TOWARDS IMPROVING THE QUALITY OF STELLAR PHOTOMETRY - SPATIALLY DEPENDENT ERRORS IN STELLAR MAGNITUDES

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Abstract

Systematic errors in stellar photometry as a function of spatial distribution of stellar images over the CCD chip have been investigated. New terms in the calibration equations aimed to reduce these errors are suggested. It is shown that this procedure improves the scatter in magnitudes and refines the photometry zero-point.

Introduction

An important procedure in stellar photometry is the transformation of instrumental magnitudes to a standard photometry system. The equations commonly applied have the following general form:

$$m = M + m_0 + f(X,CI)$$

Here $\boldsymbol{m}$ marks instrumental stellar magnitudes, $\boldsymbol{M}$ are the corresponding standard magnitudes and $\boldsymbol{m_0}$ the photometry zero-point, $\boldsymbol{X}$ is airmass at which target is observed, $\boldsymbol{CI}$ is the standard star color index. Coefficients in this equations are established for standard star magnitudes applying the least squares method. As a rule standard stars instrumental magnitudes are derived by means of the aperture photometry.

Accounting that the competitive method for assessment stellar brightness based on the PSF model of stellar image is spatially dependent ([1] Stetson, DAOPHOTII) we developed a method reducing aperture magnitudes for possible positional dependence. Sec.2 describes the observations; Sec.3 presents the method and basic results and Sec. 4 is devoted to the solution of the problem and conclusions.

2 The observational strategy

To detect probable spatially dependent systematic errors one have to ensure uniformly spread over the CCD chip stellar images which brightness is well known. This could be reached in two ways: a) multiple images of one and the same standard star to be taken moving the telescope between exposures in order stellar image to be suited at different regions of the focal field or b) rich uniformly populated standard fields to be used. The former approach is very time consuming as well observing as reducing the images because we prefer the second one. Suitable Stetson's standard fields ([2] Stetson) were observed multiple slightly moving the telescope between consecutive exposures in one and the same pass-band. Observations were taken in the RC focus of the Bulgarian National Astronomical Observatory 2-m telescope. Image reduction and data analyze were performed with IRAF. When this was possible some frames were summed before photometry process.

3 The methodology and main results

For every single frame standard stars were detected and their aperture magnitudes derived. In order to account the changes in photometry conditions during separate runs and even during the night (atmospheric transparence and extinction), instrumental magnitudes for every frame have been reduced to the standard system with some average for that sample value. This manner instrumental magnitudes from different frames have been set to a common photometry zero. However all they still are instantly disturbed from color and spatial dependencies if any. To establish the value of probable spatial dependence the differences "instrumental (commonly reduced) minus standard magnitudes" (hereafter residuals) as a function of stellar image position on the chip have been investigated. Fig.1 demonstrates these relations along columns (X direction, down panel) and rows (Y direction, upper panel) of the CCD chip in the case of V pass-band. Significant spatial dependence of stellar magnitudes could be easy detected. Fig. 2 shows the same relation for sparse field in the same pass-band but only for one direction. It demonstrates the importance of the quantity of standard stellar images in a single field. Sparse fields should be taken multiple in one and the same pass-band moving the telescope between exposures in order standard star images to be detected at different regions of the chip.

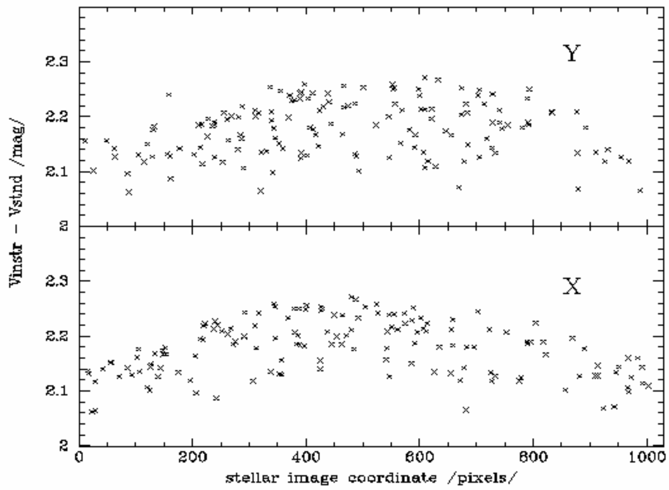

Fig.1. Spatial dependence of residuals (instrumental minus standard magnitudes) along columns (upper panel) and rows (down panel) for the case of rich standard field in V pass-band. Coordinates in both directions (abscissa) are in pixels and are related to the CCD frame. Residuals (ordinate) demonstrate significant spatial dependence

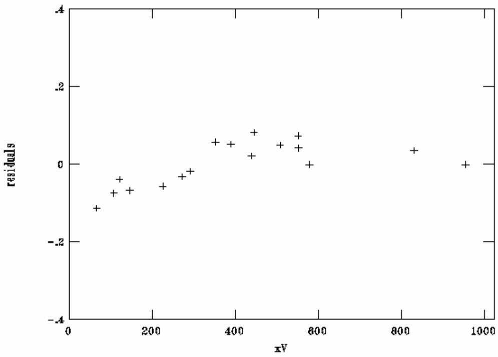

Fig.2. Spatial dependence of residuals for the case of sparse standard field in V pass-band. The meaning of the two axes is like in fig.1. Here is demonstrated spatial dependence only along the columns

4 Solution of the problem and conclusions

To reduce stellar magnitudes for these systematic errors we suggest terms dependent on stellar image position on the chip to be involved in the equations transforming instrumental magnitudes into standard system. The new terms suggested are:

$$c_1*(x/512.5 - 1)^2 + c_2*(y/512.5 - 1)^2$$

Here c_1 and c_2 are column and line oriented positional coefficients respectively but x and y are stellar image center coordinates. In this presentation the stellar image coordinates related to the CCD frame are normalized in the range [-1, 1]. At this stage we solve equations only for spatial dependence neglecting color terms. The coefficients m_0, c_1 and c_2 were derived by means of least squares method and their values for different observing runs are listed in Table 1.

V pass-band

RUN	m_0	c_1	c_2
1	0.095±0.004	-0.158±0.014	-0.138±0.015
2	0.072±0.002	-0.145±0.004	-0.135±0.005
3	0.042±0.007	-0.128±0.014	-0.044±0.014
4	0.036±0.004	-0.104±0.010	-0.077±0.009

B pass-band

RUN	m_0	c_1	c_2
1	0.056±0.005	-0.154±0.022	-0.135±0.014
2	0.063±0.003	-0.129±0.006	-0.114±0.007
3	0.054±0.006	-0.109±0.014	-0.116±0.015
4	0.049±0.005	-0.102±0.014	-0.107±0.013

Table 1: The values of transformation equation coefficients and their instrumental uncertainities for different observing runs. Column 1 presents observing run, column 2 the photometric zero-point, but columns 3 and 4 the 'spatial dependent' coeffitients.

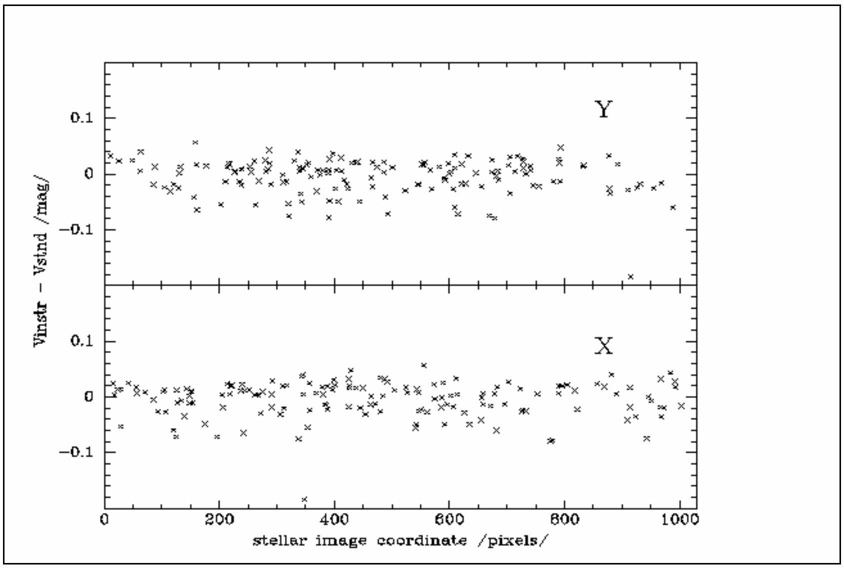

Fig.3. Spatial dependence of residuals after instrumental magnitudes were corrected. The meaning of the axes is like in the above figures. Apart from the straight form of the dependence the scatter is significantly lowered that hints on better photometric quality

$\boldsymbol{m_0}$ variation from run to run (Tab. 1 column 2) is an important result in our investigation. It points that neglecting the spatial dependence of stellar magnitude leads to uncertainty in photometry zero-point up to 0.1 mag.

Fig. 3 demonstrates results after correcting instrumental magnitudes for spatial dependence. Comparing Fig. 3 and Fig. 2 it gets evident that the method we offer improves the quality in stellar photometry. It should be applied taking care for good signal/noise level of stellar images and their uniform spread over the CCD chip.

References

[1] P.B.Stetson, (1992), "User's manual for DAOPHOTII"
[2] P.B.Stetson, PASP 112 (2000) 925, "Homogeneous photometry for star clusters and resolved galaxies. II. Photometric standard stars"