Eclipse comparisons of the symbiotic nova V1413 Aql from visual photometry

Gary Poyner

Visual photometry of the 2011 eclipse of the symbiotic nova V1413 Aquilae is reported, together with a 17-year lightcurve showing intrinsic variability within the system. Comparisons between eclipses in both bright and faint 'states' are made, with eclipse profiles revealing something of the physical state of the hot component. Mid-eclipse timings are studied, and an eclipse ephemeris is created from a revised period of 433.5d.

Introduction

Symbiotic stars are widely separated, long orbital period interacting binary stars consisting of a late-type giant star and a hot compact companion, usually a white dwarf. The companion accretes material from either a stellar wind from the giant star or directly from the giant star itself through roche lobe overflow. The spectrum reveals both absorption lines from late-type stars (most notably titanium oxide, TiO) and bright HI and HeI emission lines from the hot compact companion.[1] Symbiotic stars are popular with both visual and CCD amateur variable star observers, and the special characteristics of the physical makeup of the systems lead to interesting and unpredictable activity which is detectable with small to moderate-sized telescopes, and on a few occasions with binoculars. The prototype star in this class is Z Andromedae, after which the group is named. For a more detailed discussion on symbiotic stars, the reader is referred to reference 1.

V1413 Aql (also known as AS 338) was discovered in 1950 by Merrill & Burwell whilst searching objective prism plates taken by the 10-inch [25cm] telescope at Mount Wilson for objects with bright Hα lines. The spectrum revealed the symbiotic nature of the object with both emission lines and TiO lines showing strongly.[2] There is then a delay of over 30 years until the star was observed to be much brighter by R. Schulte–Ladbeck, who was carrying out a multi-filter linear polarisation survey of 16 symbiotic stars in 1983.[3] From this time V1413 Aql received much more attention.

In his study 'Symbiotic Stars (VI)',[5] U. Munari noted that a 6-year lightcurve by M. Wakuda reveals deep eclipses from which a P_{orb} of 434.1±0.2 days is derived. Munari revised Wakuda's original eclipse ephemeris to min= JD 2446650±15d. He also concluded that the outburst is due to a thermonuclear runaway, as there is no evidence for any accretion driven event as eclipse profiles do not reveal the presence of a notable accretion disc. Further evidence for this was obtained from the late-type giant star, which was not undergoing roche lobe overflow and whose spectral characteristics remained unchanged during the outburst.[4,5]

However later work by E. A. Kolotilov *et al.* suggests that the late-type giant star is roche lobe filling, and that the outbursts are driven by an unsteady disc accretion, although this model has yet to reproduce the observed broad P Cygni profile.[6] In this work the dates of minimum are revised to min(V)= JD 2448822, which relates to a difference of +2d on the previous ephemeris by Munari.

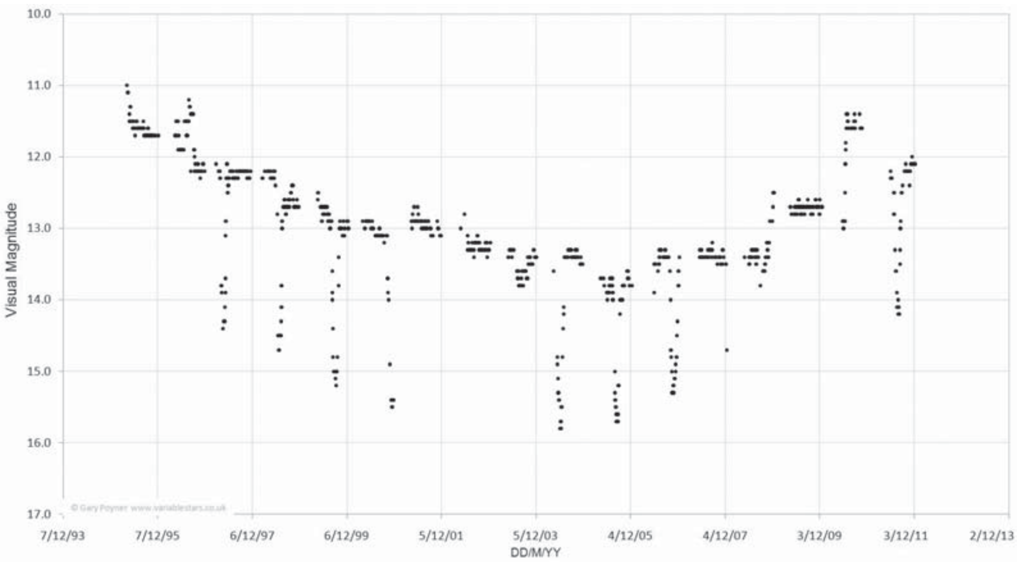

Figure 1. Lightcurve of V1413 Aql during 1994–2011 showing both intrinsic variations within the system and eclipses.

Intrinsic variations within the system have been observed by the author visually since 1994. During this time V1413 Aql has varied by ~3 magnitudes – fading from 11.0mv in 1993/94 to 14.0mv in 2005, then recovering slowly to 11.5mv in 2010 (Figure 1). If the late-type giant has not altered state over time, then any variability within the lightcurve will be due to the hot companion. With the physical diameter of the hot companion changing over time, along with the brightness of the material surrounding the whole system, the profile of the eclipse will be variable in width depending on the intrinsic brightness of the system at the time of the eclipse.[7] As the eclipses are long in duration (>50d), and deep (~2 mv), this leads to the possibility of detecting this variation in eclipse width using simple visual photometry, following established procedures used by variable star observers.

Observing the eclipses

Since visual monitoring by the author began in 1994, eight eclipses have been observed in detail. Others have been missed during late winter and early spring due to the presence of localised obstructions in and around the author's observatory. Four telescopes have been used to observe V1413 Aql during this time: a 40cm f5 Newtonian reflector, a 45cm F4.5 Newtonian reflector, a 35cm SCT and a 51cm F4 Newtonian reflector, which was used to observe the 2011 eclipse.

A selection of finder charts and comparison stars has been used, including charts and sequences drawn up by the AFOEV, Henden/Sumner/Simonsen and more recently the AAVSO. Visual observing is hampered somewhat by the presence of a 13th magnitude star some 14 arcseconds north and slightly east of the variable (Figure 2). Although this may seem to be a major obstacle when V1413 Aql is faint, visual photometry is possible to 0.1 magnitude accuracy if care is taken.

The end of the eclipse is assumed when the magnitude reaches the same level as that before the eclipse began. If any changes to the intrinsic brightness had occurred during the eclipse, this would have shown up in the lightcurve and would have been taken into consideration. However this scenario did not occur.

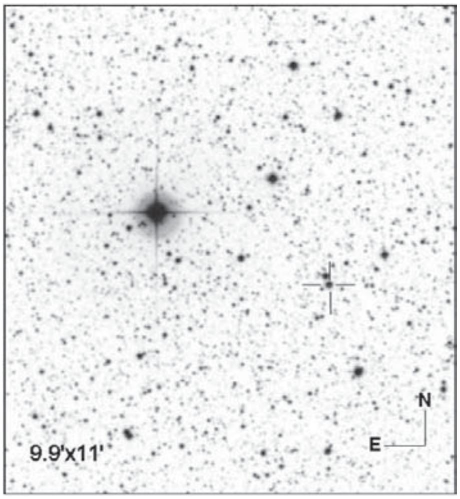

Figure 2. *Digitised Sky Survey* image of the field of V1413 Aql, showing the close 13th magnitude field star.

Comparing eclipses

For this exercise, three eclipses occurring at different levels of intrinsic brightness of the combined system were plotted and examined to see if the eclipse width variations mentioned above would show in visual photometric data. Table 1 gives details of the brightness of the system, the depth and duration of the eclipses and the durations of the decline and recovery. The terms 'high', 'middle' and 'low' have been used to describe the brightness of V1413 Aql at the time of the eclipse – high being the brightest and low the faintest.

Figure 3 shows the eclipses plotted on one graph, with 5th order polynomial curves applied as a best fit. The deepest of the three eclipses occurred in 1999, when V1413 Aql was at an intrinsic 'middle' level of brightness at 13.0mv, although the difference between this eclipse and the 2005 event, when V1413 Aql was in a 'low' state at 14.0mv, proves to be only 0.2 magnitudes, almost within the error margin for visual photometry. The 2011 eclipse however is shallower by 0.5 magnitude than in 1999. This is to be expected as the intrinsic brightness of the hot component adds to the overall brightness of the system even when in eclipse, as the surrounding environment of the binary system is illuminated by the hot component, and as this extends beyond the eclipsing source it is not affected by the eclipse.

The eclipse width is the main indicator of the physical state of the eclipsed hot component, and we can see from both Table 1 and from Figure 3 that the intrinsically brighter V1413 Aql is before eclipse, the longer the eclipse lasts – a full 21 days from low to high state. This suggests that a brighter and perhaps physically larger hot component is being eclipsed, as compared to the width of the 2005 eclipse when the system was fainter and the hot component is possibly both fainter and smaller in size. However as we have already seen, the origin of the eclipsed object remains very much a debatable subject. One can also see a very small degree of asymmetry in

Table 1. Eclipse comparisons

	1999	*2005*	*2011*
State	Middle	Low	High
Eclipse depth	2.3mv	2.1mv	1.8mv
Decline (d)	34	34	45
Recovery (d)	40	30	40
Eclipse duration (d)	74	64	85

Table 2. Eclipse ephemeris

Year	*JD*	*Calendar date*
2012	2456202.2	2012 October 01
2013	2456635.7	2013 December 09
2015	2457069.2	2015 February 15
2016	2457502.6	2016 April 24
2017	2457936.1	2017 July 01

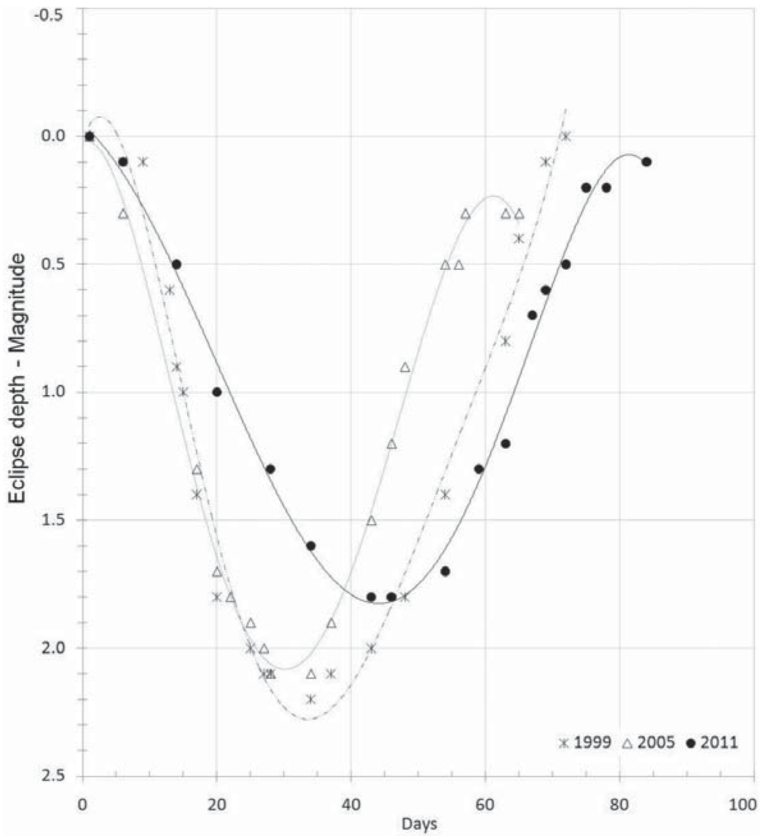

Figure 3. Eclipse profiles for 1999, 2005 & 2011.

Table 3. Mid-eclipse timings for observed eclipses shown in Figure 4

JD	*Calendar date*
2450569	1997 May 1
2451001	1998 July 7
2451430	1999 September 9
2451869	2000 November 21
2453166	2004 June 10
2453601	2005 August 18
2454038	2006 October 30
2455768	2011 July 26

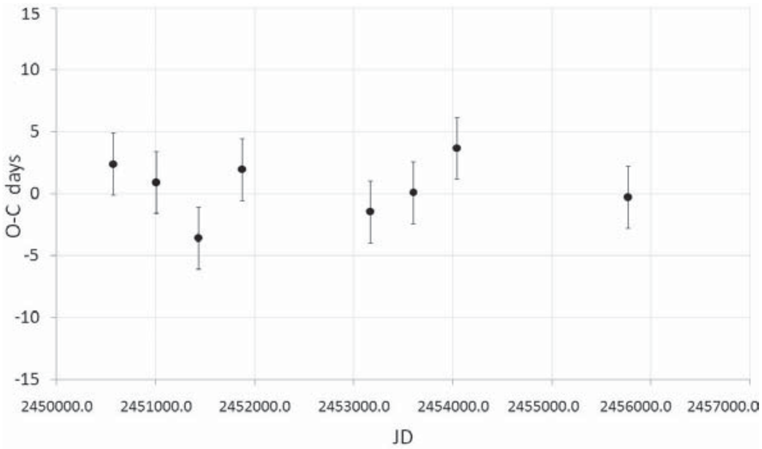

Figure 4. O–C diagram of the eclipses.

the eclipse profile, the decline being faster in the deepest eclipse of 1999 than the recovery, whilst in both 2005 and 2011 the recovery is faster. One can speculate that this may possibly relate to the size and/or brightness of the eclipsed object.

The late-type giant star is a high infrared source,[6] and it is possible that this might affect the colour perception of the eye when making magnitude estimates, as of course the giant star is the primary source of light during eclipses. However the errors will be small (~0.2mv), and have therefore been ignored, as the primary aim of this exercise is the measurement of eclipse widths.

Eclipses ephemeris

From observations presented here, mid-eclipse in 2011 was determined to have occurred on July 26 (JD 2455768). Using the eclipse ephemeris given by Munari in reference 5 and Kolotilov in reference 6, mid-eclipse was due on 2011 July 21–23. A more detailed examination of each of the mid-eclipse times shown in Figure 1 was undertaken in order to attempt to improve the existing eclipse ephemeris and period. Each eclipse (starting from 1997) was numbered consecutively and plotted against JD, resulting in a new revised mid-eclipse time for 1997 of JD 2450567.11 with a period of 433.47d. From this an O–C plot was created from observed and calculated minima using data presented here to determine the range of scatter within the period.

Figure 4 shows that the error range of ±15d given in ref. 5 has now been reduced to ±5d. New mid-eclipse timings are calculated from the revised period, and are shown for the next five eclipses in Table 2. Table 3 gives the JD for mid-eclipse timings used to produce the ephemeris in Table 2 and the O–C diagram in Figure 4.

Summary

It has been shown that from relatively basic visual photometry, details in eclipse profiles in V1413 Aquilae can be seen to vary from one eclipse to another, with variable widths and depths of eclipse as well as slightly asymmetrical decline and recovery times. This in some small way confirms our current understanding of the physical changes occurring in the eclipsed hot component within the system. By measuring the eclipse width, we can postulate the physical size of the eclipsed hot component and the surrounding environment, and by identifying the mid-time of eclipses observed since 1997, compute predictions for forthcoming eclipses from a revised period.

Acknowledgments

My thanks go to Jeremy Shears for proofreading this paper, for his advice on eclipse O–C diagrams and encouragement in general. Also to Prof Ulisse Munari for his remarks on the author's lightcurves for V1413 Aql, and for his personal correspondence on this subject. My thanks also go to the referees Dr Robert Smith and Dr Tom Lloyd–Evans, for their comments which have improved this work. The author's 0.51m telescope is part supported by a British Astronomical Association Ridley Grant. This research has made use of NASA's Astrophysical Data System and of the *Aladin Sky Atlas*.[8]

Address: 67 Ellerton Road, Kingstanding, Birmingham B44 0QE. [garypoyner@blueyonder.co.uk]

References

1 Kenyon S. J., *The Symbiotic Stars*, Cambridge University Press, 1986
2 Merrill P. W.& Burwell G. G., *ApJ* **112**, 72–89 (1950)
3 Schulte–Ladbeck R., *Messenger* **39**, 3 (1985)
4 Wakuda M., *Variable Star Bulletin* No.5, 1988 February
5 Munari U., 'Studies of Symbiotic Stars VI: The eclipsing symbiotic nova AS 338', *A&A* 257, 163–176, 1992
6 Kolotilov E. A *et al.*, 'Minimum of the lightcurve of the classical symbiotic star AS 338 in 1999', *Astronomy letters* **27**, 1, 51–57, 2001
7 Munari U., Private communication, August 2011
8 Bonnarel F. *et al.*, 'The *ALADIN* interactive sky atlas: A reference tool for identification of astronomical sources', *A&ASupp.*, **143**, 33–40, 2000

Received 2011 October 2; accepted 2012 January 25