The Astronomical Journal, 160:32 (22pp), 2020 July https://doi.org/10.3847/1538-3881/ab952c

New Beta Cephei Stars from the KELT Project

Jonathan Labadie-Bartz[1,2,3], Gerald Handler[4], Joshua Pepper[3], Luis Balona[5], Peter De Cat[6], Daniel J. Stevens[7,8], Michael B. Lund[9], Keivan G. Stassun[10,11], Joseph E. Rodriguez[12], Robert J. Siverd[10], David J. James[12,13], and Rudolf B. Kuhn[5,14]

[1] Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo, Rua do Matão 1226, Cidade Universitária, 05508-900 São Paulo, SP, Brazil; jbartz@usp.br

[2] Department of Physics & Astronomy, University of Delaware, Newark, DE 19716, USA

[3] Department of Physics, Lehigh University, 16 Memorial Drive East, Bethlehem, PA 18015, USA

[4] Nicolaus Copernicus Astronomical Center, Bartycka 18, 00-716 Warsaw, Poland

[5] South African Astronomical Observatory, P.O. Box 9, Observatory, 7935, Cape Town, South Africa

[6] Royal Observatory of Belgium, Av Circulaire 3-Ringlaan 3, B-1180 Brussels, Belgium

[7] Center for Exoplanets and Habitable Worlds, The Pennsylvania State University, 525 Davey Lab, University Park, PA 16802, USA

[8] Department of Astronomy & Astrophysics, The Pennsylvania State University, 525 Davey Lab, University Park, PA 16802, USA

[9] Caltech IPAC—NASA Exoplanet Science Institute 1200 E. California Avenue, Pasadena, CA 91125, USA

[10] Department of Physics and Astronomy, Vanderbilt University, Nashville, TN 37235, USA

[11] Department of Physics, Fisk University, 1000 17th Avenue North, Nashville, TN 37208, USA

[12] Center for Astrophysics | Harvard & Smithsonian, 60 Garden Street, Cambridge, MA 02138, USA

[13] Black Hole Initiative at Harvard University, 20 Garden Street, Cambridge, MA 02138, USA

[14] Southern African Large Telescope, P.O. Box 9, Observatory, 7935, Cape Town, South Africa

Received 2019 July 25; revised 2020 March 27; accepted 2020 April 16; published 2020 June 18

Abstract

We present the results of a search for Galactic β Cephei stars, which are massive pulsating stars with both pressure modes and mixed modes. Thus, these stars can serve as benchmarks for seismological studies of the interiors of massive stars. We conducted the search by performing a frequency analysis on the optical light curves of known O- and B-type stars with data from the Kilodegree Extremely Little Telescope exoplanet survey. We identify 113 β Cephei stars, of which 86 are new discoveries, which altogether represent a 70% increase in the number currently known. An additional 97 candidates are identified. Among our targets, we find five new eclipsing binaries and 22 stars with equal frequency spacings suggestive of rotational splitting of nonradial pulsation modes. Candidates for runaway stars among our targets and a number of interesting individual objects are discussed. Most of the known and newly discovered β Cephei stars will be observed by the Transiting Exoplanet Survey Satellite mission, providing by far the most comprehensive observational data set of massive main-sequence pulsating stars of sufficient quality for detailed asteroseismic studies. Future analysis of these light curves has the potential to dramatically increase our understanding of the structure of stellar interiors and the physical processes taking place therein.

Unified Astronomy Thesaurus concepts: Beta Cepheid variable stars (148); Asteroseismology (73); Stellar oscillations (1617); Multi-periodic variable stars (1079); Pulsating variable stars (1307); Short period variable stars (1453); Early-type variable stars (432); Light curves (918); Light curve classification (1954); Surveys (1671); B stars (128)

Supporting material: data behind figure, machine-readable tables

1. Introduction

Despite recent advances, there remain uncertainties regarding the evolution and structure of massive stars. Currently, the roles of rotation, internal angular momentum distribution and transport, and internal mixing are not satisfactorily understood in the context of stellar evolution. Mixing of material into the hydrogen-burning stellar core ("convective overshooting") considerably affects the main-sequence lifetime of massive stars (e.g., Mowlavi & Forestini 1994) and causes surface abundances to change. Rotation influences this process, but the details remain poorly constrained (e.g., Maeder 1987). Differential rotation is sometimes measured in massive stars, but there are significant uncertainties regarding the coupling between the stellar core and envelope, and the degree to which angular momentum is transported from the core outward (Aerts et al. 2017). Strong surface magnetic fields exist in about 10% of massive stars (e.g., Grunhut et al. 2017; Sikora et al. 2019), which adds further complications. These fields influence stellar structure and evolution in important ways, including causing more rapid spin-down through magnetic braking (Meynet et al. 2011), suppressing mass lost through winds (Petit et al. 2017), and possibly diminishing the amount of convective overshooting (Briquet et al. 2012). To make further progress in understanding the nature of massive-star interiors, studies of massive stars that are amenable to seismology are needed.

As a class, β Cephei stars are massive, non-supergiant variable stars with spectral type O or B with photometric, radial velocity, and/or line profile variations caused by low-order pressure and gravity mode pulsations (p and g modes; Stankov & Handler 2005). Most of them are early B-type stars (roughly spanning spectral types B0–B2.5) with masses between 8 and 17 $M_{\odot}$. They are characterized by their relatively high-frequency pulsations (with typical periods between 2 and 7 hr) driven by the κ mechanism (Moskalik & Dziembowski 1992; Dziembowski et al. 1993).

The pulsational properties of β Cephei stars make them particularly well-suited for detailed asteroseismic studies. They tend to oscillate in several nonradial modes and sometimes have both p- and g-mode pulsations (e.g., Handler 2009). Because the frequency of each oscillation mode is determined by the physical conditions in the region in which it propagates, measuring these frequencies (and knowing their geometries on the stellar surface and the interior) translates to constraints on the physical conditions in the stellar interior. Seismic modeling of a small number of β Cephei stars has already yielded significant progress. Quantitative estimates of the core overshooting parameter have been derived for the β Cephei star HD 129929 (Aerts et al. 2003), which is also found to undergo nonrigid internal rotation (Dupret et al. 2004). Similar analyses have been done for β CMa (Mazumdar et al. 2006), δ Ceti (Aerts et al. 2006), 12 Lac (Handler et al. 2006; Dziembowski & Pamyatnykh 2008), V2052 Oph (Briquet et al. 2012), and a few others. Asteroseismology can also be used to measure stellar mass and radius, the surface rotation rate, and the evolutionary stage. Given that these stars are fairly massive, they are correspondingly rare: only about 250 such pulsators are known in our Galaxy (Stankov & Handler 2005; Pigulski & Pojmański 2008; F. Kahraman Aliçavuş 2016, personal communication).

The technique of asteroseismology relies on having a long-enough time baseline and a high-enough cadence and precision to identify the periodic signals of as many pulsation modes as possible. Space-based time-series photometry provides excellent data for these purposes. Although current and past space observatories have been successfully used for asteroseismology, only a small number of the high-mass β Cephei–type stars have been observed, and subsequently modeled, to date in this capacity (e.g., HD 180642 with CoRoT, Aerts et al. 2011; δ Ceti with Microvariability and Oscillations of Stars, Aerts et al. 2006; β Cen with BRITE, Pigulski et al. 2016)—there have been no comprehensive asteroseismic studies of this class of star.

The recently launched NASA Transiting Exoplanet Survey Satellite (TESS) mission (Ricker et al. 2014) is a nearly all-sky photometric survey with a photometric precision similar to that of the Kepler mission, but designed primarily to target stars some five magnitudes brighter. The photometric precision for a 10th magnitude star in one hour of TESS observations is estimated to be 200 ppm. While the primary science goal of the TESS mission is to discover transiting exoplanets, TESS light curves will be leveraged for a host of ancillary science efforts. Among these is the use of TESS data for an asteroseismic study of a large sample of β Cephei stars. To maximize the scientific yield, we are mining ground-based time-series photometric data to identify as many β Cephei stars as possible, to then be targeted by TESS for the purpose of asteroseismology. The TESS light curves of these stars will allow for detailed modeling of an unprecedented number of massive stars across a wide range of parameter space and will result in important constraints on theories regarding stellar structure and evolution.

In Section 2, we introduce the data used for our search, and the cuts used to narrow down the number of light curves to be analyzed. Section 3 describes the methods by which the data are analyzed. Our results are presented in Section 4, and a summary of our main conclusions is given in Section 5.

2. Data

The source of data used for our analysis is the Kilodegree Extremely Little Telescope (KELT) survey (Pepper et al. 2007, 2012). KELT is a photometric survey designed to discover transiting exoplanets orbiting stars in the magnitude range of $7 \lesssim V \lesssim 12$, with light curves for $\sim$4.9 million objects across $\sim$70% of the sky. The KELT survey employs two small-aperture (42 mm) wide-field ($26° \times 26°$) telescopes, with a northern location at Winer Observatory in Arizona in the United States, and a southern location at the South African Astronomical Observatory near Sutherland, South Africa. The effective passband is roughly equivalent to a broad R-band filter. With time baselines of up to 10 yr, a typical cadence of 30 minutes, and the precision to detect periodic signals down to approximately one to a few millimagnitudes, KELT light curves are well-suited to the detection of the periodic variability exhibited by β Cephei stars. The utility of KELT light curves to detect periodic oscillations in brightness was demonstrated by Cargile et al. (2014), Wisniewski et al. (2015), and Labadie-Bartz et al. (2017).

The goal of this work is the identification of new and candidate β Cephei stars. We begin with a star catalog that is used internally by the TESS target selection committees and maintained by one of us (L.B.; http://redcliffcottage.co.za/tess/), which contains stars brighter than 12th magnitude, and includes literature spectral types compiled from Skiff (2014) and photometric magnitudes in multiple passbands. All stars with a spectral type between O4 and B7 were selected. These 16,682 stars were then cross-matched to the KELT catalog of all fields reduced until 2016 February, resulting in 5840 matches. The KELT light curves of these 5840 O4–B7 stars are then analyzed for the signatures of β Cephei pulsation. The range of stellar brightnesses covered by KELT coincides very well with that of a large fraction of TESS targets, which makes KELT an extremely valuable source to preselect targets to be later observed from space.

3. Analysis

For each of the 5840 light curves for stars with spectral types between O4 and B7, a Fourier periodogram was computed in the range of 0–20 day^{-1}. To perform a preselection of candidates, each periodogram that had the strongest peak in the range of known β Cephei star pulsation frequencies ($f \gtrsim 3$ day^{-1}) was visually inspected, as were the light curves phased to twice the recovered period. On the basis of these plots, and in doubtful cases based on additional frequency analyses, all stars that had either untrustworthy data, showed no significant variability, exhibited obvious binary or rotational light curves, and those whose periodograms could be explained solely by reduction imperfections (residual differential color extinction) were rejected. Those that were not rejected were scrutinized, and a few more obvious nonpulsators were removed. The remaining stars were preliminarily classified into β Cephei stars and candidate β Cephei stars.

Objects preclassified as β Cephei stars either showed periodic variability at a single frequency between 4 and 14 day^{-1} and have spectral types between B0 and B2, or showed periodic variability at multiple frequencies in the range 4–14 day^{-1} (suggesting they are multi-mode pulsators), but without further spectral type cuts. The choice of the low-frequency limit near 4 day^{-1} is justified by this being approximately the expected value of the radial fundamental mode frequency at the end of the main sequence in the β Cephei mass range, but also as a reasonable cutoff to discriminate against close binaries, rotational variables, or other pulsators.

The group preclassified as candidates contains stars that do not fall in the previous category, but have primary frequencies in the range of 3–22 day^{-1} (sometimes with multiple significant frequencies), and stars where only one frequency is detected (if their spectral type is outside the range of B0–B2) and the light-curve shape suggests a pulsational origin for the variability. This group likely contains genuine β Cephei stars but is certainly contaminated by other types of variable stars.

Other types of variable objects are found near β Cephei stars in the H-R diagram. Slowly pulsating B (SPB) stars tend to have spectral types between approximately B2–B9 and pulsate in relatively lower frequency g modes compared to β Cephei stars (De Cat 2002). However, very rapid rotation can lead some of these g modes to attain frequencies in the β Cephei domain (Salmon et al. 2014). There are also "hybrid" pulsators, oscillating in low-frequency g modes and high-frequency p modes simultaneously (Handler et al. 2002; De Cat et al. 2007; Pigulski & Pojmański 2008; Handler 2009). Classical Be stars span the entire spectral range of B-type stars (even extending into the O and A types), and can also be pulsators, often with multiple modes. They are very rapidly rotating as a class, on average rotating at about 80% of their critical (or breakup) velocity, and occasionally eject matter to form a circumstellar disk (Rivinius et al. 2013). The rapid rotation of classical Be stars can complicate the observed frequency spectrum (e.g., Kurtz et al. 2015), as can variability in the circumstellar environment (Štefl et al. 1998; Rivinius et al. 2016). Whereas some of the hotter Be stars can also be β Cephei pulsators, some of their gravity modes may also attain sufficiently high frequency to constitute a source of confusion.

The pixel scale of KELT is large (23″), and some stars in our sample lie in relatively crowded fields near the Galactic plane. As a result, light from other sources will sometimes be blended with the target star in the aperture used by KELT. If a neighboring star is blended with the target star and is variable, then this variability can appear in the light curve for the target. This contamination issue is addressed by first inspecting images of high spatial resolution (DSS and Two Micron All Sky Survey images) that show a patch of sky in the vicinity of the target and identifying any neighboring sources that are close enough to the target to be blended in KELT photometry. Then, difference images of the pixels in the KELT images are analyzed to determine precisely which pixels are the source of the detected variability. This blending analysis can robustly identify contaminating sources further than two KELT pixels away from the target and is effective at determining which source is variable in somewhat crowded fields. Through this analysis, we reject three stars that would have otherwise been classified as candidates. Additionally, three stars that were preselected as β Cephei were found to have their signal originating in a neighboring star that could possibly be of a spectral type consistent with β Cephei pulsation, and this variable source is included in our list of candidates. Another consequence of blending is that the measured amplitude of variability will be diluted proportionally to the amount of flux from neighboring sources that leaks into the aperture used to extract the target star light-curve. Therefore, all photometric amplitudes quoted here should be understood as a lower limit, although this effect is small in practice for the majority of stars in our samples. Because it is primarily the frequency (and spectral type or number detected of modes) that was used to preclassify the stars in this work and not the photometric amplitude, the amplitude suppression is not a significant concern for the purposes of classification. Of course, there can be cases where the amplitude suppression is so severe that we would miss the stellar signal completely. Another important cause of amplitude suppression is CCD saturation for bright stars. In this case, only nonsaturated pixels would carry the stellar signal, but the total flux would include the saturated ones, resulting in a net decrease in amplitude in units of magnitude.

Keeping in mind the considerations above, the stars that survived the preselection (148 objects preliminarily identified as β Cephei stars, and an additional 90 candidates) were frequency-analyzed by hand. To this end, we used the PERIOD04 software (Lenz & Breger 2005). This package applies single-frequency Fourier analysis and simultaneous multifrequency sine-wave least-squares fitting. It also includes advanced options such as the calculation of optimal light-curve fits for multiperiodic signals including harmonic, combination, and equally spaced frequencies.

It is important to discuss under which conditions the detection of a variability signal is considered significant. The classical approach is to evaluate the signal-to-noise ratio (S/N) of a peak in the Fourier amplitude spectrum. We computed the noise level as the average amplitude in a 2 day^{-1} interval centered on the frequency of interest, i.e., considering possible additional stellar signals as noise at each prewhitening step. For ground-based campaign observations, $S/N > 4$ is usually considered a safe choice (Breger et al. 1993). On the other hand, in their search for β Cephei stars in ASAS data whose basic characteristics should be similar to those of our data sets, Pigulski & Pojmański (2008) adopted a more conservative criterion of $S/N > 5$. After careful examination of all our "borderline" cases that have the strongest signal within $4 < S/N < 5$, we decided to select $S/N > 5$ as the threshold for a star to be classified as a β Cephei pulsator, and a more relaxed $S/N > 4$ for candidates. At this stage, two stars were rejected because they were found to have met the S/N criterion only because of uncorrected artifacts in the data. Two further stars were rejected because of heavy crowding in the center of a cluster and likely data artifacts. Two more stars separated by 89″ showed the same variability frequencies, suggesting the same source of origin of the variations. Our blending analysis unambiguously shows this signal as coming from the brighter of this pair, and so this brighter source (ALS 7011) is selected as a candidate while the other is not.

Following that, the astronomical literature was checked for each of the individual stars. The position of these stars on the H-R diagram was determined, or at least estimated. In most cases, only a luminosity estimate from the Gaia DR2 parallax (Gaia Collaboration et al. 2016, 2018; Luri et al. 2018) and Galactic reddening determinations (Chen et al. 1998) could be obtained, which is usually sufficient to judge whether a given object is an early B-type star, but for some stars more information such as accurate multicolor photometry was available, mostly in the Strömgren system (Paunzen 2015); calibrations thereof (Napiwotzki et al. 1993) were applied to estimate T_{eff} and $\log g$. These criteria allowed us to identify stars with frequency spectra similar to β Cephei pulsators but with different stellar properties (such as δ Scuti and sdB pulsators). Based on these examinations, a few stars were moved in between the two groups (β Cephei stars and candidates), and 22 more were rejected. Such cases are

Table 1
β Cephei Stars Identified in This Work

ID	TIC ID	Freq. (day^{-1})	Amp. (mmag)	Num. modes	R.A. (2000)	Decl. (2000)	V (mag)	SP	Known?	Cluster?	Remarks
GSC 05124-02524	5076425	5.6387	36.3	4	18 35 53.63	−07 09 53.6	11.91	B3			M
HD 339003	10891640	6.7997	12.7	2	19 51 02.86	+25 57 15.4	9.93	B0.5III			M
HD 228699	11696250	7.5964	2.7	6	20 16 36.74	+37 41 12.8	9.46	B0.5III		IC 4996	M
HD 228690	11698190	5.8721	9.3	4	20 16 29.22	+37 55 21.2	9.29	B0.5V			A
HD 229085	13332837	6.8744	5.5	3	20 21 35.13	+38 36 47.8	9.8	B0V		NGC 6913	
HD 194205	13967727	4.4455	11.5	2	20 23 01.50	+39 20 40.5	9.08	B2III			A
HD 166331	25070410	7.4476	12.6	6	18 09 50.41	+10 46 26.5	9.39	B1.5III			A, M
CD-44 4876	29123576	7.7826	16.9	2	08 50 16.09	−45 23 02.5	10.94	B3/5			A
CD-45 4663	29585482	8.0717	5.5	1	08 52 29.74	−45 37 03.9	11.31	B1/4			
KK Vel	31921921	4.6373	14.8	1	09 07 42.52	−44 37 56.8	6.78	B1.5II	SH05		M
HD 227728	41327931	8.9711	1.2	2	20 06 49.54	+38 01 39.4	9.91	B2V			
HD 227977	42365645	7.8305	20.1	9	20 09 17.22	+37 30 07.9	9.68	B2III			A, M
HD 228101	42940133	6.2998	4.1	6	20 10 36.69	+37 27 30.6	8.49	B1IV			A
HD 228290	43881045	7.1226	7.5	1	20 12 20.66	+38 00 07.6	9.47	B1II			
HD 171305	44980675	5.1586	8.3	2	18 34 15.85	−04 48 48.8	8.72	B3III	PP08		A
HD 253021	45799839	7.5753	3.7	2	06 11 42.41	+21 37 58.7	10.16	B2			
ALS 10035	55702566	6.5490	6.3	4	18 53 57.85	−03 48 49.0	11.4	B0.5III			A
HD 178987	61516388	7.1466	7.6	2	19 12 59.64	−47 09 39.5	9.83	B2II	PP08		A, M
KP Per	65166720	4.9558	15.5[d]	5	03 32 38.98	+44 51 20.7	6.41	B2IV	SH05		A, M
HD 80279	75745359	7.2591	3.1	2	09 17 14.93	−46 16 30.2	9.45	B3II/III			A
ALS 8706	80897625	4.4060	4.6	2	06 06 28.15	+27 18 32.3	11.68	B1IIIe			A
TYC 2682-73-1	89756665	8.4179	3.8	2	20 05 57.78	+35 57 13.7	10.09	B1Vn			
HD 74339	93723398	5.2201	25.1	5	08 41 32.97	−48 01 30.7	9.38	B2III	PP08	IC 2395	A
CD-49 3738	93730538	5.4451	7.2	5	08 41 38.55	−49 35 52.9	9.69	B3			M
HD 86248	101423289	7.4897	6.2	6	09 56 33.26	−31 26 31.0	9.56	B3II	PP08		M
HD 190336	105517114	4.4571	21.7	6	20 03 18.68	+33 26 59.7	8.62	B0.7II-III	JSH09		M
HD 61193	123211175	7.1893	0.7	1	07 36 14.33	−42 04 56.2	8.2	B2Vn			
12 Lac	128821888	5.1789	7.6[d]	4	22 41 28.65	+40 13 31.6	5.22	B2III	SH05		A
16 Lac	129538133	5.8503	4.4[d]	3	22 56 23.63	+41 36 13.9	5.58	B2IV	SH05		A
HD 73568	141292310	4.5453	3.9	4	08 37 19.48	−45 12 26.0	8.36	B2III/IV	PP08		A
V836 Cen	159932751	6.9661	8.2[d]	8	14 46 25.76	−37 13 20.1	8.05	B3V	SH05		A, M
HD 225884	168996597	5.8220	2.9	5	19 48 15.12	+37 21 59.2	9.43	B5			A
HD 180642	175760664	5.4869	28[d]	1	19 17 14.80	+01 03 33.9	8.29	B1.5II	SH05		A
ALS 10186	180952390	6.6275	6.9	2	19 10 27.87	+02 07 32.3	11.67	B0.5V			
BD-02 4752	182714198	6.9779	7.0	2	18 49 25.06	−02 21 09.8	10.48	B0.5V			A
HD 173006	184874234	5.8779	35.1	1	18 43 26.26	−05 46 47.7	10.06	B0.5IV	PP08		A, M
HD 73918	185476952	8.2949	2	5	08 39 53.96	−30 29 59.9	9.7	B5III			
HD 33308	187483462	6.7355	0.9	1	05 11 07.96	+37 18 06.8	8.78	B3			
HD 172367	197332002	4.6882	8.5	2	18 40 09.71	−07 15 02.0	9.54	B2III			A
HD 332408	216976987	6.7778	2.5	1	19 42 07.98	+28 59 45.6	8.94	B2IV			A
ALS 9955	225687900	5.4431	23.9	2	18 45 34.43	−05 21 59.0	11.02	B1.5II			blend
BD+35 4258	232846315	7.5905	2.9	1	20 46 12.66	+35 32 25.6	9.46	B0.5Vn			M
HD 48553	234068267	5.5980	9.8	3	06 44 09.94	+02 23 29.6	9.08	B2III[a]	PP08		
HD 49330	234230792	10.8591	1.7	2	06 47 57.27	+00 46 34.0	8.95	B0nnep	H09		A
BD+57 614	245719692	6.9250	2.4	2	02 42 19.47	+58 05 30.0	10.69	B2III			A
BD+57 655	251196433	6.3730	6.5	3	02 53 28.41	+58 19 32.9	10.12	B2III		IC 1848	
ALS 7546	251250184	4.1204	16.3	5	02 55 36.68	+59 24 40.1	10.52	B3III		IC 1848	
ALS 7541	251250634	12.2005	1.9	2	02 54 57.47	+59 15 57.6	10.71	B2II		IC 1848	
HD 186610	251637508	5.4999	15.4	5	19 45 27.32	−03 09 06.6	9.7	B3n	PP08		M
ALS 6426	255974332	4.8242	10.7	5	00 59 49.44	+64 39 37.4	10.99	B2III			A
BD+56 488	264612228	6.2736	5.3	4	02 18 13.52	+57 21 30.9	10.1	B		NGC 869	M
V611 Per	264613043	5.8246	3.2	1	02 18 29.83	+57 09 03.1	9.35	B0.5I/V	SH05	NGC 869	A
V757 Per	264613619	4.0769	7.9	7	02 18 23.05	+57 00 36.7	8.43	B0.5III		NGC 869	A, M
HD 14014	264615882	4.8970	6.3	6	02 18 00.02	+56 13 57.3	8.86	B0.5V			
V665 Per	264731122	4.1275	20.4	5	02 18 48.02	+57 17 07.9	9.38	B2V	SH05	NGC 869	
HD 232874	266338052	5.7400	5.6	3	04 02 15.74	+53 45 11.8	8.92	B2III			A
ALS 12866	269228628	4.9919	44.6	3	23 17 13.70	+60 00 27.9	10.9	B0.5V			blend
ALS 13180	272922818	8.0279	35	1	23 47 51.68	+61 05 45.9	11	B0III			
HD 345370	279236955	8.0541	18.8	4	19 56 58.66	+21 19 49.7	9.75	B2III			
BD+68 1373	279659875	5.8301	3.8	2	23 22 50.65	+69 00 34.7	9.14	B2III			A
HD 343642	282529703	7.5007	11.2	2	19 01 46.01	+22 34 17.8	10.42	B3			
ALS 6392	283136444	7.9518	13.5	1	00 53 35.57	+60 47 08.7	10.32	B2IVnn			
HD 140543	287467101	5.6086	2.0	1	15 44 56.66	−21 48 53.9	8.88	B0.5IIIn			A, M

Table 1
(Continued)

ID	TIC ID	Freq. (day^{-1})	Amp. (mmag)	Num. modes	R.A. (2000)	Decl. (2000)	V (mag)	SP	Known?	Cluster?	Remarks
HD 339039	287690192	8.2695	9.5	5	19 48 46.69	+24 48 21.0	9.69	B1.5V			A
IL Vel	293680998	5.4598	28.7	4	09 17 31.15	−52 50 19.5	9.16	B2III	SH05		A, M
HD 81370	295435513	7.7088	10.1	2	09 23 17.73	−52 44 52.3	8.81	B0.5IVn			
HD 298411	296570221	6.0909	5.4	5	09 26 27.12	−52 09 33.0	10.53	B2/5			blend
HD 199021	297259536	11.3847	2.2	3	20 52 53.21	+42 36 27.9	8.49	B1IV			A
HD 231124	299821534	4.5432	30.9	4	19 18 52.34	+14 19 41.0	11.1	B2III			A, M
HD 232489	308954763	5.3769	7.5	7	01 39 12.85	+51 49 19.1	9.26	B5			A, M
HD 228365	311943795	8.2886	4.8	4	20 13 01.17	+41 01 42.1	9.97	B1V			A
HD 228461	312626970	4.7912	8.5	6	20 14 06.42	+38 14 38.4	9.56	B2II			M
HD 228463	312630206	6.0847	17.3	12	20 14 03.30	+37 45 30.1	9.6	B1V			A
HD 228456	312637783	8.1827	5.5	6	20 14 02.31	+36 48 07.0	10.2	B2IV			M
HD 228450	312639883	5.9532	4.7	5	20 13 59.02	+36 32 37.9	9.24	B0.5p			blend
BD+55 2899	314833456	4.1698	20.4	9	23 07 08.78	+56 00 21.1	10.29	B1IIIp			M
HD 236664	331782797	7.9873	33.9	1	01 13 41.79	+59 05 57.4	10.05	B0.5V			
ALS 12345	337105253	5.9461	15.9	2	22 21 51.49	+60 17 09.7	10.43	B3V			
BD+64 1677	338076483	4.7785	2.8	2	22 31 13.58	+65 27 58.5	9	B2III-IV			A
HD 13338	347486043	4.6360	6.3	4	02 12 19.17	+57 56 27.1	9.17	B1III			A, M
BD+54 490	347684339	5.8959	3.5	2	02 14 20.11	+55 03 33.6	9.53	B1V			
BD+56 477	348137274	6.3488	6.1	3	02 17 04.49	+56 58 07.2	10.02	B		NGC 869	M
BD+56 537A	348231245	6.8061	2.3	1	02 19 39.13	+57 16 13.2	10.34	B2V[b]		NGC 869	blend
BD+56 540	348232246	7.7903	3.2	1	02 19 42.66	+56 58 45.8	10.28	B0.6V		NGC 869	blend
BD+56 560	348443241	5.1899	4.4	1	02 21 32.75	+57 34 07.1	10.24	B2III		NGC 884	A
HD 14357	348506748	4.6030	2.5	6	02 21 10.44	+56 51 56.4	8.52	B2II/III		NGC 884	A, M
BD+56 584	348607991	4.5816	3.8	3	02 22 29.86	+57 12 28.8	9.61	B0.7I[c]	S13	NGC 884	
ALS 7146	348668924	5.5486	6.2	2	02 23 14.38	+58 09 49.5	10.56	B1V			
NGC 884 2579	348671634	4.4147	3.9	2	02 22 50.28	+57 08 50.7	11.91	B3e	S13	NGC 884	
HD 160233	349332755	7.6411	4.1	1	17 38 40.64	+04 20 09.8	9.04	B2IV/V			M
HD 174298	357853776	10.2571	5.3	1	18 48 55.63	+24 03 21.1	6.53	B1.5IV	KE02		
HD 344775	360063836	5.1399	7.4	6	19 43 09.76	+23 26 15.7	10.36	B1III		NGC 6823	A
HD 344894	361324132	6.5681	9.5	8	19 45 48.21	+23 11 42.7	9.61	B2IIIn			A, M
BD+58 241	370128780	4.8896	1.6	1	01 27 54.88	+59 14 08.9	9.91	B1V			A
V1143 Cas	372724051	5.2636	19.8	3	01 43 35.58	+64 02 06.8	10.86	B1	HM11	NGC 637	A
BD+60 416	374038418	5.7341	1.6	1	02 01 44.21	+61 03 13.0	9.61	B0.5III			
HD 350202	377088966	4.2299	9.5	3	19 38 41.60	+20 07 46.8	10.3	B1.5III			
HD 344842	378429048	6.5255	6.3	1	19 41 44.28	+21 29 03.5	9.78	B2III			
BD+62 258A	389532846	4.3293	8.3	2	01 30 06.14	+63 34 57.2	10.32	B1IV			
ALS 10538	391082033	9.3965	24.3	1	19 48 53.68	+19 58 07.0	11.33	B1V			
HD 30209	391836737	6.1933	12.2	2	04 47 30.26	+42 19 11.8	8.39	B1.5V			A
ALS 10332	392965683	6.0443	12.9	3	19 33 11.45	+01 56 44.2	12.07	B2			M
V372 Sge	393662110	6.0859	17.5	6	20 09 39.59	+21 04 43.6	8.34	B0.5IIIe	H05		A, M
NGC 6634	399436828	5.1536	5.6[d]	1	01 46 39.00	+61 14 06.1	11.06	B5	SH05	NGC 663	A, blend
CD-47 4562	400852783	6.8803	8.6	3	08 58 23.73	−48 11 08.7	10.9	B5V			
BW Vul	419354107	4.9741	27.6[d]	2	20 54 22.40	+28 31 19.2	6.54	B2III	SH05		A, M
ALS 6331	421117635	5.2183	4.5	2	00 45 35.06	+63 21 07.4	10.55	B0.5V			
HD 14645	445619007	5.2131	1.7	1	02 24 01.13	+58 19 25.9	9.43	B0IVnn			A
HD 344880	451932686	9.4929	1.3	1	19 45 42.31	+23 59 04.0	9.34	B0.5IIInn		Roslund 2	A, M
HD 338862	452018494	8.6542	4.0	1	19 46 18.34	+27 27 37.4	9.92	B2V			
CD-44 4596	461607866	6.6530	5.6	7	08 36 59.62	−45 17 23.1	9.3	B1III			M
HD 86214	469221047	4.4426	12.4	2	09 54 58.43	−59 49 46.7	9.21	B1III	PP08	NGC 3114	A
HD 86162	469223889	7.8416	1.1	3	09 54 47.75	−59 16 03.3	9.21	B01/IV			A

Notes. Columns include the ID, TIC number, information about the primary frequency and number of modes, coordinates, V-band magnitude and spectral type, a citation if the star is known to be a β Cephei star, a note if the star is a known cluster member, and information about remarks. Stars labeled "M" in this column are discussed in the main text, stars labeled "A" are commented upon in the Appendix, while "blend" indicates that there are bright nearby sources contributing flux in the aperture used by KELT (and likewise with TESS). The citations for known β Cephei stars are as follows: SH05 = Stankov & Handler (2005), H05 = Handler (2005), PP08 = Pigulski & Pojmański (2008), H09 = Huat et al. (2009), JSH09 = Jurcsik et al. (2009), HM11 = Handler & Meingast (2011), S13 = Saesen et al. (2013). Other information is compiled from the literature and is available at http://redcliffcottage.co.za/tess/. Spectral types are from Skiff (2014) unless otherwise indicated.

[a] Liu et al. (2019).

[b] Spectral type corresponds to the temperature reported in Huang & Gies (2006).

[c] Currie et al. (2010).

[d] Amplitudes may be largely suppressed.

(This table is available in machine-readable form.)

discussed in the notes to Tables 1–3. We finally classify 113 stars as β Cephei and 97 as candidates; 27 and 3 of those, respectively, have been reported in the literature before.

4. Results

4.1. New and Candidate β Cephei Systems

Basic information on the stars investigated is listed in Tables 1–3 sorted by increasing the TESS Input Catalog (TIC; Stassun et al. 2018) identifier. In addition to a primary identifier, the primary frequency and its photometric amplitude, the number of independent modes detected in the β Cephei domain, coordinates, the *V*-band magnitude, and the spectral type are listed. All reported amplitudes are the semiamplitudes. The next column indicates if the star is previously known to belong to the β Cephei class (showing the appropriate reference), followed by a column that indicates whether the star is a known cluster member. Remarks are listed next, which are especially useful if the target has close visual companions (which is important input for TESS target selection). The amplitudes listed in Tables 1 and 2 should be viewed as lower limits, because light from neighboring sources can blend with the target star, acting to dilute the signal, as discussed in Section 3. This dilution is strongest in crowded fields. The sky positions of the β Cephei and candidate stars identified in this work are shown in Figure 1. KELT does not uniformly observe the sky. Some regions have no data, and there can be a large range in the number of observations from field to field. The distributions in Figure 1 are some convolution of KELT sampling and the intrinsic distribution of β Cephei and candidate stars across the sky.

In Figure 2, we show the distribution of the primary detected frequency and its photometric amplitude, separated by spectral type bins. The overall median primary frequency is 6.04 day^{-1} for the β Cephei group and 5.53 day^{-1} for the candidates, and the median amplitudes are 6.5 mmag and 3.0 mmag, respectively. Figure 3 shows histograms of the frequency, amplitude, number of modes, and *V*-band brightness for the β Cephei and candidate stars. There are no apparent correlations between frequency, amplitude, and number of detected modes. The frequency distribution is similar to that of Stankov & Handler (2005), where 93 β Cephei stars are analyzed from inhomogeneous data sets in the literature.

In Figure 4, we show the detection level (S/N = 4) for pulsations in the β Cephei domain for the stars with detections. Despite a few outliers (mostly blended faint stars), it is satisfactory, with a median detection level of 1.15 mmag and a mean value of 1.8 mmag. This is approximately a factor of 3 lower than that of Pigulski & Pojmański (2008), largely due to higher photometric precision and greater number of observations. As can be expected, there is a dependence of detection level on stellar magnitude, with median levels of 0.7 mmag for $8 < V < 9$, 1.0 mmag for $9 < V < 10$, 1.3 mmag for $10 < V < 11$, and 2.3 mmag for $V > 11$. The brightest stars we could detect variability for are the known β Cephei pulsators 12 and 16 Lac; the faint end lies at $V = 12.1$, which is however more of a limitation in the availability of spectral classification (the major historical star catalogs have a magnitude limit of $V \approx 10$) than of the KELT time-series data.

To demonstrate how this work can be applied in the context of new and upcoming data from the NASA TESS mission, Figure 5 shows the frequency spectrum of a typical and arbitrarily chosen β Cephei star from this work, with the upper panel displaying the spectrum computed from KELT data and the lower panels showing the results from TESS 2 minute cadence data. The two significant frequencies identified in this work from the KELT data are indicated with red triangles. These are also the most significant frequencies in the TESS data. Additional significant frequencies found in the TESS data are indicated with red tick marks. The lowermost panel zooms in on these peaks. A comprehensive analysis of available TESS data for the stars in our sample is beyond the scope of this work.

4.2. Interesting Systems

During the process of manual inspection for each new and candidate β Cephei systems, a number of systems show interesting features in addition to the periodic photometric signals characteristic of β Cephei stars. Here we identify and briefly discuss these cases.

4.2.1. Eclipsing Binaries

Approximately two-thirds of all stars with spectral types that would put them into the β Cephei domain are located in binary systems (e.g., Chini et al. 2012). Therefore, it can be expected that some of our targets show eclipses. Indeed, we found five objects that can confidently be classified as eclipsing binaries; others may also have binary-induced light variations and are mentioned in Appendix A. We show phase-folded light curves of the pulsation-removed light curves of the eclipsing binaries in Figure 6. We give ephemerides for the times of primary minimum in Table 4, in the form

$$\min_I = T_0 + E * P_{\rm orb}.$$

It should be pointed out that we classified only the first three stars in Table 4 as definite β Cephei pulsators; V447 Cep is among the candidates and HD 254346 among the rejected stars (see discussion in Section A.3).

Inspecting Figure 6, one notices a reflection effect in the light curve of HD 339003 in addition to the total eclipses. Given this light curve, the companion star must be of grossly different surface temperatures and smaller than the β Cephei pulsator. This means that it could either be an evolved star or belong to the recently proposed class of binaries by Moe & di Stefano (2015), containing a hotter main-sequence star and a cooler pre-main-sequence companion. HD 227977 is the shortest-period eclipsing system we have discovered. There is some evidence for geometrical (ellipsoidal) distortion of the primary. The star also has a rich pulsation spectrum, which is discussed in Section 4.2.4. HD 344880, on the other hand, is the longest-period system detected. Its orbit is obviously eccentric; the secondary eclipse lasts approximately four times as long as the primary eclipse. At $V = 7.46$, V447 Cep is the brightest new eclipsing system in our sample. The light curve appears to have a short phase of totality. Finally, HD 254346 also shows some evidence for a reflection effect, suggesting the presence of a secondary similar to that of HD 339003. Follow-up observations of all these stars are underway.

4.2.2. Stillstand Phenomenon

Some β Cephei stars show the "stillstand phenomenon," where the phased light curve shows a marked departure from a pure sinusoid. This rare phenomenon was first observed in a β

Table 2
Candidate β Cephei Stars

ID	TIC ID	Freq. (day^{-1})	Amp. (mmag)	Num. modes	R.A. (2000)	Decl. (2000)	V (mag)	SP	Known?	Cluster?	Remarks
HD 130195	92193	5.9765	1.6	1	14 47 31.92	−24 12 05.2	10.66	B6II[a]			M
TYC 4032-93-1	11158867	12.9147	2.0	1	01 58 38.10	+60 05 55.7	10.68	B3			A
TYC 3151-109-1	12249117	3.2891	3.0	1	20 17 43.65	+39 20 36.2	11.02	B5V			
ALS 7011	12647534	3.5118	5.7	1	02 15 24.53	+60 08 21.4	10.63	B0III		IC 1805	A
TYC 4050-1949-1	13839931	4.9542	3.9	1	02 30 19.98	+63 00 23.4	11.21	B7V		IC 1805	
TYC 3152-1307-1	13971092	9.6946	1.8	1	20 23 06.70	+38 49 15.6	10.62	B5		NGC 6913	A
HD 229171	13973539	3.5030	9.8	2	20 23 02.88	+38 27 20.8	9.38	B0.5IIIne		NGC 6913	A
CD-44 4871	28949811	13.127	1.2	1	08 50 09.76	−44 37 22.5	10.44	B1/3V			A
CD-46 4639	29036690	7.9231	0.7	1	08 49 39.68	−46 50 53.2	10.05	B3He			A
HD 76307	29598925	4.0110	4.9	1	08 53 28.33	−47 31 07.6	9.27	B2/3V			A
HD 76967	30569481	5.5781	5.2	2	08 57 54.00	−43 09 12.7	9.07	B3/5V			A
HD 192003	43301361	8.8495	3.0	2	20 11 16.85	+38 13 48.0	8.85	B2IV			A
ALS 7310	49721269	11.6465	1.3	2	02 33 43.00	+61 26 12.2	10.89	B2III		IC 1805	blend
TYC 4030-800-1	53709049	6.6171	7.3	2	01 11 12.15	+61 06 06.2	11.96	B5			A
BD+60 185	53961302	9.3790	1.5	1	01 13 05.69	+61 24 44.9	10.07	B7V			
BD+60 192	53968977	6.0136	9.5	1	01 14 30.29	+60 53 28.8	9.39	B5			A
HD 59259	60245596	6.4427	1.5	2	07 27 03.03	−44 10 40.2	9.95	B7/8V			
HD 18100	65516748	8.5481	1.6	1	02 53 40.81	−26 09 20.4	8.44	B5II/III			M
HD 237204	72696935	7.3604	13.1	1	04 00 23.28	+56 54 05.7	9.18	B2III			M
ALS 7879	72944678	3.3264	10.4	1	04 05 03.97	+56 13 06.3	11.79	B0p			
CD-45 4896	74197071	2.9677	4.7	3	09 08 50.23	−46 25 58.9	10.75	B7IV			A
HD 249179	78499882	3.7216	2.8	1	05 55 55.05	+28 47 06.4	10	B5ne			A
HD 67980	80814494	5.4045	2.3	1	08 08 44.04	−42 37 07.6	10.53	B7II			A
HD 74533	93923487	3.4462	1.2	1	08 42 28.52	−49 45 53.1	9.17	B5IV			
HD 74581	94000461	4.5450	15.1	1	08 42 47.92	−48 13 31.1	9.12	B6/8V		IC 2395	A
HD 248434	114249288	3.1336	4.0	1	05 51 38.52	+21 32 28.1	10.68	B5ne			
HD 60794	123036723	4.7814	4.3	1	07 34 06.86	−46 38 37.7	8.73	B3/5IIIe			
HD 62894	123828144	5.5254	1.0	1	07 44 15.56	−43 01 04.2	9.6	B7/9e			A
HD 183535	137489662	11.5196	1.6	1	19 28 38.16	+36 46 45.1	8.64	B5[b]			A, M
CD-44 4484	140309502	7.1391	3.2	1	08 30 53.51	−44 58 33.2	9.76	B5			A
HD 72090	140429699	6.1756	1.6	1	08 28 52.24	−48 11 25.6	7.84	B6V			
CD-44 4571	141190209	4.7460	1.5	1	08 35 52.40	−44 39 23.5	10.88	B5V			
CD-46 4437	141903641	5.2911	5.8[f]	2	08 40 35.29	−47 14 08.4	10.24	A2			A
HD 279639	143530557	3.2317	4.1	3	04 18 03.37	+38 57 47.0	11.06	B7			A
CPD-52 1713	145672806	3.1628	1.8	1	08 51 15.55	−53 27 03.0	11.3	B7e			A
HD 29332	155977294	4.4491	1.5	1	04 39 04.89	+41 15 00.0	8.71	B3ne			
TYC 2682-3173-1	172560369	8.9049	2.4	1	19 58 39.75	+37 00 23.3	11.72	B5			
CD-40 4269	184226481	3.7008	4.4	1	08 27 31.64	−41 24 48.4	10.35	B1/3			
HD 76554	190783321	15.5906	1.0	3	08 55 25.94	−41 04 43.9	8.33	B2Vne			A
BD+41 3731	193573033	3.5563	2.8	1	20 24 15.72	+42 18 01.4	9.84	B2/3ne		NGC 6910	
BD+41 3736	193608395	6.9397	2.6	2	20 24 33.90	+42 14 15.5	10.55	B6[c]		NGC 6910	
HD 258853	207045768	6.1398	2.5	1	06 31 14.87	+09 47 25.0	8.83	B3Vnn			A
HD 261172	220238856	3.7193	11.3	3	06 38 31.56	+09 25 12.2	10.1	B2III		NGC 2264	
HD 261589	220298408	6.0890	5.1	1	06 39 44.90	+06 27 35.6	11.43	B7		NGC 2244	
ALS 9974	226144867	12.676	6.4	1	18 47 15.69	−05 00 57.5	12.21	B1V			
TYC 746-578-1	231149746	9.0529	2.9	2	06 41 53.08	+08 24 17.7	11.68	B6/9			A
HD 262595	231177417	5.9053	5.9	1	06 43 06.31	+07 36 03.8	11.19	B3/5			
TYC 750-467-1	231236273	9.6644	2.3	1	06 44 16.00	+10 28 11.8	11.26	B6/9		NGC 2264	
HD 339483	244327575	3.7241	17.8	1	20 04 00.75	+26 16 16.8	8.98	B1IIIe	KE02		M
TYC 3324-92-1	252864874	5.3848	7.1	3	03 26 04.74	+50 49 46.6	11.33	B7		Melotte 20	A
BD+61 2515	272625912	3.3052	11.6	1	23 45 43.89	+62 17 31.2	10	B0.5V			
GSC 00155-00374	281533292	5.5399	7.9	1	06 38 13.40	+05 33 20.0	11.9	B7V		NGC 2244	
HD 333172	282737511	3.2152	6.9	1	19 57 53.88	+28 19 51.2	10.35	B1II			
ALS 14570	285122116	7.9203	1.1	1	00 49 11.38	+64 11 21.9	11.28	B3IV			
ALS 6915	285684866	3.0730	7.1	1	02 06 08.56	+63 22 11.8	10.24	B0.5:ep			
HD 69824	286352720	6.0635	3.6	2	08 16 38.69	−48 26 11.2	9.09	B4/6V	PP08		
HD 78507	290300414	4.3680	0.9	2	09 05 39.03	−62 06 12.6	8.12	B6V			A
GSC 01314-00792	294306184	7.2264	5.4	1	06 12 02.90	+15 23 10.0	11.5	B5			
ALS 1302	296449179	5.9676	8.6	1	09 25 42.12	−53 14 19.5	11.73	OB+[d]			M
ALS 11602	297264447	8.7851	1.3	1	20 53 04.97	+43 37 13.2	11.21	B2Vn			
HD 260858	307944768	5.8902	1.2	1	06 37 46.71	+12 46 05.1	9.15	B6He[e]			A
HD 220300	319302209	3.3830	8.7	1	23 22 10.46	+56 20 53.6	7.93	B6IVne			A
V447 Cep	335484090	3.1845	18.1	1	22 10 59.56	+63 23 58.5	7.46	B1Vk			A, M

Table 2
(Continued)

ID	TIC ID	Freq. (day^{-1})	Amp. (mmag)	Num. modes	R.A. (2000)	Decl. (2000)	V (mag)	SP	Known?	Cluster?	Remarks
BD+05 4404	345652701	3.1828	2.4	1	20 04 42.72	+05 33 19.6	10.47	B5			
V352 Per	347585038	3.6438	2.9	1	02 13 37.02	+56 34 14.3	9.31	B1III			A
BD+56 579	348609224	3.9560	1.5	1	02 22 19.23	+57 37 12.9	10.88	B7IVe			A
LS II +23 36	360749347	4.8883	11.8[f]	1	19 44 26.15	+23 17 54.1	10.68	OB			A
CD-49 4294	364146227	3.0901	5.7	1	09 18 19.05	−50 18 46.9	11.24	B3/5			
ALS 6216	366108295	12.9568	2.0	1	00 28 37.71	+62 29 17.7	10.2	B0.5V			A
BD+66 1651	368237682	7.2884	1.8	2	23 52 12.14	+67 10 07.5	9.97	B3Ve			A
HD 261630	369708912	3.2593	2.6	1	06 39 49.73	+05 04 37.7	10.07	B5		NGC 2244	
BD+55 334	370269139	5.9102	1.5	1	01 28 39.05	+56 21 04.3	10.41	B2e			A
BD+57 579	372115570	3.9621	4.0	1	02 30 14.05	+57 40 30.3	10.09	B2III			A
HD 236939	374696382	5.7791	3.6	1	02 04 33.68	+56 33 00.6	10.19	B5			
BD+29 3644	379932247	8.3034	2.4	1	19 33 49.91	+29 29 56.3	11.27	B5			blend
HD 78206	384257658	3.6997	1.8	2	09 04 22.00	−59 09 24.9	8.84	B7/8V			A
CD-56 2603	384540878	3.5513	3.6	1	09 05 41.99	−57 00 02.9	11.76	B1III/Ve			M
CPD-55 2071	386513392	3.1218	1.6	1	09 18 11.17	−56 01 33.3	10.8	B7e			
HD 42896	386693012	13.597	7.3	3	06 14 06.19	+20 10 10.9	8.62	B1Vnn			A
BD-09 4742	387153140	11.3216	2.1	2	18 28 20.13	−09 35 05.2	10.5	B2V			A
CD-47 4494	400080677	9.0207	0.6	1	08 54 20.85	−48 25 49.5	9.69	B5			
TYC 3683-1328-1	400533469	11.1849	4.5	1	01 39 47.92	+58 45 24.4	11.68	B5			
CD-48 4390	401847213	5.1564	4.9	1	09 04 23.69	−48 46 25.1	11.32	B4/6			
HD 280753	408941991	4.6168	1.4	1	05 18 05.96	+38 17 40.6	10.21	B3			
HD 277933	408991617	5.7713	1.4	1	05 17 51.12	+40 23 27.0	10.14	B3			
BD+61 77	419246605	8.0205	1.2	1	00 26 23.21	+62 45 38.9	9.61	B1IV			A
ALS 6330	420545430	3.3131	2.5	1	00 45 17.23	+63 42 36.8	11.1	B1III			
TYC 4031-1324-1	421691939	6.0165	3.5	2	01 27 04.47	+60 49 08.1	11.07	B5			
BD+59 254	422533344	5.3948	3.8[f]	2	01 28 15.06	+60 13 45.8	10.07	A2			A
HD 37115	427396133	5.9099	5.8	2	05 35 54.08	−05 37 42.3	7.4	B7Ve			A
CD-45 4501	430625041	5.7728	2.3[f]	1	08 45 19.49	−45 57 34.4	9.08	B8			A
HD 298610	440971753	3.1712	4.1	2	09 39 00.81	−54 03 45.3	9.83	B2/4e			
HD 77769	447933173	5.4681	3.9	3	09 02 48.21	−46 57 48.9	9.37	B3IV	PP08		A
HD 19635	458911894	3.8763	2.4	3	03 12 56.84	+63 11 12.4	8.94	B4			A
BD+60 770	459014234	11.7894	10.8	5	04 00 49.57	+61 17 26.5	9.8	B5			A
BD+62 647	459105076	10.9253	2.3	1	04 05 34.01	+62 47 28.6	9.58	B2V		NGC 1502	
TYC 8610-895-1	469095496	8.0080	4.3	1	09 53 23.95	−58 57 36.2	11.23	B5/7			blend

Notes. Table of candidate stars identified in this work, including their ID, TIC number, information about the primary frequency and number of modes, coordinates, V-band magnitude and spectral type, a citation if the star is known to be a β Cephei star, a note if the star is a known cluster member, and information about remarks. Stars labeled "M" in this column are discussed in the main text, stars labeled "A" are commented upon in the Appendix, while "blend" indicates that there are bright nearby sources contributing flux in the aperture used by KELT (and likewise with TESS). The citations for candidate β Cephei stars are as follows: PP08 = Pigulski & Pojmański (2008), KE02 = Koen & Eyer (2002); some of these were already listed as candidates by Stankov & Handler (2005). Other information is compiled from the literature and is available at http://redcliffcottage.co.za/tess/. Spectral types from Skiff (2014) unless otherwise indicated.
[a] Wright et al. (2003).
[b] Cannon & Pickering (1993).
[c] Ikhsanov (1959).
[d] Stephenson & Sanduleak (1971).
[e] Renson & Manfroid (2009).
[f] Amplitudes may be largely suppressed.

(This table is available in machine-readable form.)

Cephei star in BW Vul (Sterken et al. 1986). As the brightness is increasing, the brightness stalls for some time and then continues to increase toward its maximum value (Sterken et al. 1987). The ensuing decrease in brightness is relatively steep. Hydrodynamic models of BW Vul suggest that shocks generated below the photosphere can give rise to the stillstand phenomenon (Mathias et al. 1998; Fokin et al. 2004).

Only a handful of β Cephei stars have been found to exhibit the stillstand phenomenon to date (e.g., Sterken et al. 1986; Pigulski & Pojmański 2008; Degroote et al. 2009). Of the four β Cephei stars in the present sample that show the stillstand phenomenon, three have been previously reported as β Cephei stars that have this characteristic (BW Vul, HD 173006, HD 180642). The fourth, HD 231124, is identified here for the first time, having been so far not known to pulsate. Light curves for these four stars are shown in Figure 7, and they are marked in Table 1.

4.2.3. Other Nonsinusoidal and Unusual Behavior

Besides the four systems showing the stillstand phenomenon, there are two β Cephei stars and three candidates with unusual or nonsinusoidal behavior that we briefly discuss below. These are shown in Figure 8.

Table 3
Rejected Stars in This Work

ID	TIC ID	Freq. (day^{-1})	Amp. (mmag)	Num. modes	R.A. (2000)	Decl. (2000)	V (mag)	SP	Known?	Cluster?	Remarks
TYC 4033-2268-1	12647620	3.5118	4.6	1	02 15 28.61	+60 09 44.6	11.69	B3		IC 1805	A, nei.
HD 221991	26283875	14.2427	0.8	1	23 36 32.16	+52 37 12.6	9.84	B5			A, δ Scuti
HD 75290	28709025	5.4869	1.9	3	08 47 33.74	−42 29 07.0	8.09	B3/5V		Trumpler 10	A, SPB
HD 190088	40102236	5.2399	3.0	1	20 01 45.46	+38 44 06.9	7.86	B5			A, SPB
HD 59446	60320306	7.0191	0.8	1	07 27 42.78	−47 24 50.4	7.59	B6II/III			A, sat.
HD 144941	67985749	6.344	1.5	1	16 09 24.55	−27 13 38.2	10.02	B1/2II			A, M, eHe
HD 72539	90134626	2.9852	1.6	2	08 31 22.31	−48 44 56.9	7.97	B5V			A, SPB
omi Vel	93549165	3.9746	0.7	1	08 40 17.59	−52 55 18.8	3.63	B3/5V			A, sat.
HD 331621	102161004	3.3436	1.2	2	19 56 59.97	+31 17 16.0	9.98	B7			A, SPB
HD 29450	118680798	4.6172	0.7	1	04 39 13.54	+22 39 08.1	8.57	B7V			A, SPB
HD 62755	123754451	3.4328	0.8	5	07 43 23.09	−47 02 48.0	7.85	B5V			A, SPB
HD 290564	138905907	8.6575	12.2	4	05 32 08.73	+00 07 36.8	11.2	B5			A, δ Scuti
CD-46 4432	141903541	5.2911	5.8	2	08 40 30.48	−47 12 35.2	10	B5			A, nei.
HD 151654	157535787	12.5893	6.4	1	16 48 49.41	−03 36 39.4	8.6	F0V[a]			A, δ Scuti
HD 181124	162012064	22.1863	2.2	3	19 19 18.34	−01 22 50.4	9.62	B5			A, δ Scuti
HD 35612	264485563	9.0839	0.8	1	05 26 06.00	+00 50 02.4	8.3	B7Vn			A
TYC 4804-1086-1	281803267	3.9139	18.5	1	06 50 31.54	−02 19 45.9	11.91	B5			A, nei.
HD 59325	291556636	3.7152	3.9	3	07 26 56.07	−51 11 07.0	10.55	B7V			A, SPB
HD 190066	352529679	7.0184	15.6	0	20 02 22.10	+22 09 05.2	6.6	B1Iab			A, sat.
ALS 10464	360661624	4.8883	11.8	1	19 44 21.08	+23 17 05.9	11.82	B0.5V			A, nei.
V652 Her	377498419	18.6905	7.6	1	16 48 04.69	+13 15 42.4	10.51	B2He			A, M, eHe
TYC 3315–1807-1	384992041	3.7614	44.1	1	03 21 39.63	+47 27 18.8	11.73	B7		Melotte 20	A, binary
NGC 6632	399436782	5.1536	5.6	1	01 46 35.61	+61 13 39.1	12.31	B1Ve			A, nei.
HD 196035	417438983	4.0083	2.8	1	20 34 09.98	+20 59 06.7	6.47	B3IV			A, sat.
TYC 4031-1770-1	422533347	5.3948	3.8	2	01 28 21.97	+60 14 43.9	10.94	B5			A, nei.
HD 350990	424032547	5.0251	3.4	1	19 58 49.85	+20 31 29.9	10.32	B7II/III		Roslund 3	A
TYC 1624-299-1	424032634	7.0305	1.4	1	19 58 41.30	+20 31 48.6	12.04	B7IVnnp		Roslund 3	A
HD 254346	426520557	17.1232	4.2	4	06 16 57.32	+22 11 42.0	9.74	B2/3III			A, M, nei.
CPD-45 2977	430625174	5.7728	2.3	1	08 45 10.44	−45 58 54.7	10.98	O9.5II			A, nei.
TYC 4269-482-1	434178307	5.9868	1.9	2	22 50 26.49	+62 42 03.0	10.78	B5/8V			A
HD 282433	446041643	4.4838	5.2	3	04 45 28.76	+30 16 54.4	9.52	B5[b]			A, SPB

Notes. Table of candidate stars rejected in this work, including the ID, TIC number, information about the primary frequency and number of modes, coordinates, V-band magnitude and spectral type, a citation if the star is known to be a β Cephei star, a note if the star is a known cluster member, and information about remarks. Stars labeled "M" in this column are discussed in the main text; stars labeled "A" are commented upon in the Appendix. The most likely explanation for the originally detected signal that met our preselection criteria is in the remarks according to the following—"nei.": the signal comes from a neighboring star, "sat.": saturation effects cause the signal, "eHe": extreme helium star, "δ Scuti": δ Scuti pulsation, "SPB": slowly pulsating B star. More information is in the Appendix. Other information is compiled from the literature and is available at http://redcliffcottage.co.za/tess/. Spectral types are from Skiff (2014) unless otherwise indicated
[a] Houk & Swift (1999).
[b] Nesterov et al. (1995).

(This table is available in machine-readable form.)

In the course of the discovery of β Cephei pulsations in KK Vel, Cousins (1982) noticed the nonsinusoidal light curve. Aerts et al. (1994) verified the presence of an additional frequency at twice the primary frequency, noticing differences in the color behavior between these frequencies. The primary frequency of KK Vel is somewhat variable. This was already pointed out by Cousins (1982), who could not phase his three seasons of data (with photometry from 1980 to 1982) with a single frequency. He reported the main frequency to vary between $f = 4.6351 \pm 0.0001$ and $f = 4.6361 \pm 0.0001$ day^{-1}. Heynderickx (1992) finds $f = 4.63637 \pm 0.00003$ day^{-1} with observations in 1987 March and 1988 March with Walraven five-color observations, and 1988 November 22–1989 January 25. Also in this work, we see evidence for a variable main pulsation frequency, which also has a variable amplitude. In the 2009/2010 observing season, the frequency was $f = 4.6342 \pm 0.0002$ day^{-1} with an amplitude of $A = 13.1 \pm 0.2$ mmag; in 2012/2013, $f = 4.63717 \pm 0.00004$ day^{-1} and $A = 21.2 \pm 0.4$ mmag; and in 2013/2014, $f = 4.63760 \pm 0.00004$ day^{-1} and $A = 16.6 \pm 0.4$ mmag. The amplitude and frequency variations are likely present on timescales shorter than a single observing season. Unfortunately, our data and the previous data are too sparsely sampled in time to facilitate a deeper analysis, although TESS observations may prove valuable in this regard.

We have classified BD+35 4258 as a β Cephei star. Apart from the single pulsation frequency (at $P = 0.13174$ days), the shape of the light curve suggests binary-induced or rotational variability with a base period of 0.67834 days (Figure 8, top

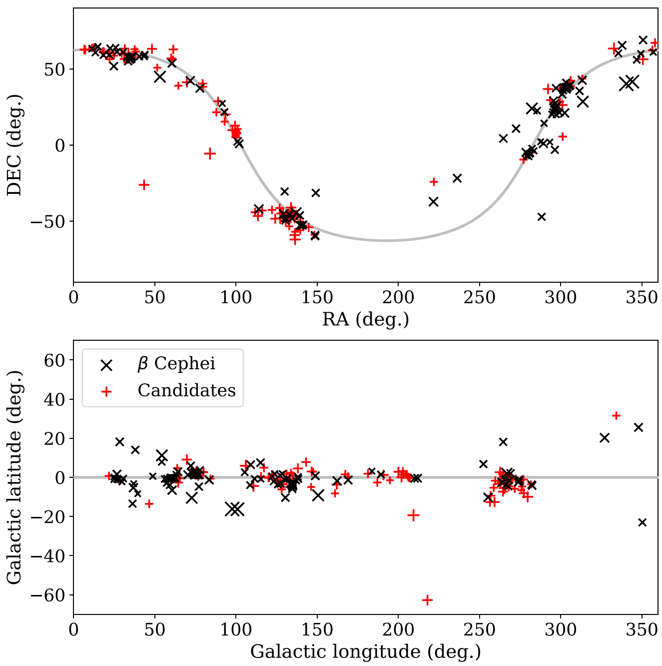

Figure 1. Distribution of β Cephei and candidate stars according to their R.A. and decl., and Galactic longitude and latitude (epoch J2000). Marker size is proportional to V-band magnitude.

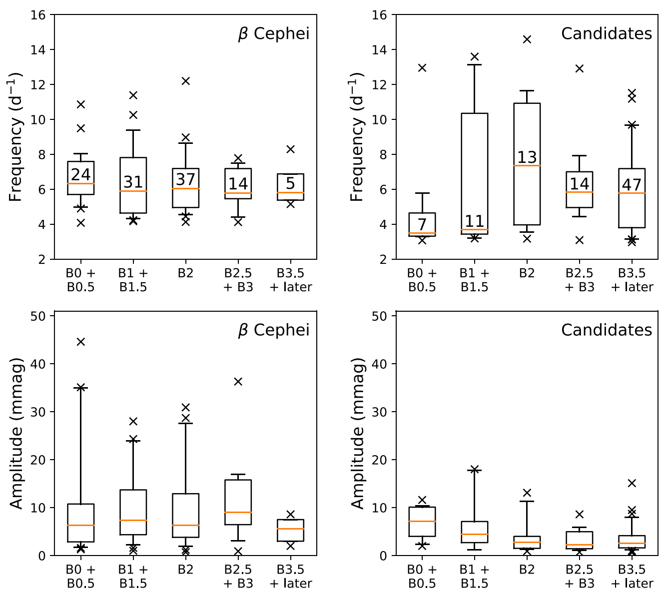

Figure 2. Box plot showing the frequency (top row) and the amplitude (bottom row) distributions for the β Cephei stars (left column) and the candidates (right column). These are split into bins according to their spectral types, as reported in the literature. The numbers in the boxes in the top row indicate the number of objects in that bin. The corresponding bins in the lower row contain the same number of stars. The middle red line in each box is the median, the top and bottom of the boxes mark the 25th and 75th percentiles, and the lower and upper whiskers denote the 5th and 95th percentile. Outliers are shown as X's. The β Cephei star HD 190336 has a spectral type of B0.7, and candidate, CPD-45 2977, has a spectral type of O9.5, both of which are in the first bin in their respective categories.

right), which appears to be rather short for an early B-type star. Vilnius photometry (Sudzius & Bobinas 1992) and its calibration (Straizys et al. 1993) indicate $T_{\rm eff} \approx 26{,}000$ K, log $g \approx 3.9$. From the Gaia DR2 parallax and Galactic reddening, one can estimate $M_v < -3.6$. With bolometric corrections and the spectral-type−temperature calibration by Pecaut & Mamajek (2013), one derives $M_{\rm bol} < -6.2$, hence $R > 7.6\ R_\odot$ for the star. A rotational modulation with a period of 0.67834 days hence requires $v_{\rm rot} > 560$ km s^{-1} , which is close to breakup speed. Estimating a mass of 13 $M_\odot$ for BD+35 4258 by placing it into a theoretical H-R diagram (e.g., Martins & Palacios 2013) and assuming a binary scenario with a massless companion and an orbital period of 0.67834 days requires a semimajor axis of $R = 7.6\ R_\odot$, which is similar to the primary's radius. Alternative hypotheses would be SPB-type pulsation with a nonsinusoidal light curve (Kurtz et al. 2015) or a base period that is twice as long. Another possible scenario is that this signal arises from a close binary system with an orbital period of 0.67834 days, which is not spatially resolved with respect to the B-type star in which we detect the β Cephei pulsation. The light-curve shape and period are suggestive of a close binary where both stellar surfaces are gravitationally deformed (i.e., an ellipsoidal variable).

The remaining stars discussed in this section are all classified as candidate β Cephei pulsators. The light curve of HD 237204 (Figure 8, middle left) can be decomposed into two frequencies related exactly by 2:3, suggesting binary-induced or rotational variability with a base period of 0.27172 days (Figure 8, middle left). Similar to the previously discussed star, one can estimate $T_{\rm eff} \approx 29{,}000$ K, $M_v < -3.2$ from Vilnius photometry (Zdanavičius & Zdanavičius 2005), and the Gaia DR2 parallax. The bolometric corrections and the spectral-type −temperature calibration by Pecaut & Mamajek (2013) then yields $M_{\rm bol} < -6.0$, hence $R > 5.6\ R_\odot$ for HD 237204. A rotational modulation with a 0.27172 day period thus requires $v_{\rm rot} > 1000$ km s^{-1}, far above breakup speed. Estimating a mass of 15 $M_\odot$ for HD 237204 in a possible binary scenario with a massless companion and an orbital period of 0.27172 days requires a semimajor axis of $R = 4.3\ R_\odot$, smaller than the primary's radius. For these reasons, we favor an interpretation in terms of pulsation, although the light-curve shape with a descending branch steeper than the rising branch would be remarkable in this case.

ALS 1302 has two variability frequencies that are harmonically related and give rise to a light-curve shape (Figure 8, middle right) reminiscent of rotational or binary-induced variation. However, the base period ($P = 0.33514$ days) would again be too short for such explanations. We appear to be left with an interpretation in terms of pulsation with an unusual light-curve shape (e.g., see Figure 6 of Handler et al. 2006).

The light curve of HD 339483 (Figure 8, bottom left) when phase-folded with respect to the strongest variability signal shows an unusual double-humped maximum. Just as for HD 237204, the short period of this signal ($P = 0.26852$ days) effectively rules out a binary or rotational origin. The observation that the rising branch of the phase-folded light curve is steeper than the descending branch suggests that pulsation could be responsible for this variability; perhaps we are seeing a stillstand phenomenon shortly before light maximum, or a curious superposition of a base and a harmonic frequency (e.g., Figure 1 by Kurtz et al. 2015). Although HD 339483 is classified as a classical Be star (Jaschek & Egret 1982), it is not clear that there is evidence to support this designation. None of the spectra that are published in the literature or are publicly available show evidence of the

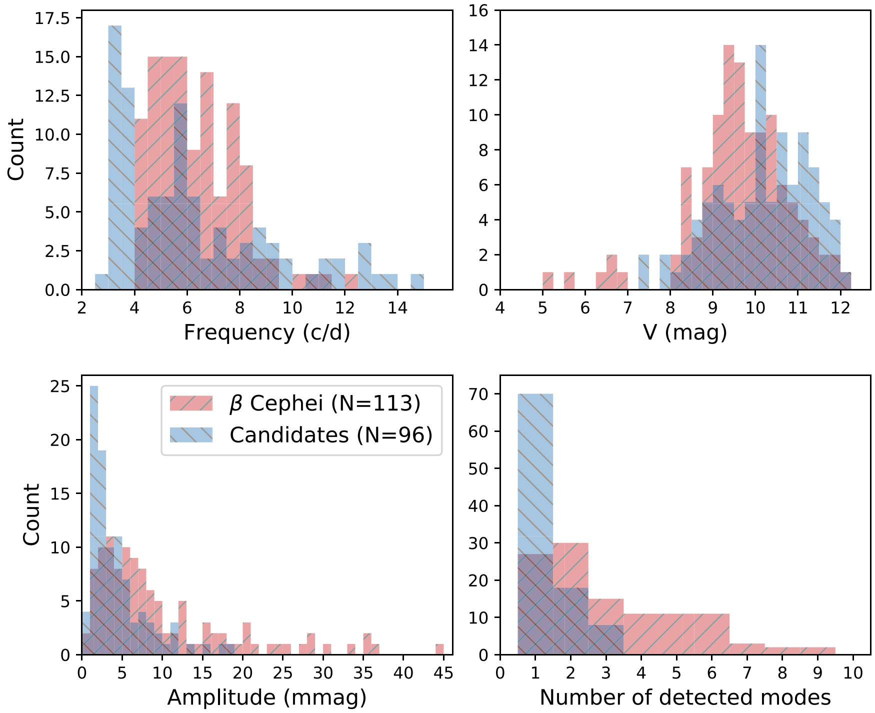

Figure 3. Histogram of the primary frequency (top left) and the corresponding amplitude (bottom left) recovered, the V-band magnitude (top right), and the number of detected modes (bottom right) for the β Cephei and candidate stars.

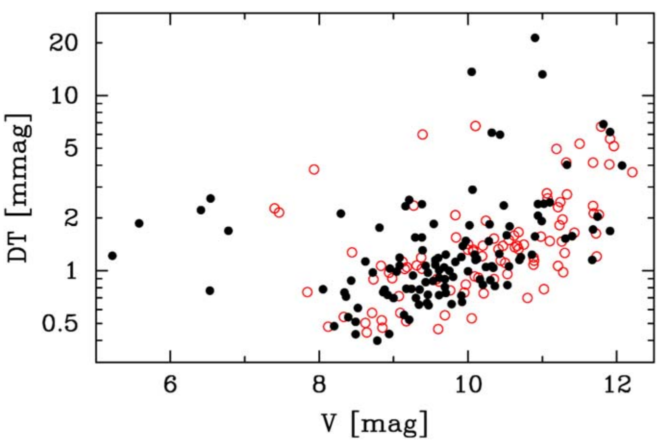

Figure 4. Detection level of periodic variability in the β Cephei domain for stars classified as β Cephei pulsators (filled black circles) and candidates (open red circles). Note the logarithmic ordinate scale.

circumstellar disk characteristic of classical Be stars. This includes five optical spectra in the Be Star Spectra (BeSS) database[15] that span the dates 2015 September 5 through 2018 September 12, five optical spectra with one observation taken on 1998 August 3, and the next four taken between 2009 September and 2010 November (Barnsley & Steele 2013), an optical spectrum taken on 1998 August 2 (Steele et al. 1999) (from which the $v \sin i$ is measured to be $79 \pm 11\ \mathrm{km\ s^{-1}}$), a K-band spectrum taken on 1996 June 28 (Clark & Steele 2000), and an H-band spectrum taken on 1996 June 29 (Steele & Clark 2001). There is, however, a somewhat nebulous feature that is readily apparent in the far-IR Wide-field Infrared Survey

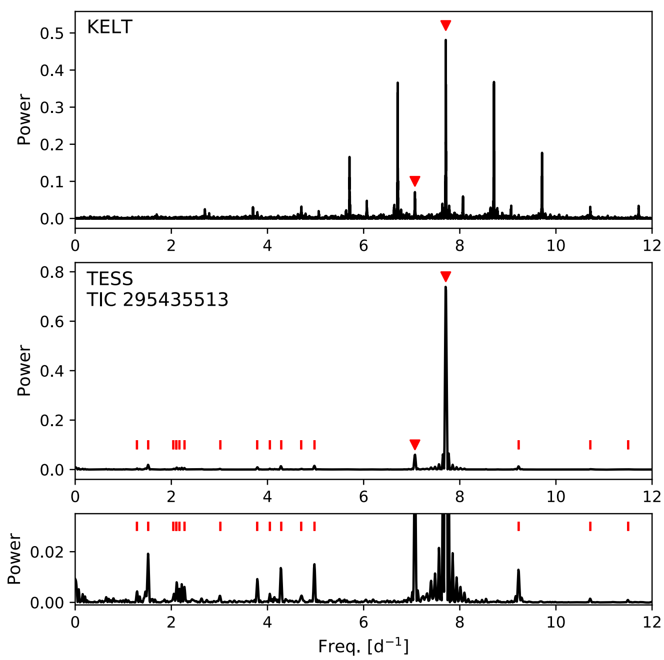

Figure 5. Frequency spectrum of the β Cephei star TIC 295435513 computed from KELT (top) and TESS (middle) data. The two frequencies identified in this work from KELT data are marked with red triangles. Additional frequencies detected in the TESS data are indicated by red tick marks. The lower panel shows these frequencies more clearly. The unmarked peaks in the top panel are aliases of the marked frequencies.

Explorer W4-band photometry in the vicinity of this object (Wright et al. 2010) that may be responsible for the excess at long wavelengths. This star is classified as a β Cephei star in Pigulski & Pojmański (2008), and while they find the same frequency with ASAS and Hipparcos data as we find in the KELT data, the unusual shape of the phased data is not reported.

[15] http://basebe.obspm.fr

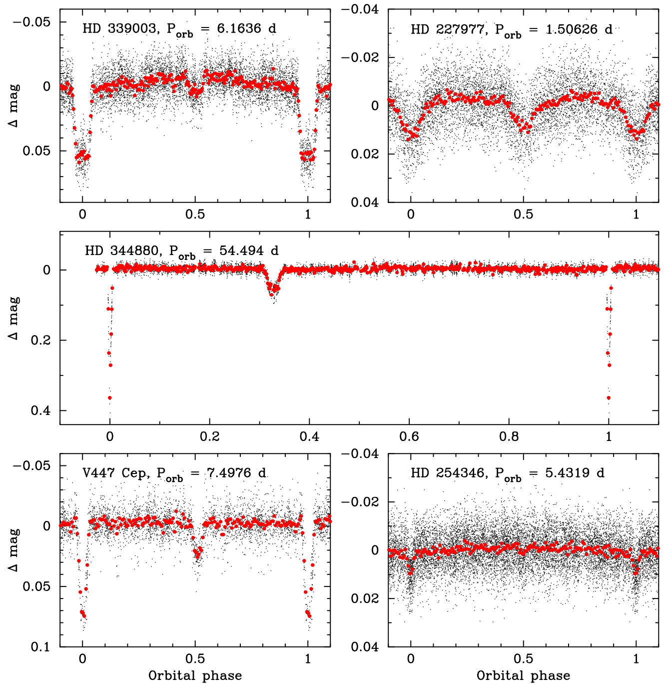

Figure 6. Phase-folded light curves of the eclipsing binaries discovered in this work; the pulsational variability has been removed for clarity. Black points show the KELT data and red points show the binned data to illustrate the basic light-curve shape.

Table 4
Ephemerides of the Eclipsing Binaries Containing a β Cephei or Candidate Star

ID	P_{orb} (days)	T_0 (HJD)
TIC 10891640 = HD 339003	6.1636(1)	2456003.90(1)
TIC 42365645 = HD 227977	1.50626(1)	2456001.131(6)
TIC 451932686 = HD 344880	54.494(2)	2456050.2(1)
TIC 335484090 = V447 Cep	7.4976(7)	2456006.06(2)
TIC 426520557 = HD 254346	5.4319(3)	2456002.15(4)

Note. Error estimates are given in parentheses after the last significant digit.

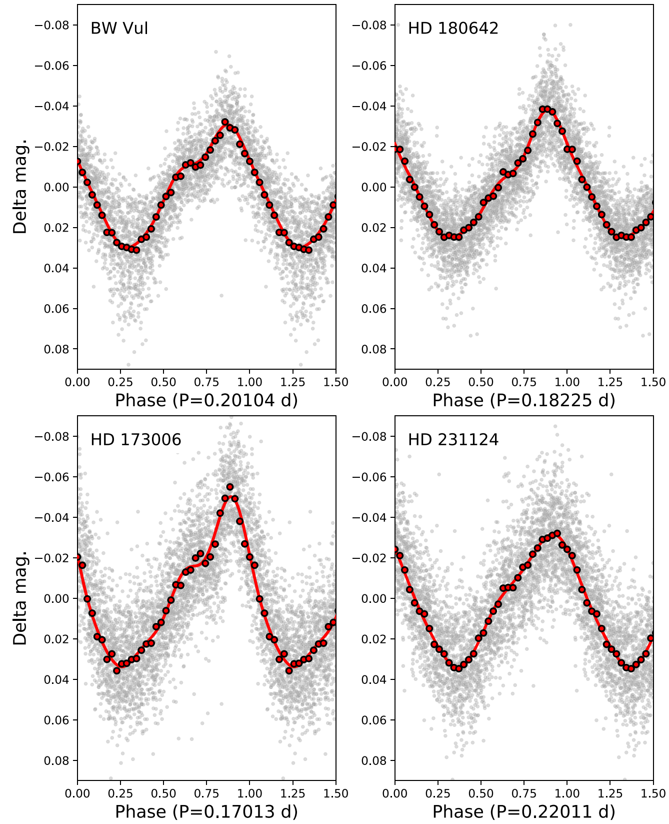

Figure 7. Phased light curves of the four β Cephei stars whose light curves show the "stillstand phenomenon," when phased to their primary period. Black points show the KELT data; red points show the binned data, with 35 bins in phase; and the red curve shows a four-term sinusoidal fit to the binned data. Of these, HD 231124 is the only newly reported β Cephei star. The other three are known β Cephei pulsators where the stillstand phenomenon has previously been reported. The light-curve data for all β Cephei, candidate, and rejected stars included in this paper are available in machine-readable format as data behind the figure.

(The data used to create this figure are available.)

4.2.4. Stars with Frequency Splittings

β Cephei stars often show nonradial pulsations. Stellar rotation introduces frequency splittings into the pulsation spectra, which can be used to determine their interior rotation (e.g., Dupret et al. 2004; Pamyatnykh et al. 2004). Thus, stars that show frequency splittings are highly interesting for asteroseismology, although it needs to be cautioned that such splittings may also occur by coincidence (see Handler et al. 2006 for an example). We have examined the targets classified as β Cephei stars for frequency splittings, keeping in mind that second-order effects of rotation make them somewhat uneven, in the sense that within a given pulsation-mode multiplet, the frequency separations of consecutive signals slightly decrease with increasing frequency (Dziembowski & Goode 1992), and that some frequency multiplets may be incomplete. We found a total of 22 stars with frequency splittings (Figure 9, Table 5) that could reveal their rotation rate. The splittings of two of those stars, IL Vel and V836 Cen, were already known; those of the 20 other stars are new discoveries and await confirmation and/or resolution of ambiguities via pulsational mode identification. Pinpointing possible rotational frequency splittings in this way is expected to be successful only in cases of slow to moderate rotation. For fast rotators (50% of breakup speed or more), the asymmetry of the rotationally split multiplets hampers their identification from the underlying frequency pattern only (Deupree & Beslin 2010). Figure 10 shows the possible frequency spacings versus $v \sin i$ for those stars with $v \sin i$ measurements. This is suggestive of a trend of increasing frequency spacing with $v \sin i$ (as expected), but the number of systems is too few and the ambiguity in the frequency spacing in most cases make this relationship tenuous. Magnetic fields can also induce frequency splitting, but these splittings are perfectly evenly spaced, unlike those induced by rotation, and the split frequencies are much smaller in amplitude relative to the main frequency (by a factor of about 10^{-3} in the magnetic β Cephei pulsator β Cephei; Shibahashi & Aerts 2000). All of the splittings found here are best explained by rotation, given the modest amplitude ratios and the slight dependence on frequency of the splittings within a given multiplet.

Our results for V836 Cen deserve a separate discussion. This star has been among the first to be successfully modeled asteroseismically (Dupret et al. 2004). Aerts et al. (2003)

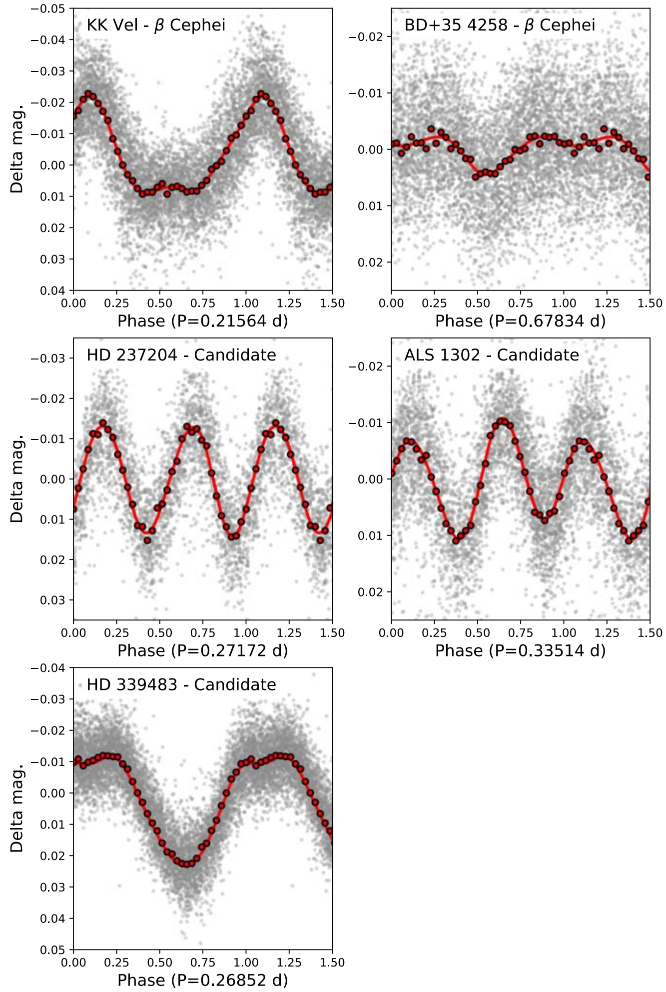

Figure 8. Phased light curves for systems with nonsinusoidal signals. Symbols are the same as in Figure 7.

identified a radial oscillation, a rotationally split triplet of dipole modes and two components of a quadrupole mode. Our analysis adds two more components (one of which is already tentatively reported by Aerts et al. 2004) to the quadrupole-mode quintuplet, of which four consecutive components are detected now (see tables in the Appendix). This reduces the previous four possibilities for the axisymmetric component of the quadrupole mode to two, and rules out the conjectured identification of this axisymmetric mode by Aerts et al. (2004). Furthermore, the relative amplitudes of the oscillations in the two nonradial-mode multiplets have changed in the approximately two decades that lie between the two data sets. Also, whereas Aerts et al. (2003) find a first-order rotational splitting of 0.0121295 day^{-1} for the triplet of dipole modes, we obtain a slightly, but statistically significantly, larger value of 0.01238 ± 0.00002 day^{-1}. This suggests that the rotation rate in the resonant cavity of the dipole mode of V836 Cen has increased in the meantime, counterintuitive to what would be expected from evolutionary stellar expansion.

4.2.5. Galactic Distribution

Because β Cephei stars are massive main-sequence pulsators, they are relatively young stars. In most cases, they should not have had the time to move away from the Galactic plane where they were formed. However, some interactions with other stars, such as a supernova disrupting a binary system (Zwicky 1957) or ejection of a star from a young open cluster (Poveda et al. 1967), are able to move a young star away from the Galactic plane. Given the interesting evolutionary histories such stars will have, they are of increased interest for asteroseismic investigations.

We have therefore computed the distance from the Galactic plane of our targets with parallaxes with a relative error below 25% and show the result with respect to Galactic longitude in Figure 11; Table 6 lists all stars that are located more than 400 pc off the Galactic plane. We also quote their radial velocities if available. Some of these stars have rather large radial velocities, adding evidence for a possible runaway nature.

We noticed that there are several stars that failed our criterion for the precision of their parallaxes, but that are rather faint (hence distant in any case) and that are located at relatively high Galactic latitude. These are therefore also good candidates for runaway stars. Among the β Cephei pulsators, these are TIC 25070410 = HD 166331 ($b = -14\overset{\circ}{.}1$, RV = $+33$ km s^{-1}), TIC 101423289 = HD 86248 ($b = -18\overset{\circ}{.}1$, RV = $+73$ km s^{-1}), and TIC 287467101 = HD 140543 ($b = -25\overset{\circ}{.}5$); among the candidates, TIC 384540878 = CD −56 2603 ($b = -6\overset{\circ}{.}6$) stands out in this respect. Finally, we remark that V836 Cen ($b = +20\overset{\circ}{.}2$, RV = $+66$ km s^{-1}) has already been suspected to be far away from the Galactic plane (Waelkens & Rufener 1983; Aerts et al. 2004). There is no reliable and precise parallax for the star, but its luminosity has been derived asteroseismically (Dupret et al. 2004). Using these results and reddening estimates from Chen et al. (1998) and Strömgren photometry, we find $z \approx 430$ pc for this star.

4.2.6. Extreme Helium Stars

Extreme helium stars are rare objects that are not main-sequence B-type stars such as the β Cephei pulsators. They are believed to be more likely the product of a merger of two white dwarfs than post-asymptotic-giant-branch objects that underwent a final helium flash (see Jeffery 2014). Nevertheless, two of these stars, V652 Her (a known pulsator) and HD 144941, survived the preselection criteria for β Cephei pulsators or candidates.

HD 144941 was initially identified as having a tentative low-amplitude signal within the frequency range of the β Cephei stars. However, further analysis suggests this detection was spurious. Jeffery & Ramsay (2018) have analyzed K2 photometry and find somewhat complex light variations with a period of 13.9 days and a full amplitude of 4 parts per thousand. This variability is attributed to the rotation of an inhomogeneous surface. We do not recover this signal in the noisier KELT data. Further, the high-frequency signal that was tentatively detected in our original analysis (Table 3) is not found in the publicly available K2 data (within a limit of 40 μmag). The lack of pulsation in HD 144941, despite it lying in the instability strip, may be attributed to its low metallicity, as suggested by Jeffery & Ramsay (2018), or the possible presence of a large organized magnetic field (which the implied surface inhomogeneities may be associated with) could act to suppress pulsation.

V652 Her was readily detected in our analysis, but its dominating frequency is the first harmonic of the actual pulsation frequency due to the unusual light-curve shape of this star (see, e.g., Kilkenny et al. 1999). Also, its rapid period

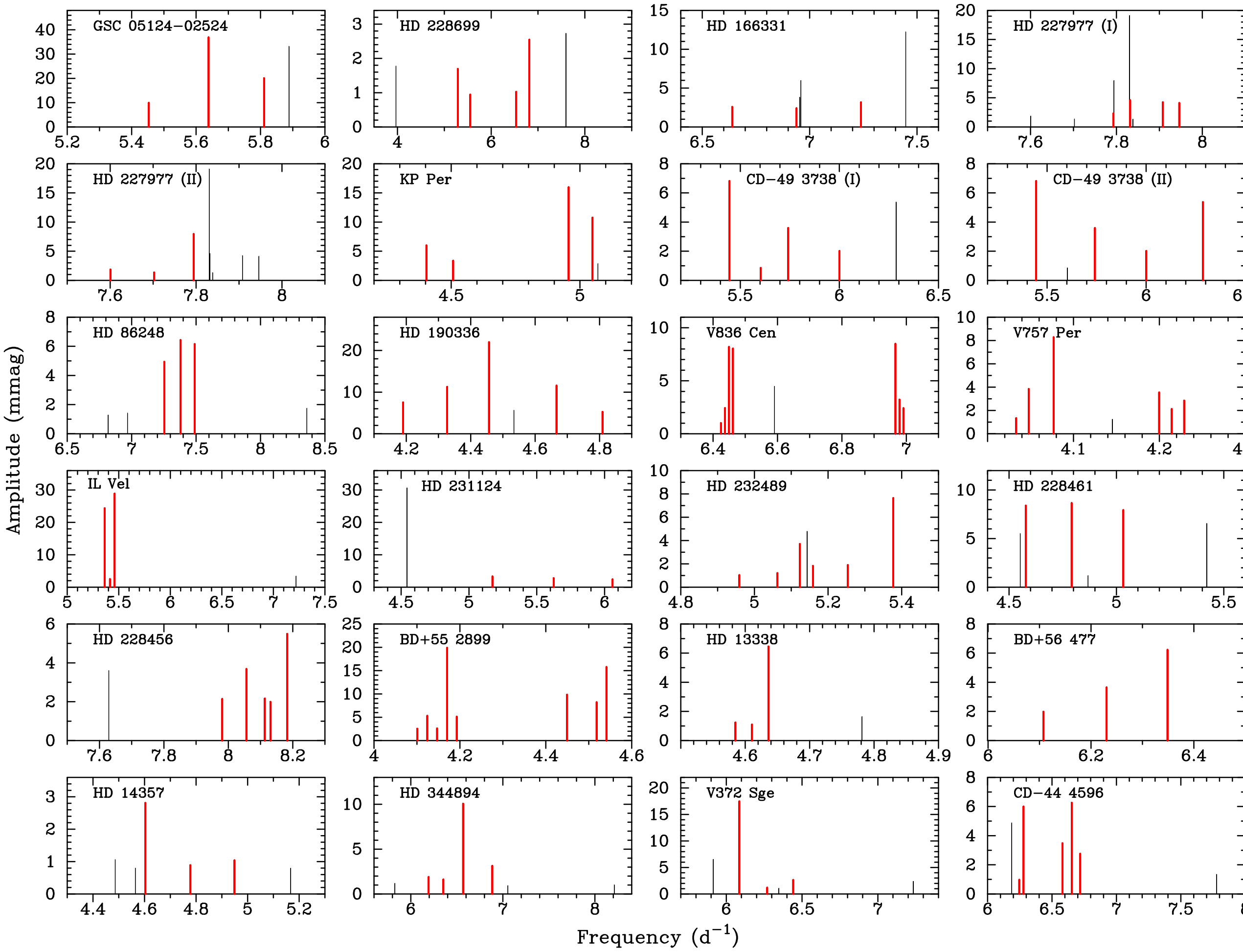

Figure 9. Schematic β Cephei mode spectra for stars with equal frequency splittings. The signals suspected to form multiplets are indicated with thick red lines, other oscillation frequencies with thin black lines. Note that some of these possible multiplets are incomplete, that some stars have more than one splitting with the same spacing (that may sometimes even overlap in frequency), and that for two stars, HD 227977 and CD-49 3738, there are two possibilities for the base splitting frequency; see Table 5 for more information.

change (Kilkenny et al. 2005) is evident in our data that cannot be phased with a constant period. We show a comparison of the "instantaneous" period for our yearly data sets of V652 Her with the fit obtained by Kilkenny et al. (2005) to their earlier period measurements in Figure 12. Given the $\approx$6 yr gap between the latest measurements in this paper and the first ones in ours, the general trend of a decreasing pulsation period is still well-preserved. However, systematic deviations are also visible, likely a consequence of the nonlinear nature of the period change of this star.

5. Discussion and Conclusions

Through a periodicity analysis of light curves from the KELT survey for O- and B-type stars, we identify 113 β Cephei pulsators, of which 89 are new discoveries. We identify a further 97 stars as β Cephei candidates, a group that likely contains a mix of genuine β Cephei stars, plus other O- and B-type variables. Additionally, we identify 27 stars that meet the preselection criteria, but are rejected upon a more scrupulous investigation.

Our preselection was based on a visual inspection of the Fourier spectra of the KELT light curves. Based on our experience with these data, we derived some preselection criteria that can be used to facilitate more automatic identifications of β Cephei pulsators and candidates from similar data sets. For stars to be preclassified as β Cephei pulsators, we required variability frequencies between 4 and 13 day^{-1}, an S/N of the strongest signal in the amplitude spectrum to exceed 5, a light-curve shape not indicative of binary-induced variability, and a spectral type between O9 and B5 (allowing for inaccurate spectral classifications). β Cephei candidates would be stars not classified as β Cephei that have to have frequencies between 3 and 15 day^{-1}, S/N $>$ 4, and spectral types O–B7. This preselection resulted in 148 β Cephei identifications plus 90 candidates.

The previously described criteria are necessary to be fulfilled, but not sufficient: after a careful literature search and taking into account their position on the H-R diagram, we had to reject 7 stars (5%) preclassified as β Cephei stars as well as 18 candidates (20%; see Appendix A.3 for short discussions of each individual star). In addition, we moved 27 (18%) stars from β Cephei to candidate status to err on the side of caution, but also "upgraded" 3 from candidate to β Cephei because reliable spectral classifications not available in our input catalog were found in the literature. Further, three stars selected as β Cephei stars were found to be blended with a variable neighbor, and in all cases, the neighbor is possibly of the correct spectral type and is thus classified as a candidate.

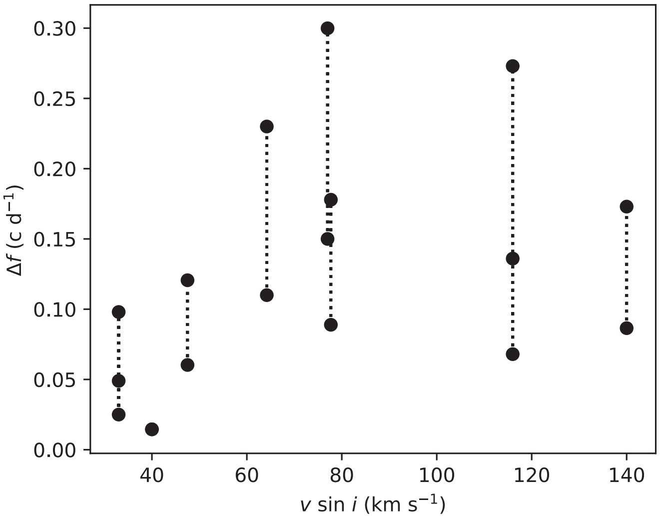

Figure 10. For the eight stars with literature $v \sin i$ values, the possible frequency spacings are plotted against $v \sin i$. In cases with multiple $v \sin i$ values, the mean is used.

Table 5
Stars with Detected Frequency Spacings and Estimates of the First-order Rotational Splitting

ID	Δf (day^{-1})	$v \sin i$ (km s^{-1})
TIC 5076425 = GSC 05124-02524	0.0895 or 0.1790	…
TIC 11696250 = HD 228699	0.068 or 0.136 or 0.273	116 ± 10[a]
TIC 25070410 = HD 166331	0.1500 or 0.2999	77[b]
TIC 42365645 = HD 227977	0.0383 or 0.0484 or 0.0968	…
TIC 65166720 = KP Per	0.025 or 0.049 or 0.098	41.2[b], 20 ± 27[a], 40[c]
TIC 93730538 = CD-49 3738	0.073 or 0.1388 or 0.146 or 0.291	…
TIC 101423289 = HD 86248	0.059 or 0.118	…
TIC 105517114 = HD 190336	0.070 or 0.140	…
TIC 159932751 = V836 Cen	0.0124	…
TIC 264613619 = V757 Per	0.0145	25 ± 15[a], 55.6[b]
TIC 293680998 = IL Vel	0.0483	…
TIC 299821534 = HD 231124	0.221 or 0.443	…
TIC 308954763 = HD 232489	0.11 or 0.23	64.2[b]
TIC 312626970 = HD 228461	0.114 or 0.227	…
TIC 312637783 = HD 228456	0.036 or 0.072	…
TIC 314833456 = BD+55 2899	0.0460	
TIC 347486043 = HD 13338	0.0128 or 0.0257	…
TIC 348137274 = BD+56 477	0.0603 or 0.1206	64 ± 9[d], 31 ± 9[e]
TIC 348506748 = HD 14357	0.0865 or 0.1730	137 ± 7[d], 143[f]
TIC 361324132 = HD 344894	0.079 or 0.159	…
TIC 393662110 = V372 Sge	0.0889 or 0.1779	75.4[b], 80 ± 3[g]
TIC 461607866 = CD-44 4596	0.0346	…

Notes. For objects where several possible splittings were found, there is more than one solution. Literature values for $v \sin i$ are listed when available. $v \sin i$ measurements from:
[a] Huang et al. (2010).
[b] Głębocki & Gnaciński (2005).
[c] Abt et al. (2002).
[d] Marsh Boyer et al. (2012).
[e] Huang & Gies (2006).
[f] Simón-Díaz et al. (2017).
[g] Yudin (2001).

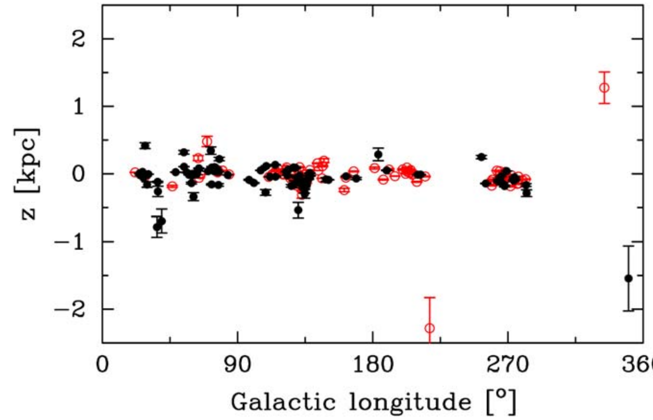

Figure 11. Distribution of β Cephei (filled black circles) and candidate stars (open red circles) according to their Galactic latitude and distance from the Galactic plane.

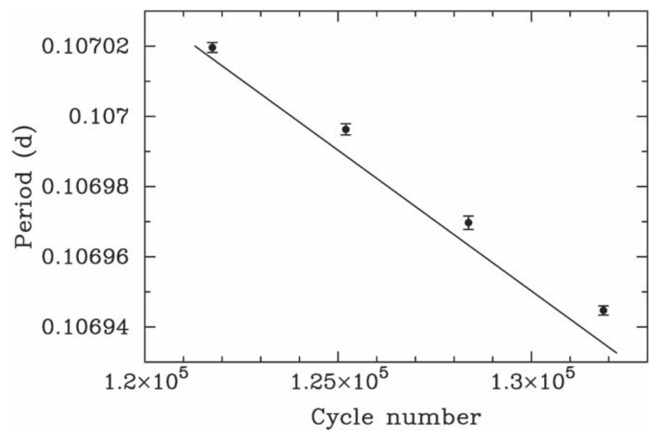

Figure 12. Yearly values of the pulsation period of V652 Her (dots with error bars) compared to the fit to earlier data by Kilkenny et al. (2005).

Table 6
Stars Located More than 400 pc away from the Galactic Plane

ID	z (kpc)	RV (km s^{-1})
	β Cephei stars	
TIC 61516388 = HD 178987	−1.5 ± 0.5	…
TIC 251637508 = HD 186610	−0.8 ± 0.2	+24.4[a]
TIC 308954763 = HD 232489	−0.5 ± 0.1	−32.0[a]
TIC 349332755 = HD 160233	+0.42 ± 0.04	+14.0[a]
TIC 392965683 = ALS 10332	−0.7 ± 0.2	…
	β Cephei candidates	
TIC 92193 = HD 130195	+1.3 ± 0.2	…
TIC 65516748 = HD 18100	−2.3 ± 0.5	+76.0[b]
TIC 137489662 = HD 183535	+0.48 ± 0.08	+14.0[b]

Notes. RV measurements from:
[a] Duflot et al. (1995).
[b] Kharchenko et al. (2007).

An additional three stars identified as candidates were rejected in this fashion. We conclude that a mistake-free selection of β Cephei stars is not possible from analyzing light curves and spectral-type information alone, but a reasonably clean sample for deeper investigation can be extracted using the criteria above.

Among the 113 stars finally classified as β Cephei, we found 22 (19%) with regular frequency spacings suggestive of rotational splitting of nonradial pulsation modes. In comparison, Pigulski & Pojmański (2008) detected only 7 such stars in their total sample of 103 (i.e., 7%). This is probably a consequence of the lower noise level in our data, only about one-third of that by Pigulski & Pojmański (2008, see Section 4.1). The average number of pulsation modes detected per star is 3.14 in our data, whereas it is 1.93 in the work by Pigulski & Pojmański (2008). On the other hand, the number of eclipsing binaries among the β Cephei pulsators is three in this work and four in Pigulski & Pojmański (2008). It is somewhat unfortunate that there is not yet a β Cephei pulsator with more than three oscillation modes that is part of an eclipsing SB2 system.

Aside from the eclipsing binaries, we found some unusual light-curve shapes for some of the pulsators. Whereas some of them can be associated with the stillstand phenomenon, others are more difficult to explain. The shapes of some of these light curves phenomenologically resemble those of close binary stars (including contact binaries), but the associated periods are too short to be explained that way. Time-resolved spectroscopy of these objects would be valuable to understand their true nature.

Some of the pulsating stars or candidates reported here are located at rather large distances from the Galactic plane and are therefore candidate runaway stars. This is interesting both from the stellar evolutionary and asteroseismic point of view because the flight time of a runaway star provides a limit on the stellar age that can be imposed on seismic models (Handler et al. 2019). Having such a constraint at hand could be of similar importance to basic stellar parameters from pulsators in eclipsing binaries.

These new discoveries (about a 70% increase over the currently known sample), plus previously known β Cephei stars, will be targeted by the TESS mission. The high-quality TESS light curves will then be used to perform asteroseismic studies on this population, which will reveal valuable information about the interior structure and evolution of massive stars.

J.L.-B. acknowledges support from FAPESP (grant 2017/23731-1). G.H. has been supported by the Polish NCN grant 2015/18/A/ST9/00578. L.B. acknowledges support from the NRF (South Africa) and thanks Mr. Trevor Robinson for database assistance. D.J.S. acknowledges support from the Pennsylvania State University's Eberly Research Fellowship. D.J.J. was supported through the Black Hole Initiative at Harvard University, through a grant (60477) from the John Templeton Foundation and by National Science Foundation award AST-1440254. This project makes use of data from the KELT survey, including support from The Ohio State University, Vanderbilt University, and Lehigh University, along with the KELT follow-up collaboration. This work has made use of data from the European Space Agency (ESA) mission Gaia (https://www.cosmos.esa.int/gaia), processed by the Gaia Data Processing and Analysis Consortium (DPAC, https://www.cosmos.esa.int/web/gaia/dpac/consortium). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the Gaia Multilateral Agreement. This research has made use of NASA's Astrophysics Data System. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France. This work has made use of the BeSS database, operated at LESIA, Observatoire de Meudon, France: http://basebe.obspm.fr.

Facilities: TESS, Gaia, KELT.

Software: astropy (Astropy Collaboration et al. 2013), Period04 (Lenz & Breger 2005).

Appendix A Notes on Individual Stars

A.1. β Cephei Stars

TIC 11698190 = HD 228690: There is a slow drift in the light curve with a timescale of about 280 days that appears to be intrinsic to the star. There is also evidence for more pulsation frequencies than detected here.

TIC 13967727 = HD 194205: The frequency spectrum is complicated, suggesting the presence of more β Cephei pulsation frequencies, but also binarity or rotational variability, or SPB-type pulsations, or any combination thereof.

TIC 25070410 = HD 166331: This star is listed as a spectroscopic binary by Bragança et al. (2012). There are also pulsation frequencies; see main text.

TIC 29123576 = CD-44 4876: The strongest pulsation frequency is likely to be variable in amplitude.

TIC 42940133 = HD 228101: Possible β Cephei/SPB "hybrid" pulsator and/or rotational modulation/binarity.

TIC 44980675 = HD 171305: Possible β Cephei/SPB "hybrid" pulsator.

TIC 55702566 = ALS 10035: More frequencies are present, but the periodogram is too complicated to push the analysis further. The low frequency detected indicates a possible β Cephei/SPB "hybrid" pulsator, or rotational modulation/binarity.

TIC 61516388 = HD 178987: This is likely a "hybrid" pulsator.

TIC 65166720 = KP Per: The pulsation amplitudes for this star are probably underestimated because of its brightness. There are regular frequency spacings; see main text.

TIC 75745359 = HD 80279: Possible β Cephei/SPB "hybrid" pulsator or rotational modulation/binarity.

TIC 80897625 = ALS 8706: The timescales of the temporal modulation of the variability amplitudes and phases of this Be star are different, which argues against a simple multifrequency beating phenomenon.

TIC 93723398 = HD 74339: There is a suspected $F6 = 5.222037$ day^{-1}, but unresolved from the strongest mode $F1$ in our data set (Table B1); Pigulski & Pojmański (2008) detected this mode.

TIC 128821888 = 12 Lac and TIC 129538133 = 16 Lac: The pulsation amplitudes of these bright famous β Cephei stars are strongly suppressed in our data as simultaneous observations from other telescopes available to one of us (G.H.) show.

TIC 159932751 = V836 Cen: Perhaps the pulsation amplitudes we determined here are somewhat suppressed due to some saturation of this bright star. See Section 4.2.4 for a detailed discussion of the pulsation spectrum.

TIC 168996597 = HD 225884: This is probably a β Cephei/SPB "hybrid" pulsator; the pulsation frequency $F4$ (Table B1) has variable amplitude.

TIC 175760664 = HD 180642: The pulsation amplitudes of this well-studied bright β Cephei star are probably somewhat suppressed in our data.

TIC 182714198 = BD-02 4752: This object shows binary-induced or rotational modulation with a base period of 2.629 days.

TIC 184874234 = HD 173006: This star shows the still-stand phenomenon (Pigulski & Pojmański 2008). We detect more harmonics of the pulsation frequency than these authors and also a very low frequency that appears to be real.

TIC 197332002 = HD 172367: This rapidly rotating star ($v \sin i = 240$ km s^{-1}; Daflon et al. 2007) is possibly a β Cephei/SPB "hybrid" pulsator.

TIC 216976987 = HD 332408: Possible shallow (≈3 mmag) eclipses with an 8.5862 day period.

TIC 234230792 = HD 49330: The CoRoT data of this Be star have been analyzed in detail by Huat et al. (2009); an alias of the strongest pulsation frequency in the latter paper is the strongest signal in our data.

TIC 245719692 = BD+57 614: Possible β Cephei/SPB "hybrid" pulsator or rotational modulation/binarity.

TIC 255974332 = ALS 6426: This heavily reddened star could be a β Cephei/SPB "hybrid" pulsator or show the effects of rotational modulation/binarity.

TIC 264613043 = V611 Per: This star could be a binary or rotationally modulated with a short period of 1.3277 days.

TIC 264613619 = V757 Per: This star was among the β Cephei candidates of Stankov & Handler (2005) and is confirmed here. It also has regular frequency spacings; see main paper text.

TIC 266338052 = HD 232874: This star could be a binary or an ellipsoidal variable or undergo rotational modulation with a period of 3.0358 days.

TIC 279659875 = BD+68 1373: This star shows some evidence for binary- or rotationally induced variability with a period of 3.2719 days.

TIC 287467101 = HD 140543: This high-Galactic-latitude, high-luminosity star (Section 4.2.5) may show "hybrid" β Cephei/SPB pulsations. Martin (2006) suggested that it could have formed in the Galactic halo and noted "irregularly shaped lines" in his spectra of HD 140543, perhaps an effect of nonradial pulsation.

TIC 287690192 = HD 339039: There appear to be many more pulsation modes of β Cephei type present in this star, yet daily aliasing and possible amplitude variations precluded their reliable detection. Some g-mode pulsations of the SPB type may also be present.

TIC 293680998 = IL Vel: We find a fourth signal in addition to the known mode triplet of the star (Handler et al. 2003); the presence of more pulsation frequencies is also indicated.

TIC 297259536 = HD 199021: Possible β Cephei/SPB "hybrid" pulsator or rotational modulation/binarity.

TIC 299821534 = HD 231124: Possible β Cephei/SPB "hybrid" pulsator or rotational modulation/binarity. There are regular frequency spacings; see main text.

TIC 308954763 = HD 232489: Strömgren photometry (Westin 1982) places this possible β Cephei/SPB "hybrid" pulsator or binary into the β Cephei domain on the H-R diagram, unlike its commonly quoted literature spectral type of B5 (Skiff 2014). There are regular frequency spacings; see main text.

TIC 311943795 = HD 228365: The frequency spectrum of the star contains two signals between the common β Cephei and SPB domains, perhaps an effect of rapid rotation. Our frequency analysis was hampered by some aliasing problems.

TIC 312630206 = HD 228463: We were able to detect as many as 12 independent mode frequencies for this star (Table B1), but the density of the frequency spectrum and some aliasing ambiguities hampered the identification of a possible rotational frequency splitting.

TIC 338076483 = BD+64 1677: Possible β Cephei/SPB "hybrid" pulsator.

TIC 347486043 = HD 13338: There are regular frequency spacings; see main text. We also find a binary or rotationally induced variation with a period of 1.7404 days.

TIC 348443241 = BD+56 560: Possible β Cephei/SPB "hybrid" pulsator.

TIC 348506748 = HD 14357: Possible β Cephei/SPB "hybrid" pulsator or rotational modulation/binarity. There are regular frequency spacings; see Section 4.2.4.

TIC 360063836 = HD 344775: The signal $F3$ in Table B1 is likely an artifact from amplitude/frequency variations of $F1$.

TIC 361324132 = HD 344894: The signal $F5$ in Table B1 is likely an artifact from amplitude/frequency variations of $F1$. There are regular frequency spacings; see Section 4.2.4.

TIC 370128780 = BD+58 241: Possible β Cephei/SPB "hybrid" pulsator or rotational modulation/binarity.

TIC 372724051 = V1143 Cas: The signals listed for this object are the combination of the star's β Cephei pulsations and that of a nearby ellipsoidal variable, V1142 Cas (see Handler & Meingast 2011).

TIC 391836737 = HD 30209: There are probably more pulsation frequencies in the β Cephei domain, but apparent amplitude/frequency variations of the dominant signal hamper their reliable detection.

TIC 393662110 = V372 Sge: Again, there is evidence for several more pulsation frequencies in the β Cephei domain, but apparent amplitude/frequency variations of the strongest signals hamper their reliable detection. There are also several possibilities for repetitive frequency splittings (Section 4.2.4).

TIC 399436828 = NGC 663 4: Whereas our algorithms originally identified this variable with the open cluster member NGC 663 2, a search in the surroundings revealed that in reality we recovered the pulsations of the known β Cephei star NGC 663 4. NGC 663 2 is thus rejected.

TIC 419354107 = BW Vul: The pulsation amplitudes of this famous "stillstand" star are suppressed in our data due to its brightness.

TIC 445619007 = HD 14645: Possible binary or rotational variable with a period of 1.58293 days.

TIC 451932686 = HD 344880: This is an eclipsing binary with an eccentric orbit and a long period; see main text for details.

TIC 469221047 = HD 86214: As for TIC 80897625, the amplitudes and phases of the two stellar oscillation modes are modulated in time. However, the present case is better described by a narrow frequency triplet ($\Delta f = 0.00327$ day^{-1}) and a frequency quadruplet ($\Delta f = 0.00492$ day^{-1}), respectively. We nevertheless prefer to list the two strongest signals only as we cannot rule out intrinsic amplitude/phase modulation.

TIC 469223889 = HD 86162: Possible β Cephei/SPB "hybrid" pulsator.

A.2. Candidate β Cephei Stars

TIC 11158867 = TYC 4032-93-1: Even though the available spectral classification for this star is B3, its dereddened $(B - V)$ color index and absolute magnitude instead point toward a δ Scuti/γ Doradus "hybrid" pulsator. We keep this star as a doubtful candidate.

TIC 12647534 = ALS 7011: We detected signals in both the β Cephei and SPB domains. This star has a B-type neighbor separated by only 89″ on the sky (TYC 4033-2268-1), and the frequency analysis of their data gives consistent results. However, a blending analysis reveals that ALS 7011, and not TYC 4033-2268-1, is the source of this variability.

TIC 13973539 = HD 229171: The low frequency $F2$ we found for this Be star (see Table B2) shows a slow amplitude and phase drift. However, as the timescales of the amplitude and phase change are different, we suspect a rotational modulation.

TIC 28949811 = CD-44 4871: The literature on this star suggests it is of early-B type, but the single frequency we found is unusually high for a β Cephei star and its S/N is low.

TIC 29036690 = CD-46 4639: This is an intermediate helium star located in the β Cephei instability strip (Groote et al. 1982).

TIC 29598925 = HD 76307: The absolute magnitude from the star's Gaia DR2 parallax is lower than expected given its spectral class.

TIC 30569481 = HD 76967: The relative amplitudes and values of the combination frequencies are unusual for a β Cephei pulsator; the pulsation amplitudes may be variable as well. The Gaia DR2 parallax and Strömgren H_β are consistent with the classification of a mid-B-type star, leading to the (inconclusive) suspicion that it may be a rapidly rotating SPB star.

TIC 43301361 = HD 192003: Taken at face value, the frequency spectrum and Gaia DR2 parallax point toward an unevolved β Cephei/SPB "hybrid" pulsator. However, an F0 star at 43″ distance may introduce some δ Scuti/γ Doradus–type variability due to blending.

TIC 53709049 = TYC 4030-800-1: The B1V star BD+60 175 is located 116″ from this object and is some 2.5 mag brighter. Therefore, we are not sure whether the reported variability indeed originates from TIC 53709049.

TIC 53968977 = BD+60 192: Our frequency analysis is based on the first two seasons of data only.

TIC 74197071 = CD-45 4896: The pulsation spectrum of this star is rather unusual for a β Cephei star, and it is near (or even below) the low-luminosity end of the β Cephei instability strip, hence it may be a rapidly rotating SPB pulsator.

TIC 78499882 = HD 249179: This Be star is located in a high-mass X-ray binary system and shows brightness variations consistent with disk variability that is typical of Be stars. It is not clear whether the high-frequency periodic variability we detected is indeed caused by β Cephei pulsation.

TIC 80814494 = HD 67980: The Strömgren H_β index for this star implies a spectral type around B3 (Crawford 1978) instead of B7II.

TIC 94000461 = HD 74581: This is a close visual double star, hence it is unclear from which source the variability originates.

TIC 123828144 = HD 62894: There is an A-type star of equal brightness 24″ distant from this object, which could be a δ Scuti pulsator.

TIC 137489662 = HD 183535: The Strömgren H_β index for this star implies a spectral type around B1 (Crawford 1978) rather than B5.

TIC 140309502 = CD-44 4484: There is some weak evidence for shallow (≈2 mmag) eclipses with a 13.721 (7) day period, but more precise photometry is required to confirm or reject this suspicion.

TIC 141903641 = CD-46 4437: In the light curve for CD-46 4432, we identified signals consistent with a possible β Cephei/SPB "hybrid" pulsator. However, the blending analysis shows this signal originating in the close visual double star CD-46 4437. Because the spectral type of the brighter of this pair is possibly consistent with β Cephei pulsation, we classify CD-46 4437 as a candidate.

TIC 143530557 = HD 279639 and TIC 145672806 = CPD-52 1713: Both stars are of later spectral type than usual β Cephei stars. We suspect they are rapidly rotating g-mode pulsators but cannot prove this as of yet.

TIC 190783321 = HD 76554: All literature information consistently suggests this is an early-B-type star, but its oscillation frequencies would be rather typical for a δ Scuti star and much higher than found among β Cephei pulsators.

TIC 207045768 = HD 258853: This star is probably not luminous enough to fall into the β Cephei strip, and each of the three variability frequencies is either the sum or the difference of the other two.

TIC 231149746 = TYC 746-578-1: The absolute magnitude of this star from its Gaia parallax is 2.6 ± 0.1. This suggests that either there is a problem with the original spectral classification (Karlsson 1972) or the parallax measurement.

TIC 252864874 = TYC 3324-92-1: The absolute magnitude of the star from Gaia DR2 and its pulsation frequencies suggest that this is a δ Scuti star rather than a β Cephei pulsator, and that perhaps there is a problem with the original spectral classification (Heckmann et al. 1956).

TIC 290300414 = HD 78507: The spectral classification and absolute magnitude of this star suggest it could be a rapidly rotating SPB star. Amplitude and frequency variations apparently occurred during the time span of our observations.

TIC 307944768 = HD 260858: This helium-rich star's absolute magnitude from the Gaia DR2 parallax and effective temperature (Netopil et al. 2008) suggest it has evolved off the main sequence. This is interesting because there is no post-main-sequence β Cephei star known to date. This star was recently found to host a strong magnetic field (Romanyuk et al. 2018).

TIC 319302209 = HD 220300: The pulsation spectrum and basic parameters of this rapidly rotating Be star are more reminiscent of a rapidly rotating SPB star than of a β Cephei pulsator. It has been detected as variable by the HIPPARCOS mission (reported by Kazarovets et al. 1999), but only Labadie-Bartz et al. (2017) described its variability in detail.

TIC 335484090 = V447 Cep: Besides the known short-period variability of this star (it was also classified as a candidate β Cephei star by Stankov & Handler 2005), we discovered that it is an eclipsing binary; see main text.

TIC 347585038 = V352 Per: This star was already listed as a β Cephei candidate by Stankov & Handler (2005).

TIC 348609224 = BD+56 579: This Be star has been identified as a visual double by Speckle Interferometry (Hartkopf & Mason 2009), which may have had an effect on its Gaia parallax measurement.

TIC 366108295 = ALS 6216: This spectroscopic binary has a pulsation frequency quite high for a β Cephei star; a 1.5 mag brighter B0.5 IV star is located 96″ away and could have had an influence on the measured variability. Our blending analysis does not indicate a blend scenario, but this is so far not conclusive.

TIC 368237682 = BD+66 1651: This Be and possible runaway star (Tetzlaff et al. 2010) shows variability in both the β Cephei and SPB star frequency domains. Its luminosity computed from the Gaia DR2 parallax is much lower than expected for its B3Ve spectral class.

TIC 370269139 = BD+55 334 and TIC 372115570 = BD +57 579: These stars have several visual companions close enough to qualify as potential sources for the observed variability.

TIC 384257658 = HD 78206: Whereas the literature spectral classification is B7/8V, the star's absolute magnitude from the Gaia parallax corresponds to that of a B2V star.

TIC 386693012 = HD 42896: This rapidly rotating ($v \sin i = 318\ \mathrm{km\ s^{-1}}$, Huang et al. 2010) luminous star shows quite high variability frequencies for a β Cephei star and several combinations thereof.

TIC 387153140 = BD-09 4742: The variability frequencies of this object are fairly high for a β Cephei star, and each of these three frequencies is either the sum or the difference of the other two.

TIC 419246605 = BD+61 77: Whereas this star is repeatedly classified as an early B spectral type in the literature, its absolute magnitude from the Gaia DR2 parallax is only +2.8. We note that the error on this parallax is unusually high and that the star has a visual companion one magnitude fainter 0.″3 apart, which may have affected the parallax measurement adversely.

TIC 422533344 = BD+59 254: In the light curve for TYC 4031-1770-1, we identified signals consistent with β Cephei pulsation. However, the blending analysis shows this signal originating in the neighboring star BD+59 254. The literature spectral type of BD+59 254 is A2, which is more consistent with δ Scuti pulsation. The frequencies we detect are more consistent with β Cephei pulsation though, so it is unclear what the nature of this object is.

TIC 427396133 = HD 37115: Because of some saturation issues (see Labadie-Bartz et al. 2017) with this data set and the removal of an apparent outburst of this Be star, the results of our frequency analysis should be treated with caution.

TIC 430625041 = CD-45 4501: We identified signals consistent with β Cephei pulsation in the light curve of CPD-45 2977. Our blending analysis shows this signal instead comes from CD-45 4501, which we estimate to have a spectral type consistent with β Cephei pulsations.

TIC 447933173 = HD 77769: Even though this star has three variability frequencies in the β Cephei domain and has been classified as such a pulsator in the past (Pigulski & Pojmański 2008), it is cooler and less luminous than the pulsators of this class. Its absolute magnitude from the Gaia DR2 parallax is −1.3, which is more consistent with a mid-B-type star.

TIC 458911894 = HD 19635: Based on the available data, it cannot be decided whether the detected triplet of frequencies is due to the beating of multiple signals or due to the amplitude/phase modulation of a single independent variation. In case of the interpretation as a triplet, it should be noted that its frequency asymmetry is of the opposite sign than expected from the second-order effect of rotation (e.g., Dziembowski & Goode 1992).

TIC 459014234 = BD+60 770: This is a visual double star with 8″ separation with the primary classified as a B5 spectral type. The pulsation spectrum is reminiscent of that of a δ Scuti star, and the Gaia DR2 parallax appears to corroborate that. However, given the visual binarity, we are not sure how accurate the parallax measurement is and keep the star in our list of candidates.

A.3. Rejected Stars

TIC 12647620 = TYC 4033-2268-1: The same signal exists in the light curves for both ALS 7011 and TYC 4033-2268-1, separated by 89″. Our blending analysis shows this signal as coming solely from ALS 7011, which we classify as a candidate.

TIC 26283875 = HD 221991/TYC 4000-2127-1: This is a visual double star with 18″ separation. The Gaia DR2 parallaxes of both objects show that they are A-type stars at very similar distances. We therefore conclude that at least one of them is a δ Scuti pulsator, responsible for the detected variability, and that the B5 spectral classification is erroneous.

TIC 28709025 = HD 75290: Levato & Malaroda (1975) give a spectral type of B9V, which is consistent with the measured Strömgren H_β index of 2.765 that suggests B8/9 (Crawford 1978), and with the star's absolute magnitude $M_v = -0.3$ from its Gaia DR2 parallax. We conclude that this cannot be a β Cephei star.

TIC 40102236 = HD 190088: As for the previous star, the Strömgren H_β index (2.748) and its absolute magnitude $M_v = -0.1$ from its Gaia DR2 parallax suggest this is a late-B-type and not a β Cephei star.

TIC 60320306 = HD 59446: Again, Strömgren photometry and the Gaia DR2 parallax of this star suggest a mid- to late-B spectral type. In addition, we are unsure whether the detected variability is not an artifact of saturation in the images of this bright star.

TIC 67985749 = HD 144941: This is an extreme helium star and therefore not of the β Cephei type; see Section 4.2.6.

TIC 90134626 = HD 72539: Also in this case, Strömgren photometry and the Gaia DR2 parallax of this star consistently point toward a mid- to late-B spectral type. The variability is therefore likely due to SPB-type pulsation, with frequencies pushed toward the β Cephei domain by rapid rotation.

TIC 93549165 = o Vel: This is a very bright prototype SPB star (De Cat & Aerts 2002). The variability detected in our light curves is certainly not due to the star, but an instrumental artifact.

TIC 102161004 = HD 331621: This is another case of a star that shows variability frequencies close to the β Cephei range, but its absolute magnitude is far below that of the known pulsators.

TIC 118680798 = HD 29450: Likewise, this star is too cool and not luminous enough to be even close to the β Cephei domain in the H-R diagram, as literature Strömgren photometry and the Gaia DR2 parallax demonstrate.

TIC 123754451 = HD 62755: Also in this case, literature Strömgren photometry and the Gaia DR2 parallax strongly argue against an interpretation of this star's variability as being caused by β Cephei pulsations due to its low effective temperature and luminosity.

TIC 138905907 = HD 290564: The absolute magnitude of this star and *UBV* photometry (Guetter 1979) suggest that this is a late-A/early-F star, and hence the variability we detected is of the δ Scuti type. Therefore, our preselection of this star was based on an incorrect spectral classification.

TIC 141903541 = CD-46 4432: Initially identified as a possible β Cephei/SPB "hybrid" pulsator. However, the blending analysis reveals that the signal originates in a source to the southwest, at the location of the close visual double CD-46 4437 (although we cannot resolve this visual double). Because it is possible that the brighter component is of the correct spectral type, we include CD-46 4437 as a candidate β Cephei star.

TIC 157535787 = HD 151654: There are two vastly different spectral classifications for this star in the literature, B0.5 V (Garrison et al. 1977) and F0 (Houk & Swift 1999). Strömgren photometry and the Gaia DR2 parallax corroborate the latter. Hence, this is a δ Scuti pulsator and not a β Cephei star.

TIC 162012064 = HD 181124: This case is similar to the former: Kelly & Kilkenny (1986) classified this star as B5, but Houk & Swift (1999) as A3 IV. The absolute magnitude of the star derived from Gaia DR2, its $(B-V)_0$ color index, and the high pulsation frequencies are clearly that of a δ Scuti and not a β Cephei star.

TIC 264485563 = HD 35612: This instance is similar to HD 62755. Again, the effective temperature from Strömgren photometry and the absolute magnitude from the Gaia DR2 parallax are incompatible with a β Cephei classification. The weak variability signal is also not convincing.

TIC 281803267 = TYC 4804-1086-1: The signal in our light curve for this object is from a relatively bright W UMa type binary 3′ to the southeast, V453 Mon.

TIC 291556636 = HD 59325: Geneva photometry of the star (Mermilliod et al. 1997) and its calibration (Kunzli et al. 1997) suggest that this is a mid- to late -B star on the main sequence. The Gaia DR2 parallax implies an absolute magnitude corresponding to a post-main-sequence star, but even so the star would not fall in any instability domain related to β Cephei stars (Daszyńska-Daszkiewicz et al. 2013). We conclude that this is most likely an SPB star with observed frequencies modified toward the β Cephei domain by rapid rotation.

TIC 352529679 = HD 190066: The variability detected in the measurements of this star could be traced to the data quality being vastly different depending on whether the telescope was pointed east or west. Removing the poor observations, no variability remains.

TIC 360661624 = ALS 10464: Initially identified as a β Cephei pulsator, although our blending analysis shows the signal coming from the star LS II +23 36, which is ~1 mag brighter and lies 85″ to the northeast. LS II +23 36 is included here as a candidate, as it may have a spectral type consistent with β Cephei pulsations.

TIC 377498419 = V652 Her: This is another extreme helium star that fulfilled our preselection criteria. The frequency solution in Table B3 is only informal due to the large rate of change of the pulsation period; see Section 4.2.6.

TIC 384992041 = TYC 3315–1807-1: A literature search readily shows that this is a close binary composed of a subdwarf star and a late-type main-sequence companion (Kawka et al. 2010).

TIC 399436782 = NGC 663 2: Whereas our algorithms identified this variable with the open cluster member NGC 663 2, a search in the surroundings revealed that in reality we recovered the pulsations of the known β Cephei star NGC 663 4, which is here categorized as a β Cephei star.

TIC 417438983 = HD 196035: The variability detected for this bright star is an integer multiple of the sidereal daily alias, suggesting that there are saturation effects in the photometry. The effective temperature of the star from Strömgren and Geneva photometry and the absolute magnitude from the Gaia DR2 parallax are both too low to place the star at least close to the known β Cephei domain in the H-R diagram.

TIC 422533347 = TYC 4031-1770-1: Initially identified as a β Cephei pulsator, although our blending analysis shows the signal coming from the neighboring star BD+59 254, which lies 77″ to the southwest. BD+59 254 is included as a candidate.

TIC 424032547 = HD 350990 and TIC 424032634 = TYC 1624-299-1: These two stars are separated by only 122″ on the sky; they are located in a dense region in the open cluster Roslund 3 that contains several stars of similar brightness, leading to blending and saturation issues. The variability detected for both of these stars occurs at frequencies that are integer multiples of the sidereal daily alias. These stars are also of too late spectral type and too low absolute magnitude to fall into the β Cephei domain.

TIC 426520557 = HD 254346: The variability detected in this data set contains both pulsations and eclipses. Whereas the amplitude of the eclipses does not significantly change depending on whether the telescope is pointed east or west, the amplitudes of the pulsations do. Furthermore, the pulsating star HD 43385, which is more than one magnitude brighter than HD 254346, is located at a distance of 112″. Strömgren photometry places HD 43385 into the δ Scuti instability strip. Hence, we interpret the observed variability as δ Scuti pulsations of HD 43385 in combination with eclipses of HD 254346, which itself shows no detectable pulsational variability; the eclipses are discussed in the main text.

TIC 430625174 = CPD-45 2977: The signal in our light curve comes from the $V = 9$ neighbor 2′ to the northeast, CD-45 4501, which is ~2 mag brighter than CPD-45 2977 in the V band. CD-45 4501 is categorized as a candidate.

TIC 434178307 = TYC 4269-482-1: Strömgren photometry and the Gaia DR2 distance point toward a very late-B or even an early-A star. The detected variability signals have poor S/N. Thus, there is no evidence that this could be a β Cephei pulsator.

TIC 446041643 = HD 282433: The effective temperature from Strömgren photometry and the absolute magnitude from the Gaia DR2 parallax are incompatible with a β Cephei classification. We allege that this is another case of a rapidly rotating SPB pulsator.

Appendix B
Frequency Tables

All recovered frequencies and their amplitudes are reported in Tables B1–B3.

B.1. β Cephei Stars

Table B1
Frequencies and Amplitudes Determined for the β Cephei Stars

ID	Freq. (day^{-1})	Amp. (mmag)
	TIC 5076425	
F1	5.63875(1)	37(1)
F2	5.88842(1)	33(1)
F3	5.81121(2)	20(1)
F4	5.45326(4)	10(1)

Note. Formal error estimates determined according to Montgomery & O'Donoghue (1999) are given in braces in units of the last significant digit. †Amplitudes may be largely suppressed.

(This table is available in its entirety in machine-readable form.)

B.2. Candidate β Cephei Stars

Table B2
Frequencies and Amplitudes Determined for the Candidate β Cephei Stars

ID	Freq. (day^{-1})	Amp. (mmag)
	TIC 92193	
F1	5.97644(5)	1.6(2)
	TIC 11158867	
F1	12.91477(8)	2.0(3)
F2	1.54085(9)	1.8(3)

Note. Formal error estimates determined according to Montgomery & O'Donoghue (1999) are given in braces in units of the last significant digit. †Amplitudes may be largely suppressed.

(This table is available in its entirety in machine-readable form.)

B.3. Rejected Stars

Table B3
Frequencies and Amplitudes Determined for the Rejected Stars

ID	Freq. (day^{-1})	Amp. (mmag)
	TIC 12647620	
F1	3.51173(5)	4.8(4)
F2	1.24177(8)	3.0(4)
	TIC 26283875	
F1	14.24270(9)	0.8(1)

Note. Formal error estimates determined according to Montgomery & O'Donoghue (1999) are given in braces in units of the last significant digit.

(This table is available in its entirety in machine-readable form.)

ORCID iDs

Jonathan Labadie-Bartz https://orcid.org/0000-0002-2919-6786
Gerald Handler https://orcid.org/0000-0001-7756-1568
Joshua Pepper https://orcid.org/0000-0002-3827-8417
Luis Balona https://orcid.org/0000-0003-1241-9792
Peter De Cat https://orcid.org/0000-0001-5419-2042
Daniel J. Stevens https://orcid.org/0000-0002-5951-8328
Michael B. Lund https://orcid.org/0000-0003-2527-1598
Keivan G. Stassun https://orcid.org/0000-0002-3481-9052
Joseph E. Rodriguez https://orcid.org/0000-0001-8812-0565
Robert J. Siverd https://orcid.org/0000-0001-5016-3359
David J. James https://orcid.org/0000-0001-5160-4486
Rudolf B. Kuhn https://orcid.org/0000-0002-4236-9020

References

Abt, H. A., Levato, H., & Grosso, M. 2002, ApJ, 573, 359
Aerts, C., Briquet, M., Degroote, P., Thoul, A., & van Hoolst, T. 2011, A&A, 534, A98
Aerts, C., Marchenko, S. V., Matthews, J. M., et al. 2006, ApJ, 642, 470
Aerts, C., Thoul, A., Daszyńska, J., et al. 2003, Sci, 300, 1926
Aerts, C., van Reeth, T., & Tkachenko, A. 2017, ApJL, 847, L7
Aerts, C., Waelkens, C., Daszyńska-Daszkiewicz, J., et al. 2004, A&A, 415, 241
Aerts, C., Waelkens, C., & de Pauw, M. 1994, A&A, 286, 136
Astropy Collaboration, Robitaille, T. P., Tollerud, E. J., et al. 2013, A&A, 558, A33
Barnsley, R. M., & Steele, I. A. 2013, A&A, 556, A81
Bragança, G. A., Daflon, S., Cunha, K., et al. 2012, AJ, 144, 130
Breger, M., Stich, J., Garrido, R., et al. 1993, A&A, 271, 482
Briquet, M., Neiner, C., Aerts, C., et al. 2012, MNRAS, 427, 483
Cannon, A. J., & Pickering, E. C. 1993, yCat, 3135, 0
Cargile, P. A., James, D. J., Pepper, J., et al. 2014, ApJ, 782, 29
Chen, B., Vergely, J. L., Valette, B., & Carraro, G. 1998, A&A, 336, 137
Chini, R., Hoffmeister, V. H., Nasseri, A., Stahl, O., & Zinnecker, H. 2012, MNRAS, 424, 1925
Clark, J. S., & Steele, I. A. 2000, A&AS, 141, 65
Cousins, A. W. J. 1982, IBVS, 2158, 1
Crawford, D. L. 1978, AJ, 83, 48
Currie, T., Hernandez, J., Irwin, J., et al. 2010, ApJS, 186, 191
Daflon, S., Cunha, K., de Araújo, F. X., Wolff, S., & Przybilla, N. 2007, AJ, 134, 1570
Daszyńska-Daszkiewicz, J., Ostrowski, J., & Pamyatnykh, A. A. 2013, MNRAS, 432, 3153
De Cat, P., & Aerts, C. 2002, A&A, 393, 965
De Cat, P., Briquet, M., Aerts, C., et al. 2007, A&A, 463, 243
De Cat, P. 2002, in ASP Conf. Ser. 259, IAU Coll. 185: Radial and Nonradial Pulsationsn as Probes of Stellar Physics, ed. C. Aerts, T. R. Bedding, & J. Christensen-Dalsgaard (San Francisco, CA: ASP), 196
Degroote, P., Briquet, M., Catala, C., et al. 2009, A&A, 506, 111
Deupree, R. G., & Beslin, W. 2010, ApJ, 721, 1900
Duflot, M., Figon, P., & Meyssonnier, N. 1995, A&AS, 114, 269
Dupret, M.-A., Thoul, A., Scuflaire, R., et al. 2004, A&A, 415, 251
Dziembowski, W. A., & Goode, P. R. 1992, ApJ, 394, 670
Dziembowski, W. A., Moskalik, P., & Pamyatnykh, A. A. 1993, MNRAS, 265, 588
Dziembowski, W. A., & Pamyatnykh, A. A. 2008, MNRAS, 385, 2061
Fokin, A., Mathias, P., Chapellier, E., Gillet, D., & Nardetto, N. 2004, A&A, 426, 687
Gaia Collaboration, Brown, A. G. A., Vallenari, A., et al. 2018, A&A, 616, A1
Gaia Collaboration, Prusti, T., de Bruijne, J. H. J., et al. 2016, A&A, 595, A1
Garrison, R. F., Hiltner, W. A., & Schild, R. E. 1977, ApJS, 35, 111
Głębocki, R., & Gnaciński, P. 2005, in 13th Cambridge Workshop on Cool Stars, Stellar Systems and the Sun, ed. F. Favata, G. A. J. Hussain, & B. Battrick (Noordwijk: ESA), 571
Groote, D., Kaufmann, J. P., & Lange, A. 1982, A&AS, 50, 77
Grunhut, J. H., Wade, G. A., Neiner, C., et al. 2017, MNRAS, 465, 2432
Guetter, H. H. 1979, AJ, 84, 1846
Handler, G. 2005, IBVS, 5667, 1
Handler, G. 2009, MNRAS, 398, 1339
Handler, G., Balona, L. A., Shobbrook, R. R., et al. 2002, MNRAS, 333, 262
Handler, G., Jerzykiewicz, M., Rodríguez, E., et al. 2006, MNRAS, 365, 327
Handler, G., & Meingast, S. 2011, A&A, 533, A70
Handler, G., Pigulski, A., Daszyńska-Daszkiewicz, J., et al. 2019, ApJL, 873, L4
Handler, G., Shobbrook, R. R., Vuthela, F. F., et al. 2003, MNRAS, 341, 1005
Hartkopf, W. I., & Mason, B. D. 2009, AJ, 138, 813

Heckmann, O., Dieckvoss, W., & Kox, H. 1956, AN, 283, 109
Heyndericks, D. 1992, A&AS, 96, 207
Houk, N., & Swift, C. 1999, Michigan Catalogue of Two-Dimensional Spectral Types for the HD Stars, Vol. 5 (Ann Arbor, MI: Univ. Michigan Press)
Huang, W., & Gies, D. R. 2006, ApJ, 648, 580
Huang, W., Gies, D. R., & McSwain, M. V. 2010, ApJ, 722, 605
Huat, A.-L., Hubert, A.-M., Baudin, F., et al. 2009, A&A, 506, 95
Ikhsanov, R. N. 1959, IzKry, 21, 229
Jaschek, M., & Egret, D. 1982, in IAU Symp. 98, Be Stars, ed. M. Jaschek & H.-G. Groth (Cambridge: Cambridge Univ. Press), 261
Jeffery, C. S. 2014, in IAU Symp. 301, Precision Asteroseismology, ed. J. A. Guzik et al. (Cambridge: Cambridge Univ. Press), 297
Jeffery, C. S., & Ramsay, G. 2018, MNRAS, 475, L122
Jurcsik, J., Sodor, A., & Hajdu, G. 2009, IBVS, 5881, 1
Karlsson, B. 1972, A&AS, 7, 35
Kawka, A., Vennes, S., Németh, P., Kraus, M., & Kubát, J. 2010, MNRAS, 408, 992
Kazarovets, E. V., Samus, N. N., Durlevich, O. V., et al. 1999, IBVS, 4659, 1
Kelly, B. D., & Kilkenny, D. 1986, SAAOC, 10, 27
Kharchenko, N. V., Scholz, R. D., Piskunov, A. E., Röser, S., & Schilbach, E. 2007, AN, 328, 889
Kilkenny, D., Crause, L. A., & van Wyk, F. 2005, MNRAS, 361, 559
Kilkenny, D., Koen, C., Jeffery, C. S., Hill, N. C., & O'Donoghue, D. 1999, MNRAS, 310, 1119
Koen, C., & Eyer, L. 2002, MNRAS, 331, 45
Kunzli, M., North, P., Kurucz, R. L., & Nicolet, B. 1997, A&AS, 122, 51
Kurtz, D. W., Shibahashi, H., Murphy, S. J., Bedding, T. R., & Bowman, D. M. 2015, MNRAS, 450, 3015
Labadie-Bartz, J., Pepper, J., McSwain, M. V., et al. 2017, AJ, 153, 252
Lenz, P., & Breger, M. 2005, CoAst, 146, 53
Levato, H., & Malaroda, S. 1975, PASP, 87, 173
Liu, Z., Cui, W., Liu, C., et al. 2019, ApJS, 241, 32
Luri, X., Brown, A. G. A., Sarro, L. M., et al. 2018, A&A, 616, A9
Maeder, A. 1987, A&A, 178, 159
Marsh Boyer, A. N., McSwain, M. V., Aragona, C., & Ou-Yang, B. 2012, AJ, 144, 158
Martin, J. C. 2006, AJ, 131, 3047
Martins, F., & Palacios, A. 2013, A&A, 560, A16
Mathias, P., Gillet, D., Fokin, A. B., & Cambon, T. 1998, A&A, 339, 525
Mazumdar, A., Briquet, M., Desmet, M., & Aerts, C. 2006, A&A, 459, 589
Mermilliod, J.-C., Mermilliod, M., & Hauck, B. 1997, A&AS, 124, 349
Meynet, G., Eggenberger, P., & Maeder, A. 2011, A&A, 525, L11
Moe, M., & di Stefano, R. 2015, ApJ, 801, 113
Montgomery, M. H., & O'Donoghue, D. 1999, DSSN, 13, 28
Moskalik, P., & Dziembowski, W. A. 1992, A&A, 256, L5
Mowlavi, N., & Forestini, M. 1994, A&A, 282, 843
Napiwotzki, R., Schoenberner, D., & Wenske, V. 1993, A&A, 268, 653
Nesterov, V. V., Kuzmin, A. V., Ashimbaeva, N. T., et al. 1995, A&AS, 110, 367
Netopil, M., Paunzen, E., Maitzen, H. M., North, P., & Hubrig, S. 2008, A&A, 491, 545
Pamyatnykh, A. A., Handler, G., & Dziembowski, W. A. 2004, MNRAS, 350, 1022
Paunzen, E. 2015, A&A, 580, A23
Pecaut, M. J., & Mamajek, E. E. 2013, ApJS, 208, 9
Pepper, J., Kuhn, R. B., Siverd, R., James, D., & Stassun, K. 2012, PASP, 124, 230
Pepper, J., Pogge, R. W., DePoy, D. L., et al. 2007, PASP, 119, 923
Petit, V., Keszthelyi, Z., MacInnis, R., et al. 2017, MNRAS, 466, 1052
Pigulski, A., Cugier, H., Popowicz, A., et al. 2016, A&A, 588, A55
Pigulski, A., & Pojmański, G. 2008, A&A, 477, 917
Poveda, A., Ruiz, J., & Allen, C. 1967, BOTT, 4, 86
Renson, P., & Manfroid, J. 2009, A&A, 498, 961
Ricker, G. R., Winn, J. N., Vanderspek, R., et al. 2014, Proc. SPIE, 9143, 914320
Rivinius, T., Baade, D., & Carciofi, A. C. 2016, A&A, 593, A106
Rivinius, T., Carciofi, A. C., & Martayan, C. 2013, A&ARv, 21, 69
Romanyuk, I. I., Semenko, E. A., Moiseeva, A. V., Kudryavtsev, D. O., & Yakunin, I. A. 2018, AstBu, 73, 178
Saesen, S., Briquet, M., Aerts, C., Miglio, A., & Carrier, F. 2013, AJ, 146, 102
Salmon, S. J. A. J., Montalbán, J., Reese, D. R., Dupret, M.-A., & Eggenberger, P. 2014, A&A, 569, A18
Shibahashi, H., & Aerts, C. 2000, ApJL, 531, L143
Sikora, J., Wade, G. A., Power, J., & Neiner, C. 2019, MNRAS, 483, 2300
Simón-Díaz, S., Godart, M., Castro, N., et al. 2017, A&A, 597, A22
Skiff, B. A. 2014, yCat, 2023, 1
Stankov, A., & Handler, G. 2005, ApJS, 158, 193
Stassun, K. G., Oelkers, R. J., Pepper, J., et al. 2018, AJ, 156, 102
Steele, I. A., & Clark, J. S. 2001, A&A, 371, 643
Steele, I. A., Negueruela, I., & Clark, J. S. 1999, A&AS, 137, 147
Štefl, S., Baade, D., Rivinius, T., et al. 1998, in ASP Conf. Ser. 135, A Half Century of Stellar Pulsation Interpretation, ed. P. A. Bradley & J. A. Guzik (San Francisco, CA: ASP), 348
Stephenson, C. B., & Sanduleak, N. 1971, PW&SO, 1, 1
Sterken, C., Snowden, M., Africano, J., et al. 1986, A&AS, 66, 11
Sterken, C., Young, A., & Furenlid, I. 1987, A&A, 177, 150
Straizys, V., Kurucz, R. L., Philip, A. G. D., & Valiagua, G. 1993, BaltA, 2, 326
Sudzius, J., & Bobinas, V. 1992, VilOB, 86, 59
Tetzlaff, N., Neuhaeuser, R., & Hohle, M. M. 2010, MNRAS, 410, 190
Waelkens, C., & Rufener, F. 1983, A&A, 119, 279
Westin, T. N. G. 1982, A&AS, 49, 561
Wisniewski, J. P., Chojnowski, S. D., Davenport, J. R. A., et al. 2015, ApJL, 811, L26
Wright, C. O., Egan, M. P., Kraemer, K. E., & Price, S. D. 2003, AJ, 125, 359
Wright, E. L., Eisenhardt, P. R. M., Mainzer, A. K., et al. 2010, AJ, 140, 1868
Yudin, R. V. 2001, A&A, 368, 912
Zdanavičius, J., & Zdanavičius, K. 2005, BaltA, 14, 1
Zwicky, F. 1957, Morphological Astronomy (Berlin: Springer)