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Long-term photometric behavior of the PMS stars V977 Cep and V982 Cep in the vicinity of NGC 7129 ⋆

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Abstract Long-term $BVRI$ photometric light curves of the pre-main sequence stars V977 Cep and V982 Cep during the period from 2000 October to 2016 August are presented. The stars are located in the vicinity of the reflection nebula NGC 7129. Our photometric data show that both stars exhibit strong photometric variability in all optical passbands, which is typical for Classical T Tauri stars. Using our observational data we analyze the reasons for the observed brightness variations. In the case of V977 Cep we identify previously unknown periodicity in its light curve.

Key words: stars: pre-main sequence — variables: T Tauri — stars: individual (V977 Cep, V982 Cep)

1 INTRODUCTION

The bright reflection nebula NGC 7129 is an active star forming region, where a large number of T Tauri stars, Herbig Ae/Be stars, Herbig-Haro objects and cometary nebulae can be found. According to Kun et al. (2009) NGC 7129 is probably associated with the Cepheus Bubble. The distance to NGC 7129 was determined as 1.15 kpc and its age is about 3 Myr (Straižys et al. 2014). Recent studies of young stellar objects in the vicinity of NGC 7129 were made by Kun et al. (2008), Kun et al. (2009), Bae et al. (2011), Straižys et al. (2014), Ibryamov et al. (2014), Dahm & Hillenbrand (2015), Movsessian et al. (2015), etc.

T Tauri type stars are pre-main sequence (PMS) stars with relatively low mass ($M \leq 2\,M_{\odot}$). T Tauri stars (TTSs) are still contracting towards the main sequence and convert their own gravitational potential energy to light. Unlike in main sequence stars, the temperature in the core of a TTS is not sufficient to start nuclear fusion.

A distinctive feature of TTSs is that they are associated with dark nebulae and molecular clouds and are grouped in so called T associations. TTSs show strong irregular photometric variability and emission line spectra (Joy 1945). Each TTS can have different photometric variations which make their classification purely by the shape of their light curve quite uncertain.

TTSs are separated into two sub-classes – Classical T Tauri stars (CTTSs) and Weak-line T Tauri stars (WTTSs). CTTSs are surrounded by a circumstellar disk, while WTTSs show no evidence of such a disk (Bertout 1989). Both sub-classes of TTSs show photometric variability with different amplitudes. The variability of a CTTS is often associated with variable accretion from the circumstellar disk and the existence of hot spots on the stellar surface (Herbst et al. 2007). The existence of cool spots or groups of spots and/or flare-like events (in the B- and U-bands) is responsible for the observed photometric variability in WTTSs.

In some PMS stars, large amplitude drops in the brightness (reaching up to 3 mag in the V-band) are observed. The stars with such photometric behavior are known as UXors (the name comes from their prototype UX Orionis). The observed drops in the star's brightness can last for several days and in some cases a few weeks. These drops are probably caused by obscuration of the young star from circumstellar clouds or dust in the line of sight to the star (see Herbst et al. 2007 and Dullemond et al. 2003). In the very deep minima, the color indices of

⋆ Based on observations obtained at Rozhen National Astronomical Observatory, Bulgaria.

UXors often become bluer; this is the so called 'blueing effect' (see Bibo & The 1990).

The stars from our study, V977 Cep and V982 Cep, are located in the vicinity of NGC 7129. Long-term multicolor observations of PMS stars are important for their exact classification. Photometric information, especially concerning long-term behavior of the stars from our study, is missing in literature.

Variability in V977 Cep (2MASS J21402965 +6626442) was mentioned in Popov et al. (2011), where photometric data of the star in the R-band (for the period 2010 February 03−March 02) and the I-band (for the period 2009 October 22−2010 February 21) are given. The authors provide a finding map of the star.

The star V982 Cep (2MASS J21413315+6622204) was included in the list of young stellar object candidates with Hα in emission in the study of Kun (1998). Kun et al. (2009) measured $B = 17.22$, $V = 15.67$, $R = 14.61$ and $I = 13.57$ magnitudes of V982 Cep. The authors defined the spectral type of the star as K4 and determined its mass as $1.60\,M_{\odot}$, its effective temperature as 4590 K and its age as 0.5 Myr. The spectrum of V982 Cep includes Hα, [OI] 6300, OI 7773, 8446, and CaII triplet emission lines, and the star was classified as a CTTS (Kun et al. 2009). Popov et al. (2011) presented photometric data in the V-band (for the period 2009 October 22−2010 February 21), the R-band (for the period 2010 February 03−2010 March 02) and the I-band (for the period 2009 October 22−2010 February 21) of V982 Cep and provided a finding map.

Section 2 in the present paper gives information about our photometric observations, telescopes and cameras used and data reduction. Section 3 describes the obtained results and their interpretation.

2 OBSERVATIONS AND DATA REDUCTION

The $BVRI$ photometric observations of the stars from our study were performed during the period from 2000 October 30 to 2016 August 06. The observations were carried out with the 50/70-cm Schmidt and the 60-cm Cassegrain telescopes administered by Rozhen National Astronomical Observatory in Bulgaria. The observations were performed with four different types of CCD cameras: SBIG ST-8, SBIG STL-11000M and FLI PL16803 on the 50/70-cm Schmidt telescope, and FLI PL09000 on the 60-cm Cassegrain telescope. The technical parameters and specifications for the telescopes and CCD cameras used are given in Ibryamov et al. (2014).

All frames were taken through a standard Johnson-Cousins set of filters. All obtained frames are dark frame subtracted and flat field corrected. The photometric data were reduced using subroutine DAOPHOT in the IDL software package. All data were analyzed using the same aperture, which was chosen to have a $6''$ radius and background annulus from $10''$ to $15''$. As a reference sequence we used the $BVRI$ comparisons reported in Semkov (2002, 2003). The average value of the errors in the reported magnitudes are 0.01–0.02 mag for the I- and R-band data, and 0.02–0.03 mag for the V- and B-band data.

3 RESULTS AND DISCUSSION

The results from our long-term $BVRI$ CCD observations of V977 Cep are summarized in Table 1. The table contains date (YYYYMMDD format) and Julian date (J. D.) of the observations, $IRVB$ magnitudes of the star, and telescope and CCD camera used. The available $BVRI$ photometric data of the star V977 Cep are plotted in Figure 1. In the figure, circles represent CCD photometric data taken with the 50/70-cm Schmidt telescope, triangles mark the photometric data obtained with the 60-cm Cassegrain telescope and empty diamonds signify the photometric data from Popov et al. (2011).

The data reported in the paper indicate that during our study the brightness of V977 Cep varies around some intermediate level. The star's brightness during the whole observational period varies in the range 15.10–16.30 mag for the I-band, 16.28–17.76 mag for the R-band, 17.32–19.05 mag for the V-band and 18.63–19.44 mag for the B-band. For V977 Cep we only have B-band data when the star is near its maximum brightness due to the photometric limit of the telescopes used (19.5 mag). The observed amplitudes for the period 2000–2016 are 1.20 mag for the I-band, 1.48 mag for the R-band, 1.73 mag for the V-band and > 0.81 mag for the B-band. Variability with such amplitudes is typical of a CTTS surrounded by a circumstellar disk and it is an indication for the presence of variable accretion from the circumstellar disk onto the stellar surface.

The measured color indices $V - I$ and $V - R$ vs. the stellar V magnitude of V977 Cep during the period of our observations are plotted on Figure 2. It can be seen that the star becomes redder as it fades, and the blueing effect is not observed. Such color variations are typical for both CTTSs and WTTSs, whose variability is produced by the rotational modulation of spots on the stellar surface.

V982 Cep is located about $7'\,45''$ from V977 Cep and at about $18'$ from the center of NGC 7129. Figure 3 shows $BVRI$ light curves of V982 Cep. The symbols used are the same as in Figure 1. The results of our long-term CCD observations are summarized in Table 2. The columns have the same contents as in Table 1. During

Table 1 Photometric CCD Observations and Data of V977 Cep during the Period 2000 October−2016 August

Date	J. D. (24...)	I [mag]	R [mag]	V [mag]	B [mag]	Telescope	CCD camera
20001030	51848.41	15.97	17.71	19.00	-	Schmidt	ST-8
20001224	51903.28	16.09	17.76	19.05	-	Schmidt	ST-8
20020205	52311.25	-	-	-	-	Schmidt	ST-8
20020206	52312.25	15.63	16.94	18.03	-	Schmidt	ST-8
20020207	52313.23	15.56	17.03	18.32	-	Schmidt	ST-8
20021003	52551.46	15.31	16.51	-	-	Schmidt	ST-8
20021029	52577.41	15.57	17.14	-	-	Schmidt	ST-8
20021030	52578.36	15.69	17.21	18.35	-	Schmidt	ST-8
20021031	52579.26	15.39	17.19	-	-	Schmidt	ST-8
20021101	52580.25	15.65	17.27	18.27	-	Schmidt	ST-8
20021126	52605.22	15.70	-	17.95	-	Schmidt	ST-8
20021128	52607.28	15.50	16.93	18.12	-	Schmidt	ST-8
20021129	52608.23	15.60	17.19	18.44	-	Schmidt	ST-8
20030403	52732.52	15.67	16.78	17.97	-	Schmidt	ST-8
20030501	52761.48	15.67	17.26	18.76	-	Schmidt	ST-8
20030502	52762.44	15.68	17.20	-	-	Schmidt	ST-8
20030505	52765.41	15.62	16.95	18.86	-	Schmidt	ST-8
20030927	52910.30	15.45	16.95	18.04	-	Schmidt	ST-8
20030928	52911.28	15.45	16.72	17.98	-	Schmidt	ST-8
20030929	52912.27	15.37	16.88	17.98	-	Schmidt	ST-8
20031002	52915.34	15.15	16.46	-	-	Schmidt	ST-8
20031003	52916.32	15.39	16.77	17.99	-	Schmidt	ST-8
20031125	52969.26	15.57	17.24	18.43	-	Schmidt	ST-8
20031219	52993.20	15.45	16.77	17.66	-	Schmidt	ST-8
20040513	53138.65	15.46	17.11	18.11	-	Schmidt	ST-8
20040715	53201.57	15.49	17.08	18.45	-	Schmidt	ST-8
20040716	53202.57	15.46	17.02	-	-	Schmidt	ST-8
20041117	53327.40	15.37	16.88	17.92	-	Schmidt	ST-8
20041118	53328.35	15.35	16.75	17.99	-	Schmidt	ST-8
20041120	53330.38	15.27	16.65	17.93	-	Schmidt	ST-8
20060424	53849.52	15.40	17.11	18.79	-	Schmidt	ST-8
20060719	53936.43	15.61	17.04	17.98	-	Schmidt	ST-8
20061020	54029.41	15.54	17.02		-	Schmidt	ST-8
20061117	54057.27	15.64	16.80	18.49	-	Schmidt	ST-8
20061118	54058.28	15.54	16.70	17.72	-	Schmidt	ST-8
20061119	54059.27	15.50	16.69	18.32	-	Schmidt	ST-8
20061120	54060.23	15.43	16.60	17.89	-	Schmidt	ST-8
20061216	54086.28	15.42	16.58	18.06	-	Schmidt	ST-8
20070818	54331.35	15.56	17.11	17.92	-	Schmidt	ST-8
20070819	54332.34	15.56	17.04	18.27	-	Schmidt	ST-8
20080229	54526.64	15.40	16.51	17.60	19.24	Schmidt	STL-11
20080827	54706.39	15.45	16.59	17.65	-	Schmidt	STL-11
20080828	54707.40	15.58	16.61	17.69	19.06	Schmidt	STL-11
20081021	54761.25	15.33	16.55	17.64	18.98	Schmidt	STL-11
20081120	54791.19	15.35	16.57	17.71	19.01	Schmidt	STL-11
20090112	54844.23	15.37	16.54	17.67	-	Schmidt	STL-11
20090326	54917.52	15.22	16.51	18.00	-	Schmidt	STL-11
20090416	54938.45	15.41	16.67	17.82	-	Schmidt	STL-11
20090628	55011.53	15.42	16.65	17.87	-	Schmidt	FLI
20090714	55027.44	15.48	16.80	18.13	-	Schmidt	FLI
20090715	55028.45	15.49	16.85	18.07	-	Schmidt	FLI
20090716	55029.45	15.17	16.48	17.64	-	Schmidt	FLI
20090821	55065.36	15.45	16.82	18.03	-	Schmidt	FLI
20090822	55066.28	15.37	16.53	17.63	-	Schmidt	FLI

Table 1 — *Continued.*

Date	J. D. (24...)	I [mag]	R [mag]	V [mag]	B [mag]	Telescope	CCD camera
20091006	55111.42	15.42	16.61	17.91	-	Schmidt	FLI
20091007	55112.37	15.37	16.54	17.86	-	Schmidt	FLI
20091008	55113.35	15.88	17.17	18.40	-	Schmidt	FLI
20091009	55114.25	15.55	16.89	17.97	-	Schmidt	FLI
20091120	55156.24	15.70	17.09	18.29	-	Schmidt	FLI
20091121	55157.27	15.67	17.00	-	-	Schmidt	FLI
20100513	55330.37	15.30	16.46	17.42	-	Schmidt	FLI
20100608	55356.42	15.31	16.63	17.80	-	Schmidt	FLI
20100610	55358.49	15.50	16.75	-	-	Schmidt	FLI
20100611	55359.51	15.52	16.85	18.21	-	Schmidt	FLI
20100612	55360.44	15.46	16.70	17.93	-	Schmidt	FLI
20100806	55415.40	15.56	16.80	17.65	-	Schmidt	FLI
20100807	55447.52	15.53	16.79	17.80	-	Schmidt	FLI
20100908	55448.43	15.78	16.97	17.97	-	Schmidt	FLI
20101104	55505.30	15.90	17.17	18.35	-	Schmidt	FLI
20101105	55506.31	15.69	17.09	18.10	-	Schmidt	FLI
20110101	55563.26	15.74	17.07	18.31	-	Schmidt	FLI
20110206	55599.23	15.26	16.48	17.83	-	Schmidt	FLI
20110404	55656.40	15.24	16.48	17.54	-	Schmidt	FLI
20110522	55704.39	15.33	16.66	17.77	19.34	Schmidt	FLI
20110523	55705.33	15.14	16.33	17.45	-	Schmidt	FLI
20110524	55706.32	15.23	16.49	17.62	-	Schmidt	FLI
20110525	55707.34	15.10	16.28	17.49	-	Schmidt	FLI
20110609	55722.36	15.16	16.35	17.37	-	Schmidt	FLI
20110621	55734.47	15.62	16.92	17.98	-	Schmidt	FLI
20110622	55735.48	15.44	16.70	17.78	-	Schmidt	FLI
20110624	55737.40	15.21	16.39	17.50	-	Schmidt	FLI
20110823	55797.37	15.28	16.58	17.77	-	Schmidt	FLI
20110824	55798.39	15.42	16.62	17.69	-	Schmidt	FLI
20110825	55799.39	15.47	16.66	17.69	18.82	Schmidt	FLI
20110923	55828.30	15.16	16.34	17.45	-	Schmidt	FLI
20111127	55893.21	15.63	16.94	17.96	-	Schmidt	FLI
20111129	55895.30	15.63	16.94	17.96	-	Schmidt	FLI
20111130	55896.28	15.64	16.83	18.12	-	Schmidt	FLI
20111229	55925.22	15.30	16.56	17.67	-	Schmidt	FLI
20120316	56003.49	15.76	17.08	18.13	-	Schmidt	FLI
20120612	56091.44	15.77	17.15	18.26	-	Schmidt	FLI
20120617	56096.45	15.21	16.42	17.50	-	Schmidt	FLI
20120711	56120.42	15.40	16.81	-	-	Schmidt	FLI
20120713	56122.42	15.36	16.73	17.68	19.44	Schmidt	FLI
20120819	56159.39	15.64	16.92	18.03	-	Schmidt	FLI
20120820	56160.38	15.52	16.76	17.73	18.68	Schmidt	FLI
20120923	56194.36	15.36	16.65	17.78	-	Schmidt	FLI
20121009	56210.27	15.59	16.98	17.95	-	Schmidt	FLI
20121118	56250.36	15.65	16.83	17.80	-	Schmidt	FLI
20130204	56328.26	15.58	16.85	18.21	-	Schmidt	FLI
20130411	56394.41	15.76	17.21	18.26	-	Schmidt	FLI
20130502	56415.47	15.41	16.68	17.63	-	Schmidt	FLI
20130530	56443.47	15.59	16.74	17.94	-	Schmidt	FLI
20130531	56444.48	15.54	17.07	18.28	-	Schmidt	FLI
20130804	56509.37	15.87	17.27	18.32	-	Schmidt	FLI
20130805	56510.43	15.42	16.64	-	-	60-cm	FLI
20130806	56511.47	15.38	16.61	17.54	-	60-cm	FLI
20130807	56512.46	15.42	16.61	-	-	60-cm	FLI
20130808	56513.45	15.61	16.93	18.02	-	60-cm	FLI
20130809	56514.41	15.45	16.63	17.78	-	60-cm	FLI

Table 1 — *Continued.*

Date	J. D. (24...)	I [mag]	R [mag]	V [mag]	B [mag]	Telescope	CCD camera
20130904	56540.38	15.80	17.05	18.48	-	Schmidt	FLI
20130905	56541.40	15.84	17.19	17.96	-	Schmidt	FLI
20130906	56542.44	16.03	17.44	18.47	-	Schmidt	FLI
20130911	56547.35	-	16.80	-	-	60-cm	FLI
20130914	56550.33	15.52	16.52	17.71	-	60-cm	FLI
20131229	56656.33	15.57	16.94	17.75	-	Schmidt	FLI
20140123	56681.27	16.30	17.66	19.03	-	Schmidt	FLI
20140321	56738.50	15.51	16.71	17.74	-	Schmidt	FLI
20140521	56799.54	15.54	16.67	17.98	-	Schmidt	FLI
20140628	56837.45	15.44	16.66	18.00	-	Schmidt	FLI
20140629	56838.42	15.35	16.66	17.86	-	Schmidt	FLI
20140629	56838.48	15.33	16.65	17.59	-	Schmidt	FLI
20140803	56873.33	15.40	16.73	17.71	-	Schmidt	FLI
20140804	56874.35	15.72	17.17	17.86	-	Schmidt	FLI
20140818	56888.38	15.81	17.15	18.25	-	Schmidt	FLI
20140819	56889.32	15.64	16.90	18.13	-	Schmidt	FLI
20140822	56892.36	15.80	17.03	17.64	-	Schmidt	FLI
20141126	56988.24	15.56	17.01	-	-	Schmidt	FLI
20141213	57005.28	15.62	16.96	18.14	-	Schmidt	FLI
20141214	57006.34	16.07	17.40	18.18	-	Schmidt	FLI
20150220	57074.54	15.40	16.69	17.87	19.31	Schmidt	FLI
20150423	57136.58	16.00	17.56	18.40	-	Schmidt	FLI
20150519	57162.49	15.41	-	-	-	Schmidt	FLI
20150521	57164.50	15.20	16.40	17.32	18.62	Schmidt	FLI
20150612	57186.51	16.07	17.73	18.68	-	Schmidt	FLI
20150716	57220.42	15.84	17.42	18.71	-	Schmidt	FLI
20150717	57221.48	15.88	17.19	18.62	-	Schmidt	FLI
20150824	57259.39	15.74	17.13	18.49	-	Schmidt	FLI
20150825	57260.38	15.83	17.23	18.13	-	Schmidt	FLI
20150903	57269.38	15.89	17.27	18.41	-	Schmidt	FLI
20151103	57330.29	15.57	16.84	18.12	-	Schmidt	FLI
20151104	57331.30	15.49	16.89	18.12	-	Schmidt	FLI
20151105	57332.29	15.66	17.01	18.20	-	Schmidt	FLI
20151106	57333.29	15.70	17.02	18.35	-	Schmidt	FLI
20151107	57334.27	15.62	16.86	18.25	-	Schmidt	FLI
20151215	57372.27	15.41	16.67	17.87	19.41	Schmidt	FLI
20160206	57425.24	15.51	16.85	17.81	19.39	Schmidt	FLI
20160406	57485.448	15.46	16.72	17.85	19.24	Schmidt	FLI
20160427	57506.511	15.44	16.58	17.75	-	Schmidt	FLI
20160513	57522.485	15.55	16.75	17.80	18.89	Schmidt	FLI
20160514	57523.471	15.36	16.55	17.55	19.00	Schmidt	FLI
20160625	57565.464	15.50	16.67	17.59	-	Schmidt	FLI
20160711	57581.451	15.54	16.79	17.79	19.33	Schmidt	FLI
20160712	57582.484	15.69	17.02	18.18	-	Schmidt	FLI
20160713	57583.470	15.65	17.04	18.10	-	Schmidt	FLI
20160804	57605.436	15.68	17.10	18.21	-	Schmidt	FLI
20160806	57607.415	15.61	16.93	18.15	-	Schmidt	FLI

our observations, the star's brightness varies in the range 13.04–14.10 mag for the I-band, 15.46–14.05 mag for the R-band, 14.99–16.75 mag for the V-band and 16.23–18.10 mag for the B-band. The observed amplitudes are 1.06 mag for the I-band, 1.41 mag for the R-band, 1.76 mag for the V-band and 1.87 mag for the B-band.

From Figure 3 we can see that for most of our CCD observations V982 Cep is at high brightness. The star shows irregular fading events in all bands with different

Table 2 Photometric CCD Observations and Data of V982 Cep during the Period 2002 October−2016 August

Date	J. D. (24...)	I [mag]	R [mag]	V [mag]	B [mag]	Telescope	CCD camera
20021003	52551.459	13.27	14.27	15.41	-	Schmidt	ST8
20041117	53327.401	13.42	14.61	15.53	-	Schmidt	ST8
20041118	53328.350	13.53	14.74	15.68	17.31	Schmidt	ST8
20041120	53330.375	13.48	14.67	16.12	17.25	Schmidt	ST8
20061216	54086.277	13.22	14.21	15.23	16.66	Schmidt	ST8
20081120	54791.191	13.45	14.54	15.55	16.96	Schmidt	STL-11
20090416	54938.543	13.26	14.33	15.44	16.82	Schmidt	STL-11
20090519	54971.420	13.48	14.60	15.58	-	Schmidt	STL-11
20090629	55011.527	13.28	14.38	15.41	16.78	Schmidt	FLI
20090714	55027.438	13.60	14.83	15.92	17.40	Schmidt	FLI
20090714	55027.440	13.58	14.78	15.91	17.36	Schmidt	FLI
20090715	55028.447	13.56	14.87	-	-	Schmidt	FLI
20090715	55028.462	13.56	14.87	15.94	-	Schmidt	FLI
20090716	55029.453	13.43	14.64	15.69	17.07	Schmidt	FLI
20090716	55029.469	13.44	14.63	15.73	17.10	Schmidt	FLI
20090821	55065.354	13.25	14.38	15.42	16.85	Schmidt	FLI
20090821	55065.377	13.24	14.36	15.28	16.84	Schmidt	FLI
20090822	55066.284	13.21	14.25	15.26	16.59	Schmidt	FLI
20091006	55111.424	13.58	14.79	15.84	17.20	Schmidt	FLI
20091007	55112.379	13.37	14.57	15.64	16.92	Schmidt	FLI
20091007	55112.390	13.40	14.60	15.62	16.91	Schmidt	FLI
20091008	55113.354	13.39	14.61	15.65	16.92	Schmidt	FLI
20091008	55113.377	13.43	14.63	15.65	17.10	Schmidt	FLI
20091009	55114.246	13.39	14.54	15.60	17.01	Schmidt	FLI
20091120	55156.238	13.21	14.30	15.32	16.67	Schmidt	FLI
20091120	55156.259	13.26	14.37	15.28	16.66	Schmidt	FLI
20091121	55157.267	13.27	14.36	15.37	16.70	Schmidt	FLI
20091121	55157.287	13.28	14.40	15.31	16.65	Schmidt	FLI
20100513	55330.355	13.33	14.48	15.45	16.91	Schmidt	FLI
20100513	55330.374	13.34	14.42	15.49	16.93	Schmidt	FLI
20100608	55356.418	13.20	14.29	15.31	16.65	Schmidt	FLI
20100608	55356.438	13.20	14.30	15.27	16.68	Schmidt	FLI
20100610	55358.468	13.20	14.26	15.28	16.68	Schmidt	FLI
20100610	55358.488	13.17	14.28	15.24	16.65	Schmidt	FLI
20100612	55359.508	13.23	14.32	15.32	16.74	Schmidt	FLI
20100612	55360.442	13.15	14.23	15.25	16.59	Schmidt	FLI
20100612	55360.456	13.19	14.31	15.19	16.64	Schmidt	FLI
20100804	55413.309	13.27	14.34	15.36	16.57	Schmidt	FLI
20100806	55415.397	13.20	14.30	15.30	16.65	Schmidt	FLI
20100806	55415.416	13.22	14.34	15.29	16.67	Schmidt	FLI
20100807	55416.360	13.18	14.26	15.26	16.66	Schmidt	FLI
20100807	55416.380	13.20	14.30	15.27	16.67	Schmidt	FLI
20100908	55447.520	13.53	14.74	15.80	17.31	Schmidt	FLI
20100908	55448.413	13.67	14.88	15.90	17.40	Schmidt	FLI
20100908	55448.435	13.64	14.85	15.95	17.36	Schmidt	FLI
20100909	55449.480	13.60	14.84	15.97	17.48	Schmidt	FLI
20101104	55505.273	13.15	14.22	15.15	16.54	Schmidt	FLI
20101104	55505.298	13.15	14.20	15.22	16.55	Schmidt	FLI
20101105	55506.288	13.18	14.31	15.22	16.64	Schmidt	FLI
20101105	55506.313	13.12	14.25	15.28	16.70	Schmidt	FLI
20110101	55563.256	13.28	14.44	15.47	16.92	Schmidt	FLI
20110206	55599.228	13.13	14.26	15.27	16.58	Schmidt	FLI
20110404	55656.398	13.32	14.41	15.47	16.70	Schmidt	FLI
20110404	55656.422	13.21	14.26	15.37	16.79	Schmidt	FLI

Table 2 — *Continued.*

Date	J. D. (24...)	I [mag]	R [mag]	V [mag]	B [mag]	Telescope	CCD camera
20110522	55704.392	13.16	14.21	15.22	16.57	Schmidt	FLI
20110522	55704.411	13.17	14.25	15.20	16.54	Schmidt	FLI
20110523	55705.335	13.07	14.13	15.15	16.47	Schmidt	FLI
20110523	55705.354	13.11	14.19	15.07	16.52	Schmidt	FLI
20110524	55706.324	13.04	14.12	15.08	16.33	Schmidt	FLI
20110524	55706.343	13.08	14.17	15.08	16.23	Schmidt	FLI
20110525	55707.335	13.13	14.23	15.19	16.53	Schmidt	FLI
20110609	55722.354	13.17	14.25	15.25	16.57	Schmidt	FLI
20110609	55722.371	13.23	14.31	15.24	16.41	Schmidt	FLI
20110621	55734.470	13.33	14.52	15.57	17.02	Schmidt	FLI
20110622	55735.475	13.38	14.54	15.58	16.97	Schmidt	FLI
20110624	55737.404	13.34	14.47	15.53	16.92	Schmidt	FLI
20110727	55770.412	13.21	14.35	15.38	16.72	Schmidt	FLI
20110823	55797.366	13.17	14.29	15.28	16.64	Schmidt	FLI
20110823	55797.386	13.20	14.31	15.26	16.63	Schmidt	FLI
20110824	55798.363	13.17	14.29	15.21	16.63	Schmidt	FLI
20110824	55798.390	13.12	14.24	15.24	16.53	Schmidt	FLI
20110825	55799.370	13.14	14.28	15.21	16.58	Schmidt	FLI
20110825	55799.392	13.10	14.22	15.26	16.60	Schmidt	FLI
20110923	55828.302	13.24	14.39	15.38	16.83	Schmidt	FLI
20111127	55893.206	13.40	14.59	15.62	17.12	Schmidt	FLI
20111129	55895.296	13.38	14.58	15.65	17.01	Schmidt	FLI
20111129	55895.316	13.44	14.63	15.62	17.09	Schmidt	FLI
20111130	55896.277	13.49	14.71	15.83	17.27	Schmidt	FLI
20111229	55925.222	13.58	14.82	15.97	17.41	Schmidt	FLI
20111229	55925.236	13.60	14.85	15.89	17.41	Schmidt	FLI
20120316	56003.488	13.21	14.37	15.37	16.74	Schmidt	FLI
20120316	56003.509	13.26	14.40	15.37	16.80	Schmidt	FLI
20120412	56030.484	13.35	14.49	15.53	16.94	Schmidt	FLI
20120612	56091.443	13.32	14.46	15.51	16.95	Schmidt	FLI
20120612	56091.462	13.25	14.34	15.25	-	Schmidt	FLI
20120617	56096.447	13.25	14.34	15.25	-	Schmidt	FLI
20120618	56096.522	13.19	14.30	15.32	16.64	Schmidt	FLI
20120711	56120.420	13.32	14.28	15.36	16.64	Schmidt	FLI
20120711	56120.447	13.20	14.27	15.28	16.60	Schmidt	FLI
20120713	56122.421	13.19	14.25	15.18	16.55	Schmidt	FLI
20120713	56122.443	13.15	14.23	15.23	16.47	Schmidt	FLI
20120714	56123.438	13.20	14.29	15.27	16.58	Schmidt	FLI
20120819	56159.393	13.21	14.34	15.34	16.71	Schmidt	FLI
20120820	56160.374	13.31	14.44	15.38	16.84	Schmidt	FLI
20120820	56160.398	13.25	14.38	15.41	16.80	Schmidt	FLI
20120821	56161.453	13.16	14.25	15.27	16.54	Schmidt	FLI
20120822	56162.378	13.15	14.24	15.27	16.63	Schmidt	FLI
20120923	56194.364	13.20	14.26	15.27	16.61	Schmidt	FLI
20121009	56210.265	13.27	14.39	15.42	16.76	Schmidt	FLI
20121009	56210.284	13.30	14.42	15.38	16.74	Schmidt	FLI
20121118	56250.355	13.67	14.91	16.02	17.41	Schmidt	FLI
20121118	56250.369	13.69	14.92	15.98	-	Schmidt	FLI
20130204	56328.241	13.70	14.96	16.11	17.60	Schmidt	FLI
20130204	56328.259	13.72	15.00	16.03	17.61	Schmidt	FLI
20130411	56394.389	13.48	14.72	15.84	17.29	Schmidt	FLI
20130411	56394.410	13.54	14.75	15.82	17.32	Schmidt	FLI

Table 2 — *Continued.*

Date	J. D. (24...)	I [mag]	R [mag]	V [mag]	B [mag]	Telescope	CCD camera
20130502	56415.467	13.31	14.48	15.46	16.88	Schmidt	FLI
20130502	56415.490	13.30	14.44	15.49	16.85	Schmidt	FLI
20130530	56443.474	13.32	14.45	15.44	16.78	Schmidt	FLI
20130530	56443.497	13.25	14.41	15.42	16.81	Schmidt	FLI
20130531	56444.433	13.32	14.51	15.46	16.97	Schmidt	FLI
20130531	56444.481	13.30	14.49	15.53	16.92	Schmidt	FLI
20130804	56509.368	13.50	14.69	15.79	17.21	Schmidt	FLI
20130804	56509.388	13.55	14.73	15.73	17.20	Schmidt	FLI
20130805	56510.452	13.65	14.79	15.89	17.33	60-cm	FLI
20130806	56511.493	13.56	14.66	15.77	17.27	60-cm	FLI
20130807	56512.481	13.53	14.62	15.69	17.16	60-cm	FLI
20130808	56513.469	13.41	14.45	15.46	16.88	60-cm	FLI
20130809	56514.427	13.41	14.43	15.45	-	60-cm	FLI
20130904	56540.376	13.23	14.36	15.37	16.70	Schmidt	FLI
20130904	56540.399	13.25	14.39	15.34	16.73	Schmidt	FLI
20130905	56541.402	13.39	14.52	15.48	16.93	Schmidt	FLI
20130906	56542.440	13.20	14.32	15.33	16.72	Schmidt	FLI
20130911	56547.351	-	14.61	15.53	16.93	60-cm	FLI
20130911	56547.471	13.38	14.41	15.39	16.92	60-cm	FLI
20130914	56550.302	13.25	14.34	15.38	16.66	60-cm	FLI
201309014	56550.330	13.24	14.42	15.40	16.80	60-cm	FLI
20131012	56578.461	13.32	14.47	15.60	17.20	60-cm	FLI
20131229	56656.327	14.06	15.46	16.62	18.10	Schmidt	FLI
20140123	56681.265	13.39	14.52	15.48	16.84	Schmidt	FLI
20140321	56738.483	13.50	14.75	15.91	17.19	Schmidt	FLI
20140321	56738.504	13.56	14.78	15.85	17.29	Schmidt	FLI
20140522	56799.515	13.26	14.41	15.51	16.78	Schmidt	FLI
20140521	56799.542	13.28	14.48	15.39	16.83	Schmidt	FLI
20140628	56837.443	13.38	14.49	15.53	16.83	Schmidt	FLI
20140629	56838.421	13.32	14.46	15.50	16.82	Schmidt	FLI
20140629	56838.478	13.37	14.50	15.40	16.81	Schmidt	FLI
20140803	56873.307	13.83	15.14	16.29	17.89	Schmidt	FLI
20140803	56873.328	13.82	15.14	16.29	17.71	Schmidt	FLI
20140804	56874.317	13.88	15.18	16.27	17.83	Schmidt	FLI
20140804	56874.351	13.82	15.13	16.36	-	Schmidt	FLI
20140818	56888.360	13.91	15.17	16.22	17.87	Schmidt	FLI
20140818	56888.381	13.90	15.16	16.34	-	Schmidt	FLI
20140819	56889.295	13.87	15.13	16.26	17.83	Schmidt	FLI
20140819	56889.318	13.84	15.15	16.30	17.75	Schmidt	FLI
20140822	56892.358	13.79	15.02	16.07	17.55	Schmidt	FLI
20140923	56924.325	13.24	14.35	15.35	-	Schmidt	FLI
20141126	56988.238	13.37	14.50	15.72	16.91	Schmidt	FLI
20141213	57005.280	13.37	14.50	-	16.80	Schmidt	FLI
20141213	57005.303	13.41	14.57	15.61	-	Schmidt	FLI
20141214	57006.340	13.38	14.52	-	16.84	Schmidt	FLI
20141214	57006.363	13.40	14.56	15.64	-	Schmidt	FLI
20150221	57074.535	13.50	14.69	16.03	17.16	Schmidt	FLI
20150424	57136.578	13.66	14.90	15.83	17.38	Schmidt	FLI
20150426	57138.548	13.67	14.93	16.07	17.52	Schmidt	FLI
20150519	57162.488	13.42	14.55	15.85	16.79	Schmidt	FLI
20150522	57164.500	13.39	14.52	15.83	16.90	Schmidt	FLI
20150613	57186.505	13.79	15.04	16.50	17.67	Schmidt	FLI

Table 2 — *Continued.*

Date	J. D. (24...)	I [mag]	R [mag]	V [mag]	B [mag]	Telescope	CCD camera
20150716	57220.423	13.89	15.17	16.53	17.80	Schmidt	FLI
20150717	57221.478	14.01	15.33	16.75	17.94	Schmidt	FLI
20150824	57259.393	13.85	15.10	16.29	17.53	Schmidt	FLI
20150825	57260.384	14.10	15.40	16.61	17.90	Schmidt	FLI
20150903	57269.381	13.73	14.99	16.25	17.64	Schmidt	FLI
20151103	57330.284	13.32	14.49	15.68	16.82	Schmidt	FLI
20151104	57331.297	13.33	14.47	15.74	16.81	Schmidt	FLI
20151105	57332.286	13.34	14.46	15.76	16.86	Schmidt	FLI
20151106	57333.286	13.39	14.55	15.79	16.96	Schmidt	FLI
20151107	57334.267	13.38	14.54	15.78	16.95	Schmidt	FLI
20151215	57372.270	13.29	14.40	15.66	16.81	Schmidt	FLI
20160206	57425.240	13.36	14.50	15.41	16.90	Schmidt	FLI
20160406	57485.448	13.40	14.53	15.47	16.97	Schmidt	FLI
20160427	57506.511	13.53	14.67	15.72	17.20	Schmidt	FLI
20160513	57522.485	13.17	14.18	15.14	16.47	Schmidt	FLI
20160514	57523.471	13.04	14.05	14.99	16.34	Schmidt	FLI
20160625	57565.464	13.17	14.22	15.19	16.52	Schmidt	FLI
20160711	57581.451	13.20	14.23	15.22	16.59	Schmidt	FLI
20160712	57582.484	13.22	14.26	15.25	16.63	Schmidt	FLI
20160713	57583.470	13.21	14.29	15.24	16.61	Schmidt	FLI
20160804	57605.436	13.19	14.22	15.16	16.50	Schmidt	FLI
20160806	57607.415	13.18	14.22	15.17	16.51	Schmidt	FLI

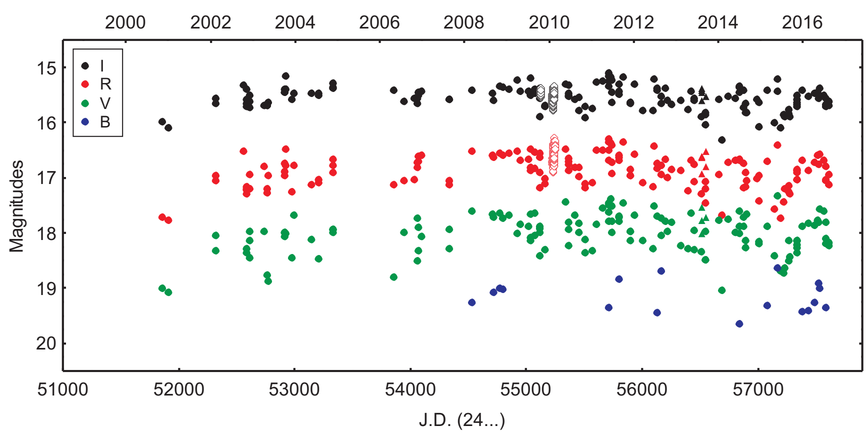

Fig. 1 $IRVB$ light curves of V977 Cep during the period 2000 October−2016 August.

amplitudes and durations. The fading events with larger amplitudes in the brightness of the star were observed in 2009 July, 2010 September, 2011 December, 2013 February, 2013 December and 2014 August. The deepest and most prolonged drop in the brightness of V982 Cep was observed in 2015 August ($\Delta I = 0.90$ mag, $\Delta R = 1.08$ mag, $\Delta V = 1.42$ mag, $\Delta B = 1.28$ mag). One could suggest that fading events happen frequently during periods with missing data.

The measured color indices $V-I$, $V-R$ and $B-V$ vs. the stellar V magnitude of V982 Cep during the period of our observations are plotted in Figure 4. The figure shows evidence of the blueing effect, which is most obvious for the $B-V$ index vs the stellar V magnitude. The amplitudes of the observed drops in the brightness of the star and the existence of the blueing effect are indications of UXor type variability. It is likely that the observed fading events in the light curve of V982 Cep are due to obscuration from circumstellar clouds of protostellar material and/or the existence of planetesimals around the star.

We used the 2MASS JHK_s magnitudes of V977 Cep and V982 Cep to construct a two-color diagram to check whether the stars have infrared excess,

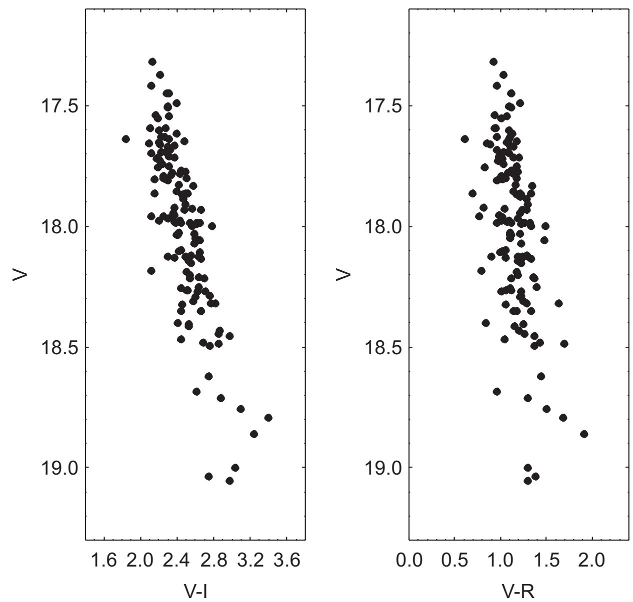

Fig. 2 Color indices $V - I$ and $V - R$ vs. the stellar V magnitude of V977 Cep during the period 2000 October−2016 August.

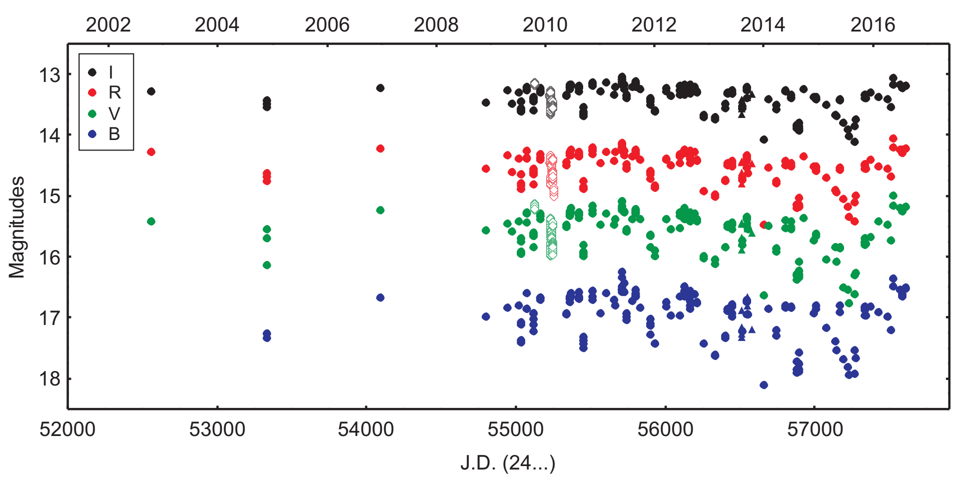

Fig. 3 $IRVB$ light curves of V982 Cep during the period 2002 October–2016 August.

which is an indication for the presence of a circumstellar disk.

Figure 5 shows the location of the main sequence (green line) and giant stars (purple line) from Bessell & Brett (1988), and the location of CTTSs (black line) from Meyer et al. (1997). A correction to the 2MASS photometric system was performed following the procedure in Carpenter (2001). The three red parallel dotted lines show the direction of the interstellar reddening vectors determined for the NGC 7129 region by Straižys et al. (2014).

From Figure 5 we can see that both V977 Cep and V982 Cep lie about 0.2 mag above the intrinsic CTTS line. Therefore the stars from our study have clear infrared excess, indicating the presence of disks around them. All existing photometric and spectral data for V977 Cep and V982 Cep suggest that they can be classified as CTTSs. Additionally, V982 Cep exhibits UXor type variability, which is known to be inherent in TTSs.

We used the software packages PERSEA (Schwarzenberg-Czerny 1996) and PERIOD04 (Lenz & Breger 2005) to search for periodicity in the light curves of the stars from our study. We did not identify any periodicity in the variations of V982 Cep, however, our time-series analysis of V977 Cep covering the period 2010–2016 showed a 8.149 ± 0.038 d period and led to

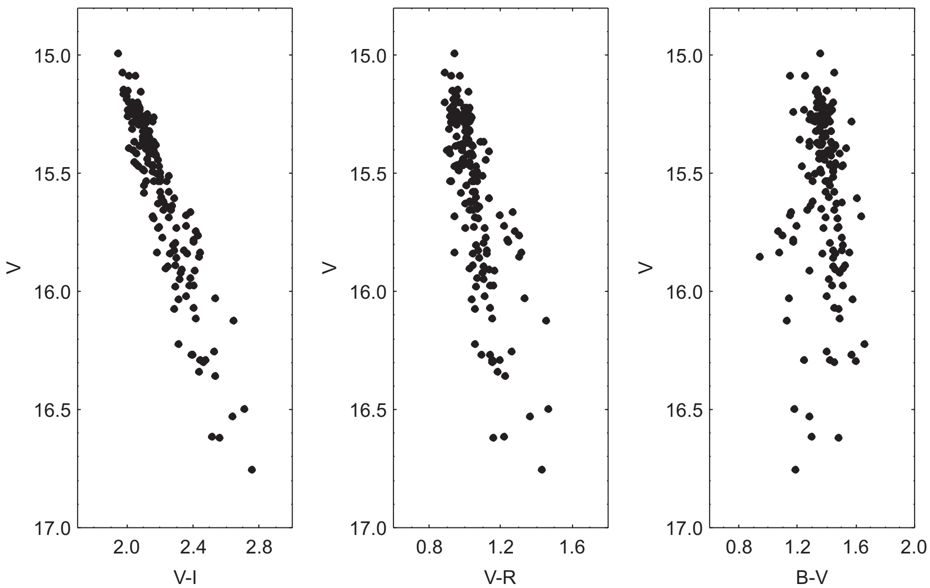

Fig. 4 Color indices $V-I$, $V-R$ and $B-V$ vs. the stellar V magnitude of V982 Cep during the period 2002 October–2016 August.

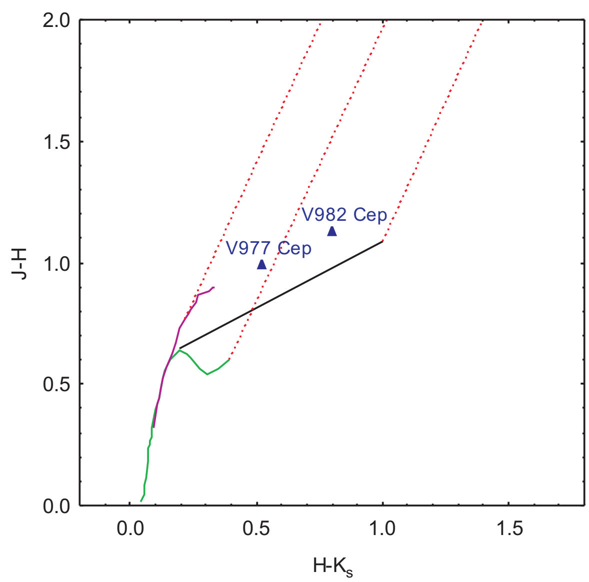

Fig. 5 The $J-H$ vs. $H-K_s$ diagram for V977 Cep and V982 Cep detected in J-, H- and K_s-bands in the 2MASS catalog.

the ephemeris

$$\mathrm{JD(max)} = 2456007.444384 + 8.149221 \times E\,. \quad (1)$$

False Alarm Probability (FAP) estimation was done by randomly deleting about 15% of the data about 10 times and then redetermining the period. The period and starting age determinations remained stable even when a subsample of about 20% of the data were removed. Figure 6 shows the I-band folded light curve of V977 Cep according to the ephemeris (1). The data obtained in the RVB-bands show the same shape of the folded light curves.

The discovered periodicity in the light curve of V977 Cep is stable during a time interval of several years. It is a typical rotational period for CTTSs (see Bouvier et al. 1995). The periodicity could be caused by rotational modulation of spots on the stellar surface. Unlike WTTSs, which have rotational periods in the range 2–

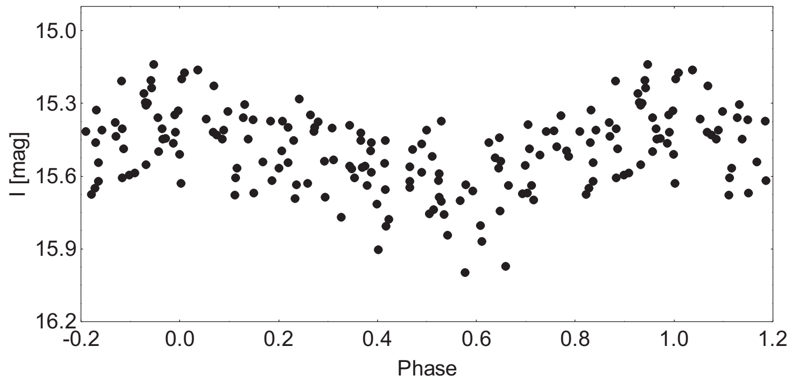

Fig. 6 I-band folded light curve of V977 Cep.

5 d, CTTSs have rotational periods in the range 6–9 d. According to Petrov (2003), it is possible that the existence of an accreting disk and stellar wind in a CTTS somehow slows down its rotation.

4 CONCLUSIONS

The long-term multicolor light curves of the PMS stars V977 Cep and V982 Cep during the period 2000 to 2016 are presented and discussed. Both stars show photometric characteristics of CTTSs. The observed amplitudes in their brightness variations, the shapes of their light curves and the found period of 8.149 d for V977 Cep confirmed that suspicion. It is highly likely that V982 Cep has a UXor type variability. We found evidence for the blueing effect in its color-stellar magnitude diagram. Further photometric and spectral observations of the stars from our study will be of great importance for determining their exact classification.

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