AN UNUSUALLY STABLE AND SHORT SPECTROSCOPIC PERIOD OF THE Be STAR 28 CMa

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1. OBSERVATIONS

Spectroscopic (1970: ESO, 12 Å/mm, 6 spectra kindly put at my disposal by Prof. A. Van Hoof; 1976: ESO, 12 Å/mm; 1977: Calar Alto Observatory, 42 Å/mm; 1979: ESO, 12 Å/mm) and photometric (1976: ESO and Cerro Tololo, Hβ, uvby) observations of 28 CMa (B2-3 IV-Ve; $3.52 < m_V < 4.18$, irregular variations on the time scale of months or years reported; v_{rot} = 80 km/s) revealed a very complex variability. All observed individual types of variations are known from at least a few other Be stars. In 28 CMa, however, for the first time a highly significant correlation between the various variations is established by a stable common period. The period is 1.365 days which seems to be the shortest stable period presently known of any Be star. There is no indication that the star's behaviour changed between 1970 and 1979. Only the equivalent widths of the emission lines increased noticeably.

A detailed description of the observations will be given elsewhere (Baade, 1981). They can be summarized as follows:

a) All stellar absorption lines have asymmetric profiles. The asymmetry is variable, line profiles differing in phase by half a period are mirror images of one another. The degree of the asymmetry is not the same for different lines. In the broad Balmer lines it is barely noticeable, in narrow lines (e.g. Si II) it is very striking.

b) Because of the different effect of the asymmetry on different lines a wide range of radial velocity (RV) amplitudes is obtained if RVs are derived from measurements of the line minima. The amplitude (2K) is the lowest for the H lines (11 km/s), intermediate for the He I lines (60 km/s) and the highest for the Si II lines (84 km/s). (RV curves for all other lines are ill defined). Within an uncertainty of about 5 km/s the line wings are stationary. Thus the RV variations are due to a shift of the line cores. The shape of all RV curves is fairly sinusoidal. A phase shift between different RV curves is not evident from the present observations.

c) The V/R ratio of all emission lines, i.e. the whole Balmer series and some Fe II lines, is variable. In Hδ the amplitude is about 70%, averaged over one period V/R=1. The correlation with the stellar absorption

M. Jaschek and H.-G. Groth (eds.), Be Stars, 167–170.

line profiles is that during maximum violet asymmetry (RV minimum) V/R < 1 whereas during maximum red asymmetry of the absorption lines (RV maximum) V/R > 1. Within the measuring accuracy, a variation of the total equivalent widths of the emission lines was not detected.

d) The RVs of all emission lines are variable, those of the whole emission lines as well as those of the violet and red components measured individually. The amplitudes are low (2K = 10 km/s), the γ-velocities are the same as for the stellar absorption lines, γ = 29 km/s. There is however a permanent phase shift of 180 degrees between the RV curves of absorption and emission lines. The RV amplitude of the central reversals is 10 km/s, the RV curve is in phase with the stellar RV curves. Since the broad stellar abscrption lines are very little affected by the asymmetry the observed variations of the emission lines cannot be due to variations of the underlying stellar lines.

e) Since at the time of the photometric observations no regular short term variations were expected and since, furthermore, the comparison star turned out to be variable, no useful light curve of 28 CMa was obtained which could be compared to the spectroscopic variations. The upper limit of the photometric amplitude is about $0^m.03$ in uvby.

2. CLASSICAL MODELS

One of the classical models for the V/R variations of Be stars, the elliptical ring model, can be easily ruled out because the period of 28 CMa is too short. On the other hand, the period is too long to be in accordance with the observed RV amplitudes and the small brightness variations if 28 CMa is assumed to pulsate radially. The latter argument partly also concerns a variable stellar wind model. Since all photospheric lines are affected by the asymmetry, the mass flow had to be considerable. This should have a significant effect on the strengths of the emission lines which are however observed to be stable on short and medium time scales.

There are two possibilities to apply a binary model to 28 CMa: The first is to assume that the asymmetry of the absorption line profiles is the direct evidence for the presence of a companion, the line profiles being therefore a blend of a broad and of a narrow line component attributable to two different stars. Since all lines are somewhat asymmetric, both stars must have nearly the same temperature. Because the luminosities cannot be very different either, both stars must have approximately the same radius. But because the RV amplitude of the line wings (i.e. the broad line component) is very low, these otherwise almost identical stars would differ in mass by almost a factor of 5! The second possibility is to assume that the asymmetry reflects only indirectly the presence of a companion. The companion could be the cause of an asymmetric brightness distribution. However, if this effect is sufficiently strong to produce the observed asymmetric line profiles, a light amplitude far higher than the observed one had to be expected.

https://doi.org/10.1017/S007418090003775X Published online by Cambridge University Press

3. NONRADIAL PULSATIONS

The idea that, because of their proximity in the HRD, there might be a relation between Be and β Cephei stars, is not new. Unfortunately the observations, in particular the lack of real periods, never allowed to pursue this idea in more detail. Another reason is the argument that we heard already yesterday during the discussion of Drs. Jerzykiewicz and Sterken's paper, namely that the observed quasiperiods are often far longer than those known from β Cephei stars (3 - 6 hours). An additional problem is linked to the β Cephei phenomenon. It seems that there is no unique explanation for their variability. Some pulsate radially, in others at least one nonradial mode is excited (c.f. Smith 1980). Since we have excluded radial pulsations from the discussion and since the time is limited, we shall investigate only whether the observed period of 28 CMa is compatible with nonradial pulsations (NRP).

I have tried (Baade, 1981) to obtain a very simple extrapolation of Ledoux's (1951) original relation for the observed periods of nonradially pulsating stars towards fast rotators:

$$\sigma_{k,m} = \sigma_{k,o} - m(1 - C_k)\omega - \frac{\omega^2}{2\sigma_{k,o}} \qquad (1)$$

If it is assumed that the nonrotating star's pulsational frequency, $\sigma_{k,o}$, is of the order of those of β Cephei stars, the observed frequency, $\sigma_{k,m}$, can be smaller than $\sigma_{k,o}$ only if m is not negative. This means that, if $m > 0$, the pulsational mode is a retrograde one, waves are travelling in the opposite direction to the rotation. Due to the high angular velocity of Be stars, ω, it is then possible that the pulsational period of the star is about the same as in the case of β Cephei stars whereas the observed period is considerably longer.

With the numerical assumptions $\ell = 2$ (this mode has been identified in several β Cephei stars), $m = 2$, $\sigma_{k,o} = 4\ d^{-1}$, and $\omega = 1.7\ d^{-1}$, relation (1) yields a frequency of $0.83\ d^{-1}$. This may be compared to the observed frequency of $0.73\ d^{-1}$. In view of the simplicity of the model it is an interesting result that a satisfactory approximation of the observed period of 28 CMa is possible by just taking into account the high rotational velocity of Be stars while all other parameters are kept in the same numerical range as observed in β Cephei stars. That the pulsational mode has to be a retrograde instead of a direct one, may also be due to the fast rotation although this is in contradiction to Hansen's et al. study (1978) of rotating nonradially pulsating stars.

References

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DISCUSSION

Endal: How did you arrive at the second order term in your equation for the non-radial pulsation periods? How important was this term in determining your m = +2 period?

Baade: I included the centrifugal term in my calculations while apart from that I follow Ledoux's approach (1951) and still neglect all other "small" terms. This is certainly not correct, but it was my intention to get just a rough idea whether such a second-order term will turn out to be very important. With the assumptions stated before, this second order term is about one order of magnitude smaller than the linear term.

Souffrin: Can you say something on the stability of the phase - i.e. the life time for phase coherence - of this oscillation?

Baade: Within the known accuracy of the period, I did not find an indication of a phase shift between 1976 and 1979. Between van Hoof's observations in 1970, whose plates I was kindly allowed to remeasure, and my observation in 1976, however, too much time had elapsed to obtain a conclusive result.

Harmanec: Could you make clear the meaning of the angular velocity of your model? Do you assume local conservation of angular momentum or a rigid-body rotation?

Baade: I tried to keep the model as simple as possible. Therefore I assumed a rigid-body rotation.

Henrichs: Is your star known to be an x-ray source?

Baade: No.

Metz: Does your model explain the behaviour of the double emission of H_ε?

Baade: This behaviour does not just concern H_ε but all hydrogen (only H_α is not resolved into two peaks) and FeII (if visible) emission lines. It is easily explained if one assumes that a small additional emission, evoked by the shock effect of the high speed of the travelling waves, moves across the line.

Metz: Is the velocity difference of both the emission peaks consistent with the velocities derived from the system?

Baade: Yes.

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