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ON THE CONTINUED IMMACULATENESS OF THE Be STAR MU CENTAURI*

The line profile variability (LPV) of Be stars is still a relatively young subject (Baade 1979), it *may* (*cf.* Baade 1987a) contain the key to the unsolved question why the mass loss from Be stars is so dramatically different from the behaviour of B stars, and it has so far been detected only by comparatively few observers, not at last because the requirements on the S/N are very high. This makes it tempting for everybody to take up the challenge and find the explanation; but evidently the given combination of circumstances also poses some risks. In particular, it is sometimes overlooked that the LPV of early-type stars is one of the most complex variability patterns known from stars other than the sun. To keep *all* its facets in mind when trying to explain the observations is very difficult, and it would be dishonest to claim that this has already been achieved by any model. However, as has been cautioned earlier (Baade 1987b), attempts to overcome the sometimes confusing multidimensionality of the observed parameter space by concentrating on just one detail are inadequate. Paradoxical though it may appear, this applies especially to the basic categorization of the phenomenon.

In a recent note, Harmanec (1987b) has renewed a proposal by himself (Harmanec 1984, 1987a) and others (for references see, *e.g.*, Harmanec 1987a and Baade 1987b) that line profile-variable early-type stars are either spotted stars or binaries or some combination thereof. He derives seemingly new arguments from the preliminary analyses of ϵ Per (B0.5 III-V) by Gies and Kullavanijaya (1987) and μ Cen (B2 IVe) by Baade (1987c) in which it had been shown that the observed LPV is due to multi-mode nonradial pulsation (NRP). I understand that Gies (1987, private communication) does not concur with Harmanec's conclusions. The following discussion is therefore formally limited mainly to the case of μ Cen, but it should have much broader applications (of Harmanec's [1987b] characterization of μ Cen and ϵ Per as being 'extremely interesting and unusual' only the first part is right).

This is by far not the first round of the discussion rotational and/or orbital modulation due to corotating stationary features (hereafter simply called 'starspots' although

*Based on observations obtained at the European Southern Observatory, La Silla, Chile.

in a binary the features may be circumstellar) *vs.* NRP's, the explanation that has been adopted by virtually all spectroscopists who have presented observations of LPV's in early type stars. But it is instructive to begin this round by repeating (*cf.*, *e.g.*, Baade 1987a,b,c) the main arguments in support of NRP's since some seem already forgotten:

- Starspots do not account for absorption line wings which during certain phases extend beyond the normal footpoint of the profile (see, *e.g.*, Fig. 1).
- Starspots do not explain phase velocities that differ from the rotational velocity.
- The advocates of the spotted star class of models have not so far forwarded a model for the generation and maintenance – including considerable amplitude variations without change of the overall geometrical structure – of starspots or complicated circumstellar structures over extended periods. If magnetic fields are thought to be involved, its is interesting to note that at the current detection threshold of about 100 Gauss magnetic fields are not known from 'normal' OBA stars. On the other hand, chemically peculiar stars which have or are suspected to have magnetic fields and which at least in some cases do show inhomogeneous chemical surface abundance distributions do not display LPV of the type discussed here.
- Starspots cannot explain non-commensurate multiple periods.

The point that Harmanec tried to make is that the non-commensurability claimed for the periods of μ Cen (Baade 1987c) is debatable.

In astronomy, the search for period commensurabilities has a long history and even dates back to the times when it was considered important to find out if the constellations of the planets repeat periodically. Today we know that they do not (if exact repetition is demanded). One step to this realization must have been the distinction between rational and irrational numbers. All numbers resulting from physical measurements are inaccurate at some level, *i.e.* the number of their decimal places that is reliably known is finite. This is the same as saying that all measured numbers are rational numbers. Then, the conclusion is trivial that *any* finite set of measured numbers are commensurate. However, for a random sample of numbers, their smallest common multiple will usually be a much larger number and accordingly rather meaningless. A remarkable point about Harmanec's (1987b) work is, therefore, that he finds a fairly small common multiple each of four periods in both ϵ Per and μ Cen. A more detailed analysis of many more observations of μ Cen from different observing seasons pending, I do not comment the fact that the preliminary study in Baade (1987c) with reasonable certainty finds only two of the four periods chosen by Harmanec (but the presence of at least one more period of order 0.1 day is evident from the data). The more important question is if Harmanec's scheme has physically sound implicatons.

In his interpretation of μ Cen, Harmanec excludes spots on a single star because already the minimum radius of 10.8 solar radii that he infers is too large for a B2 star while the correction for μ Cen's low inclination probably contributes another factor $\sim$1.5 (Baade 1987a). It is even easier to agree with Harmanec's conclusion on account of his superperiod being 35 times the $\sim$0.1 day period: As has been stated many times in connection with NRP's, the number of features visible at any one time in the profile is slightly less than one-half of the number of features distributed along the star's circumference. In μ Cen's line profiles the number of features associated with the presumable

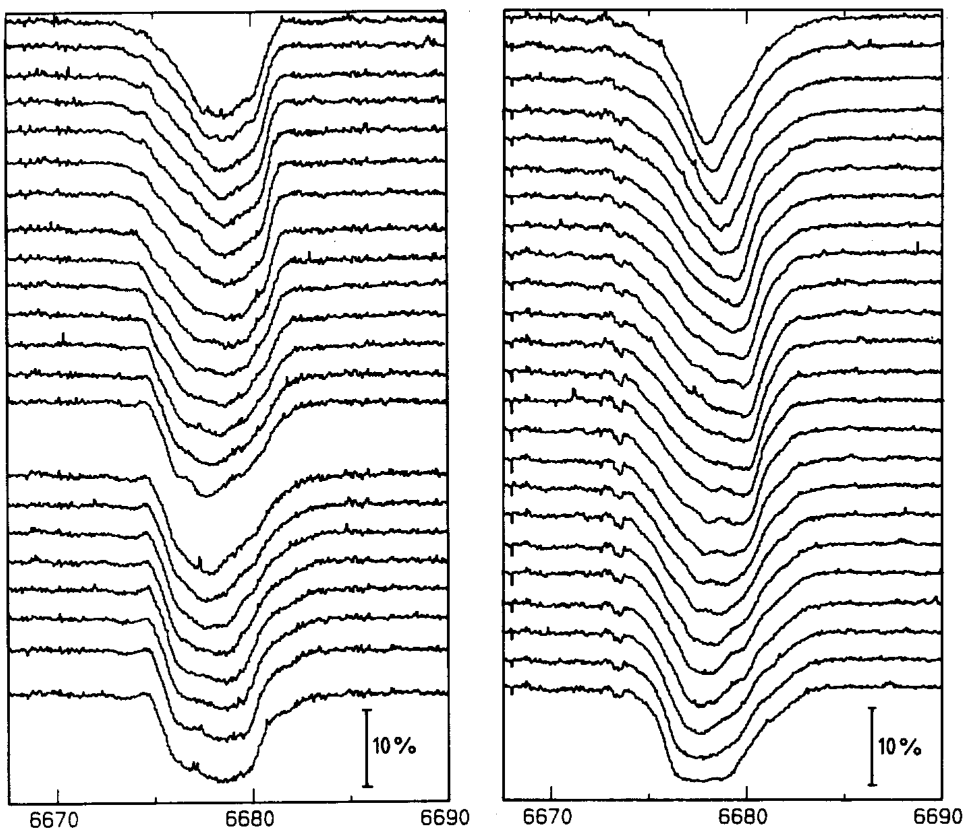

Figure 1: Profile variations of HeI λ 6678 Å in μ Centauri on 1987 April 10 (left panel) and 1987 April 17 (right panel). The spectra are normalized to the adjacent continuum flux, the scale is provided by the vertical bar in the lower right corner. In either series of spectra time increases from top to bottom. The vertical offsets between the spectra are such that one hour corresponds to 10% of the continuum flux. The first observation on April 10 was at 01:23 hrs UT, the first one on April 17 at 00:42 hrs UT. The various features to the left of the profiles of April 17 are due to imperfect flatfielding. Other spikes and artefacts were also left uncorrected.

0.1 day period (Baade 1984) never exceeds 5 (at most 6) while Harmanec's scheme predicts nearly 17! For the other periods the disagreement is similarly large, and in ϵ Per Harmanec's (1987b) numbers miss the available fits and/or estimates for the respective number of sectors (Smith, Fullerton and Percy 1987, Gies and Kullavanijaya 1987) by a factor of about 2. It was for that reason that commensurabilities involving factors larger than 4 and 5 were not considered in Baade (1987c). Harmanec simply ignores that, for surface phenomena, spectroscopy – in contrast to photometry – provides not only temporal but also spatial periods (wavelengths).

In his treatment of two preprints (Gies and Kullavanijaya 1987, Baade 1987c), Harmanec (1987b) pays regrettably little attention to one published paper which is based on a comparable set of observations of ϵ Per. On a first glance, that work by Smith, Fullerton, and Percy (1987) may have the 'disadvantage' that it does not supply a small set of simple numbers but that it gives a very complicated description of the phenomenon in terms of variable periods, variable pulsations amplitudes, oscillatory phase shifts, event like departures from a periodic behaviour, *etc.* which are all ascribed to the nonlinear superposition of basically two large-amplitude pulsation modes. Not only is such a scenario unnecessary for stationary starspots, it is also very doubtful whether one could deliberately contrive it. It is therefore essential to bear in mind that with the above terminology turned into modeling tools, Smith, Fullerton, and Percy succeeded in reproducing the observed line profiles including their simultaneous photometry. Re-analysis of the same data in the light of Gies and Kullavanijaya's results is under way but apparently has not so far (Smith and Gies 1987, private communication) identified any major inadequacies in the analysis given by Smith, Fullerton, and Percy (1987).

Harmanec's preferred solution for μ Cen is a binary with a period of either 3.535 or 7.07 days. (For ϵ Per resorting to a binary model is not justified because there is no evidence for circumstellar matter other than a wind. It needs to be asked, therefore, if a model that has to be split into two radically different versions when applied to the qualitatively fairly similar LPV of just two stars has much explanatory power.) The aforementioned difficulty for single stars is avoided in binaries because then a periodic structure in circumstellar matter can be postulated of which only some fraction will be projected on the Be star. But in order for the various structures required by multiple periods to be arranged at the same radius it is necessary that their wavelengths (spatial periods) share the *same* commensurability pattern as the periods. Future work on μ Cen (Baade *et al.*, in preparation) will show whether or not this is so.

In any case, it is important to realize that the data require *periodic* circumstellar structures and not just 'highly non-sinusoidal' ones as Harmanec (1987b) suggests. His comparison with the very structured light curves of X-ray pulsars is inappropriate so long as indications of high harmonics of their orbital periods such as the ones which Harmanec constructs for μ Cen seem to be lacking. It is difficult to imagine how a multiply periodic structure involving as many as 7+8+9+35 (if not 14+16+18+70) sectors of four different widths (plus others not yet detected) can be sustained in a circumstellar envelope against the effects of distortions by the companion and radially differential rotation. But there are other arguments (in addition to those listed above) than lack of imagination (and it deserves to be mentioned that most of them do not require access to the original data):

- Not every OB star (and not every Be star, either) is a member of a close binary system. It appears not advisable to contrive a model that has no chance to account for the ubiquity of LPV's in early-type stars (Baade 1987b). In μ Cen in particular, there is no evidence for a companion.
- Like in other Be stars, the V/R ratio of the two emission components occasionally seen in HeI λ 6678 Å seems to vary with the period of the slowest variation which in the case of μ Cen is 0.5 day. If the star is single, there are ways to understand this (*cf.* Baade 1987a). In a binary, the period of variation of emission features – whose occurence does not depend on their being projected on a background source – should be the orbital one; symmetry variations with one-seventh (if not one-fourteenth) of the orbital period appear very odd by any means.
- The probable low inclination of μ Cen (Baade 1987a; the apparent lack of eclipses may for some configurations slightly further strengthen this point in a binary model) requires that the multi-cellular structure of the circumstellar matter invoked by Harmanec is located at high stellar latitudes. If the orbital plane is not too different from the equatorial plane of the Be star, it is not clear how the companion should have such a profound effect high above the orbital plane and why duplicity is at all postulated.
- There are both prograde and retrograde features in the line profiles of μ Cen (Baade 1984, 1987a). If circumstellar matter is responsible for them, the rotation axis of the pattern must be viewed under a small angle, i_{shell}, because otherwise only the near hemisphere of an assumed circumstellar shell will be seen projected on to the Be star thereby producing only prograde features. This is inconsistent with there being only between one-half and one-third (or one-quarter and one-sixth) of all sectors visible at a given time (*cf.* the single-star case).
- The absorption features move across the whole breadth of the profile so that their v_{shell} sin i_{shell} must be similar to the stellar v_{*} sin i_{*} = 155 km s^{-1} (Slettebak 1982). From the previous point it follows that i_{shell} must be the smaller, the larger the shell's dimension is. But both the number of sectors not seen projected on the Be star as well as the suggested periods of 3.535 or even 7.07 day show that the shell would *not* be small. Accordingly, v_{shell} = 155 / sin i_{shell} km s^{-1} may easily exceed the limits imposed by any resonable binary model. If such limits shall not apply because of magnetic fields or theirlike, the whole binary model becomes obsolete.
- The relative uniformity of the propagation of the line profile distortions leaves little room for an oblique magnetic rotator. Then, the same reasoning as in the previous point brings also a single-star model into trouble because with $i_{*} = i_{shell}$ being very small v_{*} will get too large. (*E.g.*, if $r_{shell} = 2\ r_{star}$, $i_{shell} = 20°$ is too large to produce retrograde features of the observed strength. But for $i_{shell} = 15°$, v_{star} will already be 600 km s^{-1}.)
- I had not previously (Baade 1987c) succeeded in finding a single pair out of 20 nights of observations in which the LPV of μ Cen was just nearly the same. (As the example of the sun's planets shows, this has no implication as to whether or not the variations are periodic.) Harmanec now predicts that the LPV repeats every 7.07 days; but from none of six pairs of nights that are spaced by 7 days I find this confirmed. An example is shown in Fig. 1. Either Harmanec's commensurability is spoilt by additional periods that do not fit into his scheme or it vanishes with

the true values of the periods. In any case, the data do not sustain the idea that the variability of μ Cen can be represented by a single period.

In summary, the belief that the LPV of Be stars is due to starspots or circumstellar matter appears in no way supported by Harmanec's numerics.

Even though there is no *exact* commensurability, the discovery of just one more star whose periods come equally close to commensurability requiring only relatively small factors would probably call for an explanation, especially since without rotational and/or orbital modulation there is no longer an *a priori* need for perfect commensurability. Commensurabilities involving the azimuthal mode order, m, had previously been suggested for various nonradially pulsating stars (for references see Baade 1986). Both ϵ Per and μ Cen provide an example since in either star the mode with the shortest of the periods considered by Harmanec (1987b) is roughly m-commensurate with the longest period mode. Owing to the large contribution of the rotation to the observed phase velocities, these commensurabilities may only be apparent (*cf.* Baade 1987a); but that explanation does not apply to the respective three longest periods of either star which are clearly not m-commensurate. That is, their associated wavelengths do not share the commensurability, and the latter therefore exists only in the inertial, not in the corotating frame. *If* those near-commensurabilities are significant, they constitute a more general phenomenon with m-commensurability only being a special case.

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References:

Baade, D.: 1979, *The Messenger* (ESO), No. **19**, 4
Baade, D.: 1984, *Astron. Astrophys.* **135**, 101
Baade, D.: 1986, in *Highlights of Astronomy*, ed. J.-P. Swings, D. Reidel, p. 255
Baade, D.: 1987a, in IAU Coll. No. 98 *Physics of Be Stars*, eds. A. Slettebak and T.P. Snow, Cambridge Univ. Press, p. 361
Baade, D.: 1987b, in IAU Symp. No. 132 *The Impact of very high S/N Spectroscopy on Stellar Physics*, eds. G. Cayrel and M. Spite, D. Reidel, in press (= *ESO Scient. Prepr.* No. 529 A)
Baade, D.: 1987c, in IAU Symp. No. 132 *The Impact of very high S/N Spectroscopy on Stellar Physics*, eds. G. Cayrel and M. Spite, D. Reidel, in press (= *ESO Scient. Prepr.* No. 529 B)
Gies, D.R., Kullavanijaya, A.: 1987, *Astrophys. J.*, in press
Harmanec, P.: 1984, *Bull. Astr. Inst. Czechoslovakia* **35**, 193
Harmanec, P.: 1987a, in IAU Coll. No. 98 *Physics of Be Stars*, eds. A. Slettebak and T.P. Snow, Cambridge Univ. Press, p. 339
Harmanec, P.: 1987b, *Inf. Bull. Var. Stars* No. 3097
Slettebak, A.: 1982, *Astrophys. J. Suppl. Ser.* **50**, 55
Smith, M.A., Fullerton, A.W., Percy, J.R.: 1987, *Astrophys. J.* **320**, 768