Σ1348AB, LDS 3888C and NSN 594 are a physical double-double with one of these stars also eclipsing

John Greaves[1], Francisco Manuel Rica Romero[2] and Sebastian Otero[3]

1 (UK) :- cpmjg@tutanota.com
2 Orion Astronomical Group (Spain) :- frica0@gmail.com
3 American Association of Variable Star Observers (USA) :- sebastian@aavso.org

Abstract: The particulars for Σ1348AB, LDS 3888C and NSN 594 are presented along with an orbit for the AB pair and variability discovery and solutions for star A as well as the discovery that star C is an eclipsing binary revealing that this system is at least quintuple.

Introduction

During the analysis of long observed binary stars without known orbits from the Washington Double Star Catalog (henceforth WDS: eg Mason et al 2001) that have long running and numerous observational measures in tandem with evidence of physicality from proper motion and parallax data provided by GAIA DR2 (eg Brown et al 2018) it was noticed that the companion star to Σ1348AB (LDS3888C) was in fact also the double star NSN 594 which therefore constituted a CD pair which is unnoted in WDS at this time (see Table 1 for separations and position angles for these stars).

The identification of LDS3888C with what now appears to be NSN 594CD and the similarity of their astrometric particulars revealed that these pairs were in fact a double-double of true association. Furthermore, examination of lightcurves for the pairs against online time series photometry revealed that one of the AB pair was a microvariable whilst the primary of the CD pair was a detached eclipsing binary showing that in fact three stars were involved making five overall when taken in tandem with the AB pair. This triple group was also revealed to contain at least one flare star. Sufficient data were also available to attempt a preliminary orbit for the AB pair. The results are presented here.

Σ1348AB

This pair has nearly two century's of observations available via USNO WDS trailing back to at least the 1830's. The astrometric particulars for each of the pair from GAIA DR2 are presented in Table 1 alongside those for each star in the visual CD pair. With a 2015.5 separation of 1.9 arcseconds (the position angle is 314 degrees) then the mean parallax for the pair gives a distance of about 62 parsecs and a projected separation at that time of around 120 AU. According to SIMBAD (eg Wenger et al 2000) the respective radial velocities are 45.0 and 41.0 kms^{-1} for the A and B star whilst LAMOST DR5 (eg Luo et al 2015) gives 48.0 kms^{-1} for LDS 3888C.

Star	ϖ (mas)	μ_α (mas)	μ_δ (mas)	Gmag	$\rho('')$	$\theta(°)$
S1348A	16.14	-170.47	-31.59	7.35		
S1348AB	16.20	-170.41	-34.16	7.37	1.9	314
LDS 3888AC	16.16	-173.46	-32.91	13.45	123.1	325
NSN 594CD	16.37	-163.92	-35.15	15.32	1.8	22

Table 1 : Details for Σ1348AB and LDS3888C/NSN594 from GAIA DR2 (ρ and θ are derived quantities)

One of us (Rica) has derived orbits for this pair of late F spectral class dwarf stars using methods outlined in Hauser & Marcy (1999) and exemplified in Rica (2012) upon WDS sourced observations of the pair (Mason pers. comm.). This lead to three possible orbits the elements for which being given in Table 2 with the orbit plots presented in Figure 1. Orbit 1 was derived from input dynamic parameters (*x, y, dx/dt and dy/dt*) calculated using the historical astrometric points listed in the WDS, Orbit 2 was calculated using Gaia DR2 data to obtain the input dynamical parameters and Orbit 3 was calculated using an adaptive grid search algorithm (Mason *et al* 1999). Unlike the first two orbits the latter orbit was not constrained by any *a priori* assumption of the total mass of the orbiting system. Consequently although Orbit 3 gives the shorter and more compact orbit it also gives a total mass of roughly twice the other two methods.

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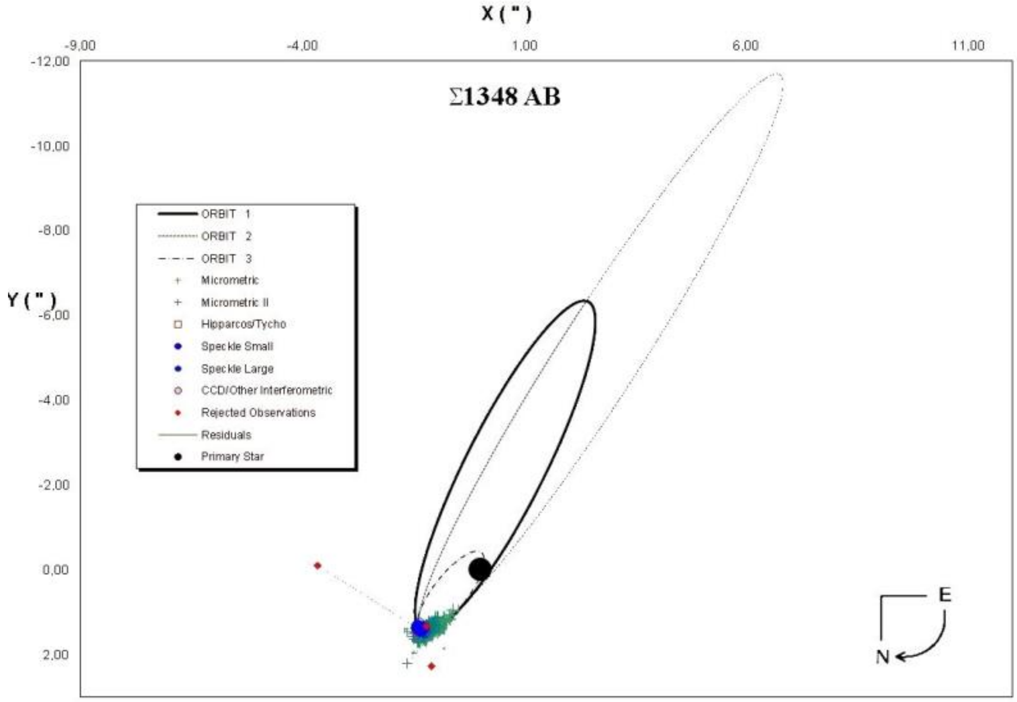

Figure 1 : The orbits of Σ1348AB.

Element	*Orbit 1*	*Orbit 2*	*Orbit 3*
P (yr)	4734.231	8612.811	568.400
T (yr)	1800.232	1839.796	1800.000
α (arcsec)	6.261	9.331	1.836
e	0.820	0.834	0.888
i (deg)	100.01	98.61	106.86
ω (deg)	117.49	317.36	63.73
Ω (deg)	148.32	-35.97	159.21

Table 2 : Orbital elements of Σ1348AB for each of the three derived orbits

Examination of TESS (TESS 2020) online data revealed that at least one of the pair displayed a roughly sinusoidal lightcurve over time, albeit only at the tens to hundreds of micromagnitude level. Given the 21 arcsecond per pixel resolution for TESS data and the near equal magnitudes of the AB stars it is not possible to know which star the signal comes from. Analysis (primarily by Otero) revealed a period of 5.03 days and is presented as a lightcurve phase folded on that period as shown in Figure 2. The nature of the lightcurve suggests that this is a Rotational Variable (ROT) albeit of remarkably low amplitude.

LDS3888C and NSN 594LDS3888C

Perusal of the GAIA DR2 data for LDS3888C revealed that it had common particulars to the AB pair, as shown in Table 1. However, the WDS also revealed that in recent times the C star had been classed as a common proper motion pair itself, NSN 594, although the connection was apparently not noted in the WDS. Table 1 reveals the similarity of the motion and distance particulars for the pair to those of the AB pair. Using the GAIA DR2 astrometric data as was done for the AB pair alongside the CD pair's separation of 1.8 arcseconds (the position angle is 22 degrees) the projected separation of NSN 594 CD was 110 AU in 2015.5 whilst the projected separation of the AB and CD pairs was around 7600 AU based on an AC separation of 123.1 arcseconds (the position angle is 325 degrees) in 2015.5. The CD pair are likely a red dwarf pair with a spectrum of M4 Ve being provided by SIMBAD for the primary, where the suffix 'e' denotes the presence of emission lines, as can be seen in the LAMOST DR5 plot at http://dr5.lamost.org/spectrum/view?obsid=232306068 where an H_α emission peak at around 656 nanometres can be seen.

Examination of online time series data revealed that the CD pair showed variability. One of us (Otero) used data from the ASAS-SN (Kochanek et al 2017) and CRTS (Drake et al 2009) to demonstrate that the system included a detached eclipsing binary (type EA) of magnitude 14.9 V at maximum with a primary minimum of

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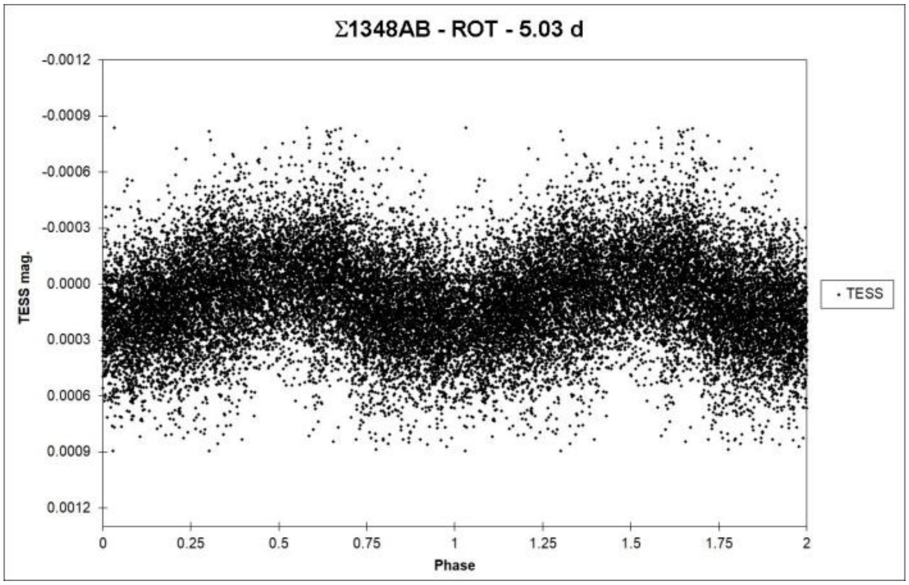

Figure 2 : TESS photometry for Σ1348 folded on 5.03 days. Magnitudes are in differential instrumental millimagnitudes plotted around the overall mean (two full cycles are shown for illustrative purposes)

15.9 V depth and a duration 0.027 of the full period (roughly 40 minutes) and a secondary minimum of 15.2 V, with those magnitudes being corrected for light contamination from the D component. The period is 2.712154 days with a primary minimum Epoch of HJD 2458501.885 from which an ephemeris can be derived (from the fact that primary minimum is equal to Heliocentric Epoch, HJD, plus the Period in days multiplied by an increasing integer until a date and time near to the date and time of required observation is obtained. This time has to be corrected to a Geocentric Julian Date, GJD, by anywhere up to +/- roughly eight minutes depending on the time of year, although the full eclipse duration is a few times larger than the maximum GJD offset which allows for this problem a little unless time of mideclipse is being looked for). The orbit doesn't appear to be eccentric to any extent so the secondary minima should be at a time halfway between two consecutive primary minima. Further examination of the lightcurve by one of us (Otero) revealed that at least one of the trio is also a flare star reaching peaks of up to 12.9 V. Thus there is both EA and UV type variability. The phase folded diagram for the eclipses is presented in Figure 3 whilst Figure 4 shows the raw lightcurve where the occasional flare can be seen.

It should be noted that any professional epochal coverage of the changing radial velocity for this eclipsing binary would enable the mass of the pair to be derived if used in tandem with epochal, possibly multipassband, photometry. This could then be used as a check and/or calibration on the mass of the whole system. NSN 594 itself appears to have sufficient differential proper motion between its two stars to suggest a possible preliminary orbit within a few decades or less which in further tandem with the S1348AB preliminary orbit and also the eclipsing orbit would lead to several different routes for checking the characterisation of the system, especially in terms of derived masses.

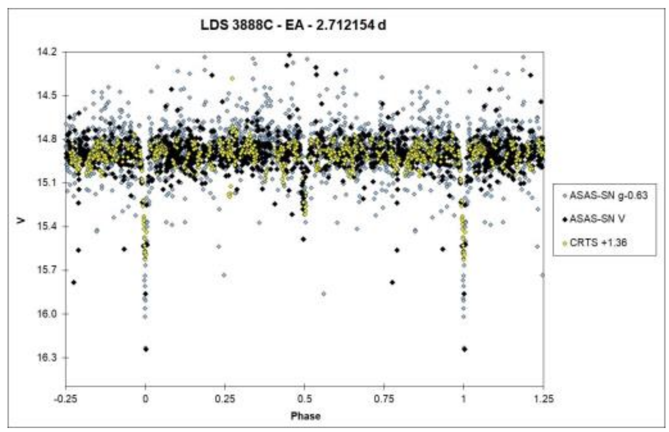

Figure 3: Phase folded lightcurve for the eclipsing binary LDS 3888C with the light contribution from the D component subtracted

Conclusion

Astrometric and photometric data reveal that S1348AB has evidence of orbital motion whilst LDS3888C is physically associated and further is the primary for the pair NSN 594 such that this is a quadruple system constituting a wide set of two close pairs (a 'double-double' so to speak), whilst revealing that LDS3888C is also an eclipsing binary.

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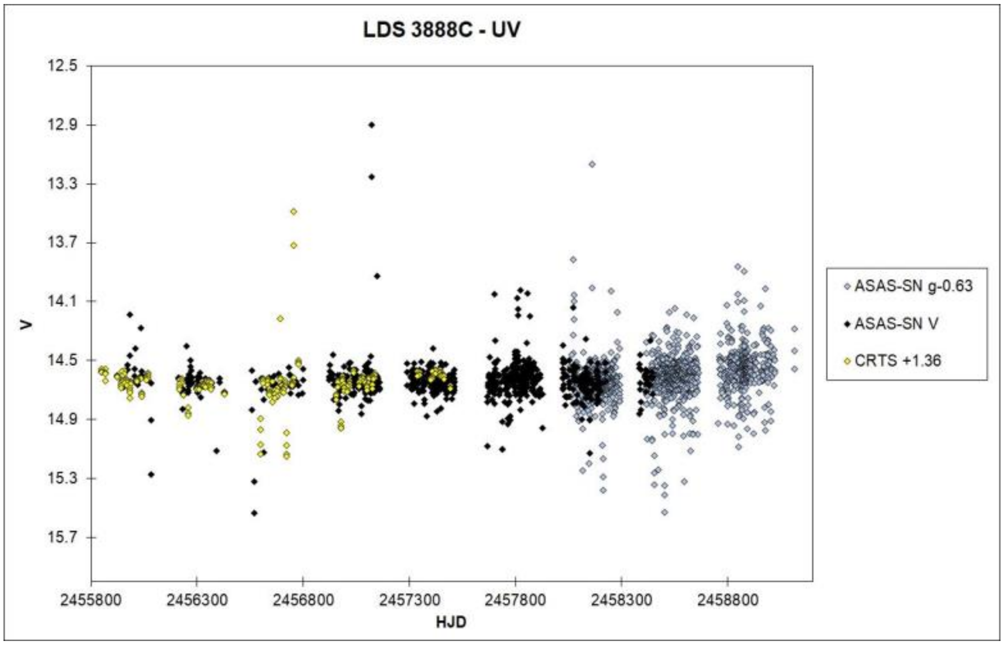

FIGURE 4 : Time series data for LDS 3888C showing the occasional point due to a flare

Accordingly this system is at least quintuple!

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