ASTEROSEISMOLOGY OF THE β CEN SYSTEM

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Abstract. The triple system β Centauri has been observed with the *BRITE*-Constellation. These photometric observations detected 19 periods, of which 8 are probably g modes and 9 are identified as p modes. As both the Aa and Ab components of the system are identified as early B-type stars, the pulsations could belong to either or both components. Preliminary asteroseismic modelling of the system has been attempted, but the rapid rotation meant that no final seismic model was produced. We have expanded that modelling, using a 2D stellar-evolution code and a 2D pulsation code to calculate models of the Aa and Ab components of the system. The 2D nature of these codes enables us to account more fully for the effects of rotation on both the structure and the pulsation frequencies of the stars. We appied the known binary constraints of the system to limit the range of the models we calculated, and to constrain our fit further. This article presents the preliminary results of our fit; it includes our conclusion as to which star produces the pulsation frequencies; we have also given the absolute rotation rates, convective core overshoot parameters, and the absolute age of the system.

Keywords: Stars: oscillations, interiors, binaries: spectroscopic, visual, individual: β Centauri, HD 122451

1 Introduction

Convective core overshoot is an important process in the structure and evolution of stars, but is poorly understood. Observations suggest overshoot is required, but the quantity remains uncertain (e.g., Rosenfield et al. 2017). It is also not clear how core overshoot changes with mass, age and metallicity of a star. Asteroseismology has proved to be a useful tool for probing the interior structure of stars across the H–R diagram, and constraints on core overshoot and rotation can be determined for many low-mass stars and evolved stars. Many B stars pulsate either in p modes as β Cep stars or in g modes as Slowly Pulsating B (SPB) stars; a few hybrid pulsators have also been observed (Pápics et al. 2012). Recent space missions, including *Kepler, TESS, CoRoT* and *BRITE*, have increased greatly the number of β Cep and SPB stars that have well known frequencies, and detailed seismic modelling of those stars is now possible.

A recent observing campaign using the *BRITE* Constellation observed the β Centaurus system for nearly 146 days, providing a detailed light-curve. Using those data, Pigulski et al. (2016) were able to detect 19 periods in the data, corresponding to 17 unique frequencies. The β-Cen system is a triple system, and contains a pair of non-eclipsing early-B stars (components Aa and Ab) with a fainter B-type companion in a wide orbit. Radial velocities from Ausseloos et al. (2006), combined with the *BRITE* photometry, enabled Pigulski et al. (2016) to derive strict constraints on the orbital parameters of the system, including the stellar masses.

2 Results

We calculated a grid of models using ROTORC (Deupree 1990, 1995) and including step overshoot (0.1, 0.15 and 0.2) and rotation (100-300 km s^{-1}). We held the masses fixed at 10.5 $M_\odot$ and 12 $M_\odot$. Pulsation frequencies were calculated with NRO (Clement 1998; Lovekin et al. 2009) for 5 points along the evolutionary track.

From the resulting grid of models we created a suite of synthetic binary systems by selecting one 10.5 $M_\odot$ model and one 12 $M_\odot$ model. Models in each synthetic binary were constrained to have the same age. We then compared the individualfrequencies observed with the model frequencies in order to determine whether each frequency was a better fit for the 10.5 $M_\odot$ or 12 $M_\odot$ model based on χ^2 statistics. Once all frequencies had been compared, the χ^2s were summed to give a total χ^2 for the synthetic binary. The frequency assignment for the synthetic binary with the lowest χ^2 are presented in columns 2 and 3 of Table 1.

Observational constraints have suggested that frequencies f_2 and f_3 must be associated with the primary star of the system. We therefore re-fitted the system, this time forcing those two frequencies to be assigned to the primary star in each synthetic binary. The results of this fit are presented in columns 4 and 5 of Table 1.

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Frequency (c/d)	Unconstrained Aa	Unconstrained Ab	Constrained Aa	Constrained Ab
f_2 = 5.54517		X	X	
f_3 = 6.41350		X	X	
f_4 = 1.59815		X		X
f_5 = 0.35367		X	X	
f_6 = 4.04180		X		X
f_7 = 1.19867	X			X
f_8 = 4.44439	X			X
f_9 = 1.52100	X			X
f_{10} = 1.32022		X	X	
f_{11} = 5.61725		X	X	
f_{12} = 4.88617		X	X	
f_{13} = 4.16793		X		X
f_{14} = 4.10357	X			X
f_{15} = 0.67907		X	X	
f_{16} = 1.63040	X			X
f_{17} = 1.34157	X		X	
f_{18} = 4.36444	X			X

Table 1. Best fit frequency assignments

Parameter	Unconstrained Aa	Unconstrained Ab	Constrained Aa	Constrained Ab
L ($L/L_\odot$)	19 500	12 700	24 900	16 200
M_V	-3.65	-3.18	- 4.00	-3.71
$T_{\rm eff}$ (K)	24 100	22 600	23 200	21 500
log g	3.70	3.72	3.52	3.53
$v_{\rm ZAMS}$ (km s^{-1})	100	150	250	150
$v_{\rm eq}$ (km s^{-1})	27	55	114	67
age (years)	$14{\times}10^6$		$17{\times}10^6$	
X_c	0.21	0.21	0.0015	0.0035
$\alpha_{\rm ov}$	0.1	0.15	0.15	0.2
$n_{\rm freqs}$	7	10	8	9

Table 2. Best fitting model parameters

The parameters of the best fitting models in the unconstrained and constrained fits are summarized in Table 2. We found that the constrained fit produces a better fit to the observational constraints than did the unconstrained fit. Both models correspond to a relatively old stellar age; the constrained fit model has reached the TAMS. This is consistent with studies of g mode excitation (Pigulski et al. 2016). In both cases, our fit shows that the Aa and Ab components of β Cen are hybrid SPB/β Cep pulsators, which signals them as good candidates for future study. The Ab component has been identified previously as a magnetic star (Alecian et al. 2011), which means that these stars could be adapted for probing interactions between convection, rotation and magnetic fields in stellar interiors.

3 Conclusions

We are able to find a good fit to the system by using the binary mass and observed frequencies as initial constraints. We have presented tentative frequency assignments for each star; the resulting fits are in good agreement with the observational constraints on the system.

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