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UV spectra of T Tauri stars from Hubble Space Telescope: RW Aur*

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Abstract. Ultraviolet spectra of the classical T Tauri star RW Aur A observed with the Hubble Space Telescope were analysed. Absorption lines of neutral and singly ionized metals, blueshifted $\sim 50\,\mathrm{km\,s^{-1}}$ relative to the star, were found. They originate in a dense $(\mathrm{N} > 10^{10}\,\mathrm{cm^{-3}})$ gas outflow, whose extension along the line of sight is less than $3\mathrm{R}_*$. The gas temperature of the wind is definitely below 10 000 K, but metals (and probably sulfur) are almost completely singly ionized by strong stellar emission in the hydrogen lines of the Lyman series. Stellar Ly_α quanta are responsible for a significant population of hydrogen upper levels. Their photoionization is the main source of free electrons and subsequent gas heating. Strong fluorescent lines of H_2 and Fe II pumped by stellar Ly_α quanta were found in the RW Aur spectra.

The emission in C IV and Si IV lines is strongly suppressed by Fe II and Ni II wind absorption features. Superposition of strong H_2 emission lines onto residual profiles additionally disturbs the picture, so C IV and Si IV line fluxes derived from low resolution IUE spectra are erroneous.

Key words: stars: pre-main sequence – stars: individual: RW Aur – ultraviolet: stars – X-rays: stars

1. Introduction

RW Aur is a classical T Tauri star (CTTS) with $\mathrm{W}_{H\alpha}$ = $50-130$ Å (Fernandez et al. 1995). The optical spectrum of the star contains numerous emission and absorption lines with a complex structure. Relative intensities and profiles vary with time (Gahm 1970; Appenzeller & Wolf 1982; Hartmann 1982; Mundt & Giampapa 1982; Grinin et al. 1985). It was recognized that the lines form in regions with different physical conditions and velocity fields: a clear evidence of mass outflow and inflow was found. The physical parameters and geometry of the stellar wind and accretion flow was still unknown.

Ultraviolet (UV) spectra can help to solve the problem. RW Aur was observed with the IUE satellite and it was found that its UV spectrum roughly resembles the solar chromosphere one, with fluxes about 200 times greater (Imhoff & Giampapa 1980). The fluxes of different lines varied in different way and some lines were transformed from emission to absorption with the increasing of RW Aur visual brightness (Imhoff & Giampapa 1983). The aim of our paper is to analyze UV spectra of the star obtained by Hubble Space Telescope (HST). An important fraction of the paper is devoted to line identification.

RW Aur is a triple star system with the brightest component, RW Aur A, separated by $1\farcs4$ from the close binary, RW Aur B-C, of separation $0\farcs12$ (Ghez et al. 1993). During HST observations RW Aur A was almost always in the center of the $2''$ aperture. Bearing in mind that contribution of RW Aur B-C to the flux below 3 000 Å is negligible (Ghez et al. 1997), our analysis of RW Aur UV spectra refers only to the primary.

2. Observations

HST observed RW Aur on 10 August 1993 (Program 3845) in 3 spectral bands with the Goddard High Resolution Spectrograph in medium resolution mode and Detector 2. Wavelength calibration lamp was used in nearly the same spectral bands. The start time of each observation, Archive Dataset name, grating designation, observed spectral band and number of independent exposures (RPTOBS+1 parameter) are presented in Table 1. The analyzed spectra were adopted from HST Archive, recalibrated using the most up-to-date reference files and processed with IRAF v2.11 and STSDAS/TABLES v2.0.2 software as recommended in Chap. 36 of "HST Data Handbook".

The standard "pipeline" wavelength calibration was improved by using the STSDAS *waveoff* task and respective W_CAL observations – see Table 1. All wavelengths are corrected for the orbital motion of the HST and the Earth (i.e. they are heliocentric) and are presented for vacuum if $\lambda < 2\,000$ Å and for air otherwise. The Van Hoof (1999) electronic database was used to identify lines in RW Aur spectra. To improve the signal-to-noise (S/N) ratio we combined all independent exposures for each spectral band and additionally smoothed them via a 4-point running mean, so the resulting spectral resolution is

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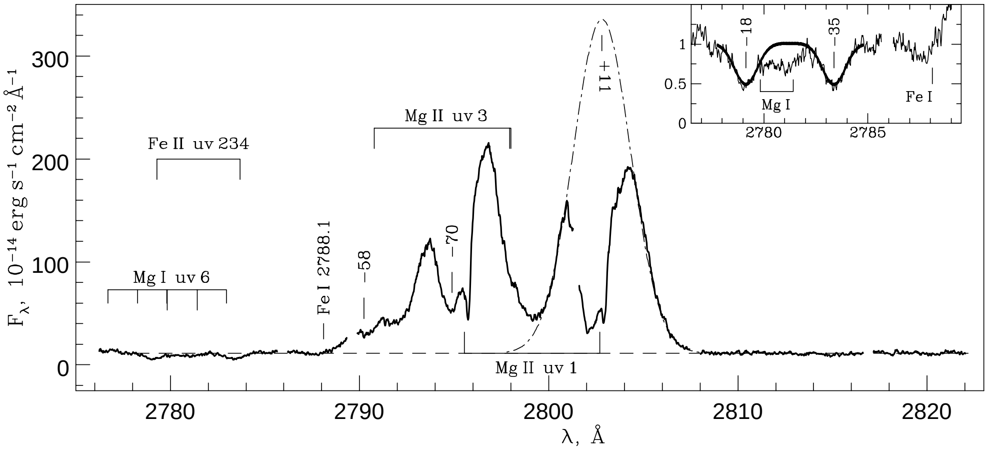

Fig. 1. RW Aur spectrum in $2778-2822$ Å spectral band with the line identification. The signed radial velocities are in km s^{-1}. The dashed line shows the gaussian fit of the Mg II h line. The fits of the Fe II line (uv 234 multiplet) are shown in the insert at top right corner

Table 1. Log of HST Program 3845 on 10 august 1993

t_0, UT	Dataset	Target	Grating	$\Delta\lambda$, ÅÅ	N
21:57	z18e0403t	W_Cal	G270M	2878–2924	1
21:58	z18e0404t	RW Aur	G270M	2777–2823	1
22:05	z18e0405t	W_Cal	G160M	1503–1539	1
22:06	z18e0406t	W_Cal	G160M	1384–1402	1
22:09	z18e0407t	RW Aur	G160M	1383–1419	3
22:25	z18e0408n	RW Aur	G160M	1532–1568	3

near 15 km s^{-1}. The five gaps in Figs. 1–3 are due to the "dead" diodes of the Detector 2.

3. Spectral interpretation

RW Aur spectrum in the $2777-2823$ Å band is shown in Fig. 1. The continuum flux was derived from a featureless part of the spectrum between 2810 Å and 2822 Å: $F_c = 1.12\,10^{-13}$erg s^{-1} cm^{-2} Å^{-1}($\simeq 10\sigma_c$). We identified the two absorption features near 2781 Å as Fe II 2779.30 and 2783.69 lines of the $\mathrm{b}\,^2\mathrm{H} - \mathrm{z}\,^2\mathrm{G}^\mathrm{o}$ multiplet (uv 234). The gaussian fit of these lines is shown in the insert in the right corner, as well as the continuum level that appears here $\simeq 1\sigma_c$ above $\mathrm{F_c}$ value. The lines are blueshifted – the respective shift in km s^{-1} is shown in the insert. Both lines have a residual intensity near 0.5, i.e. they are strong enough, while the excitation energy of their low levels is $\mathrm{E_i} \simeq 3.2$ eV.

We conclude therefore that the temperature and electron density is high in the line forming region. Therefore we connect the observed depression in the red wing of Fe II 2779.30 line with the two lines of the Mg I uv 6 multiplet: their low levels belong to the first excited term $3\mathrm{s}3\mathrm{p}\,^3\mathrm{P}^\mathrm{o}$, from which downward transitions to the ground level $3\mathrm{s}^2\,^1\mathrm{S}_0$ have low probabilities. The expected population of the $^3\mathrm{P}^\mathrm{o}$ term levels is high enough to form subordinate absorption lines, and the relative populations of the $^3\mathrm{P}^\mathrm{o}$ term levels are close to the ratio of their statistical weights. Then we conclude, from the uv6 multiplet gf-values, that the 2779.83 and 2781.42 Å lines should be the strongest within the multiplet.

One more absorption line was identified in the spectrum: Fe I 2788.10. This line should be the strongest of the $\mathrm{a}^5\mathrm{F} - \mathrm{y}^5\mathrm{G}^\mathrm{o}$ multiplet, assuming, as above, that the levels of the $\mathrm{a}^5\mathrm{F}$ term are populated proportionally to their statistical weights (Nave et al. 1994). The blue wing of the line is disturbed by an emission feature (see below), nevertheless the line center is blueshifted some tens of km s^{-1}.

The Mg II h and k lines have profiles similar and look very unusual. We fitted the Mg II h 2802.71 line wings by a gaussian, with the center at $+11$ km s^{-1} relative to the rest frame – see Fig. 1. This value is in good agreement with the radial velocity of RW Aur found from optical spectra by Hartmann et al. (1986): $\mathrm{V_r} = 14.0 \pm 4.9$ km s^{-1}. Therefore this broad ($\mathrm{FWHM_h} \simeq 380$ km s^{-1}) emission component originates at the star surface. The iron and probably the Mg I absorption lines are blueshifted relative to the star of ~ 50 km s^{-1}, so we assume they form in the stellar wind.

The narrow feature near the zero velocity position in the Mg II h and k lines is interstellar (IS), but obviously one more absorption component is present in the blue wing of the emission lines – apparently it forms in the stellar wind. Thus, the observed Mg II h and k line profiles are the result of the superposition of IS and wind absorption features onto the wide symmetrical stellar emission component – see also Imhoff & Appenzeller (1989). Unfortunately we cannot restore the blueshifted feature profile due to the lack of information from the "dead" diode. The answer crucially depends on the shape of the self-absorption feature in the central part of the stellar emission line.

Emission components of the Mg II h and k lines are so strong that their upper levels $(3\mathrm{s}\,^2\mathrm{P}^\mathrm{o}_{1/2,3/2})$ have a large population. We identified the 2791 Å emission feature with the Mg II 2790.8 line of the uv 3 multiplet: its lower level just belongs to the $^2\mathrm{P}^\mathrm{o}$ term. But stellar Mg II h and k lines can also pump the $^2\mathrm{P}^\mathrm{o}$ term levels in stellar wind matter. We conclude therefore that the two emission features near 2790 Å are not two lines, but a wide stellar 2790.8 Å emission line with a wind absorption feature in the blue wing – similar to the Ca II 8542 line profile of the star in Fig. 1d of Muzerolle et al. (1998). Minima of the absorption features are shifted relative to the central wavelength by -58 and -70 km s^{-1} in the 2790.8 Å and Mg II k lines respectively.

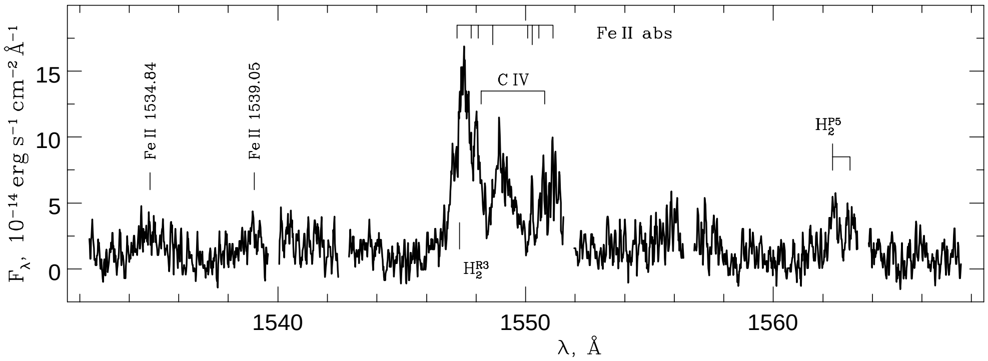

Fig. 2. RW Aur spectrum in 1532−1568 Å spectral band

It is a good agreement, bearing in mind that the 2790.8 Å line is a subordinate one, so it has no IS absorption feature. Two other lines of the uv 3 multiplet (2797.9 and 2798.0 Å) fall in the red wing of the Mg II k line, so its profile is significantly disturbed from both sides. For this reason we could not successfully fit the Mg II k line profile with a gaussian.

We explain now why only the above mentioned lines of Fe II are present in the spectrum of RW Aur, while there are more than 50 lines of the ion in the 2777–2823 Å spectral band. Assuming that the emitting region is homogeneous and the local broadening of the Fe II lines is due to thermal motion, we write the optical depth in the center of a line as follows (Mihalas 1978):

$$\tau = 1.16 \cdot 10^{-16}\, f_{ij} \lambda_{ij} \left(\frac{A}{T_4}\right)^{1/2} N_i L, \qquad (1)$$

where f_{ij} and λ_{ij} – are the oscillator strength and wavelength (in Å) of the transition; A – is the ion atomic weight (56 for Fe); T_4 – is the gas temperature in 10^4 K units; N_i – the particle density of the i–th energy level (cm^{-3}); L – the extension of the absorbing region along the line of sight (in cm).

The lowest odd energy level in Fe II is $\mathrm{z}\,^6\mathrm{D}^{\mathrm{o}}_{9/2}$, with $\mathrm{E_i} \simeq 4.77$ eV, so levels lower than this have no allowed radiative transitions between them. The populations of these levels, including that of the $\mathrm{b}\,^2\mathrm{H}$ term, are therefore likely governed by electron collisions. They probably have a Boltzmann (LTE) population at the wind electron temperature $\mathrm{T^w}$ (McMurry et al. 1999). Then the ratio of optical depths of the two Fe II lines is:

$$\frac{\tau_1}{\tau_2} = \frac{g_i f_{ij} \lambda_{ij}}{g_k f_{kl} \lambda_{kl}} \exp\left(-\frac{E_i - E_k}{kT^w}\right). \qquad (2)$$

Adopting gf and E values from Nahar (1995) we have found from Eq. (2), that the optical depths of all other Fe II lines between 2777 Å and 2823 Å are 3 times less than that of the two observed lines of the uv 234 multiplet if $\mathrm{T^w_4} = 1$ and 5 times less if $\mathrm{T^w_4} = 0.8$. It means that all other Fe II lines will be too weak to be observed if $\mathrm{T^w} < 10^4$ K, so the wind electron temperature is somewhere below this value.

From atomic data of the Fe I by Nave et al. (1994) and under the same conditions (LTE population and $\mathrm{T^w_4} < 1$) the Fe I 2788.93 line of the uv 44 multiplet should have an optical depth at least 2 times larger than other Fe I lines in the spectral band of Fig. 1. The line is weak enough to explain the absence of other neutral iron lines in the spectrum.

Table 2. Relative optical depth of Fe II lines, which can disturb the profiles of C IV 1550 and Si IV 1400 lines

λ (Å)	Transition	E_i (eV)	log(gf)	τ_{ik}/τ_{2784} 0.6	0.8	1.0
1393.21	$\mathrm{a}\,^2\mathrm{H}_{11/2} - \mathrm{x}\,^4\mathrm{H}^{\mathrm{o}}_{9/2}$	2.52	-0.77	0.30	0.23	0.20
1401.77	$\mathrm{b}\,^4\mathrm{F}_{7/2} - \mathrm{w}\,^4\mathrm{G}^{\mathrm{o}}_{9/2}$	2.83	-0.627	0.27	0.23	0.21
1403.10	$\mathrm{a}\,^4\mathrm{F}_{9/2} - \mathrm{w}\,^2\mathrm{G}^{\mathrm{o}}_{7/2}$	0.23	-1.92	0.56	0.19	0.10
1547.24	$\mathrm{b}\,^4\mathrm{D}_{3/2} - \mathrm{s}\,^4\mathrm{D}^{\mathrm{o}}_{5/2}$	3.89	-1.083	0.09	0.13	0.15
1547.80	$\mathrm{b}\,^4\mathrm{D}_{5/2} - \mathrm{s}\,^4\mathrm{D}^{\mathrm{o}}_{5/2}$	3.89	-0.693	0.22	0.31	0.37
1548.09	$\mathrm{a}\,^2\mathrm{F}_{5/2} - \mathrm{u}\,^2\mathrm{D}^{\mathrm{o}}_{3/2}$	3.42	-1.037	0.25	0.27	0.29
1548.67	$\mathrm{a}\,^4\mathrm{F}_{7/2} - \mathrm{y}\,^2\mathrm{D}^{\mathrm{o}}_{5/2}$	0.30	-2.21	2.70	0.62	0.26
1550.09	$\mathrm{b}\,^4\mathrm{D}_{7/2} - \mathrm{s}\,^4\mathrm{D}^{\mathrm{o}}_{5/2}$	3.90	-1.174	0.07	0.10	0.12
1550.27	$\mathrm{a}\,^4\mathrm{F}_{9/2} - \mathrm{x}\,^4\mathrm{F}^{\mathrm{o}}_{7/2}$	0.23	-1.090	107	24.9	10.5
1550.54	$\mathrm{b}\,^4\mathrm{D}_{3/2} - \mathrm{s}\,^4\mathrm{D}^{\mathrm{o}}_{3/2}$	3.89	-1.027	0.10	0.14	0.17
1551.11	$\mathrm{b}\,^4\mathrm{D}_{5/2} - \mathrm{s}\,^4\mathrm{D}^{\mathrm{o}}_{3/2}$	3.89	-1.084	0.09	0.12	0.15

The RW Aur spectrum in the vicinity of the C IV 1550 doublet is presented in Fig. 2. To understand this very puzzling spectrum we compared the optical depth of Fe II lines within the spectral band of Fig. 2, with that of the Fe II 2783.69 line. There are many lines with τ comparable or even larger than τ_{2784}, so they should be strong enough. But the continuum is underexposed in the spectrum and we cannot observe most of the respective absorption features. On the other hand absorption lines, whose wavelengths are close to the C IV doublet ones, should superimpose onto the strong C IV emission lines and therefore can be seen. Information on Fe II 1546 Å$<\lambda<$1552 Å lines are presented in Table 2. The last three columns show the ratio $\xi = \tau_{\rm line}/\tau_{2784}$ for three values of $\mathrm{T^w_4}$: 0.6, 0.8 and 1.0, only lines with $\xi > 0.1$ were selected. Note that semiforbidden line gf-values were adopted by Smith et al. (1996) – they are less accurate than those of the allowed transitions (Nahar 1995). It follows from Table 2 that the 1548.67 Å and 1550.27 Å lines are expected to be strong and thus should disturb the profiles of the underlying C IV emission lines. The disturbing effect of other lines from Table 2 can be significant (see Fig. 2), but the S/N ratio of the spectrum is too poor to estimate the role of each line. We only note that the 1548.67 Å line becomes strong enough only if the wind temperature is below 10^4 K, in agreement with the absence of emission lines of C I uv 3 resonance multiplet near $\lambda = 1561$ Å.

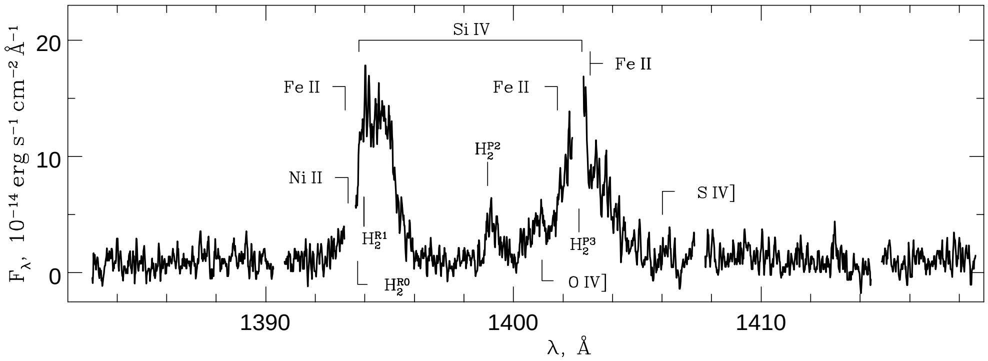

Fig. 3. RW Aur spectrum in 1383−1419 Å spectral band

There are no strong Fe I lines between 1532 Å and 1568 Å but there are many lines of Si I, which originate from fine structure levels of the ground term. It may be that the Si I 1548.72 Å and 1551.23 Å lines disturb the profile of the C IV doublet, but we should know the relative abundance of the silicon atoms in the wind in order to quantitatively estimate the effect.

Additionally, the C IV emission line profiles are disturbed by lines of molecular hydrogen H_2. Two molecular lines can be successfully identified in the spectrum: R(3) 1547.33 and P(5) 1562.39. Probably they originate close to the RW Aur H-H objects (Mundt & Eislöffel 1998) due to H_2 pumping by the stellar H Ly_α line. P(5) line looks double peaked: the red component is 130 km s^{-1} shifted relatively to the blue one. The latter is practically at stellar rest position: its heliocentric radial velocity is close to +13 km s^{-1}. Possibly one is observing H_2 emission from the RW Aur jet and counterjet discovered by Hirth et al. (1994). On the other hand these authors found that gas velocity varies in a very wide range both in the jet and counterjet.

The intensity ratio of R(3) and P(5) lines is $\simeq 1$ in spectra of T Tau (Brown et al. 1984), RU Lup (Lamzin 1999) and α Tau (McMurry et al. 1999). Apparently they originate from the same upper level $(2p\sigma B^1\Sigma_u^+\ v'=1,\ J'=4)$ and have almost equal transition probabilities (Abgrall et al. 1993). We suppose that the strong emission peak near 1547.5 Å does not only represent the H_2 R(3) line, but it is blended with the C IV 1548.20 line.

McMurry et al. (1999) observed many Fe II emission lines in α Tau spectra excited via pumping by the H Ly_α line. Probably 1534.84 Å $(v^4F^o_{3/2} \to a\,^4G_{5/2})$ and 1539.05 Å $(v^4F^o_{7/2} \to a\,^4G_{9/2})$ lines from their Table 2 are also present in the RW Aur spectrum. The pumping of these lines occurs from levels of the a^4D term, whose excitation energy is $E_i \simeq 1$ eV. The electron temperature in the region(s) where H_2 lines form does not significantly exceed 2 000 K, which seems to be too low to produce a large enough population of the a^4D term levels. Therefore the observed Fe II fluorescent lines originate in the warm wind along with the absorption lines. Profiles of the emission and absorption lines should differ significantly, because we observe emission from all regions of the wind above the accretion disk, while absorption only occurs along the line of sight. Furthermore the Fe^+ ions cannot absorb molecular hydrogen emission because it forms far outside the warm wind.

Now we consider the RW Aur spectrum in the 1383–1419 Å spectral band (Fig. 3). The profiles of the Si IV 1393.8 and 1402.8 lines differ significantly, so we have checked if this can be due to the superposition of stellar wind absorption features. There are three Fe II lines near the Si IV doublet with relatively large optical depth (see Table 2), but the Ni II 1393.32 resonance line is much stronger. Iron and nickel are predominantly singly ionised in the wind regions where the Fe II absorption lines originate – see below. If the Ni II even levels below 4 eV have a LTE population (due to the same reason as the Fe II ones – see above) then $\tau_{1393}^{\rm NiII}/\tau_{2784}^{\rm FeII} > 3$ when $T^w < 10^4$ K, with $N_{Fe}/N_{Ni} = 20$ (Allen 1973) and $f_{\rm abs}^{1393} = 0.022$ (Smith et al. 1996). Thus the Ni II 1393.32 wind absorption line almost completely cancels out the blue wing of the stellar Si IV 1393.8 emission line.

We identify an emission feature near 1399 Å as the $\lambda = 1398.95$ Å fluorescent P(2) line of molecular hydrogen. In contrast to the P(5) 1562 Å line, the P(2) 1399 Å line is not double peaked. It may be the result of the different pumping conditions of these lines (Lamzin 1999) or/and gas parameters in the jet and counterjet (Hirth et al. 1994). The R(0) 1393.72 Å line originates from the same upper level as the P(2) 1399 Å one – $2p\sigma B^1\Sigma_u^+\ v'=0,\ J'=1$ – and has $\simeq 1.9$ times less transition probability (Abgrall et al. 1993). The contribution of the R(0) line to the emission in the blue wing of the Si IV 1394 line should be relatively small if R(0) and P(2) lines are optically thin.

There are two more lines of H_2 which look much more strong: R(1) 1393.96 Å and P(3) 1402.65 Å. They originate from the common upper level $2p\sigma B^1\Sigma_u^+\ v'=0,\ J'=2$ and the ratio of their transition probabilities is near 1.4. These lines give about 50% contribution to the emission in the 1393 Å and 1403 Å features, previously attributed only to Si IV lines.

We identify the bump in the blue wing of the Si IV 1403 line with the O IV] 1401.16 line. It should be at least two times stronger than other lines of the O IV $2p\,^2P^o - 2p^4P$ multiplet in CTTS spectra (Lamzin & Gomez de Castro 1998). Probably an analogous $\lambda = 1406.02$ Å semiforbidden line of the S IV $3p\,^2P^o - 3p^4P$ multiplet is also present in the RW Aur spectrum.

4. Discussion

It follows from our analysis of the RW Aur spectra that the primary of this triple system is a source of outflowing material, where strong absorption lines of singly ionised metals originate. Physical parameters, geometry and the origin of this outflow (warm wind) are discussed below. The strong infrared excess in the RW Aur A spectrum (Ghez et al. 1997) suggests that an opaque accretion disk surrounds the star, so we interpret the observational data in the frame of the accretion disk/wind paradigm.

We have found above that the wind gas temperature is definitely below 10^4 K. It follows from calculations of Arnaud & Raymond (1992) that the abundance of Fe I should exceed 10% in the region of Fe II line formation, if the ionization of iron atoms is due to electron collisions. The Fe I 2788.1 line is much weaker than the Fe II 2783.7 line, which means that τ_{2788} is significantly less than τ_{2784}. If levels of the neutral iron have LTE populations, this can occur only when $\mathrm{N_{Fe\,I}/N_{Fe\,II}} < 0.03$. Stellar H I Ly_α quanta are responsible for the ionization excess of iron in the wind as well as the atoms of elements with an ionization potential below 10.2 eV. Hydrogen Ly_β quanta can ionize also sulfur atoms, explaining the absence of a deep absorption feature in the blue wing of the Si IV 1402.8 line that can be produced by the strong resonance S I 1401.5 line.

Brown et al. (1984) and Lamzin (1999) found that the Ly_α luminosity of T Tau and RU Lup is $\gtrsim 0.1\,\mathrm{L_{bol}}$. The equivalent width of the RW Aur Hα line is ~ 100 Å, which means that the Hα luminosity is $\sim 1\%\,\mathrm{L_{bol}}$, so the luminosity of the star in Ly_α line probably exceeds 10^{33} erg s^{-1}. Strong fluorescent lines of Fe II and $\mathrm{H_2}$ indicate that the RW Aur A Ly_α luminosity is indeed very large. Only the $\mathrm{H_2}$ lines, observed in RW Aur UV spectra, are excited by quanta with wavelengths redshifted relative to the Ly_α line up to +490 km s^{-1} as in the case of R(1) and P(3) lines. It occurs because the blue wing of stellar Ly_α line is almost completely absorbed inside the wind. This absorption is probably more stronger than the one of the blue wings of the Mg II h and k lines (Fig. 1). At the same time the observed Fe II fluorescent lines can be excited by quanta from the blue wing of the Ly_α line if they originate in the wind. Indeed the wavelengths of pumping transitions producing the Fe II 1539.05 and 1534.84 lines are shifted, relative to the center of the Ly_α line, to -470 km s^{-1} and -980 km s^{-1} respectively.

The stellar radiation of the Ly-series lines should strongly populate the excited levels of the hydrogen in the wind, explaining the presence of strong absorption lines of the Balmer and Paschen series. The photoionization of hydrogen from excited levels by Ly-series lines is a valuable source of heating of the wind and (along with collisional ionization) production of free electrons in spite of the relatively low gas temperature. Radiation pressure produced by Ly_α quanta can also play an important role in the initial acceleration of the wind matter (Lamzin 1999).

We estimate the hydrogen particle column density $\mathrm{N_H^w}$ (cm^{-2}) in the warm wind along the line of sight from the optical depth of the Fe II 2783.69 line $(\mathrm{b\,^2H_{11/2} - z\,^2G^o_{9/2}}$ transition). The relative LTE population of the $\mathrm{b\,^2H_{11/2}}$ level $(\mathrm{N_i/N_{total}})_{\mathrm{FeII}}$ is near $4\ 10^{-3}$ at $\mathrm{T^w} = 10^4$ K (and ~ 2 times less at $\mathrm{T^w} = 8000$ K). If $\mathrm{N_{Fe\,II}/N_{Fe}} \sim 1$ we find from Eq. (1), with $\mathrm{N_{Fe}/N_H} \sim 3\ 10^{-5}$, that the optical depth τ in the center of the Fe II 2783.69 line is $< 3\ 10^{-21}\,\mathrm{N_H^w}$. As above mentioned, the line looks strong enough, so τ definitely exceeds 1, and therefore $\mathrm{N_H^w} > 3\ 10^{20}\,\mathrm{cm^{-2}}$. Our estimation is very conservative and the real value of $\mathrm{N_H^w}$ could be an order of magnitude larger. It exceeds significantly the IS hydrogen column density, which can be derived from $\mathrm{N_H^{IS}} \simeq 1.8\ 10^{21}\,\mathrm{A_V}$ relation by Vrba & Rydgren (1985) with $\mathrm{A_V} \simeq 0.3$ (Ghez et al. 1997). We estimate from Cruddace et al. (1974) data that the stellar X-ray flux below ~ 0.5 keV should be absorbed by the stellar wind, unfortunately there are no suitable X-ray data to check this conclusion.

As above mentioned, the level population of the Mg I metastable $\mathrm{3s3p\,^3P^o}$ term is large enough to produce subordinate absorption lines of the uv 6 multiplet. The electron density of the wind exceeds the critical density of the $\mathrm{3s^2\,^1S_0 - 3s3p\,^3P^o_1}$ transition with respect to the Mg I] 4571.1 line. Adopting atomic data by Mauas et al. (1988) we found $\mathrm{N_e} \gtrsim 10^{10}\,\mathrm{cm^{-3}}$. We derive from the $\mathrm{N_H^w} < 3\ 10^{21}\,\mathrm{cm^{-2}}$ inequality that the extension of the wind region along the line of sight is less than $3\mathrm{R}_*$.

The observed gas outflow originates in the immediate vicinity of the star, presumably near the boundary between the stellar magnetosphere and an accretion disk. Gas acceleration up to $V_r \simeq 50\,\mathrm{km\,s^{-1}}$ occurs at distance $< 3\ 10^{11}$ cm, but the radial velocity of the jet matter is 4 times larger (Hirth et al. 1994), so the acceleration continues at larger distance. We have no reasons to exclude that there is also a gas outflow from more extended regions of the disk. We can only say that it should be much cooler than the observed one. It is not possible to deduce from our data if the Fe I and Fe II absorption lines form in the same or different regions of the wind.

Unfortunately, we can say almost nothing about the emission lines of "high temperature" ions originating presumably in an accretion shock, as well as the Mg II and H I Ly_α lines (Lamzin 1998). The O IV] 1401.2 line looks a bit stronger than the S IV] 1406.0 line, in agreement with the accretion shock model predictions (Lamzin & Gomez de Castro 1998), but a quantitative comparison is impossible due to the poor S/N ratio of the spectrum. Gomez de Castro & Lamzin (1999) have estimated the infall gas density $\mathrm{N_0} \sim 10^{11}\,\mathrm{cm^{-3}}$ by IUE data in agreement with the wind gas density found by us.

5. Conclusions

The UV emission spectrum of RW Aur A is strongly disturbed by absorption lines of singly ionised metals originating in the stellar wind. The lines look symmetrical and blueshifted relative to the star by $\sim 50\,\mathrm{km\,s^{-1}}$. The outflowing gas is dense $(\mathrm{N} > 10^{10}\,\mathrm{cm^{-3}})$ and its extension along the line of sight is less than $3\mathrm{R}_*$. The wind gas temperature is definitely below 10 000 K, but metals (and probably sulfur) are almost completely singly ionised by strong stellar emission in the hydrogen lines of the Lyman series. Stellar Ly_α quanta are responsible for a significant population of the upper levels of the hydrogen in the wind. The photoionization of this hydrogen is the main source of free electrons and subsequent gas heating. The strong emission lines of $\mathrm{H_2}$ and Fe II observed in the RW Aur A spectrum are also the result of the fluorescent pumping by stellar Ly_α

quanta. Iron fluorescent lines originate in the warm wind, while molecular hydrogen emission forms far outside, possibly near the Herbig-Haro objects.

Emission in the C IV and Si IV lines is strongly suppressed by Fe II and Ni II wind absorption features. Superposition of strong H_2 emission lines onto residual profiles additionally disturbs the picture, so the C IV and Si IV line fluxes derived from low resolution IUE spectra are strongly affected. It may explain the nontrivial character of the variability of UV lines observed by Imhoff & Giampapa (1983). This can also be true for other T Tauri stars – see Gomez de Castro & Franqueira (1997). It is clear anyway that accretion and stellar wind are related phenomena in CTTSs and the Ly_{α} emission by a accretion shock looks a valuable link between them.

The observed outflow is too cold and compact to produce the strong UV emission lines of singly ionized metals. We can interpret the UV spectra more easily than optical spectra to derive quantitative physical parameters and geometry of the accretion inflow and the wind. Of course this requires much more (and better quality) data than we have.

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