

## Polarization Variations of the RV Tauri Stars

### II. The Results for the Other Eight Stars

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## おうし座RV型星の偏光の変動について

### II. 他の8個の星に対する結果

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#### 要 旨

おうし座RV型変光星は、F型～K型のスペクトル型の準規則的な変光を示す脈動変光星で、主極小と副極小をもつ光度変化を示し、主極小光度間の変光周期は30日～150日の範囲にある。

この変光星は、可視域でのスペクトルにより酸素過剰を示すものと炭素過剰を示すものに分類され、また、その星周囲の赤外放射のエネルギー分布からも、酸素過剰の特徴を示すものと炭素過剰の特徴を示すものに分類されている。ところが、可視域での分類と赤外放射での分類が必ずしも対応しておらず、可視域で炭素過剰なグループでありながら酸素過剰な赤外放射を示すものが観測されている。

そこで、両分類の関係を調べるために、国立天文台堂平観測所の91cm反射望遠鏡の多色偏光測光装置を用いて、13個のおうし座RV型変光星を他の種類の脈動変光星3個とともに観測した。

この内、7個のおうし座RV型変光星と他の種類の脈動変光星1個の解析結果は、本研究年報の第12号で報告した。ここでは、他の種類の脈動変光星2個を含む残りの8個の星の解析結果を報告する。前回の報告に付け加わった結論は、次のとおりである。

- 1) 多くのおうし座RV型変光星が偏光の時間変動を示し、固有の偏光成分をもつことが、さらに確認された。それに対して、他の種類の3個の脈動変光星では、偏光の時間変動は確認されなかった。
- 2) 可視域で酸素過剰なグループは、そのスペクトルをもとにさらに、2つのグループに細分類されているが、それらの間では、偏光の特徴で系統的な違いは見られない。
- 3) いっかくじゅう座U星では、過去になされた2つの観測の間に固有の偏光位置角が長期的な変化をしていたが、ここでの観測値は、両者の中間の値になっていた。
- 4) おうし座RV星では、観測された偏光がQU平面上で右上への非周期的変化を示している。

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## I. Introduction

The RV Tauri stars are semiregular variables which lie between the Cepheids and the Mira-type Variables in the HR diagram. Their light curves are characterized by alternate deep and shallow minima, and the periods defined by the interval between successive deep minima range from 30 to 150 days.

On the basis of light curves the RV Tauri stars are divided into two subgroups, RVa and RVb. The RVa group is characterized by a relatively regular light curve, and the interchanges of minima do not occur frequently. The RVb group is characterized by a rather irregular light curve, especially by a superimposition of a very long wave of greater amplitude. The RV Tauri stars are generally thought as radial pulsators, but some investigators assert that they also perform a non-radial pulsation.

On the basis of spectroscopic characteristics in an optical region Preston et al. (1963)<sup>1)</sup> divided the RV Tauri stars into three subgroups, group A, group B, and group C. The group A generally shows anomalously strong TiO bands at light minima whose strength corresponds to early M-type supergiants, while intensities of metallic lines indicate the type G or K. The group B shows spectra to which a definite spectral type, in ordinary sense, cannot be assigned. The most distinctive characteristic in the spectra of the group B is that near light minima the CH and CN bands appear with considerable strength indicative of an enhanced carbon abundance. The group C shows all the characteristics of the group B except that the carbon features are weak or not present. Dawson (1979)<sup>2)</sup> divided the group A into the group A<sub>1</sub> and the group A<sub>2</sub>. The group A<sub>1</sub> shows TiO bands near light minima, while the group A<sub>2</sub> does not show TiO bands at any phase.

The RV Tauri stars show strong excess infrared radiation, which indicates that they are embedded in circumstellar dust envelopes. On the basis of energy distributions of the infrared radiations, RV Tauri stars are divided into three subgroups (Gehrz(1972)<sup>3)</sup>). The first group shows smooth, featureless, non-Planckian continua. The second group shows silicate emission features at 10 and 18  $\mu\text{m}$ . The third group shows unidentified emission features at 8-13  $\mu\text{m}$ . Thus, the infrared spectra of the second group are indicative of oxygen-rich circumstellar dust. the first group also seems to have the oxygen-rich circumstellar dust. On the other hand, the third group seems to have a carbon-rich circumstellar dust.

There is not a good correlation between the optical spectra and the infrared spectra. For example, TW Cam, DF Cyg, SU Gem, TT Oph, R Sge, RV Tau, and V Vul belong to the group A of the optical spectra, while, according to Gehrz (1972)<sup>3)</sup>, RV Tau shows the infrared spectrum of the second group and

the other stars show the spectra of the first group. Furthermore, IW Car, SX Cen, and AR Pup belong to the group B, while, according to Gehrz and Ney (1972)<sup>4)</sup>, these stars show the infrared spectra of the second group. Thus, there are the RV Tauri stars which simultaneously show the carbon-rich optical spectra and the oxygen-rich infrared spectra.

The author has been making the multicolor polarimetric observations of the RV Tauri stars in order to investigate the structures of the photospheres and circumstellar dust envelopes of these stars and to clarify the relationship between the optical spectra and the infrared spectra.

## II. Observations and Reductions

The multicolor polarimetric observations reported in this paper were obtained between 1993 October 23 and 1994 April 16. The 91cm reflector at the Dodaira Station of the National Astronomical Observatory was used with the multi-channel polarimeter. This polarimeter can measure linear polarization simultaneously at eight colors. These colors are indicated with the numbers of the channel in order of wavelength, whose effective wavelengths are 0.36, 0.42, 0.455, 0.53, 0.64, 0.69, 0.76, and 0.88  $\mu\text{m}$ , respectively. The construction and operation of this polarimeter are described by Kikuchi (1988)<sup>5)</sup>. An accuracy of better than 0.03% is obtained with this polarimeter.

Thirteen RV Tauri stars and three related stars were obtained in this study. These stars are listed in table 1. In this table, six stars underlined, TW Cam, SS Gem, AC Her, U Mon, R Sct, and V Vul have been observed polarimetrically by other observers, and the other stars were newly observed polarimetrically in this study. The results have been reported by Yoshioka (1994)<sup>6)</sup> for the seven RV Tauri stars, TW Cam, UY CMa, V360 Cyg, SS Gem, SU Gem, AC Her, and EP Lyr and for the W Virginis star, CO Aur.

In this paper, the results are reported for the other six RV Tauri stars, U Mon, TT Oph, R Sct, R Sge, RV Tau, and V Vul and for the Semi-regular variable, EI Peg and for the Irregular variable, Z Sex.

The method of reduction is described by Yoshioka (1994)<sup>6)</sup>. The only difference in reduction between the present results and the results by Yoshioka (1994)<sup>6)</sup> is the empirical formula for a wavelength dependence of the interstellar polarization. Yoshioka (1994)<sup>6)</sup> adopted the formula by Wilking et al. (1982)<sup>7)</sup> (hereafter referred to as WLR), which is given as follows:

$$p = p_{\text{max}} \cdot \exp \{ -K \ln^2(\lambda_{\text{max}}/\lambda) \}, \quad (1)$$

where  $p_{\text{max}}$  is the maximum polarization which occurs at the wavelength  $\lambda_{\text{max}}$ ;  $K$  is a linear function of  $\lambda_{\text{max}}$ :

$$K = -0.10 + 1.86\lambda_{\text{max}}. \quad (2)$$

Table 1. Data on the Stars Observed. The second column gives the classification in the General Catalogue of Variable Stars (Kholopov et al. 1985)<sup>15)</sup>. The third column gives the classification on the basis of optical spectra. Underlined stars have been observed polarimetrically before the present observations.

Star	Variable Star Class	Optical Group	Period (days)	Mean $m_v$
CO Aur	CW		1.8	7.8
<u>TW Cam</u>	RVa	A <sub>2</sub>	85.6	9.6
UY CMa	RVa	B	113.9	10.7
V360 Cyg	RVa	C	70.5	11.4
<u>SS Gem</u>	RVa	A <sub>2</sub>	89.3	8.9
SU Gem	RVb	A <sub>2</sub>	50.1	11.4
<u>AC Her</u>	RVa	B	75.5	7.5
EP Lyr	RVb	B	83.3	10.5
<u>U Mon</u>	RVb	A <sub>1</sub>	92.3	6.3
TT Oph	RVa	A <sub>2</sub>	61.1	10.2
EI Peg	SRa		61.2	9.9
R Sct	RVa	A <sub>1</sub>	140.2	5.8
Z Sex	Lb			9.4
R Sge	RVb	A <sub>2</sub>	70.6	9.2
RV Tau	RVb	A <sub>1</sub>	78.7	9.2
<u>V Vul</u>	RVa	A <sub>1</sub>	75.7	8.4

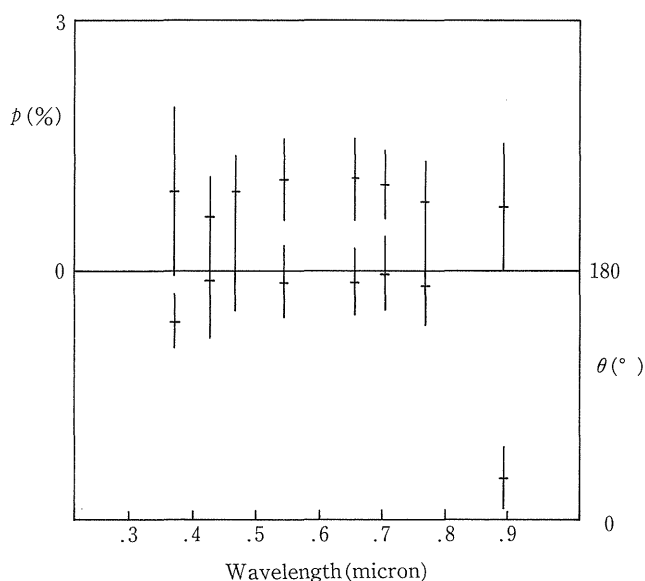


Fig. 1a. The Intrinsic Polarization of TW Cam. The formula by WLR is used in order to remove the interstellar polarization.

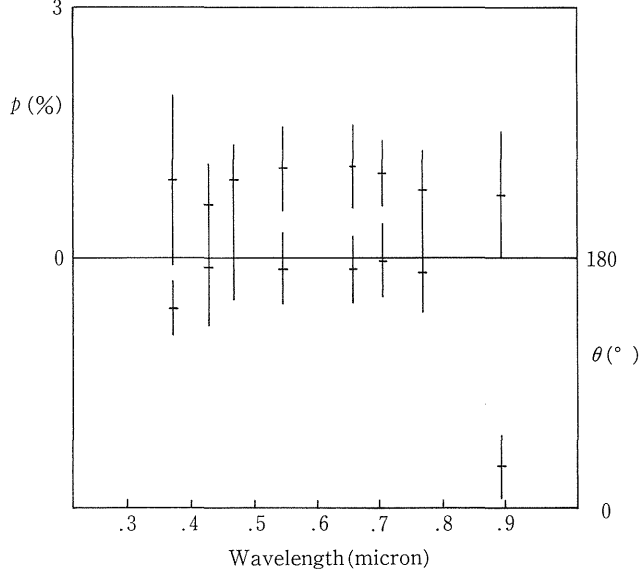


Fig.1b. The Intrinsic Polarization of TW Cam. The formula by WMHRBA is used in order to remove the interstellar polarization.

In the present analysis, the following formula by Whittet et al. (1992)<sup>8)</sup> (hereafter referred to as WMHRBA) is adopted for the linear dependence of  $K$  on  $\lambda_{\max}$ :

$$K = 0.01 + 1.66\lambda_{\max}. \quad (3)$$

Figures 1a and 1b show the intrinsic polarization of TW Cam obtained by removing the interstellar polarization with the formula by WLR (equation (2)) and the formula by WMHRBA (equation (3)), respectively. As is shown in these figures, there is no notable difference in the resulting intrinsic polarization.

### III. Results

The details of the results are as follows.

#### a) U Mon

U Mon belongs to the RVb group and to the group A<sub>1</sub>. Seven observations were made for this star on 1993 October 27/28, 1993 November 27/28, 1993 December 25/26, 1994 February 2/3, 1994 February 23/24, 1994 March 31/April 1, and 1994 April 4/5. Figure 2 shows the time variation of the polarization during the period of the observation. The data at 1994 April 4/5 are omitted, because the observational errors are large. As is shown in this figure, except for the channel 8, there is neither a wavelength dependence nor a time variation

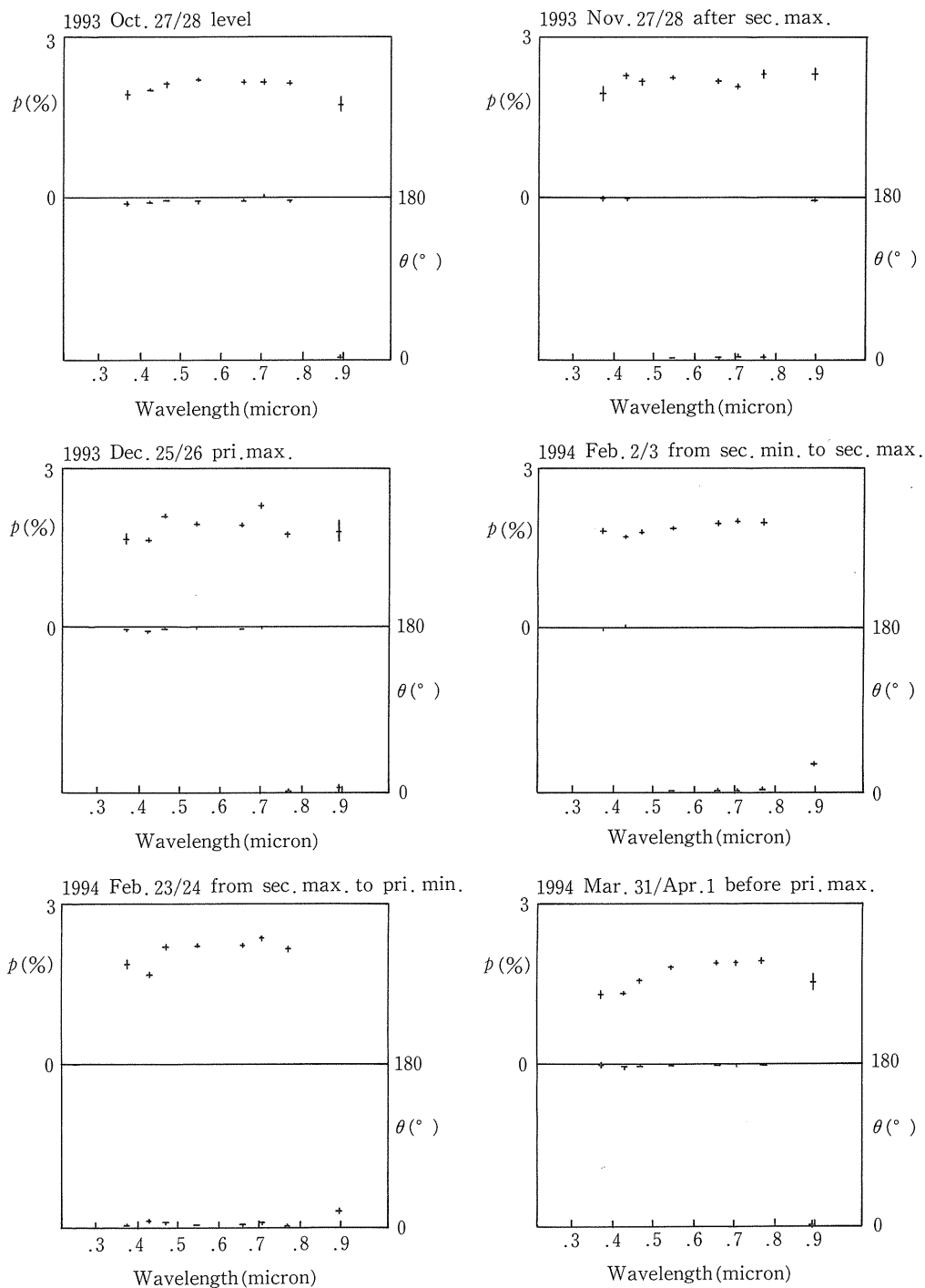


Fig. 2. The Observed Polarization of U Mon.

of the values of the position angle of polarization  $\theta$ , and its values are close to  $0^\circ$ . There is neither a noticeable wavelength dependence of the degree of linear polarization  $p$ . However, the average value of  $p$  depends on time, and its variation seems to correlate with the brightness variation. The average values of  $p$  on 1993 October 27/28, 1993 November 27/28, and 1994 February 23/24 are larger by about 0.25% than those on 1993 December 25/26, 1994 February 2/3, and 1994 March 31/April 1. According to a visual light curve by the Japan Astronomical Study Association (hereafter referred to as JASA) which was communicated to the author by Saijo (1994)<sup>9)</sup>, the times of the higher average  $p$  values correspond to the phases during darkening or near light minimum, and the times of the lower average  $p$  values correspond to the phases during brightening or near light maximum. There is a noticeable time variation of the normalized Stokes parameter  $U$ . The  $U$  values are negative for the most channels on 1993 October 27/28, 1993 December 25/26, and 1994 March 31/April 1, while the  $U$  values are positive for all the channels on 1994 February 23/24. There seems to be no correlation between the  $U$  values and the  $p$  values. There is a slight tendency for the  $U$  values to increase with wavelength.

U Mon has been observed polarimetrically by Shakhovskoi (1964)<sup>10)</sup>, Aliev (1965)<sup>11)</sup>, Serkowski (1970)<sup>12)</sup>, Wolf (1972)<sup>13)</sup>, and Nook et al. (1990)<sup>14)</sup>. Shakhovskoi (1964)<sup>10)</sup> observed on 1961 December 5/6 and 1961 December 6/7. The detector of his observations was an antimony-cesium photocathode without filters. Owing to insufficient data, he could not draw definite conclusions on the time variation of polarization for U Mon. The average  $p$  value of 1.67% of his observations is within the range of our observations, but the average  $\theta$  value of  $13.3^\circ$  is larger than that of our observations. Aliev (1965)<sup>11)</sup> observed between 1964 November 30 and 1965 March 11. He observed the time variation of polarization. The values of  $p$  and  $\theta$  observed by him are within the ranges from 0.9% to 2.6% and from  $0^\circ$  to  $30^\circ$ , respectively. The  $p$  and  $\theta$  values for our observations are within the above ranges, though our  $\theta$  values are close to the lowest limit of the above range. Serkowski (1970)<sup>12)</sup> observed between 1967 November 27 and 1969 June 18. He observed in the  $U$ ,  $B$  and  $V$  bands with the 61cm reflector at Siding Spring Observatory. He observed the time variation of polarization. The values of  $p$  and  $\theta$  observed by him are within the ranges from 0.5% and 3.3% and from  $176^\circ$  to  $36^\circ$ , respectively. His  $\theta$  values are also slightly larger than our values. Wolf (1972)<sup>13)</sup> observed twice on 1969 December 16/17 and 1969 December 22/23. He observed at six colors from the  $U$  to  $R$  bands with the 91cm reflector at Kitt Peak National Observatory. He observed not only a linear polarization but also a circular polarization, but he found no evidence for circular polarization. His  $p$  values are within the range from 1.7% to 2.6%, and

the values at the  $U$  and  $B$  bands are larger than those for the other colors with longer wavelengths. His  $\theta$  values are within the range from  $13^\circ$  to  $20^\circ$ , which values are also slightly larger than our values. Nook et al. (1990)<sup>14)</sup> observed three times on 1986 November 24/25, 1986 November 26/27, and 1987 February 17/18. They observed at four colors from  $0.4828\ \mu\text{m}$  to  $0.6877\ \mu\text{m}$  with the 91cm reflector at the University of Wisconsin's Pine Bluff Observatory. The first two observations were made during brightening towards primary light maximum, and the third was observed during brightening towards secondary light maximum. They observed both the wavelength dependence and the time variation of polarization, though the observed positions in the  $QU$  plane are significantly different from that observed by Serkowski (1970)<sup>12)</sup>. Their  $p$  and  $\theta$  values are within the ranges from 1.4% to 2.5% and from  $178^\circ$  to  $4^\circ$ , respectively.

The intrinsic polarizations of this star are yielded from our observations by removing the following interstellar polarization:

$$p_{\text{max}} = 1.85\%, \quad \theta = 10^\circ, \quad \text{and} \quad \lambda_{\text{max}} = 0.50\ \mu\text{m}, \quad (4)$$

which were determined by Serkowski (1970)<sup>12)</sup> on the assumptions that the interstellar polarization in the  $B$  band is the same as in the  $V$  band and that its value is equal to the average of the observed polarization in the above two bands. Figure 3 shows the intrinsic polarizations obtained in this way. As is shown in this figure, there is not a noticeable wavelength dependence of the  $p$  values. However, the average  $p$  values depend on time and vary from 0.6% to 1.0%. There seems no definite correlation between its variation and the brightness variation. On the other hand, the average  $\theta$  values discernibly depend on time, and its variation seems to depend on the brightness variation. The average  $\theta$  value on 1994 March 31/April 1, that is, is smaller than the other values by about  $10^\circ$ . According to the visual light curve by JASA, the phase on 1994 March 31/April 1 corresponds to that of shortly before primary light minimum, and the other phases correspond to those of primary light minimum or of after primary light minimum. This correlation is consistent with the time variation of the intrinsic  $\theta$  values with phase observed by Serkowski (1970)<sup>12)</sup>. The intrinsic  $\theta$  values by us has a slight tendency to increase with increasing wavelength. Nook et al. (1990)<sup>14)</sup> also yielded the intrinsic polarizations from their observations by adopting the same values of  $p_{\text{max}}$ ,  $\theta$ , and  $\lambda_{\text{max}}$ , and the formula by WLR. They obtained the time variation of  $\theta$  values similar to that observed by Serkowski (1970)<sup>12)</sup>. However, the  $\theta$  values by Nook et al. (1990)<sup>14)</sup> are systematically smaller than those by Serkowski (1970)<sup>12)</sup> by up to  $30^\circ$ . Our  $\theta$  values seem to be larger by about  $10^\circ$  than those by Nook et al. (1990)<sup>14)</sup>, but further observations are necessary in order to obtain the properties of the time variation of  $\theta$  values.



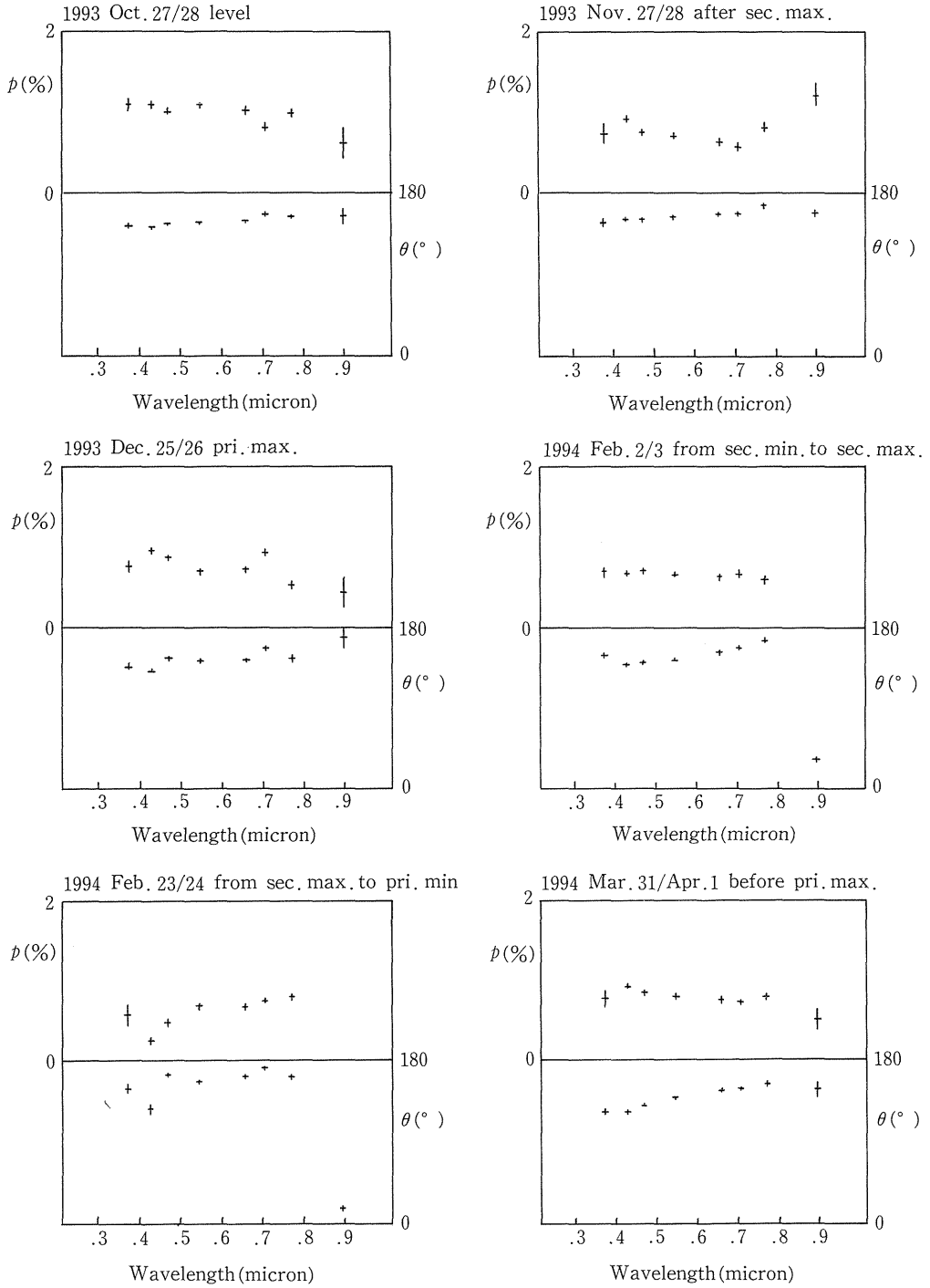


Fig.3. The Intrinsic Polarization of U Mon.

## b) TT Oph

TT Oph belongs to the RVa group and to the group A<sub>2</sub>. Six observations were made for this star on 1994 February 19/20, 1994 February 21/22, 1994 March 29/30, 1994 March 31/April 1, 1994 April 4/5, and 1994 April 15/16. Neither  $p$  values nor  $\theta$  values do not depend on time noticeably, but the  $U$  values slightly depend on time. The  $U$  values on 1994 February 19/20 are smaller by about 0.2% and the  $U$  values on 1994 April 4/5 are larger by about 0.5% than those on the other dates. According to a visual light curve by JASA, the phases on 1994 February 19/20 and on 1994 April 4/5 correspond to those during brightening and during darkening, respectively, and the other phases correspond to that near light maximum. Further observations are necessary in order to obtain definitely a correlation between the variation of  $U$  values and the brightness variation.

## c) EI Peg

In the *General Catalogue of Variable Stars* (Kholopov et al. (1985)<sup>15)</sup>), EI Peg is classified as Semi-regular variable with regular light curves. This star was observed once on 1993 November 24/25. Except for the channel 1 and the channel 8 of the polarimeter, neither  $p$  values nor  $\theta$  values show a noticeable wavelength dependence. The  $p$  and  $\theta$  values are close to 0.5% and 80°, respectively.

## d) R Sct

R Sct belongs to the RVa group and to the group A<sub>1</sub>. Two observations were made for this star on 1993 November 24/25 and 1994 February 21/22. According to a visual light curve by JASA, the phases of the first and the second observation correspond to those during darkening and during brightening, respectively. Except for the channel 1 and the channel 8, neither  $p$  values nor  $\theta$  values show a noticeable wavelength dependence. The  $\theta$  values are within the range from 30° to 39°. The  $p$  values are close to 1.0%, though the values on 1994 February 21/22 are slightly smaller than those on 1993 November 24/25 by up to 0.2%.

R Sct has been observed polarimetrically by Shakhovskoi (1964)<sup>10)</sup>, Dombrovskij et al. (1970)<sup>16)</sup>, Serkowski (1970)<sup>12)</sup>, and Landsreot and Angel (1977)<sup>17)</sup>. Shakhovskoi (1964)<sup>10)</sup> observed between 1961 June 11 and 1961 October 6. He observed with the the same instruments that he observed U Mon. He observed the time variation of polarization which correlates with the brightness variation. His  $p$  and  $\theta$  values are within the ranges from 0.5% to 1.3% and from 30° to 60°, respectively, within which our values range. Dombrovskij et al. (1970)<sup>16)</sup> observed between 1967 May 29 and 1968 October 15. They observed in

the  $U$ ,  $B$ ,  $V$ , and  $R$  bands. They also observed the time variation of polarization. The ranges of variation have a tendency to increase with decreasing wavelength. For example, the  $p$  and  $\theta$  values in the  $U$  band range from 0.3% to 3.1% and  $10^\circ$  to  $47^\circ$ , respectively, while the  $p$  and  $\theta$  values in the  $V$  band range from 0.9% to 1.4% and  $28^\circ$  to  $45^\circ$ , respectively. Our  $p$  and  $\theta$  values are within the above ranges. Serkowski (1970)<sup>12)</sup> observed between 1967 March 21 and 1969 October 2. He observed with the same instruments that he observed U Mon. He also observed the time variation of polarization. His  $p$  and  $\theta$  values are within the ranges from 0.3% to 2.9% and from  $165^\circ$  to  $54^\circ$ , respectively, within which our values range. The ranges of his  $p$  and  $\theta$  values have a tendency to increase with decreasing wavelength, though his observational errors increase with decreasing wavelength. Landsreot and Angel (1977)<sup>17)</sup> observed on 1973 June 20/21 when the phase of brightness variations, counted from the deep minimum, is equal to 0.46. They observed spectropolarimetrically with the multi-channel spectrophotometer on the 5m reflector at Mount Palomar Observatory. Their  $p$  values range from 0.5% to 1.3% and have a slight maximum at about  $0.6\mu\text{m}$ . Their  $\theta$  values are nearly constant of about  $35^\circ$  to the red about  $0.55\mu\text{m}$ , while, to the blue of this wavelength, they increase gradually to the value of about  $90^\circ$  at  $0.33\mu\text{m}$ . They interpreted this result as indicating that this star showed little or no intrinsic polarization to the red of about  $0.55\mu\text{m}$  and that, to the blue of this wavelength, the contribution of intrinsic polarization increased. They did not observe a notable change in polarization across absorption lines except for a possibly real drop in  $p$  values coinciding with the ultraviolet Fe I lines.

According to Shakhovskoi (1964)<sup>12)</sup>, there is a linear relationship between  $Q$  and  $U$ . They attributed this relationship to the variation of intrinsic  $p$  values, with the intrinsic  $\theta$  values remaining constant. They determined the interstellar  $\theta$  value for the region near R Sct by averaging of observed  $\theta$  values for seven early-type stars within a radius of  $5^\circ$  from R Sct. Then, they determined the interstellar  $p$  value by finding the point of intersection in the  $QU$  plane of the regression line for the above relationship and the line with an inclination of  $2\theta$  passing through the origin. They obtained the following interstellar polarization:

$$p=0.64\% \text{ and } \theta=53.6. \quad (5)$$

By removing the above interstellar polarization from the observed polarizations, they yielded the intrinsic polarizations. The intrinsic  $p$  values thus yielded show a time variation and range from 0% to 1.2%. Serkowski(1970)<sup>12)</sup> also determined the interstellar polarization on the same assumptions that were assumed in the case of U Mon. He obtained the following interstellar polarization :

$$p_{\text{max}}=1.15\%, \theta=32^\circ, \text{ and } \lambda_{\text{max}}=0.50\mu\text{m}. \quad (6)$$

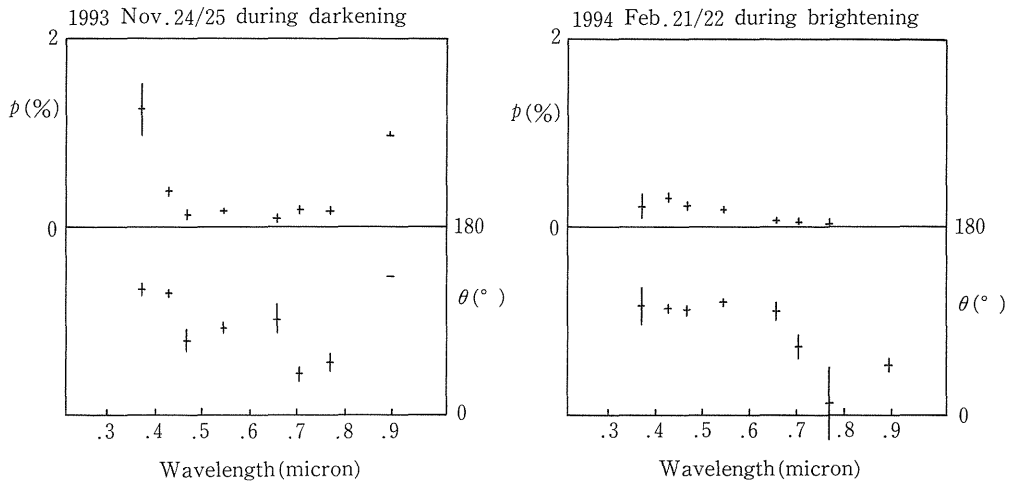


Fig.4. The Intrinsic Polarization of R Sct.

By removing the above interstellar polarization, he yielded the intrinsic polarizations. The intrinsic  $p$  values thus yielded show the time variation and range from 0% to 1.1%. The intrinsic  $\theta$  values also show the time variation and range from  $0^\circ$  to  $180^\circ$ . However, the variations in both the  $p$  values and the  $\theta$  values do not seem to repeat from cycle to cycle.

The intrinsic polarizations of this star are also yielded from our observations by removing the same interstellar polarization that Serkowski (1970)<sup>12)</sup> determined (expression(6)). Figure 4 shows the results. As is shown in this figure, except for the channels 1 and 8, the intrinsic  $p$  values do not show a noticeable wavelength dependence and are smaller than 0.4%. On the other hand, the intrinsic  $\theta$  values show a wavelength dependence. The  $\theta$  values shortward of 0.65  $\mu\text{m}$  are larger than  $70^\circ$ , while the  $\theta$  values longward of this wavelength are smaller than  $70^\circ$ .

#### e) Z Sex

In the *General Catalogue of Variable Stars* (Kholopov et al. (1985)<sup>15)</sup>), Z Sex is classified as Irregular giant. Four observations were made for this star on 1993 November 27/28, 1994 February 19/20, 1994 February 21/22, and 1994 March 29/30. Except for the channels 1 and 8, the  $p$  values are smaller than 0.5% and show noticeably neither time variation nor wavelength dependence. On the other hand, the  $\theta$  values show a noticeable wavelength dependence. These values range from about  $30^\circ$  to about  $10^\circ$ , and take a maximum at the channel 4, 5, or 6.

## f) R Sge

R Sge belongs to the RVb group and to the group A<sub>2</sub>. Three observations were made for this star on 1993 October 24/25, 1993 October 27/28, and 1993 November 28/29. The  $\theta$  values are close to 0° and show noticeably neither time variation nor wavelength dependence. The  $p$  values also do not show a noticeable wavelength dependence. However, the average  $p$  values show a slight time variation. The average  $p$  value for the last observation, that is, is equal to about 0.8%, while the other values are equal to about 0.6%. According to a visual light curve by JASA, the phase of the last observation corresponds to that of secondary light maximum, while the other phases correspond to that shortly before primary light maximum. Therefore, this difference in the average  $p$  value may be due to the difference in phase.

## g) RV Tau

RV Tau belongs to the RVb group and to the group A<sub>1</sub>. Eight observations were made for this star on 1993 October 23/24, 1993 October 27/28, 1993 November 27/28, 1993 December 22/23, 1993 December 23/24, 1994 February 2/3, 1994 February 19/20, and 1994 February 23/24. According to a visual light curve by JASA, the phases on 1993 October 23/24 and on 1993 October 27/28 correspond to those of shortly before secondary light minimum and of secondary light minimum, respectively; the phase on 1993 November 27/28 corresponds to that during darkening from secondary light maximum to secondary light minimum; the phases on 1993 December 22/23 and on 1993 December 23/24 correspond to that of primary light maximum; the phase on 1994 February 2/3 corresponds to that of shortly after secondary light maximum; the phases on 1994 February 19/20 and on 1994 February 23/24 correspond to that of secondary light minimum.

Figure 5 shows the part of the results of our observations. As is shown in this figure, the most  $\theta$  values are within the range from 16° to 33°, and they show noticeably neither time variation nor wavelength dependence. On the other hand, the  $p$  values show a discernible wavelength dependence. The  $p$  values, that is, take a maximum at the channels between 4 and 7, and the wavelength of the maximum  $p$  value changes with time. Furthermore, the average positions in the  $QU$  plane changed toward upper-right direction during the period of observation. Corresponding to this change, the  $p$  values increased during this period. For example, the  $p$  value for the channel 4 increased from 1.47% to 2.92% during this period. Because these changes are one-directional, they are not due to the difference in phase. Moreover, the time rates of these changes seem to vary with time.

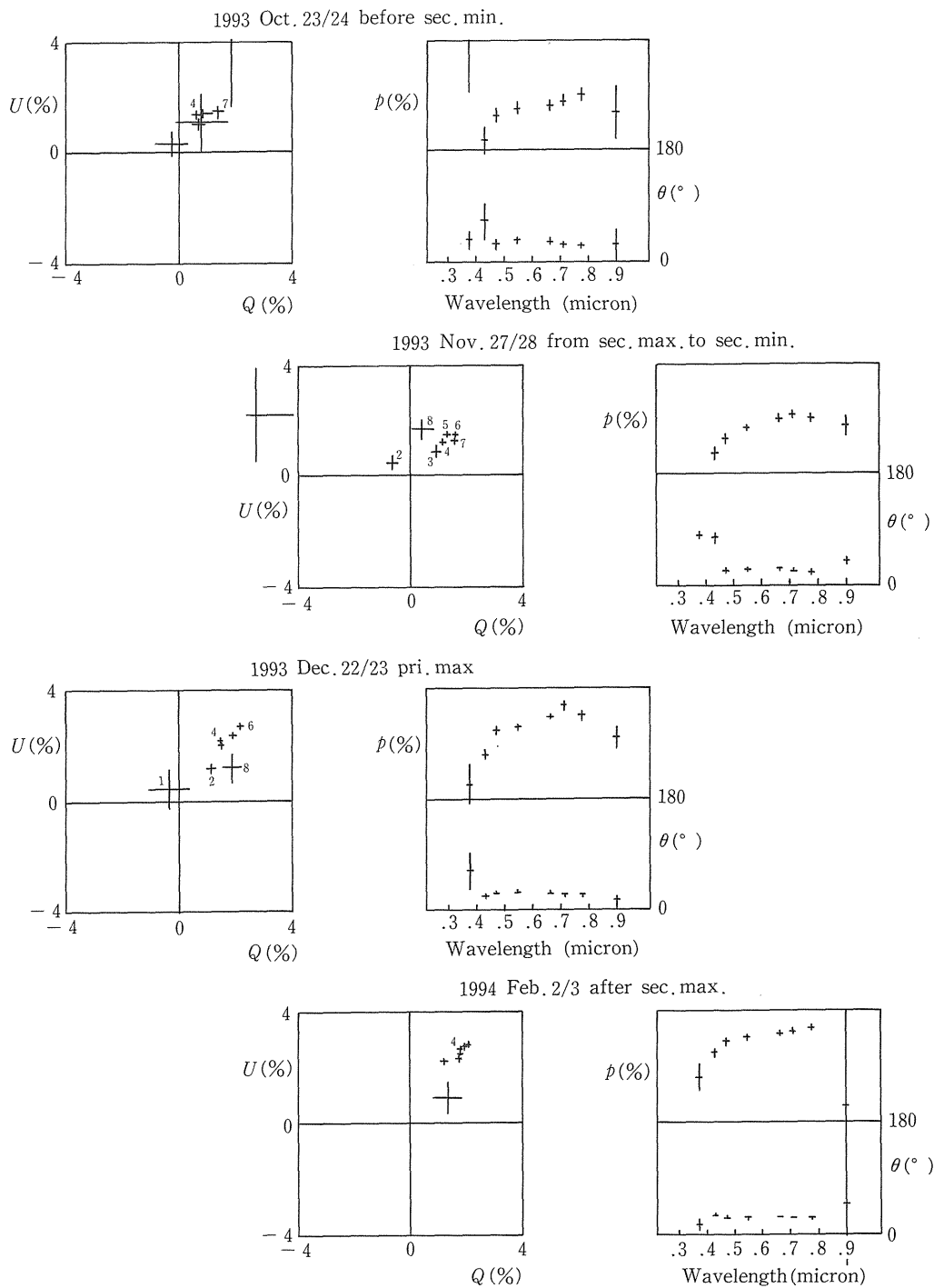


Fig.5. The Part of the Observed Polarization of RV Tau.

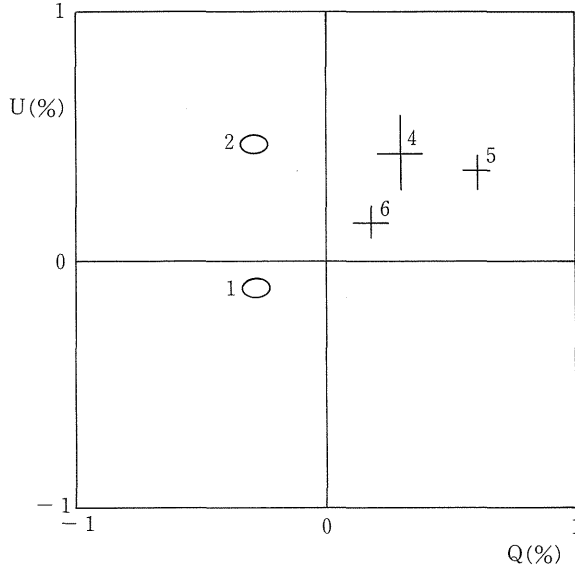


Fig.6. The  $QU$  Plane for the Observed Polarization of V Vul. The data points labeled 1 and 2 represent the data on 1987 August 3/4 and on 1987 August 19/20, respectively, which were observed by Nook et al. (1990)<sup>11)</sup>. The ellipses on their data points represent  $1\sigma$  errors about the observed  $QU$  values. The data points labeled 4, 5, and 6 represent our observations which were observed on 1993 October 24/25, 1993 October 27/28, and 1993 November 28/29, respectively.

#### h) V Vul

V Vul belongs to the RVa group and to the group  $A_1$ . Three observations were made for this star on 1993 October 24/25, 1993 October 27/28, and 1993 November 28/29. Except for the channels 1 and 8, the  $\theta$  values are within the range from  $8^\circ$  to  $36^\circ$  and show noticeably neither time variation nor wavelength dependence. The  $p$  values do not show a noticeable wavelength dependence, but they show a slight time variation. The average  $p$  values on 1993 October 24/25 and on 1993 October 27/28, that is, are close to about 0.6%, while the average  $p$  value on 1993 November 28/29 is close to about 0.3%. Furthermore, the  $Q$  and  $U$  values for the last observation are smaller than those for the other observations. According to a visual light curve by JASA, the phases of the first and the second observations correspond to that during brightening, and the phase of the last observation corresponds to that during darkening. Thus, the above time variations may be due to the difference in phase.

V Vul has been observed polarimetrically by Nook et al. (1990)<sup>11)</sup>. They observed twice on 1987 August 3/4 and 1987 August 19/20. They observed with the same instruments that they observed U Mon. They also did not observe a

noticeable wavelength dependence, but they observed an appreciable time variation. As is shown in figure 6, that is, their average  $Q$  values over wavelength did not change noticeably, while their average  $U$  values varied by 0.56%. Their first observation was made shortly after primary light minimum during brightening, and their second observation was made near primary light maximum. Thus, this time variation seems to be due to the variation in phase. Our results also are shown in figure 6. As is shown in this figure, our  $U$  values are within the range of their  $U$  values. On the other hand, our  $Q$  values are positive, while their  $Q$  values are negative. This discrepancy in the  $Q$  values may be also due to the difference in phase. Further observations are necessary in order to confirm this correlation between the  $Q$  values and the phase.

### III. Discussion

We cannot yet obtain the conclusion concerning directly with the main purpose of this study from the polarimetric observations made until now. However, some conclusions have been obtained concerning the polarimetric properties of the RV Tauri stars. These conclusions are described in the following, which include the conclusions described by Yoshioka (1994)<sup>6)</sup>.

1) Our observations made at the Dodaira Station of the National Astronomical observatory give consistent results with those obtained at other observatories.

2) Many RV Tauri stars observed show the time variations of polarization, which is indicated in table 2. In this table, Confirmed Stars are the stars whose time variations for many channels are larger than three times the standard deviation of measurement ( $3\sigma$ ); Possible Stars are the stars which show discernible time variations but the ranges of variations are smaller than  $3\sigma$ ; Unknown Stars are the stars which are observed only once or the stars which are observed two times but an error of one observation is too large to draw a significant conclusion; Underlined stars are the stars whose time variations have been observed by other observers. This table indicates even the possibility that all the RV Tauri stars observed show time variations. The time variations of polarization mean that the polarizations include intrinsic components of polarization. Therefore, it can be concluded that many RV Tauri stars have the intrinsic polarizations and all the RV Tauri stars may have the intrinsic polarizations.

On the other hand, noticeable time variations of polarization did not observed for the three stars other than RV Tauri stars, CO Aur (W Virginis star), EI Peg (Semi-regular variable), and Z Sex (Irregular giant).

3) The RV Tauri stars observed more than two times show a tendency for the observed  $p$  values at light minimum to be larger than those at light maxi-



Table 2. Results as to the Time Variation of Polarization.

Confirmed Stars	TW Cam	<u>AC Her</u>	<u>U Mon</u>	<u>R Sct</u>
	RV Tau	<u>V Vul</u>		
Possible Stars	UY CMa	SS Gem	SU Gem	TT Oph
	R Sge			
Unknown Stars	V360 Cyg	EP Lyr		

mum, as has been observed by other observers.

4) The RV Tauri stars belonging to the group B or C show a tendency for the observed  $p$  values to take a maximum at the channel 4 or 5, especially at light minimum.

5) No systematic difference in polarization is observed between the group  $A_1$  and the group  $A_2$ .

6) The intrinsic polarizations of U Mon show the time variations. The variations in  $\theta$  values correlate well with the phase of brightness variation, while variations in  $p$  values do not seem to correlate with the phase, as has been observed by other observers.

7) The intrinsic  $\theta$  values for U Mon show the long term variation with time, and the average positions of the observed polarizations in the  $QU$  plane for RV Tau show the one-directional time variation.

Further multicolor polarimetric observations for RV Tauri stars, especially for the groups B and C, are being made at the Dodaira Station of the National Astronomical Observatory in order to achieve the main purpose of this study.

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