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Features of Intrinsic Polarization for 3 RV Tauri Stars

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3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、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、12個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3個の星に対して固有偏光成分を求めた。星間偏光成分はnear-neighbor法を一部変えた方法で求めた。求めた星間偏光成分の内、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ので、決定的なことはいえない。しかし今回は、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てきた傾向とは逆の結果が得られた。このことは、星周圏ダスト殻の数が必ずしもA，Bグループと相関してはいないことを示唆しているのかも知れない。

ABSTRACT

The RV Tauri stars are semiregular variables whose light curves are characterized by alternate deep and shallow minima. On the basis of spectroscopic characteristics in an optical region the RV Tauri stars are 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 Dodaira Station on the National Astronomical Observatory. Among the 17 stars we have already obtained the intrinsic polarization of 12 stars by removing the interstellar polarizations.

In this paper we report the intrinsic polarizations of other 3 stars. The interstellar

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polarizations are determined by the modified near-neighbor method. The errors in the degree of interstellar polarization are large, though the errors in the position angles of interstellar polarization are small. However, our results for the 3 stars are contrary to the tendency for the 12 stars already analyzed that the degree of intrinsic polarization for the group A takes a maximum at an intermediate wavelength, while that for the group B takes a minimum at an intermediate wavelength.

This may indicate that the number of circumstellar dust envelope does not strongly correlate with the spectroscopic characteristics.

Ⅰ. Introduction

The RV Tauri stars are semiregular variables which lie between the Cepheid 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.

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 curves, 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. The group B shows CH and CN bands near light minima 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(1797)[2] divided the group A into the group A_1 and 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 (hereafter referred to as CDE). The RV Tauri stars are generally regarded as post-asymptotic giant branch (hereafter referred to 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 91cm reflector at the Dodaira Station of the National Astronomical Observatory.

We had obtained the intrinsic polarizations for 12 RV Tauri stars, TW Cam, EQ Cas, V360 Cyg, SS Gem, SU Gem, AC Her, EP Lyr, U Mon, TT Oph, TX Oph, R Sct, and RV Tau from the observed polarizations by removing the interstellar polarizations (Yoshioka(2000)[4], Yoshioka (2001)[5], and Yoshioka (2002)[6]). We obtained the intrinsic polarizations for the other 3 stars, UZ Oph, CT Ori, and R Sge. We report the results for these stars in this paper.

Ⅱ. Observations and Reductions

The multi-channel polarimeter can measure liner 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.

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.

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)[7] for a wavelength dependence of interstellar polarization p_{IS}, which is given as follows :

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

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} ;

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

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

$$Q_*=Q-p_{max}\cdot\exp[-K\cdot\ln^2(\lambda_{max}/\lambda)]\cdot\cos2\theta_{IS}, \quad (3)$$

and $$U_*=U-p_{max}\cdot\exp[-K\cdot\ln^2(\lambda_{max}/\lambda)]\cdot\sin2\theta_{IS}, \quad (4)$$

here Q and U are 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:

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

and $\theta^*=0.5\cdot\tan^{-1}(U_*/Q_*)$.

The p_{max}, λ_{max}, and θ_{IS} values are determined from stars near target stars which are thought to have no intrinsic polarization. We applied the modified near-neighbor method. The near-neighbor method is described by Bastien(1985)[8]. 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)[9], (hereafter referred to as ISPOL) as the catalogue of stars with no intrinsic polarization. The ISOPOL contains 13969 data for several wavelengths collected from 45 literatures.

Ⅲ. Results

The position, subclass, and distance for 3 stars reported in this paper are given in table

1. The details of the results are as follows.

a) UZ Oph

UZ Oph belongs to the RVa group and the group A. UZ Oph was observed 2 times on 1996 February 27/28 and 1997 February 22/23.

We found 36 stars from ISPOL database which are within 6° circle centered on UZ Oph. We selected 21 stars (25 data) for the estimation of the θ_{IS} values among the above 36 stars whose θ values are determined. The selected 21 stars satisfy the conditions that their distances are larger than 100pc and their δ_{1950} values are smaller than 10°. We excluded the stars with distance smaller than 100pc because the scatter in θ values for these stars are large, as is shown in figure 1. We also excluded the stars with δ_{1950} values larger than 10° because the θ values for these stars are systematically large, as is shown in figure 2. The estimated value is ; $\theta_{IS}=74°$. In this estimation, the dependence of θ values on distance and α_{1950} were taken into account.

We selected 19 stars (19 data) for the estimation of $p_{IS}(B)$ value, where $p_{IS}(B)$ means the p_{IS} value for B color. The selected 19 stars satisfy the condition that their distances are larger than 200pc. We excluded the stars with distance smaller than 200pc, because the scatter in $p(B)$ values for these stars are large, as is shown in figure 3. The estimated value is; $p_{IS}(B)=0.847\%$. In this estimation, the dependence of $p(B)$ values on α_{1950} was taken into account. We determined from the above $p_{IS}(B)$ value that $p_{max}=0.86\%$ as the least-squares solution. In the above determination, we prescribed the λ_{max} value. We excluded $p(V)$ and $p(G)$ values for the above determination, where $p(G)$ means the p value for G color, because all the distances for $p(V)$ and $p(G)$ values are smaller than 200pc. The distances for $p(B)$ values are smaller than 1820pc and most distances are smaller 600pc, as is shown in figure

Table 1. Data on the R V Tauri Stars analyzed for Intrinsic Polarization. Period is a formal period. Distances are taken from Dawson(1979)[2], except for C T Ori whose distance is taken from Jura(1986)[3]. The sixth column gives the classification in the General Catalogue of Variable Stars (Kholopov et al. 1985)[10]. The seventh colum gives the classification on the basis of optical spectra.

Star	α_{1950}	δ_{1950}	Period (day)	Distance (pc)	Variable Star Class	Optical Group
U Z 0ph	$17^h19^m34^s$	+06° 57' 36"	87.7	4000	RVa	A
C T 0ri	06 07 07	+09 52 30	135.5	1700	RV	B
R Sge	20 11 45	+16 34 42	70.6	2860	RVb	A_2

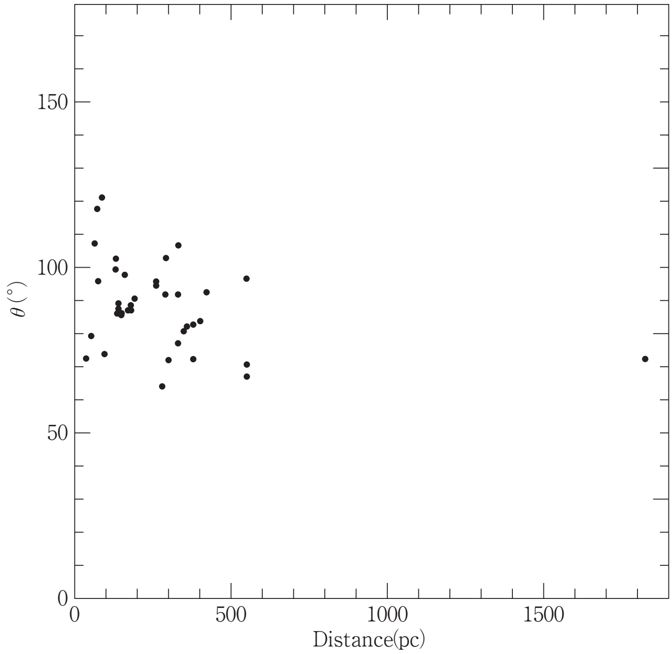

Fig. 1 Dependence of the θ values near UZ Oph on distance.

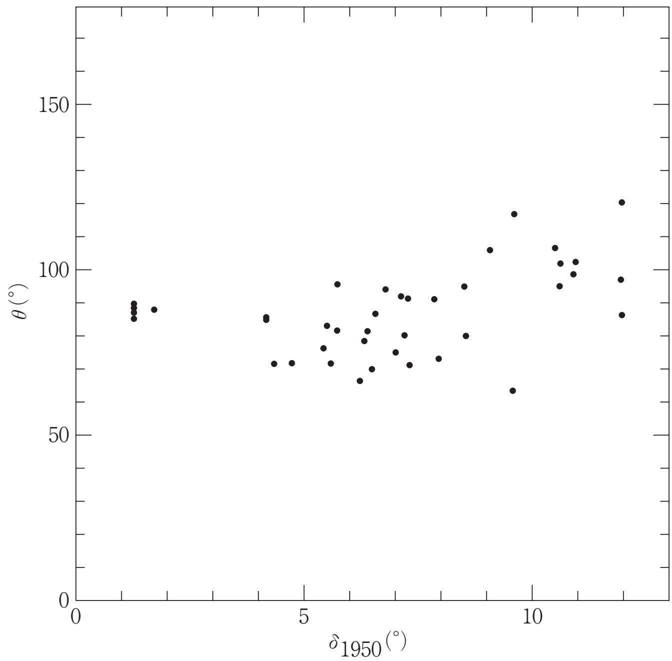

Fig. 2 Dependence of the θ values near UZ Oph on δ_{1950}.

3, while the distance of UZ Oph equals to 4000pc. 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. As is shown in figure 4, the p_* values on 1996 February 27/28 show slightly a tendency to take a minimum at an intermediate wavelength (hereafter referred to as the 凹 type dependence). On the other hand, the p_* values on 1997 February 22/23 decrease with wavelength, especially for the channels smaller than 3. However, these p_* values have large observational errors, thus the latter dependence is doubtful.

b) CT Ori

CT Ori belongs to the group B. According to the General Catalogue of Variable Stars (Kholopov et al. (1985)[10]), this star is not definitely classified as RV Tauri stars. Actually, according to Dawson (1979)[2], the mean DDO colors suggest CT Ori is a giant, and the formal period of this star is rather large (135.5 days). On the other hand, according to the abundance analysis by Gonzalez et al.(1997)[11], CT Ori shows the experienced fractionation process that has preferentially depleted their atmospheres of elements with high condensation temperatures, which is typical for the group B.

CT Ori was observed 8 times on 1994 October 19/20, 1994 December 21/22, 1994

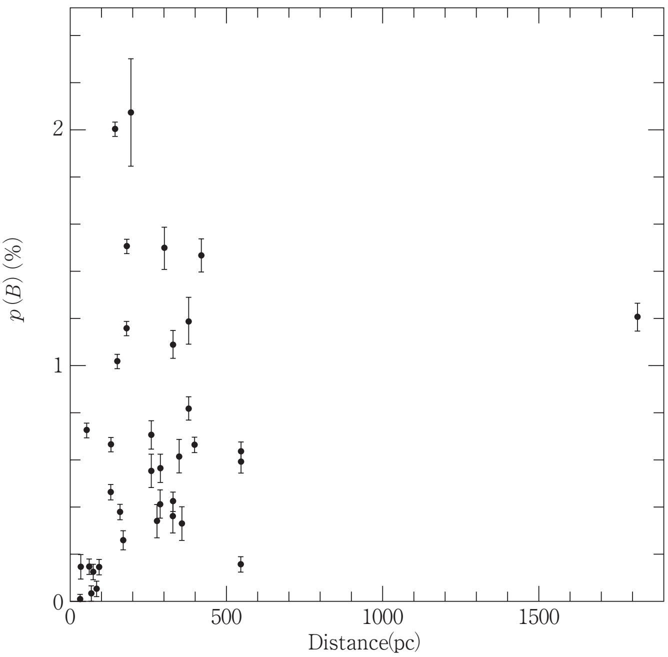

Fig. 3 Dependence of the $p(B)$ values near UZ Oph on distance.

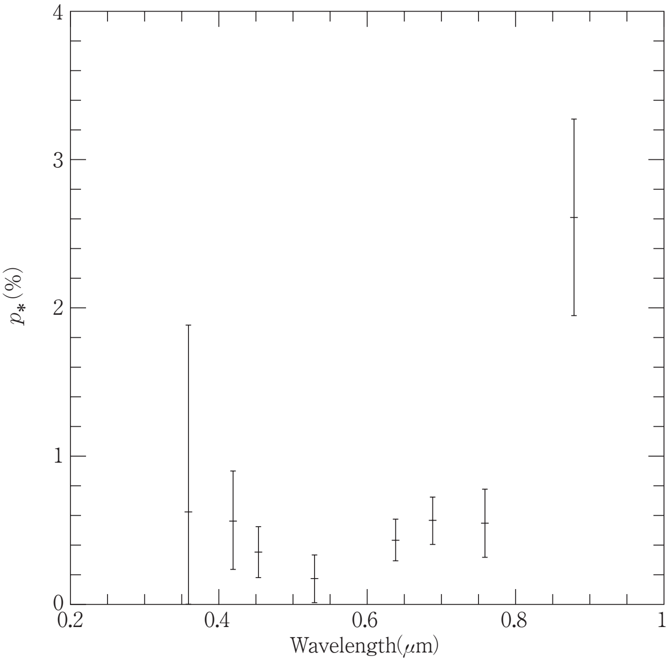

Fig. 4 Wavelength dependence of the p_* values of UZ Oph on 1996 February 27/28.

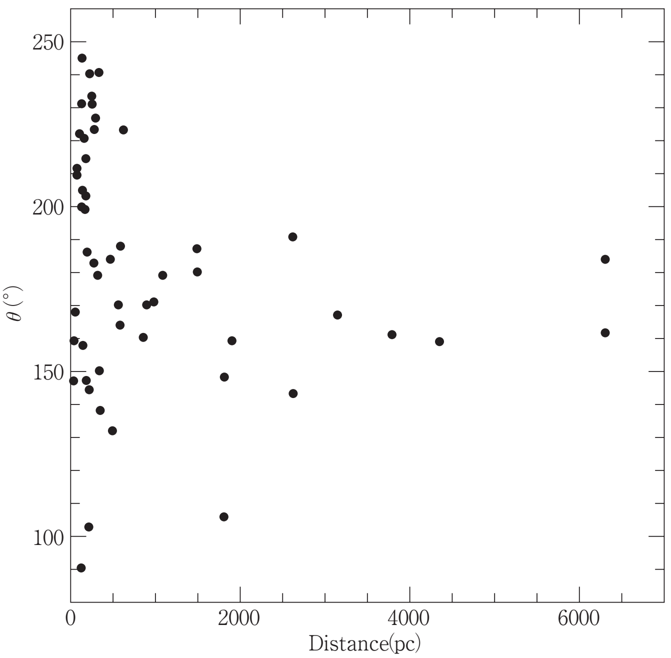

Fig. 5 Dependence of the θ values near CT Ori on distance.

December 24/25, 1995 January 19/20, 1995 February 16/17, 1995 December 12/13, 1996 November 25/26, and 1997 February 26/27.

We found 52 stars from ISPOL database which are within 6° circle centered on CT Ori. We selected 20 stars (23 data) for the estimation of the θ_{IS} values among the above 52 stars whose θ values are determined. The selected 20 stars satisfy the conditions that their distances are larger than 500pc. We excluded the stars with distance smaller than 500pc because the scatter in θ values for these stars are large, as is shown in figure 5. The estimated value is; $\theta_{IS}=176°$. In this estimation, the dependence of θ values on α_{1950} was taken into account.

We selected 8 stars (9 data) for the estimation of $p_{IS}(B)$ value. The selected 8 stars satisfy the condition that their distances are larger than 500pc and their δ_{1950} values are smaller than 13°. We excluded the stars with distance smaller than 500pc, because the $p(B)$ values for these stars are systematically small, as is shown in figure 6. We also excluded the stars with δ_{1950} values larger than 13°, because the $p(B)$ values for these stars are systematically large. The estimated value is; $p_{IS}(B)=0.602\%$. In this estimation, the dependence of $p(B)$ values on δ_{1950} was taken into account. We selected 7 stars (7 data) for the estimation of $p_{IS}(V)$ value. We selected these stars on the same condition as for $p(B)$ values by the same reason as for $p(B)$ values. The estimated value is; $p_{IS}(V)=0.839\%$. We determined from the above $p_{IS}(B)$ and $p_{IS}(V)$ values that $p_{max}=0.73\%$ and $\lambda_{max}=0.5\mu$m as the least-squares solu-

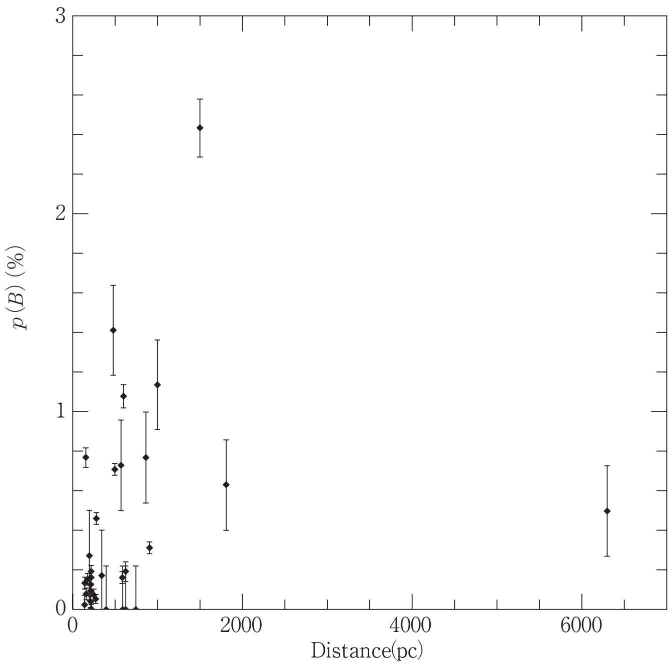

Fig. 6 Dependence of the $p(B)$ values near CT Ori on distance.

tion. In the above determination, we prescribed the λ_{max} value, because the least-squares solution gives unrealistic λ_{max} value when not only p_{max} but also λ_{max} is taken as a free parameter. The scatter of p value is rather large as is exemplified in figure 6. 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. Generally speaking, the p_* values with relatively high observational accuracy show slightly a tendency to take a maximum at an intermediate wavelength (hereafter referred to as the 凸 type dependence), as exemplified in figure 7. On the other hand, the p_* values with low observational accuracy show slightly a tendency of the 凹 type dependence, as exemplified in figure 8. The θ_* values with middle channels are nearly constant with time about 150°, as is shown in figure 9. The θ_* values near both ends of channels change with time, which may be an apparent variation caused by large observational errors.

c) 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.

We found 11 stars from ISPOL database which are wlthin 6° circle centered on R Sge. We selected 8 stars (13 data) for the determination of the θ_{IS} values among the above 11

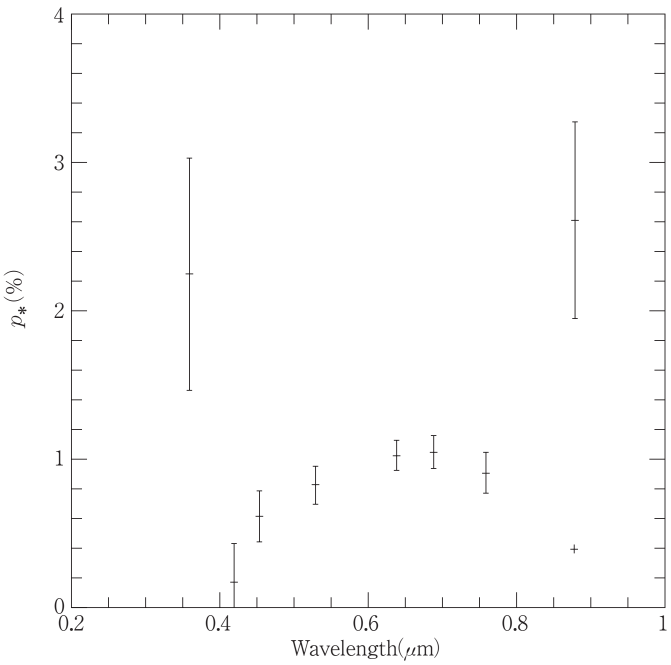

Fig. 7 Wavelength dependence of the p_* values of CT Ori on 1998 February 12/13.

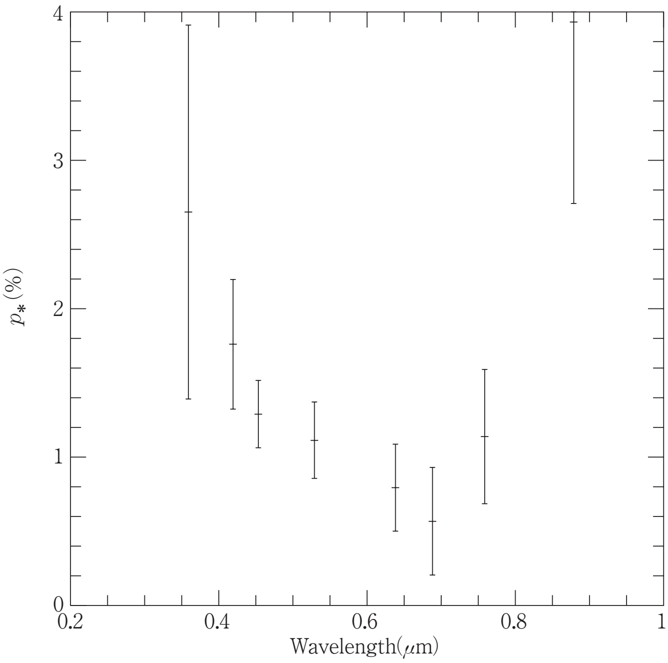

Fig. 8 Wavelength dependence of the p_* values of CT Ori on 1995 January 19/20.

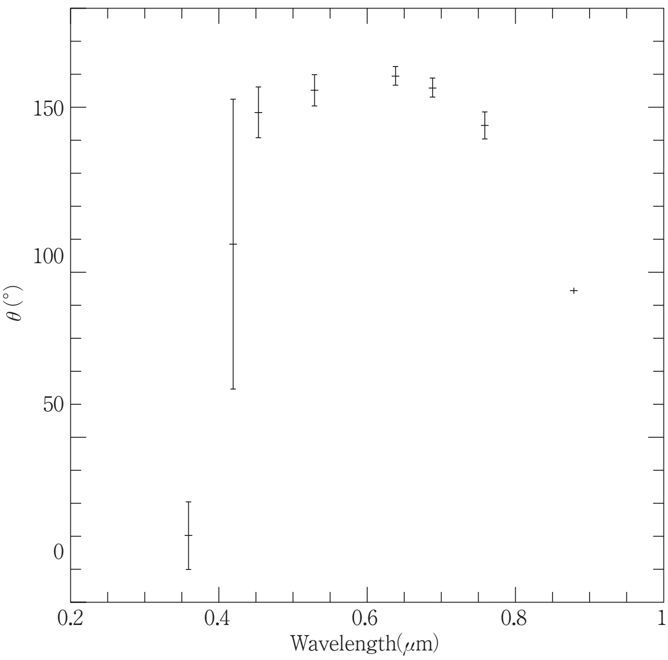

Fig. 9 Wavelength dependence of the θ_* values of CT Ori on 1998 February 12/13.

stars whose θ values are determined. The estimated value is; $\theta_{IS}=2°$. In this estimation, the dependence of θ values on δ_{1950} was taken into account.

We selected 10 stars (14 data) for the estimation of $p_{IS}(B)$ value. The estimated value is; $p_{IS}(B)=1.070\%$. In this estimation, the dependence of $p(B)$ values on distance was taken into account. We selected 3 stars (4 data) for the estimation of $p_{IS}(V)$ value. The estimated value is; $p_{IS}(V)=1.362\%$. In this estimation, the dependences of $p(V)$ values on α_{1950}, δ_{1950}, and distance were taken into account. We determined from the above $p_{IS}(B)$ and $p_{IS}(V)$ values that $p_{max}=1.23\%$ and $\lambda_{max}=0.5\mu$m as the least-squares solution. In the above determination, we prescribed the λ_{max} value, because the least-squares solution gives unrealistic value for 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 R Sge 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. While the observed p values on 1993 November 28/29 are larger by about 0.2% than the values on the other nights (Yoshioka (1997)[12]), the intrinsic p values on this night are smaller by 0.1~0.2% than the other nights. The intrinsic p values do not show a noticeable wavelength dependence, as is shown in figure 10.

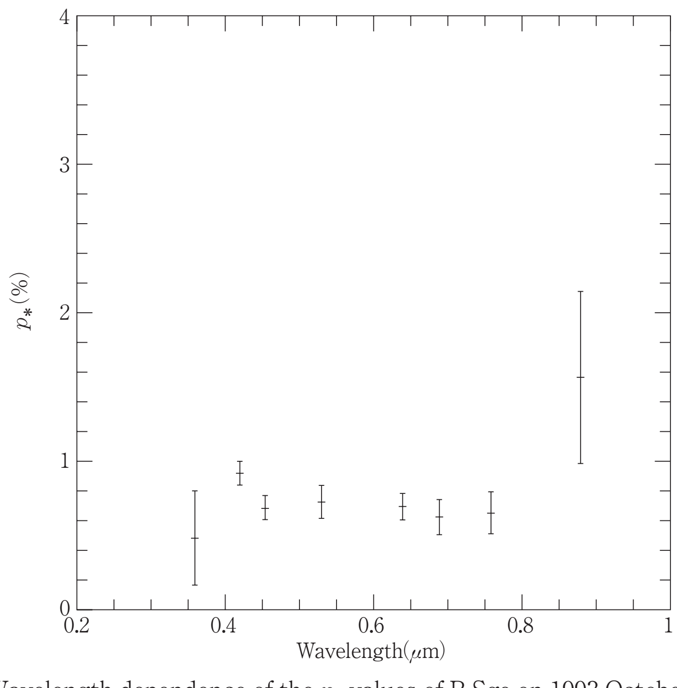

Fig.10 Wavelength dependence of the p_* values of R Sge on 1993 October 27/28.

Ⅳ. Discussion

We obtained the intrinsic polarization for another 3 star, for which the interstellar polarizations have not been obtained by other observes. Generally speaking, our θ_{IS} values seem to be fairly reliable, because the scatter in θ values near each star is small. On the other hand, the accuracy of our p_{max} values seem to be rather low, because the scatter in p values near each stars is large and/or the distances of the stars used for the estimation of p_{max} are much smaller than the relevant star in the case of UZ Oph and R Sge. Thus, a definite conclusion cannot be obtained concerning the wavelength dependence of intrinsic polarization.

According to our results, the observed p values of the stars belonging to the group A have a tendency to show the 凸 type dependence, while for the observed p values of the stars belonging to the group B have a tendency to show the 凹 type dependence. Our results for the intrinsic p values of the stars analyzed before this paper do not violate the above tendency (Yoshioka (2000)[4], Yoshioka (2001)[5] and Yoshioka (2002)[6]). We interpreted that the 凹 type dependence of the group B is caused by more than two circumstellar dust shells with different grain size distribution. However, our results of this paper are contrary to the above tendency. The p_* values of the group A star, UZ Oph, i.e., show the 凹 type dependence or decrease with wavelength, while the p_* values of the group B star, CT Ori, seem to show the 凸 type dependence, though the p_* values with low observational accuracy show the 凹 type dependence. This result may indicates that some stars of the group B have a single CDE, though we cannot draw a conclusion, as the accuracy of the interstellar polarizations for these three stars are rather low,

We are analyzing the other two stars, AD Aql and V Vul, in order to obtain the intrinsic polarization.

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