RECENT THEORETICAL RESULTS FOR CEPHEID PULSATION

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Detailed theoretical investigations of stellar pulsation need a mass and a composition before models can be constructed for study. Unfortunately, for the last ten years the masses of the Cepheids, which can be determined with reasonable accuracy by six different methods, have been in dispute. One possible way to resolve these various mass anomalies is to postulate an inhomogeneous composition envelope structure. Thus the principal problem in current theoretical studies is: What are both the masses and envelope compositions of Cepheids?

Stellar evolution theory has indicated that main sequence B stars evolve to become red giants or supergiants and then loop blueward in the Hertzsprung-Russell diagram to cross again the pulsation instability strip the second and third (or even more) times. The second and third crossings are the slowest for models of evolutionary masses between 4 and 13 $M_\odot$. Both below and above this mass the stars become Cepheids (or δ Scuti variables at the lowest masses) on their sole crossing to the red. Massive stars do not become cool enough to become Cepheids if the main sequence mass is above 18 $M_\odot$.

For those stars between about 4 and 13 $M_\odot$ that can have blue loops, stellar evolution theory insists that any mass loss more than 20 percent in the red giant stage will prevent these blue loops. Thus main sequence masses persist through the Cepheid stages on first, second, or third crossings. Only at the highest masses (13-18 $M_\odot$) is any appreciable mass loss expected after the main sequence, and that is due to the radiation pressure wind, well known to occur for O and B stars.

I am able to report (Cox 1979) that evolution masses based on the yellow giant mass-luminosity relation in blue loops (Becker, Iben, and Tuggle 1977) now agree very well with those based on pulsation theory. This comparison is limited to those 16 or fewer cases where the luminosity is known from cluster or association membership. This known luminosity is used in the evolutionary M-L relation (to give M_{ev}) and also with the observed color and then T_e to give a radius. This photometric mean radius inserted into the period-mean density relation with

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a linear theory determined constant (Q) gives the pulsation mass. The Wesselink radius can also be directly used in the period-mean density relation to give a so called Wesselink mass. This recent agreement between evolution and pulsation theory is due to a new larger distance scale and to new smaller reddenings.

One of the remaining mass anomalies is for those 5-15 day Cepheids with bumps in their light curves. Nonlinear calculations by Christy (1968), Stobie (1969), and now most recently by Adams, Castor, and Davis (1979) at Los Alamos and Fadeyev (preprint) in Russia indicate, by the bump phases, a 30, 40, or even 50 percent smaller mass than evolutionary theory masses. Two recent ideas which change the envelope structure and hence the period ratio Π_2/Π_0, the second overtone to fundamental period ratio which determines the bump phase (Simon and Schmidt 1976), might increase these pulsation theory masses. They are a tangled magnetic field proposed by Stothers (preprint) and high surface helium content caused by a Cepheid wind proposed by myself and several collaborators (Cox, Michaud, and Hodson 1978). These ideas are being actively pursued.

The worst mass anomaly is for the eleven 2-6 day beat or double-mode Cepheids where the period ratio Π_1/Π_0 indicates conventionally very low masses. Since this anomaly between evolution and pulsation masses of typically a factor of three is very serious in understanding pulsation theory, much recent effort has been concentrated here. As the best recent ideas, John Cox (1974) proposes nonradial contamination of the pulsations, Stothers proposes his pressure producing tangled magnetic field, and I propose a high surface helium composition. These latter two proposals reduce the density gradient in the pulsating regions of the star increasing Π_0 more than Π_1 to give a smaller Π_1/Π_0 and a larger implied mass. Are any of these proposed conditions sufficiently stable to really occur in 5 $M_\odot$ Cepheids?

The H-R diagram for the various helium enhancements shows that at 0.7 day for the triple-mode Cepheid AC And the surface Y is best set at 0.48, at 2-6 days for the beat Cepheids at 0.65, at 5-15 days for the bump Cepheids at 0.75 and for the higher periods the normal value of 0.28. A true mass loss occurs near 15 $M_\odot$ which seems to be detected by Wesselink radius masses for periods greater than 15 days.

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