

Features of Intrinsic Polarization for 6 RV Tauri Stars

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6個のおうし座RV型星の固有偏光の特徴について

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要 旨

おうし座RV型星は、主極小と副極小を交互にくり返す光度変化に特徴がある半規則的な変光星である。この変光星は、光度変化をもとにRVa型とRVb型に細分類されており、RVb型が脈動周期の光度変化に重なって長周期の光度変化を示すのに対して、RVa型にはそのような長周期変化は見られない。また、この変光星は可視域のスペクトルをもとに、酸素過剰なAグループと炭素過剰なB、Cグループに細分類されている。

われわれは、国立天文台堂平観測所の91cm反射望遠鏡を用いて、おうし座RV型星の多色偏光観測を行った。観測された17個の星の内、6個の星に対してはすでに星間偏光成分を取り除いて固有偏光成分を求めている。

本論文では、さらに6個のおうし座RV型星の固有偏光成分の特徴を報告する。星間偏光成分はnear-neighbor法を一部変えた方法で求めた。一般的に、星間偏光成分の内、偏光位置角の決定誤差は小さいが、偏光度の決定誤差は大きい。したがって、固有偏光成分に対して確定的なことは言えない。しかし、Aグループの星の固有偏光成分の偏光度が中間の波長域で極大値をとり、Bグループの星の星では中間の波長域で極小値をとるというこれまで得られきた傾向は確認された。Bグループの星の波長依存性は、星周圏ダストが2種類の異なるサイズをもつことを示唆している。さらにBグループの星には、固有偏光成分の偏光度が波長とともに増加したり減少したりする星が見られるが、これは2種類のダストの偏光に対する寄与の変化として解釈することができる。一方、Cグループの星では、固有偏光成分の偏光度の波長依存性はないようである。

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Abstract

The RV Tauri stars are semiregular variables whose light curves are characterized by alternate deep and shallow minima. On the basis of light curves the RV Tauri stars are divided into RVa and RVb groups. The RVa group is characterized by a relatively regular light curve, while the RVb group is characterized by a superimposition of a long-term variation. On the basis of spectroscopic characteristics in an optical region the RV Tauri stars divided into the oxygen-rich group, the group A, and the carbon-rich group, the group B and the group C.

We made the multicolor polarimetric observations of 17 RV Tauri stars, using the 91cm reflector at the Dodaïra Station on the National Astronomical Observatory. Among the 17 stars we have already obtained the intrinsic polarizations of 6 stars by removing the interstellar polarizations.

In this paper we report the intrinsic polarizations of other 6 stars. The interstellar polarizations are determined by the modified near-neighbor method. Generally speaking, the errors in the degree of interstellar polarization are large, though the errors in the position angle of interstellar polarization are small. Thus, a definite conclusion cannot be obtained concerning intrinsic polarization. However, our results seem to confirm the tendency obtained hitherto that the degree of intrinsic polarization of the stars belonging to the group A takes a maximum at an intermediate wavelength, while that of the stars belonging to the group B takes a minimum at an intermediate wavelength, whose wavelength dependence suggests that the stars of the group B have two circumstellar dust envelopes and each of the envelopes has a different grain distribution. Furthermore, for one star of the group B, the wavelength dependence of the degree of intrinsic polarization changes from the increase with wavelength to the decrease with wavelength, which can be interpreted as the change in the contribution of two types of grains to polarization. On the other hand, the stars belonging to the group C seem to show no wavelength dependence of the degree of intrinsic polarization.

1. 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. The periods between two adjacent deep minima, which are called double periods or formal periods, range between 30 to 150 days. The RV Tauri stars have relatively regular periods, but the magnitudes of maxima and minima are not constant. Interchanges of minima sometimes occur, i.e. two deep or shallow minima occur in succession.

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 minima do not occur frequently. The RVb group is characterized by a rather irregular light curve, especially by a superposition of a long-term brightness variation.

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 G or K-type. The group B shows spectra to which a definite spectral type cannot be assigned. The most distinctive characteristics 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 A₁ and A₂. The group A₁ shows TiO bands near light minima, while the group A₂ 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 (hereafter referred to as CDE). The RV Tauri stars are generally regarded as post-asymptotic giant branch (hereafter referred as post-AGB) stars which left the AGB recently. Their CDE's are thought to be formed as a result of mass loss at the final stage of the AGB phase (Jura(1986)³⁾).

The author, together with Dr.Saijo and Associated Prof.H.Sato, has made the multicolor polarimetric observations of 17 RV Tauri stars between 1993 October 23 and 1998 October 29, using the multi-channel polarimeter attached to the 91 cm reflector at the Dodaira Station of the National Astronomical Observatory.

We had obtained the intrinsic polarizations for 6 RV Tauri stars, TW Cam, SS Gem, AC Her, U Mon, R Sct, and RV Tau from the observed polarizations by removing the interstellar polarizations (Yoshioka(2000)⁴⁾ and Yoshioka(2001)⁵⁾). We obtained the intrinsic polarizations for other 6 stars, EQ Cas, V360 Cyg, SU Gem, EP Lyr, TT Oph, and TX Oph. We report the results for these stars in this paper.

2. Observations and Reductions

The multi-channel polarimeter can measure linear polarizations 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 0.88 μm , respectively. The construction and the operation of this polarimeter are described by Kikuchi(1988)⁶⁾. An accuracy of better than 0.03% can be obtained for bright stars with this polarimeter.

Using this polarimeter, we observed the degree of polarization p and the position angle of polarization θ . We also obtained the normalized Stokes parameters Q and U . The program by Hirarta (1993)⁷⁾ was used for the reduction of the raw data into the quantities of p , θ , Q , and U .

We obtained the intrinsic polarization from the observed polarization by removing the interstellar polarization. We adopted the empirical formula given by Whittet et al.(1992)⁸⁾ for a wavelength dependence of interstellar polarization p_{IS} , which is given as follows:

$$p_{\text{IS}} = p_{\text{max}} \cdot \exp \left[-K \ln^2 (\lambda_{\text{max}}/\lambda) \right], \quad (1)$$

where p_{max} is the maximum degree of linear polarization which occurs at the wavelength λ_{max} ; K is a linear function of λ_{max} ;

$$K = 0.01 + 1.66 \lambda_{\text{max}}. \quad (2)$$

The normalized Stokes parameters for the intrinsic polarization Q_* and U_* are calculated by the following equations:

$$Q_* = Q - p_{\max} \cdot \exp[-K \ln^2(\lambda_{\max}/\lambda)] \cdot \cos 2\theta_{\text{IS}}, \quad (3)$$

$$\text{and } U_* = U - p_{\max} \cdot \exp[-K \ln^2(\lambda_{\max}/\lambda)] \cdot \sin 2\theta_{\text{IS}}, \quad (4)$$

where Q and U are the observed quantities and θ_{IS} is the position angle of interstellar polarization. Then the intrinsic polarization p_* and θ_* are calculated by the following equations:

$$p_* = \sqrt{Q_*^2 + U_*^2}, \quad (5)$$

$$\text{and } \theta_* = 0.5 \cdot \tan^{-1}(U_*/Q_*). \quad (6)$$

The p_{\max} , λ_{\max} , and θ_{IS} values are determined on the basis of the modified near-neighbor method. The near-neighbor method is described by Bastien(1985)⁹⁾. The modified near-neighbor method are described by Yoshioka(2000)⁴⁾. The main modification point is that a distance is used as the parameter for obtaining p_{IS} , instead of $E(B-V)$.

We used the interstellar polarization database compiled by Hirata(1999)¹⁰⁾, hereafter referred to as ISPOL) as the catalogue of stars with no intrinsic polarization. The ISPOL contains 13969 data for several wavelengths collected from 45 literatures.

3. Results

The position, subclasses, and distance for the 6 stars are given in table 1. The details of the results are as follows.

Table1. Data on the RV Tauri Stars analyzed for Intrinsic Polarization.

The period is a formal period. Distances are taken from Dawson (1979)²⁾, except for EQ Cas and EP Lyr whose distances are taken from Wahlgren(1992)¹⁹⁾. The sixth column gives the classification in the General Catalogue of Variable Stars (Kholopov et al. 1985)¹²⁾. The seventh column gives the classification on the basis of optical spectra.

Star	α 1950	δ 1950	Period (day)	Distance (pc)	Variable Star Class	Optical Group
EQ Cas	23 ^h 50 ^m 19 ^s	+54 44 24	58.3	800	RVa	B
V360 Cyg	21 ^h 08 ^m 22 ^s	+30 27 42	70.5	7250	RVa	C
SU Gem	06 ^h 10 ^m 48 ^s	+27 43 48	50.1	5930	RVb	A ₁
EP Lyr	19 ^h 16 ^m 17 ^s	+27 45 00	83.3	2720	RVb	B
TT Oph	16 ^h 47 ^m 06 ^s	+03 43 06	61.1	4270	RVa	A ₂
TX Oph	17 ^h 01 ^m 32 ^s	+05 03 06	135.3	2720	RVa	A ₂

a) 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.

We found 51 stars from ISPOL database which are within 6° circle centered on EQ Cas. We selected 41 stars (66 data) for the estimation of the θ_{IS} value among the above 51 stars whose θ values and distances are determined. In the estimation of θ_{IS} value, HD221253 and HD224355 were excluded because their θ values are too large. The estimated value is; $\theta_{\text{IS}} = 65^\circ$. The scatter of θ values is rather large, and the accuracy of our estimation seems to be rather low.

We selected 24 stars (27 data) for the estimation of $p_{\text{IS}}(B)$ value, where $p_{\text{IS}}(B)$ means the p_{IS} value for B color. The above 24 stars satisfy the conditions that their distances are larger than 50pc, their α_{1950} values are larger than $23^{\text{h}}18^{\text{m}}$, and their δ_{1950} values are within the range from 50.5° to 60° . The estimated value is; $p_{\text{IS}}(B) = 1.055\%$. In this estimation, the dependence of $p(B)$ values on distance was taken into account. Figure 1 shows this dependence. We selected 17 stars (18 data) for the estimation of $p_{\text{IS}}(V)$ value, where $p_{\text{IS}}(V)$ means the p_{IS} value for V color. The above 17 stars satisfy the condition that their distances are within the range from 50pc to 4000pc, their α_{1950} values are larger than $23^{\text{h}}30^{\text{m}}$, and their δ_{1950} values are smaller than 60° . The estimated value is; $p_{\text{IS}}(V) = 1.026\%$. In this estimation, the dependences of $p(V)$ values on

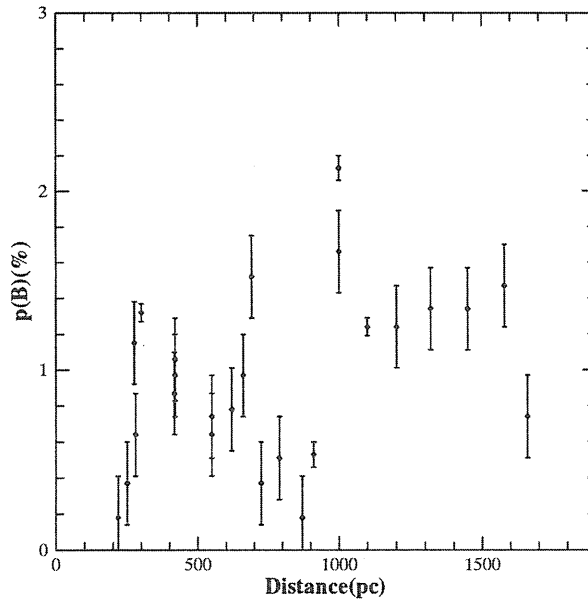


Fig.1. Dependence of the $p(B)$ values near EQ Cas on distance.

The data satisfies the conditions that distances are larger than 50pc, α_{1950} values are larger than $23^{\text{h}}18^{\text{m}}$, and δ_{1950} values are within the range from 50.5° to 60° .

α_{1950} and distance were taken into account. We determined from the above $p_{\text{is}}(B)$ and $p_{\text{is}}(V)$ values that $p_{\text{max}}=1.06\%$ and $\lambda_{\text{max}}=0.45\mu\text{m}$ as the least-squares solution. Both of the scatters of $p(B)$ and $p(V)$ values are rather large, as exemplified in figure 1, and the accuracies of p_{max} and λ_{max} seem to be rather low.

We obtained the intrinsic polarization by removing the interstellar polarization of our values. Except for the data on 1995 November 10/11 and 1995 December 11/12, observational errors are too large to judge the wavelength dependence of p values. The p values on 1995 November 10/11 increase with wavelength, while those on 1995 December 11/12 decrease with wavelength, as are shown in figures 2 and 3. Moreover, the θ values for 1 ~ 4 channels on 1995 November 10/11 increase with the decrease in wavelength. The phase on 1995 November 10/11 differs from that on 1995 December 11/12. However, we cannot conclude the above difference in wavelength is due to the difference in phase, because there is a possibility that the above observations were done near light maximum

b) 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.

We found 16 stars from ISPOL database which are within 6° circle centered on V360 Cyg. We selected 9 stars (9 data) for the estimation of the θ_{is} value among above 16 stars whose θ values are determined. In the estimation of θ_{is} value, HD197702 and HD205618 were excluded because their θ values are too small or too large. The estimated value is; $\theta_{\text{is}}=71^\circ$. The scatter of θ_{is} values is rather large, and the accuracy of our estimation seems to be rather low.

We selected 11 stars (11 data) for the estimation of $p_{\text{is}}(B)$ value. In this estimation, HD197702 and HD205618 were also excluded because their $p(B)$ values are too large. The estimated value is; $p_{\text{is}}(B)=0.068\%$. We selected 4 stars (4 data) for the estimation of $p_{\text{is}}(V)$ value. The estimated value is; $p_{\text{is}}(V)=0.207\%$. We determined from the above $p_{\text{is}}(B)$ and $p_{\text{is}}(V)$ values that $p_{\text{max}}=0.14\%$ and $\lambda_{\text{max}}=0.50\mu\text{m}$ as the least-squares solution.

In the above determination, we prescribed the λ_{max} value, because the least-squares solution gives unrealistic values for p_{max} and λ_{max} when not only p_{max} but also λ_{max} is taken as a free parameter. Both of the scatters of $p(B)$ and $p(V)$ values are rather large, as exemplified in figure 4, and the distance of V360 Cyg is far beyond the range of the above 11 stars. Thus the accuracy of p_{max} seems to be rather low.

We obtained the intrinsic polarization by removing the interstellar polarization of our values. The p_{max} value is small in comparison with the observed p values, so that the results for intrinsic polarization do not differ markedly from those for the observed polarization. Generally speaking, the observational errors are large, so that the definite conclusion cannot be obtained concerning the wavelength dependence of the intrinsic polarization. The data with the least observational error were obtained on 1995 November 9-10 and, according to a visual light curve by the Variable Star Observers League of Japan (hereafter referred to as VSOLJ), the phase of this

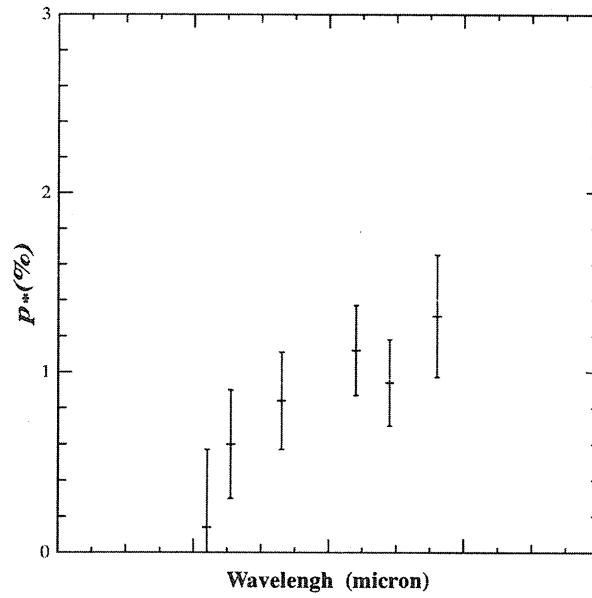


Fig.2. Wavelength dependence of the p_* values of EQ Cas on 1995 November 10/11.

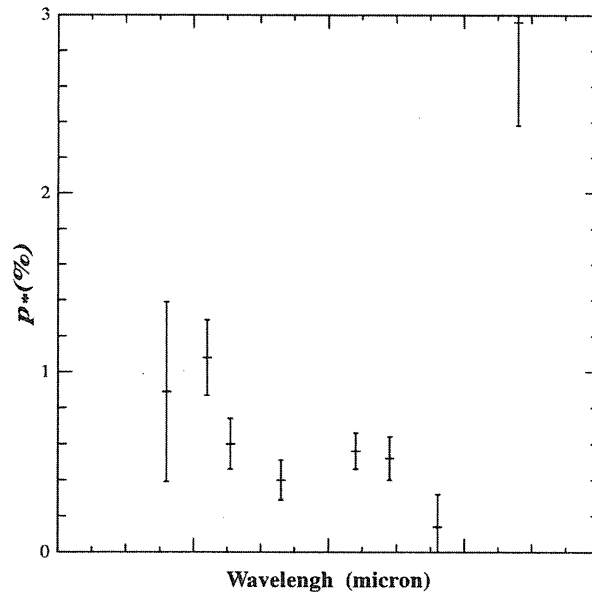


Fig.3. Wavelength dependence of the p_* values of EQ Cas on 1995 December 11/12.

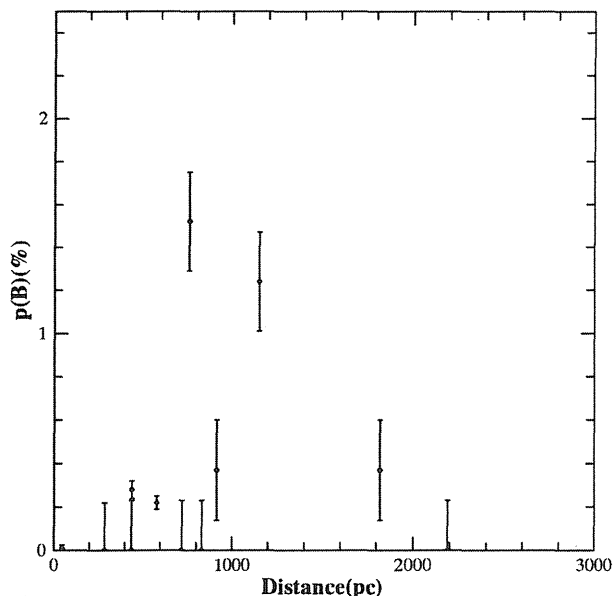


Fig.4. Dependence of the $p(B)$ values near V360 Cyg on distance.
Both of the values for HD197702 and HD205618 are also plotted.

date corresponds to that of primary light minimum. As is shown in figure 5, the p_* values on this date do not depend on wavelength. As is shown also in figure 5, the θ_* values within $0.455 \mu\text{m}$ increase with wavelength, which is also shown on the other dates.

c) SU Gem

SU Gem belongs to the RVb group and the group A₂. SU Gem was observed 9 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, 1997 February 26/27, 1997 December 10/11, and 1997 December 11/12.

We found 51 stars from ISPOL database which are within 6° circle centered on SU Gem. We selected 44 stars (94 data) for the estimation of the θ_{IS} values among above 51 stars whose θ_{IS} values are determined and whose distances are larger than 300pc. We excluded the stars with distance smaller than 300pc because the scatter in θ values for these stars is large, as is shown in figure 6. The estimated value is; $\theta_{\text{IS}} = 161^\circ$. In this estimation, the dependences of θ values on α_{1950} and distance were taken into account.

We selected 4 stars (4 data), 15 stars (18 data), and 3 stars (3 data) for the estimation of $p_{\text{IS}}(B)$, $p_{\text{IS}}(V)$, and $p_{\text{IS}}(G)$ values, respectively, where $p_{\text{IS}}(G)$ means the p_{IS} value for G color. In the estimation of these values, the stars within 1600pc were excluded because these stars seem to show the dependence on distance which is different from that for the stars with distance of

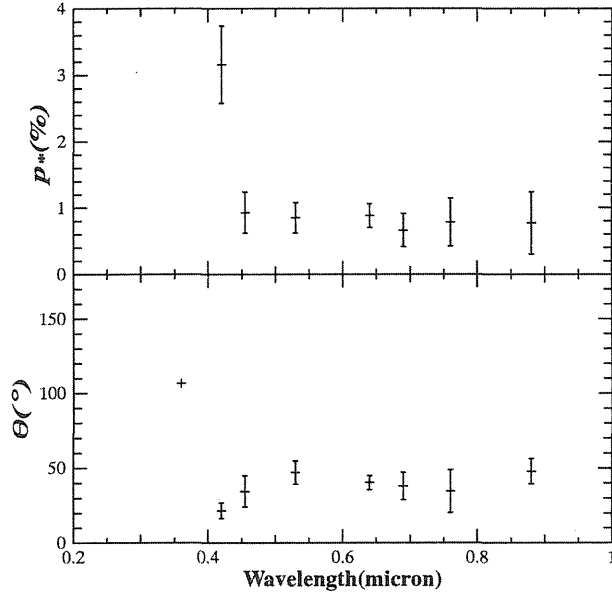


Fig.5. Wavelength dependence of the p_* and θ_* values of V360 Cyg on 1995 November 9/10.

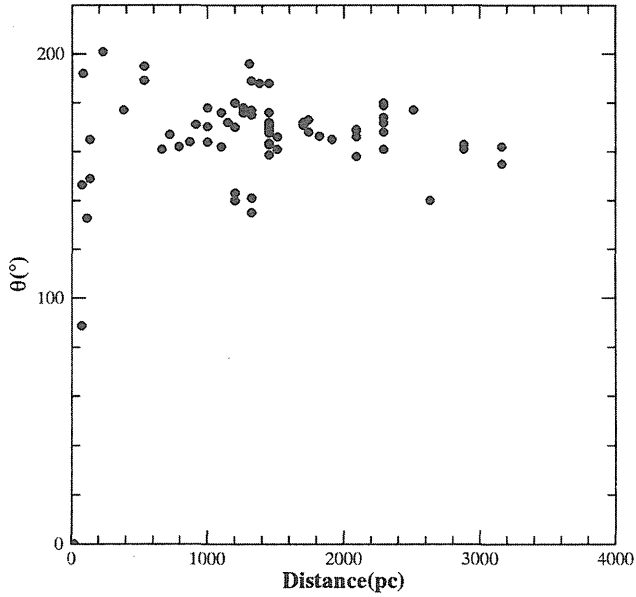


Fig.6. Dependence of the θ values near SU Gem on distance.
For the θ values lower than 80° , 180° is added in order to keep the continuity of the variation in θ values in this graph.

more than 1600pc. The estimated values are: $p_{\text{IS}}(B)=2.75\%$; $p_{\text{IS}}(V)=2.07\%$; $p_{\text{IS}}(G)=2.31\%$. We determined from the above $p_{\text{IS}}(B)$, $p_{\text{IS}}(V)$, and $p_{\text{IS}}(G)$ values that $p_{\text{max}}=2.40\%$ and $\lambda_{\text{max}}=0.50\mu\text{m}$ as the least-squares solution. In the above determination, we prescribed the λ_{max} value, because the least-squares solution gives unrealistic values for p_{max} and λ_{max} when not only p_{max} but also λ_{max} is taken as a free parameter. The scatters of p values are large and the distance of SU Gem is beyond the range of the stars used to determine the interstellar polarization. Thus the accuracy of p_{max} value seems to be rather low.

We obtained the intrinsic polarization by removing the interstellar polarization of our values. Since the observational errors and the uncertainty of p_{max} value are large, the definite conclusion cannot be obtained concerning the wavelength dependence of intrinsic polarization. However, the change of observed p values in wavelength dependence between 1995 December 12/13 and 1997 December 10/11 (Yoshioka(1998)¹¹⁾) does not appear for the intrinsic p_* values. Yoshioka(1998)¹¹⁾ reported that the observed p values before 1995 December 12/13 take a maximum at an intermediate wavelength (hereafter referred to as the \square type dependence), while the observed p values after 1997 December 10/11 take a minimum at an intermediate wavelength (hereafter referred to as the \square type dependence), as is shown in figure 7. On the other hand, the intrinsic p_* values observed at 1997 December 10/11 does not show the \square type dependence, as is shown in figure 8.

d) EP Lyr

EP Lyr belongs to the group B. According to the General Catalogue of Variable Stars (Kholopov et al.(1985)¹²⁾), EP Lyr belongs to the RVb group. Mantegazza(1978)¹³⁾ claimed the presence of a wave with a cycle length of 7067 days in the O–C diagram but using only the light minima published by Wachmann(1968)¹⁴⁾. On the other hand, Zsoldos(1995)¹⁵⁾ analyzed all the available photometric data and concluded that EP Lyr belongs to the RVa group, because the light and color curves do not show a long-term time variations.

EP Lyr was observed 3 times on 1993 October 24/25, 1993 November 24/25, and 1995 December 10/11.

We found 33 stars from ISPOL database which are within 6° circle centered on EP Lyr. We selected 18 stars (18 data) for the estimation of the θ_{IS} value among the above 33 stars whose distances are larger than 500pc. We excluded the stars with distance smaller than 500pc because the scatter in θ values for these stars is large, as is shown in figure 9. We also excluded HDE332108 because the θ value of this star is too large ($\theta=96^\circ$). The estimated value is; $\theta_{\text{IS}}=21^\circ$. In this estimation, the dependence of θ values on distance was taken into account.

We selected 20 stars (20 data) for the estimation of $p_{\text{IS}}(B)$ value. The above 20 stars satisfy the condition that their distances are larger than 250pc, because the $p(B)$ values for the stars with distance smaller than 250pc are systematically small, as is shown in figure 10. We also excluded HDE344313 because the $p(B)$ value of this star is too large ($p(B)=2.30\%$). The estimated value is; $p_{\text{IS}}(B)=0.757\%$. In this estimation, the dependence of $p(B)$ values on d_{1950}

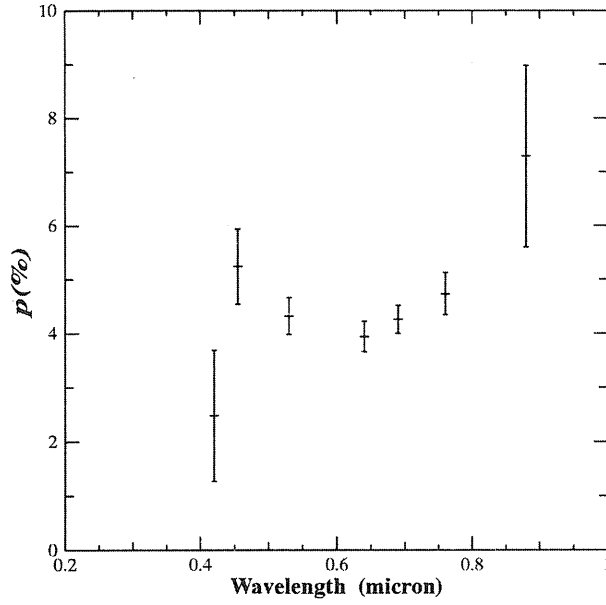


Fig.7. Wavelength dependence of the p values of SU Gem on 1997 December 10/11.

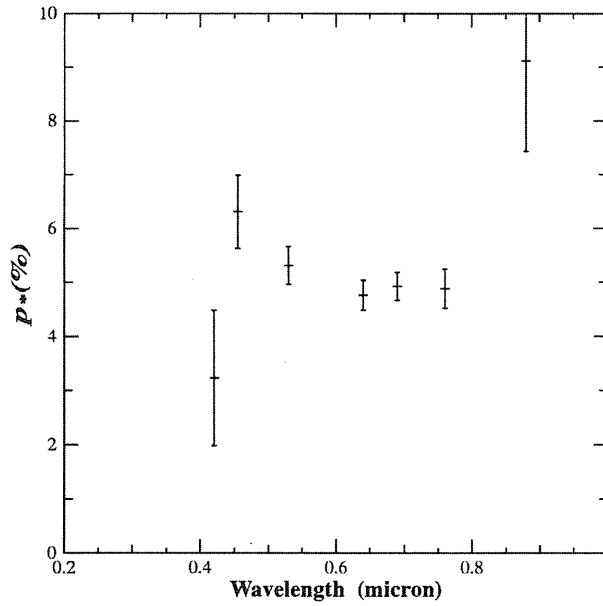


Fig.8. Wavelength dependence of the p^* values of SU Gem on 1997 December 10/11.

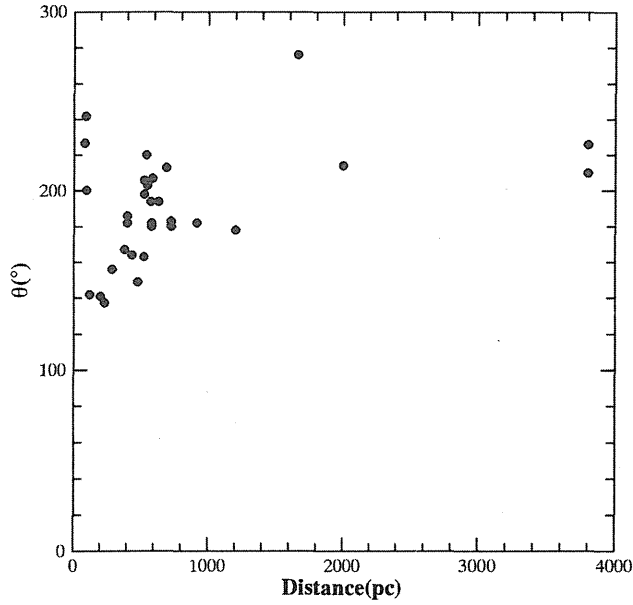


Fig.9. Dependence of the θ values near EP Lyr on distance.
 For the θ values lower than 100° , 180° is added in order to keep the continuity of the variation in θ values in this graph. The highest point indicates the θ value of HDE332108.

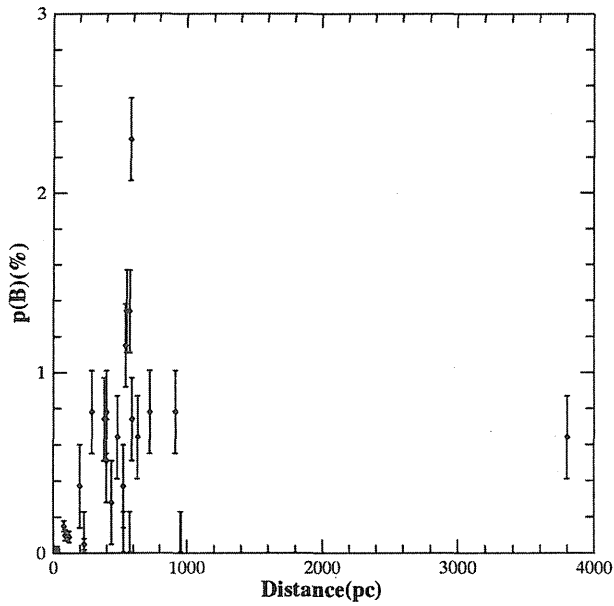


Fig.10. Dependence of the $p(B)$ values near EP Lyr on distance.
 The highest point indicates the $p(B)$ value of HDE344313.

was taken into account. We selected 4 stars (5 data) for the estimation of $p_{\text{is}}(V)$ value. The above 4 stars satisfy the condition that their distances are larger than 500pc and their $p(V)$ values are smaller than 2% , because the $p(V)$ values for the stars with distance smaller than 500pc are systematically small, and most of the $p(B)$ values are smaller than 2% , as is shown in figure 10. The estimated value is; $p_{\text{is}}(V)=0.850\%$. We determined from the above $p_{\text{is}}(B)$ and $p_{\text{is}}(V)$ values that $p_{\text{max}}=0.81\%$, and $\lambda_{\text{max}}=0.50\mu\text{m}$ as the least-squares solution. In the above determination, we prescribed the λ_{max} value, because the least-squares solution gives unrealistic values for p_{max} and λ_{max} when not only p_{max} but also λ_{max} is taken as a free parameter. Both of the scatters of $p(B)$ and $p(V)$ values are rather large, as is exemplified in figure 10. Thus the accuracy of p_{max} seems rather low.

We obtained the intrinsic polarization by removing the interstellar polarization of our values. The p_{max} value is rather small in comparison with the observed p values, so that the results for intrinsic polarization do not differ markedly from those for the observed polarization. As indicated in the observed polarization, the intrinsic polarization suggests the \square type dependence as is exemplified in figure 11, though other types of wavelength dependence cannot be excluded.

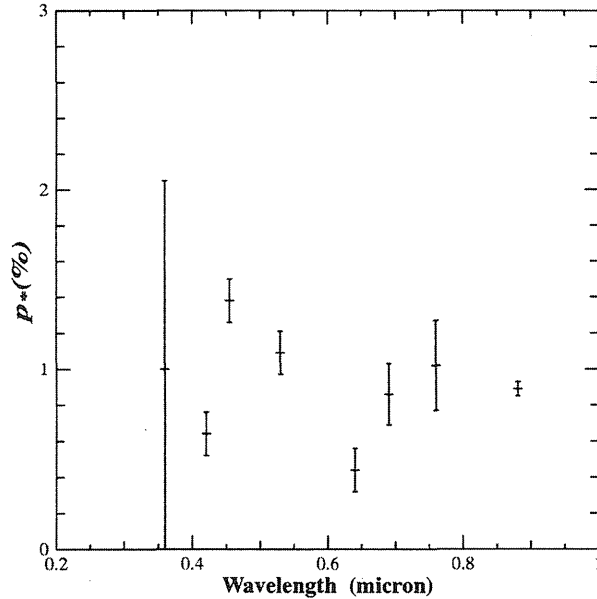


Fig.11. Wavelength dependence of the p^* values of EP Lyr on 1995 November 10/11.

e) TT Oph

TT Oph belongs to the RVa group and the group A₂. According to Dawson(1979)²⁾, TT Oph shows Balmer emission on rising light, which is unusual because all the other stars in the group A₂ do not show emission. On the other hand, according to Preston et al.(1963)¹⁾, this star may be related to the group B because Ca II lines are weak for the assigned spectral type which is the feature of the group B.

TT Oph was observed 12 times on 1994 February 19/20, 1994 February 21/22, 1994 March 29/30, 1994 March 21/April 1, 1994 April 4/5, 1994 April 15/16, 1995 March 20/21, 1996 February 28/29, 1996 April 4/5, 1997 January 3/4, 1997 February 21/22, and 1997 February 23/24.

We found 31 stars from ISPOL database which are within 6° circle centered on TT Oph. We selected 14 stars (14 data) for the estimation of the θ_{IS} value among the above 31 stars whose distances are larger than 70pc. We excluded the stars with distance smaller than 70pc because the scatter in θ values for these stars is large. The selected data is those for *B* color. The estimated value is; $\theta_{\text{IS}}=87^\circ$. In this estimation, the dependence of θ value on α_{1950} was taken into account.

We selected 11 stars (11 data) for the estimation of $p_{\text{IS}}(B)$ value. The above 11 stars satisfy the condition that their distances are larger than 110pc, because the $p(B)$ values for the stars with distance smaller than 110pc are systematically small, as is shown in figure 12. We also excluded HD153115 because the $p(B)$ value of this star is too large ($p(B)=1.706\%$). The

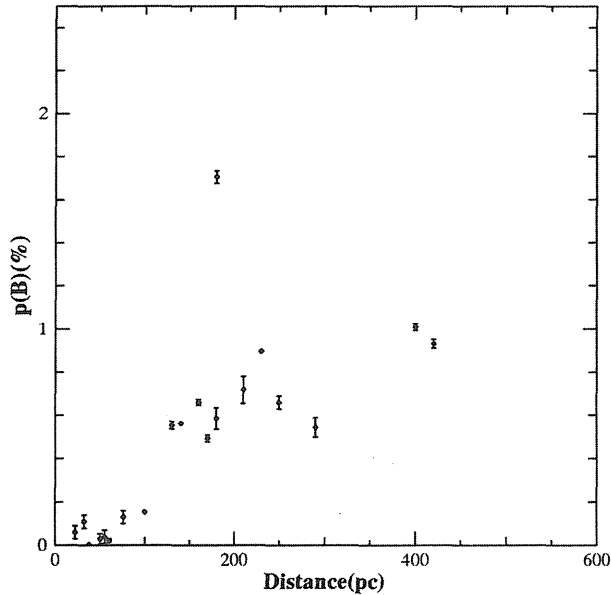


Fig.12. Dependence of the $p(B)$ values near TT Oph on distance. The highest point indicates the $p(B)$ value of HD153115.

estimated value is; $p_{\text{is}}(B)=0.698\%$. As is shown in figure 12, the $p(B)$ values seem to increase with distance. In the estimation of the above $p_{\text{is}}(B)$ value, however, this dependence was not taken into account, for the distance of TT Oph is far larger than those of the stars selected for the above estimation so that there is no guarantee that this dependence apply to the $p(B)$ values near TT Oph. In fact, when this dependence is taken into account, we obtain very large $p_{\text{is}}(B)$ value ($p_{\text{is}}(B)=6.230\%$) near TT Oph. We determined from the above $p_{\text{is}}(B)$ value that $p_{\text{max}}=0.71\%$ and $\lambda_{\text{max}}=0.50\mu\text{m}$ as the least-squares solution. In the above determination, we prescribed the λ_{max} value because we used only one color (B color). We excluded $p_{\text{is}}(V)$ values for the above determination, because the distances for $p(V)$ values are very small (lower than 29pc) and $p_{\text{is}}(V)$ values are very small (lower than 0.022%). As above described, we estimated $p_{\text{is}}(B)$ value near TT Oph from the $p(B)$ values whose distances are much smaller than that of TT Oph. Thus the accuracy of the p_{max} value seems to be rather low.

We obtained the intrinsic polarization by removing the interstellar polarization of our values. The p_* values with small errors do not show a noticeable wavelength dependence, as is shown in figure 13, which also applies to the observed p values, though the p_* values observed after 1997 January 3/4 indicate a slight tendency of the \square type dependence, as is shown in figure 14.

f) TX Oph

TX Oph belongs to the RVa group. According to Preston et al. (1963)¹⁾, TX Oph belongs to the A group. According to Dawson(1979)²⁾, TX Oph does not show TiO band around minimum light, so that this star belongs to the A₂ group. However, according to Dawson(1979)²⁾, TX Oph

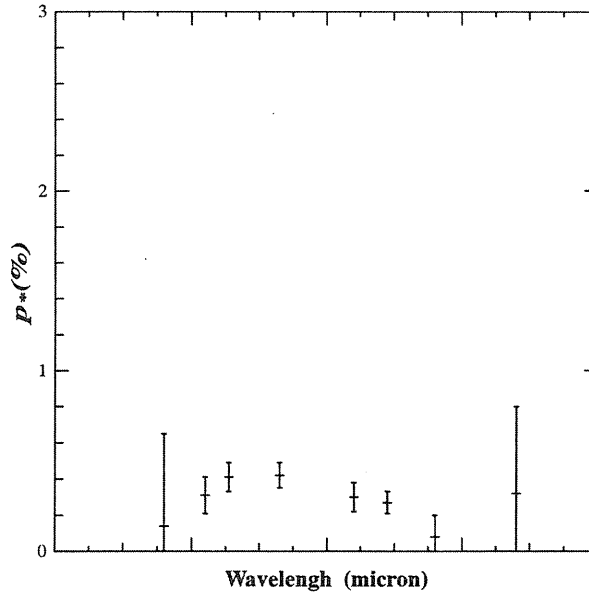


Fig.13. Wavelength dependence of the p_* values of TT Oph on 1994 March 29/30.

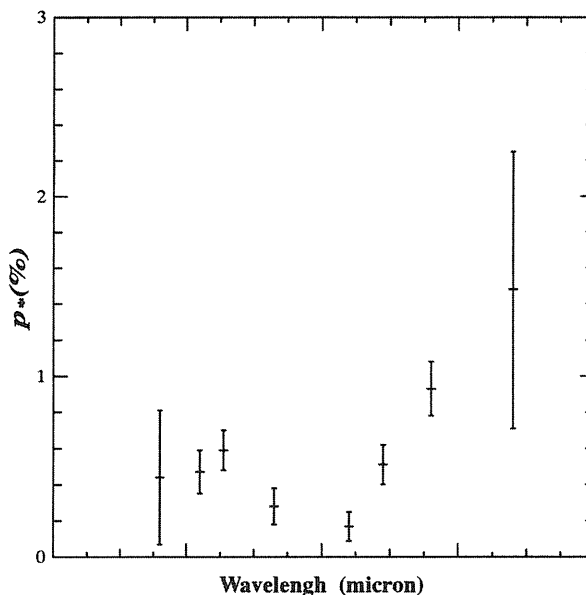


Fig.14. Wavelength dependence of the p_* values of TT Oph on 1994 February 21/22.

shows Balmer emissions during brightening, whose emissions are usually seen in the A₁ group. Dawson(1979)²⁾ also suggest that this star is not an RV Tauri star because its light curve is sharply peaked and its color maxima do not precede V maximum (Color maxima usually precede V maximum for RV Tauri stars). Furthermore, the formal period of this star (=135 days) is quite long.

TX Oph was observed 2 times on 1997 February 22/23 and 1997 February 25/26.

We found 44 stars from ISPOL database which are within 6° circle centered on TX Oph. We selected 28 stars (43 data) for the estimation of the θ_{IS} value among the above 28 stars whose distances are larger than 60pc. We excluded the stars with distance smaller than 60pc because the scatter in θ values for these stars is large. The estimated value is; $\theta_{\text{IS}}=87^\circ$. In this estimation, the dependence of θ value on δ_{1950} was taken into account.

We selected 21 stars (21 data) for the estimation of $p_{\text{IS}}(B)$ value. The above 21 stars satisfy the conditions that their distances are larger than 100pc and their δ_{1950} values are larger than 2° . We defined these conditions because the $p(B)$ values for the stars with distance smaller than 100pc are systematically small and the scatter in $p(B)$ values for the stars with δ_{1950} smaller than 2° is large, as is shown in figure 15. The estimated $p_{\text{IS}}(B)$ values are $p_{\text{IS}}(B)=0.893\%$: In this estimation, the dependence of $p(B)$ values on α_{1950} was taken into account. We determined from the above $p_{\text{IS}}(B)$ value that $p_{\text{max}}=0.91\%$ and $\lambda_{\text{max}}=0.50\mu\text{m}$ as the least-squares solution. In the above determination, we prescribed the λ_{max} value. We also excluded $p_{\text{IS}}(V)$ and $p_{\text{IS}}(G)$, in the above estimation, because most of the δ_{1950} values for these $p(V)$ and $p(G)$ values are

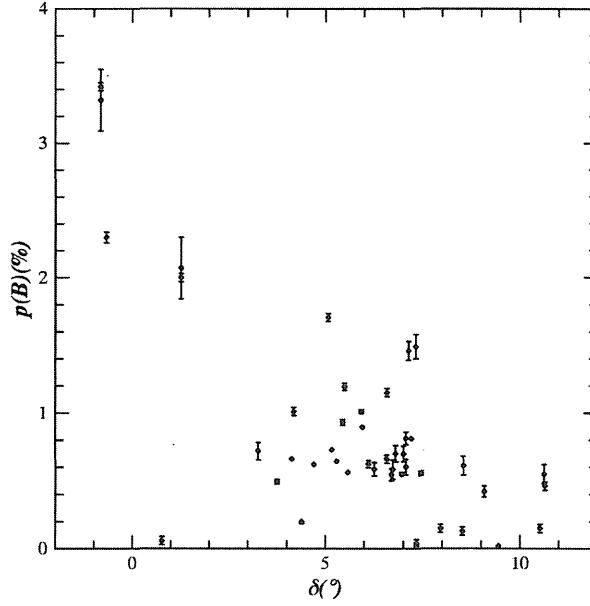


Fig.15. Dependence of the $p(B)$ values near TX Oph on δ_{1950} .

smaller than 2° and these $p(V)$ and $p(G)$ values are systematically large. The distance of TX Oph is far beyond the range of the above 21 stars, so that the uncertainty of p_{\max} seems to be rather large.

We obtained the intrinsic polarization by removing the interstellar polarization of our values. As the observational errors are fairly large, as is exemplified in figure 16, no definite conclusion is derived concerning to the time variation and the wavelength dependence of intrinsic polarization.

4. Discussion

We obtained the intrinsic polarization for another 6 stars, for which the interstellar polarizations have not been obtained by other observers. Generally speaking, our θ_{IS} values seem to be fairly reliable, because the scatter in θ_{IS} values near each star is small. On the other hand, the accuracy of our p_{\max} values seem to be rather large, because the scatter in p_{IS} values near each star is large and/or the distances of the stars used for the estimation of p_{\max} are much smaller than those of RV Tauri stars. Furthermore, the observational errors are generally large for the 6 stars. Thus, a definite conclusion cannot be obtained concerning the wavelength dependence of intrinsic polarization.

However, our results seem to confirm the tendency for the observed p values of the stars belonging to the group A to show a \square type dependence, while for the observed p values of the stars belonging to the group B to show a \square type dependence (Yoshioka (1997)¹⁶). In fact, the

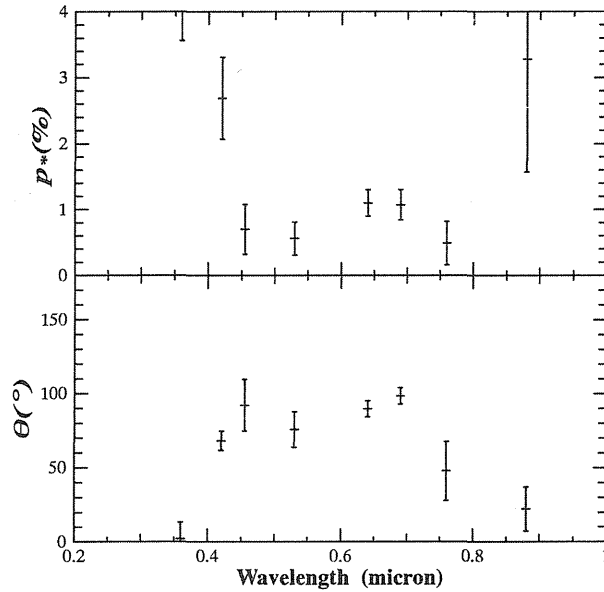


Fig.16. Wavelength dependence of the p_* and θ_* values of TX Oph on 1997 February 22/23.

wavelength dependences of our p_* values do not violate the above tendency. Some of the p_* values of the group A₂ star, TT Oph, show a slight tendency of the \square type dependence, but this star has also the feature of the group B. The \square type dependence of the group B can be interpreted that the stars of the group B 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)¹⁷⁾ suggested the presence of at least two distinct CDE's for AC Her belonging to the group B. Furthermore, on the basis of infrared observation with 10m Keck I reflector, Jura et al. (2000)¹⁸⁾ found an edge-on dust ring around AC Her and they concluded that the ring has two types of grains with size of less than 0.1 μ m and with size of more than 200 μ m. Our observation that the group B star, EQ Cas, shows the time variation of p_* values in wavelength dependence can be interpreted as the change in the contribution of two types of grains to polarization. The only analyzed star of the group C, V360 Cyg, does not show a wavelength dependence of p_* values, which may be a feature of the group C.

The analysis are being made for the remaining 5 stars.

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