

Three eclipsing white dwarf plus main sequence binaries from SDSS.

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Abstract. We identify SDSS 0110+1326, SDSS 0303+0054 and SDSS 1435+3733 as three eclipsing white dwarf plus main sequence binaries from the Sloan Digital Sky Survey, and report on their follow-up observations. Orbital periods for the three systems are established through multi-season photometry. Time-resolved spectroscopic observations lead to the determination of the radial velocities of the secondary stars. A decomposition technique of the SDSS spectra is used to estimate the surface gravities and effective temperatures of the white dwarfs, as well as the spectral types of the secondaries. By combining the constraints from the spectral decomposition, the radial velocity data and the modeling of the systems' light curves, we determine the physical parameters of the stellar components. Two of the white dwarfs are of low mass ($M_{\text{WD}} \sim 0.4 M_{\odot}$), while the third white dwarf is unusually massive ($M_{\text{WD}} \sim 0.8 - 0.9 M_{\odot}$) for a post-common envelope system.

1. Introduction

We have selected possibly eclipsing white dwarf plus main sequence (WDMS) binaries from the Sloan Digital Sky Survey (SDSS) based on the available information on the radial velocities of their companion stars, and/or evidence of a strong reflection effect.

Initially, we used SDSS spectroscopy to measure the radial velocity of the companion star either from the Na I $\lambda\lambda 8183.27, 8194.81$ absorption doublet, or from the H α emission line. SDSS J030308.35+005444.1 (henceforth SDSS 0303+0054) and SDSS J143547.87+373338.6 (henceforth SDSS 1435+3733) exhibited the largest secondary star radial velocities among ~ 1150 WDMS binaries which have SDSS spectra of sufficiently good quality. For SDSS J011009.09+132616.1 (henceforth SDSS 0110+1326) two SDSS spectra are available, which differ substantially in the strength of the emission lines from the heated companion star. Photometric time series observations revealed white dwarf eclipses in all three objects. Table 1 lists the full coordinates and SDSS u, g, r, i, z magnitudes of the three systems.

Table 1. Full coordinates and u, g, r, i, z magnitudes of the three systems.

SDSS J	u	g	r	i	z
011009.09+132616.1	16.51	16.53	16.86	17.02	16.94
030308.35+005444.1	19.14	18.60	18.06	16.89	16.04
143547.87+373338.5	17.65	17.14	17.25	16.98	16.66

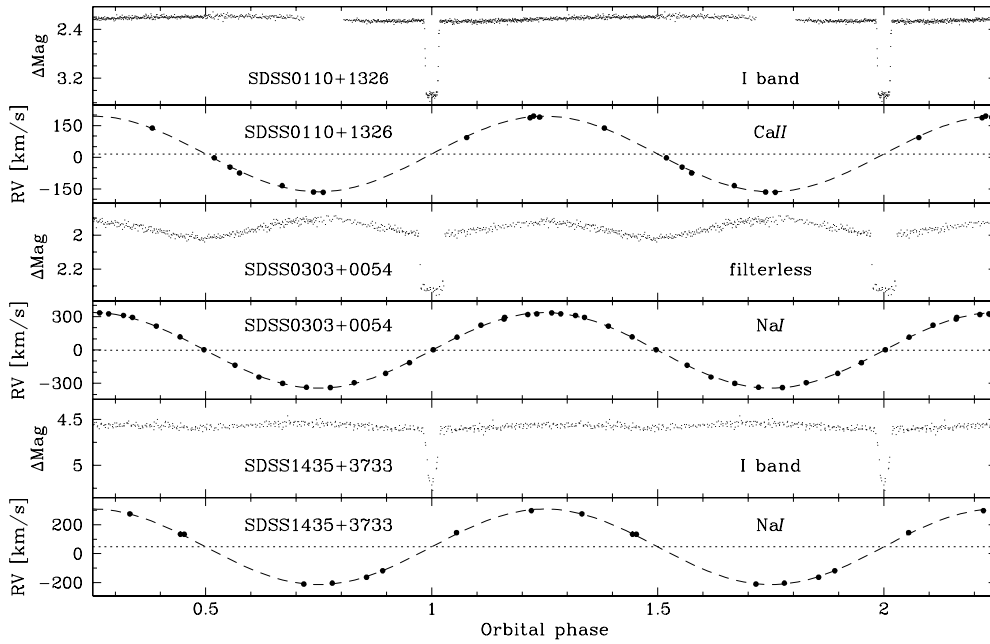


Figure 1. Sample phase folded light curves and radial velocity curves of the three systems. The system's name, the filter used in the photometric observations and the spectral line used to measure the respective radial velocity are indicated in each panel. A full orbit has been duplicated for clarity.

2. Orbital periods and radial velocities

Follow-up photometric and spectroscopic observations were obtained at the 4.2 m WHT, the 2.2 m Calar Alto, the 1.2 m Mercator and the 80 cm IAC telescopes, for a total of 32 nights for all systems. Figure 1 show sample light curves and radial velocity curves of the three systems.

For each system, we measured the eclipse mid-points in the light curves and established the orbital periods and the orbital ephemerides. These are: $T_0(\text{HJD}) = 2453994.447876(95) + 0.3326873265(62)\text{E}$ for SDSS 0110+1326, that is, $P_{\text{orb}} = 7.984495836(89)\text{h}$, $T_0(\text{HJD}) = 2453991.616419(26) + 0.1344377259(15)\text{E}$ for SDSS 0303+0054, that is, $P_{\text{orb}} = 3.226505422(80)\text{h}$ and $T_0(\text{HJD}) = 2454148.703615(62) + 0.125631039(04)\text{E}$ for SDSS 1435+3733, that is, $P_{\text{orb}} = 3.015144936(10)\text{h}$. The ephemerides were then used to fold the available photometric and spectroscopic data over phase.

From our spectroscopic observations we were able to measure the radial velocities of the secondary stars for all three systems. For SDSS 0110+1326 we used the $\text{Ca II } \lambda\lambda 8498.02, 8542.09, 8662.14$ emission triplet, whereas for SDSS 0303+0054 and SDSS 1435+3733 the $\text{Na I } \lambda\lambda 8183.27, 8194.81$ absorption doublet. The results, regarding the radial velocity and the systemic velocity of each system, are: $K_{\text{sec}} = 178.8 \pm 2.4 \text{ km s}^{-1}$ and

$\gamma = 15.2 \pm 2.4 \text{ km s}^{-1}$ for SDSS 0110+1326, $K_{\text{sec}} = 339.7 \pm 1.9 \text{ km s}^{-1}$ and $\gamma = -4.0 \pm 1.4 \text{ km s}^{-1}$ for SDSS 0303+0054 and $K_{\text{sec}} = 260.9 \pm 2.9 \text{ km s}^{-1}$ and $\gamma = 47.4 \pm 2.2 \text{ km s}^{-1}$ for SDSS 1435+3733.

3. Spectral decomposition

A decomposition technique, based on template spectra, was used to isolate the white dwarf and the M-dwarf contributions. M-dwarf templates were used in the first step, to determine the spectral type of the secondary and its flux contribution. After the best fit was found (see also Figure 2), it was subtracted from the total spectrum, leaving only a residual white dwarf spectrum. The Balmer line profiles of the DA white dwarfs in SDSS0110+1326 and SDSS1435+3733 were then fitted with model white dwarf spectra (see also Figure 3). In this fashion, we also determined the white dwarf effective temperatures and surface gravities, as well as the distances to the systems. Using these values, one can obtain an initial estimate for the mass of the white dwarf. We should note that SDSS0303+0054 contains a DC white dwarf, hence only the spectral type of the M-dwarf was determined.

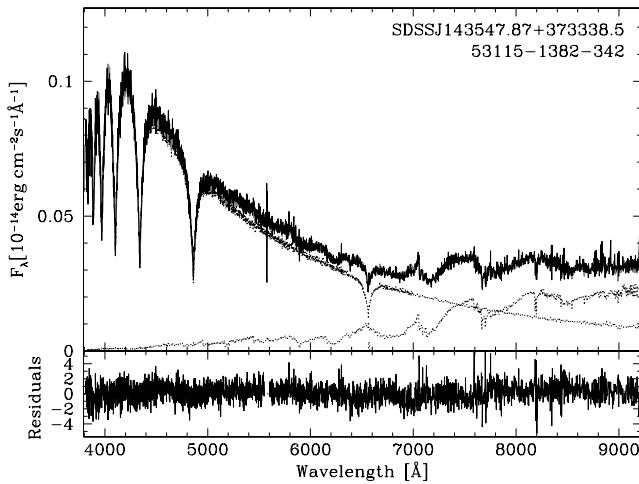


Figure 2. Two-component fit to the spectrum of SDSS 1435+3733.

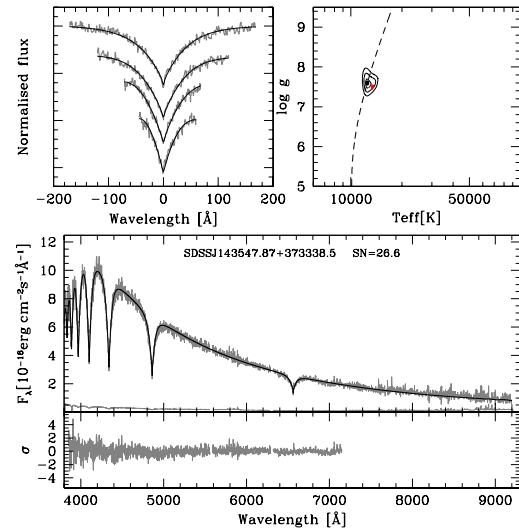


Figure 3. Spectral model fit to the white dwarf in SDSS 1435+3733, obtained after subtracting the best-fit M-dwarf template.

4. Light curve model fitting

We used TRM's close binary systems fitting code to model the light curves of the three systems and obtain additional constraints for the stellar parameters, mainly the masses and radii of the stellar components and the inclination angles of the three systems. The code uses a file of supplied parameters (the mass ratio q , the inclination angle i , the two radii scaled by binary separation $r_1 = R_{\text{WD}}/a$ and $r_2 = R_{\text{sec}}/a$ and the effective stellar temperatures T_{WD} and T_{sec}) to compute the model, which is afterwards fitted to the data using Levenberg-Marquardt minimisation. To illustrate the quality achieved in the fits, Figures 4 and 5 show sample fits for SDSS 0110+1326 and SDSS 0303+0054 respectively.

5. Results

Table 2 contains the values for $\log g$ and $T_{\text{eff,WD}}$, as well as the spectral type of the secondary, obtained from the decomposition of the spectra, as described in Section 3. These values, along

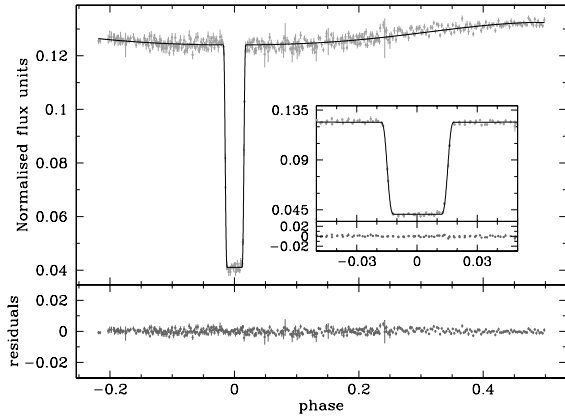


Figure 4. Sample model fit to the light curve of SDSS 0110+1326, for $M_{\text{WD}} = 0.48 M_{\odot}$ and $M_{\text{sec}} = 0.22 M_{\odot}$.

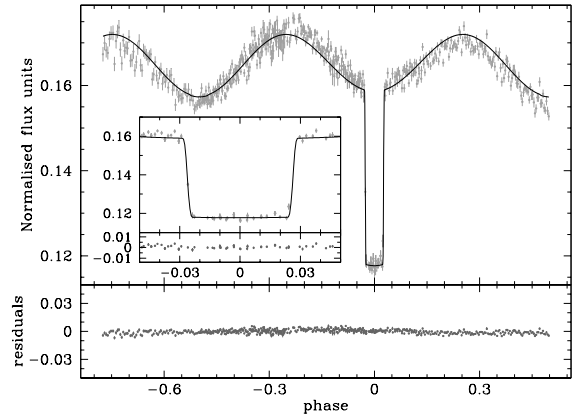


Figure 5. Sample model fit to the light curve of SDSS 0303+0054, for $M_{\text{WD}} = 0.91 M_{\odot}$ and $M_{\text{sec}} = 0.25 M_{\odot}$.

Table 2. Mass and radius values for the stellar components, white dwarf surface gravities and effective temperatures and secondary spectral types for all three systems, after combining the constrains from the available photometric and spectroscopic data sets.

SDSS J	$M_{\text{WD}} [M_{\odot}]$	$R_{\text{WD}} [R_{\odot}]$	$\log g$	$T_{\text{eff,WD}} [\text{K}]$	$M_{\text{sec}} [M_{\odot}]$	$R_{\text{sec}} [R_{\odot}]$	Sp(2)
0110+1326	0.45-0.49	0.016-0.017	7.65	~ 26000	0.20-0.30	0.21-0.29	M4 \pm 1
0303+0054	0.88-0.95	0.008-0.009	8.45-8.56	< 8000	0.22-0.28	0.25-0.27	M4.5 \pm 0.5
1435+3733	0.48-0.53	0.014-0.015	7.58	~ 12500	0.19-0.25	0.22-0.25	M4.5 \pm 0.5

with the results of the light curve modeling, presented in Section 4, lead to a range of possible masses and radii for the stellar components. Both the former and the latter are also shown in Table 2.

6. Conclusion

The three systems presented here bring the total number of known eclipsing WDMS binaries to 14 systems. SDSS 1435+3733 has the shortest orbital period among them all. SDSS 0110+1326 and SDSS 1435+3733 have masses in line with the expectations from close binary evolution. SDSS 0303+0054 seems to be unusually massive. All three systems have late M-type secondaries. Higher temporal resolution light curves, leading to more accurate determination of masses and radii, will provide valuable data for the calibration of M-R relations for low-mass stars and testing the M-R relation of white dwarfs.

References

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