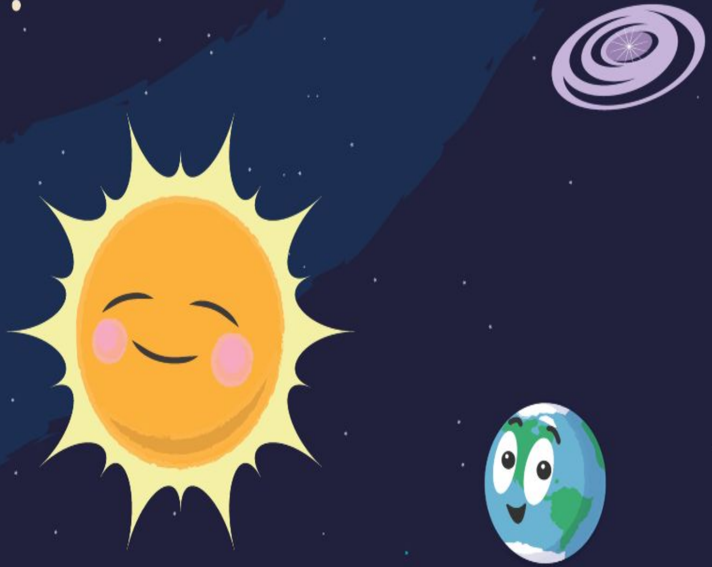
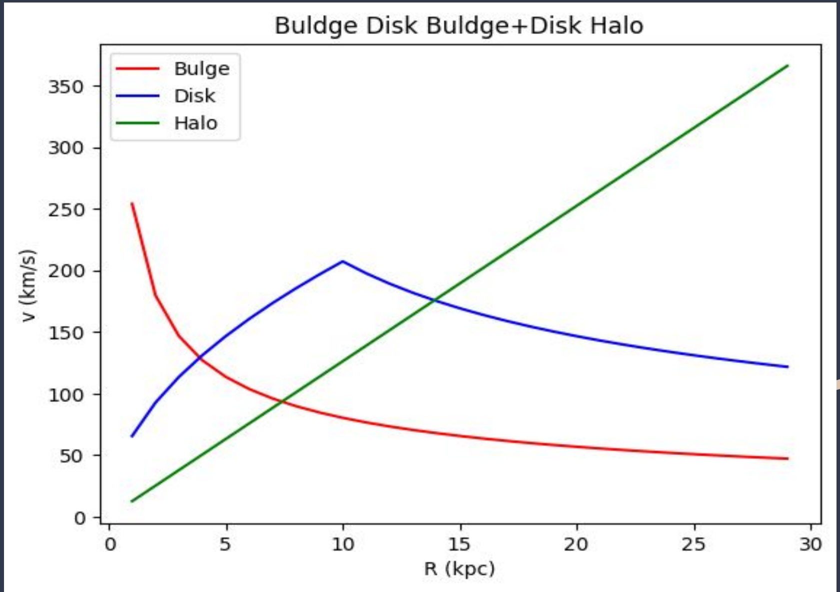
Rotation Curve of the Milky Way Galaxy



Motivations

- The main motivation for the creation of our code was to model the rotation of the Milky Way galaxy
  - by calculating the orbital velocities of enclosed masses, consisting of celestial objects at certain radii from the center we were able to do so
  - by also taking into consideration the effects of each of the mass components (including the bulge, disk, and dark matter halo), we were able to compare the theoretical model we created to the actual observed data
- Through our project, ultimately we were able to use Python to better understand galactic dynamics as well as the role Dark Matter plays in the rotation curves of galaxies

Methods



- In order to calculate the rotation curve of the milky way we calculated the orbital velocity (based on different radii values) of the galactic bulge, disk, and halo

- A base equation of V = sqrt (GM/r) was used and altered in order to fit each of the elements

- In the end each galactic element was plotted with x representing the radius in kiloparsec and y being the orbital velocity

For each galactic element the total mass was defined but a separate mass was defined within a function for each of the element in order to calculate the enclosed mass based on the array created to define the radii

```
[ ] def calculatingOrbitalVelocity (M,R) :  #Defining the function for calculating orbital velocity | we input M as the mass and R for the Radius
      orbitalVelovity = np.sqrt(ac.G * M / R) # General variable that arent specific to the different elements of the milkyway
      return orbitalVelovity
```

```
def calculatingEnclosedMassForDisk(R, density=318 * 1e6 * u.solMass/u.kpc**2): # Input the radius and default value for density to calculate mass
    """
    Calculate enclosed mass for the disk component
    Input: R - orbital radius, density - density of the disk as calculated above
    Output: M - enclosed mass
    """
    if R < 10 * u.kpc:
        M = np.pi * (R**2) * density
    else:
        R = 10 * u.kpc # any radius larger than 10 kpc will be trucated at 10 kpc because of the extent of the disk component
        M = np.pi * (R**2) * density
    return(M)
```

```
[ ] # from re import M
    def calculatingEnclosedMassForHalo(R, density=density_halo): # Defining calculations for enclosed mass of Halo
      M_halo = 4/3 * np.pi * (R**3) * density # calculations for mass of Halo
      return(M_halo)
```

In the end each defined equation was used to create a final equation which combined the enclosed masses and solved for the orbital velocities of the milky way galaxy

```
[ ] def calculatingEnclosedMassForMilkyWay(R, density_disk=318 * 1e6 * u.solMass/u.kpc**2, M_bulge = 1e10 * u.solMass): #Calculating mass of milky way with the
        """
        Note that the halo mass is missing here, so that is what you will work on this Friday
        """
        M_disk = calculatingEnclosedMassForDisk(R, density=density_disk)
        M_total = M_disk + M_bulge
        return(M_total)
```

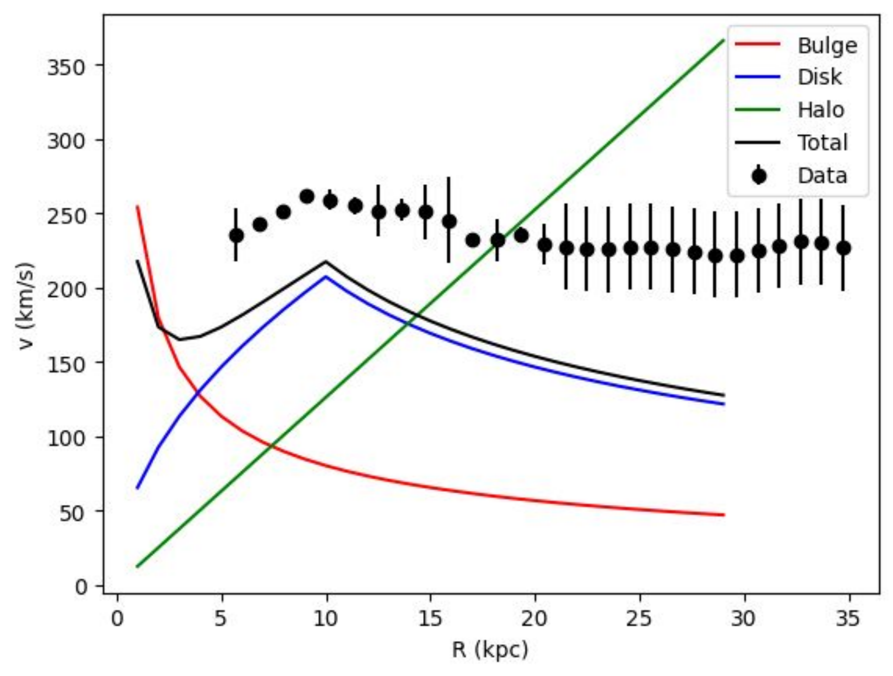
Example of how the orbital velocities were calculated based on the defined function and different radii

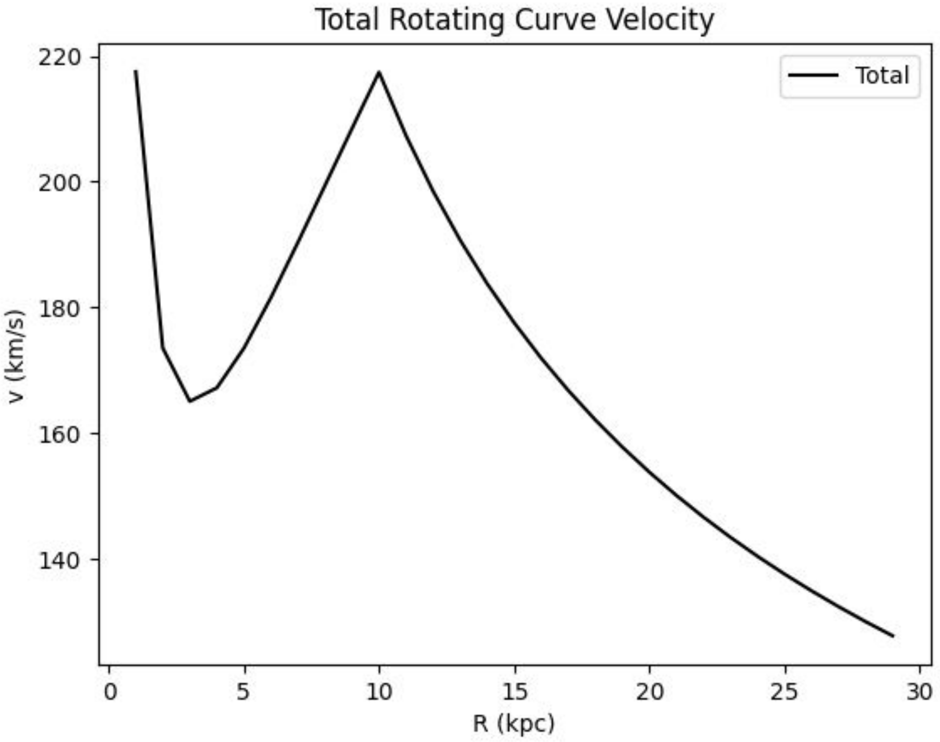
```
[ ] V_Halo_arr = calculatingOrbitalVelocity(M_halo_arr, Halo_arr) # Calculating orbital velocity of Halo based on calculated mass and inputs for radius
    print(V_Halo_arr.to(u.km/u.s)) # print orbital velocity values

[ 12.62114227  25.24228454  37.86342681  50.48456908  63.10571135
  75.72685363  88.3479959  100.96913817 113.59028044 126.21142271
 138.83256498 151.45370725 164.07484952 176.69599179 189.31713406
 201.93827634 214.55941861 227.18056088 239.80170315 252.42284542
 265.04398769 277.66512996 290.28627223 302.9074145  315.52855677
 328.14969904 340.77084132 353.39198359 366.01312586] km / s
```

Results

- In the end after compiling all of the data and formulas the following graph was created which presents the calculated rotation curve of the milky way galaxy and the galactic elements
- Data compiled from a file presents the actual observed data which we included in our final graph as a reference
- The final rotation curve and the data both share a max velocity at 10 kiloparsec
- Based on the graph we can see that the calculated rotation curve of the milky way galaxy reaches a max velocity of about 217.41 km/s at 0 and 10 radii before declining as its radius expands
- The halo component appears to have a constant positive slope which matches with its geometric shape
- The disk component also reaches a max velocity at around 10 kiloparsec


Bulge
Disk
Halo
Total
Data
v (km/s)
R (kpc)
0
50
100
150
200
250
300
350
0
5
10
15
20
25
30
35


Total Rotating Curve Velocity
Total
v (km/s)
R (kpc)
140
160
180
200
220
0
5
10
15
20
25
30

Conclusions

- The rotation curve of the milky way galaxy was able to be calculated using simple python functions as well as a few outside resources

- With the data we collected we can estimate the impact that dark matter has on the rotation of the milky way

- Based on the final rotation curve graph we are pushed to believe that around 10 kiloparsec there is a presence of dark matter which causes the velocity to increase (The outside data also supports this idea)