# Characterization of Coudé CCD Spectrograph

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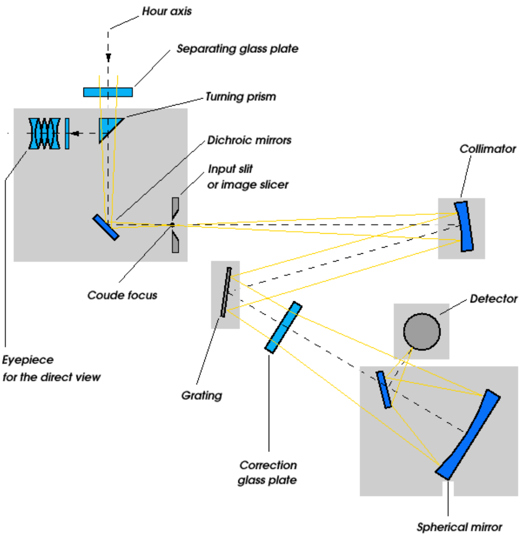
# Overview

# Instrument Overview

- **Location:** Perek 2-meter telescope, Ondřejov Observatory.
- **Setup:** Coudé Spectrograph (700 mm focal length).
- **Detector:** PyLoN eXcelon CCD (E2V 42-10 BX).
- **Cooling:** Liquid nitrogen ($-115^{\circ}$C).
- **Goal:** Characterize noise, uniformity, and gain for data reduction.

# Spectrograph Optical Layout



# Zero (Bias) Frame Analysis

- **Data:** 15 frames at shortest exposure.
- **Processing:**
  - Created master zero frame using median combination, run basic statistic.
  - Purpose: Analyze read noise, fixed-pattern.
- **Statistics:**
  - Master Mean: 600.15 ADU.
  - **Read Noise:** 3.62 ADU (calculated from stack).
  - Fixed Pattern: Negligible ($\sigma \approx 1.18$ ADU in master).

# Read Noise Distribution

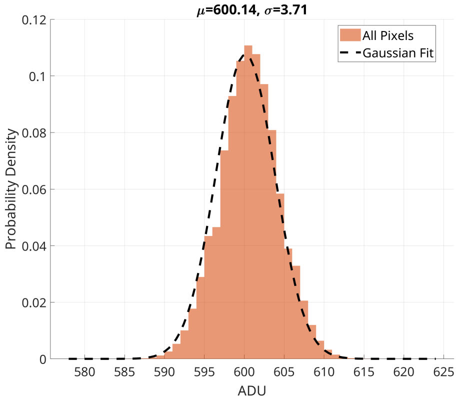



Figure: Histogram of bias frames follows expected Gaussian distribution.

# Dark Frame Analysis

- **Data:** 4 frames $\times$ 1 hour exposure.
- **Processing:**
  - Subtract master zero, run basic statistic.
  - Purpose: Analyze dark current noise, map hot pixels.
- **Hot Pixels:**
  - Exhibit high values over mean in all images.
  - Threshold: $> 5\sigma$ of master dark.
  - Count: 252 pixels (0.024% of sensor).
  - Distribution: Mostly isolated (177 pixels)
- **Dark Current:**
  - Value: $0.255 \times 10^{-3}\ \mathrm{e^{-}s^{-1}px^{-1}}$.

# Hot Pixel Map


Figure: Map of hot pixels (dilated).

# Hot Pixel Map

- Separation from read noise is impossible due to similar level
- CLT doesn't apply here - Can't model just as Gaussian.

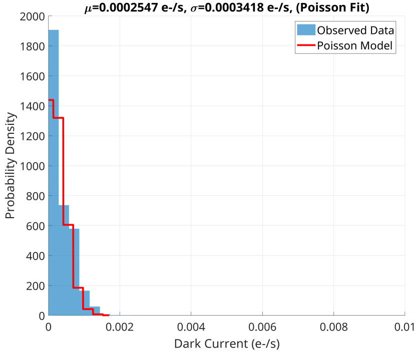



Figure: Dark Current Distribution

# Gain Calculation: Problem & Dataset

- **Dataset Description:**
  - Source: Ambient illumination in the telescope dome.
  - Exposures: Series of frames with varying exposure times (0.1s – 10s).
  - Count: 60+ frames covering whore dynamic range
- **Objective:** Calculate Gain ($g$) in $\mathrm{e^{-}ADU^{-1}}$ using:

$$\sigma^2 = \frac{\overline{x}}{g} + \frac{\sigma_{\mathrm{ro}}^2}{g^2}. \tag{1}$$

- **The Constraint:**
  - Spectrograph cannot be uniformly illuminated.
  - Less data for higher signal values.

# Failed Method 1: Inter-frame Analysis

- **Method:** Variance between frames of identical exposures.
- **Result:** Failed due to lack of high-signal data (¡6000 ADU), weird effects.

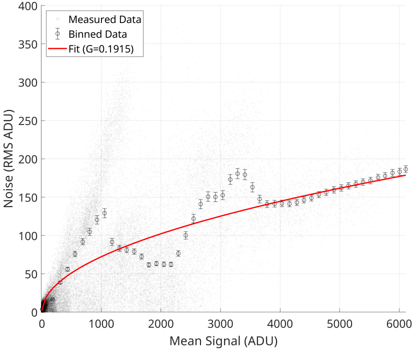



Figure: PTC showing non-linear trends at low ADU.

# Failed Method 2: Spatial Analysis

- **Method:** Calculating variance within small sliding windows (spatial statistics).
- **Result:** Variance changed drastically with bin size due to fiber profile (non-uniform illumination).

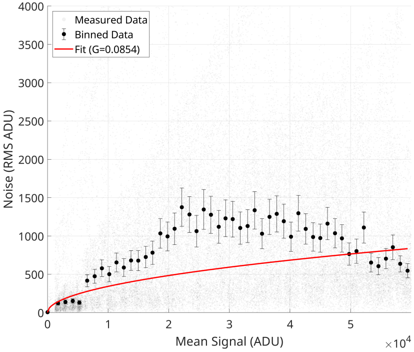



Figure: Spatial Photon Transfer Curve displaying incoherent variance vs signal.

# Successful Method?: Residual Analysis

- **Concept:** Compare data against a "noise-free" model.
- **Workflow:**
  1. **Model:** Create mean normalized model from all flats.
  2. **Scaling:** Scale model to match flux of each frame.
  3. **Residuals:** Calculate $\sigma^2 = Data - Model$.
  4. **Rejection:** Median Absolute Deviation (MAD) to remove outliers.
  5. **Function fitting:** Fit in mean vs sigma dependence to estimate gain.

# Residual Method: 10s Model

- **Approach:** Constructing the model using pictures of a single exposure

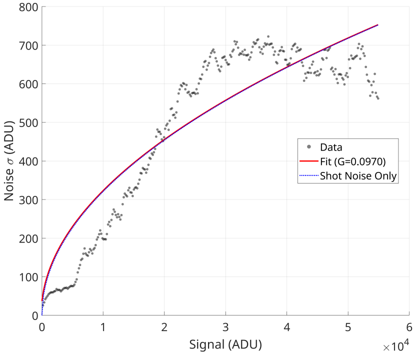



Figure: Photon Transfer Curve – Residual Analysis, 10 s Exposure Model

# Residual Method: 10s Model

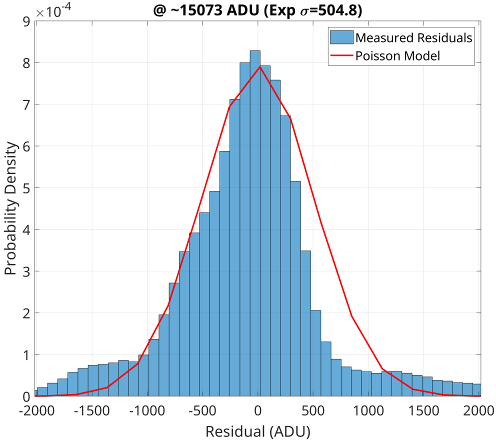



Figure: Histogram of residuals using 10s model

# Residual Method: Global Model

- **Approach:** Constructing the model using **all** flat frames.
- Gain $g = 0.6114 \pm 0.0045\ \mathrm{e^{-}ADU^{-1}}$

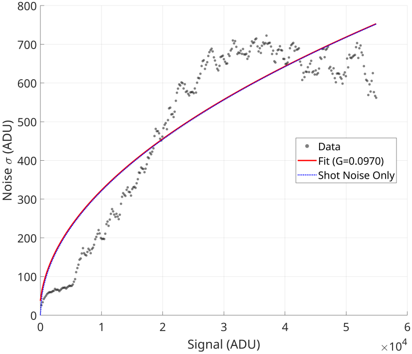



Figure: Photon Transfer Curve – Residual Analysis

# ThAr & Conclusion

- **ThAr Verification:**
  - Compared lamp spectra against atomic atlases.
  - Verified grating resolution matches documentation.
- **Final Characterization:**
  - **Read Noise:** 3.62 ADU (Low).
  - **Dark Current:** Negligible for standard ops.
  - **Gain:** $\approx 0.61\ \mathrm{e}^{-}\mathrm{ADU}^{-1}$.
- **Verdict:** System is exhibits low noise, behaves uniformly, gain analysis is trouble due to nature of the dataset.