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Participants of the conference

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INTRODUCTION

In November 2015, the Variable Star and Exoplanet Section of Czech Astronomical Society organized traditional autumn conference on research and news in the field of variable stars.

The conference was held in a comfortable spaces of Ostrava Planetarium. In addition to the many contributions that were presented on site, we had the opportunity to hear lectures of invited speakers from abroad via Internet transmission. All presented contributions can be viewed on our YouTube channel.

I would like to thank all conference participants, and all speakers for their presented contributions. I also would like to thank the Director of Ostrava Planetarium Mrs. Markova and her colleagues for providing venues for conferences and helpfulness to our needs.

Ladislav Šmelcer
president of Variable Star and Exoplanet
Section of Czech Astronomical Society
Valašské Meziříčí, January 2016

NOTES

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RR Lyrae stars in eclipsing systems – historical candidates

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Abstract: Discovery of binary systems among RR Lyrae stars belongs to challenges of present astronomy. So far, none of classical RR Lyrae stars was clearly confirmed that it is a part of an eclipsing system. For this reason we studied two RR Lyrae stars, VX Her and RW Ari, in which changes assigned to eclipses were detected in sixties and seventies of the 20th century. In this paper our preliminary results based on analysis of new photometric measurements are presented as well as the results from the detailed analysis of original measurements. A new possible eclipsing system, RZ Cet was identified in the archive data. Our analysis rather indicates errors in measurements and reductions of the old data than real changes for all three stars.

Abstrakt: Objevení dvojhvězd mezi RR Lyrae hvězdami patří k výzvám současné astronomie. Zatím u žádné klasické RR Lyrae hvězdy nebylo prokazatelně potvrzeno, že je součástí zákrytového systému. Studovali jsme proto dvě RR Lyrae hvězdy, VX Her a RW Ari, u kterých byly v 60. a 70. letech 20. století detekovány změny přisouzené zákrytům. V tomto příspěvku jsou prezentovány předběžné výsledky založené na nových fotometrických měřeních a výsledky z detailního rozboru původních měření. V archivních datech se podařilo objevit nový možný zákrytový systém RZ Cet. Naše analýza poukazuje spíše na chyby při měření a zpracování u starších dat, než na reálné změny u všech tří hvězd.

Introduction

Detection of eclipsing binary (EB) systems with RR Lyrae component has the highest priority in the beginning of the 21st century. According to the literature and new database of candidates for RR Lyrae stars in binary systems (RRLyrBinCan, Liška et al., 2015, Liška & Skarka, 2016) several EB candidates were identified in the past. Many of known candidates were discovered accidentally in photometric data as strange drop(s) in the light curve – VX Her (Fitch et al., 1966), RW Ari (Wiśniewski, 1971), V80 in Ursae Minor Dwarf galaxy (Kholopov, 1971), and RZ Cet (Liška, 2015).

Systematic search for this kind of EB systems is still limited. Richmond (2011), who analysed data for RR Lyrae stars from MACHO database (more than three thousand objects), did not succeed. On the other hand, research based on similar data quality from OGLE project, gave promising results. Soszyński et al. (2003) found 3 variable stars in the Large Magellanic Cloud (LMC), which show pulsating and eclipsing behaviour. Unfortunately, these stars were probably only blends of EB system with RR Lyrae star (Soszyński et al., 2003, Prša et al., 2008). Soszyński et al. (2009) found another object in LMC OGLE-LMC-03541, which could also be blend. Soszyński et al. (2011) detected brightness drops in light curves of three RR Lyrae stars from the Galactic Bulge, which could be eclipses, but expected orbital periods are unknown. They also revealed the best studied candidate, OGLE-BLG-02792, which, unfortunately, does not contain a classical RR Lyrae component. This star became a prototype of a new class of pulsating stars – Binary Evolutionary Pulsators (Pietrzyński et al., 2012, Smolec et al., 2013).

The number of candidates is still very low regarding tens of thousands known RR Lyrae stars. Therefore, search for new objects and confirmation of all known candidates is very desirable. In this study we present an investigation of measurements of the EB candidates, which were revealed on the historical photometric data (VX Her, RW Ari, RZ Cet), because detailed analysis of these objects is missing.

Observations and analysis

We used original photoelectric *UBV* measurements for VX Her from Fitch et al. (1966) and for RW Ari and RZ Cet from Bookmeyer et al. (1977). In addition, we used data from ASAS-3 database (Pojmanski, 2002) for VX Her and RZ Cet. In RZ Cet also data from Sturch (1966) and Epstein (1969) was investigated. To complete available data we obtained new CCD observations of RW Ari and VX Her at Masaryk University Observatory (MUO) and Brno Observatory and Planetarium, both in Brno, Czech Republic. Old photoelectric data was compared with the newest CCD measurements. Phased light curves were reconstructed for all stars and phase shifts caused by period changes were reduced. More details are in Liška et al. (2015), or will be present in forthcoming paper.

VX Her

Variability of VX Her was discovered by Raymond (see Campbell & Pickering, 1917) based on photographic measurements, who determined pulsation period of 0.365 d, which is 1-day alias of the correct period. The period was refined by Esch (1918) to 0.456 d.

Fitch et al. (1966) obtained photoelectric photometry in *UBV* filters for VX Her in 5 nights. The brightness of the star was anomalous in one of their observing nights. It was about 0.7 mag fainter (in *V*-band) than in normal minimum and its brightness was almost constant. They proposed eclipsing binary hypothesis for explanation of the observed brightness depression. Their study is probable the first publication in history, where eclipsing behaviour among RR Lyrae stars is mentioned. It is quite surprising that for a long time no other study was focused on binarity of VX Her. Until now, probably only Perry et al. (2015) tried to detect eclipses in a systematic way, but their dataset is not sufficiently homogeneous and extensive. Our attempt to test binary hypothesis using analysis of *O–C* diagram is described in Liška et al. (2015).

For this study we performed detailed analysis of data from Fitch et al. (1966) and compared it with our results based on MUO and ASAS-3 (*V*-band) data. We found that in the strange night (JD 2439217) the star had constant brightness despite the fact, that its brightness should increase towards maximum (Fig. 1, the left panel). Colour changes differ of about 0.1 mag in *B–V* and *U–B* than in normal nights (Fig. 1, the right panel). It can correspond to different colour of the secondary component, if the binary hypothesis is valid. Nevertheless, these distinctions can be explained also by fault identification of measured star in the night JD 2439217. For example, there are 3 stars in a close vicinity of VX Her (closer than 15‘), which have similar brightness and colour indices (see Table 1). The most similar is TYC 1510-155-1. In addition, our photometric data shows no variation larger than 0.02 mag.

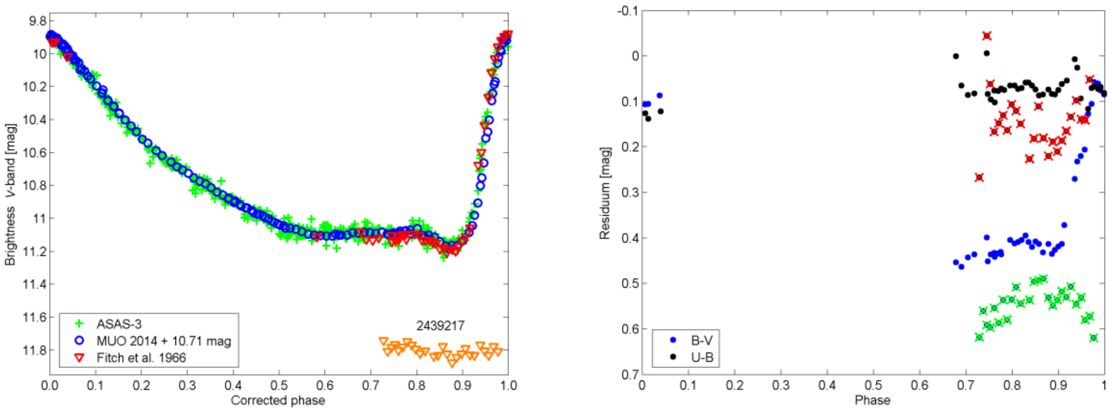

Figure 1: The light curve of VX Her in *V*-band from Fitch et al. (1966), ASAS-3 database and our observations phased with pulsation period (the left panel). Variations in colours in observations from Fitch et al. (1966) – green and red crosses mark *B–V* and *U–B* indices from the night JD 2439217.

Table 1. Stars in the vicinity of VX Her (up to 15‘) with similar brightness as VX Her (in JD 2439217). Coordinates and magnitudes were taken from Simbad database (Wenger et al. 2000).

Star	Angular distance [‘]	RA [h m s]	DEC [° ‘ “]	*V* [mag]	*B* [mag]
TYC 1510-149-1	3.2	16 30 27.66	+18 22 46.7	11.74(13)	12.65(21)
TYC 1510-36-1	7.8	16 30 20.51	+18 28 09.2	11.93(15)	12.13(12)
TYC 1510-155-1	11.2	16 30 05.56	+18 29 29.9	11.82(13)	12.31(15)
VX Her (JD 2439217)	–	16 30 40.80	+18 22 00.5	11.80(3)	12.35(3)

RW Ari

RRc type star RW Ari has a similar history like VX Her. Detre (1937) found its variability on photographic plates and established incorrect period of 0.2614151 d (1-day alias). Notni (1962) determined correct value of 0.3543184 d.

For our goal, the most important study is the paper by Wiśniewski (1971), who obtained observations of RW Ari in 19 nights (measurements were published later in Bookmeyer et al. 1977). Behaviour of the star was anomalous in three nights, in JD 2439384 and 2439505 it was fainter of about 0.6 mag (in *V*-band), and in 2439411 only of about 0.1 mag than in normal state. He proposed, that the variation is caused by eclipses by another object in the system, and the deeper and shallower drops are primary and secondary minima, respectively. He estimated the orbital period as 3.1754 d. According to the colour changes during primary eclipse (in JD 2439384 *B*–*V* was growing with decreasing *V*-brightness), Wiśniewski estimated that the secondary component is bluer and hotter than RW Ari.

Several authors tried to confirm EB hypothesis of RW Ari. Woodward (1972) and Sidorov (1978) independently found brightness depression of about 0.2 mag in one night in photographic data from Detre (1937). On the other hand, Penston (1972), Edwards (1978), Goranskij & Shugarov (1979) detected nothing unusual in their new observations and their results do not support the binarity of RW Ari. Another strange finding comes from Dahm (1992) and his new analysis of data from Wiśniewski (published in Bookmeyer et al. 1977). Dahm found more atypical variations in another three nights (depressions and extreme brightening, see his Figs. 1 and 2 or our Fig. 2). Dahm determined different value of the orbital period (4.639094 d) based on the data.

Our analysis shows that measurements of RW Ari in Bookmeyer (1977) were mistakenly mixed with the data of UU Boo (see Fig. 2). Dahm (1992) did not notice the problem and thus he came to meaningless results.

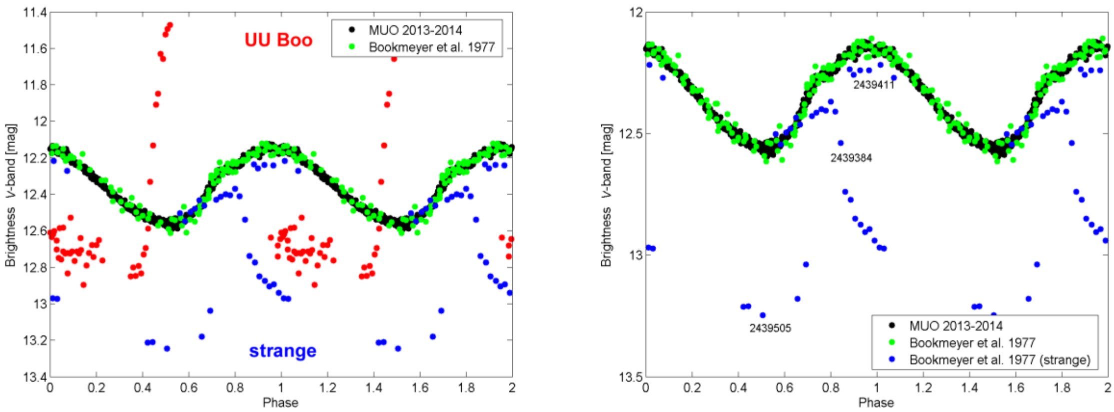

Figure 2: The light curve of RW Ari in *V*-band from Bookmeyer et al. (1977) and our observation at MUO phased with the pulsation period, the red part of the curve belongs to UU Boo (the left panel). The light curve is similar like the curve in Dahm (1992). After the selection of data only for RW Ari the light curve is the same as obtained by Wiśniewski (1971).

We reconstructed the variations in RW Ari with subtracted pulsations similarly as Wiśniewski (1971) performed. We found that changes were different in *B* and *U* than for *V*-band. In the night JD 2439384 brightness was decreased in all filters (up to 0.6 mag), but in JD 2439505 the star was fainter of about 0.6 mag in *V*-band and in *U* and *B*-bands RW Ari was even brighter than usually was (see Fig. 3). This strange behaviour indicates some observational problem, not the real changes. Therefore, results from Wiśniewski (1971) should be accepted with attention.

Preliminary analysis of our data (Hájková 2015) brings information about phase variations and possible modulation which was already expected by Edwards (1978). No sign of eclipse with amplitude larger than 0.04 mag was detected.

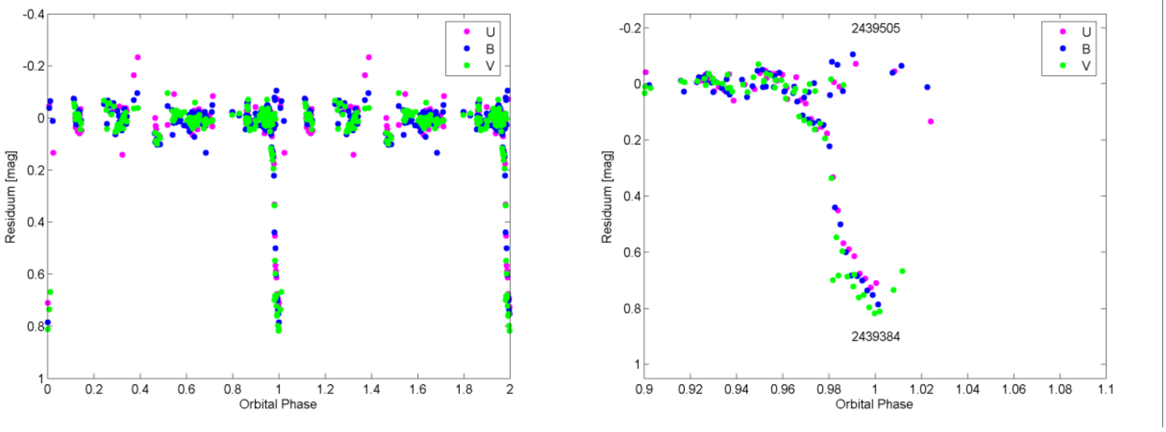

Figure 3: The light curve of RW Ari in *UBV*-bands from Bookmeyer et al. (1977) after subtraction of mean pulsation changes and phased with orbital period of 3.1754 d (the left panel). The detail of the primary minimum in the right panel shows completely different behaviour in *U* and *B* filters in the night JD 2439505.

RZ Cet

Variability of RZ Cet was found by Hoffmeister (1929) on photographic plates. Later Zessewitsch (1932) determined pulsation period as 0.5105 d. Binarity of RZ Cet was discussed by Le Borgne et al. (2007) and Liška et al. (2015) on the basis of variation in *O–C* diagram.

Photometric data from 7 nights for the star is available also in Bookmeyer et al. (1977). Data from one of their nights (JD 2439746) is anomalous as was firstly mentioned in Liška (2015). The brightness of the star is of about 0.4 mag lower in *V*-band than usually is (Fig. 4, the left panel). This could be explained by eclipse. In this case the colour of the star during the eclipse is the same as in the normal nights (Fig. 4, the right panel). There are also some discrepancies in Bookmeyer et al. (1977) and ASAS-3 data in phases 0.7 – 1.0 which could be related to the Blazhko effect. The possible modulation in RZ Cet was already mentioned in Kovács (2005) without its period determination.

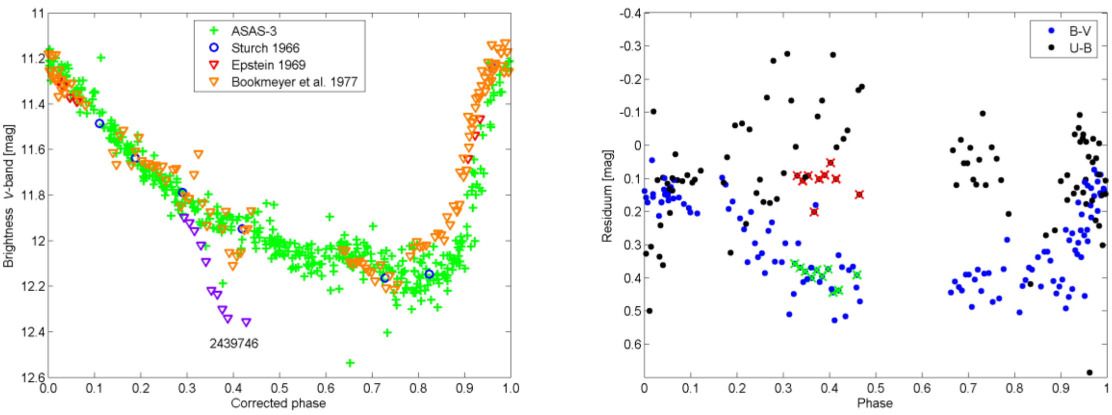

Figure 4: The light curve of RZ Cet in *V*-band from Bookmeyer et al. (1977), Sturch (1966), Epstein (1969), and ASAS-3 database phased with pulsation period (the left panel). Variations in colours in observations from Bookmeyer et al. (1977) – green and red crosses mark *B–V* and *U–B* indices from the night JD 2439746 (the right panel).

Conclusions

We present analysis of VX Her and RW Ari, the historical candidates for EB systems with RR Lyrae component. New photometric data was obtained for both stars. We identified another possible EB system, RZ Cet.

Our study brings some interesting findings. Brightness dips for all three stars were recorded by the same observing group in which Wiśniewski was a member (publications by Fitch et al. 1966, Wiśniewski 1971, Bookmeyer et al. 1977). The photometric measurements were obtained by a single-channel photometer in *UBV* filters in Arizona (Catalina observing stations of LPL). The observing strategy was the same for all three stars – no comparison star was used. Observers used only standard stars from the list Johnson & Harris (1954). Unfortunately, most of the 108 standard stars are included in the International Variable Star Index with note “suspected from variability”. For example one extreme variable “standard” star is a Be star V1294 Aql ($\Delta V \sim 1$ mag). For this reason, the brightness drops could be also caused by variability of the used “standard” stars.

The brightness dips were detected in a very short interval from April 1966 (VX Her) to September 1967 (RZ Cet). It is very improbable that all three RR Lyrae stars are EBs, because the group observed only about 200 RR Lyrae stars. High amplitudes of "eclipses" are also highly improbable (VX Her – 0.7 mag, RW Ari – 2 times 0.6 and 0.1 mag, RZ Cet – 0.4 mag). In addition colour variations during "eclipses" in VX Her and RW Ari differ significantly, in RZ Cet the colour is normal. Proper confirmation of eclipses for all mentioned stars was not performed yet. Our observations also contain no sign of eclipses.

We will present a detailed analysis of the VX Her, RW Ari and RZ Cet data in our forthcoming paper(s).

Acknowledgement

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References

Bookmeyer, B. B., Fitch, W. S., Lee, T. A., et al. 1977, Rev. Mexicana Astron. Astrofis., 2, 235

Campbell, L., & Pickering, E. C. 1917, Harvard College Observatory Circular, 201, 1

Dahm, M. 1992, BAV Rundbrief, 41, 62

Detre, L. 1937, Astronomische Nachrichten, 262, 81

Edwards, D. A. 1978, A photometric investigation of the variable RW Arietis, master thesis, University of Texas, Austin, USA

Epstein, I. 1969, AJ, 74, 1131

Esch, M. 1918, Astronomische Nachrichten, 208, 9

Fitch, W. S., Wiśniewski, W. Z., & Johnson, H. L. 1966, Communications of the Lunar and Planetary Laboratory, 5, 3

Goranskij, V. P., & Shugarov, S. Y. 1979, Peremennye Zvezdy, 21, 211

Hájková, P., 2015, Fotometrická měření pulzující proměnné hvězdy RW Arietis, Středoškolská odborná činnost (High school scientific activity), Gymnázium Brno-Řečkovice, Brno, Czech Republic

Hoffmeister, C. 1929, Astronomische Nachrichten, 236, 233

Johnson, H. L., & Harris, D. L. 1954, ApJ, 120, 196

Kholopov, P. N. 1971, Peremennye Zvezdy, 18, 117

Kovács, G. 2005, A&A, 438, 227

Le Borgne, J. F., Paschke, A., Vandenbroere, J., et al. 2007, A&A, 476, 307

Liška, J., Skarka, M., Zejda, M., & Mikulášek, Z. 2015, arXiv:1504.05246

Liška, J. 2015, Changes of orbital periods in binary systems, PhD thesis, DTPA, Masaryk University, Brno, Czech Republic

Liška, J. & Skarka, M. 2016, in Proceedings of High-Precision Studies of RR Lyrae Stars, Information Bulletin on Variable Stars, in prep.

Notni, P. 1962, Mitteilungen über Veränderliche Sterne, 1, 667

Penston, M. J. 1972, MNRAS, 156, 103

Perry, K., Castelaz, M., Henson, G., & Boghozian, A. 2015, American Astronomical Society Meeting Abstracts, 225, 343.02

Pietrzyński, G., Thompson, I. B., Gieren, W., et al. 2012, Nature, 484, 75

Pojmanski, G. 2002, Acta Astronomica, 52, 397

Prša, A., Guinan, E. F., Devinney, E. J., & Engle, S. G. 2008, A&A, 489, 1209

Richmond, M. W. 2011, Journal of the American Association of Variable Star Observers (JAAVSO), 39, 201

Sidorov, K. A. 1978, Peremennye Zvezdy, 20, 557

Smolec, R., Pietrzyński, G., Graczyk, D., et al. 2013, MNRAS, 428, 3034

Soszyński, I., Udalski, A., Szymanski, M., et al. 2003, Acta Astronomica, 53, 93

Soszyński, I., Udalski, A., Szymański, M. K., et al. 2009, Acta Astronomica, 59, 1

Soszyński, I., Dziembowski, W. A., Udalski, A., et al. 2011, Acta Astronomica, 61, 1

Sturch, C. 1966, ApJ, 143, 774

Wenger, M., Ochsenbein, F., Egret, D., et al. 2000, A&AS, 143, 9

Wiśniewski, W. Z. 1971, Acta Astron., 21, 307

Woodward, E. J. 1972, Journal of the American Association of Variable Star Observers (JAAVSO), 1, 68

Zessewitsch, W. 1932, Leningr. Eph., 2, 24

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PHOEBE – step by step manual

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Abstract: An easy step-by-step manual of PHOEBE is presented. It should serve as a starting point for the first-time users of PHOEBE analyzing the eclipsing binary light curve. It is demonstrated on one particular detached system also with the downloadable data and the whole procedure is described easily till the final trustworthy fit is being reached.

Abstrakt: Jednoduchý manuál pro prvouživatele programu PHOEBE. Může sloužit jako jakýsi startovací bod pro toho, kdo chce analyzovat světelnou křivku zákrytové dvojhvězdy. Jako příklad je ukázána analýza jednoho konkrétního odděleného systému včetně stáhnutelných dat a celý process je popsán až do dosažení konečného důvěryhodného fitu.

Introduction - PHOEBE

PHOEBE (PHysics Of Eclipsing BinariEs) is the program used for modelling the light curves of the eclipsing binaries and the radial velocity curves. Its computing core is based on modelling the Roche geometry using the Wilson-Devinney (1971) algorithm and its recent modifications. It is being developed more than 14 years by the team around Andrej Prša (see e.g. Prša & Zwitter 2005). Its recent updates and new versions incorporate much more physics and effects than the original one and are still in development.

The most updated version of the code can be downloaded from the websites of the project.[1]

The authors provide some stable versions for the various platforms (Linux, Windows, Mac), while there are also some development versions and one can easily joint the development team helping to build a new stable version.

Here for the purpose of this manual we decided to use a slightly older version from 2012, which can be downloaded from our website.[2]

While the data for modeling can be downloaded via this link.[3]

We decided to present a step-by-step manual how to use the PHOEBE code on quite simple example of the light curve for one detached eclipsing binary located in the Large Magellanic Cloud from the OGLE (Graczyk et al. 2011) database. This is due to the fact that the detached binaries are relatively the easiest for modelling, the light curve is well-covered in time and also symmetric.

Using this manual one should be able to use the PHOEBE for modelling the eclipsing binary, at least some "easy" one. If one has the reliable photometric data and knows the orbital elements for the binary, it should be an easy task to follow the step-by-step instructions below and obtain the final trustworthy fit to the data. The whole manual is divided into several sections, following the procedure of the analysis.

Step 1: Preparing the data

The data acquisition is the very first task to do, however we believe that the user already has the photometric data for the particular system. It is recommended to have the data as precise as possible, covering several orbital cycles of the system. What is also recommended is to have the data transformed into the standard system that one is able to compare the magnitudes with some other photometry. However, PHOEBE is also able to model the system having only the relative magnitudes (differential magnitudes to some comparison star), but one cannot obtain some results on the physical characteristics of the components. Generally, we can say that even the differential magnitudes can.

[1] http://phoebe-project.org/
[2] http://sirrah.troja.mff.cuni.cz/~zasche/phoebe.zip
[3] http://sirrah.troja.mff.cuni.cz/~zasche/OGLE_10220.dat

The photometric data should be stored in a separate file with two or three columns. No header is needed. In these columns there should be the Julian Date (heliocentric, in the first column), the magnitude (absolute or relative) in the second column. The third column with the error (uncertainty or weight) is not obligatory. All the numbers should use decimal point (not comma).

What is also needed is the linear ephemerides of the binary. At least the orbital period is needed, the initial HJD_0 can be estimated in the program shifting the light curve in the x-axis. The PHOEBE code is not the tool for deriving the orbital period! If one has the data acquired over many orbital cycles of the binary, it is much better case and the results can be much more significant.

Step 2: Starting the program

If we have the data and the ephemerides of the binary, we can now proceed to the program PHOEBE itself. Installing the PHOEBE on Windows computer usually does not bring any problems. Running the program and skipping the first welcome screen one has to set some parameters before the start of modelling. At first all paths to the particular directories has to be set. This can be done also later by clicking on Settings-Preferences. It is advisable to leave almost all of the directories on the default values. Working directory should be the "Temp", while the data directory can be left to the default one (data subdirectory in the PHOEBE directory), or can be changed to some your data directory, where you have stored all of your relevant files. The limb darkening tables should be set to the PHOEBE tables located in the "*ld*" subdirectory. In the "options" tab there can also be changed the units of angles (degrees or radians).

The whole work with PHOEBE is very easy and relatively intuitive. We start with the default values of parameters and mostly clear spaces in the first window. There are four different tabs (Data – Parameters – Fitting – Plotting) in the upper "Tab1", see figure 1 below. Clicking on these four tabs one can switch between the different modes of the program.

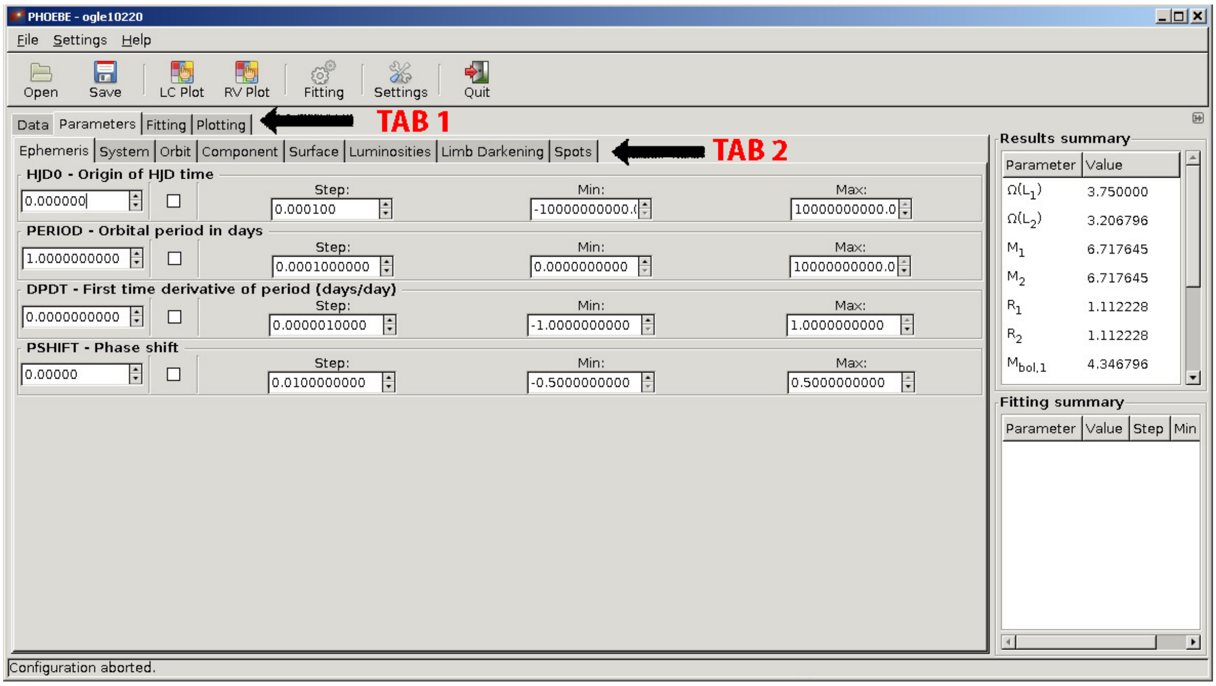

Figure 1: The window of PHOEBE with the parameters as appears on the screen when starting with default values. "Tab1" and "Tab2" refers to two different sets of switching tabs (see the text for details).

The first tab is named "Data" and is used only in the beginning for the input of the data files. The second is the "Parameters" and this one is being used later during the fitting process. Various different parameters defining the shape of the light curve appears there when clicking on the second "Tab2" (see figure 1). There are more than 20 parameters which can (or should) be fitted with PHOEBE during the fitting process. The third tab in the upper "Tab1" is the option "Fitting" and this one obviously is being used during the fitting process. And finally, if you want to check whether your fit is OK, or still needs some improvement, you can click on the last "Plotting" tab, where you can see your light curve, its residuals, or the radial velocity curve, or even the 3D shape of the binary.

Step 3: Input the data

The process of recording the data to the program is relatively easy. Go to the “Data” tab, where everything concerning the input can be done. You should type the name of your binary in the first empty line “Binary star name”. Then – the “LC data” space is for your input. It means here you can upload your data files. It can be done via clicking on the button “Add” on the right. There appears a subwindow “Add observed light curve data”. Type the name of your dataset here on the first line (e.g. “ogle” in our case). Then choose your file from your computer. Be careful about the structure of the file with two or three columns. If we follow our testing example of the OGLE data, we can see the three columns below. It means that the first one is the “Time (HJD)”, the second is the “Magnitude”, and the third one is the error. Hence, we have to change the column 3 description to the “standard deviation” instead of the original one. If you do not have the errors of individual data points, you can also use “unavailable”. On the right there are also the two fields “Sigma” and “Filter”. The value of sigma can also be left to the default value of 0.01. This value makes some sense if you have different datasets and you can set a different weight to them. If you have only one dataset (e.g. observation in one filter), this number almost makes no difference. However, it modulates the final chi-square value (cost function), and could also be used when you have the light curves together with the radial velocity curves and you need to assign different weights to both datasets. And finally, the last “Filter” option allows you to choose which filter you have in your observations. Our testing example is “Cousins – I filter”. If you have done this, you can confirm it and it should appear in the main data window. Using this method you can upload there many different datasets – e.g. different photometric filters, data from different observatories and different instruments, etc.

There are many other options in this tab “Data”, but we will leave them to the default values except for two. The first one is very important option named “Model” (upper right corner of the window). Here you can set the type of your system which you have. The easiest seems to be the detached configuration of the system. Sometimes it is evident that the binary is of W UMa type, hence it is probably some “over-contact” case. However, to distinguish which configuration is a right one is not easy task and one needs usually some modelling. One possibility is to perform a few fitting steps and then to switch to the correct configuration according to the solution (the solution seems to converge to too low values of potential, then the system is semi-detached or contact). In our testing example please set the “detached” binary case.

The second one is the parameter at the very bottom of the window named “Zero magnitude”, or the normalizing magnitude. Setting this value to some proper value can be done via a following method. Switch to the “Parameters” tab and the “Ephemerides” tab there. Input the correct orbital period of the binary instead of the original one. Here for the case of our testing OGLE star the period is 2.007940 days. Type this value to the “Period” field. Now we can check whether our data really show the eclipsing light curve. Switch to the “Plotting” tab, where at the bottom should appear your new dataset (named ogle in our case). Place a tick mark in the small box for the “observed” light curve (there are two small squares, but the synthetic one is still away from our correct solution). And press the “Plot” button. There should appear the classical shape of the light curve for this system with two minima of different depths, but rather well-detached (clearly shaped eclipses and the outside-eclipse phase). However, this light curve is plotted only with the y-axis in “Flux”. You can switch it to magnitudes (upper part of the window) and press “Plot”. Now the curve is plotted with magnitude in y-axis. You can check what value of magnitude is at the quadrature (near phase 0.25 or 0.75). Zooming the plot or checking the values of the actual position of the mouse pointer (right bottom corner) is relatively easy task. So, we can see that the quadrature magnitude is of about 13.90. This is exactly the value which should be written to the “Zero magnitude” field in the “Data” tab. So write there 13.9.

However, it is advisable to mention here that whatever parameter you would like to change, you have to type your new value of the parameter, but then do not forget to press “enter” (as the confirmation of the new value). Otherwise your new value will not be stored in the PHOEBE.

Now you can check that your new value of the zero magnitude is OK. Go back to the “Plotting” and plot the light curve of your system. However, switch the y-axis back to the “Flux” units. Now (if the zero magnitude is OK) the magnitude near quadrature should be very close to 1.

Nevertheless, we can see that our primary minimum is not placed in the phase 1.0 (or 0.0), so we have to change the ephemerides of the system. This can be done via changing the HJD0 value, which can be found in the tab “Parameters” – “Ephemerides”. The correct time of the initial minimum can be set to: 53557.8214. Placing this value to the field “HJD0” makes the light curve plot correctly centered to the 0.0 at primary minimum. We can omit the term 2400000 because also the input data were stored without the 24+… Hence, be careful when inputting the data and check in which format the data are.

Now we can check how good our initial fit is. Go to "Plotting" tab and click on the "Synthetic" box to place a tick there. If both observed and synthetic curves are marked, then press "Plot" button to see how good the current fit is. We can see two problems. At first, the theoretical (synthetic) curve is too badly sampled. To make the whole curve smoother, change the number of vertices (upper left corner of the plotting window). From the original one (100) change to some higher value (e.g. 500 or 1000).

The second problem is that the theoretical curve is away from the observed data. It means the total luminosity as assumed by the PHOEBE model is too high and we have to shift it to lower values. This change can be done in the "Parameters" tab, where in the "Luminosities" tab are the "passband luminosities" for the primary and secondary. If we double click on the particular line (our ogle data set), or click on the "edit" button, we can see the current primary luminosity value and possibly change it. So we can try to change it to 11, and to check whether there is some different in the plot. It seems like it is still too high. So change it to 10, or 8, or even 5 (and confirm it with pressing enter). We can now see that the synthetic curve is much closer to the observed data, but its shape is still very different.

Step 4: First fitting steps

We can now try to compute this best value of luminosity by the PHOEBE itself. In the tab "Luminosities", there is a small clickable box just next to the parameter itself (Primary luminosity). If we click on this field, there appears this one particular parameter in the "Fitting summary" in the right bottom corner of the screen. It means that we have placed one parameter into the fitting procedure.

Now switch to the "Fitting" tab, where you can see our first parameter stored. There is written the initial value of the parameter (e.g. 5.000000 what we have manually set there), and the new value is still zero as well as the error. Now we can proceed to the "Calculate" button in the bottom right hand side of the window. Pressing this button once, there appears some new values on the screen. The computation ran only a while, and some new value as well as its error are given in the field. Moreover, there also appears a value of the "cost function" (for the testing OGLE example it is of about 29.7)[4]. Keep in mind that now the value stored in PHOEBE is still the old one and nothing was done to the fit. To update the value of the parameter you have to press the button "Update all". Until you press the update button, there still be stored the original values!

Doing this kind of fitting you can shift the cost function (something like a goodness of fit) to slightly lower values. In the case of our testing OGLE system the cost function value decreased to 29.53. We can now check that the fit is still poor when comparing it with the real data.

However, the problem is that the real eclipses are much more wide and also much deeper than our fit. The depth of eclipses is obviously the problem of the inclination of the binary. As we get closer to the 90^0, we will get deeper and deeper eclipses. We can try it in the tab "Parameters"- "System", where is the value of "INCL"- inclination in degrees. From the starting value of 80^0 we can manually change it to 85 (and pressing enter for confirming). Now check what happened in the plotting tab. The eclipses are obviously deeper. So change it to some higher value, e.g. 88^0.

But what about the width of the eclipses? For the duration of the eclipses there plays a significant role the sizes of the components. In the PHOEBE there is no radius parameter, but the radii of both components are stored in the parameters like "PHSV" and "PCSV" (or POT1, POT2 - primary and secondary surface potentials) stored in the "Parameters"-"Component". From the original value of 10 we can shift the value to 8 (i.e. lower the value, bigger the star). Change both PHSV and PCSV values to 8 and take a look what happened with the plotting window. It seems like both eclipses are now wider. Now if we set both potentials to 6, it seems like the widths of both eclipses are OK.

What is still problematic is the difference between the depths of both eclipses. This is due to the fact that in our solution both components have the same temperatures. It is obvious that the two components are rather different, hence also their radii and temperatures have to be different.

So the task is to fix the primary temperature and to fit the secondary one. Using the PHOEBE and having the photometry only, one can only derive the temperature ratio, not the primary temperature itself. Its value is usually quite problematic to derive. We can set the primary temperature T1 (TAVH stored in the "Parameters"- "Component" tab) using the spectra or at least the photometric indices. The photometric indices (like (B-V), (V-R), or (R-I)) can be found in various databases in the CDS. For example for many galactic sources up to the

[4] However, this value always depends on the sigma for the particular dataset

magnitude 15 there is quite a common way of estimating the primary component's color the use of 2MASS catalogue and the JHK infrared magnitudes. The link between some spectral type, temperature and the photometric indices exist (but I have to emphasize that any such relation is viable only for the main sequence stars).[5]

Therefore, for the purpose of our testing example here we can set the primary temperature to 20000K. Now we can see how the fit changed. Going back to the "Fitting" tab we can calculate (and update - calculate - update) again the primary luminosity parameter. Checking how the fit changed we can judge whether is our fitting process going to the better solution or not. In the „Fitting" tab there is the cost function of the current fit and we can see that its value is now much lower than originally.

Step 5: Several comments

Of course incorporating another more and more parameters and changing their values one will get closer and closer to the final fit and the residuals will be minimal. However, before proceeding to fitting more parameters in one step I would like to point out several other issues.

At first – you are able to get the final fit in PHOEBE also with absolutely incorrect parameters. There are too many free parameters (degrees of freedom) that also an incorrect combination of parameters can led to the end. It means the cost function will be minimal, but the parameters will be odd (nonphysical, out of physical limitations, or anyhow wrong).

Secondly, there is advisable to obtain as good starting fit as possible manually (shifting the parameters by hand and checking whether the final fit is better only by a naked eye). As closer you will get, as much time you are able to spare during the automatic fitting process.

Sometimes the fitting process diverges away from the correct solution and the cost function will rapidly go up. Sometimes you are not able to return back and reproduce the original (and more probable) values. Therefore, it is advisable to save the working file after each successful iteration of the fit. Saving can be done clicking on the "Save" button.

The better the fit you are trying to achieve, so you need many different parameters to converge. On the other side, also many physics have to be considered and sometimes some or your original assumptions can be found odd (for example eccentric orbit instead of original circular one, presence of spots, etc.)

If you need to construct much more detailed model of the system, you also need to increase the number of data points on the surface of both components. It can be done changing the numbers stored in "Parameters"-"Component" in the bottom left corner (known as fine and coarse grid raster). You can shift these values from the original ones 20x5 (for both components) e.g. to 35x15. It will achieve a better fit, but also much increases the computing time required for each iteration.

There are still some parameters which we were ignoring until now. If we have the circular orbit, then the parameters like eccentricity, argument of periastron and the first time derivative of periastron can be ignored. What easily cannot be ignored are the parameters like synchronicity parameters (F1, F2), the albedo coefficients (ALB1, ALB2) and the gravity brightening coefficients (GR1, GR2). On the other hand, what can be ignored if you have only the photometry is the VGA-center of mass velocity, SMA-semimajor axis, and RM-mass ratio?

If you have only photometry and no radial velocities, then exactly the same fit can be obtained with very much different values of the semimajor axis. More complicated situation is with the mass ratio. Generally, the value of the mass ratio cannot easily be computed if you have the detached system. If you have some semidetached or contact system, some derivation of the mass ratio only from the photometry can be done, but its uncertainty is usually rather high. However, you have to be very careful when fitting the mass ratio in PHOEBE.

Concerning the synchronicity, albedo and gravity brightening coefficients, the situation depends on the particular system and quality of the input data. If you have a super precise data from the Kepler satellite, you can fit (almost whatever you want). On the other hand, if you have standard data with 0.01 mag precision, some of these parameters should stay fixed during the fitting process. Generally, it is advisable to follow this scheme: if you have a star having the convective envelope (cca $T < 7200K$) then fix ALB=0.5 and GR=0.32, on the other hand

[5] http://www.pas.rochester.edu/~emamajek/EEM_dwarf_UBVIJHK_colors_Teff.txt

if you have radiative atmosphere (T > 7200K) then fix ALB=1.0 and GR=1.0 (Lucy 1968). You can try to fit the F1 and F2 values, but sometimes is better to leave them to the default 1.0 values.

Regarding the limb darkening values, it is also advisable not to fit them but interpolate them from the tables (van Hamme (1993) or the PHOEBE itself, as set in the preferences).

Another parameter not mentioned earlier is the “Third light”, which represents some additional contribution to the total luminosity at all phases of the binary. It could indicate some hidden component in the system or some another star in the aperture. It can also be derived, but only very carefully.

Sometimes it can happen that some of the values converge to rather nonphysical values. E.g. the third light, albedo or potential to negative values, temperature to surprisingly high values, etc. If this happens, it is advisable no to update this fitting step, but return to the previous one. Such a value only shifts your solution away from the minimal cost function value and makes your fitting process too long.

One can also switch on some additional effects. This can be for instance the reflection effect (in the tab “Luminosities”). This effect is sometimes visible in very luminous stars orbiting very close to each other, which is being well-noticeable in the light curve shape as a high curvature of the outside-eclipse variation. However, sometimes it’s switching on extends the computing time significantly (especially for multiple reflections).

Applying all of the abovementioned rules and following these instructions (leaving the fixed F, ALB and GR values to 1.0) and fitting the other parameters for our testing OGLE example yielded the cost function value to of about 0.22.

Step 6: Further fitting

Now we can proceed to the final step in the fitting process. Of course, one is able to fit simultaneously several different parameters in one step. However, it is rather bit tricky and one has to be very careful.

Clicking a tick mark next to the particular parameter one can add different parameters into the fitting process. On the other hand, it is advisable to start only with one parameter (after manually shifting the value) and slowly increase number of simultaneously fitted ones. The experience after analyzing several hundreds of eclipsing binaries tell us something about a suitability of fitting selected parameters with some others.

For example we can try to fit primary luminosity together with the inclination. After several steps of fitting (calculate-update) we can try to use a combination of primary potential plus secondary temperature or secondary potential plus inclination, etc. Slowly adding more parameters we will be able to force the program to decrease the cost function to lower and lower values.

It is advisable time to time save the working file as well as to interpolate the limb darkening coefficients from the tables.

And finally, if we are still unsatisfied with the solution, and obviously there are still some systematics in the data which are not able to be described with the model – we can try to use also the other fixed parameters carefully. For example here the F, ALB, and GR values. If I try to fit also these values, I will get the cost function for our testing example of about 0.047 only (which is the minimum I am able to get).

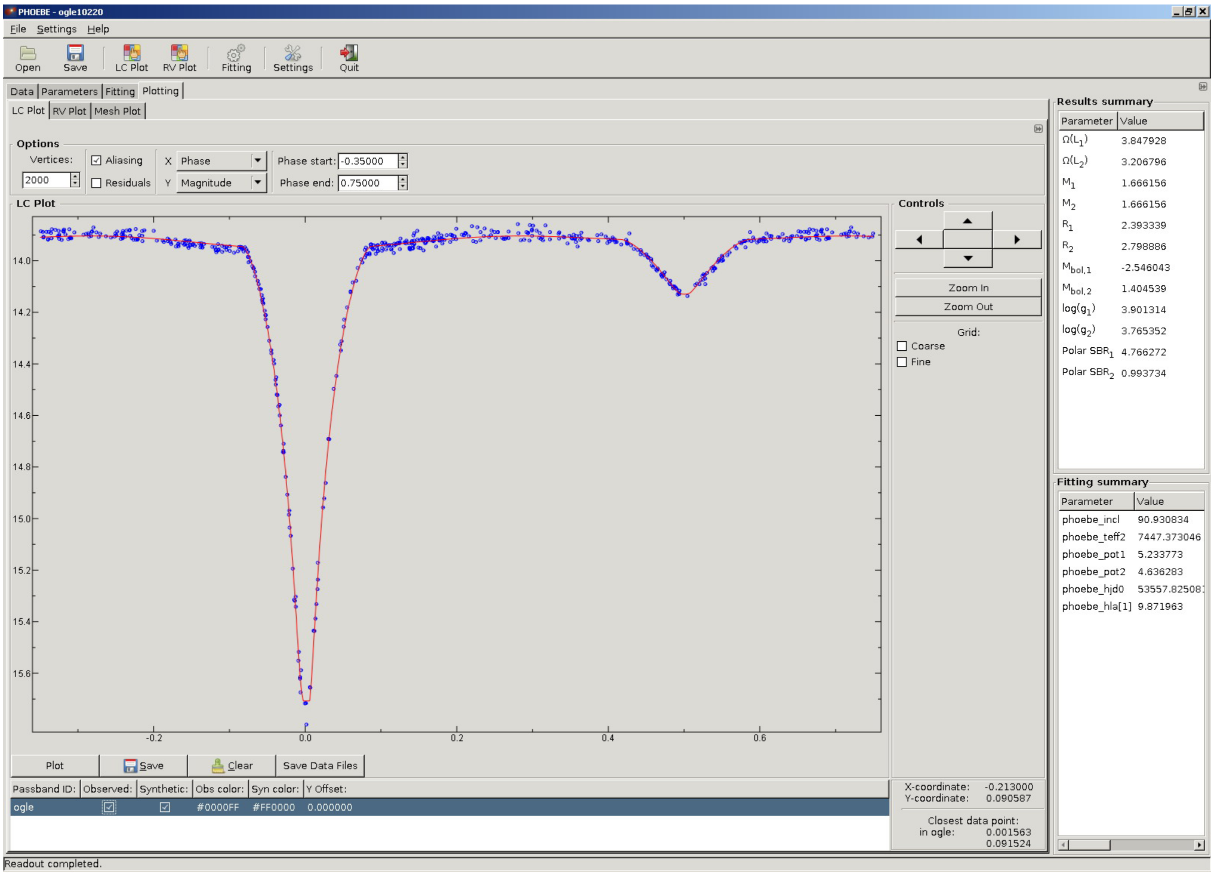

Figure 2: The plot of the final fit for our testing OGLE example as provided after the PHOEBE fitting.

Generally, we can divide all the parameters into two sets. The first one is the set of very important parameters, which could also be roughly estimated by a naked eye and very significantly changes the shape of the light curve. These are mainly the luminosity, inclination, ratio of the temperatures and both potentials. On the other hand, there are also the "second-order" parameters, which cause only slight modulation of the light curve shape. These can be fitted by PHOEBE (very carefully), but only after successfully converging the parameters from the first group. If one tries to find e.g. the parameters like albedo with incorrect value of e.g. temperature, the program will converge to some wrong values and the whole fit would diverge away from the minimal cost function value.

Until now there was not even mentioned that some of the parameters which are being fitted in one fitting step can correlate with some others significantly, hence it is rather problematic to fit both of them in one fitting step. For example the inclination and the value of the third light usually correlate with each other, or the temperature and the potential also. For this purpose it is advisable to use a so-called "Covariance matrix" (or the correlation matrix). If you have several parameters in your fitting window and press the calculate button, then you can also click on the "correlation matrix" button at the left bottom side. New window appears with the correlation values between all of the fitted parameters. On diagonal of your matrix there should be only values 1.000, but the other cells of the matrix should tell us something about our in/appropriate parameter selection for the fitting process. If there appears some higher number (e.g. higher than 0.8), it is advisable to take care of that combination of parameters for the fitting and remove one of the parameters from this fitting step. If you would not follow these correlations, the program would diverge away from the right solution.

One can also ask what physical parameters of the components or of the binary system can be reached with PHOEBE, or what can be learned about the components. Unfortunately, having only the photometry with no radial velocities, it is quite problematic. The semimajor axis as well as the radii in absolute units, as well as the masses are unreachable with pure photometry. It means that having the period of the binary, with the PHOEBE fitting one is able to get the inclination, the temperature ratio or the temperature of the secondary (if the primary's temperature is known), the relative radii of both components (relative means in the units of the semimajor axis of the system, and not in absolute units). And also the relative luminosities of both components (in % of the total luminosity) in the particular photometric filter (or eventually also the third light contribution). If we know the masses, we can derive the semimajor axis and hence also the radii in absolute units, but not having this information one can only roughly estimate this.

Conclusion

One can ask when the end is. When: It seems like the cost function is not decreasing significantly, only oscillates around some value and no further progress is visible. Also the residuals (can be plotted in the plotting window) are relatively symmetrically distributed around a zero line and no systematic deviations are visible there. Sometimes there remains some part of the light curve that was not fitted properly, but this can also be due to the limitations of the program itself and only limited physics incorporated into it.

Fitting of the spots or generally the asymmetric light curves is quite a different task. It is much more complicated, so it is waiting for someone else (with more experience on that) to be described step-by-step.

If you have any questions concerning the PHOEBE fitting, do not hesitate to contact me and I will try to do my best helping you with the problem.

Acknowledgement

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References

Graczyk, D., Soszyński, I., Poleski, R., et al. 2011, AcA, 61, 103

Lucy, L.B. 1968, ApJ, 151, 1123

Prša, A., & Zwitter, T. 2005, ApJ, 628, 426

van Hamme, W. 1993, AJ, 106, 2096

Wilson, R.E., & Devinney, E.J. 1971, ApJ, 166, 605

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CCD photometry on Observatory Úpice

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Abstract: This paper informs about the results of photometric observations made with CCD technology and new remotely controlled telescope on Observatory Úpice and about activities related to the robotics of existing equipment. We describe the technical solution, its weaknesses and plans for the future, as well as present way of data acquisition. Finally we present statistical summary and some planned additional enhancements and modifications of the observing program as well as of technical facility.

Abstrakt: V této práci informujeme o výsledcích fotometrických pozorování konaných CCD technologií novým vzdáleně řízeným dalekohledem na Hvězdárně v Úpici a o aktivitách spojených s robotizací stávajícího zařízení. Popisujeme technické řešení, jeho slabiny a plány do budoucna, včetně způsobu pořizování dat. Závěrem prezentujeme statistický přehled a další plánovaná vylepšení a modifikace pozorovacího programu i technického vybavení.

Introduction

The location and personal and technical facility of Observatory Úpice (Fig. 1) represents appropriate workplace for photometric observations of different objects. Due to the relatively dark sky, we decided to test several combinations of telescopes and CCD cameras suitable for observing both bright and faint objects. Especially observing of relative bright objects is right starting observational program, using cheap and easily available technical equipment.

Figure 1: Observatory Úpice

Present state and development

Our intention was cheaply, quickly, remotely and reliably control the telescope to exploit most suitable nights without physical personal presence at the observatory. At first we use Windows 7 operating system and Maxim DL control and processing software, remotely managed by software TeamViewer. Our long-term plan is run our telescope, mount and dome on non-Windows platform with scripting software and simple web interface. We would like to automate gradually all process with ability to make decisions without human supervise. Our preference is to use mainly INDI a RTS platform.

We built observing telescope composed from cheap equatorial mount Celestron CGEM, Newton-type telescope 200/800 mm and CCD camera SBIG ST-402ME with photometric filters during development of our equipment. The camera was kindly loaned by American society AAVSO, the rest of this equipment was acquired by our own means. All this equipment is located in observing house with displaceable roof. Because of requirement of remote operation we added control system for power and focus driving based on Arduino platform. Roof control system is adapted from water valve control system and it propels moving mechanism adapted from gate opening system.

The weather condition is watched by full-sky observing system. It is completed from second-hand digital camera CANON and metallized convex part of condenser from old film magnifier. Exposure is realized by Aurdino system and transfer of data from camera is realized through the independent Linux server.

We identify some weaknesses of still realized and presented system. The first one is roof construction, which is too weak to hold big amount of snow during the winter season. It will be necessary to reinforce it in the future. Fortunately, it was now so much snow during operation of this equipment to disrupt observation or destroy the observing house.

The next weak part of this system is operating system of control computer and access to it. Although the Úpice observatory use relatively quality and strong internet connection, managing software TeamViewer sometimes occupy such big amount of system and data transfer resources, which collide with other control processes. We suppose to protect such failures by watch-dog process which autonomously stop the observing. The power system should by independently backed. We debug new control system at present time. It will be used in the next version of remotely controlled telescope which is planned. Security of safe operation of telescope is realized personally by “man on phone” at present time, because, from this point of view, our system is not fully automated now.

The part of the system, which is based on Arduino platform is stable and reliable, as well as home-made control electronic of stepping motors and switching relays. Because of used electronics and utility software are relatively easy used and realized, it is easy to complete such system. We tested Arduino platform in Windows (C-applications), OS X and Linux platforms without any problems. We suppose to use described platform in the future, although we assume to add some modules for other platforms like MLAB.

Data processing

At present time we process especially data obtained during some observing campaigns. We use now C-Munipack software due its friendly using and big amount of data. We would like to use other system of data processing in the future. We plan to construct robust archive of processed data compactible with Virtual observatory data archive. The connection with our archive will be realized through friendly user and multiplatform interface. The data transformed to the international system would be freely available to all interested subjects. We develop the sustainable form of such archive, based on newly developed version of Munipack (released in 2015). It will be incorporate to our present web pages and will be freely available.

Moreover, we obtain the set of control pictures of actual weather situation during observations in 4-minute cadency, which are also available. These pictures are captured by full-sky camera.

Future plans

We successfully tested remote control of EQ and CGEM mounts, cameras SBIG and FLI, using Linux library Indilib and we plan to use them to the routine operation. It is very easy to replace TeamViewer software by very undemanding transfer of text instructions using web interface with responsive template. We have not still tested rain detector, therefore we suppose that the observer will personally watch the weather situation on weather web server. Of course, we suppose to change this operation to the automatic run as soon as possible.

Our new plans also supposed to add the second telescope, suitable for observing of interesting faint objects. Although it is possible to use 20 cm Newton telescope for observing of 15-19 mag objects, it is more appropriate to use it for bright objects, which are difficulty observable using biggest telescopes. This is the reason to use the next telescope – Meade LX200 (30 cm of diameter) with FLI ProLine camera (Fig. 2) with photometric filters.

Figure 2: FLI ProLine camera.

Present observations

During two past years (2014, 2015) we observed realized this program:

- observing campaigns AAVSO and CBA

- eclipsing stars GR Tauri type

- GRB optical counterparts DG CVn, supernovaes and novaes (Fig. 3)

- bright cataclysmic variable stars

- Be stars (OY Gem)

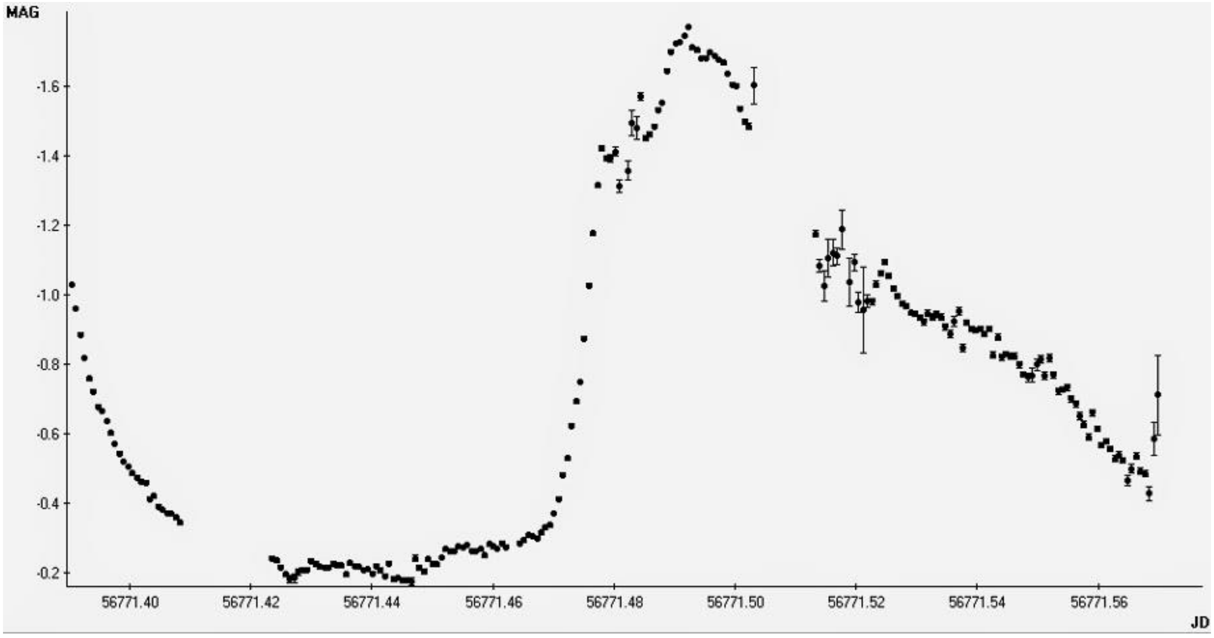

Figure 3: DG CVn flare, which was detected by SWIFT satellite as possible gamma flash. The second brightness.

Conclusion

Described observing equipment is not the only one solution for variable star observing. Conversely, there are dozens of more sophisticated solutions, but, they are usually more expensive. Moreover, our solution is more variable and it offers greater personal inventiveness, than turnkey solutions.

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Outburst activity of the symbiotic binary AG Dra

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Abstract: The outburst activity of the symbiotic system AG Dra has been studied using extensive spectroscopic observational material. High luminosity and temperature of the hot component of AG Dra indicate that quasi-steady thermonuclear shell burning takes place on the surface of the white dwarf. The major (cool) outbursts at the beginning of active phases might occur due to enhanced thermonuclear burning triggered by disk instability. Smaller scale hot outbursts might be explained by the accretion disc instability model like in dwarf novae. We discovered significant similarities in photometric and spectroscopic behaviour of AG Dra and prototypical symbiotic star Z And.

Abstrakt: Využitím rozsiahleho spektroskopického materiálu sme študovali aktivitu symbiotického systému AG Dra. Vysoká teplota a svietivosť horúcej zložky AG Dra naznačujú, že hlavné vzplanutia sú pravdepodobne spôsobené zvýšeným termonukleárnym horením materiálu, ktorý bol na povrch bieleho trpaslíka akreovaný z chladnej, vyvinutej zložky tejto interagujúcej dvojhviezdy. Vedľajšie vzplanutia by mohli byť spôsobené nestabilitami v akréčnom disku, podobne ako v trpasličích novách. Významnú podobnosť správania sa symbiotických systémov AG Dra a Z And sme zistili na základe korelačnej analýzy fotometrických, ako aj spektroskopických pozorovaní.

Introduction

AG Dra is one of the best-studied symbiotic stars. The cool component is a giant of early K spectral class instead of M as in most other symbiotic systems. The hot component of AG Dra is considered to be a white dwarf sustaining a high luminosity ($\sim 10^3$ L$_\odot$) and temperature ($\sim 10^5$ K) due to the thermonuclear burning of accreted matter on its surface (Mikołajewska et al. 1995). The accretion most likely takes place from the stellar wind of the cool giant. Both components are in a circumbinary nebula, partially ionized by the hot component. The orbital period of the binary system is 550 d (Meinunger 1979, Fekel et al. 2000). A shorter period around 350 – 380 d has also been detected in photometric and spectroscopic variability of AG Dra (Bastian 1998; Gális et al. 1999; Friedjung et al. 2003). Gális et al. (1999) ascribed this period to the pulsations of the K giant.

By its photometric variability, AG Dra can be classified as a classical symbiotic star of Z And type. Its light curve, available since 1890 (Robinson 1969), shows the quiescent and active phases with a brightening of about 1 – 1.4 mag in the *V*/visual band and up to 2.3 and 3.6 mag in the *B* and *U* bands, respectively. Major outbursts occur in intervals of 12 – 15 yr. (in 1936, 1951, 1966, 1980, 1994 and 2006), and are usually followed by minor-scale outbursts in intervals of about 1 yr. González-Riestra et al. (1999) have distinguished between cool and hot outbursts of AG Dra. Major outbursts at the beginning of active phases are usually cool, during which the expanding pseudo-atmosphere of the WD cools down and the He II Zanstra temperature drops. In smaller scale hot outbursts, the He II Zanstra temperature increases or it remains unchanged.

The outburst activity of AG Dra over 120 yr. was studied in our recent paper (Hric et al. 2014), using mostly photometric observations. However, a lot of open questions remain concerning the nature and physical mechanism of the outbursts in particular. In the present paper, we study the outburst activity of the symbiotic system AG Dra from a spectroscopic point of view.

Observations and analysis

The spectroscopic observational material consisting of 83 radial velocity values with a relatively high precision (typical errors of 0.4 – 0.8 km s^{-1}) has been extracted from Mikołajewska et al. (1995), Smith et al. (1996), Tomov & Tomova (1997) and Fekel et al. (2000). All radial velocities have been determined using spectral absorption lines formed in the atmosphere of the giant. The observations incompletely cover the time interval from JD 2446578.5 to JD 2451676.9, but with good oversampling of individual sets. The zero-point problem of separate radial velocity sets was solved by numerical minimization of the sum of residual squares of the observational points with respect to the preliminary synthetic curve of radial velocities.

Intermediate-dispersion spectroscopy of AG Dra was carried out at the Tartu Observatory in Estonia. Altogether, 515 spectra obtained during almost 14 yr. (from JD 2450703.3 to JD 2455651.5) on the 1.5-metre telescope, are analysed in the present paper. Reductions of the spectra were done with the help of the ESO MIDAS software package, applying the standard procedures of subtracting the bias and sky background, calibrating into the wavelength scale and normalizing to the continuum.

We focus on the strongest emission lines in the wavelength regions under study: the hydrogen Balmer lines Hα (λ6563) and Hβ (λ4861), the neutral helium He I line at λ6678, the ionized helium He II line at λ4686 and the Raman scattered O VI line at λ6825. Equivalent widths (EWs), peak intensities relative to the continuum and the positions of these lines were measured. Uncertainties of the EWs were estimated from repeated test measurements of a few spectra, and they range from about 3 percent for the strongest lines to about 10 percent for weak lines.

Period analysis of the observations was performed using an advanced implementation of the Date-Compensated Discrete Fourier Transform. We used a Fisher Randomization Test for determining the significance of the obtained periods. The minimum error of period *P* was determined by calculating a 1σ confidence interval on *P*, using the method described by Schwarzenberg-Czerny (1991).

Analysis of the absorption line measurements

For the analysis of AG Dra radial velocities based on absorption-line measurements we used our own method (for more details see Gális et al. 1999) which consists of several iteration steps for particular responses. The results of this period analysis are depicted in Fig. 1. In the corresponding power spectrum, part (a) shows three significant peaks: the largest two of them are related to the orbital period (548.9 d) and its 1-year alias (218.3 d), the third one (355.0 d) is probably related to cool-component pulsations. The middle power spectrum (Fig. 1, part b) shows the result after the removal of the orbital response from the data: only the pulsation peak is clearly visible. No significant periods are detected after removing the orbital and pulsation responses from the radial velocities of AG Dra (the bottom power spectrum, Fig. 1, part c).

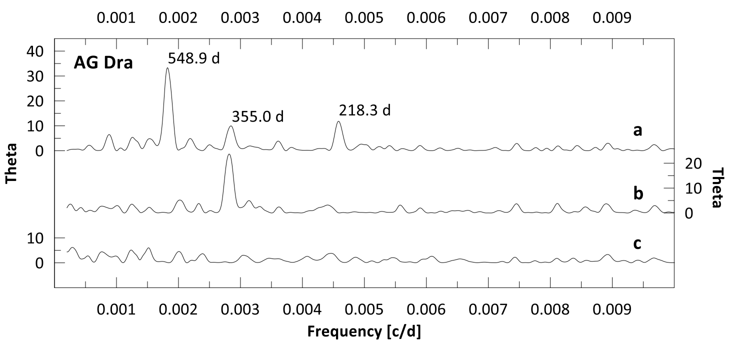


Figure 1. Power spectra of AG Dra obtained from the period analysis of the combined radial velocities based on absorption-line measurements: original data (a), data with orbital response removed (b), and data with both orbital and postulated pulsation response removed (c).

In the next iteration steps we have improved the parameters of orbital motion and postulated pulsation of the giant. After the removal of the pulsation response from the data, the period analysis gives the following parameters of the orbital motion: γ_O = (-147.6 ± 0.1) km s^{-1}, K_O = (4.9 ± 0.4) km s^{-1}, P_O = (551.0 ± 1.5) d, JD_O (max) = (2 448 996.4 ± 2.8) d. After removing the orbital response from data, the period analysis gives the parameters of pulsation as follows: γ_P = (-147.4 ± 0.1) km s^{-1}, K_P = (1.7 ± 0.4) km s^{-1}, P_P = (355.7 ± 1.9) d, JD_P (max) = (2 449 181.0 ± 5.8) d. The synthetic radial velocity curves for orbital and pulsation response together with radial velocity measurements are depicted in Fig. 2 (upper panel) by the blue and green lines, respectively. The complete curve of the orbital plus pulsation response is shown by the red line in the same figure. It is obvious that the complete curve better fits the observational radial velocities than the orbital response alone. The phase diagrams of the orbital and pulsation radial velocities are shown in Fig. 3 (lower panels).

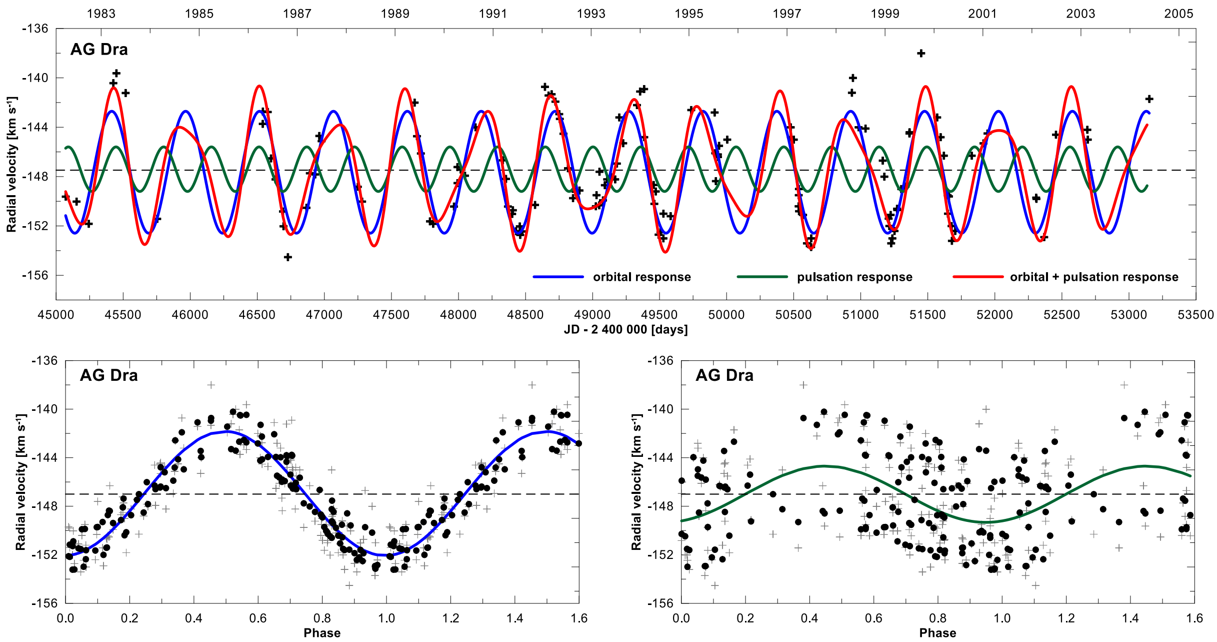


Figure 2: The radial velocities of AG Dra and the synthetic curves for individual responses (*upper panel*). The phase diagrams of orbital (*lower left panel*) and pulsation (*lower right panel*) radial velocities and the corresponding synthetic curves. The original data are depicted by crosses and the data after subtraction of the pulsation (orbital) response are plotted by circles.

Analysis of the emission line measurements

The variability of EWs of the studied emission lines (Hα (λ6563), Hβ (λ4861), He I (λ6678), He II (λ4686) and the Raman scattered O VI line at λ6825) together with the *U* light curve is presented in Fig. 3. One of the most interesting features of this variability is the significant increase of the EWs of all the five emission lines considered, but in particular that of Hα and O VI (λ6825), during about 150 – 200 days around JD 2453600 (second half of 2005). This episode corresponds to the minor outburst E10. There was another shorter episode of brightening of the emission lines at about JD 2454500 (early 2008) at the end of the active stage F2, but this was only noticeable in the EWs of the Hα and Hβ lines. This event was followed by an unusually weak Hα line from JD 2454650 (July 2008) to JD 2454900 (March 2009) while the star was in the quiescent stage Q6.

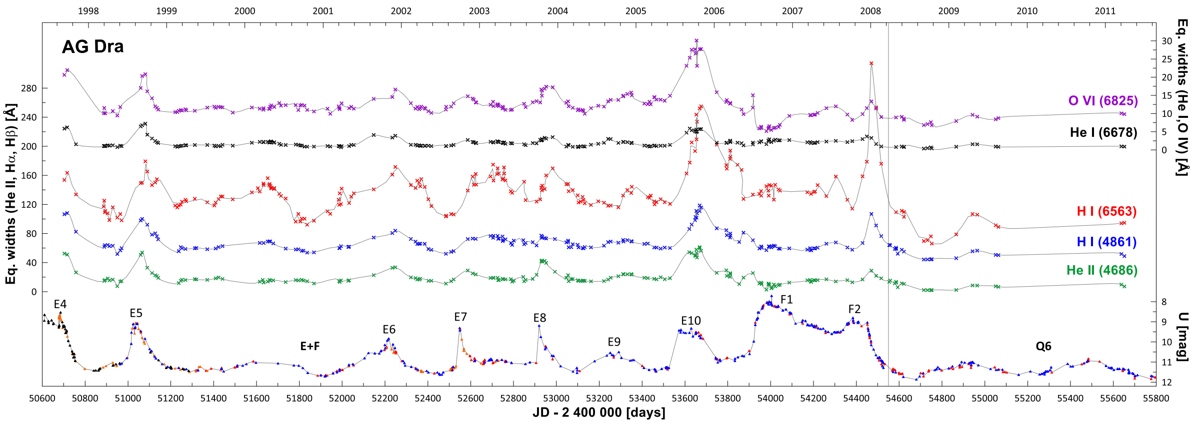


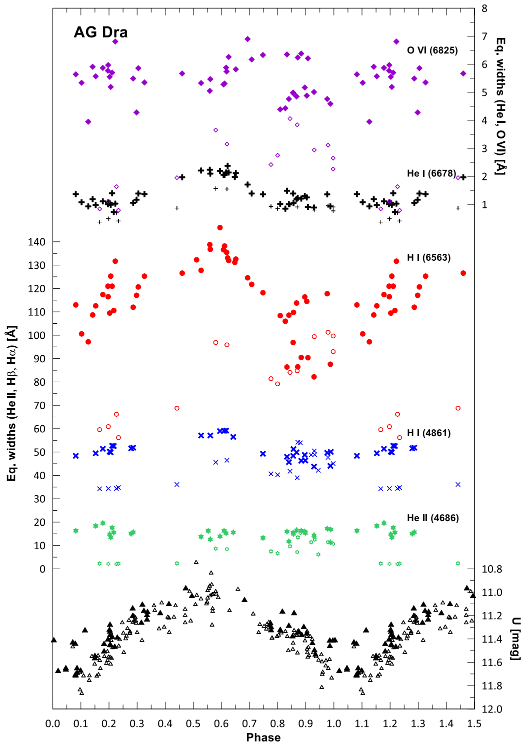
Figure 3: The curves of EWs for particular spectral lines together with the light curve of AG Dra in *U* filter. The scales on the left and right axes are valid for EWs of He I (6678 Å) and He II (4686 Å), respectively. Particular outbursts are assigned as E4 – E10, and F1, F2. The active (E+F) and quiescent (Q6) stages are distinguished by the vertical line. The thin curves show spline fits to the data points.

The major (cool) outburst F1 of AG Dra, that started after JD 2453900 (July 2006) is not specifically distinct in the fluxes of hydrogen and helium lines, but the weakening of the Raman scattered O VI (λ6825) line is very well seen. A simple interpretation of this behaviour could be that during the cool outburst, the temperature of the hot component considerably decreased, so that the high excitation O VI (λ6825) line significantly faded and almost disappeared[6], but leaving the lower excitation lines mainly unaffected.

The period analysis of the EWs, absolute fluxes and radial velocities of the studied emission lines confirmed the results obtained for radial velocities based on absorption-line measurements. Detected periods are close to the orbital period (511 – 568) d and to the time interval between individual outbursts (366 – 383) d. The period related to the pulsation of the giant (350 – 357) d was marginally detected. We can confirm that the data did not contain variability with longer periods.

It has long been debated whether the spectral lines of AG Dra vary regularly with orbital phase. As the characteristics of emission lines strongly depend on the outburst activity, it is clear that such regularity should only be searched for in the quiescence data. Fig. 4 (left panel) shows the emission-line EWs in quiescence phased to the orbital period P_{O} = 549.73 d (Gális et al. 1999) together with the *U* light curve. In the latter, the well-known wave-like variability is clearly seen. A very similar variability can be detected in the EWs of the Hα line, and to a lesser extent in the Hβ and He I (λ6678) lines. These low excitation lines most likely arise in an extended gaseous volume, which also emits continuum radiation in the near-ultraviolet and optical spectral region.

[6] The formation of the Raman scattered O VI (λ6825) emission line requires specific physical conditions – the simultaneous presence of a hot radiation source, capable of ionizing oxygen atoms five times, and enough neutral hydrogen atoms that scatter the photons of the O VI resonance line.



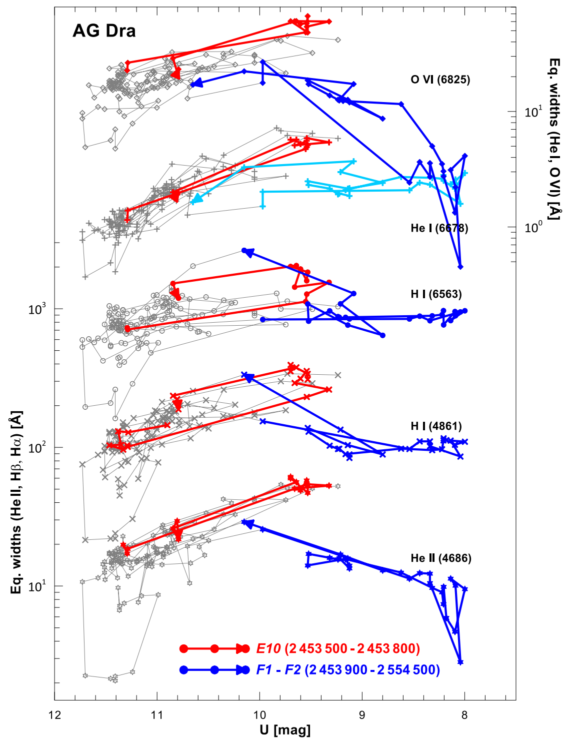


Figure 4: *Left panel*: Dependence of EWs of the studied emission lines and the *U* brightness on the orbital phase. Full symbols correspond to the possible quiescent episode between active stages E and F (JD 2451200 – JD 2452100). Empty symbols correspond to the quiescent stage Q6 (after JD2 454 550). *Right panel*: EWs of the strongest emission lines in logarithmic scale versus *U* magnitude. Data points are connected chronologically. The red line connects the points that correspond to the outburst episode E10, and the blue line connects those from the major outbursts F1 and F2.

The high excitation He II (λ4686) line practically does not vary with orbital motion. This line should have its origin close to the hot component. The EWs of the other high excitation line, O VI (λ6825), exhibit a large scatter because both the vicinity of the hot component and the extended volume of the neutral hydrogen are involved in the formation of this line.

Periodical outbursts and their relation to periodicities in the symbiotic system AG Dra have been a matter of long-term debate. As mentioned in the introduction, González-Riestra et al. (1999) have distinguished between cool and hot outbursts of AG Dra according the spectroscopic behaviour of this interacting binary observed in the far ultraviolet. In the present paper, we study the outburst activity of the symbiotic system AG Dra using the emission-line measurements in optical.

In Fig. 4 (right panel), we present (in logarithmic scale) the dependence of the EWs of the emission lines on the *U* magnitude over the time interval from 1997 to 2011. Chronological connection of the points enables us to see the different behaviour of the EWs during hot and cool outbursts. The EWs of all lines increase with the brightening in *U* filter, until *U* magnitude reaches a value of 9.5 – 9.4 mag. A different behaviour is seen at brighter magnitudes. The EWs of Hα and He I (λ6678) remain more or less constant. In Hβ, a light decrease is seen for brighter *U* magnitudes. Finally, the high excitation He II and O VI lines show a remarkable decline. Hence, the magnitude $U \sim 9.4$ mag apparently marks the brightness limits above which the onset of a cool outburst of AG Dra can be expected.

The He II/H*β* ratio can actually be considered as a proxy to the temperature of the hot component. Iijima (1981) has provided a simple formula for assessment of the effective temperature of a central source of ionizing photons from the nebular emission-line fluxes. With some simplification, the EW ratio can be used instead of the flux ratio and the time dependence of He II/Hβ can be hence regarded as representative for the temporal evolution of the hot component's temperature variations. The temperature decrease (minimum value ~ 108 000 K) during the major (cool) outburst F1 around JD 2454000 is clearly seen in Fig. 5 (left panel). Other episodes of low He II/H*β* values centre on JD 2454480 (F2) and JD 2454840 (quiescence Q6). We can also see a few exceptionally high He II/Hβ values around JD 2452940 and 2453620 which correspond to the hot component's temperature of ~

210 000 K. Interestingly, those episodes can be associated with hot outburst type brightening (E8 and E10) where the *U* magnitude reaches the turning point in Fig. 4 (right panel).

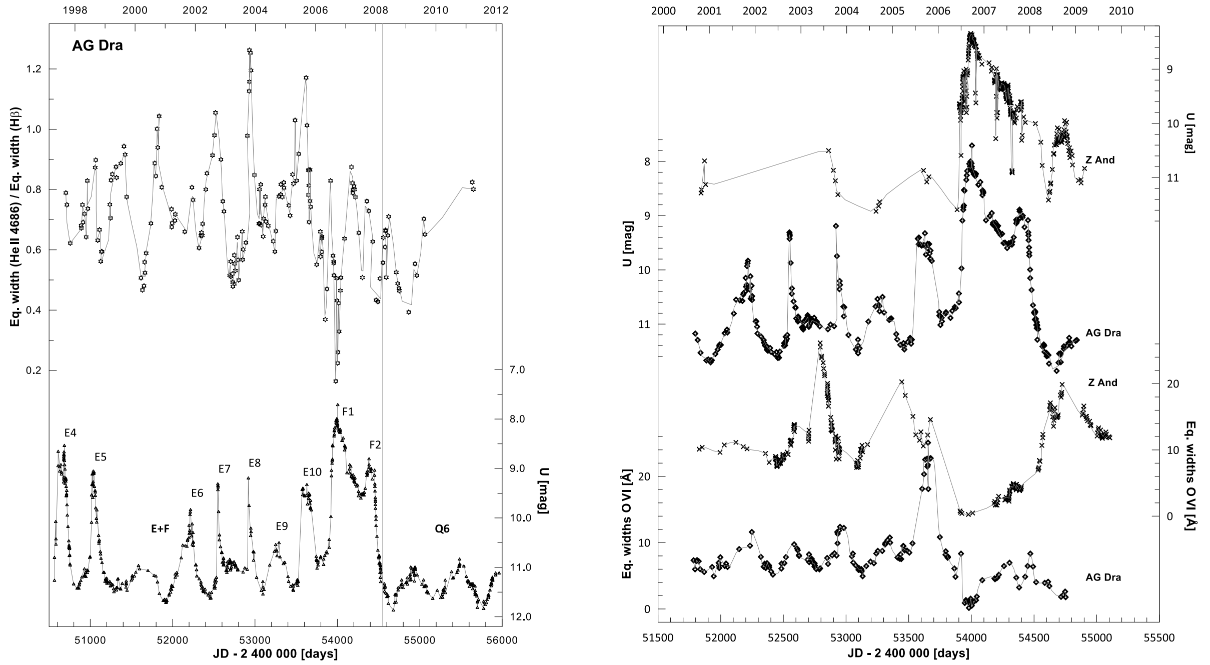


Figure 5: *Left panel*: Ratio of the EWs of the two strong emission lines, He II (λ4686) and Hβ, and the *U* brightness in time. *Right panel*: The *U* light curves (top) and EWs of the O VI line at λ6825 (bottom) of AG Dra and Z And. The curves of Z And are time-shifted by 2108.7 and 2102.7 d for photometric and spectroscopic data, respectively.

AG Dra vs. Z And

The major (cool) outburst of AG Dra, started after JD 2453900 (July 2006) is not specifically distinct in the fluxes of hydrogen and helium lines, but weakening of the Raman scattered O VI (λ6825) line is very well seen. Burmeister & Leedjärv (2007) detected a similar weakening of this line in the spectrum of the prototypical symbiotic star Z And in the summer of 2006 when the star underwent a strong outburst accompanied by the ejection of bipolar jets.

We selected time intervals of about 3000 d from the *U*, *B* and *V* light curves of both AG Dra and Z And, and performed a cross-correlation analysis. The results of such analysis for curves with complex behaviour depend on the selection of a particular time interval. Therefore, we performed around 20 runs with different starting times and lengths of the analysed time intervals (1520 – 3066 d). In all runs, the cross-correlation functions manifested the significant maxima only for the time-shift with a value around 2110 d. Such significant correlations might not be so surprising as we know that the *U*, *B* and *V* light curves of AG Dra correlate well between themselves during active stages (Hric et al. 2014), and the same can be concluded from the visual inspection of the light curves of Z And.

It would be more intriguing to find similar correlations in some spectroscopic features. Sokoloski et al. (2006) have published the EWs of the most prominent emission lines of Z And. We selected the O VI line at λ6825 and performed a similar cross-correlation analysis of its EWs in AG Dra and Z And. In all runs, the maximum value of the cross-correlation function appeared for the time-shift around 2290 d. Moreover, in many runs, this maximum has a double-peaked structure with the second maximum around 2100 d. These results show a strong similarity of the photometric and spectroscopic behaviour of AG Dra and Z And. The difference between the time-shift for the light and the EW curves (around 180 d) is not essential, because the value of the time-shift for the EW curves does indeed lie in the range 2100 – 2300 d, and its particular value depends only on the selection of the time interval. The correspondingly shifted *U* light curves and EW variability curves of AG Dra and Z And are shown in Fig. 6. These reasonable correlations could imply some similarity of the nature of the hot components and the mechanisms of the outbursts in AG Dra and Z And.

Outburst mechanisms

It was established long ago that a WD alone is not capable of ionizing the nebulae of symbiotic stars to produce the characteristic emission-line spectrum. Quasi-steady thermonuclear shell burning on the surface of the WD can provide additional energy, and this phenomenon appears to be common in most symbiotic systems (e.g. Sion & Ready 1992). An accretion rate of a few times 10^{-8} $M_\odot$ yr^{-1} is sufficient to produce a luminosity of 10^3 $L_\odot$ by a thermonuclear shell burning (Sokoloski et al. 2006). However, the classical symbiotic outbursts, recurring every few years or decades, do not fit well into this picture. They are by far too frequent to be nova-like thermonuclear runaways like those in symbiotic recurrent novae (Mikołajewska et al. 1995).

The combination nova model proposed by Sokoloski et al. (2006) seems to be a promising explanation, at least for the behaviour of Z And. Smaller-scale hot outbursts (e.g. in 1997) are explained by the accretion disc instability model, as in dwarf novae (Warner 1995). The 2000 – 2002 outburst of Z And was similar to the major (cool) outbursts of AG Dra. According to Sokoloski et al. (2006), the disc instability in this case triggered enhanced thermonuclear shell burning on the WD surface, thus resembling a classical nova outburst. For the 0.65 $M_\odot$ WD, an average accretion rate of 5×10^{-8} $M_\odot$ yr^{-1} would be enough both to fuel the quasi-steady nuclear burning and to accumulate enough material in the disc to trigger a combination nova event on time-scales of 10 yr. The major (cool) outbursts of AG Dra occur on a similar time-scale (12 – 15 yr). However, there is a fundamental difficulty because we do not have firm evidence for the presence of an accretion disc in AG Dra. No evidence of collimated bipolar jets, as in Z And (Burmeister & Leedjärv 2007), or short time-scale flickering (Sokoloski, Bildsten & Ho 2001) has been found in AG Dra.

A combination nova model might be applicable to AG Dra, provided that a trigger mechanism for thermonuclear shell flashes can be found. Triggering of major (cool) outbursts seems to take place close to some critical threshold, as in some cases (active stages A and C in Hric et al. 2014) there has not been enough power to ignite additional nuclear reactions required to initiate a cool outburst.

Conclusion

Our conclusions can be briefly summarized as follows.

(i) We carried out a complex and detailed period analysis of spectroscopic data of AG Dra obtained from absorption as well as emission line measurements. The results of period analysis of all these data are two real periods present in this symbiotic system: 550 and 350 d, related to the orbital motion and postulated pulsation of the cool component, respectively.

(ii) Cool and hot outbursts of AG Dra can be clearly distinguished by the behaviour of the emission lines in the optical spectrum of this symbiotic system.

(iii) The Raman scattered O VI line λ6825 almost disappeared during the cool outburst of AG Dra started after JD 2453900 (July 2006), confirming a drop in the hot component's temperature, as was also found from the variations of other emission lines.

(iv) Emission lines of hydrogen and neutral helium did not change significantly during the cool outbursts of AG Dra. They are correlated with the orbital motion of this interacting binary in quiescence and become stronger in hot outbursts.

(v) The similarity of the outbursts of AG Dra and prototypical symbiotic star Z And shows that a combination nova model might explain the outbursts of AG Dra. The presence of an accretion disc in the system still needs to be confirmed.

One of the promising explanations of at least some individual outbursts of AG Dra might be the combination nova model proposed for Z And by Sokoloski et al. (2006). In this model, when accretion rate onto the white dwarf exceeds some critical value, thermonuclear reactions are ignited and luminosity of the hot component increases significantly. One of the next tasks would be to study whether the outbursts of AG Dra will fit into such a picture.

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References

Bastian U., 1998, A&A, 329, L61

Burmeister M., Leedjärv L., 2007, A&A, 461, L5

Fekel C. F., Hinkle K. H., Joyce R., Skrutskie M. F., 2000, AJ, 120, 3255

Friedjung M., Gális R., Hric L., Petrík K., 2003, A&A, 400, 595

Gális R., Hric L., Friedjung M., Petrík K., 1999, A&A, 348, 533

González-Riestra R., Viotti R., Iijima T., Greiner J., 1999, A&A, 347, 478

Hric L., Gális R., Leedjärv L., Burmeister M., Kundra E., 2014, MNRAS, 443, 1103

Iijima T., 1981, in Carling E. B., Kopal Z., eds, Photometric and Spectroscopic Binary Systems. Kluwer, Dordrecht, p. 517

Meinunger L., 1979, IBVS, 1611

Mikołajewska J., Kenyon S. J., Mikołajewski M., Garcia M. R., Polidan R. S., 1995, AJ, 109, 1289

Robinson L., 1969, Peremennye Zvezdy, 16, 507

Sion E. M., Ready C. J., 1992, PASP, 104, 87

Smith V. V., Cunha K., Jorissen A., Boffin H. M. J., 1996, A&A, 315, 179

Schwarzenberg-Czerny, A., 1991, MNRAS, 253, 198

Sokoloski J. L., Bildsten L., Ho W. C. G., 2001, MNRAS, 326, 553

Sokoloski, J. L., Kenyon, S. J., Espey, B. R., 2006, ApJ, 636, 1002

Tomov, N. A., & Tomova, M. T. 1997, in Physical Processes in Symbiotic Binaries and Related Systems, ed. J. Mikołajewska, Copernicus Foundation for Polish Astronomy, Warsaw, 185

Warner B., 1995, Cataclysmic Variable Stars. Cambridge University Press, Cambridge

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Report on observational activity in (summer) 2015

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Abstract: A short report on the author's observational activity in 2015 and the last 20 years is given. In total this means almost 900 nights, about a half million of CCD frames and thousands of photometric measurements.

Abstrakt: Krátká zpráva zahrnuje přehled pozorovacích aktivit autora nejen v roce 2015, ale také za posledních 20 let. V souhrnu to představuje takřka 900 nocí, půl milionu CCD snímků a tisíce fotometrických měření.

Introduction

The unusual summer of 2015 provided a unique opportunity for high observational activity in Central Europe. There were 53 observational nights in the astronomical summer that the author used for photometric measurements of variable stars, namely eclipsing binaries. This situation, together with a later personal jubilee, prompted the author to do a review of his observational career.

Observatories

The observations in 2015 were made at five observatories:

- Masaryk University Observatory (MUO) – The observatory is located close to the city centre on Cow Hill. The main telescope is a 60cm Newton equipped with a Moravian instruments camera G2-4000 with Johnson BVRI filters. During the summer a mini-telescope (34mm refractor on table mount EQ1 with CCD camera G2-402 with Johnson BVRI filters) was also used. The observatory belongs to the Department of Theoretical Physics and Astrophysics, Faculty of Science, Masaryk University, Brno. http://astro.physics.muni.cz/observatory/
- Leopold Figl Observatory (FOA) is the facility of the Department of Astrophysics at the University of Vienna. It is situated in a forest 60 km to the southwest of Vienna. In collaboration with Vienna University we can use the main telescope – 150cm reflector with a SBIG ST10 camera upon request. https://astro.univie.ac.at/en/foa/home/
- Hvar Observatory was established in 1972 as a joint endeavor of the Council for Scientific work of the Socialistic Republic of Croatia and the Astronomical Institute of the Czechoslovak Academy of Sciences, Ondřejov. The first telescope was a 60cm reflector with a photoelectric photometer. Later the Faculty of Geodesy of the University of Zagreb together with the University of Vienna installed a 1.06m Ritchey-Chrétien (Austro-Croatian Telescope, ACT) telescope at the Croatian site. This telescope is now waiting to be upgraded. It is currently used with a small CCD camera G2-402. http://oh.geof.unizg.hr/
- Tübitak National Observatery (TUG) is located 40 km above Antalya, Turkey. There are several telescopes, but in cooperation with dr. Volkan Bakis we used only the newest one, 61cm Ritchey-Chrétien telescope of Akdeniz University Antalya equipped with an Apogee CCD camera. http://www.tug.tubitak.gov.tr/
- La Silla Observatory belongs to the European Southern Observatory (ESO). It is the oldest ESO site with several telescopes. Until September 2018, we'll continue to use the Danish Ritchey-Chrétien 154cm telescope every year for several nights from January to March and from October to December. The camera on this telescope has a 2k*2k CCD with a pixel scale of 0.40" and a FOV of 13 arcmin. The telescope and camera can be controlled remotely. http://www.eso.org/public/teles-instr/lasilla/danish154/

The observational programs

We participated in several observational and research programs. With Turkish colleagues we continue with EVRENA project which concentrates on the study of eclipsing binaries in young open clusters and associations. Recent statistical studies show a high ratio of multiplicity in stellar formation regions (SFRs). Therefore a detailed study of multiple systems in SFRs, especially eclipsing systems, provides fundamental stellar parameters more directly and with higher precision than a study of individual stars.

Stellar evolution, a crucial part in the evolution of especially close binary stars, is the main aim of the project with our Chinese colleagues, which is concentrated on near contact binaries (NCBs). NCBs are systems where components (almost) fill their Roche lobes. It is important to establish how different types of these systems evolve to/from the contact stage.

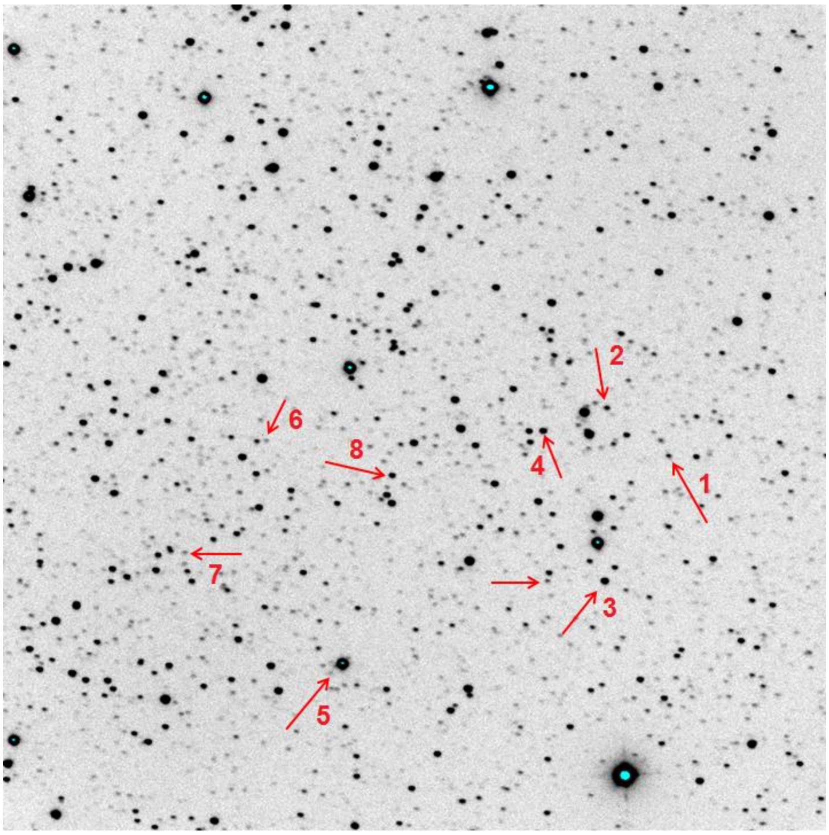

Figure 1: The surroundings of two well-known eclipsing binaries QU Cyg and QX Cyg. CCD frames from MUO 0.6m telescope + CCD camera G2-4000, R-filter.

In this study we observed several selected systems in our Galaxy and in the Magellanic clouds. A small example of these observations are shown in the small field of the Cygnus constellation. This region, 13 x 13 arcmins (see Fig. 1), is rich in variable stars. Most of them are eclipsing binaries (EBs). The Italian amateur astronomer, Nello Ruocco, discovered three new eclipsing variables in this field. Another one is known from the HAT survey and two others were found by the author. Table 1 shows the list of eclipsing binaries that were discovered. We here found a real laboratory with all types of EBs and we were able to test both types of modelling – physical and phenomenological, respectively.

Table 1. The list of eclipsing binaries located in the area surrounding QU and QX Cygni

No.	Star	*Discoverer*	*Type*	*M_0*	*P* [d]
1	**QU Cyg**		E	2455561.62442	0.34691087
2	**QX Cyg**		E/DW	2456339.78501	0.89949448
3	**GSC 03137-03322**	HAT	EB	2455390.6286	0.70532533
4	**2MASSJ19584213+3814080**	NR	EA	2456054.6233	1.920791
5	**2MASSJ19590752+3808528**	MZ	EA	2456238.465	1.194
6	**3UC257_183634**	NR	EB	2456157.3340	0.5269
7	**3UC257_183888**	MZ	EW	2457265.368	0.612162
8	**2MASSJ19585960+3813158**	NR	DSCT/E?	2456148.4440	0.2486

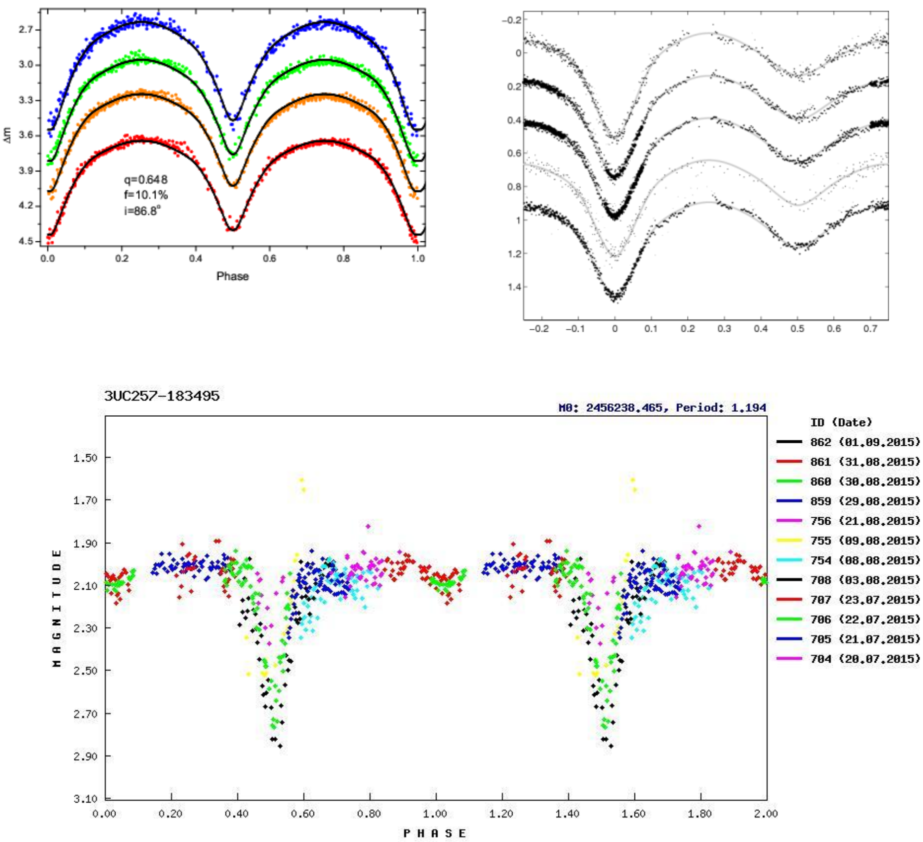

Figure 1: The light curves of studied systems. Upper left: QU Cyg – BVRI curves with fits according to the physical model made by WD (taken from the paper Zejda et. al, 2016). Upper right: QX Cyg – BVRCI curves with fits according to the phenomenological model (taken from the paper Zejda et. al, 2016). Bottom: The light curve in R of a newly found Algol-like variable (2MASSJ19590752+3808528) from the MUO and FOA observatories.

Table 1 also shows the light ephemeris obtained by phenomenological modelling using all available photometric data. The complete results will be published this year in a prepared paper.

Another observational activity was aimed at obtaining new data of neglected short periodic variables, mainly NCBs. There are more than 1500 eclipsing variable stars in SIMBAD brighter than 12 mag (V) with their number of references lower than 6. They are thus practically unstudied, without sufficient and detailed photometry and modelling. Such stars can be observed very well by many amateurs to obtain very useful new data.

Observations in 1995-2015

The personal jubilee of the author was a good opportunity to look back and summarize the observational activities over the last two decades. The results are given in the graph in Figure 2. The observations were done at 14 observing places in Europe, Asia, New Zealand, and South America using telescopes over a wide range of diameters from 0.03m to 2m. The number of stars in one CCD frame varied from 3 to about 25000. Assuming an average of 100 stars in one frame, 50 million photometric measurements were made. There are many variable star observers around the world. Summing their output, one can reach a fascinating number of photometric measurements that is comparable with the largest survey.

Conclusion

A summary of observations of variable stars made by the author in the summer of 2015 was introduced. The results based on these observations will be published in individual papers of studied objects and as a list of brightness minima of eclipsing binaries.

Two decades of observations made over almost 900 nights produced half a million CCD frames and more than 50000 individual measurements done by photoelectric photometer.

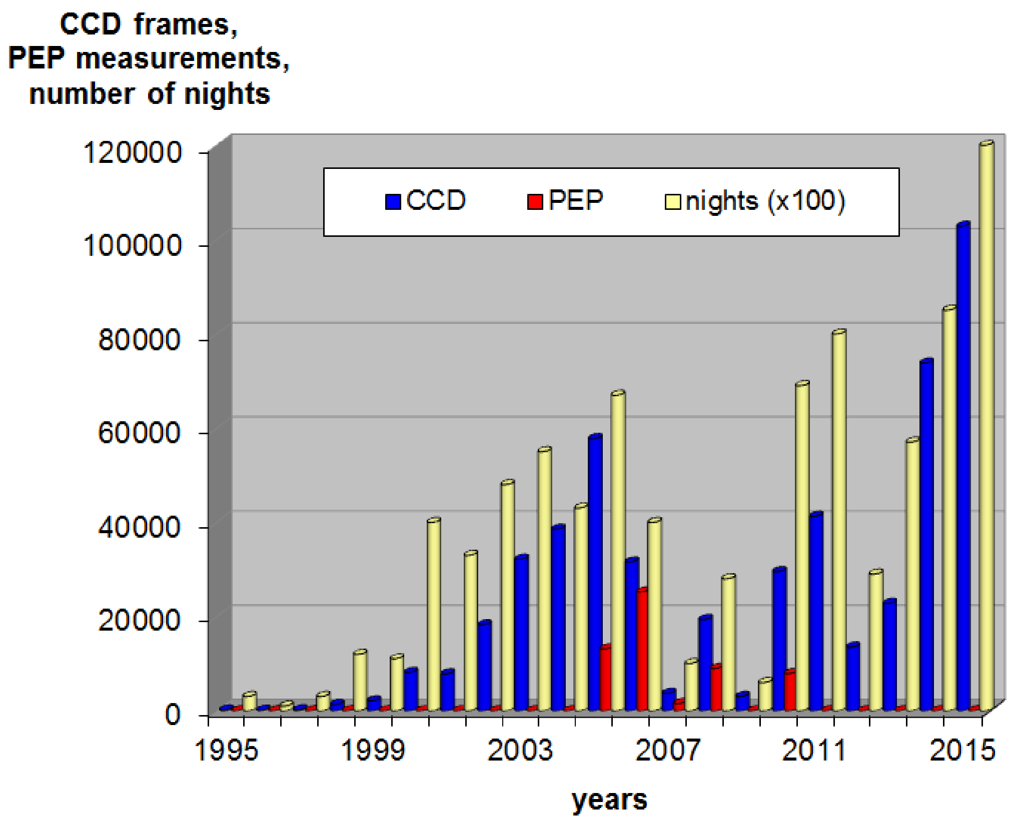

Figure 2: The observational statistics: Numbers of CCD frames, photometric measurements done by photoelectric photometer and number of observational nights scaled by a factor of 100.

Acknowledgement

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References

Zejda, M., Mikulášek, Z., Zhu, L.-Y., Qian, S.-B., Pribulla, T., Vaňko, M., Ruocco, N., 2016, in preparation

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Phemenological Modeling of Eclipsing Binary Stars

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Abstract: We review the method NAV ("New Algol Variable") first introduced in 2012Ap.....55..536A which uses the locally-dependent shapes of eclipses in an addition to the trigonometric polynomial of the second order (which typically describes the "out – of – eclipse" part of the light curve with effects of reflection, ellipticity and O'Connell). Eclipsing binary stars are believed to show distinct eclipses only if belonging to the EA (Algol) type. With a decreasing eclipse width, the statistically optimal value of the trigonometric polynomial *s* (2003ASPC..292..391A) drastically increases from ~2 for elliptic (EL) variables without eclipses, ~6-8 for EW and up to ~30-50 for some EA with narrow eclipses. In this case of large number of parameters, the smoothing curve becomes very noisy and apparent waves (the Gibbs phenomenon) may be seen. The NAV set of the parameters may be used for classification in the GCVS, VSX and similar catalogs. The maximal number of parameters is m=12, which corresponds to s=5, if correcting both the period and the initial epoch. We have applied the method to few stars, also in a case of multi-color photometry (2015JASS...32..127A), when it is possible to use the phenomenological parameters from the NAV fit to estimate physical parameters using statistical dependencies. For the one – color observations, one may estimate the ratio of the surface brightnesses of the components. We compiled a catalog of phenomenological characteristics based on published observations. We conclude that the NAV approximation is better than the TP one even for the case of EW – type stars with much wider eclipses. It may also be used to determine timings (see 2005ASPC..335...37A for a review of methods) or to determine parameters in the case of variable period, using a complete light curve modeling the phase variations. The method is illustrated on 2MASS J11080447-6143290 (EA-type), USNO-B1.0 1265-0306001 and USNO-B1.0 1266-0313413 (EW-type) and compared to various other methods from the literature.

Introduction

Numerous discoveries of the variable stars and the variety of their types of variability argue for a necessity of adequate mathematical methods, which will allow the best modeling. Of course, the best is to determine physical parameters of the stars (masses, radii, temperatures, magnetic field etc.). However, the majority of discoveries are being done using photometrical observations only (sometimes even with one or even no a filter). In this case, one may determine only so-called „phenomenological" parameters needed for determine its classification adopted in the „General Catalogue of Variable Stars" (GCVS, Samus', 2015), „Variable Star Index" (VSX[7]) – co-ordinates, precession, maximum and minimum brightness, type of variability, and, if periodic, the period P and the initial epoch T_0. An important parameter is D (the full width of the minimum in eclipsing binaries in per cent of the period) or, alternately, $M-m$ (phase difference between the „Maxima" (M) and minima (m) for periodic pulsating variables, also in per cent of the period).

In the GCVS classicafication, the Algol-type stars (EA) have the property that „it is possible to specify, for their light curves, the moments of the beginning and end of the eclipses", contrary to other types – EB and EW, in the „light curves for which it is impossible to specify the exact times of onset and end of eclipses".

In this paper, we discuss the algorithm NAV („New Algol Variable") introduced by Andronov (2010, 2012) and illustrate it by an application to newly discovered variables – an EA-type system 2MASS J11080447-6143290 (Nicholson 2009), as the "main" star, and EW-type systems USNO-B1.0 1265-0306001 and USNO-B1.0 1266-0313413 (Hambsch 2007). More detailed description of the method and its application to other stars was presented by Andronov, Tkachenko & Chinarova (2016).

[7] http://aavso.org/vsx

Methods of the analysis

Trigonometrical polynomials: asymmetric vs. asymmetric

We use a set of complementary methods. The periodogram analysis is carrried out using the trigonometric polynomial (TP) approximation of order s of the light curve

$$x(t) = C_1 + \sum_{j=1}^{s} (C_{2j} \cos(2\pi fj(t-\bar{t})) + C_{2j+1} \sin(2\pi fj(t-\bar{t}))), \quad (1)$$

where $\bar{t}$ is the sample mean of times of the observations, $f = 1/P$ - frequency, and C_α are the coefficients computed the method of the least squares (MLS). The test-function $S(f) = \sigma_C^2 / \sigma_O^2$, where σ_C^2, σ_O^2 are variances of the „calculated“ and „observed“ values at the times of the observations. The function was described by Andronov (1994, 2003) and has a sense of the square of the correlation coefficient between the observational and computed values (sometimes referred as r^2). The MLS is statistically justified, contrary to simplified methods of „Fourier Transform“ (FT), which use formulae derived for a restricted case of equidistant data only. From mathematical point of view, this means that some or many elements of the normal equations are set to zero instead of being computed and taken into account (e.g. Deeming, 1975, Lomb, 1976, Scargle, 1982). Mikulášek (2007) noted this as a „frequent syndrome of variable stars observers, which could be named *Matrixphobia*“.

In our program, the coefficients are determined using correct formulae. Moreover, our program „Multi-Column View“ (MCV), Andronov & Baklanov (2004) allows to make periodogram analysis with taking into account the possible algebraic polynomial trend of needed degree, contrary to the method of „prewhitening“, a kind of methods with a „*Matrixphobia*“.

In Fig. 1, the periodograms for some degrees of the trigonometrical polynomial fit are shown. One may see that there is no peak at the true period for $s = 1$, but occurs at $s \geq 2.$. This is explained by two nearly equal eclipses seen in Fig. 2, so formally the „better“ photometric period is twice smaller than the true one. With an increasing s, the height and number of peaks increase. It should be noted, that the peak at the true period remains lower than at the half-period even for a relatively large degree of the trigonometrical polynomial $s = 8$. This is explained by a very narrow eclipse (what is indeed typical for the EA – type systems), because much larger values of are needed for better approximation.

Another problem is to determine the statistically optimal degree of the trigonometrical polynomial s. Andronov (1994, 2003) and Andronov & Marsakova (2006) discussed criteria based on:

1. the Fischer statistics with setting the limiting value of the „False Alarm Probability" (FAP);

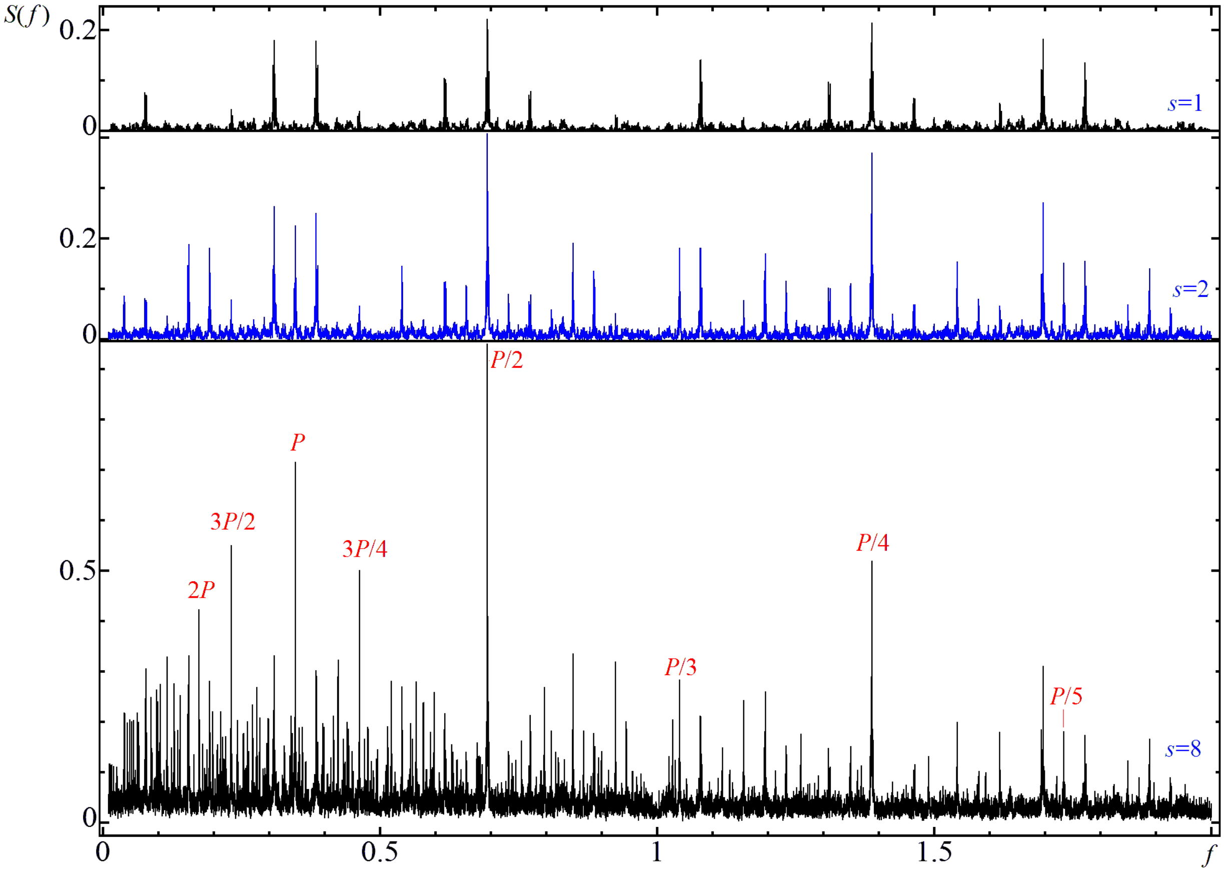

Figure 1: Periodograms $S(f)$ using trigonometric polynomial fits of orders $s = 1, 2, 8$. The positions of peaks related to the main period are marked.

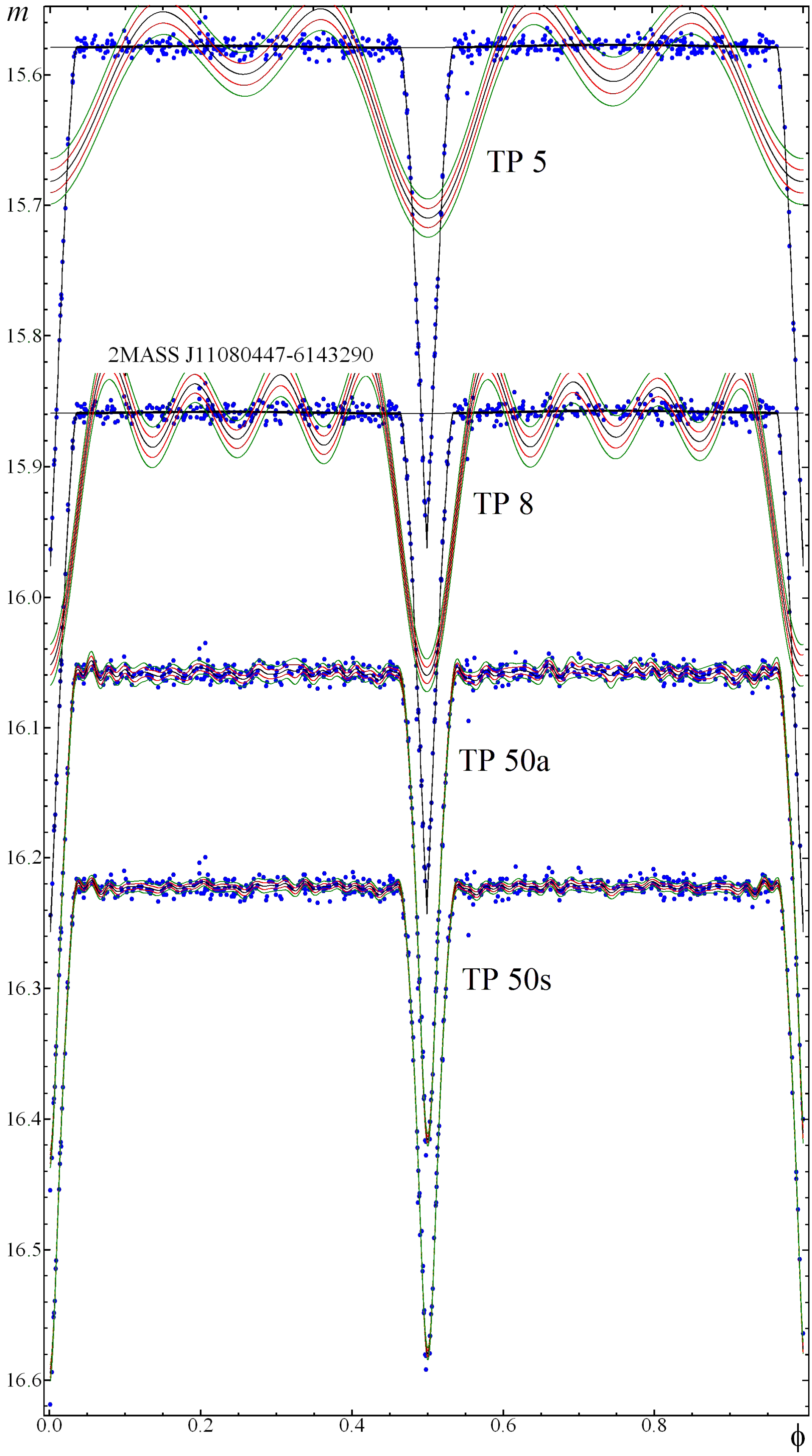

Figure 2: Trigonometric polynomial approximations of orders $s = 5, 8, 50$ („a" – asymmetric and „s" – symmetric). The „$\pm 1\sigma$" and „$\pm 2\sigma$" error corridors are shown in red and green.

2. the minimization of the error estimate (with modifications – r.m.s. error of the smoothing function at all observations $\sigma[x_C]$; at some specific time or phase $\sigma[x_C(t_0)]$; or of the time of the extremum $\sigma[t_e]$);

3. the maximum „signal-to-noise“ ratio $\sigma_C / \sigma[x_C]$, i.e. the ratio of the r.m.s. deviation of observations from the sample mean to the r.m.s. error of the approximation.

In Fig. 2, the TP approximations are shown for different values of the parameter s, which argue for larger number of s. also we show the „large order“ fits in Fig. 3 is shown the dependence of the coefficients of the „symmetric“ trigonometric polynomial fit

$$x(t) = C_1 + \sum_{j=1}^{s} C_{j+1} \cos(2\pi fj(t - T_0)), \qquad (2)$$

where T_0 – is the „initial epoch“, which, in this case, is the point of symmetry of the calculated light curve. Generally, the asymmetric fit is needed to check the presence of the asymmetry (the O'Connell (1951) effect). For this star, the asymmetry is not statistically significant, thus we do not show the coefficients. Also the even coefficients C_{2k+1} do not exceed the „ $\pm 3\sigma$ “ corridor and formally are not statistically significant. They describe the difference in the shape of the minima, so they are small for this star with similar minima. This is not the case for the systems with significantly different minima, e.g. 2MASS J11080308-6145589 (Andronov, Tkachenko & Chinarova, 2016). However, the cumulative effect of these coefficients is present, and there is a small difference in depth between the two minima, as is seen in Fig. 2, and will be discussed below.

Very interesting is a dependence of the even coefficients C_j, $j = 2k$ on j. It resembles a one-sided gaussian, and is well approximated as

$$C_j = A \exp(-Bj^2) \qquad (3)$$

with the parameters $A = 0.0459, B = 0.00345$ obtained using non-linear MLS. This differs for a nearly linear decrease seen for another EA – type star 2MASS J11080308-6145589 at Fig. 4 of Andronov, Tkachenko & Chinarova (2016).

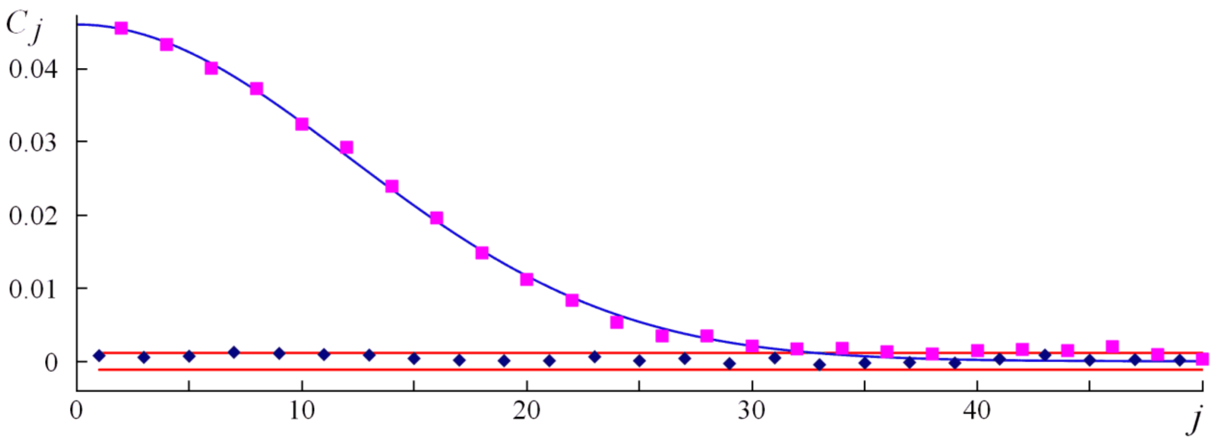

Figure 3: The coefficients of the „symmetric“ TP approximation: the even ones C_{2k} are shown by squares and the odd ones C_{2k+1} – by rombs. The red horizontal lines show the „ $\pm 3\sigma$ “ corridor. The blue line is a gaussian – type approximation.

Using the „ $\pm 3\sigma$ “ criterion, the statistically optimal degree is $s = 46$. If avoiding the coefficients within the wider „ $\pm 8.9\sigma$ “ corridor, one may suggest a significantly smaller value $s = 28$. However, even using a larger value $s = 50$, the approximations do not fit well in depth both minima (Fig. 2). Similarly to Fig. 8 of Andronov et al. (2016), the brightness at minima (both primary and secondary) of the approximation decreases with j, even if the coefficients are statistically not significant.

Combined „constant – line“ approximation

For a comparison, in Fig. 4 we show the „sampling“ approximation of the phase light curve using 50 sub-intervals, as typically used as the input data for the programs of physical modeling (e.g. Zoła, Kolonko. & Szczech, 1997, Zoła, S., Gazeas, K., Kreiner, J.M. et al., 2010). Contrary to an usual method of computing sample mean values in each sub-interval, and creating a set of weighted „observations“ $(\bar{t}, \bar{x}, \sigma[\bar{x}])$, in the program MCV (Andronov & Baklanov, 2004), we realized a combined method: the data in the current sub-interval are approximated by a constant and by a line (algebraic polynomials of the degrees $p=0$ and $p=1$, respectively). Then the approximation is chosen, for which the error estimate of the smoothing function at the mean moment of observations is smaller.

This definitely has an advantage at the intervals of drastic changes (ascending and descending branches). At the out-of-eclipse phases, the line becomes „better“ for a few times, when the number of points in the interval is too small (2 – 3), so statistical errors have bad accuracy themselves. The resulting table of the observations remains the same for the line and constant, but the error estimates at the ascending and descending branches become more realistic, because systematic deviation of the curve from a constant overestimates the stastistical error, and so underestimates the weight of the mean point.

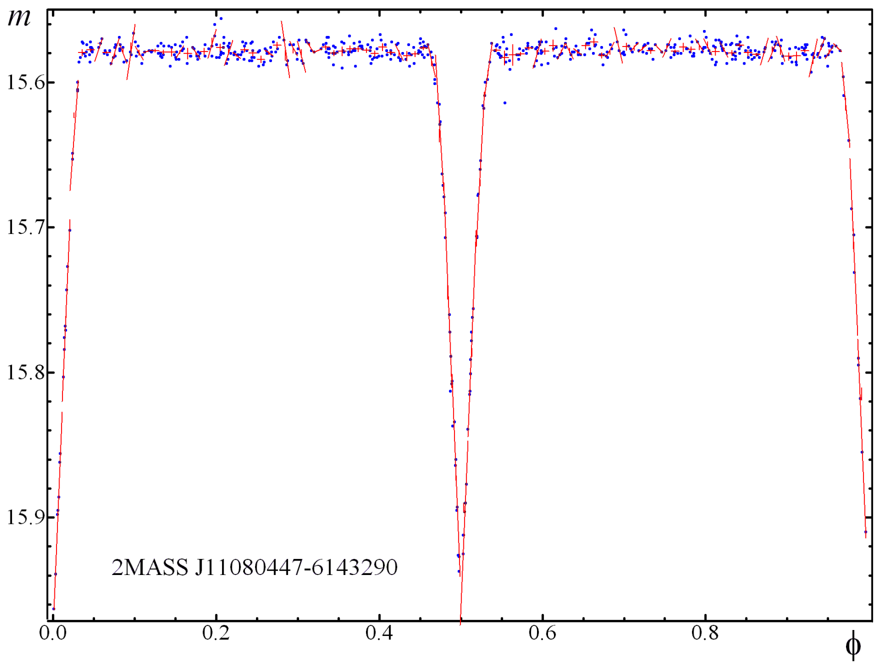

Figure 4: Approximation of the phase light curve (blue points) by a constant / line in 50 phase intervals (red lines).

Because the lines from individual sub-intervals do not form a joint continuous function, the approximation may be described as the „polynomial spline of degree 1 and defect 2“. An application of splines to variable stars was discussed by Andronov (1987). However, in future analysis, only a discrete set of such averaged observations is needed, thus this discontinuity of the smoothing curve is replaces by a continuous light curve obtained from phenomenological or physical modeling.

Similar approximation was used for fast periodogram analysis by Marraco & Muzzio (1980). They have used only linear approximations, but in MCV the statistically better (among „constant“ or „line“) approximation is chosen.

Obviously, the mean points computed in this manner, can not be outside of the interval of observational values. However, the extrapolation in the sub-intervals close to the minimum can, and we see sharp „triangle – shaped“ minima, contrary to the more smooth trigonometric polynomials.

Comparison of the approximations of the eclipses

For the determination of the moments of eclipses, which is the major activity of studies at small telescopes, the most popular method in the computer era is the method of Kwee and van der Woerden (1956), which is implemented in the commercial software PERANSO[8] . This method makes a „saw-tooth"-like (spline of power 1 and defekt 1) interpolation of the observations in the user-determined interval (near the extremum), and then a search of the „symmetry point" is determined with a discontinuous derivative, what may significantly underestimate the statistical error. So Mikulášek, Chrastina, Liška et al. (2014) recommend to „retire" this method.

Sometimes may occur an error due to a „division by a zero", if the observations contain points with equal arguments (e.g. observations at the same time from different observers) or phases (e.g. determination of the initial epoch for the phase light curve containing observations from different cycles of variability). In our realization of the method in the program „Observation Obscurer" (first version introduced by Andronov (2001)), the points with equal arguments are averaged.

Despite formally one may determine an interpolated value of the extremum, the error estimate of the interpolated value is typically is not defined.

Other methods are based on the least squares (e.g. Anderson 1958, Andronov 1994, 2003, Mikulášek, 2007, 2015, Chrastina, Mikulášek, & Zejda, 2014). Kurochkin (1963), Nikonov (1971) and many further authors recommend to use for the approximation of the observation in the interval around trial extremum by an algebraic polynomial of degree p

$$x(t) = C_1 + \sum_{j=1}^{p} C_{j+1}(t - T_p)^j , \qquad (4)$$

where T_p is some time close to (or inside) the interval near the extremum.

Then the moment of extremum may be found by solving the equation $x'(t_e) = 0$, e.g. using the iterations $t_e := t_e - x'(t_e)/x''(t_e)$ with an error estimate $\sigma[t_e] = \sigma[x'(t_e)]/|x''(t_e)|$ (e.g. Andronov, 1994, 2005, Mikulášek, 2007, 2015). Contrary to the software PERANSO, which asks the user for the degree of the polynomial p, we prefer to use the statistically optimal value, which corresponds to the best accuracy of the timing $\sigma[t_e]$. Using this algorithm, Chinarova & Andronov (2000) determined characteristics of 6509 extrema, which are the part of their „Catalogue of Main Characteristics of Pulsations of 173 Semi-Regular Stars".

Another method of „asymptotic parabola" fit was developed by Marsakova & Andronov (1996), where the smoothing function is a spline with different degree (1;2;1), or two lines connected with a parabola in such a way that the function and its first derivatives are continuous. This method is effective for pulsating variables with asymmetric extrema, but needs determination of the interval near each extremum, which has nearly linear parts of the ascending and descending branches. Recently Andrych, Andronov, Chinarova et al. (2015) realized both these methods in the VBA program. A comparison of the algebraic polynomial vs. „asymptotic parabola" may be seen in Fig. 5.

An extension of the method of algebraic polynomials is again a spline with a special shape $H(z) = H(-z)$, which is monotonically decreasing from $H(0) = 1$ to $H(1) = 0$ and $H(z) = 0$ for $|z| \geq 1$. Here $z = (\phi - \phi_0)/\Delta\phi$, where ϕ_0 is the phase of symmetry of the minimum (typically 0 and 0.5 for the primary and secondary minimum, respectively, but may be corrected, if shifted), and $\Delta\phi$ is a half-duration of the eclipse.

[8] http://peranso.com

The simplest form of such function may be $H(z)=1-|Z|^{\beta}$. In Fig. 6, the approximations are shown for $\beta=1$ (triangle), $\beta=2$ (parabola) and also symmetric polynomial of degrees 4 $(H(z)=1-(1-D_4)z^2-D_4z^4)$ and 6 :

$$H(z)=1-(1-D_4-D_6)z^2-D_4z^4-D_6z^6 \qquad (5)$$

Here we used an „out-of-eclipse“ part of the curve, which is approximated (for this star with flat maxima) by a constant, so $x(\phi)=C_1+C_2H((\phi-C_3)/C_4)$.

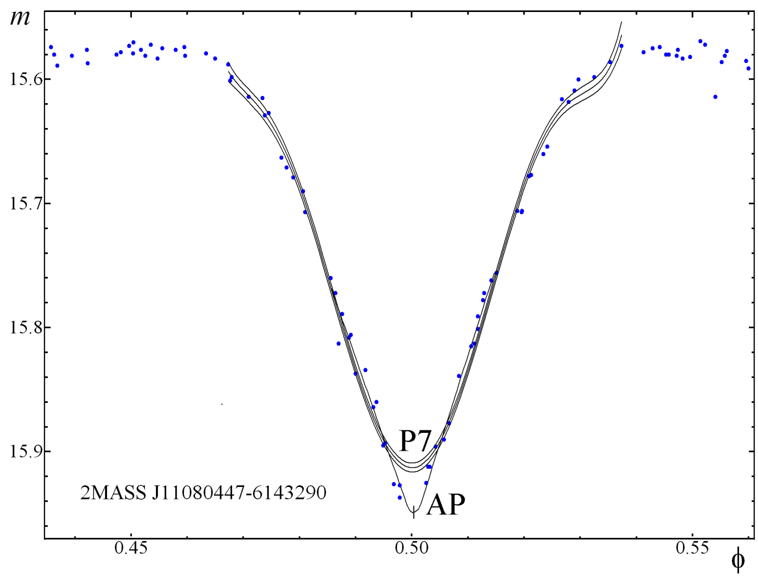

Figure 5: Approximation of the part of the phase light curve near the secondary minimum (blue points) by the polynomial with 7 parameters (6-th order) „P7“, for which the „ $\pm 1\sigma$ “ error corridor is shown, and the „asymptotic parabola“ („AP“) fit.

Moreover, the coefficients in Eq. (5) may be renamed as $C_5=D_4, C_6=D_6$. Even the visual comparison shows that the best approximations are „S1“ and „S6“. Next two fits are based on the gaussian: $H(z)=\exp(-z^2/2)$ and its highly improved version listed in Eq.(14) of Mikulášek (2015):

$$H(z)=(1+C_6z^2+C_7z^4)(1-(1-\exp(1-\cosh(z)))^{C_5}) \qquad (6)$$

Generally, one may expect that, with an increasing number of the parameters, the quality of the fit will increase. And this was exelently illustrated by Mikulášek (2015) for a case of short ascending/descending branches and a „shallow parabola-like” minimum during a planet transit in the system HD209458b.

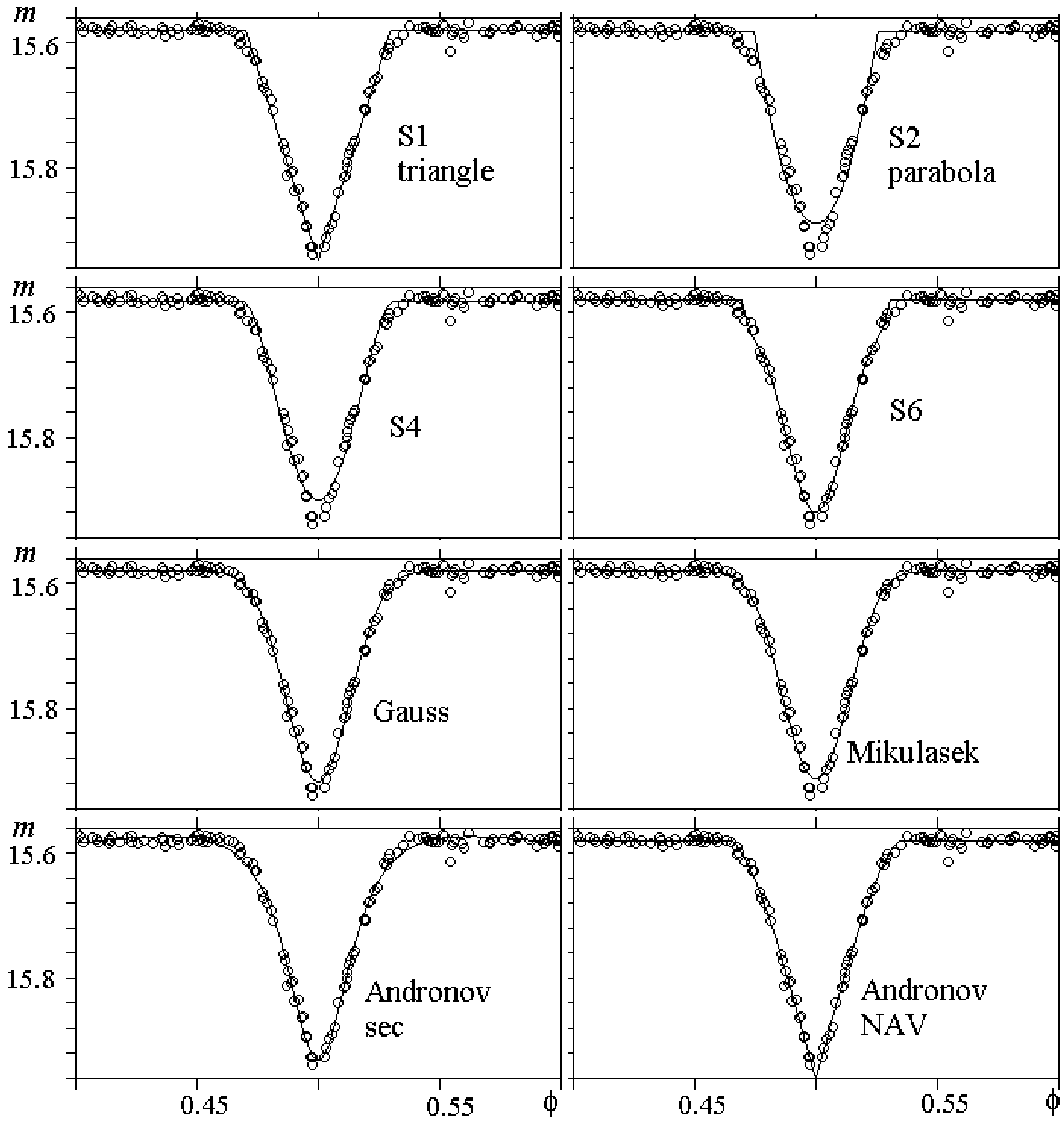

Figure 6: The approximations of the vicinities of the secondary minimum using various approximations described in the text.

However, for our example of the EA – type star with no „plateau“ at the bottom of the eclipse, the function (6) describes the light curve (particularly, the depth of the minimum) even worse than the gaussian. The approximations „S1“ and „S6“ are worse for a complete light curve, but better in depth of the minimum.

Another extension of the hyperbolic function was proposed by Andronov (2005) for the case of the asymmetric maxima (pulsations or outbursts), assuming asymptotically exponential rise and decay:

$$H(z) = \frac{1}{\exp(-z) + \exp(+C_5 z)} \tag{7}$$

In the case of symmetric minima (assumed for eclipsing binaries without O'Connell effect), this function may be simplified to $H(z) = 1/(2\cosh(z))$, or, better, to scale by a factor of 2: $H(z) = 1/\cosh(z) = \mathrm{sech}(z)$. The corresponding fit is worse near the beginning/end of the eclipse, but better at the center of the eclipse. One may try other modifications with additional parameters (in an order of decreasing importance) like

$$H(z)=(1+C_7z^2+C_8z^4)\mathrm{sech}^{C_5}(|z|+C_6z^2). \quad (8)$$

Both the gaussian and the functions (6), (7), (8), despite good approximating properties, do not allow to determine the width of the minimum (which is one of the main parameters „*D*“ needed to register the star in the „General Catalogue of Variable Stars“ (Samus‘, 2015)), as the corresponding functions $H(z)$ formally reach zero only asymptotically, but not at the finite values of $|z|=1.$ To solve this problem, Andronov (2010, 2012) proposed to use a locally defined function, and, among few, had chosen

$$H(z)=(1-|z|^{C_5})^{3/2}. \quad (9)$$

This function has a correct asymptotic behaviour at $|z|\to 1$, and was found to be effective for dosens of eclipsing binaries already studied. It seems also to be the best in Fig. 6. This phenomenological approximation was called „NAV“ („New Algol Variable“).

The initial algorithm for a fixed phase curve (i.e. the period and the initial epoch determined using other methods, e.g. the trigonometrical polynomial fit of statistically optimal degree) was improved in such a way, that the period and the epoch are determined as additional „non-linear“ parameters. Obviously, one may add terms taking into account any model of the period variations similar to other fits (cf. Andronov, 1987, Mikulášek, 2015).

The fits and raw graphs shown in Fig. 6 were obtained using the trial version of the software WinCurveFit v. 1.1.2 (Kevin Raner Software), which realized determination of the coefficients of the non-linear models. Unfortunately, the program works unstable, and the solution often does not converge even with good initial point. Other fits were computed using MCV (Andronov & Baklanov, 2004) and other own programs. In the Table 1, we list some characteristics of some fits for a comparison.

As the quality of the fit we use the value of r^2 (best, if equal to unity), but, for the quality of the fit near the mid-eclipse, we use the value at the minimum and redefine $C_1=x(\phi_0)$. In this case, we introduce the function $G(z)=1-H(z)$, so $x(\phi)=C_1-C_2G((\phi-C_4)/C_3)$.

Table 1: Characteristics of the fits of observations near the secondary minimum. The error estimates are in parenthesis in units of the last decimal digit.

$G(z)$	$C_1 = x(\phi_0)$	C_2	$C_3 = \Delta\phi$	$C_4 = \phi_0$	C_5	C_6	σ_0
NAV: $1-(1-\lvert z\rvert^{C_5})^{3/2}$	15.9586(50)	0.3794(52)	0.03489(41)	0.499908(84)	1.083(30)		0.99581
sech2: $(1-\mathrm{sech}(z))(1+C_5 z^2)$	15.9312(32)	0.3614(35)	0.01135(19)	0.499970(116)	-0.00073(17)		0.99253
sech1: $(1-\mathrm{sech}(z))$	15.9346(34)	0.3609(34)	0.01082(15)	0.499979(124)			0.99121
Sech3: $(1-\mathrm{sech}(z))^{C_5}$	15.9175(42)	0.3420(46)	0.00936(34)	0.499981(118)	1.415(115)		0.99229
Kwee &van Woerden (1956)				0.499905(167)			
S1: $\lvert z\rvert$	15.9483(25)	0.3684(26)	0.02985(23)	0.499932(102)			0.99381
S2: z^2	15.8884(40)	0.3055(43)	0.02534(31)	0.499965(208)			0.97538
S4: $(1-C_5)z^2 + C_5 z^4$	15.8994(31)	0.3185(34)	0.03148(85)	0.499887(157)	-1.00(11)		0.98748
S6: $(1-C_5-C_6)z^2 + C_5 z^4 + C_6 z^6$	15.9192(28)	0.3393(30)	0.0304(33)	0.499956(105)	-3.51(21)	1.73(14)	0.99382
Gauss: $(1-\exp(-z^2/2))$	15.9166(24)	0.3379(25)	0.01321(13)	0.499932(106)			0.99412
Mikulášek: $(1-\exp(1-\cosh(z)))^{C_5}$	15.9164(28)	0.3377(31)	0.1356(9746)	0.499931(107)	105(1512)		0.99411
Mikulášek: $(1-\exp(1-\cosh(z)))^{C_5}(1+C_6 z^2)$	15.9165(28)	0.3372(40)	0.1676(20966)	0.499932(107)	161(4038)	0.010(236)	0.99411
$(1-\exp(1-\cosh(z)))^{C_5}(1+C_6 z^2 + C_7 z^4)$	15.9159(28)	0.3407(70)	0.1251(10409)	0.499930(107)	88(1461)	-0.086 (1506)	0.99416
Asymptotic parabola ($m=5$)	15.9489(38)			0.500223(20)			
Polynomial (best, *m* = 7 parameters, 6th degree)	15.9126(36)			0.499996(203)			
Symmetric polynomial (*m* = 10, 18th degree)	15.9385(46)			0.499934(95)			
Trigonometric polynomial (*m* = 93, 46th degree)	15.9244(21)						

Some fields are missing because the sets used for different methods are different: the trigonometrical polynomial fit is computed for all the data $(n = 560)$; the asymptotic parabola – for the smallest interval near mid-eclipse (points 276..305 after sorting in phase), where the ascending/descending branches were nearly linear; the remaining approximations were done for the points 264..319. The observations were sorted according to phases computed for the ephemeris (Table 2) obtained for the NAV fit for all data. The best accuracy (smallest $\sigma[\phi_0]$) is estimated for the asymptotic parabola fit, the second one in this reyting is the NAV fit, which is preferrable because of using the complete light curve and thus all phenomenological parameters may be determined. Previous studies (Andronov, 2012, Andronov, Tkachenko and Chinarova, 2016) had shown that the NAV fit typically has much smaller r.m.s. statistical error than the trigonometric polynomial, even if the accuracy of the curve is nearly the worst near the phases of mid-eclipses due to sharper shape than that of the trigonometrical polynomial.

A comparison of the exponent-based fits shows that the complification of the basic functions (the gaussian, the hyperbolic secant) makes minor improvements to the quality of the fit, but the error estimates of the additional parameters typically exceed these parameters by a factor of many times.

Discussion of the NAV approximation of the complete curve

As was shown above, the basic function („special shape“) for the eclipse is $H(z;\beta) = (1-|z|^{\beta})^{3/2}$, $-1 \le z \le +1$, where $\beta = C_5$ is the parameter describing behaviour close to the mid-eclipse (0 – very narrow, 1 – triangular, 2 – parabolic, >>2 – flat).

The complete function includes a TP2 part (a trigonometrical polynomial of the second order), which approximates three effects: reflection, ellipticity and O'Connell and has 12 parameters, including two for the corrected initial epoch and the period (Andronov, Tkachenko & Chinarova, 2016):

$$x(\phi) = C_1 + C_2\cos(2\pi(\phi-\phi_0)) + C_3\sin(2\pi(\phi-\phi_0)) + C_4\cos(4\pi(\phi-\phi_0)) + C_5\sin(4\pi(\phi-\phi_0)) + \\ + C_6 H((\phi-\phi_0)/C_8; C_9) + C_7 H((\phi-\phi_0-0.5)/C_8; C_{10}). \qquad (10)$$

In previous works (Andronov, 2012), we used $\phi_0 = 0$, but, in this recent work, we added two parameters $(C_{11,}\ C_{12})$ to correct the initial epoch and the period. Of course, when needed, it is possible to add more parameters to describe the possible period changes.

Some of these and related parameters are listed in Table 2. The corresponding light curves are shown in Figure 7. It is clearly seen, that the eclipses are well pronounced not only for the EA star, but also for two EW-type variables.

This is also seen in 6 more stars analyzed by Tkachenko, Andronov & Chinarova (2015). The „zero amplitudes“ of the „eclipse shapes“ appear only in low-amplitude stars, where the variability is due to ellipsoidality only, without any eclipses. An additional advantage of such parametrization is also a possibility to estimate the degree of eclipse $Y = d_1 + d_2$ (equal to zero, if no eclipses, and unity, if both eclipses are total) and the ratio of the mean brightnesses at the maximum phase of primary and secondary eclipses $\gamma = d_1/d_2$. If neglecting the limb darkening, this will be the ratio of the brightnesses of the limbs of two stars, so one may estimate physical parameters, as the „first guess“ (="initial values") for the physical modeling. Details and references to this model, may be found in Tkachenko & Andronov (2013).

Table 2: Phenomenological characteristics of the eclipsing variable stars.

Star	2MASS J11080447-6143290	USNO-B1.0 1265-0306001	USNO-B1.0 1266-0313413
Reference	Nicholson (2009)	Hambsch, 2007	Hambsch, 2007
T_0	2450941.22839(16)	2454300.36951(28)	2454312.87437(12)
P	2.88349387(38)	0.57930071(41)	0.3003726(34)
$\Delta\phi$	0.03480(27)	0.11901(131)	0.10902(120)
$Y = d_1 + d_2$	0.5978(43)	0.2686(46)	0.2548(36)
$\gamma = d_1/d_2$	1.0288(125)	1.5389(337)	1.0971(203)

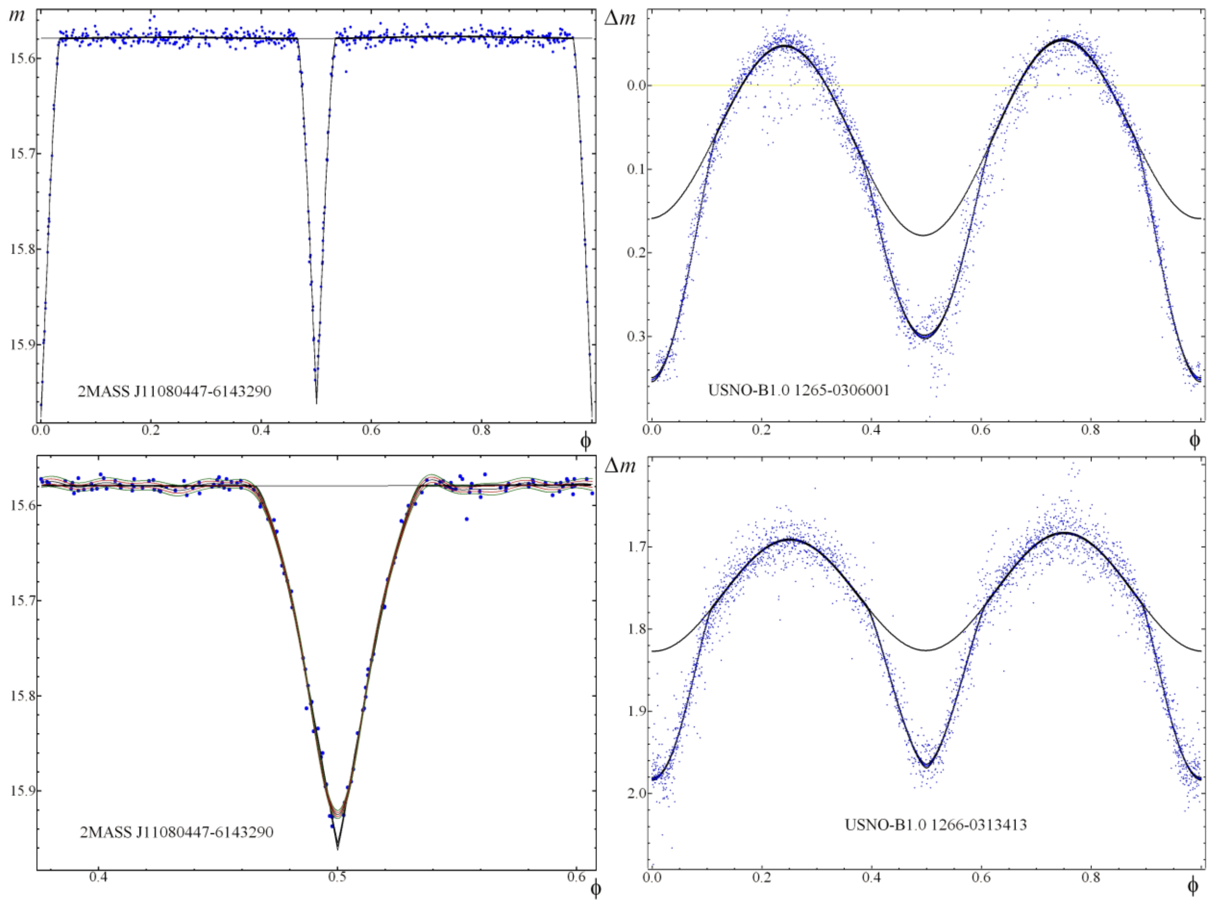

Figure 7: The NAV fits for the EA-type star (left) and two EW-type stars (right). At the bottom left figure, the vicinities of the secondary minimum are shown with the NAV and TP46 fits. The line above the fit at the phase interval of the eclipse is a TP2 part of the Eq. (10), which describes possible reflection, ellipticity and the O'Connell effects.

Multi-color observations

While searching the „Open European Journal on Variable Stars“[9] for multicolor observations of eclipsing binaries (3 – 4 filters), we have found only the papers by Jurýšek & Hoňková (2012) and Devlen (2015). Such observations are important to determine color indexes and to estimate temperatures of the stars, what allows to make estimates of the physical parameters using phenomenological modeling. An example of such an analysis using the statistical „mass-radius-temperature-luminosity“ relations was presented by Andronov, Kim, Kim et al. (2015) for the system 2MASS J18024395 + 4003309 = VSX J180243.9+400331.

Summary

Different methods for an approximation of the light curve either „global“ (i.e. a complete light curve), or local (intervals near minima), are compared. The characteristics of variability of the three stars chosen for the analysis, show an efficiency of the NAV algorithm. Even if more complicated models may be comparable in accuracy, the smallest possible number of the NAV parameters and their cleas physical sense is the advantage. The corrected values of the period and the initial epoch are more accurate than that obtained by other methods, sometimes by a factor of many times. Thus the NAV algorithm is recommended to be used for phenomenological modeling of newly discovered or poorly studied stars, for which the physical modelling is impossible (in the sense of solution in the region of the parameter space instead of the single point) because of unknown temperatures and mass ratios.

[9] http://var.astro.cz/oejv

In future, we plan to compile a catalogue of characteristics of a group of eclipsing binaries with published original observations – either that needed for the GCVS, or additional ones proposed while applying the method.

References

Anderson, T.W. 1958, An Introduction to Multivariate Statistical Analysis, J.Wiley & Sons, 374p.

Andrych, K.D., Andronov, I.L, Chinarova, L.L., Marsakova, V.I. 2015, Odessa Astron. Publ., 28, 158

Andronov, I.L. 1987, Publ. Astron. Inst. Czechoslovak. 70, 161

Andronov, I.L. 1994, Odessa Astron. Publ., 7, 49

Andronov, I.L. 2001, Odessa Astron. Publ., 14, 255

Andronov, I.L. 2003, ASP Conf. Ser., 292, 391

Andronov, I.L. 2005, ASP Conf. Ser., 335, 37

Andronov, I.L. 2010, Int. Conf. KOLOS-2010 Abstract Booklet, 1,

Andronov, I.L. 2012a, Astrophysics, 55, 536

Andronov, I.L. 2012b, Częstochowski Kalendarz Astronomiczny 2013, ed. B.Wszołek & A. Kuźmicz, 133,

Andronov, I.L. & Baklanov, A.V. 2004, Astronomy School Reports, 5, 264

Andronov, I.L., Kim, Yonggi, Kim, Young-Hee, Yoon, Joh-Na, Chinarova, L.L.& Tkachenko, M.G. 2015, Journal of Astronomy and Space Science, 32, 127

Andronov, I.L. & Marsakova, V.I. 2006, Astrophysics, 49, 370

Andronov, I.L.& Tkachenko, M.G. 2013, Odessa Astron. Publ., 26, 204

Andronov, I.L., Tkachenko, M.G. & Chinarova, L.L. 2016, Phys.J., 2, 140

Chinarova, L. L. & Andronov, I. L. 2000, Odessa Astron. Publ., 13, 116

Chrastina, M., Mikulášek, Z. & Zejda, M. 2014, Contributions of the Astronomical Observatory Skalnaté Pleso, 43, 422

Deeming, T.J. 1975, Ap&SS, 36, 137

Devlen, A. 2015, OEJV, 171, 1

Hambsch, F.-J. 2007, OEJV, 67, 1

Juryšek, J. & Hoňková, K. 2012, OEJV, 152, 1

Kwee, K. K. & van Woerden, H. 1956, Bull. Astron. Inst. Netherlands, 12, 327

Lomb, N.R. 1976, Ap&SS, 39, 447

Marraco, H. G. & Muzzio, J. C. 1980, PASP, 92, 700

Mikulášek, Z. 2007, OAP, 20, 138

Mikulášek, Z. 2015, A&A, 20, 584A, 8

Mikulášek, Z., Chrastina, M., Liška, J., Zejda, M., Janík, J., Zhu, L.-Y. & Qian, S.-B.

Nicholson, M.P. 2009, OEJV, 102, 1

O'Connell, D.J.K. 1951, Publ. Riverview Coll. Obs., 2, 85

Tkachenko, M.G., Andronov, I.L. & Chinarova, L.L. 2015, Odessa Astron. Publ., 28, 181

Samus', N.N. (ed.) 2015, General Catalog of Variable Stars

Scargle, J.D. 1982, ApJ, 263, 835

Zoła, S., Kolonko, M. & Szczech, M. (1997). Analysis of a Photoelectric Light Curve of the W UMa-Type Binary ST Ind. A&A, 324, 1010

Zoła, S., Gazeas, K., Kreiner, J.M., Ogloza, W., Siwak, M., Koziel-Wierzbowska, D. & Winiarski, M. 2010, MNRAS, 408, 464

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BRITE – constellation
Project of astronomical nanosatellites

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Abstract: Description of international project of astronomical nanosatellites BRITE is given. The project is open for collaborative ground-based photometric and spectroscopic (amateur) observations.

Abstrakt: Je uveden popis mezinárodního projektu astronomických nanosatelitů BRITE. Podpůrná pozemní fotometrická a spektroskopická pozorování objektů v projektu jsou vítána. Uplatnění tak mohou nalézt i amatérští pozorovatelé.

Introduction

The project BRITE was established according to successful Canadian project MOST about 2004 as a joint Canadian-Austrian project. Later Poland joined the project. Between February 2013 and August 2014, all six nanosatellites were launched. Five of them are working in their orbit, but the last one was not deployed from the platform. The first BRITE science conference Science with BRITE-Constellation: initial results was held in Gdansk, Poland, 14-18 September 2015. The conference presentations are available on this webpage https://www.camk.edu.pl/konferencje/brite_science/.

BRITE nanosatellites

Nanosatellites of the project BRITE are cubes with edges of 20 cm and weights less than 8 kg. For details see Figure 1. The main equipment on board is a five-lens (in 5 cases, in Heweliusz satellite only four-lens) telescope with an aperture of 3 cm and an interline CCD detector from Kodak, KAI 11002-M. The field of view is 24 degrees and the resolution is 30 arcseconds per pixel. Each of the participating countries has a pair of nanosatellites with different fixed photometric filters – see Figure 2.

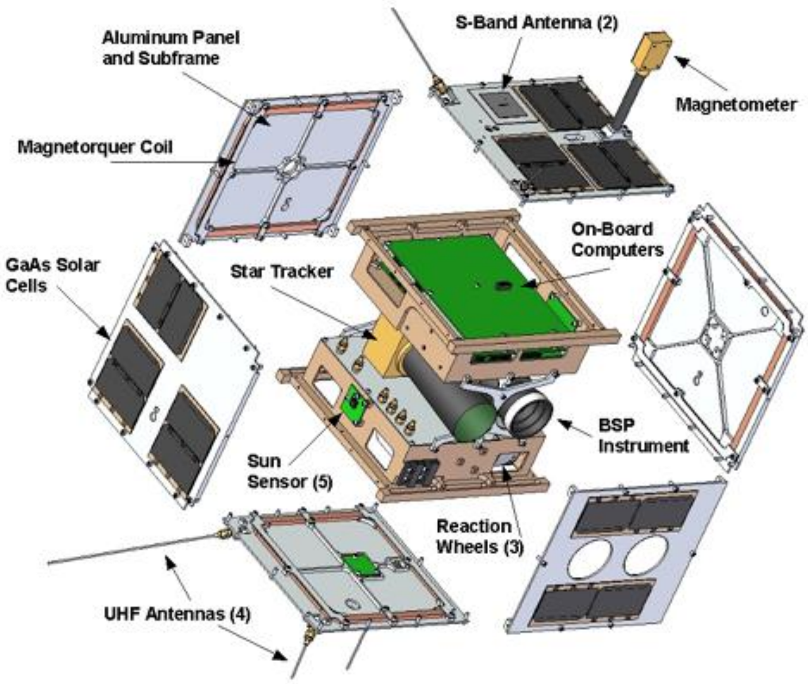

Figure 1: The structure of BRITE nanosatellite. Image taken from brite-constellation.at, http://www.urania.edu.pl/wiadomosci/polski-satelita-naukowy-lem-wystartuje-za-miesiac.html

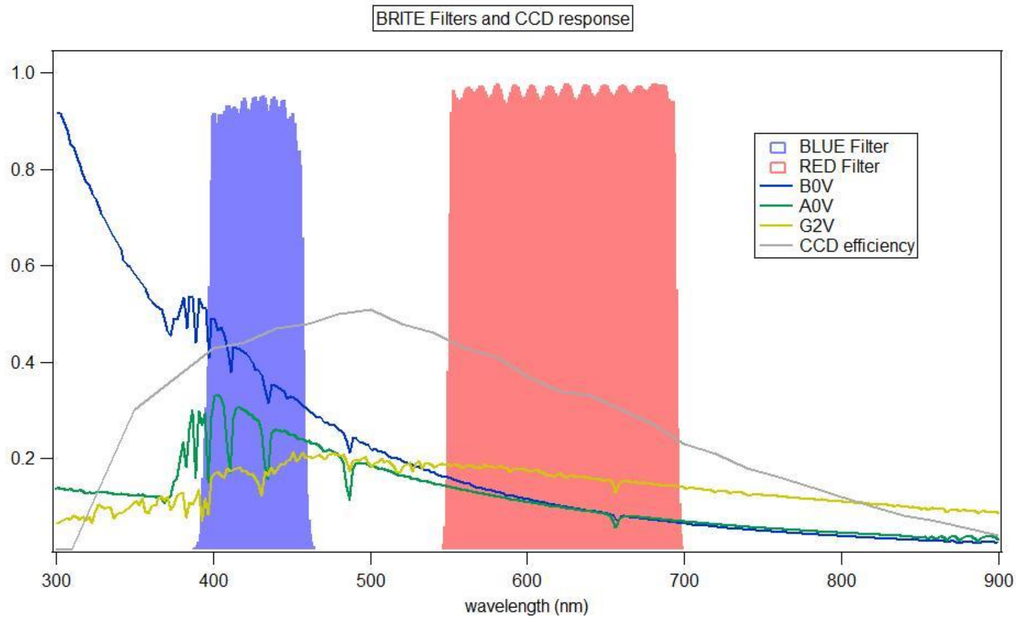

Figure 2: Photometric filters used on board of the BRITE satellites. Image taken from http://www.univie.ac.at/brite-constellation/html/filters.html

Targets of observations

The brightest stellar objects in the sky are usually too bright to be observed by any large survey. They were observed using photoelectric photometer, but in the era of the CCD technology, they are again too bright for most telescopes and instruments. The project BRITE (BRIght Target Explorer) tries to solve this problem and fill the gap in photometric data. Furthermore, the objects in this range of magnitudes (up to 6-7 mag) are really interesting from the astrophysical points of view. For details see e.g. http://www.brite-constellation.at.

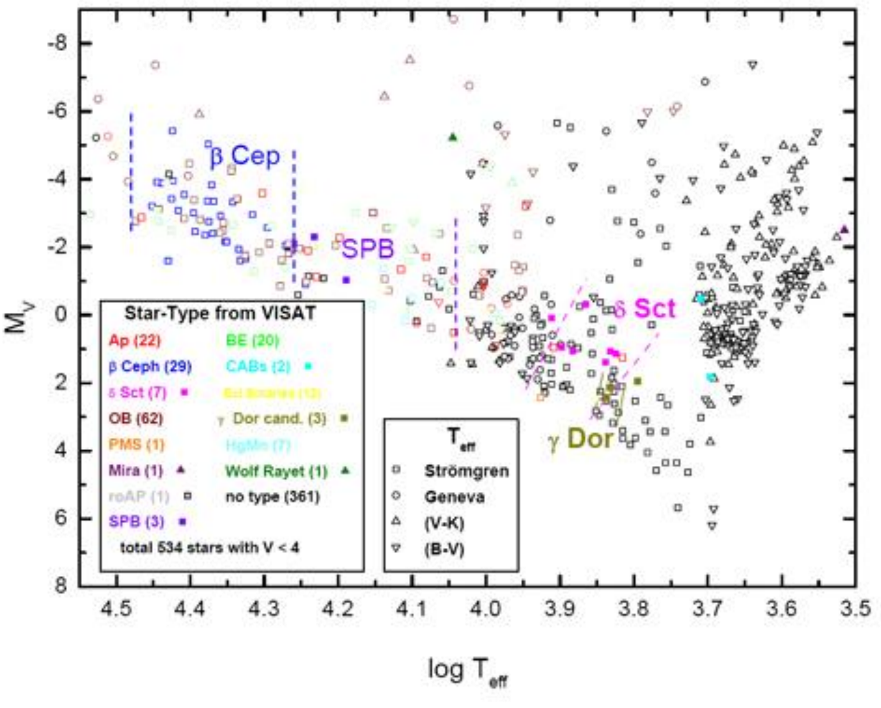

Figure 3: Hertzsprung-Russell Diagram with 534 stars brighter than V <= 4 mag with the object types taken from the VISAT (VIenna Selection of Astronomical Targets). For more detail see Weiss et al. (2014). Taken from http://casca.ca/?p=6760

Ground based support

BRITE project scientists welcome all ground based support observations, photometric as well as spectroscopic. It is very useful to have photometric data in a wide range of passbands and also spectroscopic observations of selected targets. Such supporting data should help to derive fundamental parameters for all target stars, such as effective temperatures, surface gravities, abundances, and projected rotation velocities (*v*.sin *i*). Because of the brightness of the targets, there is a wide space for collaborations and participations also for amateur astronomers. For more observations see brite-constellation.at or contact Dr. Konstanze Zwintz (konstanze.zwintz_AT_uibk.ac.at).

Conclusion

BRITE is a successful project of several photometric nanosatellites which results in high accurate photometric measurements of brighter stellar targets in the sky. The first results have been published (e.g. Baade et al., 2016, Pigulski et al., 2016, Weiss et al., 2016). The participation of other astronomers including amateurs in ground-based support observations is very much welcome.

References

Baade, D. et al., 2016 arXiv:1602.01744

Pigulski, A. et al., 2016 arXiv:1602.02806

Weiss et al. 2014, PASP 126, 573

Weiss, W. et al., 2016, arXiv:1601.04833

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(Sub-)stellar variability: from 20 M_{sol} to 13 M_{Jup}

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Abstract: Massive early-type stars vary; low-mass late-type brown dwarfs vary, too. I will make a short, but illustrative, summary of my previous studies on stellar and sub-stellar photometric variability (including the discovery of the most variable brown dwarf in the whole sky), and explain how amateurs can help professional astronomers with our investigations.

Abstrakt: U hmotných hvězd ranných spektrálních typů, ale také u málo hmotných hnědých trpaslíků, obvykle pozorujeme změny jasnosti. V tomto příspěvku podávám krátké, ale názorné shrnutí své předchozí studie hvězdné a sub-hvězdné proměnnosti (včetně objevu extréního případu dosud nejvíce se měnícího hnědého trpaslíka), a ukazuji, jak se mohou amatérští pozorovatelé zapojit do zajímavého výzkumu ve spolupráci s profesionály.

Introduction

This is the proceeding corresponding to an invited oral contribution that I gave on-line at the *47. konference o výzkumu proměnných hvězd a exoplanet*, held in November 2015 in Ostrava, Czech Republic. The conference, oriented for both professional and advanced amateur astronomers, was organised by the "Variable Star and Exoplanet Section" of the Czech Astronomical Society.

As I state in the abstract, I wished to "make a short, but illustrative, summary of my previous studies on stellar and sub-stellar photometric variability". I structured my talk exactly with the same format as another talk of mine in the IV international Pro-Am meeting on binary and multiple stars, held in September 2015 in Vilanova i la Geltrú, Spain. This decision was not taken because of laziness, but because of the favourable reception by an heterogeneous, international audience of professional and amateur astronomers with, in some cases, limitations in the use of English.

A bit of history

For warming up the audience (or, in this case, the reader), I raise a question with a debatable answer: *which was the first variable star?*

It has been widely accepted for years that the first reported variable star was Mira (o Cet), recorded for the first time by David Fabricius in August 1596. Johannes Holwarda determined in 1638 the period of photometric variability of the *nova stella* (new star) at 11 months. Later, Johannes Hevelius (1662) gave the star its current name in his work *Historiola Mirae Stellae*, and Ismaël Bullialdus (1667) determined accurately its period at 333 d, very close to the modern value of 332 d. Astronomers (or astrologists) of Babylonia, China, Korea or Greece may have discovered the Mira's variability well in advance of Fabricius, but it is is a matter of discussion among experts (Manitius 1894; Schaumberger 1935; Hoffleit 1997; Wilk 2007).

During some weeks in the Autumn of 1604, a few years before Holwarda determined an approximate period for Mira, the latest observed supernova in the Milky Way, Kepler's SN1604, was the brightest source in the night sky after the Moon. Before, in November 1572, more than two decades earlier than Fabricius found Mira to be variable, Tycho's SN1572 rivaled Venus in brightness. In summer 1054, the Chinese, as well as the Japanese (Meigetsuki), Arab (Uyun al-Anba) and, perhaps, Ancestral Puebloans (Peñasco Blanco) astrologists recorded SN1054. In Spring 1006, Zhou Keming, Shonghshi, Ali ibn Radwan, monks in Saint Gall, sky-watchers of Yemen and *most of the world population* saw SN1006, which peaked at $V \approx -7.5$ mag and was visible even during daytime. SN185 is believed to be the first supernova for which records exist (by the Chinese astronomers in the *Book of Later Han* and probably by the Romans – Stothers 1977). Supernovae (of Type Ia in the cases above) represent an extreme class of cataclysmic variable stars, so SN185 should take the Mira's place of honour as the first variable star.

Algol (β Per) was reported to be variable by Geminiano Montanari (1669), a couple of years after Bullialdus measured the Mira's period. However, according to Jetsu et al. (2013), Algol's variability was recorded by ancient Egyptian scribes in the Cairo Calendar as soon as 1224 B.C. Actually, from the scribes data, Jetsu et al. recovered an Algol's period of 2.850 d, quite similar to the value measured for the first time by Goodricke

(1873) at 2.867 d, which in turn is very close to the modern value of 2.867326 d. That Algol is really the first variable star should not be a surprise, since its name cames from the Arabic *ra's al-ghül*, which was a Mesopotamian demon and, in Indi, Algol was also known as *Majavati*, "The Changeful".

Ultracool variability

At the end of the past century, there were almost 40,000 variable stars known (e.g., as tabulated by the Combined General Catalog of Variable Stars[10]), ranging in the whole spectral type interval from O to M. At the same time, the first brown dwarfs and "ultracool" dwarfs with L and T spectral types were discovered (Rebolo et al. 1995; Nakajima et al. 1995; Delfosse et al. 1997). L and T dwarfs have effective temperatures below 2200 K and 1300 K, respectively, masses at or below the deuterium burning limit at about 0.07 M_{sol} and radii of only about 0.1 R_{sol} (i.e. 1 R_{Jup}). Their small size would facilitate the detection of Earth-size planets around them with the transiting method, but it also translates into very low luminosities and, thus, very faint magnitudes.

Before the start of my PhD thesis in October 2000, several authors had investigated the photometric variability of ultracool dwarfs, but mostly of late M dwarf stars and some early-type L dwarf, and always in the optical range (Martín & Zapatero Osorio 1997; Bailer-Jones & Mundt 1999; Terndrup et al. 1999; Tinney & Tolley 1999). The first photometric monitorisation of ultracool dwarfs in the near-infrared (*J*, *H* and *Ks* bands), where mid- and late-type L dwarfs and early-T dwarfs emit the bulk of their radiation, was accomplished during late 2000 and the whole 2001 with CAIN-2 at the 1.5 m Telescopio Carlos Sánchez in the Canary Islands. Caballero & Rebolo (2002) and Caballero et al. (2003) published some preliminary results of this monitorisation. For example, we were able to get a 1σ scatter of 8 mmag in the light curve of Kelu 1 AB, an L2+L3.5 binary dwarf of J = 13.4 mag and I = 16.8 mag (visual magnitude should be close to $V \approx 20$ mag; Fig. 1). In spite of our continued efforts, the combination of an old and relatively small telescope with an instrument of moderate field of view and suboptimal detector prevented us from detecting any transit (Caballero 2010a), but paved the way to next studies of "weather in brown dwarf atmospheres" (Goldman et al. 2008), which eventually succeeded with the first uncontrovertible detection of photometric variability in two early T dwarfs with periods of 2.4−7.7 h by Artigau et al. (2009) and Radigan et al. (2012).

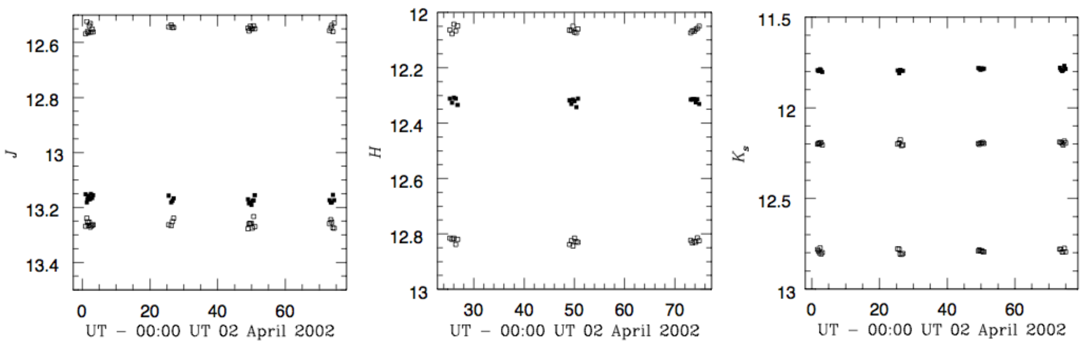

Figure 1: Temporal series of Kelu 1 AB (J1305-25, filled symbols) and of two nearby reference stars of similar brightness (open symbols) in the near-infrared *J*, *H* and *Ks* bands. The monitoring consisted on 4-h series during four consecutive nights (Caballero 2006).

Variability in σ Orionis

I applied what I learned on near-infrared photometric variability of ultracool dwarfs in the solar neighbourhood to photometric variability in the optical and near-infrared of objects of the same mass but at least ten times further… And much more variable, too! They were young low-mass and brown dwarfs in the σ Orionis cluster ($\tau \approx 3$ Ma, $d \approx 385$ pc), a star-forming region that takes its name from the homonymous σ Ori trapezium-like stellar system, which illuminates the famous Horsehead Nebula. The σ Orionis cluster is not only famous because of its prominent position in the Orion Belt, but also because of its population of X-ray emitters, discs at 3 Ma, the prototypical helium-rich magnetically-active B2Vp star σ Ori E, its Herbig-Haro objects, studies on accretion rates and frequency and, especially, the most complete cluster initial mass function (from 20 to 0.006 M_{sol}; Caballero 2008). The σ Orionis cluster is perhaps the one with the largest number of known brown dwarfs per square degree and *with low extinction*. Thus, in a single shot with a wide field imager, one can investigate the

[10] http://www.sai.msu.su/gcvs/

photometric variability of a few dozen young very low-mass stars and brown dwarfs. Because of their youth, most cluster stars are still in the T Tauri phase; photometric variability due to photospheric activity or accretion from a circumstellar disc is one of the main features of a T Tauri star. In the early 2000s the formation mechanism of brown dwarfs was not well understood, and it was not known wether they could also undergo a T Tauri phase, with all its implications.

A pilot study of optical and near-infrared variability of a young brown dwarf in σ Orionis was first accomplished by Zapatero Osorio et al. (2003). There, we investigated the brown dwarf S Ori 45, of spectral type M8.5 and approximate mass of 25 M_{Jup}. We investigated it in detail because of its kniwn strong Hα emission (another T Tauri star signpost). We found a tentative period of photometric variability in S Ori 45 of 2.5−3.6 h. This short value is at the limit of disruption of a fast rotating body, but it was expected from the angular momentum evolution of such a young low-mass body at the end of the main contraction phase.

Caballero et al. (2004) extended the analysis of S Ori 45, and studied it and another 27 brown dwarfs and very low-mass stars with the Wide Field Camera at the 2.5 m Isaac Newton Telescope in the *I* band. Perhaps not surprisingly, 50% of them displayed variability of amplitude 0.01-0.40 mag (Fig. 2). The faintest brown dwarfs in our study had magnitudes $I > 21$ mag (i.e. $V > 25$ mag) and masses close to the deuterium burning limit of 13 M_{Jup}, which is the lowest boundary of the brown dwarf domain. Below that, one enters in the planetary domain. The low-mass stars and brown dwarfs investigated by Caballero had photometric variability at all time scales: from minutes, through days, to years. Palla & Baraffe (2005) used some of the detections of very short period variability for supporting their scenario of pulsations induced by deuterium burning. Eventually, our work was cited by Trimble et al. (2006) in their *Astrophysics in 2005* review.

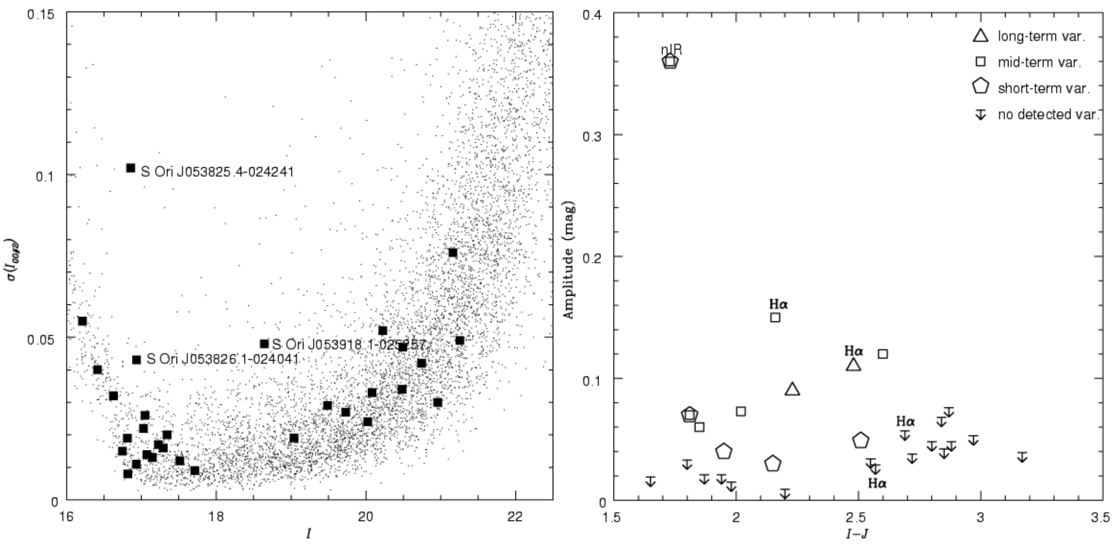

Figure 2: *Left panel:* Standard deviation of the differential light curves versus *I* magnitudes for each target (small dots) in the second WFC 2000 night. Only objects with σ(*I*) < 0.15 mag are shown. Mean photometric errors are below 5, 15 and 100 mmag for objects brighter than *I* = 18, 20 and 22 mag, respectively. Filled squares denote the brown-dwarf candidates. Short-term variable brown dwarfs are labelled. V2728 Ori is "S Ori J053825.4−024241". *Right panel:* Amplitudes of variability versus *I−J* colour. Open triangles, squares and pentagons denote long-, mid- and short-term variables, respectively. Upper limits are shown for the rest of the objects in our sample. Strong Hα emission and near-infrared excess are also indicated (Caballero et al. 2004).

As expected from a simple extrapolation of the T Tauri stellar phase to lower masses, Caballero et al. (2004) found that the stronger the Hα emission, the larger the amplitude of photometric variability of a brown dwarf. However, we had not spectroscopy collected for the most variable brown dwarf of all, dubbed V2728 Ori, for which however there were hints of near-infrared flux excess due to a circumsubstellar disc. We carried out a spectroscopic analysis of V2728 Ori using LRIS at 10.0 m Keck I and ALFOSC at the 2.6 m Nordic Optical Telescope, accompanied with a new multi-wavelength photometric monitoring mainly with the 1.5 Telescopio Carlos Sánchez in the near-infrared, the 1.0 m ESA Optical Ground Station and the 0.8 m IAC80.

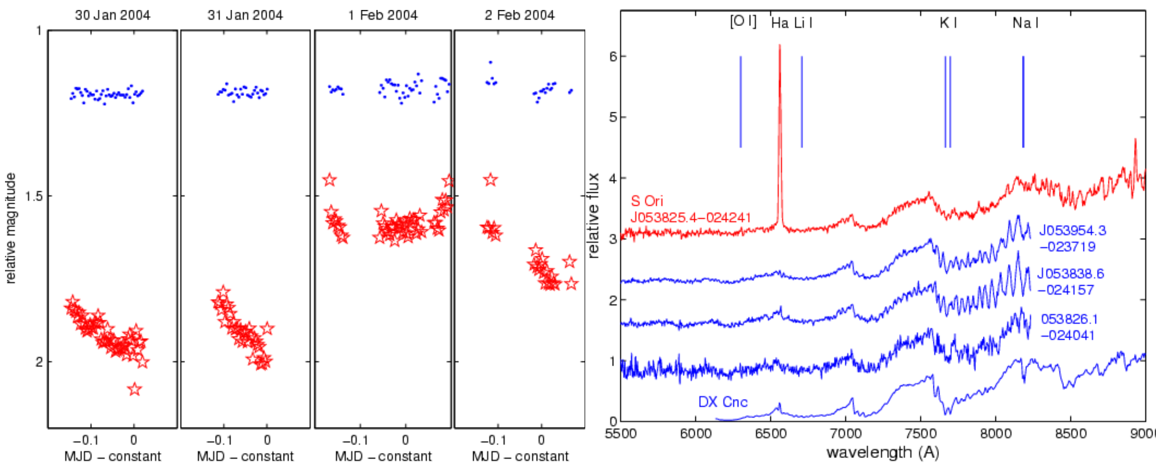

Figure 3: *Left panel*: OGS optical light curve of V2728 Ori (stars) and of a reference star (dots). Our target was monitored for 3-6 h on each of these four observing nights. *Right panel*: Low-resolution NOT spectra of σ Orionis candidates. The top spectrum corresponds to V2728 Ori. For the other objects, the data redwards of 8200 Å are not displayed because of their very poor signal-to-noise ratio. The spectrum of the field M6.5V-type dwarf DX Cnc, which has been degraded to the same resolution as the NOT data, is also displayed for comparison (Caballero et al. 2006).

Caballero et al. (2006) summarised the results of our spectro-photometric follow-up (Fig. 3). We confirmed the irregular photometric variability of V2728 Ori at all timescales. Variations, which did not show any obvious modulation pattern, were significant from blue wavelengths up to the *J* band. The maximum amplitude of variability was of 0.7 mag in scales of less than one day. The Hα line was in persistent broad emission with a pseudo-equivalent width of −250 Å, which made the brown dwarf one of the objects in Orion with the largest Hα-to-bolometric luminosities ratio. Actually, we identified other signspots of T Tauri phase, such as other permitted and forbidden emission lines, blue veiling and strong flux excess in the near- and mid-infrared (Harvey et al. 2012 found that V2728 Ori was the source with the highest disc luminosity in 70 μm and 120 μm in their *Herschel* sample). A decade later, V2728 Ori is still *the most variable brown dwarf* found to date.

The relationship between Hα emission and variability in σ Orionis was revisited again, but with a larger telescope (the 10.4 m Gran Telescopio Canarias with a filler programme) and a large sample of stars and brown dwarfs from several solar masses to a few Jupiter masses (Caballero et al. 2012). With *I* ~ 17.3 mag, and much fainter magnitudes at bluer wavelengths, V2728 Ori is not accesible to most facilities of amateur astronomers. However, Mayrit 459340 (StHa 50), with *V* ~ 11.3 mag and a timescale of variability of months, can be a nice target for them. Caballero et al. (2008) classified it as an A2-6 Ve star of about 1.4 Msol. In spite of its spectral type, it has an Hα emission of −10 Å, mid-infrared excess and very abnormal blue colours. It seems that the star is a Herbig Ae/Be UX Ori variable by which it suffers a blueing effect by an edge-on disc. However, it seems that it underwent a brightening of ~0.9 mag between 2005 and 2006 from spectra flux ratios. These episodes depend on the relative position of the star, disc and observer. In the box below I enumerate the first task that the Czech Astronomical Society (ČSA) or any other team of advanced amateur astronomers worldwide can carry out:

Task #1. Quantify long-term high-amplitude variability of Mayrit 459340 (05 38 34.4 −02 28 48)

Mayrit 459340 is not the only interesting star in the σ Orionis cluster that is accesible to amateur astronomers. For example, Manjavacas et al. (2013) measured a short period of *P* = 1.61 h and a small but significant amplitude of Δ = 0.017 mag on the bright early-type star Mayrit 524060 (HD 37564, A0 V, *V* ~ 8.5 mag). It was part of a Pro-Am collaboration and an MSc thesis in which we used the 30-cm Montcabrer telescope MPC213 for monitoring in white light a large area of σ Orionis. The interest of an star with such an early spectral type and short period is that Mayrit 524060 became one of the very few 3-Ma δ Scuti candidates known, which may make it as a cornerstone for the study of the interior of very young stars of masses slightly larger than that of the Sun. Although it has a better visibility from Italy and is being monitored already (G. Sordiglioni, priv. comm.), here it is the second task for the ČSA:

Task #2. Better constrain *P* and Δ of Mayrit 524060 (05 39 15.1 −02 31 37.6)

One can also investigate the X-ray variability of stars in σ Orionis by using public data from space missions (Caballero et al. 2009, 2010b). However, high-energy astrophysics may not be of practical interest for "Variable Star and Exoplanet Section" of any astronomical society.

Variability "off the shoulder of Orion"

With the aim of finding new interesting *photometric* variable stars similar to those in σ Orionis, Caballero et al. (2010a) used public data of the All Sky Automated Survey in a 25 deg^2-area covering the Orion Belt (including the purported clusters around Alnilam –ε Ori– and Mintaka –δ Ori–, and the Flame Nebula near Alnitak –ζ Ori–). They identified the 32 most variable bright stars in the area: 16 young Herbig Ae/Be an T Tauri stars, 8 giants (see one example in Fig. 4) and 8 miscellanea stars (cataclysmic, eclipsing, contact binaries). Of them, 16 stars are new, which are related to the third task for the ČSA:

Task #3. Improve light curves of the 16 new Orion Belt variable stars (V = 11.5-15.0 mag)
- 6 giants
- 6 eclipsing and poorly-known variables
- 4 young stars: Mayrit 528005 AB, Kiso A-0903 135, StHa 48, HD 290625

Coordinates provided by Caballero et al. (2010a)

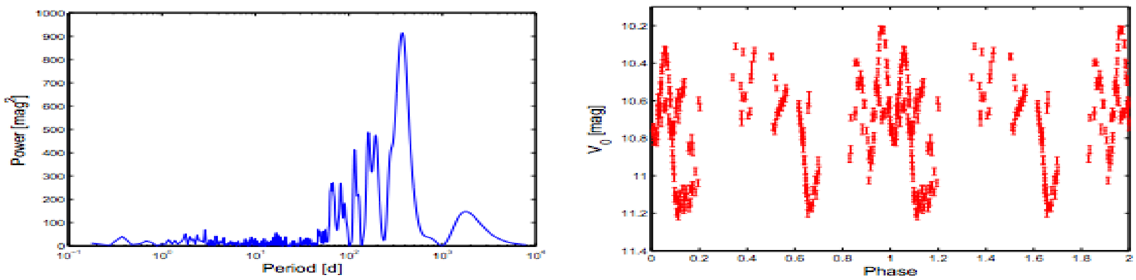

Figure 4: *Left panel*: Periodogram of the ASAS light curve of the new variable giant IRAS 05354–014. *Right panel:* phase-folded light curve of IRAS 05354–0142 to the period P = 373.31 d. This extremely red, high-amplitude variable star could be V1299 Ori (Caballero et al. 2010a).

Some of the four young Orion Belt stars that can be followed with amateur telescopes could resemble V1247 Ori, a Herbig Ae/Be star with very particular occultation events as deep as 1.20-1.65 mag in V band (Caballero 2010b; Fig. 5). The star is however very stable out of occultation, which is probably originated by clumps in a gapped pre-transitional disc (Caballero & Solano 2008; Kraus et al. 2013). With $V \approx 9.85$ mag, V1247 Ori is also available to amateur facilities.

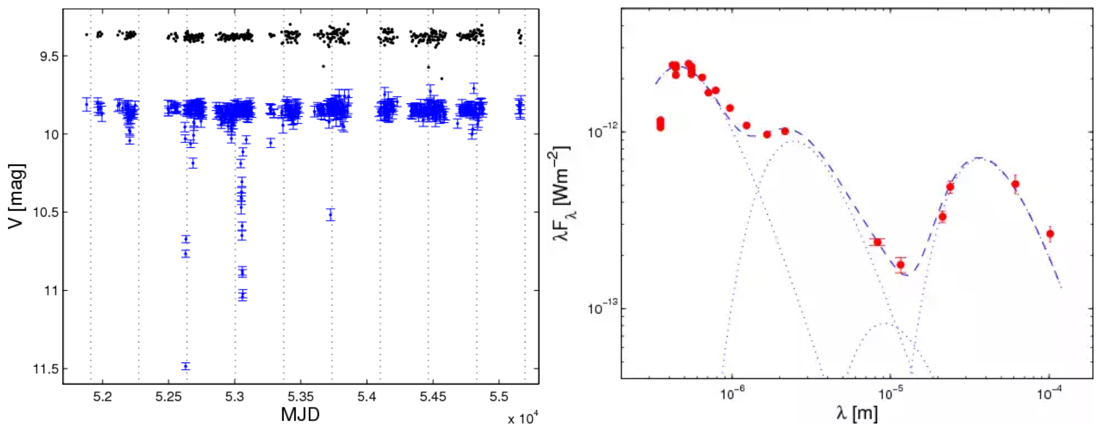

Figure 5: *Left panel:* ASAS light curves of V1247 Ori (bottom blue error bars) and a nearby, slightly brighter, field late-K star for comparison (HD 290760, ρ ~ 19 arcmin; top, dots). Vertical dotted lines indicate the first day of the years 2001 to 2010. The two main occultations events in V1247 Ori occurred in 2002 Dec. (V_{min} = 11.50 mag) and 2004 Feb. (V_{min} = 11.05 mag). Note the seasonal gaps. *Right panel:* Spectral energy distribution of V1247 Ori. Data points correspond, from left to right, to $U, B_T, B, V_T, V, R_C, R, I_C, I, J, H, Ks$, and 8, 12, 21, 25, 60, and 100 μm. Only as a guidance and without any fitting purpose, four spherical black bodies of T_{eff} = 8000, 1500, 400 and 100 K are plotted with dotted blue lines. The result of combining the four black bodies is marked with a dashed blue line (Caballero 2010b).

M-dwarf variability, CARMENES and exoplanets

In the last half a dozen years, I have been deeply involved in a new project. CARMENES *[kár-men-es]* (Calar Alto high-Resolution search for M dwarfs with Exoearths with Near-infrared and optical Échelle Spectrographs[11]) is a next-generation instrument built for the 3.5m telescope at the Calar Alto Observatory by a consortium of German and Spanish institutions (Quirrenbach et al. 2014). It consists of two separated spectrographs covering the wavelength ranges from 0.52 to 0.96 μm and from 0.96 to 1.71 μm with spectral resolutions R = 80,000−100,000, each of which performs high-accuracy radial-velocity measurements (∼1 m s^{-1}) with long-term stability. The fundamental science objective of CARMENES is to carry out a survey of ∼300 late-type main-sequence stars with the goal of detecting low-mass planets in their habitable zones. We aim at being able to detect 2 M_{Earth} planets in the habitable zone of M5V stars. The CARMENES first light with the two NIR and VIS channels working simultaneously occured in Nov 2015; the science survey of Guaranteed Time Observations started on 01 Jan 2016 and will last for at least three years.

CARMENCITA, the CARMENES Cool star Information and daTa Archive, is the M-dwarf database from where we will choose our best target sample of ~300 M dwarfs (Caballero et al. 2013; Alonso-Floriano et al. 2015). CARMENCITA currently catalogues about 2200 carefully-selected M dwarfs northern of $\delta > -23$ deg. For each star, we tabulate dozens of parameters (accurate astrometry, spectral typing, photometry in 20 bands from the ultraviolet to the mid-infrared, rotational and radial velocities, X-ray count rates and hardness ratios, close and wide multiplicity data and many more) compiled from the literature or measured by us with new data. The private on-line catalogue, including preparatory science observations (i.e., high-resolution imaging, low- and high-resolution spectroscopy), will be eventually public as a CARMENES legacy.

We study the variability of our CARMENCITA stars, especially of the 300 GTO targets. For the ones with exoplanet candidates, we will do a photometric follow-up with a battery of telescopes (1.23 m Calar Alto, 1.2 m TIGRE HRT, 0.8 m IAC80, LCOGT.net...). The aim of this follow-up is to discriminate between planetary signal and rotation period after a radial-velocity detection. However, we have also done a target preparatory work of compiling in advance all available photometric periods from the literature (Hidalgo 2015). These periods, together with $v\sin i$ from our high resolution spectra and stellar radii from theorical models, allow us to derive the stellar inclination angle i. Since the higher the inclination, the higher the transit probability, we have identified a few M dwarfs that should be monitored in detail: any transiting earth-size planet with a precise radial-velocity curve obtained with CARMENES would be a cornerstone for planetary studies, especially if the planet lies in the stellar habitable zone. After this, here it comes my last task to the ČSA:

Task #4. Confirm photometric periods of three CARMENCITA M dwarfs
- J00428+355 (FF And): i = 81 deg, P = 2.17 d, V = 10.4 mag
- J05068−215E (BD−21 1074A): i = 79 deg, P = 13.3 d, V = 10.4 mag
- J13007+123 (DT Vir AB): i = 79 deg, P = 2.89 d, V = 9.75 mag

Coordinates provided by Simbad

Conclusions

The "Variable Star and Exoplanet Section" of the Czech Astronomical Society *and any amateur astronomer in the world* can do a lot of useful things! Hopefully, the examples of what I have done on stellar and substellar photometric in variablity during my career and the tasks proposed here may help them to do new exciting science.

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[11] http://carmenes.caha.es

References

Alonso-Floriano, F. J., Morales, J. C., Caballero, J. A. et al. 2015, A&A, 577, A128

Artigau, É., Bouchard, S., Doyon, R., Lafrenière, D. 2009, 701, 1534

Bailer-Jones, C. A. L. & Mundt, R. 1999, A&A, 348, 800

Bullialdus, I. 1667, *Ad astronomos monita duo*

Caballero, J. A. 2006, PhD thesis, Universidad Complutense de Madrid, Spain

Caballero, J. A. 2008, A&A, 478, 667

Caballero, J. A. 2010a, ASSP, 14, 79

Caballero, J. A. 2010b, A&A, 511, L9

Caballero, J. A. & Rebolo, R. 2002, ESASP, 485, 261

Caballero, J. A. & Solano, E. 2008, A&A, 485, 931

Caballero, J. A., Béjar, V. J. S., Rebolo, R. 2003, IAUS 211, 455

Caballero, J. A., Béjar, V. J. S., Rebolo, R., Zapatero Osorio, M. R. 2004, A&A, 424, 857

Caballero, J. A., Martín, E. L., Zapatero Osorio, M. R. et al. 2006, A&A, 445, 143

Caballero, J. A., Valdivielso, L., Martín, E. L., Montes, D., Pascual, S., Pérez-González, P. G. 2008, A&A, 491, 515

Caballero, J. A., López-Santiago, J., de Castro, E., Cornide, M. 2009, AJ, 137, 5012

Caballero, J. A., Cornide, M., de Castro, E. 2010a, AN, 331, 257

Caballero, J. A., Albacete-Colombo, J. F., López-Santiago, J. 2010b, A&A, 521, A45

Caballero, J. A., Cabrera-Lavers, A., García-Álvarez, D., Pascual, S. 2012, A&A, 546, A59

Caballero, J. A., Cortés-Contreras, M., Alonso-Floriano, F. J. et al. 2013, *Protostars and Planets VI*, Heidelberg, 15-20 July 2013. Poster #2K020

Delfosse, X., Tinney, C. G., Forveille, T. et al. 1997, A&A, 327, L25

Goldman, B., Cushing, M. C., Marley, M. S. et al. 2008, A&A, 487, 277

Goodricke, J. 1783, RSPT, 73, 474

Harvey, P. M., Henning, T., Liu, Y. et al. 2012, ApJ, 755, 67

Hevelius, J, 1662, *Historiola Mirae Stellae*

Hidalgo, D. 2015, MSc thesis, Universidad Complutense de Madrid, Spain

Hoffleit, D. 1997, JAVSO, 25, 115

Jetsu, L., Porceddu, S., Lyytinen, J. et al. 2013, ApJ, 773, 1

Kraus, S., Ireland, M. J., Sitko, M. L. et al. 2013, ApJ, 768, 80

Manitius, K. 1894, *Hipparchi in Arati et Eudoxi Phaenomena Commentariorum libri tres*

Manjavacas, E., Caballero, J. A., Naves, R., Creevey, O. L., Tingley, B. 2013, *Highlights of Spanish Astrophysics VII*, Valencia, 9-13 July 2012. 658

Martín, E. L. & Zapatero Osorio, M. R. 1997, MNRAS, 286, L17

Montaniari, G. 1669, *Prostasi fisicomatematica*

Nakajima, T., Oppenheimer, B. R., Kulkarni, S. R. et al. 1995, Nature, 378, 463

Palla, F. & Baraffe, I. 2005, A&A, 432, L57

Quirrenbach, A., Amado, P. J., Caballero, J. A. 2014, SPIE, 9147, E1F

Radigan, J., Jayawardhana, R., Lafrenière, D. et al. 2012, ApJ, 750, 105

Rebolo, R., Zapatero Osorio, M. R., Martín, E. L. 1995, Nature, 377, 129

Terndrup, D. M., Krishnamurthi, A., Pinsonneault, M. H., Stauffer, J. R. 1999, AJ, 118, 1184

Tinney, C. G. & Tolley, A. J. 1999, MNRAS, 304, 119

Trimble, V., Aschwanden, M. J., Hansen, C. J. 2006, PASP, 118, 947

Schaumberger, J. 1935, *Sternkunde und Sterndienst in Babel*

Stothers, R. 1977, Isis, 68, 443

Wilk, S. R. 2007, *Medusa, solving the problem of the Gorgon*

Zapatero Osorio, M. R., Caballero, J. A., Béjar, V. J. S., Rebolo, R. 2003, A&A, 408, 663

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The Variable Stars Program of Júlia Observatory & Computer Tomography Insight into the Surrounding Structures of the Close Binaries

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Abstract: Before all we introduce our observatory named „Júlia“, with its technical equipment and with its scientific observational program. The core of our paper there is the presentation of the achieved results in the DSLR observations of the selected eclipsing binaries. The results obtained in this field after the change to the observations with the CCD Camera MI G2-1600 will be also presented. Finally we present and prove our possibilities in the modeling of the surrounding of the close binaries by the computer tomography method.

Abstrakt: Predovšetkým predstavíme našu hvezdáreň „Júlia“, s jej technickým vybavením a pozorovacím programom. Jadrom práce je prezentácia výsledkov dosiahnutých DSLR pozorovaní vybraných zákrytových premenných hviezd. Výsledky dosiahnuté v tomto smere po prechode na pozorovania kamerou MI G2-1600 budú tiež prezentované. Záverom prezentujeme a dokážeme naše možnosti v oblasti modelovania okolia tesných dvojhviezd metódou počítačovej tomografie.

Introduction

We have realized small astronomical observatory in the peripheral part of the village Zvolenská Slatina named Sebechov. The observatory is as the bodywork of the farm out-building of our family house. See the figure 1. We have named our observatory after our well-bellowed grand-daughter Júlinka – Júlia Observatory. Over the ground part of the farm out-building there is our working room. The dimensions of this room there are 6 x 5 m and we have there the working table, and the library before all. Next there is here the computer end station of the system for video meteor observations. In the dome we have firmly installed the telescope Celestron 9.25“. It is the system Schmidt – Cassegrain. See figure 2. The elevation of the dome over the terrain is 8 m. The mounting is not the original CG5 yet. We have replaced it with the mounting NEQ6/Pro which is certain sense better. The telescope is equipped with the Omegon 50/350 and the laser finder scopes. The laser finder scope is of brand Omegon too. We remark that this finder scope is for us of specially use in the process of the so called three stars alignment. We recommend to realize this alignment owing to control every half year even if the telescope is in a satisfactory manner adjusted.

The camera – guider Lacerta belong to our telescope too. This camera – guider is attached to the next finder scope Omegon 30/350 too. We have the Omegon imaging flip mirror attached to our telescope too. This device we use to use for the visual control of the telescope adjustment or for the observation of the selected objects of the sky with relatively frequent child or adult visitors of our observatory.

The DSLR camera Cannon EOS 50D or the CCD camera MI G2-1600 is attached to our telescope according to the circumstances or scientific goals. The CCD camera is until now without the filters.

Generally we consider our facilities as the fair ones and we mention that we have from 150 to 220 clear sky nights in a year. The year 2015 had given us 193 clear nights in common. But one thing is to have the observatory or the telescope or the clear sky and the second thing is to produce or participate in the real scientific co-work. That is to say that the scientific work requires (from its nature) orderliness, endurance and the purposefulness. The occasional look into the eyepiece or the telescope from the sake of image in front of a fireplace in the living room is not enough for the scientific work!

The scientific program of the Júlia Observatory

Meteors

We have selected three branches of work – of research in the correspondence with our instrumental facilities and possibilities in astronomy. Before all we switch on our video camera for the video meteors observations everyone a bit clear night. We are the part of the CEMeNt team and e.g. we present with the figure 3 our results from the October 2015 only.

Figure 1: The Júlia Observatory – general view. The dome, videocamera, sundial and the terrace for the visual observations.

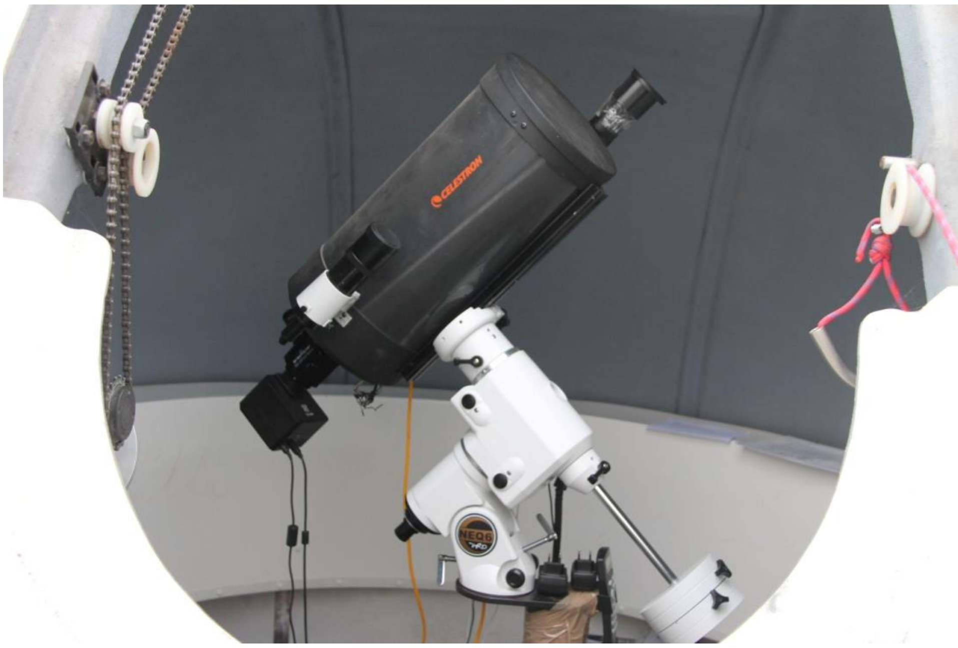

Figure 2: The telescope in the dome of Júlia Observatory.

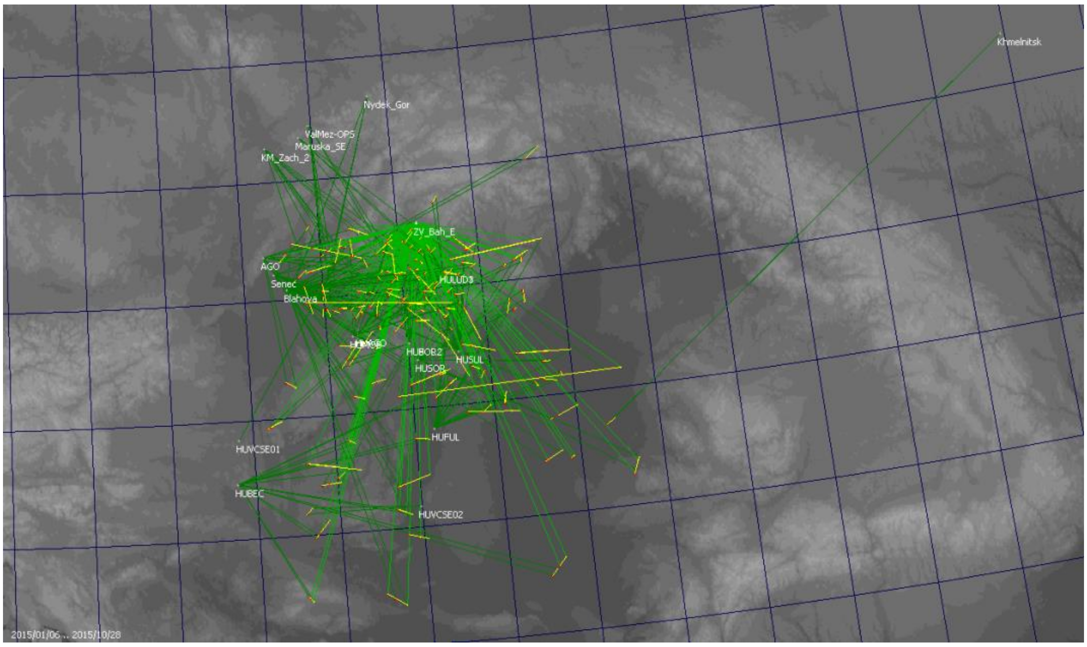

Figure 3: The paired trails of meteors from the Júlia Observatory, October 2015.

Next we participate in the „Bright Bolid Watch“ program of the IMO in the field of the meteor astronomy. We use the whole sky objectives of so called fish eye type and we have successfully registered more than 500 trials of bright meteors in the period of five years of observations. There are some bright bolides' in our records. Our system is relatively simple as there is documented with the figure 4. We do not expose in the time of bright Moon.

Figure 4: The Pentacon Six TL camera with the fish eye objective Zodiac. We expose on the 6 x 6 film, 400 ASA. The individual photos are exposed no longer than three hours.

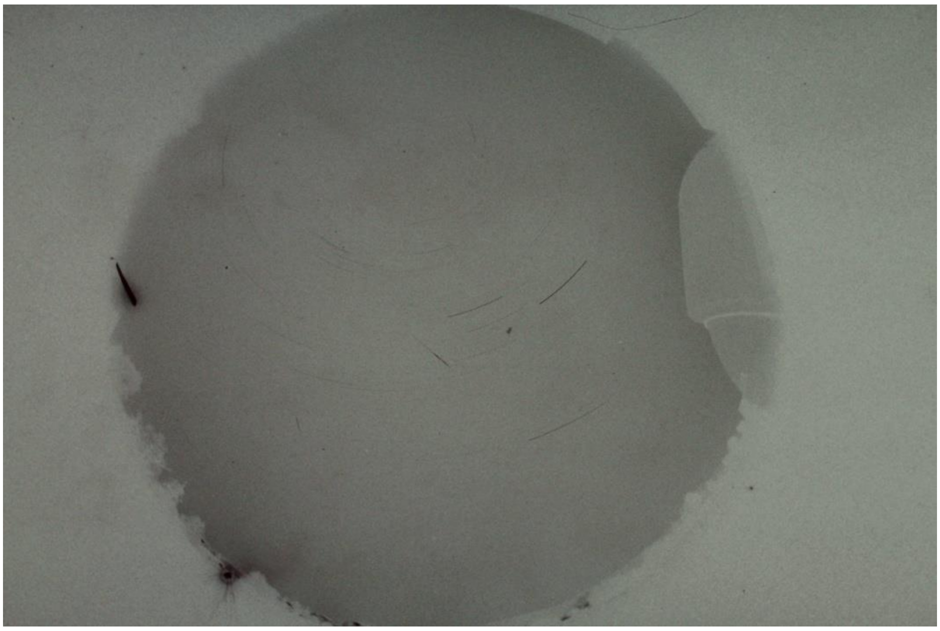

Figure 5: One of our registered bright meteors just near the so called summer triangle.

Asteriods

The astrometry and to some extent the photometry of the asteroids is the next fields of our interest. We are proud of the possibility to take the part in the international co-work or project named “Target Asteroids” which is managed from the University of Arizona, Tuscon. We have realized the measurements of approximately 30 asteroids. We have measured more than 100 positions and photometric data in common. These our measurements have been submitted to the MPC through the colleagues from Tucson. Independently we address our effort to the astrometry and photometry of the asteroids with some relationship to our family e.g. asteroid Julia or they have something common with our home Slovakia e.g. such asteroids as Tatry, Slovakia or Milanstefanik. The comets we observe or take the photos occasionally only.

All our results – observations and measurements from this field we submit to the relevant periodic or they are sent to the responsible international center. Our effort had been rewarded e.g. with the lower given certificate.

Popularization

The popularization of astronomy is very important and integral part of our work. This work consists from the lectures for publicity or roughly three hours long so called “Up to stars evenings” (Dohviezdne večery – in Slovak.) for the visitors of our observatory “Julia”. We are proud of the fact that as far back as two times we can welcome in our house the colleagues – “ebicyklists, at the head with Dr. Grygar. We feel us exceedingly enriched spiritually and professionally from these “reunions”.

Figure 6: The Ebicyklists 2014 „Slovak co-lalocks” (Slovenské kolaloky – in Slovak.). The man in the local national dress is one of the authors welcoming the guests traditionally as there is used in Slavic countries – with bread and salt.

Variable stars

In any case the variable stars especially the close binaries are the concernment of our “heart”. There is the matter of the fact that we have gave up with these topics in the time of our stay at the Skalnaté Pleso observatory. We have started with the β Lyrae system and step by step we have worked us through the AG Dra or AR Aur up to the BT Tri system. We are so satisfied with these results.

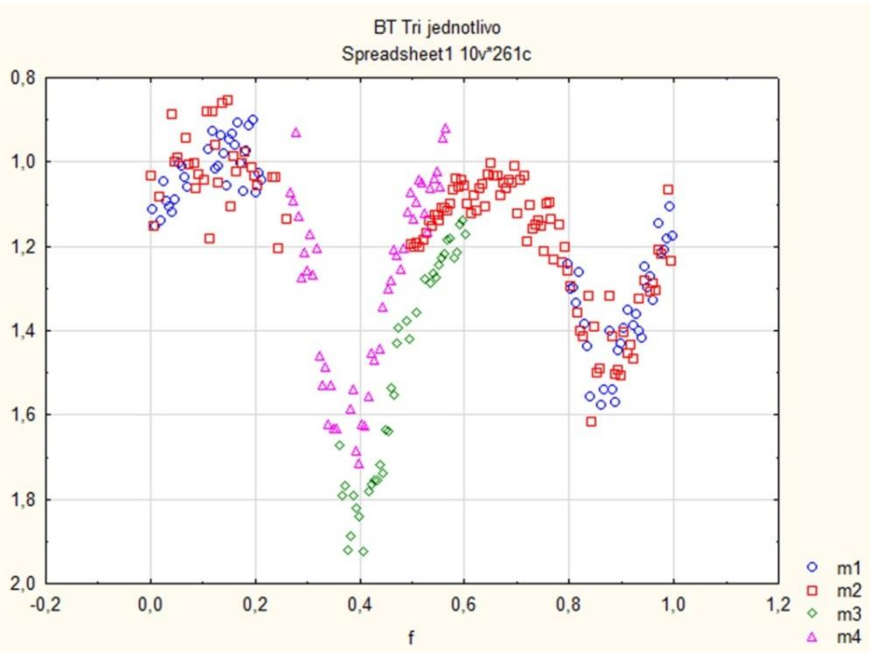

Figure 7: The “rough” light curve of the BT Tri system.

That is to say that we have learned to observe the whole four years and of course we have learned us on our own mistakes mainly. Today we allow us to conclude that the variable stars observations are mastery for us. We orient the telescope according to the coordinates of the desired object (of course) after the night begins and we start as the guider as the camera and we begin to gather the data. The cross over the meridian is in certain point of view a problem but we have mastered it rather longer ago and this “passage” is no problem for us or we have no difficulties with it. If we have some difficulties they are from the wrong weather of course.

The computer tomography

Professor J. M. Kreiner stated before years “There is no sense to observe owing to the observations” („Nema sensu observovat dľa observacij“ – in Polnish language.) In accordance with this we have think about the problem of next and deeper interpretation of any observation. Especially if we have found for the β Lyrae system that the light curve shows certain quasi periodic changes in the primary and in the secondary minimum too for the period roughly speaking 20 years. See the figure 8.

At that time we have subjoined them to the existence of some kind of clouds of the interstellar matter between the binary components. But the word was not sleeping and we was not sleeping too of course.

We have devoted long years of our life to the computer tomography and in the frame of this work we have implemented the relevant algorithms in the C++ Builder language. The computer tomography is known almost to everybody today as this screening method got fully in the medicine from the year 1970 as the year of its discovery. Today perhaps there is nobody who is able to imagine the situation that the medicine doctor will not send a heavy ill person to screen it with the computer tomography. But the computer tomography got through almost any natural science branch. If there is the wood science (in this field of science we have been active), archeology, biology or nondestructive testing of materials. So there is no wonder that the computer tomography – image methods had found their way into the astronomy too.

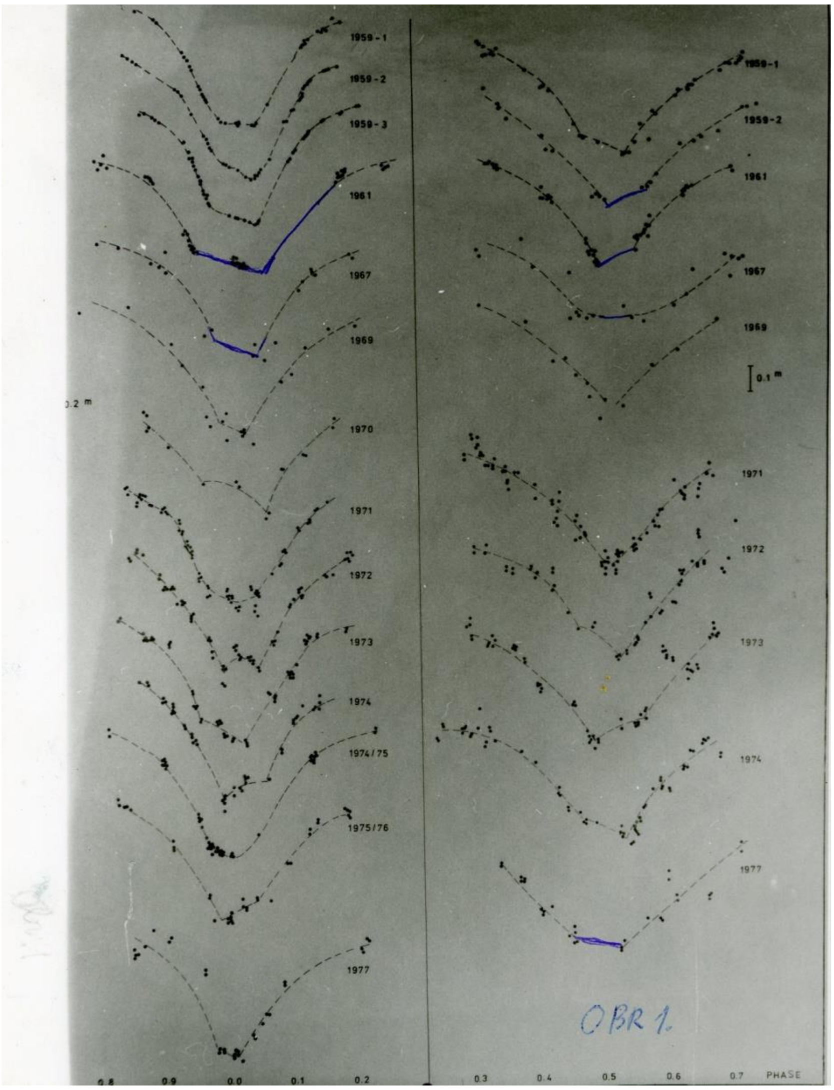

Figure 8: The structure of the primary (left) and of the secondary minima of the light curve of the β Lyrae system.

We bethink that in the beginning of the eightieths of the past century the pioneer in this field in our country there was Mr. J. Hekela. We are sorry to say that in such events if someone overruns his époque for many years he is usually for derision for the contemporary people. And this had been true in the case of Mr. J. Hekela too. But the time, as usually find time and bear up him. Today we can study the papers of Prof. Mercedes Richards or the papers of T. R. Marsh or K. Horne. These papers are applying this method (the computer tomography method) in the field of the close binaries especially.

We will turn off here and we will shortly zoom in the principles and methods of the computer tomography. There is far from us to threaten anyone with mathematics. But if someone wish, let it kindly take in his hands the book Kak – Slaney (1988) submerge in it and he enjoy it to heart`s content. But let us to be very short. If we have some function we can evaluate its integral by the Newton / Leibnitz formula. This formula gives us (in certain case) the content of the (plane) pattern delimited with the sub-integral function *f(x)*.

$$\int_a^b f(x)\,dx = F(b) - F(a).$$

The other in certain sense inverse problem is if we have the values of the integrals along some lines intersecting certain object. We will help us with the medicine for explanation and understanding. Such a kind of integral the fact if we know the X-ray pictures e.g. of a head and we would like to know the density of bones or tissues along the trajectory of the penetrated X-ray. So from the mathematical point of view we know the integral and we should to know the function *f(x,y)*. In the case our example there are the local densities of bones and tissues in the human head. There may be of some interest that this problem had been solved yet in the year 1917 imperial – king's mathematics of Czech origin J. Radon. But after fifty years when G. N. Hounsfield had constructed his tomograph (the first in the word), his co-worker A. Cormack should whole these mathematics work out once about. There is strongly emotive if you see how precisely there are the formulas of J. Radon and A. Cormack the same. The time should find the time! According to our opinion the basic formula is making anybody tired and it is as follows.

$$\mathcal{R}[f](\alpha, r) = \int_{-\infty}^{\infty} f\big(r\sin(\alpha) - t\cos(\alpha), r\cos(\alpha) + t\sin(\alpha)\big)\mathrm{d}t$$

Or instead of empty words let we see the figure 9. There is a structure of two circles in its center (it is not dissimilar to the close binary). There are so called projections at the sides. The projections are in the matter of fact the integrals along the lines parallel with the delimitative dashed lines through the both circles or through the individual circles. And in the computer tomography we have these integrals (projections) and we are looking for the structure of the objects which these integrals generate. In our example there are the structures of the both circles on the figure 9. And this is all. After this there are the years of tests, study of the mathematical texts and deep programming and designing.

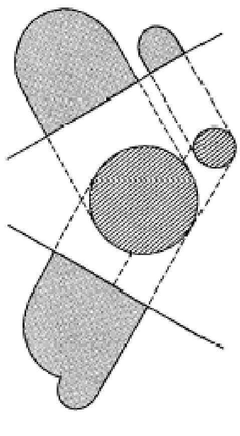

Figure 9: The principle of the computer tomography.

We offer the computer tomography method for as wide usage as possible for the study of the interstellar space around the close binaries. Illustratively we are giving in this work the figure 10 which is the result of the "reconstruction" of the primary minima light curves of the β Lyrae system from the figure 8.

Figure 10: The "reconstruction" of the structure characterizing the primary minimum of the eclipsing system β Lyrae.

The figure number 10 clearly shows that in the interstellar surroundings of the components of the β Lyrae system there are present certain "inhomogeneity". These "inhomogeneity" are than responsible for the behavior of the light curves of the system in the individual years in such a way as these structures are visible on the courses of the light curves for these individual years.

As the proof we help us with the tomographic reconstruction of the real non-uniform and inhomogeneous object. And even if there is impossible to go to any eclipsing system as near as we are able independently proof not only our but anyone tomographic reconstruction we allow us to mention that just the first "nonmedical" application of the computer tomography there had been the scanning of the Moon surface – structure with the radar rays.

Figure 11: The tomographic reconstruction of the real object. The circle is the circle. The edge is the edge. The line is the line. The software is reconstructing the picture "the structure" correctly so as it is created by the individual projections and not otherwise.

For the information integrity and ending there is inevitable to add that our access differs from the accesses of the other authors concretely M. Richards, T. R. March and K. Horne. The mentioned authors are reconstructing the internal structure of the binary system on the base of the velocity field of the inter component space of the close binary. This access allows them to obtain the picture of the structure of the space between the stars – components of the binary system from the one light curve only.

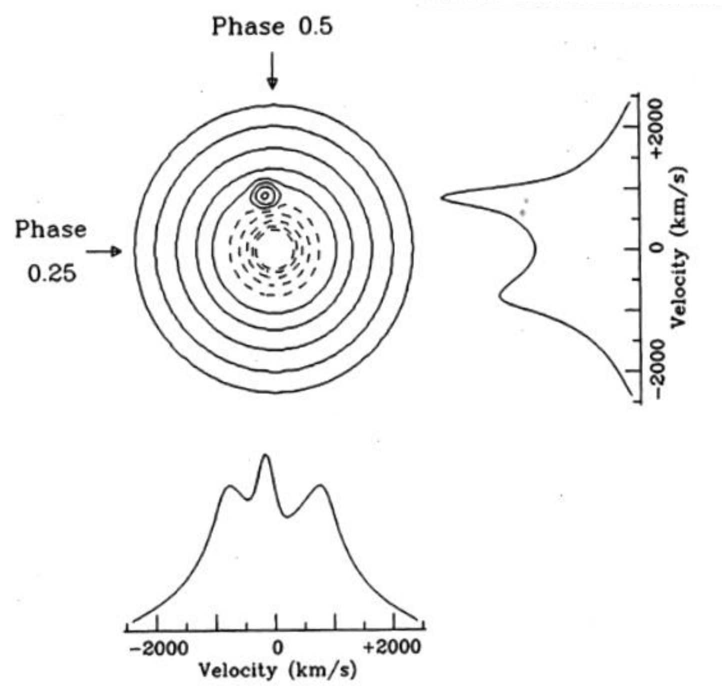

Figure 2. The lines formed at two binary phases from the velocity space image of a disc are projections of that image at two different angles. The contour levels increase from the outside in by factors of two until the dashed line region where they decrease towards the centre by the same factor.

Figure 12: The projections and the structure of the velocity field of the binary system.

We include in our paper in this sense for better understanding and illustration the figure 12 which is the copy of the figure 2 from the paper T. R. March and K. Horne (1988). Of course the matter is not as simple as it seems to be. In the paper of the authors (Richards M and all. 2009) there had been inevitable to treat-to obtain 3500 spectra to cover the whole light curve of the selected system!!! And these spectra have not been whatever but from the 1 m Kitt Peak telescope or 9 m Hobby-Eberly Telescope. Well, per aspera ad astra. But this access is impassable for the astronomers equipped e.g. with the 9.25” Celestron. But and we hope in agreement of everybody that under the hill La Silla astronomy is not ending but beginning. Especially for those who have not studied astronomy at the university.

Of course we have not at our disposal the field of velocities of any close binary system. That is to say or however in any system in binary system we observe so called tapping of the line of apsids. So if we have at our disposal the light curves which cower the rotation of the apsida for 180 degrees we have from the point of view of the computer tomography the system “covered” with the projections and this allow us to realize the tomographic reconstruction of the internal space of the double star. From the point of view of mathematics there is the same if we are rotating the object or we are rotating around the object in the process of the computer reconstruction of the internal structures of the object.

So if we have the light curves we can reconstruct from them the double system to which they belong to. There are the systems for which the apsida rotates for 180 degrees roughly for less than ten years. If there is more years no matter there is substantial that we have the light curves at our disposal. We are able to reconstruct. We comment that the best is if the light curves are equally spaces through the time. But we have at our disposal the software with which we are able to certain extend solve the problem if the light curves ate not (in time of course) equally spaced round the apsida rotation.

Conclusions

This is our result. This we are proposing and in this field we are prepared to co-work in such a way that any observation of the close binary system will not be more “the observation for the sake of observation”. We stress that anybody who would like to be able to see into the interior of his binary system and if he has enough observations or is able to obtain them is welcomed.

References

Horne, H. Images of accretion discs – I. The eclipsing mapping method. Mon. Not. R. astr. Soc. (1985) 213, 129 – 141.

March, T. T. – Horne, K. Images of accretion discs – II. Doppler tomography. Mon. Not. R. astr. Soc. (1985) 235, 269 – 286.

Richards, M. – Slobounov, E. – Conover, M. – Fisher, J. Displaying 2D and 3D Images of Gas Flows in Interacting Binary Stars. 2011, poster.

Kak, A. C. – Slaney, M. Principles of Computerized Tomographic Imaging, IEEE Press, 1988.