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Blue stragglers: an observational overview

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Abstract. I summarize the current state of observations about blue stragglers in a variety of environments, with an emphasis on how those observations help us understand the formation mechanism(s) of this exotic stellar population.

Key words. stars: blue stragglers – methods: observational

1. Introduction

Blue stragglers are normally defined as main sequence stars that are bluer and brighter than the main sequence turnoff of the system in which they are found. By implication, they are more massive than they should be for the system age. This definition is clear in the usual places where blue stragglers are studied (open and globular clusters), since those envinronments have (mostly) a single age and metallicity. Those clusters also have essentially no gas and certainly no signs of recent star formation. Therefore, the presence of a small population of nominally younger stars poses a puzzle. Since their identification by Sandage in the globular cluster M3 (Sandage 1953), many formation mechanisms have been proposed. Most researchers agree that either binary evolution (through mass transfer) or collisions (involving single, binary, or even triple stars) are responsible for creating blue stragglers. There are indications that both mechanisms could be important in the same environment. For more details about blue straggler formation mechanisms, see the review by Davies in this volume.

In this review, I describe the observed properties of blue stragglers. Most of these results are best shown in a plot, but page constraints for this proceedings prevents me from including them. I encourage the reader to follow the references for a visual representation of what I describe here. Each bit of observational evidence can be considered to be a puzzle piece to answer the question of blue stragglers. Some of the pieces make the picture clearer, while others don't fit into the frame yet.

2. Photometric properties

Blue stragglers are typically identified by their position in a colour-magnitude diagram. Stars that follows the extension of the main sequence brighter than the turnoff are considered to be blue stragglers, but this definition is not necessarily unique. In globular clusters, the brightest blue stragglers and the bluer end of the horizontal branch tend to merge in optical CMDs. The separation is clearer when a UV filter is used (Ferraro et al. 2003), but in some clusters, the two sequences still come together. Typically blue stragglers spread from the turnoff to about two magnitudes brighter; in some clusters the brightest blue straggler can be as much as 3 magnitudes brighter than the turnoff. The lower luminosity limit is not always clear either. For example, in open clusters, there are stars that are at the turnoff luminosity or fainter, but closer to the ZAMS and therefore younger. We also expect that there could be binary mass transfer products or collision products hidden on the main sequence below the turnoff.

Blue stragglers cover a wider range in colour than the normal main sequence of the cluster. Stars throughout the whole Hertzsprung gap from the ZAMS to the giant branch are usually identified as blue stragglers, or sometimes called red or yellow stragglers. Most globular clusters show stars in this region of the CMD, which is hard to explain through single-star evolution. One possibility is that they are stars that are currently out of thermal equilibrium, probably because they are currently undergoing mass transfer. The evolved descendants of blue stragglers have also been identified in some clusters, above and on the red side of the horizontal branch and on the asymptotic giant branch (e.g. Sills et al. 2009).

Often, the masses of blue stragglers are inferred by placing normal stellar evolutionary tracks on the CMD and determining the track closest to the blue straggler's current position. This should be done with caution. We know that in open clusters, the photometric masses of some blue stragglers are very different than their masses determined directly from their binary orbits (e.g. Sandquist et al. 2003). Also, normal stellar evolutionary tracks do not include any modifications to stellar evolution from either collisions or mass transfer. The differences in evolution between normal and merged stars are not necessarily large, but can cause slight differences in the inferred masses of blue straggler stars (Sills et al. 1997).

In a few clusters (M30, Ferraro et al. 2009), NGC 362 (Dalessandro et al. 2013), NGC 1261 (Simunovic et al. 2014), high-precision HST photometry has shown that the blue stragglers form two more-or-less parallel sequences in the CMD. Both sequences are offset to the red of the ZAMS; the blue sequence is well-fit by models of collision products, if the collisions all occurred 1-2 Gyr ago. The red sequence starts about 0.75 magnitudes above the ZAMS, and covers a region of the CMD which is populated by binaries that are currently undergoing mass transfer. This result has been interpreted as evidence of some dynamical event, such as core collapse, occurring at the time that the collision products were formed. However, recent binary mass transfer models (Jiang, this volume) might provide an alternative explanation for the blue sequence, weakening the link to core collapse.

3. Chemical abundances

Relatively little is known about the surface chemical abundances of blue stragglers. High-resolution spectroscopy, particularly in the crowded environments of globular clusters, is quite difficult. However, the outskirts of some clusters have been targeted, as well as sparser open clusters. Most blue stragglers seem to have the same surface abundances as normal stars in the cluster. However, a small population of stars in some clusters show carbon and possibly oxygen depletion (Ferraro et al. 2006), probably indicating that this material has been CNO-processed and then accreted by the blue straggler. In the open cluster NGC 6819, 5 blue stragglers out of 12 have enhanced barium abundances of up to 1.5 dex higher than normal stars (Milliman et al. 2015). The normal explanation for this chemical pattern is that the stars have accreted material from an AGB companion, but none of these systems have binary properties consistent with an AGB donor.

4. Rotation rates

Since rotation is also measured spectroscopically, we know little about rotation rates, of blue stragglers. A few clusters have been studied, and most blue stragglers are slow rotators, as one would expect for stars of these masses and ages. However, we also see a few blue stragglers which have high rotation rates, between 50 to 120 km/s. There is also some evidence to suggest that there is an environmental dependence, where denser clusters have fewer fast rotators (Ferraro et al. 2015). We know more about rotation rates of blue stragglers in open clusters. There it is clear that again, there are a substantial fraction of blue stragglers that rotate quite rapidly (up to 50 km/s), and that they are rotating more rapidly than normal stars of the same temperature (i.e. mass) (Mathieu & Geller 2015)

5. Binarity

Thanks to long-term spectroscopic monitoring, we have an excellent understanding of the binary properties of blue stragglers in a few open clusters (M67, NGC 188, NGC 6819). Blue stragglers have a significantly larger binary fraction than normal stars in the cluster: a detected fraction of over 70% in the blue stragglers compared to about 25% in the normal main sequence stars (Mathieu & Geller 2015). We also know of some double-lined systems, in which we can directly detect a companion and infer a mass of each star. And we have even detected and characterized some white dwarf companions to blue stragglers in NGC 188 (Gosnell et al. 2014), providing direct evidence for mass transfer from a red giant and an asymptotic giant branch star as the formation mechanism in those systems.

We know less about the binary properties of blue stragglers in globular clusters, although W UMa contact binaries have been known among the blue straggler populations of globular clusters for many years (Mateo et al. 1990). Binaries in globular clusters are often identified by their offset to the red of the main sequence ridge line, and since the ridge line for blue stragglers is poorly defined, we cannot clearly identify blue straggler binaries by their position in the CMD alone. Photometric monitoring continues to find WUMa systems (e.g. Salinas et al. 2016), but spectroscopic monitoring will need to be undertaken to fully characterize the binary nature of blue stragglers in globular clusters.

6. Radial distributions in globular clusters

Blue stragglers are, in general, more centrally concentrated than the normal stellar populations in globular clusters. In many clusters, the radial distribution is more complicated: there is usually a peak of blue stragglers (per unit luminosity or per unit 'normal stellar population') at the centre, a lack of blue stragglers a little further out (reaching a minimum at a radius $r_{\min}$ and then the frequency of blue stragglers rises again to a constant value in the outskirts of the cluster. The position of $r_{\min}$ has been found to correlate with the dynamical age of the cluster (Ferraro et al. 2012), with the least dynamically evolved clusters having a flat blue straggler distribution (no $r_{\min}$), then $r_{\min}$ moving gradually outward with dynamical age until the most evolved clusters don't show the rise to a constant blue straggler frequency at all. This creation of $r_{\min}$ and its evolution with dynamical time is speculated to be caused by dynamical friction of the heavier blue straggler progenitors against the normal stars in the cluster causing them to fall into the centre with time.

7. Correlations with environment

Blue stragglers have been identified in globular clusters, open clusters, the bulge (Clarkson et al. 2011), the disk and halo (Santucci et al. 2015), and in external dwarf galaxies (Santana et al. 2013). The specific frequency of blue stragglers is basically the same (and high) in the low-density environments of dwarf galaxies, the Milky Way halo, and open clusters, and even in the lowest density globular clusters. However, at a sufficiently high density, the specific frequency of blue stragglers begins to drop, and continues to decrease as the density increases. This is contrary to expectations if blue stragglers are produced through stellar collisions, but may in fact be telling us that blue stragglers are primarily made through binary processes. As the stellar density increases, the collision rate increases and destroys the binaries which would have made blue stragglers if they had been left undisturbed.

Milky Way globular clusters provide additional evidence that binaries are more important than collisions in producing blue stragglers. The number of blue stragglers in the cores of globular clusters is not correlated with collision rate in the core, but instead correlates best with the core mass, and hence the number of core binaries (Knigge et al. 2009), even in the highest density clusters. In addition, we see a correlation between core binary fraction and the number of blue stragglers in low density clusters (Sollima et al. 2008) .

8. Summary

Over the past 5 years, our observational understanding of blue stragglers has improved dramatically, thanks in large part to the work of the CosmicLab project and of the WIYN Open Cluster Survey. We now have much more information about their distribution in the CMD, in the cluster, and in the universe. We are starting to probe their masses, surface abundances, binarity, and rotation rates. The models of collision products and binary mass transfer products are currently lagging the observations.

Some open questions remain, some of which were asked during the question period of this talk. Probably the most important question has to do with the definition of a blue straggler. The photometric definition, that of stars that are bluer and brighter than the main sequence, only works well when the underlying population has only one age. And I will take this opportunity to remind the community that using more than one colour to study populations is very important as an object which shows up in the blue straggler region in one colour may be somewhere else entirely in the CMD in another colour – interesting in its own right, but not a bona fide blue straggler (Sills et al. 2000; Salinas et al. 2016).

Similarly, we are fairly sure that we have not yet identified all blue stragglers in any environment. There are likely 'blue-stragglers-to-be' lurking below the main sequence turnoff in any cluster – lower-mass collision or mass transfer products. What about barium stars, Ap stars, Am stars, sub-subgiants, and other stellar exotica? Are those also 'blue stragglers'? Should we be including them in our theoretical analysis? In fact, should we be looking for a single formation mechanism, or for multiple paths? And should we expect that one explanation will work in all environments?

The goal of the CosmicLab project was to probe the complex interplay between dynamics and stellar evolution by using globular clusters as laboratories, and using blue straggler stars as test-particles. Those test particles turned out to be useful as probes, but also continue to contain secrets in their own right which keep us looking at the heavens and wondering why.

References

Clarkson, W. I. et al. 2011, ApJ, 735, 37
Dalessandro, E. et al. 2013, ApJ, 778, 135
Ferraro, F. R., et al. 2003, ApJ, 588, 464
Ferraro, F. R., Sabbi, E., Gratton, R., et al. 2006, ApJ, 647, L53
Ferraro, F. R., Beccari, G., Dalessandro, E., et al. 2009, Nature, 462, 1028
Ferraro, F. R., Lanzoni, B., Dalessandro, E., et al. 2012, Nature, 492, 393
Ferraro, F. R., et al. 2015, in Ecology of Blue Straggler Stars, ed. H.M.J. Boffin, G. Carraro, G. Beccari (Springer, Berlin), ASSL, 413, 99
Gosnell, N. M., Mathieu, R. D., Geller, A. M., et al. 2014, ApJ, 783, L8
Knigge, C., Leigh, N., & Sills, A. 2009, Nature, 457, 288
Mathieu, R. D., & Geller, A. M. 2015, in Ecology of Blue Straggler Stars, ed. H.M.J. Boffin, G. Carraro, G. Beccari (Springer, Berlin), ASSL, 413, 29
Mateo, M., Harris, H. C., Nemec, J., & Olszewski, E. W. 1990, AJ, 100, 469
Milliman, K. E., Mathieu, R. D., & Schuler, S. C. 2015, AJ, 150, 84
Salinas, R., Contreras Ramos, R., Strader, J., et al. 2016, arXiv:1605.06517
Sandage A. R., 1953, AJ, 58, 61
Sandquist, E. L., et al. 2003, AJ, 125, 810
Santana, F. A., Muñoz, R. R., Geha, M., et al. 2013, ApJ, 774, 106
Santucci, R. M., Placco, V. M., Rossi, S., et al. 2015, ApJ, 801, 116
Sills, A., Lombardi, J. C., Jr., Bailyn, C. D., et al. 1997, ApJ, 487, 290
Sills, A., Bailyn, C. D., Edmonds, P. D., & Gilliland, R. L. 2000, ApJ, 535, 298
Sills, A., Karakas, A., & Lattanzio, J. 2009, ApJ, 692, 1411
Simunovic, M., Puzia, T. H., & Sills, A. 2014, ApJ, 795, L10
Sollima, A., et al. 2008, A&A, 481, 701