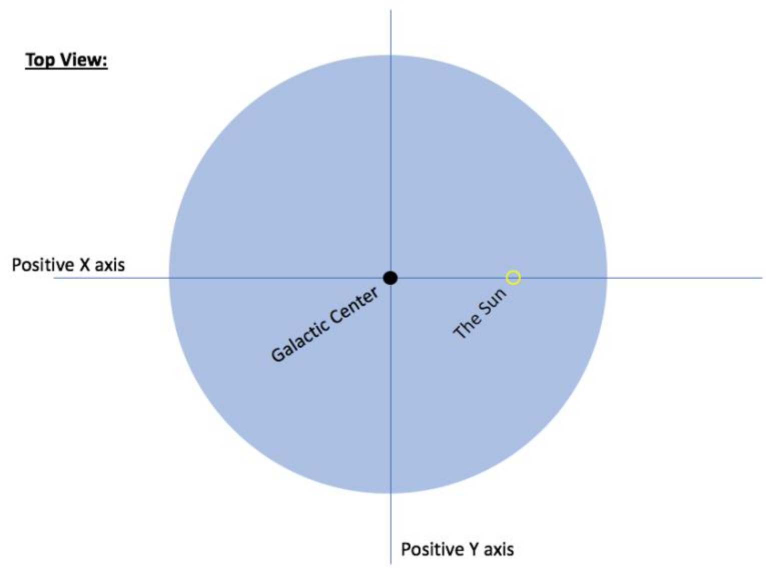
<u>Mapping the Local Milky Way:</u>

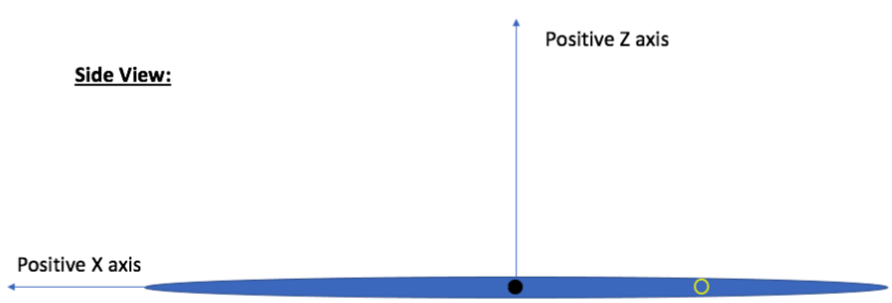
<u>Background:</u>

There are hundreds of billions of stars in our Milky Way Galaxy. Indeed, our Galaxy is absolutely massive – about 100,000 light years across! To communicate the location of a particular star system in this vastness, we can specify its coordinates. While there are many choices of coordinate systems, we will be using “Galactocentric Rectangular Coordinates.” This coordinate system is defined as follows:

- The origin is the center of the Galaxy.
- X – The direction pointing from the center of the Galaxy away from the Sun
- Y – The direction of rotation of the Galaxy near the Sun
- Z – Perpendicular to the plane of the Milky Way

A depiction of the coordinate system is included below:





Skills:

First, we'll need to learn a few new things about python syntax and Kaggle:

- We'll be writing python programs in Kaggle notebooks.
    - Each little block of code is called a cell.
    - Run each cell sequentially – running cells out of order can cause trouble

```
[ ]:  # Python 3 environment

      import numpy as np # linear algebra
      import pandas as pd # data processing, CSV file I/O (e.g. pd.read_csv)
      import matplotlib.pyplot as plt # for plots

[ ]:  #This will read in the csv file and create an object called a Data Frame
      data = pd.read_csv("/kaggle/input/galacticcoordswithgaia/gaiaDataNearSun.csv")

[ ]:  # Inspect data:
      data.head(10)
```

- We'll make use of various libraries, which contain useful tools we can use:

```
import numpy as np # linear algebra
import pandas as pd # data processing, CSV file I/O (e.g. pd.read_csv)
import matplotlib.pyplot as plt # for plots
```

- The pandas library is particularly useful, as it excels in data science contexts.
- To read in data from a file and create a "Data Frame", use the following:

```
#This will read in the csv file and create an object called a Data Frame
data = pd.read_csv("/kaggle/input/galacticcoordswithgaia/gaiaDataNearSun.csv")
```

- To see the first 5 entries in a Data Frame with three columns (a, b, and c), use the .head() method:

```
[12]:  df.head()
```

[12…

	a	b	c
0	1	10	1
1	2	20	4
2	3	30	9
3	4	40	16
4	5	50	25

- To access a particular column (in this case the column named c) in a Data Frame, you can code the following (note the first column just tells you the index):

```
[14]: df.c

[14… 0     1
     1     4
     2     9
     3    16
     4    25
     Name: c, dtype: int64
```

- You can do mathematical operations with each column:

```
[15]: df.a + df.c

[15… 0     2
     1     6
     2    12
     3    20
     4    30
     dtype: int64
```

- You can assign a variable with the following syntax, and the program will know what that variable represents:

```
m = 21

v, w = 0, 1

print(m, v, w)

21 0 1
```

Problems:

1. In Kaggle, go to the following notebook template that has been created for you: https://www.kaggle.com/code/austinhinkel/plottingtutorial-mapthelocalmilkyway. Click the three dots at the top right and select copy and edit notebook.

2. Run the first few cells in your Kaggle notebook template – they have been completed for you and will prepare the data for us. Notice the .head() command shows us the first 5 entries in the data set. What is the X coordinate of the first star in the data set?

3. We'll be creating four plots today. The code for the first plot has been written for you. Run the cell and take some time to read through the code and think about how it connects to the resulting plot.

4. Using the information above and following the directions in the notebook template, create another plot of the y and z coordinates of stars near the Sun. Include the Sun in your plot. Describe how the stars are distributed. Does this make sense based on what you know about the Milky Way Galaxy?

5. There are 6 different star systems mentioned below. Include them in a new version of each of the two above plots. Be sure to follow the links for each star system to learn more about them.
   a. **Kepler-22 star system** – plot as a cyan square ('cs') – The Kepler-22 star system is home to an exoplanet dubbed Kepler-22b, potentially within the habitable zone of its sun-like star. (Note: habitable zone means liquid water *could* exist on the planet -- it does not mean there is confirmed life on the planet.) Discovered in 2011, Kepler-22b may be a "super-Earth" planet -- a planet kind of like Earth but around two times larger in diameter. It may even be covered in a planet-wide ocean! It is approximately 200 parsecs away from the Sun with coordinates: X = -7.9640 kpc, Y = 0.1866 kpc, Z = 0.0538 kpc.

   b. **TRAPPIST-1 star system** – plot as a maroon diamond ('md') – The TRAPPIST-1 star system is home to SEVEN exoplanets all orbiting closer to their star than Mercury does to the Sun! However, because the star is a cooler M-type Red Dwarf, some of the 7 planets fall into the habitable zone. Indeed, the planets are clustered so closely together around their host star that you'd be able to see all of the other planets from the surface of one of them, not too dissimilar from how we see the moon! The link above takes you on a guided tour through an artist's impression of the system. The coordinates for the TRAPPIST-1 system are X = -7.9976 kpc, Y = 0.0064 kpc, Z = -0.0104 kpc.

   c. **PDS-70 star system** – plot as a blue pentagon ('bp') – The PDS-70 star system is rather unusual. There are at least two exoplanets in the system, but recently evidence for a third planet has been found. However, the third planet would share the exact same orbit as one of the other already known planets! While it is not yet clear if this third planet exists or not, its position places it a very special location: a Lagrange Point. Material can get trapped in these special locations -- Jupiter has thousands of asteroids (called "Trojan Asteroids") trapped in its Lagrange Points! Material trapped in these locations share an orbit with the planet. The PDS-70 system is located at X = -7.9210 kpc, Y = -0.0709 kpc, Z = 0.0370 kpc.

d. **Kepler-186 star system** – plot as a black X ('kX') – The Kepler-186 star system contains an exoplanet with the designation Kepler-186f. Kepler-186f is one of the closest exoplanets in size to the Earth, and orbits in its star's habitable zone. Indeed, it is the first discovered instance of an Earth-sized world orbiting in a star's habitable zone. Its coordinates are X = -7.9650 kpc, Y = 0.1722 kpc, Z = 0.0252 kpc.

e. **55 Cancri star system** – plot as a green star ('g*') – The 55 Cancri star system is home to 55 Cancri e, a so-called "lava world" exoplanet. In fact, 55 Cancri e orbits so close to its host star that it is likely covered in a planet-wide ocean of molten rock. The lava planet is so close to its star that a 55 Cancri e year is only about 18 hours long! It is about two times larger in diameter than Earth. The coordinates for the 55 Cancri system are X = -8.0095 kpc, Y = -0.0029 kpc, Z = 0.0077 kpc.

f. **TOI-700 star system** – plot as a red triangle ('r^') – TOI-700 is a star system with four planets located about 31 parsecs from the Sun. (Note: TOI stands for TESS Object of Interest. TESS is a mission that detects dips in the brightness of stars when an exoplanet passes between the Star and Earth.) One exoplanet in this system, TOI-700 e, orbits right on the inner edge of the star's habitable zone. However, the orbit is not perfectly circular so the planet spends some time in the habitable zone and the other half of its orbit slightly too close to its star. It is unclear how exactly this could affect the habitability of the planet -- imagine for a moment what it'd be like to live on such a world! The coordinates for the TOI-700 system are X = -7.9974 kpc, Y = -0.0276 kpc, Z = -0.0141 kpc.

Your instructor will check your Kaggle notebook and will sign off here when it is complete:

____