Homework 2

Characterize an Open Cluster

Your goal here is to select and characterize a known open cluster, trying to constrain as many of the physical properties of the cluster as possible. You may pick any known open cluster you like (I will make a few suggestions below), some will be "easier" than others. The intent here is not to necessarily get the perfect answer, but to think about why your answers might be wrong (as compared to the literature).

Rules

You must obtain and utilize Gaia DR3 data. Other supplemental data sources are fine to use (e.g. cross matches to other catalogs, etc), but are not required!

You may not use known cluster membership catalogs. One explicit goal here is to practice selecting cluster members! You can use results from known catalogs (e.g. average proper motions), but the catalogs are off limits. You *are* welcome to check your membership against known catalogs in your discussion, but that is not required.

Part 1

(25pts)

1.1. Select an Open Cluster for study.
You may choose any known cluster for your analysis. There are **many catalogs** for clusters, I would probably suggest picking something dense that has been known for a while (rather than a new cluster identified only in Gaia with no other literature), and something in the Milky Way so you can get useful proper motion selection (i.e. I wouldn't go for any LMC clusters).

Suggestions include:

- **Hyades** (very nearby, easy to study with the Gaia Catalog of Nearby Stars datafile alone!)
- **Pleiades** (nearby, famously tricky to agree on parameters)
- **M44** (the "beehive", close and middle aged)
- **NGC 869/884** (h and χ Persei, the "double cluster")
- **M67** (Solar age benchmark, relatively nearby, extremely well studied)
- **NGC 188** (an older cluster)
- **NGC 6791** (the oldest open cluster)

1.2. Do a "cone search" (or box search) for stars around the cluster in Gaia DR3 data.
You don't want to download *too* much data, so keep this query to something manageable. Ideally you'll select a region of sky that is a few times wider than the cluster to get a good estimate of the "field star" population. (If your cluster is very spread out across the sky you might have to analyze the cluster center.)

You can use any mirror of the Gaia DR3 archive. The official **Gaia Archive** is not difficult to use, but there are good versions hosted elsewhere too (e.g. you can use **astroquery**, **CDS**, **ARI**, topcat, MAST…) . You'll need to at *least* get proper motions, Parallaxes, magnitudes (G, BP, RP). Uncertainties on these measurements are useful for throwing out spurious measurements. Additional columns including extinction, distance, velocities, or other photometric filters can be very helpful, but are not required!

Note: if you select a cluster contained with the GCNS you don't have to do this part, but you do need to make selection cuts from the big file.

Be sure to document where/how you got your data!

1.3. Create a list of probable members for the cluster using proper motions.
Select likely members for the cluster based on their proper motions. You can optionally include selection based on tangential distance from the known cluster center, line of sight distance, as well as position on the color-magnitude diagram (be careful with this one!)

Your selection can be as simple as a binary classification (cluster versus field), or you could use methods like mixture models to estimate membership probabilities. Make sure you show clearly how you make your sample selection, and how many stars it includes.

Part 2

(50pts)

2.1 Fit an isochrone model.
These models are useful in determining cluster-wide properties such as age and distance, and also in identifying things like binary stars and estimating per-star masses.

I like the **MIST isochrones** for most things these days, but **PARSEC**, **Dartmouth**, and **YaPSI** and others are also useful.

Fitting isochrones can be tricky business, and you don't need to build an entire model-fitting and interpolation suite or use MCMC, etc… **It's OK to simply grab a small grid of isochrones near the known literature values for age and [Fe/H], and determine which track has the best reduced χ^2 for your cluster stars on the Gaia CMD.** If filing the whole CMD is challenging, use different portions to constrain each parameter individually: e.g. stars near the Turn-Off to constrain age, giant stars to constrain metallicity, main sequence stars to estimate distance.

Make sure you have a plot of the Color–Absolute Magnitude Diagram with the best isochrone overlaid, and your best parameters clearly listed (see next part below).

2.2 Characterize the cluster.
There are *many* possible properties you can measure for the cluster from this data, but you should at least attempt to constrain its:

1. Age and Metallicity (from isochrones)
2. Distance (from isochrones)
3. Mean proper motions (in both RA and Dec)
4. Mean parallax (in mas)
5. Cluster radius
6. Cluster mass

For #5, you can use many definitions for “radius” based on the radial density distribution of stars you create. This can include something empirical like FWHM, or fit a profile model such as a Cauchy or Gaussian distribution or a **King profile** to find a characteristic radius. A simple radial profile equation to fit could look like:

$$n(r) = n_{bkgd} + \frac{n_0}{1 + (r/R_c)^2}$$

where R_c is the characteristic core radius of the cluster you’re after, n_{bkgd} is the density of field stars, and n_0 is the central cluster density you measure.

For #6, you’ll need to at *least* count up the stars in your sample (estimating their masses based on your best-fit isochrone). You could do fancier things including fitting the luminosity or mass functions.

2.3. Binary or Odd Stars?
Can you identify any obvious binary stars, unusual stars (e.g. sub-sub giants), or stars that are very likely cluster members but don’t track the isochrone well?

2.4. Discussion
Any other interesting cluster properties, or considerations that are impacting your analysis? How do you compare to the literature? Any “simple” methods you used that have obvious problems? Where are you most or least certain of your cluster membership (e.g. high mass or low mass stars)?

Turn In

Use this Dropbox Link to turn in a PDF of your write-up.

This could simply be a saved Jupyter notebook with lots of annotation/discussion, or could be formatted in LaTeX with embedded figures. Remember to **show your work**, meaning the provenance of your data and the decisions you’ve made to create your figures.

Collaboration is encouraged for problem solving. Please list clearly all your collaborators! Each person is responsible for turning in an obviously unique work product (i.e. you write your own code, your own discussion, etc). This is a graduate course: I don’t care about you getting the *right* answer as much as I want to see the efforts of your thoughts and synthesis!

Nominal Due Date: 2023-Feb-07