

Variable Star and Exoplanet Section of Czech Astronomical Society and Štefánek Observatory

Proceedings of the 48th Conference on Variable Stars Research

Štefánek Observatory, Prague, Czech Republic, EU

11th – 13th November 2016

Editor-in-chief **Radek Kocián**



Participants of the conference

TABLE OF CONTENTS

| | |
|--|----|
| The BVRI photometry of the UZ Equulei system..... | 2 |
| <i>V. BAHÝL, M. GAJTANSKA, P. HANISKO</i> | |
| Variable Stars in the Field of V729 Aql..... | 8 |
| <i>P. CAGAŠ</i> | |
| FrameSmooth software - new tool for the calibration of astronomical images..... | 16 |
| <i>P. A. DUBOVSKÝ, O. B. BRIUKHOVETSKYI, S. V. KHLAMOV, I. KUDZEJ, Š. PARIMUCHA, A. V. POHORELOV, V. E. SAVANEVYCH, V. P. VLASENKO</i> | |
| Outburst activity of the symbiotic binary AG Dra..... | 24 |
| <i>R. GÁLIS, J. MERC, L. LEEDJÁRV</i> | |
| Disentangling of spectra of variable stars | 29 |
| <i>P. HADRAVA</i> | |
| Astronomical satellite Gaia: First results | 34 |
| <i>P. KOUBSKÝ</i> | |
| Binary systems with an RR Lyrae component – progress in 2016..... | 37 |
| <i>J. LIŠKA, M. SKARKA, Á. SÓDOR, Zs. BOGNÁR</i> | |
| Phenomenological modelling of light curves of non-eclipsing double stars..... | 40 |
| <i>Z. MIKULÁŠEK, T. PRIBULLA, M. ZEJDA, M. VAŇKO</i> | |
| The Keplerian revolution of variable stars | 41 |
| <i>L. MOLNÁR</i> | |
| Multiple variability in RR Lyrae stars..... | 47 |
| <i>Z. PRUDIL</i> | |
| Long-term activity of cataclysmic variables | 51 |
| <i>V. ŠIMON</i> | |
| Eclipsing binaries – selection of targets | 57 |
| <i>P. ZASCHE</i> | |
| B[e] Stars - Penetrating the Mystery of the Circumstellar Matter..... | 59 |
| <i>D. KORČÁKOVÁ, A. MIROSHNICHENKO, S.N. SHORE</i> | |

FrameSmooth software - new tool for the calibration of astronomical images

P. A. DUBOVSKÝ¹, O. B. BRIUKHOVETSKYI², S. V. KHLAMOV³, I. KUDZEJ¹, Š. PARIMUCHA⁴, A. V. POHORELOV³,
V. E. SAVANEVYCH², V. P. VLASENKO²

- (1) Vihorlat Observatory, Mierová 4, 066 01 Humenné, Slovakia, var@kozmos.sk
- (2) Western Radio Technical Surveillance Center, National Space Agency of Ukraine
- (3) Kharkiv National University of Radioelectronics, Kharkiv, Ukraine
- (4) Institute of Physics, Šafárik University, Košice, Slovakia

Abstract: The traditional procedure of image calibration in differential photometry is based on correction for dark-frame and flat-field. This approach don't remove big scale non-uniformities in the detector illumination caused by Moonlight or other scattered light. This can be corrected by mathematical methods. Ukrainian developers of CoLiTec software use inverse median filter for astrometric tasks. We have tested the possibility to use it for photometry also. The answer is generally positive. There is a chance to skip the flat-field calibration in some cases. We present the FrameSmooth software which performs different image calibration procedures and also able to operate in fully automatic mode.

Abstrakt: Klasický postup pri redukcii astronomických snímok určených na diferenciálnu fotometriu spočíva v korekcii na darkframe a flatfield. Tento prístup neodstráni veľkošálové nerovnomerosti v osvetlení čipu spôsobené napríklad Mesiacom, alebo iným parazitným svetlom. To sa dá odstrániť matematickými metódami. Skupina ukrajinských tvorcov programu CoLiTec používa pri riešení astrometrických úloh inverzný mediánny filter. Testovali sme, či sa takto upravené obrázky dajú použiť aj na fotometriu. Odpoveď je v zásade áno. Dokonca v niektorých prípadoch je možné vynechať redukcii na flatfield. Predstavujeme softvérový balík FrameSmooth, ktorý umožňuje kalibráciu obrázkov rôznymi spôsobmi a to aj v plne automatickom režime už počas pozorovania.

Introduction

Traditionally, equalization of astronomical frame background is made by hardware calibration. The calibration of astronomical images is reduced to pixel by pixel subtraction of Master-dark frame and dividing by Master-flat frame (McLean 2008, Howel 2006). Methods for calibration frame formation are fully described in the specialized literature (McLean 2008, Howel 2006, Berry & Burnell 2005, Warner 2006). The most time-consuming and inconvenient hardware calibration operation is advance (before night observation) preparation of the flat frame. Many astronomers want to abandon this due to a number of reasons. This leads to decreasing the quality of observational data. Hardware calibration of astronomical frames does not allow eliminate background from temporary parasitic illumination.

Andruk et al. (2002) proposes astronomical frame processing method within the MIDAS package (Buccheri et al. 1992) that does not use flat frames. The method is based on the separation of coarse-grained component of flat field from the frame using median filter. The disadvantage of this technical solution is using of third-party software. Also there is no analysis of quality indicators of proposed method of brightness equalization in this paper.

For brightness equalization of image background the low-pass filtering may also be used (Berry & Burnell 2005, Gonzales & Woods 2002, Solomon & Breckon 2011, O'Gorman et al. 2008, Martinez & Klotz 1998). The disadvantage of high-pass filtering is the necessity of representation an integer image in a floating point format in order to perform Fourier transformation. This tightens requirements for memory size. The presence of "ring"-type artefacts around bright objects on the equalized images (Gonzales et al. 2009) also limits usage of high-pass filtering for image equalization.

Substantiation of the inverse median filtering method usage for brightness equalization of astronomical images

Astronomical digital images may be divided into coarse-grained and fine-grained components. Each of these components has its own physical nature. Coarse-grained components correspond to the illumination of the image during astronomical observations at full moon or at sunrise/sunset and cover large part of frame. Fine-grained components correspond to the images of stars, asteroids and comets. The size of fine-grained components usually takes $5 \div 10$ pixels and no more than $50 \div 60$ pixels.

Difference between the images of interest (stars, asteroids, comets) and image background (coarse-grained components of astronomical images) makes it possible to use image frequency filtering for increasing the signal-to-noise ratio or decreasing the dynamic range of the image background. To remove coarse-grained components from the image it is advisable to use a high-pass filter that both attenuates low-frequency harmonics of the image spectrum and passes high-frequency harmonics. It is known that median filter with a certain window size may also perform functions of low pass filter. In this case high-pass filtering can be obtained by simple subtraction of the result of median filtering of the frame from initial frame.

In other words, difference between the sizes of images of objects of interest (stars, asteroids, comets) and image background (coarse-grained components of astronomical images) allows using image median filtering for coarse-grained components extraction. In this regard, described method has been called “inverse median filtering”.

Median filtering is non-linear image processing method. The median filter is implemented as a local processing procedure with sliding window of specified sizes (d_x, d_y) which includes an odd number of source image pixels A_{in} . Average count in this ordered set (median) is replaced by the central pixel of the filtered image window A_{med} (Fig. 1).

Gaussian values $G_k(m, n)$ are defined as:

$$G_k(m, n) = a_k \exp \left\{ -\frac{(m - m_k)^2 + (n - n_k)^2}{2\sigma_k^2} \right\} \quad (1)$$

where k is the gaussian number;

a_k is the amplitude of the k gaussian;

m_k, n_k – the center coordinates of the k gaussian;

σ_k – the gaussian shape parameters.

Gaussians with shape parameters of $\sigma_2 = 1$, $\sigma_2 = 2$, $\sigma_3 = 3$ have respectively of 28, 113, 254 pixels which have brightness more than $0.01 a_k$.

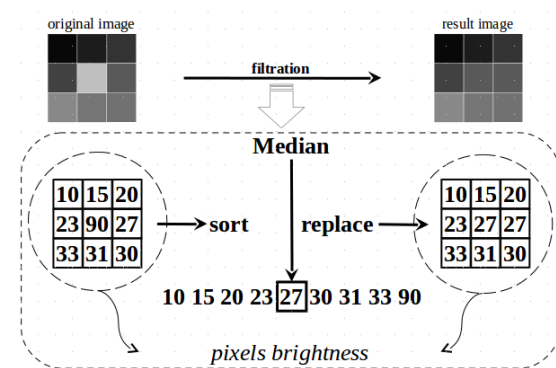


Figure 1: Median filtration

Using Calibration frames in Frame Smooth software

Proposed method of brightness equalization of frames has been implemented in the Frame Smooth software (Savanevych et al. 2016). This software may use calibration frames. It is especially important to use a master-dark frame. All master-frames are formed pixel by pixel. 10% of the largest and 10% of the smallest values of brightness of the each pixel is tentatively discarded. For the remaining K_1 values the pixel (m, n) brightness $A_k(m, n)$ related to used calibration frames the mean value is calculated:

$$\Delta_{K_1}(m, n) = \frac{1}{K_1} \sum_{k=1}^{K_1} A_k(m, n). \quad (2)$$

and RMS:

$$\sigma_{K_1}(m, n) = \sqrt{\sum_{k=1}^{K_1} (A_k(m, n) - \Delta_{K_1}(m, n))^2 / (K_1 - 1)}. \quad (3)$$

Brightness of the master-dark frame pixel is considered equal to the mean value of the pixel brightness only for K_2 ($K_2 \leq K_1$) pixels that do not differ from the mean $\Delta_{K_1}(m, n)$ (2) by more than three sigma $\sigma_{K_1}(m, n)$ (3):

$$\sqrt{(A_k(m, n) - \Delta_{K_1}(m, n))^2} \leq 3 \cdot \sigma_{K_1}(m, n). \quad (4)$$

1. Preparation of the calibration frames.

1.1. The master-bias frame is formed on the basis of the bias frames according to the expressions (2) ÷ (3).

1.2. The master-dark frame is formed on the basis of the dark frames according to the expressions (2) ÷ (3). If there is a master-bias frame then before the formation of the master-dark frame the master-bias frame is subtracted from each of the original dark frame.

1.3. The master-flat preparation. If dark flat frames and/or master-bias frame exist, then the master-dark flat is tentatively formed similar to section 1.2. Then, the master-bias and the master-darkflat frames are subtracted from flat frames. After this operation, the flat frames are reduced to the same level of mean brightness of pixels per frame. This level is defined as the brightness level of the first frame. Normalization is performed by multiplying each pixel of the flat frame (except the first) on the normalization factor. This factor is equal to a ratio of the sum of all pixels brightness of the first frame to the sum of all the pixels brightness of the analyzed frame. Then, from the transformed flat frames the master-flat frame is formed using operations similar to section.1.1.

2. Brightness equalization of CCD-frames. Brightness equalization of image is performed as operation of pixel by pixel subtraction of master-flat from CCD frame. Obtained result is divided by the master-flat frame and filtered with use of inverse median filter. The use of the master-flat frame during inverse median filtration is optional and does not significantly affect the obtained results.

Testing on real images

Every mathematical method should be tested on real data. We have performed testing using images acquired on several telescopes of Astronomical Observatory on Kolonica Saddle (Kudzej et al. 2007) during regular observing sessions. Generally the test consisted in comparison of traditional way of calibration with the new one proposed in this paper. Traditional way means the reduction of the images as usually was done in the observatory: calibration by master-dark (subtraction) and master-flat (division). Master-dark is usually constructed as median of 20 dark frames taken in the same temperature and with the same exposure time as raw images. Master-flat is the average of sky flats subtracted by corresponding master-dark. The new way means the calibration using the inverse median filter. There are several ways how to include the inverse median filtration into the calibration process. Here we present results of the most logical and most simple configuration: master-dark subtraction, master-flat division and than inverse median filtration.

The first step of testing was the visual inspection of the calibrated images. Actually, the images deteriorated by strong scattered light were flattened after the application of inverse median filter. The application only of the master-flat was not able to remove the large background structures on the images. One example is presented in Fig. 2.



Figure 2: Images from VNT telescope affected by scattered light. From left to right: raw image; image calibrated using classical procedure [master-dark + master-flat]; image calibrated with FrameSmooth software [master-dark + master-flat + inverse median filter]; image calibrated with FrameSmooth software [master-dark + inverse median filter without master-flat]

The second step of our testing was comparison of the values of standard stars obtained by differential photometry on the images calibrated by traditional way and the images calibrated by proposed approach. For this test we have chosen images without scattered light, without big background structures, already well flattened by master-flat. In these conditions one has to expect the same result independent on the way of image calibration. Moreover, any unwanted impact of the inverse median filter application should be visible. Here we present results from four time series runs on C14 telescope (Celestron Edge HD CGE Pro 1400 equipped with Moravian Instruments G2-1600 camera). After the calibration the reduction process was the same for all images. The photometry was performed using the C-Munipack software (Motl 2009). Then the method of artificial comparison star was applied as implemented in the MCV software (Kim et al. 2004). This method use the concept of the main comparison star which brightness should be entered arbitrary. As we were not interested in absolute values of the photometry, we used the value 0 for the main comparison star. To avoid the influence of some trends caused by extinction we have selected only short segments (~ 30 minutes) of the time series. The mean values of measured stars were compared for classical calibration process (C) and the calibration with inverse median filter (F). The results are shown in the Figure 3 and Table 1. It is evident that two methods are equivalent in this situation.

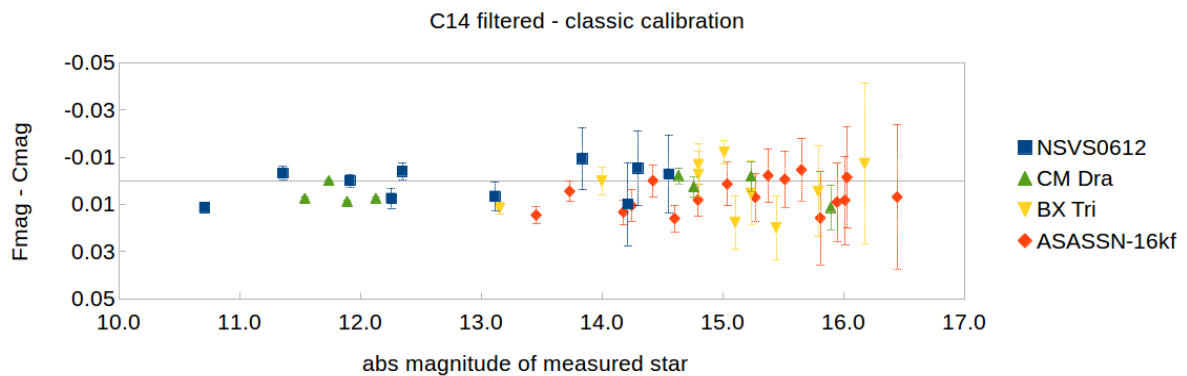


Figure 3: Differences between photometry on images calibrated in classical way (Cmag) and images calibrated by inverse median filter (Fmag). Results for 4 different time series runs on C14 telescope are shown. Only images well calibrated by classical master-flat were selected.

Table 1. Differences between photometry on images calibrated by inverse median filter (F) and classical calibration using C-Munipack software (C).

| Time series run on target: | Filter | Number of measured stars | Average error of determination of mean magnitudes of measured stars [mag] | Mean value of F-C [mag] | RMS (F-C) [mag] |
|----------------------------|--------|--------------------------|---|-------------------------|-----------------|
| NSVS0612 2016-08-30 | Rc | 11 | 0.011 | 0.001±0.007 | 0.007 |
| ASASSN-16kf 2016-09-09 | Clear | 17 | 0.012 | 0.006±0.006 | 0.009 |
| CM Dra 2016-09-09 | V | 10 | 0.012 | 0.003±0.011 | 0.011 |
| BX Tri 2016-09-12 | Rc | 8 | 0.003 | 0.004±0.005 | 0.007 |

The third step of testing consists in the repetition of the second step but on the images with severe impact of scattered light. We chose the observation of VNT telescope (Kudzej & Dubovsky 2010) during moonlight. Figure 2 came from this time serie. Now the difference between the traditional and the new method of calibration becomes visible. In the Figure 4 we present comparison of classical result with filtered one without using master-flat. The values obtained by the second way are much more closer to the values of Henden's photometry (Henden 2005). It is clearly visible that the discrepancies depend on the value of the master-flat image around the position of the given star. So the problem is caused by wrong master-flat. One can say that this is only happy coincidence and the “correct” values are those obtained by classical procedure. There are several ways how to reveal wrong data. For example, the $r-R$ values should have some dependency on colour index of standard stars. In the Figure 5 we present these plots. The filtered points are usable for determination of the transformation coefficient. The classical values do not show significant dependency.

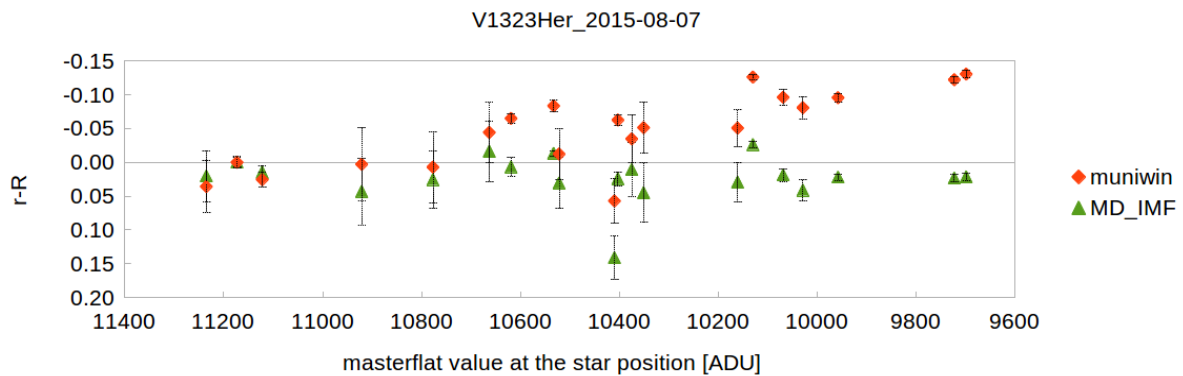


Figure 4: Measurements of standard stars in the field of V1323 Her. R - standard values from Henden's photometry, r – measured values on our images, 'muniwin' stands for classical procedure, 'MD_IMF' means result of FrameSmooth software using master-dark and inverse median filter without application of master-flat. In order to show the influence of wrong master-flat we use the value of the corresponding master-flat at the position of the measured star as the abscissa value.

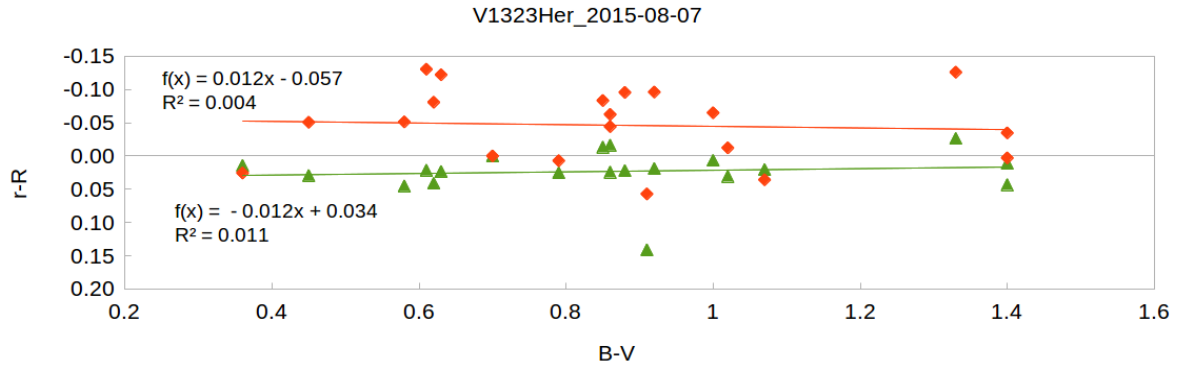


Figure 5: The same values as in Figure 4 plotted against color index B-V of standard stars. Linear fits are also shown.

Another proof of correctness is comparison of differential photometry on the frames with significant shift in physical position of stars on the detector. Actually, this is the principle of the method of stellar calibration of CCD flat fielding proposed by Manfroid (1995). In real life the meridian flip on german equatorial mount can be used without loss of observing time. Unfortunately, VNT telescope has fork mount so we have had to wait to accidental failure of autoguiding system to obtain frames with stars gradually drifting on the detector. The result of photometry in such conditions is depicted in the Figure 6. Although the background was well flattened by sky master-flat, there are severe trends present on the photometry of constant stars. No trends are present on the frames calibrated by FrameSmooth software using the inverse median filter.

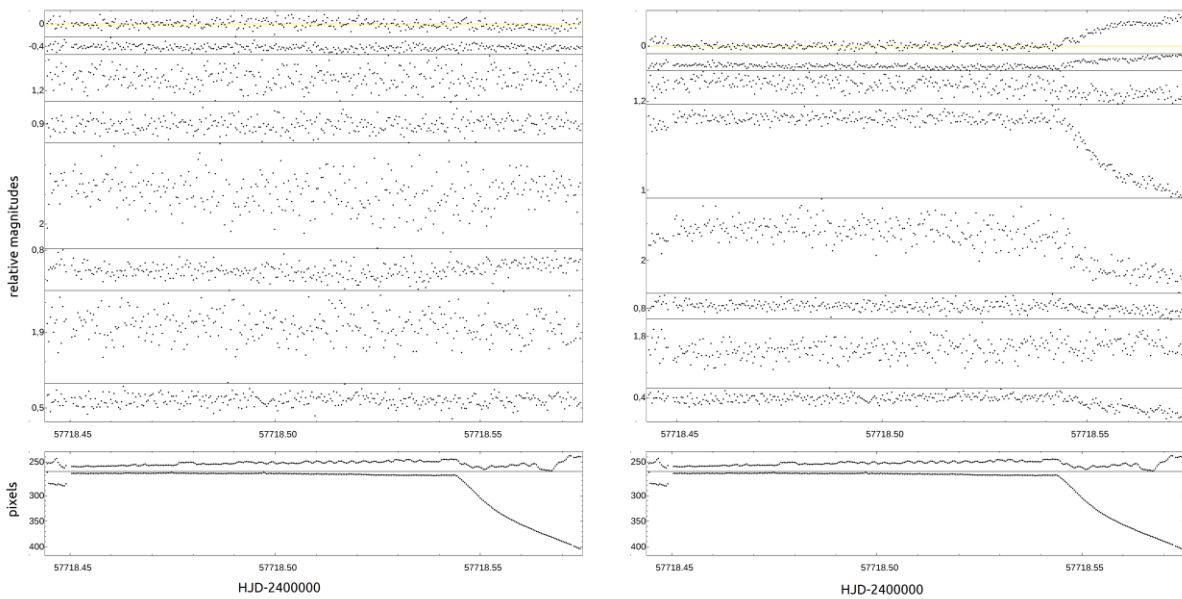


Figure 6: The light curves of comparison stars in the field of the variable GJ3236 restored using the “multi-comparison star” method implemented in “MCV” software (Kim 2004). Left: frames calibrated with inverse median filter. Right: Frames calibrated by conventional master-flat. Bottom: Tracking errors in RA and Dec respectively.

Conclusions

This article describes the computational method of brightness equalization of astronomical images based on the inverse median filtration and implementation of proposed method for large images. As indicators of the background equalization quality we introduced estimation of the mean values and standard deviation of the background pixels brightness both on the original and equalized frame's segments. The analysis of quality indicators of equalization of the astronomical images background have been carried out. Results demonstrated that the range of mean values of background pixels brightness was reduced in two times by the 5% level of the maximum histogram value. This decrease is greater the larger the size of the window is being used.

Furthermore, utilization of equalized images leads to increasing of astrometry accuracy indicators and stars photometry quality as well as the quality indicators of asteroids and comets detection.

Proposed computational method increases the signal-to-noise ratio and reduces the dynamic range of astronomical images background. Method was implemented and successfully used as part of CoLiTec (Savanevych et al. 2015a, Savanevych et al. 2015b, Pohorelov et al. 2016) software of automatic discovering of asteroids and comets on a series of digital frames This method has also been implemented in the Frame Smooth free software (Savanevych et al. 2016).

The proposed method of inverse median filter application can be used for calibration of astronomical images without negative influence on the results of the photometry. It can replace the master-flat application if there are no structures on the images background with size similar to the sizes of the stars. It is usually enough when the aim is relative photometry at 0.01 mag level. When absolute photometry with high accuracy is required, one has to be aware that even excellent uniformity of the background doesn't mean correct calibration for stellar sources. See Tobin (1993) for details.

Acknowledgement

This work was supported by the by the project APVV-15-0458 "Interacting binaries - Key for the Understanding of the Universe".

References

- Andruk, V. N., Ivaschenko Yu. N., Butenko G. Z., 2002, Обработка ПЗС-изображений звездных полей в пакете MIDAS/ROMAFOT. Abstr. Int. Conf. ASTROECO- 2002 "Current status and prospects of international research in observational astronomy, ecology and extreme physiology in the Elbrus region", 71-74
- Berry, R., Burnell, J., 2005, The Handbook of Astronomical Image Processing (Second English Edition), Willmann-Bell, 684
- Buccheri, R., Crane, P., di Gesù, V., et al., 1992, Data Analysis in Astronomy IV. Ettore Majorana International Science Series, Springer Science & Business Media New York, 59.
- McLean, I. S., 2008, Electronic Imaging in Astronomy. Detectors and Instrumentation (Second Edition), Springer, 552
- Howell, S. B., 2006, Handbook of CCD Astronomy (Second Edition), Cambridge University Press, 208
- Gonzales R., Woods, R., 2002, Digital Image Processing, Prentice Hall
- Gonzales R., Woods, R., Eddins, S., 2009, Digital Image Processing using MATLAB 2nd ed., Prentice Hall
- Henden, A. 2005, <ftp://ftp.aavso.org/public/calib/j1803.dat>
- Kim, Y., Andronov, I.L., Jeon, Y. B., 2004, J. Astron. Space Sci., 21, 191-200
- Kudzej, I., Dubovsky, P. A., 2010, Odessa Astronomical Publications, 23, 70
- Kudzej, I., Karetnikov, V. G., Dubovsky, P. A., et al. 2007, Odessa Astronomical Publications, 20, 100
- Manfroid, J.; 1995, Astron. Astrophys. Suppl. Ser., 113, 587-591
- Martinez, P., Klotz, A., 1998, A practical guide to CCD astronomy, Cambridge University Press
- Motl, D. 2009, C-Munipack, <http://c-munipack.sourceforge.net/>
- O'Gorman, L., Sammon, M. J., Seul, M., 2008, Practical algorithms for image analysis: description, examples, and code, Cambridge University Press

Pohorelov, A.V., Khlamov, S.V., Savanevych, et al., 2016, Odessa Astronomical Publications, 29, 136–140.

Savanevych, V. E. et al., 2016, FrameSmooth, http://www.neoastrosoft.com/filter_en/

Savanevych, V. E., Briukhovetskyi, O. B., Ivashchenko, Yu. N., et al., 2015, Kinematics and Physics of Celestial Bodies, 31, 302–313.

Savanevych, V. E., Briukhovetskyi, O. B., Sokovikova, N.S., 2015, MNRAS, 451, 3287–3298.

Solomon, Ch., Breckon, T., 2011, Fundamentals of Digital Image Processing. A Practical Approach with Examples in Matlab, Wiley-Blackwell

Tobin, W., 1993, in Stellar photometry – Current techniques and future developments, IAU Coll. 136, (Cambridge University Press) 304.

Warner, B. D., 2006, A Practical Guide to Lightcurve Photometry and Analysis, Springer