The Optical Gravitational Lensing Experiment. Planetary and Low-Luminosity Object Transits in the Carina Fields of the Galactic Disk*

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ABSTRACT

We present results of the second "planetary and low-luminosity object transit" campaign conducted by the OGLE-III survey. Three fields ($35' \times 35'$ each) located in the Carina regions of the Galactic disk ($l \approx 290°$) were monitored continuously in February–May 2002. About 1150 epochs were collected for each field.

The search for low depth transits was conducted on about 103 000 stars with photometry better than 15 mmag. In total, we discovered 62 objects with shallow depth (≤ 0.08 mag) flat-bottomed transits. For each of these objects several individual transits were detected and photometric elements were determined. Also lower limits on radii of the primary and companion were calculated.

The 2002 OGLE sample of stars with transiting companions contains considerably more objects that may be Jupiter-sized ($R < 1.6\ R_{\rm Jup}$) compared to our 2001 sample. There is a group of planetary candidates with the orbital periods close to or shorter than one day. If confirmed as planets, they would be the shortest period extrasolar planetary systems.

In general, the transiting objects may be extrasolar planets, brown dwarfs, or M-type dwarfs. One should be, however, aware that in some cases unresolved blends of regular eclipsing stars can mimic transits. Future spectral analysis and eventual determination of the amplitude of radial velocity should allow final classification. High resolution spectroscopic follow-up observations are, therefore, strongly encouraged.

All photometric data are available to the astronomical community from the OGLE INTERNET archive.

1. Introduction

Observations of photometric transits caused by small objects passing on the disk of a hosting star and obscuring part of its surface are one of the most promising methods of detection of extrasolar planets and other small size objects like brown dwarfs or small stars. When combined with precise spectroscopic observations, the method provides a unique opportunity to unambiguously determine all important parameters of a small companion like its size and mass.

*Based on observations obtained with the 1.3 m Warsaw telescope at the Las Campanas Observatory of the Carnegie Institution of Washington.

Detection of planetary transits requires, however, extremely accurate photometric data. For instance, the drop of brightness caused by a Jupiter size planet transiting across a solar-like star is of only 1% order. Thus a millimagnitude accuracy of measurements is needed for detection. This is not easy to achieve from the ground. For firm detection and to find the photometric orbit and orbital period observations of several (≥ 3) transits are necessary. On the other hand, when the photometric orbit is well known, only a few spectroscopic measurements at appropriate phases (around 0.25 and 0.75) suffice to determine firm masses or at least constraints on the mass. It is often not realized that radial velocity measurements with accuracy of only 1–2 km/s are sufficient to distinguish between planetary and more massive object domains if no variation is found, provided that the star is not blended with an unresolved neighbor, physically related or optical. That limit can be achieved for very faint stars with the largest 8-m class modern telescopes with efficient spectrographs. Thus, the planetary search with transit method can be conducted even among objects located at large distances from the Sun, contrary to spectroscopic surveys limited to the solar neighborhood.

Low probability of favorable orientation of the companion's orbit requires large number of stars to be monitored photometrically for detection of objects with transiting companions. Therefore a long term photometric program must be conducted for selection of candidates and determination of their photometric orbits. Several such programs have been undertaken during the last couple of years (Gilliland *et al.* 2000: 47 Tuc; Quirrenbach *et al.* 2000, Street *et al.* 2002, PISCES project – Mochejska *et al.* 2002: open clusters; EXPLORE project – Yee *et al.* 2002: Galactic disk fields; STARE project – Brown and Charbonneau 2000, VULCAN project – Borucki *et al.* 2001: brighter stars) but only single transit-like light curves have been reported so far. It is worth noting that the only known object with planetary transiting companion – HD 209458 (Henry *et al.* 2000 and Charbonneau *et al.* 2000) was discovered in the opposite way: after detection during the spectroscopic survey, the star was monitored photometrically for transits.

Search for planetary and low luminosity transiting objects around main sequence stars became one of the highest priority goals of the third phase of the Optical Gravitational Lensing Experiment survey (OGLE-III). After the upgrade of detector with a wide field 8192×8192 pixel eight chip mosaic CCD camera and the software photometric data pipeline with algorithms based on the technique called "image subtraction" or "difference image analysis" (DIA) developed by Alard and Lupton (1998), Alard (2000) and Woźniak (2000), the OGLE project became capable to monitor millions of stars with the long term accuracy of a few millimagnitudes for the brightest stars.

The first "planetary and low-luminosity object transit" campaign was conducted by OGLE in June and July 2001 (Udalski *et al.* 2002ab). Three fields ($35'\times35'$ each) of extremely high stellar density in the direction of the Galactic bulge were monitored continuously with the time resolution of about 12 minutes. Altogether 59 objects out of 52 000 Galactic disk stars with photometry better than 1.5% were found to show small depth, flat-bottomed transits indicating presence of small size companions around these stars. For the vast majority of objects photometric elements could be derived as the individual transits were observed many times. Preliminary analysis of light curves indicated that several companions can be Jupiter-sized, so they could be planets, brown dwarfs or late M-type dwarfs. Unfortunately, the photometry alone cannot unambiguously distinguish between these objects, as all of them may have the radii of the order of 0.1–0.2 $\mathrm{R}_\odot$ (1–2 R_{Jup}). Therefore measurements of the radial velocity amplitude of the primaries are needed to determine the masses of transiting companions. Several of the OGLE-III transiting objects were followed-up spectroscopically with moderate resolution to better constrain sizes of the companions (Dreizler *et al.* 2002) as well as with high resolution spectroscopy. However, results of the latter have not been known at the moment of writing this paper. Apart from the final outcome of the first OGLE-III campaign, it clearly proved that the photometry of huge number of stars with high photometric accuracy necessary for transit detection can be obtained, and massive detection of low depth transits is feasible.

The Galactic bulge line-of-sight is certainly not a perfect one for transit search. Luminous background of the Galactic bulge causes higher probability of the so called blending effect. Additional unresolvable light within the seeing disk of a star with a transiting object makes the depth of the transit shallower. In the worst case of very high blending, regular eclipsing star can mimic low amplitude transit. While in general the amount of blending can be modeled from the shape of transit or estimated from HST observations, it is desirable to lower the probability of blending by selection of fields in much less crowded areas like, for instance, the Galactic disk.

In this paper we present results of the second "planetary and low-luminosity object transit" campaign conducted by OGLE-III in February–May 2002. Similarly to our first campaign three fields were monitored regularly with high time resolution. These fields were located in the Carina regions of the Galactic disk at $l \approx 290°$. Analysis of the collected data led to discovery of more than 60 new objects with low-luminosity transiting companions. The sample contains many Jupiter-size objects – very good candidates for extrasolar planets. Depth of some of the transits is at only several millimagnitude level.

Similarly to our first transit sample (Udalski *et al.* 2002ab) we decided to release the photometric data of our new candidates from the Carina fields to public domain so the follow-up spectroscopy could be made in short time scale by astronomers worldwide. Details and pointers to the OGLE INTERNET archive can be found at the end of this paper.

2. Observational Data

Observations presented in this paper were collected with the 1.3-m Warsaw telescope at the Las Campanas Observatory, Chile (operated by the Carnegie Institution of Washington), equipped with a wide field CCD mosaic camera. The camera consists of eight 2048×4096 pixel SITe ST002A detectors. The pixel size of each of the detectors is 15 μm giving the 0.26 arcsec/pixel scale at the focus of the Warsaw telescope. Full field of view of the camera is about $35'\times35'$. The gain of each chip is adjusted to be about 1.3 e^-/ADU with the readout noise of about 6 to 9 e^-, depending on the chip.

The photometric data were collected during 76 nights spanning 95 days starting from February 17, 2002. Three fields located in Carina regions of the Galactic disk were observed continuously with the time resolution of about 15 minutes. The fields were monitored up to 6 hours per night. Acronyms and equatorial coordinates of the fields are provided in Table 1. One of the fields, namely CAR100, was also sporadically observed before the main campaign.

Table 1

Equatorial coordinates of transit fields

Field	RA (J2000)	DEC (J2000)
CAR100	$11^{\rm h}07^{\rm m}00^{\rm s}$	$-61^\circ06'30''$
CAR104	$10^{\rm h}57^{\rm m}30^{\rm s}$	$-61^\circ40'00''$
CAR105	$10^{\rm h}52^{\rm m}20^{\rm s}$	$-61^\circ40'00''$

All observations were made in the *I*-band filter. We decided to increase the exposure time compared to the OGLE-III 2001 campaign to probe somewhat fainter stars, *i.e.*, in general of later spectral types. Therefore the exposure time of each image was set to 180 seconds, at the cost of somewhat smaller time resolution (about 15 minutes). Altogether about 1150 epochs were collected for each field during our 2002 campaign. The median seeing of the entire dataset was about $1\overset{''}{.}2$.

3. Data Reductions

All collected images were preprocessed (de-biasing and flat-fielding) in real time with the standard OGLE-III data pipeline. Photometric reductions were performed off-line after the end of campaign when all frames were collected. Similarly to our 2001 campaign we applied the new OGLE-III photometric data pipeline based on the difference image analysis (DIA) method (Alard and Lupton 1998, Alard 2000) and implementation of this method by Woźniak (2000). For more details the reader is referred to Udalski *et al.* (2002a). We only note here, that the reference images were obtained by averaging of about 12 best images taken at the seeing of about $0\farcs8$–$0\farcs9$.

At this phase of the OGLE-III project observations are mainly focused on the variability. Therefore no calibration to the standard system of the images collected so far has been performed. No standard stars were observed during the 2002 campaign as well. Fortunately, part of the CAR100 field overlaps with CAR_SC1, CAR_SC2 and CAR_SC3 fields observed and well calibrated during the OGLE-II phase. Based on the mean magnitudes of 13 transit candidates observed during both – OGLE-II and OGLE-III phases we determined the mean shift of the magnitude scale between the OGLE-III magnitudes and OGLE-II calibrated data. This shift was applied not only to CAR100 but also to the remaining Carina fields. Our previous experience indicates that the error of the magnitude scale should not exceed 0.1–0.15 mag. Although OGLE-II photometry exists for 13 of our candidates, it should be noted that it is not suitable for search or even confirmation of transits because of much worse photometric quality obtained with the standard PSF fitting technique, much smaller number of observations and non-appropriate sampling.

Astrometric solution for the observed fields was performed in similar manner as for the 2001 campaign data (Udalski *et al.* 2002a), *i.e.*, by cross-identification of about 2000 brightest stars in each chip image with the Digitized Sky Survey images of the same part of the sky. Then the transformation between OGLE-III pixel grid and equatorial coordinates of the DSS (GSC) astrometric system was calculated. This method was modified to obtain the initial transformation using WCSTools package (Mink 1997) and USNO-A2.0 Catalogue (Monet *et al.* 1998). The systematic error of the DSS astrometric solution can be up to about 0.7 arcsec, while the internal error of the transformation is about 0.2 arcsec.

4. Search for Transits

Before the transit search algorithm was applied to the collected data, a preselection procedure was performed. Similarly to the 2001 campaign we limited our search to stars with very precise photometry. We set the threshold of photometric accuracy at ≤ 15 mmag (*rms* from the entire time series). However, contrary to the 2001 campaign we did not make any limitation based on colors of preselected stars. In the Galactic bulge case that step was necessary to get rid of the Galactic bulge giants having similar magnitude as foreground Galactic disk stars. In the Carina Galactic disk fields the number of giants is very small, what can be deduced from the OGLE-II Carina fields color-magnitude diagrams, so they do not contaminate the sample in any significant way. Additionally, by lifting color constraints we do not miss, for instance, late K or M-type nearby objects which could also potentially host planets or other small companions. About 103 000 stars passed our "good photometry" cut.

In the next step, all stars were subject to the transit search algorithm. We decided to run the BLS algorithm (Kovács, Zucker and Mazeh 2002) which we find to be very fast and efficient, based on our experience from the 2001 campaign (Udalski *et al.* 2002b). We used similar parameters of the BLS algorithm as in the 2001 campaign and limited our search for transits to periods from 1.05 to 10 days.

To our surprise, the BLS procedure run on our time series produced initially a huge number of artifacts, with transit-like light curves and similar pattern of periodicities. It was soon realized that photometry on a few nights was affected by the same variability pattern that folded to transit-like light curve shape and was triggered by the BLS algorithm. Most likely the photometry on these nights was affected by clouds or non-photometric conditions. After removing the data from these (four) nights the BLS procedure rerun on the entire dataset triggered much more reasonable number of candidates.

The final list was prepared after a careful visual inspection of all light curves which passed the BLS algorithm. We left on the main list of candidates only those stars which we believe have a significant probability of being true transits. We removed a large number of small amplitude events caused by grazing eclipses of regular stars of similar size and brightness (V-shaped eclipses) or somewhat deeper (>0.1 mag) transits which occasionally passed our filters. However, we should stress that in the case of more noisy light curves it is not easy to distinguish between grazing eclipses and very non-central transits. Therefore, some of the stars on our list might be double stars, what can be easily verified in the future by spectroscopy.

The final periods of our candidates were found after a careful examination of the eclipse light curve – by minimizing dispersion during the eclipse phases that are very sensitive to the period changes. When only small number of transits was registered we always adopted the shortest period consistent with our remaining data. The formal accuracy of periods depends on the number and span of individual transits and it is of the order of $5\cdot10^{-4}$–$2\cdot10^{-4}P$.

5. Results of 2002 Campaign

Sixty two stars passed our filtering. We decided to keep on the list all stars with transiting companions when the transit depth was smaller than 0.08 mag. Such a limit corresponds to the companion size of 1.4 $R_{\rm Jup}$ if the stellar radius is half of the solar. Although our search was limited to periods longer than 1.05 days, a few objects with shorter periods also entered the list. They were detected with the period of $2P$.

Table 2 contains all basic data on our Carina objects with transiting companions. To preserve our notation from the OGLE-III 2001 campaign the first object in Table 2 is designated as OGLE-TR-60. In the subsequent columns of Table 2 the following data are provided: Identification, equatorial coordinates (J2000), orbital period, epoch of mid-eclipse, I-band magnitude outside transit, the depth of transit, number of transits observed ($N_{\rm tr}$) and remarks. Accuracy of the magnitude scale is of about 0.1–0.15 mag. OII abbreviation in the remarks column indicates that the object was also observed during the OGLE-II phase.

Additionally, we present in Appendix the light curves and finding charts. For each object the full light curve and close-up around the transit are shown. Please note that the magnitude scale changes in the close-up windows, depending on brightness, noise and transit depth. The finding chart is a $60'' \times 60''$ subframe of the I-band reference image centered on the star. The star is marked by a white cross. North is up and East to the left in these images.

Table 2

OGLE-III planetary and low luminosity object transits

Name	RA (J2000)	DEC (J2000)	P [days]	T_0 −2452000	I [mag]	ΔI [mag]	$N_{\rm tr}$	Rem.
OGLE-TR-60	$11^{h}08^{m}37.^{s}25$	$-61^{\circ}20'16.''7$	2.30890	75.77838	14.60	0.016	11	OII
OGLE-TR-61	$11^{h}08^{m}41.^{s}13$	$-61^{\circ}07'58.''5$	4.26800	76.62809	16.26	0.030	8	OII
OGLE-TR-62	$11^{h}08^{m}37.^{s}24$	$-61^{\circ}10'45.''3$	2.60119	77.66751	15.91	0.038	10	OII
OGLE-TR-63	$11^{h}08^{m}58.^{s}01$	$-61^{\circ}01'29.''4$	1.06698	74.24553	15.75	0.011	12	OII
OGLE-TR-64	$11^{h}07^{m}50.^{s}90$	$-61^{\circ}05'39.''9$	2.71740	75.85150	16.17	0.022	7	OII
OGLE-TR-65	$11^{h}07^{m}53.^{s}46$	$-61^{\circ}04'18.''2$	0.86013	76.31928	15.94	0.034	18	OII
OGLE-TR-66	$11^{h}07^{m}04.^{s}18$	$-60^{\circ}54'21.''0$	3.51407	74.42473	15.18	0.053	6	
OGLE-TR-67	$11^{h}08^{m}57.^{s}92$	$-60^{\circ}52'58.''9$	5.27980	78.76236	16.40	0.053	5	OII
OGLE-TR-68	$11^{h}05^{m}48.^{s}85$	$-60^{\circ}54'50.''6$	1.28870	73.10520	16.79	0.030	12	
OGLE-TR-69	$11^{h}06^{m}06.^{s}40$	$-60^{\circ}56'19.''9$	2.33708	75.19708	16.55	0.038	5	
OGLE-TR-70	$11^{h}05^{m}12.^{s}33$	$-61^{\circ}14'00.''2$	8.04060	77.22138	16.89	0.053	4	OII
OGLE-TR-71	$11^{h}06^{m}52.^{s}67$	$-61^{\circ}14'16.''4$	4.18760	76.34670	16.38	0.022	5	OII
OGLE-TR-72	$11^{h}05^{m}59.^{s}06$	$-61^{\circ}10'08.''1$	6.85400	77.39865	16.44	0.048	4	OII
OGLE-TR-73	$11^{h}05^{m}33.^{s}61$	$-61^{\circ}08'45.''3$	1.58105	73.42506	16.99	0.034	9	OII
OGLE-TR-74	$11^{h}06^{m}10.^{s}71$	$-61^{\circ}14'52.''7$	1.58511	76.33895	15.87	0.030	11	OII
OGLE-TR-75	$11^{h}06^{m}37.^{s}91$	$-61^{\circ}19'15.''5$	2.64270	77.35886	16.96	0.034	8	OII
OGLE-TR-76	$10^{h}58^{m}41.^{s}90$	$-61^{\circ}53'12.''3$	2.12678	323.54517	13.76	0.022	6	
OGLE-TR-77	$10^{h}58^{m}02.^{s}03$	$-61^{\circ}49'50.''9$	5.45550	326.45043	16.12	0.022	4	
OGLE-TR-78	$10^{h}59^{m}41.^{s}62$	$-61^{\circ}55'15.''0$	5.32038	328.81199	15.32	0.030	4	

Table 2

Concluded

Name	RA (J2000)	DEC (J2000)	P [days]	T_0 −2452000	I [mag]	ΔI [mag]	$N_{\rm tr}$	Rem.
OGLE-TR-79	$10^h59^m35\overset{s}{.}54$	$-61°56'59\overset{''}{.}2$	1.32452	324.28819	15.28	0.030	13	
OGLE-TR-80	$10^h57^m54\overset{s}{.}36$	$-61°42'02\overset{''}{.}5$	1.80730	325.49707	16.50	0.016	12	
OGLE-TR-81	$10^h59^m26\overset{s}{.}49$	$-61°36'49\overset{''}{.}0$	3.21650	323.10755	15.41	0.022	6	
OGLE-TR-82	$10^h58^m03\overset{s}{.}07$	$-61°34'25\overset{''}{.}8$	0.76416	323.08758	16.30	0.034	22	
OGLE-TR-83	$10^h57^m42\overset{s}{.}48$	$-61°36'23\overset{''}{.}3$	1.59920	323.20108	14.87	0.016	12	
OGLE-TR-84	$10^h59^m00\overset{s}{.}00$	$-61°34'43\overset{''}{.}0$	3.11300	324.98303	16.69	0.059	6	
OGLE-TR-85	$10^h59^m00\overset{s}{.}18$	$-61°37'41\overset{''}{.}1$	2.11460	324.44012	15.45	0.048	12	
OGLE-TR-86	$10^h58^m19\overset{s}{.}30$	$-61°29'27\overset{''}{.}3$	2.77700	323.92937	16.32	0.065	7	
OGLE-TR-87	$10^h59^m39\overset{s}{.}33$	$-61°24'07\overset{''}{.}3$	6.60672	332.12239	16.32	0.059	3	
OGLE-TR-88	$10^h59^m22\overset{s}{.}23$	$-61°25'21\overset{''}{.}0$	1.25012	323.58871	14.58	0.034	15	
OGLE-TR-89	$10^h56^m11\overset{s}{.}27$	$-61°29'55\overset{''}{.}4$	2.28990	323.00793	15.78	0.013	5	
OGLE-TR-90	$10^h56^m36\overset{s}{.}63$	$-61°28'46\overset{''}{.}5$	1.04155	322.67722	16.44	0.022	15	
OGLE-TR-91	$10^h57^m31\overset{s}{.}20$	$-61°27'21\overset{''}{.}7$	1.57900	324.30930	15.23	0.043	9	
OGLE-TR-92	$10^h57^m23\overset{s}{.}43$	$-61°26'45\overset{''}{.}4$	0.97810	322.96414	16.50	0.038	20	
OGLE-TR-93	$10^h55^m20\overset{s}{.}36$	$-61°24'59\overset{''}{.}4$	2.20674	324.91426	15.20	0.019	12	
OGLE-TR-94	$10^h55^m48\overset{s}{.}86$	$-61°28'44\overset{''}{.}5$	3.09222	327.38138	14.32	0.043	6	
OGLE-TR-95	$10^h55^m19\overset{s}{.}38$	$-61°32'12\overset{''}{.}0$	1.39358	325.30146	16.36	0.019	14	
OGLE-TR-96	$10^h56^m33\overset{s}{.}99$	$-61°37'10\overset{''}{.}5$	3.20820	323.51865	14.90	0.043	6	
OGLE-TR-97	$10^h55^m17\overset{s}{.}94$	$-61°54'35\overset{''}{.}7$	0.56765	322.83189	15.51	0.016	25	
OGLE-TR-98	$10^h56^m51\overset{s}{.}77$	$-61°56'15\overset{''}{.}0$	6.39800	327.77953	16.64	0.034	5	
OGLE-TR-99	$10^h55^m12\overset{s}{.}80$	$-61°54'54\overset{''}{.}8$	1.10280	323.36419	16.47	0.034	16	
OGLE-TR-100	$10^h52^m56\overset{s}{.}91$	$-61°50'54\overset{''}{.}9$	0.82670	323.32754	14.88	0.019	20	
OGLE-TR-101	$10^h52^m58\overset{s}{.}59$	$-61°51'43\overset{''}{.}1$	2.36180	324.23024	16.69	0.038	8	
OGLE-TR-102	$10^h53^m29\overset{s}{.}65$	$-61°47'37\overset{''}{.}2$	3.09790	323.79252	13.84	0.019	5	
OGLE-TR-103	$10^h53^m33\overset{s}{.}53$	$-61°47'04\overset{''}{.}3$	8.21690	324.30267	16.69	0.048	4	
OGLE-TR-104	$10^h53^m27\overset{s}{.}04$	$-61°43'20\overset{''}{.}3$	6.06800	328.02979	17.10	0.053	2	
OGLE-TR-105	$10^h52^m24\overset{s}{.}07$	$-61°31'09\overset{''}{.}4$	3.05810	324.37986	16.16	0.026	3	
OGLE-TR-106	$10^h53^m51\overset{s}{.}23$	$-61°34'13\overset{''}{.}2$	2.53585	324.78332	16.53	0.022	6	
OGLE-TR-107	$10^h54^m23\overset{s}{.}58$	$-61°37'21\overset{''}{.}1$	3.18980	323.55936	16.66	0.053	7	
OGLE-TR-108	$10^h53^m12\overset{s}{.}65$	$-61°30'18\overset{''}{.}7$	4.18590	325.78009	17.28	0.048	3	
OGLE-TR-109	$10^h53^m40\overset{s}{.}73$	$-61°25'14\overset{''}{.}8$	0.58909	323.74379	14.99	0.008	24	
OGLE-TR-110	$10^h52^m28\overset{s}{.}37$	$-61°29'31\overset{''}{.}8$	2.84857	326.36185	16.15	0.026	6	
OGLE-TR-111	$10^h53^m17\overset{s}{.}91$	$-61°24'20\overset{''}{.}3$	4.01610	330.44687	15.55	0.019	9	
OGLE-TR-112	$10^h52^m46\overset{s}{.}46$	$-61°23'17\overset{''}{.}7$	3.87900	327.53260	13.64	0.016	8	
OGLE-TR-113	$10^h52^m24\overset{s}{.}40$	$-61°26'48\overset{''}{.}5$	1.43250	324.36394	14.42	0.030	10	
OGLE-TR-114	$10^h52^m20\overset{s}{.}79$	$-61°29'45\overset{''}{.}2$	1.71213	323.24893	15.76	0.026	5	
OGLE-TR-115	$10^h50^m20\overset{s}{.}50$	$-61°28'34\overset{''}{.}4$	8.34670	329.94514	16.66	0.059	3	
OGLE-TR-116	$10^h50^m24\overset{s}{.}79$	$-61°26'12\overset{''}{.}2$	6.06430	324.21555	14.90	0.077	5	
OGLE-TR-117	$10^h51^m40\overset{s}{.}48$	$-61°34'15\overset{''}{.}7$	5.02260	325.29544	16.71	0.030	5	
OGLE-TR-118	$10^h51^m32\overset{s}{.}10$	$-61°48'08\overset{''}{.}3$	1.86150	326.26908	17.07	0.019	7	
OGLE-TR-119	$10^h51^m58\overset{s}{.}75$	$-61°41'20\overset{''}{.}5$	5.28260	323.67601	14.29	0.038	7	
OGLE-TR-120	$10^h51^m09\overset{s}{.}34$	$-61°43'11\overset{''}{.}3$	9.16590	331.49765	16.23	0.077	4	
OGLE-TR-121	$10^h50^m36\overset{s}{.}41$	$-61°40'37\overset{''}{.}2$	3.23210	325.68889	15.86	0.071	6	

6. Discussion

Sixty two new objects with transiting companions were discovered during the second "planetary and low-luminosity object transit" observational campaign conducted by OGLE-III in 2002 increasing the total number of transiting objects found by OGLE to 121. For each new object several individual transits were detected and determination of the photometric ephemerides was possible.

Transits can be caused by extrasolar planets or brown dwarfs or small late M-type dwarfs. To distinguish between these possibilities, radial velocity measurements are necessary and we hope they will be obtained in the near future. However, one should remember that blending of a regular totally eclipsing star with a close optical or physically related (wide binary system) unresolvable neighbor can produce transit-like light curve. Therefore some of our candidates listed in Table 2 can actually be faked transits caused by blending effect. High resolution spectroscopy should also clarify this problem.

Photometric data alone allow to draw conclusions only on sizes of transiting objects. Unfortunately, without any additional information on the radius of the primary it is not possible to obtain actual size of the companion in a system with transits when the errors of individual observations are comparable to the transit depth. Due to well known degeneracy between radii of the host star and companion, R_s, R_c, inclination, i, and limb darkening, u, similar quality photometric solutions can be obtained for different inclinations of the orbit and radii of components (in the I-band the transit light curve is practically insensitive to the limb darkening parameter u). Such additional information can come from moderate resolution spectroscopy suitable for spectral classification (Dreizler *et al.* 2002) or, in principle, from colors of host stars. Unfortunately, the latter are of no use in the case of the pencil beam survey of the Galactic disk, because usually the significant and unknown interstellar extinction makes dereddening of individual stars practically impossible.

Because the spectral types of stars from our sample are not known and the primary radius cannot be constrained, only the lower limit on the size of the companion can be calculated assuming that the transit is central, $i.e., i = 90°$. The corresponding radius of the primary is also the lower limit. Table 3 lists lower limits of the components radii calculated using formulae provided by Sackett (1999) under the assumption that the mass of the primary is equal to $M_s = 1\ M_\odot$. It should be remembered that the values in Table 3 scale as $M_s^{1/3}$. Details of the modeling of transit light curve are given in Udalski *et al.* (2002a).

Solid line in the close-up windows in Appendix shows the transit model light curve calculated for the central passage. As it can be seen, in some cases the fit is not satisfactory indicating the inclination smaller than 90°. However, in most cases the central passage fit is practically indistinguishable from others so at this stage it is impossible to derive other values than the lower limits of radii provided in Table 3.

The limits of radii of transiting companions may be used for the first preselection of our 2002 transit sample. For several objects the lower limits of radii of the companions are larger than 0.25 $R_\odot$. These systems almost certainly contain M-type dwarf companions. The remaining objects can be either planets or brown dwarfs or late M-type dwarfs. The smaller size of the companion – the larger probability that the companion is an extrasolar planet. But, on the other hand, one should always remember that the figures in Table 3 are only the lower limits and the real radius of the companion in any given case might be much larger.

T a b l e 3

Dimensions of stars and companions for central passage ($M_s = 1$ $M_\odot$)

Name	R_s [$R_\odot$]	R_c [$R_\odot$]	Name	R_s [$R_\odot$]	R_c [$R_\odot$]
OGLE-TR-60	1.60	0.176	OGLE-TR-91	1.43	0.257
OGLE-TR-61	3.46	0.519	OGLE-TR-92	0.90	0.153
OGLE-TR-62	1.66	0.282	OGLE-TR-93	1.70	0.204
OGLE-TR-63	1.16	0.104	OGLE-TR-94	0.89	0.161
OGLE-TR-64	1.14	0.148	OGLE-TR-95	1.25	0.150
OGLE-TR-65	1.00	0.160	OGLE-TR-96	1.09	0.196
OGLE-TR-66	1.08	0.216	OGLE-TR-97	1.11	0.122
OGLE-TR-67	1.82	0.364	OGLE-TR-98	1.42	0.227
OGLE-TR-68	1.08	0.162	OGLE-TR-99	0.98	0.156
OGLE-TR-69	1.28	0.217	OGLE-TR-100	0.98	0.117
OGLE-TR-70	0.34	0.067	OGLE-TR-101	0.70	0.120
OGLE-TR-71	0.75	0.097	OGLE-TR-102	1.12	0.134
OGLE-TR-72	1.08	0.206	OGLE-TR-103	1.36	0.258
OGLE-TR-73	0.84	0.134	OGLE-TR-104	1.84	0.368
OGLE-TR-74	0.95	0.143	OGLE-TR-105	1.17	0.163
OGLE-TR-75	1.55	0.247	OGLE-TR-106	1.22	0.159
OGLE-TR-76	0.85	0.110	OGLE-TR-107	1.11	0.222
OGLE-TR-77	2.25	0.292	OGLE-TR-108	1.37	0.259
OGLE-TR-78	0.97	0.146	OGLE-TR-109	1.23	0.099
OGLE-TR-79	1.27	0.190	OGLE-TR-110	0.98	0.138
OGLE-TR-80	1.56	0.172	OGLE-TR-111	0.90	0.108
OGLE-TR-81	2.18	0.284	OGLE-TR-112	3.05	0.336
OGLE-TR-82	0.76	0.122	OGLE-TR-113	0.86	0.129
OGLE-TR-83	0.99	0.109	OGLE-TR-114	0.97	0.136
OGLE-TR-84	1.28	0.269	OGLE-TR-115	0.66	0.139
OGLE-TR-85	1.28	0.244	OGLE-TR-116	1.25	0.300
OGLE-TR-86	0.78	0.172	OGLE-TR-117	1.76	0.264
OGLE-TR-87	1.26	0.264	OGLE-TR-118	2.12	0.233
OGLE-TR-88	1.28	0.206	OGLE-TR-119	1.82	0.310
OGLE-TR-89	0.96	0.096	OGLE-TR-120	1.08	0.260
OGLE-TR-90	0.68	0.088	OGLE-TR-121	1.02	0.235

One can notice that the number of objects with the limits on the companion smaller than 1.6 $R_{\rm Jup}$ is large in our 2002 sample (26) – much larger than on the 2001 object list (11). Also the limits on radii of primary stars are smaller than the values of those discovered during the 2001 campaign. This is very likely because of the deeper range of our 2002 survey (longer exposures) so we probe on average later spectral type stars than during the 2001 season. If so, the probability of detection of extrasolar planets in our 2002 sample should be larger. Additionally, we detected many more objects with the transit depth of only several millimagnitudes compared to the 2001 campaign.

The list of the promising planetary transit candidates among our objects is quite long so we enumerate only a few: OGLE-TR-71, OGLE-TR-113, OGLE-TR-111, OGLE-TR-90, OGLE-TR-89, OGLE-TR-101, OGLE-TR-100. We would also like to draw attention to a group of about ten objects with orbital periods close to or smaller than one day. Short distance from the host star makes the transits long in phase, but the limits from Table 3 suggest solar type primaries. Very small depth of transits indicates that companions are well in the planetary range of sizes. Unfortunately, in many cases the observational scatter is somewhat too high to definitively recognize the transit light curve shape, so some of them might be grazing eclipses. If confirmed by future follow-up spectroscopy as planetary systems, the companions in these objects would be the shortest orbital period extrasolar planets providing important constraints on the modeling of the origin and evolution of planetary systems.

It is worth noting that not only extrasolar planetary cases are of great astronomical importance. Discovery of brown dwarfs among our candidates would contradict the existence of the so called "brown dwarf desert" (lack of brown dwarfs at small orbits in binary systems) and allow for the first time to precisely measure their masses and sizes. Also determination of masses and sizes of late M-type dwarfs is extremely important as the mass-radius relation of the lower part of the main sequence is poorly known. Therefore we strongly encourage astronomers worldwide to make follow-up observations. During the next seasons (2003 and 2004) most of our photometric ephemerides should be accurate enough that only a few observations per star should suffice to determine precise masses.

7. Data Availability

The photometric data on the objects with transiting companions discovered during the 2002 OGLE-III campaign are available in the electronic form from the OGLE archive:

http://www.astrouw.edu.pl/~ogle

ftp://ftp.astrouw.edu.pl/ogle/ogle3/transits/carina_2002

or its US mirror

http://bulge.princeton.edu/~ogle

ftp://bulge.princeton.edu/ogle/ogle3/transits/carina_2002

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