1.2.2 POLARIMETRY OF THE ZODIACAL LIGHT AND MILKY WAY FROM HAWAII

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I. INTRODUCTION

This paper describes the results of a program of observations of the polarized intensity vector of the night sky in the anti-solar hemisphere obtained on 72 nights between May 1973 and November 1974. The observations were made with the night sky polarimeter at Mt. Haleakala, Maui, Hawaii, using a 5300A interference filter, 62A wide, to define the passband. They were made at fixed altitudes from 35° to 90° along the north-south meridian and repeated in sequence throughout the night. The diameter of the field of view was 6.0° and the integration time per point was either 30 or 120 seconds. Polarization was detected using a rotating polaroid (11 1/4 revs sec^{-1}); the signal from the polaroid drive generator provided a phase trigger allowing the photomultiplier signal to accumulate and be digitized for each of the four 90° phase intervals of the polarization modulation cycle. This process continued for the entire integration period. The digitization and data handling and recording (paper tape and teletype) was carried out by a PDP-8I computer, and calibrated Stokes parameters (I, Q, U) and the polarized intensity pI were calculated later. Intensity calibration in S_{10}(V,G2V) units was obtained using a C_{14} low brightness source, and the amplitude and phase of the polarization modulation were checked each night.

II. DATA ANALYSIS

The polarized intensity vectors of the observations for a given night were plotted in a solar ecliptic coordinate diagram. Averages of these vectors for a given new moon period were calculated at standard points in $(\beta, \lambda-\lambda_{\odot})$ by averaging Q and U over small equal areas (appr. 64 sq. deg.). Next, data for all months at galactic latitudes $|b^{II}|>45^{\circ}$ (where we suppose the influence of Milky Way polarization is negligible) were averaged similarly to obtain the average zodiacal light (AZL), i.e., the zodiacal light uncontaminated by galactic polarization. Finally we calculated the polarized intensity of the Milky Way by subtraction of the Stokes parameters (Q, U) of the AZL from those of the nightly observations. The resulting Stokes parameters of the Milky Way were area-averaged.

The potential sources of error in our observations are photon noise, red leak of the filter, tropospheric scattering and instrumental polarization. (a) For a typical sky brightness at 5300A of I=500 S_{10}(V) the photon count--including photons from the red leak discussed in (b)--for a 30 second integration time was 2×10^{7} corresponding to a standard error in pI of 0.14 S_{10}(V) and the polarization orientation angle χ of 2.8° for a typical low polarized intensity of 2 S_{10}(V). (b) Concerning the red leak, our 5300Å filter is only partially blocked at wavelengths longer than 7000Å. OH airglow dominates the sky brightness at these wavelengths and although the effective

*On sabbatical leave from the Institute for Astronomy, University of Hawaii red response is down by a factor of 12 in the red (mainly due to the decreasing sensitivity of our EMI 9558 QAM photomultiplier) the total sky brightness is 5 times higher in the red so that we calculate that 30% of the measured intensity signal is contributed by this red leak. Analysis of night sky observations with this filter and a narrower blocked 5300Å filter yield 20% contribution. The corresponding contribution of the red leak to the measured polarized intensity signal is fortunately much less, namely 8%. This is because the ratio of the polarized intensities rather than the ratio of the straight intensities (at 4300Å and in the red) is involved, these two ratios being 1:1 and 5:1 respectively. (c) We have studied the importance of tropospheric scattering at 5300Å by following regions of fixed solar ecliptic coordinates through a wide range of zenith distances. In over 90% of the cases studied the orientation angle, χ, deviated from the value close to the zenith by less than $\theta=\pm 10^{\circ}$. The trospospheric component associated with this deviation, namely (pI) trop $\approx (pI)_{ZL}$ $\tan\theta$, can amount to as much as 3 $S_{10}(V)$ at 35° altitude. During the course of the year the tropospheric component at a fixed point in solar ecliptic coordinates changes in magnitude and direction (relative to the direction of the north ecliptic pole) because of the change in altitude and in the relative orientation of the ecliptic, galactic and alt-azimuth coordinate systems. By averaging our data over the year we expect the influence of the tropospheric component to be reduced to a much smaller *level than 3 $S_{10}(V)$. We take the standard errors of the pI values of the AZL to be* a measure of this reduction: for $pI < 20$ $S_{10}(V)$ the error is 0.5 $S_{10}(V)$, and we take 0.5 $S_{10}(V)$ to be a typical value of the residual tropsopheric component in the AZL data. This in turn corresponds to a tropospheric influence on χ of 7° (0.7°) for $pI=2$ (20) $S_{10}(V)$. (d) The instrumental polarization of 0.16% introduces a polarized component typically of 1.0 $S_{10}(V)$. Again, because of changes in the direction of the instrumental polarization vector (fixed in alt-azimuth coordinates) relative to the direction of the north ecliptic pole during the course of a year, our data averaging over the year reduces this to a small value.

III. RESULTS

The average zodiacal light is shown in Fig. 1. Below we list its main features. 1. The angle, $\Delta\chi$, between the observed direction of the polarization vector and the direction for positive polarization is large relative to its standard error at many points within about 40° of the anti-solar point, and in these regions the polarization is generally neither positive nor negative. Smaller but statistically significant deviations occur elsewhere. 2. $\Delta\chi$ averaged over the entire anti-solar hemisphere is essentially zero. 3. Along the anti-solar meridian the pI distribution with respect to the ecliptic is asymmetric, being negative between $\beta= -30^{\circ}$ and $+10^{\circ}$ with a minimum of $pI= -3$ $S_{10}(V)$ at $\beta= -15^{\circ}$. 4. South of the ecliptic there is symmetry in the orientation of the pI vectors relative to the anti-solar meridian. 5. Along the ecliptic pI never becomes negative although significant rotations away from the positive polarization direction occur at $180^{\circ}<\lambda - \lambda_{\odot}<220^{\circ}$. 6. Some representative values of pI and $\Delta\chi$ are shown in the table (n is the number of observations).

The Average Zodiacal Light at 5300A

pI	$S_{10}(V)$	19	6.2	4.9	18	7.7	2.6	0.7	3.3	0.3	5.4
σpI	"	0.4	0.3	0.2	0.4	0.3	0.5	0.4	0.3	0.4	0.6
Δχ	(°)	2.6	0.1	-4.5	-1.6	2.5	7.3	53	85	85	1.8
σΔχ	"	1.0	3.6	2.4	0.8	2.1	14	14	2.7	29	2.4
β	"	0.0	0.0	0.0	0.0	47	33	13	-12.9	-33	-47
$\lambda-\lambda_o$	"	121	147	213	239	180	180	180	180	180	180
n		13	28	31	17	25	24	20	36	24	12

7. At the anti-solar point pI=1.5±0.5 $S_{10}(V)$ (n=30) and the polarization plane is oriented along a direction 21°±10° counterclockwise relative to the direction to the north ecliptic pole, as seen from outside the celestial sphere.

We do not propose to discuss the interpretation of these results here except to comment on point 1. If the interplanetary dust particles were spherical or non-spherical and randomly oriented, then the polarization of the zodiacal light would be either positive ($\Delta\chi=0^\circ$) or negative ($\Delta\chi=\pm90^\circ$). The existence of intermediate values of Δχ, as pointed out in 1, requires that a significant fraction of the particles are non-spherical and partially oriented.

The pI-vectors of the Milky Way are shown in Fig. 2. They are predominently oriented normal to the galactic plane as expected for the diffuse galactic light. By using tabular values of the integrated starlight (Roach & Gordon 1974), assuming the polarized intensity of the integrated starlight is much less than that of the diffuse galactic light and adopting an albedo of 0.5 for the interstellar grains, we deduce the degree of polarization of the diffuse galactic light: at $\ell^{II}=17^\circ$ we obtain values ranging from 2.1% to 6.9% at $-33^\circ<b^{II}<+33^\circ$. A region of enhanced pI is present centered at $b^{II}=20^\circ$, $\ell^{II}=105^\circ$. Although the polarization orientation is consistent with that of nearby vectors the large values of pI are difficult to understand. The region is not far from the north ecliptic pole ($b^{II}=28^\circ$, $\ell^{II}=123^\circ$) and consequently observations of the zodiacal light at high ecliptic latitudes must be corrected for Milky Way polarization. This has not been realized formerly and may account for some of the differences in published values of pI at the north ecliptic pole.

For a full description of this work see (Bandermann & Wolstencroft 1975).

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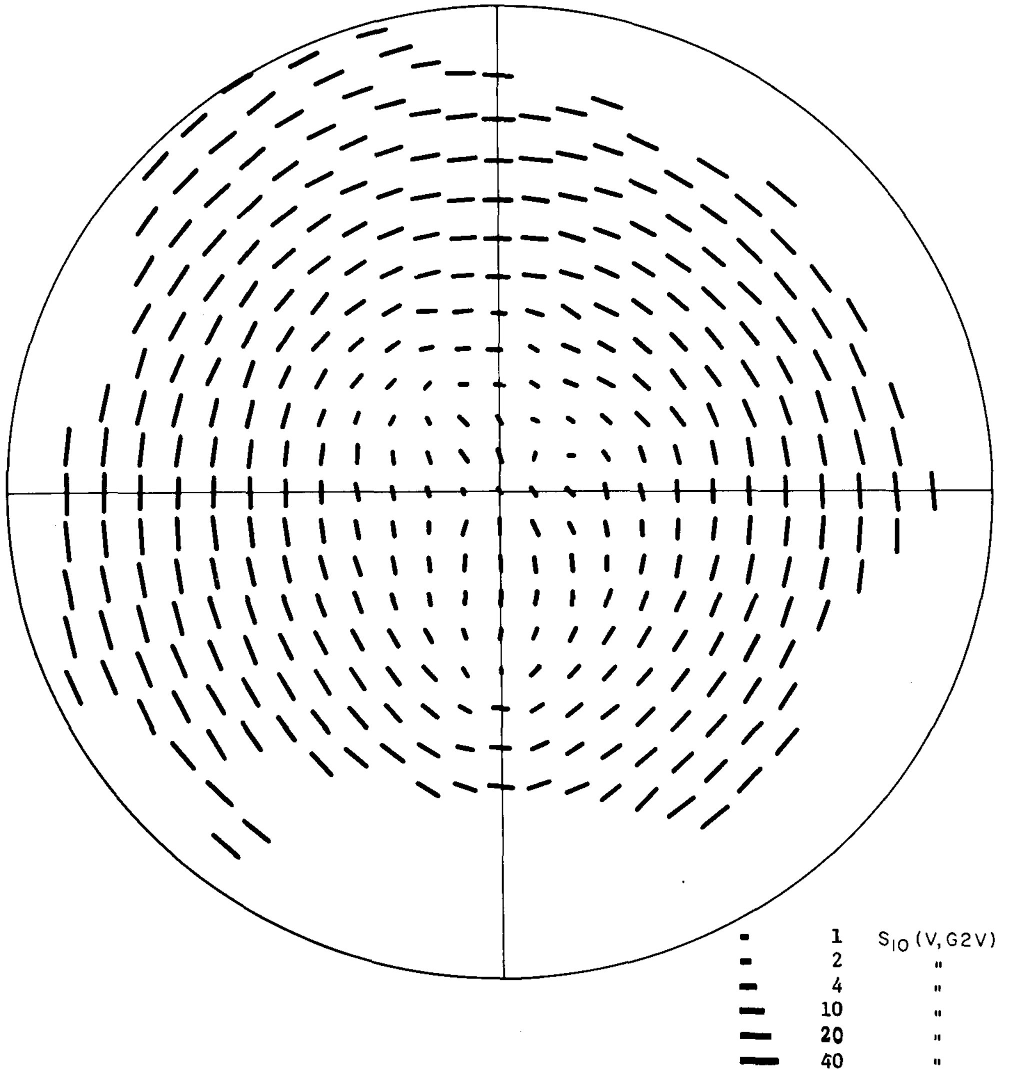

Fig. 1 The average zodiacal light at 5300A in the anti-solar hemisphere: May 1973 to November 1974. The length of each vector is proportional to log(1 + pI) where pI is the polarized intensity in S_{10}(V, G2V) units. The solid circle represents 90^{o} solar elongation; the horizontal line is the ecliptic and the vertical line the anti-solar meridian. The north-ecliptic pole is at the top; λ-λ_{o} increases from left to right.

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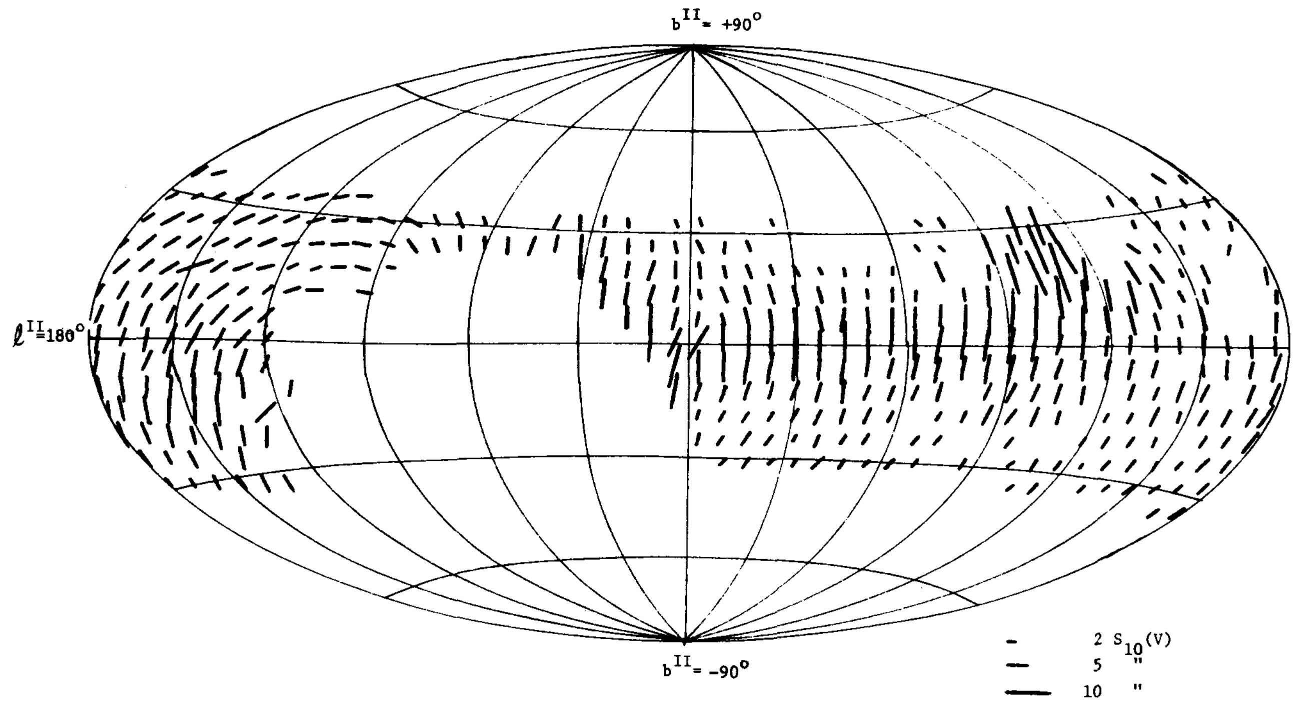

<u>Fig. 2</u> The polarized intensity of the Milky Way at 5300A. The length of each vector is proportional to pI where pI is the polarized intensity in S_{10}(V, G2V) units. Galactic longitude increases from left to right, the galactic center being at the center of the diagram.

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