Times of Minima for Eclipsing Binaries 2017–2020 from Stellar Skies Observatories and 2004–2009 SuperWasp Data Mining

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Abstract A total of 96 times of minima (ToMs) are reported for 68 eclipsing binary systems from our observations and 134 times of minima for 12 of these eclipsing binaries collected by SuperWasp data mining. We discuss our data mining criteria for minimum timing and remark on the value of data mining for filling in ToM histories.

1. Introduction

Prior to 2018 we compiled a number of observations of eclipsing binary minima, most taken from the AAVSO Legacy Program. We reported these data to the AAVSO, but we were interested in going a step further by compiling times of minima (ToMs) of our observations and beginning a program that concentrated on poorly observed eclipsing binaries. This paper reports the first of our combined research efforts and contains a number of eclipse timing of binary systems with few previously reported times of minima.

In addition to our own observations, we sought to increase the number of ToMs for some systems through data mining. Through the AAVSO Variable Star Index (VSX: Watson *et al.* 2006) we accessed SuperWasp data (Butters *et al.* 2010) for some poorly observed and well-observed eclipsing binaries. We developed criteria for accessing the quality of the SuperWasp data for suitability of estimating times of minima based on comparisons of previous data reported by Nelson (2020).

2. Equipment

Both observatories are part of the Stellar Skies LLC observatory consortium near Pontotoc, Texas (location: 30.98° N 98.94° W).

a. Live Oaks Observatory, Wiley (WEY). Mount: AstroPhysics Ap900 (German Equatorial). OTA: Celestron HD with focal reducer, 280 mm f/7. Detector: Moravian G21600 Mk.1 (1536 × 1024 pixels, 9-micron square pixels). Filters: B, V, I_c. Flats: Light box. Capture software: PD Capture. Field of View: 24 × 14 arcminutes.

b. Caliche Observatory, Ludington (LWHA). Mount: Bisque Paramount ME (German Equatorial). OTA: Meade SCT with focal reducer, 356 mm f/6.4. Detector: SBIG STT-1603ME (1536 × 1040 pixels; 9-micron square pixels). Filters: B, V, R_c, and I_c. Flats: Dusk Flats or Electro-luminescent Panel. Capture software: MaxIm DL Version 6. Field of View: 21.5 × 14.5 arcminutes.

3. Data reduction

We calibrated images using bias, dark, and flat frames. We performed aperture photometry using VPhot (AAVSO 2012) or LesvePhotometry (de Ponthière 2010) and data uploaded to the AAVSO International Database (AID). Times, magnitudes, and errors were saved as text and imported into Peranso 2.5 (Vanmunster 2013), where any times not already in Heliocentric Julian Dates (HJD) were converted to HJD. Minimum timing determination was performed using the Kwee-van Woerden (1956) algorithm except in a few cases where a fifth-order polynomial fit was employed as implemented in Peranso 2.5. Observed versus calculated (O–C) values were computed from light elements in Nelson (2020) who cites original sources. Times of minima and their associated errors were entered into Nelson spreadsheets (Nelson 2020) as a quality check.

To supplement our observational data, we accessed SuperWasp data through the VSX portal. We downloaded data for a number of these variables and found several where cadence and data density revealed eclipses that might be amenable to analysis. Data (HJD, magnitude, and errors) for each potential target were sorted by errors and all data with errors over 0.05 magnitude were eliminated. The data were then imported into Peranso 2.5 and visually inspected for potential minima. Each eclipse identified in the data was examined for (1) the cadence of eclipse data points, and (2) the errors associated with those data points. In short, if the eclipse appeared to be well-covered by data and the errors appeared reasonable, a ToM was calculated using the Kwee-van Woerden (1956) algorithm. This is an admittedly qualitative rather than quantitative selection criterion. Therefore, we employed an additional round of inspection using the resulting O–C calculations which, again, were based on light elements in Nelson (2020). We imported each ToM and error into Nelson spreadsheets (Nelson 2020) and examined the data relative to the least squares fit. SuperWasp ToMs exceeding the linear fits of previously reported ToMs taken from the literature were rejected. In most cases these discrepant ToMs differed from other SuperWasp ToMs taken at times close to the discrepant ToM. The reasoning for omission is that any radical difference between O–C linear fits on a short time scale was likely due to non-physical causes such as unsuitability of the eclipse for measurement. In some cases, we adjusted the cycle in order to obtain a solution that fit the existing Nelson least squares solution so as not to reject a valid ToM because the published period was old enough to cause the cycle count to be inaccurate.

4. Results and discussion

A total of 96 times of minima for 68 eclipsing binaries imaged by us is shown in Table 1. WEY and LWHA are Wiley and Ludington, respectively. Table 2 reports 134 ToMs for 12 eclipsing binaries taken from SuperWasp data ranging from May 2004 to 9 August 2009.

SuperWasp data mining has been used in adding data used in modeling binary systems (e.g., Alton 2020) and we were pleased to add data mining to our first paper reporting times of minima. We began our data mining efforts with 18 candidate systems, 12 of which contained at least two or more ToMs that met our criteria. Of the twelve systems, only two (V596 Aur, V640 Aur) had SuperWasp ToMs that did not fill a gap of at least one year with no ToM record in the Nelson spreadsheets.

5. Acknowledgements

This research makes use of a number of databases and programs of the AAVSO, Cambridge, Massachusetts, including the International Variable Star Index (VSX) database, VPhot, and WebObs. We used data from DR1 of the WASP data database (Butters *et al.* 2010) as provided by the WASP consortium and the computing and storage facilities at the CERIT Scientific Cloud, reg. no. CZ.1.05/3.2.00/08.0144, which is operated by Masaryk University, Czech Republic. We also used databases of the Centre de Données astronomiques de Strasbourg. We thank two colleagues, Kevin Alton and Gary Billings, whose informal reviews of the manuscript resulted in substantial improvements.

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Table 1. Sample of 10 times of minima for 68 eclipsing binaries.*

System	*Class*	*Filter*	*HJD (+2400000)*	*Error*	*Cycle*	*O–C*	*Observer*
RT And	EA/RS	I_c	58811.6517	0.0001	27237	0.0057	LWHA
RT And	EA/RS	V	58811.6518	0.0001	27237	0.0058	LWHA
RT And	EA/RS	V	58111.6536	0.0001	26982	–0.0116	WEY
WZ And	EB	V	58108.6774	0.0001	24777	0.0791	WEY
IO Aqr	EA	V	58315.8046	0.0002	2443	–0.0619	LWHA
IO Aqr	EA	B	58315.8056	0.0002	2443	–0.0609	LWHA
V0596 AUR	EW	V	58825.6898	0.0001	14643.5	0.1040	WEY
V640 Aur	EW	V	58825.8086	0.0002	16892	–0.0338	WEY
V0644 Aur	EA/SD	V	58225.6448	0.0001	8632	0.0004	LWHA
CV Boo	EA	V	58262.6572	0.0001	14227	–0.0109	LWHA

**Whole cycles are primary eclipses, fractional cycles are secondary eclipses. Full table available at: ftp://ftp.aavso.org/public/datasheets/WileyLudington491-Table1.txt .*

Table 2. Sample of 10 times of minima for 12 eclipsing binaries observed by SuperWasp.*

System	*Class*	*HJD (+2400000)*	*Error*	*Cycle*	*O–C*
V600 And	EW	54318.5899	0.0005	7353.5	–0.0030
V600 And	EW	54321.5664	0.0007	7361	–0.0025
V600 And	EW	54337.6377	0.0003	7401.5	–0.0013
V0644 Aur	EA/SD	54050.6263	0.0002	3282.5	–0.0008
V0644 Aur	EA/SD	54070.5276	0.0004	3308	–0.0010
V0644 Aur	EA/SD	54111.5015	0.0004	3360.5	–0.0007
V0644 Aur	EA/SD	54115.4042	0.0004	3365.5	–0.0003
V0644 Aur	EA/SD	54122.4293	0.0002	3374.5	0.0008
V0644 Aur	EA/SD	54124.3801	0.0012	3377	0.0005

**Whole cycles are primary eclipses, fractional cycles are secondary eclipses. Full table available at: ftp://ftp.aavso.org/public/datasheets/WileyLudington491-Table2.txt .*