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Chinese Astronomy and Astrophysics 39 (2015) 16–27

CHINESE
ASTRONOMY
AND ASTROPHYSICS

Dependence of Pulsation Stability on the Helium Abundance of Stellar Convective Envelope† ⋆

XIONG Da-run△1 DENG Li-cai[2] WANG Kun[2]

[1] *Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210008*

[2] *National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012*

Abstract By using a non-local and time-dependent theory of convection, the linear non-adiabatic oscillations of radial and low-degree non-radial F-p8 modes are calculated for the stellar evolutionary models in the mass range of 1.4∼3.0 $M_\odot$, with three helium abundances of convective envelope (Y =0.28, 0.13, 0.00), and the solar metal abundance (Z =0.02). The numerical results show that the red edge of theoretical δ Scuti instability strip almost does not change with the helium abundance. With the decrease of the helium abundance, the blue edge of the δ Scuti instability strip moves toward the direction of low temperatures, the high-temperature stars on the hot side of instability strip become more stable, while the low-temperature stars on the cold side of instability strip become more instable. It seems to be impossible to explain the non-variable stars in the δ Scuti instability strip by using the diffusion of helium. However, the ratios of non-variable stars to variable stars in the hot and cold sides of the δ Scuti strip may be taken as the observational evidence of helium diffusion.

Key words stars: variables: δ Scuti—stars: oscillations—stars: abundances, convection

1. INTRODUCTION

δ Scuti variables are a group of main-sequence and subgiant variables with the spectral types A∼F located in the lower end of the classical pulsation-instability strip on the H-R diagram. The typical pulsation periods are in the range of 0.02∼0.25 d. The pulsation amplitudes

† Supported by National Natural Science Foundation (10773029, 10573022)

Received 2013–11–20

⋆ A translation of *Acta Astron. Sin.* Vol. 55, No. 4, pp. 279–287, 2014

△ xiongdr@pmo.ac.cn

0275-1062/15/$-see front matter
doi:10.1016/j.chinastron.2015.01.004

of most δ Scuti variables are very small, the amplitudes of light variations are in the range from several thousandth magnitude to several hundredth magnitude, and they are radial or low-degree non-radial low-order P-mode oscillations. Only a very small number of δ Scuti variables have large-amplitude light variations, and these δ Scuti stars with large-amplitude light variations are radially pulsating. δ Scuti variables are situated in the main-sequence branch or the evolutionary stage from main-sequence stars to giant stars, their interior structures and evolutionary states are fairly clear. Although the amplitudes of their light variations are rather small, but in respect to the oscillations of sun-like stars, the amplitudes of their light variations have been several orders of magnitude larger, and very suitable for photometrical studies, hence the δ Scuti stars are ideal objects for the research of stellar seismology.

In the δ Scuti variable pulsation-instability strip, only third to half of stars have detectable light variations. So far we don't understand why at the same place on the H-R diagram some stars are variables, and some stars have no light variations observable. As the study deepens, and the photometric accuracy improves, it is found that around the detectable limit, there exist many variables with small-amplitude light variations. Hence, some stars originally considered to have a constant luminosity are not really invariable stars, just because their light variations are too small in amplitude to be easily detected. Then, a problem arises, namely, what is the reason to cause such kind of differences of their amplitudes of light variations? Up to now we are not certain what is the real cause. A conventional point of view believes that this may relate with the stellar chemical composition. Because of the effect of gravity separation, in the process of stellar evolution, in respect to hydrogen, helium will deposit downward. With the decrease of helium abundance in the stellar convective envelope, the excitation effect of doubly-ionized helium region on the stellar pulsation decreases, so that the stars will become non-pulsating, or pulsating with a marginally detectable amplitude[1−2]. Breger discovered that the classical Am-type stars are non-pulsating, or pulsating with a very small amplitude[3]. Am-type stars are just a kind of manifestation of the element diffusion effect, hence it seems to be favorable to the suggestion that the helium diffusion may cause the existence of a variety of invariable stars in the δ Scuti variable pulsation-instability strip. However, the problem is actually much complicated, the final conclusion awaits still further in-depth studies. This paper aims to study the effect of the helium abundance in stellar convective envelope on the pulsation stability. Sec.2 describes briefly the scheme of this study, Sec.3 gives the results of numerical calculations, and the final section presents the conclusion and a short discussion.

2. SCHEME OF THIS STUDY

The standard stellar evolution theory does not take account of the diffusion of helium. In order to study comprehensively the hypothesis of helium diffusion for interpreting the existence of invariable stars in the δ Scuti pulsation-instability strip, we have to calculate