Variable Stars in the MOA Database

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Abstract

The Microlensing Observations in Astrophysics (MOA) Collaboration has generated a large volume of photometric data during its routine microlensing survey observations. Data were collected by MOA using a 0.6-m telescope (MOA-I) at Mt John University Observatory, New Zealand. In 2004, a new 1.8-m wide-field telescope (MOA-II) was commissioned and became fully operational at the beginning of this year. Tens of millions of stars will be monitored simultaneously every clear night and a total amount of about 10 TB of new data will be accumulated per year. This paper shows a preliminary analysis of MOA-I database in search for new and unusual variables. The observational data of about 12000 variable stars towards the Galactic Bulge obtained from 1999 November till 2005 November have been analysed. In addition to well known types of regular and semi-regular variable stars, a number of irregular variables has also been found.

1 Introduction

The MOA group was established in 1995 as a collaboration of astronomers and physicist in New Zealand and Japan with the primary aim of detecting microlensing events towards the Magellanic Clouds and the Galactic Bulge. However this project has generated a large volume of photometric data of variable stars as well. Some analyses from the MOA database have already been published on long-period variables[1] and eclipsing binaries[2] from the LMC and SMC. With the new 1.8-m MOA telescope, the amount of data will be further increased and therefore there is a clear need for automated procedure for classification of variable stars. A preliminary analysis that is presented here is part of our project aimed at developing an automated classification of variable stars.

2 Data analysis

The observations were carried out with the 0.6-m Boller and Chivens Cassegrain reflector at Mt John University Observatory, New Zealand, between 1999 and 2005. The data were taken using the wide field camera, MOA-cam2, that was constructed by the MOA group[3]. In this study, the broad MOA red filter (630 – 1000 nm) was used. A total of 14 MOA-cam2 fields towards the Galactic Bulge, covering an area of ≈ 17 deg^2 were observed.

The extraction of variable stars was made using difference imaging photometry for crowded fields, as developed by the MOA team[4]. Photometric fluxes of all objects are relative, since they represent the difference between the observed and reference flux for each object. A database of light curves of variable stars has been generated, including all objects that vary in brightness. The astrometric calibration of reference images has been performed, however, at this moment, there is no photometric calibration, so that the light curves are given in flux units only. A proper photometric calibration procedure is under development for all MOA systems, including the new 1.8-m telescope. Some indication of the magnitude difference between the minimum and maximum of a light curve for a given star has been obtained by a preliminary photometric calibration for that star based on aperture photometry of the reference image, as it is observed with the current MOA red filter.

Our observations cover a period of about five years, between JD 2451600 and JD 2453700. There are six groups of observations, with a typical separation of about 150 days between them. The data were processed using the Lomb-Scargle period search algorithm[5]. Specialised software was developed to combine the results of the Fourier analysis with a linear least-squares fit, in order to compute the amplitudes, frequencies and initial phases of the most prominent harmonics. The frequency of the highest peak in the periodogram is selected to be the fundamental frequency of the signal. Higher harmonics are then added in an iterative procedure, as long as the RMS error of the new fit is improved by at least 10% relative to the previous fit. The input parameters to the Lomb-Scargle procedure need to be adjusted so that either long-period or short-period variables are separated.

3 Variable stars

Using this procedure two groups of regular variables were separated: long-period ones, with periods over 30 days, and short-period ones, with periods less than 30 days. All the light curves were then examined by eye and any unreliable light curves (with excessive scatter) were rejected. As a result of this procedure, from an initial sample of 12540 stars, 11622 have been classified. The most reliable classification is for long-period regular and semi-regular variables, with periods longer than 30 days (see Figures 1, 3 and 4). About 35% of stars from the sample (4068) were classified in this group. This includes Miras, semi-regular variables and RV Tauri stars. Some Cepheids and eclipsing binaries with periods above 30 days are probably included in this group as well. About 25% of stars (2905) were classified as short-period variables including Cepheids, RR Lyrae and eclipsing binaries. Further period analysis, as well as full photometric calibration is needed to refine the classification and avoid any contamination between different classes. From all remaining stars, 1620 were classified manually as irregular variables (Figure 4), while 3029 stars were left unclassified. This last group includes some eruptive and unusual variables (Figure 2), 31 microlensing events, but also some stars that clearly do not belong to the other three groups.

The main goal of this analysis was to examine the potentials of the MOA database and develop algorithms necessary to start a detailed search for new and unusual types of stellar variability.

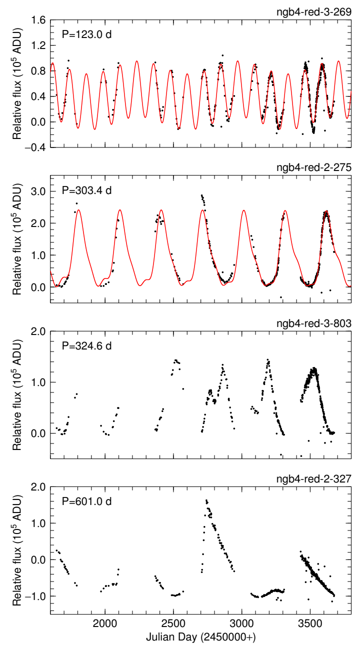

Figure 1. Long-period variables (with periods between 120 and 600 days) with light curves typical for Miras.

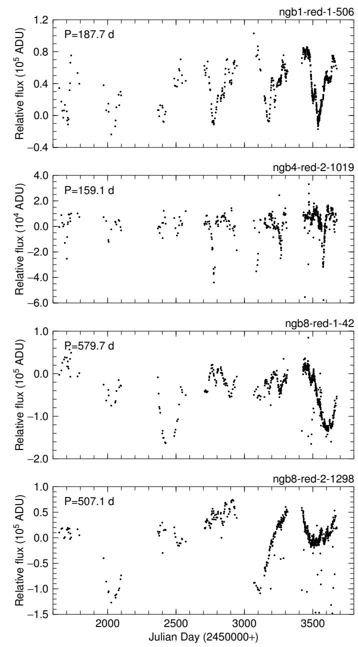

Figure 2. Possible examples of eruptive variables. The star 'ngb1-red-1-506' shows a typical light curve of R Coronae Borealis eruptive variable.

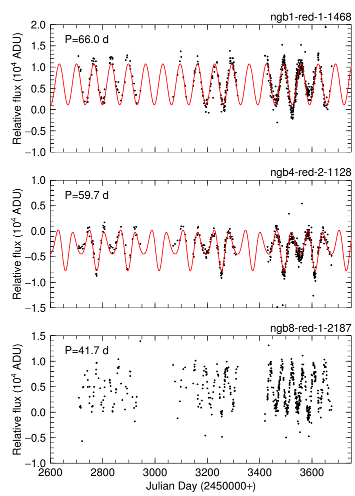

Figure 3. Pulsating variable stars with periods less than 70 days. The star 'ngb4-red-2-1128' shows a typical curve of RV Tauri a.

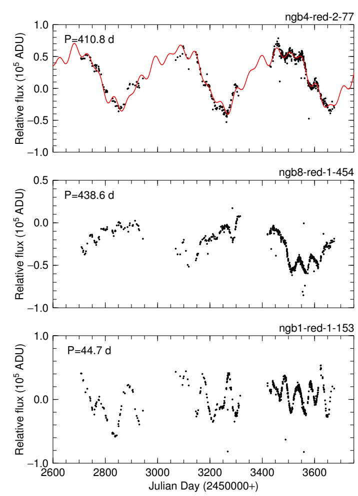

Figure 4. Long-period variables. The star 'ngb1-red-1-153' was classified as irregular variable. First two stars exhibit the light curves of RV Tauri b type.

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