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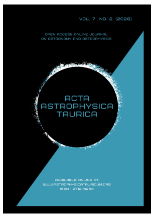

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Telescope for recording coronal mass ejections SPOT-CME

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ABSTRACT

We present a project of the new patrol telescope for regular solar observations with a cadence of about one minute. The instrument is intended to detect and determine parameters of coronal mass ejections and solar flares. It allows one to observe velocity fields in both the solar atmosphere and coronal ejections. The telescope is designed based on an air-proof single-volume scheme, may be mounted without a pavilion, and operates as a robotic telescope. It can be used within the Solar Service network.

Key words: Sun, solar observations, solar telescopes

1 Introduction

Timely and reliable space-based information about our environment forms the basis for infrastructure elements that are of crucial importance for modern society. From economic and social perspectives, reliable information on the state of the geospace environment is essential for a wide range of applications. Of particular note are the uninterrupted use of radio signals supporting navigation and communication and the counteraction to the negative effects arising from the deceleration of satellites in low near-Earth orbit during periods of enhanced solar activity. Furthermore, high-energy particles can cause damage to hardware and personnel in space, while currents induced in ground-based systems can interfere and disrupt electrical power grids.

The Sun is the primary driver of space weather (SW) through its effect on the Earth's surface and the atmosphere at its lower boundary. The particles and magnetic fields of the solar wind form the magnetosphere and govern the influence of galactic, cosmic, and solar rays on our planet.

The most significant advances in SW research have been achieved in the United States, where a comprehensive system of observations, analysis, and modeling has been developed to support operational forecasting and recommendations. In the United States, the official national source of SW warnings is the Space Weather Prediction Center (SWPC) in Boulder, Colorado. SWPC is one of nine National Centers for Environmental Prediction (NCEP) within the National Weather Service (NOAA), and it coordinates activities, products, and services on a daily basis with colleagues from the 557th Weather Wing of the Department of Defense, located at Offutt Air Force Base in Bellevue, Nebraska.

SWPC provides a broad range of products and services covering space weather conditions on the Sun, in interplanetary space, and on Earth, which are continuously updated and displayed on the SWPC website. Information is presented in both textual and graphical formats, employing the NOAA SW scales for geomagnetic storms, solar radiation storms, and radio blackouts, as well as a variety of other indices and parameters. The primary product distribution channels include an email product subscription service with more than 58 000 subscribers. SWPC also provides access to a number of real-time SW measurements, which are used directly by end users or by commercial service providers to generate value-added products for end users.

The principal components of the SW forecasting system are the assessment of high-speed solar wind streams and the prediction of the geoeffectiveness of coronal mass ejections (CMEs). CMEs are the large-scale ejections of magnetized plasma from the solar corona, which are one of the primary factors of intense geomagnetic disturbances. CMEs originate both in active regions of the Sun, for example during solar flares, and outside active regions, for example during the eruption of quiescent filaments. The matter ejection takes a time interval of several tens of minutes to several hours. Therefore, regular round-the-clock observations with a cadence of no worse than 5–15 minutes are required for the detection of CMEs and determination of their parameters.

In our country, a SW forecasting service based on domestic observations is expected to be established. In this paper, based on the experience of existing solar patrol telescopes, we examine the capabilities of ground-based observational facilities for CME detection and present a project of the new solar patrol telescope.

2 Telescopes for recording CMEs

One of the primary objectives of SW forecasting is the detection and determination of the initial parameters of CMEs.

Coronal mass ejections are the dominant factor governing intense geomagnetic storms. CMEs propagate through the solar wind. Understanding the mechanisms of CME propagation in the solar wind and the ability to predict their expected arrival time on Earth are the key research issues and challenges for SW forecasting centers. Despite some progress in this area, the evolution of CMEs in terms of the solar wind and the heliosphere remains insufficiently studied due to scarce heliospheric observations and unresolved issues regarding CME structure.

Regular CME observations are essential for successful SW forecasting. In the United States, NOAA/SWPC has conducted and continues to conduct such observations using spaceborne coronagraphs. Among the most widely utilized is the Large Angle and Spectrometric Coronagraph (LASCO) operating in white light, employed within the framework of the NASA/SOHO mission. Prior to 2007, coronal ejections could be regularly observed only in the vicinity of the Sun (typically within 30 solar radii). After the launch of the STEREO mission in 2007, it became possible to observe CME propagation from the solar corona through the inner heliosphere to near-Earth orbit using white-light coronagraphs.

No space-based solar observatories exist in our country, and their development will evidently take an extended period. Thus, CME observation and detection is a critically important capability that needs to be mastered as soon as possible. For this aim, ground-based optical (Tlatov et al., 2017; Berezin et al., 2023) and radio telescopes may be employed, capable of recording processes on the full solar disk and operating in continuous mode. In this paper we consider the operational experience of optical telescopes.

The observation, detection, and determination of CME parameters can be performed using ground-based patrol telescopes. Such telescopes provide regular full-disk solar observations with a cadence of about one minute in the Hα and Ca II K chromospheric lines. Prototypes of such telescopes were developed at the Kislovodsk Mountain Astronomical Station (MAS) of the Main Astronomical Observatory of the Russian Academy of Sciences (GAO RAS). The automated telescope spectroheliograph SPOT (Solar Patrol Optical Telescope) operating in the Ca II K line has been installed at MAS GAO and has been conducting regular observations since 2012. In 2015, an automated patrol spectroheliograph was constructed for regular observations in the Hα line. Researchers from MAS has so far accumulated extensive experience in long-term observations with automated spectroheliographs.

The patrol telescopes developed at MAS differ in design. The patrol telescope operating in the Ca II K line is built based on a single-volume scheme. The telescope axis is aligned with the polar axis, and during observations the entire instrument rotates, including the spectrograph. Scanning over the spectrograph slit is implemented using magnetic moving elements. In the Hα line, the telescope is designed according to the standard spectroheliograph scheme. Solar tracking is performed by a Jensch coelostat in which the primary and fold mirrors are mounted on a single moving column. This arrangement enables observations over an extended daytime period during which the coelostat mirrors do not obscure one another. The rotation rates of the mirrors differ by approximately a factor of two. The light beam is then directed onto the telescope, which is a refractor with an objective lens diameter of 10 cm and a focal length of 150 cm. Solar scanning over the slit is performed using a movable platform with two flat mirrors, able to move in two directions for focus adjustment and scanning. The development of this new functional element for solar observation in the Hα line incorporated a number of original engineering solutions, which were covered by Patent No. 126854 issued on April 10, 2013.

The scanning time of the solar disk is between 50 and 120 seconds, depending on the exposure time and the time required for solar positioning on the photoguide. The number of frames acquired during the passage of the solar disk across the spectrograph slit is 2000. To record a spectrum, a Prosilica GT 3300 CCD matrix with a 14-bit ADC is used. The spectral resolution is 40 000, with a linear dispersion of $\sim$0.16 Å/pixel. The maximum number of full-disk images obtained during a single day can reach 450, corresponding to 6.5–8 hours of regular observations.

3 Project of the new SPOT-CME patrol telescope

In this paper we present a project of the new patrol chromospheric telescope, preliminary designated as the Solar Patrol Optical Telescope for recording CMEs (SPOT-CME). The telescope is based on a single-volume scheme typical of spectroheliographs (Fig. 1). Such a scheme will allow constructing a compact automated telescope without a pavilion, which may be mounted, for example, on building roofs.

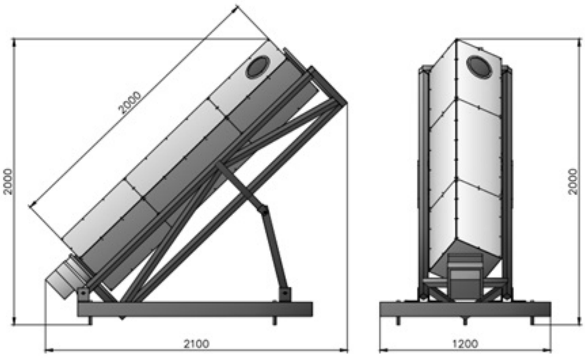

Fig. 1. Layout of the SPOT-CME solar patrol telescope.

The telescope enables observing the solar atmosphere in selected spectral lines. An achromatic lens with d $\sim$ 100 mm and f $\sim$ 1300 mm may be used as the primary objective. Full solar images are acquired by displacing the solar disk across the entrance slit of the spectrograph. During the solar disk scanning process, spectral images are recorded to the computer memory. Images in the Hα or Ca II K line are registered at a cadence of about one minute. Upon completion of scanning, the acquired spectral images are read out to construct the solar disk image in the core of the spectral line and in its wings. Registration of the full spectral line profile enables

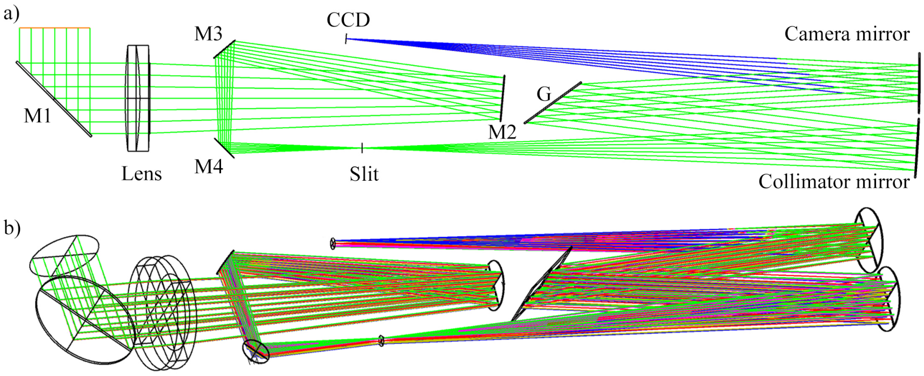

Fig. 2. Calculating optical rays in the telescope: a) direct projection, b) side view.

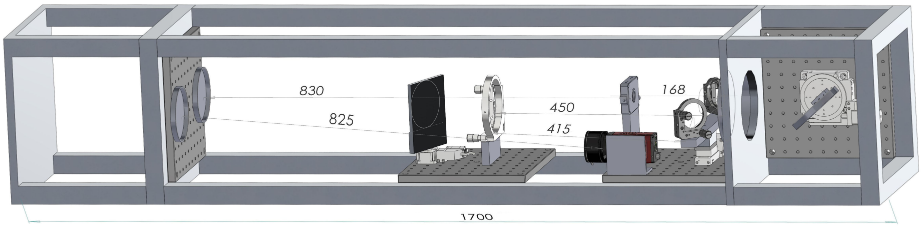

Fig. 3. Scheme of the principal components within the telescope.

reconstruction of the principal parameters of the solar atmosphere and determination of CME characteristics. Switching between spectral lines is performed by rotating the spectral grating and by changing the focal length.

Figure 2 presents the calculation of optical rays. The solar image is constructed at the spectrograph slit (Fig. 2a, Slit) using the achromatic objective (Fig. 1a, Lens) and a series of fold flat mirrors M1–M4. Scanning across the spectrograph slit is performed by displacing the mirror pair M3 and M4 placed on an optical bench. The spectrograph comprises an entrance slit, a collimator mirror ($f = 0.8$ m), a reflective diffraction grating (Fig. 2a, G), and a camera mirror ($f = 0.8$ m). Spectral recording is performed using a CCD matrix. The calculated spectral resolution of the instrument is 40 000. Commercially manufactured optomechanical components are supposed to be employed. Figure 3 presents the scheme of the principal optomechanical components of the telescope structure. The Prosilica GT 3300 CCD matrix is planned to be used as a detector.

4 Conclusions

The paper presents a project of the new solar telescope intended for regular solar observation at a registration cadence of about one minute. This telescope will be incorporated into a Solar Service network comprising at least six observing stations. The instrument is designed for the detection and determination of parameters of coronal mass ejections and solar flares, and it enables observation of velocity fields in both the solar atmosphere and coronal ejections. The operational characteristics of the new telescope are close to those of the instruments already installed at Kislovodsk; however, the new instrument will be more compact, lighter, and less expensive. The telescope is air-proof, fully automated, and may be mounted without a pavilion on an open site.

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