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Activity Cycles of a Single G5 III–IV Giant HD 199178

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Abstract—We obtained a unique series of photometric data for more than a hundred years for a rapidly rotating single G5 III–IV giant HD 199178 (V1794 Cyg), belonging to FK Com type stars. The analysis of the long-term variation of the activity of this star in the filter B is based on all measurements available in literary sources. To evaluate the brightness of HD 199178 in the era preceding photoelectric and CCD-observations, the measurements of photographic plates from the SAI MSU archive were shot at the Krasnopresnenskaya Observatory of Moscow State University in Moscow (4 records shot from 1898 to 1903, and 41 records for the period from 1935 to 1958) were performed. As a result, a total of 2142 assessments of the brightness of the star in the filter B were received. They have a unique duration of 118.3 yr and cover the time interval from 1898 to July 2016. Evidence was found of the existence of long-term cycles of photometric variability lasting for about 25–60 years. We put forward an assumption on existence of possible activity cycles of 2000, 3165, 5050, 9000, and $21\,600^d$ (respectively, 5.5, 8.7, 16.6, 24.7, and 59.2 years). The results are compared with other estimates of activity cycles in HD 199178. The most reliable should be recognizing the existence of a cycle lasting 8.7–9 years. It was found that in order to combine data into a single array, the convertation of B magnitudes into V magnitudes using the average value of the color index ($B–V$) is not possible due to the changes (including cyclic) of color index ($B–V$) over time.

Keywords: *s*tars, activity, cycles, photometry

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1. INTRODUCTION

The study of cool spots on the surface of the late-type stars has a large importance in analyzing the processes of generation of magnetic fields. For the studies of this kind, it is extremely important to trace both the long-term and short-term evolution of active areas on the surface of the star. It is necessary to have quite long time series of observations.

As a rule, the photometric series of observations of stars accessible for analysis cover the time interval of several decades. The expansion of their range is possible using archival data (see, e.g., [1, 2]). As a result, unique series of observations lasting about a hundred or more years become available for analysis.

Our attention was attracted by the possibility of construction such a series of photometric data for the star HD 199178 (V1794 Cyg), belonging to the FK Com type stars. In the first part of this work, the results of the analysis of the manifestations of the cyclic activity of HD 199178 are presented. In the second one—the results obtained were used to assess the variability of color index ($B–V$).

2. SINGLE G5 III–V GIANT HD 199178

A small group of stars of the FK Com type includes rapidly rotating single higly active G-K giants (see, e.g., [3]) which are named after its prototype, FK Com star. The evolutionary status of stars of this group is still not clear. The prototype of the group, FK Com, is the rapidly rotating G2–G7 III giant. Its activity is similar to the activity of RS CVn type stars, has a strong emission in the lines Ca II H and K, H_α. The photometric variability is associated with the rotational modulation of the radiation of the star, the surface of which is covered by cool spots. It was the studies of the photometric variability of the FK Com that led to the discovery of the phenomenon of the change of active longitudes (flip-flop phenomenon) [4]. The main information about FK Com and stars of this type can be found, for example, in the series of articles of Jetsu, Korhonen and their co-authors, in our publications [5].

The conclusion about membership of the HD 199178 (V1794 Cyg) in the FK Com stars group was made in [3]. Like FK Com itself, this star is a fast-rotating single G5 III–IV giant, with projection of the rotation velocity onto the line of sight $V \sin i =$ 80 km/s [6]. In favor of this star being single, testifies

the constant value (within 2 km/s) of the radial velocity of HD 199178 [6].

Bopp et al. [7] found that the photometric period of the star is equal to 3.337^d. According to the results of paper [8], the more accurate value of the period is $P = 3.337484^d$, and its phase remained constant over the time interval for 14 yr. In addition, in [8], from the changes in the amplitude of the brightness, the long-period cycles of the activity of a star lasting 9.07 and 2.84 yr were found.

The main results of the studies of HD 199178 are given [8–12], the data on the parameters of the star presented below are taken from literature. The mass of the star is 1.65 $M_\odot$, and its luminosity is 11 $L_\odot$. The radius of the star is 5 $R_\odot$, the updated value of the parameter $v\sin i = 72$ km/s, and the inclination angle is estimated as 60°. For the modeling, the following atmosphere parameters were used $T_{\rm eff} = 5300$ K and $\log(g) = 3.5$.

The object is identified with the source Gaia EDR3 2162 964 329 341 318 656, and its parallax is $\pi = 8.8912 \pm 0.0147$ mas.

A review of all surface temperature heterogeneities of the HD 199178 obtained by the Doppler mapping method can be found in [10]. The authors of [10] constructed 41 maps of surface temperature heterogeneities of HD 199178 using spectral observations of 1994–2017. According to their calculations, configuration of spots evolves, but a large high-lattitude spot is observed in all maps. According to the data on the changes of the amplitude of the variability of brightness, on switching longitudes of the most active region from one to another, etc., it was found that the long-period activity cycles range from 2 to 9 years.

3. ANALYSIS OF PHOTOMETRIC RESULTS OF THE HD 199178 OBSERVATIONS IN THE FILTER *B* PRESENTED IN LITERARY SOURCES

The analysis of the long-term variability of the HD 199178 we performed is based on all the data on the brightness of the star in the filter *B* available in literary sources. In this study, we limited ourselves to an analysis of the literary data of observations only in this one filter, since (see below) the data of archival photographic observations we consider well consistent with the results of a standard photometric system *B*.

The results of photoelectric measurements from three main papers [9, 11, 13] were used. In [13], the results of the photometry of HD 199178 in the bands $V(RI)c$ were presented, obtained with the 0.75-m Amadeus robotic telescope at the Fairborn observatory, equipped with an EMI-9828 photomultiplier. Technical characteristics and features of this tool are presented in [13]. The authors obtained 70 brightness measurements of HD 199178, relative to the HD 199956 standard (SAO 50313).

The authors of [11] published data of 242 photometric measurements of HD 199178 relative to the HD 117876 standard. Observations were made with the 60-cm Zeiss-600 telescope of the Rozhen National Astronomical Observatory equipped with an electrophotometer. In [9], photometric data of the studied star for 1975–1995 obtained at various observatories around the world were collected, The authors presented a combined array of HD 199178 $UBV(RI)c$ photometry from the papers published in 1982–1992, as well as previously unpublished own data. The largest number of observations were made with the following telescopes: the 25 cm Phoenix 10 of the Mount Hopkins observatory, the 48 cm AZT-14 of the Maidanak observatory, the 0.6 m telescope of the Mount Laguna observatory, the 40 cm telescope of the Kvistaberg observatory and the 60 cm telescope of the La Palma observatory. The photometry was carried out relative to the SAO 50313, SAO 50205, and SAO 50260 standards. The authors reduced all stellar magnitudes to the standard Johnson–Cousins system, which allowed us to conduct a comprehensive analysis of all the data presented.

In addition, the possibility of using the photometric data of the automatic sky surveys ASAS-SN and WASP was studied. Most sky surveys, such as WASP, have a non-standard photometric band, and the reduction of their photometry to the standard system gives large errors exceeding the variability amplitude of the star HD 199178. In addition, the star under study is rather bright, and all its photometric measurements in surveys have low accuracy due to the overaccumulated signal from the star at the CCD receiver.

Finally, data from the long-term Kamogata Widefield Survey (KWS) were used in our analysis. The review presents observations of the star in the filters Finally, data from the long-term KWS were used in our analysis. The review presents observations of the star in the filters B, V and Ic. We limited ourselves to considering the data for the filter *B* obtained in the interval from May 2015 to July 2016 (duration 433^d or 1.2 years) (HJD 2457163.28–2457597.17).

4. PHOTOMETRY USING STERNBERG INSTITUTE PLATES LIBRARY

To estimate the brightness of HD 199178 in the era preceding photoelectric and CCD observations, measurements were made of photographic plates from the SAI archive, taken at the Krasnopresnenskaya Observatory of Moscow State University in Moscow. Photographic plates of the S and T series, 24 × 30 cm in size, were studied. These series of plates are described in [14]. The S series was made on the Steinheil multilens camera in 1895–1933. The instrument had an objective diameter of 9.7 cm and a focal length of 64 cm.

In total, about 1200 plates were obtained. The T series was obtained on a Tessar multi-lens camera with a lens diameter of 16 cm and a focal length of 82 cm. During the observation period from 1914 to 1958, more than 2770 plates were obtained. Multilens objectives in combination with color-blind emulsions reproduce well the standard photometric system *B*. Therefore, the results of processing the studied photographic plates are well comparable with data from other sources.

For photometry of HD 199178, plates with α Cyg center were selected: 4 plates from the S series, taken in 1898–1903, and 41 plates of the T series from the period 1935–1958. We note that the estimates of the brightness of the star were carried out by eye, i.e., did not exceed $\sim 0.06^m$.

The stars SAO 50313 ($B = 7.713^m$), SAO 50205 ($B = 7.338^m$), and SAO 50260 ($B = 8.193^m$) were used as comparison stars. Each measurement was carried out relative to two of them so that the magnitude of HD 199178 lies between the corresponding values for the standards. The magnitudes of the standards in the band *B* were calculated as a weighted average of measurements from [9]. According to [15], the SAO 50313 and SAO 50260 standards have spectral types G8 III and K0 III, respectively. They are close to the spectral type of HD 199178 (G5 III–IV) [16]. At the same time, the spectral class of SAO 50205 [15] is estimated as B8 III. Therefore, measurements by the first two standards are less prone to systematic errors due to the difference in the emulsion sensitivity curves and the difference of the S and T series photometric systems from the standard B band. Comparison stars are not known variable objects; no changes in the brightness difference between them were noticed in our observations.

Table 1 shows the characteristics of the measured photographic plates, the comparison stars used for each measurement, and the results of the evaluation of the plates.

5. THE CYCLES OF ACTIVITY OF HD 199178

As a result, we obtained a combined data array, which includes measurements of photoelectric and CCD observations of HD 199178, as well as the results of measurements of photographic plates from the SAI archive. Table 1 shows the characteristics of the measured photographic plates, the comparison stars used for each measurement, and the results of the evaluation of the plates.

A total of 2142 star brightness estimates in the filter *B* were considered. They have a unique duration and cover the time interval from 1898 to July 2016. The duration of the considered series of observations is 43 166.8 days (118.3 years) (HJD 241 4430.396–245 7597.170).

The data presented in Fig. 1 (top), undoubtedly indicate the presence of cycles in the brightness variation of HD 199178. Based on the constructed power spectrum, we can assume the existence of possible activity cycles lasting 2000, 3165, 5050, 9000, and 21 600 days (5.5, 8.7, 16.6, 24.7, and 59.2 years) (bottom chart). Periodograms were constructed using the standard IDL LNP-TEST program based on the Lomb–Skargle method. Attention is drawn by the found evidence of existence of long-term cycles of photometric variability with values on the order of 25–60 years. The error of the given values is quite high: if it is estimated from the half-width of the peaks in the power spectrum, it is about 500–1000 days for the first two cycles and 2000–3000 days or more for the remaining two. It is obvious that the given values are only estimates, since the observational data have rather large gaps and are nonuniform in time, the measurement data for the photo library (light symbols) are sparse, etc., so that it is not possible to perform a rigorous periodogram analysis. However, the very presence of long-term variability on a time scale of about 60 years is beyond doubt. The vertical dotted line indicates the period corresponding to the year-long variability.

In [12], we presented the results of an analysis of photometric observations of HD 199178, in which, in addition to the usual analysis of brightness variability in filter *V*, we reconstructed the distribution of temperature inhomogeneities on the surface of the star. It was found that spots on the surface of HD 199178 are concentrated near two selected longitudes separated by 0.5 of phase (180° in longitude). In addition to the switching of the longitudes of the most active region from one to another that we found, which occurs quasi-periodically with cycles of 2.1–2.4 years or 4.1 years, we assume that two active regions move along the surface of the star, approaching each other, and merge into a single formation.

The cyclicity of the change of the stellar brightness in the filter *V*, which we found in [12], is about 8.0 years and it is also well traced in the changes in the star's spottedness. Based on the results of data analysis for the filter, it can be noted that the peak corresponding to the cycle length of 8.7 years is also dominant.

In [9], two characteristic periods of long-term variability of HD 199178 were distinguished: 9.07 years (according to the average light curve) and 2.8 years (according to the brightness amplitude variability). The authors of [11] did not confirm any of these cycles, but suggested the existence of a 4.2 years long cycle. The cyclicity of the change in the brightness of the star found by us [12] is 2925^d (8.0 years) and is well traced in the changes in the spottedness of the star. In addition, it was noted that both periods from [9] are present as peaks in the power spectrum of the changes in the brightness amplitude. According to [12], the switching of active longitudes (flip-flop) has a cyclicity of 1504^d (4.1 years), which coincides with the variability

Table 1. Results of measurements of photographic plates

Plate	Emulsion	Julian date	Stellar magnitude	Standards
S51	?	241 4430.396	7.85	A, B
S54	?	241 4499.401	7.90	A, B
S153	?	241 5257.350	7.80	A, B
S218	?	241 6343.384	7.95	A, B
T366	IM	242 8043.349	7.63	A, C
T376	IM	242 8081.261	7.76	A, B
T384	IM	242 8082.250	7.76	A, B
T391	IM	242 8408.352	7.90	A, B
T393	IM	242 8426.365	8.00	A, B
T395	IM	242 8427.341	8.05	A, B
T397	IM	242 8433.254	7.85	A, B
T398	IM	242 8516.150	8.14	A, B
T399	IM	242 8539.144	8.09	A, B
T465	IM	242 8653.485	8.09	A, B
T488	IM	242 8750.383	8.05	A, B
T499	F	242 8759.455	7.81	A, B
T508	F	242 8762.374	7.76	A, B
T512	F	242 8776.368	7.76	A, B
T516	F	242 8779.336	7.81	A, B
T518	F	242 8781.367	7.67	A, C
T1876	A	243 3917.232	7.67	A, C
T1881	A	243 3949.315	7.76	A, B
T1888	A	243 3951.183	7.85	A, B
T1897	A	243 3952.220	7.90	A, B
T1909	A	243 3953.194	7.95	A, B
T1910	A	243 3953.218	7.51	A, C
T1954	A	243 4121.522	7.67	A, C
T1971	A	243 4127.492	7.76	A, B
T1979	A	243 4128.459	7.95	A, B
T1988	A	243 4146.454	7.81	A, B
T1989	A	243 4223.354	7.67	A, C
T1993	A	243 4224.343	7.67	A, C
T1998	A	243 4229.301	7.67	A, C
T2003	A	243 4239.334	7.81	A, B
T2013	A	243 4250.429	7.76	A, B
T2142	A	243 4477.491	7.85	A, B
T2164	A	243 4610.413	7.81	A, B
T2618	A?	243 5724.279	7.81	A, B
T2624	A?	243 5773.169	7.76	A, B
T2627	A?	243 5829.125	7.81	A, B
T2687	A	243 6071.349	7.90	A, B
T2727	A	243 6128.257	7.81	A, B
T2734	A	243 6134.338	7.76	A, B
T2776	A	243 6520.226	7.67	A, C
T2777	A	243 6520.246	7.67	A, C

For the emulsion of photographic plates (second column), the following designations are accepted: the sign "?"—no information on emulsion type, IM—Ilford Monarch, F—Fulgur, A—Agfa Astro. Designations of comparison stars (fifth column): A—SAO 50313, B—SAO 50260, C—SAO 50205.

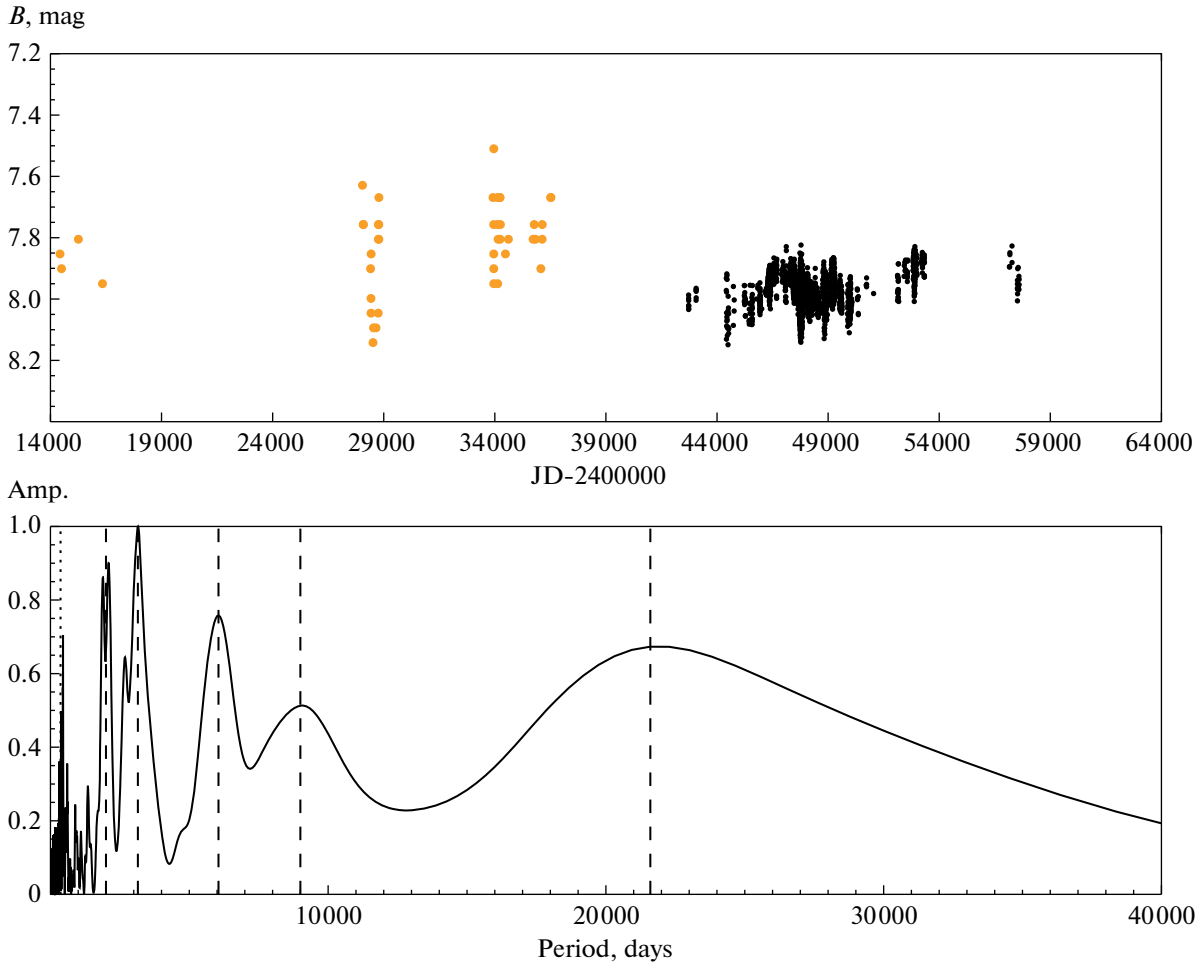

Fig. 1. Upper panel: photometric observations of HD 199178 in the filter B based on photoelectric and CCD observations from the literature and measurements of photographic plates from the SAI archive (open circles). Bottom panel: power spectrum for this data, vertical dashed lines refer to activity cycles of 2000, 3165, 5050, 9000, and 21600^d (respectively, 5.5, 8.7, 16.6, 24.7 and 59.2 years). The dotted line is the peak corresponding to the seasonal (about 365^d) period.

found in [11] and is, on the one hand, equal to half of the cycle of changes in the brightness of a star and its spottedness, and on the other hand, this is a double cycle of switching the position of active longitudes.

Obviously, as data are accumulated over a longer period of observations, the reliability of the conclusion about the truth and constancy in time of one or another cyclicity increases.

The set of star brightness estimates in a filter B obtained by us has a unique duration of 118 years (from 1898 to 2016), as well as a number of literary sources, indicate an increasing reliability of the existence of a cycle of 8.7–9 years (the dominant peak in Fig. 1).

6. THE CYCLES OF ACTIVITY OF HD 199178 DERIVED FROM VARIATIONS OF COLOR INDEX (B–V)

As it is mentioned above, the set of star brightness estimates in the filter B used in our study is unique in duration (118 years). However, in terms of completeness (data volume, duty cycle, etc.), it is inferior to the star brightness data array in the filter V. It would be natural to consider the possibility of combining these data into a single array. There are examples of such an operation in the literature, including our studies [17] (see also, e.g., paper [18], the authors of which combined measurements of the chromospheric activity of the star HD 166620 and photometric data obtained in filters b and y into a common array). The resulting combined time series showed a good match between activity and brightness, showing that as the star transitioned from cyclical variability to stable behavior, its brightness became weaker. In [17], we acted in a similar way, combining for HD 166620 into a single array all observations from the KWS in the filters B, V, and Ic.

In the study [2], the brightness variability of V833 Tau was studied over the time interval 1899–2019. The photographic values B were converted to values V using the accepted average value of the color index

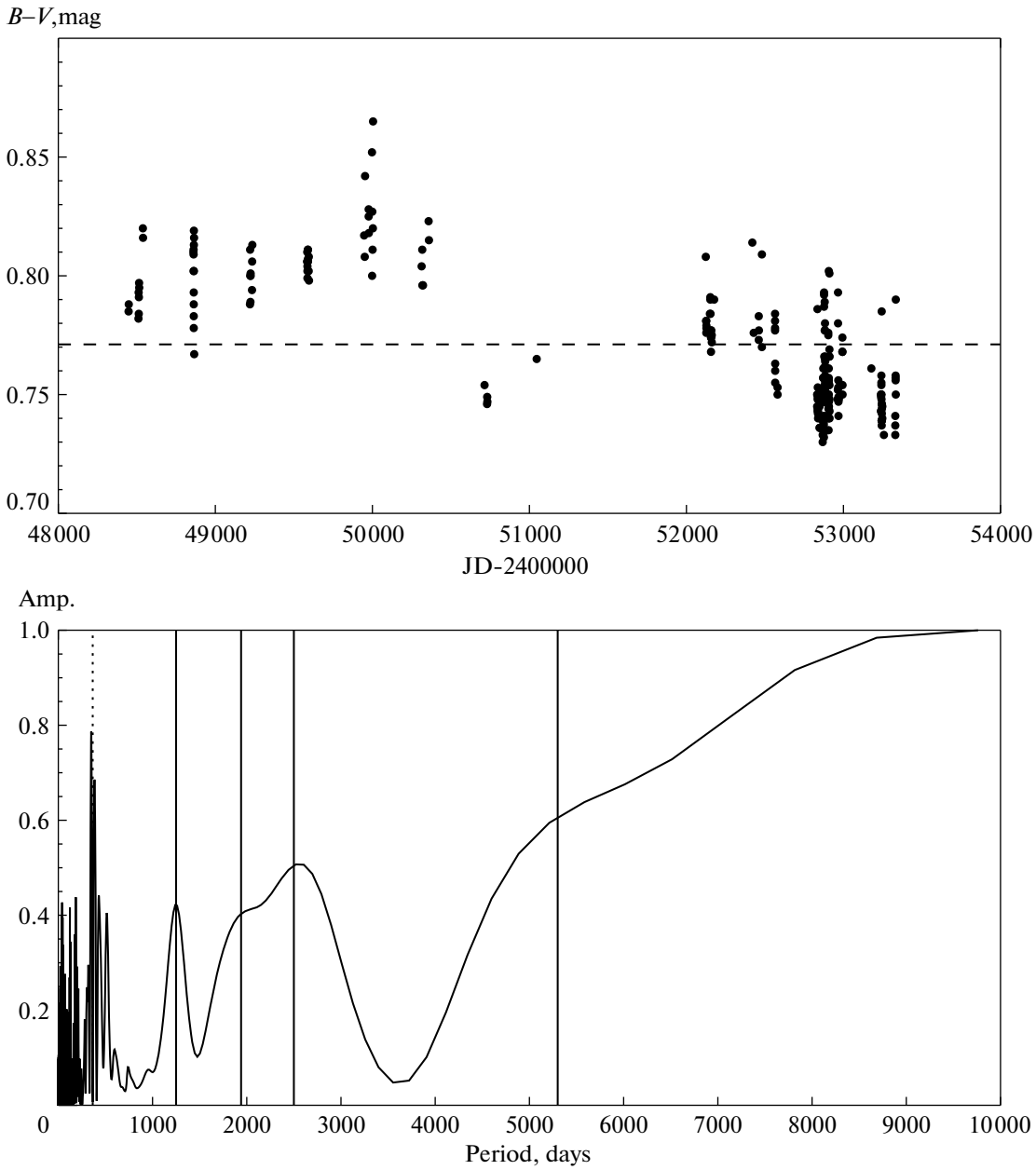

Fig. 2. Upper panel: changes of the color index ($B–V$) over time. Bottom panel: power spectrum for this data, vertical lines refer to activity cycles 1250, 1940, 2500, 5300^d (respectively, 3.4, 5.3, 6.9, 14.5 years). The dotted line indicates the peak corresponding to the seasonal (about 365^d) period.

$(B–V) = 1.07^m$. As shown below, this approach turned out to be unacceptable in the case of data analysis for HD 199178.

We considered the available data on the changes in the color index ($B–V$) over time, obtained from simultaneous observations in the filters B and V (238 measurements over an interval of 13.4 years, Fig. 2). A general trend towards a decrease in the value of the color index and cyclicity are seen.

The bottom panel of Fig. 2 shows the power spectrum for the cycles, the vertical lines refer to activity cycles 1250, 1940, 2500, 5300^d (3.4, 5.3, 6.9, 14.5 years, respectively).

The average value of the color index ($B–V$) for the period under consideration is 0.771^m, and its median value is 0.765^m. Obviously, going directly from the data in the filter B to the values in the filter V will undoubtedly introduce false cycles.

7. CONCLUSIONS

The goal of our work was to construct a unique series of photometric data with a duration of about a hundred years for the star HD 199178, which belongs to the FK Com group of stars. Our analysis of the long-term periodicity of the brightness variability of this star is based on all measurements of its brightness in the filter B available in the literature. We limited ourselves to the analysis of published observational data only in this one filter, since the data of archival photographic observations considered by us are quite well comparable with the results of the standard photometric system B. The usage of photometric data from the ASAS-SN and WASP automatic sky surveys is not possible due to either a non-standard bandwidth, or an overaccumulated signal level, etc. To estimate the brightness of HD 199178 in the era preceding photoelectric and CCD observations, measurements were made of photographic plates from the SAI archive, taken at the Krasnopresnenskaya Observatory of Moscow State University in Moscow. For photometry, 4 plates from the S series, taken in 1898–1903, and 41 plates of the T series for the period 1935–1958 were selected.

As a result, we created a combined data array, which included measurements of photoelectric and CCD observations from literary sources, as well as measurements of photographic plates from the SAI archive. A total of 2142 star brightness estimates in the filter B were considered. They have a unique duration and cover the time interval from 1898 to July 2016 with a duration of 118.3 years. Evidence has been found for the existence of long-term cycles of photometric variability with the values on the order of 25–60 years. Based on the constructed power spectrum, an assumption was made about the presence of possible activity cycles of 2000, 3165, 5050, 9000 and, 21600^d (respectively, 5.5, 8.7, 16.6, 24.7, and 59.2 years). The results obtained are compared with other estimates of activity cycles in HD 199178. Our results and data from a number of literature sources indicate an increasing reliability of the existence of a cycle lasting 8.7–9 years (the dominant peak corresponds to it on the power spectrum).

Unfortunately, the conversion of values B into values V using the accepted average value of the color index $(B–V)$ (to combine data into a single array) is not possible due to the change of the color index $(B–V)$ over time.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

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