OPEN EUROPEAN JOURNAL ON VARIABLE STARS
December 2015 http://var.astro.cz/oejv ISSN 1801–5964

MAXIMUM TIMES OF RR LYRAE STARS

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Abstract: We present the first list comprising 102 maxima times of 40 RR Lyrae stars observed within the Czech RR Lyrae Observation Project between years 2012 and 2015. In addition a method of maxima determination is briefly described.

1 Introduction

Variable stars of the RR Lyrae type are extremely important stellar objects having many applications in various astrophysical fields (e.g. they serve as distance indicators, metallicity tracers, stellar and pulsation theory testing objects, etc.). Therefore understanding them is of very high importance.

Research of recent years shows that about half of RR Lyrae stars could show days long to thousands of days long modulation of their light curves. This is known as the Blazhko effect which has not been explained yet (see e.g. Jurcsik et al., 2009; Kovács, 2009; Kolláth et al., 2011). RR Lyrae stars can also show significant period changes with periods in order of years (or longer), possibly caused by binarity (Hajdu et al., 2015; Liška et al., 2015), and/or even longer period variations, caused by stellar evolution (Le Borgne et al., 2007). All these effects make the investigation of RR Lyrae stars even more important but, on the other hand, also much more difficult and time consuming.

At the beginning of 2012 the Czech RR Lyrae observational project was establish in cooperation with amateur astronomers using professional equipment (Skarka et al., 2013, 2015). The survey aims to collect accurate measurements of RR Lyrae stars over the whole pulsation cycle and to search for modulation. Maxima times are, therefore, a by-product of this survey, not the main goal. We present maxima times which have not been published yet, as well as maxima which are not used in detail studies (in preparation, or that have been already submitted for publication elsewhere).

2 Method of maxima times determination

Due to all previously listed effects the determination of maximum time is not straightforward. We searched for a fast and universal method which could generally be applied to modulated stars and stars with stable light curves. We decided to use classical algebraic polynomials of low order in combination with bootstrap technique. All the analysis is performed via OCTAVE/MATLAB code.

Because of characteristics of low-order algebraic polynomials, only parts of the light curve around maximum can be used for maximum time estimation. Therefore it is necessary to choose the appropriate part of the light curve. This can generally not be done automatically due to different rise times (time from minimum to maximum light) of different objects and different data quality. Thus the observer has to set the part of the light curve before maximum which will be used for fitting. For the descending part (after maximum) we take a 1.5 multiple of this value.

Then the data are fitted via the Least-squares-method (LSM) using polynomials of order between 2 and 6. For choosing the best-order polynomial we use BIC criterion (Schwarz, 1978). Because LSM gives unrealistically low error of maximum time we use bootstrap method to have better idea of the errors. The data used for fitting are then randomly chosen 5000-times from the basic sample and fitted with a polynomial of a previously chosen degree. The error we give is calculated from the statistics of uncertainties of particular fits.

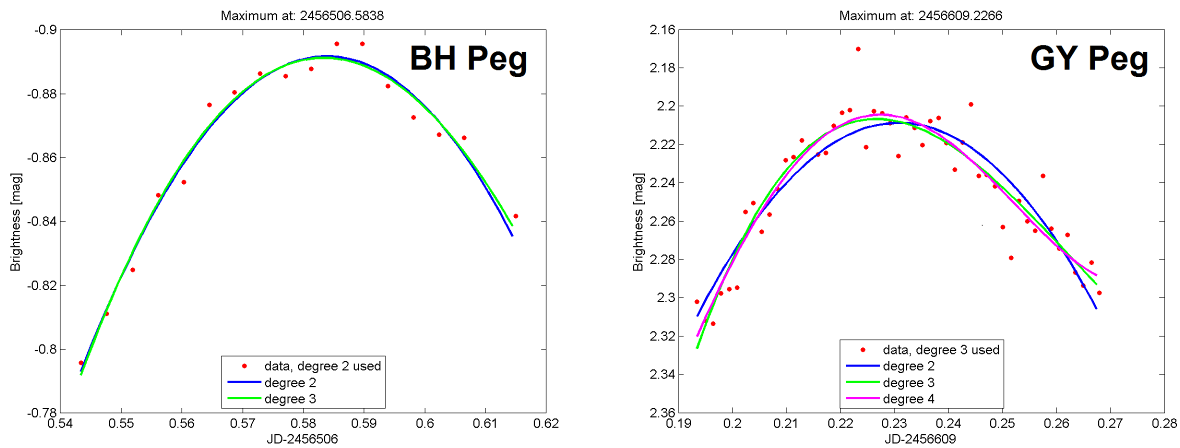

Figure 1: Examples of polynomial fits for different stars. It is clear which fit has the lowest RMS. The legend below indicates which fit was used for maxima determination.

3 Observers

The vast majority of observers are members of the Section of Variable Stars and Exoplanets of the Czech Astronomical Society. They use appropriate instruments mounted at low-aperture telescopes with diameter typically about 20-30 cm. All observers are listed in Tab. 1.

Table 1: Observers and number of maxima they gathered.

Code	Name	N_{max}	Code	Name	N_{max}	Code	Name	N_{max}
RFA	Reinhold F. Auer	25	RD	Radek Dřevěný	22	JL	Jiří Liška	21
KH	Kateřina Hoňková	16	JJ	Jakub Juryšek	16	MM	Martin Mašek	14
SV	Stefanus N. de Villiers	1	BH	Bohuslav Hladík	3	MS	Marek Skarka	14

Table 2: Observing places and their short cuts used in Tab. 3.

Code	Observatory	Code	Observatory
POP	Private Observatory Praha, Czech Republic	MUO	Masaryk University Observatory, Brno, Czech Republic
POB	Private Observatory Brno, Czech Republic	BOP	Brno Observatory and Planetarium, Brno, Czech Republic
POZ	Private Observatory Znojmo, Czech Republic	PAO	Pierre Auger Observatory, Malargue, Argentina
POCT	Private Observatory Cape Town, South Africa	SMO	South Moravian Observatory, Chudčice, Czech Republic
PlO	Planetarium Ostrava, Czech Republic	SAAO	South African Astronomical Obsevatory, Sutherland, South Africa

Table 3: Times of maximum light.

ID	T_{max} (HJD)	δT_{max}	Observer	Observatory	Telescope	CCD	Filter
SW And	2456934.4193	0.0005	RFA	SMO	N 300/1410 mm	MII G2-1600	V
XX And	2456918.6002	0.0007	RFA	SMO	N 300/1410 mm	MII G2-1600	V
AT And	2456959.3602	0.0005	MS	BOP	SC 355/3910 mm	MII G4-16000	V
WY Ant	2457057.6630	0.0008	KH,JJ,MM	PAO	SC 300/3000 mm	MII G2-1600	V
WY Ant	2457061.6826	0.0006	KH,JJ,MM	PAO	SC 300/3000 mm	MII G2-1600	V
WY Ant	2457064.5535	0.0008	KH,JJ,MM	PAO	SC 300/3000 mm	MII G2-1600	V
RS Boo	2456815.3746	0.0006	JL	POB	PhL Sonnar 4/135 mm	ATIK 16IC	green
RS Boo	2456818.3950	0.0006	JL	POB	PhL Sonnar 4/135 mm	ATIK 16IC	green
SW Boo	2457100.4504	0.0008	MS	BOP	SC 355/3910 mm	MII G4-16000	V
SW Boo	2457105.5856	0.0014	MS	BOP	SC 355/3910 mm	MII G4-16000	V
SZ Boo	2457178.5159	0.0010	MS	BOP	SC 355/3910 mm	MII G4-16000	V
DG Boo	2457180.5330	0.0007	RFA	SMO	N 300/1410 mm	MII G2-1600	V
EW Cam	2455958.4912	0.0009	KH,JJ	PlO	N 200/1200 mm	SBIG ST8XME	V
EW Cam	2455990.5309	0.0013	KH,JJ	PlO	N 200/1200 mm	SBIG ST8XME	V
W CVn	2456746.3204	0.0009	RD	POZ	SC 200/2000 mm	MII G2-0402	V
W CVn	2456747.4266	0.0005	RD	POZ	SC 200/2000 mm	MII G2-0402	V
W CVn	2456754.5983	0.0005	RD	POZ	SC 200/2000 mm	MII G2-0402	V
RU CVn	2457181.3509	0.0006	RFA	SMO	N 300/1410 mm	MII G2-1600	V
UZ CVn	2457069.3914	0.0007	RFA	SMO	N 300/1410 mm	MII G2-1600	V
UZ CVn	2457099.3959	0.0005	RFA	SMO	N 300/1410 mm	MII G2-1600	V
AL CMi	2456709.2702	0.0006	RD	POZ	SC 200/2000 mm	MII G2-0402	V
AL CMi	2456731.2896	0.0009	RD	POZ	SC 200/2000 mm	MII G2-0402	V
AL CMi	2457069.3039	0.0006	RD	POZ	SC 200/2000 mm	MII G2-0402	V
AL CMi	2457070.4068	0.0011	RD	POZ	SC 200/2000 mm	MII G2-0402	V
V1059 Cas	2457264.3984	0.0031	RFA	SMO	N 300/1410 mm	MII G2-1600	V
V0595 Cen	2456347.5805	0.0019	SV	POCT	SC 280/2800 mm	SBIG-ST8XME	V
S Com	2456750.5872	0.0007	RD	POZ	SC 200/2000 mm	MII G2-0402	V
S Com	2456803.3838	0.0009	JL	POB	PhL Sonnar 4/135 mm	ATIK 16IC	green
S Com	2456813.3515	0.0015	JL	POB	PhL Sonnar 4/135 mm	ATIK 16IC	green
S Com	2456814.5259	0.0013	JL	POB	PhL Sonnar 4/135 mm	ATIK 16IC	green
BV CrB	2457239.4417	0.0008	RFA	SMO	N 300/1410 mm	MII G2-1600	V
UY Cyg	2456906.4848	0.0005	RFA	SMO	N 300/1410 mm	MII G2-1600	V
V1949 Cyg	2457225.4785	0.0030	RFA	SMO	N 300/1410 mm	MII G2-1600	V
V1949 Cyg	2457241.4462	0.0006	RFA	SMO	N 300/1410 mm	MII G2-1600	V
V1949 Cyg	2457243.4381	0.0009	RFA	SMO	N 300/1410 mm	MII G2-1600	V
V1949 Cyg	2457245.4411	0.0005	RFA	SMO	N 300/1410 mm	MII G2-1600	V
V1949 Cyg	2457248.4290	0.0005	RFA	SMO	N 300/1410 mm	MII G2-1600	C
V1949 Cyg	2457256.4058	0.0005	RFA	SMO	N 300/1410 mm	MII G2-1600	C
SU Dra	2456966.5424	0.0009	RFA	SMO	N 300/1410 mm	MII G2-1600	V

Table 3: continued.

ID	$T_{\max}$ (HJD)	$\delta T_{\max}$	Observer	Observatory	Telescope	CCD	Filter
SW Dra	2457101.3299	0.0005	RFA	SMO	N 300/1410 mm	MII G2-1600	V
SW Dra	2457122.4085	0.0007	RFA	SMO	N 300/1410 mm	MII G2-1600	V
BK Dra	2457154.5040	0.0004	MS	BOP	SC 355/3910 mm	MII G4-16000	V
BT Dra	2457261.4496	0.0012	MS	BOP	SC 355/3910 mm	MII G4-16000	V
VZ Her	2456726.5835	0.0006	MS	BOP	SC 355/3910 mm	MII G4-16000	V
VZ Her	2456815.5298	0.0005	MS	BOP	SC 355/3910 mm	MII G4-16000	V
VZ Her	2457181.4436	0.0007	MS	BOP	SC 355/3910 mm	MII G4-16000	V
CW Her	2457213.4837	0.0007	JL	BOP	SC 355/3910 mm	MII G4-16000	V
V Ind	2456190.3526	0.0010	JL	SAAO	PhL Helios 2/58 mm	MII G2-0402	V
V Ind	2456199.4675	0.0012	JL	SAAO	PhL Helios 2/58 mm	MII G2-0402	V
RR Leo	2457070.4720	0.0008	MS	BOP	SC 355/3910 mm	MII G4-16000	V
RR Leo	2457100.3329	0.0007	MS	BOP	SC 355/3910 mm	MII G4-16000	V
TV Lib	2457198.7207	0.0007	KH,JJ,MM	PAO	SC 300/3000 mm	MII G2-1600	V
TV Lib	2457216.5157	0.0005	KH,JJ,MM	PAO	SC 300/3000 mm	MII G2-1600	V
TV Lib	2457258.5766	0.0006	KH,JJ,MM	PAO	SC 300/3000 mm	MII G2-1600	V
TT Lyn	2456356.4929	0.0009	RD	POZ	SC 200/2000 mm	MII G2-0402	V
AQ Lyr	2456622.2162	0.0010	JL	MUO	N 600/2780 mm	MII G2-4000	y
AQ Lyr	2456819.3625	0.0006	JL	MUO	N 600/2780 mm	MII G2-0402	V
AQ Lyr	2456842.5622	0.0012	JL	MUO	N 600/2780 mm	MII G2-0402	V
AQ Lyr	2456845.4191	0.0005	JL	MUO	N 600/2780 mm	MII G2-0402	V
AQ Lyr	2456872.5735	0.0006	JL	MUO	N 600/2780 mm	MII G2-0402	V
AQ Lyr	2456906.4989	0.0009	JL	BOP	SC 355/3910 mm	MII G4-16000	V
AQ Lyr	2456918.2944	0.0004	JL	MUO	N 600/2780 mm	MII G2-4000	y
CN Lyr	2456894.4710	0.0011	RFA	SMO	N 300/1410 mm	MII G2-1600	V
CN Lyr	2456897.3498	0.0006	RFA	SMO	N 300/1410 mm	MII G2-1600	V
CN Lyr	2457238.3870	0.0006	RFA	SMO	N 300/1410 mm	MII G2-1600	V
CN Lyr	2457242.4964	0.0008	RFA	SMO	N 300/1410 mm	MII G2-1600	V
BH Peg	2456153.3856	0.0013	RD	POZ	SC 200/2000 mm	MII G2-0402	V
BH Peg	2456160.4317	0.0004	RD	POZ	SC 200/2000 mm	MII G2-0402	V
BH Peg	2456167.4829	0.0011	RD	POZ	SC 200/2000 mm	MII G2-0402	V
BH Peg	2456169.4059	0.0013	RD	POZ	SC 200/2000 mm	MII G2-0402	V
BH Peg	2456180.3079	0.0010	RD	POZ	SC 200/2000 mm	MII G2-0402	V
BH Peg	2456181.5947	0.0020	RD	POZ	SC 200/2000 mm	MII G2-0402	V
BH Peg	2456187.3633	0.0011	RD	POZ	SC 200/2000 mm	MII G2-0402	V
BH Peg	2456506.5838	0.0008	RD	POZ	SC 200/2000 mm	MII G2-0402	V
BH Peg	2456510.4253	0.0023	RD	POZ	SC 200/2000 mm	MII G2-0402	V
BH Peg	2456521.3365	0.0011	RD	POZ	SC 200/2000 mm	MII G2-0402	V
BH Peg	2456522.6125	0.0010	RD	POZ	SC 200/2000 mm	MII G2-0402	V
BH Peg	2456542.4751	0.0014	RD	POZ	SC 200/2000 mm	MII G2-0402	V
BH Peg	2456897.5872	0.0011	RD	POZ	SC 200/2000 mm	MII G2-0402	V
GY Peg	2456508.5088	0.0009	MS	BOP	SC 355/3910 mm	MII G2-4000	y
GY Peg	2456510.5228	0.0004	MS	BOP	SC 355/3910 mm	MII G2-4000	y
GY Peg	2456513.5439	0.0006	JL	BOP	SC 355/3910 mm	MII G2-4000	y
GY Peg	2456515.5628	0.0004	MS	BOP	SC 355/3910 mm	MII G2-4000	y
GY Peg	2456516.5730	0.0006	JL	BOP	SC 355/3910 mm	MII G2-4000	y
GY Peg	2456519.6033	0.0012	JL	BOP	SC 355/3910 mm	MII G2-4000	y
GY Peg	2456609.2266	0.0011	JL	MUO	N 600/2780 mm	MII G2-4000	y
AT Ser	2457210.4130	0.0015	JL	POB	PhL Sonnar 4/135 mm	ATIK 16IC	C
VW Scl	2456936.6278	0.0006	KH,JJ,MM	PAO	SC 300/3000 mm	MII G2-1600	V
VW Scl	2456939.6929	0.0005	KH,JJ,MM	PAO	SC 300/3000 mm	MII G2-1600	V
VW Scl	2456961.6604	0.0020	KH,JJ,MM	PAO	SC 300/3000 mm	MII G2-1600	V
VW Scl	2456967.7923	0.0009	KH,JJ,MM	PAO	SC 300/3000 mm	MII G2-1600	V
VW Scl	2457028.5897	0.0011	KH,JJ,MM	PAO	SC 300/3000 mm	MII G2-1600	V
VX Scl	2456975.6521	0.0005	KH,JJ,MM	PAO	SC 300/3000 mm	MII G2-1600	V
VX Scl	2457017.7056	0.0010	KH,JJ,MM	PAO	SC 300/3000 mm	MII G2-1600	V
VX Scl	2457026.6222	0.0006	KH,JJ,MM	PAO	SC 300/3000 mm	MII G2-1600	V
RV UMa	2456744.3773	0.0005	JL	MUO	N 600/2780 mm	MII G2-0402	V

Table 3: continued.

ID	$T_{\max}$ (HJD)	$\delta T_{\max}$	Observer	Observatory	Telescope	CCD	Filter
TU UMa	2457070.6912	0.0005	RFA	SMO	N 300/1410 mm	MII G2-1600	V
TU UMa	2457106.3811	0.0005	RFA	SMO	N 300/1410 mm	MII G2-1600	V
EX UMa	2457067.5577	0.0008	RFA	SMO	N 300/1410 mm	MII G2-1600	V
AF Vir	2457150.4557	0.0009	BH	POP	PhL 3.5/200 mm	ATIK 320E	C
AF Vir	2457178.4971	0.0014	BH	POP	PhL 3.5/200 mm	ATIK 320E	C
AF Vir	2457179.4645	0.0007	BH	POP	PhL 3.5/200 mm	ATIK 320E	C

Short cuts of instruments: SC – Schmidt-Cassegrain, N – Newtonian, PhL – photo lens.
Note: in SC and N the first number is diameter, the second is focal length, in PhL the first number is the ratio focal length/diameter, the second number is focal length.

Acknowledgements: This research made use of the International Variable Star Index (VSX) database, operated at AAVSO, Cambridge, Massachusetts, USA. Support of MUNI/A/1110/2014 and LH14300 is acknowledged. The operation of the robotic telescope FRAM has been supported by the EU grant GLORIA (No. 283783 in FP7-Capacities program) and by the grant of the Ministry of Education of the Czech Republic (MSMT-CR LG13007). MS acknowledges the support of the postdoctoral fellowship programme of the Hungarian Academy of Sciences at the Konkoly Observatory as host institution.The support of Brno Observatory and Planetarium and SAAO is acknowledged.

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