CCDs

October 23, 2022

[1]:
```python
# IMPORTS #

# For handeling FITS files
from astropy.io import fits
import scipy
from glob import glob

import numpy as np
from matplotlib import pyplot as plt
```

[2]:
```python
# The below commands make the font and image size bigger
plt.rcParams.update({'font.size': 26})
plt.rcParams["figure.figsize"] = (12,12)
```

1 Determining Readout Noise and Gain

[3]:
```python
bIm = fits.open(r"/home/daraghhollman/jupyter/UCD_PASS_Labs/CCDs/Data_D1/
 ↪daragh_ccd/bias/bias_01.fit")
print(bIm[0].header)
```

```
SIMPLE  =                    T
BITPIX  =                   16
NAXIS   =                    2
NAXIS1  =                  100
NAXIS2  =                  100
BZERO   =         32768.000000
BSCALE  =             1.000000
DATAMIN =             0.000000
DATAMAX =         65535.000000
INSTRUME=         'ATIK-314L: fw rev 3.01'
FILTER  =         'Position 1'
EXPTIME =         0.001
DATE-OBS=         '2022-10-05T14:01:39.2'
XPIXSZ  =         6.450
YPIXSZ  =         6.450
XBINNING=         1
YBINNING=         1
```

```
XORGSUBF=            661
YORGSUBF=            489
XPOSSUBF=            661
YPOSSUBF=            489
CBLACK  =            216
CWHITE  =            297
CCD-TEMP=            -7.5
SWCREATE=            'Artemis Capture'
END
```

[4]:
```python
fIm = fits.open(r"/home/daraghhollman/jupyter/UCD_PASS_Labs/CCDs/Data_D1/
↪daragh_ccd/flat/flat_03.fit")
print(fIm[0].header)
```

```
SIMPLE  =                    T
BITPIX  =                   16
NAXIS   =                    2
NAXIS1  =                  100
NAXIS2  =                  100
BZERO   =            32768.000000
BSCALE  =              1.000000
DATAMIN =              0.000000
DATAMAX =            65535.000000
INSTRUME=            'ATIK-314L: fw rev 3.01'
FILTER  =            'Position 1'
EXPTIME =            0.100
DATE-OBS=            '2022-10-05T14:29:49.7'
XPIXSZ  =            6.450
YPIXSZ  =            6.450
XBINNING=            1
YBINNING=            1
XORGSUBF=            661
YORGSUBF=            489
XPOSSUBF=            661
YPOSSUBF=            489
CBLACK  =            16450
CWHITE  =            18030
CCD-TEMP=            -7.2
SWCREATE=            'Artemis Capture'
END
```

[5]:
```python
biasFilesA = glob(r"/home/daraghhollman/jupyter/UCD_PASS_Labs/CCDs/Data_D1/
↪daragh_ccd/bias/bias*")
biasFilesB = glob(r"/home/daraghhollman/jupyter/UCD_PASS_Labs/CCDs/Data_D1/
↪daragh_ccd/bias_1/bias*")

biasFITSA = [fits.open(el) for el in biasFilesA] # A list of 30 fits files
```

```
biasFITSB = [fits.open(el) for el in biasFilesB] # A list of 30 fits files
biasFITS = biasFITSA+biasFITSB
```

[6]:
```
flatFiles = glob(r"/home/daraghhollman/jupyter/UCD_PASS_Labs/CCDs/Data_D1/
    ↪daragh_ccd/flat/flat*")

flatFITS = [fits.open(el) for el in flatFiles] # A list of 15 fits files
```

[7]:
```
# Inputs a list of images, loops through every pixel of each image. Returns a␣
    ↪list of the average value of each image
def findAverageCounts(fitsList):
    averages = [0] * len(fitsList)

    n = 0
    for image in fitsList:
        total = 0
        count = 1
        for line in image[0].data:
            for el in line:
                total+=el
                count+=1
        averages[n] = total / count
        n+=1
    return averages
```

[8]:
```
# Biases
i=0
myFlats = list()
while i < len(flatFITS):
    # Check if there are still pairs left
    if (len(flatFITS) - i) >= 2:
        myFlats.append([flatFITS[i], flatFITS[i+1]])
        i+=2

j = 0
myBiases = list()
while j < len(biasFITS):
    # Check there still exist pairs
    if (len(biasFITS) - i >= 2):
        myBiases.append([biasFITS[j], biasFITS[j+1]])
        j+=2

def gainAndReadnoise(flats, biases, std=False):
    # where flats and biases are lists with elements containing pairs of flats␣
    ↪or biases

    gainList = list()
```

```
    readnoiseList = list()

    for flatPair, biasPair in zip(flats, biases):
        meanFlats = [flatPair[0][0].data.mean(), flatPair[1][0].data.mean()]
        meanBiases = [biasPair[0][0].data.mean(), biasPair[1][0].data.mean()]

        flatDiff = abs(flatPair[0][0].data - flatPair[1][0].data)
        biasDiff = abs(biasPair[0][0].data - biasPair[1][0].data)

        std_flatDiff = flatDiff.std()
        std_biasDiff = biasDiff.std()

        gain = ((meanFlats[0] + meanFlats[1]) - (meanBiases[0] +␣
↪meanBiases[1])) / (std_flatDiff**2 - std_biasDiff**2)
        readnoise = gain * std_biasDiff / np.sqrt(2)

        gainList.append(gain)
        readnoiseList.append(readnoise)

    averageGain = np.mean(gainList)
    std_gain = np.std(gainList)
    averageReadnoise = np.mean(readnoiseList)
    std_readnoise = np.std(readnoiseList)

    if std==True: return [[averageGain, averageReadnoise], [std_gain,␣
↪std_readnoise]]
    else: return [averageGain, averageReadnoise]

res = gainAndReadnoise(myFlats, myBiases, std=True)
gain = res[0][0]
readnoise = res[0][1]

print(f"Gain: {gain} with standarad deviation: {res[1][0]}")
print(f"Readnoise: {readnoise} with standarad deviation: {res[1][1]}")
```

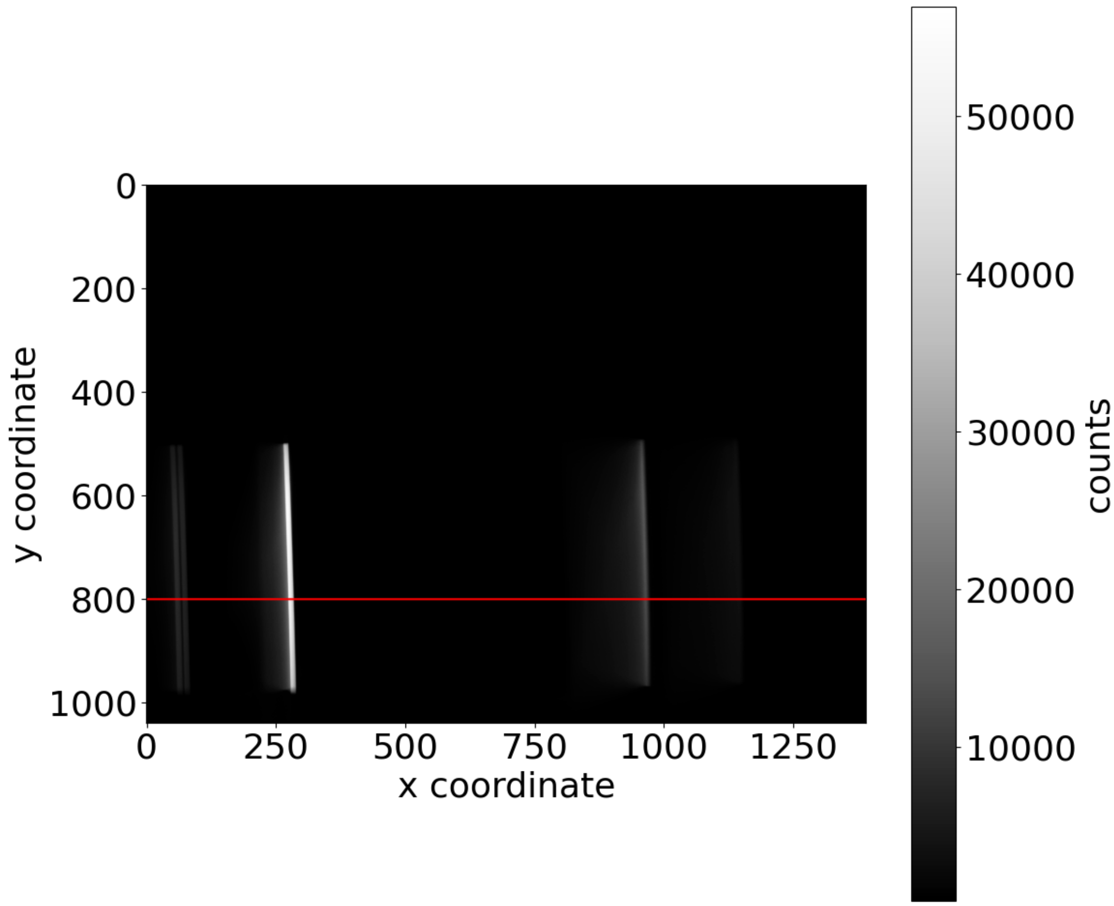
```
Gain: -0.001577846989986806 with standarad deviation: 0.000748331061405
Readnoise: -36.53031784248212 with standarad deviation: 17.324857482162162
```

2 Spectrum of the Arc Lamp

[9]:
```
arcImage = fits.open(r"/home/daraghhollman/jupyter/UCD_PASS_Labs/CCDs/Data_D1/
↪daragh_ccd/Hg/Hg_02.fit")
plt.imshow(arcImage[0].data, cmap="Greys_r")
plt.plot(np.arange(0, 1391, 1), [800]*(1391), color="red")
plt.colorbar(label="counts")
plt.xlabel("x coordinate")
```

```python
plt.ylabel("y coordinate")
```

[9]: Text(0, 0.5, 'y coordinate')



[10]:
```python
line_values = arcImage[0].data[800]
print(max(line_values))
```

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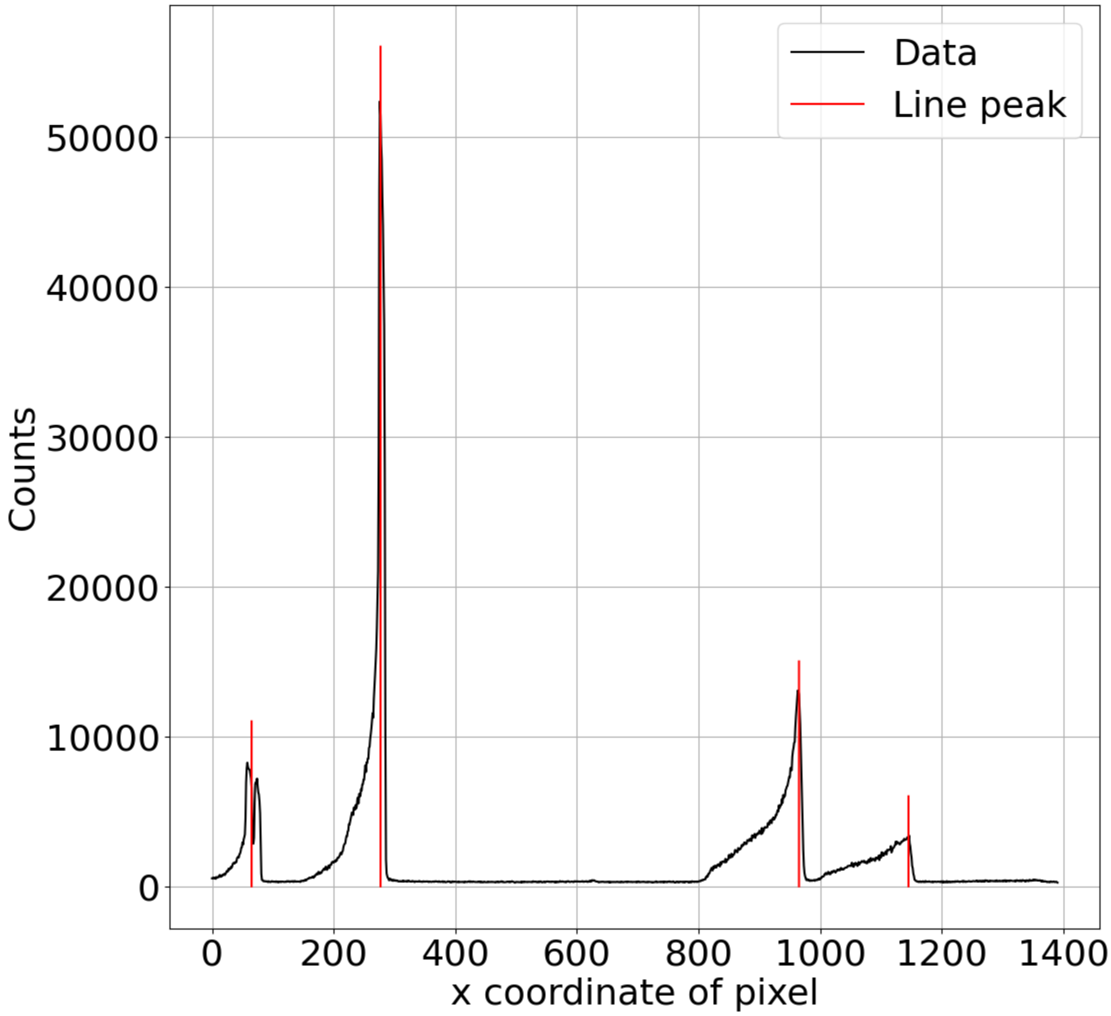
[11]:
```python
x= list()
y= list()

i = 0
for el in line_values:
    x.append(i)
    y.append(el)

    i+=1
```

```
[12]: def gaussian(x, mu, std, scale):
    ans = list()
    for el in x:
        ans.append(scale * np.exp(-(el-mu)**2/(2*std**2)))
    return ans

pars01, cov01 = scipy.optimize.curve_fit(gaussian, x[0:150], y[0:150], [80, 10,
 ↪10000])
pars02, cov02 = scipy.optimize.curve_fit(gaussian, x[260:290], y[260:290],
 ↪[278, 4, 52000])
pars03, cov03 = scipy.optimize.curve_fit(gaussian, x[920:980], y[920:980],
 ↪[950, 4, 12000])
pars04, cov04 = scipy.optimize.curve_fit(gaussian, x[1050:1200], y[1050:1200],
 ↪[1125, 10, 400])

meanX = [pars01[0], pars02[0], pars03[0], pars04[0]]
```

```
[13]: # First peak : [0:150]
# Second peak : [200:350]
# Third peak : [800:1100]
# Fourth peak : [1050:1200]

plt.plot(x, y, color="black", label="Data")
# Plan is to plot vertical lines displaying the estimated x and the uncertainty

# Peak 1
plt.plot([65]*11000, np.arange(0, 11000, 1), color="red")

# Peak 2
plt.plot([277]*56000, np.arange(0, 56000, 1), color="red", label="Line peak")

# Peak 3
plt.plot([965]*15000, np.arange(0, 15000, 1), color="red")

# Peak 4
plt.plot([1145]*6000, np.arange(0, 6000, 1), color="red")

plt.legend()
plt.grid()
plt.xlabel("x coordinate of pixel")
plt.ylabel("Counts")
```

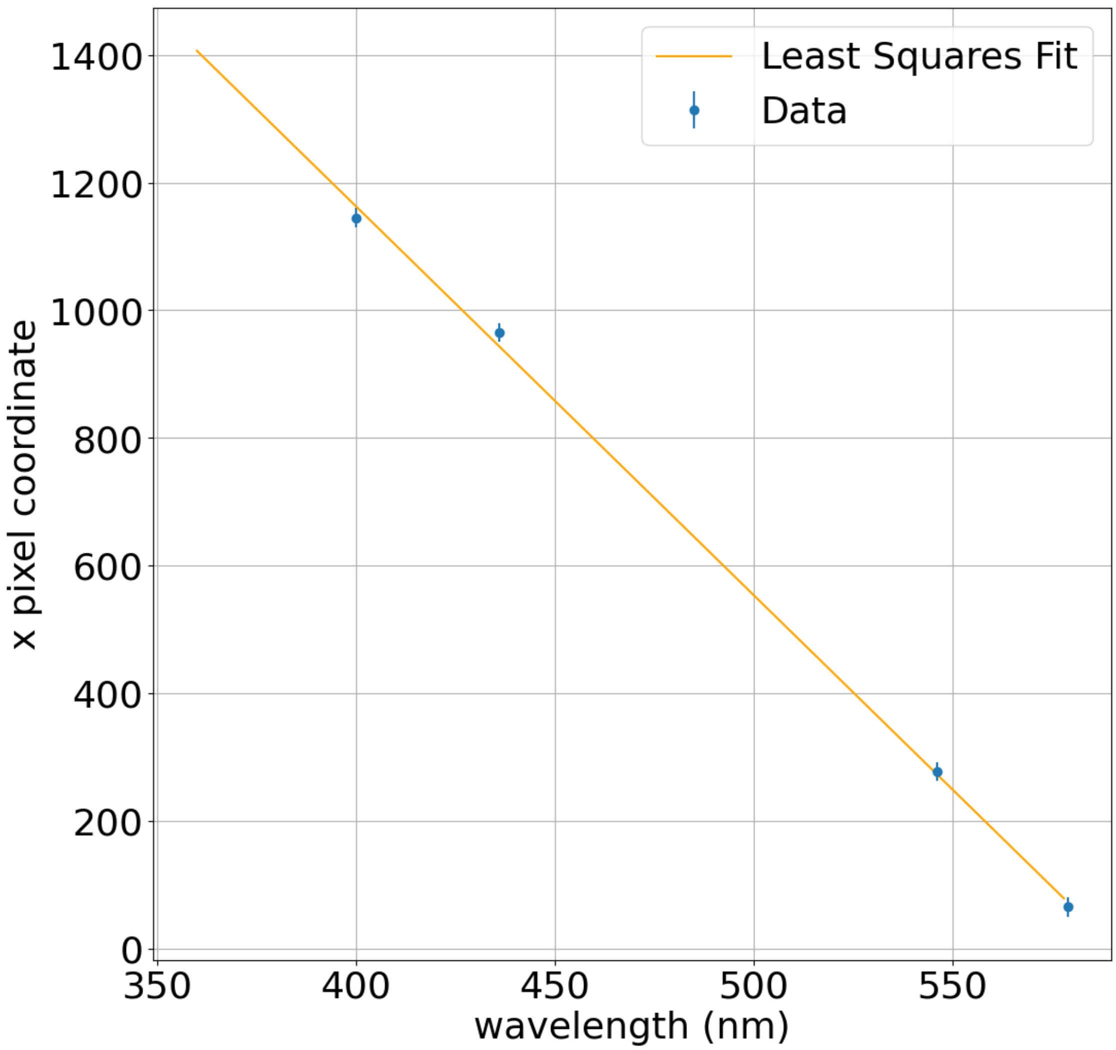
```
[13]: Text(0, 0.5, 'Counts')
```



[14]:
```
peakXs = [65, 277, 965, 1145]
wavelengths = [579, 546, 436, 400] # reference : https://zeiss-campus.magnet.
↪fsu.edu/articles/lightsources/mercuryarc.html

def wavelengthToX(lam, m, c):
    return m*lam + c
def xToWavelength(x, m, c):
    return (x - c) / m

linPars, linCov = scipy.optimize.curve_fit(wavelengthToX, wavelengths, peakXs)

plt.errorbar(wavelengths, peakXs, yerr=15, label="Data", fmt="o")
plt.plot(np.arange(360, 579, 1), \
         wavelengthToX(np.arange(360, 579, 1), linPars[0], linPars[1]),␣
↪color="orange", label="Least Squares Fit")
```

```
plt.legend()
plt.grid()
plt.ylabel("x pixel coordinate")
plt.xlabel("wavelength (nm)")
```

[14]: Text(0.5, 0, 'wavelength (nm)')



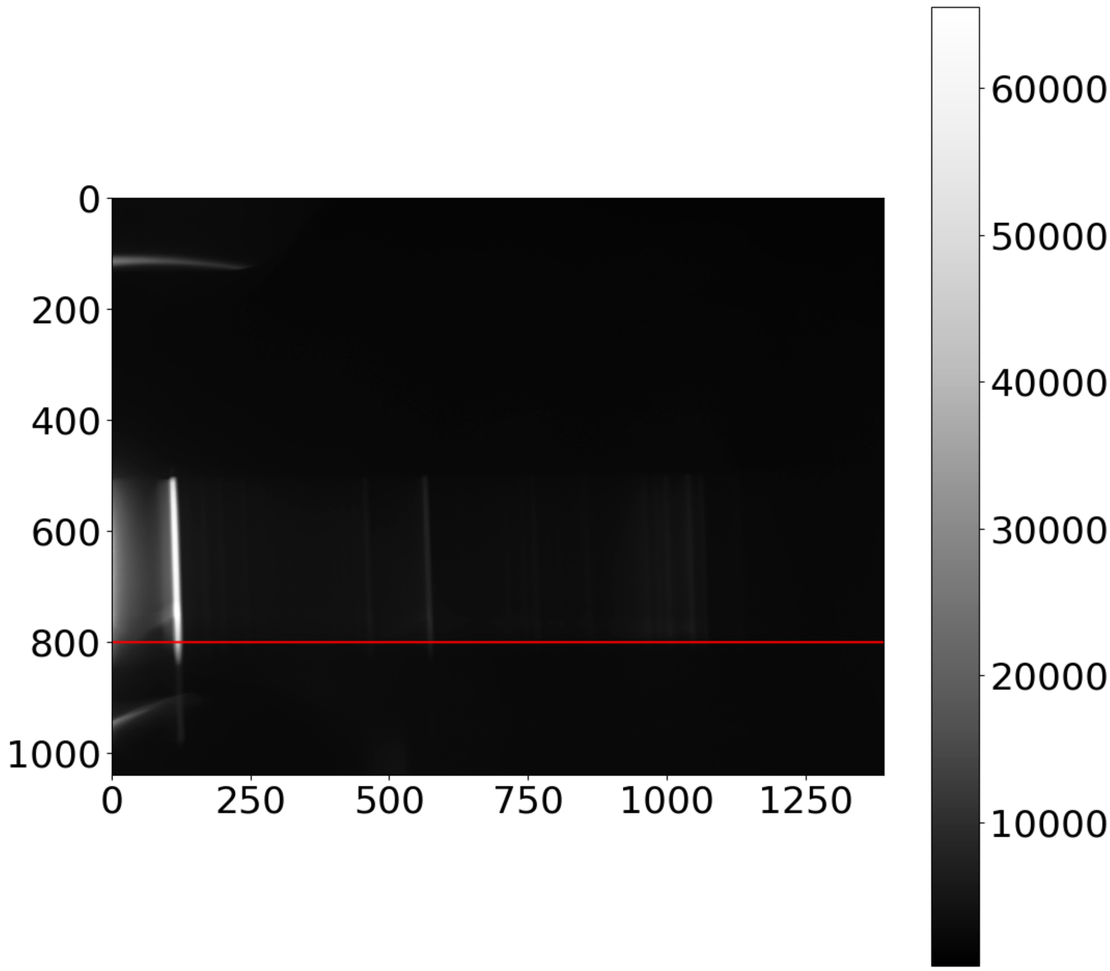
3 Investigate the Resolution of the Spectrograph

[15]:
```
imageNa = fits.open(r"/home/daraghhollman/jupyter/UCD_PASS_Labs/CCDs/Data_D1/
↪daragh_ccd/Na_Main/Na_Main/Na_204.fit")
print(np.shape(imageNa[0].data))
```

(1039, 1391)

[16]:
```
plt.imshow(imageNa[0].data, cmap="Greys_r")
plt.plot(np.arange(0, 1391, 1), [800]*(1391), color="red")
plt.colorbar()
```

[16]: <matplotlib.colorbar.Colorbar at 0x7f90a4fb7be0>



[17]:
```
line_valuesNa = imageNa[0].data[800]
print(max(line_valuesNa))
```

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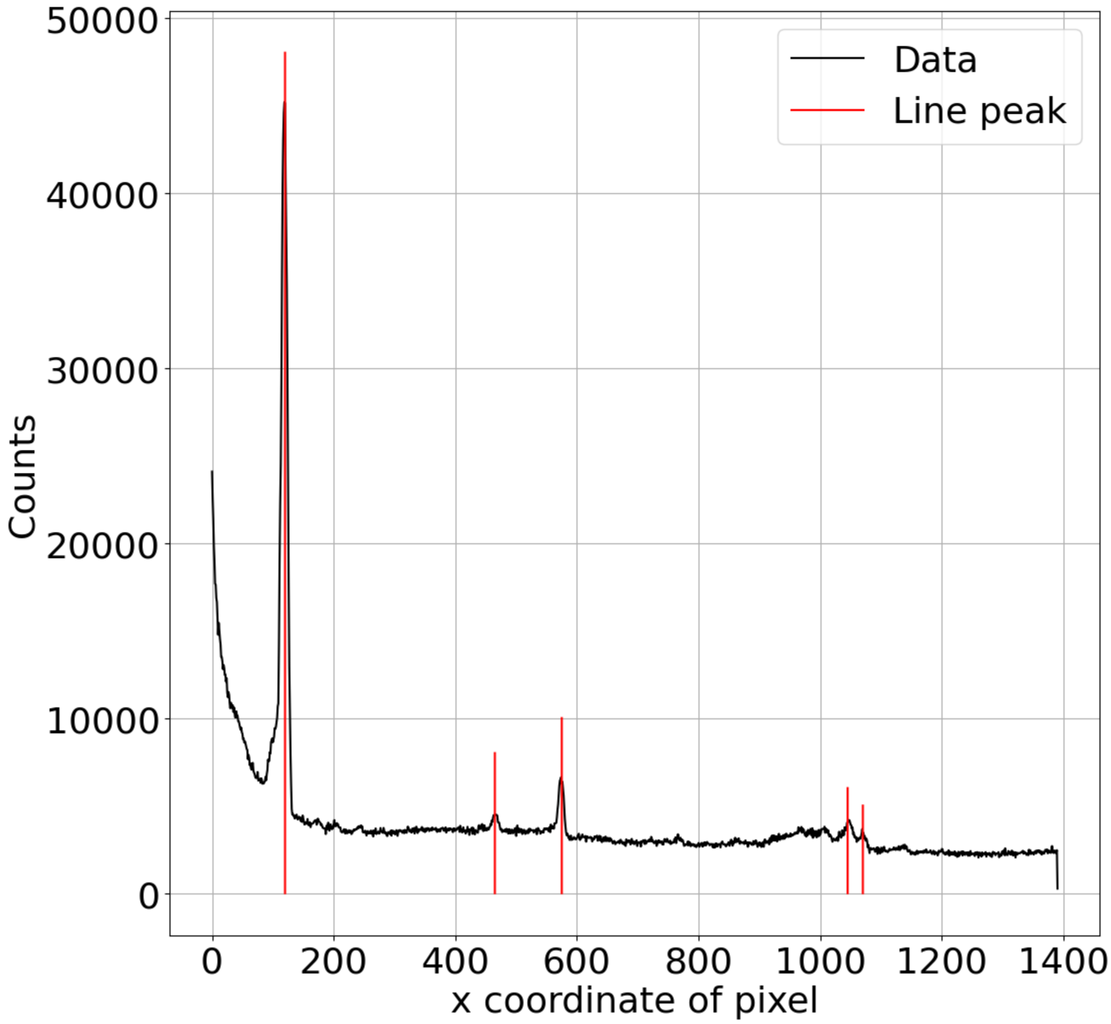
[18]:
```
xNa = list()
yNa = list()

k = 0
```

```python
for el in line_valuesNa:
    xNa.append(k)
    yNa.append(el)

    k+=1
```

[19]:
```python
plt.plot(xNa, yNa, color="black", label="Data")

# Peak 1
plt.plot([120]*48000, np.arange(0, 48000, 1), color="red")
# Peak 2
plt.plot([465]*8000, np.arange(0, 8000, 1), color="red", label="Line peak")
# Peak 3
plt.plot([575]*10000, np.arange(0, 10000, 1), color="red")
# Peak 4
plt.plot([1045]*6000, np.arange(0, 6000, 1), color="red")
# Peak 5
plt.plot([1070]*5000, np.arange(0, 5000, 1), color="red")

plt.legend()
plt.grid()
plt.xlabel("x coordinate of pixel")
plt.ylabel("Counts")
```

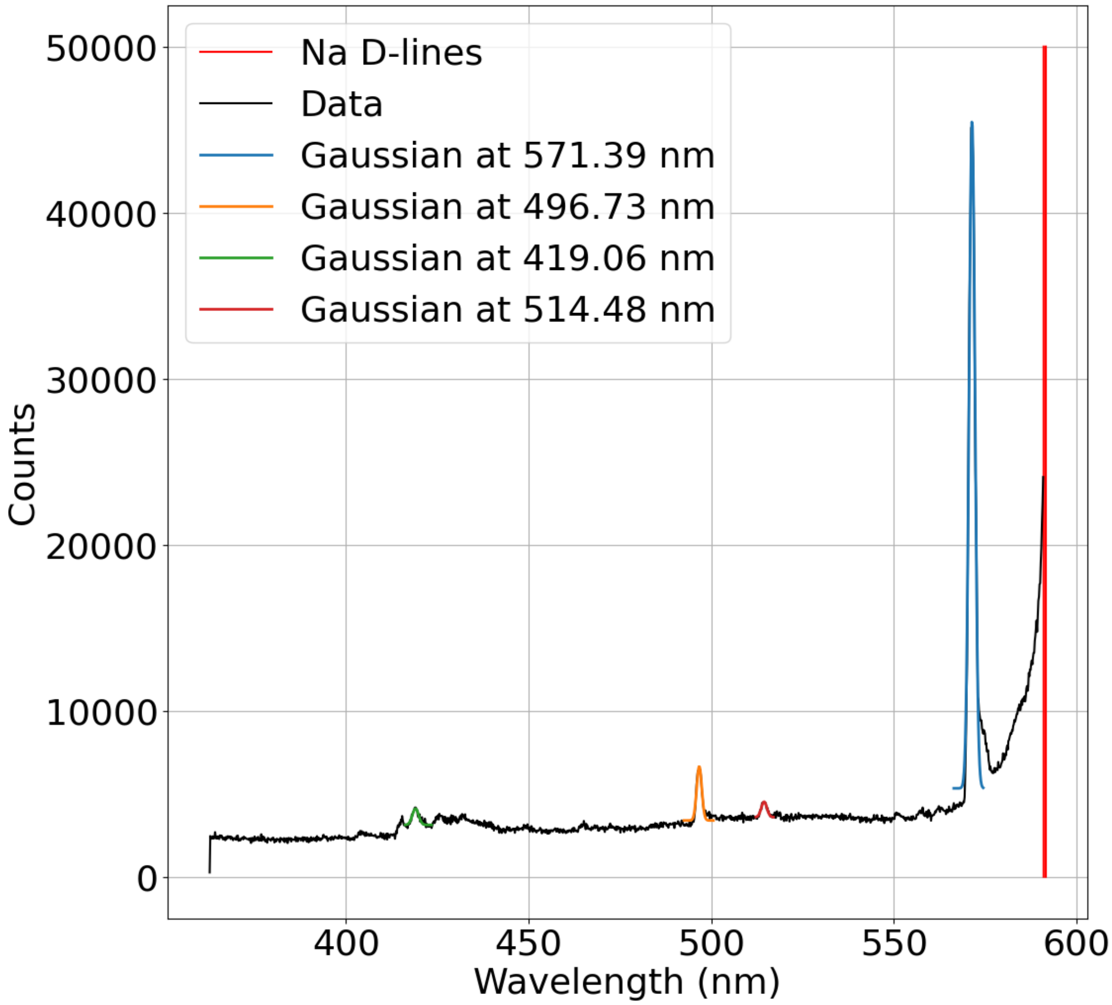
[19]:
```
Text(0, 0.5, 'Counts')
```



[20]:
```
peaksNa = [120, 465, 575, 1045, 1070]

# https://www.chem.uci.edu/~unicorn/249/Handouts/RWFSodium.pdf
NaDWavelengths = [588.995, 589.5924]
plt.plot([NaDWavelengths[0]+2]*50000, np.arange(0, 50000, 1), color="red",␣
 ↪label="Na D-lines")
plt.plot([NaDWavelengths[1]+2]*50000, np.arange(0, 50000, 1), color="red")

# Plot of Na data
NaWavelengths = [xToWavelength(el, linPars[0], linPars[1]) for el in xNa]

plt.plot(NaWavelengths, yNa, color="black", label="Data")

# Gaussian Fit
def gaussian(x, mean, std, C, H):
```

```python
    A = C / (abs(std) * np.sqrt(2 * np.pi))
    B = np.exp(-0.5 * ((x - mean) / abs(std))**2)

    return A*B + H

gaussPars01, gaussCov01 = scipy.optimize.curve_fit(gaussian, NaWavelengths[100:
 ↪150], yNa[100:150], \
                                                [565, 10, 40000, 5000])
gaussPars02, gaussCov02 = scipy.optimize.curve_fit(gaussian, NaWavelengths[550:
 ↪600], yNa[550:600], \
                                                [495, 5, 8000, 5000])
gaussPars03, gaussCov03 = scipy.optimize.curve_fit(gaussian, NaWavelengths[1020:
 ↪1065], yNa[1020:1065], \
                                                [410, 5, 4000, 3000])
gaussPars04, gaussCov04 = scipy.optimize.curve_fit(gaussian, NaWavelengths[450:
 ↪480], yNa[450:480], \
                                                [520, 5, 6000, 5000])



plt.plot(NaWavelengths[100:150], gaussian(NaWavelengths[100:150],␣
 ↪gaussPars01[0], gaussPars01[1], gaussPars01[2],  \
                                           gaussPars01[3]), label=f"Gaussian at␣
 ↪{gaussPars01[0]:.2f} nm", linewidth="2")
plt.plot(NaWavelengths[550:600], gaussian(NaWavelengths[550:600],␣
 ↪gaussPars02[0], gaussPars02[1], gaussPars02[2],  \
                                           gaussPars02[3]), label=f"Gaussian at␣
 ↪{gaussPars02[0]:.2f} nm", linewidth="2")
plt.plot(NaWavelengths[1020:1065], gaussian(NaWavelengths[1020:1065],␣
 ↪gaussPars03[0], gaussPars03[1], gaussPars03[2],  \
                                           gaussPars03[3]), label=f"Gaussian at␣
 ↪{gaussPars03[0]:.2f} nm", linewidth="2")
plt.plot(NaWavelengths[450:480], gaussian(NaWavelengths[450:480],␣
 ↪gaussPars04[0], gaussPars04[1], gaussPars04[2],  \
                                           gaussPars04[3]), label=f"Gaussian at␣
 ↪{gaussPars04[0]:.2f} nm", linewidth="2")


plt.legend()
plt.grid()
plt.xlabel("Wavelength (nm)")
plt.ylabel("Counts")
```

[20]: Text(0, 0.5, 'Counts')



3.1 Find Resolution

[21]:
```
def resolution(std, wavelength):
    dL = 2.355 * std
    res = wavelength / dL
    return res
```

[22]:
```
def resUncertainty(wavelength, FWHM, uW, uFWHM):
    return np.sqrt((1/FWHM)**2 * uW**2 + (wavelength/(FWHM**2))**2 * uFWHM**2)
```

[23]:
```
point1 = resolution(gaussPars01[1], gaussPars01[0])
point2 = resolution(abs(gaussPars04[1]), gaussPars04[0])
point3 = resolution(gaussPars02[1], gaussPars02[0])
point4 = resolution(gaussPars03[1], gaussPars03[0])
resolutions = [point1, point2, point3, point4]
```

```
print(f"Resolution of the spectrograph at {gaussPars01[0]:.2f} nm: {point1:.
 ↪5f}")
print(f"Resolution of the spectrograph at {gaussPars04[0]:.2f} nm: {point2:.
 ↪5f}")
print(f"Resolution of the spectrograph at {gaussPars02[0]:.2f} nm: {point3:.
 ↪5f}")
print(f"Resolution of the spectrograph at {gaussPars03[0]:.2f} nm: {point4:.
 ↪5f}")
```

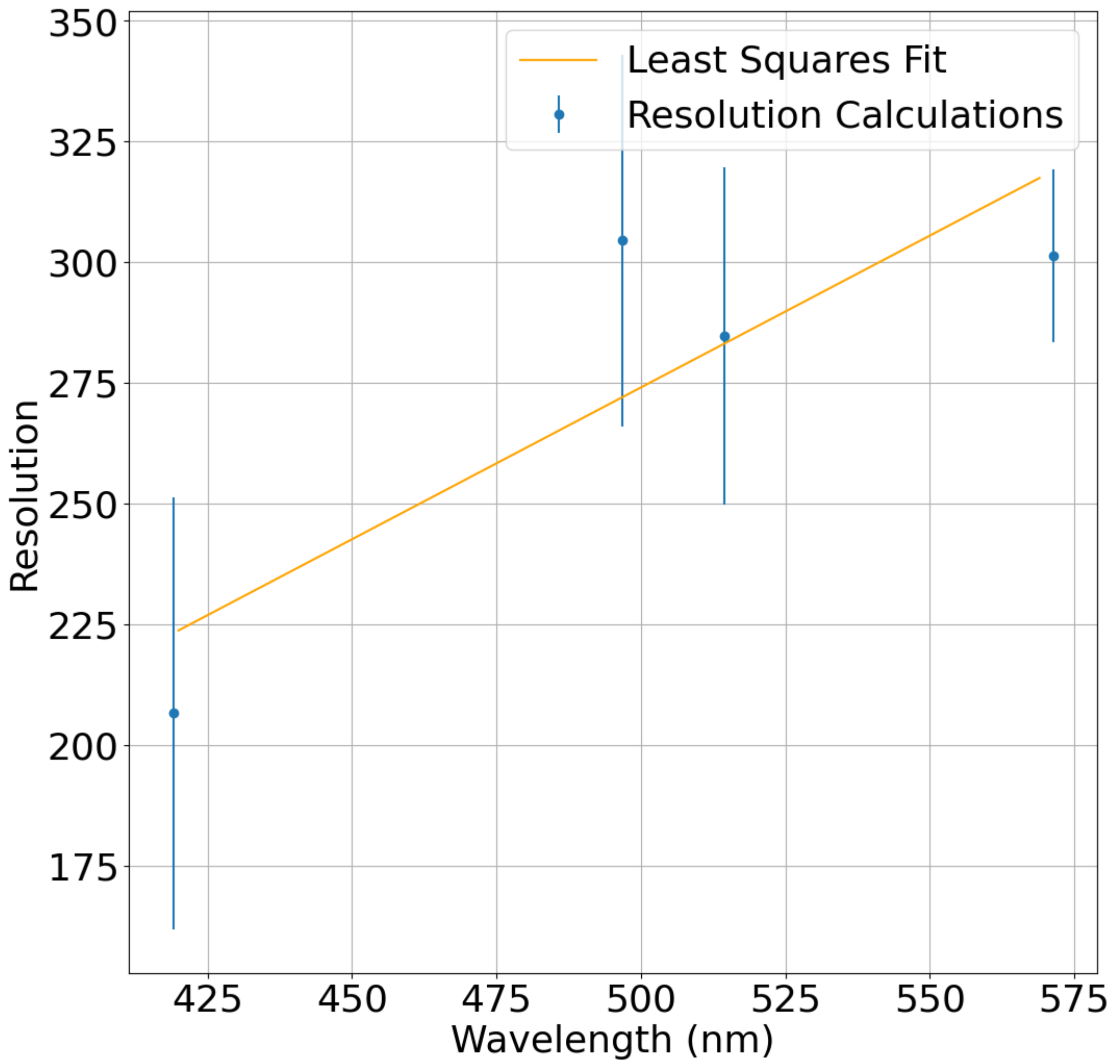
```
Resolution of the spectrograph at 571.39 nm: 301.36518
Resolution of the spectrograph at 514.48 nm: 284.79700
Resolution of the spectrograph at 496.73 nm: 304.49310
Resolution of the spectrograph at 419.06 nm: 206.63528
```

[39]:
```
uR1 = resUncertainty(gaussPars01[0], gaussPars01[1],np.sqrt(gaussCov01[0][0]),␣
 ↪np.sqrt(gaussCov01[1][1]))
uR2 = resUncertainty(gaussPars02[0], gaussPars02[1],np.sqrt(gaussCov02[0][0]),␣
 ↪np.sqrt(gaussCov02[1][1]))
uR3 = resUncertainty(gaussPars03[0], gaussPars03[1],np.sqrt(gaussCov03[0][0]),␣
 ↪np.sqrt(gaussCov03[1][1]))
uR4 = resUncertainty(gaussPars04[0], gaussPars04[1],np.sqrt(gaussCov04[0][0]),␣
 ↪np.sqrt(gaussCov04[1][1]))
uR = [uR1, uR2, uR3, uR4]
print(uR)
```

```
[17.86805221558772, 34.89525500297671, 38.51343788860465, 44.725515255856266]
```

[40]:
```
peaksForRes = [gaussPars01[0], gaussPars04[0], gaussPars02[0], gaussPars03[0]]
plt.errorbar(peaksForRes, resolutions, yerr=uR, label="Resolution␣
 ↪Calculations", fmt="o")

def linFit(x, m, c):
    return x*m + c

resPars, resCov = scipy.optimize.curve_fit(linFit, peaksForRes,resolutions)
plt.plot(np.arange(420, 570, 1), linFit(np.arange(420, 570, 1), resPars[0],␣
 ↪resPars[1]),\
         color="orange", label="Least Squares Fit")

plt.legend()
plt.grid()
plt.xlabel("Wavelength (nm)")
plt.ylabel("Resolution")

print(resPars[0], resPars[1])
print(np.sqrt(resCov[0][0]), np.sqrt(resCov[1][1]))
```

```
0.628751594086656 -40.313700669343525
0.2629224814699645 132.34737527398428
```



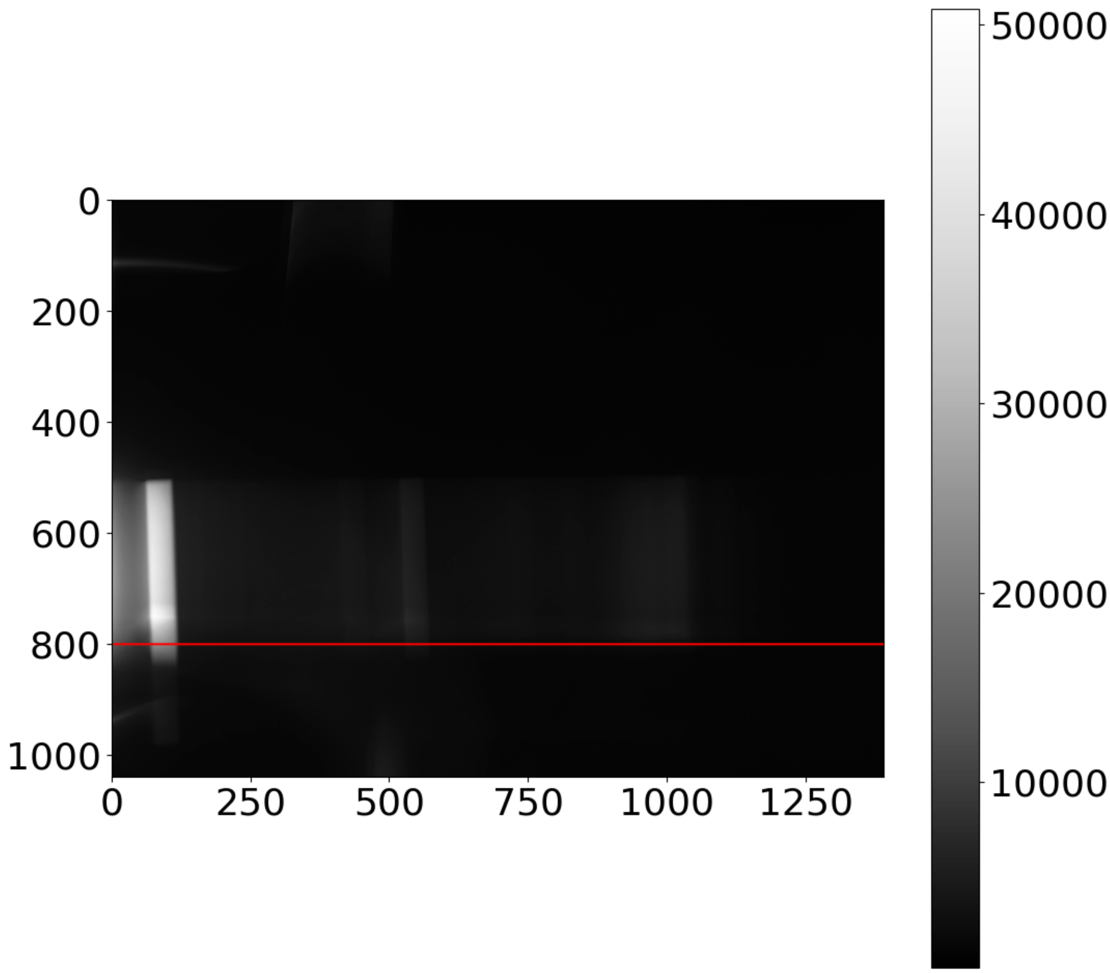
4 Effect of slit width on the resolution

[26]:
```python
imageSlit = fits.open(r"/home/daraghhollman/jupyter/UCD_PASS_Labs/CCDs/Data_D1/
↪daragh_ccd/Na_Slit_big/Na_Slit_big/big/Na_773.fit")
print(np.shape(imageSlit[0].data))
```

```
(1039, 1391)
```

[27]:
```python
plt.imshow(imageSlit[0].data, cmap="Greys_r")
plt.plot(np.arange(0, 1391, 1), [800]*(1391), color="red")
plt.colorbar()
```

[27]: <matplotlib.colorbar.Colorbar at 0x7f90a493fe80>



[28]:
```
line_valuesSlit = imageSlit[0].data[800]
print(max(line_valuesSlit))
```

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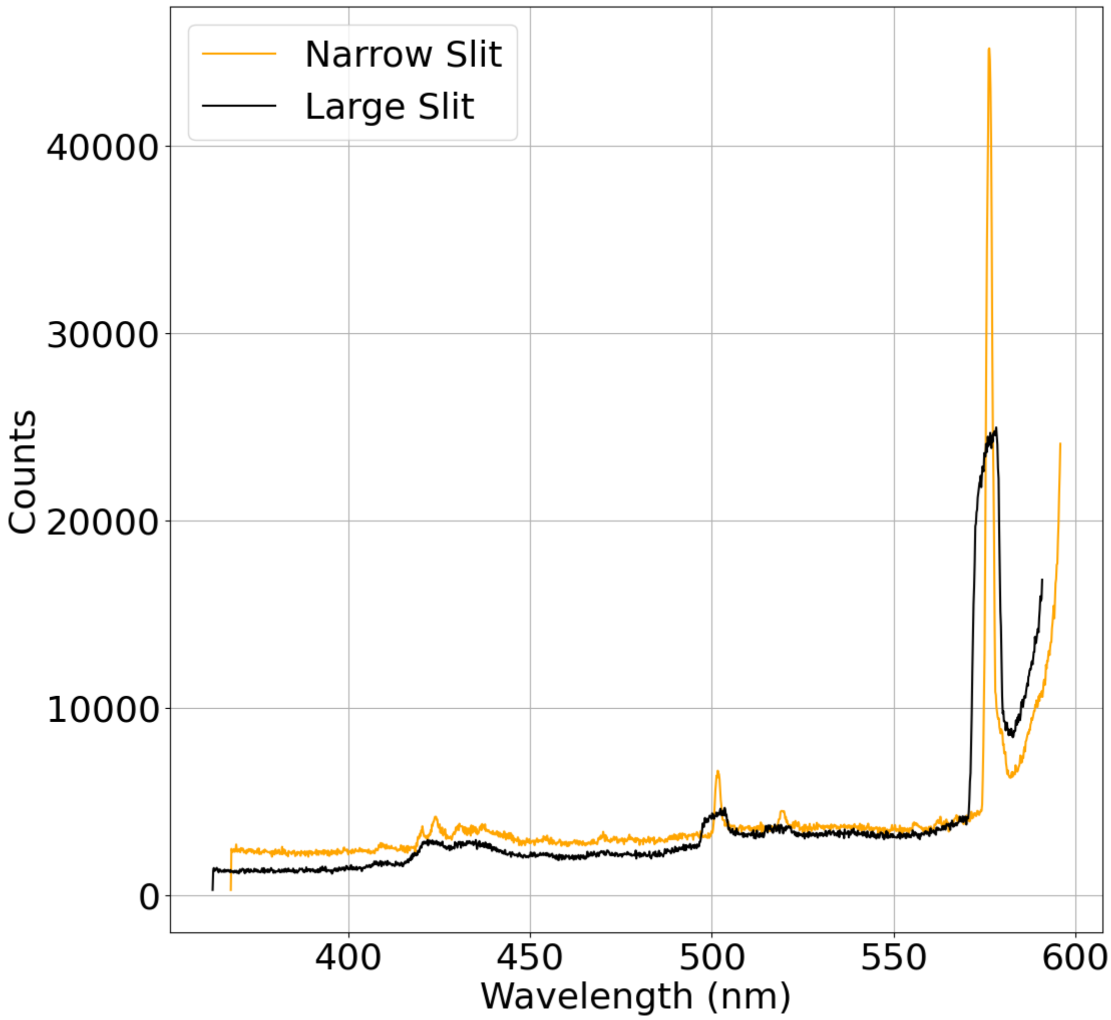
[29]:
```
xSlit = list()
ySlit = list()

k = 0
for el in line_valuesSlit:
    xSlit.append(k)
    ySlit.append(el)

    k+=1
```

[30]:
```
offset = 5
plt.plot([el + offset for el in NaWavelengths], yNa, color="orange",␣
 ↪label="Narrow Slit")
plt.plot(xToWavelength(xSlit, linPars[0], linPars[1]), ySlit, color="black",␣
 ↪label="Large Slit")

plt.legend()
plt.grid()
plt.xlabel("Wavelength (nm)")
plt.ylabel("Counts")
```

[30]:
```
Text(0, 0.5, 'Counts')
```



Note that the peaks are all wider which will yield a larger standard deviation and hence a smaller resolution, accuracy decreases. The images were taken at different exposures to avoid peaking the data however it is clear that the larger slit has wider peaks.

```
[ ]:
```