THE VARIABILITY OF T TAU, RY TAU, AND RW AURIGAE FROM 1899 TO 1952

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ABSTRACT

We present the historical light curve of T Tau derived from photographic plates in the Harvard College Observatory archives. We find that the optical light of T Tau varied by 2–3 (or more) mag on timescales as short as a month prior to ~1917, consistent with the 1949 results of Lozinskii. Extreme light fluctuations of greater than 2 mag abruptly ceased in the late 1910s and, to the best of our knowledge, have not repeated since this time. We compare the observed light variations of T Tau with the T Tauri stars RY Tau and RW Aur, whose light curves we also constructed from inspection of the archival plates. We find that variable extinction along the line of sight to the star is the most likely explanation for the observed light fluctuation of T Tau during the early part of the 20th century.

Key words: stars: individual (T Tauri) — stars: pre-main-sequence

1. INTRODUCTION

Joy (1945) identified T Tauri stars as a distinct class of variable stars and Ambartsumian (1947, 1949) first suggested that they represent solar-like stars in the early stages of formation. They have since that time become understood as such and have been studied vigorously (e.g., Menard & Bertout 1999 and references therein).

The prototype and one of the brightest members of the class T Tauri was discovered in the mid 1800s to vary significantly in visual magnitude. However, T Tau is a complicated system and is not a typical member of the T Tauri class. Three optical nebulosities are associated with it. Hind’s variable nebula (NGC 1555) and a small nebulosity (NGC 1554) lie ~45° and ~4° to the west, respectively (Herbig 1950). The third, Burnham’s nebula, extends ~5° from the star at a P.A. = 152° (Burnham 1890). Multiwavelength observations reveal complex distributions of gas and dust associated with the remnant protostellar envelope, molecular outflows (van Langevelde et al. 1994; Momose et al. 1996; Schuster, Harris, & Russell 1997), arcs and filaments of material traced by molecular hydrogen (Herbst et al. 1996; Herbst, Robberto, & Beckwith 1997), and two Herbig-Haro jets (Böhm & Solf 1994; Solf & Böhm 1999).

T Tau is a young triple system; it consists of T Tau, a K0 star at a V magnitude of ~10 (Herbig & Bell 1988), and an infrared companion (IRC), 0.7° to the south (Dyck, Simon, & Zuckerman 1982), which is itself a binary with a projected separation of 0.05 (Koresko 2000). We monitored the near infrared flux of the system and found that the optically visible star does not vary significantly in magnitude in the K (2.2 μm) and L’ (3.8 μm) photometric bands (Beck et al. 2000; Beck 2001). The IRC binary does vary in near infrared flux on timescales as short as a week. However, the IRC has never been detected at wavelengths shortward of 1.2 μm to a limiting V-band magnitude of 19.6 (Stapelfeldt et al. 1998), and therefore does not contribute to the optical variability of the system.

Lozinskii (1949) compiled the historical light curve of T Tau from nearly 2000 observations spanning the interval 1858 to 1941. From 1858 to about 1915, T Tau dimmed and brightened randomly in visible light, between 10 and 14 mag in the visible. After 1915, T Tau appeared mostly bright at ~10 mag. Lozinskii’s light curve represents a smoothed 10 day average, and the sources of the individual measurements are unrefereenced. We were therefore interested to use the independent data of the photographic plates available in the Harvard College Observatory archives in order to determine the light curve of T Tau to confirm its large light variations at the beginning of the 20th century. Since the classical T Tauri stars RY Tau and RW Aur appear on the same plates as T Tau, we took advantage of the opportunity to measure their light curves as well.

2. DATA

We estimated the brightness of T Tau, RY Tau, and RW Aur by inspection of over 150 archival AC and AM series photographic plates of the Harvard College Observatory archive. These patrol plates were obtained using a telescope equipped with a 1.5 inch (3.8 cm) aperture Cooke lens and provided data with a plate scale of 600° mm⁻¹ spanning the time interval 1899 to 1952. We supplemented the T Tau data with more than 125 measurements from the plates in the RH and RB series, which were obtained using 3 inch (7.6 cm) aperture Ross lens at a scale of 390° mm⁻¹ and covered the period 1928 to 1952.

The spectral response of the photographic plates was essentially blue, so we estimated the magnitude of T Tau, RY Tau, and RW Aur by comparison with the B magnitudes of nearby stars. The estimated magnitudes of our targets are therefore B magnitudes in this relative sense. We first obtained the B-band magnitudes for three dozen stars within 1° of T Tau using the SIMBAD database and USNO catalog (Monet et al. 1996). By identifying these reference stars on plates spanning several decades we eliminated the obvious variables among them and determined the limiting sensitivities of the AC/AM and RH/RB plates to be 12–13.5

1 A translation of Lozinskii’s paper is available at http://www.ess.sunysb.edu/2001aj/beck01.html.
Fig. 1.—Light curve of T Tau derived by inspection of over 275 archival plates of the Harvard College Observatory.

Fig. 2.—Light curve of RY Tau derived by inspection of over 150 archival plates of the Harvard College Observatory.
mag and 14–15 mag, respectively. We estimated the magnitude of T Tau, RY Tau, and RW Aur with reference to 16 stars with $B$ magnitudes ranging from 9.6 to 13.8 in increments of 0.2 to 0.3 mag. The internal precision of the estimated magnitudes of the targets is about $\pm 0.3$ mag and is determined by the magnitude spacing of the calibrators and the accuracy of their individual $B$-band magnitudes. Figures 1–3 present the derived light curves for T Tau, RY Tau, and RW Aur. A table of the data used to generate these light curves is available on-line at the Web site referenced in §1. Inspection of Digitized Sky Survey images revealed that the target stars are the brightest objects within a 3′ radius, hence we attribute the observed light fluctuations solely to them.

3. RESULTS

The light curve presented in Figure 1 is similar to that determined by Lozinskii (1949) in that the magnitude of T Tau dimmed and brightened randomly in the early part of the 20th century from $B \sim 11$ to fainter than the detection limit on timescales as short as a month. To demonstrate the timescale of the observed light variations, Figure 4 presents 15 measurements of the magnitude of T Tau during 1902. From 1902 January 10 to February 10 T Tau brightened from 13 mag to $\sim 11$ mag, and six measurements in 1902 October–November show that it varied by $\sim 1$ mag on timescales of less than two weeks. A Lomb normalized periodogram analysis (Press et al. 1994) of the light curve between 1899 and 1917 shows no significant periodicity on timescales of less than $\sim 5$ yr. From the late 1910s to 1952, T Tau stabilized at a $B$ magnitude of $\sim 11$ and, aside from brief dimming events of 1.5 mag in 1925 and 0.8 mag in 1931, did not vary further at a statistically significant level. Additional data on the variability of T Tau, obtained from the on-line database of Herbst et al. (1994, hereafter H94) and the American Association of Variable Star Observers (AAVSO; J. Mattei, 2000, private communication), show that between 1937 and the present it has not varied by more than about $\pm 0.5$ mag from its average. Observations of the optical variability of T Tau taken during a single week reveal that it presently does not vary by more than $\sim 0.1$ $V$-band magnitudes on this timescale (Ismailov 1997). The “flickering” of 2–3 mag observed in T Tau in the early
years of 20th century was real and ceased abruptly in about 1917.

The light curve of RY Tau (Fig. 2) is characterized by two timescales. It varies by 2–3 mag over approximately a decade and by ~1 mag on timescales of less than a year. This type of variability has continued to the present (H94; Holtzman, Herbst, & Booth 1986; Petrov et al. 1999). RW Aur varied by 2–3 mag on timescales as short as a month throughout the 1899-1952 interval (Fig. 3). H94 report similar variability; apparently this behavior has continued for at least a century. Although the amplitudes and timescales of the light fluctuations of RW Aur and T Tau before 1917 are similar, we argue in § 4 that their variability is probably caused by different mechanisms.

4. DISCUSSION

Parenago (1954) described a classification which is useful to categorize the light curves of T Tauri stars as follows (see also Herbig 1962):

Class I. The star is more often bright than dim; its brightness is most frequently found in the brighter half of the observed magnitude range.

Class II. The fluctuations are generally close to the middle of the observed range in magnitude.

Class III. The star is more often dim than bright; its brightness is most frequently found in the fainter half of the observed magnitude range.

Class IV. The stellar brightness is observed at all levels of its magnitude range; it is not more likely to be found in a bright, faint, or average state.

Based on this scheme, T Tau was a class IV variable from 1899 to 1917, and a class I from 1917 to the present. RY Tau and RW Aur are class IV variables during the interval we have sampled, although breaking the RY Tau data into sections, as in Figure 2, suggests that its variability may be migrating from one class to another on decade-long timescales.

Parenago’s classification is useful because it draws attention to the fact that the character of T Tau’s variability changed significantly and abruptly. It does not, however, provide interpretation of the causes of the variability. In their study of the light and color variability of ~80 T Tauri stars, H94 argued that the variability of most T Tauris is produced by one, or a combination of three distinct mechanisms, as follows:

Type I. Rotational modulation by cool star spots. This type of variability is periodic.

Type II. Variable accretion rate or the rotation modulation of accretion hot spots. This type of variability can be periodic or random.

Type III. Random variations of light, which are likely produced by variable obscuration along the line of sight to the star (Herbst & Shevchenko 1999; Bertout 2000).

Photometric and spectroscopic monitoring studies show that the optical variability of RY Tau is likely caused by variable obscuration (Holtzman et al. 1986; Petrov et al. 1999), thus it is best described as a type III variable. H94 argued that T Tau is the only star in their sample that shows characteristics of all three variability mechanisms. Herbst et al. (1986) discovered rotational modulation of T Tau’s light with a period of 2.8 days. The amplitude of the rotational modulation is small, ~0.02 mag, so it seems very unlikely that this modulation could account for the 2–3 mag fluctuations in the early 1900s.

The results of Herbst, Holtzman, & Phelps (1982) and Basri & Bathala (1990) show that the light fluctuations of RW Aur correlate with Hz and veiling emission. The variability of RW Aur is therefore best classified as type II (H94). Although the amplitude and timescale of the light variations of T Tau in the early years of the 20th century are similar to those of RW Aur, it is improbable that variable accretion was responsible for T Tau’s variability. It is very difficult to imagine how the accretion rate, after varying significantly enough to produce light fluctuations of 2–3 mag, could stabilize in a high state with a sufficiently constant amplitude to produce light variations of less 0.5 mag around B ~ 11.

The most likely explanation for the observed variability of T Tau prior to 1917 is variable extinction along the line of sight to the star. T Tau is now observed by A, ~ 1 (Cohen & Kuhl 1979), but clumpy material with 2–3 mag of extinction moving through the line of sight to the star could explain the observed dimmings. The eventual clearing of this material would result in a more or less constant light output. Hogerheijde et al. (1997) and Akeson, Koerner, & Jensen (1998) detect a circumstellar disk around T Tau by its emission at mm wavelengths and conclude that it is observed nearly face-on. Variations in extinction toward T Tau are therefore not likely to be caused by material in its own disk, unless it is strongly warped.

Weintraub, Masson, & Zuckerman (1989) found evidence for Keplerian rotation in material surrounding T Tau, and Momose et al. (1996), Schuster et al. (1997), and Weintraub et al. (1999) detected complex distributions of material associated with the T Tau system. Two Herbig-Haro flows are associated with T Tau; HH 155 originates from the optically visible star, and HH 355 from the IRC (Böhm & Solf 1994; Herbst et al. 1997; Solf & Böhm 1999). Hence, it is conceivable that material associated with the envelope or outflows in the T Tau system could have caused the observed extinction variability of T Tau. The “flickering” and abrupt clearing of the obscuring material implies significant density inhomogeneities on spatial scales of a few stellar radii. It is reasonable to speculate that the possible variation in extinction presently observed toward the T Tau IRC (Beck, Prato, & Simon 2001) is caused by a similar distribution of material responsible for the optical variability of T Tau in the early 1900s.

In a region as complex as that of T Tau, it seems impossible to identify now the material that would have produced ~3 mag of extinction a century ago. A reasonable scenario for the variable obscuration must also explain the abrupt cessation and apparent nonrepeatability of the variability. It is worth noting that the components of the T Tau triple system were likely positioned differently a century ago. Raddier et al. (2000) and Ghez et al. (1995) monitored the orbital motion of the T Tau north-south system from 1989 to 1999 and found that the position angle of the IRC has changed by ~6° with respect to T Tau, but that it has not varied significantly in angular separation (<0:03). Hence, the period of the T Tau north-south system, at a 100 AU separation, is likely on the order of ~500-700 yr. The variability may have been the result of the different geometry of obscuring material associated with the disks or outflows of...
the system components. Like T Tau’s historic variability, we speculate that other puzzling aspects of T Tauri behavior, such as the discovery of the IRC to UY Aur when it was bright in the visible (Joy & van Biesbroeck 1944), may have extrinsic rather than intrinsic causes. A more complete understanding of the orbital motion and orientation of the disks and outflows of these systems will enable tests of this idea.

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