White Dwarfs as probes of fundamental physics and tracers of planetary, stellar & galactic evolution
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Double Degenerate Candidates in the Open Cluster NGC 6633

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Abstract. The study of white dwarfs, the end stage of stellar evolution for more than 95% of stars, is critical to bettering our understanding of the late stages of the lives of low mass stars. In particular, the post main sequence evolution of binary star systems is complex, and the identification and analysis of double degenerate systems is a crucial step in constraining models of binary star systems. Binary white dwarfs in open star clusters are particularly useful because cluster parameters such as distance, metal content, and total system age are more tightly constrained than for field double degenerates. Here we use the precision astrometry from the Gaia Data Release 2 catalog to study two other white dwarfs which were identified as candidate double degenerates in the field of the open star cluster NGC 6633. One of the two objects, LAWDS 4, is found to have astrometric properties fully consistent with that of the cluster. In such a case, the object is significantly overluminous for a single white dwarf, strongly indicating binarity. The second candidate binary, LAWDS 7, appears to be inconsistent with cluster membership, though a more thorough analysis is necessary to properly quantify the probability. At present we are proceeding to model the photometric and spectroscopic data for both objects as if they were cluster member double degenerates. Results of this latter analysis are forthcoming. Our results will add crucial data to the study of binary star evolution in open star clusters.

Keywords. binaries: general, white dwarfs, open clusters and associations: individual (NGC 6633)

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1. Introduction

White dwarfs are the final stage of stellar evolution for low mass stars. Over 95% of stars, including the Sun, will eventually become a white dwarf. This makes white dwarfs critical remnants for the study of stellar evolution. Furthermore, the evolution of binary star systems is more complex than the evolution of single star systems, and since the majority of stars are part of binary star systems, the evolution of such systems is another crucial component to our understanding of stellar evolution. In particular, the evolution of binary star systems in well-studied open clusters provides observational constraints on difficult theoretical questions, such as the binary frequencies and mass distributions resulting from cluster star formation and subsequent evolution of these systems in complex dynamical gravitational systems (e.g., Geller *et al.* 2013).

In this work we further the ongoing study of two candidate binary white dwarf systems in the intermediate-age open cluster NGC 6633. In Williams & Bolte (2007), two white dwarfs in the cluster field were identified as potential binary systems, as they are twice as luminous as would be expected for a single cluster-member white dwarf based on their spectroscopically measured effective temperatures and masses.

Since binary white dwarfs with short orbital periods will eventually merge and may explode as Type Ia supernovae, Williams *et al.* (2015) used high resolution spectra to determine that while both candidates may be binary, their orbital periods are much longer than those needed for a merger within a Hubble time.

Here we present initial results from our most recent study that uses astrometric data from Gaia Data Release 2 to test the cluster membership of both candidate binary systems.

2. Results

The Gaia mission is tasked with making the most precise measurements of stellar parallax and proper motions ever taken for more than 1.3 billion stars across the entire sky, including both white dwarfs. We identified both white dwarfs in the Gaia DR2 catalog (Gaia Collaboration; Brown *et al.* 2018) by searching for coordinate matches within 1 arcsecond resulting in a unique match for each star; the Gaia photometry is consistent with previously published broadband measurements. The position of NGC 6633 LAWDS 4 is RA(J2000)=18h27m10.40s and Dec(J2000)= +06d26m15.70s, while NGC 6633 LAWDS 7 has a RA(J2000)=18h27m49.90s and Dec(J2000)= +06d20m51.80s.

We then extracted the measured proper motions and parallaxes for each star after checking appropriate data quality flags. We used the cluster parallax and proper motions from Gaia observations of open star clusters (Gaia Collaboration; Babusiaux, C., *et al.* 2018). These data are given in Table 1 and illustrated in Figures 1 and 2.

Quantitative measurements of cluster membership probability require iterative procedures considering the astrometric properties of both cluster and field stars as a function

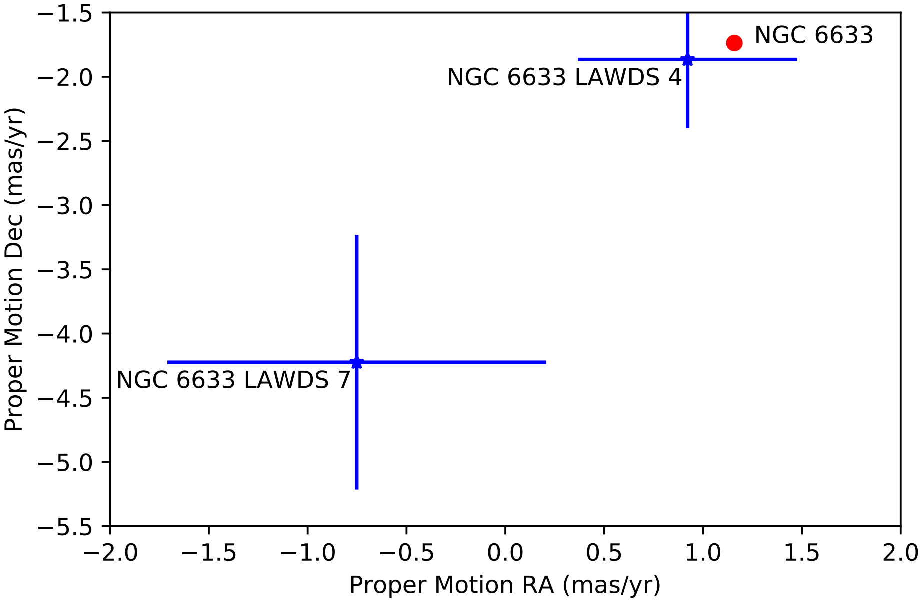

Figure 1. Gaia DR2 proper motion data for NGC 6633 and the two candidate double degenerates, with 1σ error bars. The uncertainties and dispersions for the cluster are smaller than the data point. This plot shows that the proper motions of LAWDS 4 are consistent with cluster membership, while LAWDS 7 appears to be inconsistent.

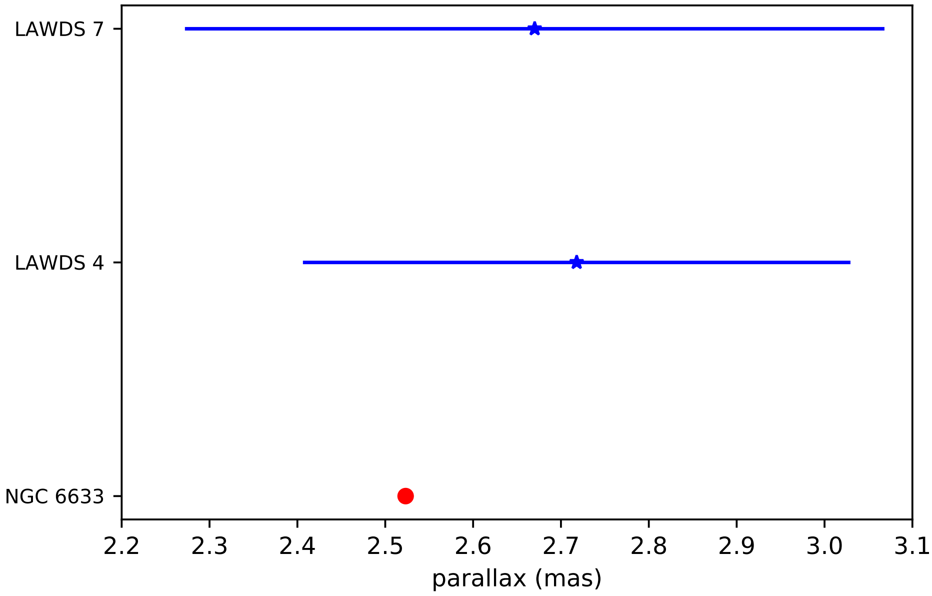

Figure 2. Gaia DR2 parallax data for NGC 6633 compared with that of the double degenerate candidates, with 1σ error bars. Note that the error bars for NGC 6633 are smaller than the point. This plot shows that the parallax of both white dwarfs, while as yet poorly constrained due to the stars' faint fluxes, is nonetheless consistent with cluster membership. Future Gaia data releases should more precisely determine the parallax of each white dwarf.

of position and magnitude (e.g., Gaia Collaboration; Babusiaux *et al.* 2018, Dias *et al.* 2006, Sanders 1971). At present we have not finished this analysis. However, we estimate membership probabilities by assuming that the stated Gaia measurement uncertainties have Gaussian distributions and are uncorrelated, and that the field contamination is negligible. These assumptions are not technically correct but are likely reasonable given that the Gaia DR2 errors on the white dwarfs' astrometry are likely primarily due to their faint magnitudes.

In Table 1 we list the probability that a bona fide cluster member with identical measurement uncertainties would exhibit deviations from the cluster astrometry larger than those observed for each white dwarf. As inferred from qualitative inspection of Figures 1 and 2, we find that LAWDS 4 is fully consistent with cluster membership and that LAWDS 7 is likely not consistent with cluster membership. Even so, based on parallax data alone LAWDS 7 is likely to still be overluminous and thus a double degenerate.

3. Ongoing Efforts

Our ongoing work strongly suggests that at least one of our candidate binaries, LAWDS 4, is indeed a member of NGC 6633 and therefore a double degenerate. The next step in our analysis is to fit binary white dwarf models to the existing spectra of both objects under the assumption of cluster membership.

Once we have these parameters, we will be able to consider various evolutionary scenarios for each system, including the potential of past binary interactions and estimates

Table 1. Table 1: Gaia DR2 astrometric measurements for NGC 6633 and the candidate binary white dwarfs. P is the likelihood that a random identical cluster member would have measured astrometry more discrepant than that of the white dwarf.

Object	μ_α mas yr^{-1}	σ_{μ_α} mas yr^{-1}	μ_δ mas yr^{-1}	σ_{μ_δ} mas yr^{-1}	ϖ mas	$\sigma\varpi$ mas	P
NGC 6633	1.1584	0.0199	-1.7371	0.0200	2.5232	0.0023	
NGC 6633 LAWDS 4	0.9219	0.5546	-1.8654	0.5332	2.7179	0.3116	0.428
NGC 6633 LAWDS 7	-0.7518	0.9580	-4.2236	0.9916	2.6701	0.3981	0.0013

of the progenitor star masses. These data will inform our planned future analyses of candidate double degenerates in numerous additional open clusters. Combined, these data will allow glimpses into the evolution and fate of the numerous multiple star systems observed in open clusters.

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