THE VARIABILITY OF T TAURI STARS

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For many years we have monitored the variability of some bright T Tauri stars with the 0.6 m "Perkin telescope" at Van Vleck Observatory. Collaborators in this endeavor have included several astronomers at the Crimea Astrophysical Observatory, at Capidomonte Observatory, at the U.S. Naval Observatory, and even some sophisticated amateurs.

As has long been known, the typical variation exhibited by T Tauri stars is irregular in nature. While several studies have shown periodic components (or even purely cyclic behavior) in the light variations of some T Tauri stars (especially the "weak" or "naked" T Tauri stars; e.g. Rydgren and Vrba, 1983; Herbst et al., 1986; Bouvier and Bertout, 1989), these remain the exceptions. Exhaustive studies of many stars fail to reveal distinctive periodicities (Herbst et al., 1987). Periods found at one epoch may also be different from those at other epochs, an example being TW Hya (Herbst and Koret, 1988). The periodic variations are attributed to spots - either cool or hot - on or close to the stellar surfaces. The cause of the irregular variations remains unknown. In this paper we discuss the best studied example of a spotted T Tauri star, V410 Tau, and then mention a newly discovered constraint on the mechanism for the irregular variation.

V410 Tau is a K3 star with weak Hα emission and little or no infrared or ultraviolet excess. It is a variable, non-thermal radio source and lies quite far from the main sequence in the HR diagram. Conventional pre-main sequence tracks imply that it is about a one million year old, one solar mass star. Its light variation was discovered by Mosidze (1968) and was believed to be irregular. Rydgren and Vrba (1983) showed, however, that it was purely cyclic in 1981, and Vrba, Herbst and Booth (1988; Paper I) and Herbst (1989; Paper II) have confirmed that this is so at all epochs. The period is 1.871 days, and is interpreted as the rotation period of the star. Color variations show that the spots on this star must be cool - about 1300 K cooler than the photosphere.

The amplitude and shape of the light curve (but not its period) has changed substantially over the years as

L. V. Mirzoyan et al. (eds.), Flare Stars in Star Clusters, Associations and the Solar Vicinity, 169–172.

shown in Papers I and II. At least two spots must be present to account for the double-peaked nature of the variation at some epochs. The spots must be enormous to explain the very large amplitude of variation (up to 0.55 mag in V). The inclination angle of the rotation axis to the line of sight must also be close to 90° to account for the large v sin i and the shape of the light curve. Finally, we can infer from the light curve that the spots must be centered at latitudes of 50° or more from the equator.

In Paper II detailed modeling of the spot variations has been carried out which substantiates the claims of the previous paragraph. The results of this modeling are summarized in Table 1.

Table 1. Results of Spot Modeling for V410 Tau (Paper II)

Rotation Period: 1.871 days
Photospheric Temperature: 4400 K
Spot Temperature: 3100 K
Unspotted apparent V mag.: 10.6
inclination angle: 75°-85°
Number of spots: at least two
spot latitudes: +55° to +75° and -50° to -65°
spot radii: 40° to 60°
Spot lifetimes: The principal spot has been present since at least 1983 and perhaps much longer

The observed changes in amplitude and shape of the light curve in V410 Tau can be understood as changes in the relative longitudes of the two spots. The two spots approached each other from 1983 until 1986 reaching a minimum separation of about 90° and are now receding. It is expected that the light curve amplitude will diminish for a couple of years and become double-peaked again as the spots move to opposite sides of the star. Continued observation of this very important star is highly desirable.

It has often been suggested that there is a connection between the periodic and aperiodic variation of T Tauri stars, the latter being attributed to spots which change their extent on time scales comparable to or shorter than a rotation period (e.g. Holtzman, Herbst and Booth, 1986; Bouvier and Bertout, 1989). In order to test the hypothesis that cool spots are responsible for the irregular variations R. Levreault and I undertook a program of Wing system photometry of six T Tauri stars. The bluest filters of this system are designed for study of the TiO feature which is expected to be enhanced in cool spot regions. We observed T Tau, RY Tau, CO Ori, RW Aur, SU Aur, and V410 Tau at Van Vleck Observatory during the 1988/89 Milky Way season. The results have been submitted for publication to the Astronomical Journal but a brief summary is given here.

The principal result is that we detected variation in the TiO feature in only one star - V410 Tau. This positive result is important because it confirms, both qualitatively and (to within the errors) quantitatively the general picture of spot induced periodic variations. In other words, it gives us direct evidence of the presence of cooler regions associated with the star V410 Tau and demonstrates that when there is an increase in the fraction of light coming from these cooler regions, the total light of the star is diminished. We also find that, for its color, V410 Tau is unusually enhanced in TiO absorption even near maximum light. This demonstrates that we do not see the spot-free star, even then. In principle this should eventually help us construct better spot models by providing a constraint on the apparent magnitude of the unspotted star.

The absence of any change in TiO strength even during large excursions in brightness is, at least in the case of RY Tau, rather strong evidence that its irregular variations are not caused by changes in the cool spot coverage. Furthermore, the fact that, for its color, it does not appear unusual in its TiO index, at any light level, suggests that it simply is not extensively covered with spots at any brightness level. It appears that we will have to search elsewhere for the cause of the irregular light variations in this and, presumably, other T Tauri stars. Hot spots are one possibility, generated either by solar flare-like phenomena or by accretion. Another, possibly related possibility is changes in contributions to the total light from disks and/or boundary layers.

It is a pleasure to acknowledge the assistance of the Perkin Fund and the NSF in supporting astronomy at Wesleyan University. I also thank the large number of undergraduates who have contributed to these studies over many years and my collaborators in the Soviet Union and elsewhere.

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PETROV: The large spots on V410 Tau could be seen by the Doppler imaging technique. Has anyone observed this star spectroscopically with high resolution?

HERBST: A few high resolution spectra exist, taken by Strom and by Basri. An attempt to use these for Doppler imaging is underway. It would be important to abtain more.

GAHM: V410 Tau is a very rapid rotator. Is it the record among T Tauri stars or are there stars spinning even faster?

HERBST: I believe there are stars with larger v sin i's, although this one is very fast.

https://doi.org/10.1017/S0074180900187662 Published online by Cambridge University Press