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POLARIMETRIC OBSERVATIONS OF NGC 5128 (CEN A) AND OTHER EXTRAGALACTIC OBJECTS

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ABSTRACT

Photoelectric observations have been made with a dc polarimeter in an attempt to detect polarization in the light from 15 extragalactic objects. Considerable polarization was found in NGC 3034 (M82) and in NGC 5128 (Cen A). The investigation of M82 has been reported by A. Elvius (1).

In NGC 5128 the light from the dark band crossing over the object turned out to be partially polarized, up to 6%, with the strongest electric vector roughly parallel to the dark band. Of the two inner "hot spots" observed by the radio astronomers (2, 3, 4) the northeast one is known to be strongly polarized in radio wavelengths (5, 6). Our optical observations in this region reveal small polarization with the position angle (θ) of the electric vector definitely different from that of the radio data. We find optically $\theta=70°\pm8°$, whereas a position angle $\theta=147°$ was predicted by the radio astronomers after allowance had been made for the Faraday rotation influencing the radio observations (7, 8). Spectra and photographic colors were obtained for many stars surrounding NGC 5128 and measures of the polarization of nine selected objects were obtained. When our data are corrected for the foreground polarization indicated by the data for these field stars, it seems improbable that any intrinsic, optical polarization has been detected in the northeast "hot spot" of NGC 5128.

The light from the Andromeda galaxy M31 (NGC 224) and four other galaxies in the same region of the sky was found to be slightly polarized. This polarization, however, is most probably due to interstellar polarization in the Milky Way. The absorbing matter in our Galaxy seems to introduce a polarization $\Delta m_P=0.^m018$ ($\pm0.^m003$) and $\theta=90°$ ($\pm10°$) in the general direction of M31. This would correspond to a total visual absorption $A_V\geq0.3$ magnitude and a reddening $E_{B-V}\geq0.1$ magnitude.

Other extragalactic objects included in the program have the following NGC numbers: 185, 205, 221, 253, 891, 2841, 3031, 3077, 4258, 4565, 4631, 5195, 7331. The polarization effects recorded in the light from these galaxies usually did not exceed the uncertainty in the observations by a significant amount. The conclusion to be drawn for these objects is that polarization is either small or absent in the observed areas.

Observations

A search for polarization in the light from extragalactic objects was started in the fall of 1961. The first few observations were made with the 24-inch Ronnie Morgan Reflector at the Lowell Observatory. Observations made in the spring of 1962 and of 1963 were carried on entirely with the 69-inch Perkins Reflector of Ohio Wesleyan University and the Ohio State University at the Lowell Observatory. This telescope, located 10 miles SE of Flagstaff, was advantageous, not only because of its large aperture, but also because of the dark sky background which is so essential for observations of faint extended sources.

Through the kindness of Dr. Haro it was possible to continue the study of NGC 5128 with the 40-inch reflector at Tonantzintla in March, 1964. Here the air mass for this southern object (Decl = $-42°\ 45'$), when on the meridian, is 2.1 as compared to a value of 4.8 at Flagstaff. Although the sky background was somewhat higher than at Flagstaff, the Tonantzintla data not only confirmed the Flagstaff results, but also included much needed observations of distant galactic stars in the general direction of NGC 5128.

All observations were made with a photoelectric photometer used with a direct current amplifier and Brown recorder. The 1P21 photomultiplier, used in the interval 1961-1963, was always cooled with dry ice. The Tonantzintla observations were made with an EMI 6256S which operates very satisfactorily at room temperature. In most polarization measurements the analyzer, consisting of a polaroid disk, was rotated manually to different positions. For a given region sequences of settings were usually made at

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position angles 0°, 90°, 0°, 45°, 135°, 45°. Further details of the equipment including the color response of the photometric system are given in reference (1).

The polarization of the sky background was measured near the object being studied, and the observations of the object were always corrected with these measures. In many cases both the light intensity and the degree of polarization of the sky background exceeded the corresponding values for the object alone.

An offset guider, mounted between the telescope and the polarimeter, was used to set the telescope with high precision at any desired region of the object relative to the position of a guide star or the nucleus of the galaxy under observation.

Most observations with the Perkins telescope (scale $6\overset{\prime\prime}{.}6$/mm) were obtained with a circular aperture, 6 mm or 4 mm in diameter. For observations with the Morgan telescope (scale 22″/mm) a circular hole 2 mm in diameter was often used. In some cases elongated and especially-oriented apertures were used in an effort to measure the polarization of elongated objects.

A depolarizer was mounted between the cathode of the photomultiplier and the analyzer in order to avoid spurious polarization. A second depolarizer was occasionally placed directly in front of the analyzer to measure possible instrumental polarization. A cylindrical lens, mounted immediately in front of the Fabry lens, was used to produce an elliptically-shaped image (5 x 8 mm) on the cathode of the 1P21 photomultiplier.

Standard stars of known polarization were measured for calibration of position angles. Other stars, known to be unpolarized or very slightly polarized, were observed in an attempt to discover possible instrumental polarization.

Table I gives a summary of different investigations of instrumental polarization. Because of changes in the optical system the instrumental effects were studied separately for each year. All results in Table IIA, except those obtained with the Morgan telescope, and the main part of the results in Table IIB were obtained during 1962.

It was found that no systematic instrumental effect can be detected in the polarization measures made during 1962. The mean error in one polarization measure for the objects studied in 1962 and given in Table I was found to be 0.3 per cent ($\Delta m_p = 0\overset{m}{.}007$).

In the observations made during April and May 1963 the random errors seem to be higher than before, because of an instrumental effect which appeared when a new offset guider was first introduced. These observations seem to contain a systematic error of the order of 0.5 per cent polarization in position angle $\theta = 75°$. We have applied a correction for this effect. The only objects observed during this period are NGC 4258, 4631, and 5128.

A number of observations were made at Tonantzintla in an effort to detect possible systematic errors. These were found to be comparable to those shown in Table I for the 1962 observations.

TABLE I. Investigations of Systematic Effects.
PERKINS TELESCOPE

Type of object	Aperture	No. Obs	Polarization P (%)	Polarization θ_E
1962 Observations				
Unpol. star	27″	2	0.08	3°
Unpol. star	40	2	0.11	81
	Mean		0.03	—
Star + depol.	27	3	0.18	168
Star + depol.	40	4	0.08	122
	Mean		0.09	155
Gal. + depol.	27 or 40	2	0.17	101
All Obs. with depol.		9	0.07	—
April and May 1963 Observations				
Laboratory tests + obs. at telescope	Var.	6	0.5%	75°

During 1962-63 extensive polarization and color measurements have also been made with the same equipment in the Merope nebula and other nebulosities within the Pleiades cluster. These observations will be described in a separate paper.

Results of the Polarization Measurements

Table IIA. The galaxies listed in Table IIA are all fairly close together in the sky. NGC 205, 221 (M32), 224 (M31) form a multiple system and the nuclei of these galaxies are seen within an area of one square degree. The systems NGC 205 and 221 are elliptical galaxies and there is little reason to expect them to be polarized because of light absorption or scattering within the systems themselves. We used them as test objects. They were both found to show a polarization of 0.8 per cent with the electric vector in position angle 80°±5° and 84°±5° respectively. This indicates that the observed polarization is most probably due to the polarizing action of interstellar matter in our own Galaxy. The nucleus of NGC 224 (M31) was found to be polarized by 0.8±0.1 per cent in position angle 95°±6°. This polarization is close enough to that found in the other two galaxies to be explained in the same way. This is also true for several other regions measured in M31.

The results contained in Table IIA provide independent checks on the negligibly small instrumental polarization indicated by the data in Table I. Some regions of M31 have been measured both with the 69-inch telescope and with the 24-inch telescope. Most observations were made with the polarimeter mounted in position angle 0° and some in position angle 90°. No systematic differences have been found between these different series of observations.

According to an investigation by Hiltner (9) the ratio of polarization (expressed in magnitudes) to total visual absorption is less than or equal to 0.06. The polarization found for the M31 group is equivalent to $\Delta m_p = 0\overset{m}{.}018 \pm 0\overset{m}{.}003$. This would indicate a total visual absorption in the same region of $A_V \geq 0\overset{m}{.}3 \pm 0\overset{m}{.}05$. This would also correspond to a reddening of light from M31 with $E_{B-V} \geq 0\overset{m}{.}1$.

A possible galactic absorption and reddening of the light from M31 has often been neglected in photometric investigations and distance determinations. Th. Schmidt (10) tentatively used the value $A_{pg}=0^m.2$ (corresponding to $A_V=0^m.15$) in deriving a distance modulus for M31 of $m-M=24.4$. With a higher correction for interstellar galactic absorption we would now get from his data $m-M\leq 24.3$. More recently Sandage (11) has published more accurate results based on a very careful study of cepheid variables in M31 which was carried out by Henrietta Swope. Her investigation (12) gives a true distance modulus of $m-M=24^m.20\pm0^m.14$ and a color excess of $E_{B-V}=0^m.16\pm0^m.03$.

An independent indication that there may be some interstellar reddening in the direction of M31 may be found in the results derived by Kron and Mayall (13) in their investigation of the colors of globular clusters. They found the M31 clusters to be about 0.2 magnitudes redder than the clusters of our galaxy. Their conclusion that the color difference is probably due to an intrinsic color difference between clusters belonging to the two galaxies cannot be ruled out. It now seems probable, however, that at least part of the color difference is due to interstellar reddening.

TABLE IIA. Polarization Data for Five Galaxies in the Region $0^h < \alpha < 3^h$ and $+40° < \delta < +50°$

Designation				Br. Region	Polarization		
NGC	Region	No. Obs.	Aperture	Sky	P%	θ_E	Rem.
185	Nucleus	1	40″	2.3	2:	97°	
205	Nucleus	2	27,40	5.3	0.8	80	
221	Nucleus	2	27,40	50	0.8	84	M32
224	Nucleus	2*	44	40	1.0	95	M31
"	Nucleus	1	40	82	0.7	94	
"	Nucleus	3		Mean	0.8	95	
"	1	2	27	11	0.7	93	
"	2	2	27	22	0.7	90	
"	3	5*	44	20	0.6	74	
"	4	1*	44	10	0.5:	65:	
"	4	2	27,40	8	1.2:	71:	
"	4	3	Weighted	mean	0.9	69	
"	5	1*	44	2.0	1.9:	155	
"	5e	1*	66x132	1.9	2.0:	118	
"	6	4	{40, 20x40}	1.0	1.8	85	Mean
"	7	2*	44	5	1.5:	60:	
"	7	1	40	4	0.5	50	
"	7	3	Weighted	mean	0.8	55	
891	Nucleus	3	27	0.7	1.2:	133:	
"	Nucleus	1	13x53	0.4	3.8:	82:	
"	1	1	13x53	1.1	≤1.0:	—	
"	2	1	13x53	1.3	≤1.5:	87:	
"	Mean (used in Figure 1)				1.0	110°	

*Morgan Telescope observations 1961.

θ_E is the position angle of the electric vector with reference to equatorial coordinates. For simplicity this is referred to as θ in the text.

: Low weight.

For 891 an elongated aperture parallel to the dark lane was used. Relative to the center of 891, region 1 was 7″ S and 7″ E and region 2 was 7″ N and 13″ W.

Figure 1 is a map of the region around the galaxies listed in Table IIA. Polarization vectors have been drawn on this map to show the polarization of the galaxies and surrounding field stars. The data for the stars were taken from catalogues by Behr (14), Hall (15), and Lodén (16). The polarization of the light from the galaxies is seen to be quite similar to that of stars in the same region of the sky. When making such a comparison we must remember that most of the stars observed in this area are apparently bright and, therefore, nearby objects. The degree of polarization cannot be expected to be high for such stars. The position angles of the electric vector are more significant, however, provided it can be assumed that the dust particles in the polarizing clouds are oriented in approximately the same way over large distances. In the polarimetric investigation of the Kapteyn Selected Area 20 by Lodén (16) no systematic change of position angle with distance or with degree of polarization was found.

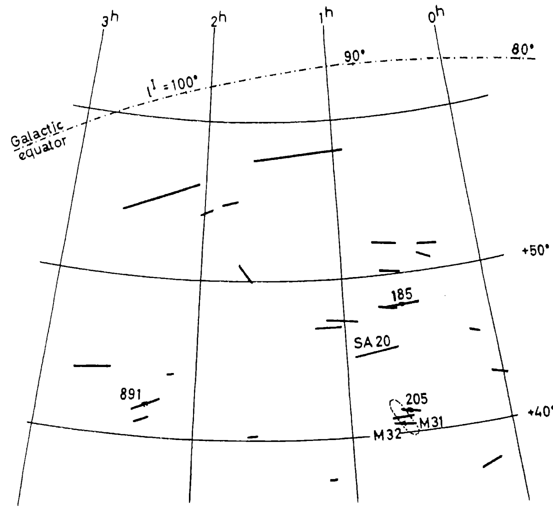

Figure 1. Polarization found for NGC 185, 205, 221, 224, and 891 and for stars in the same area of the sky. It is apparent that most of the polarization found for the galaxies may be produced by the interstellar medium associated with the Milky Way.

The polarization measurements in the Andromeda galaxy M31 are exhibited in some detail in Figure 2.

In some regions of M31 there may be a significant amount of polarization caused by particles in the clouds of the galaxy itself. Thus in region 7 in the dark lane we find the polarization vector roughly parallel to the lane (especially if correction is made for the general polarization mentioned above). There we might have an effect caused by the selective ab-

Figure 2. Some evidence of intrinsic polarization in M31 (NGC 224) is apparent for regions 5, 6 and 7. Photograph—Stockholm Observatory. (Details for data presented here and in Figures 3 and 4 are given in Tables IIA and IIB.)

sorption of light in clouds of elongated particles in M31 oriented in a magnetic field parallel to the spiral arms. This would agree with results obtained by Hiltner (17). The same is true for region 5 which contains the globular cluster No. 93 on Hiltner's list.

Table IIB. In our survey of polarization in the light from extragalactic objects we find that most galaxies show little or no polarization. These negative results may, however, be of some value in the discussion of general polarization effects and may also help future observers to choose more promising objects for their polarization measurements. The data can often provide information on the total galactic polarization in the direction of these objects. Therefore, our results for the observed regions have been listed in detail in Table IIB. In some cases the measured polarization was of the order of 2 or 3 per cent and these regions might be of some interest for further study.

The mean error of a single observation is estimated to be of the order of 0.5 to 1.0 per cent polarization, depending on the brightness of the region (compared to the sky) and possible disturbances due to the strong intensity gradients sometimes encountered. The degree of polarization in the night sky is also an important factor. When the observed region is fainter than the sky background, the result is very sensitive to possible errors in the measured sky polarization. Depending upon a number of factors, this was anywhere from 0 to 10 per cent. Observations of faint, extended objects made when the thin crescent of the moon was visible proved to be valueless and were always rejected.

The observed regions have been marked with numbers as shown in Figures 3 and 4 where, when detected, the polarization is indicated. The same numbers appear in the second column of Table IIB. The number of observations of each region is given in the third column. The brightness of the region is roughly indicated by the ratio of region brightness to sky brightness given in the fifth column.

The objects included in our survey are of different types and were chosen for different reasons. NGC 7331 is a spiral which was earlier studied photographically by A. Elvius (18) who found that significant polarization was indicated in some small regions near the center. The photoelectric measurements reported in the present paper do not include the same regions, however, because of their steep intensity gradients. NGC 2841 and 3031 are Sb spirals

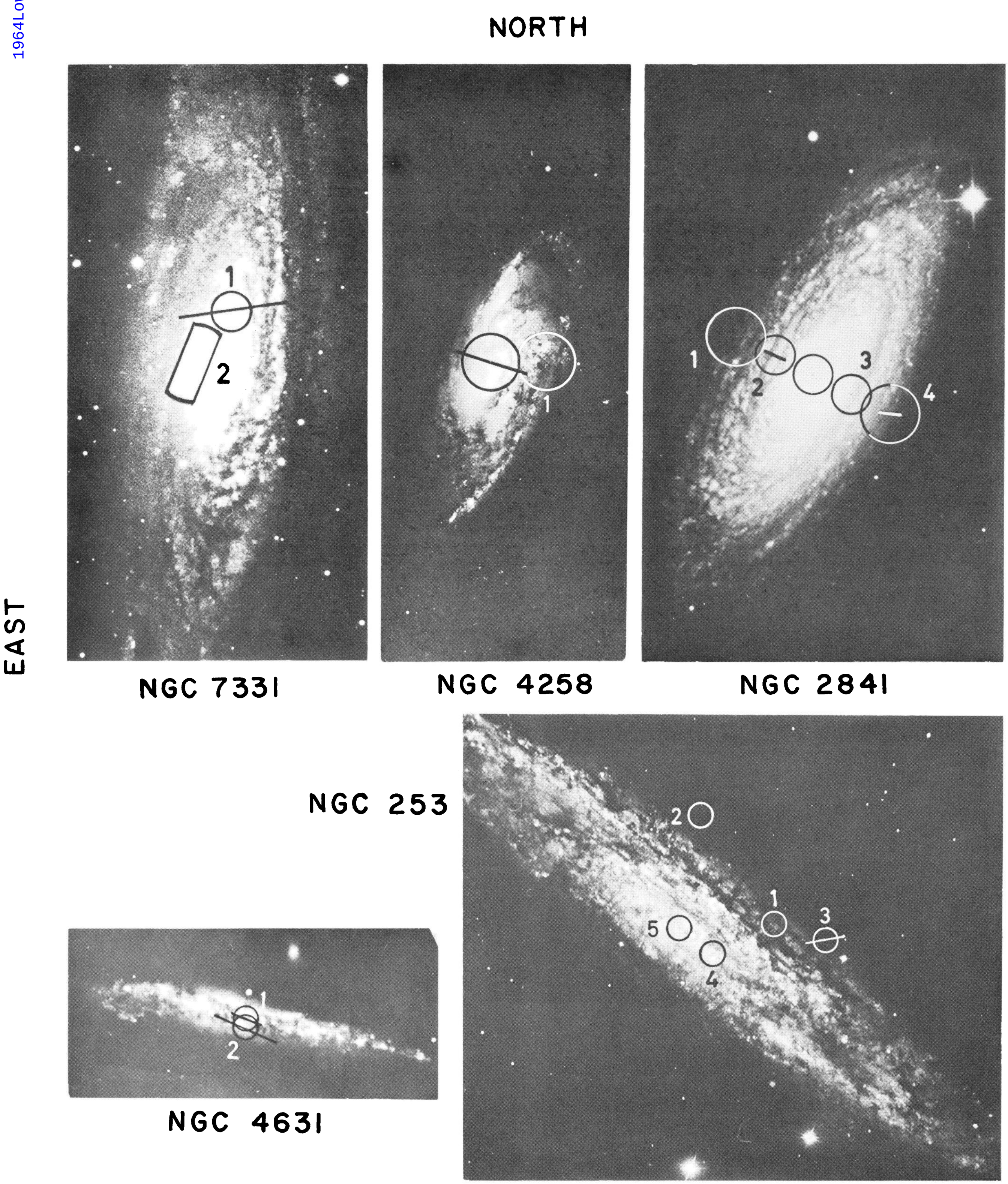

Figure 3. The observations of none of these galaxies show strong evidence of intrinsic polarization. Photographs of NGC 7331, 4258, 2841 and 253 were reproduced from *The Hubble Atlas of Galaxies,* (A. Sandage), and NGC 4631 is copied from a paper by G. and A. de Vaucouleurs (Ap. J., *137,* 363, 1963).

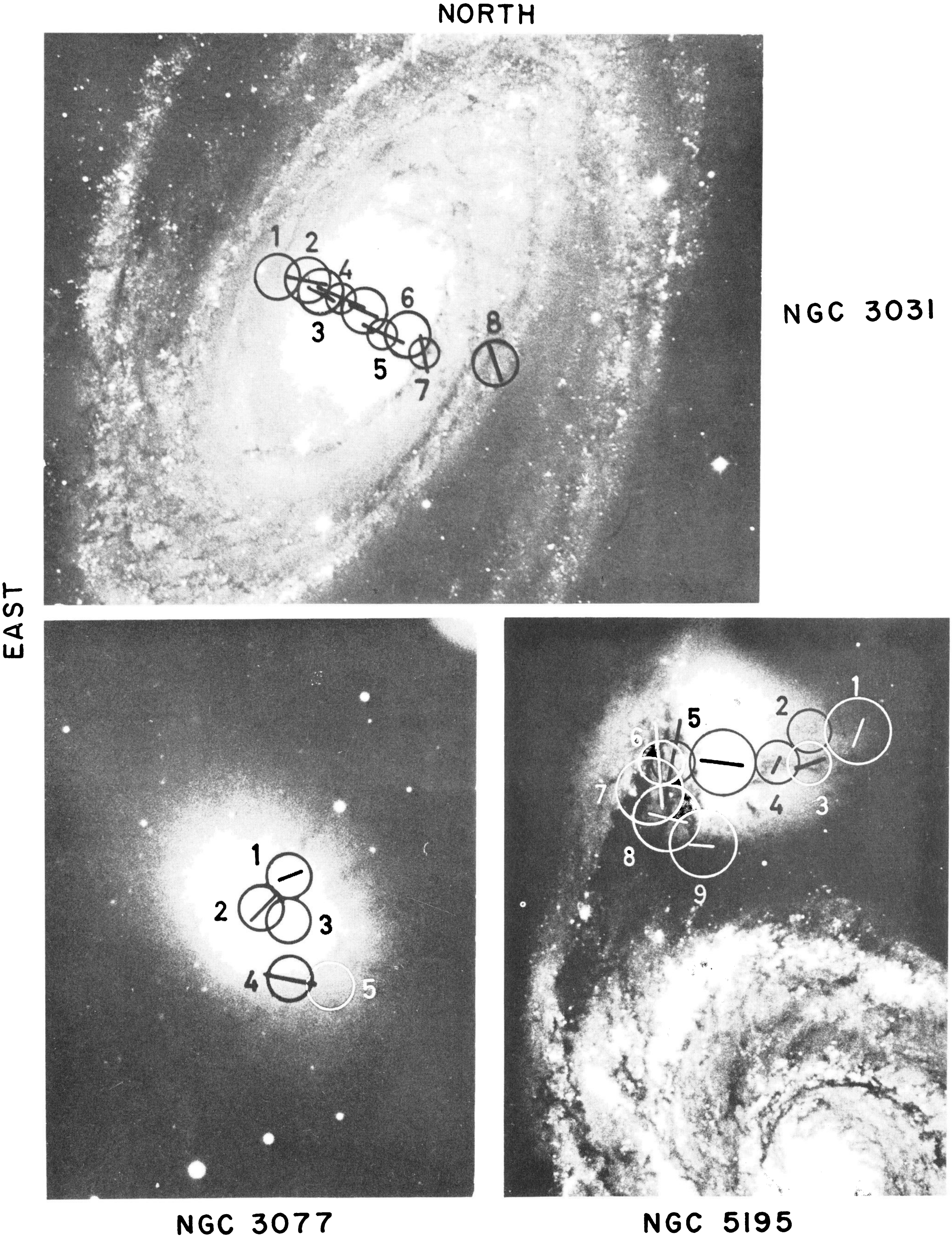

Figure 4. It is probable that intrinsic polarization is present at the nucleus of NGC 5195 and within the dark lane east of this nucleus. These regions also correspond to areas of obscuration referred to by Sandage in the Hubble Atlas and by S. Sharpless and O. G. Franz (P.A.S.P. *75,* 222, 1963). E. Holmberg (Medd. Lund, Sr. 11, Nr. 136) found a color index for 5195 of $+0^{m}\!.98$ on the international system. Photographs—Hubble Atlas.

TABLE IIB. Polarization Measures of Other Galaxies

Designation NGC	Region	No. Obs.	Aperture	Brightness Region/sky	Polarization P%	θE
253	1	1	40″	1.8(?)	0.3	—
”	2	1	40	0.7	0.9	116°
”	3	1	40	0.3	2.2	101
”	4	1	40	1.7	<2	—
”	5	1	40	3.1	<1	—
2841	Nucleus	2	27	14	0.2	—
”	1	1	40	0.2	<2	—
”	2	2	27	2.2	0.6	67
”	3	1	27	2.0	0.2	—
”	4	1	40	1.6	0.5	83
3031	Nucleus	4	40	32	0.5	65
”	Nucleus	1	27	48	0.4	64
”	1	1	40	2.1	<1	—
”	2	2	40	3.5	0.7	78
”	3	1	40	34(?)	0.6	60:
”	4	1	27	12	0.8	66
”	5	1	27	10	0.7	66
”	6	1	40	6.8	<0.5	—
”	7	2	27	2.3	0.6	13
”	8	1	40	1.0	<2	20:
3077	1	1	27	1.4	0.4	109:
”	2	1	27	3.9	0.5	136:
”	3	1	27	7.9	<0.1	—
”	4	1	27	1.9	0.6	79
”	5	1	27	1.2	0.5	—
4258	Nucleus	2	40	4.7	1.0	73
”	1	1	40	1.5	1	—
4565	Nucleus	1	27	6.4	0.8	169
”	1	1	27	1.5	1	—
4631	1	1	40	2.0	1.2	73
”	2	1	40	1.2	3.3	70
5195	Nucleus	1	40	5.9	1.2	82
”	Nucleus	1	27	10	0.7	86
”	1	2	40	0.5	0.7	159
”	2	2	27	0.9	0.2	—
”	3	1	27	0.9	1	109
”	3	1	40	1.1	0.6	44
”	4	2	27	1.1	0.5	151
”	4	1	40	2.0	1.9	54
”	5	1	27	0.8	2.4	169
”	6	1	27	0.8	2.4	6
”	7	3	40	0.8	0.3	—
”	8	2	40	0.6	1	84
”	9	1	40	0.8	0.6	87
7331	1	1	27	2.3	2	98°
”	2	1	20x54 PA 160°	1.5	<2	—

where polarization effects similar to those found in 7331 could possibly be expected. No strong effects have been found. NGC 4565 is a spiral seen edge on. Polarization due to absorption in the dark lane or to scattering at the bright edges could be expected. The two effects may annul one another and no convincing results were obtained in our two measures. NGC 4258 was included because of its somewhat peculiar character. No definite polarization was found, but the nucleus may be slightly polarized.

The remaining objects NGC 253, 3077, 4631, and 5195 were chosen because they show some similarity to the galaxy M82 (NGC 3034) where strong polarization has been reported (1). No similar polarization effects were found. NGC 5195 was studied on several nights and a polarization of about one per cent in the nuclear region might be real and due to absorption in a dark band crossing over the nucleus in an east-west direction. A faint region 30 seconds of arc east of the nucleus may also show significant polarization.

Preliminary observations (with new equipment) of NGC 2685 indicate the presence of a few per cent of polarization in the northeast part of the object with the electric vector roughly parallel to the dark bands seen projected against the bright background of this interesting galaxy.

It may not be necessary to point out that the regions studied by us do not cover the whole objects. It is still possible that interesting effects could be found in other parts of these same galaxies. Because of the brightness and polarization of the night sky, the measures were usually very time consuming, and it was considered best to make a survey rather than to study only one object in considerable detail.

The Peculiar Galaxy NGC 5128 (Cen A)

NGC 5128 is one of the most interesting and puzzling objects in the entire sky. It has been suggested that it consists of a spiral and an elliptical galaxy in collision (19). More recently another model has been suggested (20) in which the elliptical galaxy is surrounded by a broad band of dust and gas, which is rotating at an unexpectedly high speed and also falling inwards. Furthermore, the galaxy is located within a strong radio source, Centaurus A. Recent observations by Bracewell, Cooper and Cousins (5) with the 210-ft. telescope of the Australian National Radio Astronomy Observatory have revealed the existence of linearly polarized radiation from this source. The polarization was also detected independently by Mayer, McCullough, and Sloanaker (6). These data strongly suggest that synchrotron radiation of high intensity in the radio region is emitted from Cen A.

In spite of its very low declination (−43°) we found it desirable to include this object in our survey. As is seen in Table III we found polarization of light in several regions. At the 69-inch it was found that under the best sky conditions reliable results could be obtained only when the object was within 1¼ hours of the meridian. The consistency of the data proved to be surprisingly good even though the light traversed 5 atmospheres. However, these restrictions limited us to relatively few hours of observation during a single observing season.

The strongest polarization was found in the dark lane crossing over the bright parts of the nebula. We note that in Figure 5 the electric vectors of the polarized light are roughly parallel to the dark band. Elsewhere there was a strong tendency for the electric vectors to lie in a position angle of between 70° and 90°. It was, therefore, suspected that all observations of NGC 5128 were strongly affected by galactic polarization—even though this object is 19° from the galactic plane. Further observations, which included distant stars in this part of the sky, were highly desirable.

Through the kindness of Dr. Roslund several photographic plates in different colors, together with objective prism spectra, were obtained in Australia with Sweden's Schmidt Telescope and made available to the authors. Nine stars, which are probably between 0.1 and 2 kpc from the sun, were selected for observation.

TABLE III. Polarization Measures in NGC 5128

Ang. Dist. from Offset Star		No. of Obs.	Br. Reg. Sky	Polarization		Year of Obs.	Remarks
				P%	θ_E		
E	N						
+160″	+ 27″	3	0.2	2.1	177°	1964	Star
+110	− 46	1	0.3	3.8	80	63	Star
+ 77	+ 24	2	0.3	0.9:	140:	64	Star
+ 77	+ 24	1	0.7	0.0	—	62	Star
+ 53	+ 53	3	0.4	3.6	101	64	Star
+ 43	+ 51	1	0.4	5.3	91	62	
+ 43	+ 51	1	0.9	1.4	123	63	
+ 43	+ 66	2	0.4	2.7	85	64	
+ 18	+ 67	1	0.5	6	99	62	27″Ap.
+ 17	+ 66	1	0.6	3.3	117	64	
+ 7	+ 80	2	0.8	2.6	119	64	
+ 7	+ 81	1	0.8	4.0	113	62	
+ 4	+ 82	2	0.9	3.8	112	62	
+ 4	+ 82	1	0.7	4.6	107	63	
0	+ 78	1	0.6	2.4	105	62	27″Ap.
0	+ 78	1	0.6	6.3	104	63	
0	+ 80	1	0.6	5.7	104	63	
− 9	+ 61	1	0.9	3.5	105	62	
− 9	+ 61	1	1.3	1.6	107	63	
− 42	+115	1	1.3	1.3	114	63	
− 71	+115	1	0.5	1.7	39	62	
−101	+127	1	0.4	4.3	80	63	
− 62	+129	1	0.3	1.2	71	64	Star
−102	+146	2	0.6	2.0	52	64	
− 56	+ 27	1	1.2	0.6:	46:	62	27″Ap.
− 65	+ 21	1	1.2	0.6	84	62	
− 70	+ 28	2	1.5	0.9	69	64	27″Ap.
−106	+ 27	1	0.5	0.6:	33:	64	
−106	+ 27	1	0.5	2.0	105	63	
−130	+108	1	0.5	0.9:	60:	64	
−131	+109	1	0.6	2.1	64	62	
+110	+ 91	1	0.6	2.7	74	63	Star
+ 20	+135	1	1.6	1.5	75	62	Star
+ 20	+135	1	1.7	1.4	82	63	Star
− 6	+135	1	1.5	1.0	95	62	
− 6	+135	1	0.8:	0.6	92	63	
− 9	+132	1	1.4	1.0	95	62	27″Ap.
+106	+155	6	0.7	1.4	65	64	Radio
+107	+156	1	0.5	2.0	93	63	Radio
+100″	+185″	1	0.4	3.2	72°	1963	Radio

Note. Unless otherwise indicated, all apertures were 40″ in diameter. Whenever a foreground star may have influenced the observation the word "star" is included under remarks. The 1963 polarization data reported here have been corrected for an instrumental effect of 0.5% polarization at position angle $\theta=75°$. The 1962 and 1963 observations were obtained with the Perkins 69-inch telescope and the 1964 observations with the Tonantzintla 40-inch telescope. No corrections for galactic polarization have been applied.

In order to observe them and to make further observations of 5128 under favorable conditions it was apparent that a telescope situated at a more southerly latitude should be used. At the kind invitation of Dr. Haro, we were given an opportunity to use the excellent 40-inch reflector at Tonantzintla. In March 1964 observations were obtained on half a dozen nights.

The polarization found for the foreground stars, together with other pertinent data, are shown in Table IV. (cf. page 134). The spectral types were determined in Uppsala from Roslund's spectral plates. His spectral and photometric plates were used together with photoelectric measures with color filters, made at Tonantzintla, to derive the visual magnitudes and colors shown in Table IV.

The electric vectors found for the polarization observations are plotted in Figure 6. A well-observed star, about 1 kpc from the sun and only half a degree from NGC 5128, showed a polarization of $\theta=72°$, and $p=0.8\%$. Other stars at the same average distance showed less polarization but indicate the presence of a general polarization with a position angle close to 70°.

In our study we made a special attempt to measure polarization of light in the northeast part of 5128. In order to avoid the inclusion of many stars (within our own galaxy) we naturally had to choose a much smaller aperture than would correspond to the beam used by the radio astronomers. The spot selected within the limits of the polarized radio source, (106″E, 155″N), turned out to be polarized also in the optical region. The degree of polarization was small and the position angle of the strongest electric vector was not the one predicted by the radio astronomers. We found $\theta=70°$ and $p=1.4\%$; θ is far from the 147° predicted by the radio data. If real, this is an indication that the optical polarization is due to some mechanism other than synchrotron radiation or that the position angle of the polarization vectors changes considerably over small angular distances. The last mentioned possibility seems less plausible because it makes it difficult to explain the rather high degree of polarization observed in the radio wavelengths where a large area is included in the measurements.

The observations of the stars in the vicinity of 5128 strongly suggest a polarization of at least 0.8% at $\theta=70°$. We consider it quite possible that the total galactic polarization could be as high as 1.4% in this direction. Transmitted starlight in the Milky Way near the same galactic longitude, as found by E. v.P. Smith (21), is polarized with electric vectors within the range 70°−95°.

In Figure 5 we have plotted the observed data without any correction for the effect of galactic polarization. If we assume that this amounts to 1.4%

at $\theta=70°$, and correct the vectors accordingly, we find (cf. Figure 7) that the only significant polarization is in the dark lane. A comparison of Figures 5 and 7 also shows that the vectors are more nearly parallel to the dark lane after the correction for galactic polarization has been applied.

In their spectral investigation of NGC 5128 E. M. Burbidge and G. R. Burbidge (22) found a strong blue continuum in a bright spot at the northern edge of the dark lane. They suggested that the light emitted there might be synchrotron radiation. We have measured this bright spot but found very little, if any, polarization.

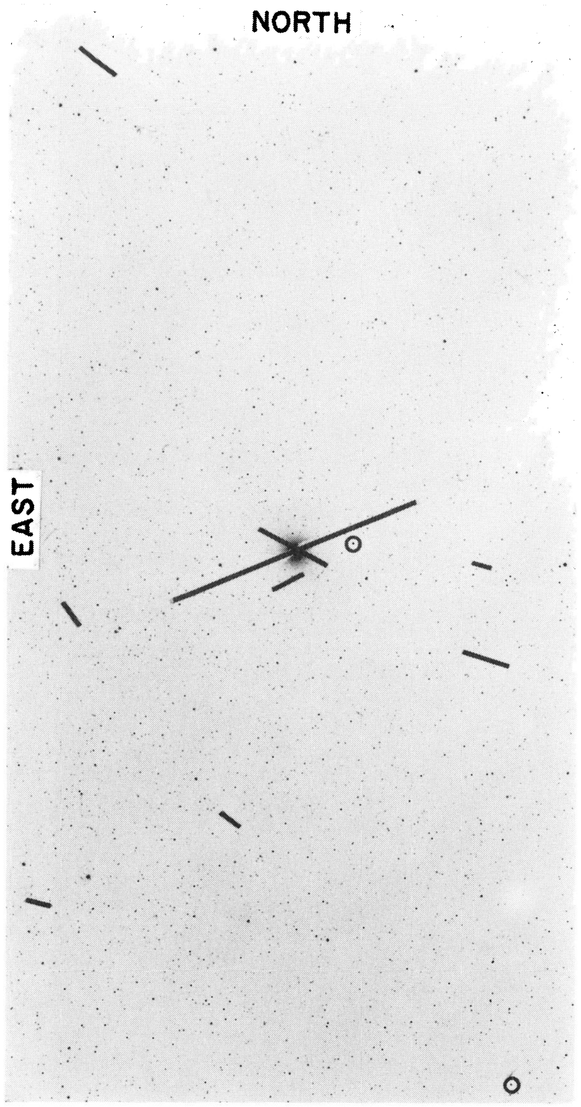

Figure 6. Polarization found for distant stars near NGC 5128. When the weights of our observations and the distances of the stars (cf. Table IV) are considered, it appears probable that the polarization produced in our galaxy in the direction of 5128 is oriented in the same way as the vector which is situated just northeast of the center of 5128. The vector shown in the dark lane represents 4.5% polarization, and the angular scale of the photograph is such that this vector extends over $0\overset{\circ}{.}6$. Photograph—Tonantzintla.

The polarization in the dark band might be explained in two entirely different ways. It may be due either to interstellar absorption in the dark clouds or to the emission of optical synchrotron radiation.

If the polarization observed in the dark band is due to optical synchrotron radiation, the magnetic field in which the electrons are spinning must be roughly perpendicular to the dark band. This would probably be a field joining the radio sources. We would not expect to find optical polarization connected with this field in the brighter parts of the object because of the strong unpolarized stellar radiation dominating there.

J. L. Sérsic (23) has secured photographic observations of 5128 in different colors. He estimated the absorption in the dark band to average $2\overset{m}{.}4$ in blue light and $1\overset{m}{.}8$ in the visual region, with a color excess $B-V=0\overset{m}{.}6$. The maximum absorption in visual light was estimated to be about $A_V=3$ magnitudes. If these estimates are correct, we can expect an average polarization of $p\leq5\%$ due to absorption, and $p\leq8\%$ in the regions with maximum absorption, provided that the particles in 5128 have the same optical properties as the particles in the Milky Way clouds. The degree of polarization predicted in this way is in very good agreement with the polarization observed by us in the dark band. It therefore seems plausible that the polarization in this case is due to absorption in clouds of elongated particles, oriented with their shortest axis parallel to the magnetic fields in the flat layer of dark material in 5128.

As in our own galaxy, we would expect that the lines of force should be parallel to the dark band. If so, because of the nature of the radio data, the magnetic field in 5128 probably has an interesting form. It would be roughly perpendicular to the dark layer in the major part of the object outside the layer, but parallel to the layer inside the dark layer itself. Such a configuration seems possible if the layer is rotating around its axis of symmetry at a higher speed than the main body of the galaxy. This actually seems to be the case according to data obtained by Burbidge and Burbidge (20). They found the stellar system to rotate in the same direction as the layer of gas and dust about an axis perpendicular to the dust layer; the average rotational velocity of the stellar system is about 1 km/sec/second of arc as compared to a value 3-fold greater for the dust layer. There is also a significant difference in radial velocity between the gas and the stellar system. It seems most probable that the magnetic lines of force in this fast-moving gas have been stretched in the general direction of motion in the gas.

Suggestions Regarding Polarization Observations of Faint, Extended Objects

During the past three years polarization measurements have been made of 15 extragalactic objects with three different reflecting telescopes at two observatories and with three different photoelectric polarimeters. In the hope that the experience gained

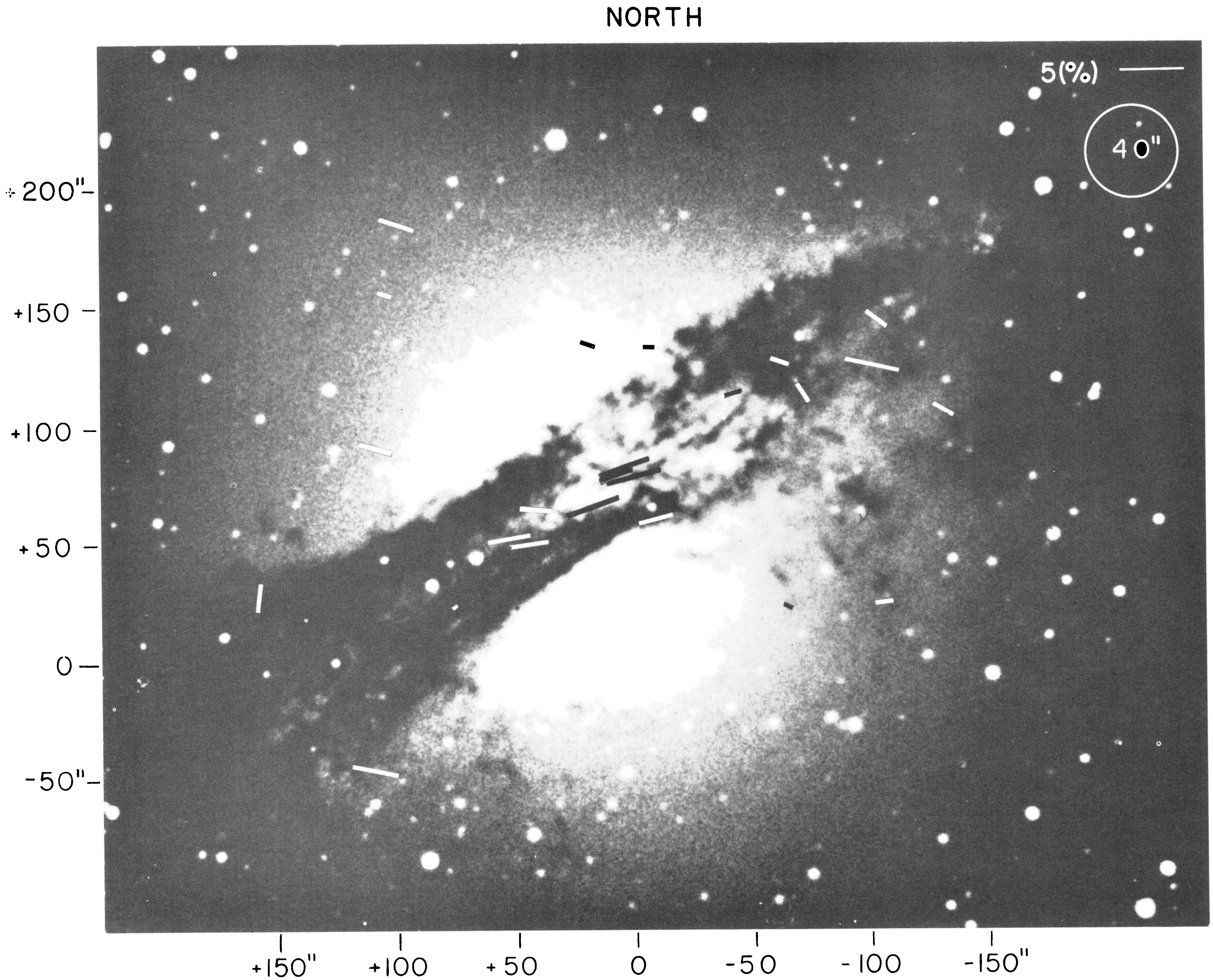

Figure 5. Polarization measures of NGC 5128 uncorrected for foreground (Milky Way) polarization. At radio wavelengths strong polarization has been observed in the northeast quadrant. Photograph—S.C.B. Gascoigne, 74-inch, 103a-D plate with Chance OY4 filter.

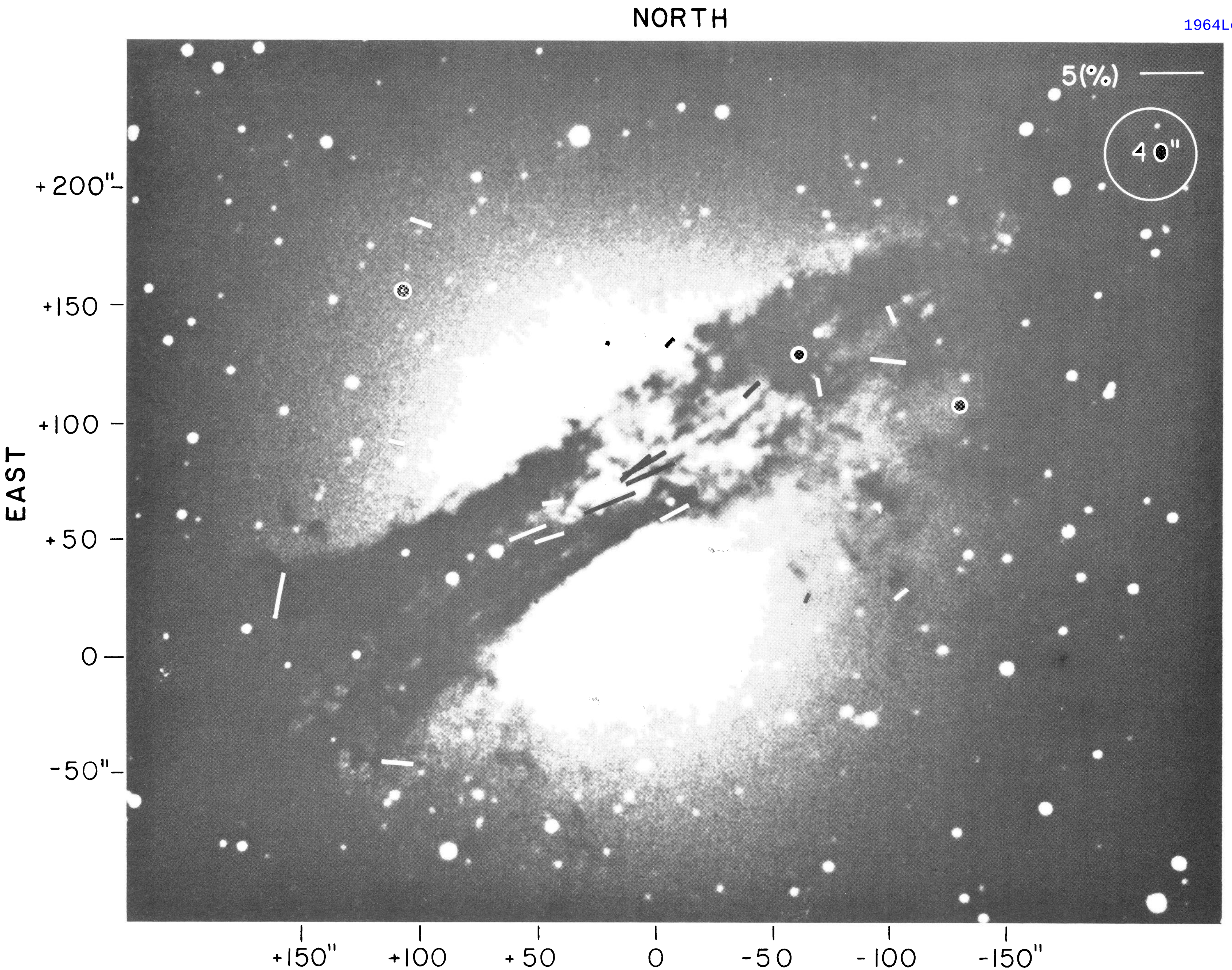

Figure 7. Polarization measures of NGC 5128 after correction for galactic polarization of 1.4 per cent at 70°. A comparison with Figure 5 shows that the vectors in the dark lane just to the east of center are now more nearly parallel to this lane. These polarization observations are of high weight and were made in regions where very strong reddening had been observed. The vectors shown elsewhere have a more nearly random distribution, and the optical polarization first measured in the northeast region is reduced to zero.

may be helpful to others, we offer the following comments:

1. In common with other polarimetric observations one must, of course, check carefully for systematic errors within the polarimeter or in the telescopic optics even though the accidental errors are likely to be large.

2. Measurements of dark sky background become more important as fainter regions are observed. When these regions are only half as bright as the sky, more sky measures than region measures should be made. The authors plan to try to increase both accuracy and efficiency by measuring the sky and region simultaneously with two different telescopes. At a given right ascension and declination the polarization of the dark sky appears to change throughout the night; measures of very faint objects can apparently best be made when near the meridian at midnight. Measurements on extragalactic or other faint objects made when there was any moonlight proved useless.

3. Corrections for galactic polarization must be determined for extragalactic objects before a true picture of their intrinsic polarization can be evaluated. For the great majority of objects we have observed, the polarization found could be entirely produced in our own galaxy. There is, therefore, an important need for extensive and very accurate studies of galactic polarization outside the "Zone of Avoidance". Perhaps the best way to do this would be to use as light sources, not only the distant stars, but also the integrated light from as many dust-free external galaxies as possible.

June 15, 1964

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TABLE IV. Observations of Stars Near NGC 5128

HD No.	RA 1964	Dec. 1964	Sp	m_V	CI	E	Dist. kpc	Polarization P%	Polarization θ_E	Wt.
116184	$13^h20^m.5$	−44°04′	A0	10.5	$+0^m.2$	$+0^m.2$	0.9	0.3	135°:	0.5
	21 .0	−43 07	A0	11.5	+0 .4	+0 .4	0.9	0.8	72	3
116239	21 .0	−42 52	A0	9.9	+0 .2	+0 .2	0.6	0.3	78:	1
116485	22 .6	−42 49	gK0	9.9	+1 .1	0 .0	0.9	0.1	—	1
116647	23 .5	−42 54	F0	9.1	+0 .4	+0 .1	0.2	0.6	126:	0.5
	24 .2	−43 27	gK0	10.9	+1 .2	+0 .1	1.3	0.4:	60:	1
	25 .9	−41 41	B9	11.0	+0 .1	+0 .2	1.3	0.8	50	2
	26 .2	−42 59	A0	12.3	+0 .5	+0 .5	1.1	0.5:	42:	1
	$13^h26^m.7$	−43°39′	A3	11.8	+0 .6	+0 .4	0.6	0.4:	65°:	1