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おうし座RV型星のHBS（偏光分光測光装置）による偏光観測とその固有偏光

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Polarimetric Observations of the RV Tauri Stars with HBS（Hennko Bunnko Sokkosochi）and Their Intrinsic Polarizations

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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 curve the RV Tauri stars are divided into the RVa group and the RVb group. The RVb group is characterized by a long-term light variation superposed on pulsation period. The RVa group do not show such 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 spectropolarimetric observations of 5 bright RV Tauri stars, using 91cm reflectors attached with the spectropolarimeter（HBS）at the Dodaira Station and the Okayama Astrophysical Observatory of the National Astronomical Observatory in Japan. We determined intrinsic polarizations for these stars by removing interstellar polarizations and we obtained the following resualts.

1）SS Gem, U Mon, and RV Tau show the time variation in wavelength dependence of the degree of intrinsic polarization.
2）Many of the above variations do not correlate with the phase of pulsation, and for some stars the above variation may correlate with the phase of long-term light variation.
3）Some observations of U Mon show that the degree of intrinsic polarization have several peaks and the wavelength of the peaks coincide with those of the dips in flux distribution.
4）For SS Gem, AC Her, and RV Tau, the position angle of intrinsic polarization show a wavelength dependence. Especially for RV Tau, the angle for the wavelength shorter than about 5500Å decreases with wavelength at the brightening phase of long-term light variation, which dependence resembles that for R Sct obtained before by spectropolarimetrical observation.

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、光度曲線をもとにRVa型とRVb型に細分類されており、RVb型が脈動周期に重なって長周期の光度変化を示すのに対して、RVa型はそのような長周期変化を示さない。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グループとCグループに細分類されている。

われわれは、国立天文台の堂平観測所と岡山天体物理観測所の91cm反射望遠鏡に偏光分光測光装置（HBS）を取り付けて、明るい5個のおうし座RV型星の偏光分光観測を行った。そして、それぞれの星に対して星間偏光を差し引いて固有偏光を求め、次の結果を得た。

ふたご座SS星といっかくじゅう座U星とおうし座RV星では、固有偏光度の波長依存性に時間変動が見られる。

上記の時間変動の多くには脈動の位相との相関が見られないが、長周期光度変化と相関がありそうな星がある。

いっかくじゅう座U星のいくつかの観測では、その固有偏光度にいくつかの波長でピークが見られ、ピークの波長が放射の吸収帯に一致している。

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ふたご座SS星とヘルクレス座AC星とおうし座RV星では、固有偏光位置角にも波長依存性が見られる。とくにおうし座RV星では、長周期光度変化の増光期に5500Å付近よりも短波長側で固有偏光位置角が波長とともに減少している。この波長依存性は、たて座R星の過去の偏光分光観測で観測されたものに似ている。

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 (hereafter referred to as MCP) attached to the 91cm reflector at the Dodaira Station of the National Astronomical Observatory. We obtained the intrinsic polarizations for all of the above 17 stars from the observed polarizations by removing the interstellar polarizations. The features of the intrinsic polarizations were reported in a series of papers by Yoshioka (Yoshioka (2000)[4], Yoshioka (2001)[5], Yoshioka (2002)[6], Yoshioka (2003)[7], and Yoshioka (2004)[8]). General features are summarized as follows.

1) Both of the group A and the group B stars show various types of wavelength dependence of the degree of intrinsic polarization p_*. Some of p_* values take a maximum at an intermediate wavelength (hereafter referred to as the 凸 type dependence), and some of p_* values take a minimum at an intermediate wavelength (hereafter referred to as the 凹 type dependence). Some of p_* values increase with wavelength and some of p_* values decrease with wavelength. Some of the stars show different wavelength dependence at different phases. But, except for CT Ori, the group B stars do not show the 凸 type dependence. On the other hand, the only C group star observed by us, V360 Cyg, does not show a noticeable wavelength dependence.

2) Generally speaking, the position angle of intrinsic polarization θ_* does not show a notable wavelength dependence. In case they show a wavelength dependence, there is a tendency that the p_* values also show a wavelength dependence.

3) The p_* values do not always take larger values at light minima. But there is a tendency that the p_* values take a maximum or a minimum values at primary light minima and that the p_* values show a wavelength dependence at primary light minima which is different from that at the other phase. They especially tend to decrease with wavelength at primary light minima.

We interpreted the above feature as follows.

1) The intrinsic polarizations of the RV Tauri stars are caused by the scattering in CDE and the feature indicates that the intrinsic polarization changes according to a phase change in CDE. The time variation in the wavelength dependence of p_* values indicates the change in the size distribution of the grain of CDE. Especially, the 凹 type dependence indicates that there are two CDE's which have different grain size distributions, and that the p_* values have two peaks in the wavelength distribution and p_* values have a minimum between the two peaks. The group B stars have a tendency to take the 凹 type dependence and, except CT Ori, most group B stars do not show the 凸 type dependence. Thus, the

Table 1. Data on the RV Tauri Stars analyzed in this paper for Intrinsic Polarization. Periods are the formal period. The fifth column gives the classification in the General Catalogue of Variable Stars (Kholopov et al. 1985)[9]. The sixth column gives the classification on the basis of optical spectra.

Star	α_{1950}	δ_{1950}	Period (day)	Variable Star Class	Optical Group
SS Gem	$06^h05^m32^s$	+22°37'48"	89.3	RVa	B
AC Her	$18^h29^m48^s$	+21°51'30"	75.5	RVa	B
U Mon	$07^h28^m21^s$	−09°40'24"	92.3	RVb	A_1
R Sct	$18^h44^m43^s$	−05°45'36"	140.2	RVa	A_1
RV Tau	$04^h43^m58^s$	+26°05'12"	78.7	RVb	A_1

group B stars seem to have a tendency to have two CDE's with different gain size distributions. Concerning CT Ori, the only B group star which show the 凸 type dependence of p_* values, the formal period is rather large (135.5days) and this star is definitely classified as RV Tauri star in the General Catalogue of Variable Stars (Kholopov et al. (1985)[9]). Furthermore, according to Dawson (1979)[2], the mean CCD colors suggest that CT Ori is a giant star, and according to Momiyama (2003)[10], the spectra of CT Ori indicate that this star is a subgiant or a dwarf star. Thus there is a possibility that none of the B group stars show the 凸 type dependence of p_* values, and that all the B type stars have more than two CDE's.

2) The feature 2) indicates that generally CDE's do not change in a geometrical arrangement. Furthermore, it indicates that the wavelength dependence of θ_* values is caused by the variation in the size distribution of grain.

2) The feature 3) indicates that the variation of intrinsic polarization is caused by the variation in the radiation from the photosphere or by that the variation of CDE's is linked with the brightness variation.

We have been observing some of the above 17 RV Tauri stars with a spectropolarimeter, HBS (an abbreviation of "spectro-photo-polarimeter" in Japanese) in order to elucidate the right or wrong of the above interpretations. The observed polarization observed with HBS were reported By Yoshioka (2005)[11]. We report the intrinsic polarizations observed with HBS in this paper.

Ⅱ. Observations

HBS measures linear polarization and flux in wavelength region between 400nm and 900nm. Its resolving power is in the range between 40 and 200. Although its resolving power is low, it can still measure the linear polarization of strong emission and absorption lines. The observational accuracy is estimated to be $[(p/50)^2+(0.05)^2]^{1/2}$ %, where p is the linear polarization degree in percent. The detailed description of HBS is described by Kawabata et al. (1999)[12].

The polarimetric observations with HBS reported in this paper were made between 1998 Mar 10 and 2000 Feb 21 at the Dodaira Station of the National Astronomical Observatory in Japan (hereafter referred to as NAOJ) and between 2001 Apr 19 and 2002 May 24 at the Okayama Astrophysical Observatory of NAOJ. Reflectors with 91cm diameter were used at both of the observatories.

Ⅲ. Results

In this paper, the intrinsic polarizations for five RV Tauri stars, SS Gem, AC Her, U Mon, R Sct, and RV Tau are reported. Data on these stars are listed in table 1.

We obtained the intrinsic polarizations from the observed polarizations by removing the interstellar polarizations for each star. We adopted the empirical formula given by Whittet et al. (1992)[13] for a wavelength dependence of interstellar polarization p_{IS}, which is given as follows:

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

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};

$$K=0.01+1.66\lambda_{max}. \tag{2}$$

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

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

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

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

$$p_*=\sqrt{Q_*^2+U_*^2} \tag{5}$$

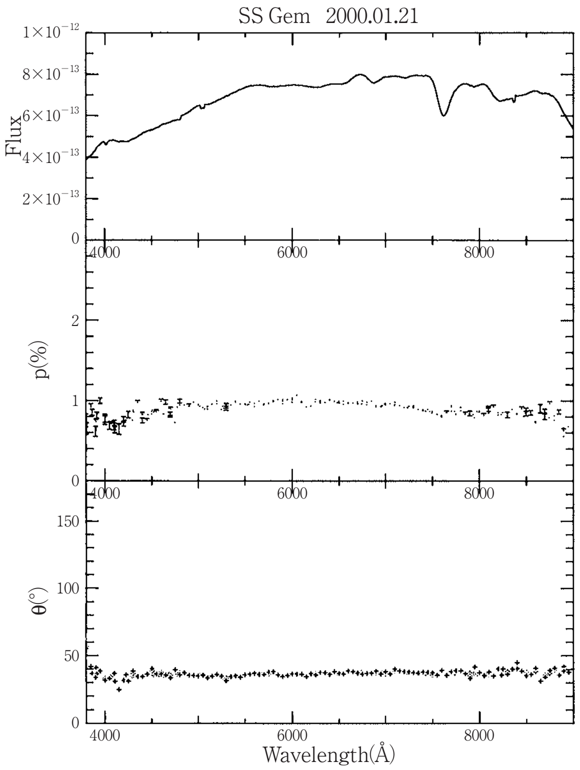

Fig 1. Wavelength dependence of the p_* and θ_* values of SS Gem on 2000 Jan 21/22.

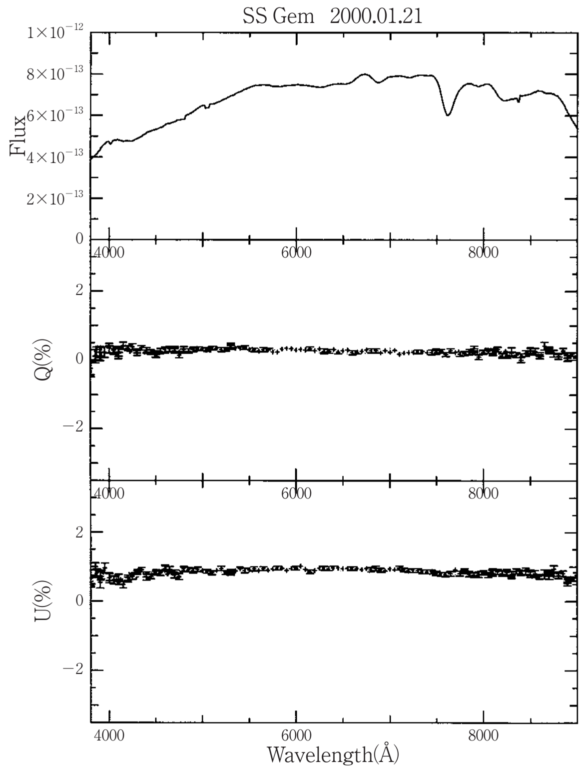

Fig 2. Wavelength dependence of the Q_* and U_* values of SS Gem on 2000 Jan 21/22.

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

The p_{max}, λ_{max}, and θ_{IS} values for the above stars are determined by Yoshioka (2000)[4] and Yoshioka (2001)[5] on the basis of near-neighbor method described by Bastien (1985)[14]. The details of the results are as follows.

a) SS Gem

SS Gem belongs to the RVa group and to the group A_2, according to Dawson (1979)[2]. According to Preston et al. (1963)[1], SS Gem may be related to the group B, because it shows strong CN bands and weak Ca II lines. Even Dawson (1979)[2] described that the DDO colors indicates that SS Gem may be a member of the group B. Furthermore, Gonzalez, Lambert, and Giridhar (1997)[15] claimed that SS Gem should be reclassified as the group B, because its spectra show numerous C I lines in the spectrum.

SS Gem was observed 5 times with HBS on 1999 Feb 4/5, 2000 Jan 20/21, 2000 Jan 21/22, 2000 Feb 18/19, and 2000 Feb 21/22. The intrinsic polarizations for the above dates were obtained by removing the following interstellar polarization for SS Gem: θ_{IS}= 171°, p_{max}= 2.81%, and λ_{max}=0.57μm, which values were obtained by Yoshioka (2000)[4]. There is a possibility that SS Gem does not have an appreciable CDE, because the estimated interstellar polarization above described is close to the following values which are determined on the assumption that SS Gem does not have an intrinsic polarization and the observed polarization is the interstellar polarization: θ_{IS}=1°, p_{max}=2.96%, and λ_{max}=0.5μm (Yoshioka (2000)[4]).

SS Gem was observed 5 times with HBS on 1999 Feb 4/5, 2000 Jan 20/21, 2000 Jan 21/22, 2000 Feb 18/19, and 2000 February 21/22.

The intrinsic polarization on 2000 Jan 21/22 is shown in figure 1. The top panel of this figure shows the flux distribution in arbitrary unit. The small dip near 5050Å seems to be mainly due to the absorptions of metallic lines such as Fe. On the other hand, the dips near 6800Å and 7600Å seem to be due to the absorptions of O_2 band of terrestrial atmosphere and the slight dip near 7200Å seems to be mainly due to water vapor of terrestrial atmosphere.

The middle and the bottom panels of this figure shows the p_* and θ_* values, respectively. As is shown in these panels, most of our observations with HBS reproduce the observations with MCP. Most of the p_* values with small observational errors show slightly the 凸 type dependence or do not show a noticeable wavelength dependence and take values near 1%. Most of the θ_* values are within the range from 30°to 40°.

The Q_* and U_* values on 2000 Jan 21/22 are shown

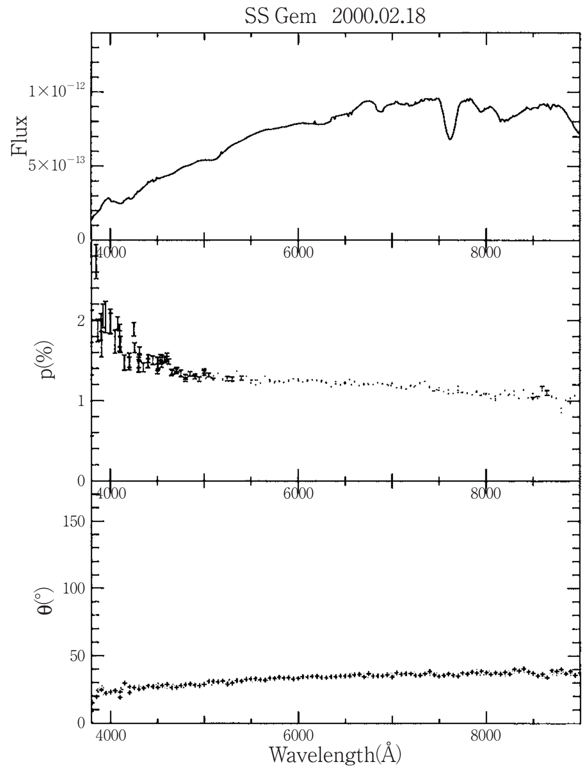

Fig 3. Wavelength dependence of the p_* and θ_* values of SS Gem on 2000 Jan 21/22.

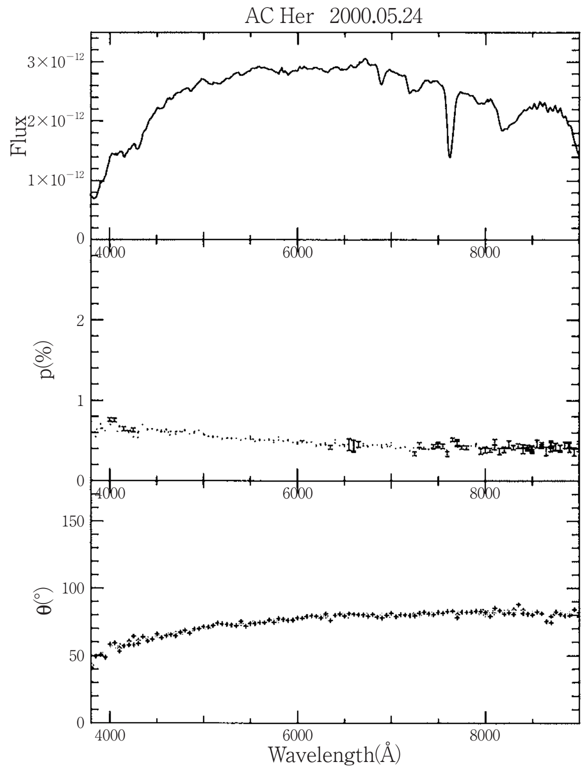

Fig 4. Wavelength dependence of the p_* and θ_* values of AC Her on 2002 May 24/25.

in figure 2. The top panel of this figure shows the flux distribution, as in figure 1. The middle and the bottom panels of this figure shows the Q_* and U_* values, respectively. As is shown in this figure, most of the Q_* values are slightly above 0%, and most of the U_* values are slightly below 1% and they do not show a noticeable wavelength dependence. The intrinsic polarization on 2000 Feb 18/19 are shown in figure 3. As is shown in this figure, the p_* values decrease slightly with wavelength and the θ_* values increase slightly with wavelength. This wavelength dependence was also observed with MCP.

On the other hand, the p_* values on 1999 Feb 4/5 are small, which are near 0%. These small p_* values were not observed with MCP. The above three observations were obtained at different phases. According to the visual light curves by the American Association of Variable Star Observers (hereafter referred to as AAVSO), the observations on 1999 Feb 4/5, 2000 Jan 21/22, and 2000 Feb 18/19 correspond to the phases from secondary light minimum to secondary light maximum, near secondary light minimum, and from secondary light maximum to primary light minimum, respectively. Thus, the variation of intrinsic polarization seem to be due to the variation in phase.

b) AC Her

AC Her belongs to the RVa group and to the group B. AC Her was observed 5 times with HBS on 2001 Apr 22/23, 2001 May 10/11, 2001 May 12/13, 2002 May 23/24, and 2002 May 24/25. The intrinsic polarizations for the above dates were obtained by removing the following interstellar polarization : $\theta_{IS}=10°$, $p_{max}=0.70\%$, and $\lambda_{max}=0.5\mu m$, which values were obtained by Yoshioka (2001)[5].

The intrinsic polarization on 2002 May 24/25 is shown in figure 4, which is typical of our observations with HBS. The p_* values decrease slightly with wavelength from about 0.6% to about 0.4%, and the θ_* values increase with wavelength from about 50°to about 80°. These wavelength dependences are also observed on other phases. The above wavelength dependence of p_* values is also observed with MPC (Yoshioka (2001)[5]). On the other hand, the above wavelength dependence of θ_* values is also observed with MPC, but other wavelength dependences are observed with MPC. The reason of the above difference in the wavelength dependence of θ_* values is not yet understood.

c) U Mon

U Mon belongs to the RVb group and to the group A_1. U Mon was observed 13 times with HBS on 1998

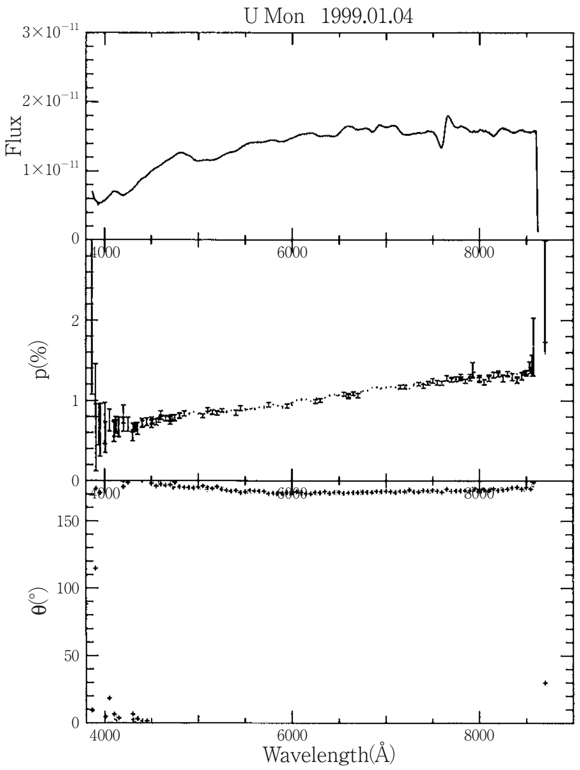

Fig 5. Wavelength dependence of the p_* and θ_* values of U Mon on 1999 Jan 4/5..

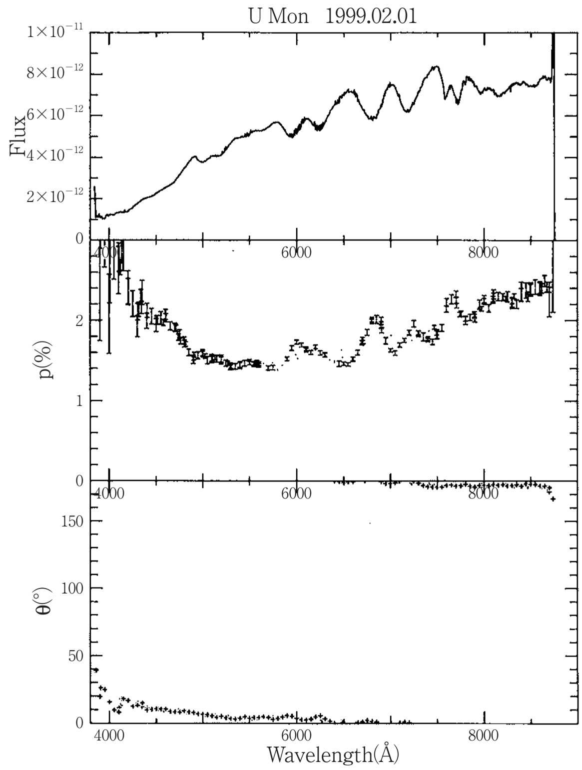

Fig 6. Wavelength dependence of the p_* and θ_* values of U Mon on 1999 Feb 1/2.

Mar 10/11, 1999 Jan 4/5, 1999 Jan 7/8, 1999 Feb 1/2, 1999 Feb 6/7, 1999 Mar 1/2, 1999 Mar 3/4, 1999 Nov 29/30, 2000 Jan 21/22, 2001 Feb 21/22, 2001 Apr 19/20, 2001 Apr 22/23, and 2001 May 10/11. The intrinsic polarizations for the above dates were obtained by removing the following interstellar polarization : $\theta_{IS}=3°$, $p_{max}=0.77\%$, and $\lambda_{max}=0.5\mu m$, which values were obtained by Yoshioka (2000)[4].

The observation on 1999 Jan 4/5 is shown in figure 5, which is typical of our observations with HBS. As is shown in this figure, the observed values are within the range of those values observed with MCP. As is shown in this figure, the p_* values increase with wavelength from about 0.6% to about 1.4%. On the other hand, the θ_* values do not show a noticeable wavelength dependence. Most of the values are within the range between 170°to 10°. This wavelength dependence often is seen in our MCP observations, especially at darkening phase.

According to the visual light curve by AAVSO, the observation on 1999 Jan 4/5 corresponds to the phase near the secondary light maximum. The observation on 1999 Feb 1/2 is shown in figure 6 and 7. As is shown in figure 6, the p_* values show several humps and dips, and the humps exist at the wavelength of the dips of the flux. As is shown in figure 7, these humps and dips are also seen for the Q_* and U_* values. This wavelength dependence is also seen on some other observations. This dependence does not correlate with the phase. For example, according to the visual light curve by AAVSO, the observation on 1999 Feb 1/2 corresponds to the phase near the primary light minimum, while the other observations with this wavelength dependence correspond to the phase near the primary light maximum and to that slightly before the secondary light minimum. U Mon also shows another wavelength dependence. The observation on 1999 Nov 29/30 is shown in figure 8. As is shown in figure 8, the p_* values in the wavelength range shorter than about 6500Å are lower than those longer than about 7500Å by about 0.8%, and increase from about 6500Å to about 7500Å.

On the other hand, the θ_* values do not show a noticeable wavelength dependence. The phase on 1999 Nov 29/30 corresponds to that between the secondary light minimum and the secondary light maximum. The similar wavelength dependence also is seen for the observation on 2000 Jan 21/22, while the phase of this observation corresponds to that between the secondary light maximum and the primary light minimum. Thus, this wavelength dependence either does not correlate with the phase of the formal period.

This wavelength dependence was observed during

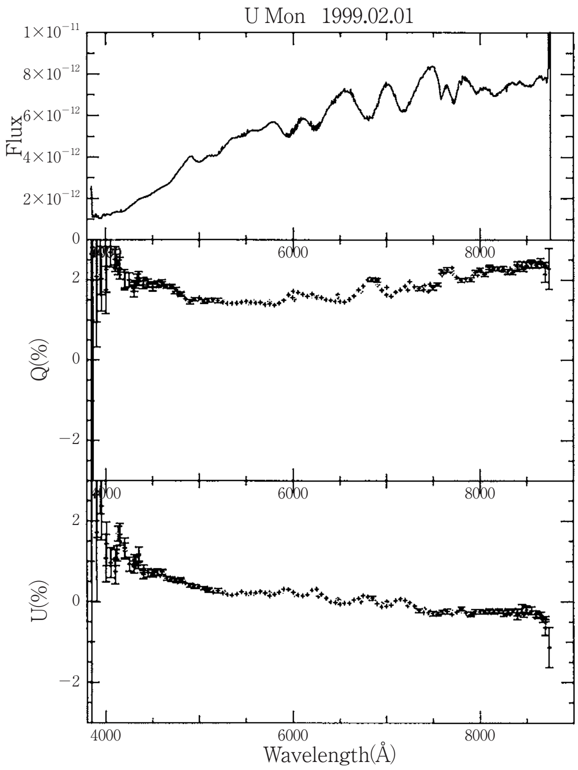

Fig 7. Wavelength dependence of the the Q_* and U_* values Q_* and U_* values of U Mon on 1999 Feb 1/2.

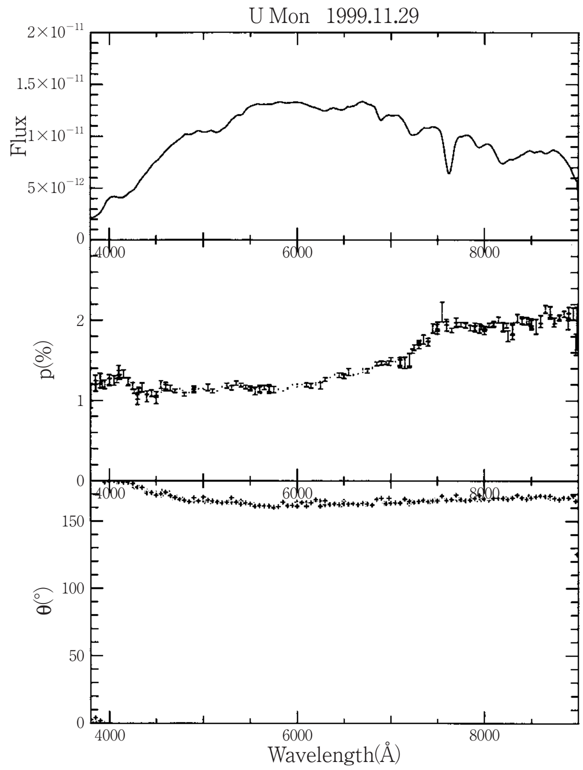

Fig 8. Wavelength dependence of the p_* and θ_* values of U Mon on 1999 Nov 29/30.

brightening period of the long-term light variation. Thus, this dependence may correlate with the phase of the long-term light variation.

d）R Sct

R Sct belongs to the RVa group and to the group A_1. R Sct was observed only one time on 2001 May 13/14.

The intrinsic polarizations for the above dates were obtained by removing the following interstellar polarization：θ_{IS}=59°, p_{max}=0.46%, and λ_{max}=0.55μm, which values were obtained by Yoshioka（2000）[4].

This observation is shown in figure 9. As is shown in this figure, the p_* values decrease slightly with wavelength by about 0.4%, while the θ_* values do not show a noticeable wavelength dependence and are near 20°. These values are within the range of those values observed with MCP, but the wavelength dependence of p_* values for HBS is different from that for MCP. The p_* values observed with MCP rather increase slightly with wavelength.

According to the visual light curve by AAVSO, the observation on 2001 May 13/14 corresponds to the phase slightly before the primary light maximum. The phases for the three observation with MCP are different from that with HBS and they are darkening phases. Thus, this difference in wavelength dependence may correlate with the phases.

According to Landstreet and Angel（1977）[16], who observed R Sct spectropolarimetrically with resolution between 20Å and 40Å at the phase of 0.46, the p values have a slight peak near 6000Å and for the wavelength lower than about 5500Å the θ values decrease with wavelength from about 80°to lower than 40°. These wavelength dependences, especially that for the θ values, are not seen in our HBS and MCP observations. For example, the θ values obtained with HBS without removal of interstellar polarization are near 30°.

e）RV Tau

RV Tau belongs to the RVb group and to the group A_1. Six observations were made for RV Tau on 1999 Jan 5/6, 1999 Feb 7/8, 1999 Nov 28/29, 1999 Nov 30/Dec 1, 2000 Jan 23/24, and 2000 Jan 25/26. The intrinsic polarizations for the above dates were obtained by removing the following interstellar polarization：θ_{IS}=63°, p_{max}=0.45%, and λ_{max}=0.5μm, which values were obtained by Yoshioka（2001）[5].

The intrinsic polarizations obtained above have values within the range of those obtained with MPC.

The observation on 1999 Feb 7/8 is shown in figure 10. As is shown in this figure, the p_* values show the 凸 type dependence, while the θ_* values do not show a noticeable wavelength dependence. According to the

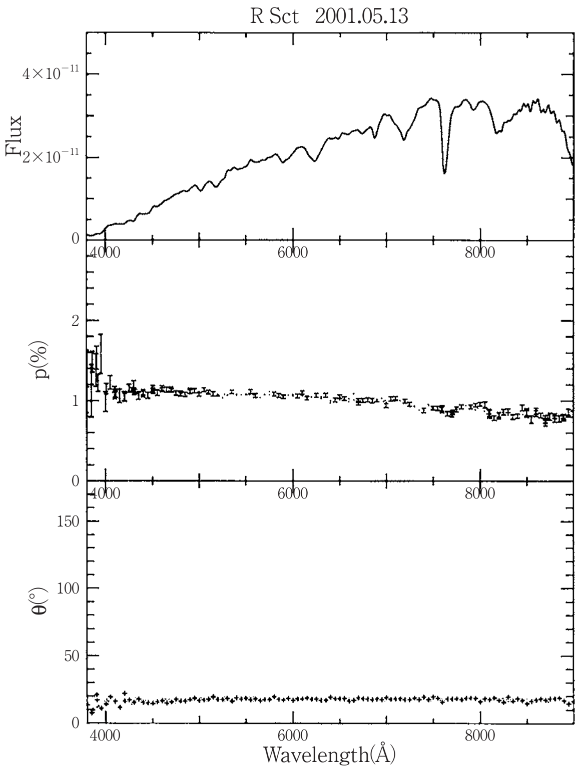

Fig 9. Wavelength dependence of the p_* and θ_* values of R Sct on 2001 May 13/14.

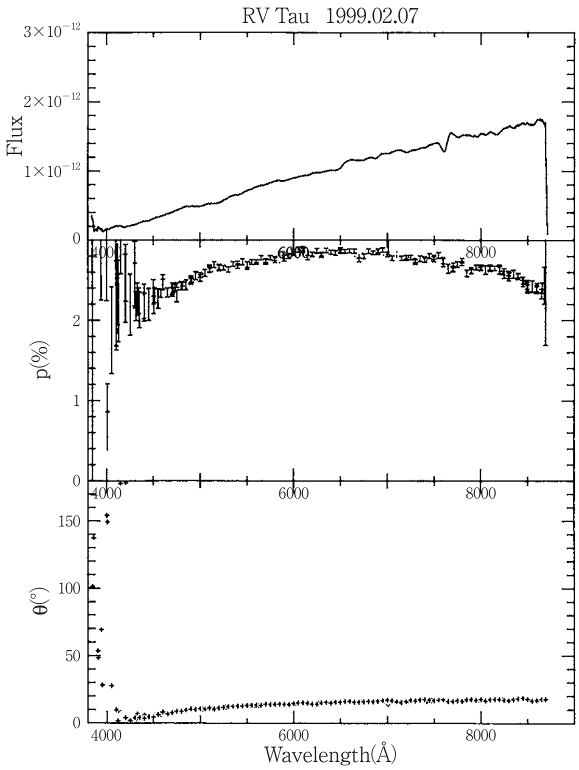

Fig 10. Wavelength dependence of the p_* and θ_* values of RV Tau on 1999 Feb 7/8.

visual light curve by AAVSO, the observation on this day corresponds to the phase slightly before the secondary light maximum.

The observation on 1999 Jan 5/6 show a similar wavelength dependence, where the phase of this date are near the primary light maximum. On the other hand, the observations from 2000 Jan 23/24 to 2000 Jan 25/26 show the wavelength dependence different from the above one, as is shown in figure 11. This figure shows that the p_* values with wavelength shorter than about 5500Å decrease with wavelength and those with wavelength longer than about 5500Å show slightly the 凸 type dependence. This figure also shows that the θ_* values with wavelength shorter than about 5500Å decrease with wavelength from about 110 to about 30°, which dependence resembles that for R Sct observed by Landstreet and Angel (1977)[16]. The observation of figure 11 corresponds to the phase near the secondary light maximum. This phase is similar to that for figure 10. Thus, the difference in wavelength dependence do not correlate with the phase of the formal period. This difference seems to correlate with the phase of the long-term brightness variation. The long-term phase from 1999 Jan 5/6 to 1999 Feb 7/8 is a darkening one, while that from 2000 Jan 23/24 to 2000 Jan 25/26 is a brightening one. On the other hand, the long-term phase from 1999 Nov 28/29 to 1999 Nov 30/Dec 1 is a minimum one and the wavelength dependence for this phase seems to indicate the transition from that for darkening phase to that for brightening phase, as is shown in figure 12. However, the correlation between the wavelength dependence and the long-term phase observed with HBS is quite different from that observed with MCP. According to the observations with MPC, the p_* values decrease with wavelength when they were observed during darkening phase of long-term light variation, and the p_* values show a 凸 type dependence at other phases.

Ⅳ. Summary

We made the spectropolarimetric observations with HBS for the bright RV Tauri stars, SS Gem, AC Her, U Mon, R Sct, and RV Tau, and obtained the following intrinsic polarization.

1) The values with HBS are within the range of those values with MCP.
2) The p_* values for SS Gem show the variation in the wavelength dependence, which indicates that SS Gem has CDE. The p_* values show two types of wavelength dependence, which correlate with the phase of light curve.
3) The p_* values for AC Her slightly decrease with

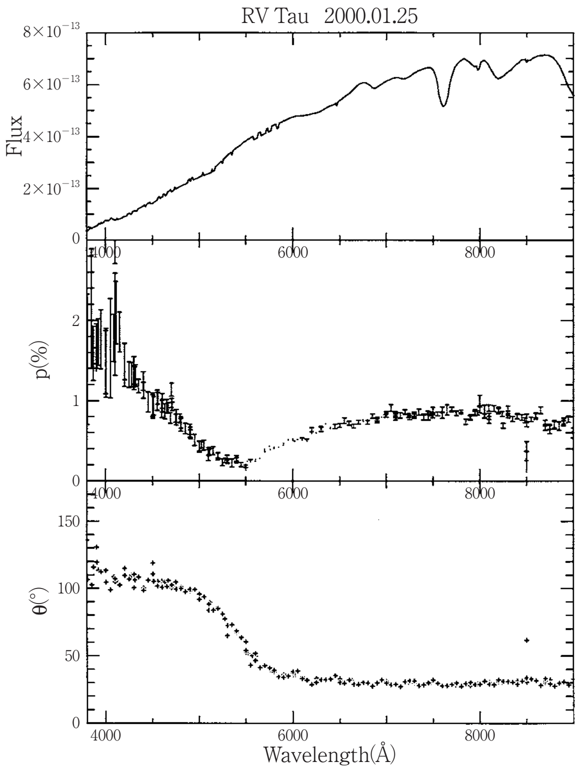

Fig 11. Wavelength dependence of the $p*$ and $\theta*$ values of RV Tau on 2000 Jan 25/26.

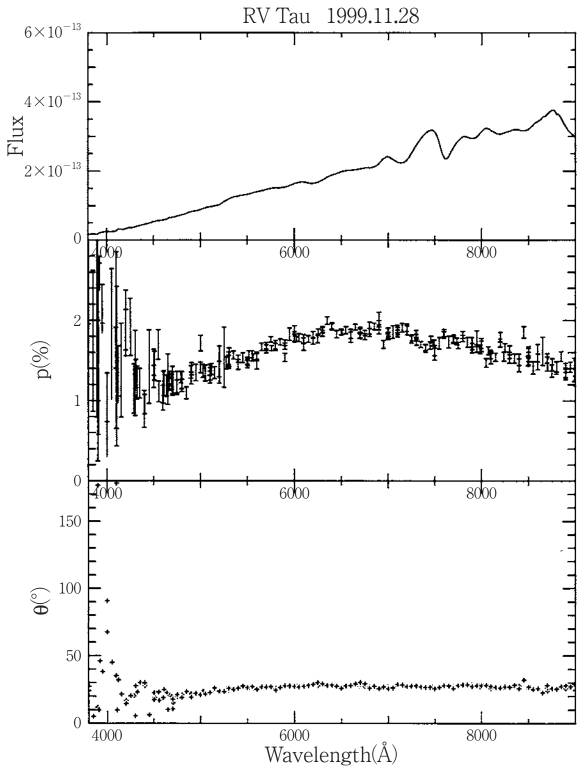

Fig 12. Wavelength dependence of the $p*$ and $\theta*$ values of RV Tau on 1999 Nov 28/29.

wavelength, which dependence exits irrespective of the phase of light curve. This wavelength dependence is not inconsistent with the 凹 type dependence which is often observed with MCP.

4) The $p*$ values for U Mon show three types of wavelength dependence, which do not correlate with the phase of formal period. For one type, the $p*$ values, together with the $Q*$ and $U*$ values, show several humps and dips and the humps exist at the wavelength of dips in the flux distribution. For another type, the $p*$ values in the wavelength range shorter than about 6500Å are lower than those longer than about 7500Å, which dependence may correlate with the phase of the long-term light variation.

5) The $p*$ values for R Sct decrease slightly with wavelength, which dependence had not been observed with our MCP observations and may correlate with the phase of formal period.

6) The $p*$ values for RV Tau show three types of wavelength dependence, which seem to correlate with the phase of long-term wavelength dependence, though the correlation observed with HBS is quite different from that observed with MCP.

7) Except for RV Tau, the $\theta*$ values do not show a noticeable wavelength dependence. For RV Tau at the brightening phase of long-term light variation, the $\theta*$ values with wavelength shorter than about 5500Å decrease with wavelength, which dependence resembles that for R Sct observed by Landstreet and Angel (1977)[16].

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