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

Number 6021

Konkoly Observatory
Budapest
16 April 2012

HU ISSN 0374 – 0676

PERIOD–AGE CORRELATIONS FOR ECLIPSING BINARIES IN STELLAR CLUSTERS

BUKOWIECKI, Ł.[1]; MACIEJEWSKI, G.[1]; KONORSKI, P.[2]; ERRMANN, R.[3]

[1] Centrum Astronomii Uniwersytetu Mikołaja Kopernika, Gagarina 11, Pl-87100 Toruń, Poland; e-mail: `gm@astri.uni.torun.pl`

[2] Warsaw University Observatory, Al. Ujazdowskie 4, 00-478, Warsaw, Poland; e-mail: `piokon@astrouw.edu.pl`

[3] Astrophysikalisches Institut und Universitäts-Sternwarte, Schillergässchen 2–3, D–07745 Jena, Germany; e-mail: `ronny.errmann@uni-jena.de`

A stellar cluster is a group of stars born at the same place, roughly at the same time, and of the same chemically homogeneous cloud of gas and dust (Karttunen et al. 2003). Clusters offer useful observational tests to a variety of astrophysical and galactic studies. Their geometrical, physical, and chemical properties are directly related to processes and mechanisms of star formation and evolution. Binary star systems are very important in astrophysics because calculations of their orbits allow us to determine the masses of their components, that in turn allows other stellar parameters, such as radius and density, to be indirectly estimated. The orbital periods of binary stars are expected to become shorter during their evolution, e.g. as a result of magnetic braking mechanism. The theory and details of angular momentum loss has been described by Schatzman (1962), Huang (1966), Mestel (1968) and more recently Li et al. (2005), Eggleton (2006), Hussain (2011) and Stepien (2011). The observational data has been discussed by Mochnacki (1981) who estimated the time scale of this effect in W UMa stars is about $10^9 - 10^{10}$ years.

Our study on β Lyrae- (EB) and W UMa-type (EW) eclipsing binaries was focused on stars that belong to open and globular clusters only, i.e. probable members and concentrated on systems with relatively short orbital periods (less than few days). We searched the literature for variable stars discovered in the fields of open and globular clusters published after 1990 AD. From them we selected the EB and EW–type stars that, according to the authors, belong to the cluster. There were several different methods to establish the cluster membership probability in those publications, e.g. they used the position of the star on the HR–diagram, the apparent distance of the star from the cluster geometrical center; proper motion technique or the formula of Rucinski & Duerbeck (1997) to compare the system's distance to the cluster's distance modulus. We are aware that the membership of some stars may be more or less doubtful. Our goal was to gather information about periods and ages for as many as possible eclipsing binary stars (EB and EW–type) inside clusters to create a catalogue to investigate the period–age correlation. Taking this into consideration we think that the completeness of our catalog is high.

As a result, we collected 159 objects (35 EB and 124 EW type) from 34 open clusters, and 56 binary stars (6 EB and 50 EW type) from 13 globular clusters in the Galaxy. We considered only binary stars that, based on the literature data, belong to the cluster.
If for a given star there is more than one paper, then the results of orbital periods were averaged. All binary systems from our list with main parameters (periods, ages) and references are listed in Tables 1 and 2. We refer to the catalogues that include eclipsing binary stars in open clusters: Popova & Kraicheva (1984) and Clausen & Gimenez (1987). Update of these catalogues was highly timely and necessary, consequently we performed this update.

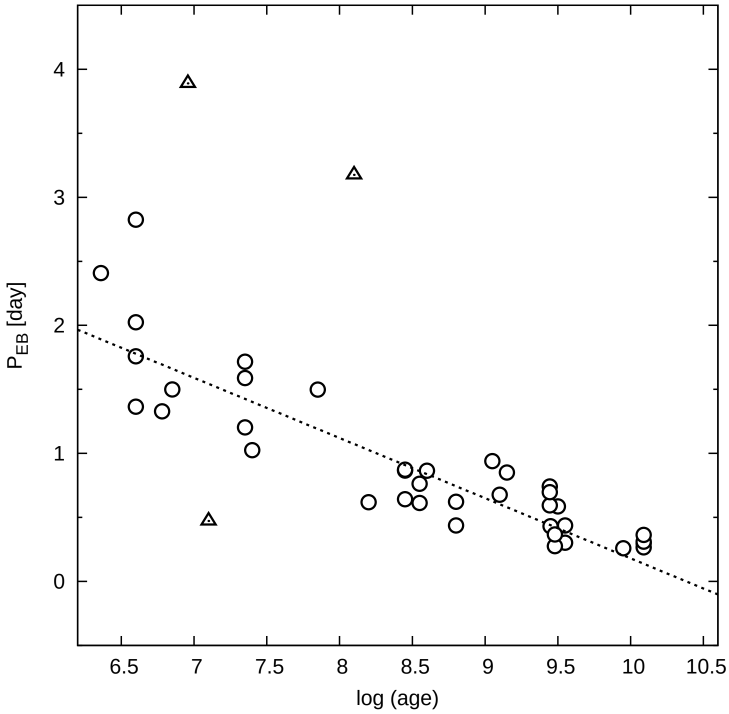

Figure 1. A relation between the orbital period of EB stars and open and globular cluster age.

In Fig. 1 we plotted the orbital period of EB stars (providing that age of binary stars is the same as the cluster age). Stars marked as triangles were rejected during fitting a linear relation. We fitted a linear trend that resulted in an equation:

$$P_{\rm EB}[{\rm day}] = (-0.47 \pm 0.05)\log({\rm age}) + (4.88 \pm 0.35), \quad (1)$$

the correlation coefficient was found to be 0.89.

For contact systems (Fig. 2) we do not observe such a significant trend. We found only one open cluster with one EW-star. That suggest that stars of this type are rare in young open clusters. Since the membership of a young EW-star is disputable, we removed this system from the further analysis. We took an average orbital period for each star from cluster, errors are represented by a standard deviation (vertical bars). In a result we obtained the relation:

$$P_{\rm EW}[\text{day}] = (-0.09 \pm 0.03)\log(\text{age}) + (1.17 \pm 0.25), \tag{2}$$

with the correlation coefficient 0.53. However, the maximum error obtained at the three sigma level suggests us to consider the age-dependence insignificant. It would be better to repeat the analysis if more EW–type stars would be discovered in less advanced age clusters. Lack of such systems in the younger clusters makes it difficult to draw general conclusions.

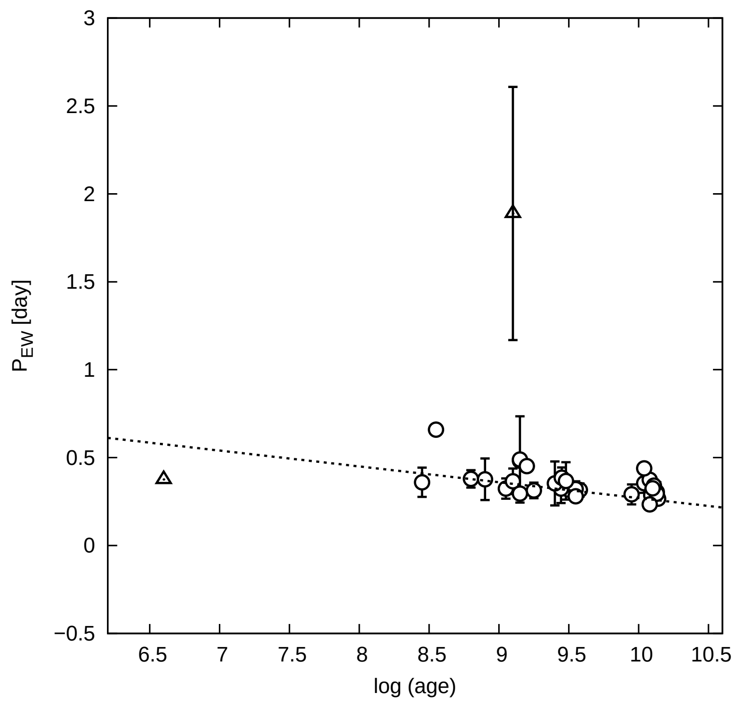

Figure 2. A relation between the orbital period of EW stars and open and globular cluster age.

The next step was to check the period-age relation for all eclipsing binaries together (Fig. 3). After empirical testing the best correlation was found for a non-linear function of the form $y = ax^{-1} + b$ with correlation coefficient equal 0.91. As a result, we obtained the relation:

$$P_{\rm EB+EW}[\text{day}] = (31.19 \pm 1.78)[\log(\text{age})]^{-1} - (2.87 \pm 0.21). \tag{3}$$

The orbital periods of binary stars in clusters become shorter with time. This is a strong effect for binaries in open clusters younger than about 600 Myr. This suggests that the orbital period of binary systems in young star clusters decrease with time. Perhaps other stars in these clusters can receive a part of the orbital energy from the binary system

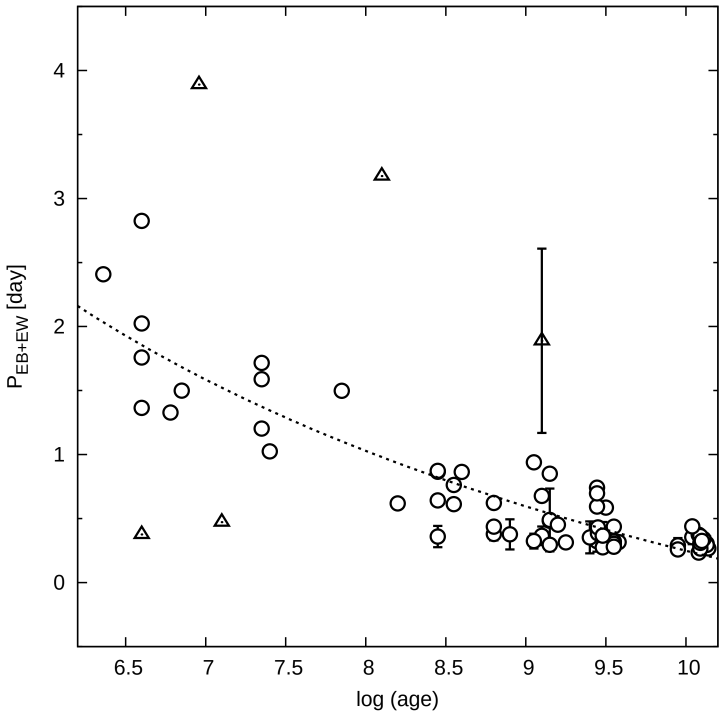

Figure 3. A relation between the orbital period of all eclipsing binaries and open and globular cluster age.

during close approach. But for the oldest systems with an age of several hundreds of Myrs orbital periods are almost constant.

A similar conclusion was obtained by Li et al. (2005) using Eggleton's code (Eggleton 1971, 1972, 1973). They noted a quasi-periodic behavior for orbital period around a constant value. So our results confirm their predictions. On the other hand Tylenda et al. (2011) observed a merger binary system. Maybe this is a result of the Darwin instability, where the tidal forces transport angular momentum from the orbit to the spin components (Chandrasekhar 1969) or it can also be caused by the aforementioned magnetic braking mechanism or a combination of both. In general the evolutionary paths of contact binaries are not exactly known and there is no unified theory in this subject, so probably this issue is more complicated (Webbink 2003, Csizmadia & Klagyivik 2004). Probably we need more well-studied binaries that belong to clusters to better understand their evolution outside and in clusters.

Acknowledgments: The research is supported by UMK grant 397-F and "Stypendium ze środków wspomagających młodych naukowców oraz uczestników studiów doktoranckich na Wydziale Fizyki, Astronomii i Informatyki Stosowanej UMK". RE would like to thank DFG for support in project NE 515 / 34-1.

Table 1. List of binary stars in open clusters, ID – identification number or the name of a star according to refereed papers, P – the period of variation, log(age) – decimal logarithm of the age (given in years). Type: EB and EW are β Lyrae and W UMa respectively.

Open cluster	log(age)	ID	Coordinates α δ J2000.0 for the binary system	Type	Period [day]
Berkeley 39[1]	9.95[2]	V3	07:46:46.9 −04:38:21.2	EW	0.38104
		V4	07:46:51.3 −04:36:07.4	EW	0.38132
		V5	07:46:52.9 −04:40:18.3	EW	0.30634
		V6	07:47:00.6 −04:38:44.4	EW	0.28444
		V7	07:46:46.2 −04:42:01.1	EW	0.27798
		V8	07:46:34.0 −04:42:27.9	EW	0.22876
		V9	07:46:47.2 −04:42:27.9	EB/EW	0.25863
Berkeley 39[3]	9.95[2]	V4	07:46:51.3 −04:35:07	EW	0.3813
		V5	07:46:52.9 −04:40:18	EW	0.2656
		V6	07:47:00.6 −04:38:44	EW	0.2844
		V7	07:46:46.2 −04:42:01	EW	0.278
		V8	07:46:33.9 −04:42:27	EW	0.2288
		V9	07:46:47.2 −04:42:28	EW	0.2598
		V11	07:46:32.7 −04:45:17	EW	0.2254
Collinder 228[4]	6.83[4]	DW Car	–	EB	1.3277493
Collinder 261[5]	9.45[2]	V2	12:37:13.6 −68:28:20	EW	0.355
		V4	12:37:57:9 −68:27:05	EW	0.3817
		V13	12:38:11.8 −68:24:10	EW	0.37494
		V15	12:38:18.5 −68.23:41	EW	0.31575
		V17	12:37:53.9 −68:23:22	EW	0.45709
		V19	12:37:47.3 −68.23.04	EW	0.34314
		V24	12:38:42.6 −68:22.04	EW	0.3543
		V25	12:38:16.5 −68:22:13	EW	0.40091
		V26	12:37:45.1 −68:22:17	EW	0.46133
		V28	12:38:10.0 −68:21:30	EW	0.38446
		V30	12:37:31.3 −68:21:28	EW	0.35132
		V31	12:37:57.5 −68:21:14	EW	0.38196
		V32	12:37:57.5 −68:20:02	EW	0.51901
		V33	12:38:12.1 −68:19:33	EW	0.28997
		V37	12:38:06.4 −68:17:39	EW	0.42947
		V39	12:39:07.3 −68:27:26	EB	0.4307
		V43	12:39:03.6 −68:16:25	EW	0.373
IC 4996[6]	6.85[2]	V2	20:14.42 +39:29:00	EB	1.499643
M11 (NGC 6705)[7]	8.45[2]	HV10	18:50:59.4 −06:13:43.3	EW	0.394555
		HV16	18:51:14.2 −06:17:42.1	EW	0.25532
M11 (NGC 6705)[8]	8.45[2]	243	18:51:14.8 −06:18:26.3	EB/EW	0.86577
		2740	18:50:59.4 −06:13:43.5	EW	0.39464
		8146	18:51:10.2 −06:12:50.1	EW	0.29357
		8641	18:51:09.3 −06:11:47.1	EW	0.4595
M37 (NGC 2099)[9]	8.9[2]	V3	05:52:33.03 +32:32:41.7	EW	0.4224
		V4	05:52:53.26 +32:33:01.2	EW	0.5585
		V5	05:53:00.63 +32:24:50.8	EW	0.3579
M37 (NGC 2099)[10]	8.9[2]	V3	05:51:33.12 +32:30:33.8	EW	0.422483
		V4	05:51:37.12 +32:40:23.4	EW	0.55819
		V7	05:51:45.62 +32:27:16.7	EW	0.357735
		V20	05:52:17.60 +32:30:12.6	EW	0.289456
		V24	05:52:40.10 +32:36:10.4	EW	0.252674
		V855	–	EW	0.564829
		V1160	–	EW	0.242092
		V1181	–	EW	0.25817
		V1194	–	EW	0.269735
		V1447	–	EW	0.296877

Table 1. – cont.

Open cluster	log(age)	ID	Coordinates α δ J2000.0 for the binary system	Type	Period [day]
M67 (NGC 2682)[11]	9.55[2]	5018	–	EW	0.28
Melotte 66[12]	9.445[13]	V4	111.57849 –47.69664	EW	0.402
		V5	111.56815 −47.64329	EB	0.7413
		V6	111.72366 −47.76692	EB	0.6974
		V7	111.56230 −47.72299	EB	0.5942
		V8	111.54562 −47.71756	EW	0.32903
		V9	111.71073 −47.75736	EW	0.2386
NGC 1245[14]	9.05[2]	20176	03:15:30 +47:14:37	EW	0.301
		20534	03:14:53 +47:16:32	EW	0.281
		60193	03:14:28 +47:11:07	EW	0.39
NGC 1647[15]	8.2[15]	M dwarf	04:46:32.86 +19:01:43.2	EB	0.61879
NGC 1850[16]	7.85[16]	39	05:08:42.8 −68:52:07	EB	1.4978
NGC 188[17]	9.5[2]	V1	0:46:54.15 +85:21:44.1	EW	0.289744
		V2	0:47:33.50 +85:16:24.8	EW	0.306905
		V3	0:50:27.77 +85:15:09.0	EW	0.285728
		V4	0:50:50.21 +85:16:12.4	EW	0.342457
		V5	0:48:22.65 +85:15:55.3	EB/EW	0.585984
		V6	0:47:16.51 +85:15:35.9	EW	0.3304345
		V7	0:46:12.23 +85:14:02.5	EW	0.3281916
NGC 188[18]	9.5[2]	V1	0:46:54.02 +85:21:43.58	EW	0.2897
		V2	0:47:33.37 +85:16:24.14	EW	0.3069
		V4	0:50:50.01 +85:16:11.66	EW	0.3425
		V5	0:48:22.53 +85:15:54.72	EB/EW	0.586
		V6	0:47:16.44 +85:15:35.31	EW	0.3304
		V13	0:51:14.99 +85:24:51.17	EW	0.3583
		V28	0:52:08.82 +85:19:05.97	EW	0.304
NGC 2099 (M37)[19]	8.6[2]	V4	05:52:53.272 +32:33:01.33	EW	0.4224
		KV12	05:51:29.340 +32:24:18.06	EB	0.864
NGC 2158[20]	9.1[2]	V12	06:07:18.7 +24:06:50.1	EW	1.0573
		V22	06:07:37.7 +24:07:40.2	EW	2.1311
		V24	06:07:43.4 +24:06:22.9	EW	2.3042
NGC 2204[21]	9.2[2]	892	06:15:55.42 -18:44:51.7	EW	0.45178
NGC 2243[22]	9.58[23]	V2	06:29:33.80 −31:17:02.8	EW	0.2853
		V3	06:29:44.87 −31:18:18.8	EW	0.356455
NGC 2243[24]	9.58[23]	V2	6:29:33.81 −31:17:03.4	EW	0.2853011
		V3	6:29:44.92 −31:18:19.4	EW	0.3564557
		V12	6:29:33.01 −31:17:53.6	EW	0.28598
NGC 2243[25]	9.58[23]	V2	06:29:33.81 −31:17:03.4	EW	0.285
		V3	06:29:44.92 −31:18:19.4	EW	0.356
NGC 2244[26]	6.36[26]	V578 Mon	06:32:00.61 +04:52:40.9	EB	2.40848
NGC 2301[27]	8.45[2]	V7	06:51:56.68 +00:25:49.2	EB	0.642
		V9	06:51:41:53 +00:23:45:5	EB	0.873
NGC 2506[28]	9.05[2]	V9	08:00:05.4 −10:43:39	EB	0.9392
NGC 2516[29]	8.1[2]	V392 Car	07:58:10.47 −60:51:57.5	EB	3.17499
NGC 457[30]	7.35[2]	V3	01:19:09 +58:17:25	EB	0.642
		V12	01:20:43 +58:28:21	EB	0.873
NGC 6253[31]	9.4[2]	41404	254.656188433 −52.616197780	EW	0.4968
		31606	254.800782797 −52.669356128	EW	0.2934
		30341	254.720919972 −52.690243537	EW	0.2692

Table 1. – cont.

Open cluster	log(age)	ID	Coordinates α δ J2000.0 for the binary system	Type	Period [day]
NGC 6259[32]	8.55[2]	V3	17:00:18.83 −44:38:02.7	EB/EW	0.763
		V15	17:01:13.97 −44:34:05.6	EW	0.6126
		V16	17:00:20.56 −44:44:02.2	EW	0.6588
NGC 633[33]	7.4[34]	V2	–	EB	1.025
NGC 6791[35]	9.55[2]	V3	19.354380 +37.769349	EW	0.31764
		V4	19.348396 +37.806652	EW	0.32568
		V5	19.346258 +37.813354	EW	0.31274
		V7	19.340271 +37.821892	EW	0.39174
		V8	19.341938 +37.865810	EW	0.33406
		V29	19.354796 +37.751386	EB	0.43662
		V117	19.343433 +37.665848	EW	0.36644
		V118	19.347500 +37.651222	EW	0.30623
		V119	19.351961 +37.916328	EB	0.30197
		01441_8	19.339422 +37.778118	EW	0.24544
NGC 6791[36]	9.55[2]	3	19:21:14.96 +37:46:09	EW	0.318
		5	19:20:53.62 +37:48:47	EW	0.2705
		7	19:20:25.30 +37:49:19	EW	0.3935
NGC 6791[37]	9.55[2]	V4	–	EB	0.325482
		V5	–	EB	0.270117
NGC 6819[38]	9.25[2]	52004	19:41:25.87 +40:12:22.2	EW	0.348687
		V2388	19:41:10.33 +40:15:18.3	EW	0.366025
		V2396	19:41:28.58 +40:16:24.8	EW	0.293151
		V2393	19:41:22.61 +40:11:07.1	EW	0.303209
		V2394	19:41:22.91 +40:14:39.5	EW	0.2561
NGC 6866[39]	8.8[40]	V5	20:03:34.93 +44:14:50.4	EW	0.321742
		V6	20:04:00.17 +44:14:03.5	EW	0.366528
		V7	20:03:49.82 +44:11:08.8	EW	0.41501
		V8	20:03:55.96 +44:10:46.5	EB	0.6222
		V9	20:03:38.79 +44:04:53.1	EW	0.43414
NGC 6866[40]	8.8[40]	0074	20:03:34.93 +44:14:50.1	EW	0.321750
		0248	20:03:38.79 +44:04:53.0	EB	0.437446
		0487	20:03:49.82 +44:11:08.5	EW	0.415110
NGC 6871[41]	6.958[42]	V453 Cyg	20:06:34.967 +35:44:26.28	EW	3.89
NGC 6939[43]	9.15[2]	V20	20:33:22 +60:37:14	EW	0.2951
NGC 7044[43]	9.15[2]	V3	21:13:16.97 +42:29:44.5	EW	0.46057
		V4	21:13:06.83 +42:29:18.7	EW	0.50262
NGC 7160[44]	7.35[2]	V497 Cep	21:52:00.4 +62:21:02	EB	1.2028351
NGC 7789[45]	9.15[2]	V2	23:57:33.51 +56:44:32.6	EW	0.72
		V3	23:57:39.49 +56:40:59.7	EW	0.5585
		V6	23:56:46.67 +56:43:23.7	EW	0.70
		V8	23:57:25.73 +56:43:32.8	EB	0.85
NGC 7789[46]	9.15[2]	V4	23:57:49.41 +56:46:59.91	EW	0.3375
		V7	23:57:24.45 +56:45:13.00	EW	0.4567
		V16	23:59:23.01 +56:35:51.05	EW	0.2317
		V20	23:57:10.65 +56:33:27.07	EW	0.279
		V22	23:56:38.70 +56:43:58.76	EW	0.3063
NGC 957[47]	7.1[2]	V2	23:30:8.17 +57:28:11.8	EB	0.47192
Tombaugh 2[48]	9.1[2]	V1	–	EB	0.6775
		V2	–	EW	0.3278
		V3	–	EW	0.4712
		V4	–	EW	0.3105
		V5	–	EW	0.3533

Table 1. – cont.

Open cluster	log(age)	ID	Coordinates α δ J2000.0 for the binary system	Type	Period [day]
Trumpler 37[49]	6.6[49]	3132	–	EW	0.3759
		3218	–	EB	1.3649
		6690	–	EB	2.0236
		7446	–	EB	2.8247
		9532	–	EB	1.7577

References – [1] Mazur et al. 1999; [2] Bukowiecki et al. 2011; [3] Kałużny et al. 1993b; [4] Southworth & Clausen 2007; [5] Mazur et al. 1995; [6] Pietrzyński 1996a; [7] Koo et al. 2007; [8] Hargis et al. 2005; [9] Kiss et al. 2001; [10] Hartman et al. 2008; [11] Sandquist 2006; [12] Zloczewski et al. 2007; [13] Mermilliod, J. C. 1996, http://www.univie.ac.at/webda/; [14] Pepper & Burke 2006; [15] Hebb et al. 2006; [16] Sebo & Wood 1995; [17] Zhang et al. 2002; [18] Mochejska et al. 2008; [19] Kang et al. 2007; [20] Koo et al. 2007; [21] Różyczka et al. 2007; [22] Kaluzny et al. 1996; [23] Anthony-Twarog et al. 2005; [24] Kałużny et al. 2006; [25] Kałużny et al. 1996b; [26] Hensberge et al. 2000; [27] Kim et al. 2001; [28] Arentoft et al. 2007; [29] Debernardi & North 2001; [30] Maciejewski et al. 2008a [31] De Marchi et al. 2010; [32] Chciechanowska et al. 2006; [33] Pietrzyński 1997; [34] Pietrzyński 1996b; [35] De Marchi et al. 2007; [36] Kałużny & Ruciński 1993a; [37] Ruciński et al. 1996; [38] Talamantes et al. 2010; [39] Molenda-Żakowicz et al. 2009; [40] Joshi et al. 2012; [41] Southworth et al. 2004; [42] Maciejewski et al. 2008b; [43] Kopacki et al. 2008; [44] Yakut et al. 2003; [45] Jahn et al. 1995; [46] Mochejska & Kałużny 1999; [47] Bukowiecki et al. 2009; [48] Kubiak & Kałużny 1992; [49] Errmann and the YETI team, in preparation

Table 2. List of binary stars in globular clusters, ID – identification number or the name of a star according to refereed papers, P – the period of variation, log (age) – the logarithm of age. Type: EB and EW are β Lyrae and W UMa respectively.

Open cluster	log(age)	ID	Coordinates α δ J2000.0 for a globular cluster	Type	Period [day]
NGC 104 (Tucanae 47)[1]	10.13[2]	V214	00:24:05.67 +72:04:52.6	EW	0.2737
		V221		EW	0.3135
		V225		EW	0.2346
		V227		EW	0.3788
		V238		EW	0.2506
		V244		EW	0.3837
		V245		EW	0.2789
		V249		EW	0.3226
NGC 288[3]	10.04[4]	V10	00:52:45.24 −26:34:57.4	EW	0.4388
NGC 3201[5]	10.11[6]	V1	10:17:36.82 −46:24:44.9	EW	0.303587
		V2		EW	0.345095
		V6		EW	0.37307
NGC 4372[7]	10.04[8]	V5	12:25:45.40 −72:39:32.4	EW	0.3403
		V16		EW	0.3084
		V22		EW	0.4150

Table 2. – cont.

Open cluster	log(age)	ID	Coordinates α δ J2000.0 for a globular cluster	Type	Period [day]
NGC 5139[9]	9.48[10]	V10	13:26:47.24 −7:28:46.5	EW	0.3687
(ω Centauri)		V11	–	EW	0.3073
		V12		EB	0.2759
		V13		EW	0.3055
		V19		EW	0.3982
		V20		EW	0.3418
		V21		EW	0.2493
		V44		EW	0.2963
		V49		EB	0.3663
		V54		EW	0.2838
		V56		EW	0.2812
		V58		EW	0.6309
		V61		EW	0.4158
		V64		EW	0.3851
		V65		EW	0.5122
NGC 5466[11]	10.10[12]	NH19	14:05:27.29 +28:32:04.0	EW	0.3421
		NH30		EW	0.2975
NGC 6121 (M4)[13]	10.09[14]	V44	16:23:35.22 −26:31:32.7	EW	0.2637
		V47		EW	0.2700
		V48		EW	0.2825
		V49		EB	0.2976
		V50		EB	0.2665
		V51		EW	0.3031
		V53		EW	0.3085
		V55		EB	0.3108
NGC 6362[15]	10.08[16]	V39	17:31:54.99 −67:02:54.0	EB	0.3633
NGC 6397[17]	10.14[18]	V7	17:40:42.09 −53:40:27.6	EW	0.2716
		V8		EW	0.2710
NGC 6397[19]	10.14[18]	V7	17:40:42.09 −53:40:27.6	EW	0.26992
		V19		EW	0.25382
NGC 6752[20]	10.13[21]	V4	19:10:52.11 −59:59:04.4	EW	0.2502
		V8		EW	0.3150
		V14		EW	0.3175
NGC 6838 (M71)[22]	10.08[23]	V1	19:53:46.49 +18:46:45.1	EW	0.3490
		V2		EW	0.3672
		V3		EW	0.3739
		V5		EW	0.4045
M22 (NGC 6656)[24]	10.08[25]	M22_03	18:36:23.94 −23:54:17.1	EW	0.220502
		M22_05		EW	0.242792
		M22_06		EW	0.239431
M55 (NGC 6809)[26]	10.10[27]	V53	19:39:59.71 −30:57:53.1	EW	0.32524682

References – [1] Kałużny et al. 1998; [2] Hesser et al. 1987; [3] Kałużny et al. 1997b; [4] Catelan et al. 2002; [5] von Braun & Mateo 2002; [6] Layden & Sarajedini 2003; [7] Kałużny & Krzemiński 1993c; [8] Alcaino et al. 1991; [9] Kałużny et al. 1997c; [10] Hilker et al. 2004; [11] Mateo et al. 1990; [12] Fakadu & Sandquist 2007; [13] Kałużny et al. 1997a; [14] Caputo 1985; [15] Mazur et al. 1999b; [16] Brocato et al. 1999; [17] Kałużny 1997d; [18] Gratton et al. 2003; [19] Kałużny & Thompson 2003; [20] Thompson et al. 1999; [21] Layden, et al. 1999; [22] Yan & Mateo 1994; [23] Grundahl et al. 2002; [24] Pietrukowiecz & Kałużny 2003; [25] Davidge & Harris 1996; [26] Kałużny et al. 2010; [27] Jimenez & Padoan 2008

References:

Alcaino, G., Liller, W., Alvarado, F., Wenderoth, E. 1991, *AJ*, **102**, 159
Anthony-Twarog, B. J., Atwell, J., Twarog, B. A. 2005, *AJ*, **129**, 872
Arentoft, T., De Ridder, J., Grundahl, F., Glowienka, L., Waelkens, C., Dupret, M.-A., Grigahcène, A., Lefever, K., Jensen, H. R., Reyniers, M., Frandsen, S., Kjeldsen, H. 2007, *A&A*, **465**, 965
von Braun, K. & Mateo, M. 2002, *AJ*, **123**, 279
Brocato, E., Castellani, V., Raimondo, G., Walker, A.R. 1999, *ApJ*, **527**, 230
Bukowiecki, Ł., Maciejewski, G., Konorski, P., Strobel, A. 2011, *AcA*, **61**, 231
Bukowiecki, Ł., Maciejewski, G., Bykowski, W., Georgiev, T., Boeva, S., Kacharov, N., Mihov, B., Latev, G., Ovcharov, E., Valcheva, A. 2009, *OEJV*, **112**, 1
Catelan, M., Bellazzini, M., Ferraro, F. R., Fusi Pecci, F., Galleti, S., Landsman, W. B 2002, *IAUS*, **207**, 116
Caputo, F., Castellani, V., Quarta, M. L. 1985, *A&A*, **143**, 8
Chandrasekhar, S. 1969, *ApJ*, **157**, 1419
Chciechanowska, A., Pietrzyński, G., Wyrzykowski, Ł., Szewczyk, O., Kubiak, M., Udalski, A., Szymański, M. K. 2006, *AcA*, **56**, 219
Csizmadia, Sz. & Klagyivik, P. 2004, *A&A*, **426**, 1001
Clausen, J. V., Gimenez, A. 1987, *PAICz*, **69**, 185
Davidge, T.J. & Harris, W.E. 1996, *ApJ*, **462**, 255
De Marchi, F., Poretti, E., Montalto, M., Desidera, S., Piotto, G. 2010, *A&A*, **509**, A17
De Marchi, F. Poretti, E., Montalto, M., Desidera, S., Piotto, G., Desidera, S., Bedin, R., Claudi, R., Arellano Ferro, A., Bruntt, H., Stetson, P.B. 2007, *A&A*, **471**, 515
Debernardi, Y. & North, P. 2001, *A&A*, **374**, 204
Eggleton, P.P. 1971, *MNRAS*, **151**, 351
Eggleton, P.P. 1972, *MNRAS*, **156**, 361
Eggleton, P.P. 1973, *MNRAS*, **163**, 279
Eggleton, P.P. 2006, Evolutionary Processes in Close Binary Stars, Cambridge Univ. Press
Errmann, R. and the YETI team, in preparation
Fakadu, N. & Sandquist, E. 2007, *ApJ*, **663**, 277
Gratton, R. G., Bragaglia, A., Carretta, E., Clementini, G., Desidera, S., Grundahl, F., Lucatello, S. 2003, *A&A*, **408**, 529
Grundahl, F., Stetson, P. B., Andersen, M. I. 2002, *A&A*, **395**, 481
Hargis, J. R., Sandquist, E. L., Bradstreet, David H. 2005, *AJ*, **130**, 2824
Hartman, J. D., Gaudi, B. S., Holman, M. J., McLeod, B. A., Stanek, K. Z., Barranco, J. A., Pinsonneault, M. H., Kalirai, J. S. 2008, *ApJ*, **675**, 1254
Hebb, L., Wyse, R. F. G., Gilmore, G., Holtzman, J. 2006, *AJ*, **131**, 555
Hensberge, H., Pavlovski, K., Verschueren, W. 2000, *A&A*, **358**, 553
Hesser, J. E., Harris, W. E., Vandenberg, D. A. 1987, *PASP*, **99**, 1148
Hilker, M., Kayser, A., Richtler, T., Willemsen, P. 2004, *A&A*, **422L**, 9
Huang S. S., 1966, *An.Ap*, **29**, 331
Hussain, G. A. J. 2011, *ASPC*, **447**, 143
Jahn, K. Kałużny, J., Ruciński, S. M. 1995, *A&A*, **295**, 101
Jimenez, R. & Padoan, P. 1998, *ApJ*, **498**, 704
Joshi, Y.C., Joshi, S., Kumar, B., Mondal, S., Balona, L.A. 2012, *MNRAS*, **419**, 2379
Kałużny, J. & Ruciński, S.M. 1993a, *MNRAS*, **265**, 34
Kałużny, J., Mazur, B., Krzemiński, W. 1993b, *MNRAS*, **262**, 49
Kałużny, J. & Krzemiński, W. 1993c, *MNRAS*, **264**, 785

Kałużny, J.; Krzemiński, W.; Thompson, I. B.; Stachowski, G. 2006, *AcA*, **56**, 51
Kałużny, J., Krzemiński, W., Mazur, B. 1996a, *A&AS*, **118**, 303
Kałużny, J., Krzemiński, W., Mazur, B. 1996b, *ASPC*, **90**, 152
Kałużny, J., Thompson, I. B., & Krzemiński, W. 1997a, *AJ*, **113**, 2219
Kałużny, J. 1997b, *A&AS*, **122**, 1
Kałużny, J., Kubiak, M., Szymanski, M., Udalski, A., Krzemiński, W., Mateo, M., Stanek, K. 1997c, *A&AS*, **122**, 471
Kałużny, J., Krzemiński, W., Nalezyty, M. 1997d, *A&AS*, **125**, 337
Kałużny, J., Kubiak, M., Szymanski, M., Udalski, A., Krzemiński, W., Mateo, M., & Stanek, K. Z. 1998, *A&AS*, **128**, 19
Kałużny, J. & Thompson I.B. 2003, *AJ*, **125**, 2534
Kałużny, J., Thompson, I.B., Krzemiński, W., Zloczewski, K. 2010, *AcA*, **60**, 245
Kang, Y. B., Kim, S.-L., Rey, S.-C., Lee, C.-U., Kim, Y. H., Koo, J.-R., Jeon, Y.-B. 2007, *PASP*, **119**, 239
Karttunen, H., Kröger, P., Oja, H., Poutanen, M., Donner, K.J. 2003, Fundamental astronomy, Fourth Edition, Berlin-Heidelberg-New York: Springer Verlag
Kim, S.-L., Chun, M.-Y., Park, B.-G., Lee, S. H., Sung, H., Ann, H. B., Lee, M. G., Jeon, Y.-B.,Yuk, I.-S. 2001, *A&A*, **371**, 571
Kiss, L. L. Szabó, Gy. M., Sziládi, K., Furész, G., Sárneczky, K., Csák, B. 2001, *A&A*, **376**, 561
Koo, J.-R., Kim, S.-L., Rey, S.-C., Lee, C.-U., Kim, Y. H., Kang, Y. B., Jeon, Y.-B. 2007, *PASP*, **119**, 1233
Kopacki, G., Drobek, D., Kołaczkowski, Z., Połubek, G. 2008, *AcA*, **58**, 373
Kubiak, M. & Kałużny, J. 1992, *AcA*, **42**, 155
Layden, A. C., Ritter, L. A., Welch, D. L., & Webb, T. M. A. 1999, *AJ*, **117**, 1313
Layden, A.C. & Sarajedini, A. 2003, *AJ*, **125**, 208
Li, L., Han, Z., Zhang, F. 2005, *MNRAS*, **360**, 272
Maciejewski, G., Bukowiecki, Ł., Brożek, T., Georgiev, TS., Boeva, S., Kacharov, N., Mihov, B., Latev, G., Ovcharov, E., Valcheva, A. 2008a, *IBVS*, **5864**
Maciejewski, G., Georgiev, Ts., Niedzielski, A. 2008b, *AN*, **329**, 387
Mateo, M., Harris, H.C., Nemec, J., & Olszewski, E. W. 1990, *AJ*, **100**, 469
Mazur, B., Krzemiński, W., Kałużny, J. 1999, *AcA*, **49**, 551
Mazur, B., Krzemiński, W., Kałużny, J. 1995, *MNRAS*, **273**, 59
Mazur, B., Kałużny, J., & Krzemiński, W. 1999b, *MNRAS*, **306**, 727
Mermilliod, J. C. 1996, *ASPC*, **90**, 475
Mestel, L. 1968, *MNRAS*, **140**, 177
Mochejska, B. J. Stanek, K. Z., Sasselov, D. D., Szentgyorgyi, A. H.,Cooper, R. L., Hickox, R. C., Hradecky, V., Marrone, D. P., Winn, J.N., Schwarzenberg-Czerny, A. 2008, *AcA*, **58**, 263
Mochejska, B.J. & Kałużny, J. 1999, *AcA*, **49**, 351
Mochnacki, S. W. 1981, *ApJ*, **245**, 650
Molenda-Żakowicz, J. Kopacki, G., Steślicki, M., Narwid, A. 2009, *AcA*, **59**, 193
Pepper, J. & Burke, Ch. 2006, *AJ*, **132**, 1177
Pietrukowiecz, P. & Kałużny, J. 2003, *AcA*, **53**, 371
Pietrzyński, G. 1996a, *AcA*, **46**, 417
Pietrzyński, G. 1996b, *AcA*, **46**, 357
Pietrzyński, G. 1997, *AcA*, **47**, 211
Popova, M., Kraicheva, Z., 1984, *AISAO*, **18**, 64
Różyczka, M., Kałużny, J., Krzemiński, W., Mazur, B. 2007, *AcA*, **57**, 323

Rucinski, S. M., Kałużny, J., Hilditch, R.W. 1996, *MNRAS*, **282**, 705
Rucinski, S. M. 2000, *AJ*, **120**, 319
Rucinski, S. M., Duerbeck, H. W. 1997, *PASP*, **109**, 1340
Sandquist, E. L. 2006, *IBVS*, **5679**
Schatzman, E. 1962, *AnAp*, **25**, 18
Sebo, K. M. & Wood, P. R. 1995, *ApJ*, **449**, 164
Southworth, J. & Clausen J. V. 2007, *A&A*, **461**, 1077
Southworth, J., Maxted, P.F.L., Smalley, B. 2004, *MNRAS*, **351**, 1277
Stepien, K. 2011, *AcA*, **61**, 139
Talamantes, A. Sandquist, E. L., Clem, J. L., Robb, R. M., Balam, D. D., Shetrone, M. 2010, *AJ*, **140**, 1268
Webbink, R. F. 2003, *ASPC*, **293**, 76
Thompson, I. B., Kałużny, J., Pych, W., & Krzemiński, W. 1999, *AJ*, **118**, 462
Tylenda, R., Hajduk, M., Kamiński, T., Udalski, A., Soszyński, I., Szymański, M. K., Kubiak, M., Pietrzyński, G., Poleski, R., Wyrzykowski, Ł., Ulaczyk, K. 2011, *A&A*, **528**, A114
Yakut, K., Tarasov, A.E., Ibanoglu, C., Harmanec, P., Kalomeni, B., Holmgren, D.E., Bozic, H., Eenens, P. 2003, *A&A*, **405**, 1087
Yan, L. & Mateo, M. 1994, *AJ*, **108**, 1810
Zhang, X. B., Deng, L., Tian, B., Zgou, X. 2002, *AJ*, **123**, 1548
Zloczewski, K., Kałużny, J., Krzemiński, W., Olech, A., Thompson I.B. 2007, *MNRAS*, **380**, 1191