The Optical Gravitational Lensing Experiment. Planetary and Low-Luminosity Object Transits in the Fields of Galactic Disk. Results of the 2003 OGLE Observing Campaigns*

A. Udalski[1], M. K. Szymański[1], M. Kubiak[1], G. Pietrzyński[1,2], I. Soszyński[1,2], K. Żebruń[1], O. Szewczyk[1], and Ł. Wyrzykowski[1]

[1]Warsaw University Observatory, Al. Ujazdowskie 4, 00-478 Warszawa, Poland
e-mail:
(udalski,msz,mk,pietrzyn,soszynsk,zebrun,szewczyk,wyrzykow)@astrouw.edu.pl
[2] Universidad de Concepción, Departamento de Fisica, Casilla 160–C, Concepción, Chile

ABSTRACT

We present results of two observing campaigns conducted by the OGLE-III survey in the 2003 observing season aiming at the detection of new objects with planetary transiting companions. Six fields of $35' \times 35'$ each located in the Galactic disk were monitored with high frequency for several weeks in February–July 2003. Additional observations of three of these fields were also collected in the 2004 season. Altogether about 800 and 1500 epochs were collected for the fields of both campaigns, respectively.

The search for low depth transits was conducted on about 230 000 stars with photometry better than 15 mmag. It was focused on detection of planetary companions, thus clear non-planetary cases were not included in the final list of selected objects. Altogether we discovered 40 stars with shallow (≤ 0.05 mag) flat-bottomed transits. In each case several individual transits were observed allowing determination of photometric elements. Additionally, the lower limits on radii of the primary and companion were calculated.

From the photometric point of view the new OGLE sample contains many very good candidates for extrasolar transiting planets. However, only the future spectroscopic follow-up observations of the OGLE sample – determination of the amplitude of radial velocity and exclusion of blending possibilities – may allow to confirm their planetary status. In general, the transiting objects may be extrasolar planets, brown dwarfs, M-type dwarfs or fake transits caused by blending.

All photometric data of objects with transiting companions discovered during the 2003 campaigns are available to the astronomical community from the OGLE INTERNET archive.

1. Introduction

Detection of planetary transits in the spectroscopically discovered extrasolar planetary system HD209458 (Henry *et al.* 1999, Charbonneau *et al.* 1999) empirically proved that the photometric method of detection of extrasolar planets, called the "transit method", can be a potentially important tool in planetary

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

searches. However, in spite of many efforts no extrasolar planet was detected in this manner during the next few years. The transit method offers many advantages compared to the traditional spectroscopic method. When the photometric observations are combined with precise spectroscopy all important parameters of a planet like its size and mass can be derived providing extremely important data to studying in detail the structure of planets and evolution of extrasolar planetary systems.

In 2002 the Optical Gravitational Lensing Experiment (OGLE) survey announced results of two photometric campaigns aimed at photometric discovery of low depth transits caused by extrasolar planets or other sort of "low-luminosity" objects (Udalski *et al.* 2002abc, 2003). About 140 stars such stars were found among about 150 000 stars in two lines-of-sight in the Galactic disk – toward the Galactic center and the constellation of Carina. It was obvious from the very beginning that the significant part of the discovered transits may be caused by stellar size companions, part can be an effect of blending of eclipsing stars with bright unresolvable neighbors while in the small number of objects the transits could be of planetary origin. Unfortunately, the photometry, which allows determination of size, cannot unambiguously distinguish planetary or brown dwarf from late M-type dwarf stellar companions as all of them may have the radii of the order of 0.1–0.2 $R_\odot$ (1–2 $R_{\rm Jup}$).

The OGLE transiting objects were subject of many follow up studies in the past two years. The most important follow up observations of the OGLE objects were high resolution spectroscopic observations for radial velocity changes. In the past two years the planetary status of four of the OGLE transiting companions was confirmed by measuring small amplitude radial velocity variation with the same period and in appropriate phase as resulting from the OGLE photometric orbits: OGLE-TR-56 (Konacki *et al.* 2003a, Torres *et al.* 2004a, Bouchy *et al.* 2004b), OGLE-TR-113 (Bouchy *et al.* 2004a, Konacki *et al.* 2004), OGLE-TR-132 (Bouchy *et al.* 2004a) and OGLE-TR-111 (Pont *et al.* 2004). Another OGLE object – OGLE-TR-10 – also very likely hosts an extrasolar planet although additional radial velocity observations are necessary to fully confirm its planetary status (Konacki *et al.* 2003b, Bouchy *et al.* 2004b). Additionally, the high resolution spectroscopy allowed to rule out possible blending scenarios making the confirmations very reliable and sound. It is worth noting that except for OGLE-TR-132, which was at the edge of detection, all the remaining OGLE planets were on the OGLE short lists of the most likely planetary candidates based on their photometric properties. The sixth known extrasolar transiting planet, TrES-1, has recently been found by the small telescope wide field TrES survey (Alonso *et al.* 2004).

Detection of the first transiting planets allowed to significantly increase the sample of extrasolar planets with precisely known masses and radii, thus providing crucial empirical data for testing the planetary models etc. Surprisingly the first three OGLE planets (OGLE-TR-56, OGLE-TR-113 and OGLE-TR-132) turned out to form a new class of "very hot Jupiters" – giant planets orbiting their hosts stars with periods shorter than 2 days. Such systems have been unknown so far in the solar neighborhood. It is clear that the detection of additional transiting planets is of high importance for extrasolar planetary science.

In 2003 the OGLE survey conducted two additional observational campaigns aimed at the detection of additional transiting exoplanets. Altogether six new fields located in the Galactic disk in the constellations of Carina, Centaurus and Musca were monitored regularly with high time resolution for a few weeks each. The search for objects with transiting companions was performed in similar manner as in the past campaigns. However, it was more focused on planetary transits. Hence, many clear detections of low mass stellar transiting companions were removed from the final sample of objects with transiting companions.

Similarly to our past transit samples (Udalski *et al.* 2002abc, 2003) the photometric data of our new objects with transiting companions from the 2003 fields can be found in the OGLE INTERNET archive. Thus the follow-up spectroscopic observations and confirmation of their planetary or non-planetary status can be made in short time scale. 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 $35' \times 35'$. 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. More details on the instrumental set-up can be found in Udalski (2003).

Two observing campaigns were conducted in 2003. The first of them – OGLE campaign #3 – started on February 12, 2003 and lasted up to March 26, 2003. The photometric data were collected during 39 nights spanning 43 days. Three fields of the Galactic disk were observed continuously with the time resolution of about 15 minutes. Acronyms and equatorial coordinates of these fields are provided in Table 1.

The second campaign – OGLE campaign #4 – started on March 25, 2003. While the main observing material was collected to the middle of May 2003, the fields were also observed from time to time until July, 25, 2003. Moreover, additional but less extensive photometric monitoring of the campaign #4 fields was conducted during the 2004 observing season – from March 14, 2004 up to July 30, 2004. As in the previous campaigns three fields of the Galactic disk were continuously monitored with the time resolution of about 15 minutes. Details on the location of these fields and their acronyms can also be found in Table 1.

All observations were made through the I-band filter. The exposure time of each image was set to 180 seconds. Altogether about 820 images were collected for each field during our OGLE campaign #3 and 1050 images in 2003 plus 460

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Equatorial coordinates of the observed fields

Field	RA (J2000)	DEC (J2000)
	Campaign #3	
CAR106	$11^{\mathrm{h}}03^{\mathrm{m}}00^{\mathrm{s}}$	$-61^{\circ}50'00''$
CEN106	$11^{\mathrm{h}}32^{\mathrm{m}}30^{\mathrm{s}}$	$-60^{\circ}50'00''$
CEN107	$11^{\mathrm{h}}54^{\mathrm{m}}00^{\mathrm{s}}$	$-62^{\circ}00'00''$
	Campaign #4	
CEN108	$13^{\mathrm{h}}33^{\mathrm{m}}00^{\mathrm{s}}$	$-64^{\circ}15'00''$
MUS100	$13^{\mathrm{h}}15^{\mathrm{m}}00^{\mathrm{s}}$	$-64^{\circ}51'00''$
MUS101	$13^{\mathrm{h}}25^{\mathrm{m}}00^{\mathrm{s}}$	$-64^{\circ}58'00''$

images in 2004 for the campaign #4 fields. The median seeing of images in both campaigns 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 (Udalski 2003).

Photometric reductions of the 2003 season images were performed off-line after the end of both campaigns. Additional 2004 season data were reduced with the same software setup in real time at the telescope. Similarly to our previous campaigns the OGLE-III photometric data pipeline based on the difference image analysis (DIA) method was used – see details in Udalski (2003).

Because no standard stars were observed during 2003 campaigns precise calibration of the OGLE photometry of transit fields to the standard system could not be obtained. However, part of the CAR106 field overlaps with CAR_SC1 field observed and well calibrated during the OGLE-II phase. Based on the mean magnitudes of several bright stars observed in both – OGLE-II and OGLE-III – the mean shift of the magnitude scale between the OGLE-III magnitudes and OGLE-II calibrated data was derived. Other fields were calibrated based on magnitudes of obtained in this manner "local" standards in the CAR106 field. The error of the magnitude scale should not exceed 0.1–0.15 mag.

Astrometric solution for the observed fields was performed similarly to the previous campaigns (Udalski *et al.* 2002ac), *i.e.*, by cross-identification of a few thousand 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.

4. Search for Transits

The search for objects with transiting companions was performed in almost identical way as in the past campaigns.

Before the transit search algorithm was applied to the collected data, two steps were performed. First a preselection procedure was run. We limited our search for transiting objects to stars with very precise photometry, *i.e.*, those with the *rms* from the entire time series collected in the 2003 season smaller than 15 mmag. Similarly to the 2002 Carina campaign we did not make any preselection based on colors of stars. About 100 000 and 130 000 stars passed our "good photometry" cut in the campaign #3 and #4 fields, respectively.

Next the photometric data of all objects were corrected for small scale systematic effects using the data pipeline developed by Kruszewski and Semeniuk (2003). Udalski *et al.* (2003) showed that this algorithm efficiently removes various small scale systematic errors present in the original data and makes it possible to detect lower depth transits.

Finally, all stars were subject to the transit search algorithm – the BLS algorithm of Kovács, Zucker and Mazeh (2002). Similar parameters of the BLS algorithm as in the previous campaigns were used. The search for transits was limited to periods from the range of 1.05 to 10 days.

The final list was prepared after careful visual inspection of all light curves which passed the BLS algorithm. The experience from our previous campaigns and spectroscopic follow up observations indicates that the size of exoplanets hardly exceeds the size of Jupiter. None of many larger size transiting companions discovered by OGLE turned out to be a planet. Therefore we set a tighter limit on the depth of transits than in the previous campaigns and removed all objects that revealed transits deeper than 0.05 mag.

It was also realized from the very beginning that when only two transits were observed during the campaign the derived periods may be uncertain. Usually, the shortest period allowed by the distribution of epochs was selected in such cases, but longer periods could not be excluded. Spectroscopic follow-up observations of Bouchy *et al.* (2004b) showed that indeed in a few cases so selected periods were inconsistent with spectroscopy. The problem is practically gone when three transits are observed. Therefore we left on our list only those objects for which three or more transits were covered during our campaigns (this constraint was lifted in two exceptions, *i.e.*, in the case of two good candidates in campaign #3 where only two transits were observed. The span of data collected for campaign #3 fields was much shorter than for the second campaign making the detection of many transits more difficult).

To minimize the number of objects contaminating our final sample we removed from the original list of detected stars a large number of small amplitude events caused by grazing eclipses of regular stars of similar size and brightness that produce V-shaped eclipses and large number of objects revealing small depth eclipses but simultaneously a small amplitude sinusoidal variation caused by distortion of the primary – a clear sign of a relatively massive companion (Udalski *et al.* 2002a, Drake 2003, Sirko and Paczyński 2003). Also evident blends of faint eclipsing systems with a brighter star were removed. However, it should be stressed that in the case of more noisy light curves of fainter stars it is not easy to distinguish between grazing eclipses and very non-central transits. Therefore, some of the stars on our list might still be double stars, what can be easily verified in the future by spectroscopy.

The final periods of our candidates were found after careful examination of the eclipse light curve – by minimizing dispersion during the eclipse phases that are very sensitive to the period changes. The formal accuracy of periods depends on the number of individual transits observed and the total duration of observations. It is of the order of $10^{-4}P$ for the only six week long campaign #3 and $10^{-5}P$ for the two season long campaign #4 (when additional transits were observed in the 2004 season data).

5. Results of the 2003 Campaigns

Seventeen stars with small transiting companions from the fields of 2003 campaign #3 have met our criteria. In the fields of 2003 campaign #4 23 objects have been found.

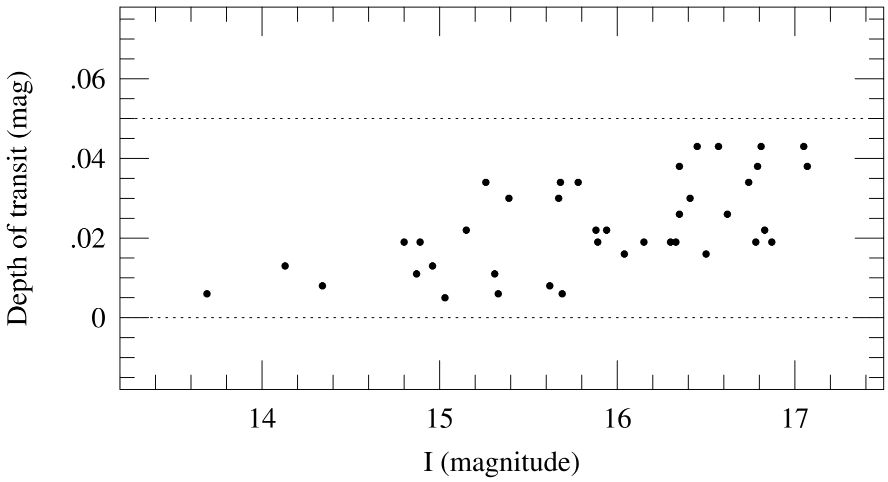

Fig. 1. Depth of transit *vs.* *I*-band magnitude of the host star. Horizontal dotted line at the depth of 0.05 marks the limit of OGLE search.

Similarly to our past campaigns we list the basic data on selected objects in Table 2. We preserve our notation started in OGLE-III 2001 campaign: the first object in Table 2 is designated as OGLE-TR-138. In Table 2 the following data are tabulated: 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. Although our search was limited to periods

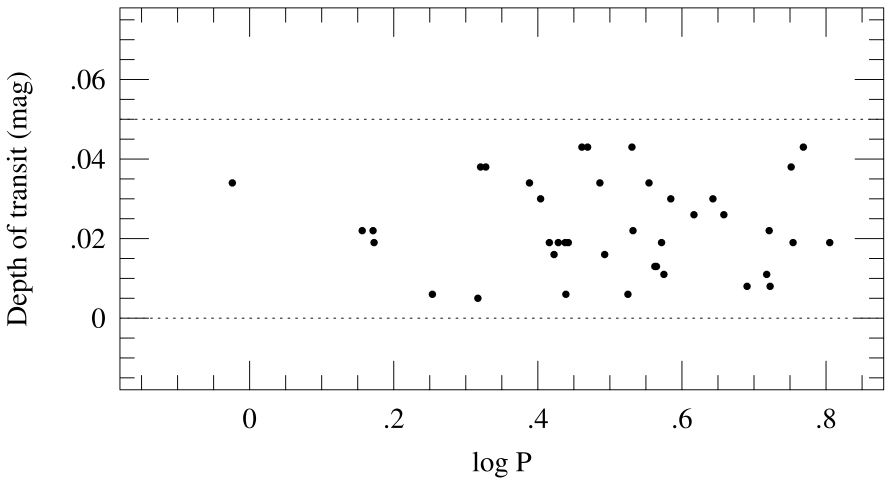

Fig. 2. Depth of transit plotted against the orbital period ($\log P$).

longer than 1.05 days, one object with shorter period (detected with the period of $2P$) also entered the list.

In the Appendix we present the light curves and finding charts of selected objects. For each object the full light curve and a close-up around the transit are shown. It should be noted 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.

Fig. 1 presents the depth of transit plotted against I-band magnitude of the host star. As expected the detection limit is roughly flat up to $I \approx 15.7$ mag and then rises slowly for noisier light curves of fainter stars. In Fig. 2 the depth of transit is shown against $\log P$. No relation or trends between these parameters are seen.

6. Discussion

Forty new objects with small transiting companions were discovered in six fields in the Galactic disk during two 2003 season OGLE campaigns. Although the number of detected objects is smaller than in the past campaigns our search in the 2003 season data was focused mainly on the smallest companions which have larger probability to be extrasolar planets. Therefore tighter selection criteria were applied and all uncertain cases, objects with longer lasting transits – evidently of stellar origin, objects revealing significant variability between eclipses suggesting more massive, stellar companions and other evident contaminators were removed from the list of detected objects. Special care was taken to detect transits as shallow as possible, as the probability of planetary origin of such cases is larger. All existing detections of transiting exoplanets indicate that the size of the extrasolar planets practically does not exceed that of Jupiter so

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Objects with planetary or low luminosity transiting companions

Name	RA (J2000)	DEC (J2000)	P [days]	T_0 −2452000	I [mag]	ΔI [mag]	$N_{\rm tr}$	Rem.
OGLE-TR-138	$11^{h}04^{m}23^{s}.77$	$-61^\circ43'10''.7$	2.64550	685.20281	16.04	0.016	3	
OGLE-TR-139	$11^{h}02^{m}43^{s}.79$	$-61^\circ37'46''.7$	2.53420	684.64467	16.41	0.030	4	
OGLE-TR-140	$11^{h}01^{m}13^{s}.91$	$-61^\circ44'21''.6$	3.39330	684.68281	16.45	0.043	4	
OGLE-TR-141	$11^{h}01^{m}52^{s}.09$	$-61^\circ58'01''.4$	5.67860	683.75001	14.80	0.019	2	
OGLE-TR-142	$11^{h}00^{m}34^{s}.75$	$-62^\circ04'09''.0$	3.06280	684.10926	15.68	0.034	4	
OGLE-TR-143	$11^{h}34^{m}03^{s}.83$	$-60^\circ54'13''.0$	3.34980	682.92526	13.69	0.006	3	
OGLE-TR-144	$11^{h}34^{m}52^{s}.78$	$-60^\circ52'35''.6$	2.44560	685.19335	16.74	0.034	5	ST
OGLE-TR-145	$11^{h}33^{m}04^{s}.34$	$-60^\circ34'04''.2$	2.74120	685.48763	16.33	0.019	4	ST
OGLE-TR-146	$11^{h}34^{m}05^{s}.52$	$-60^\circ39'38''.4$	2.94460	685.79072	16.57	0.043	5	
OGLE-TR-147	$11^{h}32^{m}30^{s}.45$	$-60^\circ38'41''.6$	3.84170	686.11365	15.67	0.030	3	
OGLE-TR-148	$11^{h}31^{m}31^{s}.66$	$-60^\circ36'52''.6$	1.43290	683.45961	16.83	0.022	7	ST
OGLE-TR-149	$11^{h}30^{m}45^{s}.10$	$-60^\circ43'57''.9$	4.55170	684.68689	16.35	0.026	3	
OGLE-TR-150	$11^{h}32^{m}29^{s}.92$	$-60^\circ58'25''.5$	2.07380	683.36717	15.03	0.005	6	
OGLE-TR-151	$11^{h}32^{m}21^{s}.84$	$-60^\circ50'45''.5$	1.48350	683.46444	15.94	0.022	9	
OGLE-TR-152	$11^{h}54^{m}05^{s}.59$	$-62^\circ04'38''.2$	3.73000	685.88809	16.30	0.019	4	ST
OGLE-TR-153	$11^{h}55^{m}21^{s}.60$	$-62^\circ03'55''.3$	4.39560	685.15132	15.39	0.030	2	
OGLE-TR-154	$11^{h}52^{m}55^{s}.80$	$-62^\circ16'53''.6$	3.66946	687.41198	14.96	0.013	4	
OGLE-TR-155	$13^{h}33^{m}26^{s}.00$	$-64^\circ16'38''.4$	5.27700	701.09815	15.62	0.008	5	
OGLE-TR-156	$13^{h}33^{m}54^{s}.81$	$-64^\circ09'43''.9$	3.58341	699.47628	15.26	0.034	8	
OGLE-TR-157	$13^{h}34^{m}22^{s}.90$	$-64^\circ07'17''.5$	5.86821	698.99295	17.05	0.043	7	
OGLE-TR-158	$13^{h}33^{m}38^{s}.08$	$-64^\circ05'23''.6$	6.38410	698.60150	15.89	0.019	5	
OGLE-TR-159	$13^{h}31^{m}54^{s}.49$	$-64^\circ02'39''.6$	2.12676	697.54746	16.35	0.038	16	ST
OGLE-TR-160	$13^{h}30^{m}42^{s}.95$	$-63^\circ57'30''.6$	4.90185	698.32754	14.34	0.008	3	
OGLE-TR-161	$13^{h}30^{m}55^{s}.71$	$-63^\circ58'38''.2$	2.74730	696.73100	15.69	0.006	4	
OGLE-TR-162	$13^{h}31^{m}01^{s}.09$	$-63^\circ58'34''.9$	3.75819	731.37770	14.87	0.011	4	
OGLE-TR-163	$13^{h}32^{m}52^{s}.59$	$-63^\circ57'44''.1$	0.94621	696.24111	15.78	0.034	23	
OGLE-TR-164	$13^{h}30^{m}58^{s}.60$	$-64^\circ11'53''.0$	2.68153	697.11292	16.15	0.019	10	
OGLE-TR-165	$13^{h}31^{m}31^{s}.55$	$-64^\circ10'51''.5$	2.89185	698.14260	16.81	0.043	9	
OGLE-TR-166	$13^{h}32^{m}23^{s}.86$	$-64^\circ10'35''.2$	5.21920	699.83984	15.31	0.011	5	
OGLE-TR-167	$13^{h}30^{m}26^{s}.30$	$-64^\circ10'09''.2$	5.26100	698.58614	15.88	0.022	4	
OGLE-TR-168	$13^{h}32^{m}12^{s}.07$	$-64^\circ32'56''.2$	3.65080	696.94702	14.13	0.013	3	
OGLE-TR-169	$13^{h}17^{m}23^{s}.43$	$-64^\circ54'54''.8$	2.76877	698.04287	16.78	0.019	13	
OGLE-TR-170	$13^{h}15^{m}14^{s}.50$	$-64^\circ49'28''.8$	4.13680	699.13261	16.62	0.026	7	
OGLE-TR-171	$13^{h}13^{m}52^{s}.00$	$-64^\circ41'30''.0$	2.09180	696.49729	17.07	0.038	9	
OGLE-TR-172	$13^{h}13^{m}12^{s}.81$	$-64^\circ47'13''.8$	1.79323	697.28151	15.33	0.006	8	
OGLE-TR-173	$13^{h}14^{m}56^{s}.11$	$-65^\circ02'00''.4$	2.60590	698.87378	14.89	0.019	4	
OGLE-TR-174	$13^{h}25^{m}58^{s}.75$	$-65^\circ14'50''.6$	3.11012	697.52261	16.50	0.016	7	
OGLE-TR-175	$13^{h}27^{m}47^{s}.31$	$-65^\circ14'34''.8$	1.48830	697.01551	16.87	0.019	11	ST
OGLE-TR-176	$13^{h}25^{m}33^{s}.73$	$-64^\circ55'34''.1$	3.40478	700.66215	15.15	0.022	5	
OGLE-TR-177	$13^{h}24^{m}48^{s}.41$	$-64^\circ51'37''.8$	5.64386	699.53686	16.79	0.038	3	

the depth of transits caused by planets transiting FG-type stars must be of the order of 10 mmag or less.

Photometric observations of the transit shape allow to derive the size of transiting companions. Unfortunately, the size alone cannot unambiguously define the type of the transiting objects. Transits can be caused by extrasolar planets or brown dwarfs or small late M-type dwarfs as all these objects can have sizes of about $R_{\rm Jup}$. To distinguish between these possibilities, radial velocity follow-up measurements are necessary to estimate masses of companions. Another important contaminator of photometrically selected transiting objects might be blending of a regular totally eclipsing star with a close optical or physically related (wide multiple system) unresolvable neighbor that can produce transit-like light curve. Therefore some of our candidates listed in Table 2 can actually be fake transits caused by blending effects.

Unfortunately, even in the clean unblended case additional information on the size of the host is necessary to derive the size of transiting body, because the depth of transit provides only the ratio of those sizes. Such additional information can come from moderate resolution spectroscopy suitable for spectral classification, IR photometry (Dreizler *et al.* 2002, Gallardo *et al.* 2004) or, in principle, from optical colors of host stars. Unfortunately, in the case of the pencil beam survey of the Galactic disk, like OGLE, significant and unknown interstellar extinction makes dereddening of optical colors of individual stars very uncertain and unreliable and thus of no use for estimation of stellar sizes.

When only single band photometry is available it is not possible to obtain actual size of the companion when the errors of individual observations are comparable to the transit depth, due to well known degeneracy between radii of the host star and the companion, R_s, R_c, inclination, i, and limb darkening, u. Photometric solutions of similar quality 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). Thus, the selection of the proper solution is practically impossible. Only the lower limit of 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 in this case also the lower limit.

In Table 3 we provide lower limits for the components radii calculated in the same manner as in Udalski *et al.* (2002abc) assuming additionally that the host star follows the mass-radius relation for main sequence stars ($R/{\rm R}_\odot = (M/{\rm M}_\odot)^{0.8}$). The resulting mass of the primary is also listed in Table 3. In practice the transits might be non-central, thus the size of the star and companion can be larger than given in Table 3. Also when the host star is evolved the estimation may be inaccurate.

The estimations of the minimum sizes of transiting companions cannot be considered as their actual dimensions as sometimes mistakenly interpreted. The final parameters of the system can only be derived when the spectroscopic observations are available. The aim of presenting Table 3 is to provide information necessary for preselection of the most promising planetary candidates from our 2003 transit sample. Objects with the estimation of the minimum radius of transiting companion larger than 0.15–0.18 $R/\mathrm{R}_\odot$ are almost certainly stellar binary systems and are marked by "ST" in the remarks column of Table 2.

Solid line in the close-up windows in the Appendix shows the transit model light curve calculated for the central passage. In most cases the central passage fit is practically indistinguishable from non-central so at this stage it is impossible to derive other values than the lower limits of radii provided in Table 3.

Because the search for transiting objects in the 2003 campaigns data was focused on planetary systems the final list contains many objects with companions for which the lower size limit is well within the planetary range. Based on the shape of transits and photometric properties one can select many very promising planetary transit candidates in our sample, for instance OGLE-TR-158, OGLE-TR-162, OGLE-TR-164, OGLE-TR-167, OGLE-TR-172, OGLE-TR-174, OGLE-TR-176. However, it cannot be excluded that other more noisy or low transit depth systems also host a planet – in such cases it is difficult to assess the real transit shape.

Results of the past OGLE transit campaigns have shown how severe a non-planetary background in the planetary transit searches can be. Very often the OGLE sample of transit stars was misinterpreted as pure "planetary" candidates whereas the inclusion of many obvious stellar companion objects was intentional as they could be very useful to derive accurate masses and sizes of stars from poorly known lower part of the main sequence (Bouchy *et al.* 2004b). Also it was clear that other contaminating cases like blending or grazing eclipses can be present in the sample. Spectroscopic follow up observations (Torres *et al.* 2004b, Torres *et al.* 2005, Bouchy *et al.* 2004b) showed that this was indeed the case. In particular, the blending turned out to be an important contaminating factor, especially in the Galactic center line-of-sight where the eclipsing stars from the Galactic bulge are very often blended with bright stars mimicking low depth transits. This was one of the reasons to switch to the much less crowded Galactic disk fields in the following OGLE campaigns.

The planetary transits have been detected so far with two different approaches – deep, narrow field surveys like OGLE and wide angle shallow surveys like TrES. The former approach is more efficient as more stars can be monitored simultaneously and allows to detect transiting planets orbiting around faint stars of 13–17 mag located at much farther distances from the Sun. On the other hand the wide field surveys can detect transiting planets around brighter stars. This is often considered as an advantage as more precise spectroscopy can be obtained, for example during the transit, for analysis of the planetary atmosphere etc. Although it is true now – in the time scale of a decade next generation >25-m telescopes will diminish this gain. On the other hand, the estimations of the number of transiting planets around bright stars available for wide angle surveys indicate very limited number of such objects in the sky (Pepper, Gould and DePoy 2003). Also, the accuracy of photometry must be well below 10 mmag to allow detection of such Jupiter-size planets transiting FG-type stars (depth of transit of about 10 mmag) from the ground. Such an accuracy is hard to achieve for wide angle small aperture telescopes. Transits of HD209458 and TrES1 have the depth of about 25 mmag – the largest of all

Table 3

Lower limits of radii of stars and companions (central passage: $i=90°$).

Name	R_s [$R_\odot$]	R_c [$R_\odot$]	M_s [$M_\odot$]
OGLE-TR-138	0.74	0.082	0.69
OGLE-TR-139	1.00	0.150	1.00
OGLE-TR-140	0.56	0.101	0.48
OGLE-TR-141	0.79	0.095	0.75
OGLE-TR-142	0.46	0.074	0.38
OGLE-TR-143	0.49	0.034	0.41
OGLE-TR-144	1.43	0.228	1.56
OGLE-TR-145	1.82	0.219	2.12
OGLE-TR-146	0.71	0.127	0.65
OGLE-TR-147	1.05	0.158	1.06
OGLE-TR-148	1.64	0.213	1.86
OGLE-TR-149	0.91	0.128	0.89
OGLE-TR-150	1.83	0.110	2.13
OGLE-TR-151	1.02	0.132	1.02
OGLE-TR-152	1.70	0.205	1.95
OGLE-TR-153	0.79	0.119	0.75
OGLE-TR-154	1.24	0.124	1.31
OGLE-TR-155	1.42	0.113	1.54
OGLE-TR-156	0.49	0.079	0.41
OGLE-TR-157	0.88	0.158	0.85
OGLE-TR-158	0.29	0.035	0.21
OGLE-TR-159	1.22	0.207	1.28
OGLE-TR-160	1.02	0.081	1.02
OGLE-TR-161	2.53	0.177	3.19
OGLE-TR-162	1.02	0.092	1.03
OGLE-TR-163	0.62	0.098	0.55
OGLE-TR-164	1.12	0.134	1.15
OGLE-TR-165	0.92	0.165	0.90
OGLE-TR-166	1.31	0.118	1.40
OGLE-TR-167	0.62	0.081	0.56
OGLE-TR-168	0.77	0.077	0.73
OGLE-TR-169	1.48	0.177	1.63
OGLE-TR-170	1.23	0.172	1.29
OGLE-TR-171	0.81	0.138	0.77
OGLE-TR-172	1.19	0.083	1.24
OGLE-TR-173	0.38	0.046	0.30
OGLE-TR-174	0.75	0.083	0.70
OGLE-TR-175	1.71	0.205	1.96
OGLE-TR-176	1.02	0.132	1.02
OGLE-TR-177	0.68	0.115	0.61

known transiting exoplanets.

Blending is the most important contaminating factor in both approaches. While in the case of the deep narrow angle survey the most likely blending scenarios are triple physically bound systems (except for the Galactic bulge line-of-sight where by chance blends dominate), by chance blending in low spatial resolution wide angle surveys is the main factor (due to small angular resolution of detectors). Additional observational tests were proposed to exclude potential blending contaminators or non-planetary cases in the photometrically selected transiting candidates. However, the most reliable tests can only be done with high resolution spectroscopy (Torres *et al.* 2005). Other methods, for example multiband photometry, can only provide weak, if any, constraints, in particular in the most important cases when the transit is of small depth below 20 mmag.

Bouchy *et al.* (2004ab) showed that the high resolution spectroscopic follow up observations of transit stars can be performed very efficiently provided the large telescope with a high resolution spectrograph can work in the multi-object mode being fed by fibers. In the cases of narrow angle surveys like OGLE, where the selected objects are located in relatively small area in the sky, spectra of many stars can be obtained simultaneously and follow up of several dozens transit stars can be made in short time providing the best observational material for full analysis of the transiting systems.

This approach seems to be the most effective and most complete. Therefore, we did not attempt to clean further our sample listed in Table 2, believing that this can be done in much more reliable way with multi-object spectroscopic follow-up observations. While it is obvious that a part of our sample will not be related to planetary companions we again remind that the discovery of brown dwarfs among our candidates would shed a new light on the so called "brown dwarf desert" problem (lack of brown dwarfs at small orbits in binary systems) and allow for the first time to precisely measure their masses and sizes. Also the mass-radius relation of the lower part of the main sequence is poorly known, thus the determination of these parameters in the case of any new low-mass stellar companion would be of great value.

7. Data Availability

The photometric data on the objects with transiting companions discovered during the 2003 OGLE-III campaigns are available in the electronic form from the OGLE archive:

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

ftp://ftp.astrouw.edu.pl/ogle/ogle3/transits/transits_2003

or its US mirror

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

ftp://bulge.princeton.edu/ogle/ogle3/transits/transits_2003

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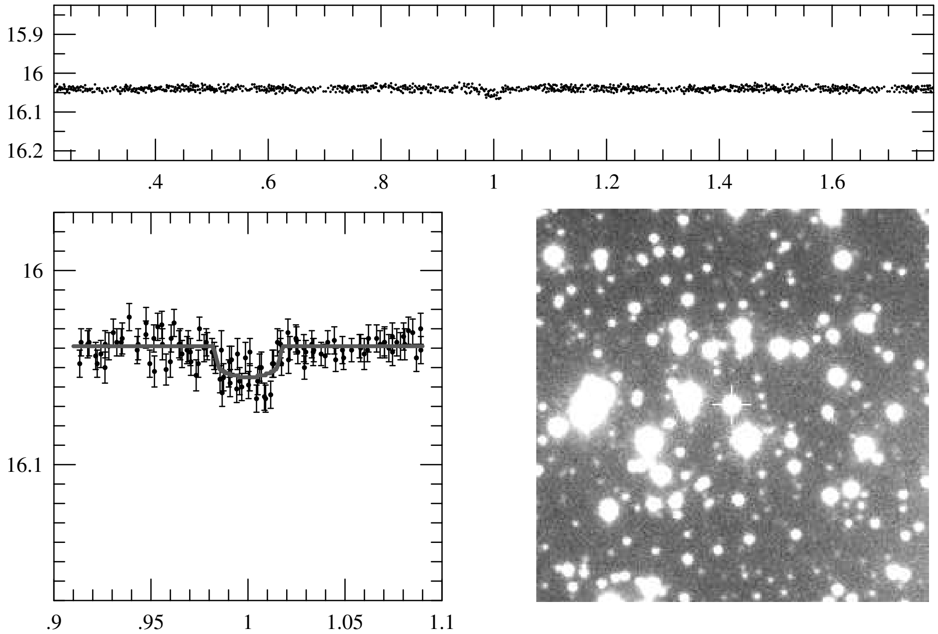
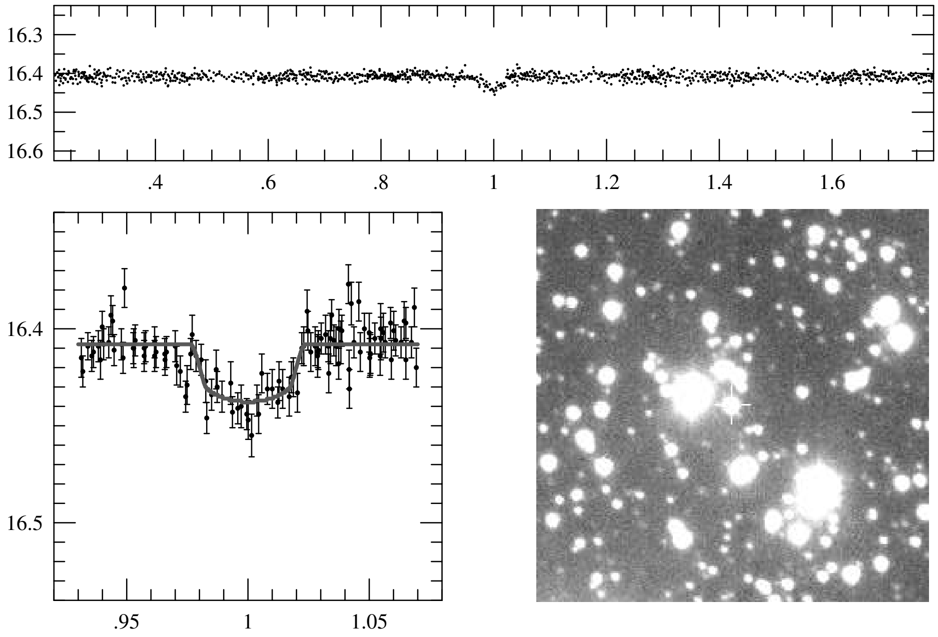
Udalski, A., Pietrzyński, G., Szymański, M., Kubiak, M., Żebruń, K., Soszyński, I., Szewczyk, O., and Wyrzykowski, Ł. 2003, *Acta Astron.*, **53**, 133.

Appendix

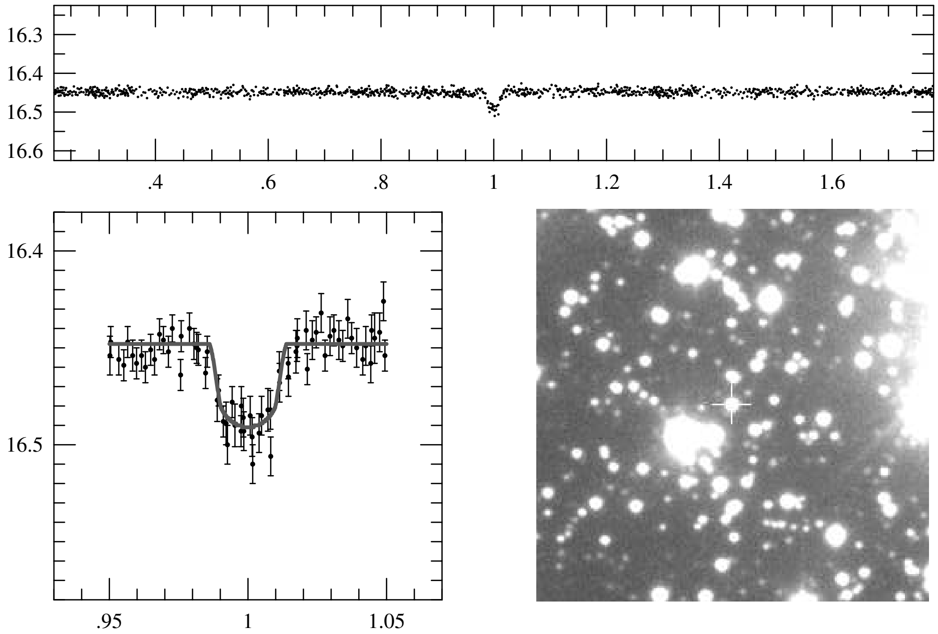
OGLE-TR-138 P=2.64550 (days)



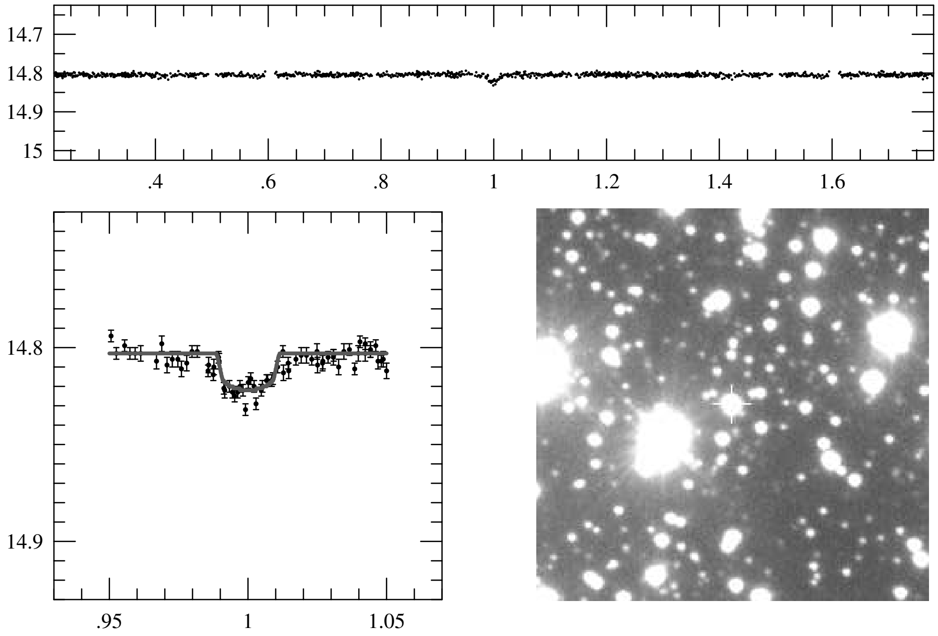
OGLE-TR-139 P=2.53420 (days)



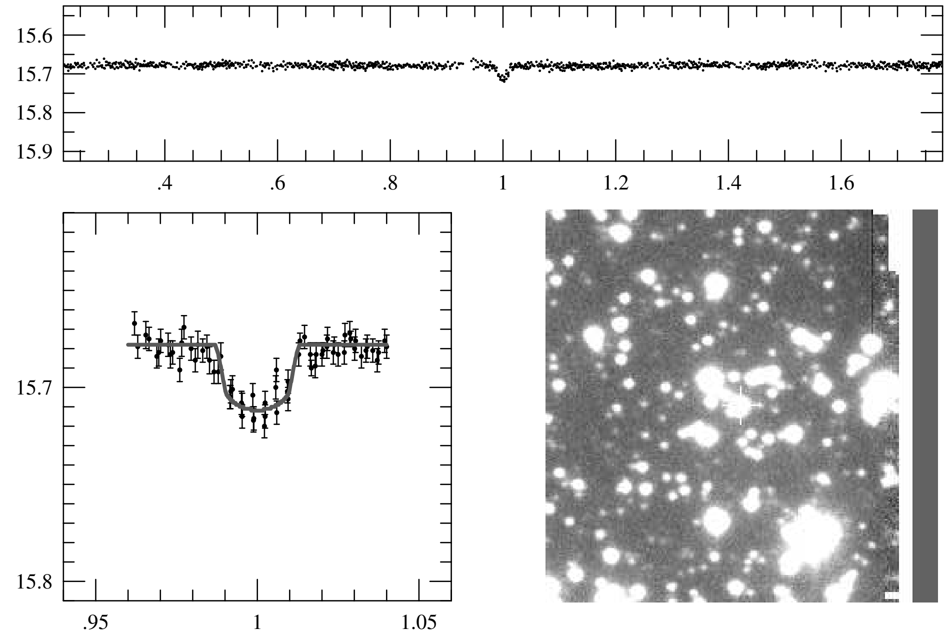
OGLE-TR-140 P=3.39330 (days)



OGLE-TR-141 P=5.67860 (days)



OGLE-TR-142 P=3.06280 (days)



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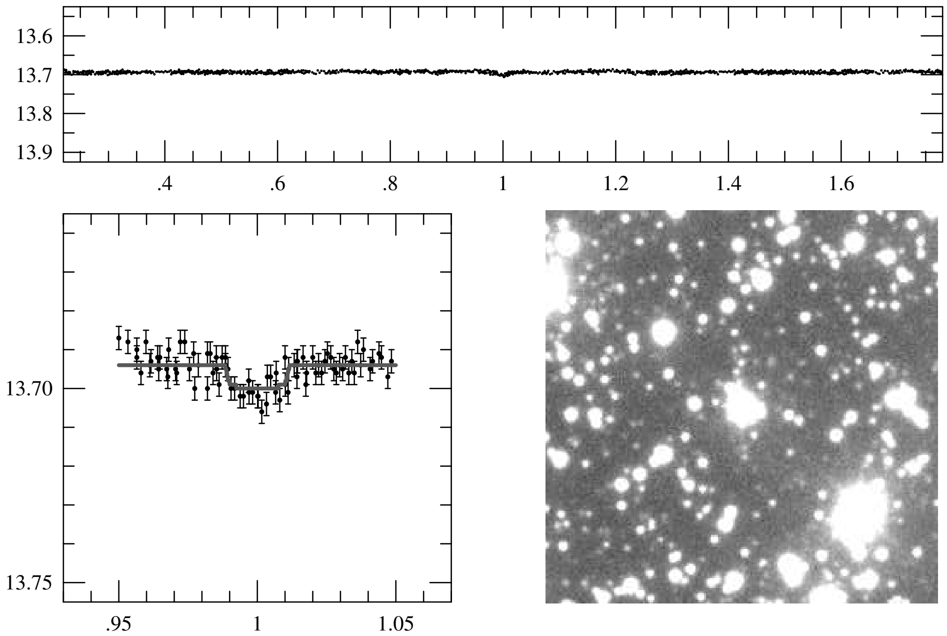

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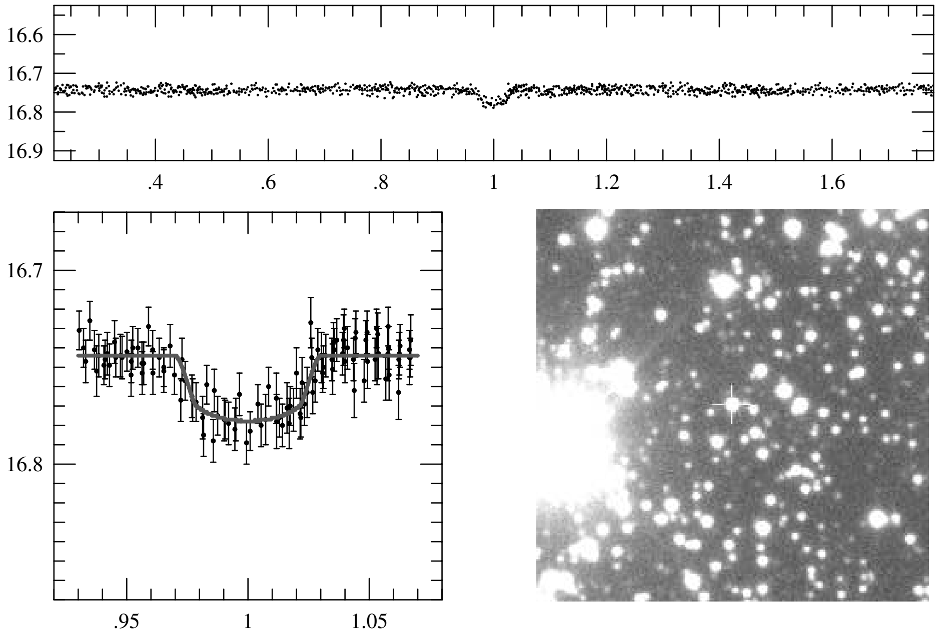

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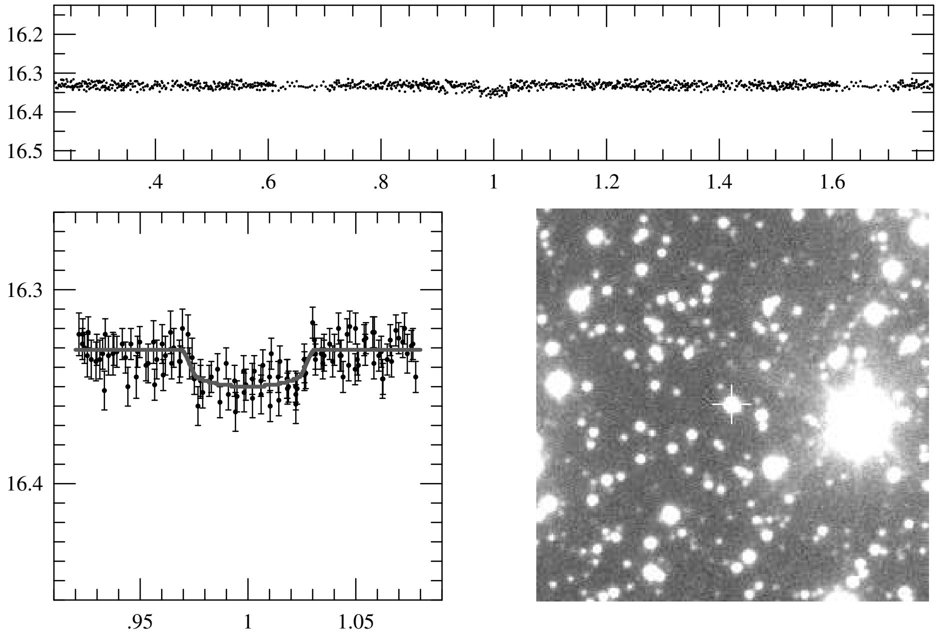

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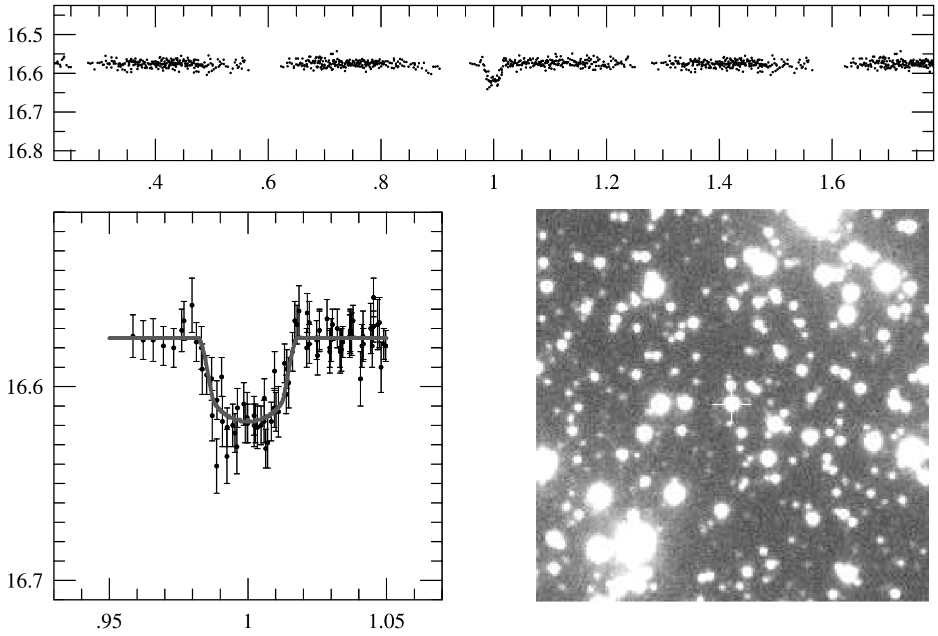
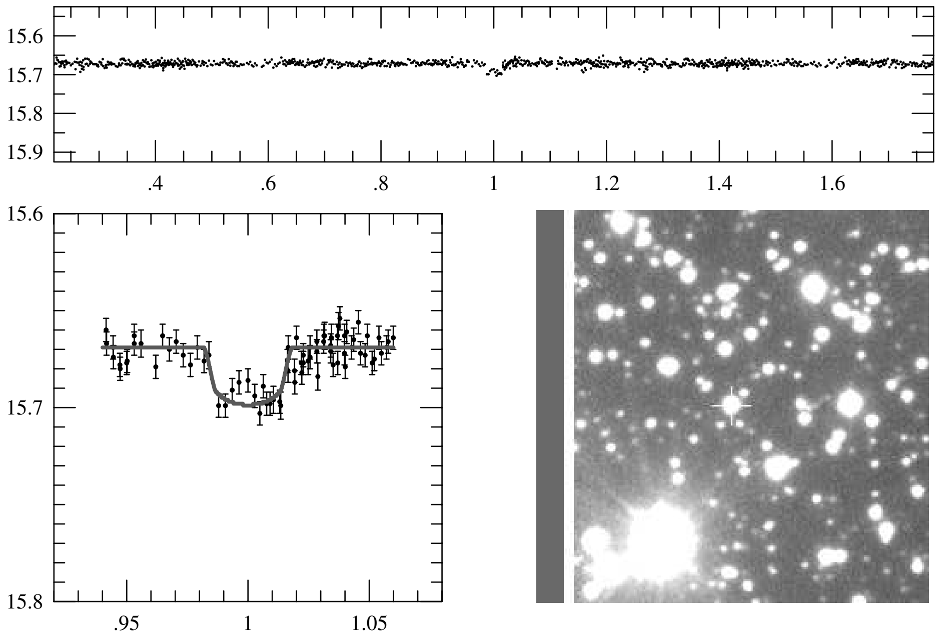
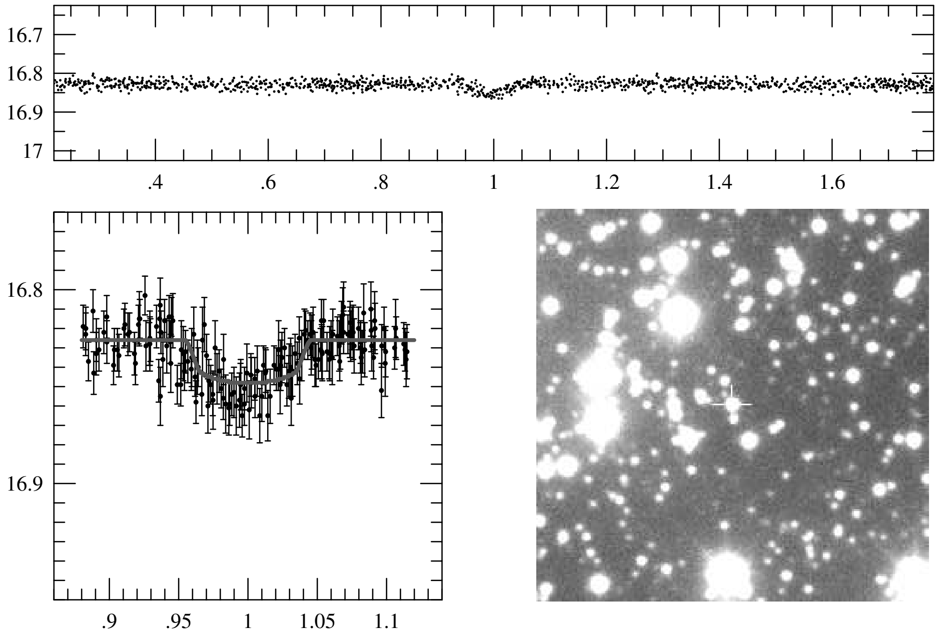


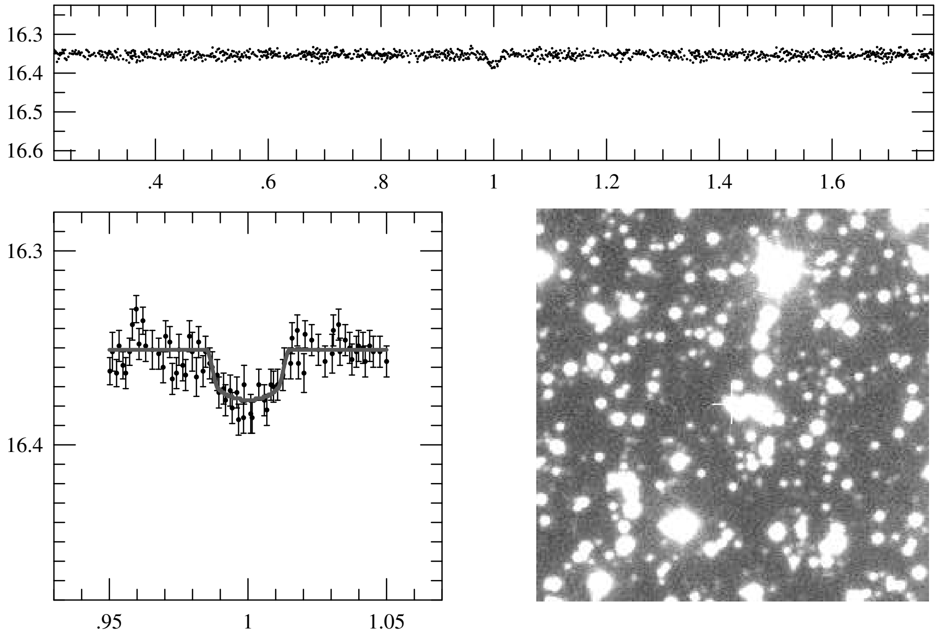
OGLE-TR-147 P=3.84170 (days)



OGLE-TR-148 P=1.43290 (days)



OGLE-TR-149 P=4.55170 (days)



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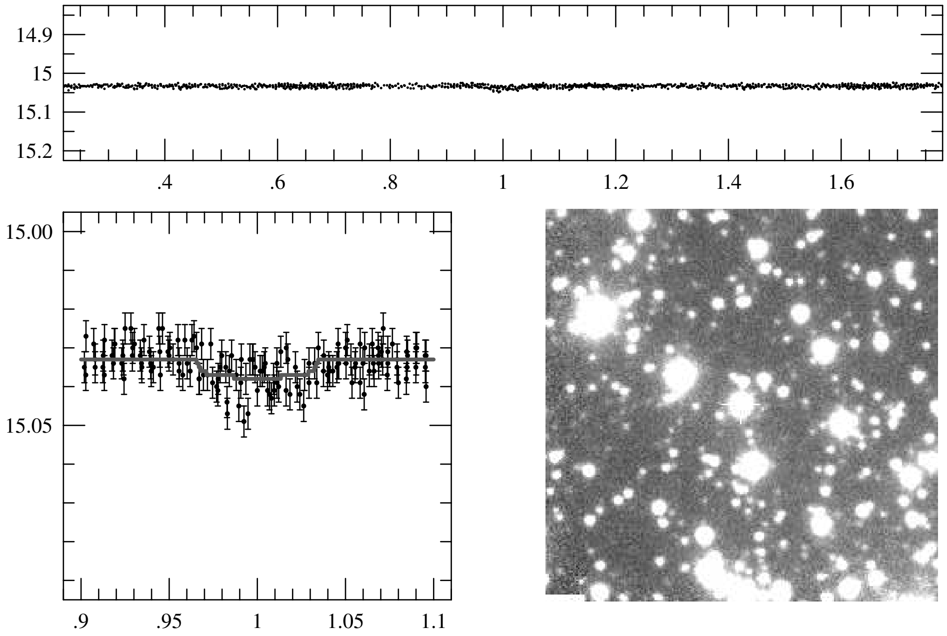
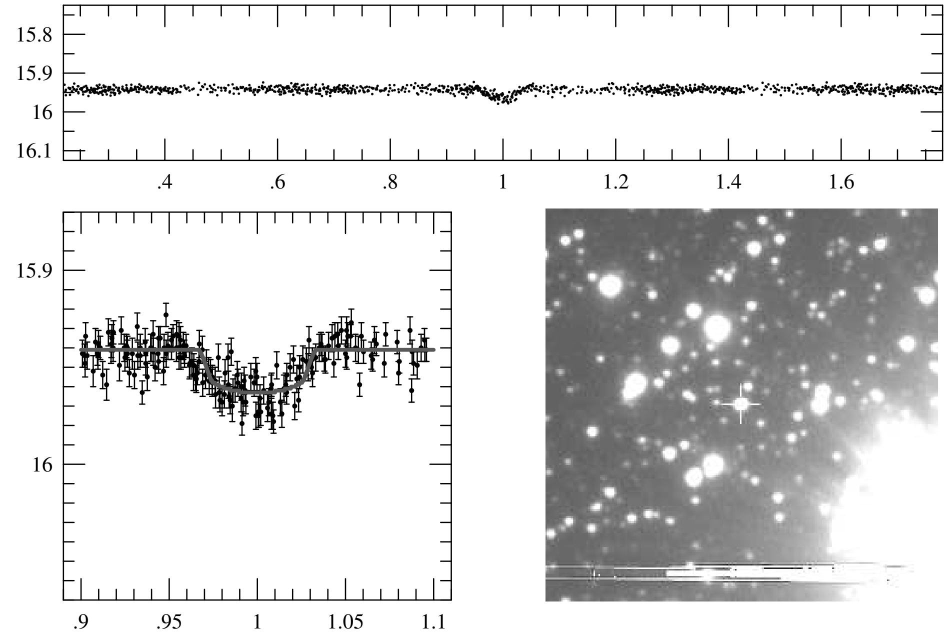
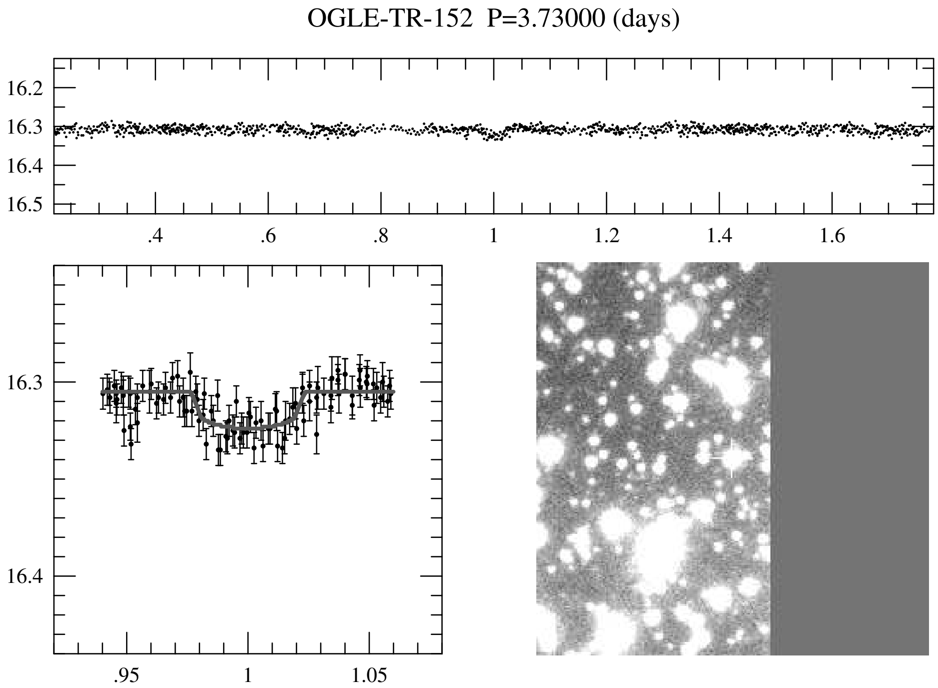
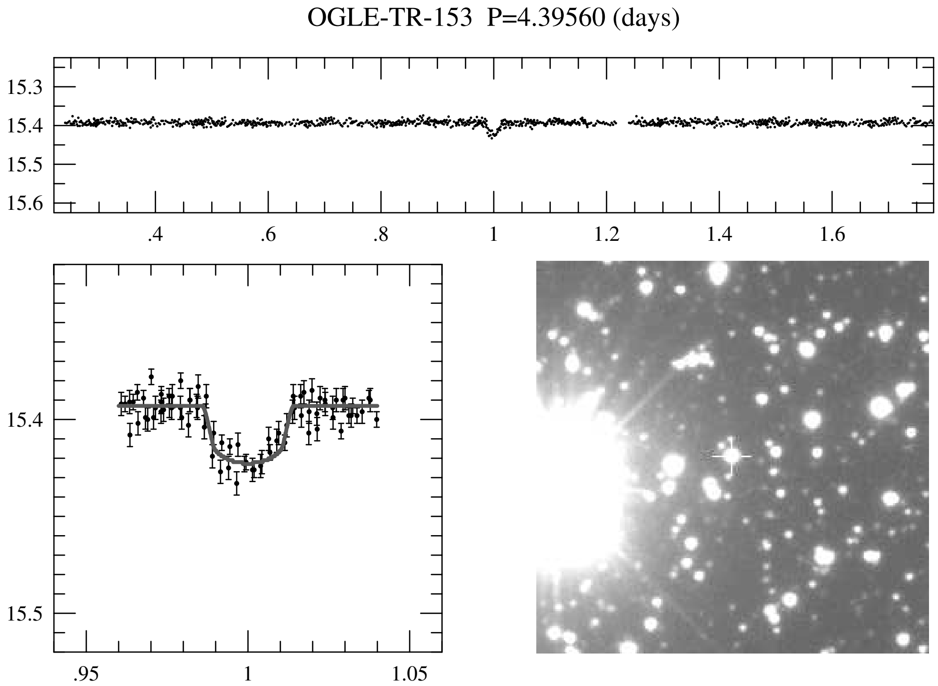


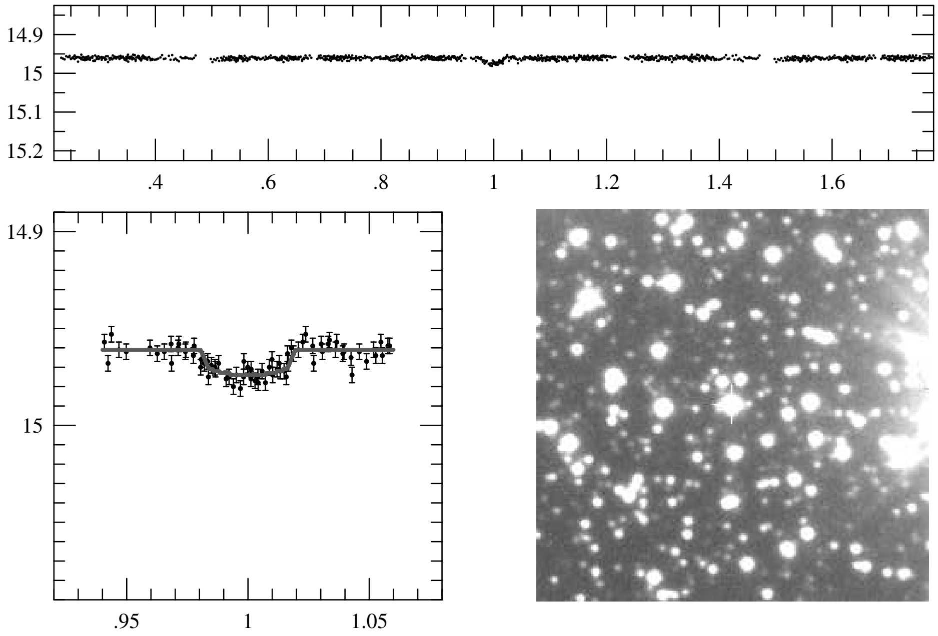
OGLE-TR-151 P=1.48350 (days)



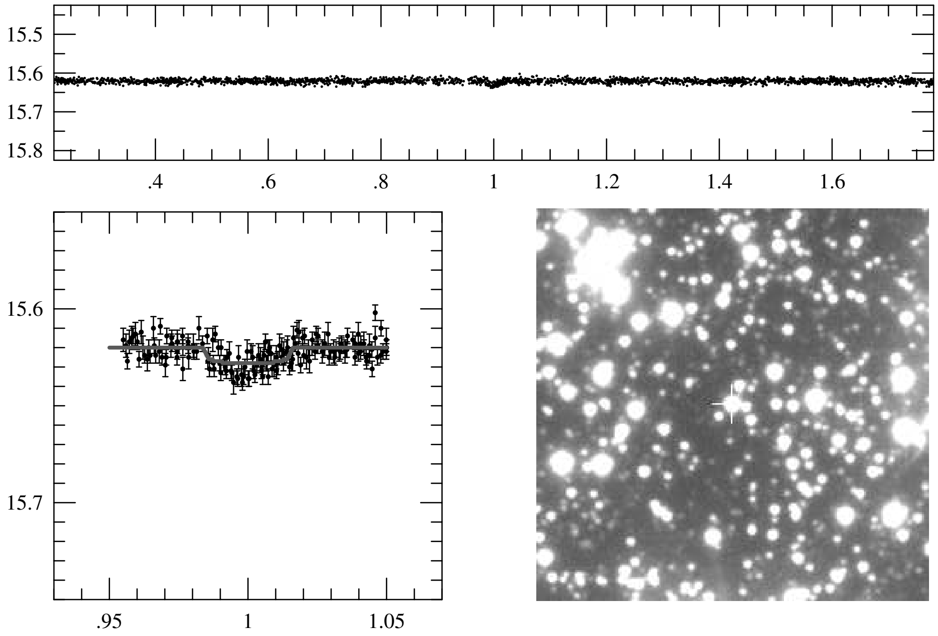

OGLE-TR-152 P=3.73000 (days)
16.2
16.3
16.4
16.5
.4
.6
.8
1
1.2
1.4
1.6
16.3
16.4
.95
1
1.05


OGLE-TR-153 P=4.39560 (days)
15.3
15.4
15.5
15.6
.4
.6
.8
1
1.2
1.4
1.6
15.4
15.5
.95
1
1.05

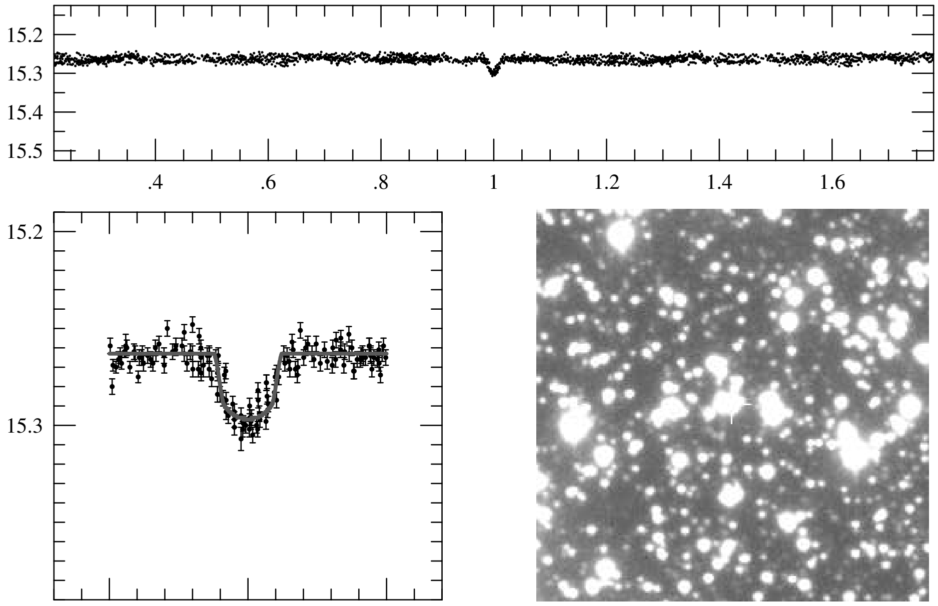
OGLE-TR-154 P=3.66946 (days)



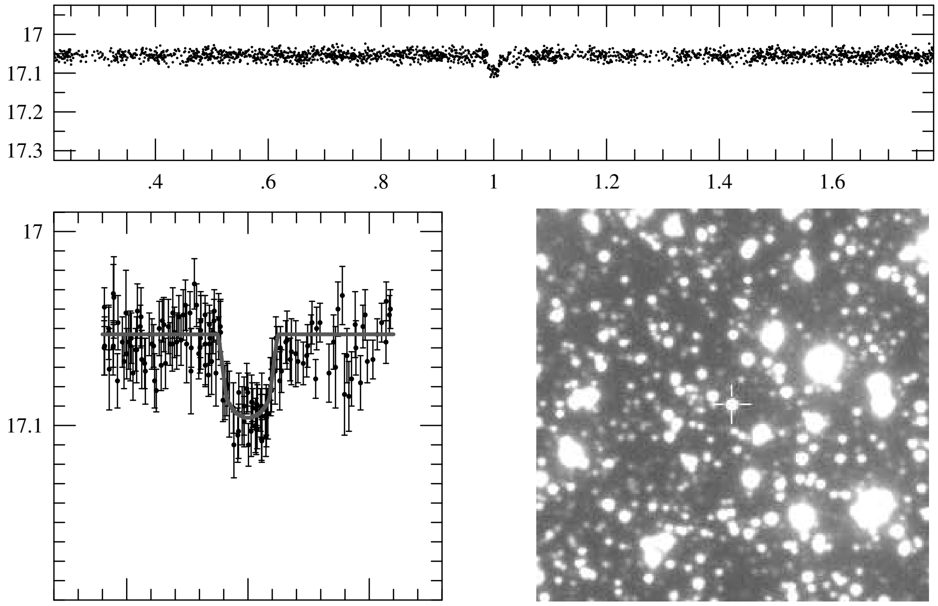
OGLE-TR-155 P=5.27700 (days)



OGLE-TR-156 P=3.58341 (days)



OGLE-TR-157 P=5.86821 (days)



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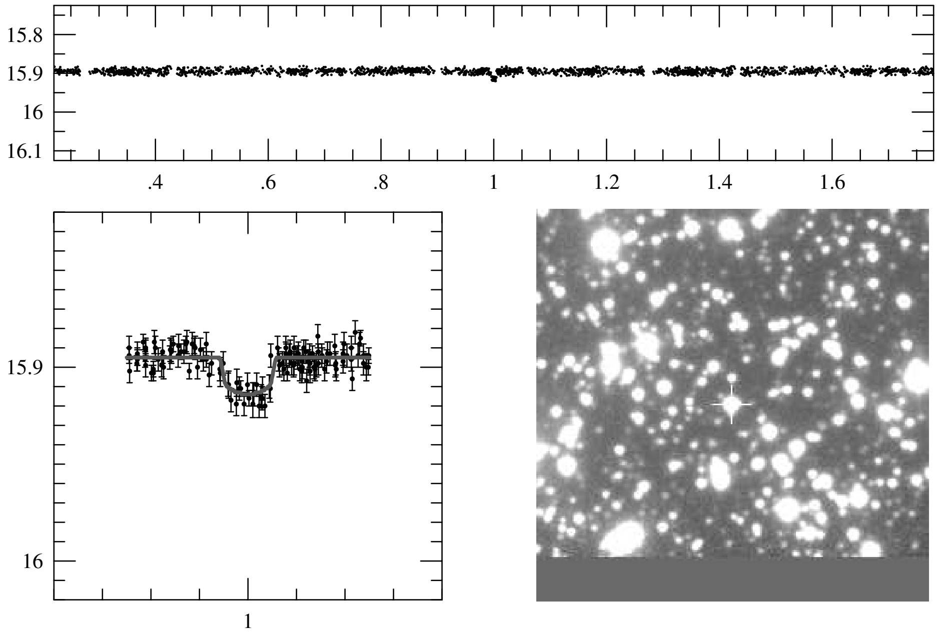

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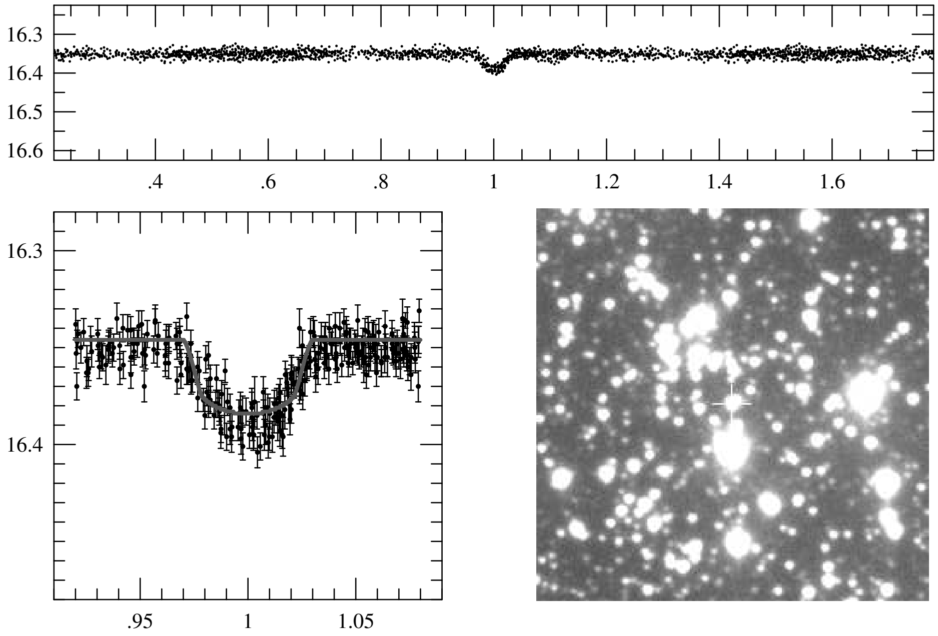
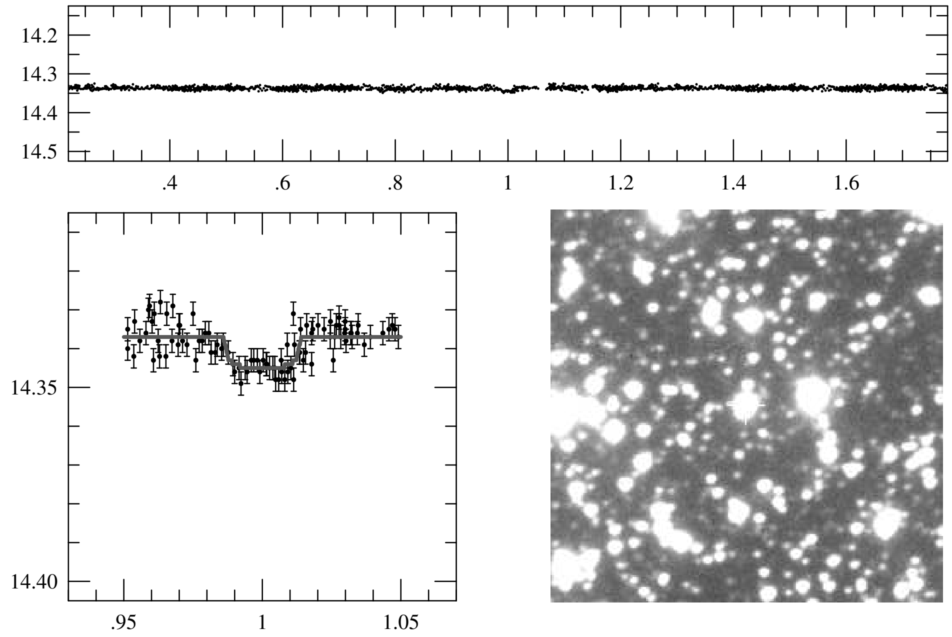
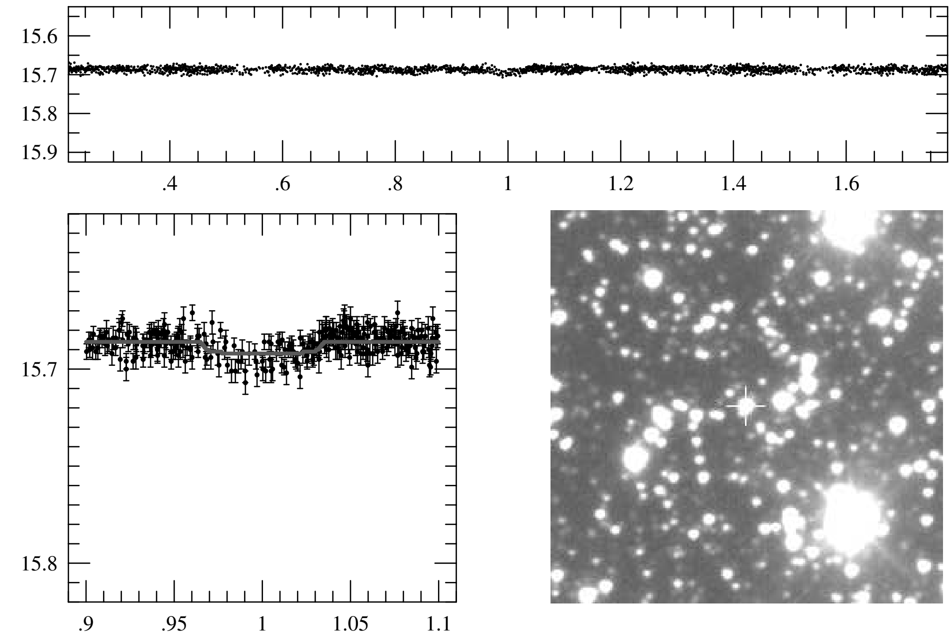


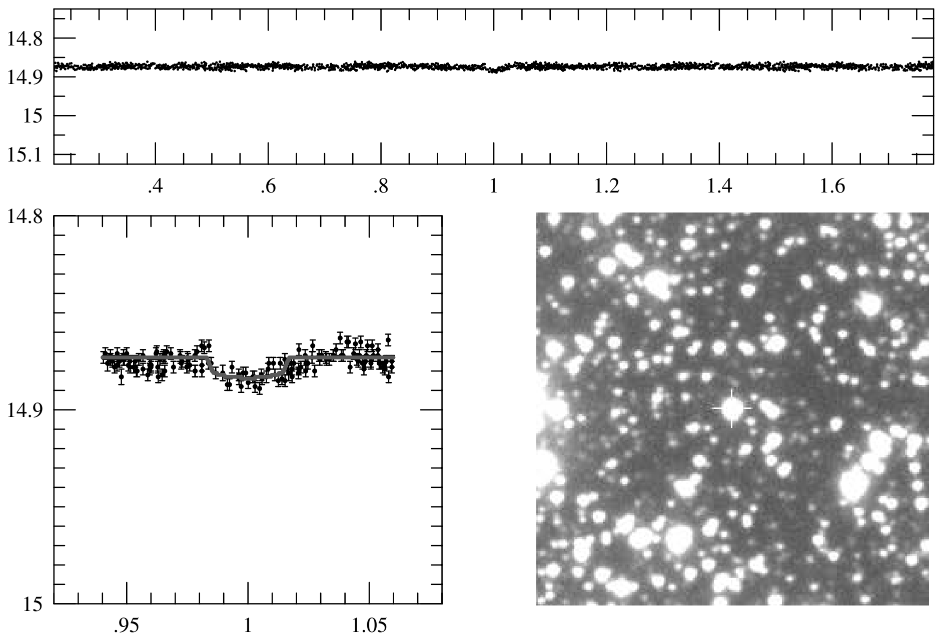
OGLE-TR-160 P=4.90185 (days)



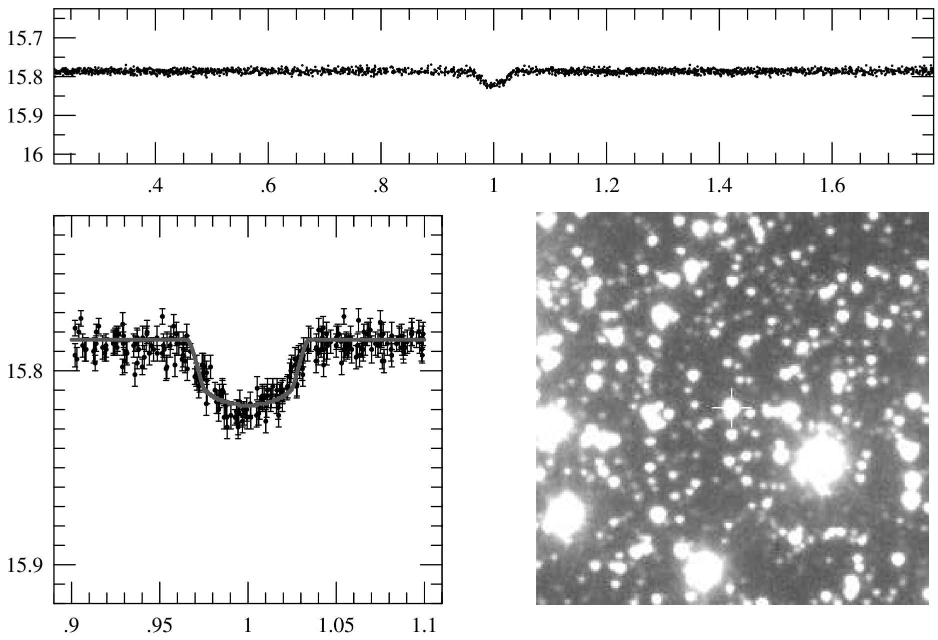
OGLE-TR-161 P=2.74730 (days)



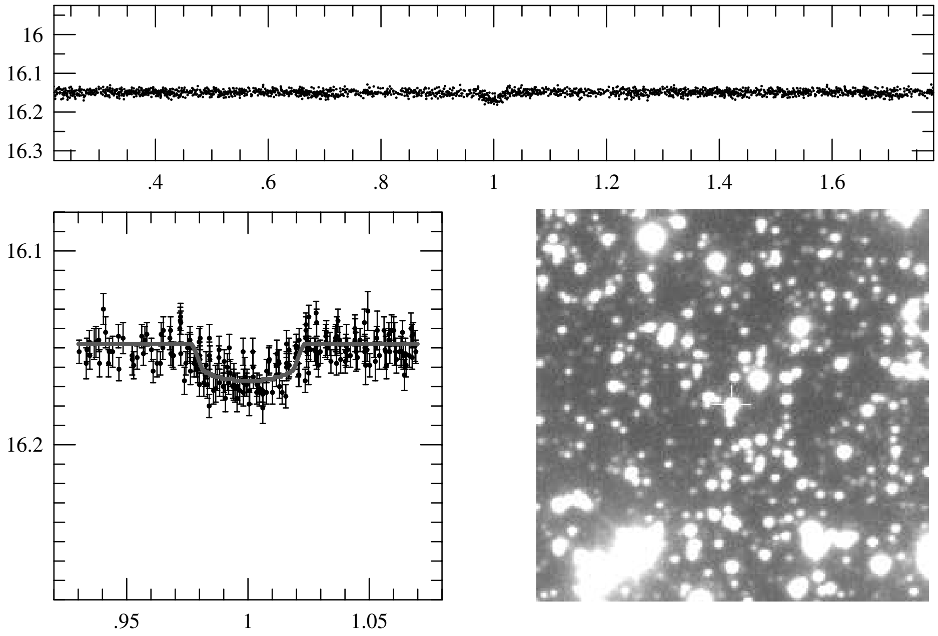
OGLE-TR-162 P=3.75819 (days)



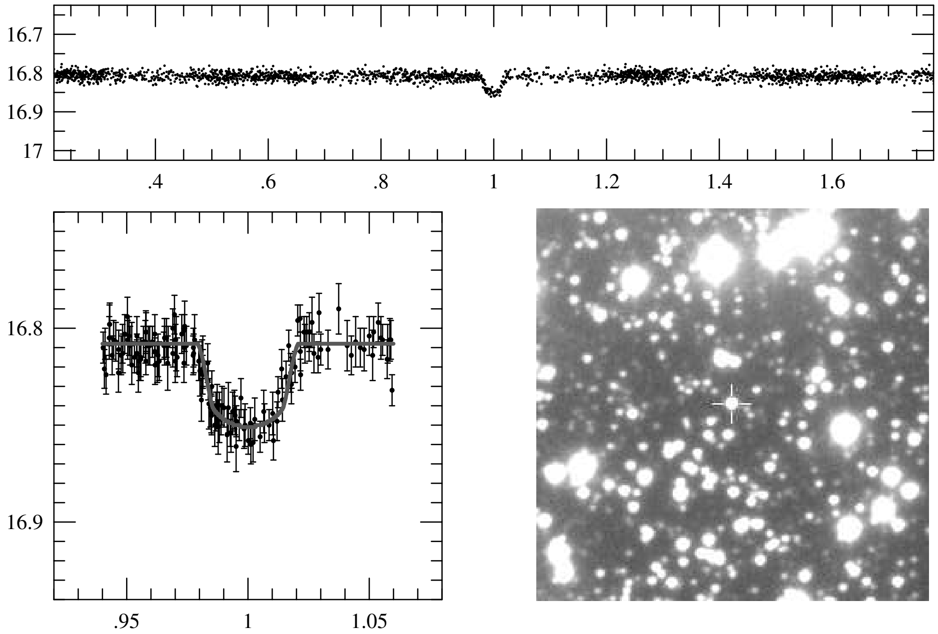
OGLE-TR-163 P=0.94621 (days)



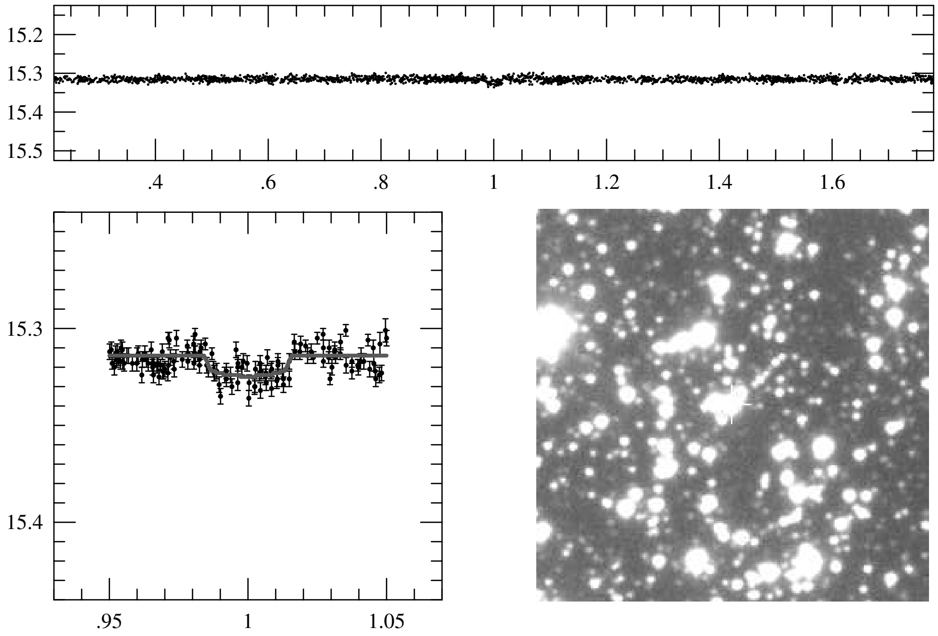
OGLE-TR-164 P=2.68153 (days)



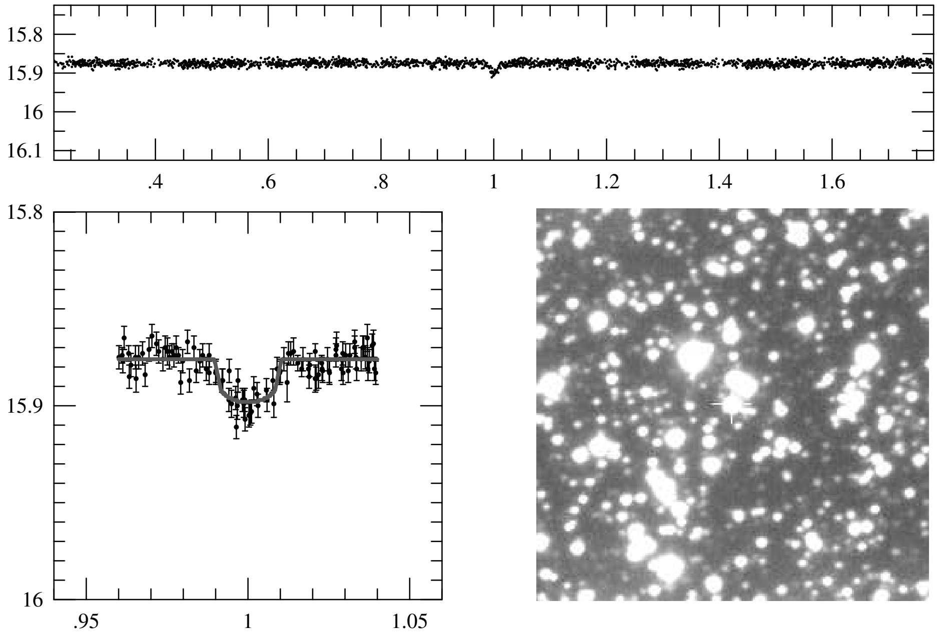
OGLE-TR-165 P=2.89185 (days)



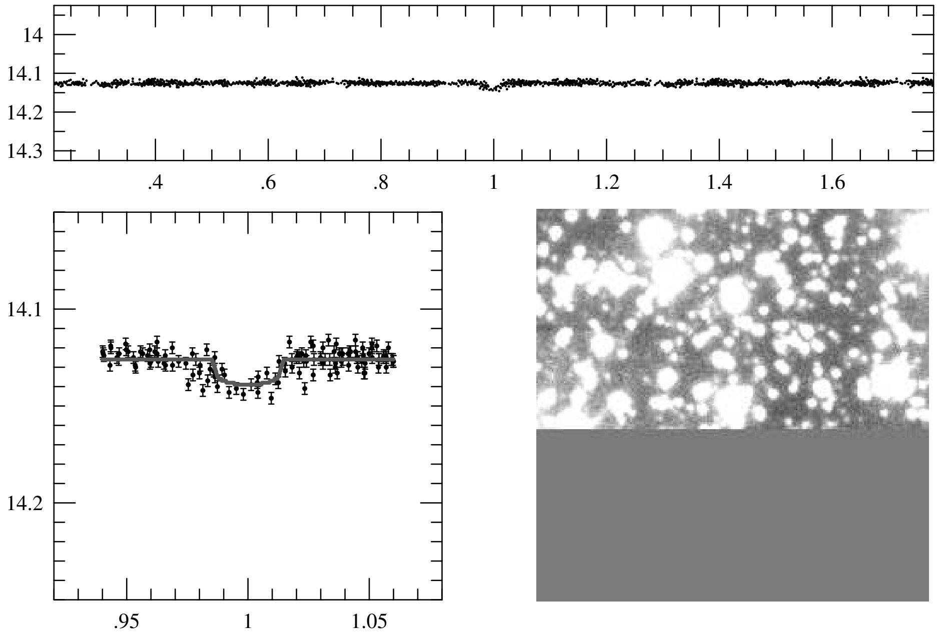
OGLE-TR-166 P=5.21920 (days)



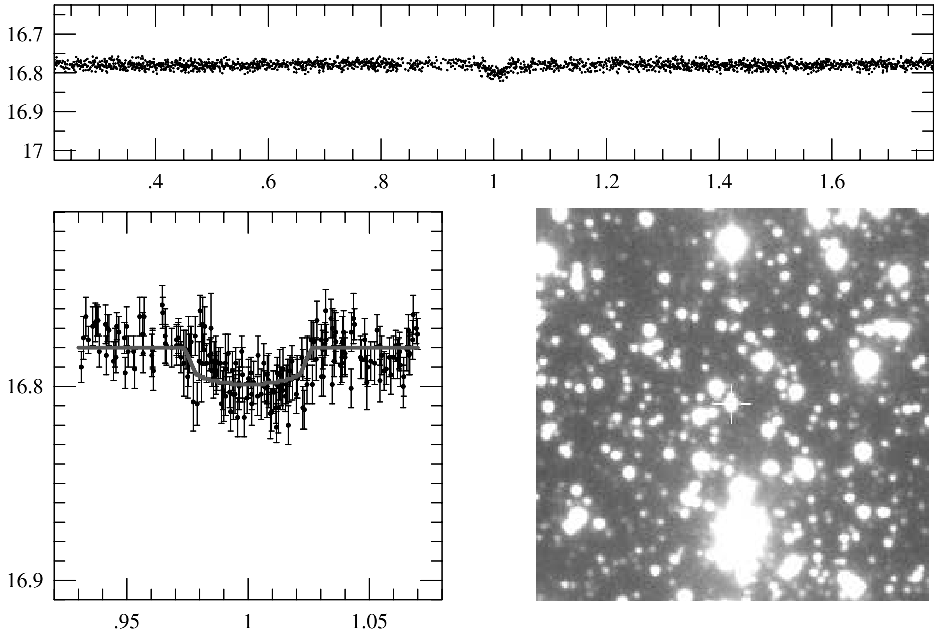
OGLE-TR-167 P=5.26100 (days)



OGLE-TR-168 P=3.65080 (days)



OGLE-TR-169 P=2.76877 (days)



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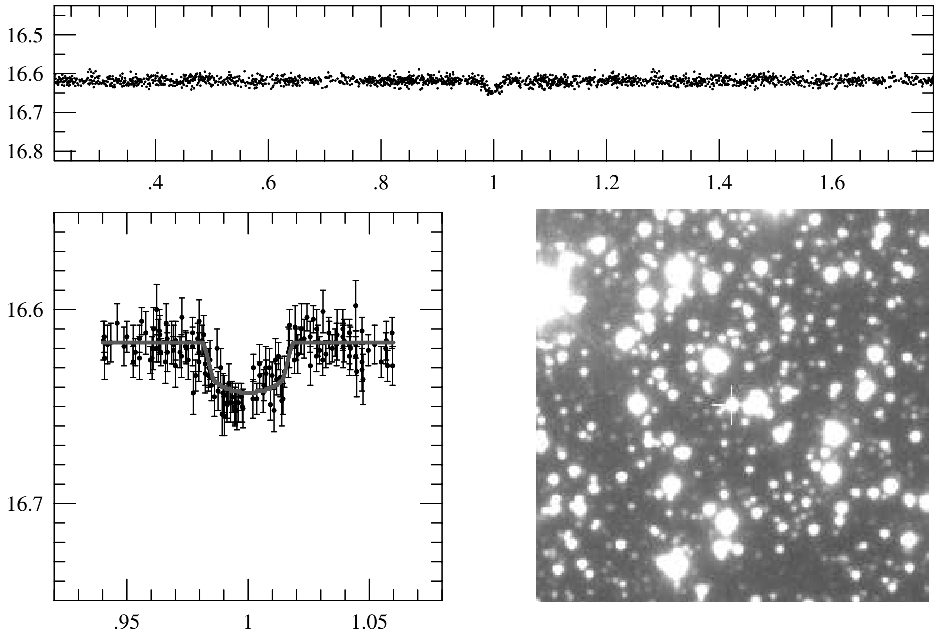

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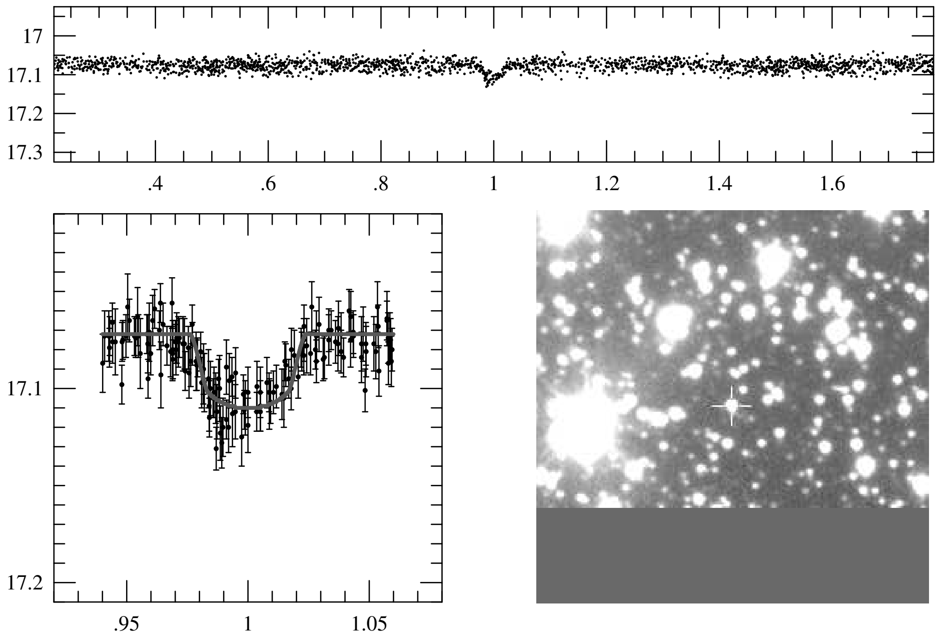
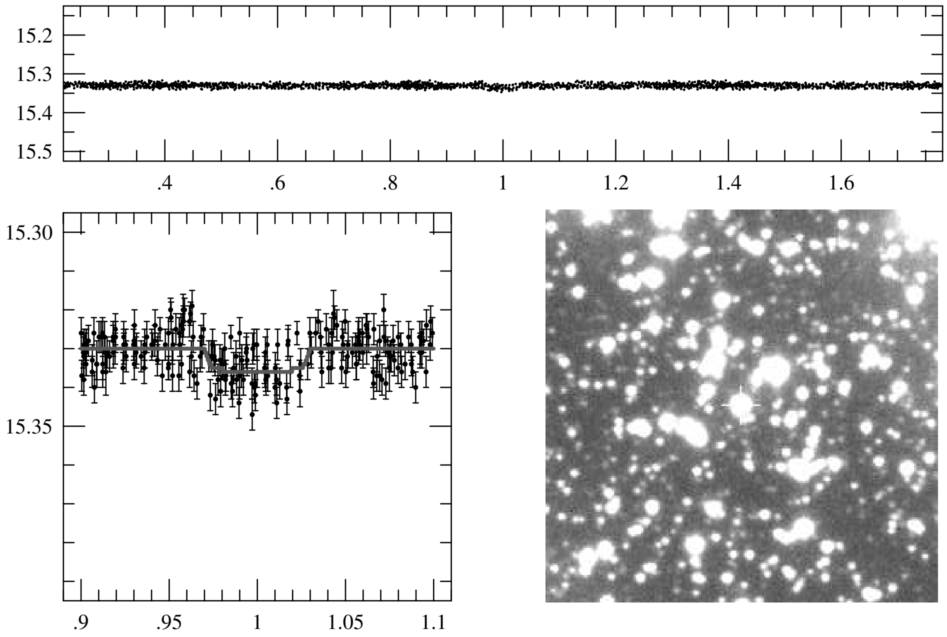


OGLE-TR-172 P=1.79323 (days)



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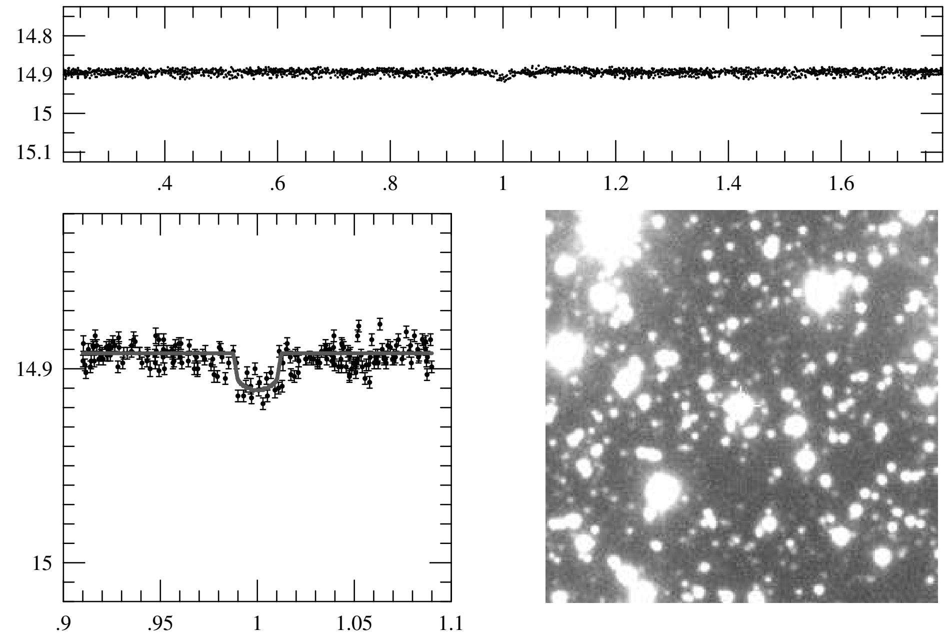

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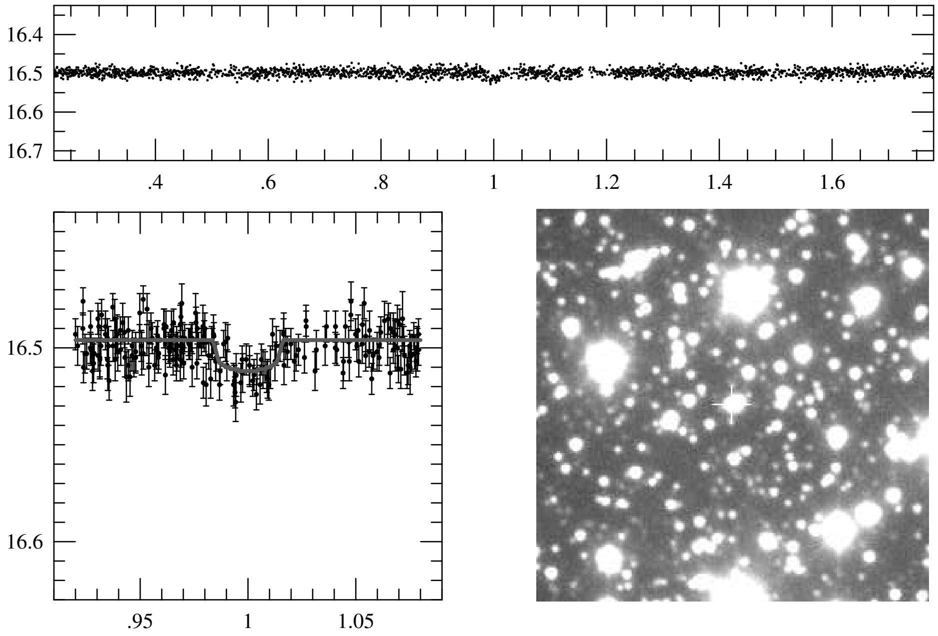
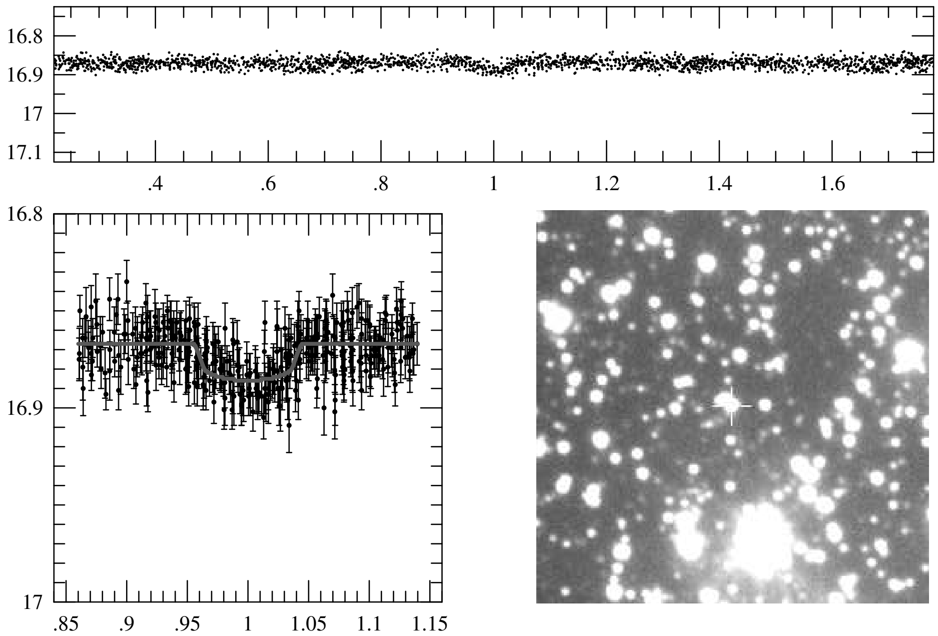
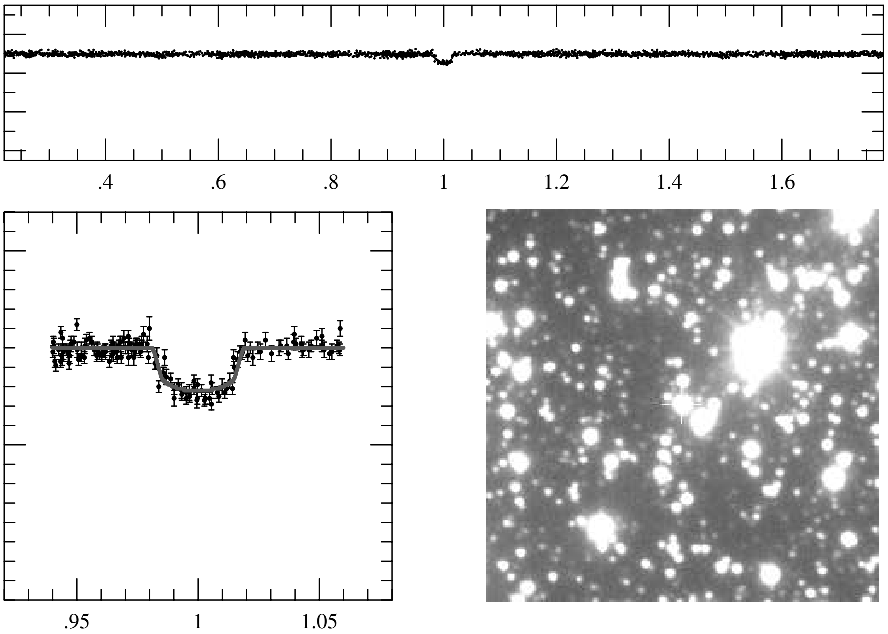


OGLE-TR-175 P=1.48830 (days)



OGLE-TR-176 P=3.40478 (days)



OGLE-TR-177 P=5.64386 (days)