

Detection of stellar variability through S-PLUS data

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Abstract. The project proposes the search for short-period stellar variability, mainly of pulsating white dwarfs (WDs), through data obtained in the context of the Southern Photometric Local Universe Survey (S-PLUS, Mendes de Oliveira et al. 2019), which is currently observing the southern hemisphere sky in 12 optical photometric bands. For the search for variability, we applied a general extension of the Lomb–Scargle (LS; VanderPlas Ivezic 2015; VanderPlas 2018) algorithm for multiband astronomical time series to recover a periodogram. The preliminary analysis of 46 stars in the white dwarf region could bring 3 variable star candidates, with 2 already known and confirmed, that is, resulting in 4 % of the WDs sample. We intend to select a sample of pulsating WDs candidates that can be studied in more detail in future works when expanding the method to the whole S-PLUS internal Data Release 4 (iDR4), whose data can be accessed at `splus.cloud`.

Resumo. O projeto propõe a busca da variabilidade estelar de curto período, principalmente de anãs brancas pulsantes (WDs), através de dados obtidos no contexto do Southern Photometric Local Universe Survey (S-PLUS, Mendes de Oliveira et al. 2019), que está atualmente observando o céu do hemisfério sul em 12 bandas fotométricas do espectro óptico. Para a busca por variabilidade, aplicamos uma extensão geral do algoritmo de Lomb-Scargle (LS; VanderPlas Ivezic 2015; VanderPlas 2018) para séries temporais astronômicas multibanda para recuperar um periodograma. A análise preliminar de 46 estrelas na região das anãs brancas trouxe 3 candidatas a estrelas variáveis, sendo 2 já conhecidas e confirmadas, ou seja, resultando em 4% da amostra de WDs. Pretendemos selecionar uma amostra de candidatas a WDs pulsantes que possam ser estudados com mais detalhes em trabalhos futuros ao expandir o método para todo o S-PLUS *internal Data Release 4* (iDR4), cujos dados podem ser acessados em `splus.cloud`.

Keywords. white dwarfs – Stars: variables: general – Methods: data analysis

1. Introduction

Stellar variability is related to the variation in the brightness of stars, which can be generated by intrinsic reasons or external factors. There are many types of variable stars and different ways to classify them. Although being possible to detect several types of variability, the targets of this project are pulsating white dwarfs, which are objects of great interest in the study of stellar structures. The reason is that they can provide important clues about the evolution of the progenitor stars during the main sequence phase or later phases, already entering the end of the active life of these astronomical sources.

2. Objectives

In this context, the project proposes the detection and study of pulsating white dwarfs using the data obtained under the S-PLUS project, in which variability detection methods are applied to individual observations in order to select a sample of candidates that could be studied in more detail in the future. As the S-PLUS is observing the southern sky with a 12-band photometric system, composed of 5 broad and 7 narrow bands distributed along the optical spectrum, we can scan a large area of the sky looking for these objects.

3. Methodology

The methodology involves exploring the cadence created by the observational strategy of the Main Survey (MS) of S-PLUS, whose images are obtained sequentially with 3 exposures for

each of the 12 filters, that is, 36 individual images of each field, allowing the analysis of the light curve for each star using a Fourier Transform (FT) in the search for possible signs of variability. The range of the S-PLUS observation window of approximately 1.5 hours and the filter cadence allows us to search for signs of the variability of WDs, which are found in very specific regions of an H-R diagram due to their low luminosity, offering the possibility for a selection of candidates to test the presence of variability. For this, two slightly different methods are used. The first consists of obtaining a normalized light curve for each individual band and then using an FT for the entire curve, while the second involves the application of an FT for each band individually and the subsequent combination to obtain the probability of an indicative signal of variability. Both methods are shown in Figure 1, along with the data obtained for the pulsating white dwarf star ZZB EC 04207-4748.

We obtained time series (TS) observations for a control sample using the time designated for the project Target of Opportunity (ToO) with the T80-South telescope (the telescope responsible for MS observations). Consisting of 80 exposures of 60 seconds each in the gSDSS filter, these observations are able to provide us with the necessary cadence to infer the quality of our results for the S-PLUS MS data. Figure 2 shows the result of applying the method to time series data in the case of the star EC 04207-4748, reiterating the signals obtained in the non-homogeneously spaced MS data.

A total of 16 fields were selected in this preliminary analysis just for convenience due to the telescope restrictions, to test the reliability of our code. Two of these fields contain known pulsating white dwarfs, and the other 14 were chosen because of the

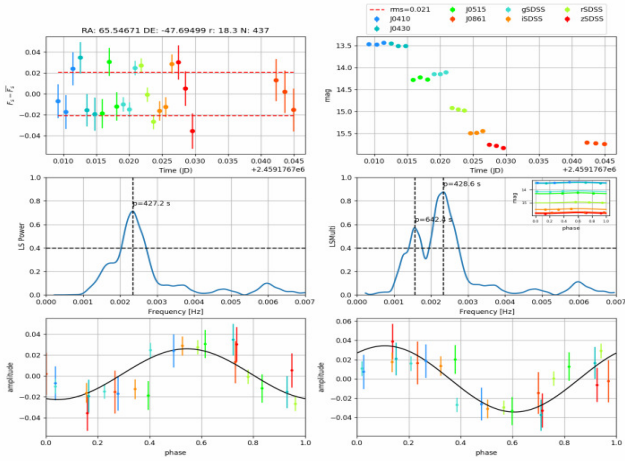


FIGURE 1. Light curves, periodograms and phase diagrams obtained for the pulsating white dwarf star ZB, known as EC 04207-4748. At the top left of the figure is the normalized light curve (LC) for the 8 S-PLUS bands (some filters were removed as they did not contribute to the detection in the range of selected periods), colored according to the legend. In the middle is the periodogram obtained using the Lomb-Scargle method (LS; Vanderplas, J. T. et al., 2018) applied to the normalized LC. At the top right there is the LC for instrumental magnitudes of the 8 S-PLUS bands and in the middle is the periodogram resulting from the application of the multiband Lomb-Scargle method (Vanderplas, J. T. et al., 2015.). The lower panels of the figure show the phase curves for the period corresponding to the highest peak of the respective periodogram.

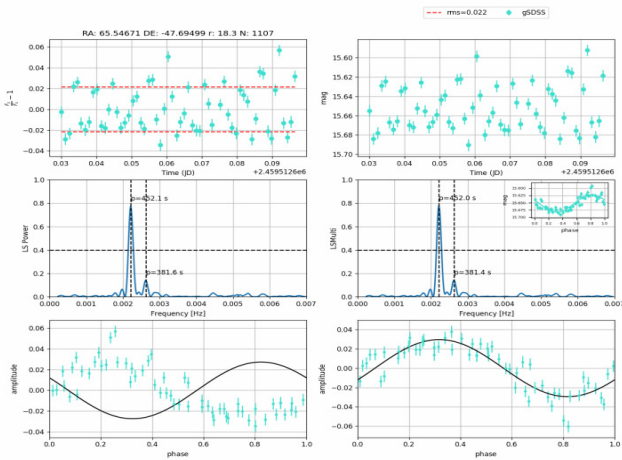


FIGURE 2. Same as Figure 1 but for a time-series observation in gSDSS band. LS was applied to the data, resulting in the detection of a with 452s (central panels). Sinusoidal adjustment for LS values (bottom panels). The star is EC 04207-4748, referenced earlier.

possibility of allocating ToO time for the observations. Using our program in the 16 fields, we select our variable candidates using the following criteria:

- signal for LS multiband power greater than 0.65 are flag 1;
- signal for LS power greater than 0.4 at TS are flag 2;
- signal at LS power greater than 0.65 on multiband MS and greater than 0.4 on TS are flag 3.

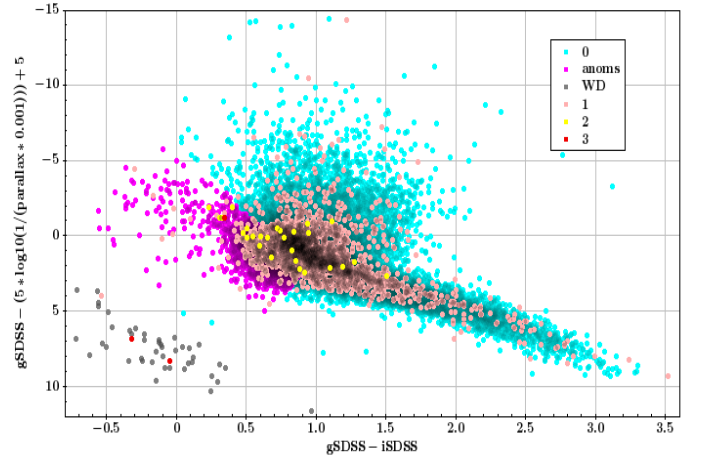


FIGURE 3. HR diagram containing the stars of the 16 fields, with the candidate variables colored according to their flag, in addition to the demarcation of the region of hot stars and white dwarfs.

4. Results

A match was done with GAIA’s EDR3 and a parallax error cut < 0.2 was applied to the resulting targets. Thus, out of the 42 176 stars from the 16 fields, 1988 were selected as candidates. The HR diagram created with these stars is shown by Figure 3. The HR diagram also delimits the white dwarf region, with 46 stars, along with the region dubbed here as the hot region, which is of our interest due to the possibility of containing anomalous objects and other types of interesting variables. This region has 5917 stars and the potential candidates found within this region will have our attention for further studies.

5. Conclusions

Considering that pulsating white dwarfs within two of the analyzed fields were already known, this preliminary analysis may have certain biases. However, it is still relevant to rely on the data we have now to obtain general statistics when expanding to the whole iDR4. Of the 46 stars in the white dwarf region, 3 were considered variables, with 2 already known and confirmed, that is, resulting in 4% of the WDs sample. The third candidate was identified as a false positive, allowing us to assume that our candidates may have 1/3 of contamination by other types of variability or spurious data. When expanding to the entire 2600 sq deg of the iDR4 area, we expect to find on the order of 50-80 candidates, although this number of candidates can be smaller due to the potential absence of objects complying with the criteria we impose on the sample. Still, the results we have so far show that we are indeed capable of recovering variability with the S-PLUS data despite the several challenges imposed by the observation strategy used for the MS.

It is worth pointing out that this is the only stellar variability detection project in S-PLUS, given that the survey was not designed for that, and it may show interesting and relevant results from the use of the survey in another way.

References

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