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THE MODERNIZED HORIZONTAL SPECTROGRAPH AT THE ONDŘEJOV OBSERVATORY

P. KOTRČ

Astronomical Institute, v.v.i., Academy of Sciences of the Czech Republic, Fričova 298, CZ–25165 Ondřejov, Czech Republic

Abstract. The large horizontal solar telescope 50/35000 cm has been changed from Czerny-Turner type to a multicamera system recently. The change of the diffraction grating from Baush & Lomb to the Richardson one enabled to use up to 5 CCD high-speed cameras working simultaneously in diagnostically important spectral lines (Hα, Hβ, HeI D3 and CaII H or K and CaIR 8542 Å). The Hα slit-jaw imaging system has been improved and another cameras operating in white light and for a full disk image taken in Hα were also implemented. The VDS Vosskuehler CCD cameras can sample several spectra and filtergrams per second in two modes (1280 x 1024 pxs, 12 bits, or 1280 x 512 pxs, 12 bits). The data are stored, archived and reduced to DF and FF in an offline regime. The observer and computer room has been moved to the basement of the pavilion to minimize possible interferences of the sensitive optical device. The observation system is flexible enough as concerns observations of dynamic phenomena of solar activity (flares, prominences, filaments, spicules, etc.). The description of the solar optical spectrograph can be found at the http://www.asu.cas.cz/~sos/ web page. Technical details of the spectrograph as well as first scientific results and plans are outlined and discussed.

Key words: Solar optical spectrograph - solar activity - observations

1. Introduction

The first solar optical spectrograph at the Ondřejov observatory is dated 1958 when a Multichannel Flare Spectrograph (MFS) was put into operation (Valníček et al., 1959). It detected spectra of solar flares and prominences on photographic plates sized 13 x 18 cm in spectral bands from Hα line through D3, Hβ, Hγ, CaII H and K and the higher members of the Balmer series up to the Balmer limit. The device was modernized several times (from electronic tubes to integrated circuits, from photographic plates through 35 mm film to first analog and then digital CCD video cameras), (see Kotrč et al., 1993; Kotrč, 1997). Due to the permanent worsening of the observing

Figure 1: The HSFA2 telescope is located in a new part of the Ondřejov Observatory, surrounded by forest at altitude of 500 m above sea level. To the right is the coelostat tower, to the left the telescope. The spectrograph pavilion is on the first floor and the controlling room in the basement.

conditions around the site of MFS, it was reduced to a simple spectrograph for testing filters, cameras and new optical systems. Solar spectral observations were moved to other Ondřejov observatory facilities. Nevertheless, both the photographic and the video archive of the MFS observations lasting until June 2004 are still a valuable source of solar activity spectra, see the http://www.asu.cas.cz/˜ sos web page.

2. HSFA Development and Modernization

In the 1960's a prototype of solar horizontal telescope with a Czerny-Turner spectrograph was developed to measure solar magnetic fields both using the photoelectric magnetograph and the photographic methods of detecting Zeeman effects (Bumba et al., 1976). Its optical schema has been used for the later horizontal telescopes and spectrographs.

Figure 2: Left: The Jensch-type coelostat consisting of two 60 cm flat mirrors is located $4-6$ m above the ground and is covered by a moving metallic shelter. Right: A look to the ϕ 32 cm flat mirror of the telescope and the upper mirror of the coelostat.

A small series of five HSFA (abbreviation from the German expression Horizontal Sonnen Forschungs Anlage, i.e. Horizontal Device for Solar Investigations) telescopes was designed by the Carl Zeiss Jena company according to the experience with the Ondřejov spectrograph and delivered to Czechoslovakia in 1980's. Two of the series (i.e. the HSFA1 which was used more or less as magnetograph, while the HSFA2 was dedicated to classical solar spectroscopy with high spectral resolution) were located in the new part of the Ondřejov observatory at about 700 m north of the solar department building. Some parameters of the HSFA2, including the instrumental profile, have been measured by Sobotka & Kotrč (1987). The device was used mostly for optical spectroscopy but also for near-infrared spectroscopy of quiescent prominences (see Heinzel et al., 1986). For a general view of the HSFA2 facility see Figs. 1 and 2. The main objective as well as the slit with the slit-jaw reflective mirror can be seen in Fig. 3.

After two decades of using the two large horizontal solar telescopes with spectrographs, both the HSFA1 and the HSFA2 underwent an important reconstruction. The original designation of the two instruments was mostly preserved. The HSFA1 stopped to be used for the measurement of magnetic and velocity fields, while HSFA2 was rebuilt to a multichannel spectrograph equipped with CCD cameras. The reconstruction of the electronic control systems was the most important task. The up-to-date electronic

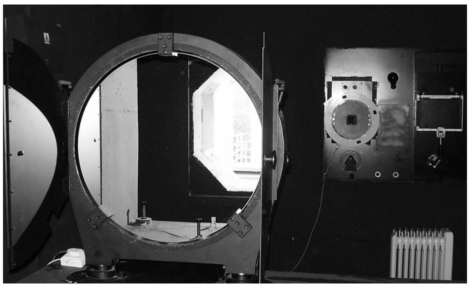

Figure 3: The HSFA main objective ϕ 50 cm, f 35 m is in the left. To the right is the entrance slit of the spectrograph with the rectangular reflecting mirror for the slit-jaw.

equipment enables a better control of numerous functions of the instruments. It is also resistive to disturbances caused by atmospheric electricity. While the previous system needed a full operator's assistance, the new telescope/spectrograph control system is designed to reduce and simplify the observer's work as much as possible. A concept for the reconstruction of the electronic control systems of the two large horizontal solar telescopes with spectrographs has been described by Klvaňa et al. (2001).

3. New possibilities

The spectrograph was rebuild from the Czerny-Turner configuration to the multicamera version, see Fig. 4. The goal of the rebuilding was to enable simultaneous spectral observations in several diagnostically important lines with the best possible spectral and temporal resolutions. We had to respect the limited width of the pavilion building. Therefore we carried out optimization of the imaging optics for CCD cameras with small chips for various options of the current and for a different diffraction grating (Kotrč & Kschioneck, 2003). We suggested an optical scheme with a folded pattern of beams, (the main camera mirror ϕ 200 mm, f 2500 mm) and put it in practice, see Figs. 4 and 5.

The lines were selected according to their diagnostic importance as well as the possible location in the spectrograph: Hα (6563 Å), D3 (5875 Å), Hβ (4861 Å), CaII K resp. CaII H (3934 resp. 3968 Å) and the CaII IR 8542 Å. Thus, instead of the one large photographic detector in the former spectrograph we have 6 CCD cameras. Five of them are placed at the lines

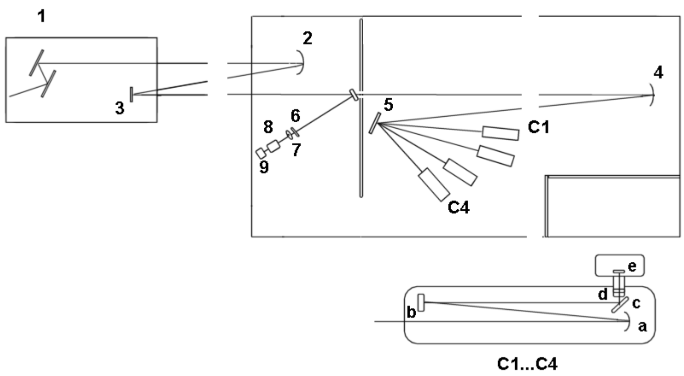

Figure 4: Optical schema of the HSFA2. 1 - ϕ 60 cm coelostat mirrors, 2 - main objective ϕ 500 mm / f 34850 mm, 3 - flat mirror ϕ 320 mm, 4 - collimator ϕ 250 mm / f 10000 m, 5 - diffraction grating, C1 ... C4 - cameras for individual spectral regions. Slit-jaw system: 6 - broad band filter, 7 - objective, 8 - narrow band Hα filter Day Star, 9 - CCD camera. Bottom right: Imaging systems for each of the four CCD cameras C1 ... C4 in the spectrograph: a - main objective mirror ϕ 200 mm / f 2500 mm, b - flat mirror, c - elliptical flat mirror, d - a slab for correction of astigmatism and coma, e - CCD camera.

and the sixth is in the new slit-jaw system with the monochromatic Hα filter, see Fig. 4. Next to it an auxiliary telescope with a video-camera giving information about position of the solar image in the slit plane is located.

The former Bausch & Lomb grating, C=632.1 mm^{-1}, width W=206 mm, height H=154 mm, angle of incidence φ=51^o, and with maximum intensity concentrated to the 4th order was replaced by the Richardson one, C=1200 mm^{-1}, width W=206 mm, height H=154 mm, blaze angle φ =17.5^o, and with maximum light concentrated into the 1st order. Therefore, after the grating replacement the spectral resolving power decreased from 521 000 to 247 000. Thus, the spectral resolution $\Delta\lambda$ for the Hα line is 26 mÅ while for CaII H or CaII K the spectral resolution is 16 mÅ. These values in combination with new small size detectors mean that the possibilities are quite satisfactory.

The fast CCD cameras VDS Vosskühler CCD-1300LN have pixel size of 6.7μm × 6.7μm, a chip size s=pH × pV=1280(H) × 1024(V) pixels and are combined with Matrix Vision grabbers. They are 12 bits and their controlling PCs are connected with the telescope/spectrograph controlling

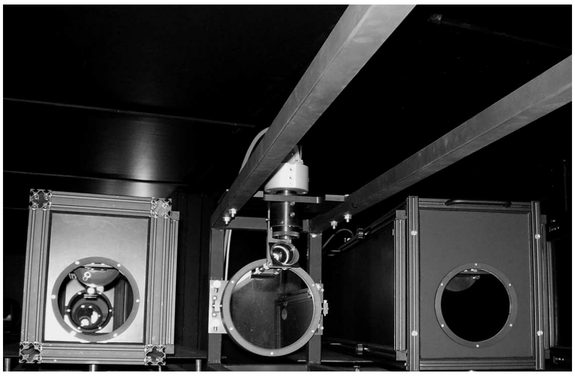

Figure 5: The main camera objectives ϕ 200 mm, f 2500 mm can be seen in the center through the metallic (usually covered by shielding) construction. Above it is the Vosskühler CCD camera.

server. The cameras can operate either in full chip resolution s =pH $\times$ pV=1280(H) $\times$ 1024(V) or with binning s1=pH $\times$ pV=1280(H) $\times$ 512(V). The second possibility increases the data acquisition frequency and the S/N ratio. Cameras can be handled either with an asynchronous or synchronous shutter, an have exposure range of 1/10 000 till 10 s, reading noise $\leq$ 14 e, saturation at $>$ 25000 e. The grabber contains a digital 12-bit output RS-644, the chip quantum efficiency reaches up to 50% in the region from 4800 Å till 5500 Å and then slowly decreases to near IR wave bands, see Fig. 6. The dynamic range is 1 : 2000.

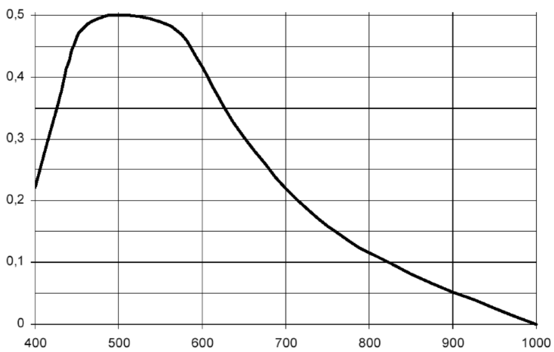

Figure 6: Quantum efficiency of the used CCD camera chip as a function of wavelength.

Before the reconstruction the observer controlled the spectrograph and telescope with a handbox near the entrance slit. Now his working place is a comfortable room in the basement of the pavilion to minimize man-made and PC-made vibrations and heating.

As compared with the MFS (Kotrč, 1997), the HSFA2 device brought several advantages as it was our first professionally-made instrument with better optics and electronics, and placed into better seeing conditions with minimal external disturbances, etc. As concerns the weaker points, the short depth of the pavilion can be mentioned as well as a limited usage when the outdoor temperature is less than 0 C due to oil viscosity in the hydraulic bearings as the Jensch coelostat is laid on oil seal.

The solar disk diameter at the primary focus is 35 cm. When this large size is combined with small CCD chip, fast orientation over the solar disk is difficult. Therefore the full solar disk is observed also with a small auxiliary telescope of 1 m focus through a Hα Coronado filter. Thus the observer has complete information what is going on at the solar disk.

Then, a linux server is connected to the data-acquisition PCs and daily observations are converted from internal *.dig files into *.fts files and moved to a disk field memory for further processing which also performs dark frames subtraction and flat-fielding.

4. Results and prospects

While comparing spectra and filtergrams of the MFS with those of the HSFA2 we notice a substantial improvement in almost all parameters, especially in spatial and spectral resolution. The dynamical range of the detected signal has improved from 8 to 12 bits. Though the temporal resolution has decreased from 25 to about 5 frames per second, it is still a satisfactorily rapid cadence when we take into account the high spectral resolution and dispersion, see Fig. 8. A key advantage of the HSFA2 is its continual readiness and availability for observations at the selected spectral lines anytime whenever the scientific interest needs it, e.g. when an ephemeral solar activity phenomenon appears on the Sun. The only limitations for observation are the weather, time of the day and season. A substantial improvement is also the decreased level of scattered light in the spectrograph and in the slit-jaw telescope, see the example in Fig. 7 and monitoring of the full solar disk in Hα filter.

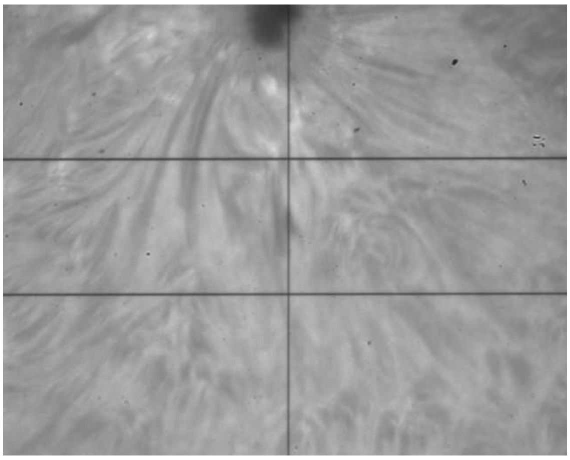

Figure 7: A raw image of active region on 4th July 2006 at 08:41:13 UT as observed through slit-jaw Hα filter (Day Star 0.5 Å University Series). Note the dark fibril on the central part of the slit.

There are still many plans to be realized, e.g. improving the quality of the spectral images, installation of a better entrance slit, enlarging focal lengths of the camera objectives et the shortest wavelengths to utilize the theoretical spectral resolution, a better handling and automation processing of the data. After improving and finishing these projects we would like to share all the data on the web on demands. However, it needs more time and funds. Nevertheless, when one compares the spectra obtained at the beginning of the HSFA2 testing operations with the latest images, see `http://www.asu.cas.cz/~sos/, years 2006 and 2007`, quite a good progress in many aspects has been achieved in a relatively short period.

The HSFA2 is still operated in a test regime to study its new parameters, to check all its weak points and find optimal solution for the further improvement. Nevertheless, the device has already actively participated in international coordinated campaigns as that for HINODE, TRACE, SOHO and Ground-based observations of quiescent prominences and filaments. HSFA2 provided calibrated Hα intensities in the prominence on 2007 April 25. Data were used for estimation of the Hα opacity and its correlations with intensities in EUV bandpass as observed by TRACE 195 Å , XRT and EIS (see Heinzel et al., 2008).

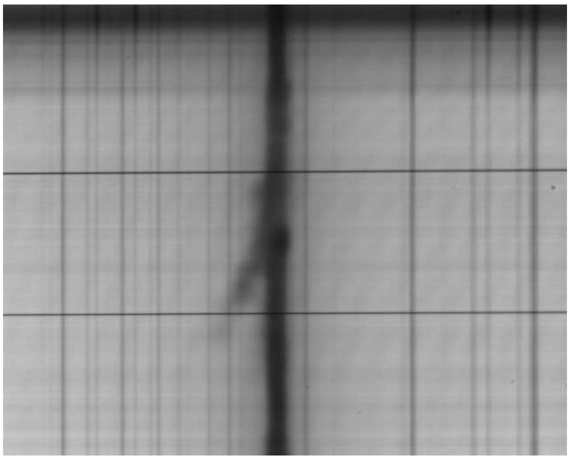

Figure 8: A raw Hα spectrum of the active region before flat fielding. Uprise and rotation of the above mentioned dark fibril is clearly visible.

Thus, the HSFA2 is a quite competitive in its availability, it offers a high temporal and relatively good spectral resolution, as well as the availability of other optical and radio observations at the Ondřejov observatory (see Kotrč et al., 1995; Ambrož & Kotrč, 2002). We consider the main HSFA2 targets as follows: Long sequences of ephemeral solar activity phenomena (flares, eruptive prominences, surges, filaments etc.) with high temporal and quite good spectral resolution can be observed. It is useful for special observations, for advanced spectral diagnostics and modelling of solar phenomena. HSFA2 participates in international coordinated observing campaigns, as e.g. for prominences and filaments. Ground based observations for support of space missions like Hinode etc. are attended. HSFA2 is also used for education and practical training of undergraduate and graduate students in spectroscopy as well as for testing of new observation and detection technics.

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