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# Search for new variable stars in the northern sky

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**Abstract.** With the aim to find and characterize new variable stars, we obtained 24 470 CCD images in 13 fields of 0.4 square degrees with a 35/51 cm Maksutov-type semi-robotic telescope at the Molėtai Astronomical Observatory of Vilnius University. From photometric time series of 3604 stars analysed, we found 11 periodic variable stars and 70 slowly varying stars with so far undefined periodicity.

**Key words:** Methods: data analysis – Catalogs – stars: oscillations

## 1. Introduction

In order to prepare optimal input catalogues for space missions, extensive ground-based observations and characterisation of possible target objects are necessary. With the aim to search for new variable stars in selected fields of the northern sky which will be observed by the NASA TESS and ESA PLATO space missions, in 2016 we started a spectroscopic and photometric survey (SPFOT, Mikolaitis et al. 2018) and present here some of our results.

## 2. Observations and method of analysis

Observations were performed at the Molėtai Astronomical Observatory (MAO, Lithuania) with a 35/51 cm Maksutov-type telescope and the Apogee Alta U47 CCD camera. A field of view of this instrument is 0.39 $\text{deg}^2$. We observed 13 fields with several different exposure times (short exposures for the variability analysis of brighter stars and the longer ones in order to analyse fainter objects). The observational data were collected in a period between JD 2457597.4 and JD 2457649.4. The shortest and longest light curves were 18 and 52 days, respectively. A majority of the light curves had about 30 days. The observations and methodology of data reduction are described in more details by Pakštienė et al. (2018), Pakštienė et al. (2019).

The observed images were processed and light curves of 3598 stars till about *Gaia G* 15 mag were derived with a *Muniwin* program (also known as $C-$

*Munipack* project), which originated from the *Munipack* package (Hroch 2014). More information about the software may be found on its website (*http://c-munipack.sourceforge.net/*). The most common value of the mean error ($\mathrm{ERR_{mean}}$) of every observed point and the most common value of the standard deviation ($\mathrm{STD_{LC}}$) of the observed light curves were obtained in a range of 0.05–0.1 mag and 0.075–0.125 mag, respectively. Both $\mathrm{ERR_{mean}}$ and STD served as indicators of observation quality for non-variable stars, but a large STD also indicated a possible stellar variability. At the same time all LCs were inspected for variability visually to reveal stars with large amplitudes of variability. For searching of smaller amplitude periodic variations we applied the mathematical tools such as the Fourier transform (FT) (Fourier 1822) and the Lomb-Scargle (LS) periodogram (Lomb 1976; Scargle 1982). We assumed that a star may be variable when a power of signal in the Lomb-Scargle periodogram exceeds a calculated detection limit for a case when false alarm probability (FAP) is 1/100. Then we applied Fourier decomposition method using the Period04 program (Lenz & Breger 2005) for a more detailed analysis of possible periodic variables.

A method of trending parameter (TR) was used for searching of long periodic variable star candidates or irregular variables. Such stars show slow changes of magnitude or their LCs have a one way trend. In the case of such variable stars we derived different magnitudes at different times. Since quality of the data was different for individual stars we reduced the reliability of magnitude differences by errors of observations, i.e. by $\mathrm{STD_{LC}}$ and $\mathrm{ERR_{mean}}$. Therefore, we calculated an observed trending parameter ($\mathrm{TR_O}$) using the following equation:

$$\mathrm{TR_O} = \frac{\mathrm{mag_{max}} - \mathrm{mag_{min}}}{\mathrm{STD_{LC}} \cdot \mathrm{ERR_{mean}}},$$

where $\mathrm{mag_{max}}$ and $\mathrm{mag_{min}}$ are differential magnitudes determined at phases when a star was faintest and brightest, respectively.

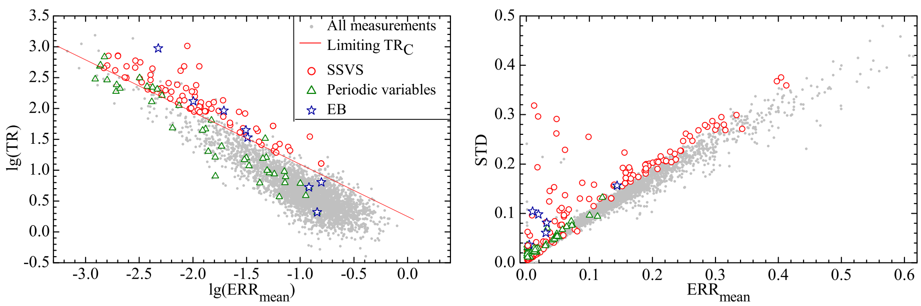


**Figure 1.** Dependencies of TR and STD parameters on the $\mathrm{ERR_{mean}}$. See the text for more explanations.

The left panel of Fig. 1 shows a dependence of the $TR_O$ parameter on the $ERR_{mean}$ for our observed data set in a logarithmic scale. The red line corresponds to the calculated limit of trending parameter ($TR_C$) for possibly slowly varying stars, which should appear above that line. A majority of the points in Fig. 1 lay below the limiting $TR_C$ parameter, however some stars have $TR_O > TR_C$ parameters than others with the same $ERR_{mean}$. Those lifted stars may have trending or slowly varying LCs. In order to recognize potential variable stars we computed a difference between observed $\log(TR_O)$ and calculated $\log(TR_C)$ at a certain $ERR_{mean}$: $\log(TR_{O/C}) = \log(TR_O) - \log(TR_C)$.

A larger value of $\log(TR_{O/C})$ gives a higher probability that a star is variable. The right panel of Fig. 1 shows a dependence of $STD_{LC}$ on $ERR_{mean}$ (STD(ERR)). Every star which appears above the densest part of STD(ERR) or STD(MAG) dependencies may be variable.

From the right panel of Fig. 1 we can see that such diagrams are sensitive to high amplitude variations (e.g. typical to eclipsing binary stars or $\delta$ Cep type stars). We also find there other stars with larger STD than normal, but they do not show any long or short periodic variability. Often those stars have a close neighbour on the sky.

## 3. New variable stars

Using the described methods we found 81 new candidates of variable stars. 11 of them were found using more than one method. They were analysed in more detail and the results are going to be published in a forthcoming paper (Pakštienė et al. 2019) which is in preparation. The remaining 70 stars were identified as possible variable stars with slow changes in brightness or with irregular variability which cannot be analysed using their amplitude spectra yet. They were selected using the method of trending parameters. The stars with the positive values of $\log(TR_{O/C})$ were attributed to a group of suspected slowly variable stars (SSVS). These stars are shown in Fig. 1 as the red circles lying above the calculated theoretical limit of the trending parameter (the red line in Fig. 1). A list of SSVS with their *Gaia G* magnitudes and *Gaia* coordinates taken from *Gaia* DR2 (Gaia Collaboration et al. 2016, Andrae et al. 2018, Gaia Collaboration et al. 2018) is presented in Table 1. We also picked up luminosities and effective temperatures from the Gaia DR2 catalogue where they were determined from parallaxes and three broad-band photometric measurements (Gaia Collaboration et al. 2016, Andrae et al. 2018, Gaia Collaboration et al. 2018), and compared these values with the Padova stellar evolutionary tracks with different masses (*http://pleiadi.pd.astro.it/*). This way we estimated approximate types of the stars and present them in the last column of Table 1. Some stars were unclassified since their luminosities were not present in the Gaia DR2 catalogue. A majority of the stars have masses smaller than 2.5 $M_\odot$, except for two red giant branch stars (524845214033292800 and 525091745154747904), which

**Table 1.** A list of suspected slowly variable stars.

| *Gaia* ID | *Gaia* $G$, [mag] | RAJ2000 | DEJ2000 | Type[1] |
|---|---|---|---|---|
| 525000859345992960 | 11.1388 | 18.0104986371 | 64.9650940284 | MS |
| 524998561542119296 | 11.1148 | 18.2651249861 | 64.9818074356 | – |
| 525107310116118528 | 10.2701 | 18.3510046419 | 65.3658881455 | RG |
| 525134866626773120 | 9.2636 | 18.4228266234 | 65.6166143921 | SG |
| 525091745154747904 | 11.2388 | 18.5474162089 | 64.9931044943 | RG |
| 524809995303314176 | 10.7714 | 18.5798221174 | 64.9279842501 | MS/SG |
| 525141772934253440 | 8.227 | 18.6043442775 | 65.7375027813 | RG |
| 525101434600987136 | 9.231 | 18.6061094894 | 65.2666027345 | RG |
| 525104389538474624 | 9.9243 | 18.6398231349 | 65.3681037685 | RG |
| 524904347144651392 | 10.8524 | 18.6742139351 | 65.0115400097 | MS |
| 524903071529044480 | 12.111 | 18.7722224484 | 64.9207124999 | SG/RG |
| 524938466365442688 | 8.8105 | 19.0149649408 | 65.3089116997 | RG |
| 524950664072456192 | 9.6144 | 19.0787520855 | 65.6565664824 | RG |
| 524888507305367552 | 10.6168 | 19.1267052896 | 64.8583234924 | MS |
| 524910699393690112 | 10.4527 | 19.1668881276 | 65.1461946054 | MS/SG |
| 524791303605806208 | 12.5398 | 19.2301447391 | 64.6828686697 | SG |
| 524933793441182080 | 11.764 | 19.3408466046 | 65.1944293021 | MS |
| 524894176662153216 | 9.8406 | 19.3586934038 | 64.9326999485 | MS/SG |
| 524935683226651520 | 11.056 | 19.3726466587 | 65.2851335846 | – |
| 524887613952295424 | 11.5937 | 19.3911079915 | 64.8214608609 | SG/RG |
| 524897127297039104 | 11.8808 | 19.3972701036 | 65.0403010267 | MS |
| 524923451159818240 | 9.5236 | 19.5136935576 | 65.2096488369 | – |
| 524893558187004032 | 11.4837 | 19.6315309338 | 65.0217548205 | – |
| 524929906487427712 | 10.3878 | 19.6892888954 | 65.362794943 | MS/SG |
| 524929051797262208 | 12.3722 | 19.7226064568 | 65.2726434851 | MS |
| 524925886398044288 | 12.374 | 19.7653883266 | 65.2333253279 | SG/RG |
| 524916093872620160 | 12.2165 | 19.8082810858 | 65.01069596 | MS |
| 524841262663818112 | 9.2175 | 19.8592736896 | 64.7205464169 | MS/SG |
| 524845214033292800 | 11.5191 | 19.8686201483 | 64.9262839528 | RG |
| 524924546368250624 | 11.7148 | 19.973093738 | 65.17397557 | SG |
| 524843324247702528 | 13.8064 | 20.0108416357 | 64.8297480449 | – |
| 524840128792064128 | 9.9412 | 20.0737982867 | 64.7619369824 | MS/SG |
| 524838548238275840 | 10.9242 | 20.0867153652 | 64.7241493734 | SG |
| 524879745571182848 | 12.8106 | 20.1083943669 | 65.2381994037 | SG |
| 524864283689156864 | 11.6354 | 20.1717913294 | 64.8518494965 | SG |
| 524869502067395584 | 12.1572 | 20.1933373926 | 64.9716598875 | RG |
| 524863974451536256 | 9.2463 | 20.2396816824 | 64.8181902335 | RG |
| 524880054808824064 | 11.1258 | 20.253494167 | 65.2663650418 | RG |
| 524866620151264256 | 11.6951 | 20.2614831216 | 64.9732018464 | SG |
| 524866620151263616 | 14.195 | 20.2700508062 | 64.9739792466 | SG |
| 524876859353184896 | 11.5323 | 20.2917155956 | 65.1443171012 | MS |
| 339010221170297472 | 14.0669 | 35.3336181038 | 41.2208428331 | MS |
| 338956074518570368 | 9.0222 | 35.3557119786 | 41.0924924935 | MS |
| 338965557806325632 | 9.3653 | 35.4621374032 | 41.327516872 | MS |
| 338963668020721536 | 9.6547 | 35.4624127663 | 41.2628849615 | RG |
| 1694320377289305600 | 12.3535 | 226.978800471 | 69.9148327953 | SG |
| 1694356871626759680 | 10.5961 | 227.930460635 | 69.6908196763 | MS/SG |
| 1694369756528664192 | 10.2955 | 228.029397185 | 69.9367877523 | MS |
| 1694358658333159296 | 12.9441 | 228.110310003 | 69.7548509882 | MS |
| 1752703796186541696 | 13.4423 | 308.416400591 | 9.7394910823 | MS |
| 1752936445975336704 | 8.4602 | 308.509720864 | 10.2531709392 | RG |
| 1752933765915721600 | 7.4819 | 308.583145863 | 10.2681214277 | RG |
| 1798520785015411840 | 9.9592 | 322.35426006 | 25.0236963089 | RG |
| 1798520892390900096 | 11.2096 | 322.368208015 | 25.047902805 | MS |
| 1784031180267825024 | 12.0245 | 322.444538562 | 16.2766138823 | SG/RG |
| 1798286829556897664 | 10.6325 | 322.447691171 | 24.6026164616 | MS/SG |
| 1798286902572778880 | 10.4316 | 322.485531726 | 24.6057297405 | RG |
| 1798287521048300672 | 10.4966 | 322.514082756 | 24.6546389142 | RG |
| 1772025406644569600 | 8.7811 | 322.759697159 | 16.3007606979 | RG |
| 1798232781688454272 | 13.3126 | 322.791905621 | 24.4678215496 | SG/RG |
| 1915157669982159744 | 12.8614 | 344.508903545 | 34.3592328576 | SG |
| 1914407837411240832 | 10.8739 | 344.694745194 | 34.3730383476 | MS |
| 1913321760441573248 | 9.5265 | 349.365342282 | 36.1495604234 | MS/SG |
| 1913310937123996928 | 8.7682 | 349.389579137 | 36.0055655426 | RG |
| 1913296437314414208 | 9.8338 | 349.405599182 | 35.9047151378 | RG |
| 1913291901828961024 | 11.6621 | 349.478195832 | 35.7936387363 | MS |
| 1913301415179710336 | 10.0586 | 349.629225625 | 35.9813449457 | MS |
| 1913404086374653184 | 9.1121 | 349.848263381 | 36.3364204108 | RG |
| 1913347319790018816 | 9.2237 | 350.002915174 | 36.0433222975 | MS |
| 2824707704618848896 | 12.0161 | 352.321691849 | 19.5538765948 | SG |

[1] MS - main sequance stars; SG - subgiant branch stars; RG - red giant branch stars.

may be more massive. Periodicity of these stars is undefined yet and they require further long term photometric and spectrometric observations in order to analyse their variability.

## 4. Conclusions

We used several methods for searching of variable stars, i.e. we used the Fourier transform spectra, Lomb-Scargle periodograms, dependencies of trending parameters and standard deviations of LCs on measurement errors. Using the described methods we analysed light curves of 3598 stars and found 81 new variable stars, 70 of them were found using a method of trending parameters and attributed to suspected slowly varying stars. We have shown that the method of trending parameters may be productive in searching of stellar variability in relatively short light curves, when amplitude spectra, such as Fourier Transform spectra or Lomb-Scargle periodograms, are not effective. We recommend to observe the newly discovered slowly varying stars presented in this contribution and also to check effectiveness of the proposed method of trending parameters.

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