Detecting White Dwarf Companions of Blue Straggler Binaries in the Old Open Cluster NGC 188

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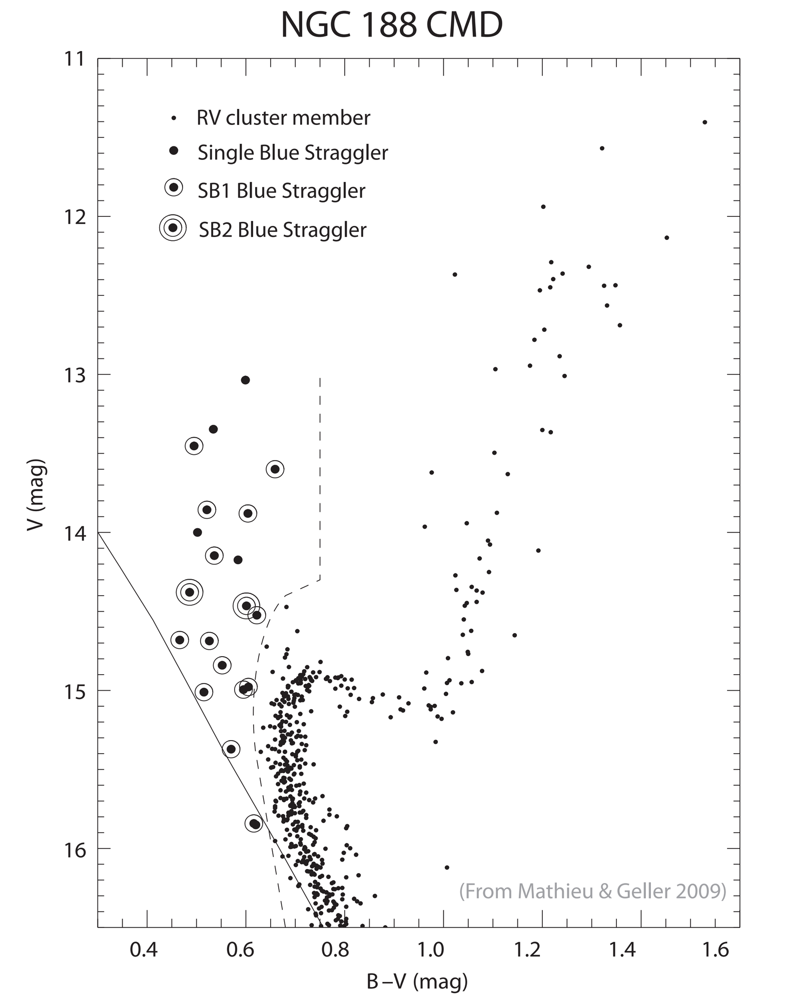


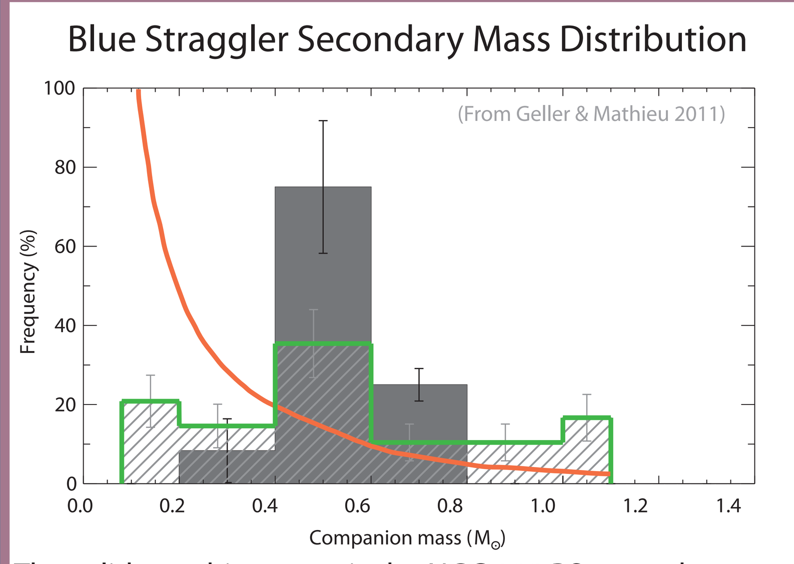
B-V vs. V CMD for NGC 188 with the BSs labeled according to their binarity. The solid line shows the ZAMS. Most of the BS binaries are of order ~1000 day periods with lower eccentricities than expected given the MS-binary eccentricity distribution.

INTRODUCTION

Currently, three blue straggler (BS) formation scenarios are in active discussion: i) Case C mass transfer in binary stars (e.g. Chen & Han 2008), ii) stellar collisions of multiple star systems (e.g. Leigh & Sills 2011), and iii) Kozai-induced mergers of an inner binary in a hierarchical triple system (e.g. Perets & Fabrycky 2009).

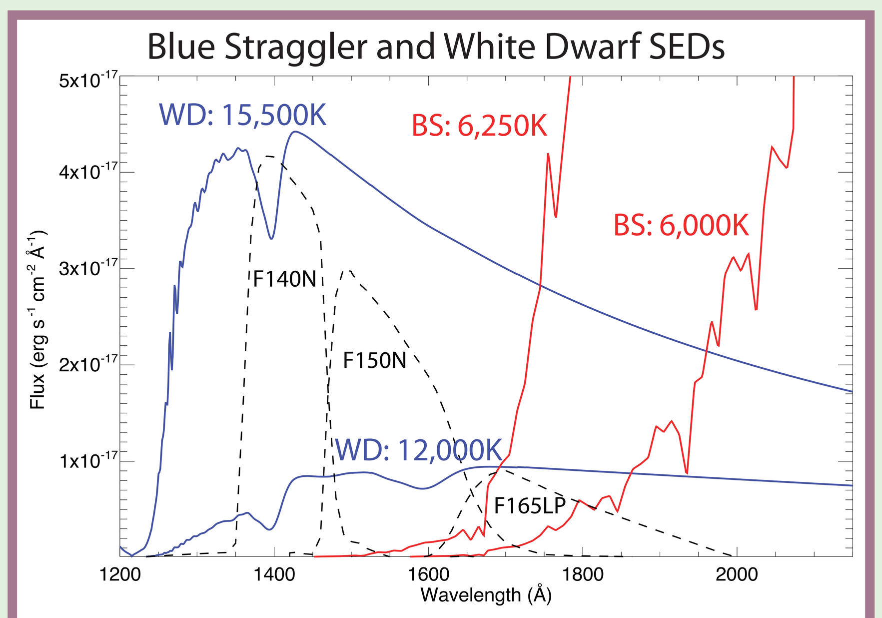
Mathieu & Geller (2009) discovered that the majority (76%) of the BSs in NGC 188 are in binary systems (see CMD at left). Geller & Mathieu (2011) found that the secondary mass distribution of BS binaries (shown on the right) in NGC 188 peaks at 0.5 $M_\odot$, the expected mass of a CO WD. The actual secondary mass distribution is statistically distinguishable from a Kroupa (2001) IMF and evolved tertiary distribution with 99% and 98% confidence, respectively.

A key distinguishing factor between these formation scenarios is the secondary companion to the blue straggler. Stellar collisions and Kozai-induced mergers would preferentially have MS companions, while Case C mass transfer would create BSs with white dwarf (WD) companions.



The solid grey histogram is the NGC 188 BS secondary mass distribution. The orange line shows a Kroupa (2001) IMF, and the green outlined histogram shows the evolved tertiary distribution, which would be the current companion distribution after a Kozai-induced merger.

HST ACS/SBC OBSERVATIONS



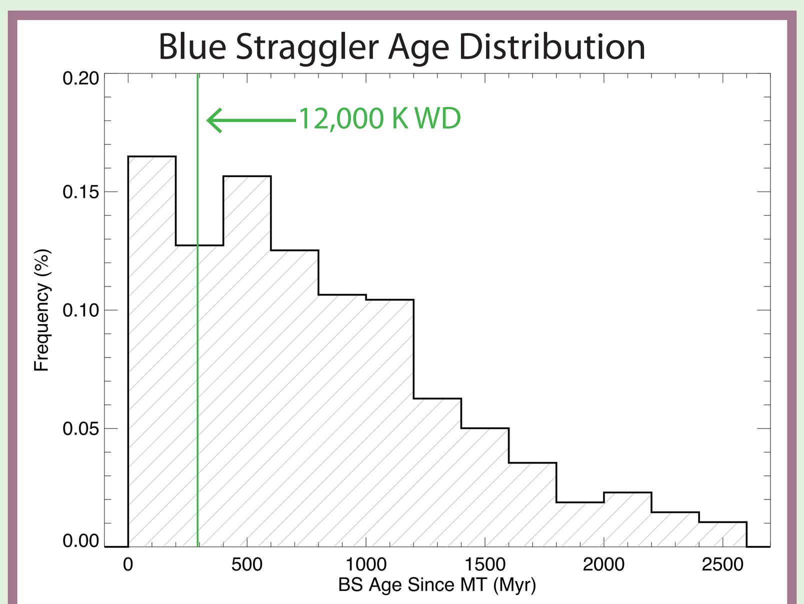
The black dashed lines show our filter choices. The extreme tail of 6,000 K and 6,250 K BSs are shown in red (Castelli & Kurucz 2003). The SEDs of 12,000 K and 15,000 K WDs are shown in blue (Bergeron et al. 2001).

NGC 188, being both old (7 Gyr) with relatively cool BSs and close (2 kpc), provides a superb opportunity to search for WD companions of BSs through photometric FUV excesses.

We designed an observing program to search for these companions using *HST*/ACS/SBC. We implement derived narrow-band filters (F140N and F150N, see Dieball et al. 2005) in order to better isolate the FUV emission.

The figure above shows our filter choices in comparison to expected BS and WD spectral energy distributions (SEDs). Our observations include all 20 SB1 and single BSs. The cooler temperatures of the BSs allow us to detect WD companions down to 12,000 K for any BS in our sample. Hotter, and therefore younger, WDs will be easier to detect.

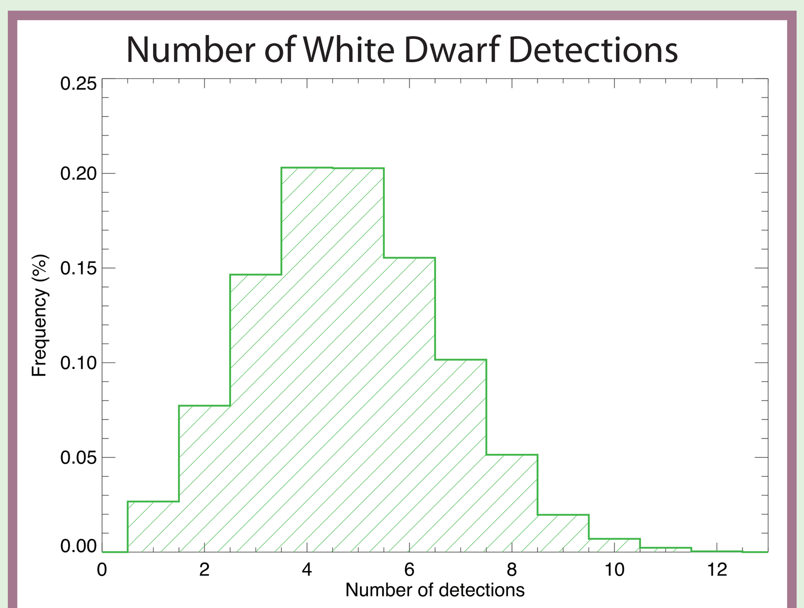
WHITE DWARF DETECTION



Age distribution of BS systems formed through mass transfer from *N*-body modeling of NGC 188 at 7 Gyr (Geller et al. 2012). We assume that the WD age is determined by the time since mass transfer occurred. The age of a 12,000 K WD is shown with a green vertical line.

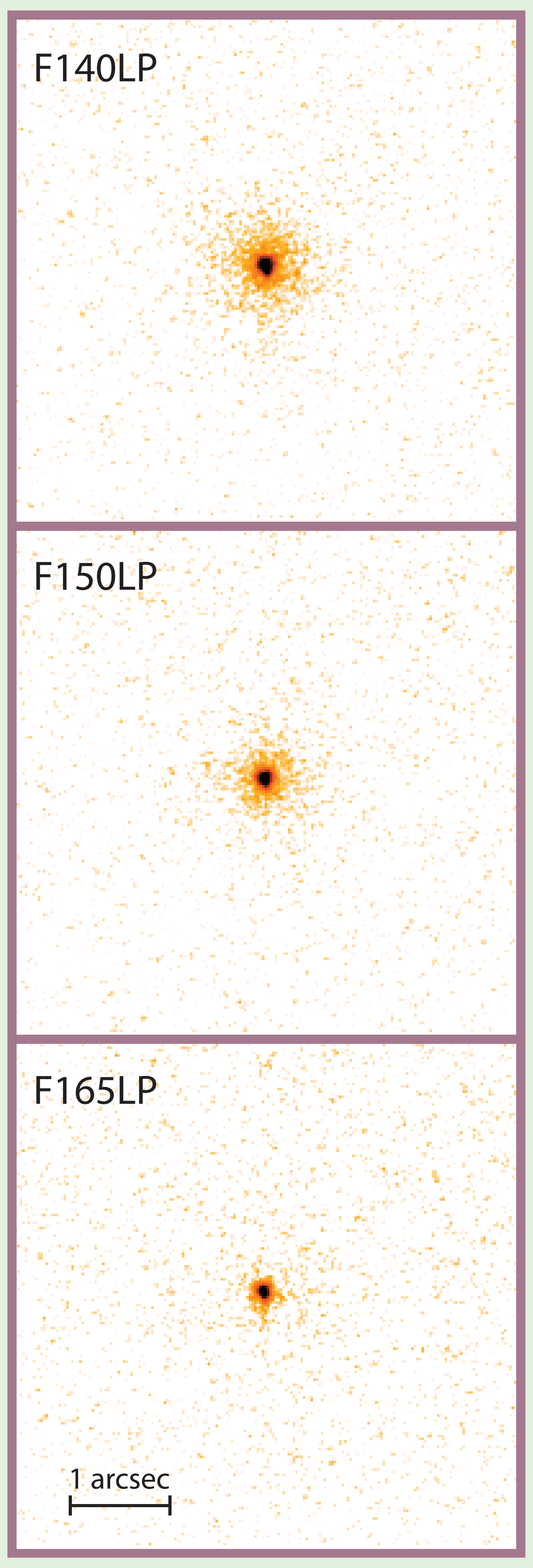
The number of white dwarfs we detect in our sample is directly tied to the age distribution of the BSs. A younger age distribution will yield more detections since the WDs will be hotter. On the left we show a possible age distribution that takes into account both cluster evolution (including dynamical encounters) and binary evolution.

We calculate the predicted number of detections by Monte Carlo sampling the age distribution for our 20 BS sample. We take the time since mass transfer as the WD age, which gives the WD temperature. On the right we show the number of detections expected given a detection limit of 12,000 K WD or hotter. We can use the actual number of detections to test the validity of the *N*-body model ages and explore other possible BS age distributions.

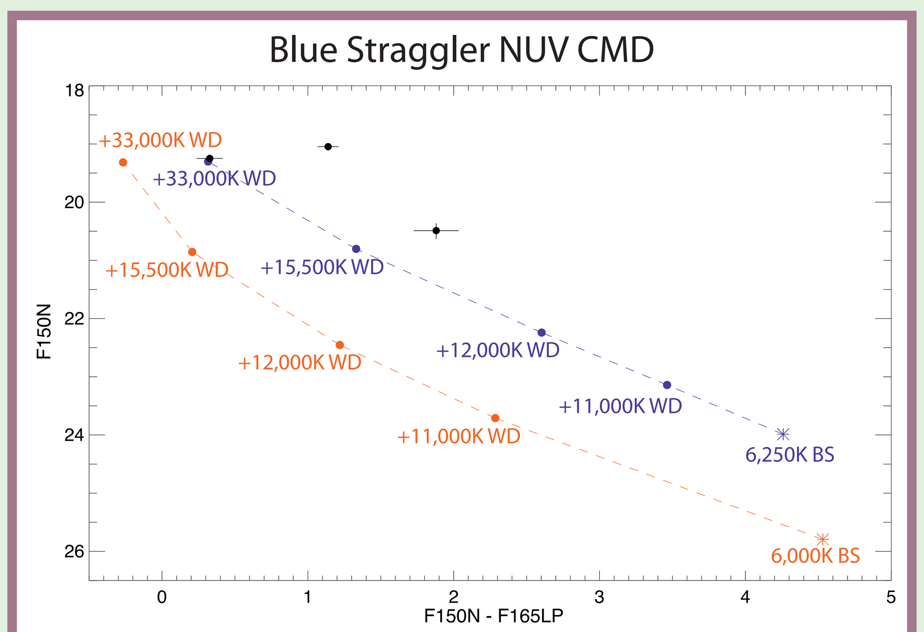


Number of WD detections expected based on sensitivity of *HST* observing program. Detections are calculated from a Monte-Carlo sample of 20 BSs drawn from the N-body model age distribution, assuming all 20 BSs have a WD companion. The green histogram shows the expected number of detections given our lower WD temperature limit of 12,000 K, which corresponds to an age limit of ~300 Myr.

INITIAL RESULTS

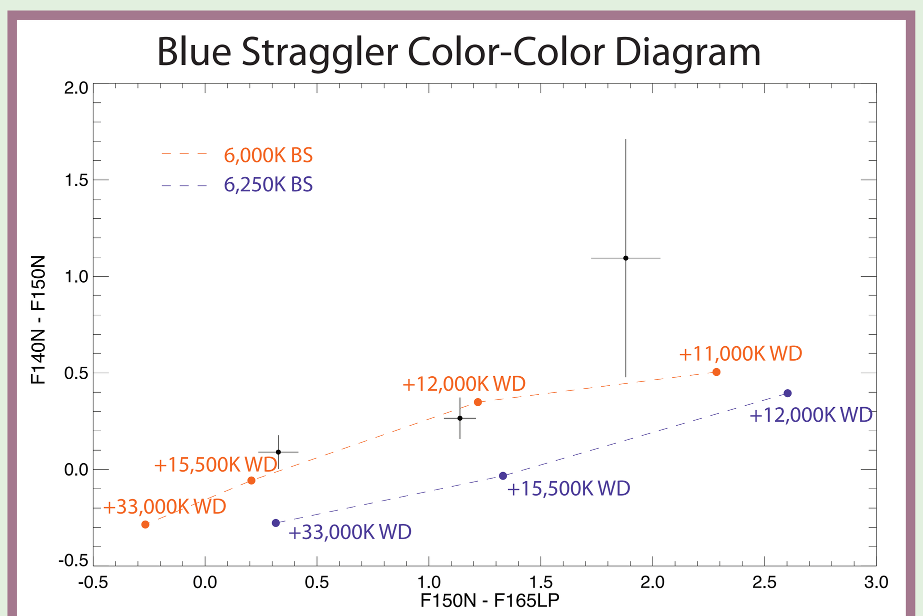


Of our 20 BSs, 11 have currently been observed (the remaining 9 will be observed by Dec 2013). All 11 of our BSs have 3σ+ detections in F150N and F165LP, and three of our BSs have 3σ+ detections in F140N. Images in our long-pass filters for one of the observed BSs are shown on the left. Using SYNPHOT and SED modeling we create a hypothetical F150N vs. F150N-F165LP CMD (shown below). The orange and blue tracks follow synthetic BS-WD pairs for 6,000 K and 6,250 K BSs, respectively. The three observed BSs with detections in F140N are shown in black.



A hypothetical CMD with modeled BS and WD pairings. The orange and blue asterisks show the location of single BSs with 6,000 K and 6,250 K temperatures, respectively. The dashed lines track the CMD location of the synthetic BS with increasingly hotter (and younger) WD companions, as labeled. Detection of three BSs are plotted in black with 2σ error bars.

A (F140N-F150N) vs. (F150N-F165LP) color-color diagram is shown to the right with the same synthetic BS-WD points and the three BS observations shown in the CMD. While our temperature resolution at intermediate temperatures is modest, the sample as a whole can provide a first look at the age distribution of the mass transfer BSs. These observations support a mass transfer formation history for these systems, and the WD temperatures may provide the first measures of BS ages.



(F140N-F150N) vs. (F150N-F165LP) color-color diagram of synthetic BS-WD pairs with increasing WD temperature. A 6,000 K BS is shown in orange and a 6,250 K BS is shown in blue. Three BS observations (with 3σ+ detections in all three filters) are shown in black with 2σ error bars.

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