

Characterization of Coudé CCD Spectrograph

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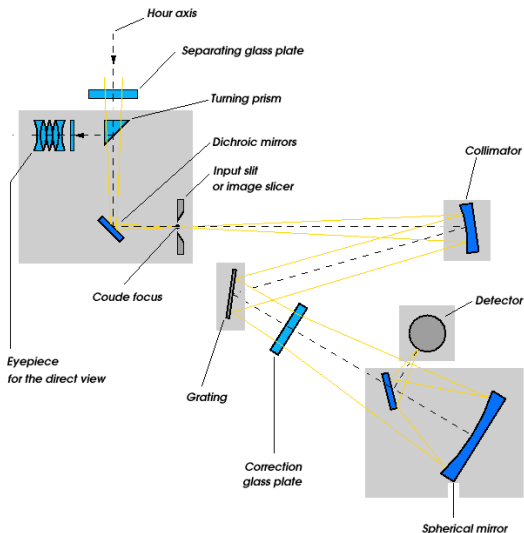
Overview

- 1 Introduction
- 2 Zero Frames
- 3 Dark Frames
- 4 Flat Fields
- 5 Conclusion

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°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 Bias using Median combination, run basic statistic.
 - Purpose: Analyze read noise and remove fixed-pattern noise.
- **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

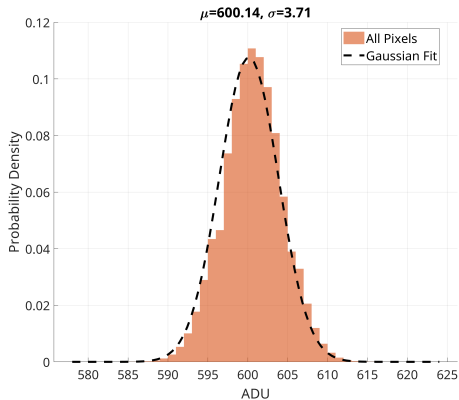


Figure: Histogram of bias frames follows expected Gaussian distribution.

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: $0.255 \times 10^{-3} \text{ e}^{-}\text{s}^{-1}\text{px}^{-1}$.

Hot Pixel Map



Figure: Map of hot pixels (dilated).

Hot Pixel Map

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

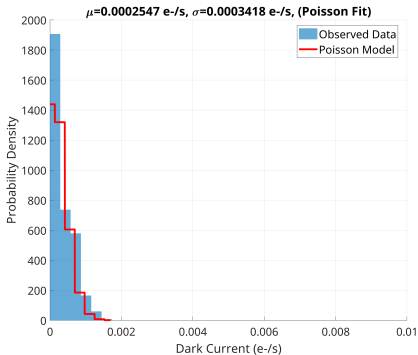


Figure: Dark Current Distribution

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 whole dynamic range

■ Objective: Calculate Gain (g) in e^-ADU^{-1} using:

$$\sigma^2 = \frac{\bar{x}}{g} + \frac{\sigma_{ro}^2}{g^2}. \quad (1)$$

■ 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.

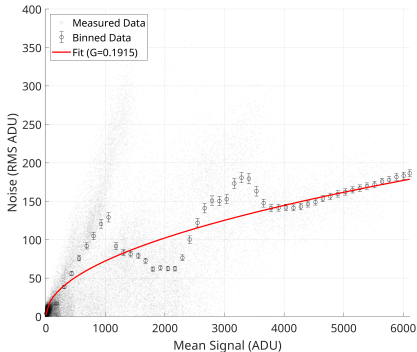


Figure: PTC showing non-linear trends at low ADU.

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).

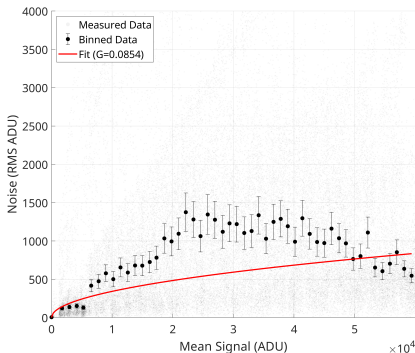


Figure: Spatial Photon Transfer Curve displaying incoherent variance vs signal.

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

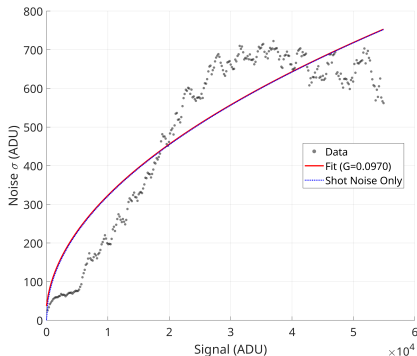


Figure: Photon Transfer Curve – Residual Analysis, 10 s Exposure Model

Residual Method: 10s Model

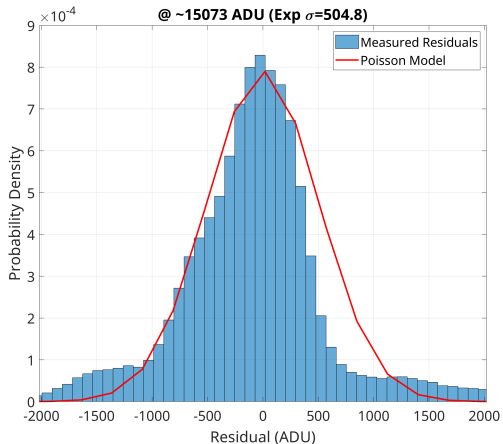


Figure: Histogram of residuals using 10s model

Residual Method: Global Model

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

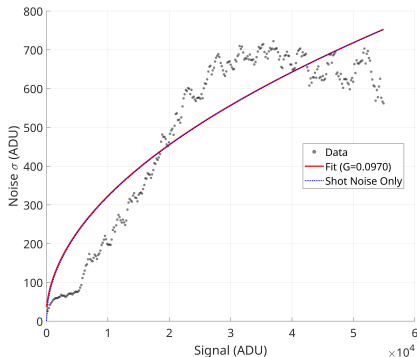


Figure: Photon Transfer Curve – Residual Analysis

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:** $\approx 0.61 \text{ e}^- \text{ADU}^{-1}$.

- **Verdict:** System exhibits low noise, behaves uniformly, gain analysis is trouble due to nature of the dataset.