Mem. S.A.It. Vol. 76, 977

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Calibration of the Arcetri Solar Archive Images

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Abstract. The non linear characteristic curve representing the relation between intensity and the measured density obtained by the digitization process constitutes one of the major problems associated with quantitative photometry based on the use of photographic plates. This paper briefly describes the pre-processing and photographic calibration procedures applied to the images obtained by the digitization of the Arcetri solar archive. This archive contains about 13000 plates of full-disk Ca II $K_{2,3}$ and H_α spectroheliograms acquired at the Arcetri Astrophysical Observatory during about 5000 observing days from 1925 to 1974.

Key words. Sun: historical data – Sun: variability – Sun: magnetism

1. Introduction

The results obtained by the synoptic observations of the solar disk stored in historic archives provide a precious temporal baseline of several decades for the study of many solar properties. For example, these observations permit a variety of retrospective analyses of the state of solar magnetism, as well as they allow to deepen the role of the Sun on the climate change noticed during the last century.
In the last few years the increasing interest toward the recovery of early observations and new hardware resources drived on several projects to digitize existing solar archives. These projects permit the preservation of the archives content, but to allow the scientific exploitation of them, it is also indispensable to develop a dedicated and optimized processing for the images produced. This paper summarizes the pre-processing and photographic calibration procedures applied to the images obtained by the digitization of the Arcetri Astrophysical Observatory solar archive. Details about the digitization work carried out by the CVS (Centre for Study the Variability of the Sun) project at the Rome Astronomical Observatory, with the sponsorship of Regione Lazio, can be found in Marchei et al. (2005).

Table 1. Transmission values of the Zeiss K 58 step filter.

λ= 6000Å	100	72	45	28	19	11
λ= 4000Å	100	68	42	29	20	14

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2. The Arcetri Solar Archive

The Arcetri archive contains 12917 plates of full-disk CaII $K_{2,3}$ and H_α spectroheliograms acquired during 5042 observing days at the Arcetri G.B. Donati tower from 1925 to 1974 (Godoli e Righini 1950). One or more spectroheliograms were daily obtained in the two spectral bands, with an average number of observations of more than 100 observations per year for each spectral band. A description of the Arcetri instrument charactersistics at the time of observations is given by Marchei et al. (2005). In brief, the archive mainly contains plates with a solar disk image of $\approx$ 6.5 cm corresponding to an image scale of 0.033 mm/arcsec. The spectral window was 0.3Å centered at the CaII K line core. However, it is worth noting that several instrumental changes occured during the about fifty years of the spectroheliograph utilization. For example, on 23 Jul. 1938 started the testing of an additional field lens to improve the image definition. This lens has been definitively utilized starting from 20 Jan. 1939. In the same period also started the utilization of filters set upon the first slit. An UG_2 filter has been utilized for the $K_{2,3}$ observations from 15 Oct. to 30 Dec. 1938, then replaced with an UG_3 filter. A RG_2 filter has been utilized for the H_α observations from 15 Oct. to 29 Jul. 1939. Moreover, on 25 May 1953 the position of the 2nd slit has been modified, decreasing its position respect to the plate from 1.3 cm to 2 mm. This change allowed a remarcable increase of the observations monocromaticity and a decrease of the stray light.

We note down all the improvements occured because these mark a few discontinuities on the data collection, that anyway exhibits a rather remarkable homogeneity.

More than 30 different emulsions were used along the whole period of observations. The spectroheliograms obtained since 22 Feb. 1938 have been calibrated through a Zeiss K 58 step filter, whose transmissions are listed in table 1. At first, only one photometric mark was stored on the plates, by placing the Zeiss filter upon the first slit and gathering the radiation emitted from the solar disk center. Starting from Sept. 1947, two photometric marks were stored on the plates by changing the width of the first slit. From Aug. 1948, there have been three photometric marks stored on each plate: the first obtained with the radiation emitted in the CaII $K_{2,3}$ or H_α from the solar disk center, the second one in the radiation of the near-continuum to the line at issue, and the third one always in the same continuum, but by doubling the width of the first slit (Fig. 1). The velocity of driving motors which translate the photographic plate during the wedge exposition was equal to that utilized during the solar image exposition. Whether more observations were obtained during the same day, the calibration wedge was stored only on the lattest plate exposed. However, being all the plates obtained in the same day photographically processed at the same time, a sole calibration wedge can be used for all the specthroheliograms of the same day and photometric measurements can be performed as well through all the plates obtained on the same day.

The digitization of the archive has been carried out through the scanner Epson Expression 1680 Pro, with the setting 1200 dpi and 16 bit significant data. The instrument and settings allowed the scanning of plates in groups of four for most of the archive; each scanning produced a tiff format 8435×11153 pixel image (179 Mb). The spatial resolution due to the digitization is 0.62 arcsec/pixel. To get an homogeneous set of data, both the solar disk and the calibration step wedge, when stored on the plate, were digitized on the same image.

3. Image pre-processing

We describe in the following the procedures developed to analyze the images obtained by the digitizztion of the $K_{2,3}$ spechtrohliograms. For all these images, we ran a pre-calibration, semi-automatic procedure which produces images corrected for the scanner flat field. The flat field response of the scanner has been obtained at the beginning of each digitization session by taking an average image of the scanner fluorescent screen.

Then the sub-image corresponding to each plate has been singled out; couples of im-

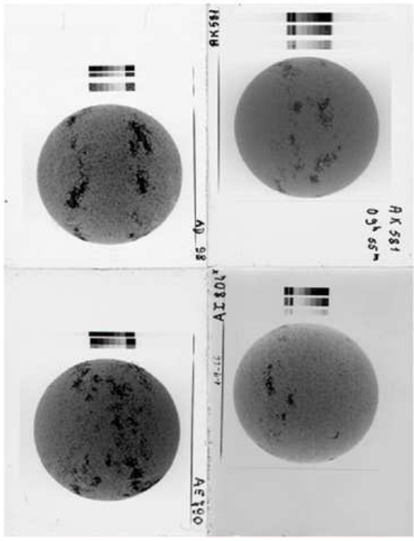

Fig. 1. Example of the images obtained by the digitization. Notice the lack of homogeneity in the upper calibration wedge, due to the intensity pattern on the solar disk center.

ages for each individual spectroheliogram, both in .fits (1020x1360 pixel) and .tiff formats (510x680 pixel) have been stored. The storing of 2k×2k fits format images is now being completed.

Whenever the calibration wedge is included in the plate, the pre-processing procedure also provides from 7 to 21 triplets of average and median transparency (or transmission, T) values, and the related standard deviations, on the wedge steps. These values are used to evaluate the calibration curve.

Given the large quantity of digitized plates we first tried to fully automatize the wedge identification procedure. However, the plates are very different one from the other: the Sun and the wedge show different shades and positions against the plate background, and their dimensions differ. We can notice a series of defects, such as lines, large-scale lack of homogeneity, scratches, and over-exposition, and all this makes it difficult to run successfully a completely automated procedure. So, the procedure developed for the identification of the subarray (3500x3500 pixel) containing the solar disk in

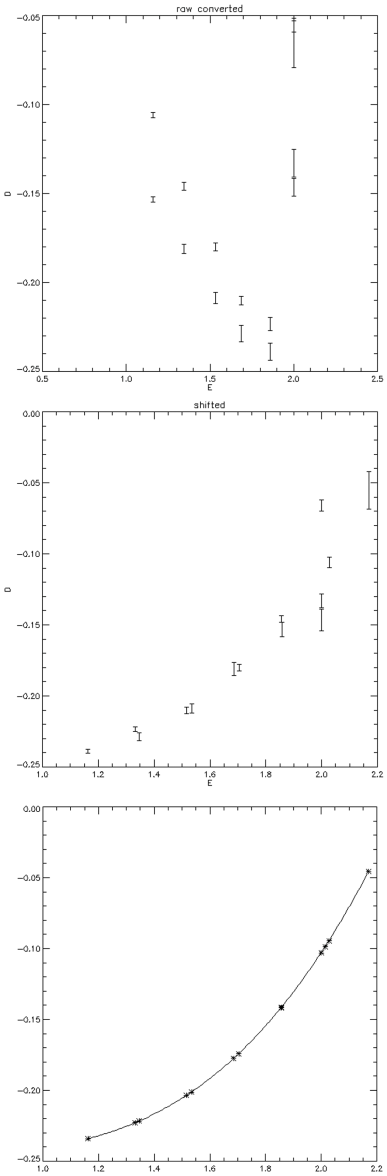

Fig. 2. The calibration curve is obtained as a 200×2 element matrix showing the correspondence between density $D = Log_{10}(1/T)$ (ordinate) and intensity (abscissa), as computed through a least squares third degree polynomial fit (bottom) of the suitably re-arranged (middle) measured density values D for the various expositions of the wedge steps (top).

the image, and for the calculation of median, average and standard deviation of transparency values in each step of the calibration wedge requires a check control.

The procedure single out a sub-array for each step, then calculates the transparency values listed above.

4. Photographic calibration

The determination of the linear characteristic curve representing the relation between intensity and the measured density obtained by the digitization process (Dainty and Shaw 1974) is considered in the following.

Whether the aim of the image analysis is an accurate measurement of the location and extent of spot and bright plages, a sophisticated photometric calibration is not necessary. To carry out these measurements we need only to be able to define edges of spot and plages by some transparency thresholds and to be sure that the location and area measurements derived are a bit sensitive to the possible calibration errors. However, while spots (as well as false spots produced by dust effects) and plages can be rather easily detected by the way of few thresholds in 'transparency', with respect to the local background of the solar disk, the contour of plage remnants and of active network are very sensitive to the 'transparency' threshold. Then the photographic calibration constitutes a key step for an accuate image processing.

Following Caccin et al. (1997), we evaluate the calibration curve, through the average values of transparency T and its standard deviation on the wedge steps. The calibration curve is obtained as a 200×2 element matrix showing the correspondence between density $D = Log_{10}(1/T)$ and intensity, as computed through a least squares third degree polynomial fit of the suitably re-arranged measured density values D for the various expositions of the wedge steps (Fig. 2). The curve computation has been applied to each plate that includes a calibration wedge. An average curve obtained by several calculated curves, has been applied to all the plates stored without calibration wedges.

5. Summary

We briefly described the procedures for both pre-processing and photographic calibration of the images obtained by the digitization of the Arcetri Solar Archive. As mentioned before more than half of the Arcetri plates include wedge calibrations. But this is not the term of other existing historic solar archives. For example, the plates of the Mt Wilson and the Kodaikanal archives, as well as those of the Sacramento Peak one obtained before 1993, do not include wedge calibrations. The Arcetri archive thus allows the optimization of calibration methods that are not based on the transparency values of exposed step-wedges, like those founded on the solar center to limb darkening or on the transparency distributions.

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