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The 1983 eclipse of the high-latitude eclipsing system BL Tel ⋆

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Summary. Strömgren (*uvby*)- and Walraven (*VBLUW*) photometry of the 1983 eclipse of BL Tel is presented and discussed. Significant differences in the depth of the minimum and the colour variations during the eclipse compared with those of the previous recorded minima, are found and discussed. The metallicity of the bright *F*-type companion is presumably nearly solar and its gravity amounts to $\log g \sim 1$–2.

Key words: photometry – variable stars – eclipsing binaries

1. Introduction

BL Tel is a high latitude long-period eclipsing system consisting of a variable *F*-type supergiant and a much less luminous *M*-type secondary, which eclipses the primary once in $\sim 778^d$. An extensive discussion on the variability of the *F*-type companion and the photometric characteristics (*VBLUW* system) of a number of eclipses is given by van Genderen (1983, hereafter called Paper I). It is of interest to notice that the *F*-type companion [BL Tel (*F*)] belongs to the newly classified UU Her-type stars, a small class of Cepheid-like supergiants at high galactic latitudes. Their characteristics are discussed by Sasselov (1983, 1985).

This paper discusses *uvby* (Strömgren system) and *VBLUW* (Walraven system) photometry of the eclipse of 1983. A number of observations in the first system were also made outside the eclipse (in 1982 and 1983).

2. The observations and reductions

The observations were made in two photometric systems: the *VBLUW* system of Walraven and the *uvby* system of Strömgren. We shall first discuss those in the *VBLUW* system, of which seven were obtained by S. Tjemkes during a fortnight in September 1983 with the 90-cm Dutch telescope at the ESO, La Silla, Chile. They are concentrated around mid-eclipse.

The variable was measured once per night with the comparison star HD 177365 (B9V, 6^m1, Houk, 1978). The diaphragm aperture was 16″. Typical integration times were 1 min. References on the photometric system are given in Paper I.

Since 1980 the *VBLUW* system has changed its characteristics slightly after a major revision. Consequently they are slightly different from the 1970/1978 system, in which the observations of Paper I are given. Transformation formulae were derived with the aid of a large number of supergiants measured in the old and new system (van Genderen et al., 1986). In order to compare the present photometry with that of Paper I which is given in the 1970/1978 system, the first has been transformed to the latter system with the aid of the formulae mentioned above, with an accuracy of ± 0.005.

Table 1 lists the J.D. and the *VBLUW* parameters of BL Tel (in log intensity scale) in the two systems. Table 2 lists them for the comparison star. The V of the *UBV* system (with subscript J and in mag scale) was obtained with the aid of the formula:

$$V_J = 6.889 - 2.5\,[V + 0.039\,(V\text{–}B)]$$

(Pel, 1983) and applied on the V and V–B in the 1980 system. The $(B\text{–}V)_J$ of BL Tel was transformed from the V–B (in the 1980 system) with the aid of a calibration based on supergiant photometry (not published). That for the comparison star was found by applying the relation:

$$(B\text{–}V)_J = -0.016 + 2.582\,(V\text{–}B)$$

and valid in the range $-0.4 < (B\text{–}V)_J < 0.2$ (Lub and Pel, 1985). The reason is that for supergiants and main sequence stars slightly different transformations are necessary.

The observations in the *uvby* system were made by Drs. O. Stahl (October 1982 and April/May 1983), F.-J. Zickgraf (August/September 1983) and H. Ott (September 1983) with the 61-cm Bochum telescope at ESO, La Silla, Chile, as part of C. Sterken's program "Long term photometry of variables" which is underway at ESO. The diaphragm aperture was 18″. Details on the reduction procedure are given by Manfroid and Heck (1982, 1984). Two comparison stars were used viz. HD 179775 [K0 III, 7.3 (Houk, 1978)] and HD 179034 [F2/3 III, 8.5 (Houk, 1978)]. The brightnesses and colour indices of both stars are given by Manfroid et al. (1986). The relative brightnesses and colours of BL Tel with respect to the first comparison star can also be found in that paper. It should however be remarked that because of some problems with the filters, the photometric parameters for the interval J.D. 2445248–2445272 are somewhat different from those of the later data. Therefore two values for each photometric parameter of the comparison star are given in the paper by Manfroid et al. (1986).

Since the variable and the comparison stars were only measured once per night, no nightly standard deviation could be derived. We expect that for the relative photometric parameters of BL Tel, the standard deviations are of the same order as those for the photometric parameters of the comparison stars averaged over all nights, thus $\pm 0^m010$.

⋆ Based on observations collected at the ESO, Chile

Table 1. Photometric data of BL Tel in the *VBLUW* system (first line 1980 system, second line 1970/1978 system) and in the *UBV* system (with subscript *J*) observed in 1983

J.D.-2440000	*V*	*V–B*	*B–U*	*U–W*	*B–L*	V_J	$(B–V)_J$
		(log intensity)				(mag)	
5581.566	−0.786	0.284	0.517	0.403	0.253	8.83	0.65
	−0.796	0.266	0.515	0.364	0.246		
5582.517	−0.807	0.293	0.511	0.407	0.252	8.88	0.67
	−0.817	0.275	0.509	0.367	0.245		
5585.681	−0.868	0.306	0.514		0.255	9.03	0.70
	−0.878	0.287	0.512		0.248		
5589.538	−0.880	0.313	0.494	0.400	0.256	9.06	0.72
	−0.890	0.293	0.492	0.361	0.249		
5593.500	−0.855	0.315	0.488		0.258	9.00	0.72
	−0.865	0.295	0.486		0.251		
5596.510	−0.796	0.305	0.501	0.409	0.258	8.85	0.70
	−0.806	0.286	0.499	0.369	0.251		
5597.500	−0.773	0.303	0.506	0.408	0.256	8.79	0.70
	−0.783	0.284	0.504	0.368	0.249		

Table 2. Photometric data of the comparison star HD 177365 in the *VBLUW* system (first line 1980 system, second line 1970/1978 system) and in the *UBV* system (with subscript *J*). The errors are standard deviations

V	*V–B*	*B–U*	*U–W*	*B–L*	V_J	$(B–V)_J$
	(log intensity)				(mag)	
0.248	−0.023	0.302	0.067	0.103	6.27	−0.08
					± 4	± 1
0.238	−0.019	0.304	0.053	0.093		
± 15	± 5	± 5	± 13	± 5		

3. The period of the binary revolution

Because of the variability of the bright *F*-type primary with a light amplitude of ~0ᵐ2 (Paper I), the shape of each minimum is slightly disturbed and the time of mid-eclipses may thus have a larger uncertainty. That is probably one of the reasons why the period for the binary revolution determined in Paper I (778ᵈ6) appeared to be slightly longer than it should be according to the new 1983 eclipse (778ᵈ3) (Figs 1 and 2). The other reason is that we had incorporated two not too well observed times of mid-eclipses viz. those of 1968 and 1977. The new time of mid-eclipse is estimated to fall at JD 2445589 ± 1^d. A visually estimated light curve by Williams (1985) revealed JD 2445591.5, which is slightly too late when compared with our light-curves. A period based on old Harvard photographic material revealed $P = 778^d21$ (Gaposchkin, 1970), which lies within the estimated uncertainty of Eq. (1). The available photoelectrically observed epochs of mid-eclipse are collected in Table 3 and the formula for the binary revolution used in the present paper is:

$$\text{J.D.min.} = 2439363.0 + 778^d3 \quad (1)$$
$$\pm 1.0 \quad \pm 0.2 \text{ e.e.}$$

The errors are estimated.

4. The light- and colour curves

Figure 1 shows the bottom part of the 1983 minimum observed in the *VBLUW* system (in log intensity scale). Phases of the binary revolution Φ_b were computed with Eq. (1). The trend of the brightness and colours of the 1966 eclipse (Paper I: Fig. 2a and b) is schematically indicated by the continuous lines.

It is of interest to remark that the new minimum is brighter by ~0ᵐ12 than the 1966 eclipse, by ~0ᵐ25 than the 1977 eclipse (Paper I: Fig. 4a) and by ~0ᵐ35 than the 1968 eclipse (Paper I: Fig. 2a). In view of the size of these differences it is not likely that this is caused by the variable *F*-type primary alone, since its peak-to-peak amplitude is 0ᵐ2 at most. Besides the mid-eclipses of 1966 and 1968, which differ in brightness by ~0ᵐ23, coincide with roughly the same phase of the pulsation of the *F*-type star, namely $\Phi_{puls} \sim 0.75$ and 0.72, respectively. Perhaps we are dealing with an *M*-type companion which is variable in size. Thus during the new 1983 eclipse the *M* star should then be smaller than during the other eclipses.

The 1983 colours *V–B* and *B–L* are redder and the *B–U* bluer than those of the 1966 eclipse by ~0ᵐ02 – 0ᵐ05 and even more with respect to most of the other eclipses (Paper I: Figs. 2b and 4b). The asymmetry of the colour curves with respect to $\Phi_b = 0.0$, is

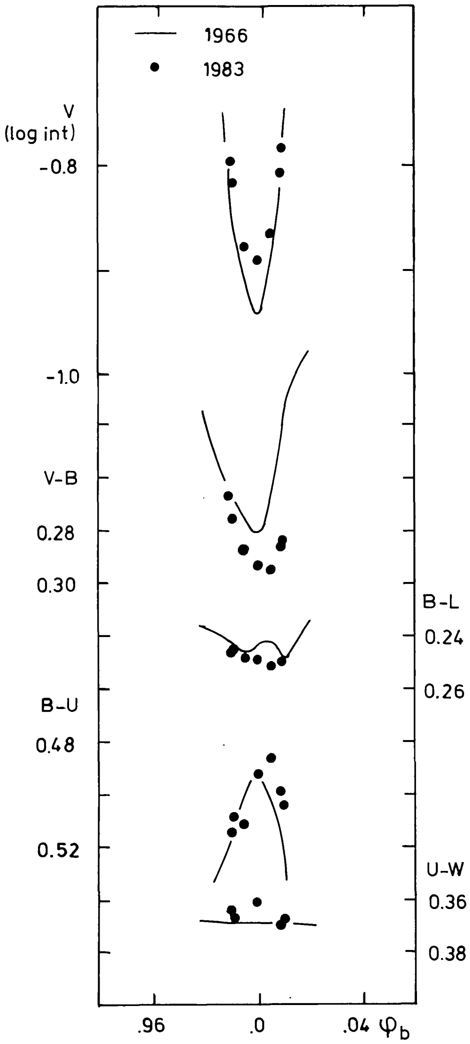

Fig. 1. The observed bottom part of the 1983 eclipse in the *VBLUW* system (in log intensity scale). The trend of the brightness and colours of the 1966 eclipse is schematically indicated (Paper I) by the continuous lines

just as for the previous eclipses also obvious, although the too low number of observations prevents any further detailed comparison.

Figures 2a and b show the *uvby* observations (in mag scale) *relative* to the comparison star HD 179775 (indicated by the Δ) as a function of Φ_b. The colour indices m_1 and c_1, which are a measure for the blocking by lines and for the Balmer jump, respectively, are defined as follows:

$$m_1 = (v-b) - (b-y)$$

$$c_1 = (u-v) - (v-b).$$

These observations represent the first of this object in the Strömgren system. A few observations outside the eclipse clearly demonstrate the variability of the *F*-type companion. A large part of the eclipse is reasonably covered. The *y* magnitude at mid-eclipse is $9^m.05$ and V_J derived from the *V* is $9^m.06$, thus both magnitude scales are practically identical. The asymmetry of the colour curves with respect to mid-eclipse is clearly visible and is caused partly by the variability of the *F*-type star and partly by the presumable presence of gas streams (Paper I). Of course no correction for the colour variation of the *F*-type star could be applied, because the *uvby* observations outside the eclipse are too low in number.

From Walraven and Walraven (1970) and Paper I we have learned that the light in different wavelengths reaches us from different atmospheric layers. Thus an important part of the strong colour variations are caused by center-to-limb effects. At the moments when half of the star is eclipsed (thus if the median luminosity has decreased by a factor two), one should expect the same colours as the outside eclipse colours, provided that the dark body is much larger and sharply edged (Paper I). These moments are indicated by two short vertical lines in the panels for the colour curves (Figs. 2a and b). At these moments *b–y* has more or less the outside eclipse value during ingress, but is redder during egress, thus similar to the *V–B* in Fig. 5b of Paper I. (The asymmetry will be discussed later in this section). The requirement mentioned above is also for the other colours not always fulfilled. Especially the *u–v* is too red by $\sim 0^m.1$ at the particular moments. (Just before this time during ingress, thus not long after the start of the eclipse, *u–v* is even redder, see further.)

At mid-eclipse *b–y* is reddest (by $\sim 0^m.25$ compared to the outside eclipse colour), indicating that the rim of the *F*-type star is redder than the center. In *v–b* the reddening at mid-eclipse is only small and in *u–v* there is even a strong bluing effect of $\sim 0^m.15$ compared to the outside eclipse colour. Apparently the rim is brighter in *u* (3500 A) than in *v* which lies at a longer wavelength (4110 A). Therefore *u–v* is reddest shortly after the start of the eclipse, which deminishes subsequently up to the moment of mid-eclipse. Such an effect is also apparent in *B–U* in Paper I (Figs. 2b and 5b).

The fact that halfway the eclipse *u–v* is still too red compared with the outside eclipse colours (and also *B–L* and *B–U* in Paper I) illustrates that center-to-limb effects are not sufficient to explain all colour variations. It should mean that if the disk of the *F*-type star is eclipsed halfway in visual light, it should be eclipsed by a smaller fraction in the shortest wavelengths of the ultra violet! Thus then one could explain that *u–v* is still too red. One has to wait until the visual light has decreased by a factor 3–4, until *u–v* has the same colour as the outside eclipse one. If the *M*-type star has an extended atmosphere, it should then be optically thin in the shortest wavelengths only and not in the longer ones. Since this is unlikely, one could propose another explanation by supposing that the visual light curve does not reflect an eclipse of the bright star only. It is possible that the eclipse of an illuminated gas ring, – disk and/or – stream, which are presumably present in the system, takes part in the visual light decrease. Consequently, the true moments of an half eclipsed *F*-type star should then rather correspond with the moments when the colours are equal to those outside the eclipse, then with a visual light decrease by a factor two. Thus the short vertical lines in Figs. 2a and b should then lie closer to $\Phi_b = 0.0$, say at $\Phi_b = \pm 0.015$ instead of ± 0.024. However, the solution is not that easy, since at the moments that the in – and outside eclips colours of the different colour curves are equal do not always coincide in time. Besides sometimes the inside eclipse colours stay redder than the outside eclipse ones, all the way from in – to egress (Fig. 2b in Paper I).

The asymmetry, which is presumably partly caused by absorbing gaseous matter in the system, (Paper I), is most obvious in *b–y* and *v–b* (and in *V–B* and *B–L*, Paper I) and practically absent in *u–v*. Apparently the absorption by the gas at both sides of the Balmer limit (which lies between *v* and *u*) was of the same intensity, resulting into and *u–v* index at egress not much different from that at ingress.

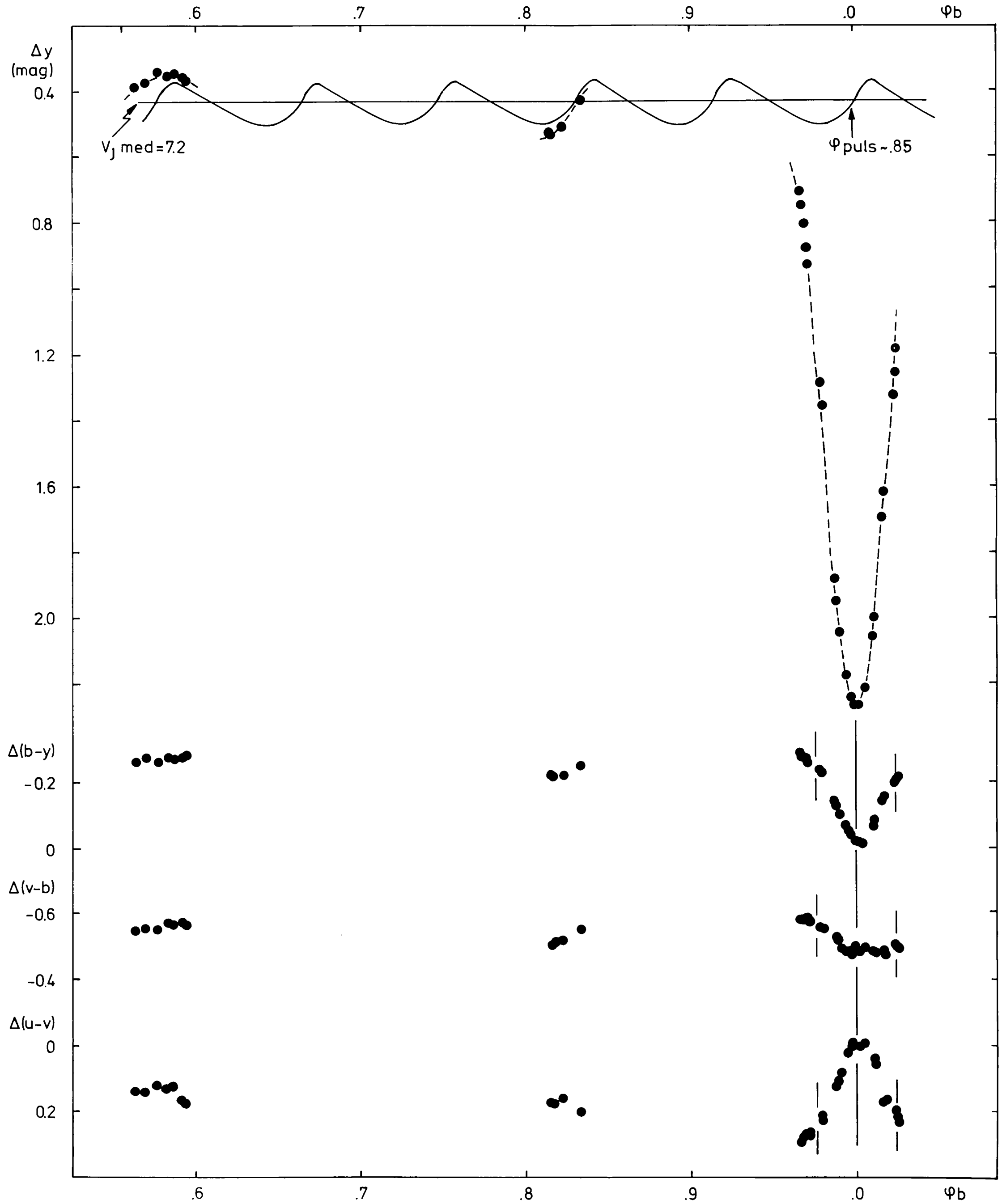

Fig. 2a. The 1983 eclipse in the *uvby* system of Strömgren (relative to the comparison star and in magnitude scale). The short vertical lines in the colour curves roughly indicate the times that half of the *F*-type star should be eclipsed. A number of cycles of the light curve of the *F*-type star is schematically indicated at the top and fitted to the outside eclipse observations

Table 4 lists the *uvby* photometric data of a few characteristic moments of BL Tel.

In Paper I it is shown that the pulsation of the *F*-type star between 1962–1968 is reasonable periodic, but that later cycles do not fit the ephemeris for the maximum as expressed in Eq. (2). This non-strict periodicity is a characteristic of all the supergiants and also of the UU Her type stars (Sasselov, 1983; Fernie, 1985). Indeed the two maxima of 1982/1983 of Fig. 2 do not fit that formula either, yet the distance between both sets of outside eclipse magnitudes is three cycles of $\sim 65^d$. In order to illustrate this we show in Fig. 2a schematically the light curve of the *F*-type star (Paper I) and fitted it as well as possible on the two sets. The result does not contradict the period of $\sim 65^d$. The median value $V_J = 7.2$ is taken from Paper I. If we speculate that the cycles can be extrapolated up to mid-eclipse, then mid-eclipse coincide with $\Phi_{puls} \sim 0.85$. In Paper I we paid attention to the amazing fact that a

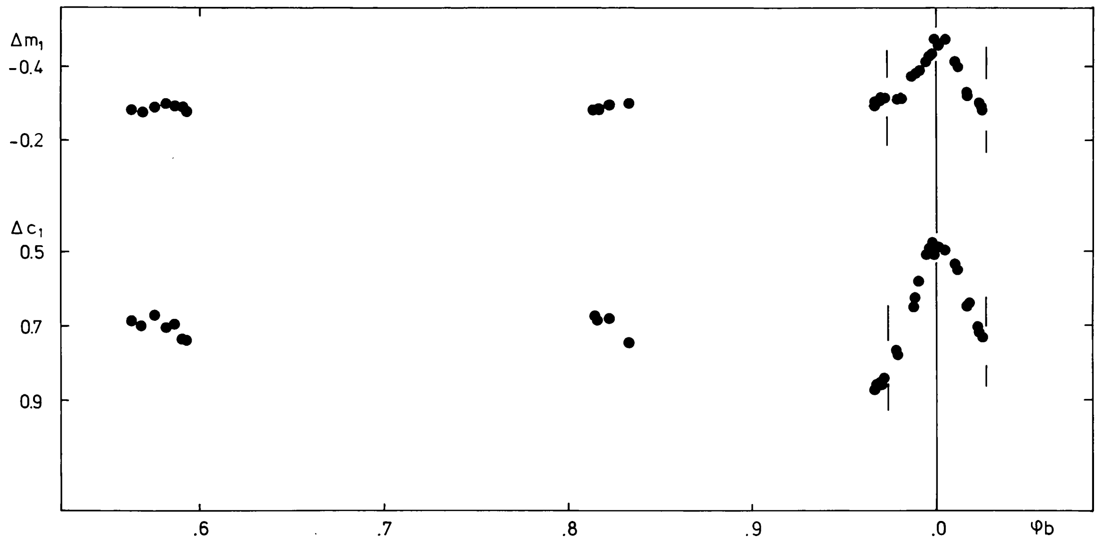

Fig. 2b. The same as Fig. 2a, but now for the colour indices m_1 an c_1.

Table 3. Photoelectrically observed epochs of primary minima of BL Tel

J.D.-2400000	Year	E	Ref.
34692.6	1953	−6	Cousins and Feast (1954)
39363.0	1966	0	Paper I
40141.5:	1968	1	Paper I
43258.5:	1977	5	Paper I
45589.0	1983	8	This paper

few of the observed mid-eclipse times seemed to coincide with roughly the same phase of the pulsation: $\Phi_{\text{puls}} \sim 0.7-0.8$. Thus there could be a kind of modulation with the binary period, since the excentricity is large. Mid-eclipse is by accident almost the position of periastron (Feast, 1967) and the length of the orbital revolution is practically an integer number (12) times the pulsation period.

The use of such an extrapolation is to correct the minimum for the variations of the *F*-star as has been done in Paper I (one would rather like to have well observed cycles just before the start and after the end of the eclipse). Since our extrapolation extends more than two cycles, one must be very cautious. Nevertheless the suggestive, but very speculative coincidence of mid-eclipse with $\Phi_{\text{puls}} \sim 0.85$, which is close to the phases during the other mid-eclipses, strengthens our conviction that more well covered eclipses of BL Tel are highly needed. Next observable eclipses will take place in March 1992, May 1994 and the most favourable one for an ample coverage of the months before in – and after egress will take place not earlier than June 1996.

5. The metallicity and the gravity of BL Tel (*F*)

Physical parameters of BL Tel (*F*), like temperature and gravity have been deduced from the *VBLUW* photometry (van Genderen, 1980). The same is done now for the *uvby* photometry. Fernie (1985) discussed recent photometry in the *uvby* system of three other UU Her type stars, viz. UU Her, 89 Her and HD 161796. In a reddening free $m_1/b-y$ diagram he found that all three stars have

Table 4. Photometric parameters of BL Tel in the *uvby* photometric system (in mag scale). Bracketed values are dereddened for $E(B-V)_J = 0.12$

	y	$b-y$	m_1	c_1
Median values outside eclipse	7.20 (6.83)	0.37 (0.28)	0.15 (0.17)	1.10 (1.08)
Bluest moment during in-or egress		0.35: (0.26:)		
Reddest moments during in-or egress			0.12: (0.14:)	1.26: (1.24:)
Mid-eclipse values	9.05 (8.68)	0.61 (0.52)	−0.04 (−0.02)	0.89 (0.87)

nearly solar metallicities, despite their large distances to the galactic plane. The same appears to be the case for BL Tel (F), if we adopt $E(B-V)_J = 0.12$ (van Genderen et al., 1974) or $E(b-y) = 0.09$. The reddening corrected photometric parameters are bracketed in Table 4. In a reddening free $c_1/b-y$ diagram Fernie found that the gravities for the three stars mentioned above turned out to be Cepheid-like or lower. For BL Tel (F) we find that $\log g$ should lie between 1 and 2, similar to the results of the *VBLUW* photometry, thus also Cepheid-like.

At mid-eclipse, when only a small crescent of BL Tel (F) is visible, the colours simulate a very low metal abundance and gravity, but how to interprete them in terms of real physical parameters of the star's rim is unknown.

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