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The Optical Gravitational Lensing Experiment. The General Catalog of Stars in the Galactic Bulge. I. The Stars in the Central Baade's Window OGLE Field BWC*

by

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ABSTRACT

This paper presents the first part of the Optical Gravitational Lensing Experiment (OGLE) General Catalog of Stars in the Galactic bulge. The Catalog is based on observations collected during the OGLE microlensing search. This part contains 33196 stars brighter than $I = 18^{\mathrm{m}}$ identified in the Baade's Window BWC field. Stars from remaining 20 OGLE fields will be presented in similar form in the next parts of the Catalog. The Catalog is available to the astronomical community over the Internet network.

Key words: *Catalogs – Stars: general*

1. Introduction

The Optical Gravitational Lensing Experiment (OGLE) is a long term observing project with the main goal of searching for dark matter in our Galaxy using microlensing (Paczyński 1986). The fourth season of observations, 1995, concluded the first phase of the OGLE project. It will be resumed in 1996 using a dedicated 1.3 m Warsaw photometric telescope installed at Las Campanas Observatory in February 1996.

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* Based on observations obtained at the Las Campanas Observatory of the Carnegie Institution of Washington

Four seasons of continuous photometric monitoring of approximately two million non-variable stars in the direction of the Galactic bulge resulted in discovery of 18 possible microlensing events (Udalski *et al.* 1993b, 1994b, 1994c).

The collected photometric data provide a unique material for studying the Galactic bulge (Paczyński *et al.* 1994, Stanek *et al.* 1994). Long span and large number of observations make it also possible to study precisely the population of variable stars toward the Galactic bulge. Three parts of the OGLE Periodic Variable Stars Catalog have already been published (Udalski *et al.* 1994d, 1995a, 1995c).

This paper is the opening of a series of papers constituting the OGLE General Catalog of Stars in the Galactic bulge. The aim of the Catalog is to provide possibly most complete reference to objects in the areas of the Galactic bulge observed regularly during the OGLE microlensing search. The Catalog is meant to be an open publication with periodic updates when more data become available and when fainter stars are included. We hope this catalog will be useful for all kind of studies of the objects in the Galactic bulge.

In this paper we present 33196 stars detected in one of the OGLE fields designated as BWC, that is in the center of the Baade's Window. In the following papers the stars from remaining 11 Baade's Window fields will be presented, followed by data from 9 fields in other parts of the Galactic bulge.

In Section 2 we describe shortly the reduction technique. Section 3 presents the Catalog and gives a sample of its data. The whole set of data, much too big to be published in a journal, is available in the electronic form (see Section 5 for details). Section 4 gives a short discussion of the completeness of the Catalog.

2. Reductions

The OGLE General Catalog of Stars in the Galactic bulge is based on observations obtained during the OGLE microlensing search. Data presented here were collected during four OGLE observing seasons, 1992 – 1995, spanning the period from April 19, 1992 to August 22, 1995. Each observing season lasted approximately from April to August/mid-September. Full logs of observations can be found in Udalski *et al.* (1992), Udalski *et al.* (1994a), Udalski *et al.* (1995b) and Udalski *et al.* (1996).

All observations were collected with the 1-m Swope telescope at Las Campanas Observatory which is operated by the Carnegie Institution of Washington. 2048×2048 Ford/Loral CCD with 15 μm pixels giving a scale of 0.44 arcsec/pixel was used as the detector. Due to the strategy adopted for microlensing search the majority of observations was made in the I-band with much less V-band measurements taken to obtain color estimates.

All the collected frames were reduced using the standard OGLE data-pipeline in which, after automatic debiasing and flat-fielding, the profile photometry of objects was derived. Reductions of frames were done in the near real time using the modified DoPHOT photometry program in the fixed position mode (Schechter *et al.* 1993). Due to significant variations of the Point Spread Function (PSF) over the chip, each frame was divided into a 7×7 grid of slightly overlapping subframes on which PSF function could be assumed as constant. The photometry from all subframes was then tied to the common photometric system using stars measured on the overlapping parts of the subframes. Depending on the quality of the photometry a grade **A** – **F** was assigned to each frame with **A** meaning the best and **F** – unacceptable quality. Details of the reduction procedure can be found in Udalski *et al.* (1992).

In order to manipulate efficiently the huge amount of data the databases for each observed field and color band were created. Photometry of each frame with grade better than **F** was aperture corrected and included in the appropriate database. Details of database structure can be found in Szymański and Udalski (1993). Transformation to the standard *VI* system is described in Udalski *et al.* (1992). The error of the zero point of the photometry is not larger than 0.04 mag. The errors of individual observations depend on magnitude of the star and frame grade – detailed analysis of errors can be found in Udalski *et al.* (1992) and Udalski *et al.* (1994b).

Over twenty $15' \times 15'$ fields were observed in the OGLE project. In this paper we present stars from the center of the Baade's Window field designated as BWC. The J2000 coordinates of the BWC field are: $\alpha = 18^{\rm h}03^{\rm m}24^{\rm s}$, $\delta = -30°02'00''$ ($l = 1\overset{\circ}{.}0$, $b = -3\overset{\circ}{.}9$).

First edition of the Catalog is limited to stars brighter than $I = 18.0$ mag. In the following updates the Catalog will be extended to fainter stars. The Catalog has also an upper limit of brightness due to saturation of bright star images in the CCD detector. This limit is approximately $14^{\rm m}$ in I. The brightest star in the BWC Catalog has $I = 13\overset{\rm m}{.}85$. The next part of the Catalog will also include a table of brighter stars identified in the Baade's Window on a small number of short exposure frames which were taken mainly for the purpose of extending the upper parts of the color-magnitude diagrams (Udalski *et al.* 1993a). It should be stressed, however, that these stars will not constitute a homogeneous sample with the main part of the Catalog, due to different procedure of reductions and small number of measurements.

The stars included in the catalog were extracted from the I-band database. To enter the catalog, a star had to have at least 25 percent of measurements of a "good quality". For the BWC field (total of 207 I frames) this equals to 52 points. The measurement was defined as "good" if it fulfilled the following criteria: the grade of the frame was **A** – **D**; the type of object assigned by the DoPHOT program was "star-like"; there was no other object detected closer than 0.75 pixel; the star was not too close to the frame edge; the magnitude error of this particular measurement was smaller than 3.0 times the upper sigma limit for a typical non-variable star of the same brightness. The limiting curves "maximum sigma for non-variable stars *vs.* magnitude" were derived from the analysis of the distribution of standard deviations of all stars (Udalski *et al.* 1993a). From about 200 000 objects in the database (roughly 44 000 with mean $I < 18^{\rm m}$) a total of 33196 stars fulfilled the above criteria and entered the catalog. Table 1 lists brightness statistics of the BWC field stars in one-magnitude bins. Fig. 1 presents all the selected stars plotted in right ascension – declination coordinates. The most pronounced "hole" to the left of the center of this plot is a big globular cluster (NGC 6522), where the density of stars is much too big to detect individual objects. Other "holes" can be easily seen in positions of bright stars which got overexposed on the frames. Bigger dots in this figure mark the positions of all 212 periodic variable stars discovered by OGLE in the BWC field (Udalski *et al.* 1994d).

Table 1

Number of BWC catalog stars in one-magnitude bins

I-magnitude	14.5*	15.5	16.5	17.5
Number of stars	2089	5313	6616	19178

* including 48 stars brighter than $14^{\rm m}$

To derive mean $V - I$ color of the star, its V-band mean magnitude was extracted from the V filter database. In 1838 cases V magnitudes were unavailable because the star could not be identified in the V database. It is worth noting that the I and V databases were constructed independently. The cross identification of stars is based on second-order transformation of pixel coordinates between the databases. The allowed difference of the transformed I database position and the V database position is 1.4 pixels. This value maximizes the number of matches (a match requires that there is only one V database object within a given distance limit).

Equatorial coordinates of the variable stars were calculated using transformation "frame position – equatorial coordinates" derived using stars from the HST Guide Star Catalog (Lasker *et al.* 1988). 21 GSC stars were identified in the BWC field and used to determine transformation. The relative accuracy of derived coordinates is about $0\farcs2$ while the absolute accuracy is worse – about $1''$.

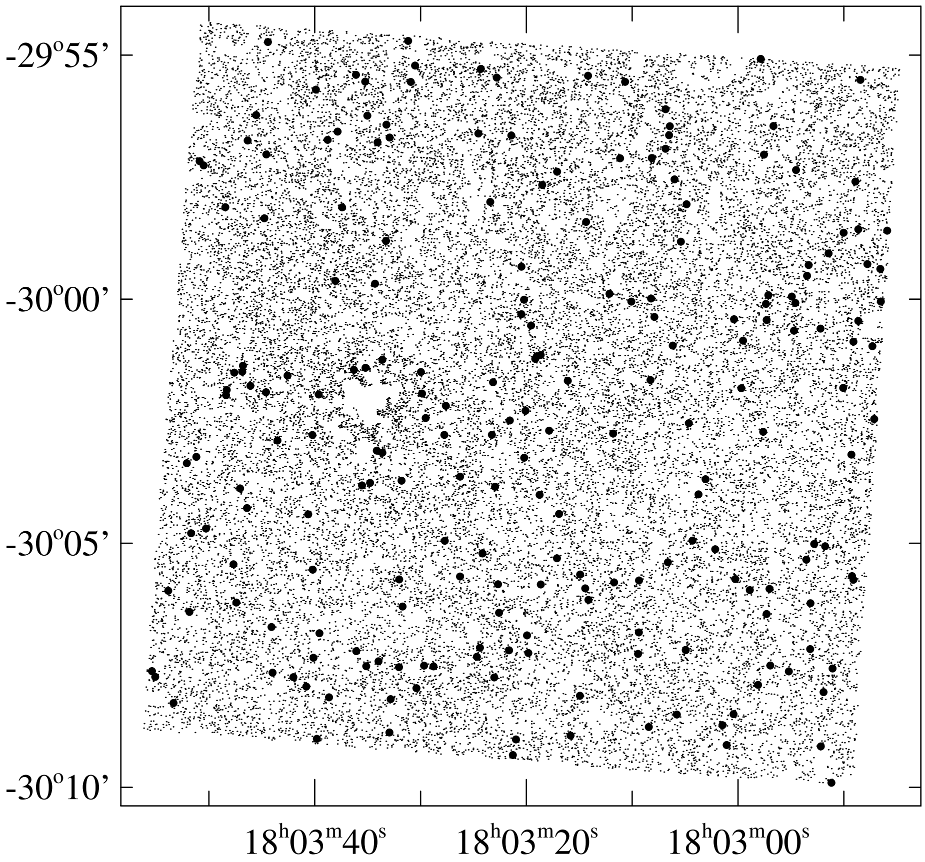

Fig. 1. BWC field catalog stars plotted in R.A. – Dec. chart. Bigger dots represent periodic variables found in the field (Udalski *et al.* 1994d).

3. The Catalog

The General Catalog of Stars in the Galactic bulge contains the following data:

1. Star designation.
   Each star is described as OGLE *field number*, where *field* is the general name of the OGLE field (see Table 1 in Udalski *et al.* 1994a) and *number* is a unique consecutive number of the star in the given field. Initially the stars are sorted according to their mean I magnitude. Thus, lower number means brighter star. This convention may be broken when the catalog is updated.
2. Right Ascention (J2000).
3. Declination (J2000).
4. I mean magnitude.
5. Standard deviation (σ_I) of good I band measurements.

6. Median photometry error (err $_{\rm med}$) of a single good measurement. I, σ_I and err $_{\rm med}$ values were calculated from good measurements after two highest and two lowest magnitude points were excluded.
7. $V-I$ estimate, if available.
8. Number of good photometry points (N_I).
9. Remarks, including references to the OGLE catalog of Periodic Variables and microlensing candidates.

Table 2 presents an excerpt from the Catalog, namely 12 stars from the beginning and 12 from the end of the whole sample. As none of these stars do have any remarks, the 9th column of the table was omitted here to ease formatting.

Table 2

The BWC catalog data

Star	R.A.(J2000)	Dec.(J2000)	I	σ_I	err $_{\rm med}$	$V-I$	N_I
BWC 1	$18^h03^m39^s.07$	$-29°57'36''.8$	13.847	0.019	0.019	1.78	123
BWC 2	$18^h03^m41^s.14$	$-29°55'59''.9$	13.853	0.021	0.019	1.69	119
BWC 3	$18^h03^m10^s.55$	$-30°00'24''.8$	13.865	0.026	0.027	2.17	133
BWC 4	$18^h03^m06^s.26$	$-30°08'59''.9$	13.881	0.017	0.013	2.09	79
BWC 5	$18^h03^m41^s.81$	$-29°58'12''.0$	13.882	0.017	0.018	1.98	106
BWC 6	$18^h03^m14^s.76$	$-30°08'14''.3$	13.892	0.020	0.014	1.85	70
BWC 7	$18^h03^m18^s.97$	$-30°06'13''.0$	13.893	0.043	0.032	1.78	66
BWC 8	$18^h03^m28^s.41$	$-30°04'57''.5$	13.893	0.020	0.024	1.68	138
BWC 9	$18^h03^m39^s.93$	$-29°57'28''.8$	13.894	0.017	0.014	1.56	97
BWC 10	$18^h03^m35^s.68$	$-30°04'38''.8$	13.901	0.015	0.019	2.00	135
BWC 11	$18^h03^m38^s.48$	$-30°01'40''.0$	13.907	0.031	0.022	2.37	113
BWC 12	$18^h03^m01^s.79$	$-30°05'16''.6$	13.921	0.025	0.022	2.28	140
...	...	...	...	...	...	...	...
BWC 33185	$18^h03^m48^s.48$	$-29°55'59''.3$	17.991	0.095	0.048	1.14	186
BWC 33186	$18^h02^m46^s.52$	$-30°00'53''.2$	17.992	0.081	0.078	0.88	155
BWC 33187	$18^h03^m04^s.14$	$-30°05'13''.8$	17.992	0.150	0.082	1.39	142
BWC 33188	$18^h02^m59^s.79$	$-30°00'06''.6$	17.992	0.049	0.045	1.34	198
BWC 33189	$18^h03^m24^s.73$	$-30°05'45''.8$	17.992	0.073	0.074	1.24	198
BWC 33190	$18^h03^m28^s.71$	$-29°56'21''.8$	17.992	0.268	0.062	1.25	195
BWC 33191	$18^h03^m14^s.49$	$-29°56'29''.9$	17.993	0.261	0.054	1.30	198
BWC 33192	$18^h03^m40^s.72$	$-29°56'01''.6$	17.994	0.176	0.096	1.13	138
BWC 33193	$18^h03^m25^s.20$	$-29°55'11''.2$	17.995	0.177	0.053	1.09	198
BWC 33194	$18^h03^m38^s.26$	$-30°07'11''.6$	17.995	0.037	0.048	0.87	168
BWC 33195	$18^h03^m25^s.37$	$-30°03'44''.2$	17.996	0.466	0.157	0.54	87
BWC 33196	$18^h03^m30^s.17$	$-29°56'57''.7$	17.999	0.362	0.067	0.57	196

4. Completeness of the Catalog

It is important to have some information concerning completeness of the Catalog. The detailed statistical analysis will be published elsewhere after next parts of the Catalog are released. In this paper we present only a crude estimate.

The main factor affecting the completeness of the catalog is determined by the fraction of all stars which entered the whole selection process. OGLE reduction procedure ignores stars which have bad photometry due to CCD defects, severe blending or are overexposed *etc.* on the so called "template" frame of a given field (Udalski *et al.* 1992). Such objects are marked and are not measured on other frames. Thus a fraction of objects is *a priori* missed. These objects had no chance to be included in the Catalog.

The other factor comes from the adopted selection criteria, mainly from the minimum number of good measurements. About one fourth of the database objects brighter than $18^{\rm m}$ had too few good photometry points. We have checked, however, that this factor is not very important, by running the selection process with much smaller lower limit of good points. The test performed with this number set to 5% of all frames (for BWC it was 10 points) revealed only 4% more objects selected. This means that the objects rejected by this criterium are, in vast majority, not true stars but rather artefacts of chip defects, bleeding columns *etc.*

It is relatively easy to determine the first factor of completeness by randomly adding artificial stars to the frame and checking how many of them have been recovered using standard reduction procedure. Such tests have already been performed for analysis of CMDs of the Galactic bulge (Udalski *et al.* 1993a). The recovery efficiency for stars brighter than $I = 18^{\rm m}$ has been found to be relatively flat and equal to $\approx 80\%$ for the densest BWC field and $\approx 87\%$ for the least dense field TP8.

Independent estimate of this factor will be obtained and presented in the next part of the Catalog describing the OGLE fields which overlap the BWC field. We will check and analyze how many stars in the overlapping regions would pass all criteria when processed independently in two adjacent fields. In a few corner regions this analysis can be done even for four fields.

The overlap analysis will provide also a better estimate of the second factor, as we will be able to check how many of the stars which had too few good points in one field did pass this criterium in the other field.

5. Summary

We present in this paper the first part of the OGLE General Catalog of Stars in the Galactic bulge – 33196 objects brighter than $I = 18^{\rm m}$ detected in the BWC field. Catalog of stars found in 20 other fields observed during the OGLE microlensing search will be published in similar form in the forthcoming papers. The Catalog will be updated regularly to include fainter stars, as well as when more data are available or additional fields are observed.

The Catalog is available to astronomical community in electronic form over the Internet network using anonymous ftp service from *sirius.astrouw.edu.pl* host (148.81.8.1), directory `/ogle/general_catalog`. See README file in this directory for details. The size of the file containing BWC field stars is 2.5 MB (0.5 MB in the compressed form). For the availability of the Catalog (as well as the Periodic Variables Catalog) on the CD-ROM and for information about OGLE mirror archive in USA, consult our WWW page: *http://www.astrouw.edu.pl/~ftp/ogle/ogle.html*.

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REFERENCES

Lasker *et al.* 1988, *Astrophys. J. Suppl. Ser.*, **68**, 1.
Paczyński, B. 1986, *Astrophys. J.*, **304**, 1.
Paczyński, B., Stanek K. Z., Udalski, A., Szymański, M., Kałużny, J., Kubiak, M., and Mateo, M. 1994, *Astron. J.*, **107**, 2060.
Schechter, P.L., Mateo, M., and Saha A. 1993, *P.A.S.P.*, **105**, 1342.
Stanek, K.Z., Mateo, M., Udalski, A., Szymański, M., Kałużny, J., and Kubiak, M. 1994, *Astrophys. J. Letters*, **429**, L73.
Szymański, M., and Udalski, A. 1993, *Acta Astron.*, **43**, 91.
Udalski, A., Szymański, M., Kałużny, J., Kubiak, M., and Mateo, M. 1992, *Acta Astron.*, **42**, 253.
Udalski, A., Szymański, M., Kałużny, J., Kubiak, M., and Mateo, M. 1993a, *Acta Astron.*, **43**, 69.
Udalski, A., Szymański, M., Kałużny, J., Kubiak, M., Krzemiński, W., Mateo, M., Preston, G.W., and Paczyński, B. 1993b, *Acta Astron.*, **43**, 289.
Udalski, A., Szymański, M., Kałużny, J., Kubiak, M., Mateo, M., and Krzemiński, W. 1994a, *Acta Astron.*, **44**, 1.
Udalski, A., Szymański, M., Stanek, K.Z., Kałużny, J., Kubiak, M., Mateo, M., Krzemiński, W., Paczyński, B., and Venkat, R. 1994b, *Acta Astron.*, **44**, 165.
Udalski, A., Szymański, M., Kałużny, J., Kubiak, M., Mateo, M., Krzemiński, W., and Paczyński, B. 1994c, *Acta Astron.*, **44**, 227.
Udalski, A., Kubiak, M., Szymański, M., Kałużny, J., Mateo, M., Krzemiński, W., and Paczyński, B. 1994d, *Acta Astron.*, **44**, 317.
Udalski, A., Szymański, M., Kałużny, J., Kubiak, M., Mateo, M., and Krzemiński, W. 1995a, *Acta Astron.*, **45**, 1.
Udalski, A., Szymański, M., Kałużny, J., Kubiak, M., Mateo, M., and Krzemiński, W. 1995b, *Acta Astron.*, **45**, 237.
Udalski, A., Szymański, M., Kałużny, J., Kubiak, M., Mateo, M., and Krzemiński, W. 1995c, *Acta Astron.*, **45**, 433.
Udalski, A., Szymański, M., Kałużny, J., Kubiak, M., Mateo, M., Krzemiński, W. and Stanek, K. Z. 1996, in preparation.