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Time scales of activity cycles in solar-type stars and K–M dwarfs

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Cycles of activity similar to the well-known spots cycle on the Sun are known now on solar-type stars and K–M dwarfs. A study of the intensity of fluxes of H&K Ca II lines in the HK project or the behavior of brightness on long-term spans allow us to find cyclic changes of activity on many objects. We collected the published data about stellar cycles and obtained our own new photometric results for 9 active G–M dwarfs using photometric databases and considered the dominant detected or suspected cycles for the sample of 65 solar-type stars and red dwarfs. About 50% of stars have activity cycles comparable with the solar 11-year cycle (7–18 yr). This group includes stars with periods of rotation >25 d. The faster rotating G–K dwarfs (15%) as the more active show longer cycles up to 40 yr. Several of K and M rapid rotating dwarfs (10%) have the longest time scale of variations in a yearly mean brightness up to 80 years. The investigation of long-term cycles of the stellar activity is limited by data series, only a few of them cover a time span of about 100 years. So, at present we can study cycles of activity less than 50 years, longer cycles can only be suspected.

Keywords: Stars: G–K dwarfs; solar-type activity: stellar activity cycles

1 Introduction

Magnetic activity of stars began to be studied since the end of the 1960s. The important results were obtained due to the systematic observation of flux in the emission core of H&K Ca II lines for 111 stars in the frame of the HK (or Mount Wilson) project (Wilson 1978, Baliunas et al. 1995). One of these results is the existence of stellar cycles produced as well as on the Sun by stellar magnetic fields and related on a rotation and an inner structure of stars.

For many G–K dwarfs a mean length of cycles are comparable with 11-yr solar cycle. The study of chromospheric indices and their connection with a rotation or the Rossby number have shown that stars rotating rapidly demonstrate a high level of activity and form the "branch of active stars" and stars with rotational periods less

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than the solar one belong to "inactive stars" (Noyes et al. 1984, Branderburg et al. 1998, Baliunas et al. 1996, Bohm-Vitense 2007).

Radick et al. (1998) made photometric and chromospheric HK emission time series measurements with high precision for 35 stars from the HK project including the Sun and showed that some stars (old as the Sun) demonstrated changes in radiation similar to the solar and become brighter in the maximum of activity, but other, younger stars are fainter. Stars with different physical parameters and ages are different in many manifestations of activity. Some stars demonstrate obvious cycles or even multicycles as the Sun, some stars show the "flat" level of activity, perhaps a similar to the known Maunder Minimum (Baliunas et al. 1995, Katsova et al. 2007).

The length and amplitude of cycles are observational parameters used to study the relation between activity and physical parameters of stars and also to support a theoretical modeling of stellar magnetic activity.

Phillips, Hartmann (1978) and Hartmann et al. (1981) have measured magnitudes of several K–M dwarfs in the Harvard photographic archive and found that the duration of cycles on cool dwarfs can exceed some decades. A current photometric rows for solar-type stars and more cool dwarfs cover 30–40 years only. Progress in the understanding of the stellar magnetic activity, differences of this phenomenon on solar-type stars and on red dwarfs could be provided by a study of extensive number of objects with different parameters and ages.

The faster rotating G–K dwarfs (15%) are more active and show longer cycles up to 40 yr. A several of K and M rapid rotating dwarfs (10%) have the longest time scale of variations in a yearly mean brightness up to 80 years. The investigation of long-term cycles of the stellar activity are limited by data series, only a few of them cover a time span of about 100 years. So, at present we can study cycles of activity less than 50 years, more longer cycles can only be suspected. Progress in the understanding of the stellar magnetic activity, features of this phenomenon on stars with different parameters and ages is associated with obtaining systematic observations of various activity indices.

In this paper, analysis of the length of cycles on G–M dwarfs is presented. We used collected information and our own results for some stars which were observed for some decades. Differences in the duration of activity cycles for solar-type stars and more rapid rotating red dwarfs are also considered.

2 Sources of data and methods to search for stellar cycles

The behavior of indicators of activity on red dwarfs demonstrates cyclic variations over time, but these variations have different origins and may be produced by evolution of active regions and changes of active longitudes (flip-flop effect), their redistribution or generation. A search and study of cyclical changes in each of these manifestations of stellar activity required observational series of different duration. The short rows limited in duration to a few years allow us to consider relatively rapid processes of evolution and decay of spots, but the processes of formation of spots in analogy to the Sun need to be studied as a data series of some decades.

For our sample of G–M dwarfs we used results of a search for stellar magnetic cycles on long-term data series more than 20 years.

Olah et al. (2016) presented new data about cycles of activity on 29 stars of the HK project which were studied on the 36 yr time span. Most of these stars demonstrate cycles of 7–18 yr that is similar to the well-known solar spots cycle. Some stars have not only simple cycles, but also shorter one or more cycles (multicycles) and also long-term trends of 25 yr or more in duration.

Photometric research on long-term intervals was made by Messina et al. (2002), and Bondar (2013) considered the rows in several decades for 40 dK–dM stars, Alekseev, Kozhevnikova (2018) published light curves for the 13 rapid rotating M stars.

For several stars the length of cycles was determined on the compiled light curves using photographic measurements and data collected in some photometric databases (Table 1). Data from ASAS catalogue (Pojmanski 1997) cover 2002–2009 time span, data from SuperWASP (`https://wasp.cerit-sc.cz/form`) are obtained in 2004–2008 with a high time resolution that allow to determine or refine a rotation periods for several stars, KWS (Kamogata /Kiso/Kyoto Wide-field Survey, `http://kws.cetus-net.org/~maehara/VSdata.py?object`) contains data for 2008–20018. Using these sources and Hipparcos photometric data we have formed a long-term rows to search for a cycles.

Analysis of variability was made by the program AVE (`http://www.gea.cesca.es`) which includes the methods of Jurkevich, Hartley, Scargle to search for a periodicity. We have considered full data rows and the calculated yearly mean magnitudes and made a search for periods taking into account the Nyquist criterion. But the longest cycles periods were limited by time span of row that leads to their uncertainties. These cycles give good phase curves, but they remain as proposals only.

3 New long-term light curves for several objects

New photometric databases allowed us to expand the investigated time intervals up to 2018 yr for 9 stars with different spectral type and rotational periods. Information about these stars is presented in Table 1. A photometric study of G dwarfs BE Cet and DX Leo on the time span 1986–2000 was made by Messina et al. (2002). For these stars they found cycles with duration of 6.7 yr and 3.21 yr respectively.

We used databases enumerated in Table 1 to add the rows from Messina et al. (2002) and have analyzed the brightness of these stars in the *V*-passband in 1986–2018. Our results show that the 6.76 yr cycle for BE Cet and 3.32 yr for DX Cnc (Fig. 1) and no long trends. Olah et al. (2016) considered the chromospheric indices for BE Cet and found few longer cycles of 7.84 yr.

For DT Vir, V647 Her, V577 Mon, DX Cnc, HU Del we used databases and our photographic measurements (Bondar 2013), the row for V1005 Ori includes new data and taken from Alekseev, Kozhevnikova (2018).

The yearly mean brightness of V647 Her slowly changes and may be cyclical on scale of 76 years (Fig. 2). The length of cycles of other two rapid rotating stars DT Vir (Fig. 3) and V577 Mon is close to 40 years.

The fast rotating stars V374 Peg with the period 0.445 d (Morin et al. 2008) study by Olah et al. (2006) on 2003–2006 interval. The light curve with spotted regions were constructed but cyclical changes were not found. Data from Hipparcos, ASAS, KWS

Table 1 Stars for a search for cycles on new photometric intervals.

Star	$B–V$	Sp.	P_{rot} (d)	P_{cyc} (yr)	A_{cyc} (mag)	Time span (yr)	Variable type	Sources
BE Cet	0.66	G 2.5	7.76	6.76	< 0.04	1986–2018	BY	2,4,5
DX Leo	0.77	G9	5.42	3.32	0.03	1989–2018	BY	1,2,4,5
V1005 Ori	1.37	M0	4.40	20.45	0.12	1976–2018	BY	1,2,4,7
DT Vir	1.48	M0	2.88	31.45	0.15	1911–2018	fl	1,2,4,6
V647 Her	1.64	M3.5	1.09	76.06	0.30	1939–2018	fl	1,2,3,4,6
V577 Mon	1.69	M4.5	8.00	39.97	0.50	1909–2018	fl	1,2,4,6
DX Cnc	2.06	M6.5	0.46	2.67	0.10	1984–2018	fl	2,4,6
V374 Peg	1.26	M3.5	0.44	var	0.10	1989–2017	fl	1,2,3,4
HU Del	1.65	M4.5	0.35	var	0.32	1940–2017	fl	2,4,6

Note: Spectral types, B–V and types of variability are from Simbad astronomy database; numbers in the sources column denote databases Hipparcos (1), ASAS (2), SuperWASP (3), KWS (4); Messina et al. 2002 (5), Bondar 2013 (6), Alekseev, Kozhevnikova 2018 (7).

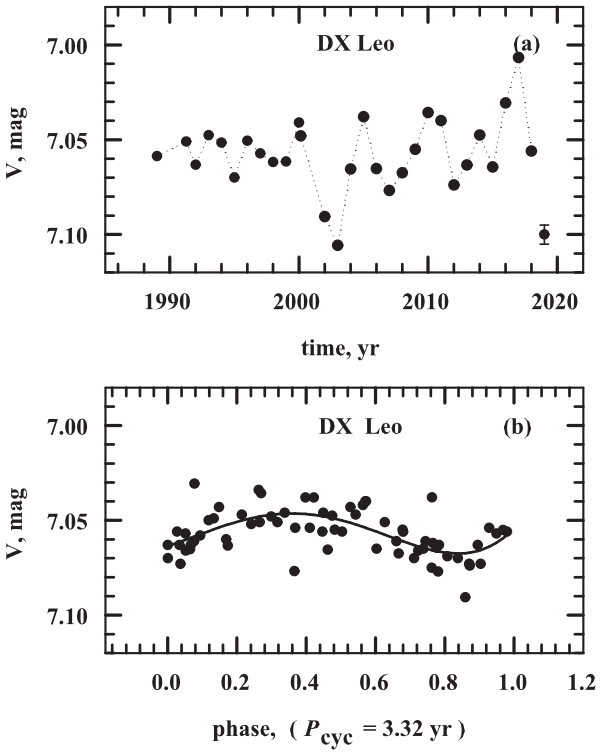


Figure 1 Light curve of DX Leo (a) and the cyclical behavior in the yearly-mean brightness (b).

allowed us to study the photometric behavior in 1989–2017 and suspected cyclical changes in yearly mean light on the 20 yr scale with a small amplitude (Fig. 4).

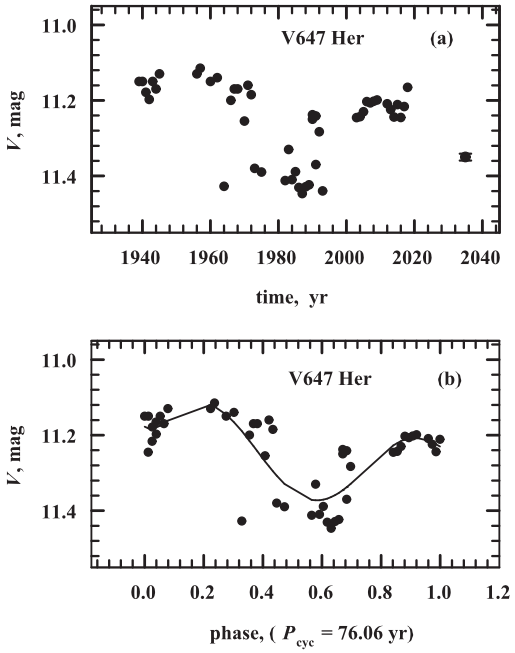


Figure 2 Light curve of V647 Her (a) and the possible long-term cycle in the yearly-mean brightness (b).

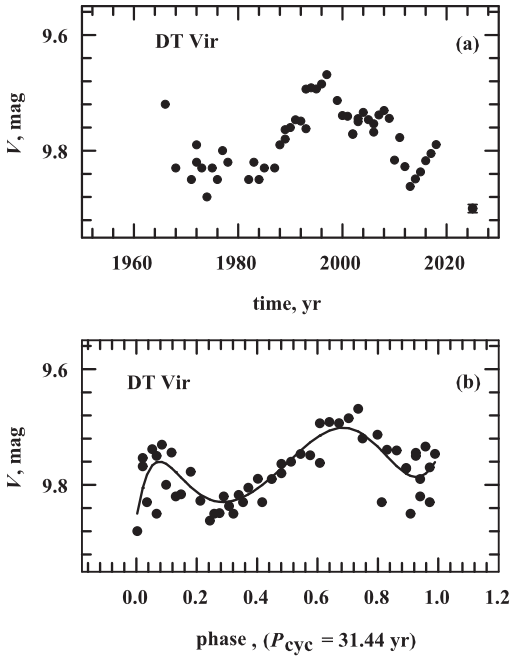


Figure 3 Light curve of DT Vir (a) and the cycle in the yearly-mean brightness (b).

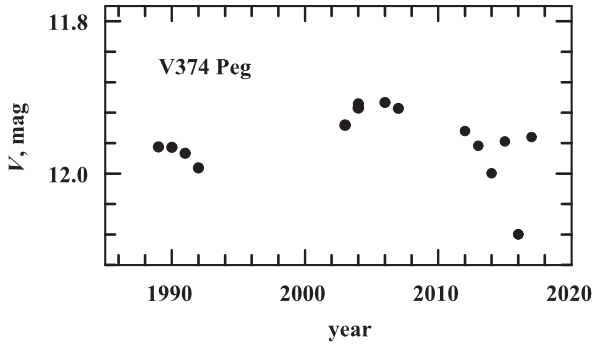


Figure 4 The yearly-mean changes in the brightness of V374 Peg.

4 Duration of activity cycles on G, K, M stars with a various rotation

Our sample contains 15 G stars including the Sun, 28 K stars and 23 M stars for which a search for cycles were made on the time span of some decades (Fig. 5a). According to the present results magnetic cycles produced by spots on red dwarfs can have a short duration of some years (for example G star BE Cet) and long cycles up to 80 years as the rapid rotating K–M stars V833 Tau (Bondar 2015) and V647 Her (this paper). Such long cycles are still suspected because the time span of photometric data are comparable with their lengths or allow us to detect only one cyclic wave as for YZ CMi for which P_{cyc} = 27.5 yr (Bondar, Katsova 2018), and DT Vir, V577 Mon (Table 1).

Figure 5b shows that 37% of the considered stars have the periods of 5–30 days, 24% of stars rotate slowly with the periods of 30–60 days and 39% are the fast rotating stars with periods less then 5 days. More of them are the cool dwarfs.

Using the numerous SuperWASP data we made a search for a rapid periodicity on the selected intervals for V374 Peg and DT Vir and confirm the stability presence

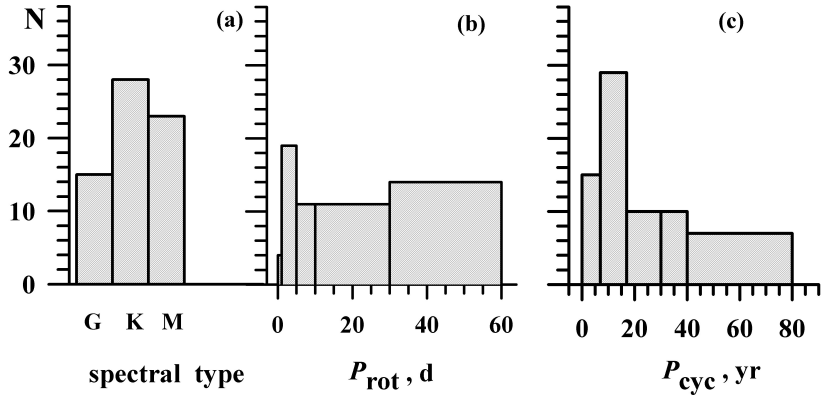


Figure 5 The numerical distribution of G–M dwarfs in our sample (a), by periods (b), and on detected or suspected cycles (c).

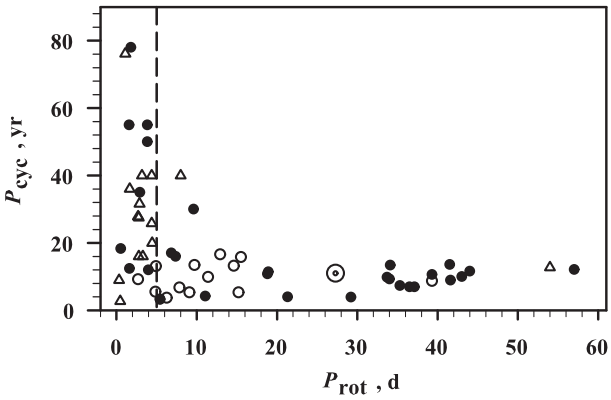


Figure 6 The relation between the duration of cycles and rotational period for G–M dwarfs. Open circles – G stars, filled circles – K stars, triangles – M stars, the dashed line marks the period of 5 days.

of the periods of 0.44 d published by Morin et al. (2008) for V374 Peg, and 2.88 d for DT Vir given in Shulyak et al. (2017). The short period of 1.09 days was found for V647 Her. As shown in Fig. 5b, most objects (29 stars) demonstrate the cycles comparable in duration with the solar one (7–18 yr), 25% of stars show the short cycles less than 7 yr, and the long-term photometric variability perhaps cyclical on scales of 40–80 yr are found for 7 stars.

The length of cycle is one of the features of the level of stellar activity and we consider the distributions of the length of cycles versus the spectral type and the period of rotation. As it follows from the diagram in Fig. 6 the stars with period less than 10 days do not have cycles longer than 20 years. The length of cycles of several stars with shorter periods can exceed 40 yr, but the longest cycles show the rapid rotating K–M dwarfs.

Conclusions

We considered the long-term cycles for 65 G–M dwarfs for which chromospheric and photometric indices of magnetic activity studied on time spans of several decades. Such cycles appear to be the dominant reflecting the processes of generation of active regions in a stellar atmosphere as phenomena of magnetic activity. The present results about the duration of magnetic cycles on red dwarfs show that cycles similar to the well-known 11-yr solar one are typical for about of 50% of the investigated G–K dwarfs, the solar-type stars. More longer cycles, up to 40 yr, can develop on G an K stars that rotate faster than the Sun, with the periods of 5–10 days. But a small percentage of stars in this group have the short cycles less than 7 yr. The longest cycles on the scale of 80 yr may be suspected for some objects among the rapid rotating cool dwarfs, but these groups of stars do not have typical dominant cycles and do not show the certain relation between a period and a length of cycles. Such uncertainty may explain the insufficient duration of the observational series and the

insufficiency/shortage of objects under study, but it is possible that it features the development of magnetic activity on the fast rotating cool dwarfs.

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