T TAURI VARIABLE STARS*

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ABSTRACT

Eleven irregular variable stars have been observed whose physical characteristics seem much alike and yet are sufficiently different from other known classes of variables to warrant the recognition of a new type of variable stars whose prototype is T Tauri. The distinctive characteristics are: (1) irregular light-variations of about 3 mag., (2) spectral type F5–G5 with emission lines resembling the solar chromosphere, (3) low luminosity, and (4) association with dark or bright nebulosity. The stars included are RW Aur, UY Aur, R CrA, S CrA, RU Lup, R Mon, T Tau, RY Tau, UX Tau, UZ Tau, and XZ Tau. They are situated in or near the Milky Way dark clouds in the direction either of the center or of the anticenter of the galaxy.

The light-curves.—The total light-changes are about 3 mag., the variations being extremely irregular as to range and time. The light-curves are not unique.

The individual variables.—The spectrographic observations of the variables are described and the significant features of the spectra pointed out.

Discussion of the spectra.—The spectral types of the T Tauri stars are estimated to be between F5 and G5, although for many of them the absorption lines generally used in classification are lacking. A small variation of type with phase was found for T Tau and RY Tau. Bright hydrogen has been found in all stars of the group, and bright *Ca* II (H and K) in all except R CrA. Most of the stars show an emission spectrum composed of many bright lines of low excitation. The strongest lines are those of *Ca* II, *H*, *Fe* II, *Ca* I, *Sr* II, *Fe* I, and *Ti* II. The identification and relative maximum intensities of 160 lines of the different stars are shown in Table 16. The intensity of the emission spectrum varies greatly from time to time in each star, the bright lines becoming more prominent at maximum light of the variable.

The lines λ 4063 and λ 4132 of the $a^3F-y^3F^0$ multiplet of *Fe* I are greatly enhanced in strength in the stars showing strong emission spectra. This distortion is probably the result of fluorescent effects.

The marked similarity of the bright-line spectrum of the T Tauri stars to that of the upper solar chromosphere is shown in Table 17.

Absolute magnitudes and color indices.—Spectroscopic absolute magnitudes of three stars of the group, together with meager indirect evidence, indicate that the T Tauri stars are dwarfs of the main sequence. Color indices for five stars show some color excess, which is probably the result of selective absorption by surrounding nebulosity.

Radial velocities.—Radial-velocity measures from absorption lines are difficult when the emission spectrum is present. Lack of agreement in the measures of both absorption and emission spectra indicates irregular atmospheric motions. In the mean the emission lines are displaced toward the violet with respect to the absorption lines.

The criteria distinguishing variable stars included in the T Tauri class are: (1) rapid irregular light-variations of about 3 mag.; (2) spectral type F5–G5, with emission lines resembling those of the solar chromosphere, particularly in the great strength of H and K of calcium; (3) low luminosity; (4) association with dark or bright nebulosity. Although little or nothing is known as to the cause of the light-variation, characteristics 1–4 are probably physically interrelated and together form a distinct stellar type which may be readily recognized. These stars differ from other known variables, especially in their low luminosity and the high intensity of bright H and K in their spectra. The well-known variable T Tauri is one of the brightest stars of the group and may properly be considered as the prototype, although there are marked differences among the stars and no two are exactly alike.

Eleven stars (Table 1) make up the list of variables whose characteristics are sufficiently alike to entitle them to membership in this class. Heretofore, they have generally been classed as "irregular" variables, and their unpredictable light-changes indicate that

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they well deserve the title. Four stars (R CrA, R Mon, T Tau, and RY Tau) are definitely involved in surrounding nebulosity (Pl. XII), and all stars of the group are situated in or near large areas of heavy obscuration by Milky Way clouds. In the course of this investigation, five others (RW Aur, UY Aur, S CrA, UX Tau, and UZ Tau) were discovered[1] to be visual double stars, leaving only two of the group (XZ Tau and RU Lup) which appear to be uninvolved either with local nebulosity or with near-by companion stars.

The galactic co-ordinates are in the fifth and sixth columns of Table 1. The peculiar distribution of these stars is evident and is shown in Figure 1. Three are in the Milky Way clouds near the direction of the center of the galaxy, and the others form a group

TABLE 1

T TAURI VARIABLES

Star	α (1900)	δ (1900)	Magnitude Range	Galactic l	Galactic b	Remarks
RW Aur	5h 1m.4	+30° 16′	9.0–12.0	142°	− 6°	Double
UY Aur	4 45.4	+30 37	*11.6–14.0*	139	− 8	Double
R CrA	18 55.1	−37 6	9.7–13.5	328	−19	Nucleus of variable comet-like nebula, NGC 6729
S CrA	18 54.4	−37 5	9.5–13	328	−19	Double
RU Lup	15 50.1	−37 32	*9.0–11.0*	307	+11	
R Mon	6 33.7	+ 8 50	9.3–14.0	171	+ 3	Nucleus of variable comet-like nebula, NGC 2261
T Tau	4 16.2	+19 18	9.0–12.8	148	−22	Near Hind's variable nebula, NGC 1555, and surrounded by a small shell
RY Tau	4 15.6	+28 12	8.8–11.1	136	−14	Nucleus of a fan nebula
UX Tau	4 24.2	+18 0	*10.5–13.4*	146	−19	Double
UZ Tau	4 26.6	+25 40	9.2–<13	140	−14	Double
XZ Tau	4 25.9	+18 1	*10.4–13.5*	146	−19	

about the anticenter in the opposite direction; but, unlike the distant Cepheids, they do not lie closely along the galactic equator as seen from the sun. The mean latitude (disregarding signs) is 14°. The mean median apparent magnitude of these two groups is practically the same, indicating equal distances from the earth if all the stars are of equal absolute magnitude and suffer equal amounts of obscuration.

THE LIGHT-CURVES

The variations in light of the T Tauri stars are so irregular and unpredictable that classification by means of their light-curves is practically impossible. Thus far, observations have been insufficient to determine definite sequences of light-changes which are uniquely characteristic of the group. The light-curves vary greatly from year to year and from star to star. Figure 2, showing light-curves of RW Aur by S. Enebo[2] and E. Zinner[3] in different years, illustrates the complicated nature of the light-variations. Other stars such

[1] A. H. Joy and G. van Biesbroeck, *Pub. A.S.P.*, **56**, 123, 1944.

[2] *A.N.*, **175**, 205, 1907.

[3] *A.N.*, **195**, 456, 1913.

as RR Tau and certain variables in Orion have similar light-changes, yet their spectra are very different. The color index for several of the stars has been determined (Table 18), but changes in color have not yet been studied. If the fluctuations in light result from the interposition of obscuring clouds, changes in color due to scattering or selective absorption might be expected.

The magnitude ranges in Table 1 are from Schneller's Catalogue.[4] The total variation is large, averaging over 3 mag. The brightness of RU Lup and RY Tau at the time of some of the spectrographic observations was certainly a magnitude or more fainter than the minimum given by Schneller.

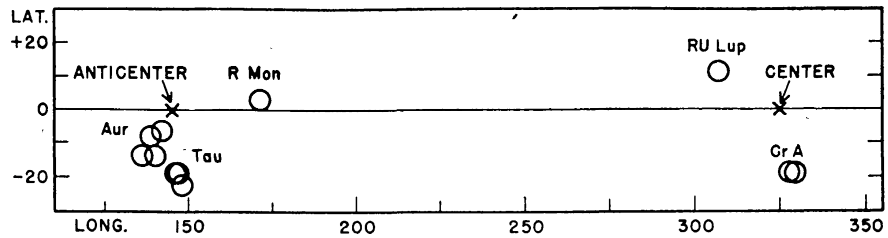

FIG. 1.—The galactic distribution of the T Tauri stars

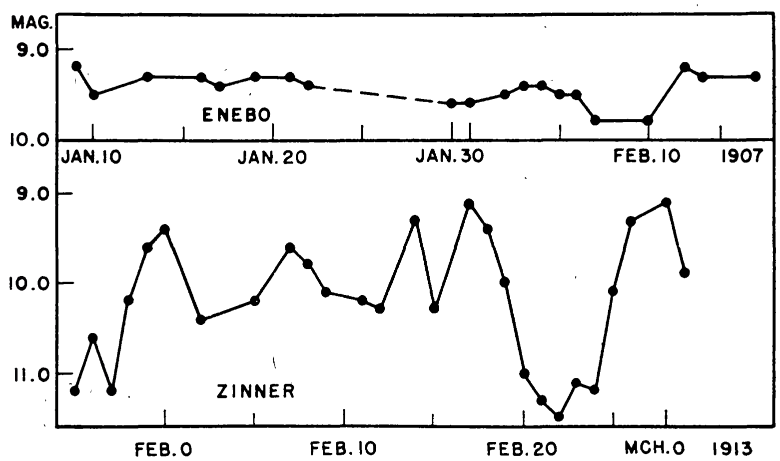

FIG. 2.—Light-curves of RW Aur by Enebo (*above*) and Zinner (*below*)

THE INDIVIDUAL VARIABLES

On account of the peculiarities of the individual variables, separate descriptions of their behavior, characteristics, and spectra are desirable. For each star the table of observations gives the plate number ("γ" signifies 60-inch one-prism spectrograph; "C," 100-inch one-prism; and "E," 100-inch two-prism); the date; the magnitude; the dispersion ($a = 35$ A/mm at Hγ, $b = 75$, $c = 115$, and $d = 220$, approximately); the velocities, together with the number of lines measured; and the relative prominence of the emission spectrum as a whole ("str" = strong, "m" = medium, and "wk" = weak). The estimated magnitudes are those recorded in the observing-record book when the spectrograms were made and have little photometric value. They are entered in the table only because no other magnitudes are available. No comparison stars were used, and the effect of haze, moonlight, and seeing may have introduced errors of the order of a magnitude on nights when the observing conditions were unfavorable.

[4] *Kleinere Veröff. Sternwarte Berlin-Babelsberg*, No. 21, 1939.

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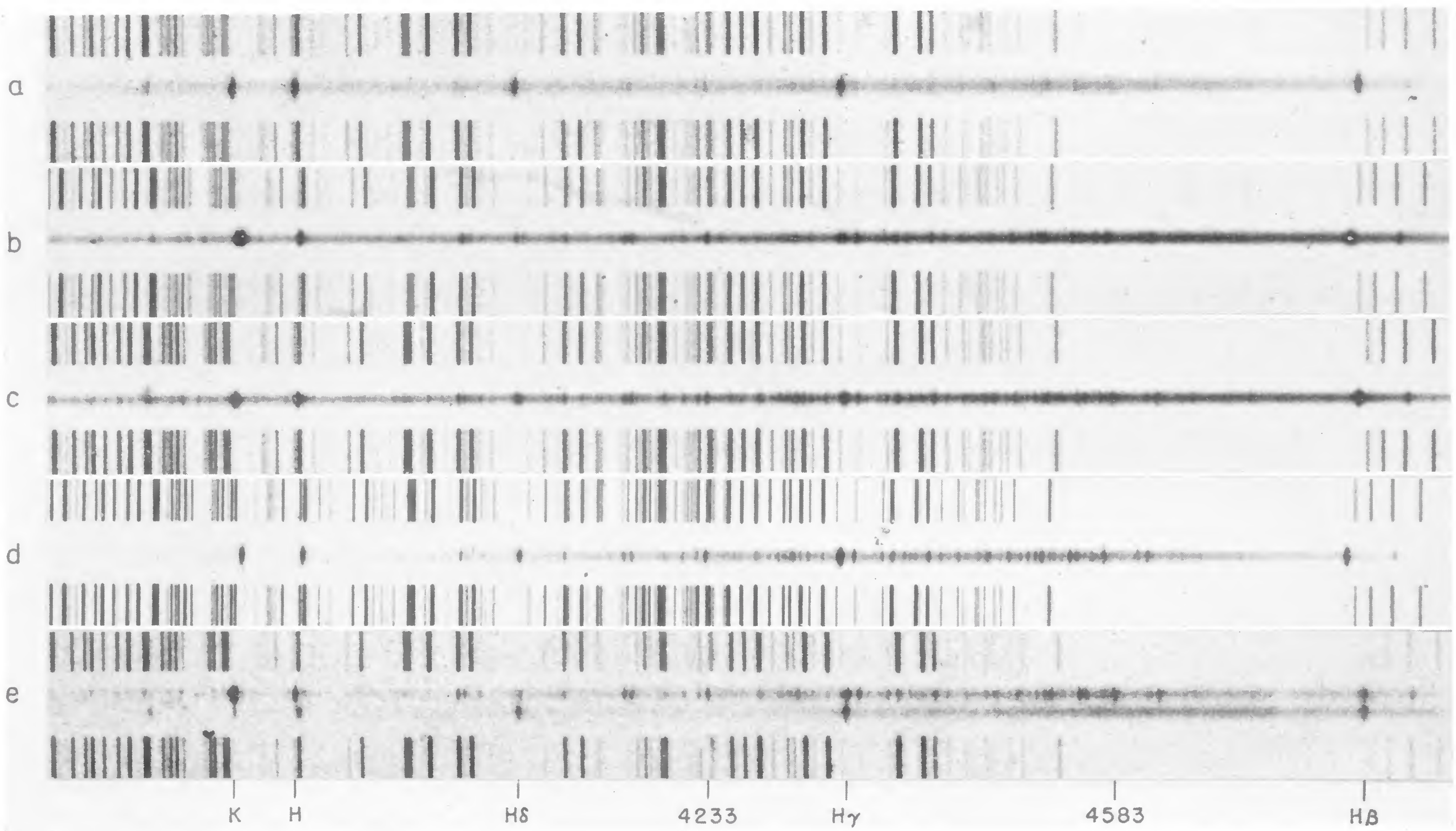
PLATE XII

SPECTRA OF T TAURI STARS

(*a*) UX Tau, E1299, 1944 December 9; (*b*) RY Tau, E560, 1942 August 31; (*c*) R CrA, E474, 1942 June 3; (*d*) T Tau, E344, 1941 November 26; (*e*) R Mon, E319, 1941 October 30; (*f*) UY Aur, E322, 1941 October 31.

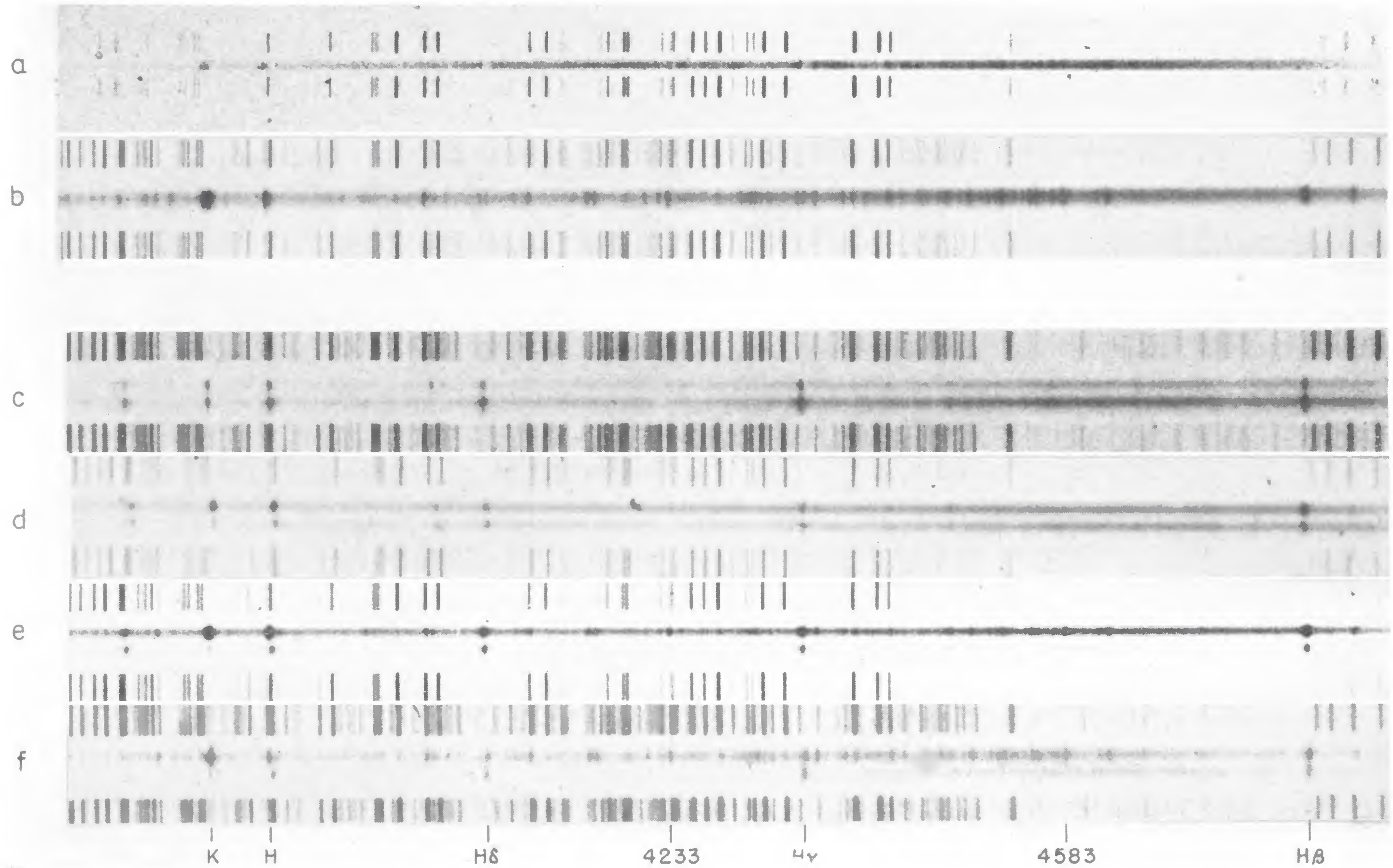
PLATE XIII



SPECTRA OF T TAURI STARS

(*a*) S CrA, E1106, 1944 June 28; (*b*) RW Aur, E1196, 1944 August 27; (*c*) XZ Tau, E1202, 1944 August 28; (*d*) RU Lupi, E833, 1943 May 11; (*e*) UZ Tau with companion below, E617, 1942 October 17.

PLATE XIV

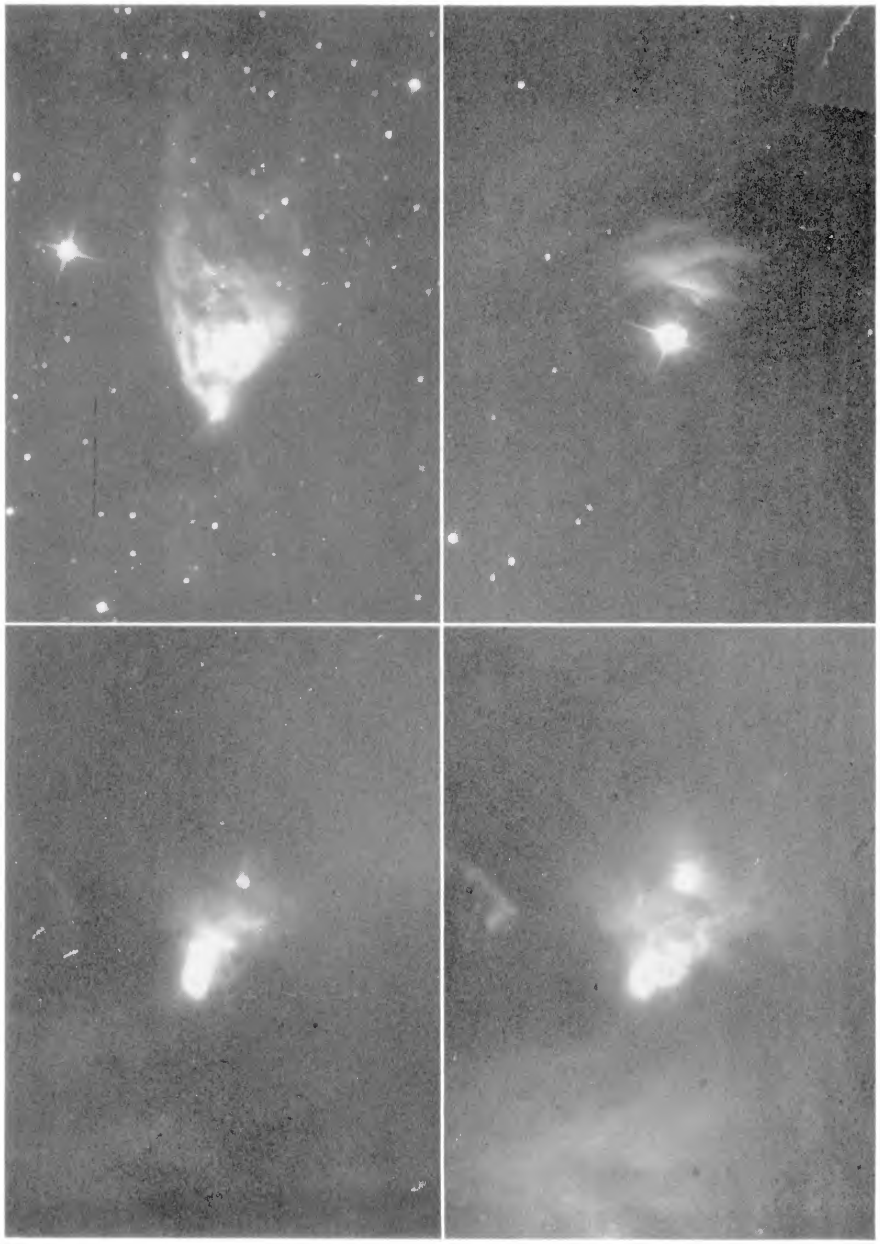


SPECTRA OF RW AUR AND UZ TAU AT DIFFERENT PHASES

RW Aur: (*a*) γ23841, November 2, 1941; (*b*) E1229, September 25, 1944.

UZ Tau with dMe companion below: (*c*)E1224, September 23, 1944; (*d*) E1047, January 4, 1944; (*e*) E1318, January 8, 1945; (*f*) E720, December 28, 1942.

PLATE XV



Photographs of Variable Stars with Associated Variable Nebulae

R Mon with NGC 2261 (*upper left*), 1920 January 26, photographed by E. Hubble; T Tau with NGC 1555 (*upper right*), 1940 September 30, photographed by W. Baade; R CrA with NGC 6729 (*lower left*), 1920 August 15, and (*lower right*), 1941 August 17, photographed by E. Hubble. 100-inch reflector.

RW AURIGAE 050130

In 1906, Mme Ceraski[5] discovered from Moscow photographs the variation in light of RW Aur. Many variable-star observers have followed its rapid and unpredictable fluctuations without finding any trace of regularity. Large changes in brightness may take place within a few days or even a few hours. The total range is 3.0 mag. (9.0–12.0 vis.). The spectral class in the *Henry Draper Extension Catalogue* is G0.

Ten spectrograms of RW Aur, listed in Table 2, have been obtained. One of these, E342, was reproduced for comparison with other variable stars in the *Publications of the Astronomical Society of the Pacific*, **54**, 17, 1942. The outstanding peculiarities of the spectrum are well shown in this illustration. H and K of *Ca* II and the hydrogen lines are strong in emission and are distorted by broad, deep, central reversals. Numerous bright lines of other elements are also present, but the absorption spectrum is weak. The estimated spectral type is G5.

TABLE 2

OBSERVATIONS OF RW AURIGAE

Plate	Date	Est. Mag.	Disp.	Metallic Lines: Emission			Metallic Lines: Absorption		H and Ca II Lines: Emission (V. Comp.)		H and Ca II Lines: Emission (R. Comp.)		H and Ca II Lines: Absorption	
				No	Vel.	Int.	No.	Vel.	No.	Vel.	No.	Vel.	No.	Vel.
					km/sec			km/sec		km/sec		km/sec		km/sec
γ21234.....	1937 Oct. 14	11.5	c	1	− 94	wk	...	....	3	−168	...	....	2	+32
E286.....	1941 Sept. 30	10	c	6	− 185	str	7	+ 52	10	−220	1	+ 80	9	−31
γ23841.....	Nov. 2	11.5	c	3	− 5	wk	6	+ 63	5	−161	1	+103	4	+36
E342.....	Nov. 25	9.0	b	38	− 51	str	9	+ 11	5	−177	3	+ 97	5	− 2
E349.....	Nov. 27	9.5	b	60	− 43	str	...	....	4	−197	4	+109	3	−35
γ24541.....	1942 Oct. 3	11.5	b	34	+ 2	m	...	....	5	−165	3	+159	4	−23
E624.....	Oct. 19	9.0	b	28	− 10	m	13	+118	5	−115	2	+189	4	+61
E1048.....	1944 Jan. 4	9.5	c	...	....	...	...	....	...	....	...	....	...	....
E1196.....	Aug. 27	11.0	c	37	+ 39	str	...	....	9	−108	3	+160	4	+29
E1229.....	Sept. 25	10.0	c	56	− 39	str	...	....	12	−173	7	+108	7	−32
Weighted mean..	....	.....	.....	...	− 25	.....	...	+ 59	...	−166	...	+125	...	− 5

The red emission components of H (*Ca* II) and of $H\gamma$, $H\delta$, and $H\epsilon$ are too weak to be seen except on the strongest exposures. The bright violet component of $H\epsilon$ falls near the absorption reversal of H(*Ca* II) and is practically obliterated; $H\beta$ appears as a strong double emission line on all plates; $H\alpha$ is a single bright line on plates E349 and E624, but the D(*Na* I) lines show only in absorption; *He* I is present on some of the plates but is too weak for reliable measurement.

Both absorption and emission lines of RW Aur lack the sharpness necessary for good measurement of radial velocity, and the accordance of the results both for individual lines and for the plate means leaves much to be desired. The discrepancies, however, are much greater than can be attributed to errors of measurement alone. A large part of the difficulty is probably due to the presence of the absorption reversals, which lie somewhat to the red of the centers of the stronger emission lines. These absorption components are especially strong in H and K (*Ca* II) and the hydrogen lines, but they are also present with varying intensity on the red side of many other lines.

[5] *A.N.*, **170**, 339, 1906.

The dark lines obviously originate in a stratum lying above that region of the stellar atmosphere in which the emission lines are formed. Variations in the intensities or positions of the dark lines tend to shift the bright components. Examples of the varying intensities of the emission components resulting from relative shift of the superposed absorption line may be found in $H\beta$. The ratios of the intensities of the violet to the red components on the spectrograms listed in Table 2 are, in order, 3 to 1, 4 to 4, 2 to 1, 3 to 1, 4 to 3, 4 to 4, 4 to 2, 3 to 2, 5 to 5, and 4 to 4. The decrement of the violet component from $H\beta$ to $H\delta$ is gradual, but the increasing width of the absorption line causes a steep decrement of the red component.

The conditions in the atmosphere seem far from stable, and no simple correlation of motion with light-variation can be drawn from the observations. A comparison of the mean velocity deduced from the few measurable low-level absorption lines with that from *Ca* II and hydrogen indicates that the upper layer is expanding with reference to the lower. The velocities from the bright lines are not readily comparable because of the interference of the absorption reversals.

The variable star RW Aur has an 11.5-mag. visual companion ($d = 1''.2$; $p = 254°$). A spectrogram of the companion was obtained on January 4, 1944, but on account of the proximity of the principal star its interpretation is uncertain. Additional observations are needed before its spectrum can be described with confidence. No strong bright lines are present, but in the region of $H\beta$ some emission is suspected.

Although obscured areas may be found near by, the sky in the immediate vicinity of RW Aur seems practically free from absorbing clouds.

UY Aurigae 044530

The variation of UY Aur was discovered in 1913 as a result of studies of Moscow photographs by Mme Ceraski.[6] Later observers have reported rapid irregular changes in brightness within intervals of a few days. The photographic-magnitude range is from 11.6 to 14.0. The spectrum was first observed[7] at Mount Wilson in 1932 and found to be like that of T Tau except that the lines of enhanced iron were comparatively weak at that time.

Ten spectrograms of UY Aur (Table 3) have been obtained. The spectrum is outstanding in the T Tauri group for strength of the bright lines of hydrogen and helium. On plate E619, $H\alpha$ is extremely strong, and on most of the spectrograms λ 4026 and λ 4471 of *He* I are well marked. The line λ 4685 of *He* II was measured on one plate; D_1 and D_2 of *Na* I are fairly strong in absorption, but emission is weak or absent; D_3 (5875 *He* I) is probably present in emission. The extraordinary strength of the hydrogen series may result from the combined emission of both stars of the visual pair.

Considerable variation in the intensities of the emission lines of the metallic elements is indicated in the seventh column of Table 3. The hydrogen, calcium, and helium lines are not greatly affected by these changes and maintain about the same intensity at all phases. On plate E606 seven hydrogen lines were measured to the violet of $H\zeta$. As in the other stars of the group, the metallic emission lines are stronger and more numerous when the star is brighter. The absorption spectrum of UY Aur is poor; the lines are few and diffuse; the spectral type is not far from G5; and the absolute magnitude is that of the main sequence, λ 4435 and λ 4454 being well marked. Titanium oxide bands are suspected on some of the plates, but they may originate in the companion star.

On September 30, 1941, a twelfth-magnitude visual companion was discovered ($d = 0''.8$; $p = 212°$). The spectrogram of UY Aur obtained at that time indicated that some of the bright lines were displaced slightly along the length of the lines as if they had their origin in the companion star. This appearance is also present on several other plates with more or less certainty, depending upon the seeing and the accuracy of guid-

[6] *A.N.*, **193**, 439, 1913.

[7] A. H. Joy, *Pub. A.S.P.*, **44**, 385, 1932.

ing. On account of the proximity of the two stars, it has not thus far been possible to resolve the images sufficiently to separate the two spectra entirely. Further observations are needed before an adequate description of the two stars can be given.

R Coronae Australis 185537

The variable star, R CrA (CD−37°13027, mag. 9.7), is situated in the nucleus, near the preceding edge of the variable nebula, NGC 6729. The nebula is about 1.5 minutes of arc in length and extends beyond the neighboring star T CrA. Variation of both star and nebula was found by J. F. J. Schmidt in Athens and later confirmed photographically by R. Innes[8] and H. Knox-Shaw.[9] The remarkable changes in the form and appearance of the nebula are shown in Plate XV, but the relationship between the variations of star and nebula has not yet been satisfactorily determined. The nebula so enshrouds the star that, except with the lowest magnification, the object resembles the head of a comet rather than a stellar point and measures of the brightness of the variable are affected by the adjacent nebulosity. The extreme range in the brightness of the star as recorded by various observers is nearly 4 mag. The Harvard plates [10] indicate rapid irregular changes of about 2 mag. within a few days, superposed on slower changes over several years.

TABLE 3

OBSERVATIONS OF UY AURIGAE

Plate	Date	Vis. Mag.	Disp.	Emission Lines			Absorption Lines	
				No.	Vel.	Int.	No.	Vel.
					km/sec			km/sec
C6135	1932 Sept. 12	12.0	c	5	+18	wk	....	....
6150	Oct. 10	11.7	c	6	−19	m	3	+38
E285	1941 Sept. 30	11.6	c	29	+ 7	str	12	+34
322	Oct. 31	11.6	c	16	−40	m	2	−15
345	Nov. 26	11.6	c	25	−15	str	....	....
606	1942 Oct. 1	12	c	16	+ 3	m	6	+38
619	Oct. 18	12	c	29	+19	str	....	....
677	Nov. 16	11.5	c	11	−18	wk	....	....
726	Dec. 29	12.5	c	12	+10	wk	3	+11
1233	1944 Sept. 26	12	c	15	−14	wk	2	+39
Weighted mean	....	....	....	....	− 3	....	....	+30

The spectrum was photographed in 1917 by V. M. Slipher,[11] who suspected that it was like that of R Mon. Observations by E. Hubble[12] in 1920–21 showed "bright unsymmetrically reversed hydrogen and enhanced iron lines on an absorption spectrum that is approximately G-type but which has contradictory characteristics" and led to the conclusion that "the spectrum resembles that of T Tauri except that it has no bright H and K."

[8] *Union Obs. Circ.*, No. 36, p. 282, 1916.

[9] *Bull. Helwan Obs.*, **1**, 141, 1920.

[10] S. Gaposchkin, *Harvard Ann.*, **105**, 514, 1937.

[11] *Bull. Lowell Obs.*, **3**, 66, 1918.

[12] *Mt. W. Contr.*, No. 241; *Ap. J.*, **56**, 181, 1922.

All the Mount Wilson spectrographic observations are included in Table 4.

The emission lines are not sharp, and few absorption lines can be distinguished with the dispersion used. On no plate are H and K definitely present in emission; but the exposures in that region are not adequate to make it certain that the lines are absent, although they are evidently weaker than in any other star of the group. This may be a sufficient reason for excluding R CrA; on the other hand, its connection with the variable nebula, its location in a dark lane, and its spectrum, in general, make it probable that it is related in some way to the T Tauri variables. The line $H\beta$ is fairly strong in emission, and the decrement of the hydrogen series toward the violet is rapid. As in the spectrum of RW Aur, the 1920–1921 plates show a strong absorption reversal in the normal position dividing the emission of $H\beta$ unsymmetrically, the violet component being the stronger. Later plates are quite different in this respect. On D1213 and E474 the absorption is weak or absent, and the emission is in the normal position. On plates C7509 and E539 the emission at $H\beta$ is weak, and $H\gamma$ is an absorption line about as strong as in an early F star with no emission showing. The bright *Fe* II lines vary in intensity. They are best

TABLE 4

OBSERVATIONS OF R CORONAE AUSTRALIS

Plate	Date	Vis. Mag.	Spec.	Disp.	Emission Lines			Absorption Lines		Observer
					No.	Vel.	Int.	No.	Vel.	
C583.....	1920 Aug. 21	......	F5	b	......	......	wk	......	......	E. P. Hubble
588.....	Aug. 22	......	......	b	......	......	wk	......	......	E. P. Hubble
1099.....	1921 June 28	......	F5	b	......	......	m	......	......	E. P. Hubble
7509.....	1940 June 26	12.5	F5	c	......	......	wk	......	......	....
D1213.....	Aug. 10	14±	F5	d	......	......	wk	......	......	E. P. Hubble
E474.....	1942 June 3	12	F5	c	2	−97	m	2	−36	....
539.....	Aug. 3	13.5	F5	d	......	......	wk	......	......	....

seen on plates C1099, June 28, 1921, and E474, June 3, 1942. Helium is not present, and no other chromospheric lines are recognized on our plates, but further observation at other times might be more favorable for their appearance. On plate E539, August 3, 1942, the bright lines are very weak; even $H\beta$ is hardly visible. The absorption components of hydrogen are present, however, in considerable strength. The spectrum on this plate somewhat resembles that of T CrA. Other than the lines of hydrogen, few absorption lines can be distinguished in the spectrum of R CrA.

Partly because of the strong hydrogen absorption lines, $H\gamma$ and $H\delta$, the spectral type of R CrA appears to be earlier than that of R Mon and might be estimated as F5. The spectroscopic absolute magnitude cannot be determined on account of the absence of absorption lines. Since it is embedded in nebulous matter, the apparent magnitude of the star may be considerably diminished.

The spectral type of T CrA, which lies in the direction of the tail of the cometary nebula, 5 seconds of time following and 0.8 minutes of arc south of R CrA, is F0. Three spectrograms taken at minimum light show no bright lines or abnormal spectrographic features. On the other hand, S CrA, 12.5 minutes of arc distant in the same lane of dark nebulosity as R CrA, is one of the most advanced of the T Tauri stars.

S CORONAE AUSTRALIS 185437

The variability of S CrA, which is 43 seconds of time preceding and 0.3 minutes of arc south of R CrA, was discovered by J. F. J. Schmidt in Athens in 1866. He followed its light-changes for nearly twenty years but was unable to find any regularity in its behavior. Suspected periods were of the order of 6 days.

Since 1925 the star has been observed by members of the American Association of Variable Star Observers, and magnitude estimates have been published yearly in *Harvard Circulars*. The variation has usually been between 11.5 and 12.5 mag., but in 1933 and 1941 estimates brighter than 11.0 mag. were reported.

Six spectrograms of S CrA (Table 5) were obtained at Mount Wilson in the years 1941–1944. The first spectrogram, which was obtained when the star was one or more magnitudes brighter than at the dates of later exposures, shows a rich emission spectrum characteristic of the T Tauri class. The bright lines of *Ca* II, *Fe* I, *Sr* II, and *Ca* I are nearly as well shown as in RU Lup. These lines are much reduced in intensity on later plates. The strong lines of *Ca* II (H and K) and hydrogen remain practically unchanged. Weak absorption reversals, which are not readily measurable, are superposed upon the strong emission; *He* I (λ 4026 and λ 4471) and *He* II (λ 4685) are stronger than in any other star

TABLE 5

OBSERVATIONS OF S CORONAE AUSTRALIS

Plate	Date	Vis. Mag.	Disp.	Emission Lines		
				No.	Vel.	Int.
					km/sec	
E287	1941 Oct. 1	11.4*	c	50	−24	str
510	1942 July 4	12.5	c	21	−39	m
556	Aug. 31	13	c	7	−39	wk
859	1943 June 21	13	c	26	−27	wk
881	July 11	12.5	c	9	−19	wk
1106	1944 June 28	12	c	25	−56	m
Weighted mean					−33	

* A.A.V.S.O. estimate.

of the group. None of the observations cover the red portion of the spectrum. No absorption lines are visible, and estimates of spectral type and spectroscopic absolute magnitude are impossible.

A companion of S CrA of magnitude 13.5 was observed on July 4, 1942 ($d = 1''$; $p \doteq 135°–140°$). On account of its faintness it probably has little effect on the spectrum of the brighter star.

RU Lupi 1550*37*

The variation in brightness of this star (HD 142560, CoD−37°10602) was detected by Miss J. C. Mackie[13] on Harvard photographs after Miss Cannon[14] had noted bright lines of hydrogen and calcium in its spectrum. The survey plates show irregular changes in brightness from 1893 to 1912 with a magnitude range from 9 to 11. Probably on account of its southern declination, it has been neglected by variable-star observers for nearly thirty years. No further observations are recorded until 1940, when P. W. Merrill[15] photographed its spectrum and called attention to the presence of strong emission of *Fe* II and *Ti* II, as well as of *H* and *Ca* II. He also found weak lines corresponding to *Fe* I, *Mg* II, *Cr* II, and *Sc* II. The appearance of bright lines of *Fe* I and strong H and K of *Ca* II indicated at once that the spectrum was related to that of T Tauri. Dr. Merrill

[13] *Harvard Circ.*, No. 196, 1916.

[14] *Harvard Circ.*, No. 201; *A.N.*, **207**, 215, 1918.

[15] *Pub. A.S.P.*, **53**, 342, 1941.

has been kind enough to place at my disposal two spectrograms of RU Lup, together with his line identifications and velocity measures for discussion in this paper.

Ten additional spectrograms, listed in Table 6, were obtained at the 100-inch telescope. The magnitude estimates may be influenced by atmospheric absorption, since the minimum zenith distance of RU Lup at Mount Wilson is 72°. The star was certainly much fainter in March and April, 1942, than at the other dates of observation.

With the dispersion used, no absorption lines can be distinguished, although the distribution of light in the continuous spectrum suggests a temperature lower than G0. No titanium oxide bands are present. The lack of absorption lines may be accounted for, in part, by the great number of emission lines of neutral, as well as ionized, atoms. Probably many lines having insufficient emission to show above the continuous spectrum have enough radiation to fill up the absorption in the lines. On one plate, E878, however, a faint central absorption line appears within the emission of both H and K.

TABLE 6

OBSERVATIONS OF RU LUPI

Plate	Date	Vis. Mag.	Disp.	Emission Lines			Observer
				No.	Vel.	Int.	
					km/sec		
C7535	1940 July 20	11	b	13	−22.5	m	P. W. Merrill
7680	1941 May 16	10.5	b	44	− 7.1	str	P. W. Merrill
E424	1942 Mar. 25	12	c	4	− 8.5	wk	
447	Apr. 24	12	c	18	−13.0	wk	
465	May 22	11	c	29	+ 8.5	m	
469	May 23	11	b	10	− 5.1	m	
496	June 21	10.5	b	78	− 9.0	str	
833	1943 May 11	11	b	70	− 6.7	m	
854	June 19	11.5	b	64	− 8.1	m	
878	July 10	11	b	52	− 1.8	str	
1393	1945 Apr. 20	11	d	....	....	m	
1407	May 21	10.5	c	....	....	m	
Weighted mean	....	....	....	....	− 6.4	....	....

The bright lines of RU Lup as well as of other stars of the T Tauri group are much wider than those of the Me variables or of stars like Z And, and the accuracy of measurement is correspondingly decreased. The apparent width of *H* and *Ca* II lines is about 4.5 A. Lines of other elements are, perhaps, one-half as wide, but none can be called sharp.

In the spectral region λλ 3900–6500, 120 emission lines have been measured and identified. The 15 elements represented, together with the number of lines, are shown in Table 7 in order of their line intensities. Many other blended lines are probably present in RU Lup, but they are not resolved on account of the width of the lines and the low dispersion. This list, however, will be sufficient to give a general idea of the characteristics of the emission spectrum of the T Tauri stars. The metallic lines were greatly weakened in March and April, 1942, when the light of the star diminished.

The radial velocities (Table 6) from the emission lines were practically constant during the period of observation. The weighted mean velocity is −6.4 km/sec. Likewise, the range in velocity among the different elements is small, as indicated by Table 8, in which the elements are arranged in order of atomic weight. For most of the elements the agreement of the individual lines is satisfactory, but for *Ca* II the measures indicate a discrepancy of 36 km/sec between H and K. The effect is systematic and is seen on all plates measured, K being displaced 21 km/sec toward the red and H 15 km/sec toward the violet with reference to the mean of all lines. Both lines appear to be quite symmetrical. The faint emission of *Hε* would have little influence on the position of *H*, but it is possible that absorption in the hydrogen line might decrease the intensity of *H* on the red edge and tend to shift the line toward the violet. No explanation for the displacement of K, however, seems evident.

RU Lup is located in one of the dark lanes of the southern Milky Way but is not known to have any companion or to be enveloped in local nebulosity.

R Monocerotis 063308

The variable star R Mon (BD+8°1427) is the nucleus of the comet-shaped variable nebula, NGC 2261. Its light-changes were detected by J. F. J. Schmidt[16] in Athens in

TABLE 7

ELEMENTS REPRESENTED IN RU LUPI

Atom	No. Lines	Atom	No. Lines	Atom	No. Lines	Atom	No. Lines	Atom	No. Lines	Atom	No. Lines
H.......	5	*Ti* II....	35	*Ca* I....	1	*He* I....	1	*Ni* II...	1	*Na* I...	2
Ca II....	5	*Sr* II....	2	*Sc* II....	5	*Cr* I.....	3	*Mg* II...	1	*He* II...	1
Fe II....	28	*Fe* I.....	24	*Cr* II....	6						

TABLE 8

RADIAL VELOCITIES OF ELEMENTS IN RU LUPI

Element	Vel.	No. Lines	Element	Vel.	No. Lines	Element	Vel.	No. Lines	Element	Vel.	No. Lines
	km/sec			km/sec			km/sec			km/sec	
H.......	−10.7	4	*Sc* II....	− 3.6	5	*Cr* II....	+ 4.0	6	*Ni* II....	− 7.2	1
Ca I.....	−12.0	1	*Ti* II....	− 8.5	35	*Fe* I.....	− 6.7	22	*Sr* II....	+11.5	2
Ca II....	− 3.0	2	*Cr* I.....	− 3.0	2	*Fe* II....	−11.0	28			

1861, and later observations indicated that the variations were irregular, with a range of at least 4 mag. It is difficult to make precise estimates of brightness on account of the surrounding nebulosity. With high magnification the star resembles the nucleus of a comet near the sun.

From direct photographs taken with the 24-inch reflector of the Yerkes Observatory, E. Hubble[17] in 1916 discovered that marked changes in the outline of the nebula occurred within a period of a few months. In size and general form it is similar to NGC 6729, except that the outer parts of NGC 2261 are longer, extending to a distance of 2.5 minutes of arc.

The spectrum of the star and that of the nebula were photographed by V. M. Slipher[18] at the Lowell Observatory in 1917 and found to be identical, indicating that the light of the nebula is reflected radiation from the star. He suggested that the emission spectrum resembled that of Nova Aurigae. The lines that can be identified from his measures are those of *H*, *Ti* II, and *Fe* II, which do not necessarily pertain to novae, although, soon

[16] *A.N.*, **55**, 91, 1861.

[17] *Proc. Nat. Acad.*, **2**, 230, 1916; *Ap. J.*, **44**, 190, 1916, and **45**, 351, 1917.

[18] *Op. cit.*, p. 63.

after maximum, bright lines of ionized metals are prominent in most novae and at minimum they may appear in such stars as RS Oph.[19] The high-excitation features characteristic of the spectra of novae are entirely lacking in R Mon. On the other hand, the Mount Wilson spectra of R Mon and probably the Lowell spectrum, as well, correspond closely with the spectra of the T Tauri variables. The bright hydrogen lines are accompanied by moderately strong dark lines on the violet side as in T Tau, and the decrement of the series toward the violet is steep. The H and K lines are present in emission but are not nearly so strong as in T Tau. Helium and the nebular lines are definitely lacking. The normal absorption spectrum is extremely weak.

By attributing the formation of cometary nebulae to the action of radiation pressure from the star upon the surrounding material particles, R. Minkowski[20] finds that the radiation of dwarf stars is insufficient to produce nebular forms such as NGC 2261 or NGC 6729 from surrounding material and concludes that if the spectrum is G-type, as appears from the distribution of light in its spectrum and from analogy with other stars of

TABLE 9

OBSERVATIONS OF R MONOCEROTIS

Plate	Date	Vis. Mag.	Disp.	Emission Lines			Absorption Lines		Observer
				No.	Vel.	Int.	No.	Vel.	
					km/sec			km/sec	
D1158.......	1939 Nov. 13	......	d	......	....	wk	.....	....	E. Hubble
1159.......	Nov. 13	......	d	......	....	wk	.....	....	E. Hubble
E319.......	1941 Oct. 30	13	c	19	+18	m	7	+12	
727.......	1942 Dec. 29	13	c	7	+28	wk	.....	....	
Weighted mean....	....	......	.....	......	+21	......	.....	+12	....

the group, the stars must be giants with absolute magnitudes of +0.7 or brighter. Since the absorption lines are poorly shown in the spectra, the spectroscopic absolute magnitudes cannot be well determined. A. van Maanen[21] estimates the trigonometric parallax of R Mon to be smaller than 0".005, which, without allowance for obscuration, would indicate an absolute magnitude brighter than +2.8 at maximum and +7.5 at minimum.

The Mount Wilson spectrographic observations of R Mon are listed in Table 9. Plates D1158 and D1159, taken with the 3-inch camera, are excellent, but the dispersion is too low to allow accurate measurement. On plate E319 the stronger chromospheric lines are well represented, and the resemblance of the emission spectrum to that of T Tau is beyond question.

The K line is three or four times as strong as H, and both are considerably weaker than in any of the other stars of the group except R CrA and UX Tau. None of the observations, however, were made at maximum light.

Although R Mon is deeply imbedded in nebulosity, its spectrum shows no marked effect of selective absorption, as far as can be estimated by visual inspection of the distribution of the continuous spectrum.

T Tauri 041619

The variable T Tau (BD+19°706) has been chosen as the typical star of this group of peculiar variable stars because it is the best known, is among the brightest, and rep-

[19] Adams, Joy, and Humason, *Pub. A.S.P.*, **39**, 366, 1927.

[20] *Pub. A.S.P.*, **54**, 190, 1942.

[21] *Mt. W. Contr.*, No. 237, 1922.

resents the group with respect to both emission and absorption spectra. It has an extended history, its variation in light having been discovered by Hind in 1852. It is 2.3 seconds of time following, 37 seconds of arc north of, the faint irregular patch of nebulosity well known as Hind's variable nebula (NGC 1555). The star itself is surrounded by faint variable shell, 4″ in diameter, observed by S. W. Burnham[22] in 1890 and by H. D. Curtis[23] in 1899. On Dr. Baade's remarkable photograph of T Tau, reproduced on Plate XV, this shell appears as a semicircular protuberance between the two diffraction rays on the right-hand side.

TABLE 10

OBSERVATIONS OF T TAURI

Plate	Date	Est. Mag.	Spec.	Disp.	Emission Lines			Absorption Lines		Observer
					No.	Vel.	Int. Metal. Lines	No.	Vel.	
						km/sec			km/sec	
P76......	1915 Jan. 12	11	G5	d	5	(+86)	str	....	....	F. G. Pease
γ4479......	Nov. 18	......	G5	b	2	+ 0.7	wk	7	+ 3.9	W. S. Adams
Σ24......	1918 Oct. 5	10	G4	d	....	....	str	....	....	R. F. Sanford
C121......	1919 Oct. 13	......	G5	a	10	+23	wk	35	+29	R. F. Sanford
C3128......	1925 Jan. 11	10	G6	b	5	+26.4	str	7	+21.6	R. F. Sanford
C5350......	1929 Oct. 21	9.5	G7	b	....	....	wk	....	....	R. F. Sanford
G1554......	1940 Sept. 20	9	.....	b	1	+21	wk	9	+41.4	R. F. Sanford
G1555......	Sept. 20	9	.....	b	....	....	wk	....	....	R. F. Sanford
γ23821......	1941 Oct. 12	9.0	G8	c	4	+15.0	wk	5	− 8.9	
E321......	Oct. 31	9.0	G5	c	19	− 5.8	str	15	+ 6.6	
E344......	Nov. 26	9.0	G4	b	45	+36.2	m	22	+18.3	
γ23928......	Dec. 4	10	G8	b	15	− 2.0	wk	17	+21.7	
E366......	Dec. 26	9.0	G3	b	5	+34.5	wk	11	+41.7	
γ24022......	1942 Feb. 6	9.2	G5	c	4	+18.2	wk	4	+23.3	
E596......	Sept. 29	9	G5	b	8	+10.9	wk	19	+10.2	
E620......	Oct. 18	9	G6	c	11	+11.9	m	6	+10.2	
E752......	1943 Jan. 15	9.0	G6	b	12	+18.6	wk	4	+46.0	
G1838......	Sept. 12	9	.....	c	....	....	.....	....	....	
E1237......	1944 Sept. 27	11.0	G8	c	33	+25.8	m	10	+41.4	
Weighted mean....	....	......	.....	.....	....	+19.6	.....	....	+24.6	

The brightness of T Tau changes erratically from magnitude 9.0 to magnitude 12.8. It may vary rather quickly in the course of a few weeks, or the fluctuations may be delayed for months. In the last three years the brightness, at the time of observation, has remained near maximum.

The spectrograms show emission and absorption lines, both of which lack the sharpness needed for accurate measurement. The spectral type is about G5, and the spectroscopic absolute magnitude based on the Mount Wilson system of 1935 is +5.0.

The Mount Wilson observations are collected in Table 10. I am greatly indebted to Dr. W. S. Adams and Dr. R. F. Sanford for the use of their plates and measures in this study. The first known slit-spectrogram of T Tau was obtained in 1915 by F. G. Pease, and many of the interesting features of the spectrum were described by Adams and

[22] *M.N.*, **51**, 94, 1890.

[23] *Pub. A.S.P.*, **27**, 242, 1915.

Pease.[24] On account of the low dispersion used, the published radial velocity and some of the identifications of lines have little weight. Fifteen emission lines were measured, H and K being the most intense. The *Fe* I lines, λ 4063 (probably blended with λ 4068 [*S* II]) and λ 4132, which they did not identify, are stronger than the lines of *Fe* II. Lines of *Ti* II are too weak for measurement. The metallic lines are extremely weak on the second plate taken ten months later, and only a few lines of *Fe* II were measured in addition to those of *H* and *Ca* II. Dr. Sanford's low-dispersion spectrogram of 1918 is very similar to that of 1915.

Higher dispersion was used for C121 than for any other plate of this series, but unfortunately it was obtained at a time when the emission lines were comparatively weak. Sanford[25] measured 11 bright and 35 absorption lines, which he estimated to be 3–4 A in width. The metallic bright lines measured were without exception the strongest lines of *Fe* II.

The region of the D lines is well shown on G1554. Sodium is doubtless present in emission in T Tau, although the strength of the lines is not much greater than that of the adjacent continuous background. Bright D_1 and D_2 show, according to Dr. Sanford's measures, approximately normal velocities, but they are accompanied by strong absorption, which is displaced 165 km/sec to the violet, as compared with the mean of the bright lines. Similar violet displacements of absorption adjacent to the strong emission lines of hydrogen and *Ca* II (H and K) appear on plates showing the violet regions of the spectrum. On G1554, the bright lines of *Fe* II are distinctly weak, and the hydrogen lines $H\beta$ and $H\alpha$, only moderately strong as compared with the continuous spectrum.

The infrared region, λλ 6400–8700, of the spectrum is shown on plate G1838. Although the spectrogram is underexposed, it shows that the $3^2D - 4^2P^0$ triplet of *Ca* II (λλ 8498, 8542, 8662) cannot be present in any great strength either in emission or in absorption.

In general, the *Ca* II (H and K) emission lines of T Tau appear with an intensity unsurpassed by any star of the group; the hydrogen lines are strong, $H\gamma$ being only slightly fainter than *H* (*Ca* II), but the metallic lines are weaker than those of most of the other stars of the group. The metallic bright lines are not prominent features of the spectrum of T Tau on most of our spectrograms.

Although the absorption lines are wide, they are not greatly affected by the emission spectrum, and measures of radial velocity based on a considerable number of lines should give reliable results. The mean velocities of the emission and absorption lines agree closely, but the range in both is more than can reasonably be attributed to errors of measurement. The scatter among the mean velocities of the various elements is comparatively small and probably is not significant.

RY Tauri 041528

The variation in brightness of RY Tau (BD+28°645; 9.1 mag.) was discovered from Harvard photographs by Miss Leavitt[26] in 1907. The range was estimated to be 1 mag. with slow and irregular changes. Few photometric observations have been reported since its discovery.

The star RY Tau is at the head of a faint fan-shaped nebula about 7 minutes of arc in length, which spreads out in two tails toward the dark nebula, Barnard 214. The close connection between the star and the bright nebula is apparent from photographs by E. E. Barnard[27] and by O.C. Collins.[28] The image of the star at the telescope appears stellar because of the faintness of the nebulosity.

[24] *Pub. A.S.P.*, **27**, 132, 1915.

[25] *Pub. A.S.P.*, **32**, 59, 1920.

[26] *Harvard Circ.*, No. 130, 1907.

[27] *Atlas of the Milky Way*, Pl. 5, 1927.

[28] *Ap. J.*, **86**, 543, 1937.

The Mount Wilson observations and velocities are listed in Table 11. The first three spectrograms were obtained by E. Hubble, who estimated the spectral type to be F8±.[29] These plates are, unfortunately, not suitable for radial-velocity determinations. Later spectrograms show some evidence of variation in type between F8 and G2. The absorption lines are only slightly widened and should give good measures of radial velocity and spectroscopic absolute magnitude.

The four lower members of the hydrogen series and the calcium lines H and K are the only emission lines found in RY Tau. As indicated in the eighth column of Table 11, the strength of the bright H and K lines varies considerably. They appear in emission on all fully exposed plates but are especially strong on plate E272, where they are about 5 A in width and K is much stronger than H. On plates E560 and E1273, H and K are divided

TABLE 11

OBSERVATIONS OF RY TAURI

Plate	Date	Est. Mag.	Spec.	Disp.	*Ca* II Emission Lines			Absorption Lines		Observer
					No.	Vel.	Int.	No.	Vel.	
						km/sec			km/sec	
C587	1920 Aug. 21	......	......	b	.....	....	.....	......	....	E. Hubble
934	1921 Mar. 9	9.6	G0	b	.....	....	.....	......	....	E. Hubble
2526	1923 Nov. 11	11.0	G0	b	.....	....	.....	......	....	E. Hubble
γ21100	1936 Dec. 5	10	F8	b	.....	....	wk	12	+25	
E272	1941 Sept. 28	10	G2	c	1	0	str	13	+32	
γ23840	Nov. 2	9	G0	b	.....	....	wk	6	+23	
23922	Dec. 4	9	G2	c	.....	....	wk	10	+32	
E407	1942 Feb. 22	10	......	b	.....	....	.....	6	+18	
560	Aug. 31	8.8	G0	b	2	+15	str	15	+32	
621	Oct. 18	9	F8	c	2	−20	str	13	+26	
γ24669	Nov. 13	8.8	F8	b	.....	....	m	14	+22	
E1273	1944 Nov. 7	9.5	G0	b	2	$\begin{cases}-116\\+44\end{cases}$	m	14	+24	
Weighted mean	....	......	......	.....	.....	−8	.....	......	+26.2	....

by deep absorption. The violet component of K has about twice the intensity of the red component, but the strong absorption of $H\epsilon$ greatly weakens the red component of H. The violet emission components of $H\gamma$ and $H\delta$ appear as faint bright edges of the wide absorption lines. On the red-sensitive plate E621, $H\alpha$ is a strong bright line and $H\beta$ is faintly visible.

The radial velocities from the absorption lines show little or no variation. Measurements of bright H and K are uncertain on account of the width of these lines and of insufficient exposure on some plates.

UX Tauri 042418

The variability of UX Tau (BD+17°736; 9.5 mag.) was discovered from Harvard photographs by Miss H. Locke in 1917.[30] Photographic observations by P. P. Parenago,[31] H. Rugemer,[32] and M. Esch[33] indicate that the light-changes are rapid and con-

[29] *Mt. W. Contr.*, No. 241; *Ap. J.*, **56**, 182, 1922.

[30] *Harvard Circ.*, No. 201, 1918.

[31] *Nishni-Novgorod, Veränderliche Sterne*, **4**, 154, 1933.

[32] *A.N.*, **255**, 180, 1935.

[33] *Valkenburg Obs. Veröff.*, No. 7, p. 13, 1937.

tinuous. Periods of a few days were, at first, suggested but have not been confirmed by later observers. The extreme photographic range was found to be nearly 3 mag., from 10.5 to 13.4 mag. The spectral type was estimated as G5 by Miss Cannon.[34]

Eight spectrograms of UX Tau were obtained at Mount Wilson, as listed in Table 12. The star was near maximum light at the time of observation. In this star H and K are faintly bright on all plates sufficiently exposed in the violet region. On the red-sensitive plate, E622, *Hα* is a moderately strong emission line, and *Hβ* is faintly bright. On the remaining plates of the series, *Hβ* is present in absorption but appears to be somewhat weakened on E309 and E568. No other lines appear in emission in UX Tau.

The absorption spectrum indicates that the spectral type is dG5. The range in velocity shown in the last column is somewhat larger than would be expected for stars of constant velocity.

TABLE 12

OBSERVATIONS OF UX TAURI

Plate	Date	Vis. Mag.	Spec.	Disp.	*Ca* II Emission Lines		Absorption Lines	
					No.	Vel	No.	Vel
						km/sec		km/sec
E309..........	1941 Oct. 28	10.5	G6	c	......	....	17	+27
425..........	1942 Mar. 25	10.5	G5	c	......	....	6	+42
568..........	Sept. 2	10.5	G6	c	2	− 6	13	+ 9
622..........	Oct. 19	10.5	G6	c	3	− 5	10	+ 2
676..........	Nov. 16	10.5	G5	c	......	....	9	+16
995..........	1943 Oct. 14	10	G0	c	......	....	6	+27
γ26339..........	1944 Dec. 6	10.5	G5	b	2	+31	17	+30
E1299..........	Dec. 9	10.5	G5	c	2	+20	11	+22
Weighted mean.	....	....	......	......	......	+18	....	+24

UX Tau is situated in the center of a densely obscured area. A thirteenth-magnitude companion, 5.7 seconds of arc preceding, shows a spectrum whose type is dM2e, with bright hydrogen and *Ca* II (H and K). Its radial velocity agrees with the mean for the variable star, and they probably form a physical double.

UZ TAURI 042625

The variable star UZ Tau, whose light-changes were first noticed by K. Bohlin[35] on photographs taken in 1921, has been described as "nova-like." Maxima brighter than 9.5 were observed on October 4, 1921, by Bohlin and on January 6, 1924, by M. Esch.[36] P. P. Parenago[37] reported photographic magnitudes as faint as 15.0 in 1934, and K. Himpel[38] estimated the visual magnitude to be about 13.2. On 148 Harvard photographs from January, 1890, to November, 1900, and from September, 1913, to January, 1941,[39] Miss Dorrit Hoffleit found that the magnitudes generally varied irregularly from 13.5 to 14.5 and no maximum was brighter than 11.7.

[34] *Harvard Bull.*, No. 897, 1934.

[35] *A.N. Beob.-Zirk.*, **3,** 55 (No. 32), 1921.

[36] *A.N. Beob.-Zirk.*, **6,** 5 (No. 2), 1924.

[37] *Nishni-Novgorod, Veränderliche Sterne,* **4,** 228, 1934.

[38] *A.N.*, **270,** 185, 1940.

[39] *Pub. A.S.P.*, **54,** 33, 1942.

The star UZ Tau is 53 seconds of time following and 1 minute of arc south of BD+24°719. At the time of the first Mount Wilson observation,[40] the star was discovered to be double ($d = 3''.7$; $p = 92°$; mag. 13.0 and 13.3, vis.). Since, on the first spectrograms, both stars appeared to be of class dMe, the conclusion was erroneously drawn that the variation previously observed pertained to a dwarf M-type star with emission lines of hydrogen and *Ca* II. Later observations[41] made in October and December, 1942, revealed that the following star had increased in relative brightness by half a magnitude or more and its spectrum had so changed that it became clear that the star belonged to the T Tauri group, although the titanium bands remained faintly visible on most of the plates. Further observations are needed to determine with certainty whether two or three stars are involved and whether the variable star and the preceding dMe star are physical companions.

TABLE 13

OBSERVATIONS OF UZ TAURI

Plate	Date	Vis. Mag.	Disp.	Emission Lines: No.	Emission Lines: Vel.	Emission Lines: Int.	Observer
					km/sec		
E341........	1941 Nov. 25	13.5	c	4	− 5	wk	
367........	1942 Jan. 12	13.3	d	....	....	wk	M. L. Humason
396........	Feb. 3	13.2	d	....	....	wk	
571........	Sept. 3	13.2	c	5	+ 6	wk	
617........	Oct. 17	13.0	c	83	− 6	str	
633........	Oct. 21	12.5	d	....	....	str	
711........	Dec. 15	13.0	c	....	....	....	
720........	Dec. 28	12.5	c	59	−16	str	
1047........	1944 Jan. 4	12.8	c	11	− 1	wk	
1224........	Sept. 23	14.0	c	6	+25	wk	
1318........	1945 Jan. 8	12.5	c	81	+ 1	str	
Weighted mean....	....	....	......	....	− 5	....	....

Eleven spectrograms of UZ Tau have been obtained (Table 13). Since the position angle of the stars is nearly 90°, images of both fall on the slit of the spectrograph and may be photographed at the same exposure. On account of the faintness of the stars, observations can be made only with low dispersion and with favorable seeing. Three plates—E367, E396, and E633—were made with the 3-inch Schmidt camera and, on account of low dispersion, were not used for radial-velocity determinations. Plate E711, which was sensitive to the red portion of the spectrum, is weak but shows the hydrogen $H\alpha$ emission line in both stars, that of the variable being the fainter of the two, although the stars were estimated to be of equal visual brightness at the time of observation.

Absorption lines in the spectrum of UZ Tau are weak and cannot be measured with certainty. The changes in the spectrum are extraordinary (Pl. XIV), varying from close resemblance to that of BD+20°2465 (dM3) with indistinct absorption lines (E341) to a spectrum with a strong continuous background upon which are superposed, at different times, few (E1047) or many (E720) emission lines. In general, a greater number of bright lines appears when the star is more luminous. However, E1047 shows distinct peculiarities. The magnitude, according to the estimate made at the time this spectrogram was

[40] A. H. Joy, *Pub. A.S.P.*, **54**, 33, 1942.

[41] A. H. Joy, *Pub. A.S.P.*, **55**, 38, 1943.

taken, was somewhat brighter than the mean, and the titanium bands are obliterated, yet bright lines, other than hydrogen, H and K, *Fe* II, and λ 4068 [*S* II] are few and weak. The peculiar features of E1047 have not been detected in spectrograms of any other star of the group, although E677 and E726 of UY Aur are similar in certain respects. The *He* I line, λ 4471, and the [*S* II] pair, λ 4068 and λ 4076, are enhanced with respect to the *Fe* II lines; H and K are tremendously strong and of nearly equal intensity, while on plates having large numbers of the low-level bright lines H is considerably weaker than K. Although few bright lines are visible, no measurable absorption lines are present.

Continual change seems to be characteristic of the spectrum of UZ Tau. On the other hand, the preceding star of the visual pair, which was the brighter of the two when the duplicity was first discovered, is apparently unaffected by the peculiar behavior of its neighbor and its spectrum shows no certain changes. The mean velocity of the Me companion determined from its emission lines is +16.0 km/sec, which is not in good agreement with −5 km/sec for the variable, as shown in Table 13. This lack of accordance may be due to instability in the atmosphere of the variable and to the effect of absorption components on the position of the emission lines.

Measurements of proper motion and trigonometric parallax are much needed, but near-by comparison stars are few because of heavy obscuration.

TABLE 14

OBSERVATIONS OF XZ TAURI

Plate	Date	Vis. Mag.	Disp.	Emission Lines			Absorption Lines	
				No.	Vel.	Int.	No.	Vel.
					km/sec			km/sec
E350	1941 Nov. 28	12.5	c	39	+48	m	....	....
610	1942 Oct. 2	13.5	c	98	+25	m	26	+109
1202	1944 Aug. 28	12.0	c	91	+32	str	....	....
Weighted mean	....	....	....	....	+32	....	....	+109

XZ TAURI 042518

The star XZ Tau follows UX Tau by 97 seconds of time in nearly the same declination. Its variability was discovered in 1928 by Mme G. Schajn[42] from an examination of photographs taken at Simeis in the Crimea. The photographic range was estimated to be from 11.3 to 13.5 mag. From the nine plates at her disposal a long period of 260 days was suspected. Observations by M. Esch[43] in the following year indicated that the variations were irregular and that large changes in brightness (9.5–13.2 mag.) occurred within a few days. H. Rugemer[44] also found the changes in light to be irregular, with variations between 10.4 and 13.5 mag.

In the last four years, at times when observations could be made on Mount Wilson, XZ Tau was faint. The three spectrograms obtained (Table 14) indicate that it is one of the most remarkable members of the T Tau group. Even at minimum light, when only low dispersion could be employed, 105 bright lines were measured, the largest number measured on any single plate of the T Tauri series. Observations at maximum light should be most interesting if, as is usually found in stars of the group, the chromospheric lines are stronger and more numerous at maximum than at minimum. Spectrograms in the red and at maximum light will be obtained when opportunity permits.

[42] *A.N.*, **234**, 41, 1928.

[43] *A.N. Beob.-Zirk.*, **11**, 10 (No. 4), 23 (No. 9), 1929.

[44] *A.N.*, **255**, 180, 1935.

No companion star or bright nebulosity has been detected near XZ Tau, which is, however, in the edge of the heavy obscuring cloud which surrounds UX Tau.

GENERAL DISCUSSION OF THE SPECTRA

Only three of the T Tauri stars (T Tau, RY Tau, and UX Tau) have absorption spectra sufficiently well defined to permit a precise determination of the spectral type (Table 18). For RW Aur, UY Aur, and R CrA, rough estimates may be made with the aid of such lines as are available. A variation of three- or four-tenths of a class was found for T Tau and RY Tau. The remaining stars, in which the bright-line spectrum is dominant, have few absorption lines; but, from the distribution of light and the general appearance of the spectrum, we conclude that the physical conditions correspond to those of about type G5. For some stars of the group, selective absorption by surrounding nebulosity may introduce uncertainty. Peculiar features of the spectra such as are mentioned in the preceding descriptions of the individual stars are often so prominent that the usual criteria of classification cannot be employed.

As shown in Plates XII and XIII the intensity of the emission spectrum varies greatly from star to star. When arranged according to the increasing prominence of the emission spectrum, the sequence of the stars is that of Table 15. Although the observations cover

TABLE 15

GREATEST STRENGTH OF EMISSION SPECTRUM

Star	Relative Strength of Emission	Star	Relative Strength of Emission	Star	Relative Strength of Emission	Star	Relative Strength of Emission
UX Tau......	0	T Tau.......	4	S CrA.......	8	RU Lup.....	10
RY Tau......	1	R Mon.......	4	RW Aur....	9	UZ Tau.....	10
R CrA.......	2	UY Aur......	5	XZ Tau.....	9		

a considerable period of time and indicate a marked change in the intensity of emission for each star, the maximum possible strength of the emission spectrum for an individual star may not, thus far, have been observed, and, therefore, the order of the arrangement may not be final.

The changes occurring in the spectra of individual stars are illustrated in Plate XIV. The emission spectrum is usually more prominent at maximum light.

Table 16 is a complete list of all identified bright lines arranged according to the atomic number of the elements. In the successive columns appear the laboratory wave length and intensity from the M.I.T. Table, the electron transitions, the low and high excitation potential, and the maximum relative intensity observed in each of the seven stars showing extensive bright-line spectra. The intensities are on an arbitrary scale and are intended only to give an idea of the relative strengths. An intensity of zero is assigned to lines too faint or indefinite for good measurement. The varying quality of the spectrograms and the difference in the dispersion have made it necessary to adjust the values of the intensities of the lines so that they will be more or less comparable for different plates.

In addition to *H* and *He*, 17 different metallic atoms are represented by more than 160 lines which arise from low levels of excitation. Iron contributes about half the total number of lines. Both neutral and ionized atoms are represented, and a trace of the strongest forbidden lines seems reasonably certain. A large number of additional lines would certainly be found by the use of higher dispersion and by an extension of the search to other spectral regions of shorter or longer wave length.

The line λ 4068.62 [*S* II] is remarkably persistent in the stars with conspicuous emission spectra. Its changes in intensity do not appear to be correlated with the variations

TABLE 16

RELATIVE INTENSITIES OF EMISSION LINES IN T TAURI STARS

Laboratory λ	Laboratory Int.	Transition	E.P. (Volts)	Emission Intensity in Star: T Tau	R Mon	UY Aur	S CrA	RW Aur	XZ Tau	RU Lup	UZ Tau
				H							
3770.63...	15	$2^2P^0-11^2D$	10.2–13.4	.....	.....	2	.....	3	1	.....	1
3797.91...	20	$2^2P^0-10^2D$	10.2–13.4	.....	.....	2	1	2	3	.....	2
3835.40...	40	$2^2P^0-\ 9^2D$	10.2–13.4	.....	.....	5	0	2	3	.....	3
3889.05...	60	$2^2P^0-\ 8^2D$	10.2–13.3	2	.....	15	4	4	5	2	4
3970.07...	80	$2^2P^0-\ 7^2D$	10.2–13.3	2	.....	4	.....	.....	.....	3	2
4101.74...	100	$2^2P^0-\ 6^2D$	10.2–13.2	20	0	35	15	16	15	20	10
4340.46...	200	$2^2P^0-\ 5^2D$	10.2–13.0	30	5	40	20	25	30	40	15
4861.33...	500	$2^2P^0-\ 4^2D$	10.2–12.7	40	15	40	30	40	40	40	30
6562.82...	3000	$2^2P^0-\ 3^2D$	10.2–12.0	50	.....	50	.....	50	.....	50	40
				He I							
4026.19...	70	$2^3P^0-\ 5^3D$	20.9–23.9	0	.....	1	1	0	.....	1	....
4471.48...	100	$2^3P^0-\ 4^3D$	20.9–23.6	0	.....	3	2	1	2	2	2
5875.62...	1000	$2^3P^0-\ 3^3D$	20.9–23.0	.....	.....	.....	.....	1	.....	.....	....
				He II							
4685.75...	300	$3^2D-\ 4^2F^0$	48.2–50.8	.....	.....	1	1	.....	.....	0	....
				Na I							
5889.95...	9000	$3^2S-\ 3^2P^0$ $\frac{1}{2}-1\frac{1}{2}$	0.0– 2.1	1	.....	.....	.....	.....	.....	1	....
5895.92...	5000	$\frac{1}{2}-\frac{1}{2}$	....	0	.....	.....	.....	.....	.....	1	....
				Mg I							
3829.35...	100	$3^3P^0-\ 3^3D$ 0–1	2.7– 5.9	.....	.....	.....	.....	.....	1	.....	....
3832.31...	250	1–2	....	.....	.....	.....	.....	.....	0	.....	0
3838.26...	300	2–	....	.....	.....	.....	.....	.....	1	.....	0
5167.34...	100	$3^3P^0-\ 4^3S$ 0–1	2.7– 5.1	.....	.....	.....	.....	1	.....	.....	....
5172.70...	200	1–1	....	.....	.....	.....	.....	2	.....	.....	....
5183.62...	500	2–1	....	.....	.....	.....	.....	3	.....	.....	....
				Al I							
3944.03...	2000	$3^2P^0-\ 4^2S$ $\frac{1}{2}-\frac{1}{2}$	0.0– 3.1	.....	.....	.....	.....	1	1	.....	2
3961.53...	3000	$1\frac{1}{2}-\frac{1}{2}$	....	.....	.....	.....	.....	1	1	.....	1

TABLE 16—*Continued*

Laboratory λ	Laboratory Int.	Transition	E.P. (Volts)	Emission Intensity in Star: T Tau	R Mon	UY Aur	S CrA	RW Aur	XZ Tau	RU Lup	UZ Tau
		Si I									
3905.53...	20	$3p\,^1S-4S\,^1P^0$ 0–1	1.9–5.1	1	.....	0	2	2	2	2	4
		[*S* II]									
4068.62...	......	$p^3\,^4S^0-p^3\,^2p^0$ $1\frac{1}{2}-1\frac{1}{2}$	0.0–3.1	1	0	2	2	2	2	2	4
		Ca I									
4226.73...	500	$4\,^1S-4\,^1P^0$ 0–1	0.0–2.9	0	.....	0	3	2	3	5	4
		Ca II									
3933.67...	600	$4\,^2S-4\,^2P^0$ $\frac{1}{2}-1\frac{1}{2}$	0.0–3.1	40	3	45	15	45	25	20	50
3968.47...	500	$\frac{1}{2}-\frac{1}{2}$	....	35	1	50	20	35	25	15	25
8498.02...	300	$3\,^2D-4\,^2P^0$ $1\frac{1}{2}-1\frac{1}{2}$	1.7–3.1	.....	.....	.....	.....	.....	.....	10	....
8542.09...	1000	$2\frac{1}{2}-1\frac{1}{2}$	....	.....	.....	.....	.....	.....	.....	20	....
8662.14...	1000	$1\frac{1}{2}-\frac{1}{2}$	....	.....	.....	.....	.....	.....	.....	..20	....
		Sc II									
4246.83...	80	$a\,^1D-z\,^1D^0$ 2–2	0.3–3.2	.....	.....	0	0	2	1	2	0
4314.08...	50	$a\,^3F-z\,^3D^0$ 4–3	0.6–3.5	.....	0	0	3	2	1	4	4
4320.74...	50	3–2	....	.....	.....	.....	1	0	0	2	1
4325.01...	50	2–1	....	.....	.....	.....	0	.....	.....	1	....
4670.40...	100	$b\,^1D-z\,^1F^0$ 2–3	1.4–4.0	.....	.....	.....	1	1	.....	2	....
		Ti II									
3900.54...	30	$a\,^2G-z\,^2G^0$ $4\frac{1}{2}-4\frac{1}{2}$	1.1–4.3	.....	.....	.....	.....	.....	1	.....	1
3913.46...	40	$3\frac{1}{2}-3\frac{1}{2}$	....	.....	.....	.....	.....	.....	1	.....	1
4012.39...	35	$a\,^2F-z\,^4G^0$ $2\frac{1}{2}-2\frac{1}{2}$	0.6–3.6	.....	.....	.....	0	1	1	0	0
4163.65...	35	$b\,^2F-x\,^2D^0$ $3\frac{1}{2}-2\frac{1}{2}$	2.6–5.5	1	.....	1	2	3	.....	2	0
4171.90...	15	$2\frac{1}{2}-1\frac{1}{2}$	....	.....	.....	.....	1	0	.....	1	....
4294.12...	60	$a\,^2D-z\,^2D^0$ $2\frac{1}{2}-2\frac{1}{2}$	1.1–4.0	0	.....	.....	2	.....	0	0	1
4337.92...	70	$1\frac{1}{2}-1\frac{1}{2}$	....	1	.....	.....	2	.....	.....	.....	2

TABLE 16—*Continued*

Laboratory		Transition		E.P. (Volts)	Emission Intensity in Star							
λ	Int.				T Tau	R Mon	UY Aur	S CrA	RW Aur	XZ Tau	RU Lup	UZ Tau
							Ti II—*Continued*					
4290.23*..	35	$a^4P-z^4D^0$	1½–2½	1.2– 4.0	.....	.....	.....	.....	.....	.....	.....	.....
4300.05...	40		2½–3½	....	1	.....	.....	0	1	1	1	1
4301.93...	25		½–1½	....	0	.....	.....	1	1	.....	2	1
4307.90*..	100		1½–1½	....	.....	.....	.....	.....	.....	.....	.....	.....
4312.87...	35		2½–2½	....	1	.....	0	1	1	1	2	1
4320.96...	12		1½–½	....	0	.....	.....	1	1	0	1	1
4330.71...	15		2½–1½	....	.....	.....	.....	0	1	1	1	0
4399.77...	40	$a^2P-z^4D^0$	1½–2½	1.2– 4.0	.....	.....	.....	1	.....	0	3	3
4407.68...	2		½–½	....	.....	.....	.....	1	.....	0	0	0
4395.04...	50	$a^2D-z^2F^0$	2½–3½	1.1– 3.9	.....	1	2	3	3	3	5	3
4443.80...	80		1½–2½	....	.....	2	2	2	3	3	6	4
4450.49...	12		2½–2½	....	.....	.....	0	.....	1	1	2	2
4417.72*..	40	$a^4P-z^2D^0$	1½–2½	1.2– 4.0	.....	.....	.....	.....	.....	.....	.....	.....
4468.50...	80	$a^2G-z^2F^0$	4½–3½	1.1– 3.9	1	2	.....	1	2	1	4	2
4501.27...	60		3½–2½	....	1	2	0	2	2	1	4	2
4529.46...	5	$a^2H-z^2G^0$	4½–4½	1.6– 4.3	.....	.....	.....	.....	.....	.....	2	.....
4549.63*..	100		5½–4½	....	.....	.....	.....	.....	.....	.....	.....	.....
4571.98...	150		4½–3½	....	2	.....	1	2	3	4	4	3
4533.97...	30	$a^2P-z^2G^0$	1½–2½	1.2– 4.0	1	1	0	1	1	0	3	2
4563.77...	100		½–1½	....	0	.....	1	1	2	1	2	1
4589.95...	40		1½–1½	....	2	1	1	0	1	0	1	1
							Cr I					
4254.35...	5000	$a^7S-z^7P^0$	3–4	0.0– 2.9	.....	.....	.....	0	.....	0	1	.....
4274.80*..	4000		3–3	....	0	1	1	2	0	2	2	2
4289.72*..	3000		3–2	....	.....	.....	.....	4	2	3	4	3
							Cr II					
4558.66...	20	$b^4F-z^4D^0$	4½–3½	4.1– 6.8	0	.....	0	1	1	1	1	2
4588.22...	10		3½–2½	....	2	.....	0	.....	0	1	1	0
4616.66...	4		1½–1½	....	.....	.....	.....	.....	.....	.....	2	...
4618.83...	6		2½–1½	....	0	.....	.....	0	.....	1	1	2
4634.09...	5		1½–½	....	1	.....	.....	.....	.....	.....	2	...
4824.12...	4	$a^4F-z^4F^0$	4½–4½	3.9– 6.4	.....	.....	.....	2	1	0	3	2
4848.27...	2		3½–3½	....	.....	.....	.....	0	1	.....	1	2

TABLE 16—*Continued*

Laboratory λ	Laboratory Int.	Transition		E.P. (Volts)	T Tau	R Mon	UY Aur	S CrA	RW Aur	XZ Tau	RU Lup	UZ Tau
				Mn I								
4030.76...	500	$a^6S-z^6P^0$	2½–3½	0.0– 3.1	....	....	....	....	0	1	....	2
				Fe I								
3727.62...	200	$a^5F-y^5F^0$	3–2	0.9– 4.2	....	....	....	....	1	1	....	0
3758.24...	700		3–3	....	....	....	....	....	2	0	....	....
3767.20...	500		1–1	....	....	....	....	....	....	0	....	0
3787.88...	500		1–2	....	....	....	....	....	....	0	....	1
3795.00...	500		2–3	....	....	....	....	....	....	1	....	1
3815.84...	700	$a^3F-y^3D^0$	4–3	1.5– 4.7	....	....	....	....	2	0	....	1
3827.82...	200		3–2	....	....	....	....	....	1	....	....	1
3820.43...	800	$a^5F-y^5D^0$	5–4	0.9– 4.1	....	....	1	....	1	0	....	2
3825.88...	500		4–3	....	....	....	....	....	0	1	....	1
3840.44...	400		2–1	....	....	....	....	....	0	0	....	0
3849.97...	500		1–0	....	....	....	....	....	1	0	....	0
3872.50...	300		2–2	....	....	....	....	....	2	1	....	1
3878.02*..	400		3–3	....	....	....	....	....	....	....	....	....
3824.44...	150	$a^5D-z^5D^0$	4–3	0.0– 3.2	....	....	....	....	2	2	....	1
3856.37...	500		3–2	....	....	....	....	....	1	1	....	1
3859.91...	1000		4–4	....	....	....	1	....	2	3	....	3
3878.58*..	300		2–1	....	....	....	....	....	2	2	....	2
3886.28...	600		3–3	....	....	....	....	....	3	2	....	3
3895.66...	400		1–0	....	....	....	....	....	1	1	....	0
3899.71...	15		2–2	....	....	....	....	....	1	1	....	0
3920.26...	500		0–1	....	....	....	....	....	....	1	....	0
3922.91...	600		3–4	....	....	....	....	....	1	2	....	2
3927.92...	500		1–2	....	....	....	....	....	0	1	....	1
4005.25...	250	$a^3F-y^3F^0$	3–2	1.6– 4.6	....	....	....	1	....	0	1	2
4045.82...	400		4–4	....	....	....	0	2	2	2	2	3
4063.60...	400		3–3	....	2	....	3	5	5	4	5	8
4071.74...	300		2–2	....	....	....	....	....	1	....	1	0
4132.06...	300		2–3	....	2	....	1	4	2	3	4	8
4143.87...	400		3–4	....	0	....	....	1	1	1	2	2
4139.92...	40	$a^5F-z^3F^0$	2–2	1.0– 4.0	0	....	0	0	....	....	0	....
4202.03...	400	$a^3F-z^3G^0$	4–4	1.5– 4.4	0	....	....	2	2	3	2	2
4250.79...	400		3–3	....	....	....	0	....	1	2	1	1
4271.76...	1000		4–5	....	....	....	1	1	2	2	4	4
4307.91*..	1000		3–4	....	2	....	0	3	2	4	3	2
4325.76...	1000		2–3	....	2	2	....	1	1	3	3	3
4282.41...	600	$a^5P-z^5S^0$	3–2	2.2– 5.0	0	....	0	1	1	1	2	1
4294.13...	700	$a^3F-z^5G^0$	4–4	1.5– 4.4	0	....	....	2	....	1	2	1
4383.55..	1000		4–5	....	3	2	2	5	4	4	6	8
4404.75...	1000		3–4	....	0	....	....	2	1	1	4	2
4415.12...	600		2–3	....	....	1	1	2	1	1	2	1

TABLE 16—*Continued*

Laboratory λ	Laboratory Int.	Transition		E.P. (Volts)	Emission Intensity in Star: T Tau	R Mon	UY Aur	S CrA	RW Aur	XZ Tau	RU Lup	UZ Tau
				Fe I—*Continued*								
4375.93...	500	$a^5D-z^7F^0$	4–5	0.0–2.9	1	1	2	3	2	3	5	5
4427.31...	500		3–4	....	1	1	1	1	2	2	3	3
4435.15...	70		2–1	....	.....	.....	.....	1	.....	1	1	1
4461.65...	300		2–3	....	0	.....	0	1	0	1	2	2
4466.55...	500		1–0	....	.....	.....	0	0	1	0	3	2
4482.17...	150		1–2	....	0	0	1	1	2	1	3	2
4494.57...	400	$a^5P-x^5D^0$	2–3	2.2–4.9	.....	.....	.....	0	.....	.....	1	0
4528.62...	600		3–4	....	1	.....	0	1	0	0	2	1
				Fe II								
3914.48...	2	$a^4P-z^6D^0$	2½–1½	1.7–4.8	0	.....	.....	.....	1	1	1	1
3938.29...	2		2½–2½	....	0	.....	.....	.....	1	1	0	2
4122.64...	4	$b^4P-z^4F^0$	2½–2½	2.6–5.5	0	0	1	1	1	0	1	1
4178.87...	10		2½–3½	....	2	2	3	6	4	4	10	12
4258.16...	2		1½–1½	....	1	0	.....	0	1	.....	2	2
4296.58...	2		1½–2½	....	1	0	1	2	0	1	2	2
4173.48...	8	$b^4P-z^4D^0$	2½–2½	2.6–5.5	2	2	3	5	5	5	8	12
4233.17...	100		2½–3½	....	6	4	5	5	6	6	12	16
4273.32*..	3		1½–½	....	.....	.....	.....	.....	.....	.....	.....	.....
4303.17...	12		1½–1½	....	1	3	2	3	2	2	6	6
4351.76...	30		1½–2½	....	1	3	3	8	4	6	10	20
4385.38...	4		½–½	....	2	1	0	2	1	1	3	2
4416.82*..	7		½–1½	....	1	3	3	4	3	3	8	10
4489.18...	2	$b^4F-z^4F^0$	3½–2½	2.8–5.6	0	2	1	3	2	3	6	4
4491.41...	2		1½–1½	....	1	2	2	3	2	3	4	4
4515.34...	10		2½–2½	....	1	1	2	2	2	2	7	4
4520.24...	40		4½–3½	....	3	2	2	3	3	3	4	5
4555.90...	12		3½–3½	....	1	2	2	4	3	4	8	6
4629.33...	7		4½–4½	....	4	3	3	5	5	5	10	12
4666.75...	2		3½–4½	....	.....	.....	.....	2	0	1	3	3
4508.28...	40	$b^4F-z^4D^0$	1½–½	2.8–5.6	1	1	1	1	3	1	8	5
4522.63...	60		2½–1½	....	2	2	2	3	3	3	5	6
4541.52...	2		1½–1½	....	1	.....	.....	0	0	1	3	2
4549.47*..	100		3½–2½	....	3	2	2	4	3	3	10	10
4576.33...	3		2½–2½	....	1	1	0	.....	1	.....	2	2
4583.85...	150		4½–3½	....	4	4	3	7	5	6	12	15
4620.52...	3		3½–3½	....	1	.....	1	.....	1	.....	4	5
4731.49...	5	$a^6S-z^4D^0$	2½–3½	2.9–5.5	0	.....	0	2	1	1	4	3
4923.92...	30	$a^6S-z^6P^0$	2½–1½	2.9–5.4	6	3	4	4	10	6	10	10
5018.44...	80		2½–2½	....	5	3	4	3	15	4	6	5
5169.03...	2		2½–3½	....	5	.....	5	.....	10	.....	6	.....

TABLE 16—*Continued*

Laboratory λ	Laboratory Int.	Transition		E.P. (Volts)	Emission Intensity in Star: T Tau	R Mon	UY Aur	S CrA	RW Aur	XZ Tau	RU Lup	UZ Tau
				Fe II—*Continued*								
5197.59...	10	$a^4G-z^4F^0$	$2\frac{1}{2}-1\frac{1}{2}$	3.2–5.6	1	.....	2	.....	2	.....	1	....
5234.63...	5		$3\frac{1}{2}-2\frac{1}{2}$	....	.....	.....	4	.....	3	.....	.....	....
5275.99...	2		$4\frac{1}{2}-3\frac{1}{2}$	....	.....	.....	2	.....	2	.....	.....	....
5316.61...	150		$5\frac{1}{2}-4\frac{1}{2}$	....	4	.....	4	.....	2	.....	3	....
				[*Fe* II]								
4243.97...	......	a^4F-a^4G	$4\frac{1}{2}-5\frac{1}{2}$	0.2–3.2	1	1	0	1	0	0	.....	1
4359.34...	......	a^6D-a^6S	$3\frac{1}{2}-2\frac{1}{2}$	0.0–2.9	.....	1	0	.....	.....	1	.....	1
				Ni I								
3736.81...	300	$a^1D-z^5F^0$	2–2	0.4–3.7	.....	.....	.....	.....	.....	1	.....	3
3783.53...	500		2–3	....	.....	.....	.....	.....	.....	0	.....	0
3775.57...	500	$a^1D-z^3D^0$	2–2	0.4–3.7	.....	.....	.....	.....	1	0	.....	0
3807.14...	800		2–3	....	.....	.....	.....	.....	.....	1	.....	1
				Sr II								
4077.71...	400	$5^2S-5^2P^0$	$\frac{1}{2}-1\frac{1}{2}$	0.0–3.0	.....	.....	1	3	3	2	2	4
4215.52...	300		$\frac{1}{2}-\frac{1}{2}$	....	.....	.....	2	3	3	3	5	5

* Probable blends: λ 3878.58 *Fe* I –λ 3878.02 *Fe* I; λ 4274.80 *Cr* I –λ 4273.32 *Fe* II; λ 4289.72 *Cr* I –λ 4290.23 *Ti* II; λ 4307.91 *Fe* I –λ 4307.90 *Ti* II; λ 4416.82 *Fe* II–λ 4417.72 *Ti* II; λ 4549.47 *Fe* II–λ 4549.63 *Ti* II

of the other bright lines. At times λ 4068 remains practically undiminished when most of the metallic lines have disappeared. The measures support the identification with [*S* II]. The companion line at λ 4076.22 is probably blended with λ 4077.71 *Sr* II and has not been separately observed. These sulphur lines arise from a low metastable level and are frequently found in novae and occasionally in nebulae. None of the other characteristic nebular lines have been observed in these stars.

Distorted Multiplets of *Fe* I

When the emission spectrum appears in the T Tauri stars, λ 4063 and λ 4132 of *Fe* I are much strengthened as compared with the other members of the multiplet $a^3F - y^3F^0$ and are probably affected by some such fluorescent mechanism as that proposed for λ 4202 and λ 4307 of the $a^3F - z^3G^0$ multiplet in Me variable stars.[45] Under

[45] Thackeray and Merrill, *Pub. A.S.P.*, **48**, 331, 1936.

the most favorable conditions, λ 4063 may rival λ 4233 *Fe* II in strength. This phenomenon is unique in the stars of this group and does not occur in the solar chromosphere. The two lines λ 4063 and λ 4132, together with λ 3969, arise from the same upper level of the atom. The latter line has not been observed in emission, possibly because its identity is lost in the complex structure of the region between *H* and *Hε*. All the remaining members of the multiplet have been observed as bright lines of relatively low intensity in the T Tauri stars.[46]

Comparison with the Solar Chromosphere

The most significant characteristic of the spectra of the T Tauri stars is the low-excitation bright-line spectrum which is prominent in most of the stars at certain phases. It occurs with varying intensity in all the stars of the group except RY Tau and UX Tau,

TABLE 17

Comparison of Emission Lines in T Tauri Stars and Solar Chromosphere

Element	Chromosphere			T Tau Stars		Element	Chromosphere			T Tau Stars	
	No. Lines	Mean Intensity	Mean Height	No. Lines	Mean Max. Intensity		No. Lines	Mean Intensity	Mean Height	No. Lines	Mean Max. Intensity
Ca II	2	200	14,000 km	2	50	*Sc* II	4	24	2,220 km	4	2
H	6	160	8,900	6	40*	*Al* I	2	30	2,000	2	2
Sr II	2	70	6,000	2	4	*Fe* II	7	25	1,700	7	12
Ca I	1	40	5,000	1	5	*Ba* II	4	29	1,550	0	.....
Mg I	6	46	4,170	6	1	*Cr* I	3	21	1,500	3	2
He I	11	20	3,840	3	2	*Na* I	2	22	1,500	2	1
He II	1	2	3,500	1	1	*Cr* II	1	15	1,500	1	2
Ti II	21	29	2,410	19	2	*Fe* I	25	13	1,470	21	3

* Mean of four lines ($H\alpha$–$H\delta$) only.

which may be considered as rudimentary members of the T Tauri class as far as the spectrum is concerned, showing only *H*, *K*, *Hα*, and *Hβ* in emission.

This bright-line spectrum is quite different from other stellar emission spectra, but its resemblance to that of the solar chromosphere is sufficient to invite a detailed comparison.

The mean heights (> 1000 km) and intensities[47] of chromospheric lines between λ 3750 and λ 6600 are arranged in Table 17 according to height. The numbers of these same chromospheric lines found in the T Tauri stars and their estimated mean maximum intensities (on quite a different scale) are shown in the last two columns of the table. A marked similarity between the emission spectra of the stars and that of the higher levels of the chromosphere is apparent. The bright lines of calcium (H and K) and of hydrogen are outstanding in both. In the stars, as well as in the sun, *Fe* I and *Ti* II have the greatest number of lines of high intensity. The low-excitation *Fe* I lines are more generally represented in emission in these stars than in any other known stellar source, and their maxi-

[46] Since this paragraph was written, George H. Herbig (*Pub. A.S.P.*, **57**, 166, 1945) has reported his observations of this phenomenon in the spectrum of RW Aur and attributed the enhancement of λ 4063 and λ 4132 to populating the y^3F level through the action of λ 3968.47 *Ca* II upon λ 3969.26. The width of the calcium line in the T Tauri stars is more than sufficient to cover the difference in wave length.

[47] S. A. Mitchell, *Ap. J.*, **71**, 11, 1930.

mum strength is relatively greater than in the chromosphere. The *He* I lines are few and decidedly weak in the stars. Only the triplet members, λλ 4026, 4471, and 5875, are certainly present; λ 4685 *He* II was measured in the spectra of three stars, but it is faint; and *Mg* I and *Sc* II are weaker than in the sun. On the other hand, *Fe* II is relatively stronger, and its lines are surpassed in strength only by those of *H* and *Ca* II. The lines λ 4077 and λ 4215 of *Sr* II are well shown but do not have the excessive intensity found in the sun.

The stellar emission lines are much broader than those of the chromosphere, and the strong lines of *H* and *Ca* II often suffer distortion by deep reversals which are not observed in the sun, yet the general resemblance of the spectra leads to the conclusion that they must have their origin under similar physical circumstances. The excitation seems to be somewhat lower in the T Tauri stars than in the solar chromosphere, while in the stars with combination spectra, such as Z And, the excitation is higher.[48]

ABSOLUTE MAGNITUDES AND COLOR INDICES

The spectroscopic absolute magnitudes of T Tau, RY Tau, and UX Tau may be estimated from their absorption lines. The results shown in Table 18 indicate that these

TABLE 18

SPECTRAL TYPES, SPECTROSCOPIC ABSOLUTE MAGNITUDES, AND COLOR INDICES

Star	Spectral Type	M_{sp}	Color Index and Source
RW Aur	dG5	....	+0.7 mag.; P. P. Parenago, *op. cit.*, **4**, 222, 1933
UY Aur	dG5	....	
R CrA	F5	....	+0.97 mag.; C. Payne-Gaposchkin, *Harvard Ann.*, **89**, 193, 1935
T Tau	dG5	+5.0	
RY Tau	dG0	+4.3	+0.93 mag.; O. C. Collins, *Ap. J.*, **86**, 551, 1937
UX Tau	dG5	+5.2	+1±mag.; *Harvard Circ.*, No. 201, 1918
UZ Tau	....	....	>+1 mag.; K. Himpel, *A.N.*, **270**, 185, 1940

three stars are dwarfs of the main sequence. For UX Tau and UZ Tau additional evidence may be sought from their visual companions, assuming that they are physically related. The spectral types of both companions are dM3e, and the absolute magnitudes are estimated to be +10.5. If we use 13.3 as the estimated apparent visual magnitude of both companions, $m - M = +2.8$. Applying this modulus to the visual magnitudes (9.9 and 9.2) at maximum of the two variable stars, we obtain values of 7.1 and 6.4, respectively, for their absolute magnitudes, 1.9 and 1.2 mag. fainter than that determined from the spectral lines of UX Tau. On the basis of these data, the variables must be subdwarfs—an inference which does not seem justified. The matter can be harmonized only by concluding that the companions have peculiar spectra, that the stars are not physical pairs, or that general or local obscuration has a greater effect in reducing the visual luminosity of the variable star than that of its fainter and probably redder companion. Both stars are in lanes of heavy obscuration, but no surrounding shells have been observed. The large color indices of Table 18 show a definite color excess, but hardly enough to meet the difficulty.

The spectra of R CrA and R Mon differ considerably from those of other members of the group, and positive evidence of low luminosity is lacking. On the assumption that the

[48] H. H. Plaskett, *Pub. Dom. Ap. Obs.*, **4**, 152, 1928.

changes in the appearance of the attached nebulae result from the passage of light from one part of the nebula to another, the distance of R CrA has been computed by E. P. Hubble[49] and found to be 100 parsecs, which corresponds to a minimum absolute magnitude of +4.7. For the same star, Gaposchkin and Greenstein[50] find from star counts a distance of 150 parsecs, giving a minimum absolute magnitude of +3.9. Elimination of the effect of obscuration on the apparent magnitudes would give brighter absolute magnitudes but probably not sufficient luminosity to rank them among the giants.

A trigonometric parallax of $-0\overset{''}{.}011$ relative to near-by comparison stars was found by A. van Maanen[51] for R Mon. This negative result probably indicates that the distant background stars of this field are obscured and that only foreground stars are available for comparison. On account of the presence of obscuring material in the regions surrounding most of the T Tauri stars, the trigonometric method offers little hope for determining distance, absolute magnitude, or proper motion. In some of the fields close comparison stars are completely lacking.

TABLE 19

MEAN RADIAL VELOCITIES OF T TAURI STARS

Star	Emission Lines		Absorption Lines		Abs.−Em.	Star	Emission Lines		Absorption Lines		Abs.−Em.
	No. Plates	Vel.	No. Plates	Vel.			No. Plates	Vel.	No. Plates	Vel.	
RW Aur....	9	−25	4	+ 59	+84	RY Tau..	4	− 8	9	+ 26.2	+34
UY Aur....	10	− 3	6	+ 30	+33	UX Tau..	4	+18	8	+ 24	+ 6
R CrA.....	1	−97	2	− 36	+61	UZ Tau...	7	− 5	.....	....	......
S CrA......	6	−33	.....	....	......	XZ Tau...	3	+32	1	+109	+67
RU Lup....	10	− 6.4	.....	....	......						
R Mon.....	2	+21	1	+ 12	− 9	Weighted mean..	.....	....	.....	....	+25
T Tau......	14	+19.6	14	+ 24.6	+ 5						

No determinations of absolute magnitude, parallax, or color index have been made for RW Aur, UY Aur, S CrA, RU Lup, or XZ Tau. Such observations are needed, but there is no reason to suspect that the physical properties of these stars differ from those of the other members of the group.

Although values of absolute magnitude and distance are made uncertain by the presence of absorbing clouds, the available evidence indicates that the T Tauri stars belong to the main sequence and that their distance is of the order of 100–150 parsecs.

RADIAL-VELOCITY MEASURES

The measures of radial velocity from both emission and absorption lines are summarized in Table 19. The differences (Abs. − Em.) show that in the mean the emission lines are displaced toward the violet with respect to the absorption lines. This result agrees in direction with that found for the irregular Me variables[52] and the Mira stars,[53] but the measured displacement is somewhat greater for the T Tauri stars.

49 *Mount Wilson Obs., Annual Reports*, p. 252, 1921.

50 *Harvard Bull.*, No. 904, 1936.

51 *Mt. W. Contr.*, No. 237, p. 14, 1922.

52 A. H. Joy, *Mt. W. Contr.*, No. 668; *Ap. J.*, **96**, 165, 1942.

53 P. W. Merrill, *Mt. W. Contr.*, No. 644; *Ap. J.*, **93**, 380, 1941.

Lack of agreement in the measures of different plates of the same star indicates that the radial velocities may be variable, with a range of 30–40 km/sec. It seems probable that both the emission and the absorption strata are subject to irregular motions but that, in general, the emission layers are rising with respect to the absorbing clouds.

CONCLUDING REMARKS

Only 11 stars have been found which have the qualifications necessary for inclusion in the T Tauri group. The spectral criteria were given high weight. Probably other stars which have similar characteristics exist and will be recognized when competent objective-prism observations can be extended to the faint stars of the Milky Way. However, stars of this class may be expected to be comparatively few because of the peculiar circumstances of their location and their relationship to the galactic absorbing clouds.

Solely on the basis of their light-curves, RR Tau, WW Vul, and perhaps some of the irregular variables in Orion might have been included, but their spectra are of earlier type (A3–F8) and without extensive emission. Other variables, such as Z And and CI Cyg, are similar in some respects but of higher luminosity. Their emitting atmospheres have bright *Ca* II[54] and some faint *Fe* I[55] lines, although, in general, their spectra show lines requiring much higher excitation than that of the T Tauri stars. Their numerous sharp forbidden lines, doubtless, originate in an extended tenuous atmosphere which favors high ionization, while, on the contrary, the presence, in general, of lines of neutral and easily ionized atoms in the T Tauri stars points to a source of considerably lower excitation and higher density. Also, the high-luminosity variables with combination spectra showing strong 4686 *He* II lines are not associated with dark lanes of the Milky Way or with reflection nebulae.

The changes which occur from time to time in the spectra of the T Tauri variables merit more detailed study than can be given in this general survey. They should be definitely correlated with the variation in brightness of the stars. As a result of the higher density of the gases and the smaller dimensions involved, the changes are quite different in nature from those observed in other variable stars. With further observations, the effect of near-by companion stars or of surrounding shells may be investigated. Maximum brightness, which, for some of the stars of the group, bears a resemblance to the outburst of a nova, has not been observed spectrographically. Such extreme activity might furnish a valuable clew to the interpretation of the problem.

[54] P. W. Merrill, *Mt. W. Contr.*, No. 688; *Ap. J.*, **99**, 15, 1944.

[55] Swings and Struve, *Ap. J.*, **97**, 206, 1943.