Isochronal Ages of Some Eclipsing Binary Stars with Eccentric Orbits

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Abstract. Isochronal ages of the 32 eclipsing binary stars with eccentric orbits from the catalog of Bulut and Demircan (2007) were computed using the Y^2 stellar evolution models. First, we derived the metallicity Z-values from evolutionary sequences. Then, using these metallicity in the Y^2 models, a set of isochrones were computed. Lastly, the ages were found from the isochrone that was best-fitting the locations of both components. 19 of the 32 ages were calculated with a 20% accuracy. These were compared with the circularization times-scales.
Key words: Stars: binaries; Stars: binaries: eclipsing; Stars: evolution

1. Introduction

In order to determine the ages of stars, there are several methods which are based on either the kinematics or expansion of stars, the lithium depletion, the gyrochronology, activity, asteroseismology or isochrones models. These methods are described by Soderblom (2010).

Isochrones are defined as the locus of equal age points on the evolutionary tracks of stars of different masses in the Hertzsprung–Russell (HR). These are used for measuring the ages of star clusters and galaxies. In addition to this, the technique is also used for determining the ages of binary stars with the assumption that binary stars were born at the same time and with the same initial chemical composition. In this method, the most important stellar parameters are the mass and the metallicity (usually quantified as [Fe/H] or [Me/H]).

In this study, isochrone fitting technique has been applied to some selected eclipsing binary stars with eccentric orbits. Their absolute parameters and orbital parameters have been taken from the catalogue of Bulut and Demircan (2007).

2. The systems

We chose the eclipsing binary systems for which the absolute parameters are known and which have masses between 0.4 $M_\odot$ and 5 $M_\odot$ in the catalogue of eclipsing binary stars with eccentric orbits by Bulut and Demircan (2007). In fact, this catalogue contains information for 124 systems with eccentric orbits. Out of these, 32 systems have $M \leq 5\ M_\odot$ or $M \geq 0.4\ M_\odot$, which are the limits of the mass range covered by the Y^2 models. The absolute parameters for these systems are listed in Table 1 as follows: number, name of the system, orbital eccentricity (e), masses ($M_{1,2}$), radii ($R_{1,2}$), temperatures ($T_{1,2}$) and surface gravities ($g_{1,2}$) of the binary components. For all the data, the error on the least significant digit is given in parentheses.

The mass-radius diagram for the stars in Table 1 is shown in Fig. 1. All stars have been located between the theoretical zero-age main sequence (ZAMS) and the theoretical terminal age of the main sequence (TAMS) in this diagram.

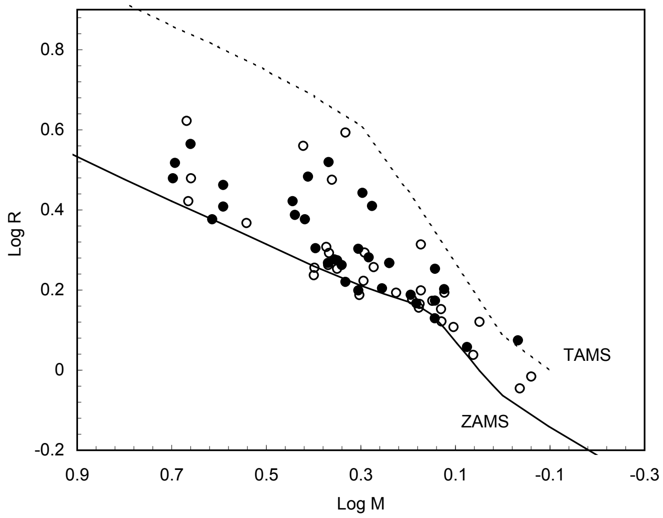

Fig. 1. The mass–radius diagram for the stars in Table 1. The open and filled circles stand for primary and secondary stars, respectively. The dashed and dotted lines show the ZAMS and the TAMS for solar metallicity, respectively.

3. Isochrones Fitting

In order to estimate the ages of the eclipsing binary systems, we used the Yonsei–Yale (Y^2) stellar evolution models by Yi et. al. (2001), incorporating an updated prescription for convective core overshooting as described by Demarque et. al. (2004). In these models, the range of chemical compositions covers $0.00001 \leq Z \leq 0.08$. They also employ an initial helium abundance Y = 0.23 + 2Z, and a constant mixing length of 1.7432 times the pressure scale height. The mass range is approximately 0.4–5 $M_{\odot}$. The models are evolved from the pre-main-sequence stellar birthline to the onset of helium burning in the core at the red giant branch tip. The age range of the full isochrone is set to 0.1 – 20 Gyr, while younger isochrones of age 1 – 80 Myr are also presented up to the main-sequence turn-off.

In order to determine the age of a star, we performed the following steps. First, we computed the evolutionary tracks for the exact masses given for each star in Table 1, using the code provided by Yi et al. (2001), for a heavy-element abundance equal to that of the Sun (which is Z = 0.01812 in these models). In the second step, we adjusted the values of the metallicity Z. The evolutionary tracks were used for estimation of the metallicity. Among the evolutionary tracks computed for the exact masses with their errors, the metallicity of the system was chosen as the Z-value of

Table 1. Absolude parameters.

No	Name	e	M_1 [$M_\odot$]	M_2 [$M_\odot$]	R_1 [$R_\odot$]	R_2 [$R_\odot$]	$T_{eff,1}$ (K)	$T_{eff,2}$ (K)	log g_1 (cgs)	log g_2 (cgs)
1	BW Aqr	0.17	1.39(2)	1.49(2)	1.79(4)	2.06(4)	6450(100)	6350(100)	4.075(22)	3.981(19)
2	WW Cam	0.0098	1.920(13)	1.873(18)	1.911(16)	1.808(14)	8355(135)	8240(135)	4.1586(77)	4.1960(86)
3	IT Cas	0.0797(16)	1.330(9)	1.328(8)	1.593(15)	1.56(4)	6470(105)	6470(105)	4.158(9)	4.175(20)
4	MU Cas	0.193	4.57(9)	4.66(10)	3.67(4)	4.19(5)	15100(500)	14750(500)	3.969(10)	3.861(10)
5	V459 Cas	0.0244(4)	2.02(3)	1.96(3)	2.009(13)	1.965(13)	9140(300)	9100(300)	4.136(6)	4.144(6)
6	EK Cep	0.109(3)	2.02(1)	1.12(1)	1.58(15)	1.32(15)	8995(210)	5690(200)	4.35(15)	4.25(15)
7	EY Cep	0.4415(12)	1.523(8)	1.498(14)	1.463(10)	1.468(10)	7000(100)	7000(100)	4.290(6)	4.280(6)
8	TV Cet	0.0545(4)	1.39(5)	1.27(4)	1.49(1)	1.28(1)	7000(150)	6610(140)	4.233(8)	4.328(8)
9	α CrB	0.37	2.58(45)	0.92(25)	3.04(30)	0.90(4)	9700(200)	5800(300)	3.89(9)	4.50(4)
10	V477 Cyg	0.328(2)	1.80(10)	1.35(8)	1.60(3)	1.42(3)	8730(245)	6530(185)	4.29(4)	4.26(4)
11	V541 Cyg	0.479(3)	2.24(9)	2.24(8)	1.88(3)	1.79(4)	9890(230)	9950(230)	4.24(2)	4.28(2)
12	V1143 Cyg	0.54	1.391(16)	1.347(13)	1.346(23)	1.323(23)	6460(100)	6400(100)	4.323(16)	4.324(16)
13	V1147 Cyg	0.275(12)	2.15	2.01	1.66	1.54	8500	8200	4.33	4.37
14	RX Her	0.022(8)	2.75(6)	2.33(5)	2.44(10)	1.96(10)	10350(740)	9660(450)	4.06(4)	4.24(4)
15	AI Hya	0.230(2)	1.98(4)	2.15(4)	2.77(2)	3.92(3)	7100(70)	6700(60)	3.85(1)	3.58(1)
16	RW Lac	0.0098(10)	0.928(6)	0.870(4)	1.186(4)	0.964(4)	5760(100)	5560(150)	4.257(3)	4.409(4)
17	SS Lac	0.136	2.62(16)	2.64(19)	2.38(2)	3.63(7)	8750(300)	8542(309)	4.10(3)	3.74(5)
18	V364 Lac	0.2873(14)	2.333(15)	2.296(25)	3.307(38)	2.985(35)	8250(150)	8500(150)	3.767(10)	3.849(11)
19	GG Lup	0.1546(10)	4.116(40)	2.509(24)	2.379(25)	1.725(19)	14750(450)	11000(600)	4.301(11)	4.364(10)
20	RR Lyn	0.0782(9)	1.89(7)	1.49(5)	2.57(4)	1.58(4)	7570(120)	6980(100)	3.894(19)	4.214(25)
21	TZ Men	0.035(7)	2.487(25)	1.504(10)	2.016(20)	1.432(15)	10400(500)	7200(300)	4.225(10)	4.303(9)
22	U Oph	0.0030(2)	4.93(5)	4.56(4)	3.29(6)	3.01(5)	16900(1500)	16000(1500)	4.10(1)	4.14(2)
23	V451 Oph	0.0120(5)	2.78(6)	2.36(5)	2.64(3)	2.03(3)	10800(800)	9800(500)	4.038(14)	4.196(15)
24	EW Ori	0.079	1.190(14)	1.154(14)	1.142(10)	1.091(10)	5970 (100)	5781(95)	4.40(1)	4.42(1)
25	GG Ori	0.2218(39)	2.342(16)	2.338(17)	1.852(25)	1.830(25)	9950(200)	9950(200)	4.272(12)	4.282(12)
26	ζ Phe	0.0113	3.9(2)	2.5(1)	2.9(2)	1.8(1)	14454(1030)	10116(350)	4.1(1)	4.3(1)
27	PV Pup	0.0503(11)	1.565(12)	1.554(14)	1.542(16)	1.499(16)	6920(310)	6935(310)	4.256(10)	4.278(10)
28	YY Sgr	0.1587(5)	3.90(13)	3.48(9)	2.56(3)	2.33(5)	14790(700)	14125(665)	4.21(2)	4.25(3)
29	V526 Sgr	0.2204(4)	2.27(7)	1.68(6)	1.89(2)	1.56(2)	10140(190)	8710(100)	4.24(2)	4.28(2)
30	V1647 Sgr	0.4142(11)	2.19(4)	1.97(3)	1.83(2)	1.67(2)	9595(315)	9100(300)	4.253(11)	4.289(11)
31	V760 Sco	0.0270(5)	4.98(9)	4.62(7)	3.01(6)	2.64(5)	16900(500)	16300(500)	4.18(2)	4.26(29)
32	BP Vul	0.0355(27)	1.737(15)	1.408(9)	1.852(14)	1.489(14)	7700(150)	6800(150)	4.142(7)	4.240(8)

the evolutionary tracks that best match with the locations of both components in the system within the error limits in the *M* and g plane (Figs. 2-5). In the last step, we computed a set of isochrones using the same reference Z-value in the Y^2 models. The age value is determined from the isochrone that fits best the positions of both components. The corresponding isochrones and the evolutionary tracks on the T_{eff} - g plane are illustrated in Figs. 6-9. Since all of the systems are detached binary stars, we neglected the possibility that any mass transfer has previously occurred in the system.

The estimated chemical composition values and the ages are given in Table 2 as follows: number, name of the system, metallicity Z, helium abundance Y, iron abundance [Fe/H], age t and circularization time t_{circ}.

4. Summary

In this study, we calculated the ages for 32 eccentric orbit eclipsing binary stars by interpolating in a grid of Y^2 isochrones. We determined the age assuming that both components are formed at the same time and have the same chemical composition. We based our age determination on the isochrones plotted on the $T_{eff} - g$ plane for both components. We compared these with the circularization times-scales (t_{circ}) that were computed for the systems by Khaliullina (2010) from the theory of Zahn (1977). As can be seen in Table 2, the evolutionary ages of the systems are consistent with the t_{circ} values, calculated by the Zahn'n (1977) theory.

Table 2. Isochronal Ages.

No	Name	Z	Y	[Fe/H]	t (Gyr)	Mean relative error (%)	t_{circ} (Gyr)	log (t/t_{circ})
1	BW Aqr	0.02	0.27	0.046	2.49(21)	8	–	–
2	WW Cam	0.02	0.27	0.046	0.510(68)	12	33.88	−1.82
3	IT Cas	0.017	0.264	0.03	2.48(17)	7	–	–
4	MU Cas	0.01	0.25	−0.273	0.089(10)	11	10964.78	−5.09
5	V459 Cas	0.01	0.25	−0.273	0.605(13)	3	53703.18	−4.95
6	EK Cep	0.015	0.26	−0.088	0.020(13)	65	–	–
7	EY Cep	0.023	0.276	0.113	0.103(76)	74	–	–
8	TV Cet	0.012	0.254	−0.19	1.25(51)	41	–	–
9	α CrB	0.01	0.25	−0.273	0.44(20)	47	–	–
10	V477 Cyg	0.015	0.26	−0.088	0.55(30)	55	–	–
11	V541 Cyg	0.015	0.26	−0.088	0.197(50)	25	35481.34	−5.26
12	V1143 Cyg	0.033	0.296	0.298	0.43(15)	36	–	–
13	V1147 Cyg	0.009	0.248	−0.32	0.183(25)	14	1023292.99	−6.75
14	RX Her	0.02	0.27	0.046	0.225(58)	26	70.79	−2.50
15	AI Hya	0.025	0.28	0.153	0.987(89)	9	32359.37	−4.52
16	RW Lac	0.012	0.254	−0.19	10.80(40)	4	–	–
17	SS Lac	0.02	0.27	0.046	0.378(28)	7	3981.07	−4.02
18	V364 Lac	0.017	0.264	−0.03	0.642(30)	5	6.03	−0.97
19	GG Lup	0.015	0.26	−0.088	0.011(4)	36	14.45	−3.12
20	RR Lyn	0.017	0.264	−0.03	1.06(15)	14	–	–
21	TZ Men	0.02	0.27	0.046	0.115(18)	12	–	–
22	U Oph	0.01	0.25	−0.273	0.059(5)	8	0.02	0.43
23	V451 Oph	0.015	0.26	−0.088	0.283(25)	9	1.35	−0.68
24	EW Ori	0.04	0.31	0.386	1.25(35)	28	–	–
25	GG Ori	0.02	0.27	0.046	0.083(32)	39	9549.93	−5.06
26	ζ Phe	0.017	0.264	−0.03	0.081(20)	25	0.23	−0.45
27	PV Pup	0.03	0.29	0.241	0.135(11)	7	10.72	−1.90
28	YY Sgr	0.01	0.25	−0.273	0.073(13)	18	3.55	−1.69
29	V526 Sgr	0.008	0.246	−0.373	0.387(52)	13	6.46	−1.22
30	V1647 Sgr	0.015	0.26	−0.088	0.225(40)	18	346.74	−3.19
31	V760 Sco	0.012	0.254	−0.19	0.045(7)	16	0.08	−0.27
32	BP Vul	0.02	0.27	0.046	0.84(27)	32	–	–

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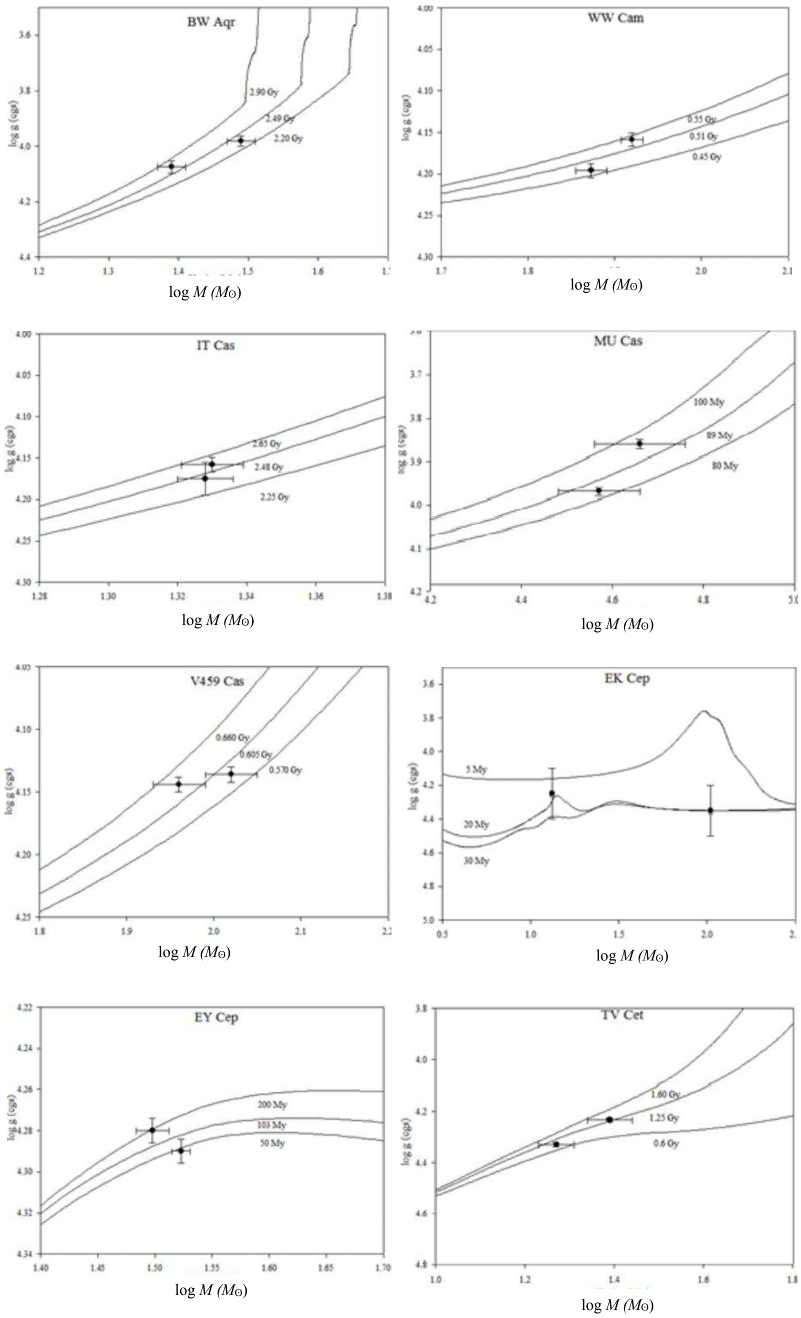

Fig. 2. The isochrones that best match the locations of both components in the systems.

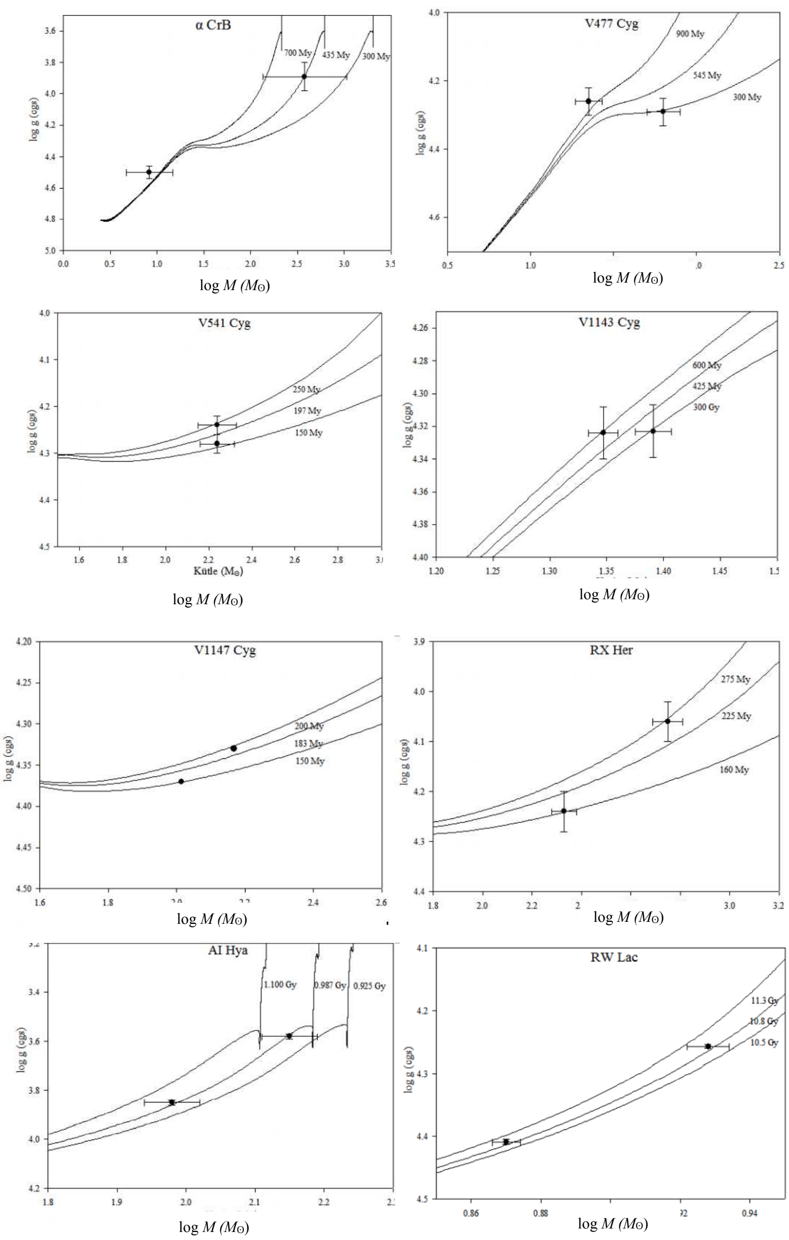

Fig. 3. As per Fig. 2.

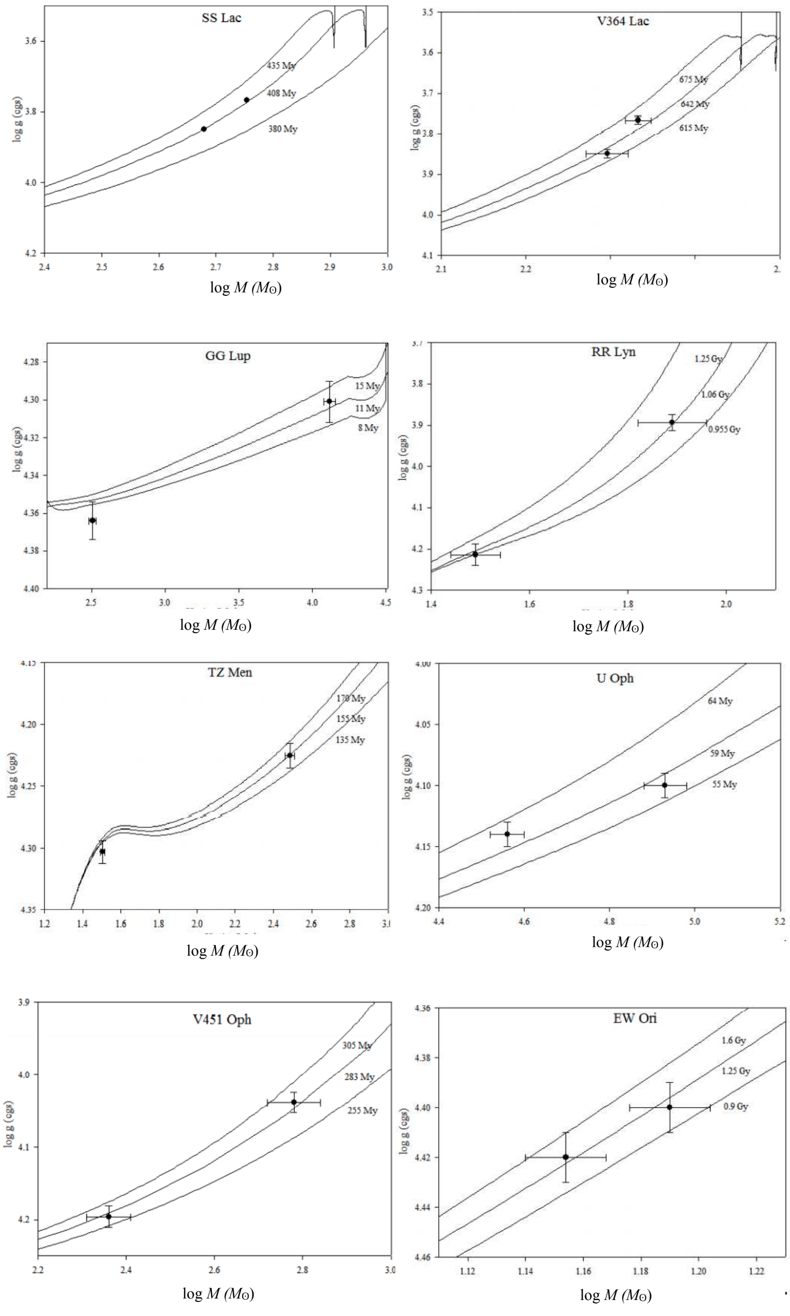

Fig. 4. As per Fig. 3.

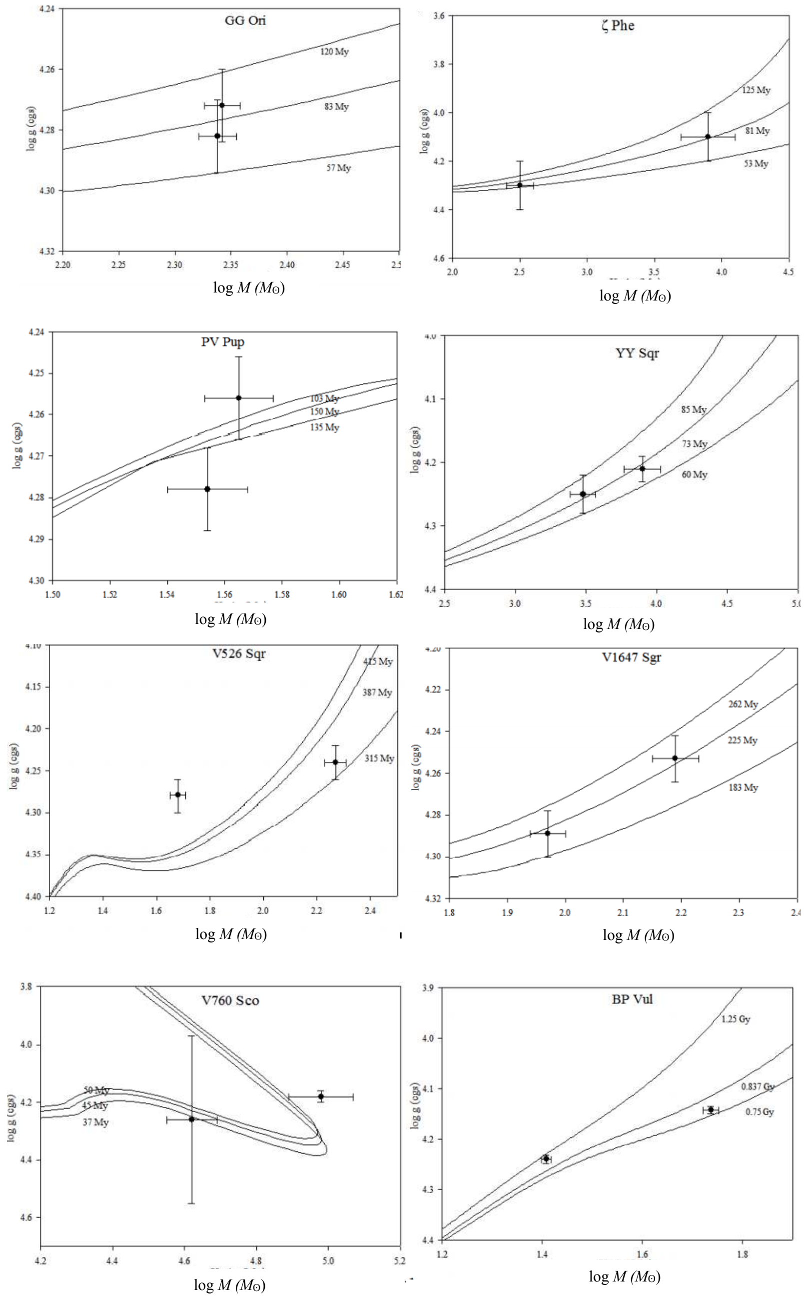

Fig. 5. As per Fig. 3.

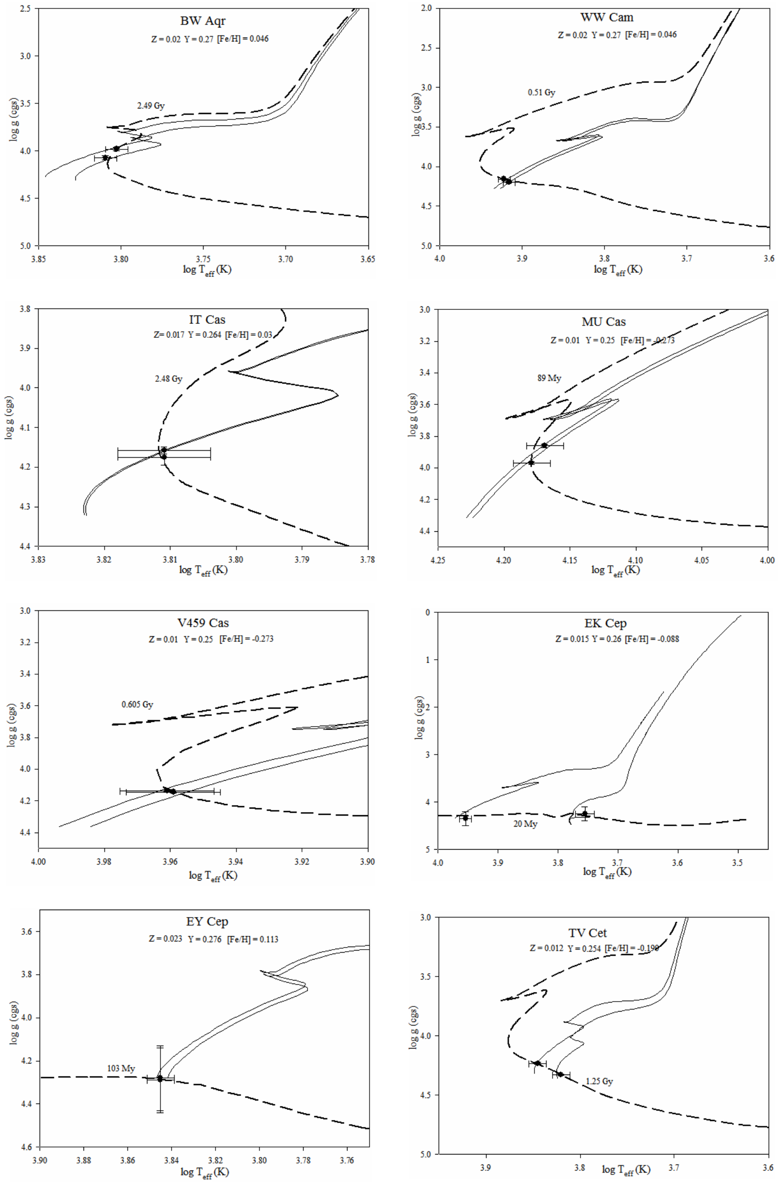

Fig. 6. The evolutionary tracks compared against the observations. The isochrones for the best-fitting composition are represented with dashed line.

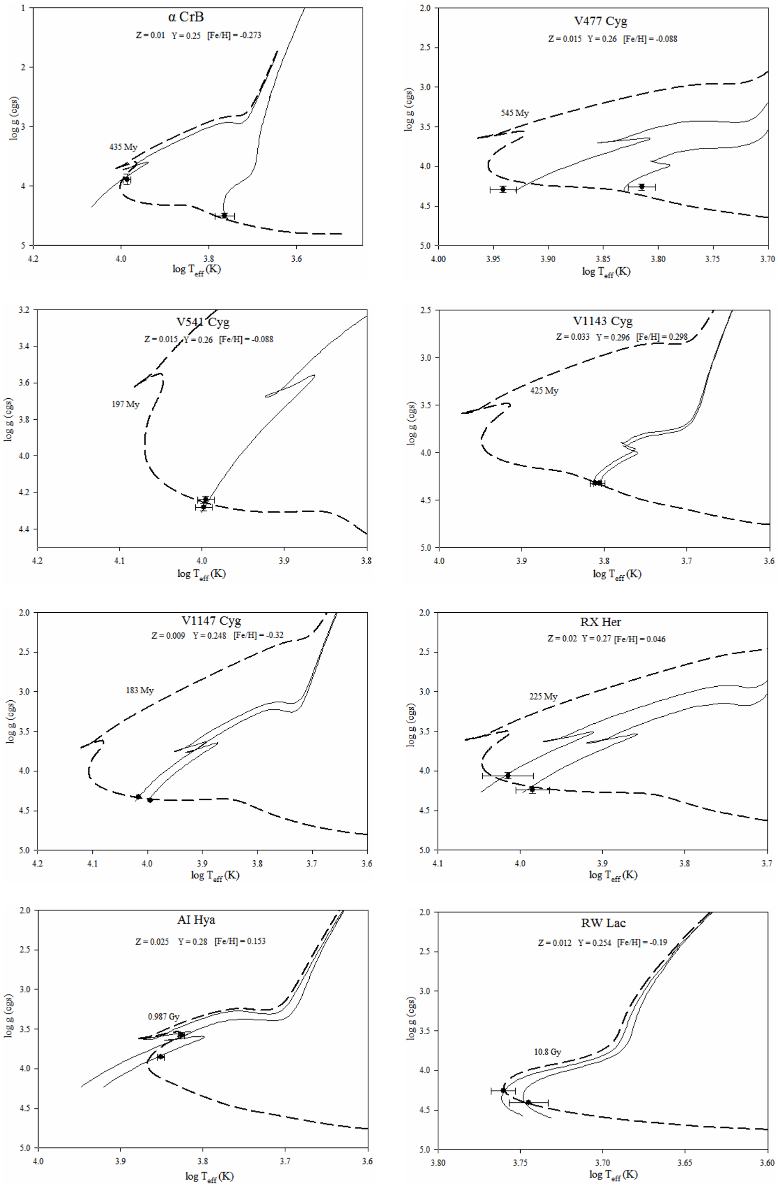

Fig. 7. As per Fig. 6.

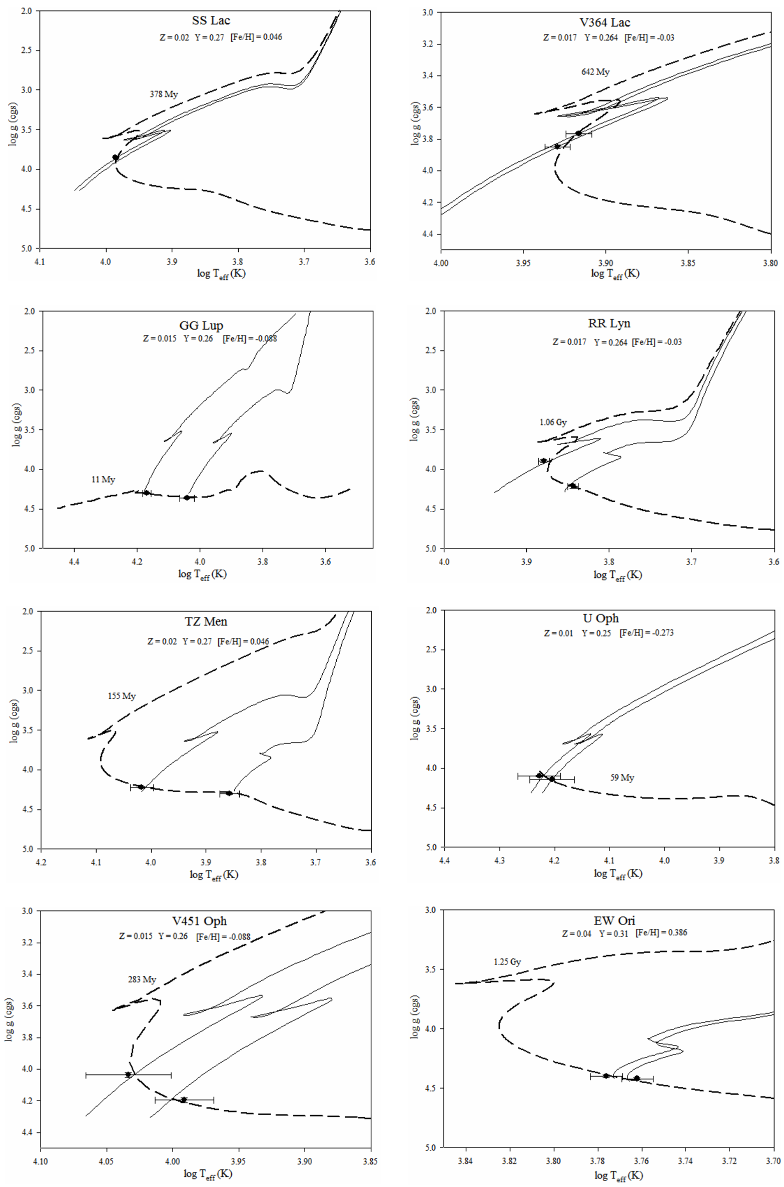

Fig. 8. As per Fig. 6.

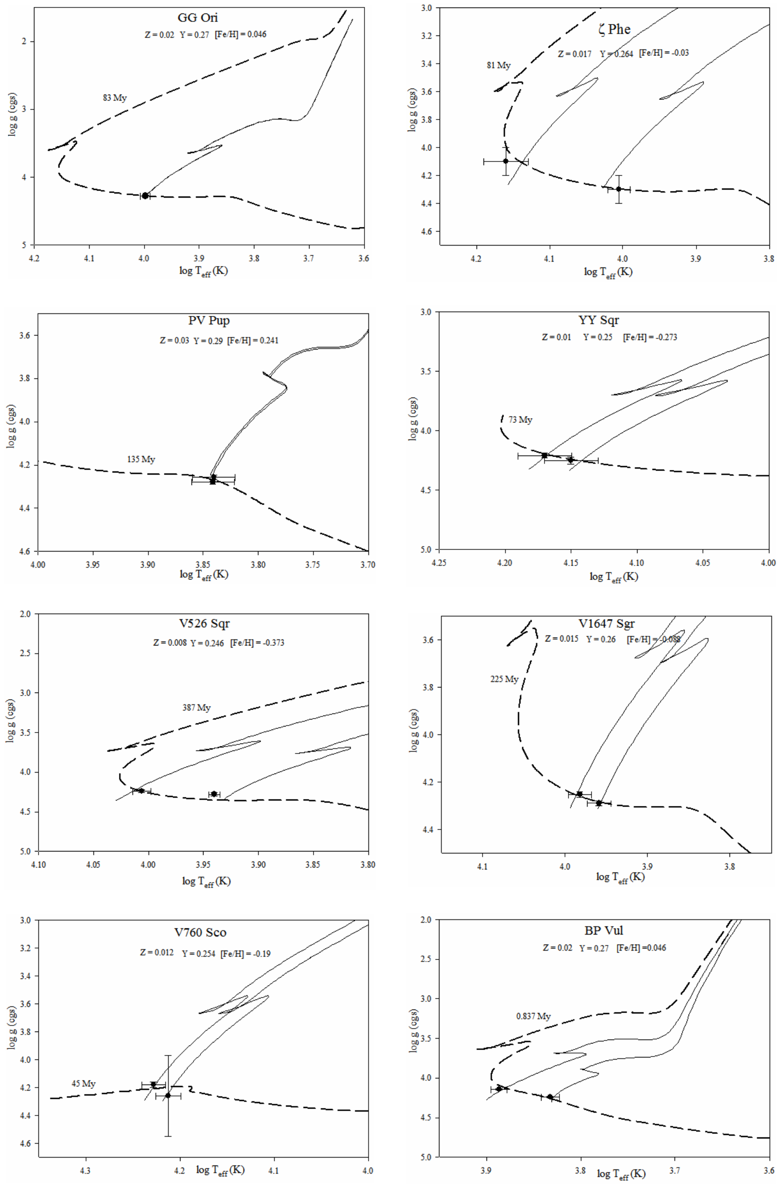

Fig. 9. As per Fig. 6.