放送大学研究年報　第19号（2001）95-112頁
Journal of the University of the Air, No.19 (2001) pp.95-112

The Characteristics of Intrinsic Polarization for RV Tau and AC Her

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おうし座RV星とヘルクレス座AC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型変光星の多色偏光観測を行った。観測された17個の星の内、４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２個の星、おうし座RV星とヘルクレス座AC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。ヘルクレス座AC星に対して求めた星間偏光成分の方が信頼度は高い。

おうし座RV星に対する星間偏光成分は小さいので、その特徴は観測された偏光に対するものと大きくは違わない。この星の固有偏光成分は、脈動周期に伴う時間変動とともに長周期光度変化に伴う変動も行う。この星の固有偏光成分の偏光度は中間の波長域で極大値をとり、Aグループの星の傾向に従う。ヘルクレス座AC星の固有偏光成分は、脈動周期に伴う時間変動とともに公転周期に伴う変動も行う。この星の固有偏光成分の偏光度は、短波長側で波長の減少とともに増加するが、これはこの星の星周圏ダストが２種類の異なるサイズをもつことを示唆している。

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 are divided into the oxygen-rich group, the group A, and the carbon-rich group, the group B and the group C.

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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 polarizations of 4 stars by removing the interstellar polarizations.

In this paper we report the intrinsic polarizations of other two stars, RV Tau and AC Her. The interstellar polarizations are determined by the modified near-neighbor method. The values of interstellar polarization for RV Tau is not so reliable than those for AC Her.

The intestellar polarization for RV Tau is small, so that the results does not differ markedly from those for the observed polarization. RV Tau shows the time variation of intrinsic polarization not only with the formal period but also with the long-term brightness period. The intrinsic degree of linear polarization of RV Tau conform to the wavelength dependence to take a maximum at an intermediate wavelength, which is the tendency for the group A. AC Her shows the time variation of interstellar polrizazion not only with the formal period but also with the orbital period. The intrinsic degree of linear polarizatin of AC Her has a tendency to decrease with wavelength for shorter wavelength region, which indicates that circumstellar dust has two different grain size distributions.

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 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 91 cm reflector at the Dodaira Station of the National Astronomical Observatory.

We obtained the intrinsic polarizations for 4 RV Tauri stars, TW Cam, SS Gem, U Mon, and R Sct, from the observed polarizations by removing the interstellar polarizations (Yoshioka (2000)[4]). The following results were obtained.

1) Except for U Mon, the position angle of intrinsic polarization θ_* shows neither a noticeable time variation nor a noticeable wavelength dependence. Except for U Mon, the degree of linear polarization of intrinsic polarization p_* does not show a conspicuous time variation. These results suggest that except for U Mon the geometrical arrangements of CDE of these stars do not change with time. For U Mon, the geometrical arrangement of CDE seem to change with the short-term and the long-term brightness variation. For TW Cam and R Sct, the definite conclusion concerning the time variation cannot be drawn, because the observational errors are large and/or the observations were made at about the same magnitudes.

2) Except for SS Gem, the p_* values do not show a conspicuous wavelength dependence or take a maximum at an intermediate wavelength (hereafter referred to as the 凸 type dependence). the p_* values for SS Gem take a minimum at an intermediate wavelength (hereafter referred to as the 凹 type dependence) near the primary light minimum. According to Preston et al. (1963)[1] the observed 4 stars belong to the group A, though Gonzalez et al. (1997)[5] claimed that SS Gem should be reclassified as the group B based on numerous C I lines in its spectrum. These results confirm the tendency for the observed p values for the stars belonging to the group A without the removal of interstellar polarization to show the 凸 type dependence (Yoshioka (1997)[6]). Furthermore, these results support the reclassification of SS Gem by Gonzalez et al. (1997)[5], because the stars belonging to the group B have a tendency for the observed p values to show the 凹 type dependence (Yoshioka (1997)[6]). There is another possibility for the intrinsic polarization of SS Gem that SS Gem has no intrinsic polarization, because the interstellar polarization determined from nearby stars ($\theta_{IS}=171°$, p_{max}

$=2.81\%$, $\lambda_{max}=0.57\mu m$) is close to the interstellar polarization ($\theta_{IS}=1°$, $p_{max}=2.96\%$, $\lambda_{max}=0.56\mu m$) which are determined on the assumption that SS Gem has no intrinsic polarization. This possibility supports the observation that the observed polarization of SS Gem does not show a discernible time variation.

We have obtained the intrinsic polarizations for two other stars, RV Tau and AC Her, from the observed polarizations by removing the interstellar polarizations. We report the characteristics of intrinsic polarizations for these stars.

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 0.88μm, respectively. The construction and the operation of this polarimeter are described by Kikuchi (1988)[7]. 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)[8] 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)[9] for a wavelength dependence of interstellar polarization p_{IS}, which is given as follows:

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

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:

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

and

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

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:

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

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 mordified near-neighbor method. The near-neighbor method is described by Bastien (1985)[10]. 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)[11], (hereafter referred to as ISPOL) as the catalogue of stars with no intrinsic polarization. The ISPOL contains 13969 data collected from 45 literatures.

3. Results

The position, subclass, and distance for RV Tau and AC Her are given in table 1. The details of the results are as follows.

a) RV Tau

RV Tau belongs to the RVb group and the group A_1. According to the General Catalogue of Variable Stars (Kholopov et al. (1985)[12], hereafter referred to as GCVS), the formal period of RV Tau is 78.70days and the long-term brightness period is 1224days. Zsoldos (1996)[13] made a period analysis using visual observations done between 1980 and 1995, and he derived 78.57days and 1168days as the formal and the long-term brightness periods, respectively. He also analyzed using the data between 1925 and 1940, and he derived 78.42 days and 1190days as the formal and the long-term brightness periods, respectively. There is a drastic decrease in the amplitude of the long-term brightness variation. This amplitude between 1925 and 1940 is $0^m.61$, while that between 1980 and 1995 is $0^m.21$. On the other hand, the amplitude for the formal period is practically the same. He guessed that the change had occurred rather abruptly around 1940's.

RV Tau was observed 19 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, 1997 January 28/29, 1997 December 10/11, 1998 February 9/10, and 1998 February 10/11.

We found 32 stars from the ISPOL which are within a 6° circle centered on RV Tau. We selected only 5 stars (5 data) for the estimation of the θ_{IS} value among the above 32 stars whose distances are larger than 300pc. The value of 300pc was adopted, because for the stars with distance of more than 300pc the scatter of θ_{IS} values becomes small, as is shown in figure 1. The estimated value is $\theta_{IS}=63°$. In this estimation, the dependence of θ_{IS} values on δ_{1950} was taken into account.

We selected only 2 stars (3 data: 2 data for B band and one datum for V band) for the estimation of p_{IS} value whose distance are larger than 500pc. The value of 500pc was adopted, because for the stars within 500pc the scatter of p_{IS} values are large, as is shown in figure 2. The average value of the above 3 data is adopted

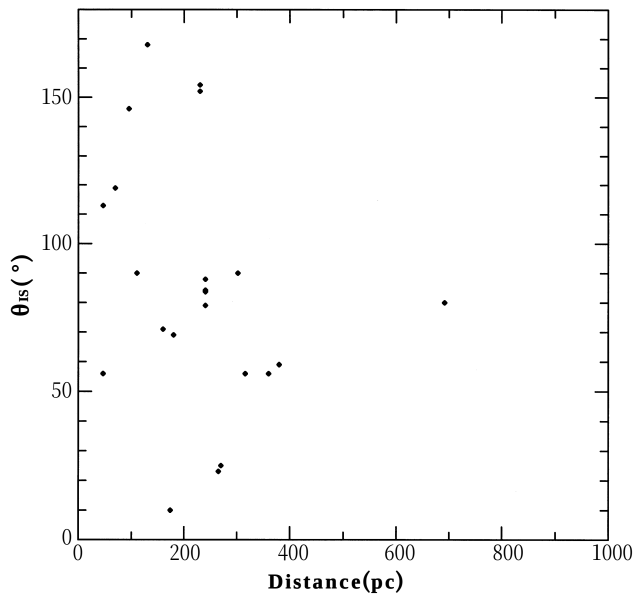

Fig.1. Dependence of the θ_{IS} values near RV Tau on distance.

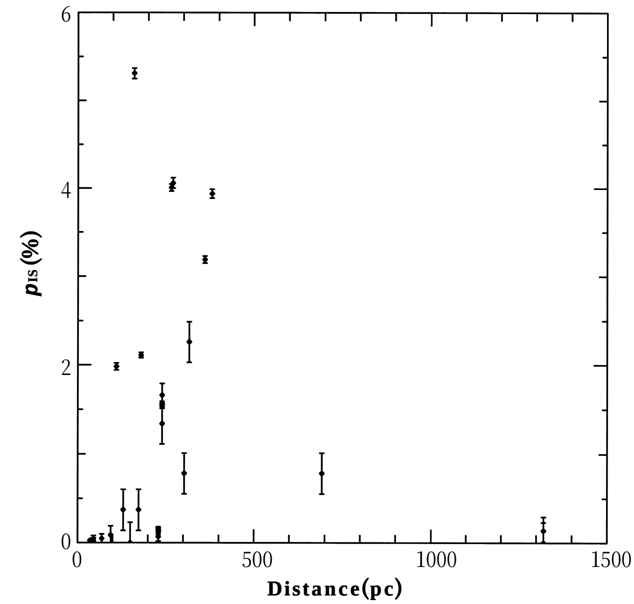

Fig.2. Dependence of the p_{IS} values near RV Tau on distance.

as the p_{max} value. The average value is $p_{max}=0.45\%$. We assumed that $\lambda_{max}=0.5\mu m$.

In the above estimations, we adopted 2330pc as the distance of RV Tau from Dawson (1979)[2]. As is shown in figures 1 and 2, the distances of all the above 32 stars are smaller than 2330pc. The most largest distance of the 5 stars used for the estimation of θ_{IS} value is 692pc. That of the 2 stars used for the estimation of p_{IS} value is 1320pc. Both of these values are noticeably smaller than 2330pc. Hence, the accuracy of our determination does not seem to be high.

We obtained the intrinsic polarization of RV Tau by removing the interstellar polarization of the above values. Yoshioka (1998)[14] found that the observed polarization of this star shows a long-term time variation with the period which is close to the long-term brightness periods. The intrinsic polarization also shows the long-term time variation. For example, the p_* values for RV Tau with small observational errors show a slight 凸 type dependence as is shown in figure 3, when both Q_* and U_* values are positive. On the other hand, the p_* values decrease with wavelength as is shown in figure 4, when the Q_* values are positive and the U_* values are negative. The θ_* values does not show discernible wavelength dependence, as is shown in figures 3 and 4. The same dependence for the observed p values have already been found by Yoshioka (1998)[14].

The p_* values show the long-term time variation, while the time variation with formal period is not conspicuous. Figure 5 shows the time variation of p_* values in the channel 5. A solid line indicates the least-squares solution which is given by the following expression which is obtained on condition that the period is 1224days.

$$p_*(\%)=0.89\cdot\cos[2\pi(t-49760)/1224)]+3.06, \quad (7)$$

where t=Julian date−2400000. Between the periods of 1168days and 1224days, except for the channel 2, gives the period of 1224 days the least-squares solution with smaller standard deviation. On the other hand, Yoshioka (1998)[14] obtained that the period of 1224days gives the least-squares solution with slighly smaller standard deviation for the observed Q values, while, except for the channels 2, 3, and 7, the period of 1168days gives the one with smaller standard deviation for the U values.

The θ_* values also show the long-term time variation, while the time variation with formal period is not conspicuous. Figure 6 shows the time variation of θ_* values in the channel 4. A solid line indicates the least-squares solution which is given by the following expression which is obtained on condition that the period is 1168days.

$$\theta_*(^\circ)=25.2\cdot\cos[2\pi(t-49558)/1168)]+187.4, \quad (8)$$

where t=Julian date−2400000 and the original θ_* values with less than 100° are added 180° in order to smooth the time variation. Between the periods of 1168

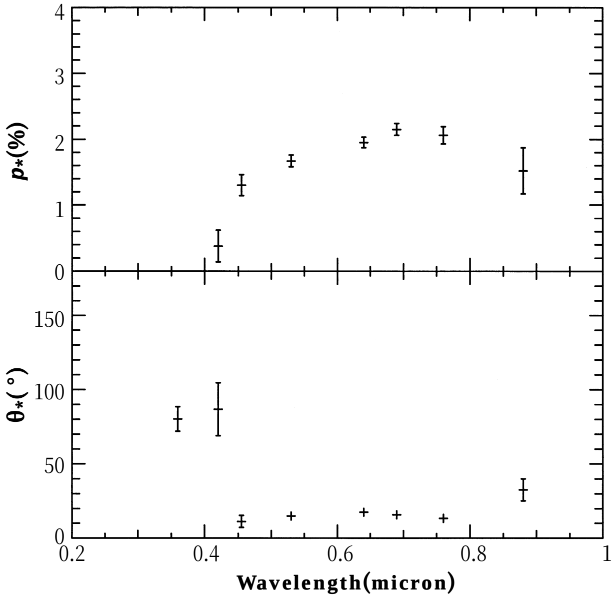

Fig.3. Wavelength dependence of the p_* and θ_* values of RV Tau on 1993 November 27/28 when both Q_* and U_* values are positive.

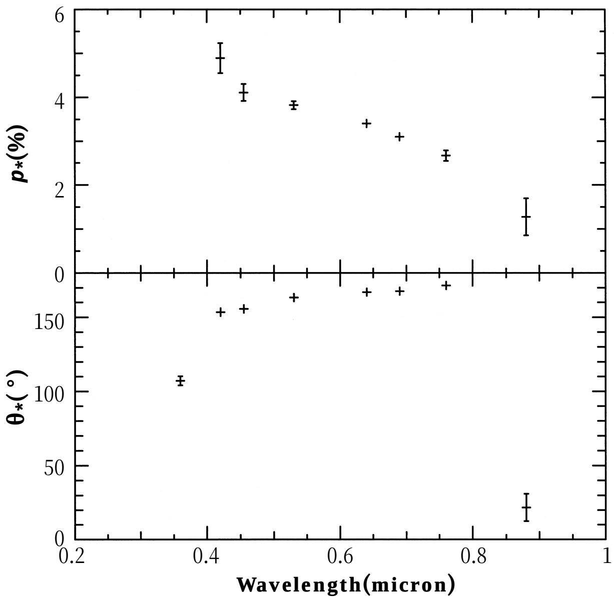

Fig.4. Wavelength dependence of the p_* and θ_* values of RV Tau on 1995 December 8/9 when the Q_* values are positive and the U_* values are negative.

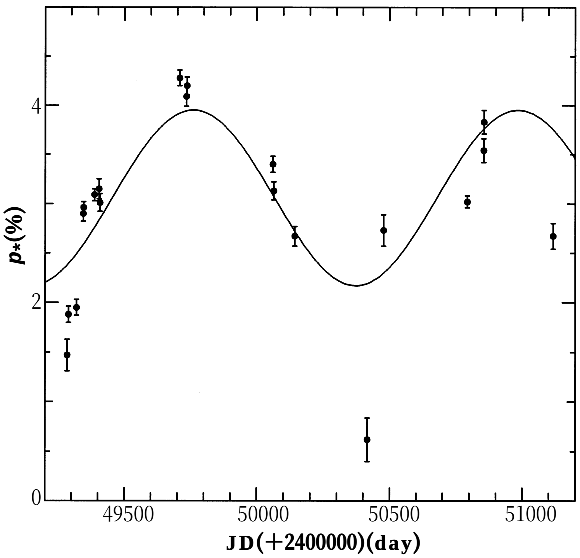

Fig. 5. Time variation of the p_* values of RV Tau in the channel 5. The solid line indicates the least-squares solution described in the text.

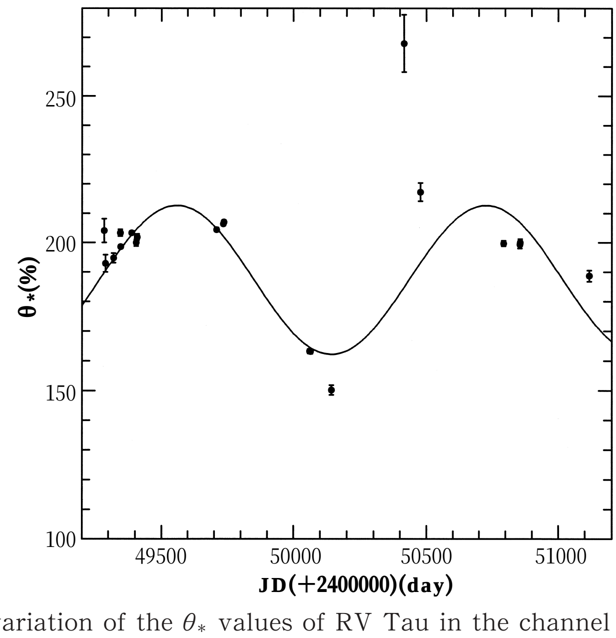

Fig. 6. Time variation of the θ_* values of RV Tau in the channel 4. The solid line indicates the least-squares solution described in the text.

days and 1224days, except for the channels 2 and 7, gives the period of 1168days the least-squares solution with smaller standard deviation. The semiamplitudes of the long-term time variation decrease with wavelength from 35.°3 for the channel 2 to 19.°6 for the channel 7.

b) AC Her

Ac Her belongs to the RVa group and the group B. According to GCVS, the formal period of AC Her is 75.46days. Sanford (1955)[15] observed radial velocities and found that the systemic velocities for low-level lines of Fe I shows a time variation with about a period of 1240days. He suggested that AC Her is a binary whose orbital period is about 1240days. Winckel et al. (1998)[16] measured radial velocities with the CORAVEL radial velocity spectrometers and confirmed the binary nature of this star. They analyzed the radial velocity curve taking the pulsation into account and obtained the orbital elements. According to them, the eccentricity of orbit is 0.12±0.02 and the orbiral period is 1194±6days.

AC Her was observed 11 times on 1993 November 24/25, 1994 February 23/24, 1994 March 29/30, 1994 April 15/16, 1995 Janurary 14/15, 1995 Janurary 15/16, 1995 Januray 16/17, 1995 March 20/21, 1996 February 3/4, 1996 February 28/29, and 1996 April 2/3.

We found 26 stars from ISPOL which are within a 7° circle centered on AC Her. We selected 18 stars (27 data) for the estimation of the θ_{IS} value among the above 26 stars. The estimated value is $\theta_{IS}=190°$. In this estimation the dependences of θ_{IS} values on α_{1950}, δ_{1950}, and distance were taken into account. For example, figure 7 shows the dependence of θ_{IS} values on α_{1950}.

We selected 19 stars (21 data) for the estimation of $p_{IS}(B)$ value whose distances are larger than 70pc, where $p_{IS}(B)$ means the p_{IS} value for B band. The value of 70pc was adopted, because for the stars within 70pc the p_{IS} values are noticeably smaller than the other values, as is shown in figure 8. The estimated value is $p_{IS}(B)=0.61\%$. In this estimation, the dependence of $p_{IS}(B)$ values on δ_{1950} was taken into account. We selected 4 stars (7 data) for the estimation of $p_{IS}(V)$ value, where $p_{IS}(V)$ means the p_{IS} value for V band. The distances of all the above 4 stars are larger than 70pc. The estimated value is $p_{IS}(V)=0.78\%$. In this estimation, the dependences of $p_{IS}(V)$ values on δ_{1950} and distance were taken into account. Figure 9 shows the dependence of $p_{IS}(V)$ values on distance. Assuming that $\lambda_{max}=0.5\mu m$, we determined that $p_{max}=0.70\%$ as the least-squares solution. 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 free parameters. In the above estimations, we adopted 640pc as the distance of AC Her from Wahlgren (1992)[17].

Yoshioka (1997)[6] found that the observed polarization of AC Her shows the

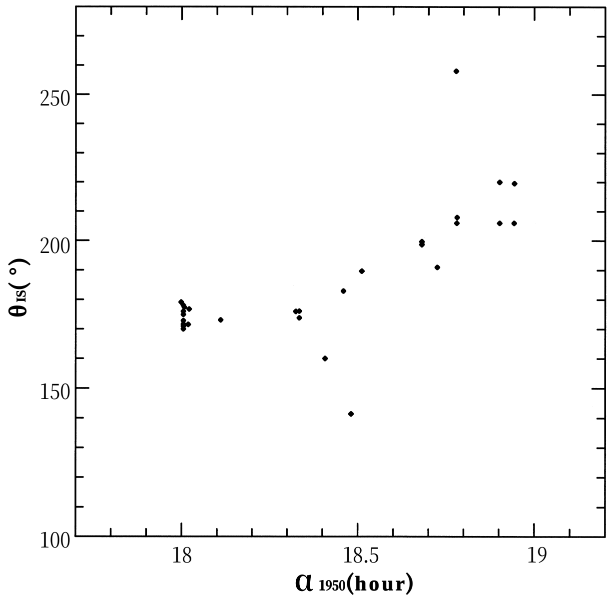

Fig.7. Dependence of the θ_{IS} values near AC Her on α_{1950}.

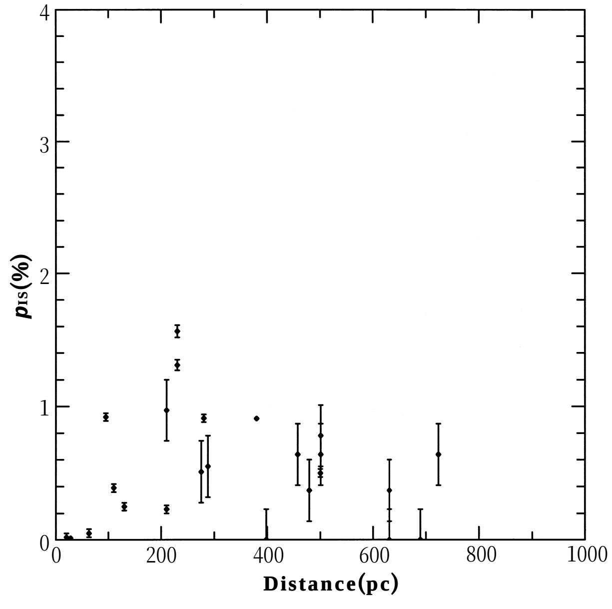

Fig.8. Dependence of the p_{IS}(B) values near AC Her on distance.

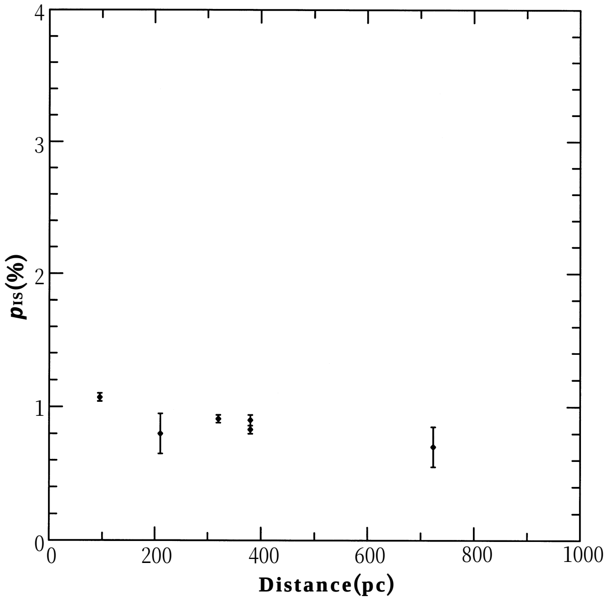

Fig. 9. Dependence of the p_{IS}(V) values near AC Her on distance.

time variation with the formal period. According to Yoshioka (1997)[6], there is a tendency for the observed p values to show the 凸 type dependence, and its dependence becomes prominent near light minimum. Shakhovskoi (1964)[18], Henson et al. (1985)[19], and Nook et al. (1990)[20] also observed the time variation of observed polarization. Especially, Henson et al. (1985)[19] and Nook et al. (1990)[20] detected the time variation with the formal period.

We detected also signs of the long-term time variation with the orbital period. Generally speaking, between the periods 1194days and 1240days the period of 1240days gives the least-squares solution with smaller standard deviation. Figure 10 shows the time variation of observed Q values in the channel 2. A solid line indicates the least-squares solution obtained on condition that the period is 1240 days, which is given by the following expression,

$$Q(\%)=0.43\cdot\cos[2\pi(t-49858)/1240)]+0.21. \quad (9)$$

Generally speaking, Q values give larger semiamplitudes and the least-squares solutions with smaller standard deviation than U values, which is consistent with the observation by Henson et al. (1985)[19] that the repeatability of the Q values from cycle to cycle for the formal period is not so good as that of the U values. Henson et al. (1985)[19] fitted the time variations of the observed Q and U values in the B band with third harmonics using a standard linear regression technique. They found that the variation of the Q values is mostly defined by the first harmonic component, while that of the U values is mostly defined by the third

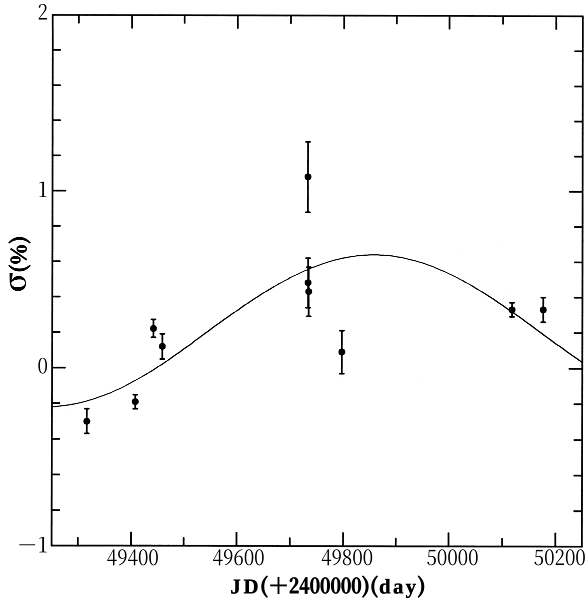

Fig.10. Time variation of the observed Q values of AC Her in the channel 2. The solid line indicates the least-squares solution described in the text.

harmonic component. The semiamplitudes of the first, second, and third component of their harmonics for the Q values which are estimated by us are 0.37%, 0.14%, and 0.10%, respectively, while those for the U values are 0.25%, 0.21%, and 0.27%, respectively.

We obtained the intrinsic polarization of AC Her by removing the interstellar polarization of the above values. The p_* values do not show the noticeable 凹 type dependence. There is rather a tendency that p_* values decrease with wavelength for the channels eqaul to and smaller than 4 and beyond the channel 4 their values are nearly constant. The tendency becomes prominent near primary light minimum, as is shown in figure 11.

The intrinsic polarization of AC Her also indicate signs of the long-term time variation with the orbital period. For example, between the periods of 1194days and 1240days, the period of 1194 days gives the least-squares solution with smaller standard deviation for the time variation of p_* values in the channels 2, 3, and 7, while the period of 1240days gives the one with smaller standard deviation in the channels 4, 5, and 6. Figure 12 shows the time variation of p_* values in the channel 4. A solid line indicates the least-squars solution which is given by the following expression,

$$p_*(\%) = 0.15 \cdot \cos[2\pi(t-49014)/1240] + 0.09 \cdot \cos[(2\pi(t-49714)]/75.46] - 0.06 \cdot \cos[4\pi(t-49703)/75.46] - 0.09 \cdot \cos[6\pi(t-49701)/75.46] + 0.46, \quad (10)$$

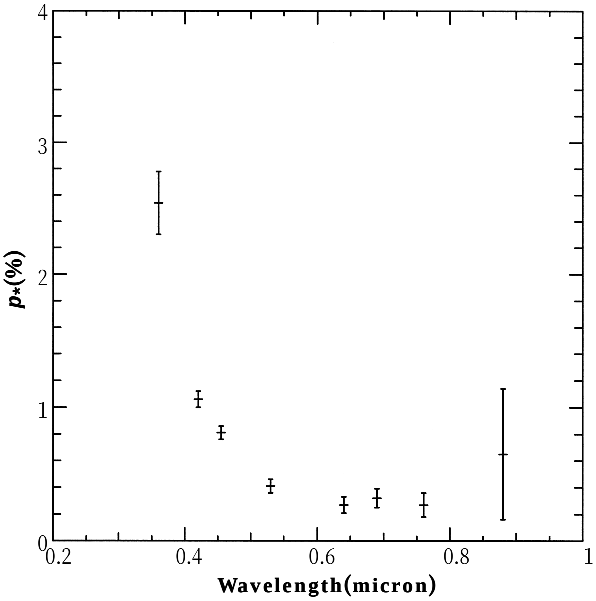

Fig. 11. Wavelength dependence of the p_* values of AC Her on 1994 April 15/16 when AC Her is at the primary light minimum.

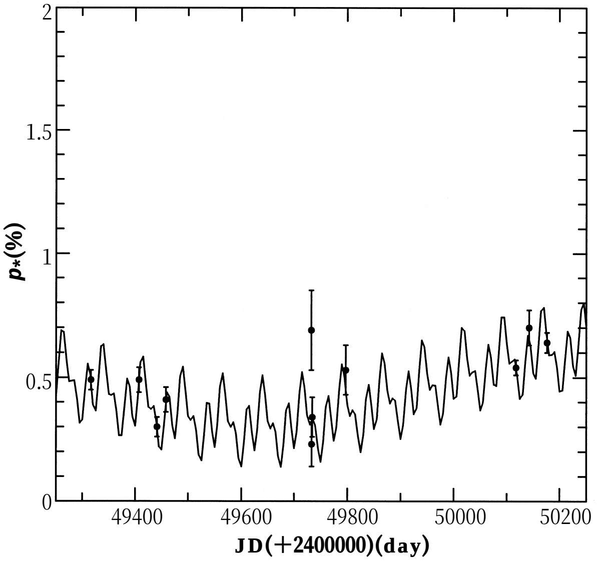

Fig. 12. Time variation of the p_* values of AC Her in the channel 4. The solid line indicates the least-squares solution described in the text.

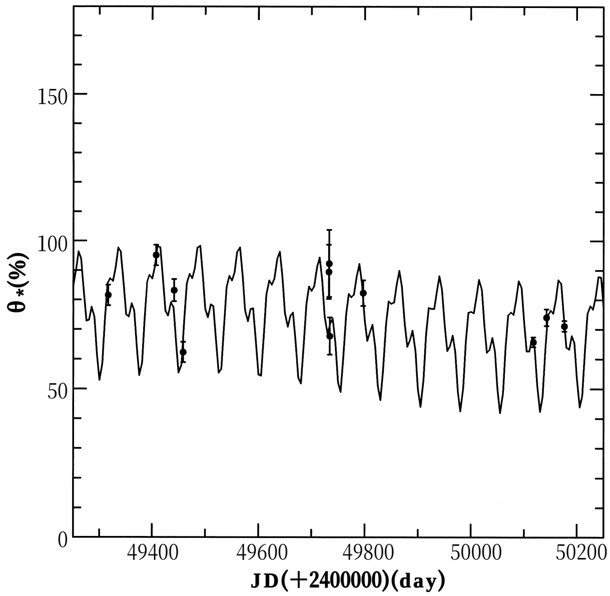

Fig.13. Time variation of the θ_* values of AC Her in the channel 4. The solid line indicates the least-squares solution described in the text.

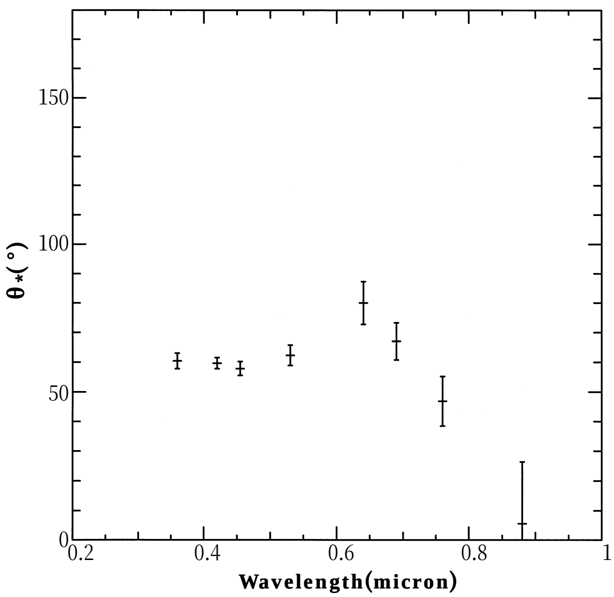

Fig.14. Wavelength dependence of the θ_* values of AC Her on 1994 April 15/16 when AC Her is at the primary light minimum.

which is obtained firstly by determining the long-term variation on condition that the period is 1240days and secondly by determining the short-term variation on condition that the long-term is the above one and the period of short-term is 75.46days. Furthermore, the θ_* values also indicate signs of the long-term variation. Except for the channels 6 and 7, the period of 1240days gives the least-squares solution with smaller standard deviation for the time variation of θ_* values. Figure 13 shows the the time variation of θ_* values in the channel 4. A solid line indicates the least-squars solution which is given by the following expression,

$$\theta_*(^\circ)=6.3\cdot\cos[2\pi(t-49448)/1240]+15.7\cdot\cos[(2\pi(t-49787))]/75.46]-3.8\cdot\cos[4\pi(t-49795)/75.46]-7.5\cdot\cos[6\pi(t-49804)/75.46]+73.5, \tag{11}$$

which is obtained by the same process as that for the p_* values. Generally speaking, the long-term variation for the θ_* values is not so conspicuous as that for the p_* values.

4. Discussion

We for the first time detemined the intrinsic polarizations for RV Tau and AC Her by the modified near-neighbor method from the ISPOL. The θ_{IS} values are determined more reliably than the p_{IS} values, which results were also obtained for TW Cam, SS Gem, U Mon, and R Sct. The values of interstellar polarization for RV Tau is not so reliable as those for AC Her, because the distance of RV Tau are larger than the most distant star used to determine the interstellar polarization. However, the p_{max} value for RV Tau 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. On the other hand, the p_{max} value for AC Her is comparable to the observed p values, so that the results for intrinsic polarization differ from those for the observed polarization in some points.

Both RV Tau and AC Her show the time variation of the intrinsic polarization not only with the short-term period but also with the long-term period. This suggests that for both RV Tau and AC Her the geometrical arrangement of CDE change not only with the short-term period but also with the long-term period. For RV Tau the long-term change is more conspicuous than the short-term change, while for AC Her the short-term change is more conspicuous.

The results for RV Tau confirm the tendency that the p_* values for the stars belonging to the group A show the 凸 type dependence (Yoshioka (2000)[4]). The results for AC Her does not confirm the tendency that the observed p values for the stars belonging to the group B show the 凹 type dependence (Yoshioka (1997)[6]). Nevertheless, the wavelength dependence of p_* values for AC Her also indicates that AC Her has more than two CDE's and each of CDE has a different grain size distribution. In fact, on the basis of multiwavelength observations, Shenton et al. (1992)[21] suggest that the presence of at least two distinct CDE's for AC Her. Furthermore, Jura et al. (2000)[22] obtained 11.7μm and 18.7μm images of AC Her with the 10m Keck I reflector and found the two distinct spots with an approximately north-south alignment that are separated by about 0."6. They concluded that there is an edge-on ring; The radius of the ring is about 300AU; There are both warm grains with size of less than 0.1μm and gravitationally bound orbital grains with size of more than 200μm. Our wavelength dependence of p_* values is consistent with their observation, though, as is shown in figure 14, our θ_* values are not equal to about $0°$ which value is expected for the orientation of the ring.

The analysis are being made for the remaining 11 stars.

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（平成13年11月８日受理）