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PROPERTIES OF THE IONISATION GLITCH: INSIGHTS FROM AN IONISATION REGION MODELLING

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Abstract. The work described here presents the first of two parts towards the development of a seismic method for obtaining unbiased estimates of the helium abundance in low-mass stars. This approach seeks to best exploit the information contained in the ionisation glitch by relying on a physically introduced model of the ionisation region. This model depends explicitly on quantities of interest (such as helium abundance) and thus aims to avoid both the reliance on ad hoc glitch modelling as well as the need for calibration, which are both part of the current methods. We present here how the model is conceived as well as some properties about the ionisation region structure that can be derived from it.

Keywords: stellar interior, ionisation, abundances, glitches, oscillations

1 Introduction

Asteroseismology, by combining information on resonant modes and a physical model of the star, provides strong constraints on internal stellar processes involved. The information thus obtained depends on what physics is included which may result in modelling biases. A well-known example is the mass/helium degeneracy first described in Lebreton & Goupil (2014) and based on a detailed seismic study of HD 52625. It highlights in particular the many mass-helium couples (M, Y) that satisfy the constraints provided by the oscillation frequencies, thus leading to a high degree of uncertainty on both quantities.

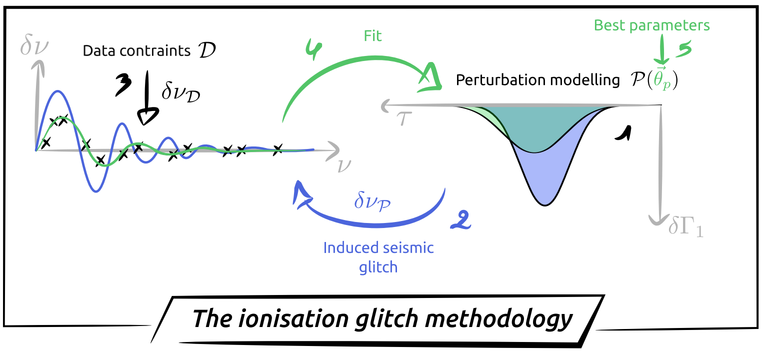

Fig. 1. Scheme of the ionisation glitch procedure. Based on a certain perturbation form $\mathcal{P}$ (1), we aim to find the induced signature (2) that best approximates the seismic constraints (3). The fit (4) thus provides the best parameterisation $\vec{\theta}_p$ (5) of $\mathcal{P}$ which gives information regarding the structure responsible for the observed signature.

Overcoming this issue may be achieved through an alternative approach that is the exploitation of the ionisation glitch (and whose procedure is schematised in Fig. 1). Rather than a whole stellar structure, this

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method only seeks to model a perturbation $\mathcal{P}$ with a given shape (examples of the first adiabatic exponent perturbation $\delta\Gamma_1$ can be found in Monteiro et al. (1994); Gough (2002); Monteiro & Thompson (2005)) in order to identify its signature in the oscillation frequencies. The information thus retrieved lies in the parameterisation $\vec{\theta}_p$ of this perturbation (cf Fig. 1). However, this approach presents two main flaws: first, one must assume the form of the perturbation $\mathcal{P}$ *a priori* and we might legitimately wonder about the consequences if the form of the actual perturbation differs from it. Secondly, if the information needed is not contained in $\vec{\theta}_p$, calibration on realistic models (Houdek & Gough 2011; Verma et al. 2014, 2019) becomes necessary to relate it to known physical quantities such as the helium abundance.

2 Ionisation region modelling

To address these difficulties, we derived a model of the ionisation region based on adequate assumptions for a mixture in an ionisation region (cf Fig. 2 with i designating the chemical species and r the ionisation states).

Theoretical framework

Isentropic region	*Chemical equilibrium*	*Uniform abundances*	*Electroneutrality*
$dS = 0$	$\mu_i^r + \mu_e - \mu_i^{r-1} = 0$	$\sum_r N_i^r = \text{cnst}$	$\sum_i \sum_r r N_i^r = N_e$

Fig. 2. Assumptions used to derive an expression of the first adiabatic exponent Γ_1

The analytical expression of the first adiabatic exponent Γ_1 resulting from these assumptions is found to depend on the density ρ, the temperature T and the helium abundance Y as illustrated in Fig. 3. The whole structure is determined through the integration of the hydrostatic equilibrium and Poisson's equation.

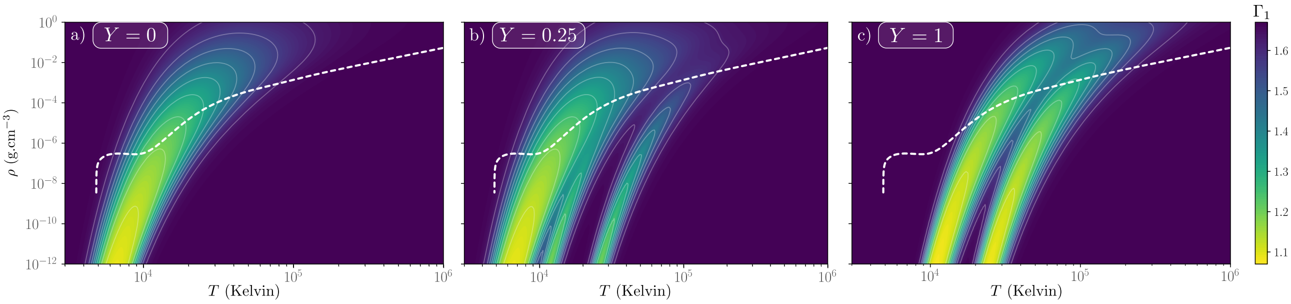

Fig. 3. $\Gamma_1(\rho, T, Y)$ as a function of density ρ and temperature T for multiple helium abundances. (a) : $Y = 0$, (b) : $Y = 0.25$, (c) : $Y = 1$. The dashed line present on each panel shows a relation $\rho(T)$ extracted from a realistic solar model.

The resulting model $\mathcal{M}$ can be parameterised by 3 quantities: the helium abundance at the surface Y_s, the electron degeneracy parameter in the convection zone ψ_{CZ} and a parameter controlling the position of the ionisation region ε. A forthcoming article (Houdayer et al. submitted) describes a method for exploiting the ionisation glitch by using a difference of these models $\delta\mathcal{M}$ instead of an ad hoc perturbation $\mathcal{P}$. The approach presented enables more elaborate perturbations to be considered as well as providing more direct access to the quantities of interest such as the helium abundance.

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