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# The field high-amplitude SX Phe variable BL Cam: results from a multisite photometric campaign*

## II. Evidence of a binary – possibly triple – system

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**ABSTRACT**

*Context.* Short-period high-amplitude pulsating stars of Population I ($\delta$ Sct stars) and II (SX Phe variables) exist in the lower part of the classical (Cepheid) instability strip. Most of them have very simple pulsational behaviours, only one or two radial modes being excited. Nevertheless, BL Cam is a unique object among them, being an extreme metal-deficient field high-amplitude SX Phe variable with a large number of frequencies. Based on a frequency analysis, a pulsational interpretation was previously given.

*Aims.* We attempt to interpret the long-term behaviour of the residuals that were not taken into account in the previous Observed-Calculated (O–C) short-term analyses.

*Methods.* An investigation of the O–C times has been carried out, using a data set based on the previous published times of light maxima, largely enriched by those obtained during an intensive multisite photometric campaign of BL Cam lasting several months.

*Results.* In addition to a positive $(161 \pm 3) \times 10^{-9}$ yr$^{-1}$ secular relative increase in the main pulsation period of BL Cam, we detected in the O–C data short- (144.2 d) and long-term (~3400 d) variations, both incompatible with a scenario of stellar evolution.

*Conclusions.* Interpreted as a light travel-time effect, the short-term O–C variation is indicative of a massive stellar component (0.46 to 1 $M_\odot$) with a short period orbit (144.2 d), within a distance of 0.7 AU from the primary. More observations are needed to confirm the long-term O–C variations: if they were also to be caused by a light travel-time effect, they could be interpreted in terms of a third component, in this case probably a brown dwarf star ($\geq$0.03 $M_\odot$), orbiting in ~3400 d at a distance of 4.5 AU from the primary.

**Key words.** stars: variables: $\delta$ Scuti – stars: individual: BL Camelopardalis – stars: oscillations – binaries: general – techniques: photometric

## 1. Introduction

SX Phe-type stars of the Galactic field are high-amplitude Population II pulsators located in the lower part of the classical (Cepheid) instability strip, close to the main sequence, among the high-amplitude Population I $\delta$ Scuti variables (e.g., Nemec & Mateo 1990; Breger 2000; Rodríguez 2003). Only a few (14) field SX Phe-type stars have been found to date. However, more than one hundred SX Phe variables have been discovered among the blue straggler population of globular clusters, and in nearby dwarf galaxies (e.g., Rodríguez & López-González 2000; Jeon et al. 2003, 2004; Mazur et al. 2003).

Multiperiodicity with more than two independent modes is not a common feature among the high-amplitude pulsators of the low instability strip. However, BL Cam (= GD 428, $\alpha_{2000}$ = 3h47m19s, $\delta_{2000}$ = +63°22′07″, $\langle V \rangle \sim 13.1$ mag, $\Delta V$ = 0.33 mag) is one of these very few exceptions. In addition to its main pulsation frequency $f_0$ = 25.5769 cycles per day (d$^{-1}$), the multiperiodicity of this extreme metal-deficient ([Fe/H] = −2.4 dex; McNamara 1997) field SX Phe-type star has been claimed by different authors (cf. Fauvaud et al. 2006, for a review, hereafter F06). Analysis of the main period temporal changes of BL Cam has also revealed a secular increase in its main period and the possibility that this star is a member of a detached binary system (F06).

Since BL Cam is a very attractive target for observational asteroseismology, we initiated the first multisite photometric campaign for this object to investigate in detail its pulsational behaviour. The results of a frequency analysis (Rodríguez et al. 2007, hereafter R07) has largely allowed the reduction of the daily alias and provided the true value of the first overtone frequency (32.6 d$^{-1}$). R07 confirmed the existence of a very dense pulsational frequency spectrum in this star, in addition to the already known high-amplitude main periodicity.

In this paper, we present a new analysis of the main period variation of BL Cam by means of the Observed-Calculated (O–C) diagram of the O–C times. From a general point of view,

* Table 2 is only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/515/A39

**Table 1.** Journal of observations carried out from October 2007 to February 2009.

| Observatory | Location | Telescope(m) | Filters | Nights | Hours |
|---|---|---|---|---|---|
| SPM | San Pedro Mártir (México) | 0.84 | *Vby* | 22 | 97.8[a] |
| Cal | Carona (Switzerland) | 0.14/0.30 | no | 14 | 81.1 |
| PiM | Pic du Midi (France) | 0.60 | *V* | 6 | 34.9 |
| O3k | Treize-Septiers (France) | 0.20 | no | 6 | 19.5[b] |
| Ond | Ondrejov (Czech Republic) | 0.65 | *R* | 6 | 14.9 |
| Gil | Gilman (USA) | 0.30 | *V* | 2 | 4.8 |
| Mar | Blacksburg (USA) | 0.35 | *V* | 2 | 4.4 |
| Gras | Mayhill (USA) | 0.30 | *R* | 1 | 2.2 |
| Ves | Vesqueville (Belgium) | 0.20 | V | 1 | 1.9 |

**Notes.** Observatory code: Cal = Calina Observatory; Gil = Gilman Observatory; Gras = Global Rent-a-Scope Observatory; Mar = Martin Observatory; O3k = Observatoire des trois korrigans; Ond = Ondrejov Observatory; PiM = Observatoire du Pic du Midi; SPM = San Pedro Mártir Observatory; Ves = Vesqueville Observatory. [(a)] Strömgren *b* and *y* filters were used during one night. [(b)] *V* filter was using during 2 h.

the O–C method (see, e.g., Sterken 2005) allows us to assess the consistency between the measurement of an observable phenomenon and its prediction, and the possible importance of the light travel-time (LTT) effect in the O–C diagram. A historical example of this method is the discovery made by Olaüs Römer, in 1676, of the finite velocity of light, obtained observing the eclipse phenomena of Jupiter's Io satellite (Débarbat 1978; Sterken 2005). The variable LTT effect, caused by the different positions of the Earth on its orbit, makes it necessary to convert Julian dates into Heliocentric Julian dates. In variable star studies, the analysis of the O–C diagram is a widely used tool.

The paper is organized as follows. The observations and data reduction are presented in Sect. 2. A new ephemeris and a description of the O–C diagram are given in Sect. 3. An interpretation of the O–C values is proposed in Sects. 4, and 5 is devoted to a discussion. A conclusion and perspectives are given in Sect. 6.

## 2. Observations and data reduction

Our multisite photometric campaign was performed between August 2005 and February 2009, from 24 professional and amateur observatories located in Europe and North America. The participating sites from August 2005 to March 2007, their instrumentation and the methods of data reduction, including the selescted comparison stars, were described in R07.

From October 2007 to February 2009, new photometric observations of BL Cam were carried out mainly from Observatorio Astronómico Nacional San Pedro Mártir (Baja California, México), Calina Observatory (Switzerland), and Observatoire du Pic du Midi (France). Some other data were collected at stations located in Belgium, Czech Republic, France, and USA. Table 1 presents a summary of the observations with the list of the observatories. All data were obtained with CCD cameras using various filters, including some observations without any filter.

The times of the observed light maximum were determined by fitting each peak of the light curves by a third or a fifth degree polynomial, using the software package Peranso (Vanmunster 2008). We estimate the standard deviation ($1\sigma$) in an individual maximum to be between ~0.0003 and 0.0006 d (~26 and 52 s). Comparing the maximum times sets obtained by different observers during simultaneous runs indicates, however, a scatter of between ~0.0001 and 0.002 d (~10 and 200 s), yielding a typical $1\sigma$ uncertainty of ~0.0008 d (i.e., ~70 s).

A total of 930 new times of light maximum, listed in Table 2, were recorded during our runs. Table 2 also includes 9 maximum times based on measurements from the AAVSO database, and 20 maxima that we estimated from light curves of Martin (1996, 2001). Our new analysis of the O–C residuals for the main period of BL Cam is based on a data set consisting of 1510 times of light maximum, constituted by those used in F06 (with the 61 unpublished maxima from Delaney et al. 2000), including the light maxima of Table 2, and an additional 2 and 73 maxima published in Klingenberg et al. (2006) and Fu et al. (2008), respectively. Our complete data set spans from December 1976 to February 2009, i.e., more than 30 years.

Even though not explicitly mentioned, the light maximum times published in previous papers are commonly assumed to be in coordinated universal time (UTC). However, the fluctuations of the Earth's rotation rate (e.g., Souchay 2007; McCarthy & Seidelmann 2009) affect UTC, which runs with irregular jumps of a full second. Over the past 30 years, the deviation of UTC from a fixed frame of time reference has increased in steps of 1 s, making it roughly an average of 1 s yr$^{-1}$. The consequences become significant for LTT effects when a time baseline longer than a few years is considered, and when the amplitude of the effect is small (Ribas 2005). In addition, the secular decrease rate of the Earth's spin induces a slow decrease in the variation in the pulsation period of a star (Bastian 2000). To avoid these problems, we converted all UTC timings into barycentric dynamical time (TDB), using the expressions of Seidelmann & Fukushima (1992) and corrections provided by Berthier (2009 private communication). Thus, TDB-UTC varies from +47.184 s in 1976 to +66.184 s in 2009.

Table 2 gives both the calculated $HJD_{\rm max}$ and $BJD_{\rm max}$ times of light maximum, expressed in Heliocentric Julian Days (HJD in the UTC scale) and Barycentric Julian Days (BJD, i.e. HJD in the TDB scale), respectively. However, our analysis of the O–C diagram was performed using $BJD_{\rm max}$.

## 3. The O-C diagram

A weight ($\frac{1}{\sigma^2}$) was assigned to each time of maximum for the data set described in Sect. 2. When no uncertainty was published, a median uncertainty $\sigma$ = 0.0005 d was adopted (F06). Hereafter, $E$ is the cycle number elapsed since the initial epoch of the ephemeris (i.e., JD ~ 2443125.8).

We first checked and revised the linear ephemeris of Zhou et al. (1999, Eq. (2)). The best-fit least squares regression to the entire weighted light maxima data set gives the new linear ephemeris

$$BJD_{\rm max} = BJD\ 2443125.80068(4) + 0.0390978897(2)E \qquad (1)$$

which has a standard deviation of $\sigma$ = 0.0025 d (the uncertainty in the last digit is indicated in parentheses).

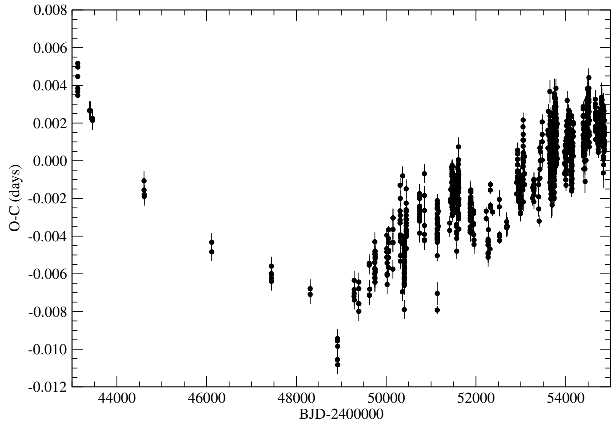

**Fig. 1.** O–C diagram for BL Cam using the new linear ephemeris (Eq. (1)).

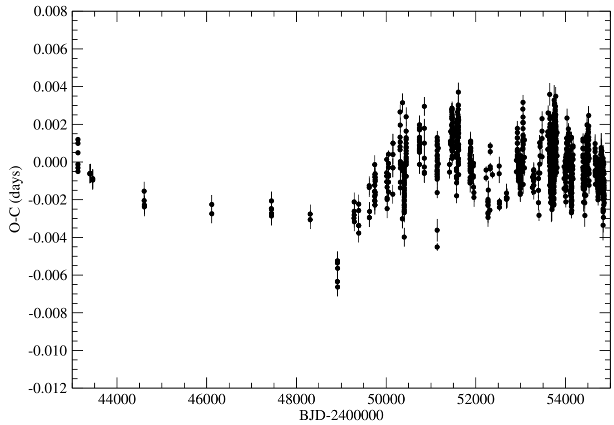

**Fig. 2.** O–C diagram for BL Cam using the new quadratic ephemeris (Eq. (2)).

Despite the revision of Zhou et al.'s linear ephemeris, a parabolic trend remains in the O–C diagram (Fig. 1), and the period and initial epoch do not match the light maxima. The parabolic shape indicates that the main period of BL Cam slowly increased with time, which can be represented by a second-order polynomial. The best-fit relation of the data yields the new, more accurate, quadratic ephemeris

$$BJD_{\max} = BJD\,2443125.80466(6) + 0.0390977846(6)E + 3.367(15)\times 10^{-13}E^2 \quad (2)$$

The standard deviation is $\sigma = 0.0013$ d (Fig. 2). The squared term implies a secular increase rate $\mathrm{d}P/(P\mathrm{d}t) = (4.41 \pm 0.06)\times 10^{-10}\,\mathrm{d}^{-1} = (161 \pm 3)\times 10^{-9}\,\mathrm{yr}^{-1}$ of the main pulsation period $P$ of BL Cam with time $t$, i.e., a period increase of about 1 s per 1800 yr.

If we remove the parabolic shape, significant residuals remain in the O–C values (Fig. 2), which have a long periodic modulation, of a timescale of several years. These residuals have already been reported and interpreted as a LTT effect (with a semi-amplitude of 148 ± 12 s and a period of 10.5 ± 0.2 yr, according to F06), i.e., a cyclic light timing signal as received by a terrestrial observer, due to the wobble of the main star's barycentre induced by a companion.

If we focus on the period between August 2005 and February 2009, these new intensive observational run data indicate that a short-term (~0.4 yr) periodic O–C shift also appears. A careful inspection of the O–C diagram shows that this behaviour was present in the past. No single observation conflicts with this observed O–C oscillation. Indeed, this short-term variation is:

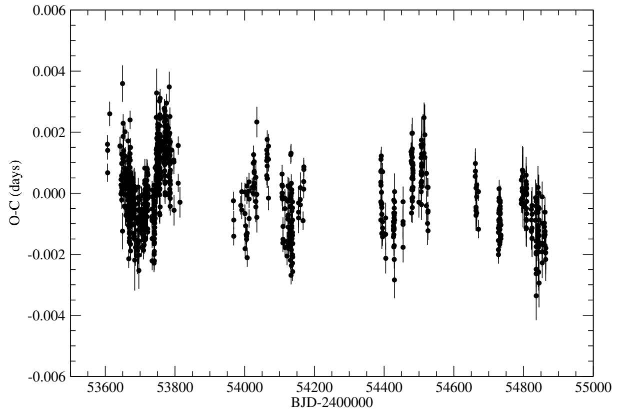

**Fig. 3.** Detail of Fig. 2 (August 2005 to February 2009), showing a periodic short-term variation.

- obvious during our multisite campaign (Fig. 3), i.e., between August 2005 and February 2009 (JD 2453606 to 2454863);
- probable between September 2003 and March 2004 (JD 2452906 to 2453085);
- very possible between August 1999 and March 2000 (JD 2451415 to 2451620), and from August 1996 to January 1997 (JD 2450310 to 2450450).

These long- and short-term modulations – and their large amplitude residuals – are compatible with neither stellar evolution on a secular timescale nor the timescale of the pulsations (~1 h). As period changes in pulsating variable stars are related to the mean density variation of a star during its evolution (Eddington 1918), this basic interpretation is insufficient to explain the observations in numerous cases (e.g, Handler 2000). For the SX Phe variables, the discrepancy between the theoretical period changes and the observed rates shows that non-evolutionary or non-linear processes must be invoked (e.g., Rodríguez 2003, for a review). On the one hand, several physical processes have been suggested to explain the observed non-evolutionary period changes, for example stellar companions, and non-linear effects in pulsation caused by stellar rotation or resonant coupling frequencies (e.g., Breger & Pamyatnykh 1998; Szeidl 2005; Templeton 2005). On the other hand, according to a study of Percy et al. (2007) of three SX Phe-type stars, the contribution of random cycle-to-cycle period fluctuations seems insufficient to explain the non-parabolic shape of the O–C diagram.

While the parabolic main trend of the O–C diagram of BL Cam is likely a consequence of a period increase due to secular evolution, the time constants (~10 and 0.4 yr) involved in the long- and short-term oscillations point at non-evolutionary processes. Although adjustments in the internal structure of the star cannot be completely ruled out to generate abrupt period changes (see F06), our simple interpretation that we propose here is that two bodies orbit BL Cam, producing LTT effects in its O–C diagram.

## 4. BL Cam as a binary system, and the possible existence of a third body

A Fourier analysis of the O–C values, obtained from Eq. (2), was carried out with the Period04 software developed by Lenz & Breger (2005). The long-term modulation was investigated, as

**Table 3.** Orbital solutions for the companion BL Cam B.

| | BL Cam B |
|---|---|
| LTT semi-amplitude (s) | 96.6 ± 0.5 |
| Eccentricity | 0.19 ± 0.01 |
| Argument of periastron (°) | 87.5 ± 2.9 |
| Orbital period (d) | 144.19 ± 0.02 |
| Periastron passage (BJD) | 2454119 ± 3.831 |

well as the short one in the JD ranges described in Sect. 3, with a 0.01 $d^{-1}$ frequency step. Two periods were found, ~7 yr and ~144 d, with semi-amplitudes ~52 s and ~105 s, respectively. However, the oldest data (JD < 2 449 000) are sparse or might have large uncertainties. Therefore, our Fourier analysis focused on the data obtained after JD 2 449 000, which infers periods of ~8.6 yr and 144.18 d, with respective semi-amplitudes ~82 s and 102.6 s.

A three-body model fit of the O–C diagram was then performed on the highest quality O–C data (JD > 2 449 000). Historically, such a triple system was first suggested by Chandler (1892) for Algol, precisely based on the assumption of LTT effects.

The basic equations describing the LTT effect of a binary system as a function of the orbital motion were first proposed by Irwin (1952). The formalism used in this study was described in Ribas et al. (2002); these authors developed a model that takes into account all the binary parameters such as semi-amplitude, eccentricity, argument of periastron, orbital period, and time of passage at periastron.

Since our LTT effect computing program can only deal with one orbit at a time, we used an iterative process where we first introduced the short orbital period. The fitting of the data started with the period and semi-amplitude obtained from the Fourier analysis. The short period orbit was first considered to be circular, and when all the other parameters are settled, the computation of the eccentricity was carried out.

In the case of the long period orbit, the residuals in the short period LTT effect were first computed, and we then started a new computation, based on the values derived from the previous Fourier analysis. We then searched for solutions of fixed eccentricity by scanning different values (leaving all other parameters free). An independent attempt to fit the data, leaving all parameters free, was unsuccessful.

Table 3 presents the final results of the best fit obtained for the LTT effect caused by the short orbit, when considering JD > 2 449 000 data. The standard deviation of the fit is 78.8 s. The 144.19 ± 0.02 d periodicity is found for BL Cam B, assuming a mass of 0.99 $M_{\odot}$ for BL Cam A (McNamara 1997). Figure 4 shows the phase-folded fit corresponding to this short period.

If it were caused a third object, a LTT effect analysis would infer a long orbit consistent with a rather high eccentricity (>0.6), a ~9.3 yr period, and a semi-amplitude around 60 s (this last value being especially sensitive to the eccentricity). An eccentricity of 0.7 yields a 3390 ± 26 d period (i.e. 9.28 ± 0.07 yr, with a 65.6 ± 1.2 s semi-amplitude). Although a long oscillation is clearly visible in the O–C diagram and is unlikely to be spurious, the data cover only about two cycles, meaning that this LTT model (Fig. 5) has a weaker significance compared to the short 144 d orbit already found.

These large O–C variations could also be accounted for by successive abrupt period changes (i.e., straight segments in the O–C diagram, instead of a stable periodic variation). As mentioned before, our actual phase coverage is insufficient to establish an unambiguous interpretation. In the case of a third (BL Cam C) object, its derived orbital properties strongly depend on the long-term correction of the O–C trends (either linear or quadratic). Thus this possibility has to be confirmed by future continuous monitoring of the star. In the following steps of this study, we decided not to rule out the hypothesis of a second companion, even if only suspected.

Since we do not observe any eclipse in our photometric observations of BL Cam, the inclination of the system cannot be precisely determined. However, the Kepler's third law can be used to estimate the minimum masses and minimum semi-major axes of the two companions BL Cam B and BL Cam C, BL Cam A being the primary and SX Phe variable star of the system (e.g., Hilditch 2001). Indeed, assuming a mass of 0.99 $M_{\odot}$ for BL Cam A, BL Cam B should have a mass $m_B \geq 0.46\ M_{\odot}$ and its orbit a semi-major axis $a_B \geq 0.6$ AU; BL Cam C should be less massive than BL Cam B, with a mass $m_C \geq 0.030\ M_{\odot}$ (i.e. $m_C \geq 31.5\ M_{\mathrm{Jupiter}}$) and a semi-major axis $a_C \geq 4.4$ AU (Table 4).

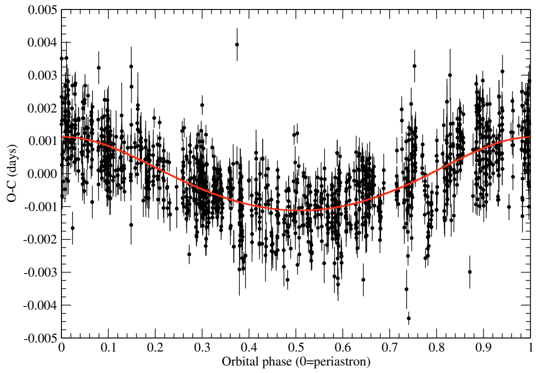


**Fig. 4.** O–C diagram for BL Cam phased against the short orbital period (144.19 ± 0.02 d), according to the best-fit LTT model (Table 3).

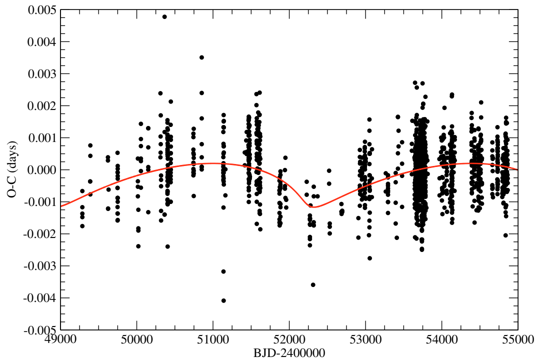


**Fig. 5.** O–C diagram for BL Cam phased against the long orbital period (3390 ± 26 d) fitting, according to the best-fit LTT model.

**Table 4.** Predicted properties of the two companions of BL Cam A.

| BL Cam B | | | BL Cam C | | |
|---|---|---|---|---|---|
| $m_B$ ($M_{\odot}$) | $i_B$ (°) | $a_B$ (AU) | $m_C$ ($M_{\odot}$) | $i_C$ (°) | $a_C$ (AU) |
| 0.99 | 35.0 | 0.68 | 0.99 | 2.7 | 5.5 |
| 0.50 | 69.8 | 0.62 | 0.50 | 4.4 | 5.0 |
| 0.46 | 90 | 0.61 | 0.08 | 22.9 | 4.5 |
| | | | 0.03 | 90 | 4.4 |

## 5. Discussion

### 5.1. Frequency of the main pulsation and its variation

The main frequency pulsation of BL Cam published in R07 ($f_0 = 25.57647$ d$^{-1}$) was obtained from the Fourier analysis of only a small part of the time series available for the whole 2005-6 campaign. They considered fewer than 47% of the total observing hours, fewer than 31% of the total number of nights, and fewer than 24% of the total time span of the campaign (128 d over its total 540 d duration). Their $f_0 = 25.57647$ d$^{-1}$ value (a period of 0.0390984370 d) was significantly shorter than the one calculated in this work, this time dealing with all available times of light maxima. We obtain here $f_0 = 25.57690$ d$^{-1}$ (a period of 0.0390977846 d, cf. our Eq. (2)). This value is identical to that determined previously (with a smaller amount of data but with a rather wide time base) in F06. The difference between the two published values (here and in F06, versus R07) is quite large, amounting to 0.00043 d$^{-1}$, i.e., 1 cycle per 6.37 yr.

The increasing rate of change in the main pulsation period of BL Cam estimated in Sect. 3 is based on a parabolic fit to the O–C diagram. Even if the existence of period jumps in the O–C diagram cannot be ruled out a priori (F06), the large and positive rate of period change found here, i.e., $\frac{dP}{Pdt} = (4.41 \pm 0.06) \times 10^{-10}$ d$^{-1}$ $= (161 \pm 3) \times 10^{-9}$ yr$^{-1}$ is much larger than those predicted by the evolutionary tracks of SX Phe pulsators (Rodríguez 2003).

### 5.2. Predicted properties of the companions of BL Cam A

The masses of the two companions of BL Cam A estimated in Sect. 4 are the minimum values derived from a Keplerian orbit. Of course, these calculations of the masses depend strongly on the system inclination.

For a triple system and an eccentricity of 0.7 for BL Cam C orbit, Table 4 shows that the possible mass range of BL Cam B, between 0.46 and 0.99 $M_\odot$, corresponds to inclinations of between 90 and 35°, and semi-major axes between 0.61 and 0.68 AU. Hence BL Cam B could be either a white or a red dwarf, i.e., in the case of a red dwarf, a M-type star that would be 4–5 mag fainter than BL Cam A in the $V$-band. Although this rather massive companion is in the vicinity of BL Cam A, a Roche lobe geometry approximation (e.g., Warner 1995; Hameury 2007) shows that the two bodies should be a detached binary system.

In the case of a synchronized orbit – for which the orbital period (144.2 d) is equal to the rotational period of the star –, we can obtain a minimal value of the equatorial rotational velocity of BL Cam A. With a 1.16 $R_\odot$ radius (McNamara 1997), we obtain 0.4 km s$^{-1}$. This estimation is much lower than the uncertain upper limit $v \sin i \leq 18$ km s$^{-1}$ (where $\upsilon$ is equatorial rotation velocity, and $i$ is inclination angle of a spin axis to our line of sight) given by McNamara (1985) from spectroscopic data. Both values yield a low rotational velocity for BL Cam A.

In the same way, Table 4 shows that the suspected component BL Cam C could be either a brown dwarf (of mass between 0.03 and 0.08 $M_\odot$ for an inclination of between 90 and 23°), a low-mass red star (of mass between 0.08 and 0.5 $M_\odot$ for an inclination of between 23 and 4°), or even a more massive star i.e., a white dwarf (of mass between 0.5 and 1 $M_\odot$ for an inclination of between 4 and 2.5°). In these three cases, the semi-major axis should be, respectively, about 4.5, 4.5 to 5.0, and 5.0 to 5.5 AU. A random distribution of orbital inclinations yields a higher 0.92 probability of a brown dwarf, and a lower 0.077 probability of a low mass red star, while a more massive companion seems very unlikely (probability 0.0015).

If BL Cam C were a brown dwarf, it should be located in the "brown dwarf desert", given its 4.5 AU separation from BL Cam A. This "brown dwarf desert" is not yet a well understood region, in which brown dwarf companions located within a few astronomical units of their host stars are not detected (e.g., Grether & Lineweaver 2006; Kürster et al. 2008, and references therein).

### 5.3. Hypothesis about the formation of the BL Cam system

It is impossible to know whether the system formed as a multiple (binary or triple) system, or its companions have been driven around BL Cam A by a capture mechanism. In the case of a third component (BL Cam C), its probable low mass, long period, and possible high eccentricity favours a capture process (e.g., Halbwachs 2007). As stellar collisions are very uncommon in the halo field (e.g., Preston & Sneden 2000), the system might have formed together by means of the fragmentation of a collapsing cloud or disk, about 5.4 Gyr ago (McNamara 1997). This scenario would be in agreement with: (i) the low eccentricity (0.19 ± 0.01, cf. Table 3) of BL Cam B, possibly resulting from the tidal circularization of its orbit (Claret & Cunha 1997); (ii) the respective closer (<0.68 AU) and larger (>~4.5 AU) distances of BL Cam B and BL Cam C from the main star. In the case of a triple system, this scenario is consistent with a stable three-body system configuration over a Gyr timescale (e.g., Harrington 1968; Szebehely & Zare 1977; Quirrenbach 2006).

Assuming a simultaneous formation of the components of the BL Cam system, one can argue that the orbits of BL Cam B and BL Cam C should be coplanar – even though the actual observations infer these preferential values for the inclination (cf. Tokovinin 2008). In this case, the possible inclination of BL Cam C would be restricted to the range of inclinations permitted for BL Cam B, i.e., from 35 to 90°. In this case, the range of possible BL Cam C masses is from 0.030 to 0.053 $M_\odot$ (i.e., 32 to 56 $M_{\rm Jupiter}$).

### 5.4. Multiplicity among the field SX Phe stars and eventual connection of BL Cam with the blue straggler objects

Since many SX Phe-type stars have been discovered among the blue stragglers of globular clusters, the possible connection between these two populations has been analysed by several authors (e.g., Nemec & Mateo 1990).

The blue stragglers (Sandage 1953) have been found in the halo of the Milky Way, in globular and open clusters, and in dwarf galaxies. Their formation and evolutionary status remains unclear. To explain the increase in the lifetime of these main sequence stars, several hypotheses have been proposed: the most probable is that the blue stragglers are interacting binaries, produced by direct stellar collisions or binary evolution (see, e.g., reviews by Livio 1993; and Stryker 1993), but they could also be the product of primordial hierarchical triple stars (Perets & Fabrycky 2009; see also the results of Ferraro et al. 2009; and Mathieu & Geller 2009).

Over the past two decades, large photometric and radial velocity surveys of metal-poor blue stars (i.e., halo field blue stragglers, following Jorissen & Frankowski 2008) have been carried out, mainly by Preston & Sneden (2000, and references therein) and Carney et al. (2005, and references therein). They have led to the discovery of three new SX Phe-type stars. Until now, fourteen field SX Phe-type stars have been identified (thirteen in Table 1 of Rodríguez 2003, and CS 22871-040 mentioned in Preston & Sneden 2000). Three of these field SX Phe are binary or multiple stars: KZ Hya, CS 22966-043, and now BL Cam. Both CS 29499-057 and CY Aqr are possible binaries, although this requires confirmation (for more details, see Liu et al. 1991; McNamara 1997; Preston & Sneden 2000; Fu & Sterken 2003; Rodríguez 2003; Fu et al. 2008). This reduced sample cannot provide robust statistics in our analysis, but it raises a question about the connection between the SX Phe stars and the blue straggler objects as interacting binaries. The orbital periods are typically some hundreds of days, and the three multiple known systems have low eccentricities. According to Preston & Sneden (2000), these characteristics are consistent with a mass transfer model.

One may speculate about the observational difference for field stars between a Population II star (low metallicity, evolved) and a more recent binary system where the main component has been cannibalized by its companion, leading to eventual metallic depletion. On the one hand, BL Cam has the low metallicity of all field SX Phe variables, and the multiplicity expected of blue stragglers in the more usual hypotheses, but, being a field star, no conclusion can be reach about its age and evolution.

## 6. Conclusion and future prospects

From 2005 to 2009, an intensive photometric campaign has been dedicated to the SX Phe-type star BL Cam. This campaign has allowed a large amount of observations to be gathered by amateurs and professionals from Europe and North-America. This multisite campaign has led to a new pulsation analysis of BL Cam. An analysis of the O–C diagram has been performed to investigate the main pulsation period of the star. A short period ($144.19 \pm 0.02$ d) has been detected in the O–C variations, as well as a possible long-term periodic ($3390 \pm 26$ d) variation. We therefore invoked a light travel-time effect to interpret the short-term variation, and proposed the presence of a rather massive stellar companion (from $\sim$0.5 to 1 $M_{\odot}$), closer than $\sim$0.7 AU to BL Cam, with a short period orbit (144.2 d). In addition, about two long cycles of quasi-periodic fluctuations have been observed over a period of about two decades. This long timescale O–C modulation could also be interpreted as a light travel-time effect, which is indicative of an additional object orbiting BL Cam. If real, it should be a low mass object ($\geq$0.03 $M_{\odot}$), very probably a brown dwarf, orbiting in $\sim$9.3 yr within a $\sim$4.5 AU distance.

The analysis of the O–C diagram has also allowed us to measure a positive secular increase in the main period at the rate $(4.41 \pm 0.06) \times 10^{-10}$ d$^{-1}$ = $(161 \pm 3) \times 10^{-9}$ yr$^{-1}$. A continuous photometric monitoring is essential for obtaining a superior knowledge of the oscillations and behaviour of the main pulsation period of BL Cam, and confirming the three-body system hypothesis.

BL Cam is quite distant ($\sim$1000 pc; McNamara 1997), and its companion(s) are too faint and too closely orbiting to be observed by direct imaging techniques. The spectrum of BL Cam has only a few lines – mostly of hydrogen (McNamara & Feltz 1978; Alvarez & Fox-Machado, private comm). From the above orbital parameters, we can infer that the radial velocity curve should have a semi-amplitude of $\sim$15 km s$^{-1}$. This could be within the reach of modern spectrographs, provided we achieve a high enough signal-to-noise ratio to unambiguously detect and identify lines.

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