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Polarimetry of the near synchronous magnetic cataclysmic variables 1RXS J083842.1-282723 and IGR J19552+0044

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Abstract. In this work we study photometric and polarimetric time series of the systems 1RXS J083842.1-282723 (J0838) and IGR J19552+0044 (J1955), which are near synchronous magnetic cataclysmic variables, i.e., with spin period (P_{spin}) different from, but close to, the orbital period (P_{orb}). This characteristic differs them from other magnetic cataclysmic variables: the intermediate polars (IPs), which have typically $P_{spin}/P_{orb} \simeq 0.1$ and the polars, which have $P_{spin}/P_{orb} = 1$. A possible explanation for the observed period ratios is that the two objects are in a transition stage before reaching synchronism and are, therefore, candidates for progenitors of polar systems. In particular, these systems are at the limit of synchronism. J0838 is a possible IP with P_{orb} of 98.4 minutes and P_{spin} of 94.8 minutes. J1955 is a possible asynchronous polar (AP) with P_{orb} of 83.6 minutes and P_{spin} of 81.3 minutes. We performed in 2018 three observing runs at Pico dos Dias Observatory, using the IAGPOL polarimeter, in order to collect time series of those objects. The detection of periodically modulated polarized emission confirms the existence of the cyclotronic emission from the accretion column of J1955. Polarized emission was not clearly detected in J0838. These results corroborate the previous classification of AP for J1955 and IP for J0838. In this work we used, for the first time in the reduction of time series and circular polarization data, the new software for astronomical data processing written in Python language called Astropop.

Resumo. Neste trabalho estudamos séries temporais fotométricas e polarimétricas dos sistemas 1RXS J083842.1-282723 (J0838) e IGR J19552+0044 (J1955), que são variáveis cataclísmicas magnéticas (VCMs) quase síncronas, ou seja, com período de rotação (P_{rot}) diferente, mas próximo, do período orbital (P_{orb}). Essa característica as difere de outras VCMs: as polares intermediárias (PIs), que possuem tipicamente $P_{rot}/P_{orb} \simeq 0,1$ e as polares, que possuem $P_{rot}/P_{orb} = 1$. Uma possível explicação para a razão de períodos observada é a de que os dois objetos estão em um estágio de transição antes de atingir o sincronismo e são, portanto, candidatos a progenitores de sistemas polares. Em particular, esses sistemas estão no limite do sincronismo. J0838 é uma possível PI que possui um período orbital de 98,4 min e um período de rotação de 94,8 min. Já J1955 é uma possível polar assíncrona (PA) que possui um período orbital de 83,6 min e um período de rotação de 81,3 min. Em 2018, foram realizadas três missões no Observatório Pico dos Dias com o polarímetro IAGPOL, dedicadas à coleta de séries temporais desses objetos. A detecção de emissão polarizada e modulada confirma a existência de emissão ciclotrônica da coluna de acreção para J1955. O mesmo não foi observado de maneira evidente para J0838. Esse resultado corrobora com a classificação de PA para J1955 e PI para J0838. Estamos usando pela primeira vez, na redução de séries temporais e de polarização circular, o novo software para processamento de dados astronômicos em linguagem Python chamado Astropop.

Keywords. cataclysmic variables – binaries: general – Polarization – Methods: observational

1. Introduction

Cataclysmic variables (CVs) are compact binary systems where a red dwarf fills its Roche lobe and throws mass into its white dwarf (WD) companion. When the WD have a magnetic field sufficiently intense to alter the flow of mass, they are classified as magnetic CVs (MCVs), and can be divided into polars and intermediate polars (IPs).

The main difference between polars and IPs is the relation between the orbital period (P_{orb}) of the system and the spin period (P_{spin}) of the WD. Polars have $P_{spin} = P_{orb}$ and IPs have usually $P_{spin} \leq 0.1 P_{orb}$. We know a few examples that contradicts those relations. They are called near synchronous MCVs, that is, polars with $P_{spin} \neq P_{orb}$ and possible IPs with $P_{spin} > 0.8 P_{orb}$. Currently, 10 near synchronous MCVs are known. Table 1 shows all 10 near synchronous MCVs together with 6 IPs with $P_{spin} > 0.1 P_{orb}$. Possible explanations for the observed period ratios involve a transition evolutionary stage between asynchronism and synchronism or a nova event that takes the system out of synchronism temporarily.

V1432 Aql is the only asynchronous polar with $P_{spin} > P_{orb}$. Synchronisation time scales of about 170 and 200 years where observed for V1500 Cyg (5) and V1432 Aql (16), respectively. A

Table 1. Near synchronous MCVs and IPs with highest degree of synchronism known so far, listed by degree of synchronism, with its orbital periods, spin periods and classification.

Objects	P_{spin}	P_{orb}	P_{spin}/P_{orb}	Classification
V1432 Aquilae	12150	12116	1.003	AP
V1500 Cyg	11890	11994	0.991	AP
CD Ind	6579	6649	0.989	AP
BY Cam	11961	12089	0.989	AP
IGR J19552+0044	4877	5016	0.972	-
SDSS J084617.11+245344.1	16236	16704	0.972	-
1RXS J083842.1-282723	5688	5904	0.963	-
SDSS J134441.83+204408.3	6099	6830	0.893	-
Swift J0503.7-2819	4363	4899	0.891	-
Paloma	8205	9432	0.833	-
EX Hydrae	4022	5895	0.682	IP
V598 Pegasi	2500	4987	0.501	IP
DW Cancri	2315	5166	0.448	IP
V1025 Centauri	2147	5077	0.423	IP
IGR J18173-2509	1663	5520	0.301	IP
RX J2015.6+3711	7196	45940	0.157	IP

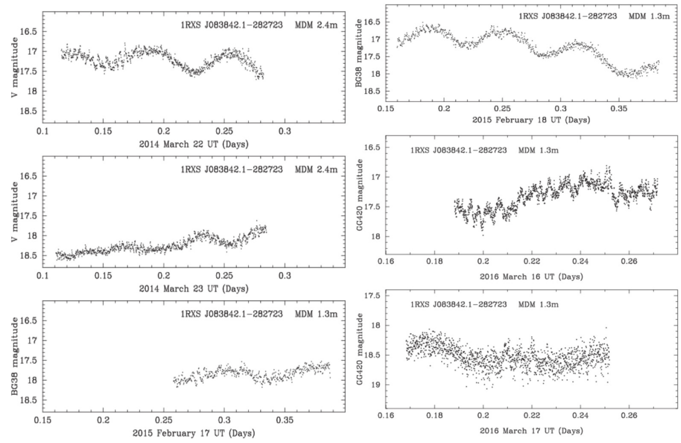

Figure 1. Light curves of J0838. Source: Halpern et al. (2017).

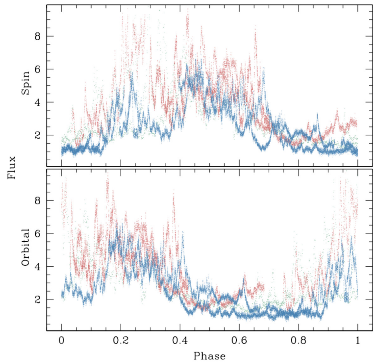

Figure 2. Light curves of J1955 with flickering. Source: Tovmassian et al. (2017).

recent nova explosion is the most probable explanation for those detections. Although, there are no gas clouds observed around novae V1432 Aql, CD Ind, BY Cam, and EX Hya, the case of a recent nova eruption causing a desynchronisation of periods in these systems can not be discarded, since many novas does not show this characteristic (11). EX Hya is the most synchronised IP (P_{spin} ~ 67 min and P_{spin}/P_{orb} = 0.68) and one of the few IPs bellow the period gap.

The systems Paloma (15), Swift J0503.7-2819 (4; 13), SDSS J134441.83+204408.3 (7), SDSS J084617.11+245344.1 (6), 1RXS J083842.1-282723 (J0838), and IGR J19552+0044 (J1955) show asynchronism between 3% and 20%, these latter objects are study here, which are extremely desynchronised polars or extremely synchronised IPs.

Swift J0503.7-2819, SDSS J134441.83+204408.3, and SDSS J084617.11+245344.1 were discovered recently and more details about those systems can be found in the indicated papers.

Paloma and J1955 are systems with short P_{orb}. Paloma, with P_{orb} = 157 min is in the middle of the period gap, while J1955, with P_{orb} = 101 min is bellow period gap. Both are probably in a transition state before reaching synchronism and are possible polar progenitors. Together with J0838, the study of these systems can improve our knowledge about the evolution of MCVs.

1.1. J0838

J0838 was discovered in 1996 using data from the ROSAT mission. In 2013, it was classified as a CV by Masseti et al. (2013) (10) based on the helium and Balmer emission lines. In 2017, two works, Halpern et al. (2017) (3) and Rea et al. (2017) (12), were dedicated to studying this source in greater depth.

The optical light curve of J0838 showed complex behavior, highly variable on short and long time scales, as shown in Figure 1.

Rea et al. (2017) found three periods for this object: 88.2 min (P_{spin}), 98.4 min (P_{orb}), and 15.2 h (P_{beat}). Halpern et al. (2017) found slightly different periods: 94.8 min (P_{spin}), 98.4 min (P_{orb}), and 14.7 h (P_{beat}). Based on this, we can confirm that the orbital period is 98.4 min. Both works present phase resolved optical spectroscopy with this result. Also, those studies detected a modulation around 15 h, consistent within the errors. We consider the period of 94.8 min presented by Halpern et al. as the WD spin period.

1.2. J1955

J1955 was discovered in 2006 using data from INTEGRAL mission. It was classified as a CV by Masetti et al. (2010) (9) based in its optical spectroscopy. In 2013, Thorstensen et al. (2013) (17) obtained spectroscopic and photometric time series, but with insufficient coverage to determine the system periods without ambiguity. Bernardini et al. (2013) (1) studied the object's X-ray behaviour. These authors point out that J1955 is a highly variable X-ray source. Furthermore, they infer a mass of 0.77 $M_{\odot}$ for the WD and a low accretion rate. Their period analysis were inconclusive about the origin of the periods (WD spin, orbital, or beat period). Based on the detection of hard X-ray spectrum and multiple periodicities, they proposed the nature of AP to the object.

Tovmassian et al. (2017) (Tovmassian et al.) proposed the basic parameters of the binary. The authors found that the light curve of J1955 presents complex variability, especially in the infrared. Also, they found two periodicities, 81.3 min in the photometric data and 83.6 min in the spectroscopic data. Therefore, a ratio of periods is P_{spin}/P_{orb} = 0.972. There is a great erratic variability (flickering), as shown in Figure 2.

2. Observations and data reduction

We performed in 2018 three observing runs at Pico dos Dias Observatory, using the IAGPOL polarimeter (8), in order to collect photometric and polarimetric time series of J0838 and J1955. All data was obtained at 1.6-m Perkin-Elmer telescope, which is managed by the Laboratório Nacional de Astrofísica (LNA). The observations were made using a quarter-wave plate ($\lambda/4$) with Johnson's B and V filters and Cousin's R_C and I_C filters.

The time span of J0838 data is a total of 25 h of observations using the B and I_C filters, while the time span of J1955 data is a total of 20 h of observations using the I_C filter.

Table 2 shows the details of these observations.

The data reduction was performed using the Python software called ASTROnomical POlarimetry and Photometry pipeline (Astropop) (2), which was created with the aim of providing a complete tool for reducing photometry and polarimetry data.

Table 2. Log of the observations.

Object	Date	Filter	t_{exp} (s)	Number of Images
J0838	17/03/2018	V	120	169
	18/03/2018	B	100	39
	18/03/2018	B	120	60
	18/03/2018	I_C	120	56
	19/03/2018	V	120	144
	25/04/2018	V	100	113
	26/04/2018	V	180	28
J1955	09/07/2018	I_C	20	435
	10/07/2018	I_C	30	460
	11/07/2018	I_C	40	475
	12/07/2018	I_C	20	758

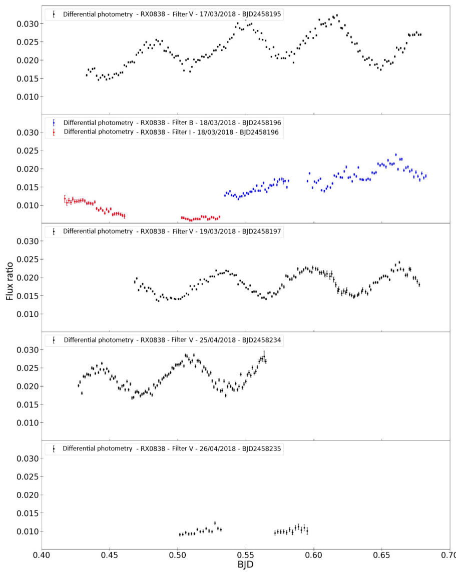

FIGURE 3. Photometric time series of J0838.

3. Results and Analisys

3.1. J0838

3.1.1. Fotometry

Figure 3 shows the photometric time series for the five nights on which J0838 was observed. For comparison purposes, all figures presented have the same scale on both X and Y axes, for the same variable of the same object. The V band was used on four nights and B and I_C bands were used on one night (see Table 2). We noted that there is a variation in the flux with a period of approximately 95 min. At the same time, a longer variation is observed, on the order of a day (for example, in the upper panel of the same figure, the sinusoidal pattern of the star's light curve shows an upward trend, which is repeated on the second night). This observation is consistent with Halpern et al. (2017), who proposed the observation of a period of 94.8 min and a period of 14.7 h. Halpern et al. (2017) together with Rea et al. (2017) also proposed a period of 98.4 min as the orbital period.

3.1.2. Polarimetry

Figure 4 shows the linear polarization light curves of J0838. We observed that the linear polarization remains equal or close to zero (value represented by the dotted line) on all nights. A more detailed analysis, considering the periodicity of the object and

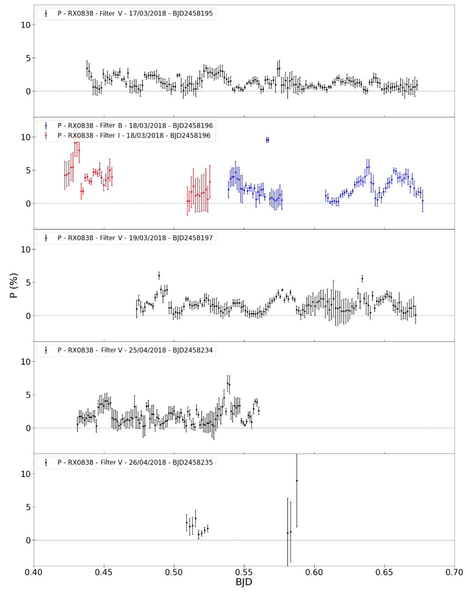

FIGURE 4. Linear polarization time series of J0838.

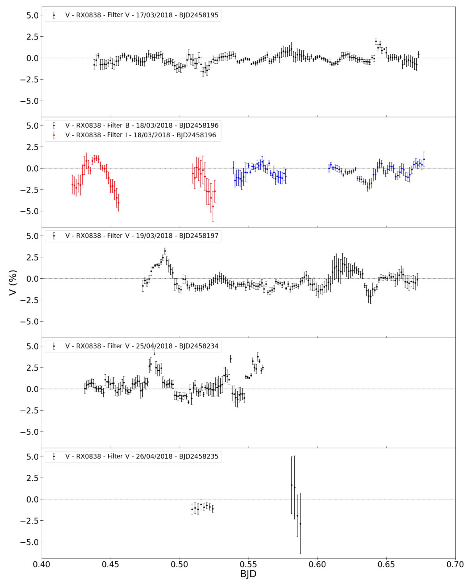

FIGURE 5. Circular polarization time series of J0838.

combined data from several nights, is needed to assess whether there is any real linear polarization peak. This would indicate that the accretion column is viewed from an angle at which the magnetic field is approximately in the plane of the sky.

Figure 5 shows the circular polarization light curves of J0838. It is possible to notice that this object has a small circular polarization, with some peaks with a value of up to 3% distributed over the observed nights. This is an indication of the existence of a not very intense magnetic field.

3.1.3. Search for periodic signals

Figure 6 shows the result of the Lomb-Scargle method (14) applied to the photometric curves of J0838 in filter V. The first panel shows the period of 94.91 min (peak at 15.17/d) as the most likely for this system. The dashed line represents the false alarm probability of 0.1%. The periodogram shows the presence of peaks well above this line. The second panel shows the

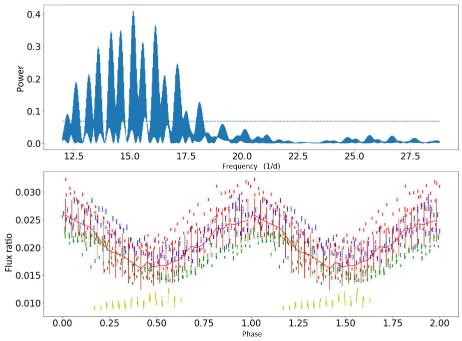

FIGURE 6. Lomb-Scargle results from the photometric data of J0838.

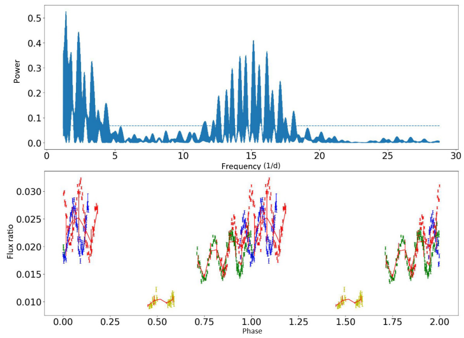

FIGURE 7. Lomb-Scargle results from the photometric data of J0838 for longer periods.

phase diagrams of J0838 as a function of the photometric phase of 94.91 min. The zero phase moment was chosen visually to make it as close as possible to the flux peak and has a BJD value of 2458195.55. The red dots represent data from the night of 17/03, the green from the night of 19/03, the blue from the night of 25/04 and the yellow from the night of 26/04. Data from the night of 18/03 were omitted due to the fact that they were obtained using different filters from the rest of the nights. The solid red line shows the mean value with the error bars being the standard deviation of the mean value. It is possible to see that the fitting for this frequency is good, with the curves following the same modulation every night.

Our data shows that, in addition to the 94.91 min variation, there is a flux variation on longer time scales. This has already been reported by Rea et al. (2017) and Halpern et al. (2017). Therefore, we did the Lomb-Scargle analysis, this time considering longer periods, up to 1200 min. The results indicate that there is a variation consistent with a period of 1018 min, or 16 h and 58 min. Figure 7 shows these results.

3.2. IGR J19552+0044 (J1955)

3.2.1. Fotometry

Figure 8 shows the photometric time series for the four nights in which J1955 was observed. On all nights, only the I_C filter was used. It shows large variations in the object's flux, of almost 10 times, which are repeated throughout all the observed nights. With a visual inspection it is not simple to identify a single period for these flux variations. At some times it is possible to see peaks with little temporal separation, other times the temporal separation is greater. Some peaks are short and well defined, others are long and with high flux variability. The Lomb-Scargle analysis will reveal the existence of a periodic signal consistent with that observed by Tovmassian et al. (2017).

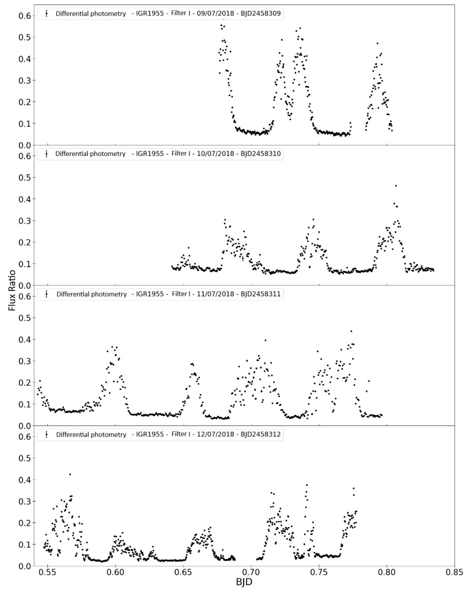

FIGURE 8. Photometric time series of J1955.

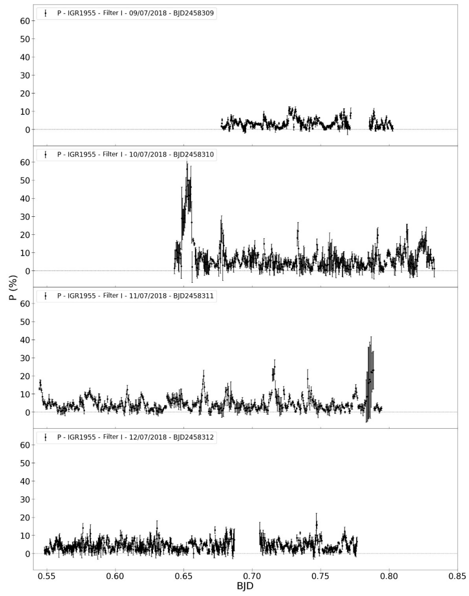

FIGURE 9. Linear polarization time series of J1955.

3.2.2. Polarimetry

Figure 9 shows the linear polarization light curves of J1955. The linear polarization values for this object are, at almost all observed moments, very close to zero. At the beginning of the second night (07/10/2018) there is a linear polarization peak of 60% that is not observed at any other time. At the end of the third night (07/11/2018) there is also a linear polarization peak, but with large error bars. In this work we do not verify whether these linear polarization peaks are real.

Figure 10 shows the circular polarization light curves of J1955, which are highly modulated, with values between -20% and 30%. This circularly polarized emission is cyclotron emission generated by one accretion column and is an indication of a strong magnetic field in this system. The shape of these curves

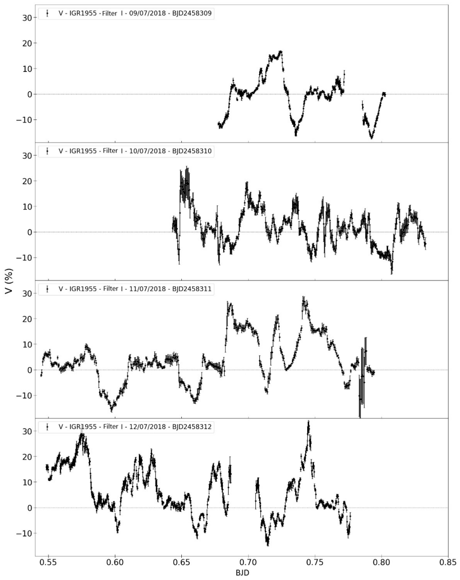

Figure 10. Circular polarization time series of J1955.

is complex and variable over the observed nights. It is possible to see that the modulation in circular polarization occurs, at least in a visual assessment, in synchrony with the photometric modulations.

On the first night, it is possible to observe a pattern, in which two nearby photometric peaks are accompanied by a positive peak and a negative peak in circular polarization. In this work, we propose that the explanation for this observation is the existence of accretion on two magnetic poles separated by less than 180º on the WD's surface.

On the other nights, it is possible to observe a behaviour compatible with the existence of an accretion that alternates poles, due to the difference between the system's P_{orb} and P_{spin}. Also, there is an evident feature that periods of photometric minimum are always simultaneous to periods of zero circular polarization. This is compatible with a scenario of a self-occultating accretion region.

3.2.3. Search for periodic signals

Figure 11 shows the result of the Lomb-Scargle method applied to the photometric curves of J1955. The first panel shows the spectral distribution of the photometric periods of J1955. The most significant peak occurs at 81.27 min (peak at 17.72/d), which is proposed here as the WD spin period. The dashed line indicates a false alarm probability of 0.1%. The second panel shows photometric data from all nights in which J1955 was observed as a function of the period of 81.27 min. The data from the night of 09/07/2018 is represented in red, from the night of 10/07/2018 in green, from the night of 11/07/2018 in blue and from the night of 12/07/2018 in yellow.

Unlike what occurs in J0838, in which the photometric light curve has a sinusoidal shape, in J1955 there are periods of high flux and high photometric variability, interrupted by periods of low flux and low photometric variability. This may be an indication that the accretion is being hidden according to the rotation of the WD. Another piece of evidence that corroborates this statement is the observation that the photometric minimum is the same every night, which shows us that we do not see the accretion region at those moments.

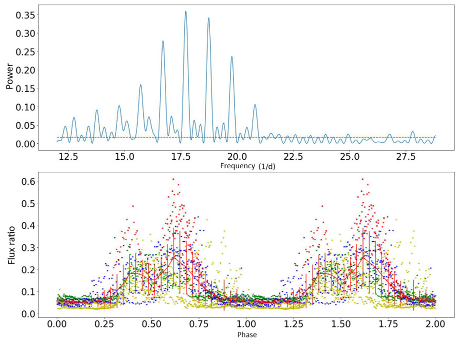

Figure 11. Lomb-Scargle results from the photometric data of J1955.

4. Conclusions

In this work we used polarimetric and photometric data to study two near synchronous MCVs, J0838 and J1955. We applied the Lomb-Scargle analysis in the photometric light curves in order to obtain its modulations. We show that our results agree with previous works.

In J0838, we obtained a P_{spin} of 94.9 min, a beat period of about 15 h to 17 h and small linear and circular polarimetry. The circular polarization can be modulated with P_{spin}. If we confirmed these results, we can corroborates the proposal of the existence of a magnetic field sufficient to produce cyclotron radiation in the WD.

In J1955, we obtained a P_{spin} of 81.3 min, a small linear polarization and circular polarization of 30% modulated with P_{spin}. We also observed the possible self-eclipse of the emission region and the probable existence of more than one accretion region.

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