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Small amplitude variable red giants

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Abstract. Small amplitude variable red giants were discovered long time ago (Eggen 1969, Henry *et al.* 2000, Jorison *et al.* 1997). The revolutionary turning point for the study of this type of variable was due to the work of Wood (2000) and Soszyński *et al.* (2004) based on the very large stellar sample of the Magellanic clouds MACHO project and OGLE photometric data. By using our non-local time-dependent theory of convection (Xiong 1989), we carried out a linear stability survey for red giants with initial mass of $M = 1 - 3M_{\odot}$. Explanations for the observed variabilities and analysis of mode identifications in red giant stars are presented in this work.

Keywords. Convection, stars: late-type, stars: oscillations

By analyzing large stellar sample of observations did for the Magellanic clouds in MACHO project, and the OGLE photometric data set, Wood (2000) and Soszyński *et al.* (2004) started a new epoch for the study of variable red giants discovered long time ago (Eggen 1969). It is concluded (Soszyński *et al.* 2004) that the pulsating red giants can be classified into two group with distinct properties:

(*a*) Long period variables (LPVs) including Mira variables and semi-regular variables, whose primary period is located in the sequence C on their period-M_I diagram, while the second and the third dominant periods are located in sequences B and C, none of them goes in sequence A (see Fig. X of Soszyński *et al.* 2004);

(*b*) Small amplitude variable red giants (SARGs), whose primary period is located in the sequence A, while the second and the third dominant periods are located in sequences A and B, none in sequence C.

Red giants have extended convective envelopes, therefore the coupling between convection and oscillations is the principal mechanism of excitation (damping) for their oscillations. Dealing with the coupling between convection and oscillations accurately is the major goal that have to be realized in the study of red giant variables. The amplitude growth rates in SARGs is found to be smaller than that in LPVs by 4-6 order of magnitudes, this makes the study of SARGs even more difficult.

Following our non-local time-dependent theory of convection (Xiong 1989), linear non-adiabatic oscillations for stars of 1-3$M_{\odot}$ are calculated. Figure 1 shows the distributions of the pulsation stability in the fundamental–the 4^{th} overtone in these models. The solid dots stands for the pulsationally stable modes, while the open circles, crosses, triangles, inverse triangles and squares are respectively the pulsationally unstable models in the fundamental mode–4^{th} overtone. Two instability strips are clearly shown in Figure 1. The one in the middle of the plot is the δ Scuti instability strip, and the other one located near the Hayashi limit is the second instability strip for red giants. There is a region of pulsationally stable yellow giants which firewalling these two instability strips. For the low luminosity red giants in the red giant branch (RGB), all the modes from the fundamental to the 4^{th} overtone are all pulsationally stable. When $\log L/L_{\odot} \geqslant 1.2$, the

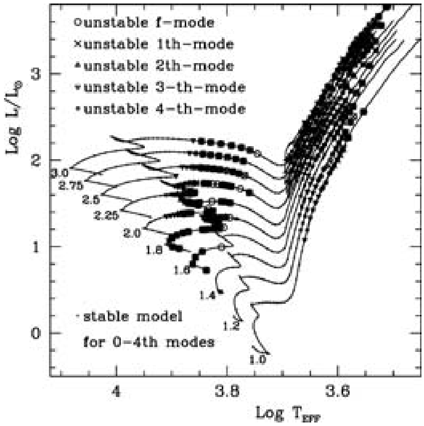

Figure 1. The pulsationlly stable (solid dots) and unstable (other type of symbols, see text for details) models in HR diagram.

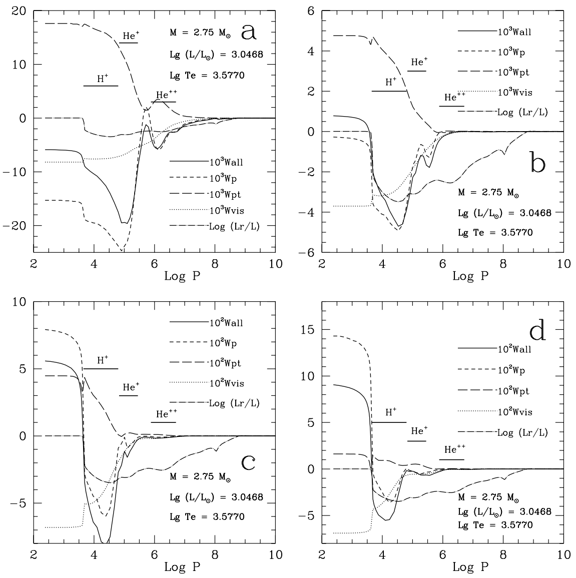

Figure 2. The integrated works vs. depth ($\log P$) for a model of red giant. a)-d) are respectively for the fundamental mode to 3^{th} overtone.

4^{th} and the third overtones start to become unstable. For higher luminosity and lower effective temperature models, pulsational instability tends to expand towards lower order modes, this agrees qualitatively with the observations of SARGs. They are very different from LPVs at even higher luminosity and lower temperature, which tend to pulsate at the fundamental and low order overtones, all modes higher than 4^{th} overtone are stable (Xiong, Deng& Cheng 1998).

Using a common method, the the two distinct types of variables are understood naturally. The δ Scuti stars are excited by radiative κ-mechanism, in that the thermodynamic coupling between convection and oscillations is a damping mechanism which is actually the major cause for the red edge of δ Scuti strip. Turbulent pressure, however, is a excitation mechanism of oscillation that plays a key role in exciting the red variables. The four

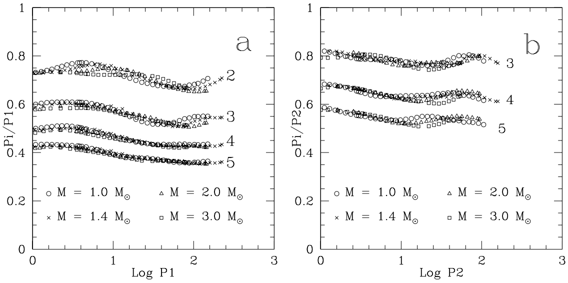

Figure 3. The theoretical Peterson diagram: a). $P_i/P_1(i = 2 - 5)$ vs. $\log P_1$; b). $P_i/P_2(i = 3 - 5)$ vs. $\log P_2$

panels in figure 2 illustrate the variation of the integrated works as the function of depth ($\log P$), respectively for the fundamental mode to the 3^{th} overtone of a model of red giant. The black line is the sum integrated works W_{all}, which is equal to the sum of the following components: W_p due to gas pressure (dashed line, it includes the contribution of both of radiative and convective energy transfer), W_{pt} due to turbulent pressure (long dashed line), and W_{vis} due to turbulent viscosity (dotted line), i.e. $W_{all} = W_p + W_{pt} + W_{vis}$. The fractional radiation flux (dash-dotted line) is also drawn in figure 2. It can be seen from the figures that in the deep interior of convection zone, where the radiative flux is far less than the convective one, W_p decreases for decreasing $\log P$. That means that the contribution of convective energy transfer, namely the thermodynamic coupling between convection and oscillation, is a damping effect. W_p increases rapidly towards the surface due to the modulated excitation in the surface zone of radiation flux gradient (Xiong, Cheng & Deng, 1998). W_{pt} increases with decreasing $\log P$, that means that the turbulent pressure is a exciting mechanism for oscillations of stars. The turbulent viscosity is always a damping mechanism. It can be found that W_{vis} increases more quickly towards higher overtone compared with W_{pt}.

Figures 3a and 3b are the theoretical Peterson diagrams for our models. Our study shows that the P4 identified by Soszyński *et al.* (2004) is very likely the 5^{th} overtone instead of 4^{th} one. The reason for such a conclusion is that none of the models in our calculations can have $P3/P1$ and $P4/P1$ can be as small as ≈ 0.50 and ≈ 0.39 respectively as what observation tells. If the observed "P4" is identified as the 5^{th} overtone and "P3" is identified as the mixing of the 3^{th} overtone and 4^{th} overtone, then all conflicts will disappear.

Acknowledgements

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