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# VARIATION OF LINEAR POLARIZATION IN THE R AQUARII SYSTEM

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## ABSTRACT

Linear polarization measurements of the R Aqr system are reported here. The R Aqr system shows strong wavelength dependence of percent polarization and position angle, which are strongly time dependent also. There is a large variation in percent polarization in the ultraviolet, whereas the variation decreases toward the red region. Contrary to the variation of percent polarization, the variation of polarization angle is small in the *U* band and large in other bands, toward the red region. These observations support a binary model in which a hot white subdwarf accretes material from a Mira variable forming a disk around the subdwarf. When the accreting mass exceeds a critical limit, a jet-like structure at the polar regions of the subdwarf is formed. The *U*-band position-angle variations are suggestive of precession of the jet-like structure.

*Key words:* Mira variable–white subdwarf–polarization–symbiotic star–accretion disk

## I. Introduction

R Aquarii is a symbiotic system which embodies a number of characteristic properties that distinguish it from other peculiar stars. The visual spectrum indicates the presence of a cool Mira variable (period about 387 days) in close association with a hot unresolved ionizing source of radiation that appears to be responsible for the higher excitation nebular emission (Merrill 1950; Wallerstein and Greenstein 1980). Encircling this spatially unresolved ionized region is an extended ring-like nebula which extends to about 60″ east and 75″ west of the star, and this nebulosity moves outward (Hubble 1943; Baade 1944). Also there is a nebulosity much closer to the star, which to some extent is variable in brightness and structure; it tends to be extended north and south of the star at right angles to the outer arcs. R Aqr indicates the existence of a "jet-like" feature (hereafter referred to as a jet) of about 6″ with a position angle of 29° from the central star (Sopka *et al.* 1982; Mauron *et al.* 1985). Observations by Kafatos, Hollis, and Michalitsianos (1983) reveal two discrete knots of emission—one at a distance of about 6″ and the other at 2″–3″ from the central object with P.A. of about 29°.3 and 45°, respectively. *IUE* observations indicate that a hot ionizing source of radiation in the central object, probably a subdwarf, is responsible for the intense line and continuum radiation observed (Johnson 1982; Michalitsianos, Kafatos, and Hobbs 1980). Several models have recently been advanced to explain the appearance of the emission features of R Aqr. Kafatos and Michalitsianos' (1982) model invokes supercritical mass exchange at periastron between the tenuous envelope of the Mira and the hot subdwarf moving in a highly eccentric ($0.84 \leq e \leq 0.92$) orbit with a 44-year period. Spergel, Giuliani, and Knapp (1983) have suggested a different model. According to their model, discrete clumps form in the neutral stellar winds of the Mira variable which are eventually illuminated and excited by the UV flux from the orbiting companion when these clumps enter the Strömgren volume.

Linear polarization measurements are important in understanding the peculiar geometry of the material surrounding the central object and the jet associated with the subdwarf. Wavelength and time dependence of polarization can be used to put constraints on the geometry of the object and to identify the mechanism(s) responsible for the polarization. In view of this, we have carried out linear polarization measurements of R Aqr in the *UBVRI* bands. Our observations give additional support for a binary model for the R Aqr system and suggest precession of the jet.

## II. Observations and Analysis

Observations were made during November-December 1984 on the 1-m telescope of the Indian Institute of Astrophysics, Kavalur, with a dual-channel photopolarimeter discussed elsewhere (Deshpande *et al.* 1985). The filter system is *UBVRI* and the photomultipliers are dry-ice-cooled RCA 31034 A, a GaAs surface. The polarimeter works on a rapid modulation principle and data are recorded every two ms and are processed on-line with a microprocessor. Details of the observing procedure, data acquisition, and analysis are discussed elsewhere (Deshpande *et al.* 1985). Measured values of percent polarization ($P$) and position angle ($\theta$) at different phases, and earlier observations of Serkowski (1974) and Ladbeck (1985), are listed in Table I. Error in polarization is estimated using photon count statistics. The error in position angle can be estimated using the relation (Serkowski 1962)

$$\epsilon_\theta = 28.^\circ65 \; \epsilon_p/p \; (\text{for } \epsilon_p \leqslant P) \; .$$

## III. Discussion and Conclusions

Figure 1 shows the observed wavelength dependence of linear polarization in the *UBVRI* bands at different phases. Observations of Serkowski (1974) and Ladbeck (1985) are also plotted for comparison. It is clear from the figure that R Aqr shows strong wavelength and time dependence of polarization and position angle. As R Aqr is comparatively near to us (about 200 pc) and is located at high galactic latitude (−70°), the interstellar polarization is expected to be negligible. Hence the observed large percent of polarization and its variation with time are intrinsic to R Aqr. In Figure 1 we see several interesting features in the percent polarization ($P$) as well as in the position angle ($\theta$): (a) In the ultraviolet the polarization is large and varies between 5.37% and 19%. The data, as indicated in Table I, were obtained between 1974 and 1984. These data show short-term (one-month) as well as long-term (ten-year) variations in $P$. (b) The position angle in the ultraviolet has remained unchanged at an angle of about 120°, though small variations with time are observed. (c) The polarization in the *VRI* bands is small (between about 0.5% and 4%). (d) The polarization in the *B* band shows a mixed type of variation wherein it changes from about 0.5% to 7%. (e) The position angles in the *VRI* bands, unlike in the *U* band, show large changes ranging from 20° to 170°.

All of these observations support, and may be explained through, the binary model for the R Aqr system in which a hot white subdwarf is orbiting around a Mira variable. When the white subdwarf is close to periastron, mass transfer from the Mira variable takes place with the formation of a disk around the white subdwarf. When the mass accretion exceeds a critical limit, jet structures are formed (Kafatos and Michalitsianos 1982). The optical and radio observations (Sopka *et al.* 1982; Hollis *et al.* 1985) of R Aqr indicate the existence of a jet. When the gas in the jet is heated by the intense UV radiation from the white subdwarf, a high degree of polarization arises due to Thompson scattering. This explains the observed feature (a) above. The observed jet has a position angle of 29° (Sopka *et al.* 1982). If the polarization in the *U* band arises

TABLE I

Polarimetric Observations of R Aquarii

| Date | Filter | $\lambda_{eff}$ (μm) | P (%) | $\varepsilon_P$ (%) | θ (°) | $\varepsilon_\theta$ (°) | References |
|---|---|---|---|---|---|---|---|
| Oct. 14, 1974 | N | 0.345 | 19.00 | 0.90 | 108 | 1 | Serkowski, 1974 |
| | U | 0.365 | 6.80 | 0.20 | 109 | 1 | |
| | B | 0.450 | 0.50 | 0.10 | 3 | 6 | |
| | V | 0.530 | 1.79 | 0.07 | 20 | 1 | |
| | R | 0.660 | 2.14 | 0.03 | 34 | 0.4 | |
| | I | 0.880 | 2.25 | 0.02 | 31 | 0.2 | |
| Sept. 28-Oct. 17, 1983 | U | 0.360 | 7.00 | 0.46 | 133 | 2 | Ladbeck, 1985 |
| | B | 0.440 | 4.02 | 0.17 | 137 | 1 | |
| | OIII Cont. | 0.514 | 1.34 | 0.40 | 154 | 8 | |
| | TiO | 0.622 | 0.39 | 0.32 | - | - | |
| | Hα Cont. | 0.636 | 0.43 | 0.20 | - | - | |
| | Hα | 0.657 | 0.28 | 0.14 | - | - | |
| | RK | 0.798 | 0.35 | 0.07 | 173 | 6 | |
| Nov. 2, 1984 | U | 0.36 | 5.37 | 0.95 | 136 | 5 | Present observations |
| | B | 0.44 | 3.96 | 0.26 | 139 | 2 | |
| | V | 0.55 | 1.50 | 0.09 | 148 | 2 | |
| | R | 0.62 | 0.44 | 0.11 | 156 | 7 | |
| | I | 0.80 | 0.23 | 0.03 | 164 | 4 | |
| Dec. 19, 1984 | U | 0.36 | 13.56 | 0.88 | 120 | 2 | Present observations |
| | B | 0.44 | 7.89 | 0.34 | 105 | 1 | |
| | V | 0.55 | 3.67 | 0.20 | 122 | 2 | |
| | R | 0.62 | 0.92 | 0.13 | 126 | 4 | |
| | I | 0.80 | 0.14 | 0.02 | 121 | 4 | |

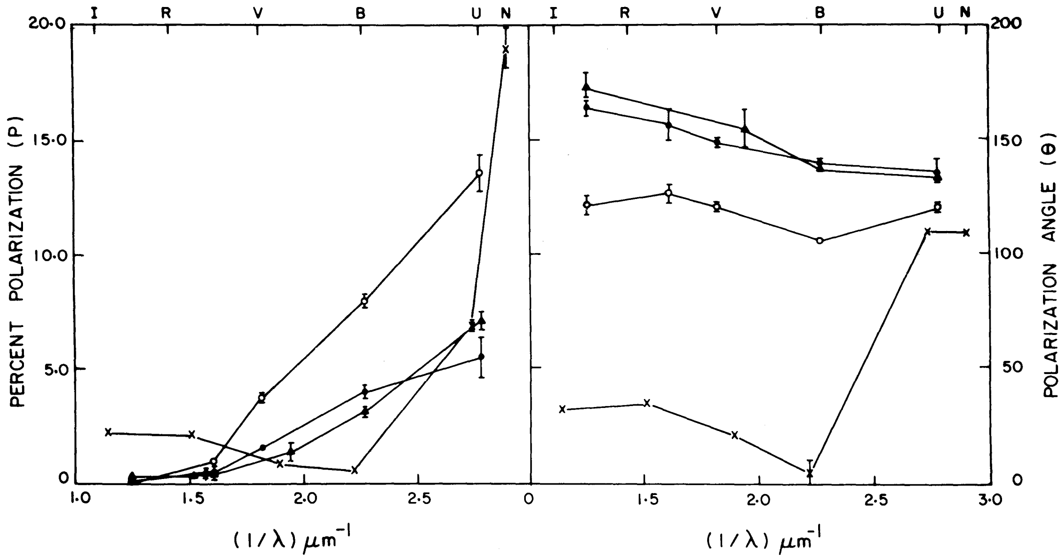


FIG. 1–Polarization and position angle plots. X Serkowski (1974); ▲ Ladbeck (1983); ● present data (November 1984); and ○ present data (December 1984).

from the jet one would get a value of 119° for the $U$ band; the observed values are close to 119° as given in Table I. This explains the observed feature (b) above. The small variations in position angle in the $U$ band around the expected value of 119° may be due to precession of the jet around an axis; however, more data are required to confirm this. The above findings indicate that the effects observed in the ultraviolet are mainly due to the white subdwarf. As we come to longer wavelengths, especially in the $R$ and $I$ bands, it appears that the main contribution comes from the Mira variable. The polarization in these bands may be due to the dust shell around the R Aqr system (as observed in (c) above). The large changes in position angle at the $V$, $R$, and $I$ bands may be due to changes in the nebulosity around the R Aqr system.

The above findings strongly suggest that R Aqr has a Mira variable around which a white subdwarf is moving in an elliptical orbit. Close to periastron, the white dwarf accretes material from the Mira variable. A jet-like structure is formed when the accretion exceeds a critical value. It is likely that the jet may be precessing (Fig. 2). Though the model proposed by Spergel *et al.* (1983) explains most of the features we have observed (a, c, d, and e), it fails to explain feature (b)—i.e., the position angle in UV remains almost unchanged. Further observations are needed to explore (a) whether polarization and the orbital period of a white subdwarf have any correlation, (b) whether the jet weakens at apastron, (c) whether the jet precesses, and (d) whether a 387-day periodicity in the Mira variable has any correlation with the $I$-band polarization.

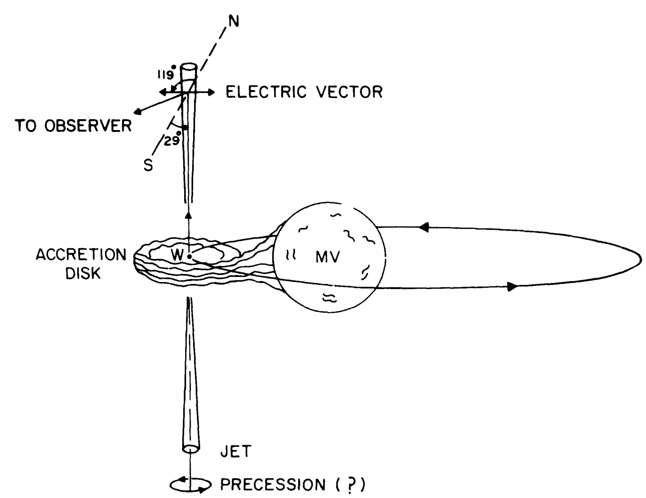


FIG. 2–The binary model for the R Aqr system. MV is the Mira variable, and W is the subdwarf. The high polarization in UV arises due to scattering of the light of the subdwarf from the material in the jets, whereas in the $R$ and $I$ bands the main contribution to the polarization comes from scattering in the circumstellar shell around the Mira variable.

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