PHYSICS 761 (Fall 2025) Assignment 1

Due date: Tuesday September 30th at the start of class.

Q1) Astrometry [10 points]

ESA's Gaia mission was launched in 2013 with the goal to map the 6D kinematics of 1 billion stars throughout the Milky Way (i.e. $\sim 1\%$ of all the galaxy's stars). Astrometric measurements of individual sources are available under the *SEARCH* tab on the Gaia Archive. Use this link to look up the celestial coordinates (α, δ), proper motions (μ_α, μ_δ), parallax (ϖ), and radial velocity $(v_{\rm rad})$ of the closest star to the Sun: Proxima Centauri. Ensure that you query the Gaia data release 3 (i.e. gaiadr3.gaia_source).

Note that the calculations asked below should be completed *by hand* without the use of Python packages or equivalent.

a) [2 points]

Calculate the distance to Proxima Cen in pc.

b) [2 points]

Write out Proxima Cen's right ascension and declination in the more conventional notation of hh:mm:ss.s and dd:mm:ss.s, respectively.

c) [2 points]

The reference epoch for Gaia DR3 is J2016.0. What were the celestial coordinates of Proxima Cen at J2000.0?

d) [3 points]

Proxima Centauri is a member of a triple star system whose brightest member is Alpha Centauri. Alpha Cen's J2000.0 coordinates are $(\alpha, \delta) = (14^h 39^m 36.5^s, -60^\circ 50' 02.3'')$. What was the angular separation between Proxima Cen and Alpha Cen at J2000.0?

e) [1 points]

What was the projected separation of Proxima Cen and Alpha Cen at J2000.0 in au?

Q2) Kinematic stellar associations [10 points]
Figure 1 depicts the 6D kinematics of confirmed members of the ~ 10 Myr-old TW Hydrae stellar association. Figure 1 uses the galactic cartesian coordinate system, which were calculated from each source's Gaia astrometry provided here.

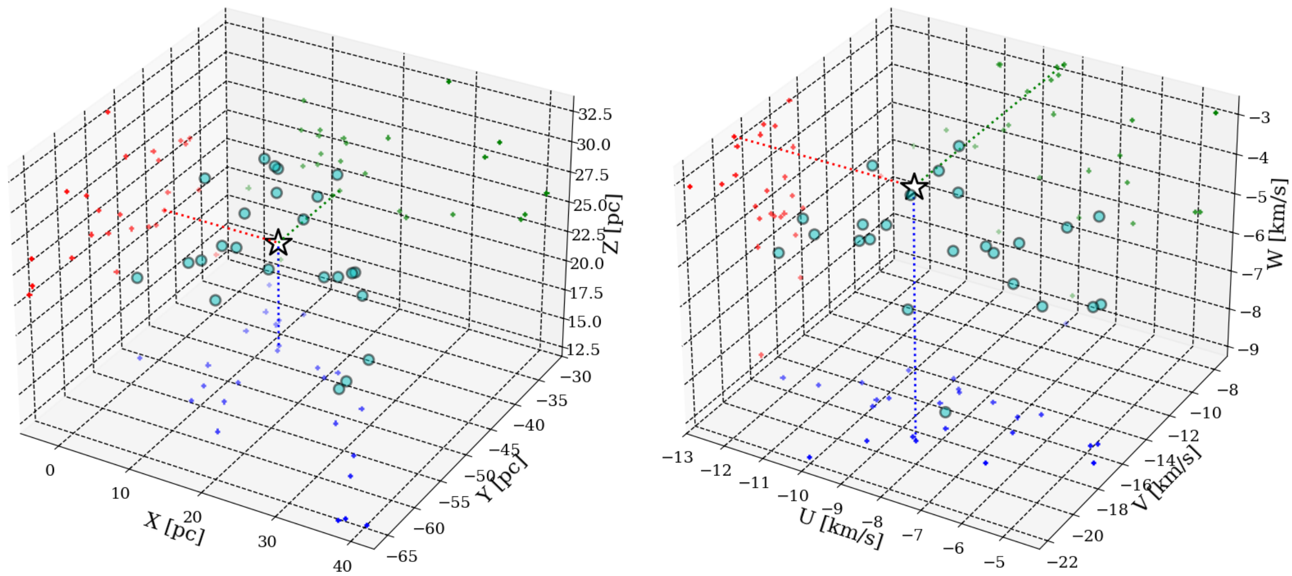

Figure 1: Space positions XYZ and velocities UVW in galactic cartesian coordinates of confirmed members of the TW Hydrae stellar association (TWA). A randomly chosen association member is plotted as a *white star marker* with projection 'stems' that highlight its position in each plane.

a) [7 points]
Download the file linked above. Convert the Gaia astrometry of the TWA members therein to galactic cartesian coordinates and produce your own version of Figure 1.

Hints: you might find the Python packages `astropy.units` and `astropy.coordinates` useful for your coordinate transformations. Also, you may find the example code at the end of this document helpful when creating your 3D plots.

b) [3 points]
Query the Gaia Archive for the two sources below (continuing to use Gaia DR3). Add both sources to your plots from part **a)** and clearly highlight them by unique marker shapes, sizes, colours, etc. Comment on whether you believe either of these targets are members of the TW Hydrae association based on their kinematics and why.

1. Gaia DR3 3481965141177021568
2. Gaia DR3 5413438219396893568

Q3) Photometry [10 points]
Consider idealized, blackbody stars with effective temperatures $T_{\rm eff}$ in the range $3000 - 50,000$ K.

a) [5 points]
For three selected temperatures that span this temperature range, calculate the colour index $B-V$ for these idealized stars. This calculation requires the filter transmission profiles, which you should download for the *Generic.Bessell* B and V bands from this useful resource. Set the zero-point by assuming $B - V = 0.65$ for the Sun ($T_{\rm eff} = 5770$ K). Plot a graph of $B - V$ vs. $T_{\rm eff}$ for your stars. Include in your graph the model provided in this csv file.

Hint: you might consider using `astropy.modeling.models.BlackBody` to compute your blackbody spectra.

b) [5 points]
For the same three temperatures chosen above, calculate the bolometric correction BC. Plot a graph of BC vs. $T_{\rm eff}$ for your stars and include the model contained within the same csv file as in part **a)**.

Q4) Fundamental Stellar Parameters [10 points]
Consider an eclipsing binary with a period of 30 days and a total single-eclipse duration of 6 hours. We observe a flat eclipse minimum for 56 minutes. The radial velocity amplitudes for star 1 and star 2 are $v_{r,1} = 30$ km/s and $v_{r,2} = 40$ km/s, respectively. For a circular orbit, what are the masses of and radii of both stars?

```python
# skeleton code to produce a 3D scatter plot of XYZ
import numpy as np
import pylab as plt
from mpl_toolkits.mplot3d import Axes3D

ax = plt.figure().add_subplot(projection='3d')

# plot XYZ positions
ax.scatter(X, Y, Z)

# hardcode the axes limits (will be helpful later)
ax.set_xlim3d(ax.get_xlim3d())
ax.set_ylim3d(ax.get_ylim3d())
ax.set_zlim3d(ax.get_zlim3d())

# plot 2d plane projections as plus signs
ax.scatter(X, Y, np.ones_like(Z)*ax.get_zlim3d()[0], c='b', marker='+')
ax.scatter(X, np.ones_like(Y)*ax.get_ylim3d()[1], Z, c='g', marker='+')
ax.scatter(np.ones_like(X)*ax.get_xlim3d()[0], Y, Z, c='r', marker='+')

# highlight a random star
index = np.random.choice(range(len(X)))
ax.scatter(X[index], Y[index], Z[index], marker='*')

# plot ‘stems’ to highlight the star’s position in each 2D projection
args = X[index], Y[index], Z[index]
ax.stem(*args, orientation='x', bottom=ax.get_xlim3d()[0])
ax.stem(*args, orientation='y', bottom=ax.get_ylim3d()[1])
ax.stem(*args, orientation='z', bottom=ax.get_zlim3d()[0])

ax.set_xlabel('X [pc]'), ax.set_ylabel('Y [pc]'), ax.set_zlabel('Z [pc]')
```