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THE OPTICAL POLARIZATION OF SCORPIUS X-1

J. D. LANDSTREET
Department of Astronomy, Columbia University, and Department of Astronomy, University of Western Ontario, London 72, Ontario, Canada*

AND

J. R. P. ANGEL†
Columbia Astrophysics Laboratory, Columbia University
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ABSTRACT

Observations of the wavelength and time dependence of the optical polarization of Sco X-1 show that the effect is consistent with an interstellar origin.

The X-ray source Sco X-1 is known to have a slight linear polarization in visible light (about 0.69 percent at a position angle of 115°) from the measurement of Hiltner *et al.* (1967). Our objective in making further observations has been to try to establish whether the origin of the polarization is intrinsic to the source or interstellar. In an earlier paper (Angel 1969), it was shown that the accretion model of Sco X-1 could very well result in linear polarization, as a result of electron scattering in an aspherical plasma. On the other hand, the effect could be due to the interstellar medium, in which case, as Hiltner and Mook (1970) have pointed out, a careful study of the polarization of field stars should yield a distance for Sco X-1.

Intrinsic polarization can be recognized if it does not have the characteristic wavelength dependence of the interstellar effect, or if it is time variable. Interstellar polarization shows a broad maximum in the visible part of the spectrum, with the position angle independent of wavelength (Coyne and Gehrels 1966, 1967). The wavelength dependence of the polarization of Sco X-1 has been studied by Elvius (1968), but she did not obtain sufficient accuracy to distinguish between intrinsic and interstellar polarization. We report here studies of both the wavelength and time dependence of polarization.

Measurements of linear polarization for wavelength dependence were made in five different wavelength bands covering the range from 3100 to 7100 Å, using glass filters to isolate the bands. The photoelectric polarimeter described by Angel and Landstreet (1970) was used at the 107-inch (272 cm) telescope of McDonald Observatory on 1970 July 5/6. In this instrument linearly polarized light is first made circular by a wave plate, and is then analyzed by a fixed Pockels cell and Wollaston prism.

The measured values are listed in Table 1 and shown in Figure 1, where the points are plotted at the mean wavelength of the filter-photocathode sensitivity curve, and the horizontal error bars extend to the points of half-maximum sensitivity. The wavelength limits of the measurement made without a filter are defined in the red by the decrease in sensitivity of the S-20 photocathodes, and in the blue by the dispersion of the Wollaston prism, which causes ultraviolet light from the star to miss the small photocathodes. The vertical error bars are standard deviations, and include the effects of counting statistics and variability in the night sky.

The wavelength dependence is, within the statistical accuracy obtained, quite con-

* Present address.
† Alfred P. Sloan Fellow.

TABLE 1

LINEAR POLARIZATION OF SCORPIUS X-1

Mean Wave-length of Filter (Å)	Wavelengths at Half-Power Points (Å)	Time of Measurement (JD 2440000+)	Measured Polarization (%)	Measured Position Angle (°)	Filter*
3550.......	3175, 3925	743.81	0.59±0.12	115±6	S.T. Corning 7-54†
4300.......	3800, 4775	743.66	0.70±0.11	126±4	S.T. Corning 5-59†
4900.......	3800, 5850	743.71	0.67±0.03	126±3	unfiltered†
		1041.88	0.72±0.03	126±2	
5850.......	5075, 6450	743.74	0.56±0.13	121±7	S.T. Corning 3-70
6550.......	6000, 7000	743.77	0.50±0.13	134±6	S.T. Chance OR-2

* S.T. = standard thickness.

† Effects of 1 atm of absorption included in tabulated filter characteristics.

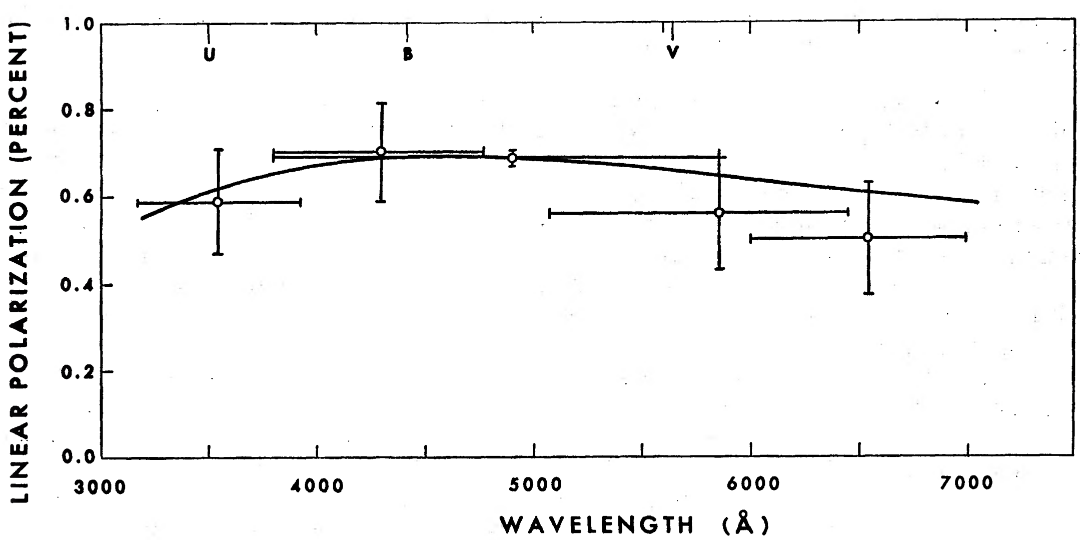

FIG. 1.—Measured linear polarization of Sco X-1 as a function of wavelength. The significance of the error bars and the smooth curve is explained in the text.

sistent with an interstellar effect. The position angles in different colors do not deviate significantly from the mean value of 125°, which is also consistent with the mean position angle of $\theta = 115° \pm 20°$ (s.d.) for the sixteen stars in the catalogs of Hall (1958) and Mathewson and Ford (1970) which lie in a $10° \times 10°$ square centered on the position of Sco X-1 and have more than 0.2 percent polarization. The magnitudes are quite adequately fitted by the typical interstellar curve drawn on the figure. This curve is the wavelength dependence of interstellar polarization measured by Coyne and Gehrels (1966) for stars with $p^V/p^B = 1.0$, normalized to give the best fit to our data. The value of p^V/p^B was chosen by using the correlation found by Serkowski (1968) between p^V/p^B and the ratio R of total to selective extinction; $p^V/p^B = 1$ corresponds approximately to $R = 3.8$, as measured by Johnson (1968) for this galactic longitude. While this gives a particularly good fit, in fact the data are not seriously inconsistent with any normal curve of interstellar wavelength dependence.

Scorpius X-1 is well known to show flickering of a few percent over periods of order 10–100 seconds, and we have searched for polarization variations on this timescale. The observations for time dependence were made in unfiltered light at the 82-inch (208 cm) telescope at McDonald Observatory on 1971 April 1. The quarter-wave plate was held with fixed orientation for some 20 minutes while the output from the circular analyzer was printed every 11 seconds. A second measurement was then made with the wave plate rotated 45°. The data have been analyzed by comparing the standard deviation of the measured values from their mean to standard deviation predicted from counting statistics, and the results are shown in Table 2. A comparison of columns (6) and (7) shows that the observed fluctuations in polarization are accounted for by counting statistics. Real random fluctuations with a standard deviation of more than 0.20 percent on the 10^s timescale and 0.13 percent on the 1^m timescale would show clearly in this analysis (Trumpler and Weaver 1962).

Real fluctuations would also give a positive correlation in the polarization values derived independently from the two beams emerging from the circular analyzer. The signals were checked for this, and no effect was present. We conclude that at the time of observation there is no evidence for fluctuations on this timescale. It would still be worthwhile checking for short-term variability when the star is active. While our instrument does not give accurate photometry, it was clear that the star did not vary in magnitude by more than 10 percent during the whole observation.

On a much longer timescale, our observations of polarization 9 months apart do not show any significant change in position angle or magnitude, and are in fair agreement with the result of Hiltner *et al.* (1967).

Scorpius X-1 has also been observed for circular polarization. None was detected in unfiltered light, the measured value on JD 2441150.624 being $+0.06 \pm 0.10$ percent.

In conclusion, we find no evidence for unusual polarization properties in Sco X-1 that would point to an intrinsically polarized source, although this cannot be excluded. The case for interstellar polarization would become very strong if stars in the immediate vicinity are found to be polarized with the same position angle.

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TABLE 2

ANALYSIS FOR SHORT-TERM VARIABILITY OF POLARIZATION

Component Measured (1)	Uncorrected Mean Polarization (%) (2)	Integration Period (seconds) (3)	Number of Periods (4)	Mean Counts per Period (5)	Standard Deviation of Measured Values (%) (6)	Standard Deviation Predicted from Counting Statistics (%) (7)
p_x	−0.20	10	130	127,700	0.25	0.28
		66	21	765,000	0.08	0.11
p_y	−0.60	10	130	128,700	0.27	0.28
		66	21	773,400	0.10	0.11

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