1a. BASIC PROPERTIES OF NOVAE

THE LONG TERM BEHAVIOUR OF CLASSICAL OLD NOVAE

A. Bianchini

Osservatorio Astronomico, 35100-Padova, Italy

Abstract Quiescent novae are more stable against mass transfer rate than dwarf novae. They may however show cyclical variations of their quiescent magnitudes on time scales of years, probably caused by solar–type cycles of activity of the secondary. The probability density function of the periods of the cycles observed in CVs is similar to that for single stars. Sometimes, periodic or quasi periodic light variations on time scales of tens to hundreds of days are also observed. Although the magnitudes of prenovae and postnovae are essentially the same, the definition of the magnitude of a quiescent nova is still uncertain. At present, the hibernation theory for old novae seems to be supported only by the observations of two very old novae.

1. Introduction. Classical old novae are variable stars. They vary spectroscopically and photometrically on time scales which may range from a few seconds to years, centuries and, most probably, millennia. We can try to define the variability of old novae according to the different time scales which are typically observed as follows:

i) **Very short-term variability.**– It occurs on time scales of seconds to tens of minutes. It is connected with rotational and pulsational phenomena associated with the magnetized white dwarf, turbulent processes in the mass flow from the secondary, inhomogeneities in the accretion disc, instabilities in a boundary layer if present or, alternatively, in accretion columns.

ii) **Short-term variability.**– The time scales range from a few hours to a few days. It can be caused by orbital motion, reprocessed radiation by parts of the system, hot spots, rotation of the magnetized white dwarf, instabilities in the accretion process.

iii) **Medium-term variability.**– It occurs on time scales of tens of days to hundreds of days. These time scales might be appropriate for physical phenomena such as the disc instability mechanism (Osaki 1974, Hoshi 1979, Meyer & Meyer-Hofmeister 1984) or instability events in the atmosphere of the secondary (Bath 1973, Bath & Pringle 1981). Dwarf nova-like behaviour has been observed only in a few old novae like GK Per (Hudec 1981, Bianchini et al. 1986, Cannizzo & Kenyon 1986), WY Sge (Duerbeck 1984a) and V3890 Sgr (Dinerstein & Hoffleit 1973). Periodic or quasi periodic small amplitude sinusoidal light oscillations with time scales of tens to hundreds of days have been discovered in the long term light curves of some old novae by Shugarov (1983), Della Valle & Rosino (1987) and Della Valle & Calvani (these proceedings). However, this type of variability is still poorly studied and not understood.

iv) **Long-term (Secular) variability.** – Typical time scales range from a few years to tens of years. It seems to be mainly characterized by periodic or quasi periodic variations of the mass transfer rate and the quiescent luminosity, probably due to cycles of activity of the secondary (Bianchini 1988a,b, Warner 1988). For this reason, no conclusion should be drawn from the apparently monotonic trends which are observed in the light curves of some old novae.

v) **Very long-term variability.**– *The time scale may range from tens of years to* millennia. This variability is supposed to be connected with the evolution of the binary system. Simple statistical arguments suggest that all novae recur after time intervals which depend on theoretical models of nova explosion (Vogt 1981,1987; Duerbeck 1984b; Shara et al. 1986; Prialnik & Shara 1986; Warner 1987). It has been suggested that a hundred years after the explosion, the mass transfer rate within post nova binaries decreases. Old novae should then spend part of their quiescent life as dwarf nova systems and might finally experience a more or less long hibernation phase in which the mass transfer from the secondary is totally suppressed.

This classification shows that the secular evolution of old novae is strongly characterized by variations of the mass transfer rate. For this reason, the long term history of a post nova can be often studied directly from its light curve. The questions now are: i) what does the body of the observational data tell us about the long and very long term evolution of old novae?; ii) can we uniquely define the magnitude of an old nova?; iii) does there exist a general behaviour for all the novae during the years before and after the explosion?

2. Pre novae and post novae. Robinson (1975) has shown that the magnitudes of pre novae and post novae are essentially identical. Most prenovae are however variable and present light fluctuations or gradual rises in brightness before the explosion. Reanalysis of the observational data shows that, out of 10 pre novae, 6 have a rise before the outburst, 3 remain constant or have irregular light variations, and one, V446 Her (1960), presents a 12–yr cycle, similar to those discovered in old novae and dwarf novae by Bianchini (1988a,b) and Warner (1988). On the other hand, out of 6 post novae, 5 are characterized by cyclical light variations, 2 of them presenting also declining light curves, and 1 by a decline only. The main characteristics observed in the light curves of pre novae and post novae are summarized in Table 1. Unfortunately, the long term photometric behaviour of quiescent novae is usually hard to analyze because of the poor coverage of individual objects and the fragmentary nature of the observations. For this reason, we cannot exclude that the types of variability exhibited by the objects of Table 1 might also characterize any quiescent nova. In spite of these problems, we give in Table 2 a list of revised magnitudes of pre and post novae. Novae more recent than 1975 have not been included because it is improbable that they have already reached their quiescent state. Although large differences between preoutburst and postoutburst magnitudes are not rare, 70% of the novae of Table 2 show differences of not more than 0.5 mag. It is then possible, though not sure, that a few objects like CP Pup, V1500 Cyg, V446 Her and IV Cep can be considered as anomalous cases.

Before its 1942 outburst, CP Pup was certainly fainter than 17 mag. This makes CP Pup very similar to V1500 Cyg. At present, these two old novae are in a sort of 'standstill' and no one can say how long they will survive at the present luminosity level.

Table 1

Object	epoch of the outburst	t_2 (yr)	period of observation (d)	type of variability (yr)	Ref.
pre-novae					
GK Per	1901	6	1897-1901	rise	1
DI Lac	1910	20	1887-1910	stable ?	1
DQ Her	1934	67	1894-1934	eclipses	1
CP Lac	1936	5	1914-1936	rise	1
BT Mon	1939	140	rise 6 years before outburst		1
V446 Her	1960	5	1896-1960	12-yr cycle	1,4
V533 Her	1963	22	1941-1963	rise	1
HR Del	1967	152	1935-1967	oscillations ?	1
LV Vul	1968	21	1935-1964	rise	1
V1500 Cyg	1975			rise?	3
post novae					
V841 Oph	1848	56	1919-1989	decline (sudden?) + cycles	4
Q Cyg	1876	11	1907-1982	cycles	5
GK Per	1901	6	1901-1917	decline	4,5
			1917-1940	rise	4,5
			1940-1950	strong cycles	4,5
			1950-1981	decline + cycles	4,5
			1981-1989	new rise?	4
V603 Aql	1918	3.5	1935-1989	decline	4
RR Pic	1925	80	1960-1984	decline + cycles	2
DQ Her	1934	67	1934-1982	cycles	6

References:1) Robinson 1975; 2) Warner 1986; 3) Wolf 1977; 4)present work; 5) Bianchini 1988a,b; 6) Warner 1988

Table 2

Nova	year	t_2 (d)	m(pre) (mag)	rise	m(post) (mag)	decline
V1016 Sgr	1899	12	15.0		14.9	
GK Per	1901	6	13.8	yes	13.1	yes(?)
DI Lac	1910	20	14.0		14.5	
OY Ara	1910	44	17.5		17.5	
V999 Sgr	1910	220	16.5		16.5	
DN Gem	1912	17	15.5		15.8	
GI Mon	1918	13	15.1		15.1	
V603 Aql	1918	3.5	10.5		12.1	yes
GR Sgr	1924	120	16.6		16.6	
RR Pic	1925	80	12.7		12.3	yes
V441 Sgr	1930	75	16.0		16.5	
DQ Her	1934	67	14.7		14.7	
CP Lac	1936	5	15.5	yes	15.6	
V356 Aql	1936	150	16.5		16.5	
BT Mon	1939	140	16.8	yes	15.8	
CP Pup	1942	5	17		15.1	standstill(?)
V465 Cyg	1948	200	17.5		17.5	
EU Sct	1949	14	16.3		17.0	
FS Sct	1952	14	16.6		16.6	?
V446 Her	1960	5	18		15.8	
V533 Her	1963	26	14.2	yes	14.4	
HZ Pup	1963	35	18.5		18.5	?
V655 CrA	1967	10	17		17	?
HR Del	1967	152	12.3		12.1	
LV Vul	1968	21	16.9	yes	16.9	?
V2572 Sgr	1969	20	13		14.8	
V1229 Aql	1970	25	19.4		17.6	
V368 Sct	1970	16	19.3		19.3	?
FH Ser	1970	40	16.1		16.1	?
IV Cep	1971	16	15.4		19.3	
V1500 Cyg	1975	2	21	yes(?)	16.5	standstill(?)

The existence of standstills has been often associated with the presence of a hot central object which illuminates the accretion disc. It has been shown that this can cause overestimate of the accretion rate (Friedjung 1985). We note that the very fast nova V446 Her could also be in a similar situation. The behaviour of IV Cep, whose postoutburst luminosity is much lower than the preoutburst one, is the opposite. RR Pic, though declining (Warner 1986), still has a negative m(post)–m(pre) value. V603 Aql, which is also declining, is instead now considerably fainter than during its observed prenova state. As a conclusion, we can say that, besides the particular case of standstills, the major source of uncertainty in the determination of the magnitudes of novae at quiescence is the presence in the light curve of monotonic rises (pre–novae) and declines (post–novae) and/or of long term cycles. Perhaps, a first level of postnova brightness could be defined for the old novae Q Cyg, DI Lac and V603 Aql, if we assume that the 0.4 mag step observed about 18 years after maximum (Della Valle 1989) indicates the shutoff of the white dwarf. We shall see, however, that V603 Aql is still declining.

3. On the stability of old novae against mass accretion. Fig. 1 plots the absolute magnitudes of the accretion discs of old novae and nova like systems with known orbital inclination as a function of the orbital period. Absolute magnitudes of dwarf novae at mean light are also displayed. The data have been taken from Warner (1987). The absolute magnitudes of the old novae V603 Aql, V841 Oph, have been corrected according to the revised apparent magnitudes of Table 2.

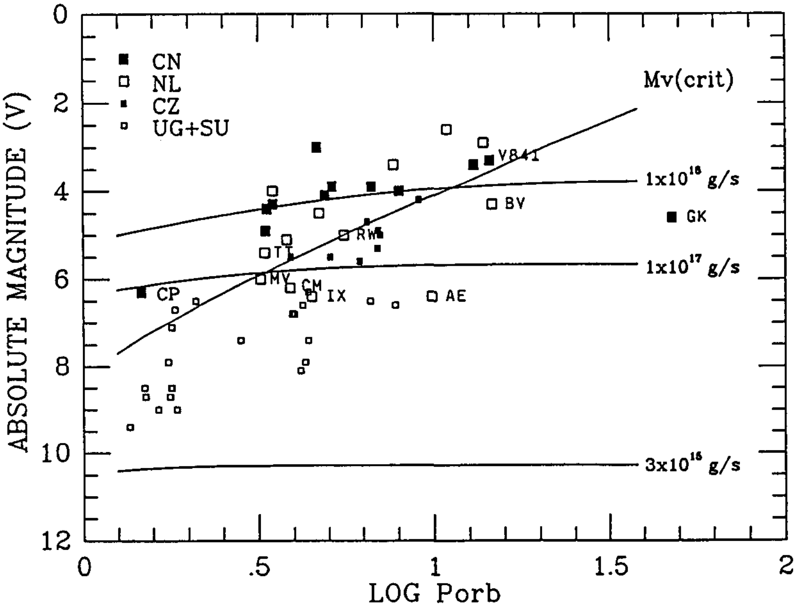

Fig.:1 Plot of the absolute magnitudes of the accretion discs of CVs as a function of the orbital period. The $M_{V_{crit}}$ line separates the region of stable discs (above) from that where dwarf novae outbursts occur.

The orbital periods of V841 Oph and CP Pup are given by Bianchini et al. (these proccedings); their orbital inclinations have been derived from the equivalent widths of hydrogen emission lines and also considering the lack of eclipses. The orbital inclination of GK Per is assumed to be 60°, as for a grazing binary system.

According to the disc instability model, when the mass transfer rate from the secondary of a given close binary system is lower than a certain critical value, the outer regions of the accretion disc become unstable and produce dwarf nova outbursts. The $M_{V_{(crit)}}$ line of Fig. 1 has been drawn assuming the Lynden-Bell & Pringle (1974) temperature distribution of the steady-state accretion disc, the LTE stellar atmosphere approximation with a limb darkening coefficient of 0.6, a 1 $M_\odot$ white dwarf, and imposing that the effective temperature of the outer edge of the disc be T_e=6000 K, which ensures the onset of the unstable transition region (Cannizzo & Wheeler 1984). The inner edge of the disc has been calculated for any mass transfer rate assuming a magnetic white dwarf having $B=4 \times 10^4$ Gauss. The temperature distribution of theoretical accretion discs has been then calculated starting from their inner radii. This choice produced a better fit to the observed magnitudes at shorter orbital periods. The $M_{V_{(crit)}}$ line separates the region of stability, where most old novae and nova like systems lie, from that of unstable discs, mainly populated by dwarf novae. The only exception amongst old novae is GK Per, whose very large accretion disc falls in the unstable region, in agreement with the dwarf nova–like properties exhibited by this old nova.

These results could however be criticized for the simple reason that they strongly depend on two major uncertain assumptions which have been made. The first consists in having assumed that old novae possess "normal" accretion discs. In fact, Williams (1989) has recently suggested that the emission lines of several novae and nova like systems originate in rotating polar accretion columns and not in accretion discs. This situation could explain in another way the observed stability of old nova systems compared with dwarf novae, and, perhaps, also the similarity of their quiescent luminosities. The second assumption is represented by the uncertain determination of quiescent magnitudes due to the variability of old novae.

4. Monotonic light declines ? According to Livio (these proceedings), an increase of the orbital separation caused by the mass loss and the cooling of the white dwarf after the nova explosion should not result in a drastic decrease of the mass transfer rate. Thus, the idea that old novae should evolve towards an hibernated state is still in search of a theoretical justification. As for the standstills, the light declines shown by a few old novae could also be connected with the presence of a slowly cooling hot central object.

Evidences for steadily declining luminosities of classical post novae have been collected only for RR Pic (Warner 1986), V841 Oph, V603 Aql and GK Per. The light curve of V603 Aql (Fig. 2) is obtained from the data by Steavenson (1920-1935), from two photoelectric observations by Walker (1957) and the photographic estimates by Favero & Dalmeri (1989). The light curve of V841 Oph (Fig. 3) has been compiled using the data by Barnard (1921), Peek (1925,1926,1927), Steavenson (1921-1953), two photoelectric measurements by Walker (1957) and two estimates derived from our 1988 ESO spectrophotometric observations of the nova. In this case, instead of a monotonic light decline we observe a sudden 1 magnitude drop of the luminosity around JD

2434000. However, a recalibration of the magnitudes of the comparison stars used by more ancient observers is badly needed.

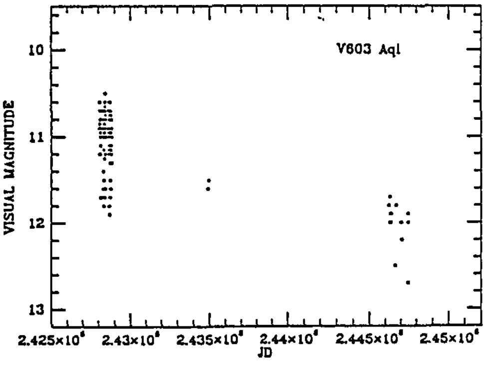

Fig.:2 Long-term light curve of the old nova V603 Aql.

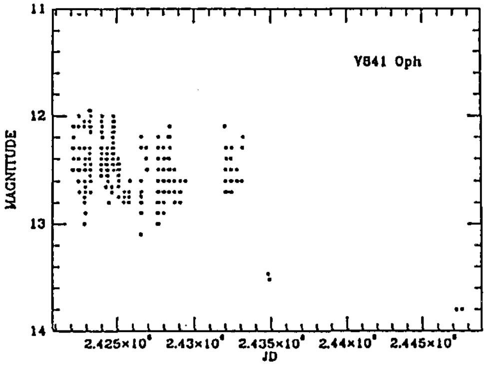

Fig.:3 Long-term light curve of the old nova V841 Oph.

The decrease of the quiescent luminosity of GK Per between 1950 and 1981 (Bianchini et al. 1986) might be only a transitory phenomenon. In fact, as shown in Fig. 5, during the last 8 years, the old nova seems to have returned to the brightness it had during the forties. More details on the behaviour of GK Per will be given in the next section. A statistical approach can be attempted by plotting the absolute magnitudes of old novae as a function of the epoch of their explosion. Data are from Warner (1987; and references therein). The distribution of data points of Fig. 4 might be consistent with a minimum rate of decline for all the old novae of the order of 0.03 mag/yr, that is not too far from the values derived for RR Pic and V603 Aql. This might suggest that novae tend to hibernate within 300-400 yrs after the explosion. However, such a conclusion is suggested mainly by the position in Fig. 4 of only two objects, namely, WY Sge(1783) and CK Vul (1670) which might not be classical.

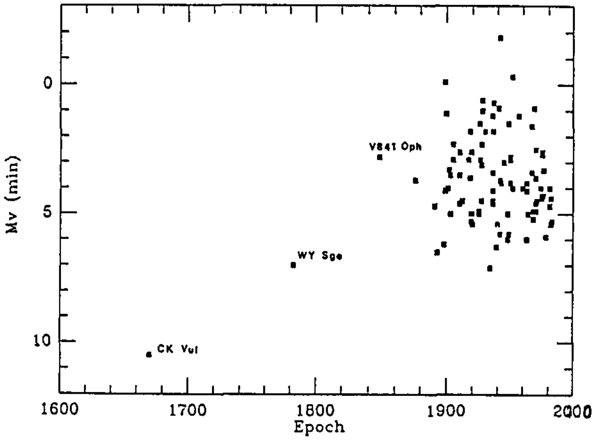

Fig.:4 Absolute magnitudes of old novae as a function of the epoch of their explosion.

The very old nova V841 Oph (1848), though declining, is however still bright. The secondary of U Leo, recently recovered by Downes & Szkody (1989), is still heated by the white dwarf remnant after 130 yrs.

5. Solar type cycles. Analysis of the long term behaviour of the different types of CVs led Bianchini (1988a,b, 1989) and Warner (1988) to use four independent diagnostics to evaluate the variations of the mass transfer rate within a close binary system. They are: (i) variations of the quiescent luminosity; (ii) variations of the time intervals between consecutive outbursts of dwarf-nova systems; (iii) variations of the orbital period and (iv) of the rotational regime of the mass accreting magnetic white dwarfs. Warner (1988) demonstrated that the changes of stellar radius $\Delta R/R \simeq 1. \times 10^{-4}$ derived from these mass overflow-sensitive techniques are all in agreement with the hypothesis that they are due to solar-type magnetic cycles.

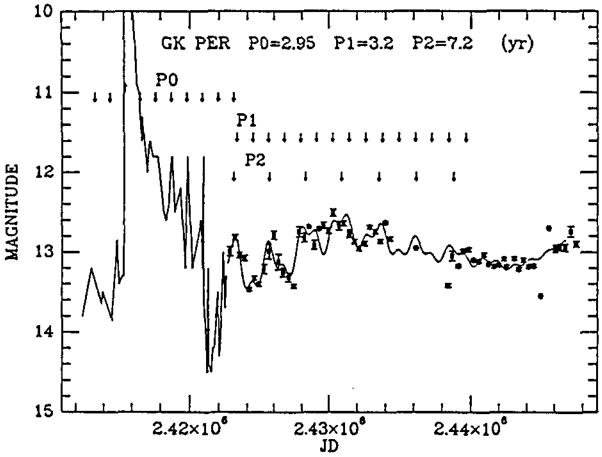

Fig.:5 Historical mean light curve of GK Per. Filled squares with error bars represent mean annual magnitudes. The post outburst minihibernation phase occurred in 1917 (around JD 2421800). The continuous line which fits the mean annual magnitudes, represents the χ^2 solution involving periods P_1 and P_2. The arrows indicate the maxima of the oscillations during the light decline and of the sinusoids corresponding to periods P_1 and P_2.

Up to now, the presence of cyclical activity of the secondary has been recognized in 20 close binary systems (Bianchini 1989). Of these, 6 are classical novae. The cycles discovered in old novae are shown in Table 3. The 60 yr extra period for GK Per is rather uncertain and will be discussed later on. The table contains also the periods of the medium term modulation (MTM) discovered by Della Valle (1989). Two periods are detected in the light curve of Q Cyg, two (or three) in that of GK Per. The presence of more (correlated ?) periodicities seems to be a characteristic of several CVs. Usually, the main cycle has an amplitude of 0.2-0.3 mag.

The preoutburst light curve of the symbiotic nova RR Tel shows strong coherent oscillations with a period of 11 years. During the decline from the 1946 light peak the oscillations were still present though with a smaller amplitude. There are reasons however of believing that this is due to orbital motion (Bianchini 1989).

Table 3

Nova	P_{orb} (hr)	P_{cyc} (yr)	$P_{(MTM)}$ (d)	*Diagnostic*	*Ref.*
GK Per	48	7.2,3.2,60?	n×400?	(i)	1
Q Cyg	?	6.4,3.6	55-65	(i)	1,3
V841 Oph	14.4	3.4	51.7	(i)	1,3
DQ Her	4.65	13.4		(i)(iii)	2
T Aur	4.91	23		(iii)	2
RR Pic	3.48	14		(i)	2
V446 Her	?	12*	71.5	(i)	4,3

*: observed during the pre-nova state;1)Bianchini 1988;
2) Warner 1988; 3) Della Valle 1989;4) this work;
(i),(ii),(iii) refer to the diagnostics of section 1.

As we have anticipated, the case of GK Per is extremely important for the understanding of the effects which may be produced by the activity of the secondary. The historical mean light curve of GK Per is shown in Fig. 5. Pre-eruption magnitudes are from Robinson (1975, and references therein); the light curve in the years 1901-1983 is from Sabbadin & Bianchini (1983, and references therein); the period 1984-1989 is covered by the photographic observations of Dalmeri et al. (1988) and Dalmeri & Favero (1989). As suggested by Bianchini et al. (1986), the 1917 deep minimum might represent a mini-hibernation episode probably caused by thermal instability of the secondary following a phase of an enhanced mass transfer rate. The decline light curve of the nova is characterised by strong oscillations with period $P_0 = 2.95$ yr. We note that these oscillations seem to start coinciding with the nova outburst, while the two peaks of the preoutburst light curve are uncorrelated. At the end of the minihibernation phase, two main periodicities are revealed by the χ^2 technique, at $P_1 = 3.2$ yr and $P_2 = 7.2$ yr. They roughly correspond to the former period, P_0, and to its double, respectively. The amplitudes of these oscillations (the largest being associated with the longer period) decrease with time. In fact, since 1948 the light curve of the old nova became flatter and flatter and well defined dwarf nova-like outbursts appeared (Bianchini et al. 1986). For this reason, the optical outbursts have been excluded from our analysis and so they do not contribute to the mean magnitudes of Figure . In the period 1945–1975 the nova luminosity decreased at a rate of 0.007 mag/yr. However, during the last 14 years we observed a constant increase of the luminosity so that we are tempted to see in all this the presence of an even longer cycle (see Table 1). Most of the optical outbursts of GK Per at quiescence occur at time intervals given by relation $\Delta T = n(400 \pm 40)$ days, where n can be 1, 2, 3, or 5 (Sabbadin & Bianchini 1983). The very recent outburst of July-August 1989, however, occurred about 973 days after the 1986 one. This time interval is just in antiphase with the proposed recurrence period but also coincides with the time interval between the 1978 and 1981 outbursts. Cannizzo & Kenyon (1986) suggested that the outbursts of GK Per are caused by disc instability events starting from the inner regions of the disc. Bianchini et al. (1986) suggested that the accretion disc is cold and stable most of the time and that an unstable transition region can be occasionally formed in its inner regions only in coincidence of maxima of activity of the secondary, that is when the mass transfer rate reaches a certain critical value. Considering the existence of the solar type cycle, one could perhaps argue that the observed time intervals between the outbursts might be submultiples of the 7-yr cycle (about 2400 days). However, the lack of more observational data, as well as of a general model for solar type cycles, does not allow too many speculations in this direction.

In Fig. 6 we present the histogram of the periods of the solar-type cycles discovered in CVs compared with that for late-type main sequence stars (Bianchini et al. 1989).

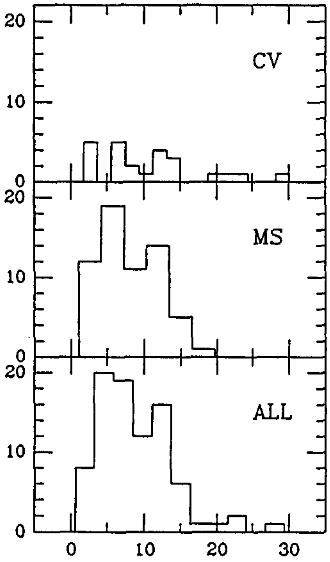

Fig.:6 Histogram of the periods of the Solar-type cycles found in CVs compared with that for late type main sequence stars.

The two distributions can be considered similar at 90% confidence (Kolmogorov–Smirnov test). The density distribution estimate of the sum of the two samples is asymmetric and peaked around 6 yrs. This result is confirmed if we include in the analysis also RS CVn stars. If we analyse the data in the the frequency domain the estimate of the probability density function peaks around 0.095 yr^{-1}.

6. Conclusions.

i) The term "minimum magnitude" of a nova is still unclear. If the 0.4 mag step claimed for three novae (Q Cyg, DI Lac and V603 Aql) about 18 years after maximum is real (Della Valle 1989), this could indicate shutoff of the white dwarf. A first level of a post nova brightness could then be defined. A systematic search to test the reality of this type of effect needs therefore to be undertaken.

ii) Besides the particular case of post outburst standstills (e.g. CP Pup, V1500 Cyg) the magnitudes of prenovae and postnovae are essentially the same. Up to now, evidence for hibernation is based on the observations of only two old novae, one of which (CK Vul) might not be classical.

iii) An effort should be made to confirm the existence of periodic medium term light oscillations.

iv) The presence of what appears to resemble the effect of solar-type cycles should provide a warning about the possible presence of even longer period cycles. We therefore need to live for a thousand years!

v) The probability density distribution of the periods of solar-type cycles discovered in CVs is similar to that for single late-type MS stars and is peaked around 6 yrs.

References

Bath, G. T. (1973). Nature Phys. Sc. 246, 84

Bath, G. T. & Pringle, J. E. (1981). Mon. Not. R. Astron. Soc. 194, 964

Bianchini, A. (1988a). Mem. S. A. It., Vol 58, 245

Bianchini, A. (1988b). Inf. Bull. Var. Stars, N. 3136

Bianchini, A. (1989). (Submitted to Astron. J.)

Bianchini, A., Sabbadin, F., Favero, G. C. & Dalmeri, I. (1986). Astron. Astrophys. 160, 367

Bianchini, A., Maceroni, C., Rodonò, M., Van't Veer, F. & Vio, R. (1989) (work in preparation)

Cannizzo, J. K., Wheeler, J. C. (1984). Astrophys. J. Suppl. 55, 367

Cannizzo, J. K. & Kenyon, S. J. (1986). Astrophys. J. Letters 309, L43

Dalmeri, I., Favero, G. C., Milani, A., Tonello, A., Monella, R. (1988). U. A. I. Astronomia, N. 5, 13

Della Valle, M. & Rosino, L. (1987). Inf. Bull. Var. Stars N. 2995

Della Valle, M. (1989). Ph. D. Thesis, Astron. Dept. University of Padova.

Dinerstein, H., Hoffleit, D. (1973). Inf. Bull. Var. Stars, N. 845

Downes, A. D., Szkody, P. (1989). Astron. J. 97, 1729

Duerbeck, H. W. (1984a). In: "Double Stars, Physical Properties and Generic Relations", eds. Hidayat, B., Kopal, Z., Rahe, J., I.A.U. Colloquium N. 80, Reidel, 363

Duerbeck, H. W. (1984b). Astrophys. Space Sci. 99, 363

Favero, G. C., Dalmeri, I. (1989). U. A. I. Astronomia, (in press)

Friedjung, M. (1985). Astron. Astrophys. 146, 366

Hoshi, R. (1979). Progr. Theor. Phys. 61, 1307

Hudec, R. (1981). B.A.C. 32, 93

Lynden-Bell, D. & Pringle, J. (1974). Mon. Not. R. Astr. Soc. 168, 603

Meyer, F. & Meyer-Hofmeister, E. (1984). Astron. Astrophys. Letters 140, 35

Osaki, Y. (1974). Publ. astron. Soc. Japan 26, 429

Prialnik, D. & Shara, M. M. (1986). Astrophys. J. 311, 172

Robinson, E. L. (1975). Astron. J. 80, 515

Sabbadin, F., Bianchini, A. (1983). Astron. Astrophys. Suppl. Ser. 54, 393

Shara, M. M., Livio, M., Moffat, A. F. J., Orio, M. (1986). Astrophys. J., 314, 653

Shugarov, S. Yu. (1983). Variable Stars 21, N. 6, 807

Vogt, N. (1981). Mitt. Astr. Gesell. 57, 79

Vogt, N. (1987). In:"Classical Novae", eds. Evans, A., and Bode, M.F., John Wiley.

Walker, M. F. (1957). In: "Non Stable Stars", ed. Herbig, G. H., IAU Symp. N. 3, 46
Warner, B. (1986). Mon. Not. R. Astron. Soc. 219, 751
Warner, B. (1987). Mon. Not. R. Astron. Soc. 227, 23
Warner, B. (1988). Nature, Vol. 336, 129
Williams, R. E. (1989). Astron. J. 97, 1752
Wolf, B. (1977). In: "The Interaction of Variable Stars with Their Environment", eds. Kippenhahn, R., Rahe, J., and Strohmeier, W., Bamberg, Remeis-Sternwarte, 151