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Var C: (Semi-)Periodic Long-Term Variability*†

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Abstract: Luminous Blue Variables (LBVs) are characterised by irregular photometric and spectral variabilities. So far the underlying mechanism for these variations is not known. It is neither known under which circumstances massive stars become LBVs, nor what triggers the instabilities causing the variabilities, and if all massive stars in a certain mass range evolve into LBVs or not.

To find out more about the nature of the variabilities of LBVs, we investigated the long-term photometric and spectroscopic behaviour. One aspect of our analysis was the check for periodicity in the variations. Periodicity on smaller timescales in the order of approximately a few years is already known to occur in LBVs (van Genderen 2001). Detecting possible periodicity on larger scales (in the order of decades) was always difficult since most of the light curves do not reach back far enough and/or are much to fragmentary.

Combining historical and new data, we produced a light curve of significant length to perform a systematic search for long-term periodicity. We assume to have found long-term (semi-)periodicity of approximately 40 years being present in Var C. Seeing more than two full cycles gave us the possibility to make a prediction for the next maximum (2027±2).

1 Introduction

The LBV phase is a short (it only takes time in the order of 10^4 years) phase in the lifetime of evolved massive stars. LBVs belong to the most luminous (10^6 $L_\odot$) stars in the Universe.

As the name already indicates, LBVs are characterised by irregular photometric and spectral variabilities. These variations occur on quite different time scales, which range from months up to years or even decades, and with different amplitudes, ranging from some tenth of magnitudes up to >2 mag (Humphreys & Davidson 1994). Different kinds of variabilities can also be superimposed. The photometric variability intrinsic to LBVs, the so called S Dor variability, occurs on time scales of about 10-40 years and with amplitudes of 1-2 mag and can be subdivided into long (>20 years, L-SD) and short (<10 years, S-SD) S Dor variability (van Genderen 2001).

The photometric S Dor variabilities are caused by spectral variations. During phases of minimum visual light in this S Dor cycle LBVs show spectra of hot supergiants with H, He, Fe II and [Fe II] lines in emission, which often also show P-Cygni profiles. During a photometric maximum the spectrum

*Based on observations collected at the Centro Astronómico Hispano Alemán (CAHA) at Calar Alto, operated jointly by the Max-Planck Institut für Astronomie and the Instituto de Astrofísica de Andalucía (CSIC).

†Based on observations collected at the Thüringer Landessternwarte (TLS) Tautenburg.

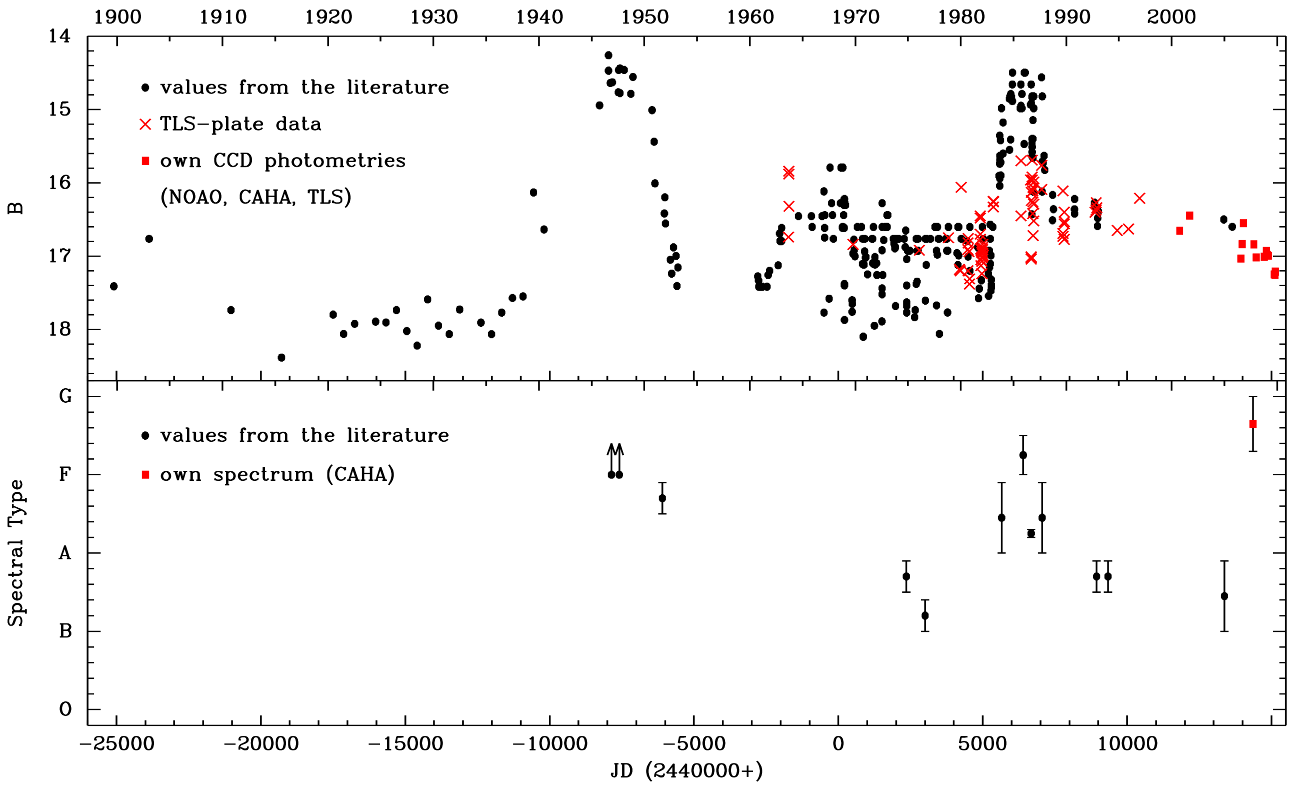

Figure 1: B Light curve (upper panel) and corresponding spectral type (lower panel) of Var C. Data points from our analyses are marked in red (red crosses: TLS-plate data, red squares: CCD photometries). Data points from the literature are marked with black dots (details will be presented in an upcoming paper).

turns into that of an A–F type star (Humphreys & Davidson 1994). These spectral changes lead to the star being brighter in the optical while it is cooler.

So far, the underlying mechanism that causes these variations is not known. It is still unclear under which circumstances massive stars become LBVs, what triggers the instabilities, and whether all massive stars in a certain mass range evolve into LBVs or not.

Var C (α=1:33:35.14, δ=30:36:00.55) is located about 5′ south-west of the centre of M33 (see Fig. 3). It was first noticed to be variable by Hubble & Sandage (1953). Var C is one of the classical LBVs in M33.

2 Data

To investigate the long-term photometric behaviour and to check for periodicity in the variations of Var C (Fig. 3), we generated a light curve of significant length. Therefore, we observed at the Centro Astronómico Hispano Alemán (CAHA) at Calar Alto (three data points) and at the Thüringer Landessternwarte (TLS) Tautenburg (ten data points). Additionally, we retrieved analyses on archival data from the National Optical Astronomy Observatory (NOAO) Local Group Survey (LGS) (Massey et al. 2001; two data points). For data from NOAO and TLS we carried out photometric analyses using IRAF/DAOPHOT. For CAHA data photometry, the analysis was performed using DOLPHOT (Dolphin 2000). Supplemental photometry was derived from several scanned archival photographic plates taken at the TLS between 1963 and 1996 (77 data points).

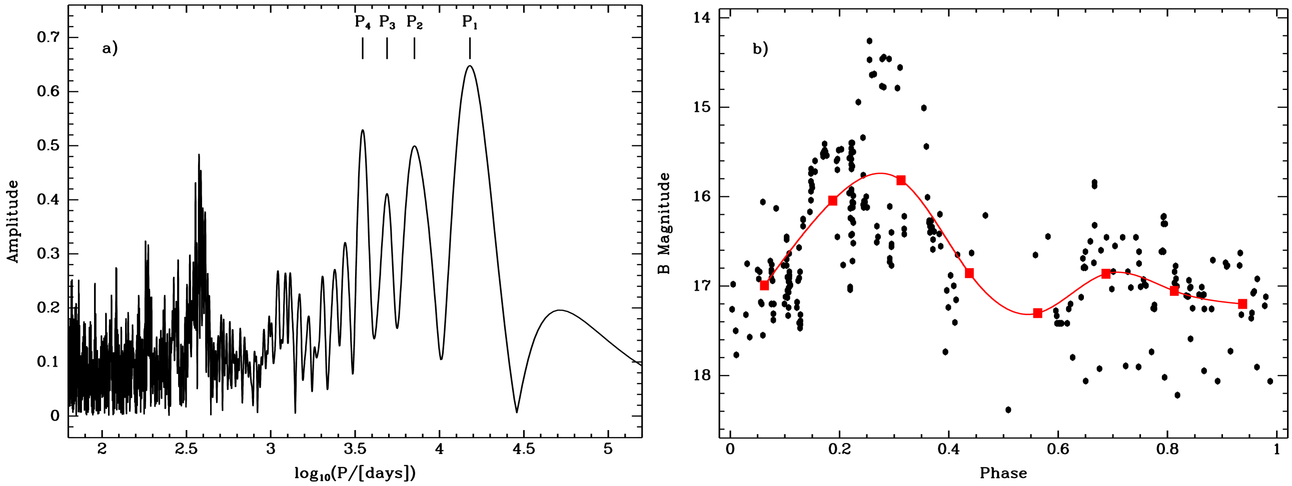

Figure 2: (a) Power spectrum derived for the B values given in Fig. 1. (b) Phase diagram corresponding to a frequency of $\nu_1 = 6.589 \cdot 10^{-5}$ 1/d ($P_1 = 15176\,\mathrm{d} = 41.5\,\mathrm{years}$). The data have been binned into eight bins (red squares) and a cubic interpolation of these binned values is given (red line).

In addition, we obtained a spectrum using the 2.2m-telescope at CAHA in order to further pinpoint the present evolutionary stage of Var C. Data reduction was carried out using IRAF.

To complete our own measurements, photometric and spectral data from the literature were gathered (all together 286 data points). Where necessary, we converted photographic and photoelectric data values into Johnson B magnitudes. For this purpose, we used the conversion given by Macri, Sasselov, & Stanek (2001), who derived a transformation between a photographic magnitude scale and CCD B magnitude in the standard system using comparison stars.

3 Periodicity of Var C

Periodicity on small timescales of the order of approximately one year is already known to occur in LBVs like e.g. AG Car (van Genderen 2001). Periodicity in the order of decades was only found to be a beat cycle as the result of these smaller periods. Detecting possible periodicity on lager scales (in the order of decades) was always difficult since most of the light curves do not reach back far enough and/or are much too fragmentary.

We combined historical and new data to produce a light curve (Fig. 1) of a significant length for Var C to analyse the long-term variability by carrying out a systematic search for long-term periodicities. Therefore, we performed Fourier transformation analysis (Fig. 2(a)) on our data set of B magnitudes by using the Period04 software (Lenz & Breger 2005). No weights were applied to the data but two data sets from the literature (100 data points) were excluded due to magnitude uncertainties equal to or larger than 0.5 mag.

In order to check whether the long-term variability occurred as a result of a beat cycle caused by variabilities on smaller timescales, a search for such smaller variabilities was performed on a homogeneous subsample of the data with an appropriate high data coverage.

Figure 1 shows the B Light curve between 1899 and 2009 (upper panel) and if measured the corresponding spectral type (lower panel) of Var C. Aside from two prominent maxima (around 1946 and 1986) and variations on smaller time scales, a secular trend of Var C getting brighter is seen in the light curve. Such a long-term trend of brightening was also found to be present in e.g. η Car (Humphreys, Davidson & Smith 1999).

Comparing the light curve with the changes of the spectral types shows that during maximum light the star resembles an A or F type star. During phases of minimum light an O or B type star is seen. Such a behaviour is well in agreement with the S Dor cycle. Of special interest is the latest development of Var C. Even though the B light curve does not show an increase in luminosity, the spectrum in September 2007 of Var C resembles that of a quite cool star. Here the photometric and spectral behaviours of Var C seem not to follow the typical S Dor properties. However, recently gained additional data indicate irregular variations on smaller scales (in the order of months). Detailed analyses will be presented in an upcoming paper.

Figure 2(a) shows the power spectrum derived for the B magnitudes given in Fig. 1. The highest peak (at $\log(P_1) = 4.181$) corresponds to a period of $P_1 = 15176\,\mathrm{d} = 41.5$ years ($\nu_1 = 6.589 \cdot 10^{-5}$ 1/d). The peak around $\log(P) \approx 2.6$ corresponds to a period of approximately one year and is most probably due to the data sampling. The very broad and low amplitude peak around $\log(P) \approx 4.7$ reflects the secular trend of an overall increase of the luminosity. At least three more distinct peaks are present (at $\log(P_2) = 3.851$, $\log(P_3) = 3.689$, and $\log(P_4) = 3.545$ corresponding to periods $P_2 = 19.4$ years, $P_3 = 13.4$ years, and $P_4 = 9.6$ years).

The phase diagram corresponding to a frequency of $\nu_1 = 6.589 \cdot 10^{-5}$ 1/d ($P_1 = 15176\,\mathrm{d} \approx 41.5$ years is displayed in Fig. 2(b). The data have been binned into eight bins (red squares) and a cubic interpolation of these binned values is given (red line). At least one pronounced maximum is seen, a second, smaller maximum at roughly half of the period might be assumed, but data scatter due to irregular variations on smaller time scales is large and renders it quite uncertain.

Together with an amplitude of approximately 1.5-2.5 mag for the major peak this puts Var C in the category of a strong-active S Dor member with a long S Dor cycle according to the subdivision as defined by van Genderen (2001).

With the last major maximum of Var C being around 1986 and a presumable period of $P \approx 41.5$ years, we predict the next bright maximum phase of Var C to occur around 2027±2.

4 Conclusions

Combining historical and new data we produced a light curve of a significant length for Var C to analyse the long-term variability by carrying out a systematic search for long-term periodicity using a Fourier transformation analysis.

We assume a long-term (semi-)periodicity of 41.5 years being present in Var C. Seeing more than two full cycles gave us the possibility to make a prediction for the next maximum which should occur around 2027±2. Var C is the first LBV to show a periodicity in the order of decades without periodicities on smaller time scales. This indicates that the long-term periodicity has to be a result of a different underlying mechanism, which is not yet understood.

Recent unexpected changes in Var C's spectrum (from a B to an F-G type star) make it necessary to further trace both the photometric and spectral behaviour of this LBV in order to fully understand Var C's evolutionary stage.

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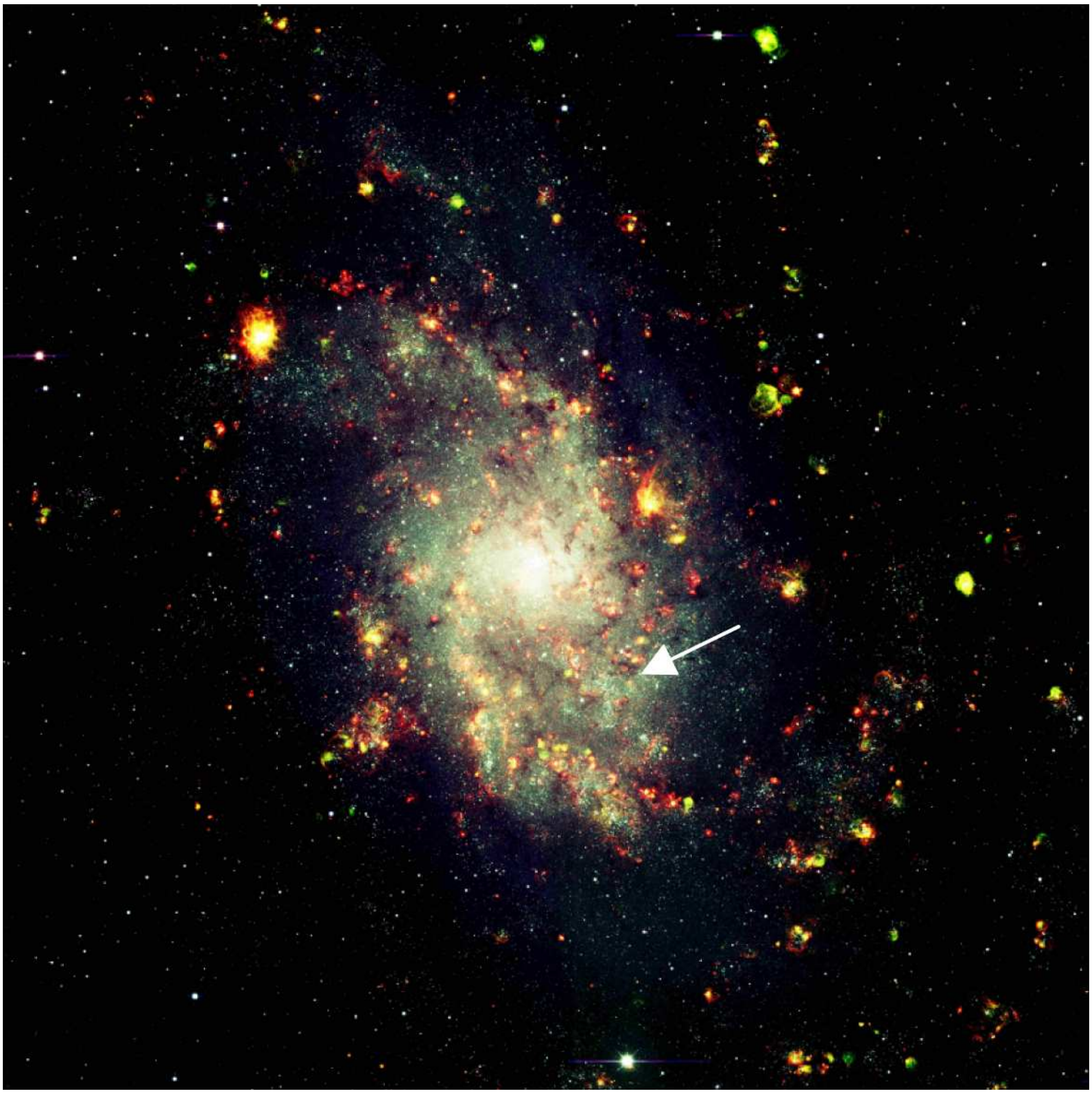

Figure 3: RGB (H_α, [O III], V) colour image of M33 produced by us using NOAO LGS data (Massey et al. 2001). North is up and east to the left. The image has a size of $\approx 36' \times 36'$. The position of Var C is marked with an arrow.

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