# Photometric observations of PMS stars with the telescopes of Rozhen NAO

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**Abstract.** Results from UBVRI photometric observations in the regions of star formation NGC 7129, NGC 2068, IC 348 and CB 34 are presented in the paper. Selected young stellar objects classified as PMS stars are investigated. We present long-term light curves and color-magnitude diagrams based on dozens of years of observations. We show the effectiveness of the 2m RCC and the Schmidt telescope of NAO Rozhen for a long period photometric monitoring.

**Key words:** Stars: pre-main sequence, Stars: circumstellar matter, Stars: individual: V 350 Cep, V 391 Cep, V 1184 Tau, V 718 Per, V 1647 Ori

**Фотометрични наблюдения на PMS звезди с телескопите на НАО Рожен**

Евгени Х. Семков

В настоящата статия представяме резултати от UBVRI фотметрични наблюдения в областите на звездообразуване NGC 7129, NGC 2068, IC 348 и CB 34. Изследвани са отделни млади променливи обекти, класифицирани като звезди преди Главната последователност. Представени са кривите на блясъка и диаграми цвят-звездна величина, обхващащи интервали до няколко десетки години. Показана е ефективността на 2-м RCC и Шмид телескопа на НАО Рожен за фотометричен патрул на променливи обекти.

## 1 Introduction

The investigations of photometric variability of the Pre-Main Sequence (PMS) stars are very important to understand stellar evolution. Both classes of PMS stars - the wide spread low mass ($M \leq 2M\odot$) T Tauri Stars (TTSs) and the more massive Herbig Ae/Be Stars (HAEBESs) - show various types of photometric variability. Herbst et al. (1994) defined three main types of brightness variation concerning PMS stars. Type I of variability is due to rotation of large cool magnetic spots and it is typical for Weak line T Tauri Stars (WTTSs). By analogy with the Sun the cool spots are produced by magnetic activity but they are much larger - up to 40% of the stellar surface. Periods of variability on time scales of days and amplitudes up to $0\overset{m}{.}8$(V) are observed in WTTSs. Type II of variability occurs predominantly in Classical T Tauri Stars (CTTS) and it is caused by superposition of cool and hot surface spots. The hot spots are relatively small (<1% of the stellar surface) and they seem to be produced by accretion from circumstellar disks. Non-periodic variations with amplitudes up to $3^{m}$ (V) are often observed in CTTSs. Type III shows more complicated variability observed in HAEBESs and some early F-G type CTTSs. The brightness variations are supposed to be produced by obscuration from dust clumps or clouds. The variability is either irregular or periodic (quasi-Algol) on time scales of days or weeks and the observed amplitudes exceed up to $2\overset{m}{.}8$ (V). Very rare phenomena, but with a great significance in pre-main sequence evolution are the FU Orionis (FUOR) (Herbig 1977) and EX Lupus (EXOR) (Herbig 1989) outbursts.

## 2 Observations

Our data were obtained with the 2-m Ritchey-Chretien-Coude and 50/70/172 cm Schmidt telescopes of the National Astronomical Observatory Rozhen (Bulgaria). Photographic observations of selected regions of star formation were made up to 1993. Since

1993 the CCD photometric observations have been made with the both telescopes. Observations with the 2-m RCC telescope were made with SBIG ST-6, Photometrics and Vers Array CCD cameras. All frames are bias subtracted and flat fielded. Observations with the 50/70 cm Schmidt telescope were made with SBIG ST-6 and ST-8 CCD cameras. CCD frames obtained with the Schmidt telescope were dark subtracted and flat fielded. All frames were taken through a standard Johnson-Cousins set of filters. Aperture photometry was performed using DAOPHOT routines. Some observations made with the 1.3-m Ritchey-Chretien telescope of the Skinakas Observatory (Crete, Greece) are also included in the present paper.

## 3 Results and Discusion

### 3.1 V 350 Cep

V 350 Cep is located in the field of the reflection nebula NGC 7129, a region of active star formation. The variability of V 350 Cep was discovered by Gyulbudaghian & Sarkissian (1977) by comparing their photographic observations in NGC 7129 with the POSS charts. The long-term light curve of V350 Cep resembles the FUOR type stars (Fig.1) but its spectrum is similar to the CTT stars (Semkov 2004). It is impossible to define a moment of rising of V 350 Cep because of the absence of deep photometric observations in the period 1962-1970. The period of fast increase of brightness finishing about 1978 is followed by a period of irregular variability lasting up to now. Therefore, the star keeps its maximum brightness in the past 30 years.

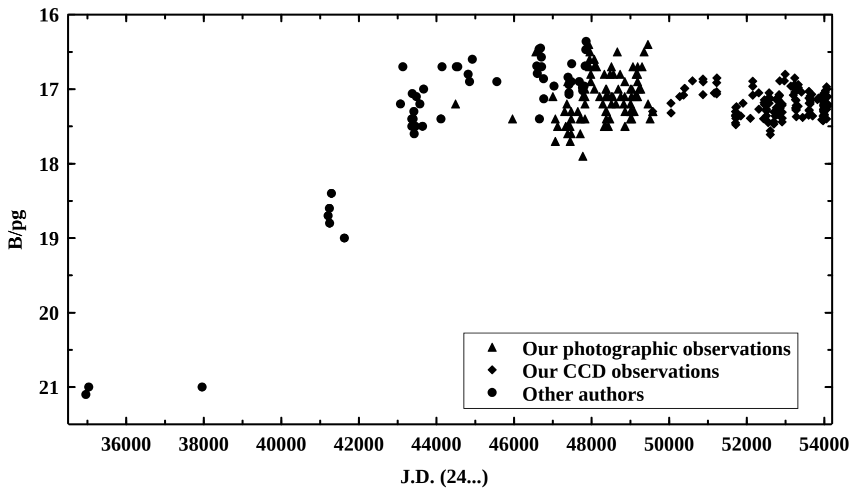


**Fig. 1.** B-light curve of V350 Cep for the period 1950-2006

The V-light curve of V350 Cep from all our CCD observations is shown in Fig. 2. It is seen from the figure that for the 14 year period of observations the star shows long-term brightness variations on a time-scale of about one thousand days. Such long-term variability is typical of HAEBE stars or related objects called UXors (Herbst and Shevchenko, 1999). The cause for the variability of UXors can be obscuration from orbiting circumstellar matter or variable accretion from a circumstellar disk. In contrast to HAEBE stars and UXors, V350 Cep is a low-mass star from M2 spectral type. The observed amplitude in V-light in the period 1993-2006 is only $0^{\mathrm{m}}.8$.

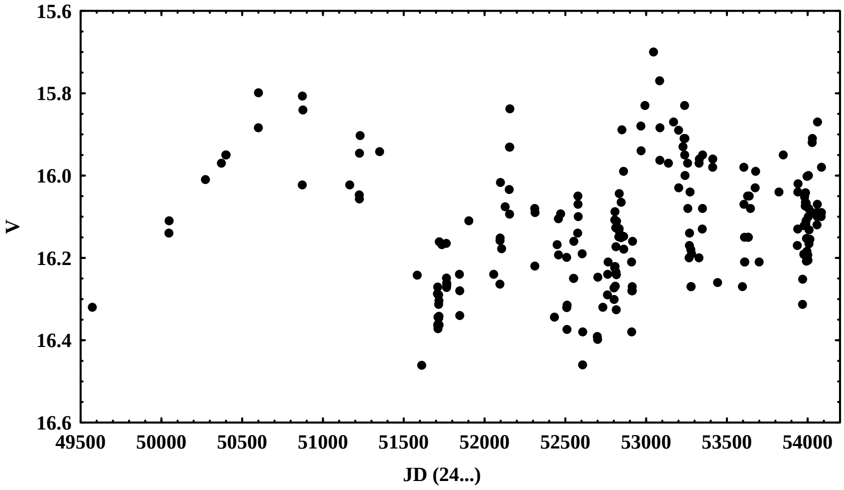


**Fig. 2.** V-light curve of V 350 Cep for the period 1993-2006

Another important result from our photometric study is the variation of color indices with stellar brightness. The measured color index V-I versus the stellar magnitude V during the period of our CCD observations is plotted in Fig. 3. A clear dependence can be seen from the figures: the star becomes redder as it fades. Such color variations are typical of stars with large cool spots whose variability is produced by rotation of the spotted surface (WTTs). Consequently, V350 Cep shows photometric characteristics of FUORs (5 magnitudes outburst), UXors (long-term brightness variations) and WTTs (variability with small amplitude in a time scale of days).

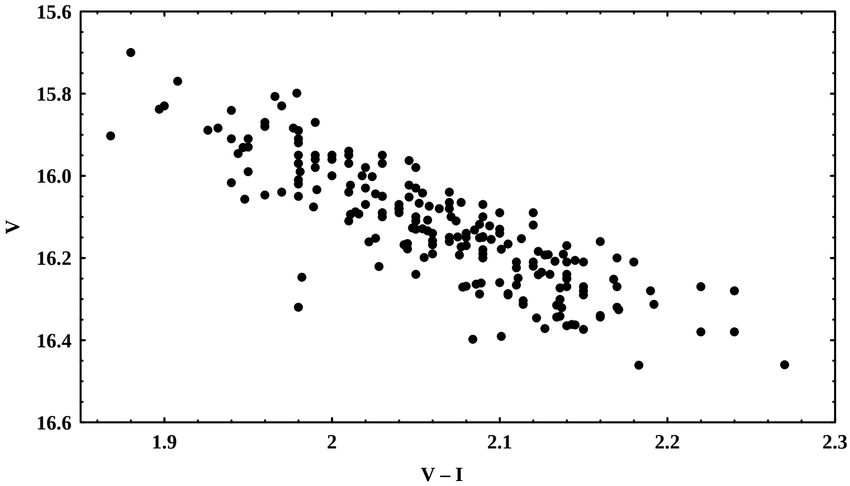


**Fig. 3.** Relationship between V and V-I for V 350 Cep

### 3.2 V 391 Cep

V391 Cep is a PMS star located in the dark clouds northwest of the emission nebula NGC 7129. The star was discovered as a strong $H_\alpha$ emission source in our objective prism survey (Semkov and Tsvetkov 1986). Our photographic photometry suggests that the star is an irregular variable with an amplitude of about 2 magnitudes. The optical spectrum of V391 Cep obtained in 1992 (Semkov 1993) shows the main spectral characteristics of the CTT stars. The star is surrounded by a small cometary nebula seen in the deep red and infrared images.

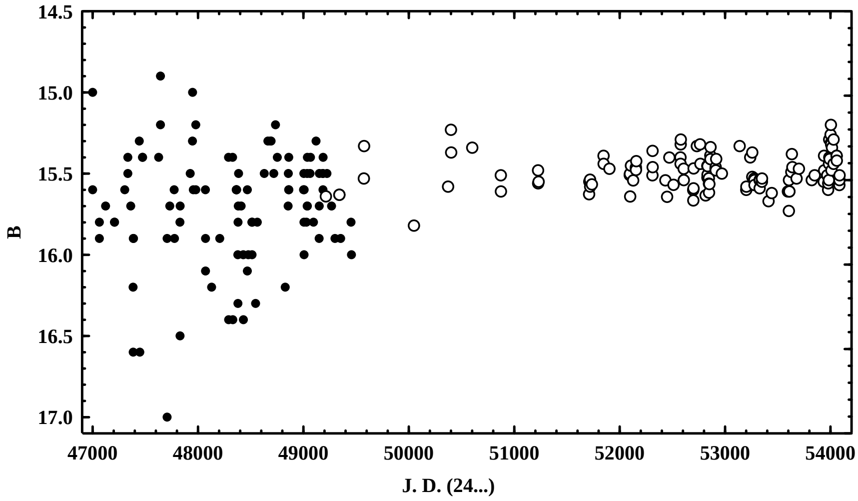


**Fig. 4.** B-light curve of V 391 Cep for the period 1984-2006

Fig. 4 shows the long-term B-light curve of V 391 Cep in the whole period of observations (1984-2006). In the figure the filled circles denote our photographic observations and the open circles denote CCD photometric data. A considerable change of the amplitude of brightness of V 391 Cep is seen in the figure. Since 1986 the amplitude of brightness has been gradually decreasing from $2\overset{m}{.}1$ to $0\overset{m}{.}5$ at the present time. It is generally accepted that CTTs are surrounded by extended circumstellar disks and such change of activity of V 391 Cep can be produced from an irregular accretion rate.

### 3.3 V 1184 Tau (CB34V)

The unusual PMS object V 1184 Tau (CB 34V) was discovered in the Bok globule CB 34 (Yun et al. 1997). Comparison of CCD frames obtained in 1993 with the Palomar Observatory plates (1951) reveals the increasing brightness of this object of 3.7 mag in the red. On the basis of suspected outburst the authors assume a FUOR nature of this object. Our first photometric and spectroscopic investigation (Semkov 2003) reveals V 1184 Tau as a possible WTT star with an amplitude of $0\overset{m}{.}6$ (V) and spectral variability. We drew attention to the fact that such photometric behavior is typical of stars with large cool spots whose variability is produced by rotation of the spotted surface (WTTS). In our second paper (Semkov 2004) the beginning of a new deep minimum of the light curve of V 1184 Tau was reported.

Fig. 6 shows the I-light curve of V 1184 Tau in the whole period of our observations (2000-2007). Our photometric data suggest that from October 2000 to April 2003 the

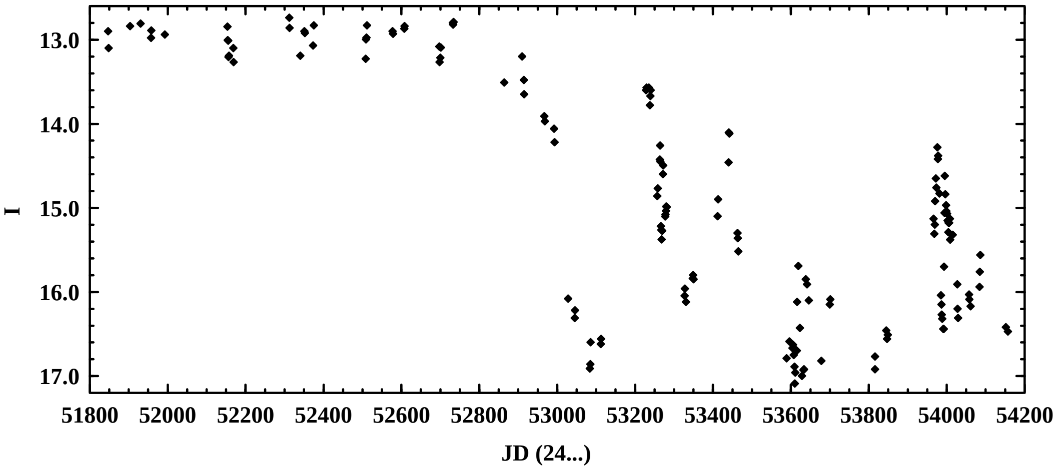


**Fig. 5.** I-light curve of V 1184 Tau for the period Oct. 2000 - Feb. 2007

brightness of V 1184 Tau varies with an amplitude of about $0^m.5$ (I) without increasing or decreasing. Since August 2003 a gradual decreasing of star brightness has begun and the I magnitude of V 1184 Tau has decreased with $\sim 4^m$ until March 2004. The first observed minimum extended one year approximately and a second minimum of brightness started immediately after it (August 2004). The second observed minimum was shorter and lower than the first one and it continued till March 2005. Since April 2005 a new third brightness decrease has started and on August 2005 we observed the deepest value for the I magnitude of V 1184 Tau ($17^m.09$).

Another important result of our photometric study is the variation of color indices with stellar brightness. In Fig. 7 we plot the measured color index V-I versus the stellar magnitude V during the period of our observations. In the figure the open circles denote photometric data obtained in the period of maximum brightness, the filled triangles represent photometric data obtained during the deep minima. A clear dependence can be seen out of the figure: the star becomes redder as it fades. The tendency towards reddening becomes very considerable since August 2003. While in the period of maximum brightness the color index V-I varies between $2^m.15$ and $2^m.40$, it reaches a value of $3^m.22$ in October 2004. From a certain turning point (V $\sim 18^m.5$) V 1184 Tau gets bluer fading further to V-I = $2^m.44$ in March 2004. In this case we suggest that the reddening of the star is produced by the variable extinction from the circumstellar environment (Type III from the Herbst et al. (1994) classification). Our recent photmetric data (August 2005) suggest that in the deep minimum the V-I index increases back to $3^m.01$ (open squares in Fig. 7).

### 3.4 V 1647 Ori

V1647 Ori attracted a great interest in the past three years because of the sudden outburst documented by McNeil (2004). The object is located in the Linds 1630 dark cloud of the Orion B star formation complex, 12′ south of the reflection nebula NGC 2068 (M78). According to Briceño et al. (2004) the outburst began in November 2003 and the star brightness rose by 5 mag till February-March 2004. The nebula aroud V 1647 Ori is not seen on the POSS plates and an eruptive object like FUOR or EXOR illuminates it. Fig. 2 shows the V, R and I light curves of V1647 Ori for the period of

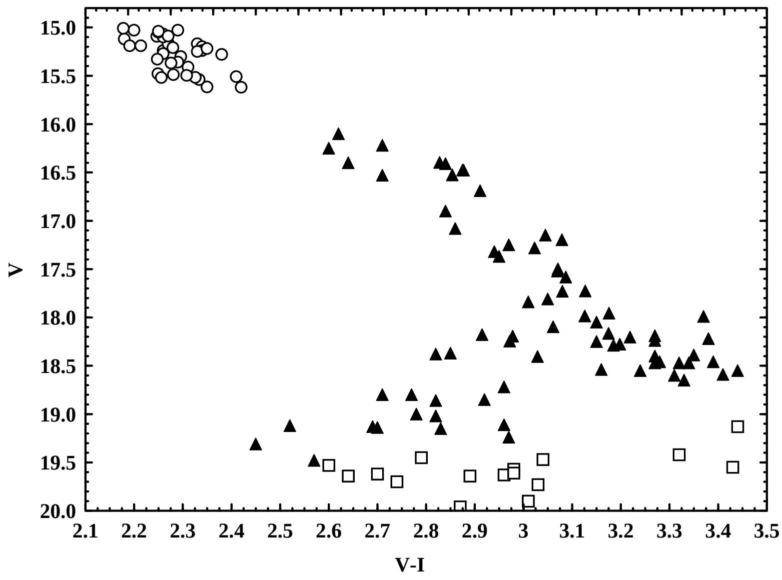


**Fig. 6.** Color behavior of V 1184 Tau with V magnitude

our photometric observations. It is seen from the figure that V1647 Ori varies with an amplitude of $0\overset{m}{.}5$ and a very slight decrease of brightness can be observed. Since March 2004 the brightness of V1647 Ori has been slowly going down, resembling the other young eruptive variables. From March till October 2005 the star brightness faded by approximately $1\overset{m}{.}5$ (I). But since the end of October 2005 a rapid fading has started and the object brightness dropped to the pre-outburst magnitude (Kóspál et al. 2005).

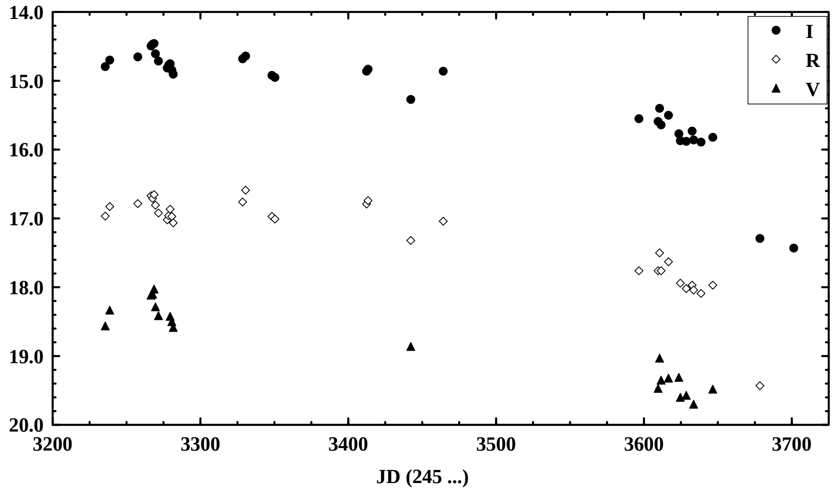


**Fig. 7.** V, R and I light curves of V1647 Ori

The type of observed outburst of V 1647 Ori (FUOR or EXOR) is still undefined. The prototypes of FUORs and EXORs seem to be T Tauri stars with massive circumstellar disks. In both cases the observed outburst is explained by increased accretion from the circumstellar disk. The EXORs are less luminous than the FUORs and spectroscopically different. In contrast to FUORs, EXORs have a T Tauri like spectrum during the maximum light. While the EXORs spend only a few weeks or months in the maximum brightness, the outbursts of FUORs extend some decades. These are only empirical differences and the presence of an intermediate type (1-3 years outburst) can be expected.

### 3.5 V 718 Per (HMW15)

The variability of PMS star V 718 Per (HMW15) in the young cluster IC 348 was documented by Cohen et al. (2003). The authors observed an eclipse lasting 3.5 years with an amplitude of $0\overset{m}{.}7$ (I), much longer than any other eclipsing variable. The second eclipse, with similar parameters to the first one was observed in the period 2004-2007. The I-light curve of V 718 Per from our data during the second documented eclipse is plotted in Fig. 8. The color behavior of the object during the observed eclipse is shown in Fig. 9.

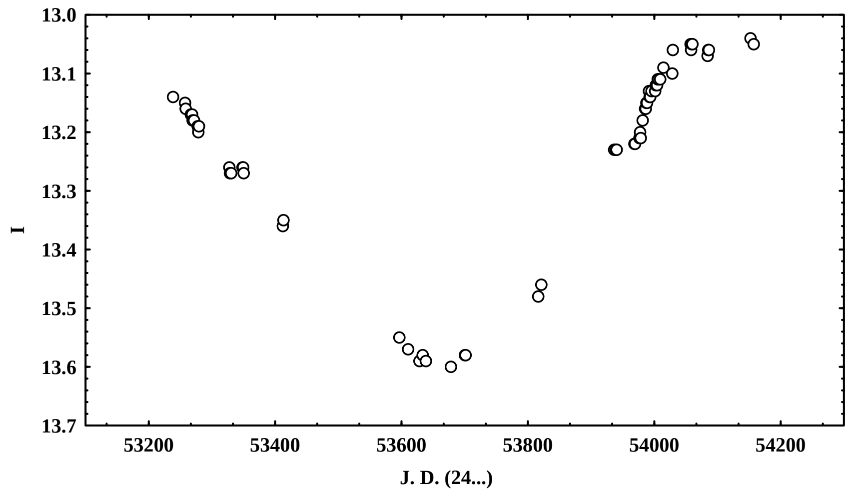


**Fig. 8.** I-light curve of V 718 Per for the period Aug. 2004 - Feb. 2007

Taking into account the observed duration of the eclipse we must reject the hypothesis that V 718 Per is an ordinary eclipsing binary system. Therefore, the eclipsing body must be much more extended than the star and optically thick enough to produce such an eclipse. The model of a high eccentricity binary system occulted by a circumbinary or circumstellar disk seems to be the most probable at the moment (Nordhagen et al. 2006).

## Conclusion

The results presented in the paper show the effectiveness of the 2-m RCC and the Schmidt telescopes of NAO Rozhen for a long period photometric monitoring. The

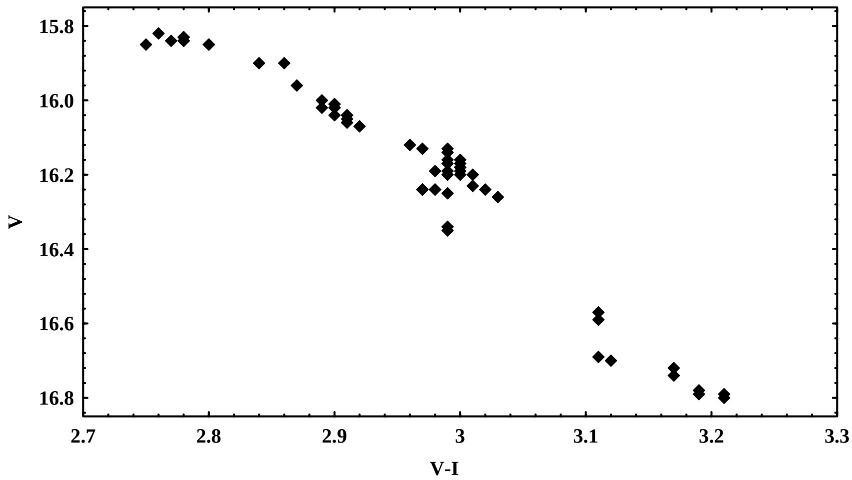


**Fig. 9.** Relationship between V and V-I for V 718 Per

Schmidt telescope is suitable for monitoring of objects with brightness from 10 to 17 magnitudes. The photometric system of the telescope (CCD camera and UBVRI filters) reproduces very well the standard Johnson-Cousins system. The 2-m RCC telescope is suitable for monitoring of low brightness objects, but the observers must pay attention to the existing errors depending on the spatial distribution of the stellar images on the CCD chip (Markov 2005).

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