ACTA ASTRONOMICA
Vol. **65** (2015) pp. 63–79

A Low-Resolution Spectroscopic Exploration of Puzzling OGLE Variable Stars*

P. Pietrukowicz[1], M. Latour[2], R. Angeloni[3], F. di Mille[4], I. Soszyński[1], A. Udalski[1] and C. Germanà[5]

[1] Warsaw University Observatory, Al. Ujazdowskie 4, 00-478 Warszawa, Poland
e-mail: pietruk@astrouw.edu.pl
[2] Dr. Karl Remeis-Observatory & ECAP, Astronomical Institute, Friedrich-Alexander University Erlangen-Nuremberg, Sternwartstrasse 7, D-96049 Bamberg, Germany
[3] Gemini Observatory, Casilla 603, La Serena, Chile
[4] Las Campanas Observatory, Casilla 601, La Serena, Chile
[5] Departamento de Física, Universidade Federal do Maranhão, São Luís, MA, Brazil

Received March 11, 2015

ABSTRACT

We present the results of a spectroscopic follow-up of various puzzling variable objects detected in the OGLE-III Galactic disk and bulge fields. The sample includes mainly short-period multi-mode pulsating stars that could not have been unambiguously classified as either δ Sct or β Cep type stars based on photometric data only, also stars with irregular fluctuations mimicking cataclysmic variables and stars with dusty shells, and periodic variables displaying brightenings in their light curves that last for more than half of the period. The obtained low-resolution spectra show that all observed short-period pulsators are of δ Sct type, the stars with irregular fluctuations are young stellar objects, and the objects with regular brightenings are A type stars or very likely Ap stars with strong magnetic field responsible for the presence of bright caps around magnetic poles on their surface. We also took spectra of objects designated OGLE-GD-DSCT-0058 and OGLE-GD-CEP-0013. An estimated effective temperature of 33 000 K in OGLE-GD-DSCT-0058 indicates that it cannot be a δ Sct type variable. This very short-period (0.01962 d) high-amplitude (0.24 mag in the *I*-band) object remains a mystery. It may represent a new class of variable stars. The spectrum of OGLE-GD-CEP-0013 confirms that this is a classical Cepheid despite a peculiar shape of its light curve. The presented results will help in proper classification of variable objects in the OGLE Galaxy Variability Survey.

Key words: *Stars: variables: Cepheids – Stars: variables: delta Scuti – Stars: variables: T Tauri, Herbig Ae/Be – Stars: peculiar*

1. Introduction

The Optical Gravitational Lensing Experiment (OGLE) is a long-term large-scale sky variability survey conducted at Las Campanas Observatory, Chile. It

*Based on observations obtained with the 2.5-m Irénée du Pont telescope at the Las Campanas Observatory of the Carnegie Institution for Science under the CNTAC program CN2014A-65.

started in 1992 with the prime aim of searches for microlensing events in dense stellar regions of the Galactic bulge (Udalski *et al.* 1992). In 1997 the project entered the second phase (OGLE-II) with the beginning of operation of the dedicated 1.3-m Warsaw Telescope. An upgrade from a single-chip camera to a 8-chip mosaic camera started its third phase (OGLE-III) in 2001, which lasted until 2009 (Udalski 2003). Since March 2010 the project is in its fourth phase. The OGLE-IV camera consists of 32 chips and has a field of view of about 1.4 deg^2. Currently, OGLE measures brightness in the *I*- and *V*-bands of over a billion stars of the Galactic bulge and disk and the Magellanic System, covering a total area of about 3000 deg^2 of the sky (see Udalski, Szymański and Szymański 2015 for details).

Regular observations conducted for many years allow finding and exploring the variety of variable objects (*e.g.*, Soszyński *et al.* 2008, 2013, 2014, Poleski *et al.* 2010, Mróz *et al.* 2013, Pietrukowicz *et al.* 2013a). However, for some variables the obtained photometry is insufficient to properly classify the objects or even explain their nature. It happens sometimes in the case of Milky Way stars with unknown distance and reddening. For this reason we have conducted a spectroscopic follow-up of selected puzzling objects detected in the OGLE-III fields toward the Galactic disk and bulge. Among the targets are pulsating stars that could not have been properly classified based on photometry only (Pietrukowicz *et al.* 2013b). Another group is formed of variables showing irregular fluctuations up to 2.0 mag in their light curves. We also took spectra of several periodic variables (periods of a few days) that exhibit brightenings or waves lasting for more than half of the period.

2. Spectroscopic Observations and Reductions

The spectra were obtained with the 2.5-m Irénée du Pont telescope at Las Campanas Observatory on two nights, April 27/28 and April 28/29, 2014. The observatory is operated by the Carnegie Institution for Science. We used the Boller and Chivens spectrograph with the lowest grating of 300 line/mm giving a resolution of 3.0 Å/pixel with a wavelength coverage of about 6200 Å. The spatial scale on the du Pont telescope is 0.70 arcsec/pixel and the slit length 271″. The two observing nights were generally clear with some cirrus clouds at the end of the second one. For the first seven hours of the night we took spectra of stars in the OGLE-III Galactic disk fields while for the last three hours selected stars in the OGLE-III bulge area. Since all targets are relatively faint objects located in dense fields, special care was taken to precise pointing of the instrument and aligning the slit. For the majority of observations the slit was aligned at the parallactic angle to avoid light loss due differential refraction, but in several cases we had to set a different angle to avoid contamination from neighboring stars. The observed variable stars are listed in Table 1, in which we give information on coordinates, average brightness, exposure times, and the reason of taking the spectrum. For each program

Table 1

OGLE variable stars for which spectra were obtained

ID or name	RA(2000)	Dec(2000)	$\langle V\rangle$ [mag]	$\langle I\rangle$ [mag]	$A_{1,I}$ [mag]	P_1 [d]	P_2 [d]	P_3 [d]	$t_{\rm exp}$ [s]	Puzzle
CAR118.5.9107	$10^{h}36^{m}24^{s}\!.80$	$-63^\circ09'03''\!.3$	16.66	15.90	0.115	0.12655899(9)	0.1229418(5)	0.0735669(4)*	3×600	δ Sct or β Cep?
CAR116.5.7705	$10^{h}36^{m}27^{s}\!.08$	$-62^\circ35'08''\!.1$	15.93	15.05	0.048	0.1192127(2)	0.1670429(12)	0.198133(2)*	2×750	δ Sct or β Cep?
CAR116.2.30884	$10^{h}37^{m}43^{s}\!.31$	$-62^\circ46'50''\!.9$	15.08	14.55	0.046	0.05203784(5)	0.05318510(7)	0.05106081(5)	2×480	δ Sct or β Cep?
CAR115.6.12025	$10^{h}38^{m}51^{s}\!.55$	$-62^\circ04'49''\!.6$	14.25	13.56	0.049	0.1854823(8)	0.1847128(6)	0.1812189(4)*	2×180	δ Sct or β Cep?
CAR118.4.1153	$10^{h}39^{m}00^{s}\!.95$	$-63^\circ11'04''\!.0$	15.11	14.27	0.043	0.1670464(4)	0.1595196(8)	0.1709402(8)*	2×480	δ Sct or β Cep?
CAR110.7.13663	$10^{h}40^{m}31^{s}\!.51$	$-61^\circ39'58''\!.0$	14.67	13.90	0.032	0.1053973(5)	0.1164492(10)	0.1266376(13)*	2×300	δ Sct or β Cep?
CEN106.6.8162	$11^{h}31^{m}35^{s}\!.92$	$-60^\circ47'45''\!.1$	14.94	14.13	0.025	0.140374(11)	0.135072(7)	0.14592(3)*	3×150	δ Sct or β Cep?
CEN106.2.38514	$11^{h}33^{m}28^{s}\!.13$	$-60^\circ53'44''\!.1$	15.80	14.80	0.036	0.133966(8)	0.138426(9)	0.130682(10)	3×300	δ Sct or β Cep?
CEN107.2.26501	$11^{h}55^{m}39^{s}\!.22$	$-62^\circ05'11''\!.6$	14.87	14.09	0.028	0.116041(7)	0.0624465(12)	0.12649(3)*	3×300	δ Sct or β Cep?
CEN107.4.32037	$11^{h}56^{m}12^{s}\!.94$	$-61^\circ47'44''\!.7$	14.96	13.96	0.037	0.104286(6)	0.107450(5)	0.169142(17)*	3×300	δ Sct or β Cep?
CEN108.6.93566	$13^{h}31^{m}32^{s}\!.10$	$-64^\circ06'46''\!.4$	16.28	15.05	0.021	0.08542011(4)	0.2138035(6)	0.08542535(15)	2×900	δ Sct or β Cep?
CEN108.4.43244	$13^{h}34^{m}43^{s}\!.73$	$-64^\circ02'48''\!.1$	16.30	15.06	0.074	0.12975290(2)	0.1648194(2)	0.14203803(16)*	2×900	δ Sct or β Cep?
MUS101.3.34906	$13^{h}26^{m}16^{s}\!.46$	$-64^\circ55'40''\!.0$	16.71	15.60	0.104	0.14610250(1)	0.11689411(5)	0.09741818(13)*	2×900	δ Sct?
OGLE-GD-DSCT-0012	$10^{h}42^{m}51^{s}\!.62$	$-61^\circ35'21''\!.4$	14.17	13.69	0.060	0.1674796(13)	0.1315341(11)	0.1323302(9)*	3×120	δ Sct?
OGLE-GD-DSCT-0058	$10^{h}41^{m}48^{s}\!.77$	$-61^\circ25'08''\!.5$	17.71	17.22	0.231	0.01962154(1)	0.01891531(4)	0.02038256(6)	3×600	δ Sct?
OGLE-GD-CEP-0013	$11^{h}33^{m}02^{s}\!.68$	$-60^\circ52'04''\!.5$	16.73	15.11	0.293	5.2436(9)	–	–	3×600	δ Cep?
CAR117.5.6157	$10^{h}41^{m}12^{s}\!.18$	$-62^\circ33'42''\!.6$	18.05	16.75	1.35	–	–	–	2×1800	CV or dusty?
MUS100.3.59946	$13^{h}16^{m}20^{s}\!.52$	$-64^\circ44'55''\!.0$	16.27	15.25	0.48	–	–	–	2×900	dusty?
BLG179.1.111115	$17^{h}50^{m}29^{s}\!.48$	$-30^\circ50'18''\!.1$	18.17	15.26	2.10	–	–	–	2×1800	dusty?
CAR106.7.14162	$11^{h}00^{m}40^{s}\!.09$	$-61^\circ54'49''\!.3$	15.08	14.38	0.14	3.20182(6)	–	–	2×900	magnetic?
CAR106.7.46218	$11^{h}01^{m}26^{s}\!.94$	$-61^\circ51'02''\!.2$	15.61	15.12	0.207	5.21579(3)	–	–	2×900	magnetic?
BLG130.2.137067	$17^{h}47^{m}44^{s}\!.92$	$-34^\circ16'15''\!.2$	13.72	13.01	0.063	6.59504(9)	–	–	2×600	magnetic?
BLG183.4.156561	$18^{h}01^{m}43^{s}\!.65$	$-30^\circ24'54''\!.0$	14.36	13.70	0.055	1.524444(5)	–	–	2×600	magnetic?
BLG249.1.133775	$18^{h}06^{m}07^{s}\!.50$	$-26^\circ05'08''\!.5$	13.91	13.08	0.075	3.77762(4)	–	–	2×600	magnetic?
OGLE-GD-DSCT-0011	$10^{h}42^{m}45^{s}\!.67$	$-61^\circ35'37''\!.2$	14.60	13.93	0.303	0.11309448(3)	–	–	3×100	δ Sct
ASAS111308-6106.8	$11^{h}13^{m}07^{s}\!.29$	$-61^\circ06'50''\!.0$	9.53	9.20	0.033	0.1931041(15)	–	–	2×30	β Cep

The group of candidate pulsating variables is followed by a group of variables with irregular light variations and periodic variables with waves in their light curves. The last two objects are *bona fide* δ Sct and β Cep type pulsators which spectra served for comparison. Asterisks in the column with P_3 denote stars in which more than three modes were detected (Pietrukowicz *et al.* 2013b).

star we took two or three exposures and one 90-s Ne-He-Ar lamp exposure in between for the wavelength calibrations. Additional calibration images included bias and dome flat-field images, and spectra of flux standards.

Table 2

Equivalent widths (in Å) of some lines in the spectra of puzzling variables

ID or name	CaIIK 3934	CaIIH+Hε 3968	Hγ 4102	Hδ 4340	G band 4307	Sp. type
CAR118.5.9107	5.7	7.8	6.4	5.6		F0
CAR116.5.7705	6.5	7.6	5.4	5.7		F0
CAR116.2.30884	3.6	8.9	9.5	10.1		A5
CAR115.6.12025	6.1	8.6	7.1	8.1		F0
CAR118.4.1153	5.9	7.9	5.7	5.7		F0
CAR110.7.13663	6.4	8.2	6.1	6.8		F0
CEN106.6.8162	5.2	8.2	5.3	7.4		F0
CEN106.2.38514	3.6	6.7	4.6	5.7		A7
CEN107.2.26501	5.7	8.4	7.0	8.8		F0
CEN107.4.32037	7.7	8.6	6.6	6.6		F2
CEN108.6.93566	5.0	8.7	6.3	7.5		F0
CEN108.4.43244	6.0	9.7	9.2	10.0		F0
MUS101.3.34906	3.5	7.1	7.0	7.6		A7
OGLE-GD-DSCT-0012	5.4	8.5	7.1	7.3		F0
OGLE-GD-DSCT-0058			3.4	4.2		O9
OGLE-GD-CEP-0013	16.1	10.7		0.8	7.8	G0
CAR117.5.6157	7.0	2.0			3.2	G3
MUS100.3.59946	6.4	7.1	4.6	4.6	3.8	F5
BLG179.1.111115	1.9	9.8	9.1	12.4		A5
CAR106.7.14162	4.8	7.6	8.4	7.1		A7
CAR106.7.46218	1.3	10.2	11.1	11.1		A0
BLG130.2.137067	0.4	7.7	7.6	7.8		A0
BLG183.4.156561	0.7	9.1	8.6	9.4		A0
BLG249.1.133775	0.6	9.9	10.3	10.5		A0

For the reductions we used the utilities provided in the IRAF package[†]. In the first step, we combined the bias and flat-field frames and then processed the science images through trimming, bias and flat-field correction. In the next step, we extracted one-dimensional spectra and applied the wavelength calibration to all single spectra. By combining multiple observations of the same objects we improved signal to noise and removed deviant pixels caused by cosmic rays. Based on the spectra of flux standards we determined the sensitivity and extinction functions and applied them to all program objects. Finally, in normalized spectra we measured equivalent widths of selected lines and determined spectral types of our objects (based on Jaschek and Jaschek 1987). They are compiled in Table 2.

[†]IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the National Science Foundation.

3. Results

3.1. Pulsating Stars

Pietrukowicz *et al.* (2013b) reported the identification of 221 pulsating stars and candidates for such objects in the OGLE-III Galactic disk fields. Sixty of the stars are short-period multi-mode pulsators that are either of δ Sct or β Cep type. The main mode in these stars has a period $0.05 < P_{\rm main} < 0.19$ d and *I*-band amplitude between 0.025 mag and 0.12 mag. Due to unknown distance and reddening the objects could not be properly classified based on photometric data only. Measurements of their surface temperature or only a rough determination of the spectral type from low-resolution spectra should provide discrimination between these types of variables. The known β Cep type stars are of spectral types O9–B5 (based on data in Stankov and Handler 2005, Pigulski and Pojmański 2008ab) or surface temperatures in the range 16 000–36 000 K. The δ Sct type stars are of spectral types A0–F9 or surface temperatures in the range 6000–9000 K (based on catalog in Rodríguez *et al.* 2000).

We observed a dozen of the sixty unclassified pulsators, mostly the brightest ones. Their light curves can be seen in Fig. 1. Low-resolution spectra of these objects are shown in Figs. 2 and 3, in which we also present spectra of a *bona fide* δ Sct type star OGLE-GD-DSCT-0011 (Pietrukowicz *et al.* 2013b) and β Cep type star ASAS111308-6106.8 (Pojmański 2002, Pigulski and Pojmański 2008b). Spectral types of the stars are between A5 and F2, thus all of these pulsating variables are of δ Sct type. Since their period ratios differ from those in radially pulsating δ Sct stars, it is very likely that many of the observed periodicities come from non-radial modes. We give new names, refered to the variability type of these stars, in the form OGLE-GD-DSCT-NNNN, where NNNN is a four digit consecutive number starting from 0059 (see Table 3).

We also observed four other, likely pulsating stars, which spectra are presented in Fig. 4. One of them is OGLE variable MUS101.3.34906 with a short period of 0.14610250(1) d $\approx$ 3.50646 h and an unusual looking light curve. Period analysis reveals another two periodicities, but with suspicious period ratios: $P_2 = 0.800083P_1$ and $P_3 = 0.666780P_1$ (see light curves in Fig. 5). The observed period ratios would indicate a δ Sct type star pulsating in the first-, second-, and third-overtone modes. The obtained A type spectrum confirms such identification. We name this object OGLE-GD-DSCT-0071.

Another investigated target, a double-mode star OGLE-GD-DSCT-0012 could not be reproduced by models in the Petersen diagrams, shown in Fig. 11 in Pietrukowicz *et al.* (2013b). The obtained spectrum confirms that this is indeed a δ Sct type variable. Probably, one of the modes is non-radial.

In Fig. 4, we present a spectrum of OGLE-GD-CEP-0013. This object with the period of 5.2436 d seems to have a peculiar light curve if one looks at the sequence of light curves of variables classified as classical Cepheids and ordered by period

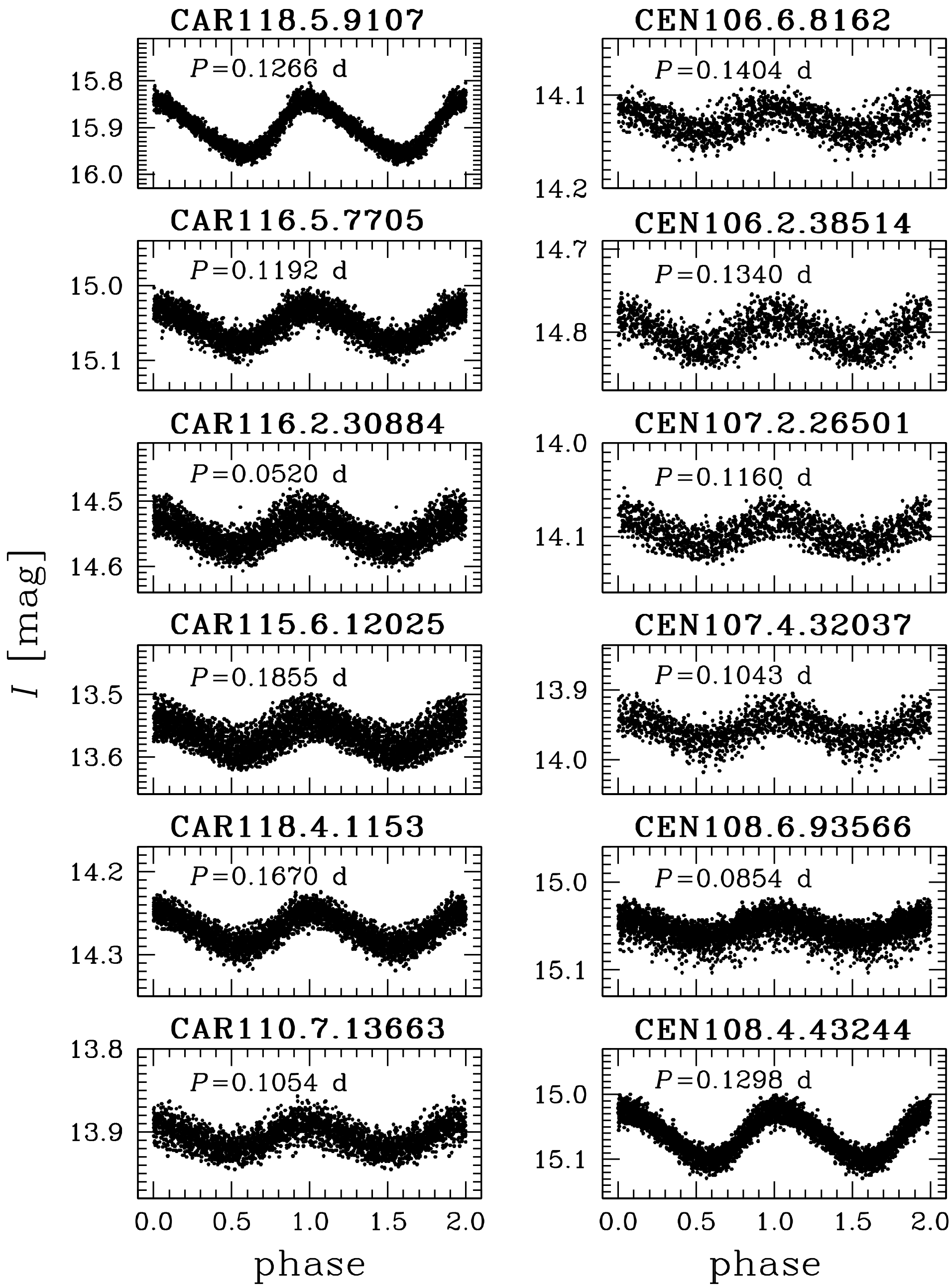

Fig. 1. Light curves of twelve previously unclassified short-period multi-mode pulsating stars phased with the main period. Spectra of the stars in the *left column* are presented in Fig. 2, while in the *right one* in Fig. 3.

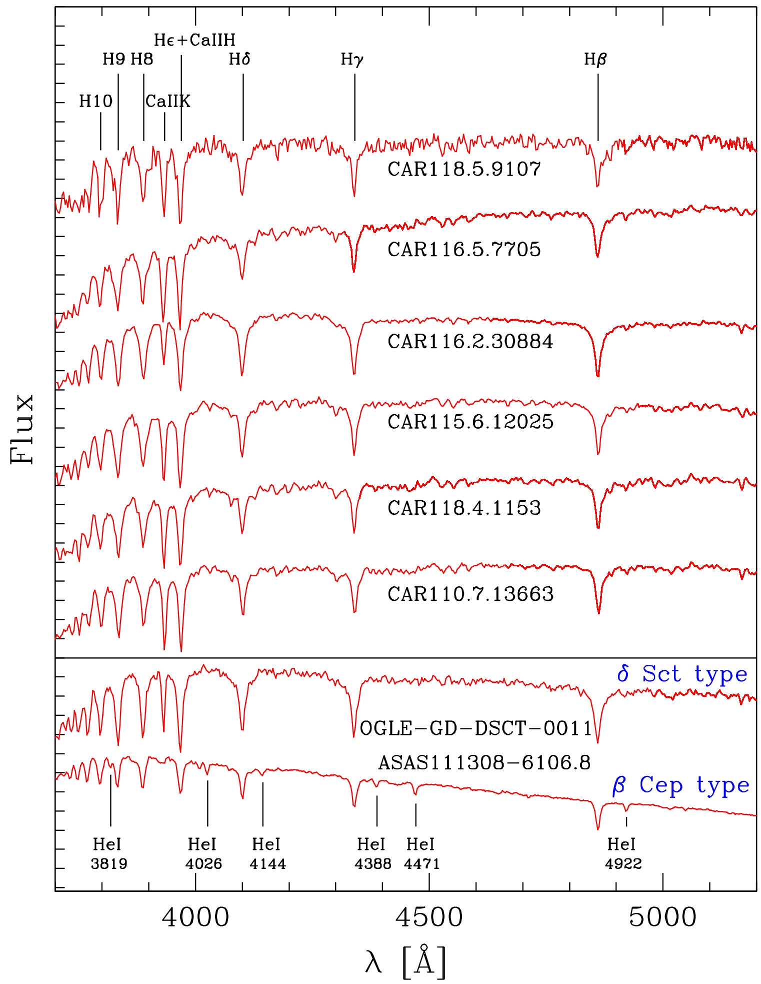

Fig. 2. Spectra of six previously unclassified short-period multi-mode pulsating stars detected in the OGLE-III disk fields in comparison to the spectra of stars known as the δ Sct (OGLE-GD-DSCT-0011) and β Cep type (ASAS111308-6106.8). All six stars have spectra very similar to that of OGLE-GD-DSCT-0011 and therefore all of the variables are of δ Sct type.

in Fig. 1 in Pietrukowicz *et al.* (2013b). The rising part lasts for about half of the period, in comparison to about 20% of $P = 5.3664$ d in the case of the prototype star δ Cep itself and about 35% of $P = 4.8609$ d in the first-overtone star V335 Pup (see. Fig. 6). The obtained spectrum shows a continuum strongly inclined to the red with weak Balmer series in absorption and many metal lines, such as the CaII K+H doublet (λλ 3934+3968 Å), the MgI triplet (λλ 5167, 5173, 5184 Å), FeII λ 5267 Å, the Na I D doublet (λλ 5890, 5896 Å), and the G band formed of Fe, Ti, Ca lines around 4307 Å. Such a spectrum is characteristic for a metal-rich star around G0 type. Classical Cepheids cover a wide range of spectral types between F5 and K2. The observed shape of the light curve with an *I*-band amplitude of 0.29 mag in

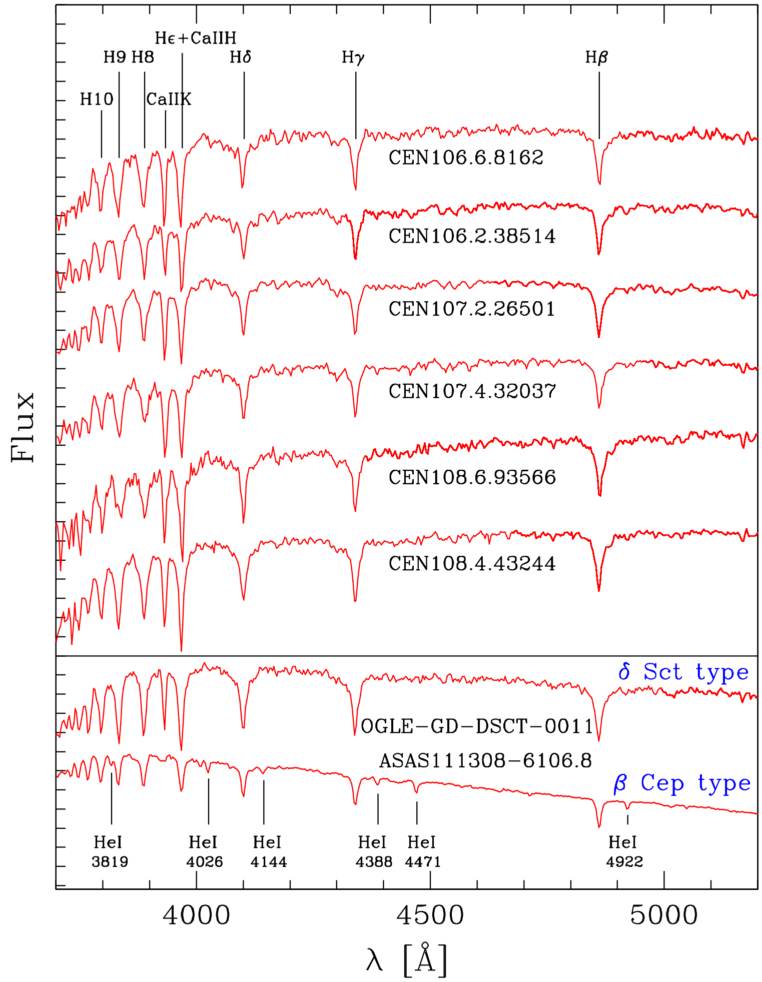

Fig. 3. Spectra of another six previously unclassified short-period multi-mode pulsators from OGLE-III in comparison to the spectra of a δ Sct type and β Cep type variables. The spectra clearly indicate that the six variables are also of δ Sct type.

a G0 type star can only be explained as pulsations. OGLE-GD-CEP-0013 pulsates in the first-overtone mode rather than in the fundamental mode.

3.2. Mysterious Object OGLE-GD-DSCT-0058

In Fig. 4, we also present the low-resolution spectrum of object OGLE-GD-DSCT-0058. In Pietrukowicz *et al.* (2013b), it was classified as a δ Sct type star with a very short period of 0.01962154(1) d = 28.255018(1) min. The power spectrum revealed two additional peaks equally distant from the dominant mode in the frequency space, ± 1.9028 d^{-1} from 50.9644 d^{-1}, and of a similar power (*I*-band amplitudes ≈ 0.025 mag *vs.* the dominant mode of 0.231 mag). The three peaks were interpreted as a dipolar triplet, in which the dominant peak is due to a radial

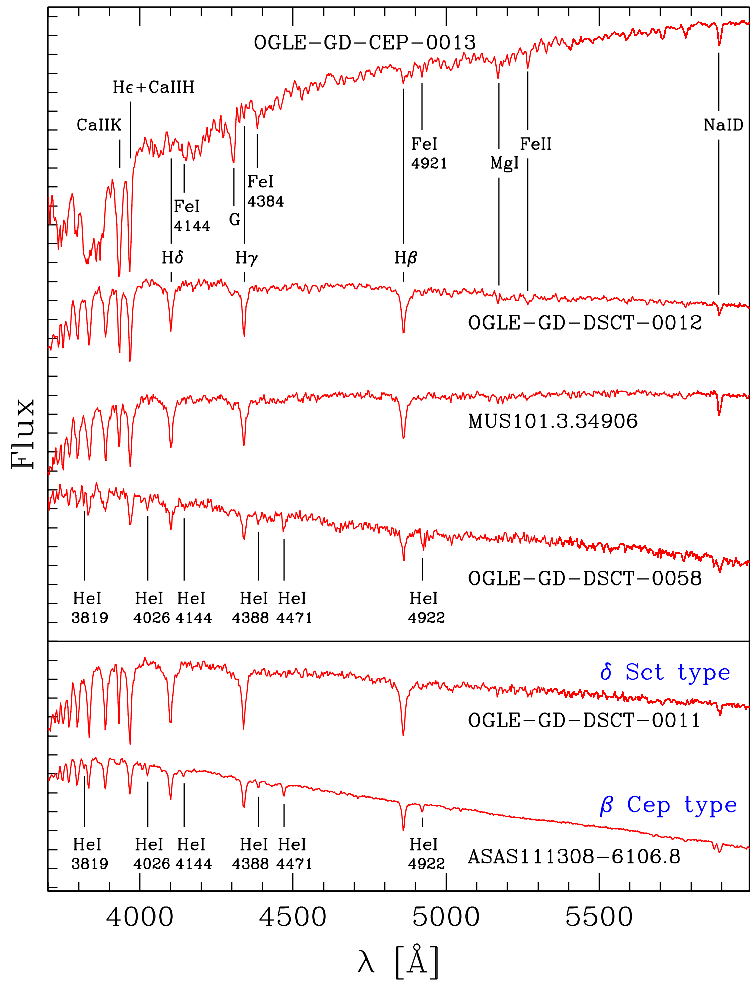

Fig. 4. Spectra of four peculiar OGLE variables compared to the spectra of stars known as the δ Sct and β Cep type.

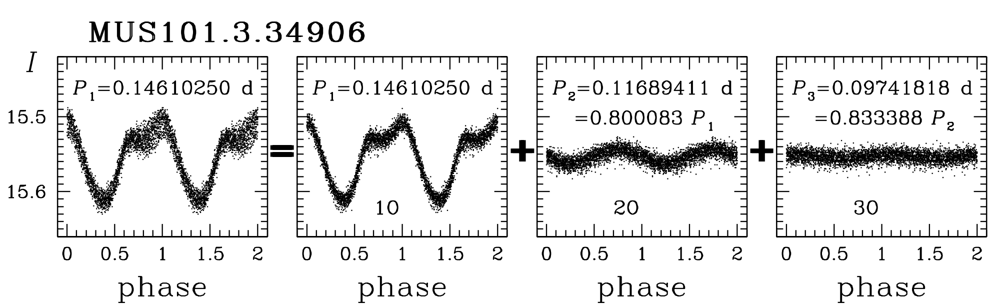

Fig. 5. Decomposition of the light curve of object MUS101.3.34906, confirmed to be a triple-mode δ Sct type star.

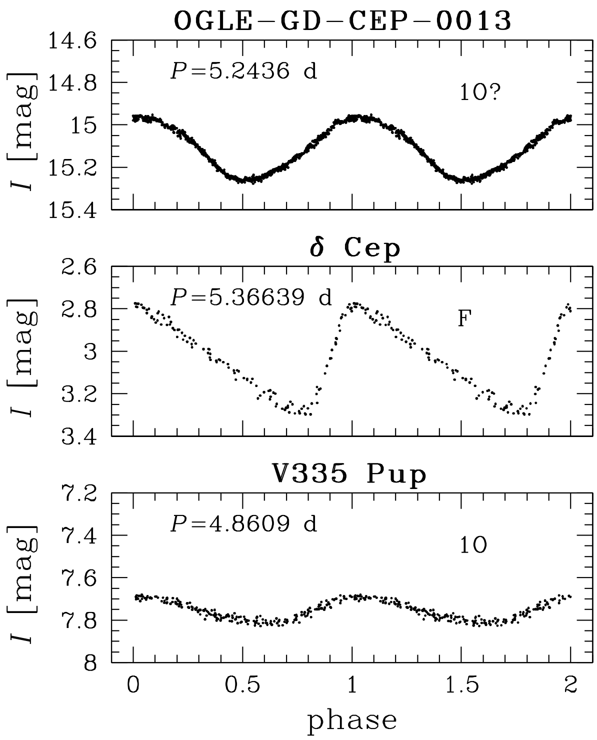

Fig. 6. Comparison of the *I*-band light curve of object OGLE-GD-CEP-0013 with light curves of two known classical Cepheids of similar periods: the prototype star δ Cep pulsating in the fundamental mode and V335 Pup pulsating in the first-overtone mode. The magnitude range is the same in all panels. It seems that OGLE-GD-CEP-0013 is a first-overtone pulsator. The data for δ Cep come from the AAVSO observations, while for V335 Pup from the ASAS project (Pojmański 2002).

mode and the two side oscillations are dipole modes split by stellar rotation. Fig. 7 shows the overall and decomposed light curve of this object.

Surprisingly, the obtained low-resolution spectrum is characterized by a strong continuum rising to the blue. Superimposed are relatively weak hydrogen lines (when compared to typical δ Sct spectra) as well as helium ones, thus indicating a high temperature for the object. A quick literature search allowed us to find some

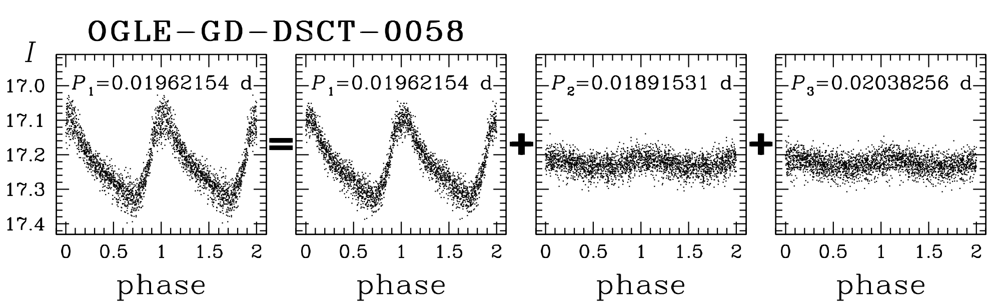

Fig. 7. Decomposition of the light curve of OGLE-GD-DSCT-0058.

similarities between the spectrum of OGLE-GD-DSCT-0058 and those of moderately helium-enriched hot subdwarf stars of B and O type (sdOB, Vennes *et al.* 2007, Drilling *et al.* 2013). This is why we tentatively fitted the Balmer and helium lines observed with a grid of TLUSTY non-local thermodynamic equilibrium (NLTE) model atmospheres suited for hot subdwarf stars (see Brassard *et al.* 2010, Latour *et al.* 2014). The model grid covers a rather large range of parameters: 20 000 K < $T_{\rm eff}$ < 50 000 K, 4.6 < $\log g$ < 6.4, and finally $-4.0 < \log N(\mathrm{He})/N(\mathrm{H}) < 0.0$. The metallicity used in the models is one appropriate for typical hot subdwarfs, as measured by Blanchette *et al.* (2008): solar abundances for N, S and Fe, and one tenth solar for C, O, and Si. The best fit solution is shown in Fig. 8, note that the uncertainties are the formal ones given by the χ^2 minimization procedure. The high temperature found ($T_{\rm eff} \approx 33\,000$ K, corresponding to type O9) confirms that this object cannot be a single δ Sct type star. The high surface gravity of $\log g = 5.3 \pm 0.2$, which is much higher than values for high-mass main sequence stars ($\log g$ between 4.2 and 4.3, according to models in Pamyatnykh 1999), and the high amplitude at the extremely short period rule out the possibility that this is a β Cep type star.

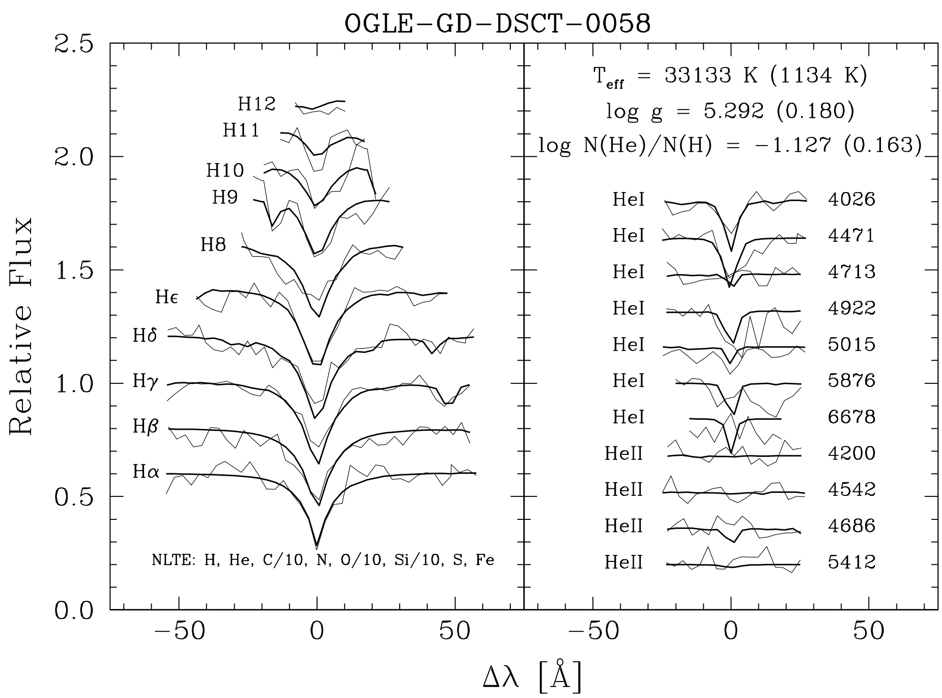

Fig. 8. Best fit (thick line) to the hydrogen and helium lines of observed spectrum (thin line) of OGLE-GD-DSCT-0058. For each spectral line, the continuum is normalized to 1.0 and shifted by 0.2 in flux units.

The interpretation of OGLE-GD-DSCT-0058 as a pulsating hot subdwarf does not agree with predicted and observed pulsation properties for this class of objects

(Charpinet *et al.* 2009, Heber *et al.* 2009). The rapid p-mode sdOB pulsators (of V361 Hya type) having $T_{\rm eff}$ from 28 000 K to 35 000 K and $\log g$ between 5.2 and 6.1 oscillate with periods between about 1.0 min and 10 min and amplitudes rarely exceeding 0.01 mag in V (0.12 mag in the most extreme case of star Balloon 090100001, Oreiro *et al.* 2004, Baran *et al.* 2009). The cooler g-mode pulsators (of V1093 Her type), with $T_{\rm eff}$ between 23 000 K and 30 000 K and $\log g$ around 5.4, have periods ranging from about 45 min to 120 min and amplitudes lower than p-mode stars (of millimagnitudes).

The obtained surface gravity for OGLE-GD-DSCT-0058 is far too low for a white dwarf, while the temperature far too low for a planetary nebula nucleus. Moreover, pulsating objects from the above classes show much lower amplitudes. The shape of the light curve of OGLE-GD-DSCT-0058 resembles those of high-amplitude fundamental-mode pulsators in the main instability strip. There is a possibility that OGLE-GD-DSCT-0058 is not a single object. We cannot rule out an option that the observed light variations are not due to pulsations. High-resolution spectroscopic observations should help to reveal the true nature of this object.

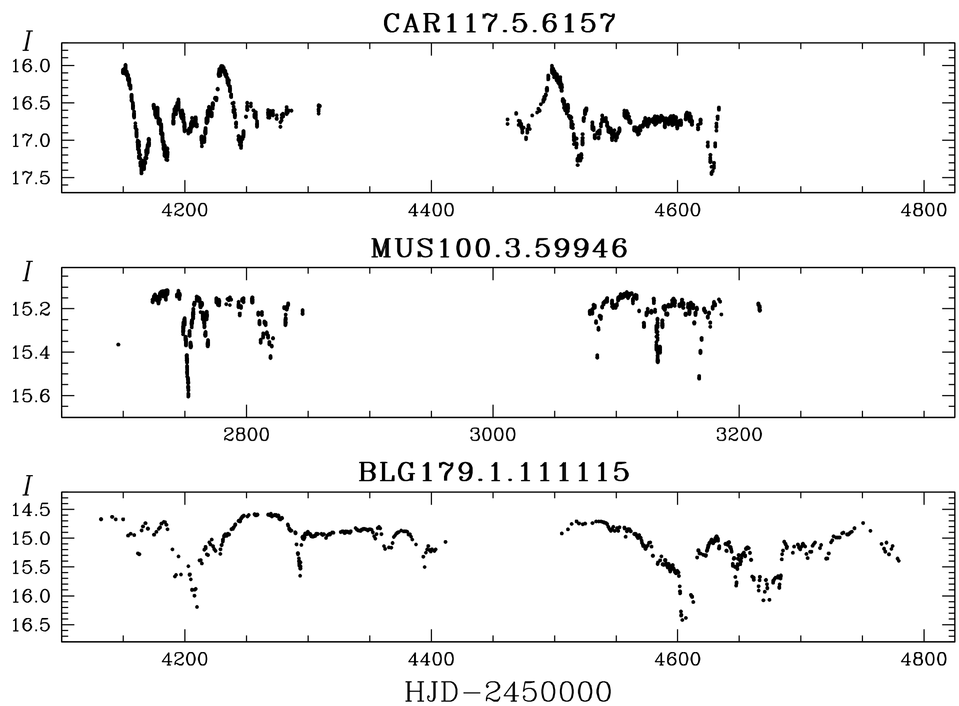

Fig. 9. Three variable stars with irregular fluctuations. The light variations in the first star are similar to those observed in Z Cam type dwarf novae, while in the other two objects to hydrogen-deficient stars of DY Per type. Their spectra, presented in Fig. 10, indicate that all of them are young stellar objects.

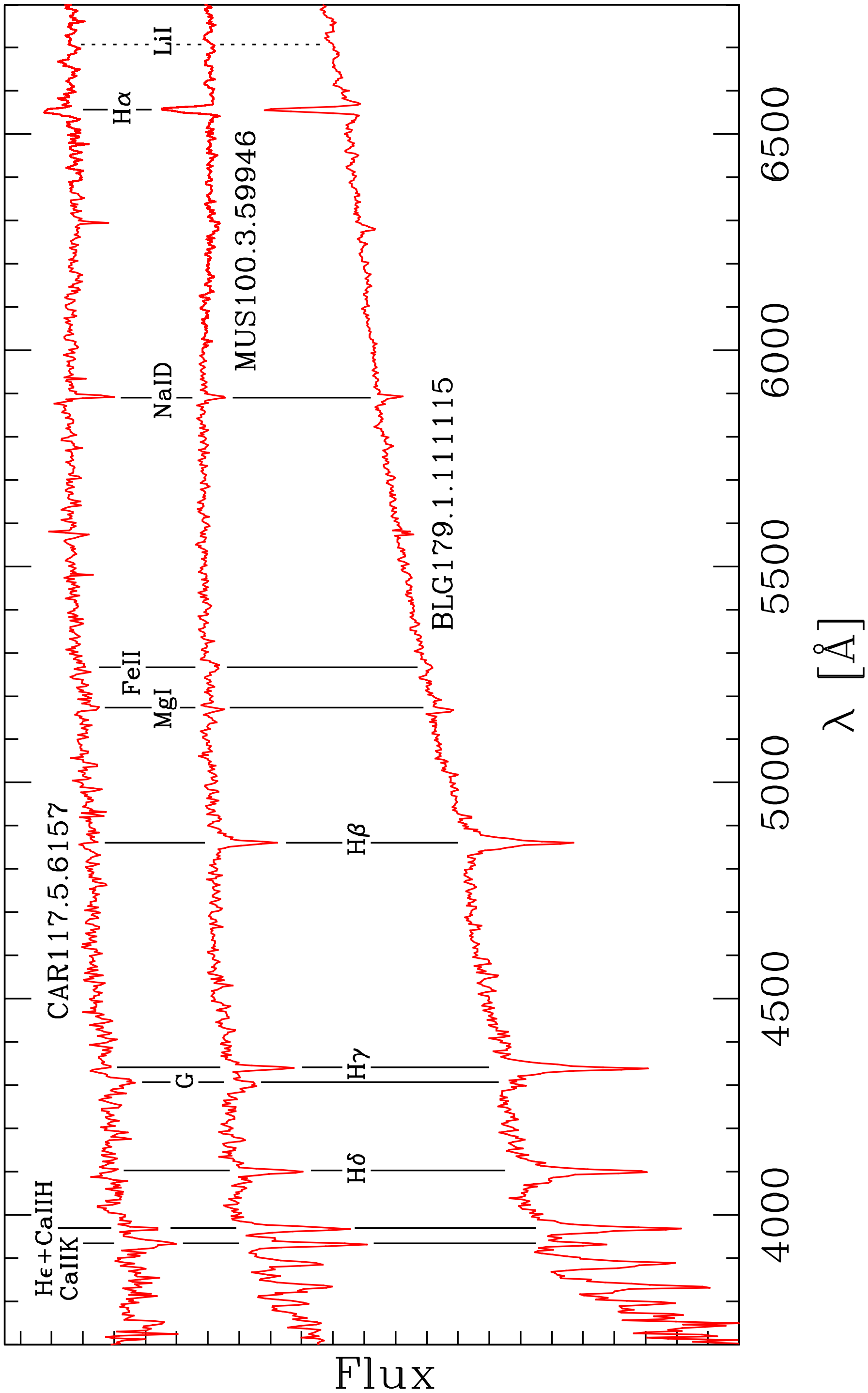

Fig. 10. Spectra of the three variable stars with irregular fluctuations. All stars show deep CaII HK and NaI D lines, and Hα in emission. The G band is particularly prominent in CAR117.5.6157. All these objects are of T Tau type.

3.3. Variable Stars with Irregular Fluctuations

Three of the observed stars are characterized by irregular light variations on time scales from hours to days and amplitudes reaching 2.0 mag in *I*, as it can be seen in Fig. 9. Based on the OGLE-III photometry star CAR117.5.6157 might be classified as a Z Cam type dwarf nova. This type of cataclysmic variables exhibit standstills during which outbursts cease for days to years. The photometric behavior of the other two stars, MUS100.3.59946 and BLG179.1.111115, resembles light changes observed in hydrogen-deficient stars of DY Per and R CrB type.

In Fig. 10, we present the spectra of the three interesting objects. They are very similar to each other. The spectra are characterized by a flat or red continuum upon which Balmer series is superimposed. Whereas the higher members of the series are in absorption, Hα is found in emission. Other recognizable features are absorption lines of CaII, MgI, FeII, NaI D, and the G band. This kind of spectra are typical for young stellar objects (see examples in Kamath *et al.* 2014). The spectral types between A5 and G3 indicate that these stars are low-mass objects ($< 3M_\odot$) of T Tau type. We searched for the presence of lithium, the line LiI λ 6708 Å. Lithium is expected to be abundant in the matter from which the star was formed, but it can be depleted already in the pre-main sequence phase. We were not able to detect this element in our low-resolution spectra.

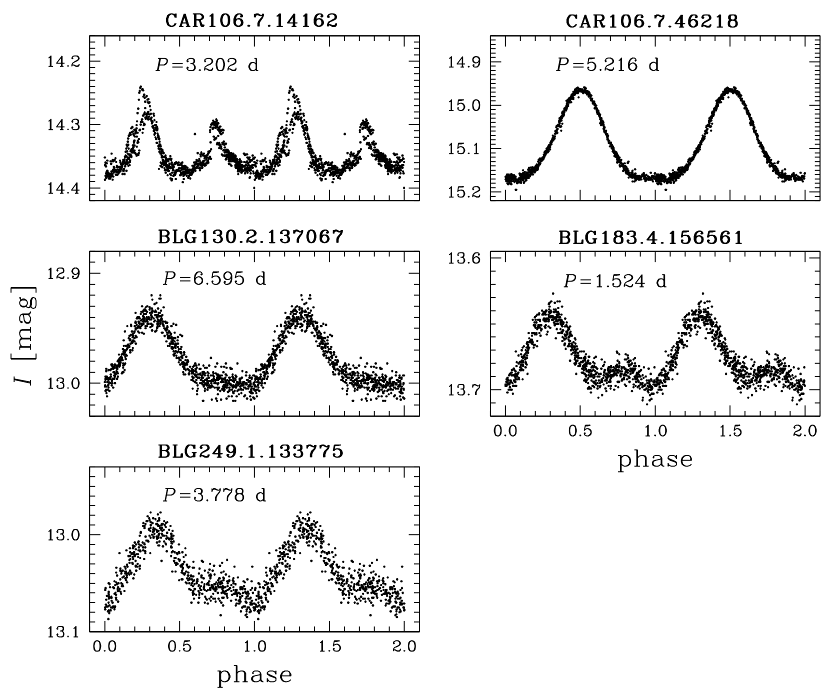

Fig. 11. Phased light curves of five OGLE stars showing periodic brightenings or waves.

3.4. Periodic Variables with Brightenings

We also took spectra of five periodic objects displaying brightenings or waves with *I*-band amplitudes up to 0.2 mag in their phased light curves (Fig. 11). The objects show a single or double wave over the period, which is between 1.5 d and 6.6 d. In the case of CAR106.7.14162, the shape and amplitude of the light variations are not stable. In the other four stars, the waves seem to be stable over the years. Some of them last for more than half of the period. The spectra of these stars, presented in Fig. 12, show strong hydrogen absorption lines characteristic for spectral type A and also enhanced lines of elements such as silicon. All five

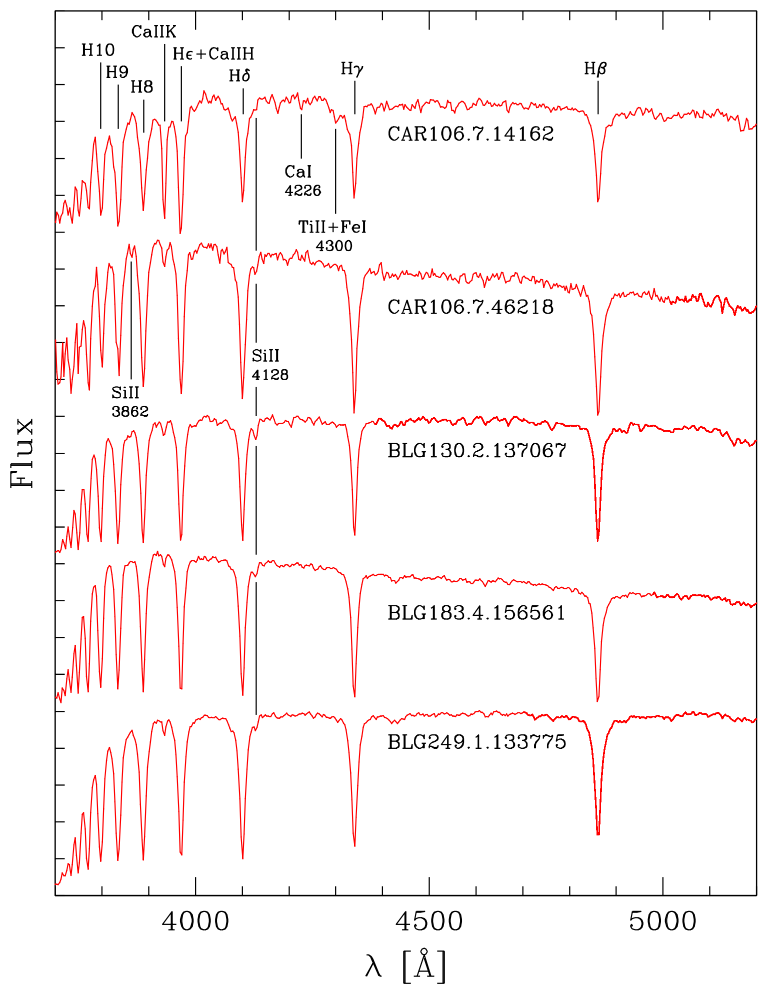

Fig. 12. Spectra of the stars with periodic brightenings. These are very likely Ap stars of Si type.

objects are very likely chemically-peculiar Ap type stars with a relatively strong global magnetic field which axis is inclined to the rotation axis, as it is described in the oblique-rotator model (Stibbs 1950, Preston 1967). The observed single or double wave is a result of changing aspect of their spotted surface with the rotation period (*e.g.*, Stępień 1968, Catalano and Leone 1991, Manfroid and Renson 1994, Bychkov *et al.* 2005). This kind of variables are classified as α^2 CVn type stars.

3.5. Summary

We summarize the results of our spectroscopic follow-up in Table 3. For all but one object the obtained low-resolution spectra have allowed us to make a definitive classification. In the case of OGLE-GD-DSCT-0058, the spectrum shows that it cannot be a single δ Sct type star. The observed properties of this object do not fit to any kind of known pulsating variables. We hope that high-resolution spectra taken over different phases will help to answer the question on the true nature of this enigmatic object.

Table 3

Final classification of the target OGLE variables

ID or name	Sp. type	Var. type	New name
CAR118.5.9107	F0	δ Sct	OGLE-GD-DSCT-0059
CAR116.5.7705	F0	δ Sct	OGLE-GD-DSCT-0060
CAR116.2.30884	A5	δ Sct	OGLE-GD-DSCT-0061
CAR115.6.12025	F0	δ Sct	OGLE-GD-DSCT-0062
CAR118.4.1153	F0	δ Sct	OGLE-GD-DSCT-0063
CAR110.7.13663	F0	δ Sct	OGLE-GD-DSCT-0064
CEN106.6.8162	F0	δ Sct	OGLE-GD-DSCT-0065
CEN106.2.38514	A7	δ Sct	OGLE-GD-DSCT-0066
CEN107.2.26501	F0	δ Sct	OGLE-GD-DSCT-0067
CEN107.4.32037	F2	δ Sct	OGLE-GD-DSCT-0068
CEN108.6.93566	F0	δ Sct	OGLE-GD-DSCT-0069
CEN108.4.43244	F0	δ Sct	OGLE-GD-DSCT-0070
MUS101.3.34906	A7	δ Sct	OGLE-GD-DSCT-0071
OGLE-GD-DSCT-0012	F0	δ Sct	-
OGLE-GD-DSCT-0058	O9	?	-
OGLE-GD-CEP-0013	G0	δ Cep	-
CAR117.5.6157	G3	T Tau	OGLE-GD-YSO-0001
MUS100.3.59946	F5	T Tau	OGLE-GD-YSO-0002
BLG179.1.111115	A5	T Tau	OGLE-BLG-YSO-0001
CAR106.7.14162	A7p	α^2 CVn	OGLE-GD-ACV-001
CAR106.7.46218	A0p	α^2 CVn	OGLE-GD-ACV-002
BLG130.2.137067	A0p	α^2 CVn	OGLE-BLG-ACV-001
BLG183.4.156561	A0p	α^2 CVn	OGLE-BLG-ACV-002
BLG249.1.133775	A0p	α^2 CVn	OGLE-BLG-ACV-003

Acknowledgements. It is a pleasure to acknowledge discussions with Dr. W. Dziembowski and Dr. K. Stępień. We thank Dr. G. Pojmański for providing ASAS data. In this work, we have also used observations from the AAVSO International Database contributed by observers worldwide. This work has been supported by the Polish Ministry of Sciences and Higher Education grants No. IP2012 005672 under the Iuventus Plus program to PP and No. IdP2012 000162 under the Ideas Plus program to IS. The OGLE project has received funding from the European Research Council under the European Community′s Seventh Framework Programme (FP7/2007-2013)/ERC grant agreement No. 246678 to AU, PI of the project. ML acknowledges funding by the Deutsches Zentrum für Luft- und Raumfahrt (grant 50 OR 1315). CG acknowledges full financial support from the postdoctoral fellowship program PNPD/CAPES-Brasil.

REFERENCES

Baran, A.S., *et al.* 2009, *MNRAS*, **392**, 1092.
Blanchette, J.-P., Chayer, P., Wesemael, F., Fontaine, G., Fontaine, M., Dupuis, J., Kruk, J.W., and Green, E.M. 2008, *ApJ*, **678**, 1329.
Brassard, P., Fontaine, G., Chayer, P., and Green, E.M. 2010, *AIP Conf. Proc.*, **1273**, 259.
Bychkov, V.D., Bychkova, L.V., and Madej, J. 2005, *A&A*, **430**, 1143.
Catalano, F.A. and Leone, F. 1991, *A&A*, **244**, 327.
Charpinet, S., Fontaine, G., and Brassard, P. 2009, *A&A*, **493**, 595.
Drilling, J.S., Jeffery, C.S., Heber, U., Moehler, S., and Napiwotzki, R. 2013, *A&A*, **551**, A31.
Heber, U. 2009, *Ann. Rev. Astron. Astrophys.*, **47**, 211.
Jaschek, C., and Jaschek, M. 1987, "The classification of Stars", Cambridge University Press.
Kamath, D., Wood, P.R., and Van Winckel, H. 2014, *MNRAS*, **439**, 2211.
Latour, M., Fontaine, G., Green, E.M., Brassard, P., and Chayer, P. 2014, *ApJ*, **788**, 65.
Manfroid, J., and Renson, P. 1994, *A&A*, **281**, 73.
Mróz, P., *et al.* 2013, *Acta Astron.*, **63**, 135.
Oreiro, R., Ulla, A., Pérez Hernández, F., Østensen, R., Rodríguez López, C., and MacDonald, J. 2004, *A&A*, **418**, 243.
Pamyatnykh, A.A. 1999, *Acta Astron.*, **49**, 119.
Pietrukowicz, P., *et al.* 2013a, *Acta Astron.*, **63**, 115.
Pietrukowicz, P., *et al.* 2013b, *Acta Astron.*, **63**, 379.
Pigulski, A., and Pojmański, G. 2008a, *A&A*, **477**, 907.
Pigulski, A., and Pojmański, G. 2008b, *A&A*, **477**, 917.
Pojmański, G. 2002, *Acta Astron.*, **52**, 397.
Poleski, R., *et al.* 2010, *Acta Astron.*, **60**, 1.
Preston, G.W. 1967, *ApJ*, **150**, 547.
Rodríguez, E., López-González, M.J., and López de Coca, P. 2000, *A&AS*, **144**, 469.
Soszyński, I., *et al.* 2008, *Acta Astron.*, **58**, 163.
Soszyński, I., *et al.* 2013, *Acta Astron.*, **63**, 21.
Soszyński, I., *et al.* 2014, *Acta Astron.*, **64**, 177.
Stankov, A., and Handler, G. 2005, *ApJS*, **158**, 193.
Stępień, K. 1968, *ApJ*, **154**, 945.
Stibbs, D.W. 1950, *MNRAS*, **110**, 395.
Udalski, A. 2003, *Acta Astron.*, **53**, 291.
Udalski, A., Szymański, M., Kaluzny, J., Kubiak, M., and Mateo, M. 1992, *Acta Astron.*, **42**, 253.
Udaski, A., Szymański, M.K., and Szymański, G. 2015, *Acta Astron.*, **65**, 1.
Vennes, S., Kawka, A., and Smith, J.A. 2007, *ApJ*, **668**, L59.