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Search for and Study of Photometric Variability in Magnetic White Dwarfs

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Abstract—We report the results of photometric observations of a number of magnetic white dwarfs in order to search for photometric variability in these stars. These V-band observations revealed significant variability in the classical highly magnetized white dwarf GRW+70°8247 with a likely period from several days to several dozen days and a half-amplitude of about $0\overset{m}{.}04$. Our observations also revealed the variability of the well-known white dwarf GD 229. The half amplitude of its photometric variability is equal to about $0\overset{m}{.}005$, and the likely period of this degenerate star lies in the 10–20 day interval. This variability is most likely due to the rotation of the stars considered. We also discuss the peculiarities of the photometric variability in a number of other white dwarfs. We present the updated "magnetic field–rotation period" diagram for the white dwarfs.

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1. INTRODUCTION

In this paper we report intermediate results of the program of photometric observations of single magnetic white dwarfs [1–3]. These investigations were mostly motivated by the discovery of the connection between magnetic and photometric properties of white dwarfs [3–5] and the need to study it in detail. The tasks to be addressed by the program also include constructing selection-independent "rotation period–magnetic field" diagram for white dwarfs.

As a by-product, the project may also partly answer the question of the possible existence of planets orbiting isolated white dwarfs. In particular (see, e.g., [6]), iron planets orbiting in close vicinity to the surfaces of their parent white dwarfs may be both generators of strong magnetic fields on their parent stars and unipolar inductors of closed electric currents in their atmospheres. As a result of ohmic dissipation these currents may heat the atmosphere causing the inversion in their upper layers and overall instability. This may cause photometric variability modulated by the influence of massive planets. We thus arrive to another important goal of our study: search for anomalies in the rotation periods of white dwarfs in the context of the search for planets orbiting these stars.

Another aim of these studies is to test the long-term regularity of the rotation-modulated photometric variability, which is important for the study of the temporal evolution of the surface magnetic fields in white dwarfs and the possible discovery of planets orbiting these stars. The expected time scale required

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for detecting these variations is of about ten or more years [3]. In this sense the program is currently at its initial stage because except for our long-term observations of the white dwarf WD 1953−011 [1, 3, 4] a substantial part of observations has been acquired within the last three years. Meanwhile, during this time a number of results that we consider to be of importance for the community have been obtained for several white dwarfs. In most of the cases no precise periods have been yet determined for the objects studied, however, the very discovery of new variable objects, determination of their amplitudes and of the variability limits of their photometric properties allows us to augment the already available versions [5, 7] of the "rotation period—magnetic field" diagram for white dwarfs, which is the principal aim of this study.

2. OBSERVATIONS

Photometric observations of white dwarfs (in the general case, not limited to magnetic stars with known surface fields) have been carried out regularly since 2012 on the following telescopes: 1-m telescope of the Special Astrophysical Observatory of the Russian Academy of Sciences, 1.25-m telescope of the Crimean Astrophysical Observatory, 1.3-m Indian telescope of Devasthal Observatory (India), and the group of small telescopes located at the North Caucasian Astronomical Station of Kazan (Volga Region) Federal University (KFU). Observations are mostly performed with the broadband V -filter, however, long-term monitoring involving other filters and photometric systems becomes possible as more telescopes join the program. A detailed description of the techniques of observations and data reduction can be found in our previous papers (see, e.g., [2]).

3. RESULTS

In this section we describe the actually obtained results of the monitoring of some stars. We are planning to make our individual photometric measurements of each target publicly available.

3.1. GRW+70° 8247

The GRW+70°8247 object is the first white dwarf where magnetic field has been detected (the famous paper by Kemp et al. [8]). It belongs to the class of most highly magnetized white dwarfs with surface magnetic fields stronger than 300 MG [9]. GRW+70°8247 belongs to the hypothetical group of highly magnetized white dwarfs whose rotation periods were estimated by [7, 10] to be longer than one hundred years. However, the rotation periods of these stars can also be too short to be detectable (see

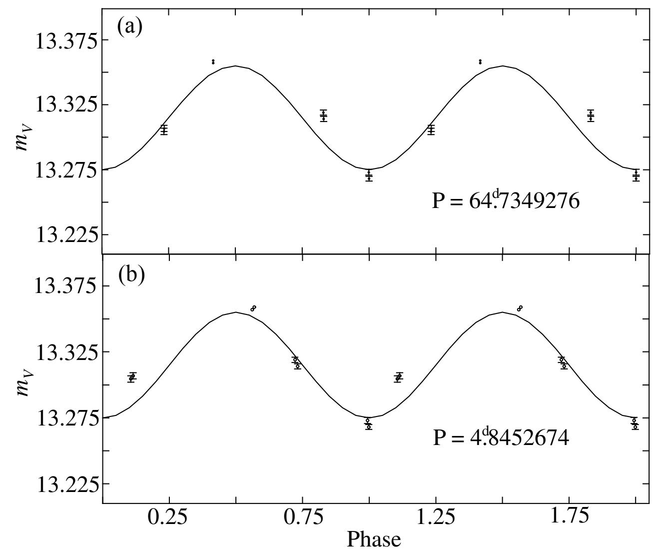

Fig. 1. Phased light curve of GRW+70°8247 with two possible periods. We present two closely spaced data points per night, which agree with each other within the error bars.

Table 1. Photometric results for GRW+70°8247

JD, days	$T_{\rm exp}$, s	m_V	$\sigma(m_V)$
2456537.3200	4320	13.3190	0.0020
2456537.3700	3990	13.3140	0.0020
2456548.3300	1700	13.2730	0.0023
2456548.3540	2300	13.2680	0.0018
2456563.4070	3600	13.3045	0.0024
2456563.4490	3600	13.3068	0.0023
2456575.3039	3600	13.3570	0.0010
2456575.3440	3600	13.3590	0.0012

the explanation below in the text). The conclusion that this star is non-rotating was based on the fact that polarimetric observations revealed no signs of rotation-modulated variations of circular polarization in the spectrum of this object. Photometric monitoring also did not produce any significant result although variations on the time scale of four days have been suspected [5].

At the same time, the hypothesis of Schmidt and Norsworthy [7] about the class of highly magnetized "static" white dwarfs is, in our opinion, rather disputable if for no other reason than for the fact that such stars with magnetic fields of comparable strength also include rapidly rotating older white dwarfs. Furthermore, we did not rule out the possible rapid variability (on time scales shorter than one minute) of the star [11, 12]. This fact, combined with the suspected photometric variability of GRW+70°8247 [5], motivated us to continue photometric observations of this object.

In the fall of 2013 we observed GRW+70°8247 over several nights on the 1-m telescope of the Special Astrophysical Observatory of the Russian Academy of Sciences in fast photometry mode with a sampling time of several seconds. We found no signs of rapid variability with the amplitude above $0^{\rm m}_{.}01$ on time scales from ten seconds to several hours. However, more recent photometric observations performed on the 1.25-m telescope of the Crimean Astrophysical Observatory [2] and oriented toward the search for long-term periodicity in the object yielded a positive result. These observations were made in June–October, 2016 with a characteristic sampling time of several minutes and more. A search for periods in the interval from several dozen minutes to several hours also did not yield any positive result. At the same time, integration of all data acquired during each observing night and the search for periods with a characteristic sampling time of several hours confidently demonstrated photometric variations of the star with a half-amplitude of about $0^{\rm m}_{.}04$ in the V-band filter. The photometric measurements are listed in Table 1.

A period search using the Lafler–Kinman method [13] reveals many peaks in the periodogram corresponding to possible periods ranging from several days to several tens of days. Unfortunately, because of the poorly sampled dataset and scarcity of available measurements no particular period can be currently identified as the most significant. In this study we limit ourselves just to stating the discovery of variability with a V-band half-amplitude of $0^{\rm m}_{.}04$, and point out that the most likely period is of about four to five days. Figure 1 shows the phased light curve obtained by folding photometric data with two possible periods. Note that the four-day period (the lower panel in Fig. 1) confirms the hypothesis suggested in [5]. Further observations of the object will make it possible to refine the period.

3.2. GD 229

Schmidt and Norsworthy [7] classify the magnetic white dwarf GD 229, like GRW+70°8247, as a "static" (see [14] and references therein) or a very rapidly rotating star [11, 12]. Berdyugin and Piirola [15] also report evidence suggesting that the object rotates with a period of one hundred or more years. However, our observations carried out in August–October, 2016 on the 1-m telescope of the Special Astrophysical Observatory of the Russian Academy of Sciences and on the 1.25-m telescope of Crimean Astrophysical Observatory revealed evident variability of the star with a period from ten to several dozen days. Figure 2 presents the most likely rotation period, which yields sinusoidal variation of the field strength with a period of about 20 days. Like in the previous case, we use the results of nightly integrated measurements (see Table 2). The characteristic uncertainty of each such estimate is equal to $0^{\rm m}_{.}001$, suggesting the discovery of photometric variability in the white dwarf GD 229 with the half amplitude of $0^{\rm m}_{.}005$.

We estimate the variability period to be from ten to several dozen days with the most likely value of 20.7 days. Such a weak variability does not allow us to confidently state that it is due to the rotation of the star. However, we consider this interpretation to be the most likely one. We also do not rule out the possibility that the detection of secular variability of

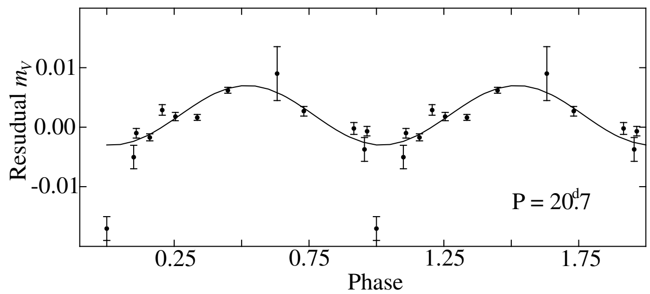

Fig. 2. Light curve of GD 229 folded with the probable period of about 20 days.

Table 2. Results of photometric observations of GD 229

JD, days	$T_{\rm exp}$, s	Residual m_V	$\sigma(m_V)$
2457613.5130	4700	−0.0037	0.0020
2457614.4274	950	−0.0170	0.0020
2457616.5120	7400	−0.0050	0.0020
2457621.3830	28500	0.0016	0.0005
2457633.4130	10400	−0.0002	0.0010
2457634.4160	10600	−0.0007	0.0008
2457637.4130	11400	−0.0010	0.0008
2457638.4500	17000	−0.0017	0.0006
2457639.4120	11300	0.0029	0.0009
2457640.4100	11500	0.0018	0.0007
2457644.4383	3600	0.0062	0.0050
2457648.2276	2000	0.0090	0.0070
2457650.2790	11500	0.0027	0.0008

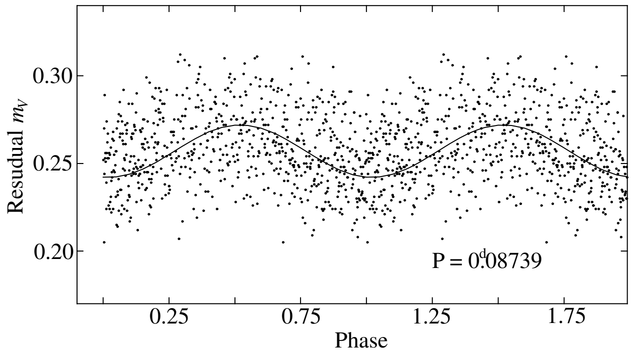

Fig. 3. Light curve of GD 356 with the probable period of 0.0874 days.

GD 229 in [15] is not an observational artefact—there is the possibility of secular evolution of the surface magnetic field in the degenerate star. At the same time, we consider the conclusion that this variability is due to slow rotation (with the period of about one hundred years) rotation to be questionable, like in the case of GRW+70°8247. No signs of "rapid" variability could be found.

3.3. GD 356

The most interesting and unique highly magnetized white dwarf GD 356 (its dipole field has a polar strength of 13 *MG* [16]) is known for its purely hydrogen spectrum exhibitings all Balmer lines in 100% emission [17]. We consider the explanation suggested by Wickramasinghe et al. [6] to be the most interesting interpretation of this phenomenon. According to this interpretation, the inversion of the spectrum may be due to an iron planet orbiting close to GD 356, and this planet may, in its turn, serve as an unipolar inductor of electric currents in the atmosphere of the degenerate star. Ohmic dissipation leads to the heating that cause the observed inversion of the atmosphere of GD 356.

Our photometric monitoring of GD 356 was motivated by the discovery of regular photometric variability with a period of 115 minutes in this star [18]. We carried out these observations in 2004 and our main interest was to look for eventual changes in the regularity of the photometric variations of the object over the twenty years that elapsed since then, which could have been cased by the presence of a hypothetical iron planet in an orbit around the star.

We observed GD 356 over several successive nights in September and October, 2016. Our analysis of the data shows the classical variability of the object with the periodicity similar to that discovered in the earlier study [18]. Our analysis yielded a somewhat longer period of $P = 125$ minutes. However, this difference is not significant given the uncertainty due to the gaps, sampling problems, and the total length of the observing data set. We plan to continue observing the object.

3.4. Magnetically-Induced Variability of WD 1953–011, WD 0009+501, and WD 1748+708

Figures 4, 5, and 6 show the already published results of observations and analysis of three magnetic white dwarfs for which the magnetically induced nature of photometric variability had been confidently established by combined photometric and spectropolarimetric studies. The corresponding studies for WD 1953−011 were described in detail in [1, 3, 4, 19, 20]. It follows from the behavior of the main observed quantities (see Fig. 4) that the times of photometric minima correlate with the times of maxima of integrated magnetic field and projected area of the most magnetized region of the star (the two lower panels in Fig. 4). In our paper [3] we explained this effect by the global control of the convection process by the (several hundred Gauss strong) magnetic field. Our primary aim when starting the program of photometric study of white dwarfs was to detect a similar effect in other degenerate stars. This aim was rapidly achieved in our observations of the white dwarf WD 0009+501.

Observations of WD 0009+501 and our analysis of the data (see [2, 21] for details) showed regular variations of photometric variability with the rotation period known from [21]. The V-band variation amplitude is of about $0^{m}_{.}01$. Its behavior with a double wave over one rotation cycle also suggests that the integrated flux from the star is related to its surface magnetic field. According to [2], during its fill rotation cycle WD 0009+501 shows twice the two different poles of its magnetosphere to the observer. The magnetic-field strength at these poles is estimated to be about 300 G [21], and such field is strong enough [3] to suppress the external convection in these regions. As a result, dark spots are formed at the poles of the magnetosphere of WD 0009+501 inducing the photometric variability. Figure 5 demonstrates fragments of the most precise observations of the star, which illustrate the above points. We are currently continuing our observations of this object in various filters using all the telescopes mentioned above. The most recent data obtained on the 1.3-m Indian telescope confirm the regular behavior of the variability of the star.

This important corroborative evidence has initiated us to search for new white dwarfs with strong magnetic fields using joined observations (photometric and broadband polarimetric ones) on telescopes of Crimean Astrophysical Observatory. The very first

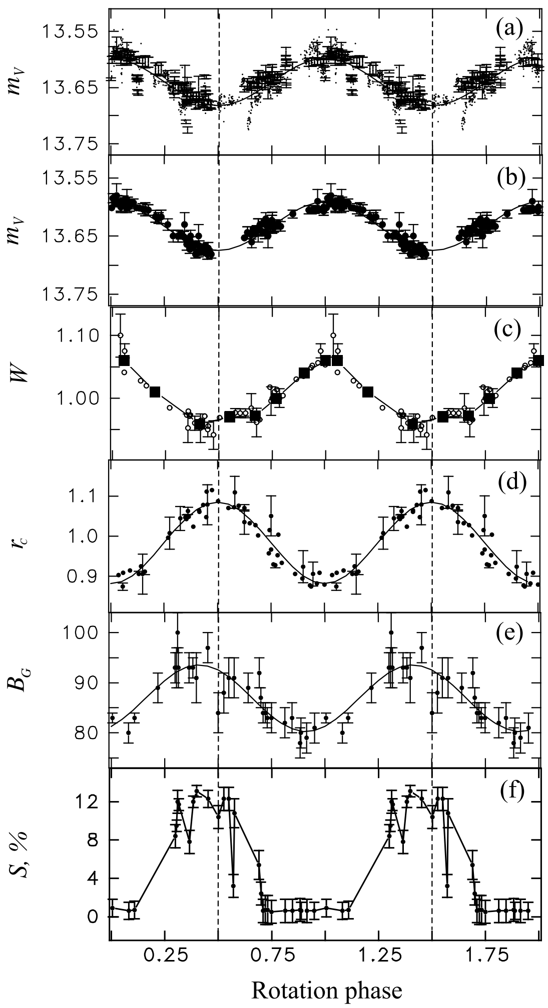

Fig. 4. Phased curves of observed variation of the magnetic-field strength in the white dwarf WD 1953−011 with the rotation period. From top to bottom: V-band magnitude according to all the currently available observations of the object; V-band magnitude according to observations made on the 1.25-m telescope of Crimean Astrophysical Observatory; Hα equivalent width W; residual intensity r_c; surface magnetic field B_G, and the effective area S of the most magnetized region on the star's surface projected onto the line of sight. The vertical lines correspond to the minimum of the light curve.

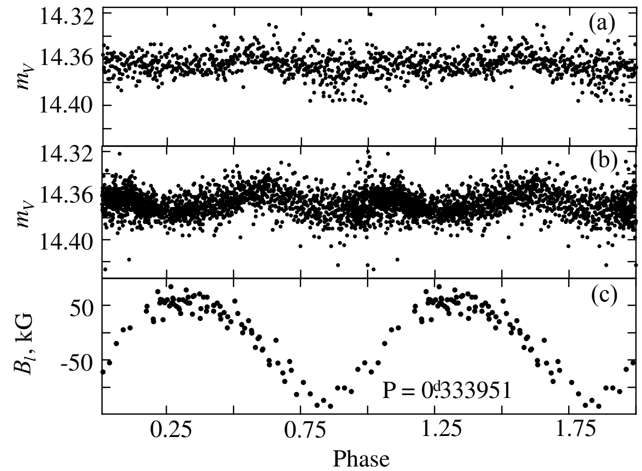

Fig. 5. Phased curves of the variation of the observed quantities of the white dwarf WD 0009+501 with the rotation period. From top to bottom: V-band magnitude of the object according to observations made on the 1.25-m telescope of Crimean Astrophysical Observatory; V-band magnitude of the object according to observations made on the 1-m telescope of the Special Astrophysical Observatory of the Russian Academy of Sciences, and the longitudinal magnetic field B_l of the star.

such observations [22] gave positive results. We detected a new white dwarf, WD 1748+708, exhibiting significant circular polarization and whose photometric variations demonstrated the behavior predicted in [2, 3]. Observations of this object are continued and Fig. 6 presents a brief result of the already observed quantities. A detailed analysis can be found in [22].

3.5. Other White Dwarfs

Within the framework of our program we also observe other white dwarfs and hot subdwarfs, both suspected to possess large-scale magnetic fields (see, e.g., the list presented in Fig. 6 of [23]), and newly discovered objects of these types [24]. We are also observing some nonmagnetic objects, which, however, are of interest other points of view. Figure 7 shows an example of the observation of a planetesimal transit across the recently discovered [25] white dwarf WD 1145+017 with the disrupting planet moving in a close orbit around it. The aim of these observations was to track the orbital evolution of planetesimal debris.

4. CONCLUSIONS

We reported intermediate results of the photometric investigations of magnetic white dwarfs that we have been carrying out on a regular basis since 2012. Observations in the V-band revealed variations in the highly magnetized white dwarf GRW+70°8247 with a period from several days to several tens of days and a half amplitude of about $0\overset{m}{.}04$. We also found photometric variability in another highly magnetized white dwarf GD 229. The variability amplitude of this degenerate star is of about $0\overset{m}{.}005$, and the possible period lies in the 10–20 day interval. The variability of these stars is most likely due to their rotation. If this is the case then the detection of rotationally modulated variability in these two stars puts in question the idea that highly magnetized white dwarfs may include a class of stars with peculiar rotation on time scales shorter than one minute or on the order of several hundred years. The stars GRW+70°8247 and GD 229 have so far been believed to be the most typical members of this class.

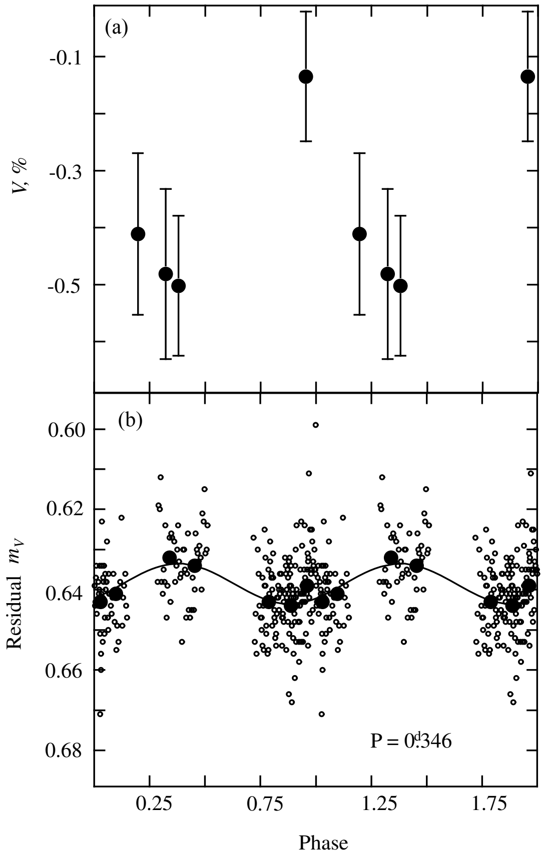

Fig. 6. Periodic variations of V-band circular polarization (the top panel) and V-band flux (the bottom panel) of WD 1748+708 as a function of the phase of variability with the possible period of 8.3 hours. The filled circles in the bottom panel illustrate the results of averaging photometric observations in 0.1-phase bins. The error bars of the averaged data do not exceed the radii of the circles. The solid line in the bottom panel shows the result of the sine fit to observational data.

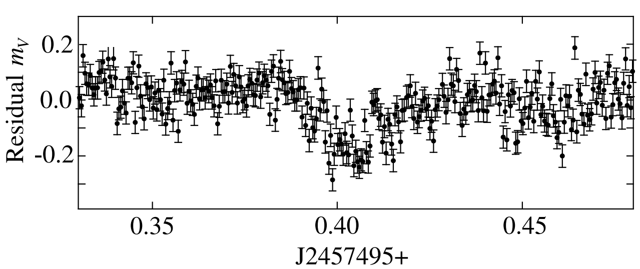

Fig. 7. The light curve of the white dwarf WD 1145+017 during the transit of a planetesimal.

Briefly we also present the results of the study of other program stars. Our so far obtained and analyzed observations allow us to complement the "magnetic field—rotation period" [5, 7] diagram and present its updated version (Fig. 8). Unlike Schmidt and Norsworthy [7] and their hypothesis concerning the existence of two populations among white dwarfs—the common ones and the group characterized by fast rotation, our analysis of the new version of the diagram shows no signs of any reasonable relation between the magnetic field strength and rotation period. In view of our finding of quite common rotation periods for two stars of this group, we suggest that to reveal variability of several other objects believed to belong to this group they should be further observed at a higher level of precision. We did not include these objects into our final diagram (Fig. 8).

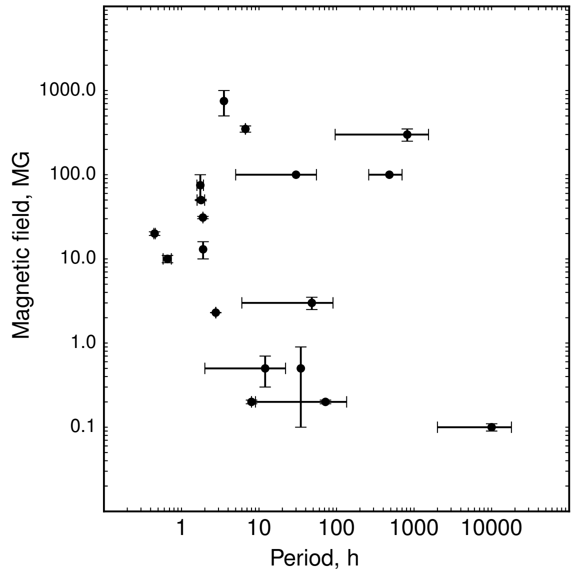

Fig. 8. The "magnetic field—rotation period" diagram. Periods are in hours to make convenient the comparison with the version of the diagram shown in Fig. 27 in [5].

A joint analysis of our observations with those performed by other authors allowed us to develop the strategy for further observations—we will perform them in order to refine the periods and identify new photometrically variable white dwarfs.

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