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Letter to the Editor

A new deep minimum in the light curve of the PMS star V 1184 Tauri (CB 34V)

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Abstract. We present results from optical photometry of the pre-main sequence star V 1184 Tau. The star is associated with the Bok globule CB 34 and it was considered as a FUOR candidate in previous studies. Our CCD photometric data (*UBVRI*) obtained from October 2000 to April 2003 show that the star brightness varies with an amplitude of about $0\overset{m}{.}6$ (*V*) without increasing or decreasing. The comparison of our photometric and spectroscopic results suggests that V 1184 Tau has the characteristics of a WTTS in this period. The photometric data obtained from August 2003 to March 2004 show the beginning of a gradual decrease of the star brightness ($\sim 4^m$ in *I*-light). The analysis of the photometric data suggests that V 1184 Tau shows two types of variability produced (1) by the presence of large cool photospheric spots and (2) by occultation from circumstellar clouds of dust or from an orbiting extended body. The behavior of the $V-I$ index indicates that the star becomes redder towards minimum light, but from a certain turning point it gets bluer fading further. The possible scenarios to explain the observed eclipse are briefly discussed.

Key words. stars: pre-main sequence – stars: individual: V 1184 Tau

1. Introduction

Photometric variability is a basic characteristic of the Pre-Main Sequence (PMS) stars. Both classes of PMS stars – the wide spread low mass ($M \leq 2\ M_{\odot}$) 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 basic types of brightness variation concerning PMS stars. type I of variability is typical for "naked" or Weak line T Tauri Stars (WTTSs). The variability is due to rotation of large cool surface spots. 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 0.8 mag in *V* are observed in WTTSs. type II of variability occurs predominantly on Classical T Tauri Stars (CTTS) and it is caused by superposition of cool and hot surface spots. The hot spots are relatively small (<1% from stellar surface) and they seems to be produced by accretion from circumstellar disks. Non-periodic variations with amplitudes up to 3 mag in *V* are often observed on CTTSs. type III is more complicated variability observed on HAEBESs and some early F-G type CTTSs. The brightness variations are supposed to be produced by obscuration from circumstellar dust. The variability is either irregular or periodic on time scales of days or weeks and the observed amplitudes exceed up to 2.8 mag in extreme cases.

A very rare phenomenon in pre-main sequence evolution is the FU Orionis (FUOR) outburst (Herbig 1977). An increase in optical brightness of the order of 4–5 mag, an 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 prototypes of FUORs seem to be TTSs with massive circumstellar disks.

The unusual PMS object V 1184 Tau (CB 34V) was discovered in the Book 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. Alves et al. (1997) determined the spectral class of V 1184 Tau as G5 (III-IV), the mass as 2 $M_{\odot}$ and the age as 10^6 years. The two possible explanations of the observed outburst are (1) a high accretion episode (FUOR) and (2) time variable extinction from non-uniform circumstellar environment, and they have been discussed in detail. In conformation to the extinction hypothesis Alves et al. (1997) noticed the spectral similarity of V 1184 Tau to the type III PMS variable SU Aur.

Recently Tackett et al. (2003) discovered a 2.372 days rotation period of V 1184 Tau suggesting for the presence of cool surface spots. The possible similarity of V 1184 Tau to the eclipsing PMS variable KH 15D (Kearns & Herbst 1998; Hamilton et al. 2001) is discussed in that paper. Our photometric and spectroscopic investigation (Semkov 2003) reveals V 1184 Tau as a possible WTTS with an amplitude of $0\overset{m}{.}6$ (*V*) and spectral variability. Significant changes in the profile and

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Letter to the Editor

Table 1. *UBVRI* photometric observations of V 1184 Tau.

Date	JD	*V*	*U*	*B*	*R*	*I*	Tel.
2002 Aug. 22	2452508.601	15.48	–	–	14.40	13.23	1.3 m
2002 Aug. 23	2452509.581	15.19	17.67	16.67	14.15	13.00	1.3 m
2002 Aug. 24	2452510.585	15.19	17.76	16.73	14.13	12.98	1.3 m
2002 Aug. 25	2452511.584	15.01	17.30	16.50	13.98	12.83	1.3 m
2002 Oct. 30	2452577.535	15.17	–	16.78	14.16	12.90	50 cm
2002 Oct. 31	2452578.616	15.21	–	16.80	14.21	12.93	50 cm
2002 Nov. 28	2452607.418	15.22	17.87	16.77	14.18	12.87	50 cm
2002 Nov. 30	2452608.606	15.10	–	–	14.10	12.84	50 cm
2003 Feb. 26	2452697.417	15.33	–	–	–	13.08	2 m
2003 Feb. 27	2452698.382	15.52	–	–	–	13.26	2 m
2003 Mar. 1	2452700.319	15.49	–	–	–	13.21	2 m
2003 Mar. 2	2452701.279	15.37	–	–	–	13.09	2 m
2003 Apr. 2	2452732.275	15.05	–	16.66	14.06	12.80	50 cm
2003 Apr. 3	2452733.266	15.09	–	16.64	14.06	12.82	50 cm
2003 Apr. 4	2452734.280	15.04	–	16.58	14.03	12.79	50 cm
2003 Aug. 13	2452864.589	16.22	–	–	–	13.51	1.3 m
2003 Sep. 27	2452910.476	15.62	–	17.31	14.53	13.20	50 cm
2003 Oct. 2	2452914.513	16.10	–	–	14.95	13.48	50 cm
2003 Oct. 3	2452915.503	16.25	–	–	15.08	13.65	50 cm
2003 Nov. 23	2452967.487	16.55	–	18.44	15.18	13.91	2 m
2003 Nov. 24	2452968.463	16.68	–	–	–	13.97	2 m
2003 Dec. 18	2452992.270	16.90	–	–	15.61	14.06	50 cm
2003 Dec. 19	2452993.238	17.08	–	–	15.80	14.22	50 cm
2004 Jan. 23	2453028.329	>18.1	–	–	17.9:	16.08	50 cm
2004 Feb. 9	2453045.286	>18.3	–	–	18.1:	16.31	50 cm
2004 Feb. 10	2453046.265	19.0:	–	–	18.0:	16.22	50 cm
2004 Mar. 19	2453084.351	19.48	–	–	18.16	16.91	2 m
2004 Mar. 20	2453085.284	19.31	–	–	18.06	16.86	2 m
2004 Mar. 21	2453086.263	19.12	–	–	17.95	16.60	2 m

strength of the emission lines Hα and [OI] (λ 6003) were found. In spite of existing discrepancies, V 1184 Tau was included in some lists of FUOR objects (Sandell & Weitraub 2001; Herbig et al. 2003).

2. Observations and results

The present data are a continuation of our investigation of V 1184 Tau (Semkov 2003). Our photometric data were performed in two observatories with three telescopes: the 2-m Ritchey-Cretien-Coude and 50/70/172 cm Schmidt telescopes of the National Astronomical Observatory Rozhen (Bulgaria) and the 1.3-m Ritchey-Cretien telescope of the Skinakas Observatory[1] of the Institute of Astronomy, University of Crete (Greece).

The photometric *UBVRI* data presented in this paper were collected from August 2002 to March 2004. Photometrics CCD cameras with the 2-m RCC and 1.3-m RC telescopes and SBIG ST8 camera with the 50/70 cm Schmidt telescope were used. The technical parameters for the CCD cameras used, observational procedure and data reduction process are described in Semkov (2003). As a reference the *UBVRI* comparison sequence reported there was used. The recent results of our photometric observations of V 1184 Tau are summarized in Table 1. The columns give: date of observation, Julian Date, *VUBRI* magnitudes, and telescope used. Observations on 2004 January 23 and 2004 February 9 were made under poor atmospheric conditions and only the *V* magnitude limit is given in the table.

It is seen from Table 1 that a gradual decreasing of star brightness starts in the summer of 2003. To illustrate this finding CCD images of V 1184 Tau from two different periods are presented in Fig. 1. North is at the top and east to the left on the figure, and the frames are ~2′ on a side. The estimated difference of *I* magnitudes between the two frames is $3\overset{m}{.}43$.

The *I*-light curve of V 1184 Tau during the period of our observations (Semkov (2003) and this paper) is shown in Fig. 2. From October 2000 to April 2003 the star brightness varies with amplitude of about $0\overset{m}{.}5$ without increasing or decreasing. Such brightness variations can be seen in the other passbands. Similar photometric results for the period

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

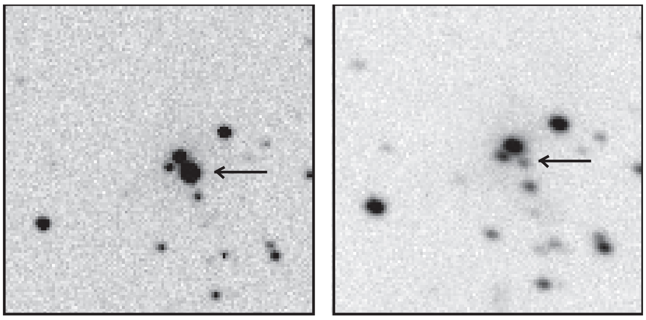

Fig. 1. CCD frames of V 1184 Tau obtained with the 50/70 cm Schmidt telescope through a *I* filter. *Left*: on 2003 April 4 ($I = 12\overset{\rm m}{.}79$). *Right*: on 2004 February 10 ($I = 16\overset{\rm m}{.}22$). The object is marked by arrow.

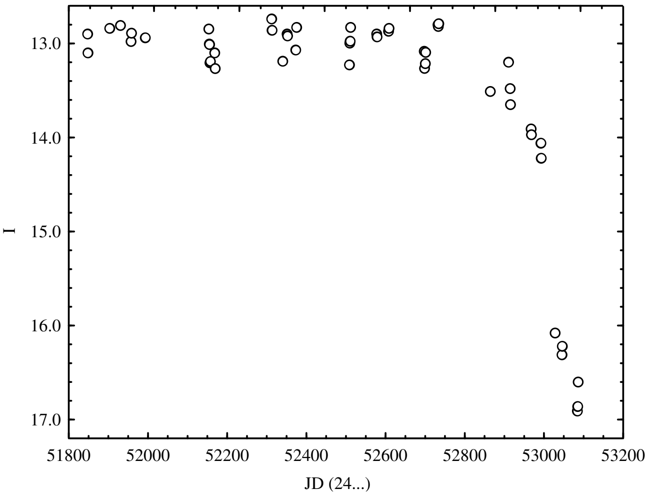

Fig. 2. A *I*-light curve of V 1184 Tau in the period October 2000–March 2004.

November 2001–March 2002 were published by Tackett et al. (2003). Although only differential photometry was reported in that paper the authors estimated an amplitude of $0\overset{\rm m}{.}65$ (Cousins *I*) for V 1184 Tau. Since August 2003 a gradual decreasing of star brightness has begun and the *I* magnitude of V 1184 Tau decreased with $\sim 4^{\rm m}$ until March 2004.

Another important result from our photometric study is the variation of color indices with stellar brightness. In Fig. 3 we plot the measured color index $V-I$ versus stellar magnitude V during the period of our observations. A clear dependence can be seen from the figure: the star becomes redder as it fades. In our first paper (Semkov 2003) we draw attention to the fact that such color variations are typical of stars with large cool spots whose variability is produced by rotation of the spotted surface (WTTS). In conformation of this statement Tackett et al. (2003) found a rotational period of 2.372 days. At this stage our photometric data are insufficient for an independent search for a period. The cool surface spots are short lived (weeks or months) and our data are not enough in any observational season.

The tendency toward reddening becomes very considerable in the period August–December 2003. While in the period of maximum brightness the color index $V-I$ vary between $2\overset{\rm m}{.}15$ and $2\overset{\rm m}{.}40$ it reaches a value of $2\overset{\rm m}{.}85$ on December 2003. Such color variations are observed as well for $R-I$ index. In this

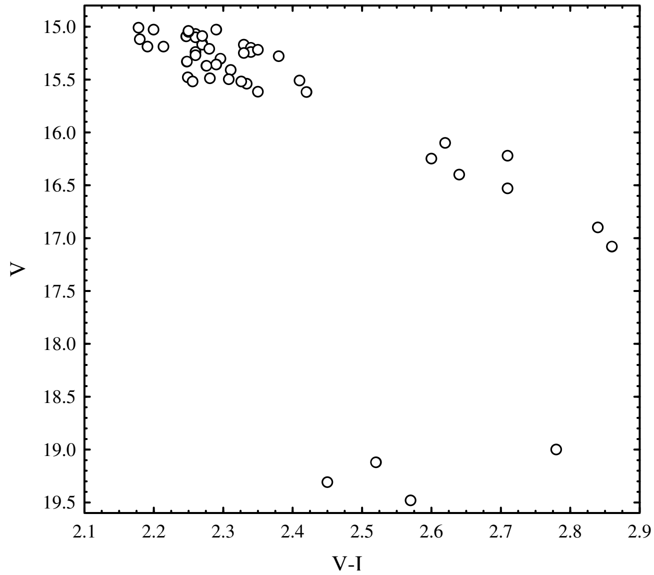

Fig. 3. Relationship between V magnitude and $V-I$ color index for the period of observations.

case we suggest that the reddening of the star is produced by the variable extinction from circumstellar environment (type III from the Herbst et al. 1994, classification). Our observations from February–March 2004 confirm the statement of Alves et al. (1997) for a possible "blueing effect" in the minimum light. Such effect was described by Bibo & The (1990) in the photometric study of the HAEBE star UX Ori. From a certain turning point ($V \sim 18^{\rm m}$) V 1184 Tau gets bluer fading further to $V-I = 2\overset{\rm m}{.}5$ in March 2004 (Fig. 3).

Therefore, the variability of V 1184 Tau can be explained as a superposition of two independent phenomena: (1) variability caused by rotation of spotted surface and (2) occultation from circumstellar clouds of dust or from an orbiting extended body.

3. Discussion

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. 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. To understand the nature of eclipsing object we need the answers of two main questions: (1) is the eclipse periodic and (2) how long the star passes in the minimum light.

The resent depth of the light curve of V 1184 Tau is the second documented minimum after the photographic observations with the Palomar Schmidt telescope. According to Alves et al. (1997) the magnitude of V 1184 Tau estimated from the red Palomar plate (1951 November 27) is $\sim 18^{\rm m}$. Our *R* magnitudes obtained from January–March 2004 (Table 1) have similar values, so that the star goes back to the same brightness as in 1951. The photometric behavior of the star in the period between the two minima is difficult to define. The available now regular photometric observations cover only the short period 2000–2004 (Fig. 2). The *BVRI* magnitudes of V 1184 Tau on December 1993 estimated by Yun et al. (1997) and on February 1996 estimated by Alves et al. (1997) have values close to our magnitudes in the period of maximum brightness. According to Yun et al. (1997) the star has kept its higher brightness on December 1994, too. Unfortunately, there are no published observations of the star in the period 1997–1999 and a possible minimum in this time can't be rejected. We propose that if the eclipse is recurrent the possible period range from 5 to 52 years. One possibility for correct determination of the period is a search in the photographic plate archives.

It is seen from Fig. 2 that the gradual decreasing of brightness continues at least 8 months. Assuming that the shape of the depth is symmetric we can predict that the total time of eclipse must be more than one year. Taking in to 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. According to Bertout (2000) occultation of PMS stars by circumstellar disks can be responsible for type III of photometric variability.

The unusual photometric behavior of V 1184 Tau has not precise analogies in the PMS stars. Only a few PMS objects have been found to show eclipses such as KH 15D (Hamilton et al. 2001; Herbst et al. 2002) or HMW 15 (Cohen et al. 2003). The eclipsing PMS star KH 15D varies with amplitude of 3–4 mag and a period of 48.36 days. The cause of the eclipses is an extended feature in its circumstellar disk according to Hamilton et al. (2001). The unique PMS object HMW 15, found in the field of IC 348, has amplitude of observed obscuration $0\overset{m}{.}66$ and duration of eclipse 3.5 years which is the longest value of any known eclipsing variables. According to Cohen et al. (2003) an eclipse of one component of a binary star by an optically thick cloud is the most probable explanation of the eclipse. The exact determination of the eclipse parameters is necessary in order to choose which scenario explains better the variability of V 1184 Tau.

An open question is the observed spectral variability of V 1184 Tau. Comparison of our spectral observations (Semkov 2003) with the spectra obtained in 1995 (Yun et al. 1997) and 1996 (Alves et al. 1997) reveals major changes in the Hα and [OI] (λ 6003) line profiles. The equivalent width of the Hα line measured from our spectrum is 4 Å. Hamilton et al. (2003) reported significant changes of the profile of the Hα line of the eclipsing PMS star KH 15D. During egress and eclipse totality the equivalent width was found to increase several times in comparison with those in maximum light. But all spectral observations of V 1184 Tau (Yun et al. 1997; Alves et al. 1997 and Semkov 2003) were made in the maximum light (out of eclipse) and the observed spectral variability can not be connected with the eclipsing episode.

Thus, the available photometric and spectroscopic data suggest that V 1184 Tau has the characteristics of a WTTS in the maximum light. On the other hand the observed eclipse resembles the light-curves of the type III PMS variables. We encourage the observers heaving interest from PMS variables to follow V 1184 Tau in the future. We suppose that the exact determination of the period of eclipse, amplitude and color behavior of this unique object is important for the studding of PMS evolution and formation of protoplanetary disks.

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