Detection of a White Dwarf Companion to a Blue Straggler Star in the Outskirts of Globular Cluster NGC 5466 with the Ultraviolet Imaging Telescope (UVIT)

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Abstract

We report the discovery of a hot white dwarf (WD) companion to a blue straggler star (BSS) in the globular cluster (GC) NGC 5466, based on observations from the Ultra-Violet Imaging Telescope (UVIT) on board AstroSat. The Spectral Energy Distribution (SED) of the Far-UV detected BSS NH 84 was constructed by combining the flux measurements from four filters of UVIT, with GALEX, GAIA, and other ground-based observations. The SED of NH 84 reveals the presence of a hot companion to the BSS. The temperature and radius of the BSS (T eff = 8000±1000 K, R/R⊙ = 1.44 ± 0.05) derived from Gemini spectra and SED fitting using Kurucz atmospheric models are consistent with each other. The temperature and radius of the hotter companion of NH 84 (T eff = 32,000 ± 2000 K, R/R⊙ = 0.021 ± 0.007) derived by fitting Koester WD models to the SED suggest that it is likely to be a hot WD. The radial velocity derived from the spectra along with the proper motion from GAIA DR2 confirms NH 84 to be a kinematic member of the cluster. This is the second detection of a BSS-WD candidate in a GC, and the first in the outskirts of a low-density GC. The location of this BSS in NGC 5466 along with its dynamical age supports the mass-transfer pathway for BSS formation in low-density environments.

Key words: blue stragglers – globular clusters: individual (NGC 5466) – binaries: general – ultraviolet: stars – white dwarfs

1. Introduction

Globular clusters (GCs) are ideal laboratories to study the formation and properties of exotic interacting stellar systems such as blue stragglers (BSSs), X-ray binaries, cataclysmic variables, etc. BSSs are stars located above the main-sequence turn-off (MSTO) in the color–magnitude diagram (CMD; Sandage 1953). They are brighter and bluer than the upper main-sequence (MS) stars in the cluster (see, e.g., Simunovic & Puzia 2016). The two main leading scenarios proposed for their formation are stellar collisions leading to mergers in high-density environments (Hills & Day 1976) and mass transfer (MT) from an evolved donor to a lower-mass star in a binary system in low-density environments (McCrea 1964; Chen & Han 2008).

NGC 5466 is a metal-poor ([Fe/H] = −2.0; Carretta et al. 2009) Galactic GC containing a large fraction of binaries (~6%) and BSSs (Beccari et al. 2013). Being a low-density GC (log10 ρV ∼0.84 L⊙/pc3; McLaughlin & van der Marel 2005) as expected to be the dominant BSS formation mechanism where the primordial binaries can evolve in isolation in such environments (Beccari et al. 2013).

Ultraviolet (UV) observations are very effective at identifying BSS binaries with a hot companion as they show excess emission in the UV, which, in general, is not expected from BSSs alone. Based on the FUV spectroscopy and spectral energy distributions (SEDs) of 48 blue objects in 47 Tuc obtained with Hubble Space Telescope (HST), Knigge et al. (2008) discovered several interesting binary objects, including one BSS-WD binary in the cluster. Gosnell et al. (2014, 2015) detected white dwarf (WD) companions to seven BSSs in the open cluster NGC 188 based on Far-UV (F140LP, F150LP, and F165LP) observations with the HST. Subramaniam et al. (2016a) detected a hot companion (post-AGB/BB) to a BSS in NGC 188 using Ultra-Violet Imaging Telescope (UVIT) data on AstroSat, thus showing the importance of UV observations of BSSs.

Using a large sample of GC CMDs from HST observations, Knigge et al. (2009) and Leigh et al. (2011) showed that the number of BSSs in the cores of GCs is strongly correlated with the total stellar mass of the core of the cluster. Leigh et al. (2007, 2013) found that there is little or no correlation of the BSS population with the collision rate in the core of the cluster, thus favoring binary evolution as the dominant channel for the formation of the BSSs. It was also found that the frequency of
BSSs in GCs is correlated with the binary fraction (Knigge et al. 2009; Milone et al. 2012).

Ferraro et al. (2009) discovered two BSS sequences in the optical CMD of GC M30, suggesting that the redder ones arise from the evolution of close binaries that are still experiencing MT, which was in agreement with binary evolution models. Another explanation for the two BSS sequences in M30 was given by Jiang et al. (2017), where they showed that binary evolution contributes to the formation of BSSs in both sequences. Thus, identification of BSSs with hot companions using UV observations is crucial for understanding their formation mechanism in binary systems.

In this paper, we present the SED analysis of a BSS candidate of GC NGC 5466 based on UVIT and Gemini observations. We outline the observations and data reduction in Section 2, the UV CMD in Section 3, spectroscopic analysis in Section 4, and SED of the BSS in Section 5, followed by discussion, summary, and conclusion in Sections 6 and 7.

2. Observations and Data Reduction

The cluster was observed with the UVIT telescope as a part of the GT proposal (G05_009) during 2016 June 3–4. UVIT is one of five payloads on board AstroSat, which is operated by the Indian Space Research Organization (ISRO). The calibration of the instrument can be found in Tandon et al. (2017b). Full details of the telescope and instrument are available in Tandon et al. (2017a) and Subramaniam et al. (2016b).

The data were acquired in four filters of UVIT, two in the FUV (F148W and F169M), and two in NUV channels (N245M and N263M). The images were processed using the CCDLAB software (Postma & Leahy 2017), which corrects for the satellite drift, flat field, and distortion. Isolated stellar sources in the UVIT images have FWHM ~1\arcsec{} and ~1\arcsec{}2 in the FUV and NUV channels, respectively. In terms of angular resolution, the UVIT images are thus far superior to those of GALEX (4\arcsec{}5–5\arcsec{}5). Crowded-field photometry was performed using DAOPHOT/IRAF tasks and packages (Stetson 1987). Aperture and saturation corrections were done to obtain the final magnitudes in the AB system, details can be found in Tandon et al. (2017b). The photometric errors in magnitude for all the UVIT filters are found to be within 0.4 down to 24th magnitude.

3. UV Color–Magnitude Diagram

We cross-matched UVIT data with HST–ACS survey data of the GC NGC 5466 (Sarajedini et al. 2007) for the central regions with FOV 3\arcmin{}\times{} 3\arcmin{} and ground-based data provided by Peter Stetson for the region beyond the FOV of HST. We separated them into various stellar populations such as HB and BSS based on their locations in both the optical and UV CMDs. The parameters of the cluster adopted in this study are given in Table 1.

To check their cluster membership, we used the GAIA DR2 Proper Motion (PM) catalog of the cluster NGC 5466 given by Gaia Collaboration et al. (2018b). Their catalog consists of the list of PM member stars of the cluster where the procedure for the member selection is described in detail in Appendix A.1 of their paper. The vector-point diagram of BSSs (blue squares) relative to other cluster members (gray dots) in the PM catalog is shown in Figure 1 where we clearly notice that the FUV-detected BSSs are grouped around the mean PM derived by Gaia Collaboration et al. (2018b); Table 1 except for BSS NH 48. According to the HST PM study by Simunovic & Puzia (2016), this BSS is a PM member. In total, we found 14 BSSs detected in all the UVIT filters to be PM members. In addition, 63 HB stars are also found to be PM members. The typical uncertainties in the PMs are ~0.12 and 0.42 mas yr\(^{-1}\) for the HB and BSSs respectively. These 14 BSSs are marked in the FUV (F169M) and NUV (N245M) images as shown in Figures 2 and 3, where we can clearly see that the BSSs are spatially resolved and PSF photometry can be successfully performed.

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### Table 1

Parameters of NGC 5466 Used in This Paper

| Parameter    | Value            | References                      |
|--------------|------------------|---------------------------------|
| R.A. (J2000) | 14 05 27.29      | Goldsberry et al. (2010)        |
| Decl. (J2000)| +28 32 04.0      | Goldsberry et al. (2010)        |
| [Fe/H]       | −2.0 dex         | Carretta et al. (2009), Arellano Ferro et al. (2008)  |
| Distance     | 16.0 ± 0.6 kpc   | Jiang et al. (2017)             |
| Core radius, \(r_c\) | 1/43             | McLaughlin & van der Marel (2005) |
| Half-light radius, \(r_h\) | 2/3              | McLaughlin & van der Marel (2005) |
| \(\mu_{RA}\) | −5.404 ± 0.004 mas yr\(^{-1}\) | Gaia Collaboration et al. (2018b) |
| \(\mu_{Decl}\) | −0.791 ± 0.004 mas yr\(^{-1}\) | Gaia Collaboration et al. (2018b) |

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**Figure 1.** Vector-point diagram of the 14 BSSs (blue squares) detected by UVIT relative to other cluster members (gray) in the catalog given by Gaia Collaboration et al. (2018b). The red triangle in the figure is BSS NH 84.
The PM cleaned F169M versus (F169M–N245M) CMD (right panel) along with the optical CMD (left panel) are shown in Figure 4 where the detected BSSs are shown as blue squares. The UV CMD is overplotted with a Padova model (Marigo & Girardi 2007; Marigo et al. 2008) isochrone (black line and dots) of age 12.6 Gyr, metallicity [Fe/H] = −1.98 (Carretta et al. 2009) for a distance modulus of 16.0 (Arellano Ferro et al. 2008). The isochrone is generated by convolving Padova models with UVIT filter response curves (Tandon et al. 2017b) using the Flexible Stellar Population Synthesis (FSPS) code (Conroy et al. 2009; Conroy & Gunn 2010). The FSPS generates a locus of BSSs, assuming that they are MS stars with masses in excess of the turn-off mass, which uniformly populates 0.5 mag above the MSTO to 2.5 mag brighter than the MSTO as shown in the figure. Reddening is not corrected as it is close to zero, $E(B-V) = 0.00$ (Zinn 1985). The cross symbol in the figures is a known Anomalous Cepheid (Zinn & Dahn 1976). The bright star in the UV CMD at F169M, F169M–N245M $\sim 17.5, −0.4$, lying close to the PAGB evolutionary model track is classified as a AGB-manqué star by Schiavon et al. (2012).

Fekadu et al. (2007) presented BVI photometry of Red Giants and BSSs based on their observations with the KPNO 0.9 m telescope. They identified 94 BSS candidates based on their locations in optical CMDs. Of the 14 BSSs detected by UVIT, which are listed in Table 2, 13 BSSs were found to be in common with their catalog (Fekadu et al. 2007), suggesting that we have an additional BSS named UV-BSS1 (Table 2). The GALEX magnitudes of the BSSs given in the table are obtained by performing PSF photometry on the GALEX FUV and NUV intensity maps (OBJECT ID-GI1_056017_NGC5466). We used the BSS nomenclature from Nemec & Harris (1987) for our study.

Figure 2. Location of BSSs on FUV-F169M (left) and NUV-N245M (right) images of UVIT.
Figure 3. Continuation of Figure 2.

Figure 4. F169M, (F169M−N245M) UV CMD (right panel) and its corresponding V, (V−I) optical CMD (left panel) with BSSs detected in all the UVIT filters. Open symbols are UVIT cross-matched ground (CFHT) detections and closed symbols are the UVIT cross-matched HST detections. Cyan dots are the objects detected down to F169M = 24 mag. The cross symbol is an anomalous Cepheid whereas the lower triangles are RR lyrae variables. The UV CMD is overplotted with a Padova model isochrone (black line and dots) of age 12.6 Gyr and metallicity [Fe/H] = −1.98 (Carretta et al. 2009).
Table 2
UV Magnitudes of the FUV-Detected BSS Candidates in All the UVIT and GALEX Filters That Are PM Members (Gaia Collaboration et al. 2018b)

| BSS ID | R.A. (J2000) | Decl. (J2000) | \( r \) | F148W (mag) | F169M (mag) | N245M (mag) | N263M (mag) | FUV (mag) | NUV (mag) | \( \mu_{\text{R.A.}} \) (mas yr\(^{-1}\)) | \( \mu_{\text{Decl.}} \) (mas yr\(^{-1}\)) |
|--------|--------------|---------------|--------|-------------|-------------|-------------|-------------|-----------|---------|-------------------------------|-------------------------------|
| UV-BSS 1 | 211.3393 | 28.51122 | 1.83 | 23.08 ± 0.30 | 22.55 ± 0.19 | 21.02 ± 0.06 | 21.09 ± 0.09 | 23.24 ± 0.20 | 21.13 ± 0.07 | −5.63 ± 0.58 | −6.69 ± 0.49 |
| NH 7 | 211.32196 | 28.53361 | 2.22 | 22.88 ± 0.30 | 22.26 ± 0.18 | 20.80 ± 0.05 | 20.63 ± 0.08 | 22.63 ± 0.15 | 20.81 ± 0.04 | −5.98 ± 0.34 | −3.8 ± 0.33 |
| NH 9 | 211.33525 | 28.55766 | 2.06 | 23.15 ± 0.31 | 23.14 ± 0.28 | 21.05 ± 0.07 | 21.65 ± 0.18 | … | … | −6.09 ± 0.56 | −0.80 ± 0.55 |
| NH 17 | 211.35456 | 28.52768 | 0.64 | 20.05 ± 0.08 | 19.91 ± 0.06 | 19.45 ± 0.03 | 19.43 ± 0.04 | 19.96 ± 0.08 | 19.56 ± 0.04 | −4.95 ± 0.26 | −1.21 ± 0.25 |
| NH 19\(^a\) | 211.35267 | 28.53305 | 0.6 | 21.66 ± 0.16 | 21.76 ± 0.12 | 20.51 ± 0.05 | 19.97 ± 0.10 | 21.68 ± 0.11 | 20.30 ± 0.06 | −6.07 ± 0.37 | −1.34 ± 0.35 |
| NH 21 | 211.38859 | 28.51381 | 1.79 | 22.39 ± 0.20 | 22.36 ± 0.16 | 20.55 ± 0.05 | 20.37 ± 0.09 | 22.60 ± 0.18 | 20.33 ± 0.04 | −5.52 ± 0.31 | −0.47 ± 0.28 |
| NH 22 | 211.37913 | 28.4753 | 3.64 | 23.59 ± 0.35 | 23.33 ± 0.26 | 21.48 ± 0.09 | 21.47 ± 0.13 | … | … | −5.14 ± 0.62 | −0.61 ± 0.57 |
| NH 26 | 211.34568 | 28.54491 | 1.15 | 22.23 ± 0.18 | 22.12 ± 0.17 | 20.60 ± 0.07 | 20.39 ± 0.08 | … | … | −5.69 ± 0.46 | −1.51 ± 0.44 |
| NH 30\(^a\) | 211.37085 | 28.52038 | 0.92 | 23.32 ± 0.36 | 22.84 ± 0.20 | 21.26 ± 0.09 | 21.66 ± 0.14 | … | … | −5.73 ± 0.45 | −0.30 ± 0.44 |
| NH 31\(^a\) | 211.39603 | 28.52215 | 1.84 | 22.15 ± 0.22 | 21.70 ± 0.13 | 20.55 ± 0.06 | 20.48 ± 0.06 | 21.82 ± 0.12 | 20.42 ± 0.07 | −5.68 ± 0.36 | −0.90 ± 0.35 |
| NH 48 | 211.37318 | 28.54648 | 0.87 | 23.17 ± 0.33 | 22.84 ± 0.25 | 21.03 ± 0.07 | 20.97 ± 0.13 | … | … | −4.97 ± 0.50 | 1.43 ± 0.52 |
| NH 49\(^b\) | 211.35802 | 28.51746 | 1.07 | 23.68 ± 0.39 | 23.17 ± 0.25 | 21.30 ± 0.07 | 21.31 ± 0.10 | 23.53 ± 0.34 | … | −5.56 ± 0.52 | −0.83 ± 0.55 |
| NH 90 | 211.3281 | 28.54438 | 1.92 | 22.84 ± 0.28 | 22.81 ± 0.25 | 20.87 ± 0.09 | 20.56 ± 0.10 | … | … | −5.10 ± 0.38 | −1.32 ± 0.35 |
| NH 84 | 211.22649 | 28.69703 | 12.15 | 22.47 ± 0.25 | 22.04 ± 0.14 | 20.67 ± 0.06 | 20.39 ± 0.09 | 22.28 ± 0.13 | 20.68 ± 0.03 | −5.17 ± 0.44 | −0.87 ± 0.36 |

Notes. The UV-BSS1 does not have a counterpart in the BSS catalog of Fekadu et al. (2007).
\(^a\) Eclipsing and contact binaries (Mateo et al. 1990).
\(^b\) SX Phe variable (Jeon et al. 2004; Arellano Ferro et al. 2008).
Among the UV detected BSSs, NH 17 is the brightest BSS, as shown in the left panel of the Figure 4. NH 19 and NH 30 are known W-UMa type contact binaries and NH 31 is an eclipsing binary (Mateo et al. 1990). BSS NH 49 is a known SX Phe variable (Jeon et al. 2004). One of the BSSs from the Fekadu et al. (2007) catalog, NH 87, is found to be bluer than the BSS model track in the UV CMD (empty blue box in right panel of Figure 4) whereas other BSSs are distributed around the track. This BSS does not have the PM information from GAIA DR2. We obtained the GMOS-N spectra of this object (see Section 4). The location of the FUV-detected BSSs from Table 2 are shown as blue circles in Figure 5 overlaid on UVIT’s N245M filter image of the cluster. The red square in the figure is BSS NH 84. We found that most of the BSSs (12 out of 14) are located inside the half-light radius of the cluster.

4. GMOS-N Spectroscopic Data

We obtained spectroscopic data using the GMOS-N spectrograph mounted on the 8.1 m Gemini-North telescope for two sources detected in FUV filters, namely NH 87 and NH 84 (see Table 2). The observations were part of the Gemini program GN-2018A-FT-113 (PI: M. Simunovic) and were taken during 2018 June. We used the R400 G5305 grating and a 0''75 long slit, which yielded a dispersion of 0.074 nm/pix and a spectral resolution \( R \approx 1300 \) for the \( \sim 460-900 \text{ nm} \) spectral range. We took \( 4 \times 330 \text{ s} \) exposures in each central wavelength (700 and 705 nm) in order to cover the GMOS-N detector chip gaps. The data was reduced using standard IRAF routines available in the Gemini/GMOS package, which resulted in flux-calibrated spectra at a signal-to-noise of \( \sim 60 \), shown in Figure 8 for NH 84.

The spectra of NH 87 showed a flat continuum and strong emission lines consistent with an H II region, suggesting it to be a star-forming galaxy at redshift \( z \sim 0.09 \). This also supports the previous classification by SDSS of this object as a galaxy. Hence we discard this object as a contaminant and focus on the spectroscopic analysis of NH 84, which is confirmed as a stellar source.

4.1. Radial Velocity and Spectral Fitting of NH 84

The stellar parameters \( T_{\text{eff}} \) and \( \log g \) were obtained by fitting the shape of the H\( \alpha \) line, which is commonly used as a \( T_{\text{eff}} \) and \( \log g \) indicator that is also independent of rotational broadening. The spectral fitting method was a \( \chi^2 \) minimization using the pPXF python package (Cappellari 2017) with a grid of synthetic spectra from the Coelho library (Coelho 2014), fixed at [Fe/H] = -2.0 dex. The grid was limited to \( T_{\text{eff}} \) values between 7000 and 12,000 K in 250 K steps, whereas \( \log g \) were taken between 2.0 and 5.0 in 0.5 steps. The synthetic spectra were then degraded to the spectral resolution of the GMOS-N data and the pPXF spectral fitting was performed allowing only a radial velocity shift and no kinematic broadening. The observed spectrum of NH 84 and best-fit model are shown in Figure 6. We obtained \( T_{\text{eff}} = 8000 \text{ K} \) and \( \log g = 4.0 \) for the best-fit parameters of NH 84. As it can be seen in the lower panel of Figure 6, the distribution of \( \chi^2 \) is not uniformly distributed around the minimum, and hence asymmetric uncertainties are present. To obtain robust uncertainties, we take the best-fit synthetic model and add random Gaussian noise such that its signal-to-noise = 60, as in the observed data, and run pPXF to obtain the best-fit model of this artificial data sample. We run 1000 iterations and obtain probability distributions for the best-fit parameters. This way, we adopt \( T_{\text{eff}} = 8000^{+1000}_{-250} \text{ K} \) and \( \log g = 4.0^{+0.5}_{-0.3} \) as the uncertainties, obtained from the parameter distribution interval that contains...
95% of the probability, as found with our Monte Carlo approach.

We used the Fourier cross-correlation method to derive the radial velocity of NH 84. The data were cross-correlated against the best-fit synthetic spectra using the FXCOR routine in IRAF. The measured heliocentric radial velocity for NH 84 is \(v_{\text{helio}} = 128 \pm 30 \text{ km s}^{-1}\), which is consistent with previous measurements of the systemic radial velocity of NGC 5466 found in the literature. Harris (1996) reports 110.7 km s\(^{-1}\), while Shetrone et al. (2010) measured a weighted average value of 118.0 \pm 0.4 km s\(^{-1}\) for 67 stars, and Lamb et al. (2015) obtains an average value of 121.05 km s\(^{-1}\) from 3 stars in NGC 5466. Hence, our results are consistent with NH 84 being a kinematic cluster member.

5. SED of BSS NH 84

In order to understand the multiwavelength energy budget of the FUV-detected BSSs, we generated their SEDs and estimated the temperature, luminosity, and radius. We used the virtual observatory tool, VOSA (VO SED Analyzer; Bayo et al. 2008) for SED analysis. VOSA calculates synthetic photometry for a selected theoretical model using filter transmission curves. It performs a \(\chi^2\) minimization test by comparing the synthetic photometry with observed data to get the best-fit parameters of the SED. We estimated the reduced \(\chi^2\) value using the expression given by

\[
\chi^2_{\text{red}} = \frac{1}{N - N_f} \sum_{i=1}^{N} \left(\frac{F_{o,i} - M_d F_{m,i}}{\sigma_{o,i}}\right)^2,
\]

where \(N\) is the number of photometric data points, \(N_f\) is the number of free parameters in the model, \(F_{o,i}\) is the observed flux, \(M_d F_{m,i}\) is the model flux of the star, \(M_d = \left(\frac{R}{D}\right)^2\) is the scaling factor corresponding to the star (where \(R\) is the radius of the star, and \(D\) is the distance to the star) and \(\sigma_{o,i}\) is the error in the observed flux. We used Kurucz stellar atmospheric models (Castelli et al. 1997; Castelli & Kurucz 2003) for the BSSs, which covers the UV to IR wavelength range. The model’s free parameters are \([\text{Fe/H}], T_{\text{eff}}\) and \(\log g\). We fixed the metallicity \([\text{Fe/H}] = -2.0\), close to the cluster metallicity and varied the other two parameters \((T_{\text{eff}}\) and \(\log g\)) in the Kurucz models to fit the SED of the BSSs.

The SED of the BSS NH 84 was constructed by combining the flux measurements of UVIT (4 passbands) with GALEX (FUV and NUV), GAIA DR2 (3 passbands) (Gaia Collaboration et al. 2016, 2018a), KPNO (3 passbands), SDSS (4 passbands) (Ahn et al. 2012), and PAN-STARRS (2 passbands) (Chambers et al. 2016) surveys (upper panel, Figure 7) obtained from VO photometry. The number of photometric points used for constructing the SED of NH 84 is 16. The UV flux measurements of NH 84 along with the exposure times are given in Table 3. We found that fitting the full SED with a single Kurucz model spectrum of \(T_{\text{eff}} = 8000 \pm 125\) K and \(\log g = 4.0 \pm 0.5\) resulted in a large \(\chi^2_{\text{red}} \approx 5.75\) for the given degrees of freedom (14). This is clear from the residual plot shown in the lower panel of Figure 7, which shows the difference between the observed flux and the synthetic flux normalized with respect to the observed flux, corresponding to the flux measurements in each passband. We find that the residual plot shows a rise in flux in the UV wavelengths for a single spectrum fit (shown as light-red empty triangles in the figure). Similarly, we checked the SEDs and the residual plots of other 13 BSSs. If we find the residual to be more than 50% in the FUV wavelengths, we classify the BSS as having UV excess. We found that out of 14 BSSs, there are 6 BSSs that show UV excesses of \(10\) ppm. Our focus is on BSS NH 84 in this study as we have the radial velocity membership confirmation from our spectroscopic study (Section 4).

In order to address the UV excess found in BSS NH 84, we generated a composite spectrum by combining the fluxes of Kurucz models for BSS (Castelli et al. 1997; Castelli & Kurucz 2003) and Koester WD models (Tremblay & Bergeron 2009) for the hot component. We independently obtained the SED fit parameters of the BSS using Kurucz models for a fixed metallicity ([Fe/H] = -2.0) considering wavelengths longer than 2000 A and found that it is in agreement with the parameters obtained from spectra.
The hot component has a luminosity of $\sim (4.1 \times 10^{-24} \pm 8.8 \times 10^{-28})$ erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$ from very low resolution spectral models, which explains why the Balmer absorption features redward of the H$_g$ line are telluric bands. Note also that the shown model (gray line) comes from very low resolution spectral models, which explains why the Balmer line shapes are not well matched, as compared to Figure 6. We found $T_{\text{eff}} = 8000$ K as the best-fit value for the cool component from both the SED and the spectrum. Keeping the SED parameters fixed, we varied the parameters of the Koester WD models assuming a log $g = 7.5$, to get the best-fit combination for the full SED as given in Table 4.

The UV excess part of the SED fitted with a single Kurucz spectrum and composite spectrum are shown in a zoomed-in plot of the SED (upper panel of Figure 7) where the light-red empty triangles indicate the single-component Kurucz synthetic flux and gray empty squares indicate the combined synthetic flux (Kurucz + Koester) in the respective FUV filters. When inspecting the zoomed-in panel in Figure 7, the reader should focus their attention on the synthetic flux points (light-red empty triangles and gray empty squares) when comparing to the observed data points, instead of comparing to the solid-line model spectra, which give the misleading impression of a bad fit. Large residuals found for single spectrum fit reduce to almost zero with the composite spectrum fit, in particular, for the residuals in the UV filters (shown as gray empty squares in the lower panel of Figure 7). Thus, NH 84 is found to have a hotter WD companion of temperature $32,000 \pm 2000$ K. The $\chi^2_{\text{red}}$ value for the composite spectrum of NH 84 is $\sim 1.62$ corresponding to a 95% confidence level. We note that the largest nonzero residuals are still at the far blue end, where the WD fit is supposed to compensate.

We estimated the basic parameters (luminosities and radii) of the components of BSS NH 84 using the values ($T_{\text{eff}}, M_g$) obtained from the SED fitting. For estimating the radii of the components, we used the relation of $M_g$ as mentioned in Equation (1) by adopting a distance of 16 $\pm$ 0.6 kpc (Arellano Ferro et al. 2008). The radius of the cool component of BSS NH 84 is $\sim 1.44 \pm 0.05$ $R_{\odot}$, whereas that of the hot component is $\sim 0.021 \pm 0.001$ $R_{\odot}$, which is close to the typical radii of WDs (Tremblay et al. 2017). The uncertainties in the radii are estimated using the equation $\Delta R = \frac{R_g \Delta g}{g_{\odot}}$, where $\Delta g = 0.6$ kpc taken from Arellano Ferro et al. (2008). We calculated the luminosities of the components of the BSS using the relation:

$$ L = \left( \frac{R}{R_{\odot}} \right)^2 \left( \frac{T_{\text{eff}}}{T_{\odot}} \right)^4. $$

The hot component has a luminosity of $\sim 0.42 \pm 0.11$ $L_{\odot}$ whereas the cool component has $\sim 7.58 \pm 1.10$ $L_{\odot}$.

### Table 4

| Parameters | BSS | WD |
|------------|-----|----|
| $T_{\text{eff}}$ | 8000 $\pm$ 250 K | 32000 $\pm$ 2000 K |
| log $g$ | 4.0 $\pm$ 0.5 | 7.5$-$7.75 |
| $M_g$ | 4.1E-24 | 8.8E-28 |

In order to evaluate the upper limit of uncertainty found in the $T_{\text{eff}}$ estimate of the BSS from spectroscopy (Section 4), we checked the SED fits for the BSS temperatures ranging from 8000 to 9000 K using Kurucz models. We found that fitting the SED of the BSS with $T_{\text{eff}} = 8250$ K has less $\chi^2_{\text{red}}$ than that of 8000 K. Though, it brings down the residuals in the UV wavelengths to 30% from 50%, but the individual $\chi^2$ for the passband near the Balmer jump (KPNO B) increases with increasing $T_{\text{eff}}$. As the Balmer jump is very sensitive to $T_{\text{eff}}$ of the cooler component, 8000 K is more appropriate for the $T_{\text{eff}}$ of the BSS from the SED fits. We also note that, if we consider a $T_{\text{eff}}$ of 8250 K for the BSS, then the best-fitting parameters using Koester models ($T_{\text{eff}}$ and $R$) are 30,000 K and 0.014 $R_{\odot}$, which are also consistent with the hot component being a WD. The total $\chi^2_{\text{red}}$ value increases for temperatures larger than 8250 K for the BSS.

The typical log $g$ values for the WDs reported in the GCs (NGC 6397, NGC 6752, and 47 Tuc), based on the spectra from earlier studies (Moehler et al. 2000, 2004; Knigge et al. 2008) lie in the range of 7.5$-$7.8. The log $g$ values available in the Koester models that fall in this range are 7.5 and 7.75. We found that, for a fixed temperature and scaling factor, the SED fit is insensitive to the above two log $g$ values. This shows that the log $g$ value is not well constrained by the SED fit. We calculated the mass of the WD for two different log $g$ values (7.5 and 7.75) using the relation:

$$ \frac{M}{M_{\odot}} = \left( \frac{g_{\odot}}{g} \right) \left( \frac{R}{R_{\odot}} \right)^2. $$

For a fixed $T_{\text{eff}}$ and $R$ of the WD given in Section 5, we found that the mass of the WD varies from 0.5 to 0.9 $M_{\odot}$ for log $g$ values of 7.5 and 7.75. We assumed log $g = 7.5$ in the SED fit as it corresponds to a WD mass $\sim 0.51 M_{\odot}$ for the given radius, which is close to the average mass of WDs (0.53 $\pm$ 0.02 $M_{\odot}$) suggested in GCs (Renzini & Fusi Pecchi 1988; Renzini et al. 1996).

### 5.1. Uncertainties in the WD Parameters

From the SED analysis, we found that 6 out of 14 BSSs show significant excess in UV, among which one is a known contact binary (NH 19) and one is an SX Phe variable (NH 49). We studied the UV excess of BSS NH 84 in detail, as we have the radial velocity measurements from Gemini spectra in

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6. Discussion

From the SED analysis, we found that 6 out of 14 BSSs show significant excess in UV, among which one is a known contact binary (NH 19) and one is an SX Phe variable (NH 49). We studied the UV excess of BSS NH 84 in detail, as we have the radial velocity measurements from Gemini spectra in
addition to PM from GAIA DR2. The rest of the UV excess BSSs will be studied in detail in the future.

The mass of the BSS NH 84 is $\sim 1.1 M_\odot$ when compared with the Padova isochrone (Figure 4). The mass of WD ranges from 0.5 to 0.9 $M_\odot$, as described in Section 5.1. This suggests that the hot component of the BSS NH 84 is more likely to be a C/O WD as inferred from the fit parameters and the associated uncertainties.

A comparison of the $L$ and $T_{\text{eff}}$ of the hot companion of BSS NH 84 with the Bergeron WD cooling models, which are basically for C/O WDs (Tremblay et al. 2011) suggests that the mass of the WD varies from 0.45 to 0.62 $M_\odot$ with a cooling age $\sim 15$ Myr. This indicates that the system might have recently undergone MT. According to the initial–final mass relationship by Althaus et al. (2015) for low metallicity systems ($Z = 0.0001$), the progenitor mass corresponds to $0.8 M_\odot$ for a final WD mass of $\sim 0.51 M_\odot$ ($\log g = 7.5$). This suggests that the progenitor mass is likely to be only slightly higher than the MSTO mass of the cluster. Thus, we speculate that the BSS could have formed as a result of a Case B or C MT (Paczynski 1971). The WD parameters obtained for BSS NH 84 are similar to the parameters derived by Knigge et al. (2008) for a BSS-WD system in 47 Tuc. This is the second BSS-WD system to be detected in a GC after the first detection of such a system in 47 Tuc (Knigge et al. 2008).

We checked the PM membership of all the BSSs available in the catalog given by Fekadu et al. (2007) using GAIA DR2 and found 8 of them to be nonmembers. Of the 8 nonmembers, 3 of them (NH 64, 83, and 86) are classified as quasars by Ahn et al. (2012) and Flesch (2015). Three BSSs (NH 85, 87, and 89) that do not have PM information from GAIA DR2 are classified as galaxies by the SDSS survey (Alam et al. 2015). These 6 sources (galaxies and quasars) are mainly located outside 2$r_h$ of the cluster. Thus, we find that $\sim 15\%$ of the BSS population reside outside 1$r_h$ corresponding to 12 sources. In this study, where we have identified 14 BSSs in FUV, $\sim 14\%$ (2 BSSs) of the BSS population lie outside 1$r_h$ of the cluster. This shows that the distribution of FUV-detected BSSs is consistent with the distribution of optically identified BSSs in the cluster.

Beccari et al. (2013) found the radial distribution of BSSs in NGC 5466 to be bimodal with a centrally concentrated and an outer BSS subpopulation, with a minimum in the radial surface density distribution at about $r \approx 180''$. They estimated the binary fraction in the cluster outskirts ($400'' < r < 800''$) to be $\sim 5\%$. NH 84 is located at $r \approx 730''$ ($\sim 8.5 r_h$, McLaughlin & van der Marel 2005) from the cluster center, which is at half the distance of the tidal radius of the cluster ($r_t \approx 1580''$, Micocchi et al. 2013). They concluded that the unperturbed evolution of primordial binaries could be the dominant formation mechanism for the BSSs in the low-density environments. According to Ferraro et al. (2012), NGC 5466 is in its dynamical infancy. The binaries present in the cluster outskirts has just recently begun to segregate toward the GC center. In light of the bimodal radial BSS density distribution, we speculate that NH 84 might be an MT binary system that has not yet experienced any significant dynamical interaction with the ambient stellar population and has evolved in relative isolation so far. The consistent picture of the location of NH 84 in NGC 5466 and its dynamical age together with the radially bimodal density distribution suggests that MT is one of the primary BSS formation mechanisms in the low-density environments (Knigge et al. 2009; Geller & Mathieu 2011; Leigh et al. 2013; Gosnell et al. 2014).

7. Summary and Conclusions

The first results for the metal-poor GC NGC 5466 from UVIT are presented here. The results are based on our observations in four filters of UVIT (2 FUV and 2 NUV) along with Gemini spectra.

Our study has led us to the following conclusions:

1. We detected 14 BSSs in NGC 5466, all of which have measured fluxes in all four UVIT filters and are likely proper motion members according to GAIA DR2.
2. The parameters of the BSS NH 84 obtained from the GMOS-N spectrum are $T_{\text{eff}} = 8000^{+1000}_{-350}$ K and $\log g = 4.0 \pm 0.5$. It is a radial velocity ($\sim 128 \pm 30$ km s$^{-1}$) member.
3. The SED decomposition analysis found the presence of a hot component in the SED of BSS NH 84. The hot component is found to have a temperature of $T_{\text{eff}} = 32000 \pm 2000$ K and a radius $\sim 0.02 R_\odot$ suggesting it to be a WD.
4. NH 84 is the first BSS-WD candidate found in the outskirts of a low-density GC. This is the second BSS-WD system reported in a GC. As NGC 5466 is a dynamically young cluster, this result suggests an MT pathway for BSS formation in low-density environments.

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