In [1]:
```
#pip install seaborn
#pip install astropy
#pip install intersect
```

In [2]:
```
from astropy.io import fits
import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
import glob
from datetime import datetime, timedelta
from sklearn.linear_model import LinearRegression
from intersect import intersection
from PIL import Image
```

In [3]:
```
"""
Methodology:
loop through timestamps of skyprobe measurements, for each one find a timest
minute as well as an ASIVA image with a timestamp within +/- 1 minute.
output a csv file with 5 columns as follows:
1 - skyprobe timestamp
2 - Skyprobe attenuation
3 - telescope Az
4 - Telescope Alt
5 - ASIVA Image Filename
"""
```

Out[3]:
```
'\nMethodology:\nloop through timestamps of skyprobe measurements, for each
one find a timestamp in the telescope data within +/- 1 \nminute as well as
an ASIVA image with a timestamp within +/- 1 minute. \noutput a csv file wi
th 5 columns as follows:\n1 - skyprobe timestamp\n2 - Skyprobe attenuation
\n3 - telescope Az\n4 - Telescope Alt\n5 - ASIVA Image Filename\n'
```

In [4]:
```
"""File Parsing:
Skyprobe Data:
Column 1: Time in UNIX EPOCH
Column 4: Zeropoint (Attenuation)

Telescope Data:
Column 1: Time in UNIX Epoch
Column 2: Alt
Column 3: Az

ASIVA Images:
naming example: asiva202301251900.png
naming format: asivaYYYYMMDDHHMM
HH in military time
"""
```

Out[4]:
```
'File Parsing:\nSkyprobe Data:\nColumn 1: Time in UNIX EPOCH\nColumn 4: Zer
opoint (Attenuation)\n\nTelescope Data:\nColumn 1: Time in UNIX Epoch\nColu
mn 2: Alt\nColumn 3: Az\n\nASIVA Images:\nnaming example: asiva20230125190
0.png\nnaming format: asivaYYYYMMDDHHMM\nHH in military time\n'
```

In [5]:
```
DF_skyprobe = pd.read_csv("skyprobe_data.csv", low_memory=False)
DF_skyprobe.columns = ['Time', 'skip1', 'skip2', 'attenuation', 'skip3', 'sk
DF_skyprobe = DF_skyprobe.drop(columns = ['skip1', 'skip2', 'skip3', 'skip4'
DF_telescope = pd.read_csv("tcs_data.csv", low_memory=False)
DF_telescope.columns = ['Time', 'Alt', 'Az', 'skip']
DF_telescope = DF_telescope.drop(columns = ['skip'])
DF = pd.merge_asof(DF_skyprobe, DF_telescope, on = "Time", direction="neares
DF = DF.dropna()
print(DF.head)
```

```
<bound method NDFrame.head of                 Time  attenuation      Alt
Az
0        1274851510        0.107  89.8103  279.5074
1        1274851809        0.155  67.7496   80.3481
2        1274851870        0.144  67.7496   80.3481
3        1274851929        0.559  67.7496   80.3481
4        1274851989        0.121  67.7496   80.3481
...             ...          ...      ...       ...
2125491  1694792290       -0.108  64.9583   48.1660
2125492  1694792350        0.151  64.9213   48.1046
2125493  1694792407       -0.183  64.8382   48.1806
2125494  1694792470        0.004  65.0426   47.9788
2125495  1694793600        0.004  64.9767   48.1581

[1647649 rows x 4 columns]>
```

In [13]:
```
#we now have a combined dataset of skyprobe data with corresponding Alt and
#Now we need to find ASIVA images with close timestamps and add the filename

folder = "../images"
filenames = []
timestamps = []
for file in glob.glob(folder + '/*.png'):
    filedate = file.split('/')[2].split('asiva')[1].split('.')[-2]
    time = datetime.strptime(filedate, '%Y%m%d%H%M') + timedelta(hours=10)
    timestamp = datetime.timestamp(time)
    filenames.append(file)
    timestamps.append(int(timestamp))
    #convert filedate/time to UNIX. Add 10 hours for converting HST to UTC
DF_ASIVA = pd.DataFrame(timestamps)
DF_ASIVA.columns = ["Time"]
DF_ASIVA["filenames"] = filenames
DF_ASIVA = DF_ASIVA.sort_values(by="Time")
print(DF_ASIVA.head)
```

```
<bound method NDFrame.head of               Time                         filenam
es
1409  1674727200  ../images/asiva202301251900.png
1442  1674727260  ../images/asiva202301251901.png
1251  1674727320  ../images/asiva202301251902.png
1208  1674727380  ../images/asiva202301251903.png
868   1674727440  ../images/asiva202301251904.png
...          ...                              ...
247   1687974900  ../images/asiva202306280355.png
75    1687974960  ../images/asiva202306280356.png
107   1687975020  ../images/asiva202306280357.png
2742  1687975080  ../images/asiva202306280358.png
2701  1687975140  ../images/asiva202306280359.png

[2999 rows x 2 columns]>
```

In [7]:

```
#perform another merge_asof to add asiva filenames to the main dataframe
DF = pd.merge_asof(DF, DF_ASIVA, on = "Time", direction="nearest", tolerance
DF = DF.dropna()
DF = DF.reset_index()
print(DF.head)
```

```
<bound method NDFrame.head of         index        Time  attenuation      Alt
Az  \
0    1581249  1675601947        0.092  32.4534  321.3330
1    1581250  1675602000        0.092  32.4534  321.3330
2    1581251  1675602006        0.095  32.4534  321.3330
3    1581252  1675602007        0.095  32.4534  321.3330
4    1581253  1675602187        0.103  31.4518  321.3330
..       ...         ...          ...      ...       ...
882  1616383  1687964890       -0.021  56.4768  142.2442
883  1616384  1687964950       -0.001  57.4772  142.2442
884  1616385  1687965010       -0.027  57.4772  143.2486
885  1616386  1687965067       -0.084  57.4772  143.2486
886  1616387  1687965130       -0.018  57.4772  143.2486

                           filenames
0    ../images/asiva202302042200.png
1    ../images/asiva202302042200.png
2    ../images/asiva202302042200.png
3    ../images/asiva202302042200.png
4    ../images/asiva202302042203.png
..                               ...
882  ../images/asiva202306280108.png
883  ../images/asiva202306280109.png
884  ../images/asiva202306280110.png
885  ../images/asiva202306280111.png
886  ../images/asiva202306280112.png

[887 rows x 6 columns]>
```

In [8]:

```
## Code from https://scipython.com/blog/direct-linear-least-squares-fitting-
## Posted by: christian on 9 Aug 2021

def fit_ellipse(x, y):
    """
```

```python
    Fit the coefficients a,b,c,d,e,f, representing an ellipse described by
    the formula F(x,y) = ax^2 + bxy + cy^2 + dx + ey + f = 0 to the provided
    arrays of data points x=[x1, x2, ..., xn] and y=[y1, y2, ..., yn].

    Based on the algorithm of Halir and Flusser, "Numerically stable direct
    least squares fitting of ellipses'.


    """

    D1 = np.vstack([x**2, x*y, y**2]).T
    D2 = np.vstack([x, y, np.ones(len(x))]).T
    S1 = D1.T @ D1
    S2 = D1.T @ D2
    S3 = D2.T @ D2
    T = -np.linalg.inv(S3) @ S2.T
    M = S1 + S2 @ T
    C = np.array(((0, 0, 2), (0, -1, 0), (2, 0, 0)), dtype=float)
    M = np.linalg.inv(C) @ M
    eigval, eigvec = np.linalg.eig(M)
    con = 4 * eigvec[0]* eigvec[2] - eigvec[1]**2
    ak = eigvec[:, np.nonzero(con > 0)[0]]
    return np.concatenate((ak, T @ ak)).ravel()


def cart_to_pol(coeffs):
    """

    Convert the cartesian conic coefficients, (a, b, c, d, e, f), to the
    ellipse parameters, where F(x, y) = ax^2 + bxy + cy^2 + dx + ey + f = 0.
    The returned parameters are x0, y0, ap, bp, e, phi, where (x0, y0) is th
    ellipse centre; (ap, bp) are the semi-major and semi-minor axes,
    respectively; e is the eccentricity; and phi is the rotation of the semi
    major axis from the x-axis.

    """

    # We use the formulas from https://mathworld.wolfram.com/Ellipse.html
    # which assumes a cartesian form ax^2 + 2bxy + cy^2 + 2dx + 2fy + g = 0.
    # Therefore, rename and scale b, d and f appropriately.
    a = coeffs[0]
    b = coeffs[1] / 2
    c = coeffs[2]
    d = coeffs[3] / 2
    f = coeffs[4] / 2
    g = coeffs[5]

    den = b**2 - a*c
    if den > 0:
        raise ValueError('coeffs do not represent an ellipse: b^2 - 4ac must
                         ' be negative!')

    # The location of the ellipse centre.
    x0, y0 = (c*d - b*f) / den, (a*f - b*d) / den
```

```python
    num = 2 * (a*f**2 + c*d**2 + g*b**2 - 2*b*d*f - a*c*g)
    fac = np.sqrt((a - c)**2 + 4*b**2)
    # The semi-major and semi-minor axis lengths (these are not sorted).
    ap = np.sqrt(num / den / (fac - a - c))
    bp = np.sqrt(num / den / (-fac - a - c))

    # Sort the semi-major and semi-minor axis lengths but keep track of
    # the original relative magnitudes of width and height.
    width_gt_height = True
    if ap < bp:
        width_gt_height = False
        ap, bp = bp, ap

    # The eccentricity.
    r = (bp/ap)**2
    if r > 1:
        r = 1/r
    e = np.sqrt(1 - r)

    # The angle of anticlockwise rotation of the major-axis from x-axis.
    if b == 0:
        phi = 0 if a < c else np.pi/2
    else:
        phi = np.arctan((2.*b) / (a - c)) / 2
        if a > c:
            phi += np.pi/2
    if not width_gt_height:
        # Ensure that phi is the angle to rotate to the semi-major axis.
        phi += np.pi/2
    phi = phi % np.pi

    return x0, y0, ap, bp, e, phi


def get_ellipse_pts(params, npts=100, tmin=0, tmax=2*np.pi):
    """
    Return npts points on the ellipse described by the params = x0, y0, ap,
    bp, e, phi for values of the parametric variable t between tmin and tmax

    """

    x0, y0, ap, bp, e, phi = params
    # A grid of the parametric variable, t.
    t = np.linspace(tmin, tmax, npts)
    x = x0 + ap * np.cos(t) * np.cos(phi) - bp * np.sin(t) * np.sin(phi)
    y = y0 + ap * np.cos(t) * np.sin(phi) + bp * np.sin(t) * np.cos(phi)
    return x, y
```

In [ ]:

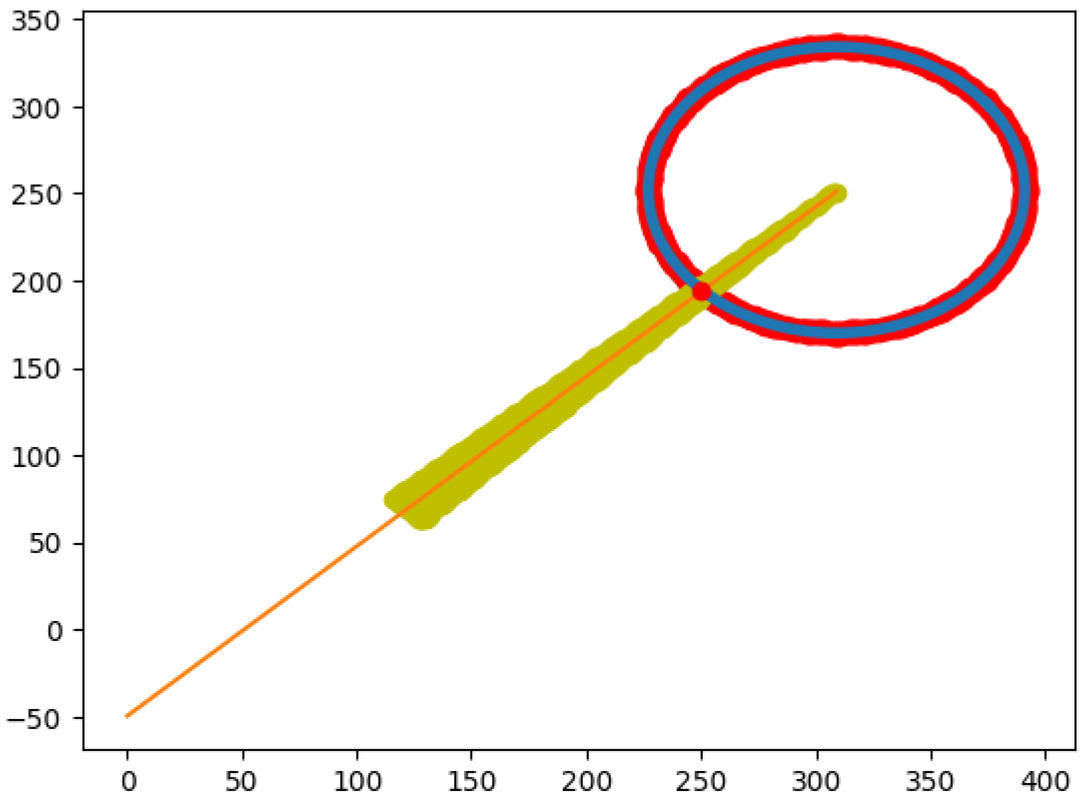
```python
```

In [9]:

```python
"""
Now need to find the location within each ASIVA image and save a 12x12 kerne
along with a corresponding attenuation value
Azimuth.fits gives f(x,y) = Az   -- from an (x,y) pair in an ASIVA image giv
Altitude.fits gives g(x,y) = Alt   -- from an (x,y) pair in an ASIVA image g
```

```python
I want to construct:
f-1(Az) = (x,y) -- from an Az value input give a set of (x,y) on an ASIVA im
g-1(Alt) = (x,y) -- from an Alt value input give a set of (x,y) on an ASIVA

I then want to find the intersection between f-1 and g-1  -- that's where I'
"""
#These indices have azimuth values that want to form vertical lines, doen't
#DF = DF.reset_index()
problems = [73, 74, 75, 76, 819]
DF = DF.drop(index=problems)
hdul_az = fits.open("azimuth.fits")
hdul_alt = fits.open("altitude.fits")
az_image = hdul_az[0].data
alt_image = hdul_alt[0].data
vals = DF[['Az', 'Alt']]
i = 0
kernel_locs = []

for index, row in vals.iterrows():
    #print(i)
    #if(i not in problems):
    Az = np.float32(row[0])
    Alt = np.float32(row[1])
    az_locs = list(zip(*np.where(abs(az_image - Az) <= 2)))
    alt_locs = list(zip(*np.where(abs(alt_image - Alt) <= 0.5)))
    #Plot Alt data and get regression model for ellipse
    y, x = zip(*alt_locs)
    x = np.array(x)
    y = np.array(y)
    plt.scatter(x, y, color="r")
    coeffs_ellipse = fit_ellipse(x, y)
    x0, y0, ap, bp, e, phi = cart_to_pol(coeffs_ellipse)
    x_e, y_e = get_ellipse_pts((x0, y0, ap, bp, e, phi), npts=1000)
    plt.plot(x_e, y_e, linewidth=4)

    #Plot Az data and get regression model for line
    y, x = zip(*az_locs)
    x = np.array(x)
    y = np.array(y)
    midx = np.mean(x)
    plt.scatter(x, y, color="y")
    x_r = x.reshape((-1, 1))
    model = LinearRegression().fit(x_r, y)
    coeffs_line = [model.coef_, model.intercept_]
    x_pred = np.linspace(0, x0, len(y_e)).reshape((-1, 1))
    y_pred = model.predict(x_pred)
    plt.plot(x_pred.reshape((-1, 1)), y_pred)
    #find the intersection point between the linear and elliptical models.
    x_loc, y_loc = intersection(x_pred, y_pred, x_e, y_e)
    #idx = np.argwhere(np.diff(np.sign(y_e - y_pred))).flatten()
    #x_loc = x_pred[idx]
    #y_loc = y_pred[idx]
    x_loc = int(x_loc[0])
    y_loc = int(y_loc[0])
    kernel_locs.append((x_loc, y_loc))
```

```
    if(i == 67):
        plt.plot(x_loc, y_loc, 'ro')
        plt.show()
    i += 1
    plt.clf()

DF["Kernel_Location"] = kernel_locs
print(DF.head)
hdul_az.close()
hdul_alt.close()
```




```
/Library/Frameworks/Python.framework/Versions/3.7/lib/python3.7/site-package
s/ipykernel_launcher.py:85: RuntimeWarning: divide by zero encountered in dou
ble_scalars
/Library/Frameworks/Python.framework/Versions/3.7/lib/python3.7/site-package
s/ipykernel_launcher.py:85: RuntimeWarning: divide by zero encountered in dou
ble_scalars
/Library/Frameworks/Python.framework/Versions/3.7/lib/python3.7/site-package
s/ipykernel_launcher.py:85: RuntimeWarning: divide by zero encountered in dou
ble_scalars
```

```
<bound method NDFrame.head of         index        Time  attenuation      Alt
Az  \
0    1581249  1675601947        0.092  32.4534  321.3330
1    1581250  1675602000        0.092  32.4534  321.3330
2    1581251  1675602006        0.095  32.4534  321.3330
3    1581252  1675602007        0.095  32.4534  321.3330
4    1581253  1675602187        0.103  31.4518  321.3330
..       ...         ...          ...      ...       ...
882  1616383  1687964890       -0.021  56.4768  142.2442
883  1616384  1687964950       -0.001  57.4772  142.2442
884  1616385  1687965010       -0.027  57.4772  143.2486
885  1616386  1687965067       -0.084  57.4772  143.2486
886  1616387  1687965130       -0.018  57.4772  143.2486

                           filenames Kernel_Location
0    ../images/asiva202302042200.png      (220, 435)
1    ../images/asiva202302042200.png      (220, 435)
2    ../images/asiva202302042200.png      (220, 435)
3    ../images/asiva202302042200.png      (220, 435)
4    ../images/asiva202302042203.png      (219, 437)
..                               ...             ...
882  ../images/asiva202306280108.png      (251, 370)
883  ../images/asiva202306280109.png      (253, 367)
884  ../images/asiva202306280110.png      (255, 368)
885  ../images/asiva202306280111.png      (255, 368)
886  ../images/asiva202306280112.png      (255, 368)

[882 rows x 7 columns]>
<Figure size 640x480 with 0 Axes>
```

In [12]:

```
"""
The format of DF is now 6 columns as follows:
1 - skyprobe timestamp
2 - Skyprobe attenuation
3 - telescope Az
4 - Telescope Alt
5 - ASIVA Image Filename
6 - (x, y) position of the skyprobe measurement in the corresponding ASIVA i

I now need to parse through each filename in the dataframe and extract a ker
location

"""
size = 6
images = DF[["filenames", "Kernel_Location", "attenuation"]]
image_kernel_filenames = []
image_kernel_attenuations = []
for index, row in images.iterrows():
    filename = row[0]
    attenuation = row[2]
    oldimagename = filename.split('../images/')[1].split('.png')[0]
    loc = row[1]
    im = Image.open(filename)
    x = loc[0]
    y = loc[1]
    imk = im.crop((x-size, y-size, x+size, y+size))
```

```
    newfilename =  oldimagename + "_12x12" '.png'
    image_kernel_filenames.append(newfilename)
    image_kernel_attenuations.append(attenuation)
    imk.save('../kernels/' + newfilename)
    if(attenuation > 0.2):
        #also sample around the target location
        offset = int(size)
        xs = [x-offset, x-offset/2, x, x+offset/2, x+offset]
        ys = [y-offset, y-offset/2, y, y+offset/2, y+offset]
        for x_pos in xs:
            for y_pos in ys:
                if(x_pos != x or y_pos != y):
                    imk = im.crop((x_pos-size, y_pos-size, x_pos+size, y_pos
                    newfilename =  oldimagename + "_12x12" + "_(" + str(x_po
                    image_kernel_filenames.append(newfilename)
                    image_kernel_attenuations.append(attenuation)
                    imk.save('../kernels/' + newfilename)



#write CSV file containing kernel filenames and corresponding attenuations

attenuations = pd.DataFrame(image_kernel_attenuations)
attenuations.columns = ["attenuation"]
attenuations["filename"] = image_kernel_filenames
attenuations.to_csv("../kernels/attenuations.csv")
```

In [ ]:

```
# demonstrate example kernels and attenuation values.
```