THE ULTRAVIOLET VARIABILITY OF THE T TAURI STAR RW AURIGAE[1]

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ABSTRACT

Between 1978 and 1979 the visible brightness of RW Aurigae increased by $0\overset{m}{.}9$. During this time (a) CIV and SiIV increased by factors of 2 to 4 while the lower ionization lines remained unchanged, (b) the fluorescent OI line increased by a factor of 8, (c) the shell spectrum changed from emission to absorption, and (d) the ultraviolet continuum brightened by $2\overset{m}{.}3$. On a time scale of a week the continuum varied by as much as $0\overset{m}{.}8$ but the MgII emission lines showed no variability over 10%. We hypothesize an active chromosphere, transition region, and envelope cooled by mass loss in order to explain the ultraviolet observations of RW Aur.

INTRODUCTION

A large portion of our IUE observing program has been devoted to an extensive study of RW Aurigae, a well-known T Tauri star with strong emission characteristics. Our two main objectives have been (a) to obtain the best possible data for the star, utilizing multiple observations in order to generate a spectrum with good signal-to-noise across a broad wavelength range and attempting high dispersion observations, and (b) to study the star's variability in the ultraviolet continuum and emission lines.

The results of our first set of observations have been reported in our first paper (ref. 1). A complete discussion of all our observations of RW Aur is in preparation. In this paper we present a preliminary discussion of these results, concentrating on the ultraviolet variability of the star.

RW Aur has been observed during two periods, the first during July 30 to 31, 1978, and the second over April 2 to 9, 1979. The individual observations are separated by intervals as short as half a day and as long as nine months. The observations during the latter period are more extensive, but for both runs long and short wavelength observations were made. Between July 1978 and April 1979 the star brightened from $V=11\overset{m}{.}5$ to $10\overset{m}{.}6$, according to the IUE fine error sensor. Variability in the ultraviolet spectrum was seen in the short wavelength emission lines, the shell lines at longer wavelengths, and the

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ultraviolet continuum.

RESULTS

The short wavelength spectrum of RW Aur exhibits a number of emission lines, including HI, CI, CII, CIII, CIV, NIV, OI, SiI, SiII, SiIII, and SiIV. Figure 1 depicts the spectrum as seen in 1979. Between our 1978 and 1979 observations the lower ionization lines (except for OI) remained at essentially the same flux levels. However the highly ionized lines increased in strength, CIV by a factor of 2.1 and SiIV by 3.8. NV 1240 and HeII 1640 are not observed in RW Aur. The enhancement of the higher temperature lines indicates a change in the structure of the star's emission region (thought to be either a chromosphere or shocked zone) that is reminiscent of the changes seen in solar and stellar flares. The OI 1304 emission lines are also seen to strengthen by over a factor of 8. Since these lines are fluorescent with Lyman-β, the variability signals a change in the flux and/or line profile of the Lyman-β line.

How do the emission fluxes for RW Aur compare to solar and stellar chromospheric fluxes? To make this comparison we convert the observed fluxes to surface fluxes corrected for extinction. As for many T Tauri stars, the spectral type of RW Aur and the amount and nature of the extinction affecting it are uncertain. We have therefore considered two cases which should embrace the most likely parameters describing RW Aur: the "liberal" Case I, a G5 star affected by $1^{m}.69$ of visual extinction characterized by R=6 and the θ Orionis extinction law, and the "conservative" Case II, a K2 star affected by $0^{m}.17$ of normal extinction. The two cases yield different radii (2.6 and 3.0 $R_{\odot}$) for the star but the largest difference in the derived surface fluxes comes from the assumptions about the extinction. We find that even in the conservative Case II, the surface fluxes for RW Aur exceed the quiet solar chromospheric fluxes (ref. 2) by a factor of about 2000. Thus the surface fluxes for RW Aur exceed those of the active chromosphere dwarfs (ref. 3) and even the RS CVn stars (ref. 2). Figure 2 has been adapted from Dupree's (ref. 4) figure 6 to show RW Aur compared to a number of other stars. Conservative Case II is depicted; Case I yields surface fluxes a factor of 8 higher.

In stars with active chromospheres, one sees both an increase of the emission line surface fluxes over the solar values and an additional enhancement of the high temperature SiIV, CIV, and NV lines, as well as HeII (thought to be due to recombination after X-ray ionization). In RW Aur we see very high surface fluxes but an apparent weakening of the higher temperature lines. CIV is weaker than SiIV, while for NV and HeII we can only set upper limits. There are also curious deviations in the weakness of CII and the strength of SiII.

These results are in general repeated in IUE observations of other T Tauri stars (ref. 5,6,7,8). We note the following general behavior: (a) CII is weak compared to other lines. CIV 1550/CII 1335 ranges from 2.0 to over 6; the ratio is 1.3 in the quiet Sun. (b) CIV is weakened in the strong emission stars. CIV 1550/SiIV 1400 is around the solar value of 2.3 and higher for weak emission stars but only 0.9 in S CrA, RU Lup, and RW Aur. (c) HeII 1640 and NV 1240 have been detected only in the weak and moderate emission stars. (d) The density sensitive ratio CIII] 1909/SiIII 1892 decreases from 2.3 in T Tauri to 0.1 for RW Aur. This reflects an increase in electron density from under 10^8 cm^{-3} to 4×10^{10} cm^{-3}, if calculated curves (ref. 9) may be applied to these stars. According to these indicators, RW Aur is the most extreme T Tauri star that has thus far been observed with IUE.

We are currently exploring a possible explanation of the behavior of the T Tauri stars in the ultraviolet. We hypothesize an active chromosphere that is affected by mass loss. The mass loss is greatest in the strong emission stars such as RW Aur. It cools the chromosphere-corona sufficiently that T_{max} in RW Aur is only 80,000 K; the density increases and follows an r^{-2} distribution (ref. 10). The existence of such a low T_{max} may produce two regions of intermediate temperature, the traditional transition region and an outer extended region, both of which may contribute to the fluxes of lines such as CI, SiI, SiII, FeII, and HI. Further evidence for a temperature turn-over comes from a derived temperature of 5000 K or less at 5 R_* for the fluorescent FeI lines in RW Aur (ref. 11). For stars with smaller amounts of mass loss, the deviation from normal chromospheric structure is smaller.

We obtained several short exposures of RW Aur in order to determine the MgII emission line flux. The observed emission lines are the strongest in RW Aur of several T Tauri stars surveyed; only a 3 minute exposure was required. Four different images obtained in 1979 yield an observed flux of 1.55×10^{-11} erg cm^{-2} s^{-1}, with agreement to 10%. Thus we have no evidence for variability of the MgII lines over 10% in a week's time span.

The great strength of the MgII lines encouraged us to attempt high dispersion observations of the lines; a 3 hour exposure was sufficient (figure 3). Each line is extremely broad (7 Å full width) with a deep central reversal at line center. The interpretation of the line profiles seen in T Tauri stars is a wide-open question; we defer a discussion of these lines to a later paper. We are planning to make additional high-resolution observations of the MgII lines this fall simultaneously with ground-based high-resolution data obtained for the Balmer lines, NaI D, and CaIIH and K.

The MgII lines are surrounded by numerous low excitation lines of FeII, CrII, and MnII. In some T Tauri stars observed with IUE these lines are in absorption, others in emission. The long wavelength ultraviolet spectrum of RW Aur, however, changed from emission in 1978 to absorption in 1979. It is difficult to understand this behavior unless it is due to an extended shell. In fact one may ascribe the change from emission to absorption as related to the brightening of the star. One might consider that any line produced in a shell around the star is the combination of an absorption component produced by the gas in the line of sight to the star and an emission component from the extended shell. At low resolution, the line appears in absorption or emission depending upon the geometric extent of the shell, the brightness of the star, the strength of the absorption lines and the strength of the emission. If the brightness of the star increases, the absorption contribution is enhanced over the emission (assumed unaffected by the variability). If this is so, one may expect absorption to predominate when the star is bright, emission when it is faint. The large range of variability in the ultraviolet indicates that this behavior can be seen most easily in this wavelength range.

A confirmation of the shell nature of the absorption lines comes (surprisingly) from one of our high resolution spectra of the MgII lines. In a 7 hour exposure the ultraviolet continuum is well enough exposed to show individual absorption lines. Although the signal-to-noise is only about 5, the lines are broad (1 Å) and dip to zero residual intensity making them easily visible. The source of the ultraviolet excess is therefore interior to the shell. We have performed line identifications over the wavelength range 2600 to 3100 Å. Numerous lines of low excitation multiplets have been identified, including MgI(1), TiII(1), VII(1,2,3), CrII(5,6,7,8,11), MnII(1,5,18,19), and FeII(1,60,61,62,63,64,78).

The ultraviolet continuum from 2000 to 3300 Å showed variations on all observed time scales. Between 1978 and 1979 the ultraviolet continuum at 3050 Å rose by $2^m.3$; at the same time the visual brightness increased by $0^m.9$. During the 1979 run, a variation of $0^m.4$ was seen in half a day and $0^m.8$ in a week. The tendency for variability to increase at shorter wavelengths in T Tauri stars is thus continued into the ultraviolet.

A composite energy distribution for RW Aur was formed from several exposures of different durations. Good signal-to-noise was thus obtained over a range from 2000 to 3300 Å . The 2200 Å graphite feature is definitely weak or absent. No more than a few tenths of a magnitude of visual extinction may be present if the extinction law is normal. If larger amounts of extinction are present then the extinction law must be peculiar, perhaps resembling that found for θ Ori. Both Case I and Case II discussed above are consistent with these results. In both of these assumed cases the energy distribution of the ultraviolet excess may be determined. As noted in our first paper, the resemblence to Balmer bound-free emission is unmistakable.

CONCLUSIONS

In summary we may state that the ultraviolet variability of RW Aur has exhibited the following behavior as the star brightened: (a) The high temperature lines of CIV and SiIV increased by factors of 2 to 4 while the lower ionization lines remained unchanged. (b) The fluorescent OI lines increased by over a factor of 8. (c) The shell spectrum at longer wavelengths changed from emission to absorption. (d) The ultraviolet continuum increased by $2^m.3$ and varied by smaller amounts on shorter time scales. In addition the MgII emission line fluxes did not vary by over 10% in one week. We hypothesize an active chromosphere and transition region affected by mass loss to explain the ultraviolet observations of RW Aur. It is clear that the variability of the T Tauri stars in the ultraviolet can provide valuable information on the nature of these stars.

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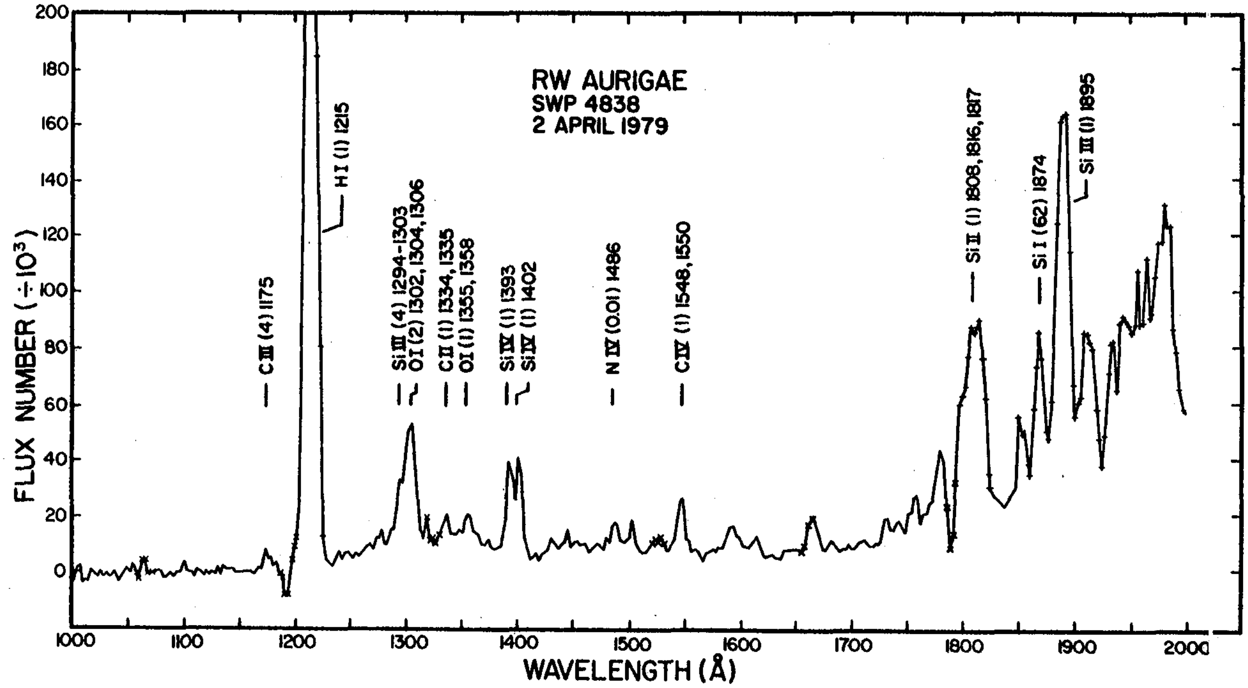

Figure 1. - The short wavelength ultraviolet spectrum of RW Aurigae obtained in 1979. IUE relative intensity is plotted against wavelength. The crosses denote the presence of reseaux, while the plusses indicate saturated pixels.

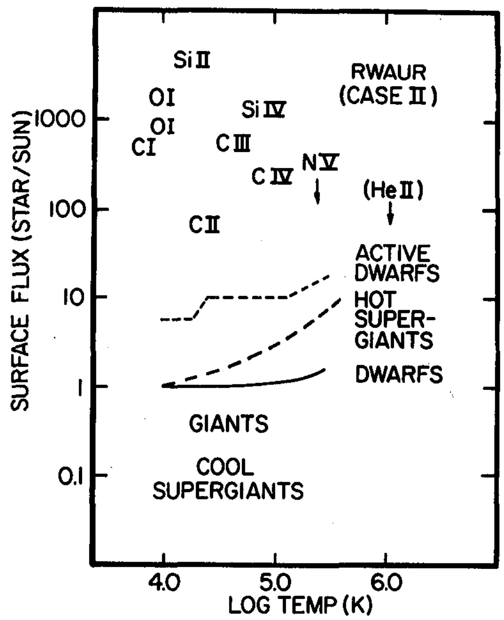

Figure 2. - Comparison of the surface fluxes for RW Aurigae (for Case II) with other stars. Individual ultraviolet lines are indicated. Only upper limits for NV and HeII can be given.

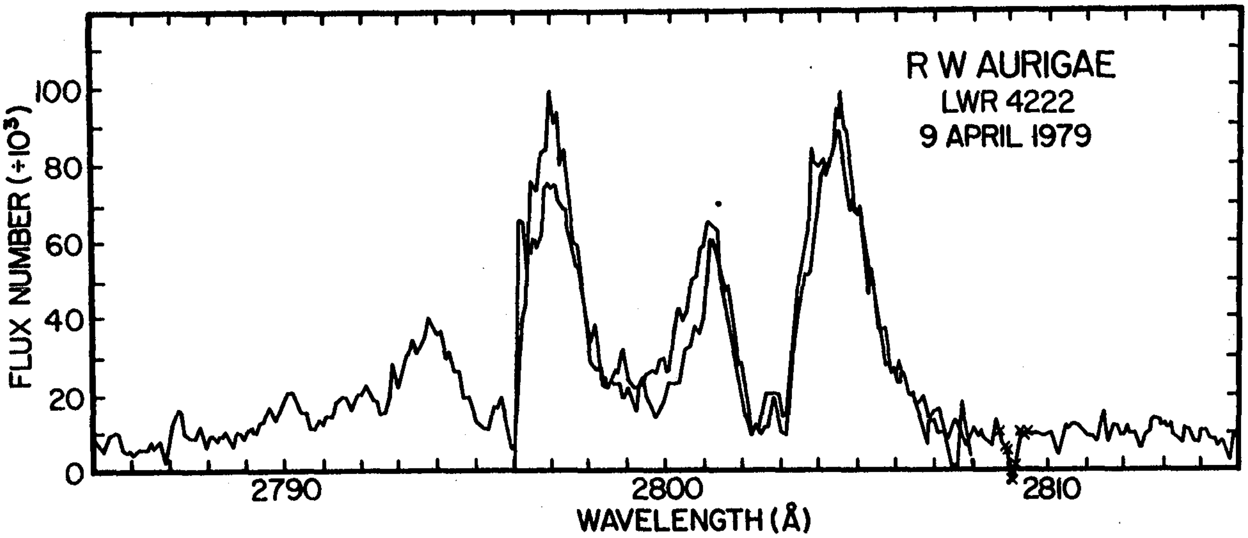

Figure 3. - The MgII lines observed with high resolution. Low resolution observations set a flux scale of 1 FU = 4.22×10^{-14} erg cm^{-2} s^{-1} $Å^{-1}$.