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ACCURATE POSITIONS OF VARIABLE STARS IN THE WESTERN PART OF THE LARGE MAGELLANIC CLOUD BAR

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Three catalogues of variable stars in the Large Magellanic Cloud have been published recently (Grison et al., 1995, Alcock et al., 1997, Udalski et al., 1999). They are based on observations with CCD detectors for gravitational lensing experiments. Analogous work of Hughes (1989) was performed on the base of photographic observations in the LMC. In these catalogues, besides photometric data, equatorial coordinates of variable stars are given. The authors of the three cited papers used observations carried out with Schmidt telescopes or the Digitized Sky Survey (DSS) to determine the positions of stars. DSS is also based on observations with Schmidt telescopes. Such star positions can contain systematic errors of 0.6–0.7 arcsec (Udalski et al., 1999, Udalski et al., 1998).

In order to facilitate the procedure of position determinations, we have compiled a catalogue of reference stars in the western part of the LMC bar. This catalogue contains accurate positions of 436 stars in the Tycho frame (Høg et al., 1998), the positions are given in the electronic Table 1 (5047-t1.txt). It constitutes a reference net with the mean density of 200 stars per square degree in the bar area and can be a reference catalogue for accurate position determinations with CCD detectors. The overwhelming majority of stars (405) in this catalogue are Harvard variables (Hodge and Wright, 1967). Other stars are 18 Dublin variables (Butler and Wayman, 1974) and 7 variables discovered by Kurochkin et al. (1989). Several reference stars in our catalogue are not variables. Why variable stars were chosen as reference ones? The variables with good history are the best studied objects in the LMC (finding charts, photometry, positions and so on). Therefore we can easily identify them and compare our coordinates with those in other catalogues. Moreover, position determinations for variable stars in the modern reference frame would be useful.

We had at our disposal a number of plates of the LMC taken with two telescopes, the double meniscus astrograph AZT-16 (F = 207 cm, D = 70 cm, field $5^\circ \times 5^\circ$) at Cerro Roble Astronomical Station and the 1-m reflector (F = 712 cm, field diameter 2.5°) at Las Campanas Observatory, both in Chile. Unfortunately it was impossible to measure the plates of the 1-m reflector because of their large size exceeding the maximum size of a plate which we can measure using our ASCORECORD measuring machine. We have prepared contact film copies of these plates and measured them instead of the plates. The 1-m reflector has a high resolution. So two faint stars at a distance of 2 arcsec are seen apart. However, the images of Tycho reference stars ($10^{\rm m}$–$12^{\rm m}$ in B) are too large on the plates of the reflector and cannot be measured accurately. Thus we cannot determine accurate star positions in the Tycho frame using these plates directly.

On the other hand, the astrograph is very suitable for such a procedure. It has a large field without any distortion. The images of Tycho stars on the astrograph plates are well measurable. However, the astrograph has a short focal length, therefore additional errors appear in star positions because of star crowding if we deal with such areas as the LMC bar. Let us consider briefly this problem.

Many stars of the LMC bar look on the plates as complex images consisting of two or more very close components. The distances between them are smaller than the image size on the astrograph plates because of the short focal length. If the plates are photographed in different observing conditions, such as differing spectral bands, different exposures, brightness changes due to variability, the complex image looks variously on different plates. After measurements of such plates, we shall get various positions for stars with complex images. The coordinate differences for the double meniscus astrograph can exceed the typical position error by a factor of 3 or even more. As a measure of star crowding influence upon the derived coordinates, we use two values, R_ξ and R_η, of coordinate ranges

$$R_\xi = \xi_{\rm max} - \xi_{\rm min}, \qquad R_\eta = \eta_{\rm max} - \eta_{\rm min},$$

where ξ, η are the standard coordinates, derived from measurements of m plates, $\xi_{\rm max}$ and $\xi_{\rm min}$ are maximum and minimum coordinates of a star among these m values (similarly for the η coordinate).

The typical position error for the double-meniscus astrograph is 0.2 arcsec. We had 3 measurable astrograph plates (2 in B and 1 in V band) and got 3 values of right ascension and declination for each star. The values R_ξ and R_η varied from zero to 1 arcsec and more. To use the best properties of both telescopes, we have applied a two-stage reduction method. At the first stage, the so-called "first determination", we measured three plates of the astrograph, derived the equatorial coordinates of variable stars and the values R_ξ and R_η. We assigned that there were no significant systematic errors because of crowding in the positions of stars with R_ξ, R_η of 0.5–0.6 arcsec and less, as these values also included errors of measurements. Therefore we regarded the positions derived in the first determination with R_ξ, R_η less than 0.65 arcsec as final ones, as the maximum range exceeds the mean-square error approximately four times for variates.

All measurements in the first determination were subdivided into 8 series. In each series, we used 20–25 reference Tycho stars for determinations of plate constants and equatorial coordinates of 50–60 variable stars. Turner's linear method was used for transformation of the measured coordinates to the reference frame. Mean deviations of the measured and the Tycho positions were 0.2–0.3 arcsec. If we know the mean values of R_ξ, R_η for some stars, we can estimate the values of standard errors σ_ξ, σ_η (Smirnov and Dunin-Barkovskij, 1969). For 266 variable stars having, in the first determination, R_ξ, R_η less than 0.65 arcsec, these values and their 98% confidence regions are, in arcsec,

$$\sigma_\xi = 0.20 \quad \text{(conf. reg. 0.19–0.22)}; \qquad \sigma_\eta = 0.18 \quad \text{(conf. reg. 0.17–0.20)}.$$

These stars are denoted in the 4th column of Table 1 as 'DMA'.

37% of the catalogue stars had, at this stage, at least one value of R_ξ or R_η in excess of 0.65 arcsec because of the crowding effect. The coordinates of such stars have been redetermined at the second stage. For this purpose, we measured film copies of two plates taken with the 1-m reflector in B and in V bands. At this stage, the variable stars with R_ξ, R_η less than 0.4–0.5 arcsec were used as reference ones. The influence of star crowding in this case was less than at the first stage because of the long focal length of the reflector, accordingly the ranges R_ξ, R_η were usually 0.1–0.2 arcsec. The standard errors σ_ξ, σ_η of variable stars coordinates at the second stage are 0.1 arcsec. Such values are typical for the telescope of 7 m focal length and confirm the possibility to use the film copies instead of the original plates. These stars are denoted in the 4th column of Table 1 as '1 m vs'.

Some variable stars formerly regarded as single ones have proved visual doubles, with a typical distance between their components of about 2 arcsec. If we cannot indicate the variable star in such a pair, we give the coordinates of both components.

It is impossible to form a reference frame consisting of variable stars around a star situated at the edge of the area covered by the catalogue. Around each of such stars, a second reference frame containing 7–9 nearest field stars in a small area, not more than $10' \times 10'$, was formed . The coordinates of the secondary reference stars were determined by means of the same procedure as that used in the first determination, *i.e.* three astrograph plates were measured. We have determined the positions of 26 variable stars using such small reference frames. These stars are denoted in the 4th column of Table 1 as '1 m fs'.

The catalogue now presented is not uniform in the sense of positional accuracy. The most accurate positions are those for stars with images remeasured on the reflector plates. Their accuracy is 0.1 arcsec, but this value shows only that there is a good agreement of two individual positions. In reality, there are systematical errors in these positions, at least because of the magnitude equation.

Using our catalogue, we have estimated the accuracy of the positions in the GCVS Volume V and in the OGLE catalog (Udalski et al., 1999). The accuracy of the first catalog is 0.4–0.9 arcsec in the LMC bar, but there are systematic errors of 0.3–1.1 arcsec. These values have been derived from the comparison of 403 star positions in our catalogue and in GCVS one like as described further for the OGLE catalogue. The comparison of our catalogue with the OGLE catalogue has been carried out using 196 stars in common. We divided them into 14 groups (14 star in each group) in right ascension direction and calculated, for each group, the mean coordinate differences between the two catalogues. These mean values we regarded as systematical differences between the two catalogues for 14 discrete values of right ascension. They depend on coordinates and change from 0.3 to 0.6 arcsec and from 0.0 to 0.3 arcsec in right ascension and declination respectively. The authors of the OGLE catalogue wrote about a possible systematic error about 0.6 arcsec due to the reduction procedure using the DSS as the reference means. We believe that the cause of the systematical differences is the complex distortion of Schmidt plates the DSS was based on, as the double-meniscus astrograph has no distortion and our measurements of the reflector plates were corrected for third-order distorsions.

We identified EROS, MACHO and OGLE variables using the coincidence of their coordinates only. The coordinates of any star in these catalogues differed from those in our catalogue not more than by 1 arcsec. Some Cepheids in close pairs were identified using OGLE positions.

The analysis of the coordinate differences depending on right ascension only made us to reject our assumption that there were no significant systematic errors because of crowding in the positions of stars with small values of R_ξ, R_η. We have found some stars with small values (0.3–0.4 arcsec) of R_ξ, R_η but with significant deviations (to 0.3–0.4 arcsec) of our positions from the OGLE ones, after accounting for the systematic differences between these catalogues. Therefore we have redetermined the positions of 34 such stars previously determined using the plates of the astrograph. We have remeasured their images on the plates of the 1-m telescope and have achieved a significant decrease of the position differences with the OGLE catalogue. Thus, the small values of R_ξ, R_η in the first determination do not signify that there is no noticeable error (to 0.4 arcsec) because of star crowding in the positions of such stars. Note that the OGLE catalogue was based on observations with a telescope of more than 12 m focal length, therefore the influence of star crowding was significantly less than in the case of the double meniscus astrograph. Having discovered this fact, we have decided to improve our catalogue by redetermining the position of those stars. These are the stars denoted in the 4th column of Table 1 as 'DMA'. For this end, we have to measure the plates of the 1-m telescope.

However, while working on this project, it would be reasonable to publish the first version of our catalogue, which has been created in the most modern reference frame and is free from systematic errors inherent to those catalogues which are based on observations with Schmidt telescopes.

The catalogue presented consist of two parts: a table of coordinates with identifications and plate information and remarks to individual stars. This file is supplementing the IBVS publication and can be retrieved electronically from the IBVS website as well as from http://astrometric.sai.msu.ru/.

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References:

Alcock, C., Allsman, R.A., Alves, D. et al., 1997, *AJ*, **114**, 326

Butler, C.J. and Wayman, P.A., 1974, *Dunsink Publ.*, **1**, No. 7

Grison, J.-P., Beaulieu, J.-P., Pritchard, J.D., 1995, *Astron. Astrophys. Suppl. Ser.*, **109**, No. 3, 447

Hodge, P.W. and Wright, F.W., 1967, The Large Magellanic Cloud, Smithsonian Press, Washington, D.C.

Høg, E., Kuzmin, A., Bastian, U. et al., 1998, *Astron. Astrophys.*, **335**, L65

Hughes, S.M.G., 1989, *AJ*, **97**, 1634

Kurochkin, N.E., Tokovinin, A.A., Loggins, A., 1989, *IBVS*, No. 3365

Smirnov, N.V., Dunin-Barkovskij, I.V., 1969, Kurs Teorii Veroyatnostej i Matematicheskoj Statistiki dlya Tekhnicheskikh Prilozhenij, Moskva, "Nauka" (Probability Theory and Mathematical Statistics for Technical Applications; in Russian)

Udalski, A., Szymanski, M., Kubiak, M. et al., 1998, *Acta Astronomica*, **48**, 147

Udalski, A., Soszynski, I., Szymanski, M. et al., 1999, *Acta Astronomica*, **49**, 223