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Discovery of Two Faint White Dwarf Candidates in Open Cluster NGC 2516

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The mass that distinguishes stars that form neutron stars from those that form white dwarfs (WDs) remains poorly determined to this day. One method of constraining this mass involves characterizing massive ($M \gtrsim 1 M_\odot$) WDs and identifying the initial masses of the stars that formed them. The initial mass determination is often the problematic part of the procedure, as it involves finding a WD in a system that can be accurately age dated. Star clusters are such systems, and the open cluster NGC 2516 has an age ($\sim 130-200$ Myr; Sung et al. 2002; Salaris et al. 2009; Cummings et al. 2018) that implies that it should have started forming WDs relatively recently. Study of the WDs in this cluster can therefore help to delineate the initial-final mass relation for WDs, and help us extrapolate toward the presumptive transition mass. Four WDs were previously discovered in the cluster and were initially studied by Reimers, & Koester (1982). Recent studies have found the stars to have masses just below that of the Sun (Cummings et al. 2018), which is significantly above the masses of the majority of field WDs.

Using *Gaia* Data Release 2 (Gaia Collaboration et al. 2018), we searched a wide field of radius 5° around the center of NGC 2516, and identified possible cluster members with proper motions within 2.5 mas/yr and parallaxes within 0.75 mas of the respective median values found in table A.4 of Gaia Collaboration et al. (2018). As shown in Figure 1, the search yielded six stars with positions, proper motions, and parallaxes most consistent with membership in the cluster, as well as *Gaia* photometry characteristic of WDs. We note that all of these sources appear as high-probability WD candidates in Gentile Fusillo et al. (2019).

The two stars that were not previously known WDs have positions on the sky put them fairly far (both $1.^{\mathrm{d}}5$) from the cluster center, which is the likely reason they were not identified previously. They are within the cluster's halo, however. Candidate 1 appears to be the coolest of the WDs, and possibly the lowest in mass as well. Candidate 2 is the bluest of the WDs, possibly indicating a higher mass. In both cases, models indicate cooling ages near 100 Myr, consistent with WD production within the cluster.

	C1	C2
Gaia ID	5289447182180342016	5294015515555860608
RA	$7^{\mathrm{h}}46^{\mathrm{m}}1.^{\mathrm{s}}55$	$7^{\mathrm{h}}49^{\mathrm{m}}6.^{\mathrm{s}}66$
DEC	$-61°3'14.''9$	$-59°47'54.''5$
G	19.508	19.453
$G_{BP} - G_{RP}$	−0.154	−0.330
NUV	18.85 ± 0.06	
FUV	18.31 ± 0.07	

To further validate the WD candidates, we gathered photometry for spectral energy distributions (SEDs) for them and the spectroscopically verified WDs. The confirmed WDs have measured effective temperatures between 29000 and 35500 K (Cummings et al. 2016). We found ultraviolet photometry (NUV and FUV bands) for candidate 1 from GALEX (Morrissey et al. 2007) that confirms its high temperature. Two of the confirmed WDs have been observed with Swift/UVOT, and we collected photometry in the $uvw1$ and $uvw2$ bands using the UVOT interactive analysis tool[1], and converted to fluxes using Poole et al. (2008). $UBVI_C$ photometry for the previously known WDs was available from Sung et al. (2002), and optical data from (Gaia Collaboration et al. 2018). Fluxes in the $UBVI_C$

[1] http://www.asdc.asi.it/mmia/

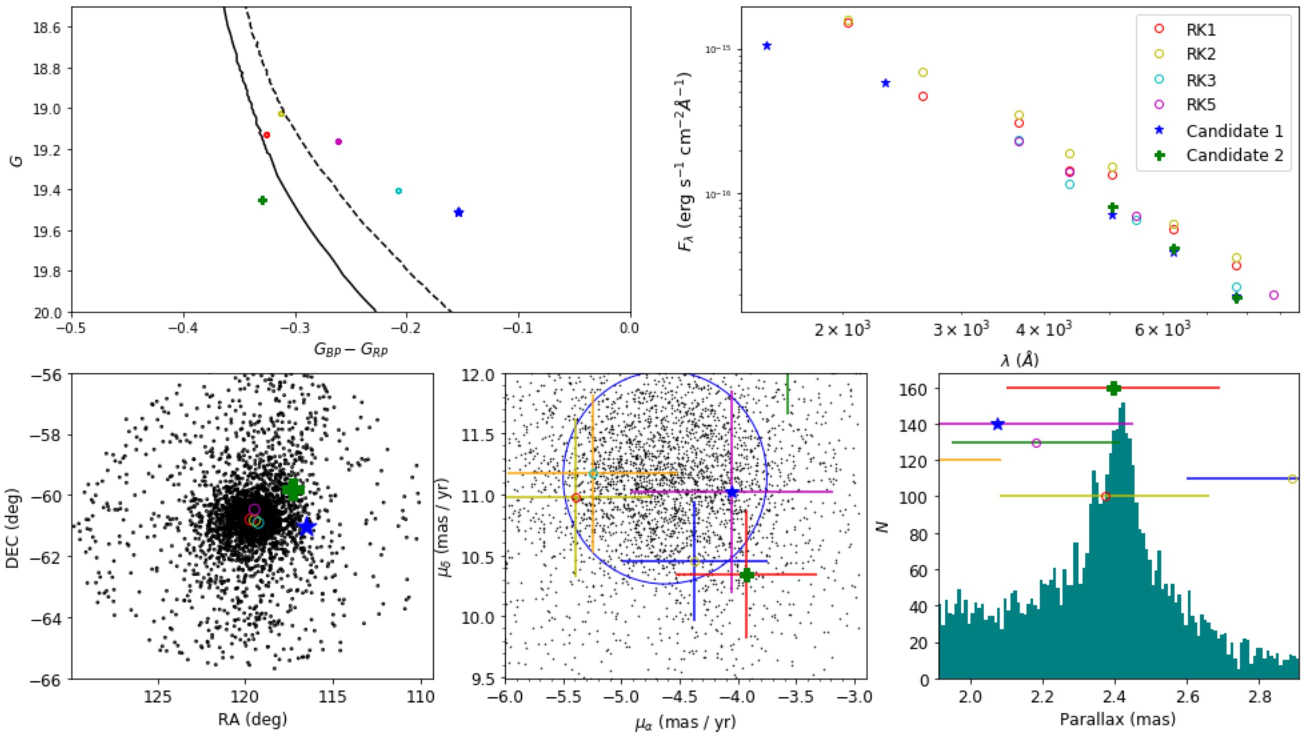

Figure 1. Characteristics of spectroscopically confirmed WD and candidates. Upper left: $G_{BP} - G_{RP}$ vs G color-magnitude diagram, along with $1M_\odot$ (*solid line*) and $0.87M_\odot$ (*dashed line*) DA WD cooling tracks (Salaris et al. 2010) shifted for the distance and extinction of NGC 2516. Upper right: Spectral energy distributions. Lower left: Sky positions for cluster members selected by parallax and proper motion. Lower center: Proper motions for stars selected by parallax. The blue ellipse has a 1.75 mas yr^{-1} radius. Lower right: Histogram of parallax values for stars within the proper motion range shown in the middle panel.

bands were calculated using reference magnitudes from Bessell et al. (1998), and for *Gaia* data were calculated using magnitude zeropoints from Evans et al. (2018). In all cases, the SEDs suggest peak fluxes deep in the UV, showing the high surface temperatures of young WDs.

Because these candidates are very likely to be WDs, follow-up spectroscopic observations of these candidates can be used to estimate their masses. These add significantly to the population of dateable massive WDs that delineates the high-mass end of the initial-final mass relation.

Facilities: Gaia, GALEX, Swift

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