LIGHT CURVE TYPES OF CLASSIC T TAURI STARS

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ABSTRACT. By using the archive photometric data's obtained for a long time intervals we have carried out a master light curves of 28 classical T Tauri type stars. For the physical character of variability mainly 5 type light curves can be separated. We have proposed a new scheme of classification among the examined light curves. The proposed scheme suggests a qualitative interpretation in terms of interaction of the central star with its circumstellar accretion disk.

Keywords: T Tauri stars, variability, master light curves, classification.

1. Introduction

T Tauri stars were first identified as an interesting pre-main sequence class of objects because of their unusual spectral and photometric properties (Joy, 1945, Herbig, 1962). Classical T Tauri stars are possess strong emission lines (hereafter CTTS) (stars with equivalent widths W(Hα)≥10Å) and are now recognized as pre-main sequence stars accreting material from an extended circumstellar disk. There are also T Tauri stars (hereafter TTS) with weak emission lines and circumstellar disk indicators (so-called "weak-line" TTS: WTTS) or without emission lines and disks (hereafter naked TTS: NTTS). Despite a large amount of observational material obtained for last 60 years, there remains unclear a physical causes of the light variations of TTS.

Researches of last year's show that there are only a rather limited number of plausible mechanisms by which a star could conceivable change its apparent brightness. At this time such mechanisms were proposed: 1) the rotation of the star with an asymmetrical distribution of cool spots, 2) variable hot spots on the stellar surface, 3) stellar flares and accretions, 4) grows and decay of large active regions on the photosphere and, 5) obscuration by circumstellar dust (e.g., Herbst et al.,1994).

The classification scheme for "Orion variables"— now called T Tauri stars — firstly suggested in 1954 by Parenago (1954) based on photographic observations is still relevant today. In this scheme, the most important factor is the shape of the light curve. Following Parenago's (1954) scheme Herbig (1962) classified the forms of light curves into four classes. Then Herbst et al.(1994) were divided TTS light curves into four types based on the color and spectral variations.

The relationship between Herbig's "class" and Herbst et al.'s "type" is not clear, but may reflect the different time scales of variability, i.e., longer for the "class" (10-100 days) and shorter for the "type" (0.5-30 days). Moreover, both proposed classification schemes make difficulties in separation of the different type of light curves. Our purposes in this report are consideration of the forms of CTTS light curves obtained on the more rich observational data.

2. Observational data and results

We used the photoelectric *UBVRI* observation results from the Wesleyan University database (ftp://sun.astro.wesleyan.edu) (Herbst et al.1994) and from archive Grankin et al. (2005) which is a collection of many-year observations by various authors. These data do not cover all available observations for individual objects, but the amount of material is sufficient to study the general characteristics of the T Tauri stars represented in the database. To avoid biases due to observational selection effects, we chose objects with as many data points as possible accumulated over decades. Moreover we included to this material for some stars results from ASAS database (www.astrouw.edu.pl/asas) for *V* and *I* bands.

We selected a total of 28 classical T Tauri stars with more than 300 observations as a minimum in various filters. The typical photoelectric photometry uncertainties are about $\pm 0.01^m$ in *B* and *V* and, as a rule, no more than $\pm 0.03^m$ in *U*. For the ASAS data average uncertainties is relatively large (at $\pm 0.05^m$), while we have not discovered some systematic differences with data's from other catalogues. We were not able to correct for systematic differences between the data of different authors, but most of the observations for individual stars appear uniform, indicating that such systematic differences are not significant. İn the Figure 1 demonstrated plotted master light curves of some CTTS.

After plotting the light curves for all 28 stars, we attempted to identify general tendencies and differences among these curves. Figure 2 displays an example of each of the light curve types we found among the T Tauri stars in our sample. The arrows in Figure 1b schematically explain our approach to estimating the amplitudes of brightness variations for (i) active states with high amplitudes (ΔV_1) and (ii) quiet states with low amplitudes (ΔV_2), at approximately the same brightness level. A list of selected objects, amplitudes ΔV_1 and ΔV_2, full amplitudes of color indexes Δ(U-B), Δ(B-V) and determined types on our classification scheme are presented in the Table 1.

Both existing photometric studies of T Tauri stars and our results show the following common features in the light curves. All the T Tauri stars display irregular brightness variations over several days during various observing seasons. The stars show both quiet and active states. In the quiet state, the daily brightness variations (we will use this term to refer to all brightness variations with time scales within 1–15 days) for individual stars can have amplitudes from 0.07^m to1.6^m (V866 Sco), but, in most cases, the *V* amplitude is within 1^m.

Rapid daily brightness variations are observed in both the active and quiet states. The amplitudes of the brightness variations in the active and quiet states, ΔV_1 and ΔV_2 (Fig. 1b), differ, with their ratio being almost constant, on average higher than two.

We determine the active and quiet states of a star as follows. As a rule, during a given time interval, a star displays brightness variations that can be described with two parameters: the mean brightness and the amplitude of the daily variations. Both parameters can differ considerably from season to season. To study these variations, we selected the extreme states of both parameters. Thus, we can characterize the states of the highest and lowest mean brightness. We call these extreme states of the amplitude of the daily variations the star's "active" and "quiet" states. The star's mean brightness in its active and quiet states can be different or virtually the same.

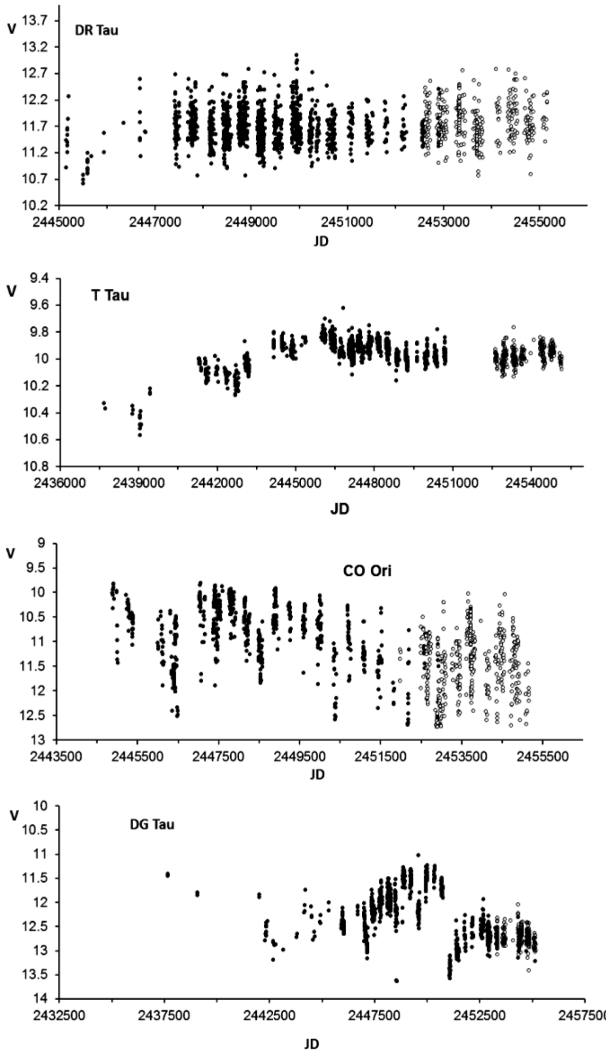

Figure 1: Examples of master light curves for some CTTS. Dark cycles-from catalogue Herbst et al.(1994), open cycles from ASAS database.

Our analysis shows that we can clearly distinguish five different types of light-curve shapes. We distinguish the following principal types based on light-curve shape:

type I: constant mean brightness without changes in the amplitude of the rapid brightness variability;

type II: constant mean brightness with changes in the amplitude of the rapid variability;

type III: varying mean brightness without changes in the amplitude of the rapid variability;

type IV: variations of both the mean brightness and the amplitude of the rapid variability;

type V: the variable is often bright, and rare brightness decreases (dimmings) are observed.

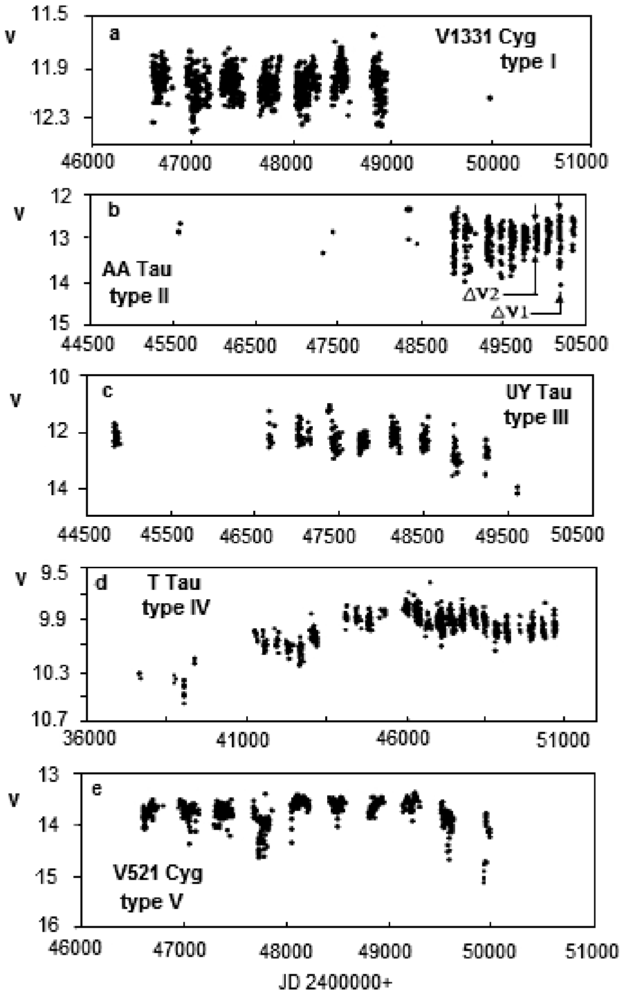

Figure 2: Selected typical examples of CTT light curves. The arrows in panel (b) explain our technique for estimating amplitudes during different brightness states of the stars.

Type I stars exhibit brightness variations whose amplitude is almost the same in different years, and whose mean brightness does not vary. Only two stars like this were found in our sample, DL Tau and V1331 Cyg (Fig. 1a). Despite the presence of some scatter about the mean level, the mean brightness itself does not vary. Such variability can be explained by brightness modulation of a cool spot on the surface due to axial rotation of the star. In this case, we must assume that the spots are very stable and that their relative area does not vary within a season or from season to season.

The mean brightness of the type II stars does not vary, but their rapid variations on time scales of several days are accompanied by gradual changes in their amplitude over several years. Typical representatives of this group are DR Tau and AA Tau (Fig. 1b). This type has the most members in our list (13 stars of 28). Such variations could be due to modulation of the star's brightness in the presence of a hot spot or to variable activity of the star itself, similar to cyclic solar activity, as well as to the appearance of additional radiation associated with non-stationary disk accretion. The light curves of this type suggest that such activity appears and then gradually disappears over five years.

Similar to the type I stars, the type III stars do not show variations in the amplitude of their rapid daily brightness variability; smooth changes of the mean brightness (trends) on time scales of several years are observed. A typical example is DN Tau (Fig. 1c). In our opinion, this type of variability requires the presence of a stellar companion whose brightness is comparable to that of the variable star and comparatively constant. Then, in principle, the brightness variations can be described fairly well using a cool spot model.

In addition to their rapid daily variations, the type IV stars exhibit simultaneous changes in their variability amplitude within a season, as well as long-term changes in their mean brightness over several years. Most ETT stars are of this type; typical representatives are T Tau and RY Tau. It is likely that, along with seasonal changes due to the star's chromospheric activity, eclipses by an invisible companion or a protoplanet also occur (Fig. 1d).

The type V stars are as a rule, in bright condition. There are sometimes rapid daily variations with amplitudes of up to 0.5^m, but abrupt dimmings with amplitudes exceeding $\sim1^m$ in V are also observed in some years. A typical representative is V521 Cyg. If objects such as this exhibit dimmings often and within short time intervals, then the star's light is probably blocked by circumstellar gas and dust (Fig. 1e).

Table 1. Observational data for the studied sample of T Tauri stars

Star	ΔV_1	ΔV_2	$\Delta(U-B)$	$\Delta(B-V)$	Sp	Type
BM And	2.35	1.04	0.79	0.38	K5V	IIII
RW Aur a	2.66	1.09	0.93	0.69	K1V	IV
SU Aur	1.1	0.17	0.51	0.38	G2III	III
UY Aur	3.18	0.82	1.06	1.61	K7V	II
GM Aur	0.74	0.3	1.36	0.49	K3V	IV
DI Cep	0.57	0.19	0.54	0.37	K1V	V
V521 Cyg	1.77	0.31	0.32	0.47	G8	II
V1082 Cyg	1.05	0.74	0.82	0.4		I
V1331 Cyg	0.73	0.42	0.58	0.12		III
V1121 Oph	0.74	0.45	0.68	0.51	K5	IV
CO Ori	2.68	0.45	0.72	0.37	F8	V
GW Ori	0.63	0.07	0.43	0.23	G5V	II
V866 Sco	3.56	1.6	0.42	0.58	K5V	IV
T Tau	1.1	0.18	0.79	0.26	K1V	IV
RY Tau	1.25	0.23	0.39	0.15	K1IV	V
UX Tau ab	2.13	0.93	0.78	0.51	K2V	II
AA Tau	1.77	0.66	1.5	1.04	K7V	II
BP Tau	1.31	0.19	0.78	1.25	K7V	II
CI Tau	1.51	0.41	1.12	0.49	K7V	II
DF Tau	1.95	0.23	1.8	1.22	M0	III
DG Tau	2.15	0.75	0.36	0.36	M?	VI
DK Tau	1.95	0.23	0.42	0.81	K7V	III
DL Tau	2.02	0.8	0.44	0.69	K7V	IIII
DN Tau	0.55	0.34	0.42	0.18	M0V	II
DR Tau	3.67	1.81	0.74	0.78	K5V	II
GG Tau	0.58	0.15	0.62	0.75	K7V	
GI Tau	2.95	1.39	2.18	1.29	K6V	
GK Tau	1.13	0.68	1.23	0.54	K7V	

3. **Conclusion**

Let us obtain a simple estimate of the accreted mass needed to provide a V-brightness variation of ΔV=0.5^m, as is typical of most CTT stars (Herbst et al. 1994)

Many photometric observations of T Tauri stars show brightness variations in the quiet phase of up to several tenths of a magnitude. Let the star have a mass and luminosity equal to the solar values (G2V spectrum). A brightness change $\Delta V = 0.5^m$ will then imply an increase of the radiated flux by a factor of 1.58, and the additional flux for such a brightness variation is $\Delta E=2.2\times10^{33}$ erg·s^{-1}. The characteristic fastest motions indicated by the observed emission lines of T Tauri stars (including those related to accretion onto the star) have velocities of about 300 km/s (e.g. Petrov et al., 1999). With such velocities for the accreting matter, the energy balance of the additional radiation flux requires a mass of up to $\Delta M = 4.7\times10^{22}$ kg, which is about a factor of 100 lower than the mass of the Earth and is comparable to the mass of the Moon. This demonstrates that the variability of stars having type I light curves (constant mean brightness and constant amplitude) can probably not be due to the accretion of matter from a circumstellar disk, because the rate of accretion onto a star cannot be constant. Type I brightness variations could be due to the presence of a cool spot and/or an active chromosphere

A simple calculation shows that a large mass, comparable to that of the solar system's planets, can fall onto the stellar surface during an outburst, apparently within a short time (days). Such large brightness variations are characteristic of type IV T Tauri stars. Various stars experience such substantial variations from once every several years to once every several decades. This shows that the interaction between the circumstellar disk and central star is active, and is accompanied by appreciable mass transfer through the circumstellar disk.

All this suggests that a typical, comparatively inactive T Tauri star should have a type I light curve. The other types of light curves can result from additional physical processes influencing the star, such as the accretion of matter from a circumstellar disk, eclipses by circumstellar matter, outbursts, effects associated with binarity, etc. This suggests that the main "stationary" object for all the light-curve types is the star itself, which probably has a magnetically active, spotted surface (e.g. Petrov et al., 1999).

Thus, the proposed classification scheme for T Tauri light curves is in reasonable consistency with current concepts concerning mechanisms for the variability of young stars. Note, however, that, bearing all these general features in mind, individual interpretation is needed for each particular observed T Tauri light curve.

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