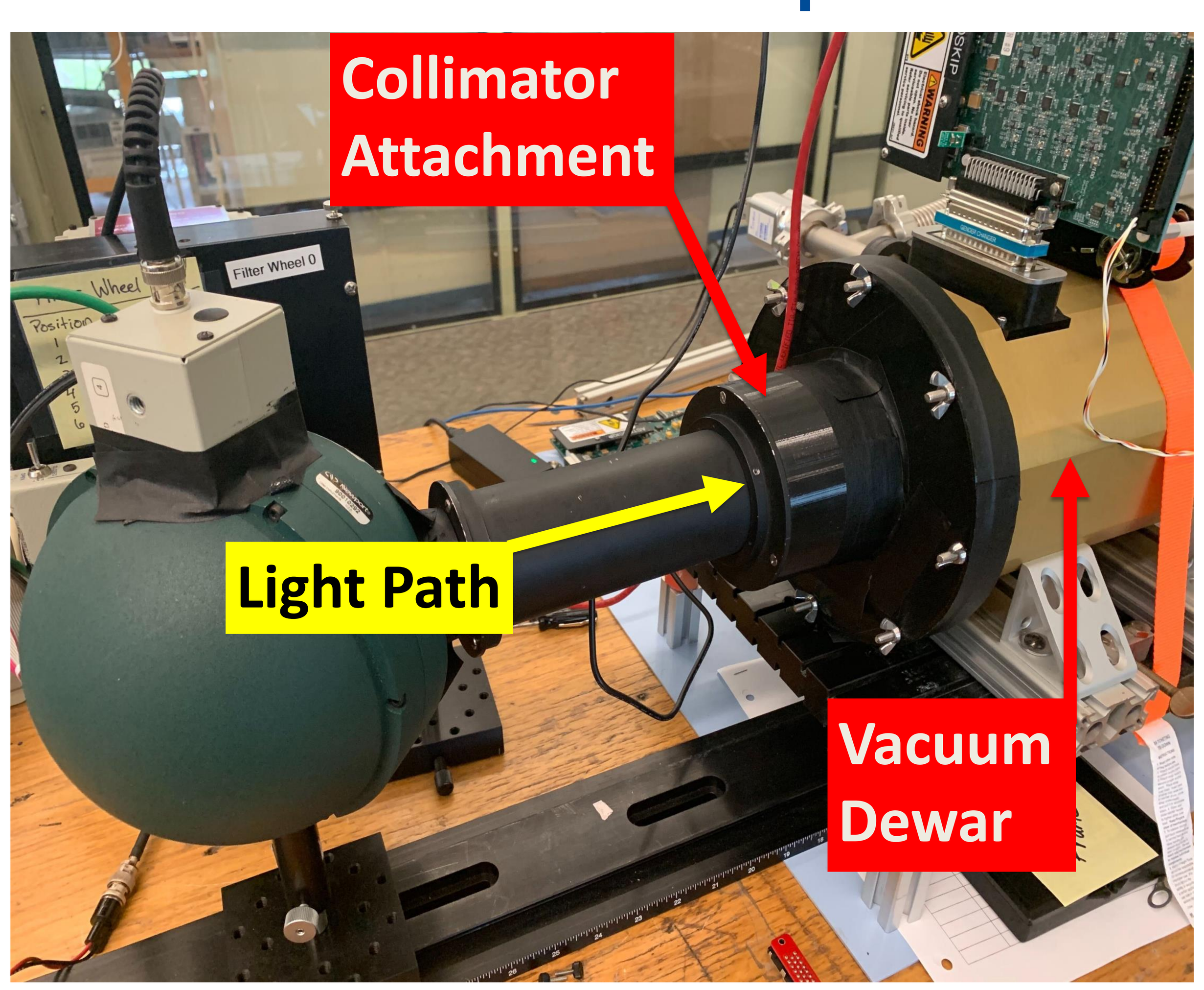
Cosmologists have determined that the majority of the universe is composed of dark energy and nonbaryonic (not made of atoms) dark matter. Dark energy is an unknown form of energy, hypothesized to be the cause of the accelerating expansion of the universe. Dark matter can not be detected electromagnetically, however cosmologists are confident it exists because of its gravitational effect on galaxies. In spiral galaxies, we observe stars that orbit at speeds that can not be accounted for by the gravitational force of visible matter. This puzzling result is contrary to standard Newtonian gravity, yet makes sense if one assumes the gravitational effects of an unseen mass[1]. Better, more sensitive detectors are required to perform detailed measurements of faint stars and galaxies that will allow us to further understand these phenomena.

## Skipper-CCDs

Charge-coupled devices (CCDs) are essential for photon detection in scientific applications. These detectors rely on the photoelectric effect to absorb incident photons and convert them into electrons that are stored in an array of pixels. Each pixel is composed of a MOS capacitor in which by manipulating the voltage level on the gates of the capacitors, the charge stored in each pixel is shifted through the array to an output amplifier where the voltage is measured and an image is produced.

"Skipper" CCDs greatly reduce readout noise through a technique that repeatedly measures the charge on each individual pixel[2]. In combination with a high-powered telescope, Skipper CCDs will be able to aid in the study of distant galaxies by providing the ability to control readout noise directly on a pixel-by-pixel basis.

## Experimental Setup



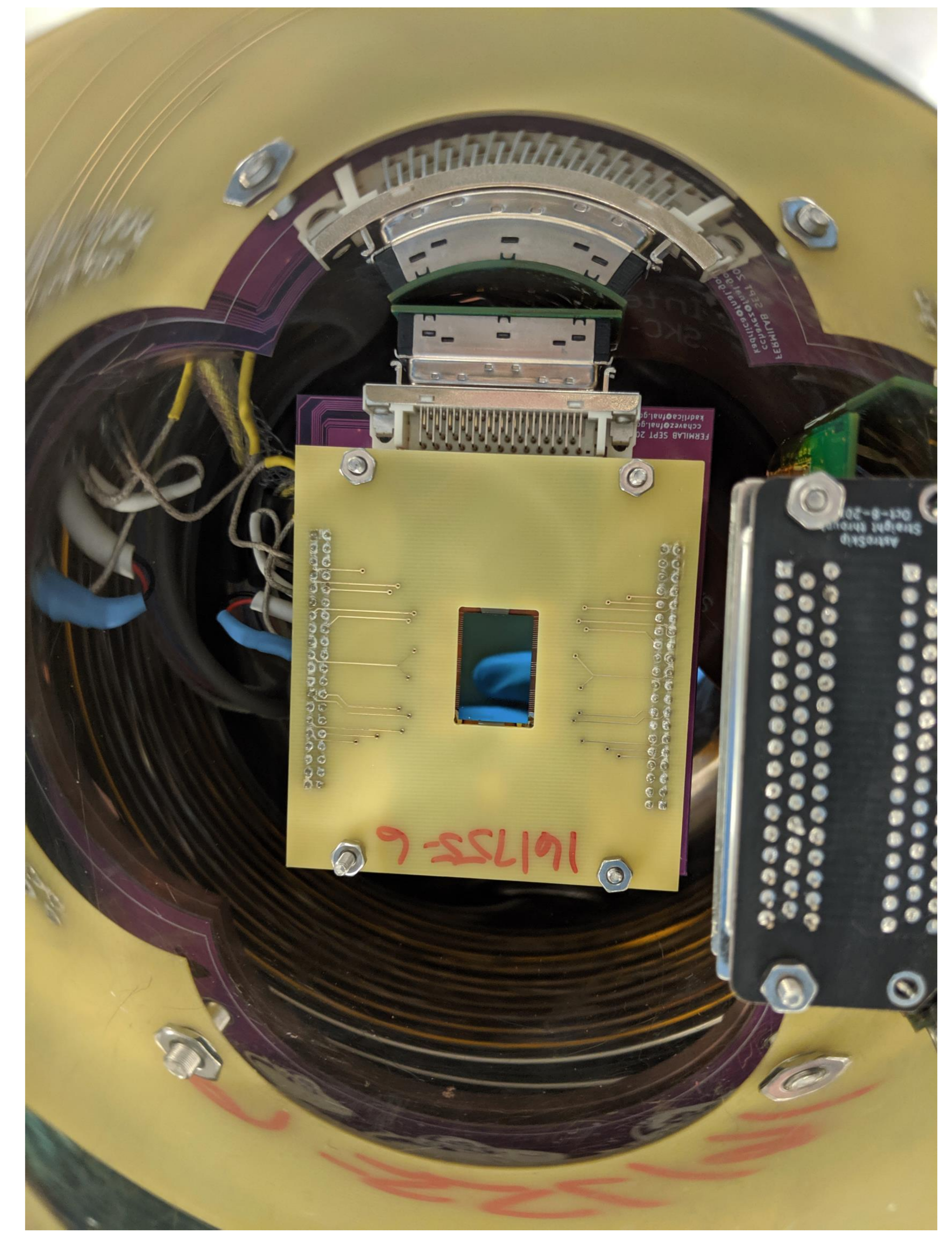

Astro Skipper testing station at SiDet Facility

The CCD is mounted in a thermally-controlled vacuum dewar that is cooled to operating temperature of 140K. A standard set of optical equipment allows for illumination of the CCD surface in the desired wavelength.

My work included the 3-D design and printing of a unique collimator attachment for the light path. This component ensures a 'light-tight' connection to the vacuum dewar.

Additionally, each device can be controlled through serial-to-ethernet gateways that I configured to be controlled remotely.

[1] Ryden, Barbara. *Introduction to Cosmology*. Pearson, 2014.
2] Tiffenberg, Javier, et al. "Single-Electron and Single-Photon Sensitivity with a Silicon Skipper CCD." *Physical Review Letters*, vol. 119, no. 13, 2017, doi:10.1103/physrevlett.119.131802.



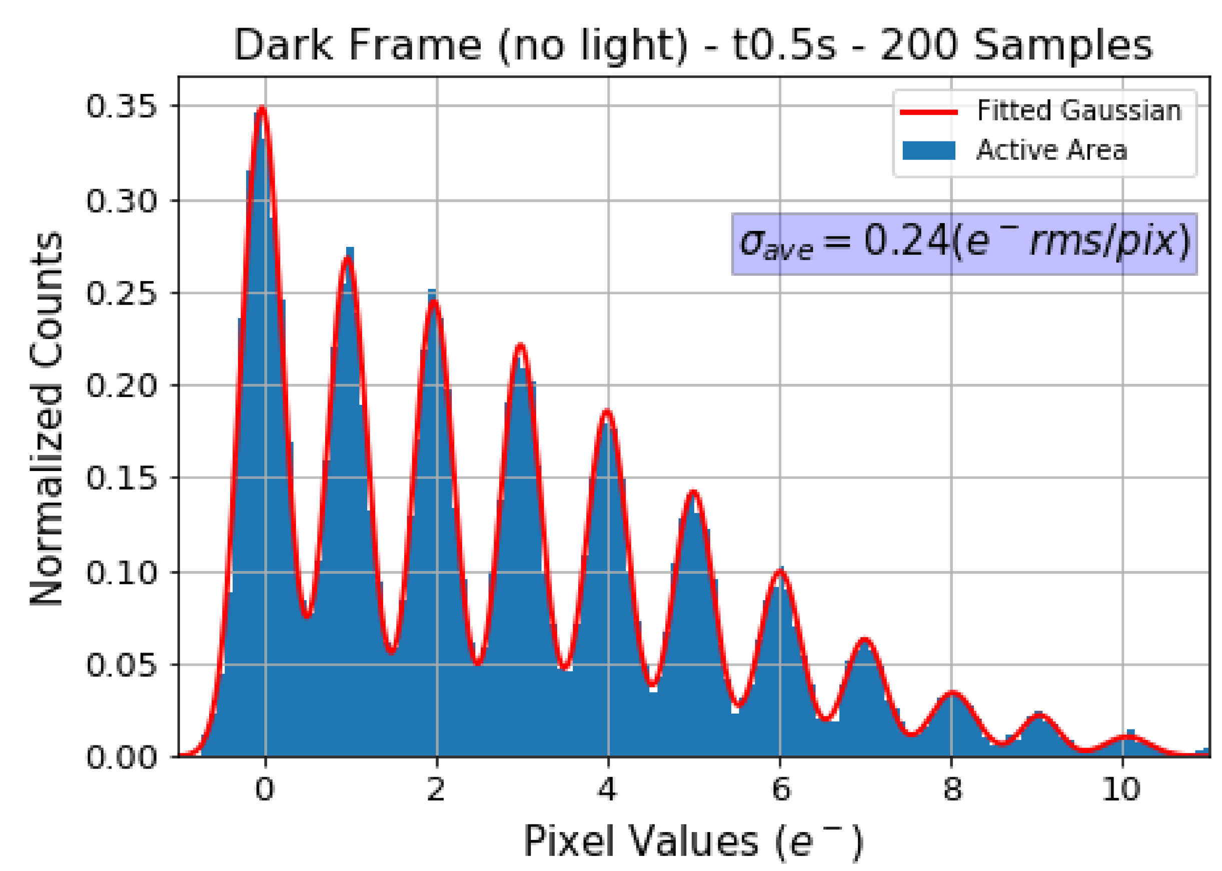
Backside-illuminated CCD mounted in vacuum dewar

## CCD Characterization

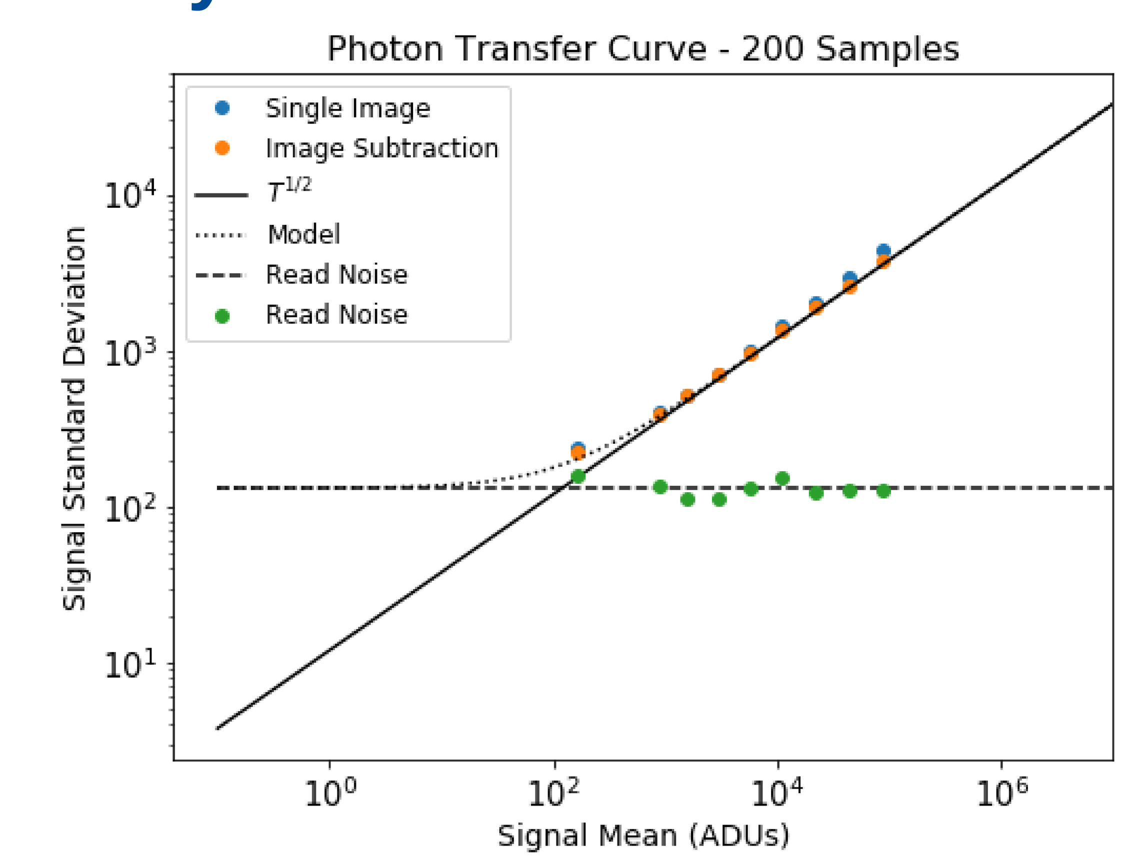
CCDs can be thought of as having three noise regimes: read noise, shot noise, and fixed pattern noise. A plot of the log of the standard deviation of the signal vs the log of the signal itself is called the Photon Transfer Curve. Read noise (or any noise independent of signal level) sets a noise floor for the device. Upon illumination, the noise becomes dominated by the shot noise of the signal. Shot noise is associated with the random arrival of photons on the CCD as governed by Poisson statistics. Finally, for large signal values, the noise is associated with fixed-pattern or pixel nonuniformity that results from sensitivity differences among pixels. The onset of full well (or saturation) is observed at some illumination level within the fixed-pattern noise regime. At this point the charge spreads between pixels, smoothing and lowering the noise component. This action causes the noise value to suddenly decrease, making full well obvious.

The low readout noise achieved by Skipper CCDs, allows charge measurement at the accuracy of individual electrons simultaneously in pixels with single electrons and thousands of electrons.

## Data Analysis




Dark exposure w/ 200 samples showing single-electron resolution




Photon transfer curve displaying three regimes of readout noise: Read noise, Shot noise, Fixed-pattern noise

## Conclusion and Future Work

The next immediate steps for this project would include a measurement of the Quantum efficiency, in addition to performing targeted skipper readouts (Smart Skipping). In the long term, we would like to take advantage of the cosmological applications that Skipper CCDs make possible.

## Acknowledgements

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