The envelopes of low-mass stars: the impact of Coulomb effects on stellar oscillations

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I. Introduction

In this work, we explore the outer layers of stars less massive than the Sun. In particular, we have computed a set of stellar models raging from 0.4 to 0.9 solar masses with the aim at determining the impact on stellar oscillations of two physical processes occurring in the envelopes of these stars. Namely, the partial ionisation of chemical elements and the electrostatic interactions between particles in the outer layers. We find that alongside with partial ionisation, Coulomb effects also impact the acoustic oscillation spectrum. The influence of Coulomb interactions on the sound-speed gradient profile produces a strong oscillatory behaviour with diagnostic potential for the future.

II. Thermodynamic properties of the turbulent outer regions

The behaviour of the first adiabatic exponent around its monatomic ideal gas value, 5/3, is influenced by two fundamental aspects. First, the increase of the degree of ionisation decreases the Γ_1 value, causing a known depression in the radial profile of Γ_1, particularly throughout the partial ionisation zones of light elements, hydrogen and helium. The second aspect that influences the behaviour of the first adiabatic exponent relates to the electrostatic interactions between charged particles, known generally as Coulomb effects. Coulomb effects increase the value of Γ_1 causing it to become larger than 5/3 in some regions of the convective zone. Also, the acoustic potential is determined by the model structure and, therefore, will be impacted by physical processes like partial ionisation of atomic species and electrostatic interactions between charged particles. Fig. 1 shows these two profiles for all the models.

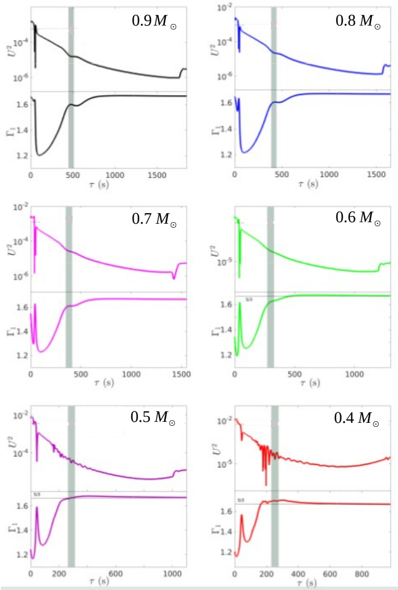

Fig. 1 Representation of the acoustic potentials (top panels) and Γ_1 (bottom panels) for the outer convective layers of all the theoretical models. The vertical shadowed grey bar highlights the region where the ionisation fraction of single ionised helium reaches its maximum value.

III. The coupling parameter

A measure of how important Coulomb effects are in the interior of a star can be expressed by the ionic plasma coupling parameter, Γ_i, given as the ratio of the average potential energy to the thermal kinetic energy in the gas. Figure 2 shows the plasma interaction parameter for all the models where it is most relevant: the outer layers, namely in the temperature range 4.2 < log T < 5.6. In this temperature range, the electrostatic interactions are known to be more significant, as this is the interval of temperatures where the helium ionisation occurs. Figure 2 also shows that the sharp features of the lowest mass models corresponding to a strong scatter of the acoustic modes can be easily related to the highest values (values close or greater than 1) of the plasma interaction parameter.

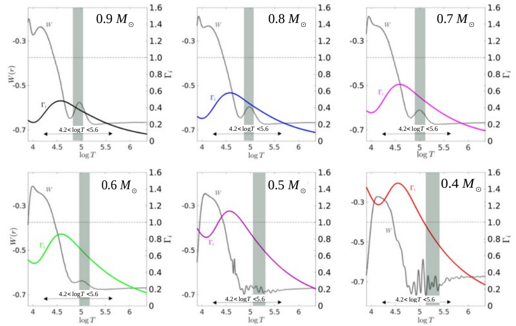

Fig. 2 The ionic plasma interaction parameter, Γ_i , as a function of temperature. Also plotted in this figure, with grey colour, is the sound-speed gradient, W(r). The sharp features shown by lower-mass models correspond to the regions where the plasma interaction parameter is close or greater than one.

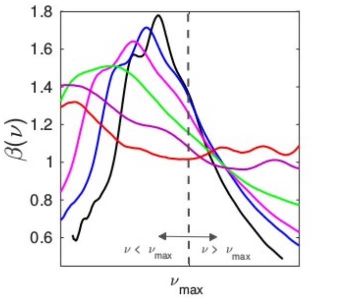

Fig. 3 All the diagnostics β(ν) shifted to collapse around the frequency of maximum power, reinforces the idea that an important internal structural transition occurs around the models with 0.6 solar masses. The distinct oscillatory signals contain valuable information about electrostatic interactions between particles.

IV. Seismology of low-mass stars: the outer regions

To describe the characteristics of the signal produced when the sound-speed undergoes an abrupt variation, we use a seismic diagnostic, β(ν), where ν stands for the cyclic frequency, which is particularly suitable to probe the outer convective layers of main-sequence stars. In Fig. 3, we can clearly see how β responds to modifications in the stellar structure. In particular, how the quasisinusoidal signal, quite marked for the 0.9 $M_\odot$ model, slowly vanishes with decreasing mass. For the 0.6 solar mass model, the signal is almost absent in the diagnostic β, as it is also absent the corresponding dip in the acoustic potential. For models with masses lower than 0.6 solar masses, the diagnostic β reflects the complex pattern of perturbations in the acoustic potential.

V. Conclusion

We find that, around the value of 0.6 solar masses, the peak/dip in the first adiabatic exponent/acoustic potential corresponding to helium ionisation zones (Fig. 1) vanishes and, consequently, does not produce an oscillatory signature in the seismic diagnostic β(ν). This is thus the reference value, for models with solar metallicity, around which occurs a transition in the characteristics of the oscillatory signal imprinted in the oscillation frequencies by two distinct physical processes. The acoustic spectrum of stars more massive than 0.6 solar masses is mostly impacted by partial ionisation processes, whereas the acoustic spectrum of stars less massive than 0.6 solar masses is predominantly impacted by Coulomb interactions.

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