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The ages of Delta Scuti Stars

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Abstract. We describe the ages of δ Scuti stars as a function of the fundamental period of pulsation. We show that the metal-poor variables (pulsating blue stragglers or SX Phe stars) should be restricted to short periods as observed. The metal-strong variables on the other hand, should show a much greater range of periods, but Log $P \geqslant -1.3$ days.

Keywords. δ Scuti stars: pulsating blue stragglers; SX Phe stars

1. Introduction

The δ Scuti variables are late A and early F stars located in the instability strip on or above the main sequence. Their typical pulsation periods are found to be in the interval of 0.03d–0.25d and exhibit total light amplitudes $<$ 0.01mag.–0.7mag. in V. Both radial and non-radial oscillations have been detected in these variables. It is generally accepted that the dominate oscillation in stars with large light amplitudes (> 0.20 in V) is radial. These variable stars are found at all metallicities. The metal-poor variables (the pulsating blue stragglers in globular clusters in particular) are called SX Phe stars. In this paper we will simple refer to them as metal-poor δ Scuti stars.

2. Stellar Models

We are currently involved in a program calculating the radii, absolute magnitudes, surface gravities, masses, temperatures, and ages of δ Scuti stars as a function of the fundamental period and metallicity. A large number of model calculations are available for this purpose. See for example the many evolutionary track calculations described in the *Astrophysics and Space Science 316, 1–261, 2008* issue dedicated to describing the evolution and seismic tools available for stellar astrophysics.

A full set of stellar evolutionary tracks is available from the Yonsei-Yale (Y^2) collaboration, Yi et al. (2003), that cover the metallicities and masses observed for δ Scuti stars. The simple equation, $\mathrm{P}\sqrt{(\mathrm{M}/\mathrm{R}^3)} = \mathrm{Q}$, was used to calculate the fundamental periods. If the mass, M, and radius, R, are expressed in terms of their solar values, and the period, P, in days, $\mathrm{Q} \approx 0.033$. Q varies only slightly with period and metallicity. These changes were incorporated in the calculations, but only change the results in a minor way from adopting a constant value for Q. Since the luminosity L, and the temperature T, are given as a function of mass, chemical composition Z, age, and $[\alpha/\mathrm{Fe}]$ in the evolutionary tracks, the radius R is calculated from $\mathrm{L} = 4\pi\mathrm{R}^2\sigma\mathrm{T}^4$, and the periods follow utilizing the pulsation equation above.

Calculations were performed only when the stars are evolving through the instability strip. We adopted a 300° wide strip defined by the observations of large-amplitude δ Scuti variables (McNamara 1997). This strip is narrower than that described by Breger

(1999), possible due to the inclusion of many stars pulsating in higher radial modes and non-radial modes in his sample. The stars in my sample tend to fall near the red edge of the instability strip defined by Breger. A word of caution, since the width of the instability strip is not precisely defined, the times spent in the strip by the stars to be described in the discussion section, are approximate.

3. Discussion of Results

We present samples of the age calculations in Figures 1 and 2 based on the evolutionary tracks for [α/Fe] = 0.00. Almost identical results are found for the [α/Fe] = 0.30 tracks. Figure 1 shows the age (Gyrs) as a function of Log P in days based on the $Z = 0.02$ tracks. The data points follow a parabola-like curve, although we used a third order polynomial to fit the data as indicated in the figure (y = age and x = Log P), to minimize the residuals. The standard deviation is 0.46 Gyrs. Mass input from 1.7 to 2.4 solar masses is required to account for the full range of observed periods. Stars of 1.6 solar masses do not enter the instability strip. The short period cut off at Log P ~ -1.3 agrees with the observational data. The lower mass stars produce the shorter period stars and the higher mass stars produce the longer period stars. The age calculations indicate that the fundamental mode δ Scuti stars with near solar metallicity (Z $\sim$ 0.02) are younger than $\sim$ 1.3 Gyrs.

Figure 2 shows the age (Gyrs) as a function of Log P in days calculated from the Z = .0001 tracks. Again we find a parabolic-like distribution with the peak shifted to Log P ~ -1.3 from the − 1.05 peak observed for the Z = 0.02 stars. To minimize residuals, we have fit the data with a cubic expression (see insert). The standard deviation is 0.18 Gyrs. Now the maximum age can reach $\sim$ 6 Gyrs. A mass range of only 1 − 1.3 solar masses accounts fully for the range of periods observed at this metallicity. The data points falling at short period on the rising branch of the curve in Figure 2 are 1.0 and 1.1 solar mass stars, while the stars falling at longer period on the descending part of the curve are 1.2 and 1.3 solar mass stars. Since by far most of the metal-poor variables (SX Phe stars, pulsating blue stragglers) found in globular clusters have Log P < -1.1 days, we conclude that the majority of variables observed are restricted primarily to a narrow mass range of 0.1 solar mass. It should be emphasized that the peaks that occur in the age-period distributions mark the division between main-sequence H core-burning stars of short period and the longer period H shell-burning stars.

In order to see the points raised in the latter part of the last paragraph from a different perspective, we have plotted the time spent by stars of various masses in the instability strip (Gyrs) for Z = 0.004 ([Fe/H] = −0.89) Figure 3, and Z = .001 ([Fe/H] = −1.52) Figure 4. It is apparent in Figure 3 that while 1.3 solar mass stars should be the major contributer to the observed variables, 1.4–1.6 mass stars should also contribute. This is typical for calculations based on tracks with Z $>$ 0.004, that is, stars at a variety of masses contribute. It is clear that the longer period H shell-burning stars make a significant contribution. A quite different scenario is encountered if Z $\leqslant$ 0.001. Note that in Figure 4 almost all the variables are produced by 1.2 solar mass stars. The time spent by the 1.3 and 1.4 solar mass stars in the instability strip is $\sim$ 1/100 the time spent by the 1.2 solar mass star and therefore can make only minor contributions. This is typical of all the calculations based on tracks with Z $\leqslant$ 0.001, that is, only one or two of the smallest solar mass stars entering the instability strip spend a long time in the strip, and thus produce almost all the variables. They are in the main-sequence stage of evolution and are restricted to short period. The difference exhibited by the time spent in the instability strip by stars of different mass in Figures 3 and 4 can probable be attributed to a transition from convective core stars to radiative core stars as the mass decreases.

Consider the pulsating blue stragglers in the globular cluster Omega Centari. Although, the cluster exhibits stars with a variety of metallicities, they center around Z $\approx$ 0.001, [Fe/H] = -1.5. The pulsating blue stragglers (SX Phe or metal-poor δ Scuti variables) according to Olech et al. (2005) in this cluster show a range of likely fundamental periods from Log P = -1.45 to Log P = -1.18 corresponding to ages of $\sim$ 0.47 Gyrs to $\sim$ 2.76 Gyrs respectively.

The current most popular mechanisms suggested to explain the presence of blue straggler stars in globular clusters is mass transfer and/or coalescence in primordial binary systems (Carney et al. 2001), and collision mergers (Bailyn 1995). In either case, the blue stragglers are 'born again' stars. If the age of a typical globular cluster is $\sim$ 12.5 Gyrs, the ages above suggest that the time spent before a merger or a mass transfer is completed is considerable longer than the pulsating blue straggler stage (96%–86% of total life of the system).

Finally, we show in Table 1 the age of a δ Scuti star with a period of Log P = -1.2 (1.5hrs) as a function of metallicity. In addition, we list the masses that produce these variables. This particular period was chosen, because variables at this period are observed at all metallicities. It is evident that the ages increase and masses decrease as the metallicity decreases.

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Table 1. The age of a δ Scuti star at Log P = -1.2 (1.5 hrs) as a function of metallicity

Z	age Gyrs	mass	[Fe/H]
0.04	0.37	1.8–1.9	0.18
0.02	0.64	1.7–1.8	−0.14
0.01	1.33	1.6–1.7	−0.47
0.007	1.57	1.4–1.5	−0.64
0.004	1.54	1.3–1.4	−0.89
0.001	2.43	1.2	−1.52
0.0004	3.99	1.1	−1.92
0.0001	6.01	1.0	−2.51
0.00001	5.74	1.0	−3.50

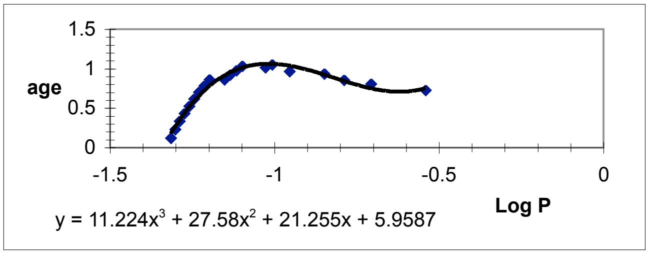

Figure 1. The age (Gyrs) of δ Scuti stars as a function of Log P (days) for Z = .02 ([Fe/H] $\sim$ 0.00). In the fitting formula, y = age and x = Log P. Stars to the left (shorter period) of the maximum are in the main-sequence evolutionary stage, stars to the right (longer period) are in the early stages of H-shell burning.

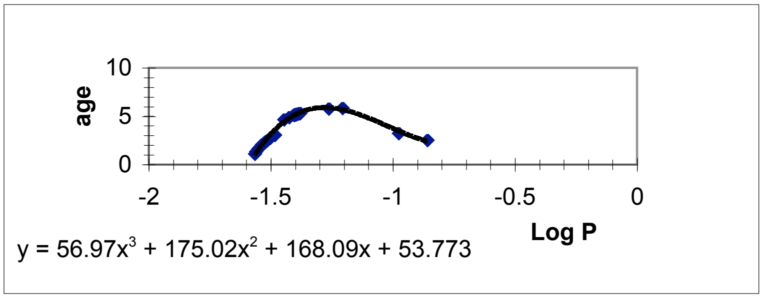

Figure 2. The age (Gyrs) of δ Scuti stars as a function of Log P (days) for Z = .0001 ([Fe/H] ~ -2.5). In the fitting formula, Y = age and x = Log P. Stars to the left (shorter period) of the maximum are in the main-sequence evolutionary stage, stars to the right (longer periods) are in the early stages of H-shell burning.

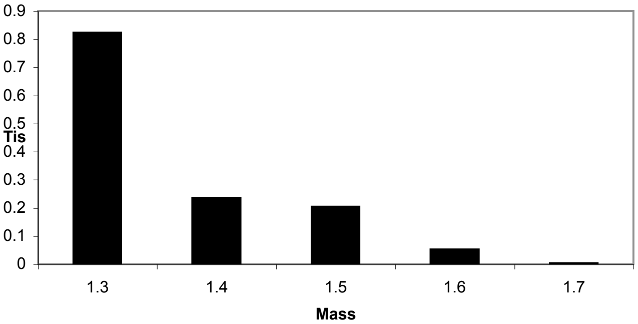

Figure 3. Time spent by stars of various mass in the instability strip, Tist (Gyrs), for stars with [Fe/H] = -0.9.

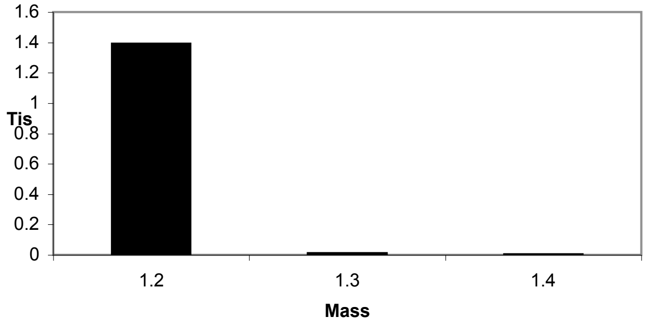

Figure 4. Time spent by stars of various mass in the instability strip Tist (Gyrs), for stars with [Fe/H] $= -1.5$