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A new asteroseismic diagram for solar-type stars

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Abstract. We propose a new kind of seismic diagram, based on the determination of the locations of sharp acoustic features inside a star. We show that by combining the information about the position of the base of the convective envelope or the He II ionisation zone with a measure of the average large separation, it is possible to constrain the unknown parameters characterising the physical processes in the stellar interior. We demonstrate the application of this technique to the analysis of mock data for a CoRoT target star. A detailed description of this technique is available in Mazumdar (2005).

Key words. stars: oscillations – stars: interiors

1. A new approach — the Δ–t diagram

The acoustic depth of the He II ionisation zone (HIZ) and the base of the convective envelope (BCZ) can be estimated using the oscillatory signal in the frequencies that they produce (e.g., Mazumdar & Antia 2001). The parameters $\tilde{t}_{\rm HIZ}$ and $\tilde{t}_{\rm BCZ}$ (denoting the acoustic radii of the two layers, respectively) can be obtained from a least-squares fit of a functional form to the second differences of the frequencies. For stars more massive than $1.5M_\odot$ this method is not reliable due to the proximity of the BCZ and the HIZ in such stars.

However, the location of the sharp features inside a star (BCZ and HIZ) are not independent of the general stratification. On the other hand, the mean large separation is indicative of the gross properties of the star. In this work we propose to connect these pieces of information in the form of a diagram (called the Δ–t diagram) to characterise the stellar interior. We plot the estimated acoustic radii of the BCZ, $\tilde{t}_{\rm BCZ}$, as a function of the mean large separation of the radial modes, $\langle\Delta\nu_0\rangle$, for a grid of stellar models (Fig. 1). Each curve on this diagram is an evolutionary track. A similar diagram may be constructed using the acoustic radii $\tilde{t}_{\rm HIZ}$, instead of $\tilde{t}_{\rm BCZ}$.

Clearly, the Δ–t diagram (Fig. 1) has diagnostic power to determine the stellar mass and age. Further, the Δ–t diagram is sensitive to the different stellar parameters such as mass, chemical composition or convective parameters such as mixing length and overshoot, which can be exploited to search for a suitable model fitting a given set of observed frequencies. Given an initial trial model, one can test its relative position on the Δ–t diagram with respect to the observed data to gain insight into how a particular parameter needs to be changed from the initial guess in order to find a better match with the data. This method is illustrated with an exercise using simulated data for the star HD 49933.

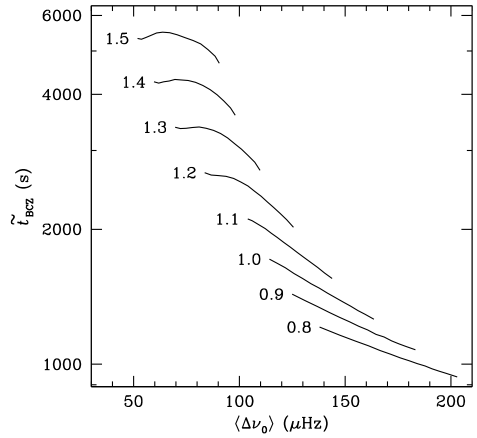

Fig. 1. An example of the Δ–*t* diagram, where the acoustic radius of the BCZ is plotted as a function of the average large separation. Each curve on this diagram is an evolutionary track of the indicated mass in solar units.

2. Application of the Δ–*t* diagram

We have successfully applied the technique of using the Δ–*t* diagram to a simulated dataset of the CoRoT primary target star, HD 49933. The average large separation was found to be $\langle \Delta\nu_0 \rangle = 90.4 \pm 0.2\ \mu$Hz. The acoustic radii were estimated through a fit of the second differences to be $\tilde{t}_{\rm BCZ} = 4085 \pm 68$ s and $\tilde{t}_{\rm HIZ} = 4866 \pm 49$ s. We use this information to place the star on a Δ–*t* diagram constructed from theoretical models. We start with an initial trial model, characterised by a set of stellar parameters (M, α, $d_{\rm ov}$, (X_0, Z_0)), lying inside the error box on the HR diagram. We place this model on a set of Δ–*t* diagrams, each consisting of a set of tracks which differ by only one stellar parameter, and compare its position w.r.t. the position of HD 49933. The relative position of the target star and the trial model on the Δ–*t* diagram for each stellar parameter indicates in which direction that particular parameter needs to be tuned. An example of the above procedure is illustrated in Fig. 2, where the possible values of the chemical composition become constrained. Similar constraints can be obtained for the other parameters from similar Δ–*t* diagrams. The closest model is approached through an iterative procedure of tuning each parameter, based on the position on the Δ–*t* diagram at every step. After several iterations, we were able to converge to a set of models that satisfied the constraints on the Δ–*t* diagram for both $\tilde{t}_{\rm BCZ}$ and $\tilde{t}_{\rm HIZ}$. The task of searching for the best possible combination of parameters is greatly reduced by the Δ–*t* diagram through the additional information about the location of the BCZ and HIZ.

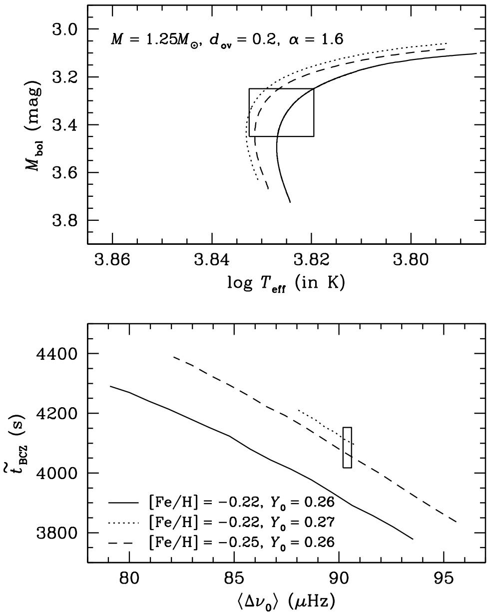

Fig. 2. *Top panel*: The position of HD 49933 is shown on the HR diagram. Three evolutionary tracks for models with a given mass, overshoot and mixing length parameter, but different chemical compositions are illustrated. *Bottom panel*: The Δ–*t* diagram for $\tilde{t}_{\rm BCZ}$ is shown with the three tracks only for the portion where they lie inside the HR box in the top panel. The derived values of $\langle \Delta\nu_0 \rangle$ and $\tilde{t}_{\rm BCZ}$ for HD 49933 are represented by a box.

References

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