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$BVRI$ observations of dwarf novae in outburst

I. AL Comae Berenices, V544 Herculis, V660 Herculis, V516 Cygni and DX Andromedae

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Abstract. In this paper we report photometric observations of AL Com, V544 Her, V660 Her, V516 Cyg and DX And taken during the descending phase after an outburst. For four of these variables we calibrated comparison stars in the field of view. Our observations cover the period in which AL Com showed the larger optical outburst since 1974, and V660 Her showed the larger outburst ever reported in the literature ($B \simeq 14.3$). The optical spectral distribution of DX And, AL Com and V660 Her shows that the model of the steady–state accretion disk does not provide a good representation of the optical continuum during the decline phase of a dwarf nova outburst.

Key words: stars: cataclysmic variables; stars: individual: AL Com, V544 Her, V660 Her, V516 Cyg, DX And

1. Introduction

Cataclysmic variable stars (CVs) are binary systems with a white dwarf primary and a late-type main sequence secondary star in orbit around each other with periods of only a few hours. The secondary star fills its Roche lobe and the mass it loses through the inner Lagrangian point forms an accretion disk around the white dwarf. In CVs accretion luminosity is usually the dominant contribution to the total light of the system.

Dwarf novae (DNs) are a sub–class of cataclysmic variables characterized by the presence of sudden increases of brightness (outbursts) in the optical light curve. The outbursts have amplitudes in the range $2-5$ mag and they occur at irregular intervals of time, typically ranging from about ten days to some months. In the case of dwarf novae, the disk instability model seems to account for most of the properties observed during a normal outburst (see, e.g., Meyer & Meyer-Hofmeister 1994).

Sometimes some dwarf novae show "superoutbursts" in the light curve, which are characterized by a larger amplitude and a longer duration than normal outbursts. Superoutbursts occur at regular, but not strictly periodic intervals of time (see, e.g., Osaki 1996). In order to explain these superoutbursts, three different models have been proposed: the enhanced mass transfer model, the thermal limit cycle model, and the thermal–tidal instability model (for a complete review, see Osaki 1996, and references therein).

So far, most of the optical observations of dwarf novae were carried out photographically or have been supplied by amateur astronomers through visual estimations, and multi–wavelength campaigns have been carried out only for a few of the brightest DNs (see, e.g., Echevarria et al. 1996). Indeed, multi-band monitoring is of special interest in order to extend the work done by amateurs, to study the spectral behavior of the optical continuum, and to explore the physics of accretion disks. For this reason we included a small sample of dwarf novae as a secondary target in our automatic monitoring program of variable sources.

We here present the photometric observations of five DNs (see Table 1) which showed a high level of activity during the period October 1994 - July 1995.

2. Observations

The observations were taken with the 0.40 m Automatic Imaging Telescope at the Perugia Astronomical Observatory (Tosti et al. 1996). The telescope is mainly devoted to the monitoring of a large sample of blazars (Fiorucci & Tosti 1996b), however, a fraction of the telescope time is dedicated to the photometric observations of DNs. The telescope is equipped with a CCD camera and B, V (Johnson) and R_c, I_c (Cousins) filters. Our photometric system has carefully been tested by observing both the M 67 sequence (Chevalier & Ilovaisky 1991) and Landolt stars (Landolt 1983a,b, 1992). No systematic errors were detected (see Fiorucci & Tosti 1996a).

Table 1. Coordinates and historical informations of the five selected objects⋆

Name	R.A. (2000)	DEC (2000)	galactic latitude	Type$^{(a)}$	Mmax$^{(b)}$	Mmin$^{(c)}$	filter$^{(d)}$
AL Comae	12 32 25.61	+14 20 57.5	+76°	UG/DQ	12.8	22	v
V544 Her	16 38 05.48	+08 37 57.4	+33°	UG	14.5	$\simeq$ 20	p
V660 Her	17 42 09.13	+23 48 30.2	+25°	UG	16.0	$\simeq$ 19	p
V516 Cyg	20 47 09.87	+41 55 26.0	0 °	UGSS	13.8	16.8	p
DX And	23 29 46.82	+43 45 03.4	−16°	UG	10.9	16.4	p

Notes: a) UG=U Gem variable, UGSS=U Gem variable (SS Cyg subtype), DQ=DQ Her variable; b) maximum apparent magnitude; c) minimum apparent magnitude; d) magnitude systems: v=visual, p=photographic.
⋆ extracted from the catalogue of Downes & Shara (1993).

All the CCD frames were corrected for bias and dark signal. Because of the high grade of uniformity of our CCD chip the usual flat field correction of the images was not required (see Tosti et al. 1996). The CCD frames were processed by REDUCE, the automatic reduction software described in Tosti et al. (1996). This photometry package, which is based on the algorithms described by Stetson (1987), finds and recognizes the stars in the frame and calculates the instrumental magnitudes through synthetic aperture photometry. The magnitudes reported in this paper have been obtained using an aperture radius of 4 arcsecs.

The data on AL Com were calibrated using Landolt stars because of the lack of sufficiently bright comparison stars within the limits of our CCD camera field of view. The correct finding chart for AL Com can be found in Howell et al. (1996).

For all the other dwarf novae reported in Table 1 we performed differential photometry using some non–variable stars present in their fields (see the finding charts shown in Figs. 1-4). The finding chart of V660 Her was already given by Downes & Shara (1993) but it was incorrect. In Fig. 4 we report the correct one.

In order to obtain B, V, R_c, I_c secondary standard sequences in the field of the dwarf novae, the comparison stars were calibrated by observing, on photometric nights, several standard stars (Landolt 1983a,b, 1992) having $(B-V)$ from −0.2 to 1.2, over a wide range of airmasses. The standard stars observations were then used to define the following transformations to the standard system:

$$B - b_0 = \alpha_b + \beta_b(b - v)_0$$
$$V - v_0 = \alpha_v + \beta_v(v - r)_0$$
$$R_c - r_0 = \alpha_r + \beta_r(v - r)_0$$
$$I_c - i_0 = \alpha_i + \beta_i(v - i)_0.$$

In the above equations, the atmospheric extinction corrected instrumental magnitudes are denoted by the index ("○"). The values of the α and β coefficients were estimated via least–squares linear regressions on each photometric night. Table 2 lists only the mean transformation coefficients, their standard errors, and the typical standard deviations of the fit (σ_f). As a result of the stability of our photometric system, we did not find appreciable differences among the values reported in Table 2 and the ones given in Fiorucci & Tosti (1996a).

Table 2. Transformation coefficients to the standard system

	α	β	σ_f
$B - b_0$	15.80 ± 0.03	−0.02 ± 0.03	0.05
$V - v_0$	16.65 ± 0.03	−0.01 ± 0.01	0.04
R_c - r_0	16.70 ± 0.03	0.00 ± 0.01	0.04
I_c - i_0	16.16 ± 0.03	0.01 ± 0.02	0.04

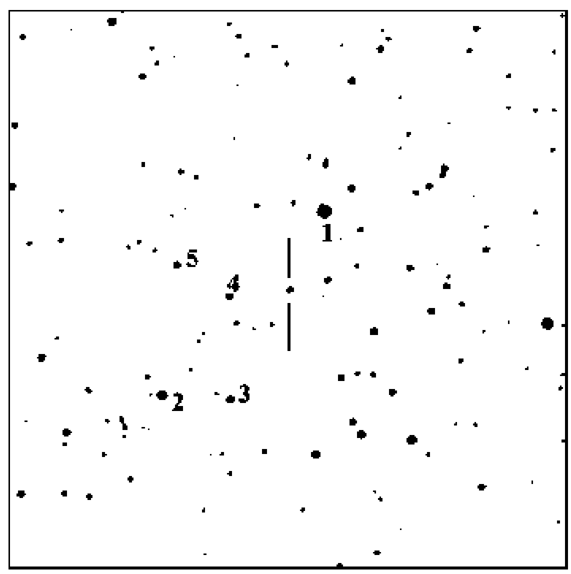

Fig. 1. Finding chart of V544 Her. North is at the top and east is to the left. The box is 10 arcmin wide

The standard magnitudes of the comparison stars reported in Table 3 are the weighted means of the values obtained during at least three photometric nights.

The B and R_c magnitudes of the comparison stars in the field of DX And are in good agreement with the measurements carried out by Drew et al. (1993).

Table 3. BVR_cI_c magnitudes of the selected comparison stars

Name	B	V	R_c	I_c
V544Her				
1	12.42±0.06	11.82±0.04	11.52±0.04	11.30±0.06
2	14.06±0.06	13.51±0.04	13.14±0.04	12.94±0.05
3		15.16±0.06	14.56±0.06	14.13±0.06
4		15.45±0.08	14.87±0.08	14.31±0.06
5		15.50±0.08	15.11±0.08	14.75±0.08
V660Her				
1	12.48±0.07	11.79±0.07	11.44±0.05	11.09±0.07
2	13.48±0.08	12.87±0.08	12.46±0.05	12.18±0.07
3		14.81±0.07	14.52±0.05	14.14±0.07
V516Cyg				
1	15.08±0.10	14.21±0.04	13.72±0.04	13.25±0.04
2		15.35±0.04	14.73±0.04	14.15±0.05
3		15.56±0.07	14.82±0.04	13.93±0.05
DX And				
1	13.42±0.05	12.72±0.05	12.25±0.05	11.92±0.05
2	13.90±0.05	13.33±0.05	12.95±0.05	12.65±0.05

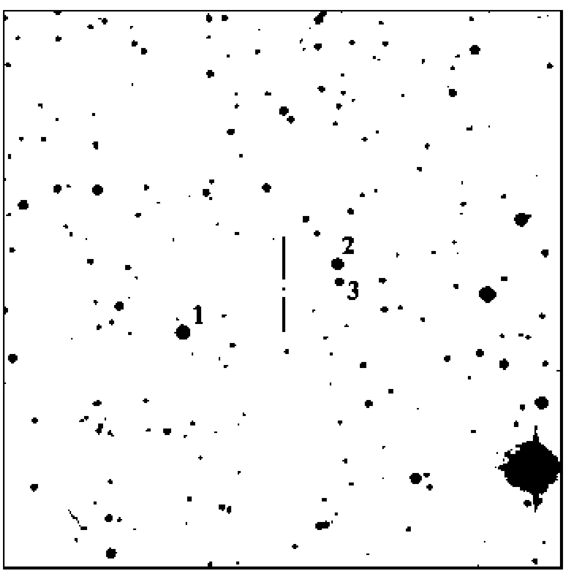

Fig. 2. Finding chart of V660 Her. North is at the top and east is to the left. The box is 10 arcmin wide

Tacking into account of the typical errors in the measurement of the instrumental magnitudes (0.02 in V, R_c, I_c, and 0.03 in B), the contribution of the colour terms present in the above transformation equations results to be negligible, at least over the range of colour indices of the comparison and variable stars here considered. Therefore, the comparison stars were used to find the value of the zero point of the magnitude scale for each CCD image and, then, to measure the dwarf nova standard magnitude and its error (see Tables 4, 5, 6, 7 and 8).

3. Notes on individual objects

3.1. AL Com

AL Com was discovered and classified as an eruptive variable star by Rosino (1961). At quiescence it is very faint ($m_{pg} \simeq 20$), but large amplitude ($\simeq$ 8 mag) outbursts have been detected in 1961, 1965, 1974 and 1975 (Bertola 1964; Moorehead 1965; Scovil 1975).

Recently, Patterson et al. (1996) and Kato et al. (1996) have suggested a period of 81.6 min as the orbital period of the binary system. There are also brightness variations in quiescence at a period which varies between 80 and 90 min (see, e.g., Howell & Szkody 1991; Abbott et al. 1992).

We intermittently monitored AL Com since 1994. It was always below the limit of detectability of our instrument, until the beginning of April 1995 when, after about 20 years of quiescence, it started to increase its brightness. The light curve during this rare superoutburst has been well sampled by the American Association of Variable Star Observers (AAVSO), by the Astronomer Group and by many others (see, e.g., Patterson et al. 1996; Kato et al. 1996; Howell et al. 1996). The peak of the outburst was visually estimated to be 11.8 mag on April 5.83 UT (JD 2449813, see Howell et al. 1996).

We observed $V = 12.57$ on April 6.87 UT (JD 2449814), a day after the maximum, and we followed the light curve decline during some photometric nights in April. Table 4 lists the BVR_cI_c magnitudes while the R_c light curve is reported in Fig. 5.

The BVR_cI_c light curves show a linear decay lasting for almost a week after the peak. We calculated the following values for the decay rates:

Table 4. BVR_cI_c magnitudes of AL Com

Date (UT)	JD (2449000+)	B	V	R_c	I_c
95/03/24	800.504			> 16.0	> 16.0
95/04/06	814.372	12.37±0.05	12.57±0.05	12.63±0.05	12.67±0.05
95/04/06	814.444	12.32±0.05	12.56±0.05	12.67±0.05	12.61±0.05
95/04/06	814.487	12.41±0.05	12.57±0.05	12.76±0.05	12.70±0.05
95/04/07	814.578	12.51±0.05	12.71±0.05	12.75±0.05	12.64±0.05
95/04/07	815.364	12.61±0.05	12.89±0.06	12.82±0.06	12.81±0.06
95/04/07	815.498	12.54±0.05	12.85±0.06		
95/04/09	817.367	12.88±0.10	13.10±0.06	13.02±0.06	13.08±0.06
95/04/11	819.408	13.14±0.06	13.33±0.05	13.31±0.05	13.26±0.06
95/04/11	819.460	13.07±0.06	13.38±0.06	13.21±0.06	13.27±0.06
95/04/21	829.357	13.72±0.12	14.01±0.09	14.00±0.08	13.98±0.08
95/05/02	839.419			16.68±0.20	> 16.0

Table 5. BVR_cI_c magnitudes of V544 Her

Date (UT)	JD (2449000+)	B	V	R_c	I_c
95/06/21	890.456			> 16.5	
95/06/27	896.388	15.20±0.08	15.20±0.08	15.18±0.05	14.97±0.08
95/06/28	897.393		15.70±0.15	15.48±0.13	15.54±0.15
95/06/30	899.352			16.45±0.12	16.10±0.15
95/06/30	899.415		16.77±0.20	16.61±0.15	16.12±0.15
95/07/01	900.358			> 17.0	16.60±0.20
95/07/06	905.417			> 17.0	

Table 6. BVR_cI_c magnitudes of V660 Her

Date (UT)	JD (2449000+)	B	V	R_c	I_c
95/06/30	899.405		> 16.5	> 16.5	16.57±0.20
95/07/01	900.417	> 16.5	> 16.5	> 16.5	16.52±0.20
95/07/06	905.368	14.40±0.07	14.38±0.04	14.29±0.04	14.29±0.06
95/07/06	905.451	14.31±0.06	14.31±0.04	14.20±0.03	14.20±0.05
95/07/07	906.369	14.46±0.09	14.40±0.05	14.33±0.06	14.47±0.08
95/07/07	906.437	14.27±0.13	14.27±0.09	14.20±0.10	14.31±0.07
95/07/08	906.593		14.34±0.09	14.37±0.07	14.24±0.08
95/07/08	907.383	14.36±0.10	14.51±0.06	14.43±0.05	14.31±0.06
95/07/09	908.383	14.39±0.08	14.36±0.06	14.31±0.05	14.37±0.06
95/07/10	909.359	14.51±0.08	14.57±0.06	14.66±0.06	14.63±0.08
95/07/11	910.366	14.76±0.11	14.85±0.10	14.72±0.07	14.58±0.10
95/07/11	910.490	14.70±0.10	14.76±0.10	14.66±0.10	14.51±0.10
95/07/13	912.362	14.65±0.12	14.96±0.08	14.87±0.07	14.87±0.12
95/07/13	912.456	14.87±0.10	15.02±0.10	14.87±0.10	14.75±0.10
95/07/16	915.388	15.22±0.07	15.20±0.10	15.23±0.07	15.32±0.10
95/07/18	917.429	16.71±0.20	16.29±0.12	16.12±0.10	16.02±0.10
95/07/23	922.372			15.97±0.10	15.92±0.13
95/07/25	924.368			> 16.5	> 16.0

Table 7. BVR_cI_c magnitudes of V516 Cyg

Date (UT)	JD (2449000+)	B	V	R_c	I_c
95/07/07	905.511		14.14±0.04	13.98±0.05	13.99±0.05
95/07/08	906.551	14.37±0.15	14.22±0.07	14.06±0.05	14.01±0.05
95/07/09	907.554	14.27±0.08	14.33±0.04	14.14±0.05	14.12±0.07
95/07/09	908.471	15.15±0.15	14.87±0.07	14.63±0.07	14.58±0.08
95/07/11	910.468	> 16.0	> 16.0	16.36±0.15	
95/07/13	912.481			16.60±0.20	

Table 8. BVR_cI_c magnitudes of DX And

Date (UT)	JD (2449000+)	B	V	R_c	I_c
94/09/28	624.46	12.03±0.06	11.93±0.04	11.79±0.03	11.69±0.04
94/09/28	624.49	11.98±0.05	11.91±0.04	11.73±0.04	11.67±0.03
94/09/29	624.52	11.97±0.05	11.93±0.04	11.76±0.04	11.66±0.04
94/09/29	624.54	12.07±0.05	11.93±0.05	11.78±0.04	11.69±0.04
94/09/29	625.25	12.08±0.06	12.00±0.04	11.85±0.06	11.74±0.04
94/09/29	625.35	12.04±0.06	12.01±0.04	11.84±0.04	11.72±0.04
94/09/29	625.44	12.07±0.06	11.98±0.04	11.86±0.04	11.71±0.04
94/10/01	627.34		12.16±0.04	11.95±0.04	11.83±0.05
94/10/03	629.37	12.49±0.05	12.36±0.03	12.16±0.04	12.04±0.04
94/10/04	630.49	12.73±0.06	12.58±0.04	12.33±0.04	12.20±0.04
94/10/05	631.37	12.92±0.04	12.77±0.03	12.59±0.05	12.30±0.04
94/10/05	631.43	12.96±0.05	12.78±0.03	12.54±0.04	12.34±0.03
94/10/06	632.28	13.18±0.04	13.01±0.04	12.78±0.04	12.57±0.03
94/10/06	632.38		13.08±0.04	12.83±0.04	12.60±0.03
94/10/06	632.44	13.25±0.05	13.06±0.03	12.84±0.04	12.59±0.03
94/10/07	633.46	13.60±0.05	13.47±0.04	13.11±0.05	12.89±0.06
94/10/08	634.34		13.77±0.05	13.49±0.05	13.16±0.06
94/10/10	636.42	15.43±0.05	14.61±0.05	14.11±0.05	13.66±0.04
94/10/13	639.28	15.67±0.08	14.86±0.05	14.26±0.04	13.75±0.04
94/10/15	641.48		14.85±0.05	14.29±0.04	13.65±0.04
94/10/22	648.48		14.84±0.06	14.30±0.04	13.75±0.04
94/10/27	653.43	15.93±0.10	14.97±0.04		
94/11/17	674.39	15.72±0.09	14.98±0.04	14.40±0.04	13.85±0.04

$$\mathrm{d}M(B)/\mathrm{d}t = 0.14 \pm 0.01 \text{ mag/day}$$
$$\mathrm{d}M(V)/\mathrm{d}t = 0.14 \pm 0.01 \text{ mag/day}$$
$$\mathrm{d}M(R_c)/\mathrm{d}t = 0.12 \pm 0.01 \text{ mag/day}$$
$$\mathrm{d}M(I_c)/\mathrm{d}t = 0.12 \pm 0.01 \text{ mag/day.}$$

In the V band, the rate is consistent with the values reported by Howell et al. (1996) and Patterson et al. (1996). It is worthy to note that the decay rate is slower at longer wavelengths. Nevertheless, during the superoutburst the colour indices remained quite stable around the mean values: $(B-V) = -0.25$, $(V-R_c) = 0.00$, $(V-I_c) = 0.03$.

At epoch 1995/05/02 UT (JD 2449839) AL Com was very faint. This point was taken during the temporary minimum reported by the above mentioned authors. Unfortunately we were not able to obtain a better sampled light curve of the variable due to bad weather conditions.

3.2. V544 Her

V544 Her was discovered and classified as a dwarf nova by Hoffmeister (1967). Also this star is very faint at quiescence ($m_{pg} \simeq 20$), but during an outburst its photographic magnitude can increase up to 14.5 (Downes & Shara 1993). Howell et al. (1990) observed V544 Her at minimum and found the presence of a possible orbital modulation having a period of about 100 minutes.

We observed this dwarf nova during July 1995. The variable was found in a declining phase after a burst which, probably, reached the maximum a few days before 1995/06/27 UT (see Table 5). Although we were able to get only a few observations, we note that our observations on 1995/06/27 UT are the first BVR_cI_c measurements of V544 Her during an outburst. At that time the

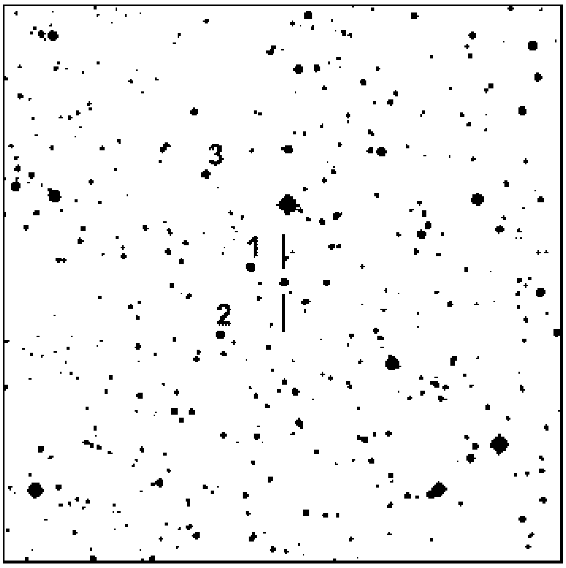

Fig. 3. Finding chart of V516 Cyg. North is at the top and east is to the left. The box is 10 arcmin wide

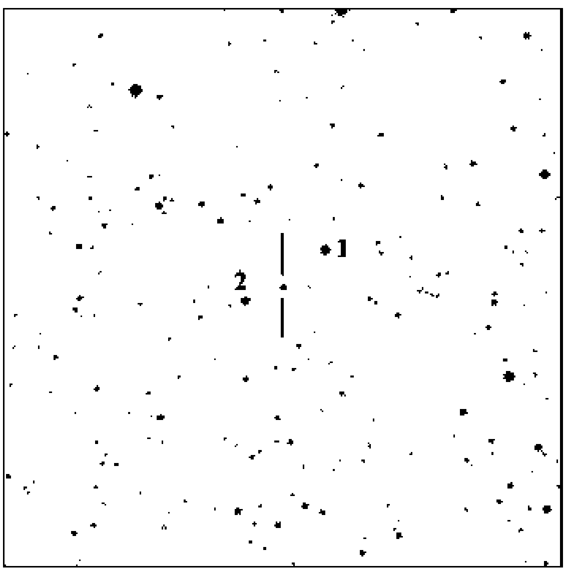

Fig. 4. Finding chart of DX And. North is at the top and east is to the left. The box is 10 arcmin wide

colour indices were $(B-V) = 0.00$, $(V-R_c) = 0.02$, $(V-I_c) = 0.23$.

3.3. V660 Her

The dwarf nova V660 Her is not well studied. As far as we know, only Shugarov (1975) observed this source during two outbursts. The first one was observed on August 4-5, 1973, while the second one occurred on August 12-13, 1974. In both the cases the estimated photographic magnitude of the variable at maximum was $m_{pg} \simeq 16$.

We observed the dwarf nova V660 Her in July 1995 during the phase of decline from a large outburst. In

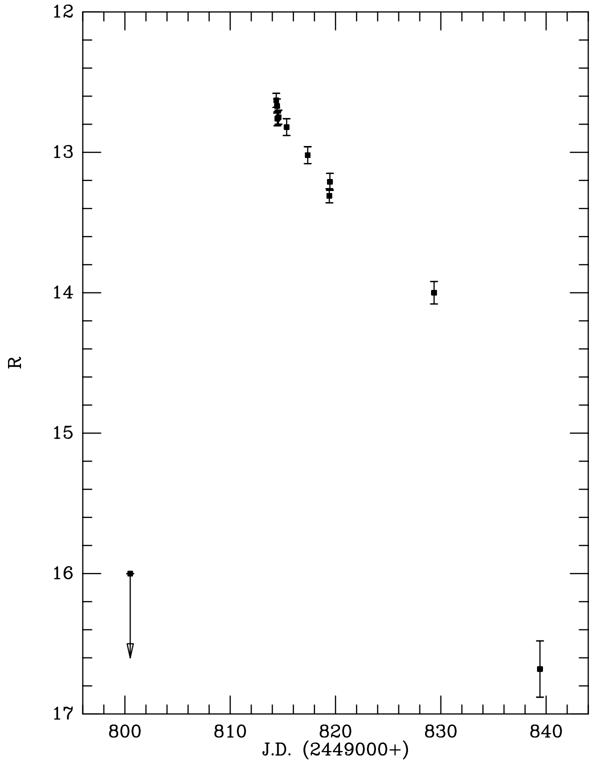

Fig. 5. R_c light curve of AL Com

Table 6 we report the BVR_cI_c magnitudes while the light curve can be found in Fig. 6. The observed maximum was $B \simeq 14.3$ (JD 2449905), a value which is almost two magnitudes higher than that previously reported by Shugarov (1975). From our data it appears that the source probably reached its maximum a few days before our first positive detection (see Fig. 6), but the true maximum brightness is not likely to be higher by more than 0.5 mag.

During the first 10 days the mean colour indices were $(B-V) = -0.04$, $(V-R_c) = 0.06$, $(V-I_c) = 0.07$, and the light curve showed a linear decay with the following rates:

$$\mathrm{d}M(B)/\mathrm{d}t = 0.14 \pm 0.03 \text{ mag/day}$$
$$\mathrm{d}M(V)/\mathrm{d}t = 0.15 \pm 0.02 \text{ mag/day}$$
$$\mathrm{d}M(R_c)/\mathrm{d}t = 0.13 \pm 0.01 \text{ mag/day}$$
$$\mathrm{d}M(I_c)/\mathrm{d}t = 0.13 \pm 0.01 \text{ mag/day.}$$

These values are quite similar to those recorded for AL Com and WZ Sge (Patterson et al. 1996).

At the end of the descending phase, the light curve showed a dip at the date 1995/07/18 UT (JD 2449917). This last part of the outburt, observed only in the R_c and I_c bands, seems to show a feature similar to the temporary minimum observed in AL Com (Howell et al. 1996) and WZ Sge (Patterson et al. 1996). The resemblance of the outburst light curve of V660 Her with AL Com and WZ Sge (especially the rates of decline which are very similar) and the large amplitude of the observed outburst suggest that V660 Her could belong to the recently

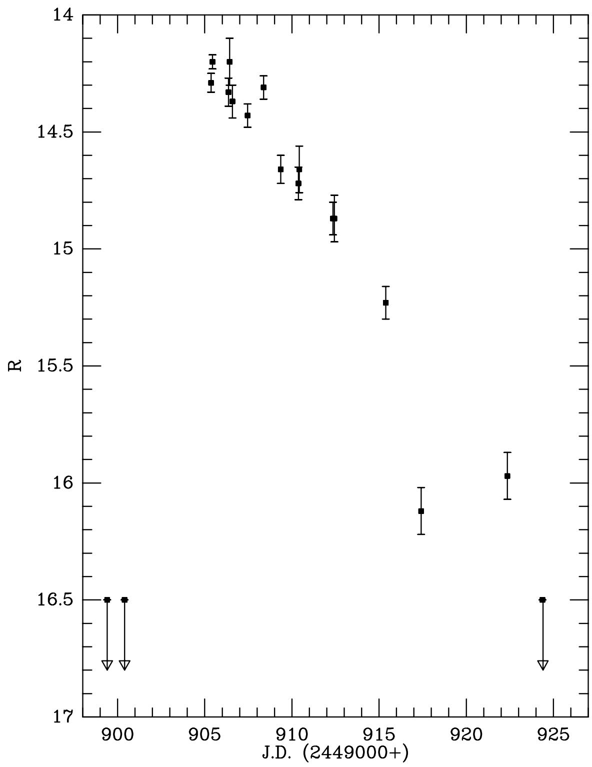

Fig. 6. R_c light curve of V660 Her

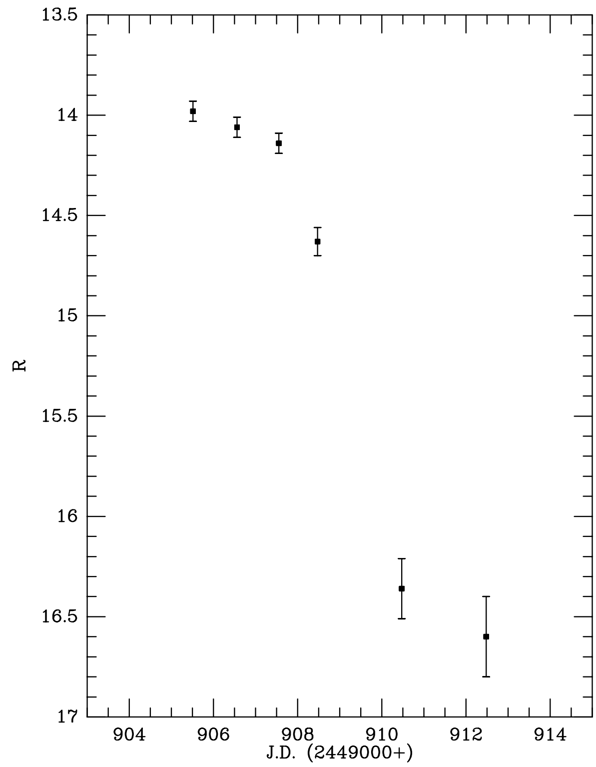

Fig. 7. R_c light curve of V516 Cyg

identified sub–class of dwarf novae called "tremendous outburst amplitude dwarf novae" (TOADs) (see Howell et al. 1995). However, further observations are required in order to know the true magnitude of V660 Her at minimum, now only estimated to be $m_{pg} \simeq 19$ (Downes & Shara 1993), and to obtain a better sampling of the light curve during the outbursts.

3.4. V516 Cyg

The dwarf nova V516 Cyg was discovered and classified as a variable star by Hoffmeister (1949). Ahnert et al. (1949) classified V516 Cyg as an RW Aur variable. It was definitively classified as a dwarf nova by Meinunger (1966) and Erastova & Tsvetkov (1978). Spectroscopic observations of V516 Cyg have been published by Bruch & Schimpke (1992), Schimpke & Bruch (1992), Zwitter & Munari (1994). In the optical, the photographic magnitude is known to vary between $m_{pg} \simeq 13.8$ and $m_{pg} \simeq 16.8$ (Downes & Shara 1993).

The BVR_cI_c photometric observations were carried out during July 1995. The data are reported in the Table 7, while Fig. 7 shows the R_c light curve. As far as we know, this is the first time that V516 Cyg was observed during an outburst in the BVR_cI_c bands. The variable remained bright for 3 days at a V magnitude of $\simeq$14, during which it had colour indices of $(B-V)=0.1$, $(V-R_c)=0.2$, $(V-I_c)=0.2$.

3.5. DX And

DX And was discovered as a variable star by Romano (1958). It was classified as a dwarf nova of the U Gem type by Weber (1962, 1963). In the optical it has been studied by Romano & Perissinotto (1966), Bond (1978), Echevarria & Jones (1984), Bruch et al. (1987). Spectroscopic observations during quiescence were reported by Bruch (1989). The IUE spectra reported by Drew et al. (1991) show absorption features at 124 nm and 155 nm due to N V and C IV respectively. Drew et al. (1993) determined a binary period of 0.44167 day and a mass ratio of 0.96, through spectroscopic observations when DX And was at minimum. Photometric observations in the Johnson B-band, Kron-Cousins R_c-band, and Gunn z-band revealed ellipsoidal variation of 0.08 mag only in Gunn z (Drew et al. 1991). Analysing the luminous variations in the R_c and I_c bands, Hilditch (1995) suggested that the inclination of the orbital plane of DX And is in the range between 45° and 53°, and that the secondary component is a K0-1 V star.

Although DX And is one of the better studied cataclysmic variables in our sample, up to date only few photometric data obtained during the phase of the outburst have been published. The interval between two consecutive outbursts varies between 8-12 months (see Drew et al. 1993).

We monitored DX And intermittently during the second half of 1994. It was always at quiescence, until

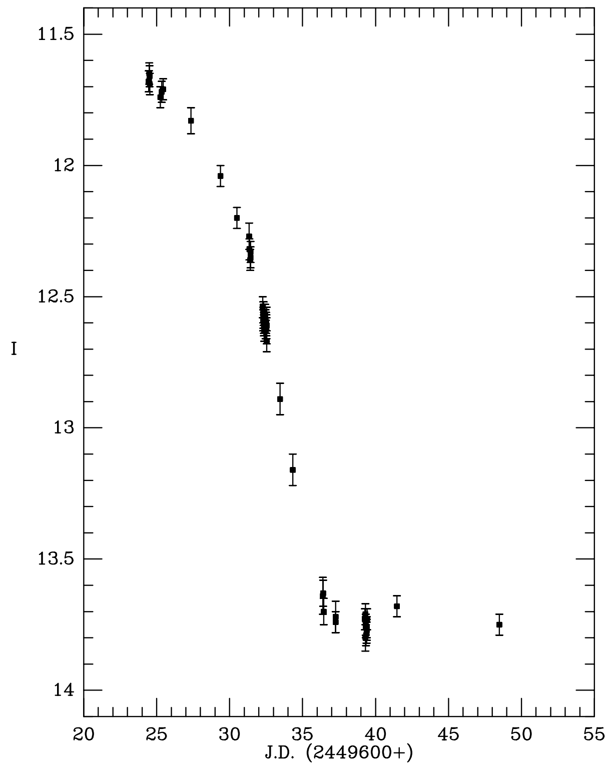

Fig. 8. I_c light curve of DX And

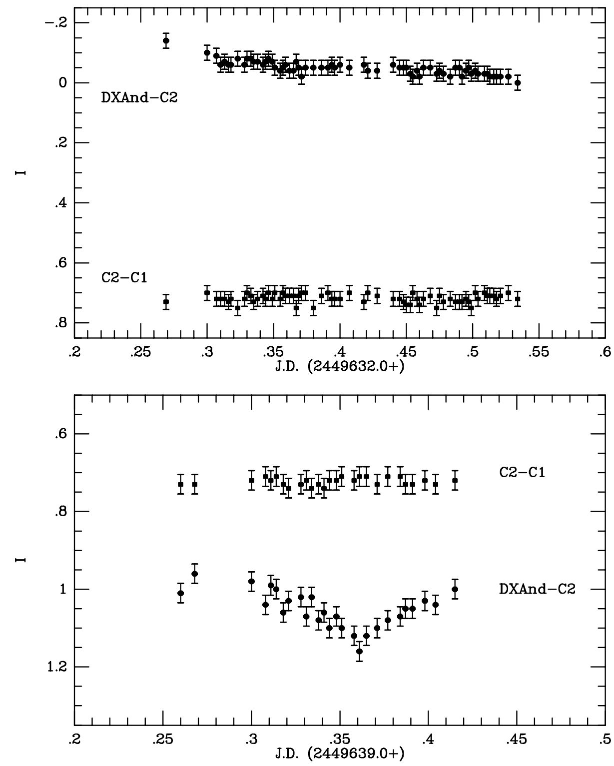

Fig. 9. Intranight light curves of DX And during the decline (top) and at the minimum (bottom)

September 28, 1994 UT (JD 2449624), when the dwarf nova was found to be in outburst. Our data are reported in Table 8. The I_c light curve is shown in Fig. 8.

We note that the outburst amplitude is larger at higher frequencies: that is $\Delta B \simeq 4$, $\Delta V \simeq 3$, $\Delta R_c \simeq 2.5$, $\Delta I_c \simeq 2$.

Soon after the maximum, DX And showed a non-linear decay, starting with a slow rate which progressively became faster. In the last part of the decline (from JD 2449631 to 2449634) the decay appear to be approximately linear, with the following rates:

$$\mathrm{d}M(B)/\mathrm{d}t = 0.37\pm0.01 \text{ mag/day}$$
$$\mathrm{d}M(V)/\mathrm{d}t = 0.34\pm0.01 \text{ mag/day}$$
$$\mathrm{d}M(R_c)/\mathrm{d}t = 0.30\pm0.01 \text{ mag/day}$$
$$\mathrm{d}M(I_c)/\mathrm{d}t = 0.28\pm0.01 \text{ mag/day.}$$

To study the rapid variability of DX And, we performed time series observations during two nights: the first one during the decline (JD 2449632) and the second one during the quiescent phase (JD 2449639). We used only the I_c filter and the data are displayed in Fig. 9. During the first run we saw a regular descending trend with a rate of 0.23±0.03 mag/day. In the second run we found a rapid variation of about 0.1 mag similar to the ellipsoidal variability observed by Hilditch (1995) during the quiescence, while this effect is not evident during the decline probably because of the presence of the bright accretion disk.

4. Discussion

BVR_cI_c observations of dwarf novae allow to evaluate the optical spectral behaviour and, therefore, they can be used as a test to compare theoretical models of accretion disk emission. In particular they can be used to verify the often quoted theoretical flux distribution of a stationary (infinitely) large accretion disk whose surface elements radiate black body spectra ($F(\nu) \propto \nu^{1/3}$).

To study the behaviour of the optical continuum of dwarf novae during the decline from the outburst, we converted the BVR_cI_c magnitudes in fluxes using the conversion factors reported by Bessell (1979).

For DX And, we corrected our observations by the interstellar extinction adopting the value $A_V = 0.6$ reported by Drew et al. (1993), and using the interpolation formulae of Cardelli et al. (1989). For the other DNs here reported, the interstellar extinction values are not known and, then, the fluxes are not corrected by this effect.

The flux spectral distributions of DX And, from the maximum to the minimum, are shown in Fig. 10 in logarithmic scale. It is worthy to note that at the minimum the spectral distribution of DX And is dominated by the emission of the secondary star, while at the maximum the spectral distribution follows a power law ($F(\nu) \propto \nu^{\alpha}$). The value of the spectral slope observed at maximum ($\alpha = 1.00 \pm 0.04$) is greater than the one predicted by the steady state accretion disk theory ($\alpha = 0.33$).

The differences in outburst amplitude as a function of wavelengths, the strong change in decay rates and the change in flux distribution with time (see Fig. 10) are all probably the expression of the same phenomenon, i.e. the the strong contribution of the secondary to the total light in quiescence.

For V660 Her we observed a descending trend comparatively coherent in the BVR_cI_c bands and a spectral flux distribution which is well described by a power law. Although this variable showed rapid spectral changes all during the outburst decline (probably related to flickering), the mean spectral slope remained quite constant around a value of $\alpha = 0.8 \pm 0.2$. This substantial stability of the mean spectral index seems to indicate the dominance of the accretion disk emission, while the contribution from the secondary star to the total light of the system seems to be negligible. This is opposite to the behaviour of DX And where the emission of the secondary star becomes soon evident after the first phase of the decline.

The spectral flux distribution of AL Com is well described by a power law with a constant slope α=1.1 ± 0.1. Szkody et al. (1996) observed AL Com with IUE at the date 1995/04/16 UT and they found an UV continuum having a spectral slope $\alpha = 1.0$, a value which is similar to that derived by us in the optical. Howell et al. (1996) give the J, H, K magnitudes obtained on 1995/04/10 and 1995/04/20 UT. Converting these values in fluxes, we computed an IR spectral slope α=1.4 ± 0.1 in both the dates. In Fig. 11, these IR fluxes are combined with our data to obtain the optical-infrared spectral flux distribution. To do this, our BVR_cI_c magnitudes obtained on 1995/04/09-11 and 1995/04/21 UT, were scaled to the same date of the near–IR observations using the decline rates previously reported. For both the dates the total spectral slopes are similar: α=1.20 ± 0.04 and α=1.26 ± 0.04 respectively.

Only for V516 Cyg and V544 Her our data show that, at least during the maximum, there is a substantial agreement with the predicted emission from an accretion disk in stationary state. In fact we obtained $\alpha = 0.3 \pm 0.1$ for V516 Cyg, and $\alpha = 0.4 \pm 0.1$ for V544 Her. However these values are obtained without the correction from the interstellar extinction and, therefore, they must be considered lower limits to the real ones.

For DX And, V660 Her and AL Com, we have seen that it is not possible to approximate their emission during the outburst as the contribute of a disk whose surface elements radiate black body spectra. On the other hand, the value of $\alpha = 0.33$ is true only for an infinitely large steady state disk. In the UV this value gives relatively reasonable fits (see., e.g., Verbunt 1987), but in the optical the emission is dominated by the outer parts of the disk, and the finite size of the disk may result in a stronger slope at these wavelengths.

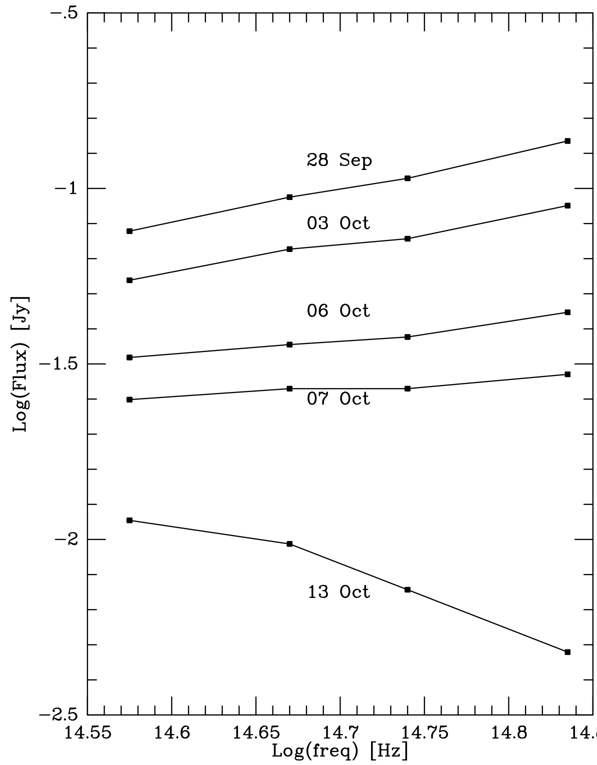

Fig. 10. Spectral flux distribution of DX And during the 1994 outburst

Atmospheric emission disk models seem to fit the observed emission spectra better than the standard Planckian emission disk model (see, e.g., Wade 1984, 1988). However, the lack of such basic parameters as the mass of the white dwarf and the inclination of the system make a proper comparison of the optical observations and any emission disk models rather uncertain (see, e.g., La Dous 1989).

5. Conclusions

For the five dwarf novae considered in this work, our data can be considered a substantial contribution to their optical database. In particular, for V660 Her our measurements detected the largest outburst ever reported, and for AL Com we observed the larger outburst since more than 20 years.

Our data suggest that at least for DX And, AL Com, V660 Her and SY Cnc (Spogli et al. 1993) steady–state accretion disk models do not provide a good representation of the optical continuum. This is a clear evidence about our poor knowledge of the true radiative transfer solution in accretion disk, and more efforts must to be made to obtain multi–wavelength observations of DNs.

These considerations show how important it is to study the dwarf novae during all the phases of the outburst, integrating photometric multi–band observations with the aim of studying both the behaviour of the light curve and

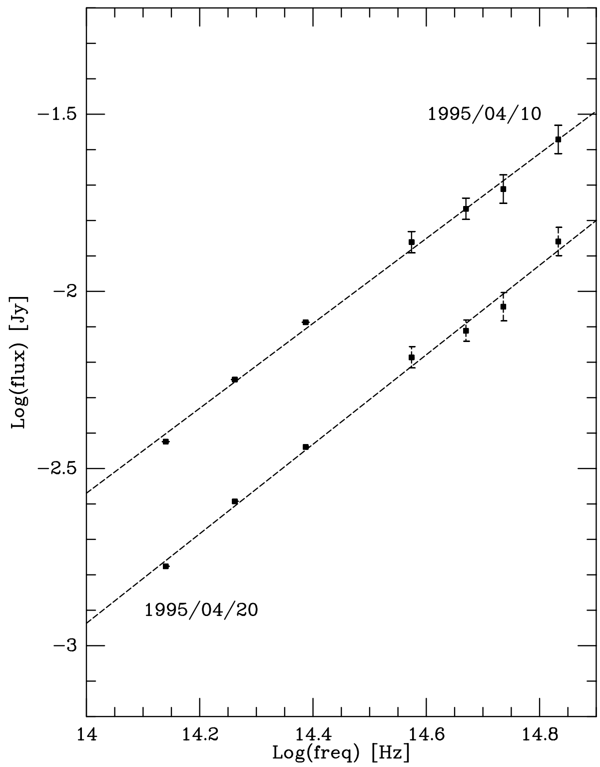

Fig. 11. BVR_cI_cJHK spectral flux distribution of AL Com during the outburst

the spectral distribution of the emitted flux. This work requires a continuous monitoring of a sample of sources and, therefore, it cannot be done with the great astronomical telescopes, because the limited availability of time that is given to every type of study. On the other hand, having to observe quite bright objects, we can use small telescopes, which are available and well suitable to carry out programs of long–term CCD photometry of dwarf novae. In this context the observations obtained at the Astronomical Observatory of Perugia can be considered an example of how a small telescope can be used to produce scientific data.

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