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Time Critical Analysis by Image Subtraction

I. Bond[1]

Department of Physics, University of Auckland, Auckland, New Zealand

Abstract. The NZ/Japan MOA Collaboration is currently carrying out observations using a 24 Megapixel CCD mosiac camera at the Mt John Observatory in New Zealand. A data analysis system based on image subtraction photometry is currently being implemented. The use of image subtraction is expected to be particularly effective in the detection of time critical astrophysical phenomena such as microlensing events and gamma ray burst. The MOA project is briefly described and along with details of the image subtraction data analysis system.

1. Introduction

The MOA project[2] is a collaboration of a number of institutes in Japan and New Zealand which undertakes observations at the Mt John Observatory in the South Island of New Zealand. From June, 1996 to July, 1998, a mosaic camera comprising 9 TI 1000×1018 pixel CCD chips was employed (Abe et al. 1996). Afterwards a new mosiac camera comprising 3 SITe 2048×4096 pixel CCD chips was comissioned and observations with this camera are continuing at present (Yanagisawa et al. 1999).

The aims of the project are to study microlensing events through follow-up observations of alerts issued by the MACHO, EROS, and OGLE groups and survey observations of selected fields towards the Magellanic Clouds and Galactic Bulge. Until now, all reductions of CCD images have been based on "profile fitting" analysis on resolved stars using the Dophot and Daophot packages. This approach has served us well but there are disadvantages. Extracting reliable photometric measurements of stars in crowded fields is very difficult. Furthemore, one usually requires stars to be resolved on some reference image making it difficult to detect microlensing events which may not be detectable at minimum light but cross the detection threshold during times of magnification. An analysis system based on image subtraction promises to overcome these problems.

[1]Department of Physics and Astronomy, University of Canterbury, Christchurch, New Zealand

[2]`http://www.phys.phys.vuw.ac.nz/dept/projects/moa`

2. Image Subtraction Method

Two images taken under conditions of different seeing are related through a convolution kernel, k, as follows:

$$i(x,y) = r \star k(x,y) + b(x,y) \tag{1}$$

where $r(x,y)$ denotes a "reference" image and $i(x,y)$ denotes a "current" image. The additional term $b(x,y)$ denotes the possibly spatially varying differential sky background between the two images.

There are two approaches in use to solve for the kernel. One is based on direct PSF matching where a PSF model is constructed for each image and the kernel is then found by deconvolution techniques (Phillips & Davis 1995; Tomaney & Crotts 1996). The other approach is to directly model the kernel itself using a number of basis analytical functions (Alard & Lupton 1998).

In the analysis system I am implementing for the MOA project I essentially follow the approach of Alard & Lupton (1998). I form a set of basis functions using a delta function along with one or more Gaussians each of which is modified by a polynomial expansion of specified degree, i.e.

$$k(x,y) = a_0\delta(x,y) + \sum_{m,n}^{m+n\leq D} a_i x^m y^n g(\theta, \sigma_x, \sigma_y, x, y) + \cdots \tag{2}$$

Here $g(\theta, \sigma_x, \sigma_y, x, y)$ denotes a generalised 2 dimensional Gaussian of orientation angle θ and widths σ_x and σ_y. Similarly the background can be written as a linear combination of polynomial terms.

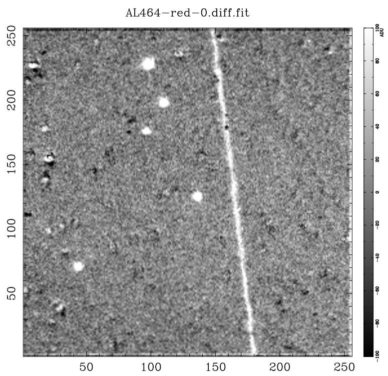

Figure 1. Observation image with a reference image subtracted after solving for the respective convolution kernel.

A solution to the convolution kernel can be found using linear techniques by solving for the coefficients of the basis functions. A subtracted image (Figure 1) may then be constructed using Equation 1. This procedure can be extended to the situation where the convolution kernel varies across the image. In this case, the coefficients in Equation 2 may themselves be modelled as a linear combination of polynomial basis functions. The size of the linear system becomes large, but one can utilise an accelerated summation technique to build the system (Alard 1999).

3. Microlensing Event MACHO-98-BLG-35

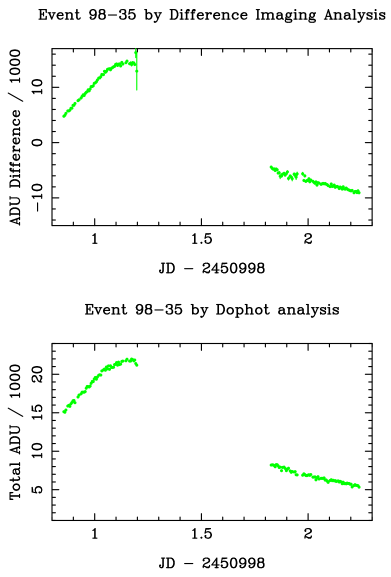

Figure 2. MOA light curve of microlensing event 98-35 obtained by image subtraction and profile fitting photometry.

4. Implementation in the MOA Project

To illustrate image subtraction, I will use MOA observations of the high magnification microlensing event MACHO-98-BLG-35 which was alerted by the MACHO group and peaked on July 4, 1998. Such events observed near their times of peak amplification can yield very stringent constraints on planetary configurations in the lensing system (Griest & Safizadeh 1998). Intense monitoring by MOA and MPS collaborations enabled them to exclude Jupiter mass planets in the lensing system and revealed evidence of a low mass planet somewhere between that of the Earth and Neptune (Rhie et al. 1999).

The published light curve of 98-35 obtained by MOA was based on profile fitting photometry using Dophot. Here I show prelininary results of a re-analysis based on image subtraction. A total of 163 CCD images were obtained by MOA during July 4–6, 1998. These images were pre-processed by flat-fielding and dark current subtraction and then geometrically re-aligned to a common coordinate system. For the image subtraction process, a reference frame was constructed by stacking 69 good seeing images. Each of the subsequent subtracted images were sampled using aperture photometry at the location of the event. The resulting light curve of flux differences is shown in Figure 2 along with the light curve obtained by profile fitting analysis using the Dophot package.

Follow-up observations obtained by MOA of microlensing events will be re-analysed using image subtraction photometry. This includes MACHO-98-BLG-35 and another high magnitude event MACHO-99-LMC-2. MOA has obtained more than 400 observations of the LMC event for 5 days around the time of peak amplification. The final analysis of this event raises the very interesting prospect of obtaining constraints on extra-galactic planets in the lensing system.

The survey observations of fields towards the Magellanic Clouds and the Galactic Bulge obtained by MOA have generated a large image data base. This is being re-analysed using image subtraction. The MACHO collaboration has re-analysed a small subset of their data base of images obtained by observations towards the Galactic Bulge. Their results are encouraging in that they find twice as many microlensing events as they did with the initial analysis (Alcock et al. 1999).

Finally, an online analysis system based on image subtraction is being implemented in the MOA project. On-site computational power at the Mt John observatory includes a Sun E450 workstation/server with 4 CPUs, 90 GB internal hard disc space, and an external DLT drive for data archiving. The aim is to allow near real time detection of microlensing events in progress. The use of image subtraction would make us particularly sensitive to high magnification events. MOA plans to be issuing alerts of microlensing events by the southern winter in 2000.

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