Open Access Online Journal on Astronomy and Astrophysics
Acta Astrophysica Taurica
www.astrophysicataauricum.org

Acta Astrophys. Tau. 5(2), 21–24 (2024)

Results of 20-year solar observations in the He I λ 1083 nm line at the Crimean Astrophysical Observatory

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Received 27 October 2021

ABSTRACT

During 1999–2018, an extensive dataset of images of the solar disk in the He I λ 1083 nm line was acquired at the Crimean Astrophysical Observatory (CrAO) with the Solar Tower Telescope – 2 (STT-2). Over this period, the image processing underwent various changes. No observations were carried out from mid-2018 to the end of 2019. In 2020, the process of observations and image processing at the telescope was modernized. Currently, all images acquired during different periods prior to modernization are being processed using a unified method to form a catalog. This work presents a brief historical overview of observations in the He I λ 1083 nm line at CrAO, a concise description, and fragments from the catalog.

Key words: CrAO, solar telescope, observations in the He I λ 1083 nm line, coronal holes

1 Introduction

Infrared observations are becoming increasingly significant in solar astrophysics as they offer entirely new perspectives. The He I λ 1083 nm (He I) line – the strongest triplet line of neutral helium – allows for the study of the physical properties of the upper chromosphere and the transition layer between the chromosphere and corona. It is in this line, formed at an altitude of about 2000–3000 km in the upper chromosphere and excited by ultraviolet radiation, that coronal holes (CHs) can be observed from Earth. This absorption line weakens within CHs, leading to increasing radiation compared to neighboring coronal areas. CHs are brighter in the He I line than the surrounding corona.

In the 1980s, led by N.N. Stepanian (Fig. 1), the Crimean Astrophysical Observatory initiated works on preparing technical capabilities and software for observations in the He I λ 1083 nm line. N.N. Stepanian was a conceptual and scientific leader of almost all works associated with organizing the He I line observations and subsequent image processing. Daily monitoring was organized, with prompt data sharing via the Internet, and extensive databases were compiled. This enabled CrAO to participate in national and international observation programs, such as Solar Service, SpaceWeather, and others.

Fig. 1. N.N. Stepanian

2 STT-2

Observations in the He I line have been carried out with STT-2 at CrAO since 1989 (Fig. 2). The telescope is equipped with a diffraction spectrograph and the Universal Spectrophotometer (USP). In 1998, USP was modernized (Stepanian et al., 2000). Regular observations in the He I line have been started since 1999.

Fig. 2. STT-2. External view and coelostat mounting

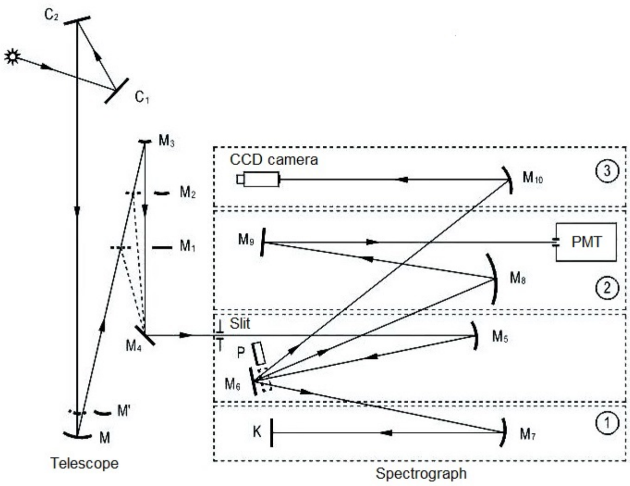

Fig. 3. Optical scheme of STT-2

STT-2 is designed for spectral and monochromatic observations of the Sun. Two primary mirrors and three Cassegrain systems allow acquiring solar images ranging from 80 to 300 mm at the spectrograph slit.

The spectrograph is equipped with two gratings and three cameras enabling spectra with different dispersion to be recorded. Photographic films, photoplates, photomultiplier tubes, and CCD cameras can serve as receivers.

The optical scheme of the telescope (Fig. 3) is described in detail in Stepanian et al. (2014). The numbers denote schemes for imaging the spectrum passing through the light beam slit: 1 – at the cassette part (used for measuring sunspot magnetic fields); 2 – at the photomultiplier tube (used for scanning the solar disk in the He I λ 1083 nm line); 3 – at the CCD camera.

This instrumental basis enables resolving a broad range of astrophysical issues. The main scientific interests of researchers who use STT-2 observations focus on determining the physical and dynamic characteristics of solar formations, such as flares, flocculae, sunspots, coronal holes, and background magnetic fields.

The spectral sensitivity of the photomultiplier tube, PMT-83 (from 390 to 1100 nm), allows for USP to be used in studying the Sun in the near-infrared range. One of the daily, routinely performed programs at the telescope includes acquiring images of the Sun and its parts in the He I λ 1083 nm line and analyzing them.

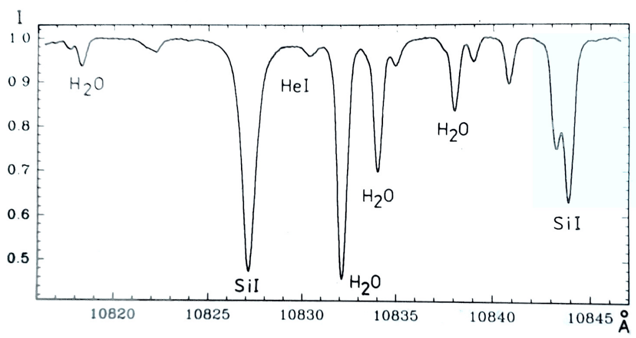

Fig. 4. Spectrum of the solar center in the He I λ 1083 nm line obtained with USP of STT-2

Solar images are constructed by scanning the optical image of the Sun at the spectrograph slit. The photometer records the intensity in the center of the He I line. An example of the spectrum of the solar center in He I, obtained with USP of STT-2, is shown in Fig. 4.

The telescope and the recording device are operated by a personal computer. Service software allows limb darkening to be taken into account and the image to be analyzed for the detection of CHs within a few minutes. One of the earlier obtained images is presented in Fig. 5. The time and date

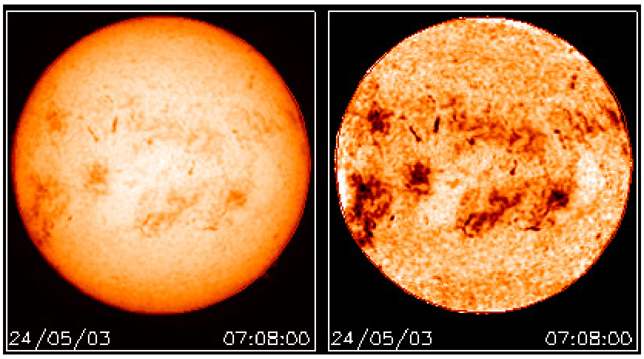

Fig. 5. Image of the Sun obtained in the He I λ 1083 nm line with USP of STT-2 on 24 May 2003. The unprocessed image (left panel) and the image processed taking limb darkening into account (right panel)

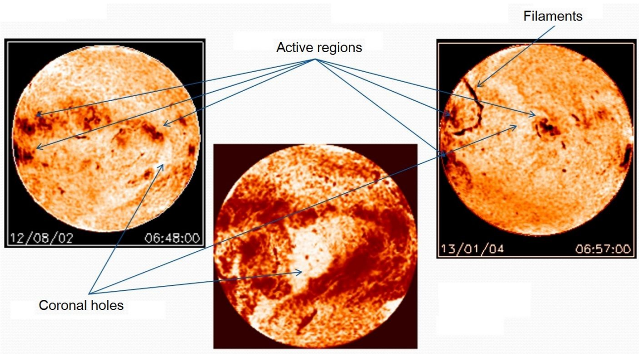

Fig. 6. Active regions, coronal holes, and filaments in solar images in the He I λ 1083 nm line obtained with STT-2

of observation are indicated in the image. The images are normalized to 4.8 × 4.8 arcsec per pixel. Figure 6 shows examples of the processed solar images, with active regions, coronal holes, and filaments being well discernible.

In Figs. 5 and 6, active regions are visible as dark formations; coronal holes, as bright elongated areas with reduced contrast; and filaments, as dark threads on the solar disk.

3 Observations in the He I λ 1083 nm line with STT-2 at CrAO

From 1999 to 2018, a number of researchers took part in the program of solar observation in the He I line at STT-2: N.N. Stepanian, M.D. Guseynov, E.V. Malanushenko, Z.A. Shcherbakova, A.V. Shumko, I.G. Panamarchuk, V.P. Tarashchuk, V.M. Malashchuk, V.A. Perebeynos, N.I. Shtertser, O.A. Andreeva, Z.S. Akhtemov, R.K. Zhigalkin. A group of engineers led by G.A. Sunitsa and D.G. Semyonov technically supported and improved the observation process. In 2016, A.V. Borisenko updated the observation visualization on the CrAO website by adding a 10-degree grid to the processed images and by normalizing images to 2.4 × 2.4 arcsec.

Over this period, the extensive observational data were collected. These data have been widely used by Crimean scientists to study CHs, as this is one of the key branches of studying physical processes on the Sun at CrAO. More than 50 works on this topic were carried out during the specified period. Under the supervision of N.N. Stepanian, E.V. Malanushenko defended the PhD thesis "Investigation of the solar atmosphere in coronal hole regions". A brief overview of works performed by the CrAO staff using observations in the He I line is presented in Malashchuk, Andreeva (2019).

From July 2018 to the end of 2019, observations were not conducted. In 2020, the observation process was modernized and regular observations in the He I line resumed.

3.1 Compiling the catalog

Currently, CrAO is compiling a catalog based on observational data obtained with a diffraction spectrograph and the Universal Spectrophotometer at STT-2 from 1999 to 2018, prior to modernization. All images acquired during various periods are processed using a unified method.

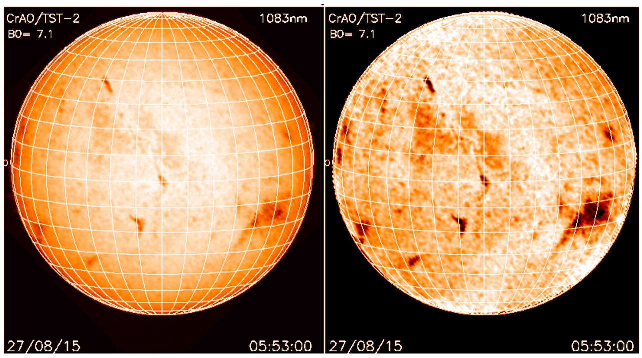

Fig. 7. Image of the Sun in the He I λ 1083 nm line obtained with STT-2 (left) and processed taking limb darkening into account (right) on 27.08.2015.

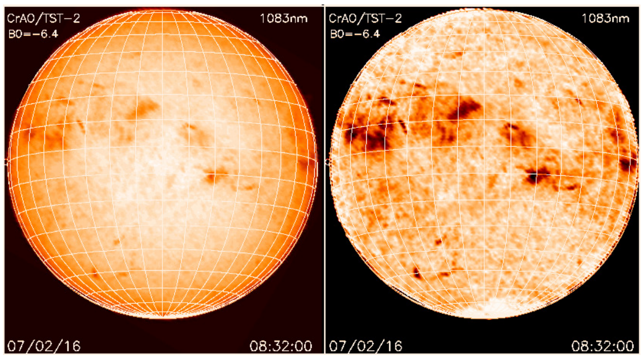

Fig. 8. Image of the Sun in the He I λ 1083 nm line obtained with STT-2 (left) and processed taking limb darkening into account (right) on 07.02.2016.

The catalog will present files in both FITS and GIF formats. FITS files contain information recorded during the scanning of the image: date and time of observation, spectral resolution, range of observed values, and B0 angle.

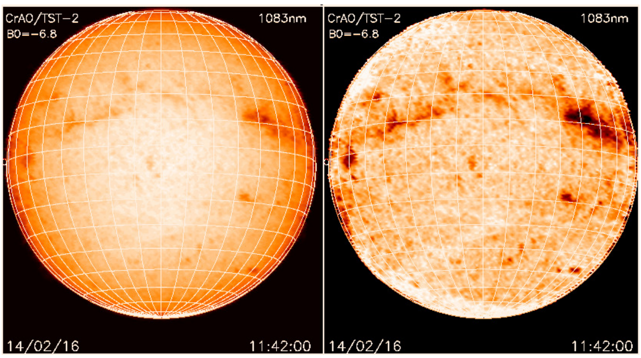

Fig. 9. Image of the Sun in the He I λ 1083 nm line obtained with STT-2 (left) and processed taking limb darkening into account (right) on 14.02.2016.

GIF files display pairs of solar disk images, normalized to 2.4×2.4 arcsec per pixel, with recorded image registration data. The left image is unprocessed, and the right one is processed taking limb darkening into account. A grid with meridians and parallels spaced at 10° is superimposed on both images.

Fragments from the catalog are presented in Figs. 7, 8, and 9.

The catalog can be useful for conducting scientific research on the nature and evolution of CHs, contributing to the solution of significant solar physics issues such as the structure and physical conditions in the solar corona, the release and transfer of energy in the solar atmosphere and the heating of the quiet corona, rotation and evolution of the large-scale magnetic field, formation of solar wind flows.

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