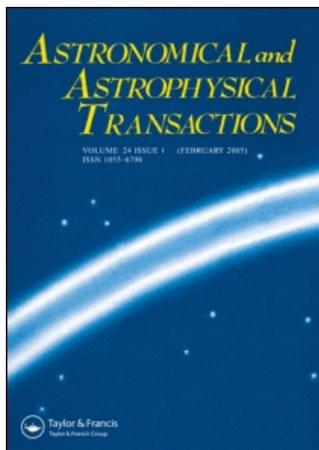


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THE $H\alpha$, $H\beta$, AND $H\delta$ LINES IN THE SPECTRUM OF RR TAURI

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The results of the spectroscopic study of the Ae Herbig star RR Tau are reported. The observations were carried out with a moderate resolution. In accordance with the presented data the $H\alpha$ line exhibits a double-peaked emission profile. The blue component is weaker than or equal to the red one. Variations of the $H\alpha$ equivalent width by a factor of 4–5 were found. The structure of this line also varies. On JD 2447148 a red absorption reversal of the $H\alpha$ profile was observed. The $H\beta$ spectral line exhibited both emission and absorption. On JD 2449664 the single-peak emission shifted to the short-wavelength range of the underlying absorption line and the red wing of the stellar line looked like a red-shifted absorption component of medium strength. The $H\delta$ line was in absorption.

KEY WORDS Young stars, Herbig Ae/Be stars, spectroscopic observations

1 INTRODUCTION

The term Herbig Ae/Be (HAEBE) stars owes its origin to the idea that it is possible to observe hot pre-main-sequence stars (Herbig, 1960). Calculations of early stellar evolution allow one to predict the properties of HAEBE stars in detail, to interpret (to a first approximation) environmental effects, and to outline an optimum programme of investigations (Strom *et al.*, 1972). The well-known peculiarity of the continuum activity is the “blueing effect” which is observed in the deep minima of those HAEBE stars which exhibit variations of a few magnitudes in the amplitude of the light (see Zajtseva, 1973; Kolotilov, 1977; Kardopolov and Filip'ev, 1985; Kilkenny *et al.*, 1985; Shaimieva and Shutiomova, 1985, for example). Recently simultaneous polarimetric and photometric measurements of some of these objects have been made, and an evident correlation between linear polarization and stellar brightness was discovered: namely, the polarized light contribution increases when the star fades (see, e.g., Grinin *et al.*, 1988; Kardopolov and Rspaev, 1989; Berdyugin *et al.*, 1990; Grinin *et al.*, 1991; Kardopolov *et al.*, 1991; Berdyugin *et al.*, 1992; Grinin *et al.*, 1994a,b).

Some of the peculiarities observed in the continuum of HAEBE stars were interpreted by Grinin (1988). In accordance with the specified model a star dips into the optically thin disk-like gaseous envelope. The opaque dust inhomogeneities move around the central body along elongated orbits. When the star is eclipsed by a dust cloud the observed brightness decreases and the polarization increases. In the deep minima, i.e. when the relative contribution of the scattered light of the gaseous envelope predominates, the colour indices decrease and the star becomes bluer.

The strong variability both of the profiles and the emission line intensities also takes place in the spectra of HAEBE stars (Strom *et al.*, 1972; Zajtseva and Kolotilov, 1973; Garrison and Anderson, 1977; Kolotilov, 1977, for example). More recently it was argued (Grinin and Tambovtseva, 1995) that the kinematic model of the gas-dust envelope explained certain details of the complicated transformations in emission lines. In general terms the following phenomena can occur. When the dust inhomogeneities move around the star the ratio of the emission line flux to the flux of the local continuum varies (owing to the variable screening of the star and the gas envelope) and the appearance of the profile must change as well.

It is necessary to remember, however, that the available observational information about the activity of these objects is still inadequate. Only a few representatives of the assumed HAEBE stars have been studied in detail. To rectify the existent deficit of information, to reveal a really homogeneous group (in the evolutionary sense) of the objects currently identified as HAEBE stars, and to determine their actual age, further investigations with different methods are required. For these reasons, spectroscopic investigations of RR Tau have been carried out.

2 OBSERVATIONS

The spectral observations of RR Tau were carried out from November 1987 to December 1994 using the slit spectrograph with a three-cascades image-tube (Denisyuk and Lipovetsky, 1974) attached to a 70 cm reflector (Almaty). The spectra were obtained in two spectral regions (3800–5100Å and 6200–7600Å) with the dispersion 20–70Å/mm and spectral resolution 1.7–5.8Å (depending on the dispersion). The spectra were registered on A600 and Kodak OaG films. The obtained spectrograms were measured with an automatic Microdensitometer and the data was then analysed using software developed by E. K. Denisyuk.

3 THE RESULTS

The dates of the observations, dispersion of the spectrograms, and the values of the equivalent widths W of the $H\alpha$, $H\beta$, and $H\delta$ lines are presented in Table 1. The errors (they were calculated when possible) characterize deviations from the average value of $W(\lambda)$. The error of a single determination of equivalent widths is about 15–20%.

Table 1. Some characteristics of spectrograms and equivalent widths of lines

244...	$D(\text{\AA}/mm)$	$W(\text{\AA})$	244...	$D(\text{\AA}/mm)$	$W(\text{\AA})$	244...	$D(\text{\AA}/mm)$	$W(\text{\AA})$
	H α		8924.4	39	40 ± 4	8278.2	62	-11
7126.4	49	64 ± 6	.4	39		.2	62	
.4	49		.4	39		8920.4	61	-8 ± 2
7147.2	54	31	8985.2	40	63 ± 3	.4	61	
7238.2	38	73	.2	40		9656.3	36	17
7444.5	42	73 ± 10	9250.4	32	52	9662.4	38	4
.5	42		9311.3	22	54	9664.4	38	3
7445.4	16	105 ± 1	9357.2	22	36 ± 2		H δ	
.4	16		.2	22		7447.4	67	-11
8271.2	64	52 ± 3	9359.2	22	34 ± 2	7448.4	68	-12 ± 1
.2	64		.2	22		.4	68	
8566.4	62	115	9365.2	22	63	.4	68	
8569.3	62	96 ± 11	9369.2	22	89	7473.3	62	-11 ± 1
.3	62		9656.3	31	150	.3	62	
.3	24		9662.4	32	81	.3	62	
8573.4	25	125	9664.3	32	86	.3	62	
8635.3	62	26 ± 6		H β		.4	62	
.3	62		7447.4	67	-5 ± 0.4	.4	62	
.3	62		.4	67		8278.2	62	-16 ± 1
.3	62		7448.4	68	-6 ± 0.1	.2	62	
8918.3	64	22 ± 4	.4	68		8920.4	61	-13 ± 1
.4	25		7473.4	62	-4	.4	61	

The behaviour of the H α , H β , and H δ lines in the spectrum of RR Tau is shown in Figures 1-3. We present only those H α profiles which were obtained with high resolution (about 1.5-2 \AA), apart from two spectra (panels 1,2 of Figure 1). These two spectrograms were obtained with a spectral resolution of about 3 \AA and they are shown here because of an interesting detail on the red side of the profile. All profiles in Figures 1-3 were corrected for the effects of limited instrumental contour (Bracewell, 1955). The intensity axes are scaled so that the continuum is about unity. The date of an observation and the exposure time are shown on each panel.

The Behaviour of the H α line

It is well known from the high resolution spectroscopic investigations of RR Tau that the H α emission line exhibits a double-peaked profile. The central absorption component reaches the local continuum level. A variation of the equivalent width $W(H\alpha)$ by a factor of approximately 2 has been reported (Garrison and Anderson, 1977; Finkenzeller and Mundt, 1984).

Our observations showed variations of $W(H\alpha)$ up to a factor of 4-5 (see Table 1). The changes in the H α profile are clearly seen in Figure 1. As a rule a double-peaked emission profile was observed, where the intensity of the blue component was less than or equal to that of the red component. Our results coincide with those of Zajtseva and Kolotilov (1973). The case when the V/R ratio is greater than unity (Garrison and Anderson, 1977; Finkenzeller and Mundt, 1984) was not seen during

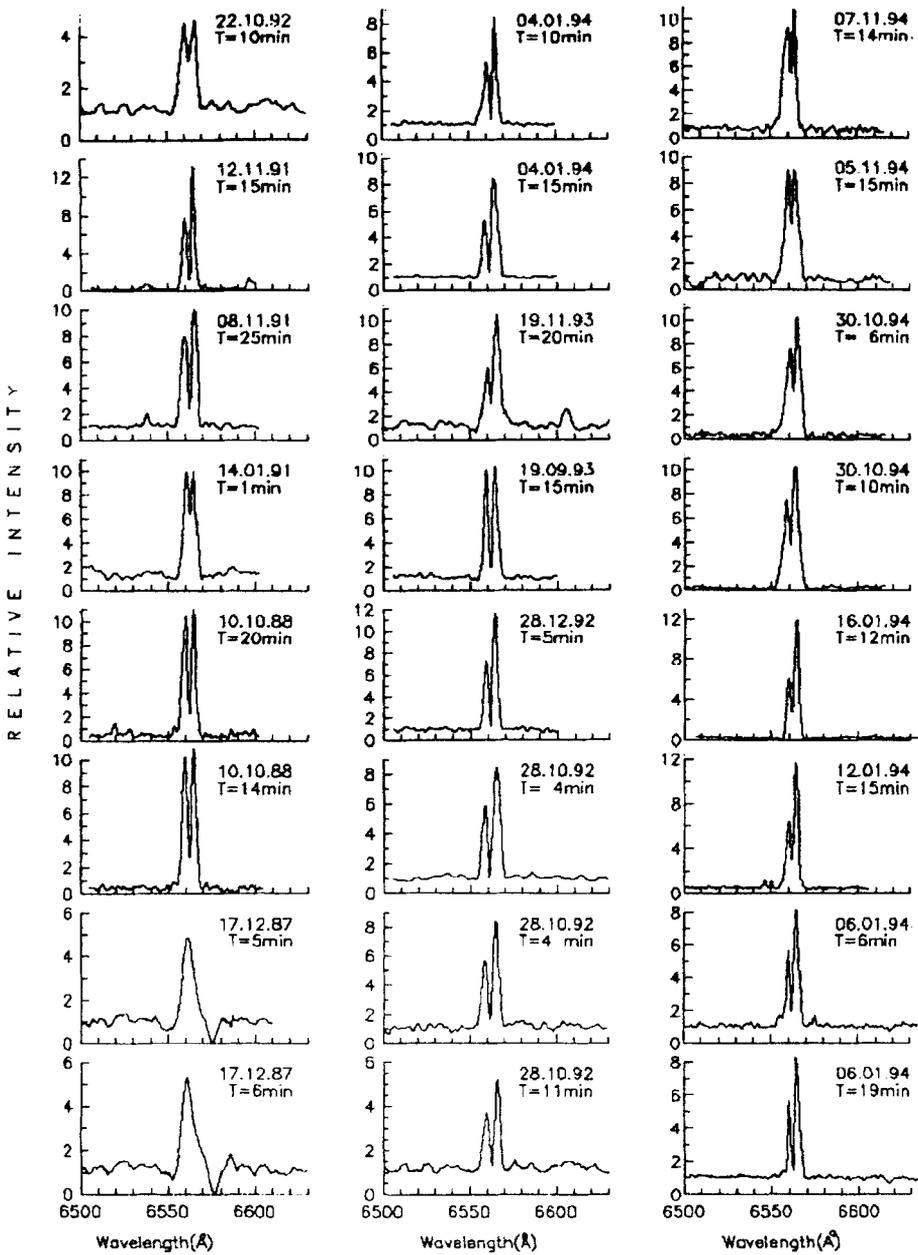


Figure 1 The variations of H α line profiles in the spectrum of RR Tau.

our observations. We can also add that the central absorption component of the H α profile reaches the local continuum level when the spectral resolution of the spectrograms is adequate.

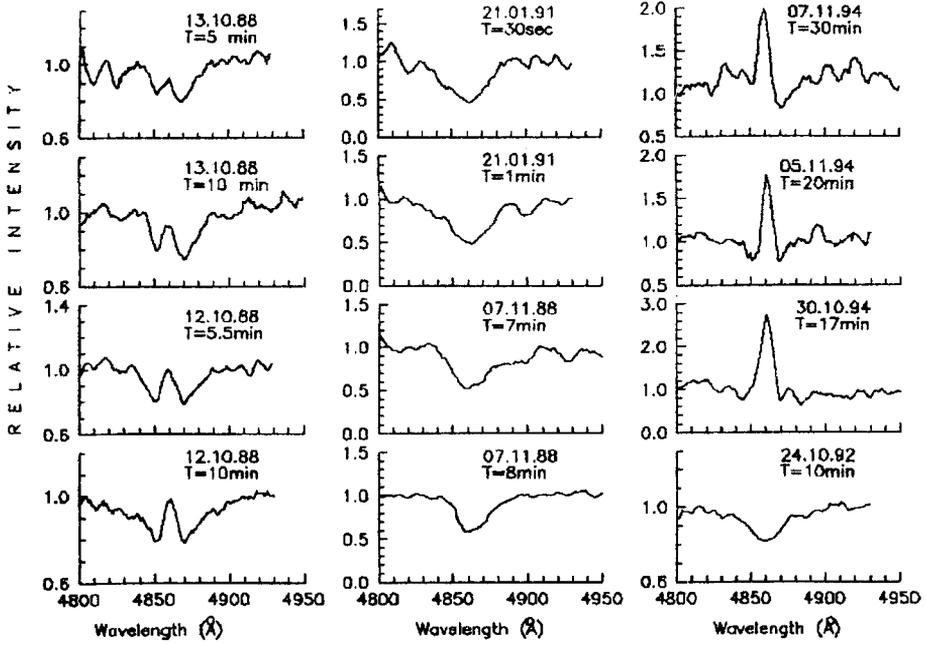


Figure 2 The behaviour of H β line profiles.

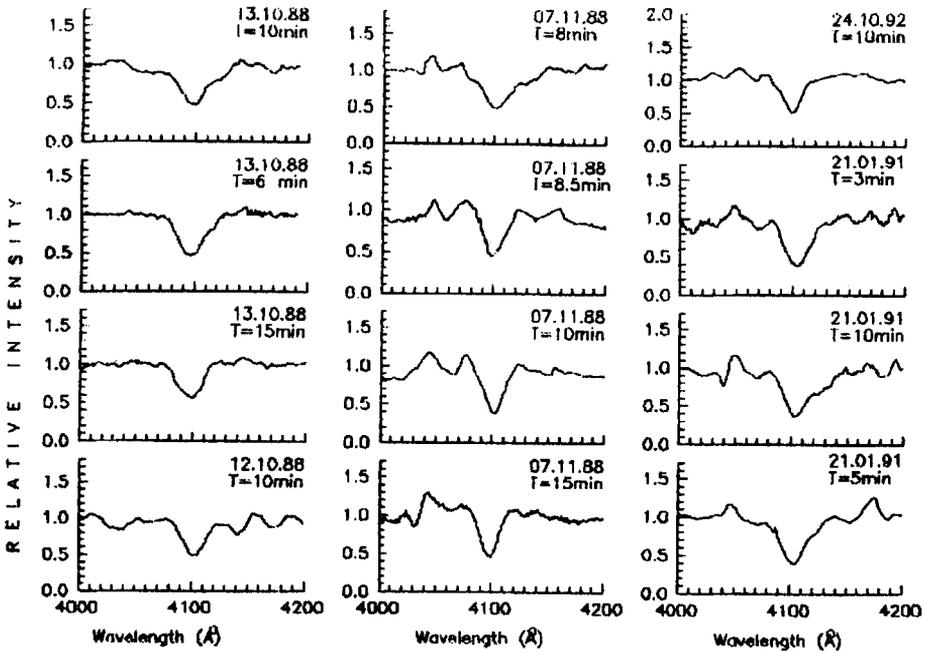


Figure 3 The appearance of the H δ line.

Red-shifted absorption details were exhibited in the $H\alpha$ profile on December 17, 1987. In spite of the rather low spectral resolution (about 3\AA) this peculiarity is clearly seen on both of the spectrograms that were obtained that night (Figure 1). Recall that a red-shifted absorption component of $H\alpha$ was also observed in the spectrum of the HAEBE star UX Ori (Zajiseva and Kolotilov, 1973; Kolotilov, 1977; Grinin *et al.*, 1994c). Kolotilov (1977) remarked that the form of the registered absorption detail coincided with that of the absorption line of the spectrum of a standard star, so it might be supposed that the red-shifted absorption, observed in the UX Ori spectrum, was merely the result of superposition of the $H\alpha$ emission (in part) and the stellar line. On the other hand, a sharper and more symmetrical red-shifted absorption was also registered at $H\alpha$ in the UX Ori spectrum. This peculiarity (an inverse P Cygni-like profile) occurs when the red emission peak disappears (Grinin *et al.*, 1994c). It is interesting that the signature of the inverse P Cygni profile has been seen in the $H\alpha$ emission line in the spectrum of the colder (MO:V) star IP Tau (Hartmann *et al.*, 1987). This star is the most likely representative of the T Tauri class of objects (Herbig and Bell, 1988). Consequently, the presence of the inverse P Cygni-like profile at $H\alpha$ is a common enough phenomenon for certain young objects.

Variability of the $H\beta$ Line

Strom *et al.* (1972) reported that the $H\beta$ line in the RR Tau spectrum exhibited weak emission. We registered perceptible activity in the $H\beta$ spectral line (Figure 2). At first we see a single emission peak which overlaps the stellar absorption line. Then, during some nights the only photospheric line was observed. The emission appeared anew on October 30, 1994, and one could see the remarkable transformation at $H\beta$ for some days: namely, the emission peak shifted to short wavelengths on November 7, 1994 and the red absorption detail strengthened. An analogous phenomenon has been discovered by Kolotilov (1977) in the spectrum of UX Ori. A weak $H\beta$ emission was discerned on some spectrograms of that HAEBE star, but the emission distorted only the blue wing of the stellar line; the red wing remained without any changes. It needs to be emphasized that the blue-shifted $H\beta$ emission in the spectrum of RR Tau on November 7, 1994 was stronger (Figure 2).

The $H\delta$ Line

Strom *et al.* (1972) reported that shell-like cores have been registered at the higher members of the Balmer series in RR Tau spectra. Our observations show rather symmetrical absorption at $H\delta$. Any emission does not leave a trace (Figure 3).

4 CONCLUSIONS

The RR Tau spectroscopic observations allowed us to follow up the behaviour of the $H\alpha$ and $H\beta$ lines in detail. The ratio of the intensity of the blue component

to that of the red one in the double-peaked $H\alpha$ profile varied from 0.6 up to 1.0. The value of $W(H\alpha)$ varies through a rather wide range. An inverse P Cygni-like profile occurred in the $H\alpha$ line during one night.

We observed wide stellar absorption in the $H\beta$ line. A peculiar emission sometimes appeared and overlapped the absorption line, but to trace the behaviour of both the $H\alpha$ and $H\beta$ profiles in more detail, further simultaneous observations of these two spectral regions are needed.

We have compared our results for RR Tau with the available observational information for UX Ori. UX Ori was investigated in detail with the spectroscopic technique, and one can see that the profiles of the $H\alpha$ and $H\beta$ lines in the spectra of RR Tau and UX Ori change as a whole in a similar manner. RR Tau and UX Ori are classified as HAEBE-type objects with large amplitude (a few magnitudes) of light variations. The behaviour of both the brightness and linear polarization are very similar for these stars. Hence, one can suppose that RR Tau and UX Ori are really similar in nature.

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