APSFFit: An automatic procedure for photometry and astrometry in crowded fields

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Abstract. *A number of astronomical problems require accurate measurements of the brightness of stars located in crowded fields. These include the search for extrasolar planets, gravitational microlensing amplification events, as well as the search for variable stars. In this work, I describe an automatic procedure for photometry and astrometry in crowded fields (APSFFit) using a methodology similar to the one used in DAOPHOT/IRAF, but with capability of processing a list of the images automatically. This procedure uses the Amoeba algorithm to fit either a Gaussian function or a Moffat function to the stellar profile. Two applications are presented: the light curve of the eclipsing binary BUL SC16 335 which is located in the Galactic bugle and the identification of the flaring components of the astrometric triple LHS 1070. Although not shown in the body of this paper, the astrometric and photometric precision obtained by APSFFit and DAOPHOT is similar.*

Resumo. *Um número de problemas astronômicos requer medidas precisas do brilho de estrelas localizadas em campos lotados que contêm sobreposição de fontes. Esses incluem a busca por exoplanetas, eventos de amplificação de microlentes gravitacionais, como também, busca por estrelas variáveis. Nesse trabalho, nós descrevemos um procedimento automático para fotometria e astrometria em campos lotados (APSFFit) usando uma metodologia similar à usada pelo DAOPHOT/IRAF, mas com a capacidade de processar uma lista de imagens automaticamente. Esse procedimento usa o algoritmo AMOEBA para ajustar ou uma função Gaussiana ou uma função Moffat ao perfil estelar. Duas aplicações são apresentadas: a curva de luz da binária eclipsante BUL SC16 335 que está localizada no bojo galático e a identificação das componentes emissoras de flares no sistema triplo LHS 1070. Embora não apresentado no corpo deste artigo, a precisão astrométrica e fotométrica obtida por APSFFit e DAOPHOT/IRAF é similar.*

1. Introduction

Accurate automatic determination of the parameters of astronomical images is a fundamental problem in modern astronomy. A procedure to obtain a list with position, intensity and other information about the stellar profile is fundamental in performing elementary classification of images in stars and galaxies, to study distribution, variability, color and proper motions of objects. All these parameters are useful for a wide variety of astronomical problems.

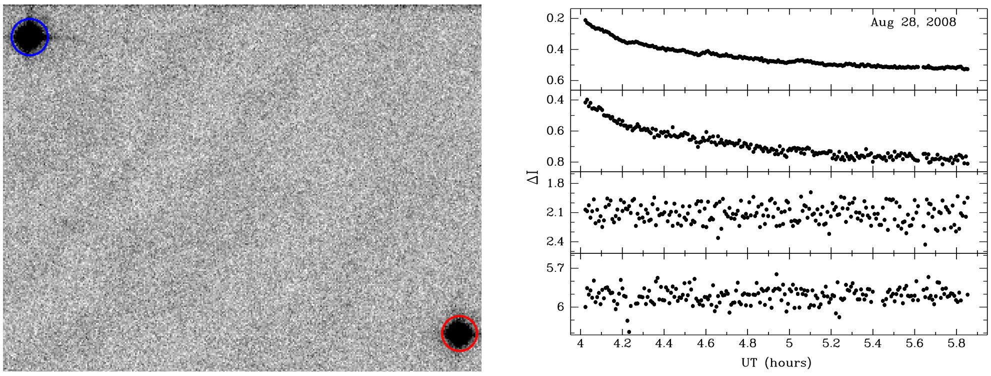

Figure 1. **Left panel: Image of the LHS 1070 field obtained using the Zeiss 0.6-m telescope on August 28, 2008. The reference star and LHS 1070 A+B+C are marked with blue and red circles, respectively. Right panel: I_C-band differential photometry of LHS 1070. From top to bottom I show the aperture photometry for LHS 1070, the results of the 2-D Moffat function fitting for LHS 1070 A and LHS 1070 B+C and the aperture photometry for a comparison star.**

When the field is not crowded the procedure to obtain the position and the intensity is relatively easy. It does not make assumptions about the actual shape of the source PSF (Profile Stellar Function) but simply collects and sums up the observed counts within a specified aperture centered on the source, this technique is called of aperture photometry. However, when one is interested in classification of the images into stars and galaxies or if the fields are crowded, aperture photometry does not work. A procedure using PSF is a way of performing differential photometry and astrometry in crowded fields. The PSF is treated as a template for all the stars in a frame, so its knowledge is fundamental for a reliable analysis. I use Gaussian and Moffat analytical functions as a model for the PSF and use the AMOEBA routine [Press et al. 1992] for the fitting procedure. The AMOEBA routine was chosen as optimization method because it is fast and easy to be implemented with non-differentiable functions, which will be done in the near future.

2. Method and Materials

In order to present the algorithm, it is described below a generic procedure. I divide the algorithm in three parts: (i) the input parameters, (ii) the execution, and (iii) the output files.

The input parameters are as follows: (i) a list with the images, (ii) a list with the position of the stars in the CCD, (iii) a normalized flat-field, (iv) a master median bias image, and (v) informations about the target and about the observation as, for example, right ascension, declination, day of observation, etc. To compose the list of position, the stars are selected with statistically significant intensity peaks above the background. This step is performed using the STARFIND/IRAF task. The isolated and bright unsaturated stars are used to compose the shape of the PSF. These stars must be the first objects at the list. In sequence must be listed the reference star, the targets and the comparisons.

In execution, the code initially subtracts a master median bias image from each program image, and divides the result by a normalized flat-field. The isolated and bright unsaturated stars are found automatically in the resulting image. Theses objects are fitted using either Gaussian or Moffat models. The models can be elliptical or circular. The average value of the PSF shape parameters is used to fit one by one the star of the field.

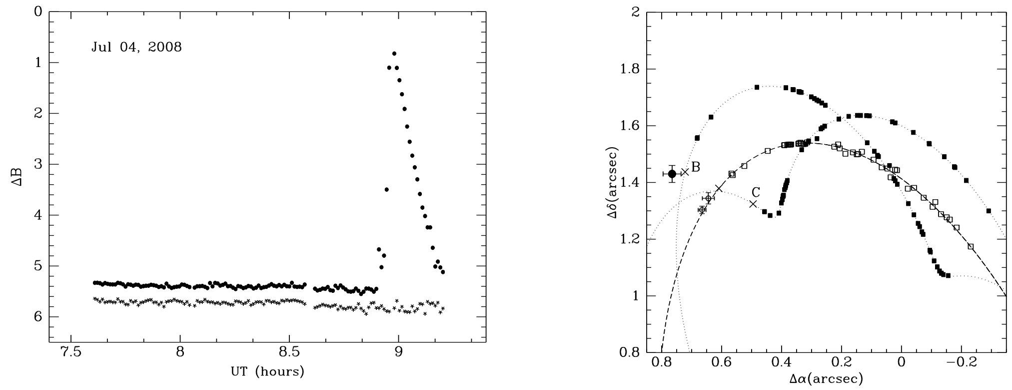

Figure 2. **Left panel: B-band differential photometry of LHS 1070. The light curves of LHS 1070 and of a comparison star are presented with full circles and stars, respectively. Right panel: Configuration of LHS 1070 on July 04, 2008. The dashed line represents the trajectory of the barycenter of LHS 1070 B+C around LHS 1070 A which is at the origin. The dotted lines show the trajectories of components B and C around the barycenter of LHS 1070 B+C, assuming the two components have the same mass. The open and full squares show the astrometric positions of LHS 1070 from 1993 to 2008 [Leinert et al. 2001, Seifahrt et al. 2008]. My measurements appear as open circles. The full circle shows the estimated position for the flaring object. The predicted positions of the barycenter of LHS 1070 B+C and of the components B and C are marked with a "$\times$" symbol.**

Thus only amplitude and position of the stars are free parameters. The code also allows to fit two or three stars simultaneously (see Section 3).

The output is composed of two files: one with the photometric results and another one with the astrometric results. In the file with the photometric results are listed: (i) the name of images, (ii) the Heliocentric Julian Day (HJD), (iii) the instrumental magnitude of the reference star, and (iv) the differential magnitudes of the targets and of the comparisons. In the astrometric file, besides image names and the HJD, the positions (x and y in pixels) of all stars in all images are listed.

3. Applications and Results

I show two applications of the APSFFit code: (i) the astrometric triple system LHS 1070 (see Figure 1), and (ii) a pre-cataclysmic variable located in the Galactic bulge (see Figure 3).

LHS 1070 is a triple system of low-mass stars at a distance of $7.72 \pm 0.15\,\mathrm{pc}$ [Costa et al. 2005]. It was observed two flare in this system. The first was an impressive 5 mag amplitude flare in the B band (see Figure 2). In the second, a descend of a long (hours time-scale) I_C band flare with a few tenths of mag amplitude (see Figure 1). As one can see in this figure, the three components are overlapped hence, aperture photometry would not be able to identifying which of components was the flaring object. In both case, it was fitted simultaneously three 2-D Moffat functions to the stellar profile leaving only the position of component A and the amplitudes of the three components as free parameters to be searched for. In Figure 2, I show the position of the flare observed in the B band together with the orbital solutions for LHS 1070 B/C and LHS 1070 A/(B+C) and conclude that component B was the flaring object. The results of the second flare is shown in Figure 1. In this case, component A was the flaring star [Almeida et al. 2011].

BUL-SC16 335 is a eclipsing pre-cataclysmic variable [Polubek et al. 2007]. This object is very interesting in the evolution study of cataclysmic variables because the phys-

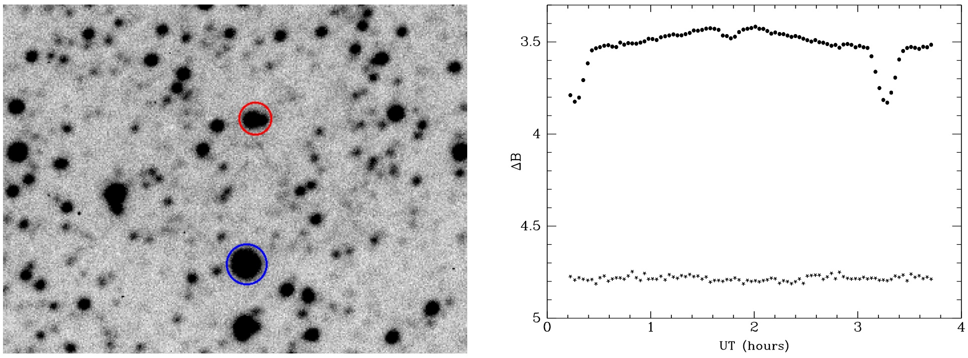

Figure 3. **Left panel: Image of BUL-SC16 335 field obtained using the Perkin-Elmer 1.6-m telescope. The reference star and BUL-SC16 335 are marked with blue and red circles, respectively. Right panel: B-band differential photometry of BUL SC16 335 on July 03, 2008. The PSF differential photometry of BUL SC16 335 and of the star overlapped is shown with full circles and stars respectively (see red circle in the right panel).**

ical and geometrical parameters of the system can be estimated with relatively good precision. However, as seen in Figure 3, the binary is overlapped for another object. Therefore, any variation in this another object could induce errors in estimating the parameters of the system. To avoid a possible contamination from that object, I used APSFFit to fit two 2-D Moffat functions to the stellar profile leaving only the position and amplitude as free parameters. In Figure 3 is shown the result of this procedure.

Acknowledgements

This study was partially supported by CAPES and Fapesp (2012/09716-6). I acknowledge Francisco Jablonski for his comments and suggestions to improve this work.

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