NEW EVIDENCE FOR MASS LOSS IN CLASSICAL CEPHEIDS

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I. Introduction

The question of apparent mass anomalies in classical cepheids was first brought up by Christy (1968) and Stobie (1969), but 15 years later there is still no definite picture concerning the reality and the possible cause of these mass anomalies. The masses obtained from application of standard evolutionary theory were always sensibly larger than the masses derived from pulsation theory using both linear and non-linear codes. Since for various reasons few people have accepted the idea that mass loss could play an important role in cepheids a number of elaborate scenarios have been proposed to account for the mass discrepancies. Among these are helium enriched outer layers and tangled magnetic fields. It is difficult, however, to see how significant mass loss can be avoided during the evolution of the more massive cepheids. In fact, practically all supergiants lose mass over the whole HR diagram, a process frequently manifesting itself in photometric micro-variability. Little hope can be placed in attempts to solve the problem by means of improved determinations of the physical parameters of cepheids; intrinsic colours, luminosities, radii, effective temperatures, and the width of the instability strip have been disputed for years with no definite results yet. Only independent observational evidence will make it possible to confirm - or reject - the mass anomalies. On account of the large number observed and because of the fairly complete sample they represent, the cepheids in the LMC, SMC and in our Galaxy are best suited for this kind of investigation.

II. The frequency-period distribution of classical cepheids

Becker et al. (1977) have carried out a detailed study of the frequency-period distribution of cepheids in several galaxies, comparing observations and standard evolutionary calculations (i.e. assuming an atmosphere in hydrostatic equilibrium and not including the effects of mass loss, convective overshooting and turbulent diffusion). Combining these results with linear adiabatic pulsation theory, Becker et al. were able to determine the period-luminosity relation and the frequency-period distribution as a function of metallicity Z and of helium content Y. Satisfactory agreement was found between theory and observations, but 2 major problems turned up: the predicted width of the frequency-period distribution was too small and the predicted absolute number of cepheids with periods in excess of 10 days was also too small. Realizing that their evolutionary results combined with the initial mass function of Salpeter (1955) were incompatible with the observations, Becker et al. postulated a two-component birthrate-function; the second, much more recent component was expected to yield 10 times more massive stars than the first, old component. We note that Lequeux (1983) does not find any indication for such a birthrate function in the Magellanic Clouds.

A way to reconcile the IMF of Salpeter with the observed frequency of luminous cepheids involves substantial mass loss. In general, cepheids having suffered substantial mass loss in previous stages of their evolution are overluminous for their mass; they thus oscillate at lower frequencies - for a given luminosity - than canonical cepheids. This leads to an increase in the number of long-period cepheids compared to the canonical case. A similar effect on the frequency-period distribution is due to convective overshooting (Matraka et al. 1982) and probably also due to turbulent diffusion (Schatzman & Maeder 1981).

Mass loss leads to an even more dramatic enhancement of the number of long-period cepheids by way of increased lifetimes in the cepheid instability strip. Evolutionary calculations including mass loss (Maeder 1981) show that for large masses lifetimes in the cepheid region may increase by a factor 5-50. The cause for this increase is open to straightforward interpretation and is not tied to obscure numerical details. Figs. 2 to 4 of Maeder (1981) show that for moderate mass loss the "horn" - the region in the HR diagram occupied by core helium burning stars - is displaced towards the red compared to the zero mass loss case. Whereas for Maeder's case A (no mass loss) the "horn" joins the giant branch at approximately $60M_\odot$, this mass drops to $30M_\odot$ for case B (moderate mass loss). The loops which are limited to masses below $15M_\odot$ for case A are predicted to extend up to at least $30M_\odot$ for case B. It is evident that this shift in the position of the horn combined with looping at higher masses will greatly affect the relative numbers of long-period cepheids.

III. Estimated cepheid mass loss rates

Based on this mass loss scenario we shall estimate the appropriate mass loss rates for Galactic and Magellanic cepheids. Almost universal agreement has emerged that there is some positive correlation between metallicity and mass loss rate for a given domain in the HR diagram. This implies that mass loss should be smallest in the SMC, somewhat larger in the LMC and most important in our Galaxy. We have chosen the following mass loss rates:
a) SMC - slightly less than case B
b) LMC - about case B
c) Galaxy - between case B and case C
This particular choice can be justified by the relative number of long-period cepheids, by the position of the maximum of the frequency-period distribution, by the longest periods encountered, and finally by the mean metallicity of the galaxies in question. Extensive surveys of Magellanic Cloud cepheids by the Gaposchkins (1966, 1971) have revealed at least 10 cepheids with periods in excess of logP=1.8 whereas

canonical theory predicts about 10 times less cepheids for this period range. Maeder's case B mass loss leads to agreement between the observed and the theoretical relative numbers of long-period cepheids in the Magellanic Clouds; for our Galaxy a somewhat higher mass loss rate appears appropriate since no cepheid with a period in excess of 50 days has yet been detected. At the same time the mean metallicity of our Galaxy is sensibly higher than the respective mean metallicities of the Magellanic Clouds (Harris 1983). Because mass loss enhances the effect of metallicity in the HR diagram, viz. the position of the "horn", it also affects the position of the maximum of the frequency-period distribution and the half width of this distribution. It is thus probable - details have to be confirmed by calculations - that mass loss can explain the observed frequency-period distribution without resorting to exotic IMFs.

Let us note that the scenario sketched above is in accord with observational data concerning Wolf-Rayet and red supergiant luminosities. Apparent magnitudes of single WR stars in the LMC range between $V=12\overset{m}{.}0$ and $V=16\overset{m}{.}5$ (Breysacher 1981). In agreement with theory which predicts a sharp drop in luminosity during the later WR stages (Maeder 1983), most low-luminosity WR stars are of spectral type WNE and WC. The brightest red supergiants are found at about $V=11^m$ whereas the most massive cepheids are observed near $V=12^m$. This lends additional support to Maeder's scenario of WR stars repre senting a post-red-supergiant stage of stellar evolution. The lack of single WR stars in the SMC indicates somewhat lower mass loss rates; uncertain WR luminosities in our Galaxy make a similar comparison with cepheids rather hazardous.

As to the other hypotheses mentioned above which have been advanced for the purpose of resolving the mass anomalies, we do not consider them particularly promising. For a more detailed discussion including overshooting and turbulent diffusion we refer to Stift (1984).

IV. The consequences for the PL and the PLC relations

Whatever effect is responsible for the disagreement between observations and the canonical theory of cepheids, all possible explanations imply an internal structure of the cepheids sensibly different from the standard case. Taking into account the cosmic dispersion of metallicity, mass loss rates, and perhaps the degree of overshooting, we expect the pulsational characteristics of cepheids to be not as uniform as claimed by Sandage & Tammann (1969) or by Martin et al. (1979). Whereas there exist period-luminosity and period-luminosity-colour relations for cepheids in the same crossing, showing identical helium and metal abundances and being neither affected by mass loss nor by convective overshooting, this is no longer true for a real-life cepheid sample. Particularly the PLC relation loses its meaning once non-canonical effects become of the same order as the effects of finite strip width. That this is indeed the case has been shown by Stift (1982) and by Fernie & McGonegal (1983) who estimate the strip width at less than $\Delta(B-V)=0\overset{m}{.}20$ at constant period. The size of the effects of a cosmic dispersion in abundances and mass loss rates, and of the relative time spent in different crossings can be estimated from the interpolation formulae given by Iben & Tuggle (1972) and by Becker et al. (1977); even for a relatively small scatter in abundances and a moderate percentage of time spent in 1st, 4th and 5th crossings, the theoretical colour coefficient of the PLC relation drops from the canonical $\beta=2.7$ to $0<\beta<2$. Chance selection effects due to a small cepheid sample and a restricted period range become very important, leading to a zero-point error up to $0\overset{m}{.}5$. On the other hand, mean magnitudes at standard period derived with the help of the PL relation are much less affected by the above-mentioned effects and should preferably be used for distance determinations - for a more detailed discussion see Wayman et al. (1984).

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