

# CCD stellar photometry with fixed aperture and the growth-curve analysis

Anton Strigachev  
Institute of Astronomy, Bulgarian Academy of Sciences  
anton@astro.bas.bg  
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**Abstract.** This paper<sup>1</sup> compares photometric results computed with fixed aperture and with growth-curve analysis. The low amplitudes of bright variable stars are better detected with fixed aperture photometry. Faint objects with long term variations that might be affected by different observing conditions, are better presented by the method of growth-curve analysis.

**Key words:** techniques: photometric

## CCD звездна фотометрия с фиксирана апертура и анализ на кривата на нарастване

Антон Стригачев

В работата са сравнени резултати от фотометрия с фиксирана апертура и с анализ на крива на нарастване. Слаби амплитуди на ярки променливи звезди могат да бъдат по-добре регистрирани с помощта на фотометрия с фиксирана апертура. Слаби обекти с дълго-времева променливост, които биха могли да бъдат повлияни от различни наблюдателни условия, по-добре се представят чрез метода на кривата на нарастване.

## Introduction

In the last decades charge-coupled devices (CCDs) received wide usage for acquiring astronomical images almost replacing the old photographic plates and photometers. This is mostly due to their high efficiency, linearity, and ease of use.

The photographic plates and photometers have their advantages. The plates have usually large fields of view (a few degrees) that might be necessary for specific astronomical tasks. However, the photographic plates need a lot of preprocessing procedures and digital recording before the output can be analyzed. The CCD detectors produce images that are directly stored in a computer. This makes working with them much easier and faster. Although the fields are usually not very large (a few arcminutes), CCDs allow to perform simultaneous photometry of many frames and objects in a reasonable time.

The reduction of CCD images is performed using computer programs. The preprocessing of the frames (bias, dark, flat-fields, cosmic rays, linearity, fringes, etc. corrections) is a straightforward task, and is usually done with

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<sup>1</sup> *Based on observations collected at Skinakas Observatory in Crete, Greece. The Skinakas Observatory is a collaborative project of the University of Crete, the Foundation for Research and Technology – Hellas, and the Max-Planck-Institut für Extraterrestrische Physik.*

standard routines running under MIDAS or IRAF environment. The next step depends on the specific astronomical task.

Basic methods and techniques for photometry of stellar objects are described in [DaCosta 1992]. The most commonly used computer program for this purpose is DAOPHOT [Stetson 1987]. It performs concentric aperture photometry, and PSF-fitting (for crowded fields). Both methods give differential magnitudes. To find the instrumental magnitudes, the first step is to compute the total magnitude of the star – this means to integrate over the whole star’s profile. Stars profiles go to infinity, so it might seem that using as large aperture as possible would give the best solution. However this is not the case, because increasing the aperture radius will increase the errors of the sky determination, the readout noise and others, that grow up in square as the radius increases linearly. In this case the signal-to-noise ratio is low [Howell 1989, Stetson 1990, DaCosta 1992].

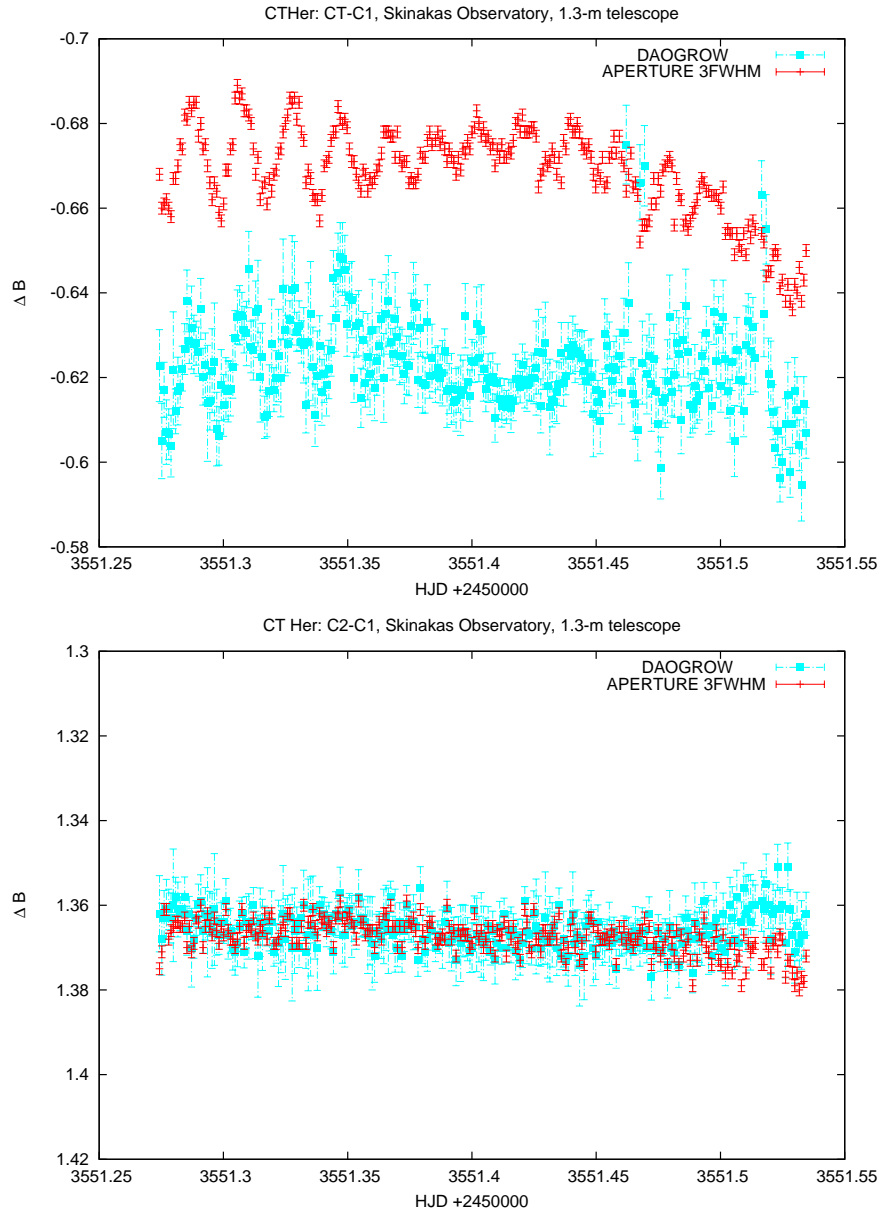
At some radius there is a magnitude with the highest signal-to-noise ratio and minimal errors. The total magnitude is not within this radius because it doesn’t contain the total flux of the star. To compute the total magnitude one needs to apply a correction, called aperture correction. It might be computed simply by measuring the magnitudes of brighter stars within small and large apertures, and then apply the difference to fainter stars. The method of growth-curve analysis computes the aperture correction in a more precise way. It finds its best value by computing the magnitude differences for a set of increasing apertures. This assumes a linear response of the detector so that the light ratio within given different radii stays the same for different stars. The aperture size where the error of the total magnitude achieves minimal value is called the best aperture. The light after the best aperture, integrated to infinity, is called aperture correction. To get the total light of the star, the aperture correction is added to the magnitude within the best aperture. All this is described in detail in [Stetson 1987], and there is a dedicated computer program called DAOGROW that performs the computations.

To convert the total light to instrumental magnitudes, they should be further corrected for exposure times, and if there are standard fields observed the same way, they might be converted to a standard system.

In some cases the magnitudes of the stellar objects are measured within a fixed aperture. This is usually done when monitoring bright variable stars. The variability is estimated by comparing one star to another (variable minus comparison star), and there is usually another check star (comparison minus check star) to see if there are any fluctuations in the comparison star. In this case there is no need to convert differential magnitudes to instrumental and/or to standard values. The selection of the appropriate value for the aperture in this case should be done in the sense of maximum value of the signal-to-noise ratio, and minimal errors.

## Observations

To compare the output from the fixed aperture photometry and from the growth-curve analysis, I used a set of frames observed at Skinakas Observatory with the 1.3-m telescope.



**Fig. 1.** Results of the observations of CT Her with fixed aperture photometry, and with growth-curve analysis

Fig. 1 shows the variable star CT Her (CT Her minus comparison star C1; and check minus comparison C2-C1). It was observed in the framework

of an international collaborative project [Lampens et al. 2008]. CT Her is an eclipsing binary with a variable ( $\delta$  Scuti) component that was first discovered by Kim et al. [Kim et al. 2004]. The goal of the observations was to study the pulsations of the variable component.

The discussed observations were done on 29 June 2005 with the CCD camera CH360. The seeing was about  $2''$ , better in the beginning and poorer toward the end of the observing run, when airmass reached  $\approx 2$ . All frames were taken through standard Johnson B filter with exposure times 35 sec. For the computations with fixed aperture, I used the same average FWHM=4 px (CH360 scale= $0.5''/\text{px}$ ), and the same aperture for all frames. The aperture radius was set to  $3 \times \text{FWHM}$  ( $\text{AP}=3 \times 4=12$  px). This value is equal to the best aperture size computed by DAOGROW ( $\approx 12$  px) for the stars CT Her, C1 and C2. The results computed with fixed aperture photometry, and for DAOGROW are marked with red with blue marks respectively.

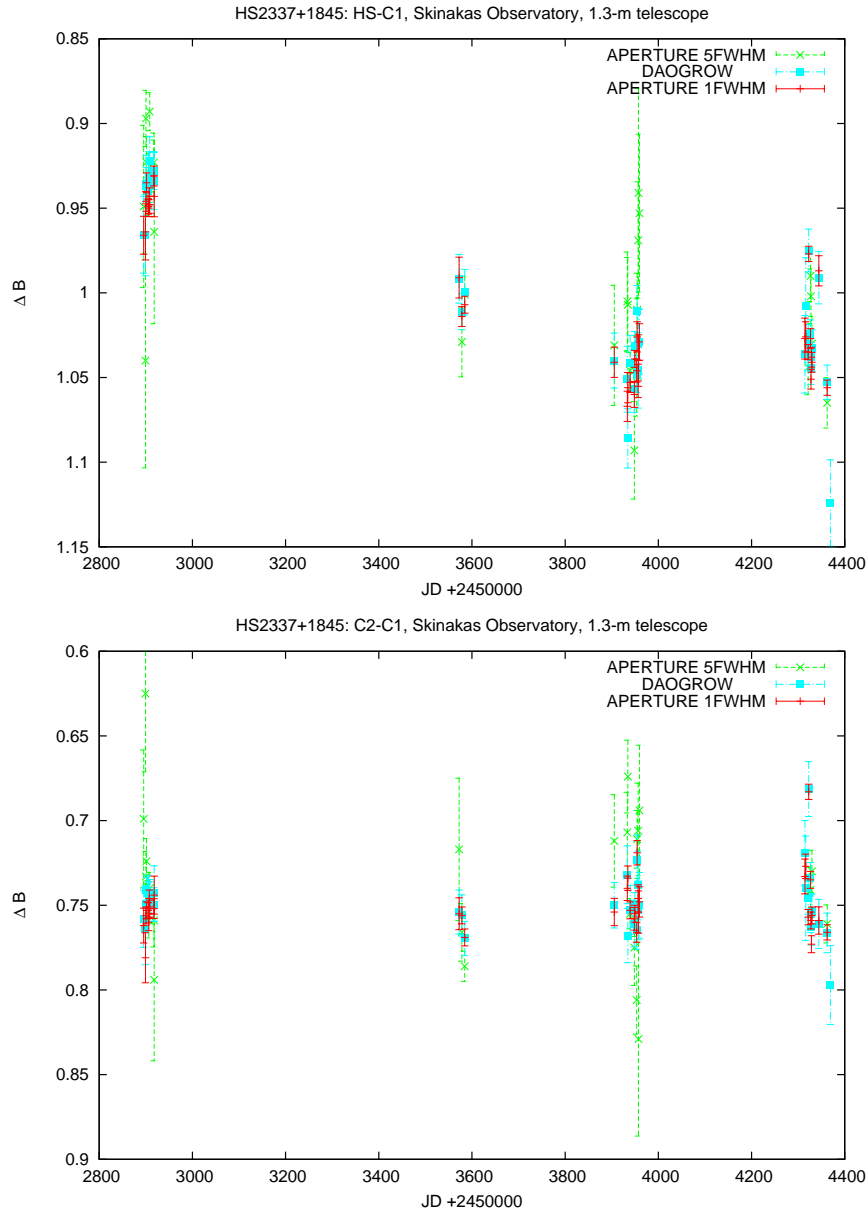
Fig. 2 shows the quasar HS2337+1845 (HS2337+1845 minus comparison star C1; and C2-C1). It was observed for some years as a part of a program for monitoring of quasars. Detailed analysis of the results of this quasar will be published elsewhere. In the years 2003, 2005, and 2006 the observations at Skinakas were performed with the CH360 CCD camera. In 2007 Skinakas Observatory employed the usage of a new CCD camera ANDOR. In Fig. 2 the first three groups of points are with CH360, the last group to the right is with ANDOR. In all cases the exposure time for the quasar was 360 sec, and the used filter was Johnson B.

In the case of HS2337+1845 the seeing during the observations performed in so many years was very different – in the range from  $1''$  to  $3''$ . I adopted average value of  $2''$  for both cameras CH360 and ANDOR. The fixed aperture photometry with CH360 is done with FWHM=4 px, and the aperture radius equal to  $1 \times \text{FWHM}$  ( $\text{AP}=4$  px). With ANDOR the average value of FWHM=7 px (ANDOR scale= $0.2825''/\text{px}$ ), and this value was used for the fixed aperture photometry. The photometry for both cameras was performed within the same aperture size on the sky ( $2''$ ) in both cases equal to  $1 \times \text{FWHM}$  ( $\text{AP}=4$  px for CH360, and  $\text{AP}=7$  px for ANDOR, scales for the cameras are given above). For both cameras this is the best aperture size computed by DAOGROW for the quasar and the comparison stars.

Fig. 2 also shows with green marks the results from fixed aperture photometry with aperture radius equal to  $5 \times \text{FWHM}$  ( $\text{AP}=20$  px CH360, and  $\text{AP}=35$  px ANDOR).

## Discussion

*CT Her*: The oscillations of the small amplitude of the  $\delta$  Scuti component of the eclipsing binary CT Her are well detected. This is clearly seen in the upper part of Fig. 1. These variations have total amplitudes of about  $0^m.02$  or less. The errors of the aperture photometry are small enough ( $\sigma \approx 0^m.001$ ) that makes even smaller amplitudes detectable. The results with DAOGROW also show these variations but the errors are much larger ( $\sigma \approx 0^m.008$ ) so the amplitudes are not so well defined. The smaller variations, (and they are real) are not well traced, and in most cases are dominated by the errors.



**Fig. 2.** Results of the observations of HS 2337+1845 for two different values of fixed aperture, and with growth-curve analysis

Regarding C2-C1, the errors of the aperture photometry are also smaller

compared to these with DAOGROW. The scatter is larger toward the end of the observations. This is due to the higher airmass ( $\sim 2$ ) at the end of the observing run.

There is a shift of  $\approx 0^m.05$  in Fig. 1 between the results of the aperture photometry and DAOGROW, and a slope in the aperture photometry toward the end of the observations. Both are due to the second term extinction coefficient that is not corrected here. To apply these corrections – zero point and slope – one should know the initial model of the binary system, and this is out of the scope of this paper. DAOGROW is taking into account these corrections, and its zero-point and slope are correct.

*HS2337+1845*: In Fig. 2 the aperture photometry of the quasar with aperture  $5\times\text{FWHM}$  doesn't allow to conclude on its variable behavior. The scatter is very large, the errors are of order  $\sigma \approx 0^m.05$ . The aperture photometry with radius  $1\times\text{FWHM}$  shows much smaller scatter, typical errors are  $\sigma \approx 0^m.005$  – that is ten times better. DAOGROW follows almost exactly the aperture photometry with  $1\times\text{FWHM}$ , and with approximately the same errors ( $\sigma \approx 0^m.005$ ). Both show a clear trend of decreasing magnitude by a factor of  $\approx 0^m.10$  over three years interval, and then a slight increase by  $\approx 0^m.03$  for the next year. Regarding C2-C1, the stars stayed constant during the four years observing period; the scatter with aperture  $5\times\text{FWHM}$  is huge; aperture  $1\times\text{FWHM}$  and DAOGROW give approximately the same result.

## Conclusions

1. The choice of appropriate value for fixed aperture photometry is of extreme importance. It can be applied to observations done with the same instrumentation and within the same observing run, and for objects of approximately equal relative brightness and colors. Both too small and too large apertures, deviating from the one with the highest signal-to-noise ratio, produce large errors, and the final result cannot be trusted. The best way to choose the appropriate value of the aperture radius is to run a test with DAOGROW, and then take the average value for the stars of interest. The value of this aperture is highly depending on the relative brightness of the stars.
2. For monitoring of variable stars the best approach would be to reduce with a fixed aperture photometry. While studying the pulsations of stars with low amplitudes, such as  $\delta$  Scuti variables, very small amplitudes ( $0^m.02$  or less) with very small errors ( $0^m.001$  or less) might be detected. This can be done with fixed aperture photometry assuming excellent other conditions – atmospheric and instrumental – and if the stars (variable, comparison, and check) have similar magnitudes and colors to give small internal errors. In this case some additional corrections might be needed concerning the second term extinction coefficient.
3. To study the variability of faint isolated stellar objects over a long time interval when observations might be affected by different seeing, telescope tracking, etc; or to compare results acquired with different instrumentation (CCD cameras, telescopes, etc); or to do an all sky photometry

and convert magnitudes to standard system, – in all these cases the best approach would be to employ the growth-curve analysis.

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