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DRASTIC CHANGES IN PHOTOMETRIC VARIABILITY OF V410 Tau

GRANKIN, K. N.; ARTEMENKO, S. A.

Crimean Astrophysical Observatory, 98409 Nauchny, Crimea, Ukraine
email: kgrankin@crao.crimea.ua, sartem@crao.crimea.ua

V410 Tau is a weak emission-line T Tauri star with a spectral type K4, lithium in absorption and a weak H_α emission (Herbig and Kameswara Rao, 1972; Cohen and Kuhi, 1979; Holtzman, Herbst, and Booth, 1986), it is also a source of highly variable, nonthermal, radio emission (Cohen, Bieging, and Schwartz, 1982; Becker and White, 1985), but exhibits no infrared excess (Rucinski, 1985). V410 Tau is a fast rotating star ($v \sin i \sim 70$ km/s; Hartmann et al., 1986) with a 1.872 day rotational period derived from its photometric variability (Rydgren and Vrba, 1983; Vrba et al., 1988; Bouvier and Bertout, 1989). The periodic light variations have an amplitude of 0.2-0.6 mag in the V-band, which is attributed to cold stellar spots that cover at least 29% of the stellar surface (Grankin, 1999). This young rapidly-rotating star thus exhibits intense surface magnetic activity, also witnessed by its large X-ray luminosity (3×10^{30} erg/s, Stelzer et al., 2003) and strong flares in the U-band (Fernandez et al., 2004). V410 Tau is indeed an ideal candidate for an in-depth study of magnetic activity in cool stars: it is relatively bright, well situated for observation from the northern hemisphere and has exhibited the largest amplitude of variability among all known spotted variables (including RS CVn and BY Dra stars).

The photometric variations of this star have been monitored for 20 years (1986-2006) at Maidanak Observatory (Uzbekistan) and continued at Crimean Astrophysical Observatory (CrAO) in Ukraine since 2007. Over nearly 18 years (1986-2004), V410 Tau has exhibited smooth periodic light variations resulting from cool spotted regions on its surface (see Grankin et al., 2008). Model calculations (Grankin, 1999) show that, (1) the spot temperature is lower than the photospheric temperature by at least 1450 K, and (2) spotted regions cover from 29% to 67% of the visible stellar hemisphere. Small variations in the mean brightness level and in the shape of the light curve over the period 1986-2004 suggest limited spot evolution over the years.

However, drastic changes started to occur in the light curve of V410 Tau from 2005 on. While the photometric variations were quite smooth, sinusoidal and repeatable over the time period 1986-2004 (see Fig. 3 in Grankin et al., 2008), the amplitude suddenly started to decrease quite significantly in 2005, reaching a minimum in 2007-2008. The optical V light curve based on photoelectric observations of 1981-2008 is shown in Figure 1. The statistical properties of long-term photometric behaviour of V410 Tau are presented in Table 1. Individual data are available upon request. It is visible from Figure 1 and Table 1 that the amplitude of variability has reached a record minimum in 2007/2008 ($0\overset{m}{.}08$-$0\overset{m}{.}06$) while the maximal amplitude was observed in 1998/1999 ($0\overset{m}{.}63$-$0\overset{m}{.}62$). The mean brightness level has been changed very little during this time interval.

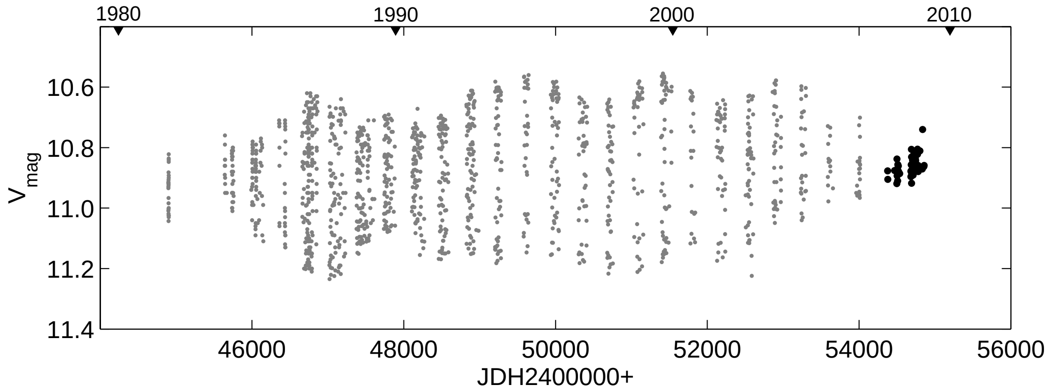

Figure 1. Optical V light curve of V410 Tau based on photoelectric observations of 1981-2008. Data are from Rydgren and Vrba (1983), Vrba, Herbst, and Booth (1988), Bouvier, Bertout, and Bouchet (1988), Herbst (1989), Grankin (1999), Grankin et al. (2008), and this paper. Observations corresponding of the minimal amplitude are indicated by the black filled circles, and other observations by the grey filled circles.

Table 1. The long-term photometric behaviour of V410 Tau. Columns are: Year - observation season, N_{obs} - number of observations, $\overline{V}$ - mean magnitude in V, σ_V - standard deviation in V, V_{max} - maximum brightness in V, ΔV - photometric amplitude in V, $\overline{U-B}$, $\overline{B-V}$, $\overline{V-R}$ - mean color index in $U-B$, $B-V$, and $V-R$ accordingly.

Year	N_{obs}	$\overline{V}$	σ_V	V_{max}	ΔV	$\overline{U-B}$	$\overline{B-V}$	$\overline{V-R}$
1981	26	10.939	0.066	10.822	0.221	0.935	1.221	1.054
1983	38	10.886	0.067	10.760	0.250	0.940	1.213	1.046
1984	59	10.895	0.086	10.770	0.320	0.918	1.211	1.041
1985	35	10.925	0.151	10.710	0.420	0.850	1.211	1.052
1986	150	10.897	0.176	10.620	0.590	0.917	1.193	1.047
1987	86	10.936	0.191	10.630	0.605	0.894	1.157	1.044
1988	104	10.934	0.135	10.690	0.461	0.929	1.165	1.039
1989	75	10.884	0.127	10.691	0.388	0.942	1.161	1.033
1990	78	10.886	0.121	10.672	0.483	0.927	1.152	1.043
1991	68	10.904	0.158	10.694	0.475	0.930	1.157	1.040
1992	77	10.853	0.169	10.612	0.540	0.912	1.151	1.036
1993	56	10.864	0.211	10.582	0.600	9.999	1.141	1.033
1994	32	10.796	0.199	10.519	0.628	0.915	1.140	1.016
1995	52	10.820	0.192	10.582	0.573	0.886	1.140	1.028
1996	42	10.872	0.180	10.634	0.548	0.917	1.147	1.039
1997	48	10.896	0.175	10.641	0.576	0.928	1.152	1.036
1998	37	10.816	0.223	10.581	0.630	9.999	1.148	1.017
1999	49	10.832	0.227	10.555	0.624	0.923	1.154	1.020
2000	21	10.830	0.191	10.613	0.504	0.884	1.149	1.025
2001	44	10.833	0.163	10.643	0.531	0.842	1.166	1.024
2002	49	10.872	0.158	10.628	0.596	0.960	1.166	1.066
2003	39	10.821	0.153	10.578	0.471	0.951	1.184	1.035
2004	27	10.823	0.144	10.597	0.443	0.971	1.180	1.049
2005	14	10.847	0.075	10.729	0.249	9.999	1.203	1.054
2006	20	10.879	0.079	10.701	0.265	9.999	1.206	1.058
2007	14	10.880	0.022	10.838	0.081	0.910	1.189	1.032
2008	42	10.852	0.031	10.805	0.055	0.922	1.172	1.046

These drastic changes in the amplitude of variability during 2005-2008 were accompanied by significant evolution of the shape of the phase light curve (see Figure 2). During the 2005/2006 and 2006/2007 seasons the phase light curve had a complex shape in the sense that two maxima and two minima were observed per cycle. Such shapes of the light curves can be a result of the existence of two extended spotted regions on opposite sides of the star. Similar light curves were observed during 1981-1985 (see Herbst, 1989). This $\sim$ 23yr evolution (from 1983 till 2006) possibly reflects a long term activity cycle similar to the 11-yr cycle occurring in the Sun. Recently some publications informs on the detection of shorter cycles of activity for this star within the range of 4-13 years (Stelzer et al., 2003; Sokoloff et al., 2008; Oláh et al., 2009). In any case, to check if V410 Tau indeed has a cycle with a quasi period of $\sim$ 23yr it is necessary to use photographic and photometric data from other observatories.

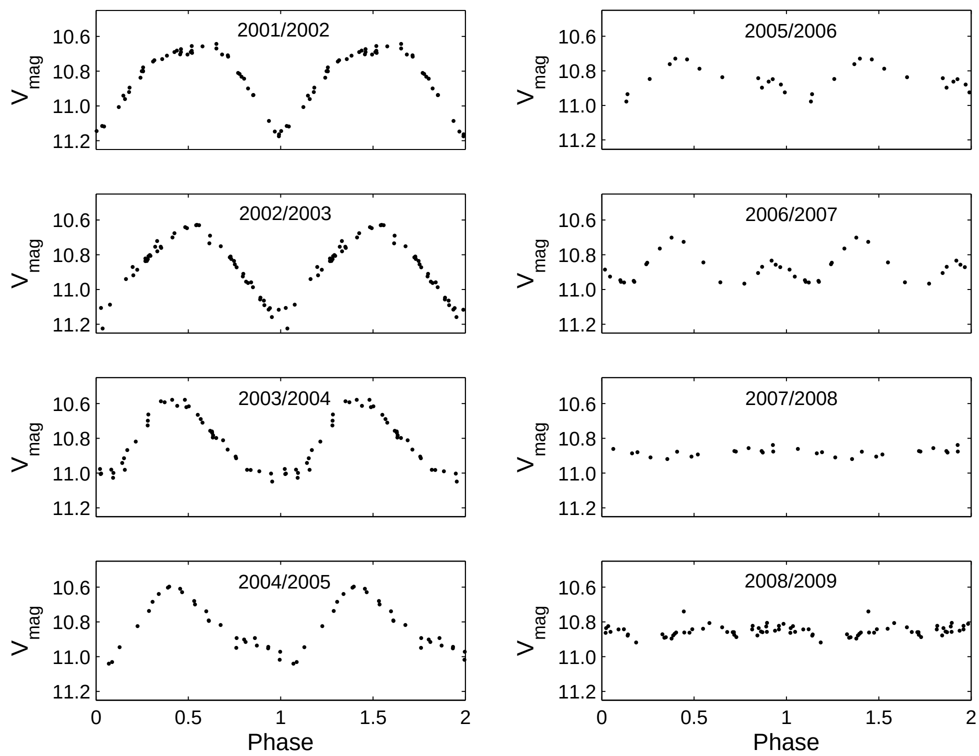

Figure 2. Phased light curves of V410 Tau for the last eight seasons, with JD (Hel.) min = 2452234.28597 + 1.87197 × E.

What happens to the spot configuration and to the underlying magnetic field distribution during the last 4 years (2005-2008) of perturbations should therefore give us hints on how dynamo processes are operating in young active stars, something on which very few constraints have been obtained so far. At least 2 possible interpretations can be put forward to explain the sudden decrease in amplitude of variability: either large monolithic spots have drifted exactly to the stellar poles, or many small spots are now nearly evenly distributed over the stellar surface. These two possible, nearly axisymmetric configurations would produce little modulation of the light curve, as observed in 2007-2008.

Preliminary simple modeling of the light curve of V410 Tau (cf. Grankin et al. 2008) showed that:

(i) The amplitude of the phased light curve depends on the degree of non-uniformity in the spot distribution more strongly than on the star's total spot area. An increase in amplitude was accompanied by an increase in the degree of non-uniformity in the spot distribution over the stellar surface from 4 to 37%.

(ii) The decrease in average magnitude is attributable to the increase in total spot area from 44 to 53% and that it is essentially independent of the degree of non-uniformity in the spot distribution over the surface (see Figure 3).

These two results shows, that the second interpretation is more likely, than the first one.

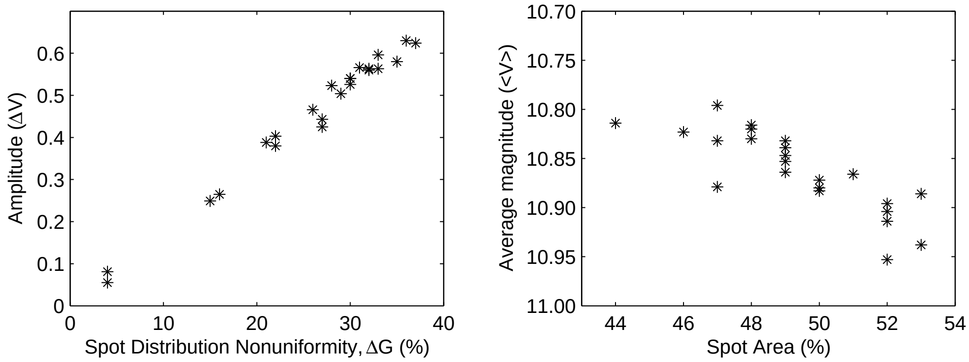

Figure 3. Plots of the amplitude of V410 Tau against the non-uniformity in the spot distribution (left) and the average level of brightness against the total spot area (right), see Grankin et al. (2008) Fig. 10. for comparison.

In order to decide between these alternatives, we need to obtain Doppler maps of the stellar surface, or even better, a Doppler-Zeeman map during several seasons. We will then be able to understand how the cool polar spots or equatorial regions develop and extend with time, how much toroidal and poloidal fields of the magnetic topology contains at each stage of the evolution process, and how much the surface of V410 Tau is sheared by differential rotation, a crucial ingredient for the dynamo process.

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