An Investigation of Blue Straggler Stars in M67

Steven Warren
San Diego State University

I worked this summer as an intern at the University of Texas at Austin run Mcdonald Observatory. I worked with Dr. Matthew Shetrone of McDonald Observatory and Dr. Eric Sandquist of San Diego State University on a project that is to become *the* definitive blue straggler star (BSS) investigation to date.

The purpose of my work was to measure radial and rotational velocities, metal abundances (lithium in particular), check for signs of binarity, and gather all known information about the BSSs across all wavelengths from the literature. In doing so, I could hopefully put constraints on formation mechanisms of each BSS as well as provide the scientific community with a broader knowledge of BSSs and how they work.

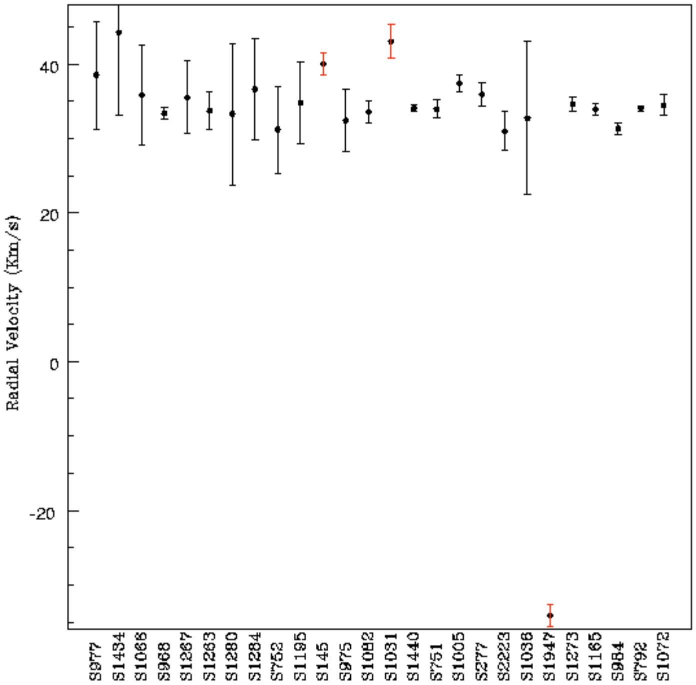
M67 makes the perfect subject for this type of research. It has a distance modulus of about 9.7 (Dinescu et al 1995) which put it about 2800 light years away. Its close proximity allows us to get high resolution spectra of individual stars. It is one of if not the only cluster we are able to do this with. Most other clusters are too far away or too dense (globulars) to separate the individual stars. It is also very well studied which allows us to better detail each star.

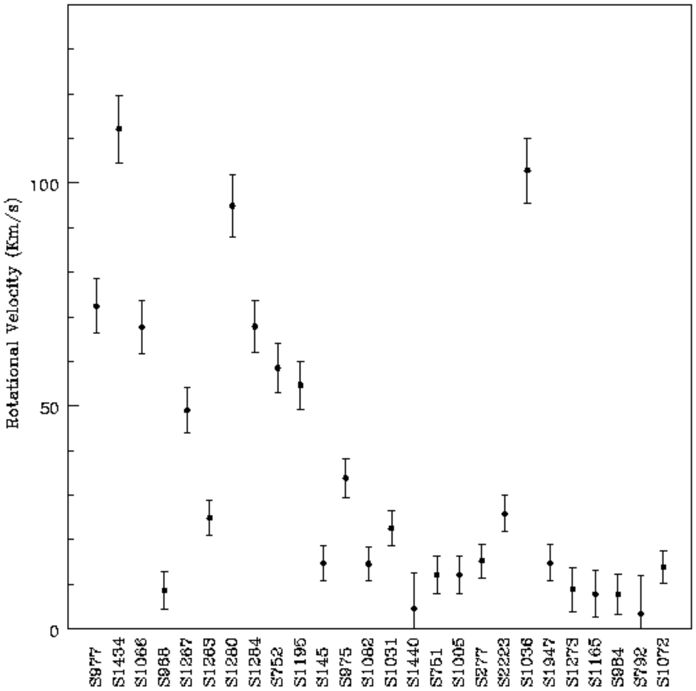
The data I worked with was obtained from both Mcdonald Observatory in Fort Davis, Texas and Mt. Laguna Observatory in San Diego, California. I dealt with two types of data, spectroscopic and photometric. The spectroscopic data was obtained from the Hobby-Eberly 9.2m telescope using the high-resolution spectrograph (HRS) as well as the 2.7m (107”) Harlan J. Smith telescope using the coudé spectrometer. My photometric data is CCD photometry and was gathered with the 1m (40”) telescope atop Mt. Laguna. It is necessary to use both photometry and spectroscopy in order to fully understand an object. Photometry provides us with the ability to pick out BSSs from a color-magnitude diagram but gives us little other information aside from temperature and light variation. Spectroscopy allows us to dig deeper into the secrets of the star and expose everything from temperature, abundances, periodicity, surface gravity, micro/macroturbulence, and many other properties.

There are two basic ways to form a BSS, direct stellar collision and binary coalescence. The two ways predict very different BSS properties. Direct stellar collision will result in a slower rotating BSS. It also predicts the destruction of an important element, lithium, through mass ejection. Surprisingly enough the lithium isn’t burned from the impact itself, but any left over lithium will be destroyed through a brief red giant type phase after the merger. Binary coalescence, however, will result in a faster rotating object (if the pair is of similar mass), and if the merger is slow enough, will allow for lithium to remain in the atmosphere of the newly formed BSS. It was my job to search for this element because it not only allowed us to put a constraint on the formation mechanism but it has also never been detected in a BSS.

My first task was to reduce the raw spectra. I employed IRAF to assist me in this task. The steps included bias and trim subtraction, overscan removal, flat fielding, and spectral line alignment amongst others. Once I had completed this I moved on to the analysis of the spectrum through many different means.

Finding radial and rotation velocities are a very important step in the analysis process. Radial velocities can tell you two important things about a cluster star. The first being if it is a member and the second if it is a binary. If a star has the same mean velocity as the cluster it has a good chance at being a member. M67's mean radial velocity is about 34 km/s, so it would be expected that the stars you study have the same radial velocities. Looking at the first figure clearly shows a trend at about 34 km/s. There are many binary stars among the BSSs in M67 and at any given time the main component may not have a radial velocity that is similar to that of the cluster, but if you have many observations you can look at its mean velocity to find out if it is a member. The three stars marked with red error bars are those that show no signs of binarity and have radial velocities much different than that of M67. We have concluded that these are possible non members.

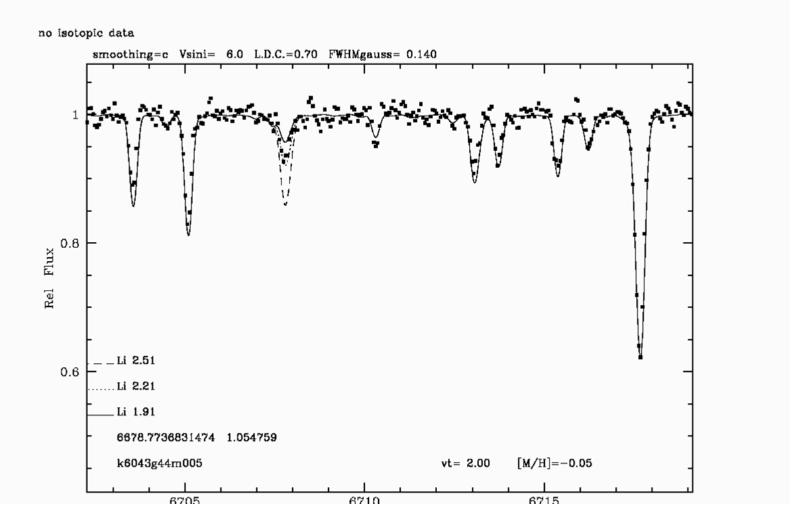




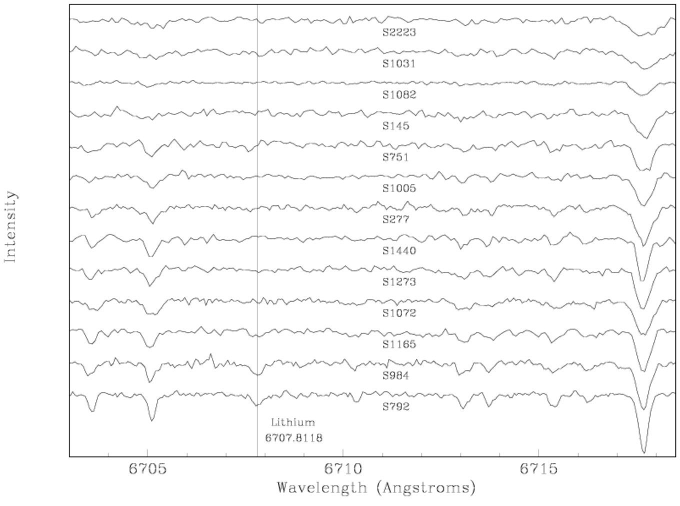
Rotational velocities are another important velocity to try and nail down. The rotational velocity can put a constraint on how the BSS was formed. Figure two shows rotational velocity vs. star ordered from blue to red in color. There is a clear correlation between the rotational velocity and color. The redder BSSs clearly rotate slower. This would imply more collision formations rather than binary coalescence, but in an open cluster one would assume that stellar collision would be exceedingly rare and would thus be an unlikely explanation for all of them. I am in the process of trying to prove that these can still be binary mergers, but between a high mass and low mass star as too conserve angular momentum one would not need to spin up the resulting BSS too much. The one high rotation BSS on the red side, S1036, is a known W UMa type contact binary and is in the process of forming a BSS. When it has completed its merger I predict that it will not only spin up a bit more, but will also move to the blue side of this plot.

In order to detect lithium in the atmosphere of a star, the surface temperature has to be low enough depending on the metalicity. Other clusters have shown a lithium 'dip' in which the detectable lithium drops significantly at certain surface temperatures. M67's dip is predicted to be around 6500 K. I chose all the BSSs with surface temperatures at or below this temperature to conduct my search with. My red sample consisted of 12 BSSs. I used the latest version of the LTE spectral analysis package MOOG (Sneden 1973) to conduct my search. This consisted of making a synthetic spectrum and overlaying the observed spectrum to look for lithium line strengths. In order to create the synthetic spectrum we had to have an initial surface temperature estimate. We used the Houdashelt method which involved B, V, I, J, and K colors. The BVI data was obtained from our photometric data while the JK colors were obtained from a GATOR search online.

With the photometric temperatures in had I made synthetic stellar spectrum using the Kurucz grid of ATLAS stellar models. The figure at left shows an example of the MOOG analysis tool. Lithium is the third line from the left with three different line strengths over-plotted. I did this for my entire red sample and plotted them one on top of another. Figure 4 shows my results from the lithium analysis.



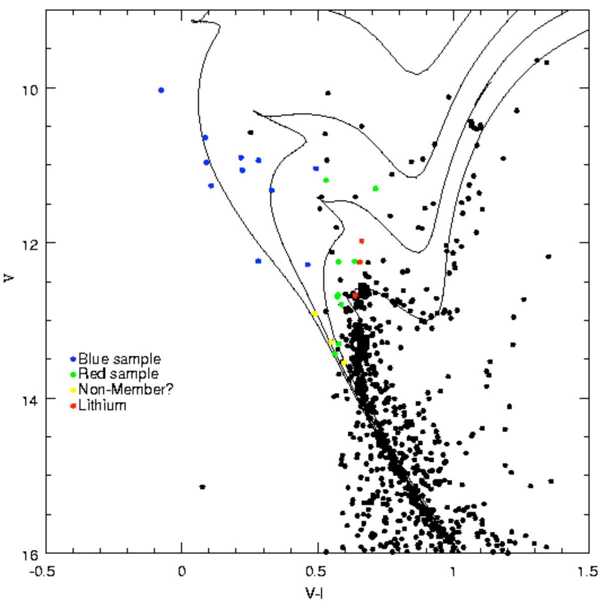
We detected Lithium in three stars S792, S984, and S1165. Upon closer analysis we have determined that these three stars are not BSSs. S792 and S984 are most likely binaries containing two turn-off stars or a light blended pair. S1165 based upon its color magnitude diagram position is most likely a turn-off star.



Metal abundances were found using the same MOOG program but with a different parameter file.

Abundances were determined by adjusting three parameters: surface gravity, microturbulence and temperature. The surface gravity was determined by forcing abundance equivalence between the FeI and FeII lines. The microturbulence was found by adjusting its strength until the slope of FeI vs. equivalent width was equal to zero. This was an iterative process done until the above parameters fit within the abundance errors.

One last piece of information I needed to gather was photometric information via color-magnitude diagrams (CMD). Figure 5 is an example of one of the CMDs I made. Plotted onto of the photometric data are four isochrones. The isochrones predict tracks of stellar evolution at different ages. From left to right the isochrone ages are 0.4 Gyr, 1.0 Gyr, 2.0 Gyr, and 4.0 Gyr. M67's current age is about 4 Gyr and the coinciding isochrone clearly shows an agreement with the stellar evolution. The interesting thing about this plot is the blue star that lies outside of the last isochrone. The 0.4 Gyr isochrone represents the double turn-off mass age, which is the age of the cluster when the turn-off mass was twice that of which it is now (1.4 solar masses). The implications of the outlying star are that it had to have been formed by more than two stars in order for its mass to be greater than 2.8 solar masses.



With all this information at hand we are currently in the process of trying to determine what it all means for each and every star. The most definite conclusion we have determined so far is that lithium is *always* destroyed in the formation of BSSs. So in the future, any BSS candidate with lithium is either in a binary system where the lithium is from a companion or the star is not a BSS, period. The final result of this project will be a ground breaking paper which will hopefully be the place to start for any future BSS research for any research team.