Six Double-Mode Variables

A. V. Khruslov

Institute of Astronomy, Russian Academy of Sciences, Moscow, Russia

#	Name	Other	Coord (J2000)	Type	Max	Min	System	Period	Epoch (JD)	type	Sp	Comment	L.Curve	Find.Chart	Data
1		GSC 3282-00145	01 36 23.21, +48 00 28.4	RRC	13.12	13.53	WASP	(see Comments)	(see Comments)	max		Comm. 1	1.PNG	chart1.PNG	1SWASP_data_1.txt
2		GSC 1340-00246	06 25 41.61, +22 06 19.5	HADS(B)	12.20	12.65	WASP	(see Comments)	(see Comments)	max		Comm. 2	2.PNG	chart2.PNG	ASAS 062542+2206.4 1SWASP_data_2.txt
3		GSC2.3 S8GA125608	17 18 24.66, -28 49 52.1	CEP(B)	16.29	16.78	Ic	(see Comments)	(see Comments)	max		Comm. 3	3.PNG	chart3.PNG	OGLE-BLG-RRLYR-00293
4		USNO-B1.0 0611-0636219	17 57 11.86, -28 51 48.3	CEP(B)	15.24	15.71	Ic	(see Comments)	(see Comments)	max		Comm. 4	4.PNG	chart4.PNG	OGLE-BLG-T2CEP-209
5		GSC 8455-00781	23 18 01.14, -45 19 55.0	HADS(B)	12.79	13.74	CV	(see Comments)	(see Comments)	max		Comm. 5	5.PNG	chart5.PNG	ASAS 231801-4519.9 1SWASP_data_5.txt SSS_data_5.txt
6		USNO-B1.0 1038-0622479	23 18 34.55, +13 51 26.2	RRC	14.48	15.02	CV	(see Comments)	(see Comments)	max		Comm. 6	6.PNG	chart6.PNG	CSS_data_6.txt

Comments:

1. The variability of GSC 3282-00145 was discovered in 2013 by Alexandr Ditkovsky (the VS-COMPAS project) from ROTSE-I/NSVS data. The AAVSO Variable Star Index suggests type RRC, with the light elements:
Max = HJD 2451541.127 + $0^d.204929 \times E$.
According to data from 1SWASP (Butters et al. 2010), it is actually an RRC star with a non-radial pulsation co-existing with the first-overtone mode. The light elements are:

Mode	Frequency, c/d	Semi-amplitude, WASP_mag	Period, days	Epoch, HJD
f_1	4.87971	0.124	0.204930	2454380.119
f_2	5.32586	0.030	0.187763	2454380.080

The period ratio is $P_2 / P_1 = 0.9162$. J–K = 0.206 (2MASS).

2. The variability of GSC 1340-00246 was discovered by Pojmanski (2002). The ASAS-3 catalog lists the variable as a DSCT star with the elements:
Max = HJD 2452622.986 + $0^d.094964 \times E$.
I re-investigated the star using the currently available ASAS-3 and 1SWASP data. It is actually a HADS(B) star, pulsating in the fundamental and first overtone modes. The light elements are:

Mode	Frequency, c/d	Semi-amplitude, WASP mag / V(ASAS) mag	Period, days	Epoch, HJD
f_1	8.524640	0.089 / 0.114	0.1173070	2454000.099
f_0	6.551002	0.066 / 0.093	0.1526484	2454000.133
$f_1 + f_0$	15.07563	0.026 / 0.037	0.0663322	2454000.0398
$f_1 - f_0$	1.97348	0.015 / –	0.50672	2454000.47
$2f_1$	17.04931	0.008 / –	0.0586534	2454000.0328
$2f_1 + f_0$	23.60038	0.006 / –	0.0423722	2454000.0215

The period ratio is $P_1 / P_0 = 0.7685$; possibly $P_2 / P_1 = 0.7870$ and $P_2 / P_0 = 0.6048$. J–K = 0.166 (2MASS). From the ASAS-3 data, the variability range is $12^m.12 – 12^m.74$ in the V band.

3. The variability of OGLE-BLG-RRLYR-00293 was discovered by Soszynski et al. (2011a). The variable was classified as an RRAB variable with the light elements:

Max = HJD 2455000.13654 + 0^d.42303636 × E.
I re-analyzed the OGLE-III observations. Actually, this is a double-mode Cepheid (type DCEP(B)) with the elements:

Mode	Frequency, c/d	Semi-amplitude, I_C mag	Period, days	Epoch, HJD
f_0	2.363865	0.1733	0.423036	2452500.419
f_1	3.398055	0.0452	0.294286	2452500.303
$f_1 + f_0$	5.761909	0.0164	0.1735536	2452500.340

Possible interaction frequencies: $f_1 + 2f_0$ (P = 0^d.123067); $2f_0$ (P = 0^d.211518). The galactic latitude is b = +5°.046. M–m = 0.33 P (fundamental mode pulsation).

4. The variability of OGLE-BLG-T2CEP-209 was discovered by Soszynski et al. (2011b). The variable was classified as a BL Her variable star with the light elements:
Max = HJD 2455000.14712 + 1^d.1812838 × E.

The cited authors give the secondary periods 0^d.83298, 0^d.48851, 0^d.34559. I re-analyzed the OGLE-III observations. Actually, this is a double-mode Cepheid (type DCEP(B)), pulsating in the fundamental and first overtone modes. The presented secondary periods correspond to the first-overtone frequency and interaction frequencies $f_1 + f_0$, $f_1 + 2f_0$; besides, we detected 8 more frequencies. The light elements are:

Mode	Frequency, c/d	Semi-amplitude, I_C mag	Period, days	Epoch, HJD
f_0	0.846532	0.2080	1.18129	2453600.43
f_1	1.200509	0.0224	0.832980	2453600.197
$f_1 + f_0$	2.047041	0.0182	0.488510	2453600.180
$f_1 + 2f_0$	2.893594	0.0162	0.345591	2453600.240
$f_1 - f_0$	0.353950	0.0078	2.82526	2453601.39
$f_1 + 4f_0$	4.58665	0.0074	0.218024	2453600.433
$4f_0 - f_1$	2.185616	0.0047	0.457537	2453600.220
$4f_0$	3.386238	0.0035	0.295313	2453600.301
$3f_0 - f_1$	1.33912	0.0035	0.74676	2453600.11
$2f_0 - f_1$	0.492577	0.0034	2.03014	2453601.83
$5f_0 + f_1$	5.43319	0.0030	0.184054	2453600.240
$5f_0$	4.23268	0.0025	0.236257	2453600.301

Analyzing the OGLE data, we rejected observations of JD 2454221 that give a too large scatter of the light curve. The galactic latitude is b = –2°.142.

5. The variability of GSC 8455-00781 was discovered by Pojmanski (2002). The ASAS-3 catalog lists the variable as a DSCT star with the elements:
Max = HJD 2451869.763 + 0^d.11501 × E.
I re-investigated the star using the currently available ASAS-3, 1SWASP, and SSS data. It is actually a high-amplitude double-mode Delta Scuti star. The light elements are:

Mode	Frequency, c/d	Semi-amplitude, WASP mag / CV(SSS) mag / V(ASAS) mag	Period, days	Epoch, HJD
f_0	8.694858	0.249 / 0.225 / 0.231	0.1150105	2454200.102
f_1	11.24637	0.075 / 0.061 / 0.077	0.0889176	2454200.071
$f_1 + f_0$	19.94121	0.047 / 0.042 / 0.049	0.0501474	2454200.0295
$f_1 - f_0$	2.551470	0.038 / 0.035 / –	0.391931	2454200.345
$2f_0 + f_1$	28.63606	0.025 / 0.023 / –	0.0349210	2454200.0145
$2f_0 - f_1$	6.143336	0.013 / 0.020 / –	0.162778	2454200.145
$3f_0 - f_1$	14.83829	0.007 / – / –	0.0673932	2454200.0465
$f_0 + 2f_1$	31.18753	0.011 / – / –	0.0320641	2454200.0065

$3f_0 + f_1$	37.33098	0.008 / – / –	0.0267874	2454200.0060
$4f_0 - f_1$	23.53312	0.006 / – / –	0.0424933	2454200.0213
$2f_0$	17.38967	0.003 / – / –	0.0575054	2454200.0550
$3f_0$	26.08433	0.002 / – / –	0.0383372	2454200.0225

The period ratio of the first-overtone and fundamental modes is $P_1 / P_0 = 0.7731$. J–K = 0.156 (2MASS). From the ASAS-3 data, the variability range is $12^m.9 - 13^m.7$ in the V band; from the 1SWASP data, $13^m.00 - 13^m.91$.

6. The variability of USNO-B1.0 1038-0622479 was discovered by Drake et al. (2014; the Catalina surveys periodic variable star catalog). The variable was classified as an RRC star with the period $0^d.258489$. I re-analyzed the CSS observations, with the RR Lyrae nature and period of the variable confirmed. A secondary (non-radial) wave is superimposed on the first overtone pulsation. The non-radial period is constant in all time interval of CSS data, the first overtone period varies. The light elements:
First-overtone period (P_1):
JD 2453500 – 2454500: HJD = $2454000.062 + 0^d.258493 \times E$;
JD 2454600 – 2455600: HJD = $2455000.175 + 0^d.258477 \times E$;
JD 2455600 – 2456600: HJD = $2456000.185 + 0^d.258464 \times E$.
Non-radial pulsation (P_2):
JD 2453500 – 2456600: HJD = $2455000.222 + 0^d.260058 \times E$.
The amplitudes of the two oscillations vary:

JD	Semi-amplitude, CV mag A_1 / A_2
2453500–2454500	0.133 / 0.078
2454600–2455600	0.159 / 0.057
2455600–2456600	0.177 / 0.048

The period ratio is $P_1 / P_2 = 0.9939 - 0.9940$. J–K = 0.095 (2MASS); B–V = 0.321 (APASS).

Remarks:

I present a new investigation of six known variable stars. I analyzed all observations available for these stars in the ASAS-3 (Pojmanski 2002), SuperWASP (Butters et al. 2010), OGLE-III, and Catalina Surveys (Drake et al. 2009) online public archives using the period-search software developed by Dr. V.P. Goranskij for Windows environment. According to these data, the variables are double-mode variables, pulsating in the radial (type HADS(B) and CEP(B)) or radial and non-radial (type RRC) modes.

The period ratios P_1 / P_0 for stars Nos. 2 and 5 are typical for radially pulsating high-amplitude double-mode Delta Scuti stars (Petersen and Christensen-Dalsgaard 1996). The period ratios P_1 / P_0 for stars Nos. 3 and 4 (Cepheids) are also similar.

Along with the light curves, I present power spectra of the variables, for the raw data and after subtraction of the first-overtone (or fundamental mode) oscillations. The structure of the power spectra shows that the secondary periods are real. In certain cases, frequencies related to interactions between the two main modes were found (see the Comments).

The tabulated coordinates of the variables were drawn from the 2MASS, GSC2.3, and USNO-B1.0 catalogs.

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

References:
Butters, O.W., West, R.G., Anderson, D.R., et al., 2010, Astron. Astrophys., 520, L10
Drake, A.J., Djorgovski, S.G., Mahabal, A., et al., 2009, Astrophys. J., 696, 870
Drake, A.J., Graham, M.J., Djorgovski, S.G., et al., 2014, Astrophys. J. Suppl., 213, 9
Petersen, J.O., Christensen-Dalsgaard, J., 1996, Astron. Astrophys., 312, 463
Pojmanski, G., 2002, Acta Astronomica, 52, 397
Sokolovsky, K.V., 2007, Perem. Zvezdy Prilozh., 7, No. 30
Soszynski, I., Dziembowski, W.A., Udalski, A., et al., 2011a, Acta Astron., 61, 1
Soszynski, I., Udalski, A., Pietrukowicz, P., et al., 2011b, Acta Astronomica, 61, 285