COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS

Number 5878

Konkoly Observatory
Budapest
25 February 2009

HU ISSN 0374 – 0676

PHOTOMETRIC OBSERVATIONS OF HIGH-AMPLITUDE DELTA SCUTI STARS

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The period evolution of High-Amplitude Delta Scuti Stars (HADS) is not well understood. Stellar evolution theory predicts an increasing period (Breger & Pamyatnykh, 1998), but also decreasing periods are possible during short times, and have been observed. Breger & Pamyatnykh (1998) suggest that most period changes in δ Scuti stars are caused by non-linear effects in pulsation and not to evolution. Furthermore it is not clear whether changes in period occur monotonously or in contrast abruptly with constant periods in between changes. The observational records are often too fragmented to decide between the two scenarios. Also detecting light time effects due to companions is of interest to better determine the pulsator's mass and understand its evolution. It is therefore important to regularly obtain accurate data to monitor the period behaviour of HADS.

In most cases times of maximum light are used for period studies. These are calculated from the observations using a variety of methods (often with polynomial fitting). The calculated times are usually based on data points close to maximum, while data from the rest of the cycle are ignored. Depending on the calculation method used (e.g. the degree of the fitted polynomial) and the selected data points, this often leads to a fairly large spread in the calculated times, larger than the quoted uncertainties. Higher accuracy can however be obtained when all the available observations are used, especially data from the ascending and descending branches of the light curve, as there the variation is largest per time unit.

Table 1: Details on the observed HADS without GCVS designation.

Star	Position (2000)		Mag. NSVS	Epoch HJD	Period (d)
GSC 4519-1078	04:57:20.99	+79:20:58.7	11.8-12.2	2454823.415	0.140316(2)
GSC 3755-0845	06:05:01.84	+55:09:51.9	10.4-10.7	2454201.293	0.07609773(1)
GSC 2977-0238	08:19:17.58	+41:59:00.5	10.6-11.0	2454204.343	0.07593393(5)
GSC 4552-1498	11:24:25.47	+77:42:15.3	12.9-13.4	2453321.535	0.05581096(1)
GSC 3832-0152	11:48:42.04	+54:43:07.1	11.7-12.1	2453489.290	0.09134218(2)
GSC 4556-1113	12:03:17.41	+80:33:42.4	11.5-11.9	2453813.332	0.086337(3)
GSC 3863-0740	14:41:38.23	+56:26:17.3	11.4-11.7	2453795.423	0.197702(2)
GSC 2566-1398	15:22:21.52	+32:58:45.6	11.9-12.3	2453896.456	0.0907090(1)
GSC 3074-0114	16:41:06.83	+40:42:26.3	13.8-14.5	2454138.969	0.05130(1)
GSC 3934-1904	19:39:55.94	+52:35:09.8	10.9-11.2	2453924.403	0.1092685(1)

The times of maximum light presented in this study are therefore calculated as follows. First an average light curve profile (Fourier series) for each star has been created using Period04 (Lenz & Breger, 2005), independently for each filter. As all the stars in the present study are single-mode radial pulsators, without noticeable changes in the light curve from cycle to cycle, these average light curve profiles can then be used to fit the observations of individual cycles, by shifting them in time (and magnitude if another comparison star has been chosen). Using this method a highly accurate and consistent determination of the time of maximum is possible, as data from at least half a cycle, and in the majority of cases a full cycle, are used in the fitting process.

The average profiles of the stars covered in this paper are available electronically. The uncertainty on the timings is measured by the average squared difference in time between the data points and the fitted light curve profile. This gives a measure of the width of the observed light curve. Changing the time of maximum by the quoted uncertainty makes the observations deviate clearly from the average profile, so that this uncertainty gives a realistic indication of the precision of the timing.

Some of the HADS for which observations are reported in this paper were found during a search for RR Lyrae stars (Wils, Lloyd & Bernhard, 2006) in the data of the Northern Sky Variability Survey (NSVS; Woźniak et al., 2004). Details of these stars are listed in Table 1. Uncertainties on the period are given between parentheses in units of the last decimal. It is impossible to distinguish between Population I and Population II (SX Phe) stars based on photometric data alone, so this distinction has not been made here. GSC 3074-0114 and GSC 4519-1078 were found independently by Khruslov (2006a,b), classifying the latter as an SX Phe star. GSC 4556-1113 was also found by Gregor Srdoc (AAVSO VSX). Phased light curves for the stars from Table 1 are shown in Fig. 1. GSC 3755-0845 has a fairly unusual light curve for a HADS with humps on both the ascending and the descending branch. GSC 3074-0114 has a peculiar bump near minimum.

The observers and their instruments are given in Table 2. The 271 times of maximum obtained for 19 HADS are listed in Table 3. When more than one filter was used, the times calculated per filter were averaged to get a single timing. One of the stars, GSC 2977-0238, seems to show a highly variable period. Its O-C curve is given in Fig. 3.

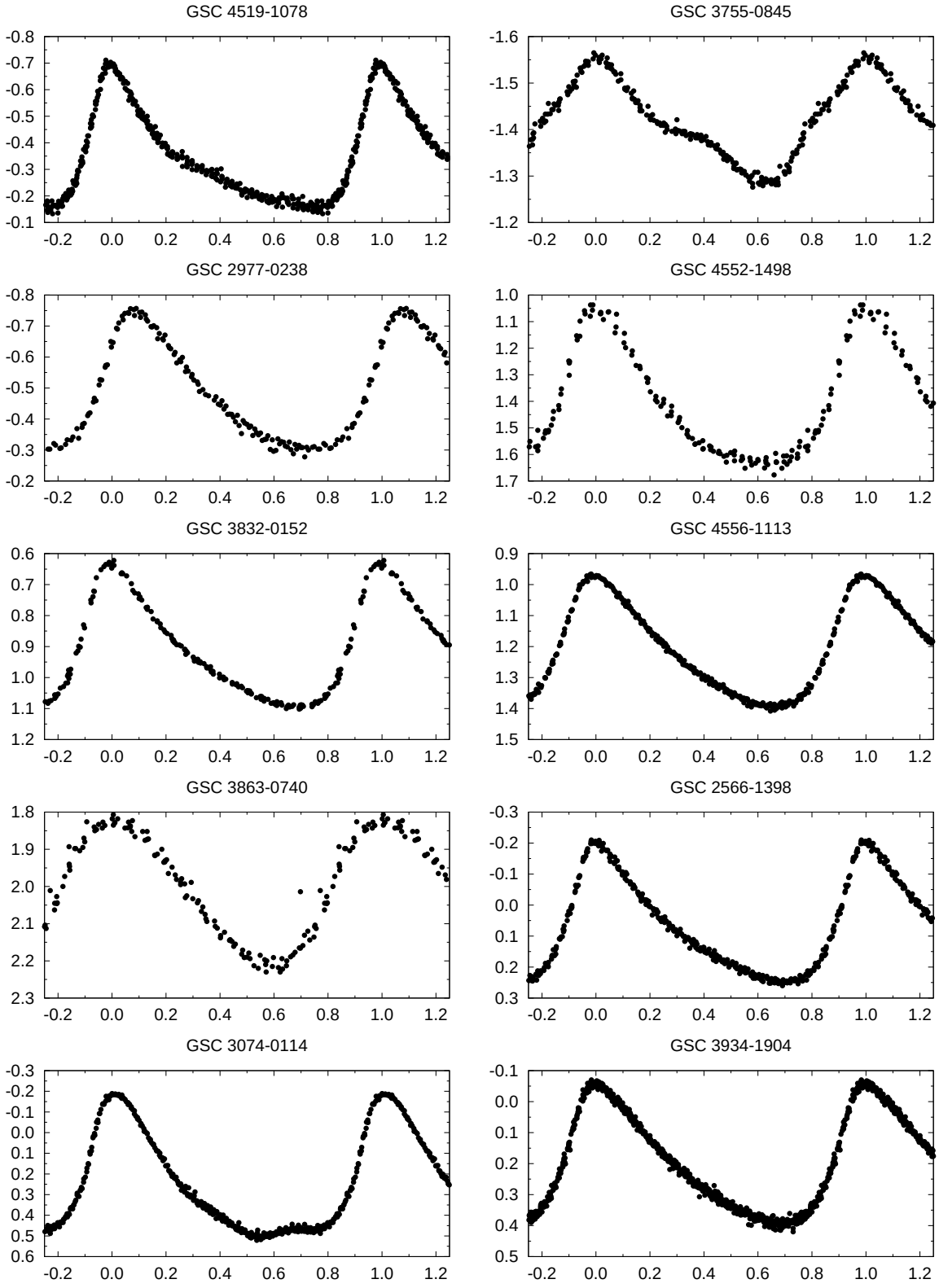

Figure 1. Phased V light curves for nine the stars from Table 1 and an unfiltered light curve of GSC 3074-0114. On the y axis differential magnitudes with respect to a comparison star are shown.

Table 2: List of instruments used for the observations.

Initials	Telescope type	Aperture	Observatory	CCD
SK	Catadioptric	30 cm	Zagori Observatory	SBIG ST-7XMEI
HMB	Cassegrain	35 cm	Mol, Belgium	SBIG ST-8
HMB2	Ritchey-Chrétien	50 cm	New Mexico, USA	STL11000XM
JVS	Newton	41 cm	Monegrillo Observatory	SX Starlight
MVL	Catadioptric	26 cm	Willebroek Observatory	SBIG ST-10XME
PL&PVC (HO)	Refractor	13 cm	R.O.B.-Humain	SBIG ST-10XME
PL&PVC (BHO)	Newton	40 cm	Beersel Hills Observatory	SBIG ST-10XME
PL&PVC (BHO2)	Refractor	18 cm	Beersel Hills Observatory	SBIG ST-10XME
CWR	Catadioptric	30 cm	SETEC Observatory	SBIG ST-8
SBL	Cassegrain	28 & 23.5 cm	Alan Guth Observatory	Starlight XPress MX-716
RP	Catadioptric	30 cm	Shobdon, UK	Starlight XPress MX7
IR	Catadioptric	35 cm	Zagori Observatory	SBIG ST-7XMEI
SD	Refractor	8 cm	Oostkamp, Belgium	SBIG ST-10XME
RG	Catadioptric	30 cm	Dworp, Belgium	Hisis24

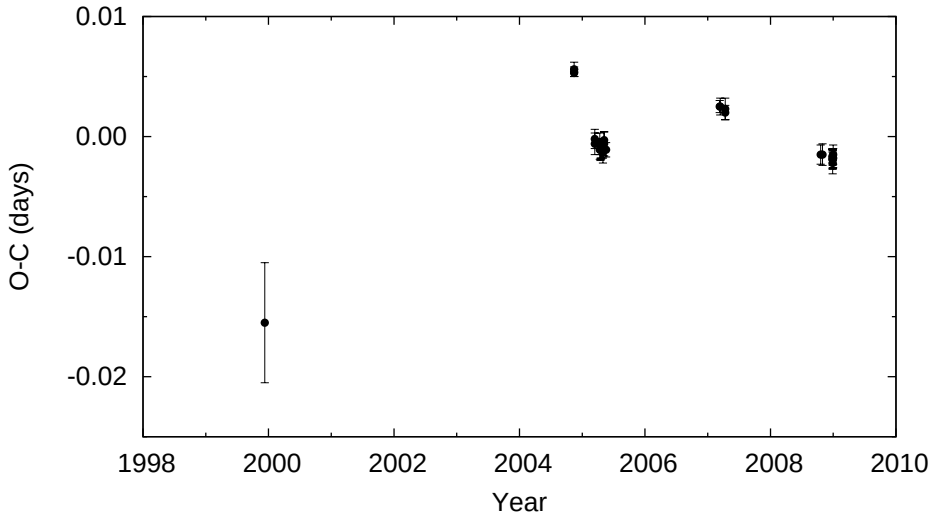

Figure 2. O-C curve of GSC 2977-0238 with respect to the elements given in Table 3. The first point was derived from NSVS data (Woźniak et al., 2004).

Acknowledgements:
This work has made use of the SIMBAD database, operated at CDS, Strasbourg, France. PVC is grateful for support from Astrotechniek. PL thanks the directors of the Royal Observatory of Belgium for financing an optical telescope at the radio observatory site of the R.O.B. (Humain). The BHO and R.O.B.-Humain data were acquired with equipment purchased thanks to a research fund financed by the Belgian National Lottery (1999).

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Table 3: Observed times of maximum (Epoch = HJD - 2400000).

Star*	Epoch	Unc.	Obs.	Filter	Star	Epoch	Unc.	Obs.	Filter
GP And	54713.4600	0.0007	HMB	V	G 2566-1398	53913.4191	0.0007	SK	V,I_C
GP And	54827.2354	0.0006	MVL	V	G 2566-1398	53916.3220	0.0008	SK	V,I_C
GP And	54827.3142	0.0006	MVL	V	G 2566-1398	53916.4127	0.0009	SK	V,I_C
GP And	54827.3929	0.0006	MVL	V	G 2566-1398	53916.5029	0.0009	SK	V
GP And	54827.4716	0.0006	MVL	V	G 2566-1398	54170.4883	0.0007	HMB	V
V460 And	54135.3080	0.0006	RP	V	G 2566-1398	54170.5788	0.0006	HMB	V
V460 And	54135.3831	0.0006	RP	V	G 2566-1398	54170.6697	0.0006	HMB	V
V460 And	54355.5266	0.0007	SK	V	G 2566-1398	54171.4865	0.0007	HMB	V,I_C
V460 And	54355.6013	0.0007	SK	V	G 2566-1398	54171.5767	0.0008	HMB	V,I_C
V460 And	54391.4424	0.0008	SK	V	G 2566-1398	54171.6673	0.0006	HMB	V
V460 And	54391.5180	0.0008	SK	V	G 2566-1398	54172.4840	0.0007	HMB	V,I_C
V460 And	54391.5923	0.0008	SK	V	G 2566-1398	54172.5748	0.0007	HMB	V,I_C
XX Cyg	54649.4459	0.0008	SBL	V	G 2566-1398	54172.6650	0.0007	HMB	V
XX Cyg	54649.5806	0.0008	SBL	V	G 2977-0238	53321.5406	0.0003	BHO	V
XX Cyg	54728.3420	0.0008	MVL	V	G 2977-0238	53321.6166	0.0004	BHO	V
XX Cyg	54728.4768	0.0007	MVL	V	G 2977-0238	53321.6927	0.0006	BHO	V
XX Cyg	54729.4208	0.0008	MVL	V	G 2977-0238	53444.1680	0.0009	SK	V
XX Cyg	54729.5558	0.0008	MVL	V	G 2977-0238	53444.2443	0.0008	SK	V
V2455 Cyg	54357.5561	0.0001	SK	B	G 2977-0238	53473.2502	0.0008	SK	V
V2455 Cyg	54642.4354	0.0003	HO	B	G 2977-0238	53473.3266	0.0009	SK	V
V2455 Cyg	54642.5296	0.0003	HO	B	G 2977-0238	53476.2117	0.0008	SK	V
V2455 Cyg	54646.4860	0.0006	SD	V	G 2977-0238	53476.2875	0.0009	SK	V
V2455 Cyg	54652.5157	0.0007	SBL	V	G 2977-0238	53481.2232	0.0008	SK	V
V2455 Cyg	54694.4383	0.0006	SD	V	G 2977-0238	53481.2992	0.0007	SK	V
V2455 Cyg	54694.5327	0.0006	SD	V	G 2977-0238	53492.2336	0.0007	SK	V
V2455 Cyg	54702.4879	0.0022	SBL	V	G 2977-0238	53492.3094	0.0009	SK	V
V2455 Cyg	54730.3298	0.0003	MVL	V	G 2977-0238	53499.2204	0.0007	SK	V
V2455 Cyg	54730.4239	0.0004	MVL	V	G 2977-0238	53499.2960	0.0010	SK	V
V2455 Cyg	54730.5182	0.0005	MVL	V	G 2977-0238	53508.2557	0.0006	SK	V
V2455 Cyg	54730.6126	0.0005	MVL	V	G 2977-0238	54172.4534	0.0005	RP	V
V2455 Cyg	54758.4031	0.0009	MVL	V	G 2977-0238	54172.5293	0.0007	RP	V
V2455 Cyg	54758.4973	0.0009	MVL	V	G 2977-0238	54204.2692	0.0006	SK	V
V2455 Cyg	54759.3447	0.0008	MVL	V	G 2977-0238	54204.3455	0.0009	SK	V
V2455 Cyg	54759.4389	0.0009	MVL	V	G 2977-0238	54759.5706	0.0008	BHO2	V
V2455 Cyg	54759.5332	0.0007	MVL	V	G 2977-0238	54768.6067	0.0009	BHO2	V
LW Dra	54369.4051	0.0007	SK	V	G 2977-0238	54827.3794	0.0007	HMB	V
DY Her	54648.5619	0.0008	MVL	V	G 2977-0238	54827.4551	0.0008	HMB	V
DY Her	54672.4912	0.0008	MVL	V	G 2977-0238	54827.5310	0.0008	MVL	V
KZ Lac	52145.5531	0.0008	RG	-	G 2977-0238	54827.5313	0.0006	HMB	V
KZ Lac	52205.3842	0.0006	RG	-	G 2977-0238	54827.6067	0.0009	MVL	V
KZ Lac	52224.4928	0.0008	RG	-	G 2977-0238	54827.6070	0.0007	HMB	V
V593 Lyr	54339.3819	0.0007	HMB	V,R	G 2977-0238	54827.6831	0.0006	HMB	V
V593 Lyr	54339.4840	0.0008	HMB	V,R	G 2977-0238	54831.5556	0.0008	MVL	V
V593 Lyr	54339.5861	0.0005	HMB	V,R	G 2977-0238	54831.6319	0.0008	MVL	V
DY Peg	54728.4433	0.0007	HO	V	G 3074-0114	54138.9693	0.0005	HMB2	-
DY Peg	54729.3912	0.0006	BHO2	V	G 3074-0114	54139.9952	0.0005	HMB2	-
DY Peg	54729.4644	0.0004	BHO2	V	G 3074-0114	54140.9699	0.0005	HMB2	-
DY Peg	54739.3530	0.0007	SBL	V	G 3755-0845	53365.3601	0.0011	SK	V
DY Peg	54739.4258	0.0007	SBL	V	G 3755-0845	53365.4353	0.0008	SK	V
DY Peg	54808.2977	0.0007	MVL	V	G 3755-0845	53389.4068	0.0008	SK	V
DY Peg	54808.3708	0.0009	MVL	V	G 3755-0845	53389.4825	0.0008	SK	V
G 2566-1398	53896.4564	0.0009	SK	V,I_C	G 3755-0845	53389.5588	0.0008	SK	V
G 2566-1398	53896.5470	0.0011	SK	V,I_C	G 3755-0845	53405.6915	0.0007	CWR	V
G 2566-1398	53903.3501	0.0008	SK	V,I_C	G 3755-0845	53419.6952	0.0016	CWR	V
G 2566-1398	53903.4409	0.0007	SK	V,I_C	G 3755-0845	53419.7698	0.0009	CWR	V
G 2566-1398	53903.5316	0.0007	SK	V	G 3755-0845	53419.8451	0.0008	CWR	V
G 2566-1398	53907.3409	0.0009	SK	V	G 3755-0845	53426.3140	0.0008	SK	V
G 2566-1398	53909.3376	0.0009	SK	V,I_C	G 3755-0845	53426.3902	0.0009	SK	V
G 2566-1398	53909.4277	0.0007	SK	V,I_C	G 3755-0845	53426.6189	0.0007	CWR	V
G 2566-1398	53909.5187	0.0009	SK	V	G 3755-0845	53426.7704	0.0007	CWR	V

* G xxxx-xxxx denotes GSC identifiers.

Table 3: Observed times of maximum (continued).

Star*	Epoch	Unc.	Obs.	Filter	Star	Epoch	Unc.	Obs.	Filter
G 3755-0845	53426.8469	0.0011	CWR	V	G 3832-0152	53510.4814	0.0007	JVS	R
G 3755-0845	53430.6517	0.0006	CWR	V	G 3832-0152	53513.3129	0.0008	SK	V
G 3755-0845	53430.7276	0.0007	CWR	V	G 3832-0152	53518.4282	0.0007	JVS	R
G 3755-0845	53430.8037	0.0006	CWR	V	G 3832-0152	53526.3747	0.0007	SK	V
G 3755-0845	53433.6193	0.0004	CWR	V	G 3832-0152	53528.3843	0.0008	IR	V
G 3755-0845	53433.6972	0.0014	CWR	V	G 3832-0152	53529.3890	0.0007	JVS	R
G 3755-0845	53433.7732	0.0015	CWR	V	G 3832-0152	53529.4805	0.0008	JVS	R
G 3755-0845	53441.3060	0.0008	SK	V	G 3832-0152	53530.3938	0.0008	JVS	R
G 3755-0845	53441.3812	0.0008	SK	V	G 3832-0152	53530.4851	0.0007	JVS	R
G 3755-0845	53468.6244	0.0004	CWR	V	G 3832-0152	53531.3071	0.0008	SK	V
G 3755-0845	54137.2956	0.0012	RP	V	G 3832-0152	53531.3983	0.0006	SK	V
G 3755-0845	54137.3714	0.0009	RP	V	G 3832-0152	53531.3986	0.0008	JVS	R
G 3755-0845	54201.2933	0.0007	SK	B,V	G 3832-0152	53531.4898	0.0006	JVS	R
G 3755-0845	54728.5743	0.0009	HO	V	G 3832-0152	53536.4221	0.0006	JVS	B
G 3755-0845	54827.2735	0.0009	HMB	V	G 3832-0152	53539.4368	0.0008	JVS	B
G 3755-0845	54827.3498	0.0008	HMB	V	G 3832-0152	53540.4411	0.0007	JVS	B
G 3755-0845	54827.3504	0.0008	SBL	V	G 3832-0152	53541.3550	0.0005	SK	V
G 3755-0845	54827.4265	0.0008	SBL	V	G 3832-0152	53541.4462	0.0006	SK	V
G 3755-0845	54827.5022	0.0009	HMB	V	G 3832-0152	53545.2820	0.0007	SK	V
G 3755-0845	54827.5025	0.0008	SBL	V	G 3832-0152	53545.3743	0.0006	SK	V
G 3755-0845	54827.5778	0.0009	HMB	V	G 3832-0152	53553.4116	0.0009	JVS	I
G 3755-0845	54827.6537	0.0008	HMB	V	G 3832-0152	53554.4173	0.0008	JVS	I
G 3755-0845	54828.2629	0.0009	HMB	V	G 3832-0152	54174.4476	0.0008	RP	V
G 3755-0845	54828.3381	0.0010	HMB	V	G 3832-0152	54174.5388	0.0006	RP	V
G 3755-0845	54828.4146	0.0008	HMB	V	G 3832-0152	54203.3114	0.0008	SK	V
G 3755-0845	54828.4910	0.0008	HMB	V	G 3863-0740	53795.4228	0.0007	SK	BV,I_C
G 3755-0845	54828.5671	0.0008	HMB	V	G 3863-0740	53795.6202	0.0006	SK	B,V,I_C
G 3755-0845	54828.6425	0.0008	HMB	V	G 3863-0740	53799.5740	0.0005	SK	B,V,I_C
G 3755-0845	54828.7190	0.0008	HMB	V	G 3863-0740	53815.3908	0.0006	SK	B,I_C
G 3755-0845	54830.2411	0.0008	HMB	V	G 3863-0740	53815.5884	0.0006	SK	B,V,I_C
G 3755-0845	54830.3169	0.0008	HMB	V	G 3863-0740	53821.5215	0.0006	SK	B,V,I_C
G 3755-0845	54830.6219	0.0009	HMB	V	G 3863-0740	53826.4626	0.0006	SK	B,V,I_C
G 3755-0845	54830.6976	0.0009	HMB	V	G 3863-0740	53835.7536	0.0007	CWR	V
G 3755-0845	54831.2302	0.0010	HMB	V	G 3863-0740	53838.7197	0.0006	CWR	V
G 3755-0845	54831.3064	0.0008	HMB	V	G 3863-0740	53842.6732	0.0008	CWR	V
G 3755-0845	54831.3827	0.0008	HMB	V	G 3863-0740	53842.8700	0.0006	CWR	V
G 3755-0845	54838.3074	0.0008	MVL	V	G 3863-0740	53843.6649	0.0006	CWR	V
G 3755-0845	54838.3834	0.0008	MVL	V	G 3863-0740	53843.8599	0.0006	CWR	V
G 3832-0152	53474.4005	0.0005	JVS	V	G 3863-0740	53845.6379	0.0008	CWR	V
G 3832-0152	53479.4247	0.0007	JVS	V	G 3863-0740	53845.8361	0.0007	CWR	V
G 3832-0152	53487.3715	0.0006	JVS	V	G 3934-1904	53924.4033	0.0008	SK	B,V,I_C
G 3832-0152	53487.4630	0.0009	JVS	V	G 3934-1904	53924.5124	0.0008	SK	B,V,I_C
G 3832-0152	53488.3764	0.0007	JVS	V	G 3934-1904	53931.3966	0.0007	SK	B,V,I_C
G 3832-0152	53488.4679	0.0008	JVS	V	G 3934-1904	53931.5057	0.0008	SK	B,V,I_C
G 3832-0152	53488.5586	0.0008	JVS	V	G 3934-1904	53935.3304	0.0008	SK	B,V,I_C
G 3832-0152	53489.2894	0.0006	SK	V	G 3934-1904	53935.4395	0.0009	SK	B,V,I_C
G 3832-0152	53489.3807	0.0007	SK	V	G 3934-1904	53941.3401	0.0008	SK	B,V,I_C
G 3832-0152	53489.3810	0.0008	JVS	I	G 3934-1904	53941.4491	0.0007	SK	B,V,I_C
G 3832-0152	53489.4720	0.0007	SK	V	G 3934-1904	53941.5586	0.0008	SK	B,I_C
G 3832-0152	53489.4723	0.0009	JVS	I	G 3934-1904	53944.3994	0.0008	SK	B,V,I_C
G 3832-0152	53489.5639	0.0006	JVS	I	G 3934-1904	53944.5084	0.0009	SK	B,V,I_C
G 3832-0152	53489.5640	0.0006	SK	V	G 3934-1904	53944.6177	0.0005	SK	V
G 3832-0152	53496.4141	0.0009	JVS	I	G 3934-1904	54368.6888	0.0009	HMB2	-
G 3832-0152	53496.5057	0.0008	JVS	I	G 3934-1904	54370.6557	0.0008	HMB2	-
G 3832-0152	53496.5973	0.0008	JVS	I	G 3934-1904	54376.6654	0.0008	HMB2	-
G 3832-0152	53497.4195	0.0008	JVS	I	G 3934-1904	54377.6487	0.0008	HMB2	-
G 3832-0152	53497.5107	0.0008	JVS	I	G 3934-1904	54379.6158	0.0007	HMB2	-
G 3832-0152	53497.6026	0.0007	JVS	I	G 3934-1904	54380.5989	0.0008	HMB2	-
G 3832-0152	53500.3420	0.0008	SK	V	G 3934-1904	54380.7083	0.0007	HMB2	-
G 3832-0152	53510.3902	0.0007	JVS	R	G 3934-1904	54649.5086	0.0008	HMB	V

* G xxxx-xxxx denotes GSC identifiers.

Table 3: Observed times of maximum (continued).

Star*	Epoch	Unc.	Obs.	Filter
G 3934-1904	54708.4470	0.0007	SBL	V
G 4519-1078	54823.4146	0.0010	HMB	V
G 4519-1078	54827.3435	0.0007	HMB	V
G 4519-1078	54828.3257	0.0008	HMB	V
G 4519-1078	54828.4660	0.0008	HMB	V
G 4519-1078	54830.4304	0.0007	HMB	V
G 4519-1078	54830.5709	0.0006	HMB	V
G 4519-1078	54830.7109	0.0009	HMB	V
G 4552-1498	53321.5354	0.0007	BHO	V
G 4552-1498	53321.5912	0.0006	BHO	V
G 4552-1498	53321.6474	0.0007	BHO	V
G 4552-1498	53321.7025	0.0007	BHO	V
G 4552-1498	53534.3983	0.0006	IR	V
G 4552-1498	53534.4543	0.0008	IR	V
G 4552-1498	53792.3008	0.0010	BHO	V
G 4552-1498	53792.3566	0.0013	BHO	V
G 4552-1498	53810.3273	0.0005	BHO	V
G 4552-1498	53810.3832	0.0006	BHO	V
G 4552-1498	53810.4388	0.0005	BHO	V
G 4552-1498	54172.3734	0.0006	HMB	V,R
G 4552-1498	54172.4290	0.0006	HMB	V,R
G 4552-1498	54172.4855	0.0007	HMB	V,R
G 4552-1498	54172.5407	0.0007	HMB	V,R
G 4552-1498	54172.5965	0.0007	HMB	V,R
G 4552-1498	54172.6521	0.0007	HMB	V,R
G 4552-1498	54209.3203	0.0009	IR	V
G 4552-1498	54209.3764	0.0008	IR	V
G 4556-1113	53813.3316	0.0006	BHO	V
G 4556-1113	53813.4178	0.0007	BHO	V
G 4556-1113	53814.3676	0.0006	BHO	V
G 4556-1113	53814.4539	0.0008	BHO	V

* G xxxx-xxxx denotes GSC identifiers.