A mass transfer origin for blue stragglers in NGC 188 as revealed by half-solar-mass companions

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In open star clusters, where all members formed at about the same time, blue straggler stars are typically observed to be brighter and bluer than hydrogen-burning main-sequence stars, and therefore should already have evolved into giant stars and stellar remnants. Correlations between blue straggler frequency and cluster binary fraction1, core mass2, and radial position3 suggest that mass transfer or mergers in binary stars dominates the production of blue stragglers in open clusters. Analytic models4, 5, detailed observations6, and sophisticated $N$-body simulations7, however, argue in favor of stellar collisions. Here we report that the blue stragglers in long-period binaries in the old (7 Gyr) open cluster NGC 188 have companions with masses of about half a solar mass, with a surprisingly narrow mass distribution. This conclusively rules out a collisional origin, as the collision hypothesis predicts a companion-mass distribution with significantly higher masses. Mergers in hierarchical triple stars9 are marginally permitted by the data, but the observations do not favor this hypothesis. The data are closely consistent with a mass transfer origin for the long-period blue straggler binaries in NGC 188, in which the companions would be white dwarfs of about half a solar mass.

The NGC 188 blue stragglers have a very high binary frequency of $76 \pm 19\%$ (for periods $< 10^4$ days).10 The orbital period distribution is remarkable: 12 of the 16 blue straggler binaries have periods of order 1000 days, and all but two of the blue straggler binaries have periods longer than 100 days. The two short-period blue straggler binaries show evidence for binary encounters were involved in their formation.10 We focus here on the "long-period" blue straggler binaries, whose orbital solutions yield periods longer than 100 days.

In Figure 1 we show the companion-mass distribution for the twelve NGC 188 blue straggler binaries with periods of order 1000 days. The orbital solutions are derived from spectroscopic data11, 12 obtained in the WIYN Open Cluster Study (WOCS). Because we do not detect the flux from the companions to these blue stragglers, the orbital solutions provide mass functions rather than mass ratios. We therefore use a statistical algorithm13 to convert the mass functions to the companion-mass distribution shown here (see Supplementary Information). The distribution is narrow and peaked with a mean of $0.53 M_\odot$ and a mode of $0.5 M_\odot$.

Predictions for the companions to blue stragglers resulting from mass transfer in solar-type stars are well established by theory. Case C mass transfer (from an asymptotic-giant to a main-sequence star) leaves a Carbon-Oxygen white dwarf companion in an orbit of order 1000 days with a mass of about $0.5 M_\odot$ to $0.6 M_\odot$, dictated by the core mass of the asymptotic-giant donor at the end of the mass-transfer phase.14–17 This prediction is qualitatively reproduced by the NGC 188 blue straggler companion-mass distribution shown in Figure 1. To check quantitatively for
consistency we compare the observed mass-function distribution (points in Figure 2) to a theoretical mass-function distribution derived assuming all companions have the typical Carbon-Oxygen white dwarf mass, $0.55 \, M_\odot$ (solid line in Figure 2). A Kolmogorov-Smirnov (K-S) test shows that the theoretical and observed distributions are indistinguishable.

Additionally NGC 188 contains one blue straggler in a binary with an orbital period of about 120 days, the companion flux of which we also do not detect in our spectra. The observed mass function and orbital period for this system are consistent with the theoretical predictions of Case B mass transfer (from a giant to a main-sequence star), where a Helium white dwarf companion with a mass of about $0.25 \, M_\odot$ to $0.5 \, M_\odot$ is expected\textsuperscript{[14–17]} Thus the companions to all long-period blue straggler binaries in NGC 188 are consistent with a mass-transfer origin.

We investigate the predicted companion-mass distribution from the collision hypothesis using a sophisticated $N$-body model of NGC 188 that incorporates detailed stellar and binary evolution with stellar dynamics, and thereby produces blue stragglers through both collisions and mass-transfer processes (see Supplementary Information). The resulting distributions of companion mass, eccentricity and period for the blue stragglers in binaries that respectively formed through the collision and mass-transfer mechanisms (Figure 3) show marked differences. We focus here on the simulated blue stragglers in binaries with periods of $100 - 3000$ days (matching the period range of our NGC 188 long-period blue straggler binaries).

The very narrow distribution and mean mass of $0.58 \pm 0.01 \, M_\odot$ for companions to the mass transfer blue stragglers in the $N$-body model are in good agreement with the population synthesis predictions discussed above. However, the mean mass of companions to collisionally formed blue stragglers is $1.11 \pm 0.02 \, M_\odot$, nearly twice that of the mass-transfer blue stragglers. This result demonstrates the finding that dynamical exchanges are more likely to insert a higher mass member of the encounter into the binary\textsuperscript{[18]}

These differences in companion mass reflect profound differences in the evolutionary states of the companions resulting from each process. All of the simulated blue straggler binaries that formed through mass-transfer processes have white dwarf companions, the remnants of the giant star donors. Fewer than 1% of the blue stragglers in binaries that formed through collisions have white-dwarf companions, whereas 80% have main-sequence companions (and the remaining have giant or blue straggler companions).

A K-S test rules out at the >99% confidence level the hypothesis that the observed mass functions for the long-period NGC 188 blue straggler binaries are drawn from a parent population of collisional origin (dotted line in Figure 2). Additionally collision products are predicted to have significantly higher eccentricities and longer periods than are observed for the NGC 188 blue stragglers (both at the >99% confidence levels, respectively). We therefore rule out the hypothesis that the long-period NGC 188 blue straggler binaries have an origin in collisions.

Three of the long-period NGC 188 blue stragglers have measured orbital eccentricities consistent with circular orbits. By contrast, no NGC 188 solar-type main-sequence binaries in this period range have circular orbits. These blue straggler circular orbits are suggestive of a mass-transfer origin. Rapid tidal circularization of the orbit during mass transfer has been a long-held expectation, as is seen in the predicted eccentricity distribution for mass-transfer products in the NGC 188 model (Figure 3b).
However observational and theoretical evidence suggests that mass transfer will not always lead to circular orbits. Proposed “eccentricity-pumping mechanisms” address this issue and are under development[^19][^20]. Thus the theoretical eccentricity distribution for blue stragglers formed by mass transfer is uncertain.

Fortuitously, the blue stragglers of the Galactic field provide a basis for empirical comparison[^22]. Specifically we compare the NGC 188 blue stragglers with a blue straggler sample identified within the population of metal-poor thick-disk and halo stars, which is found to be coeval[^23]. These field blue stragglers probably formed in isolation, presumably through mass transfer processes[^22]. In fact, the field blue stragglers are observed to have a high binary frequency, a period distribution that peaks near a few 100 - 1000 days (dotted line in Figure 3c), and a mean companion mass consistent with 0.55 $M_\odot$, all again consistent with a mass transfer origin.

These long-period field blue straggler binaries show a range of non-circular eccentricities (dotted line in Figure 3b). Enhancement of eccentricity through subsequent dynamical encounters cannot explain the non-circular orbits for field blue stragglers, due to the low stellar density of the Galactic field. Therefore, if the long-period binaries among the field blue stragglers were formed through mass transfer, this is further evidence for the existence of an eccentricity-pumping mechanism.

The eccentricity distribution of the long-period NGC 188 blue straggler binaries is shifted to higher eccentricities than that of the long-period field blue straggler binaries. However, owing to the higher densities in the cluster core, dynamical encounters may have increased the eccentricities of the NGC 188 blue stragglers. If we exclude from the analysis blue stragglers in NGC 188 within 1.5 core radii from the cluster center, the two eccentricity distributions are statistically indistinguishable. The similarity in periods, companion masses and eccentricities would be a natural consequence of both the field and NGC 188 long-period blue straggler binaries being formed by mass-transfer processes.

Finally, we investigate the possibility of blue straggler formation through mergers in hierarchical triples[^9][^24]. The potential progenitors of the blue stragglers produced through this mechanism would be triples with short-period ($\lesssim$ 10 days) inner binaries having a total mass between 1.2 $M_\odot$ and 2.2 $M_\odot$. (2.2 $M_\odot$ is twice the turnoff mass in NGC 188.) The frequency of dynamically formed triples in the NGC 188 model with these orbital parameters is never high enough to contribute considerably to blue straggler production through this mechanism. If the merger mechanism is important, triples must form primordially with suitable orbital parameters in cluster environments.

Observationally, the triple population in open clusters is poorly known, but triples are common in the field[^25]. Field triples in the Multiple Star Catalogue[^26] with measured masses indicating inner binaries of total mass between 1.2 and 2.2 $M_\odot$ and inner orbital periods less than 10 days have a nearly uniform tertiary-mass distribution populated by main-sequence stars. However, the typical age of local field stars is 4 Gyr[^27]. If we evolve the tertiary-mass distribution to 7 Gyr in isolation[^28], 15% of the tertiaries evolve to become white dwarfs. The gray hatched histogram in Figure 1 shows the resulting tertiary-mass distribution at 7 Gyr. The mass distribution is qualitatively broader than that of the companions to the NGC 188 long-period blue stragglers. However a K-S test comparing the mass-function distributions does not rule out the triple hypothesis.
The fact that we do not detect in our spectra the flux from companions to any of the long-period blue straggler binaries also constrains the companion masses. The higher-mass main-sequence stars in the evolved tertiary-mass distribution (Figure 1) would be easily detected if these were the true companions to the long-period blue straggler binaries in NBC 188. A Monte Carlo analysis yields a 6.6% probability that all companions to the long-period NGC 188 blue straggler binaries would be undetected in our spectra if drawn from the evolved tertiary-mass distribution, and only a 1.8% probability that these companions would also realize the observed mass-function distribution of the long-period NGC 188 blue straggler binaries (see Supplementary Information). Thus mergers in hierarchical triples are not favored by the observations, but the data are not sufficient to rule out this hypothesis completely.

We aim to detect directly the flux from the white dwarf companions predicted by the mass transfer mechanism with forthcoming Hubble Space Telescope observations of the NGC 188 long-period blue straggler binaries in the ultraviolet. These observations will be invaluable for distinguishing between the two remaining formation hypotheses: binary mass transfer and mergers in hierarchical triples.

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Supplementary Information is linked to the online version of the paper at www.nature.com/nature.

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Figure 1 | Companion-mass distribution for the 12 blue straggler binaries in NGC 188 with periods of order 1000 days. The distribution is peaked near the typical Carbon-Oxygen white dwarf mass of 0.55 $M_\odot$, consistent with theoretical predictions from the Case C mass-transfer hypothesis. We use a statistical method to derive the companion-mass distribution from the observed mass functions (see Supplementary Information). To do so, we first estimate masses for the blue stragglers based on standard stellar evolutionary tracks, and assume an isotropic inclination distribution. The shaded histogram shows the resulting companion-mass distribution and is normalized to show the frequency. The error bars on the histogram show the 95% confidence intervals and are converted from the Poisson uncertainties on the mass-function distribution using a Monte Carlo analysis. We note that standard evolutionary tracks may underestimate the mass of blue stragglers by up to about 15%. Accounting for this potential bias does not change the results found here (nor in Figure 2). For comparison we also plot a standard initial mass function for single stars (dotted gray line) for companion masses between 0.08 $M_\odot$ and 1.1 $M_\odot$ (from the Hydrogen burning limit to the current main-sequence turn-off mass in NGC 188). The gray hatched histogram shows the observed tertiary-mass distribution evolved to 7 Gyr in isolation. The lowest-mass bin extends from 0.08 $M_\odot$ to 0.2 $M_\odot$, and the highest-mass bin extends from 1.0 $M_\odot$ to 1.1 $M_\odot$. Both of these bins are renormalized to reflect the different bin sizes.
Figure 2 | Cumulative distribution of mass functions of the NGC 188 blue straggler binaries with periods of order 1000 days. The black points show the observed mass functions derived directly from the kinematic orbital solutions, defined as:

\[ f(M_1, M_2, i) = \frac{M_2^3}{(M_1 + M_2)^2} \sin^3 i \]  

where \( M_1 \) is the mass of the primary star (here the blue straggler), \( M_2 \) is the mass of the companion star and \( i \) is the inclination of the orbit to our line of sight. (Orbits that are edge-on have inclinations of 90°.) To test the blue straggler formation hypotheses, we compare this observed distribution to three theoretical mass-function distributions, all derived using our blue straggler mass estimates and assuming isotropically distributed inclination angles. The solid line shows the resulting distribution assuming all companions have masses of 0.55 M\(_\odot\), the typical Carbon-Oxygen white dwarf mass predicted by the Case C mass-transfer hypothesis. The dotted line shows the mass-function distribution of the predicted companion masses for blue straggler binaries formed by collisions in the NGC 188 N-body model. Finally the dashed line shows the distribution derived by drawing companion masses from the evolved tertiary-mass distribution shown in Figure 1. A K-S test rules out the collisional hypothesis at the >99% confidence level. A K-S test does not rule out the merger hypothesis. However there is only a 6.6% chance that all companions would be undetectable in our spectra if drawn from the evolved tertiary-mass distribution, and only a 1.8% chance that these companions would also realize the observed mass-function distribution shown here. The observed mass-function distribution is statistically indistinguishable from that predicted by the mass-transfer hypothesis, and all white dwarf companions would be undetectable in our spectra, given their low luminosities.
Figure 3 | Distributions of binary orbital elements for the blue stragglers in the NGC 188 N-body model. a, Companions mass; b, orbital eccentricity; c, orbital period. The top plots show blue stragglers formed in collisions (coll), and the middle plots show blue stragglers created through mass transfer (MT). The bottom plots compare the cumulative distributions for these two populations, with collision products in light gray and mass-transfer products in dark gray. The sample contains all blue straggler binaries present from 6 - 7.5 Gyr in the model, spanning the uncertainty in the cluster age. In a and b, we show only blue straggler binaries with periods between 100 and 3000 days (the period range of our NGC 188 long-period blue straggler binaries). In c, we include blue straggler binaries of all periods (with the hatched regions indicating binaries at periods beyond our detection limit). Each bin is normalized by the total number of blue straggler binaries in the sample, and the error bars show the Poisson counting uncertainties. Additionally, in the bottom panels of b and c we show the cumulative eccentricity (b) and period (c) distributions of the blue straggler binaries in NGC 188 (dashed lines) and the field (dotted lines). The N-body model predicts that collision products will have significantly more massive companions, larger eccentricities and longer periods than the blue stragglers in NGC 188. However, the predicted companion masses and periods for mass-transfer blue stragglers are consistent with those of the long-period NGC 188 blue straggler binaries. We note that the N-body model does not implement proposed “eccentricity-pumping” mechanisms that are required to reproduce the non-zero eccentricities observed for post-mass-transfer systems, including the field blue stragglers. Thus the predicted eccentricities for the mass-transfer products are uncertain, although still likely to be lower than those of the collision products.
Supplementary Information

1 Deriving the Companion-Mass Distribution

We do not detect the flux from the companions to any of the long-period blue straggler binaries in NGC 188. Thus our kinematic orbital solutions return mass functions. In order to convert the observed distribution of mass functions into a distribution of companion masses we use an iterative statistical algorithm.\(^{13}\)

First we require estimates for the primary masses of the blue stragglers, which we derive by comparing the observed luminosity and temperature of each blue straggler to theoretical stellar evolutionary tracks\(^{29}\). This analysis shows that the long-period blue straggler binaries in NGC 188 have masses between 1.2 M\(_{\odot}\) and 1.6 M\(_{\odot}\). We note that standard evolutionary tracks may underestimate the mass of blue stragglers by up to about 15%, as found for the two short-period blue stragglers in NGC 188.\(^{10}\) However the differences are small enough to neglect for the purposes of this statistical distribution.

We begin the algorithm with an initial guess of a uniform companion-mass distribution. Then for each binary we assign a distribution of inclination angles over the range allowed by each mass function and primary-mass estimate, respectively. The inclinations are first chosen to be isotropically distributed and then multiplied by a correction factor that is a function of the assumed companion-mass distribution. Using the mass functions, the primary-mass estimates and the derived inclination distributions we create a sample of synthetic binaries for each observed binary. By summing over all synthetic binary samples we derive the next estimate for our companion-mass distribution. This distribution is then used as input for the next iteration of the algorithm, and the process is repeated until the solution converges.

This method does not determine the individual companion masses for any given binary, but instead derives the distribution of companion masses for a given population of binaries. The result for the blue straggler binaries in NGC 188 with orbital periods of order 1000 days is the peaked distribution shown in Figure 1 with a mean of 0.53 M\(_{\odot}\).

For Figure 1 (and Figure 2) we are only interested in the blue straggler binaries in NGC 188 with periods of order 1000 days. Thus we exclude the one blue straggler binary with an orbital period of about 120 days, the one blue straggler binary without an orbital solution and the two short-period blue stragglers for which we detect the companions in our spectra.

This distribution is not sensitive to the blue straggler mass used in the analysis. If we simply assign the same mass to each blue straggler within the range of 1.2 M\(_{\odot}\) to 1.6 M\(_{\odot}\) derived above, the resulting distributions stay well within the uncertainties shown in the figure. If we take the extreme case of setting all blue stragglers to twice the turnoff mass (2.2 M\(_{\odot}\)), the general form of the distribution remains the same, but the peak shifts towards more massive companions by about 0.2 M\(_{\odot}\), roughly equal to the standard deviation of a Gaussian fit to the distribution shown in Figure 1. However no current model predicts a population of such massive blue straggler.

Finally, we note that the statistical algorithm is unable to fully resolve sharp features (e.g., delta functions), a property regarded as the intrinsic “instrumental profile” of the technique,\(^{13}\) which may partly explain the tails of the derived distribution.
2 NGC 188 N-body Model

The blue stragglers in the NGC 188 N-body model are derived from twenty nearly identical simulations, each starting with the same parameters (e.g., total cluster mass, binary frequency, distribution of binary orbital parameters, etc.) but with different randomized stellar positions, velocities, masses, binary orbital elements, etc. Each simulation uses the \texttt{NBODY6} code\cite{NBODY6} to model the dynamical evolution, with stellar\cite{stellar} and binary\cite{binary} evolution included. We have made slight modifications to this code to define the initial binary population and output format. Importantly the model contains detailed binary evolution prescriptions for tidal circularization and synchronization, angular momentum loss mechanisms (e.g., magnetic braking and gravitational radiation), mass transfer from Roche lobe overflow, accretion from stellar winds, common-envelope events, mergers and direct stellar collisions, thus providing numerous pathways to create blue stragglers.\cite{blue_stragglers}

The modeling of blue stragglers is given special attention.\cite{blue_stragglers, binary} In short, if a main-sequence star gains mass (e.g., through mass-transfer processes or collisions), it evolves up along the main sequence to higher luminosity and effective temperature. The lifetime of the blue straggler prior to becoming a giant is determined based on the fraction of unburned hydrogen remaining in the core of the star, which can be replenished when the star gains mass as determined by the details of the formation mechanism. Within the simulation we identify blue stragglers as being more massive than a normal main-sequence star at the turnoff, while still maintaining the structure and evolutionary state of a main-sequence star. The combination of twenty simulations helps reduce the effects of the stochastic nature of blue straggler formation in N-body simulations.

The initial parameters of any N-body open cluster simulation, and particularly those of the binary population, have a great impact on the dynamical evolution of the cluster and the production rates and mechanisms for blue stragglers (and other anomalous stars). Where possible we have attempted to base all initial parameters directly on observations. Importantly, we use detailed observations of the binary population in a young open cluster (M35; 150 Myr) to define the initial binary frequency and distributions of orbital parameters.\cite{M35_binary, M35} After 7 Gyr of evolution, the model matches the observed mass, core and tidal radii, and the main-sequence binary frequency and distributions of binary orbital parameters in NGC 188 in detail.

To investigate the blue stragglers (Figure 5) we first identify the formation mechanisms for each individual blue straggler by examining their dynamical histories, respectively. Collisions in the NGC 188 model generally occur at periastron within a binary driven to high eccentricity by a dynamical encounter. Mass transfer occurs through either the Case C or Case B mechanisms as discussed in the main text. (Low-mass blue stragglers also may form in long-period binaries if a main-sequence star accretes sufficient mass from the stellar wind of a giant star companion.\cite{long_period} However this mechanism cannot produce blue stragglers as luminous and presumably massive as the long-period blue straggler binaries in NGC 188.)

For the analysis in this paper, we include all blue stragglers present at each time step in each of the twenty simulations between the cluster age of 6 - 7.5 Gyr, covering the range in ages derived for NGC 188 in the literature. In so doing, we effectively weight the results by the lifetime of each blue straggler in a given orbital configuration.

The NGC 188 model assumes that tidal dissipation during mass transfer will rapidly circularize the binary orbit. Therefore nearly all blue straggler binaries in the NGC 188 model that
formed through mass transfer have orbital eccentricities of zero. The very few non-circular orbits are the result of dynamical encounters after the formation of the blue stragglers. However observations of post-mass-transfer systems show a wide range of non-zero eccentricities (e.g. barium-star systems\textsuperscript{34} and post-asymptotic-giant binaries\textsuperscript{35}). These new theories have yet to be included in \textit{N}-body models. Thus the eccentricities for the mass transfer blue stragglers in the NGC 188 model are uncertain, although still likely to be lower than those of the collision products.

### 3 Monte Carlo Analysis

As we do not detect the flux of the companions to any of the long-period NGC 188 blue stragglers in our spectra, we cannot directly determine their evolutionary states. If the dominant formation channel is mergers in hierarchical triples, then the companions to the blue stragglers would be the original tertiary stars, and would be drawn from the observed tertiary-mass distribution\textsuperscript{26} that has been evolved in isolation for 7 Gyr (shown in Figure 1). This evolved tertiary-mass distribution contains triples that would be the likely progenitors of the long-period blue straggler binaries in NGC 188, having inner binaries of a total mass consistent with that of the NGC 188 blue stragglers and orbital periods of $< 10$ days.

A K-S test comparing the observed mass-function distribution for the long-period blue straggler binaries in NGC 188 to that of the evolved tertiaries yields a distance statistic of 0.27 (which corresponds to a probability of 36%). Here we also determine the likelihood that such companions would produce thirteen binaries without any detected light from the companions.

To test this hypothesis we perform a Monte Carlo analysis in which we assume all companions are main-sequence stars with masses between 0.08 M\(_\odot\) and 1.1 M\(_\odot\) (from the Hydrogen burning limit to the current main-sequence turnoff mass in NGC 188). Given WIYN spectra of an NGC 188 binary, we have the ability to detect the flux from any companion that is at most 10 times less luminous than the primary\textsuperscript{12}. This sets our detectability limit for the simulated companions.

We create $10^6$ realizations of the NGC 188 long-period blue straggler binary population. For each realization we choose random companions for these thirteen NGC 188 blue stragglers from the evolved tertiary-mass distribution. We note that 15\% of the tertiaries in this distribution are expected to be Carbon - Oxygen white dwarfs with masses of about 0.55 M\(_\odot\). Both white dwarf and main-sequence star companions of this mass would be undetected in our spectra.

We then check the luminosity differences between each blue straggler and its simulated companion using a 7 Gyr Padova isochrone\textsuperscript{29}. None of the long-period NGC 188 blue stragglers have detectable companions. Therefore we reproduce this result if zero of the thirteen simulated blue straggler binaries in a given realization are detectable. Only 6.6\% of the realizations of the Monte Carlo blue straggler binary population satisfy this criterion, which we will call $P(A)$.

Finally, we wish to calculate the probability that all blue stragglers will be undetected in our spectra ($P(A)$) and the companions will reproduce the observed mass-function distribution of the long-period blue straggler binaries in NGC 188 ($P(B)$). These two probabilities are dependent and therefore $P(A \text{ and } B) = P(A) \times P(B|A)$. If the K-S distance statistic found when comparing the mass-function distribution of the evolved tertiaries to that of a given realization is greater than or equal to that found above for the NGC 188 blue stragglers (i.e., 0.27), the realization reproduces the observations. Of the 6.6\% of realization that have zero detectable companions, 26.9\% also reproduce the observed mass-function distribution ($P(B|A)$). Therefore we find a 1.8\% probability
that we detect zero companions and realize the observed mass-function distribution for the long-period NGC 188 blue straggler binaries when companions are drawn from the evolved tertiary-mass distribution.

4 Identification of Field Blue Stragglers

The field blue straggler sample used here is taken from the literature. Identification of blue stragglers in the Galactic field is not as straightforward as in open clusters because stars in the field have a wide range in age, and hence generally there is no unique main-sequence turnoff from which to separate normal main-sequence stars from blue stragglers. These particular field blue stragglers were identified within a stellar sample limited to contain only metal-poor thick disk and halo stars, which are found to be coeval and of similar age to stars in globular clusters. For a given metallicity, a blue straggler is defined as being bluer than the main-sequence turnoff of a comparable-metallicity globular cluster.

Due to this selection technique these field blue stragglers are somewhat more metal poor and older than the blue stragglers in NGC 188. Here we briefly explore the impact of these differences in the blue straggler samples.

Metallicity is known to effect the core mass of a giant star and therefore the remnant white dwarf mass. For the potential asymptotic-giant star donors to the long-period blue stragglers studied here, the difference in Carbon-Oxygen white dwarf mass is at most 0.15 $M_\odot$. This small potential difference in companion mass does not effect our conclusions.

Older main-sequence stars are less massive than their higher-mass counterparts (as high-mass stars evolve more quickly), and therefore, given their observational definition relative to the turnoff, older blue stragglers can be less massive as well. The difference in the main-sequence turnoff mass between a 7 Gyr cluster (like NGC 188) and a 12 Gyr cluster (like a typical globular cluster) is about 0.1 $M_\odot$. This small difference in blue straggler mass will not effect our comparison.

Finally at a given mass, lower metallicity stars also have smaller radii, due to the lower opacity level, which in turn results in lower mass-loss rates from stellar winds. Both of these properties may effect the probability of undergoing stable mass transfer in a binary system. For instance, it has been suggested from theory that Case C mass transfer between intermediate-mass stars of lower metallicity may occur for a broader period range than for those of higher metallicity. However the complete dependence of metallicity on mass transfer for stars of roughly solar mass has not been fully explored.

These minor selection effects do not impact the comparison shown in this paper or the conclusions drawn from this analysis.