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SPECTROSCOPIC STUDY OF 31 CYGNI*

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Abstract

The spectra of 31 Cygni were taken at the Asiago Observatory in Italy. Reduction was made using the 2nd and 4th order non-linear least square method.

Spectral lines which were relatively sharp or strong were identified within the wavelength regions from 3800 to 5100Å.

Radial velocities and equivalent widths were calculated from the Gaussian Fitting Method for this star. The measured mean radial velocity of 31 Cygni is +0.5 ㎞/sec.

Ⅰ. Introduction

31 Cygni is a typical ζ Aurigae type eclipsing binary with the period of 3784 days. McLaughlin(1950) regarded this star as an eclipsing system and later McKellar and Petrie (1958) assumed the primary star as K3 or K4 Ib which is identical to ζ Aurigae. The secondary star was classified as B5V by Faraggia and Hack(1963) and as B4 by Wright and Huffman (1968). Herczeg and Schmidt(1963) classified this system as K3. 5Ib and B4V.

The duration of the totality during eclipses was estimated as 60.5 days(Oconnell 1964, Herczeg and schmidt 1962) and the partial phase was 1.9 days. From these data the estimated diameters were calculated as 135 $R_{\odot}$ for the primary K star and 4 $R_{\odot}$ for the secondary B star. The observed period was first reported as 3806 days by Vinter-Hanser(1944) and later it was revised as 3784.3 days by many authors(Lindblad and Pipping 1963, Herczeg and Schmidt 1962, O'Connel 1964).

From the observed radial velocities at Victoria Wright and Huffman(1968) estimated the

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mass ratio as $M_K/M_B=1.49$ while the earlier investigators(Vinter-Hanson 1944, McKellar and Petrie 1958, Wright 1958) proposed somewhat higher values. The magnitude difference between 2 stars in 31 cygni was studied by many authors(Herczeg and schmidt 1963, Lindblad and Pipping 1963, Kwee and van Genderen 1962, O'Connel 1964). The mean magnitude difference was estimated as $2^m.59$.

Spectra of the component stars in 31 Cygni are quite normal and the eclipses are nearly central. However the atmosphere shows the presence of large scale clouds or prominences, and sometimes irregular pulsations. These atmospheric activities were studied using the Ca II K line variation(McKellar *et al.* 1959, Wilson and Abt 1954, Wright and Odgers 1963). Observed radial velocities during eclipse show variations. Before the totality radial velocity is more negative than the orbital velocity while radial velocity becomes more positive after the totality. These phenomena were interpreted with the connection of the presence of secondary B star. Intensity variation of the Ca II K line and the radial velocity variation in 31 Cygni may come from the passing radiation through a possible cloud which first moving away from the observer and then coming back toward him.

In this paper we made spectroscopic observations with the medium dispersions. We analysed these spectra to estimate the radial velocities and equivalent widths.

II. Observations

1. Observed Spectra

Observations were made using 122cm reflecting telescope in Asiago Observatory, Italy. Cassegrain A Spectrograph were used and the focal length of camera was 287mm with 2 prisms. The linear dispersion in $H\gamma$ was 42Å/mm and the used plates were 103a-0 with the size of 9cm×12 cm. Comparison light source was Fe I arc and the exposure time was 20 seconds. Observed materials are listed in Table 1.

Table 1. Observed Spectra of 31 Cygni

plate number	(Observed time(U. T))	Exposure time
18229	$20^h\ 35^m$	10^m
18230	$20^h\ 56^m$	30^m
18235	$22^h\ 19^m$	30^m

All plates were developed in D-19 at 20℃ for 5 minutes, fixed in acid fixer and washed in filtered water.

2. Reductions

PDS microdensitometer(Perkin Elmer PDS 1010A) at the Padova Observatory was used to scan spectral plates. Scanning size was 12.5×50 microns with the scan speed of 10㎜/sec. Measurements were made with the density mode. Density measuring system comprises a sample illumination lamp, a well designed optical-train, and a photometer that uses an EMI 9789A photocell. The photometer is operated in analog mode and the signal digitized by a twelve bit A to D converter before being sent to the computer.

In density mode the V_{out} is related to I_{IN} by the relation

$$V_{out} = OFFSET - K.\ \log[I_{IN}]$$

where V_{out} = voltage output by amplifiers and sent to the computer Analog Digital Convertor,

V_{IN} = photocell output current that is input to amplifier system,

OFFSET = offset voltage that is controlled by the density offset control,

and K = internally set gain,

Measured density was reduced at the Padova Observatory using IHAP FITS format.

Ⅲ. Wavelength Calibration

PDS readout X coordinate is not linear with the actual wavelength in the spectrum, so it is necessary to have the correlation function among wavelengths and PDS readouts. To do this we used 24 Fe I arc comparison lines as in Table 2. Numbers in Table 2 are identical with numbers in Fig. 1, which shows the Fe arc comparison spectrum with the PDS X-coordinate readout.

The correlation function between the PDS readout and wavelength was made using the 4th nonlinear least square method of 24 Fe lines.

Fig. 2 shows the correlation between the wavelength and PDS X-coordinate. The transforma-

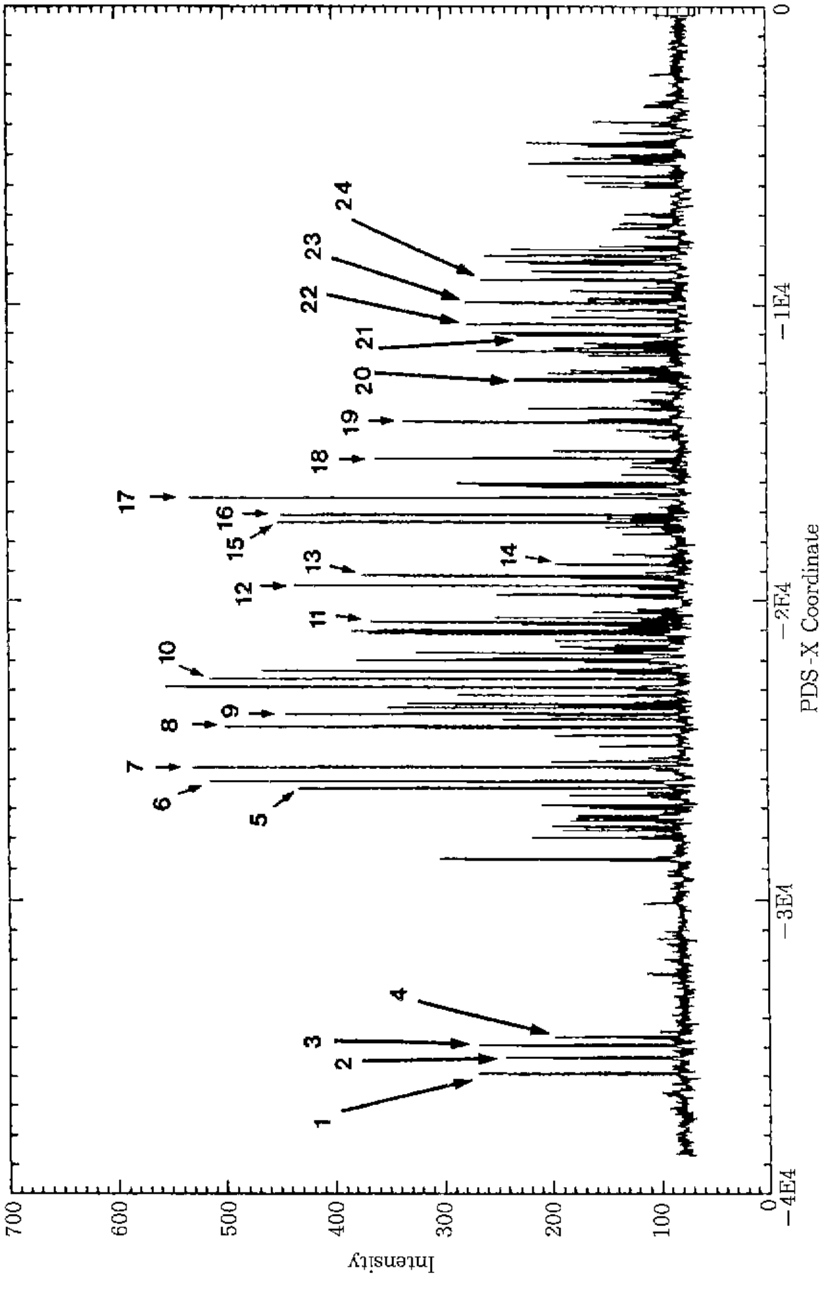


Figure 1. Identification of 24 Fe I comparison arc lines whose numbers are identical to numbers of Table 2.

Table 2. 24 Fe I comparison lines

Number	Wavelength(Å)	Number	Wavelength(Å)
1	4957.46	13	4132.06
2	4920.00	14	4118.55
3	4891.10	15	4071.75
4	4871.80	16	4063.60
5	4415.13	17	4045.25
6	4404.75	18	4005.25
7	4383.65	19	3968.00
8	4325.77	20	3923.80
9	4307.91	21	3886.29
10	4260.48	22	3878.02
11	4187.81	23	3859.91
12	4143.23	24	3841.05

tion equation of this correlation will be as

$$y = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4 \quad \cdots\cdots\cdots \quad (1)$$

where y is the wavelength, X is the PDS coordinate, a_0, a_1, a_2, a_3 and a_4 are coefficient values. These coefficient values of each plates are listed in Table 3.

Table 3. Coefficient values of the transformation equation for each plate in 31 Cygni

Star	Plate	a_0	a_1	a_2	a_3	a_4
31 Cygni	18229	3704.489	−4.326E−3	1.457E−6	3.830E−11	5.995E−16
	18230	3705.296	−4.099E−3	1.469E−6	3.851E−11	5.998E−16
	18235	3757.849	−4.457E−3	2.846E−6	1.215E−10	2.897E−15

Using this equation, we can get the calculated wavelengths. To find the accuracy of these calculated values we checked the difference between the real wavelength to the calculated ones for Fe lines as in Table 2. However the residual values are all within ±1Å. The intensity versus to the calculated wavelength of 31 Cygni spectra are plotted in Figs 3-a, b, c.

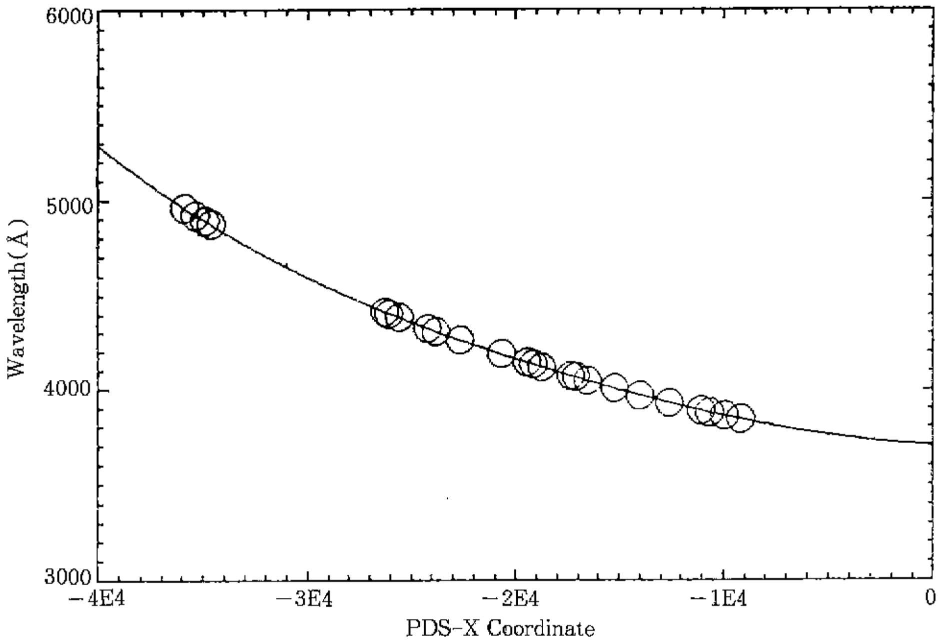


Figure 2. Correlation between the wavelength and PDS X coordinate. Open circles are Fe I arc lines and the straight lines comes from the 4th nonlinear least square fitting.

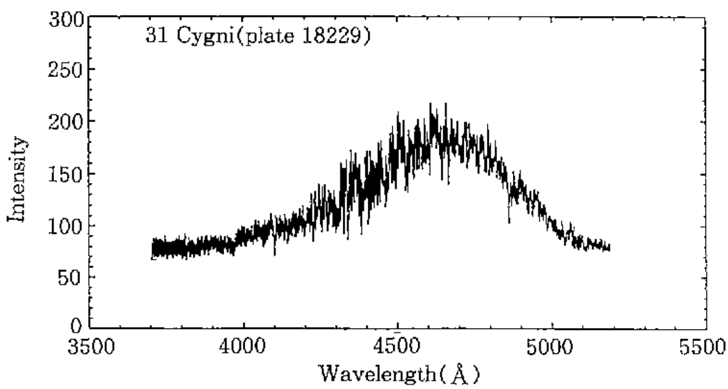


Figure 3-a. Intensity versus to the calculated wavelength for each plate.

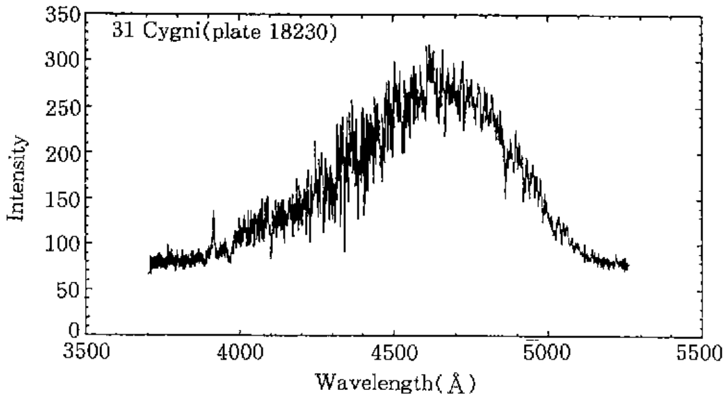


Figure 3-b. Intensity versus to the calculated wavelength for each plate.

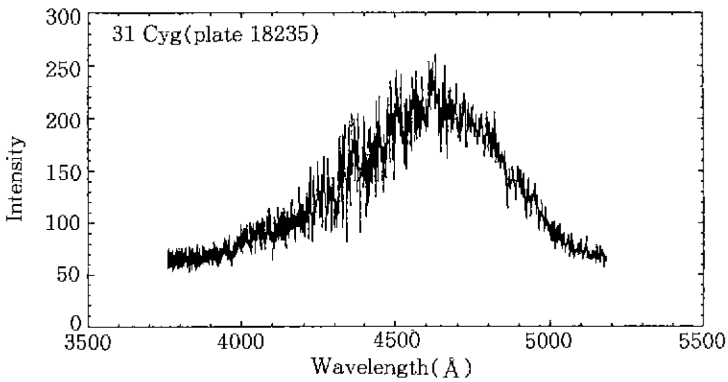


Figure 3-c. Intensity versus to the calculated wavelength for each plate.

Ⅳ. Normalization of Intensity

To compare the relative intensity of absorption lines we need the intensity normalization with the continuum level. To do this we divided several regions to the wavelength and calculated the mean intensity of each region. The standard deviation(σ) of intensity(i) was estimated and then the mean intensity was calculated from intensities less then $-\sigma \leq i \leq \sigma$. We estimated intensities from the non-linear square method using equation 1. The normalized intensities can come through equation 2 as,

$$Inom = I / Ical \cdots\cdots (2)$$

where I is the observed intensity, Ical is the calculated intensity through the normalization process and Inom is the normalized intensity. The normalized spectra of 31 Cygni are plotted in Figs 4-a, b, c.

Table 4. The calculated radial velocity of FeI lines from the plate 18229

Reference(Å)	Observation(Å)	Radial Velocity(km/sec)
3821.84	3821.74	16.2
3891.93	3891.46	−12.2
3916.74	3916.26	−12.8
3955.22	3954.71	−14.7
3971.83	3971.40	−8.5
3972.92	3972.80	14.9
4009.71	4009.54	11.3
4031.72	4031.53	9.9
4085.01	4084.68	−0.2
4124.49	4124.11	−3.6
4180.40	4179.83	−16.9
4197.51	4197.44	19.0
4710.29	4709.96	3.0
4776.07	4775.71	1.4
4842.21	4842.14	19.7
4867.64	4867.50	15.4
4930.07	4929.87	11.8
5097.01	5096.34	−15.4
Mean velocity		+2.1±3.1

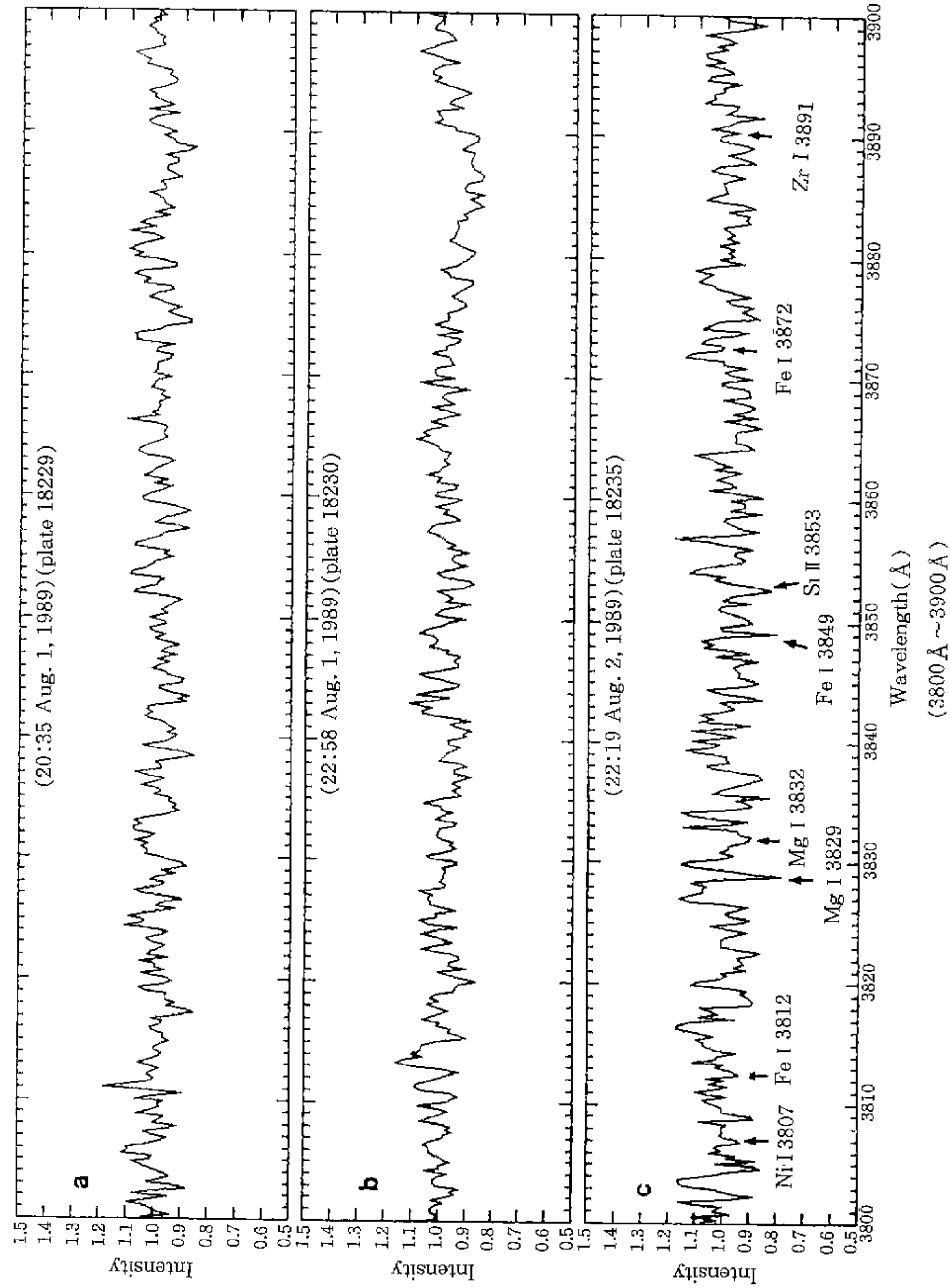
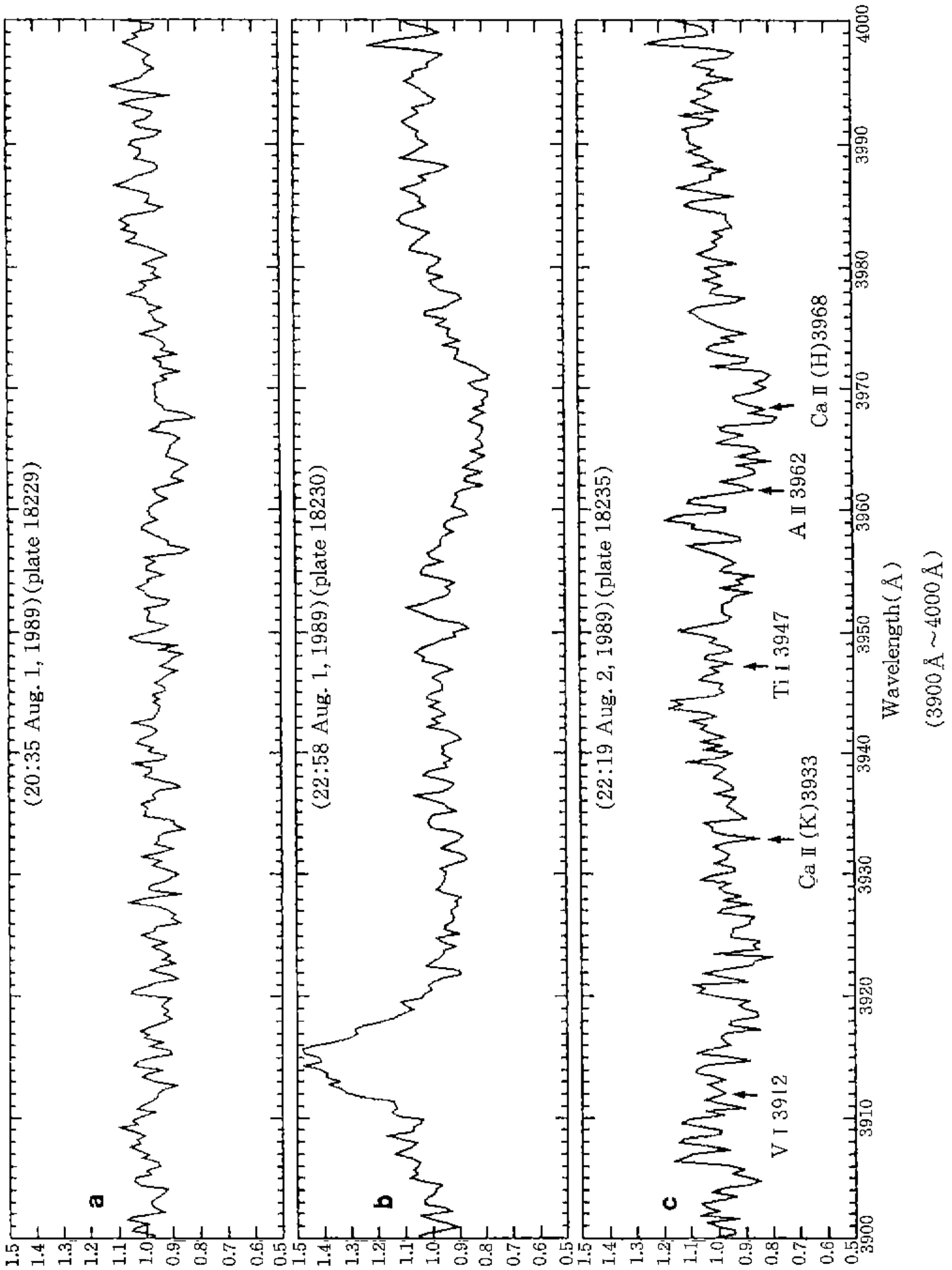
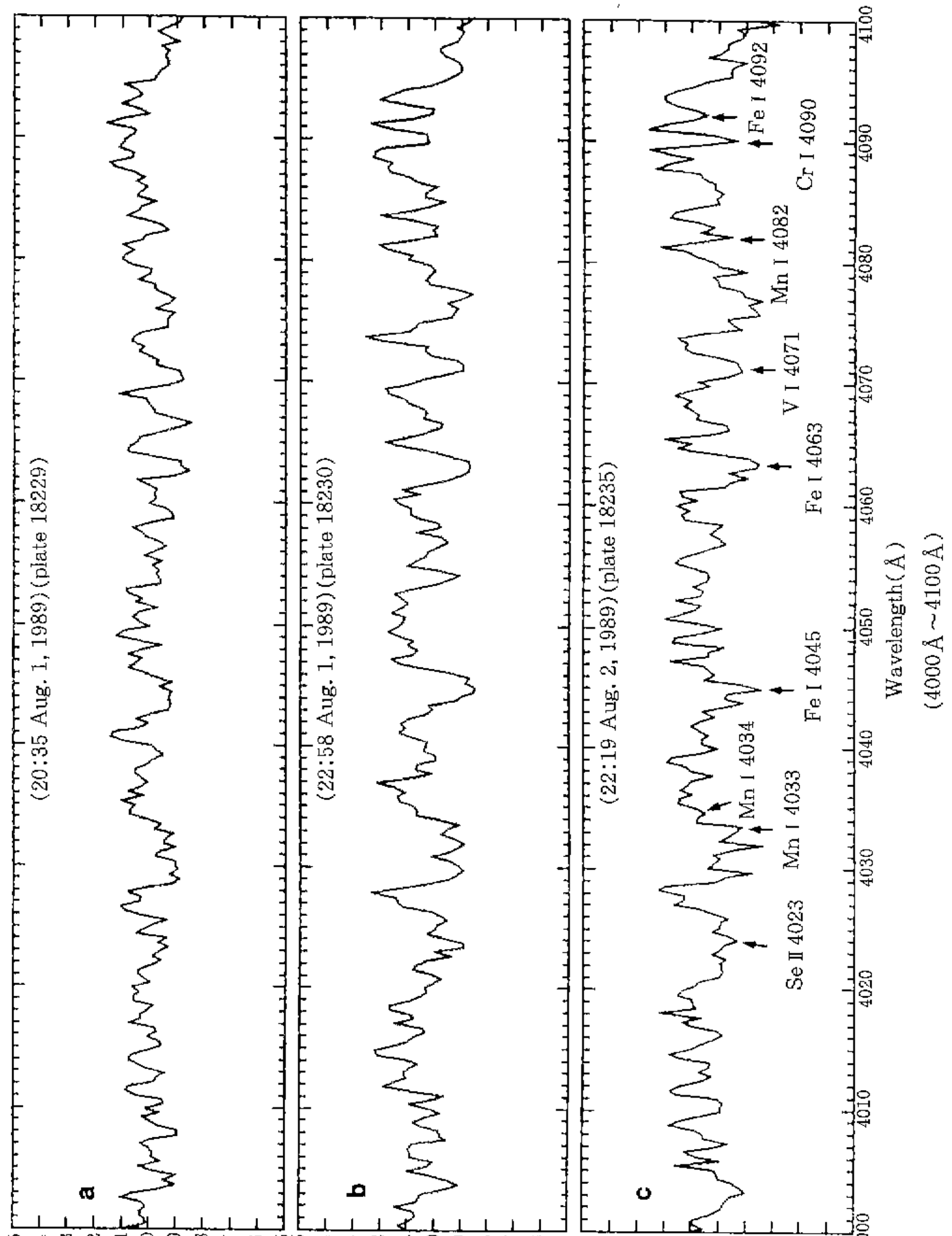
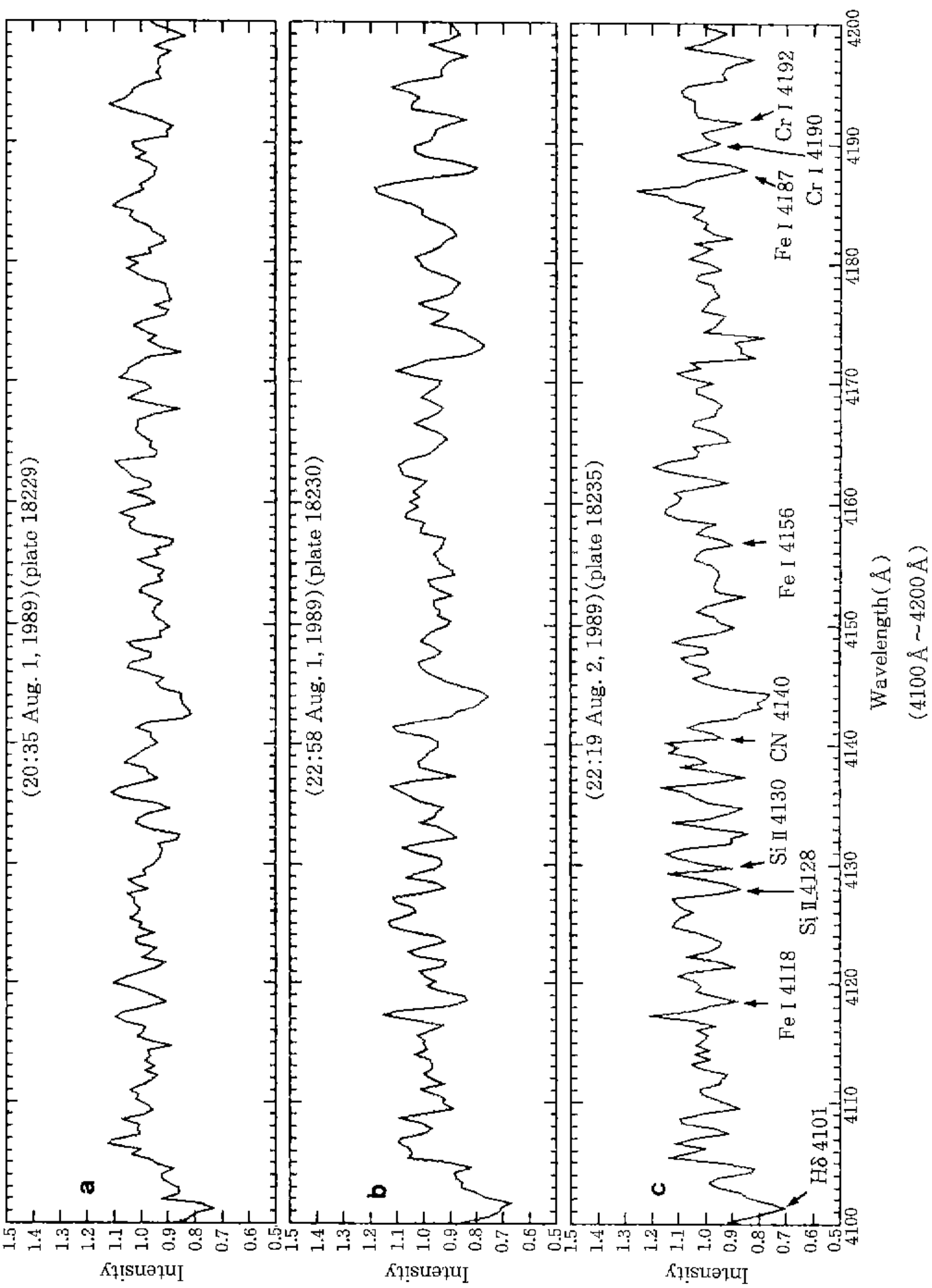
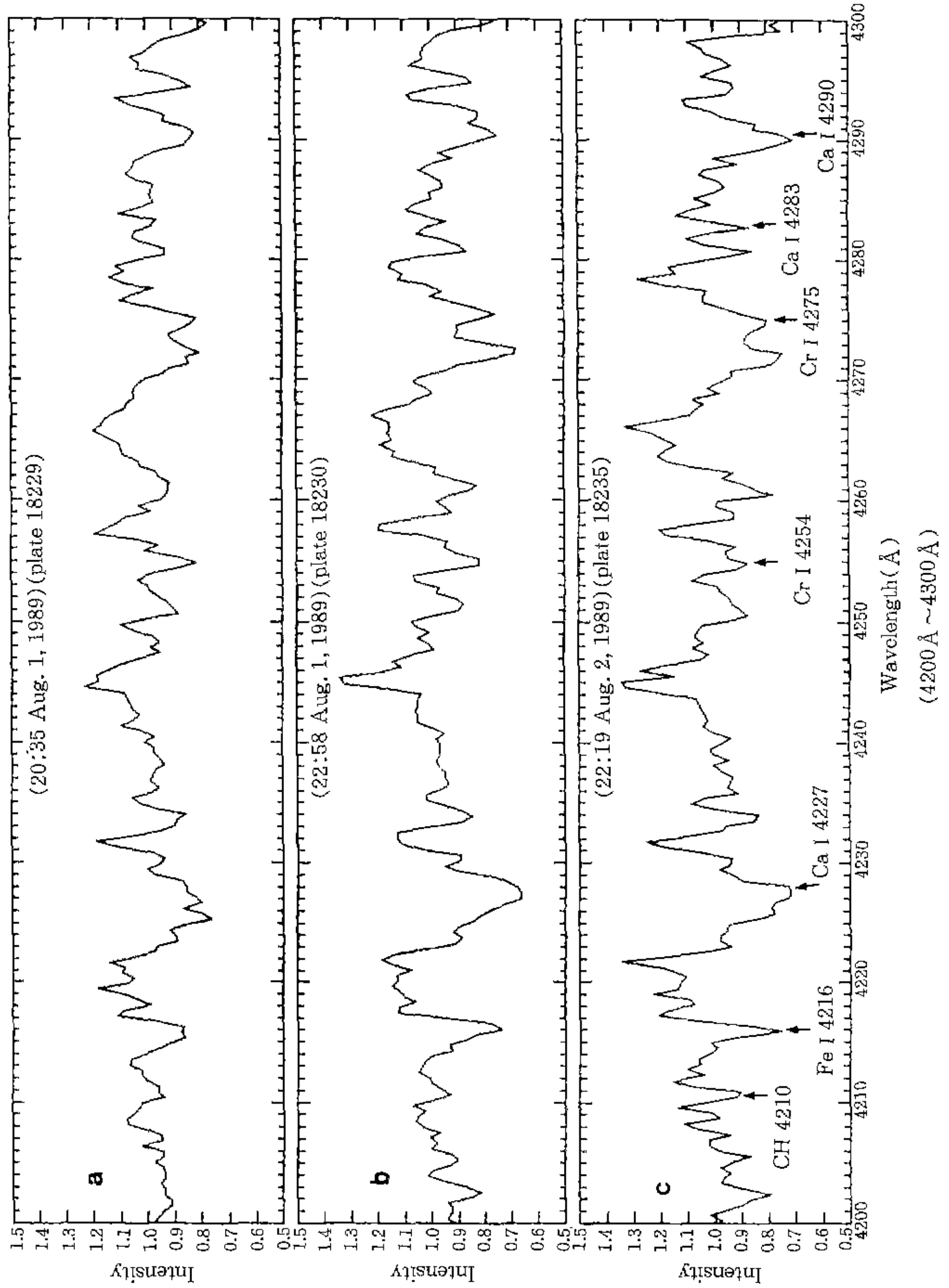


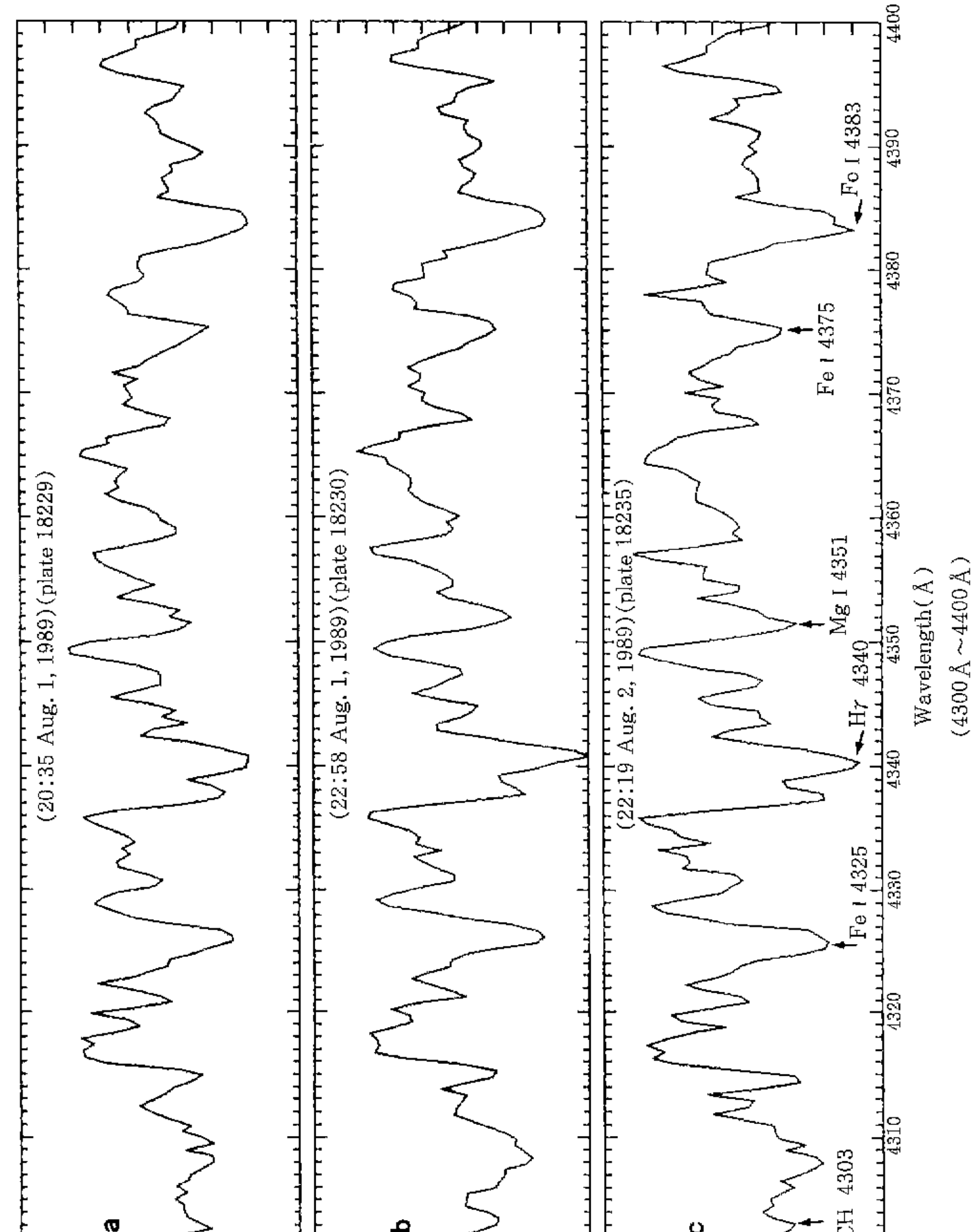
Figure 4-a, b, c. Normalized spectrum of 31 Cygni.

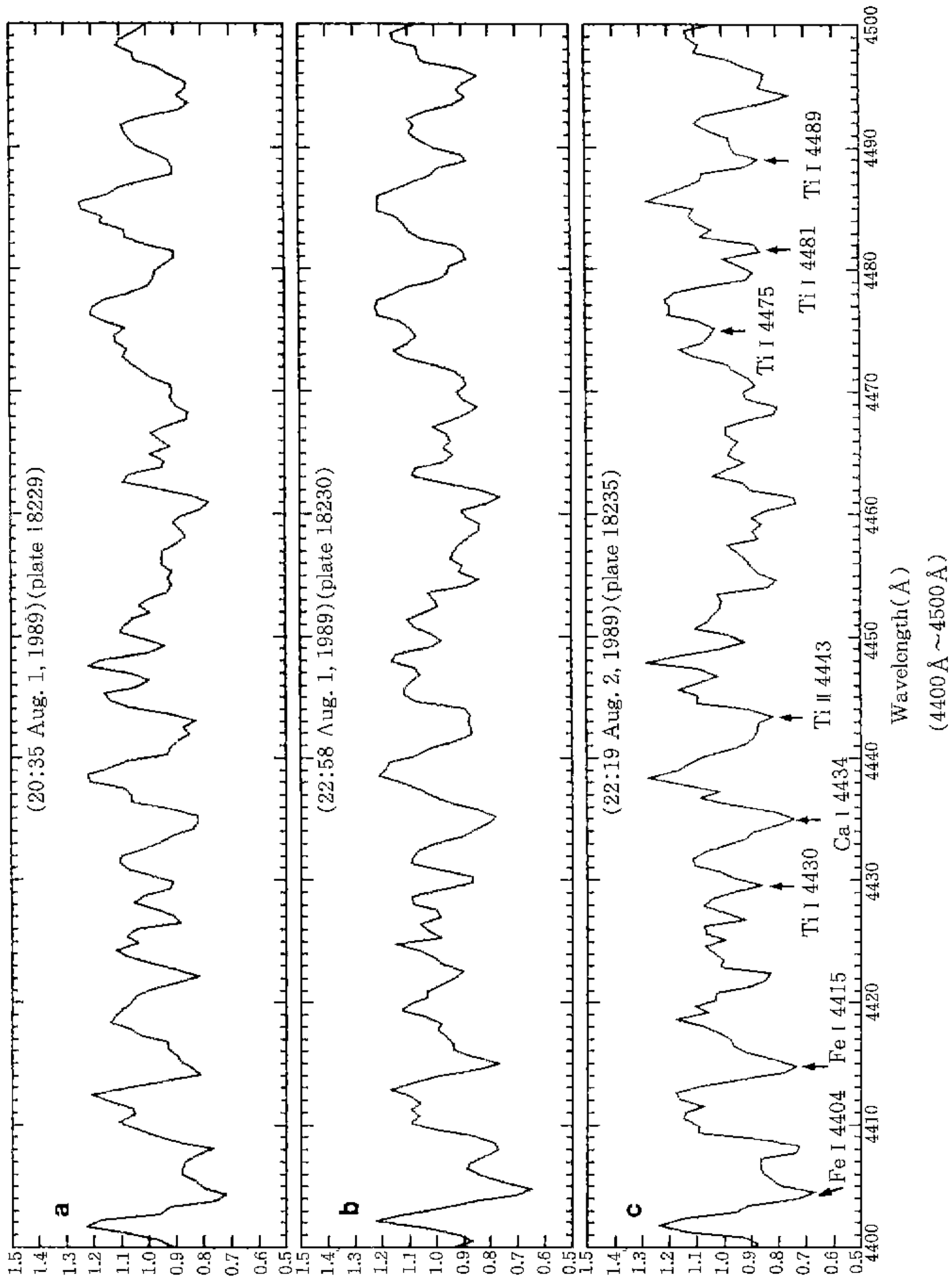

a
(20:35 Aug. 1, 1989) (plate 18229)
b
(22:58 Aug. 1, 1989) (plate 18230)
c
(22:19 Aug. 2, 1989) (plate 18235)
Intensity
V I 3912
Ca II (K) 3933
Ti I 3947
A II 3962
Ca II (H) 3968
Wavelength (Å)
(3900 Å ~4000 Å)

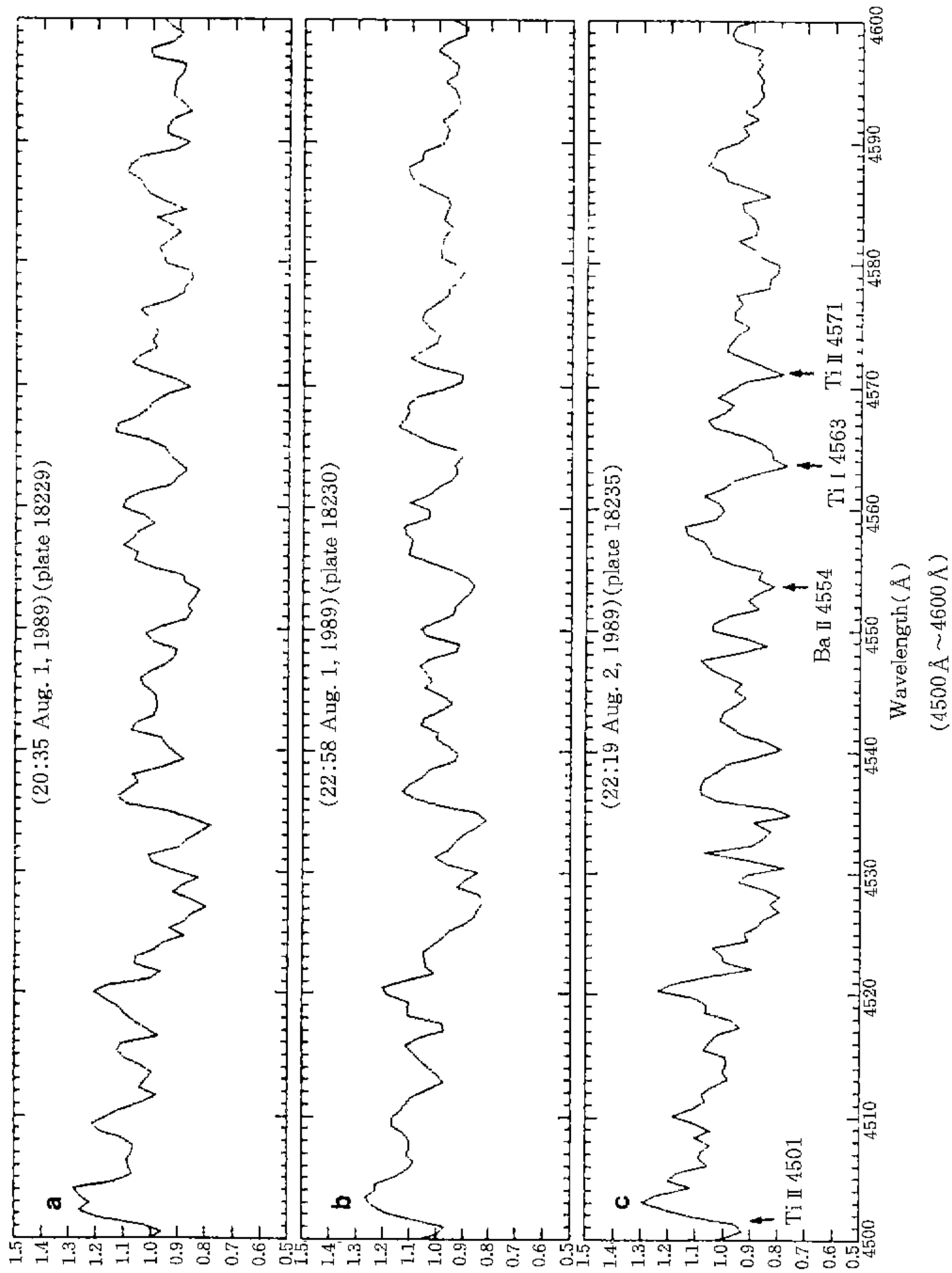

(20:35 Aug. 1, 1989) (plate 18229)
a
(22:58 Aug. 1, 1989) (plate 18230)
b
(22:19 Aug. 2, 1989) (plate 18235)
c
Intensity
Se II 4023
Mn I 4033
Mn I 4034
Fe I 4045
Fe I 4063
V I 4071
Mn I 4082
Cr I 4090
Fe I 4092
Wavelength (Å)
(4000 Å ~4100 Å)

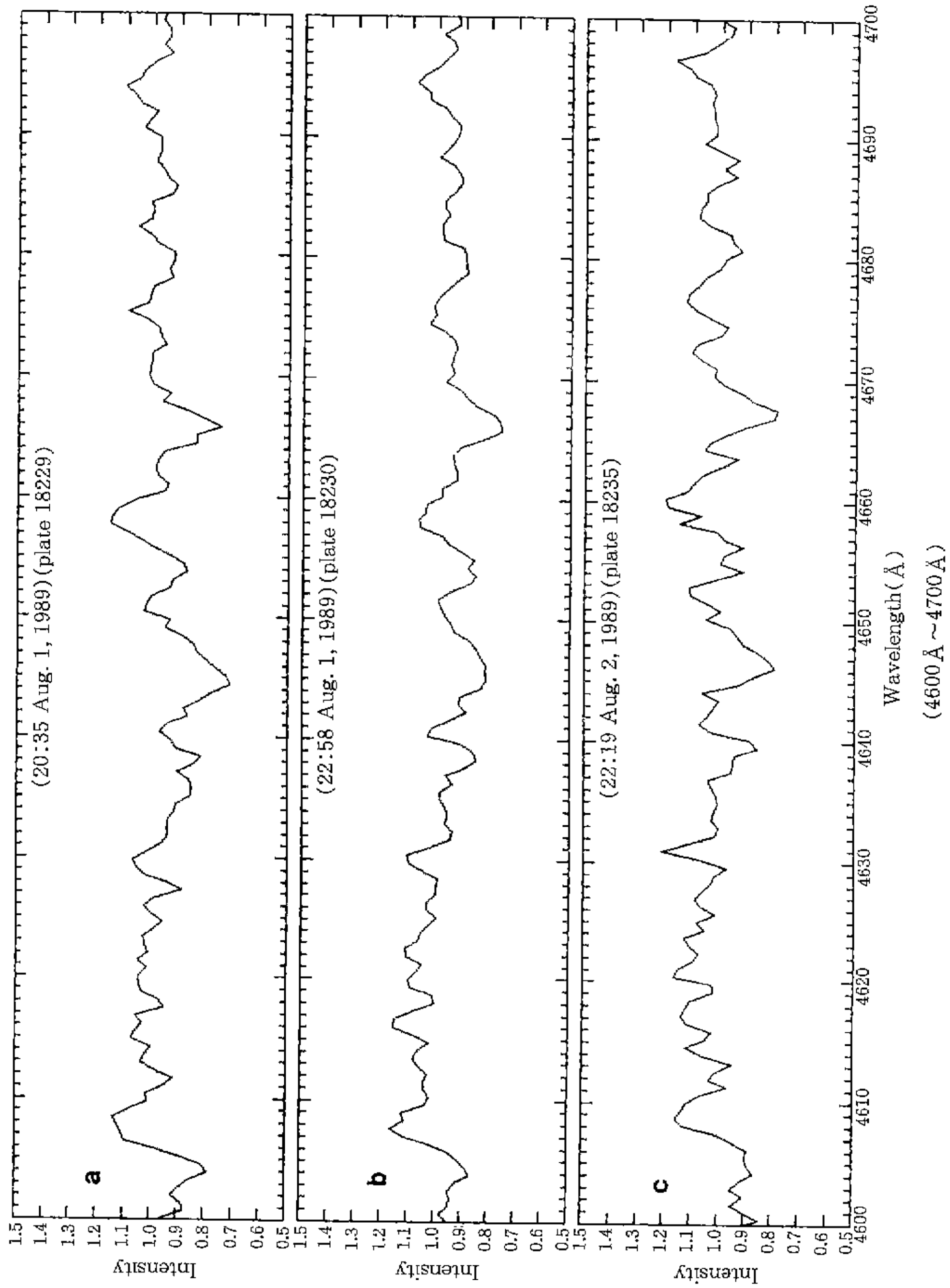

a
(20:35 Aug. 1, 1989) (plate 18229)
b
(22:58 Aug. 1, 1989) (plate 18230)
c
(22:19 Aug. 2, 1989) (plate 18235)
Hδ 4101
Fe I 4118
Si II 4128
Si II 4130
CN 4140
Fe I 4156
Fe I 4187
Cr I 4190
Cr I 4192
Intensity
Wavelength (Å)
(4100 Å ~ 4200 Å)

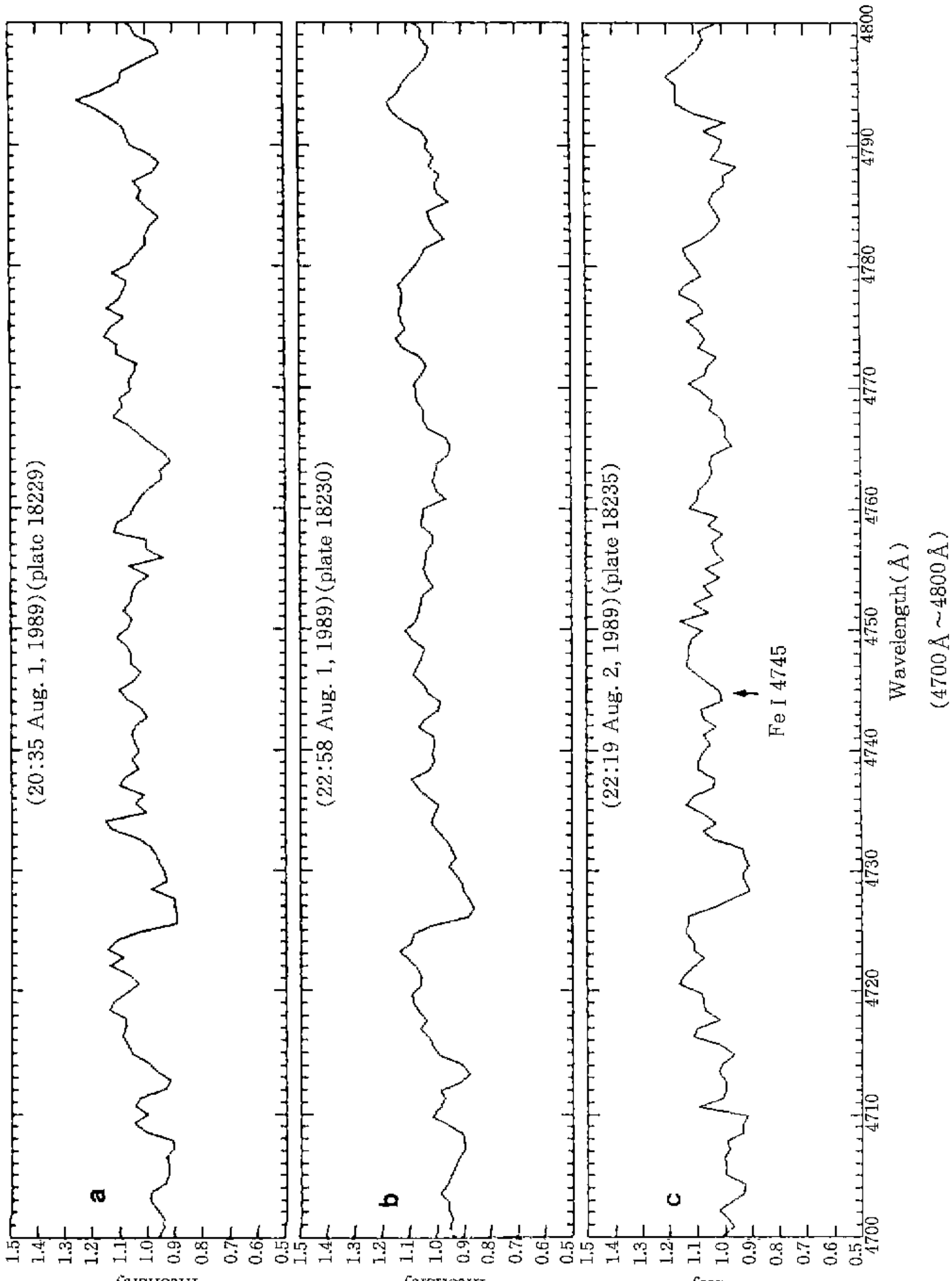

a
(20:35 Aug. 1, 1989) (plate 18229)
b
(22:58 Aug. 1, 1989) (plate 18230)
c
(22:19 Aug. 2, 1989) (plate 18235)
CH 4210
Fe I 4216
Ca I 4227
Cr I 4254
Cr I 4275
Ca I 4283
Ca I 4290
Intensity
Wavelength (Å)
(4200 Å ~4300 Å)


a
(20:35 Aug. 1, 1989)(plate 18229)
b
(22:58 Aug. 1, 1989)(plate 18230)
c
(22:19 Aug. 2, 1989)(plate 18235)
CH 4303
Fe I 4325
Hγ 4340
Mg I 4351
Fe I 4375
Fe I 4383
Intensity
Wavelength (Å)
(4300 Å ~ 4400 Å)


a
(20:35 Aug. 1, 1989) (plate 18229)
b
(22:58 Aug. 1, 1989) (plate 18230)
c
(22:19 Aug. 2, 1989) (plate 18235)
Fe I 4404
Fe I 4415
Ti I 4430
Ca I 4434
Ti II 4443
Ti I 4475
Ti I 4481
Ti I 4489
Intensity
Wavelength (Å)
(4400 Å ~ 4500 Å)


a
(20:35 Aug. 1, 1989)(plate 18229)
b
(22:58 Aug. 1, 1989)(plate 18230)
c
(22:19 Aug. 2, 1989)(plate 18235)
Intensity
Ti II 4501
Ba II 4554
Ti I 4563
Ti II 4571
Wavelength(Å)
(4500Å ~4600Å)


(20:35 Aug. 1, 1989) (plate 18229)
a
(22:58 Aug. 1, 1989) (plate 18230)
b
(22:19 Aug. 2, 1989) (plate 18235)
c
Intensity
1.5 1.4 1.3 1.2 1.1 1.0 0.9 0.8 0.7 0.6 0.5
4600 4610 4620 4630 4640 4650 4660 4670 4680 4690 4700
Wavelength (Å)
(4600 Å ~4700 Å)


a
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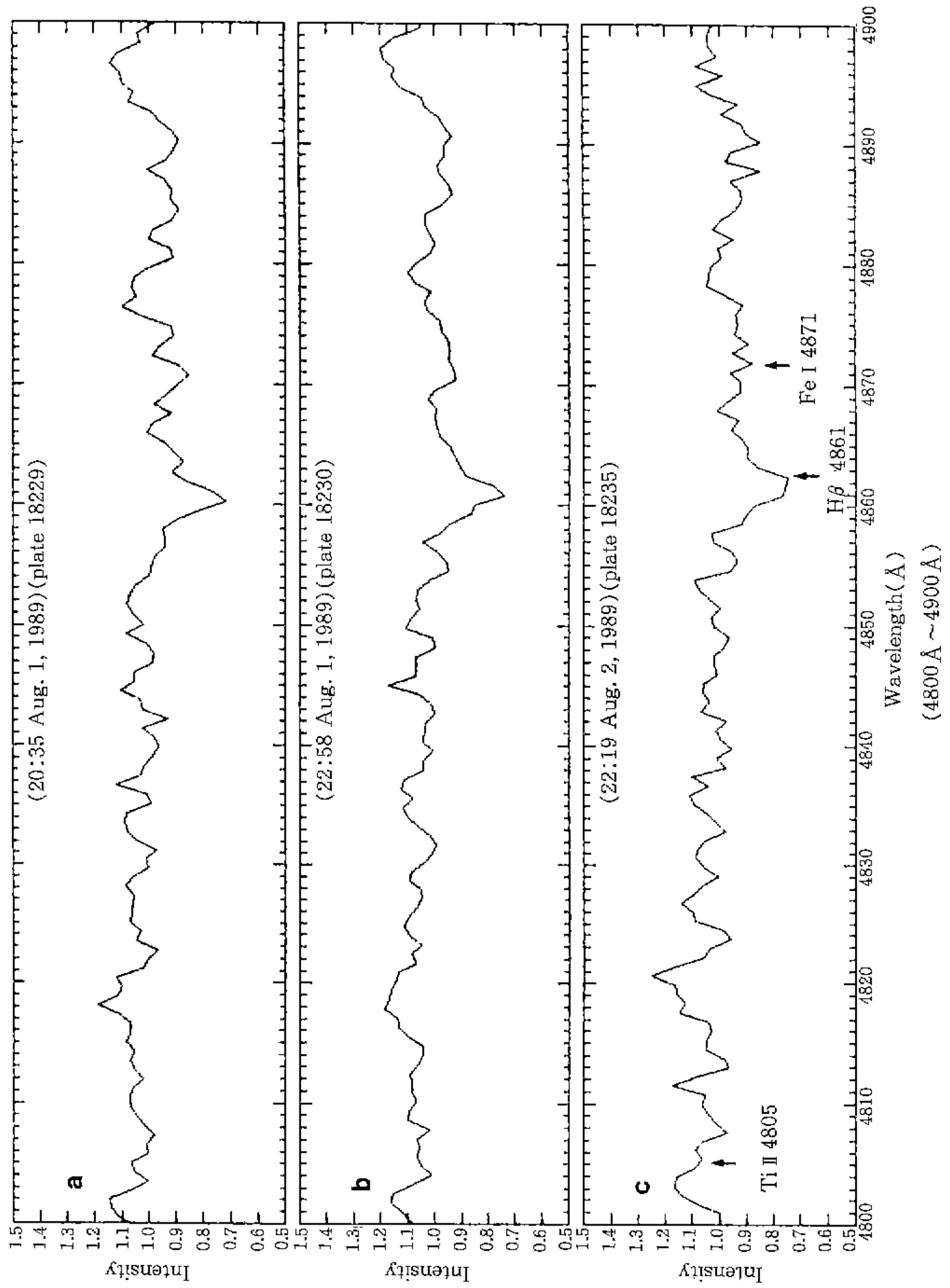
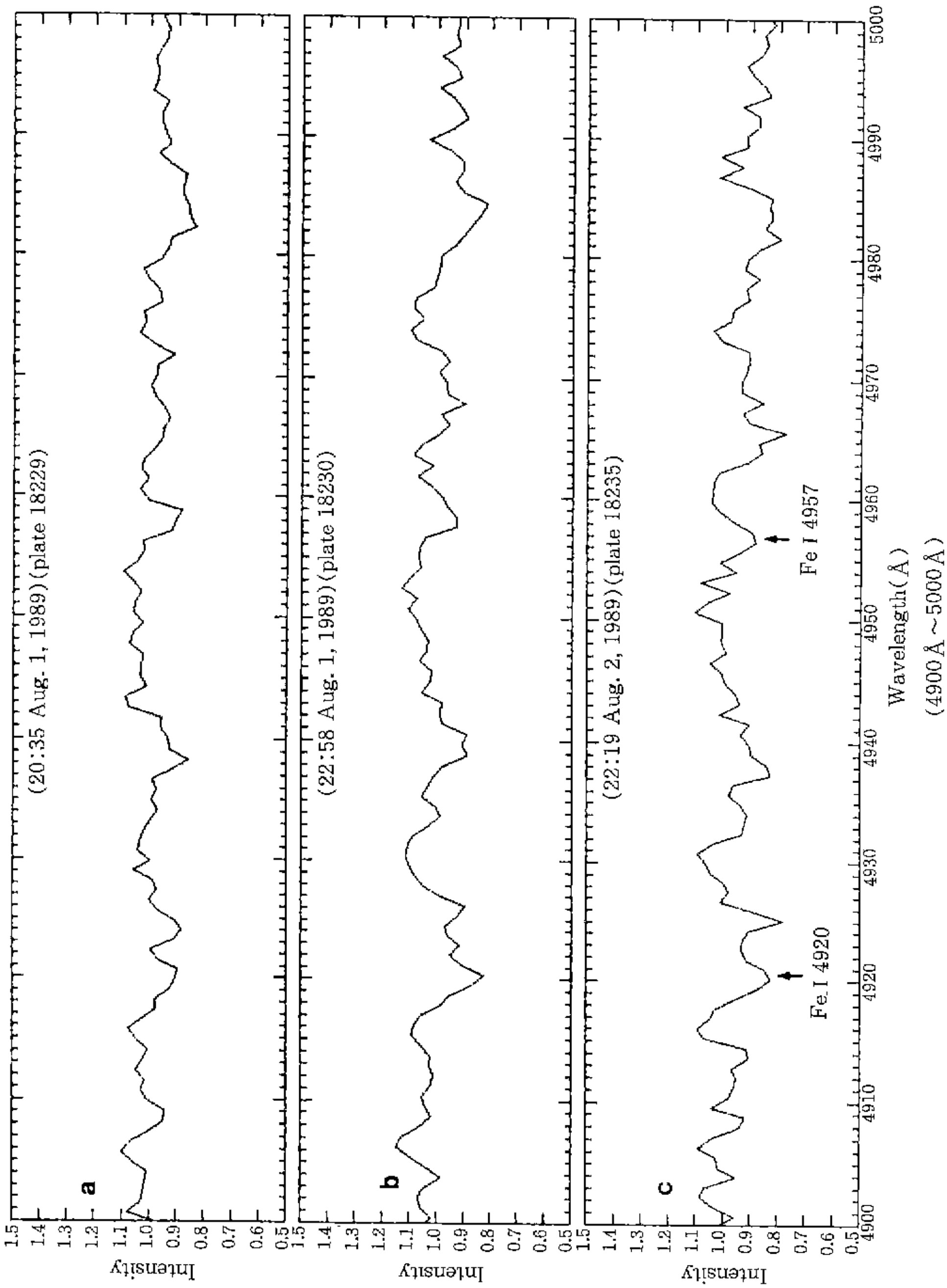
b
(22:58 Aug. 1, 1989) (plate 18230)
c
(22:19 Aug. 2, 1989) (plate 18235)
Fe I 4745
Intensity
Wavelength (Å)
(4700 Å ~ 4800 Å)


a
(20:35 Aug. 1, 1989) (plate 18229)
b
(22:58 Aug. 1, 1989) (plate 18230)
c
(22:19 Aug. 2, 1989) (plate 18235)
Ti II 4805
Hβ 4861
Fe I 4871
Intensity
Wavelength (Å)
(4800 Å ~ 4900 Å)


a
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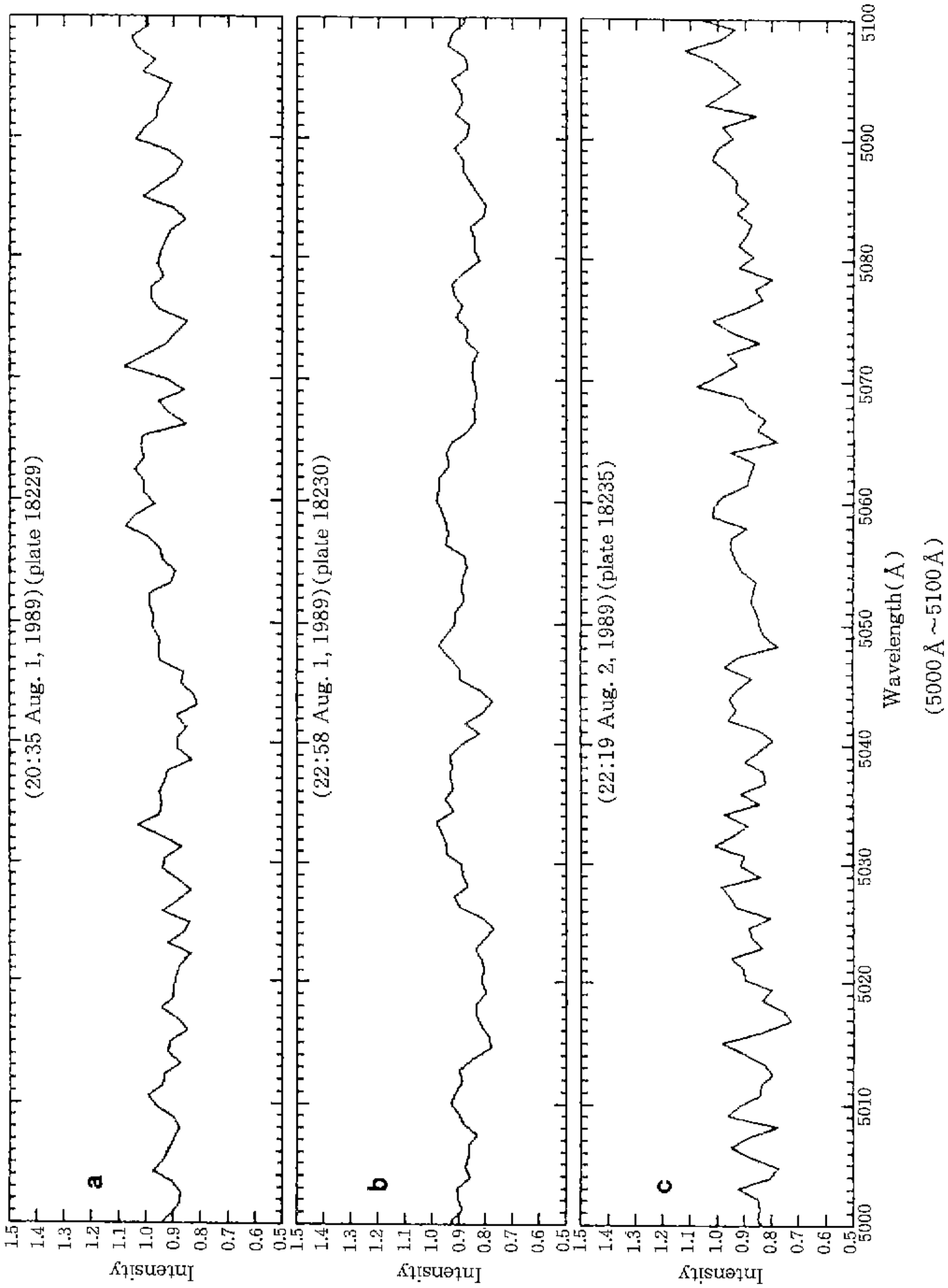
b
(22:58 Aug. 1, 1989) (plate 18230)
c
(22:19 Aug. 2, 1989) (plate 18235)
Fe I 4920
Fe I 4957
Intensity
Wavelength(Å)
(4900 Å ~5000 Å)


a
(20:35 Aug. 1, 1989) (plate 18229)
b
(22:58 Aug. 1, 1989) (plate 18230)
c
(22:19 Aug. 2, 1989) (plate 18235)
Intensity
Wavelength (Å)
(5000 Å ~ 5100 Å)

V. Radial Velocities and Equivalent Widths

1. Measurement of Radial Velocities

Radial velocities of 31 Cygni were calculated using the Gaussian fitting method of Fe I lines. Fig. 5 shows the fitting of example of sample of Fe I line. From these fitting we calculated radial velocities for each Fe I lines as in Tables 5 and 6. The calculated mean radial velocity was +0.5 km/sec. This value was compared with the previous observed values at the phase of 0.66 in Fig. 6. The straight line is the fitted radial velocity of K-type primary star, while the dotted curve indicates the radial velocity of secondary star in 31 Cygni. From this figure we can see that calculated radial velocities(pointed with arrows) are close to the previous estimated values.

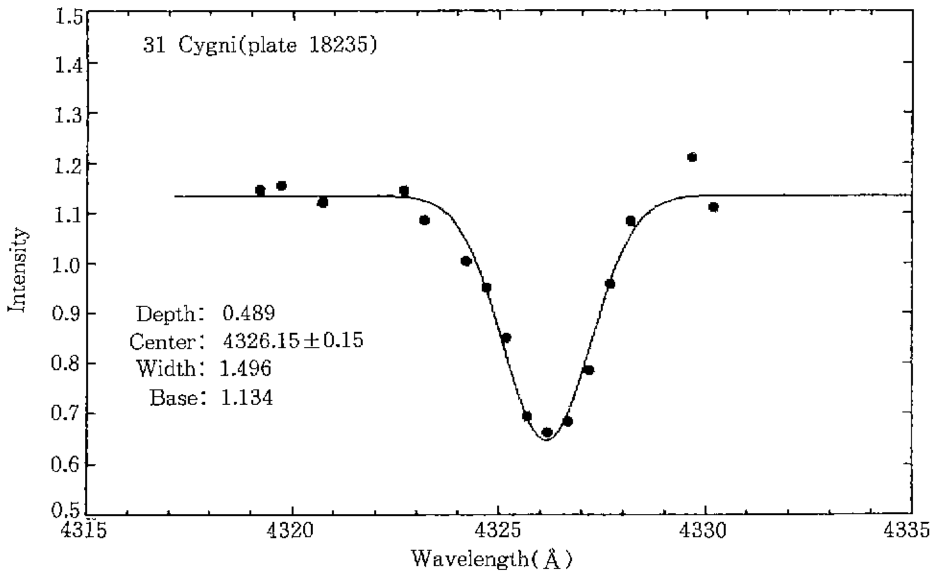


Figure 5. Gaussian fitting of Fe I line.

Table 5. Same as in Table 4 from the plate 18230

Reference(Å)	Observation(Å)	Radial Velocity(km/sec)
3836.34	3836.11	6.0
3855.85	3855.52	−1.7
3885.52	3885.02	−14.6
3944.74	3944.18	−18.6
3955.96	3955.80	11.9
3979.64	3979.23	−6.9
4160.78	4160.58	9.6
4808.16	4807.87	5.9
4835.88	4835.63	8.5
Mean velocity		+0.4±3.9

Table 6. *Same as in Table 4 from the plate 18235*

Reference(Å)	Observation(Å)	Radial Velocity(km/sec)
3817.64	3817.11	−17.6
3849.69	3849.11	−21.2
3851.59	3851.60	24.8
3867.22	3866.93	1.5
3896.62	3896.24	−5.3
3917.18	3917.34	36.3
3827.61	3927.54	18.7
3940.89	3940.62	3.4
3947.54	3947.44	16.4
3964.53	3964.07	−10.8
3980.63	3980.37	4.4
3995.21	3995.17	21.0
4238.82	4238.58	7.0
4288.27	4288.00	5.1
4425.66	4425.15	−10.6
4602.95	4602.25	−21.6
4837.67	4836.74	−33.7
4873.75	4873.50	8.6
4888.64	4887.82	−26.3
4896.44	4895.84	−12.8
4968.71	4968.21	−6.2
Mean velocity		−0.9±4.1

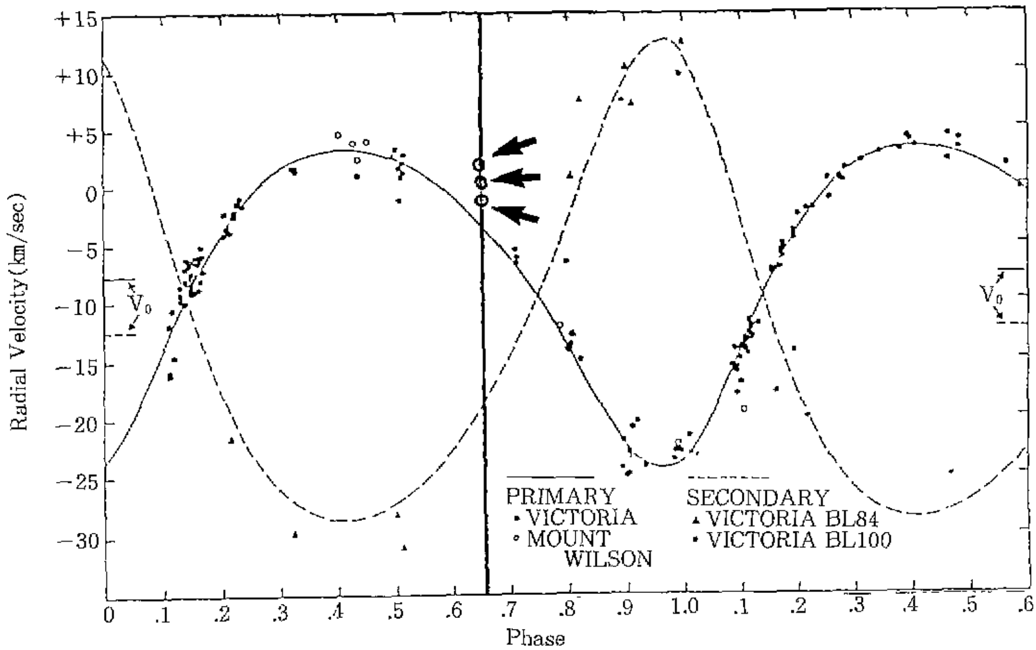


Figure 6. The radial velocity curve of 31 Cygni(Wright 1970). The straight line is the curve of the primary K-supergiant and the dotted line indicates the secondary velocity curve. Calculated radial velocities at the phase of 0.66 are plotted with arrows.

2. Equivalent Widths

Equivalent widths of absorption lines of 31 Cygni were estimated from the Gaussian fitting to lines with relatively less blended lines. All the estimated equivalent widths are listed in Tables 7, 8 and 9, where the 1st column is the identification of element, 2nd column is the standard wevelength. 3rd column is the calculated wavelength from the Gaussian fitting and the ratio of the equivalent width to the wavelength is listed in column 4. Column 5 indicates the same value of column 4 for the sun to compare with the solar abundance. Each absorption lines were divided as the neutral metal line, ionized metal line and the molecular line.

Table 7. Equivalent widths of 31 Cygni from the plate 18229

	Reference(Å)	Observation(Å)	$-\log(W/\lambda)_*$	$-\log(W/\lambda)_\odot$
Ba II	4554.03	4552.35	3.71	4.16
Ca I	4289.37	4290.35	4.03	4.52
Ca II (K)	3933.68	3933.91	4.43	2.29
Cr I	4254.34	4254.73	4.76	4.03
Fe II	4233.17	4233.61	4.25	4.47
Fe I	4118.89	4118.40	4.70	4.74
	4307.91	4308.51	4.10	3.78
	4325.00	4325.87	3.56	3.74
	4383.65	4383.76	3.61	3.64
	4415.13	4415.02	3.76	4.02
	4871.80	4870.66	4.37	4.40
	4920.51	4919.88	3.94	4.02
	4957.46	4958.71	4.12	3.85
Hβ	4861.33	4861.03	3.90	3.12
Hδ	4101.74	4101.43	4.18	3.12
Hγ	4340.47	4340.15	3.52	3.18
Ti II	4443.80	4442.69	3.64	4.55

Table 8. Same as in Table 7 from the plate 18230

	Reference(Å)	Observation(Å)	$-\log(W/\lambda)_*$	$-\log(W/\lambda)_\odot$
Ba II	4554.03	4552.35	3.96	4.46
Ca I	4289.37	4290.35	3.28	4.52
Ca II (K)	3933.68	3933.91	5.52	2.29
Cr I	4254.34	4254.73	4.02	4.03
Fe I	3824.45	3823.30	5.23	3.87
	4307.91	4308.51	3.49	3.78
	4325.00	4325.87	3.60	3.74
	4383.65	4383.76	3.46	3.64
	4415.13	4415.02	3.86	4.02
	4920.51	4919.88	3.82	4.02
	4957.46	4958.71	4.19	3.85
Hβ	4861.33	4861.81	3.90	3.12
Hδ	4101.74	4339.81	3.94	3.12
Hγ	4340.47	4101.35	3.04	3.18
Ti II	4443.80	4443.80	3.70	4.55

Table 9. Same as in Table 7 from the plate 18235

	Reference(Å)	Observation(Å)	$-\log(W/\lambda)_*$	$-\log(W/\lambda)_\odot$
Ba II	4554.03	4553.64	4.05	4.46
Ca II (K)	3933.68	3932.80	5.01	2.29
Fe I	3824.45	3823.30	3.72	3.87
	3878.02	3875.92	3.79	3.73
	3968.00	3967.50	4.90	5.75
	4045.82	4044.62	4.05	3.54
	4260.48	4260.62	3.76	3.85
	4325.00	4326.15	3.58	3.74
	4415.13	4414.95	3.72	4.02
	4871.80	4871.98	4.89	4.40
Hβ	4861.33	4861.81	3.74	3.12
Hδ	4101.74	4339.81	4.15	3.12
Hγ	4340.47	4101.35	3.29	3.18

VI. Discussion

Spectra of 31 Cygni in the blue region(3800Å −5100Å) show the typical late type star. The calculated mean radial velocity at the phase of 0.66 was 0.5 km/sec, which is very close to the velocity curve of 31 Cygni

The estimated equivalent width shows that 31 Cygni is the typical ζ Aurigae type eclipsing binary. Among the abundance comparison, we found that Ca II is very weak. This phenomenon is typical for ζ Aurigae type binary. During the ingress and egress periods the equivalent width of Ca II lines increase very rapidly, while the outside of the eclipse like the phase of 0.66 they become weaker. This phenomenon tells us the density distribution of the ionized Ca at the chromosphere of the K type supergiant.

Among neutral lines like Mn I, Ni I, Ti I, V I, Cr I and Ca I have bigger equivalent width value than the solar one. These come from the typical character of the late type K-giant. These phenomena are found at the ionized metal lines like Ti II, Ba II, Si II, and Sr II lines. These lines are stronger than the solar ones and this indicates that the primary K-giant in 31 Cygni is the normal supergiant.

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