

Assignment_updated

January 4, 2021

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[2]: # Thomas Dugdale - Radio Astronomy Assignment - Simulating a Radio
      ↳ Interferometer
      # Student ID - 10784808

      # Link to binder:
      # https://mybinder.org/v2/gh/ThomasNose/Interferometer/HEAD

      # References

      # http://www-static-2019.jmmc.fr/mirrors/obsulti/book/Segransan_1.pdf - Used
      ↳ for uv-plane equations
      # https://matplotlib.org/3.1.1/api/ - Where I collected different commands for
      ↳ matplotlib
      # https://online.manchester.ac.uk/webapps/blackboard/execute/content/file?
      ↳ cmd=view&content_id=_12102131_1&course_id=_63179_1

      import numpy as np                                #
      ↳ Importing packages
      import matplotlib.pyplot as plt
      %matplotlib inline

      def data(config,source): # Data function
          config = np.loadtxt(config)                    # Loading
          ↳ in VLA configuration D data
          source = np.loadtxt(source)                    # Source
          ↳ 1 and 2 data

          return (config,source)
      config,source = data("Dconfig.txt","source.txt")

      def configuration(config,source):                  #
          ↳ Telescope configuration
          XYZ = config[:,0:3]                             # Array
          ↳ with VLA data
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    RAh,RAm,RAs = source[:,0],source[:,1],source[:,2] #
    ↪Collecting the hours, minutes, seconds of Right Ascension
    DECh,DECm,DECs = source[:,3],source[:,4],source[:,5] #
    ↪Collecting source declinations
    JySource = source[:,6]

    Y,Z = config[:,1],config[:,2] #
    ↪Telescope coordinates
    plt.scatter(Y,Z) #
    ↪Plotting the positions of the antennas
    plt.title('VLA D configuration')
    plt.ylabel('y (ns)')
    plt.xlabel('x (ns)')
    plt.show()

    return(Y,Z,JySource)
Y,Z,JySource = configuration(config,source)

def uvcoverage(config,declination,f): # U-V coverage at HA = 0 function
    DATA = [] # Empty
    ↪arrays for modulus baselines, Azimuth and Elevation values
    for i, x_i in enumerate(config): # This
    ↪loop is for calculating all 351 baselines, elevations and azimuth components
        for j, y_i in enumerate(config):
            if i < j: # This
    ↪condition ensures no duplicate values are calculated, ie 2-1 and 1-2, 10-5
    ↪and 5-10 etc.
                DATA.append(x_i-y_i)

    DATA = np.array(DATA) # Loading
    ↪in all the antenna coordinates
    X = DATA[:,0] #
    ↪Allocating to X,Y,Z
    Y = DATA[:,1]
    Z = DATA[:,2]

    dec = declination

    Lambda = 3e8/f

    U = Lambda*(np.sin(0)*X + np.cos(0)*Y) # U-V
    ↪values, again with RA set to 0 hrs
    V = Lambda*(-np.sin(dec)*np.cos(0)*X + np.sin(dec)*np.sin(0)*Y + np.
    ↪cos(dec)*Z) # Equations taken from Neal Jackson and Segransan

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    plt.scatter(V/1e3,U/1e3,s=1) #
    ↪Plotting the UV coverage which is both the positive and negatives values of
    ↪U and V
    plt.scatter(-V/1e3,-U/1e3,s=1) # Values
    ↪for U and V are divided by 1,000 to match the units used in the VLA document
    ↪provided
    plt.xlabel('x (kilo wavelengths)')
    plt.ylabel('y (kilo wavelengths)')
    plt.title('VLA UV coverage HA=0 at dec=45 degrees')
    plt.show()

    return(X,Y,Z,dec)
X,Y,Z,dec = uvcoverage(config,np.pi/4,5e9) # 45
    ↪degree declination

def uvcoverageHA(hour,Interval,X,Y,Z,dec,f): # U-V coverage function for HA

    T = (2*np.pi/24) * hour #
    ↪Equation which converts the input time (in hours) to radians
    interval = (hour * 3600) // Interval # The
    ↪interval is every 30 seconds to this says how many data points there should
    ↪be

    t = np.linspace(-T/2,T/2,interval) # One
    ↪hour of RA in radians from -0.5 hr to +0.5hr
    u = [] # Blank
    ↪u-v arrays for appending
    v = []

    c = 3e8

    for i in range(len(X)): # Loop
    ↪for calculating u-v
        u = np.append(u, (f/c)*(np.sin(t)*X[i] + np.cos(t)*Y[i])) #
    ↪Equations taken from Segransan + Neal Jackson lectures
        v = np.append(v, (f/c)*(-np.sin(dec)*np.cos(t)*X[i] + np.sin(dec)*np.
    ↪sin(t)*Y[i] + np.cos(dec)*Z[i]))

    plt.scatter(v/1e3,u/1e3,s=5,c='black') #
    ↪Plotting the u-v plane
    plt.scatter(-v/1e3,-u/1e3,s=5,c='black') #
    ↪Negative have to be plotted for other half of u-v plane
    plt.xlabel('x (kilo wavelengths)')
    plt.ylabel('y (kilo wavelengths)')
    plt.title('VLA UV coverage HA=+/-0.5hr at dec=45 degrees')
    plt.show()

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    return(u,v)
u,v = uvcoverageHA(1,30,X,Y,Z,dec,5e9) # 1
    →hour (+/- 0.5HA) at 30 second intervals

def truesky(extent_x,extent_y): # Function to be recalled
    TrueSky = np.zeros((extent_x,extent_y)) # Blank
    →array for point sources

    centre_x,centre_y = int(extent_x/2),int(extent_y/2) # Centre
    →value of image

    TrueSky[centre_x,centre_y] = JySource[0] # This is
    →the first centred image
    TrueSky[20,50] = JySource[1] # This is
    →the second source. 3 arc minutes difference in Declination and 10 seconds
    →difference in RA.

    plt.imshow(TrueSky,extent=[-centre_x,centre_x,-centre_y,centre_y])# This is
    →an image of the two sources
    plt.colorbar()
    plt.title('Observed sources')
    plt.xlabel('RA offset (arcsec, J2000)')
    plt.ylabel('DEC offset (arcsec, J2000)')

    plt.show()
    return(TrueSky)
TrueSky = truesky(400,400)

def visibility(truesky): #
    →Function for fourier transforming to get visibilities

    Visibility = np.fft.fft2(TrueSky) # Fourier
    →transform of sources
    plt.imshow(np.real(Visibility),extent=[-200,200,-200,200]) # This
    →image shows the real fourier space of the two observed sources
    plt.xlabel('RA offset (arcsec, J2000)')
    plt.ylabel('DEC offset (arcsec, J2000)')
    plt.title('Fourier space of two point sources')
    plt.colorbar()
    plt.show()

    return(Visibility)
Visibility = visibility(TrueSky)

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def sampling(extent_x,extent_y,scale):                                     #
    ↪Function for sampling function

    Sampling = np.zeros((extent_x,extent_y))                           # Empty
    ↪array for sampling function
    for i in range(len(u)):
        Sampling[int(u[i]/scale),int(v[i]/scale)] = 1                 # Fills
    ↪in empty image array with a 1 if uv data exists
        Sampling[int(-u[i]/scale),int(-v[i]/scale)] = 1               # also
    ↪divided by 500 so all u,v data fits within sampling array
        ShiftSampling = np.fft.fftshift(Sampling)                     # Shifts
    ↪the image to the centre of the spectrum

        centre_x,centre_y = int(extent_x/2), int(extent_y/2)          # Values
    ↪for centering the image

    plt.imshow(np.
    ↪real(ShiftSampling),extent=[-centre_x,centre_x,-centre_y,centre_y]) #
    ↪Plotting sampling function
    plt.title('U-V sampling function')                                 # sampled
    ↪grid
    plt.xlabel('RA offset (arcsec, J2000)')
    plt.ylabel('DEC offset (arcsec, J2000)')
    plt.colorbar()
    plt.show()

    return(Sampling)
Sampling = sampling(400,400,500)                                       # size
    ↪400x400 with pixels being 500 data points each

def synthesise(extent_x,extent_y,sample_function): # Synthesised beam function

    centre_x,centre_y = int(extent_x/2), int(extent_y/2)              # Values
    ↪for centering the image

    Synthesised = np.fft.fft2(sample_function)                         # Fourier
    ↪transform of UV image to show synthesised(dirty) beam image
    Synthesised = np.fft.fftshift(Synthesised)                         # This
    ↪command shifts the image to the centre of the plot rather than being at the
    ↪corners
    Synthesised = np.real(Synthesised)
    plt.
    ↪imshow(Synthesised,vmin=-10,vmax=300,extent=[-centre_x,centre_x,-centre_y,centre_y])
    ↪# Real values plotted
    plt.title('Synthesised beam')                                     # vmin
    ↪and vmax values best show the dirty beam

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plt.colorbar() # Shows
→ values of the synthesised beam
plt.xlabel('RA offset (arcsec, J2000)')
plt.ylabel('DEC offset (arcsec, J2000)')
plt.show()

return(Synthesised)
Synthesised = synthesise(400,400,Sampling) # Size
→ 400x400 with sampling function as input

def dirtymap(extent_x,extent_y,sample_function,visibility): # Dirty map function

    centre_x,centre_y = int(extent_x/2), int(extent_y/2) # Values
    → for centering the image

    SampleVis = Sampling * Visibility #
    → Multiplying together to get sampled visibilities
    DirtyMap = np.fft.ifft2(SampleVis) # Inverse
    → fourier transform to get from sampled visibilities to dirty map
    plt.imshow(np.
    → real(DirtyMap),extent=[-centre_x,centre_x,-centre_y,centre_y]) # Plotting
    → and centering dirty map
    plt.xlabel('RA offset (arcsec, J2000)')
    plt.ylabel('DEC offset (arcsec, J2000)')
    plt.title('Dirty map')
    plt.show()

    return(DirtyMap)
DirtyMap = (400,400,Sampling,Visibility) # 400x400
→ dirty map

def radius(Lambda,D): # Primary beam radius in arcseconds function
    Primary = Lambda / D # Angular
    → size of primary beam in radians at 5GHz with 25m apertures
    PrimaryDeg = Primary * (180/np.pi) * 3600 # Angular
    → size of beam in arcseconds
    radius = int(np.round(PrimaryDeg/2)) # Integer
    → and rounded value for radius of primary beam in arcseconds

    return(radius)
radius = radius(3e8/5e9,25) #
→ Inputting wavelength calculated by c/f and inputting 25 metre aperture
→ diameter
# The above is the diameter of the primary beam in arcseconds

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def primarybeam(extent_x,extent_y,Radius): # Primary beam function

    centre_x,centre_y = int(extent_x/2), int(extent_y/2) # Values
    ↪for centering the image

    x = np.linspace(1,extent_x,extent_x) #
    ↪Creating lists for meshgrid that range over the width of the beam
    y = np.linspace(1,extent_y,extent_y)
    xx, yy = np.meshgrid(x,y) #
    ↪Meshgrid for calculating distance to a pixel

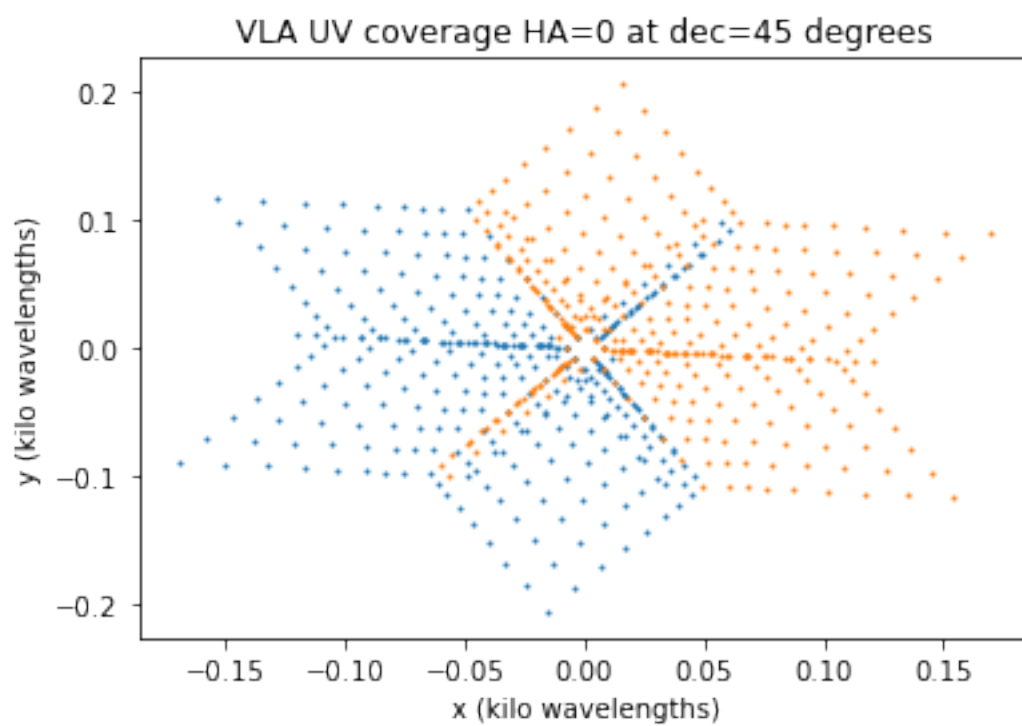
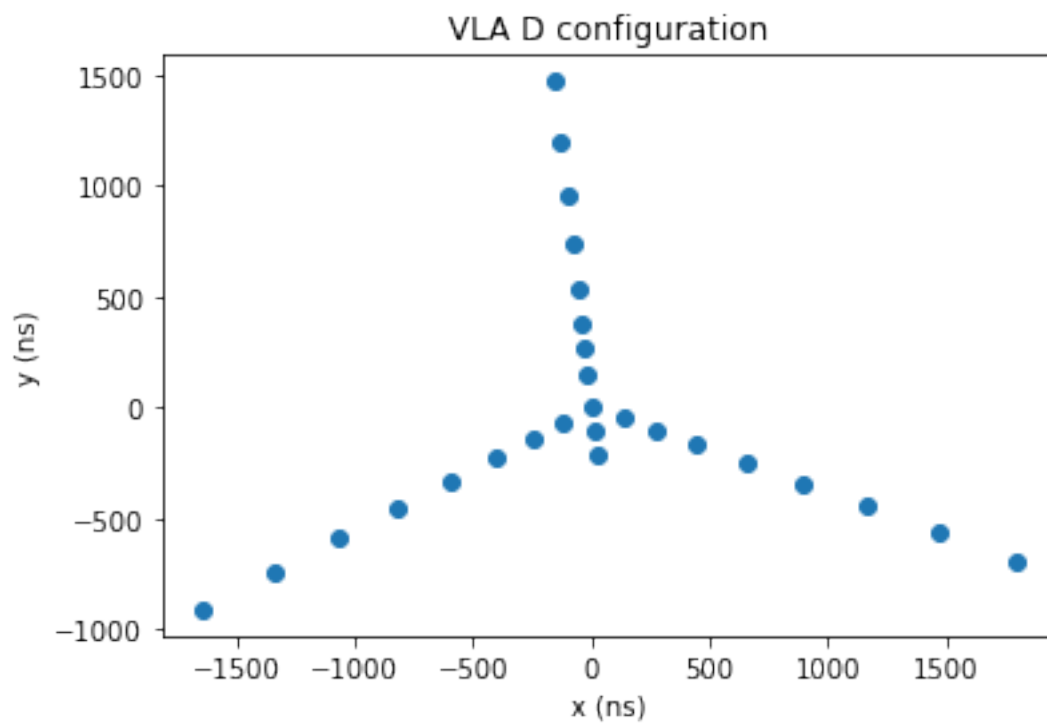
    PrimaryBeam = np.zeros((extent_x,extent_y)) # Blank
    ↪image for primary beam of size width of primary beam
    for i in range(1,2*Radius): # Loop
    ↪creating the primary beam
        r = ((xx-x[radius])**2 + (yy-y[radius])**2)**0.5 # Length
    ↪from the centre of the primary beam
        PrimaryBeam += np.exp(-(r/[i]*0.5)**2) #
    ↪'Temporary' equation for the primary beam

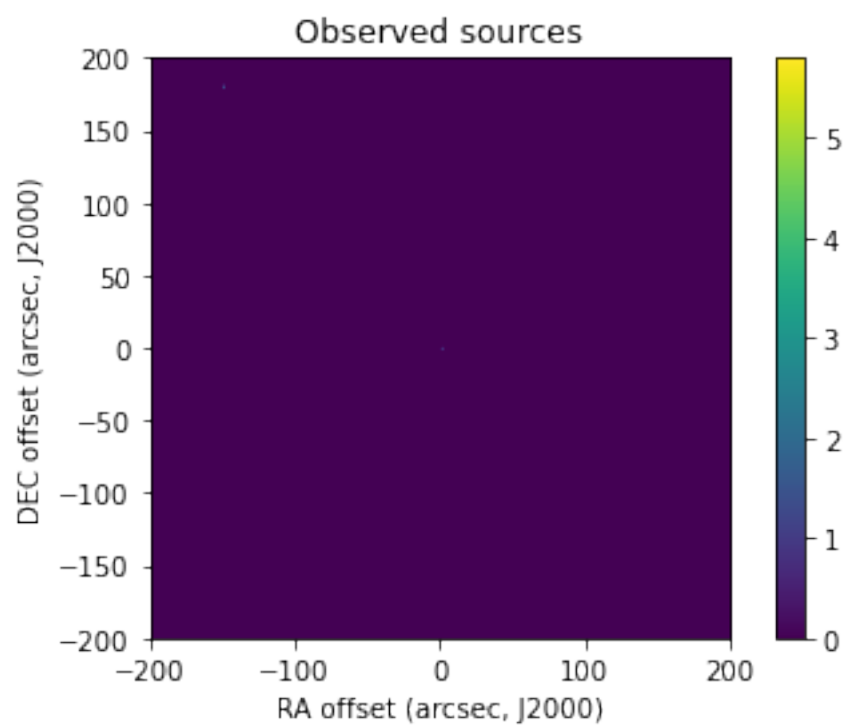
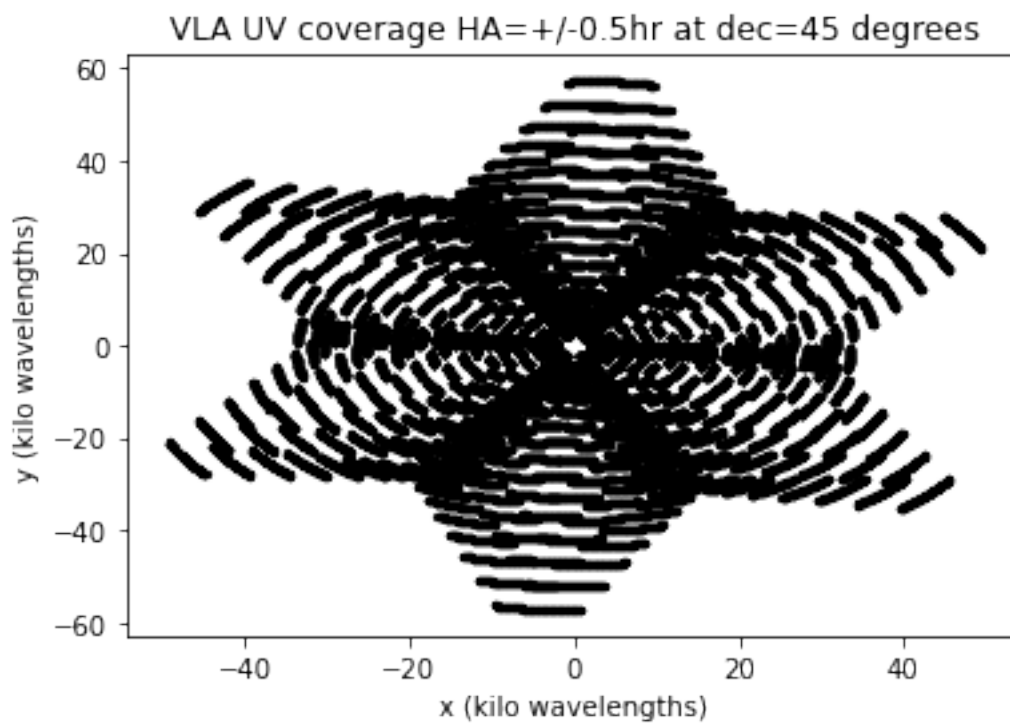
    plt.imshow(PrimaryBeam,extent=[-centre_x,centre_x,-centre_y,centre_y]) #
    ↪Primary beam plotted, centre image is [0,0]
    plt.xlabel('arcseconds')
    plt.ylabel('arcseconds')
    plt.title('Primary Beam of VLA')
    plt.colorbar()
    plt.show()

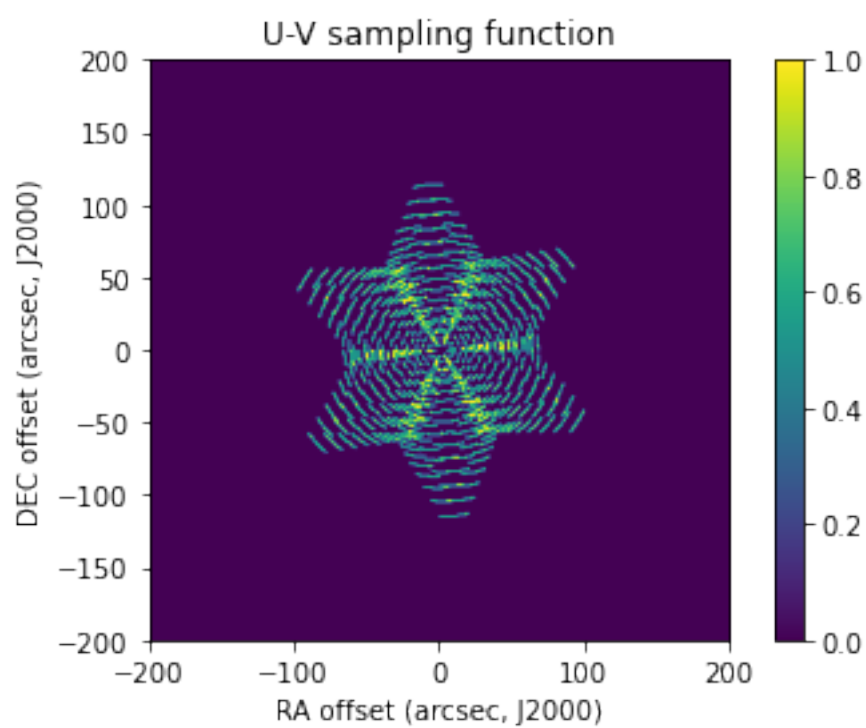
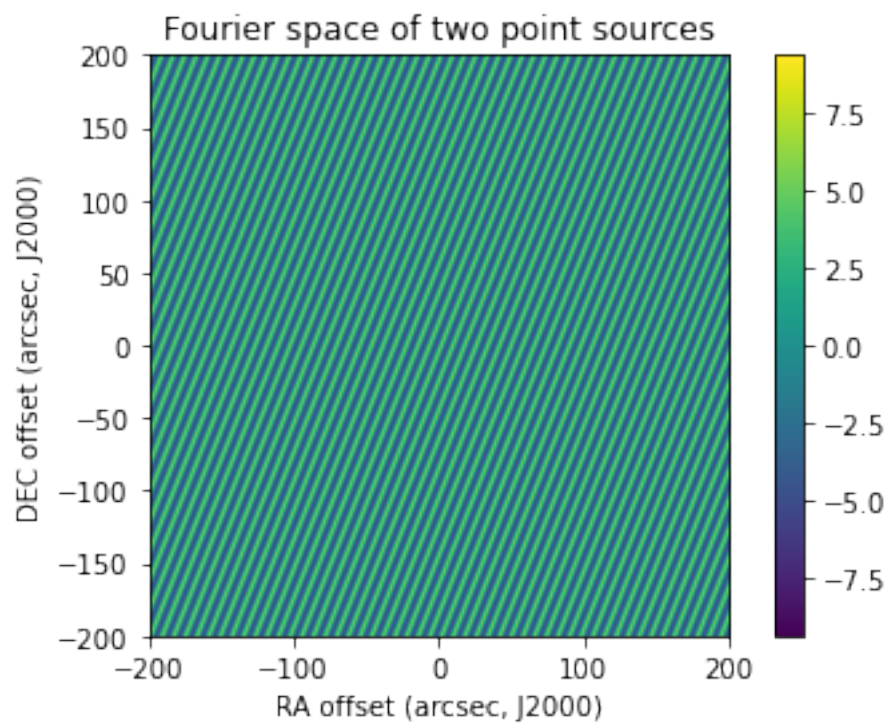
    return(PrimaryBeam)
PrimaryBeam = primarybeam(2*radius,2*radius,radius) # Primary
    ↪beam with diameter 2*radius
PrimaryBeam.resize(400,400) # Resizing
    ↪primary beam from 496x496 to 400x400

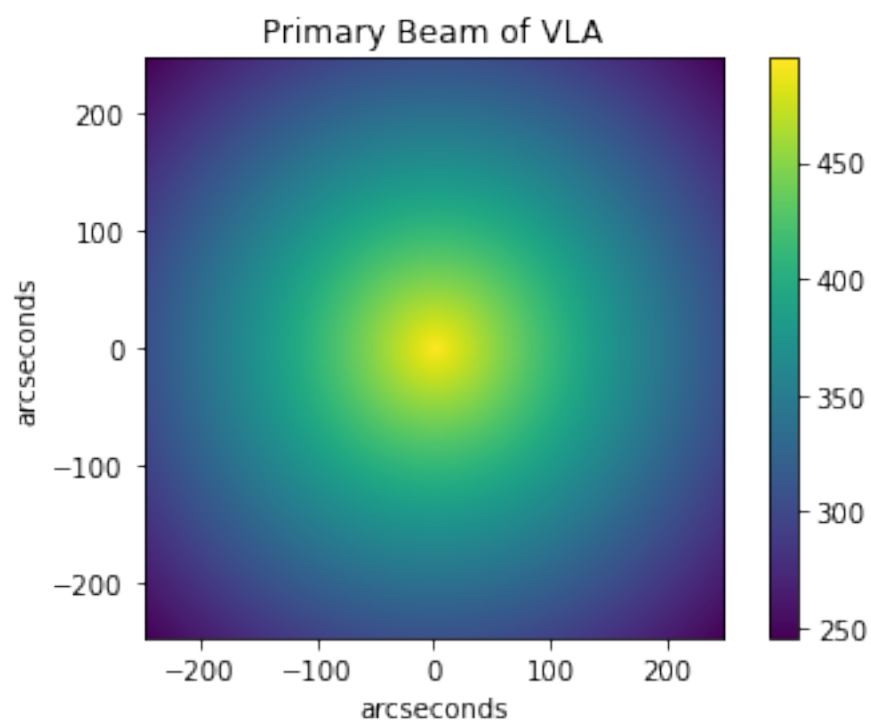
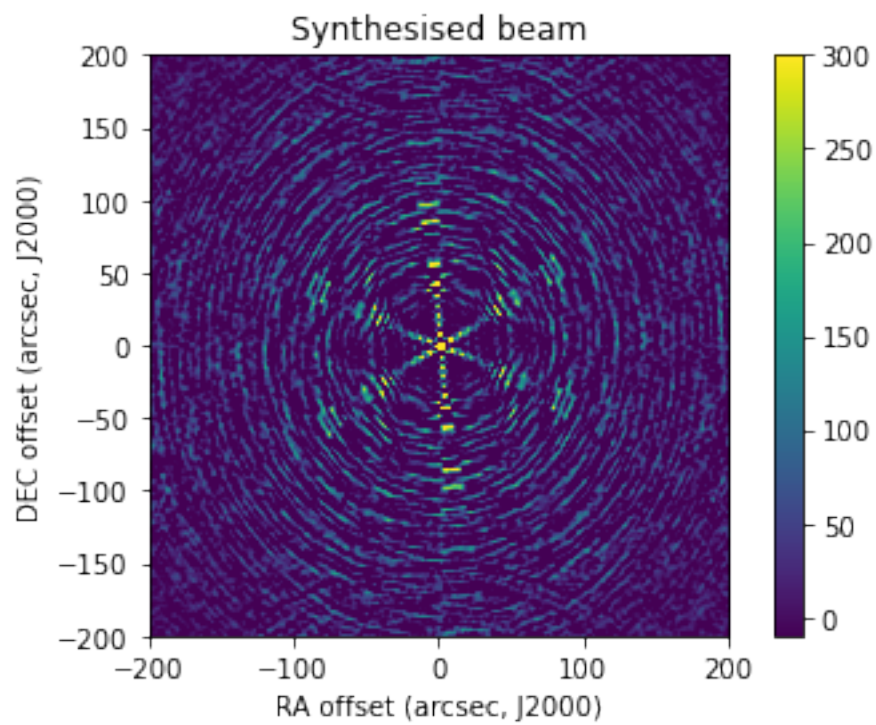
Gauss = np.random.normal(0,0.1,(400,400)) # Gaussian
    ↪noise
TrueSkyBeam = (Gauss + TrueSky) * PrimaryBeam # True Sky
    ↪multiplied by Primary Beam with Gaussian noise
plt.imshow(TrueSkyBeam,extent=[-200,200,-200,200])
plt.xlabel('arcseconds')
plt.ylabel('arcseconds')
plt.title('True Sky affected by Primary beam')
plt.colorbar()
plt.show()

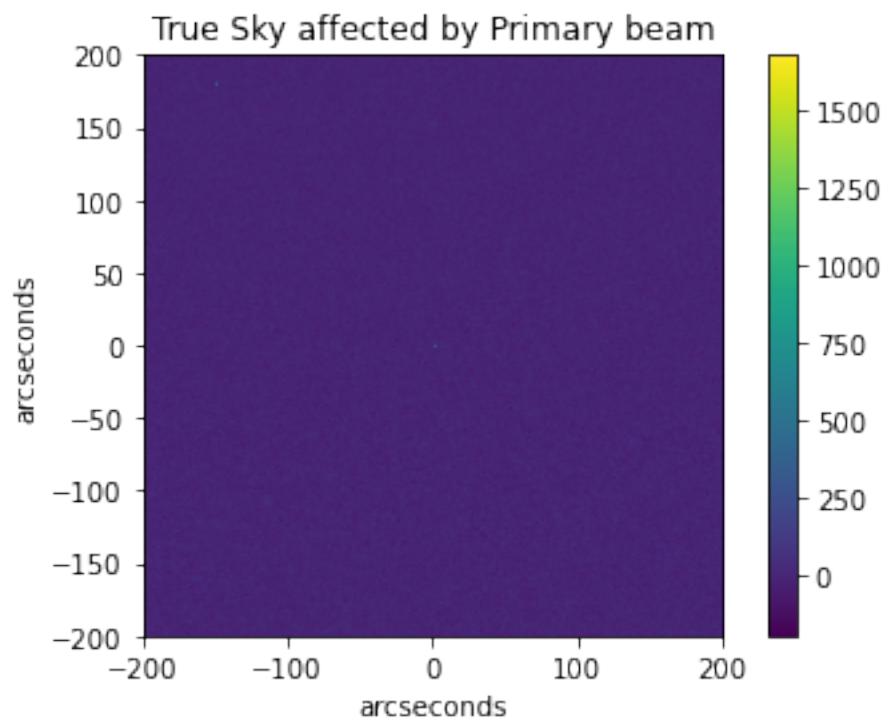
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