

The Berlin Exoplanet Search Telescope II Catalog of Variable Stars. II. Characterization of the CoRoT SRc02 field

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ABSTRACT

Time-series photometry of the CoRoT field SRc02 was obtained by the Berlin Exoplanet Search Telescope II (BEST II) in 2009. The main aim was the ground based follow-up of the CoRoT field in order to detect variable stars with better spatial resolution than what can be achieved with the CoRoT space telescope. A total of 1,846 variable stars were detected, of which only 30 have been previously known. For nine eclipsing binaries the stellar parameters were determined by modeling their light curve.

Subject headings: binaries: eclipsing — stars: variables: general — techniques: photometry

1. Introduction

CoRoT has been a 27 cm diameter space telescope equipped with four CCD-cameras. Two of them were used for observing a dozen of pulsational and other kinds of light variations of bright stars with high time-sampling (so-called astero-seismological channel), while other two CCDs were used to search for transit signals of about 6000 stars per CCD (so-called exo-channel). In the

exo-channel there were biprisms in front of the CCDs which produced a low ($\Delta\lambda/\lambda \approx 3$) resolution spectra for each stars. This avoided the saturation of many stars, and like defocusing, helped to increase the signal-to-nois ratio. Because of available telemetry rate, most of the photometric masks of the pre-selected stars were read-out in every 512 seconds, but a few hundred stars had a flux measurement in every 32 seconds as well as for a few hundred stars different parts of the photometric masks were read-out separately, yielding the so-called CoRoT-blue, -green and -red light curves. For details see Baglin et al. (2007) and Auvergne et al. (2009).

But due to this technique, the point spread function of CoRoT's exo-channel was typically 80×20 arcseconds and was varying from star to star. Therefore nearby stars in the frame can pollute the observed stars, spreading a certain amount of their flux inside the photometric mask. Such a polluting star is called contaminating star in CoRoT-terminology. The process how to determine which star is contaminating and how much is described in Pasternacki et al. (2011a) and Gardes et al. (2011), for instance. However, in those calculations the contaminating star is considered as a constant star. If it is variable then it is possible that a contaminating source is a fore-

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ground or background eclipsing binary and small amount of its light is contaminating the main target, causing a false positive as a diluted, small transit-like signal in the CoRoT-target. Therefore additional, ground-based, higher spatial resolution photometry is necessary to filter out such cases. Deeg et al. (2009) describes how different kinds of such photometric studies help to decide about the true nature of the observed CoRoT transit signals. Our previous (Karoff et al. 2007; Kabath et al. 2007, 2008, 2009a,b; Klagyivik et al. 2013; Fruth et al. 2012, 2013) and present works reports our contribution to this as well as reports the detected variables and their basic properties. Future studies on CoRoT light curves can utilize these data to remove the variability stemming from a possible contaminator.

Beyond the much better angular resolution the main advantage of our data is the different epoch of the observation. For periodic sources (e.g. eclipsing binaries, planetary candidates) this helps to determine a more accurate period, while for non-periodic sources a much longer observation is available, which is helpful to describe the nature of the light variation.

In this paper we present our independent study on the variable stars in the direction of the CoRoT field SRc02 detected by BEST II. Section 2 presents the observations and the description of the telescope used. In Section 3 we present the variable star selection method and the description of the classification scheme. The previously known and the newly detected variable stars are in Section 4. In Section 5 we present the fitted models of nine selected eclipsing binaries. Eventually the summary and conclusions of this paper can be found in Section 6.

2. Observations and data reduction

The observations were performed with the BEST II telescope located at the Universitätssternwarte Bochum near Observatorio Cerro Armazones, Chile. The system consists of a Takahashi 25 cm Baker-Ritchey-Chrétien telescope equipped with a $4k \times 4k$ Finger Lakes CCD. The corresponding field of view is $1.7^\circ \times 1.7^\circ$ with an angular resolution of $1''.5 \text{ pixel}^{-1}$. In order to maximize the photon yield and to get more accurate photometry of the fainter stars no filter was used.

The exposure time was 120s for all the images.

BEST II observed the CoRoT target field SRc02 during a total of 32 nights between 2009 May 4 and 2009 July 28. An illustration of the BEST II and the CoRoT field SRc02 is shown in Figure 1. $\sim 65\%$ of the CoRoT field is covered by BEST II, which was centered on the coordinates:

$$\begin{aligned}\alpha(J2000.0) &= 18^{\text{h}} 59^{\text{m}} 47^{\text{s}} \\ \delta(J2000.0) &= -03^\circ 07' 37''.\end{aligned}$$

The acquired observations were processed using the BEST automated photometric pipeline as described in Kabath et al. (2009a), Rauer et al. (2010), Pasternacki et al. (2011b) and Fruth et al. (2012). The resulting datasets consist of 1,307 observations of 86,944 stellar objects. Note that CoRoT observed 11,408 targets in SRc02 field, which is much less than the targets observed by BEST II. The most important difference is the target selection. Instead of observing all targets down to a certain magnitude limit, CoRoT observed a pre-selected sample of stars optimized for transiting planet detection and stellar pulsation studies. BEST II has much better angular resolution than CoRoT, which has a point spread function of $\sim 80''0 \times 20''0$, however, the typical number of BEST II objects in a CoRoT PSF is only 1-3. Another important difference is the limiting magnitude which is ~ 2 -3 magnitudes deeper for our current survey.

All stars are matched with the UCAC3 catalog (Zacharias et al. 2010) in order to assign equatorial coordinates and to adjust instrumental magnitudes to a standard magnitude system. The astrometric calibration achieves an average residual of 0.23 arcsecond. The magnitude calibration is obtained by shifting each data set by the median difference between all instrumental magnitudes and their respective catalog value (R2MAG of UCAC3). Since the photometric systems are comparable but not identical, this calibration yields an absolute accuracy of ~ 0.5 mag and ranges from 12 to 20 mag. The number of stars measured below 1% relative accuracy is 4,535. The relative photometric accuracy of all targets are shown in Figure 2.

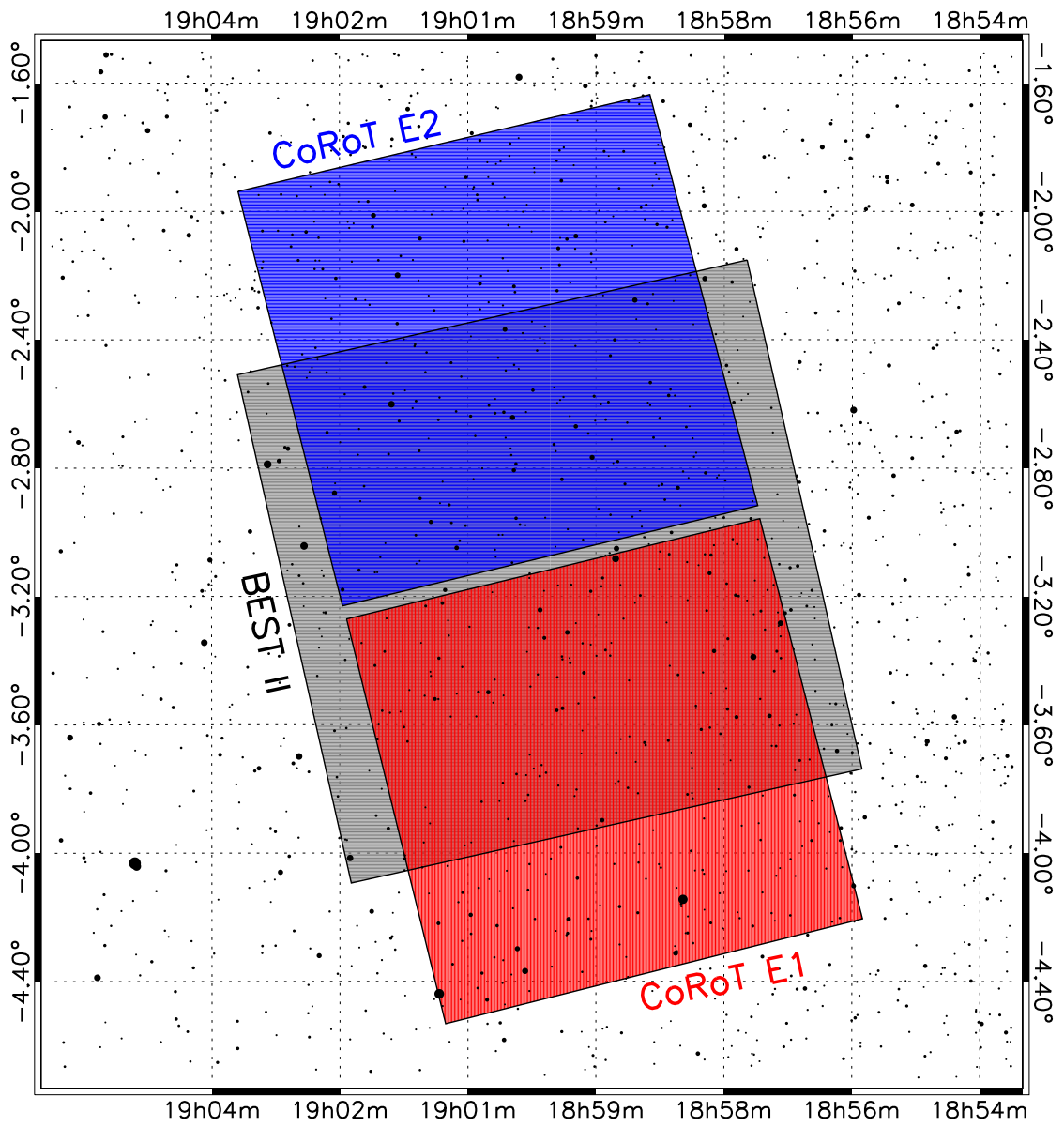


Fig. 1.— Comparison of the fields observed by CoRoT and BEST II.

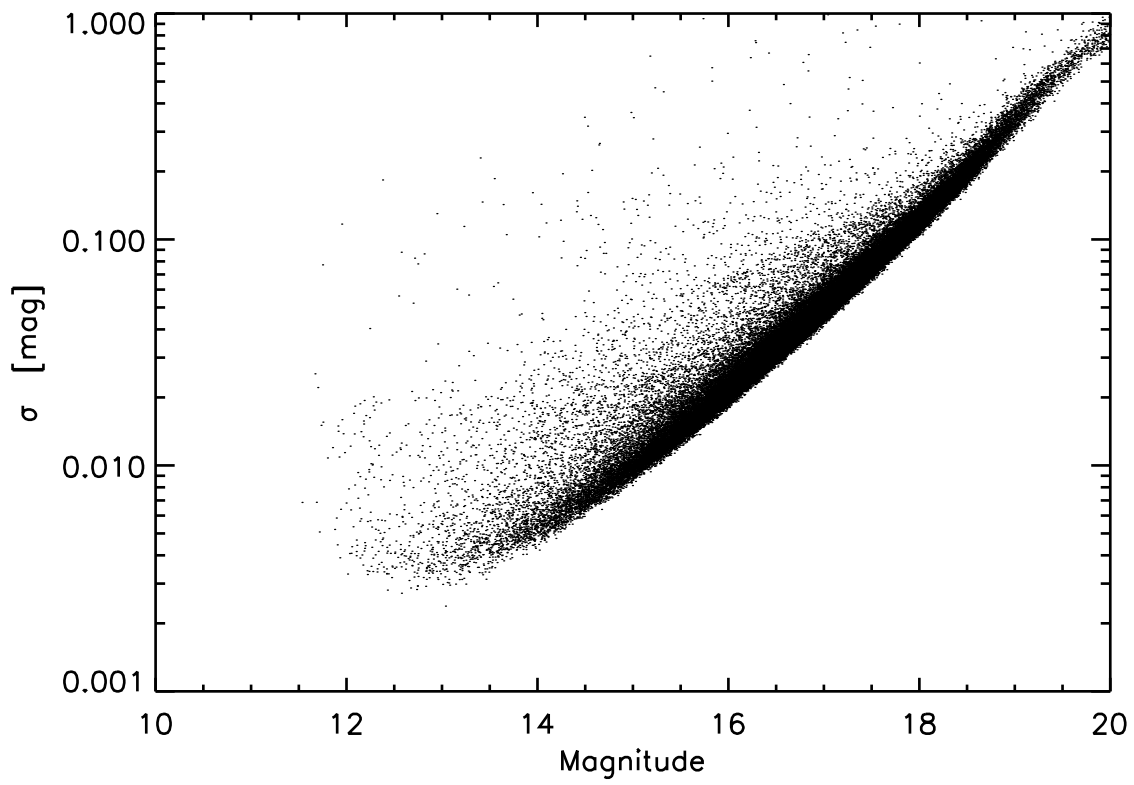


Fig. 2.— Photometric accuracy of the detected sources.

3. Variable stars

3.1. Detection

For detecting the variable sources, we apply the well functioning method described by Fruth et al. (2012). It is based on the widely-used variability index J (Stetson 1996; Zhang et al. 2003) and a multiharmonic period search (Schwarzenberg-Czerny 1996), but also involves an automatic process of dealing with systematic variability. All light curves with $J > 0$ (86%) were fitted with seven harmonics and ranked using the modified Analysis-of-Variance statistic q (see Fruth et al. 2012). A cut-off limit was set to $q > 5$ based on empirical experiments, resulting in 7,677 variable star candidates.

All candidates were inspected visually and classified on an individual basis. We detected a total of 1,846 variable stars, of which only 30 were previously known and 1,816 are new discoveries.

The variable star catalog and the observed light curves are presented here in Table 1 and Figure 3, respectively, for guidance regarding its form and content. Table 1 and Figure 3 are published in its entirety in the electronic edition of *Astronomical Journal*. The data are available upon request from the co-author A. Erikson (anders.erikson@dlr.de).

3.2. Classification

The classification of the periodic variable stars was based on the period, amplitude and shape of their light curve according to a simplified scheme based on the General Catalog of Variable Stars (GCVS, Samus et al. 2009).

Intrinsic variable stars were sorted into Delta Scuti (DSCT), γ Doradus (GDOR), Cepheid (DCEP), RR Lyrae (RR) and Beta Cephei (BCEP) types.

Eclipsing binary stars were classified as detached (Algol type, EA), semi-detached (Beta Lyrae type, EB), or contact (W Ursae Majoris type, EW) systems. The subtype of one eclipsing binary remains undefined, it is marked as E.

Variables having sinusoidal-like light curves are classified as ellipsoidal variables (ELL). Stars with light curves that exhibit features of starspots are marked as spotted stars (SP). The light variation in these objects is caused by stellar rotation.

Stars that vary on time scales longer than the

observational baseline are classified as probably long periodic (LPV). Stars with periodic variations and unstable light curve were marked as α^2 Canum Venaticorum (ACV) stars. Non-periodic variables were classified as miscellaneous (MISC). Due to the insufficient coverage of the epochs of the observations, numerous periodic variable stars can be hidden in this category. In the case of questionable light curves we marked as mixed types (EW/DSCT, ELL/SP).

An overview of the classification result is given in Table 2.

Table 2: Variable stars in and around the CoRoT SRc02 field. The number of newly detected variables are in brackets.

Type	N
Intrinsic variables	
DSCT	83 (83)
GDOR	13 (13)
DCEP	13 (13)
RR	24 (24)
BCEP	2 (2)
Extrinsic variables	
EA	125 (124)
EW	77 (76)
EB	38 (38)
E	1 (1)
ELL	44 (44)
ELL/SP	16 (16)
SP	44 (44)
ACV	37 (37)
Variables with unclear physical process	
LPV	453 (426)
EW/DSCT	38 (38)
MISC	838 (837)
All	1846 (1816)

TABLE 1
 CATALOG OF VARIABLE STARS DETECTED IN *CoRoT* FIELD SRC02, SORTED BY INTERNAL BEST II IDENTIFIERS.

BEST ID	flag	2MASS ID	$\alpha(J2000.0)$	$\delta(J2000.0)$	R_B [mag]	T_0 [rHJD]	P [d]	A [mag]	Type	Other names
SRc02_00036		18564181-0249366	$18^h 56^m 41.8^s$	$-02^\circ 49' 36.0''$	14.63	...	...	...	LPV	
SRc02_00049	c	18561019-0324329	$18^h 56^m 10.2^s$	$-03^\circ 24' 33.1''$	14.98	60.721	0.9233 ± 0.0003	0.69 ± 0.02	EA	
SRc02_00148		18562223-0311543	$18^h 56^m 22.2^s$	$-03^\circ 11' 54.3''$	14.91	...	...	...	MISC	
SRc02_00278		18555391-0344030	$18^h 55^m 53.9^s$	$-03^\circ 44' 03.1''$	14.92	61.977	7.53 ± 0.05	0.14 ± 0.05	EA	
SRc02_00309	c	18560034-0337067	$18^h 56^m 00.3^s$	$-03^\circ 37' 06.8''$	14.57	...	...	...	MISC	
SRc02_00371		18564095-0252272	$18^h 56^m 40.9^s$	$-02^\circ 52' 27.1''$	15.77	56.923	0.1832 ± 0.0002	0.04 ± 0.02	DSCT	
SRc02_00427		18560426-0333164	$18^h 56^m 04.3^s$	$-03^\circ 33' 16.4''$	15.09	60.726	0.821 ± 0.002	0.05 ± 0.02	RR	
SRc02_00436		18570987-0221013	$18^h 57^m 09.9^s$	$-02^\circ 21' 01.6''$	15.74	56.852	0.09014 ± 0.00005	0.03 ± 0.03	DSCT	
SRc02_00438		18564549-0247448	$18^h 56^m 45.5^s$	$-02^\circ 47' 44.5''$	14.65	...	...	...	MISC	
SRc02_00458		18565190-0240475	$18^h 56^m 51.9^s$	$-02^\circ 40' 47.4''$	16.01	...	...	...	MISC	
SRc02_00539		18571441-0216385	$18^h 57^m 14.4^s$	$-02^\circ 16' 38.8''$	15.51	56.768	0.06263 ± 0.00003	0.03 ± 0.03	DSCT	
SRc02_00589	c	18563332-0301561	$18^h 56^m 33.3^s$	$-03^\circ 01' 56.1''$	14.08	...	...	...	MISC	

NOTE.—The flag *c* denotes stars affected by crowding. Previously known objects are flagged with *k*. Their IDs from VSX or GCVS can be found in the last column. R_B is the apparent magnitude in BEST II photometric system. The Epoch T_0 is given in reduced Julian date [rHJD] in respect to $T = 2,454,900.0$. It denotes the first minimum in the light curve. P is the period of the light variaton and A is the amplitude of the variability. This table is published in its entirety in the electronic edition of the *Astronomical Journal*. A portion is shown here for guidance regarding its form and content.

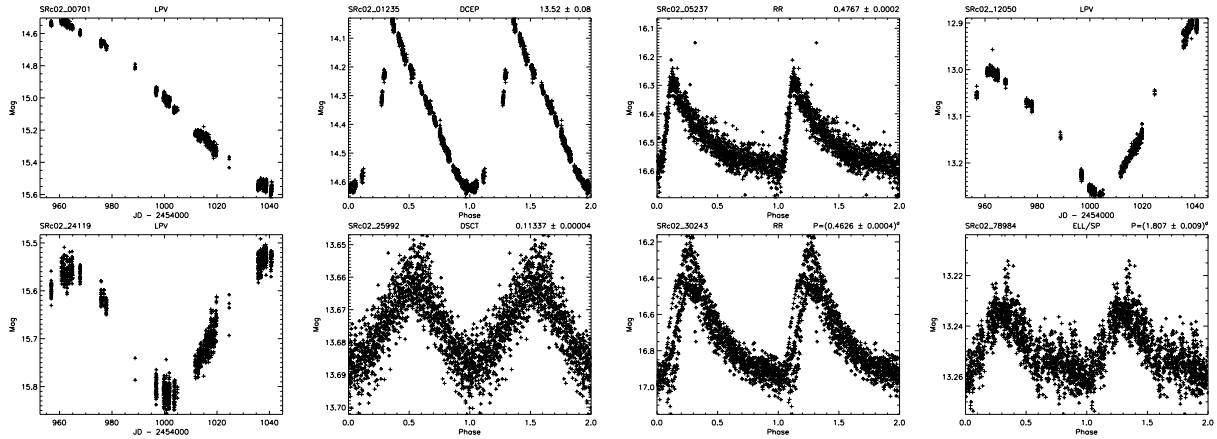


Fig. 3.— Sample light curves of some selected variable stars. For periodic stars the phase folded light curve is shown. All the light curves are available in the electronic edition of the journal.

4. Firsts results

4.1. Known variables

The stars observed with BEST II are cross-checked with the variable star index¹ (VSX) of the American Association of Variable Star Observers (AAVSO) and with the General Catalogue of Variable Stars (GCVS, Samus et al. 2009). In the variable star catalogue (Table 1) the previously known stars are marked with a flag 'k'.

Within the observed field there are 30 previously known variable stars. We could confirm the variability for all of these stars. 27 variables belong to the long period variables (LPV) type.

NSVS 13967794 was marked as an irregular variable, which is consistent to MISC in our data set. V914 Aql is an Algol type eclipsing binary with an orbital period of 3.33722 ± 0.00001 days and with quite different primary and secondary eclipse depths. This indicates a large difference between the masses of the components.

4.2. Newly detected variables

The most populous group is the long periodic variables with 453 objects. This is distinctive among the fields observed by BEST II. Another large group is the class of eclipsing binaries (EA, EB, EW and E type stars) with a total of 241 members. A more detailed study of these binaries

is discussed in Section 5.

The large number of variables in the MISC group is partially due to the insufficient epoch distribution, which does not allow us to classify more precisely.

There are many interesting variable stars in our dataset. Here we present only two of these objects. They are shown in Fig. 3.

4.2.1. SRc02_30243

SRc02_30243 is an RR Lyrae with a pulsation period of 0.46 days showing the Blazhko effect (Blazhko 1907). This effect is a periodic modulation of the light variation in the range of tens of days. The origin of this modulation is still a puzzle after more than a hundred years after its discovery.

4.2.2. SRc02_78984

This star has a similar light curve to the new class of variable young stellar object found by Rodríguez-Ledesma et al. (2012) in the Orion Nebula Cluster, Klagyivik et al. (2013) in the young open cluster NGC 2264 and Pawlak et al. (2013) in the Small Magellanic Cloud. This kind of light curve shape can be reproduced with a hot spot either on the star or on an accretion disk around it.

¹<http://www.aavso.org/vsx/>

5. Eclipsing binaries

In a recent paper we developed a simple model to calculate the fraction of observable Algol type eclipsing binaries in a random field (Klagyivik et al. 2013). On that observational run this model results a fraction of $0.104 \pm 0.004\%$. In the SRc02 field we identified 125 Algols among the total of 86,944 stars, which means $0.14 \pm 0.02\%$. This is in fairly good agreement - within 2σ - with the model.

5.1. Notes on selected eclipsing binaries

We study individual eclipsing binaries in more detail by modeling their light curve with our own code described by Csizmadia et al. (2009). All details of the modeling are the same as in Klagyivik et al. (2013). The selection criteria are the brightness and the amplitude, for bright binaries with deep eclipses are easier to model correctly.

The effective temperature of the primaries are calculated using the 2MASS $J - K$ data. Note that this method can introduce systematic errors due to unknown reddening. We use the R -band linear bolometric and quadratic limb darkening coefficients published by van Hamme (1993) and Claret & Bloemen (2011), respectively, since this is the closest filter to our filterless observations. Since all stars are cooler than 6000 K we fix the gravity darkening exponents to $g = 0.32$ and the albedos to $A = 0.5$ (cf. Lucy 1967; Rucinski 1969).

The free parameters are: mass ratio, inclination, fill-out factors of the two components, effective surface temperature of the secondary star, epoch, and height of the maximum brightness refining the normalization of the light curve. We add a stellar spot to one or both of the components if needed. We try all the possible combinations up to 2 spots in total (no spot, one spot on the primary star, one spot on the secondary component, etc.). When the fitted mass ratio ($q = m_2/m_1$) is higher than 1.0 we reverse the components to keep the primary component the more massive. The temperature of a spot is described as the temperature ratio of the spot and the star (temperature factor = $T_{\text{spot}}/T_{\text{star}}$). The fits with the smallest χ^2 value are accepted and are summarized in Table 3 and Figure 4. The errors in Table 3 include only modeling uncertainties but no systematic errors of

the input parameters. The individual systems are discussed below.

5.2. SRc02_00049

This system consists of two very ellipsoidal stars, as one can calculate from the fill-out factors and the mass ratio.

The primary star has a polar fractional radius (defined as R/a , where R is the actual stellar radius and a is the semi-major axis of the orbit) of 0.457 ± 0.004 , and the equatorial stellar fractional radii are 0.505 ± 0.005 in the direction of the other star, 0.536 ± 0.005 to the anti-companion direction, and 0.489 ± 0.004 into the direction of motion (these are called polar, point, back and side radii according to the binary star terminology). The secondary star has fractional radii of $r_{\text{pole}} = 0.219 \pm 0.002$, $r_{\text{point}} = 0.263 \pm 0.003$, $r_{\text{back}} = 0.248 \pm 0.002$ and $r_{\text{side}} = 0.226 \pm 0.002$.

The polar oblateness, defined as $1 - r_{\text{pole}}/r_{\text{side}}$, is nearly 7% for the primary and 3% for the secondary. Although the two stars are quite close to each other, they are far from Roche-lobe filling. The primary has an average radius of 74% of its own Roche-lobe size, while the secondary is only 67% of its own Roche-lobe size. Therefore it seems they have not undergone mass-transfer yet, and hence they have their original masses. The light curve modeling was able to reproduce the observed flux variations with synchronous rotation, so they are fast rotators, which means that the stellar shape is deformed by strong tidal rotation. These, and the fast rotation make this and similar objects good targets to determine and to study the relationship between internal stellar structure (and J_2 parameter) and stellar shapes under strong rotational and tidal interactions.

Although the light curve fit required a spot, the temperature factor of the spot is poorly determined and it allows also an unspotted star.

5.3. SRc02_16165

This object is a semi-detached binary where the secondary fills out the Roche-lobe. The O'Connell-effect is clearly visible, the two maxima differ from each other by 0.01 magnitude and it seems to be stable during the observational window. This was reproduced by a dark spot on the secondary. One can expect period variations dur-

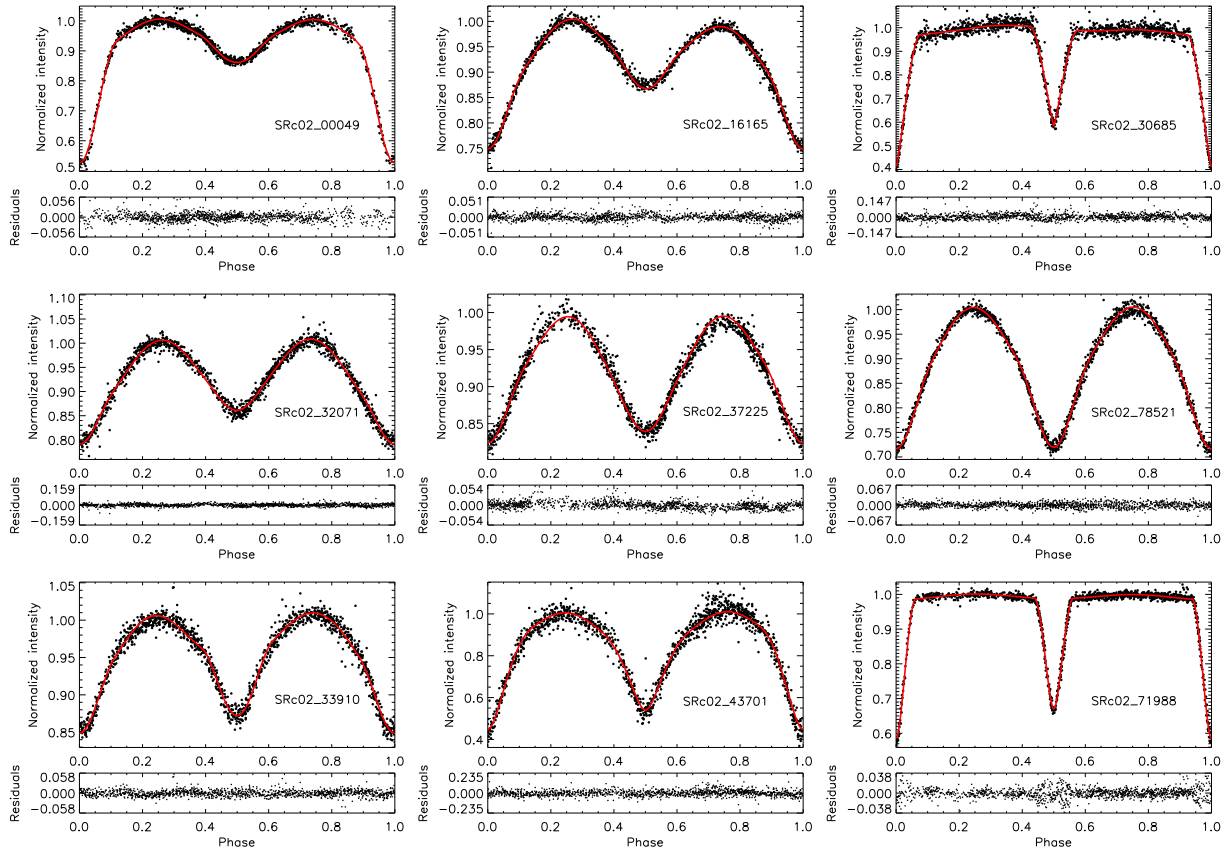


Fig. 4.— Results of the light curve modeling of the selected eclipsing binaries. The points represent the raw observations, while the solid lines (colored red in the online version) are the fits. The lower panels show the residuals.

Table 3: Fitted parameters of the modeled binary systems. The temperature factor of the spots means T_{spot}/T_{star} .

BEST ID	SRc02_00049	SRc02_16165	SRc02_30685
Orbital period (days)	0.9233 ± 0.0003	0.39607 ± 0.00006	0.7416 ± 0.0005
Mass ratio q	0.21 ± 0.03	0.21 ± 0.02	0.65 ± 0.06
Inclination i ($^\circ$)	68.2 ± 2.0	59.0 ± 1.0	89.9 ± 0.5
Fill-out factor f_1	-0.91 ± 0.52	-0.55 ± 0.30	-5.29 ± 0.37
Fill-out factor f_2	-0.54 ± 0.12	0.00 ± 0.10	-2.39 ± 0.16
Temperature T_1 (K)	3743 ± 234	3558 ± 48	3720 (fixed)
Temperature T_2 (K)	5029 (fixed)	4893 (fixed)	3772 ± 35
<i>Spot</i>			
<i>On which star?</i>	primary	secondary	primary
Colatitude ϕ_1 ($^\circ$)	179 ± 19	111 ± 64	136 ± 34
Longitude λ_1 ($^\circ$)	127 ± 142	111 ± 56	200 ± 4
Diameter d_1 ($^\circ$)	65 ± 34	19 ± 10	9.5 ± 3.6
Temperature factor	0.66 ± 0.59	0.84 ± 0.25	1.26 ± 0.07
χ^2	0.757	0.647	0.779
BEST ID	SRc02_32071	SRc02_37225	SRc02_78521
Orbital period (days)	0.7377 ± 0.0003	1.3094 ± 0.0007	0.38834 ± 0.00004
Mass ratio q	0.22 ± 0.02	0.202 ± 0.006	0.52 ± 0.08
Inclination i ($^\circ$)	55.6 ± 0.7	55.7 ± 0.5	66.2 ± 0.3
Fill-out factor f_1	0.11 ± 0.01	0.00 ± 0.21	0.04 ± 0.01
Fill-out factor f_2	0.11 ± 0.01	0.00 ± 0.21	0.04 ± 0.01
Temperature T_1 (K)	3877 ± 39	4115 ± 52	4664 (fixed)
Temperature T_2 (K)	4790 (fixed)	3968 (fixed)	4582 ± 55
<i>Spot</i>			
<i>On which star?</i>	secondary	–	secondary
Colatitude ϕ ($^\circ$)	162 ± 18	–	159 ± 42
Longitude λ ($^\circ$)	262 ± 109	–	46 ± 38
Diameter d ($^\circ$)	42 ± 17	–	15 ± 12
Temperature factor	0.14 ± 0.40	–	1.73 ± 0.28
χ^2	0.919	0.525	1.269
BEST ID	SRc02_33910	SRc02_43701	SRc02_71988
Orbital period (days)	0.28172 ± 0.00004	0.36663 ± 0.00007	1.371 ± 0.002
Mass ratio q	0.19 ± 0.03	0.72 ± 0.10	0.64 ± 0.28
Inclination i ($^\circ$)	62.5 ± 0.6	83.5 ± 0.6	84.5 ± 0.4
Fill-out factor f_1	-0.72 ± 0.08	-0.11 ± 0.05	-6.8 ± 2.1
Fill-out factor f_2	-0.80 ± 0.14	-0.07 ± 0.04	-4.3 ± 0.3
Temperature T_1 (K)	4172 (fixed)	4128 ± 30	4734 ± 52
Temperature T_2 (K)	3576 ± 18	3847 (fixed)	5055 (fixed)
<i>Spot</i>			
<i>On which star?</i>	primary	secondary	secondary
Colatitude ϕ ($^\circ$)	148 ± 48	104 ± 62	39 ± 86
Longitude λ ($^\circ$)	126 ± 141	18 ± 50	100 ± 102
Diameter d ($^\circ$)	11 ± 9	7.6 ± 4.1	4.9 ± 2.2
Temperature factor	2.0 ± 0.5	1.14 ± 0.12	0.83 ± 0.25
χ^2	1.290	0.583	1.286

ing the mass transfer, and observations of this variation on longer time-scale would be important to establish which phase of the mass transfer occurs in this system. Its brightness makes it a favourable target for further spectroscopic and photometric investigation.

5.4. SRc02_30685

SRc02_30685 is a high-amplitude system with a considerable reflexion effect and light curve distortion. From the end of the primary minimum to the beginning of the secondary minimum, the flux level increases by 0.04 magnitude due to reflection. However, from the secondary to the primary minimum the flux level is close to constant what we explain by a spot. Actually, this bright spot is necessary on the primary to explain the observed out-of-eclipse variations. Such spots are common in binaries, but less frequent than the dark spots.

5.5. SRc02_32071, 37225, 78521

These three systems are so-called contact or overcontact binary systems, where the two stars are so close to each other that both components fill out their own Roche-lobe, and thus they are geometrically in contact, or – in the case of overcontact systems – the two stellar cores have a common convective envelope.

SRc02_32071 is a low-inclination ($i = 56^\circ$) overcontact binary system with 11% over-filling factor. It belongs to the W-subtype of overcontact binaries according to the definition of Binnendijk (1965), since the secondary object is smaller ($r_{avg} = 0.253$) and warmer ($T_{eff} = 4790 K$) than the primary ($r_{avg} = 0.525$ and $T_{eff} = 3877 K$). The secondary maximum is slightly at higher flux level (by 0.01 mag) than the primary maximum, indication a negative O’Connell-effect. The O’Connell-effect was observed in several other, well-studied systems, too, but only the minority, 24% of the systems (19 out of 78) showed such a negative value in the list of Maceroni & van’t Veer (1996).

SRc02_37225 is an unspotted contact binary. It seems to be in the state of exact Roche-lobe filling. According to theoretical expectations, exact Roche-lobe filling is quite unlikely because it lasts for an extreme short time-interval. It brakes or it evolves to overcontact. More precise photometry

is needed to confirm that we have a fill-out factor of zero, so a rare type of contact binaries have been found, or we have a very low fill-out factor in this system. If it is in exact contact, then it can be an important test object for theoretical studies.

SRc02_78521 is a common A-subtype overcontact binary with well-determined fill-out factor ($f_1 = f_2 = 0.04 \pm 0.01$). In case of contact binaries, long time-scale magnetic cycles (10-20 years, e.g. Borkovits et al. 2005), spot-induced Eclipse Timing Variations (Tran et al. 2013), effect of mass transfer, third bodies and irregular variations occur (Borkovits et al. 2005; Tran et al. 2013; Quian 2001a,b, 2003; Nelson et al. 2014). Since this target is bright for even small telescopes, it is a good target for such period variation studies.

5.6. SRc02_33910, 43701, 71988

These three systems are detached Algol-type eclipsing binaries. The light curves of SRc02_33910 and SRc02_43701 show some similarities to each other, but SRc02_43701 is almost a near-contact binary while SRc02_33910 is a wider system which probably evolves later to a near-contact system. SRc02_71988 is a well-detached Algol-type system.

The SRc02_33910 system requires a new light curve solution based on multi-colour photometry which helps to establish the exact temperature difference between the components. It seems to be a short-period, detached system.

SRc02_43701 has average fractional radii $r_{pri} = 0.397 \pm 0.004$ and $r_{sec} = 0.339 \pm 0.003$. The sum of the point fractional radii are exactly 0.900 ± 0.008 (0.478 ± 0.004 and 0.422 ± 0.004 for the primary and secondary star, respectively). The inner Lagrange-point is at a distance of 0.53 ± 0.01 from the primary’s center, while the primary’s point radius is 0.478 ± 0.004 , quite close to the inner Lagrange-point. That is why this system is a pre-near-contact binary, and most likely it will later evolve to a contact system.

The residual light curve of SRc02_71988 has a significantly larger scatter in the primary and secondary minima than out of transit. This can be due to surface brightness inhomogeneties (e.g. stellar spots) on the side faced toward its companion, which is occulted during the eclipses.

6. Summary

We presented a study of the variable stars in the CoRoT field SRc02 observed by BEST II in 32 nights in 2009. We detected 1,846 variable stars out of 86,944 stars in our field of view, out of which 1,816 are new detections and only 30 were previously known. Most of them are long period variables (classified as LPV), or show irregular variability (MISC class).

The total number of eclipsing binaries is 241. There are 125 Algol-type eclipsing binaries in our database, which means 0.14% of all stars. This is in good agreement with our simple model of EAs (Klagyivik et al. 2013).

We studied the light curves of 9 eclipsing binaries using our own modeling code. SRc02.37225 seems to be in exact Roche-lobe filling and it can be an important test object for theoretical studies, while SRc02.43701 is a pre-near-contact system and will probably evolve to a contact system.

A new RR Lyrae showing Blazhko modulation was also found (SRc02.30243), however, the observational run was not long enough to determine the period of the Blazhko cycle.

Peter Klagyivik acknowledges support from the Hungarian State Eötvös Fellowship and support by grant AYA2012-39346-C02-02 of the Spanish Ministerio de Economía y Competitividad (MINECO). Petr Kabath would like to acknowledge funding from the Purkyne Fellowship programme of the Czech Academy of Sciences. This project has been partly supported by the Hungarian OTKA Grant K113117. This publication is supported as a project of the Nordrhein-Westfälische Akademie der Wissenschaften und der Künste in the framework of the academy programme by the Federal Republic of Germany and the state Nordrhein-Westfalen. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France. We also made use of 2MASS, GCVS catalogs, and AAVSO variable star search index.

REFERENCES

- Auvergne, M., Bodin, P., Boissard, L., et al. 2009, *A&A*, 506, 411
- Baglin, A., Auvergne, M., Barge, P., et al. 2007, *AIPC*, 895, 201
- Blazhko, S. 1907, *AN*, 175, 325
- Borkovits, T., Elkhateeb, M. M., Csizmadia, Sz., et al. 2005, *A&A*, 441, 1087
- Claret, A., & Bloemen, S. 2011, *A&A*, 529, 75
- Csizmadia, Sz., Paragi, Zs., Borkovits, T., et al. 2009, *ApJ*, 705, 436
- Deeg, H.J., Gillon, M., Shporer, A., et al. 2009, *A&A*, 506, 343
- Fruth, T., Kabath, P., Cabrera, J., et al. 2012, *AJ*, 143, 140
- Fruth, T., Cabrera, J., Chini, R., et al. 2013, *AJ*, 146, 136
- Gardes, B., Chabaud, P. Y., & Guterman, P. 2011, *Proc. of the 2nd CoRoT Symposium*, p. 119
- van Hamme, W. 1993, *AJ*, 106, 2096
- Kabath, P., Eigmüller, P., Erikson, A., et al. 2007, *AJ*, 134, 1560
- Kabath, P., Eigmüller, P., Erikson, A., et al. 2008, *AJ*, 136, 654
- Kabath, P., Fruth, T., Rauer, H., et al. 2009, *AJ*, 137, 3911
- Kabath, P., Erikson, A., Rauer, H., et al. 2009, *A&A*, 506, 569
- Karoff, C., Rauer, H., Erikson, A., et al. 2007, *AJ*, 134, 766
- Klagyivik, P., Csizmadia, Sz., Pasternacki, T., et al. 2013, *ApJ*, 773, 54
- Lucy, L. B. 1967, *ZA*, 65, 89
- Nelson, R. H., Terrell, D., & Milone, E. F. 2014, *NewAR*, 59, 1
- Maceroni, C., & van't Veer, F. 1996, *A&A*, 311, 523
- Pasternacki, T., Bordé, P., & Csizmadia, Sz. 2011, *Proc. of the 2nd CoRoT Symposium*, p. 117
- Pasternacki, T., Csizmadia, Sz., Cabrera, J., et al. 2011, *AJ*, 142, 114

- Pawlak, M., Graczyk, D., Soszyński, I., et al. 2013
Acta Astron., 63, 323
- Qian, S. 2001, MNRAS, 328, 635
- Qian, S. 2001, MNRAS, 328, 914
- Qian, S. 2003, MNRAS, 342, 1260
- Rauer, H., Erikson, A., Kabath, P., et al. 2010,
AJ, 139, 53
- Rodríguez-Ledesma, M. V., Mundt, R., Ibrahimov, M., et al. 2012, A&A, 544, 112
- Rucinski, S. M. 1969, Acta Astron., 19, 245
- Samus, N. N., & Durlevich, O. V. et al. 2009,
Vizie Online Data Catalog, B/GCVS
- Schwarzenberg-Czerny, A. 1996, ApJ, 460, 107
- Stetson, P. B. 1996, PASP, 108, 851
- Tran, K., Levine, A., Rappaport, S., et al. 2013,
ApJ, 774, 81
- Zacharias, N., Finch, C., Girard, T., et al. 2010,
AJ, 139, 2184
- Zhang, X., Deng, L., Xin, Y., & Zhou, X. 2003,
Chinese J. Astron. Astrophys., 3, 151