```python
# add BaITools to path
import os
import numpy as np
import sys
from IPython.display import Image
sys.path.insert(0,r'BaITools')
sys.path.insert(0,r'dlls')

dll_path = r"C:\Users\willi\OneDrive - The Webb Schools\Documents\BME Year 3\Build_Imager\Lab2\dlls"
os.environ["PATH"] = dll_path + os.pathsep + os.environ["PATH"]

# for basic functions
import numpy as np
from time import sleep
import matplotlib.pyplot as plt
from matplotlib import image as mpimg
from IPython.display import display, clear_output
import cv2
plt.rcParams['font.size'] = 16   # set the font size globally

from zelux import ZeluxCamera as Camera  # for camera
```

Fourier transform of real data

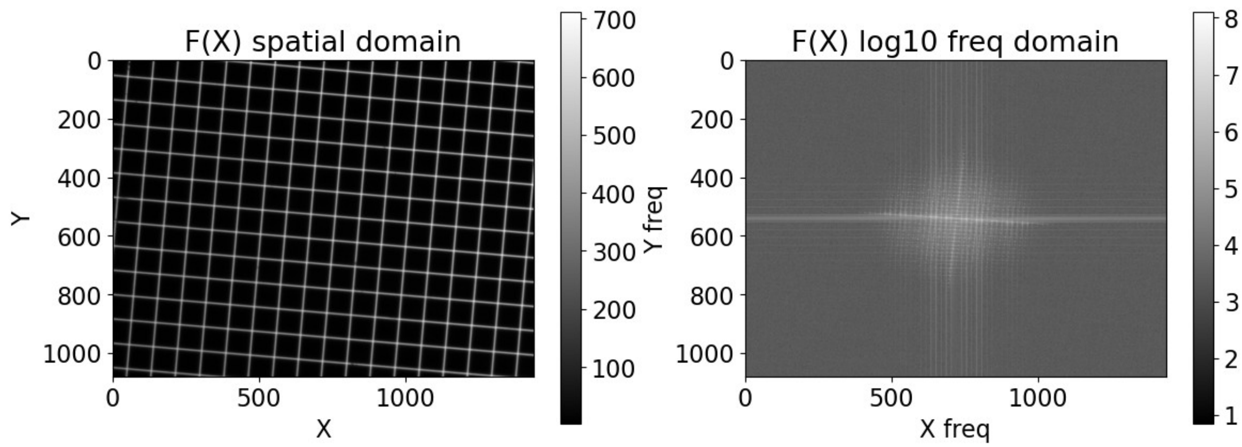
NOTE: We are using the Thorlabs CS165MU camera model, not the DCC3240M; therefore, our camera's pixel size is 3.45 microns. pixel size = 3.45 μm Average Square Length: 72 pixels Size of one pixel = 100μm / 72 pixels = 1.37 x 1.37 μm per pixel Magnification = 3.45 / 1.37 = 2.5 sampling freq = 1/1.37 μm

```python
x1 = np.array([200, 312])
x2 = np.array([206, 240])

a = x1-x2

np.sqrt(a[0]**2 + a[1]**2)
```

```
72.24956747275377
```

```python
# Image(filename=r"C:\Users\willi\OneDrive - The Webb Schools\Documents\BME Year 3\Build_Imager\Lab2\distance.png")

from numpy.fft import fft2, fftshift, ifftshift

img = np.load(r"C:\Users\willi\OneDrive - The Webb Schools\Documents\BME Year 3\Build_Imager\Lab2\distance.npy")
```

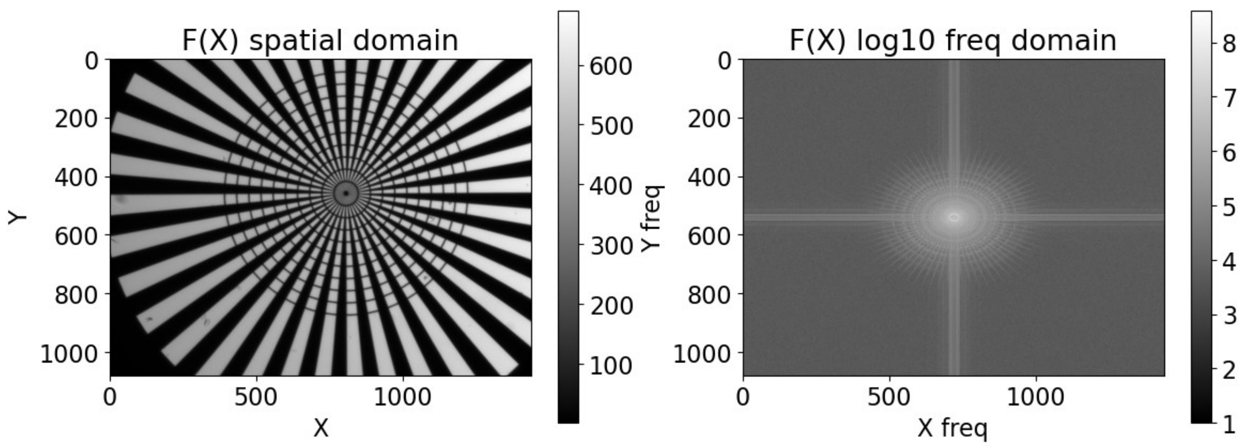
```
fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(14, 5))

x = ax1.imshow(img, cmap='gray')
fig.colorbar(x, ax=ax1)
ax1.set_title('F(X) spatial domain')
ax1.set_xlabel('X')
ax1.set_ylabel('Y')

fftshifted = fftshift(fft2(ifftshift(img)))
fftshifted = np.abs(fftshifted)
fftshifted = np.log10(fftshifted + 1)

z = ax2.imshow((fftshifted), cmap='gray')
fig.colorbar(z, ax=ax2)
ax2.set_title('F(X) log10 freq domain')
ax2.set_xlabel('X freq')
ax2.set_ylabel('Y freq')

plt.show()
```



The left image shows the spatial domain and shows the resolution target star that has concentric rings with alternating radial “spikes” that are black and white. The log10 image also contains the same radial “spikes” in the same direction as the star on the target. There is a circular central bright region, indicating strong low-frequency content. There are also concentric ring ripples similar to the concentric circles in the start target in the image. There is a faint cross-shaped structure in the X and Y direction.

```
# Image(filename=r"C:\Users\willi\OneDrive - The Webb Schools\Documents\BME Year 3\Build_Imager\Lab2\star.png")

img = np.load(r"C:\Users\willi\OneDrive - The Webb Schools\Documents\BME Year 3\Build_Imager\Lab2\star.npy")

fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(14, 5))
```

```
x = ax1.imshow(img, cmap='gray')
fig.colorbar(x, ax=ax1)
ax1.set_title('F(X) spatial domain')
ax1.set_xlabel('X')
ax1.set_ylabel('Y')

fftshifted = fftshift(fft2(ifftshift(img)))
fftshifted = np.abs(fftshifted)
fftshifted = np.log10(fftshifted + 1)

z = ax2.imshow((fftshifted), cmap='gray')
fig.colorbar(z, ax=ax2)
ax2.set_title('F(X) log10 freq domain')
ax2.set_xlabel('X freq')
ax2.set_ylabel('Y freq')

plt.show()
```

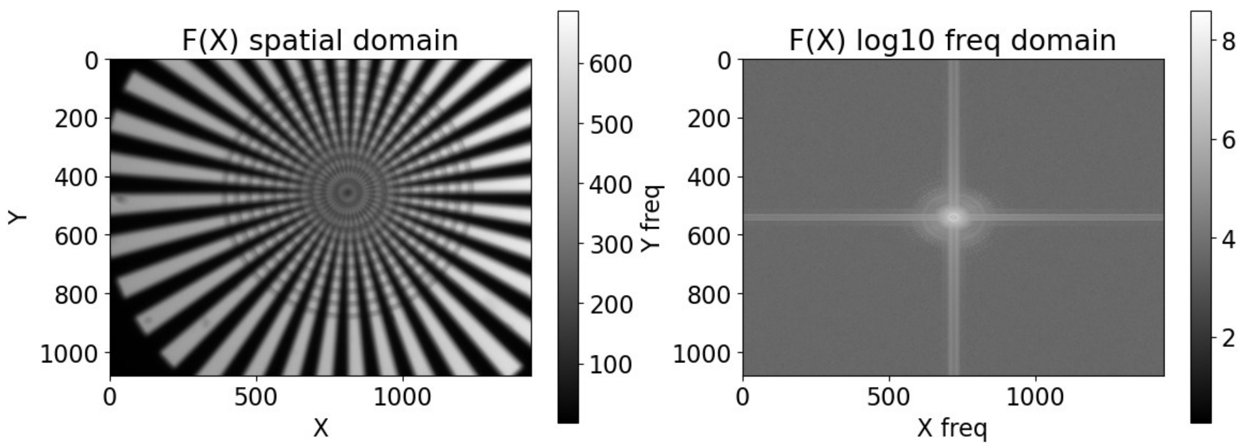


Effect of Defocus

In the left plot, the spatial domain image appears noticeably more blurred compared to the previously focused version. The radial lines are softer, and details especially near the center are harder to see. In the right plot, the log10 frequency domain shows a more prominent central cross, but there is a smaller diameter of the frequency circle, meaning we have lost high frequency signal. The concentric circles appear blurrier and smaller, and many high-frequency components are either blurred out or no longer visible. Overall, the defocus results in a loss of fine structure in both the spatial and frequency domains.

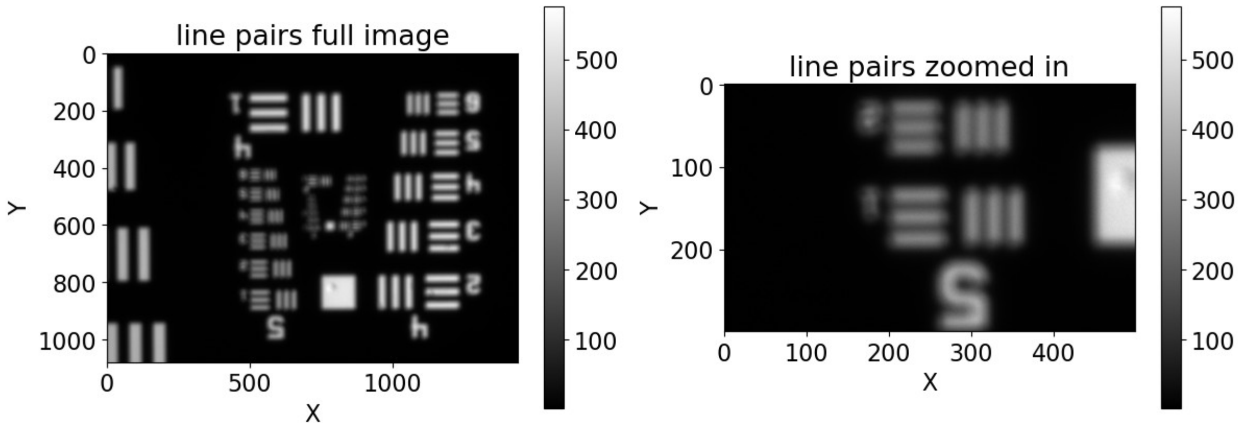
```
# Image(filename=r"C:\Users\willi\OneDrive - The Webb Schools\Documents\BME Year 3\Build_Imager\Lab2\star unfocus.png")

img = np.load(r"C:\Users\willi\OneDrive - The Webb Schools\Documents\BME Year 3\Build_Imager\Lab2\star unfocus.npy")
```

```python
fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(14, 5))

x = ax1.imshow(img, cmap='gray')
fig.colorbar(x, ax=ax1)
ax1.set_title('F(X) spatial domain')
ax1.set_xlabel('X')
ax1.set_ylabel('Y')

fftshifted = fftshift(fft2(ifftshift(img)))
fftshifted = np.abs(fftshifted)
fftshifted = np.log10(fftshifted + 1)

z = ax2.imshow((fftshifted), cmap='gray')
fig.colorbar(z, ax=ax2)
ax2.set_title('F(X) log10 freq domain')
ax2.set_xlabel('X freq')
ax2.set_ylabel('Y freq')

plt.show()
```




```python
unfocus_lines = np.load(r"C:\Users\willi\OneDrive - The Webb Schools\
Documents\BME Year 3\Build_Imager\Lab2\unfocus lines.npy")
#Group 5 Element 1
zoom = unfocus_lines[700:1000, 300:800]

fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(14, 5))

x = ax1.imshow(unfocus_lines, cmap='gray')
fig.colorbar(x, ax=ax1)
ax1.set_title('line pairs full image')
ax1.set_xlabel('X')
ax1.set_ylabel('Y')

z = ax2.imshow(zoom, cmap='gray')
fig.colorbar(z, ax=ax2)
```

```
ax2.set_title('line pairs zoomed in')
ax2.set_xlabel('X')
ax2.set_ylabel('Y')

plt.show()
```



Values are in lp/mm.

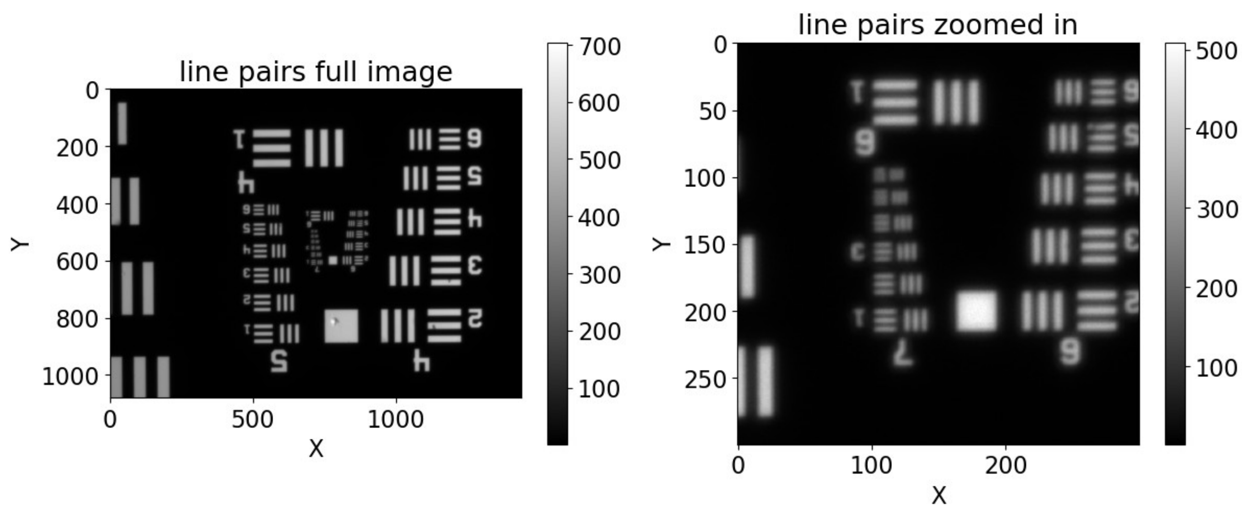
```
# Image(filename=r"C:\Users\willi\OneDrive - The Webb Schools\
Documents\BME Year 3\Build_Imager\Lab2\unfocus lines.png")
```

group 5 element 1: 32.00 line pairs/mm

When defocused, the Fourier transform of the star pattern shows fewer high-frequency components and the outer rings are blurrier and fade away in the FT of the star pattern. The maximum visible line-pair frequency in our defocused line-pair image roughly matches the highest frequency still visible in the Fourier transform which is ~32 samples/mm. We lose this high frequency signal in the FT (far away from the origin) of the star patten, which is why we see a smaller circle in the frequency domain.

```
# Image(filename=r"C:\Users\willi\OneDrive - The Webb Schools\
Documents\BME Year 3\Build_Imager\Lab2\focus lines.png")

focus_lines = np.load(r"C:\Users\willi\OneDrive - The Webb Schools\
Documents\BME Year 3\Build_Imager\Lab2\focus lines.npy")
#Group 7 Element 1
zoom = focus_lines[400:700, 600:900] #~135

fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(14, 5))

x = ax1.imshow(focus_lines, cmap='gray')
fig.colorbar(x, ax=ax1)
ax1.set_title('line pairs full image')
ax1.set_xlabel('X')
ax1.set_ylabel('Y')
```

```
z = ax2.imshow(zoom, cmap='gray')
fig.colorbar(z, ax=ax2)
ax2.set_title('line pairs zoomed in')
ax2.set_xlabel('X')
ax2.set_ylabel('Y')

plt.show()
```



group 7 element 1: 128.00

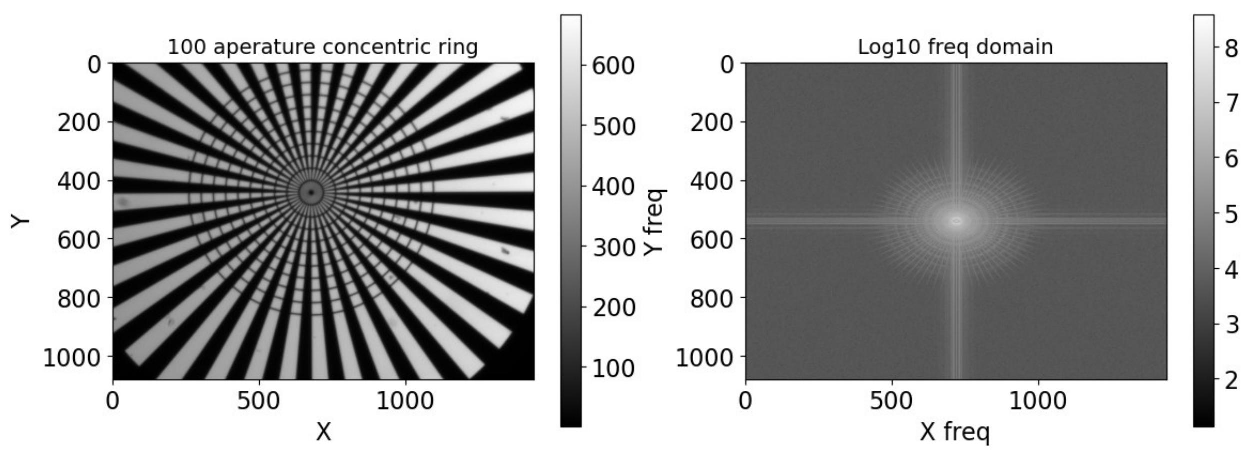
When you refocus, the FT of the star shows sharper, clearer outer rings meaning the higher frequency signal has returned. We can also now resolve much finer line pairs like Group 7 Element with 128 line pairs/mm. The visibility of finer line pairs directly corresponds to the presence of higher frequencies in the FT.

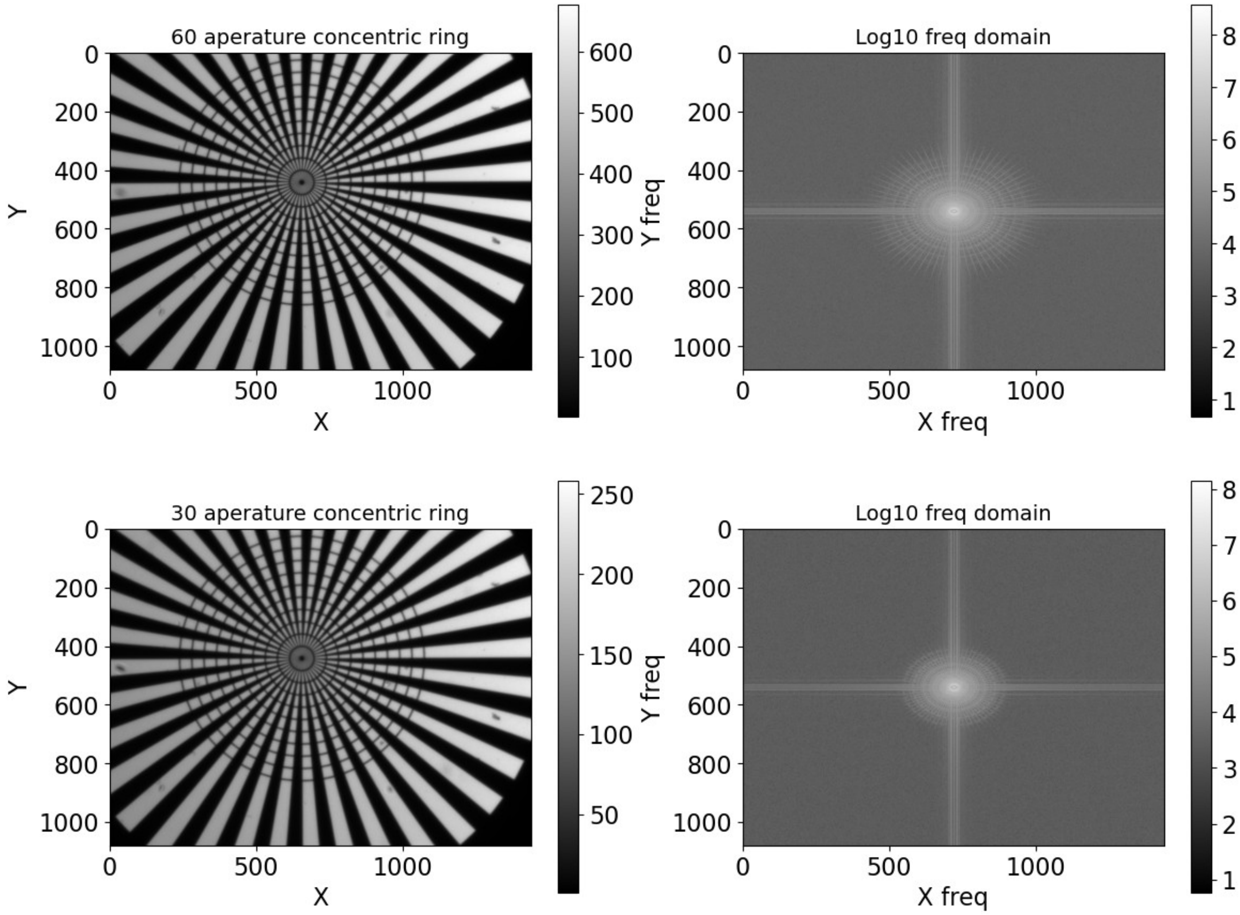
Effect of Aperture

Example aperture position: wide open (100% open), medium aperture (60% open), small aperture (30% open)

```
# Image(filename=r"C:\Users\willi\OneDrive - The Webb Schools\
Documents\BME Year 3\Build_Imager\Lab2\100aperature star.png")

# Image(filename=r"C:\Users\willi\OneDrive - The Webb Schools\
Documents\BME Year 3\Build_Imager\Lab2\60aperature star.png")

# Image(filename=r"C:\Users\willi\OneDrive - The Webb Schools\
Documents\BME Year 3\Build_Imager\Lab2\30aperature star.png")

aperature_star100 = np.load(r"C:\Users\willi\OneDrive - The Webb
Schools\Documents\BME Year 3\Build_Imager\Lab2\100aperature star.npy")
aperature_star60 = np.load(r"C:\Users\willi\OneDrive - The Webb
```

```
Schools\Documents\BME Year 3\Build_Imager\Lab2\60aperature star.npy")
aperature_star30 = np.load(r"C:\Users\willi\OneDrive - The Webb
Schools\Documents\BME Year 3\Build_Imager\Lab2\30aperature star.npy")

aps = [100, 60, 30]

imgs = [aperature_star100, aperature_star60, aperature_star30]

for index, img in enumerate(imgs):
    fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(14, 5))

    x = ax1.imshow(img, cmap='gray')
    fig.colorbar(x, ax=ax1)
    ax1.set_title(f'{aps[index]} aperature concentric ring',
fontsize=14)
    ax1.set_xlabel('X')
    ax1.set_ylabel('Y')

    fftshifted = fftshift(fft2(ifftshift(img)))
    fftshifted = np.abs(fftshifted)
    fftshifted = np.log10(fftshifted + 1)

    y = ax2.imshow(np.abs(fftshifted), cmap='gray')
    fig.colorbar(y, ax=ax2)
    ax2.set_title('Log10 freq domain',fontsize=14)
    ax2.set_xlabel('X freq')
    ax2.set_ylabel('Y freq')

    plt.show()
```





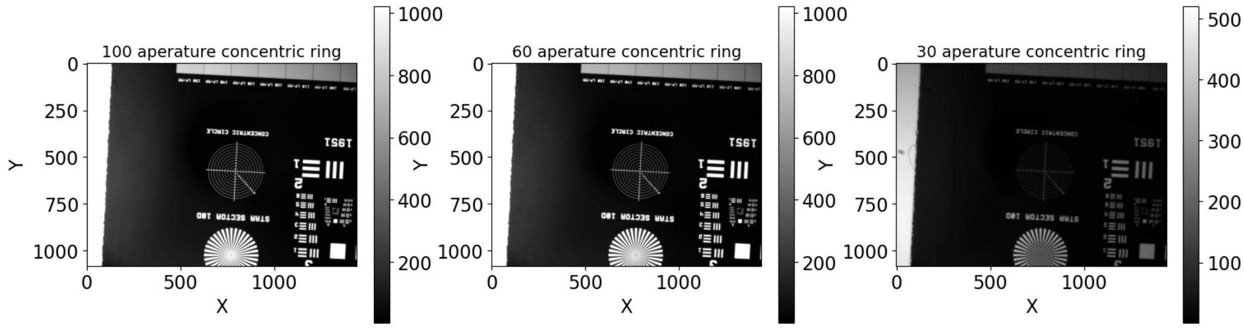
We captured star pattern images at three different aperture settings: 100 (fully open), 60 (halfway range), and 30 (small). At an aperture setting of 100, the image appears the brightest, with strong contrast in the outer rings. However, the details in the center were slightly blurry. When the aperture was adjusted to 60, the image still had good contrast like the fully open setting. The center details were blurred slightly, similar to the fully open setting. At the narrowest setting of 30, the image became dimmer and details seemed more blurred. In the frequency domain we see that as the aperature decreases, the diameter of the central circle decreases as well. This is likely because as we decrease the aperature, the image becomes more blurry and loses fine detail which is equivalent to the high frequency signal in the fourier domain (far from origin).

Low magnification system

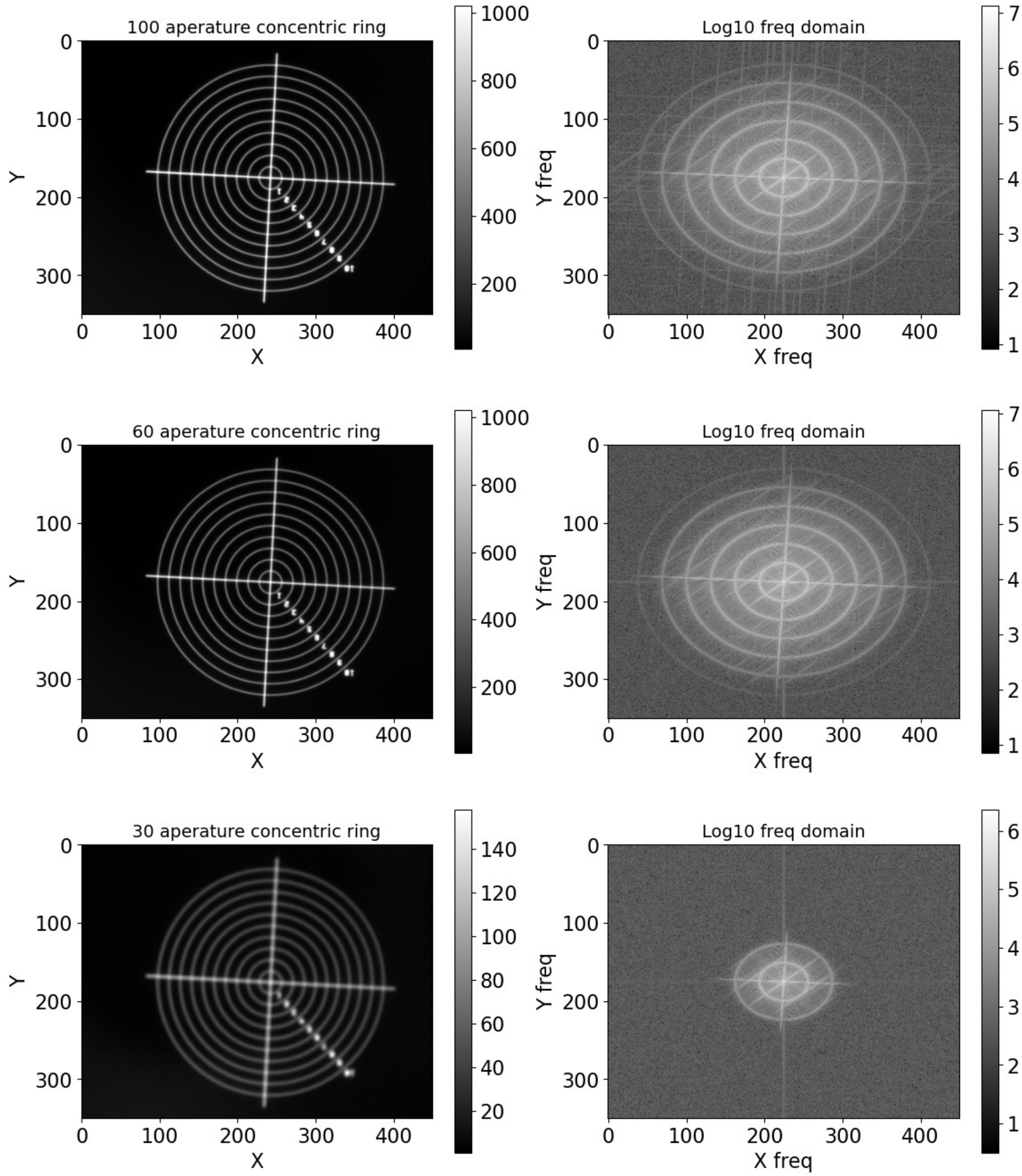
NOTE: We are using the Thorlabs CS165MU camera model, not the DCC3240M; therefore, our camera's pixel size is 3.45 microns. Pixel size = 3.45 μm Total tube length = 1-inch tube attached to the camera + 1-inch tube after the filter wheel = 2 inches Average Square Length: 16 pixels Size of one pixel = 100μm / 16 pixels = 6.25 x 6.25 μm per pixel Magnification = 3.45 / 6.25 = 0.552 sampling freq = 1/0.552 μm = 1.81 μm

```
# Image(filename=r"C:\Users\willi\OneDrive - The Webb Schools\
Documents\BME Year 3\Build_Imager\Lab2\100 aperature concentric
circle.png")

# Image(filename=r"C:\Users\willi\OneDrive - The Webb Schools\
Documents\BME Year 3\Build_Imager\Lab2\60 aperature concentric
circle.png")

# Image(filename=r"C:\Users\willi\OneDrive - The Webb Schools\
Documents\BME Year 3\Build_Imager\Lab2\30 aperature concentric
circle.png")

aperature_circle100 = np.load(r"C:\Users\willi\OneDrive - The Webb
Schools\Documents\BME Year 3\Build_Imager\Lab2\100 aperature
concentric circle.npy")
aperature_circle60 = np.load(r"C:\Users\willi\OneDrive - The Webb
Schools\Documents\BME Year 3\Build_Imager\Lab2\60 aperature concentric
circle.npy")
aperature_circle30 = np.load(r"C:\Users\willi\OneDrive - The Webb
Schools\Documents\BME Year 3\Build_Imager\Lab2\30 aperature concentric
circle.npy")
#30
fig, (ax1, ax2, ax3) = plt.subplots(1, 3, figsize=(18, 5))

x = ax1.imshow(aperature_circle100, cmap='gray')
fig.colorbar(x, ax=ax1)
ax1.set_title('100 aperature concentric ring', fontsize=14)
ax1.set_xlabel('X')
ax1.set_ylabel('Y')

y = ax2.imshow(aperature_circle60, cmap='gray')
fig.colorbar(y, ax=ax2)
ax2.set_title('60 aperature concentric ring',fontsize=14)
ax2.set_xlabel('X')
ax2.set_ylabel('Y')

z = ax3.imshow(aperature_circle30, cmap='gray')
fig.colorbar(z, ax=ax3)
ax3.set_title('30 aperature concentric ring', fontsize=14)
ax3.set_xlabel('X')
ax3.set_ylabel('Y')
```

```
Text(0, 0.5, 'Y')
```




```
zoomed100 = aperature_circle100[400:750, 550:1000]
zoomed60 = aperature_circle60[400:750, 550:1000]
zoomed30 = aperature_circle30[400:750, 550:1000]

aps = [100, 60, 30]

imgs = [zoomed100, zoomed60, zoomed30]

for index, img in enumerate(imgs):
    fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(14, 5))

    x = ax1.imshow(img, cmap='gray')
    fig.colorbar(x, ax=ax1)
    ax1.set_title(f'{aps[index]} aperature concentric ring',
fontsize=14)
    ax1.set_xlabel('X')
    ax1.set_ylabel('Y')

    fftshifted = fftshift(fft2(ifftshift(img)))
    fftshifted = np.abs(fftshifted)
    fftshifted = np.log10(fftshifted + 1)

    y = ax2.imshow(np.abs(fftshifted), cmap='gray')
    fig.colorbar(y, ax=ax2)
    ax2.set_title('Log10 freq domain',fontsize=14)
    ax2.set_xlabel('X freq')
    ax2.set_ylabel('Y freq')

    plt.show()
```



For the 100 aperture, the image is clear and sharp, and in the frequency domain, there are also 10 circles indicating a large spread of high spatial frequencies. This demonstrates that at a wide aperture, there is a strong resolution. At the 60 aperture, the image is slightly less in focus than the 100 aperture, and in the frequency domain, there is less high frequency detail. At the 30 aperture, the image is blurry, but the circles remain distinct, and in the frequency-domain, there is a concentrated center, indicating that high frequency content has been lost. This indicates that smaller apertures reduce image sharpness by blocking fine details and allowing only the blurrier, low-frequency parts of the image to pass through.