

MAVKA: manual

Kateryna D. Andrych, Ivan L. Andronov

Department “Mathematics, Physics and Astronomy”, Odessa National
Maritime University, Odessa, Ukraine

Abstract

MAVKA (Multi-Analysis of Variability by Kateryna Andrych) program was developed on base of “Observational Obscurer” (Andronov, 2001) that was rewritten in the Delphi 7 environment. It contains a set of subroutines suitable for fast viewing, interactive filtering and processing time series, determination extremum for subintervals. Program allows to view the data and move to different parts of it, to make scale transformations, to marked subintervals for later approximation and determination extrema. First of all, it has been developed for variable star observers, but it can be used for any data, not only light curves.

Key words: Data analysis; time series analysis; astrophysics; data reduction; MAVKA

Introduction

One of the aims of this program is fast visualizing the data. It also has additional possibilities oriented to data checking and reduction. After running, the data are visualized with determining the limits automatically. The cursor marks the point which characteristics are shown. This possibility allows to check the data, especially outstanding points and, if decided that this point is wrong, to delete it.

If the data consists of some groups of points of joint origin (same filter, observer), these groups can be analyzed separately. There is also a possibility of a conversion of times to scale and transform coordinates from linear to logarithmic and back, inverting etc.

We also focused on approximations, when time series are close to the extremum of brightness of the object. From such data needed to determine characteristics of extremum: moment, magnitude, width of flat part of eclipse (if there is transit) and corresponding

accuracy estimates. For this task, the software MAVKA allows to compute necessary parameters of the extrema using one out of nine realized methods.

Some types of approximation functions were divided into few groups according to different shapes of extrema and variability types.

Methods of the analysis

Eleven different groups of functions were realized in program.

For all approximations, the linear parameters are determined by the method of least squares, and for non-linear - by the method of differential corrections, after determination of an initial set of parameters corresponding to a minimum of the test function Φ at a grid.

- Algebraic polynomial approximation of different degrees α . The program automatically chooses the most precise degree, which corresponds to the best accuracy of the moment of extremum.

$$x_c(t) = \sum_{\alpha}^m C_{\alpha} \cdot f_{\alpha}(t), \quad f_{\alpha}(t) = t^{\alpha-1} \quad (1)$$

- "Symmetrical" algebraic polynomial approximation, which use only even degrees of deviation from point of symmetry.

$$x_c(t) = \sum_{\alpha}^m C_{\alpha} \cdot f_{\alpha}(t), \quad f_{\alpha}(t) = (t - t_0)^{2(\alpha-1)} \quad (2)$$

The next two methods are

- New Algol Variable, that was proposed by Andronov (2010, 2012):

$$x_c(t) = C_1 + C_2 \left(1 - \left(1 - \left(\frac{t - C_3}{C_4} \right)^{C_5} \right)^{1.5} \right) \quad (3)$$

- the function proposed by Mikulášek et al. (2015):

$$x_c(t) = C_1 + C_2 \left(1 - \left(1 - e^{\left(1 - ch\left(\frac{t - C_3}{C_4} \right) \right)} \right)^{C_5} \right) \quad (4)$$

In these forms, the functions are applied for approximation of the whole light curve. In the case, where the data are just close to the extremum, the matrix of normal equations becomes degenerate. The interval does not contain out-of-eclipse parts, and therefore we do not have enough data. Formally, the amplitude becomes infinite, and the error estimates are not available because of rounding errors.

To avoid degeneration of the matrix of the normal equation, the last two functions were expanded into the Taylor series, and the following approximations are used:

- for the "New Algol Variable" (Andronov et al., 2017)

$$x_c(t) = C_1 + C_2 |z|^{C_6} + c_3 |z|^{2C_6}, z = t - C_5 \quad (5)$$

- for the function proposed by Prof. Z. Mikulášek (2015):

$$x_c(t) = C_1 + C_2 |z|^{C_6} + c_3 |z|^{C_6+2}, z = t - C_5 \quad (6)$$

These forms of functions realized in MAVKA instead of complete versions, which were oriented to complete light curves.

In some cases, for example approximation of flat eclipses and exoplanet transitions, it is more precise to divide our data into three intervals, each of them is approximated by its own function. In this case, an additional parameter is the duration of the bottom part of the eclipse (total eclipse or a transit).

The additional parameters (the borders between the three intervals) are determined by minimizing the test function (sum of the squares of the residuals of the data from the approximation) in respect to these parameters, and then corrected using differential equations. For the visualization, we have applied an own "gradient zebra" – type colour scheme (Andrych et al., 2017) instead of a classical "lines of constant level" (e.g. Tkachenko, 2016).

We take into account a locally paraboloidal shape of the test function. Thus, we made a following routine for the 2D-plots. The test function was computed over a grid (201×201). Then we computed a dimensionless value

$$p = \sqrt{\frac{\Phi - \Phi_{min}}{\Phi_{max} - \Phi_{min}}} \quad (7)$$

which we expect to represent a set of equal levels better than (typically) without the square root. For an exact paraboloid, the constant step in p leads to concentric ellipses with a constant step in each fixed direction from the center. The interval [0,1] for p is split into $N_p = 10$ subintervals, inside each of them the color linearly changes from blue to yellow.

This makes an abrupt change of color between the subintervals. Such a kind of presentation allows to get advantages of the "gradient" and "lines" styles.

We have proposed some new methods for this case.

- The Wall-Supported Parabola method (Andrych et al., 2017): part of data that is very close to extremum is approximated by parabola, but branches are approximated by a sum of a parabola and a contribution of another degree.

Let C_5 and C_6 be transition points from one function to another.

In the case of transition or eclipse for a small deviation of time from the point of the inner or outer contact, the flux increases/decreases proportionally to the difference $(C_5 - t)$ or $(t - C_6)$ in the non-integer power 1.5.

$$x_c(t) = \begin{cases} C_1 + C_2 \left(t - \frac{C_5 + C_6}{2}\right)^2 + C_3 (C_5 - t)^{1.5}, & t < C_5 \\ C_1 + C_2 \left(t - \frac{C_5 + C_6}{2}\right)^2, & C_5 < t < C_6 \\ C_1 + C_2 \left(t - \frac{C_5 + C_6}{2}\right)^2 + C_3 (t - C_6)^{1.5}, & t > C_6 \end{cases} \quad (8)$$

- Wall-Supported Line (Andrych et al., 2017): it is nearly similar, but instead of the parabola there is a constant line for the central interval. This method is useful for flat minima and it allows one to calculate the duration of the full eclipse or transition if the limb darkening effect can be neglected.

$$x_c(t) = \begin{cases} C_1 + C_2 (C_5 - t)^{1.5} + C_3 (C_5 - t)^{3.5}, & t < C_5 \\ C_1, & C_5 < t < C_6 \\ C_1 + C_2 (t - C_6)^{1.5} + C_3 (t - C_6)^{3.5}, & t > C_6 \end{cases} \quad (9)$$

- Wall-Supported Asymptotic Parabola. The method improves the method of “Asymptotic parabola” (Marsakova and Andronov, 1996) by adding two parameters describing terms at the left and right interval, which correspond to ascending and descending branches. This method may be effective for approximation of the symmetric eclipses. For pulsating variables, it may be computed, but has no physical meaning.

$$x_c(t) = \begin{cases} C_1 + C_2 (-D^2 - 2Dv) + C_3 (C_5 - t)^{1.5}, & t < C_5 \\ C_1 + C_2 v^2, & C_5 < t < C_6 \\ C_1 + C_2 (-D^2 - 2Dv) + C_3 (t - C_6)^{1.5}, & t > C_6 \end{cases} \quad (10)$$

where

$$D = \frac{C_6 - C_5}{2}, \quad v = t - \frac{C_6 + C_5}{2}$$

- Parabolic Spline. This approximation has more parameters than previous ones. Therefore, transition points from one function to another are C_6 and C_7 . The method improves the method of “Asymptotic parabola” (Marsakova and Andronov, 1996) by adding two parameters describing parabolic terms at the left and right interval. This method allows to extend the width of the interval (and so to increase the number of points) to get a same accuracy, as the “Asymptotic parabola”.

$$x_c(t) = \begin{cases} C_1 + C_2 t + C_3 t^2 + C_4 (C_6 - t)^2, & t < C_6 \\ C_1 + C_2 t + C_3 t^2, & C_5 < t < C_6 \\ C_1 + C_2 t + C_3 t^2 + C_5 (t - C_7)^2, & t > C_7 \end{cases} \quad (11)$$

- Asymptotic Parabola.

There are two lines (the “asymptotes”), which are connected with a parabola, so the function and its derivative are continuous. Previous experience had shown, that this is one of the best methods for asymmetrical maxima of generally pulsating variables. This method was originally proposed by Marsakova & Andronov (1996).

The transition points from one interval to another are C_4 and C_5 .

$$x_c(t) = \begin{cases} C_1 + C_2 \left(|v| - D \right) D + C_3 v, & t < C_4 \text{ or } t > C_5 \\ C_1 + C_2 v^2 + C_3 v, & C_4 < t < C_5 \end{cases} \quad (12)$$

where

$$D = \frac{C_5 - C_4}{2}, \quad v = t - \frac{C_5 + C_4}{2}$$

- Hyperbolic Secant function (sech)

The hyperbolic secant:

$$\text{sech}(z) = \frac{1}{\cosh(z)} = \frac{2}{\exp(z) + \exp(-z)} \quad (13)$$

is a symmetrical function. To improve it to make it asymmetrical, the coefficients in the exponents were defined to be generally different (Andronov, 2005):

$$x_c(t) = C_1 + C_2 \left(1 - \frac{2}{\exp(C_4(t - C_3)) + \exp(-C_5(t - C_3))} \right) \quad (14)$$

Physically, this function corresponds to an exponential rise of the signal from a standstill value $C_1 + C_2$ to the value $x_c(C_3) = C_1$ and further to the extremum, which is shifted from C_3 . The characteristic timescales of the exponential change are

$$\tau_{\text{left}} = \frac{1}{C_5}, \quad \tau_{\text{right}} = \frac{1}{C_4} \quad (15)$$

Exponential shape of the signals is often observed in physics. In a logarithmic scale, the function is a good approximation of two asymptotic straight lines linked by a smooth function near the extremum. The stellar magnitudes are logarithmic values, so the ascending and descending branches of pulsating and outbursting stars are close to the straight lines, except the extremum. This approximation has 3 “non-linear” parameters, a lot of computations of the exponent, and thus is much slower than the “asymptotic parabola” with simple lines and a parabola. However, it may be useful for determining the characteristics of some outbursts or flares.

- BSK (Bódi, Szatmáry & Kiss L. L., 2016) have used another complicated function with 3 non-linear parameters, which resembles the log-normal distribution function. For exactly symmetric functions, it asymptotically tends to be a gaussian, thus is not useful in its original form. The second “non-linear” parameter is well determined

only in the case of relatively wide interval, which covers the data from the previous to the next extremum (i.e. from previous to the next minimum, if determining the maximum).

What methods are better for different cases

In program, the user can choose few methods, then the algorithm automatically defines the method, which corresponds to the best accuracy of the moment of extremum. The variance of the residuals left after subtraction of the approximation curve from the observations also takes into account.

The user can control results, because sometimes the approximation may be mathematically accurate, but formally the values of parameters are out of the physically realistic intervals. And also one can previously mark first and last points for intervals in the big data file and then Program can automatically go through all marked intervals.

We tested all MAVKA methods using generated data and real observations from the AAVSO database. The aim of the first part was to determine the most appropriate methods for each type of extrema shapes. In the second part we processed typical phase curves for the different variability types from the AAVSO database.

In the first part we generated about 5000 extrema of 7 different shapes: three symmetric (normal, sharp and flat-bottom one) and four asymmetric. We changed several additional parameters such as noise, number of points and time interval. The obtained value from was absolute average deviation between generated and computed moment of minimum.

Due to this testing we divide all methods into three groups:

- universal methods (they allows to get good approximation for both – symmetrical and asymmetrical shapes of extrema):
 - Algebraic polynomial
 - Parabolic Spline of defect 1
 - Asymptotic Parabola
- methods that are useful just for symmetrical extrema:
 - "Symmetrical" algebraic polynomial
 - New Algol Variable
 - “the function of Prof. Z. Mikulášek”
- methods for wide extrema with strong differences between the bottom and the branches:

- “Wall-Supported Parabola” (WSP)
- “Wall-Supported Line” (WSL)
- “Wall-Supported Asymptotic Parabola” (WSAP)

Due to the testing for the different variability types from the AAVSO database we get that also three groups of methods:

- first one is useful for pulsating and eruptive variables and also some eclipsing binaries with sharp extrema:
 - Algebraic polynomial
 - Parabolic Spline of defect 1
 - Asymptotic Parabola
- second group is useful for the rotating variables and some pulsating types with symmetrical extrema:
 - "Symmetrical" algebraic polynomial
 - New Algol Variable
 - “the function of Prof. Z. Mikulášek”
- last one is for the eclipsing binaries and exoplanet transits:
 - “Wall-Supported Parabola” (WSP)
 - “Wall-Supported Line” (WSL)
 - “Wall-Supported Asymptotic Parabola” (WSAP)

Running MAVKA

The arrays reserved are the following: t_i - argument; x_i - signal; s_i - error estimate (sometimes may be used as a working array); e_i - working array. Contrary to electronic tables, the number of arrays is fixed. The graph always shows a dependence of x_i vs t_i . The value i indicates a number of the current point, i_1 and i_2 are the first and last numbers of the point seen at the current screen.

After reading the columns for t and x, the data are plotted with automatic determination of the limits and corresponding scaling.

Submenu “File”

The meaning of options “Open”, “Re-open” , “Save as... ”, “Exit” are obvious. “Save” - save all data with automatically created name.

“Number of column x” - you can set number of column for the signal along vertical axis. Numeration starts from 0! By default for the horizontal axis program uses first column, and second one for the vertical axis.

“Save image” - save visible interface as an image (just without right part with text).

“Save visible” - save visible data points in the new file. The new file name contains numbers of the first and last data point due to initial file.

“File for intervals” - if you got huge data interval and want to determine parameters for some extrema in it, you can create “file of intervals”. This file contains edges for small data intervals near extrema. Then you need to upload this file in MAVKA using this function and navigate in marked intervals using Prev. Interval and Next Interval in Navigate submenu or using hotkeys. Program also can automatically go through all marked intervals if you choose feature “for all next intervals” (Fig.1). Be careful to upload a correct “file for intervals” before using this feature. If something goes wrong you can abort this evaluation using “abort do for all” in approximation submenu.

Submenu “Edit”

“Delete current point” - delete one point at the "cursor" (this is used to delete "bad" points (are also referred to as "outliers", "anomalies ", "noise", "deviations" or "exceptions"));

“Delete bad points (same level)” - delete all points with current signal value (remove horizontal line). This option may be used, if such a value indicates wrong value (out of detection);

“Sort” - if data in initial file are not sorted according to time (first column), you should sort it before reduction (the methods are oriented to analyse data between the numbered points, but not to check the whole set of data for being included in the interval);

“Average for same time” - if data file contains few values for the same time moment you can calculate averages and build them instead of initial data. This option is useful for phase curve analyses;

“Delete current author” - delete all data that marked by one author (3-symbols abbreviation of the observer). This is used, if the whole subset of data is an "outlier", e.g. the series in a different filter, or very noisy data.

Submenu “Navigate”

“First at screen” - move cursor to the first point of the screen;

“Last at screen” - move cursor to the last point of the screen;

“Next” / “Prev” - move cursor to the next/previous point;

“ScrollLeft” / “ScrollRight” - shift window to the left/right by a half-width;

“Top” - upper point of the screen;

“Bottom” - lowest point of the screen;

“Mark left” / “Mark right” - mark left/right edges for extrema subintervals. These edges (point number in file and corresponding time moment) writes in new file with the same name, but “!” in the end of data file extension;

“Prev. Interval” - previous marked data subinterval;

“Next Interval” - next marked data subinterval;

“Go to interval number” - move to the interval due to it number in “file of intervals”.

Submenu “View”

“ZoomIn” - zoom (twice pixels per argument interval);

“ZoomOut” - unzoom (twice argument interval per pixel);

“Center” - center current point at the screen;

“Inverse x” - inverse vertical axis;

“Left edge” - make current point the left limit of the interval;

“Right edge” - make current point the right limit of the interval;

“Restore interval” - restore automatic limits;

“Refresh” - resize current window according to the signal limits;

“Print precision” - set number of digits before and after the decimal point for both axes on the screen;

“Hint” - change form of cursor;

“Hint light author” - if data file contains some information about author of observation you can mark them with different colour.

Submenu “Transform”

The meaning of options “lg t” , “lg x” , “ $10 \wedge t$ ” , “ $10 \wedge x$ ” and “ $t = 1/t$ ” are obvious. But you should remember that t is expressed at a horizontal axis (abscissa), x - at the vertical one (ordinate).

“i -> m” - the data are transferred from intensities to magnitudes in the sense $x_i = -2.5 \lg(x_i/x_{max})$;

“m -> i” - the data are transferred from magnitudes to intensities in the sense $x_i = 10^{-0.4(x_i-x_{min})}$.

It should be noted that, after making opposite commands, m->i, i->m, the result will not return to the initial set of m_i , as the intensities are calibrated to the maximum intensity. So all values will be shifted by a constant m_{max} . The scaling to the maximum

brightness was made to avoid very large and very small values, which may not be readable in some external programs for the data reduction.

Submenu “Mean”

“Change NNH” - set number m of subintervals or points for mean calculation;

“Bin mean” - split interval into subintervals $l = 1..m$, compute mean \bar{x}_l for each, unbiased root mean square deviation of the data from the mean σ_l , error estimate of the mean σ_{xl} . Results $(l, x_l, \sigma_l, \sigma_{xl})$ are written (appended) to the file with a standard name "*f4.dat*";

“Point mean” - compute mean values from m subsequent points and append it to the same file as in the “Bin mean”;

“Scalegram mean” - computes the scalegram assuming a histogram-like fit (spline of power 0 and defect 1) of the data present at the current window for numbers of subintervals $m = 1..50$. Then the parameter NNH is chosen, which corresponds to the maximal value of the signal-to-noise ratio (SNR), and the “Bin mean” is computed. So the difference is in the automatic ("scalegram") or manual setting of NNH.

The weights of all the data are assumed to be the same.

The following test functions are written to the file with fixed name "*_Scale.dat*": the number of a trial subinterval m , number of subintervals with at least one point m_1 ; r.m.s. deviation of the smoothing value from the mean σ_C ; unbiased value of the r.m.s. deviation of the data from corresponding smoothing values σ_0 ; the "S/N" ('signal/noise') ratio σ_C/σ_{xc} ; the r.m.s. error estimate of the smoothing value σ_{xc} ; the number of points in the current window n . The file "*_Scale.dat*" may be studied separately, but, after running the present command, the program determines m_{max} corresponding to the maximal value of "SNR"="S/N" and uses it for showing the "histogram-like". This feature is an extension of that available by “Bin mean”, because allows to use the optimal value of m instead of the user-defined one.

Submenu “Approximation”

This submenu in program allows to determine parameters of extremum by different methods. If you click on the name of method, program evaluate approximation curve and calculate extremum parameters for data in the current window. If method divides data interval into three subintervals, the boarders between them marked by black vertical lines. The determined extremum point is specified by crossed red lines. Size of the red rectangle correspond to the error estimates for time and magnitude.

Left side of the submenu allows to approximate visible (only !) data by one among 11 functions:

- Polynomial - algebraic polynomial
- Symmetrical polynomial
- WSP - Wall-Supported Parabola
- WSL - Wall-Supported Line
- NAV - New Algol Variable in the Tailor series form
- Mikulashek - the function proposed by Prof. Z. Mikulášek
- WSAP - Wall-Supported Asymptotic Parabola
- Parabolic spline - Parabolic Spline of defect 1
- AP - Asymptotic Parabola

In addition, the user can control results, because while the approximation may be mathematically accurate, formally the values of parameters may be out of physically realistic intervals (Fig. 2). So if you click “Yes” all information about extremum will be saved in result files (read more in the corresponding subsection below).

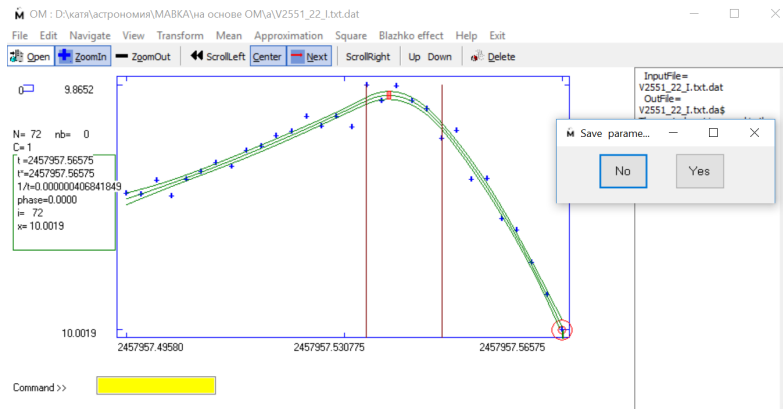


Figure 1: Visual control of approximation.

“choose approximation” - the user can choose few methods and the algorithm automatically defines the method, which corresponds to the best accuracy of the moment of extremum and root mean square. For this case you should click on methods that you want to compare.

“run approximation” - allows to evaluate approximation with the previous settings (same methods as for previous interval or file).

“do for all next intervals” - program automatically applies functions to the all next intervals from the “file of intervals” (previously chosen ones, if you have used “choose approximation” or “run approximation”, or opens the function selection menu). In this

case result (the moment of extremum and etc.) will be written in corresponding files (read more in the corresponding subsection below).

“abort do for all” - abort approximation.

“Save image” - if it is checked program save image with data points and approximation in the same folder as initial data file.

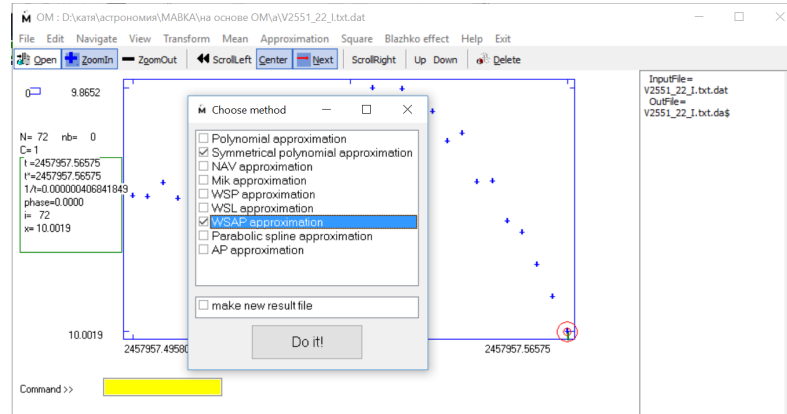


Figure 2: MAVKA submenu for choosing some approximation methods.

Option “Square”

It shows the type colour scheme for approximations, that divide data into the sub-intervals. It presents visualisation of the sum of the squares of the residuals of the data from the approximation for different values of the borders between the three intervals. Crossed black lines shows best values for these parameters.

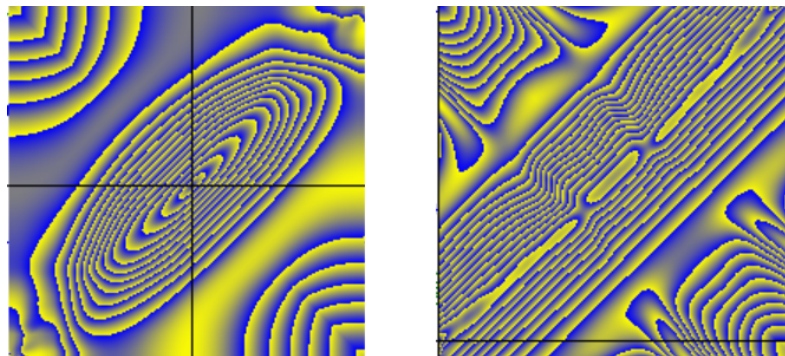


Figure 3: Two examples of the colour scheme for different intervals.

Result files

MAVKA creates few different result files. They are automatically created in the same folder as the initial data file. Each of them contains “head string” that tell you what data is in this file. For convenience, we use some abbreviations:

Point : startend - numbers of first and last points for the approximated interval in initial data file;

sigma0 - root mean square;

time - time of the extremum;

mag - magnitude of the extremum;

+- - error for the previously written in the head string parameter;

method - shorten name of the approximation method;

filename - initial data file name;

lin_coef - number of linear coefficients;

nonlin_coef - obviously, number of nonlinear parameters in basic function;

c1, c2, ... - values of corresponding coefficients for approximation (if in this method there are less than 9 coefficients excess ones are equal to zero);

max_or_min - marked it is maximum or minimum of the light curve.

If in “choose method” submenu (Fig.1) you click on option “make a new result file”, MAVKA creates two new files for extreme parametres. Name of this files are name of initial data file plus “*result.dat*” or “*ad.dat*” in the end. Depending on you answer in the “save parameter” submenu

File “OM.dat” contains all messages that are written on the right side of the interface. Typically, it may be used for debugging errors, if any.

Best approximation curve also is written in the file with ending “*appr.dat*”.

Hotkeys

The program is rapidly operated by hotkeys, contrary to the menu-oriented mouse control. This option allows to speed up the work after learning the keys for most frequently used operations.

To exit the program, press *Alt + X*. Mainly most of the hotkeys written near the options in menu.

There are some hotkeys that are not presented in visible menu.

Screen changes

+ - zoom (twice pixels per argument interval);

- - unzoom (twice argument interval per pixel);

/ + Enter - resize current window according to the signal limits;

Home - first point of the screen;

End - last point of the screen;

Down - lowest point of the screen;

Up - upper point of the screen;

Del - delete point above cursor;

Left - move cursor to the next point: let i be the serial number of point, $i := i + 1$;

Right - $i := i - 1$;

$0 + \textit{Enter} - i := i - 10;$
 $. + \textit{Enter} - i := i + 10;$
 $4 + \textit{Enter} - i := i - 100;$
 $5 + \textit{Enter} - i := i + 100;$
 $Z + \textit{Enter} - i := i - 1000;$
 $X + \textit{Enter} - i := i + 1000;$

) + *Enter*- delete all points with current signal value (remove horizontal line). This option may be used, if such a value indicates wrong value (out of detection).

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References

- Andronov, I.L.: 1994, *Odessa Astronomical Publications* **7**, 49.
- Andronov, I.L.: 2001, *Odessa Astronomical Publications* **14**, 255.
- Andronov, I.L., Antoniuk, K.A., Augusto, P., Baklanov, A.V., Chinarova, L.L., Chochol, D., Efimov, Y.S., Gazeas, K., Halevin, A.V., Kim, Y., Kolesnikov, S.V., Kudashkina, L.S., Marsakova, V.I., and, ...: 2003, *Astronomical and Astrophysical Transactions* **22**, 793.
- Andronov, I.L.: 2005, *The Light-time Effect in Astrophysics: Causes and Cures of the O-C Diagram*, 37.
- Andronov, I.L.: 2012, *Astrophysics* **55**, 536.
- Andronov, I.L., Marsakova, V.I., Kudashkina, L.S., and Chinarova, L.L.: 2014, *Advances in Astronomy and Space Physics* **4**, 3.
- Andronov, I.L., Andrych, K.D., Antoniuk, K.A., Baklanov, A.V., Beringer, P., Breus, V.V., Burwitz, V., Chinarova, L.L., Chochol, D., Cook, L.M., Cook, M., Dubovský, P., Godlowski, W., and, ...: 2017, *Non-stable Universe: Energetic Resources, Activity Phenomena, and Evolutionary Processes*, 43.
- Andronov, I.L., Tkachenko, M.G., and Chinarova, L.L.: 2017, *Astrophysics* **60**, 57.

- Andronov, I.L.: 2020, *Knowledge Discovery in Big Data from Astronomy and Earth Observation*, 191.
- Andrych, K.D., Andronov, I.L., Chinarova, L.L., and Marsakova, V.I.: 2015, *Odessa Astronomical Publications* **28**, 158.
- Andrych, K.D., Andronov, I.L., and Chinarova, L.L.: 2017, *Odessa Astronomical Publications* **30**, 57.
- Andrych, K.D., Tvardovskyi, D.E., Chinarova, L.L., and Andronov, I.L.: 2020, *Contributions of the Astronomical Observatory Skalnaté Pleso* **50**, 557.
- Bódi A.; Szatmáry K.; Kiss L. L.: 2016, *Astronomy & Astrophysics*, **596**, id.A24, 8 pp.
- Breus, V.V.: 2007, *Odessa Astronomical Publications* **20**, 32.
- Chinarova, L.L., and Andronov, I.L.: 2000, *Odessa Astronomical Publications* **13**, 116.
- Kreiner, Jerzy M., Kim, Chun-Hwey, and Nha, Il-Seong: 2001, *An Atlas of O-C Diagrams of Eclipsing Binary Stars / by Jerzy M. Kreiner*.
- Kwee, K.K., and van Woerden, H.: 1956, *Bulletin of the Astronomical Institutes of the Netherlands* **12**, 327.
- Marsakova, V.I., and Andronov, I.L.: 1996, *Odessa Astronomical Publications* **9**, 127.
- Mikulášek, Z.: 2015, *Astronomy and Astrophysics* **584**, A8.
- Mikulášek, Z., Zejda, M., Pribulla, T., Vaňko, M., Qian, S.-B., and Zhu, L.-Y.: 2015, *Living Together: Planets, Host Stars and Binaries*, 176.
- Samus', N.N., Kazarovets, E.V., Durlevich, O.V., Kireeva, N.N., and Pastukhova, E.N.: 2017, *Astronomy Reports* **61**, 80.
- Tkachenko, M.G.: 2016, *Advances in Astronomy and Space Physics* **6**, 73.
- Tkachenko, M.G., Andronov, I.L., and Chinarova, L.L.: 2016, *Journal of Physical Studies* **20**, 4902.
- Tsesevich, V.P.: 1971, *Instationary Stars and Methods of Their Investigation. Eclipsing Variables*.
- Vavilova, I.B., Yatskiv, Y.S., Pakuliak, L.K., Andronov, I.L., Andruk, V.M., Protsyuk, Y.I., Savanevych, V.E., Savchenko, D.O., and Savchenko, V.S.: 2017, *Astroinformatics*, 361.