Proceedings Paper:
Green, M.J., Marsh, T.R., Steeghs, D.T.H. et al. (5 more authors) (2017) Gaia14aae: the first fully-eclipsing AM CVn. In: Tremblay, P.-E., Gaensicke, B. and Marsh, T., (eds.) 20th European Workshop on White Dwarfs (EuroWD16). 20th European Workshop on White Dwarfs (EuroWD16), 25-29 Jul 2016, Warwick, United Kingdom. Astronomical Society of the Pacific Conference Series, 509 . Astronomical Society of the Pacific , pp. 567-570. ISBN 978-1-58381-903-6

Gaia14aae: the First Fully-Eclipsing AM CVn

M. J. Green,[1] T. R. Marsh,[1] D. T. H. Steeghs,[1] E. Breedt,[1] H. C. Campbell,[2] V. S. Dhillon,[3,4] L. K. Hardy,[3] and S. P. Littlefair.[3]

[1]*Department of Physics, University of Warwick, Gibbet Hill Road, Coventry, CV4 7AL, United Kingdom;* matthew.green@warwick.ac.uk

[2]*Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge, CB3 0HA, United Kingdom*

[3]*Department of Physics and Astronomy, University of Sheffield, Sheffield, S3 7RH, United Kingdom*

[4]*Instito de Astrofísica de Canarias, 38205 La Laguna, Tenerife, Spain*

Abstract. AM CVns are a class of cataclysmic variables consisting of a white dwarf accreting H-deficient matter from a donor star. With periods of 5 to 65 minutes, AM CVns include the shortest period binaries containing white dwarfs. AM CVns are believed to form by one of three formation channels which can in principle be distinguished by the nature of the donor star, but are difficult to constrain observationally.

Gaia14aae was one of the first transients discovered by the Gaia Science Alerts project. It eclipses on a period of 50 minutes, and is the only known AM CVn in which the white dwarf is fully eclipsed. This makes it an attractive system for parameter studies. We present an update on our attempts to measure these properties, using high-speed multi-colour photometry. Preliminary results suggest that the donor star is not as degenerate as predicted by models of white dwarf donors.

1. Introduction

AM CVn-type systems are a class of He-dominated cataclysmic variables, consisting of a central white dwarf (WD) accreting material from a H-deficient compact donor (see Solheim 2010, for a recent review). With orbital periods in the range of 5-65 minutes, AM CVns are among the most compact known binary systems. They are the result of a finely-tuned and poorly-understood evolution process, which includes 1 or 2 common envelope (CE) phases. Additionally, their compactness makes them potentially strong sources of gravitational waves in the range detectable by eLISA (Nelemans 2003), and they have been proposed as pregenitors of ".Ia" supernovae (Solheim & Yungelson 2005; Bildsten et al. 2007).

There are three proposed channels by which an AM CVn can form: the white dwarf or double-degenerate channel (Paczyński 1967), the He star channel (Savonije et al. 1986; Iben & Tutukov 1987), and the evolved CV or H star channel (Tutukov et al. 1985; Podsiadlowski et al. 2003). All channels lead to H-deficient accretion, but with considerably different configurations of the donor star.

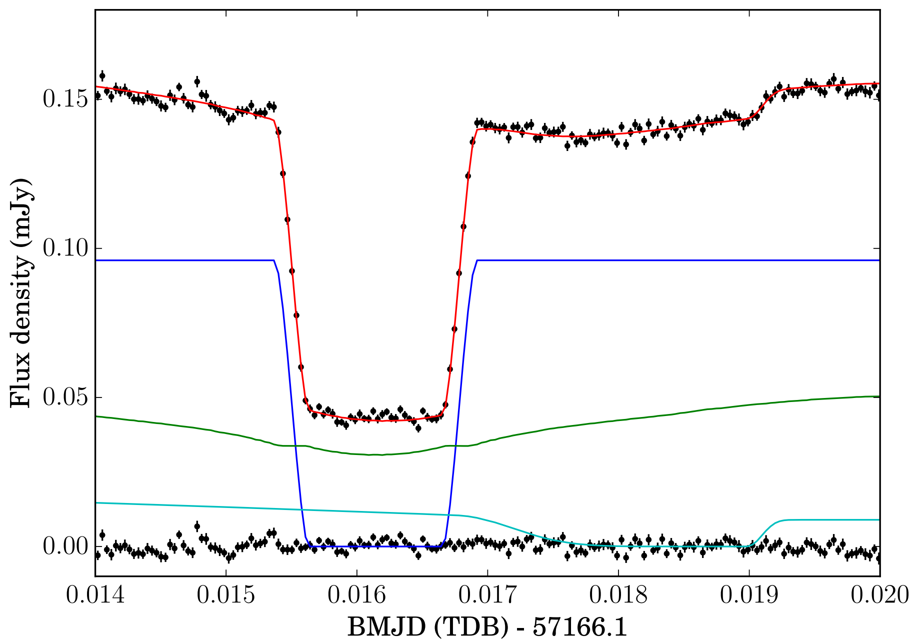

Figure 1. Phase-folded and averaged light curve of Gaia14aae *r'* data (black points), showing the eclipses of the system components by the donor. The modelled components are the white dwarf accretor (blue), the accretion disc (green) and the bright spot (cyan), with the combined model shown in red. Also shown are the residuals after subtracting the model from the data.

Both the white dwarf channel and the He star channel require two CE events, decreasing the period to shorter than that of a normal H-rich CV and reducing the total mass. In the white dwarf donor formation channel, the secondary star must evolve into a He white dwarf during the second CE stage, leaving a detached double-degenerate binary which will eventually evolve into contact through gravitational wave radiation. In the He star formation channel, the second CE instead leaves a non-degenerate donor star with a He core. In the evolved CV, or H star, channel of formation, the separation of the binary is too wide for the second common envelope phase. The binary instead evolves into a normal H-accreting CV. If the evolution is finely tuned such that the donor has a He core at the time that its H atmosphere is stripped, the CV will evolve into a long-period AM CVn. This process is expected to result in a higher percentage of atmospheric H than other processes.

Systems resulting from these three formation channels can be most easily differentiated by measuring the mass and radius of the donor star. Owing to the faintness of the donor compared to the accretor, it cannot be detected directly; instead, its mass can be inferred from the mass ratio of the donor and the accretor, $q = M_2/M_1$. Eclipse photometry has the potential to provide the most reliable estimate of q, which would come directly from orbital dynamics. However, only three eclipsing AM CVns have so far been discovered, and of these the only system in which the WD is fully eclipsed is Gaia14aae (Campbell et al. 2015), making this system ideal for parameter studies.

2. Observations

Gaia14aae has a period of 49.71 minutes, putting it at the long-period end of the AM CVn distribution. Campbell et al. (2015) measured a minimum mass ratio of 0.019 from their data, and found minimum masses for the primary and secondary of 0.78 and 0.015 $M_\odot$ respectively. To further constrain the system mass, measurements were taken using the high-speed, multi-band photometer ULTRACAM (Dhillon et al. 2007) on the 4.2m William Herschel Telescope on La Palma in January, May and June of 2015. The phase-folded average of some of these data is shown in Figure 1.

3. Results

For a Roche-lobe filling donor star eclipsing a white dwarf, there exists a relationship between the mass ratio q, the phase width of the white dwarf eclipse $\Delta\phi$, and the orbital inclination of the system i (Cook & Warner 1984; Wood et al. 1986). By measuring $\Delta\phi$ and taking $i \leq 90$ it is possible to find a lower limit on q. We refine the result of Campbell et al. (2015) by finding a new lower limit of $q \geq 0.0182$. Combining this with the minimum accretor mass $M_1 \geq 0.782\ M_\odot$ implies a new lower limit on the donor mass of $M_2 \geq 0.0142\ M_\odot$.

Even with just this lower limit we can compare Gaia14aae with donor models for the formation channels. For a system with Roche lobe-filling donor, Kepler's law combined with the Roche lobe approximation of Paczyński (1971) allows us to constrain the mean density of the donor (Faulkner et al. 1972). For several known AM CVns, lines of constant density calculated from their periods are plotted in Figure 2. The same figure also shows evolution tracks calculated by Deloye et al. (2007) for white dwarf donors in AM CVns.

Our lower limit on M_2 for Gaia14aae implies that the donor is less degenerate than models of white dwarf donors. It therefore seems unlikely that the system formed by the white dwarf donor route. Combined with the lack of visible H in the spectrum (Campbell et al. 2015) which is hard to explain by the evolved CV route, it seems most likely that this system formed by the He star evolutionary channel.

In order to measure a value for q beyond this lower limit, it is necessary to model the bright spot. Due to the tight non-linear correlation between q and i, combined with the weakness of the bright spot in this system, our models were until recently unable to converge on a consistent value of q. However, by reparametrising the model we have been able to overcome this difficulty, so will soon have an estimate of q. This will allow us to further constrain the formation channel of the system.

4. Conclusions

Gaia14aae is the first fully-eclipsing AM CVn, giving an unprecedented opportunity to directly measure a donor mass and constrain formation channel. We have found a lower limit on the donor mass, which is enough to show that Gaia14aae is less degenerate than predicted by models of the white dwarf formation channel.

Acknowledgments. MJG acknowledges funding from an STFC studentship via grant ST/N504506/1. TRM, DS and EB acknowledge STFC via grant ST/L000733/1.

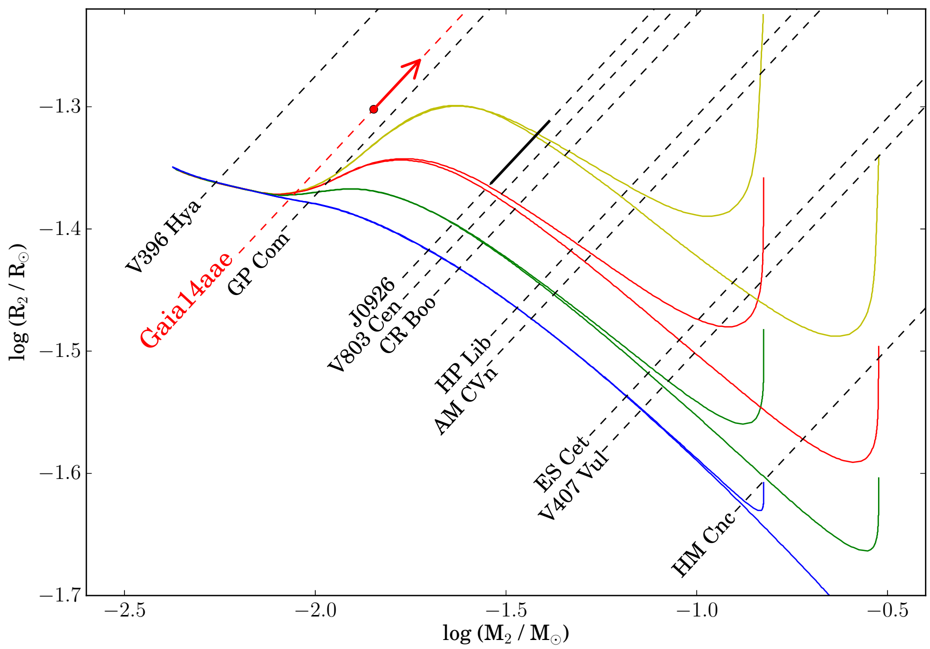

Figure 2. Lines of constant density for the donors in several AM CVns are shown as dashed lines, with a solid line showing the estimated mass range of the partially-eclipsing system SDSS J0926+3624 (Copperwheat et al. 2011). Our minimum mass for Gaia14aae is indicated by a red arrow. Also shown are models for the evolution of white dwarf secondaries with initial degeneracies of log $\psi_{c,i}$ = 3.0 (blue), 2.0 (green), 1.5 (red), and 1.1 (yellow), as derived by Deloye et al. (2007). The latter model gives the approximate boundary between degenerate and non-degenerate secondaries. This figure is based on Figure 8 from Deloye et al. (2007).

References

Bildsten, L., Shen, K. J., Weinberg, N. N., & Nelemans, G. 2007, ApJ, 662, L95
Campbell, H. C., Marsh, T. R., Fraser, M., et al. 2015, MNRAS, 452, 1060
Cook, M. C., & Warner, B. 1984, MNRAS, 207, 705
Copperwheat, C. M., Marsh, T. R., Littlefair, S. P., et al. 2011, MNRAS, 410, 1113
Deloye, C. J., Taam, R. E., Winisdoerffer, C., & Chabrier, G. 2007, MNRAS, 381, 525
Dhillon, V. S., Marsh, T. R., Stevenson, M. J., et al. 2007, MNRAS, 378, 825
Faulkner, J., Flannery, B. P., & Warner, B. 1972, ApJ, 175, L79
Iben, I., Jr., & Tutukov, A. V. 1987, ApJ, 313, 727
Nelemans, G. 2003, Classical and Quantum Gravity, 20, S81
Paczyński, B. 1967, Acta Astronomica, 17, 287
Paczyński, B. 1971, ARA&A, 9, 183
Podsiadlowski, P., Han, Z., & Rappaport, S. 2003, MNRAS, 340, 1214
Savonije, G. J., de Kool, M., & van den Heuvel, E. P. J. 1986, A&A, 155, 51
Solheim, J.-E., & Yungelson, L. R. 2005, 14th European Workshop on White Dwarfs, 334, 387
Solheim, J.-E. 2010, PASP, 122, 1133
Tutukov, A. V., Fedorova, A. V., Ergma, E. V., & Yungelson, L. R. 1985, Soviet Astronomy Letters, 11, 52
Wood, J., Horne, K., Berriman, G., et al. 1986, MNRAS, 219, 629