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Near simultaneous BV photometry and $H\alpha$ spectroscopy of the RS Canum Venaticorum binary DM Ursae Majoris

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Abstract. Differential BV photometry of DM UMa obtained over 19 nights and near simultaneous $H\alpha$ spectroscopy obtained over 7 nights during the 1990–91 observing season are presented. From an analysis of the available data we find that the light curve of DM UMa shows both periods of small and large amplitudes with remarkable changes in its mean light level. Apparently, the amplitude of light variation does not depend either on the mean brightness of the system, or on its ΔV_{max} or ΔV_{min}. The phases of light minima are found to lie on four well separated lines with different slopes. We find that the lifetime of a spot or spot group can be as short as two years. The modelling indicates the presence of spots at high latitudes. The $H\alpha$ emission equivalent width in DM UMa shows a modulation with the photometric phase so that the maximum emission equivalent width is close to the minimum of the light curve. The spectrum of DM UMa obtained on 1991 Jan 7 shows strong evidence of a flare.

Key words: stars: DM UMa – stars: activity – stars: chromospheres – binaries: spectroscopic – stars: late type

1. Introduction

The RS Canum Venaticorum binary DM UMa (= BD +61° 1211 = SAO 015338) was first proposed as the prime optical counterpart of the X-ray source 2A 1052+606 (Liller 1978; Schwartz et al. 1979). X-ray observations indicate that this star is a fairly bright soft X-ray source with a luminosity of $8.2\pm0.3\times10^{27}$ D^2(pc) erg s^{-1}, similar to that in hard X-rays, and an effective temperature of 10^7K (Walter et al. 1978). A study based on the Harvard archival plate collection showed the star to be a variable with an amplitude around 0.3 mag (Schwartz et al. 1979). Subsequent spectroscopic observations of this star revealed that it is a single-lined spectroscopic binary with an orbital period of 7.492 days and that it displays highly variable $Ca\ II$ H and K, and $H\alpha$ emission lines; the visible component of the binary has a spectral type of K2 III–IV (Crampton et al. 1979; Charles et al. 1979; Schwartz et al. 1979).

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The first photometric light curve was obtained by Kimble et al. (1981) who found that the photometric period is approximately the same as the spectroscopic orbital period. They assigned a spectral type K0-K1 III-IV to the visible component and classified the object as an RS CVn-type variable. Thus DM UMa has got the distinction of becoming the very first member among the RS CVn class of stars to be recognized via its X-ray emission.

Mohin & Raveendran (1992) analysed all the B and V light curves of DM UMa available during 1979–90 by means of a spot model which assumes that large discrete spots are responsible for the observed light variation. The method of least squares was employed to derive the best fit spot parameters. They have also reported that from 1984 onwards the brightness at light curve maximum has increased monotonically (by ~0.20 mag), whereas the amplitude of light variation has remained within a narrow range (0.16–0.23 mag) without any apparent trend. Their modelling has also indicated a slow migration of the spots towards the equator, and a gradual decrease of the spot area. They have also derived a mean spot temperature of 3400±60 K from the data obtained during ten observing seasons.

In this paper we present BV photometry and quasi-simultaneous $H\alpha$ spectroscopy of DM UMa, and discuss the results.

2. Observations and data reduction

2.1. BV photometry

DM UMa was observed over 19 nights during the 1990–91 observing season with the 34-cm reflector of Vainu Bappu Observatory, Kavalur (VBO) using standard B and V filters. The comparison stars were BD +60° 1301 and BD +61° 1210. All the observations were made differentially with respect to BD +60° 1301 and transformed to the UBV system. Table 1 gives the results for the variable star, in the sense DM UMa minus BD +60° 1301. Each value given in Table 1 is a mean of three to four independent measurements; the typical error in ΔV and in $\Delta(B-V)$ is ±0.010 and ±0.014 mag, respectively. The Julian days of observation were converted into orbital phases, given in Table 1, using the following ephemeris (Crampton et al. 1979):

$$\text{JD(Hel.)} = 2443881.4 + 7^d.492\,\text{E}\ ,$$

Table 1. The differential magnitudes and colours of DM UMa

J.D. (Hel) 2440000.+	Phase	ΔV	$\Delta(B-V)$	J.D. (Hel) 2440000.+	Phase	ΔV	$\Delta(B-V)$
8296.4220	0.298	0.156	−0.152	8297.4090	0.430	0.192	−0.138
8298.3780	0.559	0.205	−0.131	8299.3679	0.691	0.256	−0.159
8300.4229	0.832	0.334	−0.171	8301.3839	0.960	0.358	−0.123
8302.3329	0.087	0.271	−0.141	8303.4189	0.232	0.187	−0.186
8304.3991	0.363	0.151	−0.134	8305.3491	0.490	0.194	
8325.2711	0.149	0.227	−0.126	8327.2609	0.414	0.168	−0.105
8328.2670	0.549	0.220	−0.113	8329.3012	0.687	0.276	−0.141
8331.2447	0.946	0.341	−0.104	8332.2521	0.081	0.253	−0.124
8333.2169	0.209	0.151	−0.161	8334.2072	0.342	0.132	−0.151
8335.2081	0.475	0.163					

Table 2. $H\alpha$ data of DM UMa

Date	JD 2440000.+	Phase	EW1 Å	FWHM Å	Height	EW2 Å
28 Nov 1990	8224.4660	0.69	1.22	3.67	0.39	0.17
07 Jan 1991	8264.4229	0.03	1.95	3.37	0.64	0.82
06 Feb 1991	8294.4444	0.04	1.22	3.18	0.42	0.11
07 Feb 1991	8295.4521	0.17	1.08	3.42	0.30	0.12
08 Feb 1991	8296.3153	0.28	0.95	3.07	0.31	−0.04
08 Feb 1991	8296.4334	0.30	1.04	3.36	0.31	0.13
06 Mar 1991	8322.2451	0.75	1.38	3.16	0.55	0.08

where the initial epoch corresponds to the time of maximum positive radial velocity, and the period is the orbital period mentioned above.

2.2. *Hα observations*

DM UMa was observed at $H\alpha$ region during 7 nights quasi-simultaneously with the photometry. The spectroscopic observations were made with the Zeiss Cassegrain 102-cm telescope of the VBO. The observational setup and the data reduction procedure were as described in Mohin & Raveendran (1993). Two different estimates of $H\alpha$ equivalent width were made from the spectra; the first (denoted by EW1) was obtained by integrating the $H\alpha$ emission profile above the local continuum, and the second (denoted by EW2, cf. Fraquelli 1984) by subtracting the area below the continuum from that above it in the wavelength interval $\lambda\lambda$ 6550−6580. Table 2 gives the log of observations; it contains the Julian day of observation, the photometric phase, the $H\alpha$ emission equivalent width EW1, the full width at half maximum of $H\alpha$ emission (FWHM), the $H\alpha$ emission height in terms of F_λ/F_c, and the equivalent width EW2.

3. Discussion

3.1. *Spot modelling*

To convert the differential magnitude and colour of the variable to V and B magnitudes we assumed V = 0.0 mag for the comparison star, so that for the variable star $V = \Delta V$ and $B = (\Delta(B-V) + \Delta V + 1.183)$, where the constant 1.183 is the $B-V$ of the comparison star (Mohin & Raveendran 1992).

As mentioned above DM UMa is a non-eclipsing binary, hence the orbital inclination is unknown. An uncertainty in the inclination will be reflected directly on the polar distance of the spot. For the present analysis we have used $i = 40°$, the probable value suggested by the system mass function and luminosity ratio (Crampton et al. 1979; Kimble et al. 1981). Another unknown parameter is the magnitude of the unspotted star, whose assumed value has a similar direct effect on the polar distance in models that allow high latitude spots. The problems associated with the assumption of the unspotted magnitudes have already been discussed in detail by Poe & Eaton (1985). If the actual unspotted magnitude is higher than assumed in the model, then the derived spot area and temperature would be of differential nature. DM UMa has been observed every year since the discovery of its light variation. The value ΔV = 0.14 mag with respect to the comparison star BD +60°1301, observed by us, corresponds to the brightest magnitude observed so far. Hence this value of ΔV and the corresponding B=1.17 are assumed to represent the unspotted V and B magnitudes. Using the method described by Mohin & Raveendran (1992), we have modelled the observations obtained during 1990–91.

The effective temperature of the unspotted photosphere was taken as $T_* = 4700$ K, which according to Johnson (1966) approximately corresponds to K1 III–K2 IV spectral type and to $B-V$=1.03. The nature of the secondary component of DM UMa is unknown; it is probably a late-type dwarf (Kimble et al. 1981), and we neglected its contribution in the B and V spectral regions. Calculations were made with the same linear limb-darkening law for both the spots and unspotted photospheric region. The linear coefficients used, A = 0.78 for the V band and A = 0.92 for the B band, were derived by interpolating the values for solar composition tabulated by Manduca et al. (1977). They have shown that the limb darkening is remarkably insensitive to surface gravity in B and V bands. The V observations and the computed best fit V light curve are shown in the top panel of Fig. 1. The middle panel of the figure shows the $\Delta(B-V)$ data. The observations of Kimble et al. (1981) show an orbital modulation of $(B-V)$ with an amplitude of $\sim$ 0.04 mag. Because of the lower amplitude of light variation and slightly larger errors the present data do not show any modulation.

Table 3 summarizes the results of the least square analysis; it gives the polar distance, the spot longitude and temperature, the spot area as a fraction of the total surface area of the star, and the standard deviation of the fit. Our model indicates the presence of spots at high latitudes. The polar distance and the longitude derived from the present data indicate that the spot or, more likely the spot region responsible for light variation is probably the same as that originated sometime in 1988, implying a lifetime of about four years (see Fig. 4 and Sect. 3.3.). This strengthens the suggestion by Mohin & Raveendran (1992) that a centre of activity has a higher lifetime if the spots are present at higher latitudes rather than near the equator.

The single circular spot assumption, though it accounts for most of the light variation observed, leads to a rather poor fit,

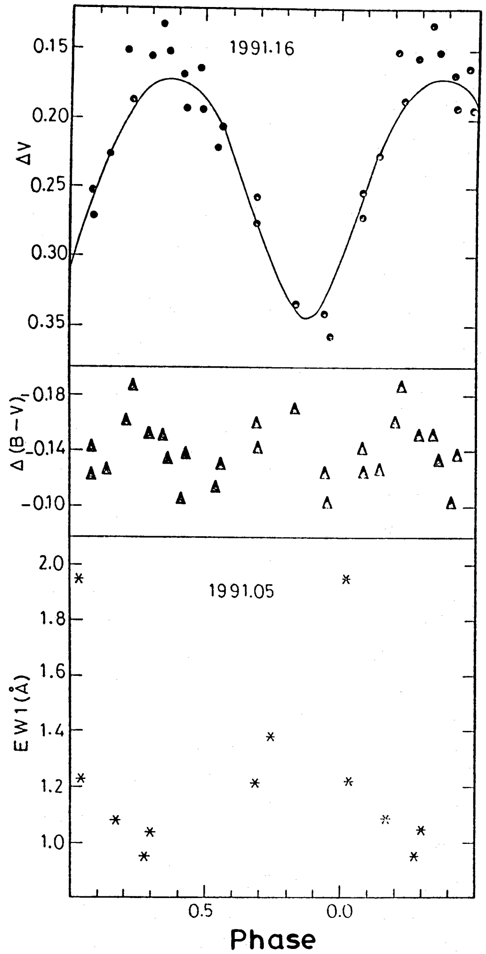

Fig. 1. Top panel: V light curve of DM UMa along with the corresponding best fit computed curve (continuous line); middle panel: $\Delta(B-V)$ data; bottom panel: the variation of EW1. Phases are reckoned from JD (Hel.) 2443881.4 using the period $7^d.492$. The mean epochs of observation are indicated in the figure

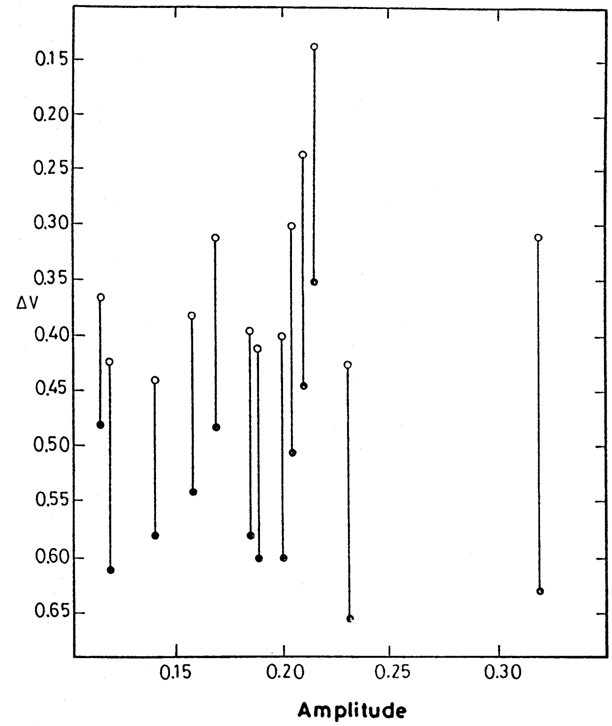

Fig. 2. Plot of the brightness at light maximum (open circles) and light minimum (filled circles) versus the V amplitude during the period 1979–91

especially close to the light maximum. This suggests either the presence of an additional smaller spot group or, an appreciable asymmetric configuration for the single spot group.

3.2. *Brightness at light maximum and minimum*

The photometric properties derived from the present observations, together with those compiled from other sources, are given in Table 4. All the quantities given in Table 4 were graphically evaluated from the observation plots except the phase of light minimum, which was derived from our spot modelling. Figure 2 shows the brightness at ΔV maximum (ΔV_{max}) and minimum (ΔV_{min}), taken from Table 4, versus the corresponding light curve amplitude. Both ΔV_{max} and ΔV_{min} show a large range of variability (about 0.30 mag). Apparently, the change in amplitude is not correlated with a change in either ΔV_{max} or ΔV_{min}. Figure 3 is the plot of ΔV_{max} and ΔV_{min}, given in Table 4, versus the corresponding epoch of observations. This figure shows that both ΔV_{max} and ΔV_{min} have similar trends. In general

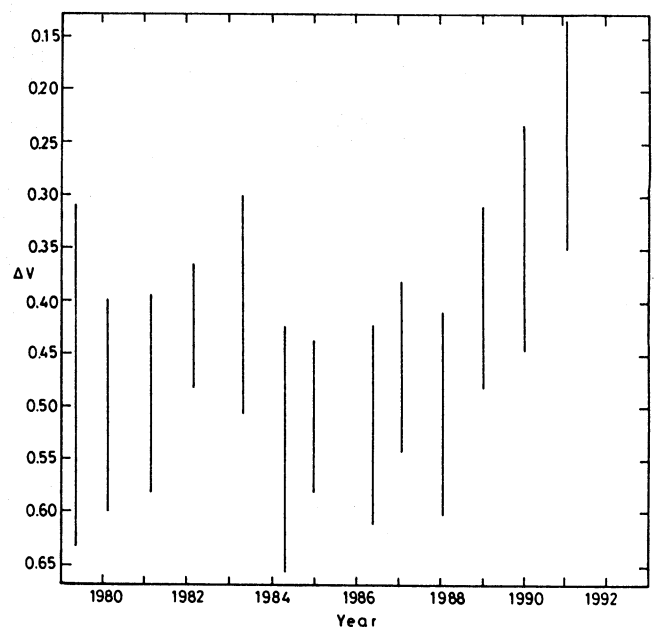

Fig. 3. Long-term V variability of DM UMa. The vertical bars indicate the peak-to-peak amplitude of the light curves during the period 1979–91

an increase in ΔV_{max} corresponds to an increase in ΔV_{min} and a decrease in ΔV_{max} to a decrease in ΔV_{min}. Both show monotonic decrease from 1988 onwards.

Table 3. The spot parameters derived for the light curve of DM UMa for 1990–91 season

Polar distance (degrees)	33.6±2.4
Longitude (degrees)	316±3
Radius (degrees)	24.2±4.3
Temperature (K)	3650±690
Fractional area	0.044±0.015
S. d. of fit (mag)	0.031

Table 4. Photometry of DM UMa

Epoch	Amplitude	ΔV_{max}	ΔV_{min}	Phase Min	Source
1979.42	0.320	0.310	0.630	0.50	1
1980.17	0.200	0.400	0.600	0.45	2
1981.22	0.185	0.395	0.580	0.19	2
				0.75	
1982.21	0.115	0.365	0.480	0.03	2
				0.49	
1983.35	0.205	0.300	0.505	0.35	2
1984.37	0.230	0.425	0.655	0.26	2
1985.06	0.141	0.439	0.580	0.15	2
1986.46	0.186	0.424	0.610	0.62	3
1987.10	0.158	0.382	0.540	0.57	2
1988.07	0.188	0.412	0.600	0.00	2
1989.02	0.170	0.311	0.481	0.00	2
1990.09	0.210	0.235	0.445	0.96	2
1991.16	0.215	0.135	0.350	0.90	4

Sources: 1. Kimble et al. (1981); 2. Mohin & Raveendran (1992); 3. Heckert et al. (1992); 4. Present study

3.3. Phase of light minimum

Figure 4 is a plot of the phases of light minima listed in Table 4 versus the corresponding mean epoch of observation. It is interesting to see that the light minima phases fall on four well separated lines. The minimum, first observed in 1979 (identified as group A), could be traced until 1982. A second minimum, which first appeared sometime in 1981 (group B), could be traced until 1985. During 1986–87 there was a short-lived minimum (group C). The minima identified as group D had originated sometime in 1988 and still existed in 1991. From the analysis of the photometry available during 1979–84, Mohin et al. (1985) have put a lower limit of about four years to the lifetime of a centre of activity (spot or spot group). But Fig. 4 indicates that the lifetime of a spot or spot group can be as short as two years (group C). It is interesting to see that all groups show migrations towards decreasing orbital phases. The photometric periods for group A, B, and D derived using the least square technique are 7.465±0.002, 7.470±0.002 and 7.487±0.001 days, respectively. If the equator is synchronized with the orbital rotation, this implies that higher latitude regions are rotating faster than the equatorial region, as suggested by Vogt & Hatzes (1991) in the case of UX Ari.

Using the method described by Raveendran et al. (1982), we find that the V band data given in Table 1 have a minimum scatter

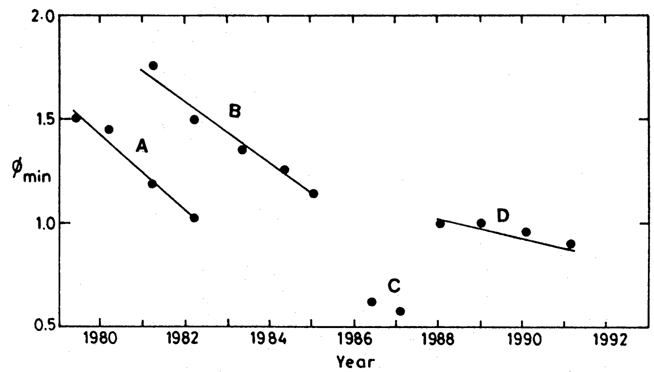

Fig. 4. Plot of the light minimum phases versus mean epoch of observation

for a period in the range 7.367–7.449 days, significantly less than that derived from the phase migration of the light minimum. This period gives a more reasonable light curve than that given in Fig. 1 only around the descending and ascending branches, and the light minimum where the observations are sparse. Around the light maximum, where about half of the observations lie, the scatter remains more or less the same. We feel that the scatter is largely due to the temporal changes that occur in the light curve within a few orbital cycles as a result of changes in the configuration of spots. It is difficult to be sure that the shorter period is the real period just because it produces less scatter at the above mentioned light curve phases. The reduction in the scatter for this period could well be as a result of the poor sampling at these phases.

3.4. Hα observations

The $H\alpha$ observations are shown in Fig. 5. The nightly EW1 values range from 0.95 Å to 1.95 Å indicating that the emission in $H\alpha$ was very strong and varied by a factor of two during the period of the observation. The average values of EW1 and FWHM are ~ 1.26 Å and ~ 3.32 Å respectively. Similar $H\alpha$ behaviour has been reported by Crampton et al. (1979) and Nations & Ramsey (1986). Significant changes in the $H\alpha$ profile and equivalent width on time scales as short as a few hours have been reported for this object (Tan & Liu 1985; Nations & Ramsey 1986).

Two of the $H\alpha$ spectra were obtained before the photometry was begun, the rest during the period of photometric observations. The bottom panel of Fig. 1 displays the EW1 data; the mean epoch of observation is also indicated in the figure. It is clear that the $H\alpha$ emission strength is anti-correlated with the photometric variations, emission being more intense near the light curve minimum.

The $H\alpha$ observations obtained on 7 Jan and 6 Feb 1991 fall nearly at the same phase, but the equivalent width of the former is significantly larger than that of the latter. Both these observations fall close to the photometric minimum. It is very likely that the larger equivalent width observed on 7 January

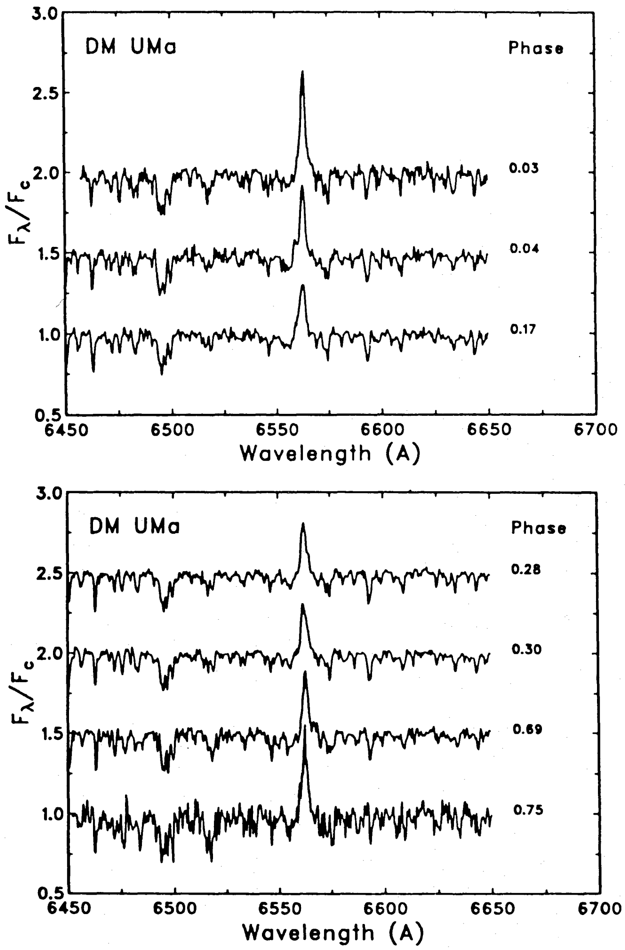

Fig. 5. $H\alpha$ spectra of DM UMa. The spectra are shifted in wavelength to line up the absorption lines. Each spectrum is normalized to continuum and vertically shifted by 0.5. Phases are reckoned as in Fig. 1

1991 is related to a flare event. This interpretation is favoured because of its coincidence with the light minimum, when the spotted region faces the observer.

4. Conclusions

Differential BV photometry of DM UMa obtained over 19 nights and quasi-simultaneous $H\alpha$ spectroscopy obtained over 7 nights during the 1990–91 observing season are presented.

We have shown that DM UMa exhibits both periods of small and large amplitudes of light curves and remarkable changes of its mean light level. Apparently the amplitude of light variation does not depend on the mean brightness of the system. In DM UMa the amplitude does not show any correlation with either ΔV_{max} or ΔV_{min}, they both show a large range of variation of about 0.30 mag. In general, an increase in ΔV_{max} is followed by an increase in ΔV_{min}, and a decrease in ΔV_{max} by a decrease in ΔV_{min}.

The investigation of the light minimum phases has shown its migration with respect to the orbital phases, indicating a difference between the photometric period and the assumed orbital period. The phases of light minima lie on four well separated lines with different slopes. It is interesting to note that all the groups show migration towards decreasing orbital phases, thus implying a photometric period smaller than the orbital period. We have also determined approximate lifetimes for different active regions from the phase migration of the light minima: the lifetime of a spot or spot group can be as short as two years.

The $H\alpha$ emission equivalent widths in DM UMa indicate a modulation with the photometric phase: the emission equivalent width is more intense close to the minimum of the photometric light curve. The spectra of DM UMa obtained during the night 1991 Jan 7 show strong evidence of a flare.

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