1990

MASS DETERMINATION IN GLOBULAR CLUSTER RRc VARIABLES

Norman R. Simon
University of Nebraska - Lincoln, nsimon@unl.edu

Confrontation Between Stellar Pulsation and Evolution,
ASP Conference Series, Vol. 11, 1990, C. Cacciari and G. Clementini, Eds., pp. 416-420.

MASS DETERMINATION IN GLOBULAR CLUSTER RRc VARIABLES

NORMAN R. SIMON
Department of Physics and Astronomy, University of Nebraska, Lincoln, NE 68588-0111 U.S.A.

The theory of horizontal branch (HB) evolution predicts the masses of RR Lyrae stars in globular clusters. These masses depend on metallicity according to a relation which can be expressed in the form (Sandage 1990):

$$\log M(RR) = -0.10\,[Fe/H] - 0.318. \quad (1)$$

Equation (1) describes the zero age HB models of both Sweigart, Renzini and Tornambe (1987) and Lee, Demarque and Zinn 1990 (hereinafter LDZ).

Using Eq. (1) we may calculate approximate RR Lyrae masses for the Oosterhoff groups. For an Oo I cluster like M3 one finds $M(RR) \cong 0.71\ M_\odot$, while an Oo II cluster like M15 gives $M(RR) \cong 0.82\ M_\odot$. These masses are in disagreement with the considerably smaller values derived from linear, nonadiabatic (LNA) pulsation models for the RRd stars (double mode pulsators), viz., $M(RR) \cong 0.55\ M_\odot$ for Oo I clusters and $M(RR) \cong 0.65\ M_\odot$ for Oo II clusters (Cox, Hodson and Clancy 1983).

The effects on the RRd masses of changes in opacity have been studied by Simon (1990a). At the very low metallicity corresponding to Oo II clusters (Z = 0.0001), these effects are found to be totally negligible. At Z = 0.001, the RRd mass again changes only negligibly unless an extremely high metals opacity is assumed. While such a large opacity might barely be allowable within constraints set by observed Cepheid period ratios (see, e.g., Simon 1990b), the effect on RRd masses in an Oo I cluster like M3 would still not be significant. The reason is that the metallicity in such a cluster (Z = 0.0004) is still too small to produce a strong effect, even given a greatly enhanced opacity. Thus the conflict between evolution and pulsation theory cannot be removed or even much ameliorated by reasonable changes in the opacity law.

While lacking RRd stars, the rich globular cluster ω Centauri contains RR Lyraes with a wide range of metallicity, and thus constitutes an interesting laboratory for testing both pulsation and evolution. In a recent study, Simon (1989; 1990a,c) constructed a large grid of hydrodynamic pulsation

models and compared the theoretical light curves with observations of the RRc stars in ω Cen. The comparison was made in terms of the Fourier phase parameter, ϕ_{31} (see, e.g., Simon 1988), which was found to be a measure of the luminosity-to-mass ratio $L/M^{1.81}$. Using this result, Simon (1990a) was able to infer masses for the ω Cen RRc stars based upon three observed quantities: ϕ_{31}, period and relative luminosity.

Figure 1 presents a plot of ϕ_{31} vs. period for 47 RRc stars in ω Cen. The dots are observational points, while the mass (times 100) written beside each dot was obtained using ϕ_{31} as indicated above. We see the clear tendency in this diagram for the higher mass stars to sink and the lower mass stars to rise. The mass scale here is arbitrary to within a constant, but the choice we have made yields reasonable temperatures for the RRc stars and places them in the first overtone instability strip, exactly where they belong. This choice is also consistent with the absence of RRd stars in ω Cen (see Simon 1990a). Finally, the masses we obtain have a range which agrees with the RRd masses in Oo I and Oo II clusters.

In Figure 2 we plot the temperatures obtained from our theoretical masses versus observed B-V colors. Since the pulsational analysis described above is completely independent of the colors, the reasonable trend in Figure 2 provides some support for our method. However, the slope of the log T_e vs. B-V relation presented here is -0.16, in absolute value less than half of the canonical slope obtained from static model atmospheres (e.g., VandenBerg and Bell 1985). Thus if our analysis is correct, the static B-V colors may not be appropriate for pulsation studies, at least in the case of the RRc stars.

According to the zero age HB models there is, within the narrow confines of the first overtone instability strip, only a narrow range of allowed masses (say, $\Delta M \sim 0.03\ M_\odot$) at given metallicity (see, e.g., LDZ). However, our pulsational analysis shows a much larger mass range in ω Cen. Figure 3 displays a plot of our theoretical masses vs. observed metallicity for 19 ω Cen RRc stars. The number beside each point gives log L for the corresponding star. The masses and luminosities were determined using ϕ_{31} as sketched above. A change in the arbitrary mass scale would merely add a fixed constant to all the masses (and to all the luminosities) in Figure 3, but would not change the mass spread.

Could the large mass range given by our analysis be explained by late evolution which carries lower mass stars redward into the instability strip to join higher mass (zero age) stars of the same metallicity? In that case the evolutionary tracks (e.g., LDZ) predict that the lower mass stars should be substantially brighter than the higher mass stars, a situation which is denied by Figure 3. In fact, it seems clear from Figure 3 that no relation exists between mass and metallicity

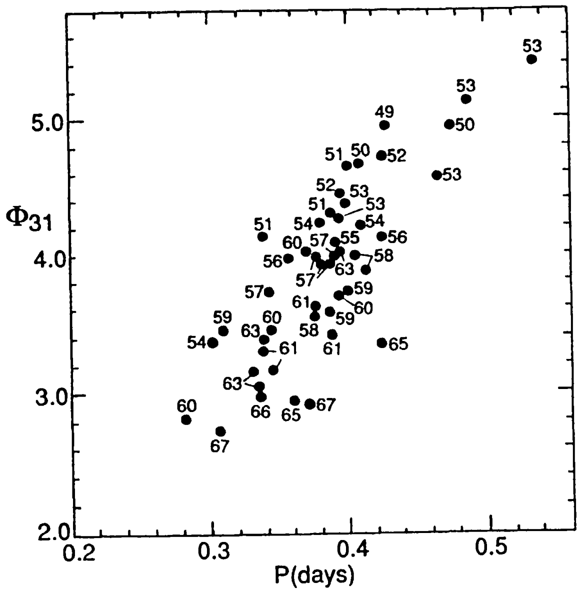

Fig. 1. ϕ_{31} vs. period for ω Cen RR_c stars. Masses (x 100) are indicated.

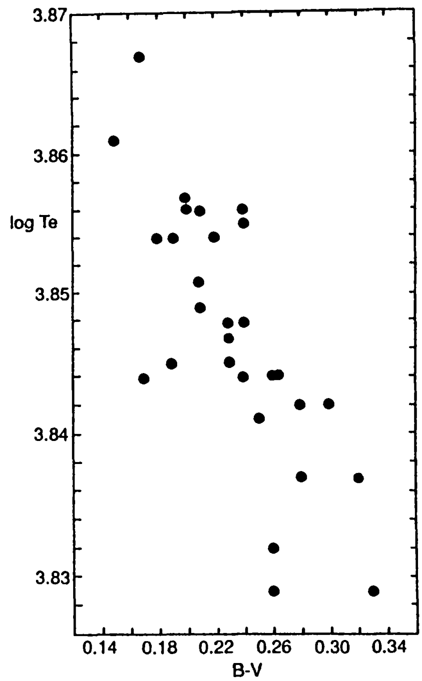

Fig. 2. log T_e vs. B-V for ω Cen RR_c stars.

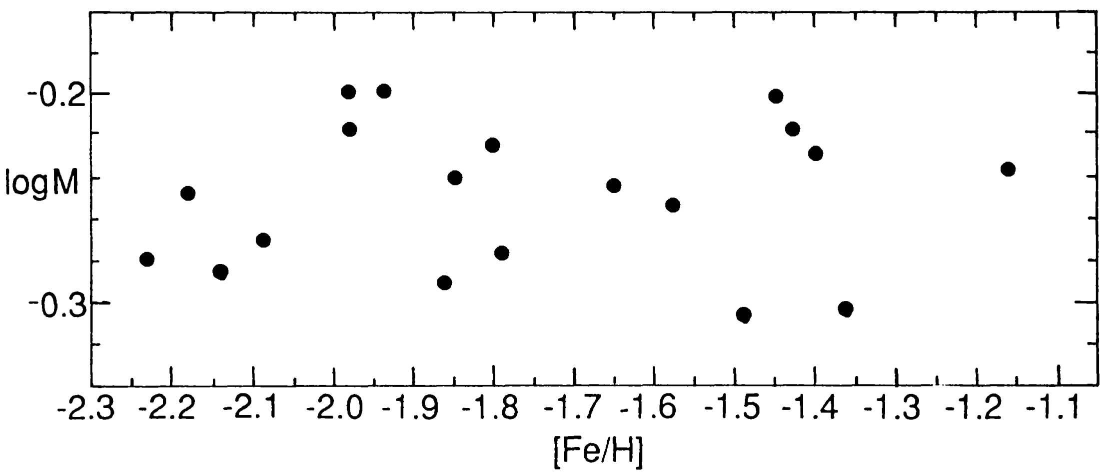

Fig. 3. Mass vs. metallicity for ω Cen RR_c stars. Values of log L are indicated.

for the RRc stars in ω Cen. It is interesting to note that the lack of a mass-metallicity relation has also emerged from Baade-Wesselink studies of RR Lyrae field stars (e.g., Liu and Janes 1990). Together these results seem to call into question any facile interpretation of the metallicity as the key parameter governing the horizontal branch.

Finally, it should be pointed out that the various pulsation studies we have mentioned span a broad range of pulsational theory. The RRd masses depend upon linear pulsation models, while the ω Cen results are derived from hydrodynamic calculations, and the Baade-Wesselink analyses use observed light and velocity curves interpreted (mainly) via theoretical infrared colors. These quite diverse studies yield consistent results which appear fundamentally at odds with the theory of HB evolution. In the author's opinion, this important conflict ought to receive much attention.

REFERENCES

Cox, A.N., Hudson, S.W. and Clancy, S.P. 1983, Ap. J. 266, 94.

Lee, Y.W., Demarque, P. and Zinn, R., Ap. J. 350, 155.

Liu, T. and Janes, K.A. 1990, preprint.

Sandage, A. 1990, Ap. J. 350, 603.

Simon, N.R. 1988, in Pulsation and Mass Loss in Stars, eds. R. Stalio and L.A. Willson (Dordrecht: D. Reidel), p. 27.

_____. 1989, Ap. J. Lett. 343, L17.

_____. 1990a, Ap. J., in press (Sept. 1).

_____. 1990b, in Confrontation Between Stellar Pulsation and Evolution, ed. C. Cacciari (San Francisco: PASP), this volume.

_____. 1990c, MNRAS, in press.

Sweigart, A.V., Renzini, A. and Tornambe, A. 1987, Ap. J. 312, 762.

VandenBerg, D.A. and Bell, R. 1985, Ap. J. Suppl. 58, 56.

Question from A. Renzini: The "severe discrepancy" you emphasize has long been known but never caused great concern for two reasons: (1) The ZAHB masses you quoted assume solar proportions for the heavy elements, while it is established observationally that oxygen is considerably enhanced relative to iron in Pop. II stars. When you allow for that, the evolutionary masses decrease by about 0.1 $M_{\odot}$; and (2) as we heard this afternoon the double mode masses have an error whose size is the same order as your "severe discrepancy."

Answer: (1) If it is accepted that oxygen is enhanced, then evolutionary tracks should be published which reflect this. I have not seen such tracks in the recent literature; and (2) I agree that pulsation theorists need to be more precise about this matter and we shall do so. However, I do not

believe that the double-mode masses will change very much unless one is willing to locate the stars far to the right of the F-mode blue edge. Such a location does not seem logical. For a further comment, please see the answer to the question of Y.-W. Lee, just below.

Question from Y.-W. Lee: First, it is important to note that ω Cen has an extremely blue HB, even bluer than M92; consequently, its RR Lyraes have all evolved an extreme amount from the blue ZAHB (even Sandage believes this!). This accounts for the lack of observed correlations between [Fe/H] and log L, log M or log P, respectively (see Lee 1990, Ap.J., Nov. 1). Perhaps enhanced oxygen tracks could do a better job here. If indeed there is no mass vs. [Fe/H] relation in ω Cen, it has important implications for the mass-loss vs. [Fe/H] relationship. Since M(RGB) is not a strong function of [Fe/H] (for $Z \lesssim 0.001$), this would suggest that there is no strong correlation between mass-loss and [Fe/H] for $Z \lesssim 0.001$!

Answer: I can only repeat what I tried to emphasize in my talk - namely, that published evolutionary tracks cannot account for a large mass spread at given metallicity unless the low mass stars are brighter, a condition which is not "observed" in either my work on ω Cen or in Baade-Wesselink studies of field stars.

Question from J. O. Petersen: Remark concerning the double mode masses of Oosterhoff type I clusters: There seems to be a clear disagreement between your views and my estimate of the uncertainties of these masses. However, in my estimates I used a metal-deficiency factor for Oo I with respect to the Sun of 20, i.e. a Z-value of about 0.001. This is higher than the value you use, so I estimate a larger effect.

Answer: I agree. The Oo I clusters have a metallicity $Z \sim 0.0004$, which reduces metallicity effects on the opacity.

Comment from J. M. Nemec: I would like to urge you to consider using bootstrap techniques for estimating standard errors in your ϕ_{31} components.