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From the minimum to the maximum: the quality of Rome-PSPT images

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Abstract. In response to the need for both measurement and interpretation of irradiance variations, two PSPTs (Precision Solar Photometric Telescope) have been designed and produced in the framework of the RISE (Radiative Inputs of the Sun to Earth) project, to provide high-precision (0.1%) photometric observations of the solar disk, with about 1 arcsec spatial resolution at three wavelength bands. As well known, these two PSPTs, installed at the Rome and the Mauna Loa Observatories, since 1996 provide daily observation of the Sun available to the community at the internet addresses http://www.mporzio.astro.it and http://www.rise.hao.ucar.edu. We present the results obtained analyzing the quality of the images acquired by the two PSPTs, with particular regard to photometric accuracy, spatial scale, scattered light level and temporal variations of the image quality.

Key words. Instrumentation – Image processing – Solar variability

1. Introduction

The PSPT is a small (15 cm) refracting telescope designed to provide high-precision (0.1%) photometric observations, utilizing a simple optical design to minimize scattered light contamination and an active mirror to reduce tracking errors. The PSPT telescope has been produced by NSO of Sacramento Peak as part of the RISE (Radiative Inputs of the Sun to Earth) project; since Rome Observatory participates to it, a PSPT has been installed at the Observatory in February 1996. From 1999 a second PSPT, operated by High Altitude Observatory, is working at Mauna Loa. The images obtained by the two PSPTs are calibrated and made available to the community at the internet addresses http://www.mporzio.astro.it/solare/index.html and http://www.rise.hao.ucar.edu. The PSPT concept and prototype are described in Coulter et al. (1994) and Ermolli et al. (1998) respectively. The current instrument operation is briefly described by Ermolli et al. (2001), with more complete description available at the OAR web page.

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The PSPT is designed to acquire full-disk solar images through a 2048 × 2048 CCD (yielding about 1 arcsec spatial resolution) in three wavelength bands with interference filters centered at the line center CaIIK (393.3±0.25nm), Blue continuum (409.2±0.25nm) and Red continuum (607.1±0.5nm). By the technical details of realization of the two telescopes, the database obtained is certainly unique for what concern photometric accuracy and continuity. It should allow detailed and systematic studies of all the geometric and photometric properties of magnetic features observed on the solar disk during the ascending phase of the current solar cycle. Nevertheless, what is in reality the accuracy of the data acquired up to now?

We present the results obtained analyzing the quality of the images acquired by the two PSPTs, with particular regard to photometric accuracy, spatial scale, scattered light level and temporal variations of the image quality.

2. Observations and data analysis

We analyzed 1kx1k images extracted from the archive of the daily observations carried out with the PSPT a the Rome Observatory (Ermolli et al. 1998, Centrone et al. 2001) from July 1996 to August 2002 on 1200 observing days (about 400 Gb of images). The images analyzed correspond to the full archive of observations available, i.e. sequences acquired to apply the flat-field calibration, snapshot photometric observations sum of 25 expositions obtained at the three wavelength bands in less than two minutes, snapshot single exposition at the three bands. However the results presented in the following concern the sub-sample of snapshot photometric observations acquired each day in sequence in less than two minutes.

The images analyzed have been calibrated for the instrumental effects (i.e. dark and flat-field corrections). Variations in the detector sensitivity ("flat-field") were determined using algorithm based on the "displaced image method" proposed by Kuhn, Lin and Loranz (1991); the algorithm is applied to 17 offset images of the solar disk, acquired with the same optical system used to observe the Sun.

The mean results obtained analyzing the Rome archive have been compared to those obtained by analyzing a sub-sample of images obtained during 40 observating days in 2000 and 2001 with the PSPT telescope at the M. Loa Observatory (about 2.5 Gb of images).

3. Results

3.1. Number of observations

The network of PSPT telescopes has been realized to get synoptic solar observations. In figure 1 we summarized the number of observing days obtained with the Rome PSPT since its first light. Note, during Summer 1997 occurred a substantial upgrade of the telescope, while during Summer 2001 occurred the move of the telescope to a new observing site.

3.2. Photometric accuracy

We have evaluated the pixel-to-pixel photometric noise level on the images acquired measuring intensity fluctuations in sub-arrays extracted by images of sunlight transmitted through a holographic Light Shaping Diffuser.

Besides, to evaluate the accuracy of the flat-field computation, we measured the mean intensity along thin annuli centered on the solar disk by original and calibrated images. As the CCD camera used on the PSPT reads out the images in quadrants through four separate amplifiers, the original, un-calibrated image exhibits a quadrant structure, with different intensity levels in the four quadrants. So, a measure of the effectiveness of the flat-field correction can be obtained analyzing how much of the quadrant structure remains in the calibrated images.

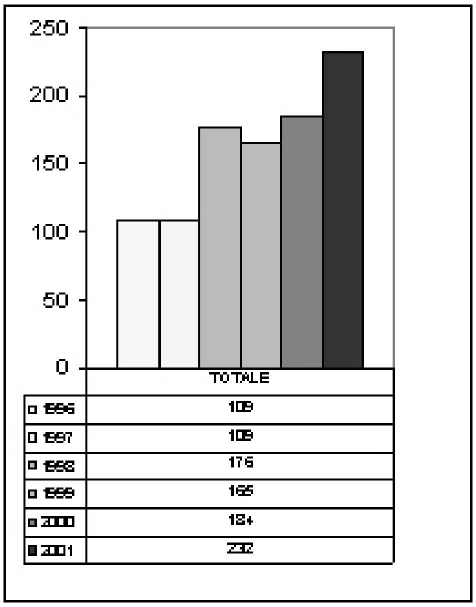

Fig. 1. Number of observing days obtained with the PSPT at the Rome site since its first light.

The results obtained are summarized in table 1.

3.3. Stray light level

The PSPT telescope utilize a very simple optical design to minimize scattered light instrumental contaminations. This important characteristic of the telescope has been verified analyzing the intensity profile in the solar aureola, i.e. the intensity distribution just out the solar disk. In figure 2 we show the intensity profiles obtained analyzing images acquired with the Red filter at Rome (M. Porzio, 2001, dashed; M.Mario, 2001, line; M.Mario, 1998, dotted) and M. Loa (dashed and dotted) sites.

3.4. Spatial scale

We performed the Fourier analysis on subarrays extracted at the disk center of the images analyzed, then studying the power

Table 1. Comparison of the results obtained analyzing images obtained with the Rome and the M. Loa PSPT telescopes.

filter	Rome	M. Loa
	diffuser	diffuser
CaIIK	0.9±0.02%	Not available
Blue	1.1±0.02%	Not available
Red	1.4±0.03%	1.5±0.12%
	Flat-field	Flat-field
CaIIK	0.74±0.20%	0.75±0.16%
Blue	0.25±0.13%	0.26±0.08%
Red	0.19±0.07%	0.17±0.09%

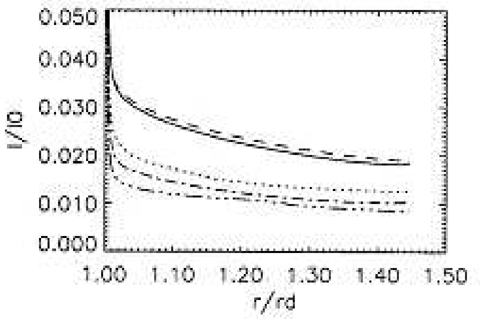

Fig. 2. Intensity profiles of the solar aureola obtained analyzing images acquired with the Red filter at Rome (M. Porzio, 2001, dash-dotted; M.Mario, 2001, line; M.Mario, 1998, dotted) and M. Loa (dash -3 dotted) sites.

spectra obtained. Besides, to evaluate the effectiveness of the active mirror used for the accurate pointing of the telescope, we studied the edge width of the solar limb.

4. Conclusions

Several tests were performed on the images acquired with the PSPT at the Rome

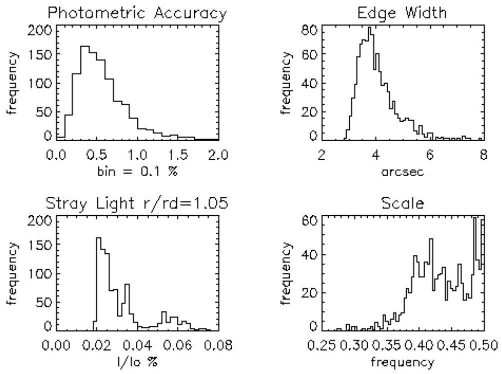

Fig. 3. Summary of the results obtained analyzing the Blue Continuum images acquired at the Rome site.

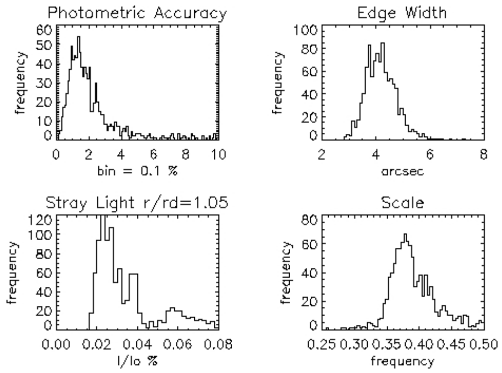

Fig. 4. Summary of the results obtained analyzing the CaII K images acquired at the Rome site.

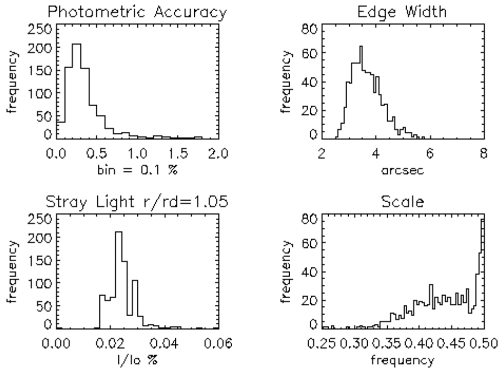

Fig. 5. Summary of the results obtained analyzing the Red Continuum images acquired at the Rome site.

Observatory to estimate the accuracy of the real data (Fazzari 2002), see figures 3,4,5 for a summary of the results obtained. On simulated images, the Kuhn et al. algorithm can recover a know flat-field to about one part in 10^4. This accuracy decreases up to 0.5-0.1% using the real solar images especially for those acquired under poor observing conditions (clouds, transparency variations, wind). The average spatial scale on the acquired images resulted of order 3 arcsec pixel; best values are obtained at Summer time, when poor observing conditions are occasional. Nevertheless, a substantial fraction of the database obtained with the Rome-PSPT is composed by particularly high quality images (i.e. about 2 arcsec spatial resolution and 0.1% pixel photometric accuracy), as required to measure small variations in the mean thermodynamic stratification of the solar atmosphere.

A seasonal variation of the data quality resulted analyzing the Rome images, probably due both to an image defocusing on the CCD camera and to the local seasonal variation of the sky transparency.

The preliminary analysis performed comparing the quality of the images acquired with the two companion PSPT telescopes at the Rome and the M. Loa sites shows the two data archives are quite comparable for what concern the image quality.

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