Asteroseismology of sdB stars with $FUSE$

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Abstract. The hot subdwarf B (sdB) stars form an homogeneous group pop- ulating an extension of the horizontal branch (HB) in the ($T_{\text{eff}}$–log $g$) diagram towards temperatures up to 40,000 K. The recent discovery that many of them are multimode pulsators has triggered a large observational and theoretical effort. We discuss the possibility of performing space-based asteroseismology with $FUSE$, and we demonstrate that periodic luminosity variations are already detectable in archival TTAG data of sdB stars. In particular, we report on the $FUSE$ observation of the pulsator PG 1219+534, which shows the presence of periodic variations at 6.9 mHz and 7.8 mHz, consistent with those reported from ground-based observations.

1. Variability in sdB stars

Subdwarf B (sdB) stars dominate the population of faint blue stars of our own Galaxy and are numerous enough to account for the “UV upturn phenomenon” observed in elliptical galaxies and galaxy bulges (Brown et al. 2000). Since the discovery of sdB stars in the globular cluster NGC 6752, evidence has accumulated that sdB stars represent late stages of stellar evolution. These are evolved objects with typical He burning cores of 0.5 solar mass surrounded by a thin H surface layer (less than 2% of the mass), and are located near the extreme horizontal branch (EHB) with effective surface temperatures ranging from 20,000 to 40,000 K. Although important questions remain as to their exact evolutionary paths and time-scales, sdB stars are widely thought to be immediate progenitors of low mass white dwarfs. Since 1997, the discovery of multimode short-period (P=2–10 minutes) oscillations among sdB stars (Kilkenny et al. 1997) has provided a unique opportunity for probing their interiors using asteroseismological methods. On theoretical grounds (Charpinet et al. 1996), the sdB instability strip is predicted to occur between 29,000 K and 37,000 K, which seems in good agreement with actual observations. However, relatively few sdB stars in this temperature range are reported to show luminosity variations, and it is not clear whether this result is a bias due to poor detection from ground-based facilities, or the effect of some intrinsic physical process.

The limitations imposed by atmospheric scintillation make mandatory the use of a space-based observatory for further asteroseismological investigations.
We show that FUSE is particularly well-suited for high-speed time-resolved spectrophotometry of sdB stars.

2. Observation of PG 1219+534

We have analyzed FUSE time-tagged archival data of PG 1219+534, recently identified as a short-period pulsating sdB star (Koen et al. 1999). This star was observed on the 16th of January 2001 for a total of 6,400 s in TTAG mode through the large aperture (LWRS), after which a considerable amount of data processing was done:

1. The raw images were first checked for known instrumental defects correlated with FUSE’s orbital motion (pointing drifts).

2. Intermittent increases in the photon count rates, known as burst events, were carefully screened out. For this purpose, off-spectrum regions were selected to monitor the bursts events, which were responsible for a loss of about 15% of useful data towards PG 1219+534.

3. Off-spectrum regions were also used to monitor the background.

4. Regions of the spectrum affected by dead-pixels and moving shadows (“worms”) were avoided. Worms typically consume about 50% of the useful data in the 110–120 nm region.

5. Airglow emission lines, which vary with orbital motion, were excluded.

Figure 1 shows the Scargle periodogram (Scargle 1982) for a single 3,200 s exposure toward PG 1219+534 and the confidence intervals for the two main frequencies. A simultaneous non-linear square fit of two sinusoids provides $\nu_1 = 6.9 \pm 0.2$ mHz and $\nu_2 = 7.8 \pm 0.2$ mHz, consistent with ground-based observations. Interestingly enough, we also find that the relative power concentrations of the two main frequencies differ from ground-based reports, here the 6.9 mHz peak being the dominant component. This is not an effect of the sidelobes of the spectral window, since the frequency difference of the two main frequencies is greater than the frequency of the first sidelobe. Instead, this may characterize either long-term variations in the power distribution, or the effect of differential FUV limb darkening caused by the geometry of different pulsation modes.

3. Prospects for space-based asteroseismology

Simulations based on our present observation and extrapolated to a 15th mag star indicate that FUSE is theoretically able to detect a 5,000 ppm luminosity variation at a frequency resolution of 110 $\mu$Hz in a single 9,000 s snapshot exposure, and may detect variations down to 800 ppm at 2.5 $\mu$Hz in a 4-day exposure (including gaps and downtimes).

Although these performances may seem modest in comparison to the future COROT mission (Baglin et al. 2001), they compare quite well with the MOST
performances (Matthews et al. 2004). Moreover, FUSE has three unique advantages: 1) its sky coverage allows for a much larger variety of targets; 2) it is the only instrument to make faint, short-period blue pulsators amenable to study; and 3) it offers the highest sampling rate, with 1 s intervals. To our knowledge, given the present status of space-based astronomy, this state of affairs will likely remain unchanged for at least the next decade.

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