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Polarization Variations of the RV Tauri Stars III. The Principal Results of Our Observations

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おうし座RV型変光星の偏光の変動について III. われわれの観測の主な結果

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要　旨

おうし座RV型星は光度曲線をもとに，RVa型とRVb型に分類されている．また，可視域のスペクトルをもとに，酸素過剰のAグループと炭素過剰のB，Cグループに分類され，さらに，AグループはTiO帯の有無をもとに，A_1グループとA_2グループに細分されている．さらにまた，赤外放射のエネルギー分布をもとに，この星は酸素過剰グループと炭素過剰グループに分類されている．

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スペクトルを示しながら，酸素過剰な赤外放射を示すものがある．

そこで，両分類の関係を調べるために，おうし座RV型星の多色偏光観測を行っている．観測は，国立天文台堂平観測所の91cm反射望遠鏡に多色偏光測光装置を取り付けて行っている．現在までに17個のおうし座RV型星が観測され，次の結果が得られている．

1）多くの星で偏光の時間変動が観測され，固有の偏光成分をもつことが確認された．
2）時間変動の検出率は，RVa型よりもRVb型が高く，また，A_2グループよりもA_1グループの方が高い．
3）Aグループでは，偏光度pが中間の波長域で極大値をもつ傾向があるのに対して，B，Cグループでは，pが中間の波長域で極小値をもつ傾向がある．
4）U MonやRV Tauでは，長期的な時間変動が見られる．この変動は周期的で，周期がそれぞれの星の光度変化の振幅の長期的変化の周期に近いようである．

以上の結果の解釈も述べられている．

ABSTRACT

On the basis of light curves the RV Tauri stars are divided into the RVa group and the RVb group. On the basis of spectroscopic characteristics in an optical region the RV Tauri stars are divided into the oxygen-rich group, group A, and the carbon-rich group, group B or C. Furthermore, on the basis of the

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presence of TiO bands the group A are divided into the groups A_1 and A_2. On the other hand, on the basis of energy distributions of the infrared radiation, RV Tauri stars are divided into the oxygen-rich group and the carbon-rich group.

There is not a good correlation between the optical spectra and the infrared spectra for the RV Tauri stars. There are the 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 clarify the relationship between the optical and the infrared spectra. The 91cm reflector at the Dodaira Station of the National Astronomical Observatory has been used with the multi-channel polarimeter. To date 17 stars have been observed, and the following results are obtained.

1) Many stars show the time variations of polarization, which indicates that many stars have intrinsic polarizations.
2) Compared with the stars of the RVa group, the stars of the RVb group have a large probability of detection of the time variation of polarization. Furthermore, compared with the stars of the group A_2, the stars of the group A_1 have a large probability of detection of the time variation of polarization.
3) The stars of the A group show a tendency for the p values to take a maximim at an intermediate wavelength, while the stars of the group B or C show a tendency to take a minimum at an intermediate wavelength.
4) U Mon and RV Tau show long term time variations of polarization. These variations seems to be periodic, whose periods are close to the periods of the long wave of amplitude of brightness variation.

The interpretations of the results also are given.

I. Introduction

The RV Tauri stars are semiregular variables. Theie light curves are characterized by alternative deep and shallow minima, and their 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 2 subgroups, RVa and RVb. The RVa group is characterized by a relatively regular light curve, and the interchanges of deep and shallow minima do not occur frequently. The RVb group is characterized by a rather irregular light curve, especially by a superposition of a very long wave of greater amplitude.

On the basis of spectroscopic characteristics in an optical region Preston et al. (1963)[1] divided the RV Tauri stars into 3 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 G or K-type. The group B shows spectra to which a definite spectral type cannot be assigned. The most distinctive characteristic is that near light minima 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)[2] divided the group A into the group A_1 and the group A_2. The group A_1 shows TiO bands near light minima, while the group A_2 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 (CDE). The RV Tauri stars are generally regarded as post-asymptotic giant branch stars and their CDE's are thought to be formed as a result of mass loss at the final stage of asymptotic giant branch phase (Jura (1986)[3]). On the basis of energy distributions of the infrared radiation, the RV Tauri stars are divided into 3 subgroups (Gehrz (1972)[4]). The first group shows smooth, featureless, non-Planckian continua. The second group shows silicate emission features at 10 and 18 μm. The third group shows unidentified emission features at 8-13 μm. Thus, the infrared spectra of the second group are indicative of oxygen-rich circumstellar dust. The first group also seems to have an 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 (1974)[4], 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)[5], 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. The goal of the observations has been to investigate the structure of the CDE's of these stars and to clarify the relationship between the optical and the infrared spectra.

II. Observations

The multicolor polarimetric observations reported in this paper were obtained between 1993 October 23 and 1997 February 27. 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 8 colors. These colors are indicated with the number 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 0.88μm, respectively. The construction and

operation of this polarimeter are described by Kikuchi (1988)[6]. An accuracy of better than 0.03% is obtained with this polarimeter.

17 RV Tauri stars were observed in this study. The results of the observations between 1993 October 23 and 1994 April 16 were reported by Yoshioka (1994)[7] and Yoshioka (1995)[8]. Yoshioka (1994)[7] reported the results for 6 RV Tauri stars, TW Cam, V360 Cyg, SS Gem, SU Gem, AC Her, and EP Lyr. Yoshioka (1995)[8] reported the results for the 6 RV Tauri stars, U Mon, TT Oph, R Sct,R Sge, RV Tau, and V Vul.

In this paper, the results between 1993 October 23 and 1997 February 27 are reported individually for the above 12 stars as well as 5 the RV Tauri stars, AD Aql, EQ Cas, TX Oph, UZ Oph, and CT Ori.

The general trends of polarization obtained from these observations are also reported. The method of reduction is described by Yoshioka (1994)[7] and Yoshioka (1995)[8].

III. Results

III. 1. The Results for Individual Stars

a) AD Aql

AD Aql belongs to the RVa group and to the group B, though Preston et al. (1963)[1] could not classify it with confidence in the group B. AD Aql was observed once on 1996 April 2/3. Except for the channels 1 (0.36μm) and 8 (0.88μm), the values of the degree of linear polarization p and of the normalized Stokes parameter Q and of the position angle of polarization θ are close to 2.0%, −1.9%, and 80°, respectively. On the other hand, the values of the normalized Stokes parameter U decrease from 1.0% to −0.2% as the wavelength increase from 0.455μm (the channel 3) to 0.76μm (the channel 7).

b) TW Cam

TW Cam belongs to the RVb group and to the group A_2. TW Cam was observed 5 times on 1993 December 23/24, 1995 January 15/16, 1996 October 29/30, 1996 November 25/26, and 1996 November 27/28. Except for the channel 1 and 8, the values of p and θ are close to 3.3% and 140°, respectively, and they do not show a noticeable time variation.

However, the Q values for some channels on 1996 October 29/30 are smaller than the other Q values by about 0.5%. According to a visual light curve by the Variable Star Observers League of Japan (VSOLJ) which was communicated to the author by Saijo (1997)[9], the phase on 1996 October 29/30 corresponds to

that of a constant brightness, which differs from those of the other observations. Furthermore, as Yoshoika (1994)[7] reported, our observations do not agree with that by Nook et al. (1990)[10]. Nook et al. (1990)[10] observed once on 1996 December when TW Cam was just before secondary light maximum. Our Q values are larger by more than 1.0% and our U values are smaller by about 0.3%. The phase of their observation also differs from any phases of our observations. Thus, the above variation of polarization seems to be due to the differnce in phase.

c) EQ Cas

EQ Cas belongs to the RVa group and the group B. EQ Cas was observed 5 times on 1995 November 10/11, 1995 December 11/12, 1996 October 27/28, 1996 November 22/23, and 1996 November 25/26. The observed porizations show a rather large time variation. For example, the p values for the channel 4 (0.53 μm) range from 1.2% to 2.4%. However, the observational errors, especially those on the latest 3 nights, are rather large, the definite conclusion cannot be obtained concerning the time variation.

d) V360 Cyg

V360 Cyg belongs to the RVa group and the group C. V360 Cyg was observed 4 times on 1993 October 24/25, 1995 November 9/10, 1996 October 30/31, and 1996 November 25/26. This star shows a discernible time variation of polarization, though the time variation is within the range of 3σ. For example, the Q values on 1995 Nobember 9/10 are larger by about 0.4% than those on 1996 November 25/26. Furthermore, the p values on 1996 November 25/26 take a minimum at an intermediate wavelength, while those on 1995 November 9/10 do not show such a wavelength dependence. According to the visual light curve by VSOLJ, the phase on 1995 November 9/10 corresponds to that shortly before primary light minimum, while the phase on 1996 November 25/26 corresponds to that of primary light maximum. Thus, the above variation of polarization seems to be due to the differnce in phase.

e) SS Gem

SS Gem belongs to the RVa group and the group A_2. SS Gem was observed 10 times on 1993 November 27/28, 1993 December 23/24, 1994 February 2/3, 1994 February 19/20, 1994 December 21/22, 1995 January 18/19, 1995 March 21/22, 1996 February 2/3, 1996 October 27/28, and 1997 January 28/29. Except for the channel 1, 2 (0.42μm), and 8, the p values are within the range from 2.7% to 3.1%, and the θ values are within the range from $-2°$ to $4°$. They do not

show a noticeable time variation, though according to VSOLJ the observations correspond to a wide range of phase. Furthmore, as Yoshioka (1994)[7] reported, the observations by Wolf (1972)[11] and by Nook et al. (1990)[10] agree approximately with our observations.

Nook et al. (1990)[10] determined the interstellar linear polarization of the region near SS Gem by the near-neighbor method described by Bastien (1985)[12], which are given as follows:

$$p_{max}=2.25\pm1.0\%,\ \theta=170^\circ\pm10^\circ,\ \text{and}\ \lambda_{max}=0.54\pm0.04\mu\text{m}, \quad (1)$$

where p_{max} is the maximum degree of polarization which occurs at the wavelength λ_{max}. They concluded that no evidence exists for an intrinsic polarization of SS Gem, because both their observed values of p and θ are within 1σ of the interstellar polarization. Our observations support their conclusion, though our values for the interstellar polarization somewhat differ from their values, which are given as follows:

$$p_{max}=2.96\pm0.3\%,\ \theta=1^\circ\pm2^\circ,\ \text{and}\ \lambda_{max}=0.56\pm0.14\mu\text{m}. \quad (2)$$

The above values are obtained from the observational data between 1993 November 27/28 and 1996 February 2/3 on the assumption that SS Gem does not have an intrinsic polarization, and the errors represent the range of the values deter-

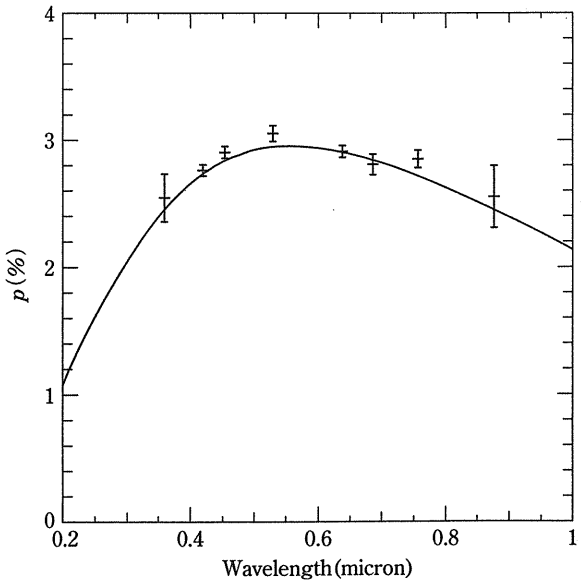

Fig. 1. The Observed p Values for SS Gem on 1993 November 27/28. The solid line shows the empirical formula for a wavelength dependence of interstellar polarization by WMHRBA, where the p_{max} and λ_{max} values are given by the equation (2).

mined from the data on individual nights. As is shown in figure 1, the above values represent well the observed polarizations, where the solid line shows the empirical formula by Whittet et al. (1992)[13] (hereafter referred to as WMHR-BA) for a wavelength dependence of interstellar linear polarization, which is given as follows:

$$p = p_{\max} \cdot \exp\left[-K \ln^2 (\lambda_{\max}/\lambda)\right], \quad (3)$$

where K is a linear function of $\lambda_{\max}$:

$$K = 0.01 + 1.66\lambda_{\max}. \quad (4)$$

f) SU Gem

SU Gem belongs to the RVb group and the group A_2. SU Gem was observed 7 times on 1993 December 24/25, 1993 December 26/27, 1993 December 27/28, 1994 March 29/30, 1995 December 12/13, 1997 January 28/29, and 1997 February 26/27. As the apparent visual magnitudes of this star are larger than +12, the observational errors were generally large. Only the observations on 1993 December 27/28, 1994 March 29/30, 1995 December 12/13, and 1997 January 28/29 give rather reliable data. These data indicate a fairly large time variation of polarization. For example, as compared with the values on 1993 December 27/28, the Q and p values on 1994 March 29/30 are smaller and larger by more than 1.0%, respectively, and the U values are smaller by about 1.0%. Furthermore, as is shown in figure 2, the polarization on 1997 January 28/29 are consider-

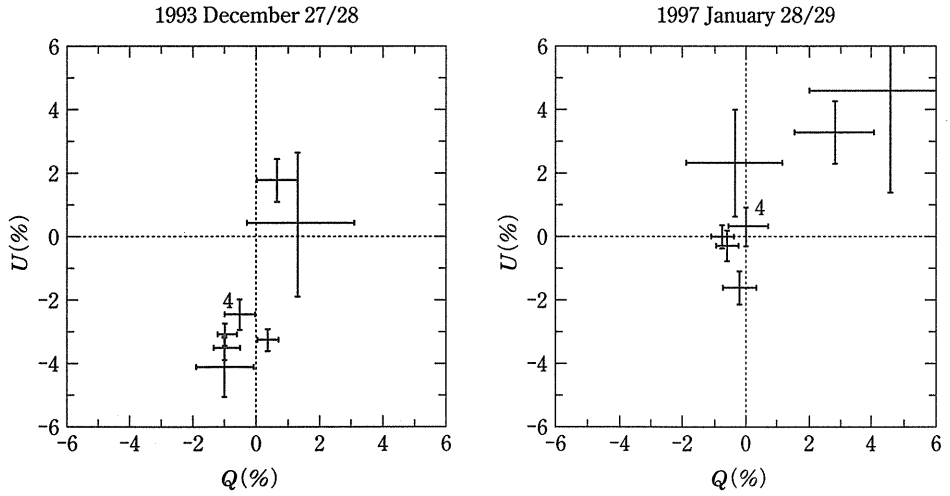

Fig.2. The QU Plane for the Observed Polarization of SU Gem. The position for the 8 channels are shown with error bars. The position for the channel 4 is indicated by the numeral.

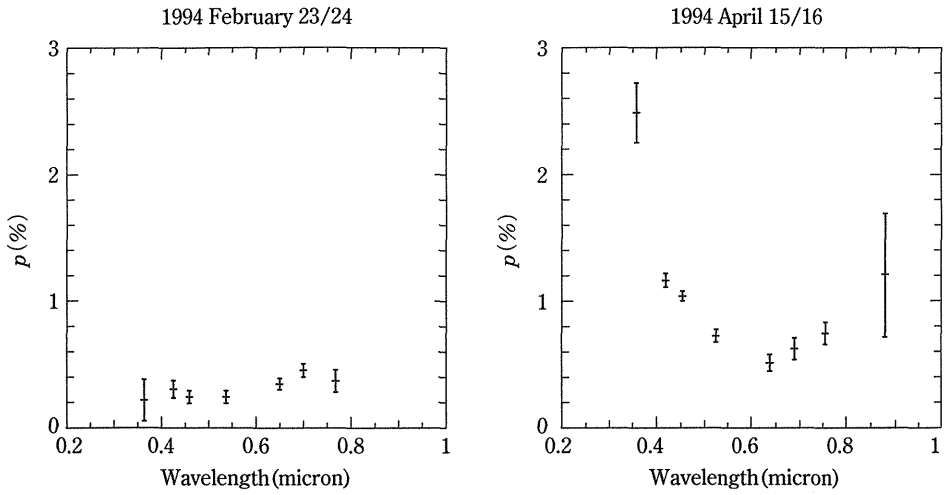

Fig.3. The Observed p Values for AC Her.

ably different from that on 1993 December 27/28. The Q and U values on 1997 January 28/29 are larger by more than 0.5% and about 3.0%, respectively. According to the visual light curve by VSOLJ, the phase on 1993 December 27/28 corresponds to that of light minimum, while the phases on 1994 March 29/30 and 1997 January 28/29 are different from that of light minimum. Thus, the above variation of polarization seems to be due to the difference in phase.

g) AC Her

AC Her belongs to the RVa group and the group B. AC Her was observed 11 times on 1993 November 24/25, 1994 February 23/24, 1994 March 29/30, 1994 April 15/16, 1995 January 14/15, 1995 January 15/16, 1995 January 16/17, 1995 March 20/21, 1996 February 3/4, 1996 February 28/29, and 1996 April 2/3. There is a time variation in the wavelength dependence of p values. For example, as is shown in figure 3, the p values on 1994 February 23/24 are approximately equal, while the p values on 1994 April 15/16 take a minimum at an intermediate wavelength (at the channel 5 whose effective wavelength is equal to 0.64μm). According to the visual light curve by VSOLJ, the phase on 1994 April 15/16 corresponds to that of primary light minimum, while the phase on 1994 February 23/24 corresponds to that during brightening to primary light maximum. As is indicated by this example, there is a tendency for the wavelength dependence of p values to become prominent at light minima. Thus, this wavelength dependence seems to be due to difference in phase. Some of the observations show a wavelength dependence of θ values, as is shown in figure

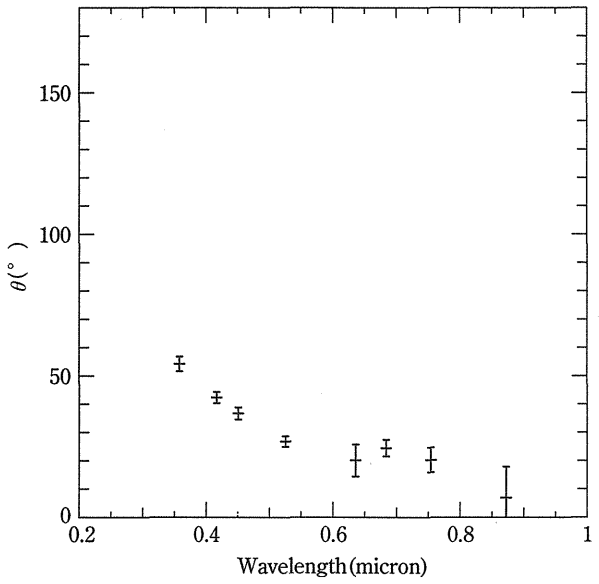

Fig.4. The Observed θ Values for AC Her on 1994 April 15/16.

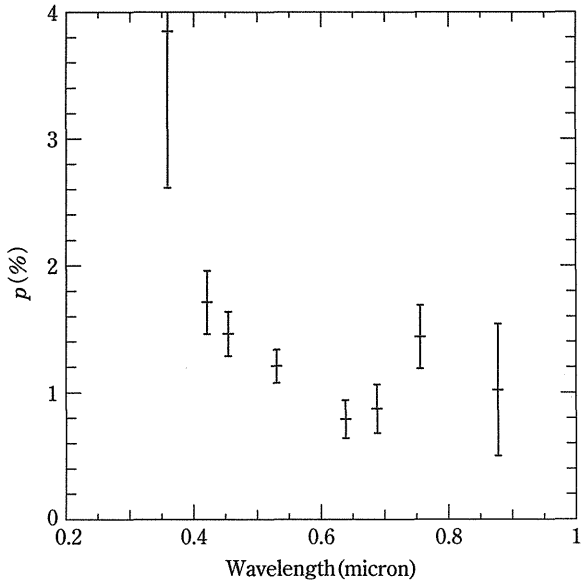

Fig.5. The Observed p Values for EP Lyr on 1993 November 24/25.

4, i.e., the θ values increase below 0.53μm. This wavelength dependence does not correlate with the phase.

As was reported by Yoshioka (1994)[7], the other observers also detected the

time variation of polarization. Especially, Hensen et al. (1985)[14] detected the variation with phase. According to them, the U values for the B band becomes larger than 1.0% near primary light minima. Our U values for the channels 2 and 3 also show the time variation similar to that observed by them.

h) EP Lyr

EP Lyr belongs to the RVb group and the group B. EP Lyr was observed 3 times on 1993 October 24/25, 1993 November 24/25, and 1995 November 10/11. As the observational errors are fairly large, except for the observation on 1993 November 24/25, the definite conclusion cannot be obtained concerning the time variation of polarization. As is shown in figure 5, the p values on 1993 November 24/25 take a minimum at an intermediate wavelength (at the channel 5). According to the visual light curve by VSOLJ, the phase of this day corresponds to that of shortly before primary ligth minimum.

i) U Mon

U Mon belongs to the RVb group and the group A_1. U Mon was observed 17 times 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, 1994 April 4/5, 1994 December 24/25, 1995 January 15/16,1995 March 20/21, 1995 December 8/

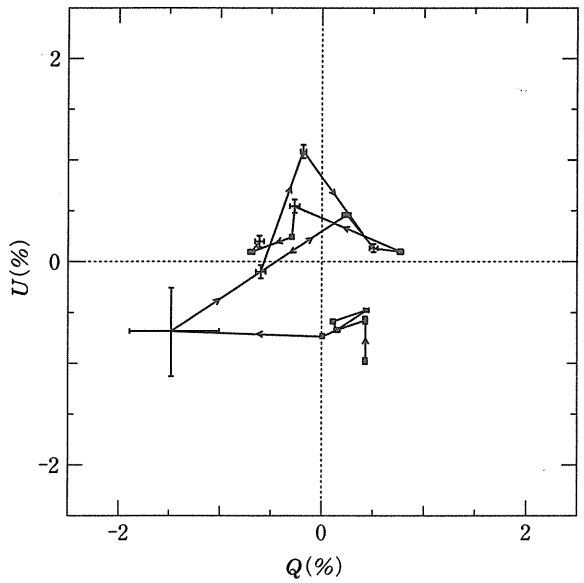

Fig.6. The Time Variation of the Intrinsic Polarization for the Channel 4 in the QU Plane for U Mon.

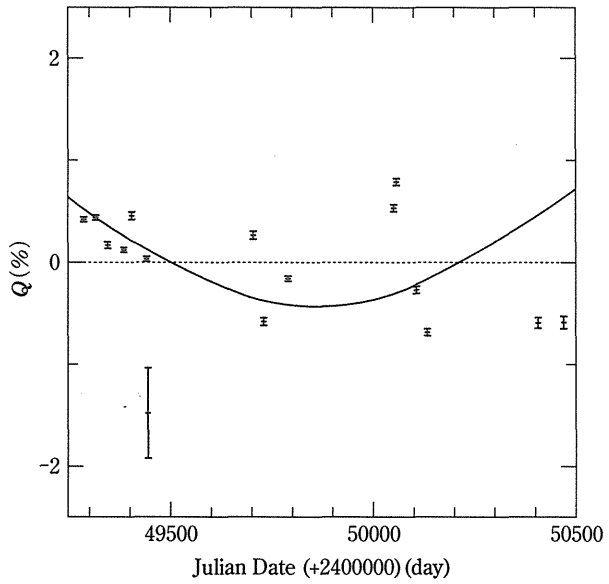

Fig.7. The Time Variation of the Q Values in the Channel 4 for U Mon. The solid line shows the least-squares solution given by $Q=\cos[2\pi(t-48698)/2320]+0.56$, which is obtained on condition that the amplitude and the period are $\pm1\%$ and 2320 days, respectively.

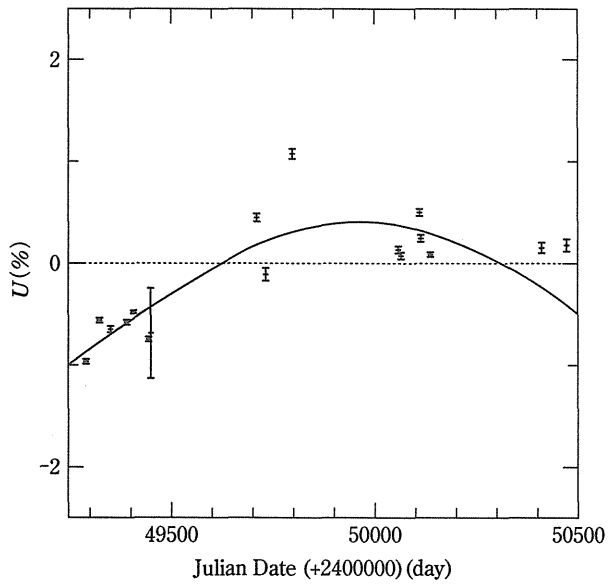

Fig.8. The Time Variation of the U Values in the Channel 4 for U Mon. The solid line shows the least-squares solution given by $U=\cos[2\pi(t-49975)/2320]-0.60$, which is obtained on the same condition as that in figure 7.

9, 1995 December 12/13, 1996 January 31/February 1, 1996 February 3/4, 1996 February 27/28, 1996 November 25/26, and 1997 January 27/28.

As was reported by Yoshioka (1995)[8], the θ values for the intrinsic polarization of this star show the time variation with phase similar to those observed by Serkowski (1970)[15] and by Nook et al. (1990)[10], where the following values are taken to be the interstellar polarization:

$$P_{max}=1.85\%, \theta=10^{\circ}, \text{and } \lambda_{max}=0.50\mu m, \quad (5)$$

which values were determined by Serkowski (1970)[15].

Nook et al. (1990)[10] found that their intrinsic θ values are systematically smaller than those by Serkowski (1970)[15] by up to 30°, which indicates that the intrinsic polarization of this star may undergo a long term variation with time as well as the periodic variation with phase. Our results confirm the long term variation. As is shown in figure 6, superposed on the periodic variation with phase with the amplitude of about $\pm 0.5\%$, the intrinsic polarizations show the long term variation in the QU plane. The long term variations also seems to be periodic with the amplitude of about $\pm 1\%$. This perodicity is also indicated in figures 7 and 8, where the time variations of the intrinsic Q and U values are shown, respectively. As the RVb group group, U Mon has a period of 2320 days for the long wave of amplitude of brightness variation. Solid lines in these figures show time variations with the period of 2320days.

j) TT Oph

TT Oph belongs to the RVa group and the group A_2. TT Oph was observed 12 times on 1994 February 19/20, 1994 February 21/22, 1994 March 29/30, 1994 March 31/April 1, 1994 April 4/5, 1994 April 15/16, 1995 March 20/21, 1996 February 28/29, 1996 April 4/5, 1997 January 31/February 1, 1997 February 21/22, and 1997 February 23/24. Except for the channel 1 and 8, the p values are within the range from 0.6% to 0.9%, and the θ values are within the range from 70° to 90°. They do not show a noticeable time variation. However, the U values change from 0.2% to 0.8%, though this change does not seem to correlate with phase. The p values on 3 nights show a wavelength dependence i.e., the p values take a maximum at an intermediate wavelength. However, the observational errors are rather large, so that further observations are necessary in order to confirm the wavelength dependence.

k) TX Oph

TX Oph belongs to the RVa group and the group A_2. TX Oph was observed 2 times on 1997 February 22/23 and 1997 February 25/26. Most θ values are within the range from 70° to 100°. As the observational errors of both nights

are fairly large, no definite conclusion is derived concerning the time variation and the wavelength dependence of polarization.

l) UZ Oph

UZ Oph belongs to the RVa group and the group A_1. UZ Oph was observed 2 times on 1996 February 27/28 and 1997 February 22/23. Although the observational errors are rather large, both p and θ values show a slight wavelength dependence. They take a maximum at an intermediate wavelength.

m) CT Ori

CT Ori belongs to the group B. CT Ori was observed 8 times on 1994 October 19/20, 1994 December 21/22, 1994 December 24/25, 1995 January 19/20, 1995 February 16/17, 1995 December 12/13, 1996 November 25/26, and 1997 February 26/27. The p values on some nights show a wavelength dependence. For example, the p values on 1994 October 19/20 and 1994 December 24/25 take a maximum at an intermediate wavelength, while the p values on 1995 February 16/17 decrease with wavelength. These wavelength dependence does not seem to be correlate with phase. As the observational errors are rather large, further observations are necessary in order to confirm the wavelength dependence.

n) R Sct

R Sct belongs to the RVa group and the A_1 group. R Sct was observed 3 times on 1993 November 24/25, 1994 February 21/22, and 1996 April 4/5. The p and θ values show neither a noticeable time variation nor a noticeable wavelength dependence, though the Q values on 1996 April 4/5 are larger than the other values by about 0.15%. Except for the channels 1 and 8, the p and θ values are within the ranges from 0.9% to 1.1% and from 32° to 40°, respectively. As was reported by Yoshioka (1995)[8], these ranges are included in the ranges of p and θ values by other observers. Contrary to our observations, other observers observed noticeable time variations of polarization. According to the visual light curve by VSOLJ, all of our observations were made at about the same magnitudes of 5.6~5.7, so that our observations seem to do not show the variation with phase. According to Landstreet and Angel (1977)[16], who observed spectropolarimetrically, the θ values increase noticeably to the blue of about 0.55μm. Our θ values do not show such a wavelength dependence.

o) R Sge

R Sge belongs to the RVb group and the group A_2 R Sge was observed 3 times on 1993 October 24/25, 1993 October 27/28, and 1993 November 28/29.

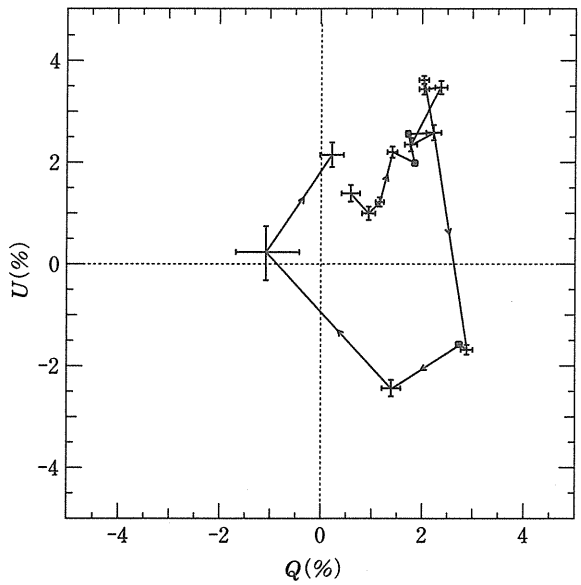

Fig.9. The Time Variation of the Observed Polarization for the the channel 4 in the *QU* Plane for RV Tau.

As was reported by Yoshioka (1995)[8], neither p values nor θ values show a noticeable wavelength dependence. However, the average p and Q values show a slight time variation, i.e., their values on 1993 November 28/29 are larger by about 0.2% than the values on the other nights. As was reported by Yoshioka (1995)[8], these differences are probably due to the difference in phase.

p) RV Tau

RV Tau belongs to the RVb group and the group A_1. RV Tau was observed 16 times 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, 1994 February 23/24, 1994 December 21/22, 1995 January 15/16, 1995 January 18/19, 1995 December 8/9, 1995 December 12/13, 1996 February 28/29, 1996 November 27/28, and 1997 January 28/29. As was reported by Yoshioka (1995)[8], the polarization of this star shows a appreciable time variation. When Yoshioka (1995)[8] reported, the time variation seemed to be one-directional. This report was based on the observations till 1994 February 23/24. However, the observations after this date indicate that the variation seems to be periodic.

As is shown in figure 9, where the locus for the channel 4 is shown in the *QU* plane, the data points turn clockwise round the points of about (1.5%,0%)

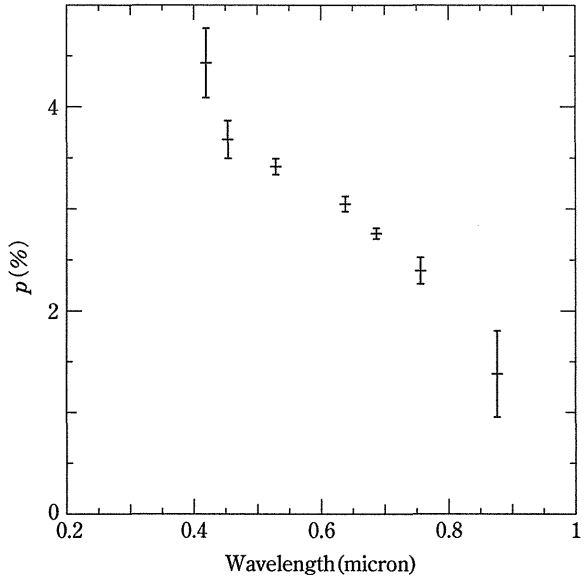

Fig.10. The Observed p Values for RV Tau on 1995 December 8/9.

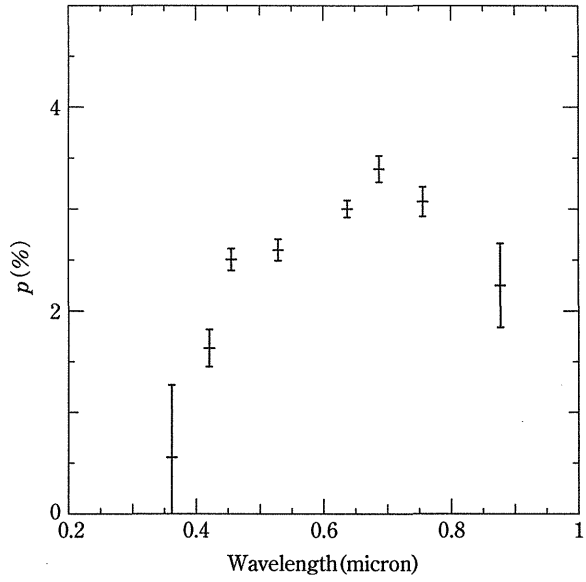

Fig.11. The Observed p Values for RV Tau on 1993 December 22/23.

with the amplitudes of about $\pm 2\%$ an $\pm 3\%$, respectively for Q and U values. The data points almost make a round during the period of our observations.

This period of 1193 days is close to a period of 1224 days for the long wave of amplitude of brightness variation. The wavelength dependence of p values varies according to the position in the QU plane. As is shown in figure 10, the p val-

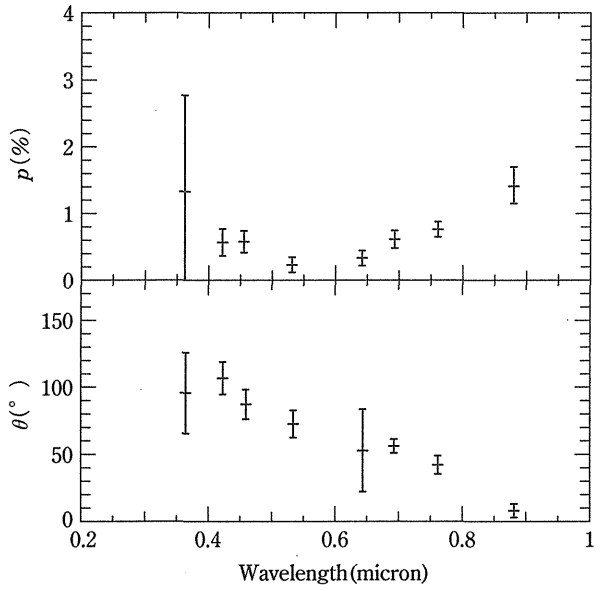

Fig.12. The Observed p and θ Values for V Vul on 1994 December 24/25.

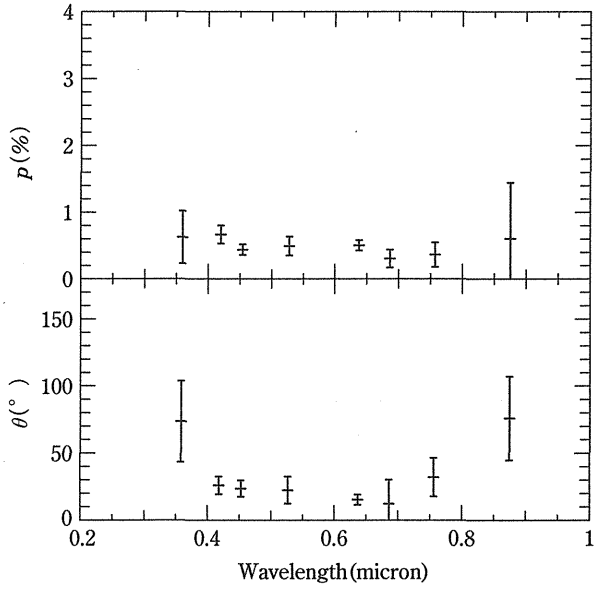

Fig.13. The Observed p and θ Values for V Vul on 1993 October 24/25.

ues decrease with wavelength, when the Q values are positive and the U values are negative. On the other hand, when both Q and U values are positive, the p values do not show such a wavelength dependence. For example, as is shown in figure 11, the p values on 1993 December 22/23 take a maximum at an intermediate wavelength.

p) V Vul

V Vul belongs to the group RVa and the A_1 group. V Vul was observed 5 times on 1993 October 24/25, 1993 October 27/28, 1993 November 28/29, 1994 December 24/25, and 1995 November 10/11.

As was reported by Yoshioka (1995)[8], the polarization of this star shows an appreciable time variation. For example, the two U values observed by Nook et al. (1990))[10] differ in sign, and the sign of their Q values are different from that of most of our Q values. Furthermore, our observations themselves show the time variation. For example, the Q values on 1994 December 24/25 are negative, while the Q values on the other nights are positive. The wavelength dependence on 1994 December 24/25 also is different from that on the other nights. That is, as is shown in figure 12, the p values on this night take a minimum at an intermediate wavelength and the θ values decrease with wavelength, while the p and θ values on the other nights do not show such wavelength dependences, as is shown in figure 13. The time variation is possibly due to the difference in phase, but further observations are necessary to confirm the relation between the time variation and the phase.

III. 2. The General Trends of Polarization and the Interpretations of Them

The general trends of polarization obtained from our observations are described in the following.

1) The time variations of polarization for the RV Tauri stars observed by us are summarized in table 1. In this table, Confirmed Stars are the stars whose time variations for many channels are larger than 3σ; Possible Stars are the stars which show the time variations but the ranges of variations are smaller than 3σ; Undetected Stars are the stars whose time variations are not detected; Unknown Stars are the stars which were observed only once or the stars which were observed more than 2 times but the observational errors are too large to draw a significant conclusion. Furthermore, in this table, the stars also are included in Confirmed Stars whose time variations have been observed by other observers or whose polarizations observed by other observers differ from our result by more than 3σ, even if our observations do not show the time variations.

Table 1. Results as to the Time Variation of Polarization.

Confirmed Stars	TW Cam (RVb, A_2)	SU Gem (RVb, A_2)	AC Her (RVa, B)
	U Mon (RVb, A_1)	R Sct (RVa, A_1)	RV Tau (RVb, A_1)
	V Vul (RVa, A_1)		
Possible Stars	V360 Cyg (RVa, C)	TT Oph (RVa, A_2)	R Sge (RVb, A_2)
Undetected Stars	SS Gem (RVa, A_2)		
Unknown Stars	AD Aql (RVa, B?)	EQ Cas (RVa, B)	EP Lyr (RVa, B)
	TX Oph (RVa, A_2)	UZ Oph (RVa, A_1)	CT Ori (RV, B)

This table indicates that many RV Tauri stars show the time variations of polarization. Considering that out of 17 stars only one star, SS Gem, has confirmedly been found to show no time variation, we can say that most RV Tauri stars may show time variation. The time variations of observed polarizations mean that the polarizations include intrinsic components of polarization. Therefore, most RV Tauri stars may have intrinsic polarizations. As the RV Tauri stars are considered to have CDE, this result seems to be reasonable.

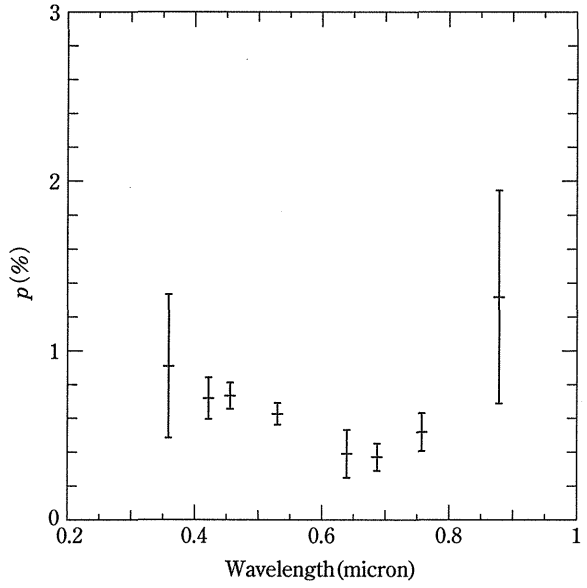

Fig.14. The Observed p Values for AC Her on 1995 January 16. According to the visual light curve by VSOLJ, the phase on this night corresponds to that of secondary light maximum, while the phases on 1994 February 23/24 and 1994 April 15/16 in figure 3 correspond to those of during darkening from primary light maximum and of primary light minimum, respectively.

Table 1 indicates that out of 10 stars of the RVa group, 5 stars (50%) belong to the Confirmed Stars or the Possible Stars, while out of 6 stars of the RVb group, 5 stars (83%) belong to the Confirmed stars or the Possible stars. Therefore, compared with the stars of the RVa group, the stars of the RVb group probably have a large probability and/or large amplitudes of time variation.

Furthermore, table 1 indicates that out of 5 stars of the groupA_1, 4 stars (80%) belong to the Confirmed Stars, while out of 6 stars of the group A_2, only 2 stars (33%) belong to the Confirmed Stars. Therefore, compared with the stars of group A_2, the stars of group A_1 probably have a large probability and/or large amplitudes of time variation.

These results seem to be reasonable. According to the JHKL photometry by Evans (1985)[17], compared with the stars of the RVa group, the stars of the RVb group have large excess at K and L, indicating the presence of CDE of comparatively high temperature near the star, where the stars of the RVa group have much thinner CDE or have dense one only at large radius. Thus it seems to be reasonable that the rate of detection of the time variation for the RVb group is larger than that for the RVa group. Furthermore, according to Dawson (1979)[2], except for TT Oph and TX Oph, the stars of the group A_2 do not show Balmer emissions at any phase, while all the stars of the group A_1 show Balmer emissions at certain phases. Balmer emissions suggests the presence of a strong shock wave in the atmospheres, so that the shock wave for the stars of the group A_1 may be stronger than that for the stars of the group A_2. If this is true, it seems to be reasonable that the rate of detection of the time variation for the group A_1 is larger than that for the group A_2.

2) The stars with time variation show a tendency for the observed p values at light minimum to be larger than those at light maximum, as is exemplified in figure 14. As is often reported, for example by Schwarz (1986)[18], such a tendency is often observed in cool giants and supergiants.

3) As is shown in figure 1, the stars belonging to the A group show a tendency for the observed p values take a maximum at an intermediate wavelength, while, as is shown in figure 3, the stars belonging to the B or C group show a tendency for the p values to take a minimum at an intermediate wavelength. This may indicate that the stars of the group B or C have more than two circumstellar dust shells and each of the shells has a different grain size distribution. In fact, on the basis of multiwavelength observations, Shenton et al. (1992)[19] suggest the presence of at least two distinct dust shells for AC Her belonging to the group B.

Further polarimetric observations for RV Tauri stars are being made at the

Dodaira Station of the National Astronomical Observatory in order to achieve the goal of this study.

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