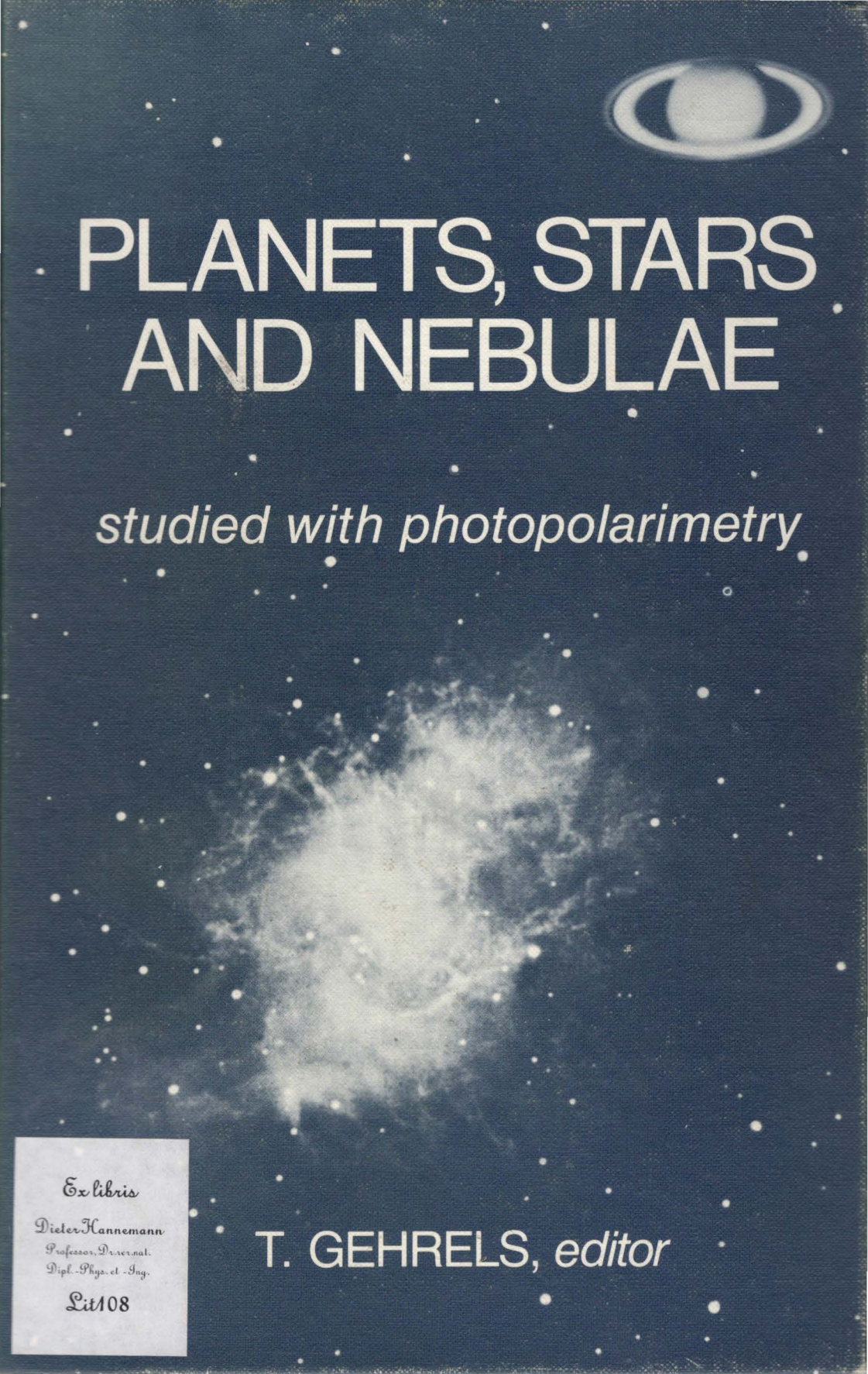

PLANETS, STARS AND NEBULAE

studied with photopolarimetry

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(Courtesy J. S. Hall, Lowell Observatory)

Merope Nebula and directions of electric vector maximum; largest polarizations are about 12 percent. North is at top, east is left.

CONTENTS

Part III — STARS AND NEBULAE

MEASUREMENTS OF THE ELLIPTICAL POLARIZATION OF SKY RADIATION: PRELIMINARY RESULTS

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A polarimeter has been built to measure quasi-monochromatically all four Stokes parameters of scattered incident solar radiation within the spectral range 0.5–1.1 μm. Ground-based measurements at 0.6 μm and 0.8 μm showed a considerable circular component in the sky radiation for polluted skies.

Multiple scattering in turbid planetary, as well as stellar, atmospheres causes linear and circular components of the polarization of scattered light. The degree and direction of polarization, the magnitude of the circular components, and the direction of rotation of the electrical vector of light, as described very elegantly by the four-dimensional Stokes vector, can be considered as signatures of various particles contained in these atmospheres. However, detailed theoretical studies with multiple scattering calculations of the relative importance of these four properties are still missing.

The investigations envisaged with the instrument described here are primarily concerned with water- and ice-clouds in the earth's atmosphere. They are in a preliminary state; thus, only ground-based measurements of sky radiation from cloudless and cloudy skies could be made.

PRINCIPLE OF THE MEASUREMENTS

The determinations of all four Stokes parameters I, Q, U, V are based in a straightforward manner on simultaneous measurements of six polarized radiances L as described by Born and Wolf (1965, Ch. 10.8) for quasi-monochromatic radiation. This is (first argument = direction of oscillation; second argument = retardation):

$$
\begin{aligned}
I &= L(0°, 0) + L(90°, 0) \\
Q &= L(0°, 0) - L(90°, 0) \\
U &= L(45°, 0) - L(135°, 0) \\
V &= L\left(45°, \frac{\pi}{2}\right) - L\left(135°, \frac{\pi}{2}\right).
\end{aligned} \tag{1}
$$

The instrumental coordinates are chosen to coincide with the local vertical (0°) and horizontal (90°) directions at the instrument. The degree of polarization is obtained from

$$s = (Q^2 + U^2 + V^2)^{1/2}/I \qquad (0 \leq s \leq 1). \tag{2}$$

The direction of the major axis (= direction of polarization) is determined by

$$\tan 2\psi = \frac{U}{Q}, \qquad (0 \leq \psi \leq \pi), \tag{3}$$

and the ellipticity is described by

$$
\begin{aligned}
\sin 2\chi &= V/(Q^2 + U^2 + V^2)^{1/2} \qquad \left(-\frac{\pi}{4} \leq \chi \leq +\frac{\pi}{4}\right) \\
&= VI/s.
\end{aligned} \tag{4}
$$

The sign of V determines the direction of rotation of the vector ($V > 0$: right-handed rotation).

INSTRUMENTAL CHARACTERISTICS

In brief, the instrument consists of an objective lens, an aperture for 7°.5 × 7°.5 field of view, and a field lens in front of a package with six analyzers and one retarder plate (for two analyzers). A filter is placed behind the analyzers to select the desired spectral range before radiation reaches 6 Si-avalanche-foto-diodes (TIXL 56). A multiplexer device enables a convenient storage for an A/D conversion before all six measurements are punched on tape for further automatic processing.

CALIBRATION

All optical components in front of the package of analyzers and the analyzers themselves change the polarization properties of incident radiation which can be described by an instrumental 4 by 4 vector matrix.

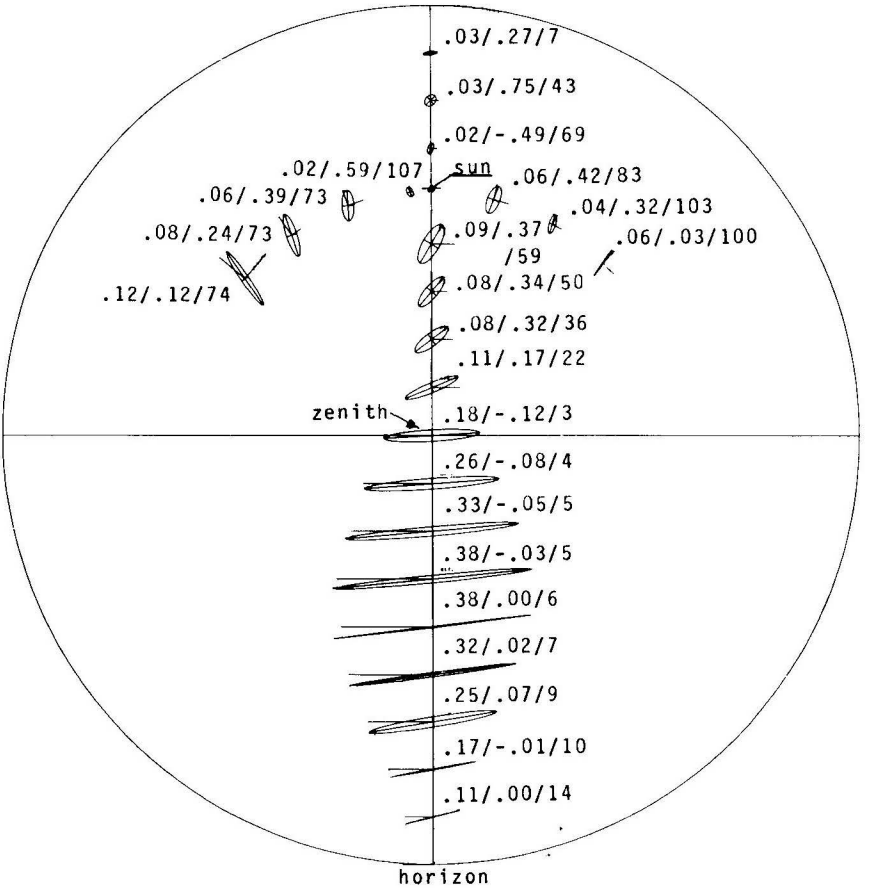

Fig. 1. Measurements obtained for cloudless but very turbid skies at Bochum (19.9.72). Sun's elevation was 39°. Numbers at each polarization ellipse give the degree of polarization, the ellipticity (positive = right-handed), and the angle of the major axis.

The elements of this matrix (Jäger and Oetken 1963)[1] can be determined experimentally using, in four successive measurements: natural (unpolarized) light, linearly polarized light in 0° and in 45° directions, and elliptically polarized light. These four types of radiation can be produced in a simple device mounted in front of the instrument which enables easy calibrations during field measurements. Further calibration procedures include determinations of the characteristics of each of the six sensors; also the finite spectral width of the filter is taken into account in determining the average retardation.

[1] Also see p. 175.

PRELIMINARY RESULTS

Figure 1 shows polarization ellipses obtained on 19 Sept. 1972 in Bochum from skylight measurements at 0.6 μm. The sun's elevation was 39° while the sky was almost cloud free but very turbid and polluted. The fog was not uniformly distributed. In this figure the numbers beside each ellipse describe the degree of polarization, the ellipticity (positive numbers indicate right-handed rotation), and the angle of the major axis with respect to the instrument's coordinates.

In the sun's vertical, where measurements were obtained every 10°, the polarization was found to vary with the zenith angle of observation as is known from many other theoretical and observational studies. The circular component (second value) was found to be small where the polarization is large. The very large value of the circular component near the sun's position might also contain a relatively large error, since there the polarization is less than 10% (see Eq. 4).

More definite evaluation of our results will be possible once the error analysis of the entire instrument has been finished and theoretical results on the sky radiation have been obtained from multiple scattering calculations. Analyses of further measurements on completely clear and on uniformly covered skies are underway.

REFERENCES

Born, M., and Wolf, E. 1965. *Principles of optics* (3rd ed.). New York: Pergamon Press.

Jäger, F. W., and Oetken, L. 1963. Zur Theorie und Praxis der instrumentellen Polarisation. *Publik. d. Astrophys. Observ. Potsdam.*