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PHOTOMETRIC AND SPECTROSCOPIC STUDY OF FIVE PRE-MAIN SEQUENCE STARS IN THE VICINITY OF NGC 7129

E. H. Semkov[1], S. I. Ibryamov[2] and S. P. Peneva[1]

[1]*Institute of Astronomy and National Astronomical Observatory, Bulgarian Academy of Sciences, 72, Tsarigradsko Shose Blvd., 1784 Sofia, Bulgaria*

E–mail: *esemkov@astro.bas.bg, speneva@astro.bas.bg*

[2]*Department of Physics and Astronomy, Faculty of Natural Sciences, University of Shumen, 115, Universitetska Str., 9712 Shumen, Bulgaria*

E–mail: *sibryamov@shu.bg*

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SUMMARY: We present results from long-term optical photometric and spectroscopic observations of five pre-main sequence stars, located in the vicinity of the bright nebula NGC 7129. We obtained *UBVRI* photometric observations in the field centered on the star V391 Cep, north-west of the bright nebula NGC 7129. Our multicolor CCD observations spanned the period from February 1998 to November 2016. At the time of our photometric monitoring, a total of thirteen medium-resolution optical spectra of the stars were obtained. The results from our photometric study show that all stars exhibit strong variability in all optical passbands. Long-term light curves of the five stars indicate the typical classical T Tauri star variations in brightness with large amplitudes. We did not find any reliable periodicity in the brightness variations of all five stars. The results from spectral observations showed that all studied stars can be classified as classical T Tauri stars with rich emission line spectra and strong variability in profiles and intensity of emission lines.

Key words. stars: pre-main sequence – stars: variables: T Tauri, Herbig Ae/Be, UX Orionis – stars: individual: V391 Cep, 2MASS J21401174+6630198, 2MASS J21402277+6636312, 2MASS J21403852+6635017, 2MASS J21403576+6635000

1. INTRODUCTION

The study of the pre-main sequence (PMS) stars is important to learn more about the early stage of stellar evolution. The most important characteristic of the PMS stars is the photometric and spectroscopic variability, discovered at the beginning of their study.

In the fields of star formation the PMS stars form in groups called stellar associations or stellar aggregates. While the high-mass star formation takes place generally in the big molecular clouds, the low-mass stars can be formed even in the smallest regions. Many PMS stars are found to be members of photometric and spectroscopic double or multiple systems (see Herbig 1962, Mathieu et al. 1989, Reipurth and Zinnecker 1993, Reipurth et al. 2002). The PMS stars are rare among field stars because the stars spend less then 1% of their life during the PMS evolutionary stage. The PMS stars are separated into two types – the low mass ($M \leq 2M_{\odot}$) T Tauri stars (TTS) and the more massive ($2M_{\odot} \leq M \leq 8M_{\odot}$) Herbig Ae/Be stars (HAEBES).

The study of TTS began in the mid-20th century with the pioneering work of Joy (1945). TTS exhibit irregular photometric variability and emission spectra. They are separated into two subclasses: the classical T Tauri stars (CTTS) surrounded by spacious accreting circumstellar disks, and weak-line or naked T Tauri stars (WTTS) without evidence of disks accretion (Ménard and Bertout 1999). CTTS are distinguished from WTTS by their strong Hα emission line and by significant infrared and ultraviolet excesses. Usually, the upper limit of EW(Hα)$\leq$5Å is used for defining the WTTS, but the optically veiled and nonoptically veiled PMS stars can be distinguished based on EW(Hα) only by taking into account their spectral type (see White and Basri 2003). Both subclasses of TTS show strong brightness variations over comparatively short time intervals (days or weeks).

According to Herbst et al. (1994, 2007) the reasons for the observed brightness variations of the PMS stars are diverse. The variability of CTTS is caused by a superposition of cool and hot spots on the stellar surface. The observed non-periodic brightness variations are produced by highly variable accretion from the circumstellar disk onto the stellar surface. Large amplitudes reaching up to 2-3 mag in the V-band are observed in CTTS.

The variability of WTTS, is due to rotation of the stellar surface covered by cool spots or groups of spots. Some TTS show a clearly expressed periodicity (see Herbst et al. 2007, Scholz et al. 2011). The periods of variability of WTTS are registered on time scales of days and with amplitudes reaching 0.8 mag. in V-band. The brightness variability in WTTS can also be due to flare-like variations in the B- and U-band. Flares are random with varying duration and amplitudes of brightness and without periodicity (Herbst et al. 2007).

Drops in brightness, lasting from few days to several weeks or months, are observed in the early type of CTTS and HAEBES. Usually, the decreases in brightness are non-periodic with amplitudes reaching 2.8 mag in the V-band. Presumably, they are a result of the circumstellar dust or clouds obscuration (Grinin et al. 1991, Herbst et al. 2007). The prototype of this group of PMS stars with intermediate mass, named UXors, is UX Orionis. In very deep minima the color indices of UXors commonly become bluer (color reverse), the so called "blueing effect" (see Bibo and Thé 1990).

Some of CTTS undergo eclipses with irregular depths and periodicity for several days, probably caused by warped inner disk viewed near to edge-on (Bouvier et al. 1999, 2007). The prototype of this group of PMS stars is AA Tau, and the number of these objects has steadily increased during the recent years (Barsunova et al. 2016, Sousa et al. 2016, Rodriguez et al. 2017, Schneider et al. 2018). As the warp in the accretion disc is presumably caused by the magnetic field of the star, the recurrence period of these eclipses, equal to a few days, is actually tracing the period of the Kepler rotation of the gas disk at a distance of the corotation radius from the star.

Our photometric and spectral study of the PMS stars has been done in the dark clouds in the vicinity of the reflection nebula NGC 7129. The region is immersed in a very active and complex molecular cloud (Hartigan and Lada 1985, Miranda et al. 1993). NGC 7129 is apparently a part of a larger structure, called the Cepheus Bubble (Kun et al. 1987) and it represents a region with active star formation (Magakian and Movsessian 1997, Kun et al. 2008, 2009). A large number of TTS, HAEBES, Herbig-Haro objects, collimated jets, and cometary nebulae are observed in this region. The distance to NGC 7129, is determined as 1.26 kpc by Shevchenko and Yakubov (1989), as 1.15 kpc by Straizŷs et al. (2014), and as 800 pc by Ábrahám et al. (2000). The age of the NGC 7129 star forming region determined by Straizýs et al. (2014) is 3 Myr.

The stars V391 Cep and V1 were discovered as strong Hα emission sources in the study of Semkov and Tsvetkov (1986). The variability of the star V2 was registered by Semkov (2003b) and the variability of V3 by Semkov (2000). According to Semkov (2003b), the stars V1, V2 and V3 are irregular variables, which belong to the class of PMS stars. The variability in the star V4 is discovered during the present study.

The present paper is a part of our photometric and spectroscopic study of the PMS stars in the vicinity of NGC 7129. The results from our previous studies have been published in Semkov (1993a, 1993b, 1993c, 1996, 2000, 2002, 2003a, 2003b, 2004a, 2004b), Semkov et al. (1999), Ibryamov et al. (2014), Ibryamov et al. (2017).

2. OBSERVATIONS AND DATA REDUCTION

2.1. Photometric observations

The photometric $UBVRI$ data presented in this paper were collected in the period from February 1998 to November 2016. The CCD observations were obtained with four telescopes, in two observatories – the 2-m Ritchey-Chrétien-Coudé (RCC), the 50/70-cm Schmidt and the 60-cm Cassegrain telescopes of the Rozhen National Astronomical Observatory in Bulgaria, and the 1.3-m Ritchey-Chrétien (RC) telescope of the Skinakas Observatory[1] of the University of Crete in Greece. The total number of the nights used for observations is 295. The observations were performed with eight different types of CCD cameras. Their technical parameters and specifications are given in Ibryamov et al. (2015).

All frames were taken through a standard Johnson−Cousins $UBVRI$ set of filters. The frames obtained with the CCD cameras at the 2-m RCC and the 1.3-m RC telescopes are bias frame subtracted and flat field corrected. All frames obtained with the

[1]Skinakas Observatory is a collaborative project of the University of Crete, the Foundation for Research and Technology, Greece, and the Max-Planck-Institut für Extraterrestrische Physik, Germany.

CCD cameras at the 50/70-cm Schmidt and the 60-cm Cassegrain telescopes are dark frame subtracted and flat field corrected.

The photometric data were reduced using the IDL based *DAOPHOT* subroutine. As a reference, the *UBVRI* comparison sequence reported in Semkov (2003a) was used. All data were analyzed using the same aperture, which was chosen as 6 arc seconds radius, while the background annulus was taken from 10 to 15 arc seconds. The complete photometric data are available in the Appendix.

2.2. Spectroscopic observations

At the time of our photometric monitoring, a total of thirteen medium-resolution optical spectra of the PMS stars in the region were obtained. The spectral observations are performed in Skinakas Observatory with the focal reducer of the 1.3-m RC telescope and ISA 608 spectral CCD camera (2000×800 pixels, 15×15 μm). Two gratings with 1300 lines/mm and 600 lines/mm, and a 160 μm slit were used. The combination of gratings and slit yields a resolving power $\lambda/\Delta\lambda \sim 1500$ at the Hα line for the 1300 lines/mm grating and $\lambda/\Delta\lambda \sim 1300$ for the 600 lines/mm grating. The exposures of the objects were followed immediately by an exposure of a FeHeNeAr comparison lamp and exposure of an spectrophotometric standard star. All data reduction was performed within IRAF.

3. RESULTS AND DISCUSSION

Fig. 1 shows a three-color image of the field located north-east from the bright nebula NGC 7129 with the marked positions of the stars from our study. The three-color image was obtained on July 23, 2007 with the 1.3-m RC telescope of Skinakas Observatory. In the figure, small cometary nebulae around V391, V2 and V3 are clearly seen.

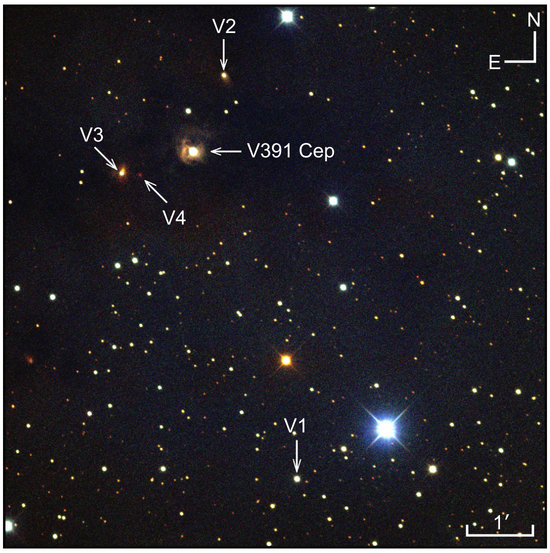

Fig. 1. *A three-color image of the field in the vicinity of NGC 7129.*

Using the JHK_s 2MASS magnitudes of the stars from our study we plot the two-color diagram to identify stars with infrared excess, indicating the presence of a disk. Fig. 2 shows the location of the main sequence (brown line) and giant stars (orange line) from Bessell and Brett (1988), the CTTSs location from Meyer et al. (1997). A correction to the 2MASS photometric system was performed following the prescription of Carpenter (2001). The three parallel dotted lines show the direction of the interstellar reddening vectors determined for the NGC 7129 region by Straizÿs et al. (2014).

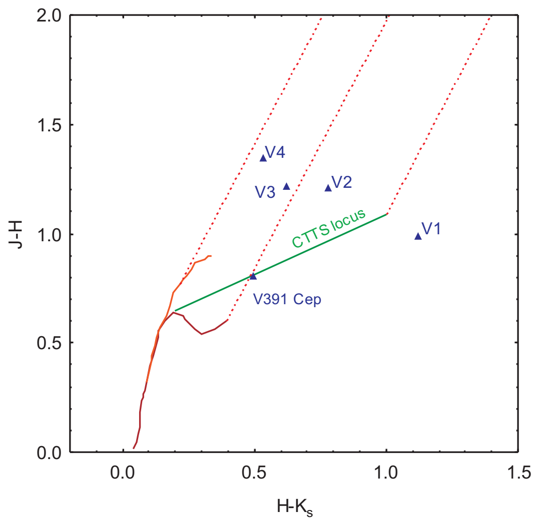

Fig. 2. *The $J-H$ versus $H-K_s$ diagram for the stars from our study. The brown line denotes the location of the main sequence, the orange line - location of giant stars, the green line - CTTS location. The dotted lines denote the direction of the interstellar reddening vectors. The blue triangles designate the PMS stars from our study.*

The positions of stars V2, V3 and V4 indicate a strong infrared excess, the star V391 Cep is located on the line of the CTTS locus, and V1 shows colors typical of more evolved young stars with limited circumstellar material. However, it will be shown in the following sections, that its SED, the nature of the photometric variability, and age fully correspond to similar parameters of the remaining studied objects. As the stars exhibit photometric variability in all passbands, their positions in Fig. 2 can vary during different time periods.

The optical and near-infrared parts of SEDs of stars from our study were constructed using all our *UBVRI* photometric data corrected for the interstellar extinction (Fig. 3). We use the extinction law given in Cardelli et al. (1989) and on the basis of visual extinction A_V for the stars by Kun et al. (2009). The fluxes corresponding to the zero magnitude were obtained from Bessell (1979) for the *UBVRI* bands, and from the 2MASS All Sky Data

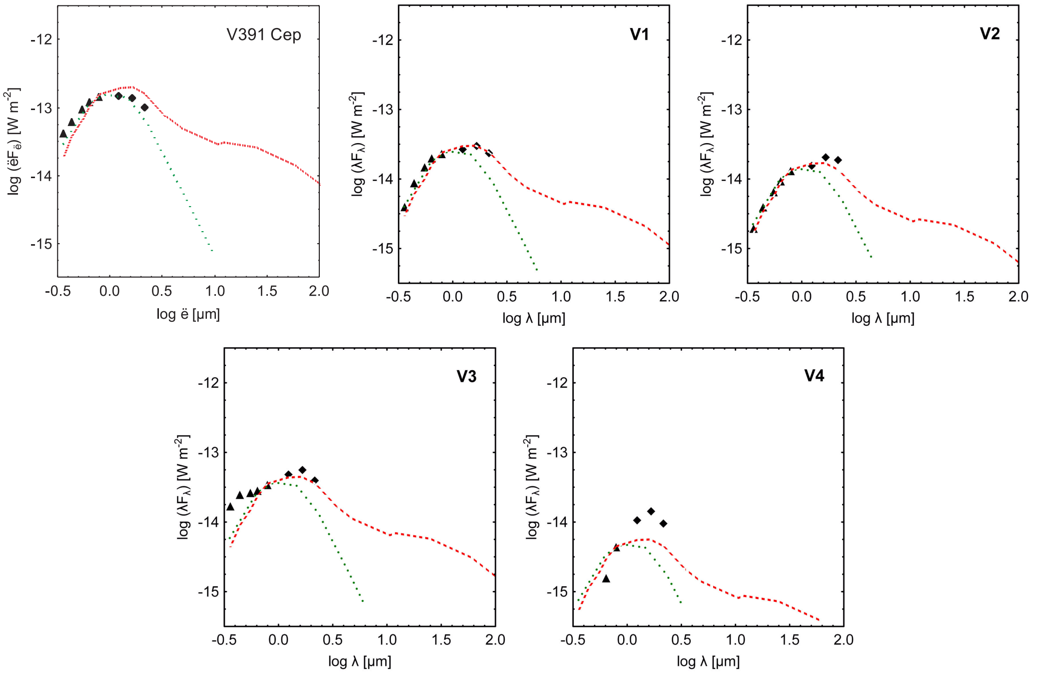

Fig. 3. *SEDs corrected for the interstellar extinction of the stars from our study, based on our UBVRI photometry (triangles) and 2MASS (diamonds).*

release Web-document[2] for the JHK_s bands. Photospheric SEDs have been drawn by green lines. Their values were determined from dereddened I magnitudes and from color indices corresponding to the spectral types. For comparison, the red lines show the median SED of the T Tauri stars of the Taurus star-forming region (D'Alessio et al. 1999).

3.1. V391 Cephei

V391 Cep is located at about 33 arc minutes from the center of NGC 7129 and at about 28 arc minutes from another T Tau star - V350 Cep (see Ibryamov et al. 2014). V391 Cep was discovered as a strong Hα emission source by Semkov and Tsvetkov (1986) and included in the list of Hα emission stars published by Kun (1998). Spectral observations of V391 Cep (Semkov 1993c, Kun et al. 2009) suggest that its spectrum is similar to the CTTS spectrum, with strong Hα line, and presence of emission lines of oxygen, iron, magnesium and other metals. Kun et al. (2009) defined the spectral class of V391 Cep as K5 and determined its mass as 1.15 $M_{\odot}$, its effective temperature as 4350 K and its age as 0.2 Myr.

The CCD observations performed by Semkov (1993c) show the presence of a small cometary nebula around the star, which is not visible on the Palomar Observatory Sky Survey prints and on the photographic plates collected in the field of NGC 7129 (Semkov 1993b). From 1986 to 2002 the variability of brightness in the B-band changes significantly, the amplitude decreases gradually from 2.1 mag to 0.3 mag According to Semkov (2003a) V391 Cep is a CTTS and the change in photometric activity can be caused by an irregular accretion rate.

The subsequent observations performed by Semkov (2000) showed that V391 Cep is a visual double system with a deep infrared component. The distance between the two components is 3 arc seconds. Semkov (2000) determined the color index $R-I$ for the second component and concluded that the object is likely a cool star in the first stages of star formation, forming double system of the PMS stars with V391 Cep.

The results of our long-term multicolor CCD observations of V391 Cep will be accessible through the CDS database. The average value of errors in the measured magnitudes are 0.01-0.02 mag for the I- and R-band data, 0.01-0.03 for the V-band data, 0.02-0.04 for the B-band data, and 0.06-0.10 for the U-band data.

The $UBVRI$ light curves of the star from all our CCD observations (Semkov 2003a and the present paper) are shown in Fig. 4. In the figure, circles denote the CCD photometric data published in the present paper and triangles – the CCD photometric data from Semkov (2003a).

The brightness of V391 Cep during the period of all our CCD observations 1993–2016 varies in the range 12.39–12.76 mag for the I-band, 13.25–13.63 mag for the R-band, 14.09–14.51 mag for the V-band, 15.15–15.82 mag for the B-band,

[2]http://www.ipac.caltech.edu/2mass/releases/allsky/doc/sec6_4a.html

and 15.03−15.82 mag for the U-band. Such photometric characteristics (variability with small amplitude in a time scale of days) are typical for both WTTS and CTTS.

The long-term UBV light curves of V391 Cep from all available published observations (1980−2016) are presented in Fig. 5. The circles denote the CCD observations published in the present study; triangles denote the CCD photometric data from Semkov (2003a) and diamonds denote the photographic data from Semkov (1993b).

The available data suggest that in the period 1986−1992 the star exhibits strong irregular variability. Increases and fading events in the star's brightness are seen during the same period. The reasons for the observed strong photometric variability may be of a different nature. Variable accretion activity, existence of cool and hot spots of the stellar surface, obscuration of the star by circumstellar material are possible reasons. The observed amplitudes in the period 1987−1992 are $\Delta V = 1.3$ mag, $\Delta B = 2.0$ mag and $\Delta U = 2.3$ mag. After 1992, the brightness of V391 Cep varies with comparatively small amplitudes around some average level. Evidences of periodicity in the brightness variability of V391 Cep are not detected. We believe this change in the amplitude of the variability is real, since the errors from photographic observations do not exceed ±0.2 mag.

The measured color indices $V-R$ and $B-V$ versus stellar V magnitude, and $U-B$ index versus B magnitude for the period of all our CCD observations are plotted in Fig. 6. In the figure, the $V/V-R$ diagram indicates that V391 Cep becomes redder as it fades while a change in the color was not observed on the V/BV diagram. Such color variations are typical for TTS with presence of cool spots or groups of spots on the stellar surface. It can be seen from Table 5, that V391 Cep shows a strong ultraviolet excess − a characteristic of CTTS.

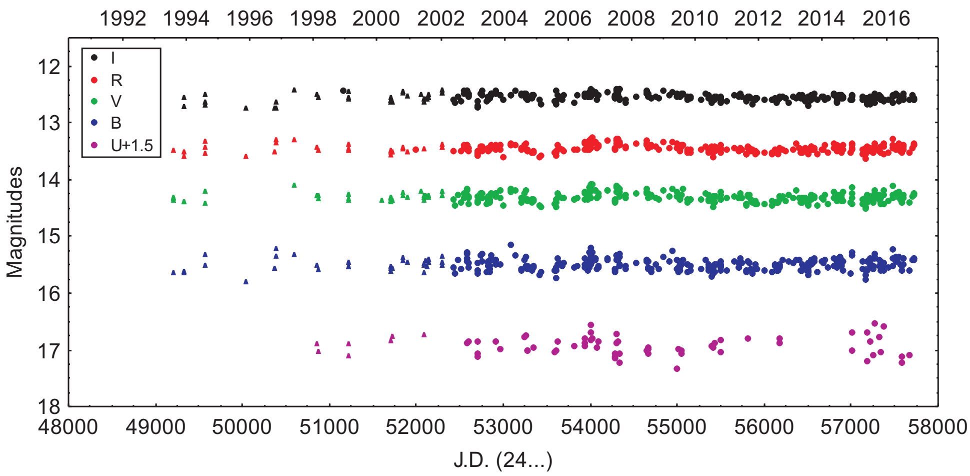

Fig. 4. *The CCD UBVRI light curves of V391 Cep for the period August 1993–November 2016.*

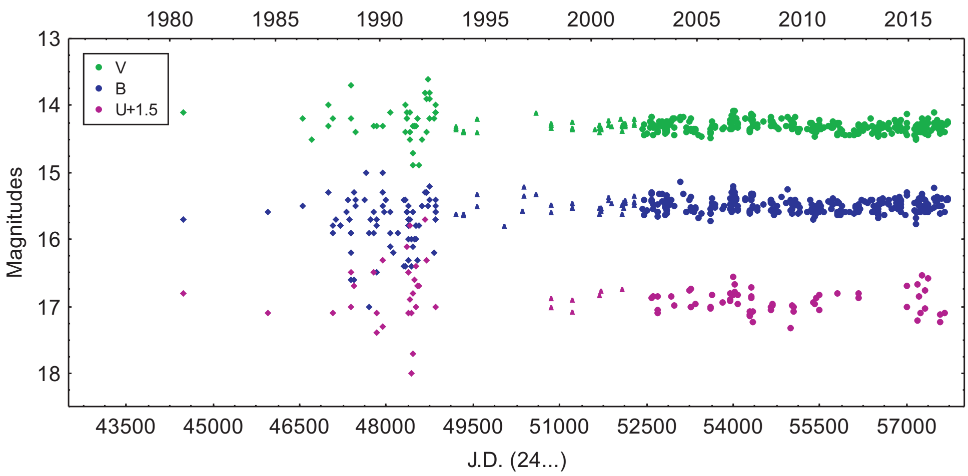

Fig. 5. *The UBV light curves of V391 Cep from all available published observations.*

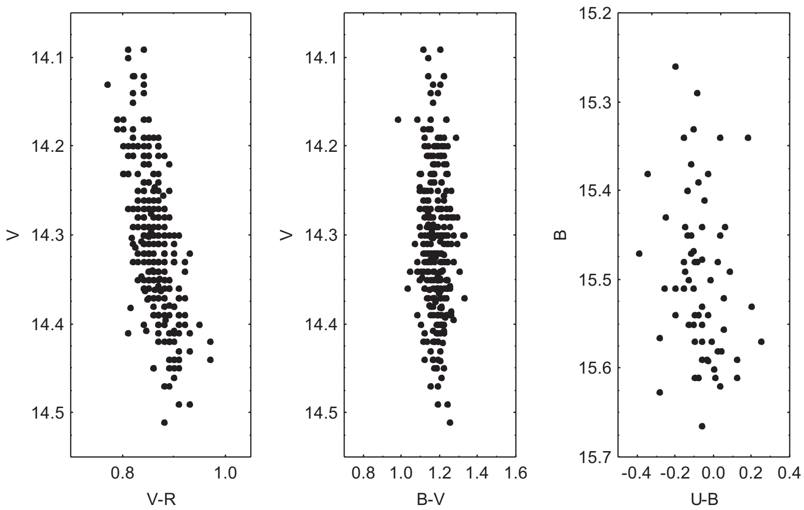

Fig. 6. *The $V - R$ and $B - V$ color indices versus the V magnitude, and the $U - B$ index versus the B magnitude for V391 Cep in the period of all our CCD observations.*

Table 1. The main spectral lines identified in the optical spectra of V391 Cep and their equivalent widths.

Date yyyymmdd	Hδ 4102	Hβ 4861	Mg I 5173	Fe I 5270	Fe II 5316	[O I] 5577	He I 5876	NaD 5890	[O I] 6300	O I 6431	Fe II 6456	Fe II 6516	Hα 6563
20010907				-1.2	-2.2	-9.4	-0.5	-1.4	-4.5	-0.8	-1.0	-1.1	-48.8
20030803			-7.3	-2.9	-2.6	-6.1	-1.3	-1.9	-3.3	-0.8	-0.9		-62.9
20030804			-6.8	-2.9	-2.6	-4.2	-1.6	-2.5	-3.5	-0.6	-1.1	-1.5	-60.0
20040819	-14.3	-14.3	-7.1	-4.9	-6.0	-9.8	-0.7	-1.5	-4.5				-63.4
20050812	-8.8	-16.6	-5.9	-3.8	-3.4	-4.6	-0.9	-1.4	-9.3				-88.0
20061004							-1.6	-3.0	-3.1	-1.2	-1.1	-1.3	-57.0
20100824		-8.6	-5.7	-3.0	-2.6	-3.1	-1.3	-1.8	-2.5	-0.7	-0.8	-1.1	-58.0

In Fig. 7 we show the contour plot from a CCD frame of V391 Cep and the surrounding nebula. The frame is taken on July 25, 2008 with the 1.3-m the RC telescope of Skinakas Observatory. The image was taken in a relatively good atmospheric seeing (around 1 arc seconds). Levels of the contour plot are selected arbitrarily. The bright nebula around the star has not changed significantly during the period of our observations.

Our spectral observations of V391 Cep revealed an extensive emission spectrum without absorption lines (Table 1). The emission lines of hydrogen, iron, magnesium, sodium and forbidden lines of oxygen dominate the spectrum of the star. The most intensive is the hydrogen Hα line, for which weak absorption components from P Cyg profile are noticeable in some spectra. All emission lines show a strong variability of intensity and of full width at half-maximum.

Consequently, in the period 1987−1992, V391 Cep shows photometric characteristics of CTTS but after 1992 its photometric variability is inherent in both WTTS and CTTS with a presence of hot and cool spots on the stellar surface. Although all our spectra were obtained in the period after 1992, cle-

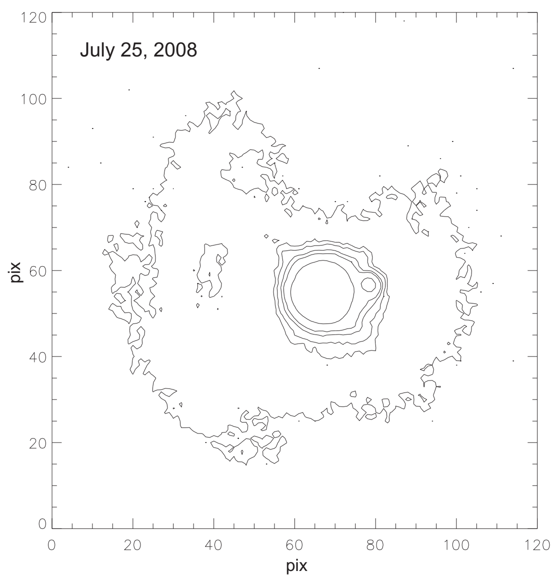

Fig. 7. *Contour plot from CCD frame of V391 Cep in R-band obtained with the 1.3-m RC telescope in Skinakas Observatory on July 25, 2008.*

arly every spectrum is eligible for CTTS. Our conclusion is that V391 Cep is a classical T Tauri star that undergoes periods of enhanced disk accretion alternated with periods of low accretion rates.

3.2. V1 (2MASS J21401174+6630198, NGC 7129 S V1)

The star 2MASS J21401174+6630198 (hereafter V1) was discovered as an Hα emission source in the study of Semkov and Tsvetkov (1986). The star is located at ∼5.4 arc minutes from V391 Cep. Kun et al. (2009) measured $I = 14.34$, $R = 15.20$, $V = 16.18$, and $B = 17.37$, the magnitudes of V1. The authors defined the spectral class of the star as K7 and determined its mass as 0.8 $M_\odot$, its effective temperature as 4060 K, and its age as 2.5 Myr. The spectrum of V1 contains emission lines of the Hα and HeI 6678 lines and it is classified as a CTTS spectrum.

Fig. 8 presents the $UBVRI$ light curves of V1 from all our CCD observations obtained in the period 2000−2016 (Semkov 2003b and the present paper). In the figure, circles denote the CCD photometric data published in the present study while triangles denote photometric data from Semkov (2003b). The results from our long-term multicolor CCD observations of V1 will be accessible through the CDS database. The average value of errors in the measured magnitudes are 0.01-0.02 for the I- and R-band data, 0.01-0.03 for the V-band data, 0.02-0.06 for the B-band data, and 0.07-0.13 for the U-band data.

It is seen from Fig. 8 that V1 spends most of the time in maximal light. During our photometric monitoring, several declines in brightness of the star in all bands are registered. The periods of decline in brightness are relatively short and sometimes we have only one photometric point in the minimum light. The brightness of V1 during the period of our observations varies in the range 14.04−14.88 mag for the I-band, 14.89−16.01 mag for the R-band, 15.76−17.02 mag for the V-band, 16.79−18.46 mag for the B-band, and 17.16−18.39 mag for the U-band. Evidences of periodicity in the brightness variability of V1 are not detected.

The measured color indices $V-I$, $V-R$ and $B-V$ versus the stellar V magnitude during the period of all our CCD observations are plotted in Fig. 9. It is seen from the figure that the star becomes redder as it fades and real color reverse is observed on the $V/B-V$ diagram.

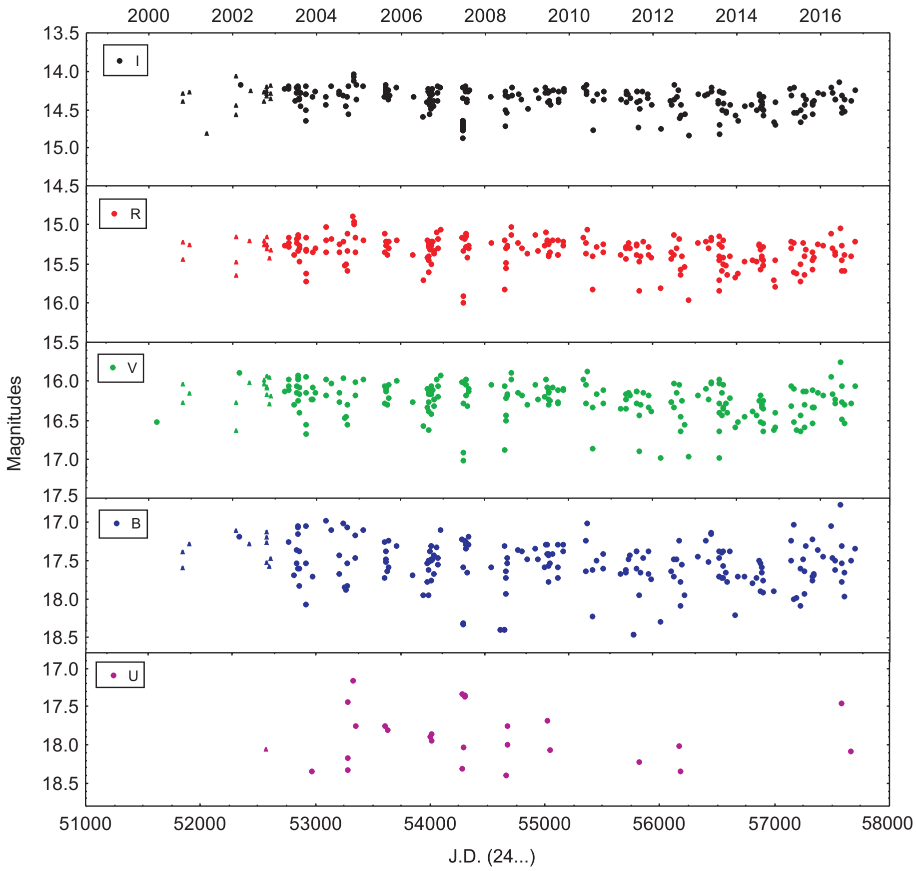

Fig. 8. *The CCD UBVRI light curves of V1 for the period March 2000−November 2016.*

The reasons of observed non-periodic drops in brightness can be different, short irregular obscuration of the star by circumstellar dust or clouds, or eclipses from multiple bodies rotating in orbits around the star. In the case that the decreases in the brightness are caused by obscuration by circumstellar material, the observed amplitudes are too small to show indication for a strong blueing effect.

The both spectra of V1 can be classified as CTTS spectra (Table 2). The Hα emission line and the forbidden line of oxygen (OI λ5577) are the most intensive, but the lines of iron are also seen in emission. The identified absorption lines are of the sodium doublet and lithium (LiI λ6707). Unlike the other stars from our study, the spectra of V1 showed no significant spectral variability.

Therefore, during the periods outside of the deep minima, V1 can be classified as CTTS with weak activity. The observed drops in brightness are probably caused by clouds of dust orbiting the star but their size and density are relatively small to cause a classical UXor phenomenon.

3.3. V2 (2MASS J21402277+6636312, NGC 7129 S V2)

Variability of the star 2MASS J21402277+6636312 (hereafter V2) was registered by Semkov (2003b). The star is located at ∼1.3 arc minutes from V391 Cep. The authors defined the spectral class of the star as M0 and determined its mass as 0.6 $M_{\odot}$, its effective temperature as 3850 K, and its age as 3.0 Myr. The spectrum of V1 contains the emission line of Hα and it is classified as a CTTS spectrum.

In Fig. 1 the existence of a small cometary nebula around V2 can be seen. The $UBVRI$ light curves of the star from all our CCD observations (Semkov 2003b and the present paper) are shown in Fig. 10. The symbols used are as in Fig. 8. The results of our long-term multicolor CCD observations of V2 will be accessible through the CDS database. The average value of errors in measured magnitudes are 0.01-0.03 for the I- and R-band data, 0.01-0.05 for the V-band data, 0.02-0.07 for the B-band data, and 0.07-0.15 for the U-band data.

From Fig. 10 it can be seen that, during the period of our observations, V2 shows variability in all bands. This variability includes short time rises and decreases of the star's brightness with small amplitudes. During the period of our observations, the brightness of the star varies in the range 14.97−16.27 mag for the I-band, 15.98−17.41 mag for the R-band, 17.04−18.42 mag for the V-band, 18.48−19.69 mag for the B-band, and 18.98−19.94 mag for the U-band. Because of the limit of our photometric data we have only nine photometric points in the U-band.

The measured color indices $V-I$, $V-R$ and $B-V$ versus the stellar V magnitude for the period of our CCD observations are plotted in Fig. 11.

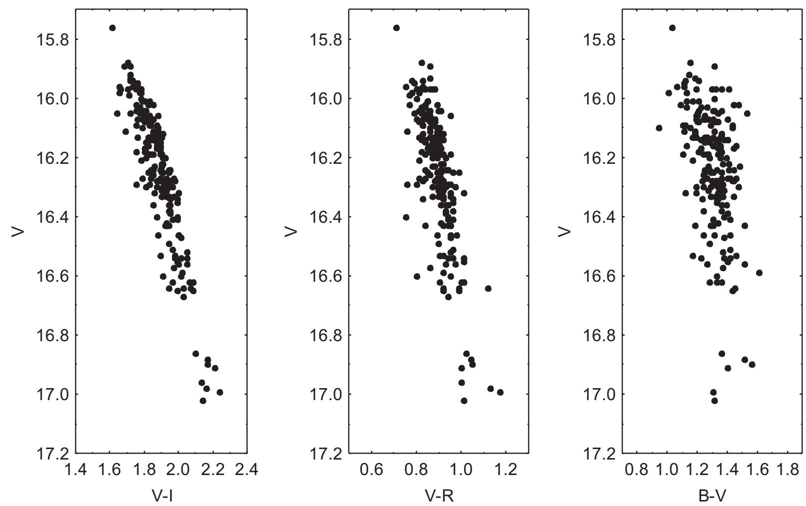

Fig. 9. *The $V-I$, $V-R$ and $B-V$ color indices versus the V magnitude for V1 in the period of all our CCD observations.*

Table 2. Spectral lines identified in optical spectra of V1 and lines' equivalent widths.

Date YYYYMMDD	Fe I 5461	[O I] 5577	NaD 5890,96	[O I] 6300	O I 6431	Hα 6563	Li I 6707	Fe I 6829
20010908	-2.5	-25.3		-3.4	-0.6	-20.7	0.5	-1.1
20030803	-1.4	-21.3	3.1	-1.5		-19.5	0.5	-1.6

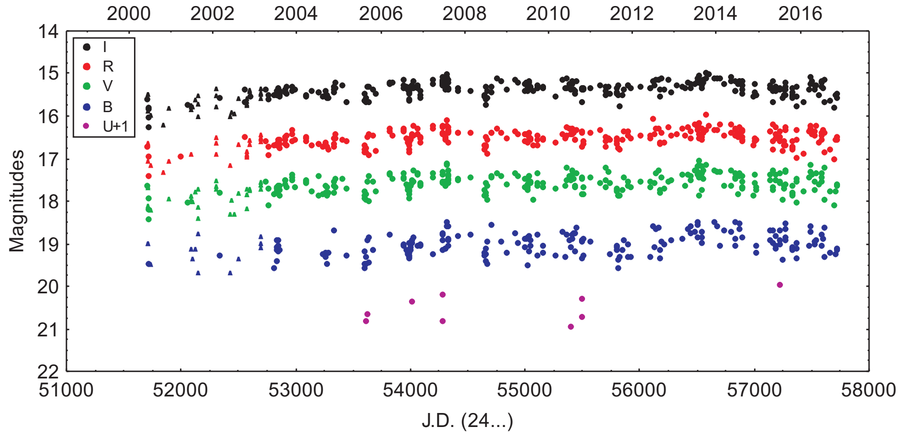

Fig. 10. *CCD $UBVRI$ light curves of V2 for the period June 2000–November 2016.*

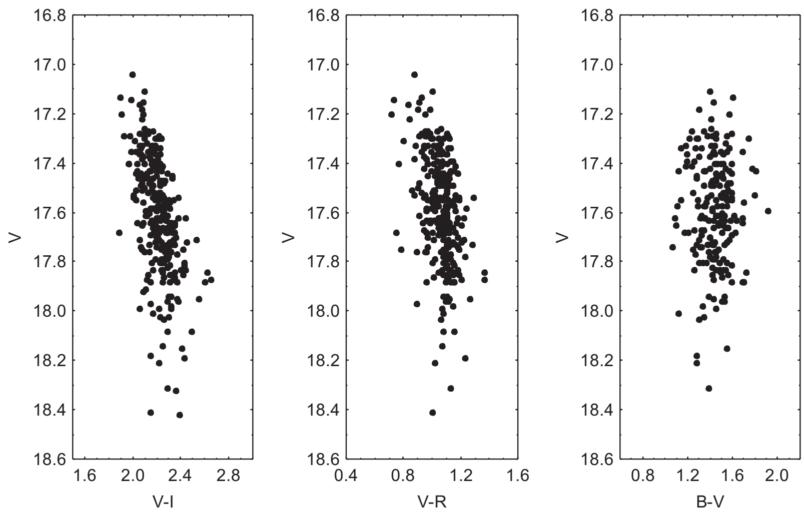

Fig. 11. *The $V-I$, $V-R$, and $B-V$ color indices versus the V magnitude for V2 in the period of all our CCD observations.*

Table 3. Spectral lines identified in the optical spectra of V2 and lines' equivalent widths.

Date yyyymmdd	Fe I 5461	[O I] 5577	NaD 5890	[O I] 6300	Hα 6563	Fe I 6829	Fe II 6862	Fe II 6922	Fe I 6948	Fe I 7248	He I 7281	Fe II 7340	Si III 7369
20020815		-53.0		-6.4	-39.3	-5.9	-3.3	-1.6	-2.3				
20141018	-12.5	-89.9	21.8	-18.6	-17.9	-8.7	-5.7	-2.8	-2.7	-15.8	-9.0	-9.8	-5.6

The long-term light curves and color indices of V2 gives grounds for prediction of different reasons for the observed variability of the star – existence of hot and cool spots on the stellar surface, and irregular obscuration of the star by circumstellar material. Fig. 11 shows evidences for color reversal, especially for the $V-R$ and $B-V$ indices. The color reversal supports the assumption that at least one of the reasons for the observed declines in star's brightness is obscuration of the star by circumstellar material.

Our spectral observations of V2 revealed an extensive emission spectrum as only the sodium doublet is observed in absorption (Table 3). The emission lines of hydrogen, iron, helium and forbidden lines of oxygen dominate the spectrum of the star. All emission lines show a strong variability of intensity and of full width at half-maximum. Therefore, the star has photometric and spectral characteristics of CTTS.

3.4. V3 (2MASS J21403852+6635017, NGC 7129 S V3)

The star 2MASS J21403852+6635017 (hereafter V3) was reported as a variable star in Semkov (2000). V3 is a part of a visual double system and is located at ∼1.2 arc mininutes from V391 Cep.

Kun et al. (2009) measured $I = 15.34$, $R = 16.45$, $V = 17.78$ and $B = 19.55$ magnitudes for V3 and $I = 16.77$ mag for the second component. The distance between the two components determined by Kun et al. (2009) is 3.2 arc seconds. The authors defined spectral class of V3 as K5 and determined its mass as 1.15 $M_\odot$, its effective temperature as 4350 K, and its age as 2.5 Myr. The spectrum of V3 shows a strong Hα emission line and the star is classified as a CTTS.

Fig. 12 presents the $UBVRI$ light curves of V3 from all our CCD observations (Semkov (2003b) and the present paper), obtained in the period 1999−2016. The symbols used are as in Fig. 8. The results of our long-term multicolor CCD observations of the star V3 will be accessible through the CDS database. The average value of errors in the measured magnitudes are 0.01-0.03 for the I- and R-band data, 0.01-0.03 for the V-band data, 0.02-0.06 for the B-band data, and 0.07-0.13 for the U-band data.

The star shows a large amplitude photometric variability in all bands. It can be seen from Fig. 12 that V3 usually spends most of the time at maximal light. During our photometric monitoring, deep declines with different amplitudes in the star's brightness are registered. It is possible to suggest the existence of frequent deep fading events during periods is due to insufficient data.

The brightness of V3 during the period of our CCD observations 1999−2016 varies in the range 14.61−16.60 mag for the I-band, 15.81−17.87 mag for the R-band, 16.88−19.20 mag for the V-band, 18.46−20.44 mag for the B-band, and 18.90−20.13 mag for the U-band. Because of the limit of our photometric data we have only six photometric points in the U-band. In a very low light the brightness of the star in the B-band is under the photometric limit of the 60-cm Cassegrain and the 50/70-cm Schmidt telescopes. Evidences of periodicity in the brightness variability of V3 are not detected.

The measured color indices $V - I$, $V - R$ and $B - V$ versus stellar V magnitude for the period of all our CCD observations are plotted in Fig. 13. It can be seen from the figure that real color reverse is registered. The observed drops in brightness are probably caused by clouds of dust orbiting the star, dense enough to cause UXor phenomenon.

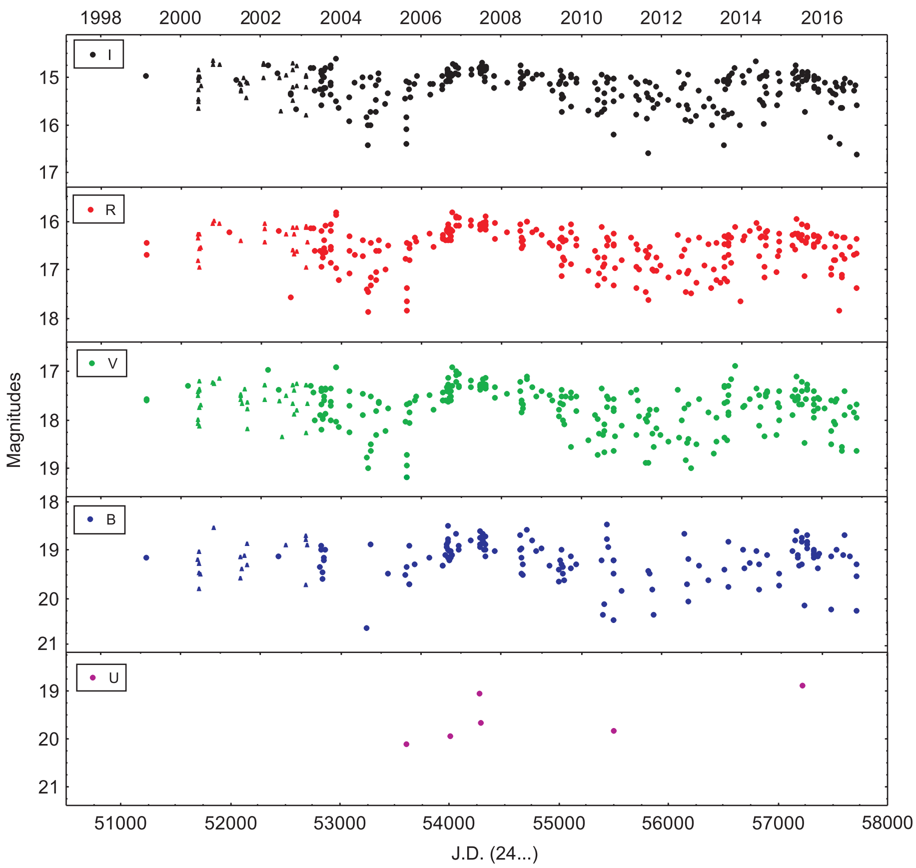

Fig. 12. *The CCD UBVRI light curves of V3 for the period February 1999–November 2016.*

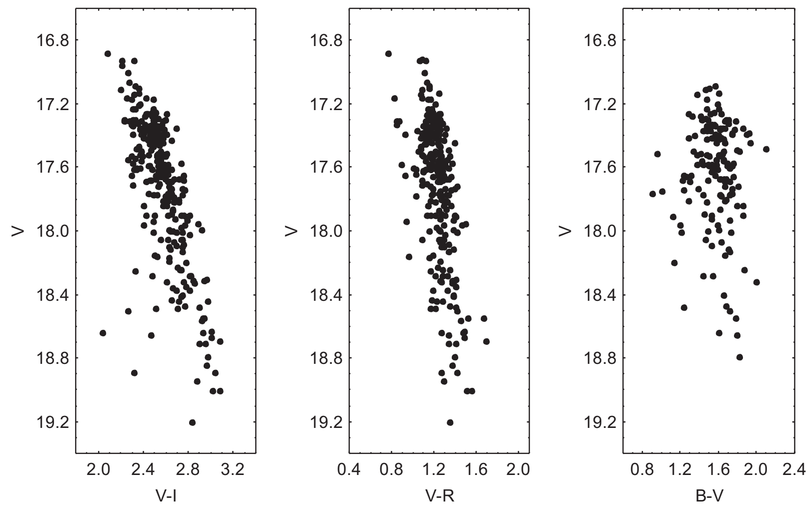

Fig. 13. *The $V-I$, $V-R$ and $B-V$ color indices versus V magnitude for V3 in the period of all our CCD observations.*

Table 4. Spectral lines identified in optical spectra of V3 and lines' equivalent widths.

Date yyyymmdd	Fe I 5461	[O I] 5577	NaD 5890	[O I] 6300	Hα 6563	Fe I 6829	Fe II 6862	Fe I 6948	Fe I 7248	He I 7340	Fe II 7369	Si III
20010907	-1.8	-32.5	-6.0	-11.1	-15.4	-2.9		-1.2				
20141018	-10.6	-64.6	-13.2	-8.3	-27.7	-5.2	-4.1	-2.4	-8.7	-5.6	-6.0	-4.0

Our spectral observations of V3 revealed an extensive emission spectrum without absorption lines (Table 4). The emission lines of hydrogen, iron, sodium and forbidden lines of oxygen dominate the spectrum of the star. All emission lines show a strong variability of intensity and of full width at half-maximum. Therefore, the star shows spectral characteristics of CTTS and photometric characteristics of both CTTS and UXor.

3.5. V4 (2MASS J21403576+6635000)

The star 2MASS J21403576+6635000 (hereafter V4) is discovered as a variable during the present study. The star is located at coordinates $\mathrm{RA}_{J2000} = 21^{\mathrm{h}}\ 40^{\mathrm{m}}\ 35\overset{s}{.}77$ and $\mathrm{Dec}_{J2000} = +66^{\circ}\ 35'\ 01''$, ~50 arc seconds from V391 Cep. V4 shows a very strong and fast photometric variability during short time periods (several minutes or hours) with large amplitude.

The photometric results from our long-term CCD observations of V4 will be accessible through the CDS database. The average value of errors in the measured magnitudes are 0.01-0.02 for the I-band data, and 0.01-0.10 mag for the R-band data. The RI light curves of V4 from our photometric observations are shown in Fig. 14.

The brightness of V4 during the period of our photometric observations 1998−2016 varies in the range 16.14−18.79 mag for the I-band and 18.40−20.48 mag for the R-band. The observed amplitudes are $\Delta I = 2.65$ mag and $\Delta R \sim 2.08$ mag in the same period. Because of the limit of our photometric data, the deeper drops in the brightness of the star in the R-band and photometric data in the V- and B-bands are not registered. The photometric monitoring for short periods shows strong variability within a few hours (Fig. 15). Evidences of periodicity in the brightness variability of V4 are not detected. The star appeared to be too faint for spectral observations with the 1.3-m RC telescope.

It can be seen from Fig. 14 that during our study the brightness of V4 varies around some intermediate level. The presence of V4 in the field of star formation, and the irregular variability with large amplitude is suggesting a PMS nature of the star. Also, from Fig. 2 can be seen that V4 have strong infrared excess − an indication of presence of a disk surrounding the star. We suggest that the V4 is a TTS and the observed fast variability with large amplitudes probably is caused by strong irregular accretion rate from the circumstellar disk onto the stellar surface.

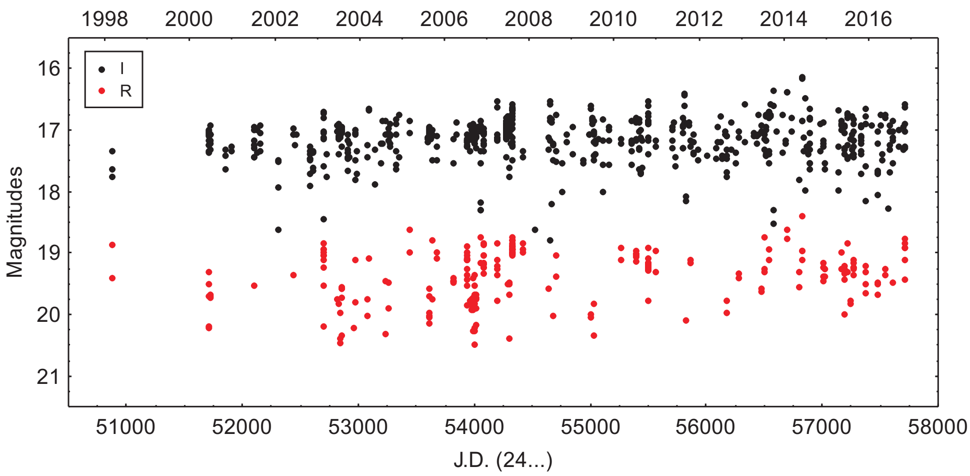

Fig. 14. *The CCD RI light curves of V4 for the period February 1998–November 2016.*

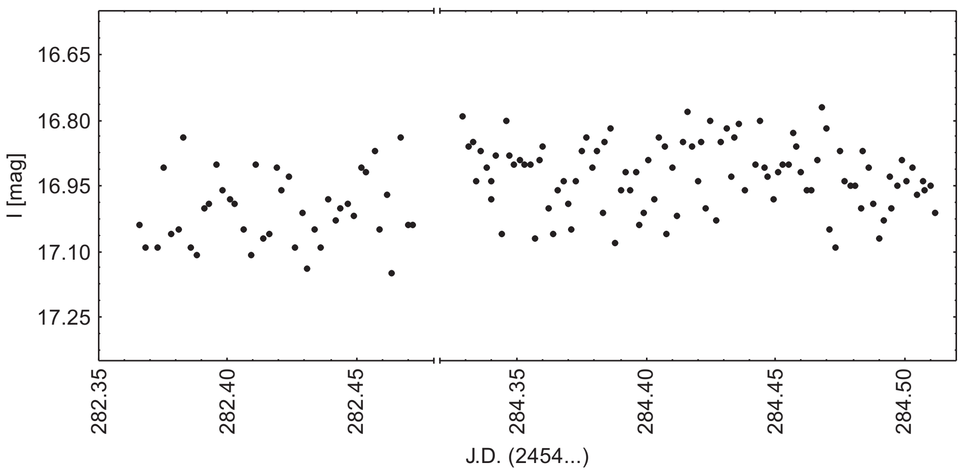

Fig. 15. *The CCD I light curve of V4 for June 30 and July 02, 2007.*

4. CONCLUSIONS

The photometric and spectral results presented in this study show that processes of intensive star formation exist in the area around V391 Cep. All monitored objects showed a very strong photometric variability and emission spectra characteristic of CTTS. V391 Cep, V2 and V3 form a small group of PMS objects with masses close to the solar mass and they probably were formed at about the same time. The stars are relatively near each other in the vicinity of a dark cloud of interstellar gas and dust. Another star from our study, V1, lies at a distance from the other PMS objects and, probably, it was formed beyond this group.

Special attention in future studies must be paid to the star V4. This PMS object belongs to the group around V391 Cep and it shows variability in brightness with extremely large amplitude. Future spectral observations of V4 could confirm or reject our suggestion about its PMS nature. Howsoever, our multicolor photometric monitoring of the PMS objects in this area shows the usefulness of long term photometric studies of TTS.

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APPENDIX

Table A1. The photometric data for star V391 Cep.

DATE	JD(24...)	*I* mag	*R* mag	*V* mag	*B* mag	*U* mag	TEL	CCD
18.12.1998	51166.237	12.43	—	—	—	—	2-m	Phot
25.03.2001	51993.601	—	13.48	—	—	—	2-m	Phot
08.06.2002	52433.536	12.60	13.50	14.36	15.54	—	1.3-m	Phot
...	...	...	...	...	...	...	...	...

* The complete table is avaiable at http://saj.math.rs/199/V391Cep.dat

Table A2. The photometric data for star V1.

DATE	JD(24...)	*I* mag	*R* mag	*V* mag	*B* mag	*U* mag	TEL	CCD
08.03.2000	51611.655	—	—	16.52	—	—	2-m	Phot
05.03.2002	52339.640	14.17	—	15.89	17.20	—	2-m	Phot
03.04.2003	52732.543	14.23	15.26	16.13	—	—	Schmidt ST-8	
...	...	...	...	...	...	...	...	...

* The complete table is avaiable at http://saj.math.rs/199/V1.dat.

Table A3. The photometric data for star V2.

DATE	JD(24...)	*I* mag	*R* mag	*V* mag	*B* mag	*U* mag	TEL	CCD
15.06.2000	51710.611	15.61	16.71	17.64	—	—	1.3-m	Phot
16.06.2000	51711.590	15.79	16.95	—	—	—	1.3-m	Phot
16.06.2000	51711.612	15.84	—	17.92	—	—	1.3-m	Phot
...	...	...	...	...	...	...	...	...

* The complete table is avaiable at http://saj.math.rs/199/V2.dat.

Table A4. The photometric data for star V3.

DATE	JD(24...)	*I* mag	*R* mag	*V* mag	*B* mag	*U* mag	TEL	CCD
16.02.1999	51225.621	—	16.69	17.58	19.15	—	2-m	Phot
17.02.1999	51226.577	14.96	16.45	17.61	—	—	2-m	Phot
08.03.2000	51611.655	—	—	17.31	—	—	2-m	Phot
...	...	...	...	...	...	...	...	...

* The complete table is avaiable at http://saj.math.rs/199/V3.dat.

Table A5. The photometric data for star V4.

DATE	JD(24...)	*I* mag	*R* mag	TEL	CCD
28.02.1998	50872.590	—	19.40	2-m	Phot
28.02.1998	50872.591	—	18.86	2-m	Phot
01.03.1998	50873.598	17.35	—	2-m	Phot
...	...	...	...	...	...

* The complete table is avaiable at http://saj.math.rs/199/V4.dat.

ФОТОМЕТРИЈСКА И СПЕКТРОСКОПСКА СТУДИЈА ПЕТ ЗВЕЗДА У ФАЗИ ПРЕ ГЛАВНОГ НИЗА У БЛИЗИНИ NGC 7129

E. H. Semkov[1], S. I. Ibryamov[2] and S. P. Peneva[1]

[1]*Institute of Astronomy and National Astronomical Observatory, Bulgarian Academy of Sciences, Bulgaria*
E–mail: *esemkov@astro.bas.bg, speneva@astro.bas.bg*

[2]*Department of Physics and Astronomy, Faculty of Natural Sciences, University of Shumen, Bulgaria*
E–mail: *sibryamov@shu.bg*

УДК 524.338.5 : 524.527.3 NGC 7129
Оригинални научни рад

Представљамо резултате вишегодишњих фотометријских и спектрокопских посматрања пет звезда које се налазе у фази еволуције пре главног низа, смештених у близини сјајне маглине NGC 7129. Фотометријски је посматрано поље центрирано на звезду V391 Cep, северозападно у односу на сјајну маглину NGC 7129, и то у *UBVRI* филтерима. CCD посматрања у више боја вршена су у периоду од фебруара 1998. до новембра 2016. године. Током фотометријских посматрања снимљено је укупно 13 оптичких спектара звезда средње резолуције. Резулатати наше фотометријске студије су да све звезде показују јаку варијабилност сјаја у оптичком домену. Криве сјаја пет звезда настале током дуготрајних посматрања указују на промене у сјају са великим амплитудама, типичне за класичне звезде типа *T Tauri*. Код свих пет звезда нисмо поуздано утврдили никакву правилност у периоду промене сјаја. Резултати спектралних посматрања показују да све посматране звезде могу бити класификоване као класичне звезде типа *T Tauri* са бројним емисионим линијама у спектру и са великом променљивошћу профила и интензитета емисионих линија.