PHYC30170: Advanced Laboratories

CCD Instruments
and
Calibration

October 27, 2020

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Abstract

A basic review of the calibration of a CCD. Using a lab environment to create calibration frames that could be used to account for noise when using the CCD to take science images. The calibration procedure saw the creation of master dark, flat and bias frames along with the calculation of gain and readout noise for the Atik 314L + CCD sensor. The readout noise was found to be $0.274 \pm 4.98 \times 10^{-3}$ and $4.345 \pm 9.48 \times 10^{-3}$ respectively. These values were in compliance with the values garnered by the manufacturer.

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1 Introduction

The purpose of forming this procedure in the lab is to calibrate a CCD instrument so that it can accurately take measurements of photon-flux when taking science images. This is completed through data reduction of noise factors such as bias, dark current and intrinsic imperfections in the CCD instrument. This is completed through data reduction of noise factors such as bias, dark current and intrinsic imperfections in the CCD instrument.

Once these noise factors are collected, they are used in conjunction to perform a data reduction to all science images gathered by the CCD to produce results that are as true as possible.

2 Theory

Charged-couple devices (CCD) are a beneficial form of performing astronomical observations. Their sensitivity in nature, coupled with the format in which the frames are taken allows for different calibration frames to remove incorrect readings from a frame and allow for corrections. This allows for the light intensity readings from the CCD chip to be reduced to provide a more accurate depiction of the desired subject.

This is due to the CCD's high quantum efficiency with most CCD's commonly reaching 80% quantum efficiency. The CCD is sensitive to a vast array of wavelengths across the electromagnetic spectrum; the quantum efficiency as a function of wavelength for various sensors can be seen in Fig. (1).

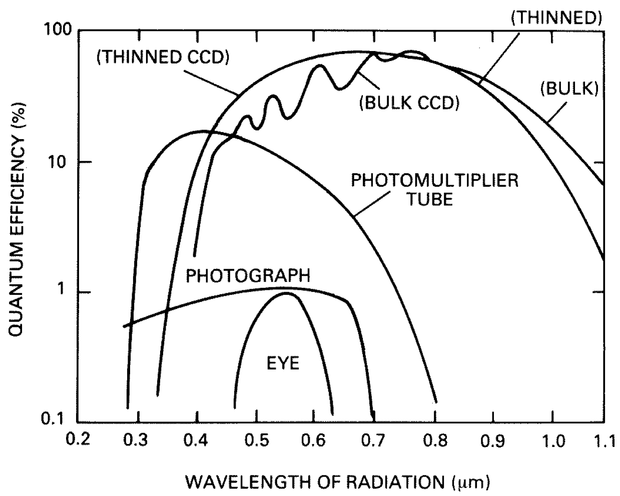

Figure 1 *Quantum efficiency as a function of wavelength for different sensors (6)*

Fig. (1) illustrates the range of wavelengths were CCD's have a high quantum efficiency and useful for observations of objects within that range of wavelengths.

CCD's use a chip which is made up of a rectangular array of photo-sensitive regions called photosites. These photosites measure the photon flux, which falls upon the array. The photon flux isn't directly measurable. Instead, the intensity is obtained by counting the amount of photon counts incident on a censor over a specific time interval. Upon incidence of a photon free electrons within each photosite accumulate in a proportional relationship. (3) The electrons are held in place by an electric charge put in place by the electronics controlling the CCD this forms a 'gate' type function, holding the electrons until the desired exposure is complete. Once the exposure is complete the electrons are counted using a digital to analog converted where these counts are represented as pixel intensities.

2.1 Types of noise in a CCD

Because the CCD takes measurements based on counting incident photon flux raw images thus possess 'unwanted' signal readings which need to be accounted for. The CCD has intrinsic systematic effects that are added to each image regardless of exposure time. This readout noise is caused by interference with the computer within the lab and other electronic equipment presents. To account for this, a 'bias' frames are taken, which will remove the constant noise applied to the CCD by subtracting the noise counts from raw images. The main factor causing bias noise is the constant voltage applied to the CCD.

Another form of noise present in raw frames obtained from CCD is dark current. This is the gradual build-up of electrons in proportion to the exposure time used in each frame. It is important to note that this noise isn't caused by photons falling on the sensor. It's caused by the pile-up of thermal electrons. There are three factors that contribute to dark current thermal generation on surface states, within bulk silicone and in the depletion region. Thus to mitigate the effect of thermal electrons causing noise is to reduce the temperature of the CCD.

The other significant form in which CCD's can be calibrated is using flat frames. This allows for small imperfections within the construction of a telescope such as dust and misalignment to be corrected. This can cause inconsistent gradients when frames are taken from the CCD. CCD's are also not uniformly illuminated from the mechanisms in which optics work in telescopes. Because of this uneven distribution of light towards the edge of the CCD. Any objects will appear systematically less intense than at the centre. By creating a master flat with the use of uniform light, the dis-proportionality in intensity can be accounted for. (2)

Throughout the duration of this experiment, various steps will be examined that can be used to calibrate a CCD instrument in the lab to eliminate these inconsistencies and 'unwanted' readings. Data reduction will be applied to science images by subtracting the bias and dividing by a normalized flat field image. The presence of using a master bias will allow the reduction of all present background noise from science images.

3 Apparatus

Throughout the duration of the experiment a CCD was used in conjunction with a light proof box. The model of CCD used in the labe was a 1.4MPixel Atik 314 +. Within the lightproof box there was a lamp integrated in order to create uniform photon-flux across the entire sensor for creating flat frames. This was controlled with a dial and switch mounted on the box with a multi-meter placed within the circuit to monitor the electrical output to the lamp. The CCD was controlled using Artemis Capture software suite created by Atik Cameras which was ran on a Windows 10 desktop environment. All data manipulation and image processing was completed using Python 3.8 and an array of packages[1].

[1]All code used for data manipulation and processing can be found in the appendices of the report.

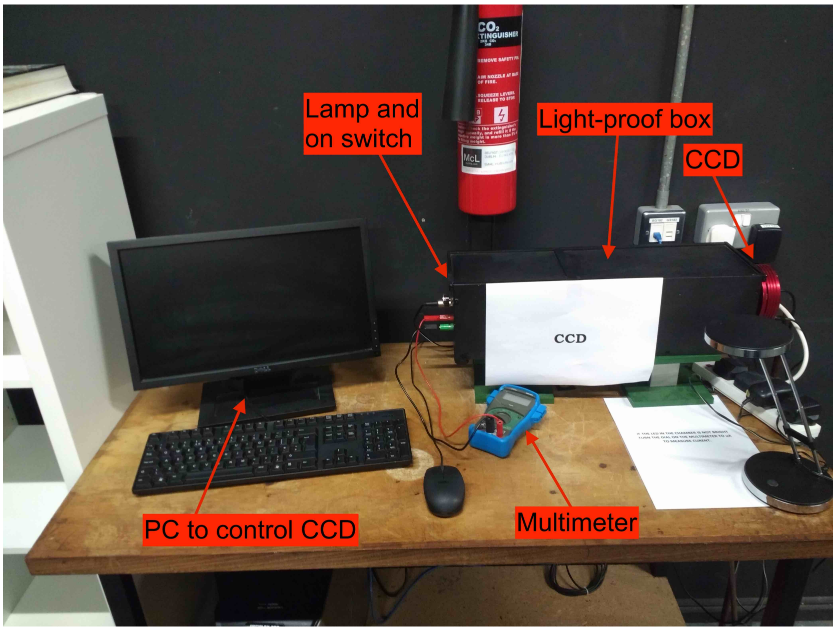

Figure 2 *Configured CCD Apparatus used in the lab (4)*

4 Experimental Methodology

4.1 Dark Current Frames

The dark count is a function of the CCD characteristics and the temperature of the CCD. The dark count present will approximately double with a rise of about 5°C increments. To take frames to determine the dark count, the CCD has to be isolated from light. Thus the frames are obtained in a dark room with all lights turned off with CCD placed in a lightproof box. Due to dark currents dependence on temperature, the CCD is also cooled to reduce the counts present.

Multiple frames were then taken for an array of exposures and temperatures. Starting at the coldest temperature allowed by the CCD then increasing in increments of 2°C until the ambient temperature of the darkroom was reached. Multiple frames were taken at these temperatures for exposures of 1s, 5s, 10s, 30s, 60s and 100s. Mean value of a 100 x 100 area in the centre of the frame was then calculated.

4.2 Bias Frames

Bias can be found when there is no presence of thermally excited and photo-electrons. This is completed by setting the exposure time to the smallest value the CCD was capable of, 0.001 seconds. This allowed for the electrons present due to voltage and other electrical interference to be isolated.

300 frames were taken with an exposure of 0.001. The mean counts from 100 x 100 area in the centre of the frame calculated. The average full frame image was created in order to make a 'master bias' frame.

4.3 Flat Field Frames

Due to imperfection in the CCD, each pixel (photo-site) will return a different count value even if the light source is uniform regardless of the presence of bias or dark counts. To find flat frames to account for the imperfection, the CCD is cooled to the coldest temperature to negate the effects of the dark count. A uniform light is targeted by the CCD in order to distribute equal photon flux on each pixel. In order to create flat field image the master bias must be subtracted. Due to the lowered temperature and the small length in exposure time the dark current is minimal. (6) (2)

5 Results

5.1 Dark Current Frames

When capturing dark frames, an array of frames were taken at multiple exposures to determine the temperature in which dark current became minimal. The counts from the frames were taken from a 100 x 100 region in the centre of the frame. The CCD captures frames at a resolution of 1391 x 1039. The centre region used during the duration of the calibration was [646-746], [470-570] where the first value in the range of pixels used in the x-axis and second value is the range of pixels used in the y-axis[2]. The relationship between counts and temperature is illustrated in Fig. (3). [3]

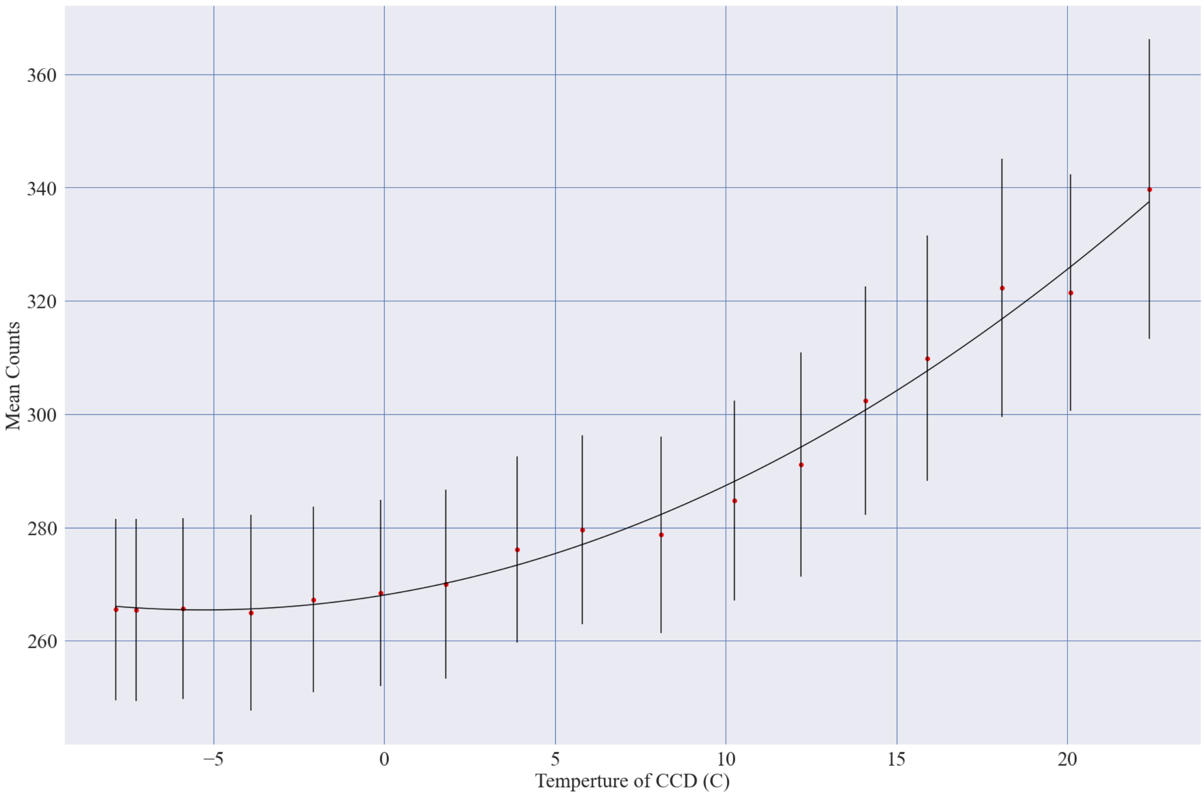

Figure 3 *Mean counts produce by dark current plotted against time.*

The change means count (ΔD) was seen to increase 100% when the temperature increased by 6°C when the differences in counts were compared between temperature increase.

[2]This is the closest approximation we can get to the centre of the screen as pixels are discrete.
[3]Uncertianties and 'goodness' of fit discussed in §I.1

From Fig. (3) it can be seen that operating the CCD at - 7.8°C negates the dark count substantially. This is the temperature used when creating the master dark.

Mean Counts	Standard Deviation (σ)	Temperture (°C)	Exposure (s)
265.468	16.053	-7.8	1
265.45	16.007	-7.35	5
265.397	16.073	-7.26	10
265.314	16.203	-7.733	30
265.496	16.227	-7.8	60
265.614	22.454	-7.867	100

Table 1 *Comparison of dark counts at various exposure times*

When creating a master dark multiple exposure times were considered as seen in table. (1). The change in counts only marginally increased for exponentially large exposures. Thus as smaller exposure of 5 seconds was used to obtain a larger sample size of 300 to create the master dark. The master dark in Fig. (4) was created from averaging 300 sigma clipped frames at a temperature average of -7.8°C and an exposure time of 5 seconds.

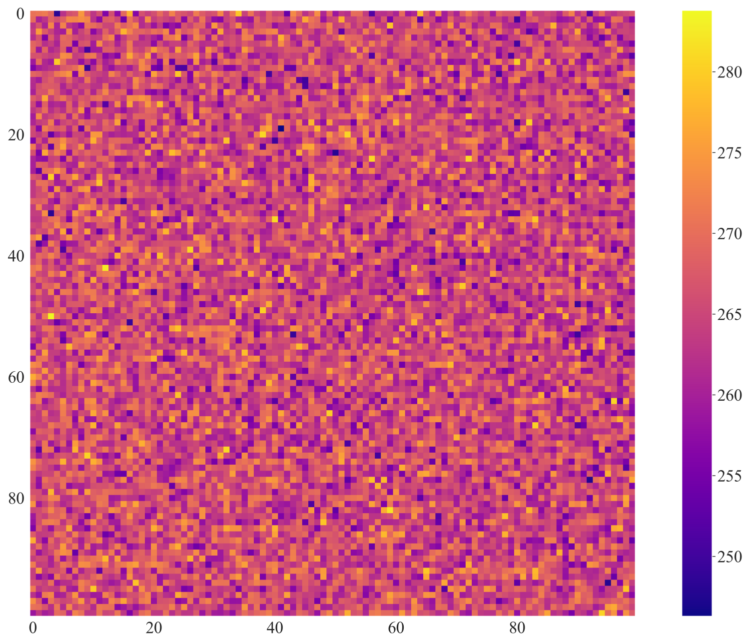

Figure 4 *Master dark obtained at -7.8°C and exposure of 5 seconds*

5.2 Bias Frames

The master bias was formed from averaging 300[4] frames at an exposure of 0.001 seconds. These conditions ensured the best isolation of electronic interference viable in the lab. The average frame was then sigma clipped to remove any extreme outliers[5].

The master bias can be seen in Fig. (5). This type of image formation can be expected from a bias as it represents random electronic interference caused my electrical presence on the CCD.

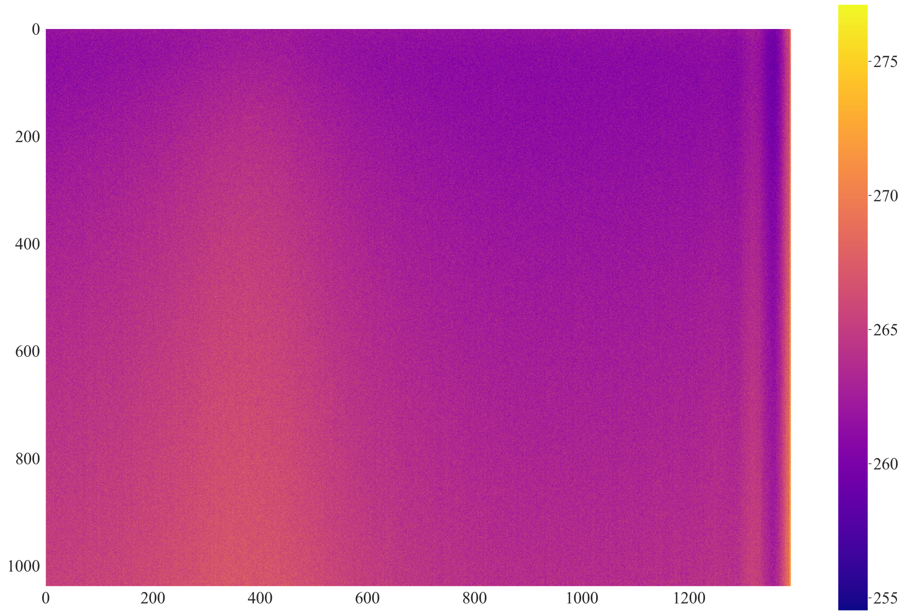

Figure 5 *Master bias obtained at -7.8°C and exposure of 0.001 seconds*

In Fig. (5) an interference pattern can be seen to the rightmost part of the master frame. This is highlighted in Fig. (6) the possible cause of this pattern could be the manufacturing of the CCD itself. As we see in Fig. (11), the dc input of the CCD runs to two connector offsets either side of the array of photo-sites. The reasoning for this being a manufacturing issue and not of further electrical interference is that this pattern was present in both apparatus present in the lab[6].

[4]Note on sample sizes in §I.1
[5]Notes on uncertainties and the use of sigma clipping can be found in §I.1
[6]In the lab both apparatus were set up parallel to each other on opposite sides of the dark room. Due to how similar the highlighted region appears on both apparatus this rules out electrical interference on a small scale.

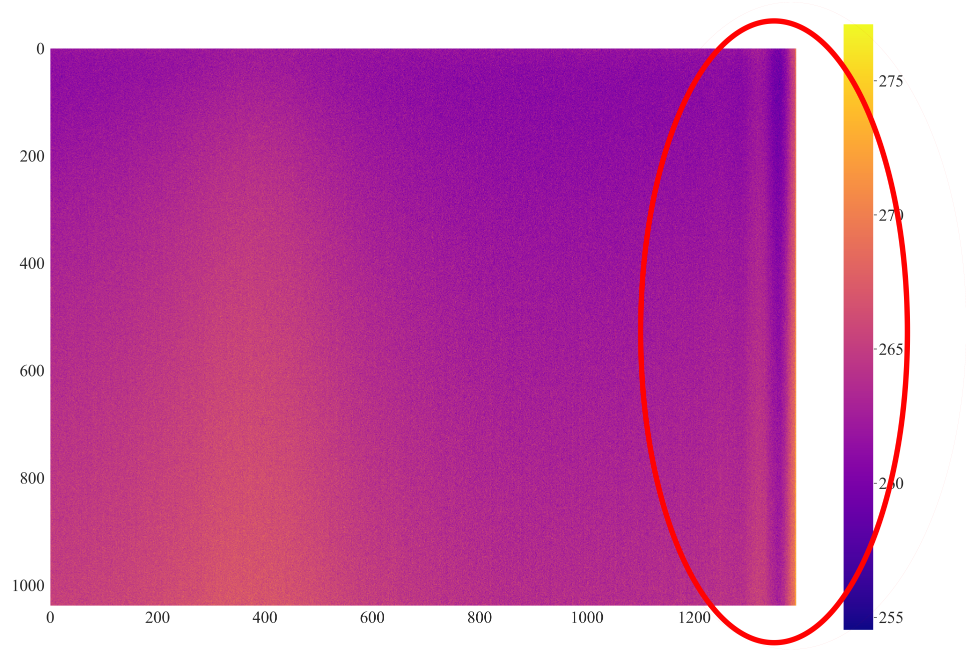

Figure 6 *Highlighted version of Fig. 5*

5.3 Flat Frames

The master flat frame found in Fig. (7) was obtained by averaging 100 sigma clipped flat frames which had a uniform light-powered at 5 mV[7]. The master flat had a mean count of 47613.485 ± 503.784 at a temperature of -8.75°C and exposure of 7 seconds.

The reason an exposure time of 7 seconds was used was to obtain a mean count of approximately less than 50,000. The CCD reaches a saturation point at 65535. By using flat frames of slightly less than 75% of the capacity of a photosite, it allows for enough deviation to find areas of imperfection and non-uniformity while also low enough that no count caps out when it reaches saturation point.

[7]Temperature and Voltage readings were both taken with an uncertainty of half the smallest increment that could be read. For the voltage reading this was 0.0005 and for temperature this was 0.05.

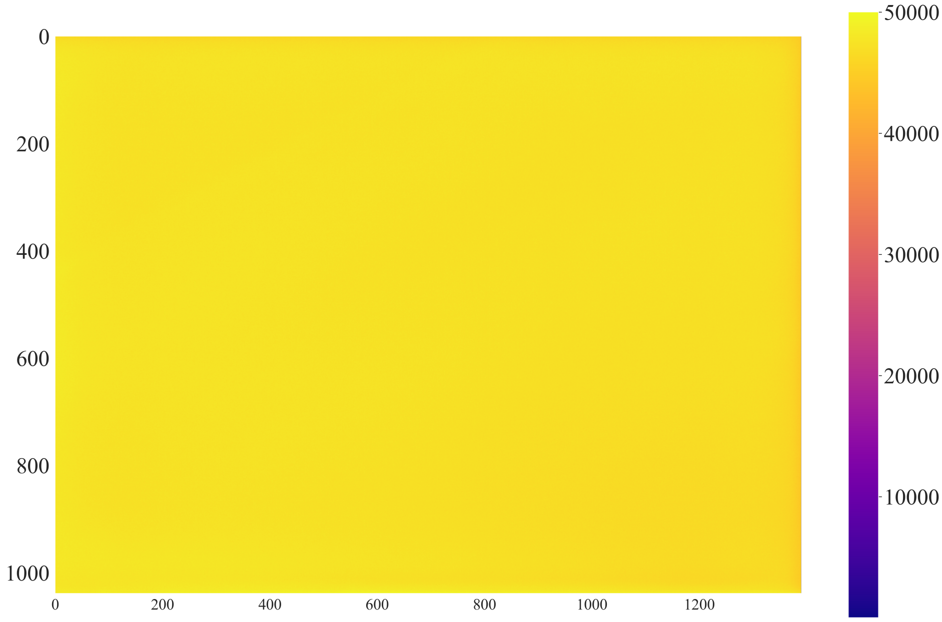

Figure 7 *Master flat obtained at -7.8°C and exposure of 7 seconds*

5.4 Gain and Readout Noise

The Gain and Readout noise was calculated using the Janesick equations(6) which are expressed as follows,

$$flatdif \ = flat_1 - flat_2 \tag{1}$$

$$biasdif \ = bias_1 - bias_2 \tag{2}$$

$$\text{gain} = \frac{(\overline{flat_1} + \overline{flat_2}) - (\overline{bias_1} - \overline{bias_2})}{(\sigma^2_{fd} - \sigma^2_{bd})} \tag{3}$$

$$\text{readnoise} \ = \ \text{gain} \times \frac{\sigma_{bd}}{\sqrt{2}} \tag{4}$$

Where each variable in the above equation represents a full frame array with a scalar intensity associated with each value representing a mean pixel count or a standard deviation of that specific array.

In the calculation of the gain and readout noise, clipped bias and flat images were used from a set of frames taken at -7.8°C. As with the flat images before, the bias frame was subtracted from the flat frame for a more accurate representation of imperfections in the sensor.

Using two frames at different exposures times. The gain and readout noise was found to be $0.274 \pm 4.98 \times 10^{-3}$ and $4.345 \pm 9.48 \times 10^{-2}$. These values fall within the range specified by that of CCD manufacturer. (1)

6 Conclusion

The investigation performed in the lab explored types of noise that could impact a CCD's result in taking a science frame.

The investigation saw the creation of a Master Dark within the central frame of the CCD this allowed for the thermal gain of any electrons that would be present in the final count of a science frame to be accounted for. It was also found that the accumulation of thermal electrons was proportional to the temperature at which the CCD operated. This meant with an increase of approximately 6°C the change in the dark count approximately doubled.

A master bias was created to account for electrical interference inherently present in the CCD and in the environment in which the CCD was operated. The master bias produced a pattern on the furthermost right side of the frame. This pattern was also present in other apparatus present in the lab and was deemed a reciprocal effect of manufacturing.

A master flat was produced to account for any imperfection in each photosite present in the CCD, and it's the ability to count incident photo-electrons. The master-bias was subtracted from the master flat so that any electrical produced noise was negated from the reading produce from the flat.

Lastly, values for readout noise and gain were found with the use of the Janesick equations. It was found that readout noise was $0.274 \pm 4.98 \times 10^{-3}$ and $4.345 \pm 9.48 \times 10^{-3}$ respectively. Both values for readout noise and gain are inline with the CCD manufacturers specifications.

References

[1] Camera Atik. *Atik Series 3 User Manual*. Atik Cameras, 1.5 edition, Jul 2015.

[2] Sara Beck, Arne Henden, and Matthew Templeton. *The AAVSO Guide to CCD Photometry*. American Association of Variable Star Observers, 1.1 edition, March, 2017.

[3] Richard Berry and James Burnell. *The handbook of astronomical image processing*. Willmann-Bell, 2nd edition, April, 2005.

[4] Morgan Fraser. *CCD Instruments and Calibration Instruction Manual*. UCD Department of Physics, 2nd edition, September, 2020.

[5] Ifan Huges and Thomas Hase. *Measurements and their Uncertainties: A practical guide to Modern Error Analysis*. Oxford, England University Press, 1st edition, December, 2009.

[6] James R. Janesick. *Scientific charge-coupled devices*. SPIE Press, 1st edition, 2001.

[7] Glenn F. Knoll. *Radiation detection and measurement*. Wiley, 2nd ed edition, 1989.

Appendices

I Uncertainties analysis & General Notes

I.1 Uncertainties

I.1.1 Overview

Due to how the operation of a CCD transpires, the results obtained in each frame are from the counting of electrons present in each photosite. Random errors fluctuate from one measurement next, which form a distribution about the average of said measurements. These systematic errors cause the entire data set such that the mean is displaced from its true value.

Sources of uncertainty in the context of the CCD calibration are things such as measurement errors from imperfections in the instrumentation and data analysis errors from using an incorrect method or model for manipulating the data.

When calculating errors in calibrating a CCD, the significance of will only become marginally apparent when applied to the subject of science image. The quantum efficiency of the CCD will allow it to detect faint sources of photons, and the uncertainty surrounding this will become integral to the image processing for science images where extreme sensitivity is required.

When taking data for the CCD as $n \longrightarrow \infty$ the $\overline{x} \longrightarrow \mu$. This is because the CCD counts incident photoelectrons a binomial distribution is a good fit as the measurements are dichotomous and random, because of this it is possible to assume a Poisson distribution because the probability of measuring outliers is proportionally small and the sample of counts measured is large.

When calculating uncertainties for the gain and readout noise the standard deviation of counts was calculated using the following two formulas based on the two distributions discussed,

$$\sigma_G = \sqrt{\frac{(x_i - \overline{x}^2)}{n-1}} \tag{5}$$

$$\sigma_p = \sqrt{n} \tag{6}$$

The reliability factor was calculated as follows,

$$R.F = \frac{S_c}{\sigma_c} = \frac{\text{Observed mean for the standard deviation of a number of counts}}{\text{Standard deviation for an average number of counts}} \tag{7}$$

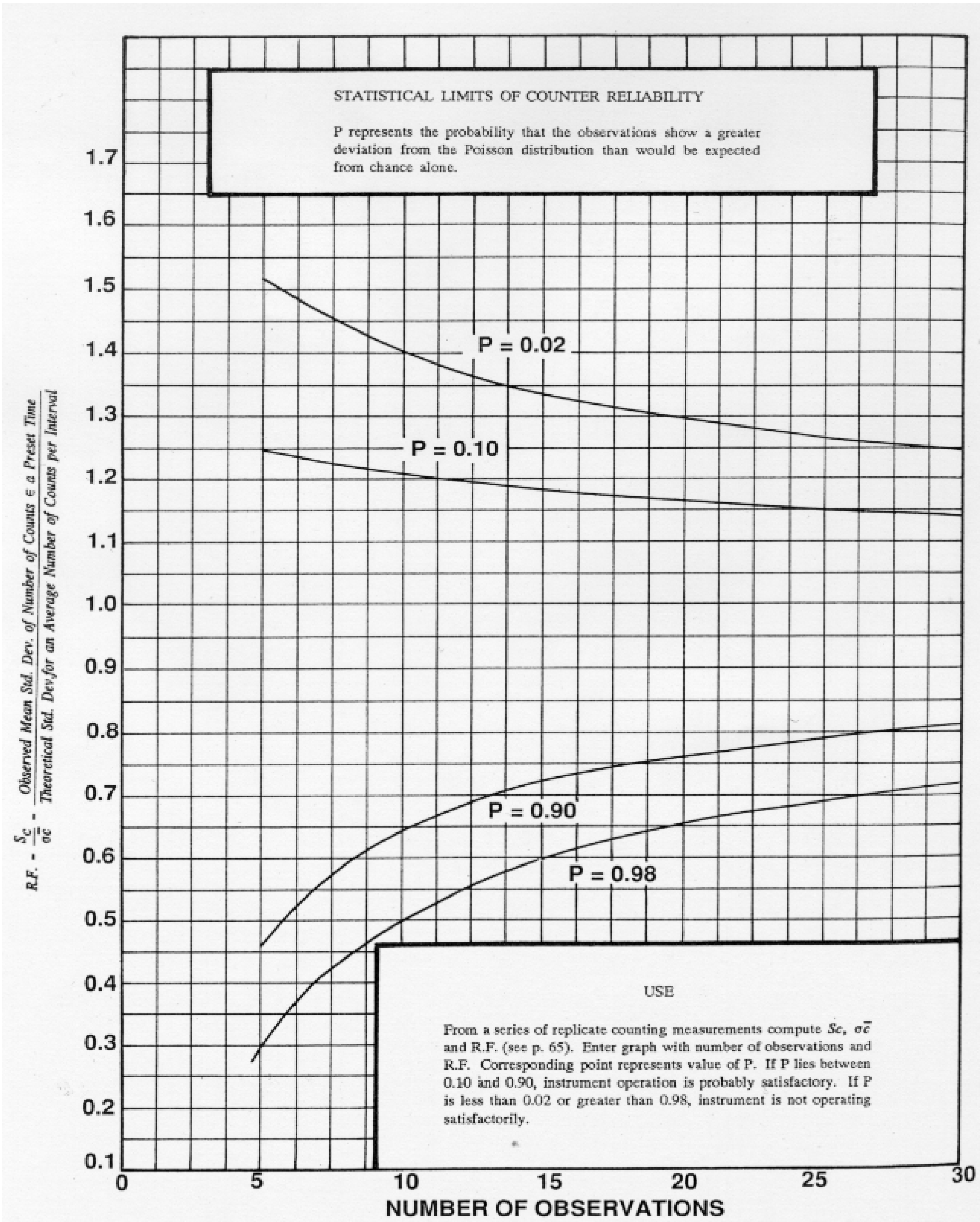

Figure 8 *Statistical limits of counter reliability (7)*

As observed in Fig. (8) as the number of trials increase, the standard deviation becomes more reliable. In the case of readout-noise and gain the reliability factor was found to be 0.969. This falls sufficiently in the range that any outliers are due to the randomness of the photoelectrons and be covered by deviation.

Relative uncertainty is propagated through the Janesick equation using,

$$\frac{u_R}{R}\sqrt{\left(\frac{u_A}{A}\right)^2+\left(\frac{u_B}{B}\right)^2+\left(\frac{u_C}{C}\right)^2} \tag{8}$$

And the values obtained for the standard deviation are propagated through obtaining uncertainty for gain and readout noise.(5)

I.1.2 Plotting fits for Data

When fitting the plot in Fig. (3), a chi-squared test was performed to determine the 'goodness' of the fit associated with the plot. This was done because the data set was heteroscedastic, and the same set was of a discrete function. The p-value obtained for the plot in Fig. (3) was found to be 0.967; this indicates that the fit is good for the data but could also be due to the size of the error bars is marginally extensive for the fit.

The errors used in Fig. (3) was the standard deviation from the data set. The reason this was used was due to the distribution of the data set in in Fig. (3) and the nature of instruments counting a Poisson distribution was assumed. (5)

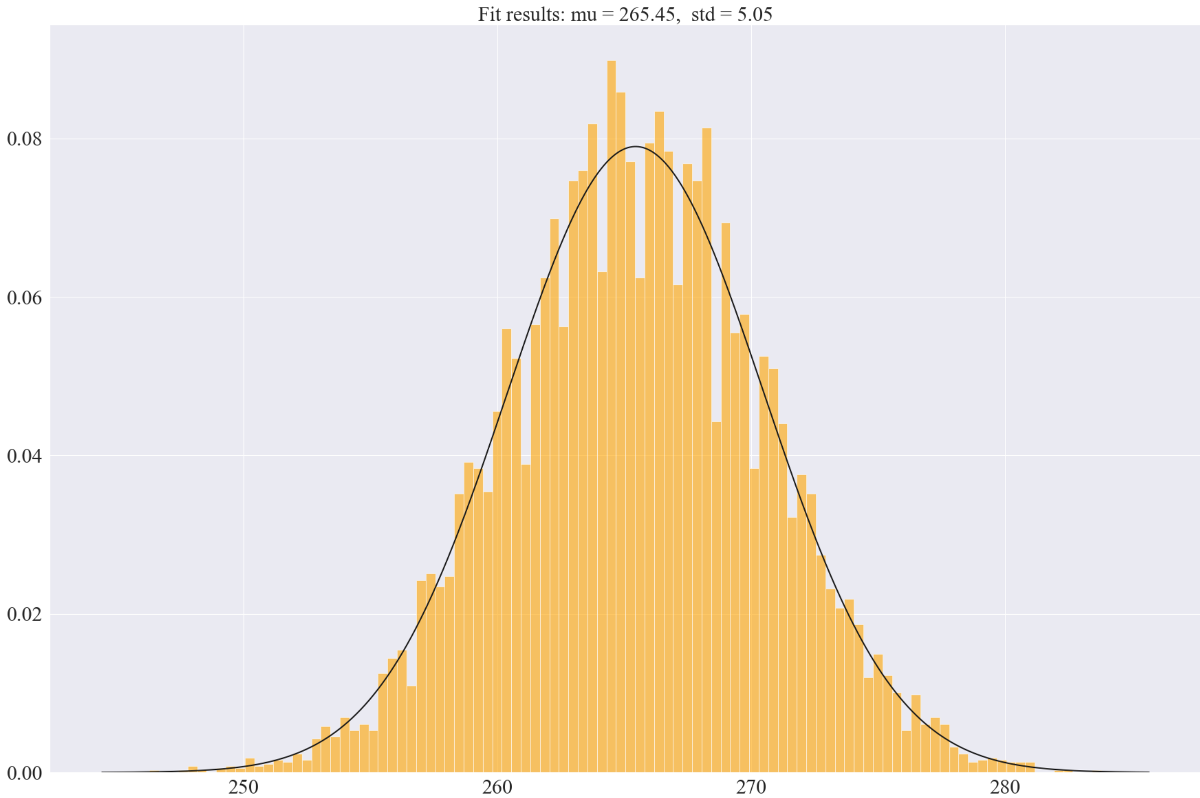

Figure 9 *Distribution of Dark Pixels from Master Dark Frame*

I.1.3 Sigma Clipping

Sigma clipping is useful because it uses the interquartile range. Due to central tendencies, the mean of counts could be skewed overall due to outliers, so the medium is used when using sigma clipping to ensure that any values that are clipped are not taken from a more true mean which the medium provides. In the case of sigma clipping though-out the calibration a standard deviation of 3 was used when sigma clipping. This caused an average of 3.76 pixels to be clipped from every 100 pixels analysed. This is an appropriate value you clip for inputted deviations this in turn creates a mean that's more central and closer to its true value.

I.2 General Notes

Averaging images ensures that the signal to noise ratio (S/N) of the frames does not introduce signifcant extra noise into the frames.

I.2.1 Pixel observation areas

The reason full frames were taken when calculating master bias and master flats was due to the imperfections that are more common towards the end of the CCD edge. It was found that if values at the center of the frame were taken for a 5 x 5, 10 x 10 and 100 x 100 area for bias and flat regions the differences would change marginally as the sample size increased.

There was large inconsistency when taking values for areas that were 5 x 5 and 10 x 10 as seen in the below table. But as the number of pixels sampled increased the mean counts and standard deviation returned similar values with standard consistencies. It was also seen when larger sample sizes were taken for percentage error for Poisson noise decreased.

Mean Counts	Standard Deviation (σ)	Pixel Region
46941.847	182.980	5×5
47114.379	241.828	10×10
47596.842	435.739	30×30
47884.994	429.671	60×60
47729.441	474.578	500×500
47613.485	503.784	1039×1391

Table 2 *Comparison of mean counts and deviations for various pixel regions.*

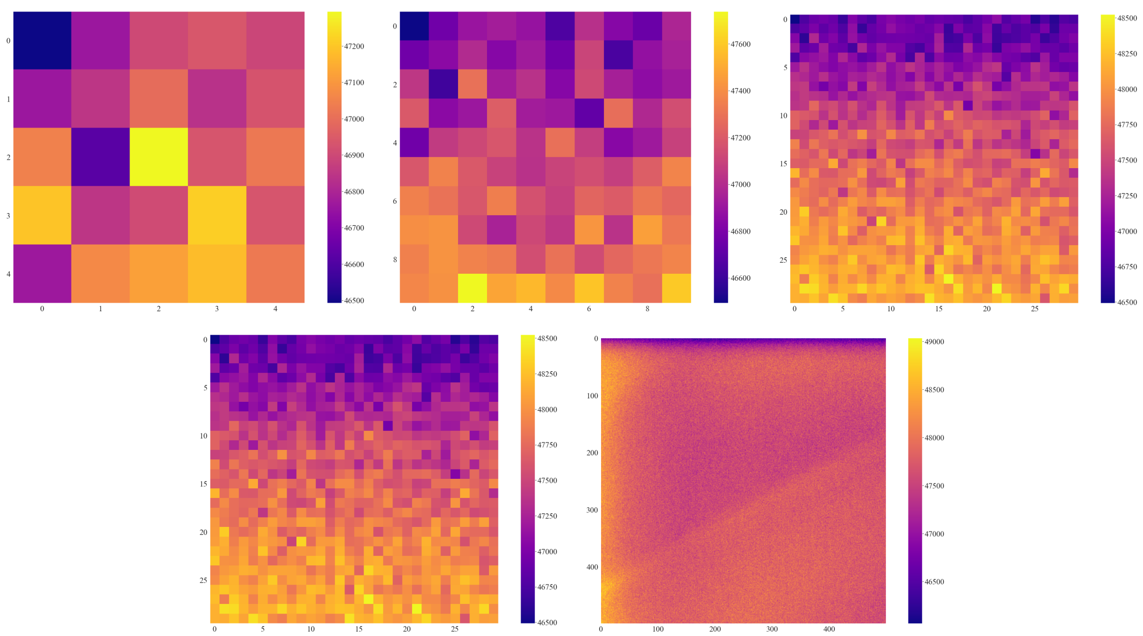

Figure 10 *Example master flat taking 5 different pixel regions of 25, 100, 900, 3600 and 25,000 (Ascending from left to right)*

I.2.2 Atik 314L + Schematic

Below is a technical drawing of the Atik 314L +

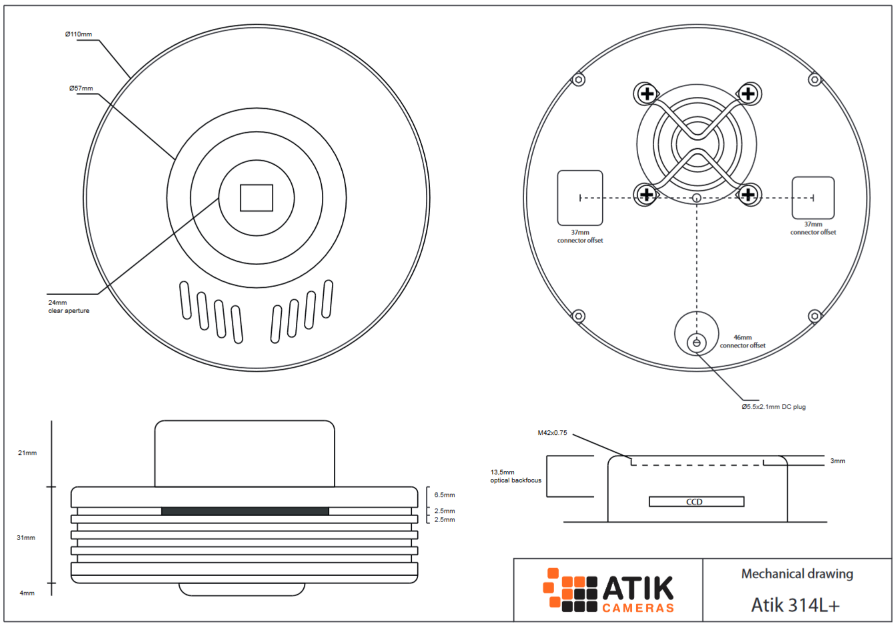

Figure 11 *Technical drawing of Atik 315L + CCD sensor. (1)*

II Code

```
import pandas as pd
import scipy
import numpy as np
import os #cwd tools
import matplotlib.mlab as mlab
import seaborn as sns
from astropy.stats import sigma_clip
from matplotlib import pyplot as plt
from scipy.optimize import curve_fit
from scipy import stats
from astropy.io import fits #allows python to interpurt fits data files
from glob import glob # Unix style pathname pattern expansion

%matplotlib inline
sns.set()
```

Listing 1 *Packages Import*

```
# —— Function that returns mean counts, deviation, temperture and exposure based on pixels a, b,
    x, y ——

# —— Print Master function ——

def master(name, a, b, x, y):
    filelst = glob(name)

    mean_array = []
    std_array = []
    temp_array = []
    exp_array = []

    for file in filelst:

        image = fits.open(file)

        mean = (image[0].data[a:b, x:y]).mean()
        mean_array.append(mean)

        std = (image[0].data[a:b, x:y]).std()
        std_array.append(std)

        temp = image[0].header['CCD-TEMP']
        temp_array.append(temp)

        exp = image[0].header['EXPTIME']
        exp_array.append(exp)

    print('Mean:', np.round(np.mean(mean_array), 3), 'counts', '  :', np.round(np.mean(std_array),
     3), 'Temp:', np.round(np.mean(temp_array), 3), ' C ', 'Exposure:', np.round(np.mean(
    exp_array), 3), 'seconds' )

```

```python

# —— Array master function ——

def master_array(name, a, b, x, y):
    filelst = glob(name)

    mean_array = []
    std_array = []
    temp_array = []
    array = []

    for file in filelst:

        image = fits.open(file)

        mean = (image[0].data[a:b, x:y]).mean()
        mean_array.append(mean)

        std = (image[0].data[a:b, x:y]).std()
        std_array.append(std)

        temp = image[0].header['CCD-TEMP']
        temp_array.append(temp)

    return mean_array, std_array, temp_array
```

Listing 2 *Defining Functions*

```python
# —— Directory Change ——

os.chdir(r'E:\Dropbox\UCD - Physics Undergrad\3 - Third Year\1. First Semester\PHYC3170 Advanced Labs\2. CCD\Data Collection\1. Dark Currents\1. Dark Currents_n8\exp_1')

# —— Data Import ——

dark_n7_exp_1 = master('dark_single ', 646, 746, 470, 570) # 100x100 center frame

image_list = [fits.getdata(image) for image in glob('dark_single ')] # Obtains an average image across all frames
mean_image_dark_n10 = np.sum(image_list, axis=0)
medium_image_dark_n10 = np.median(image_list)

# —— Plot Parameters ——

plt.imshow(mean_image_dark_n10, cmap = 'plasma')
plt.title("Average Dark Frames taken at -7.8 C and 1s exposure. ")
plt.grid()
plt.colorbar()
plt.savefig('mean_image_dark_n78.png', dpi = 300)
```

Listing 3 *Example of importing fits files and plotting*

```python
#—— Sigma Clipping ——

def master_sigma(name, a, b, x, y, std):

    files = glob(name)

    #defining arrays and variables
    all_data = []
    i = 0

    while i < len(files):
        # using a loop to obtain data for all pixels
        pixel_data = fits.open(files[i])[0].data[a:b, x:y]
        all_data.append(pixel_data)
        i += 1

    all_data_array = np.asarray(all_data)
    print(np.shape(all_data_array))

    all_data_transposed = np.concatenate(np.swapaxes((all_data_array), 0, 2)) #transposing data to sigma clip

    i = 0 #resetting counter
    clipped_data = []

    while i < len(all_data_transposed):
        clipped_data.append(sigma_clip(all_data_transposed[i], sigma = std))
        i +=1

    clipped_data_transposed = np.asarray(clipped_data)

    clipped_data_3D = np.swapaxes(np.array_split(clipped_data_transposed, len(all_data_array[0][1])), 2, 0)
    print(np.shape(clipped_data_3D))

    nonzero = np.nonzero(clipped_data_3D == 0)
    count = np.count_nonzero(nonzero)
    print(count) #counts number of clipped pixel in sample set



    return np.average(clipped_data_3D, axis = 0)

#—— Plot Parameters ——

plt.imshow(filtered_data, cmap = 'plasma')
plt.title("Average Dark Frames taken at −7.8 C  and 1s exposure. ")
plt.grid()
plt.colorbar()
plt.savefig('mean_image_dark_n78_f.png', dpi = 300)
```

Example of sigma clipping and plotting

```
# —— Flat Import and Calculation ——

os.chdir(r'E:\Dropbox\UCD - Physics Undergrad\3 - Third Year\1. First Semester\PHYC3170 Advanced Labs\2. CCD\Data Collection\3. Flats\flat_ntp_2')

flat_1_image = fits.open('flat_568.fit')
flat_2_image = fits.open('flat_627.fit')

flat_1_image_data = np.int64(flat_1_image[0].data[646:746, 470:570])
flat_2_image_data = np.int64(flat_2_image[0].data[646:746, 470:570])

flat_dif = flat_1_image_data - flat_2_image_data
 _fd  = flat_dif.std()

print('flat dif std:',  _fd )


# —— Bias Import and Calculation ——

os.chdir(r'E:\Dropbox\UCD - Physics Undergrad\3 - Third Year\1. First Semester\PHYC3170 Advanced Labs\2. CCD\Data Collection\2. Bias\bias_ntp_day2')

bias_1_image = fits.open('bias_ntp_263.fit')
bias_2_image = fits.open('bias_ntp_309.fit')

bias_1_image_data = np.int64(bias_1_image[0].data[646:746, 470:570])
bias_2_image_data = np.int64(bias_2_image[0].data[646:746, 470:570])

bias_dif = bias_1_image_data - bias_2_image_data

 _bias  = bias_dif.std()

print('bias dif std:', _bias )


# —— Main Calculation ——

top = (flat_1_image_data.mean() + flat_2_image_data.mean()) - (bias_1_image_data.mean() + bias_2_image_data.mean())
bottom =  _fd  2 -  _bias  2

gain = top/bottom
readout = gain (  _bias /np.sqrt(2))

print('Gain:', gain, 'Readout Noise:', readout)
```

Listing 4 *Calculating readout-noise & gain.*

```
# -- data import --

os.chdir(r'E:\Dropbox\UCD - Physics Undergrad\3 - Third Year\1. First Semester\PHYC3170 Advanced Labs\2. CCD\Programming')
counts, std, temp = np.loadtxt("temp_dark.dat", unpack = True) # importing data

# -- data manipulation --

def quad_func(T, a_0, a_1, a_2): # defining quadratic function.
    return a_0 + a_1 T + a_2 (T 2)

poptbfq, pcovbfq = curve_fit(quad_func, temp, counts, p0 = [1, 2, -.7], sigma = std, absolute_sigma = True)


# -- Data Manpulation for Smooth fit --

temp_s = np.linspace(np.amin(temp), np.amax(temp), 100) # using lin space to create 100 points between 0 and the max value of time
counts_s =  quad_func(np.linspace(np.amin(counts), np.amax(counts), 100), 1, 2, -.7)


# -- Plotting Graph --


plt.scatter(temp, counts, color = 'red')
plt.plot(temp_s, quad_func(temp_s, poptbfq[0], poptbfq[1], poptbfq[2]), color = 'black')

plt.errorbar(temp, counts, xerr = None, yerr = std, ls='none', color = 'black')
plt.xlabel("Temperture of CCD (C)")
plt.ylabel("Mean Counts")
# plt.legend()
plt.grid()
plt.show()

plt.savefig('countvstemp.png', dpi = 300)

# -- Goodness of fit calculation --

print(scipy.stats.chisquare(temp, quad_func(temp, poptbfq[0], poptbfq[1], poptbfq[2])))
```

Listing 5 *Example of counts vs. temperature plot*

```
# Fit a normal distribution to the data:
mu, std = stats.norm.fit(test2.flatten())

# Plot the histogram.
plt.hist(test2.flatten(), bins= 100, density=True, alpha=0.6, color='orange')

# Plot the PDF.
xmin, xmax = plt.xlim()
x = np.linspace(xmin, xmax, 1000)
p = norm.pdf(x, mu, std)
plt.plot(x, p, 'k', linewidth=2)
title = "Fit results: mu = %.2f,  std = %.2f" % (mu, std)
plt.title(title)

plt.show()
```

Listing 6 *Histogram Plot Example*