Neutral points of skylight polarization observed during the total eclipse on 11 August 1999

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We report here on the observation of unpolarized (neutral) points in the sky during the total solar eclipse on 11 August 1999. Near the zenith a neutral point was observed at 450 nm at two different points of time during totality. Around this celestial point the distribution of the angle of polarization was heterogeneous: The electric field vectors on the one side were approximately perpendicular to those on the other side. At another moment of totality, near the zenith a local minimum of the degree of linear polarization occurred at 550 nm. Near the antisolar meridian, at a low elevation another two neutral points occurred at 450 nm at a certain moment during totality. Approximately at the position of these neutral points, at another moment of totality a local minimum of the degree of polarization occurred at 550 nm, whereas at 450 nm a neutral point was observed, around which the angle-of-polarization pattern was homogeneous: The electric field vectors were approximately horizontal on both sides of the neutral point. © 2003 Optical Society of America

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1. Introduction

It has been known since the observation by Piltschikoff[1] in 1906 that at the beginning of the totality of a solar eclipse the polarization of the sky decreases drastically at 90° from the Sun. The few skylight polarization measurements performed before 1999 during total solar eclipses (summarized in Table 1) were done by point-source polarimeters with fields of view not wider than a few degrees. These polarimeters were oriented in a given direction of view in the Sun's vertical.[2–7] It was a great technical achievement when Shaw[8] was able to scan the sky along the solar–antisolar meridian during the total eclipse on 30 June 1973 in Northern Kenya. He observed the approximate cylindrical symmetry of the distribution of the degree of polarization p of the eclipse sky and near the zenith a local minimum of p. Using a numerical model, Können[9] explained quantitatively several polarization characteristics of the eclipse sky. The forerunner of imaging polarimetric studies of the eclipse sky was Gerharz,[10] who took photographs about the celestial circumsolar area of 12° × 15° through a modified Savart filter and a green (535-nm) interference filter during the total solar eclipse of 7 March 1970 near Williamston, North Carolina. From the photographed interference bands he deduced the degree and angle of polarization of light scattered from the circumsolar region of the eclipse sky and demonstrated a slight (0.5%) polarization asymmetry around the eclipsed Sun.

In spite of the scientific popularity of total solar eclipses, which appear almost every year somewhere on the Earth, the empirical knowledge accumulated about the polarization patterns of eclipse skies is rather limited, since the earlier polarization measurements were restricted to one single point in the sky or at most to the solar–antisolar meridian. Because of the recently developed methods of full-sky imaging polarimetry[11–19] the final impediment was removed for measuring the polarization pattern of the entire sky dome under the extreme illumination conditions occurring during the short period of a total solar eclipse. The first full-sky imaging polarimetric study of the eclipse sky was performed by Pomozi *et al.*[16] on 11 August 1999 in Hungary. They were able to measure and investigate the fine structure of the celestial polarization pattern and its temporal change during this eclipse. They explained qualitatively (in a simple model involving first-, second-, and third-order scattering events) the gross characteristics of the angle-of-polarization pattern of the eclipse sky and demonstrated that a neutral point should occur

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Table 1. Summary of Instrumental Observations of the Degree of Linear Polarization of Skylight at Mideclipse Measured at 90° from the Eclipsed Sun in the Sun's Vertical (apart from Gerharz[a])[b]

Reference No.	Year	Zenith Angle of the Observed Point(s) (deg)	Altitude	Wavelength (nm)	Degree of Polarization at Mideclipse (%)
2	1961	12	ground based	green	0
3	1965	41	airborne	475	0.5
				601	4.5
6	1965	65	airborne	558	31
				578	35
				610	28
				630	26
5	1966	70	airborne	475	19
				601	21
4	1970	46	ground based	475	4
				600	<0.6
10	1970	38–53	ground based	535	<2.5
8	1973	37	ground based	400	4
16	1999	Full sky	ground based	450	—
				550	—
				650	—

[a]Ref. 10.
[b]In the case of Ref. 16 the degree of polarization pattern of the entire eclipse sky was measured by full-sky imaging polarimetry; the data thus obtained cannot be given here.

near the zenith. A detailed investigation of this zenith neutral point and a search for other possible neutral points or local minima of the degree of polarization of the eclipse sky were beyond scope of their study.

As a logical continuation of the research of Pomozi *et al.*,[16] here we report on the neutral points of the eclipse sky observed on 11 August 1999 in Hungary. The forerunners of our measurements are undoubtedly Shaw[8] and Gerharz,[10] whereas Können[9] is the precursor of the theoretical interpretation and quantitative explanation of such observations. Our aim in this paper is to present observational material about the neutral points and local minima of the degree of polarization of the eclipse sky that have not been previously collected. The theoretical interpretation and quantitative explanation of our observations are beyond the scope of the present paper. Numerical calculations of the atmospheric scattering phenomena under the complex illumination conditions of the eclipse on 11 August 1999 with the use of an improved version of the quantitative model of Können[9] could be the subject of future research.

2. Materials and Methods

Our full-sky imaging polarimetric method and the calibration of the polarimeter are described in detail in earlier papers of ours.[14–17] Here we mention only that in our polarimeter an angle of view of 180° was ensured by a Nikon–Nikkor fish-eye lens (*f*-number, 2.8; focal length, 8 mm) including a built-in rotating wheel mounted with three neutral-density (gray) linearly polarizing filters with three different transmission axes ($\chi = 0°$, 45°, and 90° measured from the radius of the wheel). After every turn of the wheel, the filters can be aligned accurately into the same position, owing to the fine mechanics of the wheel. Thus there is no error resulting from the alignment of the filters. We used a broadband (275–750-nm) linear polarizer (typename HNP'B, Polaroid Corporation, Polaroid Europe Ltd., London). The use of three linear polarizers did not reduce the accuracy of the measurements, because the small (15-mm-diameter) circular filters were cut from neighboring areas of the same filter, whose high optical quality and homogeneity were guaranteed by the manufacturer. Thus all three filters possessed the same transmission curve. The elements of the reduced Mueller matrix of our polarimeter were measured with a maximum error of ~3%, which is comparable with the maximum error of ~2% for the full-sky polarimeter designed by Voss and Liu[12] and Liu and Voss.[13]

From three digitized pictures of a given sky taken with the three different alignments ($\chi = 0°$, 45°, and 90°) of the linear polarizer, we obtained the modulation of the radiance I as a function of χ. A sinusoid $I = A \sin[2(\chi - \alpha + \pi/4)] + B$ was fitted to this radiance modulation for each pixel of the picture in order to determine $I_{max} = B + A$, $I_{min} = B - A$ and the angle of polarization α, which is the angular position of I_{max}. From these parameters we calculated the radiance $I = (I_{max} + I_{min})/2 = B$ and the degree of linear polarization $p = (I_{max} - I_{min})/(I_{max} + I_{min}) = A/B$ for every pixel of the sky image.

The position of the neutral points in the eclipse sky was determined as follows: (i) In the measured pattern of the degree of polarization p those regions were determined where $p < p_{threshold} = 4\%$. (ii) In these regions the pixels were detected where $p = p^* = 0\%$. (iii) The position of the neutral point was defined as the geometric center (center of mass) of these pixels.

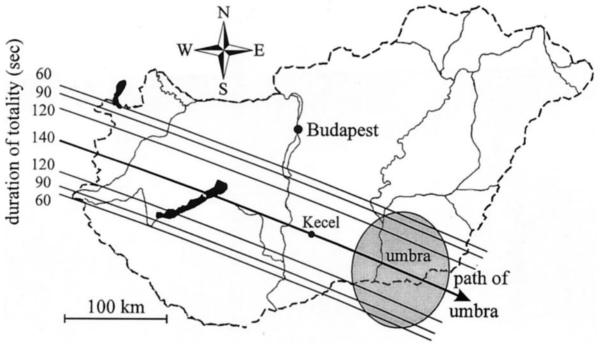

Fig. 1. Map of Hungary showing the path and shape of the umbra during the total solar eclipse on 11 August 1999. Our full-sky imaging polarimetric measurements were performed at Kecel, Hungary.

This procedure was necessary for detecting a neutral point, because, as a result of the inevitable small noise, the measured value of p was zero not only in one pixel but in a few pixels in the immediate vicinity of the real position of a neutral point. The positions of the local minima of p were determined similarly with the use of different, appropriately set values of $p_{\text{threshold}}$ and p^*.

3. Results

Our imaging polarimetric measurements were performed in southern Hungary, in the immediate vicinity of the village of Kecel (46° 32′ N, 19° 16′ E) placed on the center line of the path of the Moon's shadow (umbra) sweeping the Earth's surface (Fig. 1). The totality of the eclipse began at 12:51:34 (second contact; local summer time, UTC + 2) and finished at 12:53:56 (third contact; Fig. 2). During totality the solar zenith angle was 32°. The atmosphere was clear during the eclipse after a cold-front passage prior to the beginning of the partial eclipse (first contact).

In this paper we refer to the sky observed on 11 August 1999 immediately before or after totality (immediately before the second contact or after the third contact) of the solar eclipse as the *preeclipse sky* or the *posteclipse sky*, respectively. By *normal sky* we mean the sky observed under normal illumination conditions when the Sun was not eclipsed by the Moon but its angular zenith angle was the same (32°) as that during totality on 11 August 1999.

Figures 3 and 5 below show the celestial patterns of the degree p and angle α of polarization measured at a wavelength of 550 nm (green range of the spectrum) at 13:01:00 (local summer time, UTC + 2) on 11 August 1999, 7 min after the end of totality of the eclipse (Fig. 2), when the geometrical obscuration of the Sun's disk was 89%. Although these sky polarization patterns were observed during the partial posteclipse (between the third and the fourth contact), they are practically the same as the polarization patterns of the sky measured under normal illumination conditions. In agreement with earlier observations, we[16] also observed that when the percentage of geometric obscuration of the Sun's disk was smaller than ~98%, there were practically no polarization differences between the corresponding preeclipse, posteclipse, and normal skies.

Thus Figs. 3–6 can be considered to be an example for the polarization characteristics of the normal sky and can be used as a control sky in comparison with the sky observed during totality of the eclipse. Figures 4 and 6 represent the graphs of p and α measured along the antisolar meridian indicated by an arrow in Figs. 3 and 5. To prevent disturbing internal reflections of the direct sunlight, during the partial eclipse the Sun was screened out by a small disk, whose holding wire occluded the solar meridian.

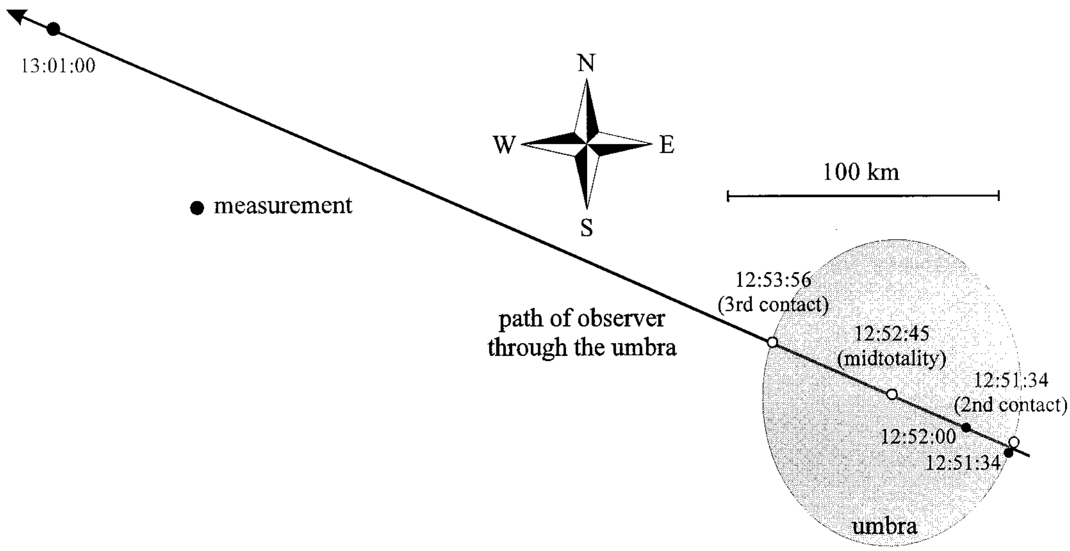

Fig. 2. Trajectory of the observer through the umbra of the total eclipse on 11 August 1999 with filled dots where and when our polarimetric measurements were taken. Open dots represent the second and the third contact as well as the midtotality.

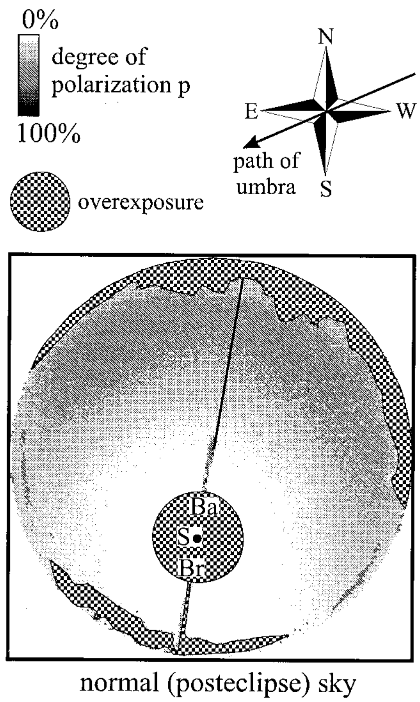

Fig. 3. Celestial pattern of the degree of linear polarization p of skylight measured by full-sky imaging polarimetry at wavelength 550 nm (green) at 13:01:00 (local summer time, UTC + 2) on 11 August 1999 in Kecel, 7 min after the end of totality (third contact, 12:53:56; Fig. 2) of the solar eclipse, when the geometrical obscuration of the Sun's disk was 89%. The position of the Sun (S) is indicated by a dot, and the estimated positions of the Babinet and the Brewster neutral points are marked with Ba and Br, respectively. The radial bar approximately parallel to the solar meridian comes from the Sun occulter (a wire holding a small disk). The graphs of Figs. 4 and 6 below are measured along the antisolar meridian indicated by an arrow in the circular pattern. East (West) is on the left (right) rather than on the right (left) of the compass rose, because we are looking up through the celestial dome rather than down onto a map.

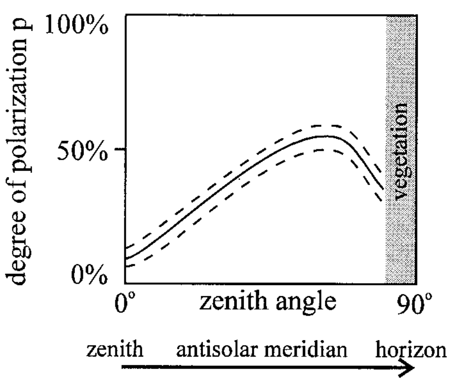

Fig. 4. Graph of the degree of linear polarization p along the antisolar meridian indicated by an arrow in the circular pattern of Fig. 3. The solid curve represents the curve fitted by the method of least squares to the measured values of p, and the dashed curves show the upper and the lower limits, between which 90% of the p values fall. In the graph the vegetation near the horizon is indicated by gray shading.

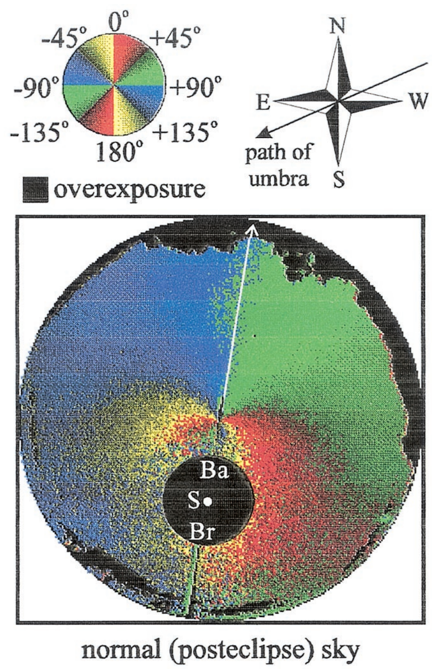

Fig. 5. As in Fig. 3 for the angle of polarization α of skylight with respect to the local meridian.

Figures 7–12 show the celestial patterns of the degree p and angle α of polarization of skylight measured at two different moments (Fig. 2), at 450 nm (blue) and 550 nm (green) during totality of the eclipse on 11 August 1999. Figures 13–18 represent the graphs of p and α measured along different meridians crossing the zenith and the neutral points or the local minima of p listed in Table 2.

The polarization of the sky exhibited a sudden and dramatic change at the beginning and the end of totality. Immediately prior to and after totality, the qualitative characteristics of the polarization pattern of the sky were practically the same as those of the normal sky (Figs. 3–6).

In comparison with the normal and preeclipse or posteclipse skies, during totality the degree of polarization p of skylight decreased (Figs. 7–9 and 13–15)

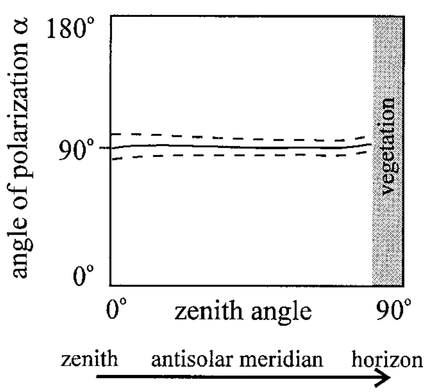

Fig. 6. As in Fig. 4 for the angle of polarization α (with respect to the local meridian) along the antisolar meridian indicated by an arrow in the circular pattern of Fig. 5.

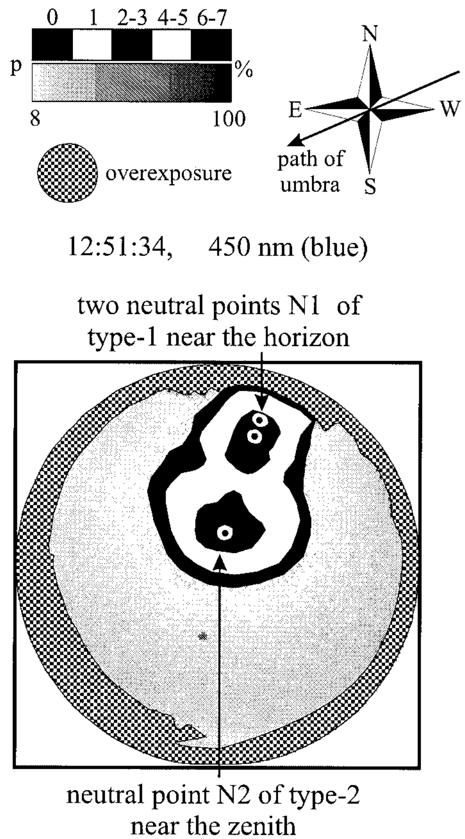

Fig. 7. Celestial pattern of the degree of linear polarization p of skylight measured with full-sky imaging polarimetry during totality of the eclipse on 11 August 1999 in Kecel at 12:51:34 (local summer time, UTC + 2) and 450 nm (blue). The p values are rounded to integers (0, 1, 2, 3, . . . , 100%). The neutral points are marked by dots.

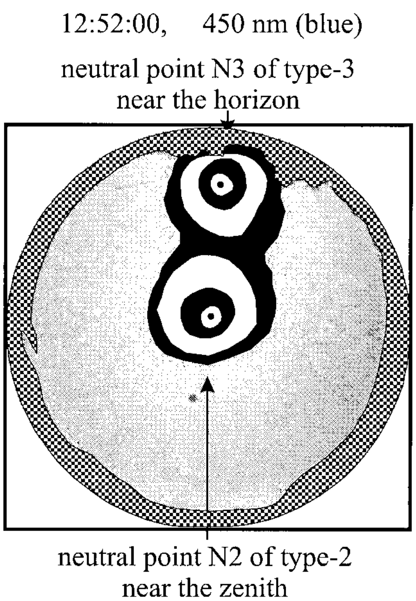

Fig. 8. As in Fig. 7 at 12:52:00.

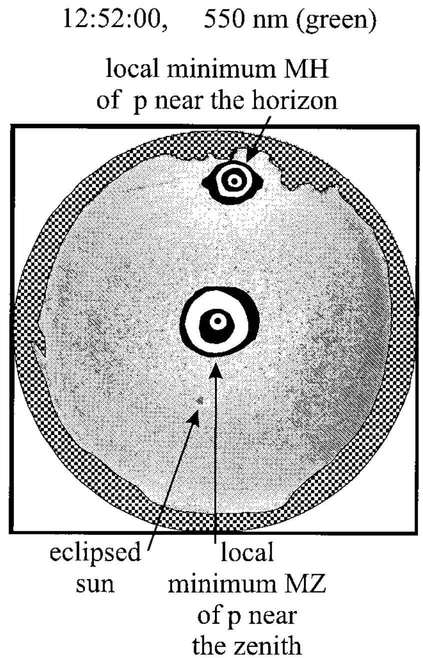

Fig. 9. As in Fig. 8 at 550 nm (green).

because of the randomizing effect of multiple scattering as reported as well by earlier authors.[3–5] During totality of the eclipse the celestial distribution of p became approximately cylindrically symmetric with

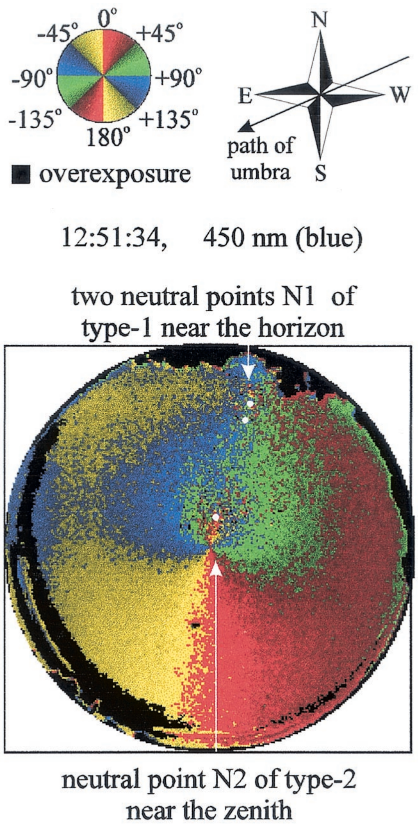

Fig. 10. As in Fig. 7 for the angle of polarization α of skylight measured from the local meridian.

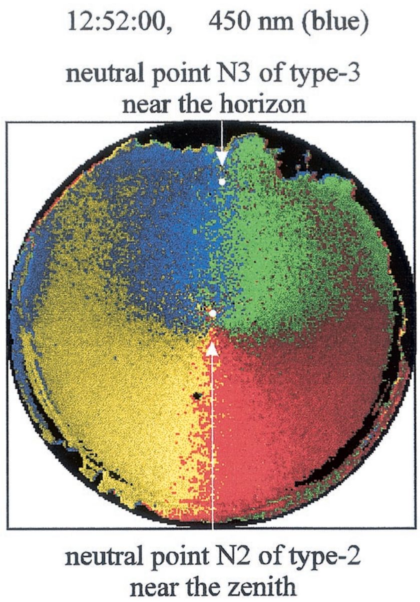

Fig. 11. As in Fig. 10 at 12:52:00.

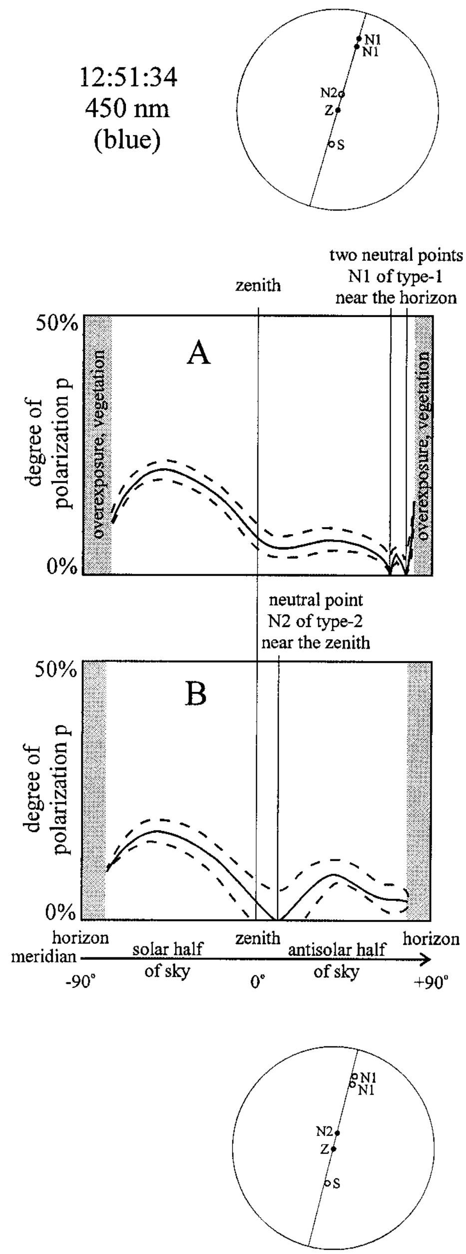

Fig. 13. Graphs of the degree of linear polarization p measured along different meridians crossing the zenith Z of the eclipse sky at 12:51:34 (UTC + 2) and 450 nm. The solid curves represent the curves fitted by the method of least squares to the measured p values, and the dashed curves show the upper and the lower limits, between which 90% of the p values falls. The circular insets show how the scans are located with respect to the pattern in Fig. 3. (A) Scan through the two neutral points N1 of type 1 near the horizon. (B) Scan through the neutral point N2 of type 2 near the zenith.

respect to the zenith (Figs. 7–9 and 13–15): The degree of polarization gradually increased from the horizon up to its maximum then gradually decreased toward its minimum near the zenith. Cylinder symmetry was also observed by Shaw[8]—at least in one plane—and explained quantitatively by Können.[9] In the solar half of the eclipse sky, slightly greater p values occurred than in the antisolar half, in distinct contrast to the distribution of p over the preeclipse, posteclipse, and normal skies, where p is usually higher in the antisolar half (Fig. 3).

Similar to the pattern of the degree of polarization,

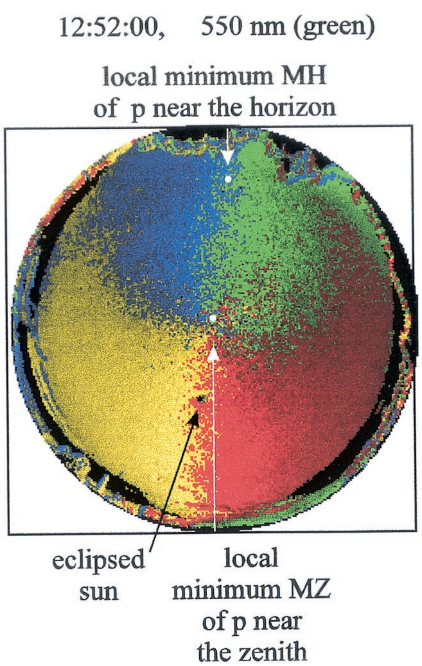

Fig. 12. As in Fig. 11 at 550 nm (green).

the celestial distribution of the angle of polarization α changed suddenly at the beginning and the end of totality of the eclipse. During totality, the pattern of α was asymmetric with respect to the zenith (Figs. 10–12 and 16–18). Compared with the preeclipse, posteclipse (Figs. 5 and 6), and normal angle-of-polarization patterns, the region of the eclipse sky where $-45° \leq \alpha \leq +45°$ with respect to the local

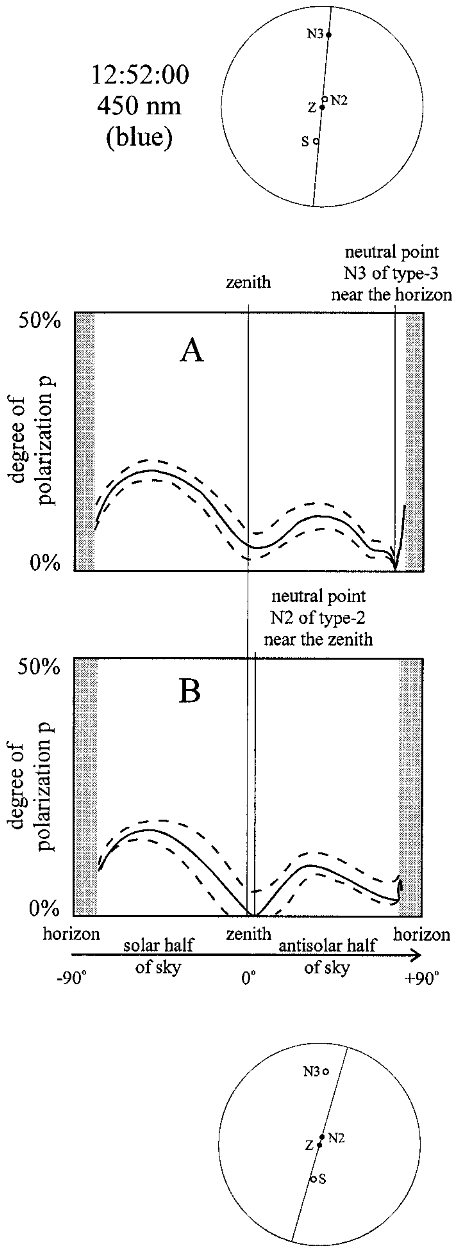

Fig. 14. As in Fig. 13 for 12:52:00. (A) Scan through the neutral point N3 of type 3 near the horizon. (B) Scan through the neutral point N2 of type 2 near the zenith.

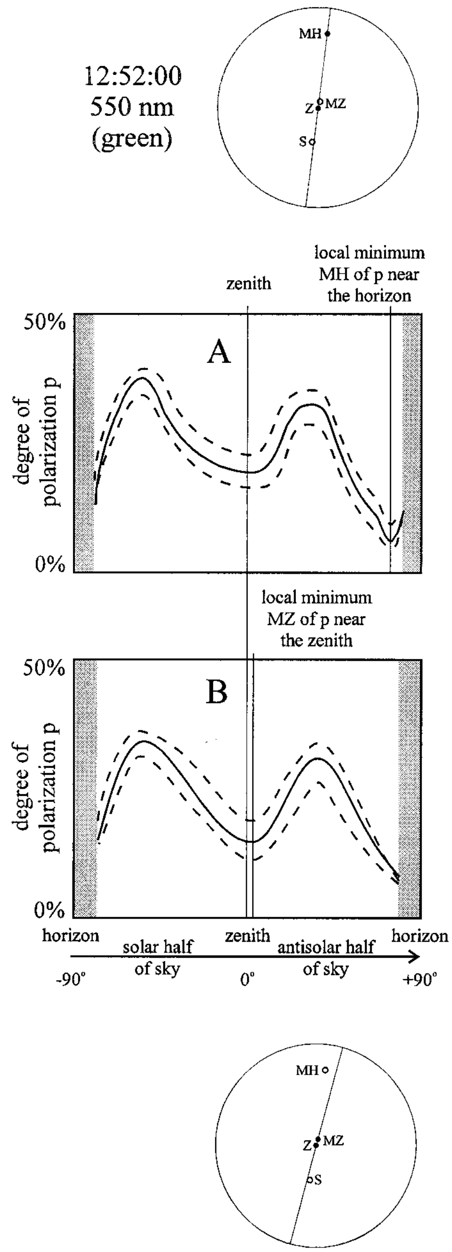

Fig. 15. As in Fig. 14 for 550 nm. (A) Scan through the local minimum MH of p near the horizon. (B) Scan through the local minimum MZ of p near zenith.

meridian (shaded with yellow and red in Figs. 10–12) was considerably extended at cost of the area where $45° < \alpha \leq 135°$ (shaded by green and blue in Figs. 10–12). This supports the theoretical prediction of Können[9] that in general the dominating aspect of the direction of polarization is more-or-less parallel to the local meridian during eclipse, especially during mideclipse.

One of the most striking features of the angle-of-polarization pattern of the eclipse sky (Figs. 10–12) is that α changes from 0° (or from 180° because of the 180° periodicity of α) to 90° near the zenith if the direction of view moves approximately along the solar–antisolar meridian. Another remarkable phenomenon in the eclipse sky is the occurrence of points, where the degree of linear polarization p is zero or has a local minimum (Figs. 7–9 and 13–15). Table 2 summarizes the zenith angles θ and azimuth angles φ (measured counterclockwise from the West) of these celestial points.

On the p patterns measured at 12:51:34 (Figs. 7 and 13B) and 12:52:00 (Figs. 8 and 14B) at 450 nm a point is discernible near the zenith where $p = 0\%$. Further on in this paper this point is called the zenith neutral point of type 2. It is called neutral point because the degree of polarization is zero at its position; and it is classified as type 2 because it can be considered to be a point where p passes through a minimum, rather than

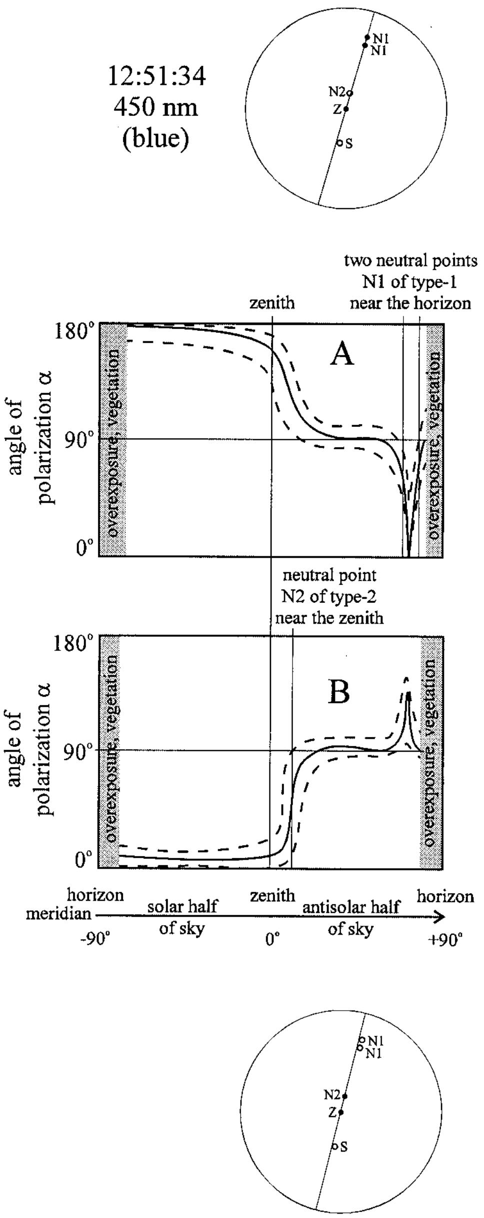

Fig. 16. As in Fig. 13 for the angle of polarization α.

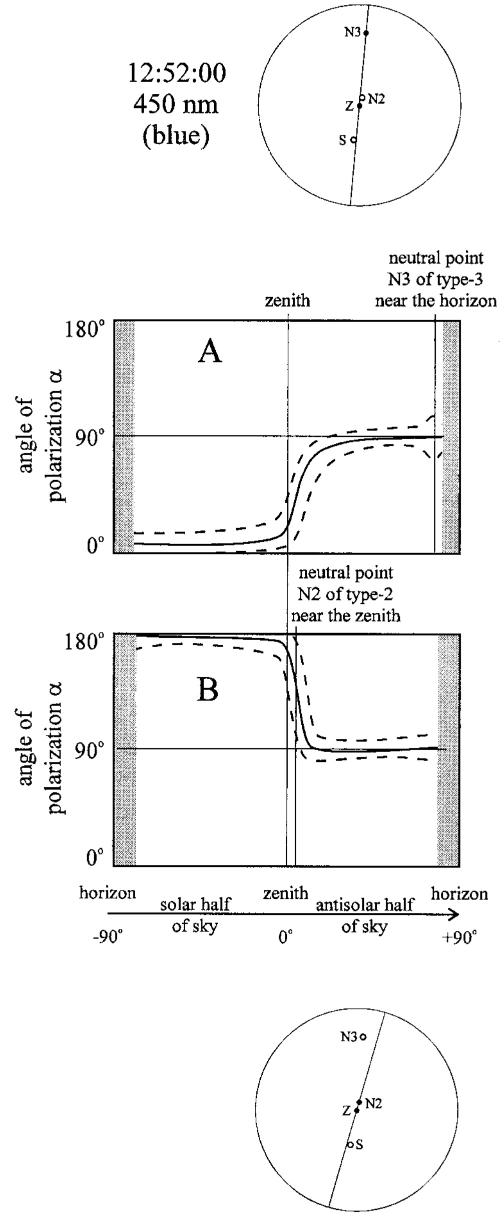

Fig. 17. As in Fig. 14 for the angle of polarization α.

a real neutral point such as the well-known Arago, Babinet, and Brewster neutral points of the normal sky,[7] classified as type 1 further on. In the type 2 zenith neutral point of the eclipse sky the absence of polarization is analogous to the absence of polarization of the sunlit sky straight in the direction of the Sun. At 12:52:00 approximately at the position of the zenith neutral point a local minimum of p occurred at 550 nm (Figs. 9 and 15B). The local minimum of p in the immediate vicinity of the zenith can also be seen in the graphs of Figs. 13A–15A.

At 12:51:34 at 450 nm (Figs. 7 and 13A) two neutral points of type 1 occurred approximately along the antisolar meridian near the horizon. They arise because the Stokes parameter Q (if $U = 0$) for single and multiple scattering cancels out, which also occurs in the usual Arago, Babinet, and Brewster neutral points.[7,14,18,20,21]

At 12:52:00, a neutral point of type 3 was observed at 450 nm (Figs. 8 and 14A) and a local minimum of p occurred at 550 nm (Figs. 9 and 15A) approximately at the position of the two type 1 neutral points. Note that there was no switch of the angle of polarization crossing the type 3 neutral point along a meridian: This celestial point is characterized by the abolition of the degree of polarization (Figs. 8 and 14A) in a celestial area where the angle-of-polarization pattern is homogeneous; that is, the electric field vectors are approximately horizontal on both sides of the neutral point (Figs. 11 and 17A). The latter feature distinguishes the neutral point of type 3 from the neutral points of type 1 and 2, which are characterized by a sudden change of 90° of the angle of polarization (Figs. 10, 11, 16A, 16B, and 17B).

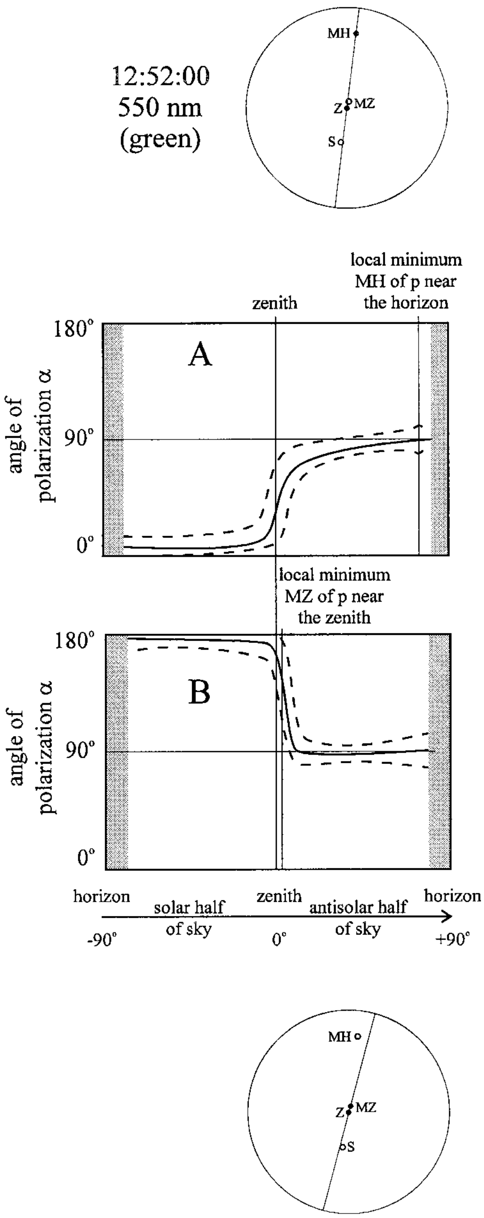

Fig. 18. As in Fig. 15 for the angle of polarization α.

4. Discussion

Pomozi *et al.*[16] gave a qualitative explanation of the origin of the neutral point or local minimum of the degree of polarization p observed near the zenith during totality of the eclipse on 11 August 1999. The exact position of the zenith neutral point or local minimum of p near the zenith depends on the wavelength of light (owing to the dispersion of polarization of scattered skylight[7]) as well as on the time-dependent geometry of the lunar shadow with respect to the Earth's surface and the observer's position. Shaw[8] observed a similar minimum of p in the eclipse sky, a phenomenon that was quantitatively explained by Können.[9]

The main cause of the slight drift of the neutral points that we observed from the solar vertical (Table 2) may be the changing geometry of the umbra with respect to the observer as the eclipse proceeded. A second cause may be distant clouds, which may disturb the distribution of singly scattered light around the observer. A third factor is the polarization of singly scattered light. Such effects may be used to explain the observed double neutral points, but calculations should prove this conjecture in the future.

Because of the the complex geometry, different atmospheric factors, and the site-dependent ground albedo, the number and the position of the neutral points occurring during totality should change from eclipse to eclipse and from site to site. Since until now the eclipse sky was studied generally only in a few directions of view—it was scanned along one meridian in a single case[8]—the chance to observe the possibly existing neutral point(s) was small. Previously, to our knowledge, only Können[9] considered the possibility of the existence of neutral points in the sky during total solar eclipses. According to the predictions of his numerical simulations, the polarization direction of the eclipse sky is essentially vertical, and the degree of polarization is cylindrical symmetric with respect to the zenith at mideclipse if the observer is in the center line and if the solar elevation is large enough. At mideclipse the zenith possesses a local minimum in the degree of polarization that may be close to zero. If the Sun's elevation is low, then the minimum (or zero polarization) may break up into two neutral points at either side of the solar vertical, which are neither type 1 nor type 2. A type 1 neutral point or minimum of polarization is to be expected in the solar vertical where the Stokes parameter Q of singly scattered light that still reaches the observer tends to exceed Q of the secondary-scattered light from the eclipse sky. At mideclipse this minimum is a neutral point in the solar vertical; otherwise, a scan of the degree of polarization in the solar vertical should exhibit a minimum.

Table 1 summarizes the earlier instrumental observations of the degree of skylight polarization at mideclipse measured at 90° from the eclipsed Sun in the Sun's vertical. Scanning the sky in the Sun's vertical during the 30 June 1973 total eclipse in Northern Kenya, Shaw[8] observed a minimum degree of polarization of 4% at the zenith during midtotality at 400 nm (blue). A neutral point was not observed by Shaw[8] in his scan, probably because of the curvature of the Earth and the extreme large major axis (300 km) of the elongated elliptical umbra in this case.

Gerharz[10] measured the polarization of the eclipse sky in the circumsolar area (zenith angle ranging from 38° to 53° at a solar elevation of 45°) and obtained that at midtotality the maximal intensity of the polarized component was ~2.5% of the scattered light in the immediate solar vicinity.

Using point-source polarimeters, other observers measured the sky polarization only at a given point of the eclipse sky, and it is logical that they never made the claim of having seen a neutral point, because for a point observation alone, this would have been

Table 2. Zenith Angles θ and Azimuth Angles φ (Measured Counterclockwise from the West, for the Antisolar Meridian: φ = 79°) of the Local Minima of the Degree of Linear Polarization *p* and the Neutral Points of Skylight Polarization[a]

Circular patterns in Figs.	7, 10	8, 11	9, 12
Graphs in Figs.	13, 16	14, 17	15, 18
Recording time	12:51:34	12:52:00	12:52:00
Wavelength	450 nm (blue)	450 nm (blue)	550 nm (green)
Neutral point N2 of type 2 near the zenith	$\theta = 14° \pm 2°$	$\theta = 5° \pm 2°$	—
	$\varphi = 76° \pm 3°$	$\varphi = 74° \pm 3°$	—
First neutral point N1 of type 1 near the horizon	$\theta = 60° \pm 2°$	—	—
	$\varphi = 74° \pm 3°$	—	—
Second neutral point N1 of type 1 near the horizon	$\theta = 66° \pm 2°$	—	—
	$\varphi = 74° \pm 3°$	—	—
Neutral point N3 of type 3 near the horizon	—	$\theta = 64° \pm 2°$	—
	—	$\varphi = 85° \pm 2°$	—
Local minimum MH of p near the horizon	—	—	$\theta = 67° \pm 2°$
	—	—	$\varphi = 83° \pm 2°$
Local minimum MZ of p near the zenith	—	—	$\theta = 4° \pm 2°$
	—	—	$\varphi = 75° \pm 2°$

[a]Observed during the total solar eclipse on 11 August 1999 in Kecel (Hungary). The numerical values are given in format $a \pm b$, where a is the average and b is its error.

highly speculative. E. de Bary *et al.*[2] observed that the degree of polarization p of skylight at 90° from the obscured Sun in the solar vertical reached zero at the time of totality on 15 February 1961 in Viareggio (Italy), and p remained low during totality. Miller and Fastie[6] observed relatively high p values ranging from 26% to 35% at 90° from the Sun in the Sun's vertical at four different wavelengths during totality on 30 May 1965. Dandekar and Turtle[4] observed that during the eclipse of 7 March 1970 in Kinston, North Carolina, at 90° from the eclipsed Sun on the antisolar meridian at totality the degree of polarization reached a minimum of 4.0% at 475 nm (blue) and was less than 0.6% at 600 nm (red) during totality. They also observed that the planes of polarization changed by approximately 48° and 55° for 475 nm (blue) and 600 nm (red), respectively, with reference to that outside totality. Moore and Rao[3] did observe a temporal change of 90° in the plane of polarization for blue (475 nm) skylight at the zenith during the total solar eclipse of 30 May 1965 with respect to that outside totality. Their observation of no change of the plane of polarization for red (600 nm) skylight is, however, difficult to understand. However, at the zenith they observed low degrees of polarization: 0.5 in the blue (475 nm) and 4.5% in the red (601 nm) spectral range.

Hence only de Bary *et al.*[2] observed exactly zero degrees of polarization of skylight (at 90° from the obscured Sun along the antisolar meridian) during totality. However, they measured at high elevation, and a type 1 neutral point is not to be expected there. The low p that they observed is obviously associated with the minimum in degree of polarization near the zenith observed also by Shaw[8] and calculated by Können.[9] Other authors reported only on almost zero or low p values at certain points of the eclipse sky. E. de Bary *et al.*[2] may have been the closest among the earlier students of eclipses to discover a neutral point during totality. Also, the researchers who observed very low degrees of polarization may have been close to observing an eclipse neutral point. To find the point with zero p they should have measured the skylight polarization also in the immediate vicinity of the selected point. A wavelength-dependent angle of polarization can be an indication that the observing point was close to a type 1 neutral point. The position of a type 1 neutral point is wavelength dependent, as in the case of the Arago, Babinet, and Brewster neutral points of the normal sky.[7,14,18,20,21] The observing points of Moore and Rao[3] and of Dandekar and Turtle[4] may have been close to a neutral point, because of this wavelength dependency.

The change of sky polarization that occurs during totality is complex and depends on the distribution and magnitude of numerous parameters, e.g., variations in ground albedo, solar zenith angle, shape and diameter of the eclipse shadow, and optical thickness of the atmosphere. With the complex geometry and the great number of control parameters, apart from the quantitative model of skylight polarization developed by Können[9] for solar eclipses, at present we know of no in-depth computation for determining the sky polarization during an eclipse. According to Können,

> Within the limited set of existing observations there is no possibility to test the model further at present. This has to wait until more detailed observations are available. Such observations should include the polarization distribution of the eclipse sky, preferably in the solar vertical plane and in the plane perpendicular to the solar vertical containing the zenith, together with simultaneous almucantar scans of radiance and polarization near the horizon, all of them preferably at various wavelengths. Only if such a complete set of measurements is available will a rigorous test of models like the present one be possible. (Ref. 9, p. 607)

Full-sky imaging polarimetry meets these requirements, and our polarimetric data presented in this study as well as elsewhere[16] make it possible to test quantitative models of the polarization of eclipsed skies.

In this study it is not possible to interpret our results in terms of a theory that would clearly define the various atmospheric, geometrical, and terrain factors determining the celestial polarization pattern during an eclipse. This could be the task of further theoretical and computational studies, such as that of Können.[9] The ground-based observation of total solar eclipses is regarded by many scientists as the domain of amateurs, and its scientific importance is frequently questioned as well. Our results obtained by full-sky imaging polarimetry demonstrate, however, that the ground-based study of eclipses can, even nowadays, yield new scientific findings.

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