The Evolutionary Stage of an RRs Star SX Phe

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Abstract

The evolutionary stage for a short period variable SX Phe is investigated. It is supposed that SX Phe is a mixed star with low metal abundance, in which the material was mixed after the star evolved off the main sequence, and is in the second hydrogen burning stage. To examine the validity of this hypothesis we constructed two evolutionary sequences with $(X,Z,M/M_\odot) = (0.5,0.004,0.75)$ and (0.5,0.001,0.70) in the hydrogen burning phase and computed the pulsation period. Agreement between theoretical results and observational data is sufficient for us to conclude that the mixed model is actually adequate for SX Phe. The applicability of this model to other RRs stars is briefly discussed.

1. Introduction

A group of short period variable stars characterized by their relatively large amplitude and extremely short period, called as RRs stars or dwarf Cepheids, has not yet been elucidated on the basis of pulsation theory. The RRs stars occupy the same range of period with short period δ Scuti stars which are the Population I pulsating stars. In the usual classification, the RRs stars were distinguished from δ Scuti stars mainly by their large amplitude of light variation ($\Delta m_v \geq 0.3$) and the difference of the shape of light curve. SX Phe is an outstanding object of these stars.

On the classification of these stars, there are some controversial problems (see review papers by Baglin et al. 1973 and Petersen 1976). Recent investigations mainly based on the intermediate band photometry (Breger 1975, 1977a, b, McNamara and Feltz 1976) suggest that RRs stars are not different from δ Scuti stars. On the other hand, there exist some evidences suggesting that at least SX Phe is significantly different from δ Scuti stars. As pointed out by Breger and Bregman (1975), since the trigonometric parallax of SX Phe yields the luminosity which is less than that of Population I zero age main sequence, we cannot suppose that SX Phe is a δ Scuti type star, because a star with Population I composition cannot pass the observed position of SX Phe during the main sequence or post main sequence evolution as δ Scuti stars. Moreover, according to the theoretical investigation by Petersen and Jørgensen (1972), low metal abundance is necessary to explain its high period ratio of first harmonic to fundamental modes.

In this paper, after discussing some possibilities of its evolutionary phase, we suppose that SX Phe is a mixed star whose material was stirred up at a phase after main sequence evolution. It will be shown that this model is in good agreement with the observed position in H-R diagram and the period. Finally we discuss the applicability of this model to other RRs stars.

2. Evolutionary Stage of SX Phe

To explain that the luminosity of SX Phe obtained from trigonometric parallax is less than that of Population I zero age main sequence (ZAMS), some possibilities on its evolutionary stage have been considered, as reviewed in detail by Petersen (1976). Here, we discuss some of those, i.e. (a) stars of mass M = 0.20-0.25 $M_\odot$ contracting towards the white dwarf stage, (b) main sequence or immediately post main sequence stage, and (c) post red giant stage of mass $M \sim 0.5\ M_{\odot}$.

(a) Dziembowski and Kozłowski (1974) constructed the model which is constituted from a degenerate helium core, very thin hydrogen burning shell, and an extended envelope. They concluded that its fundamental period and the position in H-R diagram can be explained by this model, however the period ratio of the model $P_1/P_0 \sim 0.75$ is significantly less than the observed value 0.778 for SX Phe. Therefore, this model may not be appropriate for this star.

(b) To pass the position of SX Phe on H-R diagram during the main sequence evolution it is necessary that a star have a smaller metal abundance or larger helium content than those of normal Population I stars. The low metallicity is adequate to explain the observed large period ratio as indicated by Petersen and Jørgensen (1972) and was confirmed by a spectroscopic analysis by Bessell (1969). Petersen (1976) concluded that main sequence model with (X,Z) = (0.7,0.004) would be in agreement with the observed position in H-R diagram and periods of SX Phe. However, the mass of his model is $1.1\ M_{\odot}$ and its allowable maximum age is 3×10^9 yr. Existence of a star which has a metal abundance of $\sim 1/4\ Z_{\odot}$ and is younger than the Sun conflicts with the recent conception of the chemical evolution of the Galaxy. This contradiction also appears in color of SX Phe (B-V) = 0.22 mag, i.e., its mean color is bluer than the turnoff color $(B-V)_o$ = 0.59 mag of old open cluster NGC188 and than the bluest color (Sandage 1969) of the subdwarfs $(B-V)_o$ = 0.36 mag. Therefore, above model seems also to be inappropriate to the model for SX Phe.

(c) Combining the gravity obtained from the spectroscopic analysis, Bessell (1969) estimated a mass $M/M_\theta = 0.5 \pm 0.3$ for SX Phe. This value of mass is significantly less than that of main sequence stars in the neighbor of this star in H-R diagram. He concluded that the RRs stars are in the post red giant stage. The result suggesting low mass have been derived also by Fitch (1970). The low mass is convenient to explain the large amplitude of SX Phe, because according to Kippenhahn (1965) the pulsation of low mass model is excited more strongly than that of the model with a main sequence mass in the considering region of H-R diagram.

The large value of P_1/P_0 requires that the metal abundance of SX Phe is less than that of Population I as mentioned item (b). To explain that a metal-poor star which evolves in post red giant phase is observed in the neighbor of main sequence, we consider that the material in the star was mixed by stirring and homogenized after the star evolved off the main sequence, likely at the phase of helium flash. The helium-rich homogeneous star formed as above should reach its "second" main sequence stage. The star evolves now in "second" main or immediate post "second" main sequence phase with large helium abundance in the envelope.

Supposing the above evolutionary history on SX Phe, in the following section we have constructed the evolutionary sequences in the hydrogen burning phase with helium and low metal abundances, and computed the adiabatic linear pulsation period for these models.

3. <u>Results</u>

According to the discussion of Petersen (1976), we adopted the position of SX Phe in H-R diagram as $M_{bol} = 4.0$ (+0.7,-0.9) mag and log $T_{eff} = 3.88 \pm 0.01$, which are based on the trigonometric parallax, and Bessell's (1969) spectroscopic analysis and intermediate band photometry by Jones (1973), respectively. The position of SX Phe is shown in Figure 1 with the Population I ZAMS which is based on the relation between M_V and (B-V) by Morton and Adams (1968) and between (B-V), T_{eff}, and B.C. by Code et al. (1976). Evolutionary sequences with $(X,Z,M/M_{\odot})$ = (0.5,0.004,0.75) and (0.5,0.001,0.70) were constructed from the homogeneous main sequence stage to the thick-shell hydrogen burning phase. Opacities were interpolated from the tables of Cox and Stewart (1969, 1970). In the convection zone in the envelope, the ratio of mixing length to pressure scale height was taken as $\ell/H = 1.5$. These evolutionary tracks are illustrated in Figure 1. These tracks pass near the position of SX Phe. The period of fundamental and first harmonic modes was calculated for these models. Obtained periods and period-ratios are plotted in Figure 2, with the observed period P = 0.0550 days and the period ratio $P_1/P_0 = 0.778$ for SX Phe. As indicated by Takeuti and Saio (1978), the period ratio is largest when the star is at the homogeneous stage and decreases rapidly as the central concentration of matter increases. However, after the exhaustion of hydrogen in the central region, period ratio hardly changes during the evolution, while the period continues to increase. As shown in Figures 1 and 2, the model of mixed star well reproduce the observed position in H-R diagram, the period, and the period ratio of SX Phe.

The large helium abundance in the envelope of the model as well as its low mass is a factor of increasing the excitation of pulsation. These two factors may be supposed to cause the observed large amplitude of SX Phe. The adapted mass of the model is less than that of a star at the turnoff point ($\simeq 0.8\ M_{\odot}$) of the globular clusters with Z = 0.004-0.001. This difference of mass is common to that between the masses of horizontal branch stars and a star at turnoff point of globular clusters, and it may be a consequence of mass loss in the red giant phase or at the phase of helium flash.

4. Discussion

The model considered in this paper is in agreement with Breger and Bregman's (1975) suggestion that SX Phe is a member of the "true" dwarf Cepheids which have the characteristic of Population II stars. We shall discuss other RRs stars on the consequence of the present model for SX Phe. The double periodicity has been observed for some of RRs stars (see, e.g. Fitch 1970). For most cases the period ratio is larger than 0.77. Two periods of these stars are usually recognized as those of fundamental mode and first overtone. According to Petersen and Jørgensen (1972), the period ratio between the fundamental and first harmonic oscillations cannot be greater than 0.75 for Population I chemical composition. If it is true, it is natural to think that at least the RRs stars with double periodicity belong to the same group of SX Phe or "true" dwarf Cepheids in Breger and Bregman's terminology. These should be distinguished from Population I stars. Moreover, the mixed star model discussed in this paper may be appropriate for also these stars. In this case, all of these stars are not necessarily less luminous than Population I ZAMS, because mixed star evolves and becomes luminous from its "second" main sequence.

According to the statistical investigation by Okazaki (1978), the binary frequency of RRs stars is as small as that for Population II stars, while the fraction of δ Scuti stars in binary system is similar to that of main sequence stars. This supports the classical grouping in short period Cepheids.

On the other hand, recent investigations based on intermediate band photometry already mentioned suggest that there is no significant difference between RRs stars and δ Scuti stars. Atmospheric features of these stars are determined mainly by surface gravity and the metal to hydrogen ratio Z/X. Since the mixed star has a small X, the observed metal-poorness may not be so conspicuous as for the normal Population I stars. Moreover, the metal abundance of SX Phe may be the smallest in other stars of which the evolutionary history is the same as SX Phe, because the period ratio of the former is the largest in RRs stars. It is possible that the difference of photometric features between RRs stars and δ Scuti stars may not be evident.

In conclusion, there is no fatal contradiction between observational evidences and the mixed star model presented here for SX Phe. Further investigations are necessary to confirm that present model is adequate for many other RRs stars.

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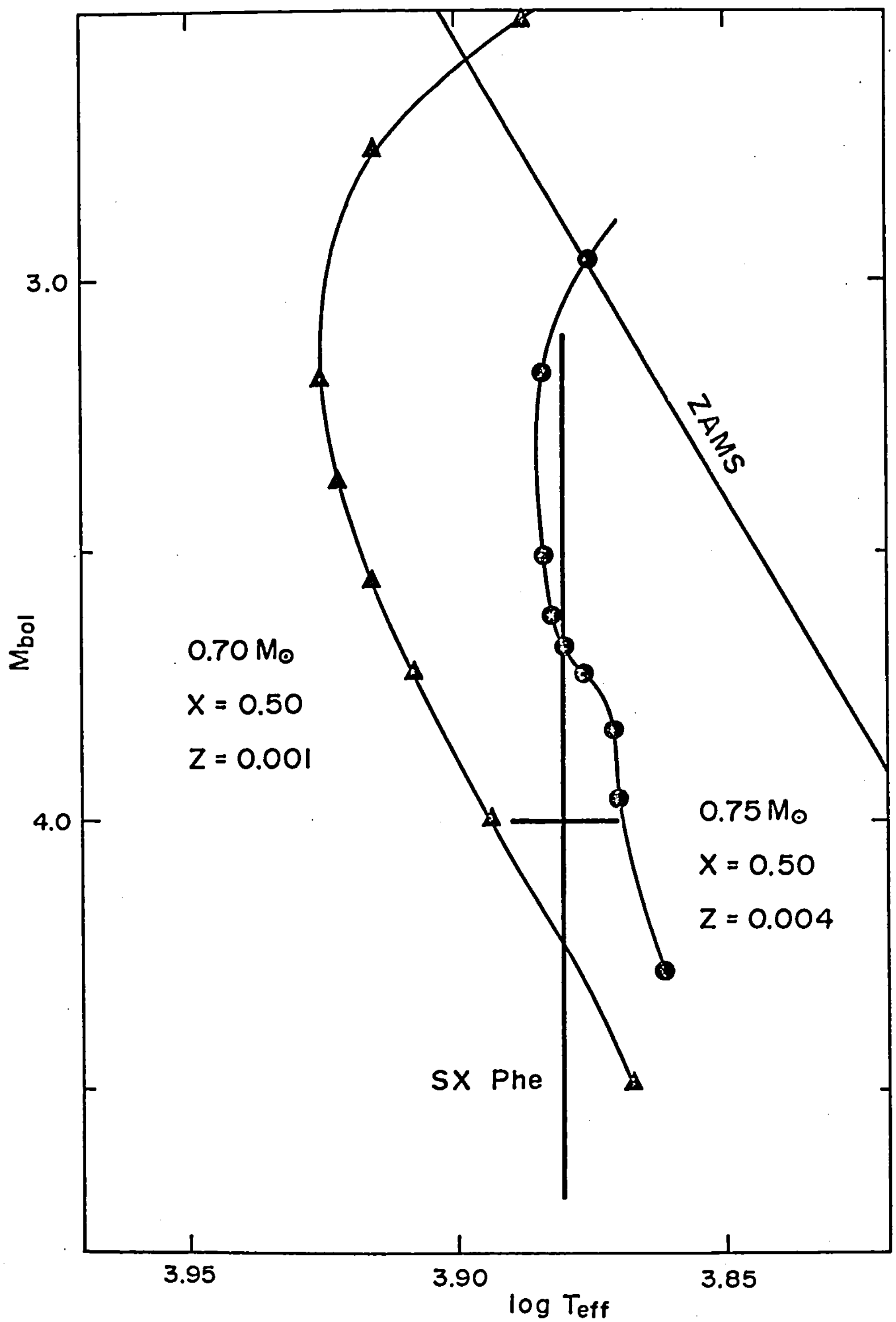

Figure 1. Computed evolutionary models with $(X,Z,M/M_\odot) = (0.5,0.004,0.75)$ and $(0.5,0.001,0.70)$ are indicated in H-R diagram. Positions of models for which pulsation periods were calculated are marked on their paths. Observed data for SX Phe are also shown.

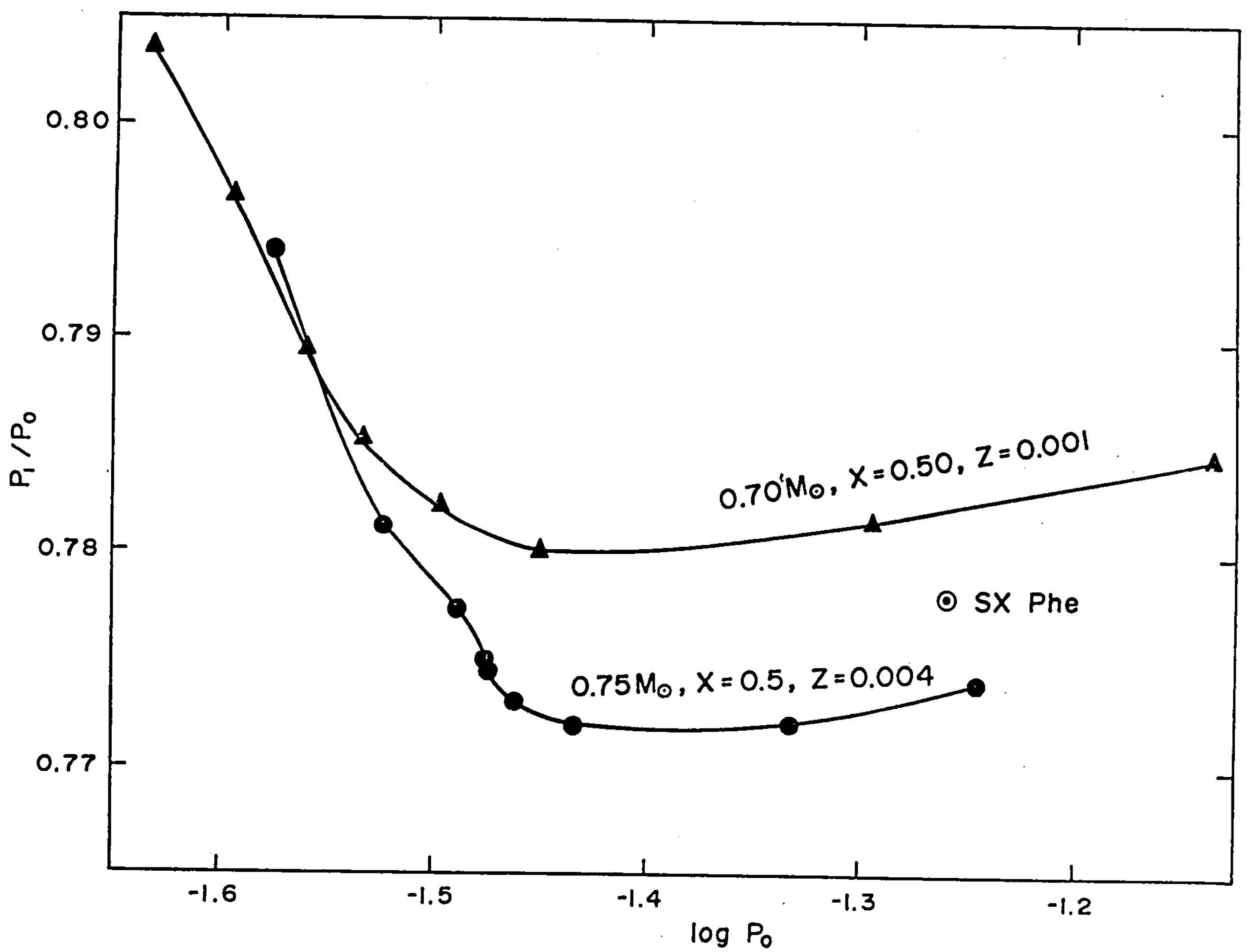

Figure 2. The period to period-ratio diagram for SX Phe and models indicated in Figure 1. Symbols are common to both diagrams.

Discussion

J. Wood: I have a comment about the monumental work by Jurgen Stock from Tololo. He tried to apply the Wesselink method and it just didn't work.

A. Cox: I am aware that Jorgensen has done the Wesselink radius method on this star also, and has been frustrated.

J. Wood:, In the latest A and A there is a second paper on this star by a group from Munich, who are also kind of throwing up their hands on this. They investigated whether it was a binary and concluded it wasn't.

A. Cox: Didn't someone get an orbital period for it?

J. Wood: Yes, obviously Kozar must disagree with Schmidt.

A. Cox: Evidently, he believes he has a correct orbital period. [Laughter] The idea here is that you have a star evolved well off the main sequence which you mix up and it comes back to the main sequence. I think that's rather unusual.