In [1]:
```
import matplotlib
import matplotlib.pyplot as plt
import numpy as np
import pandas as pd
from matplotlib import gridspec



from PIL import Image

import astropy.units as u
from astropy.constants import k_B
```

In [1]:
```
#Stating theme
import jupyterthemes as jt
!jt -t solarizedl -T -N -kl -nfs 11 -fs 11 -ofs 11 -cursc r -cellw 90%
# jt.jtplot.style()
jt.get_themes()
```

```
['chesterish',
 'grade3',
 'gruvboxd',
 'gruvboxl',
 'monokai',
 'oceans16',
 'onedork',
 'solarizedd',
 'solarizedl']
```

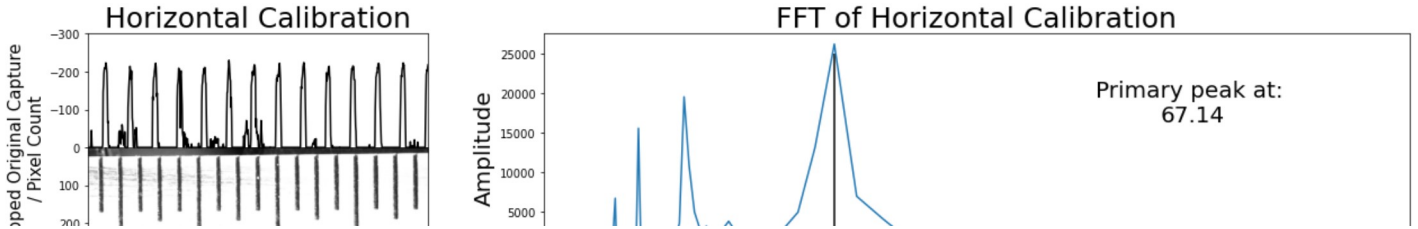
In [3]:
```
ls group02_data\stills
```

```
 Volume in drive C has no label.
 Volume Serial Number is F64F-FF16

 Directory of C:\Users\jarde\Documents\GitHub\AdvancedLab-PHSX444\lab04\group02_dat
a\stills

11/24/2021  10:44 PM    <DIR>          .
11/24/2021  10:44 PM    <DIR>          ..
11/24/2021  08:14 PM    <DIR>          __MACOSX
11/24/2021  08:14 PM         1,144,118 130V second attempt.bmp
11/24/2021  08:14 PM         1,144,118 40V second attempt.bmp
11/24/2021  08:14 PM         1,144,118 40V.bmp
11/24/2021  08:14 PM         1,144,118 Horzontal calibration bottom is mm.bmp
11/24/2021  10:44 PM           609,643 Horzontal-calibration-bottom-is-mm.png
11/24/2021  08:14 PM         1,144,118 Vertical calibration right is mm.bmp
11/24/2021  10:44 PM           929,345 Vertical-calibration-right-is-mm.png
               7 File(s)      7,259,578 bytes
               3 Dir(s)  127,143,337,984 bytes free
```

In [13]:
```
path = './group02_data/stills/'

plt.figure(figsize=(18,4))
plt.subplot(1,3,1)
im = Image.open(path + 'Horzontal calibration bottom is mm.bmp')
plt.imshow(np.array(im)[250:,:], cmap='Greys_r')
im_data = np.array(im)[1080, :]
plt.plot(im_data-np.max(im_data)*np.ones([im_data.size]), color='black')
plt.ylim(300,-300)
```

```
plt.title('Horizontal Calibration', fontsize=25)
plt.ylabel('Cropped Original Capture \n/ Pixel Count', fontsize=15)
plt.xlim(0, 900)

plt.subplot(1,3,(2,3))
freq = np.fft.fftfreq(im_data.shape[0])
data = np.fft.fft(im_data)
plt.plot(1/freq, np.abs(data.real))
plt.xlim(0,200)
plt.xlabel('1/freq (s)', fontsize=20)
plt.ylabel('Amplitude', fontsize=20)
plt.title('FFT of Horizontal Calibration', fontsize=25)

maxpos = np.where(data == max(data[1:]))
plt.vlines(1/abs(freq[maxpos]), 0, 25000, color='black')
plt.text(150, 25000*.75, f"Primary peak at: \n{float(1/abs(freq[maxpos])):.2f}", fontsi
         ha='center', va='center', color='black')
plt.tight_layout()
plt.savefig('hori_cali.pdf')
plt.show()
```

```
<ipython-input-13-53502d9c0cb1>:17: RuntimeWarning: divide by zero encountered in t
rue_divide
  plt.plot(1/freq, np.abs(data.real))
```

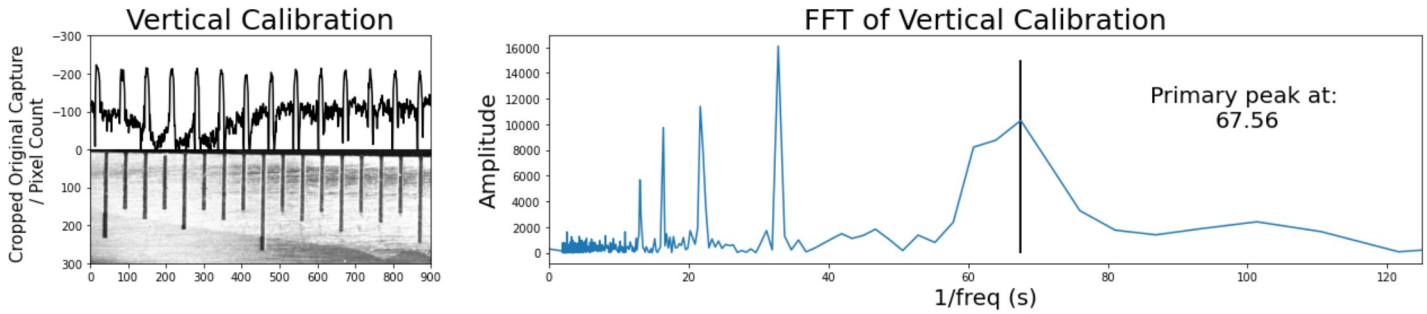


In [8]:

```
plt.figure(figsize=(18,4))
plt.subplot(1,3,1)
im = Image.open(path + 'Vertical calibration right is mm.bmp')
plt.imshow((np.array(im).T)[100:400, :], cmap='Greys_r')
im_data = np.array(im)[:, 900]
plt.plot(im_data-np.max(im_data)*np.ones([im_data.size]), color='black')
plt.ylim(300,-300)
plt.title('Vertical Calibration', fontsize=25)
plt.ylabel('Cropped Original Capture \n/ Pixel Count', fontsize=15)
plt.xlim(0, 900)



plt.subplot(1,3,(2,3))
freq = np.fft.fftfreq(im_data.shape[0])
data = np.fft.fft(im_data)
plt.plot(1/freq, np.abs(data.real))
plt.xlim(0,125)
plt.xlabel('1/freq (s)', fontsize=20)
plt.ylabel('Amplitude', fontsize=20)
plt.title('FFT of Vertical Calibration', fontsize=25)

data = np.abs(data)
maxpos = np.where(data == max(data[10:35]))
plt.vlines(1/abs(freq[maxpos]), 0, 15000, color='black')
plt.text(100, 15000*.75, f"Primary peak at: \n{float(1/abs(freq[maxpos])[0]):.2f}", for
         ha='center', va='center', color='black')
plt.tight_layout()
```

```
plt.savefig('vert_cali.pdf')
plt.show()
```

```
<ipython-input-8-017abaa11b70>:16: RuntimeWarning: divide by zero encountered in tr
ue_divide
  plt.plot(1/freq, np.abs(data.real))
```



In [6]:
```
1/abs(freq[maxpos])[0]
```

```
67.55555555555556
```

In [6]:
```
xscale = (66)
yscale = (67)
xpix = u.def_unit('xpix', 1*u.mm/xscale)
ypix = u.def_unit('ypix', 1*u.mm/yscale)
```

key for runs:

- 01: 60 Hz capture #1
- 02: 60 Hz fist bump#1
- 03: 61 Hz Capture #1
- 04: 198 Hz capture #2 (good) copy
- 05: 198 Hz fist bump #1

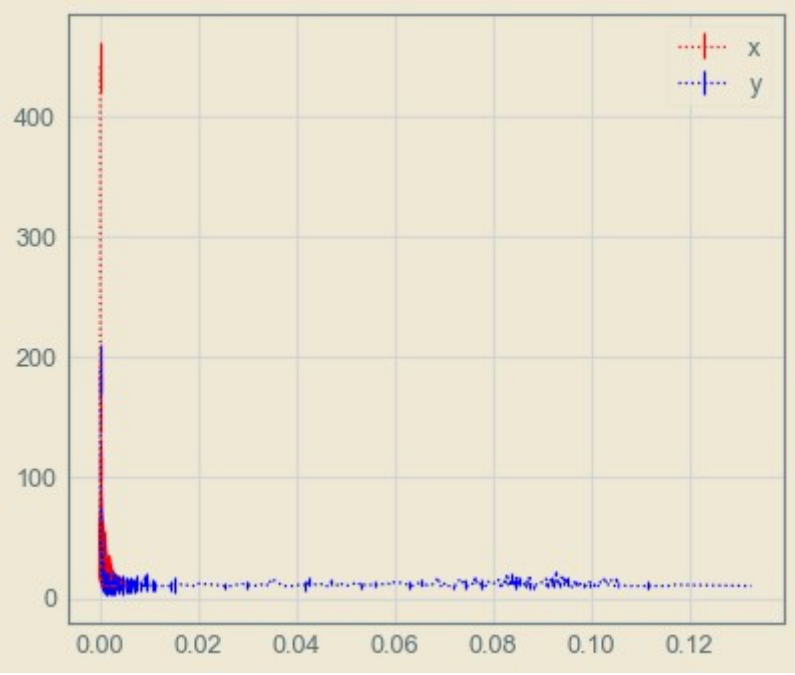
In [6]:
```
ls
```

```
 Volume in drive C is OS
 Volume Serial Number is 4E89-5B0C

 Directory of C:\Users\WillsPc\GitHub\AdvancedLab-PHSX444\lab04

11/26/2021  12:33 PM    <DIR>          .
11/26/2021  12:33 PM    <DIR>          ..
11/25/2021  01:25 AM    <DIR>          .ipynb_checkpoints
11/26/2021  12:33 PM         1,346,125 analysis.ipynb
11/26/2021  12:10 PM             8,219 Analysis.py
11/25/2021  01:25 AM               840 calibration.py
11/25/2021  01:25 AM             5,871 cross-correlate_simple.py
11/25/2021  01:26 AM    <DIR>          group02_data
11/26/2021  11:23 AM    <DIR>          images
11/05/2021  05:22 AM    <DIR>          lab_4_Paul_trapping
11/25/2021  01:26 AM    <DIR>          processed_data
11/05/2021  05:22 AM             1,583 Table of Contents.html
11/25/2021  01:25 AM    <DIR>          TheRealDay2lab04ForRealThisIsTheOneWeWant
               5 File(s)      1,362,638 bytes
               8 Dir(s)  294,293,987,328 bytes free
```

In [7]:

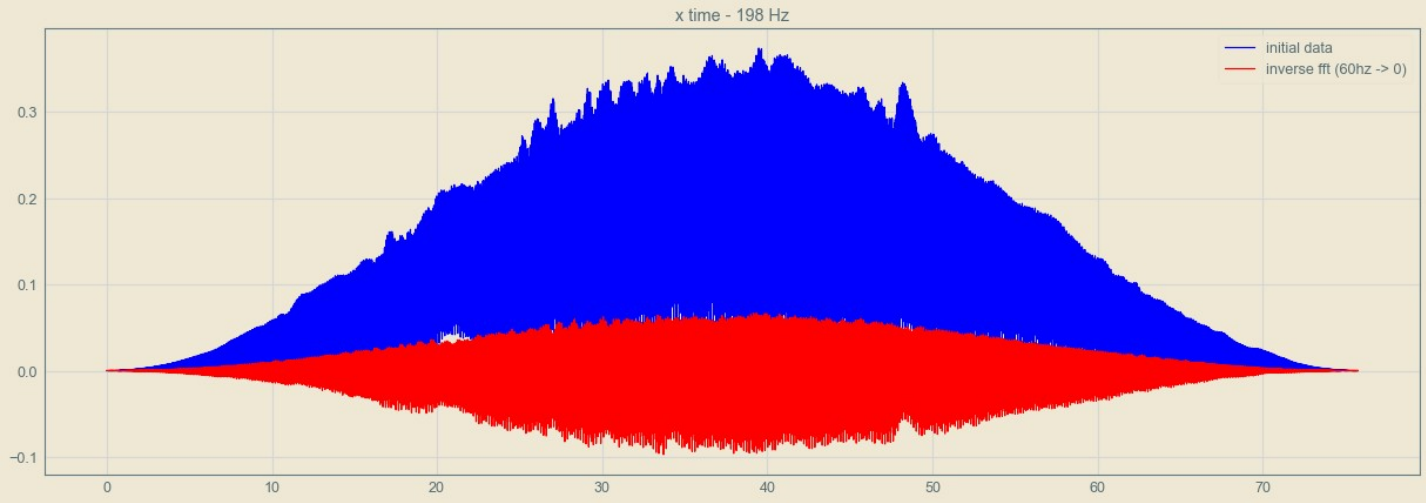
```
data = pd.read_csv("group02_data/processed_data/data_04.csv")
data.rename(columns={'# x': 'x'}, inplace=True)

data.loc[:, 'x'] = (np.array(data.loc[:, 'x']) * xpix).to(u.mm)
data.loc[:, 'y'] = (np.array(data.loc[:, 'y']) * ypix).to(u.mm)
```

In [8]:
```
hisx = np.histogram((data["x"]-np.mean(data["x"]))**2, bins=5000)
df = pd.DataFrame({'bin_right': hisx[1][1:], 'count':hisx[0], 'err':np.sqrt(hisx[0])})
df = df[df['count'] >= 10]
plt.errorbar(df['bin_right'], df['count'], yerr = df['err'], linestyle=":", marker="x",

hisy = np.histogram((data["y"]-np.mean(data["y"]))**2, bins=5000)
df = pd.DataFrame({'bin_right': hisy[1][1:], 'count':hisy[0], 'err':np.sqrt(hisx[0])})
df = df[df['count'] >= 10]
plt.errorbar(df['bin_right'], df['count'], yerr = df['err'], linestyle=":", marker="x",
plt.legend()
plt.show()
```



In [9]:
```
dat = np.sqrt(data['x']**2 + data['y']**2)*np.hanning(len(data['x']))
```

```
plt.figure(figsize=(21,7))
dat_four = np.fft.fft(dat)
freq = np.fft.fftfreq(len(dat), 1/198)
dffreq = pd.DataFrame({'freq':freq, 'data': dat_four})
plt.plot(dffreq['freq'], np.abs(dffreq['data']), color='blue', label='fft')
dffreq.loc[(dffreq['freq']>59) & (dffreq['freq']<61), 'data']=0
dffreq.loc[(dffreq['freq']<1), 'data']=0
plt.plot(dffreq['freq']+1, np.abs(dffreq['data']), color='red', label='fft (60hz -> 0)'
plt.title('x fourier - 198 Hz')
plt.legend()
plt.show()

plt.figure(figsize=(21,7))
t = np.linspace(0,len(dat)*1/198, len(dat))
plt.plot(t, dat, label='initial data',color = 'blue')
inverse_data = np.fft.ifft(dffreq['data'])
t = np.linspace(0,len(inverse_data)*1/198, len(inverse_data))
plt.title('x time - 198 Hz')
plt.plot(t, np.fft.ifft(dffreq['data']).real, label='inverse fft (60hz -> 0)', color='r
plt.legend()
plt.show()
```

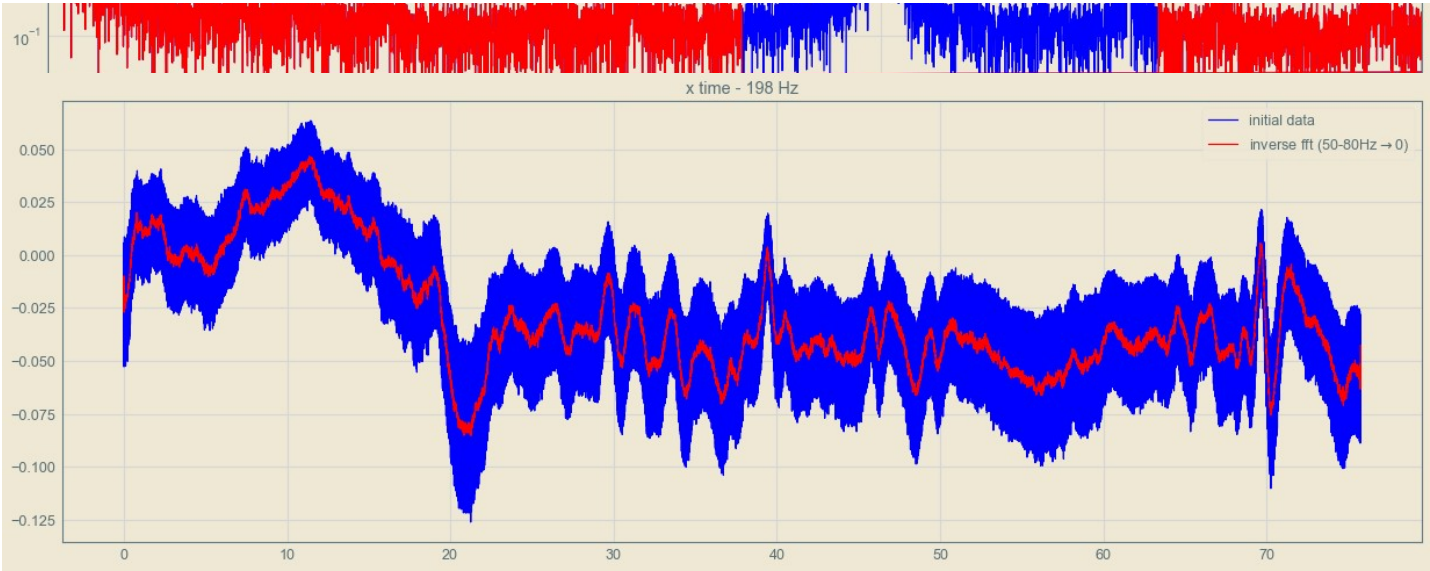


In [10]:

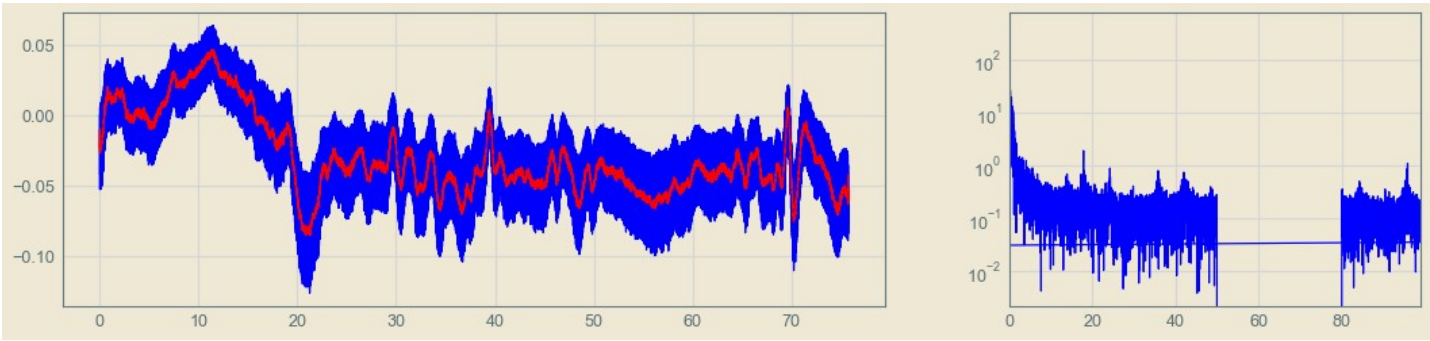
```
plt.figure(figsize=(21,7))
# datax = data['x']*np.hanning(len(data['x']))
datax = data['x']
datax_four = np.fft.fft(datax)
freq = np.fft.fftfreq(len(datax), 1/198)
dffreq = pd.DataFrame({'freq':freq, 'data': datax_four})
plt.plot(dffreq['freq'], np.abs(dffreq['data']), color='blue', label='FFT')
dffreq.loc[(np.abs(dffreq['freq'])>50) & (np.abs(dffreq['freq'])<80), 'data']=0
plt.plot(dffreq['freq'], np.abs(dffreq['data']), color='red', label=r'FFT (50-80Hz$\rig
plt.title('x fourier - 198 Hz')
plt.legend()
plt.yscale('log')
plt.xlim(0., np.max(dffreq['freq']))
plt.show()

plt.figure(figsize=(21,7))
```

```
t = np.linspace(0,len(data['x'])*1/198, len(data['x']))
# plt.plot(t, data['x']*np.hanning(len(data['x'])), label='initial data',color = 'blue'
plt.plot(t, data['x'], label='initial data',color = 'blue')
inverse_datax = np.fft.ifft(dffreq['data']).real
t = np.linspace(0,len(inverse_datax)*1/198, len(inverse_datax))
plt.title('x time - 198 Hz')
plt.plot(t, inverse_datax, label=r'inverse fft (50-80Hz$\rightarrow$0)', color='red')
plt.legend()
plt.show()
```

```
fig = plt.figure()
fig.set_figheight(4)
fig.set_figwidth(18)
spec = gridspec.GridSpec(nrows=1, ncols=2, width_ratios=[2, 1], wspace=0.2, hspace=0.5)
ax0 = fig.add_subplot(spec[0])
ax1 = fig.add_subplot(spec[1])

ax1.plot(dffreq['freq'], np.abs(dffreq['data']), color='blue', label='FFT')
ax1.set_yscale('log')
ax1.set_xlim(0., np.max(dffreq['freq']))

ax0.plot(t, data['x'], label='initial data',color = 'blue')
ax0.plot(t, inverse_datax, label=r'inverse fft (50-80Hz$\rightarrow$0)', color='red')
fig.tight_layout()
plt.show()
```



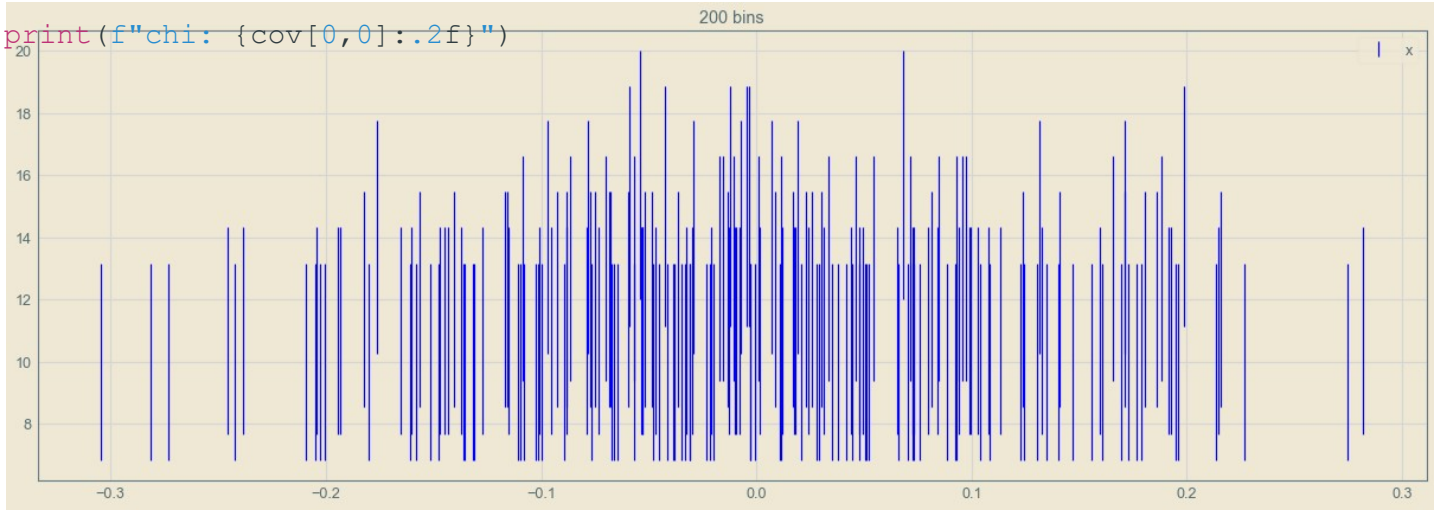

```
<ipython-input-10-60405f5ffb9e>:41: UserWarning: This figure includes Axes that are
not compatible with tight_layout, so results might be incorrect.
  fig.tight_layout()
```

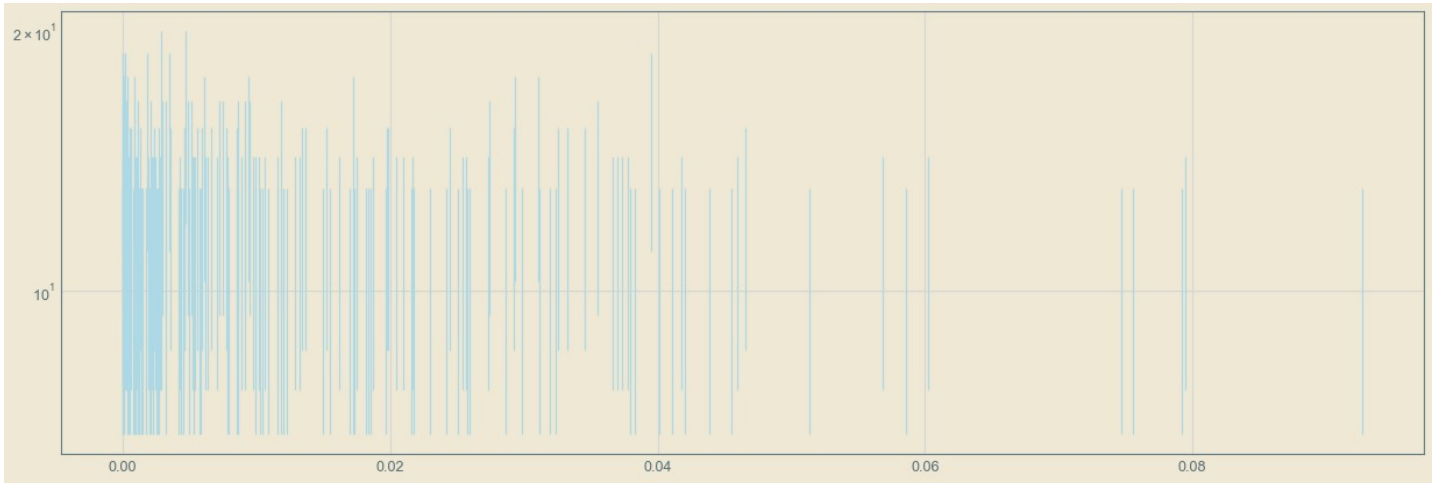


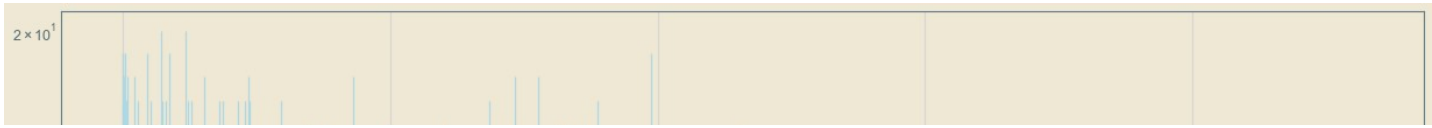
In [11]:
```
velx = (inverse_datax[1:] - inverse_datax[:-1])/(1/198)
t = np.linspace(0,len(velx)*1/198, len(velx))
```

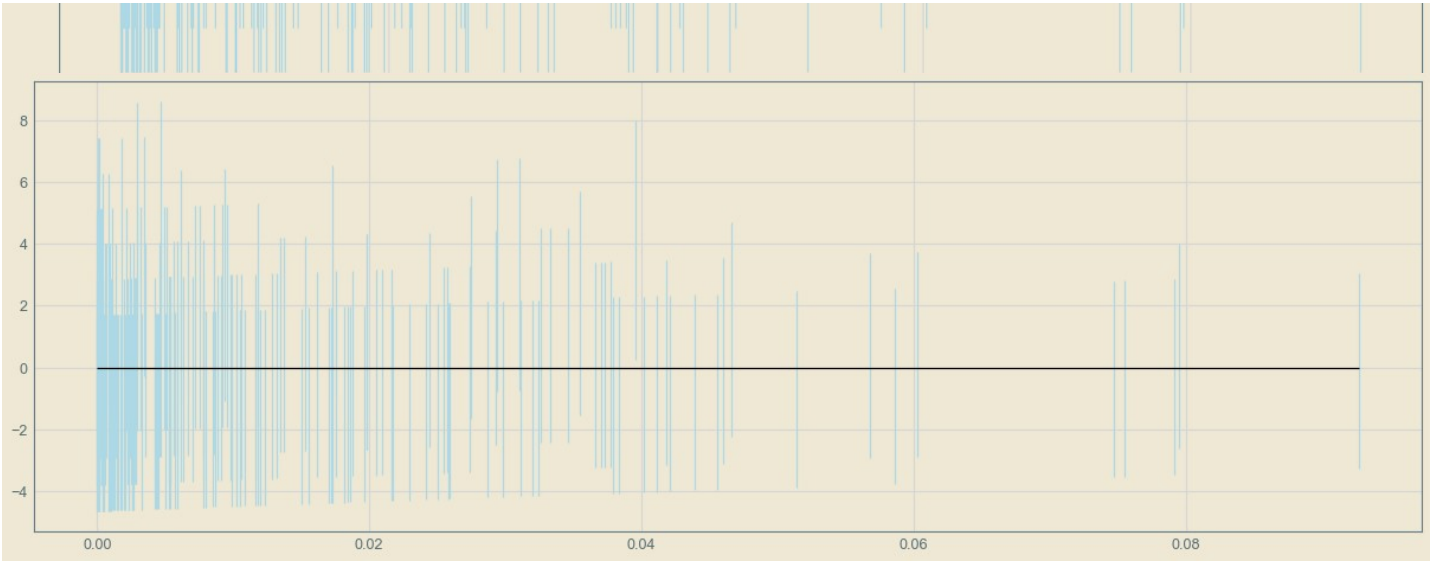
```
his_velx = np.histogram(velx, bins=20000)
df = pd.DataFrame({'bin_right': his_velx[1][1:], 'count':his_velx[0], 'err':np.sqrt(his
df = df[df['count'] >= 10]
plt.figure(figsize=(21,7))
plt.errorbar(df['bin_right'], df['count'], yerr = df['err'], linestyle="None", marker="
plt.legend()
plt.title('200 bins')
plt.show()

plt.figure(figsize=(21,7))
df['bin_right_squr'] = (df['bin_right'])**2
plt.errorbar(df['bin_right_squr'], df['count'], yerr = df['err'], linestyle="None", mar
plt.yscale('log')
plt.show()

#line fit
plt.figure(figsize=(21,7))
plt.errorbar(df['bin_right_squr'], df['count'], yerr = df['err'], linestyle="None", mar
fit, cov= np.polyfit(df['bin_right_squr'], np.log(df['count']), 1, w=np.log(df['err']),
x = np.linspace(np.min(df['bin_right_squr']), np.max(df['bin_right_squr']), 1000)
plt.plot(x, np.exp(fit[0]*x + fit[1]), color='black')
plt.yscale('log')
plt.show()

plt.figure(figsize=(21,7))
plt.errorbar(df['bin_right_squr'], df['count'] - np.exp(fit[0]*df['bin_right_squr'] + f
plt.hlines(0, np.min(df['bin_right_squr']), np.max(df['bin_right_squr']), color='black'
plt.show()
```

```
T = 298.15*u.Kelvin
m = (fit[0]*(-2*k_B * T)/(u.mm/u.s)**2).to(u.pg)
print(f"calculated mass: {m:.2e}")
print(f"chi: {cov[0,0]:.2f}")
```







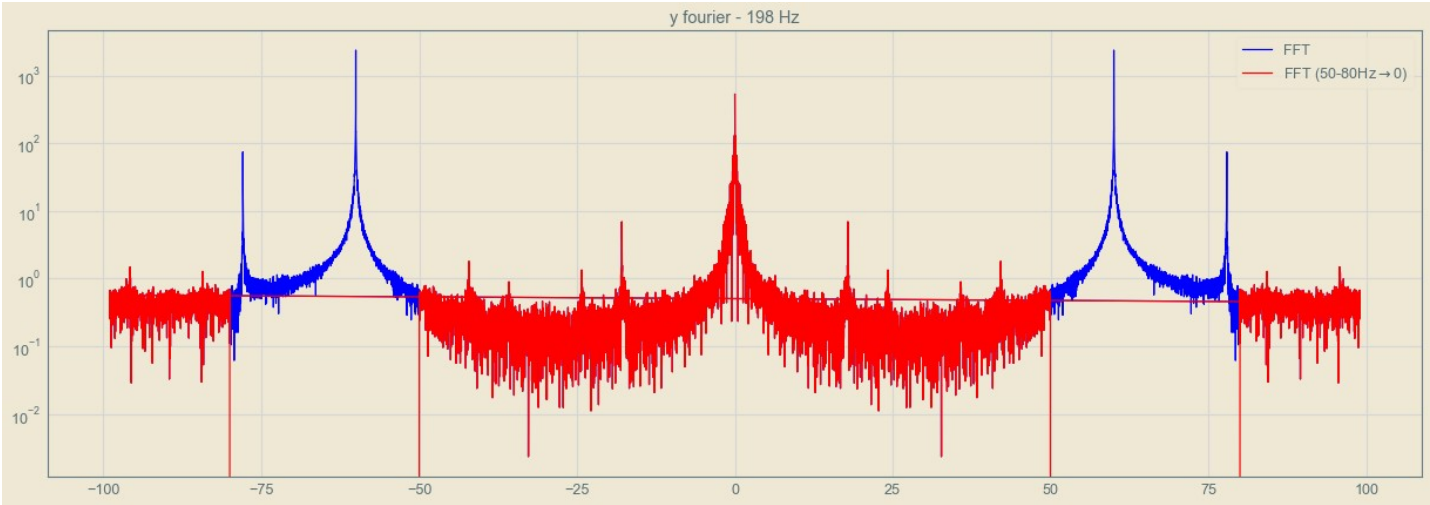


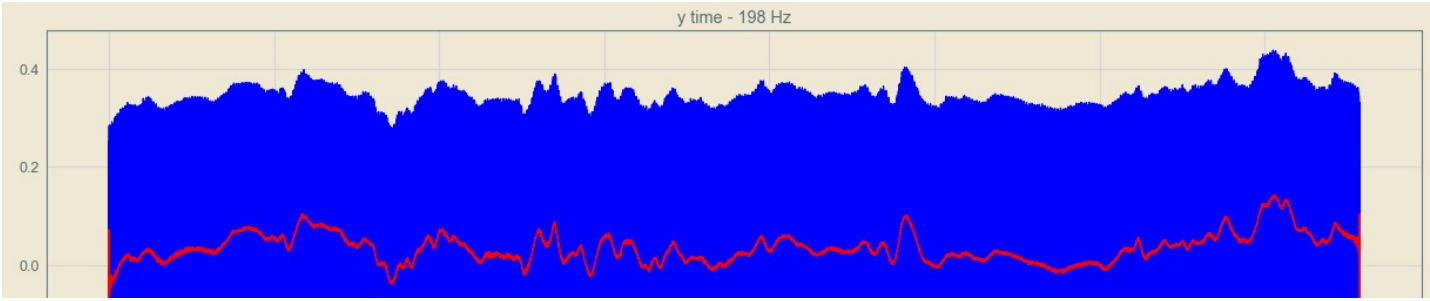

```
calculated mass: 1.12e+01 pg
chi: 0.25
```

In [29]:

```
plt.figure(figsize=(21,7))
# datay = data['y']*np.hanning(len(data['y']))
datay = data['y']
datay_four = np.fft.fft(datay)
freq = np.fft.fftfreq(len(datay), 1/198)
dffreq = pd.DataFrame({'freq':freq, 'data': datay_four})
plt.plot(dffreq['freq'], np.abs(dffreq['data']), color='blue', label='FFT')
dffreq.loc[(np.abs(dffreq['freq'])>50) & (np.abs(dffreq['freq'])<80), 'data']=0
plt.plot(dffreq['freq'], np.abs(dffreq['data']), color='red', label=r'FFT (50-80Hz$\rig
plt.title('y fourier - 198 Hz')
plt.legend()
plt.yscale('log')
plt.show()
```

```
plt.figure(figsize=(21,7))
t = np.linspace(0,len(data['y'])*1/198, len(data['y']))
# plt.plot(t, data['y']*np.hanning(len(data['y'])), label='initial data',color = 'blue'
plt.plot(t, data['y'], label='initial data',color = 'blue')
inverse_datay = np.fft.ifft(dffreq['data']).real
t = np.linspace(0,len(inverse_datay)*1/198, len(inverse_datay))
plt.title('y time - 198 Hz')
plt.plot(t, inverse_datay, label=r'inverse fft (50-80Hz$\rightarrow$0)', color='red')
plt.legend()
plt.show()
```

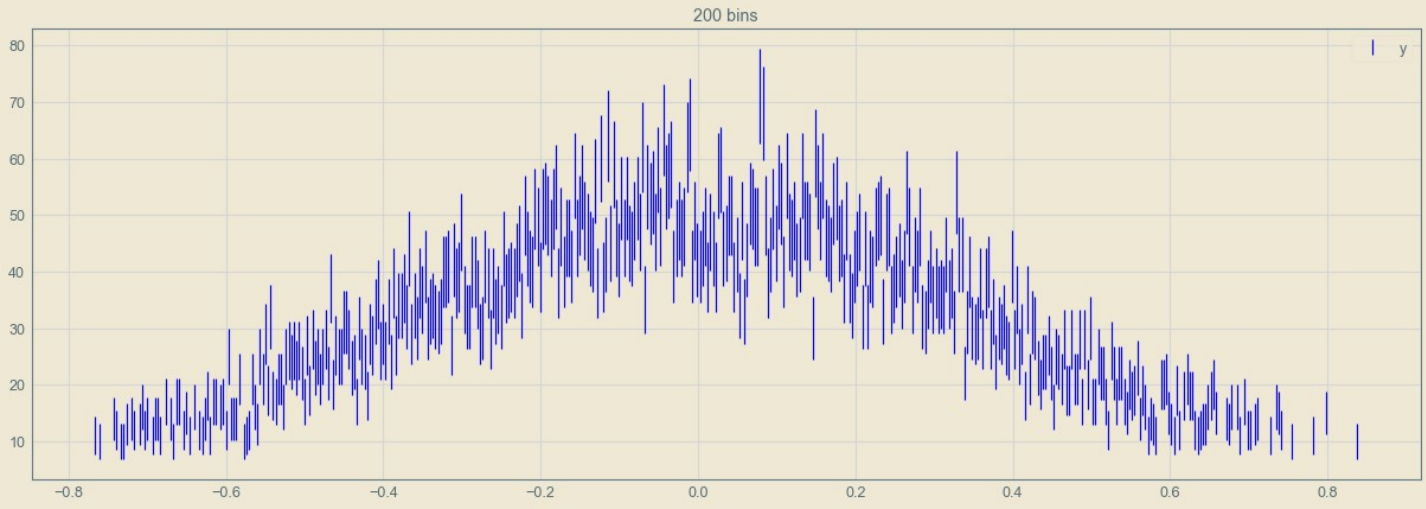


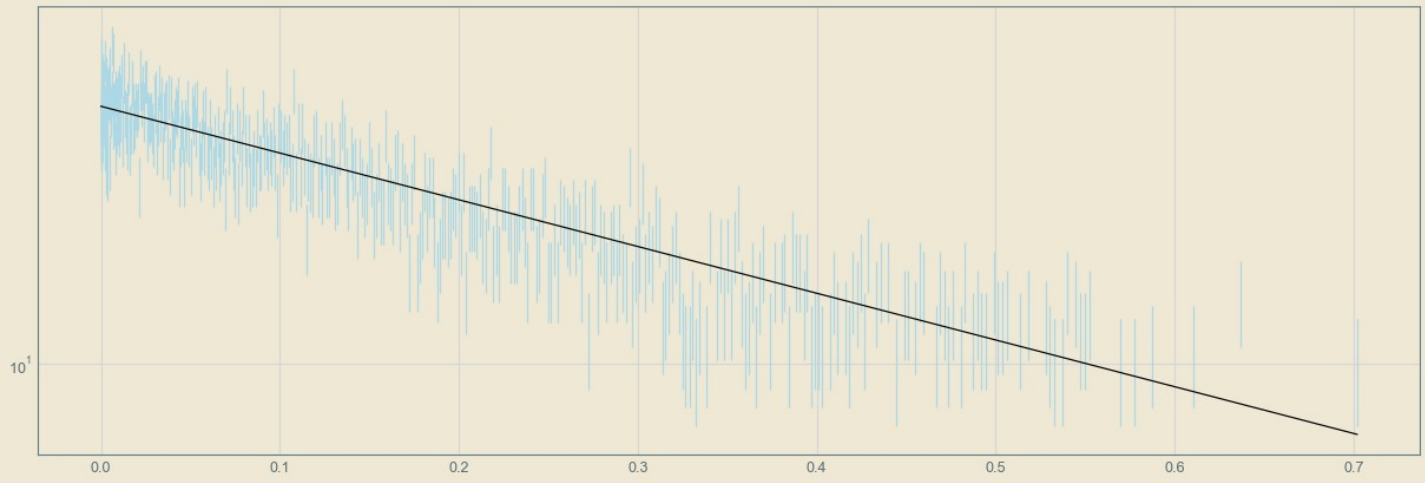


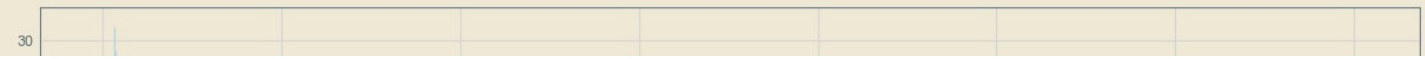
In [30]:

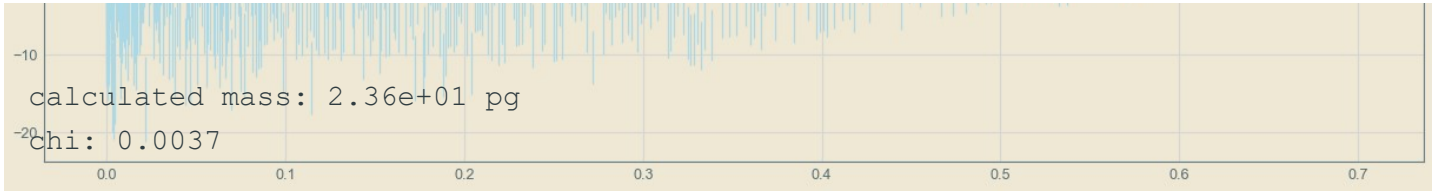
```
vely = (inverse_datay[1:] - inverse_datay[:-1])/(1/198)
t = np.linspace(0,len(vely)*1/198, len(vely))

his_vely = np.histogram(vely, bins=20000)
df = pd.DataFrame({'bin_right': his_vely[1][1:], 'count':his_vely[0], 'err':np.sqrt(his
df = df[df['count'] >= 10]
plt.figure(figsize=(21,7))
plt.errorbar(df['bin_right'], df['count'], yerr = df['err'], linestyle="None", marker="
plt.legend()
plt.title('200 bins')
plt.show()

df['bin_right_squr'] = (df['bin_right'])**2

#line fit
plt.figure(figsize=(21,7))
plt.errorbar(df['bin_right_squr'], df['count'], yerr = df['err'], linestyle="None", mar
fit, cov= np.polyfit(df['bin_right_squr'], np.log(df['count']), 1, w=np.log(df['err']),
x = np.linspace(np.min(df['bin_right_squr']), np.max(df['bin_right_squr']), 1000)
plt.plot(x, np.exp(fit[0]*x + fit[1]), color='black')
plt.yscale('log')
plt.show()

plt.figure(figsize=(21,7))
plt.errorbar(df['bin_right_squr'], df['count'] - np.exp(fit[0]*df['bin_right_squr'] + f
plt.hlines(0, np.min(df['bin_right_squr']), np.max(df['bin_right_squr']), color='black'
plt.show()
```

```
T = 298.15*u.Kelvin
m = (fit[0]*(-2*k_B * T)/(u.mm/u.s)**2).to(u.pg)
print(f"calculated mass: {m:.2e}")
print(f"chi: {cov[0,0]:.4f}")
```





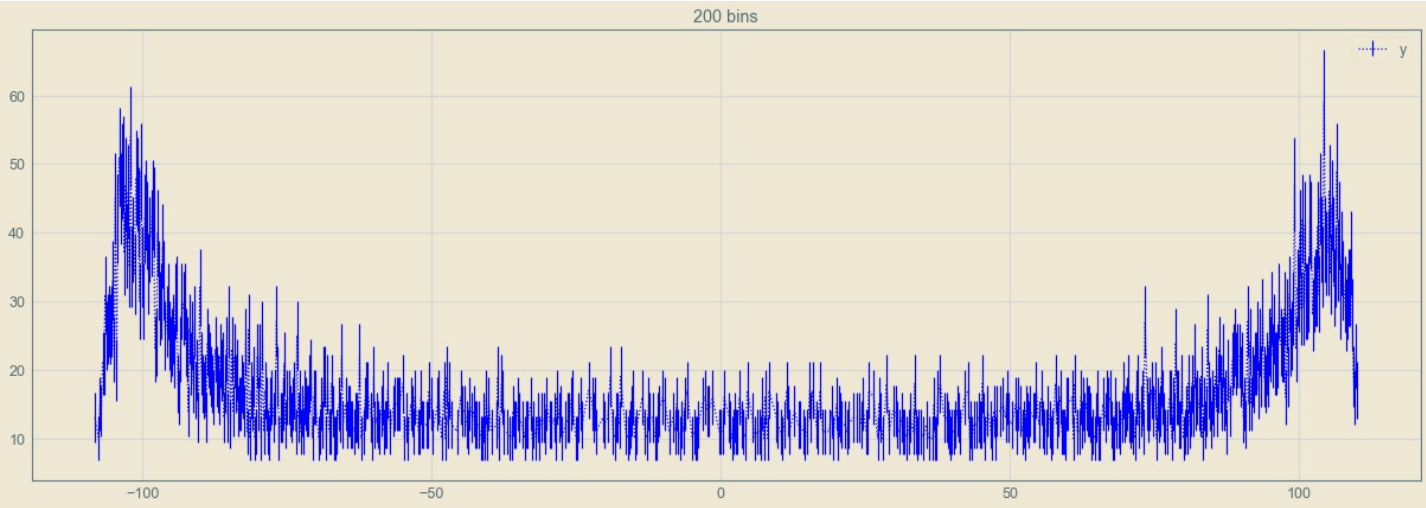


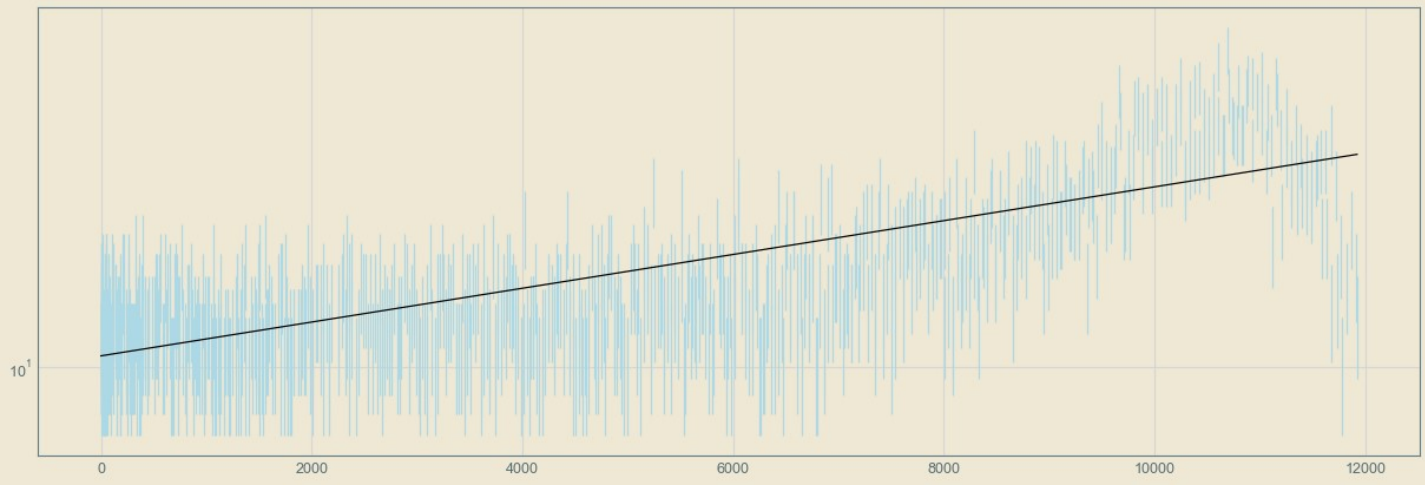


In [14]:

```
vel = (np.array(data['y'])[1:] - np.array(data['y'])[:-1])/(1/198)
t = np.linspace(0,len(vel)*1/198, len(vel))

his_vely = np.histogram(vel, bins=1000)
df = pd.DataFrame({'bin_right': his_vely[1][1:], 'count':his_vely[0], 'err':np.sqrt(his
df = df[df['count'] >= 10]
plt.figure(figsize=(21,7))
plt.errorbar(df['bin_right'], df['count'], yerr = df['err'], linestyle=":", marker="x",
plt.legend()
plt.title('200 bins')
plt.show()

df['bin_right_squr'] = (df['bin_right'] - np.mean(df['bin_right']))**2

plt.figure(figsize=(21,7))
plt.errorbar(df['bin_right_squr'], df['count'], yerr = df['err'], linestyle="None", mar
fit, cov = np.polyfit(df['bin_right_squr'], np.log(df['count']), 1, w=np.log(df['err'])
x = np.linspace(np.min(df['bin_right_squr']), np.max(df['bin_right_squr']), 1000)
plt.plot(x, np.exp(fit[0]*x + fit[1]), color='black')
plt.yscale('log')
plt.show()

T = 298.15*u.Kelvin
m = (fit[0]*(-2*k_B * T)/(u.mm/u.s)**2).to(u.pg)
```

```
print(f"calculated mass: {m:.2e}")
print(f"chi: {cov[0,0]:.2e}")
```



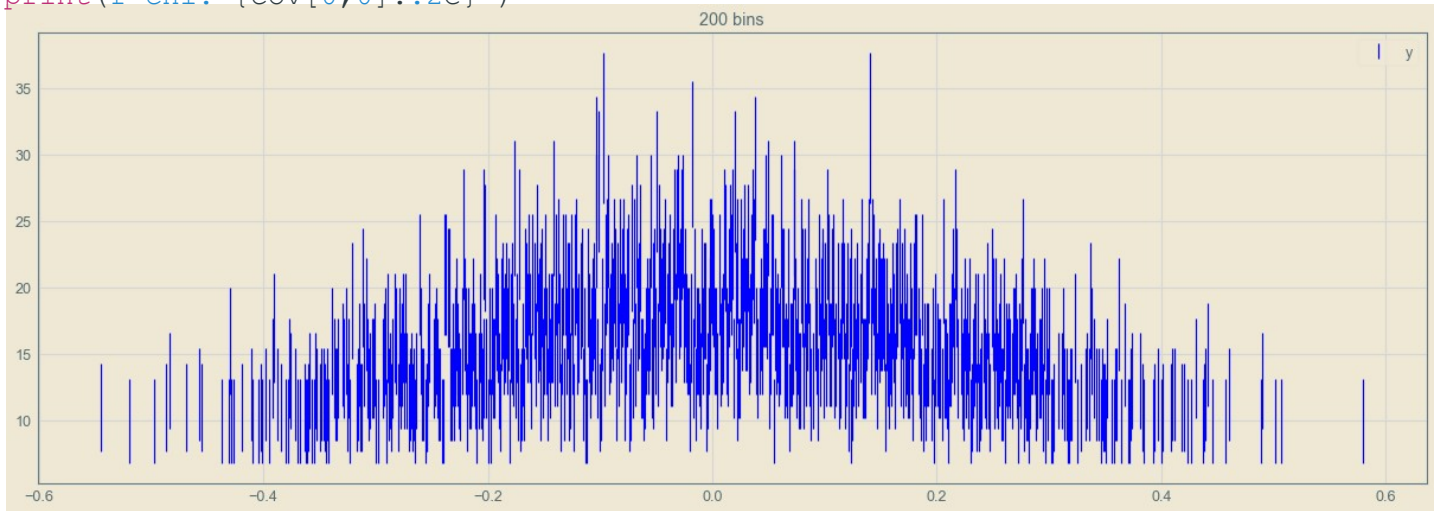


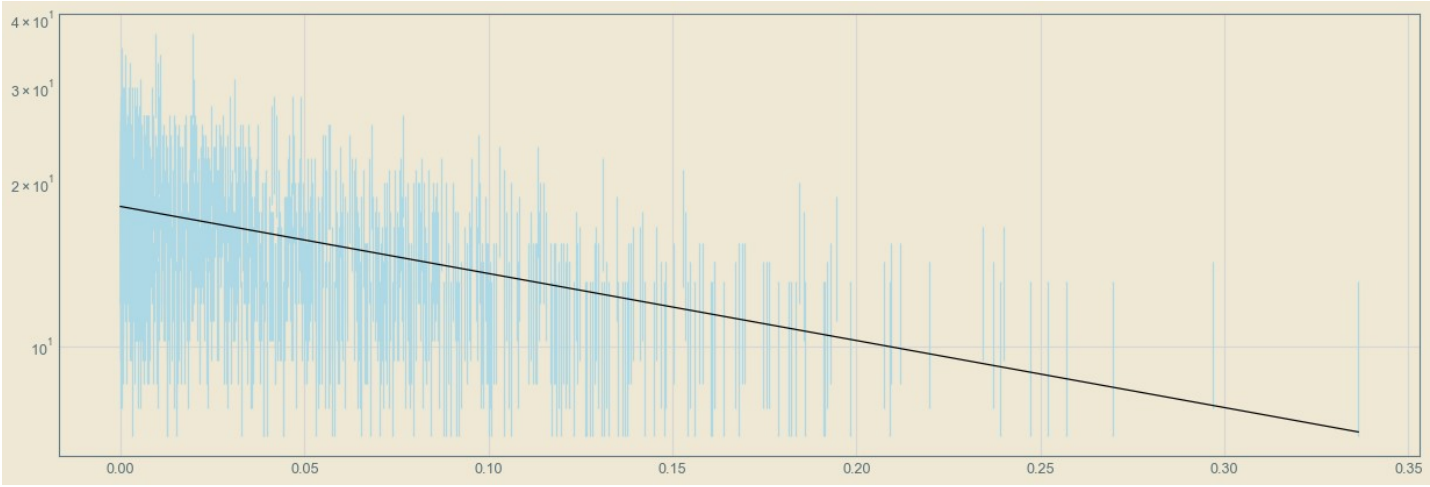

```
calculated mass: -7.77e-04 pg
chi: 6.93e-12
```

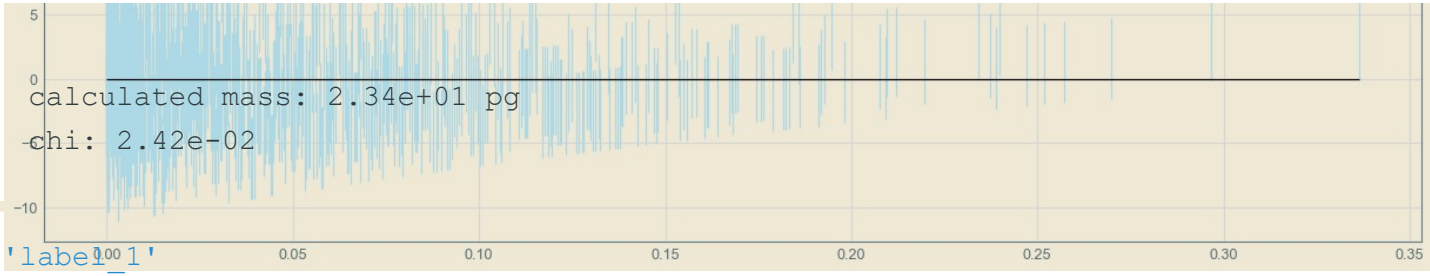
In [ ]:

In [15]:
```
inverse_data = np.sqrt(inverse_datay**2 + inverse_datax**2)
vel = (inverse_data[1:] - inverse_data[:-1])/(1/198)
t = np.linspace(0,len(vel)*1/198, len(vel))

his_vel = np.histogram(vel, bins=20000)
df = pd.DataFrame({'bin_right': his_vel[1][1:], 'count':his_vel[0], 'err':np.sqrt(his_v
df = df[df['count'] >= 10]
plt.figure(figsize=(21,7))
plt.errorbar(df['bin_right'], df['count'], yerr = df['err'], linestyle="None", marker="
plt.legend()
plt.title('200 bins')
plt.show()

df['bin_right_squr'] = (df['bin_right'])**2

#line fit
plt.figure(figsize=(21,7))
plt.errorbar(df['bin_right_squr'], df['count'], yerr = df['err'], linestyle="None", mar
fit, cov= np.polyfit(df['bin_right_squr'], np.log(df['count']), 1, w=np.log(df['err']),
x = np.linspace(np.min(df['bin_right_squr']), np.max(df['bin_right_squr']), 1000)
plt.plot(x, np.exp(fit[0]*x + fit[1]), color='black')
plt.yscale('log')
plt.show()

plt.figure(figsize=(21,7))
plt.errorbar(df['bin_right_squr'], df['count'] - np.exp(fit[0]*df['bin_right_squr'] + f
```

```
plt.hlines(0, np.min(df['bin_right_squr']), np.max(df['bin_right_squr']), color='black'
plt.show()

T = 298.15*u.Kelvin
m = (fit[0]*(-2*k_B * T)/(u.mm/u.s)**2).to(u.pg)
print(f"calculated mass: {m:.2e}")
print(f"chi: {cov[0,0]:.2e}")
```








```
calculated mass: 2.34e+01 pg
chi: 2.42e-02
```

In [16]:

```
'label_1'
'xlabel_1'
'ylabel_1'
'title_1'
'label_2'
'xlabel_2'
'ylabel_2'
'title_2'
'save_name'
```

```
'save_name'
```

In [17]:

```
import  matplotlib.pyplot as plt

X = [  (4,2,1),(4,2,2), (4,2,3), (4,2,5), (4,2,(4,6)), (4,1,4)]
plt.subplots_adjust(bottom=0, left=0, top = 0.975, right=1)
for nrows, ncols, plot_number in X:
    plt.subplot(nrows, ncols, plot_number)
    plt.xticks([])
    plt.yticks([])

plt.show()
```

In [18]:
```
X = [(1,3,(1,2)), (1,3,3)]
plt.figure(figsize=(14,4))
plt.subplots_adjust(bottom=0, left=0, top = 0.975, right=1)
for nrows, ncols, plot_number in X:
    plt.subplot(nrows, ncols, plot_number)
    plt.xticks([])
    plt.yticks([])
plt.show()
```

In [122]:
```
print(np.polyfit(df['bin_right_squr'], np.log(df['count']), 1, w=np.log(df['err']), cov
print(np.polyfit(df['bin_right_squr'], np.log(df['count']), 1, w=np.log(df['err']), cov
print(np.polyfit(df['bin_right_squr'], np.log(df['count']), 1, w=np.log(df['err']), ful
print(np.polyfit(df['bin_right_squr'], np.log(df['count']), 1, w=np.log(df['err'])))
```

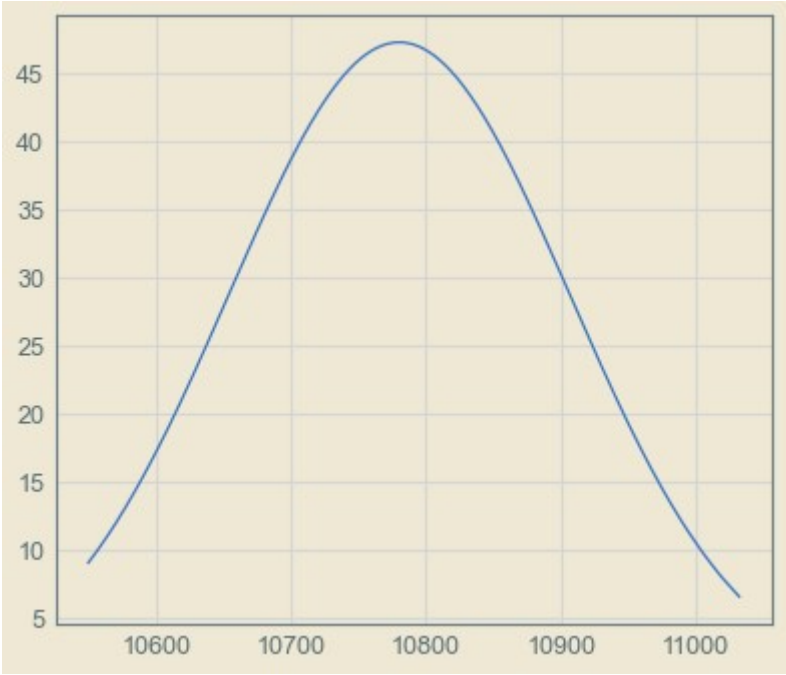
```
(array([-2.86610571,  3.8841373 ]), array([[ 0.0037412 , -0.00049914],
       [-0.00049914,  0.00014313]]))
```

In [124]:
```
p, res, x1, x2, x3= np.polyfit(df['bin_right_squr'], np.log(df['count']), 1, w=np.log(c
p, cov = np.polyfit(df['bin_right_squr'], np.log(df['count']), 1, w=np.log(df['err']),
chisq_red = float(res / (len(df['bin_right_squr']) - 2))
err_a = np.sqrt(cov[0,0])
```

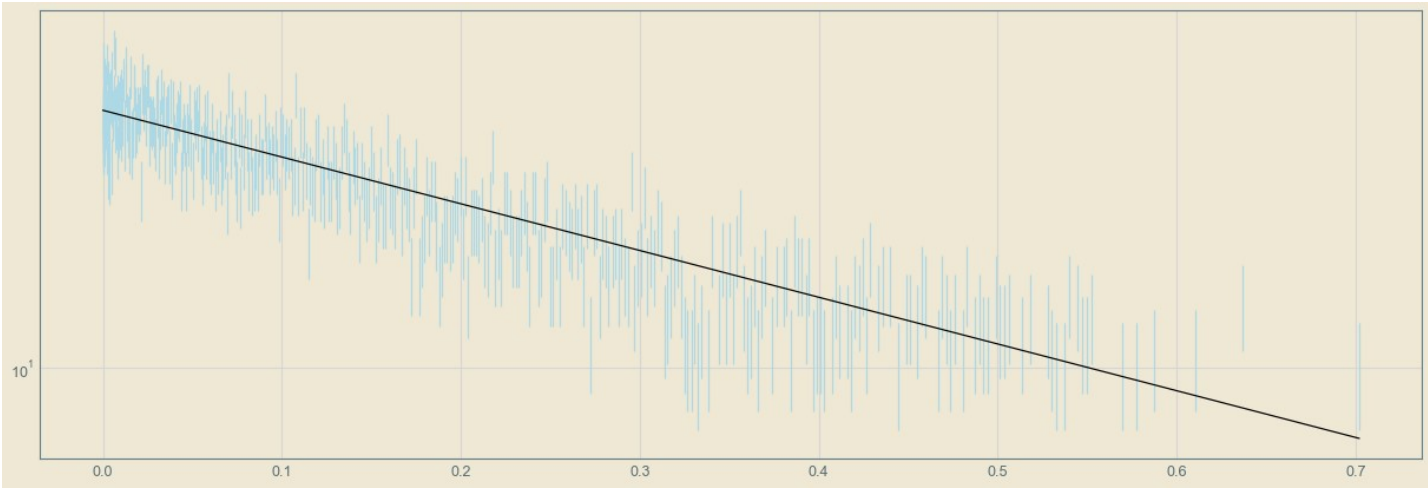
In [130]:
```
? np.polyfit
```

In [47]:
```
from numpy.polynomial import Polynomial
c = Polynomial.fit(df['bin_right_squr'], np.log(df['count']), deg=1)
plt.plot(np.exp(c(df['bin_right_squr'])))
c
```

$$x \mapsto 2.866284488582852 - 0.9898232441692835\ (-1.000002544769373 + 2.849438850436739x)$$



In [60]:
```
#line fit
plt.figure(figsize=(21,7))
plt.errorbar(df['bin_right_squr'], df['count'], yerr = df['err'], linestyle="None", mar
fit, cov= np.polyfit(df['bin_right_squr'], np.log(df['count']), 1, w=np.log(df['err']),
x = np.linspace(np.min(df['bin_right_squr']), np.max(df['bin_right_squr']), 1000)
plt.plot(x, np.exp(fit[0]*x + fit[1]), color='black')
plt.yscale('log')
plt.show()
```



In [48]:
```
fit
```

```
array([-2.86610571,  3.8841373 ])
```

In [133]:
```
(600*u.pg).to(u.ng)
```

0.6 ng