Orbital periods and waveforms of dwarf novae observed by Kepler

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(Published in: Res. Notes AAS, 5, 188 (2021))

Abstract

Kepler high cadence data are used to measure the orbital periods and to determine
the orbital waveforms of five dwarf novae. A significant improvement of the period
of V1504 Cyg is achieved, while for the other systems periods are derived which are
compatible with previous determinations. The orbital waveforms of the short period
systems V1504 Cyg, V344 Lyr and V516 Lyr are very nearly sinusoidal, while the
longer period dwarf nova V447 Lyr appears almost to be a twin of U Gem. The
unusual system KIC 9202990 exhibits distinct variations of its waveform as a function
of brightness during its outburst cycle.

Keywords: Close binary stars, Variable stars, Cataclysmic variable stars, Dwarf novae

1 Introduction

The often uninterrupted high cadence light curves of many stars generated by the Kepler
mission represent a treasure trove for innumerable aspects of variable star research. Here,
I present a small study of the orbital periods and waveforms of five dwarf novae using
all available high cadence Kepler data. The targets are the SU UMa type dwarf novae
V1504 Cyg, V344 Lyr and V516 Lyr, the U Gem type star V447 Lyr, and the system
KIC 9202990 which is unusual in the sense that instead of full fledged dwarf nova outbursts
it exhibits a continuous series of low amplitude modulations, considered by Ramsay et al.
(2016) as stunted outbursts.

Based on measurements over a time base of 6 days (Thorstensen & Taylor 1997) measured
a period 0.06951 ± 0.00005 d in V1504 Cyg. The Kepler data permit us to refine this
value by at least one order of magnitude. The periods of all other stars were derived
from their Kepler light curves [V344 Lyr: 0.087903 d (Osaki & Kato 2013b); V516 Lyr:
0.083999 d (Kato & Osaki 2013); V447 Lyr: 0.1556270 d (Ramsay et al. 2012); KIC 9202990:
0.1659404 d (Ramsay et al. 2016)], albeit using only a subset of the complete data (except for
KIC 9202990). Thus, only an incremental improvement of their precision can be expected
when the entire data set is used. However, except for the outburst states of the eclipsing
system V447 Lyr (Ramsay et al. 2012) and for KIC 9202990 (Ramsay et al. 2016) the
waveform of the orbital variations was never explored.

2 The orbital periods

In order to measure the orbital periods, only quiescent phases of the dwarf novae were re-
garded. Again, KIC 9202990 is an exception as the entire light curve was used. As is well
known from several studies of V1504 Cyg and V344 Lyr (e.g., Osaki & Kato 2013ab) sometimes positive and/or negative superhumps are observed together with orbital variations. Therefore, only light curve intervals of these stars were regarded where the orbital modulations are clearly present and not contaminated by superhumps signals. In the faint system V516 Cyg, I confirm the weak presence of the periodic signal found by Kato & Osaki (2013) during some quiescent intervals (never in outburst). Only these parts of the light curves are used here.

For the final analysis I subjected the data to a period search routine [Lomb-Scargle algorithm (Lomb 1976, Scargle 1982) for systems with approximately sinusoidal modulations (see below); analysis-of-variance (Schwarzenberg-Czerny 1989) for the others]. In V1504 Cyg I find an improved period of $0.069569 \pm 0.000002$ days. As expected, only in this case a significant improvement of the precision of the period could be achieved, while in all other stars the slightly enlarged data base yields periods which agree with previous determinations within the error limits.

## 3 The orbital waveforms

To find the waveforms of these variations and their amplitudes, the data used for the period determination were first filtered with a low pass filter (Savitzky & Golay 1964), effectively removing all variations below a given cut-off time scale of 5 times the orbital period. The filtered light curves were subtracted from the original ones, eliminating modulations on longer time scales. The results were phase folded on the orbital period and binned in phase intervals of 0.01 as shown in Figure 1. The total amplitude of the variations (regarding only the well expressed orbital humps in the case of V447 Lyr and KIC 9202990; see below), were transformed into magnitudes, yielding 0.124 mag (V1504 Cyg), 0.053 mag (V344 Lyr), 0.804 mag (V447 Lyr), 0.017 mag (V516 Lyr) and 0.037 mag (KIC 9202990). Note that these are average values for those time intervals when the system exhibited clear orbital variations. During other epochs, the modulations can be weaker or even absent.

The waveform of V1504 Cyg is a slightly skewed sinusoid with an indication of a short constant phase at minimum. Those of V344 Lyr and V516 Lyr are almost perfect sine curves (quite noisy in V516 Lyr because of the faintness of the object). The orbital waveforms of the remaining two systems exhibit more structure and are thus more interesting.

Ramsay et al. (2012) found V447 Lyr to be eclipsing. They examined the waveform during outburst, but the quiescent phase folded light curve is shown here for the first time. It is remarkably similar to the average quiescent light curve of U Gem [see, e.g., fig. 14 of Bruch (2021)], with a not very deep eclipse, preceeded by a strongly expressed orbital hump. After eclipse a much fainter secondary hump appears. The similarity between V447 Lyr and U Gem also extends to their outburst characteristics: A small number of shorter and slightly fainter outbursts are interspersed between longer and brighter ones [see fig. 2 of Ramsay et al. (2012) and the AAVSO long term light curve of U Gem]. Even the orbital periods only differ by just half an hour.

Ramsay et al. (2016) already studied the waveform of the orbital variations of KIC 9202990. Therefore, it is not surprising that the average (black in Figure 1) is quite similar to their fig. 4. Investigating the waveform as a function of the time interval between two random epochs Ramsay et al. (2016) also detected that it depends on the phase of the mini-outbursts in KIC 9202990 (their fig. 6). In a simpler approach I separately constructed phase folded light curves for the brighter and the fainter intervals of KIC 9202990 (separated by the average flux). The results are shown in red (bright phases) and blue (faint phases) in Figure 1. Five features are immediately obvious: (i) the amplitude increases with increasing
Figure 1: Average waveforms of the orbital variations of the dwarf novae of this study. The black graph for KIC 9202990 represents the average over the entire light curve. Red and blue graphs refer to bright and the faint states, respectively.
brightness, (ii) the width of the minimum, which appears as a shallow eclipse of an extended light source, is reduced when the brightness is low, (iii) the minimum occurs slightly earlier during the faint, and later during the bright phases, (iv) during the faint phases a secondary minimum develops in the waveform which is absent during the bright phases, and (v) the orbital hump is structured, exhibiting a slightly rising plateau close to maximum when KIC 9202990 is faint and developing an additional spike upon the hump when it is bright. On the whole the various elements of the waveform are quite similar to those of V447 Lyr (or U Gem), but the minimum is shallower and the secondary hump only stands out during the fainter phases. These details may tell us a lot about the structure of KIC 9202990, but a more thorough analysis is beyond the scope of this small contribution.

Acknowledgements

This paper is based on data collected by the Kepler mission (funded by the NASA Science Mission Directorate) and obtained from the MAST data archive at the STScI operated by AURA under contract NAS 526555.

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