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A small survey of UV-bright stars around the northern ecliptic pole: Seeking new p-mode sdB variables for the TESS mission

Saskia Prins

John Telting

Roy H. Østensen
Missouri State University

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Research Article

Saskia Prins*, John Telting, and Roy Østensen

A small survey of UV-bright stars around the northern ecliptic pole: seeking new p-mode sdB variables for the TESS mission

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Abstract: Starting in 2019, the TESS mission will monitor the northern ecliptic pole for 1 year. Data will be collected at 30-minute and 2-minute cadences, and only a limited amount of slots will be reserved for targets requiring a 20-second cadence. Only the 20-second cadence is sufficient to sample p-mode oscillations in sdB stars. From the seismic measurements obtained with the Kepler spacecraft we have gained a wealth of new insights in structural and rotational aspects of mainly g-mode variable sdB stars. Unfortunately only one traditional p-mode sdB variable was found in the main Kepler field. The TESS mission offers the opportunity to obtain more long-time-base coverage of p-mode sdB variables, especially at the ecliptic poles where the time-base will be longest . Thus far, there were only two known (p-mode) sdBVs around the northern ecliptic pole ($\beta > 78$): LS Dra and V366 Dra. In this paper we describe our efforts to find more. We compiled a new sample of 76 sdB candidates around the northern ecliptic pole, based on GALEX and optical colours, and we used low-resolution Balmer-line spectroscopy for classification. We identified 39 new sdB stars, of which 29 have characteristics ($T_{eff} > 28000$ K or a composite spectrum) that may put them in the p-mode instability strip. With our 39 new sdB stars, we augmented the number of known sdB stars in the the northern ecliptic pole area ($\beta > 73$) by 46%. Besides these sdB stars, among our spectral classifications are various sdO stars, He-sdB stars, blue horizontal-branch stars, white dwarfs, cataclysmic variables and main sequence B stars. We obtained time-resolved photometry of most of the p-mode sdB candidates, and found one new sdBV, J19384+5824, with a moderately high pulsation amplitude of ≥ 9 mmag.

Keywords: Asteroseismology, stars: oscillations, subdwarfs

1 Introduction

From the seismic measurements obtained with the Kepler spacecraft we have gained a wealth of new insights in structural and rotational aspects of mainly g-mode variable sdB stars. We now know that pulsating sdB stars rotate slowly (rotation periods of days to tens of days), that low-degree g-mode pulsations show regular period spacings consistent with what is expected in the asymptotic regime, that some g-mode sdB pulsators show trapped modes giving insight on radial stratification and diffusion, and that frequency splittings of high-degree multiplets vary slowly over time expressing the need to think of other mechanisms than rotation to explain the multiplets splittings. See Reed (these proceedings) for a recent overview.

While Kepler through its K2 mission still has several 3-month periods of new data projected, one of the next space missions that will be useful for sdB-star seismology will be launched in 2018. A description of the Transiting Exoplanet Survey Satellite (TESS) and its science mission can be found in Ricker et al (2015). TESS will gather data at 30-minute and 2-minute cadences, and only a limited amount of slots will be reserved for targets requiring a 20-second cadence (dedicated to seismology). Only the 20-second cadence is sufficient to sample p-mode oscillations in sdB stars, for typical p-mode periods of 2–10 minutes. The TESS mission will visit the southern sky first, and from 2019 will monitor the northern ecliptic pole (ecliptic latitude $\beta > 78$) for 1 year. Targets in the polar rim $73 < \beta < 78$ will get TESS coverage between 108 to 189 days, while targets that are closer to the

Corresponding Author: Saskia Prins: Mercator Telescope, Apartado de Correos 20, 38700 Santa Cruz de La Palma, Spain; Instituut voor Sterrenkunde, KU Leuven, Celestijnenlaan 200D, 3001 Leuven, Belgium; Email: saskia.prins@kuleuven.be
John Telting: Nordic Optical Telescope, Rambla José Ana Fernández Pérez 7, 38711 Breña Baja, Spain; Email: jht@not.iac.es
Roy Østensen: Department of Physics, Astronomy, and Materials Science, Missouri State University, Springfield, MO 65804, United States of America; Email: roy@ostensen.eu

ecliptic equator will be sampled with considerably shorter time coverage.

Since the mid-1990s (Kilkenny et al. 1997), short-period p-mode variable sdB stars have been found abundantly from ground-based photometric surveys (see *e.g.*, Østensen et al. (2010)). In contrast, only one such star consistent with the picture of a traditional p-mode pulsator has been observed during the main mission of Kepler, with more than 3 years of continuous coverage (Baran et al. 2012; Zong et al. 2016). Only long coverage will let us examine the rotational splitting of slow rotators, and the slow changes in those frequency splittings. For that reason, and because only few (hybrid) p-mode pulsators were found with Kepler, we started a spectroscopic and photometric minisurvey around the ecliptic North pole, aiming to find new (pulsating) sdB stars that can later be observed with TESS for long observing periods.

There are only two known (p-mode) sdBV around the northern ecliptic pole ($\beta > 78$): LS Dra ($g' = 15.9$) and V366 Dra ($g' = 16.7$), see Østensen et al. (2010). There are two known sdB pulsators in the northern polar rim: LM Dra and J1938+5609 (see Table 1). In this paper we describe our efforts to find more. We used colours computed from GALEX (Bianchi et al. 2014) UV photometry and optical B-band photometry to make an sdB candidate list, and obtained spectroscopic classifications for all. For the most suitable (see Section 3) sdB stars we obtained time-resolved photometry to look for p-mode pulsations.

2 The new survey sample

Apart from the known sdB pulsators listed in Table 1, we know from the sdB catalogue compiled by Geier et al. (2017) that there are 44 sd/sdB/sdOB stars in the northern ecliptic polar cap ($\beta >= 78$) and 3 sdO stars. Among these are stars with composite spectra (typically sdB + F/G spectral types). Similarly, we know of 37 sd/sdB/sdOB stars and 4 sdO stars in the northern ecliptic rim ($73 <= \beta <= 78$). Most of these were sampled for short-term variability by various investigators, but no p-modes were found from the ground. Since this known sample of sdB stars is likely to contain some unknown g-mode pulsators (with periods longer than 15 minutes), all of these are good targets for the 2-minute cadence of TESS.

In order to augment the sample of sdB stars around the northern ecliptic pole, and to find more p-mode sdB pulsators for TESS, we formed a new sample of sdB-star candidates using GALEX FUV and optical B magnitudes and colours. Our original colour constraint was set to FUV – B ≤ 1, while after re-examining the B-band photometry of some of the targets, and subsequently setting the brightness cut at B=15.8, our resulting sample obeys the following constraints. For the northern polar cap our new sample consists of 37 candidates with $-0.84 \leq (FUV - B) \leq 1.16$ and $13.6 \leq B \leq 15.8$. For the polar rim we have 38 new candidates with $-0.93 \leq FUV - B \leq 1.24$ and $14.0 \leq B \leq 15.6$, and one new candidate with the outlying colour $FUV - B = 1.71$.

There is no overlap between our new sample and the catalog of known sdB stars by Geier et al. (2017).

Table 1. Overview of known sdB pulsators in the ecliptic northern polar cap and polar rim. Ref 1: Østensen et al. (2010), ref 2: Holdsworth et al. (2017).

Northern polar cap				
Name		Type	g′ mag	Ref
LS Dra	= HS1824+5745	sdBVp	15.9	1
V366 Dra	= SBSS1716+581	sdBVp	16.7	1
Northern polar rim				
Name		Type	g′ mag	Ref
LM Dra	= PG1618+563B	sdBVp	13.5	1
J1938+5609		sdBVp	13.3	2

3 Spectral classification

During the period of 22 Feb 2017 – 24 June 2017, we obtained classification spectra (R=1000, wavelength range 3450-5350 Å), with exposure times of 300 or 480 sec, using ALFOSC at the Nordic Optical Telescope (NOT), of all 76 sdB-star candidates. We used grism #18 and a 1 arcsec slit. While we were aiming for S/N>45, due to variable observing conditions the final S/N of the spectra range from 20 to 80. The data were reduced by the on-line IRAF-based reduction facility installed at NOT.

In order to estimate the effective temperature of the single-looking sdBs, we performed preliminary LTE-atmosphere fits following Edelmann et al. (2003). To look for suitable targets we used a lower limit of 28000 K to include the instability strip of hybrid and p-mode pulsators.

From the 37 GALEX-selected new targets in the polar cap we classify 12 targets as sdB+F/G composite-spectrum binaries, 4 as cool and single-looking sdBs, 11 as single-looking sdB p-mode candidates ($T_{eff} > 28000$ K), 1 as a blue horizontal branch (BHB) star, 1 as an sdO, and 1 as a He-sdOB. With respect to the catalog of known sdB stars (Geier et al. 2017) we increased the number of sdB stars by 59% in this area on the northern sky.

From the 39 GALEX-selected new targets in the polar rim we classify 3 targets as sdB+F/G composite-spectrum

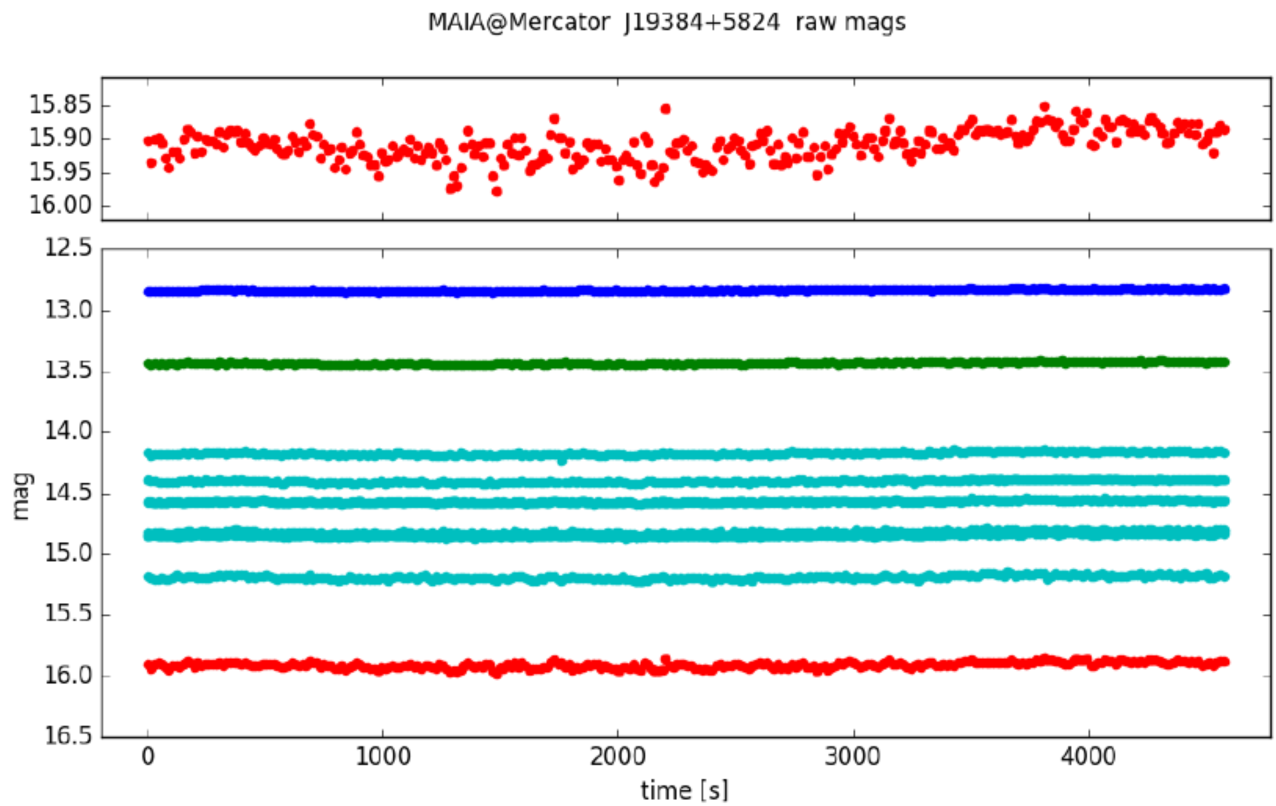

Figure 1. Time series of raw magnitudes of J19384+5824 and of comparison stars in the field of view of the Mercator telescope. The main target is depicted in red.

binaries, 6 as cool and single-looking sdBs, 3 as single-looking sdB p-mode candidates (T_{eff} > 28000 K), 1 as a blue horizontal branch (BHB) star, 1 as an sdO, and 1 as a He-sdB. With respect to the catalog of known sdB stars (Geier et al. 2017) we increased the number of sdB stars by 31% in this area. We list our spectral classifications in Table 2.

4 Time-resolved photometry

In order to find new p-mode variable sdBVs to add to the 20-second target list of TESS, we have obtained time-resolved photometry for most of the new sdB stars that have either composite sdB+F/G spectra or a single-star sdB spectrum with an estimated T_{eff} > 28000 K.

For this we mainly used the 1.2m Mercator telescope with the MAIA imager (Raskin et al. 2013) in frame-transfer mode, with 15 s exposure time while the CCD and its controller allow for 15.3-second cadence. Here we present the results of the g'-band channel of the instrument. In order to obtain a cycle time of 15.3 seconds, we could not use the full field of view (FOV) of MAIA of 9.4 × 14.1 arcmin, but applied a detector window corresponding to 9.4 × 4 arcmin. The observing time base per target was at least 60 minutes, and longer for fainter targets in order to aim for a Fourier detection limit of 2–3 mmag in the Fourier-frequency domain typical for sdB p-modes (typical periods of 2–10 minutes).

We also used the 2.6m NOT, using ALFOSC in g'-band imaging mode, FOV of 6.5 × 6.5 arcmin, with exposure time 15 s and cadence of 24 s. The observing time base per target was 60 minutes, aiming for a Fourier detection limit of 2 mmag.

We used Sextractor in PSF-fitting mode (Bertin and Arnouts 1996), to extract magnitudes for the sdB targets and for all useful comparison stars in the FOV. We computed discrete Fourier transforms of the detrended raw magnitudes of the targets stars, and of the differential magnitudes determined using an optimal set of FOV comparison stars. It depends on the atmospheric conditions during the observations which of the two methods gives best results.

Unfortunately we did not find any of our new p-mode candidates in the TESS continuous northern viewing zone (polar cap) to pulsate with p-mode periods below 10 minutes, with a typical detection limit of 2–3 mmag in the Fourier domain.

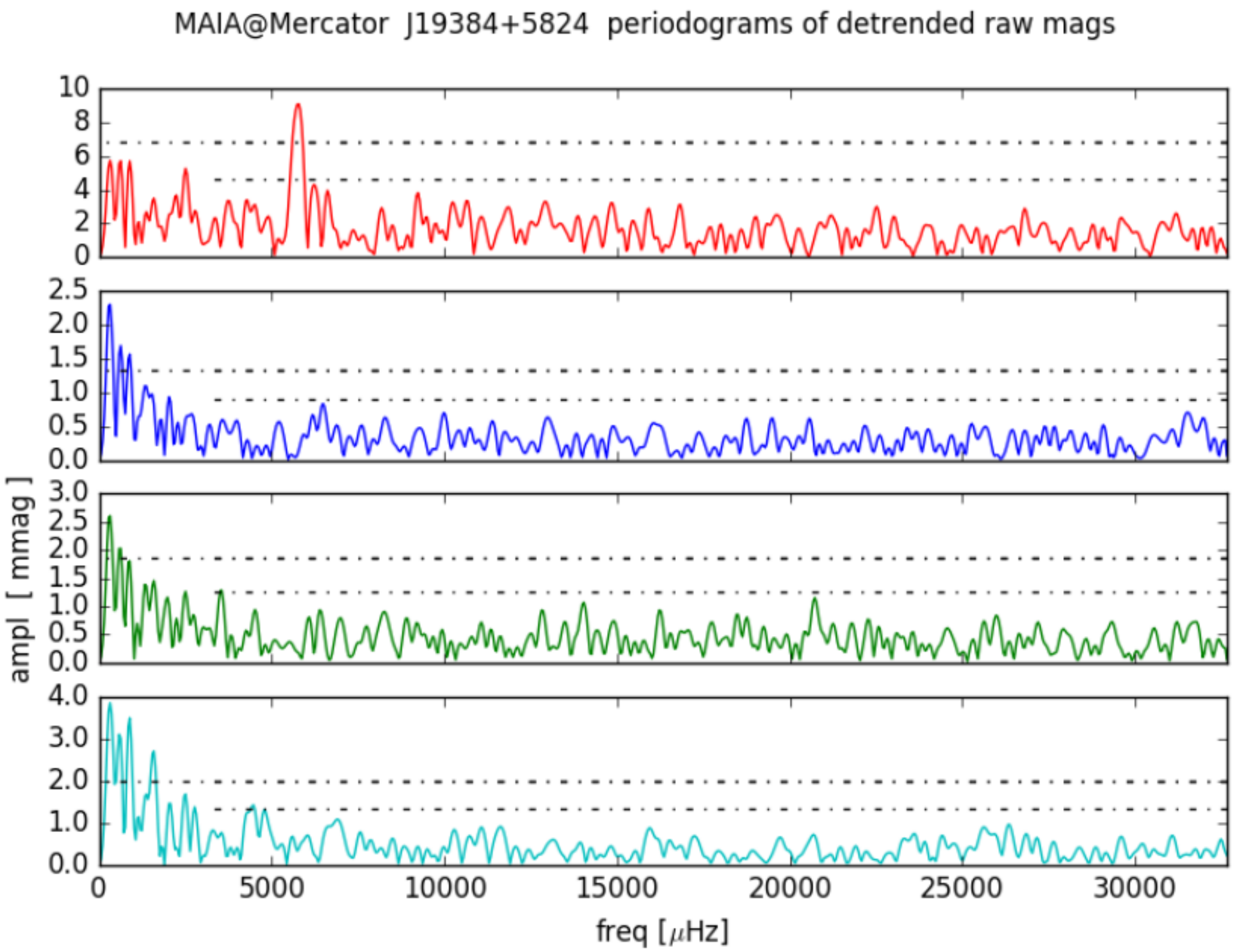

Figure 2. Periodograms of the light curves of Figure 1 after detrending, with fluxes of the faintest comparison stars summed together (bottom panel). The main target (top) is depicted in red. The 2.7σ and 4σ significance levels are indicated by dashed-dotted lines. A clear pulsation peak is visible in the periodogram of the target, at 5789.6 μHz equivalent to a period of 172 seconds.

Table 2. Spectral classifications of sdB candidates. Target name, RA (J2000), Dec (J2000), spectral classification, FUV mag , B mag, FUV–B colour, ecliptic latitude.

Target	J2000		SpClass	FUV	B	R	FUV-B	β
J19024+5803	19:02:26.97	58:03:33.1	sdB+F/G	14.569	13.6	14.0	0.97	78.9
J18426+6221	18:42:37.68	62:21:23.7	sdB	14.093	13.9	15.3	0.19	83.8
J19556+5645	19:55:38.62	56:45:31.2	He–sdB	14.596	14.0	14.9	0.60	73.4
J16575+8014	16:57:33.32	80:14:55.3	B	15.337	14.1	13.6	1.24	75.7
J18477+6151	18:47:43.94	61:51:02.7	sdB+F/G	15.185	14.2	14.3	0.99	83.0
J19161+5917	19:16:10.05	59:17:14.7	sdB+F/G	14.660	14.2	14.7	0.46	78.8
J16346+6139	16:34:38.63	61:39:46.6	Be	15.172	14.3	14.6	0.87	79.5
J16589+7907	16:58:56.13	79:07:46.3	sdB+F/G	14.548	14.3	13.6	0.25	76.7
J16092+7931	16:09:17.73	79:31:06.8	B	14.721	14.3	14.9	0.42	75.1
J16140+8208	16:14:03.60	82:08:08.8	sdF	14.577	14.3	14.4	0.28	73.2
J18164+6111	18:16:29.78	61:11:49.5	sdB+F/G	15.503	14.4	14.3	1.10	84.3
J19299+6947	19:29:55.48	69:47:45.4	sdB	14.514	14.4	14.5	0.11	81.1
J17567+5251	17:56:45.31	52:51:56.4	CV	15.192	14.4	14.0	0.79	76.3

Continued on next page

Table 2. ... continued.

Target	J2000		SpClass	FUV	B	R	FUV-B	β
J19217+5723	19:21:46.01	57:23:29.3	sdB	14.606	14.4	15.3	0.21	76.8
J17271+6145	17:27:10.84	61:45:27.4	CV	15.335	14.5	14.5	0.84	84.0
J17580+6008	17:58:04.61	60:08:01.2	sdB+F/G	15.000	14.5	14.1	0.50	83.6
J19029+6737	19:02:58.90	67:37:01.1	sdB+F/G	14.728	14.5	13.7	0.23	83.8
J20204+6255	20:20:25.51	62:55:41.9	sdB	14.936	14.5	15.4	0.44	74.8
J18300+5326	18:30:02.71	53:26:09.5	B	15.805	14.6	14.6	1.21	76.4
J18164+5423	18:16:29.34	54:23:11.8	sdB+F/G	15.417	14.7	14.4	0.72	77.7
J15535+8031	15:53:31.89	80:31:17.3	B	16.405	14.7	14.9	1.71	73.9
J18043+6215	18:04:23.60	62:15:36.3	sdB	14.423	14.8	15.7	−0.38	85.7
J18419+5338	18:41:58.05	53:38:17.6	DA	14.264	14.8	15.3	−0.54	76.1
J16554+7321	16:55:28.53	73:21:17.4	sdB+F/G	15.031	14.9	14.8	0.13	81.3
J17280+6938	17:28:01.32	69:38:38.6	DA	15.630	14.9	16.0	0.73	85.7
J17290+6516	17:29:03.88	65:16:12.7	sdB+F/G	15.170	14.9	14.9	0.27	86.6
J18167+6930	18:16:43.71	69:30:03.1	sdB+F/G	15.472	14.9	14.1	0.57	86.7
J16115+7843	16:11:32.60	78:43:20.1	CV	14.817	14.9	14.9	−0.08	75.7
J20063+6314	20:06:19.55	63:14:48.3	DC/DQ	15.217	14.9	15.7	0.32	76.4
J17577+5716	17:57:44.03	57:16:10.8	sdB+F/G	15.805	15.0	14.8	0.80	80.7
J18158+5535	18:15:52.27	55:35:36.1	B	16.159	15.0	15.0	1.16	78.9
J19563+6413	19:56:22.97	64:13:58.6	DA	15.123	15.0	15.8	0.12	77.8
J18101+5446	18:10:07.35	54:46:13.5	B	15.737	15.1	15.1	0.64	78.1
J18539+7046	18:53:57.81	70:46:24.6	sdB	15.348	15.1	15.6	0.25	83.6
J17512+5045	17:51:16.66	50:45:38.4	CV/QSO	15.892	15.1	14.6	0.79	74.2
J18087+5215	18:08:42.65	52:15:08.2	sdB	14.850	15.1	15.9	−0.25	75.7
J18483+5516	18:48:21.74	55:16:25.1	DAO	14.232	15.1	16.6	−0.87	77.3
J18544+5141	18:54:25.99	51:41:05.6	BHB?	15.731	15.1	15.2	0.63	73.7
J19047+5554	19:04:47.97	55:54:15.9	B	16.048	15.1	14.9	0.95	76.9
J19257+5657	19:25:47.29	56:57:02.6	sdB	15.254	15.1	16.1	0.15	76.2
J19436+6029	19:43:40.11	60:29:00.8	DA	15.562	15.1	16.1	0.46	77.1
J15110+7653	15:11:03.49	76:53:50.1	DA	14.973	15.1	15.2	−0.13	73.8
J20081+7328	20:08:08.53	73:28:26.6	sdB	15.683	15.2	15.9	0.48	77.3
J18067+5808	18:06:45.94	58:08:51.9	sdB	14.754	15.3	16.1	−0.55	81.6
J18119+6138	18:11:59.82	61:38:05.2	sdB	15.243	15.3	16.3	−0.06	84.9
J18233+6929	18:23:19.38	69:29:57.8	He−sdOB	15.045	15.3	16.0	−0.26	86.3
J19352+5650	19:35:15.57	56:50:49.4	DO	15.252	15.3	16.6	−0.05	75.3
J19471+5526	19:47:09.00	55:26:50.1	sdF	15.484	15.3	15.0	0.18	73.1
J17171+7245	17:17:06.32	72:45:57.7	sdOB	15.202	15.4	16.4	−0.20	82.8
J18316+5643	18:31:37.60	56:43:05.7	sdB+F/G	15.850	15.4	15.7	0.45	79.5
J19074+5957	19:07:26.21	59:57:24.2	sdB	14.691	15.4	16.4	−0.71	80.0
J19377+5900	19:37:46.01	59:00:31.2	DA	16.140	15.4	15.5	0.74	76.6
J15119+7459	15:11:56.06	74:59:20.8	?	14.842	15.4	14.1	−0.56	74.3
J16180+7729	16:18:03.25	77:29:20.6	sdB+F/G	15.636	15.4	15.2	0.24	76.8
J17120+8120	17:12:00.71	81:20:16.5	DAO	15.078	15.4	16.6	−0.32	74.9
J18137+6158	18:13:45.95	61:58:53.1	BHB	16.220	15.5	15.9	0.72	85.2
J19341+6441	19:34:09.23	64:41:06.4	sdB	15.595	15.5	16.3	0.10	80.2
J19375+5712	19:37:34.42	57:12:57.5	sdF	15.604	15.5	15.6	0.10	75.4
J20253+7900	20:25:22.99	79:00:04.3	DA	14.567	15.5	16.2	−0.93	74.1
J20026+7941	20:02:40.55	79:41:51.8	sdB	14.676	15.5	16.2	−0.82	74.6

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Table 2. ... continued.

Target	J2000		SpClass	FUV	B	R	FUV-B	β
J18215+5804	18:21:33.19	58:04:42.3	sdB+F/G	15.284	15.6	15.8	−0.32	81.2
J18320+6938	18:32:00.79	69:38:20.1	sdB	15.690	15.6	15.9	0.09	85.7
J19085+7424	19:08:34.54	74:24:47.7	sdB	15.150	15.6	15.8	−0.45	80.4
J19139+6438	19:13:54.54	64:38:06.2	sdB	15.219	15.6	16.3	−0.38	82.2
J19536+6851	19:53:38.96	68:51:41.2	DA	15.643	15.6	16.9	0.04	79.1
J20031+6613	20:03:09.08	66:13:23.9	sdO	15.593	15.6	16.1	−0.01	77.8
J19519+6031	19:51:54.01	60:31:00.3	sdB	15.074	15.6	16.6	−0.53	76.3
J19246+5505	19:24:39.67	55:05:54.9	DA	15.163	15.6	16.8	−0.44	74.7
J18039+5355	18:03:58.77	53:55:49.3	sdB	15.511	15.6	16.4	−0.09	77.4
J17297+5010	17:29:46.39	50:10:04.2	DA	16.061	15.6	16.4	0.46	73.2
J16454+6453	16:45:28.72	64:53:40.3	DA	14.862	15.7	16.2	−0.84	82.2
J17460+5726	17:46:04.45	57:26:54.7	sdO	14.923	15.7	16.8	−0.78	80.7
J18297+6002	18:29:47.77	60:02:30.6	sdB	15.131	15.7	16.1	−0.57	82.7
J19384+5824	19:38:27.97	58:24:15.4	sdB	14.773	15.8	15.5	−0.03	76.2
J17347+6629	17:34:42.21	66:29:58.4	sdB	15.598	15.8	17.0	−0.20	87.5
J18368+5727	18:36:52.70	57:27:42.4	sdB	15.478	15.8	16.7	−0.32	80.0

Concluded

In the northern ecliptic polar rim, which is to receive TESS coverage of up to 189 days, we did find one new pulsating sdBV: J19384+5824, B=15.8 (B-magnitude taken from GSC2.3). In Figure 1 we show the discovery light-curve obtained with the Mercator telescope, with the main target depicted in red. In Figure 2 we show the periodograms of the detrended raw magnitudes of the target and of the comparison stars. In these discovery data, a time series of 76 minutes, we find that the pulsation amplitude is 9.1 mmag (5.7 σ) with a period of 172 seconds, for a Fourier detection level of 2.7 σ = 4.3 mmag.

5 Concluding remarks

Even though TESS will observe with small telescopes (10cm diameter) we think that good light curves will be obtained for sdB stars. To estimate the FT noise level for TESS observations in the continous viewing zone (one year of observations), we scale the results from the Kepler main mission observations of KIC7668647 (Telting et al. 2014, three years of observations), while accounting for a ratio of telescope diameters of a factor 10, and assuming a similar filter band width and efficiency, and similar brightness in the Kepler and TESS bands. For KIC7668647, with Kepler magnitude of 15.4, and a noise level of 3.2 ppm in Fourier space, we would expect a Fourier noise level roughly 20 times higher (around 60 ppm) if it were observable by TESS in the continous viewing zone.

We have performed a mini survey to hunt for new (pulsating) sdB stars around the northern ecliptic pole, in order to be able to take full advantage of the TESS mission for seismology of sdB stars. Using FUV-B colours a new target sample was constructed, and using new low-resolution spectroscopy we identified 27 new sdB stars in the continuous viewing zone of TESS ($\beta > 78$), and 12 new sdB stars in the rim around it ($73 < \beta < 78$), altogether increasing the number of known sdB stars by 46% in the northern ecliptic pole area.

For those sdB stars with either T_{eff} > 28000K or with a composite sdB+F/G spectrum we obtained time-resolved photometry, in order to find new p-mode variables for the dedicated 20-sec cadence seismology mode of TESS. We found only one rather faint new p-mode pulsator, J19384+5824, with a pulsation frequency of 5789.6 μHz (equivalent to a period of 172 seconds).

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