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A Study of Double-Mode High-Amplitude δ Scuti Variable Stars Pulsating in the Fundamental and First Overtone Modes. I

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I present a detection of 118 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, ASAS-3, and NSVS 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 118 new double-mode HADS variables, pulsating in the fundamental and first overtone modes. 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 Northern Sky Variability Survey (NSVS, Woźniak et al. 2004).

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

Among HADS type stars of the ASAS-SN lists, I selected the stars with phased light curves showing a somewhat larger scattering. For double-mode candidates, I analyzed all observations using Deeming's method (Deeming 1975) implemented in the WinEfk code[2] written by V.P. Goranskij. For several stars, I also detected 1 or 2 additional non-radial modes (see comments to Table 1).

For HADS(B) type stars, this paper supplements our previous publications (Khruslov 2009, 2011, 2014b, 2015c, 2018, 2020).

The light curves and data from the ASAS-SN surveys 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.

[1] http://scan.sai.msu.ru/swasp_converter/
[2] http://www.vgoranskij.net/software/

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 (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).

2 Results

In the right ascension interval $00^{\rm h} - 12^{\rm h}$, I detected 118 new HADS(B) stars pulsating in the fundamental and first-overtone modes. Their magnitudes are between $10\overset{\rm m}{.}3$ and $16\overset{\rm m}{.}1$ in the V band of the ASAS-SN photometric system. The highest peak-to-peak amplitude of light variations is $0\overset{\rm m}{.}9$. The fundamental-mode periods are between $0\overset{\rm d}{.}049$ and $0\overset{\rm d}{.}219$.

The light curves for one of the stars (No. 35) are displayed in Fig. 1. Top panels present data folded with the fundamental-mode and first overtone periods. Bottom panels show the same curves after prewhitening the other oscillation (if f_1+f_0, f_1-f_0 and other 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 2 presents the light elements (period in days, and epoch of maximum, HJD), 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; other modes for two cases, "a" and "b", are given below the table.

Two of the stars are contained in the General Catalog of Variable Stars (GCVS, Samus et al. 2017), No. 57 (V0807 Aur) and No. 88 (PP Cnc). Both stars were classified as δ Scuti variables (DSCT type in the GCVS classification system).

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

Table 1. Positions, identifications, and magnitudes

No.	Coordinates (J2000)	GSC	USNO-B1.0	V, mag	Comments
1	00 10 32.32 +32 23 48.1	02264-00469	1223-0003416	14.40–14.73	1,2
2	00 19 59.60 +49 07 55.6	–	1391-0009181	14.75–15.18	3
3	00 23 38.86 +28 37 45.1	01737-01308	1186-0005809	12.78–13.21	1,2,3,4,5,6
4	00 44 23.08 +28 13 13.9	01744-00939	1182-0013918	13.25–13.75	1,2,3,4,7
5	00 54 09.83 –53 57 50.2	08473-00232	0360-0006187	14.37–14.91	3
6	01 06 06.76 –31 06 50.1	06999-00176	0588-0012017	14.31–15.00	3,4,7
7	01 13 19.52 –32 31 10.8	07002-02069	0574-0014622	12.53–12.88	8
8	01 22 42.45 +08 54 06.9	00614-01301	0989-0012023	12.14–12.65	8,9,10
9	01 28 30.96 –35 30 37.2	07004-00789	0544-0012430	13.81–14.22	3,4,7
10	01 37 21.66 +10 10 31.8	–	1001-0013950	15.24–15.74	2
11	01 38 59.08 +43 33 22.4	02826-00354	1335-0031024	14.15–14.67	2
12	02 03 28.96 –54 55 07.5	08482-00617	0350-0014997	14.28–14.68	3
13	02 14 38.20 +52 54 43.9	–	1429-0074165	15.04–15.82	–
14	02 38 00.27 +28 08 02.2	01779-01144	1181-0042094	13.25–13.88	1,3,4,5,11
15	02 59 56.45 –22 49 08.2	06438-00986	0671-0039139	14.18–14.81	1,3,7
16	03 05 41.29 +84 02 21.6	04616-01295	1740-0006756	13.84–14.45	7
17	03 11 06.90 +34 29 09.6	–	1244-0044952	15.04–15.62	1
18	03 22 28.34 –49 53 56.4	–	0401-0025899	15.18 -15.75	3
19	03 26 11.39 –59 21 25.3	08499-00895	0306-0021812	14.36–15.08	3,7
20	03 31 51.68 –09 45 45.8	05296-00428	0802-0034347	14.45–15.0	3,7
21	03 55 44.26 +44 15 25.7	02876-00685	1342-0085570	11.65–12.17	1
22	03 57 05.32 +24 56 21.4	01817-00636	1149-0046971	12.70–13.02	1,2,8
23	03 58 10.89 +19 35 13.9	01257-00447	1095-0043931	14.00–14.59	2,5,12
24	03 58 31.38 –58 43 54.1	08507-01489	0312-0024539	13.08–13.37	7,13
25	04 02 27.52 +55 20 33.6	–	1453-0119425	13.81–14.25	1,2,7
26	04 03 20.09 –83 41 58.6	09492-02623	0063-0009008	11.70–12.05	8,9,14
27	04 22 16.95 –63 18 11.3	08872-01146	0266-0027244	14.00–14.32	7
28	04 54 25.87 +15 16 00.0	01280-01425	1052-0055729	15.00–15.40	2
29	04 57 35.63 +68 09 38.2	04342-02642	1581-0114191	13.62–14.05	2,7
30	04 58 01.28 –50 11 08.0	08083-01319	0398-0040619	12.56–13.04	3,8,9
31	05 09 15.12 +44 55 01.0	–	1349-0130586	13.62–14.25	1,2,4
32	05 21 07.82 +42 04 07.0	–	1320-0146648	14.04–14.66	1,7
33	05 22 49.70 +56 52 55.6	03756-00466	1468-0165058	14.73–15.15	1
34	05 27 39.16 –11 50 14.5	05340-01215	0781-0088861	13.95–14.42	3,7,8,15
35	05 36 58.20 +38 44 37.6	02910-01193	1287-0123535	12.70–13.16	1,2,7
36	05 42 19.20 +34 52 19.9	02413-00945	1248-0108043	11.87–12.38	1,16
37	05 45 57.22 +04 51 55.5	00124-01857	0948-0067579	13.92–14.26	2,7,17
38	05 46 59.00 –13 42 36.5	05359-00679	0762-0062688	13.53–14.01	3,4,5,18
39	05 49 59.44 +57 45 10.8	03758-00811	1477-0201646	14.72–15.10	2,19
40	05 52 15.04 +38 26 21.3	–	1284-0134768	14.10–14.59	1,7
41	05 54 02.76 +31 55 00.3	–	1219-0113872	14.67–15.11	1,2
42	06 04 55.57 +05 33 43.7	00138-01752	0955-0078740	14.57–15.09	–
43	06 05 58.96 –32 06 17.5	07075-00372	0578-0105650	14.80–15.35	3
44	06 11 07.91 –33 46 00.2	07080-00744	0562-0062360	12.96–13.36	1,3,7,8
45	06 12 26.82 –26 54 53.8	06513-00659	0630-0111793	14.90–15.30	1,3
46	06 13 34.34 –25 42 21.1	–	0642-0076933	15.45–16.05	3

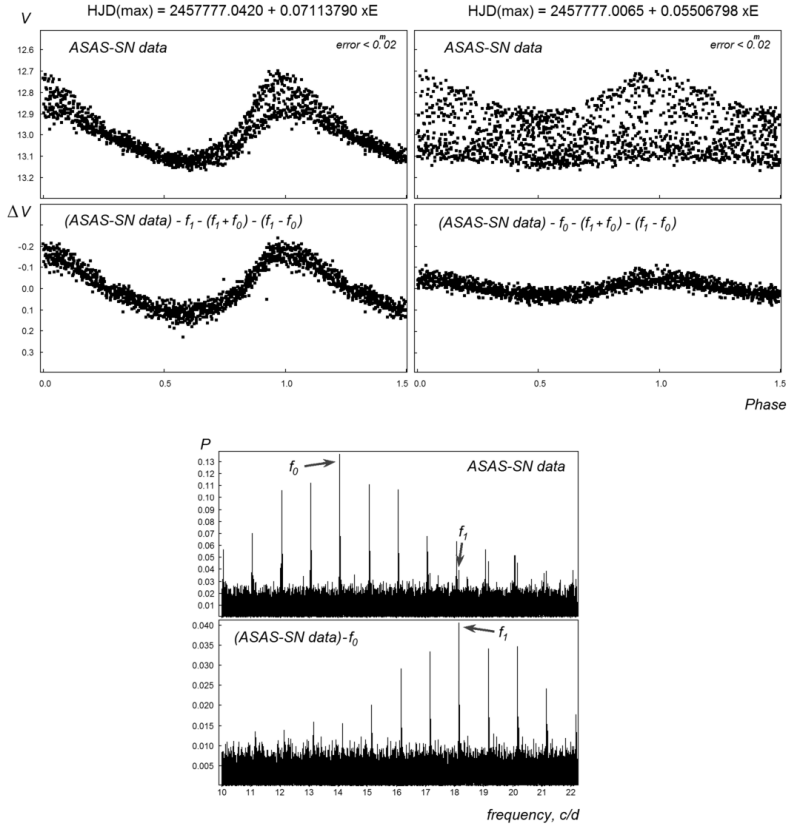

Figure 1. The light curves and power spectra of star No. 35 (GSC 02910-01193) from ASAS-SN data.

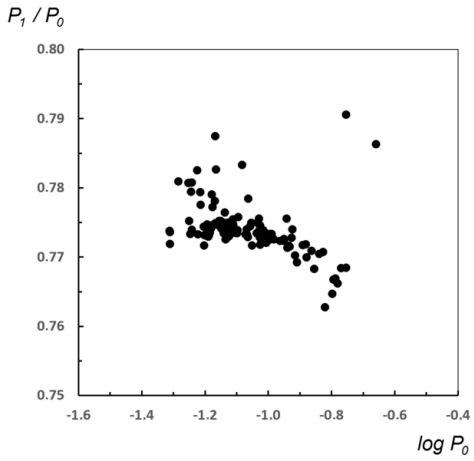

Figure 2. The Petersen diagram for the HADS(B) stars.

Table 1 (continued)

No.	Coordinates (J2000)	GSC	USNO-B1.0	V, mag	Comments
47	06 14 41.51 –27 46 48.4	06513-00255	0622-0106776	14.08–14.62	1,3,7,8
48	06 16 57.22 –28 36 08.5	–	0613-0073887	15.55–16.10	–
49	06 16 58.97 –21 33 18.9	05946-01171	0684-0088861	13.12–13.75	7,8
50	06 22 30.32 +23 19 32.9	01878-01104	1133-0125277	12.89–13.36	20
51	06 28 13.65 –12 37 12.3	05372-01751	0773-0113783	13.27–13.65	8
52	06 29 08.67 –18 29 48.2	05951-02954	0715-0083260	14.30–14.98	–
53	06 30 11.25 –25 55 05.9	–	0640-0084457	15.02–15.37	–
54	06 32 52.61 +16 08 37.7	–	1061-0110555	14.40–15.00	2,17
55	06 35 10.78 +56 30 27.9	03773-01053	1465-0179678	14.25–14.75	1,2,3
56	06 36 07.77 +20 26 14.4	01337-01189	1104-0116641	12.56–13.05	2
57	06 39 48.82 +46 57 14.9	–	1369-0180384	14.06–14.58	3,4,5,21
58	06 41 46.61 –32 45 27.5	07091-00259	0572-0111428	13.74–14.16	7
59	06 43 24.79 +21 27 36.0	–	1114-0135450	14.59–15.05	1, 2, 3
60	06 46 34.46 –25 07 51.7	06525-01065	0648-0094430	12.94–13.34	1,3,7
61	06 49 44.02 –45 16 41.2	08117-01123	0447-0065424	13.42–13.83	1,3,7,22
62	06 52 16.92 +53 55 46.6	03766-02065	1439-0177038	14.76–15.20	2,23
63	06 57 43.33 +23 37 12.9	01894-01205	1136-0131242	12.74–13.08	1,2,3,8
64	06 59 38.96 –38 01 59.0	07628-02239	0519-0082879	13.67–14.18	7,8
65	06 59 42.34 –44 41 56.0	07640-01727	0453-0068408	13.62–14.00	7
66	07 03 42.34 +20 11 54.5	–	1101-0133503	15.2–15.6	2
67	07 03 42.89 +25 21 57.6	01899-01601	1153-0134988	13.50–13.91	1,3
68	07 04 48.34 +76 11 10.2	04526-01334	1661-0044981	13.25–13.71	2,3,7
69	07 04 57.42 –50 59 43.3	–	0390-0068170	14.82–15.76	7
70	07 05 19.26 +07 21 52.9	–	0973-0155337	14.03–14.51	–
71	07 18 48.94 +14 56 20.8	–	1049-0145251	14.50–15.30	–
72	07 21 47.38 +28 27 41.3	–	1184-0151544	15.29–15.88	2
73	07 25 31.29 +19 19 15.5	–	1093-0144508	14.50–15.35	2,7
74	07 28 27.18 –02 07 59.7	04821-00218	0878-0212072	12.94–13.42	7,8
75	07 30 31.64 –44 51 51.3	–	0451-0082290	14.83–15.33	17,24,25
76	07 32 09.75 –52 09 41.9	08145-00183	0378-0110856	12.48–12.72	7,8
77	07 36 28.00 –10 04 25.2	–	0799-0140796	13.94–14.39	–
78	07 44 33.38 –09 52 47.6	–	0801-0149500	14.38–14.95	3
79	07 50 28.42 –07 07 32.6	–	0828-0201846	14.63–15.31	–
80	07 52 33.31 –10 01 42.9	–	0799-0154194	14.25–14.55	–
81	08 10 49.17 –64 37 42.8	08932-00427	0253-0100471	13.25–13.59	7,8
82	08 15 19.82 –51 18 29.2	08161-00028	0386-0095948	13.44–13.70	7,8
83	08 21 12.85 –24 38 23.9	–	0653-0192122	14.06–14.41	3
84	08 22 34.68 –10 07 00.8	–	0798-0171654	15.30–15.80	3
85	08 23 57.42 +31 41 58.5	02470-00257	1216-0165249	13.36–13.70	1,2,3,5,26
86	08 25 10.87 –66 46 29.3	08937-00164	0232-0169767	14.93–15.44	7
87	08 27 43.65 –68 22 14.7	–	0216-0153143	15.00–15.45	7
88	08 41 44.18 +25 30 30.6	01945-02080	1155-0159535	11.66–12.35	1,9,27
89	08 42 57.83 +01 36 47.8	–	0916-0169855	15.13–15.68	3
90	08 52 32.01 –29 11 48.8	–	0608-0206442	15.38–16.13	–
91	08 55 52.22 –17 01 40.2	–	0729-0267352	14.89–15.57	–
92	08 58 34.41 –30 27 02.2	–	0595-0209401	14.27–14.98	7

Table 1 (continued)

No.	Coordinates (J2000)	GSC	USNO-B1.0	V, mag	Comments
93	09 18 01.10 –07 37 44.1	05458-00494	0823-0248424	13.58–14.20	3,7,8
94	09 19 18.19 –35 39 04.9	07165-02056	0543-0195152	13.31–13.93	1,7,8
95	09 33 52.79 +77 43 17.5	04544-01447	1677-0062769	14.18–14.52	2,3
96	09 34 14.45 –08 00 45.2	05460-00148	0819-0239063	14.25–14.65	4
97	09 42 42.46 +46 24 34.7	03426-01265	1364-0207401	14.10–14.45	1
98	09 47 05.65 +32 01 55.0	02501-01015	1220-0200692	12.99–13.44	1,2,3,5,28
99	09 50 57.71 –39 45 24.9	07698-01304	0502-0197972	14.61–15.17	7
100	09 51 04.36 –77 51 51.6	09400-01546	0121-0051312	12.29–12.75	7,8
101	09 51 05.75 +19 08 26.5	01414-00707	1091-0176888	14.30–14.67	3
102	09 56 32.24 –36 15 23.8	07181-01296	0537-0216969	14.61–15.09	3
103	10 10 04.41 –37 10 36.8	–	0528-0285690	15.26–16.06	1,29
104	10 18 40.40 –21 44 49.7	06072-00342	0682-0271795	10.31–10.73	1,7
105	10 34 38.26 +52 09 43.3	03448-00306	1421-0244083	12.27–12.61	2,3
106	10 49 15.92 –48 39 08.0	08202-02421	0413-0222512	13.61–14.18	3,8
107	10 54 13.49 –77 24 12.6	09414-00551	0125-0072422	13.81–14.19	7,8
108	11 01 11.59 –51 13 45.2	–	0387-0239318	14.86–15.66	7
109	11 04 42.10 –48 47 56.4	08208-00254	0412-0232165	12.03–12.44	8,9,30
110	11 15 17.05 –42 07 10.5	07734-00267	0478-0297017	13.86–14.28	1,3,8
111	11 15 51.70 –31 29 48.1	07202-00985	0585-0261637	14.20–14.50	1
112	11 24 13.26 –08 54 54.3	05508-00686	0810-0228352	14.10–14.80	2,3,31
113	11 34 19.96 –32 54 34.5	07220-00586	0570-0335039	14.12–14.59	1,3,7
114	11 43 41.00 –06 33 48.6	04937-00474	0834-0234264	13.66–14.16	3,7
115	11 45 01.59 –71 11 20.3	–	0188-0235100	13.94–14.48	7,8,17
116	11 47 31.84 –19 30 09.7	06096-00315	0704-0249943	12.35–12.74	3,8
117	11 51 05.89 –53 12 21.0	08631-01733	0367-0336708	14.02–14.34	3,17
118	11 52 56.20 –20 38 50.0	06099-01115	0693-0265666	12.77–13.26	1,3,7,8

Comments to Table 1.

1. Data from 1SWASP were used to improve the light elements.

2. The variable is contained in the ZTF catalog, type DSCT.

3. The star is contained in the Gaia DR2 catalog as a variable, type DSCT or SXPHE.

4. Data from the Catalina survey (CSS or SSS) were used to improve the light elements.

5. The variable is contained in the Catalina surveys periodic variable star catalog (Drake et al. 2014).

6. The variable is contained in the TAROT suspected variable star catalog (TSVSC1 TN-N322130012-234-67-2, Damerdji et al. 2007).

7. The variability was detected in the ASAS-SN survey.

8. Data from the ASAS-3 survey were used to improve the light elements.

9. The variability was detected in the ASAS-3 survey (Pojmanski 2002).

10. Additional non-radial pulsation, $P_n = 0^{\rm d}.04539784$, $A_n = 0.012$.

11. Variability was detected by Wetterer and McGraw (2007), [WM2007] 42. According to V. Benishek (announcement of October 13, 2015 in the AAVSO Variable Star Index), the star is classified as a multiperiodic HADS variable, with two periods given, $P_1 = 0^{\rm d}.0824245$ (which is wrong) and $P_2 = 0^{\rm d}.1164448$. The ASAS-SN catalog gives type HADS with a wrong period, $P = 0^{\rm d}.0824245$ d.

12. Wrong type (EW) in the Catalina periodic variable star catalog (Drake et al. 2014).

13. Additional non-radial pulsation in the ASAS-SN catalog, $P_n = 0^{\rm d}.07653493$, $A_n = 0.019$.

14. Two additional non-radial pulsations. $P_{n1} = 0^{\rm d}.04610757$, $A_{n1} = 0.006$; $P_{n2} = 0^{\rm d}.04583652$, $A_{n2} = 0.005$.

15. Light elements improved only for f_0.

16. The variability was detected by E. Conseil (announcement of February 14, 2012 in the AAVSO Variable Star Index, VSX J054219.2+345219). In addition to the two radial oscillations, I detected one non-radial mode, $P_n = 0^{\rm d}.1180603$, $A_n = 0.018$. Interaction mode $f_n + f_0$: $P_{n+0} = 0^{\rm d}.06805571$, $A_{n+0} = 0.009$.

17. A close companion can somewhat influence the ASAS-SN photometry, amplitude is underestimated.

18. Additional non-radial pulsation, $P_n = 0^{\rm d}.0688260$, $A_n = 0.013$. In the CSS data, f_n is not detected.

19. The variability was discovered by Vitali Nevski (announcement of April 22, 2019 in the AAVSO Variable Star Index, NEV301).

20. P_0 possibly varies, individual light elements for the ASAS-3 and 1SWASP data time interval are given.

For ASAS-3:	f_0:	$HJD(max) = 2454000.0100 + 0^{\rm d}.1397980 \times E$;
	f_1:	$HJD(max) = 2454000.0638 + 0^{\rm d}.1074006 \times E$;
		$P_1/P_0 = 0.7683$;
For 1SWASP:	f_0:	$HJD(max) = 2454100.1023 + 0^{\rm d}.139820 \times E$;
	f_1:	$HJD(max) = 2454100.0510 + 0^{\rm d}.1074008 \times E$;
		$P_1/P_0 = 0.7681$;
		two interaction modes, $f_1 - f_0$ and $f_1 + f_0$, were detected.

21. GCVS variable (V0807 Aur), type DSCT, $P = 0^{\rm d}.1043815$. The variability was discovered by Monninger (2009, Object No.13). The new light elements were improved using Monninger's data. In the Catalina surveys periodic variable stars catalog (Drake et al. 2014), a wrong period $P = 0^{\rm d}.116583$ is given.

22. The period in the ASAS-SN catalog, $P = 0^{\rm d}.095300$, is wrong. Additional non-radial oscillation: $P_n = 0^{\rm d}.05395933$, $A_n = 0.010$.

23. Two periods P_0 and P_1 suggested in the ZTF as possibilities.

24. The star was included in the Gaia DR2 catalog as a variable, type RRAB.

25. Inaccurate coordinates are given in the ASAS-SN catalog.

26. The NSVS data were used for the light elements.

27. GCVS variable (PP Cnc), type DSCT, period $P = 0^{\rm d}.1595357$. In addition to the two radial oscillations, I detected one non-radial mode, $P_n = 0^{\rm d}.09466795$, $A_n = 0.018$.

28. The variability was detected by A. Ditkovsky (announcement of July 10, 2012 in the AAVSO Variable Star Index).

29. The variability was discovered by Denis Denisenko (announcement of May 26, 2017 in the AAVSO Variable Star Index, DDE 128).

30. Additional non-radial oscillation, $P_n = 0^{\rm d}.11628672$, $A_n = 0.008$.

31. The variability was detected by Palaversa et al. (2013), LINEAR 1426326, type δ Scuti.

Table 2. Light elements and parameters of light curves

No.	P_0	E_0	A_0	$M-m$	P_1	E_1	A_1	$M-m$	P_1/P_0
1	0.0726208	0.0392	0.052	0.50	0.0562745	0.0035	0.026	0.48:	0.7749
2	0.0678568	0.0340	0.103	0.42	0.0528000	0.0300	0.045	0.50	0.7781
3	0.09468345	0.0830	0.127	0.40	0.07318673	0.0075	0.032	0.47	0.7730
4	0.06633370	0.0076	0.149	0.37	0.05137296	0.0185	0.039	0.43	0.7745
5	0.0730171	0.0663	0.125	0.47	0.0566927	0.0450	0.050	0.42	0.7764
6	0.05965608	0.0305	0.180	0.40	0.04668118	0.0156	0.047	0.45	0.7825
7	0.05697485	0.0562	0.131	0.38	0.04440837	0.0138	0.009	0.53:	0.7794
8	0.0866064	0.0050	0.033	0.50	0.06741625	0.0159	0.152	0.41	0.7784
9	0.05734314	0.0188	0.128	0.42	0.04438018	0.0307	0.027	0.43	0.7739
10	0.0750599	0.0308	0.089	0.42	0.0580951	0.0325	0.033	0.46	0.7740
11	0.1314774	0.0535	0.076	0.44	0.1014740	0.0710	0.112	0.43	0.7718
12	0.0609297	0.0346	0.072	0.45	0.0474852	0.0062	0.058	0.42	0.7793
13	0.1090979	0.0163	0.174	0.40	0.0842605	0.0693	0.072	0.50:	0.7723
14	0.11644490	0.0555	0.077	0.41	0.08985065	0.0545	0.120	0.39	0.7716
15	0.05594349	0.0414	0.101	0.46	0.04367466	0.0340	0.110	0.45	0.7807
16	0.0923944	0.0506	0.153	0.34	0.0715963	0.0680	0.049	0.47	0.7749
17	0.07424527	0.0401	0.109	0.36	0.05753546	0.0359	0.073	0.42	0.7749
18	0.0488586	0.0115	0.137	0.40	0.0377969	0.0204	0.041	0.41	0.7736
19	0.0573055	0.0058	0.134	0.39	0.0447423	0.0202	0.094	0.41	0.7808
20	0.0647820	0.0145	0.119	0.41	0.0500718	0.0475	0.049	0.47	0.7729
21	0.1186905	0.0360	0.089	0.43	0.09171797	0.0315	0.092	0.37	0.7727
22	0.1631526	0.0469	0.086	0.44	0.1251222	0.0513	0.034	0.54	0.7669
23	0.1450347	0.0675	0.070	0.41	0.1117387	0.0602	0.102	0.41	0.7704
24	0.09511733	0.0477	0.072	0.43	0.07354215	0.0444	0.027	0.45	0.7732
25	0.09959518	0.0830	0.064	0.43	0.07701590	0.0687	0.095	0.38	0.7733
26	0.08565983	0.0032	0.133	0.43	0.06629983	0.0628	0.016	0.50	0.7740
27	0.0736922	0.0393	0.044	0.47	0.0569386	0.0465	0.045	0.48	0.7727
28	0.1143558	0.0193	0.116	0.43	0.0886835	0.0165	0.029	0.34	0.7755
29	0.1025558	0.0567	0.053	0.45	0.0793083	0.0448	0.074	0.46	0.7733
30	0.09396564	0.0241	0.196	0.32	0.07263767	0.0307	0.008	0.52	0.7730
31	0.09352360	0.0493	0.159	0.33	0.07253164	0.0386	0.050	0.45	0.7755
32	0.10091302	0.0260	0.187	0.35	0.07795395	0.0096	0.028	0.49	0.7725
33	0.08282542	0.0520	0.075	0.50	0.06487509	0.0348	0.053	0.46	0.7833
34	0.06509253	0.0311	0.144	0.39	0.0503301	0.0020	0.018	0.46	0.7732
35	0.07113790	0.0420	0.140	0.41	0.05506798	0.0065	0.036	0.45	0.7741
36	0.16067870	0.1043	0.165	0.33	0.12319683	0.0912	0.016	0.50	0.7667
37	0.0974633	0.0795	0.089	0.40	0.0753941	0.0508	0.017	0.62:	0.7736
38	0.08904091	0.0335	0.165	0.37	0.06870810	0.0183	0.020	0.41	0.7716
39	0.0767990	0.0650	0.087	0.42	0.0595345	0.0033	0.028	0.50	0.7752
40	0.2192864	0.0490	0.087	0.39	0.1724252	0.1680	0.086	0.37	0.7863
41	0.08777719	0.0827	0.080	0.41	0.06797523	0.0560	0.031	0.41	0.7744
42	0.1322361	0.112	0.068	0.50	0.1018154	0.0887	0.083	0.42	0.7700
43	0.0611311	0.0185	0.122	0.43	0.0475319	0.0445	0.036	0.43	0.7775
44	0.06275252	0.0582	0.123	0.43	0.04842434	0.0207	0.025	0.49	0.7717
45	0.1232893	0.0083	0.059	0.46	0.0948327	0.0400	0.051	0.50:	0.7692
46	0.0772017	0.0022	0.103	0.44	0.0597698	0.0540	0.050	0.47	0.7742

Table 2. Continued

No.	P_0	E_0	A_0	$M-m$	P_1	E_1	A_1	$M-m$	P_1/P_0
47	0.07234961	0.0018	0.166	0.38	0.05599595	0.0144	0.024	0.57:	0.7740
48	0.0943323	0.0884	0.125	0.43	0.0730645	0.0595	0.068	0.44	0.7745
49	0.10182476	0.0668	0.097	0.38	0.07874227	0.0115	0.106	0.37	0.7733
50	0.1397989	0.0086	0.103	0.43	0.1074014	0.1004	0.071	0.44	0.7683
51	0.05679453	0.0170	0.119	0.40	0.04391921	0.0159	0.010	0.57:	0.7733
52	0.1700172	0.0244	0.146	0.34	0.1306380	0.1240	0.068	0.40	0.7684
53	0.0785583	0.0486	0.079	0.40	0.0607636	0.0042	0.023	0.35	0.7735
54	0.1763610	0.1380	0.063	0.46	0.1355230	0.0380	0.103	0.41	0.7684
55	0.07736643	0.0440	0.107	0.39	0.05999301	0.0164	0.038	0.48	0.7754
56	0.1151140	0.0122	0.054	0.41	0.0887887	0.0484	0.106	0.41	0.7713
57	0.10438148	0.0900	0.161	0.41	0.08063586	0.0038	0.030	0.40	0.7725
58	0.0958132	0.0123	0.121	0.38	0.0740858	0.0150	0.022	0.45	0.7732
59	0.1372574	0.0330	0.076	0.46	0.1058089	0.0545	0.074	0.43	0.7709
60	0.11232503	0.0460	0.136	0.36	0.08678022	0.0415	0.012	0.41	0.7726
61	0.09527799	0.0705	0.151	0.39	0.07358515	0.0315	0.009	0.45	0.7723
62	0.08486650	0.0133	0.057	0.43	0.06562550	0.0061	0.065	0.43	0.7733
63	0.06991782	0.0473	0.109	0.44	0.05419923	0.0150	0.022	0.50	0.7752
64	0.09210623	0.0508	0.121	0.40	0.07123833	0.0390	0.069	0.43	0.7734
65	0.11930159	0.1056	0.041	0.43	0.09233415	0.0752	0.086	0.41	0.7740
66	0.07236349	0.0598	0.066	0.44	0.05596885	0.0274	0.035	0.46:	0.7734
67	0.07228580	0.0541	0.120	0.39	0.05596237	0.0253	0.030	0.41	0.7742
68	0.06434355	0.0203	0.143	0.38	0.04979364	0.0298	0.040	0.47	0.7739
69	0.07320242	0.0264	0.144	0.39	0.05669563	0.0202	0.099	0.39	0.7745
70	0.09560174	0.0165	0.071	0.48	0.07394077	0.0040	0.068	0.42	0.7734
71	0.0772149	0.0317	0.126	0.41	0.0597305	0.0512	0.099	0.46	0.7736
72	0.0660610	0.0368	0.140	0.38	0.05113813	0.0305	0.039	0.46	0.7741
73	0.0803655	0.0124	0.231	0.34	0.0623454	0.0102	0.046	0.48	0.7758
74	0.1658014	0.0452	0.152	0.37	0.1270300	0.0644	0.027	0.44	0.7662
75	0.0708421	0.0708	0.124	0.35	0.05491516	0.0170	0.029	0.50	0.7752
76	0.06731149	0.0121	0.062	0.45	0.05214632	0.0169	0.025	0.48	0.7747
77	0.07758749	0.0199	0.122	0.40	0.06010818	0.0448	0.023	0.50	0.7747
78	0.05623590	0.0564	0.088	0.48	0.04359416	0.0335	0.093	0.43	0.7752
79	0.1122287	0.0190	0.100	0.40	0.08667595	0.0724	0.096	0.40	0.7723
80	0.0942969	0.0712	0.079	0.44	0.0727752	0.0632	0.021	0.43	0.7718
81	0.06365898	0.0580	0.107	0.45	0.04921392	0.0225	0.015	0.48	0.7731
82	0.1762366	0.1480	0.055	0.44	0.1393228	0.0115	0.029	0.43	0.7905
83	0.07991623	0.0670	0.066	0.45	0.06184430	0.0353	0.042	0.45	0.7739
84	0.08854017	0.0305	0.071	0.44	0.06860936	0.0345	0.061	0.38	0.7749
85	0.06807665	0.0480	0.092	0.42	0.05275110	0.0477	0.024	0.49	0.7749
86	0.06546138	0.0582	0.092	0.45	0.05063580	0.0100	0.025	0.45	0.7735
87	0.0858664	0.0660	0.090	0.45	0.0663899	0.0050	0.046	0.47	0.7732
88	0.15953655	0.1210	0.164	0.34	0.1219950	0.1250	0.041	0.47	0.7647
89	0.0662835	0.0605	0.096	0.50	0.0516362	0.0412	0.073	0.46	0.7790
90	0.0942627	0.0353	0.135	0.45	0.0729176	0.0163	0.062	0.46	0.7736
91	0.07978169	0.0733	0.115	0.45	0.06170619	0.0260	0.080	0.46	0.7734
92	0.09658696	0.0087	0.146	0.35	0.07474365	0.0752	0.064	0.44	0.7738

Table 2 (continued)

No.	P_0	E_0	A_0	$M-m$	P_1	E_1	A_1	$M-m$	P_1/P_0
93	0.04885498	0.0208	0.177	0.35	0.03780310	0.0295	0.035	0.45	0.7738
94	0.06248116	0.0212	0.179	0.38	0.04838490	0.0073	0.060	0.44	0.7744
95	0.06410876	0.0045	0.094	0.40	0.04966603	0.0165	0.014	0.46	0.7747
96	0.07472371	0.0049	0.078	0.43	0.05780735	0.0430	0.034	0.50	0.7736
97	0.06811385	0.0272	0.069	0.47	0.05363685	0.0521	0.051	0.50	0.7875
98	0.14908390	0.0600	0.144	0.36	0.11490105	0.0840	0.014	0.53:	0.7707
99	0.1217307	0.1166	0.088	0.41	0.0937556	0.0488	0.080	0.45	0.7702
100	0.09814658	0.0150	0.100	0.41	0.07586985	0.0633	0.060	0.43	0.7730
101	0.06839633	0.0530	0.069	0.47	0.05352909	0.0350	0.041	0.48	0.7826
102	0.04895362	0.0051	0.111	0.43	0.03778475	0.0255	0.025	0.48	0.7718
103	0.09346032	0.0456	0.173	0.35	0.07230915	0.0167	0.052	0.44	0.7737
104	0.11699335	0.0055	0.096	0.40	0.09026021	0.0655	0.064	0.39	0.7715
105	0.0600389	0.0417	0.119	0.40	0.0464245	0.0053	0.018	0.45	0.7732
106	0.09402636	0.0765	0.109	0.41	0.07266560	0.0436	0.097	0.39	0.7728
107	0.1284868	0.0660	0.024	0.49	0.0991545	0.0355	0.107	0.42	0.7717
108	0.0937395	0.0678	0.165	0.39	0.0725399	0.0090	0.059	0.43	0.7738
109	0.15146130	0.1400	0.134	0.37	0.11552007	0.0750	0.023	0.47	0.7627
110	0.08632393	0.0464	0.132	0.40	0.06671833	0.0150	0.026	0.50	0.7729
111	0.06287259	0.0574	0.036	0.47	0.04861082	0.0396	0.034	0.54:	0.7732
112	0.05206046	0.0240	0.209	0.47	0.04065318	0.0285	0.033	0.46	0.7809
113	0.06673347	0.0610	0.128	0.38	0.05186660	0.0421	0.014	0.44	0.7772
114	0.06897060	0.0496	0.105	0.47	0.05342869	0.0343	0.048	0.40	0.7747
115	0.07365285	0.0083	0.142	0.40	0.05703312	0.0520	0.022	0.49:	0.7744
116	0.07519871	0.0155	0.056	0.47	0.05812928	0.0240	0.091	0.41	0.7730
117	0.09865323	0.0480	0.041	0.48	0.07616441	0.0760	0.056	0.44	0.7720
118	0.07344838	0.0065	0.147	0.38	0.05674253	0.0090	0.037	0.47	0.7725

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}	Other
1	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–
3	0.04127931	0.017	0.3223555	0.012	–	–	–
4	0.02895127	0.017	0.2277823	0.020	0.02015478	0.010	–
5	0.03191389	0.023	0.2535770	0.031	–	–	–
6	0.02618844	0.026	0.2146271	0.028	–	–	–
7	–	–	–	–	–	–	a
8	0.03790783	0.013	–	–	–	–	–
9	0.02501790	0.009	0.1963212	0.015	–	–	–
10	0.03274847	0.023	–	–	–	–	–
11	0.05727166	0.030	0.444659	0.023	–	–	–
12	0.02668695	0.016	0.215203	0.024	–	–	–
13	0.04754189	0.046	0.370099	0.037	–	–	–
14	0.05071697	0.031	0.3934226	0.029	–	–	–
15	0.02452678	0.021	–	–	–	–	–
16	0.04033822	0.033	0.3180588	0.027	0.02807918	0.016	–
17	0.03241561	0.024	–	–	–	–	–
18	–	–	0.166945	0.026	–	–	–

Table 3 (continued)

No.	P_{1+0}	A_{1+0}	P_{1-0}	A_{1-0}	P_{1+20}	A_{1+20}	Other
19	0.02512525	0.036	0.2040868	0.031	–	–	–
20	0.02824247	0.015	–	–	–	–	–
21	0.05173777	0.032	0.4036159	0.027	–	–	–
22	0.07081453	0.011	–	–	–	–	–
23	0.06311377	0.035	0.4867028	0.026	–	–	–
24	0.04147482	0.006	0.3242151	0.005	–	–	–
25	0.04343122	0.021	–	–	–	–	–
26	0.03737331	0.004	0.2933632	0.003	–	–	–
27	–	–	–	–	–	–	–
28	–	–	–	–	–	–	–
29	0.04472307	0.014	0.3498720	0.013	–	–	–
30	–	–	0.3200157	0.007	–	–	–
31	0.04085031	0.038	0.3231361	0.028	–	–	–
32	0.04397993	0.020	0.3426311	0.017	0.03063056	0.014	–
33	–	–	–	–	–	–	–
34	0.02838355	0.009	0.2219164	0.011	–	–	–
35	0.03103987	0.019	0.2437773	0.020	–	–	–
36	0.06973116	0.014	–	–	–	–	–
37	–	–	–	–	–	–	–
38	–	–	–	–	–	–	–
39	–	–	–	–	–	–	–
40	0.0965268	0.033	0.806864	0.020	–	–	–
41	–	–	–	–	–	–	–
42	0.05752391	0.023	–	–	–	–	–
43	–	–	–	–	–	–	–
44	0.02733252	0.008	0.2120846	0.008	–	–	–
45	–	–	–	–	–	–	–
46	–	–	–	–	–	–	–
47	0.03156553	0.019	–	–	–	–	–
48	0.04117343	0.030	–	–	–	–	–
49	0.04440433	0.041	0.347363	0.037	0.03092047	0.015	b
50	0.06073909	0.020	0.4634449	0.020	–	–	–
51	–	–	–	–	–	–	–
52	0.07387422	0.048	0.564029	0.025	–	–	–
53	–	–	–	–	–	–	–
54	–	–	–	–	–	–	–
55	0.03379060	0.017	0.2671553	0.016	–	–	–
56	0.05012589	0.021	0.3882436	0.032	–	–	–
57	0.04549274	0.016	0.3544606	0.022	–	–	–
58	0.04178020	0.015	–	–	–	–	–
59	–	–	–	–	–	–	–
60	0.04895718	0.008	0.3816054	0.006	–	–	–
61	–	–	–	–	–	–	–
62	0.03700804	0.022	–	–	–	–	–
63	0.03053147	0.008	–	–	–	–	–
64	0.04016972	0.025	0.3144267	0.024	0.02797070	0.011	–

Table 3 (continued)

No.	P_{1+0}	A_{1+0}	P_{1-0}	A_{1-0}	P_{1+20}	A_{1+20}	Other
65	0.05205001	0.011	–	–	–	–	–
66	–	–	–	–	–	–	–
67	0.03154260	0.017	0.2478237	0.016	0.02196017	0.009	–
68	0.02807055	0.016	0.2202047	0.013	–	–	–
69	0.03195015	0.041	0.2514304	0.042	–	–	–
70	0.04169382	0.020	–	–	–	–	–
71	0.03367828	0.037	0.2637856	0.048	–	–	–
72	–	–	–	–	–	–	–
73	0.2780419	0.036	–	–	–	–	–
74	0.07192454	0.018	0.543220	0.009	–	–	–
75	0.03093503	0.023	–	–	–	–	–
76	0.02938308	0.006	–	–	–	–	–
77	–	–	–	–	–	–	–
78	0.02455729	0.027	0.1939254	0.018	–	–	–
79	0.04890570	0.031	0.3806920	0.031	–	–	–
80	–	–	–	–	–	–	–
81	–	–	–	–	–	–	–
82	–	–	–	–	–	–	–
83	–	–	–	–	–	–	–
84	–	–	–	–	–	–	–
85	0.02972092	0.008	–	–	–	–	–
86	–	–	–	–	–	–	–
87	–	–	–	–	–	–	–
88	0.06913216	0.025	0.5184505	0.014	0.04823154	0.014	–
89	–	–	0.2336731	0.031	–	–	–
90	–	–	–	–	–	–	–
91	0.03479446	0.023	0.2723680	0.017	–	–	–
92	0.04213677	0.031	0.3305004	0.042	–	–	–
93	0.02131213	0.015	0.1671060	0.014	–	–	–
94	0.02726850	0.032	0.2144556	0.035	–	–	–
95	–	–	–	–	–	–	–
96	–	–	–	–	–	–	–
97	0.03000743	0.012	–	–	–	–	–
98	0.06488945	0.010	0.5011128	0.007	–	–	–
99	–	–	–	–	–	–	–
100	0.04279145	0.018	0.3342642	0.013	–	–	–
101	0.03002817	0.017	0.2462620	0.017	–	–	–
102	–	–	–	–	–	–	–
103	0.04076761	0.039	0.3195103	0.027	–	–	–
104	0.05095159	0.022	0.3950135	0.010	–	–	–
105	0.02618066	0.010	0.204735	0.010	–	–	–
106	0.04098874	0.028	0.319869	0.018	–	–	–
107	–	–	–	–	–	–	–
108	0.04089434	0.040	0.3207267	0.033	–	–	–
109	0.06553481	0.009	–	–	–	–	–
110	–	–	–	–	–	–	–

Table 3 (continued)

No.	P_{1+0}	A_{1+0}	P_{1-0}	A_{1-0}	P_{1+20}	A_{1+20}	Other
111	–	–	–	–	–	–	–
112	0.02282749	0.019	0.1855331	0.022	–	–	–
113	0.02918404	0.012	–	–	–	–	–
114	–	–	0.23709254	0.020	–	–	–
115	–	–	0.2527484	0.012	–	–	–
116	0.03278564	0.016	0.2560867	0.012	–	–	–
117	–	–	–	–	–	–	–
118	0.03201187	0.019	0.2494732	0.011	–	–	–

Other modes:

a $f_1 + f_0 + 1$, $P = 0\overset{\mathrm{d}}{.}0243471$, $A = 0.007$.

b $2f_1 - f_0$, $P_{21-0} = 0\overset{\mathrm{d}}{.}06419139$, $A_{21-0} = 0.014$;
$2f_1 + f_0$, $P_{21+0} = 0\overset{\mathrm{d}}{.}02839295$, $A_{21+0} = 0.013$;
$2f_0 - f_1$, $P_{20-1} = 0\overset{\mathrm{d}}{.}1440517$, $A_{20-1} = 0.013$.

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