CLASSICAL NOVAE AS WET OBJECTS

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Abstract. By two examples, we demonstrate that some classical novae may be suitable and worthwhile objects for time series photometry with the WET.

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1. Introduction

The Whole Earth Telescope was conceived and created out of observational needs for the study of pulsating white dwarfs (WDs). The pulses in these objects that are normally under investigation have characteristic times between tens of seconds and tens of minutes (e.g. Bradley and Winget, 1994). Early single site investigations were hampered by the terrestrial diurnal cycle, which allowed only fragmentary coverage of the light curve (LC) of a star. The very partial sampling creates aliases and interference patterns in the power spectrum (PS) of the observed LC, and thus limits the resolution and prevents proper identification of pulsating modes of stars. WET is an instrument for photometry of celestial bodies yielding a time series that has a uniform, or nearly uniform window function (Nather et al. 1990).

In a 10 day WET run, the number of recorded cycles of a 15 minute pulsating mode, typical for pulsating WDs, is about 1000. The spectral resolution $P/\Delta P$, attainable with WET for such a period, has a value of this order of magnitude.

In this presentation we propose that classical novae (CN), a few months or years after outburst, may become appropriate targets for WET runs. Some characteristics of their photometric behavior, just
like some of the modes for pulsating WDs, can be resolved and investigated only through a few days long, continuous LC, namely, they require the WET type campaign.

There are two unique features of WET that can be used in our proposed research. The first is the same which is important in the pulsating WDs research, namely, the large time resolving power of WET. The periodicities involved with the classical novae investigation are, however, an order of magnitude longer than those of the WD pulses. The periods that we are concerned with are the binary orbital periods of nova systems, which are of the order of a few hours. A typical WET run on a classical nova will therefore cover around 100 cycles of the binary period. The resolution attainable is therefore an order of magnitude smaller than in the case of WDs. Nevertheless, as we shall show in two examples, an important information about CN systems may probably be obtained even with this resolution, which cannot be achieved by any other way.

A second unique feature of WET, which normally is not utilized by the WD research, is its ability to identify periodicities of the order of 1 day. Such periodicities are notorious for being practically impossible to detect from a single site observatory. In one of our examples, a suspected periodicity of the order of 1 day should be looked for in a few days WET run on this object.

2. V 1974 Cygni

2.1. Observations and analysis

Nova Cygni 1992 = V 1974 Cyg is the second brightest classical nova observed near maximum in this century. It erupted in February 1992 and soon became an object of massive international multiwavelength observational study. In 1993, the star was observed by DeYoung and Schmidt (1994) who obtained a LC of the star with CCD photometry. They found a clear periodic component in the LC, with the period $P_1 = 0.081263$ d, which they interpreted as the binary orbital period of this stellar system. A second, independent periodicity with $P_{II} = 0.08506$ d was discovered in the LC of the star a few months later by Semaniuk et al. (1994, 1995) and independently also by us at the Wise Observatory (WO) (Retter et al. 1995a,b).
Fig. 1. The dominant peaks in the power spectrum of the light curve of V1974 Cyg in 1993, 1994 and 1995.

The upper curve in Fig. 1 shows the power spectrum (PS) for the LC of 1993 by DeYoung and Schmidt. Two well defined peaks dominate the PS, one at the frequency corresponding to the period $P_1$, and the other corresponds to its alias of 1 day. This curve is moved upward in the figure by 6 units, for clarity.

The dotted line in Fig. 1 is the power spectrum (PS) of the LC of the star, as measured in the $I$ photometric passband with the CCD camera of the WO in the Fall of 1994. The dominant peak in the PS corresponds here to the $P_{11}$ periodicity, with its aliases of 1 day and of harmonic fractions of a day, on both sides of it. A second significant alias, corresponding to the $P_1$ period with its own similar alias pattern on both sides, is also clearly recognizable.

The heavy solid line in Fig. 1 is the PS of the LC in the $I$ passband of the star obtained at the WO in four observing nights in early Summer of 1995. Here the signal to noise ratio is much smaller, due to small number of observations and due to distribution of the power among many aliases of each periodicity in the PS. We
have expanded the scale of the $y$ axis for this curve by an arbitrary factor so that the $y$ values in the figure do not correspond to this curve. The dominant peaks seen in the PS seem to correspond to the aliases of $P_{II}$, although slightly shifted to lower frequencies. The aliases corresponding to the $P_1$ period are also recognizable, at the limit of detectability.

2.2. Interpretation

The persistence of the $P_1$ periodicity in the LC of V 1976 Cyg for at least 14 months lends strong support to the identification of it as the binary period of the system. Semaniuk et al. (1995) suggest that $P_{II}$ reflects the rotational period of the (magnetic) white dwarf in this nova system. The rotation got slightly out of synchronization with the orbital periodicity, presumably due to the outburst event that took place on the surface of the WD in February 1992.

We have noticed that the value of $P_1$ is just below the well known period gap in the distribution of the binary periods among cataclysmic variables (CVs). In this respect, V 1974 Cyg is similar to the SU UMa subgroup of CVs, which all have periods below the period gap (Osaki 1995 and references therein). A second similarity between V 1974 Cyg and the SU UMa stars is that $P_{II}$, the second photometric period in the LC of the nova, is longer than the orbital period, just like the superhump period in the SU UMa case. Quantitatively as well, the difference between $P_{II}$ and $P_1$ fits well the value of the corresponding difference in SU UMa type stars. Fig. 2 bears this out explicitly. The figure presents the well known relation between the superhump period and the orbital period in all known SU UMa stars (Stolz & Schoembs 1981, 1984), as compiled recently by Thorstensen et al. (1995). It is the plot of the superhump fractional period excess as a function of the orbital period. Solid line is the least square best fit linear relation between these two quantities in all SU UMa stars. The square in the figure represents the same two parameters for V 1974 Cyg. The fit of the V 1974 Cyg position to the linear trend, that characterizes the SU UMa stars, is quite remarkable.

Fig. 3 shows the WO 1994 light curve of V 1974 Cyg, folded onto the $P_{II}$ period. The solid line represents the first two terms in a Fourier expansion around this period, fitted to the data by a least squares procedure. The structure of the cycle is very similar to the structure of the superhump cycle in a few SU UMa stars (laDous 1993).
Fig. 2. Fractional excess of the superhump period over the binary period vs. the binary period of SU UMa stars. The square represents the corresponding values for V 1974 Cyg.

Fig. 3. The 1994 light curve of V 1974 Cyg folded onto the period $P_{II} = 0.08506$ d.

In view of these similarities we propose that the $P_{II}$ periodicity of V 1974 Cyg represents a disk phenomenon in this classical nova system, akin to the superhump effect in SU UMa stars. According to Osaki (1995), a state of “permanent superhump” is predicted to
exist in CVs, for a class of accreting binary systems with certain values of binary and physical parameters. If our suggestion is further supported by observations, it will be a significant contribution to our understanding of the V 1974 stellar system, a few month after outburst of the nova. In particular it will imply that an accretion disk was already present in the system merely one year after maximum light. It will provide an example of a permanent superhump among classical novae, and it will set some constraints on the mass transfer rate in the system as well as on the mass ratio of the two stellar components.

2.3. Discussion

The future development of the two periodicities in the LC of V 1974 Cyg will be crucial for our proper understanding of them. In particular, the interpretation of $P_\text{I}$ as the binary period implies that it should stay stable in the years to come. The question whether $P_\text{II}$ is stable, and if not, how is it changing with time, is clearly an important clue to its nature. Also the structure of the two periodicities is another source for our understanding of them. It is therefore rather clear that a proper resolution of the two periodicities is the most important goal in the observational study of V 1974 Cyg.

The period $P_\text{II}$ is currently larger by 4% than $P_\text{I}$. The two periods should therefore be well resolved in a continuous LC containing some 25 or a larger number of cycles. A single site photometry will not do this, due to the aliasing problem. Thus a WET run producing a time series of 100 cycles is irreplaceable by any other mode of ground-based observations, and it is bound to yield the important information about this classical nova system.

4. HR Lyrae

4.1. Observations

Maximum light of the recorded outburst of the classical nova HR Lyrae occurred on November 6, 1919, when this star reached the brightness of 6.5 mag (Duerbeck 1987). At the present time, some 76 years later, its average $R = 15.5$ mag.

In a short survey of a few bright old novae, conducted at the Wise Observatory in Summer of 1991, HR Lyr was found to be highly
variable. Since then, it has become a subject of an intensive CCD photometry program there. The observations consist mainly on 6 min. exposures with the WO CCD camera, with the standard $R$ passband filter. In the first four years, a continuous or nearly continuous sequence of such exposures were taken for a few hours in each night of the project. In 1995, only one or a few measurements were taken in each night of the program. Bias and flat field exposures were also taken in each of our observing nights and were used in the standard reduction procedure of CCD frames.

The VISTA astronomical package of the Berkeley University for aperture photometry was then used to obtain from each exposure an instrumental magnitude of HR Lyr, along with the corresponding magnitudes of 4 nearby reference stars. The accuracy in an individual measurement of the magnitude of HR Lyr relative to the reference stars is 0.01 mag, as determined from the consistency of the relative magnitudes of the reference stars among themselves. The $R$ magnitude of HR Lyr was established on the international standard scale by calibrating the 4 reference stars against Landolt (1983) standard stars, with observations performed at the WO in 1992.

4.2. Results and analysis

Fig. 4 is a five year LC of HR Lyr in the $R$ passband, consisting of over 2300 measured points. The apparent vertical lines seen in the figure are in fact dense groups of individual points observed in single nights, that are unresolved in the horizontal scale of this drawing. The left hand side panel of Fig. 5 displays the individual measured magnitudes in three of these nights. A strong variability on time scale of hours is clearly seen in each of these LCs. For each night we have computed the PS, in the period range between 12 min and 4 or 5 h. These power spectra are shown on the right hand side of Fig. 5. There is a high, significant peak in each of the PSa, around the period of 0.1 d. Similar peaks dominate the PSa of LCs obtained at other nights in our program, although not in all of them. The peaks in the PSa do cluster around the period of 0.1 d, but significant migration of them away from this value by up to 0.03 d are not seldom. Fig. 6 displays the average PS of 40 nights, all those in which we had a sequence of observations extending for at least 0.1 d. A very significant broad peak, representing quasi-periodic oscillations around the 0.1 d periodicity is clearly seen in this figure.
Fig. 4. The light curve of HR Lyr of five years in the $R$ passband.

Inspection of Fig. 4 reveals that HR Lyr is varying considerably also on a time scale of tens of days. We suspected that these variations are periodic or quasi-periodic, although the amplitude of the oscillations is clearly varying from year to year. In order to look for phase coherence in these variations, we consider a normalized LC, obtained from the observed one by subtracting from each year measurements the average magnitude of the star at that year. The magnitudes are then divided by the standard deviation of the light variations in the corresponding year. The normalized LC, so obtained, has a mean magnitude of 0, and a standard deviation of 1, throughout. This normalization procedure is performed in order to eliminate from the LC any amplitude modulation on time scale of a year or longer, while preserving the phasing of the apparent oscillations. We stress, however, that all the major results of the time series analysis, that we performed on the normalized LC, are obtained with only minor differences when the observed (raw) LC is considered.

Fig. 7 is the PS of the five-year-long normalized light curve of HR Lyr, in the period range of 3–300 d. The PS is dominated by a group of high, significant peaks at the low frequency end of the spectrum. The two highest peaks correspond to the periods 63.8 d and 77.3 d. A third high peak is seen near 54.3 d. These three peaks are the one year alias pattern around the central period. The PS of the observed (not normalized) LC of the star looks much the same.
Fig. 5. Light curves of HR Lyr on three individual nights of 1991, 1992 and 1993 are shown on the left-hand side. The right-hand side shows the power spectra of the corresponding light curves.
Fig. 6. The average power spectrum of 40 nightly light curves, all those that were measured at the Wise Observatory for at least 2.4 consecutive hours.

Fig. 7. Power spectrum of the normalized light curve of HR Lyr of five years, in the period range of 3 to 300 days.

Fig. 8 is the normalized LC of HR Lyr, folded onto the 63.8 d period. Solid line is a least squares best fitted sine wave with this period. Here again, the apparent vertical lines are not error bars. They are dense group of individual points of one night, unresolved in the horizontal scale of this figure. The appearance of the 63.8 d
periodicity in the LC of HR Lyr is statistically highly significant, indicating that the $R$ magnitude of this old nova oscillates periodically, or at least quasi-periodically, at or around this period.

4.3. Discussion

4.3.1. The 2.4 h periodicity

Our single site observations at the WO over four years revealed clear quasiperiodic oscillations (QPO) around the period of 2.4 h. We interpret these oscillations as reflecting a varying light source which is closely coupled with the binary revolution of the system. The phenomenon of QPO around a period of a few hours, with oscillations that seem to be coherent for short durations, has been already detected in the LC of the recurrent nova T Pyx (Schaefer et al. 1992). These authors interpret their finding as related to the superhump phenomenon. In particular, they believe that the 2 h QPO of T Pyx conceal the strict binary periodicity of the system which has its value around this number. Non-coherence of the variations is due to the disk dynamics, as it is explained in the currently acceptable theory of the superhump phenomenon (Whitehurst 1988, Whitehurst & King 1991).
We suggest that in HR Lyr we are witnessing a similar phenomenon in a binary system which has an orbital period somewhere around 2.4 h. A WET run on this object may record ~100 successive or nearly successive cycles of these QPOs. This may reveal the nature of the quasi-periodicity, e.g. the characteristic length of the coherence time, if there is some regularity in the migration of the oscillations from the binary period, possibly the exact value of the driving clock – the orbital periodicity, the structure of individual cycles and its evolution in time and as a function of the instantaneous periodicity. All these details are potentially important clues for our understanding of the astronomical and the physical origin of the QPOs and of the dynamics of the mass transfer process and the accretion disk in this binary system.

If the broadening of the PS peak in Fig. 6 is indeed the result of a superhump-type phenomenon, it means that the binary cycle of HR Lyr is beating with some quasi-periodic precession motion of the accretion disk in this system. The half-width of the QPO feature in Fig. 6, in frequency units, is about $1.5 \, \text{d}^{-1}$. Thus the period, which is beating with the binary one, is of the order of 0.7 d. Such period is next to impossible to establish firmly with single site observations. The WET, on the other hand, may detect such a period or at least establish observational limits to its presence in the LC.

### 4.3.2. The 64 d periodicity

The nature of the 64 d variability of HR Lyr is so far unknown. Decaday variability has already been observed in a number of CVs (e.g. Della Valle & Rosino 1987). In HR Lyr, however, the 64 d periodicity seems to be phase coherent for the last 5 years (statistical analysis and evidence will be presented elsewhere: Leibowitz 1995). One possible coherent clock with such periodicity, in a 2.4 h binary system, is the well-known phenomenon of the precession of the nodes. Mazeh and Shaham (1976) describe this process in the context of a few well observed triple stellar systems. Using their Expression (1), taking 64 d as the precession period and 2.4 h as the binary period, we find for any reasonably assumed mass distribution among three stellar components, that the period of the third body in the HR Lyr stellar system should be of the order of 1 d. We therefore find again, that a search for a periodicity of the order of 1 d is a worthwhile goal in the study of HR Lyr. As discussed above, such a search cannot be performed effectively from any single site observatory, while the
WET is a suitable instrument for it. A positive result, confirming the existence of a third body in the HR Lyr stellar system, may have far reaching consequences on our understanding of the whole nova phenomenon.

5. Conclusions

We have shown by two examples that carefully selected old novae may become appropriate targets for the WET campaigns. WET is required for the proposed observational study for two of its main unique features: its high resolving power in the frequency domain, and its ability to investigate light variations on a time scale of one day. The observational requirements cannot be met by any other ground-based means. At the same time, the expected scientific revenues from the application of WET on CNs are large enough to justify at least testing this instrument in this novel area of research for it.

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References


