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Turbulent Convection and Pulsation Stability of Stars† ⋆

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Abstract The controversies about the excitation mechanism for low-temperature variables are reviewed: (1) Most people believe that γ Doradus variables are excited by the so-called convective blocking mechanism. Our researches show that the excitation of γ Doradus has no substantial difference from that of δ Scuti. They are two subgroups of a broader type of δ Stuti-γ Doradus stars: δ Scuti is the p-mode subgroup, while γ Doradus is the g-mode subgroup. (2) Most people believe that the solar and stellar solar-like oscillations are damped by convection, and they are driven by the so-called turbulent random excitation mechanism. Our researches show that convection is not solely a damping mechanism for stellar oscillations, otherwise it is unable to explain the Mira and Mira-like variables. By using our non-local and time-dependent theory of convection, we can reproduce not only the pulsationally unstable strip of δ Scuti and γ Doradus variables, but also the solar-like oscillation features of low-luminosity red giants and the Mira-like oscillation features of high-luminosity red giants.

Key words stars: variables—stars: oscillations—stars: convection

1. BRIEF HISTORIC REVIEW

In astrophysics, the study on pulsating variables started very early, and the theoretical development is also the most perfect. The light variability of the red giant Mira was discovered early over 400 years ago. The period-luminosity relation of Cepheid variable stars was found about 100 years ago, which becomes the foundation for measuring the distance of an extragalactic object. Almost at the same time Shapley determined that the variability of Cepheid variables is caused by the periodically pulsating motion of stars[1]. Eddington established the

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foundation of stellar pulsation theory in his outstanding work "The Internal Constitution of the Stars", and predicted with genius that the excitation of pulsating variables comes from the critical ionization region of hydrogen in the stellar outer shell[2]. Parallel to the study of stellar interior structure and evolution, the stellar pulsations become one of the main bodies and frontiers of astrophysics in the last century. Through a common endeavor of many astrophysicists in about one century, the theory of stellar pulsations becomes perfect day by day. This is summarized respectively in the monographs of Flügge[3], Cox[4], and Unno et al.[5].

The solar 5-min oscillation is an important discovery in the middle of last century[6]. Afterwards, the theory of helioseismology makes the people able to directly explore the interior structure and motion (the differential rotation and interior circulation) of the Sun through observing the oscillations on the solar surface[7−11]. The great success of helioseismology has triggered the establishment and development of stellar seismology, which greatly enriches the human knowledge of the interior structures and evolutions of the Sun and stars. The observations and theories are closely combined and promoted each other, which brings the research of variable stars to a fast developing track. The research on variable stars has made a great progress in recent 20 years, but there are still a lot of unsolved problems and difficulties, which are mostly associated with the nonlinear theory and stellar convection theory. This paper is limited to discuss only the stellar convection theories and the relevant problems about the pulsation stability of variable stars. Section 2 briefly introduces the development of stellar convection theories, especially the non-local and time-dependent theory of stellar convection of ours. In Section 3, according to the historic sequence, the studies of stellar pulsation stability relevant to the convection, and the new progresses in the studies of the oscillations of solar-like stars, the oscillations of long-period variable stars (Mira-like), and δ Stuti/γ Doradus stars in recent years are described. And finally, a brief summary and prospective are given in the last section.

2. STELLAR CONVECTION THEORIES

Radiation and convection are two main styles of energy transfer in stellar interiors. Except the hottest β Cep-type variable stars and the pulsating B-type variable stars along the main sequence band, almost all the Cepheid and Cepheid-like variable stars, as well as the Mira and Mira-like variable stars, possess a surface convective region extended in different degrees. Convection leads to the energy and momentum transfer, as well as the element mixing in the stellar interior, thus seriously affects the stellar interior structure, evolution, and pulsation stability, this is one of the most fundamental theories of astrophysics. Due to the extremely large scale of celestial bodies, the stellar convection always possesses a very high Reynolds number, thus the stellar convection exhibits mostly a fully developed turbulent state. The turbulence theory has developed for over 100 years up to now, but we still can not absolutely know its nature and rule very clearly, hence, it is impossible for us to