The effects of stellar population synthesis on the distributions of the asteroseismic observables $\nu_{\text{max}}$ and $\Delta \nu$ of red-clump stars

Wuming Yang$^{1,2}$, Xiangcun Meng$^1$ and Zhongmu Li$^{3,4}$

$^1$School of Physics and Chemistry, Henan Polytechnic University, Jiaozuo 454000, Henan, China.
$^2$Department of Astronomy, Beijing Normal University, Beijing 100875, China.
$^3$Institute for Astronomy and History of Science and Technology, Dali University, Dali 671003, China.
$^4$National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China.

ABSTRACT

The distributions of the frequencies of the maximum oscillation power ($\nu_{\text{max}}$) and the large frequency separation ($\Delta \nu$) of red giant stars observed by CoRoT have a dominant peak. Miglio et al. (2009) identified that the stars are red-clump stars. Using stellar population synthesis method, we studied the effects of Reimers mass loss, binary interactions, star formation rate and the mixing-length parameter on the distributions of the $\nu_{\text{max}}$ and $\Delta \nu$ of red-clump stars. The Reimers mass loss can result in an increase in the $\nu_{\text{max}}$ and $\Delta \nu$ of old population which lost a considerable amount of mass. However, it leads to a small decrease in those of middle-age population which lost a little bit of mass. Furthermore, a high mass-loss rate impedes the low-mass and low-metal stars evolving into core-helium burning (CHeB) stage. Both Reimers mass loss and star formation rate mainly affect the number of CHeB stars with $\nu_{\text{max}}$ and $\Delta \nu$, but hardly affect the peak locations of $\nu_{\text{max}}$ and $\Delta \nu$. Binary interactions also can lead to an increase or decrease in the $\nu_{\text{max}}$ and $\Delta \nu$ of some stars. However, the fraction of CHeB stars undergoing binary interactions is very small in our simulations. Therefore, the peak locations are also not affected by binary interactions. The non-uniform distributions of $\nu_{\text{max}}$ and $\Delta \nu$ are mainly caused by the most of red-clump stars having an approximate radius rather than mass. The radius of red-clump stars decreases with increasing the mixing-length parameter. The peak locations of $\nu_{\text{max}}$ and $\Delta \nu$ can, thus, be affected by the mixing-length parameter.

Key words: stars: mass-loss; stars: fundamental parameters; galaxy: stellar content; stars: oscillations

1 INTRODUCTION

Solar-like oscillations have been confirmed in many main-sequence and subgiant stars, such as α Cen A (Bedding et al. 2004), α Cen B (Kjeldsen, Bedding & Butler 2005), Procyon A (Eggenberger et al. 2004), η Bootis (Carrier, Eggenberger & Bouchy 2005), etc. Some giant stars, such as ξ Hya (Frandsen et al. 2002), η Ser (Barban et al. 2004), and ε Oph (De Ridder, Barban & Carrier 2006), have also been found the behaviour of oscillating. Asteroseismology is a powerful tool for determining the fundamental parameters of individual stars (Eggenberger & Carrier 2006, Eggenberger & Carrier 2006, Yang & Meng 2010), and it has significantly advanced the theories of stellar structure and stellar evolution.

The detection of solar-like oscillations in red giant stars opened up a new field that can be explored with asteroseismic techniques. For an ensemble of cluster stars all having the same age and metallicity, studying oscillations in the cluster stars should provide more constraints on the theory of stellar evolution than just fitting parameters of single oscillating stars (Stello et al. 2007). Thus a number of attempts have been made to detect solar-like oscillations in giant stars of clusters (Gilliland et al. 1993, Gilliland 2008, Edmonds & Gilliland 1996, Stello et al. 2007, Frandsen, Bruntt Grundahl 2007, Stello & Gilliland 2009, Stello et al. 2011, Bedding et al. 2010). The oscillations of giant stars have been detected in a few clusters, such as open cluster M67 (Stello et al. 2007), globular cluster 47 Tucanae (Edmonds & Gilliland 1996) and NGC 6397 (Stello & Gilliland 2009). However, these observations did not obtain oscillation frequencies. Recently, using the data observed by the first CoRoT (Baglin et al. 2006) 150-day long run in the direction of the galactic centre (LRc01), Hekker et al. (2009) obtained the frequencies of maximum oscillation power ($\nu_{\text{max}}$) and the large separations ($\Delta \nu$) of about 800 solar-like oscillating red giants. They found that distributions of the $\nu_{\text{max}}$ and $\Delta \nu$ are non-uniform (see Fig. 1), which provide an opportunity for detailed studies of population of galactic-disk red giants (Miglio et al. 2009). Addition-
ally, theoretical \( \nu_{\text{max}} \) and \( \Delta \nu \) can be calculated using equations (Kjeldsen & Bedding 1995)

\[
v_{\text{max}} = 3050 \frac{M/M_{\odot}}{(R/R_{\odot})^2 \sqrt{T_{\text{eff}}/5777}} \mu \text{Hz}, \tag{1}
\]

and

\[
\Delta \nu = 134.9 \frac{(M/M_{\odot})^{1/2}}{(R/R_{\odot})^{3/2}} \mu \text{Hz}. \tag{2}
\]

Thus, we can obtain the theoretical distributions of \( \nu_{\text{max}} \) and \( \Delta \nu \) by simulating the distributions of stellar mass, radius and effective temperature.

Using the stellar population synthesis code TRILEGAL, Miglio et al. (2009) identified that the oscillating giants observed by CoRoT are primarily red-clump stars, i.e. post-flash core-Heburning (CHEB) stars, and found that theoretical distributions of \( \nu_{\text{max}} \) and \( \Delta \nu \) are good global agreement with observed ones. Equations (1) and (2) show that the theoretical distributions of \( \nu_{\text{max}} \) and \( \Delta \nu \) are relative to the mass and radius distributions of population. Therefore, Miglio et al. (2009) suggested that mass-loss rate during the red-giant branch (RGB) and star formation rate may affect the distributions of \( \nu_{\text{max}} \) and \( \Delta \nu \).

In this paper, we focused the effects of mass loss, binary interactions, the mixing-length parameter, etc. on the distributions of \( \nu_{\text{max}} \) and \( \Delta \nu \) of CHEB stars. We used the Hurley rapid single and binary evolution codes (Hurley, Pols, & Tout 2000, Hurley, Tout & Pols 2002) to construct stellar models. In Hurley’s codes, mass-loss efficiency is an adjustable parameter. They can, thus, be applied to studying the effect of mass loss on the distributions.

The paper is organized as follows. We simply show our stellar population synthesis method in section 2. The results are represented in section 3. In section 4, we discuss and summarize the results.

2 STELLAR POPULATION SYNTHESIS

To simulate the stellar population observed \( \nu_{\text{max}} \) and \( \Delta \nu \) (Hekker et al. 2009), we calculated single-star stellar population (SSP) and binary-star stellar population (BSP), respectively. Stellar samples are generated by the Monte Carlo simulation. The basic assumptions for the simulations are as follows. (i) Star formation rate (SFR) is assumed to be a constant over the past 15 Gyr. (ii) The age-metallicity relation is taken from Rocha-Pinto et al. (2000a). (iii) The lognormal initial mass function (IMF) of Chabrier (2001) is adopted. Additionally, for BSP, we generate the mass of the primary, \( M_1 \), according to the IMF. The ratio \( q \) of the mass of the secondary to that of the primary is assumed to be an uniform distribution within 0-1 for simplicity. Then the mass of the secondary star is given by \( q M_1 \). We assume that all stars are members of binary systems and that the distribution of separations is constant in log \( a \) for wide binaries and falls off smoothly at close separation:

\[
\alpha_M(a) = \begin{cases} 
\alpha_{\text{app}} a / a_0 & a < a_0; \\
\alpha_{\text{app}} & a_0 < a < a_1,
\end{cases} \tag{3}
\]

where \( \alpha_{\text{app}} \approx 0.070 \), \( a_0 = 10 R_{\odot}, a_1 = 5.75 \times 10^6 R_{\odot} = 0.13 pc \) and \( m \approx 1.2 \). This distribution implies that the number of wide binary system per logarithmic interval is equal, and that approximately 50% of the stellar systems are binary systems with orbital periods less than 100 yr (Han, Podsiadlowski, & Eggleton 1995).

With these assumptions, we calculated the evolutions of 10^5 stars with an initial mass between 0.8 and 5.8 M_\odot and mixing-length parameter \( \alpha = 2.0 \). The theoretical \( \nu_{\text{max}} \) and \( \Delta \nu \) of single and binary stars are calculated using equations (1) and (2).

3 CALCULATION RESULTS

3.1 Mass-loss effect

Fig. [2] shows the distributions of the mass and radius of the CHEB stars of simulated SSP with different Reimers’ mass-loss efficiency (\( \eta \)). The distributions of the initial mass of the progenitors of the CHEB stars also are shown in Fig. [2]. Reimers mass loss mainly affects the stars with initial mass less than 2 M_\odot. With the increase in the \( \eta \), the mass lost by a star during the RGB increases, which leads to many low-mass stars cannot evolve into the CHEB stage, and the lower limit of the initial mass of stars being able to evolve into the CHEB stage increases too. For example, when the value of \( \eta \) increases from 1.0 to 2.0, the lower limit increases from about 0.95 M_\odot to 1.25 M_\odot. Thus the fraction of low-mass CHEB stars and the sample size of the simulated CHEB stars decreases with increasing \( \eta \). For \( \eta = 2.0 \), the mass distribution is almost uniform. Moreover, the distribution of logarithmic radius has a fixed peak location between 1.05 and 1.15, which is almost not affected by the mass loss.

The distributions of \( \nu_{\text{max}} \) and \( \Delta \nu \) of the simulated CHEB stars are represented in Fig. [3]. Both distributions have a dominant peak. But the peak locations are slightly lower than the observed ones. With the increase in \( \eta \), the number of the CHEB stars with \( \nu_{\text{max}} \) in the range of about 10-30 \( \mu \)Hz and \( \Delta \nu \) in the range of about 1-4 \( \mu \)Hz decreases. However, the dominant peak for \( \Delta \nu \) always locates between 3 \( \mu \)Hz and 3.5 \( \mu \)Hz, which implies that the effect of the mass loss on the \( \Delta \nu \) is not enough to change the peak location. For \( \eta \leq 1 \), the dominant peak of \( \nu_{\text{max}} \) locates between 25 \( \mu \)Hz and 30 \( \mu \)Hz. However, when the \( \eta \) increases from 1.0 to 2.0, the peak location of \( \nu_{\text{max}} \) moves to between 20 \( \mu \)Hz and 25 \( \mu \)Hz.

The changes in the distributions of \( \nu_{\text{max}} \) and \( \Delta \nu \) shown in Fig. [3] should not be due to the typical variations in Monte Carlo simulations. In order to show the effect of sample size on the distributions of \( \nu_{\text{max}} \) and \( \Delta \nu \), we calculated the evolutions of 10^5 stars which produced 3973 CHEB stars and the evolutions of 2 \times 10^5 stars which given 793 CHEB stars. Both samples have the same evolutionary parameters. Figure [4] shows that the distributions of \( \nu_{\text{max}} \) and \( \Delta \nu \) of the two samples are very similar. A Kolmogorov-Smirnov test shows that the discrepancies between the two sample distributions are not significant: the Kolmogorov-Smirnov statistic \( D \approx 0.030 \) for \( \nu_{\text{max}} \) and 0.033 for \( \Delta \nu \), and the significance level of the \( D \) is 0.61 for \( \nu_{\text{max}} \) and 0.45 for \( \Delta \nu \).

In Fig. [5] we plotted the distributions of the \( \nu_{\text{max}} \) and \( \Delta \nu \) of
The effects of SPS on the distributions of the asteroseismic observables $\nu_{\text{max}}$ and $\Delta \nu$.

Figure 2. The histograms of the mass and radius of the CHeB stars of simulated SSP with different mass-loss coefficient $\eta$. In the left panels, empty bars illustrate the mass distribution of the progenitors of the CHeB stars.

Figure 3. The histograms of the $\nu_{\text{max}}$ and $\Delta \nu$ of the CHeB stars of simulated SSP with different mass-loss coefficient $\eta$.

Figure 4. Histogram showing the effect of sample size on the distributions of the $\nu_{\text{max}}$ and $\Delta \nu$ of simulated CHeB stars. Upper panels show the results of $10^6$ model evolutions. While lower panels represent the results of $2 \times 10^5$ model evolutions. Both samples have the same other parameters. A K-S test shows that the discrepancies between two distributions are insignificant.
ary of the \( \nu_{\text{max}} \) and \( \Delta \nu \) of the stars with age approximately 5 Gyr increases too, however, the distributions of the \( \nu_{\text{max}} \) and \( \Delta \nu \) of the stars in the age range of about 2-4.5 Gyr move down slightly, which leads to the peak location in the \( \nu_{\text{max}} \) histogram moving to 20-25 \( \mu \text{Hz} \).

### 3.2 BSP effect

Fig. 5 shows the histograms of the \( \nu_{\text{max}} \) and \( \Delta \nu \) of the \( \text{CHeB} \) stars of simulated BSP with \( \eta = 0.5 \) and the distributions of the \( \nu_{\text{max}} \) and \( \Delta \nu \) as a function of stellar age. The distributions of the \( \nu_{\text{max}} \) and \( \Delta \nu \) are very similar to those of the SSP with the same \( \eta \). This is because that most binary stars evolved into \( \text{CHeB} \) stage are wide binary stars. Binary interactions such as mass transfer and mass accretion do not take effect in these wide binary stars. However, the lower panels of Fig. 5 show that the value of \( \nu_{\text{max}} \) and \( \Delta \nu \) of some stars with age > 2 Gyr is larger than 40 \( \mu \text{Hz} \) and 4 \( \mu \text{Hz} \), respectively. This is due to the fact that binary interactions lead to an obvious increase or decrease in the mass of the stars when they evolve into the \( \text{CHeB} \) stage. Consequently, the \( \nu_{\text{max}} \) and \( \Delta \nu \) of these stars are larger than those of the wide binary stars. However, the fraction of these stars is very small. Thus the effect of binary interactions on the distributions of \( \nu_{\text{max}} \) and \( \Delta \nu \) is not significant.

### 3.3 SFR effect

The star formation rate of the Galaxy is not a constant. \cite{Rocha-Pinto2000b} gave that the SFR of the Galaxy at 2-5 Gyr ago is about 2 times larger than an average SFR over the past 15 Gyr and the SFR of the Galaxy at 7-9 Gyr ago is about 1.5 times larger than the average SFR. Fig. 6 shows the distributions of \( \nu_{\text{max}} \) and \( \Delta \nu \) of \( \text{CHeB} \) stars of the simulated SSP with a constant SFR and with the Galaxy SFR given by \cite{Rocha-Pinto2000b}. Although the number of simulated \( \text{CHeB} \) stars is changed, the distributions are similar. In fact, for \( \eta = 0.5 \), Fig. 6 shows that the value of \( \nu_{\text{max}} \) and \( \Delta \nu \) of the \( \text{CHeB} \) stars with age > 2 Gyr is mainly located in the range of 10-30 \( \mu \text{Hz} \) and 1-4 \( \mu \text{Hz} \), and gathers around 25 \( \mu \text{Hz} \) and 3 \( \mu \text{Hz} \), respectively. Thus increasing or decreasing the SFR of stars at a certain age > 2 Gyr can increase or decrease the number of \( \text{CHeB} \) stars but cannot affect the peak locations of the \( \nu_{\text{max}} \) and \( \Delta \nu \) of \( \text{CHeB} \) stars. Although increasing the SFR of the young stars in the age range of 0-2 Gyr also can increase the number of stars with relatively high \( \nu_{\text{max}} \) and \( \Delta \nu \), the peak locations cannot also be affected unless the SFR is enhanced many times.

### 3.4 Mixing-length parameter effect

The distribution of the radius and of the \( \Delta \nu \) of \( \text{CHeB} \) stars have a dominant peak, but the distribution of the mass of the simulated \( \text{CHeB} \) stars with \( \eta = 2.0 \) has not a dominant peak, which implies that the non-uniform distributions of \( \nu_{\text{max}} \) and \( \Delta \nu \) may be
caused by the radius of many CHeB stars concentrating in a narrow interval. In fact, equations 1 and 2 indicate that \( \nu_{\text{max}} \) and \( \Delta \nu \) are more sensitive to the change in radius than that in mass. Furthermore, a variation of the mixing-length parameter \( \alpha \) mainly changes the stellar radius, but has almost no influence on the luminosity (Kippenhahn & Weigert 1990). Used the Eggleton’s stellar evolution code (Eggleton 1971, 1972, 1973), our calculations show that the increase in \( \alpha \) leads to a decrease in the radius of stars evolved into horizontal branch, and thus leads to an increase in the \( \nu_{\text{max}} \) and \( \Delta \nu \) of the stars. In order to study the effect of the mixing-length parameter \( \alpha \) on the distributions of \( \nu_{\text{max}} \) and \( \Delta \nu \), we modified the Hurley’s single evolution code to calculate the stellar evolution with \( \alpha = 2.4 \). Fig. 8 shows the histograms of the \( \nu_{\text{max}} \) and \( \Delta \nu \) distributions of the simulated CHeB stars with \( \alpha = 2.4 \). An increase in \( \alpha \) results in a movement of the peak location of the radius distribution towards a lower value, and leads to a movement towards a higher value for the peak locations of the \( \nu_{\text{max}} \) and \( \Delta \nu \) distributions. Furthermore, Fig. 9 represents the distributions of the \( \nu_{\text{max}} \) and \( \Delta \nu \) as a function of stellar age. Increasing the mixing-length parameter \( \alpha \) leads to the upper boundary of the distributions moving up slightly.

4 DISCUSSIONS AND CONCLUSIONS

Several points should be kept in mind when comparing the theoretical distributions of \( \nu_{\text{max}} \) and \( \Delta \nu \) with the observations. Firstly, the scaling equation 1 is obtained from the ideas that \( \nu_{\text{max}} \) is proportional to the acoustic cutoff frequency \( \nu_{\text{ac}} \) and \( \nu_{\text{ac}} \propto gT_{\text{eff}}^{1/2} \) (Brown et al. 1991), where \( g \) is the stellar surface gravity and \( T_{\text{eff}} \) is the effective temperature. The \( \nu_{\text{max}} \) given by equation 1 is not necessarily accurate (Gilliland 2008; Stello et al. 2009a). For example, the ratio of \( \nu_{\text{ac}} \) of stellar models to that calculated from the global parameters of models is always below unity (see the Figure 8 of Stello et al. 2009a). However, the scaling equation 2 is very accurate. The uncertainty of equation 2 is within a few per cent (Stello et al. 2009a). In addition, scaling equations 1 and 2 agree within a few per cent with stellar model calculations for cool models \( (T_{\text{eff}} \lesssim 6400 \, \text{K}) \) (Stello et al. 2009a). A few per cent deviations in equations 1 and 2 cannot obviously change the peak locations of \( \nu_{\text{max}} \) and \( \Delta \nu \) in our simulations. Hence, the deviations cannot affect our basic results.

The giant stars observed by the CoRoT may contain the first giant branch (FGB) stars. Our simulations show that the distributions of \( \nu_{\text{max}} \) and \( \Delta \nu \) of the FGB stars are uniform. Therefore, the \( \nu_{\text{max}} \) and \( \Delta \nu \) of the FGB stars do not affect the peak locations.

Comparing with the Miglio et al. (2009)’s simulation, we used the same IMF and age-metallicity relation. In our simulation, the SFR is a constant over the past 15 Gyr. But it is a constant over the past 9 Gyr in the Miglio et al. (2009)’s simulation. This difference could not affect the simulated results because the oldest population are impeded into the CHeB stage by mass loss. For example, for \( \eta = 1.0 \), the simulated population do not contain the stars older than about 10 Gyr. The frequencies of our simulated peak locations are lower than those of Miglio et al. (2009). This may be caused by mixing-length parameter.

For different \( \eta \), the CHeB stars with age < 2 Gyr lose only a negligible amount of mass from their surface before they evolved into CHeB stage. Consequently, the effect of the mass loss on the evolution of these stars is insignificant. The distributions of \( \nu_{\text{max}} \) and \( \Delta \nu \) of these stars are almost not affected by Reimers mass loss. However, for old population, the bigger the \( \eta \), the more the mass loss. For a big \( \eta \), stars can lose an appreciable, but from star to star different, amount of mass from their surface before the helium flash. Then the stars move to the left of the HR diagram with slightly decreasing luminosity after the flash, and the mean density of the stars is enhanced. The increase in the mean density leads to an increase in the \( \nu_{\text{max}} \) and \( \Delta \nu \) of these stars. However, the change in the mean density is different from star to star. The mass of the stars evolved into CHeB at the same age is approximate, but the extent of central helium burning is different. The stars around
the ZAHB have a smaller radius than those approaching the AGB. The fractional change caused by mass loss in the radius of the stars around the ZAHB is larger, and the change in the mean density of these stars is also larger than that of those approaching the AGB. The stars which are close to the ZAHB are located around the upper boundary of the distributions of $v_{\text{max}}$ and $\Delta \nu$ with age, while those approaching the AGB are located around the lower boundary. Therefore, the changes of the upper and lower boundary shown in Fig. 5 are different. However, for the middle age population, the stars lose only a little amount of mass from their surface before the helium flash, which hardly affect the radius and luminosity of the stars after the flash. Because the mass decrease slightly but the radius is almost not changed, the mass loss results in that the $v_{\text{max}}$ and $\Delta \nu$ of these stars decrease slightly.

The Reimers mass loss mainly affects the old population. The mass loss leads to an increase in the $v_{\text{max}}$ and $\Delta \nu$ of old population. However, a high mass-loss rate can impede the low-mass low-metal stars evolving into CHeB stage. If the Reimers mass loss is very efficient during the red-giant branch, the $v_{\text{max}}$ and $\Delta \nu$ of CHeB stars would not be observed in old clusters. The astrophysical observation on old clusters may provide a help to constrain the mass-loss rate.

For $\eta = 0.5$, the value of $v_{\text{max}}$ and $\Delta \nu$ of population with age $> 2$ Gyr is almost located in the range of 10-30 $\mu$Hz and 1-4 $\mu$Hz, and gathers about 25 $\mu$Hz and 3 $\mu$Hz, respectively. Therefore increasing or decreasing the number of stars at a certain age $> 2$ Gyr cannot affect the peak locations of the $v_{\text{max}}$ and $\Delta \nu$. So the peak locations are not sensitive to the SFR and not sensitive to whether population contains old stars. For $\eta = 1.0$, increasing the SFR of stars with age between 7-9.5 Gyr can increase the stars with $v_{\text{max}} > 25$ $\mu$Hz and $\Delta \nu > 3$ $\mu$Hz. But even enhancing the SFR to several times, the peak locations are not affected.

In BSP, some CHeB stars can lose a little mass, but some stars can accrete a little mass by the weak binary interactions. The effect of a slight mass change before the helium flash on the luminosity and radius of CHeB stars after the flash is negligible. Therefore the $v_{\text{max}}$ and $\Delta \nu$ of the CHeB stars which lost a little bit of mass decrease; whereas those of the CHeB stars which accreted a little mass increase. Hence the distributions of $v_{\text{max}}$ and $\Delta \nu$ of CHeB stars cannot be affected. However, for the strong binary interactions, on the one hand, some stars which have lost an appreciable amount of mass from their surface would move to the left of the H-R diagram with slightly decreasing luminosity, at the same time, the mean density of these stars would increase. Consequently the $v_{\text{max}}$ and $\Delta \nu$ of these stars increase. On the other hand, some stars with age $> 2$ Gyr which have accreted a considerable amount of mass would become like the stars with age $< 2$ Gyr, hence their $v_{\text{max}}$ and $\Delta \nu$ can increase obviously too. However, the fraction of these interactive binary stars appearing in our simulated CHeB stars is very small. Therefore, although the binary interactions such as mass transfer and mass accretion can affect the $v_{\text{max}}$ and $\Delta \nu$ of CHeB stars undergoing a mass accretion or mass loss, the effect of binary interactions on the distributions of the $v_{\text{max}}$ and $\Delta \nu$ of CHeB stars is not significant.

An increase in the mixing-length parameter $\alpha$ mainly leads to a decrease in the radius of all CHeB stars after the helium flash. Thus the $v_{\text{max}}$ and $\Delta \nu$ of CHeB stars increase with $\alpha$. Consequently, the peak locations of the $v_{\text{max}}$ and $\Delta \nu$ can be affected by the $\alpha$. For the middle-age population at the age of about 2 to 5 Gyr, the peak locations are more sensitive to the $\alpha$ than mass-loss rate, SFR and metal abundance. Thus the astrophysical observation on the middle age clusters may provide a help to constrain the mixing-length parameter.

The mass of simulated CHeB stars is mainly located in 1-2 $M_\odot$. For the CHeB stars with the mixing-length parameter $\alpha = 2.0$, the most of them have a radius in the range of 11-14 $R_\odot$. Therefore, even the mass distribution is uniform, the stars have an approximate mean density. Hence they have an approximate $v_{\text{max}}$ and $\Delta \nu$. Consequently, there is a dominant peak in the distributions of the $v_{\text{max}}$ and $\Delta \nu$.

A high Reimers mass loss can lead to an increase in the $v_{\text{max}}$ and $\Delta \nu$ of old population, and impedes the low-mass low-metal stars evolving into CHeB stage. On the contrary, it results in a very small decrease in those of middle-age population. However, the mass loss scarcely affect the $v_{\text{max}}$ and $\Delta \nu$ of young population. The effect of the Reimers mass loss on the peak locations of $v_{\text{max}}$ and $\Delta \nu$ of the CHeB stars is not significant unless the mass-loss rate is very high. The effect of star formation rate and binary interactions on the peak locations of $v_{\text{max}}$ and $\Delta \nu$ of the CHeB stars is also not significant. The dominant peak of $v_{\text{max}}$ and $\Delta \nu$ is due to the fact that most of CHeB stars have an approximate radius. The radius can be affected by the mixing-length parameter. The peak location also can, thus, be affected by the mixing-length parameter.

ACKNOWLEDGMENTS

We thank Shaolan Bi for her help, the anonymous referee for his/her helpful comments. This work was supported by the Ministry of Science and Technology of the Peoples republic of China through grant 2007CB815406, the NSFC though grants 10773003, 10933002, 10963001, project of the fundamental and frontier research of henan province under grant no. 102300410223, and the high-performance grid computing platform of Henan Polytechnic University.

REFERENCES

Baglin, A., Michel, E., Auvergne, M., The COROT Team., 2006, in Proceedings of SOHO 18/GONG 2006/HELAS I, Beyond the spherical Sun (ESA SP-624), 7-11 August 2006, Sheffield, UK. Editor: K. Fletcher, P34

Barban, C., De Ridder, J., Mazumdar, A. et al., 2004, in Proceedings of the SOHO 14 / GONG 2004 Workshop (ESASP-559). "Helio- and Asteroseismology: Towards a Golden Future". 12-16 July, 2004. New Haven, Connecticut, USA. Editor: Danesy, p.113

Bedding, T. R., Kjeldsen, H., Butler, P. R. et al., 2004, ApJ, 614, 380

Bedding, T. R., Huber, D., Stello, D., 2010, ApJ, 713, L176

Brown, T. M., Gilliland, R. L., Noyes, R. W., Ramsey, L. W., 1991, ApJ, 368, 599

Chabrier, G. 2001, ApJ, 554, 1274

Carrier, F., Eggenberger, P., Bouchy, F., 2005, A&A, 434, 1085

De Ridder, J., Barban, C., Carrier, F. et al. 2006, A&A, 448, 689

Edmonds, P. D., Gilliland, R., 1996, ApJ, 464, L157

Eggenberger, P., Carrier, F., Bouchy, F. Blecha, A. 2004, A&A, 422, 247

Eggenberger, P., Carrier, F., Bouchy, F., 2005, NewA, 10, 195

Eggenberger, P., Carrier, F., 2006, A&A, 449, 293

Eggleton, P. P., 1971, MNRAS, 151, 351
The effects of SPS on the distributions of the asteroseismic observables $\nu_{\text{max}}$ and $\Delta\nu$

Eggleton, P. P., 1972, MNRAS, 156, 361
Eggleton, P. P., 1973, MNRAS, 163, 279
Frandsen, S., Carrier, F., Aerts, C. et al., 2002, A&A, 394, L5
Frandsen, S., Bruntt, H., Grundahl, F., 2007, A&A, 475, 991
Gilliland, R. L., Brown, T. M., & Kjeldsen, H. et al., 1993, ApJ, 106, 2441
Gilliland, R. L., 2008, ApJ, 136, 566
Han Z., Podsiadlowski P., Eggleton P.P., 1995, MNRAS, 272, 800
Hekker, S., Kallinger, T., Baudin, F. et al., 2009, A&A, 506, 465
Hurley, J. R., Pols, O. R., Tout, C. A., 2000, MNRAS, 315, 543
Hurley, J. R., Tout, C. A., Pols, O. R., 2002, MNRAS, 329, 897
Kippenhahn, R., Weigert, A., 1990, in Stellar Structure and Evolution (Berlin, Springer-Verlag), p271
Kjeldsen, H., Bedding, T. R., 1995, A&A, 293, 87
Kjeldsen, H., Bedding, T. R., Butler, R. P. et al., 2005, ApJ, 635, 1281
Miglio, A., Montalban, J., Baudin, F. et al., 2009, A&A, 503, L21
Reimers, D. 1975, Memoires of the Societe Royale des Sciences de Liege, 8, 369
Rocha-Pinto, H. J., Maciel, W. J., Scalo, J., Flynn, C., 2000a, 358, 850
Rocha-Pinto, H. J., Scalo, J., Maciel, W. J., Flynn, C., 2000b, 358, 869
Stello, D., Bruntt, H., Kjeldsen, H. et al., 2007, MNRAS, 377, 584
Stello, D., Gilliland, R. L., 2009, ApJ, 200, 949
Stello, D., Chaplin, W. J., Basu, S., Elsworth, Y., Bedding, T. R., 2009a, MNRAS, 400, L80
Stello, D. et al., 2009b, ApJ, 700, 1589
Stello, D., Basu, S., Bruntt, H., 2010, ApJ, 713, L182
Yang, W., Meng, X., 2010, NewA., 15, 367