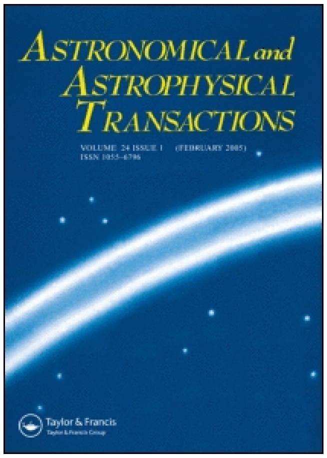

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Solar spectral observations at the Ondřejov Observatory with Moscow State University cooperation

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On the occasion of the 175-year anniversary of the Moscow State University Sternberg Astronomical Institute we would like to outline the history and some results obtained by the Institute in cooperation with the Ondřejov Astronomical Institute of the Czech Republic Academy of Sciences. The development and current state of this cooperation and the mutual solar observation results are presented. At the end of the 20th century, by a special international contract between the two institutes, one of the five Carl Zeiss new solar instruments, namely the 'Horizontal Sonnen Forschungs Anlage' (HSFA) was installed at the High-altitude Sternberg Institute Observatory near Alma-Ata. In the 1980s four other instruments were mounted in Czechoslovakia (two of them in Ondřejov and the other two in Stará Lesná and Hurbanovo). Both Ondřejov instruments (HSFA 1 and 2) were modernized over the period in the 2000–2004, mainly to improve their electronic control systems. A new spectral grating, corresponding optics and detectors were installed. The main parameters of the HSFA 2 instrument are compared with the same properties of the high-class instruments. The first observational results and several future plans are outlined.

Keywords: Solar telescope; Solar spectrograph; CCD-camera; Solar spectra; Interference filter

1. Introduction

The beginning of solar optical spectroscopy in Ondřejov should be dated to the middle of the 20th century. The first observation was that of a solar flare made by the spectrohelioscope brought to Ondřejov before World War II by Dr B. Šternberk from Stará Ďala (now Hurbanovo in Slovakia). In 1959 the Multichannel Flare Spectrograph (MFS) was installed in the new building of the Ondřejov solar department [1]. This tool permitted the photographing of solar flare and prominence spectra in 7 wavelength bands over the whole solar spectrum from the Hα line up to the CaII K lines, the higher Balmer lines and the continuum.

The MFS possessed a sufficiently high aperture, namely 1:58, to allow short exposures such as several tenths of a second for flares up to about several seconds for prominences. In the following years the MFS, named familiarly 'laborka', was permanently modernized.

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For this purpose, special control electronic tools as well as a device to obtain the Hα line photographic image of the solar chromosphere on the slit of the spectrograph, were elaborated. The installation of film cameras permitted passage from photo plate registration to 35 mm film. Later in the 1990s, analogue CCD video cameras were installed. The new small-size detector demanded also changes to the optical elements of the spectrograph. The initial conception of the tool and its future changes are described in [2] and [3]. Installation and the early observational work using the solar spectrograph and lately the magnetograph, supported by theoretical investigations, permitted the interpretation of many solar spectra.

In 1976 the east German firm Carl Zeiss Jena, with help of the Czech Academy of Sciences, elaborated a small series of HSFA instruments. In the 1980s two such horizontal solar telescopes were installed in the Ondřejov Observatory, namely HSFA 1 and HSFA 2. The third tool HSFA 3 was supposed to be used as a laboratory tool for carrying out experimental work in the Ondřejov Space laboratory. Aftersome negotiations a bilateral agreement between the Moscow State University and the Czechoslovak Academy of Sciences was signed in 1986, and HSFA 3 was allocated to the Moscow partner to install in Kazakhstan, near Alma-Ata. Over the period 1989–1994 the HSFA 3 was installed in the Zailijskij Ala Tau Mountains at the Sternberg Astronomical Institute High-Altitude Station. Here a special site for the instrument was chosen which, it was hoped, would enable good solar image quality in the southern direction due to the steep slope towards the large cold mountain Alma-Ata Lake. Here, quite near to the Zeiss Coudé refractor, a special dome for the HSFA 3 was prepared together with a hydraulically operated special cover for the coelostat.

Unfortunately, it was possible to make only a preliminary adjustment of the telescope optics to obtain the first test spectra, because the Kazakhstan Republic nationalized the HFSA 3 together with the all items belonging to the Moscow State University.

The two other HSFA instruments were installed in Slovakia, one of them in Stará Lesná at the High Tatras foothills at the new site of the Slovak Academy of Science Astronomical Institute. The fifth one appeared to be the best of all the instruments: during its manufacture it was possible to take into account the experience gained with the four other instruments in both manufacture and operation. This best instrument was installed in a fine pavilion of the Hurbanovo Observatory.

The construction of all the HSFA instruments was based on the experience gained using the rotating spectrograph and magnetograph gathered in the Ondřejov Observatory in the 1960s. The basis of this tool was the fifth model of the Astronomical Coelostat Tool made in the USSR. Separate parts of such a rotating spectrograph were made in Czechoslovak Machine-building Factories. The optics were partly made in Czechoslovakia, and partly in the USSR using cervit, a special type of glass with low factor of expansion (in Russian – sital). The electronic control system was made in Czechoslovakia. The device was used as a photoelectric magnetograph, and allowed to Dr P. Macák to make detailed measurements of the strong magnetic fields in large sunspot groups.

The opportunity to rotate this spectrograph for scanning and photographing of the various objects on the solar disk was, unfortunately, not always possible because of mechanical and design problems. Each attempt to observe a new object required the operator to undertake a number of difficult tasks to adjust the whole system.

2. Installation of the HSFA 2

After 20 years of the magnetograph and telescope usage the research work was stopped. It was decided to use the historically first special professional instrument, made by the famous firm, to carry out only solar spectral observations. The concept and technical project specification of the instrument was elaborated by Dr V. Bumba and Ing. M. Klvaňa together with a group of Carl Zeiss Jena experts. Later, when it was decided where both tools should be installed, the company 'Průmstav' (Kolín) started to work. Dr P. Ambrož organized this work.

After instrument installation was done, the first high quality results were obtained in the 1990s. However, both instruments were not often used, because a new research possibility occurred at the new solar observatory in the Canary Islands. The basic observations at this time were made by means of the Ondřejov Multichannel Flare Spectrograph.

3. Modernization of HSFA 2

At the beginning of the 21st century it was decided to modernize the HSFA1 and HSFA2 spectrographs because the control electronics made by the Hungarian company 'Vilati' (Budapest) became old and ceased to work. The work was sponsored by a grant from the Academy of Sciences of the Czech Republic, and carried out by the company 'Space Devices' (Praha). Ing M. Klvaňa [4] formulated corresponding requirements for the electronics. A digital CCD cameras produced by 'Vosskuehler' replaced photography of the spectra. The software was prepared by the observatory staff and Prague Charles University students.

In comparison to the above mentioned MFS [3], HSFA 2 presents both strong and weak points. Perfectly made optics is the positive point; also, telescope location in an astroclimatically better place (see figure 1). The weak points are: the limited size of the spectrograph room and the problems arising due to coelostat management, involving restrictions on what is connected to the hydraulics in cold seasons. The spectrograph optics change was necessary to observe different spectral orders to reach the maximum spectral and time resolution. For this purpose, spatial modelling and recalculation of the optical system to suite the new diffraction grating was made [5]. Later this optical system was revised (see figures 2 and 3). For the time being the following spectral lines are being used to observe solar events: Hα (6563 Å), D_3 (5875 Å), Hβ (4861 Å), CaII K or CaII H (correspondingly 3934 and 3968 Å).

Thus, the HSFA 2 instrument, previously being of the Czerny-Turner type, now became a multi-channel one. Instead of only one photographic plate, now there are 5 CCD cameras. Four of them to register the corresponding spectral line, and the fifth one to look at the solar chromosphere structure on the spectrograph slit. The diffraction grating was replaced by one from Bausch and Lomb, $C = 632.1\,\mathrm{mm}^{-1}$, width $W = 206\,\mathrm{mm}$, height $H = 154\,\mathrm{mm}$, the reflection angle is 51° and the maximum light in the fourth order to the Richardson grating, $C = 1200\,\mathrm{mm}^{-1}$, width $W = 206\,\mathrm{mm}$ and height $H = 154\,\mathrm{mm}$, with the maximal blaze angle 17.5°.

The maximum of light concentrates in the first diffraction order. The CCD cameras are placed in the spectrograph room and illuminated by the four camera telescopes to use the maximum of the chip surface and to obtain the maximum spatial and spectral resolution (see figure 3). The CCD cameras (VDS Vosskuehler CCD-1300LN) have pixel size 6.7×6.7 microns, the size of the chip $\mathrm{s} = \mathrm{pH} \times \mathrm{pV} = 1280\ (\mathrm{H}) \times 1024\ (\mathrm{V})$ pixels. The signals from the CCD cameras enter the computer through an input card made by Matrix Vision.

All computers and the CCD cameras are connected to a network (switch A) and enter the same personal computer (see figure 4). The CCD cameras may be used in both asynchronous and synchronous mode over the range from 1/10000 up to 10 s. The input card has a 12-bit output on the an RS-644 interface, and the dynamic range is 1:2000.

Each personal computer clock is synchronized by a radio signal (dcf). The image from each personal computer can be displayed on the monitor using the switch (B) in the observer room and in the spectrograph room as well. To obtain operational information about solar disk events a small telescope 'PST Coronado' together with the narrow band Hα ($\Delta\lambda < 1$Å) filter is used.

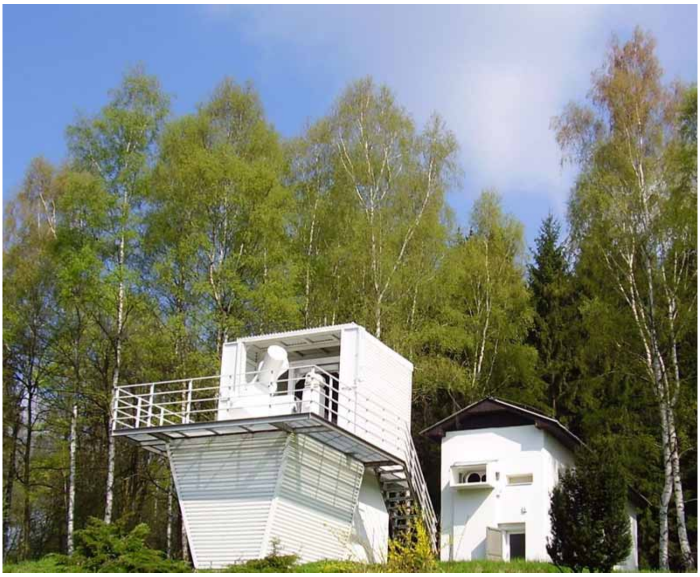

Figure 1. General view of the HSFA 2 from the south. The telescope is located at a height of 500 m above sea level in a woody district of the new part of the Observatory territory. On the left is the Jensch coelostat at a height about 4–6 m above the ground; on the right, the spectrograph pavilion.

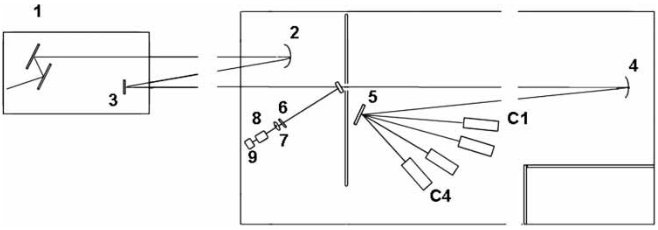

Figure 2. The optical system of HSFA 2: 1 – The Jensch coelostat. The diameter of both flat mirrors is 60 cm; 2 – the main objective of the telescope (diameter 50 cm and focal length 35 m); 3 – the additional flat mirror (diameter 25 cm); 4 – the collimator mirror (diameter 25 cm and focal length 10 m); 5 – the diffraction grating. The control system of the solar chromosphere image position on the spectrograph slit: 6 – the glass filter, 7 – the main objective, 8 – the narrow-band filter Hα, 9 – the CCD camera.

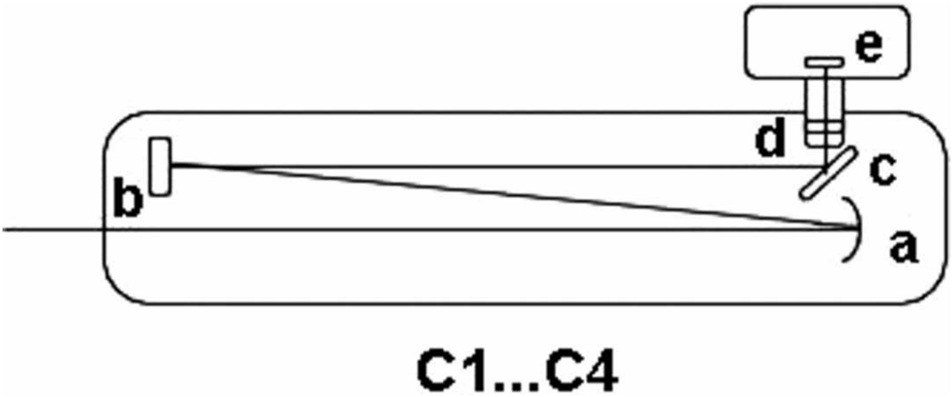

Figure 3. Optical feed system for the four CCD spectrographs C1... C4: a – the main objective, b – the flat mirror, c – the elliptic flat mirror, d – the plate to correct the astigmatic error and coma, e – the CCD camera.

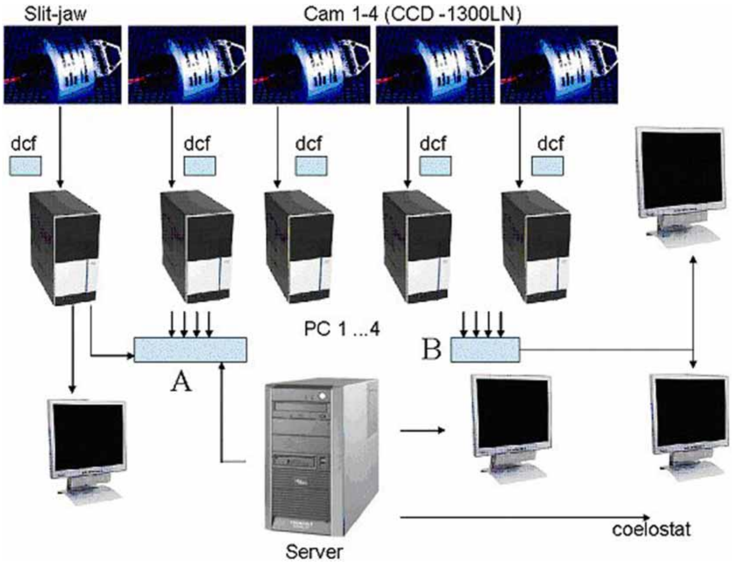

Figure 4. Diagram presenting the connection of the four CCD cameras to the controlling server.

Thus, the observer can see the solar chromosphere image on a monitor screen in real time. In contrast to the old observer's place (close to the spectrograph slit), after the reconstruction the observer sits in the basement room of the spectrograph and has a comfortable opportunity to operate the telescope.

4. Conclusions

All the above-mentioned modernizations have been performed by the Space Device Company at Prague, Ondřejov Observatory staff and Yu. A. Kupryakov from the Sternberg Astronomical Institute, who regularly participated in seasonal observations.

Comparison of the resulting solar images obtained during recent years by the multichannel solar spectrograph with those observed by HSFA2, reveals the improvement in spatial and spectral resolution of the observed objects. The dynamic range of signal detection has increased almost tenfold if one compares the analogue 8-bit receivers to the 12-bit digital cameras. If the time resolution has thus worsened, an opportunity to obtain about five pictures per second with high spectral resolution seems to be quite acceptable (see figures 5 and 6). The opportunity to observe any chosen area of the Sun, in practically all spectral lines, together with the simultaneous image of the corresponding area of the solar chromosphere on the spectrograph slit, allows one to solve many interesting problems, especially concerning ephemeral solar active phenomena.

The observational results progress may be estimated from the archive data presented on the site ⟨ http://www.asu.cas.cz/∼pkotrc/index5.html⟩. From the same site it is possible to receive from the authors of this article detailed information on the tool, observational results and data in the *.fts files format, suitable for further processing.

Regarding future plans, in the near future we hope to improve the quality of the optical system (e.g. to reduce aberrations), to make automatic calibration of the spectra and to start a new server, which will allow simplification and speed-up of data transmission and to improve their archiving.

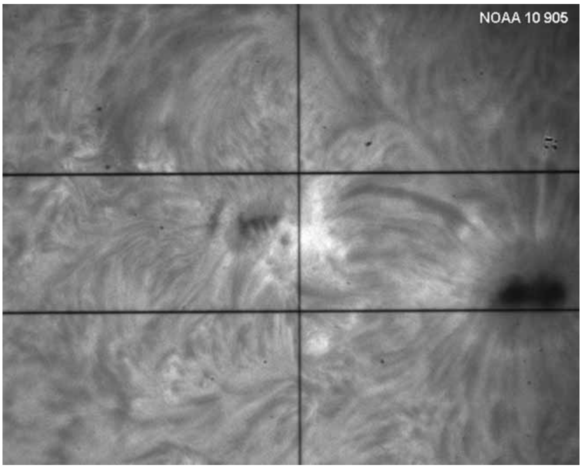

Figure 5. Solar active region NOAA 10905 24.8.2006 at 08 : 10 : 06 UT obtained through the interference filter 'DayStar' ($\Delta\lambda = 0.1$ Å).

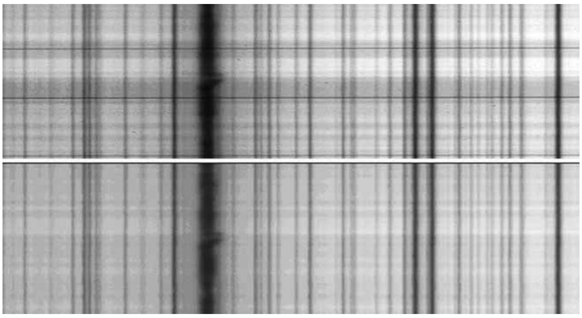

Figure 6. The Hα spectrum of the same active region before the flat-fielding correction (top). Bottom: the same region after the flat-field correction.

To obtain a long-term series of solar active events with high spatial and spectral resolution, and also the continuation of participation in the international observational programs are our priorities.

Over the last 20 years more then 20 papers have been published by scientists from both institutes. They have taken the opportunity to contact and participate in a number of collective observations [6–8].

Unique, almost regular, elliptical features were observed in the Hα spectra in the 15 May 2000 eruptive prominence [7]. These features were interpreted in the frame of the axially symmetric model of eruptive prominence. Circular rotational velocities from 7 up to 60 km/s and expansion velocities around 30–44 km/s, together with global velocities up to 160 km/s of the prominence plasma were derived.

The 1 October 2001 eruptive prominence, observed by TRACE in the 171 Å line together with the Ondřejov Hα spectra and spectroheliogrammes were presented in [8]. The evolution of this prominence was described and its velocities at several points were determined. It was found that, after the rising phase of the cold loop-like prominence, its upper part expanded and below this expanding part, around one of its legs a 'ring' structure, visible in the TRACE images, was formed. Then, at the same place, a tearing of the prominence leg was noticed. Simultaneous spectral observations of this structure reveal a very broad Hα line, what indicates strong turbulent motions. An expanding Hα envelope accompanied these processes. Due to the similarity of the observed 'ring' and tearing structures with those modelled by Lau and Finn, the prominence leg tearing is interpreted as a reconnection process between the two parallel magnetic ropes having parallel electric currents, but anti-parallel axial magnetic fields.

Acknowledgements

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