Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Skipper CCDs for Cosmological Applications

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SIST/GEM Final Presentation

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NORTH CENTRAL COLLEGE NAPERVILLE, ILLINOIS Founded 1861

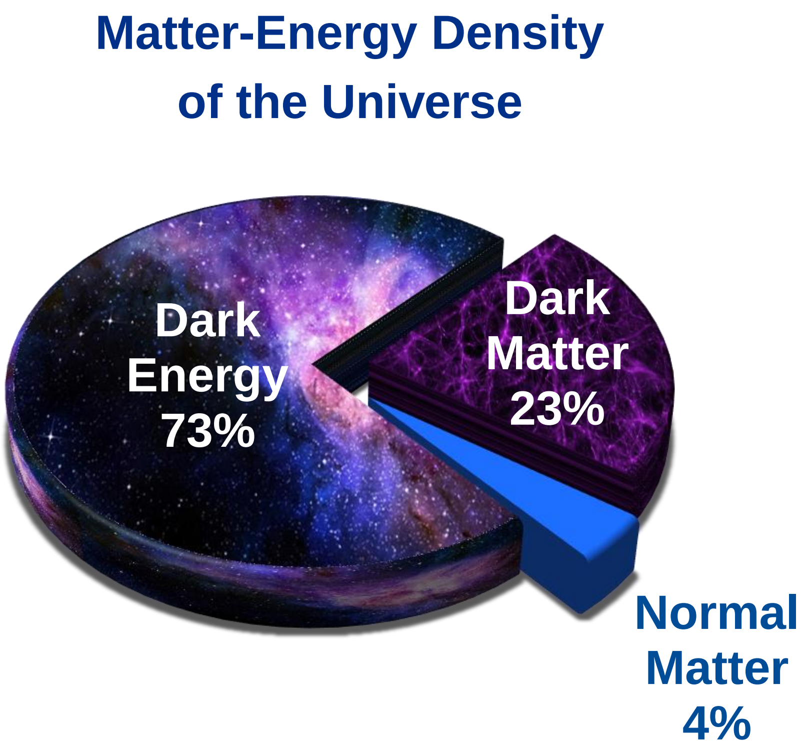
Outline

- Scientific Motivation
- Background
- My contributions to Astro Skipper

Motivation & Background

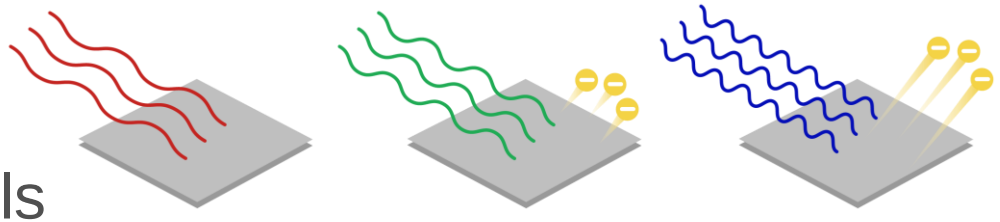
Science Motivation

- Dark Matter
  - Gravitational effect on visible matter
- Indirect detection methods
  - Orbital speeds of stars in spiral galaxies
  - Radial velocity of galaxies within large clusters
  - Gravitational lensing by dark matter
- Require powerful telescopes and imaging tools

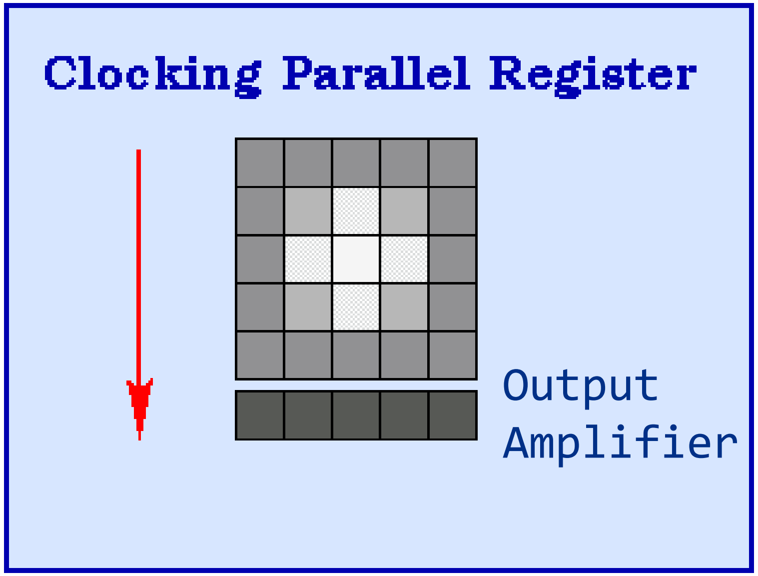


CCD Operation

- Charge-coupled device (CCD)
  - Light-sensitive integrated circuit
- Array of light sensitive pixels
  - Photoelectric effect
  - Metal-oxide-semiconductor (MOS) capacitor
  - Voltage manipulation on the capacitor gates controls charge movement
  - Vertical & Horizontal registers shift charge to output amplifier

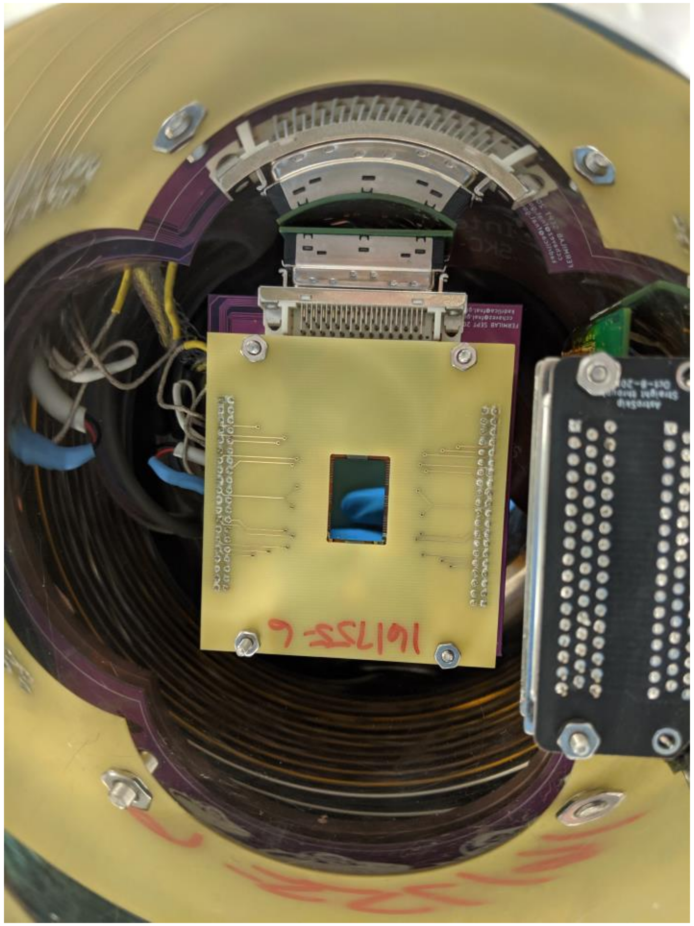


Photoelectric Effect



Skipper CCDs

- New generation of Skipper CCD design
  - Reduces low-frequency readout noise
  - Repeated measurement of the charge in each pixel
  - Allows charge measurement at the accuracy of individual electrons
- Sensitivity to light in the visible/near-infrared spectral range makes Skipper CCDs optimal for astronomical applications

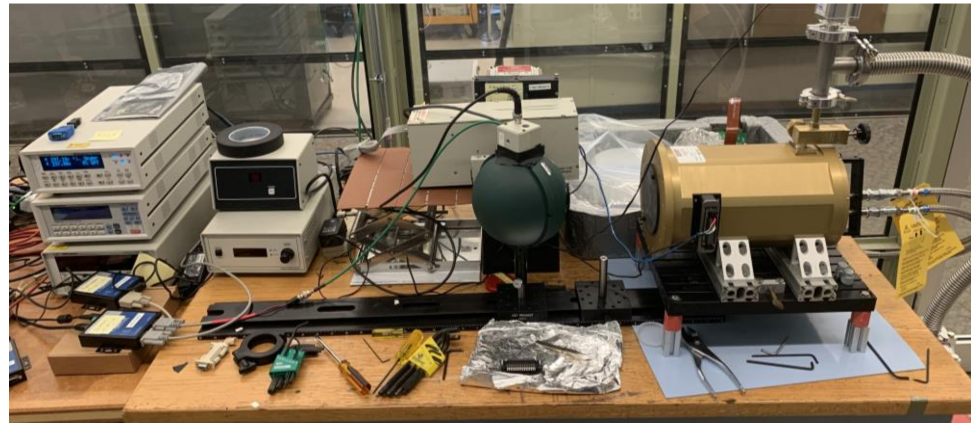


Silicon CCD package mounted in our vacuum dewar

My Work This Summer

Project Focus

- Characterize the response of a Skipper CCD with respect to optical light

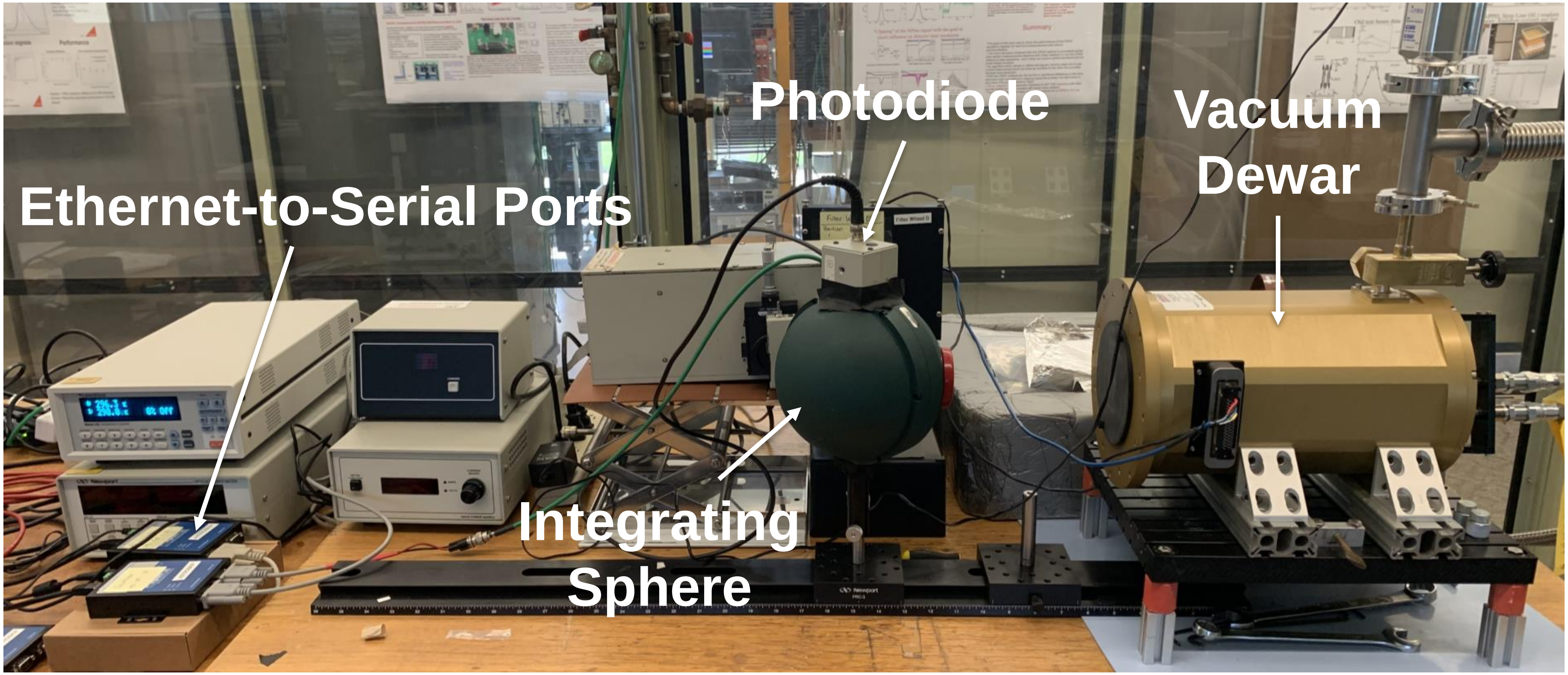


1. Experimental Setup

2. Data Analysis

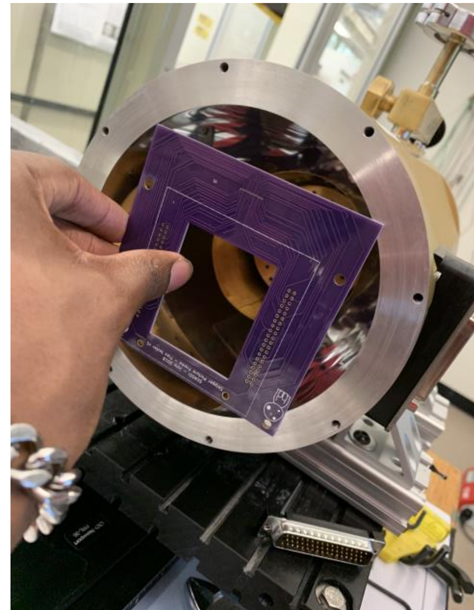
Experimental Setup

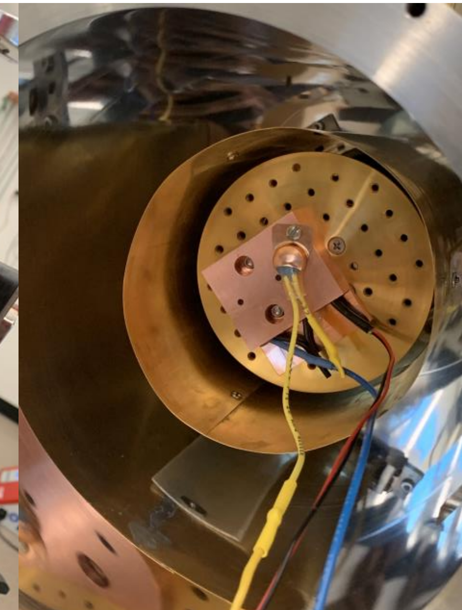
- Testing station is composed of standard optical equipment
- Dewar is specially designed to be mounted on a telescope
  - First time modern Skipper CCDs are used in this form of application

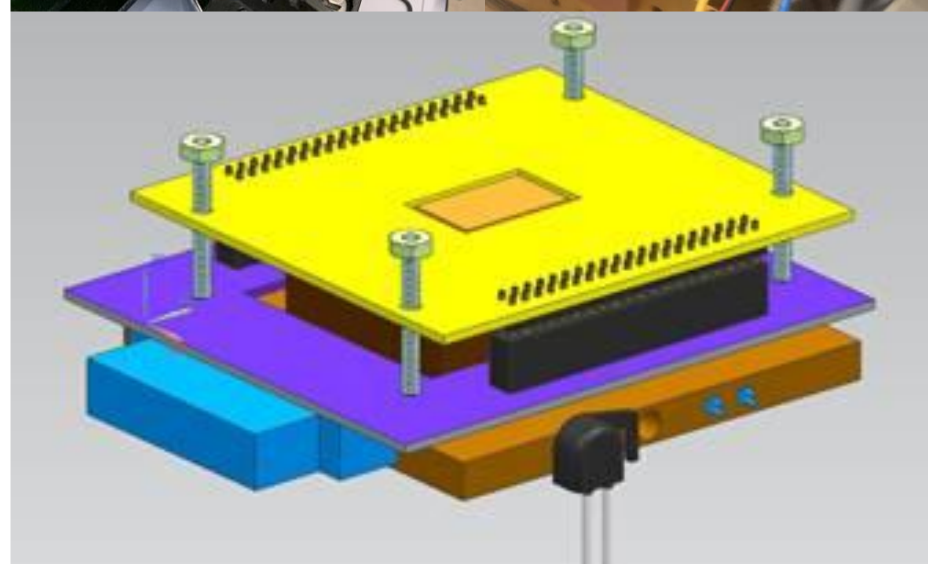


Mounting Package

- CCD picture frame (yellow)
- PCB board (purple)
  - Redesigned to fit inside astro dewar
- DB-50 output from PCB board (blue)
- Copper block (orange)
  - RTD
  - Heaters

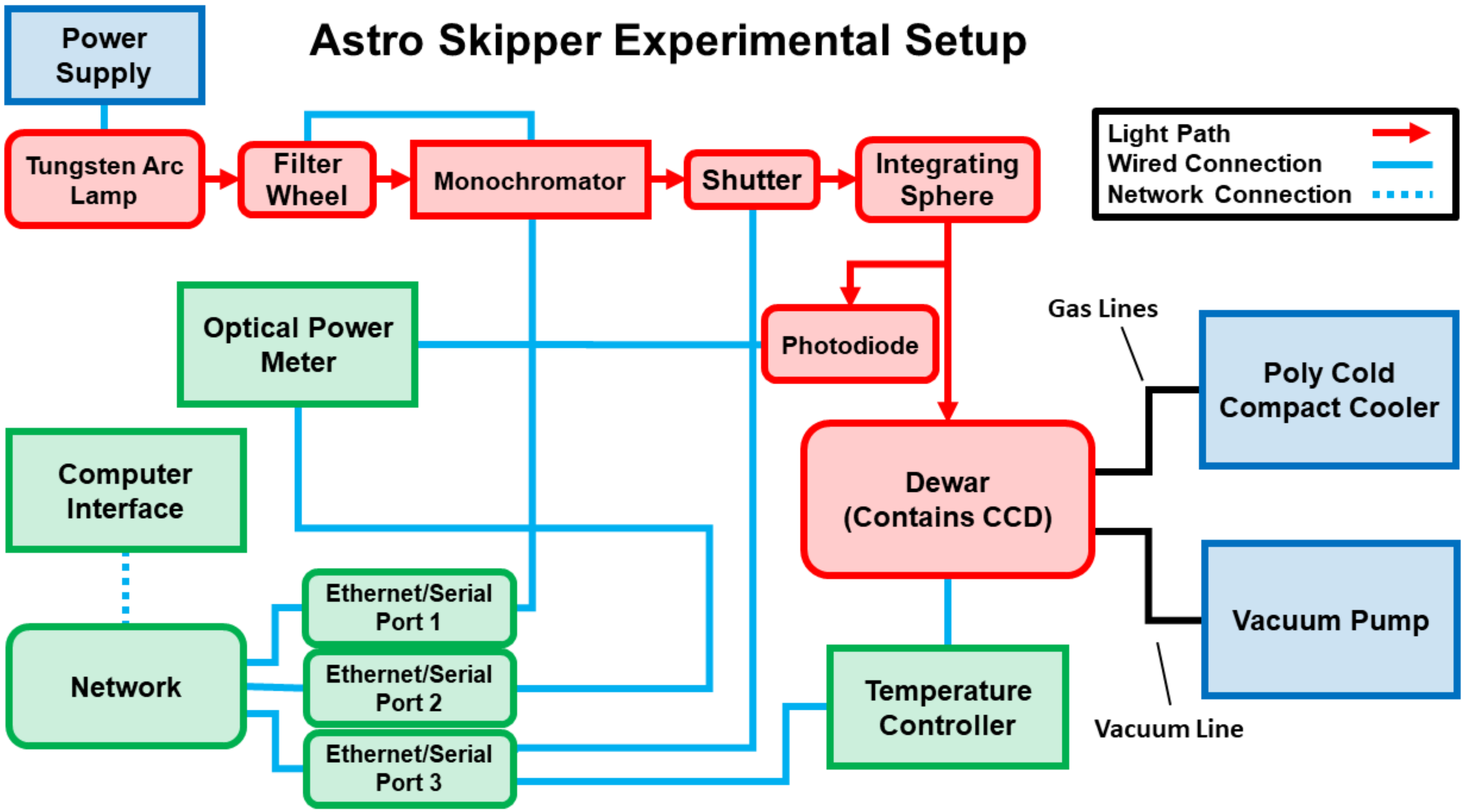






Station Overview

- Photon path is light-tight
- Operating temperature ~140 K
- Vacuum level ~1 x 10^{-5} torr



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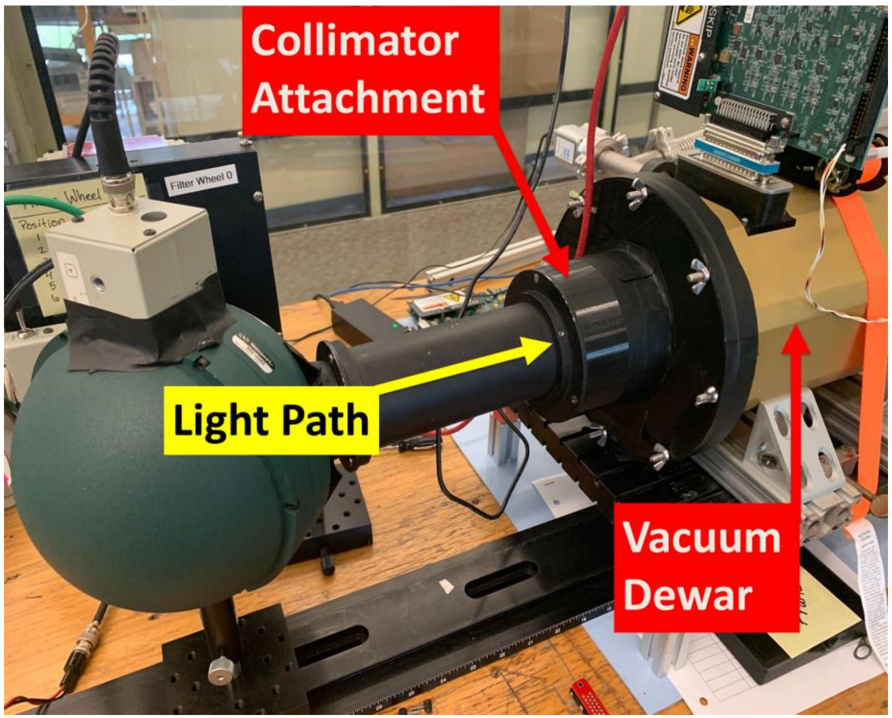
Experimental Setup cont.

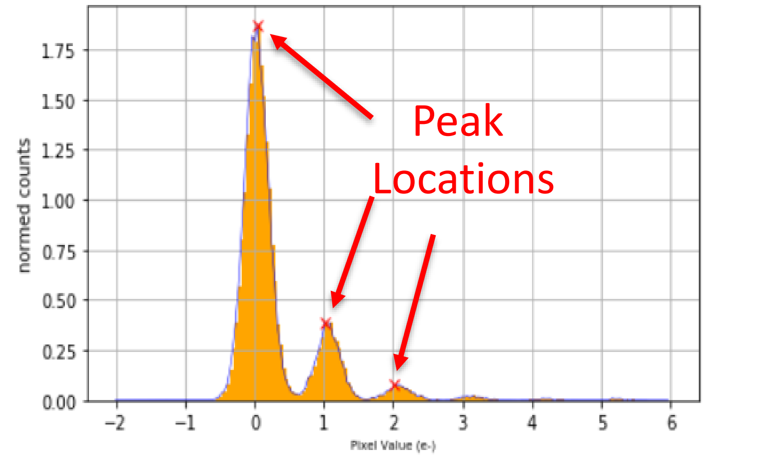
- Designed and 3-D printed a unique attachment for the light path
- Added additional light covers to minimize light leaks from ambient light



Data Analysis

Data Analysis: Gain Calculation

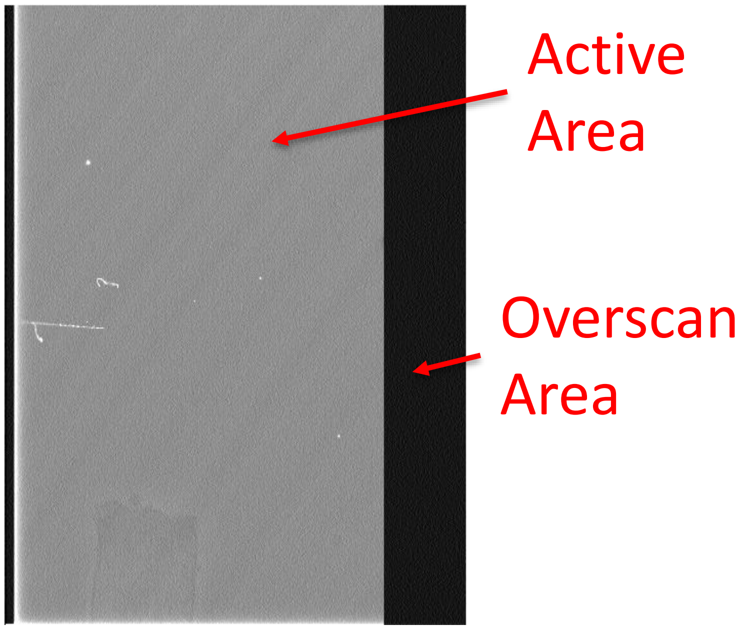
- Developed a python script that identifies electron peaks within the image data
  - Gain can be calculated from the distance between these peaks



- Gain calculation using Poisson statistics:

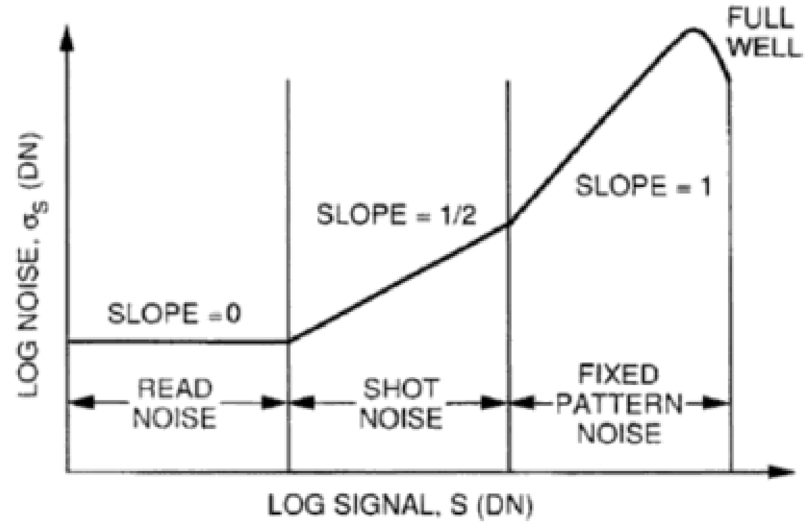
$$Gain = \frac{\mu_{Active} - \mu_{Overscan}}{Var_{Active} - Var_{Overscan}}$$

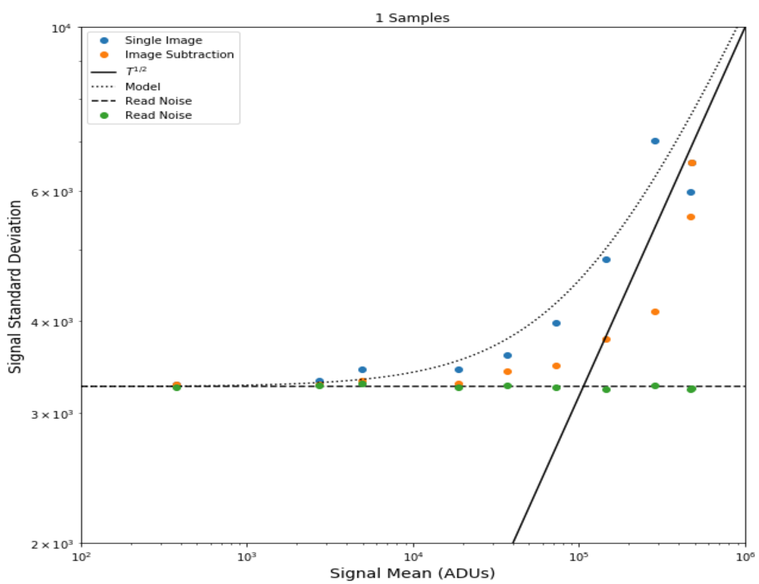
$$= 0.005\ e^{-}/ADU$$

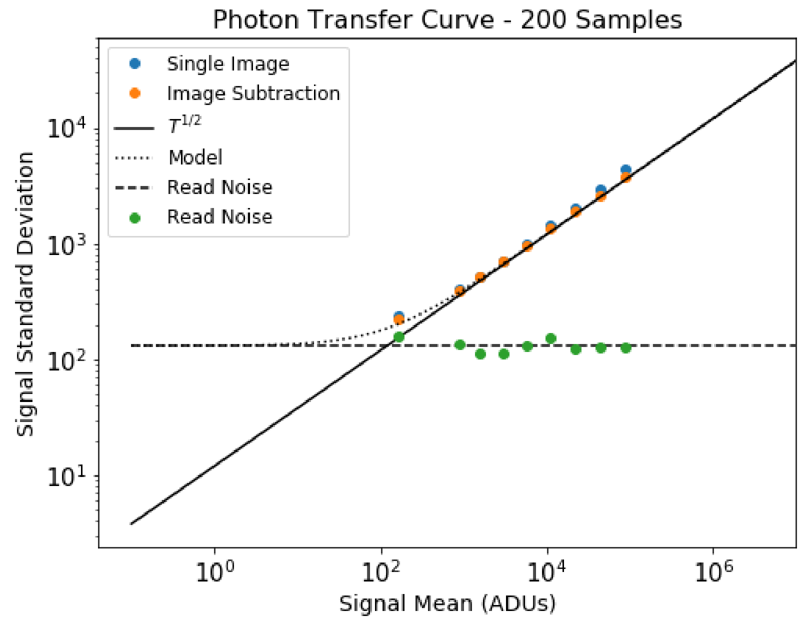


Data Analysis: Photon Transfer Curve

- CCDs can be thought of as having three noise regimes:
  - Read Noise
  - Shot Noise
  - Fixed Pattern Noise
- This detector follows the expected signal-to-noise behavior







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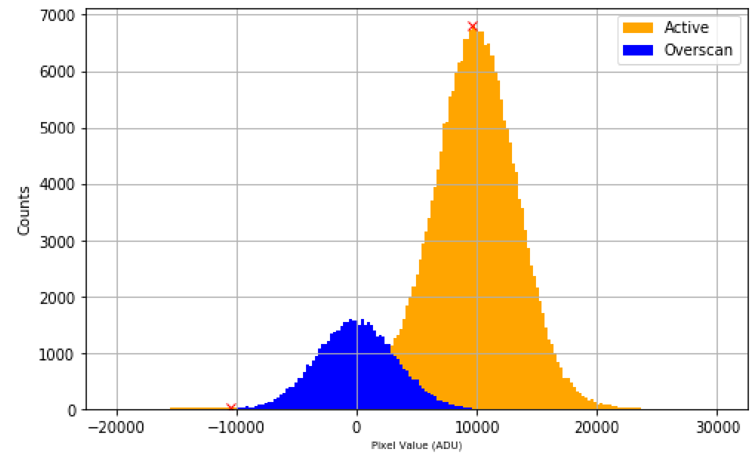
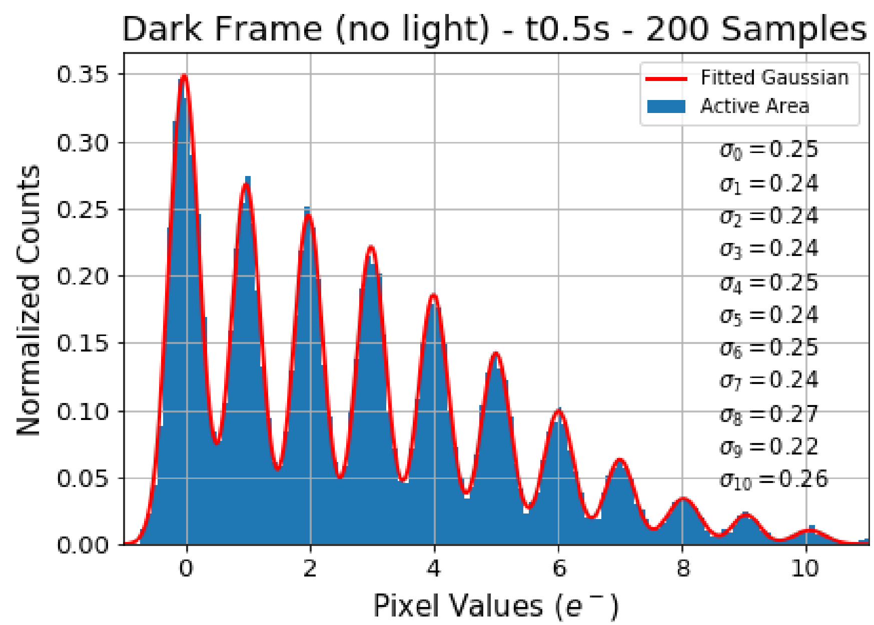
Data Analysis: Single Electron Resolution

- Initially struggled with resolving single peaks
- Low readout noise achieved by taking multiple samples
- Allows charge measurement at the accuracy of individual electrons in pixels
- Multi-gaussian fit shows that the average peak SD is ~ 0.24 e- rms/pix





Dark exposure w/ 200 samples showing single-electron resolution

Conclusion

Conclusion

- Next Immediate Steps
  - Perform absolute quantum efficiency measurements
  - Develop sequencer files to perform Smart Skipper readouts that allow for targeted readout of specific regions of the CCD
- Long Term Steps
  - Combine this new generation detector with a large telescope for future cosmological research applications

Acknowledgments

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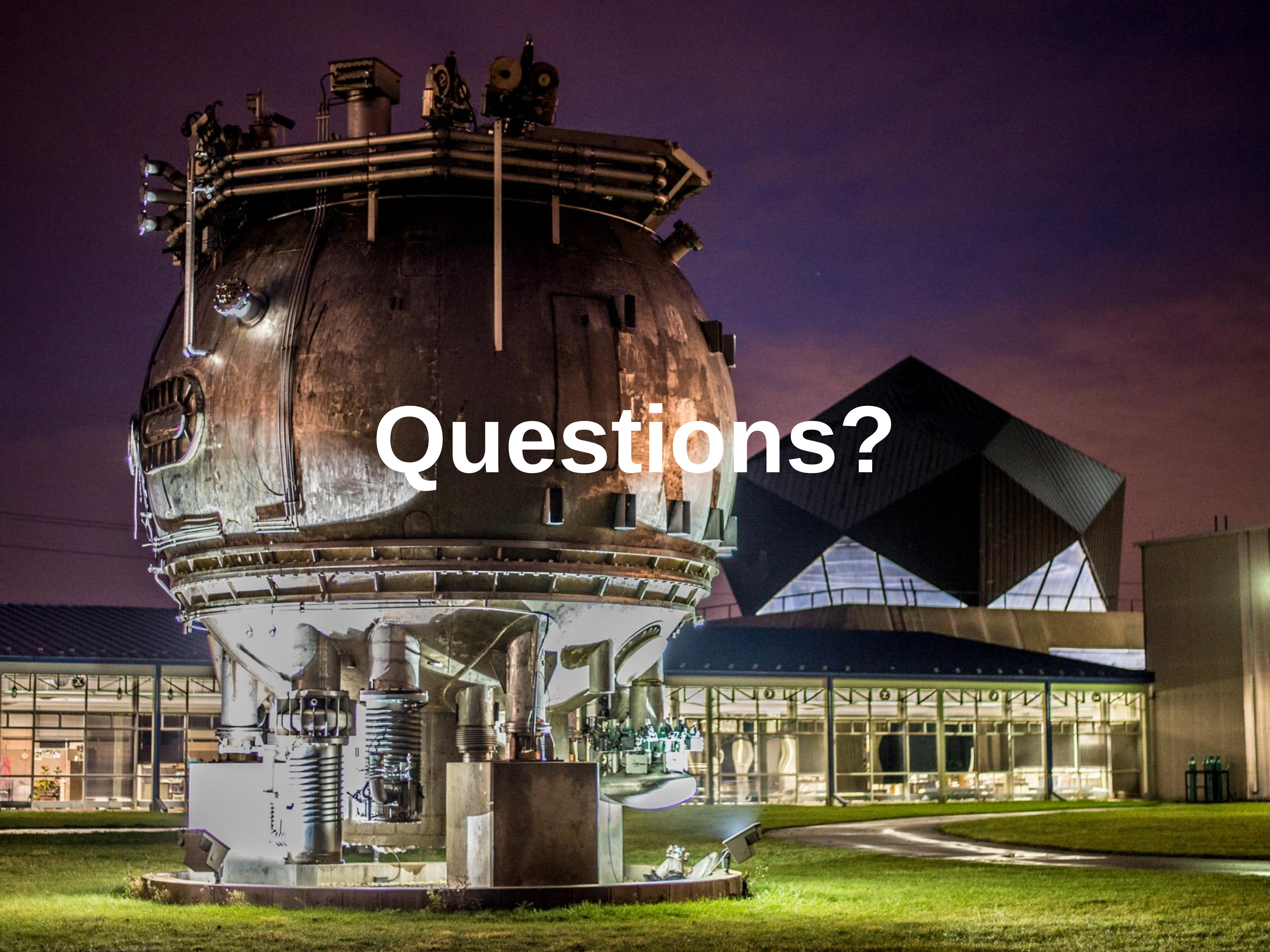
Questions?