

INNOVATIVE SPECTROHELIOGRAPH

Svetoslav Zabunov^{1✉}, Garo Mardirossian¹, Nadia Marinova²

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Abstract

The current article presents an innovative design of a spectroheliograph instrument developed at the Space Research and Technology Institute – Bulgarian Academy of Sciences. Currently, the device is being built in prototype form and is to enter testing phase soon.

The innovation is in the automation and computer control of the spectroheliograph apparatus invented in 1892 and in use since for observing and photographing the solar disk in narrowband light from near infrared to ultraviolet light wavelengths. The innovation disclosed in this paper involves computer control and automation of all functions inherent to spectroheliograph instruments along with other operations of the coupled telescope. The novel device also performs all image gathering and processing procedures using the same computer unit thus minimizing its cost, size and power consumption. Our instrument has motorized control of all possible adjustment points, control of a sunscreen protecting the optical system, image generation and processing, and performs automated observations in different absorption lines (different wavelengths) consecutively by a preset plan.

Key words: computer operated spectroheliograph, solar light absorption lines observation

Introduction. For many years scientists needed, in favour of their scientific studies and research, detailed observations of the solar disk in narrowband light throughout the visible, near infrared and ultraviolet spectrum. The first technology to offer such capabilities was the spectroheliograph instrument developed at Meudon, on the outskirts of Paris [1].

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The prominent French astronomer Jules Janssen was appointed director of the newly established astrophysical observatory at Meudon. The observatory was funded by the French government. Janssen produced the notable series of solar photographs. Those were later collected in *Atlas de photographies solaires* (1904). At Meudon and under the auspices of Jules Janssen in 1892 Henri Deslandres started work on imaging spectroscopy. He developed the spectroheliograph instrument. On Janssen's death in 1907, Deslandres became director of the observatory. Deslandres was the President of the *Société Astronomique de France (SAF)*, the French astronomical society, from 1907 to 1909 [2,3]. The spectroheliograph was invented concurrently and independently by George Hale in Kenwood (USA).

The spectroheliograph device is designed for monochromatic very narrow-band imaging of the solar atmosphere (less than $0.3 \text{ \AA}$ bandwidth). Deslandres developed two types of spectrographs – the *spectrohéliographe des formes*, which was the narrow bandpass instrument. It revealed structures in the chromosphere such as filaments, prominences and active regions. The second instrument was the *spectrohéliographe des vitesses*, i.e. the section spectroheliograph to record line profiles of cross sections of the Sun with a spatial step of $20''$ – $30''$. This apparatus was able to measure Doppler shifts of dynamic features. Deslandres finished his large quadruple spectroheliograph in 1908. Systematic observations of the Ca II K line started in 1908 and H α line observations followed in 1909. These observations continue to this day. Optical and mechanical redesign was carried out in 1989 and digital technology was implemented in 2002. The collection of data gathered through the years is large. It comprises more than 100 000 observations. Sporadic images taken between 1893 and 1907 may be found during the development phase. The systematic observations cover 10 solar cycles since 1908 in H α and Ca II K lines.

The spectroheliograph. The spectroheliograph is an optical instrument that comprises an optical telescope (refractor or reflector), a narrow slit situated at the telescope focus plane, a collimator lens, a prism or diffraction grating, an imaging lens (camera lens) and an imaging screen, photographic plate, photographic film or camera.

The whole instrument is mounted on an astronomical telescope mount in order to be directed towards the Sun. Another method used with large and heavy spectroheliograph instruments is a mirror system that directs the sunlight towards the device instead of rotating the device itself. The telescope is focused in such a way that the Sun image is projected in its focal plane where the slit is installed. The image of the Sun, which is circular, covers the slit and only a single line (a stripe) of the image may pass through the slit at a time. By scanning the solar disk line by line a whole solar disk image is reconstructed either on photographic plate or digitally using a camera and a computer.

Once the light has passed through the slit it enters a collimator lens. Its purpose is to make the light rays parallel. These parallel light rays strike a prism or

diffraction grating and are dispersed in relation to their wavelength. The dispersed light is projected using a focusing lens onto a photographic plate or digital camera sensor. In the latter variant, the image of a single stripe of the solar disk is digitized and stored in computer's memory. Then the next stripe is digitized and stored, and so on. The final image is made of many stripes. Due to light dispersion, only a very narrowband light is recorded at the desired wavelength of light. General optical lenses and telescopes are applicable to the light spectrum starting from near infrared light and ending in the low frequency ultraviolet light. For other wavelengths special optics are required (Fig. 1).

Spectroheliograph observations. The most popular observations using a spectroheliograph are done on the Fraunhofer lines of the solar atmosphere (Fig. 1). The Fraunhofer absorption lines in the light spectrum are visible as dark spectral lines. They are seen in the optical spectrum of the Sun. Fraunhofer lines are formed when the solar atmosphere absorbs light emitted by the solar photosphere. The lines were observed in 1814 by and named after the German physicist Joseph von Fraunhofer. The most studied solar lines are the H α and Ca II K lines. H α emission is observed mostly from solar flares while absorption

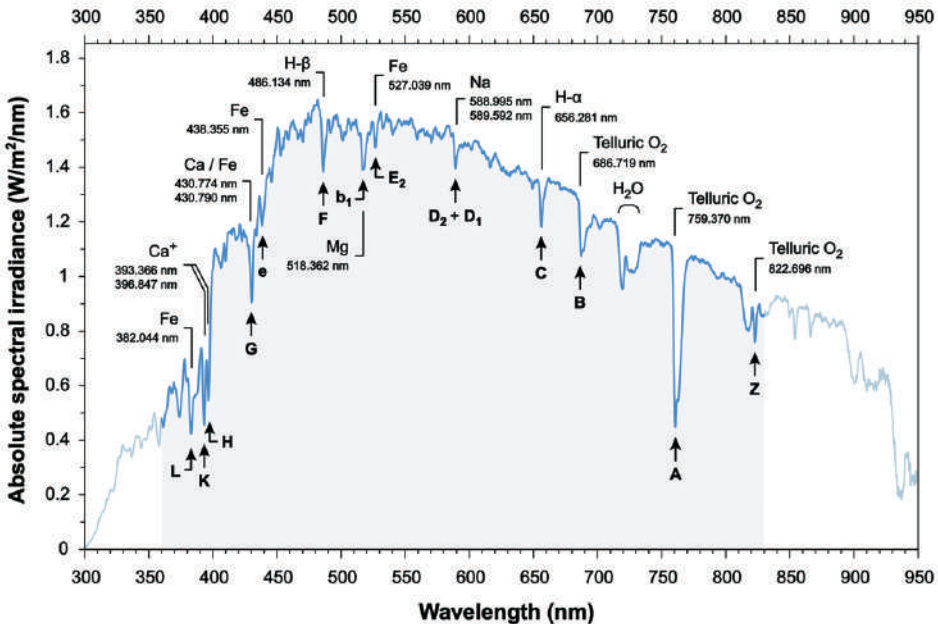


Fig. 1. Sun spectral irradiance measured with a calibrated spectrometer (Flame S-XR1-ES, Ocean Insight). The measurement was made on a sunny day on 13th of June 2022 at noon from Hauterive, Switzerland (47° 01'N 6° 58'E). For photometry and colourimetry, standard measurements are usually carried out in the range 360–830 nm (highlighted area). Correlated colour temperature (CCT): 5470 K. Image Author: Cyamahat (on wikipedia.org) licensed under the Creative Commons Attribution-Share Alike 4.0, CC BY-SA 4.0 (<https://creativecommons.org/licenses/by-sa/4.0/deed.en>)

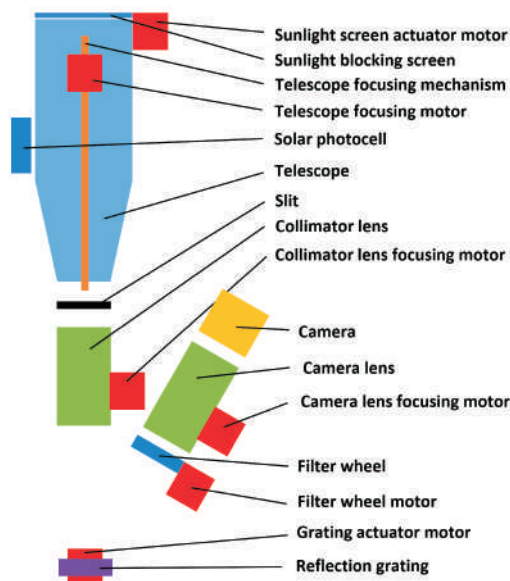


Fig. 2. Innovative computer controlled spectroheliograph component and functional diagram

lines are originating from the solar chromosphere [4]. Doppler shifts may also be observed using a spectroheliograph – the spectral line under examination has certain width. All information near the line, but slightly offset to the left or to the right is Doppler shifted to a certain degree that is easy to calibrate for each spectroheliograph instrument [5].

Innovative spectroheliograph. The innovative design of the disclosed spectroheliograph was developed at the Space Research and Technology Institute – Bulgarian Academy of Sciences. Currently, the device is being built in prototype form and is soon expected to be tested.

The device component and functional diagram is presented in Fig. 2 while its block diagram is shown in Fig. 3.

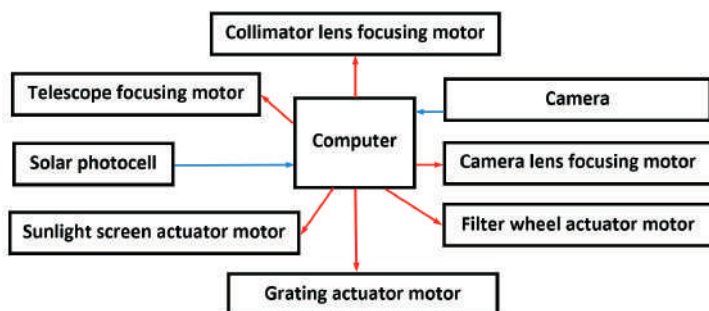


Fig. 3. Innovative computer controlled spectroheliograph block diagram

The instrument consists of a refractor telescope with absolute aperture between 80 mm and 125 mm. A telescope having smaller aperture yields unsatisfactory angular resolution while apertures larger than 125 mm are applicable in cases with very low atmosphere distortions which is not the general case when observing from low to medium altitudes. The slit is chosen appropriately with gap of 7 to 10 microns and is either made of quartz glass or stainless steel in order to resist the great heat from the sunlight. Such slits are readily available for purchase. The collimator lens is a photographic objective lens instead of simple achromatic doublet in order to achieve high resolution of the final image. Photographic lenses have much better aberrations corrections than simple doublets. The spectroheliograph uses standard reflecting diffraction grating, again readily available for purchase from optics manufacturers. The camera lens is a high quality photographic lens either standard for the used camera or separately obtained and coupled to the camera. The requirements for the camera are not as high as for astrophotography cameras because there is plenty of light and the resolution is already restricted by the seeing (atmospheric distortions) to levels of only few megapixels – in most cases only 2 megapixels. There is a filter wheel installed in front of the camera lens with the purpose of eliminating dispersion of other wavelengths from higher diffraction orders coinciding with the current wavelength under observation.

The innovations in regard to the described instrument are in the automation and computer control and comprise the motorized articulation and setting of all possible adjustment points, control of the sunscreen protecting the optical system, image generation and processing, and performing automated observations in different absorption lines consecutively by a preset plan.

The computer controlling the apparatus (Fig. 3) receives input from the optical sensor registering direct sunlight and from the camera. When direct sunlight is registered, and if the device is in acquisition mode, the sunscreen is opened. The sunscreen is closed in all cases when there is no direct sunlight because solar rays entering the telescope at an angle may damage the telescope by heating its internal parts. The outputs of the computer unit involve the control of several motors:

1. Telescope focusing motor
2. Collimator lens focusing motor
3. Camera lens focusing motor
4. Diffraction grating rotating motor
5. Telescope sunscreen actuator motor
6. Filter wheel rotating motor

Function. The spectroheliograph functions in the following way. The plan for image acquisition is being preprogrammed by the user. Then the apparatus carries out its observations automatically. The computer first focuses the telescope at the solar disk. Then it focuses the collimator lens and the camera lens. If needed, refocusing is performed several times and during imaging due to changes

in the atmosphere. According to the imaging plan, the diffraction grating is rotated to a given position corresponding to the desired wavelength of absorption line that is to be observed. The filter wheel is also rotated to an appropriate position. The image gathering proceeds line by line and finally the whole image is reconstructed by the computer. If Doppler shifts are to be calculated, this is done purely in software by the computer and no further image gathering is required.

Conclusion. The automation of the presented adjustment points and moving parts by computer control along with computer image processing and programming of a plan for different absorption lines observations renders a small scale mobile spectroheliograph highly versatile and easy to use with minor human interactions. The device nonetheless requires a mount to articulate the instrument and scan the solar disk during the imaging sessions. The team at the Space Research and Technology Institute, Bulgarian Academy of Sciences, is in development of a portable innovative German equatorial mount [6] for the purpose of coupling it with the current innovative spectroheliograph.

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¹*Space Research and Technology Institute, Bulgarian Academy of Sciences, Akad. G. Bonchev St, Bl. 1, 1113 Sofia, Bulgaria*
e-mails: svetoslavzabunov@gmail.com, garo.mardirossian@gmail.com

²*New Bulgarian University, 21 Montevideo St, 1618 Sofia, Bulgaria*
e-mail: nmarinova@nbu.bg