Analysis of a subdwarf B pulsator observed during Campaign 2 of K2

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Abstract

We present an analysis of the pulsating subdwarf B (sdB) star EPIC 203948264, observed during Campaign 2 of the extended *Kepler* mission. A time series analysis of the short cadence data set has revealed a rich g-mode pulsation spectrum with 20 independent pulsation periods between 0.5 and 2.8 hours. Most of the pulsations fit the asymptotic period sequences for ℓ = 1 or 2, with average period spacings of 261.34+/-0.78 and 151.18+/-0.34 s, respectively. The pulsation amplitudes are below 0.77 ppt and vary over time. Radial velocity measurements give no indication for binarity in this star. We did not find any clear rotationally induced pulsation multiplets, which indicates that the rotation period of the star is longer than about 46 days. By characterizing the various pulsation modes, we can constrain structural models of sdB stars. This is a promising approach to enhancing our understanding of horizontal branch stars.

Subdwarf B stars are hot, core helium burning extreme horizontal branch stars with an average mass of ≈0.47 $M_\odot$ and temperatures ranging from 20,000 to 40,000 K[1]. SdB stars differ from ordinary horizontal-branch stars because they have lost too much of their hydrogen envelope mass to sustain H-shell fusion. They represent the stripped cores of most horizontal branch stars. Both short and long period sdB pulsators have been discovered[2]. Short period, p-mode, pulsators have pulsation periods between 1 and 10 minutes, whereas long period, g-mode, are on the order of 0.5 to 2 hours. There are also hybrid pulsators. To date, over 50 sdBV stars are known.

Observations and Data Processing

The unprecedented photometric data obtained by *Kepler* has proven extremely helpful for asteroseismology of sdBV stars. During Campaign 2 of the extended *Kepler* mission (*K2*), the pulsating sdB candidate EPIC 203948264 was one of the targets observed in short cadence (1-min) mode for 83 days. We processed the pixel files into lightcurves using a custom process specifically developed for *K2* data. The figure below shows a period transform of the lightcurve for EPIC 203948264. The short blue (green) lines indicate the asymptotic ℓ=1 (2) sequence, with the full-length dashed lines indicating the periods that match the evenly spaced sequences.

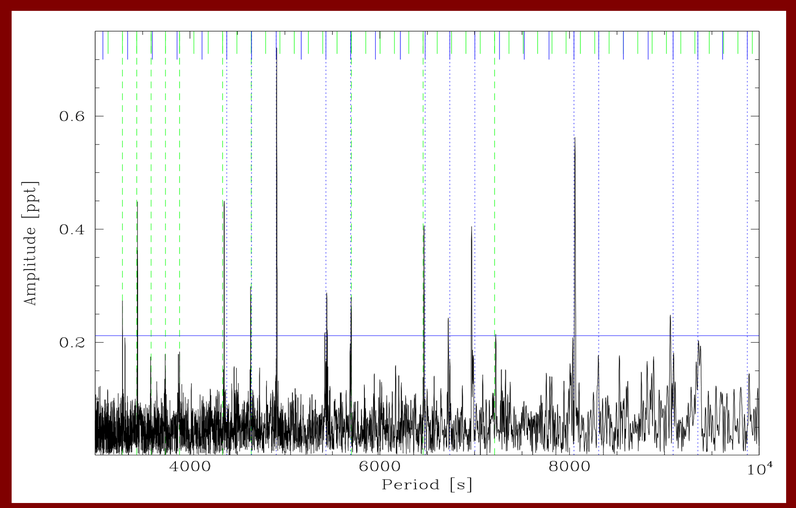


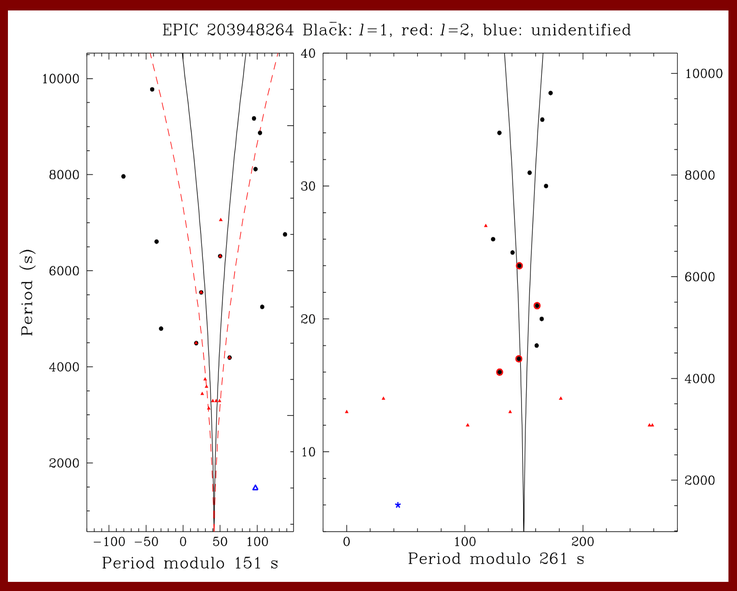
Table 1: Pulsations detected in EPIC 203948264. The table provides pulsation properties including ID, frequencies and periods with errors in parentheses, amplitude and corresponding signal-to-noise ratio (S/N) in Columns 1 through 5. Columns 6 through 10 list the mode degrees, relative radial overtone indices and the deviation from asymptotic period spacing. Note: † these periodicities have low S/N in our final processing, but match the asymptotic spacing and thus were included in the table; * this is a potential multiplet.

ID	Freq (μHz)	Period (sec)	Amp (ppt)	S/N	ℓ	$n_{\ell=1}$	$\delta P/\Delta\Pi_1$ (in %)	$n_{\ell=2}$	$\delta P/\Delta\Pi_2$ (in %)
f01	601.952 (4)	1661.262 (0.1)	0.239	4.85					
f02	304.127 (4)	3288.100 (0.5)	0.274	5.56	2			22	0.52
f03*	290.523 (4)	3442.068 (0.5)	0.276	4.01	2			23	2.56
f03*	290.316 (5)	3444.523 (0.6)	0.434	6.30	2			23	4.19
f03*	290.104 (7)	3447.040 (0.8)	0.449	9.12	2			23	5.86
f04†	278.925 (4)	3585.193 (0.5)	0.183	3.71	2			24	2.47
f05†	267.444 (6)	3739.101 (0.8)	0.179	3.63	2			25	0.35
f06†	257.093 (6)	3889.643 (0.9)	0.183	3.72	2			26	0.89
f07	229.340 (6)	4360.338 (1.2)	0.626	9.09	1 or 2	17	10.24	29	11.15
f08	215.613 (5)	4637.939 (1.1)	0.451	6.55	1 or 2	18	4.02	31	4.87
f09	203.487 (8)	4914.319 (2.0)	0.722	14.66	1	19	1.73		
f10	183.784 (4)	5441.170 (1.1)	0.288	5.85	1	21	3.33		
f11	175.482 (6)	5698.590 (2.1)	0.279	5.66	1 or 2	22	1.83	38	1.91
f12	154.620 (6)	6467.469 (2.3)	0.569	8.27	1 or 2	25	3.96	43	7.67
f13	148.743 (5)	6723.005 (2.2)	0.343	4.98	1	26	6.18		
f14	143.517 (7)	6967.816 (3.6)	0.489	7.11	1	27	12.51		
f15	138.448 (7)	7222.928 (3.5)	0.412	5.98	2			48	8.36
f16	124.103 (5)	8057.823 (3.4)	0.769	11.18	1	31	4.58		
f17†	120.424 (7)	8303.993 (4.5)	0.177	3.59	1	32	0.74		
f18	110.332 (5)	9063.554 (3.8)	0.392	5.69	1	35	10.59		
f19†	106.824 (10)	9361.192 (8.8)	0.344	4.99	1	36	3.30		
f20	101.104 (8)	9890.806 (7.5)	0.367	5.33	1	38	5.96		

Results

EPIC 203948264 is another K2 pulsator where asymptotic period spacing provided mode identification for all but one of the modes[3]. The ℓ = 1 sequence shows a "hook"-feature as observed in other sdB pulsators[4]. This is shown in the right panel of the échelle diagram. The solutions of the linear regression fits find spacings of 261.34±0.78 s for the ℓ = 1 and 151.18±0.34 s for the ℓ = 2 sequence. All the identified pulsation periods along with other useful information is listed in Table 1. One possible multiplet (f03) was discovered, which would indicate a rotation period of about 46 days. However higher amplitude modes do not show this splitting, so its detection is uncertain. Quite likely the rotation period is longer than the resolution of these data.

12 spectroscopic observations with NTT do not reveal any indications of binarity.



Conclusions

- We detected 20 pulsation periods ranging from 0.5 to 2.8 hours.
- 19 of these fit asymptotic sequences for ℓ ≤ 2 modes.
- One possible triplet was found indicating a rotation period around 46 days, but it is possible the true rotation period is longer.
- By characterizing the various pulsation modes present in pulsating sdB stars, and by examining the time-dependence of pulsation amplitudes, we can create or adapt structural models of the interiors of sdB stars. This is a promising approach to enhancing our understanding of helium fusing stars, like our Sun will be in about 5 billion years.

Acknowledgements

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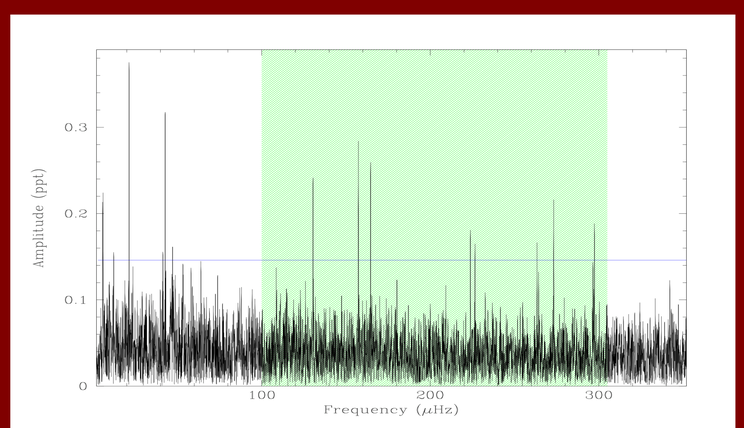
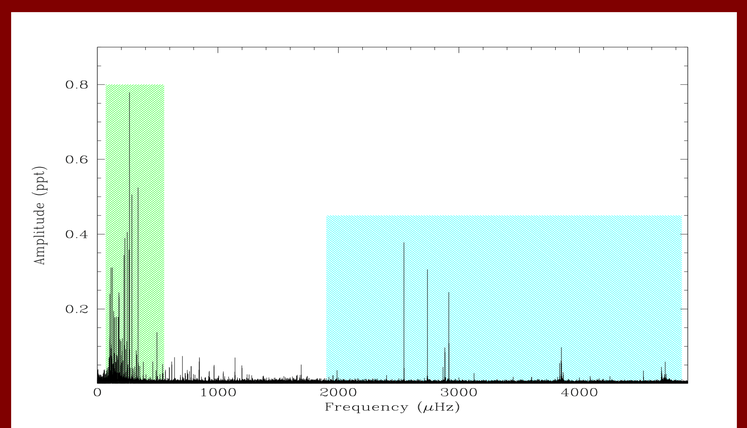
A total of 11 sdB pulsators have been discovered using K2 data through Campaign 6. Sample FTs are shown below. The gravity mode regions are highlighted in green and pressure mode regions are highlighted in blue.

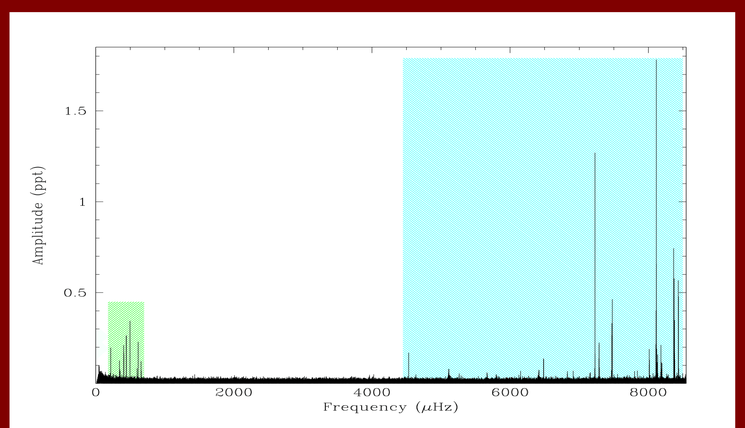
PG 1142[5] (F1)



EPIC 211779126 (F5)



EPIC 212508753 (F6)



References: [1]Heber (2009, ARA&A 47, 211); [2]Østensen (2010, Astronomische Nachrichen 331, 1026); [3]Reed et al. (2011, MNRAS 414 2885); [4]Baran and Winans (2012, ACTAA 62, 242) ; [5]Reed et al. (2016, MNRAS 458, 1417)