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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 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.

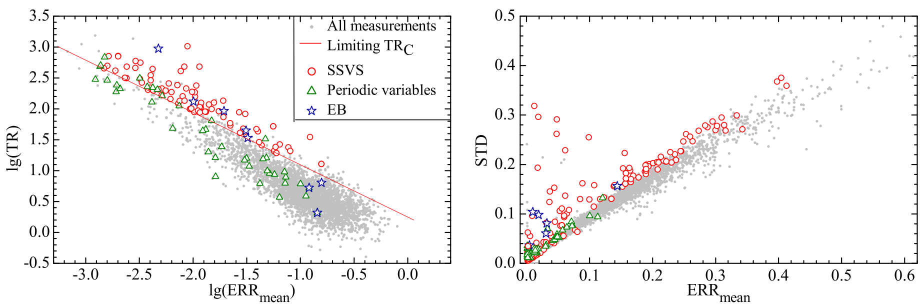

Figure 1. Dependencies of TR and STD parameters on the $\mathrm{ERR_{mean}}$. See the text for more explanations.

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 δ 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]
5250008593459992960	11.1388	18.0104986371	64.9650940284	MS
5249985615421192996	11.1148	18.2651249861	64.9818074356	–
5251073101161185228	10.2701	18.3510046419	65.3658881455	RG
5251348666267731200	9.2636	18.4228266234	65.6166143921	SG
5250917451547479004	11.2388	18.5474162089	64.9931044943	RG
5248099953033141776	10.7714	18.5798221174	64.9279842501	MS/SG
5251417729342534440	8.227	18.6043442775	65.7375027813	RG
5251014346009871136	9.231	18.6061094894	65.2666027345	RG
5251043895384746624	9.9243	18.6398231349	65.3681037685	RG
5249043471446513392	10.8524	18.6742139351	65.0115400097	MS
5249030715290444480	12.111	18.7722224484	64.9207124999	SG/RG
5249384663654426888	8.8105	19.0149649408	65.3089116997	RG
5249506640724561192	9.6144	19.0787520855	65.6565664824	RG
5248885073053675552	10.6168	19.1267052896	64.8583234924	MS
5249106993936901112	10.4527	19.1668881276	65.1461946054	MS/SG
5247913036058062208	12.5398	19.2301447391	64.6828686697	SG
5249337934411820080	11.764	19.3408466046	65.1944293021	MS
5248941766621532216	9.8406	19.3586934038	64.9326999485	MS/SG
5249356832266515520	11.056	19.3726466587	65.2851335846	–
5248876139522954424	11.5937	19.3911079915	64.8214608609	SG/RG
5248971272970391104	11.8808	19.3972701036	65.0403010267	MS
5249234511598182240	9.5236	19.5136935576	65.2096488369	–
5248935581870040032	11.4837	19.6315309338	65.0217548205	–
5249299064874277712	10.3878	19.6892888954	65.362794943	MS/SG
5249290517972622208	12.3722	19.7226064568	65.2726434851	MS
5249258863980442288	12.374	19.7653883266	65.2333253279	SG/RG
5249160938726201160	12.2165	19.8082810858	65.01069596	MS
5248412626638181112	9.2175	19.8592736896	64.7205464169	MS/SG
5248452140332928000	11.5191	19.8686201483	64.9262839528	RG
5249245463682506624	11.7148	19.973093738	65.17397557	SG
5248433242477025528	13.8064	20.0108416357	64.8297480449	–
5248401287920641128	9.9412	20.0737982867	64.7619369824	MS/SG
5248385482382758840	10.9242	20.0867153652	64.7241493734	SG
5248797455711828848	12.8106	20.1083943669	65.2381994037	SG
5248642836891568864	11.6354	20.1717913294	64.8518494965	SG
5248695020673955584	12.1572	20.1933373926	64.9716598875	RG
5248639744515362256	9.2463	20.2396816824	64.8181902335	RG
5248800548088240064	11.1258	20.253494167	65.2663650418	RG
5248666201512642256	11.6951	20.2614831216	64.9732018464	SG
5248666201512636616	14.195	20.2700508062	64.9739792466	SG
5248768593531848896	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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