Orbital variations and outbursts of the unusual variable star V1129 Centauri

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Abstract

The variable star V1129 Cen is classified in the GCVS as being of β Lyr type. Unusual for such stars, it exhibits outbursts roughly once a year, lasting for ~40 days. For this reason, a relationship to the dwarf novae has been suspected. Here, for the first time a detailed analysis of the light curve of the system is presented. Based on observations with high time resolution obtained at the Observatório do Pico dos Dias and on the long term ASAS light curve the orbital variations of the system are studied. They are dominated by ellipsoidal variations and partial eclipses of a probably slightly evolved F2 star in a binary with an orbital period of $21^h26^m$. Comparison with the characteristics of dwarf novae show that the observational properties of V1129 Cen can be explained if it is just another dwarf nova, albeit with an unusually bright and early type mass donor which outshines the accretion disk and the mass gainer to a degree that many normal photometric and spectroscopic hallmarks of cataclysmic variables remain undetected.

Keywords: Stars: binaries: eclipsing – Stars: variables: general – Stars: novae, cataclysmic variables – Stars: dwarf novae – Stars: individual: V1129 Cen

1 Introduction

Cataclysmic variables (CVs) are binary stars where a Roche-lobe filling late-type component (the secondary) transfers matter via an accretion disk to a white dwarf primary. A particular subclass of CVs are the dwarf novae which occasionally exhibit outbursts with amplitudes of a few magnitudes, lasting from days to weeks. These are caused by a temporary increase of the brightness of the accretion disks in these systems.

It may be surprising that even after decades of intense studies of CVs there are still an appreciable number of known or suspected systems, bright enough to be easily observed with comparatively small telescopes, which have not been studied sufficiently for basic parameters to be known with certainty. In some cases even their very class membership still requires confirmation.

Therefore, I started a small observing project aimed at a better understanding of these stars. First results have been published by Bruch (2016, 2017a) and Bruch & Diaz (2017). Here, I present time resolved photometry and a limited amount of spectroscopy of the
unusual system V1129 Cen. To these data I add long term observations retrieved from the ASAS-3 data archive (Pojmanski 2002).

V1129 Cen is not a normal CV. In fact, the relationship of the star to the cataclysmic variables is quite unclear. In spite of its high brightness of $\sim 9^m 7$ not many details are known about the star. It is classified as a $\beta$ Lyr type eclipsing binary in the 17th name list of variable stars (Kazarovetz et al. 2008). $\beta$ Lyr systems are binaries made up of stars in tight or even semi-detached orbits. Their evolutionary state may range from two main sequence stars to a pair with a highly evolved secondary component and a less evolved primary with mass transfer between them (Hoffman et al. 2008). Due to the proximity of the stellar components the light curves are dominated by ellipsoidal variations often in combination with mutual eclipses.

In the particular case of V1129 Cen, however, apart from variations typical for such stars, recurring at a period of 0.893025 days, S. Otero$^2$ found faint outbursts with a duration of $\sim 40$ days recurring on the time scale of one year. The ASAS (Pojmanski 2002) long term light curve contains several such events which reach an amplitude of up to $0^m 6$ (upper frame of Fig. 1). The spectral type of F2 V of V1129 Cen (Houk 1978) is later than that of the large majority of $\beta$ Lyr stars but much earlier than that of the donor star in any CV. Unusual for a star of this type, Walter et al. (2006) observed emission of He II $\lambda 4686 \AA$ on 2006, Jan 16.2 UT which, however, was absent on 2006, Jan 19.3 UT. Both of these observations occurred during an outburst as is shown by the insert in the figure, where the corresponding epochs are marked by vertical lines. The authors leave the question open whether the emission was transient or if the source was eclipsed during the second observation. It is not clear what causes this unusual (for a $\beta$ Lyr star) behaviour. Ritter & Kolb (2003) have included the star as a possible U Gem type dwarf nova in the on-line version of their catalogue.

If the system indeed contains a dwarf nova or behaves like one, persistent mass transfer through an accretion disk should take place and thus flickering should be expected to be present. Whether this would be observable or not depends on the degree of modulation of the flickering light source and its relative contribution to the total light of this peculiar system. In order to verify the presence of flickering and to investigate the question whether or not the properties of V1129 Cen are compatible with a dwarf nova classification, I observed the star on several occasions in 2014, 2015 and 2016. Because of their superior quality I will concentrate here on the 2016 light curves. These data are complemented by observations retrieved from the ASAS data archive. Additionally, I obtained a few spectra in 2015 in order to verify the eventual presence of emission lines as observed by Walter et al. (2006).

This study is organized as follows: In Sect. 2 the observations and data reduction techniques are briefly presented. Sect. 3 then deals with the results of the observations and of model calculations. A discussion follows in Sect. 4. Finally, the conclusions are briefly summarized in Sect. 5.

2 Observations and data reductions

All photometric observations were obtained at the 0.6-m Zeiss and the 0.6-m Boller & Chivens telescopes of the Observatário do Pico dos Dias (OPD), operated by the Laboratório Nacional de Astrofísica, Brazil. Time series imaging of the field around the target star was performed using cameras of type Andor iKon-L936-B and iKon-L936-EX2 equipped with back illuminated, visually optimized CCDs. A summary of the observations is given in $^2$The internet links to the corresponding communications cited in the online version of the Ritter & Kolb catalogue (http://varsao.com.ar/NSV_19488.htm) or in Walter et al. (2006) (http://ar.geocities.com/varsao/NSV_19448.htm) appear not be active any more.
Figure 1: Top: ASAS-3 long term light curve of V1129 Cen. The insert contains an expanded view of the outburst selected by the broken-lined box. The vertical lines mark the epochs of detection (blue) and non-detection (magenta) of He II $\lambda$4686 $\AA$ emission by Walter et al. (2006). Centre: The same data (without outbursts) folded on the orbital period. The outlying green data points were disregarded in the model fits discussed in Sect. 3.3. The red graph represents the best model fit. Bottom: Difference between the observed light curve and the best model fit. The zero level is indicated by the red broken line in order to better visualize systematic deviations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
Table 1: Journal of observations

| Date         | Start (UT) | End (UT) | B  |
|--------------|------------|----------|----|
| 2016 Mar 09  | 1:19       | 5:10     | *  |
| 2016 Apr 05  | 0:20       | 7:11     | 10.2|
| 2016 Apr 05/06 | 23:56   | 5:53     | 10.1|
| 2016 Apr 06/07 | 23:56    | 6:30     | 10.1|
| 2016 Apr 08  | 1:18       | 6:06     | 10.2|
| 2016 Apr 14  | 0:31       | 1:51     | 10.3|
| 2016 Apr 14/15 | 23:55    | 5:56     | 10.1|
| 2015 Feb 14  | 5:58       | 7:49     | **|

* unreliable

** spectroscopic observations

Table 1. Some light curves contain gaps caused by intermittent cloud cover or technical reasons. In order to resolve any rapid flickering variations the integration times were kept short. Together with the small readout times of the detectors this resulted in a time resolution of the order of 5 s. In contrast to observations of other targets within the observing project mentioned in Sect. 1, in spite of the short integration times the high brightness of V1129 Cen not only permitted but demanded (in order to avoid saturation) the use of a filter. A $B$ filter was chosen. Even so, I did not perform a rigorous photometric calibration but express the brightness as the magnitude difference between the target and the nearby comparison star UCAC4 223-607051 ($B = 13.564$; Zacharias et al. 2013), the constancy of which was verified through the observations of several check stars. The average nightly $B$ magnitude of the target is included in Table 1.

In addition to the photometric observations, eight spectra of 600 sec exposure time were obtained on 2015, February 14, at the 1.6-m Perkin Elmer telescope of OPD. An Andor iKon-L936-BR-DD camera was employed. Exposures of a He-Ar lamp for wavelength calibration were taken after every second stellar exposure. From the FWHM of the lines in the comparison spectra a spectral resolution of $\approx 4$ $\AA$ is estimated.

Basic data reduction (biasing, flat-fielding) was performed using IRAF. For the construction of light curves aperture photometry routines implemented in the MIRA software system (Bruch 1993) were employed. The same system was used for all further data reductions and calculations. Throughout this paper time is expressed in UT. However, whenever observations taken in different nights were combined (e.g., to fold them on the orbital period) time was transformed into barycentric Julian Date on the Barycentric Dynamical Time (TDB) scale using the online tool provided by Eastman et al. (2010) in order to take into account variations of the light travel time within the solar system.

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3It seems that the comparison star shows small variations on the time scale of months and years which, however, have no bearing on the results of this study.
3 Results

The light curves are dominated by variations on hourly time scales, reflecting the $\beta$ Lyr type variations, but contain no obvious flickering. As examples, Fig. 2 shows two light curves of 2016, April 7 and 8. The black dots represent the data points at the original time resolution, while the same data, binned in intervals of 2 minutes, are shown in red.

Before dealing in more detail with the issue of flickering, I first turn to the $\beta$ Lyr type variations of V1129 Cen. To this end, the individual light curves were folded on the above quoted period, using as zero point of phase the epoch of primary minimum (as cited on the AAVSO International Variable Star Index webpage\(^4\)). In two nights a small magnitude adjustment was applied, calculated from the difference of the differential magnitudes in the respective phase intervals during the night in question and the other nights. This is probably due to slight variability of the quite red ($B-V = 1^m53$; Zacharias et al. 2013) primary comparison star as revealed by a comparison with two check stars.

The resulting $\beta$ Lyr type light curve, shown in Fig. 3, binned in phase intervals of width 0.005, does not cover all phases. Moreover, a small shift of the primary minimum with respect to phase 0 (already corrected for in the figure) was observed. Its magnitude was determined

\(^4\)https://www.aavso.org/vsx/
to be $0.025 \pm 0.001$ by fitting polynomials of various degrees to the minimum. This means that the period communicated by Otero requires a slight correction. The observed phase shift, the minimum epoch (referring to 2002) and the minimum epoch observed in 2016 then permit to calculate updated ephemerides for V1129 Cen:

$$\text{BJD}_{\text{min}} = 2457483.584(1) + 0.8930290(2) \times E$$

where $E$ is the cycle number. This does, of course, not take into account a possible period variations such as that observed in the prototype star $\beta$ Lyr (Harmanec & Scholz 1993) at a much higher rate (19 sec/yr) that any possible variation implied by the difference of Otero’s period and the present value.

For comparison, the ASAS-3 data were also folded on the orbital period (rejecting the observations taken during outbursts; Fig. 1, bottom). While noisy, the $\beta$ Lyr type variations are obvious. The lower amplitude compared to Fig. 3 may be due to the different passband of the ASAS-3 data ($V$ vs. $B$).

### 3.1 Spectrum

Having in mind the report of Walter et al. (2006) of transient He II $\lambda 4686$ Å emission in the spectrum of V1129 Cen, I obtained the spectroscopic observations mentioned in Sect. 2. The mean of eight individual exposures is shown in Fig. 4 (black curve). Since no flux calibration of the spectra was performed it is shown here normalized to the continuum. For comparison, standard star spectra of spectral type F0 V and F3 V (i.e., close to the spectral type of V1129 Cen), taken from the compilation of Jacoby et al. (1984) and normalized in the same way are also shown in the figure (shifted upward and downward for clarity). Their resolution was degraded to match that of V1129 Cen. No trace of $\lambda 4686$ Å emission is seen.

### 3.2 Flickering

I turn my attention now to the implications of the absence of detectable flickering in the light curves of V1129 Cen.
I first determine the scatter of the data points of the binned versions of the light curves shown in Fig. 2 (adding also the night of 2016, April 6) after subtraction of the orbital variations. To this end a Gaussian was fit to the distribution of the difference between data points of the binned light curves and a Fourier filtered version of the same data which removes variations on time scales $>30^m$. In all nights it has a FWHM of about $\delta m_0 = 0.01^m$.

What must be the magnitude difference between a flickering light source and a brighter constant star in order to render the flickering unobservable? Assuming the presence of a light source in the system which flickers such that a light curve treated in the same way as above leads to a distribution of data points with a FWHM of $\delta m$ it is possible to calculate as a function of $\delta m$ the magnitude difference $\Delta m$ of that light source and of the entire system necessary for the observed FWHM not to exceed $\delta m_0$. This leads to the relationship shown in Fig. 5. Considering that the total amplitude of the flickering variations is significantly larger than the FWHM of the distribution of data points [e.g., in V504 Cen Bruch (2017b) observed a total amplitude of $0.62^m$, while the FWHM does not exceed $0.16^m$] the range of $\delta m$ in the figure extends to extremely strong flickering.

According to Gaia DR1 (Brown et al. 2016), V1129 Cen has a parallax of $3.21\pm0.40$ mas. This translates into a distance of $312\pm39$ pc. The ASAS-3 long term light curve shows that the $V$ magnitude varies between $9.47^m$ and $9.96^m$ (disregarding outburst), with an average of $9.65^m$. While the transformation of ASAS magnitudes to a standard photometric system may not be particularly accurate, errors are expected not to exceed a typical value of $0.05^m$. Moreover, the average magnitude of $9.65^m$ is identical to the $V$ magnitude cited in the Tycho-2 catalogue (Høg et al. 2000).

The interstellar absorption towards V1129 Cen appears to be small. The observed colours $B - V = 0.38; U - B = 0$; Kilkenny & Laing 1990$^6$ match quite well with those of an unreddened star of the same spectral type F2 V; $B - V = 0.35, U - B = 0.00$; FitzGerald 1970. Neglecting thus absorption, the distance and the apparent average magnitude translate into an absolute magnitude of $M_V = 2.18\pm0.29$, slightly ($\sim0.75$) brighter than an F2 type.

$^6$http://www.astrouw.edu.pl/ gp/asas/explanations.html

However, the authors marked these values as uncertain.
main sequence star (from interpolation in the tables of Allen 1973). This difference cannot
be explained by the contribution of the binary companion to the total system light since
model calculations (Sect. 3.3) show this contribution to be much less than that of the F2 star.
The difference rather indicates that the latter has slightly evolved off the main sequence.

The quiescent magnitudes of dwarf novae encompass a wide range. Fig. 3.5 of Warner
(1995) suggests that ordinary U Gem stars have a brightness fainter than $M_V = 7.02$. While
in long period systems it includes a non-negligible contribution of the mass donor, for the
sake of a conservative upper limit I consider this value to be the magnitude of a possible
accretion disk in V1129 Cen. The magnitude difference between the entire system and the
accretion disk is thus at least $\Delta m = -5.0$. Comparing this value with the graph in Fig. 5
it is obvious that the not flickering light sources in V1129 Cen can easily hide any flickering
even if the disk light would be 100% modulated.

### 3.3 Model calculations

The complete phase coverage of the ASAS data warrents an attempt to model the light curve
of V1129 Cen in the expectation that some system parameters can be delimited. To this end,
I employ the Wilson-Devinney code (Wilson & Devinney 1971, Wilson 1979) as implemented
in MIRA. Before proceeding, a word on nomenclature is in order to avoid confusion with
nomenclature usually used in CV research: I will refer to the optically dominating F2 star
as the primary component, independent whether it is the mass gainer or mass loser (if there
is mass transfer in the system) or whether it is the more massive or the less massive star. It
will be designated by the index 1 subsequently. Consequently its companion is the secondary
star (index 2). The mass ratio is defined as $q = M_2/M_1$.

Considering the large number of model parameters required by the Wilson-Devinney code
to calculate a light curve it is appropriate to fix as many of them as possible before trying
to adjust the model light curve to the observed data.

It turns out that the atmospheric parameters albedo $A$, limb darkening coefficient $u$ and
gravity darkening coefficient $g$ have only a minor influence on the results. Therefore, $u^7$ and

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*A simple linear law of the kind $I(\mu)/I(1) = 1 - u(1 - \mu)$ is used. Here, $I(1)$ is the specific intensity at*
are interpolated in the tables of Claret & Bloemen (2011) [using their results based on
ATLAS model, least squares calculations, adopting solar chemical composition, the surface
gravity of a normal F2 main sequence star and no microturbulence; for details, see Claret &
Bloemen (2011)] at the temperature of 7040 K as determined by Kordopatis et al. (2013)
for the primary star. Similarly, $u$ and $y$ for the secondary component refer to a temperature
of 4500 K (determined from preliminary model fits) and a surface gravity calculated from
the mass and radius of a main sequence star of that temperature. According to Rafert &
Twigg (1980) hotter stars with radiative envelopes should have an albedo of $A = 1.0$ while
for cooler stars with convective envelopes $A = 0.5$. I adopt the latter value for the secondary
star of V1129 Cen. The temperature of the primary falls in the transition region between the
two regimes. For simplicity, I adopt $A_1 = 0.75$. Furthermore, the primary temperature is
fixed to the above mentioned value of $T_1 = 7040$ K. A phase shift to make up for a possible
slight error of the epoch of primary eclipse was fixed to the value determined in preliminary
calculations. Any contribution of an accretion disk and/or hot spots possibly present in the
system was ignored.

The model parameters left free to be adjusted to the data where then the mass ratio
$q$ of the components, the orbital inclination $i$, the temperature $T_2$ and the dimensionless
surface potential $\Omega_2$ of the secondary star. $\beta$ Lyr stars are binaries in a tight orbit, but
it is not always evident if they are detached or semi-detached. Therefore, calculations for
both cases were performed, choosing the corresponding mode of the Wilson-Devinney code.
In the latter case the surface potential of the primary star is determined by the mass ratio
which defines the potential at the Roche surface. In the alternative case no limitations on
the size of the components relative to their Roche lobes is assumed and the surface potential
of the primary was also left free to be adjusted. Finally, the normalization constant was
also considered a free parameter. It turned out that the best fit parameters of the detached
model were not significantly different from those of the semi-detached model. Therefore, to
be definite, I will subsequently only regard the results derived from the latter.

The SIMPLEX algorithm (Caceci & Cacheris 1994) was adopted to find the optimal model
parameters which lead to the minimal $\chi^2$ between observations and calculations. Some
outlying data points in the observed light curve (green dots in Fig. 1) were disregarded. The
best fit model is shown in the central frame of Fig. 1 as a red curve. The lower frame contains
the differences between the observed and calculated data. The broken red line indicates the
zero level in order to better visualize systematic deviations of the $O-C$ curve from zero.
The fit parameters are summarized in Table 2. Here, the Roche lobe filling factor of the
secondary is calculated from its surface potential and is thus not an independent quantity.

The model fit is not completely satisfactory. There are systematic residuals between data
and fit. In particular, the fit appears to slightly underestimate the brightness after the
primary minimum (phase range $0.1 < \phi < 0.2$) and overestimates it after the secondary
minimum ($0.6 < \phi < 0.7$). The formal deficiency of the fit is also evident from the elevated
value of the reduced $\chi^2_{r,\min} = 2.9$. Some ingredients are therefore probably missing in the
model. If the outbursts of V1129 Cen are indeed related to dwarf nova outbursts this is not
surprising because an accretion disk (and possibly associated bright spots) are then expected
to be present in the system. These cannot be modeled by the Wilson-Devinney code.

Even so, considering that the orbital modulation is evidently dominated the the ellipsoidal
variations of the primary component together with a substantial primary and a smaller
secondary eclipse (all determined by the component temperatures, their relative sizes and
the mass ratio), the missing model ingredients may demand small corrections, but the best
the centre of the stellar disk, and $\mu = \cos \gamma$, where $\gamma$ is the angle between the line of sight and the emergent
radiation.
Figure 6: Two-dimensional cuts through the $\chi^2_r$ hyperspace, defined by the residuals between the observed light curve of V1129 Cen and model calculations, at the location of the best fit parameters. The colour coding (see colour bar at the top of the figure) is such that purple corresponds to $\chi^2 = \chi^2_{r,\text{min}}$ and dark red represents $\chi^2 \geq 2\chi^2_{r,\text{min}}$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
Table 2: Parameters of the model fit to the V1129 Cen light curve

| Parameter                              | Best fit (V band) | Best fit (B band) | acceptable range from V band data |
|----------------------------------------|-------------------|-------------------|----------------------------------|
| Albedo (prim.)                         | $A_1$ fixed       | 0.75              | 0.75                             |
| Albedo (sec.)                          | $A_2$ fixed       | 0.50              | 0.50                             |
| limb dark. coef. (pr.)                 | $u_1$ fixed       | 0.55              | 0.65                             |
| limb dark. coef. (sec.)                | $u_2$ fixed       | 0.79              | 0.89                             |
| grav. dark. coef. (pr.)                | $y_1$ fixed       | 0.24              | 0.29                             |
| grav. dark. coef. (sec.)               | $y_2$ fixed       | 0.64              | 0.83                             |
| Temperature (prim.) (K)                | $T_1$ fixed       | 7040              | 7040                             |
| Temperature (sec.) (K)                 | $T_2$ adjusted    | 4490              | 5210 (<4050 ... 6550)            |
| Orbital inclination ($^\circ$)         | $i$ adjusted      | 74.6              | 74.3 (67 ... 90)                 |
| Mass ratio                             | $q$ adjusted      | 0.61              | 0.61 (0.45 ... 0.77)             |
| Surface potential (sec.)               | $\Omega_2$ adjusted | 7.55              | 7.32 (5.8 ... >11)              |
| Roche lobe filling factor (sec.)       | adjusted          | 0.27              | 0.28 (0.17 ... 0.37)             |

Fit parameters should at least approximately reflect reality.

Parameter correlations make it difficult to assign meaningful statistical errors to the parameter values. In order to investigate this issue Fig. 6 shows two-dimensional cuts through the $\chi^2_r$ hyperspace at the location of the best fit parameters. In order to facilitate comparison, the colours coding of all frames is such that purple corresponds the $\chi^2_r, \text{min}$ and dark red to twice that value or higher (see colour bar at the top of the figure). It is then seen that, for instance, the orbital inclination and the mass ratio are strongly correlated (central frame in the upper row of Fig. 6) which makes it impossible to determine either of them with any degree of precision. Assuming as criterion that solutions leading to $\chi^2_r > 2\chi^2_r, \text{min}$ are unacceptable the diagram shows that the mass ratio can be anything from 0.39 up to a value beyond the limits of the explored parameter range. However, other cuts through the $\chi^2_r$ hyperspace permit to better restrict $q$ (i.e., the $q - T_2$ plane; lower left frame of Fig. 6).

Exploring the individual cuts in this way leads to permitted parameter ranges as quoted in the last columns of Table 2. As a check, the Wilson Devinney model was also fit to the $B$ light curve (red line in Fig. 3). Again, the fit is not perfect, exhibiting the same excess of observed light in the phase range after primary minium already seen in the $V$-band data. With the exception of the secondary star temperature which is higher by $\approx 700$ K when the $B$ band data are used, the best fit parameters listed in Table 2 are practically identical to those derived from the $V$ band. Even so, $T_2$ remains comfortably within the acceptable range. The agreement of the results obtained from data in different bands and using radically different observing procedures gives confidence that they are not corrupted by errors or systematics of the observations.

The results of the model calculations nicely fit in with independent knowledge about V1129 Cen. Assuming the mass $M_1$ of the primary not to be significantly different from that of a normal F2 V star ($\sim 1.55 M_\odot$; Allen 1973) the mass ratio and the orbital period together with Kepler's third law yield the component separation $A$. Using the approximation for the volume radius of the Roche lobe provided by Eggleton (1983), the assumption of a semi-detached configuration determines the radius $R_1$ of the primary in units of $A$ as a

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8The lower limit for the range of $T_2$ is ill defined because the Wilson-Devinney code issued warnings when $T_2 < 4050$ K. The corresponding model calculations were then ignored.
function of $q$. For the best fit value of $q$ this results in a primary star radius of $R_1 = 2.2 \ R_\odot$. This is 1.7 times the radius of a F0 V star according to Allen (1973), confirming the conclusion drawn in Sect. 3.2 that the star has evolved off the main sequence. Since the brightness scales with the square of the radius, the V1129 Cen primary should be $1''2$ brighter than its main sequence equivalent. This is somewhat more than the values found in Sect. 3.2 ($0''75$) but not significantly so considering the uncertainty of $M_V$ and $q$.

4 Discussion

The main issue concerning V1129 Cen is the question about the nature of the semi-periodic outbursts. Are these genuine dwarf nova type eruptions? If so, how can they come about in a system that otherwise appears to have a configuration different from normal cataclysmic variables?

Outbursts of dwarf nova are caused by an increase of matter transferred through an accretion disk and the corresponding release of energy. This may be due to a limit cycle in the disk which during quiescence is in a cool and low viscosity state. Matter transferred from a donor star increases the disk mass and its temperature until the temperature for hydrogen ionization is reached, resulting in an increased viscosity which causes the disk matter to be dumped on the central star (the thermal-viscous instability model; Lasota 2001). While this is the commonly adopted mechanism for dwarf nova outbursts, at least in some systems it seems not to work and there is evidence that instead an increased mass transfer from the companion star is responsible for the brightening of the accretions disk and thus the dwarf nova outburst [see the discussion in Baptista (2012)].

4.1 Outburst characteristics

What are the characteristics of the brightenings of V1129 Cen and how do they relate to those of normal dwarf nova outbursts? They last for about 40 days which is significantly longer than observed in most dwarf novae. However, as Szkody & Mattei (1984) and Gieger (1987) showed, there is a clear correlation between orbital period and outburst duration. Extrapolating the relation of Gieger (1987) to the period of V1129 Cen leads to 40.7 days in remarkable agreement with the average outburst duration measured in the ASAS-3 light curve.

While most dwarf nova outbursts rise rapidly and decline more slowly, the V1129 Cen outbursts are more symmetrical. This may also be a consequence of the long orbital period since outburst of other long period CVs show similar shapes [BV Cen, $P_{\text{orb}} = 0.611$ days, Bateson (1974); GK Per$^9$, $P_{\text{orb}} = 1.997$ days, Pezzuto et al. (1996), Evans et al. (2009); V630 Cas, $P_{\text{orb}} = 2.564$ days, Shears & Poyner (2009)].

Similarly, using a mean outburst interval of 347 days (from Fig. 1, assuming one unobserved outburst close to JD 2452400) V1129 Cen fits in very nicely in a linear relationship between the orbital period and the logarithm of the outburst intervals of BV Cen interval: 150 days; Menzies et al. 1986, GK Per ($\sim 1060$ days; deduced from the AAVSO long term light curve, assuming some outbursts to have been missed) and V630 Cas (17 years; Shears & Poyner 2019).

While not irrefutable proof, the similarity of the outburst properties of V1129 Cen with those of long period dwarf novae suggest that the nature of the eruptions is similar.

$^9$GK Per is well known to be a classical nova, but it also exhibits dwarf nova outbursts.
4.2 Scenarios

If the bright states in V1129 Cen are in fact dwarf nova type outbursts there must be an accretion disk somewhere in the system. In principle, at least three possible scenarios can be envisaged: (1) The source of the outbursts is accidentally in the line of sight to V1129 Cen but not physically related to it; (2) V1129 Cen is not a simple binary star but a quadruple formed by two pairs, i.e., the dominating $\beta$ Lyr type component which has a normal dwarf nova as a companion at a distance where the evolution of either system does not interfere with the other one; (3) the mass gainer in V1129 Cen is surrounded by an accretion disk as modeled, e.g., in the case of the prototype $\beta$ Lyr by Mennickent & Djurašević (2013). The first possibility can, of course, not be excluded, but it is quite unlikely considering the low space density of dwarf novae. Therefore, I will not consider it further.

4.2.1 A hierarchical quadruple system

Exploring the second scenario, I first remark that the considerations of Sect. 4.1 about correlations between the outburst duration, shape and intervals, and the orbital period are irrelevant in this case because the observed period of V1129 Cen is then not that of the dwarf nova. The question may be asked whether this scenario is compatible with basic evolutionary considerations. Are the evolutionary time scales of the $\beta$ Lyr star and the dwarf nova compatible with their co-existence in a single multiple star system? This comes down to the question if the progenitor of the white dwarf in the dwarf nova system was more massive than the F2 star because in that case the former had enough time to go through a common envelope phase and become a cataclysmic variable while the F star still remains on or close to the main sequence.

Several initial – final mass relations for white dwarfs have been published in the literature. Let $M_{\text{prog}}$ be the mass of the progenitor of a white dwarf of mass $M_{\text{WD}}$. Using any of the relations given by Zhao et al. (2012), Salaris et al. (2009) or Catalan et al. (2008), the requirement that $M_{\text{prog}} > 1.55 M_\odot$ [i.e., the mass of a F2 V star according to Allen (1973)] leads to $M_{\text{WD}} > 0.60 M_\odot$. This holds for single stars. As Ritter (2010) points out, in binaries the mass transfer sets a premature end to the nuclear evolution of the donor star. Therefore, the resulting white dwarf mass is smaller than in the case of single star evolution. The mean mass of white dwarfs in CVs is 0.83 $M_\odot$ (Zorotovic et al. 2011). Thus, there is ample space for the progenitor to have a mass high enough to evolve into a red giant and to initiate the common envelope phase which results in the formation of a CV before the main component, i.e., the F star, leaves the main sequence.

On the other hand, the observed outburst amplitude, while not rendering this scenario impossible, casts some doubt upon it. Fig. 1 shows that the amplitude of different outbursts range between $0^m 6$ and $0^m 4$. To be definite, the mean of the extremes, $0^m 5$, will be adopted here. Remembering that the absolute magnitude of the dominating F2 star in V1129 Cen is $M_V = 2^m 18$ (see Sect. 3.2) and assuming that the secondary of the $\beta$ Lyr type system and the quiescent dwarf nova contribute negligibly to the total light, the magnitude of the outbursting light source should then be $\sim 0^m 6$ fainter than the F star. Thus, its absolute magnitude is $\sim 2^m 8$. Together with the conservative limit for the magnitude difference between the entire system and the accretion disk derived in Sec. 3.2 this means that the dwarf nova should have an outburst amplitude of at least $-4^m 4$. This is an uncomfortably high value. Amplitudes as large as this are more typical for superoutbursts of SU UMa stars than for normal dwarf nova outbursts. But the ASAS long term light curves does not show evidence of the dichotomy between normal and superoutbursts characterizing those systems. Moreover, the absolute magnitude of the outbursting light source must also be
quite high in this scenario. In normal dwarf novae the absolute $V$ band outburst magnitude $M_{\text{max}}$ increases with the orbital period $P_{\text{orb}}$, reflecting the larger size of the accretion disk in systems with longer periods. The relationship given in Eq. 13 of Warner(1987) results in a range of $4.96 \geq M_{\text{max}} \geq 3.15$ for $P_{\text{orb}}$ between 1.5 h and 10 h. This holds for an average inclination of $57.7^\circ$ of the accretion disk. Assuming $i = 74.7^\circ$ (Sect. 3.3) and the inclination correction of Paczyński & Schwarzenberg-Czerny (1980) the disk is expected to be even $1^m.08$ less luminous and thus much fainter than the lower brightness limit estimated above. Therefore, the dwarf nova companion to the $\beta$ Lyr type binary in the V1129 Cen must have rather extreme properties compared to an average dwarf nova for this scenario to be viable.

4.2.2 Outbursts within the $\beta$ Lyr type binary

Turning to the third scenario, I assume that V1129 Cen consists of only two stellar components, one of which is surrounded by an accretion disk. In fact, similar models have successfully been adjusted to the light curves of several $\beta$ Lyr type systems: AU Mon (Djurašević et al. 2010), V393 Cen (Mennickent et al. 2012), V455 Cyg (Djurašević et al. 2012), OGLE 0515532-6925581 (Garrido et al. 2013) and the prototype $\beta$ Lyr itself (Mennickent & Djurašević 2013). In all of these the disk revolves around the optically dominating primary star which is thus the mass gainer, receiving matter from a Roche lobe filling secondary star of lower mass. However, in the quoted examples the binary is always much hotter and more massive than in the case of V1129 Cen, harbouring primary stars of spectral type O and B and masses ranging from $7M_\odot$ to $13M_\odot$. Moreover the accretion disks are all extremely massive, geometrically and optically thick, and hot. The usual disk instability type mechanism for dwarf nova outbursts cannot work in such disks.

But what about the alternative case where the optically dominating star is the mass donor and the accretion disk revolves around the companion? This configuration would be similar to that of a normal cataclysmic variable with the difference that the donor would have a much earlier spectral type than any other CV.

In order to evaluate the consequences of this picture I regard the results of the model calculations of Sect. 3.3. Although they provide formal values for $\Omega_2$ and $T_2$, these cannot be used to draw conclusions on the nature of the secondary star (here: the mass gainer). The Wilson-Devinney code assumes the secondary to be a spherical object (distorted by the Roche potential). If the companion to the F2 star is in reality a star surrounded by an accretion disk, the fit parameters referring to the secondary will therefore represent an ill defined mixture of stellar and accretion disk parameters.

However, this does not affect the brightness of the components. Adopting the best fit parameters the model calculations show that the primary component (here: the mass looser) is $\sim160$ times brighter than the secondary at phase 0.25. This corresponds to a magnitude difference of $-5.75$, compatible with the minimum magnitude difference derived from the absence of observable flickering (see Sect. 3.2). The stark brightness contrast between the components also demands a high S/N ratio in order to detect the contribution of the expected emission lines from the accretion disk in the spectrum (provided that the disk is in a low viscosity state; emission lines in the bright, high viscosity state tend to be weak or even replaced by absorptions). Measuring the ratio of the flux at the top of the H$\beta$ emission line to the flux of the surrounding continuum in the spectra of CVs reproduced by Zwitter & Munari (1995, 1996) yields a maximum of $\sim5$. Taking this as an upper limit for the corresponding ratio in the supposed accretion disk in V1129 Cen, a S/N ratio of at least 32 is then required for a spectrum to exhibit a trace of a H$\beta$ emission. Thus, the absence of an emission core in the H$\beta$ absorption line in Fig. 4 is not incompatible with the idea of a dwarf nova-like accretion disk around the secondary component.
While the large outburst amplitude derived in Sect. 4.2.1 may still represent a certain problem, this is different for the absolute magnitude of $\sim 2^{\text{m}}.8$ of the outbursting light source. Provided that an extrapolation of Eq. 13 of Warner (1987) [Warner (1995) restricts its validity to orbital periods $\leq 15^{\text{h}}$] to the period of V1129 Cen ($21^{\text{h}}.4$) does not lead to an excessive error, the accretion disk in outburst may be even as bright as $1^{\text{m}}.3$.

The fact that in this scenario the mass donor is of significantly earlier spectral type than in any other known CV does not invalidate it. In recent population synthesis calculations for CVs, Goliasch & Nelson (2015) explicitly took into account the nuclear evolution of high mass donor stars. They show that CVs with donor star masses corresponding to early F stars can form, in particular if the donor has already evolved off the main sequence. At first glance, the fact that all values of $q$ within the acceptable range quoted in Tab. 2 lead to a donor star mass significantly in excess of that of the mass gainer appears problematic since this is in contrast to normal CVs where the mass donor is always less massive than the mass gainer. But also in this case the calculations of Goliasch & Nelson (2015) indicate that the donor can be much more massive than the gainer, in particular if it is evolved. However, the stability and the rate of mass transfer may then become an issue. Can it be kept low enough for the disk to remain in a quiescent low state prone to dwarf nova outbursts? Using the same stellar evolution code as Goliasch & Nelson (2015), Kalomeni et al. (2016) have calculated a dense grid of evolutionary tracks for binaries with white dwarf primaries. In their Fig. 16 they plot as a function of the donor star mass and the orbital period the ratio $\dot{\mathcal{M}}/\dot{\mathcal{M}}_{\text{crit}}$ of the mass transfer rate $\dot{\mathcal{M}}$ and the critical transfer rate $\dot{\mathcal{M}}_{\text{crit}}$ above which the accretion disk is stable against the thermal-viscous instability. The latter is based on the stability criterion of Lasota (2001). The figure shows that at the orbital period of V1129 Cen and a donor star mass close the that of an unevolved (or only slightly evolved) early F type star configurations with $\dot{\mathcal{M}}/\dot{\mathcal{M}}_{\text{crit}} < 1$ occur. Thus, dwarf nova type outbursts are possible.

However, a problem arises from the large dimensions of the system which implies a high critical disk mass transfer rate $\dot{\mathcal{M}}_{\text{crit}}$ for outbursts to occur due to a thermal-viscous disk instability and, in consequence, a high outburst luminosity. Smak (1983) provides an expression for $\dot{\mathcal{M}}_{\text{crit}}$. I neglect the small correction factor involving the the ratio between the white dwarf radius and the disk radius $R_d$ and follow Osaki (1996) adopting the expression

$$\log T_{\text{eff},\text{crit}} = 3.9 - 0.1 \log (R_d/10^{10}\text{cm})$$

for the critical disk temperature and $R_d = 0.35A$, where $A$ is the component separation. $A$ is calculated from Kepler’s third law, using the typical mass of an F0 V star and the mass ratio as quoted in Table 2. The critical mass transfer rate for a disk instability to occur is then $\sim 1.8 \times 10^{-7}M_\odot/\text{y}$. This leads to an approximate lower limit of the outbursting disk luminosity of $L_{d,o} = G \mathcal{M}M_{WD}/R_{WD} = 637 L_\odot$ where $G$ is the gravitational constant and the white dwarf radius $R_{WD}$ has been calculated from its mass and the mass-radius relation of Nauenberg (1972). On the other hand, interpolation in the tables of Allen (1973) and allowing for the larger radius due to evolution leads to a luminosity of $12.6 L_\odot$ for the F-star in V1229 Cen. Since the bolometric and the visual magnitude difference between the two system components will not be grossly different, the outbursting accretion disk should outshine the F-star by more than 4 magnitudes in visual light, in contrast to what is observed.

This appears to be a serious problem if the outbursts are expected to be due to a thermal-viscous instability. Assuming the alternative, a temporarily enhanced mass transfer from the donor star, it obviously vanishes. Moreover, within the scenario of a hierarchical quadrupole system it is, of course, also not existent.
5 Conclusions

Based on its optical light curve V1129 Cen has been classified as a $\beta$ Lyrae type system. It distinguishes itself from other members of this class by quasi-periodic eruptions, suggesting a relationship of the star with dwarf novae. Here, I investigated its light curve in some detail in order to either substantiate or reject this relationship.

Based on model calculations and comparisons with cataclysmic variables it is concluded that the properties of V1129 Cen are not in contradiction with the hypothesis that the system either contains, or that it constitutes a dwarf nova, albeit with rather extreme characteristics. In the first case V1129 Cen would be a hierarchical quadruple system, formed of two pairs, the optically dominating of which being a normal $\beta$ Lyrae type variable. The second pair would be an ordinary dwarf nova. However, while this scenario cannot a priori be discarded, such a configuration appears to be rather artificial. Alternatively, V1129 Cen may consist of a Roche-lobe filling, slightly evolved F2 star which loses mass via an accretion disk to a companion star, i.e., a cataclysmic variable with an unusually early type mass donor. The high brightness of the F star is able to completely outshine the accretion disk and the mass gainer (except during the occasional outbursts) such that the normal photometric or spectroscopic hallmarks of CVs are not detected. A possible problem with this scenario arises if the outbursts are due to a thermal-viscous instability (as opposed to a temporarily increased mass transfer from the donor star) because then the accretion disk should become much brighter than observed.

As a caveat I stress that this does not mean that the nature of V1129 Cen is elucidated beyond doubt. I have shown that its properties are compatible with the hypothesis that the system is a dwarf nova with a very early type mass donor, but it would be premature to reject just for this reason another configuration for the star and alternative explanations for the outbursts.

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