Writing 5: Journal Article
Due Monday, November 23rd, 5pm

Read the journal article by Milone et al. 2010 (http://iopscience.iop.org/article/10.1088/0004-637X/709/2/1183/pdf) and answer the following questions related to the reading. Look up terms that are unfamiliar to you, and don't forget the reading strategies we have discussed in class and practiced on previous assignments.

Background:

For a long time globular clusters (clusters of many stars) were thought to be "simple" populations, meaning the stars in a given cluster all formed from the same material at the same time. Astronomers also refer to such populations as "co-eval" or "single generation." Assuming a simple stellar population, differences in brightness (or luminosity) will be due solely to differences in mass, with more massive stars being brighter. In a "single-generation" scenario like this stars in the same stage of evolution should show roughly the same elemental abundances. The paper you will read for this assignment explores this topic in greater detail.

Main sequence (MS): evolutionary state where stars spend most of their life. It is in this stage that stars fuse hydrogen to helium in their cores.

Subgiant branch (SGB): stars that are slightly brighter than a MS star but not quite yet a giant. These are stars that are probably nearing the end of hydrogen fusion in their cores.

Red giant branch (RGB): stars that are fusing hydrogen to helium in a shell around a degenerate helium core.

Color-Magnitude Diagram (CMD): This is the observer's version of the Hertzsprung-Russell Diagram we discussed in class. It plots the color of star (x-axis, proxy for temperature) against the magnitude (y-axis, proxy for brightness).

Binary mass ratio (q): refers to the ratio of the mass of the secondary star to the mass of the primary star, for example q=0.5 means the secondary is half the mass of the primary. It is believed that binaries are more likely to form in equal mass systems, i.e. with a mass ratio that is closer to one.

Na-O anticorrelation: There are different nucleosynthetic processes that occur in stars to produce all the elements heavier than H and He that we know of on earth today—we are literally made of star stuff! One such process is known as the CNO cycle, and it is responsible for fusing hydrogen into helium with CNO acting as a catalyst. This is a process that operates in stars more massive than the sun. At the temperatures at which this process occurs (in *intermediate mass, evolved* stars), Ne can be transformed into Na by proton capture while O is destroyed during the CNO cycle. This means that Na becomes enriched at the expense of oxygen. This leads to the so-called "Na-O" anticorrelation, or the idea that if Na is enriched, O will be depleted or vice versa. Observing an Na-O anticorrelation in *unevolved* stars means that these stars must have been polluted by CNO processed material from other more massive, evolved stars. This is because unevolved low mass stars do not reach the temperatures required to activate the CNO cycle and thus could not produce the Na and destroy the O necessary to produce the anticorrelation.

Helium enrichment: For stars, lower metallicity usually means a star will be bluer in color, but in the case of some globular clusters we find the populations bluer than the main sequence to be more metal rich. This means they must be enhanced in helium. If you are interested in the physics behind this, ask me, but I will not go into the details and equations here. Finding bluer, helium-enriched stars that are *unevolved* means these stars cannot have gotten this extra helium themselves; it must have come from an older population of stars that made the helium and subsequently enriched later generations. So finding a globular cluster with a population of stars that is bluer than the main sequence and helium enriched implies that globular clusters are NOT simple stellar populations (meaning stars born all at the same time out of the same material).

Detailed Questions (Paper Body):

1) Astronomers used to think of globular clusters were good approximations of "simple stellar populations." What are the qualities that would make a cluster a "simple" population?

2) What discovery led astronomers to rethink the idea of globular clusters as simple stellar populations?

3)Why do the authors bother to give so much specific detail about their observations and data reduction? Hint: think non-astrophysical sources of main sequence broadening.

4) According to Figure 4, which binary fraction best reproduces the observed results?

5) In Figure 5/Section 3.1: What is the purpose of using artificial star tests when trying to count the number of binaries in the cluster?

6)In order to reproduce the broadened MS seen in these CMDs what would the binary fraction and binary mass ration need to be for this cluster? Are these reasonable values (yes or no)?

7) How do the authors test whether the broadening of the MS is intrinsic or is due to photometric errors (i.e. errors in measuring colors)?

8) Explain how the authors make the "straightened" CMD in panel b of Figure 8.

9) The separation between the "redder" and "bluer" stars is less sharp for all but the top panel in Figure 8. Why is this the case if this figure presents the same test as Figure 7 (which looks to have better separation)? Does this mean the broadening of the MS is not intrinsic (yes or no)?

10) In section 4 the authors say that there seems to be no intrinsic spread in the subgiant branch. Copy the sentence in Section 4 that is their evidence for this claim.

11) Given the background introduction on the Na-O anticorrelation and your reading of Section 5, what population do you expect is the possible "second generation" of stars in this cluster and what population is the "first generation?" (Options: the Na poor, O rich or Na rich, O poor populations on the RGB)

Big Picture Questions

12) What is one astrophysical way the MS could be broadened? What is one non-astrophysical way the MS could be broadened? Do the authors account for both of these (yes or no)?

13) This cluster shows evidence for MS broadening. Name two clusters that show evidence for multiple MS (not just broadened MS).

14) By comparing the cluster in this paper to the clusters that show evidence for multiple MS what origins do the authors suggest for the stars in their sample that are bluer than the MS?

15) The authors do not find evidence for a split subgiant branch in this cluster like has been found in other clusters. Does this mean that this cluster likely contains a simple stellar population (single generation)? Why or why not?

16) If the second generation of stars lies bluer than the MS it is likely enriched in helium. What TYPE of stars do the authors posit could be responsible for producing this helium?

17) Why is it important that this MS shows evidence of intrinsic broadening (or perhaps even a split MS)? What previously held notion about globular clusters does this challenge?