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Construction of the Historical Light Curve of V 1184 Tauri Using the Astronomical Plate Archives

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Abstract.

We present recent results from optical photometric observations and our program for construction of the historical light curve of the pre-main sequence (PMS) 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 recent photometric data suggest that the star brightness is sill near the mimimum. The analysis of available photometric data suggests that V 1184 Tau shows two types of variability produced (1) by rotation of large cool spotted surface and (2) by occultation from circumstellar clouds of dust or from features of a circumstellar disk. In order to construct the historical light curve of V 1184 Tau a search for archive photographic observations in the Wide-Field Plate Database was made. As a result 422 photographic plates containing the field of V 1184 Tau were found.

1 Introduction

T Tauri stars (TTSs) are a widespread class of pre-main sequence objects known from the pioneering work of Joy [1]. They are determined as young low-mass stars ($M \leq 2\mathrm{M}_{\odot}$) with emission spectra and irregular 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 [2].

Herbst *et al.* [3] defined three basic types of brightness variation concerning TTS stars. Type I of variability is due to rotation of large cool surface spots and it is typical for 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 0.8 mag in V light are observed in WTTSs. Type II of variability occurs predominantly on CTTSs and it is caused by superposition of cool and hot surface spots. The hot spots are relatively small (<1% from stellar surface) and they seem 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 Herbig Ae/Be stars [4] 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 (quasi-Algol) 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 PMS evolution is the FU Orionis (FUOR) outburst [5]. An increase in optical brightness of the order of 4–5 magnitudes, 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 [6]. The observations in the case of the FUOR outburst is explained by increasing accretion caused by thermal instabilities in the circumstellar disk [7]. From the ten objects classified as FUORs only three (FU Ori, V 1057 Cyg and V 1515 Cyg) have detailed photometric observations taken during the outburst.

The unusual variable star V 1184 Tau (CB 34V) was discovered in the Bok globule CB 34 by Yun *et al.* [8]. Comparison of CCD frames obtained in 1993 with the Palomar Observatory plates (1951) [9] reveals the increasing brightness of this object of 3.7 mag in the red. Alves *et al.* [10] determined the spectral class of the star as G5 (III-IV), the mass as $2M_{\odot}$ and the age as 10^6 years. They suppose two possible explanations of the observed outburst: (1) a high accretion episode (FUOR) and (2) time variable extinction from non-uniform circumstellar environment. Our first photometric and spectroscopic investigation [11] reveals V 1184 Tau as a possible WTT star with an amplitude of 0.6 mag. (V) and spectral variability. Significant changes in the profile and strength of the emission lines $H\alpha$ and [OI] (λ 6003) were found. In our second paper [12] the beginning of a new deep minimum of the light curve of V 1184 Tau was reported. The analysis of available photometric data suggests that V 1184 Tau shows two types of variability produced (1) by rotation of large cool spotted surface and (2) by occultation from circumstellar clouds of dust or from features of a circumstellar disk.

2 Observations

From October 2000 we started a program for photometric monitoring of V 1184 Tau. The present data are a continuation of our investigation of V 1184 Tau [11–13]. Our photometric data were performed in two observatories with three telescopes: the 2-m Ritchey-Cretien-Coude and the 50/70 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 recent photometric data presented in this paper were collected from November 2005 to April 2006. Observations with the 2-m RCC telescope were made with VersArray CCD camera 1340×1300 pixels. The size of the pixel is 19 μm and scale is 0.25 arcsec/pixel. Observations with 50/70 cm Schmidt telescope were made with SBIG ST-8 CCD camera 1530x1020 pixels. The size of the pixel is 9 μm and scale 1.1 arcsec/pixel. The observational procedure and data reduction process are described in Semkov [11]. As a reference the $UBVRI$ comparison sequence reported there was used. The results of our photometric observations of V 1184 Tau are summarized in Table 1. The columns give: date of observation, Julian date, IRV magnitudes, the telescope and CCD camera used.

Table 1. Recent VRI photometric observations of V 1184 Tau.

Date	JD	I	R	V	Tel	CCD
25.11.2005	2453700.358	16.15	17.38	-	Schmidt	ST-8
26.11.2005	2453701.405	16.09	-	-	Schmidt	ST-8
21.03.2006	2453816.324	16.767	17.992	19.530	2m RCC	VersArray
26.03.2006	2453816.312	16.919	18.076	19.463	2m RCC	VersArray
19.04.2006	2453845.307	16.46	-	-	Schmidt	ST-8
21.04.2006	2453847.298	16.56	-	-	Schmidt	ST-8
23.04.2006	2453849.260	16.51	17.70	-	Schmidt	ST-8

3 Results from the Photometric Monitoring

During the first three seasons of observations (Oct. 2000 – Apr. 2003) the brightness of V 1184 Tau varies with an amplitude of about 0.6 mag in V without increasing or decreasing. Since August 2003 a gradual decreasing of star brightness has begun and the I magnitude of V 1184 Tau decreased with 4 mag. until March 2004 (Figure 1). 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 has started and on August 2005 we observed the deepest value for I magnitude of V 1184 Tau (17.09). Our resent photometric observations (Table 1) show that the star keeps its minimal braghtness and in the period Oct. 2005 – Apr. 2006. The I-light curve of V 1184 Tau during the period of our observations ([11–13] and this paper) is shown in Figure 2.

[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.

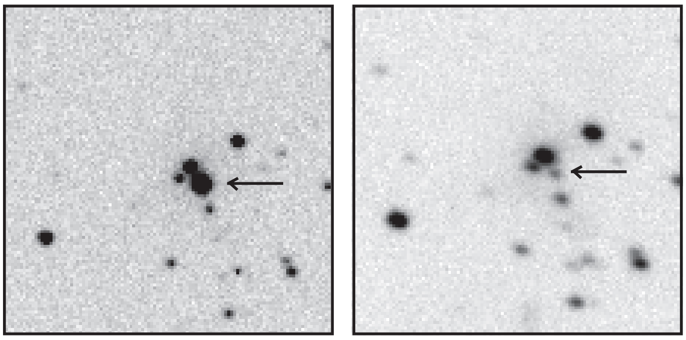

Figure 1. CCD frames of V 1184 Tau obtained with the 50/70 cm Schmidt telescope through a I filter. **Left**: on 2003 April 4 ($I = 12.79$). **Right**: on 2004 February 10 ($I = 16.22$). The object is marked by arrow.

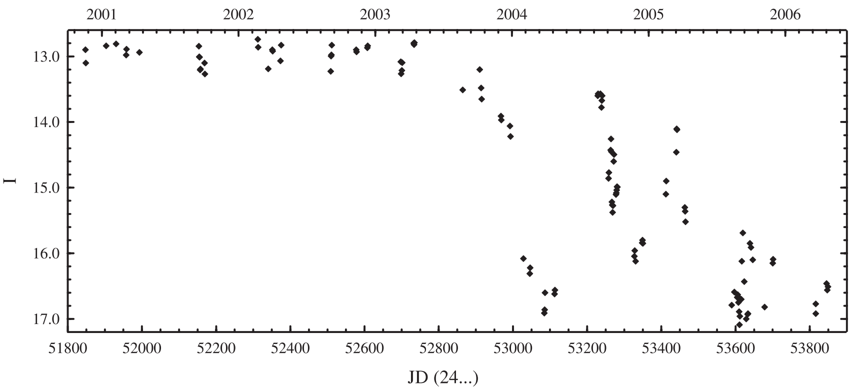

Figure 2. A I-light curve of V 1184 Tau in the period October 2000 – April 2006.

Another important result from our photometric study is the variation of color indices with stellar brightness. In Figure 3 we plot the measured color index $V - I$ versus 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 (Oct. 2000 – Apr. 2003), the filled triangles denote photometric data obtained during the first two deep minimums (Aug. 2003 – Apr. 2005) and the open squares represent photometric data obtained during the third minimum (Aug. 2005 – Apr. 2006). For the first period a clear dependence can be seen in the figure: the star becomes redder as it fades. The tendency towards reddening becomes very considerable from August 2003. While in the period of maximum brightness the color index $V - I$ varies between 2.15 and 2.40 it reaches a value of 3.22 in October 2004. From a certain turning point ($V \sim 18.5$) V 1184 Tau gets bluer fading further to $V - I = 2.44$ on March 2004 (Figure 3). In this case we suggest that the reddening of the star is produced by the variable

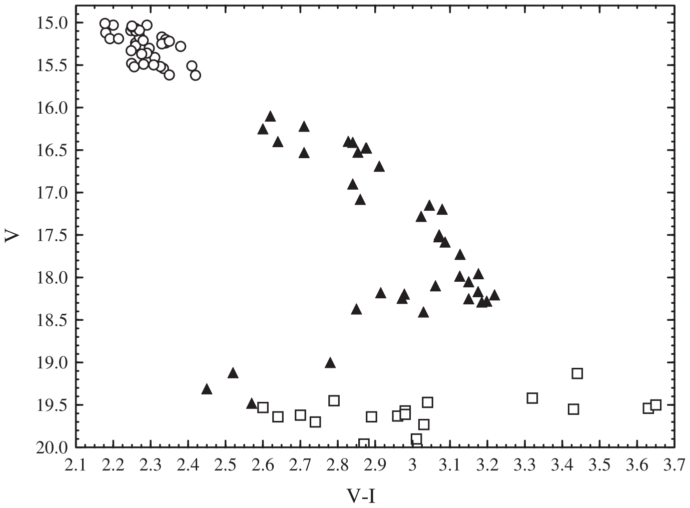

Figure 3. Relationship between V magnitude and $V - I$ color index for the period of observations.

extinction from circumstellar environment (Type III from the Herbst *et al.* [3] classification). Our photometric observations confirm the statement of Alves *et al.* [10] for a possible "blueing effect" in the minimum light. Such an effect was described by Bibo and The [14] in the photometric study of the PMS star UX Ori. Our photmetric data obtined from Aug. 2005 to the present time suggest that in the deep minimum the $V - I$ index varies from 2.60 to 3.67.

4 Search in the WFPDB

The construction of the historical light curve of V 1184 Tau would be very important for a determination of the eclipsing mechanism. The recent drops of the light curve of V 1184 Tau are the second documented minima after the photographic observations with the Palomar Schmidt telescope. According to Alves *et al.* [10] the magnitude of V 1184 Tau estimated from the red Palomar plate (1951 November 27) is $\sim 18^{\mathrm{m}}$. Our R magnitudes obtained on March 2004 and on August 2005 have similar values, so that the star shows the same brightness as in 1951.

The photometric behavior of the star in the period between the two epochs of minima is difficult to define. The now available regular photometric observations cover only the short period from 2000–2006 (Figure 2). The $BVRI$ magnitudes of V 1184 Tau on December 1993 estimated by Yun *et al.* [8] and on February 1996 estimated by Alves *et al.* [10] 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 cannot be rejected.

One possibility for the correct determination of the period of the deep minima is a search in the photographic plate archives. The results from our detailed search in the Wide-Field Plate Database [15] are summarized in Table 2. Our search was limited to clear telescope aperture ≥ 40 cm. We found 422 archival photographic observations in the plate collections of 13 telescopes. Most important for our investigation are the photographic plates from the Sonneberg and the Heidelberg observatory. The plates from both archives cover a wide time interval with regular observations. The plates from the Kiso Schmidt telescope will be scanned soon at our request. We shell try to collect in the near future digitized plates of V 1184 Tau from all archives.

The Bok globule CB 34 is located at approximately 2 deg. from the ecliptic and this region is of interest for the investigators of comets and minor planets. For instance during the recent return of the Comet Halley it passed at approximately 1 deg. from the position of V 1184 Tau (October 26, 1985). Some of the photographic observations of the comet made in this period can be very important for brightness estimation of V 1184 Tau.

Table 2. Archival photographic plates of V 1184 Tau found in WFPDB.

Observatory	Telescope Aperture	Telescope Type	Number of plates	Period
Sonneberg	40	Ast.	273	1938–1993
Sonneberg	50	Sch.	7	1961–1985
Heidelberg	40	Ast.	50	1900–1980
Palomar	122	Sch.	25	1951–1998
Harvard	61	Rfr.	19	1894–1938
Kiso	105	Sch.	11	1976–1989
Rozhen	50	Sch.	8	1985
Konkoly	60	Sch.	7	1985
Siding Spring	124	Sch.	6	1976–1985
Turku	50	Sch.	6	1941–1945
Asiago	67	Sch.	5	1963–1983
Asiago	40	Sch.	2	1985
Upsala	100	Sch.	3	1983–1985
Total			422	1894–1998

5 Discussion and Conclusions

The historical light curve of V 1184 Tau from all available photometric data is shown in Figure 4. In the figure the filled diamonds denote our photometric data, the filled triangles denote data from Palomar plates [9] and the filled circles represent photometric data published in Yun *et al.* [8] and Alves *et al.* [10]. We found also eight photographic plates obtained with the 50/70 cm Schmidt telescope at Rozhen Observatory in this period. Unfortunately, they are made with short exposures (3–6 min) and V 1184 Tau is under the plate limit (~ 16.8 pg).

Taking into account the observed amplitude and duration of the 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 optically thick enough to produce such a deep eclipse. It could be a feature from a protoplanetary disk or orbiting material of dust that periodically occults the star.

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 [16] or HMW 15 [17]. The eclipsing PMS star KH 15D varies with an amplitude of 3–4 mag and a period of 48.36 days. In recent studies Winn *et al.* [18] and Chiang and Murray-Clay [19] independently proposed that KH 15D is a binary star that is occulted by an inclined, circumbinary disk. The unique PMS object HMW 15, found in the field of IC 348, has an amplitude of observed obscuration 0.66 mag. and shows a duration of an eclipse over 3.5 years which is the longest value of any known eclipsing variables. According to Cohen *et al.* [17] an eclipse of one component of a binary star by an optically thick cloud is the most probable explanation of the eclipse. At present there is no evidence that V 1184 Tau is a binary star. But the model of high eccentricity binary system

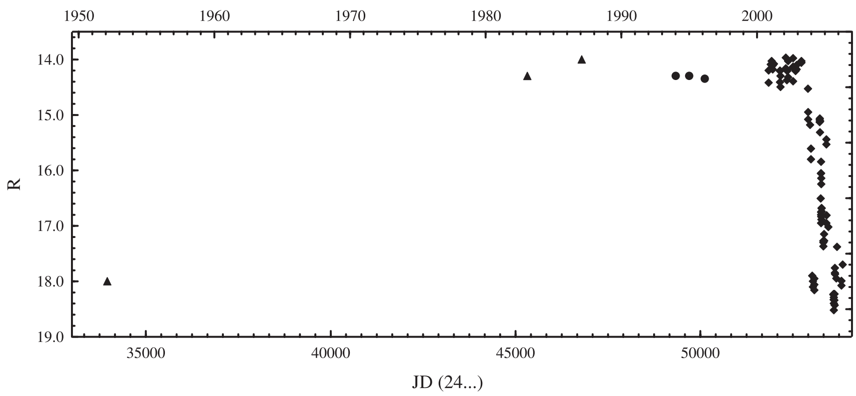

Figure 4. Historical light curve of V 1184 Tau from the available now data.

occulted by circumbinary or circumstellar disk seems to be the most probable at the moment.

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