Observations of the Symbiotic Star BD −21°3873 within the Long-Term Photometry of Variables Programme

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1. Background

It is a well-known problem that the concentration of astronomical observations at a small number of large observatories together with the Visiting Astronomer system, resulting in the allotment of small parcels of observing time to individual astronomers and large gaps in between, makes the continuous monitoring of variable stars very difficult. Many stars with variations on time scales of weeks and months cannot be studied well in this mode. Therefore, ten years ago a group of astronomers convened on invitation of C. Sterken at the Astrofysisch Instituut of the Vrije Universiteit Brussel in order to discuss ways to overcome this problem. With the support of ESO these efforts resulted in the ongoing programme "Long-Term Photometry of Variables" (LTPV).

This joint programme involves various working groups from several ESO member countries and from Chile. It may be regarded as a prototype of an ESO Key Programme although it was initiated long before this term was invented. According to well-defined rules, a limited number of variable stars (distributed into 9 different groups according to the type of variability) are observed within this programme in the Strømgren photometric system every few days (intervals varying according to priority and requirements of the particular stars) at one of the smaller telescopes at La Silla (in recent years exclusively at the Danish 50-cm telescope) for usually 3 or 4 months per application period. In this way, a more or less continuous (apart from seasonal gaps) monitoring of the variable stars over a long time base is achieved. For a detailed description of the LTPV programme and its history, see Sterken (1983) and Wolf et al. (1987).

Here, we will report about results concerning a star of LTPV group 3. This group contains mainly – but not exclusively – either confirmed eclipsing binaries or stars where eclipses have been suspected. Moreover, some symbiotic stars which may or may not undergo eclipses are included in this group as well as some systems which exhibit(ed) variations of unidentified character. The particular star to be presented in this contribution is BD −21°3873, a yellow symbiotic star.

2. The Light Curve

Little is known about BD −21°3873. Bidelman and MacConnel (1973) observed hydrogen and He II 4686 Å emission lines in its spectrum, and Allen (1979, 1984) included the object into his list of symbiotic stars. Absorption lines indicate a spectral type of approximately G8 (Schulte-Ladbeck, 1988). BD −21°3873 may therefore belong to the ill-defined group of yellow symbiotic stars (Allen, 1988).

The star had a low priority in the LTPV programme and therefore only 25 measurements are available for an analysis. They span a time base of 1671 days. In spite of the few data points, a periodogram analysis revealed a well-defined period of 283 days. The yellow light curve of BD −21°3873, folded on this period, is shown in Figure 1. It has a roughly sinusoidal shape with two minima of about equal depth and two maxima, one of which is not well covered.

The light curve alone does not allow to distinguish between the proposed period of 283 days or one with half this value. This, however, is possible with the help of the colour curves. Figure 2 shows $b-y$ (upper frame), m_1 (central frame) and c_1 (lower frame) as a function of orbital phase. They all show a more or less sinusoidal shape with only one maximum and minimum per 283-day period. Whereas the amplitude of the $b-y$ curve remains small ($\approx 0\overset{\mathrm{m}}{.}1$), the m_1 index already reaches an amplitude of $\approx 0\overset{\mathrm{m}}{.}2$, and c_1 varies by a staggering amount of more than 1^{m}.

Regarding only the light curve, two interpretations for the basic mechanism of the variations appear viable: Stellar pulsations with a period of 141.5 days or ellipsoidal variations of a deformed star in a binary orbit of 283 days period. Clearly, the colour curves rule out the first alternative.

In addition to the photometric data we obtained a few spectrograms of BD−21°3873 at the ESO 1.52-m telescope, using the B & C spectrograph and a CCD. In Figure 3 we display one of them which refers to photometric phase 0.64. These observations confirm the earlier classification: The spectrum shows prominent emission lines of H, He I and He II superposed upon an absorption-line spectrum which we classify as a type G8 and (most probably) of luminosity class III.

There are reasons to believe that we see the light of at least two components in BD−21°3873. The ellipsoidal variations in the yellow light curve indicate the strong contribution of the G8 star which also dominates the optical spectrum. However, the colour indices (mean values and total ranges are given in Table 1) have values totally different from those encountered in normal (single) stars. They are probably influenced by the superposed emission lines and the free-bound continuum of a nebula.

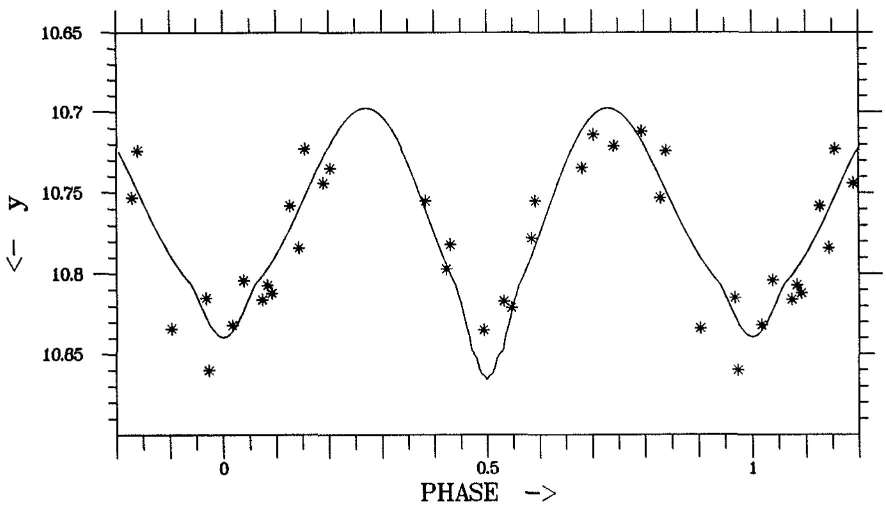

Figure 1: *The yellow light curve of BD−21°3873 folded on the period of 283 days. The superposed solid line is the best fit according to the Wilson-Devinney model. Grazing eclipses are indicated, while most of the variability is caused by ellipsoidal variations of the primary component.*

Table 1: *Mean values and ranges of colour indices*

Index	Mean	Range
$b-y$	0.952	0.905 ... 1.005
m_1	0.296	0.195 ... 0.416
c_1	−0.514	−1.070 ... 0.053

3. A Qualitative Model

The light curve together with the c_1 curve and its particularly strong variation suggests a simple qualitative model for BD−21°3873. For most of the period, c_1 is negative, reaching even values of < -1. Since this index measures the Balmer discontinuity, a strong Balmer continuum emission is probably responsible. In fact, the spectrum shown by Allen (1984) reveals a strong Balmer jump in emission. It has its origin in the gaseous emission region which is usually present in symbiotic stars. We suppose it to be centred on a small star or a compact object (to which we will refer as the primary hereafter, following the nomenclature normally used with respect to symbiotic stars) orbiting a giant of spectral type G (the secondary) which fills a considerable fraction of its Roche lobe, giving rise to the ellipsoidal variations.

The minimum of the c_1 index is observed when the emission region is best visible and contributes most to the total light of the system. It coincides in phase with one of the minima of the yellow light curve. This may be interpreted as being the phase of the lower conjunction of the primary (together with the emission region) and the secondary. The maximum value of c_1 then occurs at the phase of the upper conjunction when a part of the emission-line region is hidden behind the G star. Since the c_1 curve is approximately sinusoidal and no well-defined eclipse of the emission region is indicated in the c_1 index, it is supposed that the emitting gas is not confined to the region immediately around the primary on which it is centred, but that it envelopes the entire binary system.

4. A First Quantitative Test

Despite the fact that this is only a naive qualitative scenario, it appears to be able to explain the basic observations. Of course, it has to be subjected to a quantitative investigation. As a first step in this direction, and in order to learn more if not about reliable values for basic system parameters, but at least about orders of magnitude, we performed some preliminary model calculations.

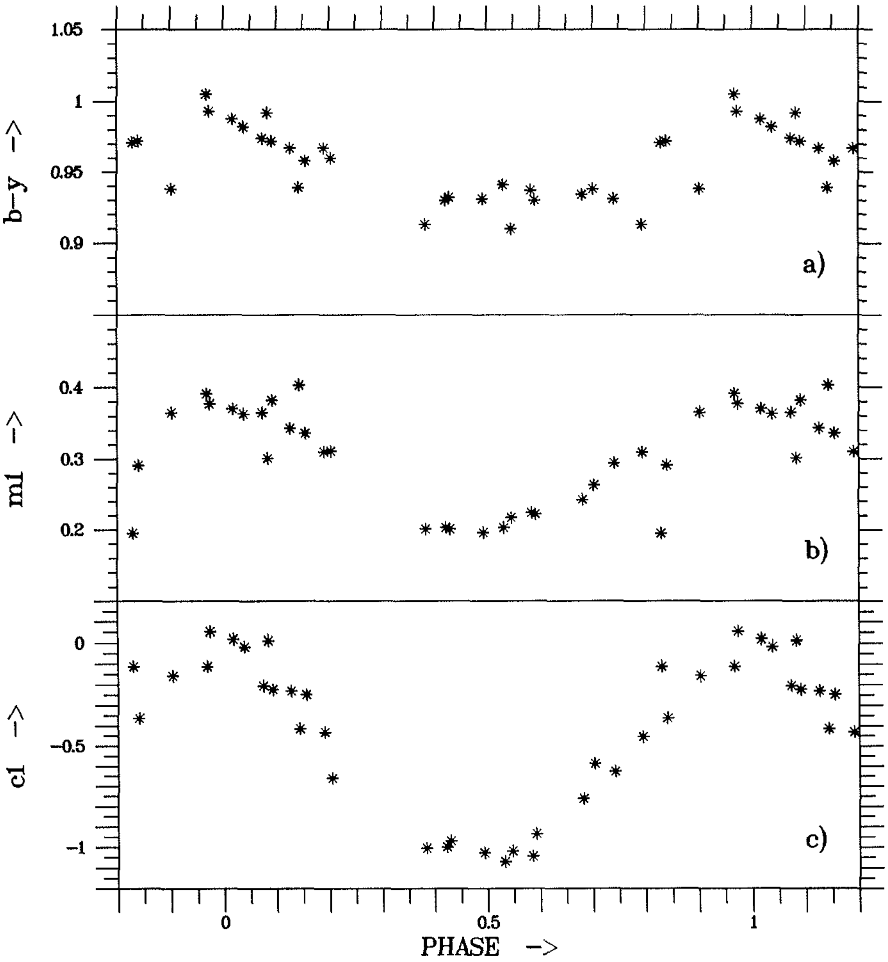

Figure 2: *Colour curves* b – y *(a),* m_1 *(b) and* c_1 *(c) of BD−21°3873, folded on the period of 283 days. In contrast to the light curve, the colour curves show only one maximum per cycle. Note the staggering amplitude of the variations of the* c_1 *index.*

We combined Wilson and Devinney's (1971) code for the calculation of light curves of binary systems with the simplex algorithm (Nelder and Mead, 1965), in order to automatically determine a set of system parameters which leads to an optimized fit of the calculated light curve to the observed data.

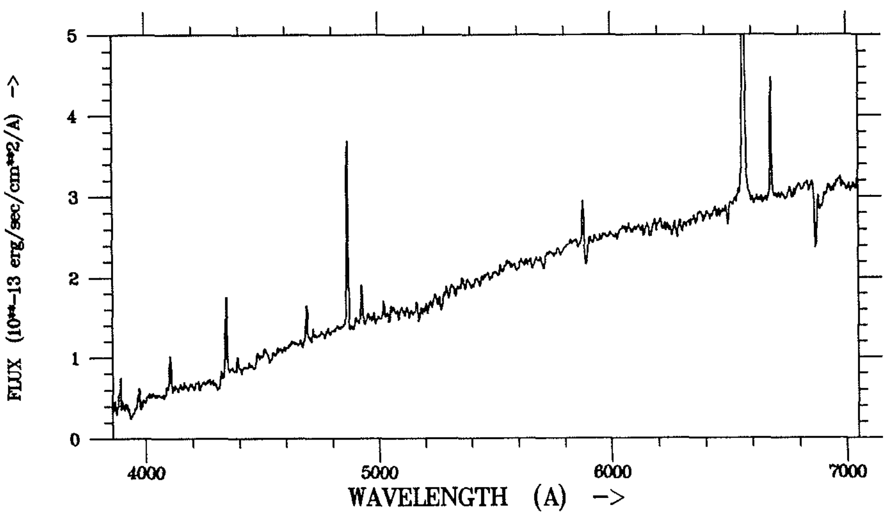

Figure 3: *A low-resolution spectrum of BD−21°3873 observed on February 24, 1988, with the ESO 1.52-m telescope, B & C spectrograph, and a CCD at photometric phase 0.64. Emission lines of H, HeI and HeII are superimposed on a reddened G8III spectrum. The truncated Hα line reaches a maximum flux of 13 × 10^{-13} erg/(sec cm^2 Å).*

We are aware that the Wilson-Devinney model cannot well describe a symbiotic binary since it supposes the stars to have a well-defined surface. Thus, it cannot handle the gaseous nebula. However, if the light of the system is dominated by the cool secondary (which can be treated as a normal star), a reasonable agreement between the calculated and the observed light curve may be found with parameters for the dominating star which are not altogether wrong. We therefore restrict our calculations to the *b* and *y* band data. It is then in fact possible to obtain a satisfactory fit. The calculated *y* light curve is shown in Figure 1 superposed upon the observed data points. The suspicion that the Wilson-Devinney model cannot be applied to data in spectral bands where the secondary does not dominate was confirmed by test calculations for the *u* and *v* bands. Here, a satisfactory fit proved not to be possible.

When performing a light curve fit it is advisable to fix as many free parameters as possible to values determined otherwise or to plausible ones, in order to relieve problems arising from correlations between them and to increase the reliability of the remaining parameters. In the present case we fixed the period to 283 days and the primary star temperature to 5000 K, appropriate for a late G-type star. Furthermore, we assumed the orbital eccentricity to be 0, the albedos of both components to be 1 and the gravity darkening parameter of the primary to be 0.32.

The results of a simultaneous fit to the *b* and *y* light curves are given in Table 2.

Here, i is the orbital inclination, T_1 the temperature of the primary, q the mass ratio defined as mass of secondary to primary, L the monochromatic luminosity, and Ω the dimensionless surface potentials. Ω_c is the potential of the Roche limit. σ is the standard deviation of the observed data points from the fitted ones.

It turns out that the light curve calculated with these parameters reproduces the observed one well. The G star is close to filling its Roche lobe as indicated by a comparison between its surface potential and the potential of the Roche limit. The system is seen under an angle where grazing eclipses of the primary are to be expected. For reasons outlined above, the parameters of the latter are, of course, unreliable.

It must be emphasized that these results are only preliminary. However, they confirm that the simple heuristic model outlined above is not altogether wrong and may serve as a starting point for more detailed investigations.

The long-term observations of BD −21°3873, although they could yield only few data so far, have thus already provided some interesting results. A further analysis of the available data and a more complete coverage of the light curve will certainly lead to a better understanding of the system. We therefore changed the priority of BD −21°3873 within the LTPV programme and gave it the highest weight within group 3. We hope that it will also be possible to obtain spectroscopic observations of the star around the orbit, although at a period of 283 days this will not be easy for someone who can only observe as a Visiting Astronomer and has no constant access to suitable observing facilities.

Table 2: *Best fit model parameters for BD −21°3873*

	b	*y*
i	68°	
T_1(K)	20100	
q	1.8	
Ω_1	10.7	
Ω_2	5.2	
Ω_c	5.0	
$L_2/(L_1 + L_2)$	0.835	0.968
σ (mag)	0.026	0.024

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The Importance of Lithium

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Recent developments increasingly emphasize the importance of lithium. Its primordial abundance is well known to severely constrain the nucleon density in the Universe (Kawano, 1988); it is now thought to be the first observational test to try to discriminate between non-standard cosmological models, such as the inhomogeneous ones inspired from the quark-hadron transition (Reeves, 1988).

Actually, the use of lithium as a cosmological barometer encounters a major obstacle: the uncertainty in the determination of its primordial abundance. Spite and Spite (1982) suggest that the constancy in the observed values of the ^{7}Li abundance toward very metal-deficient stars (Pop II) represents its primordial abundance, Log(Li/H) = −9.5 ± 0.2. In the interstellar medium and towards Pop I stars, the derived value is Log(Li/H) = −8.9 ± 0.2. If the Pop II value is typical of the primordial one (which seems to be the case, see Vangioni-Flam et al., 1989), then the explanation for a higher Pop I value becomes a crucial astrophysical issue. Furthermore, it appears that this value is slightly lower than the one measured in the solar system, derived from meteoritic measurements.

Lastly, the ^{7}Li abundance seems to be still increasing, for in the very young stars of the T Taurus molecular cloud, the abundance observed is on the average twice the Pop I value. The lithium evolution models have then to account for this galactic enrichment in ^{7}Li. Amongst them, it was suggested that ^{7}Li was produced by a slow mass-loss process in certain red giant stars (Scalo, 1976), in nova bursts under certain chemical conditions (Starrfield et al., 1978), and recently in supernova shocks (Dearborn et al., 1989).

While the red giant and nova models lead to an overproduction of ^{7}Li, the supernova process would account for