7.8 Polarization Pattern of the Moonlit Clear Night Sky at Full Moon: Comparison of Moonlit and Sunlit Skies

The light of the night sky originates from the following main natural sources (in order of brightness): moonlight, stars and planets, the Milky Way, zodiacal light, airglow, and the light from these sources scattered by the earth's atmosphere. Unfortunately, light pollution from artificial city lighting also affects many sites' night skies. Most of these sources are weakly polarized, the airglow is unpolarized (Wolstencroft and Brandt 1974), and the skylight may be strongly polarized (Können 1985). In the polarimetry of the night sky the unpolarized airglow emission and the atmospheric scattering of light of bright sources (e.g. the moon) are unwanted, because the former causes a dilution of the degree of polarization, and the latter (the so-called "sky foreground") introduces a spurious polarization. The flux of these unwanted sources can be brighter than the source of interest, depending on direction and wavelength. At full moon, in extended regions of the sky around the moon and antimoon, the moonlight scattered and polarized in the atmosphere overwhelms all other sources of the night sky. This makes more difficult astronomical measurements, thus usually one must wait for moonless night to make delicate astronomical polarimetric measurements.

Although in the last decades several extensive polarimetric investigations of the night sky were carried out (e.g. Gehrels 1974), not much attention has been paid to the polarizational characteristics of the moonlit night sky. Therefore using full-sky imaging polarimetry, Gál et al. (2001a) checked experimentally the similarities between the polarization patterns of moonlit and sunlit skies.

Figures 7.8.1A-C show the spatial distribution of radiance I, degree p and angle α of linear polarization over the entire clear moonlit night sky measured in white light[1] for different positions of the moon. Figures 7.8.1D-F represent the same patterns of the clear sunlit day sky measured in simulated white light[2] for approximately the same positions of the sun as those of the moon in the night sky. Figure 7.8.2 shows the positions of the moon, sun, lunar/solar Arago and Babinet neutral points of the clear moonlit/sunlit night/day sky evaluated from the celestial polarization patterns in columns B,C/E,F of Fig. 7.8.1.

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[1] In order to minimise the time of exposure, the polarizational characteristics of the moonlit sky must have been recorded by a highly sensitive photographic film. Gál et al. (2001a) used Kodak Tmax P3200 (pushed up to 6400 ASA) black and white photoemulsion. Thus the polarization of the moonlit night sky could be measured only in white light, that is, I, p and α were averaged by the photoemulsion over the full visible range of the spectrum.

[2] As detectors Gál et al. (2001a) used Fujichrome Sensia II 100 ASA colour reversal film for sunlight recordings. The colour pictures of the sunlit skies were transformed to averaged black and white pictures prior to polarimetric evaluation.

Comparing the measured polarization patterns of the moonlit night sky (Figs. 7.8.1B,C) with that of the sunlit day sky (Figs. 7.8.1E,F), it can be confirmed that the polarizational characteristics of a moonlit night sky are practically identical with those of a sunlit sky if the position of the moon in the firmament is the same as that of the sun. The small differences between the measured polarization patterns and positions of the neutral points (Fig. 7.8.2) of the moonlit clear night sky at full moon and those of the sunlit clear day sky can be attributed (in order of importance) to

1. the probably different meteorological conditions (e.g. aerosol concentration) during the nighttime and daytime measurements,
2. the different local ground albedo at the places of measurement with different type of area,
3. the small differences ($|\theta_{Moon} - \theta_{Sun}| \leq 2^{\circ}$) between the solar and lunar zenith angles,
4. the different types of the detector (white light for moonlight, simulated white light for sunlight),
5. the slightly different polarizational state of moonlight[3] and unpolarized sunlight,
6. the different spectral features of moonlight[4] compared with sunlight.

The Monte Carlo method used by Adams and Kattawar (1997), for example, is able to model these differences for any input state of polarization.

These results are not surprising, because they follow from the theory of light scattering: Considering the structure of the celestial polarization pattern, it is all the same if the moon or the sun is the light source. Nevertheless also this must be experimentally proven, and the importance of the investigation by Gál et al. (2001a) is the presentation of the first comprehensive experimental evidence for this theoretical prediction.

The results presented in this chapter may have functional significance for arthropod navigation. For example, Kerfoot (1967) reported that the foraging

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[3] While the sunlight is always unpolarized, the moonlight is partially linearly polarized, and at full moon it is unpolarized (Dollfus 1961; Pellicori 1971). With the increase of the phase angle β, its polarization is negative, that is, its direction of polarization is parallel to the plane of sight. The degree p of negative polarization culminates at $\beta = 11^{\circ}$, then it decreases. At $\beta = 23.51^{\circ}$ the moonlight is unpolarized again. With the further increase of β the polarization of the moonlight becomes positive, that is, its direction of polarization becomes perpendicular to the plane of the direction of sight. In the positive range of polarization, the maximum $p = 8.7\%$ is reached on the first or second day following the fourth quarter. Then p decreases again until it becomes zero three days prior to and after the new moon. Following the new moon, p increases until its maximum of 6.6% one day prior to the first quarter. Following this stage, just the same way as after the full moon, p of the moonlight decreases to zero, then its angle of polarization turns over again.

[4] Moonlight is sunlight reflected from the lunar surface. It has nearly the same spectral composition as sunlight, but with a shift somewhat toward the red (Kopal 1969).

activities of nocturnal bees last as long as the moon stays above the horizon. Furthermore, several insect and crustacean species have been shown to use the moon as a navigational aid.

Desert ants of the genus *Cataglyphis* are exclusively diurnal foragers, but when experimentally tested at night, they take the full moon for the sun, and navigate according to what a time-compensated sun-compass would predict (Wehner 1982). However, what about nocturnal insects, i.e., species that usually forage at night? Even if they do not possess a moon-compass, they could use the moon and the nighttime α-pattern as a short-term compass which is calibrated anew each time the animals start a foraging journey (see e.g. Lambrinos et al. 1997). The relatively low radiance of the moonlit night sky may not be a serious limiting factor of the navigation by nocturnal insects, because field crickets (*Gryllus campestris*), for instance, can respond to polarization at intensities that are lower than that of the clear, moonless night sky (Herzmann and Labhart 1989). Crickets are active also at night and may orient on the basis of celestial polarization patterns during dawn and dusk, or even at night when the sky is lit by the moon. They perceive the skylight polarization in the blue with the dorsal rim area of their compound eyes.

Talitrid sandhoppers use sun- and moon-compass in their offshore-onshore orientation, that is, during their movements perpendicular to the shoreline (Papi 1960; Enright 1961, 1972; Papi and Pardi 1963; Craig 1971; Ugolini et al. 1999a,b), and it was suggested that they can use the celestial polarization pattern for this task if the sun is not visible (Ugolini et al. 1999a,b). The same could be true also at night during full moon, when the moon is occluded by clouds.

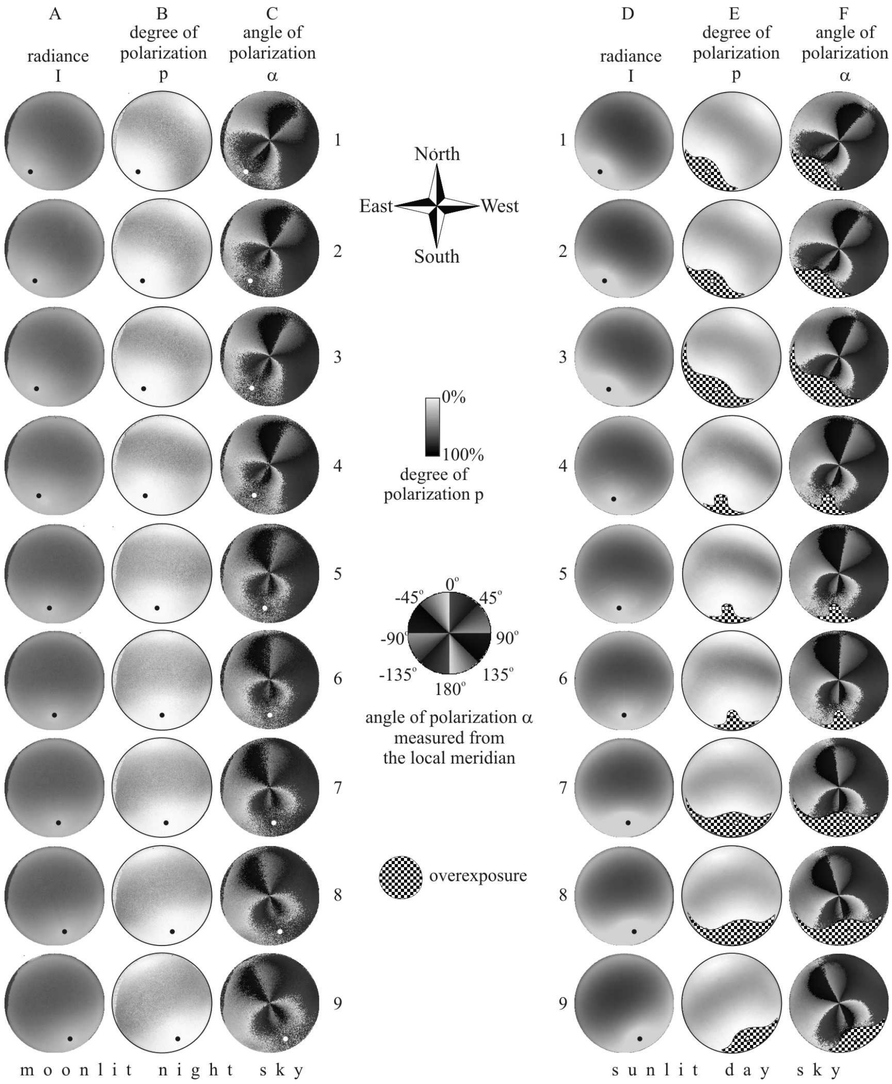

Fig. 7.8.1. A-C: Spatial distribution of radiance, degree and angle of linear polarization over the entire clear moonlit night celestial hemisphere approximately at full moon with a phase angle of 9°4' measured in white light for different zenith angles of the moon. D-F: As columns A-C for the clear sunlit day sky measured in simulated white light for approximately the same zenith angles of the sun as those of the moon. The checkered regions are overexposed. The positions of the moon and sun are indicated by black or white dots. East is on the left of the compass rose because we are looking up through the celestial dome rather than down onto a map. (After Fig. 2 of Gál et al. 2001a, p. 22650).

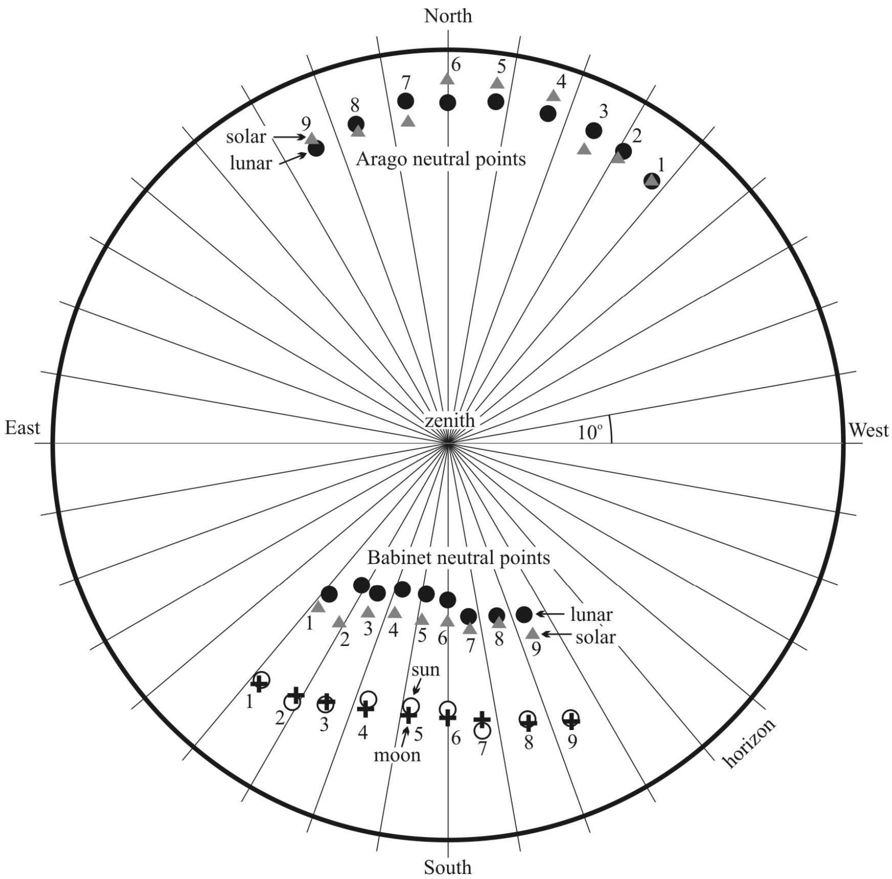

Fig. 7.8.2. Positions of the moon (crosses), sun (circles), lunar (black dots) and solar (grey triangles) Arago and Babinet neutral points of the clear moonlit/sunlit night/day sky evaluated from the measured celestial polarization patterns in Fig. 7.8.1B,C/E,F. The numbers next to the dots/triangles correspond with the row numbers in Fig. 7.8.1. (After Fig. 3 of Gál et al. 2001a, p. 22651).