Asteroseismology of extreme horizontal branch (subdwarf B) stars with TESS data

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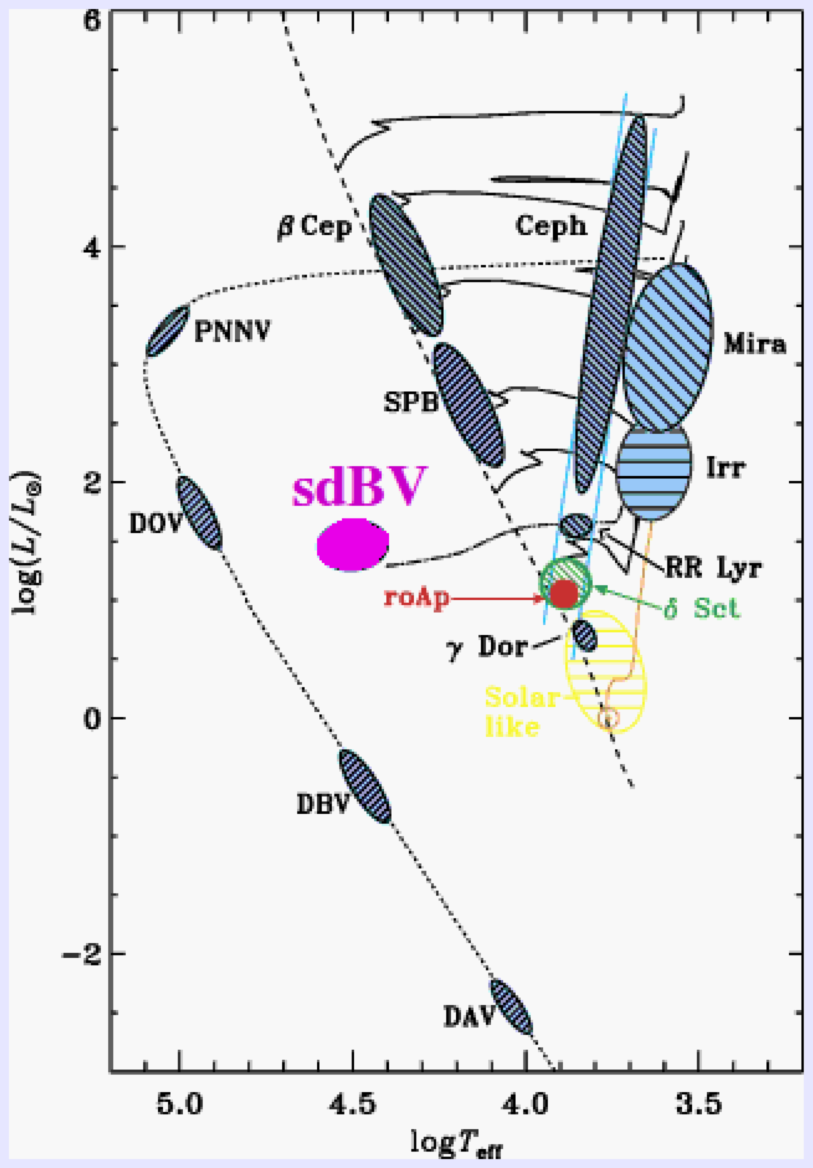
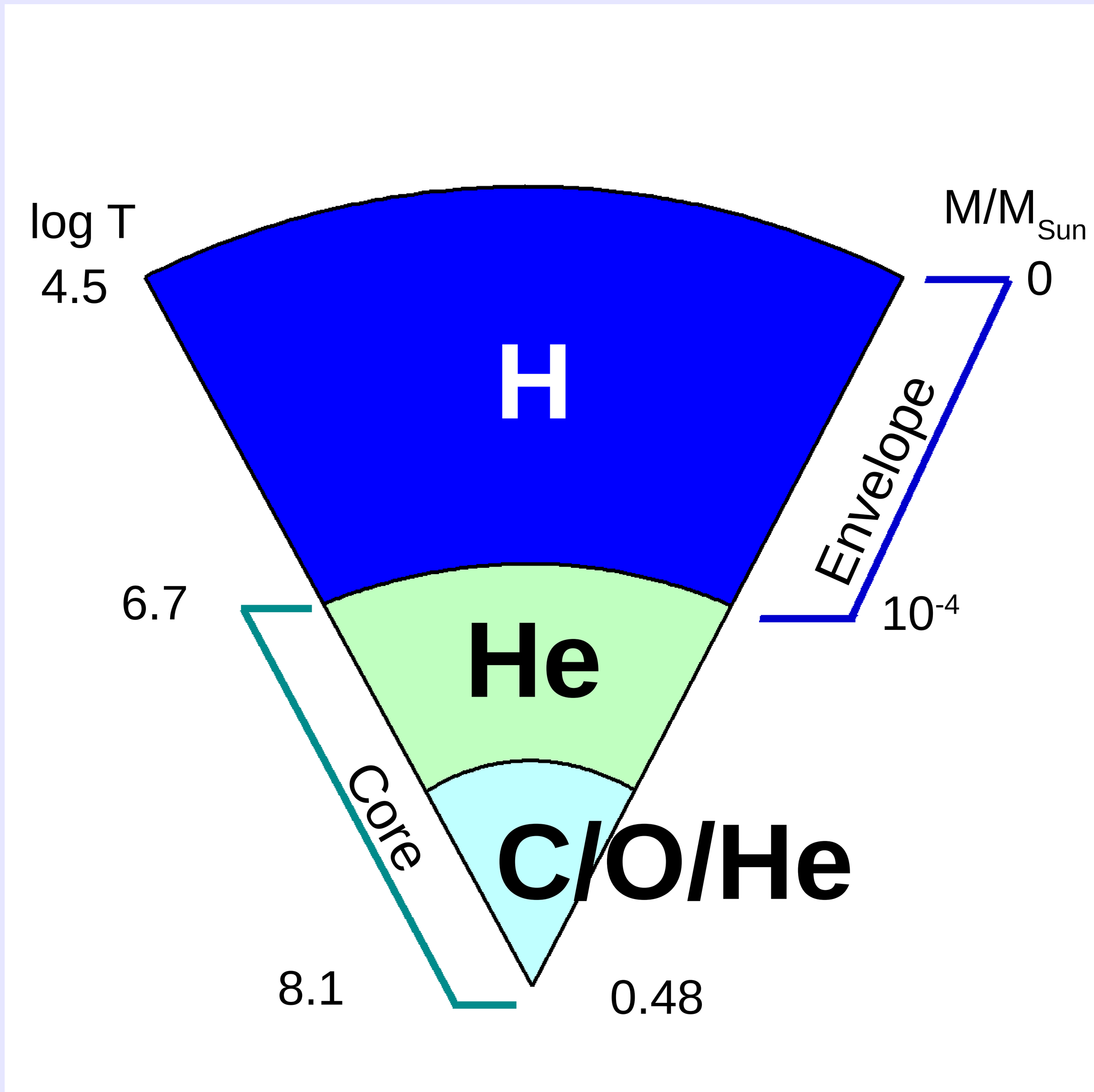
Abstract

During its primary mission, TESS observed over 550 of our target Subdwarf B (sdB) stars in short-cadence mode, from which we anticipate about 150 will be pulsating. This will allow an ensemble analysis of these interesting extreme horizontal branch stars, probing their interior structures. Combined with other all-sky surveys, such as GAIA, TESS data allow ensemble analyses of extreme horizontal branch stars, allowing us to probe the structure of helium-fusing cores.



Variable stars on the HR diagram
(Figure produced by J. Christensen-Dalsgaard)



Cutaway structure of an sdB star.

About sdBV Stars

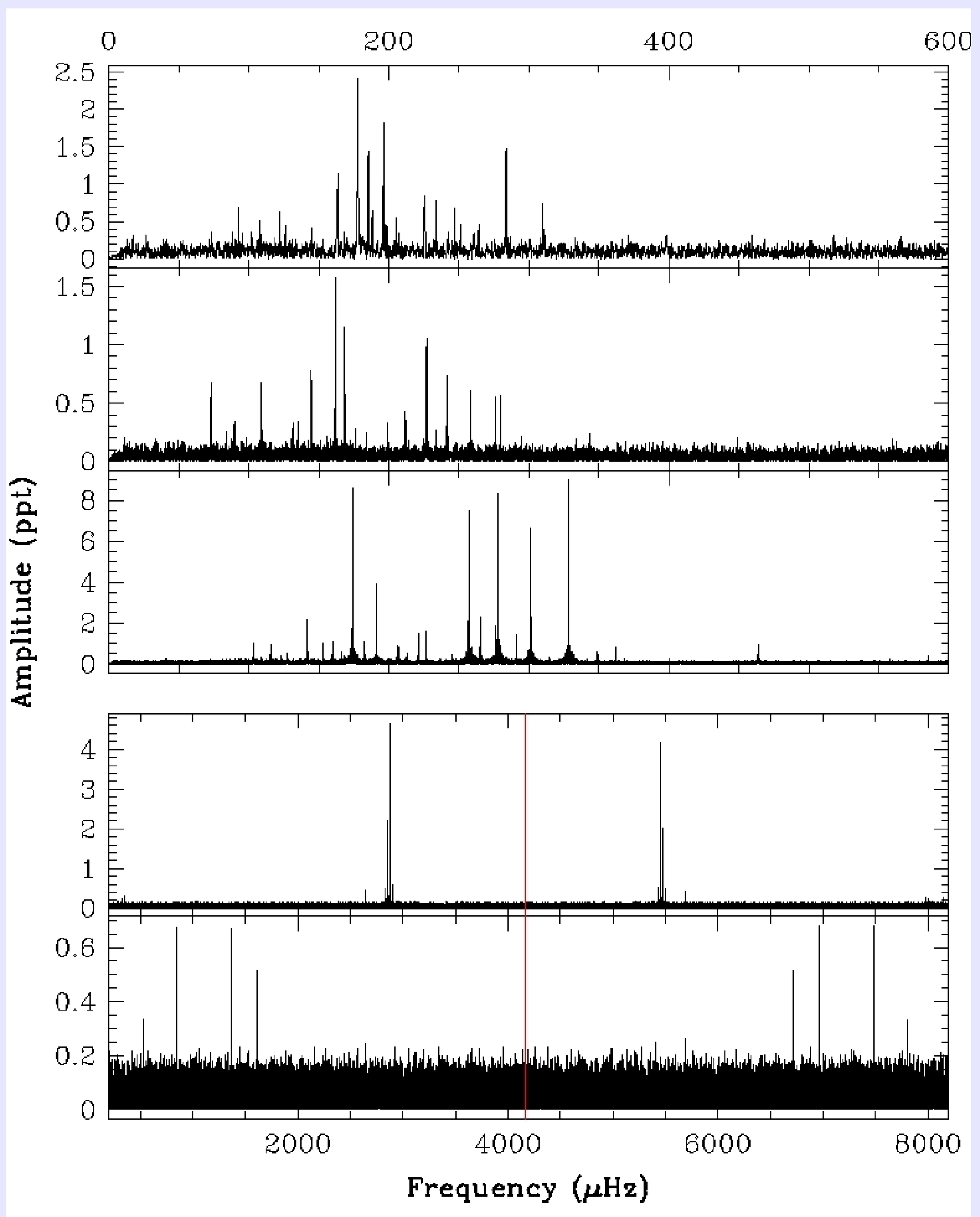
Subdwarf B (sdB) stars are on the extreme blue end of the horizontal branch (20,000-40,000K). Their thin, inert envelopes allow us to probe He-fusing cores and explore interesting physics, such as semi-convection and diffusion in extremely hot environments. How the envelopes are stripped down to $10^{-4}M_{Sun}$ is a mystery, but binarity may play a role. SdBV stars pulsate in both *p* (few minutes) and g (few hours) modes. Asymptotic sequences indicate smooth transition zones and slow rotation (10-100 days), even when in short period (0.5-10 days) binaries.

TESS' Contribution

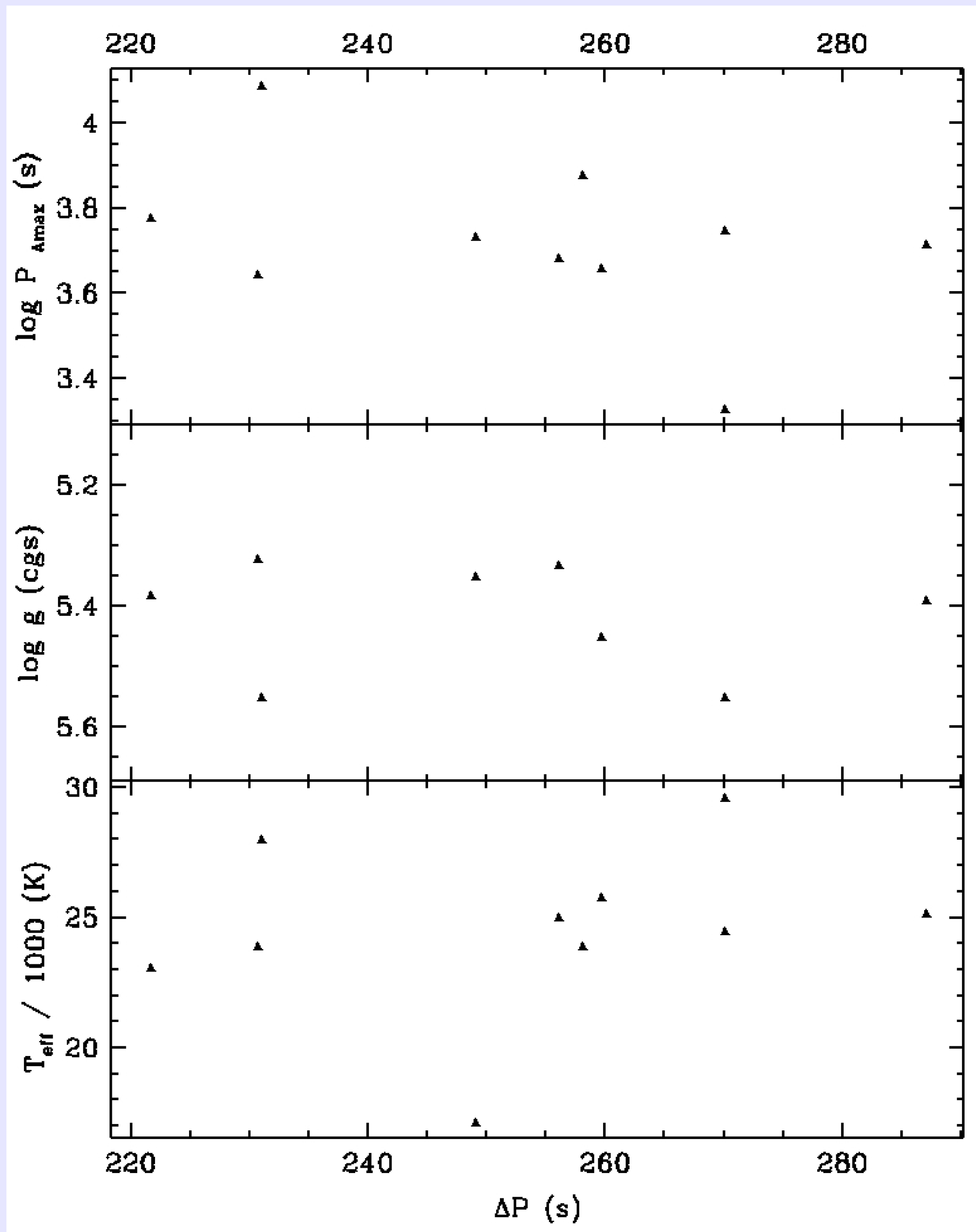
The unique nature of the TESS telescope allows us to observe stars across nearly the entire sky. During its primary mission TESS observed 314 of our program stars in the Southern Ecliptic hemisphere and 252 in the Northern Ecliptic hemisphere in 2 minute short-cadence mode.

A very preliminary analysis indicates 116 of our targets are pulsators. Of those, 82 appear dominated by g-mode pulsations with the others primarily p-mode pulsators.

The Fourier transforms (FTs) to the right show a sample of our pulsators. The top three panels show g-mode pulsators and the bottom two panels show p-mode pulsators. P-mode pulsations can occur below or above the Nyquist frequency (indicated by the red vertical line). Signals show reflections across the Nyquist and we have to discern which are pulsations and which are aliases.



A sample of pulsating sdB stars observed by TESS. Note the frequency range is different for the top 3 panels and bottom 2 panels.



Comparing asymptotic period spacings (ΔP) to the period of highest amplitude (top), gravity (middle) and temperature (bottom).

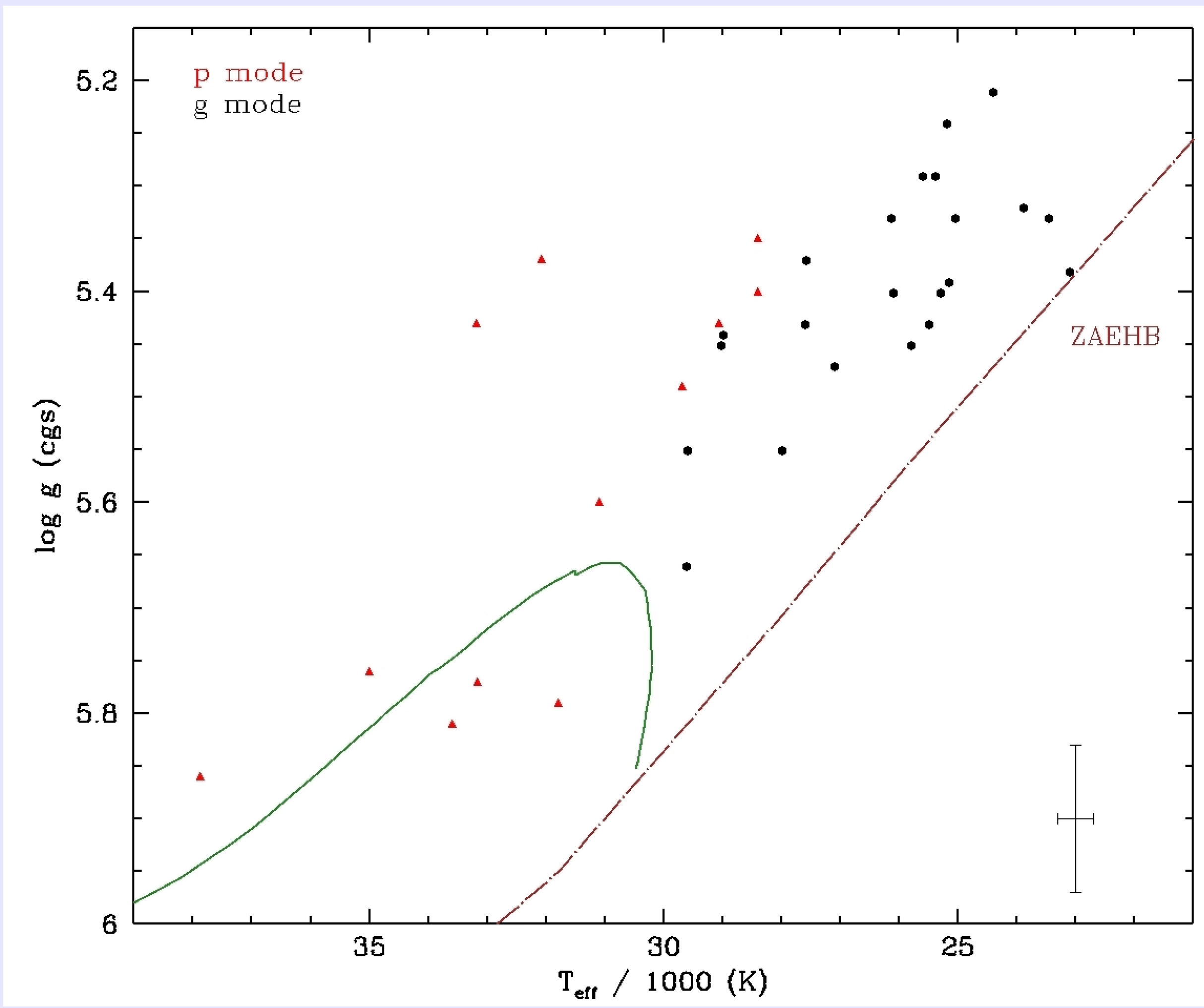
Seismic Tools

The main goal of our work is to provide observational constraints for models, from which we discern structure. It has been shown that g modes have asymptotic period sequences (ΔP) which can be useful for mode identification but it is also correlated with the structure of the reonant cavity. Trapped pulsatoins, which deviate from the asymptotic sequence can be used to probe the convective core. Frequency multiplets can provide mode identifications and rotation periods. We can also examine the period of highest-amplitude pulsation. Comparing seismic properties with spectroscopic ones can provide useful constraints.

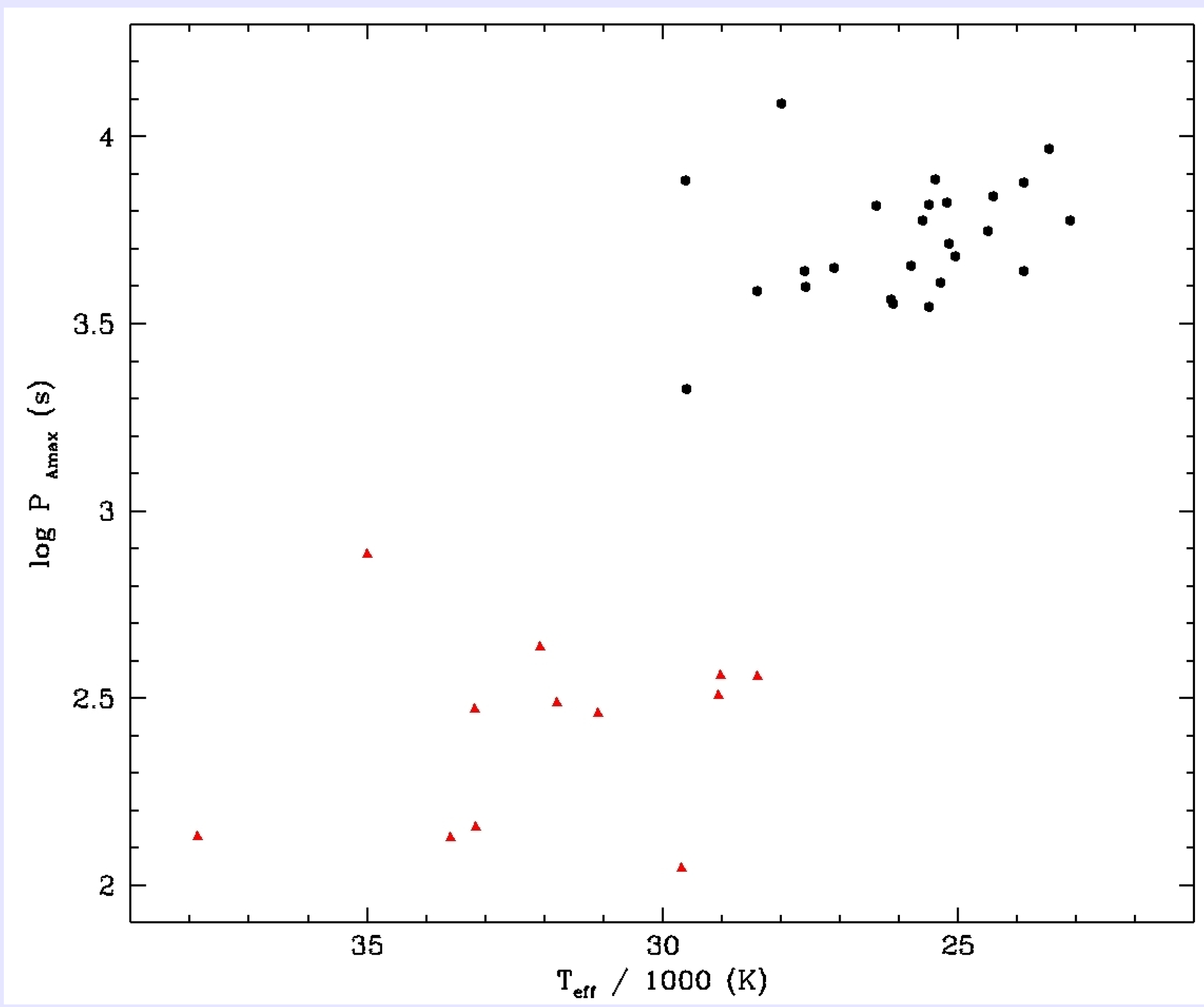
Pulsators in our Sample

We currently have spectroscopy for 40 of our program stars. The Kiel diagram (right) shows that sample with the zero-age-extended-horizontal branch (dashed line) for a $0.50M_{Sun}$ core and varying envelope thicknesses. The green line is an evolutionary model track with an envelope thickness of $0.001M_{Sun}$. The hotter stars are predominantly p-mode pulsators while the cooler ones are g-mode pulsators. Some stars are hybrid pulsators, having both p and g mode pulsations.

Publications including TESS data for sdBV stars are 1) Charpinet et al. 2019 A&A 632, 90 2) Reed et al. 2020 MNRAS 493, 5162 3) Sahoo et al. 2020 MNRAS 495, 2844 4) Uzundag et al. 2021 A&A in press



Kiel diagram of our stars for which we currently have spectroscopy. Red points indicate stars with highest-amplitude p modes and black points indicate those with g modes. The ZAEHB and a model evolution track (green) are also shown.



Comparing period of highest amplitude pulsation (P_{Amax}) with effective temperature. A correlation was noticed for g modes by Reed et al. (2021 MNRAS in press)

Future Prospects

Combining TESS data with our Kepler pulsators, we can do ensemble analyses. Other useful surveys include GAIA, from which we can get parallaxes and, combined with our spectra or archival multicolor photometry, we can determine radii, distances, and masses. By correlating physical properties with seismic ones we can tightly constrain models and in the future use only seismology to determine physical properties of sdB stars.