ASYMMETRIES IN LIMB DARKENING REANALYZED

G. H. ELSTE
The University of Michigan, Department of Astronomy, Ann Arbor, MI 48109-109, U.S.A.

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Abstract. The cause of the asymmetries in limb darkening reported by Neckel and Labs (1987) is discussed on the basis of new, stray-light-free observations, and found to be of instrumental origin.

1. Introduction


Early observers used special techniques to avoid and/or correct asymmetries in drift curves caused by the finite time constant of the receiver-recorder system. The best documented work is perhaps that by Pierce et al. (1950). With the improvement of the technology investigators became less concerned. The most surprising work is that of Wittmann (1978, 1980), who used the fast scanning technique in search for differences between equatorial and polar limb profiles. He found striking asymmetries in both, E–W and N–S scans, the preceding limb being always fainter than the following. No attempts were made to search for the cause, except by checking the mechanical drive. These asymmetries are very probably caused by the photomultiplier hysteresis, which is discussed in detail by Young (1974). The problem was given proper attention in recent limb darkening observations by Rosen et al. (1982), Petro et al. (1984), and Neckel and Labs (1989).

In the following we report about new limb-darkening observations obtained with a coronagraph. These do not show evidence of systematic differences between the two halves of a scan across the disk as found by Neckel and Labs (1987). A careful study of the repetition of their observed features with time leads to a possible explanation.

2. Observations

The new observations are carried out with a coronagraph to mainly suppress telescopic stray light. The correction for stray light in most solar telescopes is relatively uncertain. In this case the instrument is the coronagraph of the John Evans Solar Facility at the National Solar Observatory at Sacramento Peak. A small hole of 32 arc sec diameter at the prime focus ($f = 8$ m) practically eliminates telescopic stray light. Through a Coudé system the coronagraph feeds the 16 m Littrow spectrograph with entrance slit dimensions of $1 \times 28$ arc sec.

In order to minimize the effects of photomultiplier hysteresis and of the moment of...
inertia of the telescope, it is practical to use the slow scanning technique (290 s from limb to limb) rather than the drift curve technique. Data are obtained for steps of 1 arc sec in 0.15 s. The scanning is achieved by the computer controlled motion of the telescope guiding lens.

We use the image rotation, produced by the Coudé system, to scan in various fixed directions during the day, keeping the slit aligned parallel with the limb. A centering device and program provides for a precise disk center location before the start of each scan. A scan is carried out in four passes: No. 1 from the center to the NW limb for example, and 200 arc sec beyond; No. 2 goes back to the center, and continues without interruption as No. 3 to the SE limb and 200 arc sec beyond; finally No. 4 moves back to disk center. There the centering is checked, and scans with poor centering are discarded. The data sets also contain various other measurements like dark level, scattered light in the spectrograph, and disk center intensities without telescope motion.

In the scanning technique the extinction by the atmosphere constantly changes, firstly because of the change in zenith distance of disk center, and secondly because of the differential zenith distance of the scanning aperture with respect to disk center. In order to take into account the first, we simultaneously record the brightness of the entire disk and its immediate surrounding. A 100 Å bandpass interference filter, centered on the chosen continuum wavelength, eliminates the remaining wavelengths. The second variation is treated in the reduction program.

Two wavelengths were chosen to search for the possible variation of the limb darkening with time in the solar cycle. These are 4451.2 Å, already chosen by Petro et al. (1984), and 5011.5 Å, for which Wittmann (1978, 1980) found systematic asymmetries between opposite limbs. His observations were obtained with the Gregory–Coudé type telescope at Locarno, especially designed for low stray light. His results differ from those by Pierce and Slaughter (1977), obtained with the McMath telescope at Kitt Peak.

3. Reductions

In the reduction process we evaluate the change in the transparency for the varying differential zenith distance of the scanning aperture, and apply a proper correction. This depends on the angle between the direction of the scan and the zenith. How big can that correction become? Typical zenith transmission for 4451 Å is 0.82. For a zenith distance of 60 deg this gives a differential transmission between limb and center of the order of 0.2%. However, the order of scan directions is arranged in such a way to achieve the least change in zenith distance of the scan aperture during the limb to limb scan, pass 2 and 3. As an example, for a rising Sun this scan direction is downward. Thus for most of our observations the correction for varying transmission is considerably smaller than the 0.5% needed for telescopic stray light in the McMath telescope (Petro et al., 1984). It is important to remember that the correction for differential transmission is straight forward, which is not the case for the instrumental stray light.

The next important step is the precise determination of the location of the Sun’s limb