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DISCOVERY OF THE BLAZHKO EFFECT IN V1065 Aql, CzeV980, FI Sge, AND CzeV1242

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1 Introduction

The Blazhko (BL) effect (Blazhko, 1907) is a common feature present in almost half of RR Lyrae (RRL) stars pulsating in the fundamental mode (Jurcsik et al., 2009; Benkő et al., 2010). Although it is known for more than a century, not much is known about what stands behind this phenomenon and the explanation of the modulation is still missing (for a review about the Blazhko effect see e.g. Kovács (2016) and Smolec (2016)). About 400 RRLs with the BL effect are catalogued in the Galactic field (Skarka, 2013)[1] and more than 3000 in the Galactic bulge (Prudil & Skarka, 2017). Due to relatively high incidence rate it is not much difficult to discover modulation in RRL stars that were previously considered to show stable pulsation. This is also the case of V1065 Aql, FI Sge, CzeV980, and CzeV1242, the latter two being a newly discovered RRL type stars.

2 Observations

All the stars were observed in the scope of survey dedicated to searching for new variable stars (e.g. Cagaš 2017). The strategy is similar as the one of the space telescope *Kepler* – long-term monitoring of one field.

The photometric unfiltered observations were carried out at BSO[2], Zlín, Czech Republic, using 0.3m Newtonian telescope with coma-corrector (f/4.7) equipped with Moravian instruments CCD G4-16000 (KAF-16803, 4096×4096 px) with field of view (FOV) of $90{\times}90$ arcmin. The full FOVs are shown in Fig. 1 and Fig. 2 together with the identification of comparison stars. For the reduction (dark frame and flat field corrections) and

[1] `http://physics.muni.cz/~blasgalf/`
[2] `http://www.bsobservatory.org/`

aperture photometry we used SIPS software[3]. For more details about the data reduction see Cagaš (2017).

The full journal of observations with number of seasons, nights and points is listed in Table 1. Dates of start and end of the observations are given in Table 1 too. Comparison stars used are listed in Table 2.

Table 1. Journal of observations.

Star	Start JD	End JD	Seasons	Nights	Points
V1065 Aql	2456210	2457662	4	23	2534
CzeV980	2457241	2457662	2	19	2218
FI Sge	2457989	2458046	1	14	1963
CzeV1242	2457989	2458046	1	14	1955

Table 2. Comparison stars.

Star	Comp ID	RA [$^{\mathrm{h\ m\ s}}$]	DEC [$^{\circ}\ '\ ''$]	V [mag]
V1065 Aql	UCAC4 520-117983	19 57 27.21	+13 50 38.3	13.129
CzeV980	UCAC4 518-117617	19 54 16.83	+13 33 59.1	13.160
FI Sge	UCAC4 538-127230	20 13 16.21	+17 30 37.0	13.940
CzeV1242	UCAC4 532-123593	20 16 06.33	+16 18 11.5	12.590

3 Analysis

Because all our data sets have only short extent (one to four seasons) we searched for additional data in large sky surveys. Usable data were found only in the ASAS–SN survey (Kochanek et al., 2017; Shapee et al., 2017). Unfortunately, the data cannot be easily stitched together because of different amplitudes. Thus we analysed the data separately.

For the initial pulsation period estimation we used Period04 (Lenz & Breger, 2005). When the rough period was known, we used LCfit routine (Sódor, 2012) for more precise period determination and for prewhitening the frequency spectra and searching for peaks close to the main pulsation components (the consequence of the BL effect).

We also estimated times of maximum light using polynomial fitting routine described in Skarka et al. (2015) that we applied to our data. As the zero epoch we used the most-bright well-defined maximum. The light ephemerides and rough estimation of the modulation period are shown in Table 3. Only in V1065 Aql our data give more precise period estimation than ASAS–SN data. BL period was always estimated on the basis of ASAS–SN data, because our data are not appropriate for that purpose.

[3]`http://www.tcmt.org/software.html`

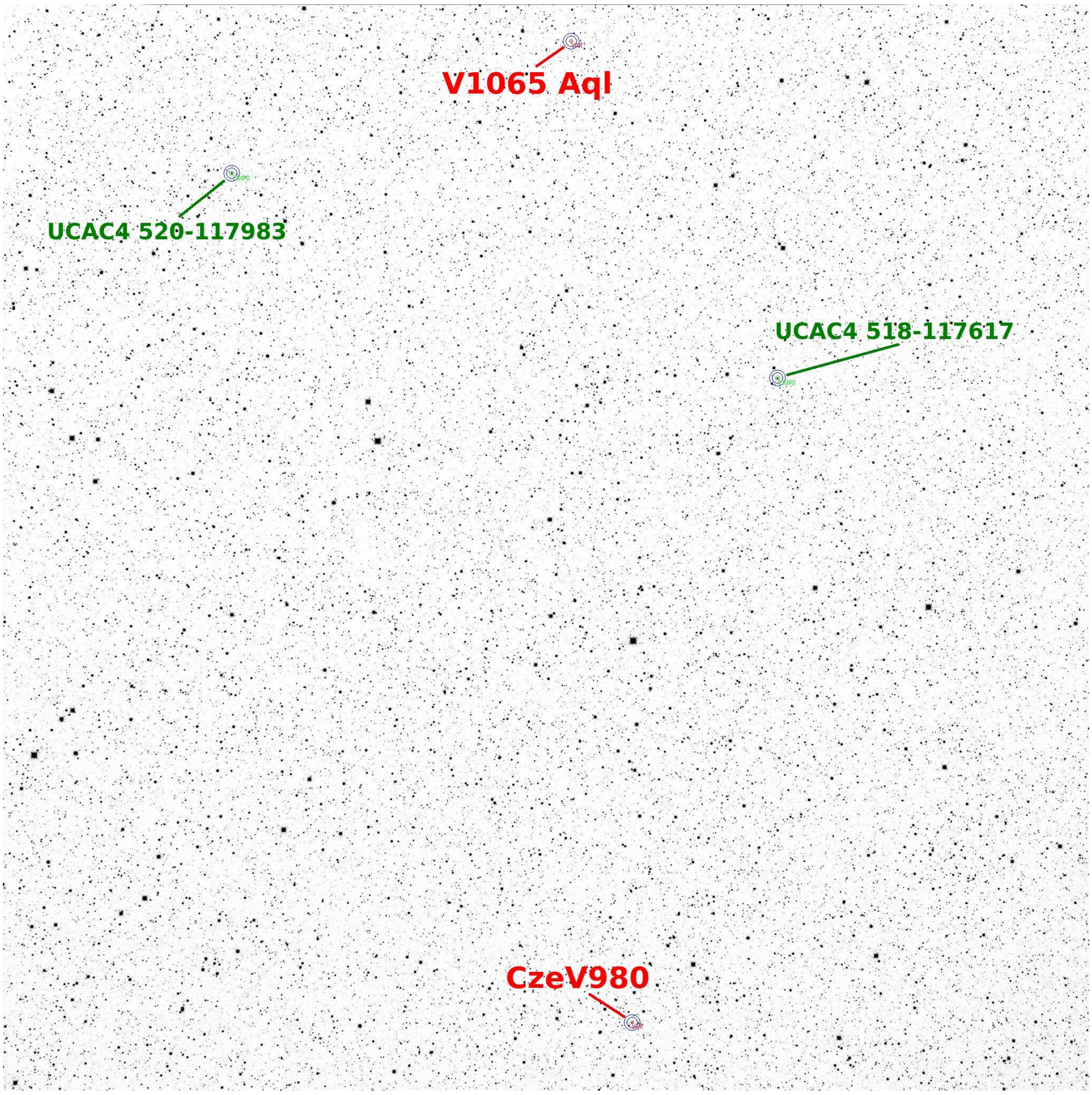

Figure 1. The full observed FOV with V1065 Aql and CzeV980 with identification of stars.

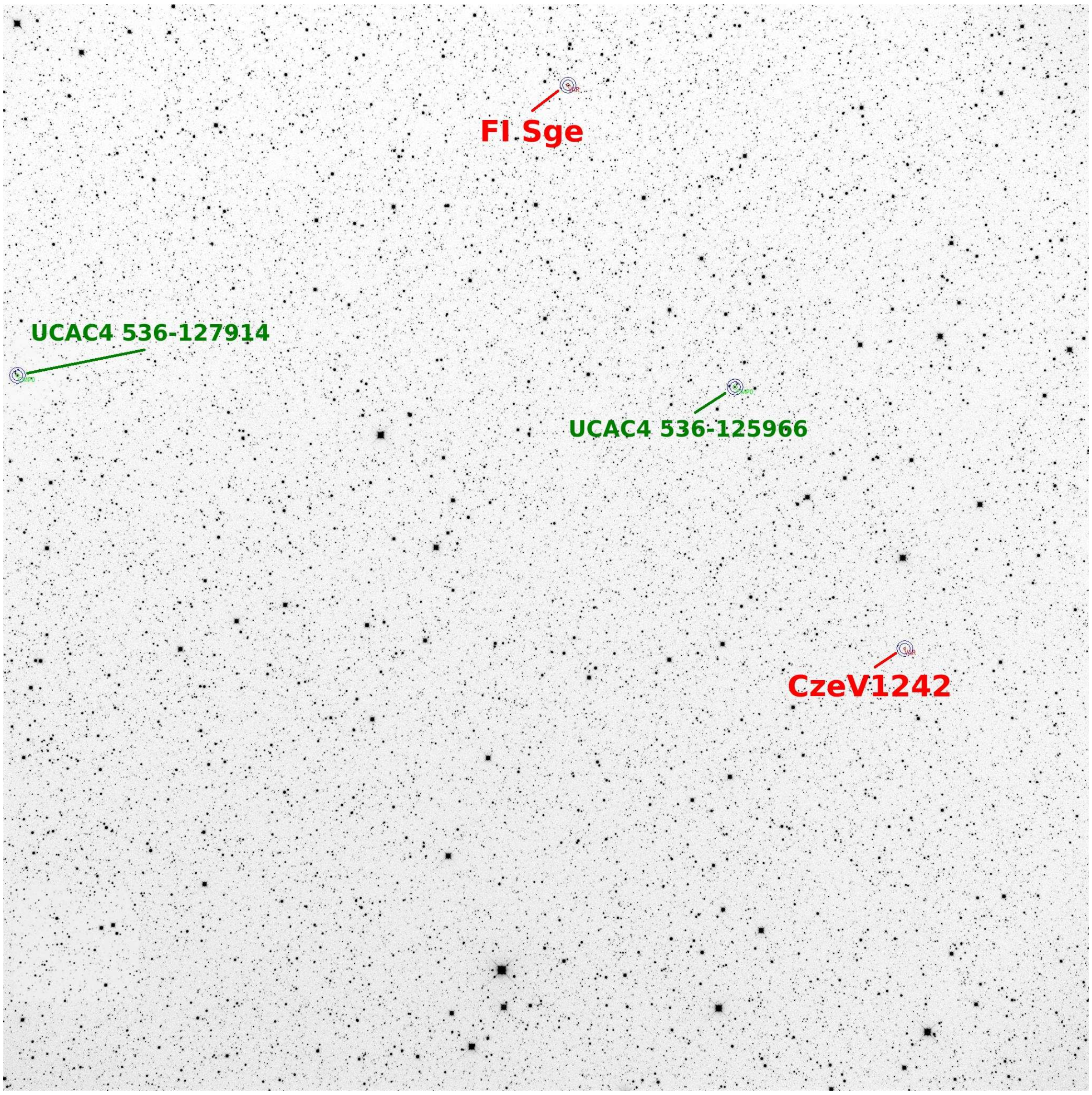

Figure 2. The full observed FOV with FI Sge and CzeV1242 with identification of stars.

Table 3. Light ephemerides and Blazhko period estimation. The upper index 'a' in pulsation period means that it is based on the ASAS–SN data.

Star	Zero epoch [HJD]	Pulsation period [d]	Blazhko period [d]
V1065 Aql	2456212.3690(4)	0.5089976(3)	~650
CzeV980	2457629.4404(2)	0.529675(3)[a]	~32.8
FI Sge	2458026.2833(2)	0.504783(2)[a]	~22.4
CzeV1242	2458043.2929(4)	0.415552(7)[a]	-

4 Remarks on individual stars

4.1 V1065 Aql

The variability of V1065 Aql (J2000 19:55:29.89 +14:02:07.5, photographic magnitude 15.5–16.5) was discovered by C. Hoffmeister (1964) on Sonneberg plates. The modulation is well apparent in variation of the amplitude of light changes in both from our and ASAS–SN data (see the two upper panels of Fig. 3). After removing 8 basic pulsation harmonics from the frequency spectra we identified a peak at 1.9632 c/d (see the detail in the bottom panel of Fig. 3), which suggests the modulation period about 650 d. From the envelope of the ASAS–SN data shown in the upper panel of Fig. 3 it is apparent that this period could be close to the correct one. However, the identified peak has signal-to-noise ratio (SNR) only about 3.8 and the data contain only one modulation cycle. Thus, the period is only the first, rough estimate.

From the phased light curve in the middle panel of Fig. 3 it is clear that the real modulation amplitude in magnitude is very likely significantly larger than we were able to estimate from our data (~ 0.34 mag).

4.2 CzeV980

CzeV980[4] (=UCAC4 514-114877, J2000 19:55:04.99 +12:39:29.26, $J = 14.463$ mag, $J - K = 0.402$ mag) lies in the same field as V1065 Aql (see Fig. 1). This star was found to be a new variable of RRab type.

The coverage of our data is very poor since we observed the star only in two consecutive seasons, in the first season having only one night (the original FOV was somewhat shifted in the first two seasons). However, even from these data the modulation is clearly recognizable (see Fig. 4). The star has the full amplitude of the light changes in maximum BL phase about 1 mag and the amplitude of the modulation is at least 0.23 mag in clear filter. Similarly as in V1065 Aql, our data are not appropriate for modulation period determination (see the detail in Fig. 4), but data from ASAS–SN survey suggest modulation period of 32.9 d (the peak to the left from the basic pulsation frequency in the detail of Fig. 4).

4.3 FI Sge

The variability of FI Sge (J2000 20:13:16.21 +17 30 37.0, V=13.94 mag) was discovered by Hoffmeister (1936). The star was observed only in 14 nights during the summer season 2017 (see Table 1). Side peak at 2.0303 c/d (SNR~4.4) suggests relatively well defined modulation period of the length of 22.4 d.

[4]Designation gives the identification in the Czech Variable star catalogue (Brát, 2005, Skarka et al., 2017).

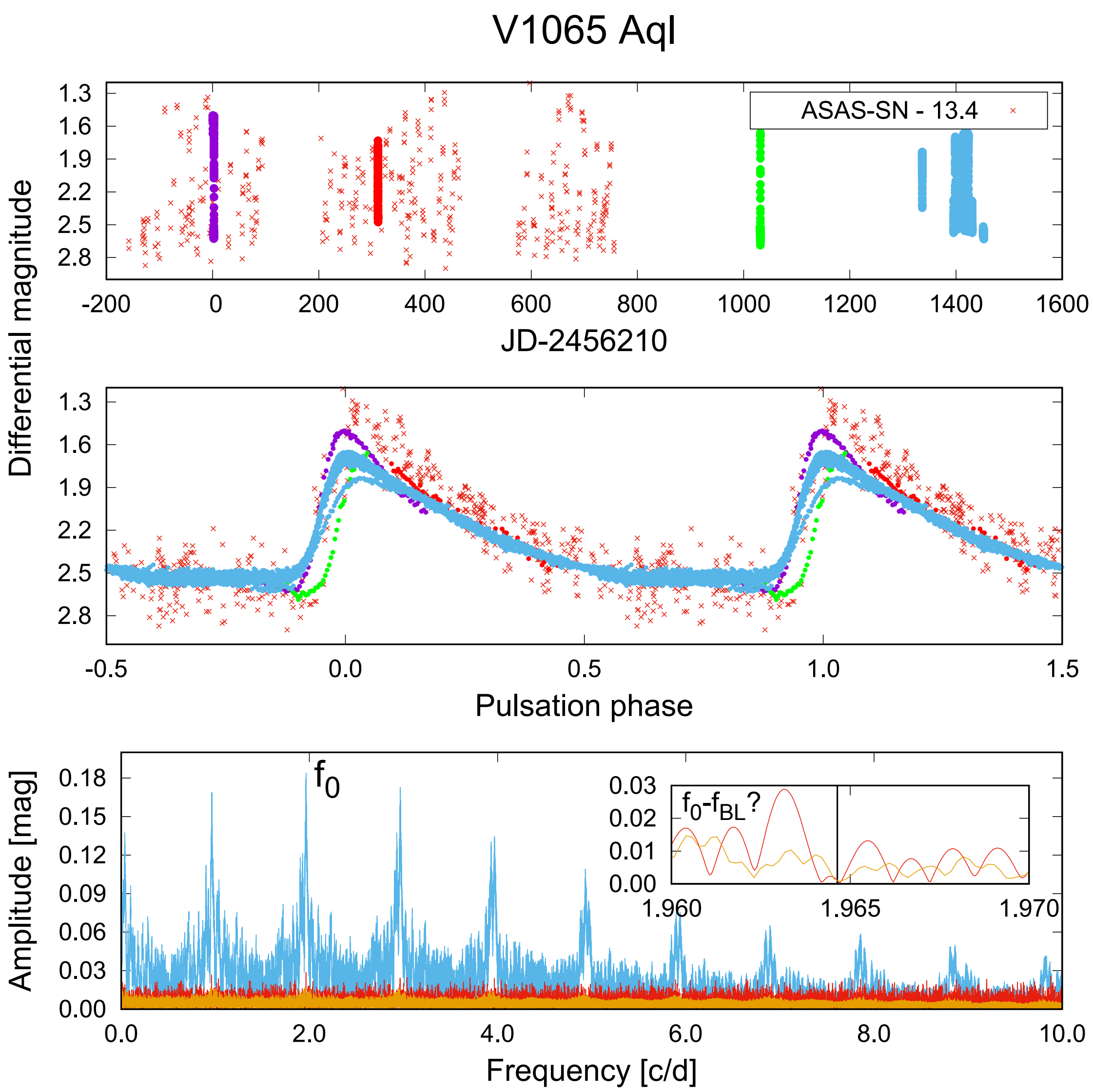

Figure 3. Distribution of V1065 Aql data (top panel), data phased according to ephemerides in Table 3 (middle panel), and corresponding frequency spectra (bottom panel). Different colours in our data (two upper panels) show different seasons, while red asterisks show ASAS–SN data. The light-blue line in the bottom panel shows the frequency spectra based on our data, yellow line shows the residuals after removing 8 pulsation harmonics. The red line shows the residual spectrum based on ASAS–SN data. The detail shows the vicinity of the main pulsation frequency (its position is shown by the black solid line).

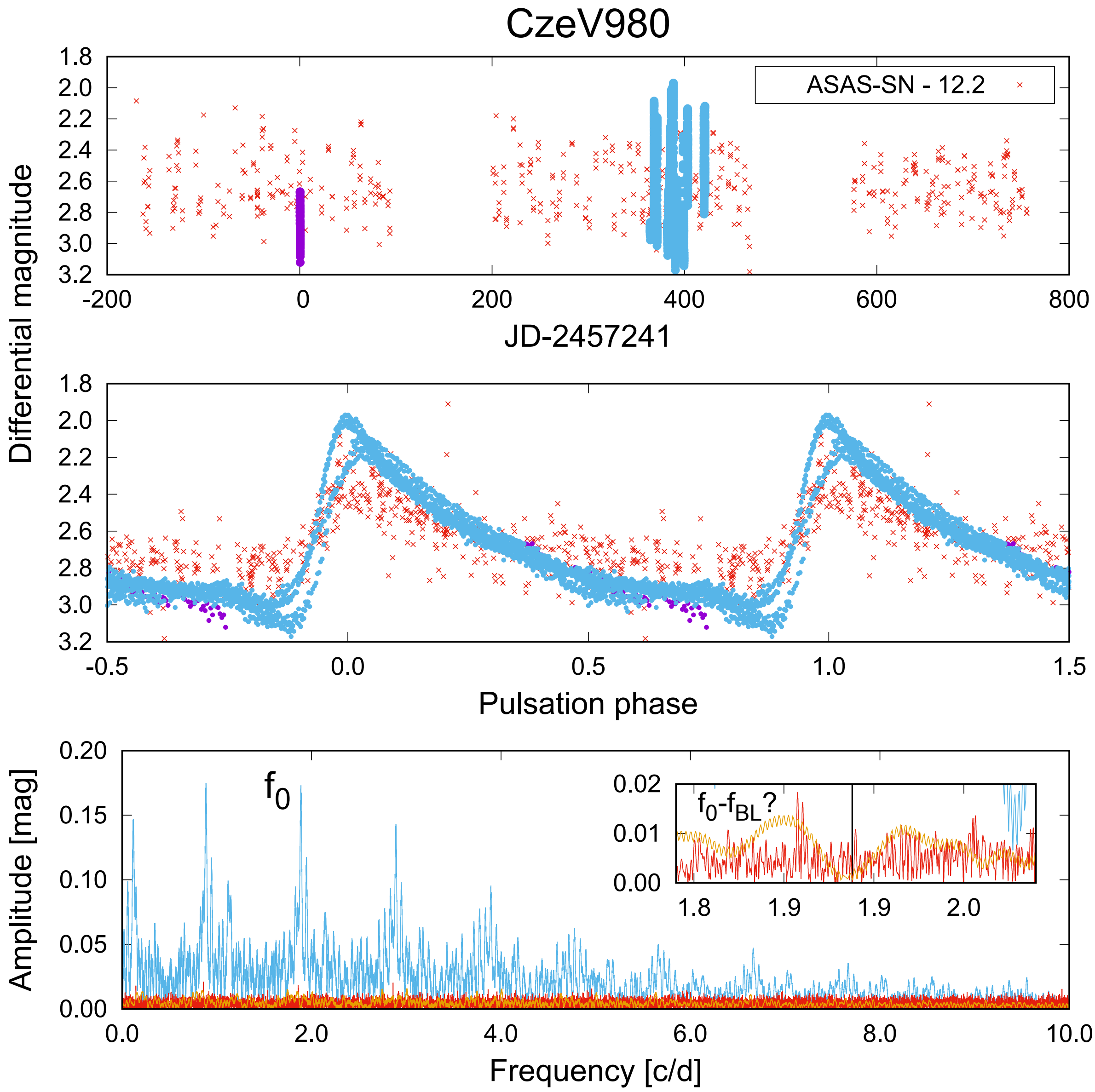

Figure 4. The same as in Fig. 3, but for CzeV980.

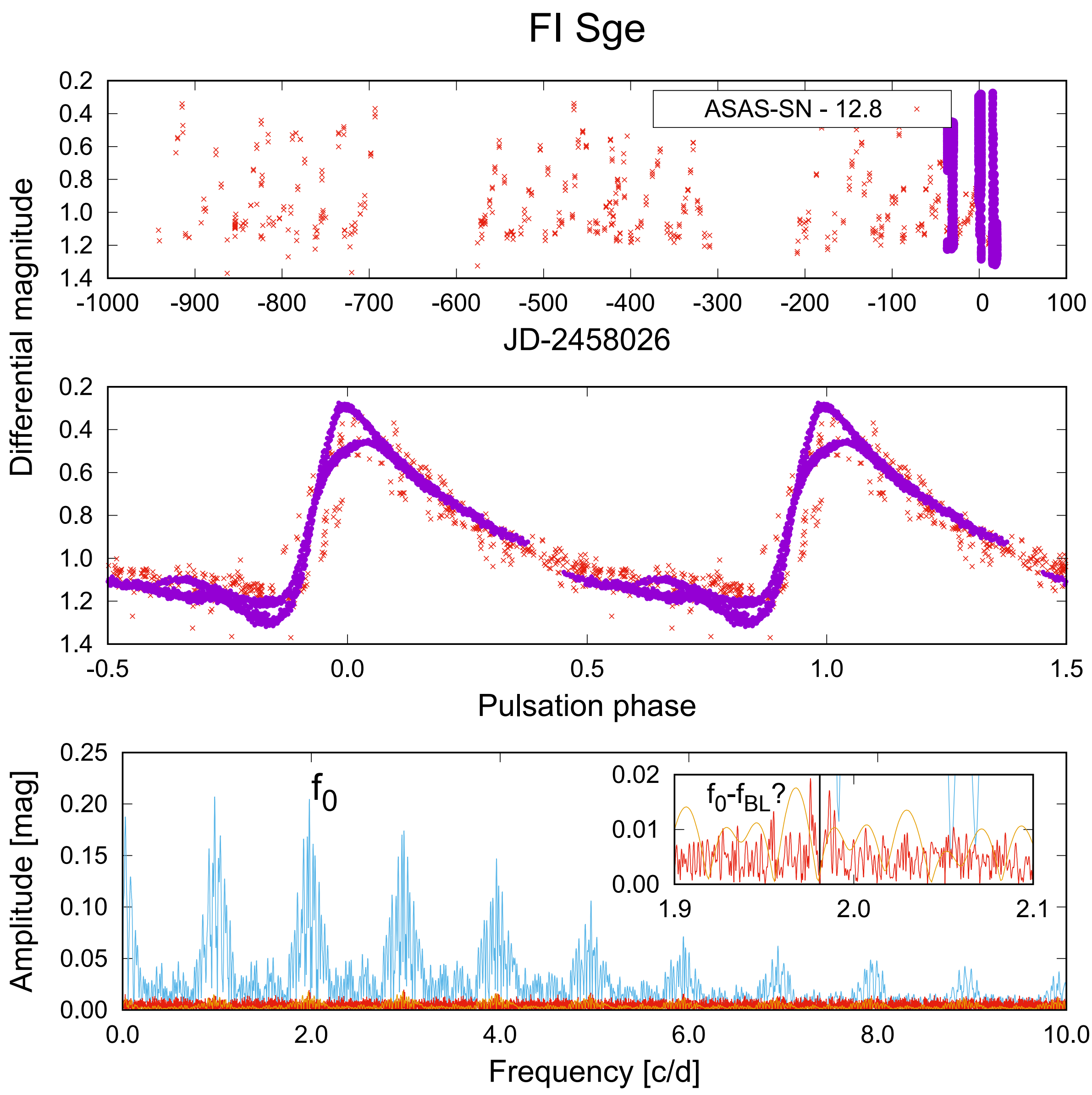

Figure 5. The same as in Fig. 3, but for FI Sge.

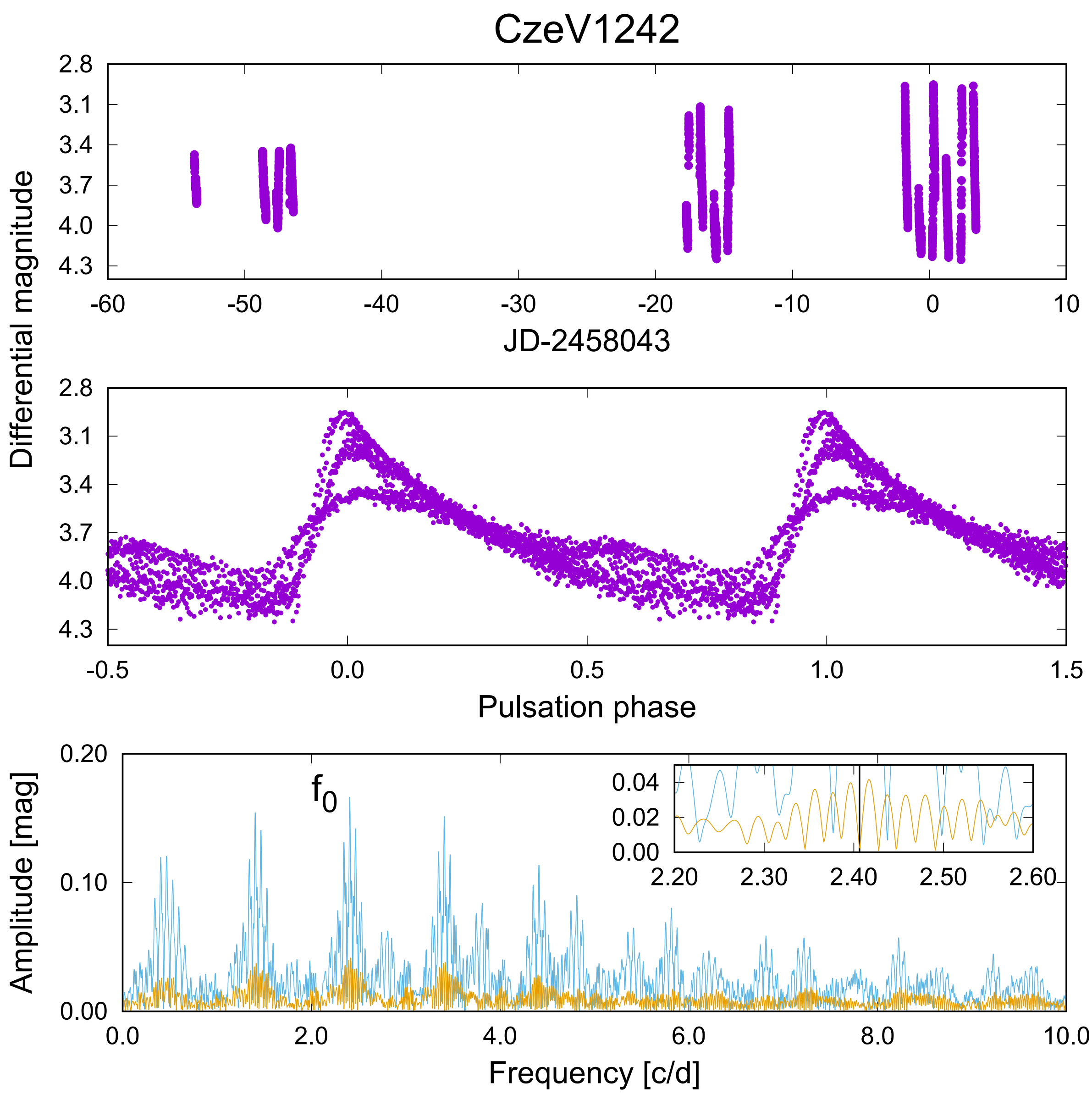

Figure 6. The same as in Fig. 3, but for CzeV1242.

4.4 CzeV1242

For CzeV1242 (USNO-A2.0 1050-16748412, J2000 20:11:14.38 +16:43:30.5, $J = 15.075$ mag, $J - K = 0.227$ mag) the ASAS–SN data were of very bad quality. However, there is no doubt about the presence of the BL effect from the middle panel of Fig. 6. Our data were also of insufficient quality for modulation period determination (the detail in the bottom panel of Fig. 6), thus, we are unable to give the rough estimate.

5 Conclusions

We report a discovery of the modulation in four RRab stars (V1065 Aql, CzeV980, FI Sge, and CzeV1242). The stars with 'CzeV' designation are newly discovered RRab stars. Pulsation periods were estimated from our and ASAS–SN data. We also determined maximum times based on our data. All stars show unambiguous signs of modulation especially in our data (except for V1065 the modulation is not apparent in ASAS–SN data set). In V1065 Aql, CzeV980, and FI Sge we give also first, rough estimates of their modulation periods. More data are needed for a better estimation of the modulation periods and better description of the modulation.

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Appendix

Table 3. Maximum times with their formal errors.

$T_{\max}$	Err($T_{\max}$)	$T_{\max}$	Err($T_{\max}$)	$T_{\max}$	Err($T_{\max}$)
V1065 Aql		2457633.4919	0.0005	2458026.2833	0.0002
2456210.3307	0.0015	CzeV980		2458027.2927	0.0003
2456212.369	0.0004	2457609.3308	0.0009	2458028.3046	0.0002
2457546.4698	0.0007	2457612.5079	0.0007	CzeV1242	
2457608.5551	0.0004	2457627.3204	0.0003	2457995.519	0.0016
2457609.5734	0.0006	2457628.3809	0.0003	2457996.3518	0.0031
2457624.3337	0.0004	2457629.4404	0.0002	2458025.4274	0.0008
2457625.3507	0.0003	2457644.2881	0.0011	2458026.2594	0.0008
2457626.3685	0.0003	FI Sge		2458028.3408	0.0008
2457627.3866	0.0004	2457989.4358	0.0003	2458043.2929	0.0004
2457628.4043	0.0004	2457994.4832	0.0005	2458043.2929	0.0004
2457629.422	0.0004	2457995.4902	0.0004	2458045.3628	0.0005
2457631.4582	0.0003	2457996.5007	0.0004		
2457632.4755	0.0002	2458025.2723	0.0003		