RADIAL VIBRATIONS IN A 5 \( M_\odot \) HYDROGEN-HELUM STAR

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Abstract. A model of first-generation intermediate mass star of 5 \( M_\odot \) with no metals has been considered. The vibrational instability of this model has been investigated. The model, in question, burns helium in the core. Calculations have been performed for the first and second harmonics as well as for the fundamental mode. The model has been found to be vibrationally stable toward radial pulsations.

1. Introduction

Looking at the positions of various types of pulsating stars in the Hertzsprung–Russell (H–R) diagram it is understood that there is a correlation with evolution. Iben (1971) and Christy (1972) pointed out the importance of the understanding of stellar evolution to have an insight into the pulsational instability in stars.

In the present work pulsational properties of a first-generation intermediate mass star of 5 \( M_\odot \) are studied. The first generation stars which have no heavy elements in their initial composition, might have contributed significantly to the early enrichment of the pre-galactic medium with nucleosynthesis products. The structure and evolution of first-generation stars was first treated by Ezer and Cameron (1971). Several others (e.g., Cary, 1974) followed them in searching for the first-generation stars' possible connection with the early evolutionary stages of the Galaxy. It was indicated by Eryurt-Ezer and Kızılca (1985) that the evolutionary history of these stars must be known in order to determine the amount of heavy elements ejected as a result of various mechanisms into the medium at certain stages of their evolution. Was helium formed primordially, hydrogen-helium stars could be born prior to any other known stellar population in the Galaxy. In fact, after encountering the difficulty of explaining the cosmic abundance of helium in terms of the nucleosynthesis in stars (Truran et al., 1965; Cameron and Truran, 1971), and the discovery of 3 K (Penzias and Wilson, 1965) microwave background radiation the idea that helium was formed primordially gained more acceptance. These ideas led us to think the investigation of the pulsational instability of first-generation stars deserved attention.

It has been known for a long time that there exists a critical mass for the vibrational stability of Main-Sequence stars (Ledoux, 1941). Schwarzschild and Härm (1959) showed that the critical mass was 60 \( M_\odot \) for normal stars with \( Y = 0.22 \) and \( Z = 0.02 \). This limit has been found to be about 280 \( M_\odot \) for pure hydrogen stars (Boury, 1963) and 9 \( M_\odot \) for pure helium stars (Boury and Ledoux, 1965; Noels, 1967) using models constructed with electron scattering as the sole opacity source. Stothers and Simon (1970) have further increased the limiting value of 9 \( M_\odot \) for pure helium stars by considering models with different compositions and using a better opacity law. Noels

and Masereel (1982) studied the vibrational stability and critical mass of helium stars. They found that for models with 2% of heavy elements in the mass, the critical mass was 16 $M_\odot$, while for pure helium models the critical mass was found to be 11.5 $M_\odot$. In the computation of these models the Astrophysical Opacity Library (Huebner et al., 1977) was used. However, for pure helium stars with electron scattering as the sole opacity source the value they obtained for the critical mass was 9 $M_\odot$. Noels and Magain (1984), by replacing the outer layers of a pure helium star by hydrogen rich ones, calculated the effect of it on the critical mass. They showed that the critical mass was extremely sensitive to the presence of a small hydrogen rich envelope. Ibrahim et al. (1981) studied the vibrational stability towards radial oscillations of homogeneous Main-Sequence stars initially composed of 80% of hydrogen and 20% of helium in mass. They found the critical mass for vibrational stability to be 123 $M_\odot$.

The basic properties of the model are given in Section 2. In Section 3 radial adiabatic oscillations and vibrational instability are discussed and results are given in Section 4.

2. Model

We studied the vibrational stability of radial oscillations in a model of 5 $M_\odot$ star with initial composition $X = 0.8$ and $Z = 0$. The model whose basic properties are given in Table I has been computed by Eryurt-Ezer and Kızılolu (1985). The model star is on the helium Main Sequence.

<table>
<thead>
<tr>
<th>$M/M_\odot$</th>
<th>$Y_c$</th>
<th>$\log T_c$</th>
<th>$\log \rho_c$</th>
<th>$q_{cc}$</th>
<th>$\beta_c$</th>
<th>$\rho_c/\rho$</th>
<th>$X_r$</th>
<th>$Y_r$</th>
<th>$\log L/L_\odot$</th>
<th>$\log T_e$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.998</td>
<td>8.063</td>
<td>4.154</td>
<td>0.008</td>
<td>0.996</td>
<td>2.782(4)</td>
<td>0.8</td>
<td>0.2</td>
<td>3.366</td>
<td>4.415</td>
</tr>
</tbody>
</table>

The number in parentheses indicates the power of 10 which multiplies the corresponding number.

3. Radial Adiabatic Oscillations and Vibrational Instability

The radial adiabatic oscillations are described by the application of the classical linear theory (Ledoux and Walraven, 1958). Equations governing the radial adiabatic oscillations are, in their linear form, given (cf. Schwarzschild and Härm, 1959; Ledoux, 1969) as

\[
\frac{d}{dx} \left( \frac{\delta P}{P} \right) = -\frac{1}{P} \frac{dP}{dx} \left( \frac{\delta P}{P} + \left( 4 + \frac{\omega^2 X^3}{q} \right) \frac{\delta r}{r} \right),
\]

(1)

\[
\frac{d}{dx} \left( \frac{\delta r}{r} \right) = -\frac{1}{x} \left( 3 \frac{\delta r}{r} + \frac{\delta \rho}{\rho} \right),
\]

(2)

\[
\frac{\delta P}{P} = \Gamma_1 \frac{\delta \rho}{\rho},
\]

(3)