The Optical Gravitational Lensing Experiment. Follow-up Observations of the MACHO Microlensing Event in the Galactic Bulge.*

by

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ABSTRACT

We present follow-up observations of a gravitational microlensing candidate found by the MACHO collaboration in the Galactic bulge. The photometric data cover a period near the maximum of the event and may be used to construct complete light curve. The position of the lensed star in the color magnitude diagram suggests that it is a Galactic bulge star located on the subgiant branch.

Key words: *dark matter – gravitational lensing – Stars: low-mass, brown dwarfs*

The Optical Gravitational Lensing Experiment (OGLE) is a long term observing project designed to detect large numbers of microlensing events. The OGLE project began in April 1992. Observations are made with the 1-m Swope telescope of the Las Campanas Observatory (LCO), operated by the Carnegie Institution of Washington. The detailed description of the project can be found in Udalski *et al.* (1992), Szymański and Udalski (1993). After three seasons of observations 12 microlensing events candidates have been found (Udalski *et al.* 1994a,b). Several side-projects have also given important results regarding the structure of the Galaxy (Paczyński *et al.* 1994b,c, Stanek *et al.* 1994) and the Sagittarius and Sculptor dwarf galaxies (Mateo *et al.* 1994, Kałużny *et al.* 1994).

In 1994 OGLE introduced the Early Warning System (EWS) allowing

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

an early detection of on-going microlensing (Paczyński 1994a, Udalski *et al.* 1994b). Nearly "on-line" detection of the events is extremely important making it possible to improve the photometric coverage of an event, especially at maximum light, allowing accurate estimation of the parameters of the lensing and resolving fine details of the phenomenon (*e.g.*, binary lenses, planets around lensing stars, lensed star disk size). Early detection also allows other observers around the world to make timely follow-up multicolor photometric and spectroscopic observations. The EWS system was routinely used during the whole 1994 OGLE season resulting with detection of two first real time microlensing events: OGLE #11 and OGLE #12 (Udalski *et al.* 1994b).

The MACHO collaboration – another group searching for microlensing phenomena – had also been working on an "on-line" detection system (Bennett – priv. comm.). On September 1st, 1994, at the end of the OGLE 1994 observing season, the MACHO group announced their first "on-line" detected microlensing event candidate (Alcock *et al.* 1994) – an object located in the direction of the Galactic bulge (α=17$^{\rm h}$59$^{\rm m}$49$\stackrel{\rm s}{.}$6, δ=−28°10′56″ (2000.0)). The star was reported to be constant at V=18$\stackrel{\rm m}{.}$8, R=17$\stackrel{\rm m}{.}$8 (V, R – approximate standard colors) during 1993 and mid-1994, and had brightened by 0$\stackrel{\rm m}{.}$85 during the week ending August 31, 1994 with no change of color index.

The star reported by the MACHO group is located in a region which was not monitored by OGLE. We decided to add the new field into our schedule and make follow-up observations of the MACHO event. Due to the schedule of nights allocated to the OGLE project at LCO we were able to collect the exposures on nights of September 1–6 and 14–15, 1994 which ended our observing season. A total of 9 I-band and 2 V-band exposures were taken in various seeing/weather conditions. Reductions were done using a modified version of the DoPHOT photometry program (Schechter, Mateo and Saha 1993) on 220 × 220 pixels subframes centered on the object. Differential photometry of the candidate relative to two nearby constant stars was derived. Instrumental magnitudes were tied to the standard VI system using calibration procedure as described in Udalski *et al.* (1992). Transformation from the instrumental to the standard system was recalculated using observations of a few dozen standard stars. It turned out to be very close to the 1992 season transformation (Udalski *et al.* 1992). We estimate the absolute magnitude scale error to be smaller than 0.03 mag. Table 1 lists the positions and V and $V-I$ magnitudes of the comparison stars. Photometric data for the MACHO event are shown in Table 2.

Table 1

Position and magnitudes of the comparison stars

	comparison A	comparison B
RA_{2000}	$17^h59^m49\overset{s}{.}5$	$-28°11'15''$
DEC_{2000}	$17^h59^m50\overset{s}{.}5$	$-28°10'39''$
V	17.475	17.574
$V-I$	2.557	2.251

Fig. 1 presents the light curve of the event in the I-band and $V-I$ color. Because we had neither magnitude nor color information for the object at its "constant" phase and the star was still fading when the OGLE season ended, we were unable to obtain a reliable fit of our data to the theoretical microlensing light curve and thus to obtain the parameters of the event. We adopted the MACHO preliminary theoretical fit (Bennett, priv. comm. – solid line in Fig. 1): time of maximum brightness T_{max}(JD hel.) = 2449599.8, time scale (the Einstein radius / transverse velocity) $t_0 = 9.85$ days, magnification $A = 3.55$, and applied magnitude offset to get the best fit to our data (the offset yielded constant I magnitude $I_0 = 16.92$). This procedure can be justified as the microlensing event should be achromatic.

Most of our data cover the period near the maximum of the event. Although some of the photometric measurements have relatively large errors due to either bad seeing or bad weather conditions, the data generally confirm microlensing as the most likely interpretation of the increase of brightness of the MACHO candidate. The light variations fit the theoretical light curve very well, the $V-I$ color seems to be constant over the course of the phenomenon. Thus our data may be used to complete the light curves obtained by other observers and to compute more accurate lensing parameters. The event seems to be a typical short-scale, moderate amplitude microlensing, similar to those observed in the Galactic bulge before. Observations near the maximum do not show any statistically significant deviation from the theoretical fit suggesting a normal, point-mass microlensing.

Figure 2 shows the color-magnitude diagram (CMD) of the 15×15 arcmins field centered on the MACHO candidate (this field has been desig-

Table 2

OGLE photometry of the MACHO Galactic bulge event

V-band						
Frame no	JD hel -2448000	Exp. time [s]	V	Error	$V-I$	Error
mr8405	1600.51501	1000	17.568	0.043	1.920	0.094
mr8570	1611.56265	780	18.695	0.046	2.007	0.058

I-band				
Frame no	JD hel -2448000	Exp. time [s]	I	Error
mr8323	1598.50715	900	15.610	0.029
mr8365	1599.50606	720	15.548	0.024
mr8373	1599.60069	720	15.610	0.028
mr8380	1599.70871	900	15.557	0.104
mr8422	1600.69561	900	15.646	0.084
mr8452	1601.50830	780	15.808	0.084
mr8493	1602.50204	780	15.846	0.022
mr8533	1610.52972	901	16.649	0.028
mr8569	1611.54965	910	16.690	0.036

nated as GB5). The procedure of constructing the CMD was similar to other Galactic bulge fields (Udalski *et al.* 1993). The position of the lensed star is shown as a white star. The lensed star lies on the subgiant branch of the CMD and is very likely located in the Galactic bulge.

The successful "real-time" discovery of the microlensing events both by OGLE and MACHO alert systems proves that in spite of their very low probability of occurrence these events can be detected in their early phases and that world wide follow-up observing campaigns can be successfully organized.

Photometry of OGLE microlensing events, as well as regularly updated OGLE status report can be found over the Internet at host *sirius.astrouw.edu.pl* (148.81.8.1), using the "anonymous ftp" service (directory /ogle, files README, ogle.status, early.warning). Information on the recent OGLE status is also available via "World Wide Web" WWW: *http://www.astrouw.edu.pl/*.

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