RADIAL VELOCITY AND PROFILE VARIATIONS OF THE ULTRAVIOLET CIRCUMSTELLAR LINES IN ζ TAURI*

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Abstract. The radial velocity and profile variations of UV lines of the shell star ζ Tau have been examined in the IUE spectra obtained in 1978–1982. The neutral atoms, and once or twice-ionized ions (except C II, Al III, Si III resonance lines) follow the same velocity variations as in the visual spectra, while the Si IV and C IV resonance lines show a constant negative velocity (~ -50 km s^{-1} at the core). The Al III, C II resonance lines and probably Fe III (mult. No. 34) are formed in both regions, i.e., in lowly-ionized and highly-ionized regions and the Si III resonance line is formed in a highly-ionized region.

1. Introduction

The shell star ζ Tau (HD 37202, B_2IIIp) is known as a single-line spectroscopic binary with a period of 132.91 days (Hynek and Struve, 1942; Underhill, 1952). In the visual spectra, this star shows a long-term cyclic velocity and V/R variation with periods of 7–4–7 years (Delplace and Chambon, 1976).

Hubert-Delplace *et al.* (1982, hereafter referred to as Paper I) reported that the radial velocities of low-ionization lines in the UV region follow the same velocity variations as in the visual region, while those of Si IV and C IV resonance lines are always negative. They ruled out a simple one-dimensional arrangement of two regions from the fact of the co-existence of positive and negative velocities, and they proposed a two-dimensional model for the circumstellar envelope of this star, which consists of highly-ionized spherical expanding region and a cool equatorial disk. As an extension of Paper I, we report here our further examination of IUE spectra, considering earlier IUE spectra and our new IUE observations of 1982.

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2. Observational Material

In Table I are presented the relevant data of high-dispersion IUE spectra analysed in this study. Spectra obtained in 1978, 1979 were collected through the World Data Center A for Rockets and Satellites. The spectra in September 1982 were obtained by one of us (R.H.) at the Goddard Space Flight Center. The image numbers with asterisk were analysed in Paper I, but are also analysed in this study for the consistency of measurement. In the visual region, the radial velocities of the circumstellar lines, referred to the star, were positive in 1978, and about zero at the end of 1979 (Paper I). The epoch of last IUE observation (September, 1982) corresponds to the second zero-velocity phase after the negative velocity phase, which was disclosed by our present analysis.

TABLE I

The IUE spectra used

SWP 2356*	LWR 2136*	1978.233.21.09	1978.233.22.09	210.58
SWP 2387		1978.236.12.58		210.60
SWP 2682		1978.261.14.42		210.79
SWP 3138	LWR 2707	1978.298.11.48	1978.298.11.51	211.07
SWP 3506*	LWR 3084*	1078.335.16.10	1978.335.16.15	211.35
	LWR 3085		1978.335.17.35	211.35
SWP 6930*	LWR 5888*	1979.293.15.30	1979.293.15.54	213.78
SWP 18114	LWR 14266	1982.269.09.52	1982.269.09.56	221.84
SWP 18115	LWR 14267	1982.269.10.49	1982.269.10.53	221.84

Column 1: Image number of SWP spectra ($\lambda\lambda$ 1150–2100 Å, resolution 0.15 Å). Column 2: Image number of LWR spectra ($\lambda\lambda$ 1850–3200 Å, resolution 0.20 Å). Column 3 (for SWP spectra) and column 4 (for LWR spectra): Epoch of observation in UT, year, day, hour, and min. Column 5: Phase of the 132.91 days cycle.

3. Radial Velocity Measurements

The line identification was made by using the table of Kelly and Palumbo (1973), Kelly (1979), and a table of expected shell line intensity which was generated with the curve-of-growth technique (see Hirata *et al.*, 1982). We selected all possible unblended lines and measured the radial velocities of the centroid of the absorption lines in the core part of the profiles. In the case of broad lines we took the mean value of central positions at several depth points in the line.

After correction for satellite and earth motion, we also corrected the instrumental systimatic shift in wavelength by using the interstellar lines, which were easily detected as a secondary absorption in the spectra obtained in 1978. The velocity of the instellar lines was assumed to be +20 km s^{-1} as in Paper I. We corrected also the stellar velocity (the center-of-mass velocity and binary motion) which was taken from Underhill (1952). Thus we reduced all measured values to those referred to the star. The accuracy of our measurement is about 10 km s^{-1} for narrow lines and about 30 km s^{-1} for broad lines.

4. Results and Discussion

Figure 1 shows the radial velocities of different ions in UV and visible regions, where the latter was taken from Paper I. The radial velocities of neutral atoms, once and twice ionized species (except C II, Al III, Si III resonance lines and Fe III mult. No. 34) vary in the same manner as in the visual region, while those of the resonance lines of highly-ionized species, such as Si IV and C IV are always negative and seem to be constant. Thus we can discriminate two regions, i.e., lowly-ionized and highly-ionized regions which are dynamically uncoupled with each other.

The radial velocities of Al III resonance lines are intermediate between those of lowly-ionized and highly-ionized species and follow the same variation pattern as of lowly-ionized species. From Figures 2a and 2b we see that the blue wing part of these lines did not change so greatly, while the red wing part displaced towards the longer wavelength in 1978 (positive velocity phase) compared to those in 1979 and 1982 (zero velocity phase). This variation cannot be attributed to the contamination by other shell lines and should be interpreted as a true variation of

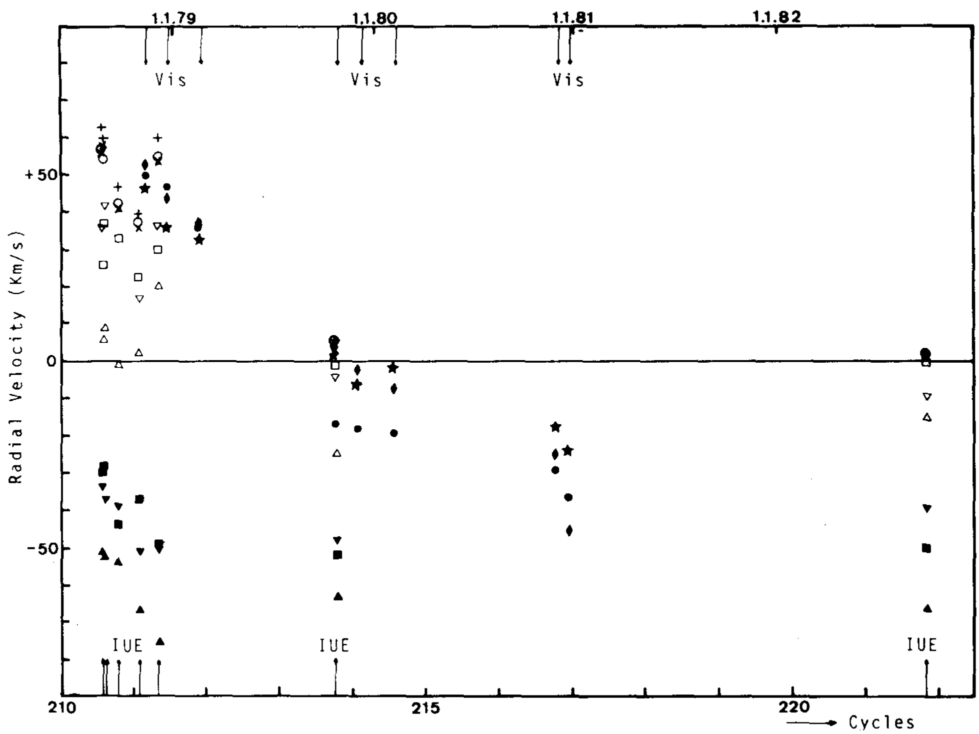

Fig. 1. Radial velocity (referred to the star) of UV and visible lines of ζ Tau in 1978–1982. Symbols have the following meanings, for UV lines, ▲; Si III, ▲; Si IV, ■; C IV, △; Al III resonance lines, □; C II resonance and non-resonance lines, ▽; Fe III (34), × ; neutral atoms, + ; once and ○ ; twice-ionized species (except Al III resonance lines. C II resonance and non-resonance lines and Fe III mult. No. 34). For visible lines (Paper I), ★; HγHδHε, ◆; $H_{19}H_{20}H_{21}$, and ●; Fe II.

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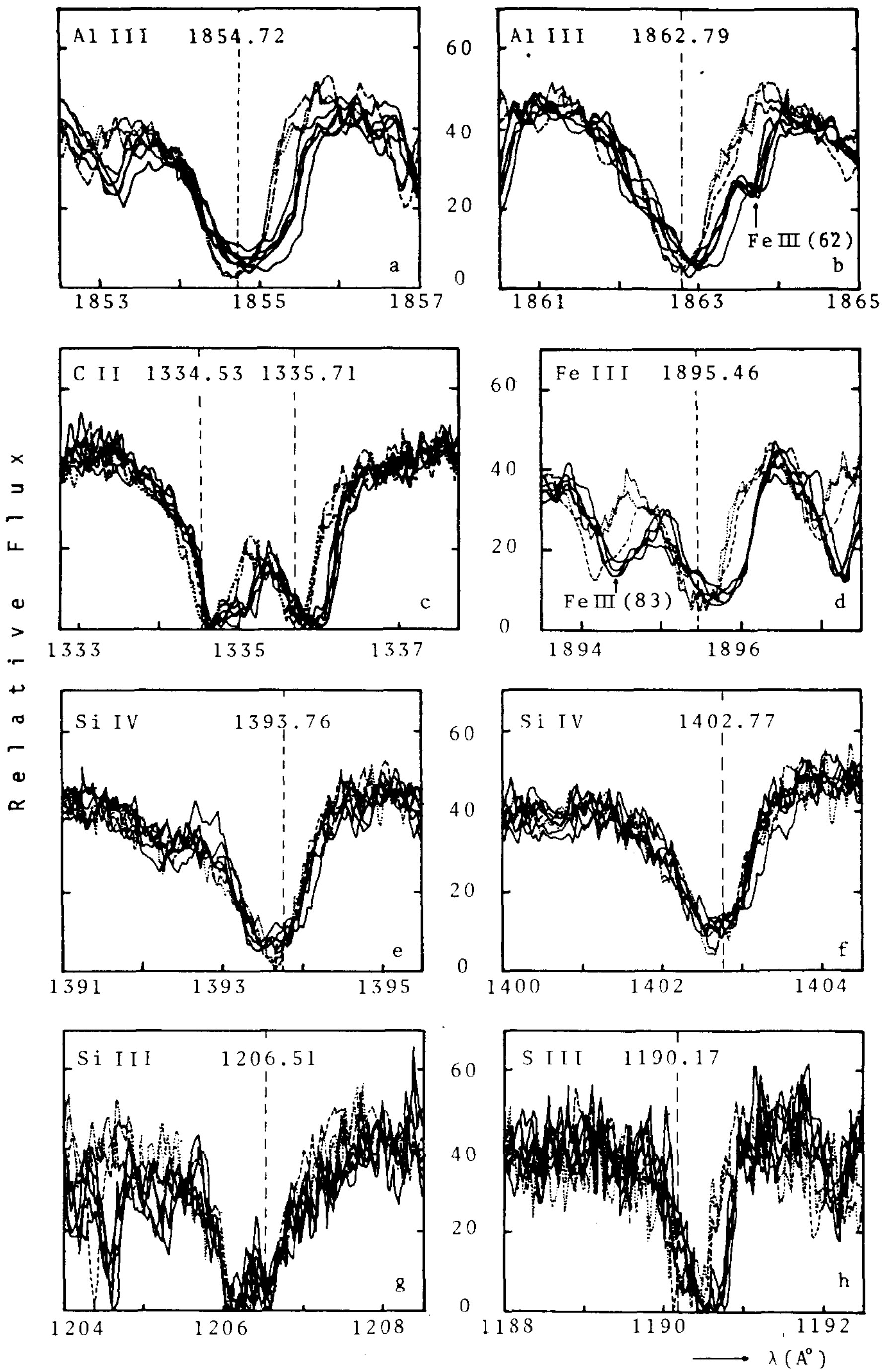

Fig. 2. Variation of line profiles of ζ Tau in 1978, 1979, and 1982. The solid lines represent the profiles observed in 1978, the dashed line in 1979 and the dotted lines in 1982.

the Al III resonance lines because, first, the same variation is seen in both resonance lines and, second, similar wing profiles are observed at two zero-velocity phases with strong shell lines (1979) and week shell lines (1982). From the characteristics of the profile variation of these lines mentioned above and from the fact that centroid velocities have just the mean value of those of lowly-ionized and highly-ionized species, we conclude that the Al III resonance lines are formed in both regions and that the contributions of both regions are approximately same.

The same profile variations are also found in the C II resonance and non-resonance lines ($\lambda\lambda$ 1334.53 and 1335.71 Å, see Figure 2c) and in Fe III mult. No. 34 ($\lambda\lambda$ 1895.46, 1914.06, and 1926.30 Å, Figure 2d is an example for $\lambda\lambda$ 1895.46 Å). Thus C II and probably Fe III (34) lines are formed also in both regions, but the contribution from the lowly-ionized region is greater than from highly-ionized region, because we see in Figure 1 that their radial velocities are intermediate between those of lowly-ionized species and Al III resonance lines, and blue wing part is displaced in the same sense as the red wing part, but with less extent.

The Si IV resonance lines are always strong, blue-shifted and blue-winged, indicating an expansion (Figures 2e and 2f). Both resonance lines have quite similar profiles. The core became narrower and deeper in 1982 than in 1978 and 1979.

The radial velocity of Si III resonance line has a constant negative value which is smaller than those of Si IV and C IV resonance lines. But the velocity difference between Si III and Si IV lies in the range of uncertainty of measurement. The profile of Si III resonance line did not change so greatly in 1978–1982 (Figure 2g). Therefore, we interpret that Si III resonance line is formed in the highly-ionized region.

The S III resonance line has the same veloctiy as those of low-ionization. From Figure 2f we can see that the blue and red wing parts of the profile are displaced towards longer wavelengths in 1978, in comparison with those in 1979 and 1982, with the same degree. From this fact we conclude that the S III resonance line is formed in the region of low ionization.

5. Conclusions

From the results given above, we can distinguish three groups of the circumstellar lines in the envelope of ζ Tau, first, the lines which are formed in the region of low ionization (cool equatorial disk), such as N I, O I, Ni II, Si II, Fe II, Al II, Ni III, Cr III, Si III, Fe III, etc., second, formed in the highly-ionized region such as Si III, Si IV, and C IV resonance lines, and third, formed in both regions such as Al III, C II resonance lines and probably Fe III mult. No. 34. The situation will become much clearer if we can observe this star at the negative velocity phase. It is highly probable that the other resonance lines of doubly-ionized species such as Fe III, C III, and N III are also formed in both regions, though the IUE spectrum does not cover those lines.

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References

Delplace, A. M. and Chambon, M. Th.: 1976, in A. Slettebak (ed.), 'Be and Shell Stars', *IAU Symp.* **70,** 79.

Hirata, R., Katahira, J., and Jugaku, J.: 1982, in M. Jaschek and H. G. Groth (eds.), 'Be Stars', *IAU Symp.* **98,** 161.

Hubert-Delplace, A. M., Mon, M., Ungerer, V., Hirata, R., Paterson-Beeckmans, F., Hubert, H., and Baade, D.: 1982, *Astron. Astrophys.* **121,** 174.

Hynek, J. A. and Struve, O.: 1942, *Astrophys. J.* **96,** 425.

Kelly, R. L.: 1979, NASA TM 80268, Goddard Space Flight Center, Greenbelt, Maryland.

Kelly, R. L. and Palumbo, L. J.: 1973, NRL Report 7599, Washington, Naval Research Laboratory.

Underhill, A.B.: 1952, *Publ. Dominion Astrophys. Obs.* **9,** 138.