SUPERGIANT PULSATIONS

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Abstract: The main data concerning the amplitudes and periods of supergiant variations are reviewed. The period-luminosity-colour relation of intermediate-term variations is compatible with pulsation motions. The Q-values seem to be larger than those corresponding to the fundamental mode and there are arguments favouring non-radial oscillations.

1. Distribution of the amplitudes in the HR diagram

From data of the Geneva photometry (Rufener, 1979) a selection of 327

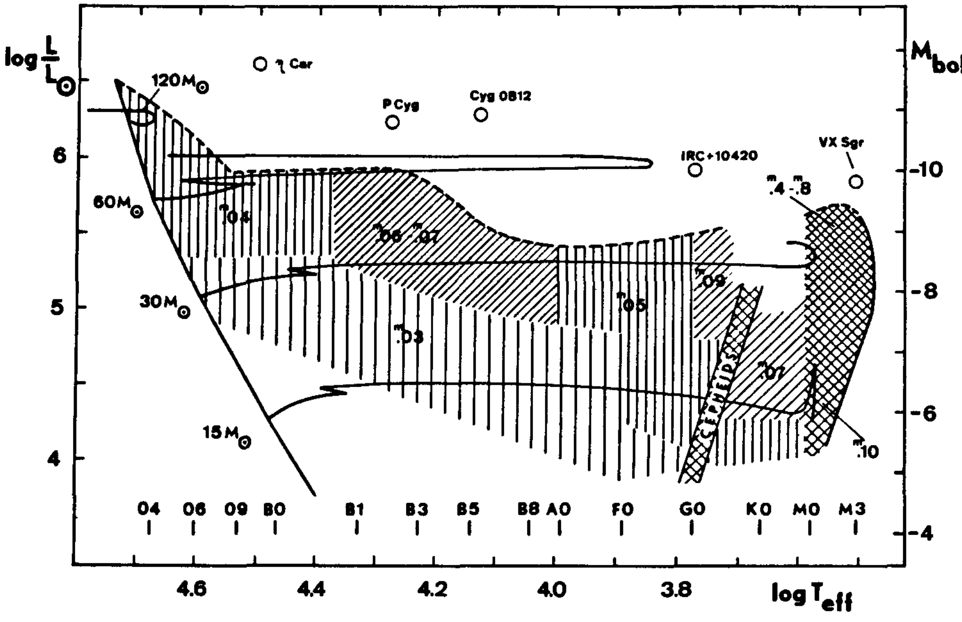

Figure 1. Distribution of the amplitudes of the variations of supergiants in the HR diagram. The evolutionary tracks are computed with mass loss (see text). The dotted line is the upper envelope in the HRD based on Humphreys' data (1979).

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stars of classes Ia to II observed more than 3 times and representing a total of 2420 measurements distributed over 20 years was obtained (Maeder, 1979). Figure 1 shows the distribution of the amplitudes of variations in V (the amplitude is defined as 3.3 times the mean square root, and is thus a peak-to-peak amplitude containing 95 % of points). The main results are: - 1) The increase of the amplitude with luminosity (cf. Maeder, Rufener, 1972). - 2) For the Ia supergiants the amplitudes increase from O-type stars to the early B-type stars, consistently with Appenzeller's results (1972) in the LMC, and then decrease up to the F-type stars. - 3) For late-type supergiants, there is a strong increase of the amplitudes which occurs at a progressively earlier Sp with increasing brightness: at G-type for Ia, at M for class II. We note that this behaviour is just similar to that of the limit of deep convection in the external layers of massive stars (see also Schwarzschild, 1975). A few extreme galactic supergiants (e.g. list in Humphreys, 1979) frequently exhibit important changes in all their spectral parameters (e.g. light, colour, Doppler shift, Sp, line strength, line profile, Hα emission, etc): for example HR 8752 which has varied from G0Ia to K2Ia between 1950 and 1977 and is now back to G0Ia (cf. Lambert and Luck, 1978). To this extreme group belong S Doradus and the extreme supergiants studied by van Genderen (1979) in the LMC as well as the Hubble-Sandage variables in M31 and M33, which show amplitudes sometimes smaller than a few tenths of magnitude over some years, but possibly reaching more than 2 m over decades.

2. Characteristic times of variations

The observations by Appenzeller (1972), Sterken (1977), Rufener, Maeder, Burki (RMB, 1978 and BMR, 1978), van Genderen (1979) indicate: - 1) Cyclic variations, which range from 15 days for B2Ia to about 90 days at G0Ia (cf. light curves by RMB, 1978), - 2) The existence of short term variations (some hours) superimposed in these cyclic variations. These nightly variations (amplitude ~ $0^{m}.015$) are present in stars exhibiting P Cygni profiles, i.e. the most luminous stars (cf. Sterken). Besides these 2 kinds of variations, there are also the long-term, sometimes quasi-catastrophic, variations mentioned above, which concern the most luminous supergiants.

Let us concentrate on the cyclic intermediate-term variations, which have so far received more attention. Abt (1957), from radial velocity observations of 8 A-F supergiants, provided arguments for the pulsational character of the variations (among others, the rather constancy of the Q-value for the examined group). Additional indications were given by Maeder and Rufener (1972) who found a semiperiod - luminosity - colour relation for B-G supergiants. At a given Sp, the P-L relation is parallel to that of the Cepheids; the P-L-C relation was found to be consistent with a $P = Q(\bar{\rho}/\rho_{\odot})^{-\frac{1}{2}}$ relation.

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From data for 32 supergiants Burki (1978) estimated empirical Q-values with masses derived from Stothers and Chin models (1977) based on Carson's opacities. Empirical Q-values have been estimated with evolutionary models (Maeder, 1979) including mass loss and based on Cox and Stewart opacities (1970). The rate of mass loss is such that it reproduces correctly, in view of Humphreys' data (1979), the upper envelope of the MS band in the HR diagram. The resulting log Q values show a dependence in M_{bol} and T_{eff}; for 15 A-F stars one finds $\log Q = -0.107\ M_{bol} - 1.95$. With the M-L relation (accounting for mass loss), the following calibration of the HR diagram in semiperiods of supergiants is obtained:

$$\log P = -.346\ M_{bol} - 3 \log T_{eff} + 10.60$$

Figure 2 shows this calibration and the overall agreement confirms the hypothesis of the pulsational character of the variations of supergiants.

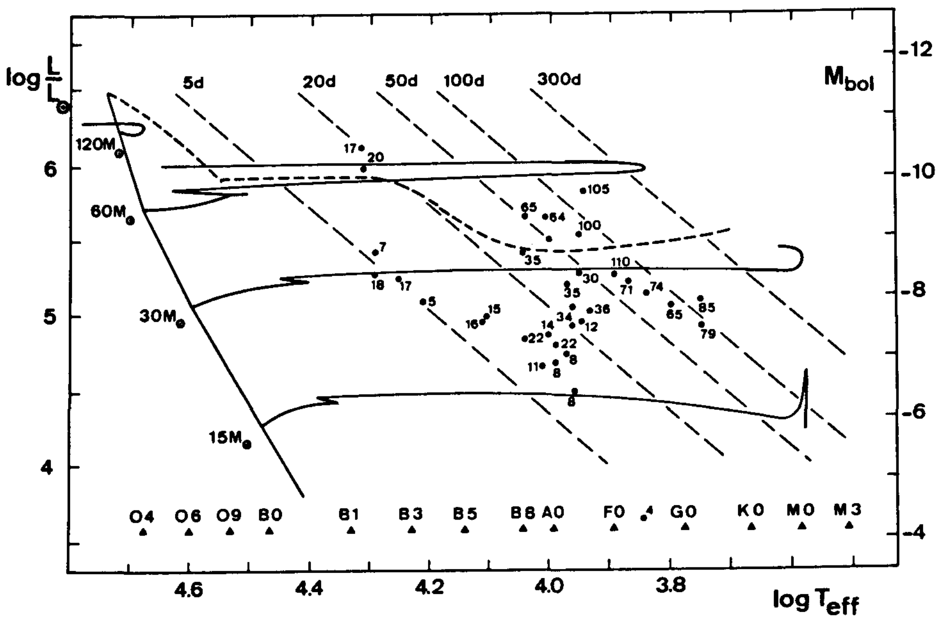

Figure 2. Distribution of the semiperiod in the HR diagram based on the author's evolutionary models with mass loss and data collected by Burki (1978).

3. Discussion and support for non-radial pulsations

The analysis by Lucy (1976) of Paddock's data in radial velocities for α Cyg (A2Ia) suggests that the variability results from the simultaneous excitation of many discrete pulsation modes; he finds 16

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terms with P from 6.9 d to 100.8 d. As several modes have P larger than the fundamental (P_o = 14.3 d), Lucy envisaged the possibility of non-radial modes. The tendency for long terms to occur in pairs supports that hypothesis, as rotation may lift (cf. Ledoux, 1951) the degeneracy of eigenfrequencies.

An additional indication in favour of non-radial pulsations comes from the comparison of theoretical log Q vs. M_{bol} relations with the empirical values. The empirical values are larger than the theoretical ones: especially for the early B-type stars where the difference is a factor 2.5. These differences may be interpreted in various manners: a) Uncertainties in the T_{eff} and BC scales. b) More mass loss than assumed (masses ~5 times smaller would be necessary for B stars). c) Differences in surface composition. Effectively, due to mass loss, stars more massive than ~30 $M_{\odot}$ have surface helium enrichment. However, stars less massive than ~30 $M_{\odot}$ also show the discrepancy. d) Non-radial oscillations. Although theoretical models of non-radial pulsations are lacking for supergiants, an evidence for this possibility comes from the fact that supergiants describe very different paths in V vs. B-V diagrams (cf. Burki, 1978). Some are bluer when brighter, like the Cepheids; others behave in the opposite manner. Such a situation could result from orientation effects of non-radially pulsating stars. A more definite answer will certainly come from the simultaneous photometric and v_{rad} observations.

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