Seismic Analysis of Pulsating Subdwarf B Star EPIC 212508753 Using the K2 Mission

Authors: John Crooke(1); Michael Reed(1); Andrzej Baran(2); John Telting(3); Roy Østensen(1)

Institutions: 1. Physics, Astronomy, and Materials Science, Missouri State University, Springfield, MO, United States.
2. Pedagogical University of Kraków, Kraków, Poland. 3. Nordic Optical Telescope, Breña Baja, Spain

Missouri State. DEPARTMENT of PHYSICS, ASTRONOMY AND MATERIALS SCIENCE

ABSTRACT

EPIC 212508753 is a subdwarf B (hot horizontal branch, sdB) star which has been observed by the Kepler Space Telescope during its extended mission, K2, in short cadence mode where a new image is obtained roughly every minute for about 80 days. Using time series analysis of the data we have found the star to be a rare hybrid pulsator with both g- and p-mode pulsations where most of the pulsations are p modes. These pulsators are extremely important as p modes sample near the surface and g modes can sample deeper, near to the core. This means that hybrid pulsators allow us to characterize the entire star. As a hotter, predominantly p-mode pulsator, EPIC 212508753 is particularly interesting for seismic study. We have discovered frequency multiplets in both the p- and g-mode regions which we use to identify pulsation modes and determine that EPIC 212508753 rotates like a solid body, in contrast to some other sdB stars

INTRODUCTION

To perform the asteroseismological analysis of sdB stars, one must associate their pulsations with spherical harmonics. sdB stars can pulsate in gravity (g) modes, with periods between 0.5 and 2 hours, or pressure (p) modes, with periods between 1 and 20 minutes[1], or both.

Previous work in asteroseismology has shown that sdB g-mode pulsations have asymptotic period spacings of ~250 s for l=1 that are indicative of asymptotic radial overtones[2]. Frequency multiplets are useful for identification of l and m modes[3] as well as to determine the rotation period of the star[4].

sdB stars have been found to rotate as solid-bodies[2,5] as well as differentially[6] with the only published K2 hybrid pulsator rotating differentially[7].

Recently, techniques to find super-Nyquist frequencies have been published[8] that allow us to distinguish sub- or super-Nyquist frequencies from their reflections.

Spectra obtained and analyzed by our collaborator, John Telting, indicate that the star has a main sequence companion, a G type star, and an effective temperature between 35kK and 40kK.

DATA

Photometric fluxes were extracted from the K2 pixel files with aperture photometry. Because *Kepler* drifts, thrusters have to fire to keep it on target. We had decorrelate positional brightness dependence, fit the data to remove longer-duration variables, and sigma clip deviant points in order to make a normalized lightcurve (**Figure 1**). We then produced a Fourier transform (**Figure 2**) of the lightcurve to analyze the pulsations.

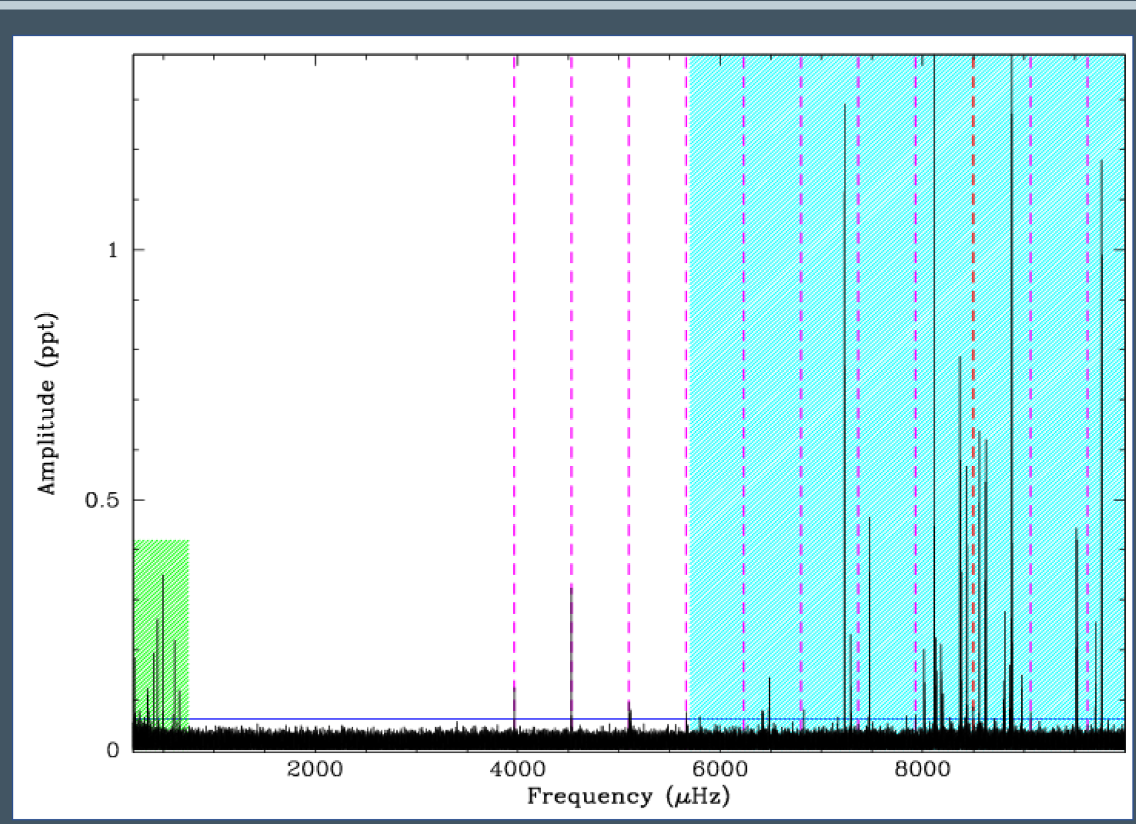

Figure 2
The Fourier transform of the normalized lightcurve showing the g-mode region in green and the p-mode region in blue. Purple dashed lines show known artifacts and the red line shows the Nyquist frequency.

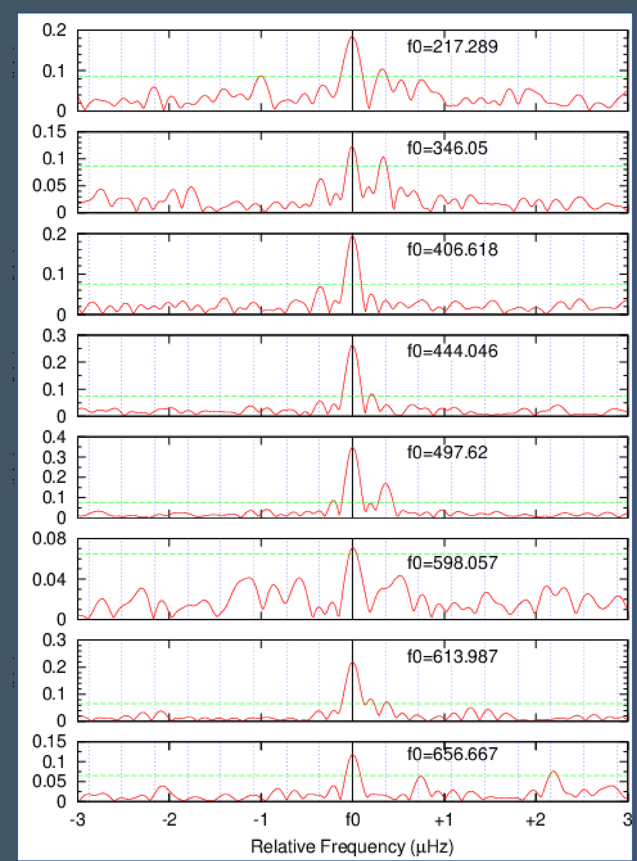

Figure 3
Close-up of the 8 pulsations in the g-mode region. Dashed blue lines show the multiplet spacing of 0.360 μHz

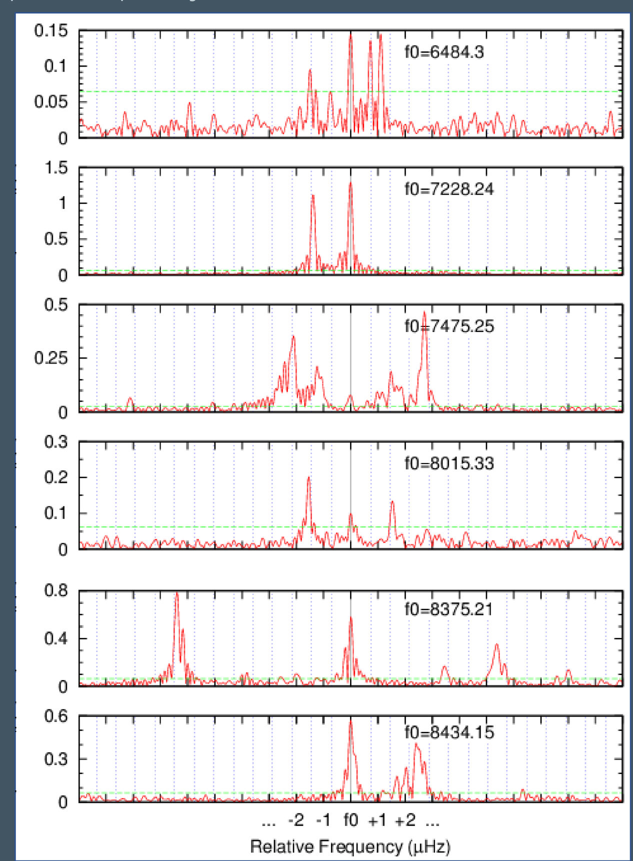

Figure 4
Close-up of 6 pulsation and their multiplets in the p-mode region. Dashed blue lines show the multiplet spacing of 0.721 μHz

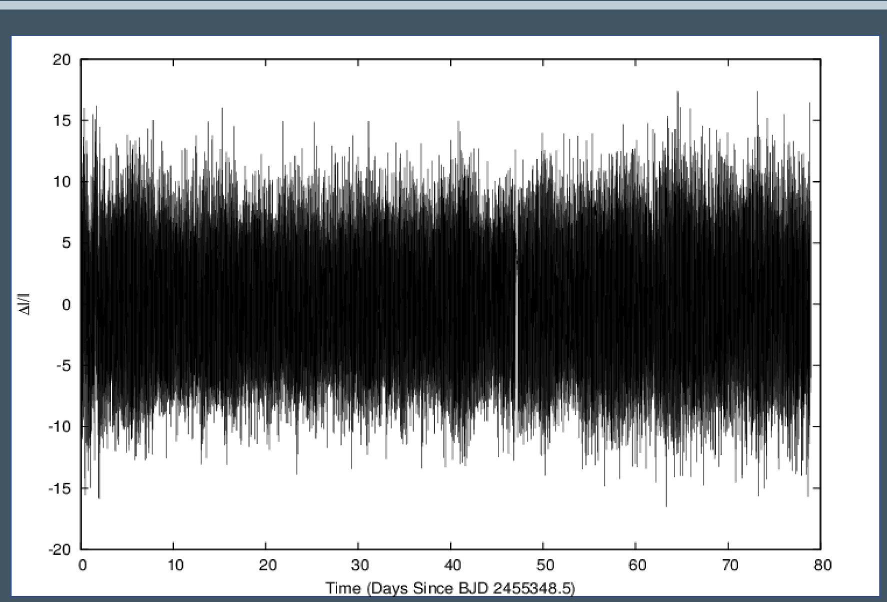

Figure 1
The normalized lightcurve of EPIC 212508753 after thruster decorrelation

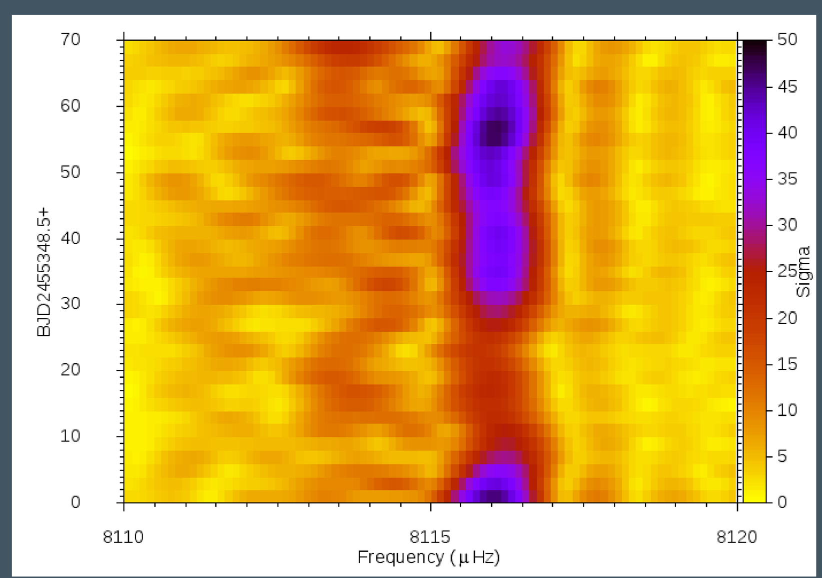

Figure 5
The sFT of the highest amplitude pulsation. The amplitude varies over time with the peak at 57 days.

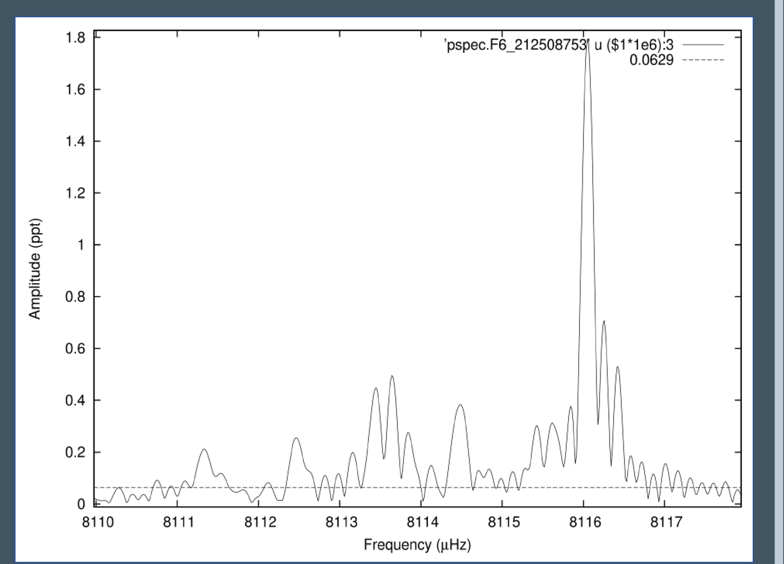

Figure 6
The FT of the same pulsation seen in **Figure 5**

ANALYSIS

In the g-mode region of the FT, shown in green in **Figure 2,** 8 independent pulsation frequencies, shown in **Figure 3**, were found. Five were determined to be l=1 with an average period spacing of 227.7±1.0 s and one was determined to be l=2. The multiplet splitting for these frequencies is 0.360 μHz.

The p-mode region, shown in blue in **Figure 2**, was much richer. We identified 13 multiplets as l=1,2,4, or 10 modes values, 3 of which were super-Nyquist frequencies, meaning they were past the Nyquist frequency of 8497.15 μHz. The frequency multiplets had a splitting of 0.721 μHz. 6 of the frequencies are displayed in **Figure 4** along with the multiplet spacing.

Using the Ledoux rotational splitting relationship:

$$\nu_{n,l,m} = \nu_{n,l,0} + m\Omega(1 - C_{n,l})$$

when $C_{n,l} = \frac{1}{l(l+1)}$ for g-modes and $C_{n,l} = 0$ for p-modes, we are able to calculate the rotation rate of the star.

Sliding FTs were created with 10 day bins stepped 2 days at a time to examine the time-stability of the pulsations. An example is seen in **Figure 5**.

CONCLUSION

80% of the g-modes were identified while 77% of the p-modes were. The l=1 g-modes follow the asymptotic period spacing of 227.7±1.0 s; the shortest observed. The multiplet splitting of 0.360 μHz among the l=1 g-modes leads to a rotation rate of 16.07 days for the interior of the star. The frequency multiplets in the p-mode region have an average value of **0.721** μHz, making the rotation rate for the exterior of the star 16.05 days. EPIC 212508753 is a solid-body rotator, not a differential rotator like some others, with a modestly short period.

The temperature is the highest for a K2 sdB with g-mode pulsations. This matches predictions as it has the shortest g-mode period spacing. The short p-mode periods are also possibly caused by the high temperature.

EPIC 212508753 is the hottest K2-observed sdB pulsator and being a hybrid is a big surprise, but it expands our coverage in the $T_{eff} - \log(g)$ plane, allowing us to probe horizontal branch cores and explore pulsation driving to higher temperature.

REFERENCES and ACKNOWLEDGEMENTS

1: Østensen R. H., 2010, Astronomische Nachrichten, 331, 1026; **2**: Reed M. D., et al. 2011, MNRAS, 414, 2885; **3**: Baran A., et al., 2012, MNRAS, 424, 2686; **4**: Aerts C., et al., 2010, Asteroseismology. Springer; **5**: Kern J., et al., MNRAS, 465, 1057
6: Foster H. M., et al., 2015, ApJ, 805, 94; **7**: Baran A., et al., A&A 2017; **8**: Reed M. D., et al. 2017, MNRAS

Funding for this research was provided by the National Science Foundation grant #1312869. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. JAC is funded by the Missouri Space Grant funded by NASA. ASB gratefully acknowledges financial support from the Polish National Science Center under project No.UMO-2011/03/D/ST9/01914. This paper includes data obtained by the *Kepler* mission. Funding for the *Kepler* mission is provided by the NASA Science Mission directorate. Data presented in this paper were obtained from the Mikulski Archive for Space Telescopes (MAST). STScI is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS526555. Support for MAST for non-HST data is provided by the NASA Office of Space Science via grant NNX13AC07G and by other grants and contracts. The spectroscopic observations used in this work were obtained with the Nordic Optical Telescope at the Observatorio del Roque de los Muchachos and operated jointly by Denmark, Finland, Iceland, Norway, and Sweden.