# SUN AND SOLAR ACTIVITY: OPPORTUNITIES FOR OBSERVATIONS AND DEVELOPMENT

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**Abstract.** The fast technological development and the new possibilities for observations allowed solving some of the theoretical issues in modern heliophysics and astronomy in general. But there are still unresolved questions regarding the physical processes of solar activity and space weather. We use the potential of both ground-based and space-based astronomical observatories to analyze the present results and understandings in the field of heliophysics. We show the current observational possibilities and perspectives for development in the research of the solar activity in Bulgaria.

## 1. INTRODUCTION

For thousand years, as history shows, scientific advances happen in stages. One observes years of dynamic and fast growth or relatively quiet periods in appearance of new scientific ideas. Of course, the new scientific proposals precede the technical applications, it is hardly possible otherwise, except when a random and unexpected experimental result happens. It is not easy to show constant development of new concepts and ideas as well as qualitative change of well-established scientific models. It looks like during the last 60 years the new approaches in science are in a quiet period. On the other hand, during the last two-three decades we witness the highest rate of development of the human civilization, in terms of new technological and engineering achievements and their applications. These achievements offer to us, astronomers, new opportunities for highly detailed research of a multitude of yet unanswered questions.

Still debatable are the questions related to: appearance, evolution, and periodicity of solar magnetic field; the processes which cause the heating of the solar corona and the acceleration of the solar wind; the causes for solar flare; processes of accretion of interplanetary material. The answers of questions related to the nature and physics of these phenomena are directly connected to constant monitoring of solar activities such as sunspots, prominences, solar flares and coronal mass ejections. Real cosmic observatories were launched on different orbits such as SOHO[1], STEREO[2],

[1]https://sohowww.nascom.nasa.gov/
[2]https://stereo.gsfc.nasa.gov/

SDO[3], Ulysses[4], GOES[5], RHESSI[6], Hinode[7], etc. It is possible today to perform solar observations in large range of the electromagnetic spectrum – gamma rays, X-rays, ultraviolet (UV), visible and infrared, radio waves. All these observations are aimed at increasing our understanding of the physics of the Sun.

Frequently we refer to the year 2020 as a new era in solar astronomy. We have a new generation of ground- and space-based observatories, which were impossible to construct up to now. We have the first images of the granulation of the solar photosphere by Daniel K. Inouye Solar Telescope, which were used for the first light press release in January 2020 and received broad coverage in the international press (Rimmele et al., 2020). Its 4-m aperture provides the highest-resolution observations of the Sun ever achieved. The telescope's field of view (FOV) using the Visual Broadband Imager is 55 arcsec$\times$55 arcsec and the resolution is close to the diffraction limit at the wavelength of 789 nm (0.04 arcsec). A newly developed data center located at the NSO Headquarters in Boulder will initially serve fully calibrated data to the international users community. Higher-level data products, such as physical parameters obtained from inversions of spectro-polarimetric data will be added as resources allow.

We need to mention also the new space-based missions ESA/NASA Solar Orbiter and NASA Parker Solar Probe. Both missions will have the opportunity to research the solar atmosphere primarily in the UV range of the electromagnetic spectrum – which is impossible for telescopes based on the Earth's surface.

Solar Orbiter, a mission of international collaboration between ESA and NASA, will explore the Sun and heliosphere from close up and out of the ecliptic plane. Understanding the coupling between the Sun and the heliosphere is of fundamental importance to understanding how the Solar System works and is driven by solar activity. To address this and other fundamental questions of solar and heliospheric physics, Solar Orbiter will combine in-situ measurements as close as 0.28 AU to the Sun with simultaneous high-resolution imaging and spectroscopic observations. These will be acquired in and out of the ecliptic plane, and Solar Orbiter will be the first mission ever to make remote-sensing observations of the Sun's polar regions (Albert et al. 2020).

Parker Solar Probe (PSP) will be the first spacecraft to fly into the low solar corona. PSP's main science goal is to determine the structure and dynamics of the Sun's coronal magnetic field, understand how the solar corona and wind are heated and accelerated, and determine what processes accelerate energetic particles (Fox et al. 2016).

In addition to delivering ground-breaking science in its own right, Solar Orbiter has important synergies with NASA's Parker Solar Probe mission, as well as other space- and ground-based observatories.

The above-mentioned three grand projects are targeted mainly at studying the minor structures of the Sun, while also including solar activity phenomena at a global aspect, related to the whole Solar System. These observations are supported by ground-based telescopes with more modest dimensions, appropriate for large-scale

[3] https://sdo.gsfc.nasa.gov/
[4] http://www.esa.int/Science_Exploration/Space_Science/Ulysses_overview
[5] https://www.goes-r.gov/
[6] https://hesperia.gsfc.nasa.gov/rhessi3/
[7] https://hinode.msfc.nasa.gov/

structures studies. Observations of total solar eclipses is still a main and powerful method for research of solar corona in the range of 1 – 10 solar radii. A comprehensive observational network, which includes space- and ground-based facilities, appears to be the most suitable form of research of the manifestations of solar activity, completed together by scientists from all over the globe.

In this paper we show our new project for observation and research of solar chromosphere through commissioning of a new 30-cm chromosphere telescope in Bulgaria. We present our intentions to develop our observational capabilities with regards to the monitoring of active manifestations of solar activity at different layers of solar atmosphere.

## 2. RESEARCH IN THE FIELD OF HELIOPHYSICS FROM BULGARIA AND THE INSTITUTE OF ASTRONOMY WITH NATIONAL ASTRONOMICAL OBSERVATORY AT THE BULGARIAN ACADEMY OF SCIENCES

At different layers of solar atmosphere (photosphere, chromosphere, transition region and corona) sporadic interactions between solar plasma and magnetic field of different space and time scales, as well as with different balance of mass and energy, happen. This complex of events is known as solar activity. There is a large number of solar activity phenomena, but the main ones, which have substantial geoeffective potential, are sunspots, prominences, solar flares, and coronal mass ejections.

Naturally at the end of the XX and the beginning of the XXI century, the space sciences and heliophysics in particular, established the term "space weather", which includes the physical conditions in the solar atmosphere, the solar wind, magnetosphere, ionosphere and thermosphere of the Earth, which could create unfavorable conditions for the normal operations of space- and ground-based technological systems or could negatively influence human health (Bonadonna et al. 2016). The Sun is major source and engine of the space weather, setting its parameters at every moment in accordance with the level and type of solar activity.

Historically, the development of Bulgarian astronomy naturally leads to the development of solar research. We owe its historical roots to the activity of Prof. Marin Bachevarov – Dean of the Faculty of Physics and Mathematics of Sofia University, Rector of the University and a pioneer for the construction of the first modern observational astronomical instrument in Bulgaria – a 6-inch refractor. From 1899 to 1905 Prof. Bachevarov, together with a group of students, began regular observations of sunspots from the Observatory in Sofia (Petrov et al. 2018, Tsvetkov and Petrov 2020). Years later, in 1961, the first research expedition to observe a total solar eclipse on February 15 was organized in Bulgaria (Dermendjiev et al. 1999).

In the very beginning of 1990s the foundations of modern observational solar physics were laid in Bulgaria by Prof. Vladimir Dermendzhiev, who built solar tower with 15-cm refractor for white-light observations of active processes. It was the first important step to the realization of the idea of own observational base in the Institute of Astronomy and National Astronomical Observatory (IANAO). Sun and Space Weather project was established by scientists from Department "Sun" at IANAO.

Since then the research done by the scientists from Bulgarian solar group relies both on ground- and space-based observations. We determined the time profiles, dynamic parameters (speed and acceleration) and the horizontal shifting of the "footpoints" of plenty of eruptive prominences observed by the telescope of the Astronomical Institute at the University of Wroclaw in Poland, SOHO, and SDO, as well as their connection to solar flares and/or CME (Duchlev et al. 2010; Tsvetkov and Petrov 2018, 2020; Tsvetkov 2020).

Research of eruptive prominences observed in UV by SDO and STEREO were performed during the last several years. A reconstruction of the coronal magnetic fields in the surroundings of prominences and a comparison of the kinematic properties of the prominences during eruption with spatial distribution of the rate of decrease of magnetic field with height was shown. This allows determining the mechanism of formation of the prominences and demonstrates the possibilities for prediction of appearance of instabilities leading to eruptions by tracking the values of the index, characterizing the decrease of the magnetic field in strength when reaching critical levels (Myshyakov and Tsvetkov 2020).

The team of the Sun and Space Weather project in IANAO has experience in processing observations of solar energetic particles (protons), their association with solar eruptive processes (flares, coronal mass ejections, prominences, radio emission), detailed analysis of particular events, as well as compiling numerous catalogues (Miteva et al. 2013, 2018) necessary for statistical studies covering almost two solar cycles (Miteva and Tsvetkov 2019; Bogomolov et al. 2018; Tsvetkov et al. 2018).

Observations and research of the solar corona at total solar eclipses are part of the activities of our team. Our main priority tasks are related to investigation of the fine structure of solar corona in white light, prominences and their surroundings (Myshyakov and Tsvetkov 2020); sublimation of dust particles in solar corona up to 10 solar radii (Gulyaev and Petrov 2003); polarization of solar corona in white light (Merzlyakov et al. 2019); as well as phenomena in the Earth's atmosphere during total solar eclipse (Tsvetkov et al. 2019).

As a result of engineering efforts, a solar coronagraph was built in the solar tower of National Astronomical Observatory (NAO) Rozhen in 2005 (Petrov et al. 2018). The renovation and progress of solar observational infrastructure in Bulgaria continued in 2019 with laying the foundations of building the first chromospheric telescope in Bulgaria.

## 3. NEW 30-CM CHROMOSPHERE TELESCOPE IN ROZHEN OBSERVATORY

Our new telescope should be designed so as to be adapted to new scientific challenges. The new 30-cm solar telescope to be installed in NAO Rozhen can be described in terms of requirements of modern solar and solar-terrestrial physics. Nowadays ground-based imaging of the Sun can be used as a complement monitoring of the solar activity. Its main advantages in the era of space-borne instruments are the relatively low cost of implementation and the ability to access the received data immediately.

We plan a new beginning for $H_\alpha$ solar observations to reveal the active nature of the solar atmosphere. The interaction between the convective motions in the photosphere and the dynamics in the hot corona happen in the chromosphere – an intermediate layer where the kinetic energy of the plasma gradually becomes weaker than the energy of the magnetic field and the plasma parameter $\beta$ shifts from $\beta >1$ (photosphere) to $\beta \leq 1$ (Rodriguez Gomez et al. 2019) before reaching low-beta values in the corona and in the active region chromosphere ($\beta <<1$) (Sakurai 2017). The chromosphere is also a region from solar atmosphere where the temperature rises in height as it is situated right above the temperature minimum layer.

Prominences/filaments, fibrils, Ellerman bombs, flares, etc. are only part of the phenomena observable in $H_\alpha$. One of the main scientific purposes of the new solar telescope is dedicated to make regular observations of various manifestations of solar activity. A free-access online database is going to be established and updated as soon as the daily observations begin.

A network with amplified magnetic field situated above the photospheric network is visible in the chromosphere during $H_\alpha$ observations. It is called chromospheric network and is outlining the supergranulation cells. A downward flow of material with typical velocity of about 1-2 km s$^{-1}$ marks their boundaries (Rieutord and Rincon 2010). Bright streams of luminous gas about 10000 km high, called spicules originate from the chromospheric network (Sterling 2000). They are one of the smallest quiet-Sun structures available for observations. The surface of the spicules is assumed as the actual boundary between the chromospheric and coronal material.

Our telescope is currently under construction although it has already received its first light. It is designed as Schmidt–Cassegrain reflector with diameter of the main mirror $D = 305$ mm and a focal length $F = 3050$ mm (Figure 1), which determines the telescope ratio – $F/10$. It is equipped with Hinode solar guider and a flat K8 glass filter with a bandwidth 6560±500 Å that provides reflection of at least 94% of the light in non-working areas of the spectrum to prevent overheating.

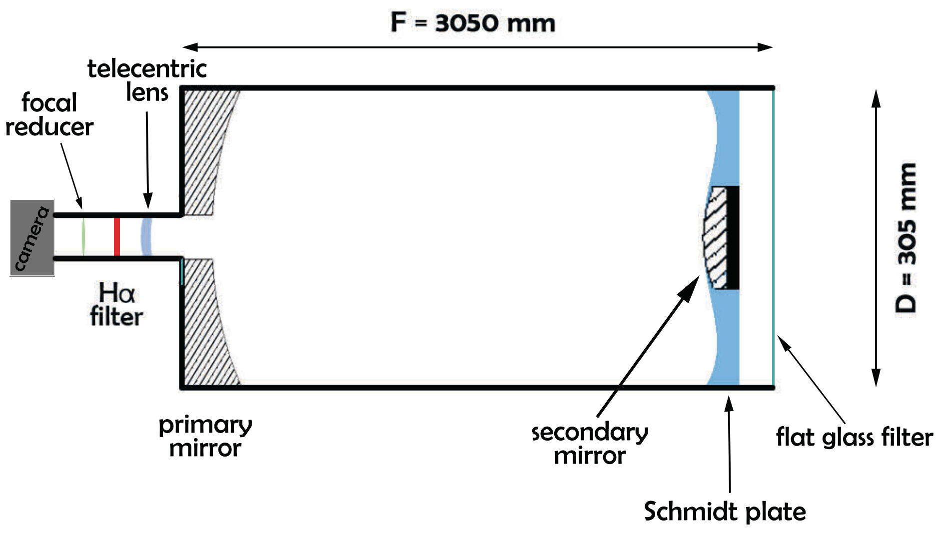


Figure 1: Optical scheme of the Schmidt–Cassegrain telescope.

The DayStar $H_\alpha$ filter that the telescope uses, works best for parallel beam of light. The larger its divergence when reaching the $H_\alpha$ filter is, the larger the bandpass width becomes. This means that at large focus distances we get better approximation of the falling light to parallel beam, resulting in higher resolution of the image.

A system of telecentric lens (up to 5x) provides the opportunity for correction of the focal length. The effective focal length $F_{eff}$ will vary in range 3050 to 15250 mm and, respectively, the field of view will change between 2.5×2.5 arcmin and 10×10 arcmin.

With this telescope, we will be able to obtain observational material from active regions in the solar chromosphere with a line-of-sight velocity resolution between 0 and 10 $\mathrm{km\,s^{-1}}$. At the end of the tube will be placed a $H_\alpha$ filter ($\lambda$=6562.801 Å) with a bandwidth ∼0.3 Å (central area of the filter) and a possibility for displacement of the center of the bandpass at ±0.5 Å by 0.1 Å step. The telescope was planned to receive its first light from the territory of NAO Rozhen in the first half of 2020, but now the deadline is indefinitely extended due to the pandemic situation.

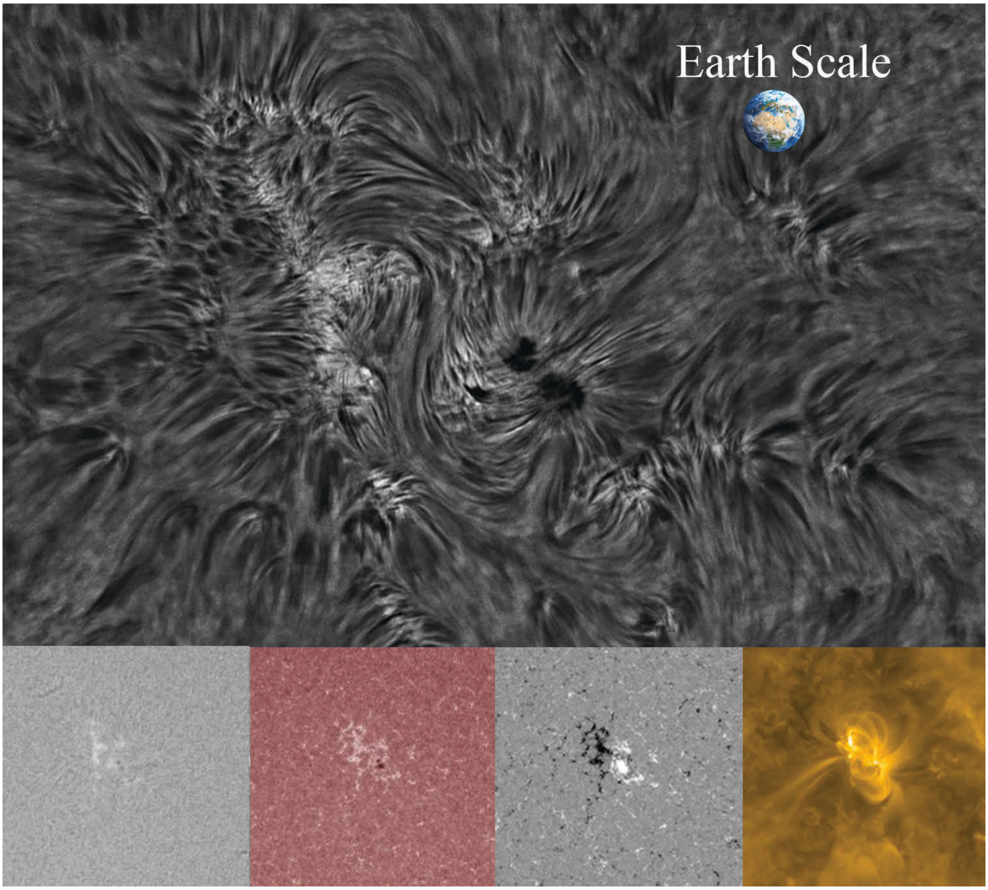


Figure 2: Upper image: A preliminary image of the telescope, taken on 2020 August 10, showing the active region 12770. Lower images: The same active region as captured by Kanzelhoehe $H_\alpha$ telescope, SDO/AIA 1700 Å, SDO/HMI magnetogram and SDO/AIA 171 Å, respectively.

Nevertheless, the optical part of the telescope is already constructed and the first calibration test image, taken at the factory is now released (Figure 2). It is captured when to the telescope $F = 3050$ mm is attached a telecentric focal extender 4.3× equal to $F = 13115$ mm. Immediately after the $H_\alpha$ filter we have optics system for reducing of the total focus distance and for forming of the final image. This focal reducer increases the FOV, increases the ratio and reduces the exposure time.

The reduction coefficient of the focal reducer is 0.65× that, finally, makes $F =$ 8525 mm. The digital camera in use is Basler ace acA1920-155um, with pixel dimensions 5.86 $\mu$m×5.86$\mu$m. The scale of the image is 0.13 arcsec/px in unfavorable weather conditions with high seeing.

Apart from the operational software for telescope control, for the analysis of the observational data, a new software product founded on existing procedures in the IDL-based software product SolarSoftware will be developed. Precise data processing is the basis for quality scientific production, which necessitates the development of a specific algorithm that will facilitate and universalize the preliminary data analysis. Processed data will be provided through a specially designed website.

Upon its completion, the telescope will serve same tasks, both in regular solar observations and in the effective training, qualification and educational activities related to heliophysics and astronomy.

## 4. CONCLUSIONS

We present an overview of the capabilities and technical specifications of the new 30-cm solar telescope that is going to receive its first light from the territory of NAO Rozhen in 2021. The telescope suggests a $H_\alpha$ view to the structures and dynamics of solar chromosphere in precise detail. Unlike most of the $H_\alpha$ telescopes used nowadays it is not going to capture full disk images of the Sun. The changeable field of view that varies between 2.5×2.5 arcmin and 10×10 arcmin will offer observations of particular separate chromospheric parts. A database with free access that is going to archive daily observations is currently under construction.

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