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Photometric and polarimetric variability of the isolated T Tauri star TW Hydrae*

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Abstract. The photometric and polarimetric observations of the isolated T Tauri star TW Hya are presented. It is found that a period 2.196 days derived from the present data satisfies all the available photometry. The steep increase in the amplitude towards shorter wavelengths indicates that the light variation is caused by hot spots. Apart from the periodic variations sudden increase in brightness of the order of 0.2 mag lasting one or two days was also noticed.

A low resolution study of the Hα emission and Li I 6708 Å absorption shows that the line strengths do not have any correlation with the rotational phase in TW Hya.

Since the synoptic linear polarization measurements obtained during 1990, 1991 and 1992 showed that TW Hya has variable polarization, further measurements were obtained over nine consecutive nights during 1993. The data indicate that the linear polarization in TW Hya has two components, namely, a low amplitude component which is present throughout and a large amplitude short-lived component which occurs randomly.

Key words: stars: activity – stars: individual: TW Hya – stars: pre-main sequence – stars: starspots

1. Introduction

TW Hya (CoD -34°7151, He 3-549, HV4089) is one of the most peculiar T Tauri stars. Herbig (1978) suggested that this star is possibly a member of the Post T Tauri stars which are supposed to be more evolved than the classical T Tauri stars. Heinze (1976) detected the presence of strong Hα emission in TW Hya. Hoffmeister (1943) reported a light variation between 10.5 and 12.2 mag in blue for TW Hya. From a spectroscopic study, Herbig (1978) found that TW Hya exhibits emissions in O I 8446 Å, He I 5876 Å and Ca II triplet lines and he assigned a spectral type of K7 Ve (Li I). Rucinski & Krautter (1983), who carried out optical and infrared photometry as well as low resolution spectroscopy of TW Hya, found that the star shows light variations in V between 10.9 and 11.3 mag, and the range in light variations decreased at longer wavelengths. They also detected uv and IR excesses. The emission equivalent width of Hα was found to vary from 70 to 100 Å. On the basis of strong Hα and other emission lines, uv and IR excesses, Lithium abundance and irregular light variations, they classified the star as a member of the Classical T Tauri (CTTS) stars. TW Hya is quite far from any star forming region, dark cloud or concentration of young protostellar material; this prompted the above authors to suggest that the star might have been formed in a tiny isolated dark cloud of low mass. Recently, using the Hipparcos parallaxes, Favata et al. (1998) estimated the distance to TW Hya to be $\sim$ 60 pc and its age $\sim$ 20 Myr.

Though Rucinski & Krautter (1983) detected short-term variability in TW Hya, they could not detect any periodic light variation. Rucinski (1988) also did not find any significant periodic light variation from the observations obtained during 1986 and 1987. However, he reported the possible presence of a 2-day period in the 1982 observations obtained earlier by Rucinski & Krautter (1983). Herbst & Koret (1988) detected the presence of a 1.28 day period from their observations made in January 1988. They also found that the star showed significant light variations during each night. Their analysis of the photometric data obtained by Rucinski & Krautter (1983) gave a period of 1.83 days. They attributed the discrepancy in the derived period to a real change in the periodicity of TW Hya that occurred within six years and the light variations exhibited by the star to the presence of a hot spot.

From a survey of IRAS sources Rucinski (1985) identified TW Hya as a strong far-infrared source. He suggested that the far-infrared spectrum is due to the presence of a steady accretion disk. Weintraub et al. (1989) reported the detection of millimeter and sub-millimeter emissions in TW Hya, possibly arising from the circumstellar accretion disk. The search for interstellar matter, which could have remained in the field, through CO emission at 115 GHz by Rucinski (1992) gave a negative result.

Franchini et al. (1992) estimated the rotational velocity V sin i of TW Hya as around 15 km s^{-1} from a high resolution study. They detected strong He I 5876 Å line emission with a radial velocity of 16.3 km s^{-1}; this is about 10 km s^{-1} larger than the radial velocity of the star. Patten & Simon (1992), who analyzed the IUE spectra of TW Hya, detected substantial variability in both Mg II lines and uv continuum on time-scales of a few hours to a few days.

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* Based partly on the observations collected at the European Southern Observatory, La Silla

Table 1. $UBVRI$ and by magnitudes of the HD 95740

U	B	V	R	I	b	y
11.419	10.004	8.704	8.033	7.431	9.493	8.705
±0.010	±0.007	±0.006	±0.004	±0.004	±0.005	±0.007

But for a few peculiar characteristics, TW Hya is a typical CTTS. The near infrared excess is not so strong in TW Hya as in other CTTS and also it is not associated with any star forming regions. So TW Hya is the prototype of another subgroup of T Tauri stars that are not associated with star forming regions and hence termed as $Isolated\ T\ Tauri\ stars$. In order to obtain a better understanding of the photometric behaviour and circumstellar environment, it is necessary that the star is investigated at all possible wavelengths. Therefore photometric, spectroscopic and polarimetric observations of TW Hya were carried out simultaneously, whenever possible.

2. Observations

Photometric observations of TW Hya were carried out on 34 nights over four seasons: 1987 (9 nights), 1988 (6 nights), 1990 (12 nights) and 1993 (7 nights). $UBVRI$ observations were done during 1987 and 1988 seasons and by observations during 1990 using the 50 cm telescope of the European Southern Observatory, (ESO) La Silla. Only V measurements were made during the 1993 season, with the 75 cm telescope of Vainu Bappu Observatory (VBO), Kavalur, as the observations were mainly aimed at getting light curve information around the times of spectroscopic and polarimetric observations. TW Hya was observed as frequently as possible each night to check for short-time scale light variations and hence only a single comparison star HD 95470, whose constancy has been well established earlier by several authors, was used. Sufficient number of standard stars were observed for the conversion of the instrumental magnitudes to the corresponding standard photometric systems. The mean $UBVRI$ and by magnitudes of HD 95470 are given in Table 1. The $UBVRI$ magnitudes of TW Hya are given in Tables 2 and 3, the by magnitudes in Table 4 and the V magnitudes in Table 5.

Spectroscopic observations of TW Hya in the Hα and Li I 6708 Å region were obtained on eight nights during March-April 1993 with the 102 cm telescope of the VBO overlapping with some of the photometric and polarimetric observations. The spectrograph set up gave a resolution of 1.38 Å/pixel in the red region.

The linear polarization measurements were made with the PRL- polarimeter (Deshpande et al.1985) attached to the 236 cm telescope of VBO. The observations were carried out in $UBVR$ bands on 20 February 1990, 9 and 11 February 1991 and 24 March 1992 to search for the possible variability. TW Hya was further observed on nine consecutive nights, mostly in V, during April 1993.

Table 2. $UBVRI$ magnitudes of TW Hya

JD 2440000+	U	B	V	R	I
6897.615	11.801	12.079	11.027	10.116	9.356
6898.527	12.041	12.034	10.986	10.146	9.374
6898.567	12.014	12.081	10.987	10.137	9.348
6898.615	11.824	12.001	10.958	10.134	9.366
6898.656	12.088	12.002	10.989	10.133	9.362
6898.720	11.984	12.040	11.006	10.152	9.361
6899.519	12.138	12.193	11.053	10.161	9.377
6899.552	12.012	12.166	11.065	10.183	9.392
6899.599	11.944	12.148	11.038	10.186	9.386
6899.644	12.111	12.191	11.103	10.186	9.401
6899.684	12.324	12.212	11.084	10.184	9.394
6900.578	11.811	11.987	10.958	10.099	9.337
6901.519	11.895	12.071	10.997	10.118	9.333
6901.565	12.012	12.101	11.020	10.141	9.341
6901.617	11.926	12.064	10.998	10.129	9.348
6901.660	12.007	12.135	11.003	10.122	9.336
6902.518	11.781	11.970	10.937	10.073	9.325
6902.561	11.621	11.941	10.943	10.067	9.316
6902.609	11.709	11.932	10.949	10.081	9.324
6092.660	11.653	11.937	10.938	10.089	9.335
6902.708	11.528	11.894	10.917	10.077	9.309
6903.519	12.081	12.149	11.053	10.145	9.362
6903.558	12.212	12.240	11.097	10.180	9.376
6903.601	12.329	12.239	11.074	10.174	9.384
6903.647	12.441	12.288	11.110	10.204	9.400
6903.709	12.312	12.265	11.102	10.186	9.379
6904.515	11.666	12.006	10.939	10.052	9.309
6904.556	11.675	11.962	10.930	10.053	9.311
6904.601	11.549	11.885	10.893	10.028	9.309
6904.642	11.625	11.876	10.909	10.032	9.317
6904.707	11.859	11.985	10.957	10.070	9.324
6905.512	11.921	12.079	11.014	10.127	9.338
6905.550	12.080	12.126	11.021	10.156	9.351
6905.599	12.048	12.138	11.031	10.153	9.347
6905.642	11.968	12.098	11.020	10.146	9.350

Table 3. $UBVRI$ magnitudes of TW Hya

JD 2440000+	U	B	V	R	I
7296.520	11.911	12.034	10.967	10.035	9.317
7296.603	11.798	12.002	10.948	10.042	9.327
7298.560	11.866	12.055	10.988	10.076	9.370
7304.550	11.948	12.081	10.990	10.095	9.327
7304.615	12.009	12.095	11.003	10.070	9.337
7305.480	11.733	11.964	10.929	10.015	9.301
7305.549	11.717	11.936	10.987	10.001	9.293
7305.630	11.651	11.864	10.882	9.973	9.297
7305.673	11.576	11.841	10.864	9.970	9.284
7307.563	11.510	11.864	10.895	10.036	9.313
7307.641	11.588	11.871	10.894	10.043	9.311
7308.494	11.480	11.735	10.847	10.028	9.299
7308.618	11.582	11.785	10.849	10.049	9.303

Table 4. by magnitudes of TW Hya

JD 2440000+	b	y	JD 244000+	b	y
7910.808	11.694	10.985	7910.856	11.640	10.976
7910.865	11.647	10.954	7911.701	11.413	10.788
7911.763	11.357	10.765	7911.840	11.330	10.742
7911.848	11.347	10.747	7912.689	11.496	10.865
7912.698	11.511	10.852	7912.755	11.439	10.769
7912.764	11.423	10.759	7912.838	11.309	10.718
7912.864	11.364	10.750	7913.669	11.552	10.877
7913.719	11.593	10.931	7913.764	11.675	10.951
7913.812	11.728	10.993	7913.848	11.772	11.000
7916.775	11.536	10.860	7916.810	11.524	10.851
7916.870	11.483	10.834	7917.651	11.695	10.971
7917.699	11.702	10.989	7917.748	11.647	10.957
7917.808	11.696	10.994	7917.845	11.759	11.006
7920.611	11.376	10.799	7920.653	11.474	10.839
7920.735	11.393	10.770	7920.774	11.387	10.792
7920.819	11.431	10.824	7921.611	11.492	10.837
7921.649	11.490	10.851	7921.709	11.524	10.853
7921.750	11.510	10 857	7924.639	11.560	10.919
7924.680	11.551	10.888	7924.729	11.463	10.834
7924.781	11.426	10.821	7924.842	11.393	10.813
7925.650	11.400	10.765	7925.686	11.470	10.837
7925.745	11.418	10.798	7925.788	11.383	10.801
7925.827	11.395	10.806	7925.869	11.380	10.784
7926.624	11.765	11.007	7926.667	11.766	11.003
7926.706	11.765	11.028	7926.750	11.762	11.014
7926.798	11.771	11.032	7926.835	11.747	11.014
7926.858	11.712	11.008	7929.642	11.247	10.696
7929.723	11.215	10.638	7929.762	11.234	10.655
7929.801	11.249	10.667	7929.831	11.213	10.638
7929.880	11.177	10.621			

Table 5. V magnitudes of TW Hya

JD 2440000+	V	JD 2440000+	V
9064.274	11.034	9064.344	11.016
9064.365	11.010	9065.224	11.078
9065.330	11.061	9065.381	11.076
9066.258	10.988	9066.318	11.020
9066.337	10.988	9067.246	10.732
9067.257	10.763	9068.218	11.040
9068.304	10.917	9069.193	10.994
9069.208	11.002	9069.282	10.953
9070.221	11.022	9070.231	10.990

3. Photometric variability

A first look at the photometry obtained during April 1987 appeared to show a period around two days for the light variation superposed on which were the short time-scale fluctuations. The observations were subjected to the period finding technique as explained in Raveendran et al.(1982) which yielded a period of 2.196 days for the light variation. The preliminary results

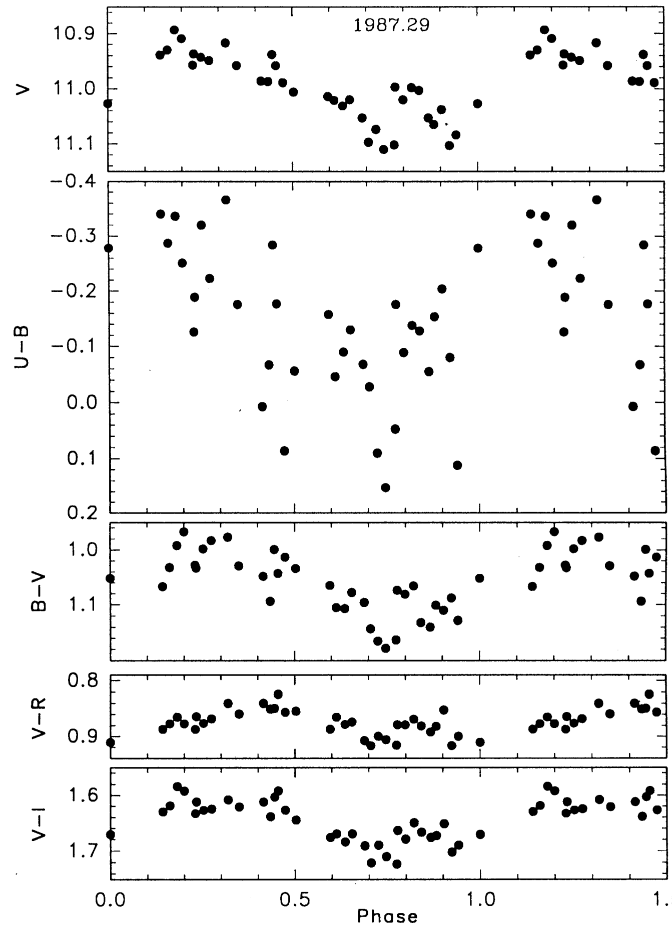

Fig. 1. Plots of V, $U-B$, $B-V$, $V-R$ and $V-I$ of TW Hya

of 1987 observations were reported in Mekkaden (1990). The photometric observations of 1987, 1988, 1990 and 1993 seasons were phased using the ephemeris,

$$JD(Hel.) = 2446897.615 + 2\overset{\mathrm{d}}{.}196E,$$

where the initial epoch corresponds to the first observation obtained during 1987. The observations listed in Tables 2, 3, 4 and 5 are plotted in Figs. 1, 2, 3 and 4e; the mean epochs of observations are indicated in the respective figures. From Fig. 1 it is seen that the colours also vary in phase with the V light. The maximum changes occur in the U band which in turn is reflected in the $U-B$ colour plot. The $U-B$ colour shows a large scatter that is far more than the observational error. A steep increase in the amplitude of light variation is observed as the wavelength decreases. This phenomenon, generally noticed in classical T Tauri stars, is interpreted as due to the presence of hot spots (Vrba et al. 1986; Simon et al.1990)

The effect of hot spots is reflected maximum in U band and it is noticed that as the wavelength increases the amplitude decreases. Apart from the effect of the hot spot, the rapid changes in chromospheric emissions and plage-like bright areas, if present, on the stellar surface also affect the flux in the U band, resulting in large variations in $U-B$ colour. The 1988, 1990 and 1993 data also satisfy the 2.196 day period, though the resulting light

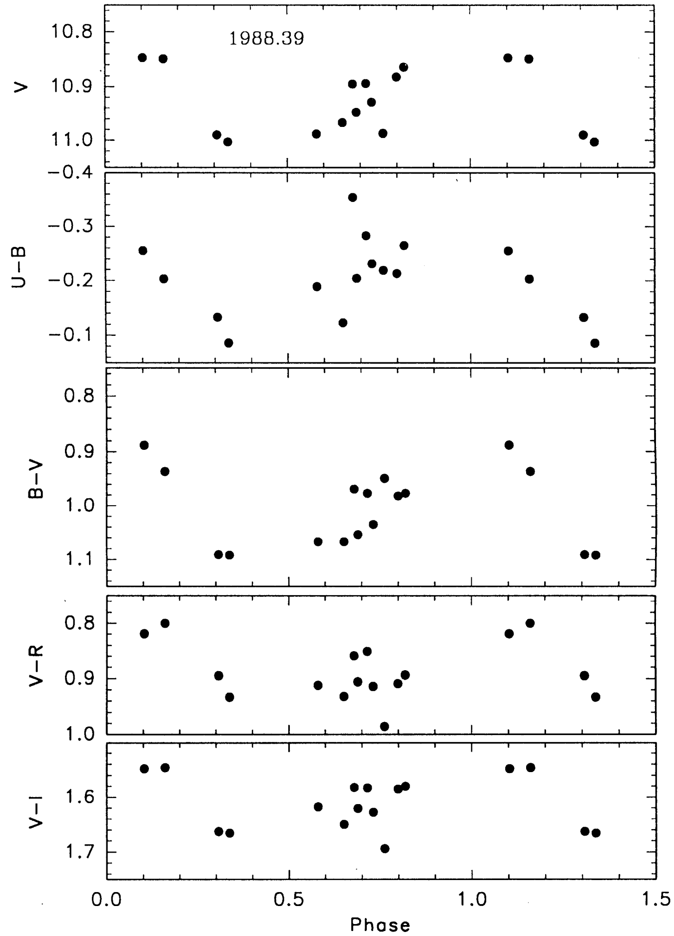

Fig. 2. Plots of V, $U-B$, $B-V$, $V-R$ and $V-I$ of TW Hya

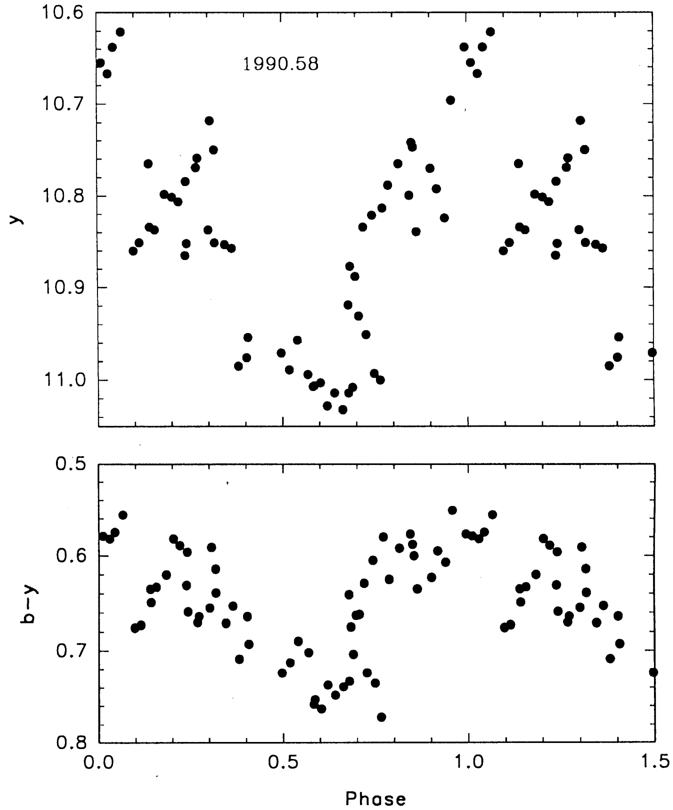

Fig. 3. Plots of y and $b-y$ of TW Hya

curves show a slightly larger scatter. Though the photometry obtained during 1988 shows an indication of periodic variation, it is not as well-defined as in the cases of the other seasons; one reason for such a behaviour could be the poor phase coverage. The light curve of the mean epoch 1990.58 showed the highest amplitude of 0.4 mag. The scatter near the maximum brightness is large when compared to that at minimum brightness. The hot spot that caused the light variation was present throughout the observational period of 12 days. From the brightness at maximum (10.62 mag), which incidentally is the brightest magnitude of TW Hya observed so far, we can assume that the hot spot was very active and the large scatter observed at the maximum indicates that the hot spot was highly variable.

In order to get an idea of the nature of the hot spot that causes the light variation, the 1987.3 observations were subjected to spot modelling using a modified version of the program of Mohin & Raveendran (1992). The spot parameters are derived by solving all the five $UBVRI$ light curves simultaneously. The photospheric temperature of TW Hya was assumed to be 4000 K corresponding to a spectral type of K7 V. Since the value of i, the orbital inclination, is not known, a value of 60°was used. Though i =60°may not represent the actual value, the large amplitude of light variation definitely indicates a high value for i. The limb darkening coefficients in $UBVRI$ namely, 1.02, 0.92, 0.79, 0.61 and 0.50, were taken from Strassmeier & Olah (1992) and Eker (1994). The minimum values in the light curves are assumed to represent the unspotted magnitudes and they are: U=12.440, B=12.288, V=11.110, R=10.204 and I=9.400 mags. However, these values may not be the true values of the unspotted star since the same can be only determined by observing the star over several seasons. From the modelling it is found that a hot spot with T = 8450 K that covers a fractional surface area of 0.001 at a polar distance of 10°could cause the observed light variations. It is significant to note that the spot is almost situated at the pole.

All the V band photometry of TW Hya available in the literature are plotted in Figs. 4a–d. The observations were folded using the ephemeris given above. The observations obtained during 1982 (Rucinski & Krautter 1983), 1987.5 (Rucinski 1988) and 1988.00 (Herbst & Koret 1988) clearly show the light modulation with the 2.196 day period presently derived while those obtained during 1986.5 (Rucinski 1988) apparently do not show any indication of a periodicity. However, if the bright V measurements which lie in the interval $0\overset{\mathrm{p}}{.}40 - 0\overset{\mathrm{p}}{.}55$ are excluded from the latter set of observations the periodic light modulation becomes apparent. An increase in brightness of the order of 0.2 mag that lasted for two days was noticed near $0\overset{\mathrm{p}}{.}0$ in the light curve of 1987.5. Similarly the 1988 light curve also shows a brightening of 0.2 mag, which lasted for a single day around $0\overset{\mathrm{p}}{.}7$. During the 1993.3 observations TW Hya brightened up to

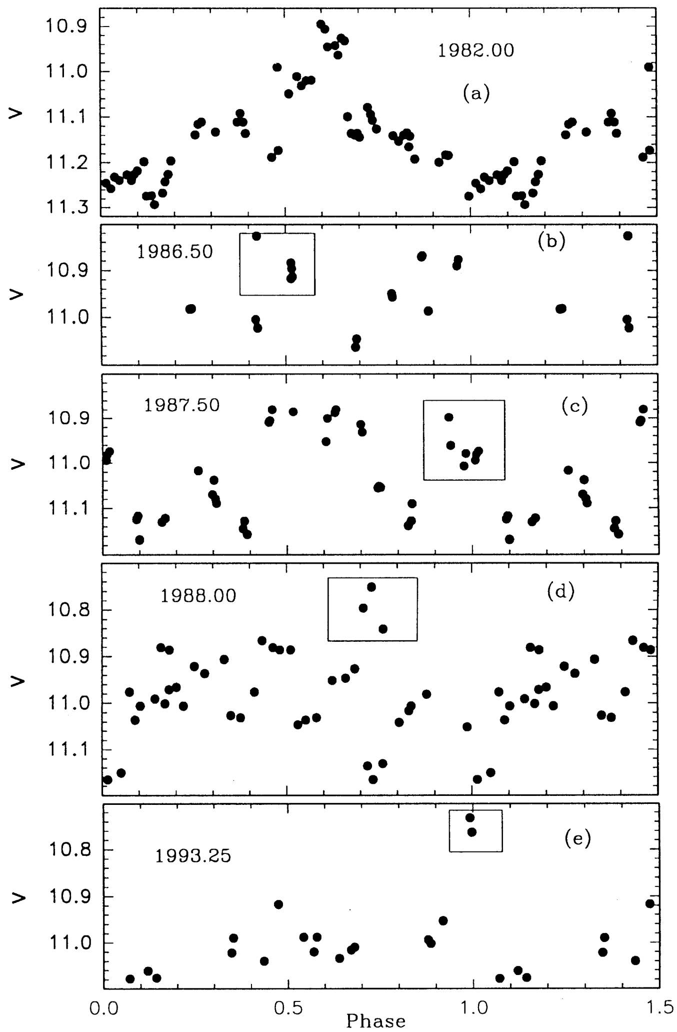

Fig. 4a–e. Plots of V of TW Hya

10.75 mag in V for a day. All the above mentioned observations are enclosed in boxes in the respective figures. Sudden brightenings which last for a couple of days seem to be a regular feature of TW Hya. This phenomenon can be either due to flaring activities or due to very short-lived hot spots produced by the interaction between the accretion disk and the star. The latter case seems to be more likely since the sudden increase in the brightness is around 0.2 mag whereas the brightness change expected due to a flare is more than 1 mag (Bertout 1989). Since the frequent brightenings could occur at any photometric phase, they could completely mask the periodic variation, and hence the period search would not give any positive result at certain epochs.

The light curves obtained by us during 1987.3 and by Rucinski (1988) one month earlier show entirely different shapes, amplitudes and phases of the maximum light, indicating sudden changes in the location of the bright spot on the stellar surface. The sudden changes in the light variation and brightening observed in TW Hya is typical of CTTS. The hot spots that cause the light variability are the zones on the stellar surface heated by the infall of a column of matter from the active accretion disk surrounding the star (Herbst et al. 1994). Bertout (1989), Simon et al. (1990) and Bouvier et al. (1993) include stellar magnetosphere as an integral component in the evolution of the star/disk system in CTTS. They interpret the hot spots as the zones where material is channelled from the disk to the star in magnetospheric flows mostly towards the pole. The observations by Johns-Krull & Hatzes (1997) also support the concept of magnetospheric accretion. The characteristics of the hot spots appear to change on time-scales of a few rotational periods or even less giving rise to rapid changes in the light variations that are noticed in CTTS. The light curve modelling of TW Hya indicates the occurrence of polar hot spot and hence support the magnetospheric accretion interpretation.

The rotational velocity V sin i estimated from the line broadening by Franchini et al. (1992) of TW Hya is around 15 km s^{-1}. Assuming that the stellar radius is 2R$\odot$, then from

$$R \sin i = \frac{Pv \sin i}{2\pi}$$

and the observed rotation period of 2.196 days, we get i = 20°, which is too small to explain the large amplitude light variability. A better estimate of V sin i is required.

4. Hα and Li I lines

Due to the low resolution employed in the observations, it is not possible to study the variations in the line profiles. However, the dispersion employed is sufficient enough to study the variation in emission strengths with respect to light variability. The values of Hα emission equivalent width (EEW) and Li I 6708 Å absorption equivalent (EW) are given in Table 5 along with the Julian days of observation and the corresponding photometric phase computed using the above mentioned ephemeris. It is found that the Hα EEW varied between 190 and 250 Å which is larger than that observed by Rucinski & Krautter (1983). The EW of Li I 6708 Å absorption line is found to be of the order of 0.6 Å, a value typical of CTTS ($\sim$ 0.50 Å). Fig. 5 displays the spectra in the region of Hα and Li I lines. The S/N of the spectra are of the order of 80 to 100. The corresponding photometric phases computed using the ephemeris given above are indicated against each spectrum. The spectrum of 1 April 1993 ($0\overset{\mathrm{P}}{.}46$) had the least H$\alpha$ EEW and also the least value of Li I EW, comparable to the values reported by Rucinski & Krautter (1983). However, any possible correlation between the strengths of these two lines could be established only with high resolution spectroscopy over a few rotational periods. The spectrum also indicates moderate emission in He I 6678 Å line. The Li I line did not show any significant day to day variations, except on 1 April 1993, indicating that no appreciable changes take place in the photospheric spectrum; however, the resolution employed in the present study is not sufficient enough to detect any small scale variations. Fig. 6 is a plot of Hα and Li I line EWs against phase. The V light curve obtained in the intervening period is also plotted in the same figure. The Hα EEW, though varies quite appreciably, does not show any correlation with photometric phase. Most of the known CTTS have Hα

Table 6. Equivalent widths of Hα emission and Li I absorption

JD 2440000+	Photometric phase	Hα (EEW) ±6 Å	Li I (EW) ±0.05 Å
9049.412	0.871	193	
9050.300	0.276	243	0.659
9051.302	0.732	212	0.636
9052.288	0.181	188	0.675
9079.250	0.458	143	0.340
9080.234	0.907	188	0.566
9081.321	0.402	209	0.580
9082.274	0.835	245	0.619

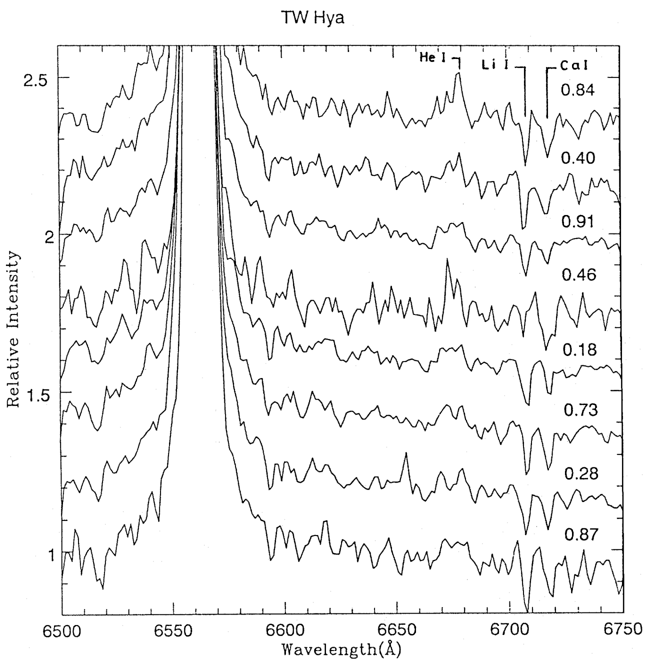

Fig. 5. Hα and Li of TW Hya

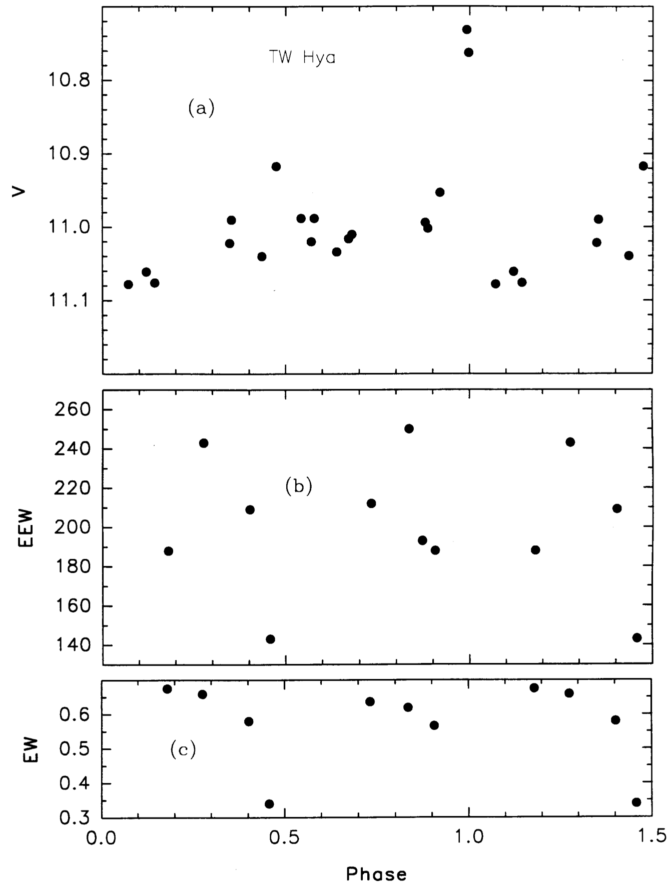

Fig. 6a–c. Plots of **a** V mag, **b** Hα emission equivalent width and **c** Li I absorption equivalent width

EEW less than 100 Å. So TW Hya shows unusually strong Hα compared to other CTTS. The mean observed R mag of TW Hya is 10.1 mag. Making use of the absolute flux calibration given by Bessel (1979) it is found that the mean flux in the Hα line is around 4.1×10^{-11} erg cm^{-2} s^{-1}.

From a spectroscopic and photometric study of CTTS, Vrba et al. (1993) found that the Hα emission strength does not show any correlation with photometric phase. They suggested that the variations in the Hα EW do not support the model of a single Hα emitting region associated with the hot spot indicated by the photometry. Johns & Basri (1995) found from their high resolution study of CTTS that most of the CTTS do not show any periodicity in the Hα profile variations. They concluded that the observed profile variations are stochastic in nature.

5. Polarimetric variability

Table 6 gives the results of the polarization measurements. Fig. 7 is a plot of linear polarization (P%) and position angle (θ°) obtained during 1990, 1991 and 1992 against the inverse of the effective wavelength of observation. The variations in both P% and θ° are quite evident from the figure. The linear polarization in B band observed on 24 March 1992 was around 3%. It is seen from the figure that the polarizations observed on all other occasions were less than or close to 1% in all wavelength bands, and did not show any appreciable wavelength dependence. The position angle also does not show any definite pattern in its variation, but there is an indication of the presence of two polarization components.

Fig. 8 shows the plots of the P% and θ° in V obtained during March 1993 and the V light curve obtained during the same period. On two consecutive nights P% was around 1%, significantly higher than that seen on other nights. TW Hya has a rotational period of 2.196 days, and hence the observations of these two nights are separated by around $0\overset{\mathrm{p}}{.}45$. If observations obtained on these two nights are excluded, then there is a slight indication of a modulation in the linear polarization with photometric phase. The values of P% are small (< 0.2%) on most of the occasions. Apparently, there is a slight phase lag between the light curve and polarization curve, with the polarization maximum preceding the light maximum. In Fig. 9 the values of P% and θ° are plotted against the Julian days of observation. It is clear from the figure that the polarization usually is less than 0.2%, and superposed on this sudden changes with an ampli-

Table 7. $UBVR$ polarimetry of TW Hya

JD 2440000+	Band	P%	$\theta°$
7914.472	V	0.27±0.13	154±15
7943.316	B	0.26±0.13	46±24
	V	0.67±0.14	7±5
	R	0.44±0.24	167±13
8297.324	U	1.03±0.40	77±11
	B	0.80±0.20	72±7
	V	0.92±0.15	86±5
	R	1.15±0.24	84±6
8297.412	U	0.78±0.40	99±14
	B	0.58±0.18	63±9
	V	0.31±0.10	101±9
	R	0.38±0.13	90±10
8297.474	V	0.16±0.10	83±18
8299.401	B	0.15 ±0.13	137±25
	V	0.26±0.11	165±12
	R	0.07±0.13	
8697.313	V	0.79±0.24	145±11
8706.274	B	3.14±0.54	176±5
	V	0.16±0.17	
	R	0.24±0.24	
8708.301	V	0.49±0.15	149±9
9059.312	B	1.350±0.28	144±6
	V	0.89±0.07	145±2
	R	0.61±0.03	45±6
9060.326	V	1.18±0.07	156±2
9061.306	V	0.30±0.08	19±7
9062.243	V	0.21±0.05	106±7
9063.292	V	0.25±0.07	76±9
9064.333	V	0.10±0.05	65±16
9065.363	V	0.26±0.02	172±6
9066.339	B	0.34±0.09	156±10
	V	0.21±0.07	145±8
	R	0.14±0.07	132±12
9067.318	V	0.12±0.06	111±13

tude around 0.8% occur at certain epochs, most likely, randomly distributed.

From simultaneous photometric and polarimetric observations, Gullbring & Gahm (1996) found that BM And exhibited anti-correlations between the brightness and linear polarization. They interpreted this as due to the presence of hot and dark spots on the stellar surface. Bastien et al. (**?**) also detected anti-correlation between photometric light variation and polarization in RY Lup. Different mechanisms, like the changes in the geometry of the scattering environment and variable illumination of the circumstellar material by the central star, have been proposed by Bastien (1988) to explain the observed polarization variability in T Tauri stars. It is of interest to note that TW Hya shows a trend of periodic variation in linear polarization. However, the amplitudes of periodic linear polarization and the corresponding light variation were quite low, possibly due to the low level of activity at that particular epoch. The sudden increase in polarization observed on two consecutive nights

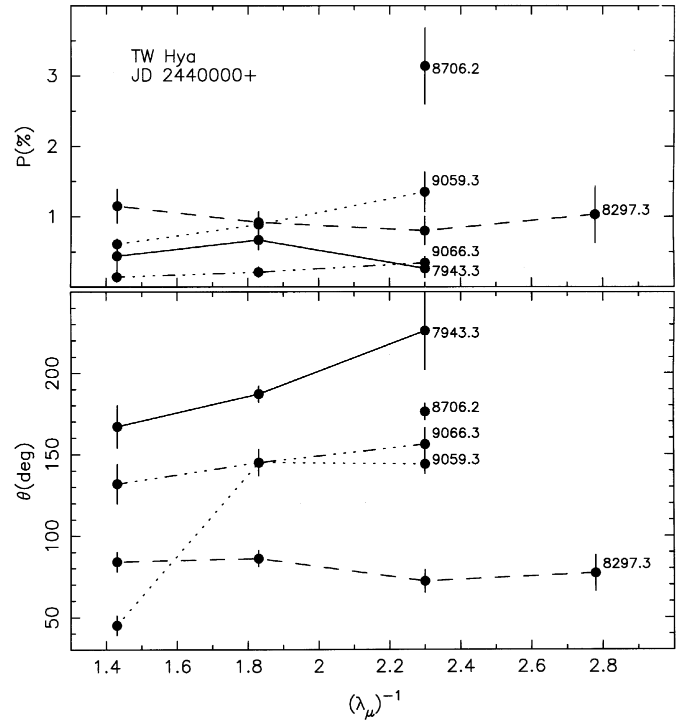

Fig. 7. Plots of linear polarization and position angle of TW Hya against the corresponding inverse of the effective wavelength of the filter band

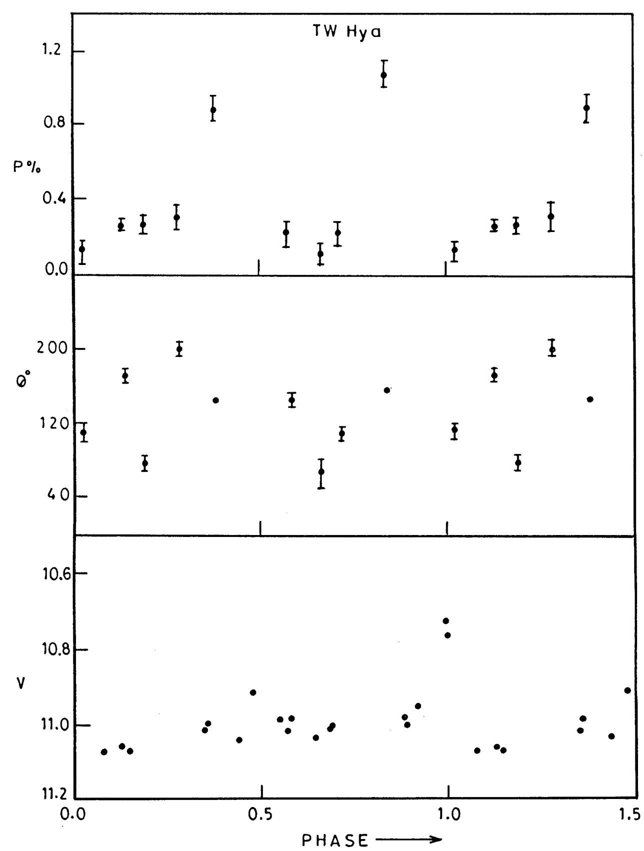

Fig. 8. Plots of linear polarization and position angle in V of TW Hya phased with the period. The lower panel is the overlapping photometry

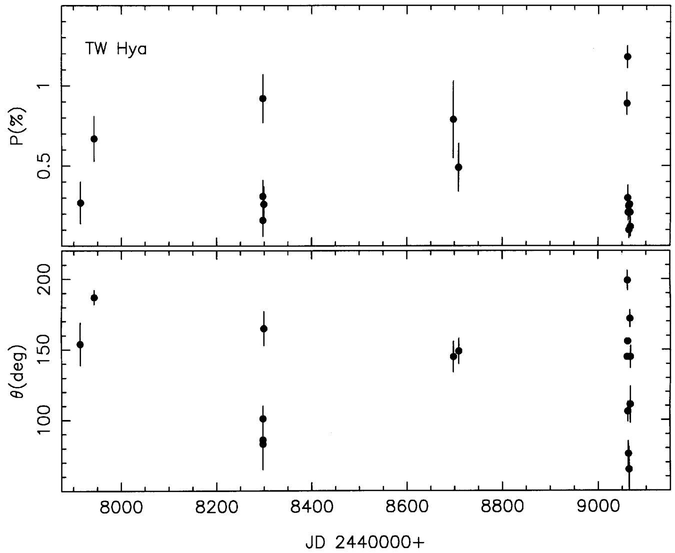

Fig. 9. Plots of the time-dependence of linear polarization and position angle in V of TW Hya

were probably caused by the presence of short-lived hot spots. Unfortunately no photometry was obtained on these two nights. However, the present photometry indicates the occurrence of short-lived spots.

6. Conclusions

Analysis of the photometry of TW Hya obtained over several seasons has shown that the star has a rotation period of 2.196 days. The sharp increase in the amplitudes of light curves towards decreasing wavelengths is attributed to the presence of highly active hot spots. The spot modelling of 1987.3 observations indicate the presence of a polar hot spot in agreement with the channelled magnetospheric accretion model. Apart from periodic variations, TW Hya was also found to show sudden increase in brightness of the order of 0.20 mag lasting a few days which might probably be due to the occurrence of short-lived hot spots. It was also noticed that the sudden brightening could occur at any photometric phase and thereby masking completely the periodic variations. The Hα EEW shows drastic changes but does not show any correlation with the light variation. The Li EW does not exhibit any appreciable variation and the value is typical of Classical T Tauri stars. From simultaneous photometric and polarimetric observations it appears that in TW Hya there is a modulation of polarization with the rotational phase with a slight phase lag between polarization and photometric light curves. The star also shows sudden increase in polarization that lasts for a few days, possibly caused by short-lived hot spots.

The Hα emission strength and light variations observed in TW Hya are typical of a Classical T Tauri star where the activity is presumed to be caused by the interaction between the accretion disc and the star. Sudden brightenings, which are supposed to be caused by short-lived hot spots lasting for one or two days, have been observed in TW Hya. Hence the large P% observed on two nights could be due to the illumination of the circumstellar dust grains by a hot spot which lasted for two days. Wood et al. (1996) made an investigation of the photopolarimetric variability of a magnetic accretion disk model for CTTS. Their model predicts a correlation between the brightness and linear polarization. The shape of the low amplitude periodic variation exhibited by TW Hya during March 1993 is similar to that derived by Wood et al.(1996).

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