Characterization of Coudé CCD Spectrograph

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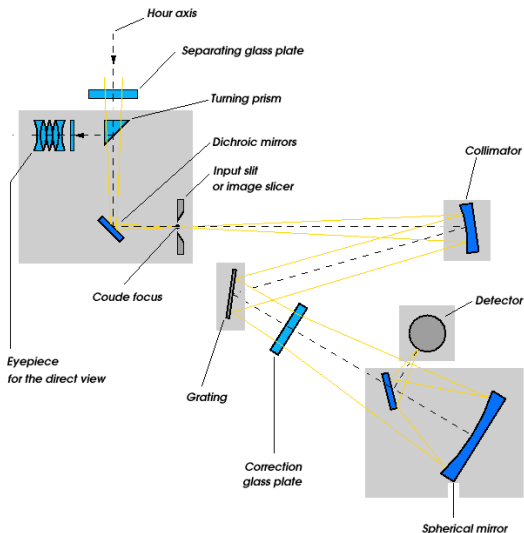
Overview

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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 zero frame using median combination, run basic statistic.
- **Objective:** 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).
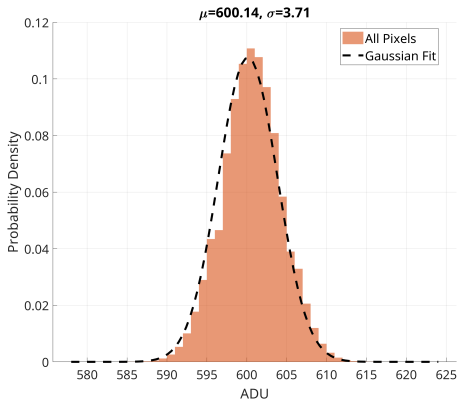
Read Noise Distribution

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.
- **Objective:** Analyze dark current noise, map hot pixels.
- **Dark Current:**
    - Value: 0.255×10^{-3} $\mathrm{e^-s^{-1}px^{-1}}$.
    - Noise at 1 hour comparable to read noise
- **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)

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Hot Pixel Map

Figure: Map of hot pixels (dilated).

Dark Current Distribution

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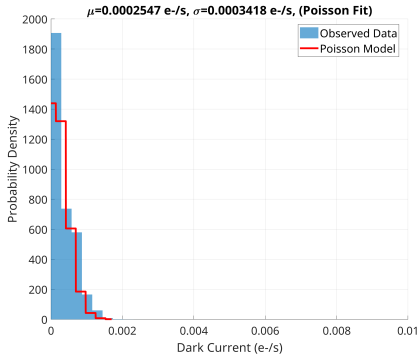- CLT doesn't apply here - Can't model just as Gaussian.

Figure: Dark Current Distribution

Gain Calculation: Problem & Dataset

- **Dataset:**
    - Source: Ambient illumination in the telescope dome.
    - Exposures: Series of frames with varying exposure times.
    - Count: $60+$ frames covering whore dynamic range

- **Processing:** Shot noise analysis – calculating gain using:

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

- **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.
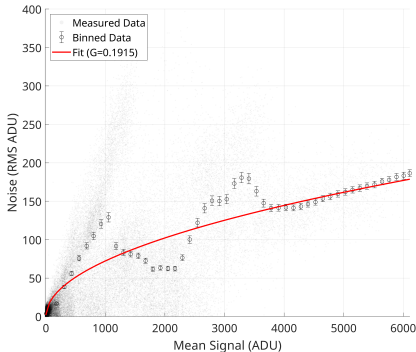- **Result:** Failed due to lack of high-signal data ($< 6000 \mathrm{ADU}$).

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

Failed Method 2: Spatial Analysis

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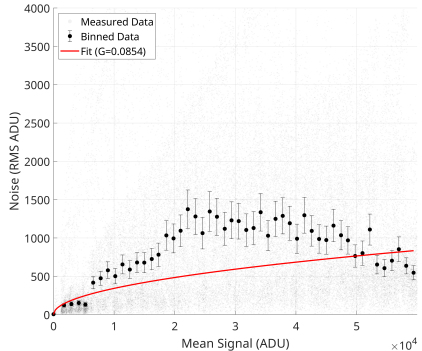- **Result:** Variance changed drastically with bin size due to fiber profile (non-uniform illumination).

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

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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. **Stratified Sampling**: Sample randomly within level bins.
    5. **Rejection:** Median Absolute Deviation (MAD) to remove outliers.
    6. **Function fitting:** Fit in mean vs sigma dependence to estimate gain.

Residual Method: 10s Model

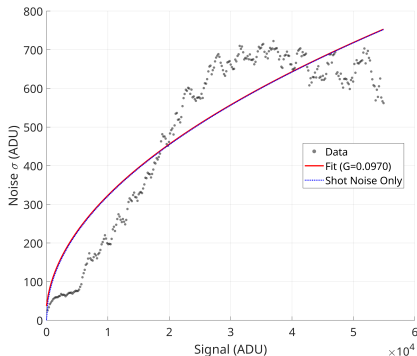- **Approach:** Constructing the model using pictures of a single exposure

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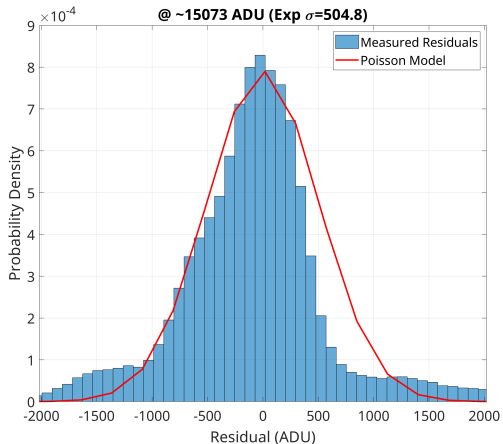
Residual Method: 10s Model

Figure: Histogram of residuals using 10s model

Residual Method: Global Model

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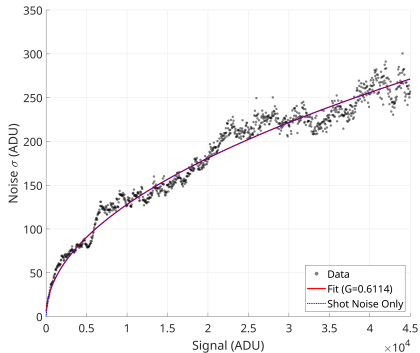- Gain $g = 0.6114 \pm 0.0045 \ \mathrm{e^- \, ADU^{-1}}$

Figure: Photon Transfer Curve – Residual Analysis

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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:** $\approx 0.61 \ \mathrm{e^- ADU^{-1}}$.
- **Verdict:** System is exhibits low noise, behaves uniformly, gain analysis is trouble due to nature of the dataset.