Contrib. Astron. Obs. Skalnaté Pleso **43**, 422 – 424, (2014)

Solution of basic tasks in eclipsing binary period analysis by genetic and LSM algorithms

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Received: October 31, 2013; Accepted: January 14, 2014

Abstract. A period analysis of eclipsing binaries can be performed effectively when using fine-tuned phenomenological models. The combination of a regression analysis and genetic algorithms is a powerful tool for such astrophysical tasks as light curve analysis, mid-eclipse time determination and O-C diagram investigation – even the apsidal motion and the light time effect can be resolved.

Key words: period analysis – binaries – regression – genetic algorithms – light curve – mid-eclipse time – O-C diagram – apsidal motion – LiTE

1. Introduction

Small telescopes are often used for photometric study of variable stars. A large number of observers, especially amateurs, obtain a huge amount of valuable data for a very long time. Times of minima (ToF) and phased light curves became the basic tools in effort to analyse the observations, find the variability reasons and determine the stellar parameters. For this purpose, several methods were developed, probably the most used is the method of Kwee & van Woerden (1956). However, no trends during night can be accounted for, as well as direct finding of a single ToF from a multicolor observation is not possible. Physical models such as JKTEBOP (Southworth 2012) or Wilson-Deviney (Wilson & Devinney 1971) codes are used to determine stellar parameters. However, they depend on a lot of unknown physical parameters. Finding the best fit usually requires iterative probing free parameters, fixating some of them and making estimations by eye. This procedure takes time and makes it unefficient.

We found that basic astrophysical tasks can be solved using the regression analysis and genetic algorithms. A well-known way to fit data to a model is by using the least squares method (LSM). It provides correct estimate of errors, however, the most astrophysical models are non-linear. The optimization problem to locate a global minimum can be solved by genetic algorithms (Obitko 1998). We still work on the method, thus explanation in more details will be published in future. In this paper we present just some preliminary results showing that the method is very promising.

2. Examples of some results

Figure 1 shows an example of mid-eclipse time determination from multicolor data. The method expects that we have color light curves with an observation of single minimum. A model function consists of a few parameters: the width, depth and sharpness of minimum, ToF and mean magnitude of an observation. Great advantage of LSM is the feature that allow process all data at the same time, so the depth and the mean magnitude are determined as free parameters for individual filters, while the remaining of paramaters are calculated to have one common value for all filters.

We tested our model function for the case of AR Aur and compared it with some published models. A synthetic V-light curve of the primary eclipse was taken and the best fit for each model function was found. Table 1 contains "scatter" s of individual fits, which is a relative error expressed in percents of the maximum depth of the primary eclipse (0.656 mag).

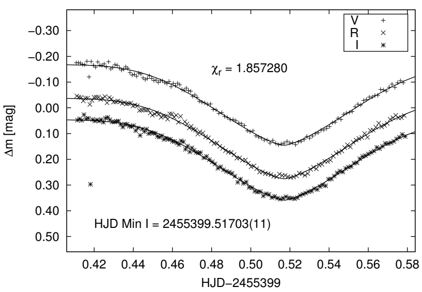

Figure 1. Single mid-eclipse time determination from a multicolor observation of V859 Cyg.

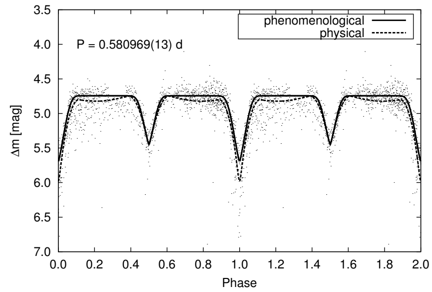

Figure 2. Comparison of the phenomenological and physical model of a USNO-B1.0 1437-0410375 light curve in R.

Table 1. Comparison of phenomenological eclipse models of AR Aur

model	s	source
$1 - \{1 - \exp\left[1 - \cosh\left(\varphi/d\right)\right]\}^{\gamma}$	0.7	this paper
$\mathrm{Real}\left(1 - \lvert\varphi/d\rvert^{\beta}\right)^{3/2}$	1.1	Andronov (2012)
$1 - \left\{1 - \exp\left[-0.5\left(\varphi/d\right)^{2}\right]\right\}^{\gamma}$	1.3	Zhu et al. (2012)
$\exp\left[-0.5\left(\varphi/d\right)^{2}\right]$	1.8	Mikulášek (2012)
$0.5\left(1 - \lvert\varphi/d\rvert + \lvert\lvert\varphi/d\rvert - 1\rvert\right)$	2.5	"triangle"

Comparison of the phenomenological and physical model is demonstrated on our discovered variable star USNO-B1.0 1437-0410375. Both models are plotted in Figure 2 for a light curve in R. We can also compare both modeling approaches via determined parameters. As we know the eclipse depth ratio is proportional to the surface brightness ratio. Our phenomenological model gives the eclipse depth ratios in individual filters: V = 0.68(4), R = 0.74(4), I = 0.62(3) and the physical model JKTEBOP gives the brightness ratios in individual filters: V = 0.55(6), R = 0.58(7), I = 0.48(6). For example R/V for the eclipse depth ratios is 1.09(9) and for the brightness ratios is 1.05(17). This shows that an appropriately chosen phenomenological model leads to results comparable to those given by physical models.

A regression analysis and genetic algorithms allows us to resolve even the light time effect (LiTE) and apsidal motion. Figure 3 shows us O-C diagram and a solution obtained using our approach. A LiTE time shift given by Irwin (1959), second Kepler's law and implicit Kepler's equation can be combined to obtain a model function for fitting of the O-C diagram (Mikulášek 2014). Lacy (1992) shows a direct solution of the apsidal motion and its implementation to our method is in preparation. For now, we use an approach described by Giménez & Bastero (1995) and the result for CO Lac is shown in Figure 4.

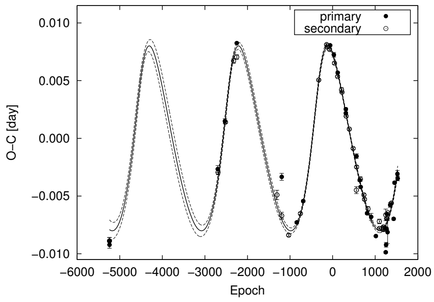

Figure 3. An O-C diagram of AR Aur and a solution of the light time effect.

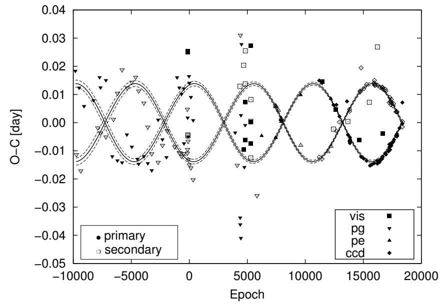

Figure 4. An O-C diagram of CO Lac and a solution of apsidal motion.

Acknowledgements. Research was supported by the Ministry of Education, Youth and Sports of the Czech Republic projects 7AMB13PL019, 7AMB12AT003 and LH12175.

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