Long-term light curves of 4 young variable stars

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Abstract. The photometric variability is a common property in the early phases of star formation. During the time of formation the young stellar objects pass through periods of a gravitational instability and a chromospheric activity. Both classes of pre-main sequence stars – T Tauri and Herbig Ae/Be stars – show various types of photometric variability. The study of different kinds of variability is very important for understanding stellar evolution. Collecting data from long-time photometry we can investigate the processes of star formation and the stellar environment around young stars. To construct the historical light curves of variable stars new data from CCD observations are complemented with data from photographic plate archives.

Key words: Stars: pre-main sequence, Stars: circumstellar matter, Stars: individual: V 350 Cep, V 1184 Tau, V 733 Cep, V 1735 Cyg [1]

Криви на блясъка на 4 млади променливи звезди за дълги периоди от време

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Фотометричната променливост на зведите е основна характеристика в ранните етапи от звездообразуването. По време на формирането си младите звездни обекти преминават през периоди на гравитационна нестабилност и хромосферна активност. Звездите преди главната последователност – T Tauri и Ae/Be звезди на Хербиг – показват многообразни типове фотометрична променливост. Изследването на различните видове променливост е от голямо значение за изучаването на звездната еволюция. Фотометричните данни за дълги периоди от време ни позволяват да изучаваме процесите на формиране на звездите и промените в тяхната непосредствена околност. За да построим историческите криви на блясъка на променливите звезди ние използваме както съвременни данни от CCD наблюдения, така и данни от архивите с астрономически плаки.

1 Introduction

Both classes of Pre-Main Sequence (PMS) stars – the T Tauri Stars (TTSs) and the Herbig Ae/Be Stars (HAEBESs) – show various types of photometric variability. It is generally accepted that TTSs can be separated into two subclasses: Classical T Tauri stars (CTTSs), surrounded by an extended circumstellar disk, and Weak line T Tauri stars (WTTSs) without evidence of disk accretion (Appenzeller & Mundt 1989; Bertout 1989). Herbst et al. (1994) defined three main types of brightness variation concerning PMS stars. A variability of Type I is due to rotation of large cool magnetic spots and it is typical for WTTSs. The periods of variability on time scales of days and amplitudes up to $0\overset{m}{.}8$ in V are observed in WTTSs. A variability of Type II

[1] This investigation is based on observing material and facilities of the Rozhen NAO, operated by the Institute of Astronomy of the Bulgarian Academy of Sciences

occurs predominantly on CTTS and it is caused by superposition of cool and hot surface spots. The variability of CTTSs is non-periodic with amplitudes up to 3^m in V. Type III shows more complicated variability, observed on HAEBESs and some early F-G type CTTSs. The brightness variations are supposed to be produced by obscuration from dust clumps or clouds.

Very important for investigation of stellar evolution are the outbursts caused by falling of matter from stellar environment on the stellar surface. According to Herbig (1989) the PMS stars undergoing such kind of outbursts can be separated in two subclasses: FUors and EXors. FUors are low-mass PMS stars defined as a class by Herbig (1977) after the discovering of V 1057 Cyg and V 1515 Cyg. An increase in optical brightness of the order of 4-5 mag., a F-G supergiant spectrum with broad blue-shifted Balmer lines, strong infrared excess and connection with reflection nebulae are the main characteristics of FUors. The observations in the case of the FUor outburst is explained by increasing accretion caused by thermal instabilities in the circumstellar disk (Hartmann & Kenyon 1996). The other class of PMS eruptive objects have for a prototype the variable star EX Lupi and they were named by Herbig (1989) EXors by analogy with FUors. The EXors show outbursts with an amplitude of up to 5 mag. and the outbursts spend only a few weeks or months. The outbursts are repetitive with roughly symmetrical light curves. Near the maximum light their spectra are dominated by emission lines, similar to the CTTSs and there is no evidence for P Cygni profiles of the Hα line.

Approximately 25% of HAEBE stars show strong photometric variability with sudden quasi-Algol drops in brightness and amplitudes up to 3^m in the V band (Natta et al. 1997). During the deep minima of brightness, an increase in polarization and specific color variability are observed. The prototype of this group of PMS objects with an intermediate mass, named UXors is UX Ori. The general explanation of its variability is a variable obscuration from orbiting circumstellar clumps of dust or an edge-on circumstellar disk (Grinin et al. 1991).

The main purpose of our investigation is a photometric study of PMS objects without regular observations up to now. We try to collect more data from $BVRI$ photometry and to search for available photographic observations in the astronomical plate archives. The Wide-Field Plate Database which is available at *http://www.skyarchive.org* (Tsvetkov et al. 1997) was used to find deep photographic plates.

2 Observations

Our CCD observations were obtained in two observatories with three telescopes: the 2-m RCC and 50/70-cm Schmidt telescopes of the National Astronomical Observatory Rozhen (Bulgaria) and the 1.3-m RC telescope of the Skinakas Observatory, Crete, Greece. The photographic observations were made with the 50/70-cm Schmidt telescope in the period 1984 – 1994. Observations with the 2-m RCC telescope were made with Photometrics and Vers Array CCD cameras. Observations with the 1.3-m RC telescope were made with Photometrics and ANDOR CCD cameras. Observations with the 50/70-cm Schmidt telescope were made with ST8, ST11000 and FLY CCD cameras. All frames were taken through a standard Johnson-Cousins set of filters. Twilight flat fields in each filter were obtained each clear evening. All frames obtained with the Photometrics, ANDOR and Vers Array cameras are bias subtracted and flat fielded. CCD frames obtained with the ST8, ST11000 and FLY camera are dark subtracted and flat fielded. Aperture photometry was performed using DAOPHOT routines.

3 Results

A photometric monitoring of some PMS objects (V 350 Cep, V 1184 Tau, V 1647 Ori, V 1735 Cyg, V733 Cep and others) was made up to now in the Rozhen and Skinakas observatories (Semkov 2006, Peneva & Semkov 2008). In the present paper we report data from recent $BVRI$ observations and from photographic plate archives of four PMS stars. In order to facilitate transformation from instrumental measurement to the standard system we tried to calibrate in $BVRI$ bands standard stars in the field of each observed star.

3.1 V 350 Cep

V 350 Cep lies in the region of active star formation NGC 7129. The variability of V 350 Cep was discovered by Gyulbudaghian & Sarkissian (1977) who compared their photographic observations with the POSS-I plates. They found the star to be brighter in 1977 more than 4^m in B band in comparison with the limit of the POSS-I plate (1952). The historical light curve of V 350 Cep resembles the FUor type stars (Semkov et al. 1999) but its spectrum is similar to the CTTs (Magakian et al. 1999). Since 1977 the star has been at maximum brightness with fluctuations of about $1\overset{m}{.}5$ (B). In Fig. 1 we plot the B/pg light curve of V 350 Cep. The blue diamonds note our CCD photometric data, the green triangles – the photographic data from the Rozhen Schmidt telescope, the purple diamonds – the photographic data from Pogosyants (1991), the pink circle – electrophotometric data from Shevchenko & Yakubov (1989), the black circles – the photographic data from the Asiago Schmidt telescope (Semkov et al 1999), the red diamonds – the photographic data from the Byurakan Schmidt telescope (Gyulbudaghian & Sarkissian 1977), the red triangle – the limit from the POSS-I and the Lick Observatory plates.

The gradual increase of brightness of V 350 Cep resembles the light curve of the FUor type star V 1515 Cyg (Clark et al. 2005). 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 1977-1978, is followed by a period of smali-amplitude variations around the maximum brightness lasting up to now. Therefore, the star keeps its maximum brightness more than 30 years. The observed outburst with an amplitude of the order of 5^m, the location of the star in the region of active star formation NGC 7129, and its connection with a reflection nebulosity are characteristics which classify V 350 Cep as a FUor type object. On the other hand the strong emission line spectrum, the low luminosity ($M_v \sim 4^m$), and the observed ultraviolet excess are properties typical for CTTs.

A similar increase of brightness was observed in some CTTs, such as DR Tau. In contrast with DR Tau the color indices $U - B$ and $B - V$ of V 350 Cep remain comparatively constant during the observed outburst. Another unique property of V 350 Cep is the relatively small brightness changes on the time scale of days. Interpretation of this fact may be in the absence of large cool and hot spots on V 350 Cep.

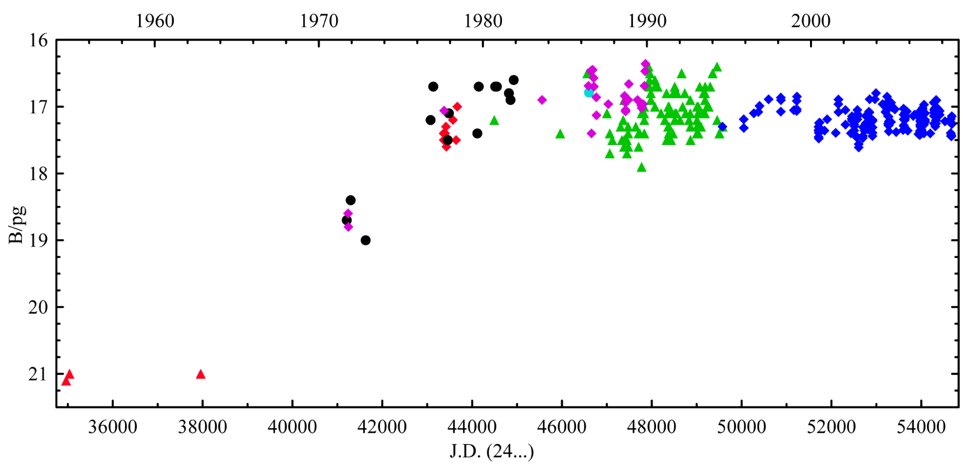

Fig. 1. B/pg light curve of V 350 Cep

3.2 V 1184 Tau

The PMS object V 1184 Tau discovered by Yun et al. (1997) lies in the field of the Bok globule CB 34. A comparison of CCD frames obtained in 1993 with the POSS-I plates reveals an increasing brightness of this object of $3\overset{m}{.}7$ (R). The first assumption of those authors about the nature of V 1184 Tau is a FUor type of outburst in optical wavelengths. Tackett et al. (2003) discovered a 2.372-day rotation period for V 1184 Tau, suggesting the presence of cool surface spots. The analysis of available photometric data suggests that V 1184 Tau shows two types of variability, produced (1) by rotation of a large cool, spotted surface and (2) by occultation from circumstellar clouds of dust or from features of a circumstellar disk (Semkov et al. 2008). Data from multicolor a photometry reveal the variation in color indices with stellar brightness typical for UXors.

Our photometric data suggest that from October 2000 to April 2003 the brightness of V 1184 Tau varies with amplitude of about $0\overset{m}{.}5$ (I) without increasing or decreasing. Since August 2003 a gradual decreasing of star brightness began and the I magnitude of V 1184 Tau decreased with $\sim 4^m$ until

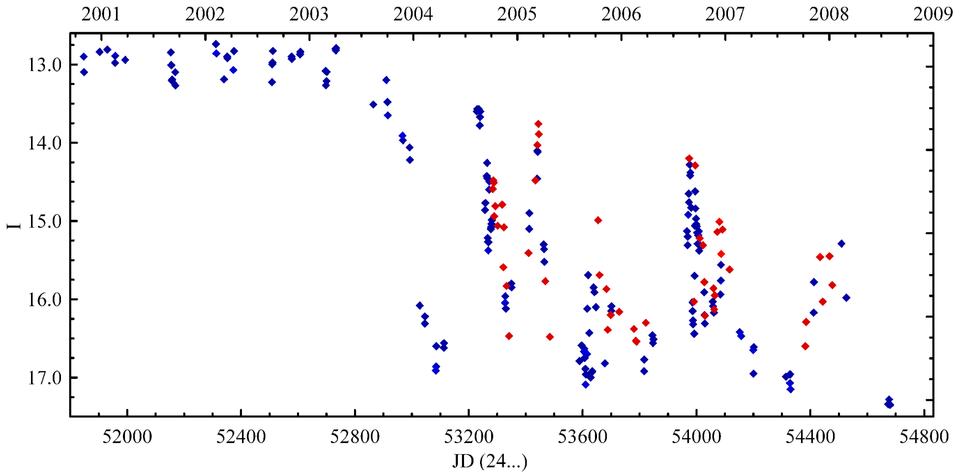

Fig. 2. I-light curve of V 1184 Tau in the period October 2000 - August 2008 (the blue diamonds - our data, the red diamonds - Grinin et al. 2008)

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 to March 2005. Since April 2005 a new third brightness decrease started.

The unusual photometric behavior of V 1184 Tau has not precise analogies in the PMS stars. At this stage it is most unlikely that V 1184 Tau is a FUor type variable. No one of the well-studied FUors shows such strong brightness decrease for a short time. Taking into account the observed amplitude and duration of eclipse we must reject the hypothesis that V 1184 Tau is an ordinary eclipsing binary system. Therefore, the eclipsing body must be much more extended than the star and thick enough to produce such deep eclipse. It could be a feature from a protoplanetary disk or orbiting material of dust that periodically occults the star. Our photometric observations suggest that V 1184 Tau can be added to the small group of PMS stars that undergo occultation from the circumstellar environment or from a circumstellar disk. Presently there is no evidence that V 1184 Tau is a binary star. But the model of high eccentricity binary system occulted by circumbinary or circumstellar disk seems to be much probable at the moment. The available photometric and spectroscopic data suggest that V 1184 Tau has the characteristics of a WTTS in the maximum light, but in the minimum the spectrum of the star is much similar to CTTs spectra. On the other hand the variations of $V-I$ color index during eclipse resemble the UX Ori variables.

3.3 V 1735 Cyg

V 1735 Cyg was discovered by Elias (1978) in an infrared survey of IC 5146. The object is under the limit of the red POSS-I plate obtained in 1952, but on a Hale Observatories plate, taken in 1965 July 5, the object has a red magnitude 15^m. The star appears to have brightened by 5^m sometime between 1952 and 1965. On the basis of an observed outburst and its spectrum, V 1735 was classified as a FUor object.

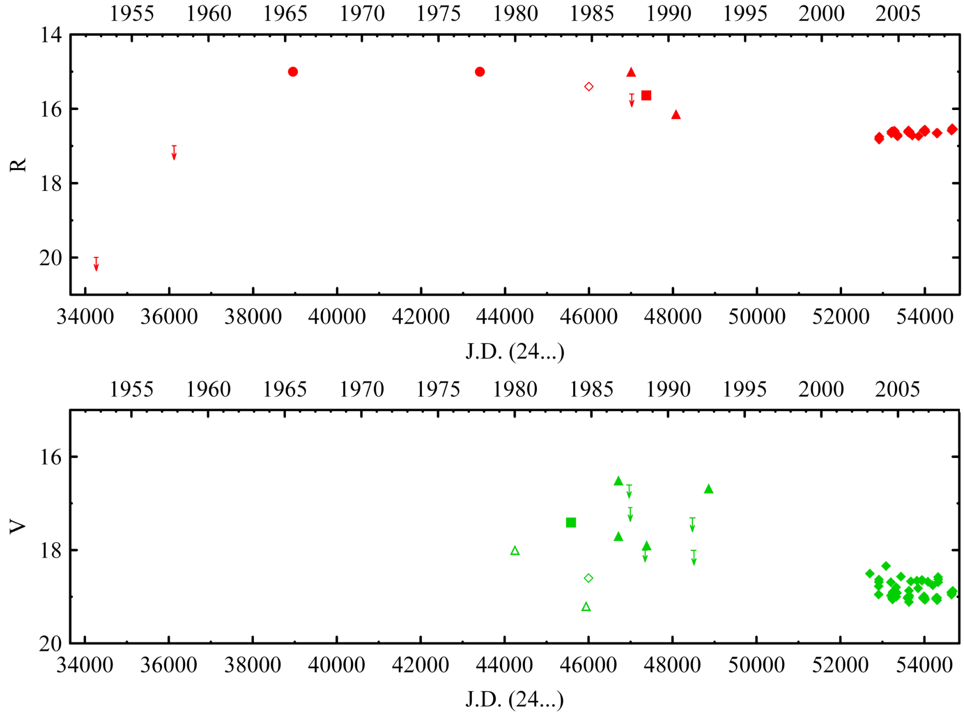

Fig. 3. R and V light curves of V 1735 Cyg in the period 1952 – 2009

In Fig. 3 the V and R light curves of V 1735 Cyg are plotted. The filled triangles denote photographic data from the Rozhen Schmidt telescope, the filled diamonds – our CCD observations, the filled squares – photographic data from the Palomar Schmidt telescope, the filled circles – the data from Elias (1978), the open triangles – magnitudes published by Levreault (1988), the open diamonds – magnitudes published by Goodrich (1987). The arrows mark the upper limits from photographic observations made with Palomar, Tonantzintla and Rozhen Schmidt telescopes. The data from photographic observations made with the 50/70-cm Schmidt telescope from 1986 to 1992, show a strong light variability ($\varDelta V = 1\overset{\mathrm{m}}{.}2$). Taking into account the magnitudes from Goodrich (1987) and Levreault (1988) the registered amplitude of V 1735 Cyg in the period 1980-1992 is $\varDelta V = 2\overset{\mathrm{m}}{.}7$. In contrast, the recent photometric data obtained from March 2003 to January 2009 show only small amplitude variations ($\varDelta I = 0\overset{\mathrm{m}}{.}3$). Such change of the photometric activity during the period of set in brightness was not observed for the other FUor objects. The analysis of existing photometric data shows a very slow decrease in star brightness – $1\overset{\mathrm{m}}{.}8$ (R) for 44 years period.

The shape of observed light curves of FUors may vary considerably from object to object. While the time of rise for FU Ori and V 1057 Cyg is of the order of 1 year, for V 1515 Cyg it is considerably longer – $\sim$ 25 years. Respectively, the rate of decrease in brightness is quite different for each of them. While the brightness of V 1057 Cyg reaches the pre-outburst level after $\sim$ 30 years, the decrease in brightness of FU Ori and V 1515 Cyg goes much slower. The available photometric data for V 1735 Cyg are not enough at present to determine the time of rise to the maximum brightness, but the rate of decrease in brightness is definitely similar to the observed in the cases of FU Ori and V 1515 Cyg. Our data show that V 1735 Cyg must be added to the group of long-lived FUors and that the time-scale of the FUor phenomenon must be much longer than the assumed in previous studies (Herbig 1977).

3.4 V 733 Cep

The variable star V 733 Cep is located in the dark cloud L1216. The star is discovered by the Swedish amateur astronomer Roger Persson in 2004. Persson compared the plate scans from the first and the second Palomar Sky Survey. He noted the presence of the star on the red POSS-II image and its absence on the corresponding POSS-I image. Reipurth et al. (2007) suspect a possible outburst in the period 1953-1984 and find great spectral similarities to FU Ori itself.

In Fig. 4 we plot the $BVRI$ light curves from all available observations of V 733 Cep. The filled triangles denote our CCD observations, the filled diamonds – photographic data from the Asiago Schmidt telescope, the filled circles – photographic data from the Palomar Schmidt telescope, the open diamonds – photographic data from the Calar Alto Observatory and the open triangle – the CCD observation from the 2.2-m telescope in Mauna Kea, Hawaii. The arrow marks the upper limit from the POSS-I red plate. Our photometric study confirms the affiliation of V 733 Cep to the group of FUor objects. The presence of an outburst in optic and a rise in brightness in the period 1971-1993 are well documented. The increase in brightness in this period passed very slowly, and for 22 years the I-band magnitude increased by $2\overset{\mathrm{m}}{.}1$. It is currently not possible to determine the time of beginning of the optical outburst due to lack of observations in the period 1953-1971. The light curve of V 733 Cep in the period of increase in brightness is similar to the observed in the case of the FUor star V 1515 Cyg, but the time of rise seems to be longer. Probably V 733 Cep has reached its maximum brightness during the period 1993-2004 in which there are no published photometric

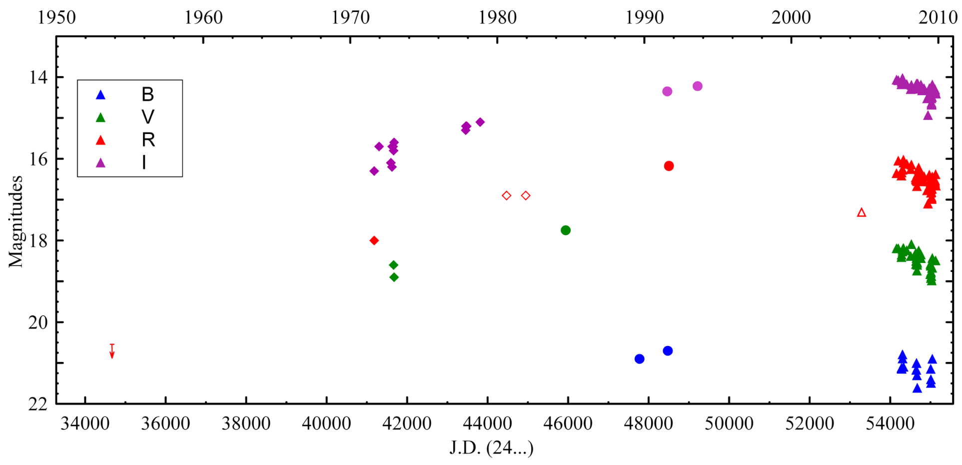

Fig. 4. Long-term *BVRI* light curves of V 733 Cep

observations. The amplitude of the observed outburst of V 733 Cep exceeds $4\overset{m}{.}5$ (R).

Our CCD photometric data suggest that from February 2007 to October 2009 a slow decrease in brightness of V 733 Cep was observed. The data from observations give a decrease in brightness of the star in *I* band – $0\overset{m}{.}15$ per year, and in *V*-band – $0\overset{m}{.}23$ per year. The decrease in brightness of V 733 Cep proceeds irregularly, as periods of short drops in brightness are observed. A typical example of such a drop in brightness is observed during June-July 2009 (decrease by $0\overset{m}{.}4$ (I) and return to its previous level). The change of the photometric activity during the period of set in brightness seems to be typical for FUor objects. A strong decrease in brightness by about $1\overset{m}{.}5$ (B) in a few months was registered in the light curve of V 1515 Cyg (Clark et al. 2005). This minimum in brightness was explained by an obscuration from a dust material ejected from the star (Kenyon et al. 1991). Evidence for a strong light variability in the time of set in brightness ($\Delta V = 1\overset{m}{.}2$) were reported in the photometric study of another FUor object – V 1735 Cyg (Peneva et al. 2009). The measured in 2004 relatively low value for the red magnitude of V 733 Cep (Reipurth et al. 2007) can be explained by a similar process of variable obscuration from a dust material.

The available photometric data for V 733 Cep are not enough at present to determine exactly the amplitude of outburst and the time of rise to the maximum brightness. Our conclusion is that the light curve of V 733 Cep in the period of rise in brightness is more similar to the light curve of V 1515 Cyg, and in the period of set in brightness it is much similar to the light curve of V 1057 Cyg. Therefore, there is evidence that V 733 Cep is probably the first FUor object with approximately symmetrical light curve (the time of rise is of the order of the time of set in brightness).

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