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Forming a unified database of solar observations in the HeI 10830 Å line acquired in 1999–2025 at the CrAO STT-2 telescope

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ABSTRACT

Experimental data on solar activity are currently widely used in fundamental and applied scientific research, namely in studying phenomena occurring on the Sun and their impact on Earth. The most valuable data are those obtained over many years of observations. The unique observational material for more than two solar cycles has been accumulated by using the STT-2 telescope. Since 1999, more than 4500 maps of the full solar disk in the HeI 10830 Å line have been acquired, which allow us to explore the evolution and characteristics of coronal holes, filaments, and active regions. Due to the fact that during this period the observational process was continuously upgraded and some changes were made in the processing programs, we have several series of solar maps of different types. In this paper we aim to process all observational material according to a unified methodology and to form a unified database of observations in the HeI 10830 Å line. The algorithm for processing observations is briefly described; a few fragments of the database and its updated structure are presented.

Key words: observations in the HeI 10830 Å line, database of solar observations, coronal holes

1 Introduction

The Solar Tower Telescope 2 (STT-2) was built in the early 1970s. It is intended for spectral and monochromatic observations of the Sun. One of the daily space weather monitoring programs is acquiring solar images in the HeI 10830 Å line (HeI).

Spectral observations in the HeI line represent a useful ground-based method for studying coronal features of the solar disk. This line is formed in the chromosphere at a height of about 2000–3000 km and is excited by ultraviolet radiation, and it is in this line that coronal holes (CHs) can be observed from Earth. On the solar disk, CHs in this line look like brighter regions as compared to the surrounding corona.

In the second half of the 1980s, under the leadership of N.N. Stepanian, work was initiated on preparing technical facilities and software for observations in the HeI line at the CrAO STT-2 telescope. The HeI line observations with the STT-2 were started in 1989, and systematic observations have been carried out since 1999. These observations need to be further continued to expand the data series for the current solar cycle.

2 Stages of the STT-2 upgrade

Meanwhile, during this period, the observation process was continuously upgraded, and the image reduction process also underwent some changes. The upgrade stages are listed below and described in detail in the following works:

1. Second half of the 1980s. The solar spectrophotometer was put into operation (Bukach et al., 1990).
2. 1998. The upgrade of the Universal Spectrophotometer (Stepanyan et al., 2000).
3. 2019. The upgrade of the spectrophotometer control system (Semyonov et al., 2021).

A. Kutsenko developed completely new software accompanying the scanning process (operates under Windows 10). A. Plotnikov wrote a new program for subsequent processing of observation results in Python using SciPy, NumPy, Matplotlib, and SunPy libraries.

The 2019 upgrade allowed improving the quality of obtained solar images in the HeI line as well as shortened observation and processing time. Let us consider this stage in more detail.

2.1 SCANNER program

Figure 1 shows the interface of the new scanning program SCANNER in “Spectrum” mode. In this mode, the program allows one to precisely align the HeI line center before scanning.

In “Spectroheliogram” mode, we obtain a solar image in the HeI line (Fig. 2). Before scanning one can center the image on the spectrograph slit, choose one of four size options

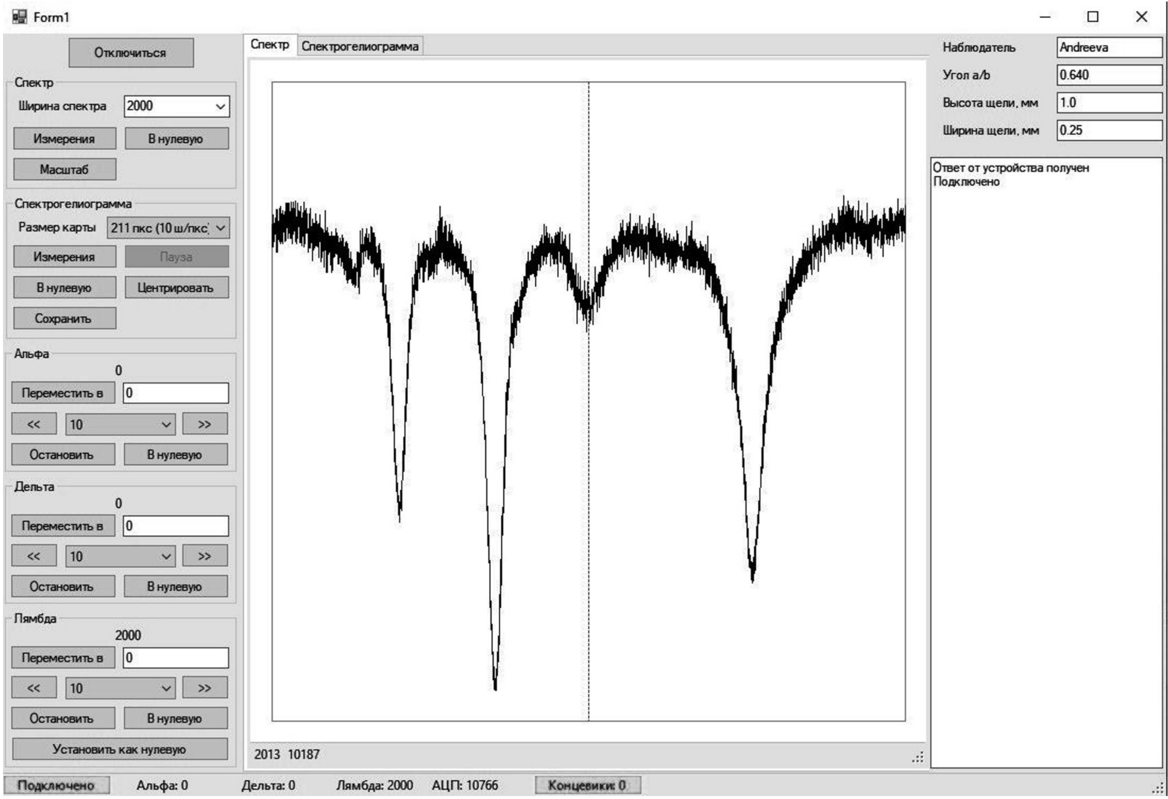

Fig. 1. SCANNER program interface in “Spectrum” mode.

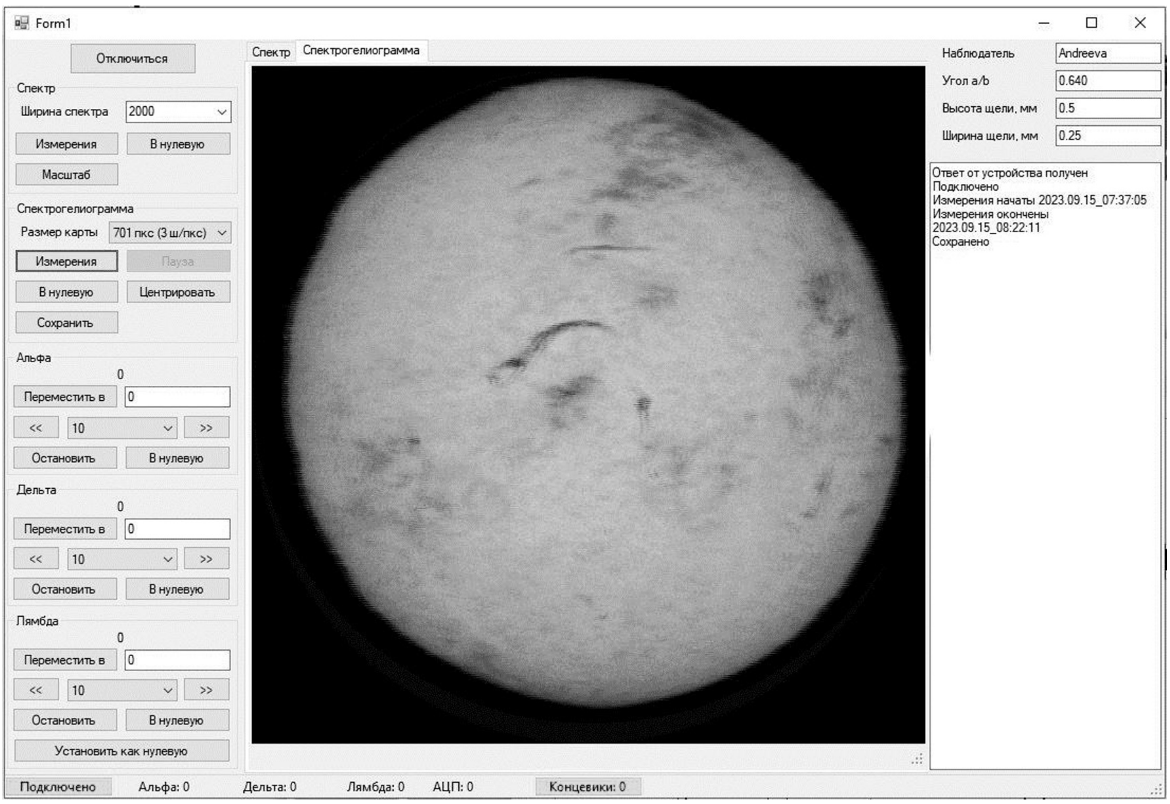

Fig. 2. SCANNER program interface in “Spectroheliogram” mode.

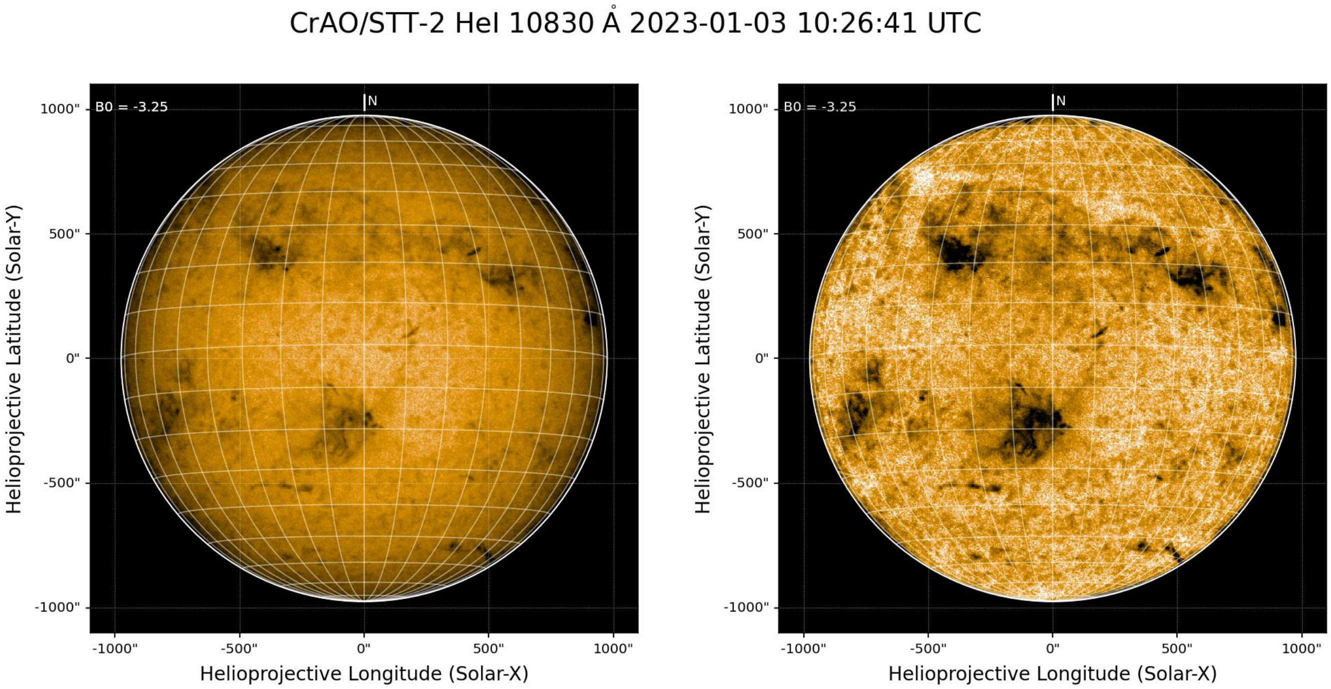

Fig. 3. Solar images obtained in the HeI line with the Universal Spectrophotometer of the STT-2 telescope. Left: processed without limb darkening correction. Right: with limb darkening correction.

(211×211 px; 321×321 px; 421×421 px; 701×701 px) for the full solar disk map and, accordingly, the scanning time: from 15 to 40 minutes. The following new capabilities have appeared: pausing observations in case of cloud appearance and then continuing scanning, which is very relevant under unstable weather conditions; saving part of the disk if necessary; and a number of others. As a result of scanning, we obtain an image that requires final processing (Fig. 2). The "notches" on the limb, limb darkening, the accounting of the inclination of the Sun's axis to the Earth's equatorial plane for a given date, as well as the position of the telescope's coelostat pair (measured before observations begin) – all these issues are resolved in the observation processing program.

2.2 Program for processing observation results

The program implements algorithms solving the following tasks:

1. Elimination of backlash consequences during scanning. Due to backlash, adjacent rows are shifted relative to each other, causing "notches" at the edges. Solution: for each scan line, the position of both disk edges is determined (the criterion is 0.5 of the maximum intensity in the line), after which all lines are aligned vertically; namely, line centers (arithmetic mean of edge positions) are reduced to one horizontal coordinate.
2. Limb darkening compensation. Intensity is multiplied by an axially symmetric function (fourth-order polynomial of radius), identical for all disks.
3. Image rotation with accounting the date and coelostat mount position at the beginning of scanning. Data are saved in FITS format in two variants: intensity map with and without limb darkening. Also, for convenience of visual analysis, data are saved as images in JPEG format with additional information added.

The JPEG file represents a pair of maps with solar disk images reduced to a resolution of 3.6 × 3.6 arcsec per pixel (Fig. 3). The maps also indicate image registration data. The left image is with limb darkening, and the right is without limb darkening. A grid with a 10° step is superimposed on both images. The corresponding B0 angle value, which is the angle between the solar equator and the line of sight, is added to the image.

All information recorded during image scanning is included in the FITS file headers: observation date and time, the width and height of the spectrograph slit, coelostat mount inclination angle, pixel size in angular units. These data enable users to easily perform coordinate transformations for desired analysis.

The new processing program allows for stream image processing, which is very important for our task of unifying the observation database visualization.

3 Formation of a unified database

At the time of the initiation of the unified database (UDB) formation, we had spectroheliograms obtained during different periods, and they differed visually (left panel, Fig. 4). There were several reasons for unification:

1. Thanks to the fact that the new software forming the final image allows analyzing a large amount of data within

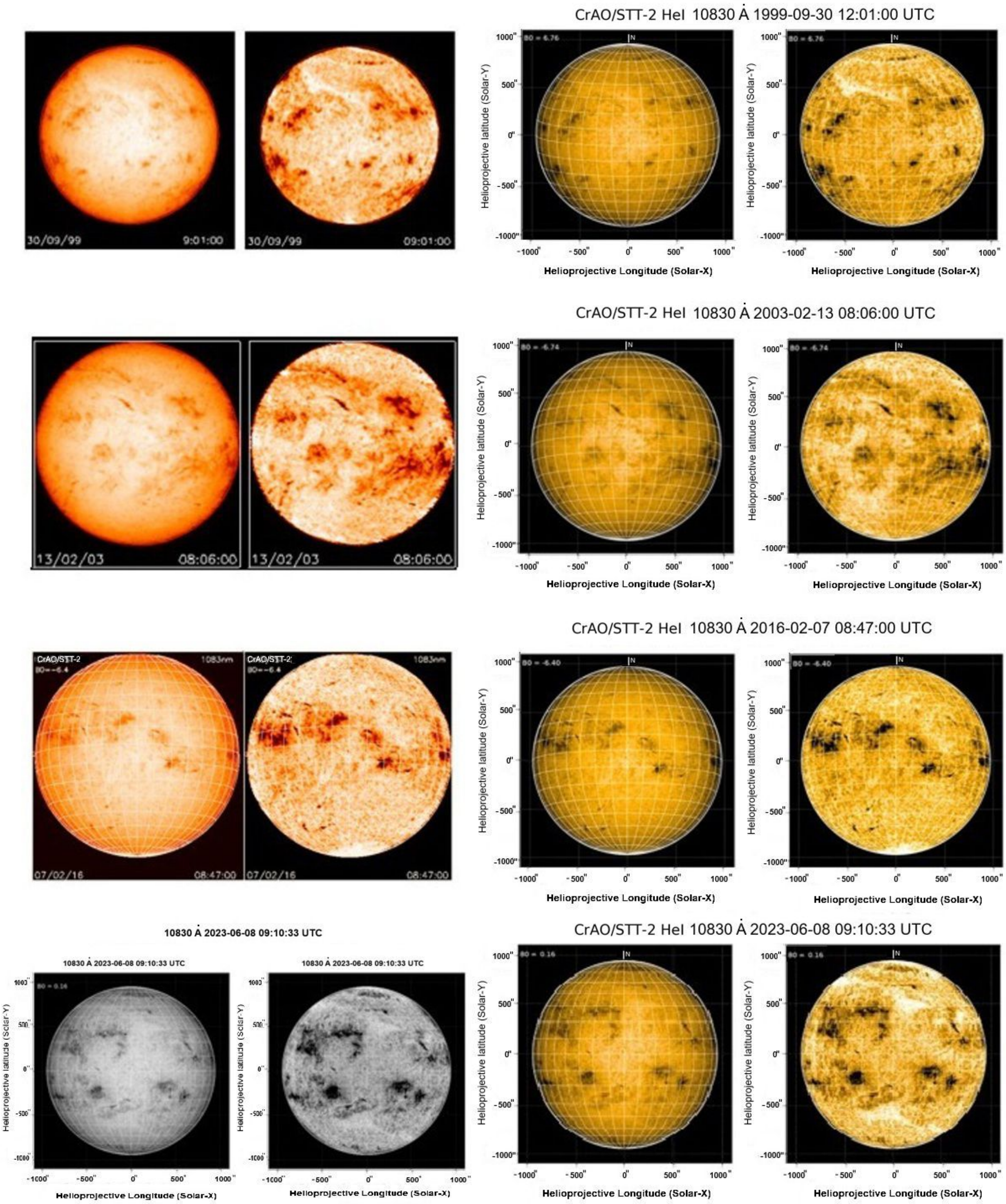

Fig. 4. Solar images obtained in the HeI 10830 Å line with the Universal Spectrophotometer of the CrAO STT-2 telescope during different periods. Left: before unification. Right: maps of the solar disk for the same dates but processed using a unified methodology.

reasonably acceptable terms, we are able to process all observational material using a unified methodology and to bring the visualization of all observations to a unified form. This is convenient for analysis, comparison, and viewing of obtained solar maps.

2. The previously published database was limited to only one image per day, although there were often more observations; the task was set to add them to the updated database as well.

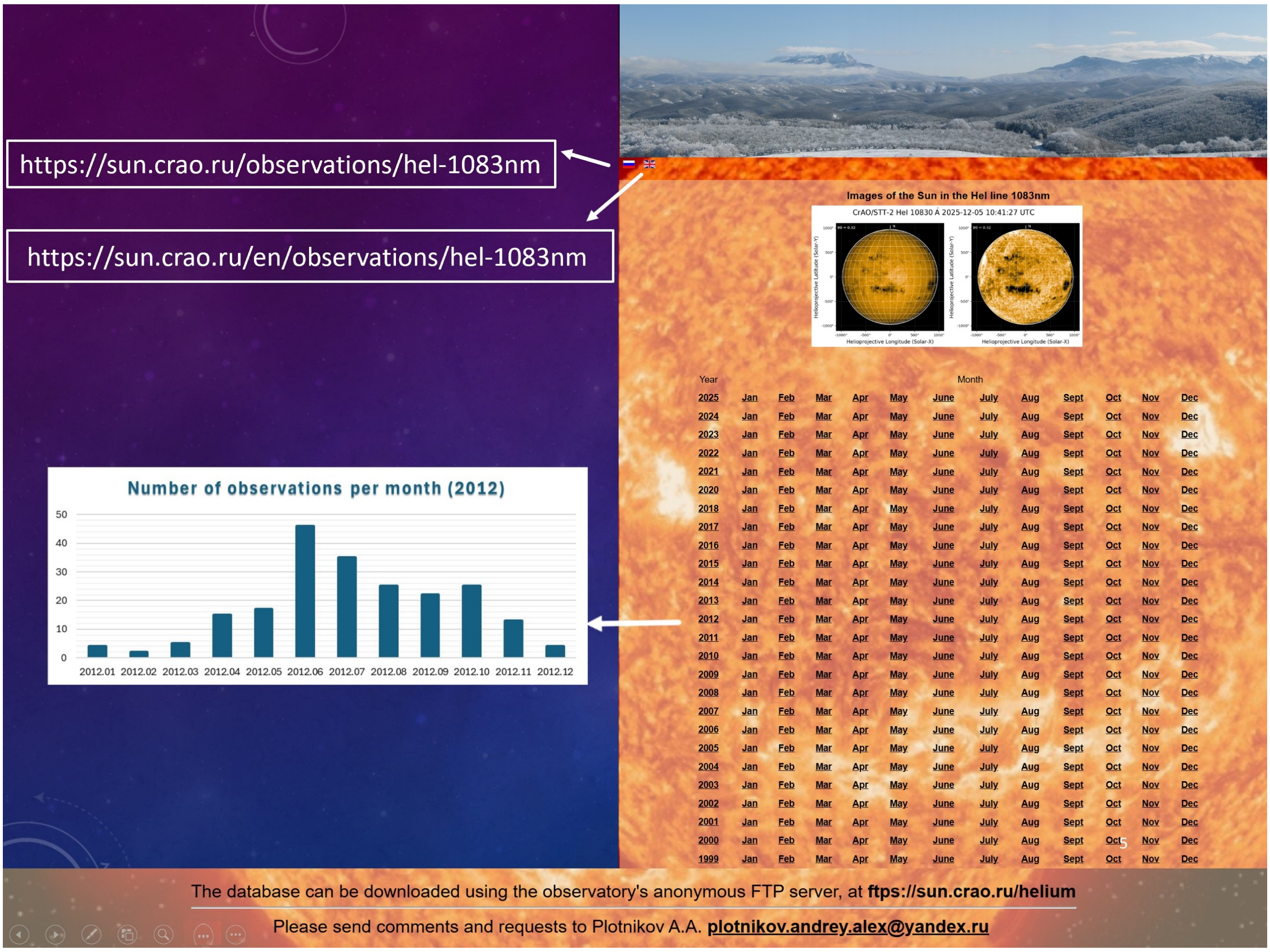

Fig. 5. Unified database of solar observations in the HeI line on the website of CrAO. Right: external view. Left and bottom: explanatory information.

3. Initially, only JPEG images of observations were available on the website, which was insufficient for computer analysis methods. The database needed to be supplemented with FITS files as well.

The idea arose to create a UDB that would be convenient for visualization and analysis of solar disk maps, and that was done. Fragments of the updated database are shown in the right panel of Fig. 4.

3.1 Unified database of solar observations in the HeI 10830 Å line acquired by the CrAO STT-2 telescope

There is currently an updated database of observations in the HeI line for the period from 1999 to 2025 publicly available on the website of CrAO.

The top of the page (Fig. 5) shows the latest posted image in the HeI line. The table of observations by year and month with links to the corresponding directories is given below. The page is available in both Russian[1] and English[2]. By clicking on the flag icons in the upper left corner, one can select the language of the website. By clicking on a year, one can see a histogram of the number of monthly observations for this year. At the bottom of the page, there is information that the database can be downloaded via the anonymous FTP server[3] of CrAO, using Windows Explorer or other available means. Additionally, one can obtain the files of interest for any period in one archive by contacting A. Plotnikov. The updated structure of the UDB is presented in Fig. 6.

In the root directory, there are folders by year and the last image in the HeI line (Latest.gif) posted on the website. Each year's folder contains 12 subfolders including observations by months and two JPEG files with histograms of the number of monthly observations of a given year for both Russian and English versions of the website. Furthermore, within each month's folder, one can find JPEG files and two folders

[1] https://sun.crao.ru/observations/hel-1083nm
[2] https://sun.crao.ru/en/observations/hel-1083nm
[3] ftps://sun.crao.ru/helium

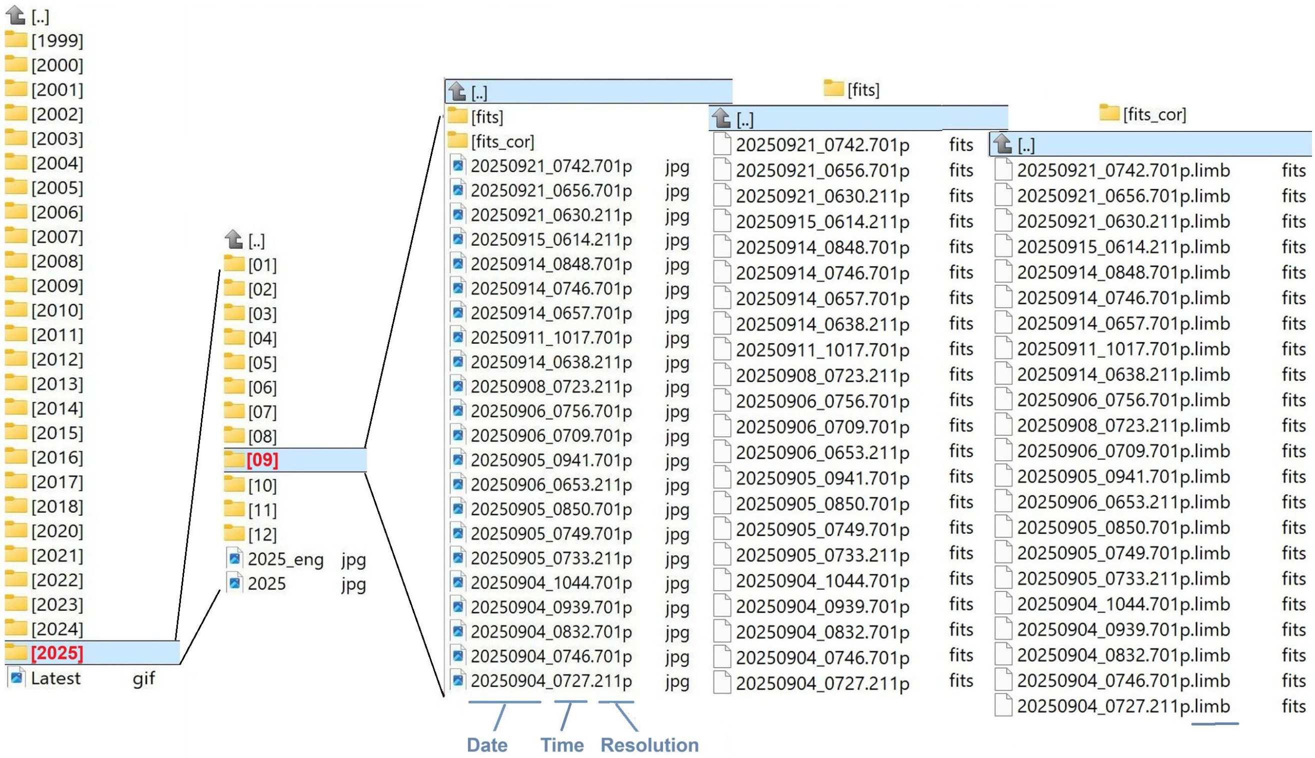

Fig. 6. Structure of the unified database of solar observations in the HeI line.

named "fits" and "fits_cor", which contain intensity maps in FITS format with and without limb darkening, respectively. The names of FITS files correspond to the names of the respective JPEG images. The titles reflect the date, time, and resolution of the image in pixels. For FITS files taking limb darkening into account, from the "fits_cor" folder, .limb is added to the file name.

Since October 2025, a link to the database has been published on the website of the World Data Center for Solar-Terrestrial Physics (WDC for STP) in the section "Solar Activity and Interplanetary Medium", as well as in the Earth Science Database of the Geophysical Center of the Russian Academy of Sciences (Andreeva et al., 2025), thus making it accessible to a broader audience within the global scientific community.

4 Conclusions

As a result of forming a unified database of observations in the HeI 10830 Å line acquired by the Universal Spectrophotometer of the CrAO STT-2 telescope from 1999 to the present, we have obtained a unified visualization of observational material convenient for viewing, analysis, and comparison. The database has been supplemented with previously missing full solar disk maps. Not only JPEG but also FITS files have become available to users. The unified database can be useful in conducting scientific research in the field of studying the nature and evolution of CHs as well as connection with other structures on the Sun. This contributes to solving such important issues of solar physics as the structure, rotation, evolution of the large-scale magnetic field, and the formation of solar wind streams. We hope that these data will be in demand not only by our staff but also by other researchers.

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