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The Emission Spectrum of T Tau in 1971–1979

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1 Introduction

The star T Tau is the prototype of pre-main sequence (PMS) low-mass T Tauri-type stars, which are at an early stage of evolution. Numerous spectral and photometric observations, carried out during many years, revealed strong variability of this unique star's emission spectrum and visual light (Joy 1945, Herbig 1977, Ismailov 1974, Zaitseva 1978, Zaitseva and Kolotilov 1977). Sometimes, the light curve shows quasi-periodic light variations with a period of $2\overset{d}{.}8$ (Zaitseva 1978, Herbst et al. 1987). Recently, a long-period wave in the star's brightness, with a nearly 6-year period, was detected (Ismailov and Samus 2003, Mel'nikov and Grankin 2005).

Studies of the recent 20 years demonstrate that T Tau is an exceptional member of the class, a triple system, with an infrared southern component (T Tau S) in $0\overset{''}{.}7$ from the northern component (T Tau N) (Dyck et al. 1982). T Tau S is itself a binary, with a projected separation of $0\overset{''}{.}07$ (Koresko 2000). Solf and Böhm (1999) found that both T Tau N and T Tau S possessed bipolar jets, the two jet systems directed perpendicularly. From spectroscopy, Tracy et al. (2001) revealed evidence for accretion of matter on T Tau S. The data from Loinard et al. (2003) demonstrate relative motions of the IR components of T Tau S. They show that the lower-mass component, T Tau Sb, is running away from the system.

During 1971–1988, Z.A. Ismailov carried out long-time homogenous low-resolution spectroscopy of T Tau at Shamakha Observatory. Some of the results based on these observations have already been published by different authors (Ismailov 1972, 1973, Guliev, 1991, 1994, Ismailov and Rustamov 1999). Below we briefly remind the basic results from this spectroscopy and from spectroscopic data by other authors.

Synchronous increase of line intensities of hydrogen Hβ, Hγ, Hδ and of H and K CaII emission lines, nearly threefold in 3 hours, was discovered (Ismailov 1974). During the star's transition from photometric quiescence to a more active state, variations of the Hα emission line profile from night to night, evidencing for mass loss from the star, were observed. The intensity of the Hα emission increased with increasing UV excess (Zaytseva 1978). 90–120 min and 18–20-day quasi-cyclic variations of equivalent widths and radial velocities of hydrogen lines and flare activity in the H, K CaII lines were revealed by Guliev (1991, 1994). The star's spectral type can be described as G8–K0V, its radial velocity is 20–22 km/s (Herbig 1977, Rustamov 1999).

In this paper, we present parameters of emission spectral lines determined from our complete spectroscopic material for 1971–1979.

2 Observations and Results

Our spectroscopic observations were carried out in the Cassegrain focus of the 2 m telescope of the Shamakha Observatory (National Academy of Sciences, Azerbaijan) using the 2×2 prism spectrograph with inverse dispersion 94 Å/mm at Hγ. The spectral range was $\lambda\lambda 3600 - 5100$ Å. The spectra were reduced using standard techniques (Guliev 1994, Ismailov and Rustamov 1999). We used microphotometer tracing with a magnification of 40 to measure equivalent widths of the strongest emission spectral lines: Hβ–Hε, H and K CaII, [SII] λ4068Å. Mean standard errors of the equivalent widths were within 15%, those of the radial velocities, within $\pm$15 km/s.

Table 1 presents all measurements of W_λ (in Å) and V_r (in km/s) for the program emission lines.

Table 1. The spectroscopic observations of HD 200775

Sp.	JD	Hβ		Hγ		Hδ	Hε+H$_8$	[SII]λ4068		H CaII		K CaII	
No.	2440000+	W_λ	V_r	W_λ	V_r	W_λ	W_λ	W_λ	V_r	W_λ	V_r	W_λ	V_r
1	989.143	3.9	–	–	–	–	–	0.6	–	1.8	–	2.2	–
2	989.158	4.3	–	–	–	–	–	0.6	–	2.7	–	2.6	–
3	989.171	2.6	20	–	–	–	–	0.9	–	2.9	–	2.2	–
4	989.187	6.2	144	–	–	–	–	0.3	–	2.4	–	2.6	–
5	989.201	2.4	97	–	–	–	–	0.4	–	1.5	–	1.5	–
6	989.237	2.1	–	–	–	–	–	0.4	–	1.5	–	1.2	–
7	989.251	4.6	–	–	–	–	–	1.1	–	1.3	–	1.3	–
8	989.274	3.8	–	–	–	–	–	0.9	–	0.5	–	0.9	–
9	990.521	1.2	–	–	–	–	–	–	–	1.2	–	1.4	–
10	990.535	2.4	–	–	–	–	–	–	–	1.1	–	1.3	–
11	990.551	4.2	–	–	–	–	–	–	–	1.9	–	1.5	–
12	990.565	3.5	–	–	–	–	–	–	–	1.6	–	1.6	–
13	995.221	2.3	–	–	–	–	–	–	–	1.5	–	1.8	–
14	995.551	2.0	–	–	–	–	–	–	–	1.9	–	1.5	–
15	998.512	2.2	–	–	–	–	–	–	–	1.6	–	1.5	–
16	998.531	3.4	–	–	–	–	–	–	–	1.1	–	1.1	–
17	998.550	4.9	–	–	–	–	–	–	–	1.5	–	1.3	–
18	1294.135	5.4	–	–	–	–	–	–	–	4.3	–	3.4	–
19	1294.159	4.9	–	–	–	–	–	–	–	5.0	–	2.6	–
20	1294.180	7.4	–	–	–	–	–	–	–	3.5	–	2.6	–
21	1294.202	3.9	–	–	–	–	–	–	–	2.2	–	1.6	–
22	1294.222	2.6	–	–	–	–	–	–	–	2.3	–	2.8	–
23	1294.246	6.2	–	–	–	–	–	–	–	2.4	–	2.2	–
24	1294.267	5.5	–	–	–	–	–	–	–	2.6	–	1.7	–
25	1294.291	4.8	–	–	–	–	–	–	–	1.8	–	1.7	–
26	1294.311	4.3	–	–	–	–	–	–	–	1.3	–	0.9	–
27	1294.334	4.8	–	–	–	–	–	–	–	1.9	–	1.5	–
28	1294.335	6.1	–	–	–	–	–	–	–	1.6	–	2.0	–
29	1374.550	5.4	22	–	–	–	–	–	–	2.6	–	2.5	–
30	1374.568	6.5	102	–	–	–	–	–	–	2.4	–	2.2	–
31	1374.588	7.3	90	–	–	–	–	–	–	2.2	–	1.7	–
32	1374.603	6.2	53	–	–	–	–	–	–	1.7	–	1.5	–
33	1374.617	5.6	54	–	–	–	–	–	–	2.2	–	2.1	–
34	1374.635	5.1	92	–	–	–	–	–	–	2.4	–	2.3	–
35	1374.656	5.3	76	–	–	–	–	–	–	2.6	–	2.4	–

Table 1 (continued)

Sp.	JD	Hβ		Hγ		Hδ	Hε+H$_8$	[SII]λ4068		H CaII		K CaII	
No.	2440000+	W_λ	V_r	W_λ	V_r	W_λ	W_λ	W_λ	V_r	W_λ	V_r	W_λ	V_r
36	1669.244	2.7	–	–	–	–	–	–	–	1.8	–	1.6	–
37	1669.268	3.0	–	–	–	–	–	–	–	1.4	–	1.2	–
38	2433.177	8.4	107	3.5	–20	1.1	–	–	–	6.7	67	4.8	57
39	2433.201	12.3	92	5.6	94	2.1	–	0.3	–	9.6	72	6.0	98
40	2433.222	10.1	168	3.3	140	3.0	–	1.0	–	13.4	80	13.9	109
41	2433.244	11.3	133	4.4	146	4.4	–	2.2	–	11.3	27	12.3	91
42	2433.264	7.5	100	3.7	128	4.6	–	0.9	–	9.7	16	10.1	70
43	2433.288	9.8	76	4.4	100	3.2	–	1.0	–	10.8	24	7.1	73
44	2433.309	6.9	141	1.6	28	1.5	–	–	–	5.7	30	4.9	73
45	2433.333	5.2	–	2.7	–	2.4	–	1.6	–	6.4	–	5.2	–
46	2433.353	7.9	–	2.1	–	1.2	–	0.8	–	3.2	–	4.2	–
47	2433.376	6.7	–	2.7	–	1.0	–	–	–	8.3	–	8.8	–
48	2433.397	8.1	–	2.5	–	–	–	–	–	6.1	–	6.8	–
49	2762.401	5.6	–	–	–	–	–	–	–	3.6	–	4.1	–
50	2762.412	5.3	–	–	–	–	–	–	–	3.6	–	3.5	–
51	2762.424	5.1	–	–	–	–	–	–	–	4.6	–	4.6	–
52	2762.435	4.6	–	–	–	–	–	–	–	3.4	–	4.1	–
53	2762.447	5.1	–	–	–	–	–	–	–	3.6	–	3.9	–
54	2762.458	4.7	–	–	–	–	–	–	–	3.6	–	3.2	–
55	2762.469	4.3	–	–	–	–	–	–	–	3.4	–	3.6	–
56	2762.480	3.3	–	–	–	–	–	–	–	4.4	–	4.6	–
57	2762.491	3.5	–	–	–	–	–	–	–	3.4	–	3.9	–
58	2762.502	4.1	–	–	–	–	–	–	–	3.2	–	3.4	–
59	2762.513	5.2	–	–	–	–	–	–	–	4.1	–	4.4	–
60	2762.524	5.5	–	–	–	–	–	–	–	4.4	–	4.6	–
61	2762.538	5.4	–	–	–	–	–	–	–	4.6	–	4.6	–
62	2762.548	5.8	–	–	–	–	–	–	–	4.1	–	4.5	–
63	2762.560	4.5	–	–	–	–	–	–	–	4.9	–	4.6	–
64	2772.309	16.8	71	8.2	99	4.5	2.3	2.6	65	11.3	80	13.6	86
65	2773.344	11.9	67	6.1	110	3.0	2.5	1.0	83	13.3	83	12.1	108
66	2773.367	13.0	113	5.0	96	4.0	1.6	1.5	96	8.1	64	8.7	97
67	2774.156	15.1	143	9.4	151	5.1	5.1	2.5	19	14.2	158	13.2	202
68	2774.180	13.4	99	6.3	144	4.9	3.9	1.2	27	12.0	178	12.6	126
69	2774.203	10.8	148	7.6	112	4.8	5.3	1.3	46	14.2	126	11.9	115
70	2774.227	12.9	100	8.9	82	4.7	4.8	2.7	41	19.0	110	17.3	123
71	2774.250	13.8	169	6.2	108	5.7	4.1	2.7	56	17.1	115	20.8	121
72	2774.271	10.6	101	6.9	145	6.1	3.2	1.8	71	15.4	114	16.0	98
73	2774.297	11.5	131	7.9	85	5.5	3.7	2.3	52	14.7	101	14.8	118
74	2774.320	11.9	–31	7.4	90	5.3	2.3	2.0	–21	14.9	68	13.9	69
75	2774.344	12.4	110	7.3	125	5.3	2.7	1.5	36	14.0	89	14.0	100
76	2774.367	9.8	25	6.5	65	3.9	3.3	1.2	30	12.1	96	12.5	113
77	2774.391	10.0	89	5.4	108	3.2	3.2	1.6	69	9.1	96	9.0	93
78	2774.414	9.7	53	4.9	68	4.1	0.9	2.2	23	7.6	94	8.2	94
79	2774.437	10.4	106	5.5	112	3.9	2.2	1.2	66	10.0	108	9.5	112
80	2796.192	7.8	60	3.0	79	1.0	–	1.3	–	6.4	58	8.7	69
81	2797.276	5.6	80	2.5	68	–	–	1.1	–	6.0	58	6.1	80
82	2800.142	4.7	46	2.2	37	–	–	1.3	–	4.3	49	5.1	79
83	3162.261	6.4	31	1.6	20	1.4	–	–	–	8.5	45	8.3	75
84	3162.303	5.5	63	1.1	–19	1.0	–	–	–	5.4	61	6.2	72
85	3164.271	5.0	–	1.0	–	0.6	–	–	–	5.0	–	4.8	–
86	3169.133	7.1	–5	1.3	44	1.0	–	–	–	3.0	26	2.8	37
87	3169.228	6.9	5	0.8	90	0.6	–	–	–	3.9	11	3.6	57
88	3169.272	4.2	75	0.7	60	0.5	–	–	–	2.7	11	2.8	93
89	3169.313	6.5	18	0.9	86	0.5	–	–	–	2.1	70	2.2	110
90	3170.181	6.7	–3	1.2	50	0.7	–	–	–	1.5	52	1.6	51

Table 1 (continued)

Sp.	JD	Hβ		Hγ		Hδ	Hε+H$_8$	[SII]λ4068		H CaII		K CaII	
No.	2440000+	W_λ	V_r	W_λ	V_r	W_λ	W_λ	W_λ	V_r	W_λ	V_r	W_λ	V_r
91	3170.330	6.7	–	1.5	–	1.1	0.8	–	–	4.6	–	4.9	–
92	3171.129	6.5	–	1.0	–	0.5	0.6	–	–	4.3	–	4.7	–
93	3171.171	6.7	–	2.9	–	1.0	0.7	–	–	8.4	59	7.8	59
94	3171.214	7.6	–	1.2	–	0.8	1.1	–	–	7.8	–	7.6	–
95	3171.259	6.5	–	3.7	–	0.6	0.7	–	–	6.4	73	6.0	90
96	3171.296	5.5	–	1.4	–	0.8	0.9	–	–	6.2	79	6.6	69
97	3171.324	5.6	–	0.8	–	0.5	0.6	–	–	6.1	72	6.2	83
98	3203.150	5.4	–	1.5	–	0.9	0.7	–	–	5.0	71	4.7	75
99	3203.185	7.5	97	1.8	37	1.2	1.0	–	–	7.8	59	7.7	71
100	3482.246	6.1	34	1.2	77	0.8	1.2	–	–	10.8	89	10.6	78
101	3482.283	11.6	11	3.2	14	1.2	0.9	–	–	7.8	22	7.6	46
102	3496.198	9.8	–236	2.3	–79	1.8	1.1	–	–	10.5	21	10.0	31
103	3496.235	9.4	–17	1.9	88	1.0	0.7	–	–	5.4	54	5.1	89
104	3496.269	10.7	–15	2.6	75	0.7	0.7	–	–	5.8	54	5.6	59
105	3497.236	5.7	–36	1.9	–	0.9	0.6	–	–	6.2	53	6.0	74
106	3498.208	3.0	–83	0.7	–	–	–	–	–	5.0	44	4.8	40
107	3503.194	2.8	–	0.6	–	–	–	–	–	4.8	–	4.4	–
108	3503.233	7.7	89	1.8	58	1.1	0.9	–	–	6.6	48	6.8	73
109	3503.269	6.6	–	1.6	–	0.9	0.9	–	–	3.8	–	4.2	–
110	3503.312	6.9	–	1.7	58	0.8	0.7	–	–	5.1	45	5.4	59
111	3503.312	6.0	–22	1.3	83	0.6	0.8	–	–	4.1	43	3.7	89
112	3503.341	5.7	–119	1.1	65	0.6	0.6	–	–	4.2	44	4.4	40
113	3503.397	4.9	–158	0.9	42	0.5	0.6	–	–	4.3	52	4.0	81
114	3504.172	8.2	–66	2.4	20	0.9	0.6	–	–	5.3	58	5.6	64
115	3504.200	9.4	–54	3.7	67	0.8	0.7	–	–	6.3	47	6.8	53
116	3504.231	8.0	54	2.6	82	1.2	1.0	–	–	4.3	40	4.5	65
117	3504.262	7.5	–117	2.4	62	0.5	0.8	–	–	4.6	53	4.8	82
118	3504.309	7.7	–	1.8	–	0.6	0.8	–	–	5.6	49	6.6	87
119	3504.339	10.8	22	3.0	–	0.8	0.6	–	–	5.0	52	5.4	81
120	3506.218	14.1	–	2.9	–	1.1	1.1	–	–	9.1	–	9.4	–
121	3506.255	16.1	–	3.7	–	1.4	1.2	–	–	9.7	–	10.8	–
122	3510.177	14.8	–	5.5	93	2.6	0.7	–	–	9.4	60	9.0	70
123	3510.219	13.8	–	4.8	119	2.3	1.1	–	–	8.4	56	8.1	62
124	3510.253	14.4	86	4.1	88	3.7	1.8	–	–	12.8	41	12.5	82
125	3510.271	15.5	63	5.1	70	2.8	2.6	–	–	13.9	38	12.9	80
126	3510.299	13.2	54	6.2	63	2.3	0.9	–	–	12.8	37	13.3	74
127	3510.335	20.3	120	4.3	69	2.2	0.8	–	–	12.1	38	12.2	78
128	3511.128	30.8	–3	14.0	57	6.3	0.9	–	–	13.0	40	12.5	82
129	3511.158	22.1	110	15.0	48	7.2	1.1	–	–	11.1	44	10.8	81
130	3511.186	24.4	42	17.0	86	6.0	0.4	–	–	10.7	41	9.8	90
131	3511.266	23.9	–	17.0	–	6.3	0.8	–	–	7.9	–	6.9	–
132	3511.297	19.2	30	13.0	53	5.3	0.5	–	–	6.7	47	5.8	57
133	3512.222	17.5	125	5.2	129	2.1	1.4	–	–	13.4	51	13.7	95
134	3512.251	14.2	116	4.8	78	1.7	1.2	–	–	12.8	84	13.2	78
135	3512.279	16.5	87	6.1	74	2.9	1.2	–	–	10.6	72	10.9	85
136	3512.314	15.3	100	5.7	93	3.2	1.5	–	–	12.4	90	12.8	92
137	3512.342	22.4	99	6.4	90	2.8	1.5	–	–	12.6	78	12.8	102
138	3512.371	17.9	–	6.8	–	3.2	1.3	–	–	17.7	–	18.0	–
139	3512.410	24.2	–	7.0	–	2.6	1.5	–	–	13.4	–	13.5	–
140	3521.283	8.1	–54	4.9	46	–	–	–	–	7.5	53	7.3	79
141	3521.314	9.6	–3	5.2	73	–	–	–	–	7.2	41	7.1	88
142	3521.345	7.8	71	4.9	26	2.5	0.9	–	–	6.8	46	6.6	70
143	3568.230	6.1	–	2.7	–	1.6	0.6	–	–	6.7	–	6.3	–
144	3568.254	9.5	–	4.5	–	2.4	0.8	–	–	6.1	–	6.1	–
145	3585.257	5.2	39	2.6	45	0.8	0.5	–	–	7.7	–	8.0	–

Table 1 (continued)

Sp.	JD	Hβ		Hγ		Hδ	Hε+H$_8$	[SII]λ4068		H CaII		K CaII	
No.	2440000+	W_λ	V_r	W_λ	V_r	W_λ	W_λ	W_λ	V_r	W_λ	V_r	W_λ	V_r
146	3585.301	7.5	46	1.7	52	0.7	0.4	–	–	3.5	–	3.7	–
147	3560.226	5.0	25	1.5	46	1.3	0.8	–	–	4.6	–	3.4	–
148	3560.324	6.8	49	2.1	29	1.5	0.9	–	–	3.2	–	4.2	–
149	3861.157	4.0	66	1.1	54	1.1	0.6	–	–	3.5	–	3.8	–
150	3861.181	3.3	67	1.3	62	0.7	0.7	–	–	2.2	–	2.0	–
151	3861.208	3.6	32	1.3	70	0.8	0.6	–	–	2.1	–	1.9	–
152	3861.234	4.0	68	0.9	18	0.7	0.7	–	–	2.5	–	2.2	–
153	3861.281	3.6	35	0.7	55	0.6	0.5	–	–	3.1	44	2.1	41
154	3861.321	2.8	33	0.7	63	0.6	0.6	–	–	2.2	–	2.5	–
155	3861.363	2.8	40	0.7	42	0.6	0.6	–	–	2.3	–	2.2	–
156	3861.403	1.5	51	0.6	39	0.5	0.5	–	–	2.6	–	2.4	–
157	3563.217	6.9	40	1.3	57	0.9	0.8	–	–	3.1	61	2.8	104
158	3563.238	2.4	63	0.9	67	0.6	0.6	–	–	1.3	–	1.2	–
159	3563.260	5.8	–	1.1	–	0.7	0.5	–	–	2.5	–	2.3	–
160	3866.380	8.9	15	2.6	13	1.8	0.8	–	–	5.9	–	6.1	–
161	3869.406	3.8	3	2.2	–	1.8	0.6	–	–	7.0	–	6.8	–
162	3869.428	2.8	–53	2.1	–	1.6	0.6	–	–	5.2	–	5.1	–
163	3887.281	6.9	96	3.0	92	2.1	0.5	–	–	4.2	–	4.0	–
164	3887.310	5.9	125	2.8	89	1.8	0.6	–	–	4.0	–	4.2	–
165	3901.187	16.4	–	3.7	–	2.1	0.7	–	–	8.2	79	8.4	55
166	3901.211	10.1	104	3.3	85	2.0	0.7	–	–	10.6	71	10.3	36
167	3901.236	11.1	42	2.2	108	1.7	0.6	–	–	11.9	33	11.5	57

To compare the star's brightness variations to our spectral parameters, we used V-band measurements from the Wesleyan University photometric database for young stars (Herbst et al., 1994). The results of this comparison are presented in Fig. 1. Its top panel shows equivalent widths (W_λ) of the Hβ and Hγ emissions versus time, the middle panel presents radial velocities of the Hγ emission, and the bottom panel displays the V-band light curve for the time interval of our spectroscopy.

It appears from the figure that the star's V-band brightness was increasing during the whole time interval and that this brightness rise occurred in two cycles, each approximately 6 years long (Ismailov and Samus 2003). The data from Mel'nikov and Grankin (2005) show the presence, besides the 6–9-year short cycles, also of a very long, 30–40-year grand cycle of light variations. In our opinion, the historical light curve shows that the combined time of the star's brightness increase and decrease is about 60 years, with small cyclic fluctuations some 6 years long. Currently, the flux from the star is decreasing. The earlier light increase was accompanied with a 6-year cycle, its amplitude being about $0\overset{\mathrm{m}}{.}2$, and the star was the brightest in 1983. The results of our spectroscopy demonstrate strong spectral emission during some cycles, especially when the star is bright. During fainter stages, the amplitude of variations of the star's spectral parameters decreases. It should be mentioned that the amplitude of the brightness variations with the 6-year cycle was $0\overset{\mathrm{m}}{.}2$ in the V band even during the bright state of the star. However, the variations of the emission-line equivalent widths followed the star's mean brightness and did not follow the 6-year cycle. Unfortunately, our spectroscopic data do not permit to verify the 2.8-day period revealed in photometry, better time and spectral resolution is needed. Nevertheless, our observations make it possible to claim that the star's spectral activity increased with its brightness.

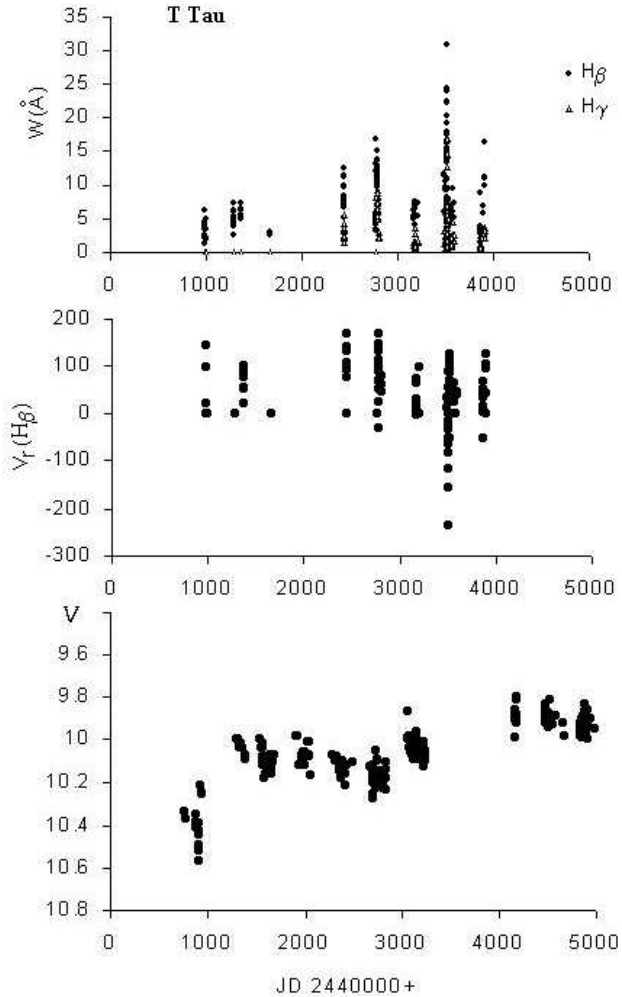

Figure 1. Variations of spectral parameters compared to brightness variations

3 Conclusions

According to the summary light curve (Mel'nikov and Grankin 2005), the star started to increase its V-band brightness from the average level of $10\overset{m}{.}6$ on JD 2438000, reached a maximum at $9\overset{m}{.}8$ on JD 2446000, and then began gradual fading, so that, on JD 2453000, it became as faint as $10\overset{m}{.}2$. Figure 1 shows that our observations mainly cover the time interval of increasing brightness, when the variation amplitude of the emission-line parameters also was gradually increasing. The brightness increase to maximum was $0\overset{m}{.}8$, so that the flux from the star increased approximately twofold, and the fall from maximum by $0\overset{m}{.}4$ is equivalent to the flux drop by a factor of 1.4. The hydrogen-emission equivalent widths varied by a factor of two during the faint state of the star and by a factor of five or more during the star's bright state. This evidences for the variability of emission lines and of brightness having the same source during the faint state. However, additional radiation in emission lines was observed during the active, bright phase. A possible additional source can be a hot spot on the star's surface resulting from disk accretion on the star's surface.

Summarizing we can make the following conclusions.

1. Variability of emission-line equivalent widths by a factor from 2 to 5, respectively during the star's faint and bright states, is observed. The spectral activity of the system differs at different stages of our observations, maybe it is of a long-cycle character.

2. Though the star's light varies with an approximately stable amplitude of $\sim 0\overset{\mathrm{m}}{.}2$ in the V band during each 6-year cycle, variations of the emission-spectrum activity occur independently of the brightness variations during such cycles. Increased activity of the emission spectrum with increasing average brightness of the star is observed.

3. The total flux variation does not coincide with the variation range for emission-line equivalent widths. This means the existence of an additional source of emission in spectral lines during the bright condition of the star. Such source can be a hot spot formed in the process of disk accretion.

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