AST 221: Problem Set 4

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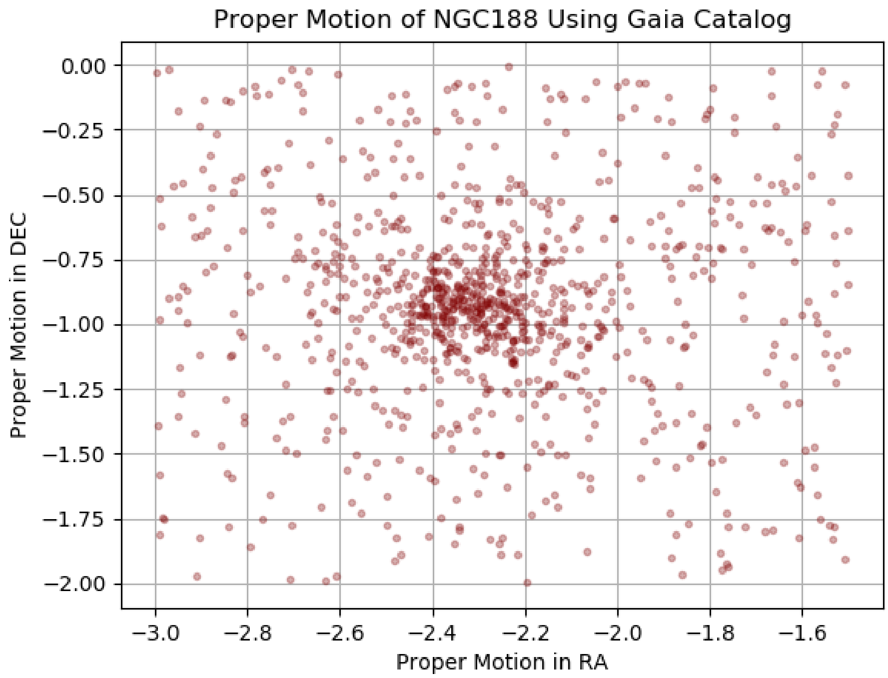
Due: Thursday, April 4 by midnight.

Problem 1. Make an HR diagram of an open (galactic) cluster based on the Gaia catalogue. You may choose any cluster EXCEPT the Pleiades (since you already did the Pleiades as an exercise last semester in AST 222). Also, please make sure you have made a UNIQUE choice of galactic cluster – do not use the same cluster as any other classmate. (I suggest posting a cluster sign-up board in the student office to be sure that no one duplicates another person's cluster). You can adjust several parameters in selecting members, including the exact position of the center of your search area and the size of your search box. You can use parallaxes and/or kinematic information (proper motions and/or space motions) to help eliminate field stars. Your objective is to get as clean an HR diagram of your cluster as possible – ie. containing enough cluster members to clearly define the cluster HR diagram with as few non-members as possible. Do NOT remove stars arbitrarily from the diagram just because they don't fit your pre-conceived notion of what the HR diagram should look like! (That's a bad practice in science ...).

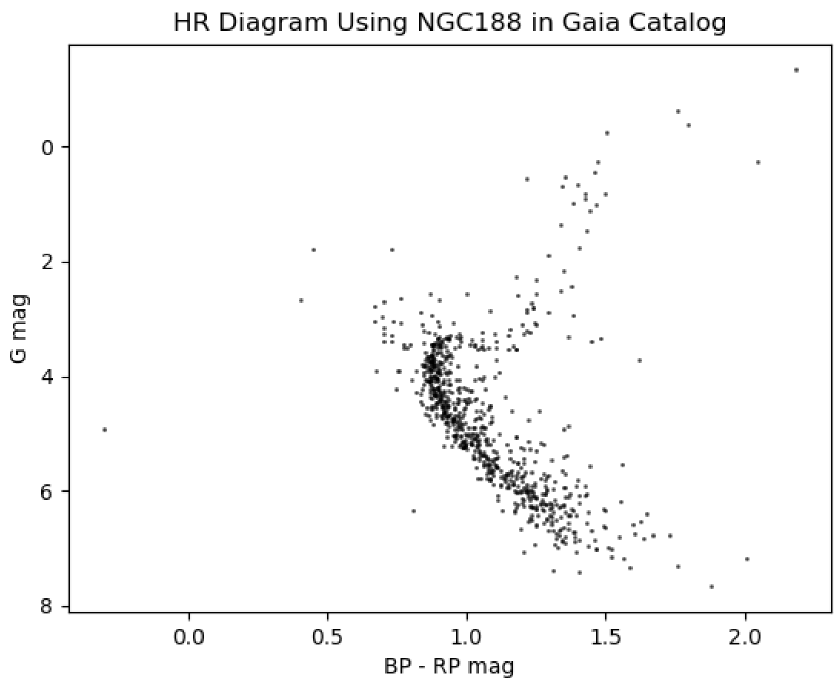
Answer 1. Here we present the HR diagram of NGC188, an open cluster. Attached, first, is the code:

We queried the Gaia DR2 catalog around the coordinates $(\alpha, \delta) = (12.11, 85.255)$. We only allowed stars within a 1° radius of the coordinate point. Next, to weave out all the stars not in the cluster, we take two cuts: one in proper motion and the other in parallax. First, consider the proper motion. We plotted all the proper motion of the stars queried. We noted the clump in the plot and saw that it was the stars that we were after since all the stars in a cluster have the same proper motion. Thus, we restrict our query to only allow proper motion values in RA between $(-3, -1.5)\mu$as and proper motion values in DEC between $(-2, 0)\mu$as. Thus, the stars we consider are:



We then cut by parallax. We know the distance to NGC188. Thus, we only accept values $\pm 0.5\mu$as. Therefore, we only consider stars that have a parallax between $(0.50, 1.5)\mu$as.

Now that we have all our constaints, we find the absolute magniutdes of the G,BP, and RP bands (these are the bands that Gaia uses). Thus, we generate our HR diagram:



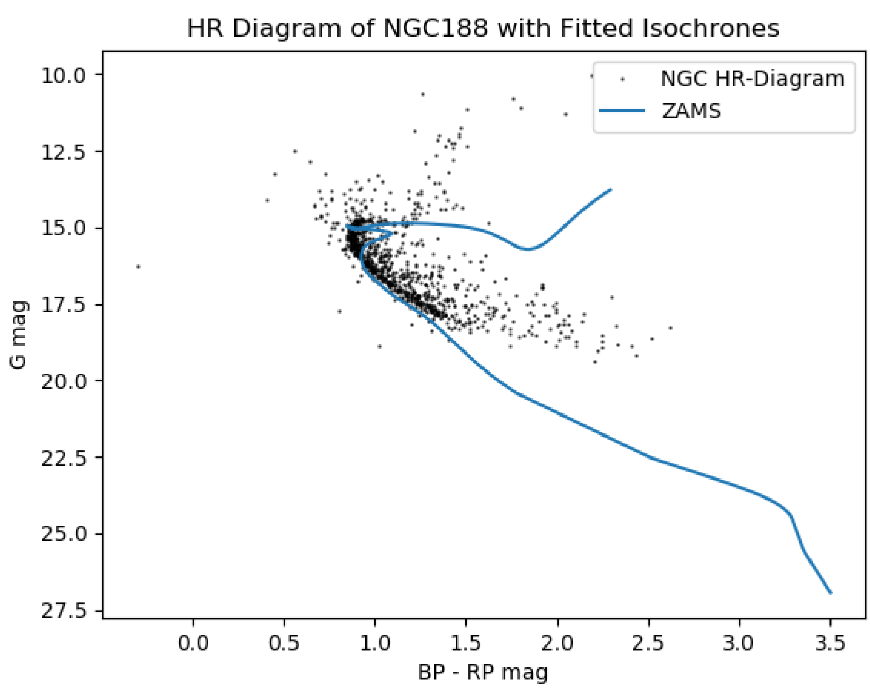
Problem 2. Once you have a nice cluster HR diagram, overlay on it a ZAMS with the metallicity appropriate to the cluster. You can use the Dartmouth Stellar Evolution Data Base (linked on the course Moodle page) to obtain model results in the Gaia magnitude system. For the galactic cluster, you can use a metallicity of 0 – i.e. solar. If it is a globular cluster, you will need to look up the metallicity of the cluster and choose an appropriate ZAMS. Adjust the horizontal location of the ZAMS to account for the foreground reddening of the cluster (which you will have to look up or figure out yourself). Then adust the vertical location of the ZAMS to match the cluster MS and use the amount of adjustment to calculate the distance to the cluster.

Answer 2. We find that NGC has a metallicity of [FE/H] = 0.0 and an age of about 6Gyr. Thus, we use the Dartmouth Stellar Evolution Data Base to find the isochrones appropriate to our cluster. When we overlay the ZAMS line, we adjust horizontally and vertically. The horizontal adjustments tell us about the reddening, where we shifted ZAMS in the horizontal direction to the right by 0.8 magnitudes. Then, we adjust in the vertical direction, which tells us about distance. We shift the ZAMS vertically down by 5 magniutdes. Therfore, using the distance modulus:

$$m - M = 5\log(\frac{d}{10}),$$

we can solve for distance. That is, we will plug in $m - M = 13$. Thus, $d = 3,981$pc.

This value is far off from the acutal distance of $d = 1660$pc, which would be at a $m - M$ value of 11, which then makes it seem as if our ZAMS is not too bad of a fit. Nonetheless, we produce this plot:

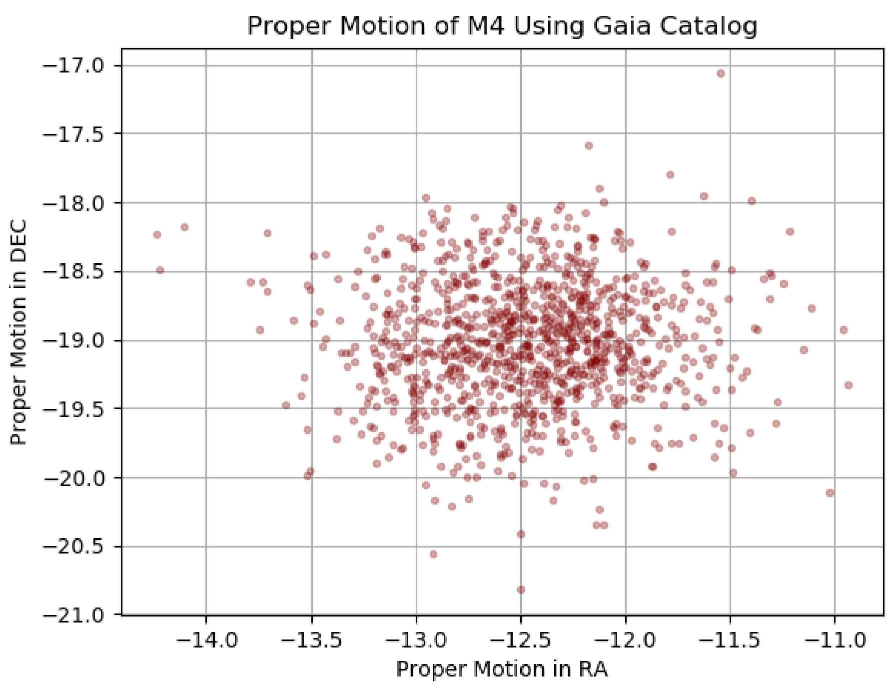


Problem 3. Repeat the process in Problems 1 and 2 for a globular cluster of your choice. Again, please make sure your choice of globular cluster is unique.

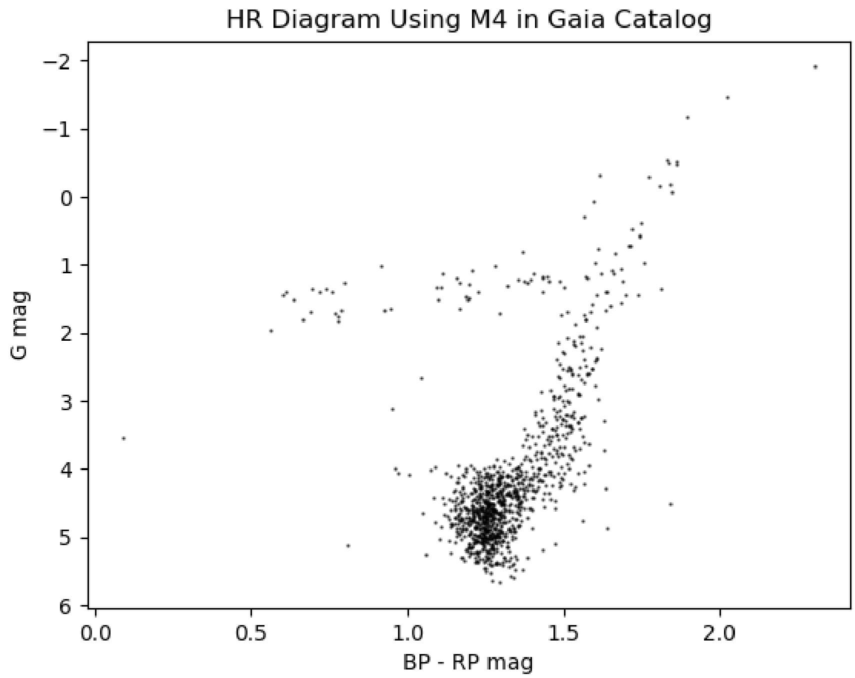
Answer 3. Now, we we present the HR diagram of M4, a globular cluster.

We once again queried Gaia DR2, this time around the coordinates of $(\alpha, \delta) = (245.8958, -26.5256)$, which are the coordinates of M4. We initally got all the stars within a 1° radius of our coordinates. In the query itself, we search a 1 degree radius around this value. The next cut we made was the parallax constraits. Knowing the distance to M4, we calculate for the parallax to M4 and accept ± 0.6 milli-arcseconds from the value of actual parallax (0.41μas). Thus, our parallax range is $(0.35, 0.48)\mu$as.

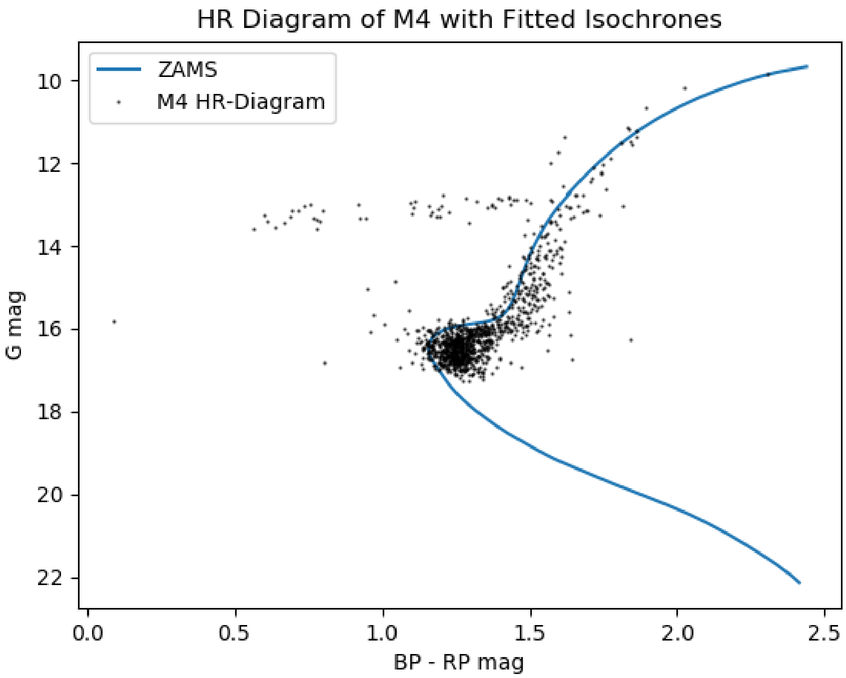
Next, we want to constrait by proper motion. We can do this because we know that all stars in the cluster will have the same proper motion. Thus, we plot all the proper motions of the stars. Immidietely, we notice a clump of stars in our plot. Thus, we only accept stars with proper motion of $(-14.5, -10.5)\mu$as in right ascension and accept $(-21, -17)\mu$as in declination. Our results proper motion plots is:



It becomes clear that we have constrained our sample of stars to only be those in the M4 cluster. Therefore, we can plot the HR diagram of M4 using this sample:



We clearly see many of the prominent features of globular clusters, which we will discuss in problem 4. Now we find the metallicity and age of the cluster to be -1.07 and 12Gyr, respectively. Using the Dartmouth Stellar Evolution Data Base, we overlay a ZAMS with the appropriate metallicity and age to generate the following. We once again move the ZAMS horizontally and vertically, our vertical displacement corresponds to the $m - M$ value in the distance modulus. Here, we get a value of $m - M = 12.5$. Thus, plugging into the distance modulus and solving for d, we get $d = 3162$pc, which is within a thousand pc of the actual value of 2.2kpc. A value of $m - M = 12$ would give a value within 300pc of this value. In any case, we present the plot here:



Problem 4. Discuss the HR diagrams above and your procedures for obtaining them. What features can you clearly see on each figure. Identify well known features such as the MS turnoff, the RG, HB, AGB features and the presence or absence of WDs. Can you see a binary sequence? Can you see blue stragglers? Can you see supergiants? Comment on any other aspects of the HR diagram or the procedure for selecting members and non-members that you find noteworthy.

Answer 4. First we discuss the HR diagram of the open cluster: NGC188.

Start at the bottom right of the diagram. We see that we still have a prominent main sequence in the cluster, but it doesn't extend too far out. Right away, this is an indication that the cluster is at a mid range age, since the structure of the diagram looks similar to that of M67. We reach the turning point after going up the main sequence which leads to the section of subgiant branch, which is the horizontal strip following the turn off point. Then, we reach the end of the diagram, where we have a diagnal branch which is the red giant branch (RGB). We see that the SBG and RGB regions are fairly dense, which is further indication that the cluster is mid-old range star.

Now we discuss the HR diagram for the globular cluster: M4.

Immidiately, we notice the lack of a main sequence region. This is a clear indication that the cluster is a very old one, which is in fact the case as noted earlier. So the clump at the bottom of the diagram is the turn off point to the cluster. Therefore, the stars in NGC188 are almost exclusively in post-main sequence stages. To the immidiate left of the turn off region, it is possible that we have a few amout of blue stragglers. Moving up the diagram, we have a very dense red giant branch followed by a region of asymptotic giant branch stars, which starts around the area where the horizontal branch stars intersect the rest of the diagram. Looking at the horizontal branch, we see that there is a blank region which could represent the location of RR Lyrae stars, which are variable and often not included in HR diagrams due to that reason. Aditionally, we see that the horizontal branch extends pretty far out from the rest of the diagram (and that there is no 'red clump'), which tells us that the cluster could be metal poor, which is in fact the case as noted earlier.