Asteroseismic modelling of the Binary HD 176465

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Abstract: The detection and analysis of oscillations in binary star systems is critical in understanding stellar structure and evolution. This is because such systems have the same initial chemical composition and age. Solar-like oscillations have been detected in both components of the asteroseismic binary HD 176465 by Kepler (White et al., 2016). This study presents an independent modelling of the two stars in this binary system. Stellar models generated using MESA (Modules for Experiment in Stellar Astrophysics) were fitted to both the observed individual frequencies and some spectroscopic parameters. The individual theoretical oscillation frequencies for the corresponding stellar models were obtained using GYRE as the pulsation code. A Bayesian approach was applied to find the Probability Distribution Functions of the stellar parameters using AIMS (Asteroseismic Inference on Massive Scale) as the optimization code. The age of the individual stars was found to agree with that obtained by White et al., (2016) of about 3.0 ± 0.5 Gyr old.

Classical & observational constraints (From White et al., 2016)

The binary HD 176465 was observed as a single star but the realization of the presence of the oscillations from the second star was done by a manual inspection of the échelle diagram of the primary companion. Refer to Figure 3 in White et al., 2016 for the échelle diagrams of both stars. In Figure 1, a power excess region which is of the form of a Gaussian-like hump comprised of equally spaced modes is a signature of solar-like oscillations.

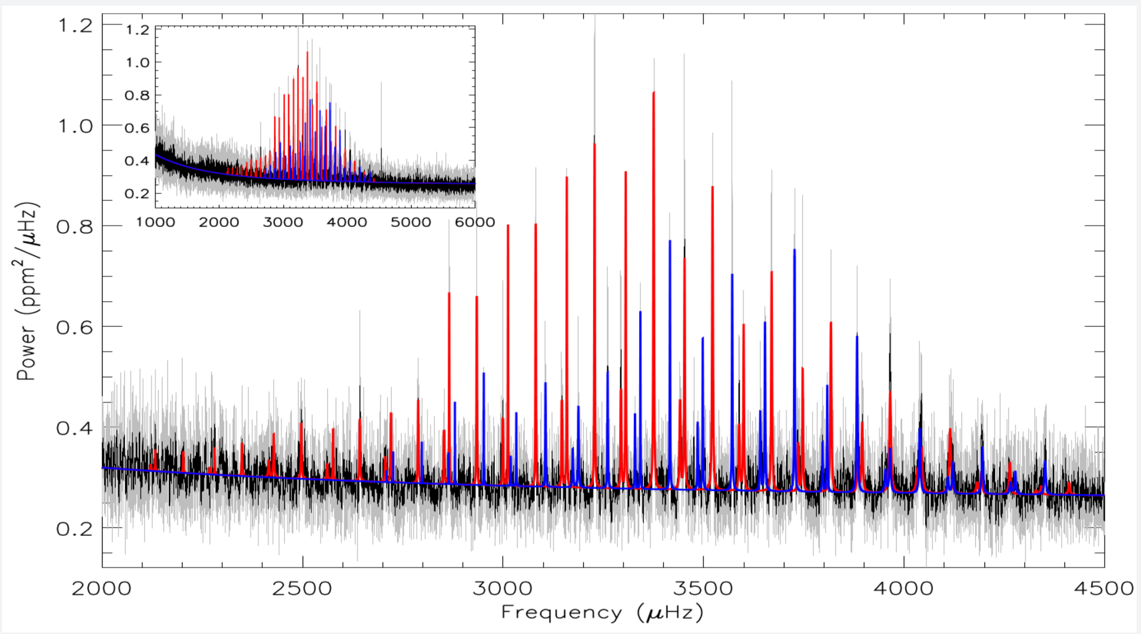

Figure 1: Power spectrum of HD 176465, smoothed by a box-car filter over 0.5μHz (gray) and 2μHz (black) adopted from White et al. 2016

Extraction of accurate and precise individual oscillation frequencies is key if they are to be used in modelling a star. The analysis of the power spectrum was performed using a Bayesian approach coupled with Markov Chain Monte Carlo (MCMC) method (Benomar, 2008). The overlapping stellar pulsations were separated by fitting the two stars simultaneously as shown in Figure 1.

Apart from the individual frequencies, spectroscopic parameters such as metallicity, surface gravity and effective temperature were used in our modelling strategies.
For more details on how the spectroscopic parameters were obtained see White et al., (2016).

Modelling

MESA was used to generate the stellar models (Paxton et al. 2013). In the models, the metal content (Z) [0.005, 0.013], mixing length [1.5, 2.2] and mass [0.7, 1.15] were varied. No convective overshooting or semiconvection were included in the models. However diffusion was.

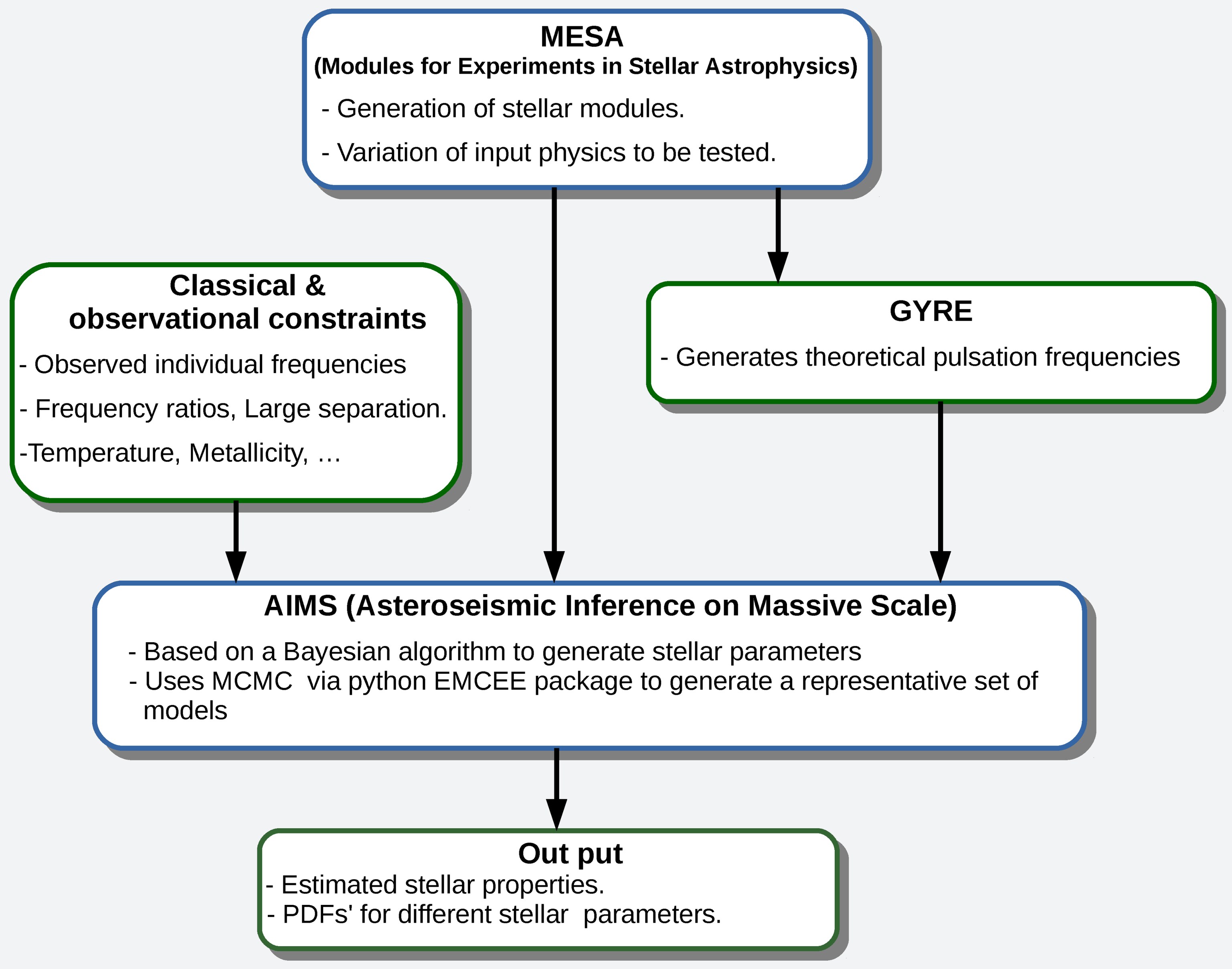

Figure 2: Structure flow of the method, inputs and expected outputs

The oscillation frequencies were generated using GYRE (Townsend & Teitler., 2013). Model frequencies were corrected for surface effects using the two-term correction described by Ball & Gizon (2014). The Probability Distribution Functions of the stellar parameters were then obtained using AIMS.

Comparison & Conclusion

Table 1: Top table corresponds to results of HD 176465 A and bottom table is for HD 176465 B. Results in this work (AIMS) are compared with those obtained using other modelling strategies (AMP, BASTA & MESA from White et al., 2016).

Parameter	AMP	BASTA	MESA	AIMS
Mass ($M_\odot$)	0.930± 0.041	$0.960^{+0.010}_{-0.011}$	0.948 ± 0.04	0.943 ± 0.011
R ($R_\odot$)	0.918 ± 0.015	$0.928^{+0.006}_{-0.003}$	0.925 ± 0.014	0.924 ± 0.004
Age (Gyrs)	3.0 ± 0.4	2.8 ± 0.3	3.20 ± 0.22	2.81 ± 0.48
Z	0.0085 ± 0.0010	0.011 ± 0.004	0.0102 ± 0.0011	0.012 ± 0.0010
α	1.90 ± 0.18	1.791	1.57 ± 0.11	1.78 ± 0.11

Parameter	AMP	BASTA	MESA	AIMS
Mass ($M_\odot$)	0.930± 0.041	$0.918^{+0.010}_{-0.011}$	1.024 ± 0.061	0.921 ± 0.015
R ($R_\odot$)	0.885 ± 0.006	$0.886^{+0.003}_{-0.006}$	0.917 ± 0.019	0.883 ± 0.005
Age (Gyrs)	2.9 ± 0.5	3.2 ± 0.4	2.97 ± 0.33	2.52 ± 0.80
Z	0.0085 ± 0.0007	0.011 ± 0.004	0.0124 ± 0.0013	0.011 ± 0.0012
α	1.94 ± 0.12	1.791	2.03 ± 0.21	1.79 ± 0.11

- The results obtained in this work are compared with those obtained using other stellar modelling tools (see Table 1). In our results, **only statistical errors are included, systematic errors are yet to be included**.
- There is a good agreement in the Z and age values obtained in our results. This is expected assuming both stars were formed from the same molecular cloud and at approximately the same time. A good agreement can also be seen when comparing with results from other modeling tools.
- The average age for all the different models is $\simeq$ 3.0 ± 0.5 Gyr which is consistent with that obtained by White et al. (2016). Independent measurement of stellar parameters in binary systems provide ways of testing stellar physics included in modelling of stars.

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