THE MASS AND EVOLUTIONARY STATUS OF AI VEL-TYPE VARIABLES*

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Abstract. Arguments are presented that the AI Velorum variables are about 0.2 $M_\odot$ objects evolving with a roughly constant luminosity toward the white dwarf stage.

The commonly accepted criterion used to distinguish between δ Scuti and AI Velorum type variables is the light curve amplitude: for δ Scuti it is always smaller than 0.2, for AI Velorum always larger than 0.3. However, these two types are not different as far as the range of periods and spectral types is concerned.

There have been suggestions that their masses and evolutionary status may also be the same (Eggen, 1970; Baglin *et al.*, 1973; Jones, 1973); namely, that they are $\sim 2\,\mathfrak{M}_\odot$ stars in the main sequence or early post main sequence evolutionary phase. On the other hand, there are strong observational evidences that the AI Velorum stars are significantly undermassive.

The absolute magnitudes derived from trigonometric parallaxes combined with values of effective temperatures and gravities determined by Bessel (1969) lead to embarrassingly low values of masses for two stars of this type: 0.1 $\mathfrak{M}_\odot$ for AI Vel and 0.24 $\mathfrak{M}_\odot$ for SX Phe. Uncertainties in these values are very large, but even allowing for a probable error in the parallax determination it is impossible to reconcile the mean parameters of these two stars with an early evolutionary phase. Moreover, because of too low luminosities, one cannot accept central helium and shell hydrogen burning models such as those believed to represent the RR Lyrae stars.

It has been suggested (Dziembowski and Kozłowski, 1974) that the AI Velorum variables are $\sim 0.2\,\mathfrak{M}_\odot$ stars evolving toward the white dwarf state after losing most of their mass during the red giant phase. Such pre-white-dwarf configurations contain most of their mass in a degenerate helium core, but their luminosity is almost exclusively due to shell hydrogen burning. In this contribution I shall briefly review the results of that work and present some new arguments in favour of such a possibility.

In Figure 1, the observed positions of the AI Velorum, δ Scuti and c-type RR Lyrae stars on a $\log T_e$ vs $\log P$ diagram (T_e is the effective temperature and P is the pulsation period in days) are compared with theoretical relationships for low mass pre-white-dwarf stars. The observational data are taken from Jones (1973). In addition, the relationships for Iben's (1967) evolutionary tracks of 1.5 and 2.25 $M_\odot$ in early evolutionary phases are shown.

Both types of models may be fitted to observational data, but only for the pre-white-dwarf models are the theoretical values of $\mathfrak{M}_{\rm bol}$ reasonably close to the observed val-

* AI Vel-type variable = dwarf Cepheid-type variable.

Sherwood and Plaut (eds.), Variable Stars and Stellar Evolution, 251–254.

https://doi.org/10.1017/S0074180900010354 Published online by Cambridge University Press

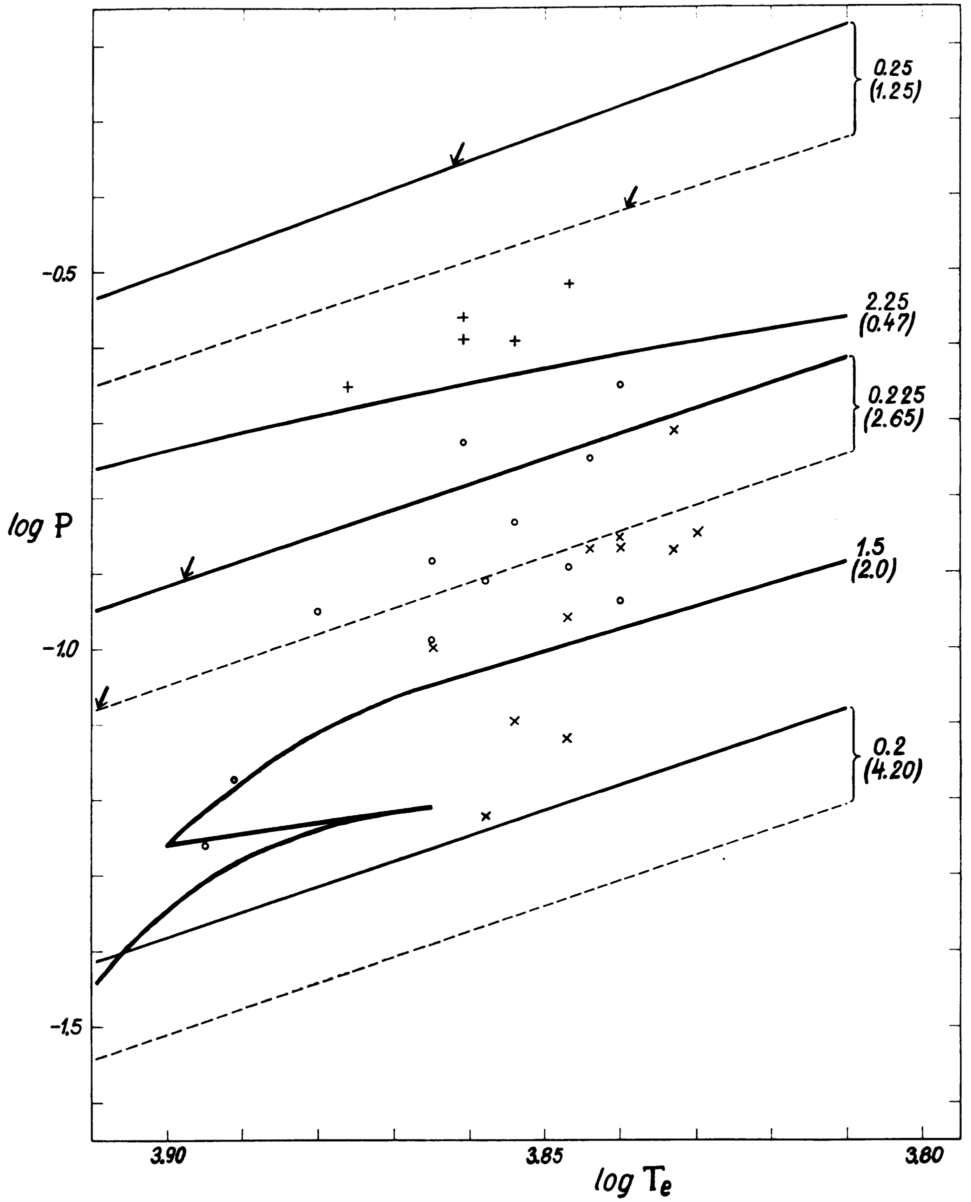

Fig. 1. Logarithm of period (in days) vs logarithm of effective temperature for short period pulsating variables. Location of the AI Velorum (circles), δ Scuti (crosses) and c-type RR Lyrae (pluses) stars is compared with theoretical relationships found for sequences of pre-white-dwarf stellar models with masses 0.25, 0.225 and 0.2 $\mathfrak{M}_{\odot}$, as well as with evolutionary sequences for a 1.5 $\mathfrak{M}_{\odot}$ star (main sequence and thick shell source phases) and a 2.25 $\mathfrak{M}_{\odot}$ star (thick shell phase). The value of M_{bol} at $\log T_e = 3.85$ is given in parentheses. Solid lines are for the fundamental mode and broken for the first overtone. Arrows indicate the high temperature boundary of the instability strip. The relationships for pre-white-dwarf sequences as well as the boundaries of the instability strip were calculated by Dziembowski and Kozłowski (1974). The chemical composition of the models is $X=0.7$, $Z=0.03$. The relationships for more massive models were based on Iben's (1967) evolutionary tracks calculated with $X=0.708$, $Z=0.02$.

ues for AI Vel and SX Phe. Moreover, adopting $\sim 2\mathfrak{M}_\odot$ models for AI Velorum stars, it is difficult to understand why these objects, which would then constitute a small fraction of the ultra-short-period variables, have such large amplitudes. It is important to notice that true δ Scuti stars with $\log T_e > 3.85$ have very small amplitudes (<0.05 mag.) and often show irregular light variations.

It was suggested (Dziembowski, 1974) that this is due to the fact that, in the main sequence δ Scuti stars, many nonradial modes may be excited simultaneously with overtones of radial pulsation. For more evolved δ Scuti models, nonradial modes are not excited, but excitation rates for radial pulsation are a few orders of magnitude less than those for RR Lyrae and for our pre-white-dwarf models as well.

It seems fair to expect that the low excitation rates imply low pulsation amplitudes, but nonlinear pulsation calculations for conventional δ Scuti models and our models of AI Velorum stars are needed to fully clarify the problem.

It is not possible to reject definitely the double energy source models for all the variables of this type. However, the experience with models of horizontal branch stars indicates that in the relevant temperature range the first overtone period is always larger than $0\overset{d}{.}2$. On the other hand, one may easily obtain an RR Lyrae model with degenerate helium core upon choosing somewhat larger masses than those appropriate to the AI Velorum.

Another piece of evidence that the masses of the AI Velorum stars should be very low comes from the values of periods for double mode pulsating objects. Christy (1974) has recently reconsidered his formulae for the period at which the transition from the fundamental to the first overtone pulsation takes place. These formulae may be equivalently written as follows:

$$\log \mathfrak{M} = 1.18 \log P_F + 0.16$$

and

$$M_{bol} = -4.38 \log P_F - 0.54,$$

where $\mathfrak{M}$ is mass in solar units and P_F is the fundamental mode period in days. We thus obtain

for SX Phe ($P_F = 0\overset{d}{.}055$) $M_{bol} = 4.98$, $\mathfrak{M} = 0.047$;
for AI Vel ($P_F = 0\overset{d}{.}112$) $M_{bol} = 3.63$, $\mathfrak{M} = 0.11$;
for VX Hya ($P_F = 0\overset{d}{.}223$) $M_{bol} = 2.32$, $\mathfrak{M} = 0.17$.

The masses are even lower than those derived from the model calculations. It should be kept in mind, however, that the formulae are based on numerical calculations for RR Lyrae models which have greater masses, so that these results should be treated only as an indication that the AI Velorum variables have significantly lower masses than the RR Lyrae stars.

One difficulty with our models is that a typical value of P_I/P_F (P_I is the first overtone period) observed in double mode pulsating variables of this type is ~ 0.77, while for our model we got ~ 0.75. The ratio P_I/P_F varies in narrow limits, so that this may be an important failure of the present theory.

If these models are accepted for the AI Velorum variables, then we have to accept that there was an extensive mass loss in the previous evolutionary phases of these stars. This is important because, in the case of low mass stars, there is no clear evidence for the mass loss on an evolutionary significant scale.

In any case, studies of the AI Velorum variables are of great interest in stellar evolution theory. Therefore, I would like to encourage variable star observers to pay more attention to variables of this type. Investigations of period changes and searches for these objects in clusters seem to be most important from this point of view.

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DISCUSSION

E. H. Geyer: As an observer I am a bit concerned about the low masses and luminosities of RRs-stars. From photometry of the RRs variable V65 in ω Cen by Szeidl and myself this object is indistinguishable in brightness from the RR Lyrae stars of this cluster and also in colour. The Greenwich proper motion measurements are not against cluster-membership! Is it perhaps possible from the theoretical point of view that pulsation in the third overtone takes place?

D. H. P. Jones: The difference between the work of Dr Dziembowski and myself lies with whether one appeals to the gravity or the luminosity as the observed quantity. Our different results indicate that the two quantities are in conflict. In fact, Dr Dziembowski's calculations which he has kindly shown me prior to publication indicate that P varies with the -0.825 power of g and that when the period is 0.1 day then $\log g = -0.84$ (solar units). This is in close accord with Otzen Petersen and Jørgensen's models, although the structure of the two sets of models is quite different. This reflects the fact that Q is defined mostly by the polytropic index in the outer envelope.

While pointing out the inaccuracies in the luminosities and gravities, I must also confess that Murray, Candy and myself have published a proper motion of Dr Geyer's variable in ω Cen. Although it is not very accurate, it suggests that the variable is not a member.

M. Breger: We have heard arguments both for high and low luminosities of Dwarf Cepheids (AI Vel stars). There may be no controversy. Some Dwarf Cepheids are Population II (SX Phe). Some are just Population I δ Scuti stars, whose amplitudes crossed the 'magical border' of 0.30 mag. (which defines the Dwarf Cepheid class). The period and narrow-band calibrations cannot tell you whether a high or low luminosity is present, since the photometric calibration only determines gravity. The space motions U, V, W show that some of Jones' Dwarf Cepheids could well be Population I δ Scuti variables.