A Pulsating Hot Subdwarf KIC 10670103, 3 Year Light Curve Data Analysis

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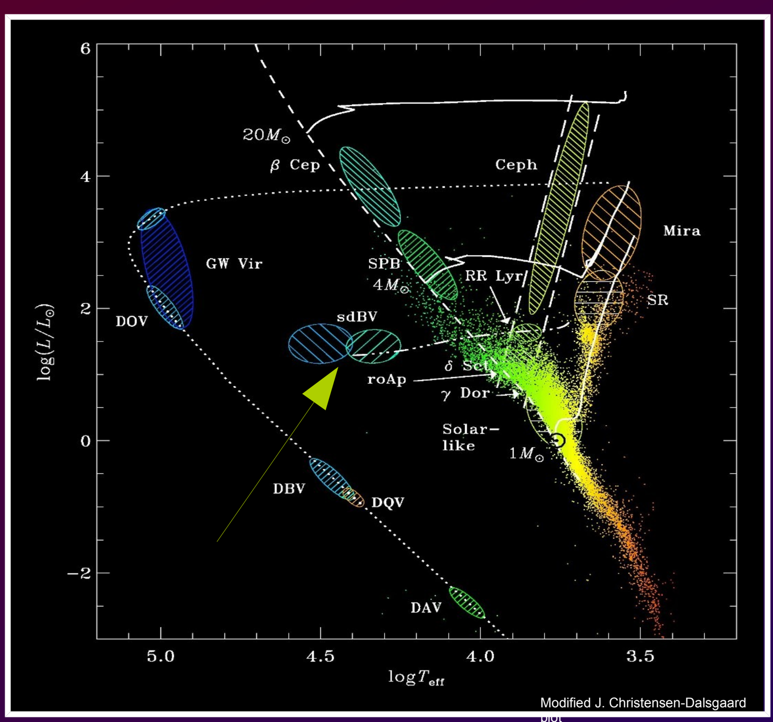
Abstract. We present the analysis of KIC 10670103, a pulsating hot subdwarf B star. Three years of Kepler data (Q5-16) allowed us to extract over 300 frequencies. Assuming asymptote of gravity modes and using multiplets we identified modal degrees. Comparing identified modes with the theoretical models we show that KIC 10670103 is a thick envelope sdBV. Multiplets detected in the amplitude spectrum allowed us to derive 90 days rotation period of the star, which is the longest among all sdB star analyzed thus far.



Hot subdwarf B (sdB) are extended horizontal branch core helium burning stars. Having lost too much of the hydrogen envelope mass before helium flash, they cannot sustain H-shell burning. Therefore, their evolutionary path leads directly to the white dwarf cooling track avoiding asymptotic giant branch phase. The average mass of an sdB star is about 0.5 $M_\odot$ while its effective temperature spans between 20 0000 - 40 000 K. Kilkenny et al. (1997) discovered the first pulsating sdB star EC 14026 (or V361 Hya). It appeared to be a p-mode pulsator. A few years later Green et al. (2003) discovered sdB stars pulsating in g-modes. V1093 Her star became a prototype of the gravity mode pulsators. P-mode sdBVs have short pulsation periods in a range of about 1-10 minutes, while g-mode sdBV periods span from several tens of minutes to few hours. There are also hybrid sdBV stars which pulsate in both, pressure and gravity modes at the same time (Schuh et al., 2005; Baran 2005). To date, we know over 50 sdBV stars.

Since the beginning of the Kepler spacecraft observations our knowledge about sdB stars have greatly progressed. Although, Kepler 's primary goal was to find Earth-size planets (Borucki et al. 2010) around cool stars, eighteen stars out of thousands of targeted objects were pulsating sdBs. The preliminary analyses were done for all of those sdBVs, while only a handful stars were studied in details. Now it was time to sit on KIC10670103.

KIC10670103 is a gravity mode pulsator, yet it has so extreme parameters which makes the star a unique among all pulsating sdB stars we know of. It has the lowest temperature (20900K) and that shifts the pulsation spectrum down to 4.5hrs (Reed et al. 2010). Using one month of Kepler exploratory data, Reed et al. (2010) identified 28 pulsation modes, which made KIC10670103 the richest pulsator among sdBV stars. Since then, Kepler has observed KIC10670103 continuously for over 3.0 years.

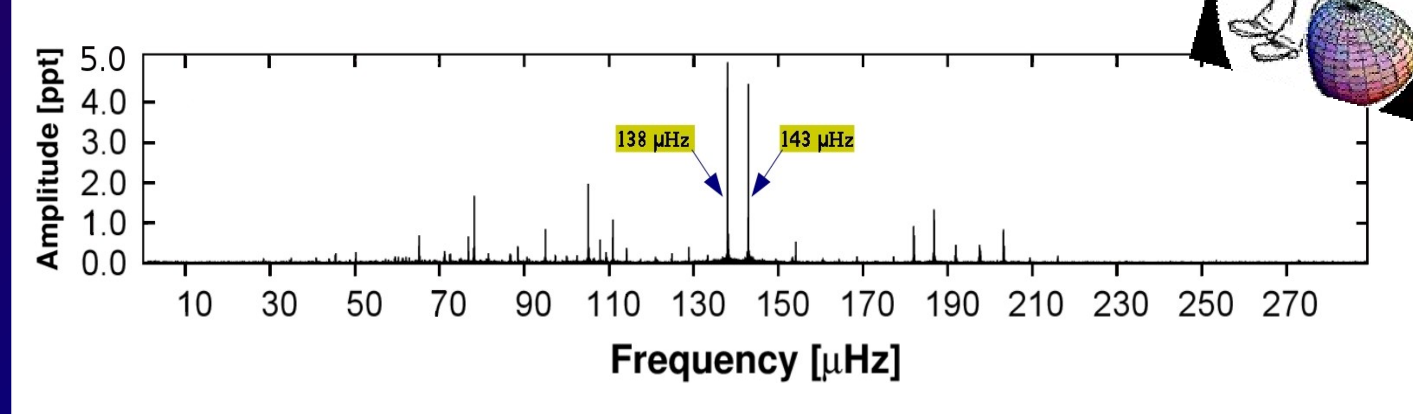


Fig. 1. FT of 3.0 years of data. Pulsation pattern of the star is dominated by two large amplitude frequencies (marked with arrows) causing 2.5 day beating in the light curve.

The Fourier transform (FT) of KIC10670103 data is shown in Fig. 1. The pulsation frequencies were selected from FT and simultaneously fitted (using non-linear least squares method) as sine waves to the time series data. Having a frequency fit to the light curve we performed mode identification in period (from period spacing) and/or frequency (from multiplets) domains (Fig. 2.).

Mode identification

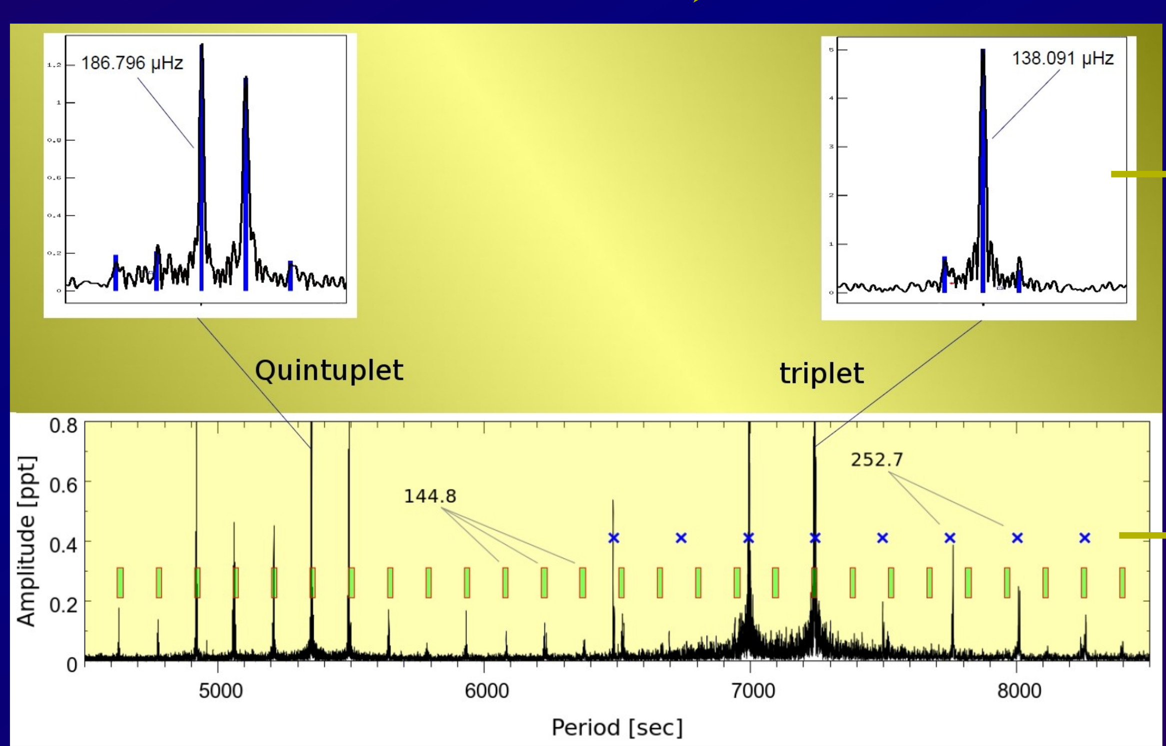


Fig. 2. Mode identification from multiplets (upper panels) and period spacing (bottom panel).Vertical rectangles mark positions of l=2 modes while crosses mark l=1 modes. 144.8 and 252.7 numbers in the figure are the mean values of period spacings (in seconds) for these modes.

The multiplet splitting can be used to derive stellar rotation. We found that KIC10670103 is a very slow rotator having one revolution in about **90 days**.

Comparing observed l=1 (and l=2) modes period spacings with theoretical models allows to determine H-envelope mass.

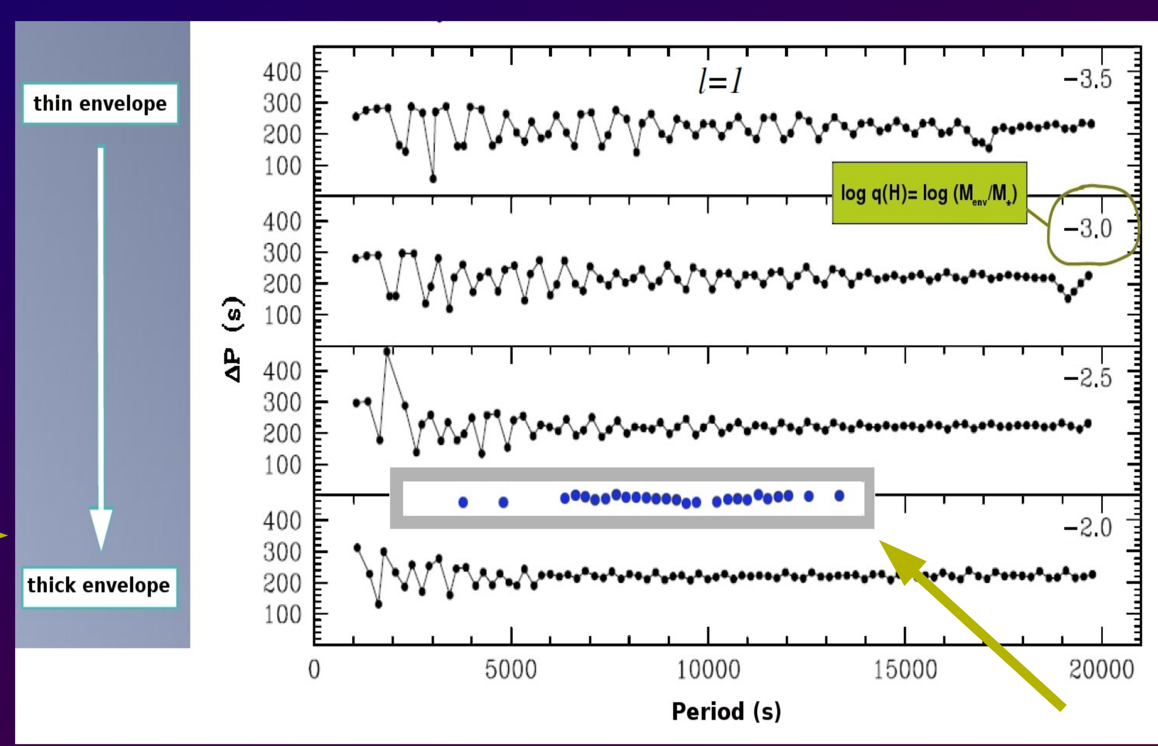
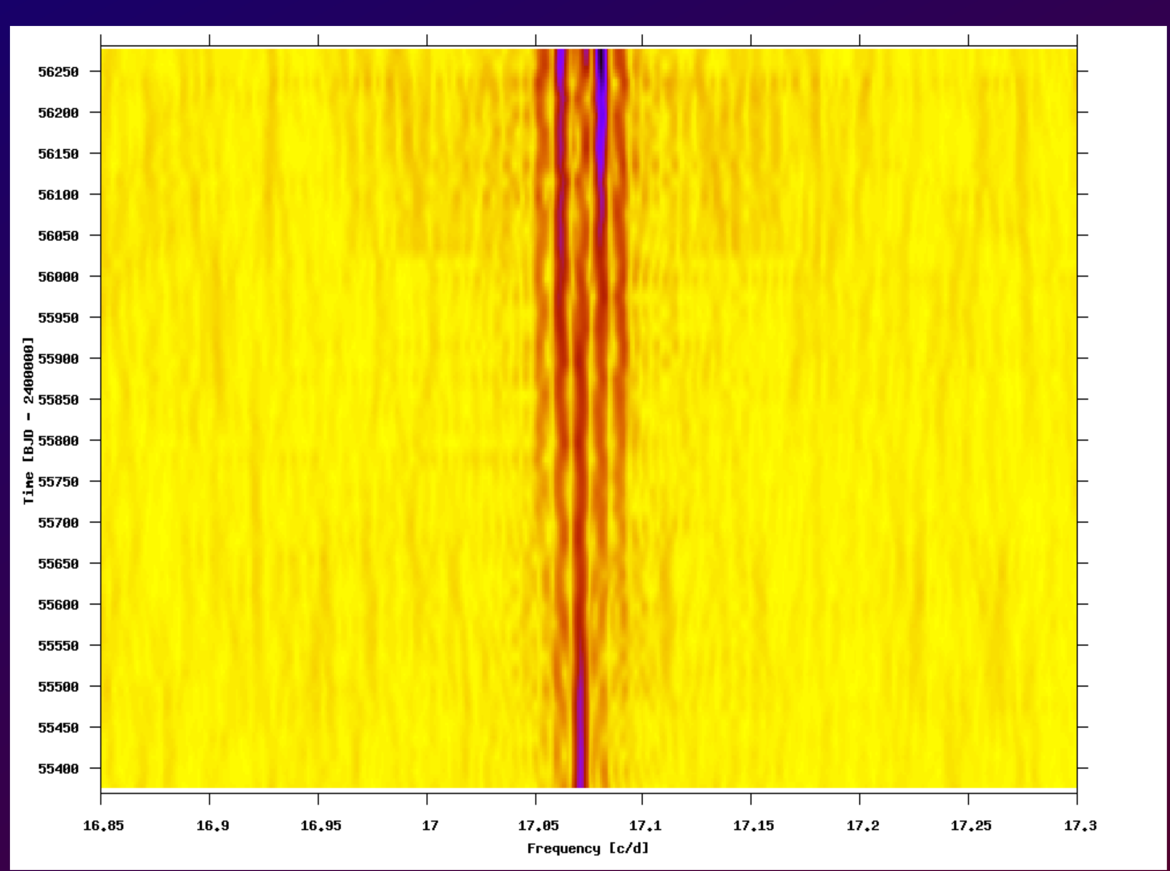


Fig. 3. A part of Fig. 4 by Charpinet et al. (2013) presenting a deviation of trapped gravity l=1 modes from equal period spacing for different thicknesses of the hydrogen envelopes. The envelope mass is shown in the upper right corner of each panel. The inlet between two lowest panels, with a sequence of solid blue circles, represents l=1 modes identified in this work. The period spacing of KIC10670103 fits models with the thickest envelopes the best.



We calculated a time-frequency (or running FT) diagram to see multiplet structure amplitude changes along time. Fig. 4. shows the running FT of a single multiplet near 17.07 c/d (197.5694 μHz). As one can see at the bottom (the beginning of Q5) only a triplet is visible and large amplitude central peak is dominating. With time (at the top), the side components are growing in amplitude, while the central one is decreasing. At the end (top of Fig. 4., Q16), a full quintuplet is visible. We noticed the same behavior in other multiplets. Such scenario fits the one presented in Fig. A.5. by Charpinet et al. (2011). In this figure, multiplet components are changing their amplitudes depending on the inclination. Is it possible that KIC10670103 rotation axis undergoes precession? If so, this would require a presence of a companion to KIC10670103 and perhaps a signal at long periods in the amplitude spectrum could be detected. Unfortunately, to remove systematics, Kepler data are usually detrended and all long period variations are removed. Therefore, a detection of such signal is difficult, if at all possible, since the star would require longer monitoring to cover the entire cycle of the precession.

Fig. 4. A "running FT" near 197.5694 μHz (17.07 c/d). A quintuplet components become visible at the end of observing period (top), while at the beginning only three components were excited (bottom).

Summary: We were able to identify over 300 frequencies in KIC10670103 light curve. Comparing them with the theoretical models we estimated the envelope *log* q(H) range between -2.5 and 2.0. This corresponds to a thick hydrogen envelope star. From multiplet splittings we obtained 90 days rotational period of the star. We also found that the multiplet structure development in the running FT might be caused by the precession of the rotation axis of the star. That however, requires further investigation of the data.

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