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A Study of Double-mode High-amplitude δ Scuti Variable Stars Pulsating in the Fundamental and First Overtone Modes. II

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I present a detection of 44 new double-mode high-amplitude δ Scuti variable stars, HADS(B) type, pulsating in the fundamental and first overtone modes. We analyzed all observations available for these stars in the ASAS-SN online public archive using the period-search software developed by Dr. V.P. Goranskij for Windows environment. Additionally, in individual cases, I used data of the SuperWASP, CSS, and ASAS-3 surveys. Light elements and parameters of the light curves of both oscillations were obtained.

1 Introduction

In the course of my study of high-amplitude δ Scuti variable stars (HADS) included in the ASAS-SN Variable Stars Database (Jayasinghe et al., 2018, 2019a, 2019b, 2020, 2021), I discovered 44 new double-mode HADS variables, pulsating in the fundamental and first overtone modes. This article continues my previous paper (Khruslov, 2021). Searching for double periodicity, I mainly used data available in the photometric archive of the All-Sky Automated Survey for Supernovae (ASAS-SN, Shappe et al., 2014, Kochanek et al., 2017). Additionally, I analyzed available data from other archives: the Wide Angle Search for Planets (SuperWASP, Butters et al., 2010), the Catalina Sky Surveys (Drake et al., 2009), the All Sky Automated Survey (ASAS-3, Pojmanski, 2002).

The SuperWASP observations are available as FITS tables, which were converted into ASCII tables using the OMC2ASCII[1] program as described by Sokolovsky (2007).

The method used to search for multiperiodicity is similar to that described in my previous paper (Khruslov, 2021).

The light curves and data from the ASAS-SN survey are available online in the html version of this paper as a zip-archive. The light curves are given in the format displayed in Fig. 1.

The radial pulsation modes were identified by the period ratio ($P_{\rm short}/P_{\rm long}$). The period ratio of pulsations in the fundamental and first-overtone modes typical of double-mode HADS stars (F/1O) is $P_1/P_0 = 0.75 - 0.78$ (Petersen & Christensen-Dalsgaard, 1996).

The stars were identified in the GSC 1.2 (Morrison et al., 2001) and USNO-B1.0 (Monet et al., 2003) catalogs. The tabulated coordinates of the variables were drawn from the Gaia DR2 catalog (Gaia Collaboration, Brown et al., 2018).

[1] http://scan.sai.msu.ru/swasp_converter/

Table 1. Positions, identifications, and magnitudes

No.	Coordinates (J2000)	GSC	USNO-B1.0	V, mag	Comments
1	12 08 10.53 –49 54 25.5	–	0400-0287767	14.02–14.57	1
2	12 10 23.35 –45 31 09.9	–	0444-0276786	14.90–15.46	2
3	12 16 31.56 –36 04 09.0	–	0539-0264614	15.12–15.72	2
4	12 17 43.89 –11 46 42.2	05529-01386	0782-0272273	13.98–14.33	2,3,4
5	12 32 21.34 –24 02 27.6	06682-00414	0659-0275812	14.30–14.73	1,2,5
6	12 45 59.08 –24 37 35.7	06688-00945	0653-0279223	14.40–15.15	2,6
7	12 49 45.36 +04 01 38.0	–	0940-0209227	14.4–15.0	2,7,8
8	12 59 13.60 –44 46 02.0	07784-01897	0452-0297280	14.30–14.94	1,9
9	13 16 19.13 –37 52 14.3	07774-00834	0521-0364332	12.75–13.14	1,2
10	13 24 50.14 –33 00 58.0	07268-00499	0569-0376858	14.52–15.11	1,2
11	13 29 01.45 –50 14 48.1	–	0397-0345242	15.2–15.7	1
12	13 29 25.93 –42 59 51.2	07795-02020	0470-0348501	12.66–13.31	5,10
13	13 33 53.05 +55 30 41.1	03853-00366	1455-0228972	13.30–13.59	1,7
14	13 35 40.37 –45 31 12.0	08261-01377	0444-0321790	12.20–12.63	1,2,5
15	13 48 09.81 –46 55 53.3	08266-03128	0430-0377207	14.47–15.35	1
16	13 50 07.59 –37 01 30.0	07291-01796	0529-0369256	13.41–13.88	1,5
17	13 55 03.49 –09 58 37.4	05553-00969	0800-0254490	14.5–14.9	–
18	13 59 10.53 –43 24 52.8	07802-00349	0465-0307388	14.55–15.28	1
19	14 12 06.96 –26 10 06.8	06734-00964	0638-0321431	13.60–14.10	1
20	14 52 11.10 –46 09 36.3	08280-00902	0438-0387168	13.15–13.45	2,5
21	14 53 13.45 –39 49 29.8	07824-01293	0501-0333265	13.76–14.16	1
22	14 53 53.44 –34 43 53.2	07306-02118	0552-0337321	13.97–14.61	1,2,5
23	15 11 30.55 –44 00 13.5	07834-02176	0459-0376147	13.43–14.02	1,2,5
24	15 20 00.03 –14 06 27.0	05606-01060	0758-0304698	14.05–14.52	–
25	15 25 39.01 –68 19 11.1	–	0216-0487098	14.4 -14.8	1
26	15 27 33.88 –67 58 49.1	09259-01071	0220-0632544	11.97–12.48	11,12
27	15 28 01.67 –39 18 40.7	07835-01463	0506-0367781	12.54–13.01	1,5

2 Results

In the $12^{\mathrm{h}} - 22^{\mathrm{h}}$ right ascension interval, I detected 44 new HADS(B) stars pulsating in the fundamental and first-overtone modes. Their magnitudes are between $10\overset{\mathrm{m}}{.}8$ and $15\overset{\mathrm{m}}{.}7$ in the V band of the ASAS-SN photometric system. The highest peak-to-peak amplitude of light variations is $0\overset{\mathrm{m}}{.}88$. The fundamental-mode periods are between $0\overset{\mathrm{d}}{.}049$ and $0\overset{\mathrm{d}}{.}198$.

The light curves for one of the stars (No. 40) are displayed in Fig. 1. The top panels present data folded with the fundamental-mode and first overtone periods. The bottom panels show the same curves after prewhitening the other oscillation (if $f_1{+}f_0$, $f_1{-}f_0$ and $f_1{+}2f_0$ interaction frequencies or non-radial frequencies were excluded, it is also noted). Along with the light curves, we present power spectra of the double-mode variables, for the raw data and after subtraction of the dominant mode (fundamental or first-overtone oscillations). The structure of the power spectra shows that the secondary periods are real.

Information on these stars is presented in Tables 1 and 2. Table 1 contains equatorial coordinates (J2000); star numbers from the GSC and USNO-B1.0 catalogs; magnitudes at maximum and minimum in the V band of the ASAS-SN photometric system; number for comments on individual stars, which are given below the table.

Table 1 (continued).

No.	Coordinates (J2000)	GSC	USNO-B1.0	V, mag	Comments
28	15 38 37.24 –27 16 08.6	06785-00473	0627-0454963	12.27–12.81	1,4,5,13,14
29	15 39 41.12 –41 46 03.7	–	0482-0418461	14.70–15.26	1
30	15 56 13.31 –79 00 28.9	09437-01620	0109-0087589	14.49–15.14	1,15
31	16 10 08.32 –67 55 22.2	09273-02948	0220-0666009	12.80–13.00	1,13,16
32	16 10 45.10 +14 32 37.4	–	1045-0266321	15.10–15.70	2,4,7
33	16 22 17.73 –66 39 43.7	09049-02231	0233-0607471	12.98–13.27	1,17
34	16 50 24.32 –51 54 31.1	08338-02654	0380-0739083	10.86–11.18	1,13
35	16 50 46.20 –84 24 26.6	09526-00038	0055-0045940	14.13–14.62	1
36	17 06 50.85 –60 11 22.5	–	0298-0712396	13.80–14.27	1
37	17 20 30.67 –53 00 23.6	–	0369-0906568	13.96–14.33	1
38	17 57 08.63 +08 46 59.3	–	0987-0333844	13.67–13.97	7
39	18 07 56.92 +09 01 48.9	01009-00503	0990-0334368	11.42–11.65	13,18
40	18 10 10.48 +78 28 41.5	04574-01244	1684-0067406	13.73–14.60	1
41	18 11 00.53 +23 33 52.5	–	1135-0277930	14.47–15.17	1
42	18 53 03.53 +34 19 56.7	02646-00538	1243-0294533	13.91–14.29	2,7
43	21 33 05.07 +20 42 19.4	01676-00916	1107-0562696	12.22–12.49	13
44	21 52 30.71 +21 02 09.0	01691-01258	1110-0569052	12.30–12.58	–

Comments to Table 1.

1. The variability was detected in the ASAS-SN survey, type HADS.
2. The star is contained in the Gaia DR2 catalog as a variable, type DSCT or SXPHE.
3. The variable is contained in the Catalina surveys periodic variable star catalog (Drake et al., 2014), the type HADS and a wrong period, $P = 0\overset{d}{.}0879278$, are given. In the ASAS-SN Variable Stars Database, the type RRC and the period $P = 0\overset{d}{.}3232124 = 4P_0$ are given.
4. Data from the Catalina survey (CSS or SSS) were used to improve the light elements.
5. Data from 1SWASP were used to improve the light elements.
6. The variability was discovered by Denis Denisenko (announcement of May 17, 2017 in the AAVSO Variable Star Index, DDE110).
7. The variable is contained in the ZTF catalog (Chen et al., 2020), type DSCT.
8. The variability was detected by Palaversa et al. (2013), LINEAR 7834923, type δ Sct or SX Phe is given.
9. Additional non-radial pulsation, $P_n = 0\overset{d}{.}06059591, A_n = 0.017$.
10. The variability was announced in GALEX TDS Alerts (May 2008 archive[2]). Later, Patrick Wils (announcement of October 05, 2010 in the AAVSO Variable Star Index) classified this variable as a HADS star.
11. The variability was detected in the ASAS-SN survey, type RRc.
12. Additional non-radial pulsation, $P_n = 0\overset{d}{.}11779922, A_n = 0.018$.
13. Data from the ASAS-3 survey were used to improve the light elements.
14. Better identification compared to GSC and USNO-B1.0: 2MASS15383724-2716085.
15. A close faint companion can somewhat influence the ASAS-SN photometry, amplitude is underestimated.
16. Light elements improved only for f_0.
17. P_0 possibly varies.

[2]http://www.galex.caltech.edu/researcher/alerts_archive/0805/

18. The variability was detected in the ASAS-3 survey (Pojmanski, 2002), type DSCT.

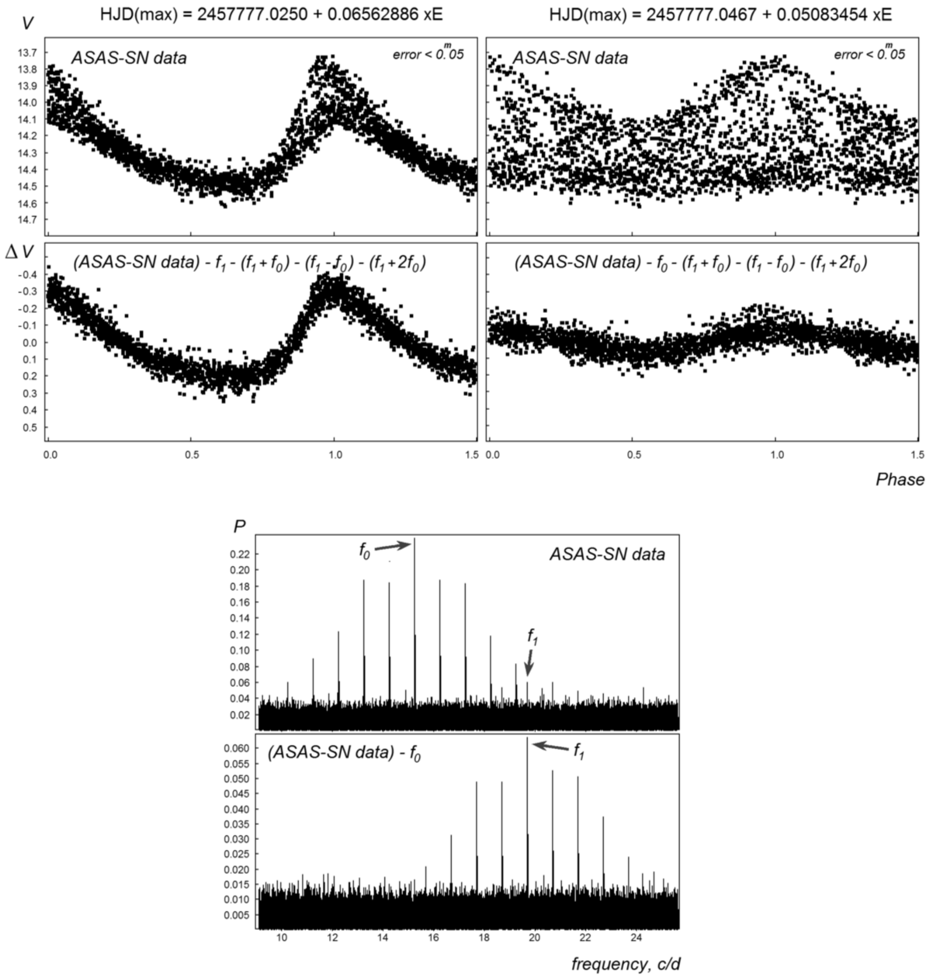

Figure 1. The light curves and power spectra of the star No. 40 (GSC 04574-01244) from ASAS-SN data.

Table 2 presents the light elements (period in days and epoch of maximum, $E = \mathrm{HJD} - 2457777.0$), semi-amplitude and asymmetry parameter $M-m$ for the fundamental mode (P_0, E_0, A_0, and $M-m$) and first-overtone mode (P_1, E_1, A_1 and $M-m$) oscillations, and the period ratio P_1/P_0.

The information on detected interaction frequencies is contained in Table 3: periods and semi-amplitudes of the frequencies f_1+f_0, f_1-f_0, and f_1+2f_0.

The Petersen diagram for double-mode HADS variables pulsating in the fundamental and first overtone modes, studied in this paper, is displayed in Fig. 2.

Acknowledgments: The author wishes to thank Dr. V.P. Goranskij for providing his software.

Erratum: In my previous paper (Khruslov, 2021), in Table 2, the epochs of maximum E_0 and E_1 should be understood in accordance with the rule $E = \mathrm{HJD}-2457777.0$, similar to designations in the present article.

Table 2. Light elements and light-curve parameters

No.	P_0	E_0	A_0	$M-m$	P_1	E_1	A_1	$M-m$	P_1/P_0
1	0.05421705	0.0288	0.130	0.48 :	0.04245730	0.0030	0.028	0.50	0.7831
2	0.0605625	0.0310	0.045	0.48	0.04693815	0.0056	0.135	0.38	0.7750
3	0.0760321	0.0537	0.108	0.44	0.0588474	0.0360	0.081	0.46	0.7740
4	0.08080310	0.0435	0.078	0.38	0.06262673	0.0583	0.038	0.47	0.7751
5	0.05299097	0.0190	0.144	0.43	0.04129606	0.0344	0.014	0.43	0.7793
6	0.07349022	0.0402	0.075	0.43	0.05787771	0.0138	0.142	0.44	0.7876
7	0.04835323	0.0397	0.109	0.45	0.03790137	0.0172	0.033	0.47	0.7838
8	0.1060661	0.0987	0.163	0.39	0.0819442	0.0125	0.040	0.42	0.7726
9	0.05385044	0.0027	0.125	0.43	0.04153844	0.0150	0.032	0.50	0.7714
10	0.0632775	0.0331	0.145	0.42	0.0488963	0.0438	0.058	0.40	0.7727
11	0.0668803	0.0535	0.071	0.44	0.0516401	0.0476	0.065	0.44	0.7721
12	0.07248921	0.0527	0.218	0.37	0.05637456	0.0528	0.034	0.50	0.7777
13	0.0545291	0.0104	0.081	0.46	0.0425803	0.0310	0.017	0.50	0.7809
14	0.11808945	0.0815	0.044	0.49	0.09104399	0.0080	0.135	0.40	0.7710
15	0.1063900	0.0818	0.195	0.38	0.0822725	0.0050	0.063	0.38	0.7733
16	0.09540190	0.0344	0.150	0.37	0.07388515	0.0620	0.028	0.48	0.7745
17	0.0909756	0.0420	0.067	0.44	0.0707977	0.0160	0.038	0.59	0.7782
18	0.0981587	0.0340	0.152	0.40	0.0758572	0.0625	0.097	0.40	0.7728
19	0.05489456	0.0384	0.091	0.41	0.04244899	0.0417	0.078	0.40	0.7733
20	0.05121980	0.0466	0.097	0.48	0.03959064	0.0085	0.016	0.50	0.7730
21	0.0716087	0.0245	0.123	0.38	0.0556071	0.0306	0.018	0.46	0.7765
22	0.07171796	0.0460	0.211	0.32	0.05568080	0.0213	0.036	0.38	0.7764
23	0.11554994	0.0100	0.141	0.40	0.08918751	0.0710	0.047	0.47	0.7719
24	0.05890204	0.0106	0.131	0.40	0.04559278	0.0250	0.023	0.48	0.7740
25	0.1273789	0.0066	0.052	0.47	0.0980794	0.0210	0.043	0.46	0.7700
26	0.1981664	0.1961	0.126	0.30	0.1512945	0.0620	0.040	0.39	0.7635
27	0.08477987	0.0308	0.154	0.37	0.06579935	0.0320	0.025	0.47	0.7761
28	0.0921824	0.0690	0.177	0.36	0.07106444	0.0670	0.030	0.47	0.7709
29	0.1079323	0.0390	0.129	0.35	0.0832761	0.0242	0.038	0.47	0.7716
30	0.06249759	0.0496	0.111	0.40	0.04840073	0.0177	0.063	0.41	0.7744
31	0.11027940	0.0310	0.065	0.45	0.0849659	0.0018	0.017	0.47	0.7705
32	0.0550930	0.0484	0.131	0.46	0.0431698	0.0187	0.028	0.51 :	0.7836
33	0.1520337	0.1486	0.086	0.44	0.1147119	0.0173	0.023	0.45	0.7545
34	0.06819099	0.0044	0.061	0.47	0.05271310	0.0203	0.027	0.47	0.7730
35	0.07040738	0.0415	0.085	0.40	0.05455083	0.0345	0.055	0.45	0.7748
36	0.1053168	0.0053	0.094	0.37	0.0814678	0.0460	0.030	0.44	0.7735
37	0.08752745	0.0864	0.102	0.40	0.0682577	0.0315	0.018	0.50 :	0.7798
38	0.0863452	0.0170	0.063	0.44	0.0671900	0.0033	0.037	0.43	0.7782
39	0.10531333	0.0177	0.075	0.45	0.08136916	0.0816	0.018	0.47	0.7726
40	0.06562886	0.0250	0.247	0.34	0.05083454	0.0467	0.058	0.44	0.7746
41	0.05119872	0.0297	0.211	0.39	0.03992636	0.0087	0.023	0.52	0.7798
42	0.0876665	0.0820	0.096	0.41	0.0676739	0.0545	0.040	0.45	0.7719
43	0.07696904	0.0560	0.061	0.45	0.05958269	0.0319	0.044	0.46	0.7741
44	0.0768717	0.0202	0.061	0.44	0.0596820	0.0021	0.046	0.46	0.7764

Table 3. Information on interaction frequencies

No.	P_{1+0}	A_{1+0}	P_{1-0}	A_{1-0}	P_{1+20}	A_{1+20}
1	0.02381086	0.020	–	–	–	–
2	–	–	–	–	–	–
3	–	–	–	–	–	–
4	–	–	–	–	–	–
5	0.02320905	0.009	–	–	–	–
6	0.03237805	0.033	–	–	–	–
7	–	–	–	–	–	–
8	0.04622891	0.022	0.3603088	0.020	–	–
9	0.02344990	0.009	0.18168206	0.009	–	–
10	0.02758248	0.023	–	–	–	–
11	0.02914020	0.023	–	–	–	–
12	0.03171217	0.020	0.25358226	0.017	–	–
13	–	–	–	–	–	–
14	0.05140885	0.016	0.3975195	0.017	–	–
15	0.04639495	0.035	0.3629301	0.031	0.03230665	0.026
16	0.04163814	0.020	0.3276010	0.014	0.02898677	0.010
17	–	–	–	–	–	–
18	0.04278941	0.028	0.3338889	0.038	–	–
19	0.02393807	0.021	0.1872339	0.026	0.01666912	0.011
20	–	–	0.1743745	0.006	–	–
21	–	–	0.2488406	0.014	–	–
22	0.03134499	0.021	0.2490127	0.019	–	–
23	0.05033576	0.022	0.3909190	0.021	–	–
24	–	–	–	–	–	–
25	–	–	–	–	–	–
26	0.08579321	0.030	–	–	0.05987247	0.012
27	0.03704679	0.014	–	–	–	–
28	0.04012877	0.018	0.31020314	0.017	0.02795813	0.010
29	–	–	–	–	–	–
30	0.02727661	0.023	0.2145814	0.036	–	–
31	–	–	–	–	–	–
32	–	–	–	–	–	–
33	–	–	–	–	–	–
34	–	–	–	–	–	–
35	0.03073655	0.014	0.2422169	0.018	–	–
36	–	–	–	–	–	–
37	0.03835072	0.014	–	–	–	–
38	0.03778613	0.013	–	–	–	–
39	0.04590280	0.005	0.3578865	0.006	–	–
40	0.02864606	0.037	0.2255053	0.031	0.01994176	0.020
41	0.02243270	0.015	–	–	–	–
42	0.0381919	0.013	0.296743	0.010	–	–
43	0.03358449	0.006	0.2637729	0.006	–	–
44	0.03359746	0.010	0.2668983	0.011	–	–

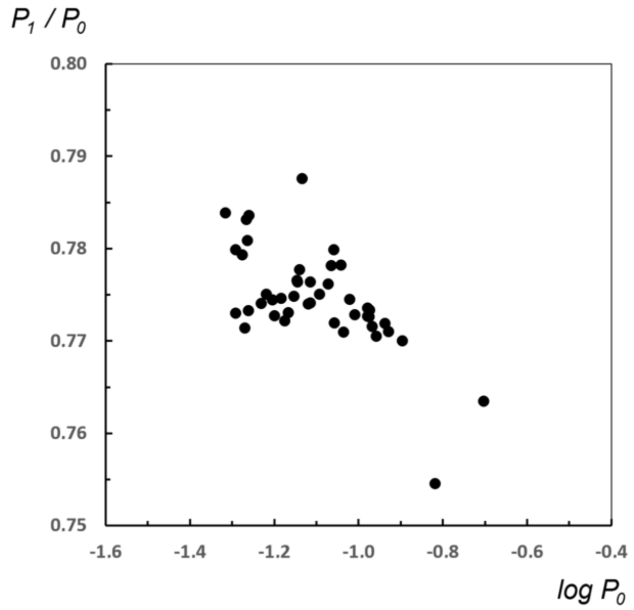

Figure 2. The Petersen diagram for the HADS(B) stars announced in this paper.

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