Spectropolarimetry of the Young Stellar Object R Mon

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Abstract
We performed low dispersion spectropolarimetry of the young stellar object R Mon, which is classified as a Herbig Ae/Be star. The polarization of $H\alpha$ emission line was different from that of the adjacent continuum. For the data on January 29, 1998, the polarization degree of the $H\alpha$ was 13.7 ± 0.6 %, and it was smaller than that of the continuum (15.1 ± 0.3 %). The position angle of the $H\alpha$ (77 degrees) was a few degrees larger than that of the continuum (75 degrees).

Our results suggest that significant portion of the $H\alpha$ emission should come from the region close to the star, because the observed polarization of the $H\alpha$ is similar to that of the continuum. However, since the polarization degree of $H\alpha$ is less than that of the continuum, part of the ionized region may be spatially more extended. It may coexist with the clouds which make light scattering.

1 Introduction

R Mon is one of the Herbig Ae/Be stars, and is associated with a cometary nebula, NGC 2261 or Hubble's nebula (Figure 1). Both R Mon and NGC 2261 show large linear polarization $\approx$ 10%-15% in the optical region.

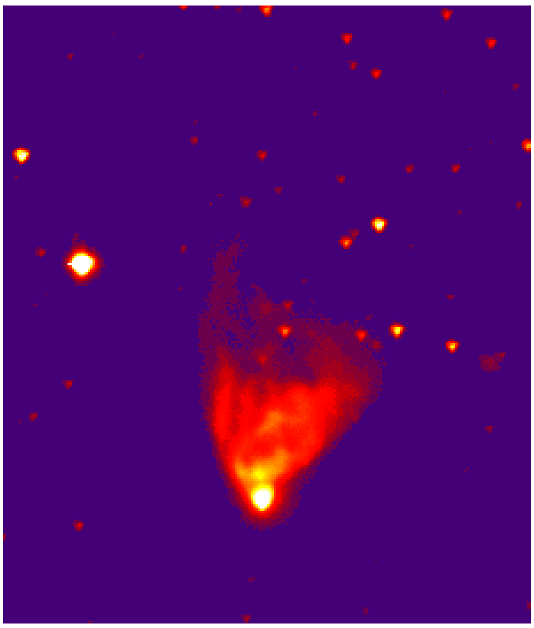

Figure 1: R-band image of R Mon and NGC 2261 in January 30, 1998. R Mon is at the apex of the cometary nebula NGC 2261. This image was obtained with the imaging-polarimeter OOPS at Okayama Astrophysical Observatory (Matsumura et al. in preparation).

R Mon shows time variations in magnitude, colors, and polarization. In a previous paper (Matsumura et al. 1999) we showed that the degree of polarization is positively correlated with the V magnitude on the basis of our simultaneous photometry and polarimetry. This correlation can be explained by the combined effect of extinction by the clouds orbiting around R Mon and scattering by diffusely surrounding medium (Grinin 1988). From the timescale of the variation ($\approx$ 10 days), we argued that the orbiting clouds should be very close to the star, i.e., $\lesssim$ 10 AU.

We have started low-resolution spectropolarimetry of R Mon since 1998, in the hope that we may obtain more information on the environment in the vicinity of the star. R Mon shows strong $H\alpha$ emission, i.e. the equivalent width is $\approx$100A. We thus may expect to study the ionized region around the star by spectropolarimetric observations. In this paper, we present the results obtained in 1998 and 1999.

2 Observations

R Mon was observed with a low-resolution spectropolarimeter, HBS (Kawabata et al. 1999), which was attached to the 91cm telescope at Dodaira Observatory. HBS uses a Pancharatnam-type achromatic half-wave plate, and a quartz Wollaston prism, as polarizer. The half-wave plate is rotated by a stepping motor. The disperser of HBS is a 300 grooves mm^{-1} reflection grating. A TI CCD with 1024x1024 pixels is used as a detector. Mean dispersion is about 6A per pixel, and we may obtain the data in the wavelength from 4000 to 9000A. Refer to Kawabata et al. (1999) for details.

We observed R Mon on three nights, i.e. January 28 and 29, 1998, and January 31, 1999. We used a slit with a width of 0.2mm in 1998 observations, and the resolution was $\approx$70A. On 31 January 1999, the weather condition was bad, so we used a diaphragm with a 1.4mm aperture instead of a slit. The resolution was more than 100A.

3 Results

Figure 2 shows the spectrum obtained on January 29, 1999 as an example. It should be noted that we have not calibrated it against spectroscopic standard stars. We see that the $H\alpha$ emission is very intense.

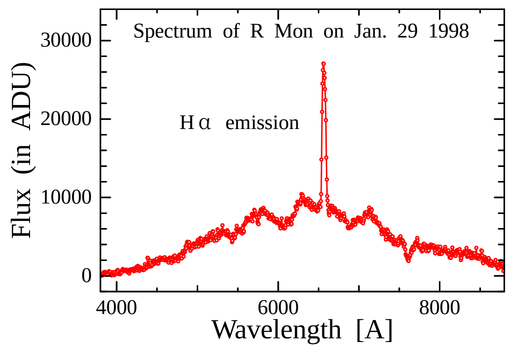

Figure 2: The spectrum of R Mon in January 29, 1999. Absolute calibration was not performed.

We derived polarimetric quantities for V and R bands (Table 1), by integrating the spectropolarimetric data with using 'digital filters', which are similar to the transmission curve of the standard photometric V and R bands. We also calculated and tabulated the polarization degree $p(H\alpha)$ and position angle $\theta(H\alpha)$ with the binning width of 50A, removing the contribution from the continuum. The values in the parenthesis in Table 1 are 1σ errors.

The polarization degree and the position angle of $H\alpha$ are similar to those of the continuum, i.e. those in R-band, but not identical. To know the differences between the $H\alpha$ and the continuum, we vectorially subtracted the continuum component from the $H\alpha$. The results are tabulated in Table 1, as $\delta p(H\alpha)$ and $\delta\theta(H\alpha)$ for polarization degree and position angle, respectively. The $H\alpha$ emission line is less polarized by a few percent. The position angle $\delta\theta(H\alpha)$ is about 140-150 degrees. If the $H\alpha$ emission is attenuated by the unpolarized light, the values of $\delta\theta(H\alpha)$ should be different by 90 degrees from the position angle of continuum, i.e. $\delta\theta(H\alpha)$ should be 165-168 degrees. Since the calculated values are different from these values, the depolarization of $H\alpha$ may not be simply due to the attenuation by natural light.

Table 1: Polarization Degree and Position Angle

Date	Int.Time (minute)	$p(V)$ (%)	$\theta(V)$ (degree)	$p(R)$ (%)	$\theta(R)$ (degree)	$p(H\alpha)$ (%)	$\theta(H\alpha)$ (degree)	$\delta p(H\alpha)$ (%)	$\delta\theta(H\alpha)$ (degree)
Jan.28,1998	140	13.5(0.9)	78.8(1.6)	13.3(0.5)	78.4(1.1)	12.8(0.8)	80.8(1.8)	1.5(0.9)	143(18)
Jan.29,1998	200	15.1(0.3)	74.6(0.7)	14.9(0.2)	75.3(0.6)	13.7(0.6)	76.9(1.2)	1.7(0.6)	147(10)
Jan.31,1999	67	16.1(0.9)	78.6(2.1)	16.0(0.4)	77.2(0.9)	13.0(1.5)	80.5(3.2)	3.4(1.7)	151(14)

One also sees in a q-u plane how the $H\alpha$ polarization is different from the continuum polarization (Figure 3), where q and u are fractional Stokes parameters. If we narrow the binning wavelength range, while keeping the central wavelength at $H\alpha$, the polarization degree and the position angle systematically vary. This is due to that the relative contribution from the continuum becomes smaller, as the binning wavelength range decreases. The signal-to-noise ratio does *not* significantly decrease even if the binning range is small, because the $H\alpha$ emission line is very intense (Figure 2).

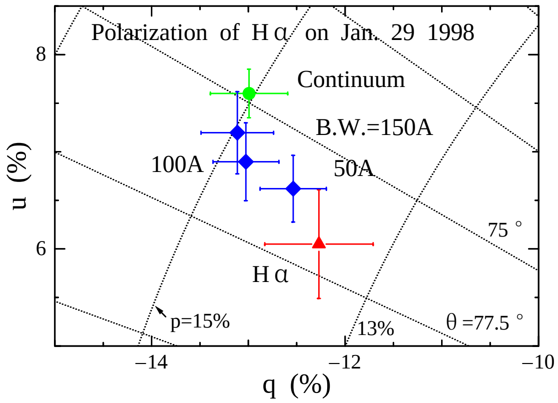

Figure 3: The difference between the $H\alpha$ emission and the adjacent continuum in the q-u plane. The polarization gradually changes as the binning width of the spectrum decreases, with keeping its center at $H\alpha$.

4 Discussion

4.1 Structure in $H\alpha$?

Our observation showed that the polarization of $H\alpha$ emission line was similar to that of the adjacent continuum. This result shows that the light scattering process for the $H\alpha$ emission is similar to that for the continuum. Since the continuum comes from the photosphere of the star, this result suggests that a significant portion of the $H\alpha$ emission also originates in a region close to the star. Theoretical models of line formation in Herbig Ae/Be stars also show that a significant part of the $H\alpha$ flux is produced quite close to the stars (e.g. Reipurth et al. 1996 for a review).

However, the polarization of $H\alpha$ emission was not the same as that of the continuum. The polarization degree was smaller, and the position angle was greater than the continuum. This suggests that the $H\alpha$ emission may consist of a few components. Each component may originate in different region around the star, and may have different polarization state. We could not resolve the $H\alpha$ line, because the resolution of our observation was more than 70A, and the line width of $H\alpha$ is about $\pm$500 km/s or $\pm$ 10A (e.g. Reipurth et al. 1996). For some other Herbig Ae/Be stars, Oudmaijer and Drew (1995) reported a structure in the $H\alpha$ polarization, i.e. the polarization is different between the blue and red parts in the $H\alpha$ line. If we can increase the spectral resolution, we may resolve the $H\alpha$ emission into some components and may obtain more information.

4.2 Temporal Variation in the $H\alpha$ Polarization?

In our observation, both the polarization of the continuum and that of the $H\alpha$ emission seem changed (Table 1). However, the difference between them, i.e. $\delta p(H\alpha)$ and $\delta\theta(H\alpha)$, did not show significant variation. The polarization degree of the $H\alpha$ emission was always a few percent smaller, and the position angle of $H\alpha$ is a few degrees larger than that of the continuum. This may suggest that the mechanism of the variation in $H\alpha$ is the same as that of the continuum.

Aspin et al. (1985) showed in their spectropolarimetry of R Mon that the degree of polarization of $H\alpha$ was 5.6% and the position angle was 168 degrees in 1983, after removing the continuum. Those values are quite different from ours, i.e. 13-14% and 77-80 degrees. It is not clear whether this difference is due to observational conditions, e.g. the different size of slit, difference of spectral resolution, etc. or it is due to the temporal variation in R Mon itself. It seems necessary to continue the observation to clear this point.

5 Conclusions

We performed spectropolarimetry of R Mon. We obtained the following conclusions:

(1) The linear polarization of $H\alpha$ is similar to that of the adjacent continuum, but it is not the same. This suggests that the most of the $H\alpha$ flux comes from the region in the vicinity of the star. However, part of the flux originates in the region far from the star.

(2) The polarization state of the $H\alpha$ emission and that of the continuum both seem temporally changed. However, the difference between them does not show significant variations. The mechanism of the polarimetric variation may be common for the $H\alpha$ and the continuum.

(3) Our observation shows that spectropolarimetry is a powerful tool to investigate the circumstellar environment of young stellar objects. It can separate the $H\alpha$ polarization and the continuum polarization, even if the spectrum resolution is low. It is desirable to continue this kind of monitoring observations to study the variable nature of these objects.

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Proceedings of Star Formation 1999