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The Characteristics of Intrinsic Polarization for RV Tau and AC Her

Kazuo YOSHIOKA

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

吉岡 一 男

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星に対する固有偏光成分の相関が信頼度が高い。

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る。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、これはこの星の星間ガスが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.
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 interstellar 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 polarization not only with the formal period but also with the orbital period. The intrinsic degree of linear polarization 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) 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) 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 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 \(\theta_s\) shows neither a noticeable time variation nor a noticeable wavelength dependence. Except for U Mon, the degree of linear polarization of intrinsic polarization \(p_s\) 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 \(p_s\) values do not show a conspicuous wavelength dependence or take a maximum at an intermediate wavelength (hereafter referred to as the \(\downarrow\) type dependence). the \(p_s\) values for SS Gem take a minimum at an intermediate wavelength (hereafter referred to as the \(\downarrow\) type dependence) near the primary light minimum. According to Preston et al. (1963)\(^3\) 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 \(\downarrow\) type dependence (Yoshioka (1997)\(^4\)). 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 \(\downarrow\) type dependence (Yoshioka (1997)\(^4\)). 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 \((\theta_{is} = 176^\circ, p_{max} = 5.39\%\))
= 2.81%, λ_{max} = 0.57\mu m) is close to the interstellar polarization (θ_{is} = 1^\circ, p_{max} = 2.96%, λ_{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 0.88\mu m, respectively. The construction and the operation of this polarimeter are described by Kikuchi (1988)^{17}. 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 \( \theta \). We also obtained the normalized Stokes parameters \( Q \) and \( U \). The program by Hirarta (1993)^{19} was used for the reduction of the raw data into the quantities of \( p, \theta, Q, \) 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)^{20} for a wavelength dependence of interstellar polarization \( p_{is} \), which is given as follows:

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

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

\[
K = 0.01 + 1.66\lambda_{max}.
\]

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

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

and

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

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

\[
p_* = \sqrt{Q_*^2 + U_*^2},
\]

and

\[
\theta_* = 0.5 \cdot \tan^{-1}(U_*/Q_*).
\]

The \( p_{max}, \lambda_{max}, \) and \( \theta_{is} \) values are determined on the basis of the modified near-neighbor method. The near-neighbor method is described by Bastien (1985)^{10}. The modified near-neighbor method are described by Yoshioka (2000)^{10}.
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The main modification point is that a distance is used as the parameter for obtaining $p_{\text{is}}$, 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 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. According to the General Catalogue of Variable Stars (Kholopov et al. (1985)$^{19}$, hereafter referred to as GCVS), the formal period of RV Tau is 78.70 days and the long-term brightness period is 1224 days. Zsoldos (1996)$^{9}$ made a period analysis using visual observations done between 1980 and 1995, and he derived 78.57 days and 1168 days 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 1190 days 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 $0\text{^m}.61$, while that between 1980 and 1995 is $0\text{^m}.21$. 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.


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 $\theta_{\text{is}}$ 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 300 pc the scatter of $\theta_{\text{is}}$ values becomes small, as is shown in figure 1. The estimated value is $\theta_{\text{is}}=63^\circ$. In this estimation, the dependence of $\theta_{\text{is}}$ values on $\delta_{\text{1950}}$ 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 $p_{\text{is}}$ value whose distance are larger than 500pc. The value of 500pc was adopted, because for the stars within 500pc the scatter of $p_{\text{is}}$ values are large, as is shown in figure 2. The average value of the above 3 data is adopted.
Fig. 1. Dependence of the $\theta_{\text{BS}}$ values near RV Tau on distance.

Fig. 2. Dependence of the $p_{\text{BS}}$ values near RV Tau on distance.
as the $p_{\text{max}}$ value. The average value is $p_{\text{max}} = 0.45\%$. We assumed that $\lambda_{\text{max}} = 0.5\mu\text{m}$.

In the above estimations, we adopted 2330pc as the distance of RV Tau from Dawson (1979)\(^9\). 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 $\theta_{\text{is}}$ value is 692pc. That of the 2 stars used for the estimation of $p_{\text{is}}$ 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)\(^{10}\) 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 $q$ 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 $\theta_*$ 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)\(^{10}\).

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)\(^{10}\) obtained that the period of 1224days gives the least-squares solution with slightly 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 $\theta_*$ 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 $\theta_*$ 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 $\theta_*$ values with less than 100$^\circ$ are added 180$^\circ$ in order to smooth the time variation. Between the periods of 1168
Fig. 3. Wavelength dependence of the $p_*$ and $\theta_*$ 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 $\theta_*$ 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 $\theta_*$ values of RV Tau in the channel 4. The solid line indicates the least-squares solution described in the text.
days and 1224 days, except for the channels 2 and 7, gives the period of 1168 days 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 75.46 days. Sanford (1955) 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 1240 days. He suggested that AC Her is a binary whose orbital period is about 1240 days. Winckel et al. (1998) 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 orbital period is 1194±6 days.


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 $\theta_{IS}$ value among the above 26 stars. The estimated value is $\theta_{IS}=190^\circ$. In this estimation the dependences of $\theta_{IS}$ values on $\alpha_{1950}$, $\delta_{1950}$, and distance were taken into account. For example, figure 7 shows the dependence of $\theta_{IS}$ values on $\alpha_{1950}$.

We selected 19 stars (21 data) for the estimation of $p_{IS}(B)$ value whose distances are larger than 70 pc, where $p_{IS}(B)$ means the $p_{IS}$ value for B band. The value of 70 pc was adopted, because for the stars within 70 pc 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 $\delta_{1950}$ 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 70 pc. The estimated value is $p_{IS}(V)=0.78\%$. In this estimation, the dependences of $p_{IS}(V)$ values on $\delta_{1950}$ 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 $\lambda_{max}$ value, because the least-squares solution gives unrealistic $\lambda_{max}$ value when not only $p_{max}$ but also $\lambda_{max}$ is taken as free parameters. In the above estimations, we adopted 640 pc as the distance of AC Her from Wahlgren (1992).

Yoshioka (1997) found that the observed polarization of AC Her shows the
Fig. 7. Dependence of the $\theta_{85}$ values near AC Her on $\alpha_{1911}$.

Fig. 8. Dependence of the $p_{85}(B)$ values near AC Her on distance.
time variation with the formal period. According to Yoshioka (1997)$^9$, there is a tendency for the observed $p$ values to show the $p$ 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)$^{18}$ 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 1194 days and 1240 days the period of 1240 days 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
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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 type dependence. There is rather a tendency that $p_*$ values decrease with wavelength for the channels equal 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 1194 days and 1240 days, 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 1240 days 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-squares solution which is given by the following expression,

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

$$ JD(+2400000) \text{ (day)} $$

$$ \sigma \% $$

$-1$ $0$ $1$ $2$

48400 48600 48800 50000 50200
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 $\theta_*$ 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 $\theta_*$ 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 1240 days 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 75.46 days. Furthermore, the $\theta_*$ values also indicate signs of the long-term variation. Except for the channels 6 and 7, the period of 1240 days gives the least-squares solution with smaller standard deviation for the time variation of $\theta_*$ values. Figure 13 shows the time variation of $\theta_*$ values in the channel 4. A solid line indicates the least-squares solution which is given by the following expression.

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

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

4. Discussion

We for the first time determined the intrinsic polarizations for RV Tau and AC Her by the modified near-neighbor method from the ISPOL. The $\theta_*$ values are determined more reliably than the $p_*$ 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 $p_{\text{max}}$ 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 $p_{\text{max}}$ 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 $\chi$ type dependence (Yoshioka (2000)). 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 $\chi$ type dependence (Yoshioka (1997)). Nevertheless, the wavelength dependence of $p_*$ values for AC Her also
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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) suggest that the presence of at least two distinct CDE's for AC Her. Furthermore, Jura et al. (2000) obtained 11.7\(\mu\)m and 18.7\(\mu\)m 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 0.1\(\mu\)m and gravitationally bound orbital grains with size of more than 200\(\mu\)m. Our wavelength dependence of \(p_\ast\) values is consistent with their observation, though, as is shown in figure 14, our \(\theta_\ast\) values are not equal to about 0\(^\circ\) which value is expected for the orientation of the ring.

The analysis are being made for the remaining 11 stars.

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4) Yoshioka, K. 2000, Journal of the University of the Air, No. 18, 133.

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