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POLARIZATION OF EARLY-TYPE STARS IN NORMA

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ABSTRACT

Linear polarization measurements of a number of heavily reddened early-type stars in the Norma region (between galactic longitudes 320° and 332°) are shown. The wavelength dependence of the polarization has been found to be in accord with that of the general interstellar field, as established by Serkowski and his co-workers. The ratio of total to selective interstellar extinction has been found to have a mean value of $R = 3.30 \pm 0.11$, corresponding to a normal value of λ_{max} between $0.48\ \mu m < \lambda_{max} < 0.68\ \mu m$. The ratios of polarization to extinction found in this region are concentrated towards the maximum value of 3% per mag, the maximum for the interstellar medium, thus implying a very efficient polarization mechanism.

I. INTRODUCTION

The observation of the interstellar linear polarization gives information on both the grain size distribution, the grain chemistry, and the dust column density. Therefore the polarization of starlight has become important in recent years as a useful tool to investigate the interstellar medium.

Serkowski, Mathewson, and Ford (1975) found that, for optical wavelengths, the wavelength dependence of interstellar polarization follows the empirical relation

$$P/P_{max} = \exp[-K \ln^2(\lambda_{max}/\lambda)], \qquad (1)$$

where λ_{max} is the wavelength of maximum polarization.

Later, Wilking *et al.* (1980,1982) extended that result to infrared wavelengths and found a better fitting if K is variable and suggested the relation

$$K = 1.86\lambda_{max} - 0.10 .$$

Serkowski and his co-workers showed that the wavelength of maximum linear polarization is a characteristic grain size parameter so that its measure may be an excellent method to find local values of R, the ratio of total to selective interstellar extinction. The relation connecting both quantities was recently reviewed by Whittet and van Breda (1978).

II. OBSERVATIONS

The "Perrine" 76-cm telescope at El Leoncito (San Juan, Argentina) was employed during July 1980 in conjunction with the rotating-analyzer polarimeter of La Plata Observatory to obtain polarization measurements in the U, B, V, R, and I bands of the Kron-Cousin's System. The analyzer was a HNP'B Polaroid sheet. Three unpolarized standards stars, selected from the *Catalogue of Nearby Stars* (Gliese 1969), were measured each night to determine the instrumental polarization, while one highly polarized standard (Serkowski 1974) was measured to calibrate the zero of the position angle system and to check for depolarization factors. It was necessary to introduce depolarization correction factors equal to 1.07 for red and 1.94 for the infrared filters. This latter value, although high, proved to be constant over the time span of the observing run. The zero of the position angle system remained fixed within 0°.2.

Each observation consisted of several 30-s integrations in each color and they were repeated as many times as it was necessary to attain a reasonably low error.

For stars observed on more than one night, weighted means were used and in this case internal and external errors were compared and the largest one was adopted.

The stars observed were selected from the catalog of Klare and Neckel (1977) of early-type stars (OB stars) and they are located in the Norma region between $332° < l < 320°$ and $-6° < b < 1°$. All the objects selected were required to have a degree of polarization greater than 2% in order to minimize the relative errors.

Abnormal stars, such as Be stars, were not included (except stars 944 and 957) in order to avoid stars with intrinsic polarization.

A comparison was made between our blue polarimetric measurements and those of Klare and Neckel (1977). Figures 1(a) and 1(b) show that both sets of measurements are in very good agreement.

The data about our program stars are listed in Table I. The columns of the catalog for each star and for each filter contain the following data: star number from Klare and Neckel (1977); the number of observations for each star; the percentage of polarization and position angle in the equatorial system together with their errors, for each filter.

III. DISCUSSION

Using a least-square fit to relation (1) but substituting $K = 1.86\,\lambda_{max} - 0.10$, the values of P_{max} and λ_{max} were

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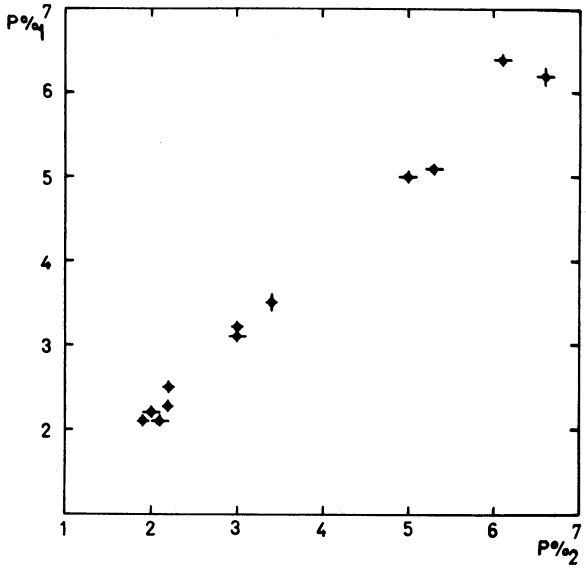

FIG. 1(a). Comparison of our blue polarization measurements (abscissa) vs those of Klare and Neckel (1977) (ordinate). The bars denote the errors.

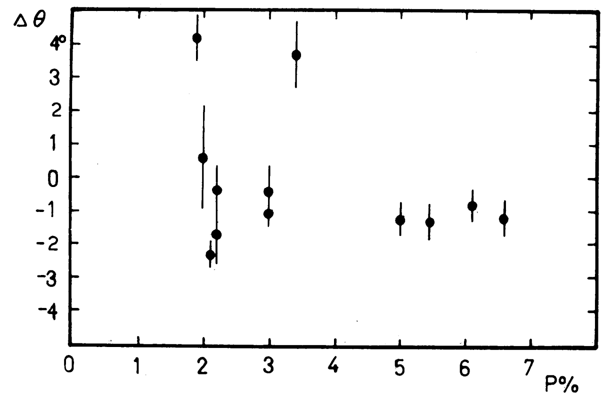

FIG. 1(b). Relation between our blue polarization measures (abscissa) and the differences between our position angles and those of Klare and Neckel (1977) in the sense our values minus theirs (ordinate). Stars 1041 and 1045 have abnormally large values of $\Delta\theta$.

TABLE I. Polarization measures of stars in Norma.

Filter No.	n	0.38 P/ϵ	P.A./ϵ	0.425 P/ϵ	P.A./ϵ	0.54 P/ϵ	P.A./ϵ	0.67 P/ϵ	P.A./ϵ	0.82 P/ϵ	P.A./ϵ	λ_{max}/ϵ	P_{max}/ϵ
943	1			6.09	61.00	6.20	60.80	6.16	62.10	5.31	62.80	0.55	6.34
				0.18	0.90	0.09	0.40	0.03	0.10	0.18	1.00	0.02	0.09
944	1			5.26	68.20	5.42	67.50	5.62	68.30	5.11	67.80	0.59	5.63
				0.17	0.90	0.11	0.60	0.15	0.70	0.15	0.80	0.03	0.11
954	2	2.75	65.53	2.97	63.66	3.20	64.56	3.23	64.98	2.84	63.21	0.58	3.28
		0.12	1.31	0.04	0.41	0.09	0.85	0.03	0.30	0.22	2.21	0.01	0.01
957	1			4.98	64.90	4.67	66.40	4.89	68.60	4.13	68.20	0.52	5.07
				0.15	0.80	0.19	1.20	0.10	0.60	0.16	1.10	0.03	0.16
958	1			6.55	61.10	6.48	62.50	6.18	63.70	5.81	66.40	0.55	6.61
				0.18	0.80	0.13	0.60	0.11	0.50	0.07	0.40	0.03	0.17
1035	2			2.17	50.63	2.44	47.88	2.47	47.01	2.03	49.14	0.59	2.49
				0.10	1.40	0.10	1.21	0.03	0.35	0.10	1.45	0.04	0.06
1041	2	1.87	48.20	1.89	48.66	1.97	46.84	1.96	46.83	2.14	44.56	0.58	2.02
		0.24	3.73	0.06	0.89	0.04	0.57	0.03	0.42	0.12	1.69	0.04	0.04
1045	1			3.41	40.90	3.30	43.30	2.85	48.30	2.53	51.50	0.46	3.33
				0.14	1.20	0.07	0.60	0.01	0.10	0.05	0.50	0.03	0.15
1119	2	1.78	40.90	2.05	40.70	2.43	40.19	2.25	38.48	2.20	37.62	0.61	2.29
		0.20	3.20	0.20	2.79	0.15	1.75	0.04	0.48	0.16	2.10	0.03	0.03
1128	1			1.95	46.40	2.15	45.50	2.15	45.50	2.03	43.80	0.60	2.18
				0.20	2.90	0.09	1.20	0.09	1.20	0.22	3.10	0.01	0.01
1133	1			2.95	46.80	3.23	46.50	3.15	45.40	3.10	42.90	0.61	3.28
				0.15	1.40	0.07	0.60	0.09	0.80	0.10	0.90	0.02	0.05
1154	1			2.23	53.70	2.67	52.50	2.18	52.50	2.55	52.00	0.57	2.50
				0.10	1.30	0.06	0.60	0.06	0.80	0.10	1.10	0.10	0.18

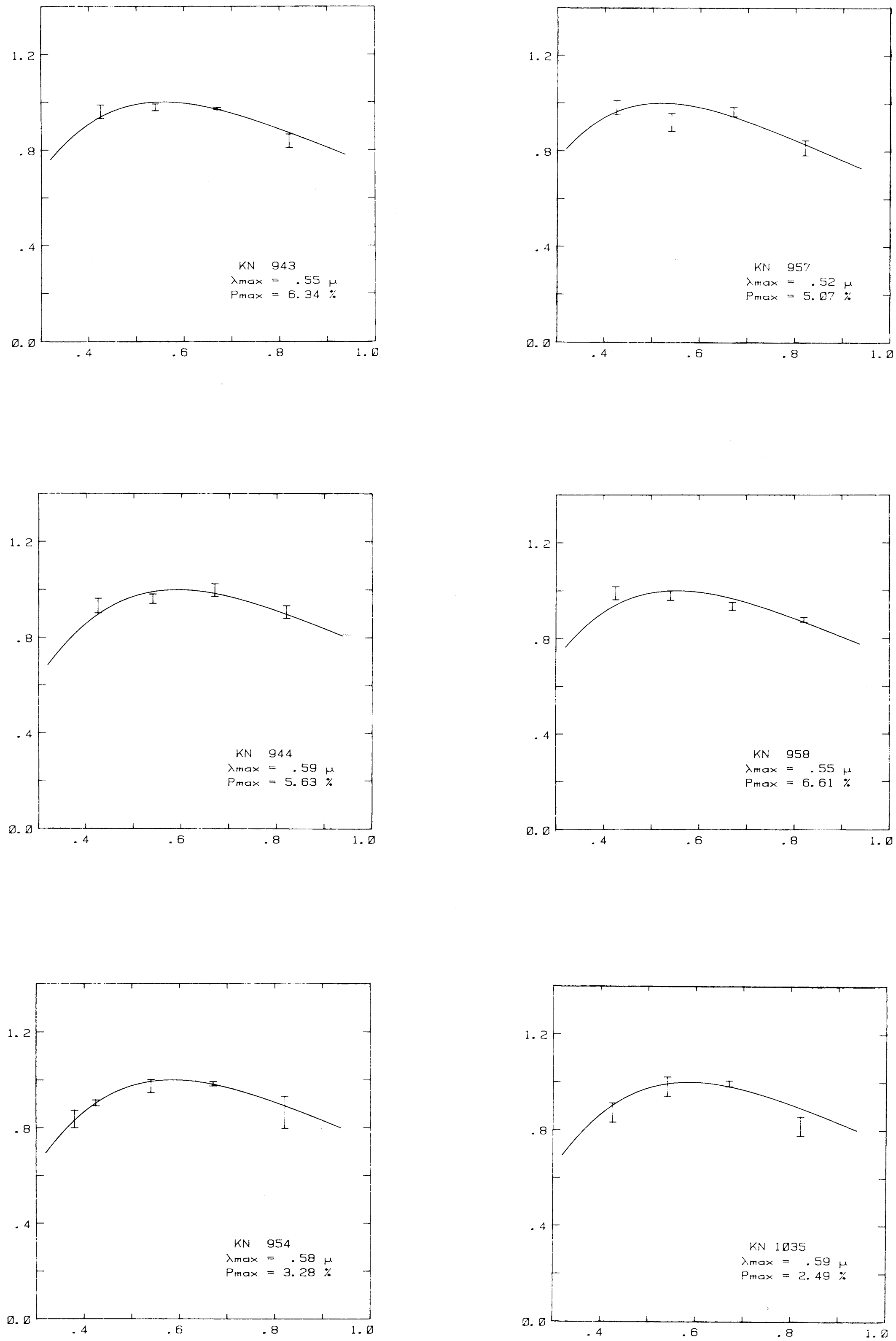

FIG. 2. The normalized wavelength dependence of interstellar linear polarization derived from a least-squares fit with our results, between 0.38 and 0.82 μm. The solid line represents Serkowski's relation, extended by Wilking *et al.* (1980, 1982).

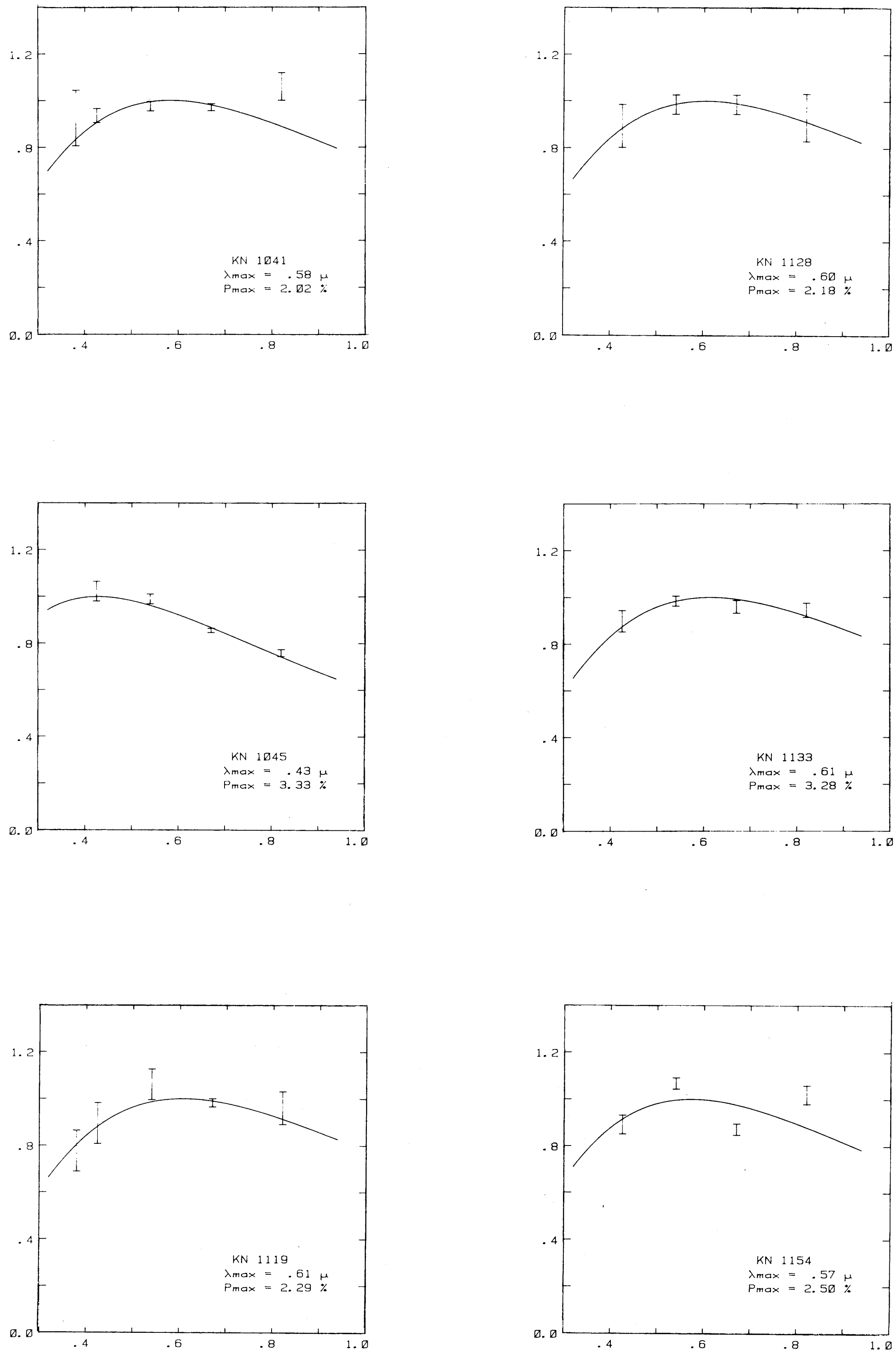

FIG. 2. (continued)

obtained. The mean errors are derived from the fit of the measurements at different spectral regions to the curve described by relation (1). They are shown in the last two columns of Table I.

For each star we have plotted the observed wavelength dependence of the interstellar linear polarization in Fig. 2. The solid lines represent Serkowski's *et al.* (1975) relation as extended by Wilking *et al.* (1980, 1982).

Figure 2 shows that the data fit well to the wavelength dependence of the general interstellar polarization represented by relation (1).

In Fig. 3 we have plotted $P_{\max}$ vs visual extinction A_v (taken from Klare *et al.* 1977). Most stars are close to the linear limit relation of 3% per mag (the line in Fig. 3) empirically found by Hiltner (1956) for the general interstellar medium. Thus our stars show a high average $P_{\max}/A_v$ ratio, which indicates a high efficiency in the polarization mechanism.

Excluding stars 957, 958, 1041, and 1045, because they may be intrinsically polarized, a mean value of $\lambda_{\max}$ equal to $\lambda_{\max} = 0.59 \pm 0.02$ (s.d.) was obtained. Three of our program stars 943, 954, and 957 which were observed in at least three colors by other authors, are shown in Table II. Serkowski's *et al.* (1975) values of $P_{\max}$ and $\lambda_{\max}$ are compared with our own values and a good agreement was found.

$\lambda_{\max}$ is related to the average size of the polarizing dust grains, and should therefore be a measure of R. Applying the empirical relation of Whittet and van Breda (1978) connecting $\lambda_{\max}$ values with the extinction law of the dust cloud, we obtained a normal value for R, equal to

$$R = 3.30 \pm 0.11 \text{ (s.d.)}$$

(excluding four stars mentioned above which possibly have intrinsic polarization).

When position angles of polarization show a wavelength dependence, a change of $\lambda_{\max}$ along the line of sight alongside with variation in the orientation of the dust grains can be suspected (Coyne *et al.* 1974). In other cases, however, the wavelength dependence of position angle is a sign of the presence of intrinsic polarization (Serkowski 1970). Serkowski *et al.* (1975) found that early-type main-sequence stars have, frequently, an extreme value of position angle near the blue spectral region where the intrinsic polarization of the Be stars has its maximum. On the other hand, supergiants usually

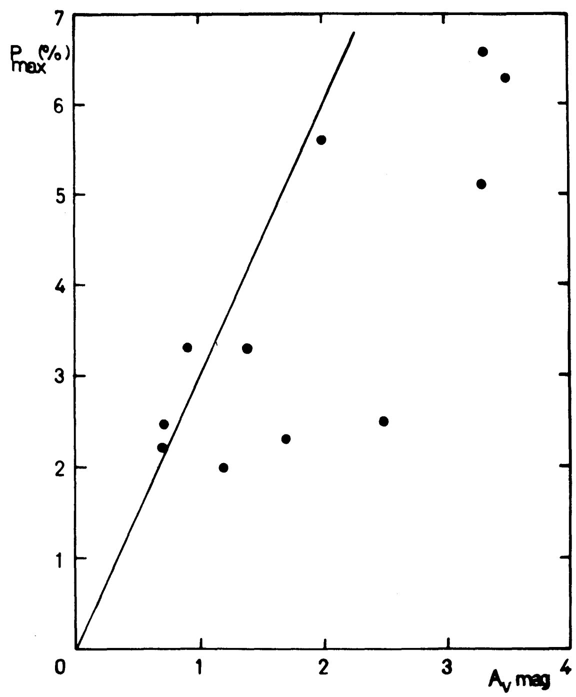

FIG. 3. Correlation of maximum polarization $P_{\max}$ and visual extinction A_v. The solid line referring to the relation $P_{\max}/A_v = 3\%$ per mag corresponds to maximum alignment efficiency and represents the maximum $P_{\max}$ possible by interstellar extinction for a given A_v. (Star 1045 has no A_v value, so it is excluded.)

show monotonic change in position angle. Four stars, 957, 958, 1041, and 1045, which present variation of their position angles have been supposed to have intrinsic polarization. In Fig. 4 we have plotted their position angles. For these stars we indicate in Table III their spectral types taken from Klare *et al.* (1977). It should be pointed out that stars 1041 and 1045 also occupied odd positions in the $\Delta\theta$-vs-P diagram in Fig. 1(b).

An attempt was made to separate the circumstellar from the interstellar component in the observed polarization. It was assumed that circumstellar polarization has a fixed position angle that decreases towards the near infrared. Under these assumptions several trial interstellar polarizations were subtracted from the observed values for these four stars. The procedure was repeated by trial and error until the circumstellar com-

TABLE II. Comparison of our polarization measures with those of Serkowski *et al.* (1975).

HD	KN	SMF(1975) $\lambda_{\max}$	ϵ	$P_{\max}$	ϵ	WM $\lambda_{\max}$	ϵ	$P_{\max}$	ϵ
134959	943	0.52	0.01	6.26	0.33	0.55	0.02	6.34	0.09
136003	954	0.57	0.01	3.28	0.02	0.58	0.01	3.28	0.01
136239	957	0.52	0.02	4.83	0.33	0.52	0.03	5.07	0.16

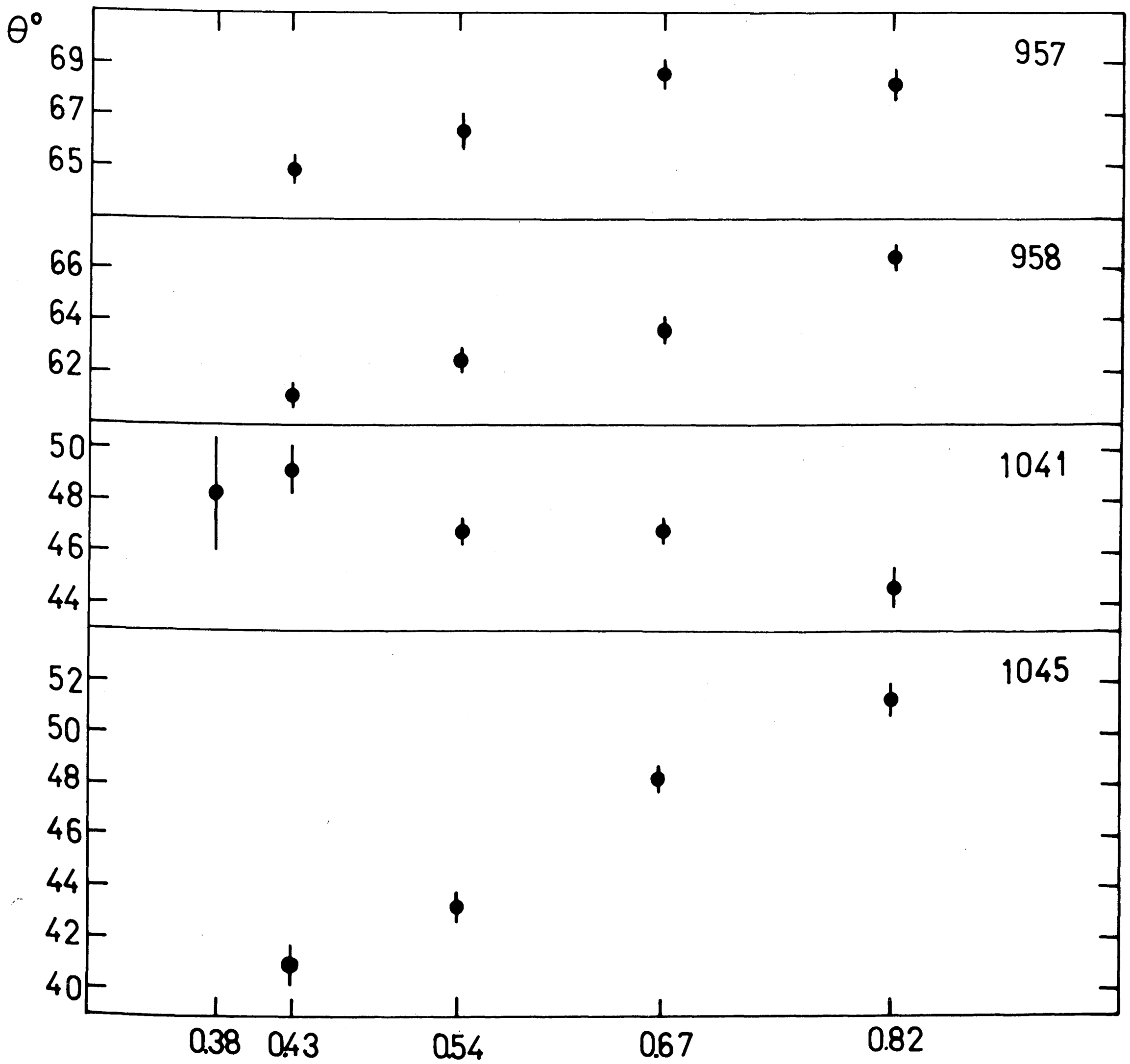

FIG. 4. Position angle vs wavelength for the four stars which probably have intrinsic polarization.

TABLE III. Spectral types of stars with possible intrinsic polarization.

KN	S.T.
957	B2IA + e
958	B5IA
1041	B1IAK

Note to Table III

Star 1045 was not listed because its spectral type is not given by Klare *et al.* (1977).

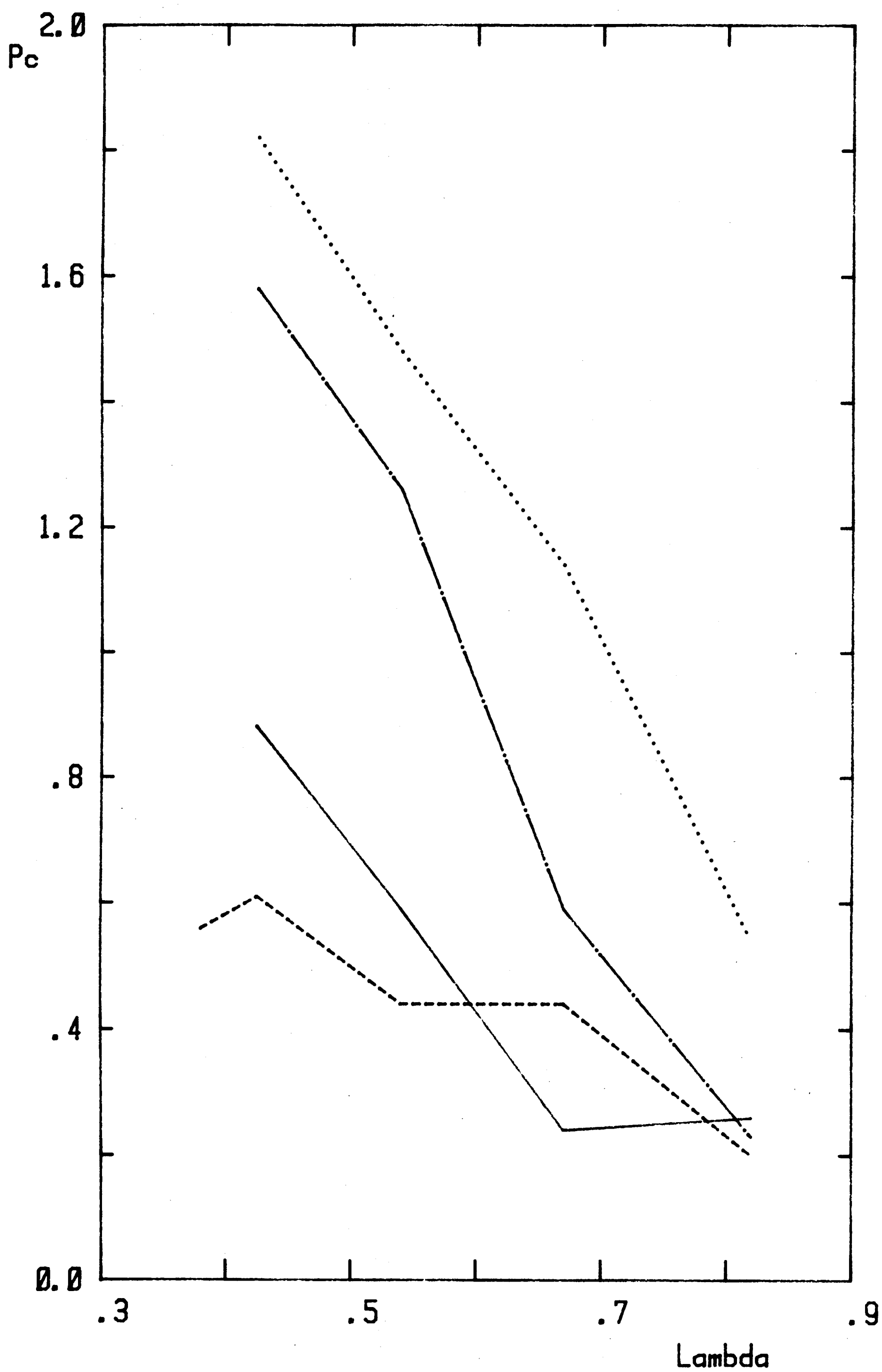

FIG. 5. Circumstellar components of the observed polarization. Solid line refers to star 957, dotted line refers to star 958, dashed refers to star 1041, and dashed-dotted line to star 1045.

TABLE IV. Circumstellar and interstellar components for stars with possible intrinsic polarization.

	957		958		1041		1045	
	P_i	P_c	P_i	P_c	P_i	P_c	P_i	P_c
0.38	—	—	—	—	2.29	0.56	—	—
0.425	4.87	0.88	6.03	1.82	2.34	0.61	2.57	1.58
0.54	4.61	0.59	6.09	1.48	2.31	0.44	2.68	1.26
0.67	4.87	0.24	5.90	1.14	2.30	0.44	2.61	0.59
0.82	4.11	0.26	5.71	0.54	2.30	0.20	2.44	0.23
P.A.	70.0	26.1	69.0	28.3	43.0	114.5	54.0	18.0
λ_{max}	0.53	—	0.59	—	0.55	—	0.59	—
ϵ	0.03	—	0.03	—	0.03	—	0.02	—
P_{max}	5.00	—	6.28	—	2.39	—	2.69	—
ϵ	0.15	—	0.18	—	0.05	—	0.04	—

ponents obtained were parallel within the computed errors. The position angle of the circumstellar polarization was obtained as the average over wavelength of the values obtained. Finally, the observed polarization was decomposed for each star assuming fixed position angles obtained as described above. The results are listed in Table IV. This table also includes the λ_{max} and P_{max} related to the new values of the interstellar polarization obtained in this way. Figure 5 shows the wavelength dependence of the circumstellar polarization. Although these stars are not Be, a similar mechanism, electron scattering, plus dilution by the Balmer and Paschen continua, can be advocated here.

The direction of the magnetic field in the Norma region is nearly parallel to the galactic equator as can be seen in Fig. 6. As most of the observed stars are within 2 Kpc and it is known (Rydgren 1974) that absorption by interstellar matter starts at 0.7 Kpc, the interstellar magnetic field we are measuring is located between these two limits. The high efficiency of the aligning mechanism displayed in Fig. 3 means that this magnetic field is roughly at right angles to the line of sight. This magnetic field is then running along the Sagittarius arm as described by Rydgren (1974).

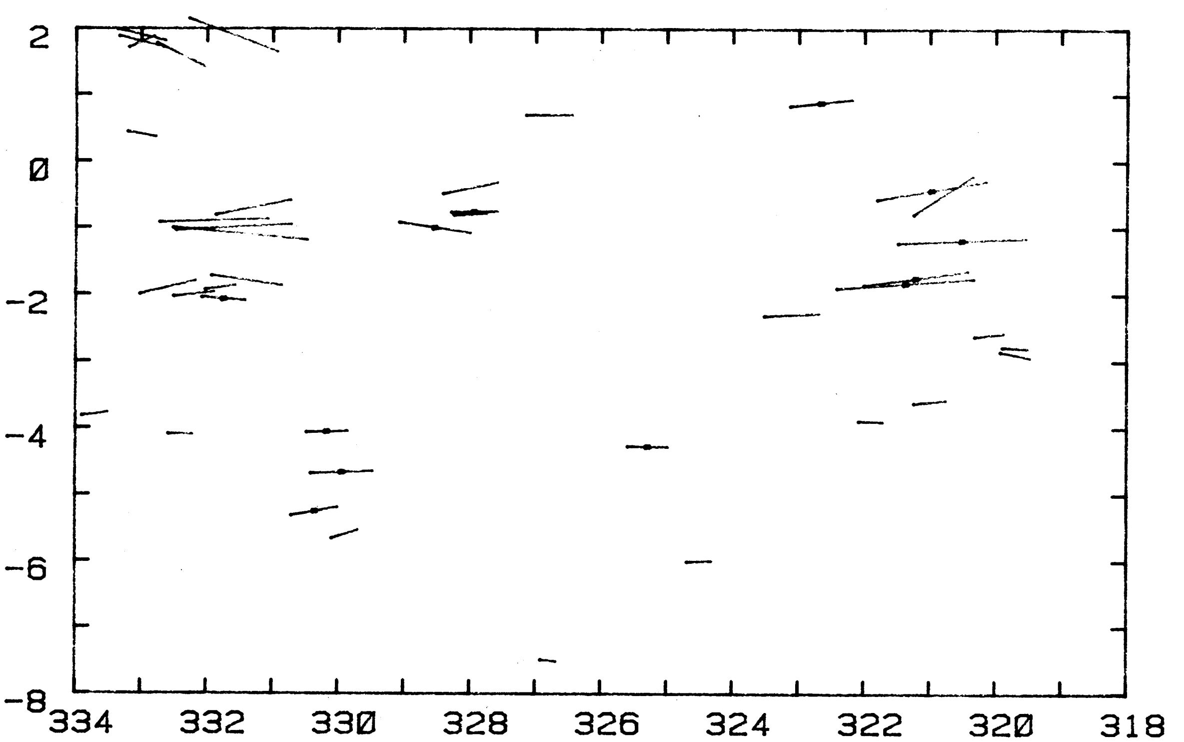

FIG. 6. The map in galactic coordinates shows the orientation of the electric vectors in the Norma region. Vectors with a dot superimposed represent stars from our program, while the other vectors represent stars which are farther than 350 pc lying between 318°⩽l⩽334° selected from the catalog of Axon and Ellis (1976).

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