Contrib. Astron. Obs. Skalnaté Pleso **50**, 774 – 778, (2020)
https://doi.org/10.31577/caosp.2020.50.4.774

What we can learn from eclipsing binaries in large surveys: The case of EA Catalina systems

A. Papageorgiou[1,2], **P.-E. Christopoulou**[3], **M. Catelan**[1,2], **A.J. Drake**[4] and **S.G. Djorgovski**[4]

[1] *Millennium Institute of Astrophysics, Santiago, Chile*
[2] *Pontificia Universidad Católica de Chile, Santiago, Chile*
[3] *Department of Physics, University of Patras, Greece*
[4] *California Institute of Technology, 1200 East California, USA*

Received: September 4, 2020; Accepted: September 28, 2020

Abstract. With the recent availability of large-scale multi-epoch photometric datasets, we were able to study EBs en masse. Large samples are useful to determine not only statistical properties but for finding strange and curious systems that no one had ever studied before, binaries with peculiarities that may reveal physical significance. We present an updated and more detailed catalog of 4680 Northern EAs in the Catalina Sky Survey (CSS). This work includes, new systems, revised period determination and ephemerides, system morphology classification based on machine learning techniques, computation of principal physical parameters with the EBAI (Eclipsing Binary via Artificial Intelligence) and detection of eclipse timing variations. We identify several groups of interesting systems including those with low mass K and M dwarfs, systems with longterm modulation of the maximum brightness, systems with longterm period modulation, potential triple systems and systems with magnetic activity.

Key words: large surveys – eclipsing binaries - data analysis

1. Introduction

Sky surveys represent a fundamental data basis for Eclipsing Binaries (EBs) since they can generate large, statistical samples or can be used to discover or generate samples of rare or unusual objects, and may lead to discoveries of some previously unknown types. In particular EBs with Algol type light curve (LC) morphology (EAs) provide a good chance not only to determine the fundamental physical properties of stars but also to investigate the interaction between the components, mass transfer, magnetic breaking and the presence of tertiary companions. All these processes play a significant role in the understanding of the origin, evolution and death of close binaries components. Another important feature of EA type systems is that they contain low-mass stars. We continue to exploit the northern data from Catalina Sky Surveys (CSS) spanning 12 yrs, (Drake et al., 2014) searching for and investigating the period variations among

4683 EAs. These were described recently by Papageorgiou et al. (2018), who revised the period, determined the phenomenological parameters of the LCs and classified the systems morphology into detached/semidetached subclasses based on machine-learning techniques.

From this sample Papageorgiou et al. (2019) by applying the Eclipsing Binaries via Artificial Intelligence (EBAI) Artificial Neural Network (ANN), exracted the physical parameters using for the first time two independent methods, based on the template fitting (Layden, 1998), and the Two-Gaussian Model (Mowlavi et al., 2017). The statistical properties of the physical parameter distributions of the above sample were similar to those characterizing the EB systems in the first release of the Kepler catalog of detached EBs (Prša et al., 2011) obtained by the method of neural networks and also with the catalog of parameter values for 257 detached double-lined EBs (Eker et al., 2014) obtained by the traditional method.

One of the well-known methods for the identification of period trends is based on the analysis of the eclipse timing variations (ETVs) of the binary, also called an O-C diagram.

2. Basic steps of the analysis

From the latter sample all LCs were cleaned by using a sigma clipping algorithm and the times were converted into Heliocentric Julian Date (HJD). We investigated only those systems whose LCs contain more than 400 points.

To determine times of minima (TOM) we used phase folded and binned LCs of ~ 300 d, using the initial periods from Papageorgiou et al. (2018). In the next step we formed a Gaussian template function for the primary and the secondary eclipses and searched for the best fitting parameters using the method of Nelder-Mead Downhill Simplex and a Markov Chain Monte Carlo (MCMC) procedure for the TOM error calculation.

In order to check that the above computation of ToM can emerge systems with period variations, we run successfully two tests, the first one on a synthetic detached LC generated using PHOEBE 2.0 engine (Prša et al., 2016) with a third component and the second on VY Cet, a well-known EB with period variations, using the LC from the All Sky Automated Survey (ASAS; Pojmanski et al., 2005). We run also a test on the TOM error calculation by evaluating the uncertainties from the LC phenomenological parameters given by Papageorgiou et al. (2018) and Eq. 1 of Pribulla et al. (2012) for the primary and secondary eclipses.

Only EBs with calculated ToM $\geqq 6$ minima were accepted for the O-C analysis. This selection resulted in 2604 EBs. By using the new TOM we updated the linear ephemeris for each EB and constructed the O-C diagram. These were fitted with a sinusoidal or/and a parabolic function using the Levenberg-Marquardt algorithm and the goodness of the solution was tested by applying a Bayesian Information Criterion (BIC), eliminating the number of EBs with potential period variations in 577 systems. After visual inspection, in the last stage, we accepted only sinusoidal variations with mean ToM error-to-amplitude ratio greater than 1.5 or parabolic variations with period changes greater than $10^{-10}\,\mathrm{d\,cycle}^{-1}$. Fig. 1 shows a representative example of the analysis and fitting of an EB with period variation.

3. Results

We have found 126 candidates EBs with period variations, among which we identified 63 EBs with cyclic variations and 63 EBs with more likely quadratic behavior. For the first group assuming that the period modulation is caused by a third companion, we calculated the mass function, the period and the LTTE amplitude (Irwin, 1959) assuming zero eccentricity, $i_3 = 90^\circ$ and $M_{12} \sim 2\,M_\odot$ and the parameters errors (Papageorgiou & Christopoulou, 2015). In addition, out of these 12 are low-mass candidates (Papageorgiou et al., 2018) and have their initial parameters derived by EBAI or the template method (Papageorgiou et al., 2019) whereas only four have already shown trends of maximum brightness modulation (Papageorgiou et al., 2018).

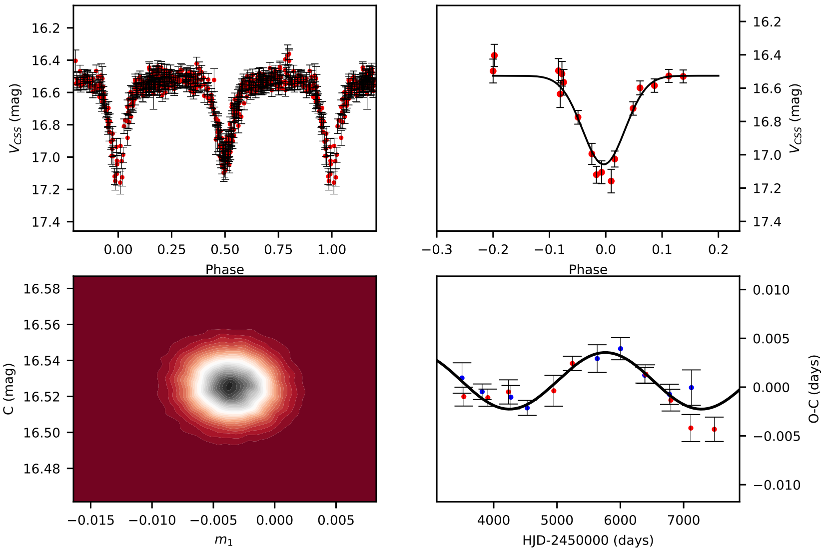

Figure 1. Representative example of the O-C analysis and the fitting prodedure. The folded LC (upper left panel), the ToM (upper right panel), the MCMC procedure (lower left panel) and the ETV data with a sinusoidal model (lower right panel).

Acknowledgements. A.P. and M.C. gratefully acknowledge the support provided by Fondecyt through grants #3160782 and #1171273. Additional support for this project is provided by the Ministry for the Economy, Development, and Tourism's Millennium Science Initiative through grant IC 120009, awarded to the Millennium Institute of Astrophysics (MAS); and by Proyecto Basal AFB-170002.

References

Drake, A. J., Graham, M. J., Djorgovski, S. G., et al., The Catalina Surveys Periodic Variable Star Catalog. 2014, *Astrophysical Journal, Supplement*, **213**, 9, DOI: 10.1088/0067-0049/213/1/9

Eker, Z., Bilir, S., Soydugan, F., et al., The Catalogue of Stellar Parameters from the Detached Double-Lined Eclipsing Binaries in the Milky Way. 2014, *Publications of the Astronomical Society of Australia*, **31**, e024, DOI: 10.1017/pasa.2014.17

Irwin, J. B., Standard light-time curves. 1959, *Astronomical Journal*, **64**, 149, DOI: 10.1086/107913

Layden, A. C., RR Lyrae Variables in the Inner Halo. I. Photometry. 1998, *Astronomical Journal*, **115**, 193, DOI: 10.1086/300195

Mowlavi, N., Lecoeur-Taïbi, I., Holl, B., et al., Gaia eclipsing binary and multiple systems. Two-Gaussian models applied to OGLE-III eclipsing binary light curves in the Large Magellanic Cloud. 2017, *Astronomy and Astrophysics*, **606**, A92, DOI: 10.1051/0004-6361/201730613

Papageorgiou, A., Catelan, M., Christopoulou, P.-E., Drake, A. J., & Djorgovski, S. G., An Updated Catalog of 4680 Northern Eclipsing Binaries with Algol-type Light-curve Morphology in the Catalina Sky Surveys. 2018, *Astrophysical Journal, Supplement*, **238**, 4, DOI: 10.3847/1538-4365/aad8a9

Papageorgiou, A., Catelan, M., Christopoulou, P.-E., Drake, A. J., & Djorgovski, S. G., Physical Parameters of Northern Eclipsing Binaries in the Catalina Sky Survey. 2019, *Astrophysical Journal, Supplement*, **242**, 6, DOI: 10.3847/1538-4365/ab13b8

Papageorgiou, A. & Christopoulou, P. E., Absolute Parameters and Physical Nature of the Low-amplitude Contact Binary HI Draconis. 2015, *Astronomical Journal*, **149**, 168, DOI: 10.1088/0004-6256/149/5/168

Pojmanski, G., Pilecki, B., & Szczygiel, D., The All Sky Automated Survey. Catalog of Variable Stars. V. Declinations 0 arcd - +28 arcd of the Northern Hemisphere. 2005, *Acta Astron.*, **55**, 275

Pribulla, T., Vaňko, M., Ammler-von Eiff, M., et al., The Dwarf project: Eclipsing binaries - precise clocks to discover exoplanets. 2012, *Astronomische Nachrichten*, **333**, 754, DOI: 10.1002/asna.201211722

Prša, A., Batalha, N., Slawson, R. W., et al., Kepler Eclipsing Binary Stars. I. Catalog and Principal Characterization of 1879 Eclipsing Binaries in the First Data Release. 2011, *Astronomical Journal*, **141**, 83, DOI: 10.1088/0004-6256/141/3/83

Prša, A., Conroy, K. E., Horvat, M., et al., Physics Of Eclipsing Binaries. II. Toward the Increased Model Fidelity. 2016, *Astrophysical Journal, Supplement*, **227**, 29, DOI: 10.3847/1538-4365/227/2/29