

7.3 Video Polarimetry of the Arago Neutral Point of Skylight Polarization

The most important optical characteristics of the clear sunlit sky are well described by the Rayleigh theory (Coulson 1988). The fine details of skylight polarization, however, differ from the ideal Rayleigh model. This failure, called the polarization defect, is caused by multiple scattering, molecular anisotropy, scattering by aerosol particles, size distribution and particle shapes of aerosol, and the light reflected from the ground. One of the most remarkable feature of this defect is the phenomenon of the neutral points where the degree of linear polarization is zero.

Under normal clear atmospheric conditions, the only neutral points of skylight polarization are the Arago, Babinet and Brewster points located along the solar and antisolar meridian (see Figs. 7.4.1A,B). Although in his pivotal paper on sky colour and polarization Strutt (1871), alias Lord Rayleigh, provided a succinct theoretical explanation for the maximum polarization of skylight at 90° from the sun, he surprisingly did not mention the neutral points observed in 1810, 1840 and 1842 along the solar and antisolar meridian by Arago, Babinet and Brewster. These neutral points have been observed much more than any other characteristic of the skylight polarization. Hulst (1952) gave an approximate derivation for the angular position of these neutral points, which vary with the solar altitude, the wavelength and the haze aerosol composition. Neuberger (1950) suggested that the systematic observation of the Arago point would provide an appropriate index of atmospheric turbidity. Sekera (1957a), Holzworth and Rao (1965) and Bellver (1987) found a reasonably good correlation between positions of the neutral points and the intensity of air pollution. The positions of the neutral points are also strongly modified by clouds and debris from large volcanic eruptions, even for periods of several years (Coulson 1988).

Most ground-based observations of the neutral points were performed visually by means of the Savart polariscope (Coulson 1988). This simple device was widely used for more than a century. The neutral points can be detected and their position can accurately be determined by using the Savart polariscope. However, this polariscope is not well suited for determining the degree of linear polarization. Modern electronic point-source polarimeters use narrow band interference filters to determine the position of the neutral points for different wavelengths. Horváth et al. (1998b) measured the spatial distributions of the degree p and angle α of linear polarization within the areas of the neutral points by video polarimetry. They recorded the neutral points under clear sky conditions on 8 August 1996 in the vicinity of Metlaoui in the mountainous area of central Tunisia. This site and time was ideal for the measurements, because the atmosphere was very clear exhibiting a minimal amount of haze and aerosol. As

a consequence, p of skylight was high enough to allow video-polarimetric imaging of the neutral points.

Figure 7.3.1A shows a video picture of the sky in the region of the Arago point. It is obvious from Figs. 7.3.1A, 7.3.1B1, 7.3.1C1 and 7.3.1D1 that the positions of the neutral points are not correlated with the radiance of skylight. In contrast, the Arago point is clearly visible in the p -patterns (row 2 in Fig. 7.3.1) and the α -patterns (row 3 in Fig. 7.3.1). As it is clearly demonstrated in row 2 of Fig. 7.3.1, skylight is unpolarized ($p = 0\%$) at the Arago neutral point, and p gradually increases with increasing angular distance from the neutral point.

The patterns of the E-vector alignment in row 3 of Fig. 7.3.1 show that the direction of polarization is more or less vertical, that is, the polarization is negative between the Arago point and the antisun, but above the Arago point the E-vectors are more or less horizontal indicating positive polarization. Furthermore as can be seen in the patterns of E-vector orientation, polarization switches from negative to positive as one passes the neutral point parallel to the antisolar meridian.

Rows 2 and 3 of Fig. 7.3.1 clearly show that the Arago point is farthest away from the antisun in the blue. The measured angular distance β of the Arago point from the antisun is $\beta_{red} = 24.4^\circ$, $\beta_{green} = 22.4^\circ$, $\beta_{blue} = 29.3^\circ$ in the red, green and blue, respectively. Hence at the time of the video-polarimetric recordings by Horváth et al. (1998b) the Arago point was slightly closer to the antisun in the green than in the red. This exceptional situation was caused by the ground reflection of light.

Reflection from rough ground surfaces can introduce more or less vertically polarized light into the atmosphere. This effect enhances the region of negative polarization of the sky in those spectral ranges in which the reflectivity of the ground is high. At the site of the video-polarimetric measurements by Horváth et al. (1998b), in the vicinity of Metlaoui in central Tunisia the soil and the mountains had a typical reddish brown colour. Thus, the ground reflection (albedo) was high in the red. The consequence was that in the red a considerable amount of vertically polarized light was reflected from the ground, which enhanced the contribution of negative polarization in the atmosphere. Thus, the Arago point shifted slightly farther away from the antisun in the red.

Similar shift of the position of the Arago point due to reflection from snow or bright sand has also been reported by other authors (e.g. Können 1985; Coulson 1988). In such cases, however, the shift of the Arago point was observed in all ranges of the spectrum, because the ground reflection was high in all spectral ranges due to the whiteness of snow or sand. Reflection of light from huge water surfaces (lakes or sea) affects the position of the Arago point in the opposite direction. Light reflected from water surfaces introduces horizontally polarized light into the atmosphere in all spectral ranges, which enhances the region of positive polarization. This effect results in a shift of the Arago point towards the antisun in every part of the spectrum (Können 1985; Coulson 1988). Figure 7.3.1 shows the main characteristics of the Arago, Babinet and Brewster neutral points:

- their angular distances from the antisun and sun
- how their angular distances vary as a function of the wavelength of light
- how ground reflection affects their position
- what regions of positive and negative polarization occur around them
- there is no correlation between the positions of the neutral points and the radiance and colour distributions in the sky

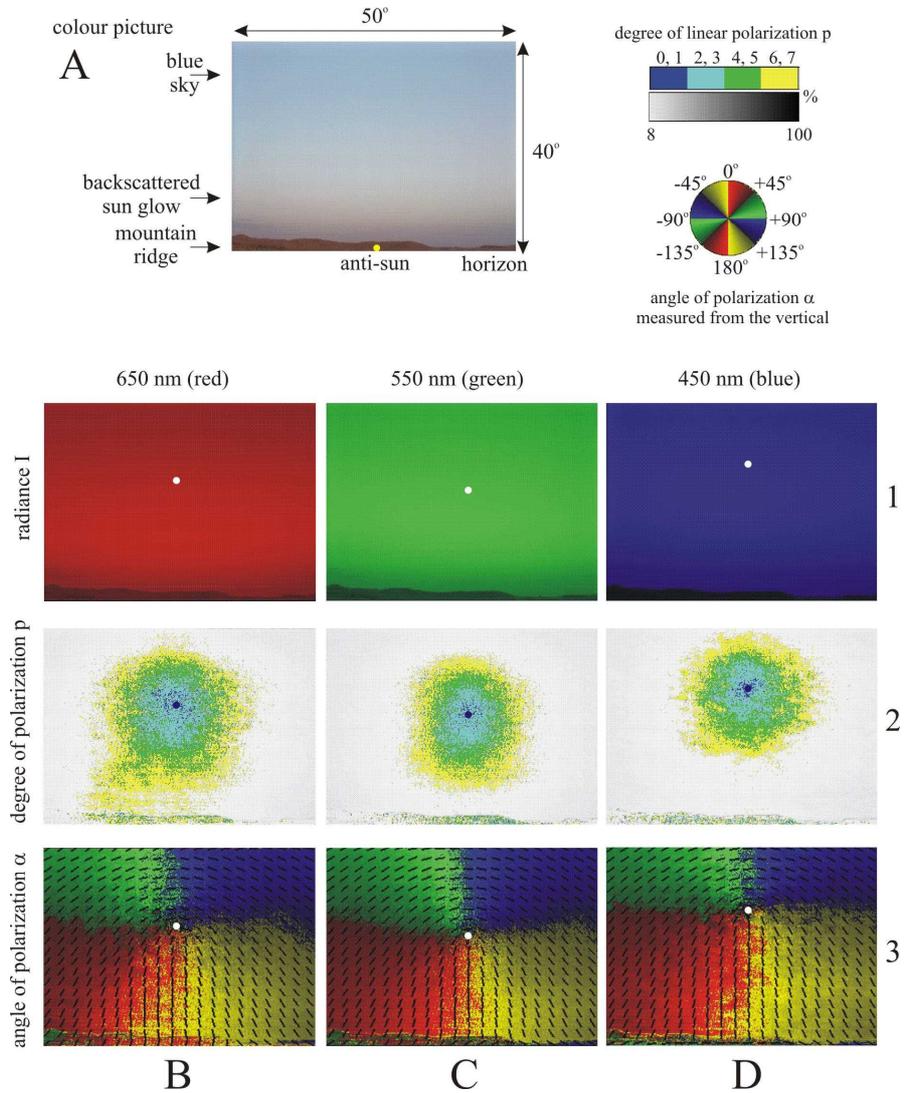


Fig. 7.3.1. Video-polarimetric imaging of the Arago neutral point of skylight polarization. A: Video picture of the sky around the Arago point. The position of the antisun is indicated by a dot. The horizon is demarcated by a mountain ridge. B-D: The patterns of radiance I , degree of linear polarization p and angle of polarization α of skylight measured by video polarimetry at 650, 550 and 450 nm. In the α -patterns any particular black bar represents the local orientation of the E-vector as averaged over a small rectangular region around the bar. The positions of the Arago point are indicated by dots. (After Fig. 2 of Horváth et al. 1998b, p. 336).