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Review Article

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Abstract: This paper reviews recent seismic findings from Kepler and K2 data. Using three years of short cadence Kepler (K1) data, it is possible to examine time evolution of pulsations in an unprecedented way. While K2 observations are shorter, only three months, they are important as they are finding more sdBV stars than K1 did. Most importantly, K2 is discovering more p–mode pulsators with coverage not possible to get from the ground.

Keywords: Kepler & K2 observations of sdBV stars

1 Introduction

The Kepler spacecraft is a 0.95 m Schmidt telescope with a CCD array which originally covered 105 square degrees. Its primary mission (K1) obtained data from May 2009 until May 2013 with the first four quarters dedicated to monthly surveys of targets. For many stars, three years of continuous data were obtained with a 92% duty cycle, allowing for unprecedented continuous monitoring.

While the mission was designed for detecting planetary transits, it also provided revolutionary data sets for variable stars. Continuous stellar monitoring meant that pulsation cycle after pulsation cycle would be observed. Therefore the Kepler space telescope is an ideal instrument for asteroseismology.

The main goal of asteroseismology is to provide observational constraints for stellar models. Those can include pulsation frequencies, but a list of frequencies without mode identifications is not especially constraining. Therefore the major goal of asteroseismology is to correlate pulsations with modes, which are described by spherical harmonics. The pulsation geometry is described by three quantized quantities dsignated as n, ℓ, and m, which represent the number of radial nodes, surface nodes, and surface nodes which pass through the pulsation axis, respectively. When observational mode identifications can be made, then overtone spacings are also constrained, and trapped modes can also be detected.

During the K1 mission, 18 pulsating subdwarf B (sdBV) stars were discovered. All were observed in short-cadence mode, which obtained a new image every 58.85 seconds. Over the course of K1 observations, this totaled over 1.55 million observations with a 1/T temporal resolution of 0.007 μHz. All of the sdBV stars observed during K1 were new discoveries. Of these, 16 are predominantly g–mode pulsators and two are p–mode pulsators. As reported in Østensen et al. (2011a) 32 sdB stars with $T_{\rm eff}$ > 28 000 K were observed during the K1 survey phase, of which two are predominantly p–mode pulsators and one predominantly a g–mode pulsator. Of the 16 sdB stars with $T_{\rm eff}$ < 28 000 K twelve pulsate with mostly g modes. Guest Observer proposals during K1 obtained data on five known sdB stars in the old open cluster NGC 6791. The two hotter stars did not pulsate and all three of the cool ones were discovered to be g–mode pulsators (Reed et al. 2012; Pablo et al. 2011).

After the second reaction wheel failed, the spacecraft began a new campaign called K2, where it observes along the ecliptic, using solar pressure and thrusters to maintain pointing (Howell et al. 2013). The spacecraft is typically in a rear-facing position which can maintain pointing balance and thermal and light shields constraints for

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no more than about 95 days. Campaign 0 (C0) began in May of 2008 and, as of this writing, data through Campaign 12 (C12) have been released, which covers observations ending in March of 2017. Through C12 our collaboration has received SC data for 71 of our proposed targets. Of these, four were previously known to be pulsators and 25 new sdB pulsators have been discovered. K2 campaigns span roughly 80 days, which is a resolution of 0.14 μHz. For SC data this results in roughly 115 000 images, and unlike K1, these are not processed into lightcurves and deposited at the Mikulski Archive for Space Telescopes (MAST). There are available PyKE programs for image processing (Still & Barcklay 2012), but we found these to be less-than-optimal for sdB stars and so we developed our own custom processing method (Baran et al. 2017). In brief, we calculate image centers and then extract fluxes using apertures which follow the stellar motion across pixels. Drift across differing pixel sensitivies (termed "thruster firings" as that is part of the cause) is then corrected using custom decorrelation programs. In this manner, we examine each K2-observed sdB star for variability one at a time.

Table 1 lists properties of 33 Kepler-observed sdBV stars, plus one BHB star, reflecting roughly the state of publications from our collaboration. As several of these publications are "in progress", final numbers may change.

As part of our follow-up work, our group has been obtaining spectra, mostly at the Nordic Optical Telescope (NOT; Telting et al. 2014). These spectra are used to determine $T_{\rm eff}$ and $\log g$, but also to look for velocity variations indicative of binarity. An additional benefit of obtaining, processing, and analyzing our own spectroscopy is that our Kiel ($T_{\rm eff} - \log g$) diagrams are on a common scale. The values might have systematic shifts but relative values are accurate and so we can examine things like the transition from p to g modes.

During the first year of the K1 mission, seismic targets were observed for one month in SC mode. For sdBV stars, those data were sufficient to discover asymptotic period sequences for g–mode pulsations (Reed et al. 2011), making mode identification possible. Asymptotic period sequences have previously been reviewed (Reed & Foster 2014; Heber 2016), so we will not repeat that here. As of this writing nine K1-observed sdBV stars have had their full data sets analyzed. Typically 60-80% of the periodicities are able to be associated with asymptotic $\ell = 1$ or 2 modes. The g–mode asymptotic period spacings are provided in Table 1.

Baran et al. (2012) discovered rotationally-split frequency multiplets in the K1 predominantly-p–mode pulsator KIC 10139564 (AKA and hereafter Saradoc). As each degree produces $2\ell + 1$ azimuthal modes ($\ell = 1$ form triplets, $\ell = 2$ form quintuplets, etc., depending on inclination angle) this allowed another method for mode identification of both ℓ and m quantum numbers. Rotation (combined with the Ledoux factor; Ledoux 1951)) usually removes the azimuthal degeneracy, and so the frequency splittings of multiplets indicate the rotation period. If multiplets are observed then rotation periods can be determined. As the Ledoux constant is near zero for p modes but is approximately $1/[\ell(\ell + 1)]$ for g modes, it can be used as another tool for identifying pulsation modes. This is especially useful when multiplets are incomplete and for distinguishing $\ell = 1$ triplets from $\ell = 2$ quintuplets which are missing the $m = |1|$ modes because of viewing inclination. This makes frequency multiplets an extremely useful tool as they provide two means of mode identifications; the number of multiplet members and the frequency splittings between them. In addition, as pulsations are a geometric effect, the pulsation amplitudes can be affected by inclination of the pulsation axis Pesnell (1985). For cases where pulsation amplitudes remain nearly constant, this was used to constrain the pulsation inclination angle (Baran et al. 2012; Reed et al. 2014; Foster et al. 2015).

We also discovered that many pulsators are hybrid, with both p and g modes. As p modes are most sensitive to surface conditions and g modes are more sensitive deeper towards the core, hybrid pulsators are able to sample a range of the stellar interior. Table 1 and Figure 1 list and show the spectroscopic properties of the various pulsation types. Solid red squares are 24 K1-observed non-pulsating sdB stars with $T_{\rm eff}$ and $\log g$ determined using the same techniques as the pulsators, for comparison. Predominantly g–mode pulsators all have $T_{\rm eff} < 30\,000$ K and five of the twelve are hybrid pulsators. However, they do not crowd around the hot edge, but rather appear intermixed with g–mode only pulsators. It might be expected that with K1 sensitivity of 1.5 million observations, that all could be detected as hybrid, but this is not the case as both the hottest and coolest hybrids have been discovered with K2 data. An additional, currently unknown, parameter or multiple parameters must be responsible for the difference.

With K1's extended duration of observations, more than three years in many cases, we can examine the time evolution of pulsations. Such an examination has brought about the development of other tools. Sliding Fourier transforms (hereafter sFTs) were found to be exquisitely useful for examining how pulsations evolve over time. An important example is shown in Fig 2. If only the first month of K1 data were examined for KIC 10670103, many multiplets would have appeared as singlets. However, over the course of the K1 observations, all members are excited

Table 1. Spectroscopic and seismic properties of Kepler-observed sdBV stars. Column 1 provides the KIC or EPIC identifications, column 2 the pulsation type where *p* are *p*–mode only pulsators, *p* + *g* are predominantly *p* mode hybrid pulsators, *g* are *g*–mode only pulsators, and *g* + *p* are predominantly *g* mode hybrid pulsators. Column 3 provides the number of pulsation periodicities, columns 4 and 5 provide spectroscopic properties, and column 6 the *g*–mode asymptotic period spacing for $\ell = 1$. Column 7 provides the binary status where sdB is listed for single stars, sdB+WD for those with white dwarf companions, sdB+dM for those with M-dwarf main sequence compansions and sdB+F or sdB+G for those with main sequence F or G companions. Column 8 provides the rotation rate and if two values are given, the first is for the envelope and the second for deeper interior. Column 9 provides the binary period and Column 10 a reference. The references are 1: Østensen et al. (2014a), 2: Baran et al. (2012), 3: Baran (2012), 4: Baran (2012); Kern et al. (2017), 5: Reed et al. (2011), 6: Usundag et al. (2017), 7: Reed et al. (2012), 8: Baran et al. (2015), 9: Reed et al. (2014), 10: Telting et al. (2014), 11: Østensen et al. (2014b), 12: Telting et al. (2012), Kern et al. (2017) (*in press*), 13: Baran et al. (2016), 14: Østensen et al. (2010a); Reed et al. (2011), 15: Baran & Winans (2012), 16: Østensen et al. (2012a), 17: Reed et al. 2017 (*in press*), 18: Crooke *et al.* 2017 (*in preparation*), 19: Ketzer et al. 2017 (*in preparation*), 20: Baran et al. (2017), 21: Ketzer et al. (2017), 22: Bachulski et al. (2016), 23: (*in preparation*), 24: Reed et al. (2014), 25: Jeffery & Ramsary (2014), 26: Jeffery et al. (2017).

KIC #	Type	No. of periodicities	T_{eff} (K/1 000)	log *g* (dex)	$\Delta\Pi_{\ell=1}$ (s)	Binary status	P_{spin} (d)	P_{orbit} (d)	Ref.
2991276	*p*	8	33.9	5.82	–	sdB	6.3	–	1
			(0.2)	(0.04)	–		–	–	
10139564	*p* + *g*	57	31.86	5.673	–	sdB	25.6	–	2
			(0.13)	(0.026)	–		(1.8)	–	
2697388	*g* + *p*	256	23.39	5.29	240.06	sdB	41.9/52.8	–	3
			(0.12)	(0.02)	(0.19)		(3.6)/(9.3)	–	
3527751	*g* + *p*	251	27.82 (0.16)	5.35 (0.03)	266.4 (0.2)	sdB	45	–	4
			(0.16)	(0.03)	(0.2)				
5807616	*g* + *p*	18	27.1	5.51	242.12	sdB	–	–	5
			–	–	–		–	–	
10001893	*g* + *p*	110	26.7	5.3	268.0	sdB	–	–	6
			–	–	(0.5)		–	–	
2437937	*g*	9	23.84	5.31	242.6	sdB	–	–	7
			(0.68)	(0.09)	(1.5)		–	–	
2569576	*g*	4	24.25	5.17	234.6	sdB	–	–	7
			(0.46)	(0.05)	(0.6)		–	–	
8302197	*g*	30	27.45	5.439	258.61	sdB	–	–	8
			(0.20)	(0.033)	(0.62)		–	–	
10670103	*g*	278	21.485	5.14	251.6	sdB	88	–	9
			(0.540)	(0.05)	(0.2)		(8)	–	
7668647	*g* + *p*	132	27.7	5.50	248	sdB+WD	50.5	14.174	10
			(0.3)	(0.03)	–		(0.5)	(0.004)	
10553698	*g* + *p*	162	27.423	5.436	263.15	sdB+WD	42.9	3.387	11
			(0.293)	(0.024)	–		–	(0.014)	
11558725	*g* + *p*	244	27.91	5.41	244.45	sdB+WD	45	10.055	12
			(0.32)	(0.012)	(0.32)		–	(0.005)	
7664467	*g*	61	27.44	5.38	260.02	sdB+WD	35.1	1.5591	13
			(0.12)	(0.02)	(0.77)		(0.6)	(0.00006)	
9472174	*g* + *p*	> 100	29.6	5.42	255.63	sdB+dM	0.1258	0.1258	14
			–	–	(0.3)		–	–	
11179657	*g* + *p*	43	26	5.14	231.02	sdB+dM	7.2	0.394	15
			–	–	(0.02)		–	–	
2438324	*g*	19	27.10	5.69	240.3	sdB+dM	9.6	0.398	15
			(0.82)	(0.10)	(2.9)		–	–	
2991403	*g*	38	27.3	5.43	268.52	sdB+dM	10.46	0.443	15
			–	–	(0.74)		–	–	
1718290†	*g*	54	21.796	4.67	276.3	BHB	96.5	–	16
			(0.144)	(0.03)	–		–	–	

Table 1. ... continued

EPIC #	Type	No. of periodicities	$T_{\rm eff}$ (K/1 000)	log g (dex)	$\Delta\Pi_{\ell=1}$ (s)	Binary status	$P_{\rm spin}$ (d)	$P_{\rm orbit}$ (d)	Ref.
211823779	p	16	36	6	–	sdB+F1V	11.5	–	17
			–	–	–		(0.8)	–	
211938328	p	8	32	5.8	–	sdB+F6V	21.5	635	17
			–	–	–		(0.6)	(146)	
212508753	$p+g$	79	37	–	–	sdB+G	16	–	18
			–	–	–		(1)	–	
220614972	$p+g$	223	35	5.6	–	sdB+G	4.39/> 45	–	19
			–	–	–		(0.48)/–	–	
211779126	$g+p$	133	28.542	5.39	253.3	sdB	16	–	20
			(0.082)	(0.01)	(0.8)		–	–	
203948264	g	22	26.76	5.26	261.34	sdB	45.9	–	21
			(0.61)	(0.09)	(0.78)		(.8)	–	
212707862	g	13	28.298	5.479	252.6	sdB	80	–	22
			(0.162)	(0.025)	(1.1)		–	–	
215776487	g	16	28.3	5.8	–	sdB	–	–	23
			–	–	–		–	–	
217280630	g	7	22.3	5.0	–	sdB	–	–	23
			–	–	–		–	–	
218366972	g	47	28.2	5.4	251	sdB	–	–	23
			–	–	–		–	–	
218717602	g	17	24.85	5.26	260	sdB	–	–	23
			–	–	–		–	–	
201206621	g	14	27.954	5.32	267.9	sdB+WD	> 45	0.54109	24
			(0.054)	(0.01)	(1.0)		–	(0.00002)	
211696659	g	10	27.12	5.419	227.05	sdB+WD	28.4	3.1621	17
			(0.64)	(0.069)	(0.56)		(1.4)	(0.0013)	
202065500	$g+p$	16	29.85	5.71	234	sdB+dM	10	0.80	25
			–	–	–		–	–	
211623711†	g	4	38.9	5.97	–	He-sdB	–	–	26
			(0.27)	(0.11)	–		–	–	

for some of the time. As had been previously reported, sdBV pulsation amplitudes can vary in unpredictable ways (Reed et al. 2004; Killkenny 2010). Sliding FTs clearly show this phenomenon, with the outcome that amplitude variations complicate the FT, often creating sidelobes and forked peaks. The practical upshot is that the traditional method of non-linear least-squares lightcurve fitting and prewhitening will not work for characterizing the pulsations. Instead, we have most often used Lorentzian fitting where the width represents the frequency error. In solar-like oscillators, Lorentzian widths are an indicator of mode lifetimes (Aerts et al. 2010), though with one exception (discussed below), we do not use them in that manner. We only use them as a proxy for frequency error as they indicate the width of the peak in the FT as caused by amplitude and/or phase variations. With the incredible precision of K1 data, frequencies can also readily be determined using by-eye fits, which has also been done. Amplitude variations make the reporting of amplitudes difficult and with little meaning. Should authors report the maximum amplitude or the average amplitude? Both have been done. Another complication is determining which frequencies to report. Ground-based data may typically span one or two weeks, at best (e.g. Reed et al. 2007) and so if one month of K1 data has a frequency with an amplitude at, say 6σ but that frequency is only observed during that month and so in the full data set it only has an amplitude of 2σ, should it be reported? If that particular month were observed from the ground, it surely would be included. Again, in some cases such frequencies have been reported (e.g. Ketzer et al. 2017) and in some cases they have not.

It is presumed that frequency multiplets are caused by rotation lifting the azimuthal degeneracy with frequency splittings of $\Delta\nu = \Delta m\Omega\left(1 - C_{n,\ell}\right)$ where $\Delta\nu$ is the frequency splitting from the $m = 0$ mode, Ω is the stellar rotation frequency, and $C_{n,\ell}$ is the Ledoux constant (Ledoux 1951). For p modes, the Ledoux constant is small, while for g modes it is $C_{n,\ell} \approx \frac{1}{\ell(\ell+1)}$. Using this information, if frequency multiplets are observed, the rotation period can readily be determined. Table 1 lists determined rota-

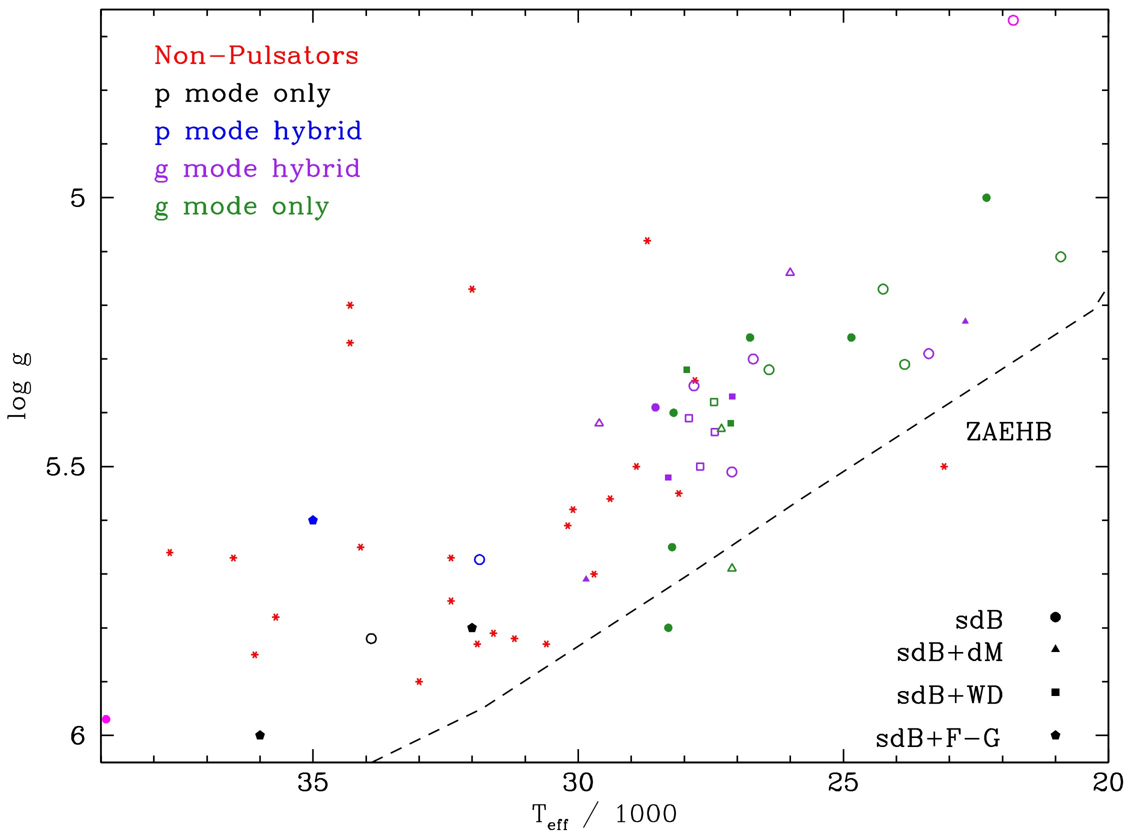

Figure 1. $T_{\rm eff}$ − log g (Kiel) diagrams of sdBV stars. K1 (open points) and K2 (filled points) sdBV stars. Red asterisks are non-pulsators (from Østensen et al. 2010b; Østensen et al. 2011a) and the magenta points are the BHB pulsator of (Østensen et al. 2012a) and the He-sdB pulsator of (Jeffery et al. 2017). Pulsator colors and point types provided in the figure. The dashed line is the zero-age extended horizontal branch for a total mass of $0.5M_{\odot}$ with varying envelope mass.

tion periods and the top right panel of Fig. 3 shows then against $T_{\rm eff}$. The first discovery is that they tend to be long, tens of days. This solves the issue of why they weren't often detected in most ground-based observations (see the discussion in Reed 2008). It also brought to light a surprising discovery: *All* sdB stars in binaries with orbital periods longer than a few hours *rotate subsynchronously*, in defiance of previous assumptions of tidal locking (e.g. Geier et al. 2011). This includes several binaries with periods near half a day! Another interesting trend which is starting to appear, and previously mentioned in Reed et al. (2014) is that lower $T_{\rm eff}$ tend to have longer rotation periods. This is especially apparent once the sdB stars with dM companions are excluded. Typically, hotter stars have had more atmosphere stripped off, and perhaps rotation is a remnant indicator of that mechanism, but it is too early to tell if that is the case. Unfortunately, K2 observations can only detect rotation periods ≤ 45 days and so can only fill in the shorter periods.

It has been observed in white dwarfs that changes in density (or mean molecular weight) can create "boundaries" which trap modes (Winget et al. 1981) and prior to K1 observations, it was presumed that mode trapping would disrupt asymptotic g mode sequences to the point of making them undetectable. However, asymptotic sequences are usually observed in every g–mode sdBV star, sometimes with extremely long, uninterrupted sequences (e.g. Reed et al. 2014). But trapped modes have been discovered in a few stars (Østensen et al. 2014b; Foster et al. 2015; Kern et al. 2017; Usundag et al. 2017). It is hoped that trapped modes in otherwise smooth sequences will be able to discern internal conditions, but it is somewhat early and all K1 sdBV stars need to be carefully examined for trapped modes.

1.1 K1 enigmas

Frequency multiplets can discern rotation and when hybrid pulsators show both p– and g–mode multiplets, rotation can be examined at differing radial depths. To date, there are five cases where this can be examined. In three

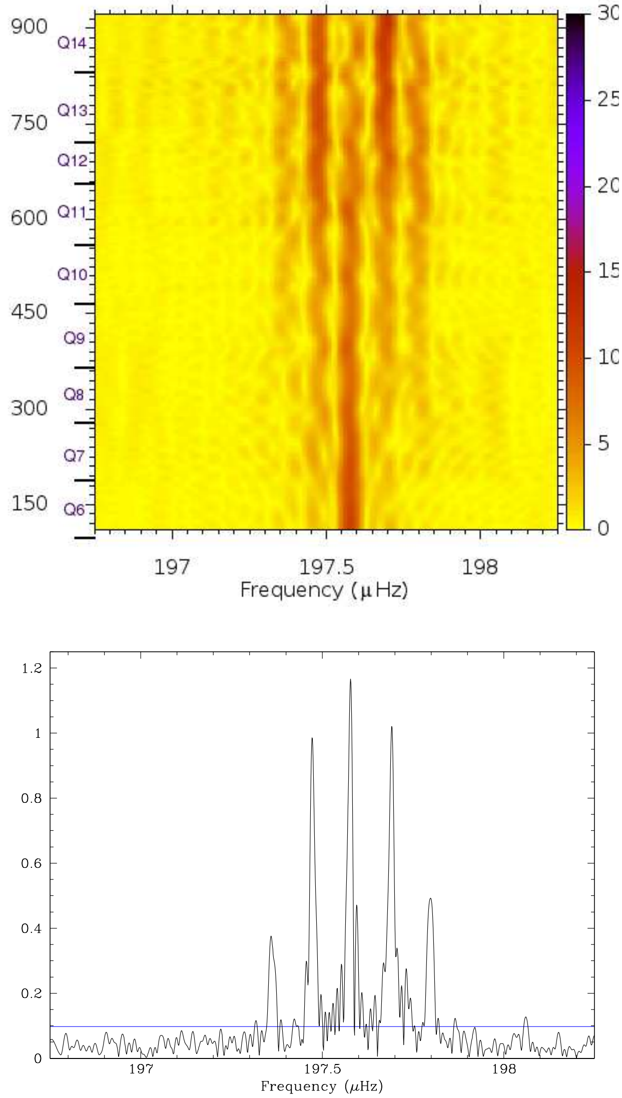

Figure 2. Sliding Fourier transforms (sFTs; top panel) shown with the FT (bottom) of the total data set. Figures from Reed et al. (2014).

stars (Kern et al. 2017; Crooke *et al.* 2017; Baran et al. 2012), multiplets indicate solid-body rotation while in two others (Ketzer et al. 2017; Foster et al. 2015) the g–mode rotation period is several times longer than the p–mode one. Again, there is no pattern as two of the solid-body rotators are $p + g$ mode hybrids and one $g + p$ mode hybrid while there is one each of the differential rotators. As there are still many Kepler-observed sdBV stars to analyze, perhaps enough will be discovered for a pattern to emerge, though at this time we have no explanation.

Asymptotic g–mode period spacings can determine overtones, but we do not have a similar tool for p modes. The only way to test overtone spacing is to have secure mode identifications via frequency multiplets. A somewhat less secure method has involved using "groupings" of pulsations if there is a barren stretch between. This was first done with ground-based data for Balloon 090100001 (hereafter BA09) where Baran et al. (2008) determined overtone spacing near 1 000 μHz, as expected from models. A similar pattern was seen in the $g + p$-mode pulsator KIC 3527751 (AKA and hereafter Samwise) with a similar overtone spacing (Foster et al. 2015). The only rich p–mode sdBV star observed during K1 is Saradoc, and it has an abundance of frequency multiplets, for which secure mode identifications could be determined. In that case, the p–mode overtone spacings were much smaller, ranging from 124 to 241 μHz. There are two K2-observed rich p–mode pulsators with many multiplets (Ketzer et al. 2017; Crooke *et al.* 2017), and while analysis is not complete, it seems their overtone spacing is also much smaller than models predict. These stars, and any others we detect like them, will be extremely important for determining p–mode overtone spacing.

Another enigma stemming from frequency multiplets are evolving frequency splittings of multiplets. Kern et al. (2017) discovered converging frequency multiplets in $\ell = 2$ and 4 g modes of KIC 2697388, while the $\ell = 1$ multiplets appear constant. Kern et al. (2017) have now detected diverging frequency splittings in KIC 11558725, but only for $\ell = 6$ models while the $\ell = 1$ and 2 multiplets are constant. An examination of Fig. 9 of Telting et al. (2014) shows an sFT of an $\ell = 8$ mode, and while mentioned in their paper, it appears to be converging. Possible explanations for this phenomenon were examined in Kern et al. (2017) and include angular momentum exchange between pulsations and rotation (Perez et al. 2011), resonant mode coupling (Zong et al. 2016), and strong magnetic fields (as in Kurtz et al. 2011) . However, all of these mechanisms are seemingly ruled out, firstly because only very weak magnetic fields have been observed for sdB stars (O'Toole et al.), and the other two mechanisms do not fit the observed time scales and are predominant effects for p modes while these are g modes. So once again, we have an unexplained enigma. Additionally, other sdBV stars will have to be closely examined for this phenomenon.

2 K2 discoveries

K2 continues the K1 mission, but with reduced observing duration. So while this is a disadvantage when extracting pulsations, it has the advantage of observing many more stars. Table 1 lists 14 K2-observed sdBV stars, and we have many more that are *in analysis*. Certainly, an important contribution of K2 are the p mode pulsators and those with

F and G companions, for which we had none in K1. We have discovered two more $p+g$ stars, from which we can examine differential rotation, and they are rich enough to test p-mode overtones.

K2 has added five more p–mode pulsators where we have detected frequency multiplets. This includes four stars with main sequence F or G companions. The K1 p–mode pulsators had the shortest rotation periods of non-binary stars and this continues with K2. Additionally, *none* of the p or $p+g$ mode stars are in post-common-envelope binaries. Four of the five K2 p or $p+g$ mode stars have F or G main sequence companions, and perhaps this points to a connection between rotation and mass-loss mechanisms. While it is too early to make such connections, we are beginning to see interesting relationships which may be useful once all of the Kepler-observed stars are analyzed.

As signal-to-noise (S/N) in a temporal spectrum (FT) is proportional to $1/\sqrt{n}$ where n is the number of measurements Kjeldsen & Frandsen (1992), in the absence of other noise correlations, we would expect to find fewer pulsations in K2 data. However, this is a complex issue for Kepler data as there is a large dependence on field crowding (contamination caused by nearby stars as Kepler's pixel size is 4"), pulsation amplitude stability, intrinsic pulsation amplitudes, and stellar brightness. The top left panel of Fig. 3 indicates the number of pulsation frequencies detected (including multiplet members) compared with the listed Kepler magnitude (K_p). While it is commonly known that K_p usually understimates the brightness of blue stars, it provides a first-approximation to K2's success. All of the K1 stars with < 20 frequencies are stars for which the full data set has not been examined and so it is apparent that K2 will not detect as many frequencies as K1 did. However, this is mostly caused by the lack of frequency multiplets when the rotation period is longer than K2's sensitivity. With three years of data, only two K1-observed sdBV stars do not show multiplets when their entire data set has been analyzed (Usundag et al. 2017; Baran et al. 2015). However, the majority of K2-observed sdBV stars *do* show at least one multiplet, and so we have had reasonable success in determining rotation periods within K2's limitations.

2.1 K2 enigmas

Our first surprise arrived with data from the first full-length K2 campaign. The K2-observed star PG 1142-037 (Reed et al. 2014, hereafter PG1142) was found to be in a 3.1 day binary with a white dwarf companion. A decomposition of the binary portion of the lightcurve found both Doppler boosting, as expected, but also ellipsoidal variation. This is the longest orbital period sdB stars to show ellipsoidal varation, which is an interesting discovery, but the real surprise was the lack of rotationally-induced frequency multiplets. The radial velocity and lightcurve variations indicate an orbital inclination well-positioned to detect multiplets, but none were found. This indicates that PG1142's rotation period is longer than K2-data sensitivity, roughly 45 days. Certainly an unexpected result as it would be presumed that when tidal forces are sufficient to deform the star, even if just by a small amount, they are sufficient to significantly decrease the rotation period. However, PG1142's rotation period, if near to 45 days, is similar to the K1-observed sdBV+WD stars.

Another new phenone mon we have observed are unusually-split p–mode multiplets. Those in K1's Saradoc were very well-behaved, consistent, and easy to interpret, but our two rich pulsators do not show that. PG 0048+091 (Ketzer et al. 2017, hereafter PG0048) is a rich pulsator over 200 periodicities detected, mostly in multiplets. However, the multiplet splittings range from 2.03 to $3.53\,\mu$Hz, averaging to $2.6\,\mu$Hz. This star has quite a high signal-to-noise and so the variation is not due to a lack of precision but something intrinsic within the star. Values can even range by $> 20\%$ within the same multiplet (see Ketzer et al. these proceedings). No multiplets are detected for PG0048's g modes, though the resolution is ample for their detection. From this, we presume PG0048 to be a differential rotator with an interior rotation period > 45 days. The situation for PG 1315-123 (Crooke *et al.* 2017, hereafter PG1315) is considerably worse, though the S/N is also worse than for PG0048. But in this case, the g modes show a consistent splitting while the p modes have a large spread. The best p–mode multiplets have spacings of $0.75\,\mu$Hz, which agree with the g modes, when $C_{n,\ell}$ differences are accounted for, but some other high S/N multiplets have spacings of $2.4\,\mu$Hz, or even 5.4 and $6.4\,\mu$Hz! These results are very preliminary and perhaps a pattern will emerge with further analyses, but currently we do not know how to interpret the unusual multiplet splittings.

Another pattern which has emerged from examining K2 pulsators are complex peak patterns in the temporal spectra (FTs). In PG0048, we see regions with many-peaked complex patterns which can span up to $50\,\mu$Hz. Similar signals were seen in the second overtone of p modes in BA09 and Samwise. As we were anticipating stochastic features in the oscillations of PG0048 from previous work (Reed et al. 2007), we have examined the broad, multi-peaked features in that context. We have found similarities and so we are investigating the possibilities of stochastic features in stars which also include sharp, well-

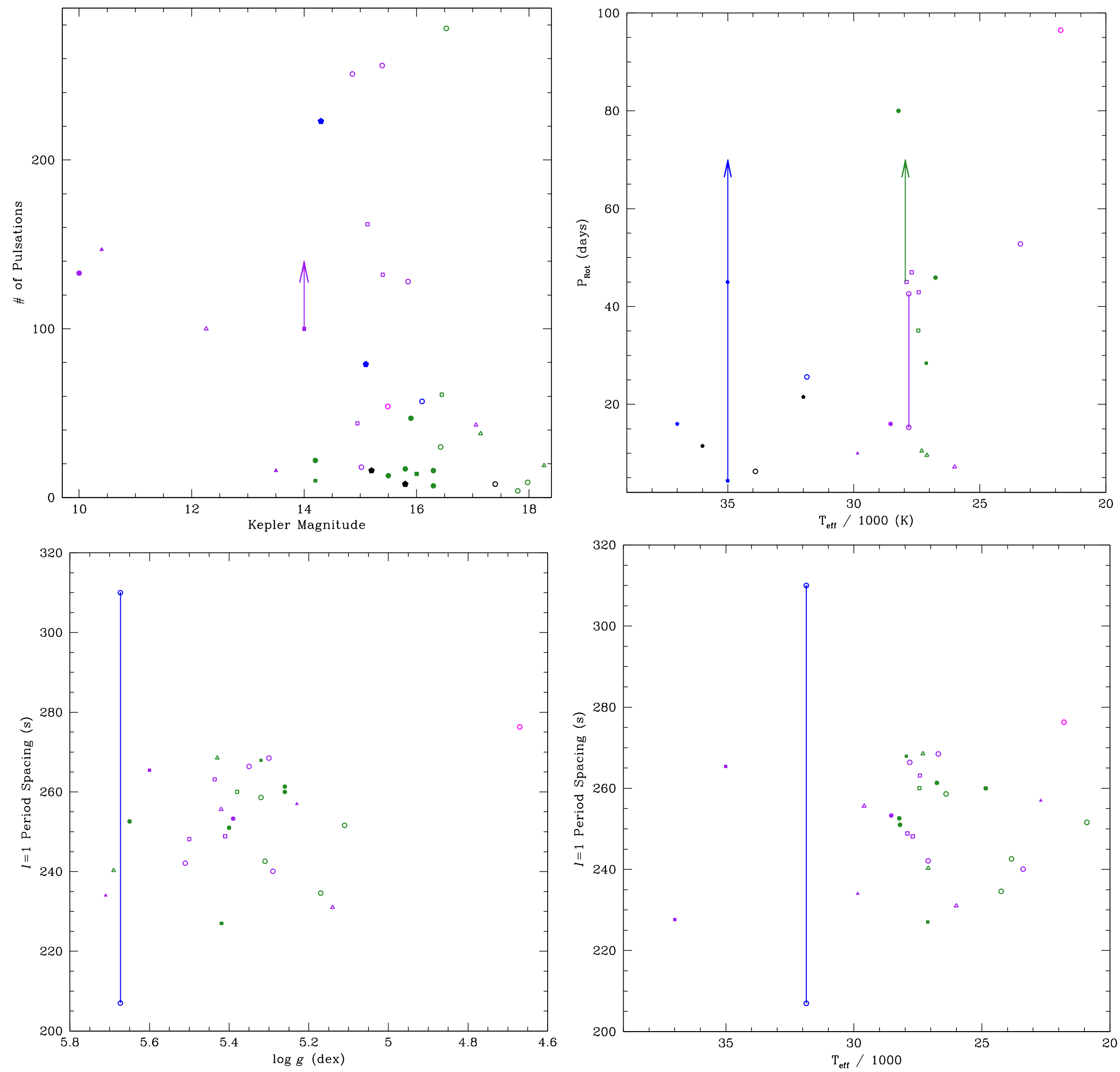

Figure 3. Comparisons of Kepler-observed pulsators. Point types are the same as in Fig. 1. Top left: Number of pulsation frequencies observed (provided in Table 1 compared with magnitude. Arrow indicates a lower limit, as that star is still in analysis. Top right: Rotation period with $T_{\rm eff}$. Arows indicate lower limits and lines indicate radially differential rotators, with the envelope having the shorter period. Bottom panels show g mode $\ell = 1$ asymptotic period spacings with log g and $T_{\rm eff}$. Lines connect the two possible period spacings for Saradoc.

defined peaks which appear very unlike stochastic features. See Ketzer et al. these proceedings for more on that work.

3 Results so far

Kepler observations of sdBV stars has been an astounding success. This can hardly be understated. Kepler data have been transformative. Never before has there been a data set of equally-spaced, long-duration, nearly-continuously sampled, single-instrument observations. The solar orbit of the telescope eliminates a lot of Earth-bound systematics and precisions could easily reach parts-per-million precision for stars of reasonable brightness. Prior to these data, asteroseismology was mostly restricted to matching model periods with observed ones, without any observational mode constraints. Now, the situation is clearly reversed and we can identify the majority of observed pulsation frequencies.

As a summary, from K1 data, over 1 275 pulsation frequencies have been observationally identified. 805 modes have been identified using frequency multiplets and 925 g modes have been identified using asymptotic period spacings. As expected, the majority have been identified as

$\ell = 1$ or 2, but 97 have been identified as $\ell = 3$ to 9, so some quite high-degree modes have been detected.

Structurally, long, reasonably smooth asymptotic sequences indicate a homogeneous pulsation cavity. As horizontal branch stars, sdB stars must have H/He and He/C-O transitions, which can produce significant mode trapping and disrupt asymptotic sequences. The proposed solution has been to smooth the H/He transition with increased diffusion (Hu et al. 2008; Constantino et al. 2015; Ghasemi et al. 2017). But now that we know what to look for, we are finding more stars with trapped modes (Østensen et al. 2014b; Foster et al. 2015; Kern et al. 2017; Usundag et al. 2017) too. They are predicted to be caused by convective core overshoot in the He/C-O transition Constantino et al. (2015); Ghasemi et al. (2017, and Yan Li et al., these proceedings).

As we anlyze more sdBV stars and obtain significant numbers of identified modes, we can begin to look at trends. We have seen a relationship with rotation period and $T_{\rm eff}$ (top right panel of Fig. 3). It is expected that the asymptotic period spacing (ΔP) should be closely tied to the resonant cavity and so we would expect trends in ΔP for stars of differing core and envelope masses, and as evolution converts more of the core to C-O. The bottom panels of Fig. 3 show ΔP against $T_{\rm eff}$ and $\log g$. In neither case are clear trends obvious. Recently, our collaboration has noted some stars which both seem to have unusually low mass and no obvious asymptotic g–mode sequence. Perhaps in those cases, clear relationships will appear.

4 Where to now?

While we have made terrific progress using K1 & K2 data, there is still a lot to be done. We have eight more K1 stars to analyze, over a dozen K2 pulsators to examine, and perhaps nine more K2 campaigns to obtain data. To this point, our collaboration has had incredible success with our K2 proposals and several prevously-known sdBV stars will be observed and for several of our K2 discoveries, second-observations will be obtained. Observationally, these are very exciting times and we anticipate continued success in associating modes with pulsations. As we continue to analyze sdBV stars, building up number of differing spectroscopic features, we can hope that relationships will appear, allowing further physical insight into sdB stars and EHB cores.

One area where we would like to see more progress is with models to interpret our findings and make use of the amazing observational constraints provided by Kepler. A new and emerging tool is the use of MESA evolutinary models (Paxton et al. 2011) and additional "modules" being added to that code. To that end, it seems taking a page out of the white dwarf seismology toolkit would seem appropriate and match "features" rather than specific frequencies. In a star with > 200 pulsation frequencies, using only the $m = 0$ component can reduce that number greatly, but in every case, there are 10-20% of frequencies which cannot be attributed to modes because they lack both multiplet structure and asympotic spacings. So how are those interpreted? Rather, period spacings, asymptotic "turn-on" and "turn-off' overtones, "hook" features, and scatter of the asymptotic sequence seem more useful. Constantino et al. (2015), though primarily focused on solar-like oscillators, was able to test core overshooting using the scatter in the asymptotic sequence for KIC 5807616 and obtain a match. Also using MESA models, Ghasemi et al. (2017) were able to match the shape of the mode trapping sequence for KIC 10553698A. These advances are directly testing core boundary layers by matching features in the temporal spectrum. Yan Li (these proceedings) is also using MESA to examine core overshoot, though at this point, we have not seen a comparison with seismology. These efforts seem fruitful and we look forward to both finishing our analyses of K1 & K2 pulsators, and more model fitting to understand the interiors of these interesting stars.

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