MASSES OF CLASSICAL CEPHEIDS AND MASS LOSS RATE AT PRE-CEPHEID STAGE

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Summary: The mass-luminosity relation for single-mode Cepheids obtained by Saio, Kobayashi, and Takeuti (1977) indicates that the masses of classical Cepheids seem to be less than those that result from evolutionary calculations without substantial mass loss. The mass loss rate at the red giant phase should be 10^{-5} solar masses per year. Some of the beat Cepheids seem to form a group among the variable stars.

Introduction:

The masses of pulsating stars can be determined from the observed physical quantities and the pulsation theory, and we can evaluate the mass loss rate at the pre-Cepheid stage of stellar evolution from the mass-luminosity relation for classical Cepheids. Recently Iben and Tuggle (1975) have demonstrated that the mass-luminosity relation obeyed by Galactic Cepheids is consistent with the theoretical evolutionary models which have a reasonable chemical composition. If so, the mass loss at the pre-Cepheid stage should be rather small. On the other hand, Simon and Schmidt (1976) have recently pointed out that the masses of the bump Cepheids are considerably lower than those derived from evolutionary calculations without significant mass loss. The beat Cepheid, U TrA, which has been classified as a Population I Cepheid in the spectroscopic study by Rodgers and Gingold (1973), should have also a considerably lower mass, as was pointed out by many authors, for example, Cox, Deupree, King, and Hodson (1977), and Petersen (1977); it has chemically homogeneous envelopes like the normal Population I Cepheids. For a discussion of the mass loss rate at the pre-Cepheid stage, the reexamination on the mass-luminosity relation for the Population I Cepheids is required.

Single-Mode Cepheids

The distance moduli of Galactic Clusters including the Cepheids are to be revised on three points:

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1. the main sequence and the evolutionary deviation curve to which the Cepheids' parent clusters have been fitted;
2. the distance modulus of the Hyades cluster; and
3. the bolometric correction.

When the theoretical main sequence is used that is calculated with the Cox-Stewart opacities (Cox and Stewart, 1969) the distance modulus is, on the average, increased by about 0.13 mag., as compared to the one that is partially based on the Keller and Meyerott opacities (Keller and Meyerott, 1955). Iben and Tuggle (1975) have adjusted the distance modulus of the Hyades cluster in order to remove the mass discrepancy between the masses derived from the evolution theory without mass loss and those derived from the pulsation theory. Their adjusted value was 3.17 mag., while Hanson's (1975) value was 3.29 mag. This difference and the one caused by the fitting procedure are significant for an evolution of the mass loss rate at the pre-Cepheid stage. The revision has been made by Kobayashi (1974) and Kobayashi, Saio and Takeuti (1976).

Recently Saio, Kobayashi and Takeuti (1977) showed fifteen Cepheids in galactic clusters in a mass-luminosity diagram. In contrast to the diagram by Iben and Tuggle (1975) SU Cas and VY Per are now well located among other cluster Cepheids. V367 Sct, a member of NGC6649, does not show any peculiarities, when the revised primary period (Efremov and Kholopov 1975) is used.

Concerning the bump Cepheids, it should be pointed out that it can hardly be considered that the Cepheids with and without bump belong to different groups, because they all show the successive change of light- and velocity-curves with periods typical for classical Cepheids (Hertzsprung relation). The model envelope derived from the revised pulsation mass for a bump Cepheid, S Nor, shows that a resonance possibly causes the bump as was suggested by Simon and Schmidt (1976). The result of Davis (1976) also confirms that pulsation and bump mass are equivalent.

The mass-luminosity relation of single-mode Cepheids with and without bump obtained by Saio, Kobayashi and Takeuti (1977), indicates that the masses of classical Cepheids seem to be lower than those masses which are determined in evolutionary calculations without significant mass loss. They differ by about twenty percent.

Double-Mode Cepheids

There are still some questions concerning the masses of beat Cepheids. The mass of a red beat Cepheid such as U TrA may be increased to that of a single-mode Cepheid, if the convective efficiency in the Cepheid envelopes is as large as it was assumed by Cogan (1977). But, for a bluer Cepheid such as TU Cas, the mass discrepancy does not disappear. According to Cox, Deupree, King and Hodson (1977), and Petersen (1977), the blue 6-day Cepheid V367 Sct shows a particular mass discrepancy . The mass derived from the period and the period-ratio is very different from the one calculated from the effective temperature, the luminosity, and the pulsation period. If the estimated color excess of V367 Sct can be decreased from 1.36 to 1.2, the above discrepancy is removed. At present, results concerning beat Cepheids depend on the theory of convection and the effective temperature. It is supposed that some of the beat Cepheids may form a different group among the variable stars than the classical Cepheids.

Conclusion

In conclusion, we cannot suppose that the revised mass-luminosity relation is consistent with the theoretical evolutionary models without substantial mass loss. The amount of mass deficiency has not been determined precisely, while according to evolutionary calculations of Forbes (1968) the mass loss rate at the red giant phase is about 10^{-5} solar masses per year.

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